4.8 A MAJOR CHALLENGE IN METEOROLOGICAL MODEL EVALUATION FOR AIR-QUALITY APPLICATIONS

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1. Introduction

A few projects of meteorological model evaluation for air-quality applications have been taken on over the past few years at the Physics Sciences Division of NOAA/Earth System Research Laboratory (the former Environmental Technology Laboratory). It has been found during these projects that meaningfully evaluating the performance of meteorological simulations remains a challenge due to the fact that meteorological observations used for the evaluation, while being sufficient to reveal the quantitative errors in the simulations at observational sites, are not adequate for the purpose of identifying the error sources in the model physics, particularly the near surface mass and energy transport. In this presentation, two case studies of meteorological model evaluation from the 2000 Texas Air Quality Study and the 2000 Central California Ozone Study are used to illustrate the challenge.

2. Typical paradigm of meteorological model evaluation

Model evaluation is a science as well as system engineering. It is a process that involves multiple components. A paradigm is necessary to relate these components to the objective of model evaluation. In these model evaluation studies, a three-component paradigm (Fig. 1) is used in which the first component in the paradigm is to identify major dynamical and physical processes through analysis of observational data collected during field experiments. The result of this component is a conceptual model. The second component involves numerical model simulations. That is, the model is run for the time period of the case study, and the model output is compared with the observations in a point-to-point fashion. As always, the statistics derived from this comparison will show discrepancies between the model simulation and the observations. Judging from the degree of the discrepancies, additional simulations will be performed in order to reveal the sensitivity of the model simulations to a variation of the model's physics. In the third component, the conceptual model derived from the observational data analysis in the first component is compared with the numerical simulations to verify how the model simulations capture the observed physical processes, such as pollution transport processes. The end results of application of this three-component paradigm are the conceptual model of major dynamical and physical processes, and the statistics of the difference between the model simulations and observations.

It should be pointed out that while the meteorological processes affecting air quality range from weather systems on various scales greater than 1 km to small turbulent eddies that are a few meters in size, the meteorological models used for air-quality applications are designed to be better suitable to simulating weather-related processes than to small-scale ones associated with turbulence. Processes associated with small turbulent eddies are typically parameterized in meteorological models. However, these small-scale processes are extremely crucial to the daily variability in air-quality associated with the forcing related to the diurnal heating and cooling cycle, and local topography. Therefore, to understand error sources in meteorological models for the purpose of improving air quality simulations, it is imperative to evaluate meteorological models in terms of not only wind, temperature and moisture, but also in terms of the near surface mass and energy transport associated with small-scale processes that couple the atmospheric boundary layer with the underneath soil and vegetation. This poses a challenge to the meteorological model evaluation community because observations taken from the past field experiments are more available to the evaluation with respect to wind, temperature and moisture than to the near surface mass and energy transport.

3. A case study from the 2000 Texas Air Quality Experiment

24-Hour meteorological forecasts for the period of 25-30 August 2000 from a coupled

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weather-chemistry model are evaluated both qualitatively and quantitatively using the observations from different instruments that were deployed in metropolitan Houston during the Texas Air Quality Study 2000 field experiment (see Bao *et al.* 2005). The qualitative comparison is carried out with respect to the meteorological processes associated with the influence of the large-scale flow on the sea breeze that are essential to the development of the surface ozone exceedances over Houston, while the quantitative comparison is focused on the errors and uncertainties of the forecasts. It is found that although the overall forecasted influence of the large-scale flow on the sea breeze compares qualitatively well to the observations, quantitative differences do exist between the forecasted and observed wind speed and direction, as well as with temperature and moisture. It is found that the forecasted low-level winds have a systematic easterly bias and the forecasted low-level temperature has a cold bias. The errors in the forecasted low-level moisture appear relatively small, but with a cold bias they lead to higher relative humidity in the forecast than in reality. There is great sensitivity of the model forecasted low-level winds to different initial conditions. The quantitative comparison also indicates that the model's effective horizontal resolution corresponding to 1.67-km grid spacing is actually about 10 km.

The results from this case study illustrate that to determine the exact causes of the biases requires more observations and further diagnosis of the large-scale uncertainties related to the model's initial and boundary conditions as well as the uncertainties in the model's physical parameterizations. In particular, it is impossible in this study to diagnose the exact causes for the quantitative differences shown in the comparisons of the atmospheric boundary layer (ABL) temperature and height due to the uncertainties in the landuse specification for the urban and non-urban areas and the lack of necessary observations of turbulence and soil thermal processes. This suggests that there is a need in the future to supplement comprehensive ABL observations to the field experiment programs such as Texas AQS 2000, including measurements of surface energy balance components and turbulence parameters at several levels within the ABL.

