FINAL REPORT

USING MESOSCALE MODELS TO SUPPORT REGULATORY DISPERSION MODELLING

VANCOUVER, BRITISH COLUMBIA

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1. INTRODUCTION

The Water Air and Climate Change Branch of the British Columbia Ministry of Water, Land and Air Protection retained Rowan Williams Davies & Irwin Inc. (RWDI) to undertake an assessment of mesoscale meteorological models to support air quality dispersion modelling in British Columbia. A brief literature was undertaken, focussing on the following issues:

- availability and relative performance of various mesoscale models (e.g., MM5, RAMS, MC2);
- potential for mesoscale models to provide required meteorological data for regulatory dispersion models;
- current mesoscale modelling activities in the Pacific Northwest;
- ability of mesoscale models to produce realistic data for British Columbia, given the complexity of the topography;
- conditions under which mesoscale models tend to produce realistic results and conditions when they do not;
- advantages of a hybrid approach using a diagnostic model (CALMET) in combination with a mesoscale model (MM5);
- studies that have used prognostic mesoscale model output to support regulatory dispersion modelling.

The findings of the literature review are presented in the following sections.

2. CURRENTLY AVAILABLE MESOSCALE METEOROLOGICAL MODELS

Meteorological models can be categorized into one of two categories: diagnostic; and prognostic or predictive. Diagnostic models use interpolation schemes to produce gridded meteorological fields from sparse, irregularly spaced observation data. In some cases, the interpolation schemes include empirical expressions to account for topographical or other localized effects that occur between observing sites. Because these models simply interpolate observations, they are not able to predict how the meteorological fields will change in the future (i.e., they cannot be used for forecasting). CALMET is an example of a diagnostic model.

Prognostic models rely on the fundamental equations of atmospheric motion to provide realistic predictions of how meteorological conditions will behave between observing stations. These models solve the equations of motion in time and space, and can be used for projecting existing conditions into the future (i.e., forecasting).

Mesoscale models are prognostic models that are intended to model meteorological phenomena at horizontal scales ranging from a few kilometres to a few hundred kilometres. Several such models have been in use in North America in recent years. The following are examples:

- Mesoscale Model 5 (MM5)
- Regional Atmospheric Modelling System (RAMS)
- MC2
- HOTMAC
- Advanced Regional Prediction System (ARPS)
- Navy Operational Regional Prediction System (NORAPS6)
- US Air Force's Relocatable Window Model (RWM)
- US Navy's COAMPS model
- Eta and Meso Eta
- MASS
- WRF

Various other mesoscale models have been in use in Europe, such as FITNAH (Germany), BOLAM (Italy), and the Swiss Model. By and large, the models are similar to each other in concept. They solve the equations of atmospheric motion over a three-dimensional grid, and use parameterizations to calculate fluxes at the boundaries of the simulation, such as radiation at the top of the model domain, and heat and radiation fluxes at the earth's surface. They also use parameterizations to estimate sub-grid scale phenomena such as the formation of convective cloud, and to achieve closure of the equations in solving for the effects of boundary layer turbulence. The models tend to differ in the choice and range of options for the various parameterizations, and may use different methods for initializing the simulations and introducing boundary conditions, different coordinate systems and domain nesting capabilities, and different numerics for solving the equations. Many of the models make use of Four Dimensional Data Assimilation (FDDA), in which field data are incorporated throughout the simulation and used to constrain the equations so that the results do not drift too far from actual observations.

Both MM5 and RAMS have been widely used to provide meteorological fields for input to regional air quality models. In the case of MM5, some examples include the Regional Modelling Adaptation Project (SARMAP) in the San Joaquin Valley, California (Seaman et al., 1994), the Southern California Air Quality Study (Seaman et al., 1996), the Pittsburgh Ozone Modeling Study (McNally and Tesche, 1998), the PATH study in Hong Kong (Physick and Noonan, 2000), regional modelling in the Lower Fraser Valley, BC (Pagowski et al., 2000), ozone modelling the Cascadia region of Oregon and Washington (Barna et al., 1998) and regional modelling in Southern Ontario (Qiu, et al., 2001). In the case of RAMS, examples include the Lake Michigan Ozone Study (Lyons et al., 1995), the Ozone Transport Group study of the eastern US (Koerber, 1998), and the Southern Appalachian Mountains Initiative (Mueller and Bailey, 1998).

