Land Surface Model Comparisons for Complex Terrain Flow

Benjamin de Foy, Luisa T. Molina, Mario J. Molina

Department of Earth, Atmospheric and Planetary Sciences,
Massachusetts Institute of Technology, MA 02139, USA
E-mail: foy@mit.edu

1. Introduction

MCMA-2003 was a major air quality field campaign in Mexico City that took place in April 2003. Mexico City lies in a basin at 2240 m altitude surrounded by high mountains on 3 sides. April is at the end of the warm dry season when the weather is influenced by a high pressure system over the Pacific to the southwest of Mexico. Subsidence over the Mexican plateau leads to clear skies and high temperatures (Jauregui, 1988). Weak synoptic forcing leads to basin-mountain flows that are strongly influenced by the interaction of the atmosphere with the land surface. It is important to be able to simulate these flows accurately as they are associated with intense photochemistry and poor air quality in the city (Fast et al., 1998). In this paper we describe the application of MM5 to a clear sky episode on 15-16 April 2003 using 3 different land surface models and 2 different initial soil moisture fields for each.

2. Model Setup

MM5 version 3.6.3 (Grell et al., 1995), was run for 3 one-way nested domains starting at a resolution of 27 km over most of Mexico down to 3 km for the Mexico City basin. The model initial and boundary conditions were taken from the global AVN run, using the analysis every 6 hours and the first forecast step to have fields every 3 hours. The model was initialized on 13 April 2003 at 12Z giving 36 hours of spin-up time. The physics options used were: Kain-Fritsch convection (KF2), MRF boundary layer scheme, Dudhia simple ice microphysics and cloud radiation scheme.

The results from 6 test cases will be reported here. The 5-layer model (5LR) (Dudhia, 1996) was run both with constant soil moisture availability specified by landuse type and with varying soil moisture initialized with the AVN model data. The NOAH scheme was run with AVN initial soil moisture and with a 50% reduction in AVN soil moisture. Finally, the Pleim-Xiu (PX) (Xiu et al., 2001) scheme was run with the AVN soil moisture and with soil moisture forced to be above the wilting point. It should be noted that whereas both 5LR and NOAH use the MRF boundary layer scheme, PX is linked to its own scheme based on the asymmetric convective model.

Soil temperature is handled differently by the three land surface schemes. PX takes the AVN ground temperature for the surface and the reservoir temperature from the terrain file for the deep soil temperature. The 5-layer scheme does the same and interpolates between the two for the intermediate levels. Neither of these fields is adjusted for elevation differences between the AVN model grid and the MM5 grid. NOAH interpolates soil temperature from the AVN 10 and 200 cm deep soil temperatures. These are adjusted in REGRID to account for elevation differences using a lapse rate of -6 K/km, leading to soil temperatures in the basin that are up to 7 K cooler. Vegetation fraction is also initialized differently, with NOAH taking the values from the global database used by TERRAIN while PX calculates a value based on landuse. As for soil moisture, the resolution from the AVN model is coarse leading to a relatively uniform field of 0.2 – 0.25 m^3/m^3 for the finest domain. This is comparable to the values from the landuse table where the urban area is the driest category at 0.1 and the surrounding grass and forest areas are around 0.3 but where there is substantial spatial variation. Model tests were performed using the tabulated values of soil moisture for NOAH and PX and also using the 5LR soil temperatures and PX vegetation fraction with the NOAH scheme. These caused very little difference in model simulations, especially surface winds. Since they are not a significant factor in the observed behavior of the model they will not be discussed further.

