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The JIFRESSE Regional Earth System Model and its application to air quality in California : Evaluation of the Control Simulation

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Background and Motivation

Meteorology, in conjunction with local emission, plays an important role in determining regional air quality (AQ) via a number of processes including pollutant transport and dispersion at various scales, radiation, and deposition. Previous studies (Hogrefe et al. 2004; Steiner et al. 2006) suggested that the climate change induced by the increase in atmospheric greenhouse gases will adversely influence future air quality. This is an important concern in Southern California which suffers from frequent severe air quality episodes. Assessments of the impact of climate change on air quality includes significant uncertainties due to uncertainties in future emissions and meteorology.

In order to improve assessments of the impact of climate change on variety sectors, the Joint Institute For Regional Earth System Science and Engineering (JIFRESSE) has been developing a Regional Earth System Model (JRESM) which consists of the WRF-ARW model and a variety of impact assessment models. The WRF-ARW used in JRESM is improved with the regional ocean model (ROM) and SSiB to simulate coastal ocean circulation and land-surface fields, respectively. Treatment of the snow field receives special attention. The AQ part of JRESM utilizes the Community Multi-scale Air Quality (CMAQ) model (Figure 1). The focus of this study is the coupling between WRF and CMAQ and the evaluation of O_3 concentration simulated using the model.

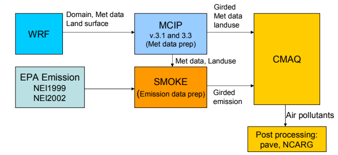

Figure 1. A schematic illustration of the AQ part of JRESM.

July 2005 Air Quality Simulation

We present results from a month-long AQ simulation for July 2005 using the RESM. The major goal of this study is to evaluate the AQ part of JRESM in preparation for a climate change study. The meteorological field was simulated at a 12km horizontal resolution using the improved WRF model and the large-scale forcing data from the North American Regional Reanalysis (NARR). The hourly met forcing data were then used to drive the CMAQ model in conjunction with an emission dataset generated using the SMOKE model in conjunction with the 1999 EPA National Emission Inventory (NEI) data. Results from the one-way nested WRF-CMAQ simulation are evaluated against the low-level meteorology from the NARR and the observational data from the California Air Resources Board (CARB) at four Southern California locations, West Los Angeles-Veterans' Hospital (WSLA), Pasadena (PASA), Riverside-Rubidoux (RIVR), and Palm Springs (PLSP). These 4 CARB stations were selected in order to stratify the model evaluation in geographically and meteorologically distinct regions.

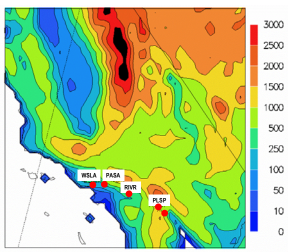

Figure 2. The model domain and terrain heights represented at a 12x12km horizontal resolution. The domain covers Southern California with a 52x52 horizontal grid and 13 σ layers in the vertical. The vertical layers are irregularly spaced with the 50m-thick lowest layer. Also presented in the figure are the locations of the 4 CARB stations (red dots) at which the simulated O_3 concentrations are evaluated.

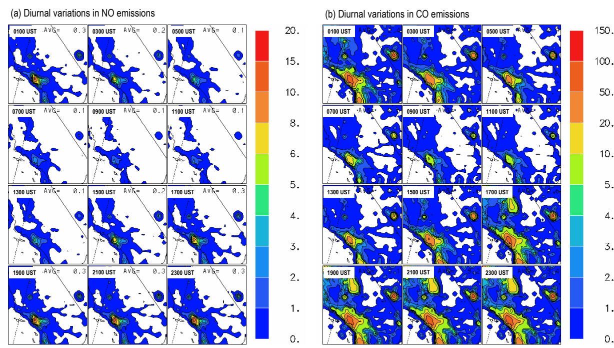

Figure 3 shows the monthly-mean diurnal cycle of NO and CO emissions (moles/s) from area, on-road/non-road mobile, point, and biogenic sources in Southern California during July 2005 in a SMOKE calculation using the EPA 1999 NEI data. Emissions of air pollutants and their precursors in the region vary strongly according to geography and time-of-day. PM10 emission (not shown) in the region also vary similarly in time and space. Further investigations of each emission source reveal that on-road mobile emissions are the primary source of air pollutants in the region.

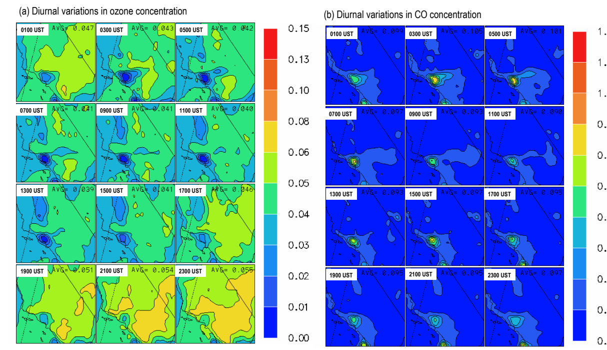

Figure 4: The simulated monthly-mean concentrations of O_3 and CO (ppmv) show strong diurnal cycle and geographical variations in Southern California. The O_3 diurnal cycle is characterized by daytime maxima and nighttime minima due to local emissions and insolation. The O_3 and CO concentrations vary according to geography as well. High O_3 values occur in inland regions where NO emission is minimum; the O_3 concentration is low in the area of heavy NO emissions. This shows that the concentration of O_3 which is mainly generated via photochemical reactions involving NO and CO is strongly affected by the low-level circulation in the region. The regional circulation is dominated by prevailing westerly winds and sea breeze that tends to transport air pollutants into the inland regions located to the east of the areas of primary emission. The geographical and temporal variation of the CO concentration generally follows that of CO emission.

