Climate Change Engineering Vulnerability Assessment

Coquihalla Highway (B.C. Highway 5) Between Nicolum River and Dry Gulch

Rev 4
June 2, 2010

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1 Introduction

1.1 Background

Engineers Canada, the business name for the Canadian Council of Professional Engineers, established the Public Infrastructure Engineering Vulnerability Committee (PIEVC) to oversee the planning and execution of a broad-based national assessment of the engineering vulnerability of Canadian public infrastructure to changing climatic conditions.

This National Engineering Vulnerability Assessment is a long-term project to evaluate the changes anticipated to the risks to Canadian public infrastructure posed by climate change. PIEVC established roads and associated structures vulnerability as one of four priorities for review. The other priority areas include stormwater and wastewater, buildings, and water resource systems. The National Engineering Vulnerability Assessment will lead to recommendations concerning the review of infrastructure codes, standards and engineering practices to accommodate future climate change anticipated over the service life of these categories of infrastructure.

For the purposes of this study, engineering vulnerability to climate change is defined as the shortfall in the ability of public infrastructure to absorb the negative effects, and benefit from the positive effects, of changes in the climate conditions used to design and operate infrastructure. The vulnerability is a function of:

- Character, magnitude and rate of change in the climatic conditions to which infrastructure is predicted to be exposed;
- Sensitivities of infrastructure to the changes, in terms of positive or negative consequences of changes in applicable climatic conditions; and
- Built-in capacity of infrastructure to absorb any net negative consequences from the predicted changes in climatic conditions.

Therefore, engineering vulnerability assessment requires assessment of all three elements.

The principal method being used to develop a national picture of the engineering vulnerability of infrastructure to climate change is through selective case studies of individual infrastructures or infrastructure systems.

This assessment not only requires a definition, and projection of climatic design parameters, but also the definition of the characteristics and components of the infrastructure, which make them more or less vulnerable to climate change. These can include, but are not limited to:

- Age and condition of the infrastructure;
- Maintenance practices;
- The rate at which system is upgraded or replaced;

- System characteristics;
- Geographical limitations on the system;
- Other factors affecting sustainability of the current system (e.g. population growth);
- The variation in design standards across the country;
- Policies and incentives; and
- Other factors that may be identified.

The Ministry of Transportation and Infrastructure, Province of British Columbia (BCMoTI) has agreed to work with Engineers Canada and the PIEVC to assess the engineering vulnerability of an area approximately 44.83km in length from the Nicolum River Bridge, North End at .90km, to the start of Dry Gulch Bridge at 45.73km in LKI Segment 2000 (the Coquihalla South Section).

1.2 *Purpose*

The principle objective of this case study was to identify those components of the Coquihalla Highway Merritt South Road Section that are at risk of failure, loss of service, damage and/or deterioration from extreme climatic events or significant changes to baseline climate design values.

The assessment was carried out using:

- ***The PIEVC Engineering Protocol, Version 9, April 2009.***

The results of this case study will be incorporated into a national knowledge base and analyzed with other case studies to develop recommendations around reviews of codes, standards and engineering practices.

1.3 *Study Scope and Timing*

The scope of the assessment encompassed the current design, construction, operation and management of this infrastructure as well as planned upgrades or major rehabilitation projects.

The Hope to Merritt section of the Coquihalla Highway, Hwy 5, in British Columbia was constructed between 1982 and 1986 through mountainous terrain bordered by the Fraser Delta to the West and the Cascade Mountain Range to the East. In addition, the Coquihalla River and Boston Bar Creek alternate alongside the length of the highway with significant road elevation change of approx 900 m from the start point to the end point. This assessment evaluated a 44.83km in length of highway from the Nicolum River Bridge, North End at .90km, to the start of Dry Gulch Bridge at 45.73km in LKI Segment 2000.

The original surfacing structure generally consisted of 75 mm of asphalt concrete pavement over 300 mm of well graded base (19 to 75 mm max size) over 600 to 900 mm of select granular sub-base.

The majority of the pavements for the Coquihalla Highway have undergone some form of rehabilitation and maintenance since initial construction in the 1980s. Since construction, rehabilitation and maintenance activities have generally consisted of hot-in-place recycling, mill and fill of 50 to 100 mm of asphalt and concrete and chip sealing.

This pilot project assessed the vulnerability/adaptive capacity of the highway infrastructure including the drainage system. Of particular interest was the capacity of ditches as well as culverts less than 3 m in diameter to withstand potential future weather events that could create flood hazard in the area. This issue is of concern in a number of areas throughout the province and it is expected the results of this assessment will be of value in a number of locations.

This project was completed over the period November 1, 2009 through March 31, 2010 and contemplated climate change effects through the year 2050.

1.4 PIEVC Engineering Protocol for Climate Change Infrastructure Vulnerability Assessment

The Coquihalla Highway climate change vulnerability assessment followed the Protocol developed by PIEVC. The Protocol provides a framework to define, evaluate, and prioritize information and relationships regarding climate change impacts on the infrastructure.

Findings supported by this framework can be used to support decision-making on future operations, maintenance, planning, and development or potential upgrading or rehabilitation of the infrastructure.

The Protocol outlines five steps in the assessment process, as follows:

- Step 1: Project Definition
- Step 2: Data Gathering and Sufficiency
- Step 3: Risk Assessment
- Step 4: Engineering Analysis
- Step 5: Recommendations

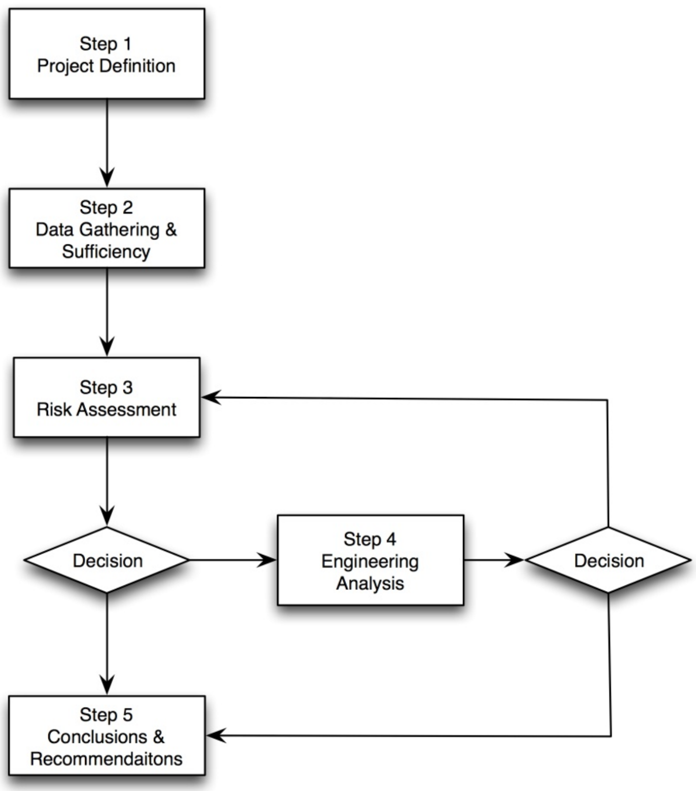
Part I of the most recent version of the Protocol, used for this study, is presented in **Appendix A**. The complete Protocol is available under license from Engineers Canada.

Each of the five steps has an associated worksheet that guides the practitioner through the assessment.

This report follows closely the steps outlined in the Protocol.

A flowchart outlining the process is presented in **Figure 1.1**. In the following sections we briefly summarize the evaluation process outlined by the Protocol.

Figure 1.1 Process Flowchart for Application of PIEVC Protocol



1.4.1 Step 1 - Project Definition

In this step the evaluation team defines the boundary conditions for the vulnerability assessment.

The team:

- Develops a general description of:
  - The infrastructure;
  - The location;
  - Historic climate;
  - Load;
  - Age;
  - Other relevant factors; and
- Identifies major documents and information sources.

1.4.2 Step 2 - Data Gathering and Sufficiency

In this step the team provides more definition about:

1. Which parts of the infrastructure will be assessed; and
2. The particular climate factors that will be considered.

This step comprises two key activities:

1. Identification of the features of the infrastructure that will be considered in the assessment:

    - Physical elements of the infrastructure;
        - Number of physical elements;
        - Location(s);
    - Other relevant engineering/technical considerations:
        - Material of construction;
        - Design parameters;
        - Age;
        - Importance within the region;
        - Physical condition;
    - Operations and maintenance practices;
    - Operation and management of the infrastructure;
        - Insurance considerations;
        - Policies;
        - Guidelines;
        - Regulations; and
        - Legal considerations.

2. Identification of applicable climate information. Sources of climate information include, but are not limited to:

    - The National Building Code of Canada, Appendix C, Climate Information;
    - Intensity - Duration – Frequency (IDF) curves;
    - Flood plain mapping;
    - Regionally specific climatic modeling;
    - Heat units (i.e. degree-days) (i.e. for agriculture, HVAC, energy use, etc.); and
    - Others, as appropriate.

The team is required to exercise professional judgement based on experience and training. This is an interdisciplinary process requiring engineering, climatological, operations, maintenance, and management expertise. The team must ensure that the right combination of expertise is represented either on the assessment team or through consultations with other professionals during the execution of the assessment.

1.4.3 Step 3 - Risk Assessment

In this step the team identifies the interactions between the infrastructure, the climate and other factors that could lead to vulnerability. These include:

- Specific infrastructure components;
- Specific climate change parameter values; and
- Specific performance goals.

The Protocol requires the team to identify which elements of the infrastructure are likely to be sensitive to changes in particular climate parameters. They will be required to evaluate this sensitivity in the context of the performance expectations and other demands that are placed on the infrastructure. Infrastructure performance may be influenced by a variety of factors and the Protocol directs the team to consider the overall environment that encompasses the infrastructure.

Based on these parameters the team performs a risk assessment of the infrastructure's vulnerability to climate change. The interactions identified are evaluated based on the professional judgement of the assessment team. The risk assessment will identify areas of key concern.

The team will identify those interactions that need further evaluation. The assessment process does not require that all interactions be subjected to further assessment. In fact, in the majority assessments most of the interactions considered will ultimately be eliminated from further consideration. Some interactions may clearly present no, or negligible, risk. Some interactions may clearly indicate a high risk and a need for immediate action. Those interactions that do not yield a clear answer regarding vulnerability may be subjected to the further engineering analysis.

At this stage, the team will also assess data availability and quality. If professional judgment identifies a potential vulnerability that requires data that is not available to the assessment team, the protocol requires that the team revisit Step 1 and/or Step 2 to acquire and refine the data to a level sufficient for risk assessment and/or engineering analysis. The team may determine that this process requires additional work outside of the scope of the assessment. Such a finding must be identified in the recommendations outlined in Step 5.

This is a key decision point in the Protocol. The practitioner is required to determine:

- Which interactions require additional assessment;
- Where data refinement is required; and
- Initial recommendations about:
    - New research;
    - Immediate remedial action; or
    - Non-vulnerable infrastructure.

1.4.4 Step 4 - Engineering Analysis

In Step 4 the team conducts focused engineering analysis on the interactions requiring further assessment, as identified in Step 3.

The Protocol sets out equations that direct the team to numerically assess:

- The total load on the infrastructure, comprising:
    - The current load on the infrastructure;
    - Projected change in load arising from climate change effects on the infrastructure;
    - Projected change in load arising from other change effects on the infrastructure;

- The total capacity of the infrastructure, comprising:
    - The existing capacity;
    - Projected change in capacity arising from aging/use of the infrastructure; and
    - Other factors that may affect the capacity of the infrastructure.

Based on the numerical analysis:

- A vulnerability exists when ***Total Projected Load*** exceeds ***Total Projected Capacity***; and
- Adaptive capacity exists when ***Total Projected Load*** is less than ***Total Projected Capacity.***

At this stage the team makes one final assessment about data availability and quality. If, in the professional judgement of the team, the data quality or statistical error does not support clear conclusions from the Engineering Analysis, the Protocol directs the team to revisit Step 1 and/or Step 2 to acquire and refine the data to a level sufficient for robust engineering analysis. The team may determine that this process requires additional work outside of the scope of the assessment. Such a finding must be identified in the recommendations outlined in Step 5.

Once the team has established sufficient confidence in the results of the engineering analysis, the Protocol reaches another key decision point. The team must decide to either:

- Make recommendations based on their analysis (Step 5); or
- Revisit the risk assessment process based on the new/refined data developed in the engineering analysis (Step 3).

1.4.5 Step 5 - Recommendations

In Step 5 the team is directed to provide recommendations based on the work completed in Steps 1 through 4. Generally, the recommendations will fall into five major categories:

- Remedial action is required to upgrade the infrastructure;

- Management action is required to account for changes in the infrastructure capacity;
- Continue to monitor performance of infrastructure and re-evaluate at a later time;
- No further action is required; and/or
- There are gaps in data availability or data quality that require further work.

The team may also identify additional conclusions or recommendations regarding the veracity of the assessment, the need for further work or areas that were excluded from the current assessment.

1.5 Project Team

Climate change engineering vulnerability assessment is a multidisciplinary process requiring a wide range of engineering, construction, operation, and maintenance skills and knowledge. Furthermore, the team must include deep knowledge of climatic and weather conditions relative to the project location. For the Coquihalla project, the primary technical and operations infrastructure knowledge was provided by BCMoTI personnel, who drove the project and were responsible for identifying and assessing the likely response of the infrastructure to projected climate change.

Staff from the Pacific Climate Impacts Consortium (PCIC) provided climate change data and forecasting as well as ongoing advice regarding the interpretation of climatic data.

The membership of the Project Team is outlined in **Figure 1.2**.

Figure 1.2 BCMoTI Project Team Membership

Area of Responsibility	Team Member
Project Manager	Shelley Pooler (To Jan 31, 2010) Jim Barnes (From Feb 1, 2010)
Chief Engineer	Dirk Nyland
Design & Survey	Andy Braacx Gar Lee Martin Van Hoof
Hydrology/Hydrotechnology	Mike Feduk
Structural	Ron Mathieson Don Shaw
Operations and Maintenance	Barry Eastman Kurt Edmunds Reg Fredrickson Jurgen Lutter Doug Wilson Peter Swetlishoff
District Technician	Loris Tommasel
Geotechnical	Brent Beatie

Figure 1.2 BCMoTI Project Team Membership

Area of Responsibility	Team Member
	Al Brown Joe Valentinuzzi
Environmental	Angela Buckingham Mike Miles (contractor)
Climate Data	Gerd Buerger Trevor Murdoch (PCIC)
Avalanche	Mike Boissonneault Ed Campbell Simon Walker

PIEVC provided ongoing advice to the project through a project advisory committee comprised of active PIEVC technical advisors.

The membership of the Project Advisory Committee is outlined in **Figure 1.3**.

Figure 1.3 Project Advisory Committee

Organization	Team Member
Engineers Canada	David Lapp
Ontario Ministry of Transportation	Hani Farghaly
Environment Canada	Heather Auld
Transport Canada	James Clarkin
B.C. Ministry of Environment	Ben Kangasniemi

BC MoTI retained Nodelcorp Consulting Inc. to facilitate the process and prepare this report.

The membership of the Facilitation and Reporting Team is outlined in **Figure 1.4**.

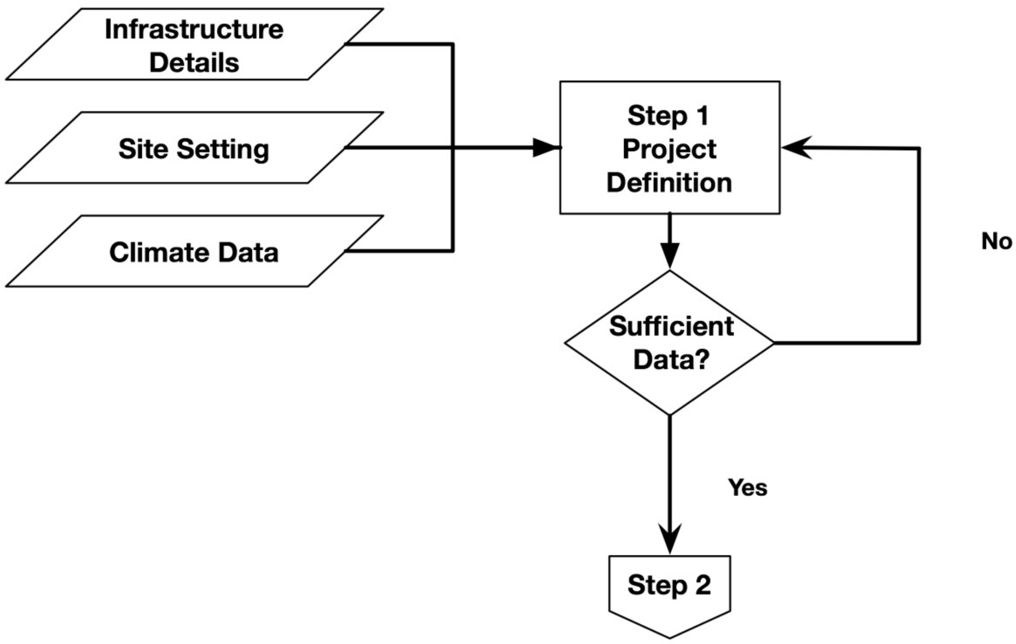
Figure 1.4 Facilitation and Reporting Team

Role	Team Member
Facilitation - Reporting	Joel R. Nodelman
Facilitation – Reporting	Joan Y.H. Nodelman
Reporting	Micah J. Nodelman

2 Step 1 – Project Definition

The team applied the Protocol process to define the project boundary conditions in space and in time. The process followed the steps indentified in the process flowchart presented in **Figure 2.1**.

Figure 2.1 Project Definition Process Flowchart



2.1 *Identify Infrastructure*

2.1.1 Pre Screening

In order to evaluate and compare potential sites that could be used in an assessment of roadway and associated infrastructure vulnerability due to climate change, BCMoTI developed a list of site selection criteria. Each criterion was assigned a weighting that indicated its relative importance in the site selection process.

For the purposes of the site evaluation, the team selected potential sites that included a section of roadway covering approximately 30 km to 40 km.

For each potential site, the BCMoTI Team assigned a rating between 0 (poor) and 5 (excellent) for each criterion on the "Site Rating" spreadsheet. This rating indicated the degree to which the site was a good candidate based on those specific criteria.

Once a site had been rated, a score for the site was calculated based on the criteria weighting and the site ratings.

The overall scores for each section of highway are presented in **Figure 2.2**.

The detailed analysis used by BCMoTI to establish the infrastructure for the study is presented in **Appendix B**. The completed Worksheet 1 from the Protocol and supporting documentation is presented in **Appendix C**.

Figure 2.2 Preliminary Screening of Potential Sites

Site	Score
Hwy 3, Kootenay Pass (between Salmo and Creston)	129
Hwy 31, Meadow Creek to Trout Lake	126
Hwy 16, Burns Lake to Smithers	130
Hwy 29, Chetwynd to Charlie Lake	117
Hwy 14, Sooke to Port Renfrew	111
Hwy 5, Coquihalla (between Hope and Merritt)	154
Hwy 3, Paulson Pass (between Christina Lake and Junction with Hwy 3B)	119
Hwy 16, Terrace to Prince Rupert	149

Based on the analysis completed by the BCMoTI Team, the stretch of Coquihalla Highway between Hope and Merritt received the highest overall rank and was selected as the focus of the first infrastructure climate change vulnerability assessment conducted by BCMoTI.

2.1.2 Infrastructure Description

The Coquihalla Highway is a 4 lane, divided, high-speed provincial roadway where the posted speed is 110 kph, maximum grade of 8% with climbing lanes and crawling lanes.

The study focused on a 44.83 km stretch of road on Highway 5 between Nicolum River (sometimes referred to as Creek) Bridge north abutment at km .90 and the south abutment of Dry Gulch Bridge at 45.73 km.

There is a significant road elevation change of approximately 900 meters from the study start point to the study end point.

The location of the infrastructure is detailed in **Figures 2.3 and 2.4**.

Figure 2.3 Map of Infrastructure Location

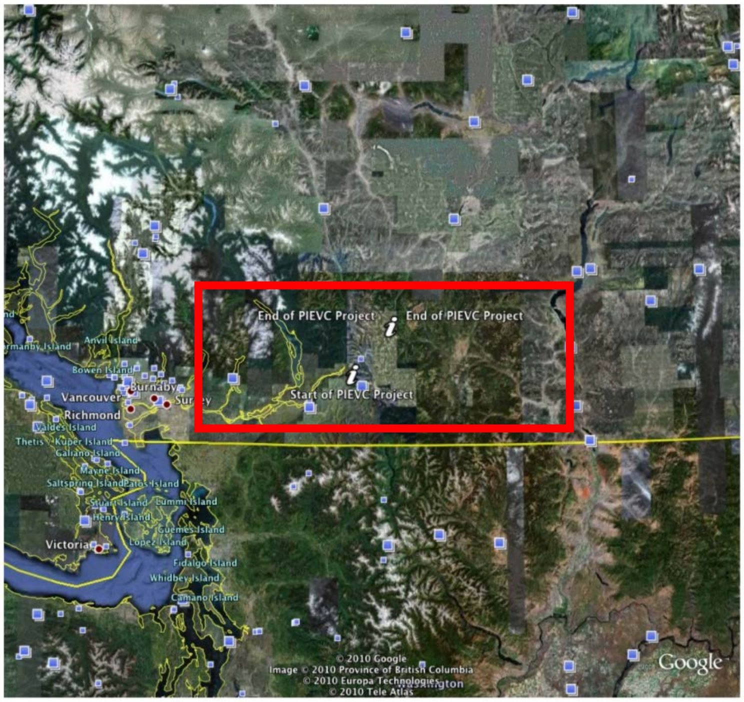


Figure 2.4 Close-up Map of Infrastructure Location

2.2 Identify Climate Factors of Interest

The team found that the identification of climate factors was a recursive process. Initially, the team identified an extensive list of potential climate factors. This list was defined in Worksheet 1 of the Protocol which is presented in **Appendix C**. This initial listing was completed on January 13, 2010 As work progressed, the team refined the list of pertinent climate factors based on their understanding of relevant interactions between the climate and the infrastructure. Thus, the list of potential climate factors identified in Worksheet 1 was adjusted throughout the assessment process ultimately arriving at the list provided in **Figure 2.5**.

The team observed that the initial list of climate parameters was more extensive than was ultimately necessary to conduct a comprehensive risk assessment and streamlined the list accordingly. Furthermore, the team noted that some relevant parameters were very difficult to define to a level sufficient to draw substantive conclusions. These parameters were identified for further studies and analysis outside of this context of this assessment.

The team also identified a number of infrastructure indicators to aid in the assessment. These indicators are specific infrastructure requirements related to the identified climate parameters. For example, the team determined that not only was high temperature a potential factor in assessing infrastructure responses to climate, they also determined, specifically, that the infrastructure would likely adversely respond to temperatures in excess of 30° C and that the number of days that the infrastructure experienced these conditions should be a consideration. These indicators were derived from design specifications and ongoing operation and maintenance considerations. The combination of climate parameter and infrastructure indicator provides sufficient definition for the team to assess specific infrastructure responses to the identified climatic condition.

Figure 2.5 Climate Parameters and Infrastructure Indicators Selected for the Risk Assessment

#	Climate Parameter	Infrastructure Indicator	Source	Comments
1	High Temperature	Number of Days with max. temp. exceeding 30° C	S6-06 Clause 3.9 – Superimposed Deformations – temperature effects to be addressed in bridge design; maximum and minimum effective temperatures given	Adjusted by PCIC from 35° C. Temperatures >30° C not observed in regional meteorological data used by PCIC.
2	Low Temperature	Days with min. temp. below -24° C	S6-06 Clause 3.9 – Superimposed Deformations – temperature effects to be	Adjusted by PCIC from -30° C. Temperatures < -30° C not observed in regional meteorological

Figure 2.5 Climate Parameters and Infrastructure Indicators Selected for the Risk Assessment

#	Climate Parameter	Infrastructure Indicator	Source	Comments
			addressed in bridge design; maximum and minimum effective temperatures given	data used by PCIC.
3	Temperature Variability	Daily temperature variation of more than 24^{o}C	S6-06 Clause 3.9 – Superimposed Deformations – temperature effects to be addressed in bridge design; maximum and minimum effective temperatures given S6-06 Clauses 6.4 and 6.5 - Foundation design and Geotechnical investigation – consider temperature change effects	Adjusted by PCIC from 25^{o}C. Temperature variations > 25^{o}C not observed in regional meteorological data used by PCIC.
4	Freeze / Thaw	17 or more days where max. temp. > 0^{o}C and min. temp.<0^{o}C	S6-06 Clause 8.11 – Durability – consider freeze-thaw deterioration of concrete S6-06 Clauses 6.4 and 6.5 - Foundation design and Geotechnical investigation – consider temperature change effects	Adjusted by PCIC from 85 days. 85 days of freeze thaw cycling not observed in regional meteorological data used by PCIC.
5	Frost Penetration	N/A	S6-06 Clause 6.4.3 – Effects on structure – consideration shall be given to frost penetration. S6-06 Clauses 6.4 and 6.5 - Foundation design and Geotechnical investigation – consider frost penetration	Assessed through empirical analysis of forecast climate conditions.
6	Frost	47 or more days where min. temp. <0^{o}C	S6-06 Clause 6.4.3 – Effects on structure – consideration shall be given to frost	Adjusted by PCIC from 147 days. 147 days of consecutive frost not observed in regional

Figure 2.5 Climate Parameters and Infrastructure Indicators Selected for the Risk Assessment

#	Climate Parameter	Infrastructure Indicator	Source	Comments
			penetration. S6-06 Clauses 6.4 and 6.5 - Foundation design and Geotechnical investigation – consider frost penetration	meteorological data used by PCIC.
7	Extreme Rainfall Intensity Over One Day	> 76mm over 24hrs.	S6-06 Clause 1.8.2.3 – Drainage systems – deck drainage required for 1/10 year storm S6-06 Clauses 6.4 and 6.5 - Foundation design and Geotechnical investigation – consider groundwater effects, slope stability, erosion	Determined empirically as PCIC used indicator based on resolution of RCMs.
8	Magnitude of Severe Storm Driven Peak Flows	Directional wind speed, temperature and precipitation all > median values.	S6-06 Clause 1.8.2.3 – Drainage systems – deck drainage required for 1/10 year storm BC Supplement to S6-06 Clause 1.9.1.2 – Hydraulic design of bridge opening for 1/200 year flood event S6-06 Clause 3.9 – Superimposed Deformations – temperature effects to be addressed in bridge design; maximum and minimum effective temperatures given S6-06 Clause 3.10 – Wind loads – depending on the structure use 1/10 year return period (sign structures) to 1/100 year return period (long span bridges). S6-06 Clauses 6.4 and 6.5 - Foundation design	Determined empirically as PCIC used indicator based on resolution of RCMs.

Figure 2.5 Climate Parameters and Infrastructure Indicators Selected for the Risk Assessment

#	Climate Parameter	Infrastructure Indicator	Source	Comments
			and Geotechnical investigation – consider frost penetration, groundwater effects, temperature change effects, slope stability, erosion	
9	Frequency of Severe Storm Driven Peak Flow Events	Directional wind speed, temperature and precipitation all > median values for three consecutive days in autumn.	S6-06 Clause 1.8.2.3 – Drainage systems – deck drainage required for 1/10 year storm BC Supplement to S6-06 Clause 1.9.1.2 – Hydraulic design of bridge opening for 1/200 year flood event S6-06 Clause 3.9 – Superimposed Deformations – temperature effects to be addressed in bridge design; maximum and minimum effective temperatures given S6-06 Clause 3.10 – Wind loads – depending on the structure use 1/10 year return period (sign structures) to 1/100 year return period (long span bridges). S6-06 Clauses 6.4 and 6.5 - Foundation design and Geotechnical investigation – consider frost penetration, groundwater effects, temperature change effects, slope stability, erosion	Determined empirically as PCIC used indicator based on resolution of RCMs.
10	Rain on Snow	10 or more days where rain falls on snow	S6-06 Clause 1.1.1 – Scope of code – for structures subject to	

Figure 2.5 Climate Parameters and Infrastructure Indicators Selected for the Risk Assessment

#	Climate Parameter	Infrastructure Indicator	Source	Comments
			avalanche retain specialists to review and advice. S6-06 Clauses 6.4 and 6.5 - Foundation design and Geotechnical investigation – consider groundwater effects, slope stability, erosion	
11	Freezing Rain	1 or more days with rain that falls as liquid and freezes on contact	S6-06 Clause 3.12.6 – Ice Accretion – design for ice accretion effects	Adjusted by team from 9 days. Any amount of freezing rain can be a concern on the highway.
12	Snow Storm / Blizzard	8 or more days with blowing snow	S6-06 Clause 3.1 – Snow loads not normally considered on bridges because a considerable snow load will cause a compensating reduction in traffic load. S6-06 Clause 12.4.1 – consider snow accumulation and snow removal from the deck when considering bridge barrier systems. Maintenance Response Standards.	
13	Snow (Frequency)	Days with snowfall >10 cm	S6-06 Clause 3.1 – Snow loads not normally considered on bridges because a considerable snow load will cause a compensating reduction in traffic load. S6-06 Clause 12.4.1 – consider snow accumulation and snow removal from the deck when considering bridge	

Figure 2.5 Climate Parameters and Infrastructure Indicators Selected for the Risk Assessment

#	Climate Parameter	Infrastructure Indicator	Source	Comments
			barrier systems. Maintenance Response Standards.	
14	Snow Accumulation	5 or more days with a snow depth >20 cm	S6-06 Clause 3.1 – Snow loads not normally considered on bridges because a considerable snow load will cause a compensating reduction in traffic load. S6-06 Clause 12.4.1 – consider snow accumulation and snow removal from the deck when considering bridge barrier systems. Maintenance Response Standards.	
15	High Wind / Downburst	Wind speed > 80.5 km/hr	S6-06 Clause 3.10 – Wind loads – depending on the structure use 1/10 year return period (sign structures) to 1/100 year return period (long span bridges)	Adjusted by project team from 63 km/hr
16	Visibility due to Fog	Decrease in stopping sight distance < 245 m	Based on engineering calculation of minimum safe stopping distance	Determined empirically

2.3 The Pineapple Express

The team expressed some uncertainty with respect to the definition of severe, localized, storm events. At this point of the evaluation the team characterized these events as "storm bombs". However, later in the assessment process the team's understanding of these events was refined to specifically refer to "Pineapple Express" events.

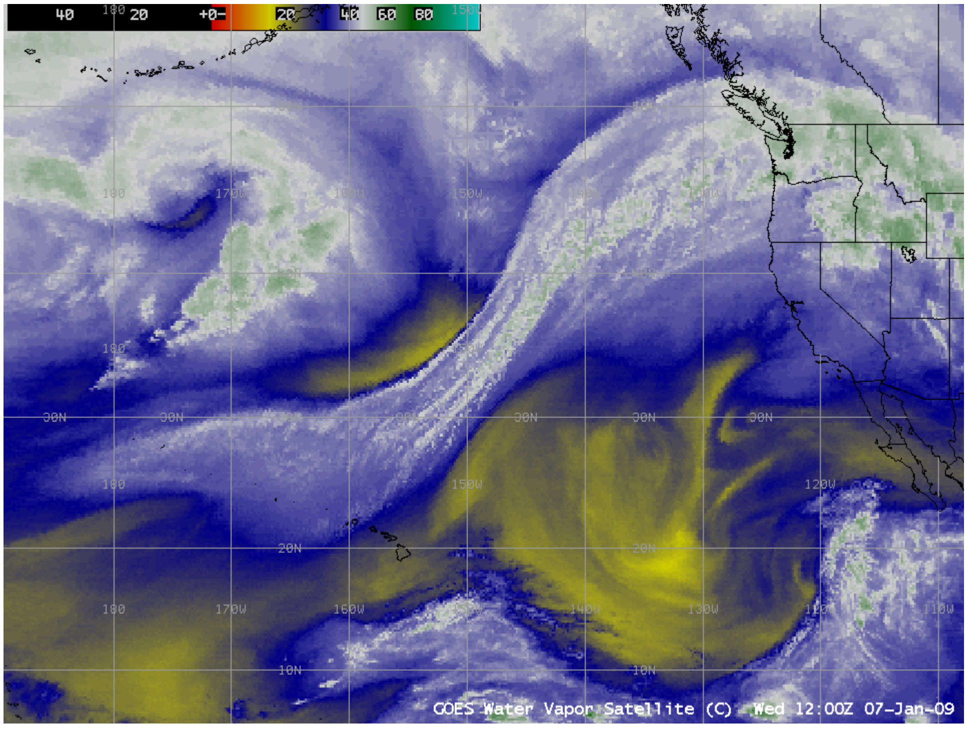
Pineapple Express is an informal name for a flow of low and mid-level moist air, driven by the subtropical jet stream, that sometimes extends from the region around Hawaii to the west coast of North America[1].

Pineapple Express events are characterized by strong, moisture-laden, winds from that impact upon the Coquihalla region of B.C. and drop significant quantities of precipitation in very short periods. The team described events where rainfall in excess of 150 mm was experienced over periods of less than 24 hours.

Figure 2.6 presents a satellite image of a typical Pineapple Express event.

Pineapple Express events have increased in both intensity and frequency. The team anticipates that these changes will continue over the time horizon of the study.

Figure 2.6 Pineapple Express Satellite Image (NOAA GOES-11 2009)



[1] University Corporation for Atmospheric Research (UCAR), http://www.ucar.edu/news/backgrounders/patterns.shtml, Retrieved May 10, 2010

2.4 *Identify the Time Frame*

The team identified a time frame for the assessment of roughly 43 years – to the year 2053. This was based on the remaining useful service life of the highway without significant rehabilitation work. They determined that:

- From the opening of highway, there was a design service life of 70-77 years;
- Without rehab and regular maintenance the functional service for the Coquihalla Highway was designed through 2053; and
- The highway has ongoing maintenance but no refurbishment scheduled at present.

Thus the assessment timeline matches the notional functional service life of the highway without regular rehabilitation and maintenance.

2.5 *Identify the Geography*

The highway is located in mountainous terrain bordered by the Upper Fraser Delta to the west and the Cascade Mountain Range to the east. The Coquihalla River or tributaries runs alongside the length of the highway infrastructure with a significant road elevation change of approx 900 meters from the start point to the end point.

There is significant climatological gradient, especially at the top end of this section of road. This can lead to dramatic differences in the climatic conditions experienced over a few kilometres of the highway.

2.6 *Identify Jurisdictional Considerations*

The team identified a long list of potential jurisdictional interests either directly related to the highway and its corridor and also with the Coquihalla region in general. These interests are identified in **Figure 2.6**.

While maintaining an awareness of these interests and discussing the implications of climate change on the highway in the context of these interests, ultimately the team did not identify a jurisdictional interest that had any incremental affect on the highway when climate change factors were taken into consideration.

These interests were discussed extensively during the working meetings of the team and were considered during the two-day risk assessment workshop. However, ultimately the team did not identify a jurisdictional consideration that was materially affected by climate change.

Figure 2.7 Jurisdictional Considerations

Jurisdiction	Consideration
Department of Fisheries and Oceans	• Fish habitat • Considered navigable
Ministry of Environment	• Wildlife and Vegetation • Fish habitat • Water Act Approvals • Biodiversity protection (e.g. fish, vegetation, wildlife, habitat) • Water Act approvals (e.g. diversions, withdrawals) • Pollution prevention (e.g. spills, contaminated runoff) • Parks and protected areas • Provincial Park at Falls Lake • Etc.
Utilities	• Pipelines • Trans Mountain (now Duke Energy) • Boston Bar • Gas/Oil Transmission • Telus (fibre optics cables directly underneath Dry Gulch) • Hydro

First Nations	• Asserted traditional territory of:
	    • Stolo Nation
	    • Yale First Nation (Traditional Use)
	    • Union Bar First Nation (Traditional Use)
	• There are no reserves along this section of the highway.

Ministry of Forests (Chilliwack Forest District)	• The highway passes through the Coquihalla Recreation Area. • Forest road access may be a concern.
Transport Canada	• Possible CEAA considerations. • Navigable Waters Protection Act (Coquihalla River considered navigable)

Figure 2.7 Jurisdictional Considerations

Jurisdiction	Consideration
Fraser Valley Regional District (Fraser Valley B)	
Chilliwack Hope Electoral District	
Access to private land or commercial enterprises	• Cut block licensee and property owner access
Environment Canada	• Wild Life • Species at Risk
Provincial Ministry of Environment Parks & Recreation	• Minor recreational spots • Small Park

2.7 *Site Visit*

A site visit was conducted on January 15, 2010. In addition, the team provided a site inspection report generated in April 2009. These inspections provide a solid basis for understanding the baseline conditions of the highway. In general, the team identified the following global issues:

- Corrosion, especially with respect to metal culverts and MSE wall reinforcement straps;
- Damage from snow removal activities especially with respect to curbs and barriers;
- Debris blocking culverts;
- Erosion from runoff;
- Avalanche considerations;
- High water flows from peak storm events; and
- Visibility issues.

In general, the highway appears to be robustly designed. Maintenance and operational activities have evolved to accommodate the climatic conditions experienced by the highway.

The observations from the site visits were reinforced through the experience of the project team. The team comprised BCMoTI staff with significant hands-on experience in the design, operation, and maintenance of this highway. A number of team members have worked with the highway since it was opened. Thus, during the workshops the team had a deep foundation of skills and experience to draw from in assessing the impact of climate change on the infrastructure.

2.8 *Assess Data Sufficiency*

Upon completion of Step 1 of the Protocol, the team determined that they had sufficient data to proceed to Step 2 of the assessment.

The team was concerned about a lack of specific design drawings with respect to the highway. However, over the course of the study, this issue did not cause material concern. In general, the experience of the team compensated for any lack of specific design data.

In retrospect, the team was correct in stating that there is sufficient data to actually assess the risk of climate change on infrastructure and accommodate most of the data gaps through experience and local knowledge.

Ultimately, two of the climate parameters were identified as areas of poor data sufficiency. These were:

- Parameter 15 - High Wind / Downburst; and
- Parameter 16 - Visibility

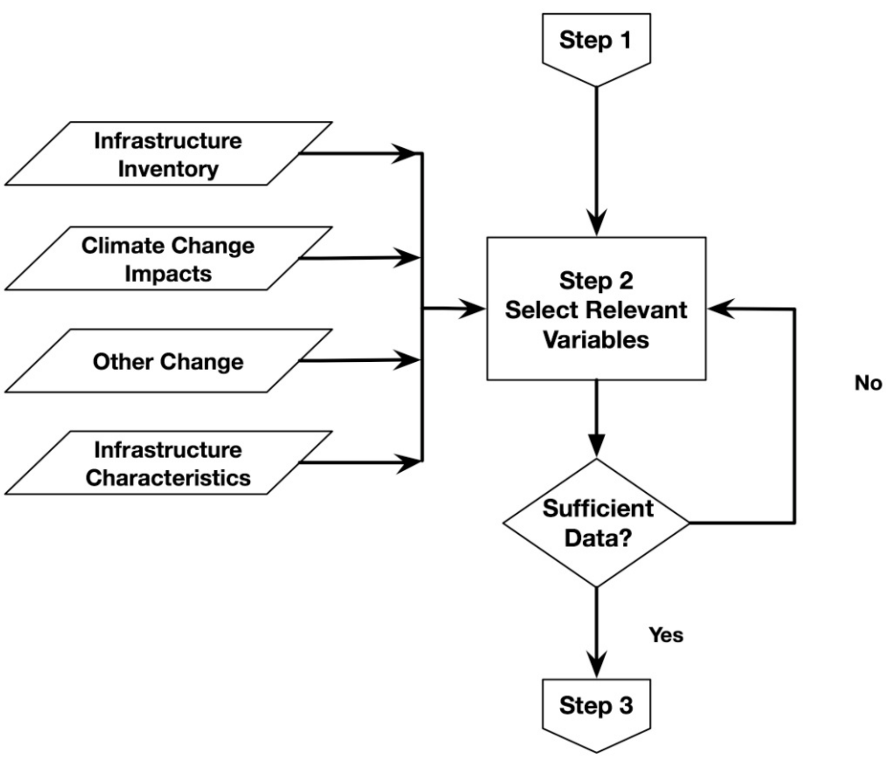
In both cases the team was unable to identify processes to backfill or augment the lack of information. However, the team remained concerned about the impact of these climate parameters on the serviceability of the highway and concluded that further work, outside of the context of the current study, is necessary to provide better resolution of these factors.

3 Step 2 – Data Gathering and Sufficiency

The Protocol applies a recursive process to identify, locate and define data used in the risk assessment process. In Step 1, the Protocol establishes the project boundary conditions. In Step 2, these definitions are further refined to provide an in-depth definition of the climate parameters and specific infrastructure sub-components to be considered in the risk assessment. This is accomplished through a detailed review of the specific characteristics of the infrastructure and its sub-components. Infrastructure components are the physical, operational and procedural features of the infrastructure that the team defines to be potentially vulnerable to climate change. Throughout the remainder of the assessment process, these components are reviewed, refined and assessed to determine the specific level of vulnerability. It is quite common that the process identifies no vulnerability for a large number of components. This is a positive outcome since it represents a focussed review of the situation and an active decision regarding vulnerability.

The process followed the steps indentified in the process flowchart presented in **Figure 3.1**.

Figure 3.1 Step 2 – Data Gathering and Sufficiency Process Flowchart



For the purposes of this section of this report, we provide the incremental or refined information that was generated through Step 2 of the process. Where no change arose in the data being used, we refer the reader to the appropriate part of Section 2 of this report.

The team undertook the analysis required for Step 2 over approximately eight weeks between early January and late-February 2010. Even so, the team further refined some climate parameter and infrastructure component definitions at the risk assessment workshop held in early March.

The complete Step 2 Worksheet for the assessment is presented in **Appendix D**.

3.1 State Infrastructure Components

The team spent considerable effort to define relevant infrastructure components for the Coquihalla Highway. As noted above, the team continuously refined this list throughout the process and finalized the list at the risk assessment workshop in early March 2010. We found this ongoing review and refinement to be very beneficial.

The team reviewed each component of the infrastructure and considered its vulnerability from a number of perspectives, based on the experience and skills represented by the team membership. This allowed the team to conduct a thorough review and ensured that, at the risk assessment workshop, there was a common understanding of the infrastructure characteristics being contemplated in the assessment.

The final infrastructure component listing is presented in **Figure 3.2**.

Figure 3.2 Infrastructure Component Listing

	Infrastructure Components
#	**Infrastructure**
1	Surface - Asphalt
2	Pavement Marking
3	Shoulders (Including Gravel)
4	Barriers
5	Curb
6	Luminaires
7	Poles
8	Signage - Side Mounted - Over 3.2 m2
9	Signage - Overhead Guide Signs
10	Overhead Changeable Message Signs
11	Ditches

Figure 3.2 Infrastructure Component Listing

	Infrastructure Components
12	Embankments/Cuts (Constructed)
13	Hillsides (Natural)
14	Engineered Stabilization Works
15	Avalanche (Inc Protective Works)
16	Debris Torrents (Inc Protective Works)
17	Structures that Cross Streams
18	Structures that Cross Roads
19	River Training Works (Rip Rap)
20	MSE Walls
21	Pavement Structure above Sub-Grade
22	Catch Basins
23	Median and Roadway Drainage Appliances
24	Sub-Drains
25	Third party utilities
26	Culverts < 3m
27	Culverts ≥ 3m
28	Asphalt Spillway and Associated Piping/Culvert
	Environmental Features
29	In stream habitat works
30	Off channel habitat works
31	Wild life fence system
32	Wild life crossing structures
33	Vegetation management
34	Invasive Plants & Pests
	Miscellaneous
35	Administration/Personnel & Engineering
36	Winter Maintenance
37	Ancillary buildings and utilities and yards.
38	Communication
39	Emergency Response
40	Maintenance (Markings, Crack Sealing)

3.2 Detailed Climate Considerations

Three approaches were used to establish the climate parameters used in the climate change risk assessment. These include:

1. Climate modeling;
2. Synoptic analysis; and
3. Sensitivity analysis.

Although climate modeling was a good tool for establishing both the baseline and future climates, the team did identify a number of infrastructure-specific climate parameters that were not amenable to modeling analysis, at least within the timeframe of the assessment.

Parameters that could not be determined using modeling were assessed using either:

- A synoptic process based on professional judgement; or
- Arbitrarily assigning climate change probabilities for specific parameters and then adjusting those probabilities using sensitivity analysis to determine the impact on risk outcomes.

All three of these approaches are sanctioned by the Protocol.

As discussed in **Section 2.7**, the team identified two climate parameters to be unnameable to any of the three approaches and recommended that further studies be conducted to resolve these parameters.

In the following sections we describe the detailed processes used to establish climate change parameters used in the assessment.

3.3 Climate Modeling

3.3.1 Global Circulation and Regional Climate Models

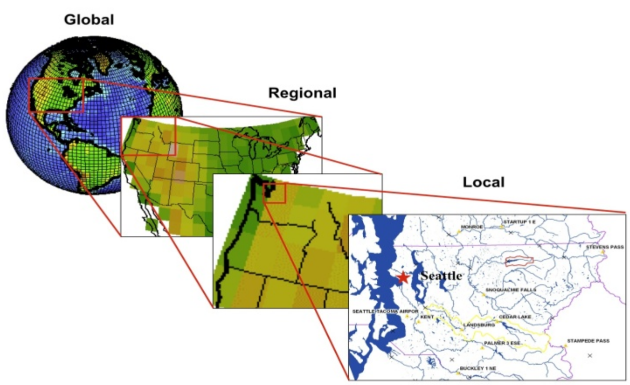
A general circulation model (GCM) , also known as a global climate model, is a computer model of the general circulation of planetary atmosphere and oceans based on fundamental thermodynamic principles. These models are used by climate scientists to predict changes in climatic conditions over extended periods.

GCMs calculate very complex thermodynamic relationships across the globe based on a theoretical segmentation of the atmosphere into rectangular boxes and quantifying the mass and energy balances across the box's boundaries.

Regional climate models (RCMs) use similar principles of conservation of energy, mass and movement to generate finer regional representation of climate. Developed using the same physical principles as GCMs, RCMs concentrate on a portion of the globe and allow production of simulations at higher spatial resolution.

RCMs are downscaled from Global Climate Models (GCMs). Typically, GCMs have a horizontal resolution of 250 km and a vertical resolution of 1 km. RCMs have a horizontal resolution of 50 km, often called a 50 km x 50 km grid. As a consequence, there is a scale mismatch between the RCMs and local climatic conditions. RCMs tend to predict more average conditions across the grid and to miss localized climate events. **Figure 3.3** gives a sense of this scale mismatch.

Figure 3.3 Scale Mismatch between, Global/Regional Climate Models and Local Conditions



3.3.2 Initial Assessment

Climate modeling for the study was provided by the Pacific Climate Impacts Consortium (PCIC). PCIC's summary report is presented in **Appendix E**.

PCIC used three regional climate models (RCMs) to project future climatic conditions. Each model derives data from a base GCM. The RCM/GCM parings used in this study are the:

- Canadian Regional Climate Model (CRCM)
  - Driven by the Third Generation Global Coupled Climate Model (CGCM3)
- Hadley Centre Regional Climate Model (HRM3)
  - Driven by the Hadley Centre Coupled Model, Version 3 (HadCM3)
- ICTP Regional Climate Model (RCM3)
  - Driven by the Third Generation Global Coupled Climate Model (CGCM3)

Each RCM projection comes in its own grid of size 50km x 50km. For this study PCIC selected for each RCM the tile that had the greatest overlap with the study area.

GCMs are based on assumed greenhouse gas emission scenarios, developed by the Intergovernmental Panel on Climate Change (IPCC). For the purposes of this study, PCIC used the following emissions scenarios.

20C3M

- Used to calculate the present climate
- 1970 to 2000
- Greenhouse gases increasing as observed through the 20th Century

SRA2

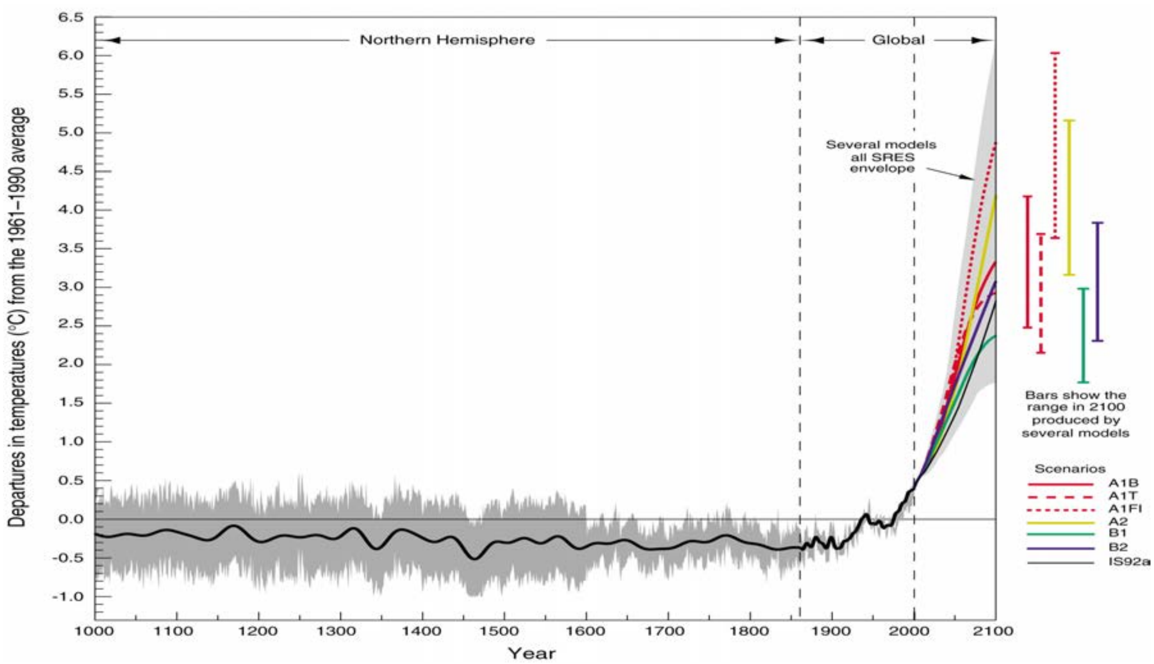
- Used to calculate the future climate
- 2040 to 2070
- Represents a very heterogeneous world. The underlying theme is that of strengthening regional cultural identities, with and emphasis on family values and local traditions, high population growth, and less concern for rapid economic development. This scenario generally assumes:
  - Independently operating, self-reliant nations;
  - Continuously increasing population;
  - Regionally oriented economic development; and
  - Slower and more fragmented technological changes and improvements to per capita income.

GCMs that apply SRA2 cover the mid mange to high range of climate change forecasts. Thus, these models provide a reasonable range of future climate scenarios without assuming the extreme worst case conditions inherent in the A1FI emissions scenario where there is a high reliance on fossil fuel use world-wide.

RCMs will yield a range of values depending on the imbedded climate assumptions, thermodynamic models and calculation methodologies. Thus, in climate change work it is normal to use a cohort of model outputs to cover a range of conditions and provide more statistical certainty. For this study PCIC applied the three models outlined above.

Figure 3.4 presents the range of future climate temperature forecasts driven by the various IPCC emission scenarios and GCMs. The range of forecast global climate conditions as well as the range of model outputs is clearly outlined in the colored bars on the right side of the figure. SRA2, represented by| the yellow bar, covers between mid-range to the upper quartile of all forecasts.

Figure 3.4 Range of Future Climate Forecasts based on Different IPCC Emission Scenarios



To compensate for scale mismatch, PCIC used statistical downscaling to tailor the RCM outputs to local conditions in the Coquihalla region. The approach involves:

- Synoptic analysis of larger scale weather systems and how they affect local conditions;
- Statistical (regression) analysis; and
- Interpolation.

PCIC also reviewed historic weather conditions in the Coquihalla region through weather data retrieved from 17 Environment Canada weather satiations dispersed throughout the region. The location of the weather stations used for the study is identified in **Figure 3.5**.

PCIC used the historic (baseline) conditions to rationalize results from the RCMs so that there is a meaningful correlation between observed and predicted climatic conditions in the study area.

The outputs from PCIC's work included:

- Percentiles and boxplots of core meteorological parameters from:
  - 17 daily station readings between 1971 and 2000
  - CRCM, HRM3, and RCM3 driven by:
    - NCEP analyses (large scale atmospheric observations)
    - GCM driven by present greenhouse gas emissions
    - GCMs driven by future greenhouse gas emissions

- Upscaled design probabilities for each future RCM
  - Extreme high and low temperature, extreme diurnal temperature range
  - Consecutive freeze/thaw cycles
  - Consecutive frost
  - Consecutive heavy rain

The climate parameter definitions used by PCIC for the purposes of this study are presented in **Figure 3.6**. In order to generate meaningful results, especially for predicted probability of specific climatic events, PCIC made a number of small adjustments to the climate parameter list identified by the project team. These adjustments had no material impact on the study considerations but allowed PCIC to generate statistically meaningful values.

Figure 3.5 Location of Weather Stations used in the Study

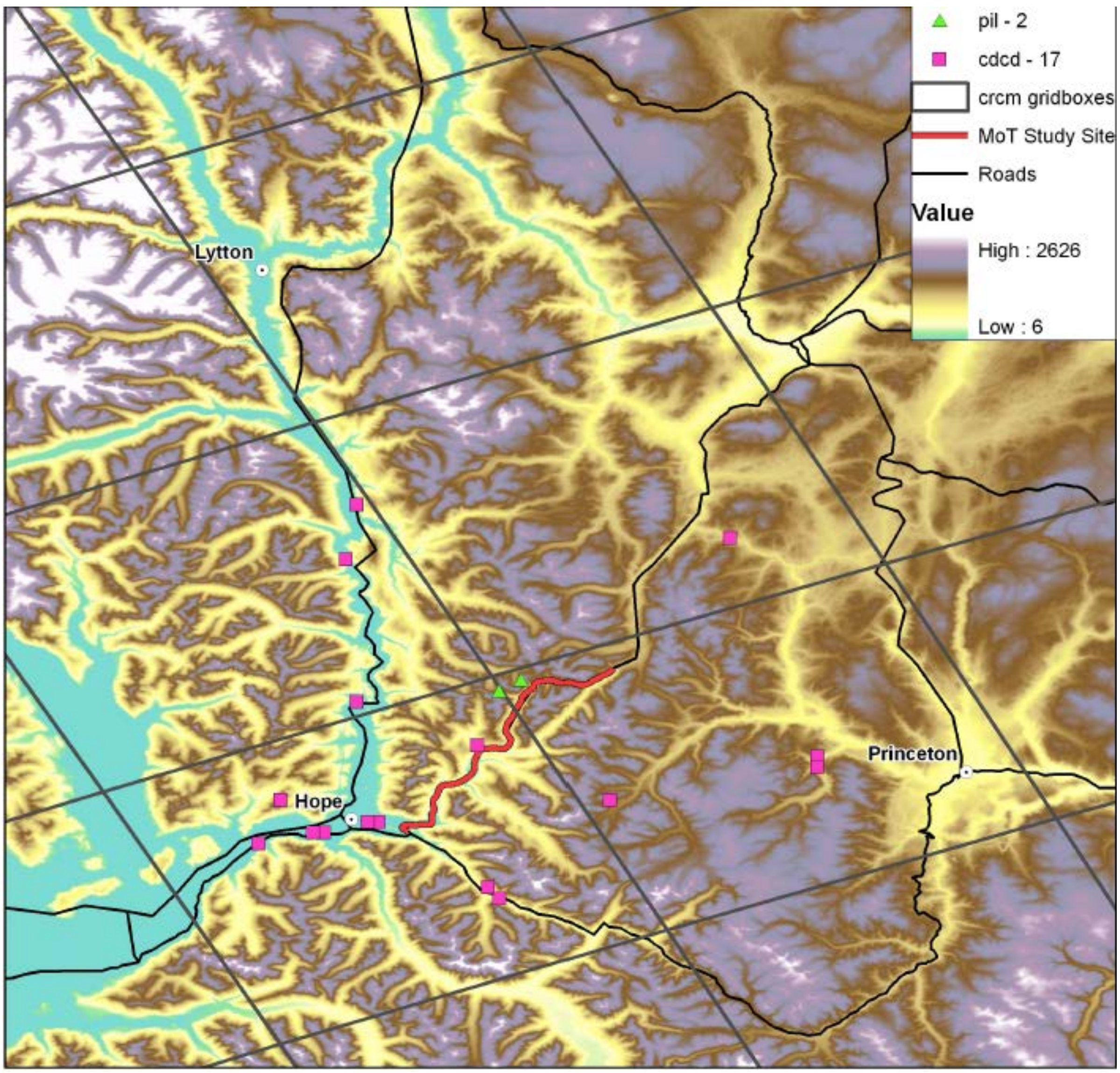


Figure 3.6 PCIC Definitions for Extreme Climate Events

Parameter	Threshold	Period
High Temp	T_{max} > 30 ºC	1 day
Low Temp	T_{min} < -24 ºC	1 day
Temp Range	T_{range} > 24 ºC	1 day
Freeze/Thaw	T_{min} < 0 ºC & T_{max} > 0 ºC	17 days
Frost	T_{min} < 0 C	47 days
Heavy Rain	P > 76 mm/d	1 day
Rain Frequency	P > 18 mm/d	5 days

One of the key outputs from PCIC's work was a probabilistic analysis of the likelihood of these extreme climatic events in both the baseline climate and in the future climate, as predicted by the RCMs. The results from this analysis are presented in **Figure 3.7**.

Figure 3.7 Event Probabilities per Year

	Present	Future		
		CRCM	HRM3	RCM3
High Temp	0.567	1.767	3.433	5.167
Low Temp	0.033	0.033	0	0
Temp Range	0.033	0	0	0
Freeze/Thaw	0.033	0	0	0.033
Frost	0.066	0	0	0
Heavy Rain	0.033	0.066	0.066	0
Rain Frequency	0.033	0.033	0.033	0.033

In addition, PCIC provided parameter-specific results for both observed and RCM predicted climatic conditions. Their results included RCM values for historic climate as well as predicted values for the future climate. This information was used to rationalize the future climate predictions with actual weather data in order to calibrate the model outputs with real world conditions. This is one method to increase confidence in the predicted model results. These results are presented in **Figures 3.8, 3.9 and 3.10**.

Figure 3.8 Maximum Summer Temperature

Percentiles [ºC]	CRCM		HRM3		RCM3		OBS
	Historic	Future	Historic	Future	Historic	Future	
1%	5.47	7.41	9.61	12.87	3.6	5.46	7.9
5%	7.37	9.31	13.05	16.99	6.75	8.37	12
50% (Median)	14.45	16.76	24.44	28.00	13.85	16.15	22.2
95%	24.36	26.42	32.86	37.54	21.92	25.91	33
99%	27.57	30.52	37.02	41.37	24.9	29.94	37

Figure 3.9 Summer Precipitation

Percentiles [mm/d]	CRCM		HRM3		RCM3		OBS
	Historic	Future	Historic	Future	Historic	Future	
1%	0	0	0	0	0	0	0
5%	0	0	0	0	0	0	0
50% (Median)	0.71	0.55	0	0	0.62	0.61	0
95%	11.32	11.29	6.91	6.24	15.82	16.09	11.53
99%	23.1	23.92	19.62	21.87	29.66	30.51	26

Figure 3.10 Wind

Percentiles [m/s]	CRCM		HRM3		RCM3	
	Historic	Future	Historic	Future	Historic	Future
1%	0.14	0.13	0.54	0.51	0.53	0.51
5%	0.53	0.51	1.07	1.06	1.14	1.12
50% (Median)	3.54	3.5	2.58	2.55	3.52	3.4
95%	7.81	7.84	5.28	5.22	7.67	7.49
99%	9.89	9.97	6.44	6.42	9.61	9.51

In the case of wind, reliable observational data was not available to PCIC. In this case they applied the RCMs to establish both the historic and future climates.

Based on this initial analysis, PCIC projected that the Coquihalla Highway will experience:

- Warming with;
  - Increasing hot extremes (very likely);
  - Decreasing periods of hard frost (very likely);
- Reduction in the range of temperatures (very likely); and
- An increase in periods of heavy precipitation (uncertain);
  - Requiring more detailed empirical downscaling to resolve.

3.3.3 Follow-up Work

Prior to the workshop in early March, PCIC was unable to provide an assessment of future climate conditions for a number of parameters. However, in discussion with the team at the workshop, PCIC identified rational approaches to develop an indication of future climate conditions for three additional parameters. The approaches involved combining results for modeled climate parameters and some synoptic analysis of the implications of the results from the models. The additional parameters included:

- Snow Storm / Blizzard;
  - Based on professional opinion of current data for precipitation, temperature and wind.
- Snow frequency,
  - Based on combining existing data on precipitation and temperature; and
- Pineapple Express Events;
  - Based on professional opinion on frequency based on review of wind data and precipitation.

This data was provided subsequent to the workshop and was used to crosscheck synoptic and sensitive analysis results.

The results from the follow-up analysis are presented in **Figure 3.11**.

Figure 3.11 Probability of Three Additional Climate Parameters

Parameter	Definition	CRCM Historic	CRCM Future	HRM3 Historic	HRM3 Future	RCM3 Historic	RCM3 Future	Observed
Snow Storm / Blizzard	P, W > median and T < 0 8 days in a row	0.067	0.000	0.067	0.200	0.100	0.000	-
Snow Frequency (> 10cm)	P > 10mm and T < 0	-	0.142	-	0.115	-	0.155	0.169
Pineapple Express	u, v, T, P > median 3 consecutive days in autumn.	0.100	0.233	0.100	0.133	0.033	0.000	-

Where:

P = Precipitation
W = Wind Speed
T = Temperature
u = Vector Wind Direction
v = Vector Wind Direction

Based on these results, PCIC offered the following projections:

- Snow storms and blizzards will slightly decrease in intensity over the study timeframe;
  - Medium level of confidence in projection;
- Snow frequency will moderately decrease over the study timeframe;
  - High level of confidence in projection; and
- Pineapple Express events will moderately increase both in magnitude and frequency over the study timeframe;
  - Medium level of confidence in projection.

PCIC indicated that the Pineapple Express analysis could be used to assess both:

- Climate Parameter 8, Magnitude of Severe Storm Driven Peak Flows; and
- Climate Parameter 9, Frequency of Severe Storm Driven Peak Flow Events.

3.3.4 Climate Modeling Gaps

Based on the project schedule and limitations in climate modeling, PCIC was unable to provide model-based projections for the following climate parameters:

- Climate Parameter 10, Rain on Snow
- Climate Parameter 11, Freezing Rain
- Climate Parameter 14, Snow Accumulation
- Climate Parameter 15, High Wind / Downburst
- Climate Parameter 16, Visibility

For Parameters 10, 11 and 14 PCIC stated that providing reliable data for these parameters could not be accomplished within the current project schedule. However, given a longer time frame, on the order of six months, they may be able to provide some input on these parameters. For Parameters 15 and 16, PCIC stated that they were not able to resolve these issues using current model data.

For Parameters 10, 11 and 14 the team agreed that a sensitivity analysis could be used to assess potential climate change risk. The assessment of these parameters is described in **Section 3.5**. However, the team was not comfortable about speculating on Parameters 15 and 16. These items were forwarded to Step 5 of the Protocol with the recommendation to conduct additional analysis following the completion of this assessment.

PCIC was consistent throughout this assessment in stating that there are inherent statistical uncertainties associated with this type of analysis. Care should be taken in applying the data in a risk assessment process. The team compensated for this uncertainty with many years of day-to-day operational experience on the infrastructure.

3.3.5 Climate Modeling Uncertainties

Climate modeling is based on inherent assumptions regarding likely emissions scenarios. Additionally, there is a significant level of statistical uncertainty associated with both the modeling and the analytical approaches used to downscale the information generated by the regional climate models to local conditions. PCIC addressed this concern by correlating model predictions with observed, baseline, climate conditions.

Socio-economic scenarios drive both RCMs and GCMs. As in any economic forecast, there is an imbedded level of speculation and statistical uncertainty associated with these scenarios. The impact of these uncertainties is a range of outputs from the various scenarios and models. As stated in **Section 3.3.2**, PCIC addressed this issue by providing output from a cohort of models.

Climate models are based on very precise thermodynamic calculations. However, the outputs from these models are only as accurate as the input assumptions. Since, there may be a relatively high degree of uncertainty associated with the imbedded assumptions, there can be a high level of uncertainty associated with the model outputs. For example, PCIC informed the team that they have a very high level of scientific confidence in temperature forecasts but were much less certain regarding precipitation events. This assessment was based on PCIC's professional understanding of the actual mechanics of the models used in this assessment.

To compensate for this uncertainty, where possible, PCIC ground-tested the data by correlating model outputs with observed meteorological data. Nonetheless, users of climate model data must routinely address a range of model outputs and confidence intervals. This is normally achieved through testing the model output against local knowledge and broader synoptic analysis.

3.4 Synoptic Analysis

Synoptic weather charts are graphics that reflect the state of the atmosphere over a large area at any given time. These are the types of graphics commonly used by weather forecasters. Synoptic analysis is the study of observations based on synoptic, or large-scale, weather charts based on the available data and professional expertise of the practitioner.

3.4.1 Workshop Analysis

During the workshop the team struggled with assigning values to Pineapple Express Events as characterized by Climate Parameter 8, Magnitude of Severe Storm Driven Peak Flows; and Climate Parameter 9, Frequency of Severe Storm Driven Peak Flow Events.

In order to gain some insight into these events the team invited Paul Whitfield from the Meteorological Service of Canada, Weather and Environmental Operations group to provide professional insight regarding Pineapple Express events. Mr. Whitfield has many years of professional experience in the meteorology of B.C. and was willing to offer synoptic analysis based on this experience. Mr. Whitfield made the following observations.

Over the study period:
- Pineapple Express events may increase in intensity by 5 to 10%;
- 70% confident that Pineapple Express events may increase in frequency;
- 90% confident that the frequency of short duration storms will increase; and
- The number of dry days may increase overall.

In general, Mr. Whitfield's assessment was consistent with the results ultimately reported by PCIC. There is agreement that Pineapple Express events will likely increase in both frequency and intensity. However, there is still significant uncertainty regarding the magnitude of future storms and the frequency of the events. Nonetheless, the synoptic analysis provided sufficient data to conduct preliminary climate change risk assessment analysis. More work will be required to further characterize these events.

3.4.2 Synoptic Assessment Gaps

The synoptic analysis was based on the professional experience of one individual. Although the analysis was supported by the experience of the team based on day-to-day operation of the infrastructure, there was some professional disagreement between Mr. Whitfield and PCIC based on the differences between PCIC's modeling data and Mr. Whitfield's synoptic based analysis of observed phenomena. This is to be expected with analysis that carries inherent observational and statistical uncertainty. However, this uncertainty must be considered in the risk assessment. As a consequence, we conducted a sensitivity analysis of the risk profiles for Pineapple Express events as part of the risk assessment process described in **Section 4**.

3.5 Sensitivity Analysis

3.5.1 Description of Analysis

Sensitivity analysis was conducted for three Climate Parameters:

- Climate Parameter 10, Rain on Snow
- Climate Parameter 11, Freezing Rain
- Climate Parameter 14, Snow Accumulation

In the absence of synoptic or climate model data, the team arbitrarily assigned a probability score of "3" indicating that it is moderate or probable that, over the study period, this parameter will change in a way that adversely affects the infrastructure. Based on these scores, the team completed the risk assessment, described in **Section 4**. Once this work was complete, we arbitrarily increased the probability score to "4" indicating that the parameter will change such that it often occurs over the study period in a way that adversely affects the infrastructure. Based on this change we reassessed the resulting risk profiles.

Based on the precipitation and snowfall information provided by PCIC, the original probably score of "3" is rational. PCIC indicates that there will be a decrease in snow frequency and intensity over the study period. This suggests that there may be the occasional season where these climate events occur in a way that could adversely affect the highway.

Since this analysis is subjective, it is important to test the assumptions by increasing the scoring to generate higher risk outcomes from the assessment. Once this is done, the team can assess the impact of the probability scoring and make rational recommendations regarding the need for additional work to further resolve these climate parameters.

3.5.2 Sensitivity Analysis Gaps

Sensitivity analysis is subjective. Probability scores are assigned arbitrarily and then tested by adjusting the scores. The results are also rationalized through the skills and experience of the assessment team. Sensitivity analysis is not the best approach for assessing risk. However, it does allow the team to screen risks and determine where more detailed study may be necessary.

3.6 State the Timeframe

The team did not adjust the timeframe based on their deliberations in Step 2. The assessment timeframe is described in **Section 2.3**.

3.7 State the Geography

The team did not adjust the geographical definition based on their deliberations in Step 2. The assessment geography is described in **Section 2.4**.

3.8 State Specific Jurisdictional Considerations

The team did not adjust the jurisdictional considerations based on their deliberations in Step 2. The jurisdictional considerations are described in **Section 2.5**.

3.9 State Other Potential Changes that Affect the Infrastructure

The team identified three situations that could result in outcomes that may adversely affect the infrastructure. These include:

- Increased traffic flow;
    - Both private vehicle and truck traffic;
- River and watershed metamorphosis; and
- Fire history including things that affect fire history such as Mountain Pine Beetle.

Of these factors, increased traffic flow considerations did not play a significant role in the climate change risk assessment.

On the other hand, river and watershed metamorphosis and fire history issues became very serious considerations in the assessment. Fire history can have an affect on the drainage characteristics of the watershed and exacerbate highway drainage, erosion, slope stability and debris torrent concerns. River morphology can have an affect on the processes affecting flooding and drainage in the highway corridor. The team discussed these factors at length and these deliberations did result in the team identifying some potential climate change risks. We will discuss this further in **Section 4**.

3.10 Site Visit to the Coquihalla Highway

The team did not conduct additional site visits as part of Step 2. The results from the site visits documented for Step 1 are presented in **Section 2.6**.

3.11 *Assess Data Sufficiency*

As indicated in **Sections 3.3.3, 3.4.2 and 3.5.2**, there is some uncertainty associated with establishing future climatic conditions. The team used a variety of approaches to establish future climate conditions. Each approach contained inherent uncertainties that were addressed by the team. For all but two of the climate parameters, the team deemed that the available climate data was sufficient to conduct the risk assessment. However, for two parameters, the team deemed that there was insufficient data to proceed to risk assessment. The rationale for these decisions is outlined in the following sections.

3.11.1 High Wind / Downburst

An area of significantly rain-cooled air that, after hitting ground level, spreads out in all directions producing strong winds creates a downburst. Unlike winds in a tornado, winds in a downburst are directed outwards from the point where it hits land or water.

PCIC was unable to provide model-based data to evaluate this situation since the wind speeds contemplated could not be resolved by the models. In addition, given the localized nature of these events it was very difficult to conduct synoptic analysis of this parameter.

The team did not believe that it had sufficient information to express an opinion regarding the assignment of arbitrary probability scores in a sensitivity analysis.

3.11.2 Visibility Due to Fog

The Coquihalla Highway is in a transition zone between the coast and interior regions of the province. Fog needs moisture to form. However, there are multiple causes of fog, including:

- Very localized, from warm air over snow;
- Valley fog; or
- Low clouds.

The team determined that this issue requires more study to define how visibility issues arise currently on the highway.

4 Step 3 – Risk Assessment

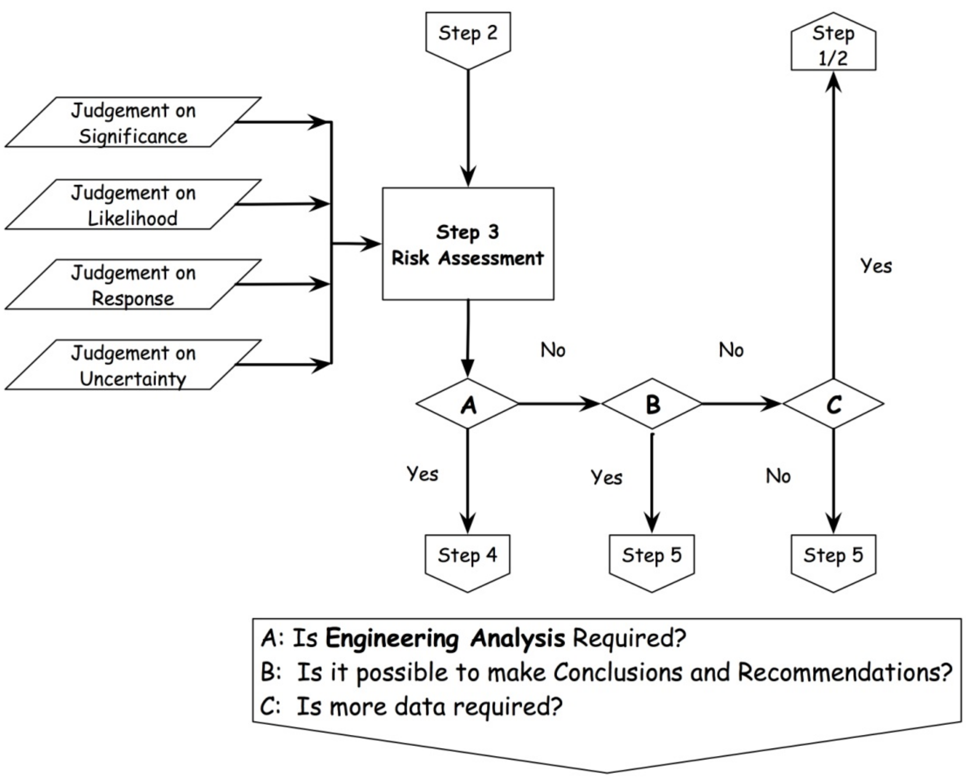
In this step the team identified the infrastructure's response to climate events. The protocol directed the team to develop:

- A list of relevant climate events; and
- A list of relevant infrastructure components.

Using a spreadsheet, the team examined interactions between infrastructure and climatic events that, potentially, could lead to vulnerability. Pairings between infrastructure components and climate events are called interactions.

The process flowchart for Step 3 of the protocol is presented in **Figure 4.1**.

Figure 4.1 Step 3 – Risk Assessment Process Flowchart



4.1 *Consultation with Owner and Operations Personnel*

BCMoTI drove the climate change risk assessment. Nodelcorp provided facilitation services and technical advice. Consequently, the project demanded a significant amount of consultation within the BCMoTI team and with PCIC to ensure that sufficient data was identified and defined to effectively conduct the two-day risk assessment workshop that formed the focus of this project. **Figure 4.2** outlines the team's deliberation process from December 2009 through March 2010.

Figure 4.2 Consultation Process

Date	Participants	Purpose
Dec 10	BCMoTI Team	Step 1
Dec 21	PCIC	Identify Climate Data Requirements
Jan 5	BCMoTI Team	Step 2
Jan 15	PCIC	Identify Climate Data Requirements
Jan 18	BCMoTI Team	Define Parameters for Step 3
Jan 25	PCIC	Identify Climate Data Requirements
Feb 2	BCMoTI Team	**Table Top Session** Step 3 **Performance Response** and **Y/N** Analysis
Feb 4	PCIC	Identify Climate Data Requirements
Feb 16	BCMoTI Team	Finalize infrastructure components for workshop.
Feb 23	BCMoTI Team - Climate Group Membership	Review climate data and define preliminary probability scores.
Feb 26	BCMoTI Team - Climate Group Membership	Review climate data and define preliminary probability scores.
Mar 2-3	BCMoTI Team - PCIC	**Workshop** Complete Risk Assessment
Mar 5	BCMoTI Team - Climate Group Membership	Define additional climate parameters to be provided by PCIC and agree to process for address outstanding climate data needs.
Mar 16	BCMoTI Team - Engineering/Technical Membership	Define interactions that will be assessed in Step 4.

4.1.1 Risk Assessment Workshop

As outlined above, the Risk Assessment workshop was conducted over a two-day period on March 2 and 3, 2010. The team used this workshop to carry out the analysis defined by Step 3 of the Protocol. At the completion of the workshop the team had resolved the climate change risk profile for the Coquihalla highway and had identified several parameters for Step 4 – Engineering Analysis.

A list of workshop participants is presented in **Appendix J**.

4.1.2 Owner's Risk Tolerance Thresholds

The Protocol directs the practitioner to confirm the infrastructure owner's risk tolerance thresholds prior to conducting the risk assessment. The Protocol suggests High, Medium and Low risk thresholds. On January 13, 2010, BCMoTI confirmed their acceptance of the risk thresholds defined by the Protocol for application in this process.

Figure 4.3 outlines the risk thresholds used for this risk assessment.

Figure 4.3 Historic Risk Tolerance Thresholds

Risk Range[2]	Threshold	Response
< 12	Low Risk	• No immediate action necessary
12 – 36	Medium Risk	• Action may be required • Engineering analysis may be required
> 36	High Risk	• Immediate action required

4.2 *Risk Assessment Methodology*

Based on the Protocol, the team developed a risk value for each of the climate-infrastructure interactions identified through Step 1 and 2 of the assessment. The Protocol defines a default risk assessment process is based on scales of 0 to 7**.** For each interaction, the team:

- Established the probability of the climate interaction occurring in a manner that may adversely affect the infrastructure;
  - Using a scale of 0 to 7, where:
    - 0 means that the adverse interaction will not occur in the timeframe of the assessment; and

[2] Risk scores range from 0 to 49 based on the 0-7 probability and severity scales used in the assessment.

  - 7 means certainty that the adverse interaction will occur in the timeframe of the assessment; and
- Established a severity resulting from the interaction;
  - Using a scale of 0 to 7, where
    - 0 means no negative consequences in the event that the interaction occurs; and
    - 7 means a significant failure will result if the interaction occurs.

Based on the protocol, the team selected the scale definitions for probability and severity that were applied consistently through the risk assessment process. **Figure 4.4** presents the probability scaling definitions that were applied by the team. **Figure 4.5** presents the severity definitions. These tables were extracted from the Protocol. The team applied the highlighted definitions. Alternative definitions, offered by the Protocol, are de-emphasized in the figures.

Figure 4.4 Probability Scale Factors

Scale	Probability*		
	Method A	Method B	Method C
0	negligible or not applicable	<0.1 % <0.1 / 20	negligible or not applicable
1	improbable / highly unlikely	5 % 1 / 20	improbable 1:1 000 000
2	remote	20 % 4 / 20	remote 1:100 000
3	occasional	35 % 7 / 20	occasional 1:10 000
4	moderate / possible	50 % 10 / 20	moderate 1:1 000
5	often	65 % 13 / 20	probable 1:100
6	probable	80 % 16 / 20	frequent 1:10
7	certain / highly probable	>95 % >19 / 20	continuous 1:1

Figure 4.5: Severity Scale Factors

Scale	Magnitude	Severity of Consequences and Effects
	Method D	Method E
0	no effect	negligible or not applicable
1	measurable 0.0125	very low / unlikely / rare / measurable change
2	minor 0.025	low / seldom / marginal / change in serviceability
3	moderate 0.050	occasional loss of some capability
4	major 0.100	moderate loss of some capacity
5	serious 0.200	likely regular / loss of capacity and loss of some function
6	hazardous 0.400	major / likely / critical / loss of function
7	catastrophic 0.800	extreme/ frequent/ continuous /loss of asset

Based on these probability and severity scales, the team calculated the climate change risk for each sub-component using the following equation:

$R = P \times S$

Where:

R = Risk
P = Probability of the interaction
S = Severity of the interaction

4.3 The Risk Assessment Spreadsheet

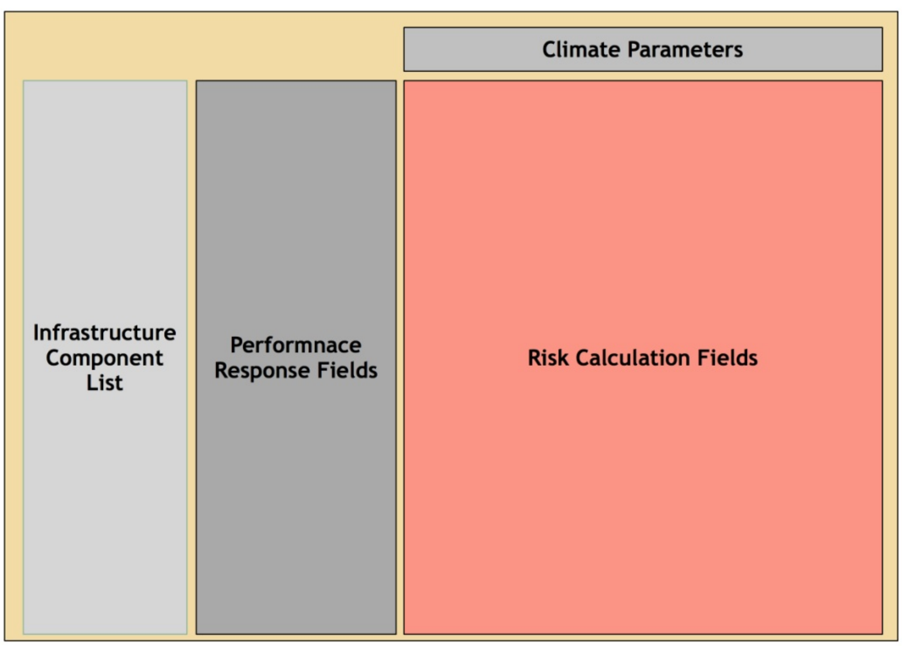
The team maintained a record of their deliberations in Worksheet 3 that is provided by PIEVC as a companion to the Protocol.

The workbook is split into four key areas:

- Columns
  - Each climate parameter has a dedicated column
- Rows
  - Each infrastructure element has a dedicated row
- Performance Response Fields:
  - Where the team identifies potential performance response characteristics for each infrastructure component
- Risk Calculation Fields:
  - Where the team notes probability and severity scores and calculations climate change risk profiles.

At first, the workbook can appear daunting. The spreadsheet is large and there is a lot of information compressed into a very small space. In the following sections we will provide a tour of the workbook and present the results that the team developed for the risk assessment. To help in this process, we have developed a legend for the workbook. The workbook legend is presented in **Figure 4.6**.

Figure 4.6 Worksheet 3 Legend



The completed Worksheet 3 is presented in **Appendix F**.

4.3.1 Spreadsheet Columns

The spreadsheet columns were used to document the climate parameters selected for the evaluation. The climate parameters developed in Section 2.2 were transferred to the title row for these columns.

Under the title row, each column was split into four sub-columns. For each climate parameter, the sub columns were used to document the results of the yes / no analysis, probability score, severity score and calculated risk for each climate-infrastructure interaction.

4.3.2 Spreadsheet Rows

The spreadsheet rows were used to document the infrastructure components selected for the evaluation. The infrastructure components developed in Section 3.1 were transferred to the title column for these rows.

4.4 Performance Response Analysis

The first step in assessing climate change risk is to identify the potential performance responses for each infrastructure component considered in the assessment.

In establishing conceivable performance responses the team considered the most likely response of each infrastructure component to contemplated climate events. This was based on the team's professional judgment and experience.

This analysis serves as a preliminary screening process. Any infrastructure component that exhibits no material performance response, in the judgment of the team, can be excluded from further assessment.

To aid in this assessment the team used the performance response listing provided in Appendix B of the protocol. The list is presented in **Figure 4.7**.

Figure 4.7 Performance Response Considerations

Structural Design	• Safety o Load carrying capacity o Fatigue o Serviceability • Deflection o Cracking and deterioration • Foundation Design considerations

Figure 4.7 Performance Response Considerations

Functionality	• Level of Service, Serviceability, Reliability
	• Level of Effective Capacity
	  o Short term
	  o Medium term
	  o Long term
	• Equipment - Component selection, design, process and capacity considerations

Watershed, Surface Water, and Groundwater	• Erosion along streams,rivers, and ditches • Erosion scour of associated or supporting earthworks • Sediment transport and sedimentation • Channel realignment / meandering • Change in water quantity • Slope stability
Operations, Maintenance, and Materials Performance	• Structural aspects • Functionality & Effective Capacity • Materials Performance (changes over time from design expectation) • Pavement Aspects (i.e. hail, softening, cracking from freeze thaw and other causes)
Emergency Response	• Storm • Flood • Ice • Water damage
Insurance Considerations	
Policy Considerations	• Codes • Public sector policy • Land use planning documents Guidelines
Social Effects	

The team conducted the performance response analysis during a teleconference on February 2, 2010.

The team did not eliminate any climate parameters from the analysis through the performance response review. However, as a result of this analysis, the team developed a consistent understanding of the infrastructure component definitions and how these particular components may respond to a variety of climatic events. This provided a very solid foundation for the subsequent steps of the risk assessment process. In fact, the team would often refer back to the performance response results during the process and amended several of their preliminary assessments in subsequent discussion.

The final performance response results for this risk assessment are presented in **Figure 4.8**.

Figure 4.8 Performance Response Results

Infrastructure Components	Structural Design	Functionality	Watershed, Surface Water, and Groundwater	Operations, Maintenance, and Materials Performance	Emergency Response	Insurance Considerations	Policy / Guidelines / Standards	Social Effects	Public Health & Safety	Environmental Effect
Infrastructure										
Surface - Asphalt	✔	✔	✔	✔			✔	✔	✔	
Pavement Marking		✔		✔			✔	✔	✔	
Shoulders (Including Gravel)		✔	✔	✔	✔		✔		✔	
Barriers		✔	✔	✔	✔	✔	✔	✔	✔	
Curb		✔	✔	✔			✔			
Luminaires		✔		✔		✔	✔		✔	
Poles	✔	✔		✔	✔	✔	✔		✔	
Signage - Side Mounted - Over 3.2 m2	✔	✔		✔	✔	✔	✔		✔	
Signage - Overhead Guide Signs	✔	✔		✔	✔	✔	✔		✔	
Overhead Changeable Message Signs	✔	✔		✔	✔	✔	✔		✔	
Ditches	✔	✔	✔	✔	✔	✔	✔		✔	✔
Embankments/Cuts (Constructed)	✔	✔	✔	✔	✔	✔	✔		✔	✔
Hillsides (Natural)	✔	✔	✔	✔	✔	✔	✔		✔	✔
Engineered Stabilization Works	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Avalanche (Inc Protective Works)	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Debris Torrents (Inc Protective Works)	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Structures that Cross Streams	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Structures that Cross Roads	✔	✔	✔	✔	✔	✔	✔	✔	✔	
River Training Works (Rip Rap)	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
MSE Walls	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Pavement Structure above Sub-Grade	✔	✔		✔			✔		✔	✔
Catch Basins	✔	✔	✔	✔	✔	✔	✔		✔	✔
Median and Roadway Drainage Appliances	✔	✔	✔	✔	✔	✔	✔		✔	✔
Sub-Drains	✔	✔	✔	✔	✔	✔	✔		✔	✔
Third-Party Utilities	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Culverts < 3m	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Culverts ≥ 3m	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Asphalt Spillway and Associated Piping/Culvert	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Environmental Features										
In-Stream Habitat Works	✔	✔	✔	✔	✔		✔			✔
Off-Channel Habitat Works	✔	✔	✔	✔	✔		✔			✔
Wildlife Fence System	✔	✔		✔	✔	✔	✔		✔	✔
Wildlife Crossing Structures	✔	✔		✔		✔	✔		✔	✔
Vegetation Management				✔			✔		✔	✔
Invasive Plants & Pests				✔			✔	✔		✔
Miscellaneous										
Administration/Personnel & Engineering	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Winter Maintenance	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Ancillary Buildings, Utilities and Yards	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Communication		✔		✔	✔			✔	✔	
Emergency Response		✔		✔	✔			✔	✔	✔
Maintenance (Markings, Crack Sealing)	✔	✔		✔				✔	✔	

4.5 *Yes / No Analysis*

The next step of the process is to assess the potential for adverse interactions between each climate parameter and each infrastructure component. At this stage of the process, the team is not assessing the magnitude of the risk. Rather, this is a second stage of screening. If the team determines that there can be an adverse interaction between a climatic parameter and an infrastructure component, the interaction is retained within the process for further risk analysis. If the team determines that there may be no material adverse impact, the interaction is eliminated from further risk assessment analysis.