3. Results

Model results are presented in figures 1-7. Time series are for the field campaign supersite at CENICA, in the southeast of the city, for 15-16 April. Observations are in black, 5LR in blue/magenta, NOAH in green/turquoise and PX in red/orange as shown in the legend in figure 2. Surface soil moisture for the six model runs is shown in figure 1. This is in the urban area with a default value of 0.1 for the 5LR scheme. The AVN soil moisture starts off considerably moister at 0.25. With the NOAH scheme, there is limited drying during the simulation of around 10%. PX on the other hand has immediate drying to the hard-coded minimum value of 0.05. In this context, initial conditions have little impact on PX and the default run corresponds to a dry case. For the second case, which was desired to be a wet condition, the moisture was forced to be above the wilting point. The deep soil moisture was around 0.2-0.25 with very little variation during the simulation except for the PX wet case where surface evaporation lead to ~10% drying.

Figure 2 shows the mixing height compared to values obtained from the radiosondes launched at 7:00, 13:00 and 19:00 at the National Weather Observatory in Tacubaya on the western slope of the basin. Observed values are obtained both by applying a threshold value to the value of potential temperature and by looking at the potential temperature gradients. 5LR and PX give very similar results that correspond well with the gradient method and are a little lower than the threshold method. NOAH values were smaller but decreasing the moisture led to an improved simulation. Values for the PX wet case were expected to be lower although the under prediction is nearly a factor of 2.

Surface wind speeds and directions are shown in figures 3 and 4. There is a strong diurnal pattern with very calm conditions at sunrise, a steady increase into the evening and a sharper drop from midnight to daybreak. This is reproduced by all the model simulations. The wet PX case is the closest to the observations, matching both the timing and the intensity of the changes. The PX base case has much stronger winds as expected from the shift of latent into sensible heat due to the dry surface conditions. The 5LR model is not very sensitive to the soil moisture initialization. It has an extended calm period from 7:00 to 11:00 and stronger winds at 18:00. This is even more noticeable for NOAH where the wind speed is next to 0 until mid-afternoon and there is a double peak, first at 18:00 and then after midnight. In terms of directions, the winds are southerly at night and in the morning then shift to northerly in the afternoon. Drier conditions lead to an earlier afternoon shift whereas for the wet PX case the shift is delayed by over 3 hours.

Figure 5 shows the vertical profiles of wind speed for the bottom 4000 m above the surface. The morning sounding shows a clear nocturnal jet around 400 m and another area of increased wind at 2000 m, corresponding to the basin rim. By midday there is a shallow layer of up-slope wind in the bottom 400 m with a narrow calm zone separating it from the stronger winds aloft. By evening the near-surface winds have increased again and the speeds are more uniform throughout the mixed layer. As expected, there is less difference between the cases than for the surface time series. The wet PX case is however substantially different, with a calm zone in the morning at the location of the secondary maximum aloft and a thick calm layer at the surface in the evening. None of the cases reproduce the remaining nocturnal jet in the morning and most overpredict the early evening jet. The calm morning surface winds of the NOAH simulations are part of a smooth boundary layer profile in the lower 500 m. In the evening however, NOAH has the strongest overprediction of the jet with peak winds of 8m/s in the lower 1000 m.

Figures 6 and 7 show the surface wind vectors for the fine domain (every third vector shown in both directions), together with terrain contours (1000 m intervals). These show that by 11am the 5LR scheme is generating upslope flows that are inducing surface winds in the basin. These are weaker with NOAH and the surface winds are calm in the whole basin. PX is more strongly influenced by northwesterly winds that are reinforcing the upslope flow in the south of the basin. The wet PX case however has much reduced northwesterly and upslope flows and a situation more similar to the 5LR scheme. In the early evening all the cases show the strong gap flow coming through the passage in the southeast of the domain and spreading through the basin (Doran et al., 2000). The soil moisture initialization makes little difference for the 5LR scheme, but the dry NOAH case shows stronger features than the AVN NOAH case. PX has a less well developed gap flow. This is especially true for the wet case where the winds are lower throughout the basin.

