J2.7 COMPARISON OF WRF AND MM5 SIMULATIONS FOR AIR-QUALITY APPLICATIONS

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1. INTRODUCTION

In the past, the NCAR/Penn State mesoscale model (MM5, Grell *et al.* 1994) has been widely used by the air-quality community in various applications. Recently, applying the newly developed weather and research forecasting model (WRF, Skamarock *et al.* 2005) in air-quality problems has become more and more attractive due to its well-designed mass-conserved numeric schemes. To help California state agencies better meet their need to improve meteorological modeling in their state implementation plans for air quality mandate, we have started an effort to compare WRF and MM5 for air quality applications in California. This effort is expected to (1) provide a baseline upon which future meteorological model improvements for the California state implementation plans can be documented and evaluated, and (2) to assess the skill of WRF in reproducing locally forced meteorological conditions for the researchers who rely on models and model simulations to provide new knowledge about the meteorological processes that influence air quality.

In this study, we focus on the comparison of the near surface meteorological conditions simulated by the most updated version 2.1 of WRF and the version 3.7 of MM5 with the observations taken in California for a state implementation plan case. Such an exercise is very relevant in air-quality applications, and thus serves as the first step in our effort to evaluate WRF for air- quality applications.

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2. MODEL CONFIGURATIONS

WRF and MM5 simulations are run using identical grid meshes of 36-12-4 km one-way nested model domains, albeit different prognostic variable staggering of the two models. Both models have 50 vertical stretched levels with 30 levels within the lowest 2 km and the lowest model level at about 12 meters above the surface. The vertical grids cannot be made identical since the two models use different vertical coordinates, but they are very close to each other. The 4 km domain encompasses the Central California Ozone Study (CCOS) field study area, which extends from the Pacific Ocean in the west to the Sierra Nevada in the east, and from Redding, CA, in the north to the Mojave Dessert in the south. Boundary and initial conditions are prescribed using the 6-hourly 40 km NCEP Eta analysis. The simulations are initialized at 12 UTC 29 July, and are run for 132 h, ending at 00 UTC 4 August 2000.

Various MM5 simulations have been run testing different combinations of surface and boundary layer parameterizations and land surface models. Comparing these simulations with observations indicated that the most overall accurate simulation is produced by MM5 when using the Eta planetary boundary layer (PBL) and surface layer schemes and the NOAH land surface model (LSM), along with the Reisner microphysics parameterization, the Dudhia short-wave, RRTM long-wave radiation parameterizations, and the Grell convective parameterization scheme on the 36 and 12 km grids. No convective parameterization scheme is used on the 4 km grid.

In order to compare with the MM5 simulations as fairly as possible, the WRF simulations are done using the same the Eta PBL and surface layer schemes and the NOAH land surface model (LSM), along the Dudhia short-wave, RRTM long-wave radiation parameterizations. Since the microphysics parameterization and convective parameterization schemes used in the MM5 simulations are not available in WRF, the Lin et al. parameterization scheme is used in the WRF 36-km, 12-km and 4-km runs. The Kain-Fritsch convective parameterization scheme is used on the 36-km and 12-km runs, no parameterization scheme is used on the 4-km runs.

In addition to the differences in the microphysics and convective parameterization schemes, there are differences in the terrain, landuse, vegetation fraction, SST, soil temperature and moisture, and reservoir temperature. These differences occur because WRF and MM5 are not initialized using the same procedure. In order to compare WRF and MM5's response to the same initial and surface conditions, a WRF simulation is also carried out in which the initial land surface conditions (i.e., the ground skin and soil temperatures, soil moisture, and vegetation fraction) are replaced with those from MM5. Here, we will only illustrate the differences between the MM5 simulation and the WRF simulation with the WRF original land surface initialization. A more comprehensive comparison of the original WRF simulation, the WRF simulation with the MM5 initial land surface conditions and the MM5 simulation will be shown and discussed at the formal presentation, along with the comparison of the simulations using the earlier version of both WRF and MM5.