The team completed the yes / no analysis at a teleconference on February 2, 2010.

The team had identified 40 infrastructure components and 16 climate parameters. Of the 16 climate parameters, two could not be defined to a level acceptable for the risk assessment. Consequently, the team initially considered risk assessment of 560 (40x14) climate / infrastructure interactions. Based on the yes / no analysis, the team identified 256 climate / infrastructure interactions for further risk assessment. Thus, 340 interactions were eliminated from further analysis.

To put this into context, based on the preliminary screening, 340 climate / infrastructure interactions were identified by the team to have no material climate change related risk. The remaining 256 interactions, were identified to have potential risk which was further resolved in subsequent steps of the process.

Figure 4.9 Yes / No Analysis

Infrastructure Components	High Temperature	Low Temperature	Temperature Variability	Freeze/Thaw	Frost Penetration	Frost	Extreme Rainfall Intensity over One Day	Magnitude of Severe Storm Driven Peak Flows	Frequency of Severe Storm Driven Peak Flows	Rain on Snow	Freezing Rain	Snow Storm/ Blizzard	Snow (Frequency)	Snow Accumulation	High Wind/ Downburst	Visibility / Fog
Infrastructure																
Surface - Asphalt	Y	Y	Y	Y	Y	Y	Y	Y	Y		Y	Y	Y	Y		
Pavement Marking	Y	Y	Y	Y							Y	Y	Y	Y		
Shoulders (Including Gravel)							Y	Y	Y		Y	Y	Y	Y		
Barriers				Y								Y	Y	Y		
Curb	Y			Y									Y	Y		
Luminaires											Y	Y	Y	Y		
Poles											Y		Y	Y		
Signage - Side Mounted - Over 3.2 m2											Y	Y	Y	Y		
Signage - Overhead Guide Signs					Y						Y	Y	Y	Y		
Overhead Changeable Message Signs					Y						Y	Y	Y	Y		
Ditches			Y	Y			Y	Y	Y	Y		Y	Y	Y		
Embankments/Cuts (Constructed)			Y	Y	Y	Y	Y	Y	Y			Y	Y	Y		
Hillsides (Natural)			Y	Y			Y	Y	Y	Y			Y	Y		
Engineered Stabilization Works				Y	Y	Y	Y	Y	Y							
Avalanche (Inc Protective Works)		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		
Debris Torrents (Inc Protective Works)	Y		Y	Y	Y	Y	Y	Y	Y	Y			Y	Y		
Structures that Cross Streams	Y	Y	Y	Y	Y	Y	Y	Y	Y		Y					
Structures that Cross Roads	Y	Y	Y	Y	Y	Y	Y	Y	Y		Y					
River Training Works (Rip Rap)		Y	Y				Y	Y	Y							
MSE Walls				Y				Y	Y							
Pavement Structure above Sub-Grade		Y	Y	Y	Y	Y										
Catch Basins				Y	Y		Y	Y	Y	Y	Y			Y		
Median and Roadway Drainage Appliances				Y	Y		Y	Y		Y	Y			Y		
Sub-Drains		Y		Y	Y	Y	Y	Y								
Third-Party Utilities							Y	Y			Y					
Culverts < 3m		Y	Y	Y			Y	Y	Y	Y						
Culverts ≥ 3m		Y	Y	Y			Y	Y	Y							
Asphalt Spillway and Associated Piping/Culvert	Y	Y		Y			Y	Y		Y	Y			Y		
Environmental Features																
In-Stream Habitat Works	Y		Y				Y	Y	Y							
Off-Channel Habitat Works	Y		Y				Y	Y	Y							
Wildlife Fence System										Y	Y	Y	Y	Y		
Wildlife Crossing Structures																
Vegetation Management	Y		Y													
Invasive Plants & Pests	Y		Y			Y										
Miscellaneous																
Administration/Personnel & Engineering																
Winter Maintenance		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		
Ancillary Buildings, Utilities and Yards		Y			Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		
Communication											Y	Y	Y	Y		
Emergency Response		Y		Y		Y	Y	Y	Y	Y	Y	Y	Y	Y		
Maintenance (Markings, Crack Sealing)		Y	Y	Y	Y	Y										

4.6 *Calculated Risk for Each Relevant Interaction*

The team calculated the risk for each interaction in two steps. First, PCIC and representatives from the team with climate expertise consulted and assigned probabilities for the climate parameters. Second, at the workshop, the team assigned severity scores for each interaction that passed the yes / no analysis.

4.6.1 Probability Scores

There are a number of possible ways to assess the climate change risk using this process. For example, in some studies the practitioner may calculate risk profiles for both the baseline climate and project future climate. Conversely, the team can assign a probability to the climate parameter changing in a manner that can adversely affect the infrastructure. In this case, the team calculates only one risk profile, that for the changing future climate. In this assessment, the team applied the second approach, calculating the risk profile for a future climate based on the projections and analysis provided by PCIC, synoptic and sensitivity analysis, as described in **Section 3**.

The team used a probability scoring process and documented their deliberations in a workbook that is summarized in **Figure 4.10**.

The team reviewed available climate data, synoptic analysis and sensitivity considerations and then expressed a professional opinion based on the consensus of the team. They also assess the nature of the change in climate, whether the anticipated change was better or worse for the infrastructure, the likely magnitude of that change and their overall confidence in the assessment based on the data availability and approaches used.

In one case, the team identified a climate change scenario that was beneficial to the infrastructure in most cases, but which had a potential adverse affect on one infrastructure component. In the case of frost, the team determined that shorter periods of hard frost would likely be beneficial to the mechanical features of the infrastructure. However, shorter periods of hard frost could also exacerbate incidents of Pine Beetle infestation. This infestation could weaken the forests above the highway making them more prone to fire. As a consequence, the watershed drainage characteristics could change resulting in increased drainage issues on the highway itself. For this parameter the team applied two separate probability scores; a score of 4 for invasive plants and pests and a score of 2 for every other infrastructure component.

Based on the analysis outlined in **Figure 4.10**, the team input probability scores to Protocol Worksheet 3. The probability scores for the interactions considered in the risk assessment are presented in **Figure 4.11**.

Figure 4.10 Assignment of Climate Change Probability Scores

			Will the Parameter Change in the Future?	Better-Neutral-Worse	Magnitude of Change?	Confidence in Forecast?	Professional Judgment	Probability Score
			Y/N	B N W	H M L	H M L	Comments	0-7
							$P = \mathcal{F}(A,B,C,D,\ \&\ E)$	
#	Climate Parameter	Infrastructure Indicator	A	B	C	D		P
1	High Temperature	Number of Days) with max. temp. exceeding 30°C	Y	W	H	H	Climate data suggests that frequency will increase from 0.6 to ~ 3 days per year. This is a significant change. The data is consistent with other predictions. This suggests that the likelihood of change affecting these particular parameters is relatively high.	6
2	Low Temperature	Days) with min. temp. below -24°C	Y	W	L	H	Data suggests that temperature will be somewhat warmer. This suggests that the likelihood is such that the number of days will either be the same or somewhat lower. Not a high likelihood for change.	3
3	Temperature Variability	Daily temperature variation of more than 24°C	Y	B	L	H	Data suggests that this temp variation occurs once in 30 years currently. It projects that the number of days with this variation goes down in the future to 0 days per year. Since the probability of daily temperature variations is decreasing and high variation is the potentially adverse impact, the probability of this changing in a way that increases vulnerability is relatively small.	2
4	Freeze / Thaw	17 or more days where max. temp. >0°C and min. temp.<0°C	Y	N	L	M	The data suggests that there may be fewer freeze thaw cycles or, according to one model, the same number of cycles. This suggests that there is a very low likelihood of climate change affecting this parameter in a way that would have a detrimental affect on the infrastructure.	3

Figure 4.10 Assignment of Climate Change Probability Scores

#	Climate Parameter	Infrastructure Indicator	Will the Parameter Change in the Future?	Better-Neutral-Worse	Magnitude of Change?	Confidence in Forecast?	Professional Judgment	Probability Score
			Y/N	B N W	H M L	H M L	Comments	0-7
							P = $\mathcal{F}$(A,B,C,D, & E)	
			A	B	C	D		P
5	Frost Penetration	Assessed through empirical analysis of forecast climate conditions.	Y	B	L	M	Data suggests that frost will decrease in the future. This is a moderate decrease from one event in 15 years to 0 events per year. Impact on the infrastructure is that this parameter will slightly change in a way that has no detrimental affect on the infrastructure.	*2*
6	Frost	47 or more days where min. temp. <0°C	Y	W	L	M	Data suggests that frost will decrease in the future. This is a moderate decrease from one event in 15 years to 0 events per year. Impact on the infrastructure is that this parameter will slightly change in a way that has no detrimental affect on the infrastructure. For these interactions the probability score is 2. Pine Beetle considerations could have impact on highway since Pine Beetle infestation can result in forest fires leading to drainage issues. For these interactions the probability score is 4.	*2/4*

Figure 4.10 Assignment of Climate Change Probability Scores

#	Climate Parameter	Infrastructure Indicator	Will the Parameter Change in the Future?	Better-Neutral-Worse	Magnitude of Change?	Confidence in Forecast?	Professional Judgment	Probability Score
			Y/N	B N W	H M L	H M L	Comments	0-7
			☟	☟	☟	☟	P = $\mathcal{F}$(A,B,C,D, & E)	
			A	B	C	D	☞	P
7	Extreme Rainfall Intensity Over One Day	Determined empirically. PCIC used > 76mm over 24hrs.	Y	W	M	L	Frequency doubles according to models. Confidence in forecast is medium to low. Can affect infrastructure. Average precipitation data is used. Not being picked up by Environment Canada stations. Micro events. Mine MOT data to seek out better data on extreme precipitation events. Paul Whitfield suggests that there is a 90% chance of this type of event increasing over the study period. There is some disagreement between the experts. However, the average opinion supports that this will increase based both on climate model and synoptic data.	6

Figure 4.10 Assignment of Climate Change Probability Scores

#	Climate Parameter	Infrastructure Indicator	Will the Parameter Change in the Future?	Better-Neutral-Worse	Magnitude of Change?	Confidence in Forecast?	Professional Judgment	Probability Score
			Y/N	B N W	H M L	H M L	Comments	0-7
							$P = \mathcal{F}(A,B,C,D, \& E)$	
			A	B	C	D	☞	P
8	Magnitude of Severe Storm Driven Peak Flows	Determined empirically. PCIC used directional wind speed, temperature and precipitation all > median values.	Y	W	M	M	Paul Whitfield suggests that there is an 80% chance of the magnitude of this type of event increasing over the study period. This opinion was supported by the local experience with managing and addressing these types of events. They have increased over the last twenty years. There is a high degree of confidence in the statement that the magnitude of event such as the Pineapple Express will increase over the study period based on synoptic data. In follow-up work, PCIC provided professional advice regarding the magnitude of Pineapple Express events. The probabilities provided by PCIC suggest that the initial probability score of 6 was reasonable.	6

Figure 4.10 Assignment of Climate Change Probability Scores

#	Climate Parameter	Infrastructure Indicator	Will the Parameter Change in the Future?	Better-Neutral-Worse	Magnitude of Change?	Confidence in Forecast?	Professional Judgment	Probability Score
			Y/N	B N W	H M L	H M L	Comments	0-7
							$P = \mathcal{F}(A,B,C,D,\ \&\ E)$	
			A	B	C	D		P
9	Frequency of Severe Storm Driven Peak Flow Events	Determined empirically. PCIC used directional wind speed, temperature and precipitation all > median values for three consecutive days in autumn.	Y	W	M	H	Paul Whitfield suggests that there is a 70% chance of the frequency of this type of event increasing over the study period. This opinion was supported by the local experience with managing and addressing these types of events. They have increased over the last twenty years. There is a high degree of confidence in the statement that the frequency of events such as the Pineapple Express will increase over the study period based on synoptic data. In follow-up work, PCIC provided professional advice regarding the probability of Pineapple Express events. The probabilities provided by PCIC suggest that the initial probability score of 6 was reasonable.	5
10	Rain on Snow	10 or more days where rain falls on snow					Unable to do this parameter within the context of the climate model data. A probability score of 3 was assigned arbitrarily. The risk analysis was subjected to sensitivity analysis by applying an alternative score of 4 to assess the impact on calculated risk.	3

Figure 4.10 Assignment of Climate Change Probability Scores

#	Climate Parameter	Infrastructure Indicator	Will the Parameter Change in the Future?	Better-Neutral-Worse	Magnitude of Change?	Confidence in Forecast?	Professional Judgment	Probability Score
			Y/N	B N W	H M L	H M L	Comments	0-7
							P = $\mathcal{F}$(A,B,C,D, & E)	
			A	B	C	D	☞	P
11	Freezing Rain	1 or more days with rain that falls as liquid and freezes on contact					Unable to do this parameter within the context of the climate model data. A probability score of 3 was assigned arbitrarily. The risk analysis was subjected to sensitivity analysis by applying an alternative score of 4 to assess the impact on calculated risk.	3
12	Snow Storm / Blizzard	8 or more days with blowing snow	Y	B	L	M	Initially, unable to do this parameter within the context of the climate model data. A probability score of 3 was assigned arbitrarily. The risk analysis was subjected to sensitivity analysis by applying an alternative score of 4 to assess the impact on calculated risk PCIC later provided probability scores and the assessment. Their subsequent data was consistent with the assigned probability score of 3.	3

Figure 4.10 Assignment of Climate Change Probability Scores

#	Climate Parameter	Infrastructure Indicator	Will the Parameter Change in the Future?	Better-Neutral-Worse	Magnitude of Change?	Confidence in Forecast?	Professional Judgment	Probability Score
			Y/N	B N W	H M L	H M L	Comments	0-7
							P = $\mathcal{F}$(A,B,C,D, & E)	
			A	B	C	D		P
13	Snow (Frequency)	Days with snowfall >10 cm	Y	B	M	H	Initially, unable to do this parameter within the context of the climate model data. A probability score of 3 was assigned arbitrarily. The risk analysis was subjected to sensitivity analysis by applying an alternative score of 4 to assess the impact on calculated risk PCIC later provided probability scores and the assessment. Their subsequent data was consistent with the assigned probability score of 4 used in the sensitivity analysis.	3
14	Snow Accumulation	5 or more days with a snow depth >20 cm					Unable to do this parameter within the context of the climate model data. A probability score of 3 was assigned arbitrarily. The risk analysis was subjected to sensitivity analysis by applying an alternative score of 4 to assess the impact on calculated risk.	3

Figure 4.10 Assignment of Climate Change Probability Scores

#	Climate Parameter	Infrastructure Indicator	Will the Parameter Change in the Future?	Better-Neutral-Worse	Magnitude of Change?	Confidence in Forecast?	Professional Judgment	Probability Score
			Y/N	B N W	H M L	H M L	Comments	0-7
							P = $\mathcal{F}$(A,B,C,D, & E)	
			A	B	C	D	☞	P
15	High Wind / Downburst	Wind speed > 80.5 km/hr	-	-	-	-	Unable to do this parameter within the context of the data provided. Team was did not have sufficient background to provide confident estimate for sensitivity analysis. This parameter was eliminated from further analysis and recommended for further study after the risk assessment.	*N/A*
16	Visibility due to Fog	Decrease in stopping sight distance < 245 m	-	-	-	-	Unable to do this parameter within the context of the data provided. Team was did not have sufficient background to provide confident estimate for sensitivity analysis. This parameter was eliminated from further analysis and recommended for further study after the risk assessment.	*N/A*

Figure 4.11 Probability Scores

Infrastructure Components	High Temperature	Low Temperature	Temperature Variability	Freeze/Thaw	Frost Penetration	Frost	Extreme Rainfall Intensity over One Day	Magnitude of Severe Storm Driven Peak Flows	Frequency of Severe Storm Driven Peak Flows	Rain on Snow	Freezing Rain	Snow Storm/ Blizzard	Snow (Frequency)	Snow Accumulation	High Wind/ Downburst	Visibility / Fog
Infrastructure																
Surface - Asphalt	6	3	2	3	2	2	6	6	5		3	3	3	3		
Pavement Marking	6	3	2	3							3	3	3	3		
Shoulders (Including Gravel)							6	6	5		3	3	3	3		
Barriers				3								3	3	3		
Curb	6			3									3	3		
Luminaires											3	3	3	3		
Poles											3		3	3		
Signage - Side Mounted - Over 3.2 m2											3	3	3	3		
Signage - Overhead Guide Signs					2						3	3	3	3		
Overhead Changeable Message Signs					2						3	3	3	3		
Ditches			2	3			6	6	5	3		3	3	3		
Embankments/Cuts (Constructed)			2	3	2	2	6	6	5			3	3	3		
Hillsides (Natural)			2	3			6	6	5	3			3	3		
Engineered Stabilization Works				3	2	2	6	6	5							
Avalanche (Inc Protective Works)		3	2	3	2	2	6	6	5	3	3	3	3	3		
Debris Torrents (Inc Protective Works)	2		2	3	2	2	6	6	5	3			3	3		
Structures that Cross Streams	6	3	2	3	2	2	6	6	5		3					
Structures that Cross Roads	6	3	2	3	2	2	6	6	5		3					
River Training Works (Rip Rap)		3	2				6	6	5							
MSE Walls				3				6	5							
Pavement Structure above Sub-Grade		3	2	3	2	2										
Catch Basins				3	2		6	6	5	3	3			3		
Median and Roadway Drainage Appliances				3	2		6	6		3	3			3		
Sub-Drains		3		3	2	2	6	6								
Third-Party Utilities							6	6			3					
Culverts < 3m		3	2	3			6	6	5	3						
Culverts ≥ 3m		3	2	3			6	6	5							
Asphalt Spillway and Associated Piping/Culvert	6	3		3			6	6		3	3			3		
Environmental Features																
In-Stream Habitat Works	6		2				6	6	5							
Off-Channel Habitat Works	6		2				6	6	5							
Wildlife Fence System										3	3	3	3	3		
Wildlife Crossing Structures																
Vegetation Management	6		2													
Invasive Plants & Pests	6		2			4										
Miscellaneous																
Administration/Personnel & Engineering																
Winter Maintenance		3	2	3	2	2	6	6	5	3	3	3	3	3		
Ancillary Buildings, Utilities and Yards		3			2	2	6	6	5	3	3	3	3	3		
Communication											3	3	3	3		
Emergency Response		3		3		2	6	6	5	3	3	3	3	3		
Maintenance (Markings, Crack Sealing)		3	2	3	2	2										

4.6.2 Severity Scores

The team assigned the severity score for each relevant climate-infrastructure interaction at the workshop in early March. The implications and potential consequences for each interaction were discussed in turn by the team. As previously indicated, the team would occasionally refer back to the performance response considerations to inform these discussions.

In some ways, the assignment of severity scores was much more straightforward than the assignment of probability scores. The team has direct, hands-on, experience in managing similar events over the life of the highway. This experience provides a solid foundation for the opinions expressed by the team membership.

During the workshop, there were occasions where team members would disagree about potential outcomes of a particular interaction. However, the team was able to fully examine these situations and arrive at a consensus regarding the severity scoring.

It is notable that the team assigned a number of severity scores of “0”. This is permitted by the Protocol. This allows a further level of screening and review. These items initially passed the yes/no analysis but, upon more detailed review, were determined to have immaterial adverse outcomes from the climate-infrastructure interaction. This ensures that the assignment of a low risk score was based on a considered evaluation of the situation.

The severity scores assigned by the team are presented in **Figure 4.12**.

Figure 4.12 Severity Scores

Infrastructure Components	High Temperature	Low Temperature	Temperature Variability	Freeze/Thaw	Frost Penetration	Frost	Extreme Rainfall Intensity over One Day	Magnitude of Severe Storm Driven Peak Flows	Frequency of Severe Storm Driven Peak Flows	Rain on Snow	Freezing Rain	Snow Storm/ Blizzard	Snow (Frequency)	Snow Accumulation	High Wind/ Downburst	Visibility / Fog
Infrastructure																
Surface - Asphalt	3	3	1	2	1	1	5	5	5		0	0	0	0		
Pavement Marking	0	0	0	0							3	6	6	6		
Shoulders (Including Gravel)							6	6	7		1	1	1	6		
Barriers				2								1	1	5		
Curb	1			1									3	3		
Luminaires											4	4	1	4		
Poles											1		0	3		
Signage - Side Mounted - Over 3.2 m2											1	4	1	0		
Signage - Overhead Guide Signs					4						1	3	1	0		
Overhead Changeable Message Signs					4						1	3	1	0		
Ditches			0	2			5	6	7	1		0	1	6		
Embankments/Cuts (Constructed)			0	6	3	1	6	7	7			0	1	6		
Hillsides (Natural)			0	5			5	7	7	3			1	1		
Engineered Stabilization Works				5	1	1	3	5	7							
Avalanche (Inc Protective Works)		1	3	3	1	4	6	6	7	5	6	5	5	6		
Debris Torrents (Inc Protective Works)	7		5	3	0	0	7	7	7	5			4	5		
Structures that Cross Streams	1	1	0	2	4	2	6	7	7		2					
Structures that Cross Roads	1	1	0	2	4	2	5	6	7		2					
River Training Works (Rip Rap)		0	0				6	7	7							
MSE Walls				1				5	6							
Pavement Structure above Sub-Grade		3	0	4	5	0										
Catch Basins				1	7		6	6	6	6	0			4		
Median and Roadway Drainage Appliances				1	7		6	6		6	0			4		
Sub-Drains		2		1	7	1	3	6								
Third-Party Utilities							5	5			7					
Culverts < 3m		1	0	2			7	7	7	5						
Culverts ≥ 3m		0	0	1			7	7	7							
Asphalt Spillway and Associated Piping/Culvert	0	1		2			6	7		5	0			3		
Environmental Features																
In-Stream Habitat Works	4		2				6	7	7							
Off-Channel Habitat Works	4		2				6	7	7							
Wildlife Fence System										6	6	6	6	6		
Wildlife Crossing Structures																
Vegetation Management	1		2													
Invasive Plants & Pests	2		2			3										
Miscellaneous																
Administration/Personnel & Engineering																
Winter Maintenance		1	1	5	5	1	4	6	7	5	6	6	3	3		
Ancillary Buildings, Utilities and Yards		1			3	1	1	2	3	5	4	3	3	5		
Communication											6	6	2	4		
Emergency Response		6		0		1	6	7	7	5	7	6	2	2		
Maintenance (Markings, Crack Sealing)		3	1	4	1	1										

4.6.3 Risk Outcomes

Based on the probability and severity scores, the team calculated the risk outcomes using the equation described in **Section 4.2**:

$$R = P \times S$$

Where:

R = Risk
P = Probability of the interaction
S = Severity of the interaction

Each outcome was assigned a high, medium or low risk score based on the risk tolerances defined in **Section 4.1.2** and color-coded, as indicated in **Figure 4.13.**

Figure 4.13 Risk Tolerance Threshold Color Codes

Risk Range	Threshold	Response
< 12	Low Risk	• No immediate action necessary
12 – 36	Medium Risk	• Action may be required • Engineering analysis may be required
> 36	High Risk	• Immediate action required

The calculated risk scores arising from this assessment are presented in **Figure 4.14**.

Figure 4.14 Summary of Climate Change Risk Assessment Scores

Infrastructure Components	High Temperature	Low Temperature	Temperature Variability	Freeze/Thaw	Frost Penetration	Frost	Extreme Rainfall Intensity over One Day	Magnitude of Severe Storm Driven Peak Flows	Frequency of Severe Storm Driven Peak Flows	Rain on Snow	Freezing Rain	Snow Storm/ Blizzard	Snow (Frequency)	Snow Accumulation	High Wind/ Downburst	Visibility / Fog
Infrastructure																
Surface - Asphalt	18	9	2	6	2	2	30	30	25							
Pavement Marking											9	18	18	18		
Shoulders (Including Gravel)							36	36	35		3	3	3	18		
Barriers				6								3	3	15		
Curb	6			3									9	9		
Luminaires											12	12	3	12		
Poles											3			9		
Signage - Side Mounted - Over 3.2 m2											3	12	3			
Signage - Overhead Guide Signs					8						3	9	3			
Overhead Changeable Message Signs					8						3	9	3			
Ditches				6			30	36	35	3			3	18		
Embankments/Cuts (Constructed)				18	6	2	36	42	35				3	18		
Hillsides (Natural)				15			30	42	35	9			3	3		
Engineered Stabilization Works				15	2	2	18	30	35							
Avalanche (Inc Protective Works)		3	6	9	2	8	36	36	35	15	18	15	15	18		
Debris Torrents (Inc Protective Works)	14		10	9			42	42	35	15			12	15		
Structures that Cross Streams	6	3		6	8	4	36	42	35		6					
Structures that Cross Roads	6	3		6	8	4	30	36	35		6					
River Training Works (Rip Rap)							36	42	35							
MSE Walls				3				30	30							
Pavement Structure above Sub-Grade		9		12	10											
Catch Basins				3	14		36	36	30	18				12		
Median and Roadway Drainage Appliances				3	14		36	36		18				12		
Sub-Drains		6		3	14	2	18	36								
Third-Party Utilities							30	30			21					
Culverts < 3m		3		6			42	42	35	15						
Culverts ≥ 3m				3			42	42	35							
Asphalt Spillway and Associated Piping/Culvert		3		6			36	42		15				9		
Environmental Features																
In stream habitat works	24		4				36	42	35							
Off channel habitat works	24		4				36	42	35							
Wild life fence system										18	18	18	18	18		
Wild life crossing structures																
Vegetation management	6		4													
Invasive Plants & Pests	12		4			12										
Miscellaneous																
Administration/Personnel & Engineering																
Winter Maintenance		3	2	15	10	2	24	36	35	15	18	18	9	9		
Ancillary buildings and utilities and yards.		3			6	2	6	12	15	15	12	9	9	15		
Communication											18	18	6	12		
Emergency Response		18				2	36	42	35	15	21	18	6	6		
Maintenance (Markings, Crack Sealing)		9	2	12	2	2										

4.6.4 Sensitivity Analysis

As described in **Section 3.5.1**, sensitivity analysis was planned for three Climate Parameters that were arbitrarily assigned probability scores at the workshop. These were:

- Climate Parameter 10, Rain on Snow
- Climate Parameter 11, Freezing Rain
- Climate Parameter 14, Snow Accumulation

In addition, subsequent to the workshop, the team expressed some reservations regarding the probability scores assigned to Pineapple Express events at the workshop. They were concerned that the probability assignment may result in an overstatement of the risk outcomes. To address this concern, we also conducted sensitivity analysis on these parameters to test the impact on calculated risk. These included:

- Climate Parameter 7, Extreme Rainfall Intensity over One Day
- Climate Parameter 8, Magnitude of Severe Storm Driven Peak Flows
- Climate Parameter 9, Frequency of Severe Storm Driven Peak Flows

The adjusted probability scores are presented in **Figure 4.15**.

Figure 4.15 Probability Score Adjustment for Sensitivity Analysis

#	Parameter	Probability Scores	
		Workshop	Sensitivity
7	Extreme Rainfall Intensity over One Day	6	5
8	Magnitude of Severe Storm Driven Peak Flows	6	5
9	Frequency of Severe Storm Driven Peak Flows	5	4
10	Rain on Snow	3	4
11	Freezing Rain	3	4
14	Snow Accumulation	3	4

The results of the sensitivity analysis are presented in **Figure 4.16**.

The workbook used to complete the sensitivity analysis is presented in **Appendix G**.

In this chart, the risk outcomes that changed as a result of the sensitivity analysis are color-coded as follows:

Changed Risk Outcomes:

Figure 4.16 Climate Change Risk Assessment Sensitivity Analysis

Infrastructure Components	High Temperature	Low Temperature	Temperature Variability	Freeze/Thaw	Frost Penetration	Frost	Extreme Rainfall Intensity over One Day	Magnitude of Severe Storm Driven Peak Flows	Frequency of Severe Storm Driven Peak Flows	Rain on Snow	Freezing Rain	Snow Storm/ Blizzard	Snow (Frequency)	Snow Accumulation	High Wind/ Downburst	Visibility / Fog
Infrastructure																
Surface - Asphalt	18	9	2	6	2	2	25	25	20							
Pavement Marking											12	18	18	24		
Shoulders (Including Gravel)							30	30	28		4	3	3	24		
Barriers				6								3	3	20		
Curb	6			3									9	12		
Luminaires											16	12	3	16		
Poles											4			12		
Signage - Side Mounted - Over 3.2 m2											4	12	3			
Signage - Overhead Guide Signs					8						4	9	3			
Overhead Changeable Message Signs					8						4	9	3			
Ditches				6			25	30	28	4			3	24		
Embankments/Cuts (Constructed)				18	6	2	30	35	28				3	24		
Hillsides (Natural)				15			25	35	28	12			3	4		
Engineered Stabilization Works				15	2	2	15	25	28							
Avalanche (Inc Protective Works)		3	6	9	2	8	30	30	28	20	24	15	15	24		
Debris Torrents (Inc Protective Works)	14		10	9			35	35	28	20			12	20		
Structures that Cross Streams	6	3		6	8	4	30	35	28		8					
Structures that Cross Roads	6	3		6	8	4	25	30	28		8					
River Training Works (Rip Rap)							30	35	28							
MSE Walls				3				25	24							
Pavement Structure above Sub-Grade		9		12	10											
Catch Basins				3	14		30	30	24	24				16		
Median and Roadway Drainage Appliances				3	14		30	30		24				16		
Sub-Drains		6		3	14	2	15	30								
Third-Party Utilities							25	25			28					
Culverts < 3m		3		6			35	35	28	20						
Culverts ≥ 3m				3			35	35	28							
Asphalt Spillway and Associated Piping/Culvert		3		6			30	35		20				12		
Environmental Features																
In-Stream Habitat Works	24		4				30	35	28							
Off-Channel Habitat Works	24		4				30	35	28							
Wildlife Fence System										24	24	18	18	24		
Wildlife Crossing Structures																
Vegetation Management	6		4													
Invasive Plants & Pests	12		4			12										
Miscellaneous																
Administration/Personnel & Engineering																
Winter Maintenance		3	2	15	10	2	20	30	28	20	24	18	9	12		
Ancillary Buildings, Utilities and Yards		3			6	2	6	10	12	20	16	9	9	20		
Communication											24	18	6	16		
Emergency Response		18				2	30	35	28	20	28	18	6	8		
Maintenance (Markings, Crack Sealing)		9	2	12	2	2	4									

4.7 Potential Cumulative Effects

The team contemplated several combined events and cumulative impacts in their assessment.

These included:

- Climate Parameter 7, Extreme Rainfall Intensity over One Day
- Climate Parameter 8, Magnitude of Severe Storm Driven Peak Flows
- Climate Parameter 9, Frequency of Severe Storm Driven Peak Flows
    - These three parameters were evaluated sequentially to assess the combined effects of frequency and magnitude on the severity of the outcomes.
- Climate Parameter 10, Rain on Snow
    - This parameter represents the combined impact of rain events during winter conditions.
- Climate Parameter 12, Snow Storm / Blizzard
    - This parameter represents the combined impact of snow and high wind conditions.
- Climate Parameter 16, Visibility due to Fog
    - This parameter represents the combined impact of humidity and temperature conditions leading to fog. This parameter could not be resolved for this study but the team recommended further analysis based on their considerations.

In addition to the above, the team considered event sequences that could lead to adverse infrastructure outcomes. For example, Mountain Pine Beetle infestation could be exacerbated by reduced periods of hard frost. Although this has no direct impact on the highway, it does weaken the forest cover in the watershed through which the infrastructure passes. This could lead to forest fires that reduce the ground cover in the watershed resulting in increased overland flow of water from precipitation events. Ultimately, this could have an impact on the highway drainage systems that were designed to accommodate flows from a watershed that had forest cover.

The above considerations did identify a number of risks that may not have resolved from considering single climate events. The above list may serve as a useful guide for further highway infrastructure studies in B.C.

4.8 Risks Ranking

The team ranked risks into three categories:

1. Low or No Material Risk
2. Medium Risk
3. High Risk

The team originally conducted the risk assessment on 560 potential climate-infrastructure interactions. Based on the analysis the team identified:

- 435 interactions with low or no material risk;
- 111 interactions with medium risk; and
- 14 interactions with high risk.

Of the 111 medium level risks, the majority were relatively minor with risk scores in the range 12 to 18.

All 14 high level risks were associated with heavy rainfall and Pineapple Express climatic events. In fact, in these categories even the medium risk items scored quite high - generally greater than 18 and often higher than 30. Thus, these climatic events are responsible for all of the high risk and high-medium risk climate-infrastructure interactions.

The sensitivity analysis did not materially change these results.

Decreasing the probability of Pineapple Express events resulted in fewer high-risk scores. However, close review of these scores indicated that they were still very high-medium risk items – generally greater than 24 and frequently greater than 30. That is, although these items shifted from high to medium risk based on the coarse scaling suggested by the Protocol, they nonetheless remained relatively serious risks.

Although increasing the probability of rain on snow, freezing rain and snow accumulation increased the risk scores; none of the identified medium level risks were escalated to the high-risk category. Some items did rise to relatively high medium-risk values but none of these values exceeded a risk score of 30. Thus, this sensitivity analysis generally supported the overall risk profile determined at the workshop.

4.9 Items Forwarded to Step 4 – Engineering Analysis

At the workshop, the team identified a number of climate-infrastructure interactions that required further resolution through Step 4 – Engineering Analysis. These included:

- Surface Asphalt & Extreme Rainfall Intensity over One Day
- Surface Asphalt & Magnitude of Severe Storm Driven Peak Flows

- Surface Asphalt & Frequency of Severe Storm Driven Peak Flows
- Structures that Cross Roads & Extreme Rainfall Intensity over One Day
- Structures that Cross Roads & Magnitude of Severe Storm Driven Peak Flows
- Structures that Cross Roads & Frequency of Severe Storm Driven Peak Flows
- Catch Basins & Extreme Rainfall Intensity over One Day
- Catch Basins & Magnitude of Severe Storm Driven Peak Flows
- Catch Basins & Frequency of Severe Storm Driven Peak Flows

There were two issues driving these interactions and the choice to forward them to Step 4.

In the case of Surface Asphalt and Structures that Cross Roads, the team decided that the issue was heavy water levels on the surface affecting the functionality of the infrastructure during Pineapple Express Events. They stated that the issue was identical for both infrastructure elements.

In the case of Catch Basins, the situation is that heavy rainfall can exceed the capacity of the Catch Basin, especially during Pineapple Express events.

At a teleconference on March 16, 2010, technical/engineering representatives from the team reviewed these interactions. They concluded that the interactions could be summarized into two categories:

1. Road Surfaces (Gutters and Stormwater Inlets) & Extreme Rainfall
2. Catch Basins (Storm Sewers) & Extreme Rainfall

Further, the team determined that they required better definition of one high-risk interaction:

3. Median and Roadway Drainage Appliances (Hwy Ditches) & Extreme Rainfall

Normally, the Protocol directs the practitioner to consider medium-risk items as potential candidates for Step 4. However, the practitioner is not limited to medium-risk items. In this case, the team determined that they required a better understanding of the nature of the risk imposed by the impact of extreme rainfall on median and roadway drainage appliances and added this high-risk item to the Step 4 Analysis. This allows the team to conduct the analysis within the timeframe and scope of the assessment and provide better definition for the arising recommendations.

4.10 *Data Sufficiency*

The team was satisfied with the quality, quantity and integrity of the data used for the risk assessment. As previously discussed, the team was not able to resolve data concerns with two climate parameters:

- High wind / downburst; and

- Visibility

The team excluded these parameters from the risk assessment process and recommended them for further study.

The team addressed other potential data gaps through synoptic and sensitivity analyses.

In general, the experience of the team compensated for any gaps in technical or design data.

4.11 Discussion

4.11.1 General

Of 560 potential climate-infrastructure interactions, the team determined that:

- 435, or 78%, of the interactions had low or no material risk;
- 111, or 20%, of the interactions had medium risk;
- 14, or 3%, of the interactions had high risk.

These low, medium and high risks are highlighted in **Figure 4.14**.

This supports the conclusion that, overall, the infrastructure is relatively robust with respect to climate change.

4.11.2 Pineapple Express

Pineapple Express events present a significant risk to the infrastructure in terms of drainage management issues. These can adversely affect the safety and serviceability of the infrastructure. The team raised concern that these events will increase in both frequency and magnitude. Furthermore, the infrastructure is already exhibiting vulnerability to high intensity rainfall events. Thus, the team concluded that these issues will be exacerbated by climate change and raise greater challenges to the ongoing operation and maintenance of the highway.

Although the west coast highways such as the Coquihalla are subject to severe storm driven peak flow events, other parts of the province may be more vulnerable to changes in snow melt driven peak flow events. This may be resolved in future case studies of on B.C. interior highway infrastructure.

BCMoTI will need to better resolve the potential frequency and magnitude of these events as they were primarily assessed through synoptic analysis. PCIC may be able to provide greater guidance on this matter through more refined statistical downscaling studies. These studies could not be concluded within the timeframe of this assessment as they may take up to six months to complete.

4.11.3 Snowfall

Although snowfall events did not generate any high-risk scores with respect to the infrastructure, they nonetheless present an ongoing medium-risk concern. The team concluded that these events are unlikely to get worse as a result of climate change. However, they do raise potential concerns regarding:

- Emergency response,
- Third party utilities; and
- Avalanche.

The team recognized that these items represent an ongoing concern. However, they concluded that climate change would not exacerbate the situation and that BCMoTI already has ongoing design, operation and maintenance procedures that address these issues. It is not likely that BCMoTI would have to modify these procedures to address climate change.

4.11.4 Unresolved Climate Parameters

PCIC was unable to provide model-based data for three climate parameters during the timeframe of the study. These included:

- Frequency of rain on snow events;
- Frequency of freezing rain events; and
- Snow accumulation.

The risk assessment was completed through the application of sensitivity analysis. Although the team concluded that the results generated by the sensitivity analysis are relatively robust, it is worthwhile pursing better definition for these parameters through more advanced statistical downscaling work. These studies could not be concluded within the timeframe of this assessment as they may take up to six months to complete.

4.11.5 High Wind / Downburst

PCIC was unable to provide model-based data to evaluate this situation since the wind speeds contemplated could not be resolved by the models. In addition, given the localized nature of these events it was very difficult to conduct synoptic analysis of this parameter. Finally, the team did not believe that it had sufficient information to express an opinion regarding the assignment of arbitrary probability scores in a sensitivity analysis.

The team concluded that these events were potentially very serious on the Coquihalla Highway and needed to be further evaluated.

4.11.6 Visibility

Poor visibility can lead to serious safety concerns on the highway. A large portion of serious accidents report fog as a cause.

The Coquihalla Highway is in a transition zone between the coast and interior regions of the province. Fog needs moisture to form. However, there are multiple causes of fog, including:

- Very localized, from warm air over snow;
- Valley fog; or
- Low clouds.

The team determined that this issue requires more study to define how visibility issues arise currently on the highway. Once BCMoTI has developed a better definition of current visibility issues, they will be better placed to assess the impact of climate change on this matter.

The team agreed that this is a potentially high risk item and has identified this issue as a matter for further study. Ultimately, this issue may require the development of specialized highway management strategies.

4.11.7 Low Probability – High Severity Events

The team identified five climate-infrastructure interactions with low probability and high severity scores, including:

1. High Temperature - Debris Torrents;
2. Frost Penetration - Catch Basins;
3. Frost Penetration - Median and Roadway Appliances;
4. Frost Penetration - Sub-Drains; and
5. Freezing Rain – Third-Party Utilities.

Risk analysis screens out these interactions since the risk score is low. However, it is worth noting that if these events should ever occur, and even low probability events have a finite likelihood of occurrence, the consequence could be very significant.

5 Step 4 – Engineering Analysis

In this step the team assessed the impact of projected climate change loads for three climate-infrastructure combinations:

1. Road Surfaces (Gutters and Stormwater Inlets) & Extreme Rainfall
2. Catch Basins (Storm Sewers) & Extreme Rainfall
3. Median and Roadway Drainage Appliances (Hwy Ditches) & Extreme Rainfall

Although the team identified these events through consideration of Pineapple Express, it should be noted that the actual vulnerability is based on extreme rainfall, regardless of the cause.

Vulnerability exists when infrastructure has insufficient capacity to withstand the projected or anticipated loads that may be placed on it. Resiliency exists when the infrastructure has sufficient capacity to withstand increasing loads resulting from climate change.

Engineering Analysis requires the assessment of the various factors that affect load and capacity of the infrastructure. Based on this assessment, indicators or factors are determined in order to relatively rank the potential vulnerability of the infrastructure elements to various climate effects.

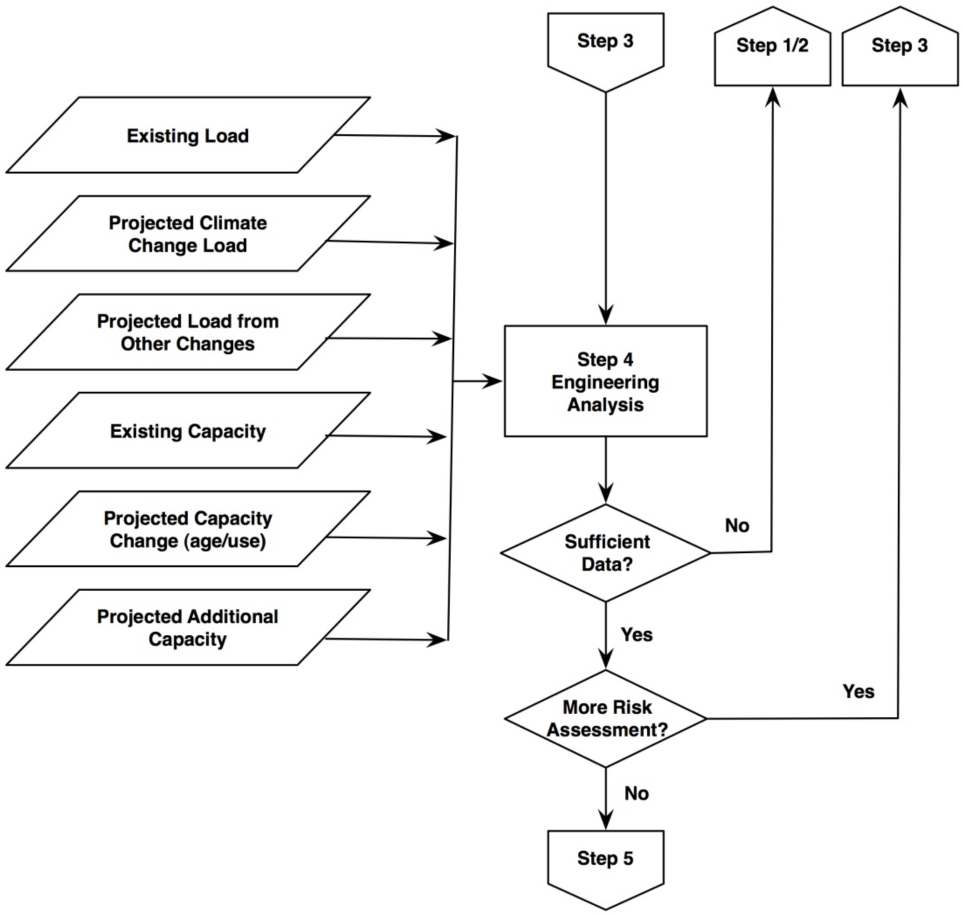
Much of the data required for Engineering Analysis may not exist or may be very difficult to acquire. Engineering Analysis requires the application of multi-disciplinary professional judgement. The results of the analysis yield a set of parameters that can be ranked relative to each other, based on the professional judgement of the team. This can be used to rank the relative vulnerability or resiliency of the infrastructure.

BCMoTI formed a small sub-committee of the team to focus on this activity. The work was completed subsequent to the workshop over the period March 16, 2010 through March 22, 2010.

The process flowchart for Step 4 of the Protocol is presented in **Figure 5.1**.

The completed Worksheet 4 from the Protocol is presented in **Appendix H**.

Figure 5.1 Engineering Analysis Process Flowchart



5.1 Calculation of Total Load

The team calculated total load for the interactions identified in Step 3 guided by the Protocol and using the Protocol worksheet to document their deliberations. The results of the total load analysis are presented in **Figure 5.2**.

Figure 5.2 Total Load

(mm/24hr)

Infrastructure Component	Existing Load	Climate Load	Other Change Load	Total Load
	L_E	L_C	L_O	$L_T = L_E + L_C + L_O$
Road Surfaces (Gutters, Stormwater Inlets) & Extreme Rainfall	88	13.2	0	101.2
Basis for Determination ☞	We assumed these structures were originally designed for a 1:5 year return period. Referencing the 1:5 return period to 24 hour rainfall data from the Rainfall Frequency Atlas for Canada (HOGG, 1985) yields rainfall as 88mm/24hrs at Nicolum River. This is the unfactored Design Load used for comparison.	We Infer from the climate models that the Pineapple Express events could go from 1:10 to 1:4 year event (over 3 days). By extrapolation for this component, we assumed a factor to increase the load back to a 1:5 event would be 10-20% (so we use 15%) and 88mm/24hrs increases to 101mm/24 hrs (for our example).	Land use changes (logging, pine beetle) could increase amounts of water but we assume little affect on this structure as it is part of the internal road drainage and likely not affected by the watershed.	
Median and Roadway Drainage Appliances (Hwy Ditches) & Extreme Rainfall	121	18.2	13.9	153.1
Basis for Determination ☞	We assumed these structures were originally designed for a 1:10 to 1:25 year return period. Referencing the 1:25 return period to 24 hour rainfall data from the Rainfall Frequency Atlas for Canada (HOGG, 1985) yields rainfall as 121mm/24 hrs at Nicolum River. This is the unfactored Design Load used for comparison.	We Infer from the climate models that the Pineapple Express events could go from 1:10 to 1:4 year event (over 3 days). By extrapolation for this component, we assumed a factor to increase the load back to a 1:25 event would be 10-20% (so we use 15%) and 121mm/24hrs increases to 139mm/24 hrs (for our example).	Land use changes (logging, pine beetle) could increase amounts of water on this structure by 10% (chapter 10 in Supplement to TAC Design Guide (2007)).	
Catch Basins (Storm Sewers) & Extreme Rainfall	121	18.2	0	139.2
Basis for Determination ☞	We assumed these structures were originally designed for a 1:10 to 1:25 year return period.	We Infer from the climate models that the Pineapple Express events could go from 1:10 to 1:4 year event	Land use changes (logging, pine beetle) could increase amounts of water but we	

Figure 5.2 Total Load

(mm/24hr)

Infrastructure Component	Existing Load	Climate Load	Other Change Load	Total Load
	L_E	L_C	L_O	$L_T = L_E+L_C+L_O$
Basis for Determination ☞	Referencing the 1:25 return period to 24 hour rainfall data from the Rainfall Frequency Atlas for Canada (HOGG, 1985) yields rainfall as 121mm/24 hrs at Nicolum River. This is the unfactored Design Load used for comparison.	(over 3 days). By extrapolation for this component, we assumed a factor to increase the load back to a 1:25 event would be 10-20% (so we use 15%) and 121mm/24hrs increases to 139mm/24 hrs (for our example).	assume little affect on this structure as it is part of the internal road drainage and likely not affected by the watershed.	

5.2 *Calculation of Total Capacity*

The team calculated total capacity for the interactions identified in Step 3 guided by the Protocol and using the Protocol worksheet to document their deliberations. The results of the capacity analysis are presented in **Figure 5.3**.

Figure 5.3 Total Capacity

(mm/24hr)

Infrastructure Component	Existing Capacity	Climate Capacity	Other Change Capacity	Total Capacity
	C_E	C_M	C_A	$C_T = C_E+C_M+C_A$
Road Surfaces (Gutters, Stormwater Inlets) & Extreme Rainfall	88	0	0	88
Basis for Determination ☞	The designers at the time may have added capacity as a safety factor to this component but is not verified. We assumed: existing capacity the same as the design load; and that the structures were built as designed to handle the load (We checked climate data 11km west of Nicolum (Environment Canada - Hope Airport 1964-1996 (IDF)) to see if capacity of structures would face changed climate conditions - but there was no noticeable indication	Assume the same condition.	Not likely.	

Figure 5.3 Total Capacity

(mm/24hr)

Infrastructure Component	Existing Capacity	Climate Capacity	Other Change Capacity	Total Capacity
	C_E	C_M	C_A	$C_T = C_E + C_M + C_A$
	of changes in climate over this time period)..			
Median and Roadway Drainage Appliances (Hwy Ditches) & Extreme Rainfall	121	0	0	121
Basis for Determination ☞	The designers at the time may have added capacity as a safety factor to this component but is not verified. We assumed: existing capacity the same as the design load; and that the structures were built as designed to handle the load (We checked climate data 11km west of Nicolum (Environment Canada - Hope Airport 1964-1996 (IDF)) to see if capacity of structures would face changed climate conditions - but there was no noticeable indication of changes in climate over this time period.) We assumed: existing capacity the same as the design load; and that the structures were built as designed to handle the load.	No reduction was used for this component however, reduced capacity due to degradation may be a consideration (May want to subtract 5 % here	Not likely.	
Catch Basins (Storm Sewers) & Extreme Rainfall	121	-6	2	117
Basis for Determination ☞	The designers at the time may have added capacity as a safety factor to this component but is not verified. We assumed: existing capacity the same as the design load; and that the structures were built as designed to handle the load (We checked climate data 11km west of Nicolum	Maturing or degradation of pipes could reduce capacity by 2-5%. So use 5% for this example. Catch basins fill with debris and require cleaning about once a year.	Maturing or degradation of pipes could reduce capacity by 2-5%. But could also erode fill at outlet end and thus increase capacity of flow. Therefore increase capacity by 2% for this example.	

Figure 5.3 Total Capacity

(mm/24hr)

Infrastructure Component	Existing Capacity	Climate Capacity	Other Change Capacity	Total Capacity
	C_E	C_M	C_A	$C_T = C_E+C_M+C_A$
	(Environment Canada - Hope Airport 1964-1996 (IDF)) to see if capacity of structures would face changed climate conditions - but there was no noticeable indication of changes in climate over this time period)..			

5.3 *Vulnerability Evaluation*

Based on the results generated for total load and total capacity, the team calculated the vulnerability ratios for the three interactions.

The vulnerability ratio is defined as:

$$V_R = \frac{L_T}{C_T}$$

Where:

L_T = Total Load
C_T = Total Capacity

The infrastructure component is deemed to be vulnerable when $V_R > 1$. That is, the projected load is greater than the projected capacity. In this case, the team is projecting a situation where there is a potential failure condition arising from the climate-infrastructure interaction. This does not mean that the infrastructure component will definitely fail. Rather, it suggests that the team is contemplating a set of realistic, foreseeable states, where the infrastructure could conceivably fail. This suggests that there is a rational basis for concluding that the infrastructure is at risk.

The infrastructure component is deemed to be resilient when $V_R < 1$. That is, the projected load is less than the projected capacity. In this case, the team is projecting a situation where there is a potential non-failure condition arising from the climate-infrastructure interaction. This does not mean that the infrastructure component will definitely not fail. Rather, it suggests that the team is contemplating a set of realistic, foreseeable states, where the infrastructure could conceivably continue to operate at an acceptable level of service. This suggests that there is a rational basis for concluding that the infrastructure is not at risk.

The results from the vulnerability evaluation are presented in **Figure 5.4**.

Figure 5.4 Vulnerability

Infrastructure Component	Total Load	Total Capacity	Vulnerability
	L_T	C_T	$V_R = \frac{L_T}{C_T}$
Road Surfaces (Gutters, Stormwater Inlets) & Extreme Rainfall	101	88	1.15
Median and Roadway Drainage Appliances (Hwy Ditches) & Extreme Rainfall	153	121	1.26
Catch Basins (Storm Sewers) & Extreme Rainfall	139	117	1.19

5.4 *Calculation of Capacity Deficit*

Based on the results generated for total load and total capacity, the team calculated the capacity deficits for the three interactions.

The capacity deficit is defined as:

$$C_D = L_T - C_T$$

Where:

L_T = Total Load
C_T = Total Capacity

This calculation is an adjunct to the vulnerability evaluation conducted in **Section 5.3**. It not only indicates whether or not the infrastructure component is vulnerable but it also gives a sense of the magnitude of that vulnerability or resiliency.

The infrastructure component is deemed to be vulnerable when $C_D > 1$. Consistent with the discussion of V_R, the projected load is greater than the projected capacity. In this case, the team is projecting a situation where there is a potential failure condition arising from the climate-infrastructure interaction. This does not mean that the infrastructure component will definitely fail. Rather, it suggests that the team is contemplating a set of realistic, foreseeable states, where the infrastructure could conceivably fail. This suggests that there is a rational basis for concluding that the infrastructure is at risk.

The infrastructure component is deemed to be resilient when $C_D < 1$. Consistent with the discussion of V_R, the projected load is less than the projected capacity. In this case, the team is projecting a situation where there is a potential non-failure condition arising from the climate-infrastructure interaction. This does not mean that the infrastructure component will definitely not fail. Rather, it suggests that the team is contemplating a set of realistic, foreseeable states, where the infrastructure could conceivably continue to operate at an acceptable level of service. This suggests that there is a rational basis for concluding that the infrastructure is not at risk.

The results from the vulnerability evaluation are presented in **Figure 5.5**.

Figure 5.5 Capacity Deficit
(mm/24hr)

Infrastructure Component	**Total Load**	**Total Capacity**	**Capacity Deficit**
	L_T	C_T	$C_D = L_T - C_T$
Road Surfaces (Gutters, Stormwater Inlets) & Extreme Rainfall	101	88	13
Median and Roadway Drainage Appliances (Hwy Ditches) & Extreme Rainfall	153	121	32
Catch Basins (Storm Sewers) & Extreme Rainfall	139	117	22

5.5 *Data Sufficiency*

This is a preliminary assessment as data to do a complete analysis is lacking. This particular analysis gives relative comparisons and is not absolute because of the nature of available data and the time frame. This analysis gives a relative ranking in broad terms and indicates areas to examine in more detail. Therefore, further study is required.

Analyzing climate data to evaluate extreme rain can be difficult as many duration and intensity event combinations can cause problems for structures. Depending on the time of concentration, storm data of various intensities (i.e. 15 min./2hrs/6hrs/etc.) are required for complete analysis. In this example, 24-hour rainfall data is used as a basis for comparison to be consistent with other data parameters. This illustrates that data is required in comparable units for engineering analysis - which is a challenge in combining structure design and climate forecasting.

An analysis of this type may require a detailed study of weather and storm data, time of concentration, IDF data, structural design specification and maintenance records to determine the capacity of the existing highway drainage. This is to answer the question: if more storms are predicted then how will infrastructure perform under these changing weather conditions?

For a thorough Step 4 analysis, BCMoTI would determine if there is a built-in design reserve capacity in the current drainage structures on this particular section of the Coquihalla Highway. To accomplish this, the team suggested doing a back-calculation study using a consultant to assess sections of the Coquihalla Highway to determine the original (or updated) design parameters and the actual drainage capacity to know if it would accommodate potential climate changes.

5.6 Discussion

The results of the engineering analysis supported the conclusions reached through the risk assessment. The team concluded that high intensity rainfall events could overload drainage infrastructure. Specifically:

- Water on roadway surfaces could impede traffic;
- Maintenance effects could include increased erosion; and
- Environmental effects of increased erosion include carrying sediments and contaminants to watercourses.

Based on these considerations the team concluded that increased rainfall intensity could require updated policies and procedures regarding design and maintenance of highway infrastructure.

The team made the following recommendations.

1. To support this preliminary analysis, further investigate current design reserve capacity of the Coquihalla Highway to handle changing hydrology from increased local extreme rainfall events. Therefore, use a consultant to conduct a back-calculation study to assess sections of the Coquihalla Highway to determine the original (or updated) design parameters and the actual drainage capacity; to determine if it would accommodate potential climate changes.

2. In general, develop relevant parameters to measure the interaction between infrastructure design and climate changes (as inputs to methodology and modeling). Specifically, use downscale analysis (of Regional Climate Model data) to determine local climate condition changes and match this with design standards of particular infrastructure under study. (E.g. changing duration and amount of rainfall within localized area and current design return period.) This will allow a systematic measurement basis for analysis (may require more complex engineering model use in future, such as, continuous rainfall analysis etc.).

3. If, due to study findings, infrastructure components require upgrading to accommodate increased rainfall intensity, this could be accomplished as a part of regular design and

maintenance activities and not as a separate program - unless a serious situation is identified (as forecast changes are 40 years into future).

4. Require contractors to document weather conditions that caused major maintenance issues. Notionally, this would include meteorological data on rainfall, wind, etc. from the nearest weather station. This would link infrastructure problems with climate data and facilitate future monitoring of this interaction.

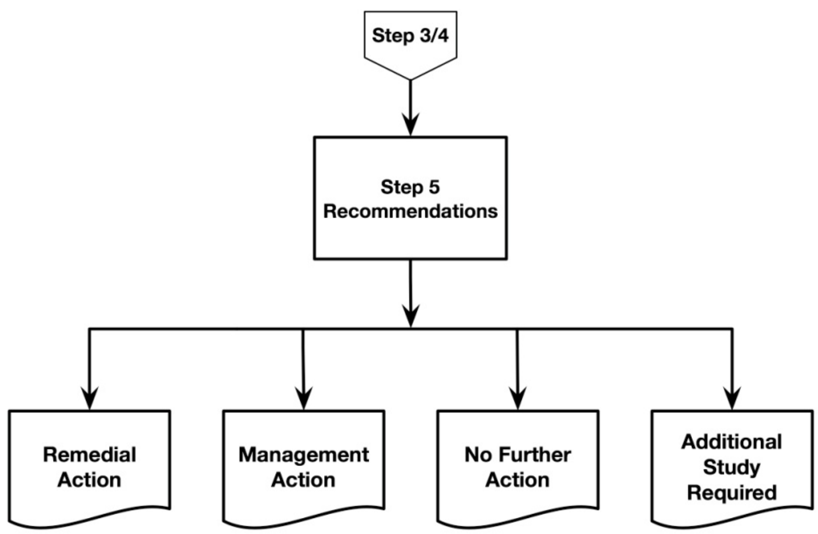
5. Investigate if UBC (or others) infrastructure failure models contemplate climate as a variable and if this can be modeled for BCMoTI purposes.

6 Step 5 – Recommendations

The process flowchart for Step 5 of the Protocol is presented in **Figure 6.1**.

The completed Worksheet 5 from the Protocol is presented in **Appendix I**.

Figure 6.1 Recommendations Process Flowchart



6.1 *Limitations*

6.1.1 Major Assumptions

The assessment was not limited by the project definition or stated timeframe. The highway is not due for major refurbishment over the timeframe contemplated by the study. However, the highway is subjected to ongoing maintenance that would tend to mitigate many of the identified climate change risks as practices typically evolve to accommodate current conditions.

6.1.2 Available Infrastructure Information

The assessment was not limited by lack of technical information regarding the highway. The team had access to the Coquihalla Highway data room. In addition, the team had access to personal files and very deep experience with the design, operation and maintenance of the highway.

6.1.3 Available Climate Data

Unresolved Climate Parameters

PCIC was unable to provide model-based data for three climate parameters during the timeframe of the study. These included:

- Frequency of rain on snow events;
- Frequency of freezing rain events; and
- Snow accumulation.

The risk assessment for these parameters was completed through the application of sensitivity analysis.

High Wind / Downburst

PCIC was unable to provide model-based data to evaluate high wind/downburst since the models could not resolve the wind speeds contemplated. In addition, given the localized nature of these events it was very difficult to conduct synoptic analysis of this parameter. Finally, the team did not believe that it had sufficient information to express an opinion regarding the assignment of arbitrary probability scores in a sensitivity analysis. These events were not considered in the evolution and lead to a recommendation for further study.

Visibility

The team determined that this issue requires more study to define how visibility issues arise currently on the highway. Once BCMoTI has developed a better definition of current visibility issues, they will be better placed to assess the impact of climate change on this matter.

6.1.4 Available Information on Other Change Effects

The assessment was not limited by lack of information regarding other sources of change. The experience of the team, and observations of day-to-day operation of the highway compensate for any gaps that may otherwise occur.

6.1.5 Uncertainty

Climate modeling is based on inherent assumptions regarding likely emissions scenarios. Additionally, there is a significant level of statistical uncertainty associated with both the modeling and the analytical approaches used to downscale the information generated by the regional climate models to local conditions. PCIC addressed this concern by correlating model predictions with observed, baseline, climate conditions.

The BCMoTI team possesses a significant level of understanding of the regional climate based on many years of day-to-day, hands-on, experience with the design, operation and maintenance of the highway. This experience provided the team with sufficient foundation to assess the veracity of the climate model projections.

6.2 High Risk Issues and Sensitivity Analysis

Highway structures, with high-risk scores, as assessed using the PIEVC methodology, indicate their performance responses (including design criteria) could be compromised or vulnerable under certain climate change scenarios. Performance criteria include:

- Structural integrity;
- Functionality (serviceability);
- Watershed, surface water and groundwater;
- Operations and maintenance;
- Emergency response;
- Insurance considerations;
- Policies and procedures;
- Economics; and
- Public health and safety.

The structural components listed in **Figure 6.2** were initially identified as either high risk or high-medium risk at the Step 3 - Workshop session. A sensitivity analysis was completed to test their high-risk vulnerability to potential climate change on the Coquihalla to 2050 by adjusting probability scale factors.

In all cases the sensitivity analysis reduced the risk score of the structure to less than 36 but in most cases still indicated a high-medium risk potential.

Examining these high-medium risk structures using an engineering analysis, as was completed for some structure/climate interactions, as outlined in **Section 5**, may be advised to more rigorously test performance responses of these structures to these anticipated climate events.

In some cases, this could indicate the structure is indeed at high risk under certain conditions, with attendant action required.

Figure 6.2 High Risk Items and Their Sensitivity Analysis Results

Infrastructure Components	Extreme Rainfall Intensity over One Day		Magnitude of Severe Storm Driven Peak Flows		Frequency of Severe Storm Driven Peak Flows	
	Risk Score	Sensitivity Score	Risk Score	Sensitivity Score	Risk Score	Sensitivity Score
Ditches	30	25	36	30	35	28
Embankments/Cuts (Constructed)	36	30	42	35	35	28
Hillsides (Natural)	30	25	42	35	35	28
Engineered Stabilization Works	18	15	30	25	35	28
Avalanche (Inc. Protective Works)	36	30	36	30	35	28
Debris Torrents (Inc. Protective Works)	42	35	42	35	35	28
Structures that Cross Streams	36	30	42	35	35	28
Structure that Cross Roads	30	25	36	30	35	28
River Training Works	36	30	42	35	35	28
Sub-Drains	18	15	36	30		
Culverts < 3m	42	35	42	35	35	28
Culverts ≥ 3m	42	35	42	35	35	28
Asphalt Spillway and Associated Piping/Culverts	36	30	42	35		
In Stream Habitat Works	36	30	42	35	35	28
Off Channel Habitat Works	36	30	42	35	35	28
Emergency Response	36	30	42	35	35	28

6.3 Recommendations

The recommendations arising from this risk assessment are outlined in **Figure 6.3**.

Figure 6.3 Recommendations

Remedial Engineering Action	Management Action	Additional Study Required

Pineapple Express

Pineapple Express events present a significant risk to the infrastructure in terms of drainage management issues. These can adversely affect the safety and serviceability of the infrastructure. The team raised concern that these events will increase in both frequency and magnitude. Furthermore, the infrastructure is already exhibiting vulnerability to high intensity rainfall events. Thus, the team concluded that these issues will be exacerbated by climate change and raise greater challenges to the ongoing operation and maintenance of the highway.

1. BCMoTI should investigate current design reserve capacity of the Coquihalla Highway to handle changing hydrology from increased local extreme rainfall events. 2. If, due to study findings, infrastructure components require upgrading to accommodate increased rainfall intensity, this should be accomplished as a part of regular design and maintenance activities and not as a separate program - unless a serious situation is identified (as forecast changes are 40 years into future).	3. BCMoTI should resolve the potential frequency and magnitude of extreme rain events as they were primarily assessed through synoptic analysis. 4. BCMoTI should require contractors to document weather conditions that caused major maintenance issues. Notionally, this would include meteorological data on rainfall, wind, etc. from the nearest weather station. This would link infrastructure problems with climate data and facilitate future monitoring of this interaction. 5. Investigate if University of British Columbia (or other) infrastructure failure models contemplate climate as a variable and if this can be adapted to BCMoTI's needs.	6. Develop relevant parameters to measure the interaction between infrastructure design and climate changes (as inputs to methodology and modeling). Specifically, use downscale analysis (of Regional Climate Model data) to determine local climate condition changes and match this with design standards of the particular infrastructure under study. (E.g. changing duration and amount of rainfall within localized area and current design return period.) This will allow a systematic measurement basis for analysis (may require more complex engineering model use in future, such as, continuous rainfall analysis, etc.).

Figure 6.3 Recommendations

<table>
<tr><th>Remedial Engineering Action</th><th>Management Action</th><th>Additional Study Required</th></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td colspan="3"><u>Snowfall</u>

Snowfall events did not generate any high-risk scores with respect to the infrastructure; they nonetheless present an ongoing medium-risk concern. The team concluded that these events are unlikely to get worse as a result of climate change. However, they do raise potential concerns regarding:

• Emergency response,
• Third party utilities; and
• Avalanche.

The team recognized that these items represent an ongoing concern. However, they concluded that climate change would not exacerbate the situation and that BCMoTI already has ongoing design, operation and maintenance procedures that address these issues.

It is not likely that BCMoTI would have to modify these procedures to address climate change.</td></tr>
<tr><td>No further action required at this time.</td><td>No further action required at this time.</td><td>No further action required at this time.</td></tr>
<tr><td colspan="3"><u>Unresolved Climate Parameters</u>

PCIC was unable to provide model-based data for three climate parameters during the timeframe of the study. These included:

• Frequency of rain on snow events;
• Frequency of freezing rain events; and
• Snow accumulation.</td></tr>
<tr><td>N/A</td><td>N/A</td><td>7. Although the team concluded that the results generated by the sensitivity analysis are relatively robust, through more advanced statistical downscaling work, BCMoTI should pursue better definition of:

• Frequency of rain on snow events;
• Frequency of freezing rain events; and
• Snow accumulation.</td></tr>
</table>

Figure 6.3 Recommendations

<table>
<tr><th>Remedial Engineering Action</th><th>Management Action</th><th>Additional Study Required</th></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td colspan="3"><u>High Wind / Downburst</u>

PCIC was unable to provide model-based data to evaluate this situation since the wind speeds contemplated could not be resolved by the models. In addition, given the localized nature of these events it was very difficult to conduct synoptic analysis of this parameter. Finally, the team did not believe that it had sufficient information to express an opinion regarding the assignment of arbitrary probability scores in a sensitivity analysis.</td></tr>
<tr><td>N/A</td><td>N/A</td><td>8. BCMoTI should conduct further evaluation into high wind / downburst issues. These are potentially very serious on the Coquihalla Highway.</td></tr>
<tr><td colspan="3"><u>Visibility</u>

Poor visibility can lead to serious safety concerns on the highway. A large portion of serious accidents report fog as a cause.

The Coquihalla Highway is in a transition zone between the coast and interior regions of the province. Fog needs moisture to form. However, there are multiple causes of fog, including:

• Very localized, from warm air over snow;
• Valley fog; or
• Low clouds.

The team agreed that this is a potentially high-risk item and has identified this issue as a matter for further study. Ultimately, this issue may require the development of specialized highway management strategies.</td></tr>
<tr><td>N/A</td><td>N/A</td><td>9. BCMoTI should conduct more study into visibility issues to define how these issues arise currently on the highway.

10. Once BCMoTI has developed a better definition of current visibility issues, they should assess the impact of climate change on this matter.</td></tr>
</table>

Figure 6.3 Recommendations

Remedial Engineering Action	Management Action	Additional Study Required
Data Management This study proved the advantage of having good data available to the assessment team. Not only was the team comprised of experts with extensive knowledge of the highway and the local climate, but the team also had accesses to good data in the Coquihalla Highway Data Room and personal files. It has been noted that many of the team members are nearing retirement and that it would be advantageous to accumulate relevant climate and infrastructure information in a centralized location. In addition to technical design and operational data, the team has noted that there will be benefits from accumulating relevant climate and meteorological data in the same data room. For future assessments, the assessment team would have all relevant information immediately available. Similarly, data rooms could be established for the other highway segments contemplated for vulnerability assessment.		
N/A	11. BCMoTI should establish central repositories for technical, engineering, design, operation and climatic data necessary to conducting climate change vulnerability assessments for each highway segment contemplated for future vulnerability assessment studies.	N/A

6.4 *Cost/Benefit of Acquiring Additional Data*

From the perspective of this study, data acquisition cost was not an issue and the costs of executing the additional studies outlined above should not pose a significant impediment to progress on these matters. Most of the data is available in-house. Data provided by PCIC is provided by an existing funding agreement between BCMoTI and PCIC.

The team found that the major impediment to data availability was the time frame required to generate the data relative to the project schedule. The team and PCIC identified a number of situations, outlined above, where the data simply could not be resolved within the project deadline. This necessitated the recommendations outlined herein.

Had the information been available at the time of the assessment, the team could have provided additional insight into a number of additional climate-infrastructure interactions. However, the additional data would not materially improve the quality of the assessment in the areas where the team has provided a professional opinion.

Armed with this background, BCMoTI is better positioned to acquire the relevant information for upcoming infrastructure vulnerability assessments.

7 Closing Remarks

7.1 Adaptive Management Process

BCMoTI initiated this study as the first phase of an ongoing climate change adaptive management process. Through this study BCMoTI:

- Assessed the climate change vulnerability of a portion of the Coquihalla Highway;
- Developed an understanding of their climate data needs to facilitate future assessments on this, and other, BCMoTI infrastructure;
- Defined an infrastructure component list suitable for application on other BCMoTI highway vulnerability assessments;
- Developed skills and expertise in using the PIEVC assessment process;
- Identified a number of climate parameters for further study and assessment; and
- Developed a solid foundation for further vulnerability assessments on other infrastructure.

BCMoTI is presently planning the next stage of this process and will assess other BC highway infrastructure through this process, as resources allow.

BCMoTI conducted this assessment using internal resources, facilitated by NCI, so that the approaches of climate change vulnerability assessment can be integrated into the general understanding of staff responsible for the highway infrastructure and imbedded into day-to-day design, management and operations activity.

As part of their ongoing work on climate change adaptation, BCMoTI has established a working relationship with PCIC. Through this relationship, they will refine climate parameters and gather data to support further vulnerability assessment work. Also, these ongoing studies will enhance and refine the climate parameters that were used in this study and will allow BCMoTI to review and revise the conclusions and recommendations from this study, as appropriate.

7.2 Coquihalla Highway Climate Change Vulnerability

Based on this risk assessment, the Coquihalla Highway is generally resilient to climate change with the exception of drainage infrastructure response to Pineapple Express events.

The risk assessment did not identify any new risks to the BCMoTI team. Rather, the process allowed the team to define, review, and document their risk assessment deliberations. Although there were no surprises, the team was able to substantiate their view of the highway's risk profile through experience, climate model data, synoptic and sensitivity analysis. Ultimately, this combination of analytical steps allowed BCMoTI to establish a robust risk profile for the highway.

8 Appendices

Appendix A	PIEVC Engineering Protocol for Climate Change Infrastructure Vulnerability Assessment
Appendix B	Site Selection Criteria
Appendix C	Completed Protocol Worksheet 1
Appendix D	Completed Protocol Worksheet 2
Appendix E	Pacific Climate Impacts Consortium Summary Report
Appendix F	Completed Protocol Worksheet 3
Appendix G	Sensitivity Analysis
Appendix H	Completed Protocol Worksheet 4
Appendix I	Completed Protocol Worksheet 5

Appendix A

PIEVC Engineering Protocol for Climate Change Infrastructure Vulnerability Assessment

Part I

PIEVC Engineering Protocol for Climate Change Infrastructure Vulnerability Assessment

Part I

April 2009

For further information about this ***Engineering Protocol*** or the ***National Engineering Vulnerability Assessment*** **Project** please contact the PIEVC Secretariat at Engineers Canada:

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Part I – Background, Overview and Guidance

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Part I – Background, Overview and Guidance

1 Introduction and Scope

This document is intended to guide practitioners through the ***PIEVC Engineering Protocol for Climate Change Infrastructure Vulnerability Assessment*** (the Protocol). The Protocol is a step-by-step process to assess the impact of climate change on infrastructure. Information developed through this assessment process will assist owners and operators to effectively incorporate climate change adaptation into design, development and management of their existing and planned infrastructure. This protocol has been successfully utilized to assess four categories of infrastructure:

1. Buildings
2. Roads and associated structures
    - Culverts
    - Surface
    - Bridges
    - Etc.
3. Stormwater and wastewater treatment and collection systems
4. Water resource systems and other water management infrastructures
    - Potable water collection
    - Treatment and distribution
    - Water control dams
    - Retention and flood control structures
    - Etc.

The Protocol describes a step-by-step process of risk assessment and engineering analysis for evaluating the impact of climate change on infrastructure. The observations, conclusions and recommendations derived from the application of this protocol provide a framework to support effective decision-making about infrastructure operation, maintenance, planning and development.

This Protocol has been developed for owners and operators to assess public infrastructure. However, the principles and steps will be similar for assessing privately owned infrastructure.

The Protocol was developed with funding contributions from Natural Resources Canada. Engineers Canada (the business name of the Canadian Council of Professional Engineers) owns the intellectual property that is the Protocol. It may be used in Canada for Canadian-based infrastructure without charge, provided the user signs a license agreement with Engineers Canada. The Protocol may be used internationally for infrastructures located outside Canada subject to the payment of a license fee and a license agreement with Engineers Canada.

The Public Infrastructure Engineering Vulnerability Committee (PIEVC) is a national steering committee set up by Engineers Canada in 2005. This committee consists of senior representatives from Federal, provincial and municipal levels of government in Canada along with several non-government organizations. It oversees the National Engineering Vulnerability Assessment project, a long term initiative of the Canadian engineering profession to assess the vulnerability of public infrastructures to the impacts of future changes in climate. This information is a vital input to propose adjustments and amendments to infrastructure codes and standards and related engineering practices.

Note that Engineers Canada provides the Secretariat for the PIEVC and is responsible for all legal and administrative agreements relating to the use of the Protocol.

PIEVC is supported by infrastructure Expert Working Groups consisting of engineers and other technical experts with design and operations experience in the particular infrastructure category as well as climate scientists and other subject matter experts. PIEVC currently has four such groups as follows:

1. Buildings
2. Roads and associated structures
3. Stormwater and wastewater systems
4. Water resource management systems

This document is divided into three main sections:

1. Description of the processes and organization for planning engineering vulnerability assessments of public infrastructure
2. Presentation of the basic principles of risk management that are applicable to this work, along with technical references
3. Procedural description of the five steps involved in executing the Protocol.

The document includes worksheets to record the work completed at each step.

2 Vulnerability Assessment Planning and Execution

Engineering vulnerability assessments normally involve one or, at most, a few individual infrastructures rather than an entire inventory. The individual infrastructure(s) should be carefully selected to provide a representative sample of the inventory. If significant vulnerabilities are detected, and there is widespread variability in nature and severity of vulnerabilities, it may be necessary to assess all individual infrastructures in an inventory to determine what adaptive actions are required for an individual infrastructure.

PIEVC has developed a five-phase process for planning and executing vulnerability assessments, including:

- Phase I – Initial Contact and Preliminary Discussions
- Phase II – Project Scoping and License Agreement
- Phase III – Procurement of Expertise

- Phase IV – Engineering Vulnerability Assessment
- Phase V – Conclusions and Recommendations

These phases are briefly described in the following sections and are presented graphically in Figure 1.

Note that the engineering vulnerability assessment of an individual infrastructure or group of infrastructures is referred to as the "Project" for the remainder of this document.

2.2 *Phase I - Initial Contact and Preliminary Discussions*

Discussion for a Project may be initiated in a number of ways:

- The PIEVC Secretariat approaches an owner or operator or their representative (the "Project Partner") and negotiate a Project. The Project Partner may be represented on one of PIEVC's various committees or may be approached due to some unique features of the infrastructure or its location;
- A potential Project Partner may approach PIEVC with a unsolicited proposal;
- The PIEVC Secretariat issues a Request for Expression of Interest to infrastructure owners, soliciting their interest in a Project; or
- Consultants may identify potential infrastructure assessment sites and approach the infrastructure owner and the PIEVC Secretariat with an unsolicited proposal.

The Protocol is the intellectual property of Engineers Canada, and owners/operators of infrastructure, as well as third-party users, (e.g. consultants) may not use it without the permission of Engineers Canada, which is normally granted through the signing of a license agreement. Part of this agreement includes the obligation to share the results of the assessment with the Federal Government of Canada, PIEVC and Engineers Canada.

2.3 *Phase II - Project Scoping*

Once the potential Project Partner confirms their serious intent to pursue an assessment, the Project enters the Project Scoping and License Agreement phase. During this phase, the project partner and the PIEVC Secretariat:

- Complete the initial stages of the project definition in sufficient detail to complete a project work statement suitable for procurement purposes
- Negotiate and sign a License Agreement between Engineers Canada and the Project Partner;
- Negotiate a memorandum of agreement (MOA) that outlines the roles and

responsibilities of Engineers Canada and the Project Partner, as well as terms and conditions that will govern the Project. It includes the License Agreement and may include additional sections that cover any financial obligations between or among the signing parties as well as any additional administrative policies and procedures needed to execute the agreement;

- Normally an outside consultant is required, and arrangements for procuring these services utilize the procurement policies and procedures of the Project Partner which may include the development of a Request for Proposal (RFP) for cases where a competitive process is required or desired.

The PIEVC Secretariat has generic versions of MOAs, works statements, and RFPs that can help guide this process. These are available through the Secretariat. However, every infrastructure owner has unique management and technical circumstances that may affect the terms and conditions that will guide this process.

Detailed instructions for developing a project definition are integral to this Engineering Protocol and are outlined in Section 8.1 of this document. Project proponents are encouraged to use these procedures and the related worksheets provided under separate cover to guide the project definition process. Obviously, at the project scoping stage, project proponents will not have access to all of the data necessary to complete this step of the engineering protocol. However, the methodology and underlying thought process will significantly aid the project proponent to identify the key components that must be incorporated in the project Work Statement to provide potential consultants with sufficient information to appropriately scope and cost the engineering assessment.

Normally, at the completion of Project Scoping PIEVC and the infrastructure owner will have developed and agreed to three key documents:

1. A Memorandum of Agreement;
2. A Project Work Statement: and
3. A Request for Proposal.

These documents along with this Engineering Protocol will guide the rest of the assessment process.

PIEVC is aware that other project management alternatives may be more suitable in some circumstances. However, in every case the project proponent and PIEVC must clearly articulate the project definition and delineate management responsibilities. In some circumstances the project management tools may differ slightly from those outlined above but the process must always result in similar management system controls for the project.

2.4 *Phase III - Procurement of Expertise*

Normally, the Project partner will manage the procurement of expertise according to their own policies and procedures.

The RFP developed in Phase II will be used to guide the technical requirements of the process.

During this stage, the PIEVC Secretariat will normally facilitate the formation of a Project Advisory Group consisting of representatives from the:

- Infrastructure owner;
- PIEVC Secretariat;
- Corresponding PIEVC Expert Working Group; and
- Other groups, as appropriate.

One of the roles of the Project Advisory Group is to assist in the evaluation of proposals and to advise the Project Partner that the technical requirements of the work are met and the project team has the requisite mix of expertise and experience to satisfy the requirements.

Representatives from the project oversight group may assist the infrastructure owner evaluate proposal documents.

In some circumstances the Project Partner may deem it appropriate to sole-source the project to a specific consultant. The PIEVC Secretariat and Engineers Canada have no objection to this approach provided that any sole-source contract meets the project management guidelines of the infrastructure owner and written justification is provided to the PIEVC Secretariat.

It is recommended that the Project Partner negotiate a consultant agreement incorporating the Work Statement developed during Phase II.

2.5 *Phase IV - Vulnerability Assessment*

The PIEVC Engineering Protocol will guide the vulnerability assessment. The protocol is detailed in Sections 3 and 4.

The consultant will provide three key deliverables.

1. Prior to initiating detailed work, it is strongly recommended that the consultant provide an engagement plan outlining their key deliverables, schedule, personnel and management controls governing the vulnerability assessment.
2. Each month, the consultant will provide a written progress report.
3. At project completion the consultant will provide a detailed project report outlining conclusions on the nature and severity of the findings, conclusions on the nature and severity of infrastructure component vulnerabilities and recommendations.

The approved project Work Statement may also identify other key deliverables specific to the particular infrastructure owner or PIEVC needs.

On a regular basis, the consultant will convene a project update teleconference/meeting including the PIEVC project oversight committee.

2.6 *Phase V - Conclusions and Recommendations*

At the completion of the vulnerability assessment the consultant will provide a set of conclusions and recommendations relating to the climate impact and adaptation of the infrastructure. These conclusions and recommendations will fall into several categories, as outlined in Section 4.5:

1. A report of infrastructure components that have been assessed to be vulnerable.

2. Initial recommendations regarding possible:
    i. Remedial engineering actions;
    ii. Monitoring of structure over a set time period;
    iii. Management actions;
    iv. Additional data collection; or
    v. Additional engineering analysis of particular infrastructure components that may be necessary to determine extent and nature of vulnerabilities.

3. A report on the infrastructure components that have been assessed to have sufficient adaptive capacity to withstand projected climate change impacts; thus requiring no further action at this time.

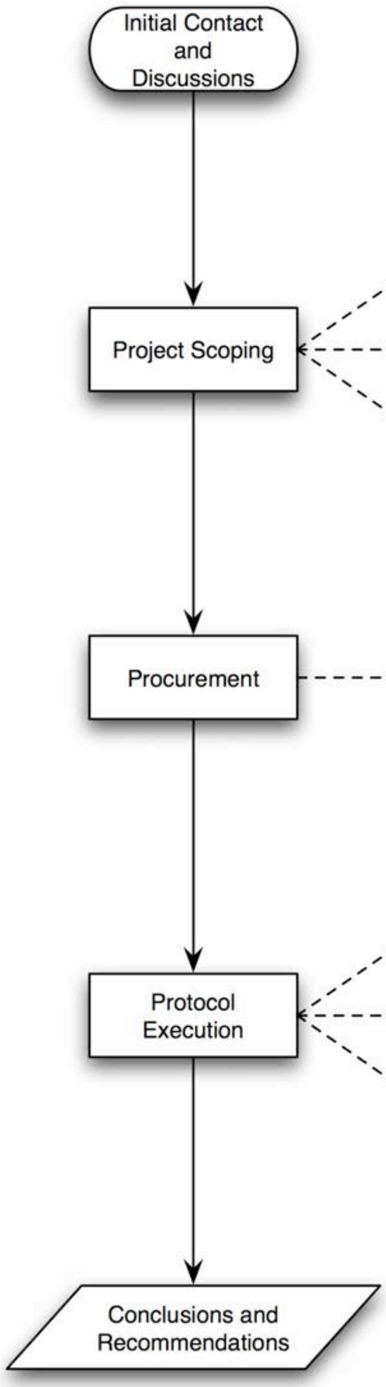
4. A report on data gaps and availability; requiring additional work or studies.

5. Identification of infrastructure components that may be evaluated in the future.

6. A report on other conclusions, trends, insights and limitations.

As part of any License Agreement with Engineers Canada, the Project Partner will forward a copy of the report, including the conclusions and recommendations to Engineers Canada. The findings will be synthesized and incorporated within a ***National Engineering Vulnerability Registry*** that is managed by Engineers Canada. The registry is used to sort, consolidate and analyze engineering vulnerabilities in the four infrastructure categories at the component level.

Figure 1: Overall Project Execution Process



3 Protocol Overview

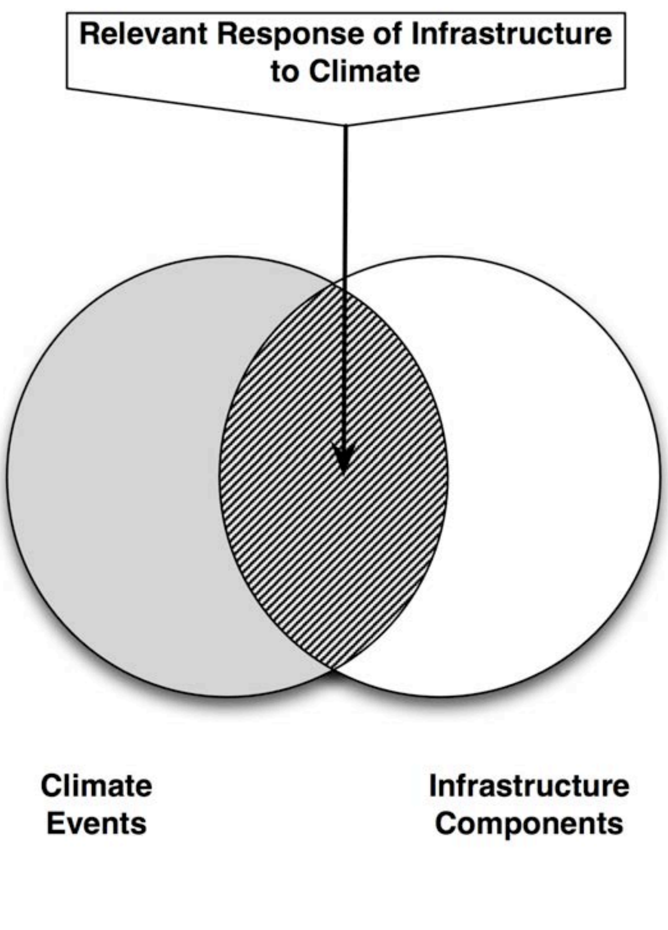
Climate data is used to design infrastructure. Under climate change, historic data may no longer be appropriate. As a result, infrastructure may be vulnerable. Existing infrastructure may not have sufficient resiliency. New infrastructure may not be designed with sufficient load and adaptive capacity.