4. Conclusions

MM5 reproduced the diurnal wind speed variations and wind direction shifts observed in the basin and correctly simulated the mixing height. Nevertheless, there are substantial differences between the 3 land surface schemes tested, which are not affected by intra-model variation due to differences in inputs. The 5-layer scheme has overly calm sunrise winds and a delayed, but too strong, increase in wind speeds. This is even more pronounced for the NOAH scheme, although the weak surface winds are a shallow phenomenon limited to the lower 500m. Pleim-Xiu shows a better agreement in the morning winds. The default model however has very rapid drying of the surface layer leading to a high Bowen ratio and strong afternoon surface winds. This may be partly due to the different boundary layer scheme and partly due to the stronger sea breeze flows from the Gulf of Mexico and the Pacific Ocean. Increasing the surface humidity leads to much better agreement at the surface but very low mixing heights and poor vertical profiles.

Further work will seek to better understand the differences between the schemes and their relationship to proposed urban parameterizations.

5. References

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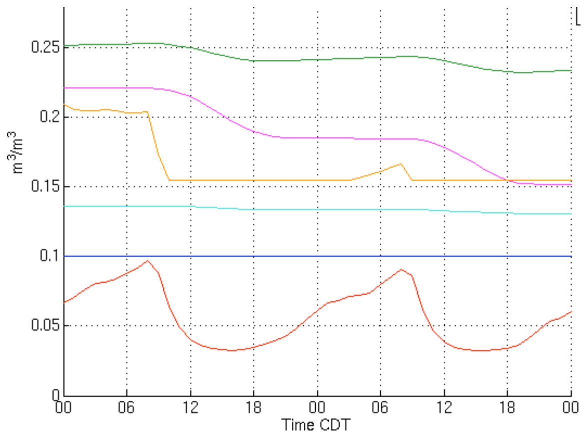

