Comparison of ACM and MRF Boundary Layer Parameterizations in MM5

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1. INTRODUCTION

Treatment of boundary layer and land surface processes has important implications for air quality simulations. Meteorological fields created by weather models are used as input to air quality models such as the Community Multiscale Air Quality Modeling System (CMAQ). Modelers who routinely use MM5 version 3.5 can now choose from seven different planetary boundary layer (PBL) parameterizations (http://www.mmm.ucar.edu/mm5/documents/tutorial-v3-notes-pdf/mm5.pdf). The choice of PBL scheme in MM5 for input to CMAQ depends on the ability to accurately represent the boundary layer within both models. A logical option scientifically is the Pleim-Chang Planetary Boundary Layer -- equivalently, the Asymmetric Convective Model or ACM (Pleim and Chang, 1992). Proper evaluation entails examining the validity of ACM's entire boundary layer structure, as done by Xiu and Pleim (2001) for the eastern half of the United States. In this study for the Pacific Northwest, we compare aircraft observations of temperature and dew point to MM5 v3.5 results using ACM and the more conventional Medium Range Forecast (MRF) model boundary layer scheme (Hong and Pan, 1996). Particular attention is given to the mixing height, a key parameter in air quality modeling.

The ACM boundary layer parameterization is advantageous because it is a sophisticated scheme and is incorporated in the CMAQ Chemical Transport Model (CTM). Early versions of CMAQ use only K-theory vertical diffusion, but more recent versions (Schere, 2002; http://www.epa.gov/asmdnerl/models3/cmaq.html) include an option for ACM. Under unstable conditions ACM mixes air non-locally upward and locally downward. Following the recommendation of Pleim and Byun (2001), we hope to take advantage of this treatment of vertical diffusion for our air quality simulations. When using the Pleim-Xiu Land Surface Model and ACM in MM5, additional meteorological parameters are saved as output. CMAQ reads these as input and therefore reduces the number of fields that it must independently re-diagnose before transporting chemical species. The additional parameters also can be applied to the CMAQ dry deposition model to produce dry deposition velocities consistent with the MM5 output. Use of Pleim-Xiu Land Surface Model has advantages in itself because it allows soil moisture and temperature to vary with meteorological conditions and employs an advanced treatment of land surface fluxes. We conducted sensitivity tests of the new PBL and land surface scheme in MM5 with an eye towards better consistency between the meteorology and air quality models. The goal is that this more sophisticated treatment will better represent the observed atmosphere.

2. METHODS

We ran MM5 at 36 and 12 km horizontal grid resolution for August 2001. The domains (Figure 1) focus on the Pacific Northwest where the air quality simulations will be performed. The simulation was initialized with 40-km ETA analyses, while 100-km ETA forecasts provided 3-hourly boundary conditions. We used analysis nudging (Stauffer and Seaman, 1990; Seaman et al., 1995) towards the 12-hourly, 40 km ETA analyses to control the solution over the multi-day simulation. MM5 was initialized at 0000 UTC 01 August with the default land temperature and moisture. We simulate the entire month of August, with reinitializations every 3-5 days to prevent excessive drift. Land temperature, land moisture, and canopy moisture parameters were carried forward from one run to the next. Other model specifications include 38 sigma levels (lowest at 0.995), Kain-Fritsch cumulus parameterization, no

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shallow cumulus parameterization, and one-way nesting of the domains. Special attention will be given to runs initialized at 1200 UTC 19 August (ending 0000 UTC 23 August) and at 1200 UTC 25 August (ending 0000 UTC 29 August) because intensive ground-based and aircraft sampling is available for 20, 26, and 27 August. For these two simulation periods, we investigated simulation sensitivity to analysis nudging (not discussed here) and to boundary layer parameterizations. Specifically, we ran MM5 with the Pleim-Xiu Land Surface Model and ACM (PX/ACM) configuration, as well as with the more conventional Five-Layer Soil Model and MRF boundary layer scheme (MRF).

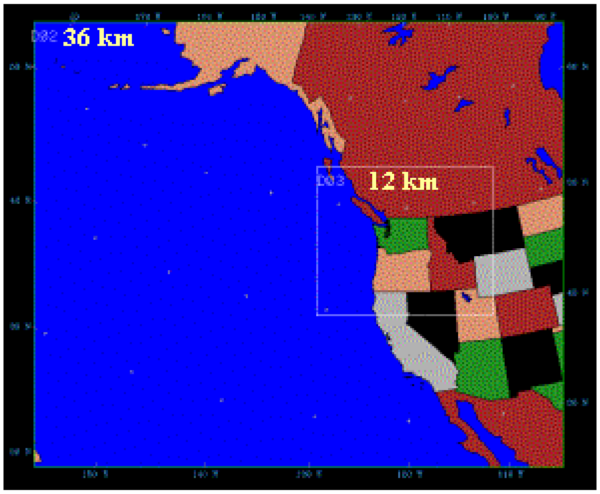


Figure 1. 36 and 12 km resolution MM5 domains.