To assess climate change infrastructure vulnerability, the practitioner must evaluate:

1. The infrastructure;
2. The climate (historic, recent and projected); and
3. Historic and forecast responses of the infrastructure to the climate.

This interaction is depicted in Figure 2.

Figure 2: Venn Diagram Illustrating Relevant Interactions between Climate and Infrastructure



A great deal of information may be available to describe the infrastructure and the climate in the region. The protocol sets out a procedure to sift the data to develop an understanding of how climate and infrastructure interact to create vulnerability. Not *all* climate and infrastructure data is necessary to complete the protocol. The initial stages of the protocol help the practitioner identify the *key* data necessary to complete the assessment. Throughout the protocol the practitioner is directed to continuously evaluate the availability and quality of data sufficient to support conclusions and recommendations.

The protocol is divided into five steps, as illustrated in Figure 3. Each step of the protocol is described in greater detail in Sections 3.1 through 3.5.

Figure 3: Overview of the Protocol

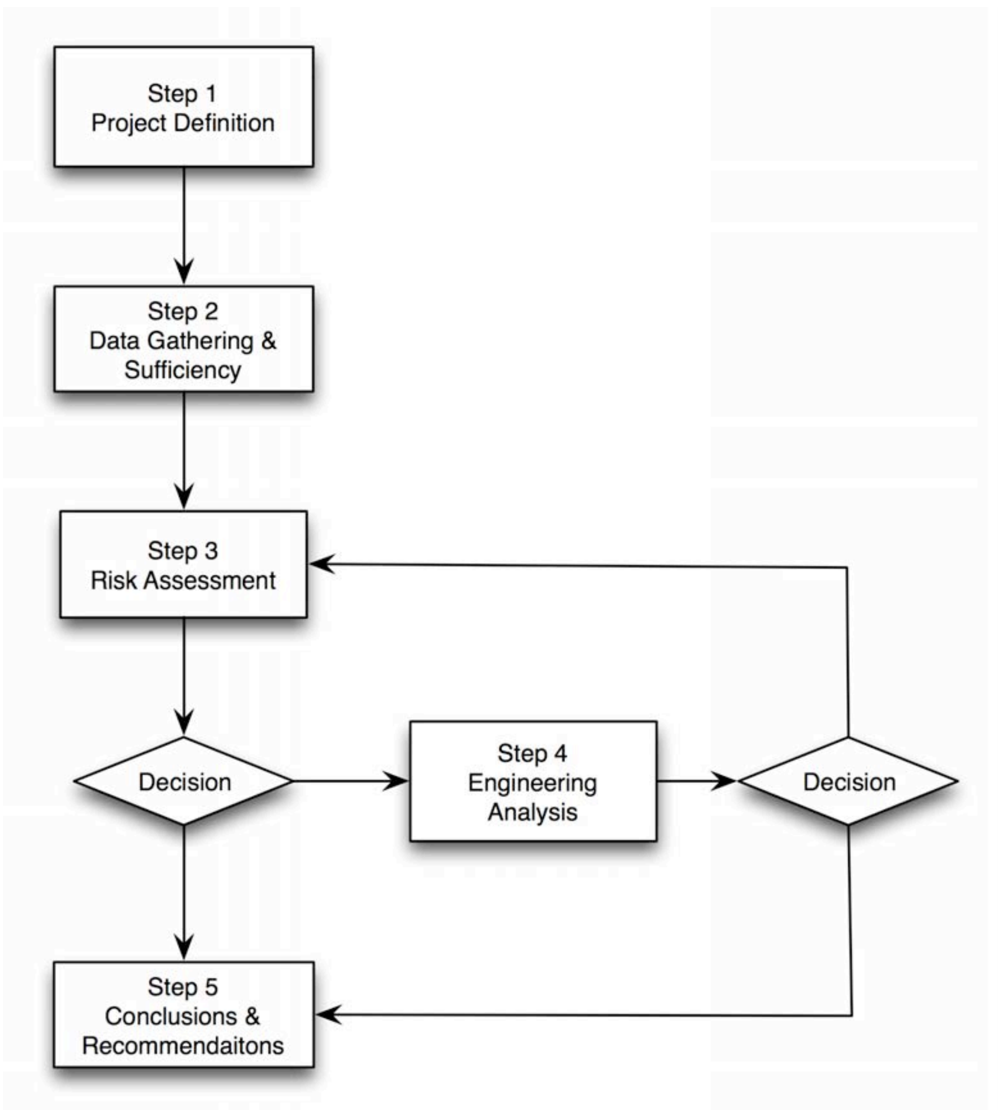
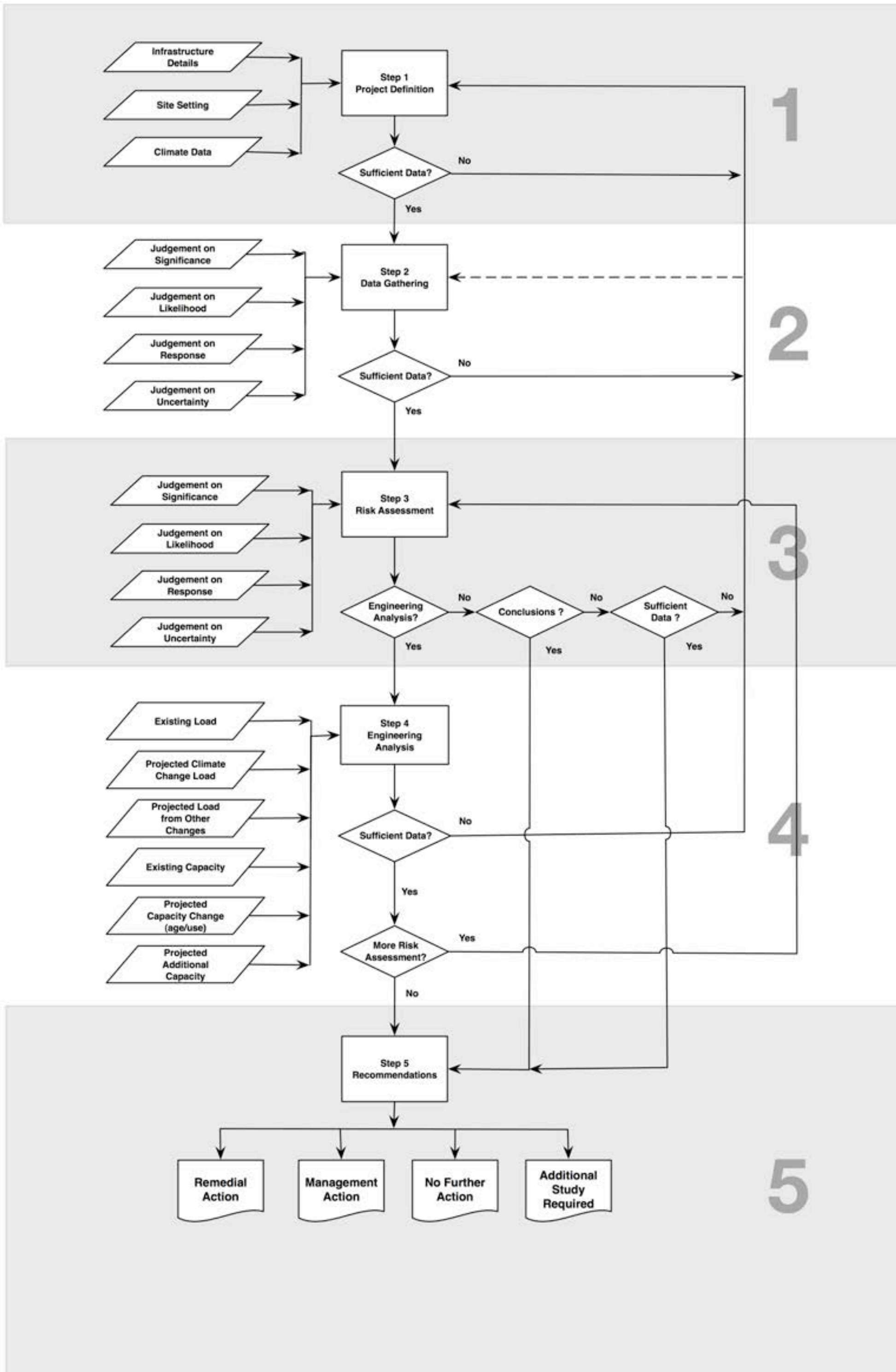


Figure 4 outlines the detailed protocol procedure. Part II of this protocol expands on this flow chart and provides specific procedures for conducting an engineering climate change infrastructure vulnerability assessment. At the completion of each step of the protocol the practitioner is required to assess data sufficiency and address the need for further, more detailed, analysis. This results in a number of feedback loops within the protocol and significant inter-linkage between steps. The detailed protocol provides guidance on how to answer these questions. However, the practitioner must take care to fully evaluate, and document, each of these key decision points to manage against scope creep and avoid iterations, unless completely justified within the context of the assessment. As general guidance, the practitioner should consider the incremental benefit gained by additional costs of data acquisition or technical analysis. This is a project specific assessment driven by budget, risk and other management factors. If the practitioner is unsure of any of these factors, they are encouraged to work with the Project Partner to ensure that all relevant factors are considered.

Figure 4: Detailed Protocol Flow Chart



3.1 *Step 1 - Project Definition*

In Step 1 the practitioner will be asked to:

- Develop a general description of:
    - The infrastructure;
    - The location;
    - Historic climate;
    - Load;
    - Age;
    - Other relevant factors; and
- Identify major documents and information sources.

In this step the practitioner defines the boundary conditions for the vulnerability assessment.

3.2 *Step 2 - Data Gathering and Sufficiency*

In Step 2 the practitioner will be asked to provide more definition about:

1. Which parts of the infrastructure will be assessed; and
2. The particular climate factors that will be considered.

Step 2 is comprised of two key activities:

1. Identification of the features of the infrastructure that will be considered in the assessment:

    - Physical elements of the infrastructure;
        - Number of physical elements;
        - Location(s);
    - Other relevant engineering/technical considerations:
        - Material of construction;
        - Age;
        - Importance within the region;
        - Physical condition;
    - Operations and maintenance practices;
    - Operation and management of the infrastructure;
        - Insurance considerations;
        - Policies;
        - Guidelines;
        - Regulations; and
        - Legal considerations.

2. Identification of applicable climate information. Sources of climate information include, but are not limited to:

- The National Building Code of Canada, Appendix C, Climate Information;
- Intensity - Duration – Frequency (IDF) curves;
- Flood plain mapping;
- Regionally specific climatic modeling;
- Heat units (i.e. degree-days) (i.e. for agriculture, HVAC, energy use, etc.); and
- Others, as appropriate.

The practitioner will be required to exercise professional judgement based on experience and training. Step 2 is an interdisciplinary process requiring engineering, climatological, operations, maintenance, and management expertise. The practitioner must ensure that the right combination of expertise is represented either on the assessment team or through consultations with other professionals during the execution of the assessment.

3.3 *Step 3 - Risk Assessment*

In Step 3 the practitioner will identify the interactions between the infrastructure, the climate and other factors that could lead to vulnerability. These include:

- Specific infrastructure components;
- Specific climate change parameter values; and
- Specific performance goals.

The protocol requires the practitioner to identify which elements of the infrastructure are likely to be sensitive to changes in particular climate parameters. They will be required to evaluate this sensitivity in the context of the performance expectations and other demands that are placed on the infrastructure. Infrastructure performance may be influenced by a variety of factors and the protocol directs the practitioner to consider the overall environment that encompasses the infrastructure.

At this point in the protocol the practitioner, in consultation with the Project Partner, management, engineering and operation personnel, will perform a risk assessment of the infrastructure's vulnerability to climate change. The interactions identified will be evaluated based on the professional judgement of the assessment team. The risk assessment will identify areas of key concern.

The practitioner will identify those interactions that need further evaluation. The assessment process does not require that all interactions be subjected to further assessment. In fact, in most assessments most of the interactions considered will ultimately be eliminated from further consideration. Some interactions may clearly present no, or negligible, risk. Some interactions may clearly indicate a high risk and a need for immediate action. Those interactions that do not yield a clear answer regarding vulnerability may be subjected to the further Engineering Analysis as outlined in Section 8.4.

At this stage, the practitioner must also assess data availability and quality. If professional judgment identifies a potential vulnerability that requires data that is not available to the assessment team, the protocol requires that the practitioner revisit Step 1 and/or Step 2 to acquire and refine the data to a level sufficient for risk assessment and/or engineering analysis. The practitioner may determine that this process requires additional work outside of the scope of the assessment. Such a finding must be identified in the recommendations outlined in Step 5.

This is a key decision point in the Protocol. The practitioner is required to determine:

- Which interactions require additional assessment;
- Where data refinement is required; and
- Initial recommendations about:
  - New research;
  - Immediate remedial action; or
  - Non-vulnerable infrastructure.

3.4 *Step 4 - Engineering Analysis*

In Step 4 the practitioner will conduct focused engineering analysis on the interactions requiring further assessment, as identified in Step 3.

The protocol sets out equations that direct the practitioner to numerically assess:

- The total load on the infrastructure, comprising:
  - The current load on the infrastructure;
  - Projected change in load arising from climate change effects on the infrastructure;
  - Projected change in load arising from other change effects on the infrastructure;

- The total capacity of the infrastructure, comprising:
  - The existing capacity;
  - Projected change in capacity arising from aging/use of the infrastructure; and
  - Other factors that may affect the capacity of the infrastructure.

Based on the numerical analysis:

- A vulnerability exists when ***Total Projected Load*** exceeds ***Total Projected Capacity***; and
- Adaptive capacity exists when ***Total Projected Load*** is less than ***Total Projected Capacity.***

At this stage the practitioner must make one final assessment about data availability and quality. If, in the professional judgement of the practitioner, the data quality or statistical error does not support clear conclusions from the Engineering Analysis, the protocol directs the practitioner to revisit Step 1 and/or Step 2 to acquire and refine the data to a level sufficient for robust engineering analysis. The practitioner may determine that this process requires additional work outside of the scope of the assessment. Such a finding must be identified in the recommendations outlined in Step 5.

Once the practitioner has established sufficient confidence in the results of the engineering analysis, the protocol reaches another key decision point. The practitioner must decide to either:

- Make recommendations based on their analysis (Step 5); or
- Revisit the risk assessment process based on the new/refined data developed in the engineering analysis (Step 3).

3.5 *Step 5 - Recommendations*

In Step 5 the practitioner is directed to provide recommendations based on the work completed in Steps 1 through 4. Generally, the recommendations will fall into five major categories:

- Remedial action is required to upgrade the infrastructure;
- Management action is required to account for changes in the infrastructure capacity;
- Continue to monitor performance of infrastructure and re-evaluate at a later time;
- No further action is required; and/or
- There are gaps in data availability or data quality that require further work.

The practitioner may identify additional conclusions or recommendations regarding the veracity of the assessment, the need for further work or areas that were excluded from the current assessment.

4 The Team

4.2 *A Multi-Disciplinary Team*

When guided by a well-balanced team of qualified professionals, the protocol is a very powerful tool, derived from standard risk management methodologies, tailored to climate change. It is quite common for practitioners to identify data gaps, poor data quality, or lack of relevant tools such as local results from regional climatic models. Often, lack of financial resources or project schedule commitments can affect the ability of the practitioner to completely address these concerns. The protocol allows a number of avenues to proceed when these issues arise. For example,

- The practitioner may identify the data gap and make a recommendation for further work outside of the context of the vulnerability assessment.
- The practitioner may identify the data gap and table any further analysis on the affected parameters.

- The practitioner may infill the missing data based on reasonable professional assumptions and precede with the analysis.

Lack of input data need not deter practitioners from making professionally based judgments and expressing opinions leading to recommendations.

Of paramount importance in addressing the types of questions raised by the protocol is a well-balanced team of professionals dedicated to the execution of the vulnerability assessment. The correct blend of professional and local expertise can support and validate assumptions that allow the practitioner to compensate for missing or poor quality data and account for the lack of other technical resources. Team composition and depth of experience has a very significant bearing on the veracity of the final assessment report. The following expertise is absolutely necessary on the assessment team:

- Fundamental understanding of risk and risk assessment processes;
- Directly relevant engineering knowledge of the infrastructure type;
- Climatic and meteorological expertise/knowledge relevant to the region;
- Hands-on operation experience with the specific infrastructure under assessment;
- Hands-on management knowledge with the specific infrastructure under assessment; and
- Local knowledge and history, especially regarding the nature of previous climatic events, their overall impact in the region and approaches used to address concerns, arising.

We cannot overstate the importance of local knowledge in conducting a vulnerability assessment. Local knowledge, filtered through the overall expertise of the assessment team, more often than not, will compensate for data gaps and provide a solid basis for professional judgment of the vulnerability of the infrastructure.

Throughout this protocol we use the term practitioner. The reader should interpret this to mean the entire assessment team. It is highly unlikely that a project proponent will identify a practitioner with all of the necessary attributes, skills, knowledge and experience in a single person.

4.3 *The Team Leader*

The team leader should be an experienced professional with demonstrated experience in management of multi-disciplinary projects. In some cases, the team leader may also contribute some of the other technical and professional skills outlined above. However, in all cases the leader must be able to coordinate and prioritize the work of the rest of the team and have sufficient background and experience to consolidate findings from different disciplines and areas of expertise. These attributes are normally developed over years of professional practice. Thus, it is generally inadvisable to assign team leadership to a junior professional.

5 Fundamentals of Risk and Risk Assessment

This PIEVC Engineering Vulnerability Protocol is derived from standard risk assessment processes. As such, there is some advantage to reviewing these concepts prior to initiating a vulnerability assessment to ensure that the entire team and workshop participants have a common understanding of the expectations established by the protocol and of acceptable approaches for addressing questions that the practitioner may identify throughout the exercise.

Risk is defined as the possibility of injury, loss or negative environmental impact created by a hazard. The significance of risk is a function of the *probability* of an unwanted incident and the *severity* of its consequence[1]. In mathematical terms:

$$R = P \times S$$

Where:

R = Risk
P = Probability of a negative event
S = Severity of the event, given that it has happened

In risk assessment, practitioners answer three questions[2]:

1. What can happen?
2. How likely is it to happen?
3. Given that it has happened, what are the consequences?

The PIEVC Protocol guides the practitioner through a process designed to answer these questions.

In risk analysis, practitioners are cautioned to ensure that their assessment of probability does not affect their assessment of severity. Basically, the consequence of an event is independent from the likelihood that the event will occur. By separating probability and severity in this way, the practitioner is able to dissect the factors that contribute to risk. Ultimately, this can yield very useful information to guide recommendations regarding approaches to risk mitigation. Practitioners can identify steps that reduce:

- The probability of an event;
- The severity of an event; or
- Both.

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[1] Paul R. Amyotte, P.Eng. & Douglas J. McCutcheon, P.Eng.; ***Risk Management – An Area Of Knowledge For All Engineers***; Engineers Canada, 2006

[2] Tim Bedford and Roger Cooke; ***Probabilistic Risk analysis: Foundations and Methods***; Cambridge University Press; Fourth Printing 2006

5.2 *Hazard Identification – What can happen?*

In this protocol, hazards are identified as interactions between identified climatic events and components of the infrastructure. The practitioner identifies conceivable climatic events that could occur in the region within the timeframe of the vulnerability assessment.

For example, the practitioner could identify that an event of 50 mm of rain in one hour is conceivable during the remaining service life of the infrastructure.

The practitioner will then review the infrastructure and determine the components and sub-components that comprise the infrastructure. This requires professional judgement. If the component analysis is not sufficiently detailed, the assessment may miss potential vulnerabilities. However, if the component analysis is overly detailed, the scope of the assessment can mushroom and become unmanageable or very expensive.

Once the component analysis and climate analysis are completed the practitioner consolidates the lists. The consolidated list yields a set of interactions between climatic events and infrastructure components.

For example, the list may suggest that, during the timeframe of the evaluation, it is conceivable that the 50 mm rain event could impact culverts within the infrastructure system.

As a final step of the hazard identification the practitioner normally will perform a pre-screening of the identified interactions. In essence, they will judge if the identified interactions could conceivably occur. It is imperative that at this stage the assessment the practitioner does not establish a numerical value for the likelihood of the interaction. In essence, they are assessing the reasonableness or conceivability of the interaction. Based on professional judgment, this “sniff test” can significantly reduce the number of interactions considered in further evaluation.

At the end of the hazard analysis, the protocol will yield a set of interactions, or hazards, that will be assessed further for likelihood and severity, finally yielding a value for risk.

Hazard analysis does not identify risks.

Hazard analysis identifies a specific set of circumstances that could potentially result in a negative outcome. In the following analysis, the practitioner will establish just how likely the interaction is and the consequences of the interaction, should it actually occur.

5.3 Probability – How likely is it to happen?

To determine risk, the practitioner must first assign a probability of an interaction occurring. In some circumstances, historical data or statistics are available to guide this assessment. However, more often than not, this guidance is not available. In such cases, the probability can be assigned based on professional judgment. This is a normal procedure in risk assessment. Thus, the lack of measured data should not impose an impediment to completing the vulnerability assessment. Standard risk assessment textbooks state:

> ***Expert judgment techniques are useful for quantifying models in situations in which, because of either cost, technical difficulties or the uniqueness of the situation under study, it has been impossible to make enough observations to quantify the model with "real data".*** [2]

This protocol addresses this issue through guidance regarding:

- The composition of the practitioner team; and
- The participants at the Vulnerability Assessment Workshop.

It is important to ensure that sufficient expertise, experience and knowledge be accessed to ensure a balanced and reliable estimate of the probability.

In the Vulnerability Assessment Workshop, participants systematically assess each of the interactions deemed to be conceivable and reasonable by the practitioner. The combined expertise and experience of the workshop participants is designed to yield a pragmatic and realistic estimate of the probability of occurrence of an infrastructure – climate event interaction.

The protocol provides guidance regarding the selection of probability values. The protocol uses a standardized probability scale of 0 to 7, where 0 means that the event will never occur and 7 means that the event is certain. Further, the protocol provides three different approaches to assigning these factors. Finally, the protocol allows the practitioner to use other methods to assess probability, should these methodologies be justified given the circumstances of the current assessment.

5.4 Severity – Given that it has happened, what are the consequences?

The second step in establishing a value for risk is to assess the consequences of an event, given that the event has happened. In some circumstances, historical data or statistics are available to guide this assessment. However, more often than not, this guidance is not available. In such cases, the severity can be assigned based on professional judgment.

It is important to ensure that sufficient expertise, experience and knowledge be accessed to ensure a balanced and reliable estimate of the severity.

In the Vulnerability Assessment Workshop, participants systematically assess each of the interactions deemed to be conceivable and reasonable by the practitioner. The combined expertise and experience of the workshop participants is designed to yield a pragmatic and realistic estimate of the severity of an infrastructure – climate event interaction, should that event ever occur.

The protocol provides guidance regarding the selection of severity values. The protocol uses a standardized severity scale of 0 to 7, where 0 means no negative consequences, should the interaction occur and 7 means significant failure, should the interaction occur. Further, the protocol provides two different approaches to assigning these factors. Finally, the protocol allows the practitioner to use other methods to assess severity, should these methodologies be justified given the circumstances of the current assessment.

5.5 *Risk – What is the significance of the event?*

Finally, the practitioner is directed to determine the risk for each interaction. As previously stated, risk is a function of the *probability* of an unwanted incident and the *severity* of its consequence. Logistically, the protocol directs the practitioner to multiply the probability and severity values derived above to establish a value for risk. If the practitioner uses the recommended probability and severity scales, the risk analysis will yield a set of risk values ranging between 0 and 49. Since, the scale factors are unitless, the resulting risk values are also unitless.

The protocol then goes on to help the practitioner define criteria for further screening the risks. Low risk interactions are eliminated from further evaluation. Medium risk interactions are normally subjected to further engineering analysis (Step 4 of the Protocol). High risk interactions are normally passed forward to conclusions and recommendations (Step 5 of the Protocol).

In simple terms, low risk interactions pose minimal threat. Medium risk interactions ***MAY*** be significant and require further refinement and analysis before the practitioner passes final judgement. High risk interactions pose a material threat and require remedial action. The protocol identifies categories of recommendations for high risk items including, but not limited to, management action, retirement, or re-engineering and retrofit.

The concept of tolerance to risk is inherent in the predefined cut-offs identified by the protocol. Basically, the protocol assumes that infrastructure owner accepts a level of risk simply by operating the infrastructure. The owner accepts this level of risk as a normal consequence of the operation and may already have procedures in place to manage the risk. In essence, no activity is risk free, but a minimal level of risk is acceptable. The protocol also assumes that as risk values increase, the owner's tolerance to the risk decreases and they are likely to undertake risk mitigation activities to address the concern and reduce the risk to a level within their risk tolerance. At the highest level, the risk exceeds the boundaries of the owner's risk tolerance and they will take urgent action. The protocol allows the practitioner to adjust the cut-off values, as appropriate, based on their professional judgment and consultation with the infrastructure owner.

5.6 *Common Myths and Misconceptions About Risk*

It is important for practitioners to understand the implications of common myths and misconceptions about risk. In this protocol, there is a significant level of involvement with laypeople. Understandably, the average layperson does not have a profound technical understanding of risk. Thus, the practitioner has the responsibility to guide the layperson through the process in a technically rigorous manner.

It is important to be able to identify and address the most common problems associated with risk analysis. Some of these common myths and misconceptions include:

> ***"Hazard is risk."*** It is very common for the average person to confuse the conceivability of an event with its risk. Simply because an event can be conceived does not mean that, in the real world, it will actually occur. Risk assessment considers the likelihood of an event in association with its consequence. Hazard assessment simply asks the question: "What events can I imagine that could result in a negative outcome."
>
> ***"Probability is risk."*** Often the average person will confuse the likelihood of an event with risk. Likelihood, or probability, is only one factor that constitutes risk. The severity of the event, should it occur, must also be considered. When probability is confused with risk, the impact of the event is neglected. It is possible to label high probability - low impact events as high risk. This can lead to unnecessary management action. Conversely, it is possible to label high severity – low probability events as low risk, resulting in little or no mitigative action.
>
> ***"Severity is risk."*** The average person may confuse the severity of an event with its risk. In this scenario, high severity events are considered to be high risk regardless of their likelihood. Similarly, low severity events are considered to be low risk even though they may occur quite frequently. As above, by neglecting one key factor of risk the actual risk may not be properly assessed or managed.
>
> ***"Probability and severity are dependent (linked) variables."*** This misconception is often the most difficult to address with a layperson. It is very challenging for the average person to separate the likelihood of an event from its consequences. For example, if they can conceive of the event, then it must be serious. The problem with this view is that it does not allow the practitioner to assess probabilities and impacts in a clinical manner. Properly executed, a risk assessment must treat severity and probability as independent variables. Although, the average person may see probability and severity as causally linked, the probability of the event is in no way related to the severity of the consequence. Severity does not cause probability, nor does probability cause severity. Probability is a function of frequency. Severity is a function of the physical nature and physics of the infrastructure and climatic event. Risk assesses the combined

implications of the two. This perspective allows the practitioner to rank the likelihood of events and the severity of events separately in order to rigorously evaluate the implications.

These concepts are technically complex and outside of the experience of the average person. Therefore it is the practitioner's duty to be vigilant in the execution of the protocol. They must ensure that these myths and misconceptions do not creep into the mindset of the practitioner team or workshop participants and compromise the veracity of the assessment results.

6 The Vulnerability Assessment Workshop

In Step 3 of the protocol, there is a requirement that the practitioner execute a workshop with the practitioner team and representatives from the infrastructure ownership and operations teams. This is the way to draw on the combined experience of the practitioner and people who have direct contact with the infrastructure. This method allows the team to apply professional judgment in a transparent and consistent manner. As stated above, this can be done in a technically rigorous way and yield results that can withstand professional scrutiny.

Where data exists, the practitioner is directly to use it. However, if the data is missing or suspect in any manner, the practitioner is directed to rely on the professional judgment of the practitioner team and workshop participants. Thus, the workshop represents the most important phase of the evaluation.

At the workshop the practitioner reviews the results of their prescreening assessment and invites participants to assess the probabilities and severities of the interactions identified by the practitioner. Although the protocol allows the practitioner to conduct the risk assessment through a series of one-on-one meetings, where necessary; experience to date demonstrates that a properly executed workshop yields the most robust risk analysis. It is therefore strongly recommend that the practitioner use a workshop unless there are significant, compelling and material, reasons to the contrary.

Given the importance of the workshop, it is critical that the right mix of knowledge, experience and professional skills be present. If the practitioner team has been structured properly, the professional skills and experience should be available to the workshop. However, the practitioner team may be missing hands-on experience with this particular infrastructure and local knowledge regarding climatic events and how the infrastructure and operations team responded to those events. Participants at the workshop can fill these gaps. It must be stressed that it is not sufficient to include only management and engineering staff from the infrastructure owner. Operations staff must also participate. It is not uncommon for operations staff and management/engineering staff to have a distinctly different perspective of climate-infrastructure interactions. Events that the management team view to be very significant may already have been encountered and addressed by the operations team.

For example, the management team may view that a severe snow event could prevent operations staff from executing their duties, while the operations staff have already experienced snow events of equal or greater severity and developed methods to address the problems they encountered. As often as not, these procedures are not formally documented and can only be described by the affected staff.

Although these perspectives may seem trivial on the surface, they are very significant indicators of how the staff will respond during severe climatic events that affect their operations responsibilities. This should emerge during the workshop discussions and forms a substantive input to the local knowledge data used by the practitioner to establish the risk profile.

Generally, participants at the workshop should include:

- The practitioner team;
- Representatives from the infrastructure management team;
- Representatives from the infrastructure engineering team;
- Representatives from the infrastructure operations team;
- Local expertise/knowledge regarding severe climatic events in the region and climatic events that may have affected the infrastructure;
- Representatives from the organization providing climate information;
- Representatives from any advisory groups or technical experts who may be supporting the vulnerability assessment; and
- Others deemed necessary by the infrastructure owner or practitioner team.

The workshop should follow a consistent agenda. Given the number of laypeople who may be involved, it is important to provided sufficient background on the exercise to all participants and establish the expected outcomes from the meeting. Generally, the workshop agenda should include:

- A brief presentation on climatic change and the implications for the region;
- A brief presentation on risk and risk assessment;
- A brief presentation on the work completed by the practitioner to date;
    - As a minimum, identifying the key interactions to be considered by workshop participants;
- Introduction of the spreadsheet or matrix developed by the practitioner in compliance with Step 3 of the protocol;
    - Explanation of the infrastructure components and climate events that the practitioner deems to be relevant;
    - Polling of the workshop to determine if potentially relevant infrastructure components or climate events have been missed;
        - At this stage of the process the probability and severity values will not have been entered into the matrix or spreadsheet;

- A tabletop exercise, drawing on the expertise of workshop participants, establishing probability and severity for each relevant interaction identified by the practitioner. This could be done by:
  - Assigning groups to input data to hard copies of the matrix distributed to the workshop;
  - Assigning groups to input data to laptops distributed throughout the workshop;
  - As a single facilitated discussion filling in a master spreadsheet projected to the entire workshop; or
  - Other methods as deemed appropriate.
- If appropriate, a site visit or tour of the infrastructure or of specific components of the infrastructure; and
- A summary of findings arising from the workshop.

Because of the length of the agenda, and the need for rigorous discussion, the practitioner should plan the workshop for one complete eight-hour day.

Given the amount of professional, billable, hours that will be consumed at the workshop, it is critical that the practitioner:

- Carefully plan the event in consultation with the infrastructure management and operations teams;
- Schedule it to maximize productive outcomes;
  - Not before screening analysis is complete or before all necessary and relevant data has been accumulated; and
- Provide as much validated data and background information as possible.

7 Economic Considerations

Economic considerations permeate climate change infrastructure vulnerability assessment.

At the project level, the Project Partner must establish a scope for the project and work that scope within budgetary limitations. This may drive decisions regarding the use of regional climate modeling, which can be expensive, and the overall depth and reach of the assessment. Thus, economics may dictate a smaller, more focused, assessment. Under such constraints, it is the practitioner's responsibility to work with the infrastructure owner to establish a scope of work that both addresses the owner's immediate issues while maximizing the opportunity to extrapolate assessment results to other areas of interest to the infrastructure owner. That is, the practitioner must work with the owner to maximize the "bang for the buck".

During the execution of the assessment, practitioners will often identify data gaps. When this occurs, the practitioner and Project Partner must assess the available mechanisms for obtaining or improving the data. This can also be an expensive exercise and must be evaluated based on the economic return associated with the task. For example, the data may be necessary to fully understand a risk associated with one sub-component of the infrastructure. If this sub-component is deemed to be critical with a significant economic penalty associated with its loss, the team may decide that the costs are justifiable. That is, the cost of the potential risk significantly outweighs the cost of filling the data gap. On the other hand, the data may be desired to characterize a risk that, in the grand scheme of things, is relatively minor. In this case, the team may decide to forego the expense of additional data acquisition. That is, the cost of the potential risk is much less than the cost of filling the data gap. These examples establish economic boundary conditions. During the actual execution of an assessment, significant professional judgment and consultation with the infrastructure owner may be required.

It should be noted that acquiring 100% of the data necessary to support a vulnerability assessment is normally outside of the economic reach of the assessment. Missing data is common and filling the gap can be very expensive. The protocol directs practitioners to use professional judgment to address these issues. One key element of this judgment is the economic implication of the methodologies the practitioner recommends to address the gap.

Finally, the practitioner may identify recommendations to address vulnerabilities identified by the assessment. Once again, the practitioner should take economic factors into consideration. For example, one potential solution to an identified vulnerability could be replacement of the infrastructure, with major capital expenditure. Since the assessment does not normally evaluate the engineering alternatives to address vulnerabilities at any depth, the practitioner should evaluate the implications of such a recommendation, in consultation with the owner, to assess the economic feasibility. Practitioners must not shy away from reporting identified vulnerabilities, but should take to care state their recommendations within the context of reasonable, economic constraints. In the example above, although full replacement may be ideal other, more cost effective, approaches may be available and should be considered. Ultimately, these considerations will play a role in the final acceptance of the assessment and its recommendations.

Appendix B

Site Selection Analysis

Climate Change Vulnerability Assessment- Site Selection Criteria

Introduction to these Spreadsheets

In order to evaluate and compare potential sites that could be used in an assessment of roadway and associated infrastructure's vulnerability due to climate change, a list of site selection criteria were developed. Each criteria has been given a weighting which indicates its relative importance in the site selection process.

For the purposes of the site evaluation, potential sites should be selected such that they include a section of roadway covering approximately 30 km to 40 km.

For each potential site(s), enter a rating between 0 (poor) and 5 (excellent) for each criteria on the "Site Rating" spreadsheet. This rating indicates the degree to which the site is a good candidate based on that specific criteria. The "Rating Guidelines" sheet provides a framework for how each rating should be selected.

Once a site has been rated on the "Site Rating" spreadsheet, a score for the site is automatically calculated on the "Site Scores" spreadsheet based on the criteria weighting and the site ratings.

Climate Change Vulnerability Assessment - Rating Guidelines for Site Selection Criteria

Site Selection Criteria		Rating Guidelines					
		0	1	2	3	4	5
Infrastructure	Infrastructure Age	Recent major improvements to roadway and infrastructure (<5 years)	Most of the roadway and infrastructure recently reconstructed (<10 years)	Most of the roadway and infrastructure is of moderate age (<20 years)	Mix of old (>50 years) and newer (<20 years) roadway and infrastructure	Most of the roadway and infrastructure is > 50 years old	No significant improvements to highway alignment or major infrastructure in >50 years
	Variety of Infrastructure	Little infrastructure beyond road structure					Wide variety of infrastructure along the route
Data Availability	Current Weather Data Available (weather stations)	No weather stations in or near (within 50 km) study area	At least 1 weather station within 200 km of study area	1 weather station within 100 km of study area	Multiple weather stations within 100 km of study area	2 weather stations within 50 km of study area	1 weather station at study area, additional weather station within 50 km
	Historic Weather Data Available (temperature, precipitation)	No historic weather data available	Historic data available for less than 50 years	Historic data available for 50 years, but station >100 km away	Historic data available for 50 years, but station >50 km away	Historic data available for 50 years and station within 50 km of study area	Historic data available for over 75 years and station within 50 km of study area
	Availability of Infrastructure Data	No information available	Limited information available - locations known for major infrastructure only (i.e. Bridges, large retaining walls)	Limited information available - locations and some details known for all major structures and some minor (i.e. Barrier, culverts)	Basic location and properties/ infrastructure types known - some drawings available for major infrastructure	Detailed information (drawings, locations, materials) available for most infrastructure	Detailed information available for all major infrastructure and most minor infrastructure
Environment	Occurrence of Extreme Environmental Events (such as flash flooding, prolonged flooding, ice jams, debris flows, landslides, avalanches, unusually high snow accumulation, etc.)	Area is not prone to extreme environmental events	One or two extreme environmental events have occurred within the past 50 years	Area is prone to one type of extreme environmental event that occurs infrequently	Extreme environmental events occur frequently, but only one type (i.e. avalanches occur most winters)	Various types of extreme environmental events have occurred, but relatively infrequently	Various types of extreme environmental events occur frequently
	Geotechnical Indicators (i.e. presence of collapsible silts, permafrost, oversteepened cuts/ fills, etc.)	No geotechnical indicators present in the area	One geotechnical indicator present in the area	Two or more geotechnical indicators present			Several geotechnical indicators present along the highway section
	Variety of Terrain	Flat terrain with few watercourses near highway, no watercourses intersecting highway	Flat terrain with few watercourses intersecting highway		Rolling or mountainous terrain with numerous water courses intersecting highway		Wide variety of terrain with numerous water courses intersecting highway
	Expected Climatic Change - Temperature	Climate change models predict no change for region (by 2050)	Climate change models predict minor temperature changes (±1°C)		Climate change models predict moderate temperature changes (±3°C)		Climate change models predict large temperature changes (more than ±5℃)
	Expected Climatic Change - Precipitation	Climate change models predict no change for region (by 2050)					Climate change models predict large precipitation changes
	Climatic Regions	N/A	Route covers 1 climatic region	N/A	Route covers 2 or more climatic regions	N/A	N/A
Other Criteria	Traffic Volumes	<300 AADT	301 to 1,000 AADT	1,001 to 5,000 AADT	5,001 to 10,000 AADT	10,001 to 20,000 AADT	> 20,000 AADT
	Strategic Importance of Route	Minor road, alternate routes available	Minor road, no viable alternate routes	Secondary route, alternate routes available	Secondary route, no viable alternate routes	Major economic corridor, alternate routes available	Major economic corridor, no viable alternate routes

Climate Change Vulnerability Assessment - Site Rating

Site Selection Criteria		Criteria Weighting 1 (less important) to 5 (more important)	Site Rating for each Criteria 0 (poor) to 5 (excellent)							
			Hwy 3, Kootenay Pass (between Salmo and Creston)	**Hwy 31, Meadow Creek to Trout Lake**	**Hwy 16, Burns Lake to Smithers**	**Hwy 29, Chetwynd to Charlie Lake**	**Hwy 14, Sooke to Port Renfrew**	**Hwy 5, Coquihalla (between Hope and Merritt)**	**Hwy 3, Paulson Pass (between Christina Lake and Jct with Hwy 3B)**	**Hwy 16, Terrace to Prince Rupert**
Infrastructure	Infrastructure Age	4	2	5	3	4	5	3	3	3
	Variety of Infrastructure	3	4	3	4	3	3	5	3	4
Data Availability	Current Weather Data Available	4	4	2	3	3	1	5	4	3
	Historic Weather Data Available	4	3	2	3	2	3	3	2	3
	Availability of Infrastructure Data	2	2	1	2	2	1	4	2	2
Environment	Occurrence of Extreme Environmental Events	5	3	5	3	2	3	3	3	4
	Geotechnical Indicators	3	4	4	3	3	2	2	2	5
	Variety of Terrain	4	3	3	3	4	3	5	2	5
	Expected Climatic Change - Temperature	2	5	5	3	3	3	5	5	3
	Expected Climatic Change - Precipitation	5	2	2	3	2	3	2	2	3
	Climatic Regions	2	1	1	1	3	1	3	1	1
Other Criteria	Traffic Volumes	2	2	1	2	1	1	4	2	2
	Strategic Importance of Route	3	4	2	5	3	2	4	5	5

Climate Change Vulnerability Assessment - Potential Site Scores

Site Selection Criteria		Criteria Weighting 1 (less important) to 5 (more important)	Site Scores (Criteria Weighting x Site Rating)							
			Hwy 3, Kootenay Pass (between Salmo and Creston)	**Hwy 31, Meadow Creek to Trout Lake**	**Hwy 16, Burns Lake to Smithers**	**Hwy 29, Chetwynd to Charlie Lake**	**Hwy 14, Sooke to Port Renfrew**	**Hwy 5, Coquihalla (between Hope and Merritt)**	**Hwy 3, Paulson Pass (between Christina Lake and Jct with Hwy 3B)**	**Hwy 16, Terrace to Prince Rupert**
Infrastructure	Infrastructure Age	4	8	20	12	16	20	12	12	12
	Variety of Infrastructure	3	12	9	12	9	9	15	9	12
Data Availability	Current Weather Data Available	4	16	8	12	12	4	20	16	12
	Historic Weather Data Available	4	12	8	12	8	12	12	8	12
	Availability of Infrastructure Data	2	4	2	4	4	2	8	4	4
Environment	Occurrence of Extreme Environmental Events	5	15	25	15	10	15	15	15	20
	Geotechnical Indicators	3	12	12	9	9	6	6	6	15
	Variety of Terrain	4	12	12	12	16	12	20	8	20
	Expected Climatic Change - Temperature	2	10	10	6	6	6	10	10	6
	Expected Climatic Change - Precipitation	5	10	10	15	10	15	10	10	15
	Climatic Regions	2	2	2	2	6	2	6	2	2
Other Criteria	Traffic Volumes	2	4	2	4	2	2	8	4	4
	Strategic Importance of Route	3	12	6	15	9	6	12	15	15
Overall Site Score			**129**	**126**	**130**	**117**	**111**	**154**	**119**	**149**

Appendix C

Completed Protocol Worksheet 1 and Attachments

In this step the practitioner will define the global project parameters. This step will define:

- Which particular infrastructure is being assessed;
- Its location;
- Unique climatic, geographic considerations; and
- Uses of the infrastructure.

This is the first step of narrowing the focus to allow efficient data acquisition and assessment.

8.1.1 Identify Infrastructure which is to be evaluated for climate change vulnerability
Choose Infrastructure: 44.83 Km stretch of road on Hwy 5 between Nicolum River (sometimes referred to as Creek) Bridge north abutment at Km .90 and the south abutment of Dry Gulch Bridge at 45.73 Km (LKI Segment 2000 north and 2005 south) referencing culverts under 3 meters
General Description: The Coquihalla Highway is a 4 lane, divided, high-speed provincial roadway where the posted speed is 110 kph, maximum grade of 8% with climbing lanes and crawling lanes.

Additional Background & Detailed Information Sources	
	Links and References
Coquihalla Hwy 5 Data Room	http://www.coquihalla.th.gov.bc.ca/
Kamloops and Victoria Drawing Repository	Shelly Keddy
Maps of location and infrastructure with elevations.	http://webmaps.gov.bc.ca/imfx/imf.jsp?site=imapbc

8.1.2 Identify Climate Factors of Interest
State general Climate factors to be considered
Temperature

• Freeze-thaw
  o Want to have idea of frequency of freeze/thaw
  o Plus how rapidly the cycle occurs (can use historical data, or maintenance records)
• Max-Min
• Maintenance schedule dependent on threshold, which triggers maintenance actions (recorded).

Freezing rain, or wet snow, or Rain + Snow
Precipitation • As snow • As rain • For historic data, IDF Curves • Mainly concerned with how rain affects the drainage capacity of the roadway.
Dry days and maximum temperature collected for 7-day periods • Need to define threshold. • Operations uses asphalt temperature to schedule resurfacing Relevance: impact on recommendations, maintenance
River flows and volumes • Water surface elevation • High water marks. Bridges are designed for 200 years flash flood, with clearance of 1.5 meters. 1990 storm showed bridges and culverts at capacity (fully charged). Would like to be able to forecast events that will bring infrastructure to capacity.
Ice
Heavy Fog and Hail • Direct weather is inferred, not measured by BCMoT • Low-level clouds, mostly anecdotal • Recorded information – maybe from Provincial Highway information   o Perhaps weather related accident reporting would be available.
Solar Radiation • How chemicals work on road and traffic signs affected by solar radiation.

• Track solar power collection at weather stations. • Data may be anecdotal or sporadic.
Change in Climatic Regions within study area

Additional background & detailed information sources	
URL fo Public Portal to Weather Data in SAWS Database (Snow Avalanche and Weather System):	https://pub-apps.th.gov.bc.ca/saw-paws/weatherstation
Coquihalla River Flood Hazard Mgmt Study, March 1994	
Local Knowledge	Joe Valentinuzzi, Mgr, Hwy Design & Surveys, SIR Peter and Jurgen – best for local knowledge Recent main work - Added avalanche wall below snow shed.
Other Stations	Provincial Climate Network coordinator (Ted Wick). May be source of climate data sets in BC
Climate Change Adaptation (CCEA) private website	http://www.ccea.tran.gov.bc.ca/
Avalanche Data	Access through ORACLE Database

8.1.3 Identify the Time Frame
To the year 2050

8.1.4 Identify the Geography
Mountainous terrain bordered by the Upper Fraser Delta to the west and the Cascade Mountain Range to the east. The Coquihalla River or tributaries runs alongside the length of the highway infrastructure with a significant road elevation change of approx 900

meters from the start point to the end point. There is significant climatologically gradient. Especially at the top end of this section of road. Dramatic difference over a few kilometers of the highway. Dry Gulch is in middle. Could affect the climate modeling depending on grid sizing
Notes: Hwy 5 is North-South. HWY 1 is East-West. East-West is Rail terminology. Use universally acceptable nomenclature. Use co-ordinates and map. • Use iMap BC.

8.1.5 Identify the Jurisdictional Considerations

Department of Fisheries and Oceans	Fish habitat • Considered navigable
Ministry of Environment	Wildlife and Vegetation, fish habitat, Water Act approvals etc
Utilities	Pipelines Trans Mountain (now Duke Energy) • Boston Bar Gas/Oil Transmission Telus (fiber optics cables directly underneath Dry Gulch) Hydro
First nations	Asserted traditional territory of Stolo Nation, Yale First Nation (Traditional Use), Union Bar First Nation (Traditional Use). There are no reserves along this section of the highway.
Ministry of Forests (Chilliwack Forest District)	The highway passes through the Coquihalla Recreation Area. Forest road access

Transport Canada	Possible CEAA considerations. Navigable Waters Protection Act (Coquihalla River considered navigable)
Fraser Valley Regional District (Fraser Valley B)	
Chilliwack Hope Electoral District	
Access to private land or commercial enterprises	Cut block licensee, property owner access
Environment Canada	Wild Life, Species at Risk
Provincial Ministry of Environment Parks & Recreation?)	Minor recreational spots Small Park
Recreation	Provincial Park at Falls Lake (other side of HWY?) TransCanada Trail

8.1.6 Site Visit

Summary of Findings from Interviews

Two site inspection reports attached to this Worksheet.

- Survey of Buried Steel and Concrete Arch Bridges - April 2009.
- Inspection Report – Jurgen Lutter and Peter Swetlishoff – January 15, 2010

Key Observations

Areas for Follow-up in Subsequent Steps

8.1.7 Assess Data Sufficiency

State Assumptions proposed for the assessment, if any	Rationale
Complete Infrastructure data available and stored electronically and there may be available info via Kettle Valley Railway historical data	Highway 25 years old and data are available through the Ministry electronic data room as well as staff involved in project still working within Ministry
Climate data available per PCIC, MOTI	Pacific Institute for Climate Solutions with Pacific Climate Impacts Consortium has confirmed they have access to BC Climate information and will seek local knowledge to include MoTI Meteorological Data Collection Stations on site
Remote Weather Sensor data is available	https://pub-apps.th.gov.bc.ca/saw-paws/weatherstation
Snow Avalanche Data is available	https://pub-apps.th.gov.bc.ca/saw-paws/weatherstation
Coquihalla Hwy 5 Data Room contains most relevant design data	http://www.coquihalla.th.gov.bc.ca/ Some as-built plans are not available. May not be part of the Coquihalla. Can be checked with archives

Where insufficient information currently available Identify process to develop data	Process
In some locations, type of riprap currently in use is unknown. As-built drawings will identify original spec. Need idea of what replacement was used in emergency response. In future refurbishment, do not have protocol to upgrade the material. Dependent of potential flood risk. E.g. Last time used 1000 kg material. Was very large, not currently available.	Coquihalla River Flood Hazard Mgmt Study, March 1994 may have some relevant information. Can take photos of site.
Storms act in cells. Need way to predict activity and intensity of occurrence of intense storm cells (Storm Bombs)	Environment Canada is investigating intensity and frequency of storms in ON as well as BC. They note that “bombs”, even those embedded in larger storm systems, act like hurricanes.

It is hard to map small-scale thunderstorms. Much easier to work with large weather storm systems which tends to miss the localized storm cells.	Current work may not be available for the BC study. Should leave opening to incorporate work into data system for future BCMOT use.

Where data cannot be developed, identify the data gap as a finding in Step 5 of the Protocol – Recommendations.
List Data Gap as findings to be sent to STEP 5 (Worksheet 5: Section 8.5.2)
1. If Environment Canada Work on localized storm cells is not complete in time to include in this assessment, leave room in the BC MoTI data system to update with the Environment Canada data as it becomes available. 2. Maintain a watching brief on the Environment Canada work on localized storm cells in BC.

Prepared by:	Joel R. Nodelman on behalf of BCMoTI Team
Date:	January 15, 2010

The Coquihalla Highway Experience:
Maintenance of Buried Steel and Concrete Arch Bridges –
Sustainability over the Long Term

The BC Government completed construction of Phase I of the Coquihalla Highway from Hope to Merritt in 1986. From Hope, the 4 lane divided highway climbs 50 kilometers through steep terrain to the Coquihalla summit at elevation of 1244m, then 65 kilometers to Merritt.

There are several bridges over watercourses, valleys and access roads with a variety of structure types, including many buried steel and pre-cast concrete structures. BC MOTI staff conduct regular annual condition assessments of all bridge structures, including buried structures 3000mm in span and greater.

The author visited 10 of the 30 available steel and concrete tunnels/culverts with local BC MOTI staff during the spring of 2009. The author wishes to recognize the contribution of Mr. Jurgen Lutter (Area Bridge Manager, Merritt South) with his work to arrange site visits and provide valuable background information.

Ongoing maintenance on the buried structures was generally limited to:

- Stream Crossings - Clearing brush and log debris from the inlet periodically.
- Vehicular Overpasses - Pressure washing the inside surfaces of vehicular overpasses in the spring to remove road salts that were placed on the road during the water
- Repairing damage to plates as a result of vehicular collisions.

Maintenance findings:

- No substantial maintenance has been required on the buried steel and concrete structure in the last 23 years.
- Some evidence of corrosion on the invert plates of the steel structures (no evidence of pitting was observed, however).
- Average service life of a typical clear span before re-surfacing = 15-20 years.
- Nearby Kingsvale bridge lasted 8 years before resurfacing again.
- Average cost for re-surface work is $450 per square metre of bridge deck.
- Average design service life of overall bridge = 50-75 years.

Observed operational and design advantages of buried steel and concrete structures:

- Minimal maintenance.
- Typical clear span deck maintenance causes traffic delays, requiring maintenance to occur only in non-peak times (spring and fall, not summer). These operational effects are non-existent with buried structures.
- The barrel length can be extended to suit embankments given skewed alignments, deep embankments without excessive added cost.
- From the driver's perspective there's no constriction of the road surface, when driving over the bridge.
- No ice-up of the bridge deck versus the road approaches (on low cover multi-plates there might be some premature ice-up directly above the pipe, but it's not significant).

Fox Farm Underpass
Multi-Plate Super-Span (11.25m span x 7.2m rise x 91.6m long horizontal ellipse)

- Curbs on inside provides protection from snow plow blades from hitting plate
- End treatment consisting of cast-in-place collar and end walls / hand rail is preferred by the Owner, as it ties into adjacent cattle fencing
- Regular maintenance work – none required.

Veale Underpass
Multi-Plate Super-Span (11.25m span x 5.65m rise x 108.0m long horizontal ellipse)

- Same comments as Fox-Farm
- Some evidence of stalagtites forming inside the structure (perhaps road salt).
- Regular maintenance work – none required.

Verona Culvert
Multi-Plate Round (5.90m diameter, 5mm WT, 3.0% grade)

- Invert corrosion observed (coating and steel loss)
- No bed load observed, 3.0% gradient
- Fish habitat blocked downstream
- Regular maintenance – not required (possible concrete invert someday)

Box Canyon Arch Culver
Pre-cast Concrete Arch (20.63m span x 5.0m rise x 65m length – 6.2% grade)

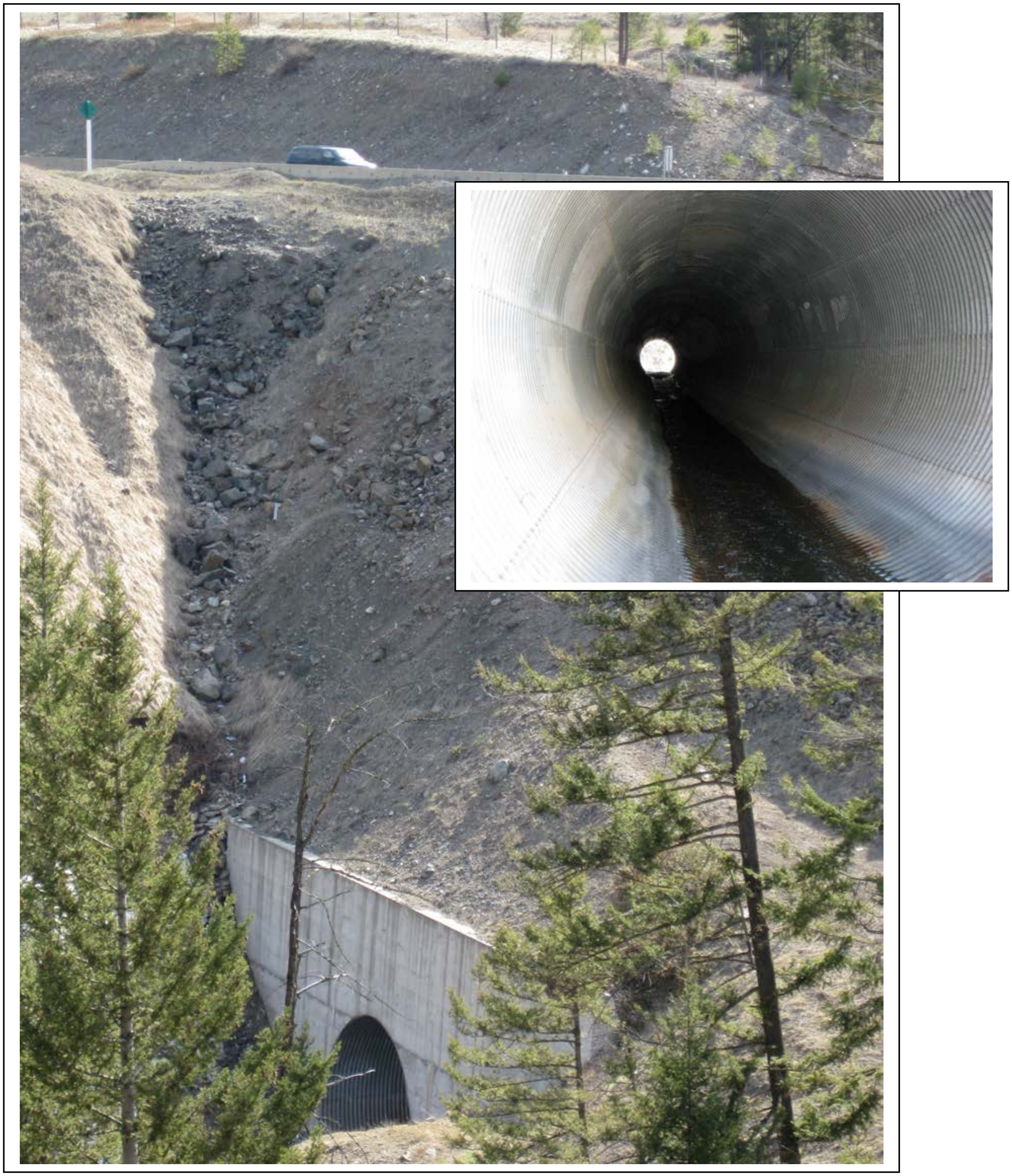
- Peak flow observed in 1990's. Ran ¾ full. Carried flow/debris without a problem.
- No evidence of footing scour – footings are "keyed" in to bedrock
- Nearby avalanche area was logged to prevent debris from clogging of culverts.
- Regular maintenance – not required.

Certees Arch Culvert
Pre-cast Concrete Arch (20.63m span x 5.4m rise x 65m length – 2.2% grade)

- Peak flow observed at 1.5m above invert.
- No evidence of footing scour
- Gasket at crown joint appeared to be dislodged. Not affecting structure.
- Regular maintenance – not required.

Montano Arch Culvert
Pre-cast Concrete Arch (20.63m span x 7.0m rise x 55m length – 2.4% grade)

- Some evidence of debris lodged upstream and gravel deposition
- No evidence of scour
- Regular maintenance – not required.



Voght Creek Culvert
Multi-Plate Round (6.94m diameter), 28.2m of cover.

- Extremely high cover
- Some corrosion of invert visible, but no perforations
- Some work done on the steep slopes to mitigate erosion near headwall
- Ongoing maintenance required on upstream end to protect streambank.

COQUIHALLA HWY. No. 5

/ 53A-P

CLIMATE CHANGE ENGINEERING ADAPTATION

PIEVC PROTOCOL

Observations taken along the Coquihalla Hwy. No.5 on Jan. 15, 2010 showing deficiencies and other problems within the highway corridor as observed by Jurgen Lutter and Peter Swetlishoff.

No where to park along guardrail (ie) median barrier and roadside barrier. (Narrow shoulders)

Water ponds on travelled portions of the highway.

Impact attenuators not installed at some intersections.

Winter sand plugging median drains especially during high runoff periods.

Water running down steeper grades either along the median barrier or shoulders and crossing the highway to the shoulders creating a hydro plane scenario.

Truckers pulling off and sleeping on the on/off ramps causing problems for maintenance.

Sharing the Hwy. R/w with other users (ie) Pipelines, LTS, Logging and Trans Canada Trails.

Recreational users. (ie) snowmobilers, hikers etc.

Snow storage problems along ditches. (ie) Summit area. Ditches to narrow.

Blower damage to luminaire poles and hydro poles during snow blowing.

Pedestrian structures damaged from high runoff. (ie) Summit Camp area.

Flat roof on Summit Avalanche Camp bldg. Snow fall hazard.

Sign damage from winter plowing and blowing operations. Also from MVA's.

Truck Stop capacity at Zopkios Brake Check inadequate; also used as a turnaround for maintenance vehicles creating bottle neck.

Access to Zopkios Underpass inadequate for maintenance trucks also hazard from snow falling on vehicles from top of this multiplate.

Parking area at Zopkios Sand shed by users for hiking and skiing creates problems for maintenance vehicles.

May require installation of a flashing sign at the Zopkios Brake Check for trucks going SB if conditions warrant the use of chains in very slippery and icy conditions going down the 8% grade.

Hazards from Ice fall from rock faces.

Logging impact along the Hwy. No. 5 corridor (mentioned earlier.)

Use of the Highway by cyclists from Portia to Hwy. No. 3. (Narrow shoulders)

Rusting multiplates and smaller culverts due to the salt.

Maintenance cross- over not having sufficient storage or width for some types of vehicles to use in emergency situations.

Inadequate breaks in median barrier for use by emergency vehicles attending MVA's.

Allowing Long Combination vehicles on the Coquihalla Hwy. No.5. (excessive weight breaking down the road base and pavements. (rutting)

Excessive damage to pavement NB from Snowshed to top of Zopkios hill from slow moving trucks and heavy winter maintenance. Also spinning out trucks with chains is tearing up the pavement causing potholes.

Longitudinal cracking (joints) separating especially on the shed hill to Falls Lake Interchange.

Avalanche debris on Hwy. and plugged trash racks.

Shoulder erosion from runoff and asphalt curb damage from maintenance operations.

Start and end of guardrail locations. (areas need extending as they do not cover locations where there is a history of accidents.)

Appendix D

Completed Protocol Worksheet 2

In this step the practitioner will provide further definition regarding the infrastructure and the particular climate effects that are being considered in the evaluation. The practitioner will undertake a data acquisition exercise and identify where, in their professional judgment, whether the data is insufficient due to:

- Poor quality;
- High levels of uncertainty; or
- Lack of data altogether.

This step further focuses the evaluation and starts to establish activities to in-fill poor quality or missing data.

8.2.1 State Infrastructure components that are to be evaluated for climate change vulnerability.

i. Only select those infrastructure components that, in the practitioner's professional judgment, are relevant to this assessment.
ii. Where available, review operations incident reports, daily logs and reports to assist in the identification of infrastructure elements with a history that could result in vulnerability and are relevant to this process.
iii. Interview infrastructure owners and operators to identify historical events that may not be documented or retrievable from databases and evaluate if these events are relevant to this assessment.

List Major Components	Information from Logs & Reports	References and Assumptions
Above Ground		
Surface - Asphalt		
Pavement Marking		Differentiate between paint and thermal plastic and other driver guidance appliances. Also long line and interchange markings. Replenished on different schedules.
Shoulders (Including Gravel)		
Barriers		Concrete shoulder and median barriers. May restrict drainage and snow plowing.

Curb		Asphalt curbing and concrete curbing. Asphalt curbing has shorter lifespan. Concrete on islands on interchanges.
Luminaires		
Poles		All sorts of poles.
Signage - Side Mounted - Over 3.2 m^2		
Signage - Overhead Guide Signs		
Overhead Changeable Message Signs		
Ditches		
Embankments/Cuts		Soil embankment and cuts and rock embankment and cuts.
Hillsides		Talus slopes in particular. Includes all slope instability features.
Protection Works		
Engineered Stabilization Works		
Avalanche		
Debris Torrents		
Diversion channels		
Structures that Cross Streams		
Structures that Cross Roads		
River Training Works		
MSE Walls		
Environmental Features		
In stream habitat works		
Off channel habitat works		

Wild life fencing		
Wild life passing structures		
Vegetation management		
Invasive Plants		
Below Ground		
Road Sub-Base		Road base. Road sub-base. Sub-grade.
Detail Drainage (what are the drainage sub-components		Sub drains in MSE walls. Already have some problems. Province has one that has already failed.
Catch Basins		Storm drainage appliances. May be some catch basins.
Median and Roadway Drainage Appliances		Storm drainage appliances. May not be actual storm sewers out there. Concrete medians may have some drainage. Median drainage.
Sub-Drains		
Distribution Systems		Wells. Water lines. Etc. Delete.
Third party utilities		High-pressure gas. High-pressure oil. Fiber optic cable – not as relevant.
Culverts < 3m		• Includes trash racks and headwalls. • Open footing vs. closed footing.
Culverts ≥ 3m		• Includes trash racks and headwalls. • Open footing vs. closed footing.
Asphalt Spillway and Associated Piping/Culvert		Usually have small diameter culverts associated. Treat with culverts.
Miscellaneous		
Administration/Personnel		
Winter Maintenance		

Ancillary buildings and utilities and yards.		Three areas plus Coquihalla mall. Avalanche control buildings. Maintenance yards including material storage.
Engineering Technical		
Habitat Maintenance		
Communication		
Emergency Response		
Reliability. Usability. Performance standard.		Do we get fewer good days for driving on the highway?
Maintenance (Markings, Crack Sealing)		

8.2.2 State Climate Baseline

State general Climate Parameters for use in STEP 3 of Assessment (Reference Appendix A– Climate Event and Change Factors) (Additional Reference – Adapting to Climate Change, Canada's First National Engineering Vulnerability Assessment of Public Infrastructure; Appendix D - Canada-Wide Sampling Study)	Climate information Source
Temperature • Freeze-thaw o Want to have idea of frequency of freeze/thaw o Plus how rapidly the cycle occurs (can use historical data, or maintenance records) • Max-Min	• Can be provided by modifying the Climdex indices. • Maintenance schedule dependent on threshold, which triggers maintenance actions (recorded).

Freezing rain, or wet snow, or Rain + Snow	• Possibly from daily or 3-hourly T and P.
Precipitation • As snow • As rain	• Can be provided by modifying the Climdex indices.
Dry days and maximum temperature collected for 7-day periods	• Using a running window?
River flows and volumes • Water surface elevation • High water marks.	• Can be provided by modifying the Climdex indices.
Ice	
Heavy Fog and Hail	
Solar Radiation	• Can be provided by modifying the Climdex indices. • Shortwave radiation
Change in Climatic Regions within study area	

List Historical Extreme Climate Events

Event	Frequency	Normal Duration	Magnitude	State Justification for Infilling Missing Data
Days with Max Temp > 35 °C				Can be provided by modifying the Climdex indices.
Days with Min Temp < 30 °C				Can be provided by modifying the Climdex indices.
Daily Temp variation > 25 °C				Can be provided by modifying the Climdex indices.

≥ 85 days with Max Temp > 0 °C and Min Temp < 0 °C				
≥ 47 days with Min Temp < 0 °C				Can be provided by modifying the Climdex indices.
≥ 5 days with > 25 mm rain				Can be provided by modifying the Climdex indices.
≥ 23 days with > 10 mm rain				Can be provided by modifying the Climdex indices.
≥ 112 with > 0.2 mm rain				Can be provided by modifying the Climdex indices.
≥ 10 days with rain or snow				Cannot be done with models.
≥ 9 days with rain that falls as liquid and freezes on contact				Cannot be done with models.
Days with snow > 10 cm				Cannot be done with models.
≥ 8 days with blowing snow				May be able to develop this with models.
≥ 5 days with snow depth > 20 cm				Cannot be done with models.
Days with precipitation falling as ice particles				Cannot be done with models.
≥ 8 days with Max winds ≥ 63 km/hr				Cannot be done with models.
≥ 10 consecutive days with precipitation < 0.2 mm				Cannot be done with models.
Average maximum temp over seven days				

Rain on snow including temperature and wind speed				The rain that is the issue
≥ 15 hours per year with visibility < 1,000 m				
				Needs to include list of factors used to predict issues. Commonly used criteria. Covers shallow landslides and debris torrents.

8.2.3 State Climate Change Assumptions	
Relevance & Applicability of Observed Global or Regional Climate Change Trends with respect to the Infrastructure	**Document How These Trends Influence the Infrastructure**
% Increase or Decrease to Climate Change Baseline Based on TRENDS	**Justification/Substantiation**
% Increase or Decrease to Climate Change Baseline Based on SENSITIVITY ANALYSIS	**Justification/Substantiation**
N/A	
% Increase or Decrease to Climate Change Baseline Based on SURROGATE INFORMATION	**Justification/Substantiation**
N/A	
% Increase or Decrease to Climate Change Baseline Based on USER DEFINED (ARBITRARY) CLIMATE CHAGE ASSUMPTIONS	**Justification/Substantiation**

N/A	
% Increase or Decrease to Climate Change Baseline Based on REGIONAL CLIMATE MODELS	**Justification/Substantiation**
Using 3 RCMs from NARCCAP, simulating actual weather (1980-2003) and present (1968-2000) and future (2038-2069) climate simulated from greenhouse gases (emission scenario A2)	

8.2.4 State Time Frame	
Infrastructure Safe Operation Time Period	**Time (Years)**
	70-77 Years
Design Life of Infrastructure Components	
Infrastructure Component	**Time (Years)**
Above Ground	
Surface - Asphalt	15 (2 years in some places including grade)
Pavement Marking	1-2
Shoulders (Including Gravel)	1
Barriers	30
Curb	1-4
Luminaires	Normally replaced as they break ~ 10 per year
Poles	15
Signage - Side Mounted - Over 3.2 m^2	
Signage - Overhead Guide Signs	
Overhead Changeable Message Signs	
Ditches	3-5
Embankments/Cuts	Life of Project
Hillsides	Life of Project
Protection Works	
Engineered Stabilization Works	

Avalanche	1
Debris Torrents	5-10 Frequent
Diversion channels	
Structures that Cross Streams	
Structures that Cross Roads	
River Training Works	
MSE Walls	
Below Ground	
Road Sub-Base	20-25
Detail Drainage	15
Catch Basins	
Median and Roadway Drainage Appliances	
Sub-Drains	
Distribution Systems	
Third party utilities	
Culverts < 3m	15
Culverts ≥ 3m	20
Asphalt Spillway and Associated Piping/Culvert	
Miscellaneous	
Administration/Personnel	Life of Project
Winter Maintenance	Life of Project
Ancillary buildings and utilities and yards.	Life of Project
Engineering Technical	Life of Project
Habitat Maintenance	Life of Project
Communication	Life of Project
Emergency Response	Life of Project
Reliability. Usability. Performance standard.	Life of Project

Maintenance (Markings, Crack Sealing)	Life of Project
Useful Life Remaining	**Time (Years)**
	To 2053 ~43 years remaining

Other Relevant Comments

- From the opening of highway, there is a design service life of 70-77 years. End of service for Coquihalla is 2053. Thus the assessment timeline and notional end of life is matched.
- No refurbishment scheduled at present
- First time use RECO MSE wall heavily. Do not know service life of the re-enforcement straps with respect to the aggressive corrosive conditions. Design drawings of the walls may not be kept with BCMOT.
- May have issue with design life of culverts made of steel or galvanized steel. Bed load of culvert (can wear the pipe through)

8.2.5 Geography

Major Components of local geography	Reference
Cascade Mountain Range to east	
Upper Fraser Delta to west	
Coquihalla River tributaries along side of highway	
Change in elevation of 900 meters from start point to end point	
Dry Gulch	
Mine Creek	Added to scope at January 5, 2010 telecon.
Dry Gulch Bridge – Cold Water Bridge becomes interior dry belt	

8.2.6 Specific Jurisdictional Considerations

Jurisdiction With Direct Control or Influence on Infrastructure	Reference
BC MoTI	
DFO	May have some influence on the design of replacement structures. Large culverts.
Industry Canada	Regulates Radio and Electronics as well as Explosive use
Pipelines (NEB)	May have some influence on maintenance and refurbishment

Sections of laws and bylaws that establish legal structure for the infrastructure	**Reference**
BC Wildlife Act	
BC Water Act	
Transportation Act	No bylaws
Motor Vehicle Act and Regulations	
Agricultural Land Reserve Act	
Agricultural Land Commission Act	
Land Act	
BC Railway Act	
Federal Railways Act	
Build BC Act	
Builders Lien Act	
Coastal Ferries Act	
Commercial Transport Act	
Dike Maintenance Act	
Diking Authority Act	
Drinking Water ACT	
Forests Act	
Sections of regulations that establish legal structure for the infrastructure	**Reference**
As defined in Worksheet 1	n/a
Relevant Standards for the design, operation and maintenance of the infrastructure	**Reference**
BC Supplements to the Design Manual	
BC Design Manual	
Best Practices Documents	

Infrastructure owner/operator administrative processes and policies as they apply to the infrastructure	**Reference**
Variances from chief engineers office	
8.2.7 Other Change Effects	
Changes in use pattern that increase/decrease the capacity of the infrastructure	**Reference**
More truck traffic. More private vehicle traffic.	
River and watershed metamorphosis.	
Fire history and things that affect fire history (Mountain Pine Beetle)	
Operation and maintenance practices that increase/decrease capacity of infrastructure	**Reference**
Rehab and Maintenance	Rehab depends on budget. Could take longer.
Changes in management policy that affect the load pattern on the infrastructure	**Reference**
N/A	
Changes in Laws, Regulations and Standards that affect the load pattern on the infrastructure	**Reference**
N/A	

8.2.8 Assess Data Sufficiency

Comment on using relatively short term measurements to make long term predictions	Limitations
The team has many years of experience with day-to-day operation of the infrastructure. They were confident that this experience augmented with solid design and climatic data mitigated concerns regarding the use of short-term measurements to make long-term projections.	

Data Evaluation	Comment	Effect on Assessment
Data Gaps	As describe below.	Unable to assess high wind/ downburst or visibility concerns.
Data Quality	Statistical data has uncertainty associated with it.	Minimal. Compensated by team experience.
Data Accuracy	Data uncertainty	Minimal. Compensated by team experience.
Applicability of Trends	Use of experience based data and synoptic analysis relies significantly on observed trends.	PCIC projections and hands-on experience were very consistent.
Reliability of Selected Climate Models	All RCMs have inherent biases and uncertainties.	Minimal. Compensated by using cohort of model results and calibrating model outputs with the observed, baseline climate.
Other Factors	n/a	n/a

8.2.8 (c)
Establish Priority in Referenced Documents

Reference Document	Reference Priority (highest reliance first)
Variances from chief engineers office	**1**
BC Supplements to the Design Manual	**2**

BC Design Manual	**3**
Best Practices Documents	**4**
8.2.8 (d)	
Data Sufficiency	
Identify process to develop data, where insufficient	
Data Needed	**Process**
Based on the project schedule and limitations in climate modeling, PCIC was unable to provide model-based projections for the following climate parameters:	
• Climate Parameter 10, Rain on Snow	Sensitivity Analysis
• Climate Parameter 11, Freezing Rain	Sensitivity Analysis
• Climate Parameter 14, Snow Accumulation	Sensitivity Analysis
• Climate Parameter 15, High Wind / Downburst	Recommended for Further Study
• Climate Parameter 16, Visibility	Recommended for Further Study
Where data cannot be developed, identify the data gap as a finding in Step 5 of the Protocol – Recommendations.	
List Data Gap as findings to be sent to STEP 5 (Worksheet 5: Section 8.5.2)	
1. Climate Parameter 15, High Wind / Downburst	
2. Climate Parameter 16, Visibility	

Date:	**March 2, 2010**
Prepared by:	**Joel R. Nodelman on behalf of BCMoTI Team**

Appendix E

Pacific Climate Impacts Consortium Summary Report

Climate Change at the Coquihalla Highway

PCIC assessment for BCMoTI

March 26, 2010

G. Buerger, PCIC
J. Hiebert, PCIC
H. Eckstrand, PCIC
T. Murdock, PCIC

Climate Change assessment for the Coquihalla Highway

1. General introduction

A changing climate will likely have a large impact on many infrastructures for all parts of BC. Adaption of the design of these infrastructures is therefore required. The PIEVC pilot project for the Coquihalla Highway (cf. Figure 1) is one example how this can be achieved. The Pacific Climate Impacts Consortium (PCIC) has provided a climate change assessment for the area of the highway, by providing localized projections, including uncertainties, of the core meteorological variables of daily minimum and maximum temperature and precipitation for the 2050s. Along with this, PCIC has provided probabilistic estimates for a number of design critical climatic events. This report outlines the various steps that were used in the assessment.

It should be noted that due to the limited time frame and resources of PCIC, no significance analysis has been conducted, and some of the high-impact, low-probability events could be assessed only with low confidence. To obtain significance levels and higher confidence, a more refined analysis is required based on a more elaborate empirical downscaling, along with subsequent hydrologic modeling.

2. Data base

Our assessment of climate change for the Coquihalla Highway is based on statistics for present climate based on station observations, combined with information derived from regional climate models (RCMs) that are driven by global climate models (GCMs), both for present and future greenhouse gas concentrations.

a) Station observations

From the 19 Environment Canada stations near the highway, listed in Table 1, the present climate of the area was estimated. We used the three core variables

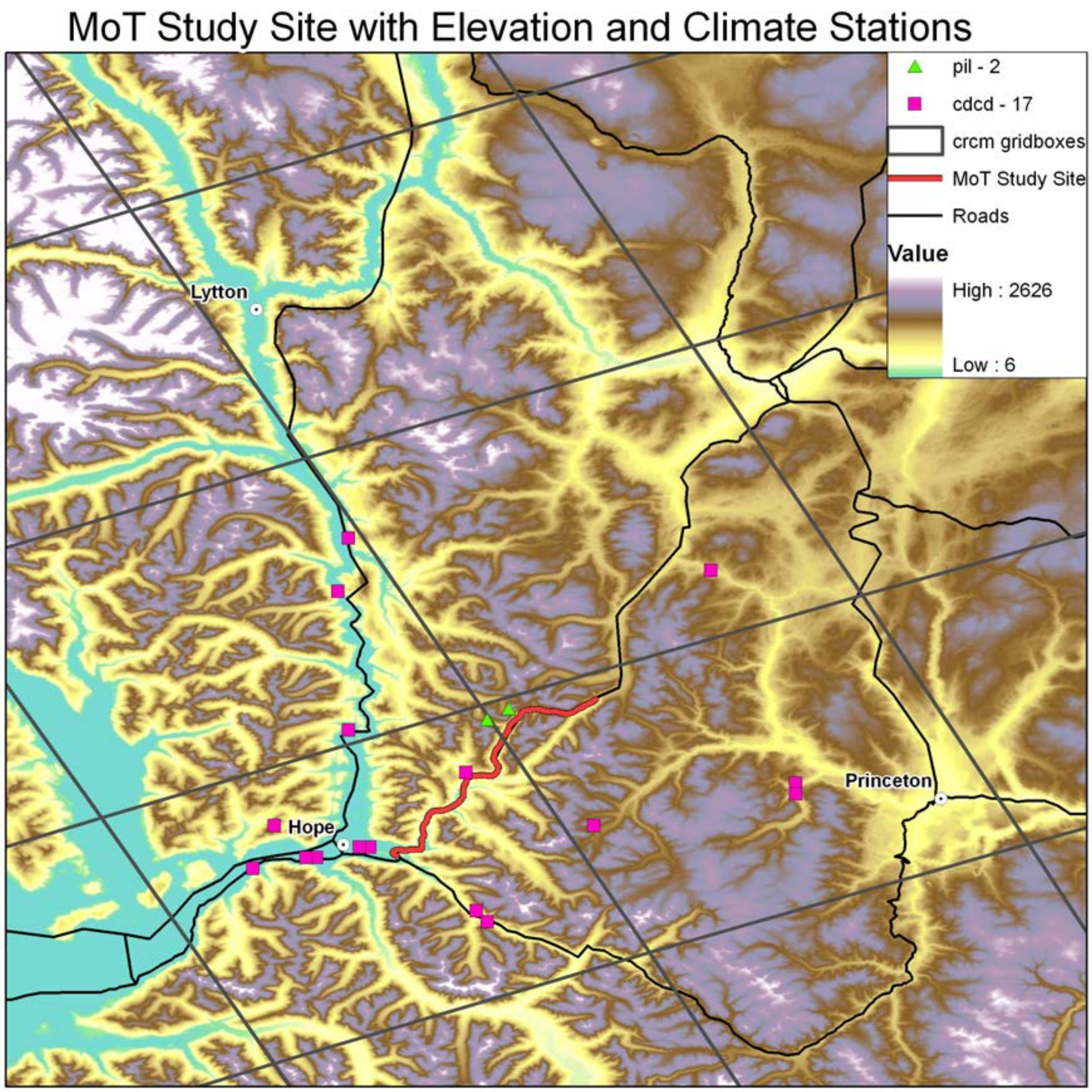


Figure 1. The Coquihalla Highway and corresponding climate sources.

- daily minimum temperature, T_{min}
- daily maximum temperature, T_{max}
- daily precipitation, *P*.

In comparisons with RCMs, we formed daily averages across the stations.

b) GCM/RCM modeling

These are the three pairs of models that were used (GCM driving RCM denoted by GCM / RCM):

- CGCM3 / CRCM
- HadCM3 / HRM3
- CGCM3 / RCM3

Details about the models can be found at http://www.narccap.ucar.edu/data/model-info.html. For brevity, the above model combinations will be referenced by the respective RCM.

Each RCM projection comes in its own grid with tiles of size 50km x 50km. For the analysis we selected for each RCM the tile that had the greatest overlap with the study area. The GCMs were driven by two different emission scenarios:

- **20C3M (1970-2000 "present"):** Greenhouse gasses increasing as observed through the 20th century.
- **SRA2 (2040-2070 "future"):** A very heterogeneous world. The underlying theme is that of strengthening regional cultural identities, with an emphasis on family values and local traditions, high population growth, and less concern for rapid economic development.

For information on the details of these scenarios please consult http://www.ipcc-data.org/ar4/gcm_data.html

3. Method

a) Boxplots

The RCM simulations of the core climate variables T_{min}, T_{max}, and P are displayed as annual and seasonal boxplots. For comparison, NCEP driven results and mean values across the station observations (approximating areal means) are also included.

The assessment of climate change is obtained along 10 typical climatic "events" that are relevant for the for the highway infrastructures, see Table 2; they correspond to the respective climate parameters of worksheet 3. To obtain probability estimates of these events for present and future climate, two different approaches were taken, distinguished by the target area.

b) Local

This method applies to events that occur at a typical *point* in the area of interest. It estimates probabilities of the event occurring under present and future climatic conditions. For the present, the probability of an event occurring *at a station* is estimated, using the average over all stations. The future probability is estimated using the method of probability mapping [*Panofsky and Brier*, 1958], as follows:

Probability mapping

For a local variable, *x*, for example, daily maximum temperature at some station, and a regional variable, *X*, say daily temperature at a corresponding RCM tile, we look at events

- $E_L(t, d)$: $x>t$ for d consecutive days (local)
- $E_R(T, d,$ "present"$)$: $X>T$ for d consecutive days (regional)
- $E_R(T, d,$ "future"$)$: $X>T$ for d consecutive days (regional)

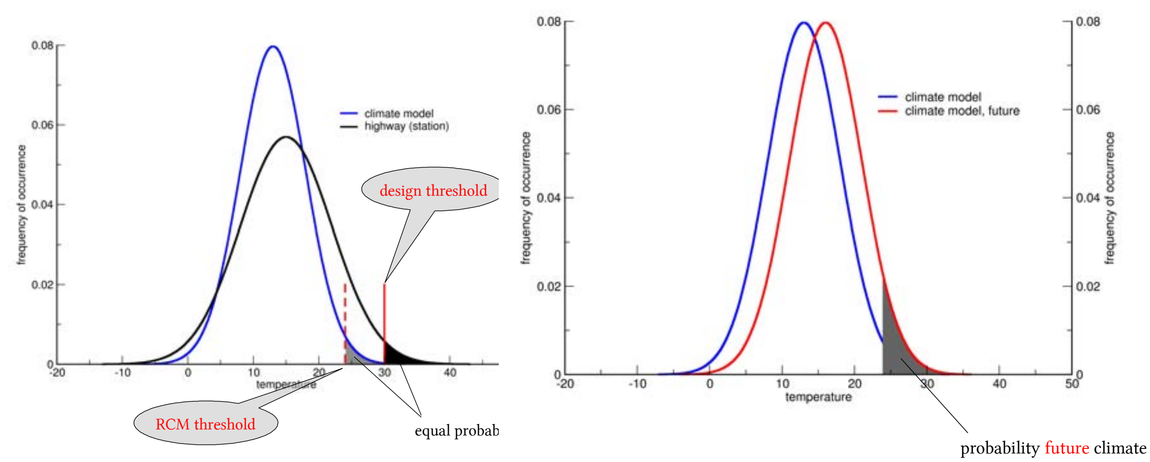


Figure 1: Probability mapping

Given some local threshold t, cf. Table 3, we determine the local probability $p_{\text{present}} = p(E_L(t, d))$. Using p_{present}, we find a regional threshold T_R, cf. Table 5, for the RCM so that $p(E_R(T_R, d,$ "present"$) = p_{\text{present}}$. Using that threshold T_R we now determine the desired future probability of the event $p_{\text{future}} = p(E_R(T_R, d,$ "future"$))$. The mapping scheme is displayed in Figure 1.

For probability mapping to function properly it is obvious that for the event in question a probability must be assigned for the present climate. For some of the thresholds as defined originally by the MoTI, no events were ever observed in the station records. In those cases we adjusted the corresponding thresholds (usually maximum or minimum of the variable) so that at least one event was observed in the relevant time frame, cf. Table 4. Obviously, this local method is confined to events that are definable from daily statistics of T_{min}, T_{max}, and P.

c) Regional

For events that have no counterpart in, or cannot be traced back to, the station records we had to rely on model information only. That means, the various RCM thresholds of the variables could not be derived from observations using probability mapping, but had to be defined using expert judgement from the predefined thresholds in worksheet 3. This was primarily the case for events which were defined using wind speed or direction, since reliable wind observations were unavailable for the study area. Details are given in Table 3. Once the thresholds are defined present and future probabilities can be calculated based on that threshold.

It must be noted that no significance analysis has been conducted. The assessment especially of the high-impact, low-probability events should therefore be taken with caution.

4. Results

The boxplot results are attached. The event probabilities for present and future climate are listed in Table 6.

5. References

Panofsky, H. A., and G. W. Brier (1958), *Some applications of statistics to meteorology*, The Pennsylvania State University Pennsylvania.

6. List of Tables

Table 1. The Environment Canada station list.

Station Name	Station ID	Elevation (m)	Latitude	Longitude
Laidlaw	1104488	27	49.35	-121.58
Boston Bar	111090M	200	49.87	-121.43
Hells Gate	1113420	122	49.78	-121.45
Hope	1113539	39	49.37	-121.48
Hope A	1113540	39	49.37	-121.48
Hope (Aut)	1113541	39	49.37	-121.5
Hope Dog Mountain	1113545	1475	49.42	-121.55
Hope Kawkawa Lake	1113550	152	49.38	-121.4
Hope Little Mountain	1113570	177	49.38	-121.42
Hope Slide	1113580	701	49.27	-121.22
Hope Slide	1113581	674	49.28	-121.23
Ladner Creek	1114474	807	49.5	-121.25
Treasure Mountain	1118235	1430	49.42	-121.05
Yale	1119002	76	49.57	-121.43
Blakeburn	1120882	1485	49.48	-120.73
Brookmere	1121090	972	49.82	-120.87
Granite Creek	1123280	1037	49.47	-120.73
Boston Bar Creek (Upper)	1D11P	1340	49.58	-121.22
Great Bear	1D15P	1660	49.6	-121.18

Table 2. Definition of climatic events (*U, V, W* wind components and speed of RCM).

worksh. #	**Event**	**Definition**	**Duration (k)**
1	High Temperature	$T_{max} > T_{thresh}$	*1 d*
2	Low Temperature	$T_{min} < T_{thresh}$	*1 d*
3	Temperature Variability	$(T_{max} - T_{min}) > T_{thresh}$	*1 d*
4	Freeze/Thaw	$(T_{min} < 0) \wedge (T_{max} > 0)$	*17 d*
6	Frost	$T_{min} < 0$	*47 d*
(7)	heavy rain	$P > P_{thresh}$	*5 d*
7	One Day precipitation	$P > P_{thresh}$	*1 d*
13	Snow (Frequency)	$(P > P_{thresh}) \wedge (T < 0)$	*1 d*
8, 9	Pineapple Express	$(U > 0) \wedge (V > 0) \wedge (T > T_{thresh})$ $\wedge (P > P_{thresh}) \wedge (W > W_{thresh})$	*3 d*
12	Snow Storm/Blizzard	$(P > P_{thresh}) \wedge (T < 0) \wedge (W > W_{thresh})$	*3 d*

Table 3. Event thresholds.