3. RESULTS

Figure 1 shows the 2-m air temperature from the WRF (Fig. 1a) and the MM5 (Fig. 1b) simulations valid at 36 hours into the simulation (0000 UTC 30 July 2000). Overall, the 2-m temperatures from the two model simulations are very similar in temporal evolution and spatial variation. However, quantitative differences are obvious. In the San Joaquin Valley, the 2-m temperature of MM5 is colder than that of WRF. Most notably, the area of temperature between 34° and 36° C in the central to southern San Joaquin Valley is greater in the WRF simulation (Fig. 1a) than in that of the MM5 simulation. The time series of the areal averaged simulated 2-m temperatures in the northern, central and southern San Joaquin Valley indicate that comparing with the CCOS observations (Fig. 2), both MM5 and WRF consistently have a warm bias in the 2-m air temperature, particularly during the night. Furthermore, WRF has a greater warm bias than MM5.

There are several possible causes for the WRF simulation to have a warm bias comparing with the MM5 simulation. One is the discrepancy between landuse, terrain height, vegetation fraction, and the initialization of the soil temperature and moisture profiles. Another is the net radiation, which is effected by the cloudiness. A comparison of the integrated cloud hyrdometeor fields (not shown) at 36 hours into the simulations shows that the MM5 simulation is considerably cloudier than the WRF simulation. One could argue that in general the differences in both the initialization of the surface conditions and cloudiness work together to lead to the differences in the surface air temperature.

The 10-m winds from the WRF simulation are also quantitatively different than those from the MM5 simulations (Fig. 3), although qualitative similarities are obvious in their temporal evolution and spatial variation. The differences in the WRF and MM5 simulations are greater in the northern and central valley than in the southern valley (see Figs. 3c and 3d). The time series of the areal averaged simulated 10-m winds (Fig. 4) show that the simulated winds in WRF are faster than in MM5 during the first two days, and slower in the last two days in the southern and central valley, but both WRF and MM5 simulated winds have a similar agreement with the CCOS observations. In the Bay Area, the averaged wind speeds are higher in WRF than MM5 on all days except for the third day. The areal averaged wind speeds in WRF in the northern valley is closer to MM5 than in the other areas, but in both model runs, the diurnal phase of the wind speed is not the same as in observations. It is also seen in these time series that there is a noticeable wind-direction bias in both the WRF and MM5 simulations. Despite these differences in the wind speeds, overall the differences in both the wind speeds and directions between WRF and MM5 are smaller than that between either of the simulations and observations.

The differences in the near surface temperature and winds are associated with the differences in the initialization of the two models, particularly in the initial specification of the land-surface conditions and coastal sea-surface temperature (not shown), rendering the simulated near surface inflow into the Central Valley different in the two model simulations. It is also expected that such differences in the initial surface conditions contribute significantly to the differences in the simulated atmospheric boundary layer (ABL). Figure 5 shows an example of the simulated ABL structure by WRF and MM5, as depicted by cross-section diagrams of the potential virtual temperature in the Central Valley. It is seen that although the ABL depth variations along the cross section are similar in both model simulations, the ABL depth of MM5 is deeper than that of WRF. Further comparison with the observations (not shown) indicates that overall the simulated ABL heights in WRF are shallower than in MM5, but are closer to observations.

Differences in the simulated near-surface winds and ABL structure lead to differences in the transport and dispersion. Figure 6 depicts the differences in the simulated forward trajectories of nearby 4 air parcels in the Bay Area that are released at 100 m (AGL) at 1200 UTC 30 August and ended at 1200 UTC 2 August. Although all the trajectories move eastward toward the Central Valley, noticeable differences are obvious in the transport of these simulated by the models. The impact of the differences in the transport as illustrated in the trajectory on the result of the chemistry modeling is discussed in a separate study (Soong et al. 2006).

4. SUMMARY

The comparison of the WRF and MM5 simulations indicate that the WRF standard initialization leads to a simulation that is qualitatively comparable to, but nevertheless quantitatively different than that of MM5. In particular,

- Both MM5 and WRF produce similar temporal and spatial variations in the 2-m temperature over the Central Valley.

- Comparing with the observations, there is a warm bias in the 2-m temperatures simulated by both models.

- Overall, WRF produces warmer 2-m temperatures than MM5.

- The simulated winds of both models are generally faster than observed, despite the similarities in temporal evolution and spatial variation.

- There is a noticeable wind direction bias in both the WRF and MM5 simulations.

- Overall, the simulated ABL height of WRF is shallower but closer to observations than that of MM5.

- There are noticeable differences in the simulated horizontal transport by the two models.

