JP1.6 INCORPORATING A FULL-PHYSICS METEOROLOGICAL MODEL INTO AN APPLIED ATMOSPHERIC DISPERSION MODELING SYSTEM

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1. INTRODUCTION

A new modeling system has been developed to provide a non-meteorologist with tools to predict air pollution transport in regions of complex terrain. This system couples the Penn State/NCAR Mesoscale Model 5 (MM5) (Grell et al. 1994), Earth Tech's CALMET and CALPUFF (Scire et al. 1999) models and a unique Graphical User Interface (GUI) developed at Pacific Northwest National Laboratory (PNNL). This modeling system has evolved from PNNL's DUSTRAN model that was designed to predict transport of fugitive dust emissions (Allwine et al. 2002a; Allwine et al. 2004). The primary advantages of the new system are the streamlined application of MM5 and CALMET, limited data requirements, and the ability to run the system on a desktop or laptop computer that is not connected to a computer network.

This system is unique in that a full-physics model is run on a local personal computer (PC). Most emergency response systems that make use of full-physics dynamical models are not PC based (e.g. Chandrasekar et al. 2003; Ryall and Maryon 1998; Saltbones et al. 1998; Iwasaki et al. 1998). PC-based systems usually use a highly parameterized diagnostic model of the atmosphere (Douglas et al. 1990; Syrakov and Prodanova 1998; Scire et al. 1999), or require that the full-physics model be run at a remote location (Warner et al. 2004).

2. THE MODELING SYSTEM

The new system was designed for field use in data-sparse regions, where there are limited observations to initialize the model or where internet access is not available. The user is able to define a domain of interest, provide details about the pollutant source term, and enter a surface weather observation or profile through the GUI. The system generates initial conditions and time constant boundary conditions for use by MM5 or initial conditions for CALMET. The meteorological model is run and results are passed to CALPUFF for dispersion calculations. Contour plots of pollutant concentration are prepared for the user, and displayed in the GUI.

2.1 METEOROGICAL MODELS

Two different meteorological models are available in the new system: MM5, an advanced full physics model; and CALMET, a diagnostic flow model that treats the effects of complex terrain on the winds, including parameterizations for slope flows, blocking and channeling of the wind. Both models are included for greater flexibility depending on the application. The user specified grid and grid spacing is used with CALMET, and is used as the innermost grid with MM5. We have configured MM5 to use 34 vertical levels and 4 nested domains. The grid spacing of the outer grids is determined from the grid spacing of the inner grid, for the results shown in Section 3, we used a grid spacing of 1 km for the inner most domain (Table 1).

Table 1. Details of the 4 nested MM5 domains used in this study.

Grid	# East-West Grid Points	# North-South Grid Points	Grid Spacing (km)
1	31	31	27
2	31	31	9
3	37	37	3
4	49	49	1

The initialization procedure for MM5 has been modified. In its standard configuration, MM5 requires initial conditions and time varying boundary conditions, which are usually obtained from a large-scale model forecast. There are situations where these products are either unavailable or take a long time to download. In these applications it is desirable to start MM5 with uniform initial conditions and boundary conditions that are constant in time. Of course, the user must exercise discretion, because application of boundary conditions that are constant in time may not always be valid.

Application of MM5 has been simplified further by limiting the physics options available to the user. The parameterizations we selected include the MRF boundary layer scheme (Hong and Pan 1996), the simple ice cloud microphysical parameterization (Dudhia 1989), the cumulus scheme of Grell et al. (1994) with the two outer grids (no cumulus parameterization is used on the two inner grids), the shortwave radiation scheme of Dudhia (1989), and the Rapid Radiative Transfer Model (RRTM) of Mlawer et al. (1997) for longwave radiation.

Starting with MM5 with uniform conditions generated by a single profile suggests that wind field will be out of geostrophic balance. A number of techniques were tried, including explicitly removing the divergence at each level and adjusting the wind field to follow the thermal wind relationship, but these methods did not improve the results. Rather, the start times for the inner model grids were staggered using a two-hour offset interval.