Event	Threshold	Source
High Temperature	35 °C	provided by MoTI
Low Temperature	24 °C	determined empirically
Temperature Variability	24 °C	determined empirically
Freeze/Thaw	0 °C	provided by MoTI
Frost	0 °C	provided by MoTI
heavy rain	18 mm	determined empirically
One Day precipitation	76 mm	determined empirically
Snow (Frequency)	10 mm	provided by MoTI

Table 4. Total number of events in observational data set.

Event	Total observations	Observed events per year
High Temperature	17	0.567
Low Temperature	1	0.033
Temperature Variability	1	0.033
Freeze/Thaw	2	0.067
Frost	2	0.067
heavy rain	1	0.033
One Day precipitation	1	0.033
Snow (Frequency)	506	16.867

Table 5. Derived regional thresholds for RCM (20C3M).

Event	CRCM	HRM3	RCM3
High Temperature	28.9	38.4	28.1
Low Temperature	-42.1	-32.4	-41.8
Temperature Variability	34.3	25.0	25.0
Freeze/Thaw	-10.2	-3.8	-3.1
Frost	-6.7	-1.5	-4.4
heavy rain	13.2	10.6	10.8
One Day precipitation	51.9	65.3	32.4
Snow (Frequency)	18.0	8.9	14.3

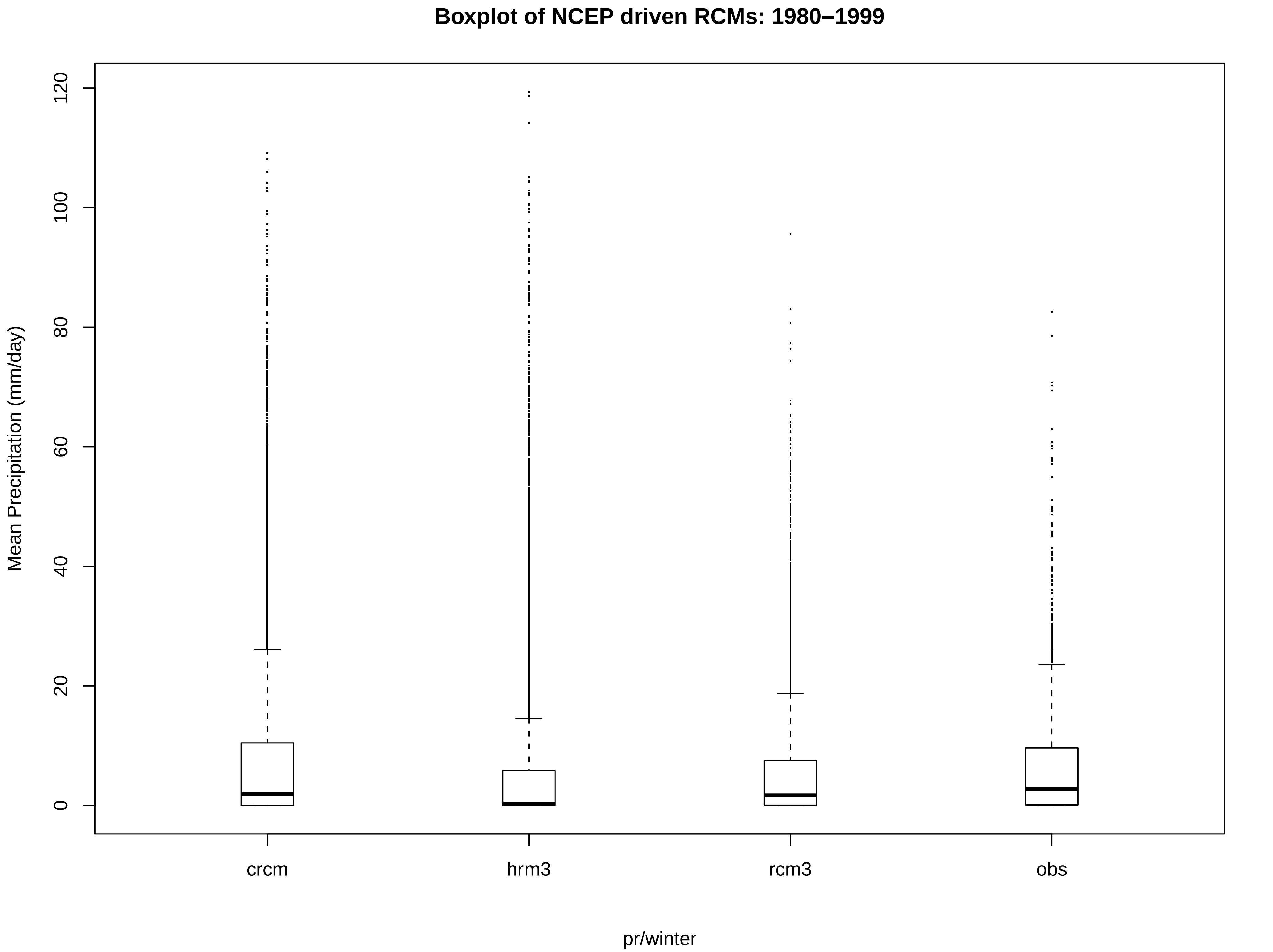
Table 6. Probabilities as events per year.

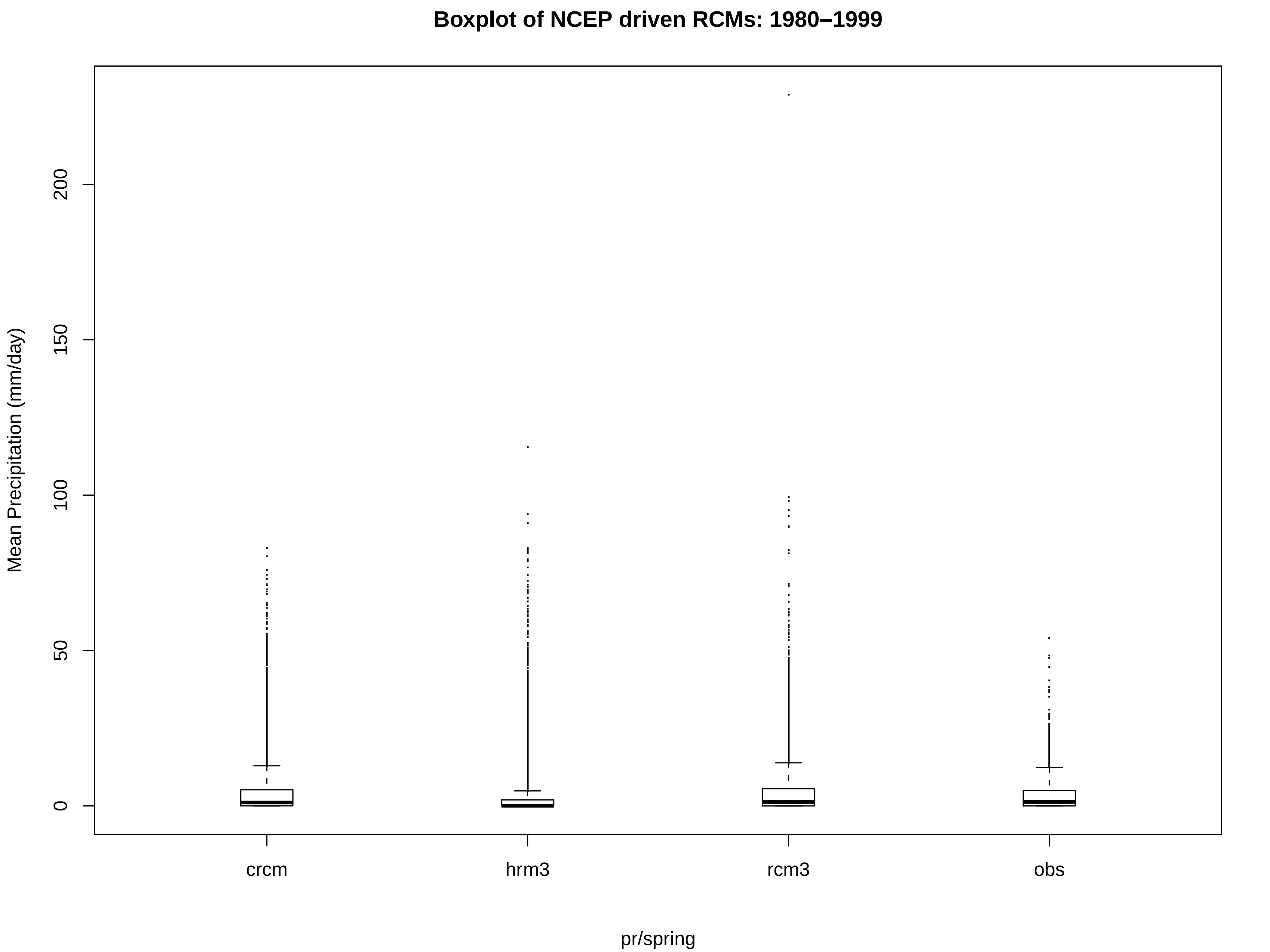
High Temperature	**OBS**	**CRCM**	**HRM3**	**RCM3**
present	0.567			
future		1.767	3.434	1.367
Low Temperature				
present	0.033			
future		0.033	0.000	0.033
Temperature Variability				
present	0.033			
future		0.000	0.000	0.000
Freeze/Thaw				
present	0.067			
future		0.000	0.000	0.000
Frost				
present	0.067			
future		0.000	0.000	0.000
Heavy Rain				
present	0.033			
future		0.033	0.033	0.100
One Day precipitation				
present	0.033			
future		0.067	0.067	0.000
Snow (Frequency)				
present (20C3M)	16.867			
future		14.169	11.468	15.502
Pineapple Express				
present (20C3M)		0.100	0.100	0.033
future		0.233	0.133	0.000
Snow storm / blizzard				
present (Winter)		0.067	0.067	0.100
future (Winter)		0.000	0.200	0.000
present (Spring)		0.033	0.100	0.167
future (Spring)		0.033	0.033	0.067

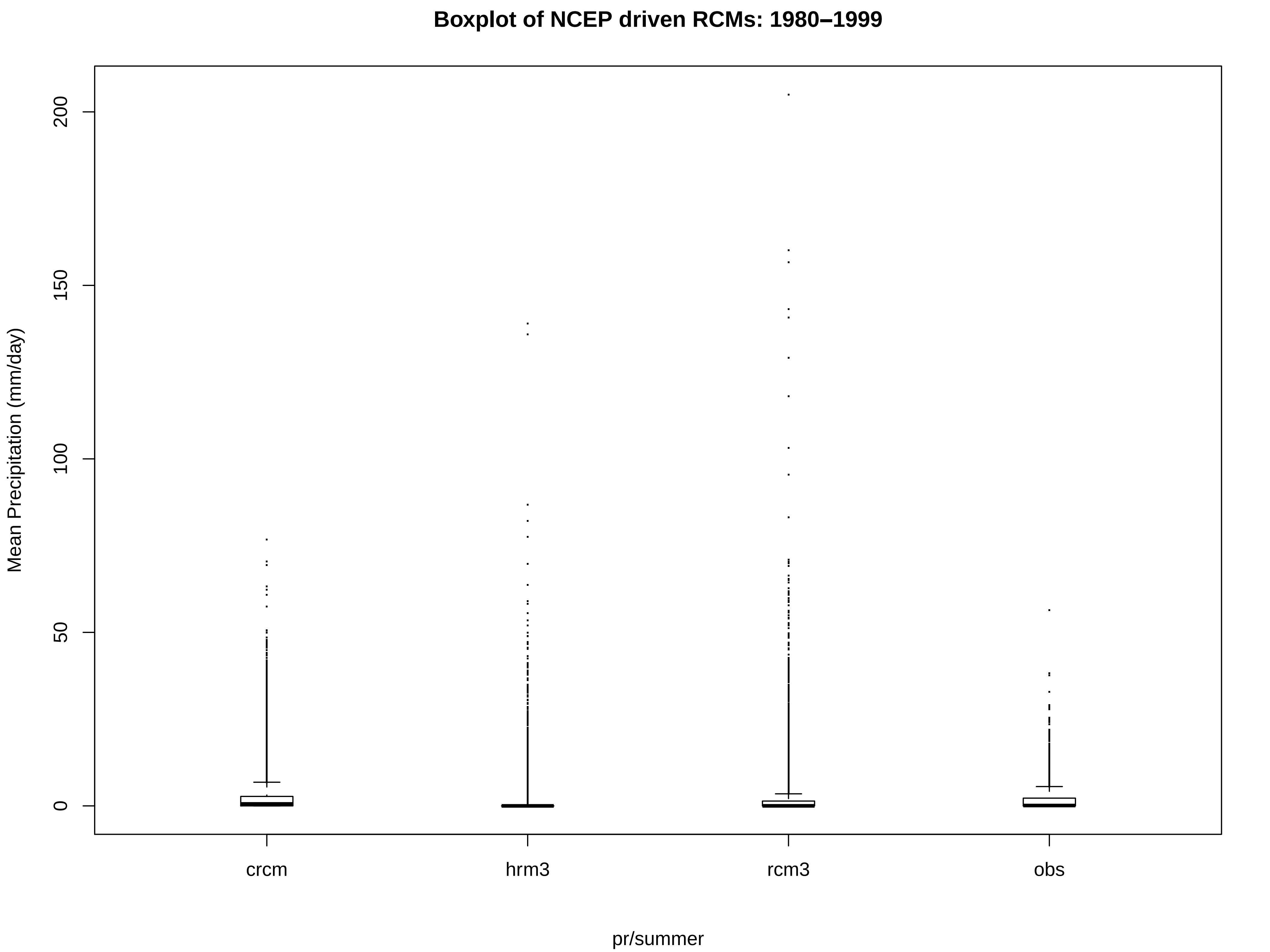
7. List of Attachments

Figures with boxplots for RCM simulations driven by

- NCEP analyses
- 20C3M GCM simulations
- SRA2 GCM simulations


Boxplot of NCEP driven RCMs: 1980–1999
Mean Precipitation (mm/day)
0
20
40
60
80
100
120
crcm
hrm3
rcm3
obs
pr/winter


Boxplot of NCEP driven RCMs: 1980–1999
Mean Precipitation (mm/day)
0
50
100
150
200
crcm
hrm3
rcm3
obs
pr/spring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Mean Precipitation (mm/day)
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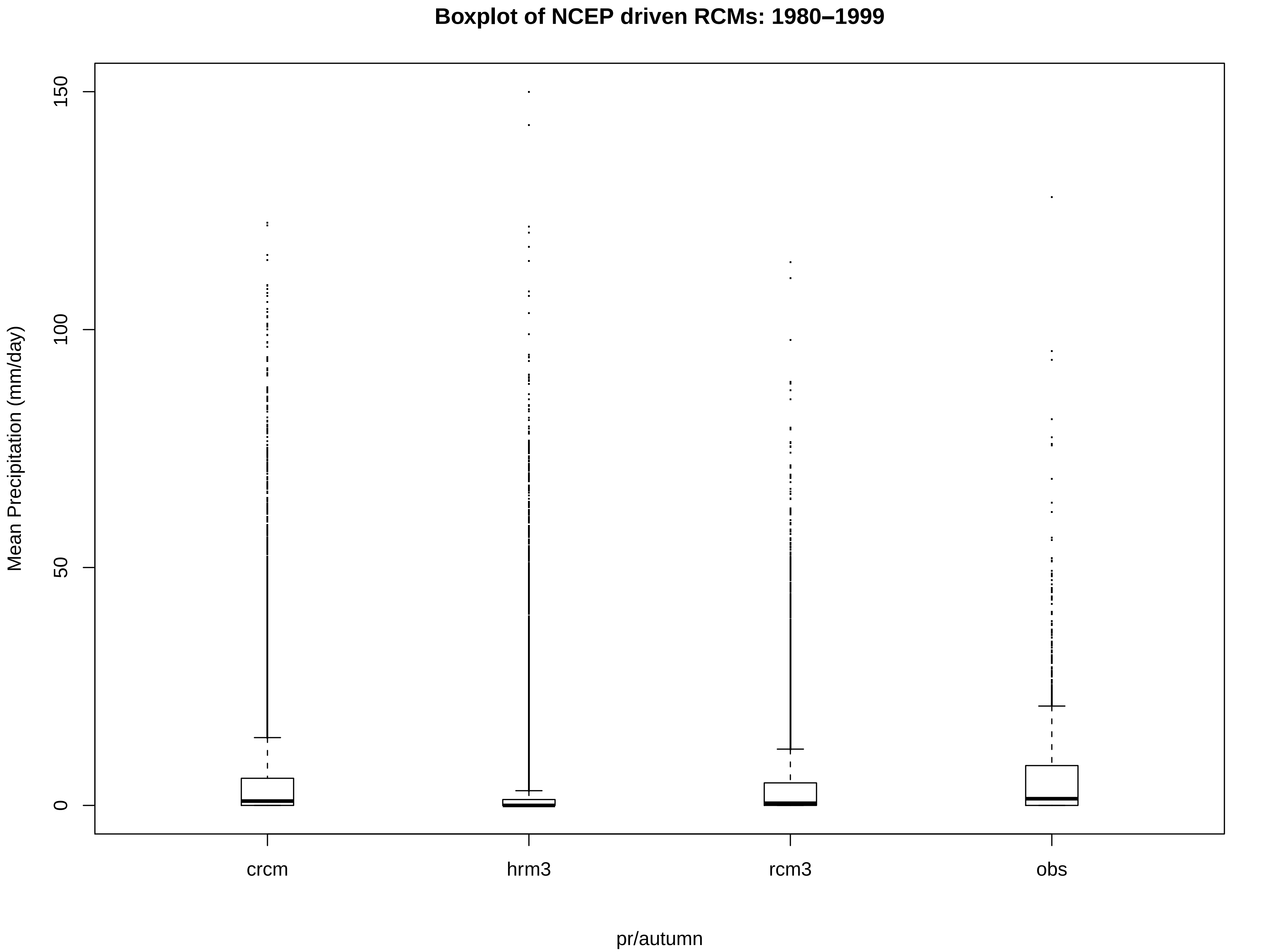
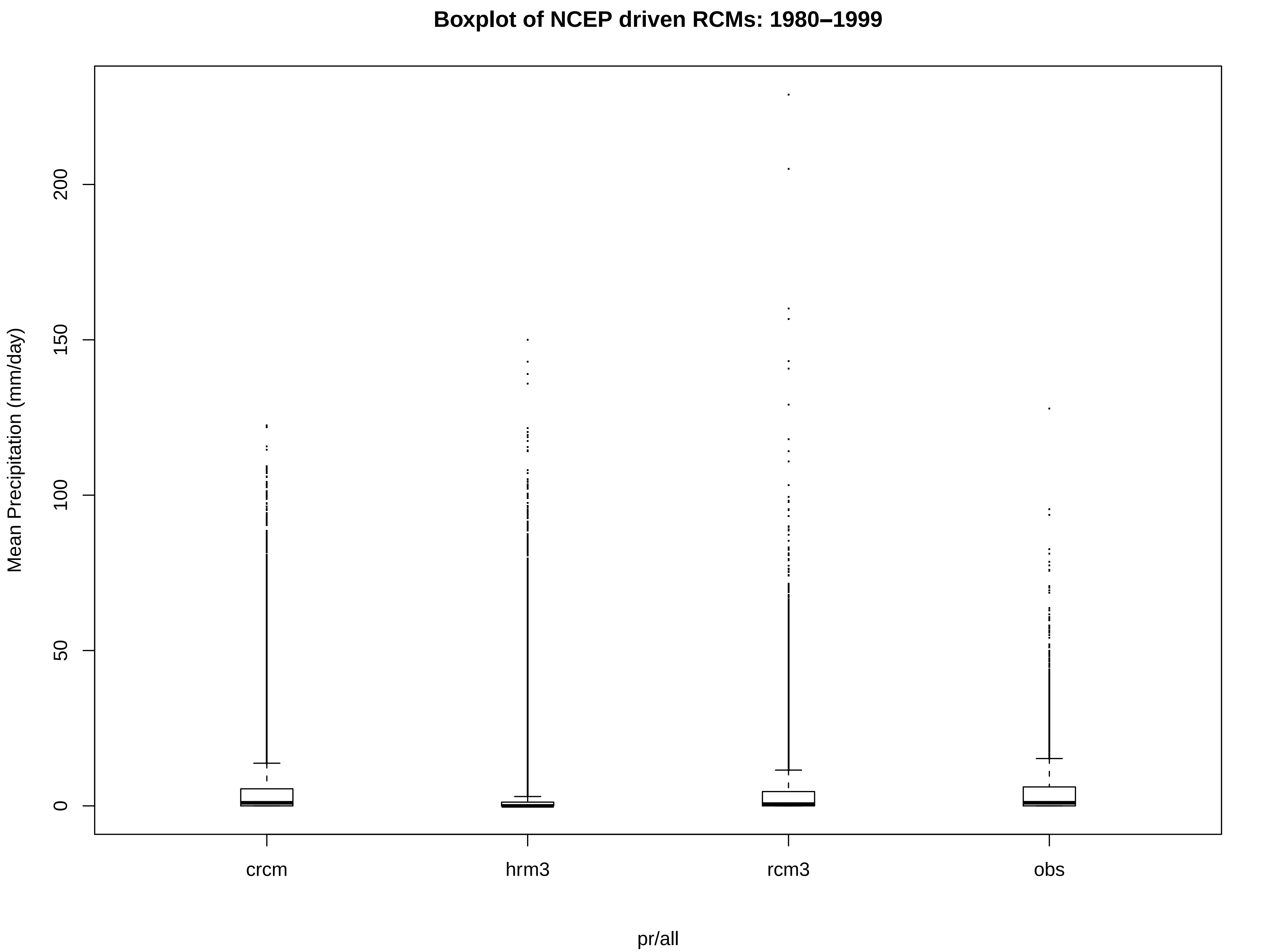
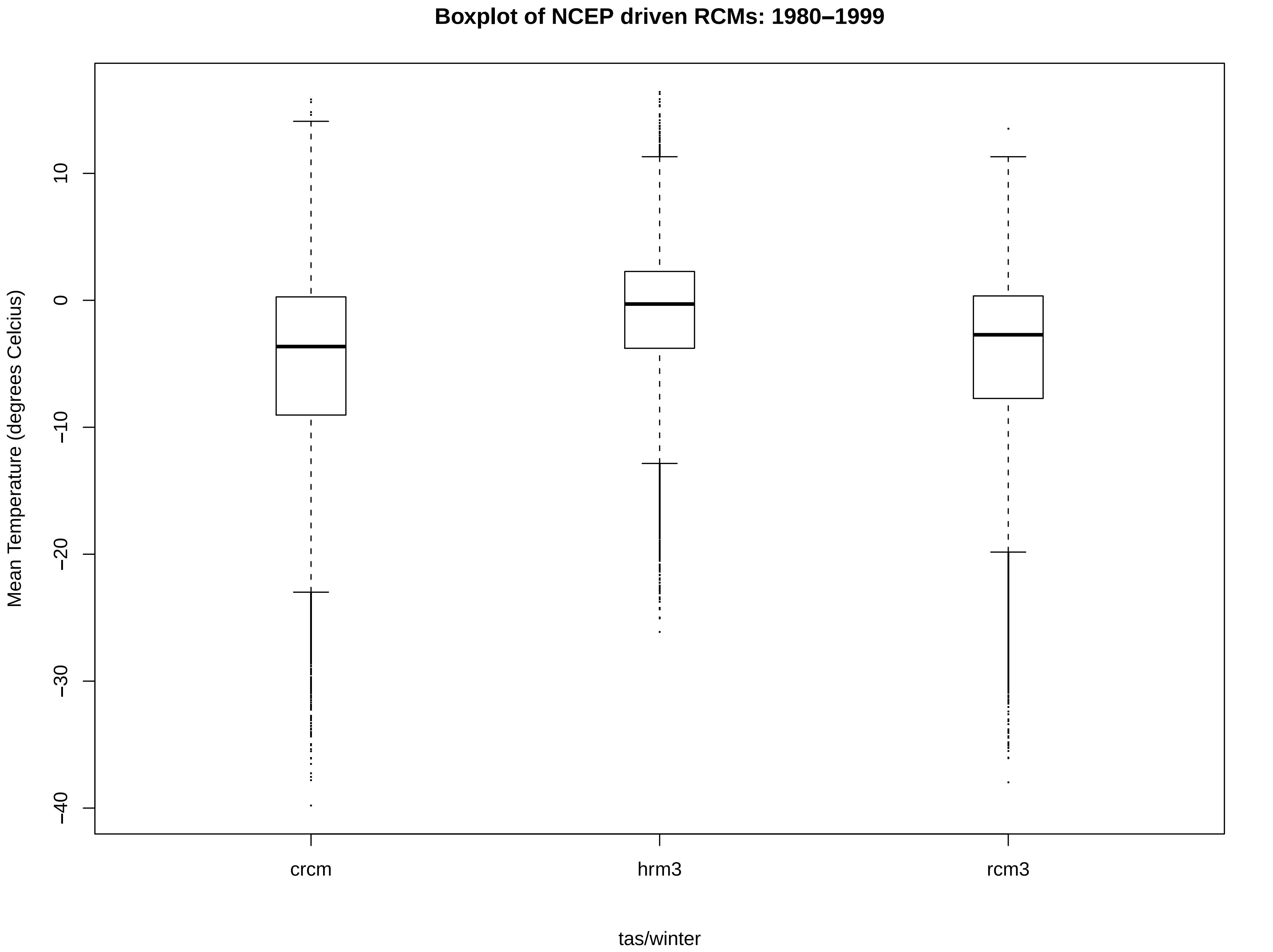
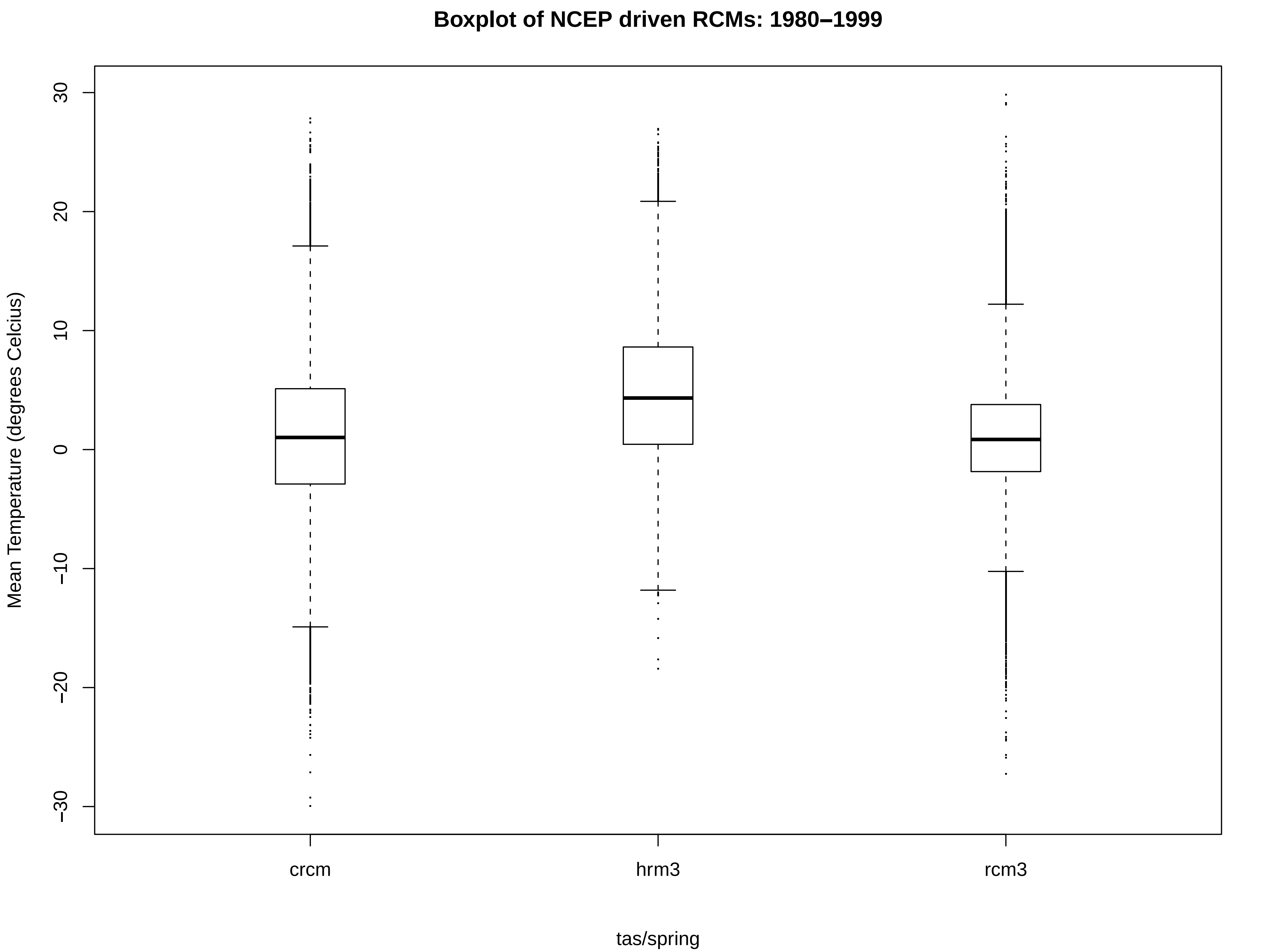
50
100
150
200
crcm
hrm3
rcm3
obs
pr/summer


Boxplot of NCEP driven RCMs: 1980–1999
Mean Precipitation (mm/day)
0
50
100
150
crcm
hrm3
rcm3
obs
pr/autumn

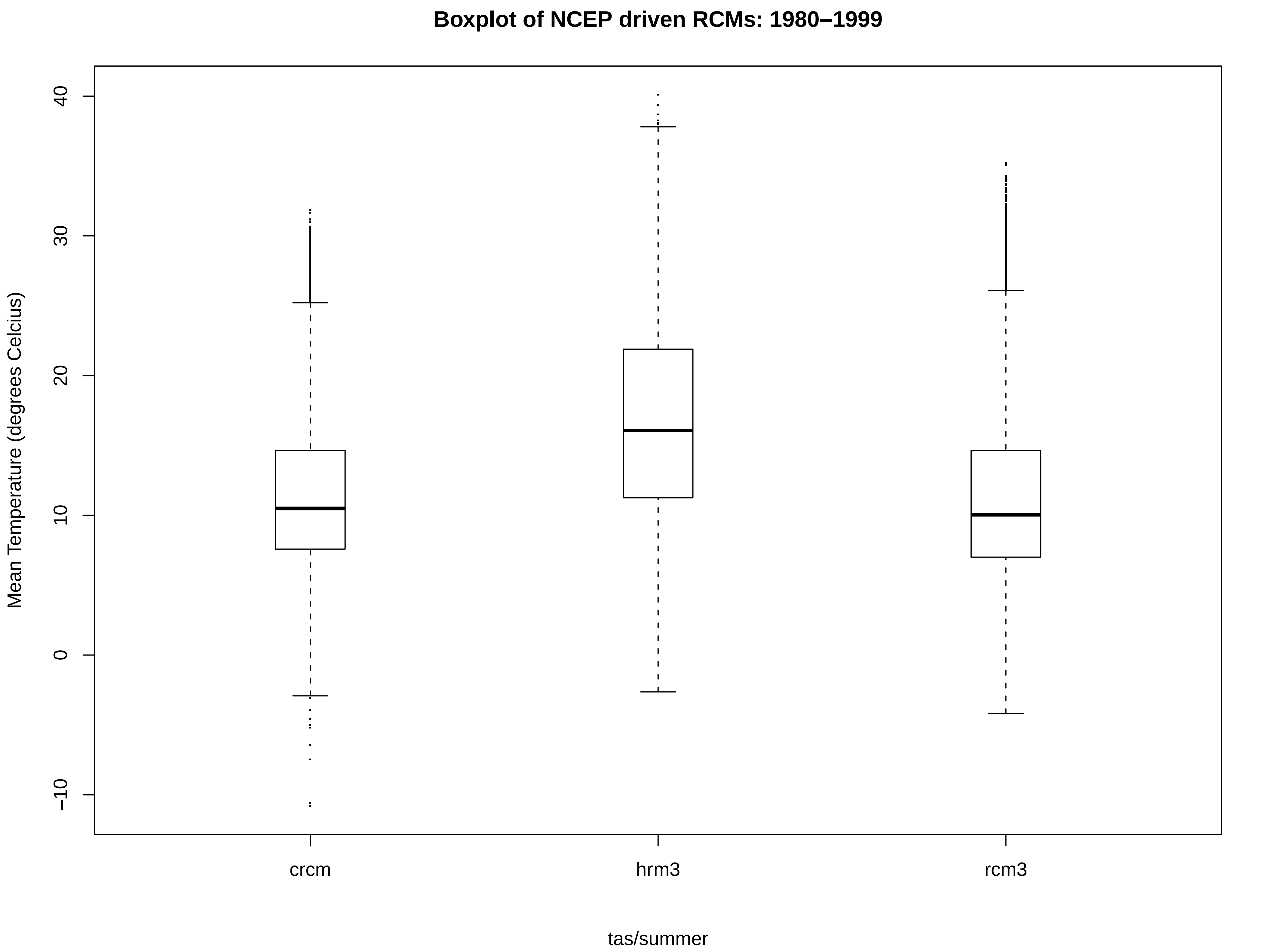

Boxplot of NCEP driven RCMs: 1980–1999
Mean Precipitation (mm/day)
0
50
100
150
200
crcm
hrm3
rcm3
obs
pr/all

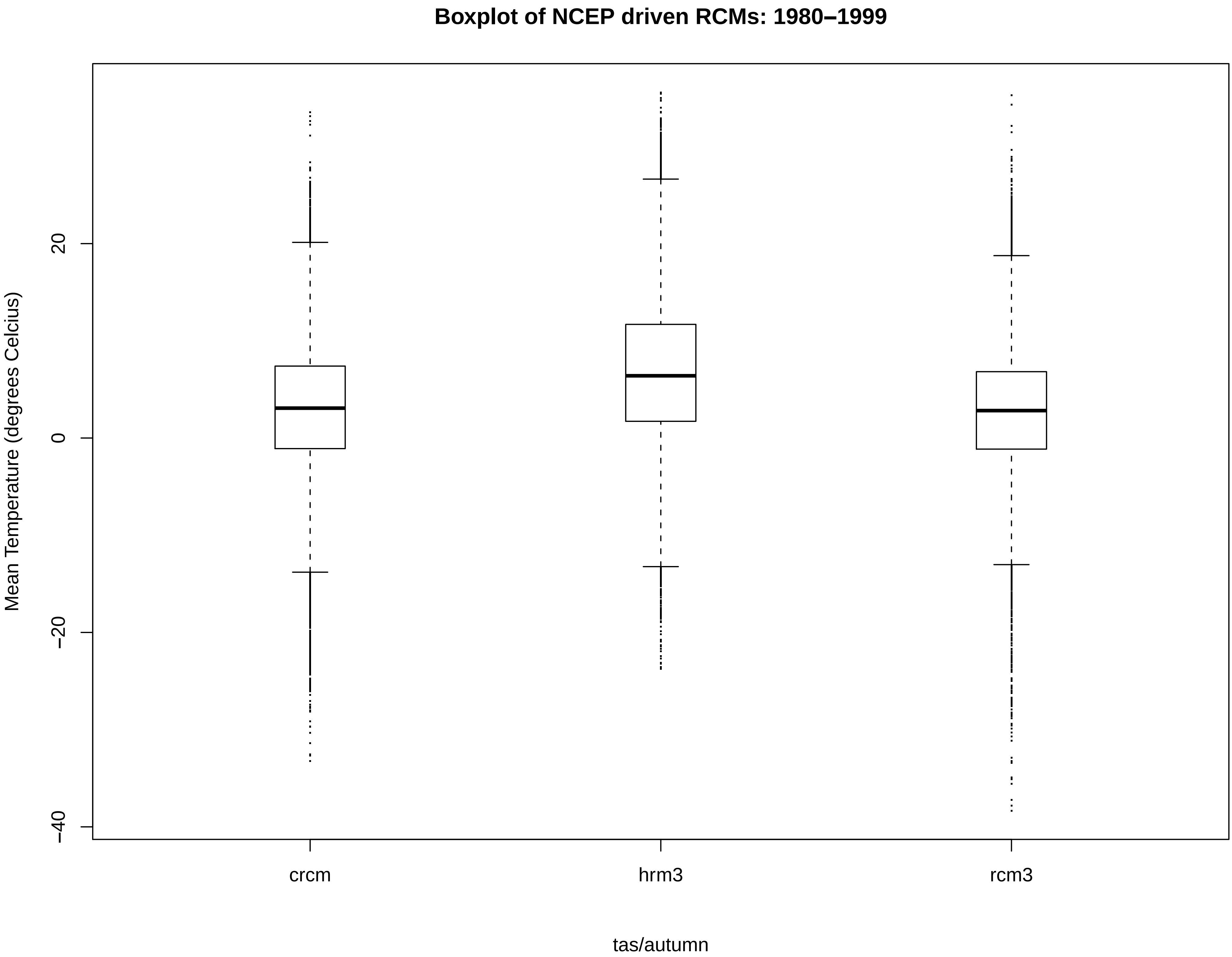


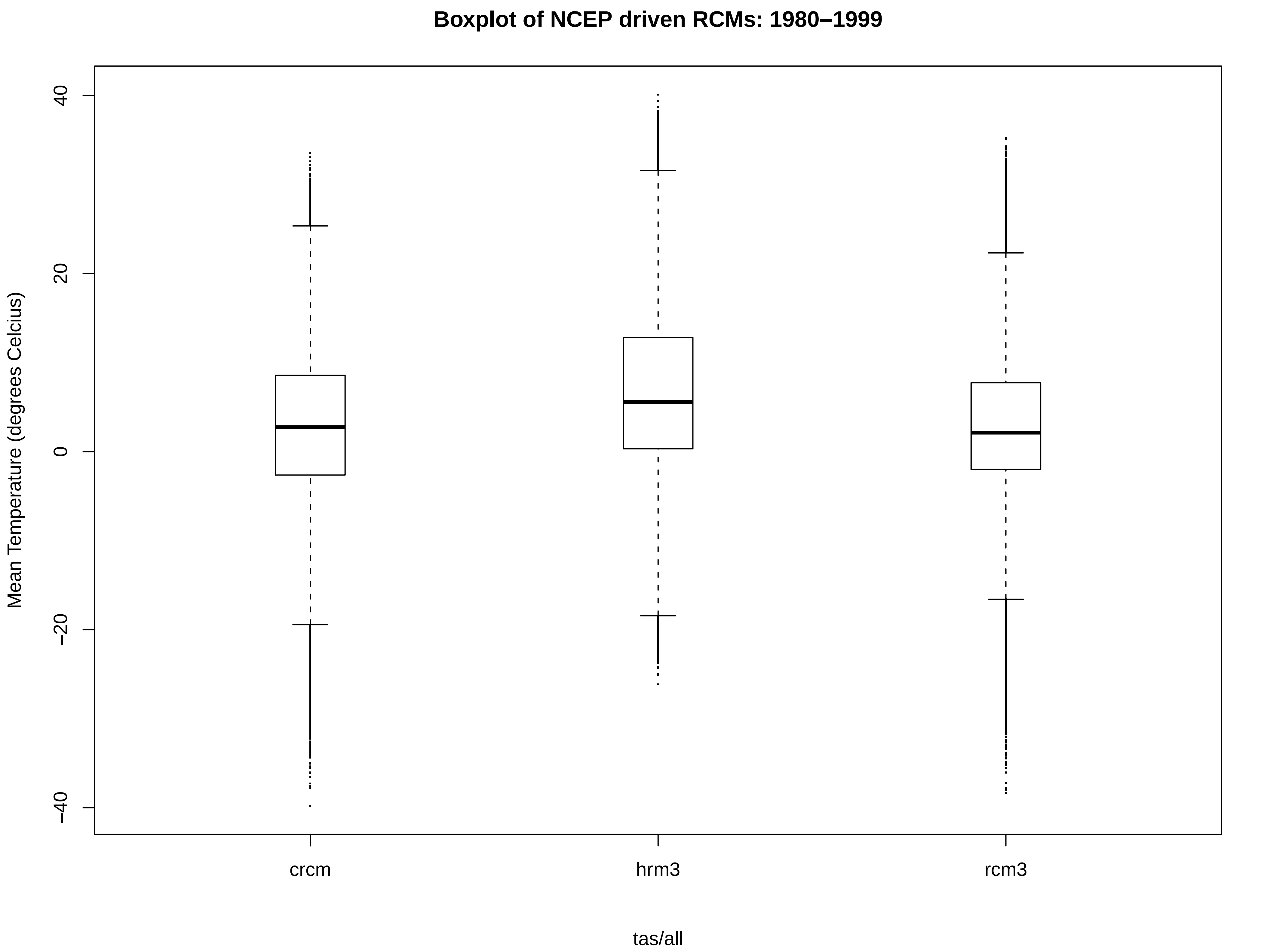
Boxplot of NCEP driven RCMs: 1980–1999
Mean Temperature (degrees Celcius)
10
0
−10
−20
−30
−40
crcm
hrm3
rcm3
tas/winter

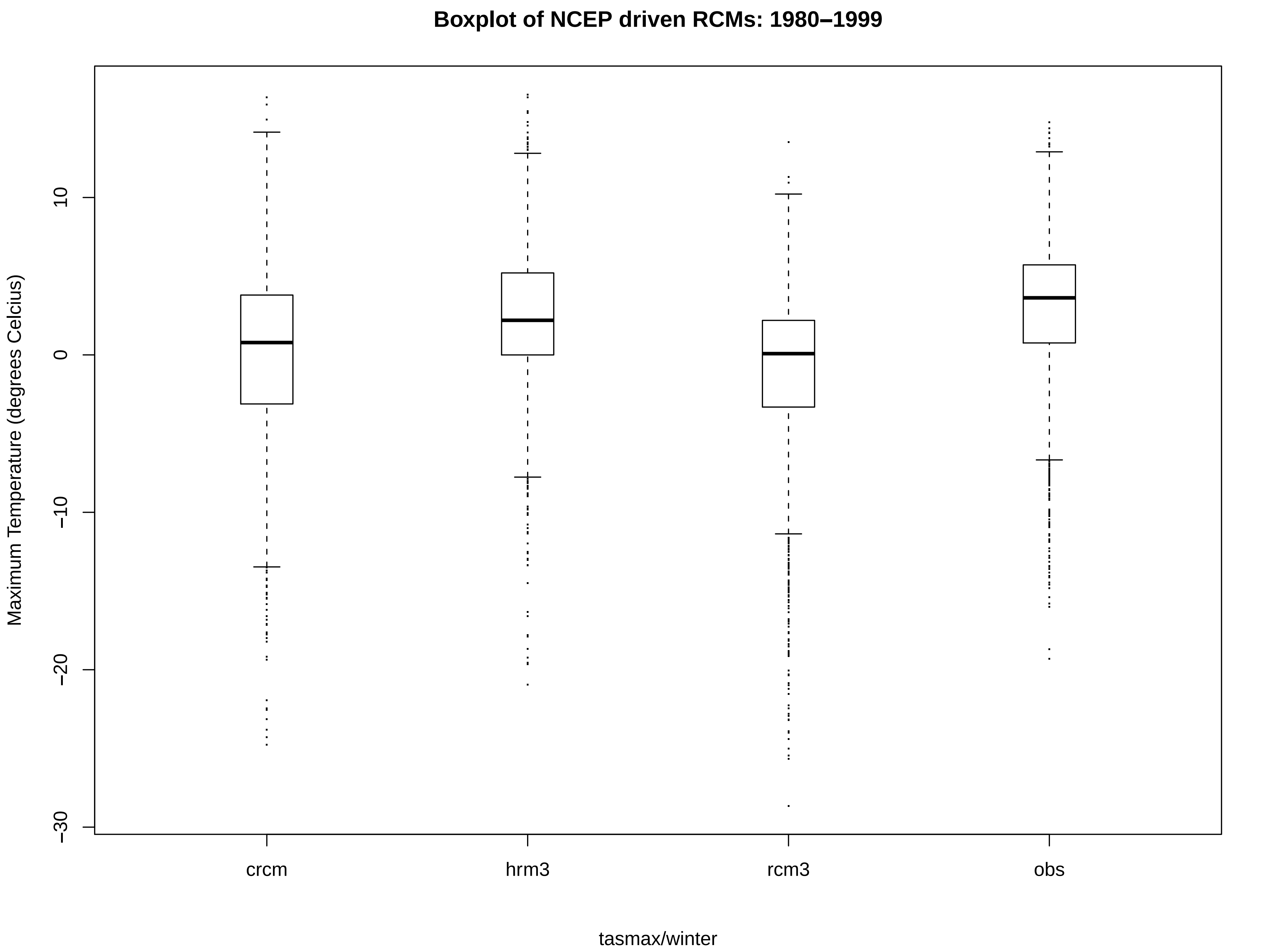


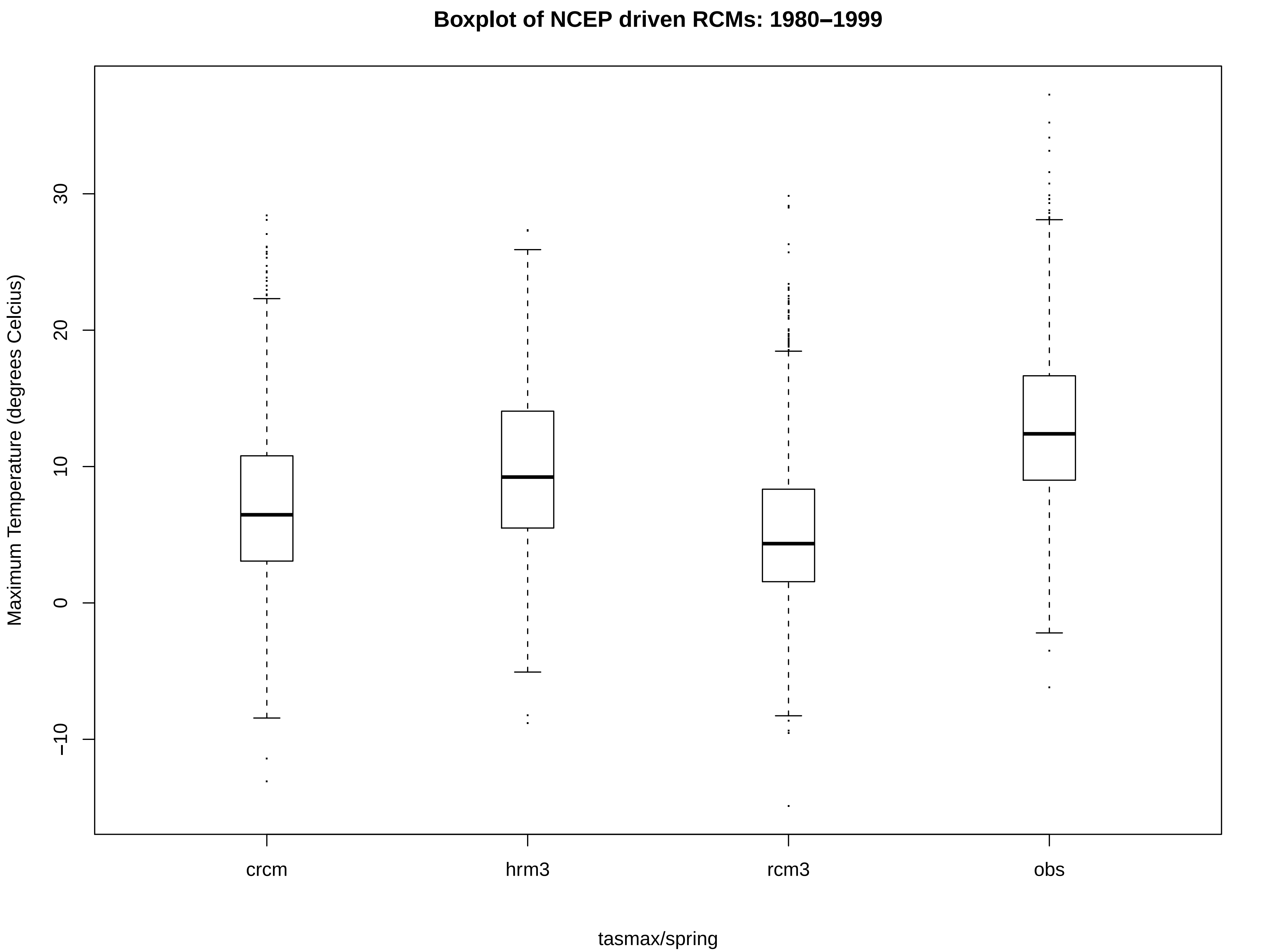
Boxplot of NCEP driven RCMs: 1980–1999
Mean Temperature (degrees Celcius)
30
20
10
0
−10
−20
−30
crcm
hrm3
rcm3
tas/spring


Boxplot of NCEP driven RCMs: 1980–1999
Mean Temperature (degrees Celcius)
40
30
20
10
0
−10
crcm
hrm3
rcm3
tas/summer

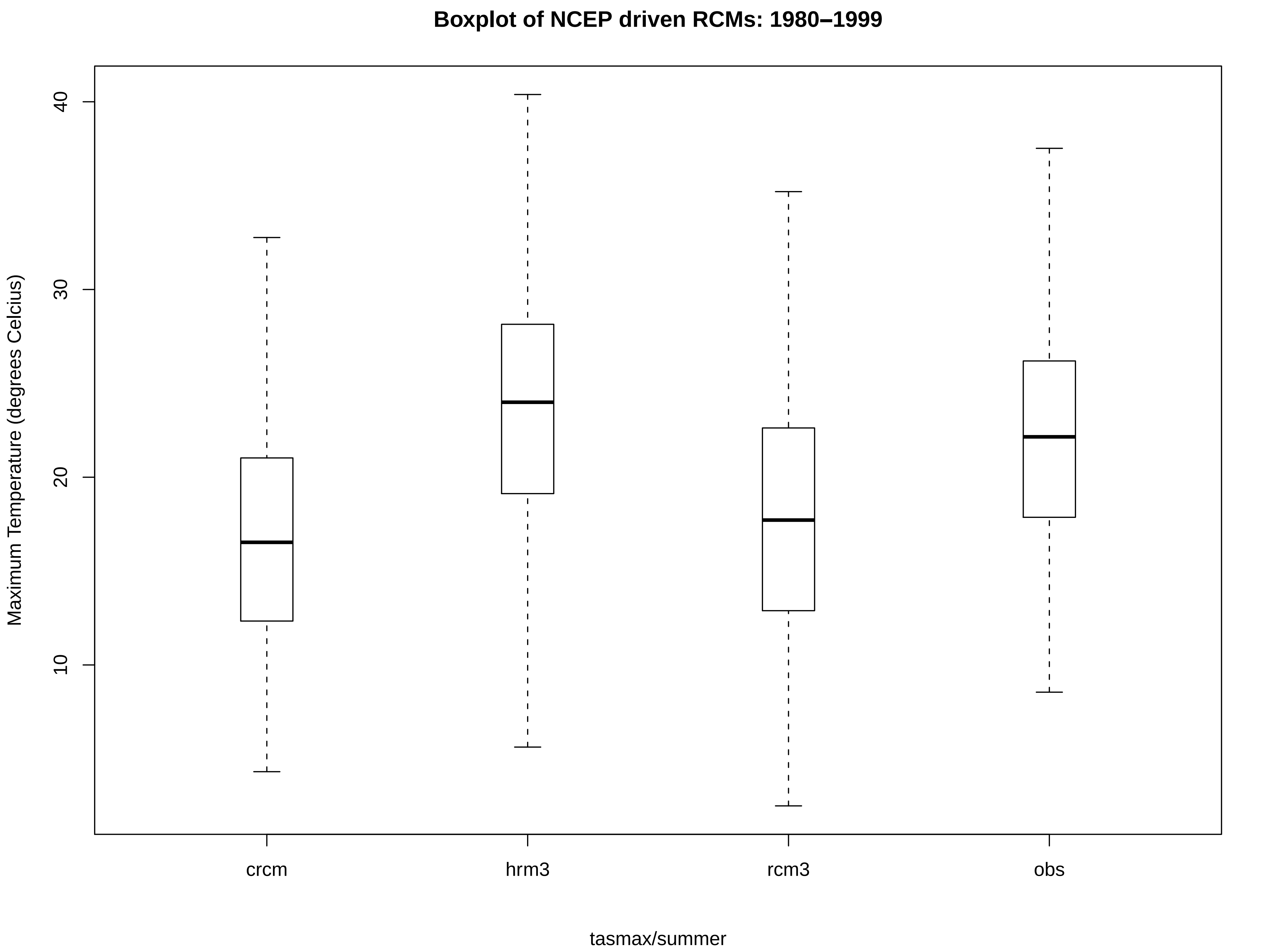

Boxplot of NCEP driven RCMs: 1980–1999
Mean Temperature (degrees Celcius)
20
0
−20
−40
crcm
hrm3
rcm3
tas/autumn

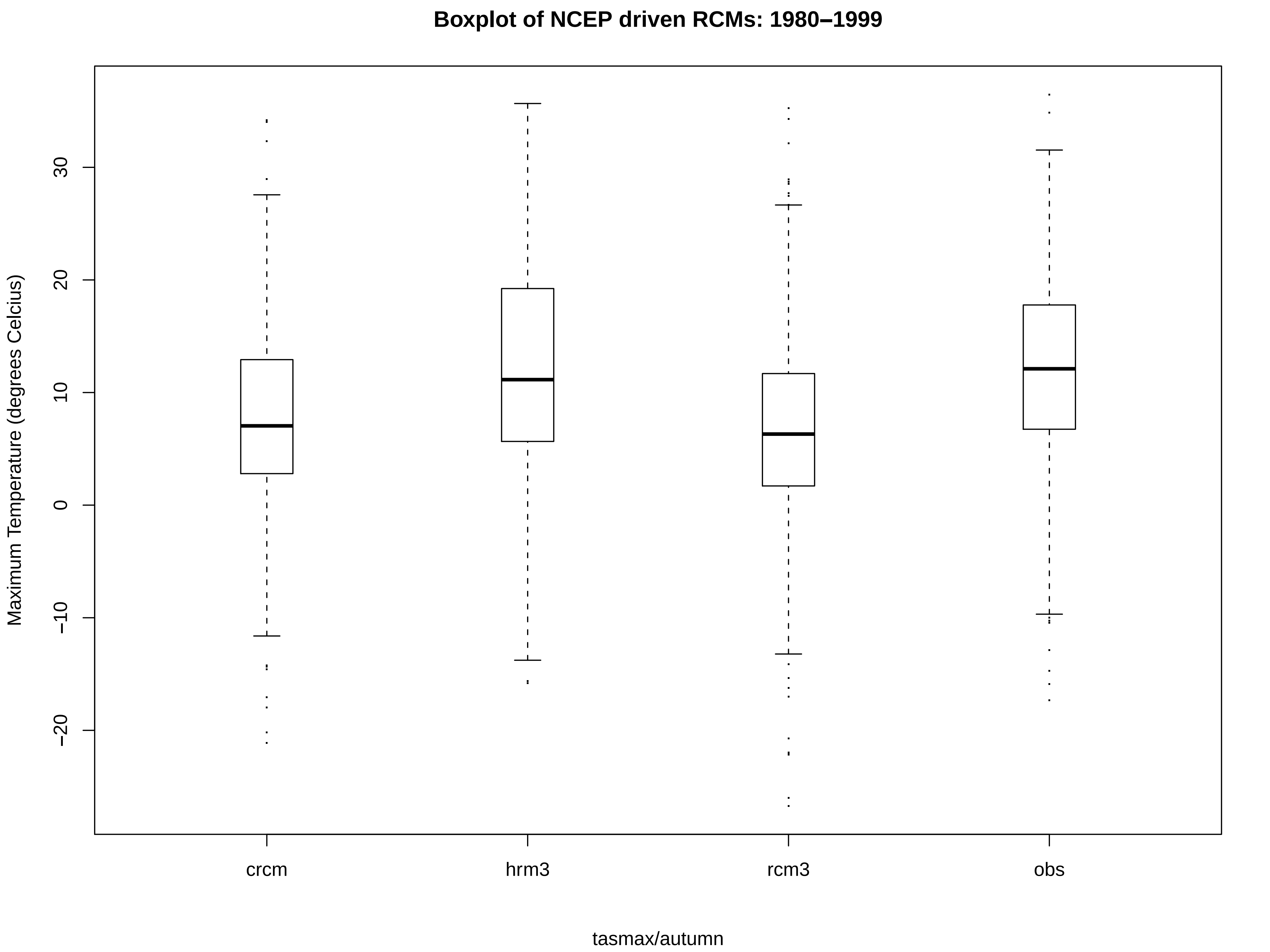

Boxplot of NCEP driven RCMs: 1980–1999
Mean Temperature (degrees Celcius)
40
20
0
−20
−40
crcm
hrm3
rcm3
tas/all


Boxplot of NCEP driven RCMs: 1980–1999
Maximum Temperature (degrees Celcius)
10
0
−10
−20
−30
crcm
hrm3
rcm3
obs
tasmax/winter

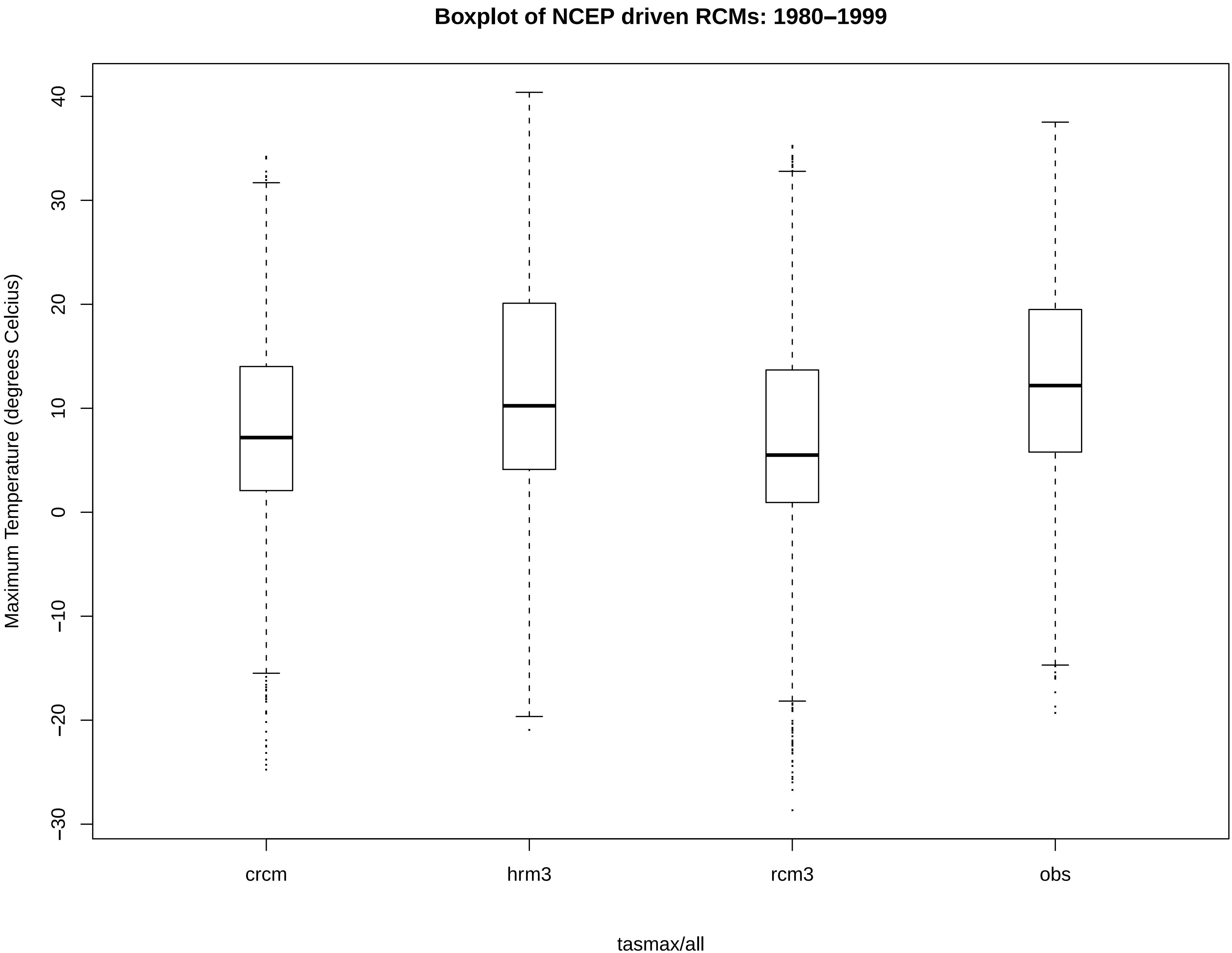


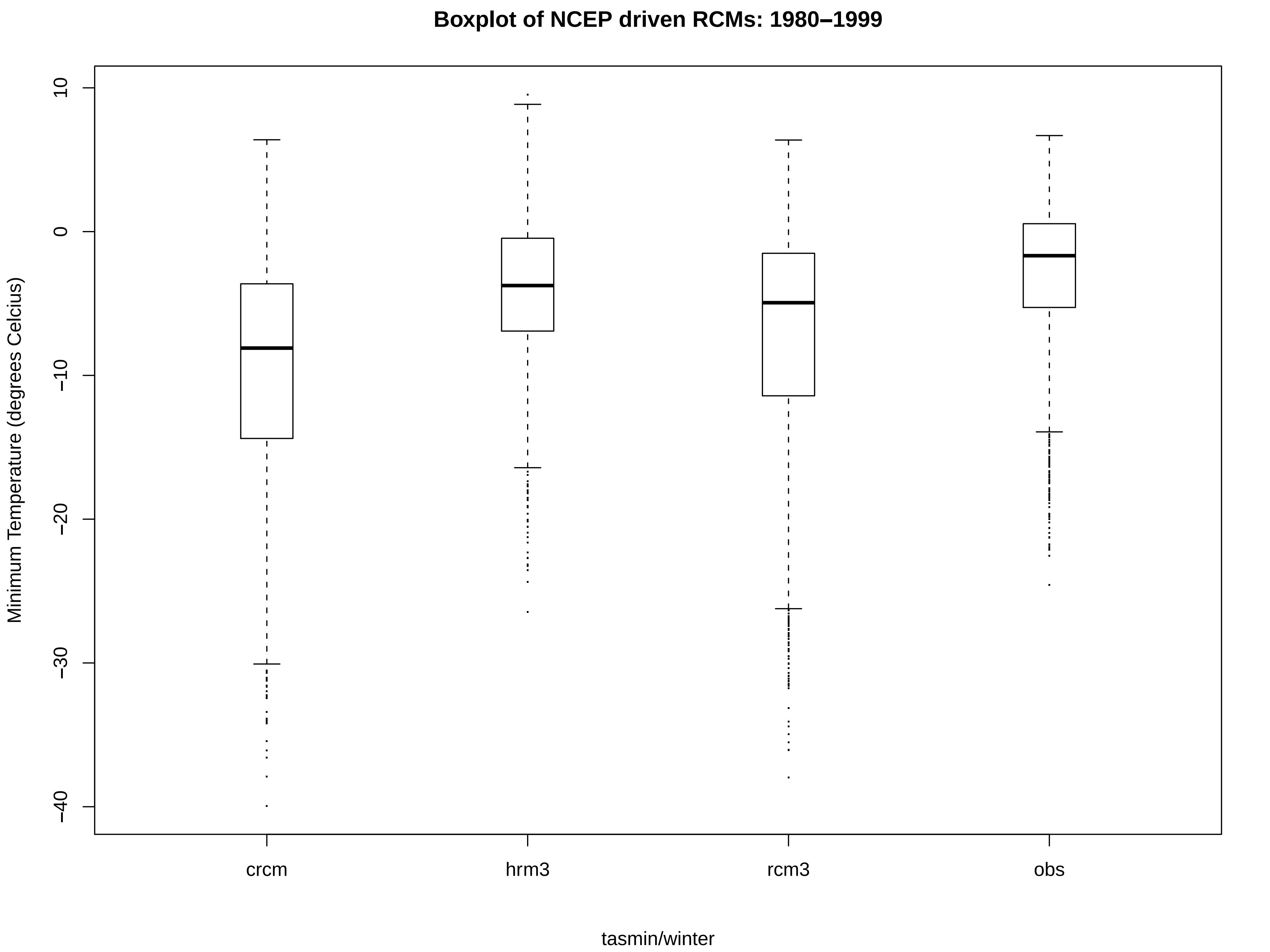
Boxplot of NCEP driven RCMs: 1980–1999
Maximum Temperature (degrees Celcius)
30
20
10
0
−10
crcm
hrm3
rcm3
obs
tasmax/spring

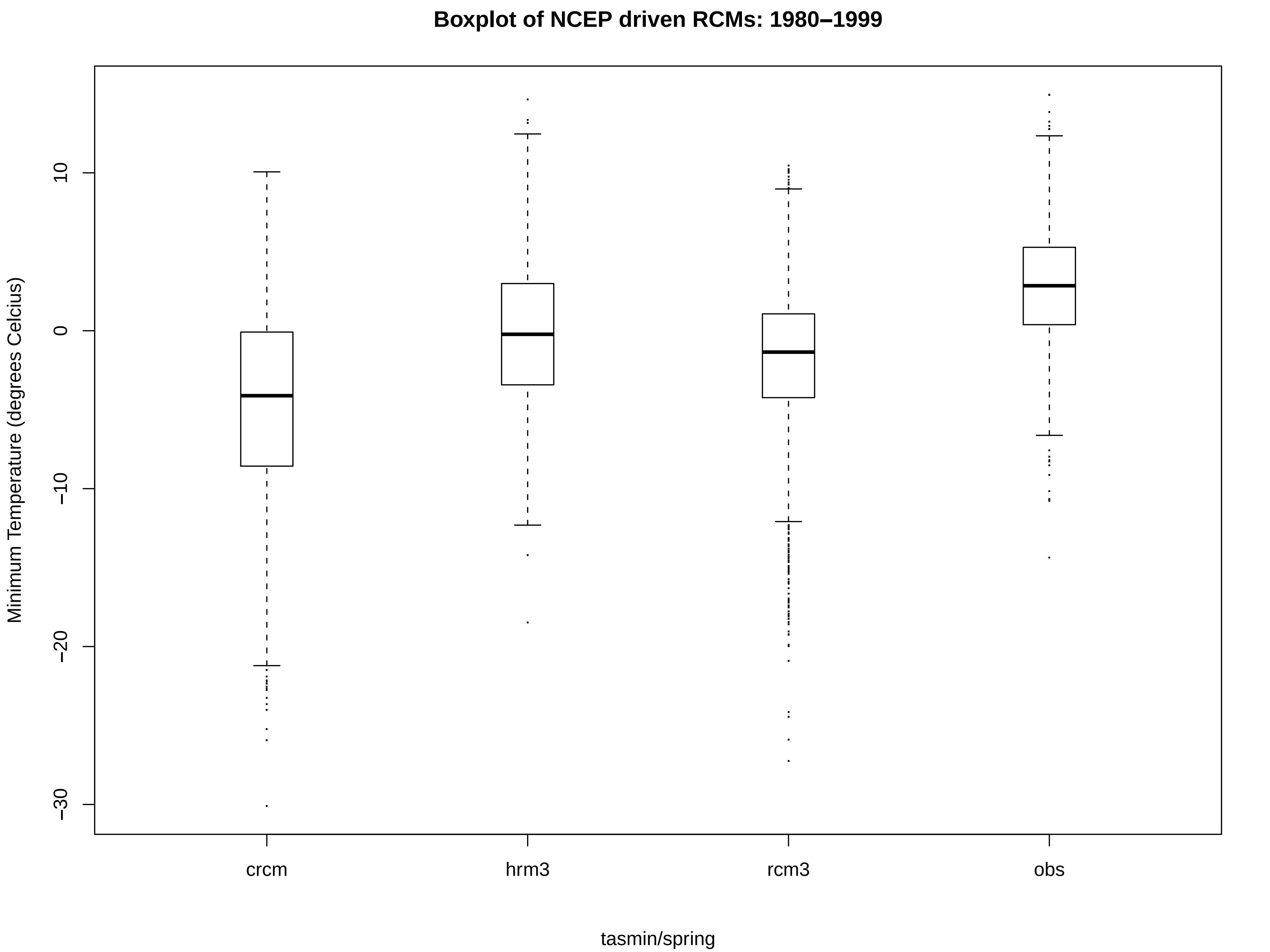

Boxplot of NCEP driven RCMs: 1980–1999
Maximum Temperature (degrees Celcius)
10
20
30
40
crcm
hrm3
rcm3
obs
tasmax/summer

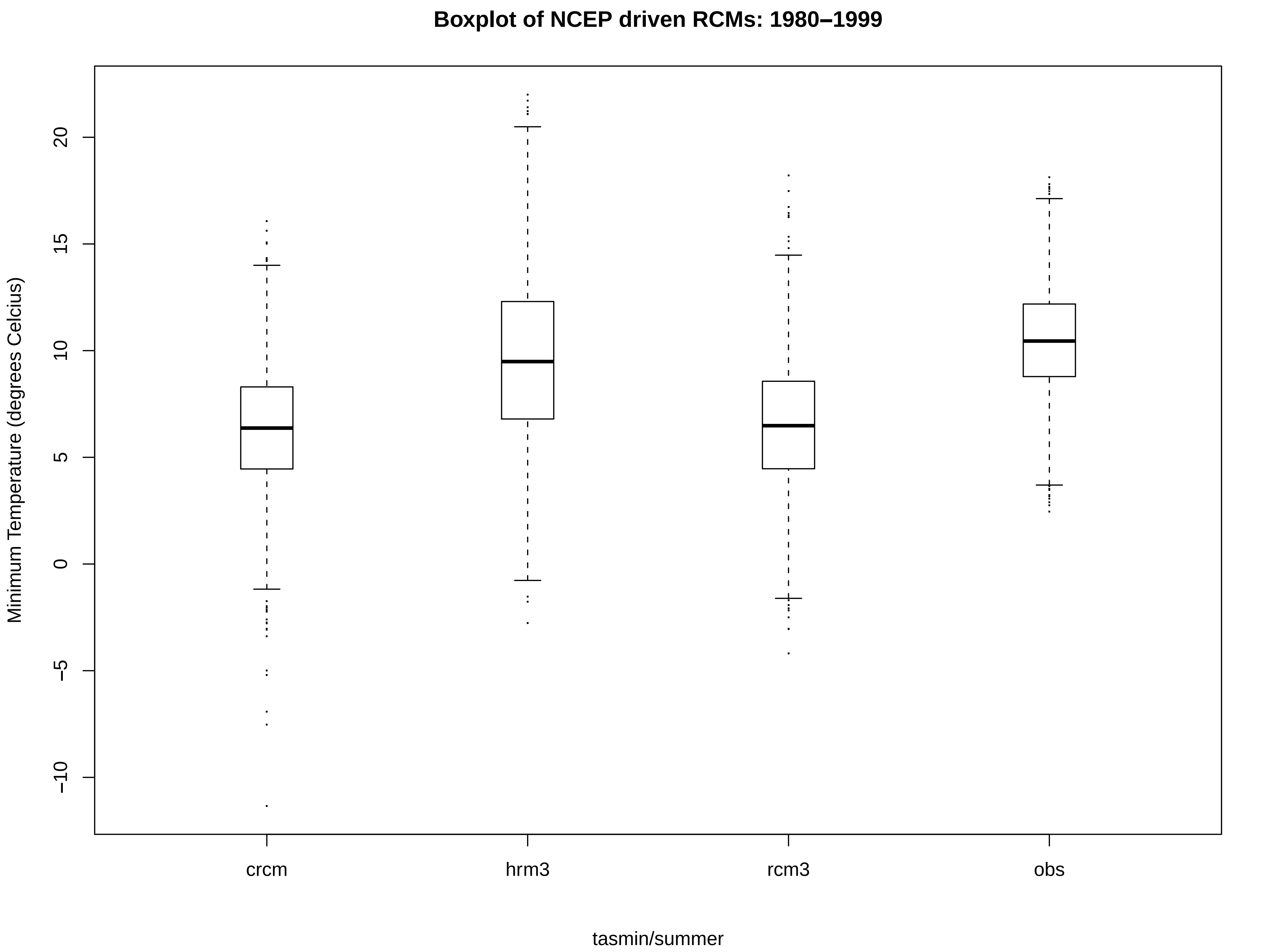


Boxplot of NCEP driven RCMs: 1980–1999
Maximum Temperature (degrees Celcius)
30
20
10
0
−10
−20
crcm
hrm3
rcm3
obs
tasmax/autumn

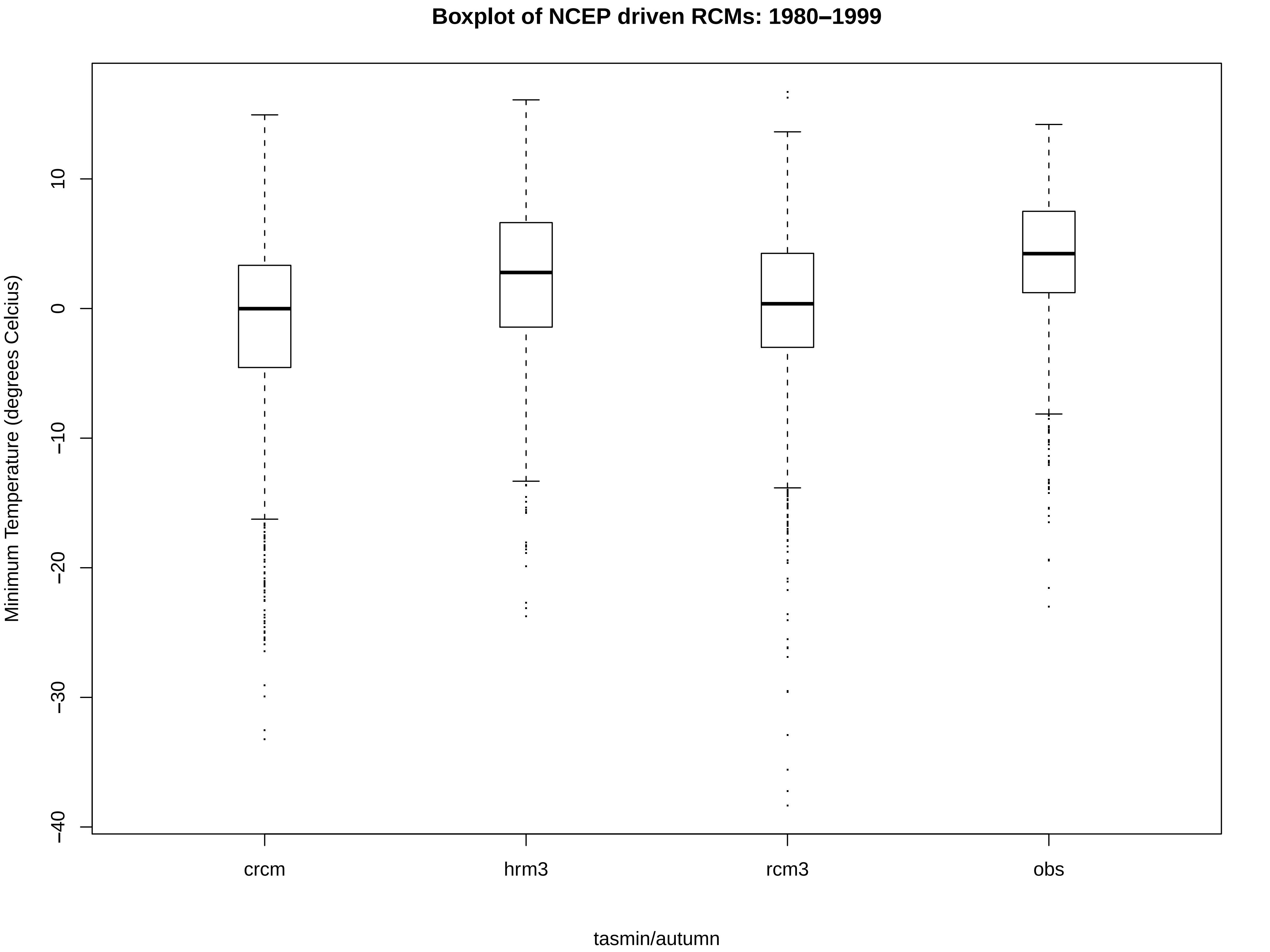

Boxplot of NCEP driven RCMs: 1980–1999
Maximum Temperature (degrees Celcius)
40
30
20
10
0
−10
−20
−30
crcm
hrm3
rcm3
obs
tasmax/all


Boxplot of NCEP driven RCMs: 1980–1999
Minimum Temperature (degrees Celcius)
10
0
−10
−20
−30
−40
crcm
hrm3
rcm3
obs
tasmin/winter

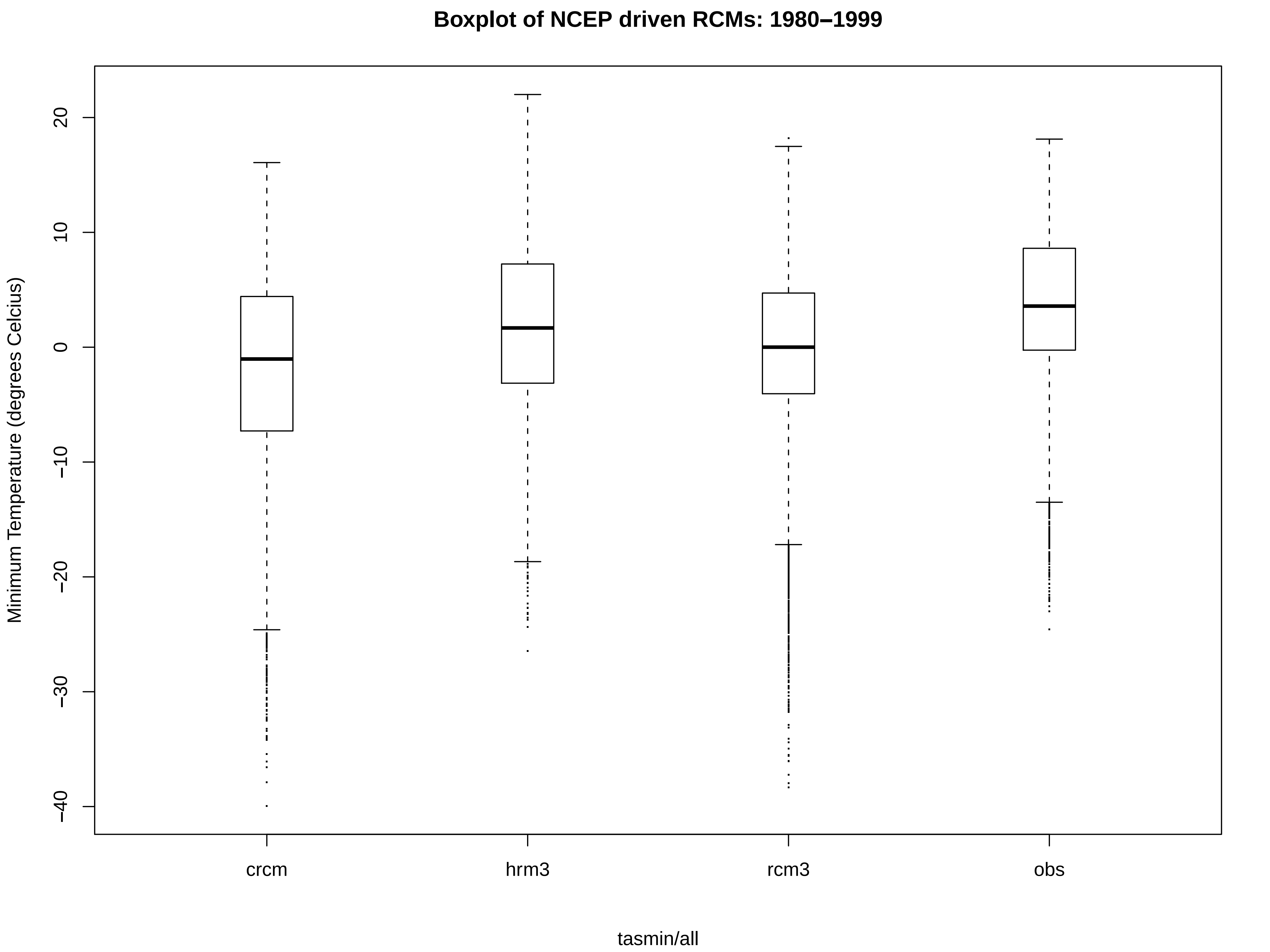

Boxplot of NCEP driven RCMs: 1980–1999
Minimum Temperature (degrees Celcius)
10
0
−10
−20
−30
crcm
hrm3
rcm3
obs
tasmin/spring

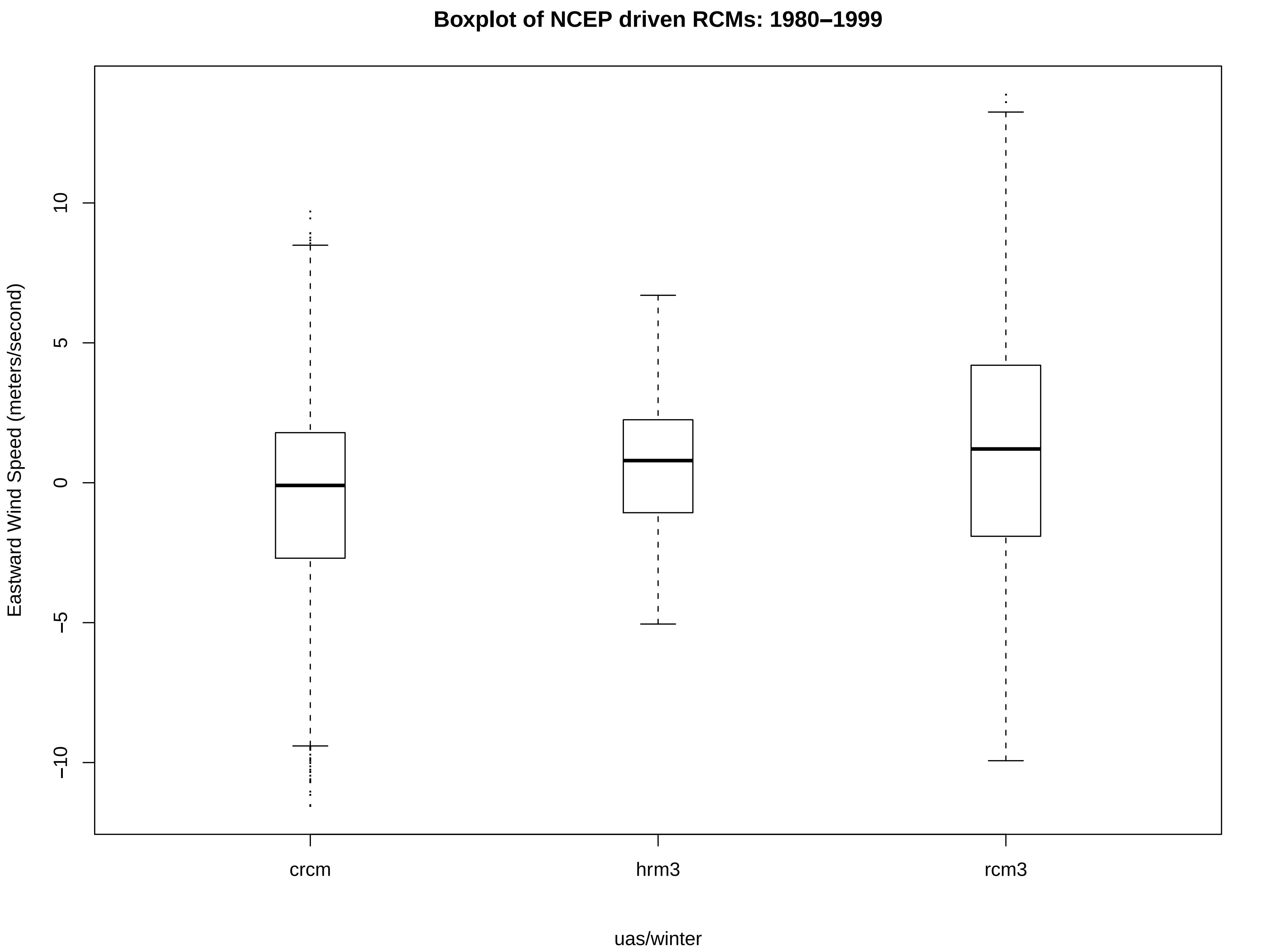


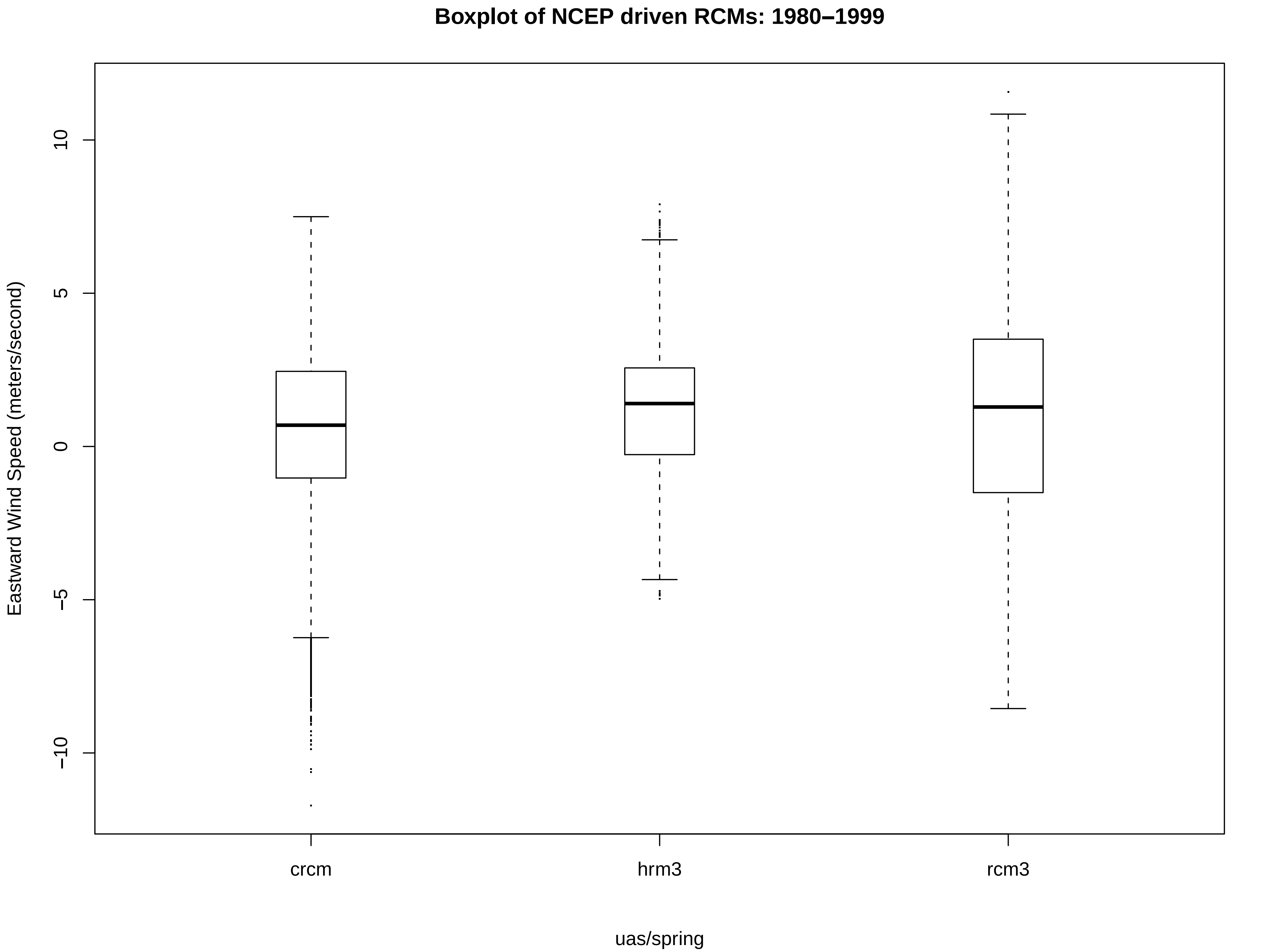
Boxplot of NCEP driven RCMs: 1980–1999
Minimum Temperature (degrees Celcius)
20
15
10
5
0
−5
−10
crcm
hrm3
rcm3
obs
tasmin/summer