The differences in the near surface temperature and winds are associated with the differences in the initialization of the two models, particularly in the initial specification of the land-surface conditions and coastal sea-surface temperature. All these results demonstrate the challenges of accurately simulating meteorological conditions for the air quality control in Central California. One of the challenges is that great uncertainties still exist in the simulated atmospheric boundary layer and the land surface processes, which are critical for transport and dispersion. If we believe that one can only reduce the uncertainties within physics parameterizations to a certain degree, the so-called statistical ensemble approach using multiple models is perhaps an alternative to further reduce the uncertainties in meteorological models and, thus, phasing WRF into use in SIP applications in Central California should be taken under consideration.

5. REFERENCES

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Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, D. M. Barker, W. Wang, and J. G. Powers, 2005: A description of the advanced research WRF version 2. NCAR/TN-468+STR, 88 pp.

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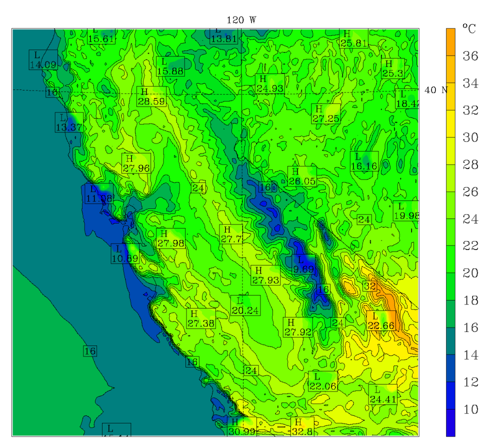
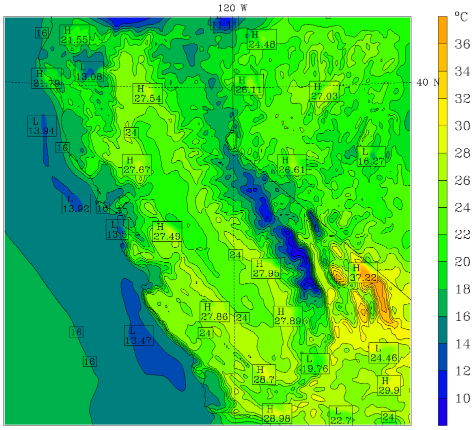
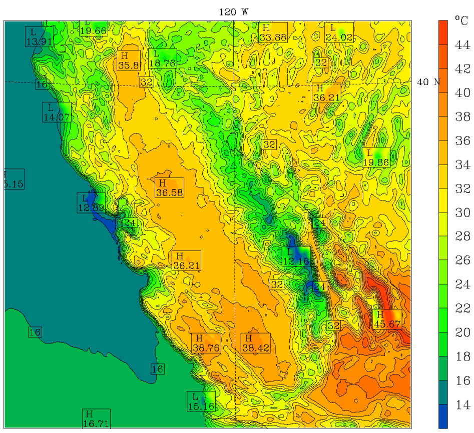


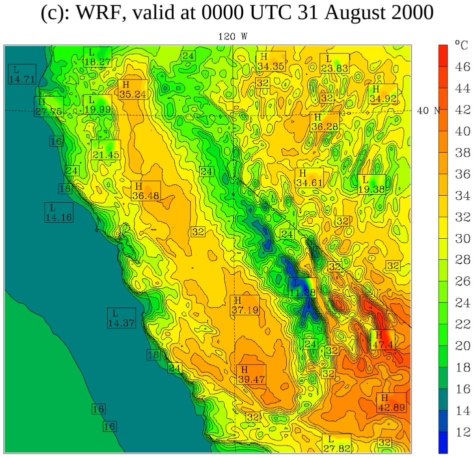
(a): WRF, valid at 1200 UTC 30 August 2000



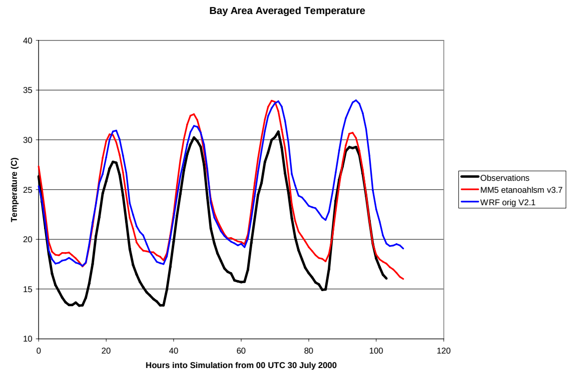
(b): MM5, valid at 1200 UTC 30 August 2000