Both MM5 and RAMS have also been used to provide meteorological information for indirect or direct input to short-range air quality models (Robe and Scire, 1998; Evans, 2002). MC2 has been used to provide input to regional air quality modelling in the lower Fraser Valley, BC (Hedley and Singleton, 1997).

How do these models perform in comparison to each other? This question can best be answered for MM5 and RAMS, which have been compared for various regional air quality modelling applications. Some inter-comparisons among other models have also been conducted.

In the late 1980's, the Mesoscale Model Comparison Project was undertaken, in which two 24-hour periods from a field study in northern California (Project WIND) were simulated using four mesoscale models: FITNAH, RAMS, HOTMAC and the Tel Aviv model, which was a derivative of MM4 (Pearce, 1994). The study domain was centred on the northern end of the San Joaqin Valley and included a significant amount of topography. The first 24-hour period coincided with hot dry weather during the summer (June, 1985), and the second 24-hour period coincided with a frontal passage during the wintertime (February, 1986).

The general conclusion from this project was that no model was clearly better or worse than the others and that each had its strengths and weaknesses (Busch, et al., 1994). All models failed to resolve the strong surface inversion at nighttime during the summer period, and this was at least partly attributed to inaccurate resolution of the topography by the 5 km grid spacing used in the simulations. The models also generally were unable to resolve the rapid changes associated with the frontal passage in the winter period, resulting in poor replication of surface wind speeds. Temperature changes and wind direction were reproduced fairly well by all the models. Some of the problems that occurred could have been improved through better treatment of boundary conditions. For example, HOTMAC was initially least successful in modelling night time surface temperatures during the summer period, but its performance was subsequently improved by using smaller values of thermal diffusivity and heat capacity of the soil.

Cox, et al. (1998) reported on an intercomparison of four mesoscale models as part of a process of selecting a model for theater operations by the US Air Force. RAMS, MM5, NORAPS6 and RWM were tested for their ability to forecast weather conditions during three 3-day periods in five regions. The first period corresponded to a period strong cyclogenesis leading to a major tornado outbreak in the lower midwest US. The second period corresponded to the passage of a trough over Korea and another trough over Alaska. The third period was associated with passage of a strong trough over Korea and presence of an intense surface low off the coast of Alaska. A 46 km grid spacing was used in all tests.

The models differed in their fine details, such as method of initialization, method of solving the equations, coordinate systems, method of introducing lateral boundary conditions, and various parameterization schemes used. Unlike MM5 and RAMS, NORAPS6 and RWM used the simplifying hydrostatic assumption, in which vertical accelerations are ignored. This is generally not a concern at a grid spacing of 46 km, but becomes a concern at smaller grid spacings where convection and topographic effects that induce significant vertical accelerations can be resolved.

The performance of each model was evaluated in terms of root-mean-square errors (RMSE) for temperature, humidity and wind. The results indicated that RAMS was the best performer overall, achieving the lowest RMSE for more of the simulation hours than any other mode. It followed by MM5. In terms of meeting specific performance criteria (e.g., predicting temperature within 2C, wind direction within 30 degrees and wind speed within 1 m/s), RAMS and MM5 edged out the other models. All models were much more successful in predicting upper level conditions than in predicting surface conditions, which is a concern for use of the models in air quality applications. With the exception of high wind speeds, the performance criteria for all surface parameters were met less than 50% of the time by all models.

Various inter-comparisons of MM5 and RAMS have been undertaken for regional air quality studies in the US. For example, Tesche and McNally (1996) present a comparison of the two models for a July 1991 meteorological event used to study ozone formation in the eastern US.

Both models were run with a series of nested grids, having horizontal grid spacings of 108 km, 36 km and 12 km. The model domain with the 108 km grid spacing covered most of North America. The domain with the 36 km spacing covered the eastern half of the US, and the domain with the 12 km spacing covered a somewhat smaller subset of the 36 km domain. The models were compared in terms of their ability to simulate surface winds, temperature, and humidity. The overall conclusion of this study was that the model performance was nearly identical for the two models, with MM5 performing slightly better at the larger spatial scales and RAMS performing slightly better at the finer scales. The performance of the models for the July 1991 episode was quite good, with average errors for surface wind speed in the 20 to 30% range, average errors for surface temperature around 10%, average errors for temperature aloft less than 10%, and average errors for surface mixing ratio in the 10 to 20% range.