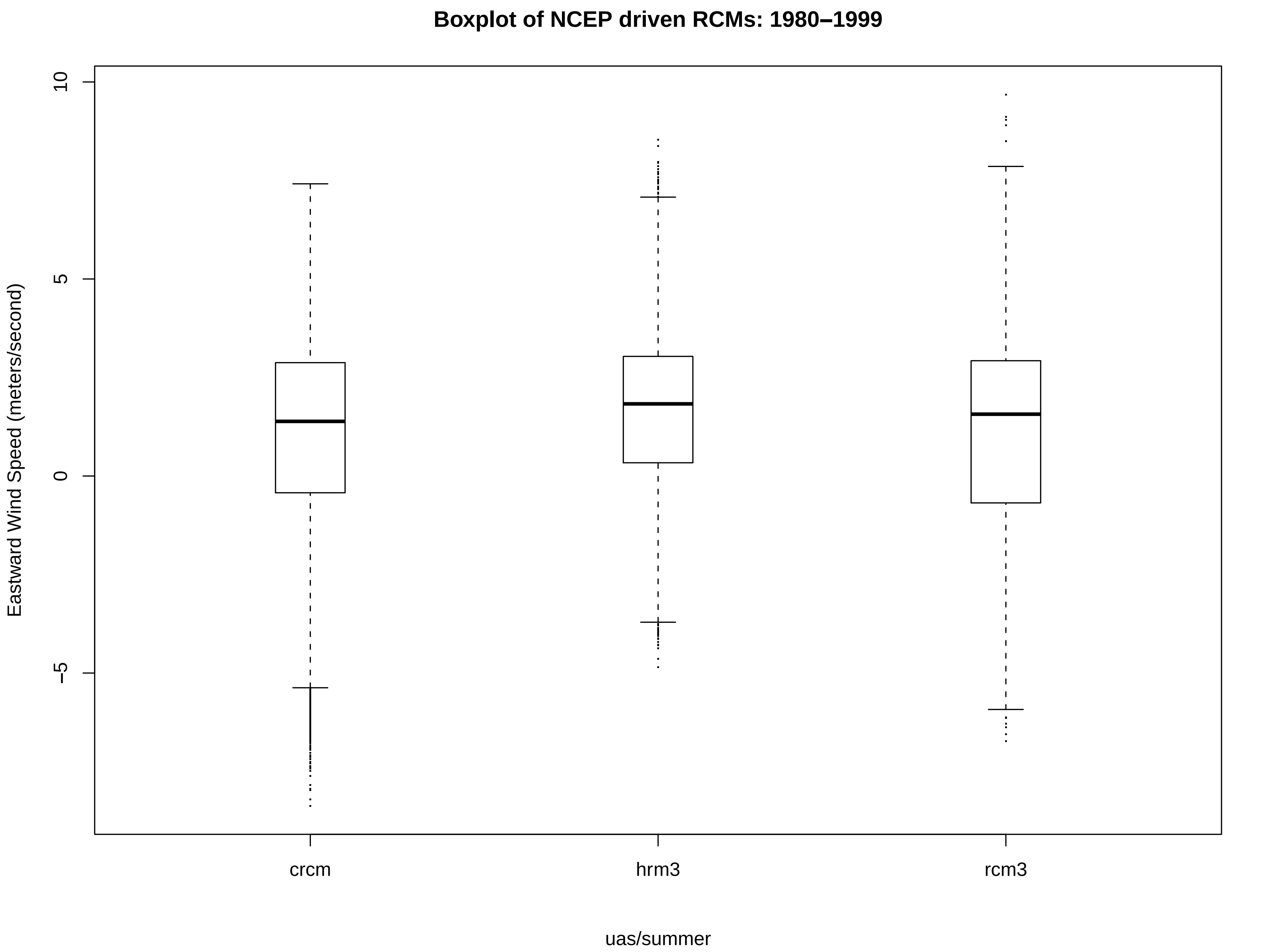
Boxplot of NCEP driven RCMs: 1980–1999
Minimum Temperature (degrees Celcius)
10
0
−10
−20
−30
−40
crcm
hrm3
rcm3
obs
tasmin/autumn

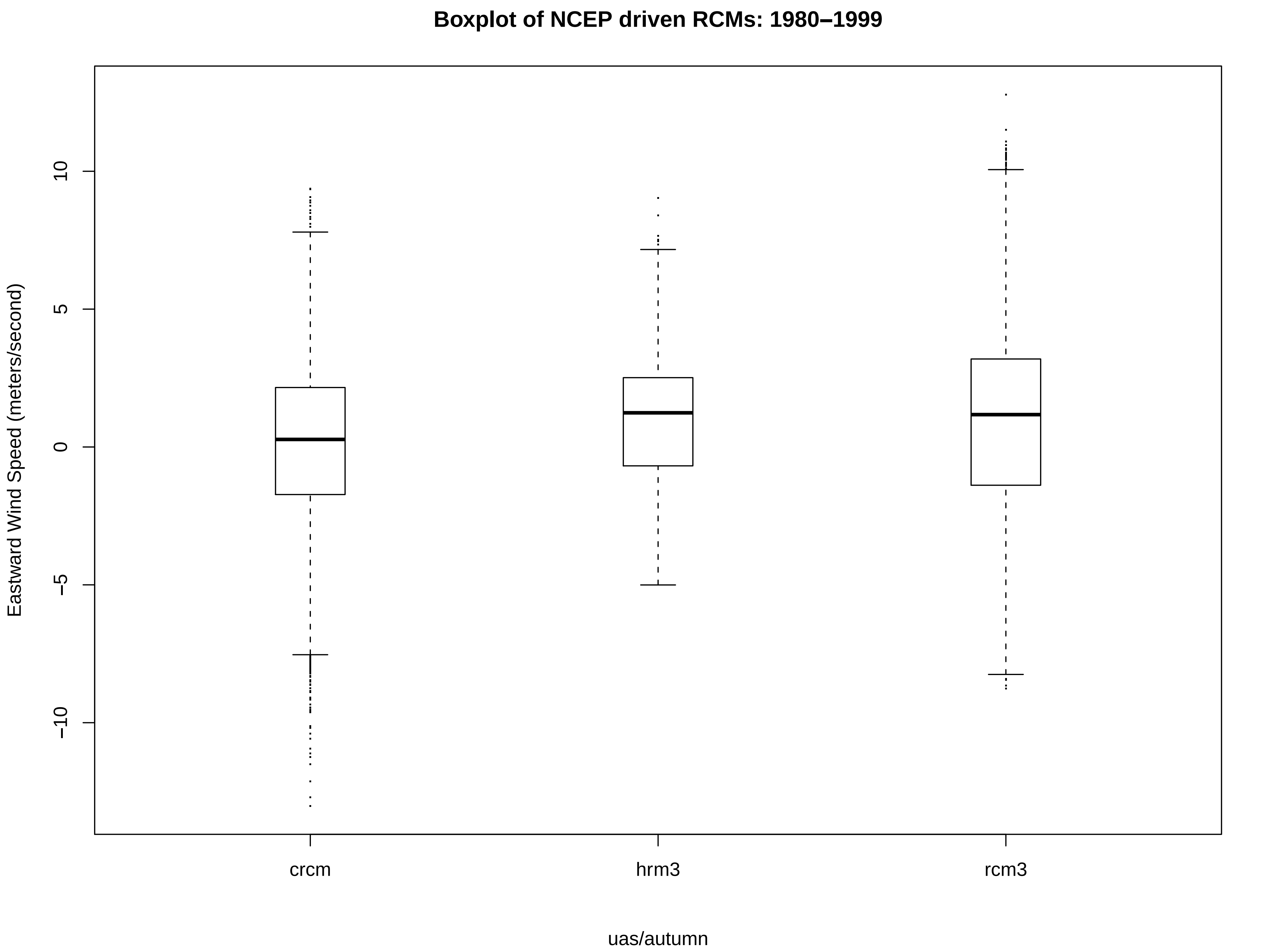

Boxplot of NCEP driven RCMs: 1980–1999
Minimum Temperature (degrees Celcius)
20
10
0
−10
−20
−30
−40
crcm
hrm3
rcm3
obs
tasmin/all

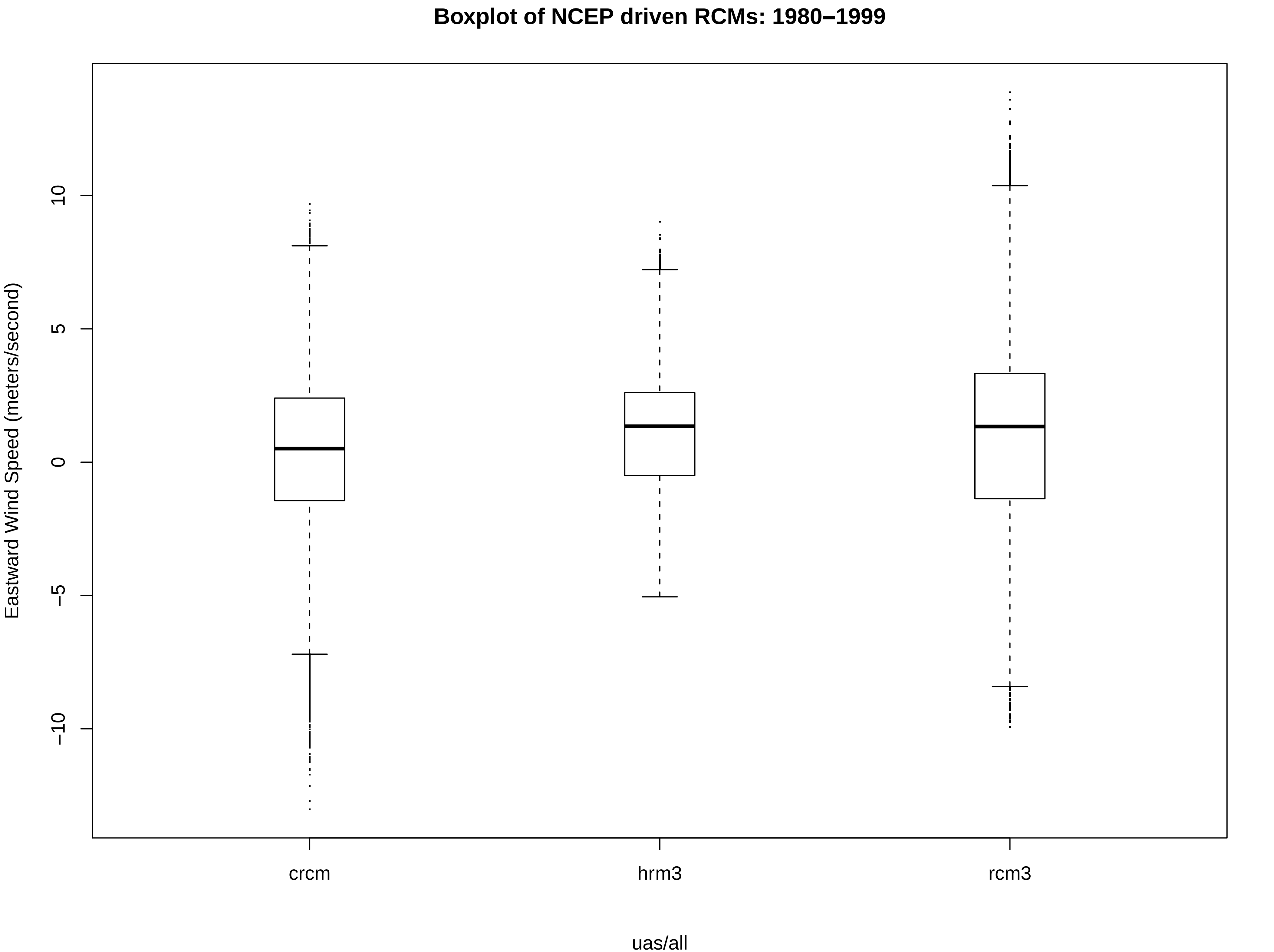

Boxplot of NCEP driven RCMs: 1980–1999
Eastward Wind Speed (meters/second)
10
5
0
−5
−10
crcm
hrm3
rcm3
uas/winter



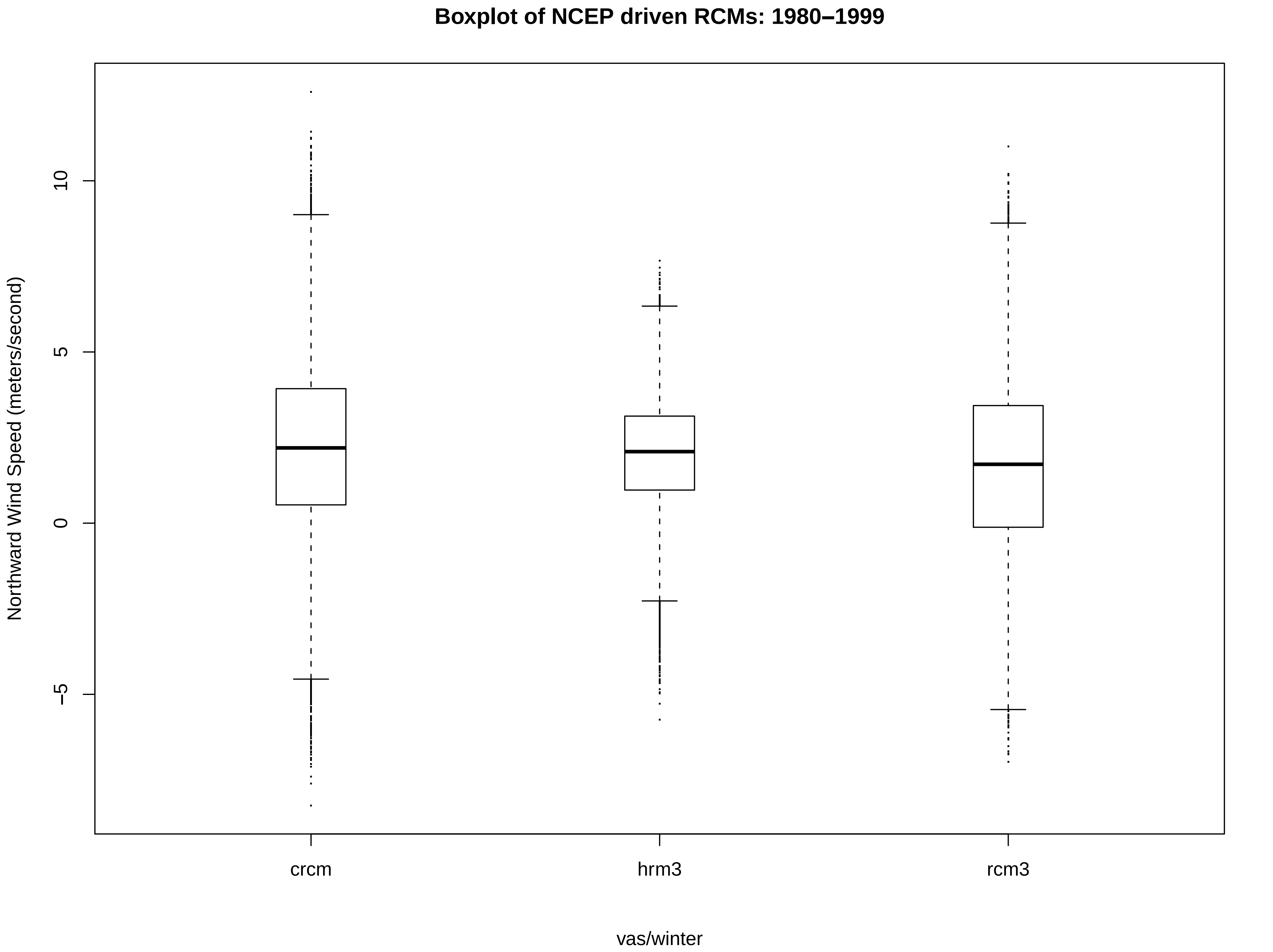
Boxplot of NCEP driven RCMs: 1980–1999
Eastward Wind Speed (meters/second)
10
5
0
−5
−10
crcm
hrm3
rcm3
uas/spring


Boxplot of NCEP driven RCMs: 1980–1999
Eastward Wind Speed (meters/second)
10
5
0
−5
crcm
hrm3
rcm3
uas/summer

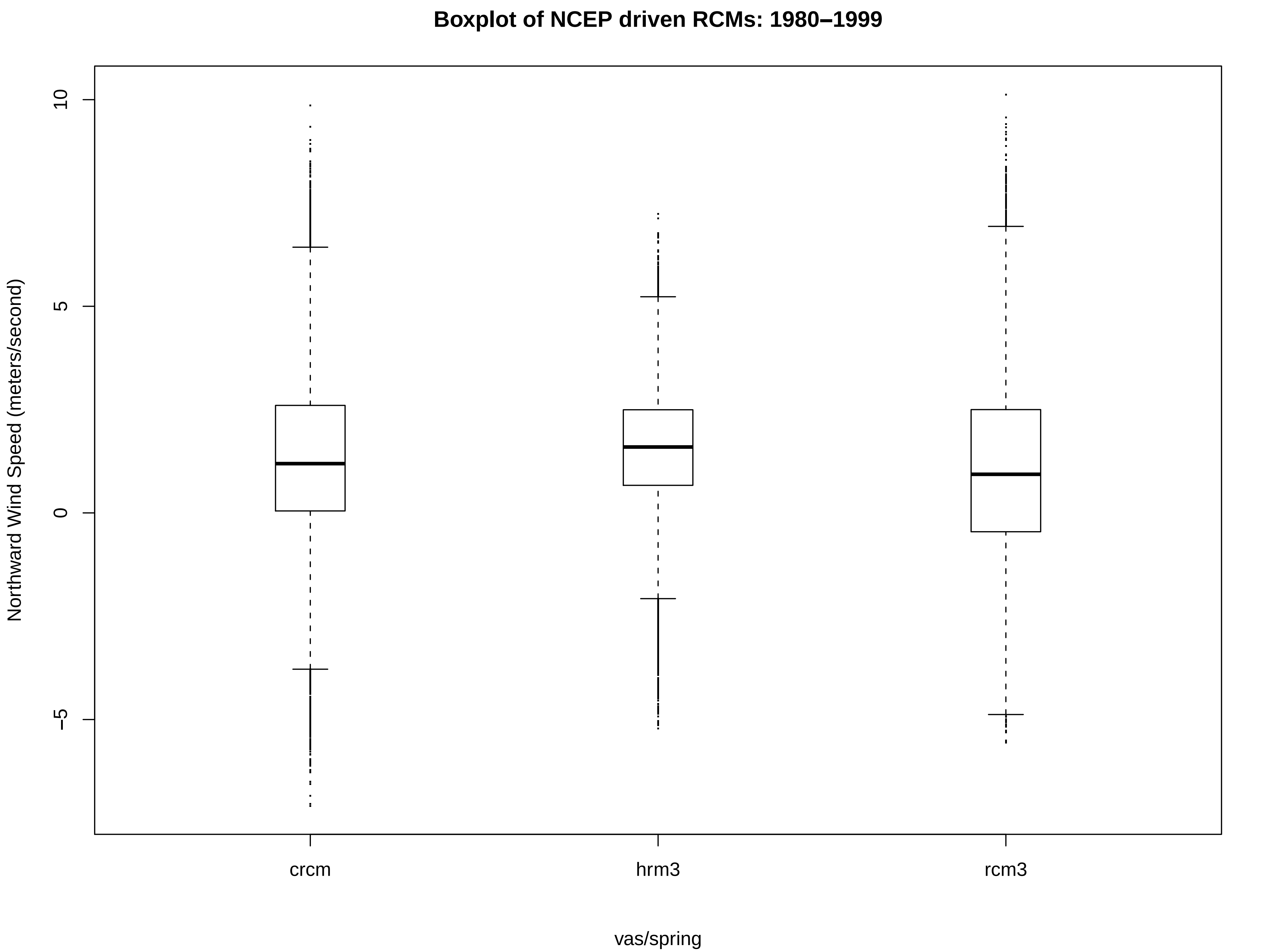

Boxplot of NCEP driven RCMs: 1980–1999
Eastward Wind Speed (meters/second)
10
5
0
−5
−10
crcm
hrm3
rcm3
uas/autumn

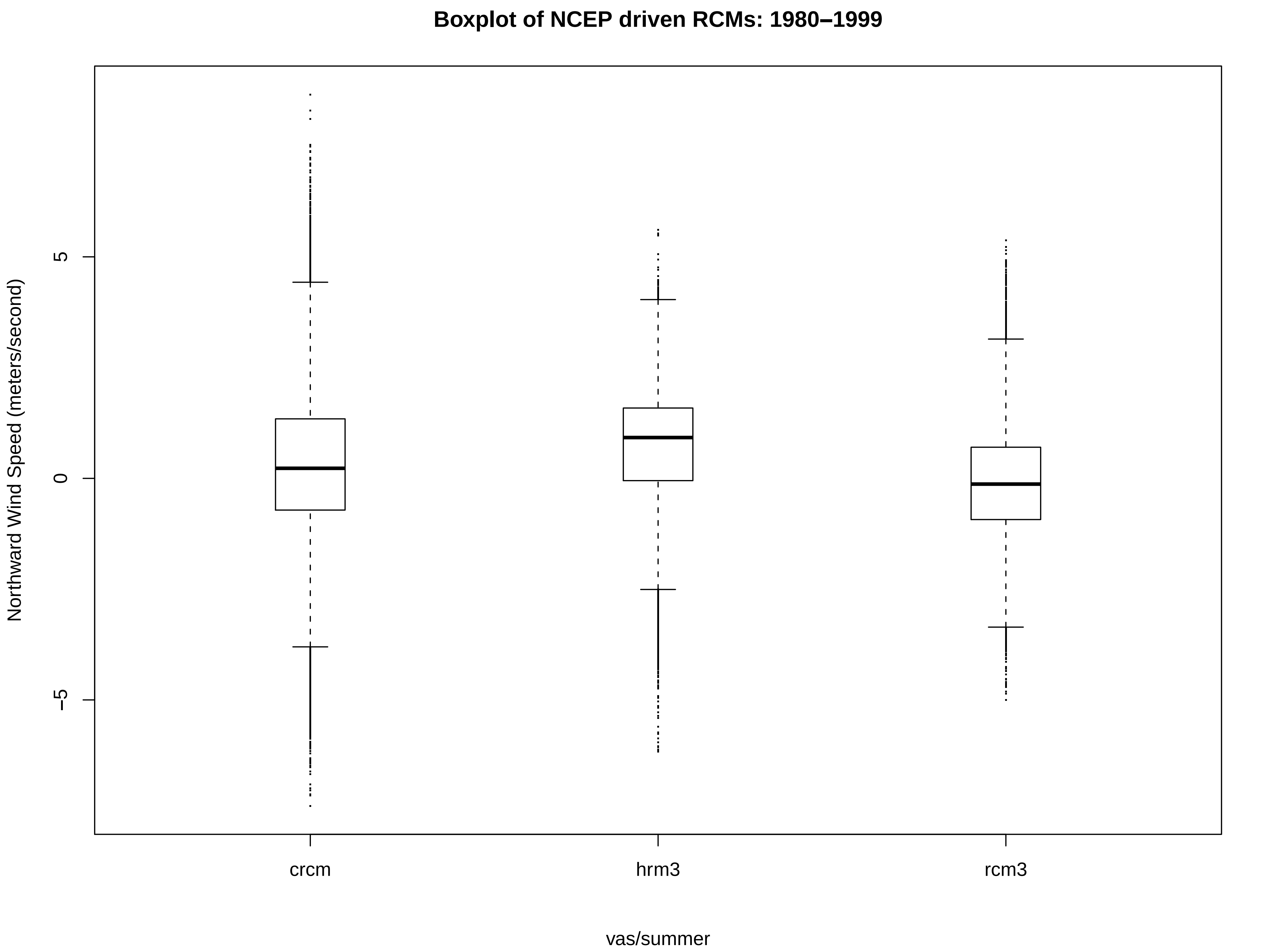


Boxplot of NCEP driven RCMs: 1980–1999
Eastward Wind Speed (meters/second)
10
5
0
−5
−10
crcm
hrm3
rcm3
uas/all

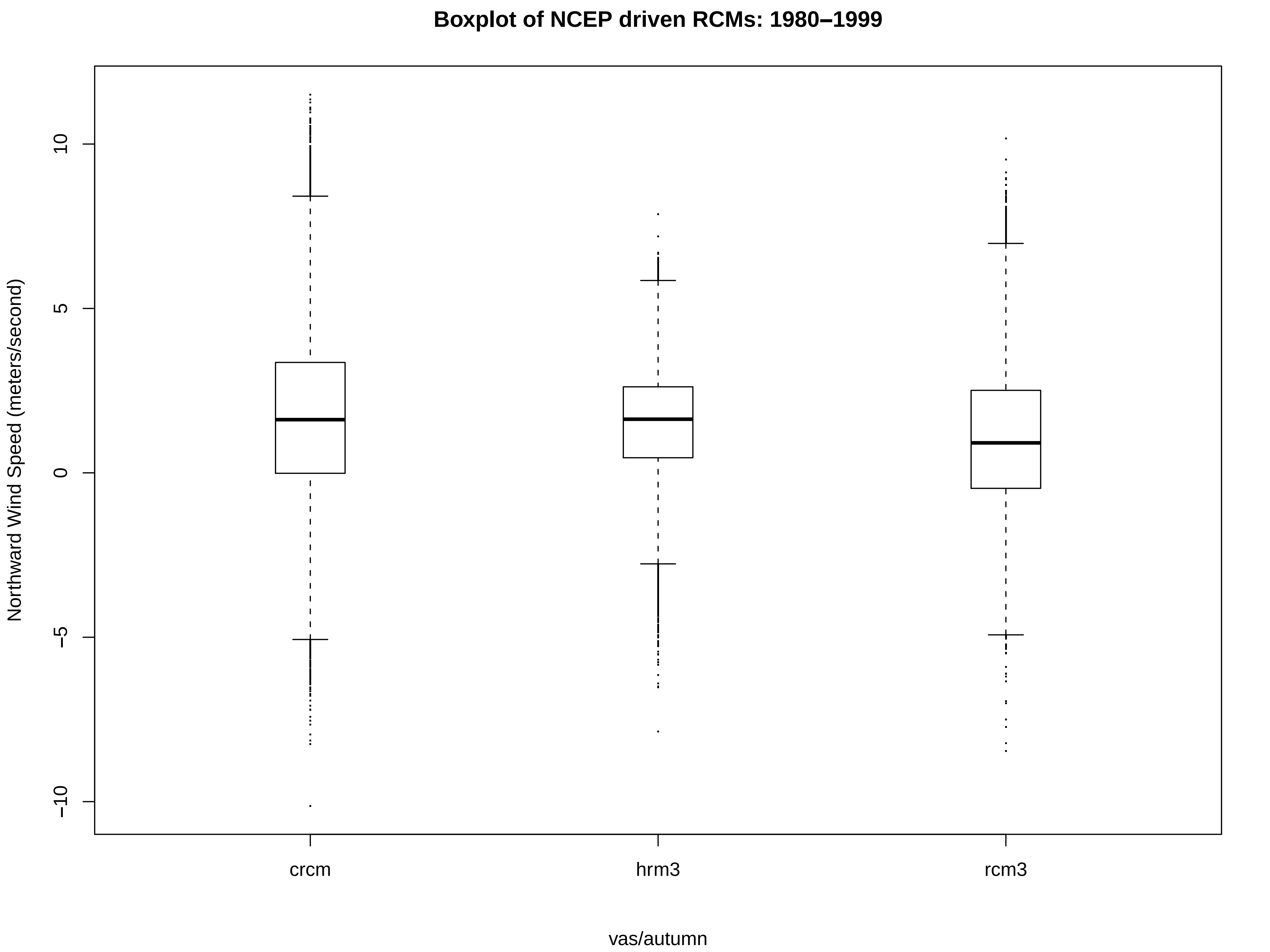


Boxplot of NCEP driven RCMs: 1980–1999
Northward Wind Speed (meters/second)
10
5
0
−5
crcm
hrm3
rcm3
vas/winter

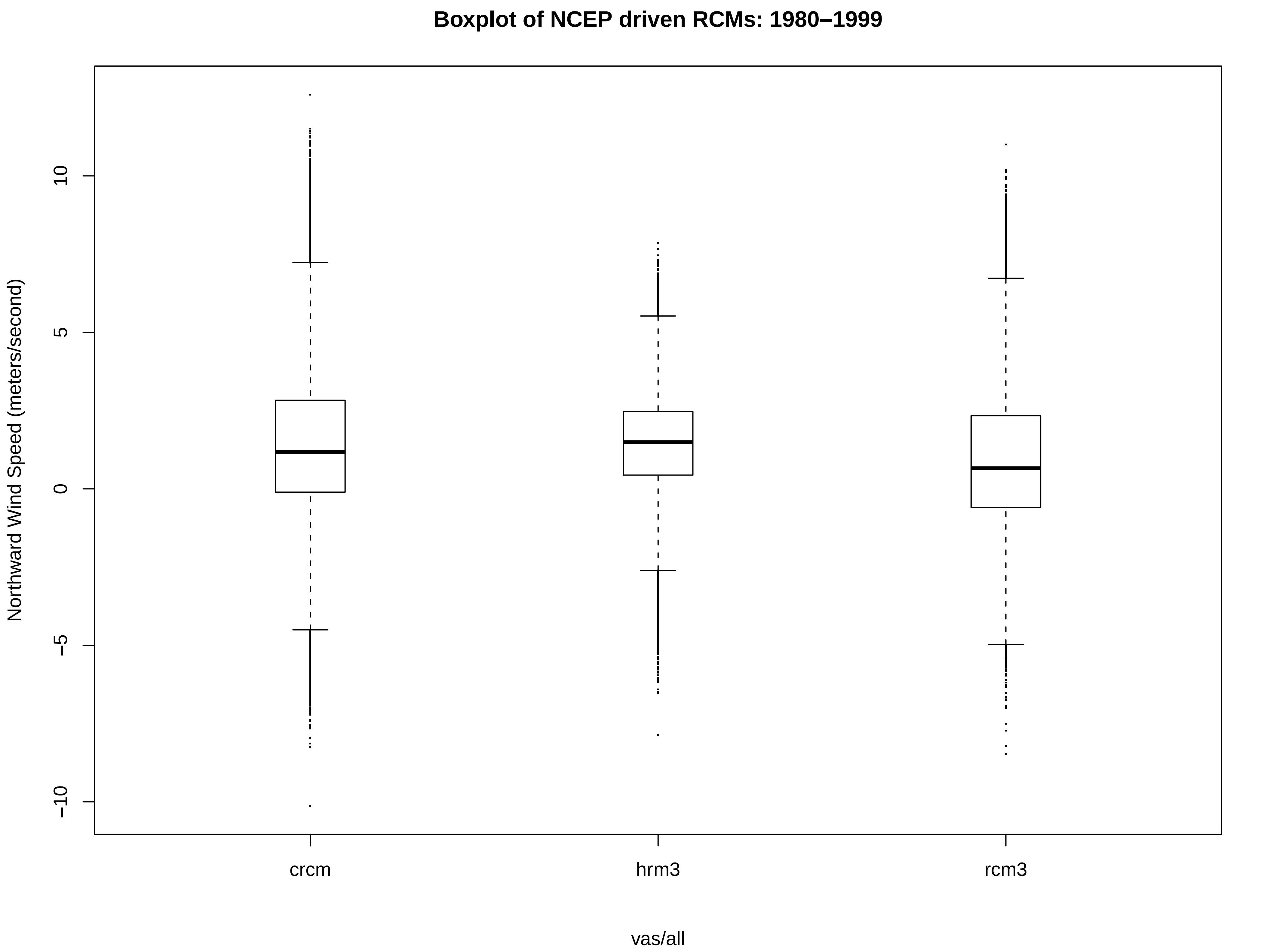

Boxplot of NCEP driven RCMs: 1980–1999
Northward Wind Speed (meters/second)
10
5
0
−5
crcm
hrm3
rcm3
vas/spring

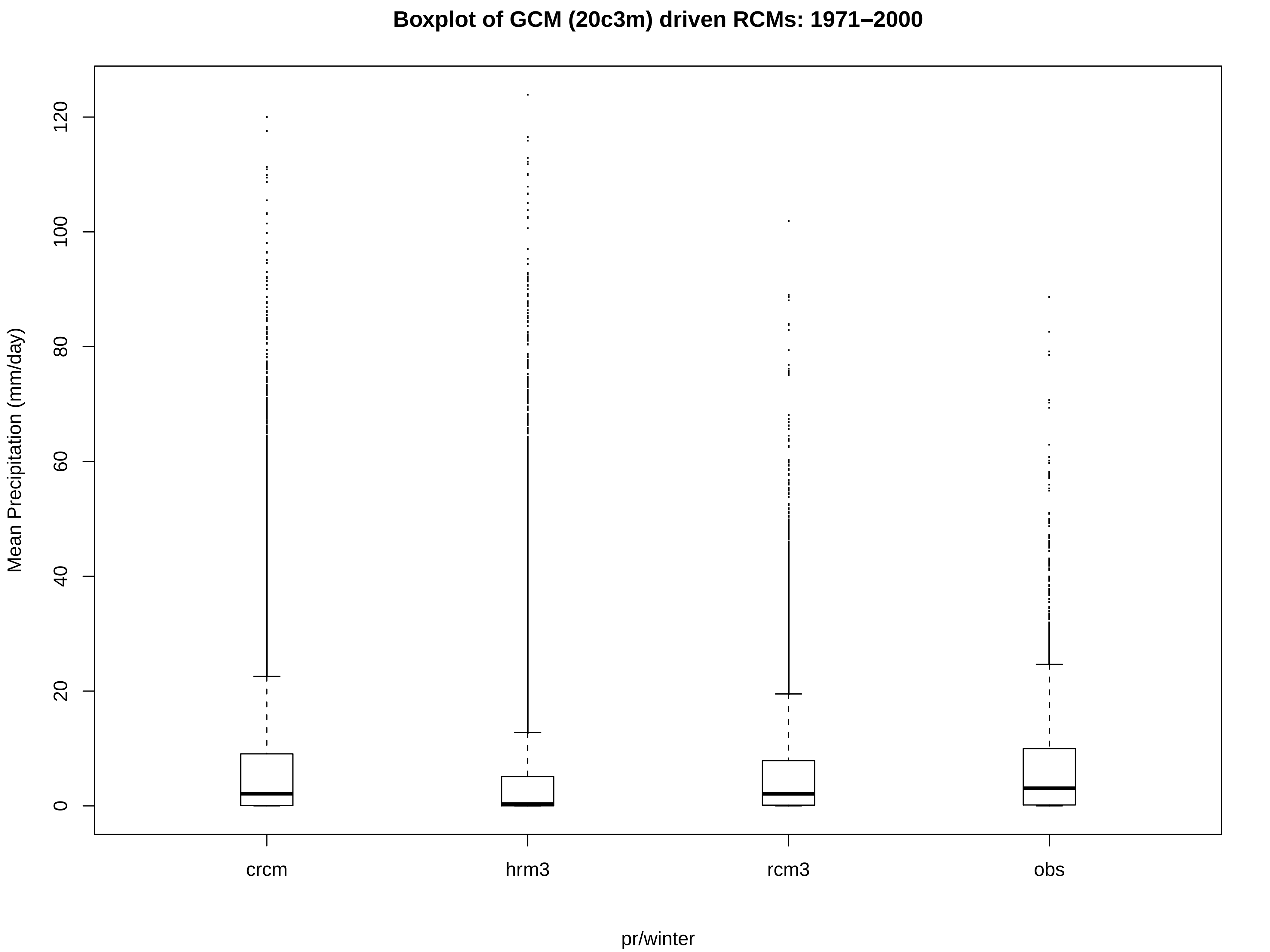


Boxplot of NCEP driven RCMs: 1980–1999
Northward Wind Speed (meters/second)
5
0
−5
crcm
hrm3
rcm3
vas/summer

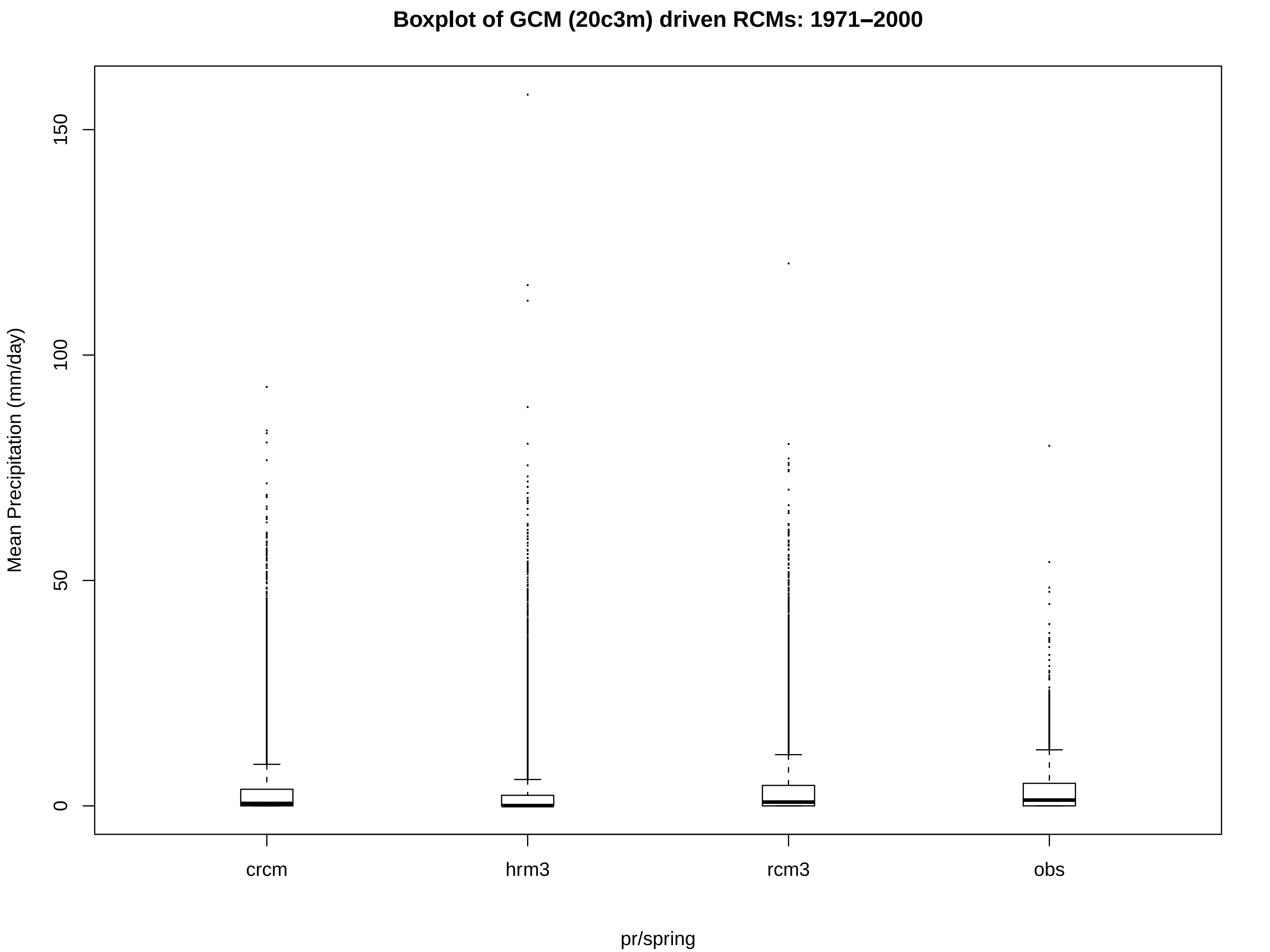


Boxplot of NCEP driven RCMs: 1980–1999
Northward Wind Speed (meters/second)
10
5
0
−5
−10
crcm
hrm3
rcm3
vas/autumn

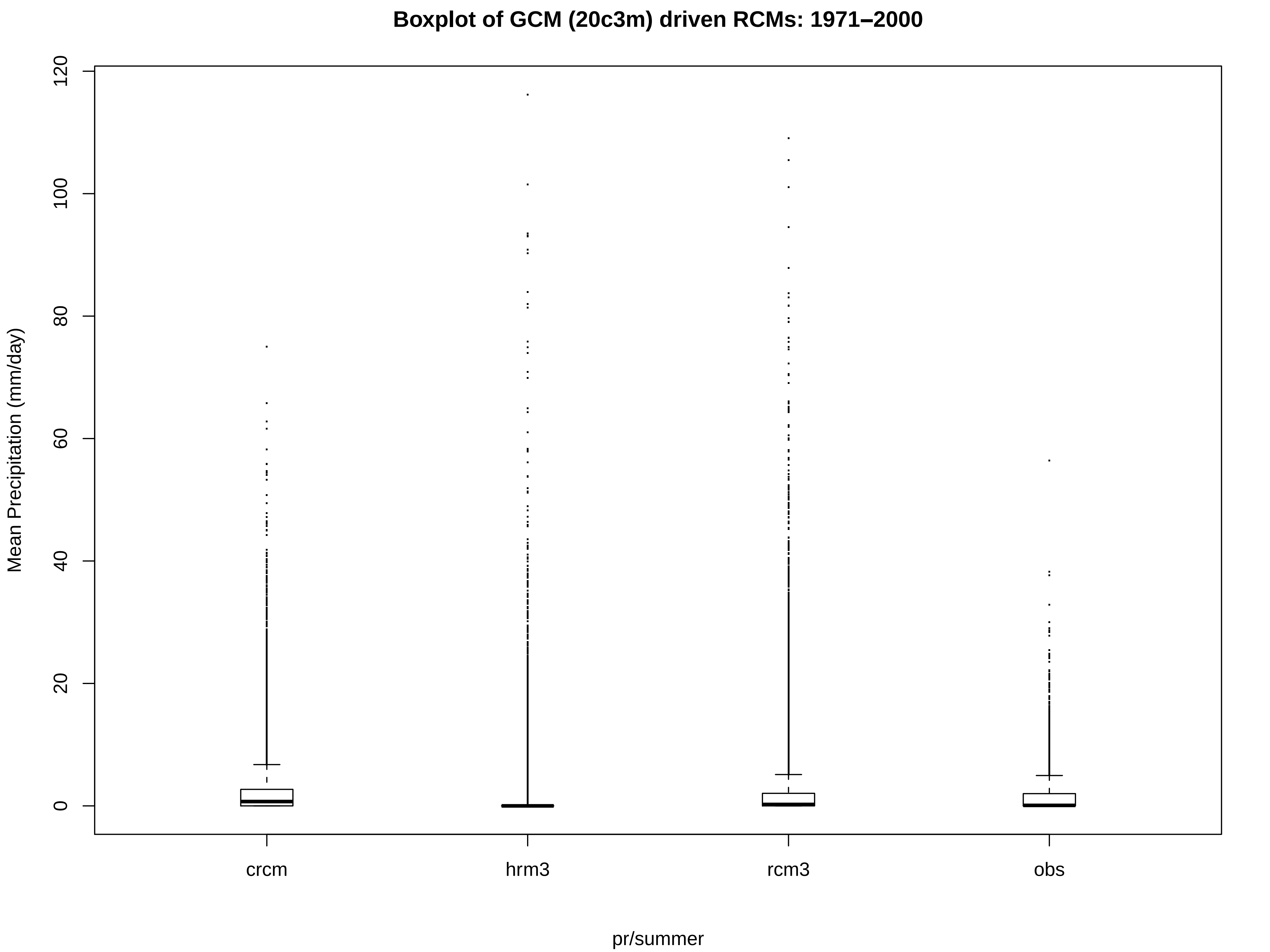

Boxplot of NCEP driven RCMs: 1980–1999
Northward Wind Speed (meters/second)
10
5
0
−5
−10
crcm
hrm3
rcm3
vas/all

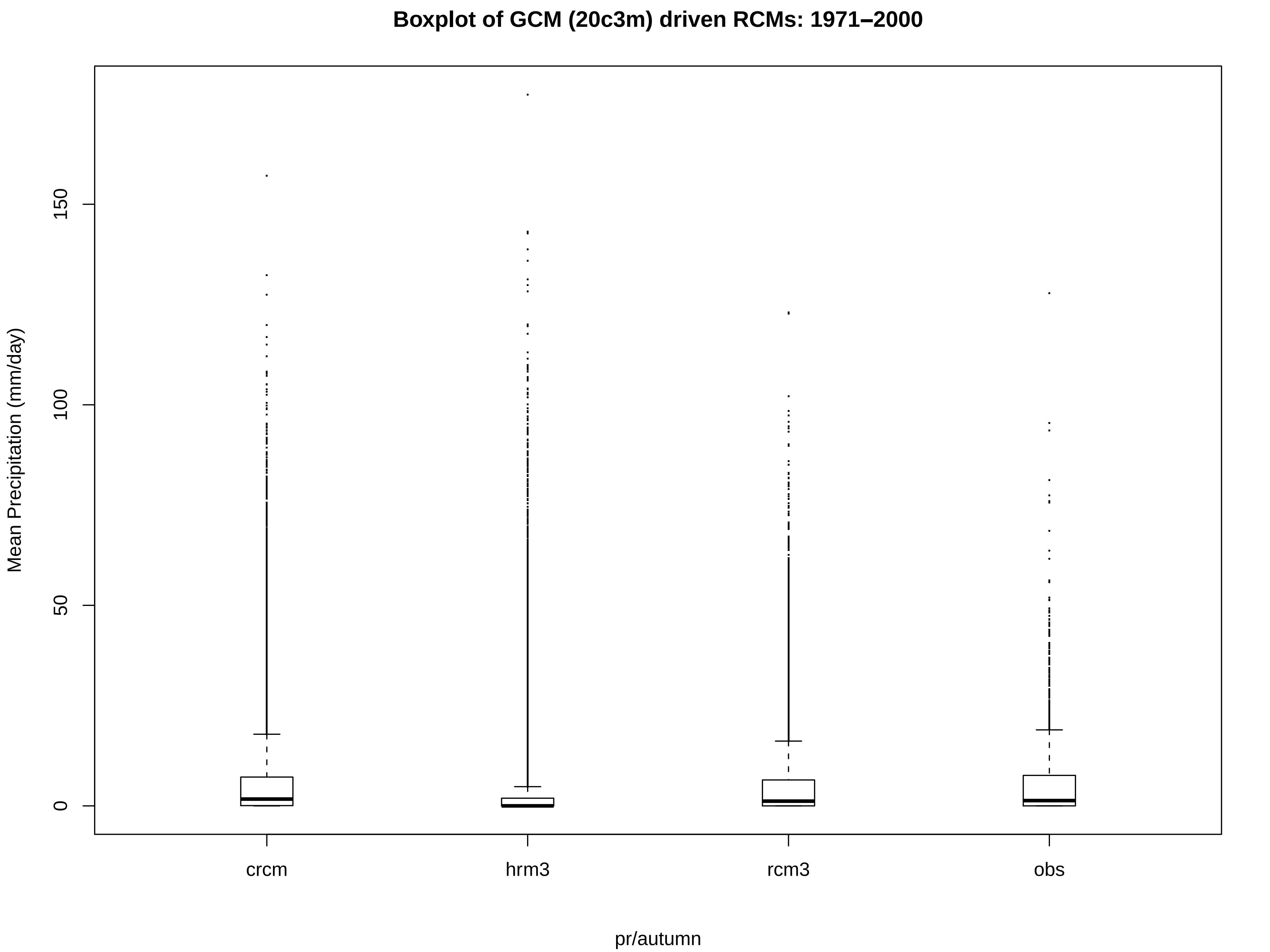


Boxplot of GCM (20c3m) driven RCMs: 1971–2000
Mean Precipitation (mm/day)
0
20
40
60
80
100
120
crcm
hrm3
rcm3
obs
pr/winter

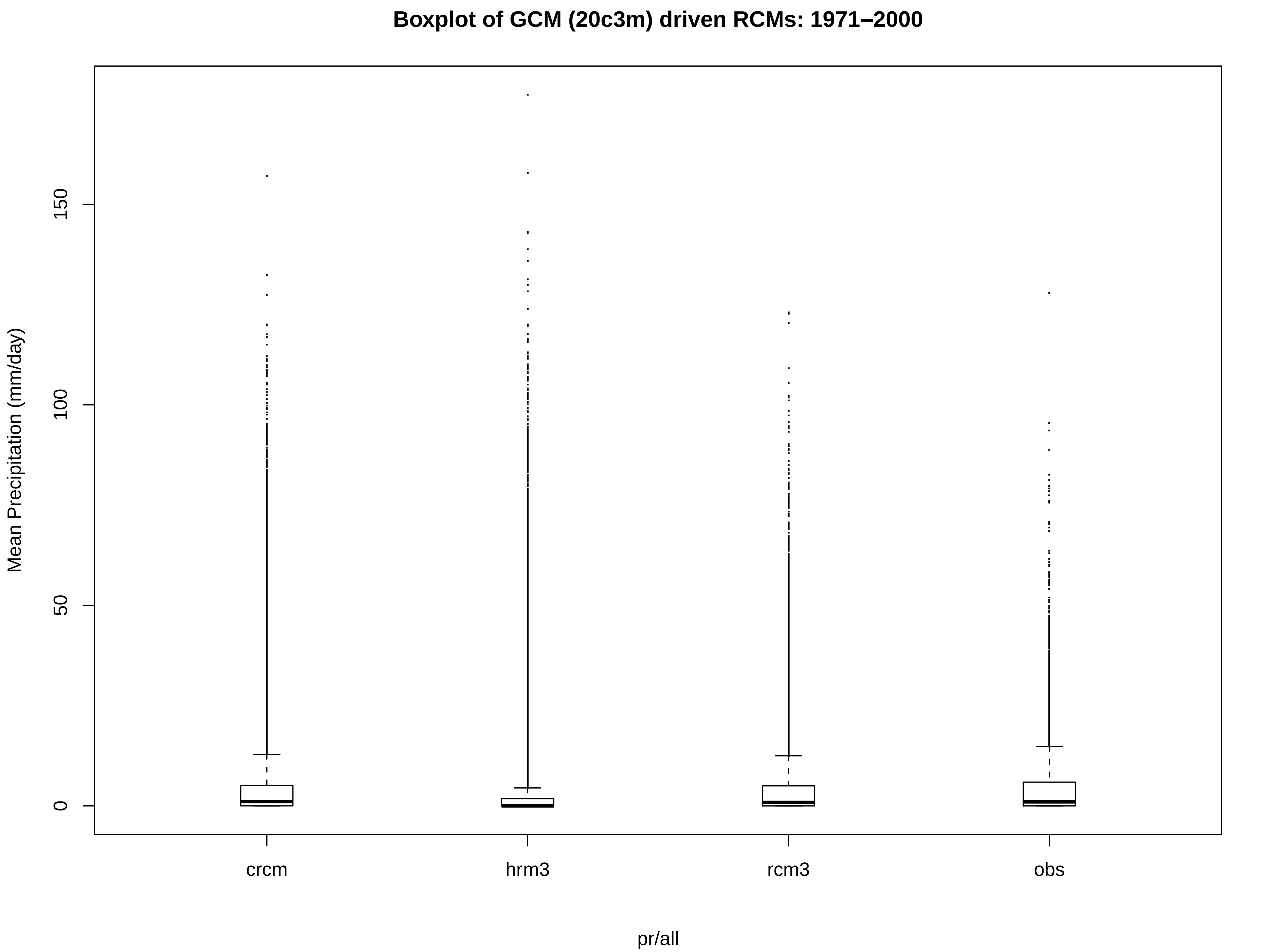


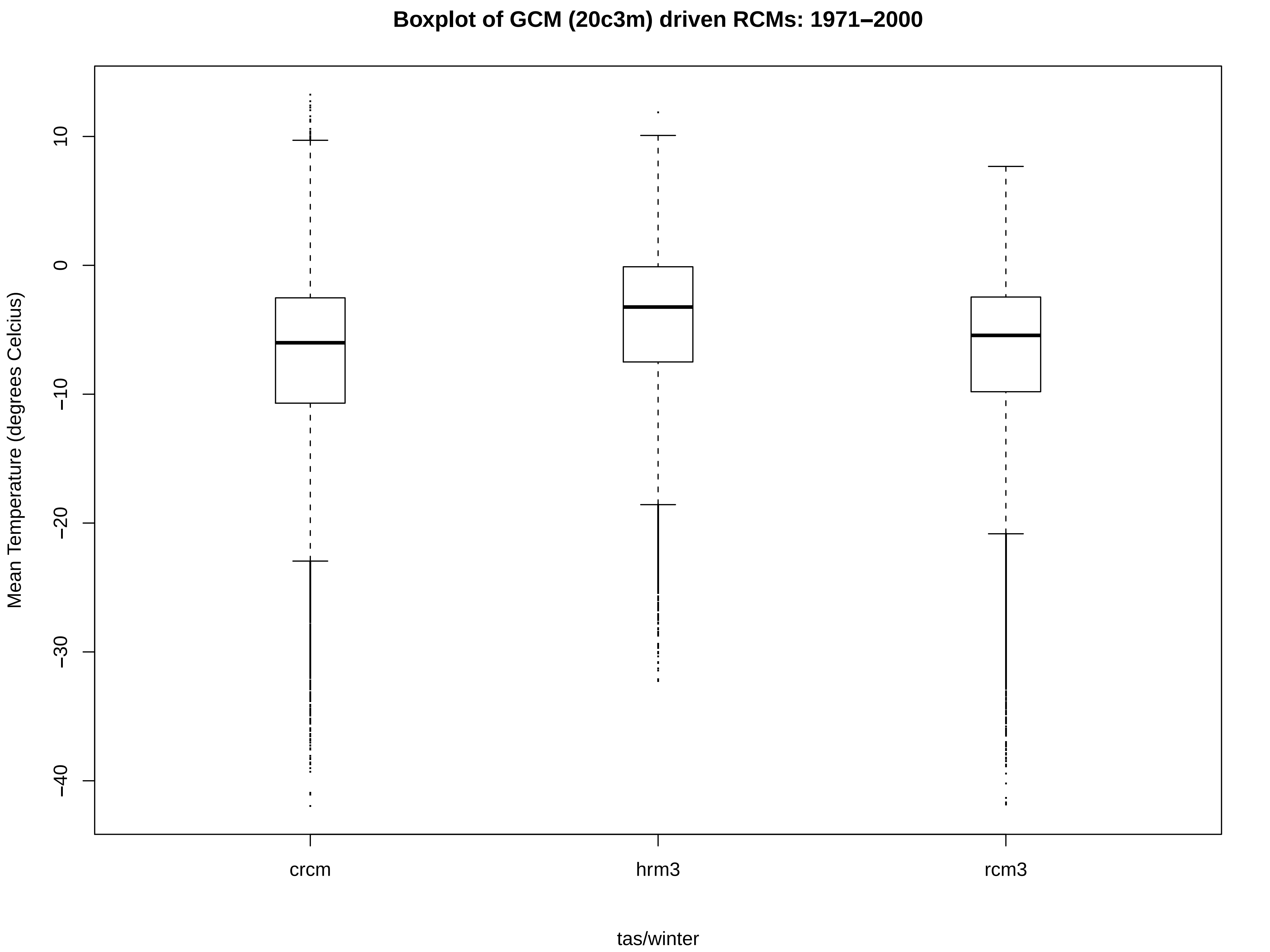
Boxplot of GCM (20c3m) driven RCMs: 1971–2000
Mean Precipitation (mm/day)
0
50
100
150
crcm
hrm3
rcm3
obs
pr/spring

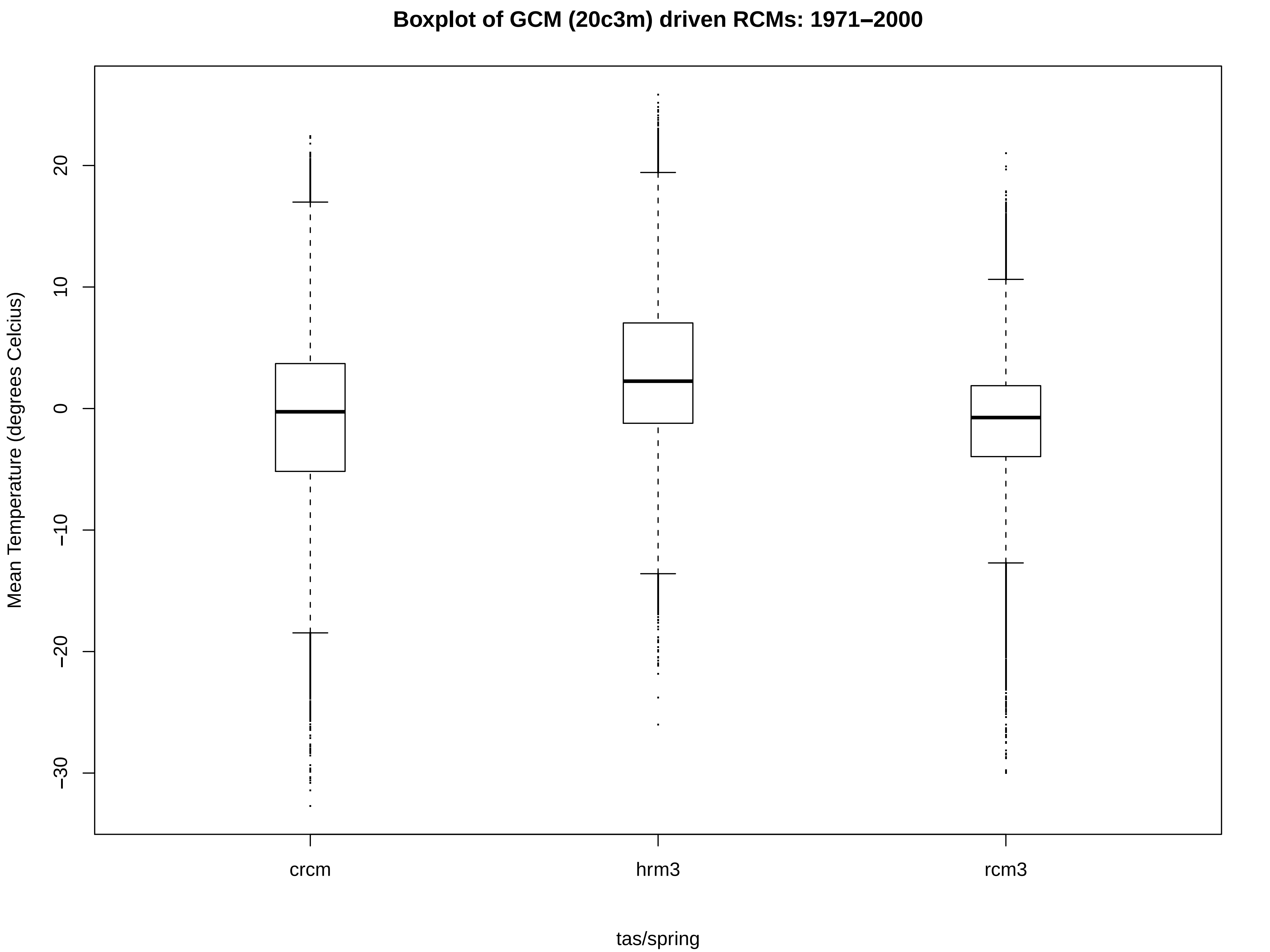

Boxplot of GCM (20c3m) driven RCMs: 1971–2000
Mean Precipitation (mm/day)
0
20
40
60
80
100
120
crcm
hrm3
rcm3
obs
pr/summer

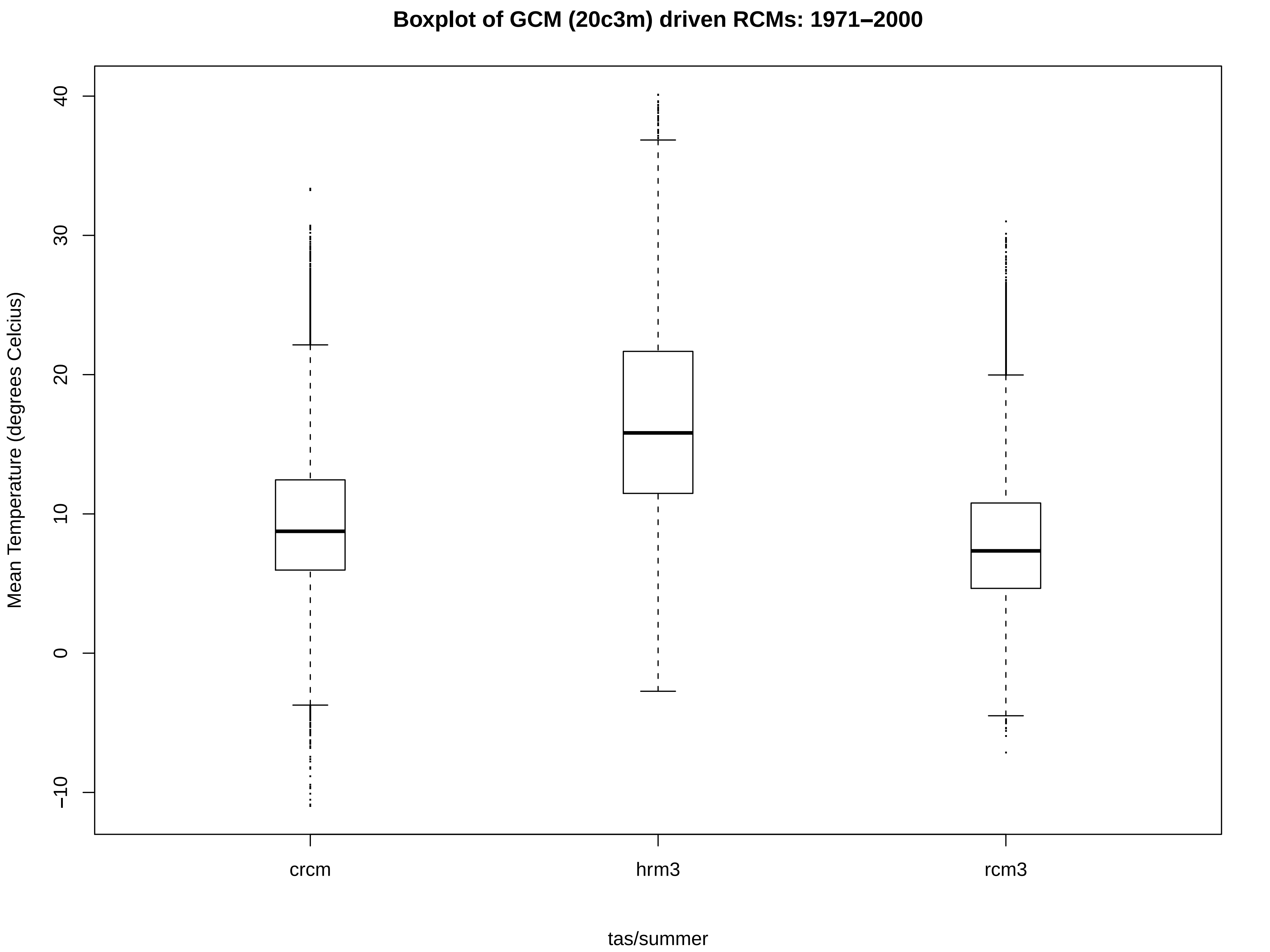


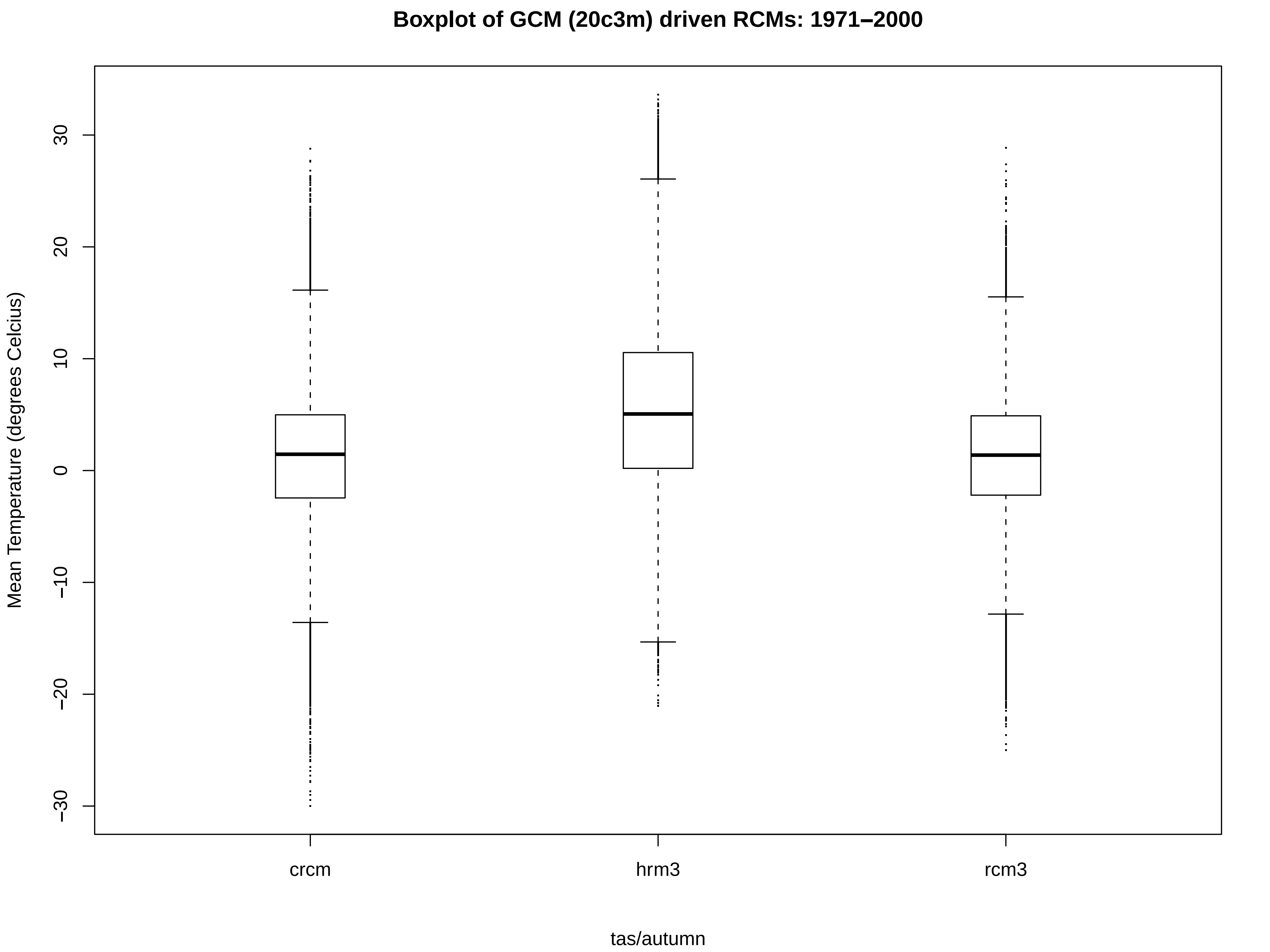
Boxplot of GCM (20c3m) driven RCMs: 1971–2000
Mean Precipitation (mm/day)
0
50
100
150
crcm
hrm3
rcm3
obs
pr/autumn


Boxplot of GCM (20c3m) driven RCMs: 1971–2000
Mean Precipitation (mm/day)
0
50
100
150
crcm
hrm3
rcm3
obs
pr/all

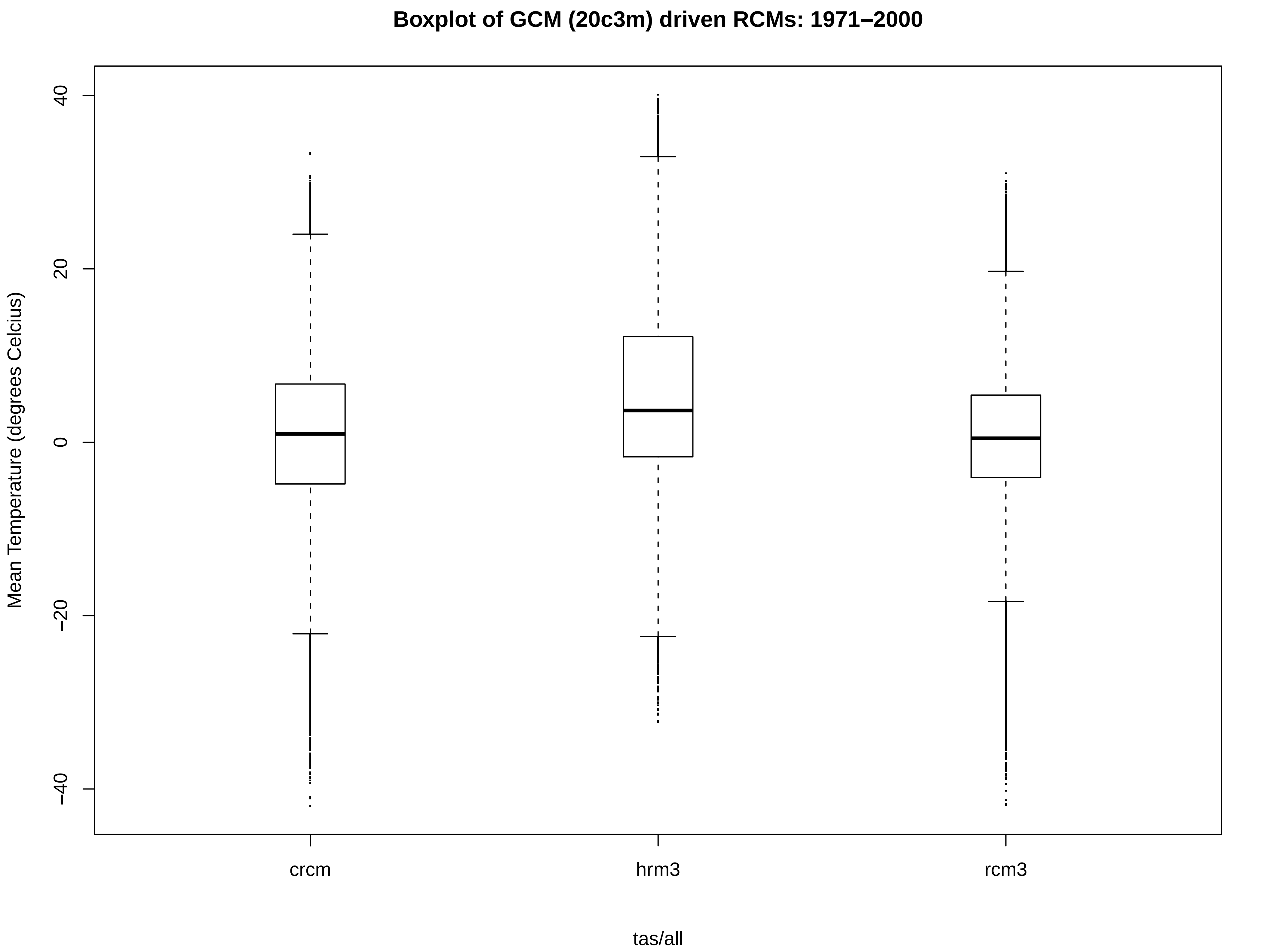

Boxplot of GCM (20c3m) driven RCMs: 1971–2000
Mean Temperature (degrees Celcius)
10
0
−10
−20
−30
−40
crcm
hrm3
rcm3
tas/winter

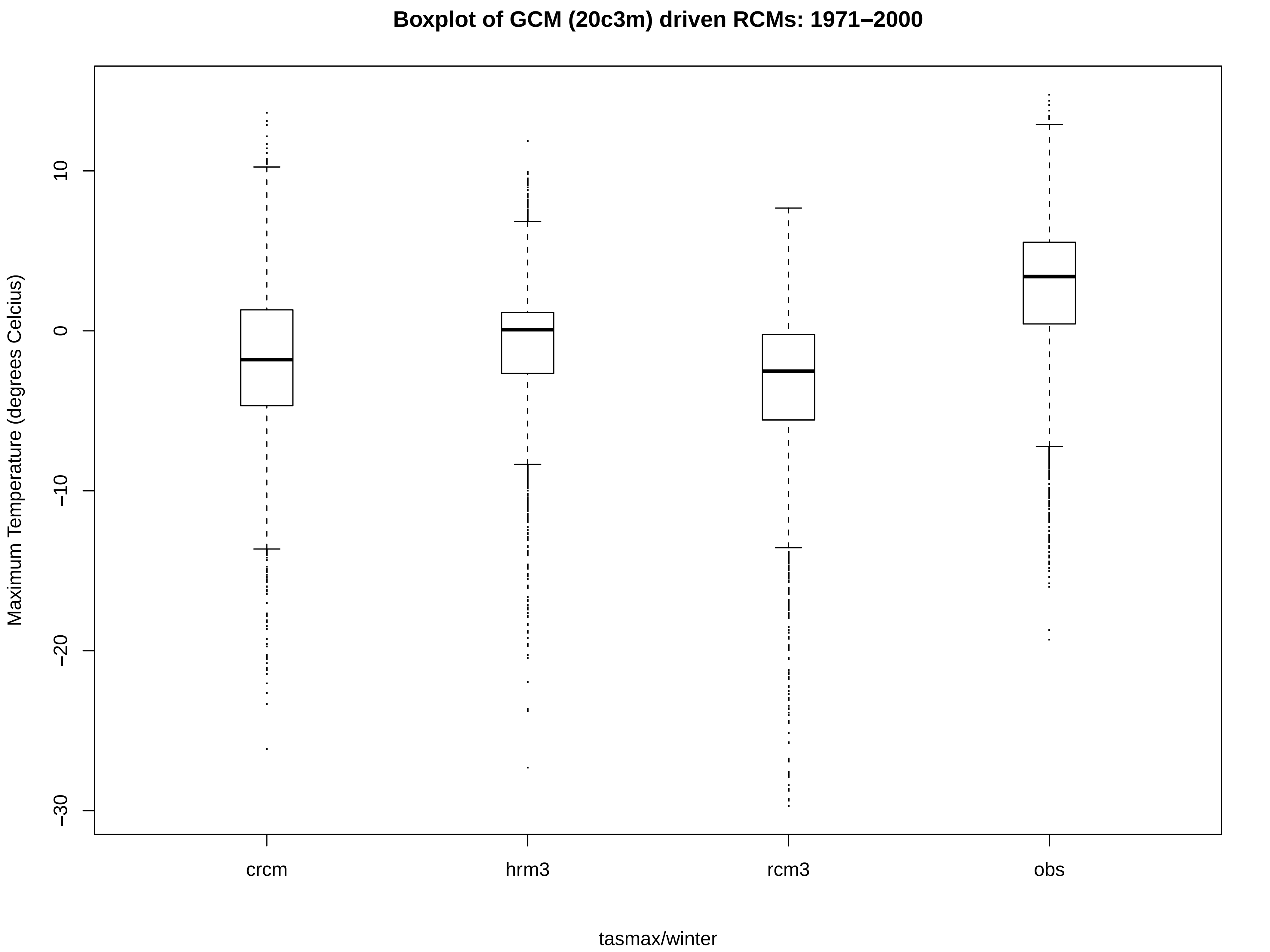

Boxplot of GCM (20c3m) driven RCMs: 1971–2000
Mean Temperature (degrees Celcius)
20
10
0
−10
−20
−30
crcm
hrm3
rcm3
tas/spring

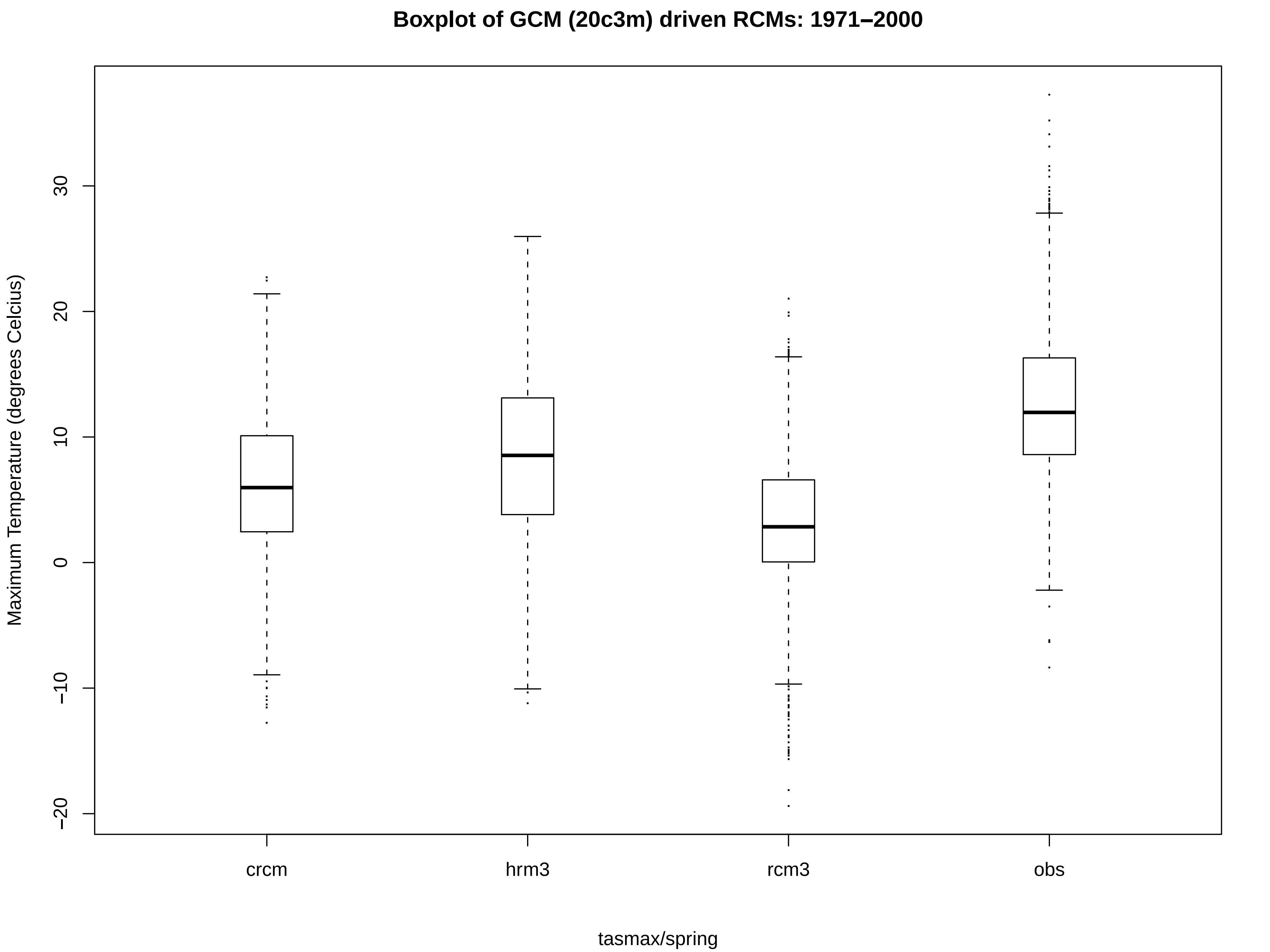

Boxplot of GCM (20c3m) driven RCMs: 1971–2000
Mean Temperature (degrees Celcius)
40
30
20
10
0
−10
crcm
hrm3
rcm3
tas/summer



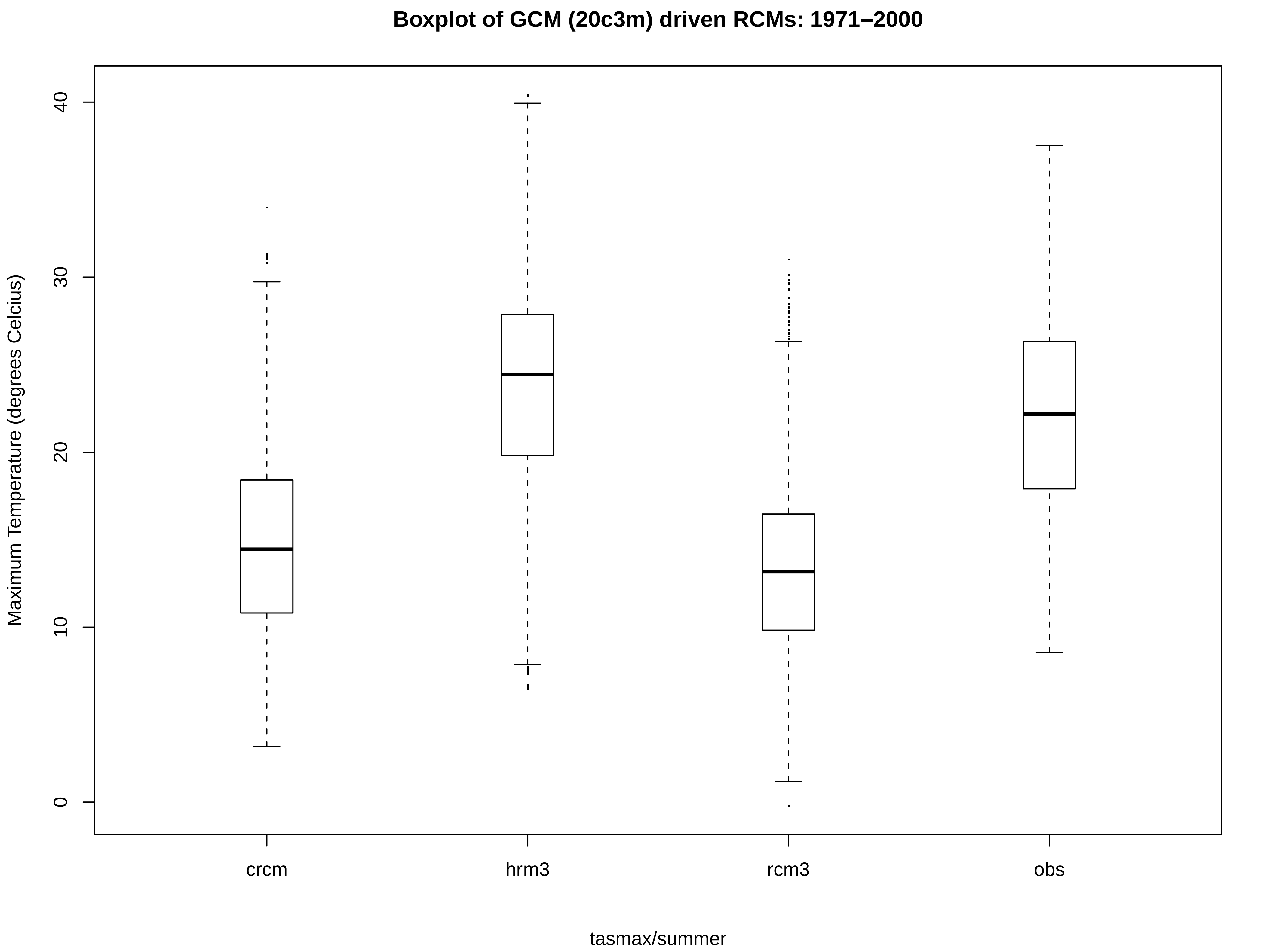
Boxplot of GCM (20c3m) driven RCMs: 1971–2000
Mean Temperature (degrees Celcius)
30
20
10
0
−10
−20
−30
crcm
hrm3
rcm3
tas/autumn


Boxplot of GCM (20c3m) driven RCMs: 1971–2000
Mean Temperature (degrees Celcius)
40
20
0
−20
−40
crcm
hrm3
rcm3
tas/all