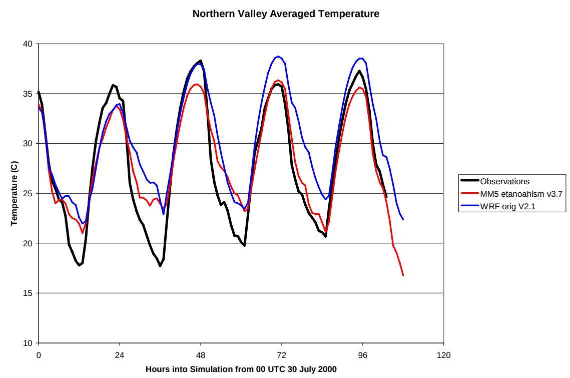
(c): WRF, valid at 0000 UTC 31 August 2000



(d): MM5, valid at 0000 UTC 31 August 2000



(a)



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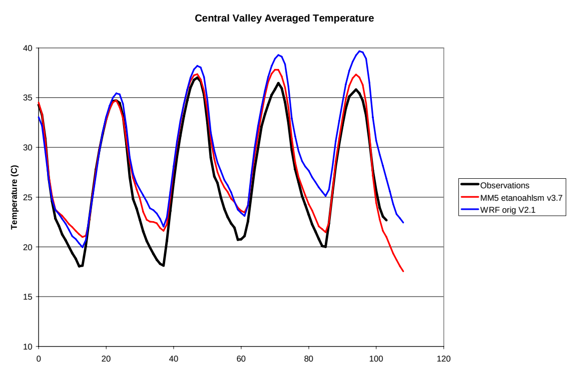
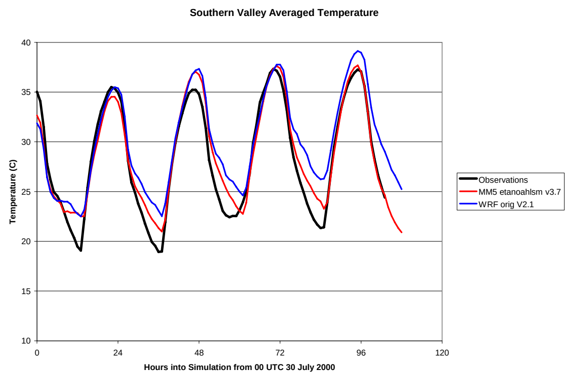


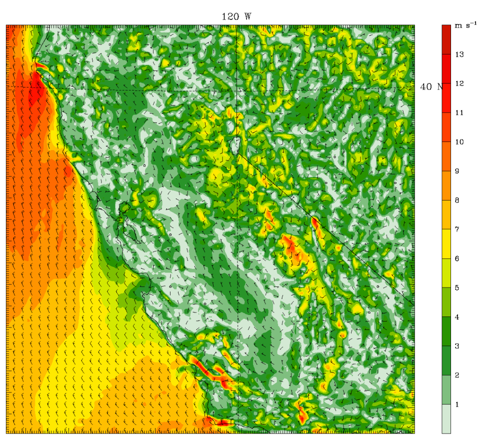
(c)

Figure 1. 2-m air temperature for (a) and (c) WRF, and (b) and (d) MM5. Color contour interval is 2° C.

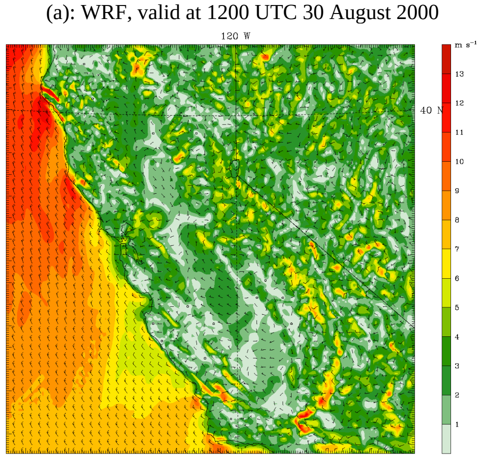


(d)