CALMET also can be used with a number of different parameterizations, including blocking of the winds by terrain, kinematic effects of terrain, slope flows and divergence removal. In this study, only the parameter-

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izations for blocking of the winds by the terrain (Allwine and Whiteman 1985) and slope flows (Mahrt 1982; Scire and Robe 1997) are used.

2.2 DISPERSION MODEL

In the DUSTRAN system, CALPUFF (Scire et al. 1999), a Gaussian puff model is used to calculate dispersion of pollutants in the atmosphere. The diffusion coefficients used in CALPUFF can be a function of the observed turbulence, observed or computed scaling variables, or based on Pasquill-Gifford, McElory-Pooler, or Complex Terrain Dispersion model (Perry et al. 1989) dispersion coefficients.

3. URBAN 2000 AND VTMX 2000

The URBAN 2000 (Allwine et al. 2002b) and the Vertical Transport and Mixing 2000 (VTMX 2000) (Doran et al. 2002) field campaigns were conducted during October 2000 in the Salt Lake Valley, Utah. The URBAN 2000 observations were focused on dispersion in and around downtown Salt Lake City, while observations associated with VTMX 2000 focused on measuring valley scale flows. All Intensive Operations Periods (IOPs) associated with the field campaigns were conducted at night during stable conditions with generally small mesoscale or synoptic influence. Profiles of wind, temperature and humidity were measured using radiosondes launched at the Wheeler Farm site (Figure 1).

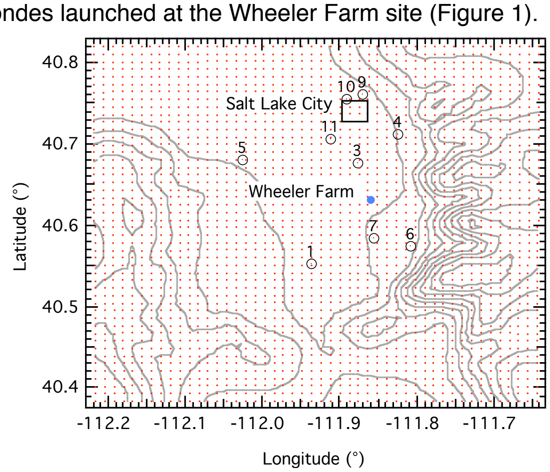

Figure 1. Salt Lake Valley terrain (gray lines in 100 m intervals), downtown Salt Lake City, PNNL station location, Wheeler Farm radiosonde launch site (blue dot) and the inner most MM5 grid points (red dots).

Two IOPs were selected to evaluate the performance of our new modeling system. The first, IOP 4, lasted form 22 LST 8 Oct. to 12 LST 9 Oct. This period was marked by clear skies and well developed drainage flows. The second, IOP 7, lasted from 22 LST 17 Oct. to 12 LST 18 Oct. This time period also had clear skies and well developed drainage flows.

In all, three different sets of simulations were completed for each IOP:

- "CALMET-Single", started with a simple profile determined using a single surface observation (Table 2) near the center of the valley. Wind and temperature profiles were computed as a function of the stability.
- "MM5-ETA", started with ETA initial conditions and run using time-changing ETA boundary conditions. The Wheeler Farm radiosonde profile was assimilated into the initial conditions.
- "MM5-Single", started with initial conditions and time constant boundary conditions generated from the Wheeler Farm radiosonde profile.

Table 2. Initial wind speed and wind direction used to start CALMET-Single.

IOP	Temperature (K)	Wind Speed (ms^{-1})	Wind Direction (°)
4	284	1.5	142
8	282	1.6	173

4. RESULTS

In order to compare the MM5 and CALMET results with the observations, the simulated winds had to be interpolated to observation location. This was accomplished by using a weighted average of the wind components from the 4 closest model grid points to the surface station. A second adjustment was made to the MM5 simulated winds to account for differences between the wind measurement height, and the height of the predicted winds. The latter adjustment was made using Businger-Dryer relationships that account for the static stability and the MM5 predicted surface fluxes (Businger et al. 1971; Dryer 1974). Similar adjustments were not made to the CALMET predicted winds because CALMET sets the Monin-Obukhov length to zero at night and a correction for stable conditions cannot be made.