We compared MM5 results at 12 km resolution to measurements collected as part of the Pacific Northwest 2001 field intensive (Jobson, 2002; http://www.pnl.gov/pnw2001/) and to routine surface meteorological measurements. The Department of Energy, Pacific Northwest National Laboratory Gulfstream-1 aircraft sampled meteorological, chemical, and optical properties of the boundary layer around the Puget Sound region of Washington state. The flight path included tight vertical spirals that are of particular interest for comparison to MM5's modeled boundary layer structure. These spirals span from near the surface to around 2000 meters elevation and back down. The result is an in-situ, well-resolved profile of temperature and dew point throughout most of the boundary layer. The aircraft performed four profiles: one at 1800 UTC (1000 PST) 20 August south of the San Juan Islands in the Puget Sound, and one each at 2300 UTC (1500 PST) 20, 26, and 27 August over Mud Mountain Dam in the Cascade foothills.

3. RESULTS AND CONCLUSIONS

The PX/ACM configuration produces mixing heights higher than the MRF PBL in all four profiles and higher than the observed mixing height in the three cases where it can be determined. Figure 2 shows the observed profile from the Gulfstream-1 aircraft over Puget Sound at 1800 UTC 20 August as dashed lines for temperature and dew point. The solid lines are temperature and dew point traces modeled by MM5 as a 30-hour forecast valid at the time of observation. Meteorological conditions at this time were dominated by moist, cool flow from the Pacific Ocean and patchy, marine stratus clouds. The most important feature of the observed profile from an air quality perspective is the stable layer below 950 mb. The MRF scheme models the presence of the temperature inversion but misses the strength and height of the inversion layer. It also gives no indication of dry air above the inversion. However, the PX/ACM parameterization misses the inversion and the dry layers entirely.

Model fits on the afternoon of 27 August (59-hour forecast valid 2300 UTC), over Mud Mountain Dam (Figure 3) are better than over the Sound on 20 August. Weak, moist, westerly flow and high clouds from a weather system in British Columbia characterize the conditions at the time. Both boundary layer schemes model an inversion that is too high by 30 to 50 mb, but the MRF PBL comes closer to the observed inversion height of 880-900 mb. Similarly, both model a boundary layer that is too warm and too dry, but the MRF PBL exaggerates the error less. Relative humidity is particularly important for aerosol modeling since it determines the aerosol state and the reduction in visibility from aerosol loading.

Both parameterizations poorly reproduce the atmospheric boundary layer on 26 August (35-hour forecast valid 2300 UTC) as show in figure 4. The weather at the time was sunny, warm, and moderately influenced by marine air. The observed boundary layer inversion is found near 900 mb, while MRF and ACM model it between 825 and 850 mb and between 800 and 825 mb respectively. This corresponds to an overestimation of the boundary layer thickness by approximately 600 to 850 meters. Near the surface ACM and to a lesser extend MRF simulate a boundary layer that is too warm and dry. The corresponding relative humidities for the lowest layer are approximately 53% and 38% for MRF and ACM. Compared to an observed relative humidity of approximately 64% these underpredictions, especially for ACM, could have a large effect on the aerosol chemistry.

In general for all four profiles we have examined, PX/ACM produced a boundary layer that is too warm, too dry, and too deep. MM5 with MRF PBL also had problems with a deep boundary layer but yielded a better representation than PX/ACM.

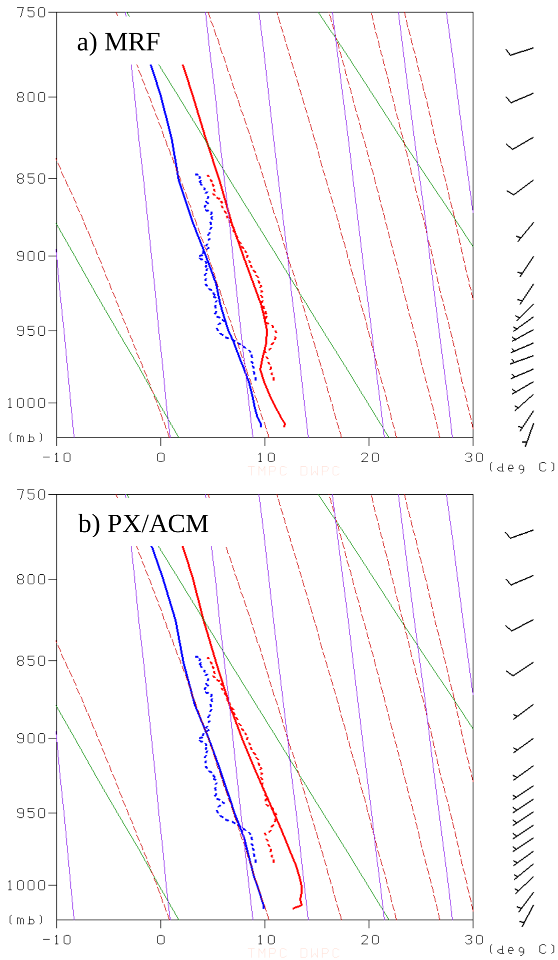


Figure 2. Profiles of temperature and dew point at 1800 UTC 20 August 2001 over Puget Sound, 25 km south of Friday Harbor, WA. The observed profile appears as dashed lines while the solid lines are modeled by MM5 using the indicated parameterizations.