Some inter-comparison between Environment Canada's model, MC2, and other mesoscale models (BOLAM and the Swiss Model) have been conducted as part of the Mesoscale Alpine Programme (MAP) in the European Alps, but published details were not found. MC2 was chosen as the official ultrafine mesomodel for the MAP field phase in 1999, despite the fact that several version of MM5 were operational in the Alps region, as well as the US Navy's COAMPS model (Benoit, 2002). In this case, the term ultrafine implies a horizontal grid spacing of 3 km.

The general conclusion from model inter-comparisons seems to be that the models are generally close in performance, and no single model stands above the others in all cases.

3. METEOROLOGICAL INPUTS FOR REGULATORY DISPERSION MODELS

What do regulatory dispersion models require in terms of meteorological inputs, and do mesoscale models provide the necessary information?

The US EPA's regulatory model, ISC3, requires hourly information on surface temperature, surface winds, atmospheric stability and mixing height. These data are normally obtained or derived using data from the nearest observing site. Preprocessing software, PCRAMMET, is used to calculate Pasquill-Gifford stability classes based on observed wind speeds, cloud cover and cloud ceiling. Mixing heights are calculated using upper level data from daily morning soundings. In cases when wet deposition is of interest, hourly precipitation data are also used.

The EPA's new model, AERMOD, requires similar data to ISC3, surface hourly winds and temperature, hourly cloud cover, and morning soundings of wind, temperature and dew point from the nearest available observation site. The data are processed using a software routine called AERMET. AERMET calculates hourly turbulence parameters, surface heat flux, friction velocity, mixing height, Monin Obukhov length and other boundary layer parameters and passes them on to AERMOD along with hourly wind speed, direction and temperature.

Both ISC3 and AERMOD operate under the assumption of uniform meteorological conditions. Normally, data from a single nearby observing site are used to represent the meteorological conditions. CALPUFF, being a lagrangian puff model, has the capability of simulating dispersion in non-uniform, spatially varying meteorological conditions. A meteorological preprocessor, CALMET, is used to produced gridded 3-dimensional meteorological fields for CALPUFF from all available surface and upper data for the region of interest. The required surface meteorological data for input to CALMET are wind speed and direction, temperature, cloud cover, cloud ceiling, surface pressure and relative humidity. When wet deposition is of interest, hourly precipitation data are also be required. The required upper air data consist of twice daily soundings of wind temperature, and pressure.

The output from CALMET, which is passed on to CALPUFF, consists of gridded 3-dimensional fields of the three components of wind and temperature, and 2-dimensional fields of stability class, friction velocity, mixing height, Monin-Obukhov length, convective velocity scale, and precipitation rate (Scire et al., 2000).

Mesoscale models, such as MM5, RAMS and MC2 provide all of the necessary meteorological information for running the regulatory dispersion models, but may not directly provide some of the derived parameters that are needed, such as mixing height, cloud cover and Monin-Obuhkov length. In addition, the mesoscale model outputs are in binary formats that are not directly readable by the dispersion models. Therefore, preprocessing of the mesoscale model outputs is needed. Since the existing meteorological preprocessors for the regulatory models, such as PCRAMMET, AERMET and CALMET, are already designed to calculate the required derived parameters for each model, it would make the most sense to develop procedures for inputting the mesoscale model outputs into these dispersion model preprocessors. This approach has already been taken for CALMET, and it currently has the capability of incorporating gridded data from MM5.

The US EPA's new regional air quality modelling system, MODELS-3, includes a module known as MCIP (Meteorology-Chemistry Interface Processor), which is intended as a preprocessor to prepare gridded meteorological data for use in the chemistry/transport module of MODELS-3, which is known as CMAQ (Byun et al., 1999). Currently, MCIP is configured to process the output from MM5. MCIP calculates all of the derived parameters that are needed by CALPUFF, such as boundary layer height, cloud cover, convective velocity scale and Monin-Obukhov length. Therefore, the possibility exists of modifying MCIP to output the data in suitable format for CALPUFF, which would bypass the need for CALMET. Without a detailed review of the procedures used in MCIP to calculate the derived parameters and ensure mass-consistency, compared to the corresponding procedures used in CALMET, it is not possible to say whether or not MCIP would present any advantage over CALMET. CALMET has at least one advantage, in that it has flexible interpolation schemes for producing output data at a different resolution from the input data.

4. MESOSCALE MODELING ACTIVITY IN THE PACIFIC NORTHWEST

A cross-section of mesoscale modelling activity in the Pacific Northwest is provided in this section.