Overall, the wind forecasts made by MM5-ETA and CALMET-Single are good, but there are significant deviations from observations (Table 3). The large wind direction bias in the simulations made using MM5-Single is the result of poor forecasts of wind direction can not be attributed to a single station, but during IOP4, MM5-Single generally over-predicted with wind direction on the eastern half of the valley.

Table 3. Wind speed and wind direction bias for the MM5-ETA, MM5-Single, and CALMET-Single using the stations in Figure 1 for MM5 forecast hours 7 through 12.

Variable	CALMET-Single	MM5-ETA	MM5-Single
Wind Speed (ms^{-1})	0.6	2	0.5
Wind Dir. (°)	10	5	33

An example time series measured at PNNL Station 4, which was located on the eastern edge of the Salt Lake Valley (Figure 1), is shown in Figure 2. When there are significant drainage flows, winds in this region are dominated by flow out of a near-by canyon. MM5-ETA did a good job predicting both the wind direction and wind speed. The MM5-Single simulations did a good job predicting the wind speed as station 4, but over-predicted the wind direction. CALMET-Single over predicted the wind speed and direction. Some of the over-prediction of the wind speed can be attributed to differences between the measurement height (3 m at this station) and height for which CALMET predicts the winds (10 m). In addition, CALMET does not represent the time evolution of the winds at night because of the single input of winds and the constant simulated sensible heat flux at night.

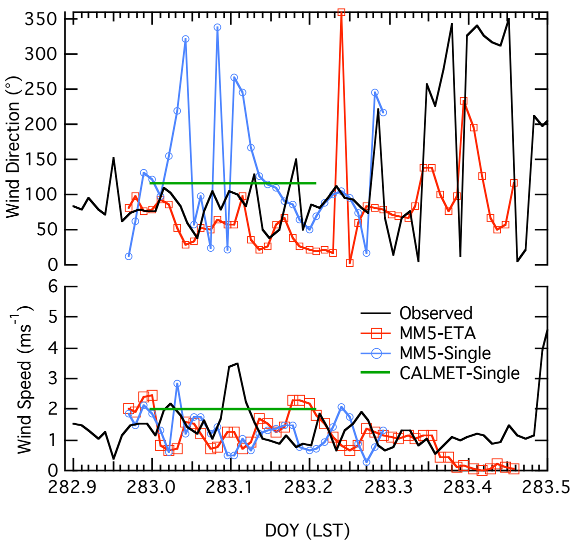

Figure 2. Observed (black line), MM5-ETA (red symbols and line), MM5-Single (blue symbols and line), and CALMET-Single (green line) predicted winds at station 4 during IOP4.

The flow patterns predicted by CALMET-Single, MM5-ETA, and MM5-Single are generally consistent with the observed wind fields (Figures 3, 4, and 5). In this example, CALMET-Single predicts much lower wind speeds at 10 m above ground than does MM5-ETA, consistent with the biases shown in Table 2. MM5-ETA appears to over predict the wind speed near the center of the valley. Some of these differences can likely be attributed to the difference in wind speed between the typical measurement height of 3 m and 10 m, the height at which MM5 predicts surface winds (note that the MM5 winds were not adjusted for station height in Figures 4 and 5). CALMET-Single and MM5-ETA predict the drainage flows on the western side of the valley, but MM5-Single shows up valley flow near Station 4 at 1 LST (Figure 5). MM5-Single continues to predict up valley flow near Station 4 through most of night, turning to down valley flow near 5:30 LST. MM5-Single does a good job over the center of the valley, and correctly predicts the turning of the wind near Station 5.