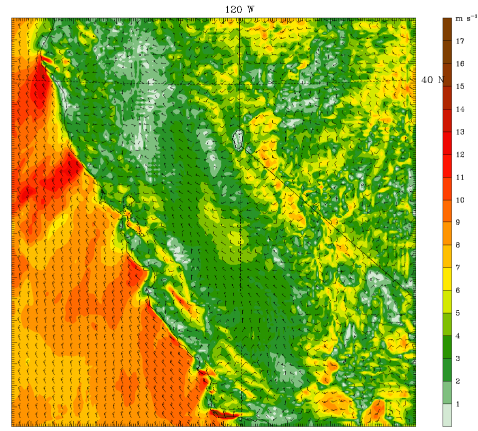
Figure 2. Time series of areal average 2-m temperature for the (a) San Francisco Bay Area, (b) Northern San Joaquin Valley, (c) Central San Joaquin Valley, and (d) Southern San Joaquin Valley. The black line is observations, the red line is MM5, and the blue line is WRF.



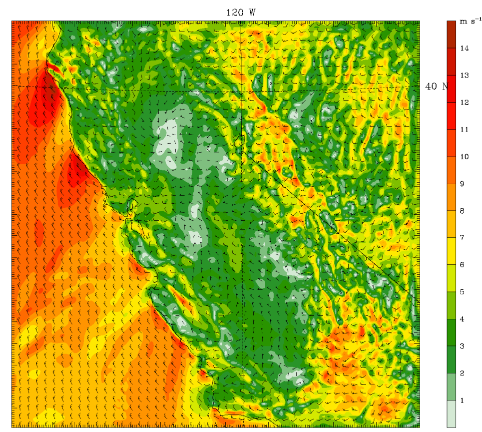
(a): WRF, valid at 1200 UTC 30 August 2000



(b): MM5, valid at 1200 UTC 30 August 2000

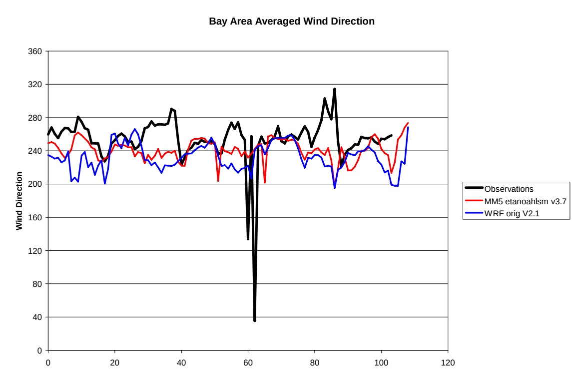


(c): WRF, valid at 0000 UTC 31 August 2000

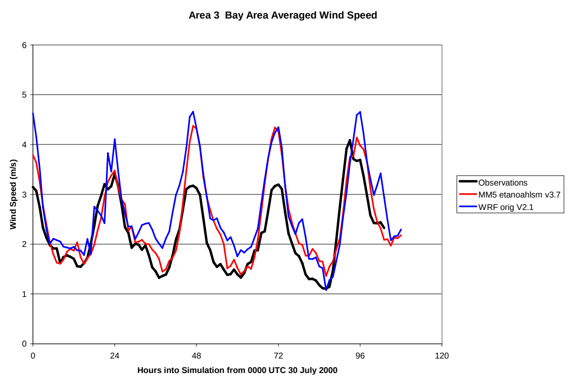


(d): MM5, valid at 0000 UTC 31 August 2000

Figure 3 10-m winds for (a) and (c) WRF, and (b) and (d) MM5. The color scale indicates wind speed.



(a)



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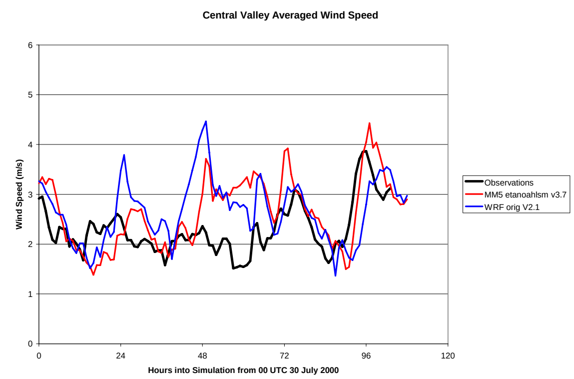
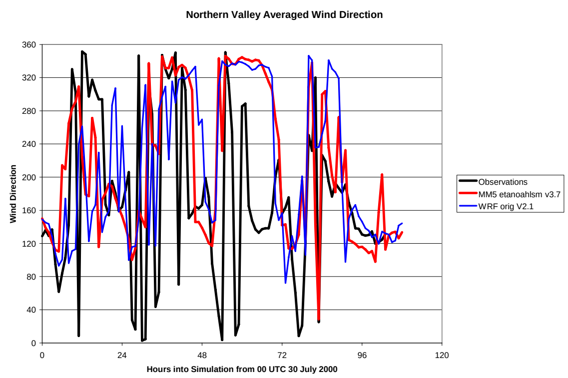