In the late 1980's, Steyn and McKendry (1988) experimented with an early version of RAMS to simulate a sea-breeze circulation observed in the Lower Fraser Valley, British Columbia. The model was run with a 5 km horizontal grid spacing over a 100 km x 70 km area, with hydrostatic equilibrium assumed. The model performed well in reproducing the diurnal surface temperature pattern and the evolution of surface wind over the course of the 24-hour period that was simulated. The model had a tendency to overestimate afternoon wind speeds somewhat, and significantly overestimated the afternoon mixing height at all of the four sites where in the Fraser River Delta where observed mixing height data were available. The reason for the latter problem, which would be of concern for air quality studies, was unclear.

Cai and Steyn (1996) used RAMS to simulate the meteorology in the Lower Fraser Valley during a 4-day smog event in July, 1985. The episode was characterized by weak synoptic-scale forcing, and surface wind flows were largely driven by local thermal gradients (i.e., sea breezes and valley flows). A nested set of grids was used, with a 2.5 km grid-spacing in the innermost nest. Overall, the model agreed very well with observed surface winds and temperature, replicating the diurnal patterns in these parameters. It tended to overestimate night time surface wind speeds and underestimate the night time surface temperatures slightly. This was attributed to inaccuracy of the long-wave radiation scheme in RAMS. The lower predicted surface temperatures resulted in slightly over predicted downslope winds. Predicted vertical profiles of wind and temperature generally agreed well with observed profiles, and the simulation also did a reasonably good job of predicting observed diurnal patterns in mixing height data.

Hedley and Singleton (1997) modelled the same July, 1985 meteorological episode in the Lower Fraser Valley, using MC2. The modelling was done on a single domain, 550 km x 550 km, with a grid spacing of 10 km. The model performed reasonably well in predicting surface temperature, but generally underestimated the daytime temperatures and overestimated the night time temperatures, particularly near the coast. Wind directions appeared to be reproduced reasonably well, except for sites on Vancouver Island and in the Straits of Georgia. This problem was attributed to the low spatial resolution of the simulation (10 km grid spacing). Significant errors in wind speed occurred at a number of sites. At Abbotsford, for example, the daytime wind speeds were significantly under predicted and the night time speeds were over predicted. The model performed well at simulating mixing heights, with somewhat poorer performance near the coast.

Comparing the results of Hedley and Singleton (1997) to those of Cai and Steyn (1996), one concludes that the RAMS simulation performed better than the MC2 simulation. In all likelihood this was more related to differences in horizontal resolution (2.5 km grid spacing in RAMS, versus 10 km grid spacing in MC2) than differences in model formulation.

Barna et al. (1999) used MM5 in combination with CALMET to provide meteorological fields for ozone modelling in the Cascadia Region of Oregon and Washington. CALMET was used to improve the MM5 simulation with observation data in certain parts of the model domain. A 4-day ozone episode in July, 1996 was simulated with a horizontal grid spacing of 5 km. Model performance was evaluated at four observation sites that were not input to CALMET. Surface wind speeds were over predicted, by 0.5 to 1.3 m/s on average. Predicted surface wind directions agreed well with the observations, on average, as did predicted surface temperatures. Predicted vertical profiles of wind and temperature at two locations generally agreed well with the observed data, although the predicted wind speed profile was relatively poor at one of the locations.

RWDI recently used MM5 to simulate meteorological conditions over a 10-day period in August, 1993, corresponding to an ozone episode that occurred during the Pacific-93 field program (Pagowski et al., 2000). A set of nested domains was modelled, with a 5 km horizontal grid spacing in the innermost domain. A network of 55 stations was available to obtain surface data for assimilation into the model run and for performance evaluation. Upper air data were available from four sites and aircraft measurements were also available. Model performance was generally similar to that obtained by Hedley and Singleton (1997) using MC2 at a 10 km grid spacing. Perhaps the most significant problem was inability to accurate reproduce surface temperatures, which were generally underestimated during the daytime and overestimated at night time. This may be related to the radiation scheme in the model, but is likely also related poor resolution of the topography at the 5 km grid spacing.

5. ABILITY TO PRODUCE REALISTIC DATA FOR BRITISH COLUMBIA

The discussion of the preceding section suggests that mesoscale models can provide realistic meteorological data suitable for regulatory air quality studies in British Columbia. However, it is clear that, given the complexity of the topography in the region, high horizontal resolution is important to the success of the modelling. Benoit (2002) suggested that a grid spacing of 3 km or less is desirable to properly model transport through valleys. Seaman et al. (1996) used MM5 with nested grids to simulate a 6-day period over Southern California, and found that a 4 km grid spacing generally reproduced the surface wind flows, but a 1.33 km grid spacing was needed to resolve some small-scale circulation features considered to be important to mixing and transport of pollutants in the region.