Evaluations: The simulated O_3 concentrations and low-level meteorology are evaluated against CARB observations and NARR below.

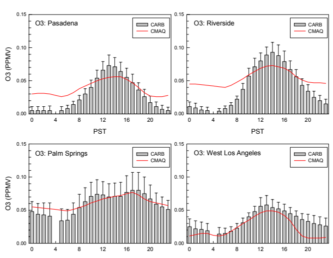

Figure 5: The monthly-mean diurnal cycle of the simulated (CMAQ) hourly O_3 concentration agrees well with the observed (CARB) values at the four verification stations, especially at Palm Springs and West Los Angeles. This suggests that JRESM has reasonable skill in simulating daily peak O_3 concentration in the selected locations. The most noticeable bias in Figure 5 is an overestimation of O_3 concentration during the nighttime in Pasadena and Riverside. The biases in nocturnal O_3 concentration at these two stations may be due to errors in the met data (wind speed, PBL depth) and too weak O_3 titration in CMAQ.

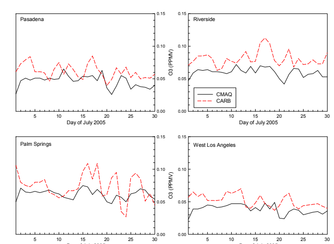

Figure 6: The simulated (black) daily timeseries of the daytime 8-hour (1100-1800 PST) mean O_3 concentration agrees well with observations (red) at the four stations. This 8-hour period represents the period in which daily maximum O_3 values occur (e.g., Figure 5). Noticeable discrepancies between the simulated and observed values occur only at the Riverside station, especially in the latter half of the month when the model systematically underestimated O_3 concentration.

Results shown in Figures 5 and 6 suggest that the RESM possesses useful skill in simulating O_3 concentration in Southern California for extended periods, an important capability for assessing the impact of climate change on the regional air quality.

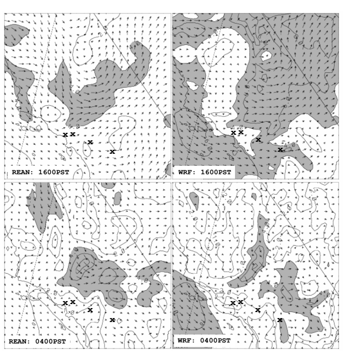

Figure 7: Comparison of the monthly-mean low-level winds in late afternoon (1600PST) and early morning (0400PST) in NARR and WRF show that the model can generate general features of daytime and nocturnal winds in the region. The results also reveal noticeable errors in the low level wind field. The daytime wind direction in the LA basin agrees well with NARR, but the corresponding wind speeds are overestimated in general. The nocturnal wind field in the LA basin also compares well with NARR, however, the model generates onshore winds, instead of weak offshore winds in NARR, at 0400PST along the coast near the WSLA point. This low-level wind error may be related with the negative nocturnal O_3 bias at WSLA (Figure 6).

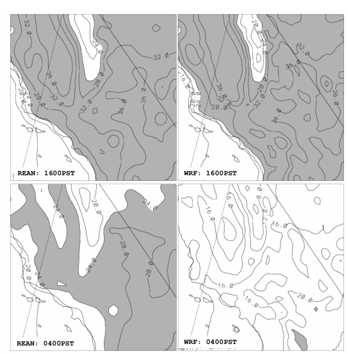

Figure 8: Low-level temperatures are closely related with the diurnal cycle of the low-level winds in the LA basin because the low-level winds in this region are strongly influenced by land-sea and mountain-valley breezes. The low-level temperatures in the simulation agrees well with those in NARR in the daytime; however, WRF generally underestimates the nocturnal temperatures. This may be due to model errors in simulating surface temperature under stable stratification. It can also be related to the fact that NARR is run at much coarser spatial resolutions than the RESM, under-representing the effects of local terrain.

Conclusions

An air quality simulation in the Los Angeles basin during July 2005 using the WRF-CMAQ part of the JRESM has been evaluated. This study was performed as a part of preparation for a study in which the impact of global climate change on the air quality in Southern California will be investigated.

Using the large-scale forcing from North American Regional Reanalysis (NARR), the WRF-ARW model was able to generate the low-level wind and temperature fields as well as their diurnal variations with reasonable accuracy.

Emissions in Southern California are characterized by a strong diurnal cycle with daytime maximum and nocturnal minimum. On-road mobile emissions are the largest source of CO and NOx in the region.

The monthly-mean diurnal cycle of the simulated ozone concentration agrees well with observations during the daytime when the peak concentration occurs. The nocturnal O_3 concentration shows positive biases at most of the verification sites, suggesting O_3 titration is too weak in CMAQ. The negative bias in O_3 concentration at the coastal West Los Angeles station during nighttime is partially related with the errors in low-level as nocturnal land breeze in the coastal region is underestimated by WRF.

The simulated time series of daily 8-hour-maximum O_3 concentration also agrees well with observations.

The evaluation study suggests that the coupled WRF-CMAQ part of the JRESM possesses useful skill in simulating long-term characteristics of O_3 concentration in Southern California.

Acknowledgement

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