(f)



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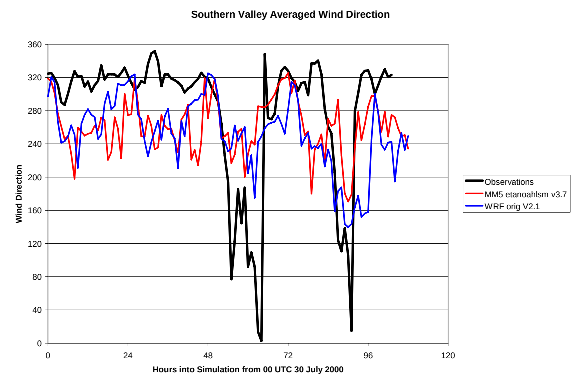

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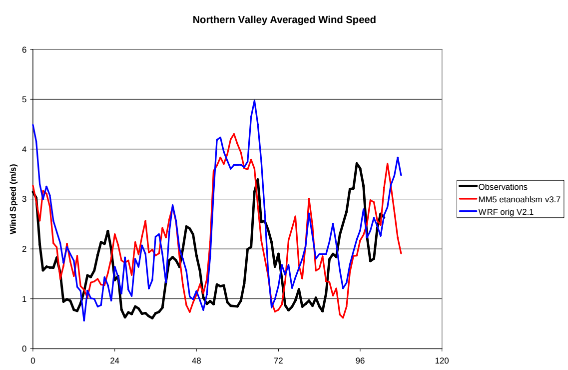
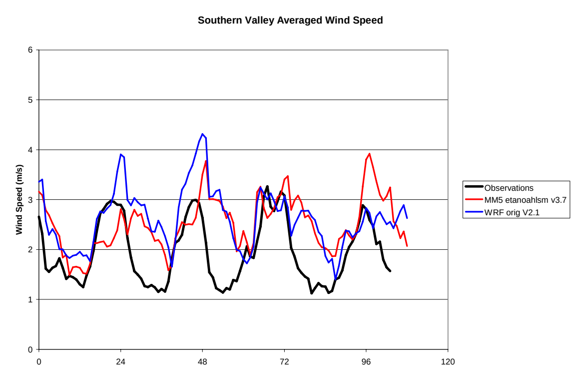


(d)



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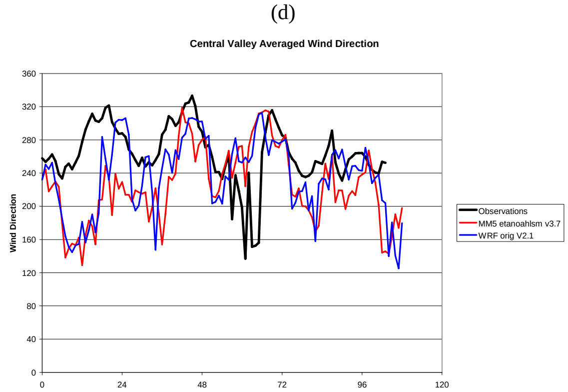

(e)

Figure 4 Time series of areal average wind direction and wind speed for (a) and (b) San Francisco Bay Area, (**c**) and (d) Northern San Joaquin Valley, (e) and (f) Central San Joaquin Valley, and (g) and (h) Southern San Joaquin Valley. The black line is observations, the red line is MM5, and the blue line is WRF.