It is also clear from the literature that assimilation of observation data into the simulations greatly improves model performance in complex terrain. Fast and O'Steen (1994) used RAMS with Four-Dimensional Data Assimilation (FDDA) to simulate meteorological conditions for an air quality study at Rocky Flats in Colorado's Front Range. A series of nested domains were used, with a grid spacing of 333 m in the innermost domain. Their simulations showed significant improvement with FDDA in predicting valley drainage flows. Seaman et al. (1995) applied MM5 with FDDA to simulate meteorological conditions in the San Joaquin Valley, California during two summertime periods in 1990. Nested domains were used, with a 4 km grid spacing on the innermost domain. The study showed that the use of a network of special observation data for FDDA on the

4 km grid produced a significant improvement in model performance for surface wind, temperature and mixing height. Mueller et al. (1996) used RAMS at a horizontal grid spacing of 4.5 km and found the model did not adequate represent air flow in the Tennessee River Valley without the use of FDDA.

Evidently, having a network of observation data helps to account for effects of subgrid scale topographical features that are not adequately resolved by the model. This means that higher horizontal resolution will be needed in areas where observational data that can be used for FDDA are scarce.

6. CHALLENGING SITUATIONS FOR MESOSCALE MODELS

Based on the comments of a number of researchers, the ability of mesoscale models to simulate elevated inversions at the top of the boundary layer (i.e., capping inversions) is a major concern (Steyn, 2002; Hanna et al., 2001). Benoit (2002) indicated that the models will not handle any large-scale shallow change in stability that is not represented in the initial conditions. Hanna et al. (2001) raised a concern about modelling the strength of both elevated inversions and nighttime surface inversions. These problems are largely related to the vertical resolution of the simulations.

Steyn (2002) also suggested that the models have difficulty with sea breeze transition periods. It is likely that similar problems would occur with transitions between upslope and downslope flows in valleys. Any flows driven by local thermal gradients, such as sea breezes and valley flows, become extremely important during periods of weak synoptic pressure gradients. Under these conditions, high spatial resolution and good characterization of the surface radiation budget is very important. The latter requires good characterization of surface conditions (soil moisture, albedo, terrain elevation, etc.).

A potential general weakness of mesoscale models for high-resolution applications in complex terrain is the fact that the boundary layer schemes tend to neglect horizontal advection terms in the turbulence equations (Benoit, 2002). The advection terms are likely to make a more significant contribution in steep topography, where strong horizontal gradients in mean flow can occur in the boundary layer.

7. USING MESOSCALE MODELS IN COMBINATION WITH A DIAGNOSTIC MODEL

Robe and Scire (1998) proposed an approach of combining coarse resolution prognostic modelling with finer resolution diagnostic modelling, as a computationally efficient means of simulating flows in complex terrain. They used MM5 at a horizontal grid spacing of 18 km in combination with CALMET at a grid spacing of 2 km. Their run time for CALMET was about one 200^{th} of the run time for MM5 at a grid spacing of 2 km.

CALMET has efficient parameterization schemes that account for the deflection of streamlines over topographical features, blocking of flows by topographical features during stable stratified conditions, and slope flows. In general, these features should do a reasonable job of simulating surface air flow features around smaller-scale topography that were not captured by the MM5 simulation. A number of approximations are used, however, and it is not clear how the uncertainties affect the results, particularly during transition periods when the flows tend to be weak and complex flows. During this brief literature review, only one published paper was found that provided any information on the performance of the MM5/CALMET approach (Robe and Scire, 1998). The model was evaluated only in terms of surface wind flow, and only for a single brief meteorological period. Barna et al. (1999) used MM5 and CALMET to produce meteorological fields for input to ozone modelling, but in their case both MM5 and CALMET were run at the same grid spacing (5 km). CALMET was used primarily as a preprocessor to prepare the MM5 output for input to the chemistry/transport model.

CALMET uses approximate methods for estimating mixing heights, and is unlikely to accurately capture the characteristics of the capping inversion and nighttime inversion strength. The prognostic mesoscale models have difficulty reproducing these effects, and diagnostic models will have still greater problems.