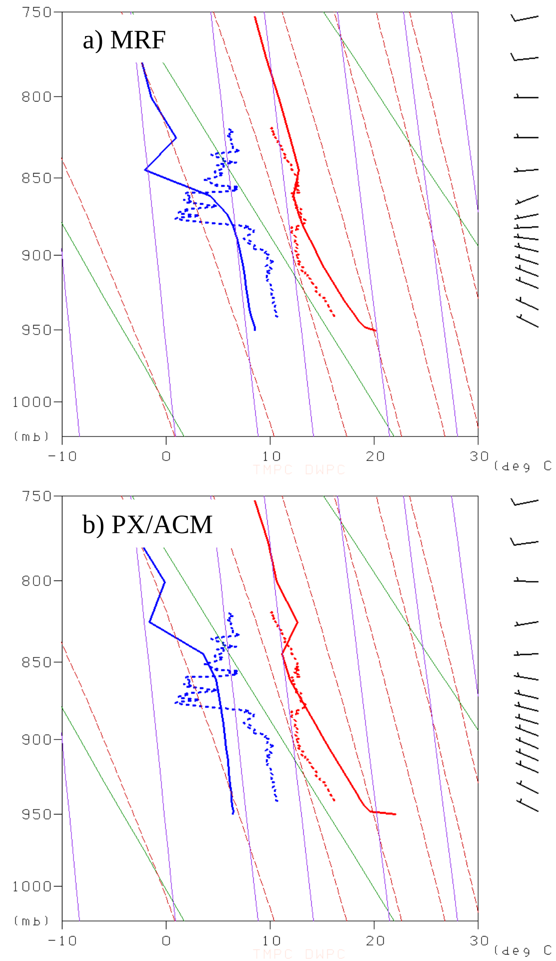
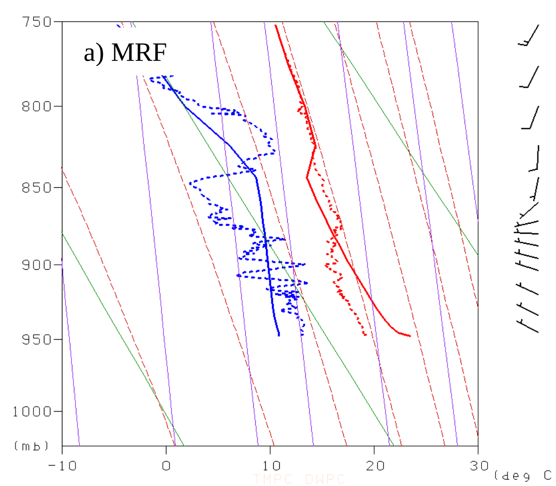


Figure 3. Profiles of temperature and dew point at 2300 UTC 27 August 2001 over Mud Mountain Dam, 50 km east of Tacoma, WA. The observed profile appears as dashed lines while the solid lines are modeled by MM5 using the indicated parameterizations.



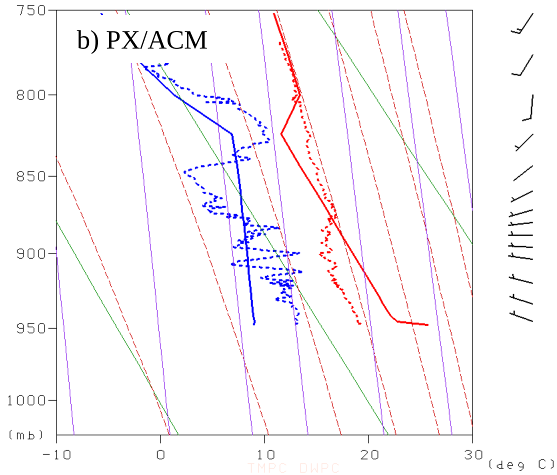


Figure 4. Profiles of temperature and dew point at 2300 UTC 26 August 2001 over Mud Mountain Dam, 50 km east of Tacoma, WA. The observed profile appears as dashed lines while the solid lines are modeled by MM5 using the indicated parameterizations.

These results apply only to the specific case presented and only for MM5 v3.5 as we have configured it. Our results may differ if we were to nudge the land surface parameters from the ETA model. Unfortunately, the highly complex topography of the Puget Sound region means that an initialization from a global analysis cannot capture important differences in soil moisture and temperature at the 40 km resolution available for August 2001. It is also possible that PX/ACM could perform better under MM5 physics options different from the set that many modelers regularly use. Most importantly, other meteorological conditions in the Puget Sound as well as conditions in other parts of the continent or world could show different performance. Regardless, for MM5 modelers and users of CMAQ this is a unique comparison of finely-resolved boundary layer measurements to the boundary layer modeled by two viable boundary layer schemes.

4. ACKNOWLEDGEMENTS

This research and presentation is funded by the University of Washington / EPA Northwest Research Center for Particulate Air Pollution and Health, and by the Joint Institute for the Study of the Atmosphere and Ocean (JISAO) under NOAA Cooperative Agreement No. NA17RJ11232, Contribution #1032.

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