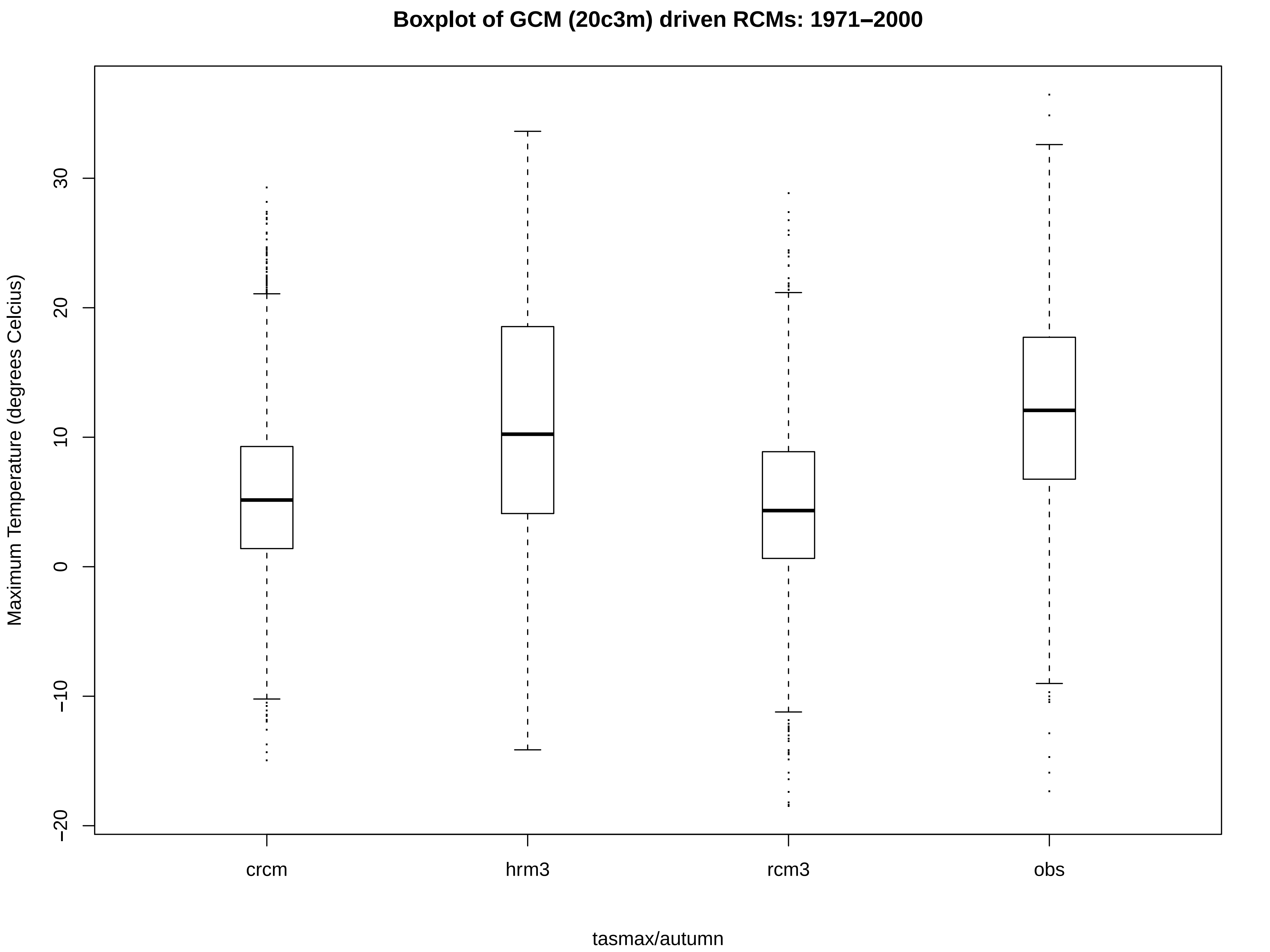

Boxplot of GCM (20c3m) driven RCMs: 1971–2000
Maximum Temperature (degrees Celcius)
10
0
−10
−20
−30
crcm
hrm3
rcm3
obs
tasmax/winter



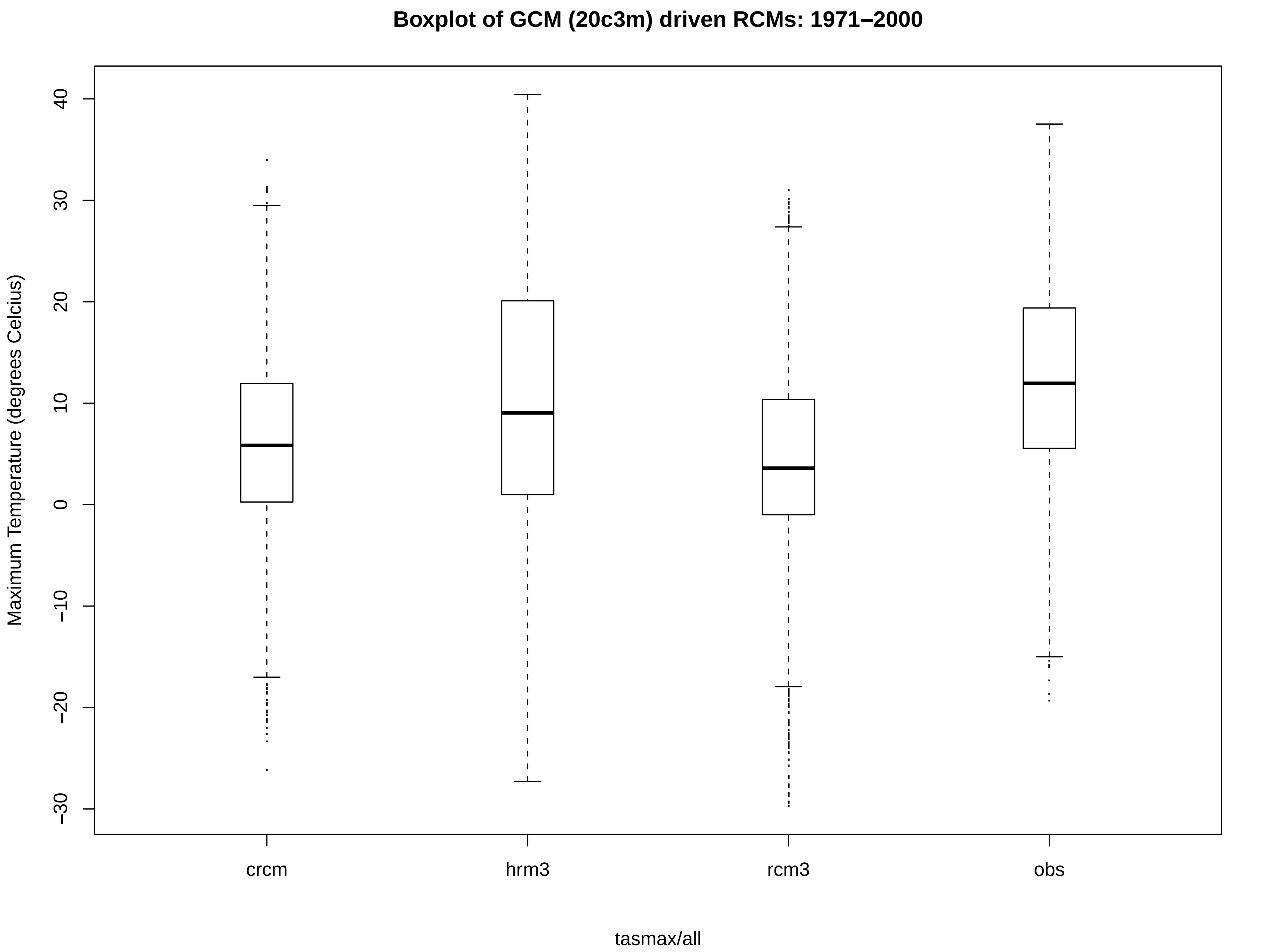
Boxplot of GCM (20c3m) driven RCMs: 1971–2000
Maximum Temperature (degrees Celcius)
30
20
10
0
−10
−20
crcm
hrm3
rcm3
obs
tasmax/spring



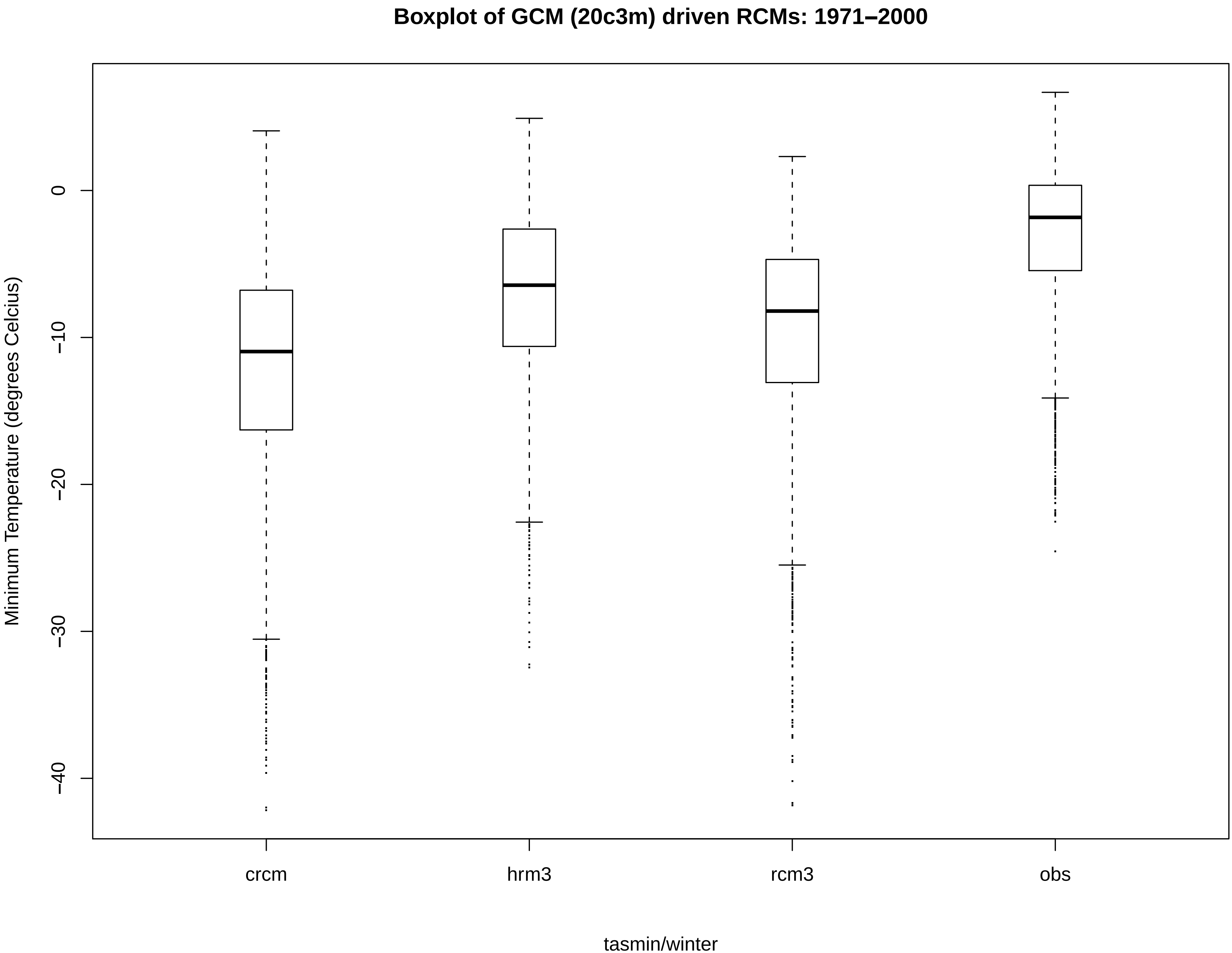
Boxplot of GCM (20c3m) driven RCMs: 1971–2000
Maximum Temperature (degrees Celcius)
0
10
20
30
40
crcm
hrm3
rcm3
obs
tasmax/summer

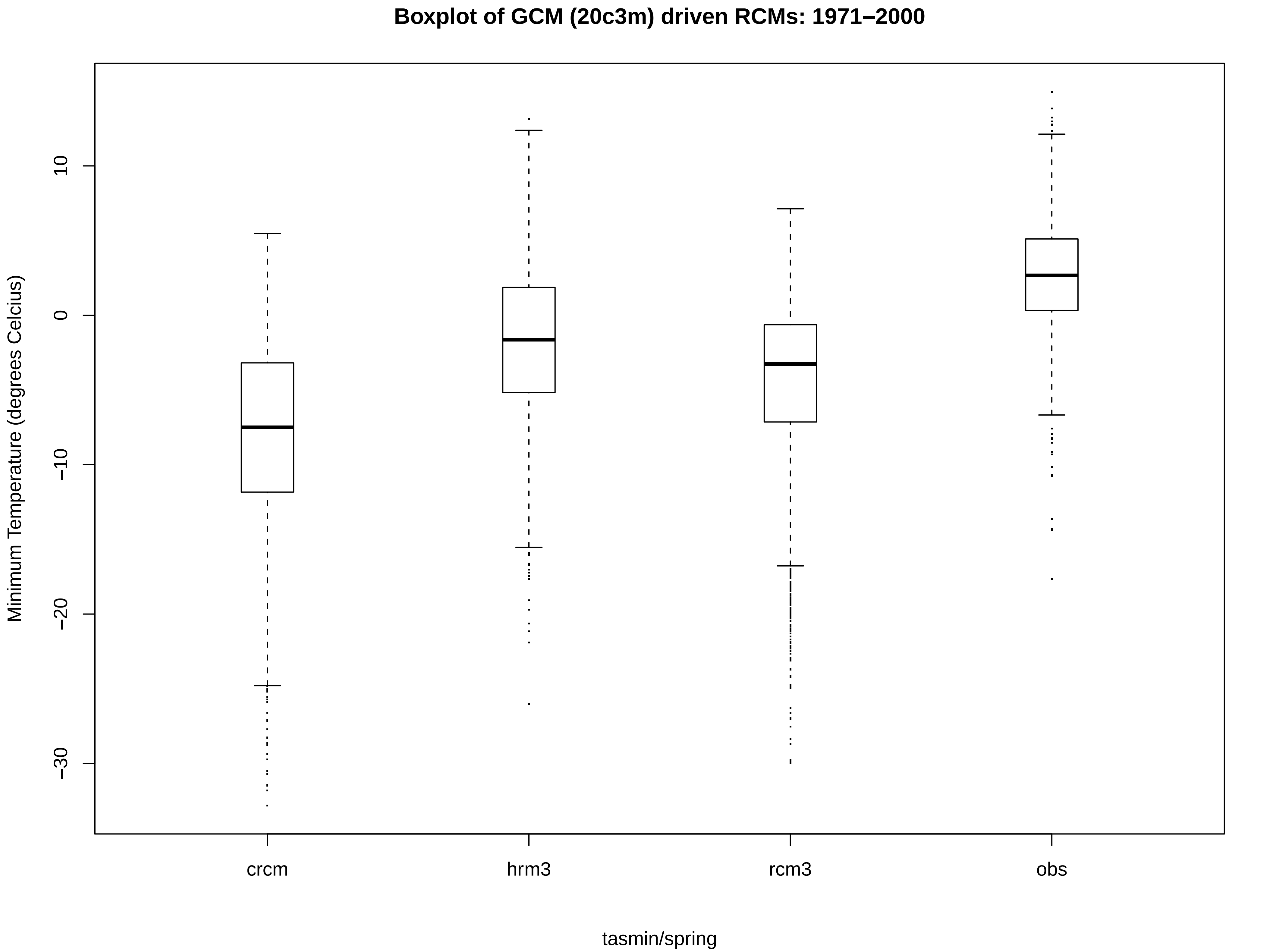


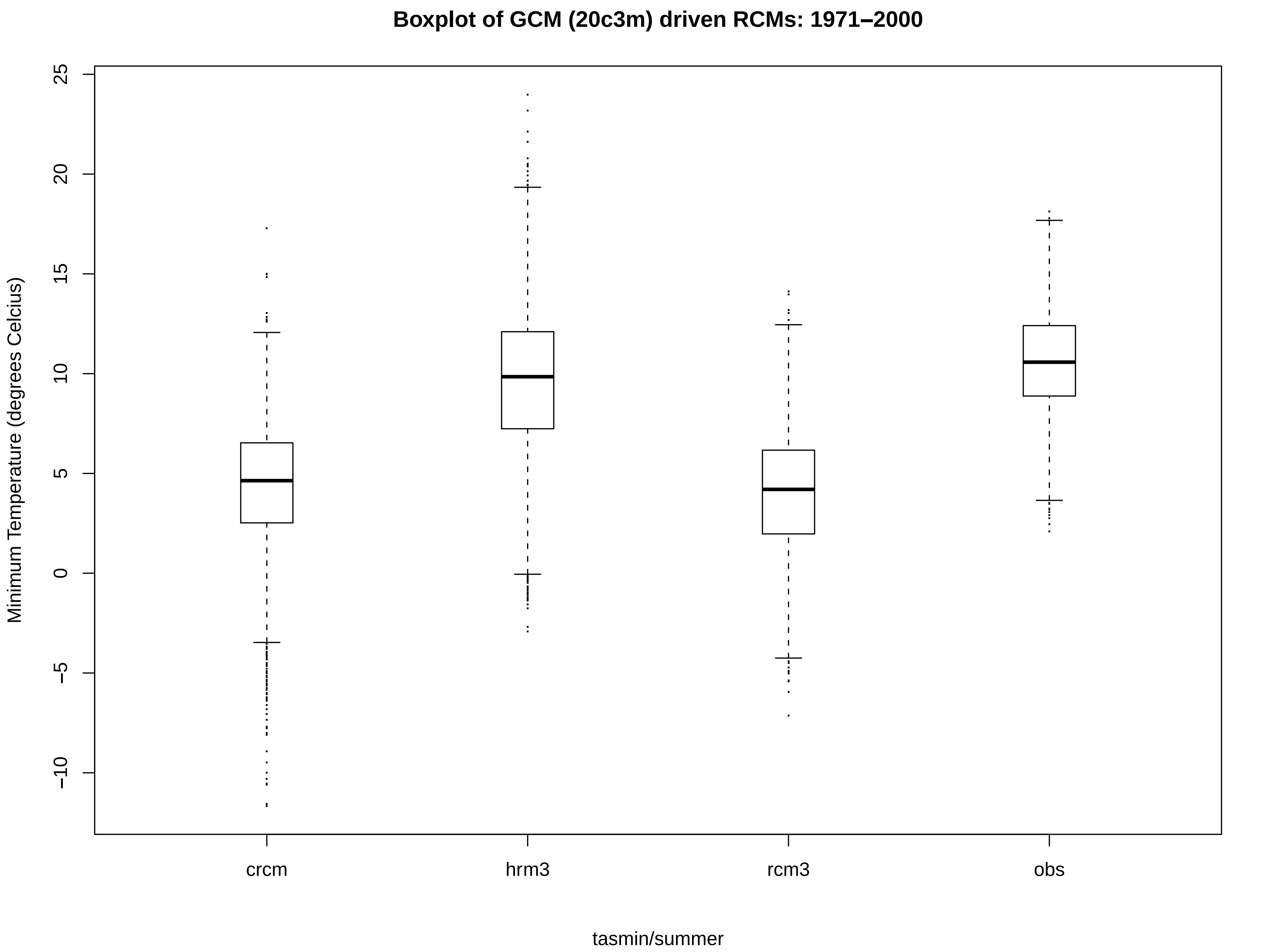
Boxplot of GCM (20c3m) driven RCMs: 1971–2000
Maximum Temperature (degrees Celcius)
30
20
10
0
−10
−20
crcm
hrm3
rcm3
obs
tasmax/autumn

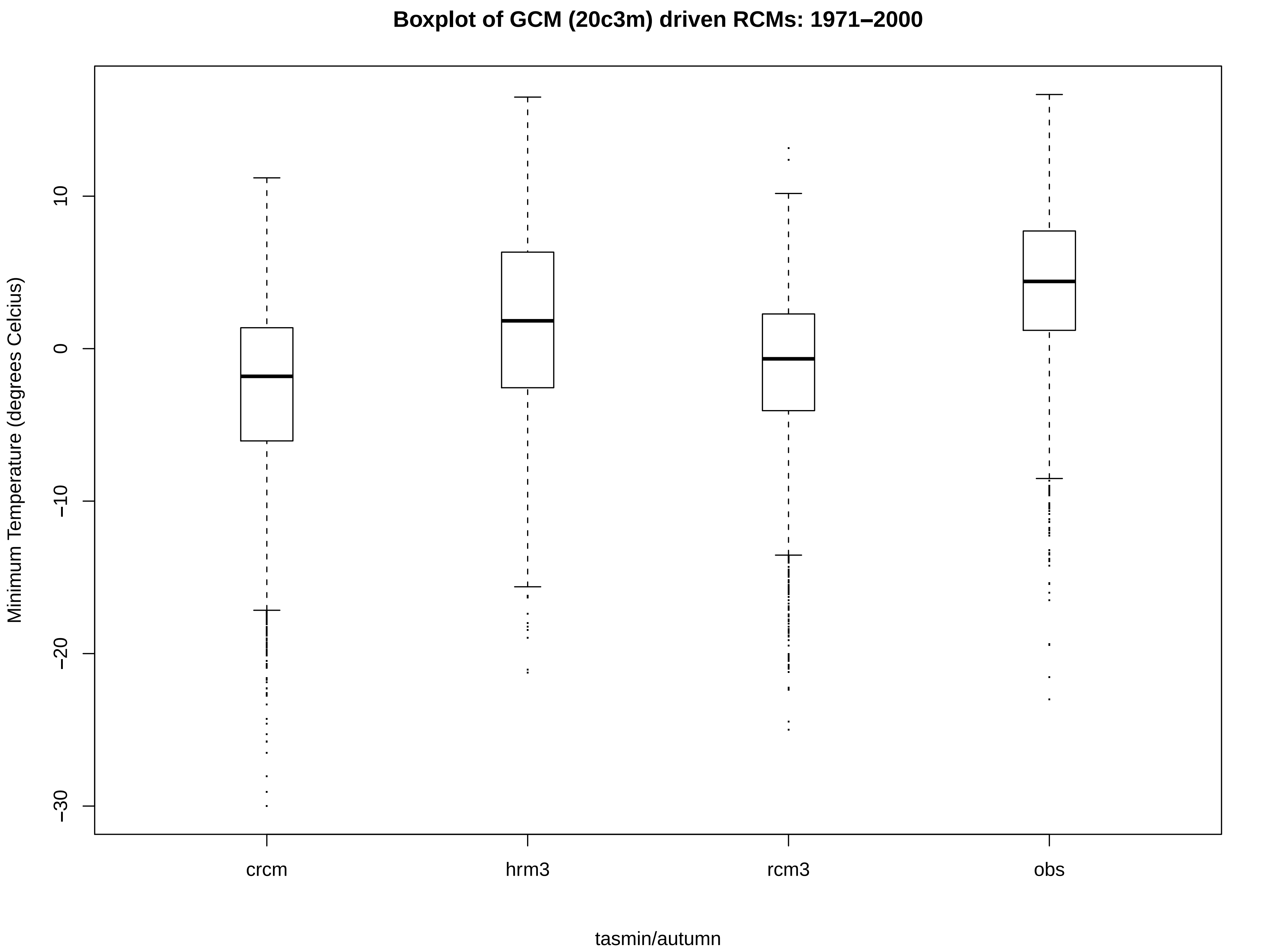


Boxplot of GCM (20c3m) driven RCMs: 1971–2000
Maximum Temperature (degrees Celcius)
40
30
20
10
0
−10
−20
−30
crcm
hrm3
rcm3
obs
tasmax/all

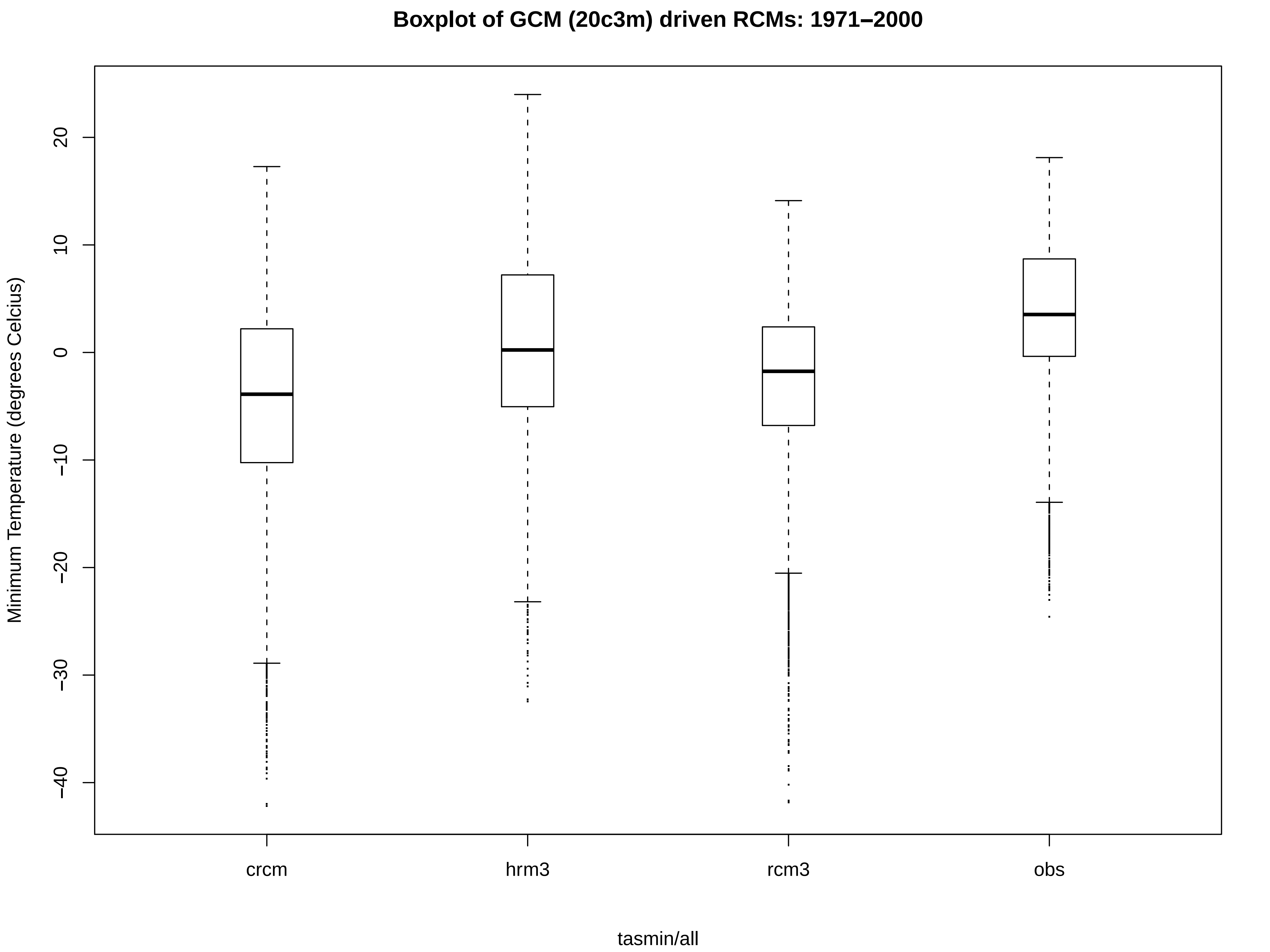

Boxplot of GCM (20c3m) driven RCMs: 1971–2000
Minimum Temperature (degrees Celcius)
0
−10
−20
−30
−40
crcm
hrm3
rcm3
obs
tasmin/winter


Boxplot of GCM (20c3m) driven RCMs: 1971–2000
Minimum Temperature (degrees Celcius)
10
0
−10
−20
−30
crcm
hrm3
rcm3
obs
tasmin/spring


Boxplot of GCM (20c3m) driven RCMs: 1971–2000
Minimum Temperature (degrees Celcius)
25
20
15
10
5
0
−5
−10
crcm
hrm3
rcm3
obs
tasmin/summer



Boxplot of GCM (20c3m) driven RCMs: 1971–2000
Minimum Temperature (degrees Celcius)
10
0
−10
−20
−30
crcm
hrm3
rcm3
obs
tasmin/autumn


Boxplot of GCM (20c3m) driven RCMs: 1971–2000
Minimum Temperature (degrees Celcius)
20
10
0
−10
−20
−30
−40
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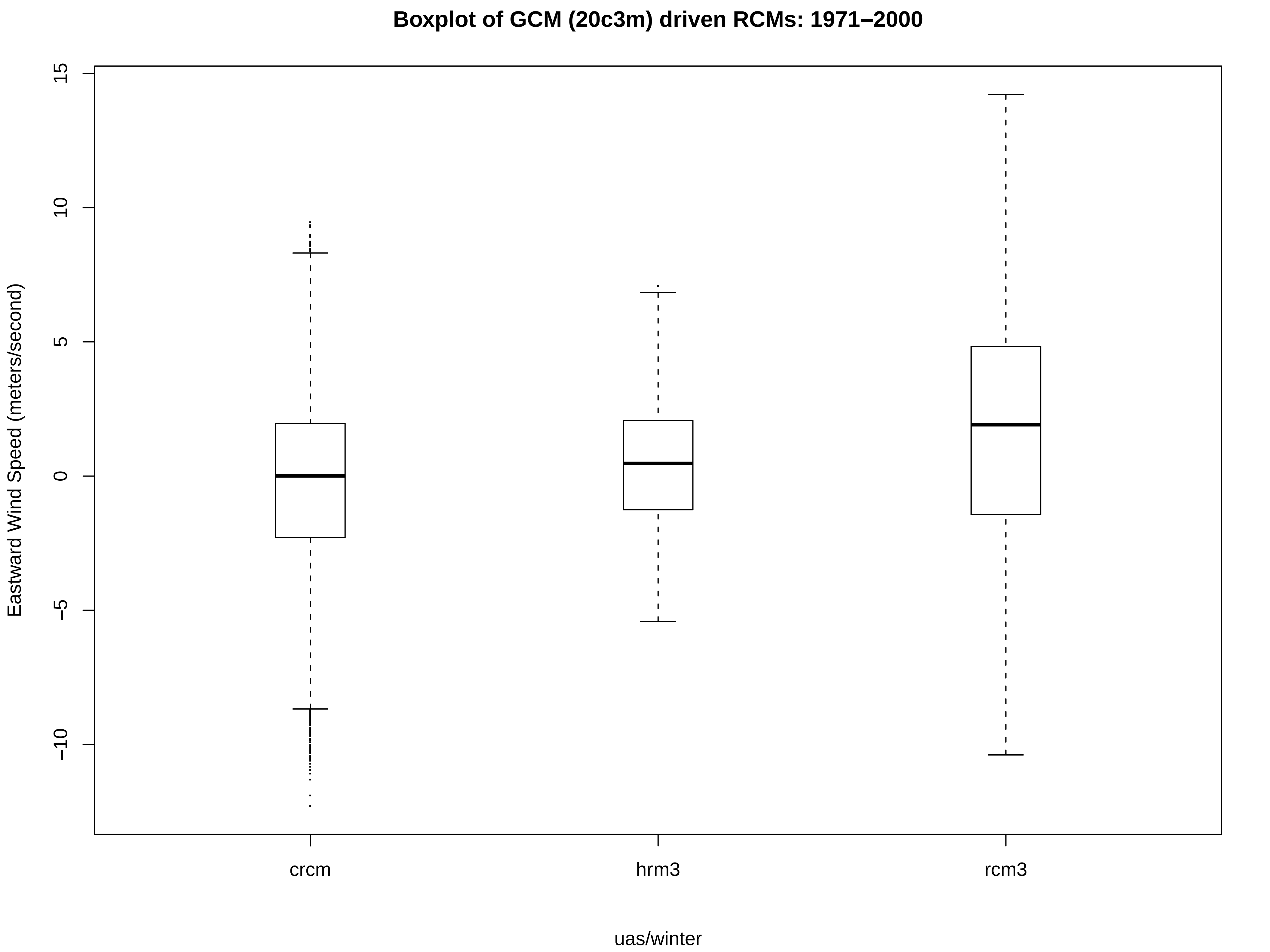
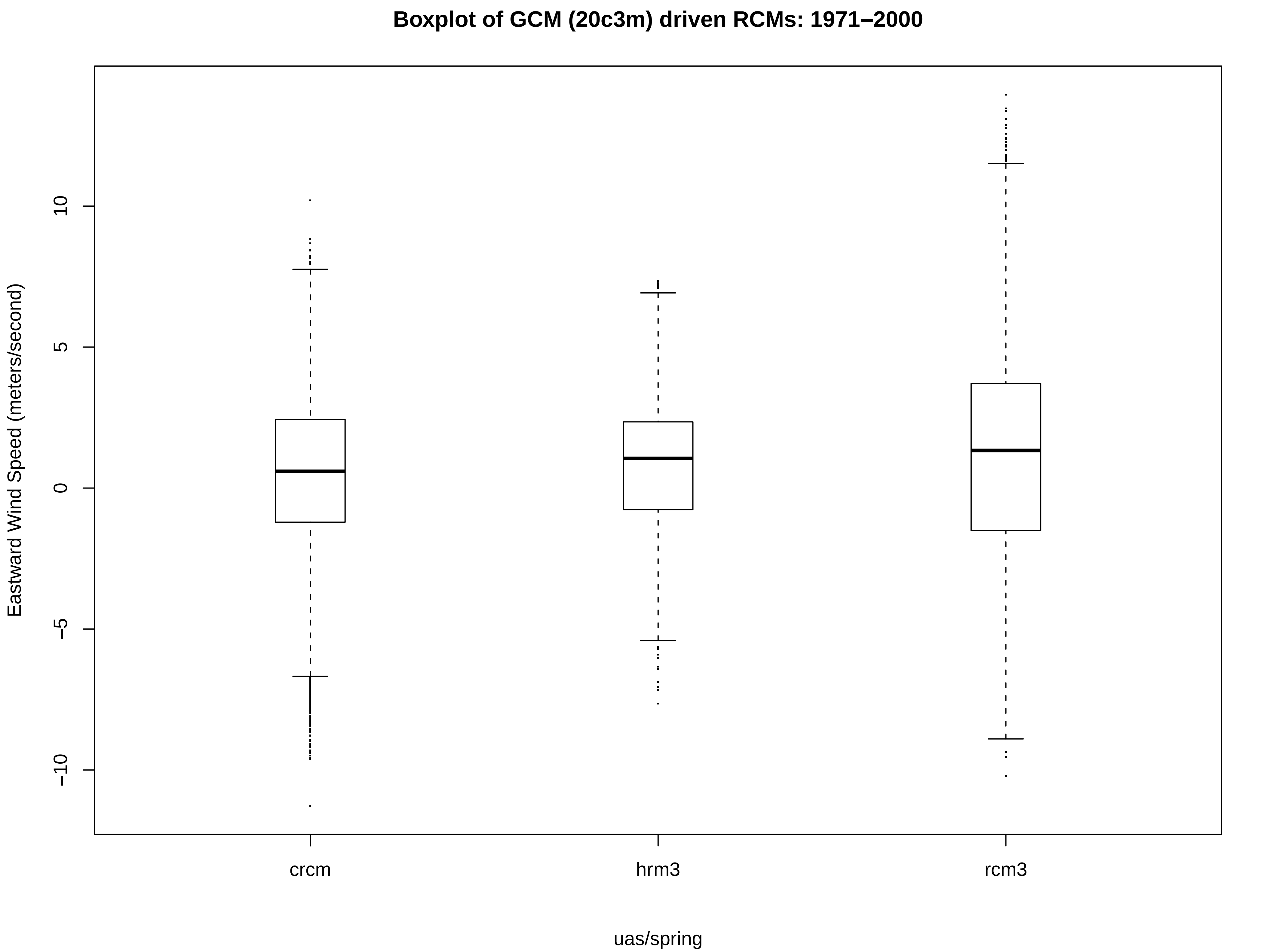
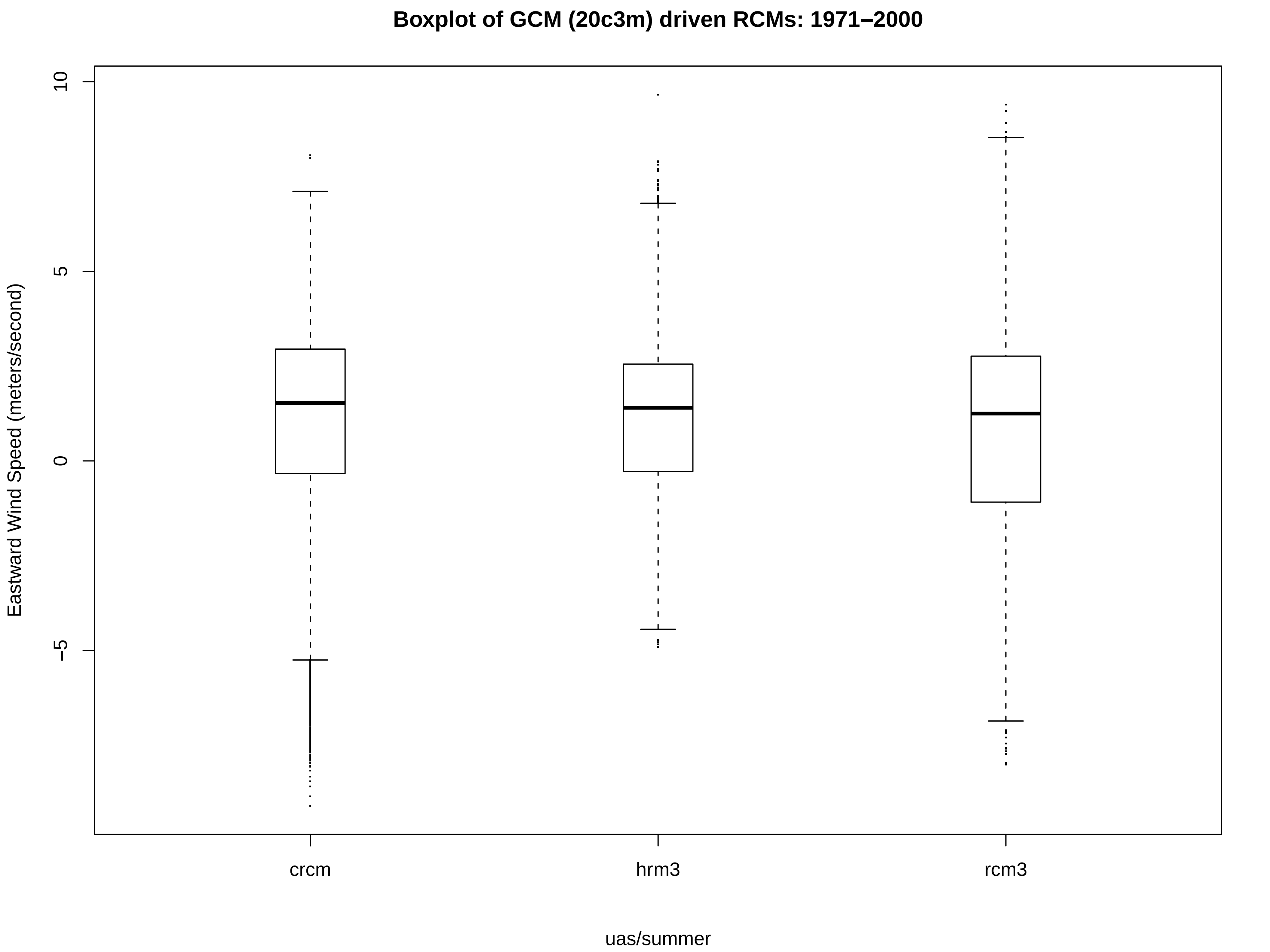
hrm3
rcm3
obs
tasmin/all


Boxplot of GCM (20c3m) driven RCMs: 1971–2000
Eastward Wind Speed (meters/second)
15
10
5
0
−5
−10
crcm
hrm3
rcm3
uas/winter


Boxplot of GCM (20c3m) driven RCMs: 1971–2000
Eastward Wind Speed (meters/second)
10
5
0
−5
−10
crcm
hrm3
rcm3
uas/spring


Boxplot of GCM (20c3m) driven RCMs: 1971–2000
Eastward Wind Speed (meters/second)
10
5
0
−5
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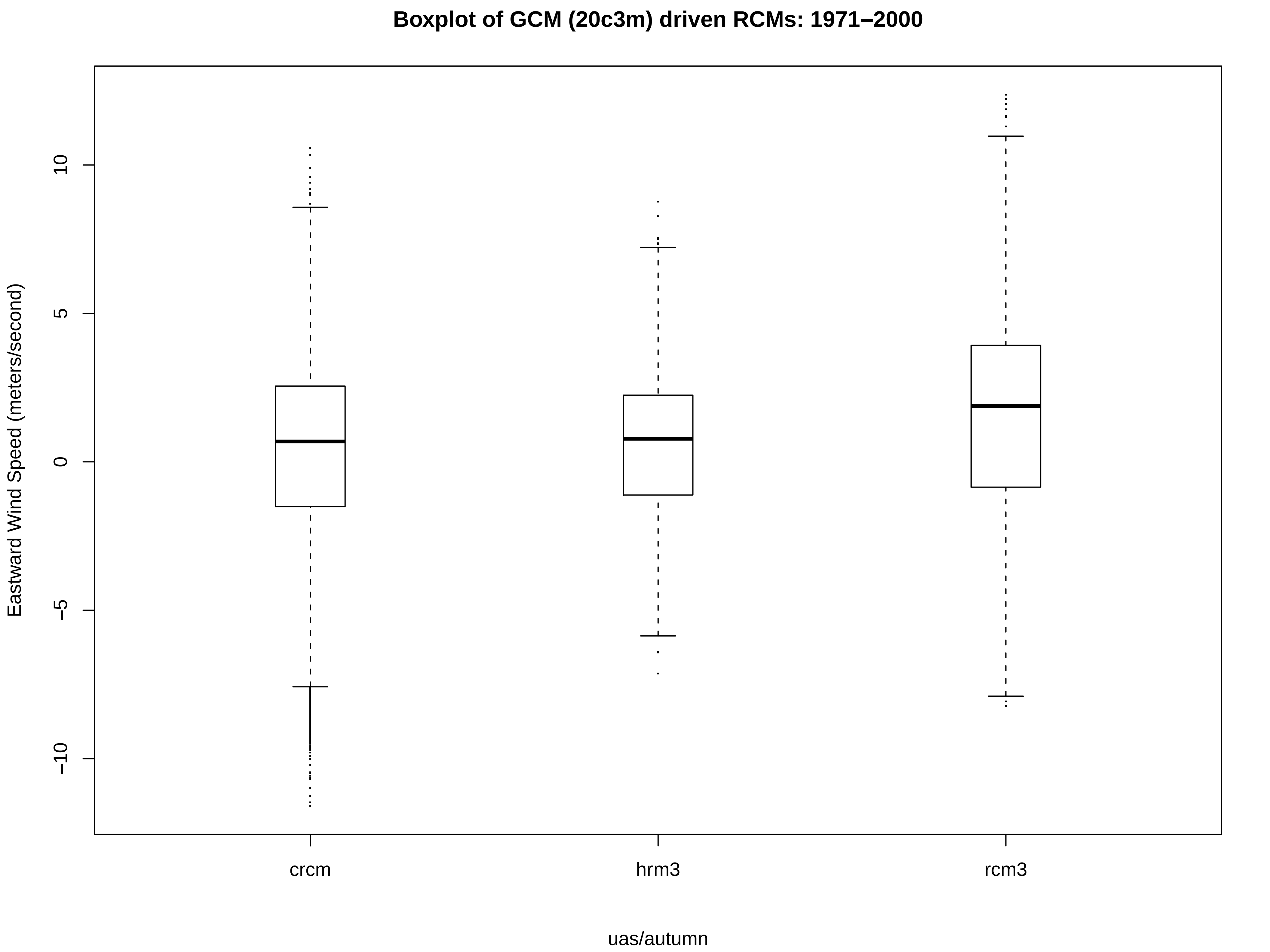
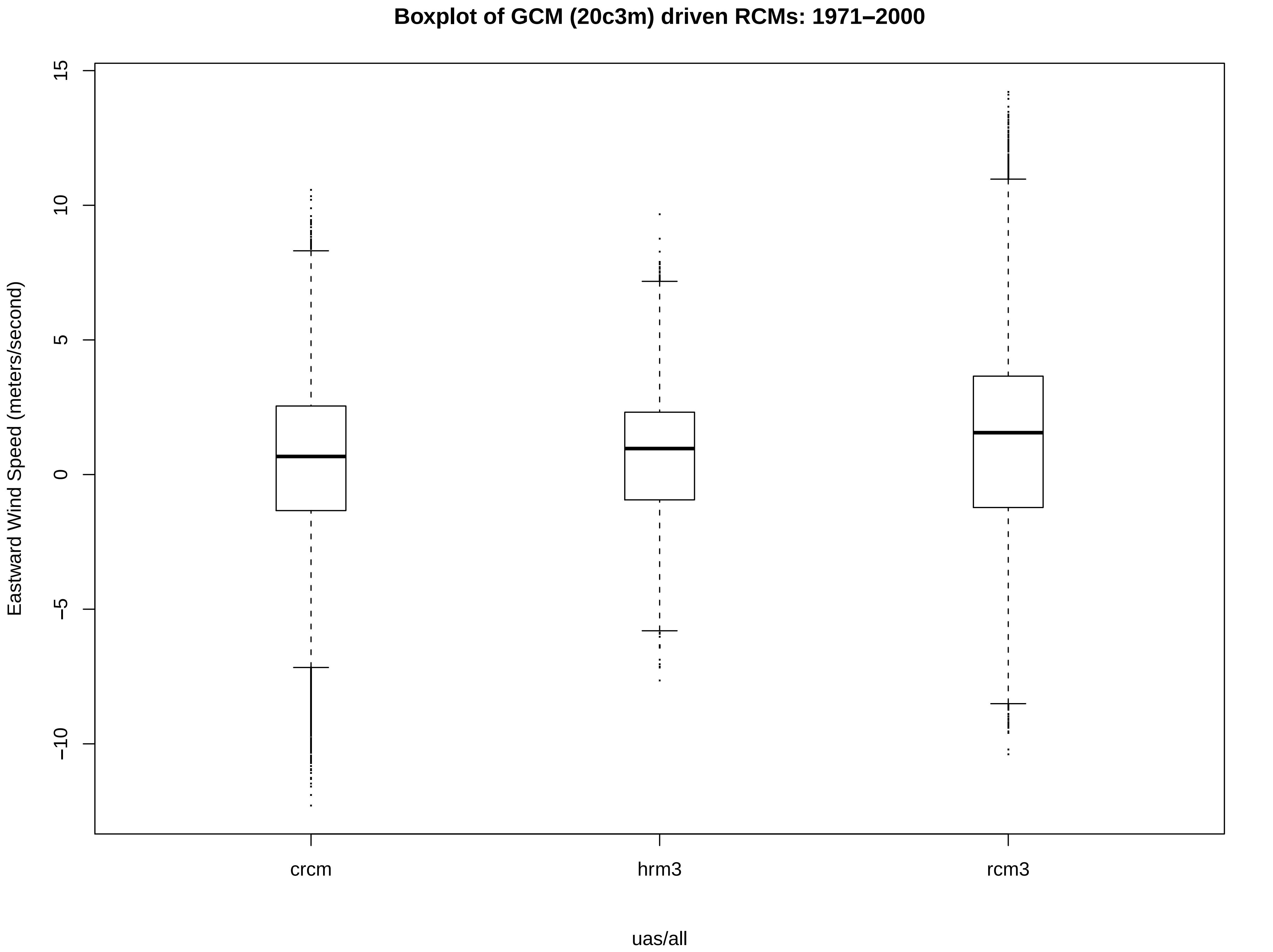
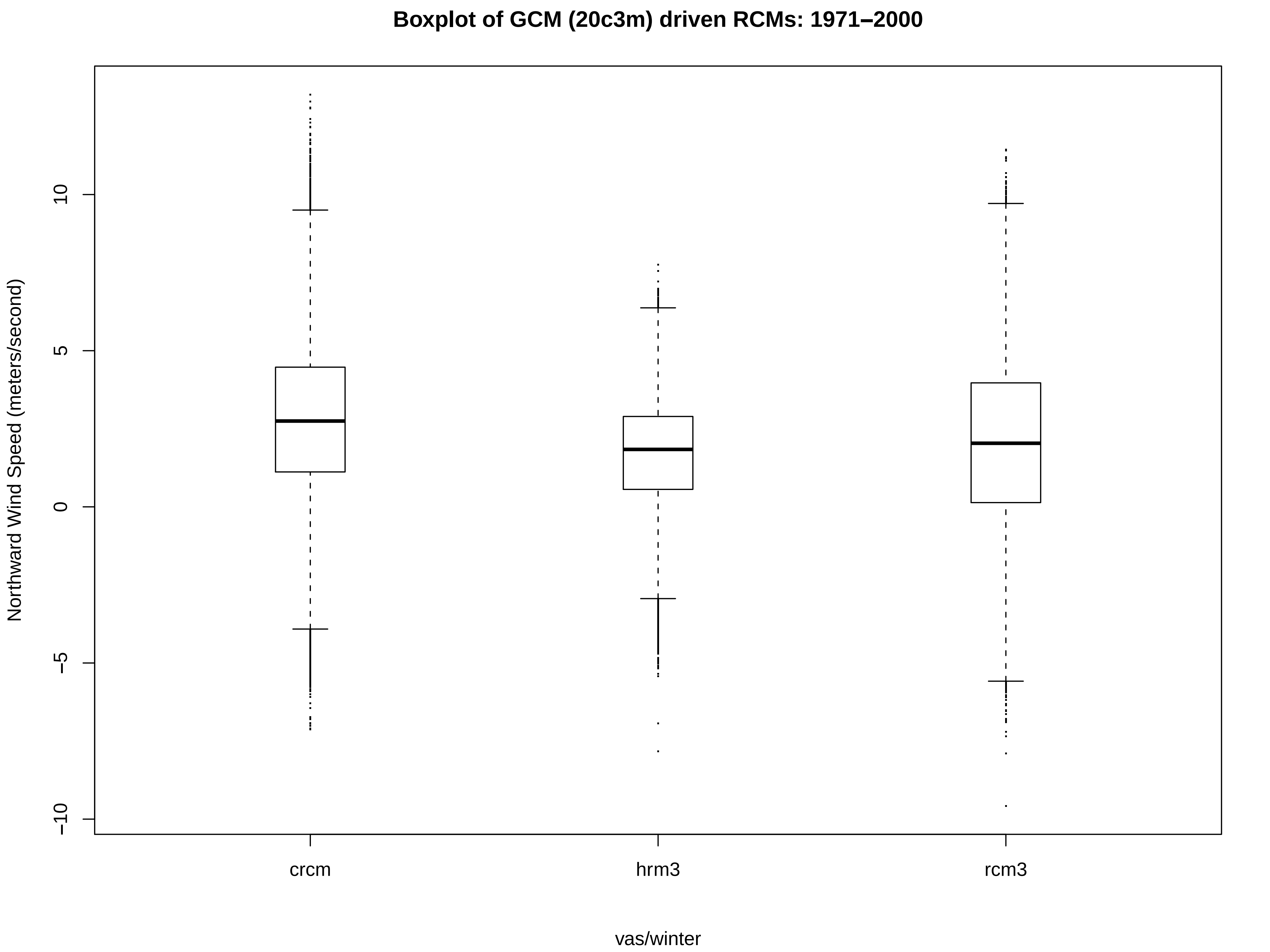
hrm3
rcm3
uas/summer

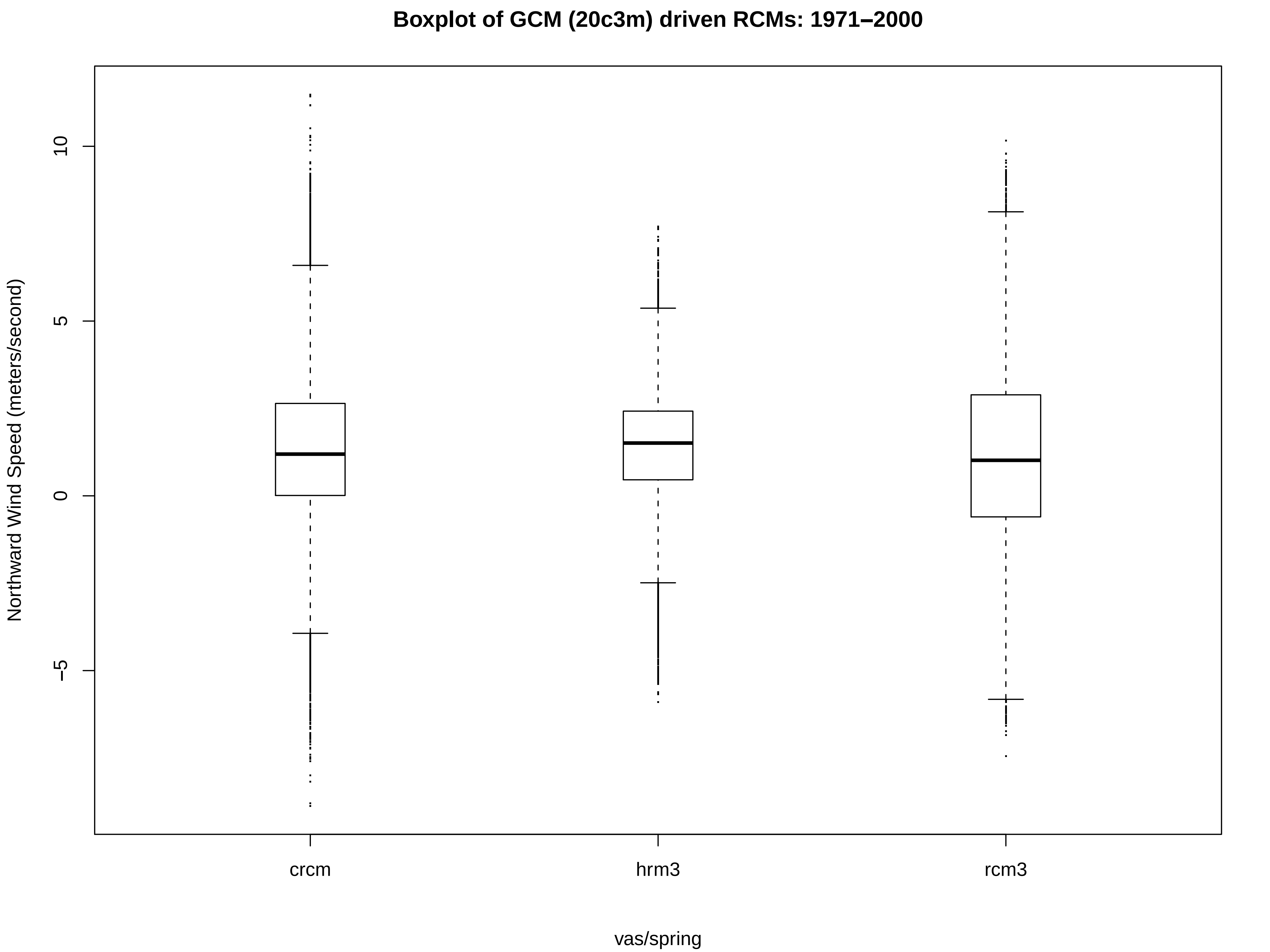

Boxplot of GCM (20c3m) driven RCMs: 1971–2000
Eastward Wind Speed (meters/second)
10
5
0
−5
−10
crcm
hrm3
rcm3
uas/autumn

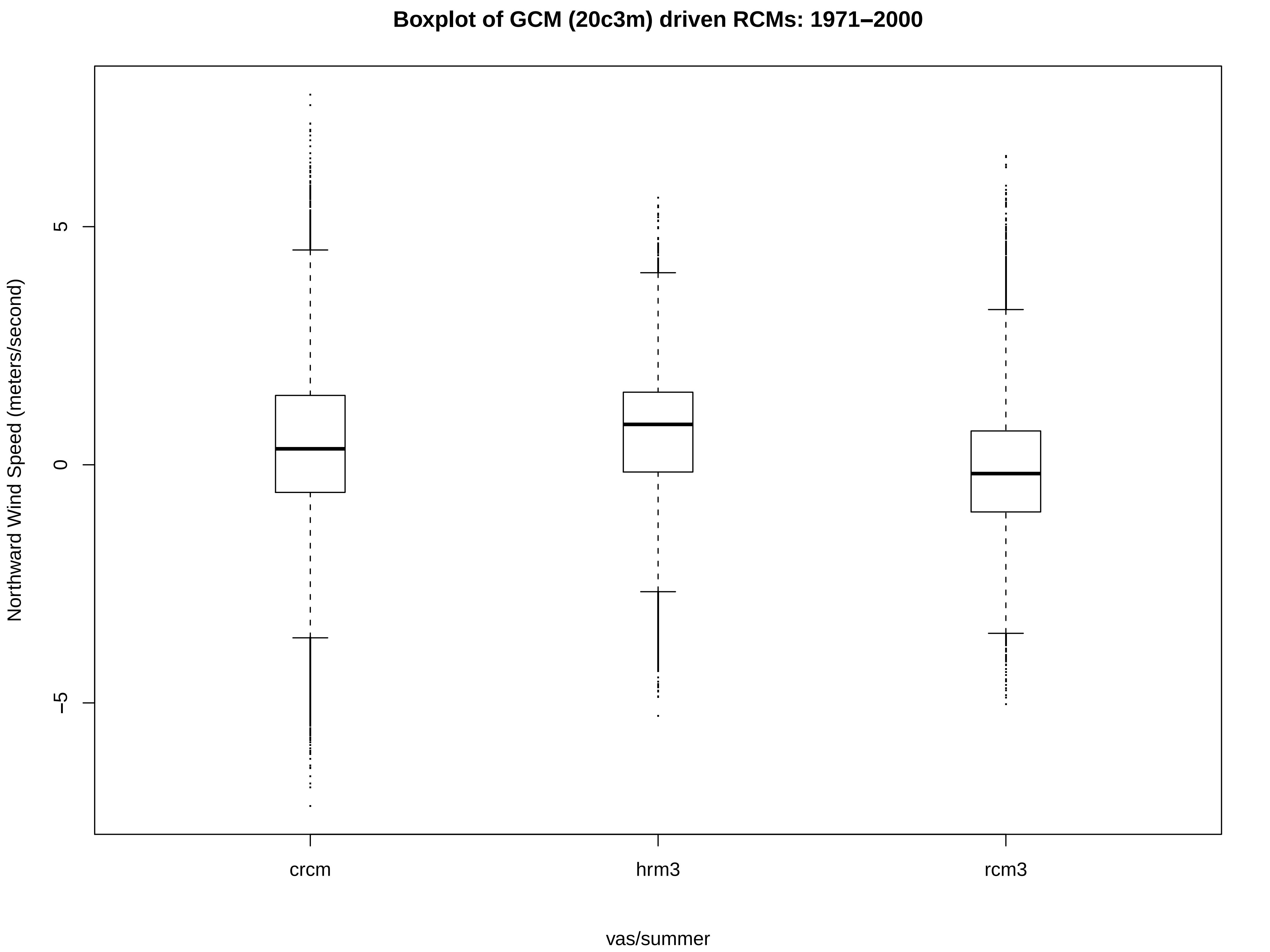


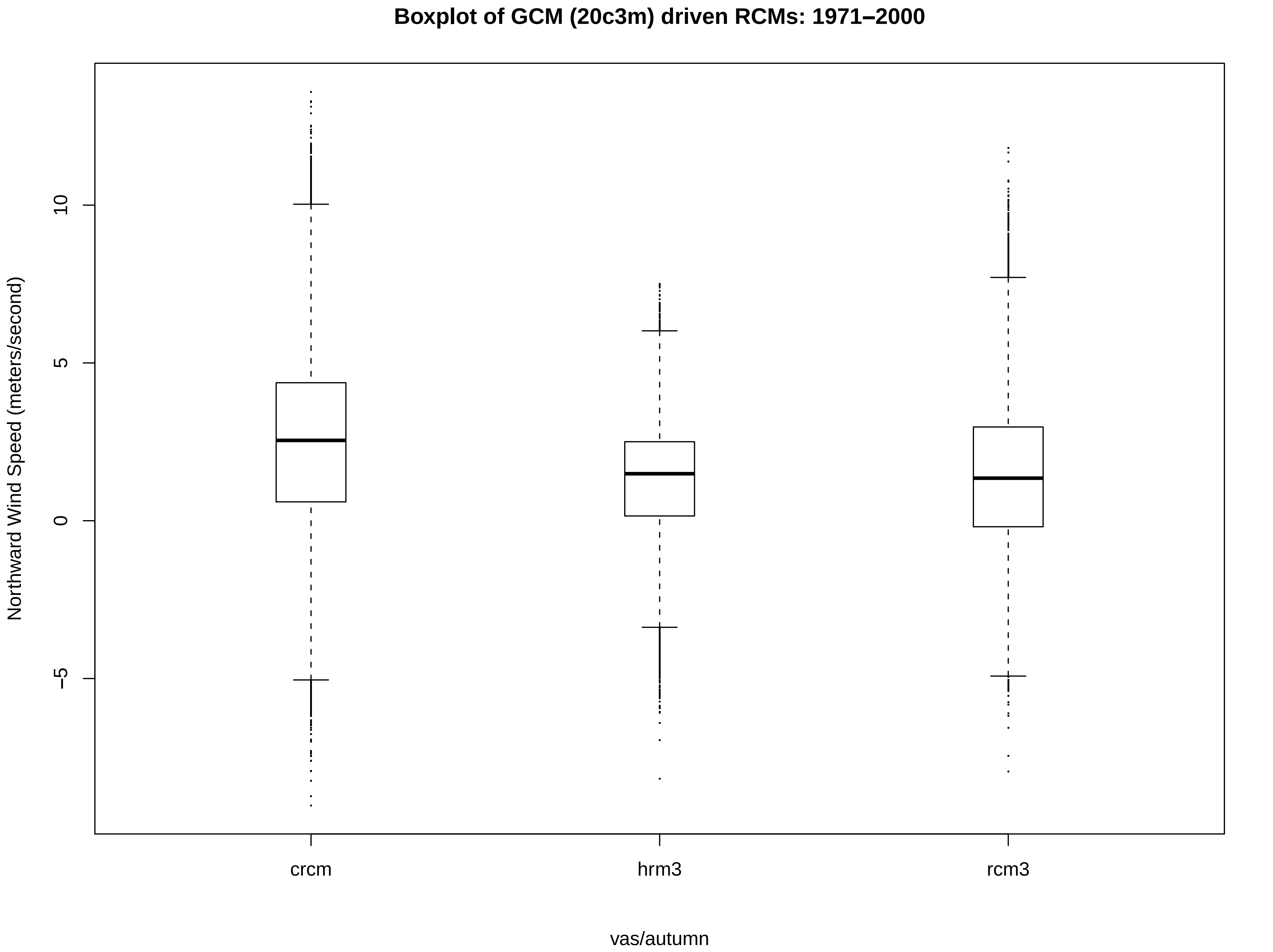
Boxplot of GCM (20c3m) driven RCMs: 1971–2000
Eastward Wind Speed (meters/second)
15
10
5
0
−5
−10
crcm
hrm3
rcm3
uas/all

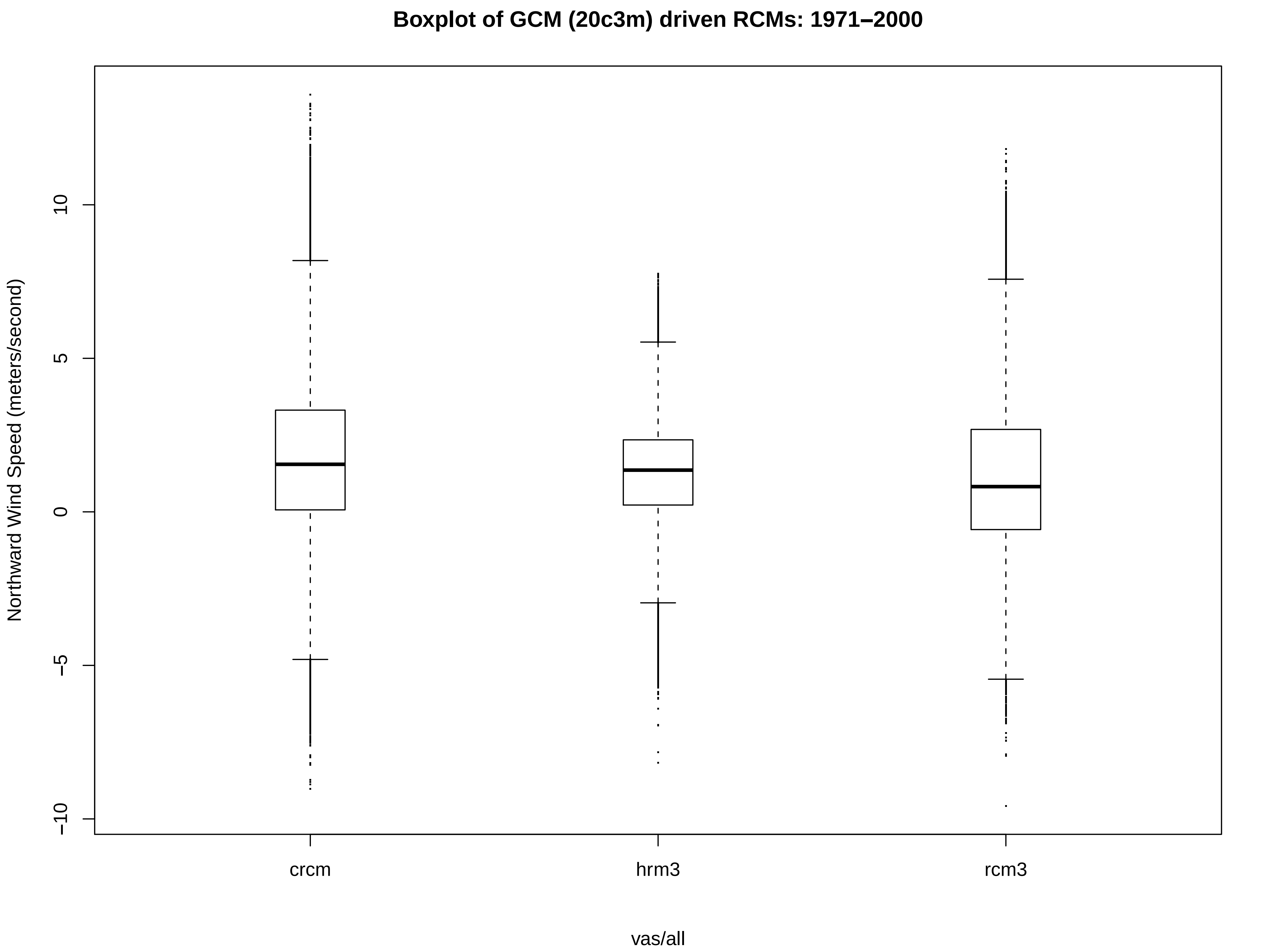


Boxplot of GCM (20c3m) driven RCMs: 1971–2000
Northward Wind Speed (meters/second)
10
5
0
−5
−10
crcm
hrm3
rcm3
vas/winter

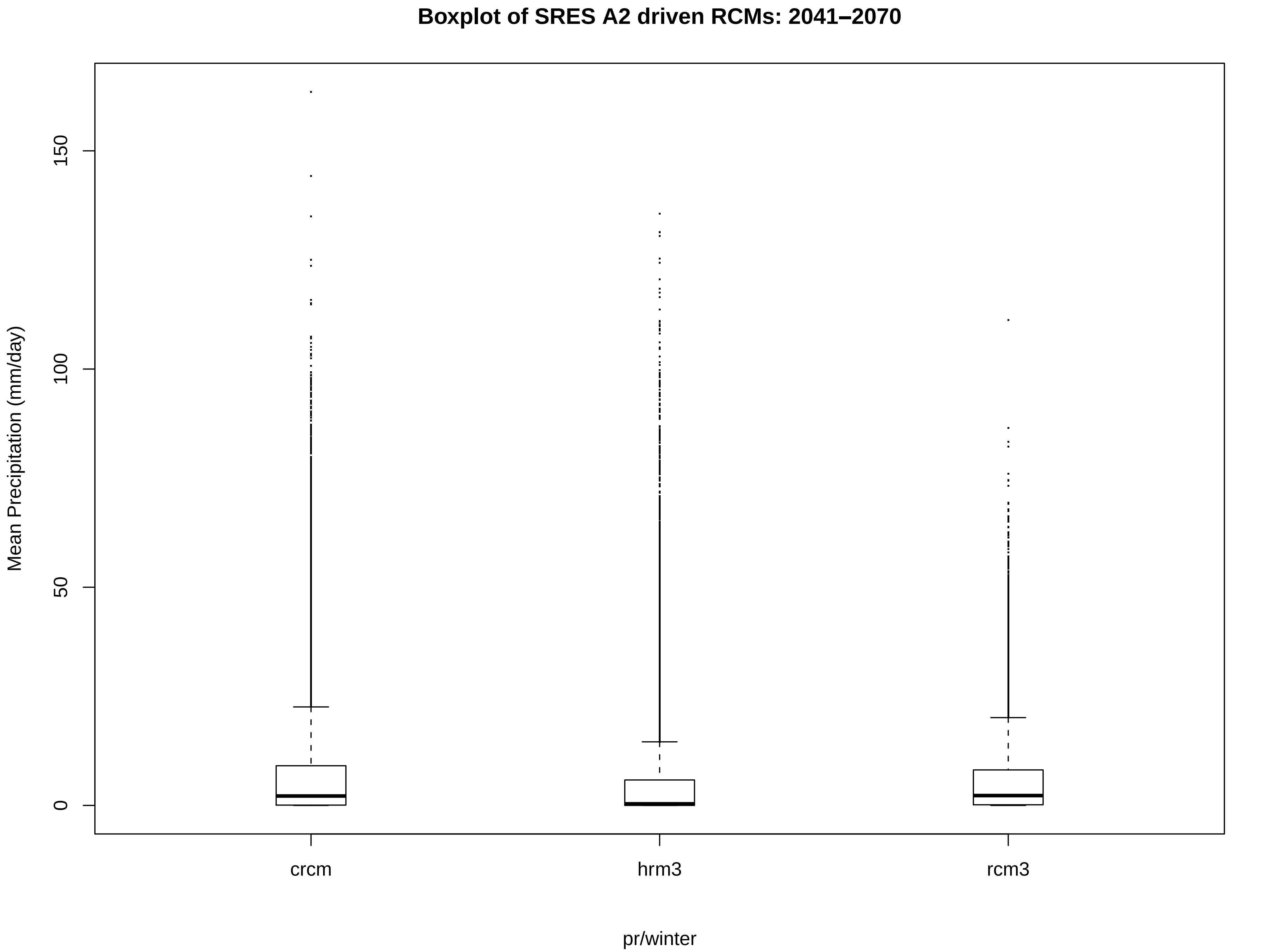

Boxplot of GCM (20c3m) driven RCMs: 1971–2000
Northward Wind Speed (meters/second)
10
5
0
−5
crcm
hrm3
rcm3
vas/spring

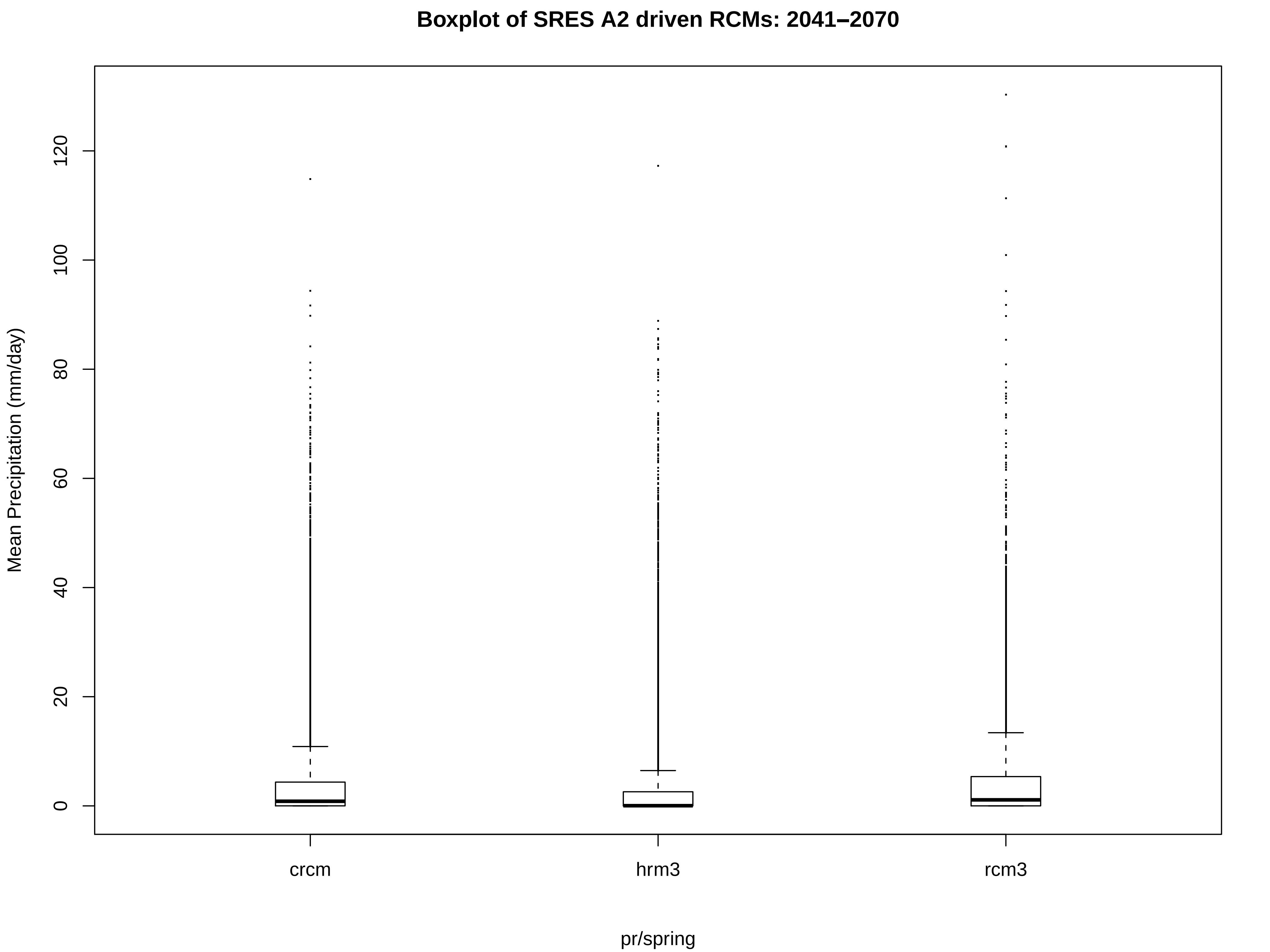

Boxplot of GCM (20c3m) driven RCMs: 1971–2000
Northward Wind Speed (meters/second)
5
0
−5
crcm
hrm3
rcm3
vas/summer


Boxplot of GCM (20c3m) driven RCMs: 1971–2000
Northward Wind Speed (meters/second)
10
5
0
−5
crcm
hrm3
rcm3
vas/autumn

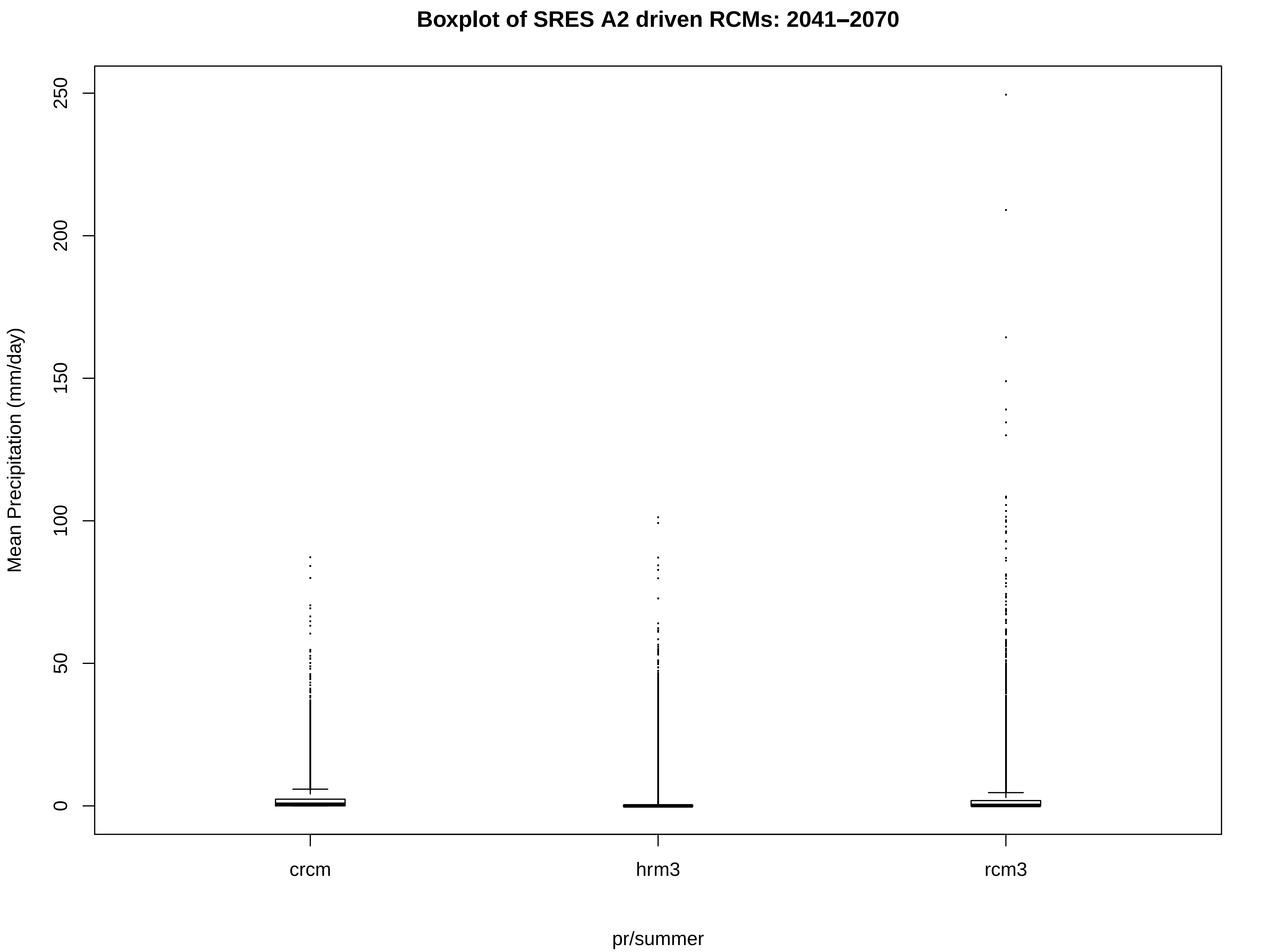


Boxplot of GCM (20c3m) driven RCMs: 1971–2000
Northward Wind Speed (meters/second)
−10
−5
0
5
10
crcm
hrm3
rcm3
vas/all

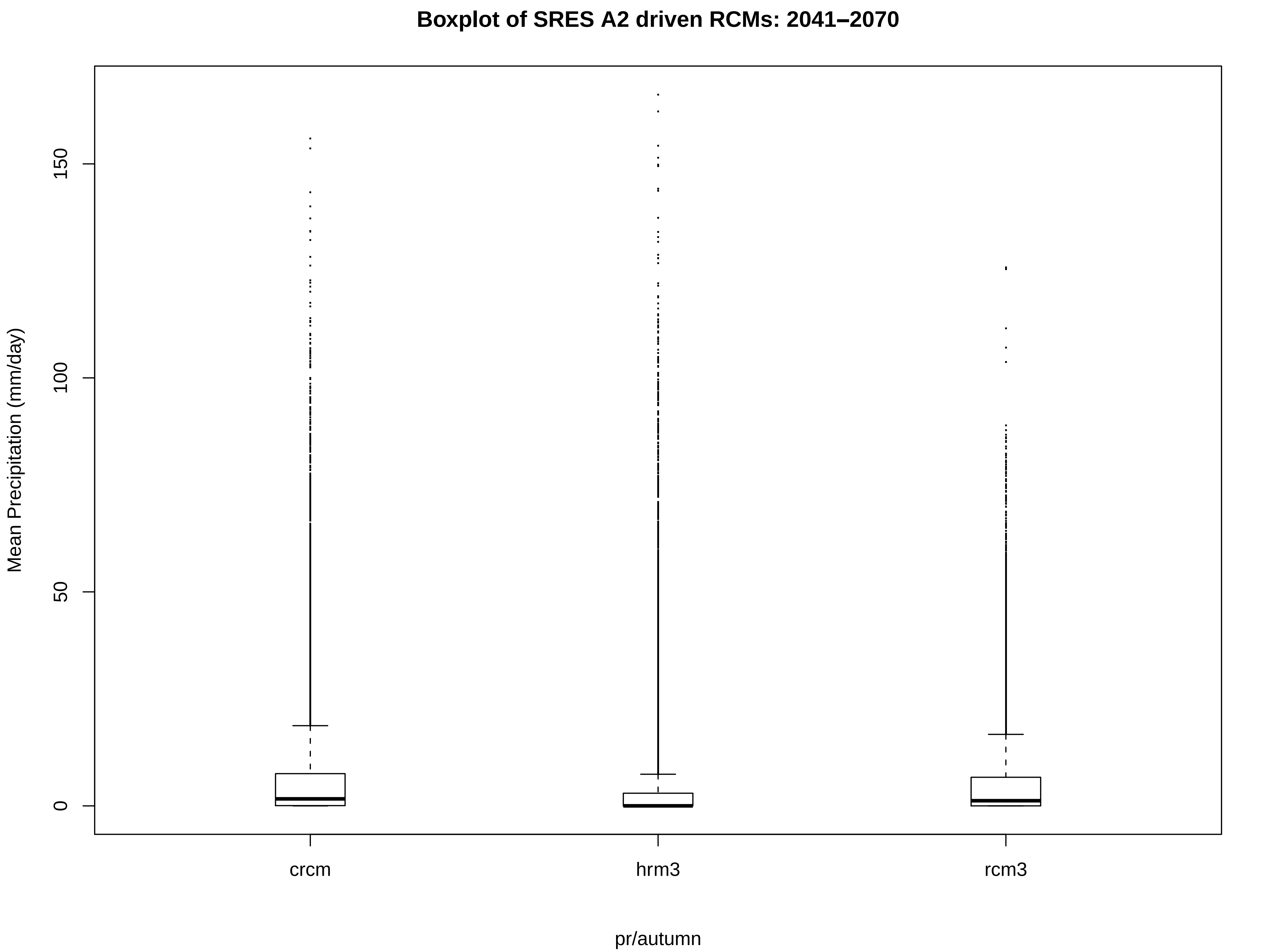

Boxplot of SRES A2 driven RCMs: 2041–2070
Mean Precipitation (mm/day)
0
50
100
150
crcm
hrm3
rcm3
pr/winter



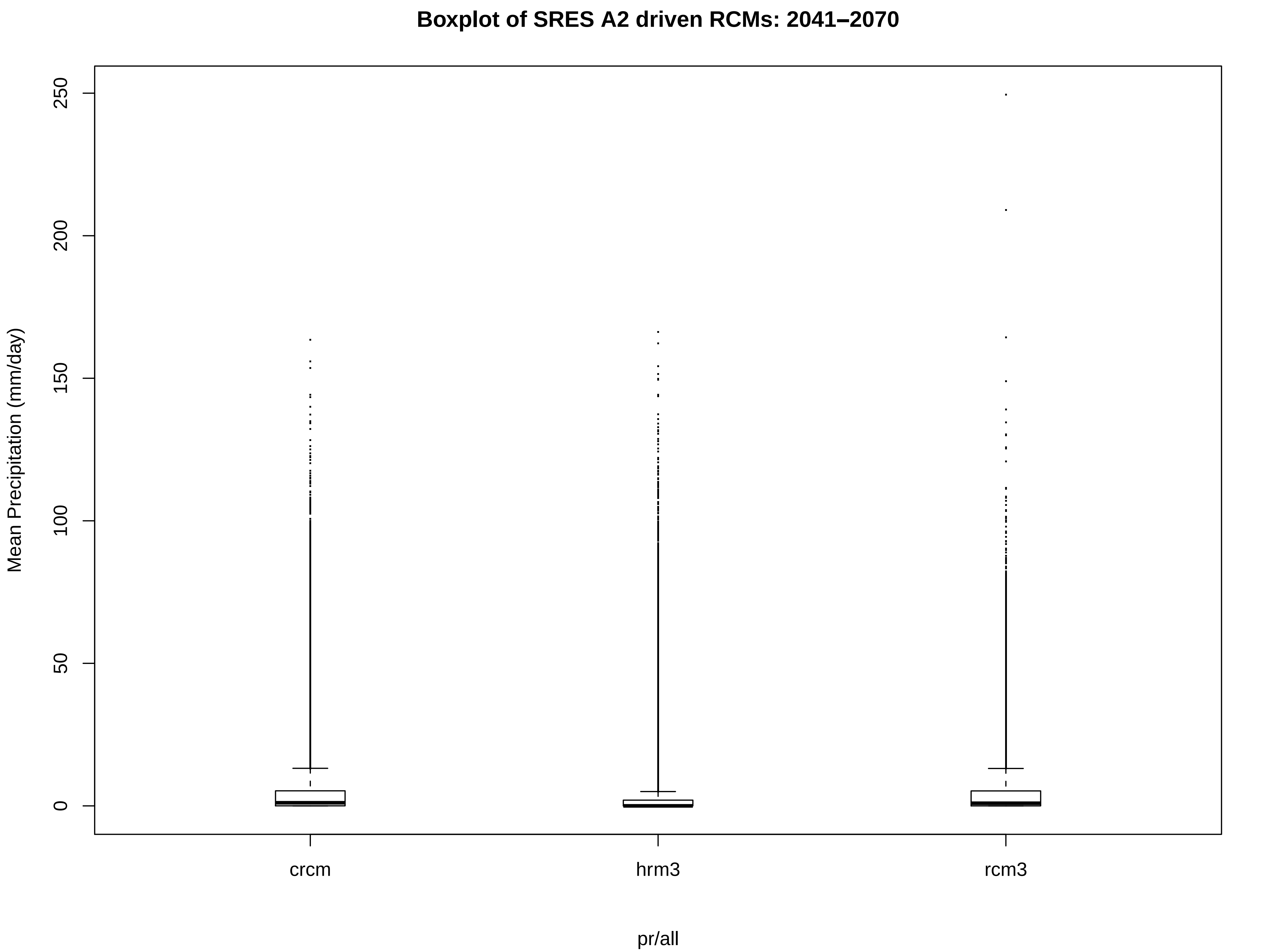
Boxplot of SRES A2 driven RCMs: 2041–2070
Mean Precipitation (mm/day)
0
20
40
60
80
100
120
crcm
hrm3
rcm3
pr/spring