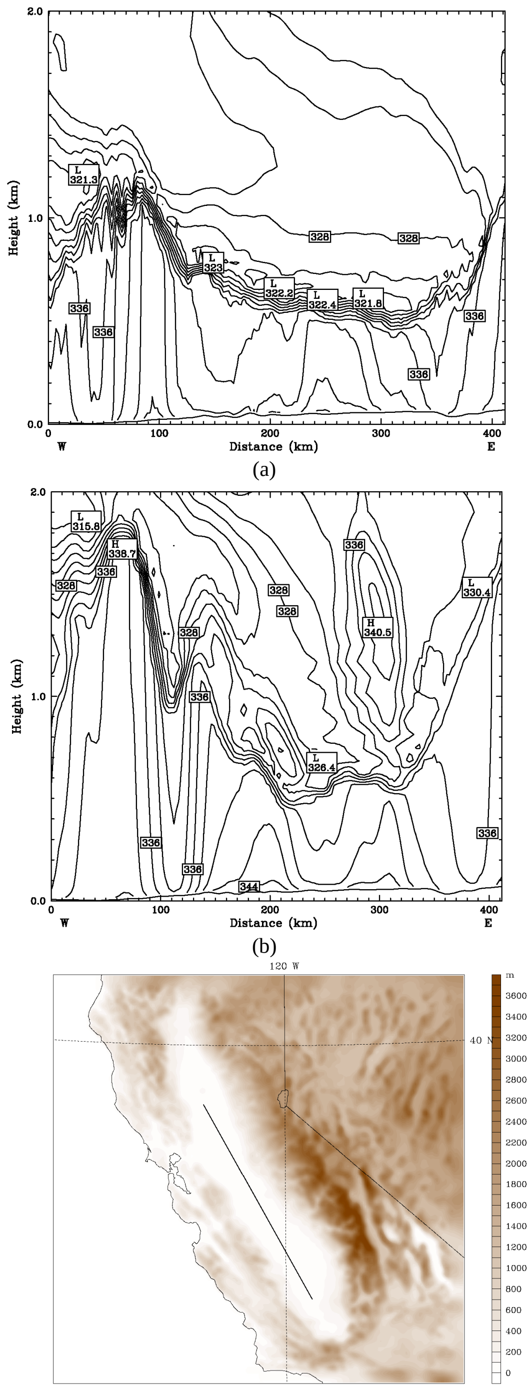

Figure 5 Cross sections of simulated potential virtual temperature with contour interval of 2 K for (a) WRF and (b) MM5. The location of both cross sections is shown in (c) with the MM5 topography. The northern end of the line is the left end of the cross section in (a) and (b).

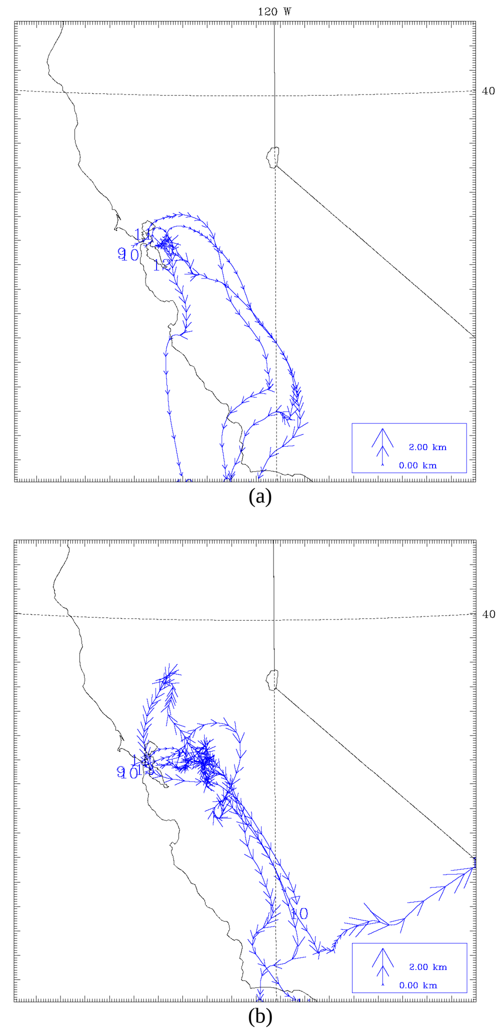

Figure 6 Forward trajectories of nearby 4 air parcels in the Bay Area that are released at 100 m (AGL) at 1200 UTC 30 August and ended at 1200 UTC 2 August. (a) is for WRF, and (b) is for MM5.