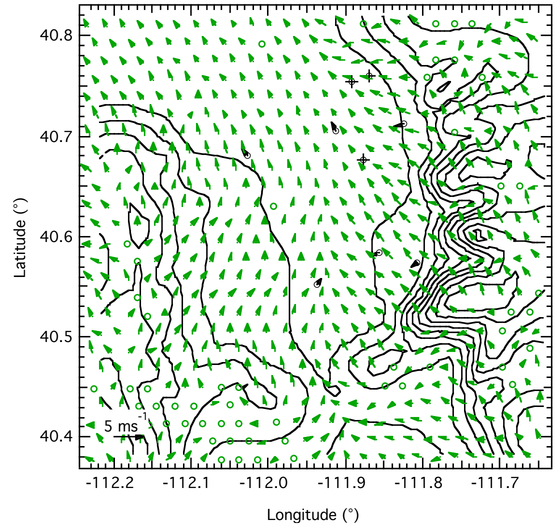

Figure 3. Observed (black arrows) and CALMET-Single predicted (green arrows) winds 10 m above the ground at 1:00 LST, 5 Oct (IOP4). The black vector in the lower left corner indicates a 5 ms^{-1} wind. Wind speeds smaller than 1 ms^{-1} are plotted as circles. Note that the model wind speed shown in this figure has not been adjusted to the measurement height.

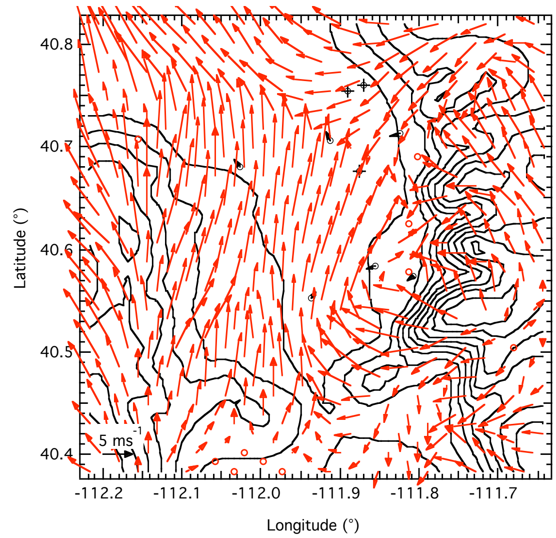

Figure 4. Observed (black arrows) and MM5-ETA 8 hour forecast (red arrows) winds at 1:00 LST, 5 Oct (IOP4). The black vector in the lower left corner indicates a 5 ms^{-1} wind. Wind speeds slower than 1 ms^{-1} are plotted as circles. Note that the model wind speed shown in this figure has not been adjusted to the measurement height.

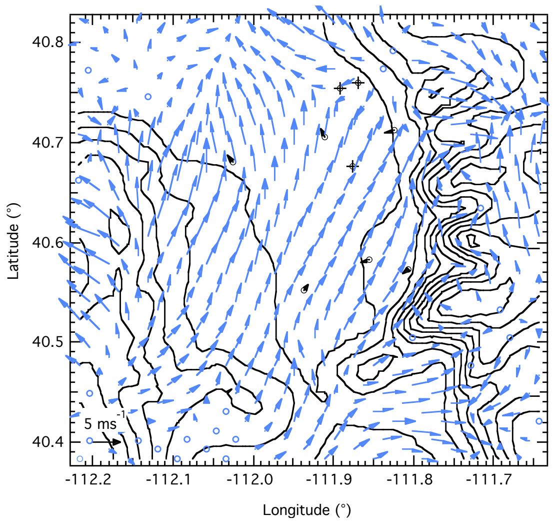

Figure 5. Observed (black arrows) and MM5-Single 8 hour forecast (blue arrows) winds at 1:00 LST, 5 Oct (IOP4). The black vector in the lower left corner indicates a 5 ms^{-1} wind. Wind speeds slower than 1 ms^{-1} are plotted as circles. Note that the model wind speed shown in this figure has not been adjusted to the measurement height.

5. CONCLUSIONS AND FUTURE WORK

The new modeling system shows promise that a full-physics mesoscale model can be used in an applied modeling system to effectively simulate locally thermally-driven winds with minimal observations as input in a few hours of wall-clock time. An unexpected outcome of this research was how well CALMET-Single, which runs in a few minutes, represented the locally thermally-driven flows using a meteorological input at a single point and a wind speed and temperature profile based on the static stability. One disadvantage of the CALMET nighttime simulations is that the wind speed and direction do not change as a function of time. This combination of CALMET and MM5 provides a powerful combination of atmospheric models on a desktop computer, and has a number of important applications, including emergency response modeling, and dispersion modeling in remote locations with complex terrain.

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