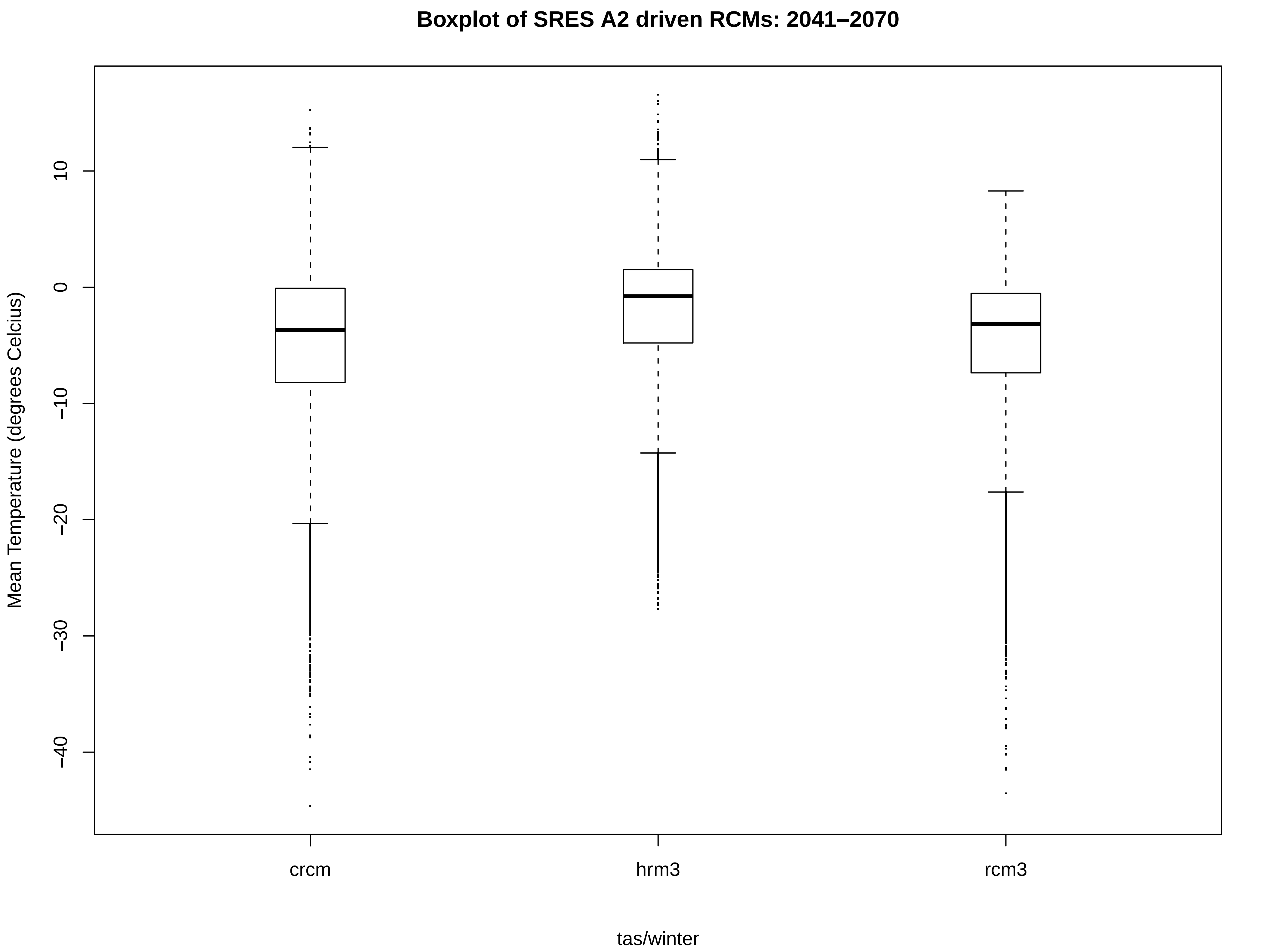


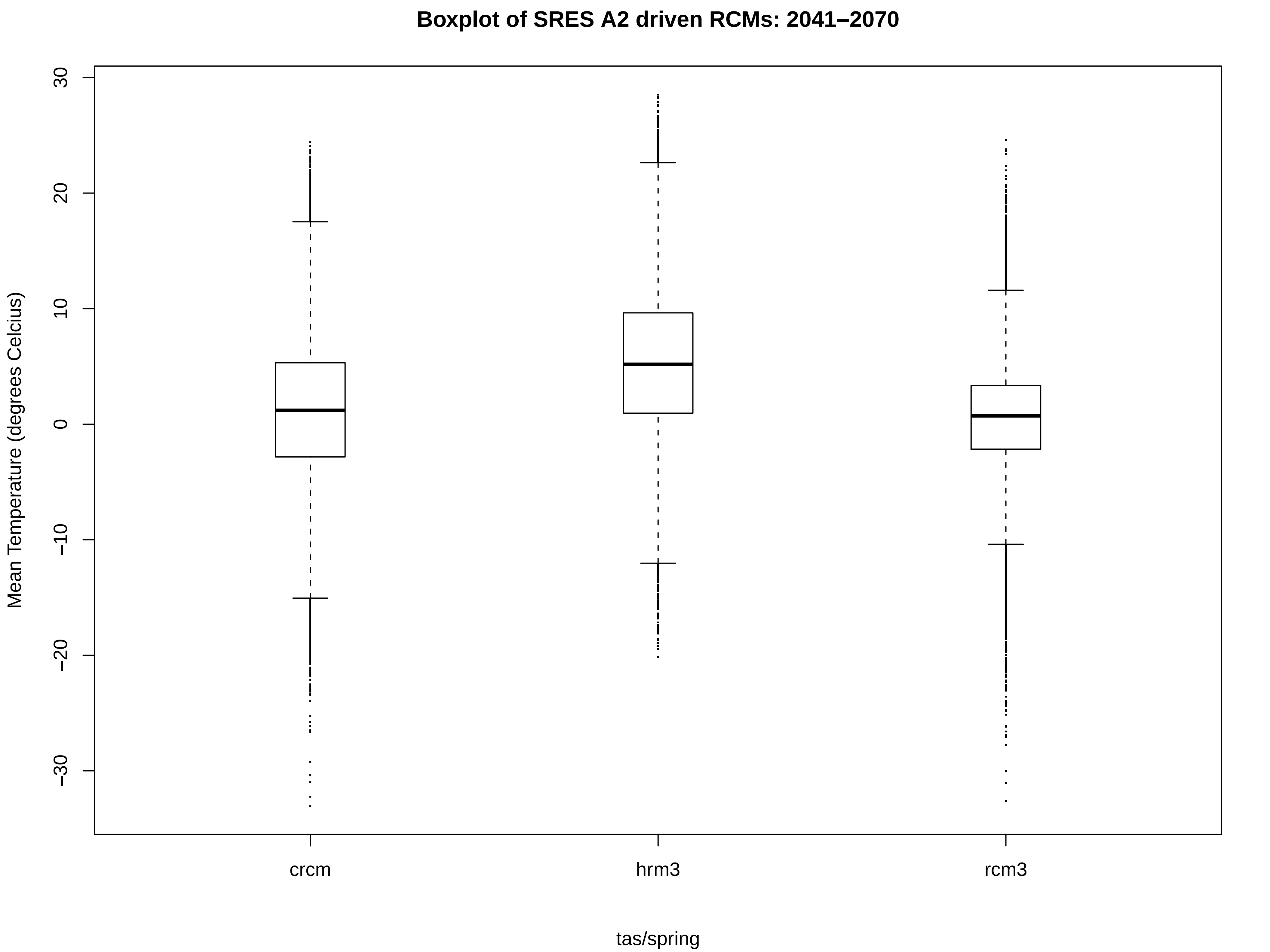
Boxplot of SRES A2 driven RCMs: 2041–2070
Mean Precipitation (mm/day)
0
50
100
150
200
250
crcm
hrm3
rcm3
pr/summer



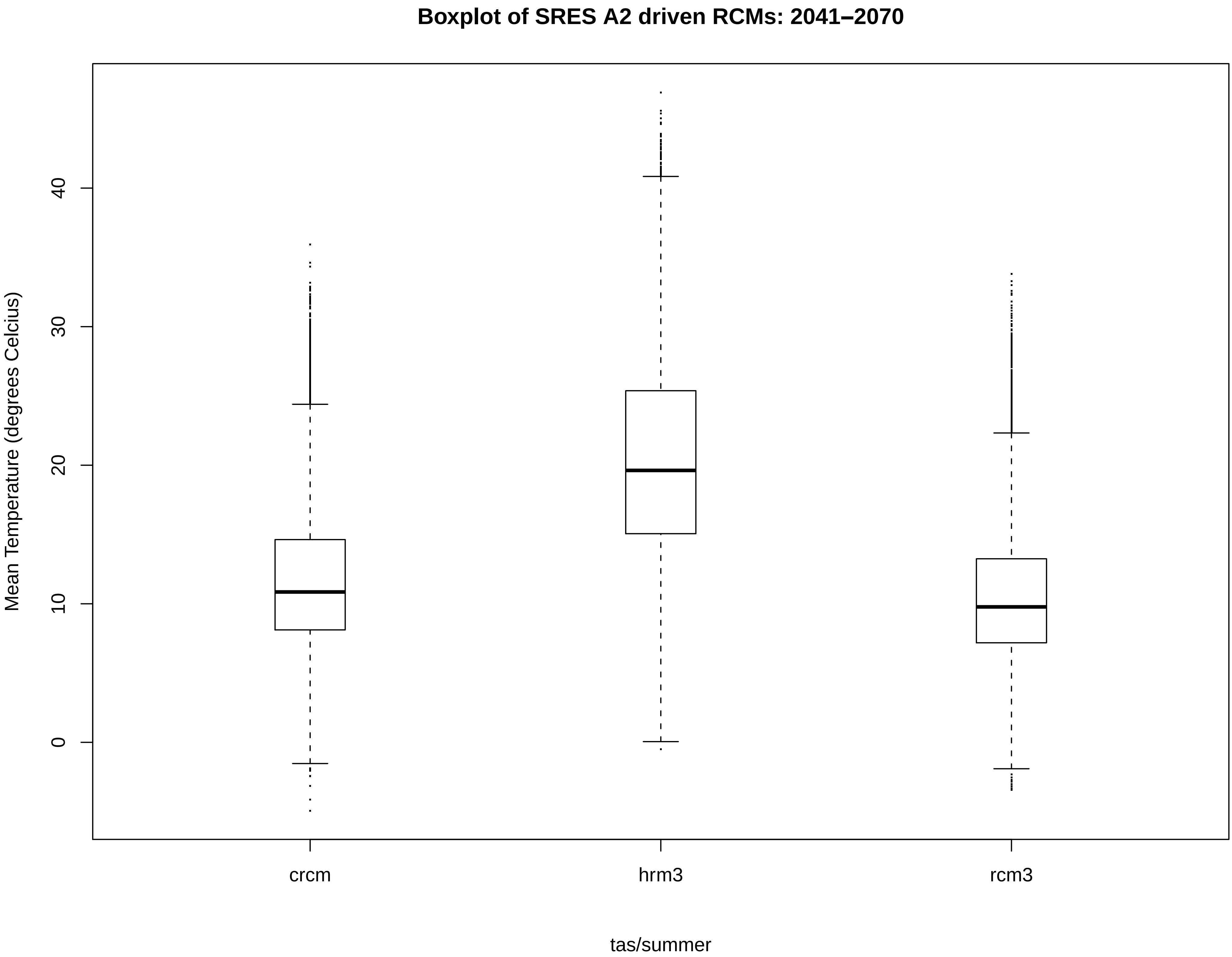
Boxplot of SRES A2 driven RCMs: 2041–2070
Mean Precipitation (mm/day)
0
50
100
150
crcm
hrm3
rcm3
pr/autumn


Boxplot of SRES A2 driven RCMs: 2041–2070
Mean Precipitation (mm/day)
0
50
100
150
200
250
crcm
hrm3
rcm3
pr/all

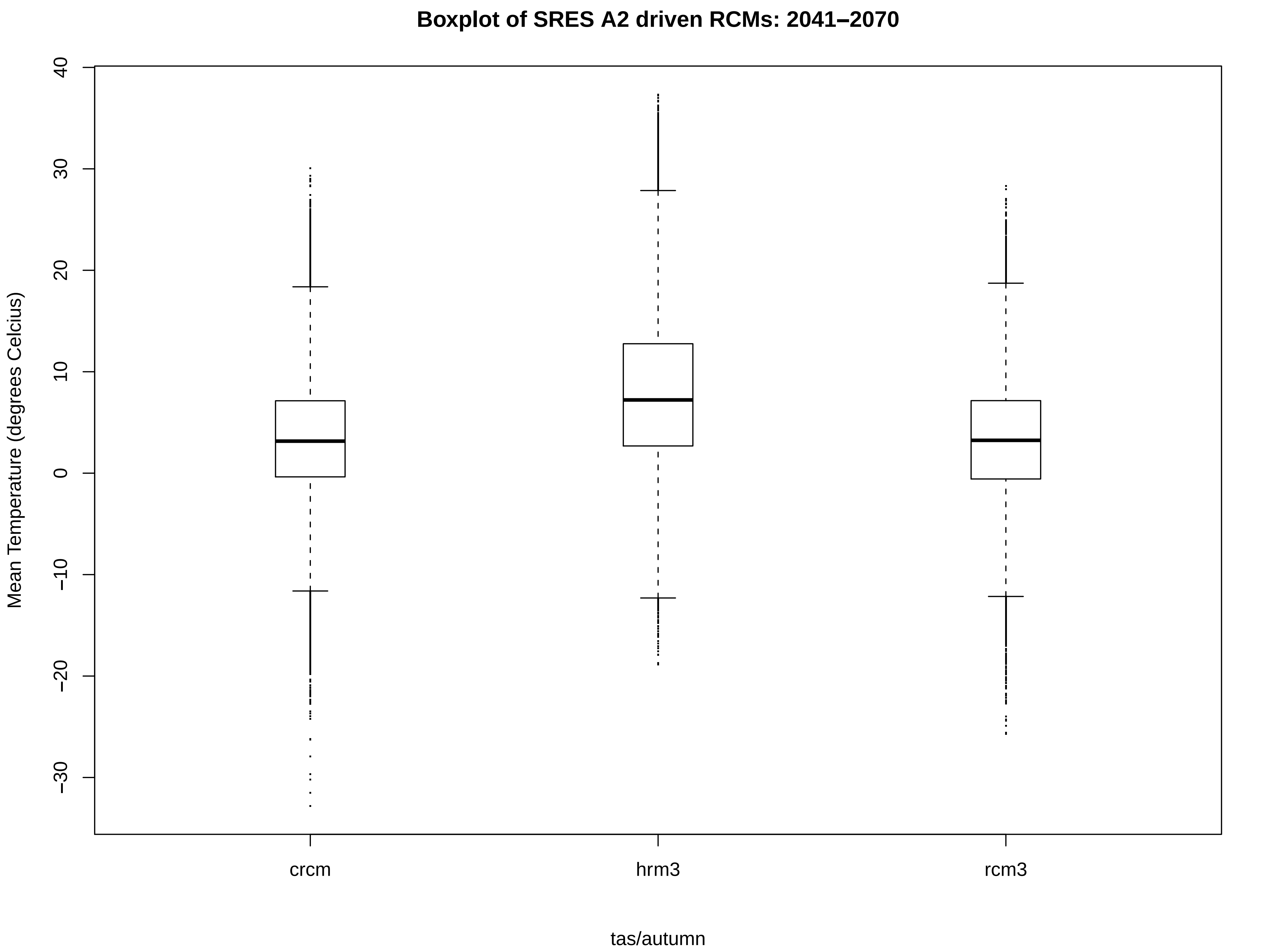

Boxplot of SRES A2 driven RCMs: 2041–2070
Mean Temperature (degrees Celcius)
10
0
−10
−20
−30
−40
crcm
hrm3
rcm3
tas/winter



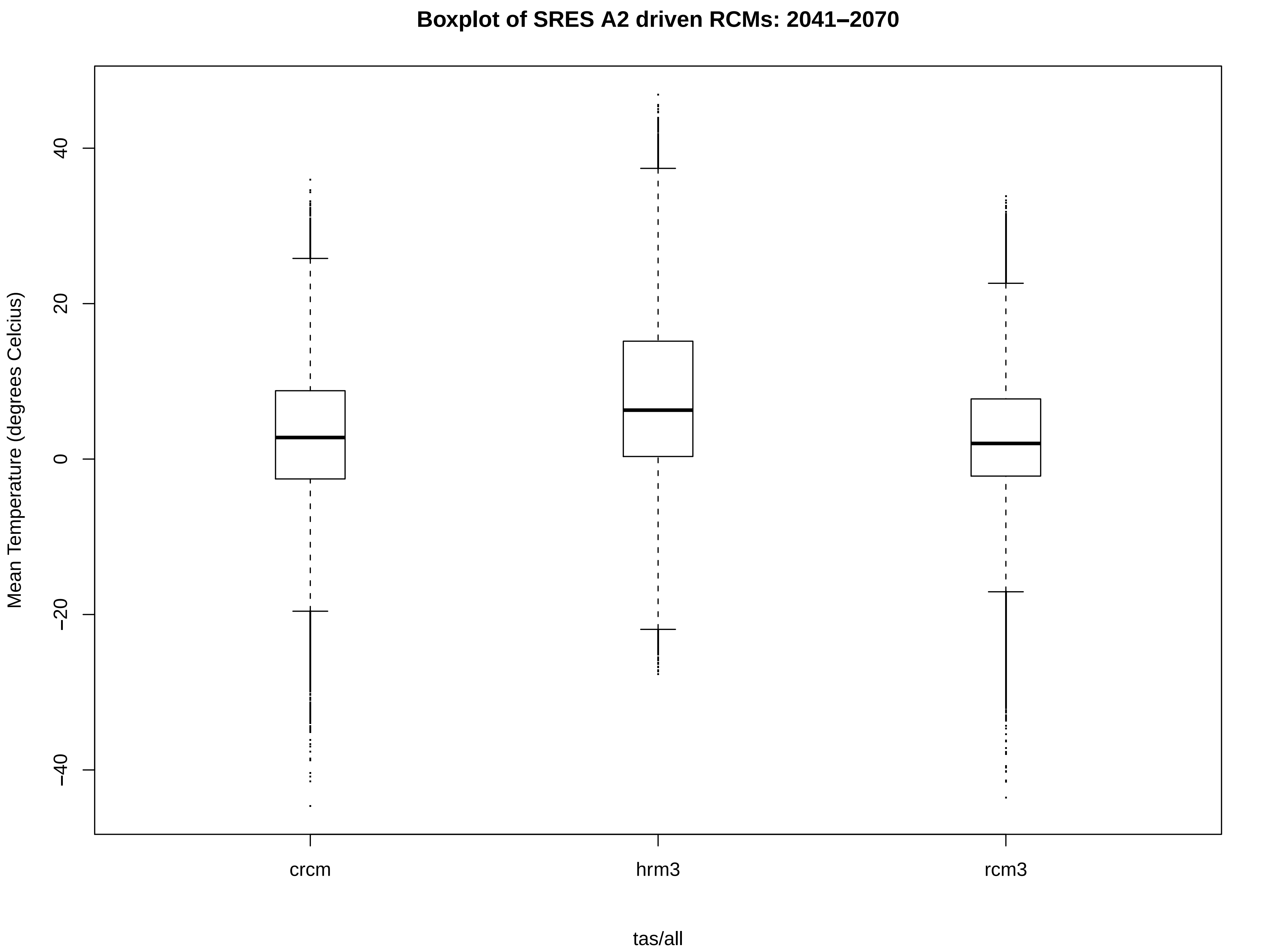
Boxplot of SRES A2 driven RCMs: 2041–2070
Mean Temperature (degrees Celcius)
30
20
10
0
−10
−20
−30
crcm
hrm3
rcm3
tas/spring

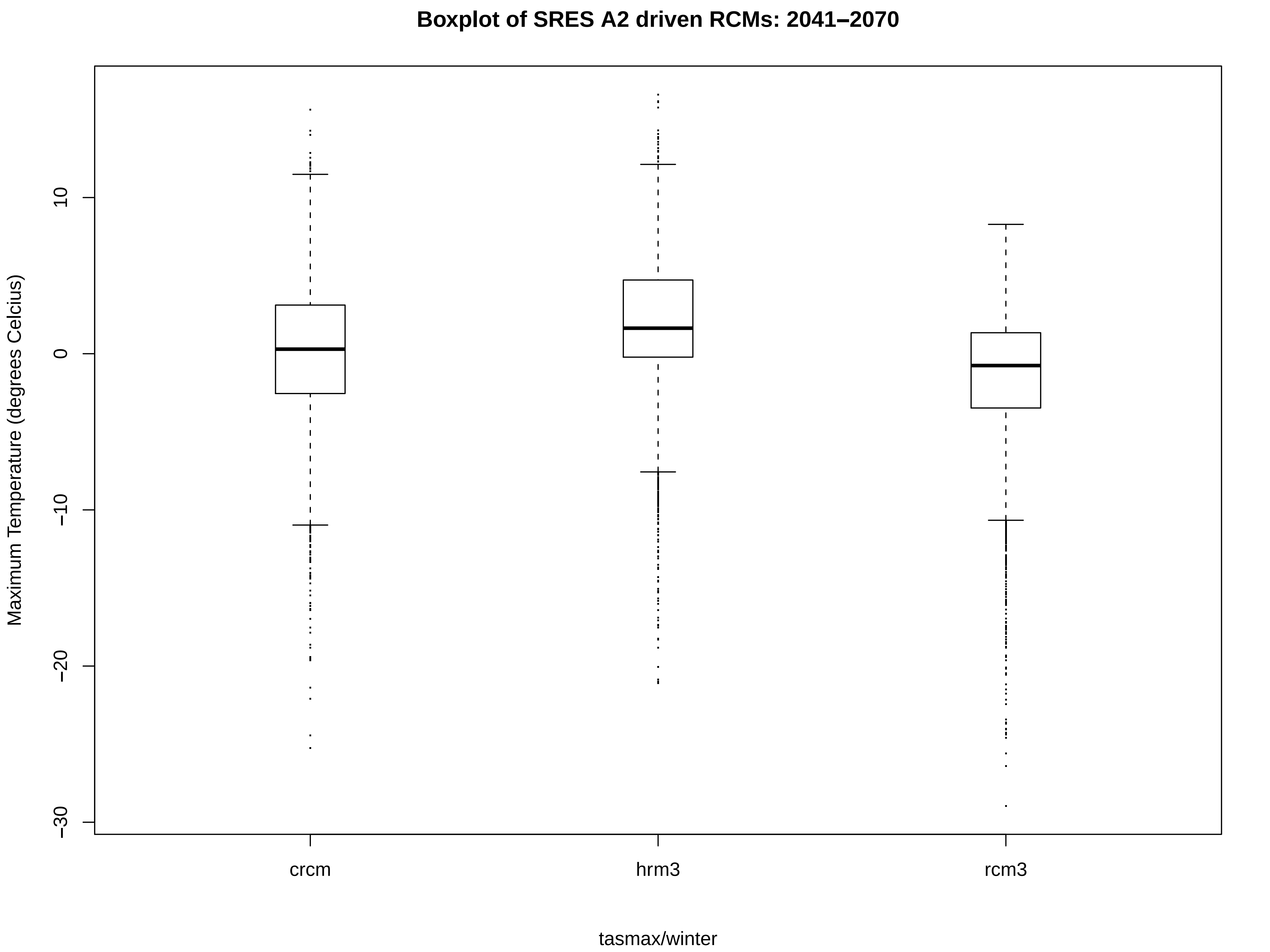


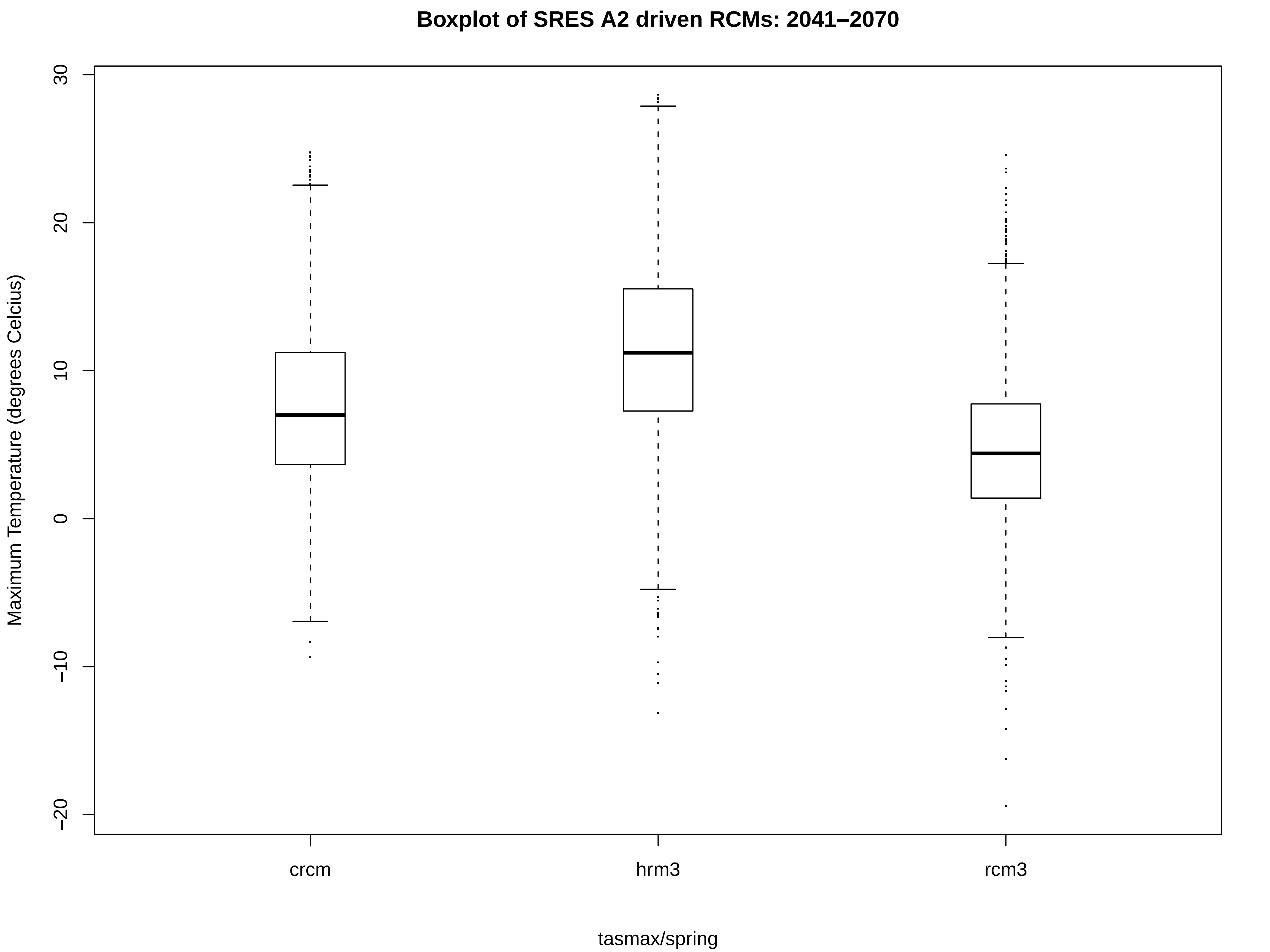
Boxplot of SRES A2 driven RCMs: 2041–2070
Mean Temperature (degrees Celcius)
0
10
20
30
40
crcm
hrm3
rcm3
tas/summer

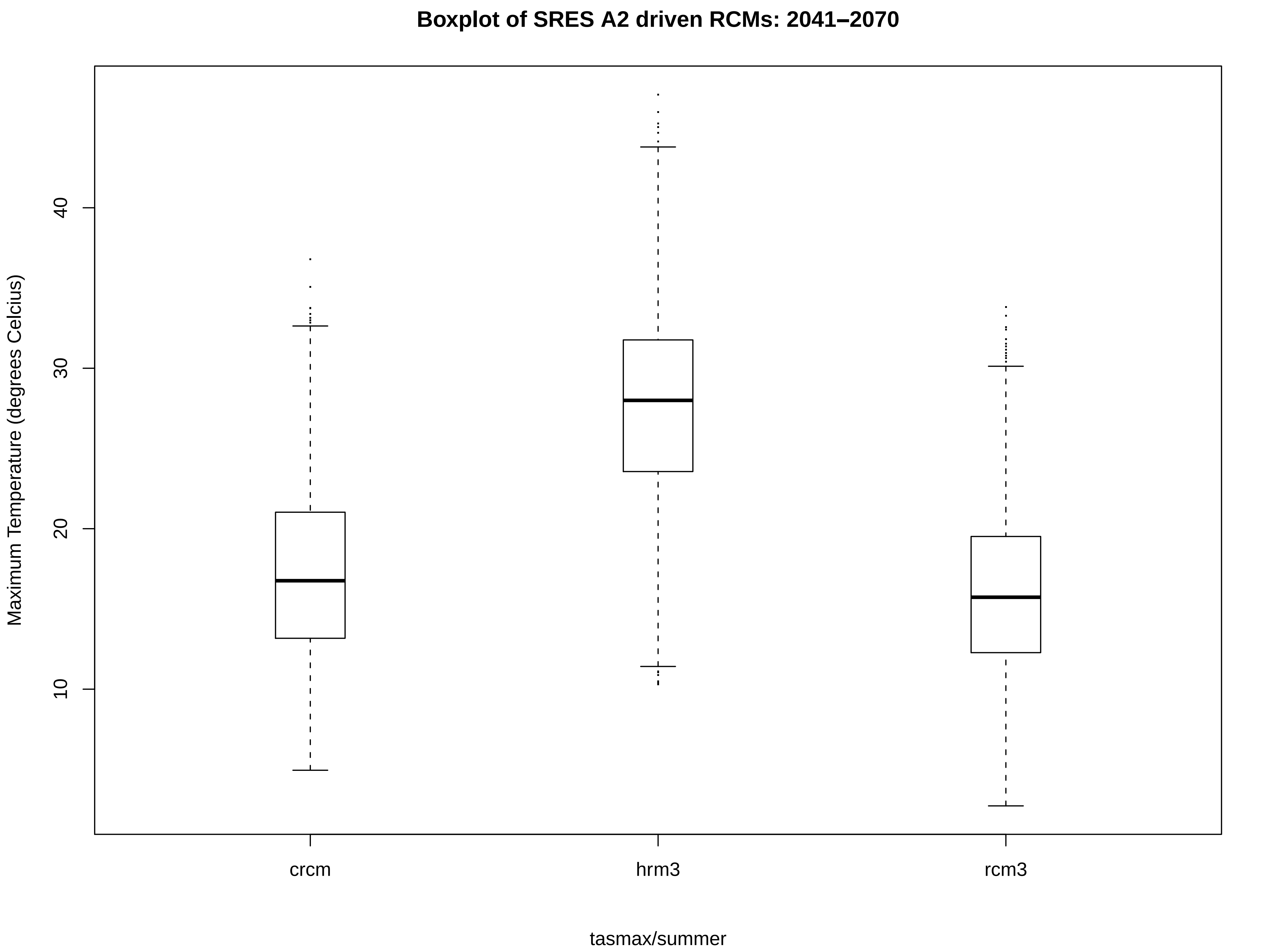


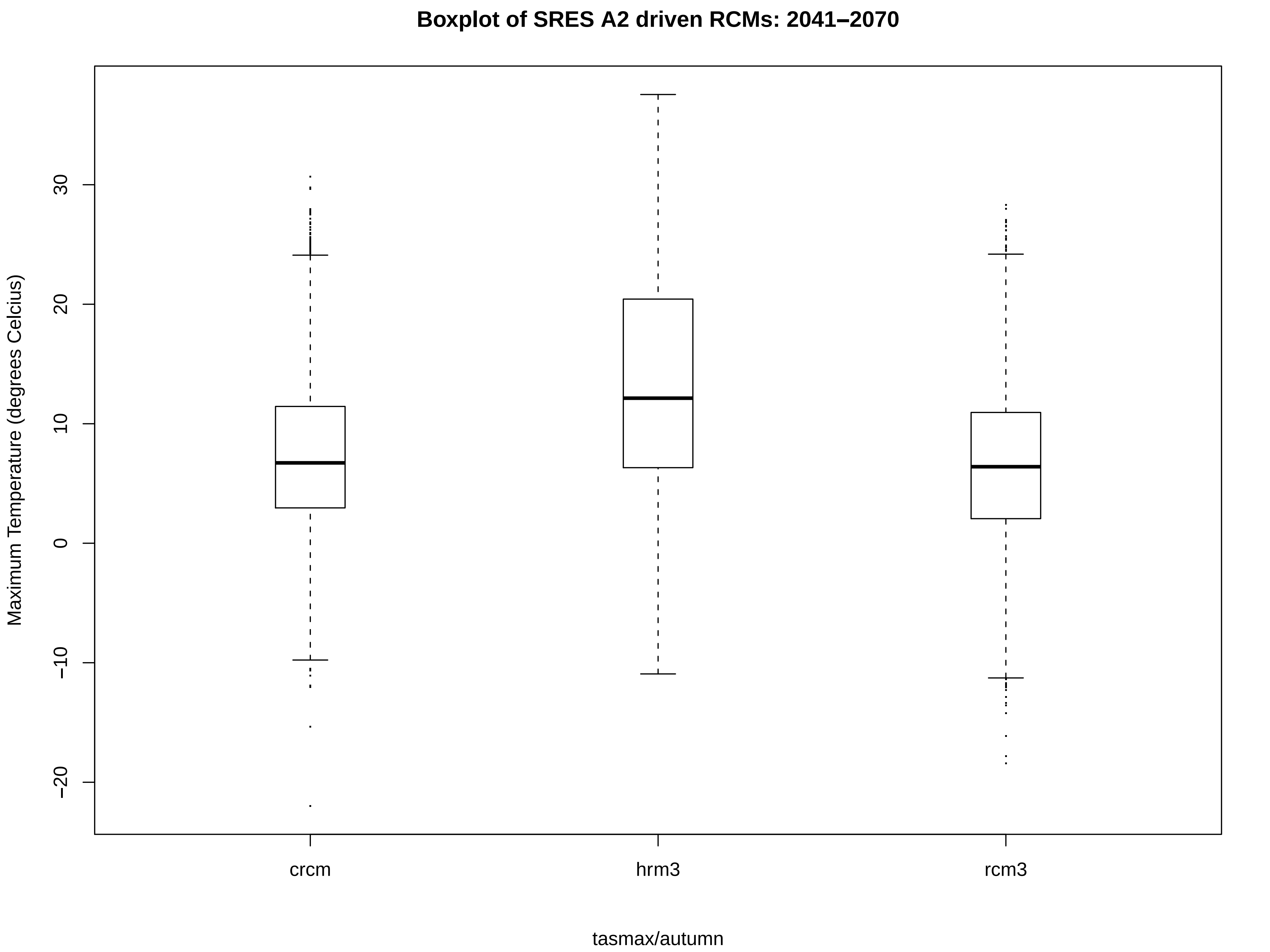
Boxplot of SRES A2 driven RCMs: 2041–2070
Mean Temperature (degrees Celcius)
40
30
20
10
0
−10
−20
−30
crcm
hrm3
rcm3
tas/autumn


Boxplot of SRES A2 driven RCMs: 2041–2070
Mean Temperature (degrees Celcius)
40
20
0
−20
−40
crcm
hrm3
rcm3
tas/all

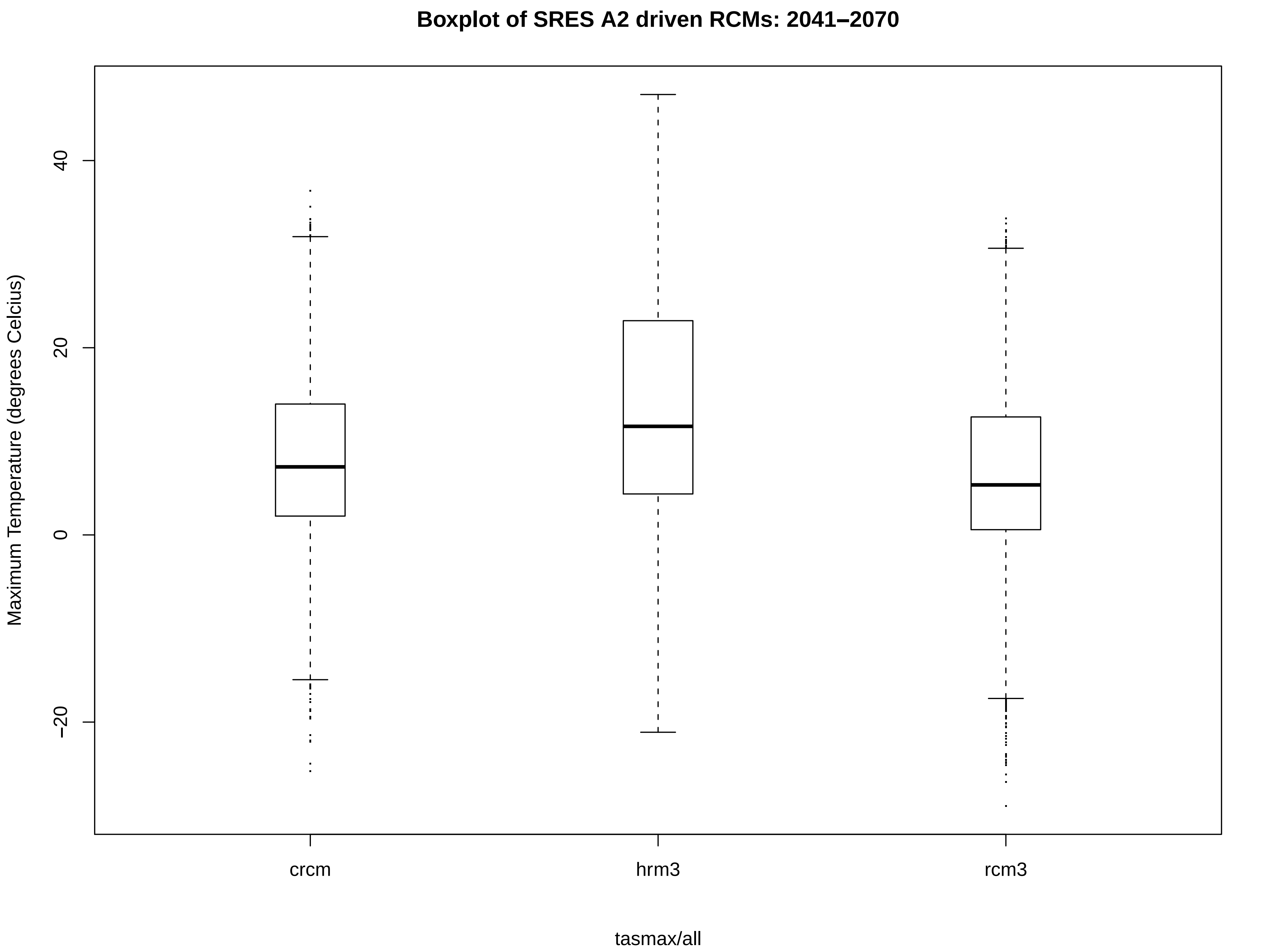

Boxplot of SRES A2 driven RCMs: 2041–2070
Maximum Temperature (degrees Celcius)
10
0
−10
−20
−30
crcm
hrm3
rcm3
tasmax/winter

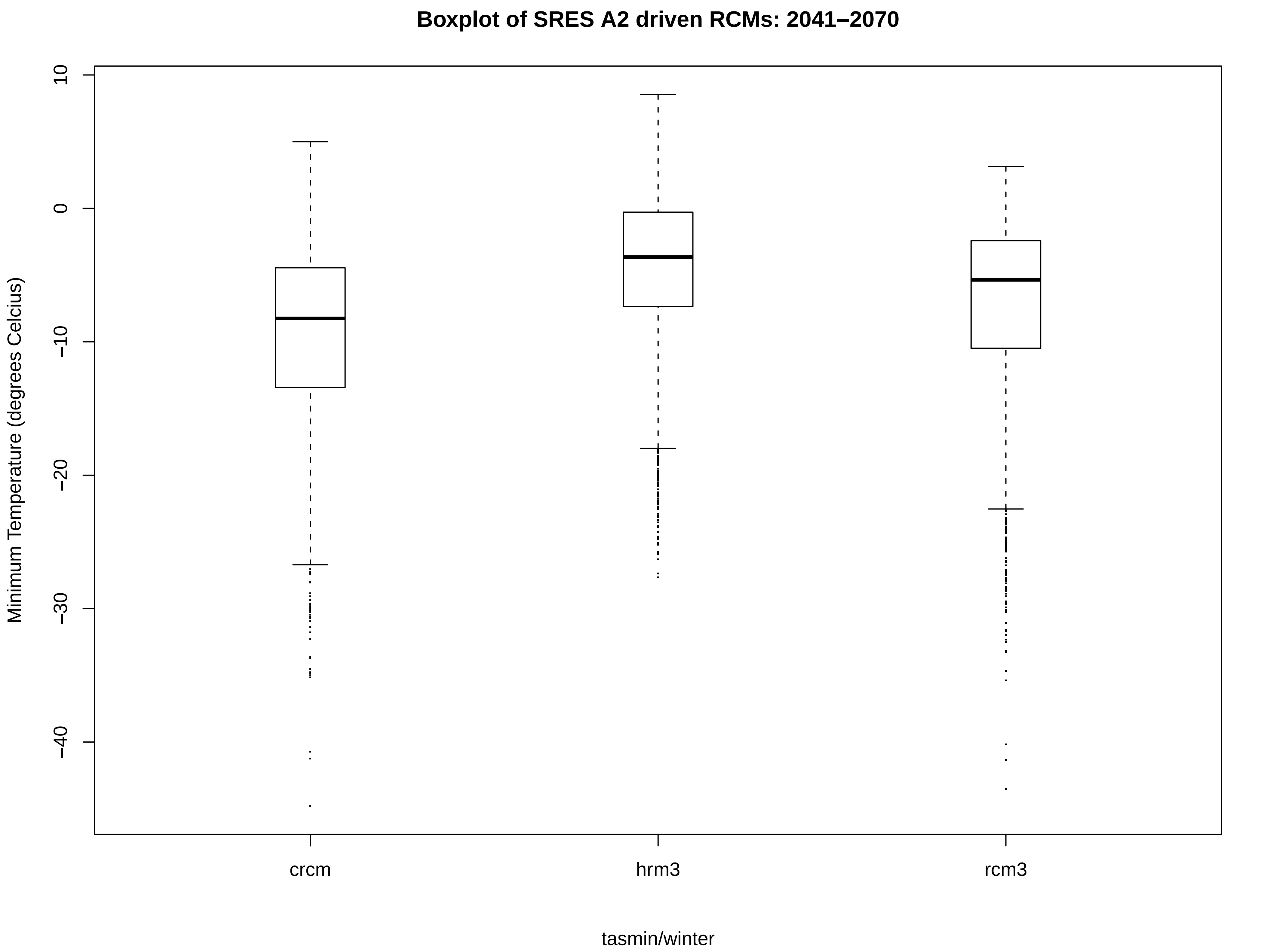

Boxplot of SRES A2 driven RCMs: 2041–2070
Maximum Temperature (degrees Celcius)
30
20
10
0
−10
−20
crcm
hrm3
rcm3
tasmax/spring

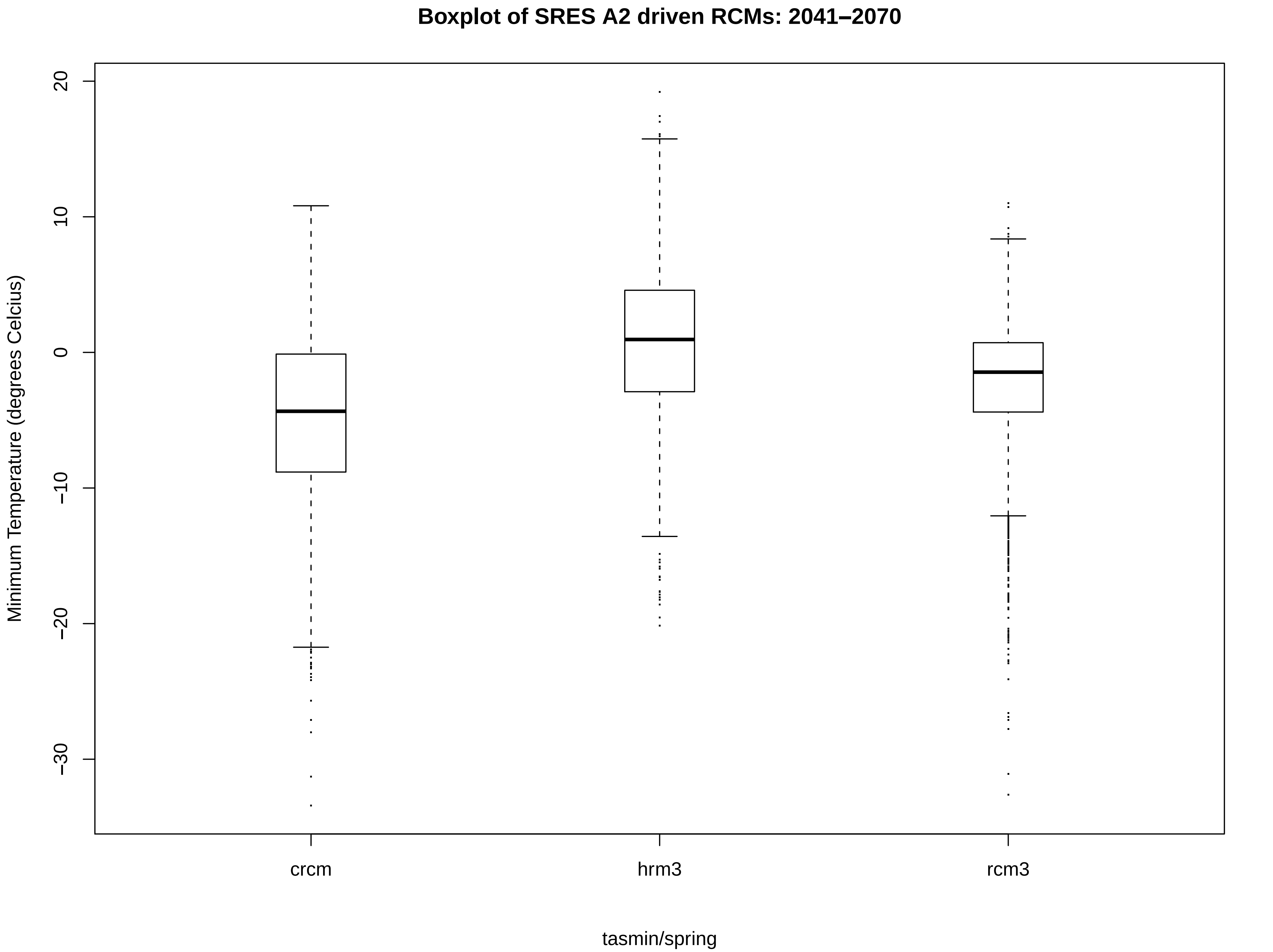

Boxplot of SRES A2 driven RCMs: 2041–2070
Maximum Temperature (degrees Celcius)
10
20
30
40
crcm
hrm3
rcm3
tasmax/summer



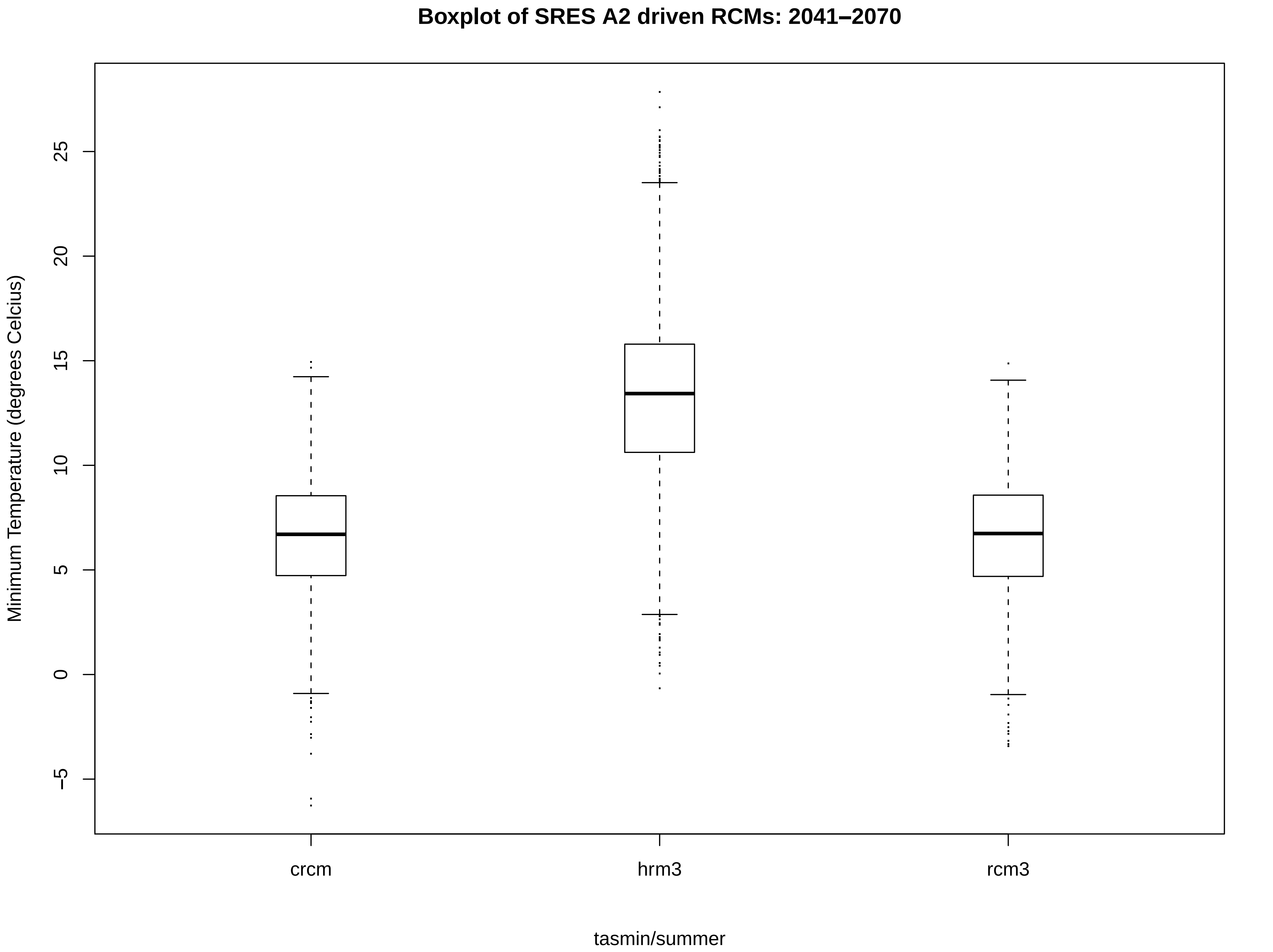
Boxplot of SRES A2 driven RCMs: 2041–2070
Maximum Temperature (degrees Celcius)
30
20
10
0
−10
−20
crcm
hrm3
rcm3
tasmax/autumn


Boxplot of SRES A2 driven RCMs: 2041–2070
Maximum Temperature (degrees Celcius)
40
20
0
−20
crcm
hrm3
rcm3
tasmax/all

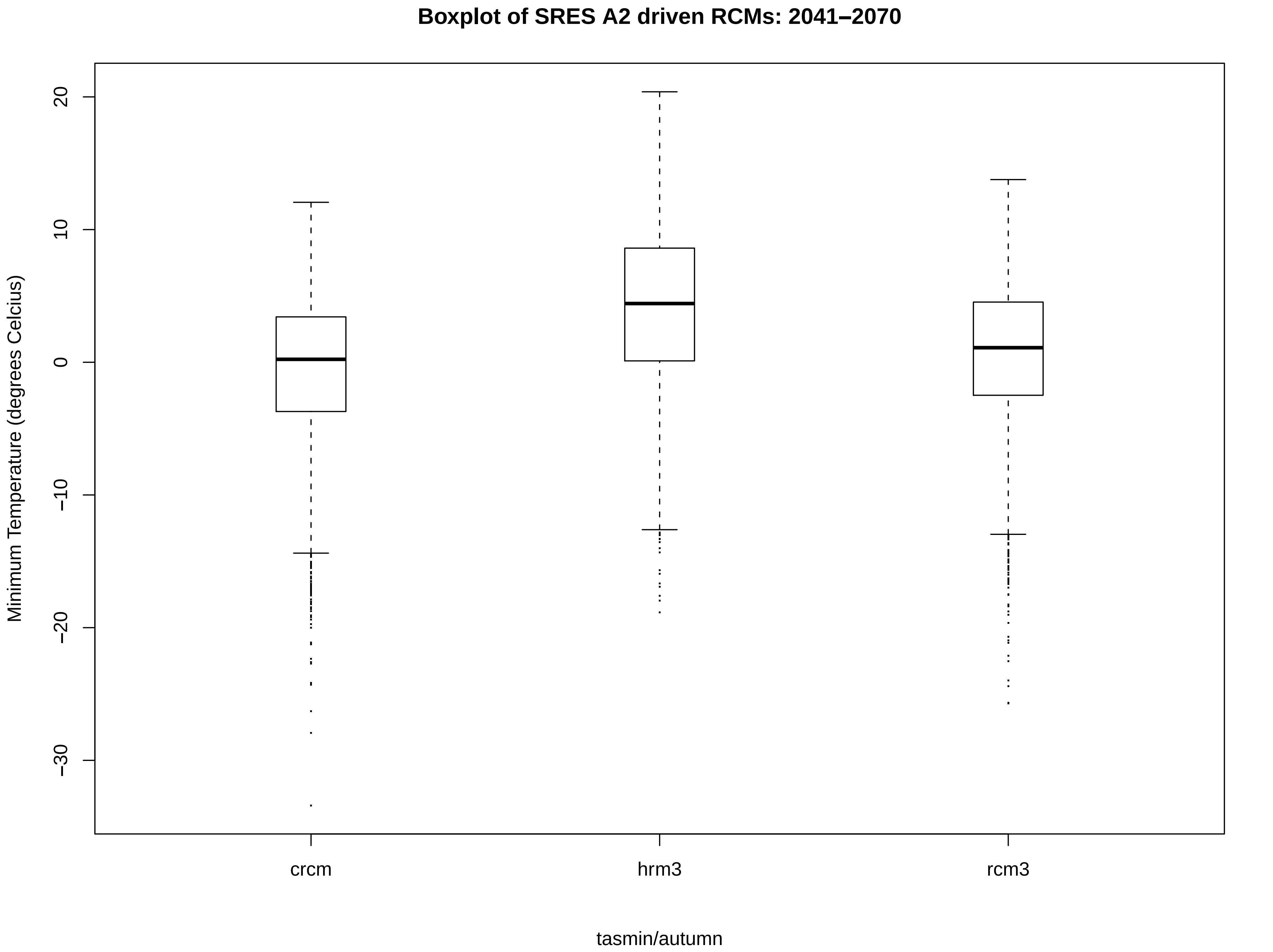

Boxplot of SRES A2 driven RCMs: 2041–2070
Minimum Temperature (degrees Celcius)
10
0
−10
−20
−30
−40
crcm
hrm3
rcm3
tasmin/winter

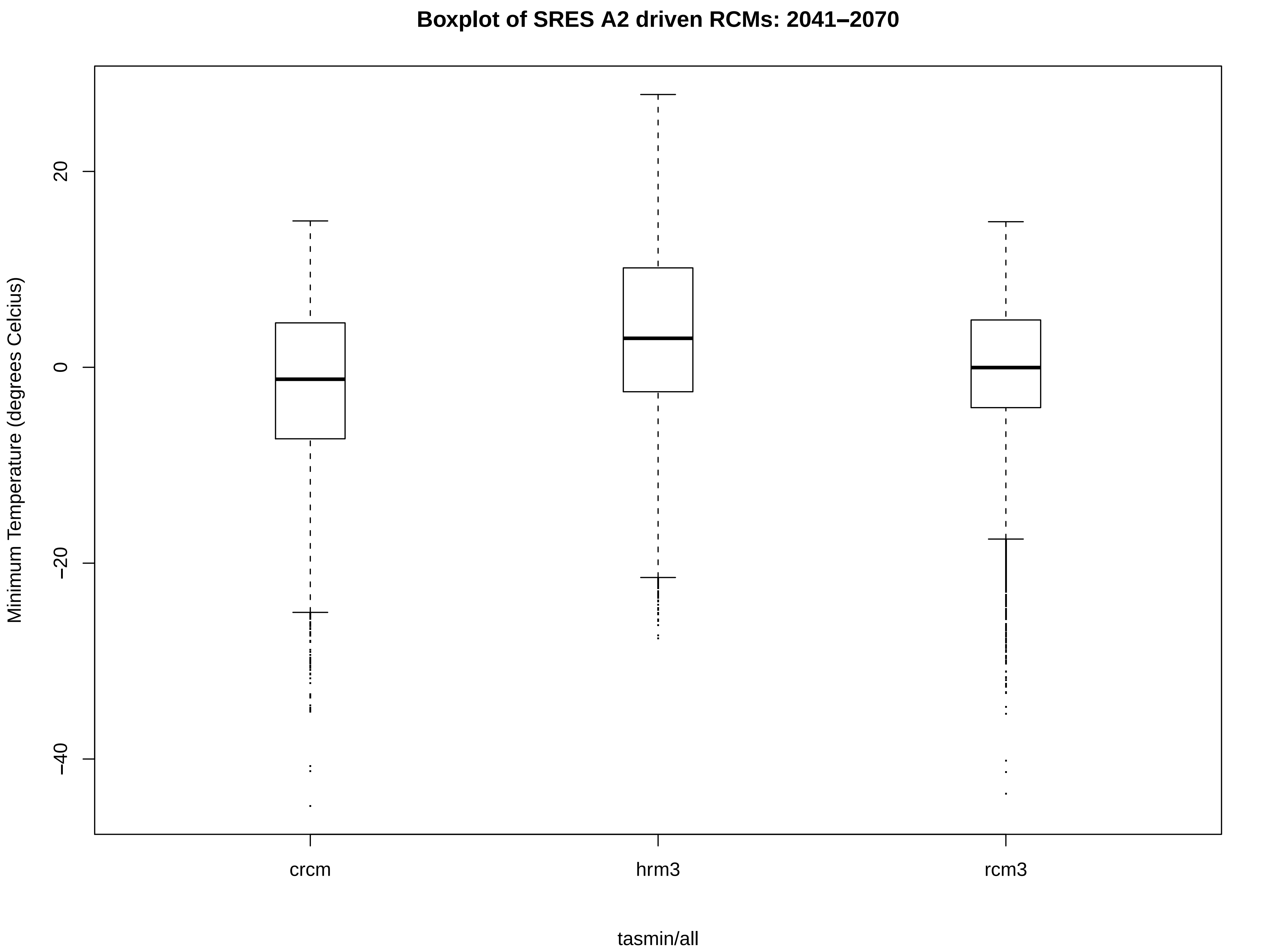


Boxplot of SRES A2 driven RCMs: 2041–2070
Minimum Temperature (degrees Celcius)
20
10
0
−10
−20
−30
crcm
hrm3
rcm3
tasmin/spring

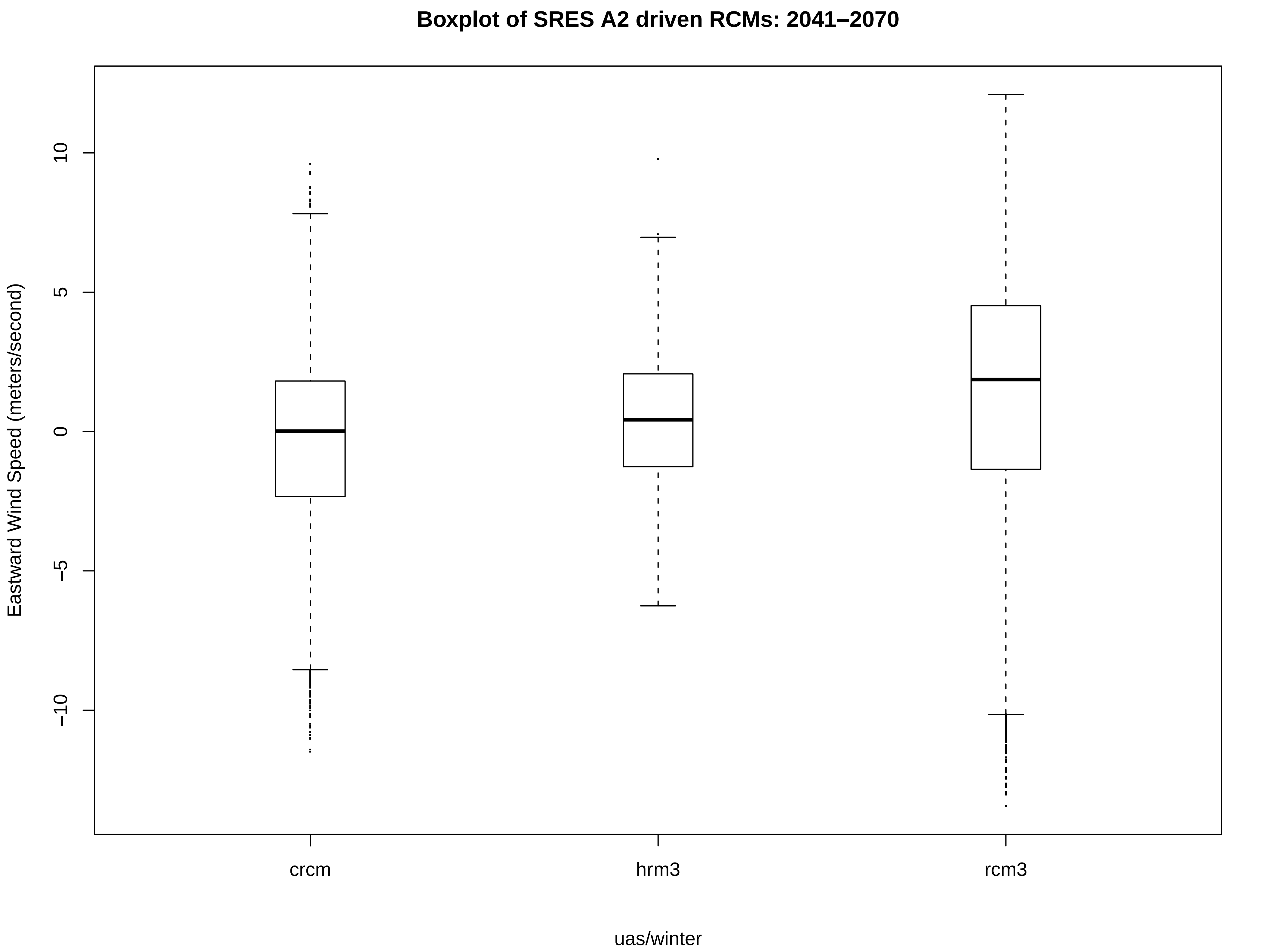


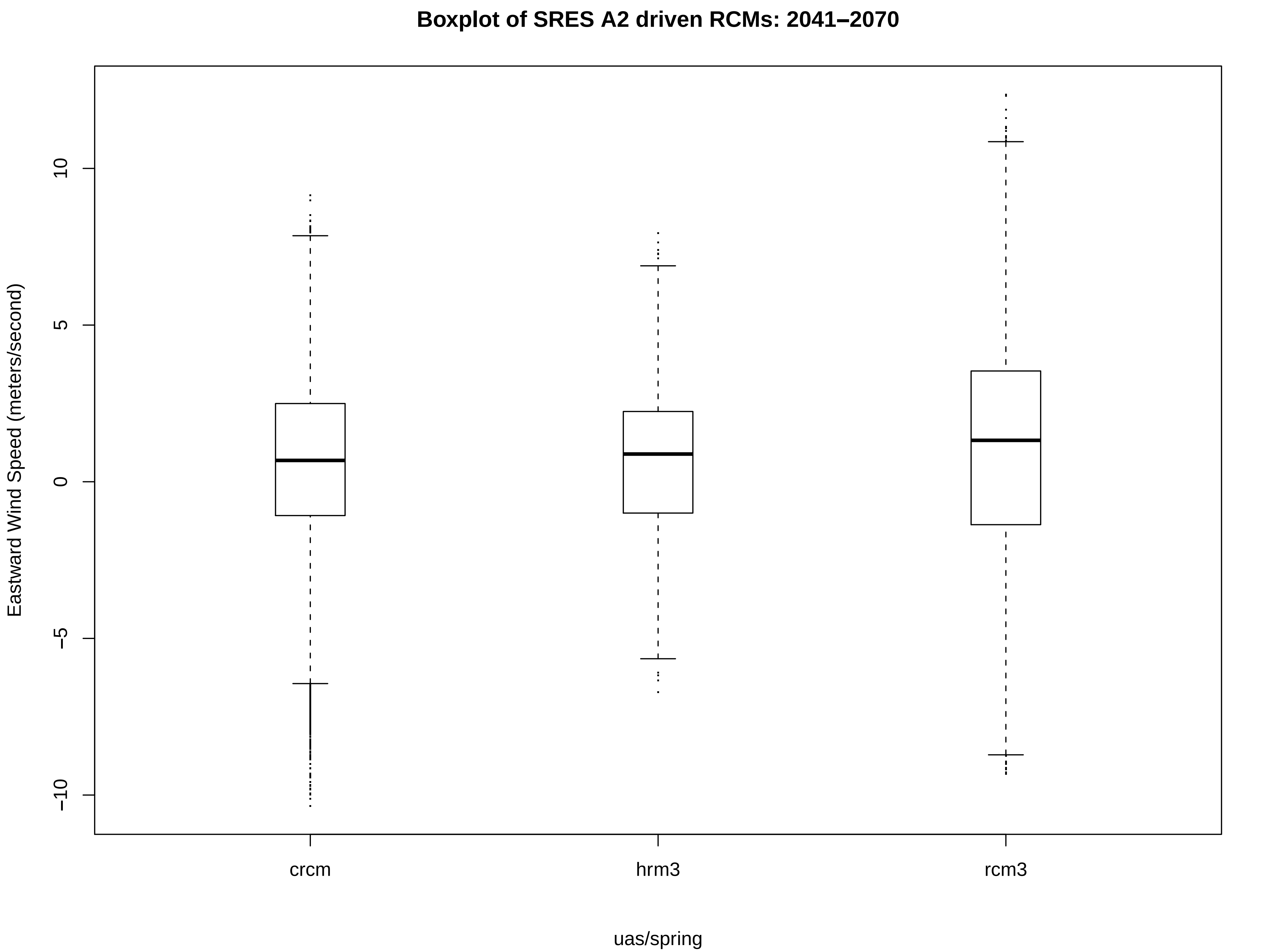
Boxplot of SRES A2 driven RCMs: 2041–2070
Minimum Temperature (degrees Celcius)
−5
0
5
10
15
20
25
crcm
hrm3
rcm3
tasmin/summer

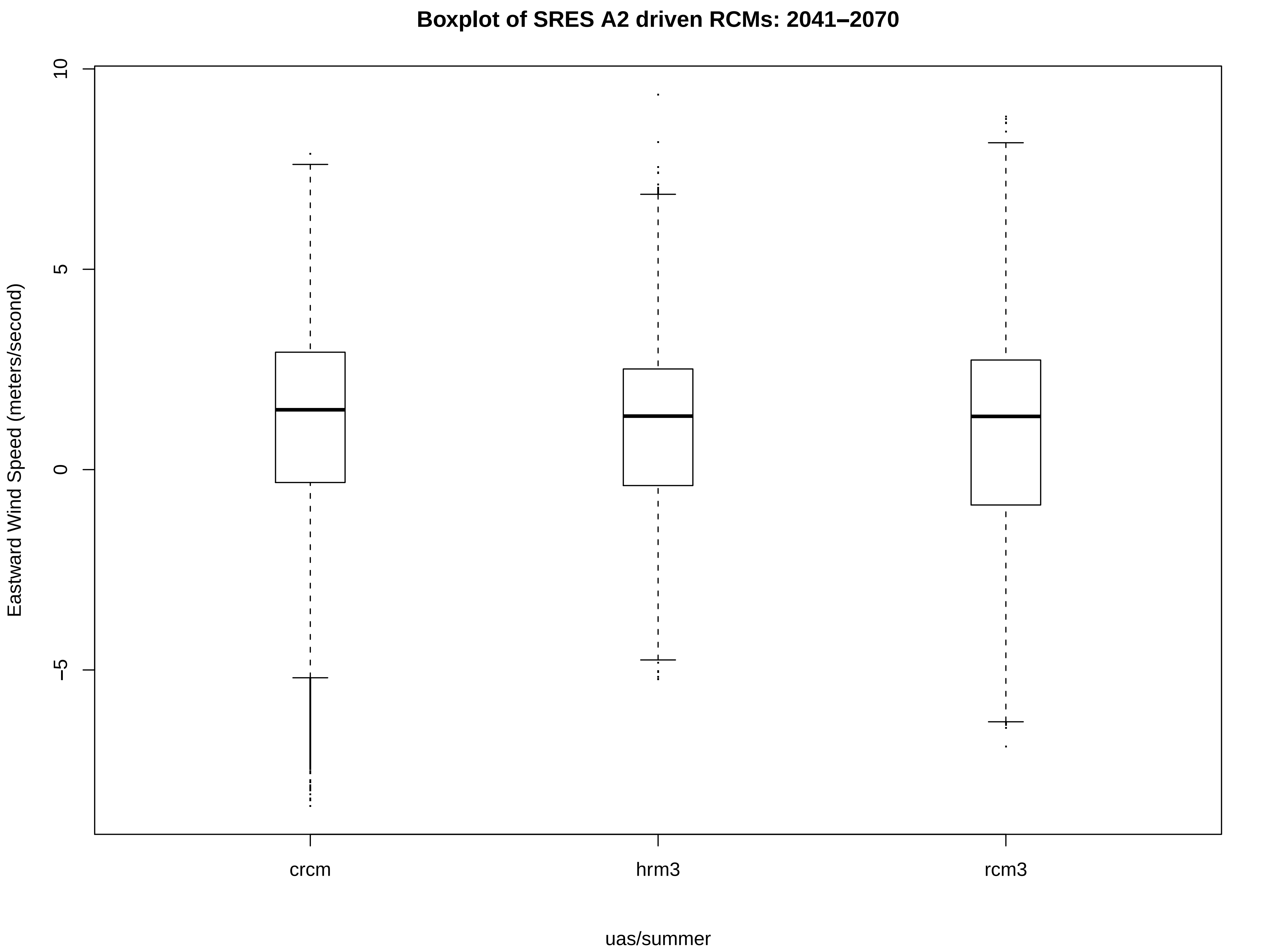

Boxplot of SRES A2 driven RCMs: 2041–2070
Minimum Temperature (degrees Celcius)
20
10
0
−10
−20
−30
crcm
hrm3
rcm3
tasmin/autumn

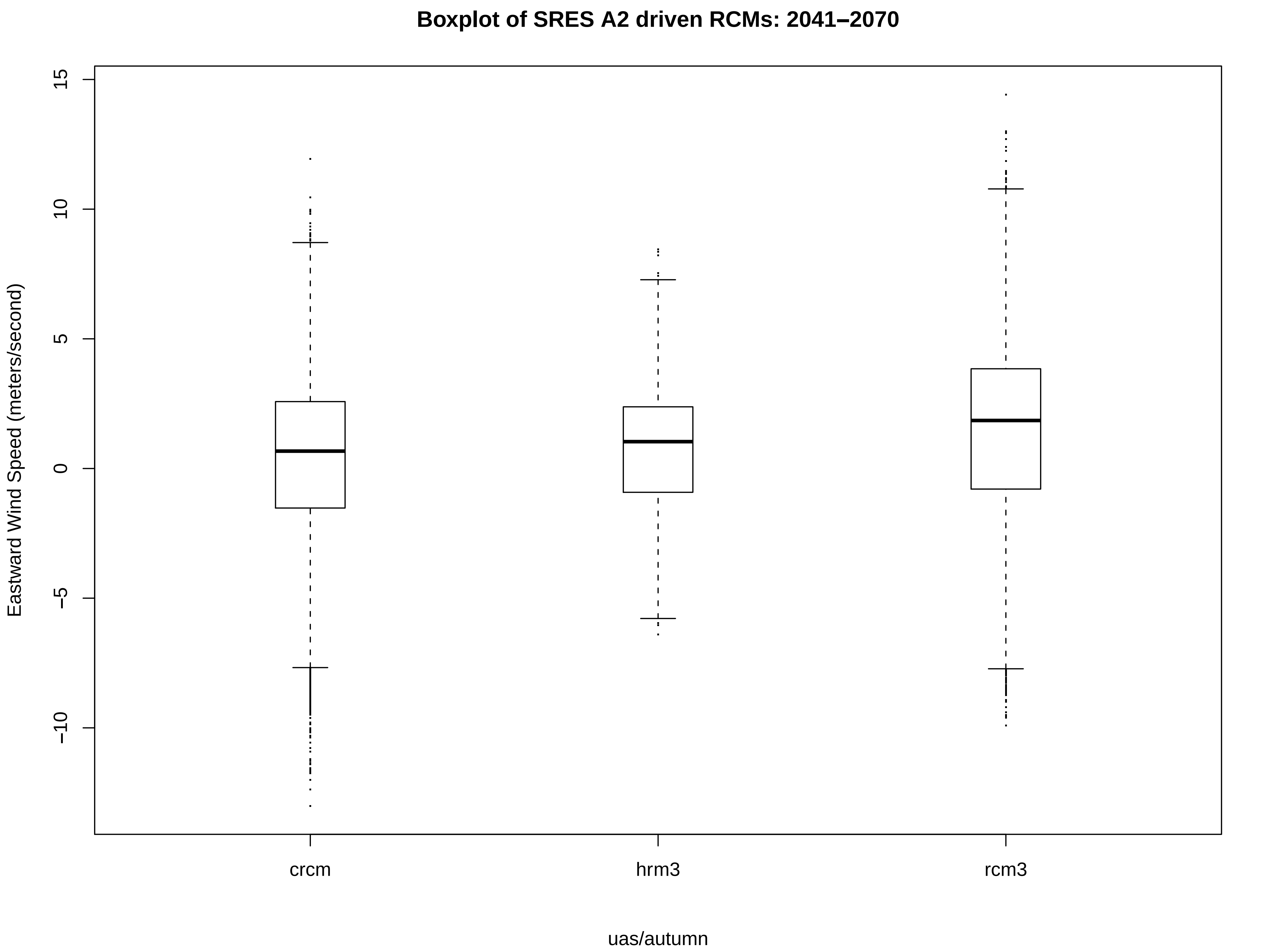


Boxplot of SRES A2 driven RCMs: 2041–2070
Minimum Temperature (degrees Celcius)
20
0
−20
−40
crcm
hrm3
rcm3
tasmin/all

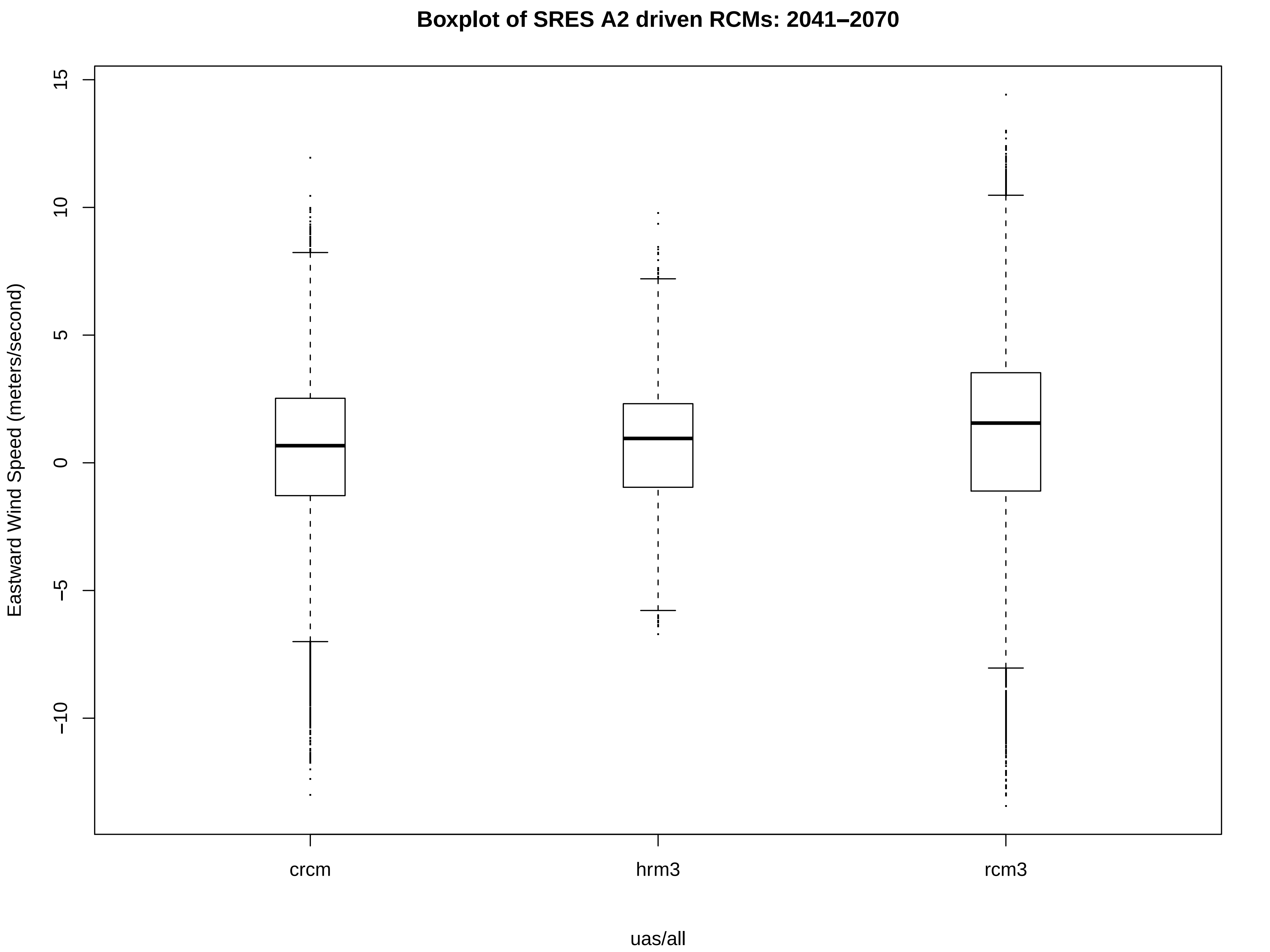

Boxplot of SRES A2 driven RCMs: 2041–2070
Eastward Wind Speed (meters/second)
10
5
0
−5
−10
crcm
hrm3
rcm3
uas/winter

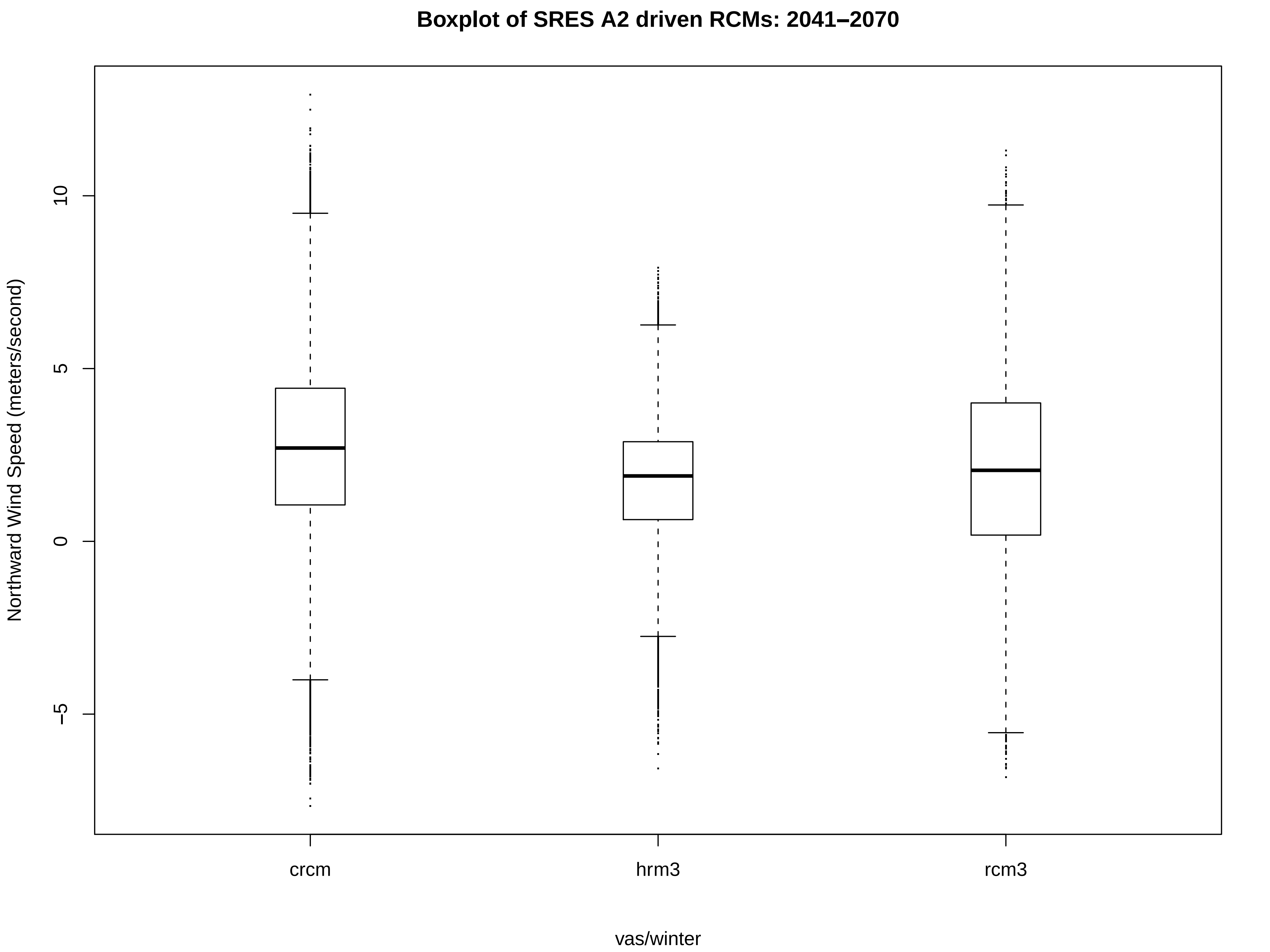

Boxplot of SRES A2 driven RCMs: 2041–2070
Eastward Wind Speed (meters/second)
10
5
0
−5
−10
crcm
hrm3
rcm3
uas/spring


Boxplot of SRES A2 driven RCMs: 2041–2070
Eastward Wind Speed (meters/second)
10
5
0
−5
crcm
hrm3
rcm3
uas/summer

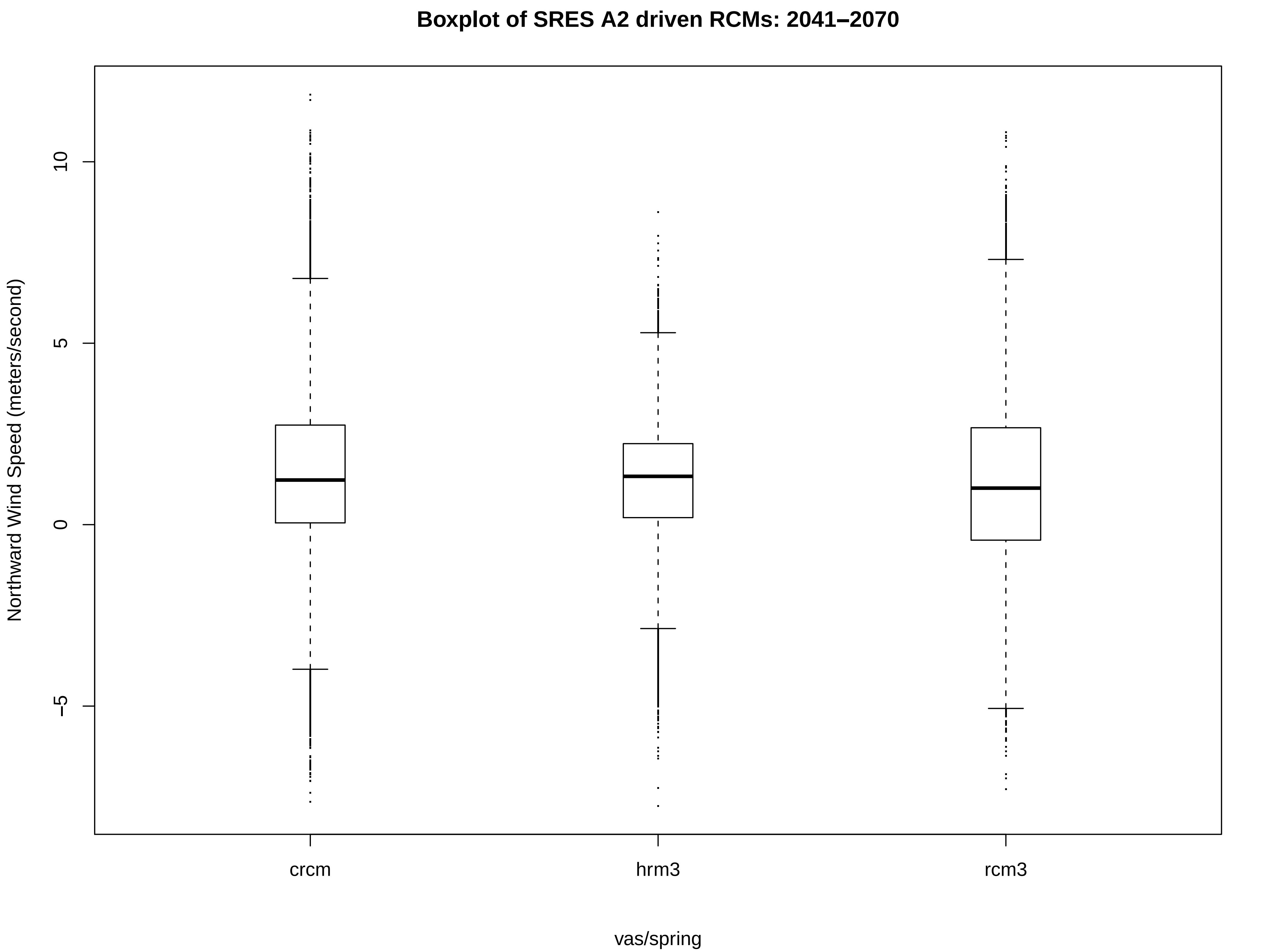


Boxplot of SRES A2 driven RCMs: 2041–2070
Eastward Wind Speed (meters/second)
15
10
5
0
−5
−10
crcm
hrm3
rcm3
uas/autumn