4. A case study from the 2000 Central California Ozone Study

The Central California Ozone Study (CCOS 2000) is a combined observational and modeling program designed to improve our understanding of the mechanisms of ozone formation and transport within Central California. During the CCOS 2000 field program, extensive meteorological and chemical observations were collected during the summer of 2000 in Central California to document high ozone episodes and the meteorology that was associated with them.

An air-quality episode case study was carried out in which the output from the meteorological modeling system for California's state implementation plans (SIPs) was compared with the wind profiler/RASS and surface observations of both wind and temperature. The meteorological model was run on a 36-12-4 km one-way nested model domain of 50 vertical levels, with the 4 km domain encompassing the CCOS 2000 field study area. Among various MM5 simulations of the chosen case with different combinations of surface and boundary layer parameterizations and land surface models, we found that the most overall accurate simulation was produced when using the Eta planetary boundary layer (PBL) and surface layer schemes along with the NOAH land surface model (LSM). The evaluation of the air quality simulation driven by this meteorological simulation has been carried out by Soong *et al.* (2006)

The direct meteorological comparison between the model simulation and the observations from the CCOS 2000 field experiment for this particular case indicates that the errors in the simulated low-level winds and surface temperature vary from one area to another. The observational data sets are available for the evaluation of simulated wind speed and direction, the surface air temperature and moisture, surface radiation fluxes (but limited) and the height of the mixing layer. There are no reliable observations for the verification of the surface turbulence fluxes and soil conditions. However, our process evaluation indicates that surface fluxes and soil conditions are important to the evolution of the local wind conditions in the central California region that are known to have a pronounced impact on ozone concentrations. These conditions include 1) the sea-breeze, which can bring cooler, moister, and less polluted air as it propagates inland; 2) flow through the San Francisco Bay area, which is the principle inflow into the central valley, and the split of this flow, which determines the relative inflow into the northern Sacramento and southern San Joaquin Valleys; 3) nocturnal low-level jets, which can rapidly transport boundary layer pollutants along the central valley; 4) local eddies (such as those in the Schultz, Fresno, and Bakersfield) which can re-circulate ozone and its precursors; and 5) slope flows, which result in transport in or out of the valleys, support boundary layer venting along mountain crests, and produce subsidence or ascending motion over the valleys. The lack of reliable observations of the surface turbulence fluxes and soil conditions renders the extent of the model evaluation to be the quantitative differences in wind, temperature and moisture. It is therefore impossible to reveal the errors in the model surface physics through the model evaluation.

5. Summary and Conclusions

The purpose of meteorological model evaluation for air-quality applications is to establish confidence in the model generated meteorological forcing in chemical simulations. The evaluation process should be scientifically sound so as to demonstrate the scientific and technical credibility of the final results from air-quality applications (such as SIPs). However, as illustrated by our case studies, meteorological observations used in the evaluation process are often inadequate to identify the error sources in the model surface physics, though they are sufficient to reveal the quantitative errors in simulated wind speed and direction, the screen temperature and dew point temperature, radiation and the height of the mixing layer. These studies also show that additional difficulties in the model evaluation for air-quality applications are associated with (1) higher-resolution simulations bring with them a spatial variability higher than the observational network can resolve; (2) no meteorological model can properly resolve flow features that are smaller than several gridlengths and thus it is impossible to evaluate the model performance of fields on scales approaching the model gridlength that may be revealed by some observations; and (3) some of the errors in high-resolution forecasts do not originate in the model domain since they are a result of larger-scale errors in the flow through the boundaries and are still counted as errors when it comes to an assessment of the simulation. It is strongly recommended that future air-quality field experiment should enhance the observations targeted for physics evaluation and improvement. In addition, investigation needs to be done to determine the most appropriate protocol of meteorological model evaluation for air quality applications.

6. References

Bao, J.-W., S. A. Michelson, S. A. McKeen, and G. A. Grell, 2005: Meteorological evaluation of a weather-chemistry forecasting model using observations from the TEXAS AQS 2000 field experiment. *Journal of Geophysical Research*, in press.

Soong, S. –Z., Y. Jia, C. L. Archer, P. T. Martien, C. A. Emery, and S. Tanrikulu, 2006: Comparison of WRF/CAMx and MM5/CAMx simulations for an ozone episode in California. *Preprint, 14th Joint Conference on the Applications of Air Pollution Meteorology with the Air and Waste Management Assoc*, American Meteorological Society, 29 January–2 February 2006 in Atlanta, Georgia.

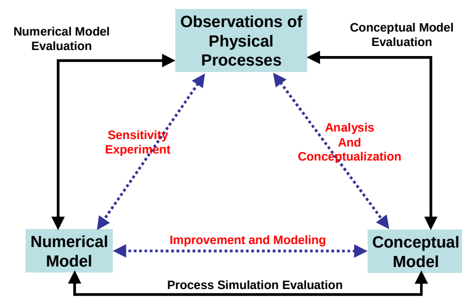

Figure 1 Diagram of a typical paradigm of meteorological model evaluation.