Overall, the hybrid approach of using a coarser resolution prognostic model in combination with a diagnostic model is promising in concept. This approach makes it practical to capture at least some of the effects of small-scale topographical features. However, all of the issues identified for prognostic models in the preceding section, and the need for high resolution and FDDA are amplified with the hybrid approach.

8. OTHER STUDIES USING THE MM5/CALMET APPROACH

Studies that have used prognostic mesoscale model outputs to support regulatory dispersion modelling are difficult to find. A few examples involving MM5 and CALMET are cited in this section.

A CALMET/MM5 study in the vicinity of Juneau, Alaska was undertaken to examine how whether or not this approach could generate accurate meteorological information for dispersion modelling purposes in an area of extremely complex topography, with relatively little observational data available. MM5 was run in a nested mode with grid spacings of 60 km, 20 km and 4 km. CALMET was run with grid spacings of 250 m and 1 km. Various combinations of CALMET and MM5 were run for a period of 1 year. In all cases, the simulations did a poor job of replicating wind roses at sites where the observation data were not assimilated into the simulations. The performance of the simulation in terms of other important parameters, such as surface temperature, vertical profiles, mixing height and stability, was not investigated.

CALMET and MM5 were used as part of an air quality study for a proposed power plant in northwestern Washington State (MFG, Inc., 2001). MM5 was run at a horizontal grid spacing of 12 km, and CALMET was run at 4 km. Observations of cloud cover, ceiling, surface temperature and relative humidity from 94 sites and vertical soundings from three sites were assimilated into the CALMET run. Observed surface winds were not assimilated. Predicted and observed summer wind roses were compared at three sites in the southern BC portions of the study domain. The wind roses generally showed poor agreement, with neither the distribution of wind direction nor that of wind speed reproduced well. At two of the sites, the mean surface wind speed was underestimated by about a factor of 2. The model performance in terms of other important boundary layer parameters was not investigated.

RWDI used MM5 and CALMET to produce hourly meteorological fields for a period of 1 year in the vicinity of Fort McMurray, Alberta. The horizontal grid spacing of the MM5 run was 20 km and that of the CALMET run was 2.5 km. Observations from three surface stations were assimilated into the runs. The results indicated that the simulation produced reasonable results at upper levels while at the surface, the number of observing stations incorporated into the analysis was not sufficient to fully resolve wind flows in the Athabasca River Valley.

Based on these studies, it appears that the hybrid approach of using a coarser MM5 run with a finer CALMET run does not adequately represent meteorological conditions in complex terrain, unless data from a large number of observing sites are available to assimilate into the simulation. Whether

CALMET is used or not, good model performance in areas of complex terrain with sparse observational data requires that the prognostic model be run at the highest possible horizontal resolution (grid spacing less than about 3 km, if possible).

9. CONCLUSION

Numerous prognostic mesoscale models are currently in use for various weather prediction and meteorological research purposes. Of these models, MM5 and RAMS have been most widely used in air quality applications (MC2 has also been used). The more advanced models, i.e., non-hydrostatic models such as MM5, RAMS, MC2 and HOTMAC, appear to be more-or-less equal in performance.

The mesoscale models generally provide all of the meteorological information needed for air quality models, but it is necessary to extract the relevant information, reformat it and calculate certain derived parameters that are needed by the air quality models. The MM5 model has previously been used in combination with the CALMET to provide input data for the CALPUFF dispersion model. Similarly, RAMS has recently been used to provide input to the AERMOD dispersion model (Evans, 2002). Since MM5 and RAMS already have been interfaced with regulatory dispersion models, they are the most promising choices for using mesoscale models in support of dispersion modelling in British Columbia.

The available evidence suggests that hybrid approach of using a relatively coarse resolution prognostic model run in combination with finer scale diagnostic model run (e.g., using MM5 in combination with CALMET) is relatively unsuccessful in complex terrain, unless observational data from a significant number of observing sites are incorporated into the simulation. It is recommended that this approach not be taken in the future.

When observation data are scare, very fine horizontal resolution is required for the prognostic model run (less than 3 km), in order to provide realistic results in the kind of topography that exists throughout most of British Columbia. Relatively fine vertical resolution is also needed.

The appropriate next step is to investigate the feasibility and practicality of running MM5 or other prognostic model at fine horizontal resolution for a one year period over key areas of the province, if not the entire province. This information can then be used to weigh the cost and benefits of mesoscale modelling against the cost and benefits of the alternative, which is to invest in more meteorological monitoring in data scarce areas.

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