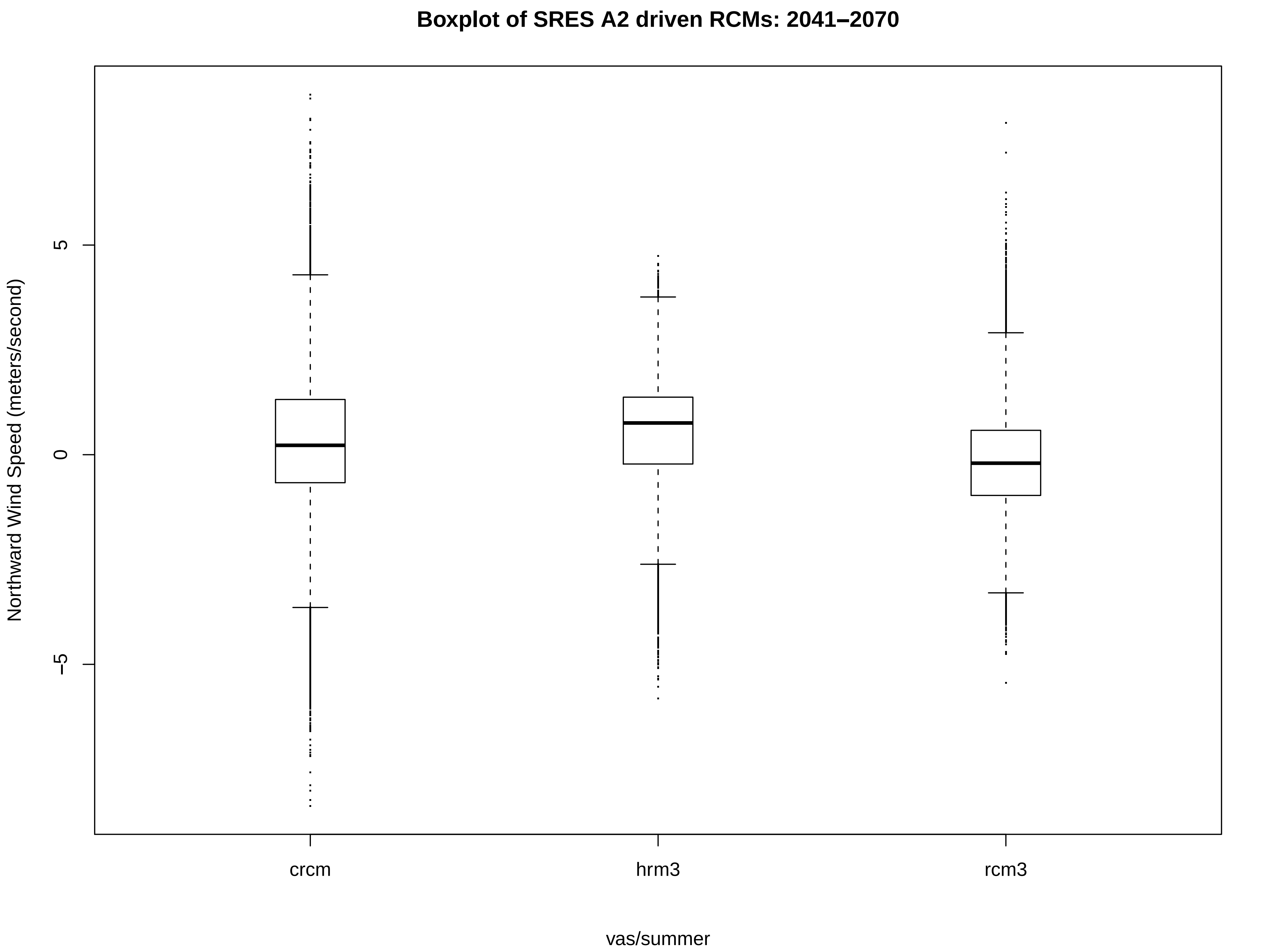

Boxplot of SRES A2 driven RCMs: 2041–2070
Eastward Wind Speed (meters/second)
15
10
5
0
−5
−10
crcm
hrm3
rcm3
uas/all



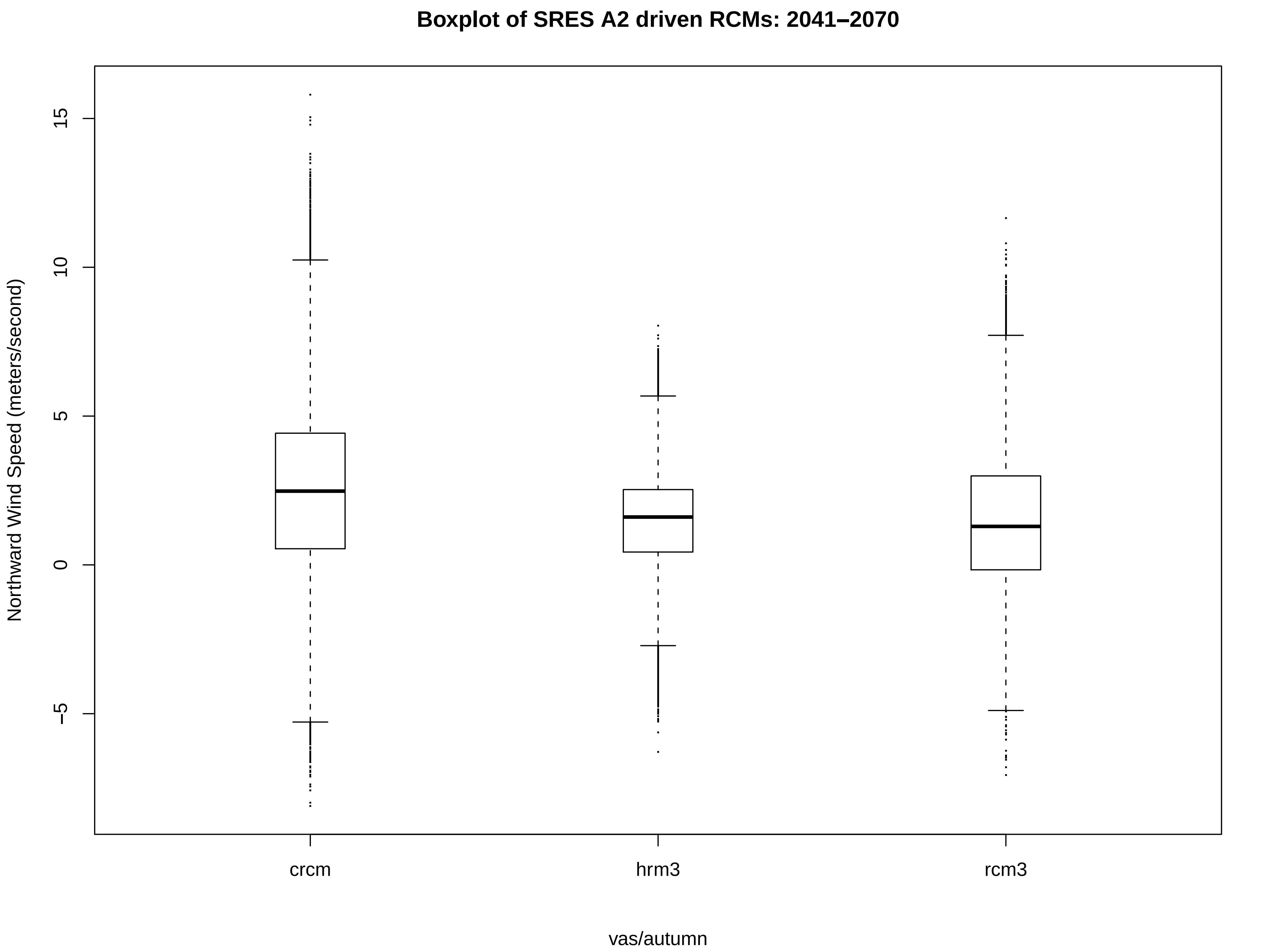
Boxplot of SRES A2 driven RCMs: 2041–2070
Northward Wind Speed (meters/second)
10
5
0
−5
crcm
hrm3
rcm3
vas/winter

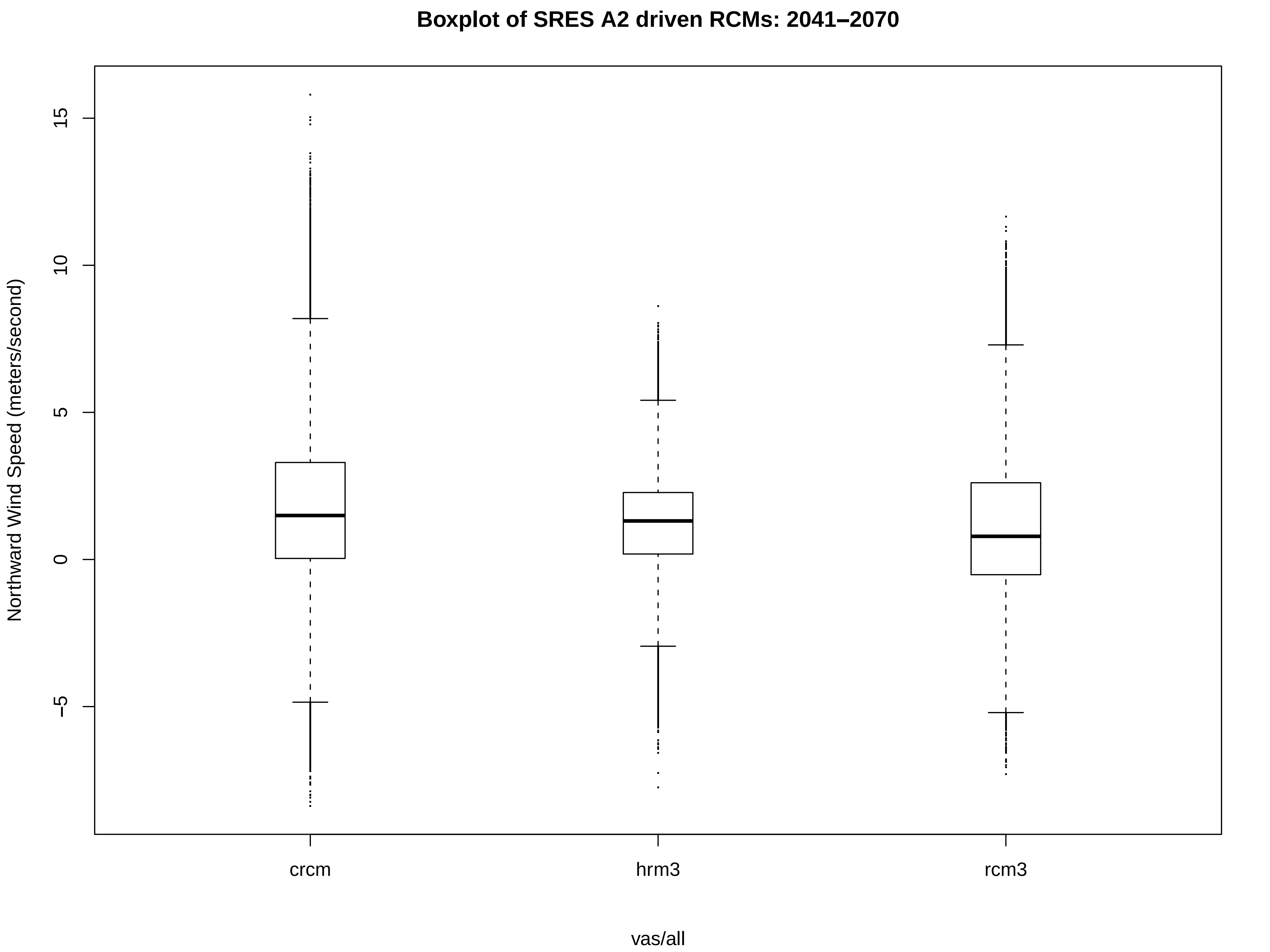


Boxplot of SRES A2 driven RCMs: 2041–2070
Northward Wind Speed (meters/second)
10
5
0
−5
crcm
hrm3
rcm3
vas/spring



Boxplot of SRES A2 driven RCMs: 2041–2070
Northward Wind Speed (meters/second)
5
0
−5
crcm
hrm3
rcm3
vas/summer


Boxplot of SRES A2 driven RCMs: 2041–2070
Northward Wind Speed (meters/second)
15
10
5
0
−5
crcm
hrm3
rcm3
vas/autumn


Boxplot of SRES A2 driven RCMs: 2041–2070
Northward Wind Speed (meters/second)
15
10
5
0
−5
crcm
hrm3
rcm3
vas/all

Appendix F

Completed Protocol Worksheet 3

#	Infrastructure Components	Structural Design	Functionality	Watershed, Surface Water, and Groundwater	Operations, Maintenance, and Materials Performance	Emergency Response	Insurance Considerations	Policy / Guidelines / Standards	Social Effects	Public Health & Safety	Environmental Effect
	Infrastructure										
1	Surface - Asphalt	x	x	x	x			x	x	x	
2	Pavement Marking		x		x			x	x	x	
3	Shoulders (Including Gravel)		x	x	x	x		x		x	
4	Barriers		x	x	x	x	x	x	x	x	
5	Curb		x	x	x			x			
6	Luminaires		x		x		x	x		x	
7	Poles	x	x		x	x	x	x		x	
8	Signage - Side Mounted - Over 3.2 m2	x	x		x	x	x	x		x	
9	Signage - Overhead Guide Signs	x	x		x	x	x	x		x	
10	Overhead Changeable Message Signs	x	x		x	x	x	x		x	
11	Ditches	x	x	x	x	x	x	x		x	x
12	Embankments/Cuts (Constructed)	x	x	x	x	x	x	x		x	x
13	Hillsides (Natural)	x	x	x	x	x	x	x		x	x
14	Engineered Stabilization Works	x	x	x	x	x	x	x	x	x	x
15	Avalanche (Inc Protective Works)	x	x	x	x	x	x	x	x	x	x
16	Debris Torrents (Inc Protective Works)	x	x	x	x	x	x	x	x	x	x
17	Structures that Cross Streams	x	x	x	x	x	x	x	x	x	x
18	Structures that Cross Roads	x	x	x	x	x	x	x	x	x	
19	River Training Works (Rip Rap)	x	x	x	x	x	x	x	x	x	x
20	MSE Walls	x	x	x	x	x	x	x	x	x	x
21	Pavement Structure above Sub-Grade	x	x		x			x		x	x

#	Infrastructure Components	1 High Temperature: Day(s) with max. temp. exceeding 35°C Y/N	P	S	R	Justification Comments	2 Low Temperature: Day(s) with min. temp. below -30°C Y/N	P	S	R	Justification Comments
1	Surface - Asphalt	Y	6	3	18	Can lead to rutting. VOC loss and hardening.	Y	3	3	9	Not much thermal cracking now.
2	Pavement Marking	Y	6	0		Not a serious concern.	Y	3	0		No effect.
3	Shoulders (Including Gravel)										
4	Barriers										
5	Curb	Y	6	1	6	Affects asphault curb. Gets softer. Not a big change.					
6	Luminaires										
7	Poles										
8	Signage - Side Mounted - Over 3.2 m2										
9	Signage - Overhead Guide Signs										
10	Overhead Changeable Message Signs										
11	Ditches										
12	Embankments/Cuts (Constructed)										
13	Hillsides (Natural)										
14	Engineered Stabilization Works										
15	Avalanche (Inc Protective Works)						Y	3	1	3	Could form transition layer that leads from this cold event followed by snow.
16	Debris Torrents (Inc Protective Works)	Y	2	7	14	Fire and avalanche hazard. Possible hydrology changes. Event sequence arising from higher temp. Not as big an issue as logging practice.					
17	Structures that Cross Streams	Y	6	1	6	Not a serious concern from direct events. May affect expansion joints.	Y	3	1	3	Marginal affect on expansion joints.
18	Structures that Cross Roads	Y	6	1	6	As above.	Y	3	1	3	Marginal affect on expansion joints.
19	River Training Works (Rip Rap)						Y	3	0		Marginal affect on expansion joints.
20	MSE Walls										
21	Pavement Structure above Sub-Grade						Y	3	3	9	Some reduction of speed.

#	Infrastructure Components	3 Temperature Variability: Daily temperature variation of more than 25°C Y/N	P	S	R	Justification Comments	4 Freeze/Thaw: 85 or more days where max. temp. >0°C and min. temp.<0°C Y/N	P	S	R	Justification Comments
1	Surface - Asphalt	Y	2	1	2	Extreme values are of more concern.	Y	3	2	6	Not a big concern on this highway.
2	Pavement Marking	Y	2	0		No effect.	Y	3	0		No effect.
3	Shoulders (Including Gravel)										
4	Barriers						Y	3	2	6	Manufactured concrete.
5	Curb						Y	3	1	3	Effect on concrete curve.
6	Luminaires										
7	Poles										
8	Signage - Side Mounted - Over 3.2 m2										
9	Signage - Overhead Guide Signs										
10	Overhead Changeable Message Signs										
11	Ditches	Y	2	0		No effect.	Y	3	2	6	Median ditches. Control with maintenance.
12	Embankments/Cuts (Constructed)	Y	2	0		No effect.	Y	3	6	18	Could cause rock fall.
13	Hillsides (Natural)	Y	2	0		No effect.	Y	3	5	15	Not as serious as embankments.
14	Engineered Stabilization Works						Y	3	5	15	Not as serious as embankments.
15	Avalanche (Inc Protective Works)	Y	2	3	6	Could potentially have some impact.	Y	3	3	9	Tend to stabilize the snow pack. Increase in small avalanches is a benefit.
16	Debris Torrents (Inc Protective Works)	Y	2	5	10	When combined with rainfall as in Pineapple Express.	Y	3	3	9	Transition across freezing can create issues.
17	Structures that Cross Streams	Y	2	0		No effect.	Y	3	2	6	Minor
18	Structures that Cross Roads	Y	2	0		No effect.	Y	3	2	6	Minor
19	River Training Works (Rip Rap)	Y	2	0		No effect.					
20	MSE Walls						Y	3	1	3	Minor
21	Pavement Structure above Sub-Grade	Y	2	0		No effect.	Y	3	4	12	Ice lensing and frost heave.

#	Infrastructure Components	5 Frost Penetration Y/N	P	S	R	Justification Comments	6: 147 or more days where min. temp. <0°C Y/N	P	S	R
1	Surface - Asphalt	Y	2	1	2	More of a pavement structure issue.	Y	2	1	2
2	Pavement Marking									
3	Shoulders (Including Gravel)									
4	Barriers									
5	Curb									
6	Luminaires									
7	Poles									
8	Signage - Side Mounted - Over 3.2 m2									
9	Signage - Overhead Guide Signs	Y	2	4	8	Frost penetration at foundation level.				
10	Overhead Changeable Message Signs	Y	2	4	8	Frost penetration at foundation level.				
11	Ditches									
12	Embankments/Cuts (Constructed)	Y	2	3	6	Minor	Y	2	1	2
13	Hillsides (Natural)									
14	Engineered Stabilization Works	Y	2	1	2	Minor	Y	2	1	2
15	Avalanche (Inc Protective Works)	Y	2	1	2	Minor	Y	2	4	8
16	Debris Torrents (Inc Protective Works)	Y	2	0		Minor	Y	2	0	
17	Structures that Cross Streams	Y	2	4	8	Minor	Y	2	2	4
18	Structures that Cross Roads	Y	2	4	8	Minor	Y	2	2	4
19	River Training Works (Rip Rap)									
20	MSE Walls									
21	Pavement Structure above Sub-Grade	Y	2	5	10		Y	2	0	

#	Infrastructure Components	Structural Design	Functionality	Watershed, Surface Water, and Groundwater	Operations, Maintenance, and Materials Performance	Emergency Response	Insurance Considerations	Policy / Guidelines / Standards	Social Effects	Public Health & Safety	Environmental Effect
		Performance Response Considerations									
22	Catch Basins	x	x	x	x	x	x	x		x	x
23	Median and Roadway Drainage Appliances	x	x	x	x	x	x	x		x	x
24	Sub-Drains	x	x	x	x	x	x	x		x	x
25	Third party utilities	x	x	x	x	x	x	x	x	x	x
26	Culverts < 3m	x	x	x	x	x	x	x	x	x	x
27	Culverts ≥ 3m	x	x	x	x	x	x	x	x	x	x
28	Asphalt Spillway and Associated Piping/Culvert	x	x	x	x	x	x	x	x	x	x
	Environmental Features										
29	In stream habitat works	x	x	x	x	x		x			x
30	Off channel habitat works	x	x	x	x	x		x			x
31	Wild life fence system	x	x		x	x	x	x		x	x
32	Wild life crossing structures	x	x		x		x	x		x	x
33	Vegetation management				x			x		x	x
34	Invasive Plants & Pests				x			x	x		x
	Miscellaneous										
35	Administration/Personnel & Engineering	x	x	x	x	x	x	x	x	x	x
36	Winter Maintenance	x	x	x	x	x	x	x	x	x	x
37	Ancillary buildings and utilities and yards.	x	x	x	x	x	x	x	x	x	x
38	Communication		x		x	x			x	x	
39	Emergency Response		x		x	x			x	x	x
40	Maintenance (Markings, Crack Sealing)	x	x		x				x	x	

#	Infrastructure Components	1 High Temperature: Day(s) with max. temp. exceeding 35°C				Justification Comments	2 Low Temperature: Day(s) with min. temp. below -30°C				Justification Comments	3 Temperature Variability: Daily temperature variation of more than 25°C				Justification Comments
22	Catch Basins															
23	Median and Roadway Drainage Appliances															
24	Sub-Drains						Y	3	2	6	Needs a combination of events to make it happen.					
25	Third party utilities															
26	Culverts < 3m						Y	3	1	3	Minimal effect.	Y	2	0		No effect.
27	Culverts ≥ 3m						Y	3	0		No effect.	Y	2	0		No effect.
28	Asphalt Spillway and Associated Piping/Culvert	Y	6	0		Not a serious concern.	Y	3	1	3	Not a serious concern.					
	Environmental Features	Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R	
29	In stream habitat works	Y	6	4	24	Could have significant effect on fish.						Y	2	2	4	Captured under extreme temp.
30	Off channel habitat works	Y	6	4	24	Could have significant effect on fish.						Y	2	2	4	Captured under extreme temp.
31	Wild life fence system															
32	Wild life crossing structures															
33	Vegetation management	Y	6	1	6	Not many existing obligations.						Y	2	2	4	Captured under extreme temp.
34	Invasive Plants & Pests	Y	6	2	12	New invasive plants could follow the climate change.						Y	2	2	4	Captured under extreme temp.
	Miscellaneous	Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R	
35	Administration/Personnel & Engineering															
36	Winter Maintenance						Y	3	1	3	Practices change with temp.	Y	2	1	2	More of a freeze/thaw issue.
37	Ancillary buildings and utilities and yards.						Y	3	1	3	Starting equipment. Freezing bathrooms. Etc.					
38	Communication															
39	Emergency Response						Y	3	6	18	Limits fire fighting capabilities. In cold weather let it burn.					
40	Maintenance (Markings, Crack Sealing)						Y	3	3	9	More work would be needed.	Y	2	1	2	More of a freeze/thaw issue.

#	Infrastructure Components	4 Freeze/Thaw: 85 or more days where max. temp. >0°C and min. temp.<0°C				Justification Comments	5 Frost Penetration				Justification Comments	147 or more days where min. temp. <0°C			
22	Catch Basins	Y	3	1	3	Minor	Y	2	7	14	If frost penetrates drainage this can cause significant damage.				
23	Median and Roadway Drainage Appliances	Y	3	1	3	Minor	Y	2	7	14	As above				
24	Sub-Drains	Y	3	1	3	Minor	Y	2	7	14	A above.	Y	2	1	2
25	Third party utilities														
26	Culverts < 3m	Y	3	2	6	Minor									
27	Culverts ≥ 3m	Y	3	1	3	Minor									
28	Asphalt Spillway and Associated Piping/Culvert	Y	3	2	6	Minor									
	Environmental Features	Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R
29	In stream habitat works														
30	Off channel habitat works														
31	Wild life fence system														
32	Wild life crossing structures														
33	Vegetation management														
34	Invasive Plants & Pests											Y	4	3	12
	Miscellaneous	Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R
35	Administration/Personnel & Engineering														
36	Winter Maintenance	Y	3	5	15	Culverts plugging.	Y	2	5	10	Road base failure from frost heave.	Y	2	1	2
37	Ancillary buildings and utilities and yards.						Y	2	3	6	Can affect foundation.	Y	2	1	2
38	Communication														
39	Emergency Response	Y	3	0		No effect.						Y	2	1	2
40	Maintenance (Markings, Crack Sealing)	Y	3	4	12	Pothole repairs.	Y	2	1	2	Minor	Y	2	1	2

		6	7					8					9					10					11				
		Frost	**Extreme Rainfall Intensity over One Day**					**Magnitude of Severe Storm Driven Peak Flows**					**Frequency of Severe Storm Driven Peak Flows**					**Rain on Snow**					**Freezing Rain**				
	Infrastructure Components	Justification Comments	**Increase**				Justification Comments					Justification Comments					Justification Comments	**Frequency**				Justification Comments	**1 or more days with rain that falls as liquid and freezes on contact**				Justification Comments
	Infrastructure		Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R	
1	Surface - Asphalt	Minor	Y	6	5	30	Designed for five-year event. Functionality is not compromised. Assess design criteria. Candidate for Step 4.	Y	6	5	30	Designed for five-year event. Functionality is not compromised. Assess design criteria. Candidate for Step 4.	Y	5	5	25	Designed for five-year event. Functionality is not compromised. Assess design criteria. Candidate for Step 4.						Y	3	0		Minor
2	Pavement Marking																						Y	3	3	9	Partially obscured
3	Shoulders (Including Gravel)		Y	6	6	36	Erosion. Issues with steep grade	Y	6	6	36	Same as 7	Y	5	7	35	Could lose part of road surface						Y	3	1	3	Minor
4	Barriers																										
5	Curb																										
6	Luminaires																						Y	3	4	12	May cause diffusers to open. Some loss of function.
7	Poles																						Y	3	1	3	Minor
8	Signage - Side Mounted - Over 3.2 m2																						Y	3	1	3	Minor
9	Signage - Overhead Guide Signs																						Y	3	1	3	Minor
10	Overhead Changeable Message Signs																						Y	3	1	3	Minor
11	Ditches		Y	6	5	30	Can overtop the ditch	Y	6	6	36	Increase in magnitude of Pineapple Express event	Y	5	7	35	Events occur more often. Could compound or exacerbate	Y	3	1	3	Minor					
12	Embankments/Cuts (Constructed)	Minor	Y	6	6	36	Erosion	Y	6	7	42	Increase in magnitude of Pineapple Express event	Y	5	7	35	Events occur more often. Could compound or exacerbate										
13	Hillsides (Natural)		Y	6	5	30	Erosion	Y	6	7	42	Increase in magnitude of Pineapple Express event	Y	5	7	35	Events occur more often. Could compound or exacerbate	Y	3	3	9	Minor					
14	Engineered Stabilization Works	Minor	Y	6	3	18	Designed for this event	Y	6	5	30	Increase in magnitude of Pineapple Express event	Y	5	7	35	Events occur more often. Could compound or exacerbate										
15	Avalanche (Inc Protective Works)	More opportunity for dry avalanche.	Y	6	6	36	Exacerbates rain on snow events	Y	6	6	36	Increase in magnitude of Pineapple Express event	Y	5	7	35	Events occur more often. Could compound or exacerbate	Y	3	5	15	Can have a significant effect.	Y	3	6	18	Exacerbates avalanche conditions.
16	Debris Torrents (Inc Protective Works)	Minor	Y	6	7	42	Can block road	Y	6	7	42	It has already failed	Y	5	7	35	Events occur more often. Could compound or exacerbate	Y	3	5	15	Trigger event for debris torrent					
17	Structures that Cross Streams	Minor	Y	6	6	36	Lost approaches for three days	Y	6	7	42	Increase in magnitude of Pineapple Express event	Y	5	7	35	Events occur more often. Could compound or exacerbate						Y	3	2	6	Minor
18	Structures that Cross Roads	Minor	Y	6	5	30	Designed for five-year event. Functionality is not compromised. Assess design criteria. Candidate for Step 4.	Y	6	6	36	Designed for five-year event. Functionality is not compromised. Assess design criteria. Candidate for Step 4.	Y	5	7	35	Designed for five-year event. Functionality is not compromised. Assess design criteria. Candidate for Step 4.						Y	3	2	6	Minor
19	River Training Works (Rip Rap)		Y	6	6	36	Local scour causing rip rap to fail	Y	6	7	42	Increase in magnitude of Pineapple Express event. Loss of rip rap.	Y	5	7	35											
20	MSE Walls							Y	6	5	30	Drain gallery is compromised. Loss of fill Sensitive to loss of rip rap in two locations.	Y	5	6	30											
21	Pavement Structure above Sub-Grade	Minor																									

	Infrastructure Components	6 Frost	7 Extreme Rainfall Intensity over One Day					8 Magnitude of Severe Storm Driven Peak Flows					9 Frequency of Severe Storm Driven Peak Flows					10 Rain on Snow					11 Freezing Rain				
		Justification Comments	Increase				Justification Comments					Justification Comments					Justification Comments	Frequency				Justification Comments	1 or more days with rain that falls as liquid and freezes on contact				Justification Comments
22	Catch Basins		Y	6	6	36	Designed for five-year event. Functionality is not compromised. Assess design criteria. Candidate for Step 4.	Y	6	6	36	Designed for five-year event. Functionality is not compromised. Assess design criteria. Candidate for Step 4.	Y	5	6	30	Designed for five-year event. Functionality is not compromised. Assess design criteria. Candidate for Step 4.	Y	3	6	18	Snow carries down with water and clogs	Y	3	0		Minor
23	Median and Roadway Drainage Appliances		Y	6	6	36	Same as catch basins	Y	6	6	36							Y	3	6	18	As above	Y	3	0		Minor
24	Sub-Drains	Minor	Y	6	3	18	Water has to penetrate to that level first	Y	6	6	36																
25	Third party utilities		Y	6	5	30	Shared right of way. Failure can affect 3rd party utilities	Y	6	5	30												Y	3	7	21	Loss of function. Obstruction on the highway
26	Culverts < 3m		Y	6	7	42	Loss of function. Over capacity.	Y	6	7	42	Increase in magnitude of Pineapple Express event	Y	5	7	35		Y	3	5	15	As above					
27	Culverts ≥ 3m		Y	6	7	42	Loss of function. Over capacity.	Y	6	7	42	Increase in magnitude of Pineapple Express event	Y	5	7	35											
28	Asphalt Spillway and Associated Piping/Culvert		Y	6	6	36	Similar to catch basin	Y	6	7	42	Increase in magnitude of Pineapple Express event						Y	3	5	15	As above	Y	3	0		Minor
	Environmental Features		Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R	
29	In stream habitat works		Y	6	6	36	Can be washed away	Y	6	7	42	Increase in magnitude of Pineapple Express event	Y	5	7	35											
30	Off channel habitat works		Y	6	6	36	Can be washed away	Y	6	7	42	Increase in magnitude of Pineapple Express event	Y	5	7	35											
31	Wild life fence system																	Y	3	6	18	Snow is heavier	Y	3	6	18	Weight brings down fences
32	Wild life crossing structures																										
33	Vegetation management																										
34	Invasive Plants & Pests	Fewer days of frost overall exacerbates pest infestation. Land use change likely to be a bigger impact on the Coq. For design work may have to adjust coverage factors. Altered probability of event due to potential impact on pest infestation.																									
	Miscellaneous		Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R	
35	Administration/Personnel & Engineering																										
36	Winter Maintenance	Minor	Y	6	4	24	Maintenance only.	Y	6	6	36		Y	5	7	35		Y	3	5	15	Compact on road, Compact breaks up. Bare pavement combined with snow.	Y	3	6	18	All sorts of issues. May have to close the highway
37	Ancillary buildings and utilities and yards.	Minor	Y	6	1	6	Minor	Y	6	2	12		Y	5	3	15		Y	3	5	15	Roof loading issues.	Y	3	4	12	Roof loading
38	Communication																						Y	3	6	18	Obscures solar panels.
39	Emergency Response	Minor	Y	6	6	36	Road could be closed.	Y	6	7	42	Increase in magnitude of Pineapple Express event	Y	5	7	35		Y	3	5	15	Increase in the number of accidents. Harder access.	Y	3	7	21	Serious implications.
40	Maintenance (Markings, Crack Sealing)	Minor																									

	Infrastructure Components	12 Snow Storm/ Blizzard: 8 or more days with blowing snow					13 Snow (Frequency): Days with snowfall >10cm				
	Infrastructure	Y/N	P	S	R	Justification Comments	Y/N	P	S	R	Justification Comments
1	Surface - Asphalt	Y	3	0		Minor	Y	3	0		Minor
2	Pavement Marking	Y	3	6	18	Can't see them.	Y	3	6	18	Can't see them.
3	Shoulders (Including Gravel)	Y	3	1	3	Minor	Y	3	1	3	Minor
4	Barriers	Y	3	1	3	Minor	Y	3	1	3	Minor
5	Curb						Y	3	3	9	Minor
6	Luminaires	Y	3	4	12	Get hit by cars	Y	3	1	3	Not on highway
7	Poles						Y	3	0		Minor
8	Signage - Side Mounted - Over 3.2 m2	Y	3	4	12	Visibility issue.	Y	3	1	3	Minor
9	Signage - Overhead Guide Signs	Y	3	3	9	Sings get blocked	Y	3	1	3	Minor
10	Overhead Changeable Message Signs	Y	3	3	9	Sings get blocked	Y	3	1	3	Minor
11	Ditches	Y	3	0		Minor	Y	3	1	3	Minor
12	Embankments/Cuts (Constructed)	Y	3	0		Minor	Y	3	1	3	Minor
13	Hillsides (Natural)						Y	3	1	3	Minor
14	Engineered Stabilization Works										
15	Avalanche (Inc Protective Works)	Y	3	5	15	Wind loading	Y	3	5	15	Makes more snow available for wind to blow around.
16	Debris Torrents (Inc Protective Works)						Y	3	4	12	Can be triggered by wet avalanches
17	Structures that Cross Streams										
18	Structures that Cross Roads										
19	River Training Works (Rip Rap)										
20	MSE Walls										
21	Pavement Structure above Sub-Grade										

	Infrastructure Components	14 Snow Accumulation: 5 or more consecutive days with a snow fall >20cm					15 High Wind/ Downburst: Wind speed > 80.5 km/hr				Hope (50 yr. = 625 Pa, 80.5 km/hr). Merritt (50 year = 430 Pa, 66.8 km/hr)	16 Visibility: Decrease in stopping sight distance < 245 m				Problem occurs when increases above normal frequency.
	Infrastructure	Y/N	P	S	R	Justification Comments	Y/N	P	S	R		Y/N	P	S	R	
1	Surface - Asphalt	Y	3	0		Minor										
2	Pavement Marking	Y	3	6	18	Can't see them.						Y				
3	Shoulders (Including Gravel)	Y	3	6	18	Buried						Y				
4	Barriers	Y	3	5	15	Loss of barrier function.										
5	Curb	Y	3	3	9	Loss of function										
6	Luminaires	Y	3	4	12	Damaged by plowing.	Y					Y				
7	Poles	Y	3	3	9	Not on highway	Y									
8	Signage - Side Mounted - Over 3.2 m2	Y	3	0		Minor	Y					Y				
9	Signage - Overhead Guide Signs	Y	3	0		Minor	Y					Y				
10	Overhead Changeable Message Signs	Y	3	0		Minor	Y					Y				
11	Ditches	Y	3	6	18	Snow storage issues										
12	Embankments/Cuts (Constructed)	Y	3	6	18	No snow storage.										
13	Hillsides (Natural)	Y	3	1	3	Minor										
14	Engineered Stabilization Works															
15	Avalanche (Inc Protective Works)	Y	3	6	18	Snow accumulation exacerbates concerns.	Y									
16	Debris Torrents (Inc Protective Works)	Y	3	5	15	Linkage with wet conditions leading to debris torrents.										
17	Structures that Cross Streams						Y									
18	Structures that Cross Roads						Y									
19	River Training Works (Rip Rap)															
20	MSE Walls															
21	Pavement Structure above Sub-Grade															

		12					13					14					15					16				
		Snow Storm/ Blizzard					**Snow (Frequency)**					**Snow Accumulation**					**High Wind/ Downburst**					**Visibility**				
	Infrastructure Components	**8 or more days with blowing snow**				Justification Comments	**Days with snowfall >10cm**				Justification Comments	**5 or more consecutive days with a snow fall >20cm**				Justification Comments	**Wind speed > 80.5 km/hr**				Hope (50 yr. = 625 Pa, 80.5 km/hr). Merrit (50 year = 430 Pa, 66.8 km/hr)	**Decrease in stopping sight distance < 245 m**				Problem occurs when increases above normal frequency.
22	Catch Basins											Y	3	4	12	Loss of function										
23	Median and Roadway Drainage Appliances											Y	3	4	12	Loss of function										
24	Sub-Drains																									
25	Third party utilities																Y									
26	Culverts < 3m																									
27	Culverts ≥ 3m																									
28	Asphalt Spillway and Associated Piping/Culvert											Y	3	3	9	Easier to clear. Spring issues										
	Environmental Features	Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R	
29	In stream habitat works																									
30	Off channel habitat works																									
31	Wild life fence system	Y	3	6	18	Drifting snow compresses fences	Y	3	6	18	More opportunity for effect	Y	3	6	18	Gets progressively worse over the summer.	Y									
32	Wild life crossing structures																									
33	Vegetation management																									
34	Invasive Plants & Pests																									
	Miscellaneous	Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R	
35	Administration/Personnel & Engineering																									
36	Winter Maintenance	Y	3	6	18	Significant. Equipment breakdowns. Etc.	Y	3	3	9	Routine plowing	Y	3	3	9	Routine	Y					Y				
37	Ancillary buildings and utilities and yards.	Y	3	3	9	Wind loading	Y	3	3	9	Minor	Y	3	5	15	Snow loading										
38	Communication	Y	3	6	18	Lose cell service.	Y	3	2	6	General snowfall does not cause problems	Y	3	4	12	Melting snow can affect wires etc.	Y					Y				
39	Emergency Response	Y	3	6	18	Makes emergency response more difficult.	Y	3	2	6	General snowfall does not cause problems	Y	3	2	6	Already have procedures to manage	Y					Y				
40	Maintenance (Markings, Crack Sealing)																Y					Y				

Appendix G

Sensitivity Analysis

#	Infrastructure Components	Performance Response Considerations									
	Infrastructure	Structural Design	Functionality	Watershed, Surface Water, and Groundwater	Operations, Maintenance, and Materials Performance	Emergency Response	Insurance Considerations	Policy / Guidelines / Standards	Social Effects	Public Health & Safety	Environmental Effect
1	Surface - Asphalt	x	x	x	x			x	x	x	
2	Pavement Marking		x		x			x	x	x	
3	Shoulders (Including Gravel)		x	x	x	x		x		x	
4	Barriers		x	x	x	x	x	x	x	x	
5	Curb		x	x	x			x			
6	Luminaires		x		x		x	x		x	
7	Poles	x	x		x	x	x	x		x	
8	Signage - Side Mounted - Over 3.2 m2	x	x		x	x	x	x		x	
9	Signage - Overhead Guide Signs	x	x		x	x	x	x		x	
10	Overhead Changeable Message Signs	x	x		x	x	x	x		x	
11	Ditches	x	x	x	x	x	x	x		x	x
12	Embankments/Cuts (Constructed)	x	x	x	x	x	x	x		x	x
13	Hillsides (Natural)	x	x	x	x	x	x	x		x	x
14	Engineered Stabilization Works	x	x	x	x	x	x	x	x	x	x
15	Avalanche (Inc Protective Works)	x	x	x	x	x	x	x	x	x	x
16	Debris Torrents (Inc Protective Works)	x	x	x	x	x	x	x	x	x	x
17	Structures that Cross Streams	x	x	x	x	x	x	x	x	x	x
18	Structures that Cross Roads	x	x	x	x	x	x	x	x	x	
19	River Training Works (Rip Rap)	x	x	x	x	x	x	x	x	x	x
20	MSE Walls	x	x	x	x	x	x	x	x	x	x
21	Pavement Structure above Sub-Grade	x	x		x			x		x	x
22	Catch Basins	x	x	x	x	x	x	x		x	x
23	Median and Roadway Drainage Appliances	x	x	x	x	x	x	x		x	x
24	Sub-Drains	x	x	x	x	x	x	x		x	x

#	Infrastructure Components	1 High Temperature					2 Low Temperature					3 Temperature Variability				
		Day(s) with max. temp. exceeding 35°C				Justification Comments	Day(s) with min. temp. below -30°C				Justification Comments	Daily temperature variation of more than 25°C				Justification Comments
	Infrastructure	Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R	
1	Surface - Asphalt	Y	6	3	18	Can lead to rutting. VOC loss and hardening.	Y	3	3	9	Not much thermal cracking now.	Y	2	1	2	Extreme values are of more concern.
2	Pavement Marking	Y	6	0		Not a serious concern.	Y	3	0		No effect.	Y	2	0		No effect.
3	Shoulders (Including Gravel)															
4	Barriers															
5	Curb	Y	6	1	6	Affects asphault curb. Gets softer. Not a big change.										
6	Luminaires															
7	Poles															
8	Signage - Side Mounted - Over 3.2 m2															
9	Signage - Overhead Guide Signs															
10	Overhead Changeable Message Signs															
11	Ditches											Y	2	0		No effect.
12	Embankments/Cuts (Constructed)											Y	2	0		No effect.
13	Hillsides (Natural)											Y	2	0		No effect.
14	Engineered Stabilization Works															
15	Avalanche (Inc Protective Works)						Y	3	1	3	Could form transition layer that leads from this cold event followed by snow.	Y	2	3	6	Could potentially have some impact.
16	Debris Torrents (Inc Protective Works)	Y	2	7	14	Fire and avalanche hazard. Possible hydrology changes. Event sequence arising from higher temp. Not as big an issue as logging practice.						Y	2	5	10	When combined with rainfall as in Pineapple Express.
17	Structures that Cross Streams	Y	6	1	6	Not a serious concern from direct events. May affect expansion joints.	Y	3	1	3	Marginal affect on expansion joints.	Y	2	0		No effect.
18	Structures that Cross Roads	Y	6	1	6	As above.	Y	3	1	3	Marginal affect on expansion joints.	Y	2	0		No effect.
19	River Training Works (Rip Rap)						Y	3	0		Marginal affect on expansion joints.	Y	2	0		No effect.
20	MSE Walls															
21	Pavement Structure above Sub-Grade						Y	3	3	9	Some reduction of speed.	Y	2	0		No effect.
22	Catch Basins															
23	Median and Roadway Drainage Appliances															
24	Sub-Drains						Y	3	2	6	Needs a combination of events to make it happen.					

#	Infrastructure Components	4 Freeze/Thaw					5 Frost Penetration					6 Frost				
		85 or more days where max. temp. >0°C and min. temp.<0°C				Justification Comments					Justification Comments	147 or more days where min. temp. <0°C				Justification Comments
	Infrastructure	Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R	
1	Surface - Asphalt	Y	3	2	6	Not a big concern on this highway.	Y	2	1	2	More of a pavement structure issue.	Y	2	1	2	Minor
2	Pavement Marking	Y	3	0		No effect.										
3	Shoulders (Including Gravel)															
4	Barriers	Y	3	2	6	Manufactured concrete.										
5	Curb	Y	3	1	3	Effect on concrete curve.										
6	Luminaires															
7	Poles															
8	Signage - Side Mounted - Over 3.2 m2															
9	Signage - Overhead Guide Signs						Y	2	4	8	Frost penetration at foundation level.					
10	Overhead Changeable Message Signs						Y	2	4	8	Frost penetration at foundation level.					
11	Ditches	Y	3	2	6	Median ditches. Control with maintenance.										
12	Embankments/Cuts (Constructed)	Y	3	6	18	Could cause rock fall.	Y	2	3	6	Minor	Y	2	1	2	Minor
13	Hillsides (Natural)	Y	3	5	15	Not as serious as embankments.										
14	Engineered Stabilization Works	Y	3	5	15	Not as serious as embankments.	Y	2	1	2	Minor	Y	2	1	2	Minor
15	Avalanche (Inc Protective Works)	Y	3	3	9	Tend to stabilize the snow pack. Increase in small avalanches is a benefit.	Y	2	1	2	Minor	Y	2	4	8	More opportunity for dry avalanche.
16	Debris Torrents (Inc Protective Works)	Y	3	3	9	Transition across freezing can create issues.	Y	2	0		Minor	Y	2	0		Minor
17	Structures that Cross Streams	Y	3	2	6	Minor	Y	2	4	8	Minor	Y	2	2	4	Minor
18	Structures that Cross Roads	Y	3	2	6	Minor	Y	2	4	8	Minor	Y	2	2	4	Minor
19	River Training Works (Rip Rap)															
20	MSE Walls	Y	3	1	3	Minor										
21	Pavement Structure above Sub-Grade	Y	3	4	12	Ice lensing and frost heave.	Y	2	5	10		Y	2	0		Minor
22	Catch Basins	Y	3	1	3	Minor	Y	2	7	14	If frost penetrates drainage this can cause significant damage.					
23	Median and Roadway Drainage Appliances	Y	3	1	3	Minor	Y	2	7	14	As above					
24	Sub-Drains	Y	3	1	3	Minor	Y	2	7	14	A above.	Y	2	1	2	Minor

#	Infrastructure Components	Structural Design	Functionality	Watershed, Surface Water, and Groundwater	Operations, Maintenance, and Materials Performance	Emergency Response	Insurance Considerations	Policy / Guidelines / Standards	Social Effects	Public Health & Safety	Environmental Effect
		Performance Response Considerations									
25	Third party utilities	x	x	x	x	x	x	x	x	x	x
26	Culverts < 3m	x	x	x	x	x	x	x	x	x	x
27	Culverts ≥ 3m	x	x	x	x	x	x	x	x	x	x
28	Asphalt Spillway and Associated Piping/Culvert	x	x	x	x	x	x	x	x	x	x
	Environmental Features										
29	In stream habitat works	x	x	x	x	x		x			x
30	Off channel habitat works	x	x	x	x	x		x			x
31	Wild life fence system	x	x		x	x	x	x		x	x
32	Wild life crossing structures	x	x		x		x	x		x	x
33	Vegetation management				x			x		x	x
34	Invasive Plants & Pests				x			x	x		x
	Miscellaneous										
35	Administration/Personnel & Engineering	x	x	x	x	x	x	x	x	x	x
36	Winter Maintenance	x	x	x	x	x	x	x	x	x	x
37	Ancillary buildings and utilities and yards.	x	x	x	x	x	x	x	x	x	x
38	Communication		x		x	x			x	x	
39	Emergency Response		x		x	x			x	x	x
40	Maintenance (Markings, Crack Sealing)	x	x		x				x	x	

#	Infrastructure Components	1 High Temperature: Day(s) with max. temp. exceeding 35°C				Justification Comments	2 Low Temperature: Day(s) with min. temp. below -30°C				Justification Comments	3 Temperature Variability: Daily temperature variation of more than 25°C				Justification Comments
25	Third party utilities															
26	Culverts < 3m						Y	3	1	3	Minimal effect.	Y	2	0		No effect.
27	Culverts ≥ 3m						Y	3	0		No effect.	Y	2	0		No effect.
28	Asphalt Spillway and Associated Piping/Culvert	Y	6	0		Not a serious concern.	Y	3	1	3	Not a serious concern.					
	Environmental Features	Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R	
29	In stream habitat works	Y	6	4	24	Could have significant effect on fish.						Y	2	2	4	Captured under extreme temp.
30	Off channel habitat works	Y	6	4	24	Could have significant effect on fish.						Y	2	2	4	Captured under extreme temp.
31	Wild life fence system															
32	Wild life crossing structures															
33	Vegetation management	Y	6	1	6	Not many existing obligations.						Y	2	2	4	Captured under extreme temp.
34	Invasive Plants & Pests	Y	6	2	12	New invasive plants could follow the climate change.						Y	2	2	4	Captured under extreme temp.
	Miscellaneous	Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R	
35	Administration/Personnel & Engineering															
36	Winter Maintenance						Y	3	1	3	Practices change with temp.	Y	2	1	2	More of a freeze/thaw issue.
37	Ancillary buildings and utilities and yards.						Y	3	1	3	Starting equipment. Freezing bathrooms. Etc.					
38	Communication															
39	Emergency Response						Y	3	6	18	Limits fire fighting capabilities. In cold weather let it burn.					
40	Maintenance (Markings, Crack Sealing)						Y	3	3	9	More work would be needed.	Y	2	1	2	More of a freeze/thaw issue.

#	Infrastructure Components	4 Freeze/Thaw: 85 or more days where max. temp. >0°C and min. temp.<0°C				Justification Comments	5 Frost Penetration				Justification Comments	6 Frost: 147 or more days where min. temp. <0°C				Justification Comments
25	Third party utilities															
26	Culverts < 3m	Y	3	2	6	Minor										
27	Culverts ≥ 3m	Y	3	1	3	Minor										
28	Asphalt Spillway and Associated Piping/Culvert	Y	3	2	6	Minor										
	Environmental Features	Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R	
29	In stream habitat works															
30	Off channel habitat works															
31	Wild life fence system															
32	Wild life crossing structures															
33	Vegetation management															
34	Invasive Plants & Pests											Y	4	3	12	Fewer days of frost overall exacerbates pest infestation. Land use change likely to be a bigger impact on the Coq. For design work may have to adjust coverage factors. Altered probability of event due to potential impact on pest infestation.
	Miscellaneous	Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R	
35	Administration/Personnel & Engineering															
36	Winter Maintenance	Y	3	5	15	Culverts plugging.	Y	2	5	10	Road base failure from frost heave.	Y	2	1	2	Minor
37	Ancillary buildings and utilities and yards.						Y	2	3	6	Can affect foundation.	Y	2	1	2	Minor
38	Communication															
39	Emergency Response	Y	3	0		No effect.						Y	2	1	2	Minor
40	Maintenance (Markings, Crack Sealing)	Y	3	4	12	Pothole repairs.	Y	2	1	2	Minor	Y	2	1	2	Minor

	Infrastructure Components	7 Extreme Rainfall Intensity over One Day: Increase				Reduce Probability from 6 to 5	8 Magnitude of Severe Storm Driven Peak Flows				Reduce Probability from 6 to 5	9 Frequency of Severe Storm Driven Peak Flows				Reduce Probability from 5 to 4
	Infrastructure	Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R	
1	Surface - Asphalt	Y	5	5	25	Designed for five-year event. Functionality is not compromised. Assess design criteria. Candidate for Step 4.	Y	5	5	25	Designed for five-year event. Functionality is not compromised. Assess design criteria. Candidate for Step 4.	Y	4	5	20	Designed for five-year event. Functionality is not compromised. Assess design criteria. Candidate for Step 4.
2	Pavement Marking															
3	Shoulders (Including Gravel)	Y	5	6	30	Erosion. Issues with steep grade	Y	5	6	30	Same as 7	Y	4	7	28	Could lose part of road surface
4	Barriers															
5	Curb															
6	Luminaires															
7	Poles															
8	Signage - Side Mounted - Over 3.2 m2															
9	Signage - Overhead Guide Signs															
10	Overhead Changeable Message Signs															
11	Ditches	Y	5	5	25	Can overtop the ditch	Y	5	6	30	Increase in magnitude of Pineapple Express event	Y	4	7	28	Events occur more often. Could compound or exacerbate
12	Embankments/Cuts (Constructed)	Y	5	6	30	Erosion	Y	5	7	35	Increase in magnitude of Pineapple Express event	Y	4	7	28	Events occur more often. Could compound or exacerbate
13	Hillsides (Natural)	Y	5	5	25	Erosion	Y	5	7	35	Increase in magnitude of Pineapple Express event	Y	4	7	28	Events occur more often. Could compound or exacerbate
14	Engineered Stabilization Works	Y	5	3	15	Designed for this event	Y	5	5	25	Increase in magnitude of Pineapple Express event	Y	4	7	28	Events occur more often. Could compound or exacerbate
15	Avalanche (Inc Protective Works)	Y	5	6	30	Exacerbates rain on snow events	Y	5	6	30	Increase in magnitude of Pineapple Express event	Y	4	7	28	Events occur more often. Could compound or exacerbate
16	Debris Torrents (Inc Protective Works)	Y	5	7	35	Can block road	Y	5	7	35	It has already failed	Y	4	7	28	Events occur more often. Could compound or exacerbate
17	Structures that Cross Streams	Y	5	6	30	Lost approaches for three days	Y	5	7	35	Increase in magnitude of Pineapple Express event	Y	4	7	28	Events occur more often. Could compound or exacerbate
18	Structures that Cross Roads	Y	5	5	25	Designed for five-year event. Functionality is not compromised. Assess design criteria. Candidate for Step 4.	Y	5	6	30	Designed for five-year event. Functionality is not compromised. Assess design criteria. Candidate for Step 4.	Y	4	7	28	Designed for five-year event. Functionality is not compromised. Assess design criteria. Candidate for Step 4.
19	River Training Works (Rip Rap)	Y	5	6	30	Local scour causing rip rap to fail	Y	5	7	35	Increase in magnitude of Pineapple Express event. Loss of rip rap.	Y	4	7	28	
20	MSE Walls						Y	5	5	25	Drain gallery is compromised. Loss of fill Sensitive to loss of rip rap in two locations.	Y	4	6	24	
21	Pavement Structure above Sub-Grade															
22	Catch Basins	Y	5	6	30	Designed for five-year event. Functionality is not compromised. Assess design criteria. Candidate for Step 4.	Y	5	6	30	Designed for five-year event. Functionality is not compromised. Assess design criteria. Candidate for Step 4.	Y	4	6	24	Designed for five-year event. Functionality is not compromised. Assess design criteria. Candidate for Step 4.
23	Median and Roadway Drainage Appliances	Y	5	6	30	Same as catch basins	Y	5	6	30						
24	Sub-Drains	Y	5	3	15	Water has to penetrate to that level first	Y	5	6	30						

	Infrastructure Components	10 Rain on Snow: Frequency				Increase Probability from 3 to 4	11 Freezing Rain: 1 or more days with rain that falls as liquid and freezes on contact				Increase Probability from 3 to 4	12 Snow Storm/ Blizzard: 8 or more days with blowing snow				Justification Comments	13 Snow (Frequency): Days with snowfall >10cm				Justification Comments
	Infrastructure	Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R	
1	Surface - Asphalt						Y	4	0		Minor	Y	3	0		Minor	Y	3	0		Minor
2	Pavement Marking						Y	4	3	12	Partially obscured	Y	3	6	18	Can't see them.	Y	3	6	18	Can't see them.
3	Shoulders (Including Gravel)						Y	4	1	4	Minor	Y	3	1	3	Minor	Y	3	1	3	Minor
4	Barriers											Y	3	1	3	Minor	Y	3	1	3	Minor
5	Curb																Y	3	3	9	Minor
6	Luminaires						Y	4	4	16	May cause diffusers to open. Some loss of function.	Y	3	4	12	Get hit by cars	Y	3	1	3	Not on highway
7	Poles						Y	4	1	4	Minor						Y	3	0		Minor
8	Signage - Side Mounted - Over 3.2 m2						Y	4	1	4	Minor	Y	3	4	12	Visibility issue.	Y	3	1	3	Minor
9	Signage - Overhead Guide Signs						Y	4	1	4	Minor	Y	3	3	9	Sings get blocked	Y	3	1	3	Minor
10	Overhead Changeable Message Signs						Y	4	1	4	Minor	Y	3	3	9	Sings get blocked	Y	3	1	3	Minor
11	Ditches	Y	4	1	4	Minor						Y	3	0		Minor	Y	3	1	3	Minor
12	Embankments/Cuts (Constructed)											Y	3	0		Minor	Y	3	1	3	Minor
13	Hillsides (Natural)	Y	4	3	12	Minor											Y	3	1	3	Minor
14	Engineered Stabilization Works																				
15	Avalanche (Inc Protective Works)	Y	4	5	20	Can have a significant effect.	Y	4	6	24	Exacerbates avalanche conditions.	Y	3	5	15	Wind loading	Y	3	5	15	Makes more snow available for wind to blow around.
16	Debris Torrents (Inc Protective Works)	Y	4	5	20	Trigger event for debris torrent											Y	3	4	12	Can be triggered by wet avalanches
17	Structures that Cross Streams						Y	4	2	8	Minor										
18	Structures that Cross Roads						Y	4	2	8	Minor										
19	River Training Works (Rip Rap)																				
20	MSE Walls																				
21	Pavement Structure above Sub-Grade																				
22	Catch Basins	Y	4	6	24	Snow carries down with water and clogs	Y	4	0		Minor										
23	Median and Roadway Drainage Appliances	Y	4	6	24	As above	Y	4	0		Minor										
24	Sub-Drains																				

		7					8				
		Extreme Rainfall Intensity over One Day					Magnitude of Severe Storm Driven Peak Flows				
	Infrastructure Components	Increase				Reduce Probability from 6 to 5					Reduce Probability from 6 to 5
25	Third party utilities	Y	5	5	25	Shared right of way. Failure can affect 3rd party utilities	Y	5	5	25	
26	Culverts < 3m	Y	5	7	35	Loss of function. Over capacity.	Y	5	7	35	
27	Culverts ≥ 3m	Y	5	7	35	Loss of function. Over capacity.	Y	5	7	35	
28	Asphalt Spillway and Associated Piping/Culvert	Y	5	6	30	Similar to catch basin	Y	5	7	35	
	Environmental Features	Y/N	P	S	R		Y/N	P	S	R	
29	In stream habitat works	Y	5	6	30	Can be washed away	Y	5	7	35	
30	Off channel habitat works	Y	5	6	30	Can be washed away	Y	5	7	35	
31	Wild life fence system										
32	Wild life crossing structures										
33	Vegetation management										
34	Invasive Plants & Pests										
	Miscellaneous	Y/N	P	S	R		Y/N	P	S	R	
35	Administration/Personnel & Engineering										
36	Winter Maintenance	Y	5	4	20	Maintenance only.	Y	5	6	30	
37	Ancillary buildings and utilities and yards.	Y	6	1	6	Minor	Y	5	2	10	
38	Communication										
39	Emergency Response	Y	5	6	30	Road could be closed.	Y	5	7	35	
40	Maintenance (Markings, Crack Sealing)										

		9					10				
		Frequency of Severe Storm Driven Peak Flows					Rain on Snow				
	Infrastructure Components					Reduce Probability from 5 to 4	Frequency				Increase Probability from 3 to 4
25	Third party utilities										
26	Culverts < 3m	Y	4	7	28		Y	4	5	20	As above
27	Culverts ≥ 3m	Y	4	7	28						
28	Asphalt Spillway and Associated Piping/Culvert						Y	4	5	20	As above
	Environmental Features	Y/N	P	S	R		Y/N	P	S	R	
29	In stream habitat works	Y	4	7	28						
30	Off channel habitat works	Y	4	7	28						
31	Wild life fence system						Y	4	6	24	Snow is heavier
32	Wild life crossing structures										
33	Vegetation management										
34	Invasive Plants & Pests										
	Miscellaneous	Y/N	P	S	R		Y/N	P	S	R	
35	Administration/Personnel & Engineering										
36	Winter Maintenance	Y	4	7	28		Y	4	5	20	Compact on road, Compact breaks up. Bare pavement combined with snow.
37	Ancillary buildings and utilities and yards.	Y	4	3	12		Y	4	5	20	Roof loading issues.
38	Communication										
39	Emergency Response	Y	4	7	28		Y	4	5	20	Increase in the number of accidents. Harder access.
40	Maintenance (Markings, Crack Sealing)										

		11					12					13				
		Freezing Rain					Snow Storm/ Blizzard					Snow (Frequency)				
	Infrastructure Components	1 or more days with rain that falls as liquid and freezes on contact				Increase Probability from 3 to 4	8 or more days with blowing snow				Justification Comments	Days with snowfall >10cm				Justification Comments
25	Third party utilities	Y	4	7	28	Loss of function. Obstruction on the highway										
26	Culverts < 3m															
27	Culverts ≥ 3m															
28	Asphalt Spillway and Associated Piping/Culvert	Y	4	0		Minor										
	Environmental Features	Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R	
29	In stream habitat works															
30	Off channel habitat works															
31	Wild life fence system	Y	4	6	24	Weight brings down fences	Y	3	6	18	Drifting snow compresses fences	Y	3	6	18	More opportunity for effect
32	Wild life crossing structures															
33	Vegetation management															
34	Invasive Plants & Pests															
	Miscellaneous	Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R	
35	Administration/Personnel & Engineering															
36	Winter Maintenance	Y	4	6	24	All sorts of issues. May have to close the highway	Y	3	6	18	Significant. Equipment breakdowns. Etc.	Y	3	3	9	Routine plowing
37	Ancillary buildings and utilities and yards.	Y	4	4	16	Roof loading	Y	3	3	9	Wind loading	Y	3	3	9	Minor
38	Communication	Y	4	6	24	Obscures solar panels.	Y	3	6	18	Lose cell service.	Y	3	2	6	General snowfall does not cause problems
39	Emergency Response	Y	4	7	28	Serious implications.	Y	3	6	18	Makes emergency response more difficult.	Y	3	2	6	General snowfall does not cause problems
40	Maintenance (Markings, Crack Sealing)															

	Infrastructure Components	14					15					16				
		Snow Accumulation					**High Wind/ Downburst**					**Visibility**				
		5 or more consecutive days with a snow fall >20cm				Increase Probability from 3 to 4	**Wind speed > 80.5 km/hr**				Hope (50 yr. = 628 Pa, 80.5 km/hr). Merritt (50 year = 430 Pa, 66.8 km/hr)	**Decrease in stopping sight distance < 245 m**				Problem occurs when increases above normal frequency.
	Infrastructure	Y/N	P	S	R		Y/N	P	S	R		Y/N	P	S	R	
1	Surface - Asphalt	Y	4	0		Minor										
2	Pavement Marking	Y	4	6	24	Can't see them.						Y				
3	Shoulders (Including Gravel)	Y	4	6	24	Buried						Y				
4	Barriers	Y	4	5	20	Loss of barrier function.										
5	Curb	Y	4	3	12	Loss of function										
6	Luminaires	Y	4	4	16	Damaged by plowing.	Y					Y				
7	Poles	Y	4	3	12	Not on highway	Y									
8	Signage - Side Mounted - Over 3.2 m2	Y	4	0		Minor	Y					Y				
9	Signage - Overhead Guide Signs	Y	4	0		Minor	Y					Y				
10	Overhead Changeable Message Signs	Y	4	0		Minor	Y					Y				
11	Ditches	Y	4	6	24	Snow storage issues										
12	Embankments/Cuts (Constructed)	Y	4	6	24	No snow storage.										
13	Hillsides (Natural)	Y	4	1	4	Minor										
14	Engineered Stabilization Works															
15	Avalanche (Inc Protective Works)	Y	4	6	24	Snow accumulation exacerbates concerns.	Y									
16	Debris Torrents (Inc Protective Works)	Y	4	5	20	Linkage with wet conditions leading to debris torrents.										
17	Structures that Cross Streams						Y									
18	Structures that Cross Roads						Y									
19	River Training Works (Rip Rap)															
20	MSE Walls															
21	Pavement Structure above Sub-Grade															
22	Catch Basins	Y	4	4	16	Loss of function										
23	Median and Roadway Drainage Appliances	Y	4	4	16	Loss of function										
24	Sub-Drains															

		14					15					16				
		Snow Accumulation					**High Wind/ Downburst**					**Visibility**				
	Infrastructure Components	**5 or more consecutive days with a snow fall >20cm**				Increase Probability from 3 to 4	**Wind speed > 80.5 km/hr**				Hope (50 yr. = 625 Pa, 80.5 km/hr) Merritt (50 year = 430 Pa, 66.8 km/hr)	**Decrease in stopping sight distance < 245 m**				Problem occurs when increases above normal frequency.
25	Third party utilities						Y									
26	Culverts < 3m															
27	Culverts ≥ 3m															
28	Asphalt Spillway and Associated Piping/Culvert	**Y**	4	3	12	Easier to clear. Spring issues										
	Environmental Features	**Y/N**	P	S	R		Y/N	P	S	R		**Y/N**	P	S	R	
29	In stream habitat works															
30	Off channel habitat works															
31	Wild life fence system	**Y**	4	6	24	Gets progressively worse over the summer.	Y									
32	Wild life crossing structures															
33	Vegetation management															
34	Invasive Plants & Pests															
	Miscellaneous	**Y/N**	P	S	R		Y/N	P	S	R		**Y/N**	P	S	R	
35	Administration/Personnel & Engineering															
36	Winter Maintenance	**Y**	4	3	12	Routine	Y					Y				
37	Ancillary buildings and utilities and yards.	**Y**	4	5	20	Snow loading										
38	Communication	**Y**	4	4	16	Melting snow can affect wires etc.	Y					Y				
39	Emergency Response	**Y**	4	2	8	Already have procedures to manage	Y					Y				
40	Maintenance (Markings, Crack Sealing)						Y					Y				

Appendix H

Completed Protocol Worksheet 4

Worksheet 4 – Engineering Analysis

This is a Preliminary analysis as data to do a complete assessment is not available at this time.

In this step the practitioner will determine the relationship between the Performance Responses loads placed on the infrastructure and its capacity. Vulnerability exists when infrastructure has insufficient capacity to withstand the effects placed on it. Resiliency exits when the infrastructure has sufficient capacity to withstand increasing climate change effects.

8.4.4 Calculation of Total Load (L_T)

Basis of Determination:

- **Definitions;**
- **Direct measurements;**
- **Engineering calculations; or**
- **Assumptions based on professional judgement.**

Infrastructure Component (from 8.3.4 from Work Sheet 3)	**8.4.1 Existing Load** State Basis of Determination L_E	**8.4.2 Climate Load** State Basis of Determination L_C	**8.4.3 Other Change Load** State Basis of Determination L_O	**8.4.4 Total Load** $L_T = L_E+L_C+L_O$
1. Road Surfaces (Gutters, Stormwater Inlets) & Extreme Rainfall	88	13.2	0	101.2
	We assumed these structures were originally designed for a 1:5 year return period. Referencing the 1:5 return period to 24 hour rainfall data from the Rainfall Frequency Atlas for Canada (HOGG, 1985) yields rainfall as 88mm/24hrs at Nicolum River. This is the unfactored Design Load used for comparison.	We Infer from the climate models that the Pineapple Express events could go from 1:10 to 1:4 year event (over 3 days). By extrapolation for this component, we assumed a factor to increase the load back to a 1:5 event would be 10-20% (so we use 15%) and 88mm/24hrs increases to 101mm/24 hrs (for our example).	Land use changes (logging, pine beetle) could increase amounts of water but we assume little affect on this structure as it is part of the internal road drainage and likely not affected by the watershed.	

Worksheet 4 – Engineering Analysis

2. Median and Roadway Drainage Appliances (Hwy Ditches) & Extreme Rainfall	121	18.2	13.9	153.1
	We assumed these structures were originally designed for a 1:10 to 1:25 year return period. Referencing the 1:25 return period to 24 hour rainfall data from the Rainfall Frequency Atlas for Canada (HOGG, 1985) yields rainfall as 121mm/24 hrs at Nicolum River. This is the unfactored Design Load used for comparison.	We Infer from the climate models that the Pineapple Express events could go from 1:10 to 1:4 year event (over 3 days). By extrapolation for this component, we assumed a factor to increase the load back to a 1:25 event would be 10-20% (so we use 15%) and 121mm/24hrs increases to 139mm/24 hrs (for our example).	Land use changes (logging, pine beetle) could increase amounts of water on this structure by 10% (chapter 10 in Supplement to TAC Design Guide (2007)).	

3. Catch Basins (Storm Sewers) & Extreme Rainfall	121	18.2	0	139.2
	We assumed these structures were originally designed for a 1:10 to 1:25 year return period. Referencing the 1:25 return period to 24 hour rainfall data from the Rainfall Frequency Atlas for Canada (HOGG, 1985) yields rainfall as 121mm/24 hrs at Nicolum River. This is the unfactored Design Load used for comparison.	We Infer from the climate models that the Pineapple Express events could go from 1:10 to 1:4 year event (over 3 days). By extrapolation for this component, we assumed a factor to increase the load back to a 1:25 event would be 10-20% (so we use 15%) and 121mm/24hrs increases to 139mm/24 hrs (for our example).	Land use changes (logging, pine beetle) could increase amounts of water but we assume little affect on this structure as it is part of the internal road drainage and likely not affected by the watershed.	

Worksheet 4 – Engineering Analysis

8.4.8 Calculation of Total Capacity (C_T)

$C_T = C_E + C_M + C_A$

Where: C_T = Total capacity of the infrastructure
C_E = Existing capacity of the infrastructure
C_M = Maturing capacity of the infrastructure
C_A = Additional capacity of the infrastructure

Basis of Determination
- Definitions;
- Direct measurements;
- Engineering calculations; or
- Assumptions based on professional judgement.

Infrastructure Component (from section 8.3.4 of Work Sheet 3)	8.4.5 Existing Capacity State Basis of Determination C_E	8.4.6 Maturing Capacity State Basis of Determination C_M	8.4.7 Additional Capacity State Basis of Determination C_A	8.4.8 Total Capacity $C_T = C_E+C_M+C_A$
1. Road Surfaces (Gutters, Stormwater Inlets) & Extreme Rainfall	88	0	0	88
	The designers at the time may have added capacity as a safety factor to this component but is not verified. We checked climate data 11km west of Nicolum (Environment Canada - Hope Airport 1964-1996 (IDF)) to see if capacity of structures would face changed climate conditions - but there was no noticeable indication of changes in climate over this time period. We assumed: existing capacity the same as the design load; and that the structures were built as designed to handle the load.	Assume the same conditon	Not likely	

Worksheet 4 – Engineering Analysis

2. Median and Roadway Drainage Appliances (Hwy Ditches) & Extreme Rainfall	121	0	0	121
	The designers at the time may have added capacity as a safety factor to this component but is not verified. We checked climate data 11km west of Nicolum (Environment Canada - Hope Airport 1964-1996 (IDF)) to see if capacity of structures would face changed climate conditions - but there was no noticeable indication of changes in climate over this time period. We assumed: existing capacity the same as the design load; and that the structures were built as designed to handle the load.	May want to subtract 5 % here	Not likely.	

Worksheet 4 – Engineering Analysis

3. Catch Basins (Storm Sewers) & Extreme Rainfall	121	-6	2	117
	The designers at the time may have added capacity as a safety factor to this component but is not verified. We checked climate data 11km west of Nicolum (Environment Canada - Hope Airport 1964-1996 (IDF)) to see if capacity of structures would face changed climate conditions - but there was no noticeable indication of changes in climate over this time period. We assumed: existing capacity the same as the design load; and that the structures were built as designed to handle the load.	Maturing or degradation of pipes could reduce capacity by 2-5%. So use 5% for this example. Catch basins fill with debris and require cleaning about once a year.	Maturing or degradation of pipes could reduce capacity by 2-5%. But could also erode fill at outlet end and thus increase capacity of flow. Therefore increase capacity by 2% for this example.	

Worksheet 4 – Engineering Analysis

8.4.9 Evaluate Vulnerability (V_R)			
$V_R = \frac{L_T}{C_T}$	Where: V_R = Vulnerability Ratio L_T = Total load on the infrastructure C_T = Total capacity of the infrastructure		
Infrastructure Component	Total Load (from 8.4.4)	Total Capacity (from 8.4.8)	$V_R = \frac{L_T}{C_T}$ Vulnerability
1. Road Surfaces (Gutters, Stormwater Inlets) & Extreme Rainfall	101	88	1.15
2. Median and Roadway Drainage Appliances (Hwy Ditches) & Extreme Rainfall	153	121	1.26
3. Catch Basins (Storm Sewers) & Extreme Rainfall	139	117	1.19
When $V_R > 1$, the infrastructure component is vulnerable			
Infrastructure Component showing vulnerability should be forwarded to Section 8.5.2 in Work Sheet 5 for STEP 5 Recommendation Evaluation.			

Worksheet 4 – Engineering Analysis

8.4.10 Calculate Capacity Deficit (C_D)

$C_D = L_T - C_T$

$= L_T - (C_E + C_M + C_A)$

Where:

C_D = Capacity deficit of the infrastructure component
C_T = Total capacity of the infrastructure
L_T = Total load on the infrastructure component
C_E = Existing capacity of the infrastructure component
C_M = Maturing capacity of the infrastructure component
C_A = Additional capacity of the infrastructure component

Infrastructure Component	Total Load (from 8.4.4)	Total Capacity (from 8.4.8)	Capacity Deficit $C_D = L_T - C_T$
1. Road Surfaces (Gutters, Stormwater Inlets) & Extreme Rainfall	101	88	13
2. Median and Roadway Drainage Appliances (Hwy Ditches) & Extreme Rainfall	153	121	32
3. Catch Basins (Storm Sewers) & Extreme Rainfall	139	117	22

Clarification

The Capacity Deficit is the amount of capacity that must be added to the infrastructure component to address the vulnerability identified by this procedure. The capacity deficit may be addressed by capacity addition projects or through infrastructure management practices.

Worksheet 4 – Engineering Analysis

8.4.11 Data Sufficiency	
Identify process to develop data, Where insufficient	
Issue	**Process**
This is a Preliminary assessment as data to do a complete analysis is lacking; 24 hr. Rainfall data is used only as a basis for comparison and to be consistent with the other climate parameters.	**Further study required. Data is required in proper units for engineering analysis - which is a challenge in combining structure design and climate forecasting.**
This particular analysis gives relative comparisons and is not absolute because of the nature of data available and the time frame. This analysis gives a relative ranking in broad terms and indicates areas to examine in more detail.	**Require a detailed study of weather and storm data, time of concentraion, IDF data, structural design specification and maintenance records to determine the capacity of the existing highway drainage. If more storms are predicted then how will infrastructure perform under changing weather conditions.**
Analyzing the climate data to evaluate extreme rain can be an issue as many duration and intensity event combinations can cause problems for structures. Depending on the Time of Concentration, storms of various intensities (i.e. 15 min./2hrs/6hrs/etc.) are required for complete analysis .	**Require a detailed study of weather and storm data, time of concentraion, IDF data, structural design specification and maintenance records to determine the capacity of the existing highway drainage. If more storms are predicted then how will infrastructure perform under changing weather conditions.**
Need to determine if there is a built-in design reserve capacity in the drainage structures .	**Recommend doing a back calculation type of study using a consultant to assess a section(s) of the Coq to determine the original (or changed) design parameters and the actual drainage capacity required for a thorough Step 4 analysis.**
Where data cannot be developed, identify the data gap as a finding in Step 5 of the Protocol – Recommendations. **List Data Gap as findings to be sent to STEP 5 (Worksheet 5: Section 8.5.2)**	
1. Recommend that contractors document weather conditions (rainfall, wind, etc. from nearest station)that caused major mainenance issues. So link up infrastructure problems with climate data for future monitoring of this interaction.	
2. Recommend that if remidial action is required because of this type of analysis that contractors and replace infrastructure with upgraded design as regular maintenance allows and not as a separate program - unless serious situation exists.	
3. UBC etc. Have models that predict infrastructure failures - do they have climate as a variable and could this be modeled for MoTI purposes.	
Conclusions	

Worksheet 4 – Engineering Analysis

High intensity rainfall events could overload drainage infrastructure:
- Surface ponding on roadway surfaces could impedee emergency response
- Environmental effects could include increased erosion (carrying sediments and contaminants to water courses)
- Increased rainfall intensity may require updated policies and procedures regarding design and maintenance of highway structures
-

Date:	18-Mar-10
Prepared by:	MoTI - Step 4 Subgroup

Appendix I

Completed Protocol Worksheet 5

Worksheet 5 Recommendations

8.5.1 State Limitations	
MAJOR ASSUMPTIONS[1]	The assessment was not limited by the project definition or stated timeframe. The highway is not due for major refurbishment over the timeframe contemplated by the study. However, the highway is subjected to ongoing maintenance that would tend to mitigate many of the identified climate change risks as practices typically evolve to accommodate current conditions.
Available infrastructure information and sources	The assessment was not limited by lack of technical information regarding the highway. The team had access to the Coquihalla Highway data room. In addition, the team had access to personal files and very deep experience with the design, operation and maintenance of the highway.
Available climate data and information	**Unresolved Climate Parameters** PCIC was unable to provide model-based data for three climate parameters during the timeframe of the study. These included: • Frequency of rain on snow events; • Frequency of freezing rain events; and • Snow accumulation. The risk assessment was completed through the application of sensitivity analysis. Although the team concluded that the results generated by the sensitivity analysis are relatively robust, it is worthwhile pursing better definition for these parameters through more advanced statistical downscaling work. These studies could not be concluded within the timeframe of this assessment as they may take up to six months to complete. **High Wind / Downburst** PCIC was unable to provide model-based data to evaluate this situation since the wind speeds contemplated could not be resolved by the models. In addition, given the localized nature of these events it was very difficult to conduct synoptic analysis of this parameter. Finally, the team did not believe that it had sufficient information to express an opinion regarding the assignment of arbitrary probability scores in a sensitivity analysis. The team concluded that these events were potentially very serious on the Coquihalla Highway and needed to be further evaluated. **Visibility** Poor visibility can lead to serious safety concerns on the highway. A large portion of serious accidents report fog as a cause. The Coquihalla Highway is in a transition zone between the coast and interior regions of the province. Fog needs moisture to form. However, there are multiple causes of fog, including: • Very localized, from warm air over snow; • Valley fog; or • Low clouds. The team determined that this issue requires more study to define how visibility issues arise currently on the highway. Once BCMoTI has developed a better definition of current visibility issues, they will be better placed to assess the impact of climate change on this matter.
Available Other Change information and sources	The assessment was not limited by lack of information regarding other sources of change. The experience of the team, and observations of day-to-day operation of the highway compensate for any gaps that may otherwise occur.

[1] Notionally, these are the same major assumptions that underlie the entire assessment as determined in Step 1 and Step 2 of this Protocol. They may include boundary conditions used to define the study area, time frame, refurbishment schedules, etc.

Worksheet 5 Recommendations

Use of Generic/specific examples to represent population	This approach was not used in the assessment.
Uncertainty and related concepts	Climate modeling is based on inherent assumptions regarding likely emissions scenarios. Additionally, there is a significant level of statistical uncertainty associated with both the modeling and the analytical approaches used to downscale the information generated by the models from 50x50 grids to regional predictions. PCIC addressed this concern by correlating model predictions with observed, baseline, climate conditions. The BCMoTI team possesses a significant level of understanding of the regional climate based on many years of day-to-day, hands-on, experience with the design, operation and maintenance of the highway. This experience provided the team with sufficient foundation to assess the veracity of the climate model projections.
Other	N/A

8.5.2 Recommendations

Showing Vulnerability from Combination Interactions Assessments (from Work Sheet 3: 8.3.3, Risk = High) **Showing Vulnerability from Engineering Assessment** (from Work Sheet 4: 8.4.9, V_R >1 **Report on Data Gaps** (from Worksheets 1-4: 8.1.7, 8.2.8, 8.3.11, 8.4.11)	**Remedial Engineering Action**	**Management Action**	**Additional Study Required**
<u>**Pineapple Express**</u> Pineapple Express events present a significant risk to the infrastructure in terms of drainage management issues. These can adversely affect the safety and serviceability of the infrastructure. The team raised concern that these events will increase in both frequency and magnitude. Furthermore, the infrastructure is already exhibiting vulnerability to high intensity rainfall events. Thus, the team concluded that these issues will be exacerbated by climate change and raise greater challenges to the ongoing operation and maintenance of the highway.		BCMoTI will need to better resolve the potential frequency and magnitude of these events as they were primarily assess through synoptic analysis.	PCIC may be able to provide greater guidance on this matter through more refined statistical downscaling studies.
<u>**Snowfall**</u> Although snowfall events did not generate any high-risk scores with respect to the infrastructure, they	No further action required at this time.		

Worksheet 5 Recommendations

8.5.2 Recommendations

Showing Vulnerability from Combination Interactions Assessments (from Work Sheet 3: 8.3.3, Risk = High) **Showing Vulnerability from Engineering Assessment** (from Work Sheet 4: 8.4.9, V_R >1 **Report on Data Gaps** (from Worksheets 1-4: 8.1.7, 8.2.8, 8.3.11, 8.4.11)	**Remedial Engineering Action**	**Management Action**	**Additional Study Required**
nonetheless present an ongoing medium-risk concern. The team concluded that these events are unlikely to get worse as a result of climate change. However, they do raise potential concerns regarding: • Emergency response, • Third party utilities; and • Avalanche. The team recognized that these items represent an ongoing concern. However, they concluded that climate change would not exacerbate the situation and that BCMoTI already has ongoing design, operation and maintenance procedures that address these issues. It is not likely that BCMoTI would have to modify these procedures to address climate change.			
<u>Unresolved Climate Parameters</u> PCIC was unable to provide model-based data for three climate parameters during the timeframe of the study. These included: • Frequency of rain on snow events; • Frequency of freezing rain events; and • Snow accumulation.			Although the team concluded that the results generated by the sensitivity analysis are relatively robust, it is worthwhile pursing better definition for these parameters through more advanced statistical downscaling work. These studies could not be concluded
<u>High Wind / Downburst</u> PCIC was unable to provide model-based data to evaluate this situation since the wind speeds contemplated could not be resolved by the models. In addition, given the localized nature of these events it was very difficult to conduct synoptic analysis of this parameter. Finally, the team did not believe that it had sufficient information to express an opinion regarding the assignment of arbitrary			The team concluded that these events were potentially very serious on the Coquihalla Highway and needed to be further evaluated.

Worksheet 5 Recommendations

8.5.2 Recommendations

Showing Vulnerability from Combination Interactions Assessments (from Work Sheet 3: 8.3.3, Risk = High) **Showing Vulnerability from Engineering Assessment** (from Work Sheet 4: 8.4.9, V_R >1 **Report on Data Gaps** (from Worksheets 1-4: 8.1.7, 8.2.8, 8.3.11, 8.4.11)	**Remedial Engineering Action**	**Management Action**	**Additional Study Required**
probability scores in a sensitivity analysis.			
<u>Visibility</u> Poor visibility can lead to serious safety concerns on the highway. A large portion of serious accidents report fog as a cause. The Coquihalla Highway is in a transition zone between the coast and interior regions of the province. Fog needs moisture to form. However, there are multiple causes of fog, including: • Very localized, from warm air over snow; • Valley fog; or • Low clouds. The team agreed that this is a potentially high risk item and has identified this issue as a matter for further study. Ultimately, this issue may require the development of specialized highway management strategies.		Once BCMoTI has developed a better definition of current visibility issues, they will be better placed to assess the impact of climate change on this matter.	The team determined that this issue requires more study to define how visibility issues arise currently on the highway.

Worksheet 5 Recommendations

8.5.2f Report on the other conclusions, trends, insights and limitations

Of 560 potential climate-infrastructure interactions, the team determined that:

- 435, or 78%, of the interactions had low or no material risk;
- 111, or 20%, of the interactions had medium risk;
- 14, or 3%, of the interactions had high risk.

These low, medium and high risks are highlighted in the attached table.

This supports the conclusion that, overall, the infrastructure is relatively robust with respect to climate change.

DATE	March 21, 2010
PREPARED BY	Joel R. Nodelman (on behalf of BCMoTI Team)

Worksheet 5 Recommendations

Summary of Climate Change Risk Assessment Scores

Infrastructure Components	High Temperature	Low Temperature	Temperature Variability	Freeze/Thaw	Frost Penetration	Frost	Extreme Rainfall Intensity over One Day	Magnitude of Severe Storm Driven Peak Flows	Frequency of Severe Storm Driven Peak Flows	Rain on Snow	Freezing Rain	Snow Storm/ Blizzard	Snow (Frequency)	Snow Accumulation	High Wind/ Downburst	Visibility
Infrastructure																
Surface - Asphalt	18	9	2	6	2	2	30	30	25							
Pavement Marking											9	18	18	18		
Shoulders (Including Gravel)							36	36	35		3	3	3	18		
Barriers				6								3	3	15		
Curb	6			3									9	9		
Luminaires											12	12	3	12		
Poles											3			9		
Signage - Side Mounted - Over 3.2 m2											3	12	3			
Signage - Overhead Guide Signs					8						3	9	3			
Overhead Changeable Message Signs					8						3	9	3			
Ditches				6			30	36	35	3			3	18		
Embankments/Cuts (Constructed)				18	6	2	36	42	35				3	18		
Hillsides (Natural)				15			30	42	35	9			3	3		
Engineered Stabilization Works				15	2	2	18	30	35							
Avalanche (Inc Protective Works)		3	6	9	2	8	36	36	35	15	18	15	15	18		
Debris Torrents (Inc Protective Works)	14		10	9			42	42	35	15			12	15		
Structures that Cross Streams	6	3		6	8	4	36	42	35		6					
Structures that Cross Roads	6	3		6	8	4	30	36	35		6					
River Training Works (Rip Rap)							36	42	35							
MSE Walls				3				30	30							
Pavement Structure above Sub-Grade		9		12	10											
Catch Basins				3	14		36	36	30	18				12		
Median and Roadway Drainage Appliances				3	14		36	36		18				12		
Sub-Drains		6		3	14	2	18	36								
Third party utilities							30	30			21					
Culverts < 3m		3		6			42	42	35	15						
Culverts ≥ 3m				3			42	42	35							
Asphalt Spillway and Associated Piping/Culvert		3		6			36	42		15				9		
Environmental Features																
In stream habitat works	24		4				36	42	35							
Off channel habitat works	24		4				36	42	35							
Wild life fence system										18	18	18	18	18		
Wild life crossing structures																
Vegetation management	6		4													
Invasive Plants & Pests	12		4			12										
Miscellaneous																
Administration/Personnel & Engineering																
Winter Maintenance		3	2	15	10	2	24	36	35	15	18	18	9	9		
Ancillary buildings and utilities and yards.		3			6	2	6	12	15	15	12	9	9	15		
Communication											18	18	6	12		
Emergency Response		18				2	36	42	35	15	21	18	6	6		
Maintenance (Markings, Crack Sealing)		9	2	12	2	2										

Appendix J

List of Workshop Participants

List of Workshop Participants

x	Dirk Nyland, Chair		Kurt Edmunds	x	Joan Nodelman
x	Heather Auld (tele)	x	Hani Farghaly	x	Joel Nodelman
x	Jim Barnes	x	Mike Feduk	x	Don Shaw
	Brent Beattie	x	Reg Fredrickson	x	Peter Swetlishoff
	Mike Boissonneault	x	Ben Kangasniemi	x	Loris Tommasel
x	Andy Braacx		David Lapp	x	Joe Valentinuzzi
x	Al Brown	x	Gar Lee	x	Simon Walker
x	Angela Buckingham	x	Jurgen Lutter		Martin VanHoof
x	Gerd Buerger	x	Ron Mathieson		Doug Wilson
x	Ed Campbell	x	Erin Moxon		
x	James Clarkin/Ryan Phillips	x	Mike Miles		
x	Barry Eastman		Trevor Murdoch		

x: Attended Workshop