Fig. 1. Surface Soil Moisture

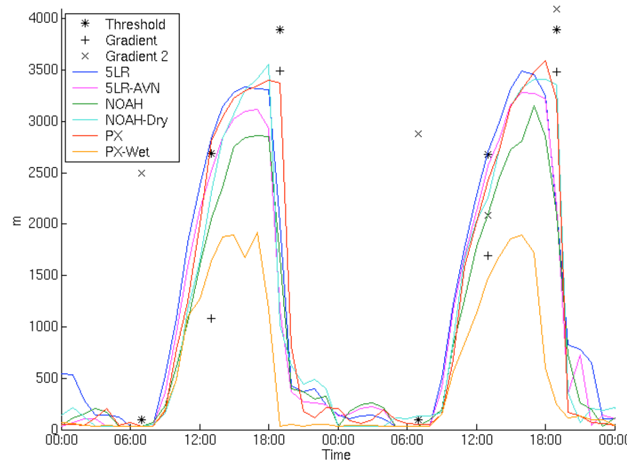

Fig. 2. Model vs. Predicted Mixing Height

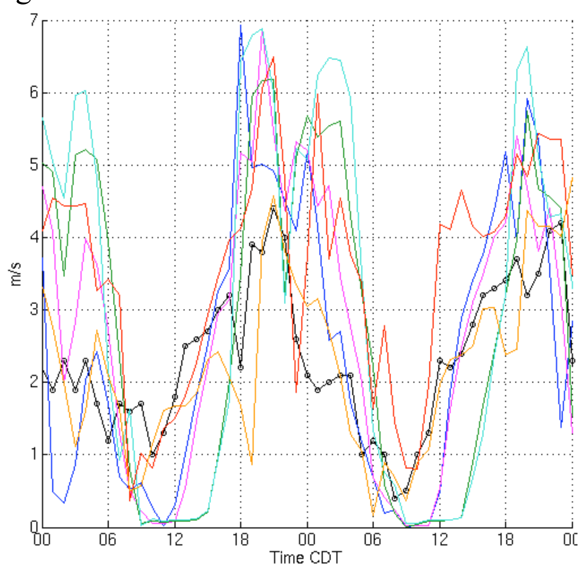

Fig. 3. Wind Speed at CENICA for 15-17 April 2003

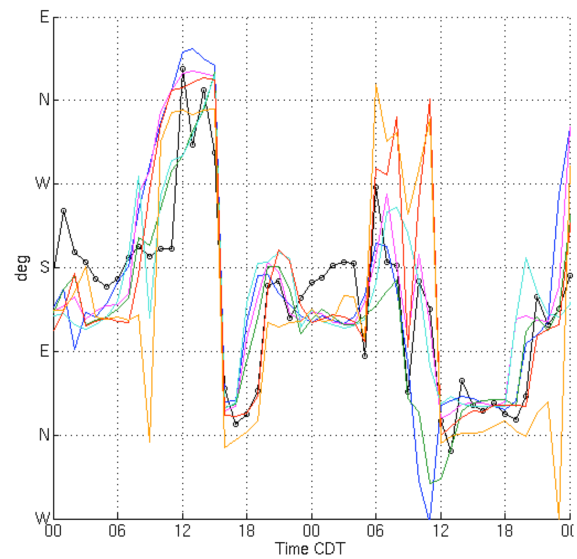

Fig. 4. Wind Direction

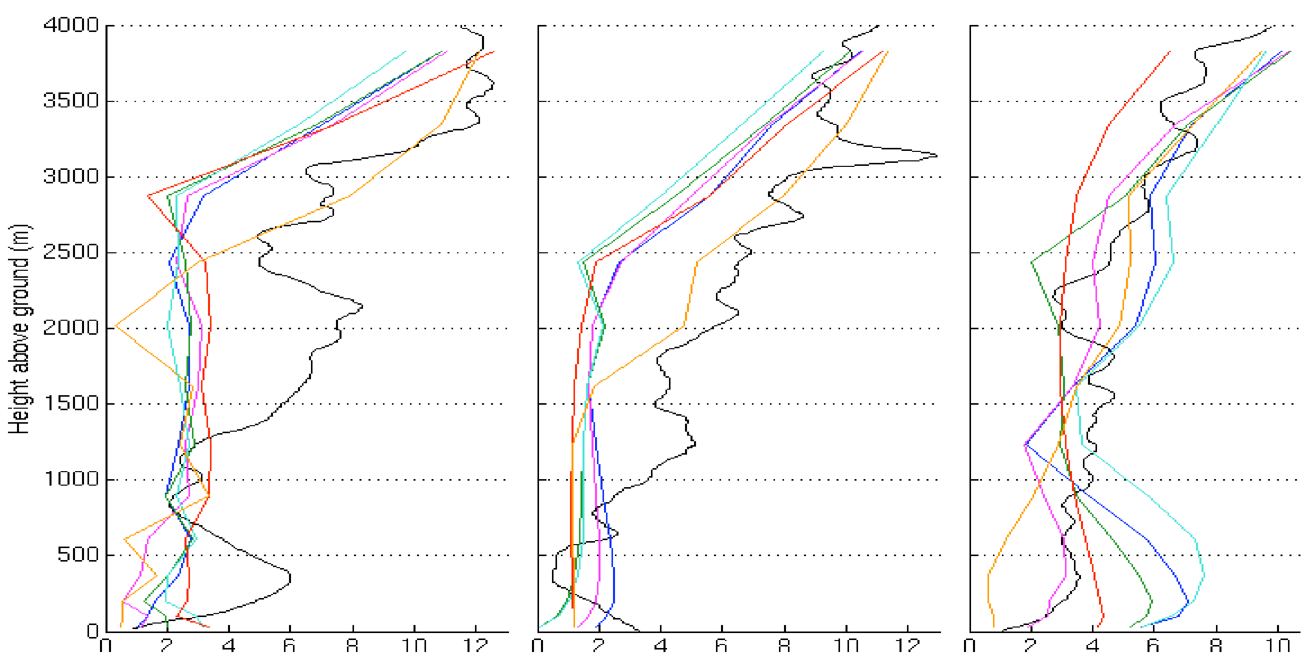

Fig. 5. Vertical Profiles of Wind Speed vs. Radiosondes for 7, 13, 19 CDT 15 April 2003

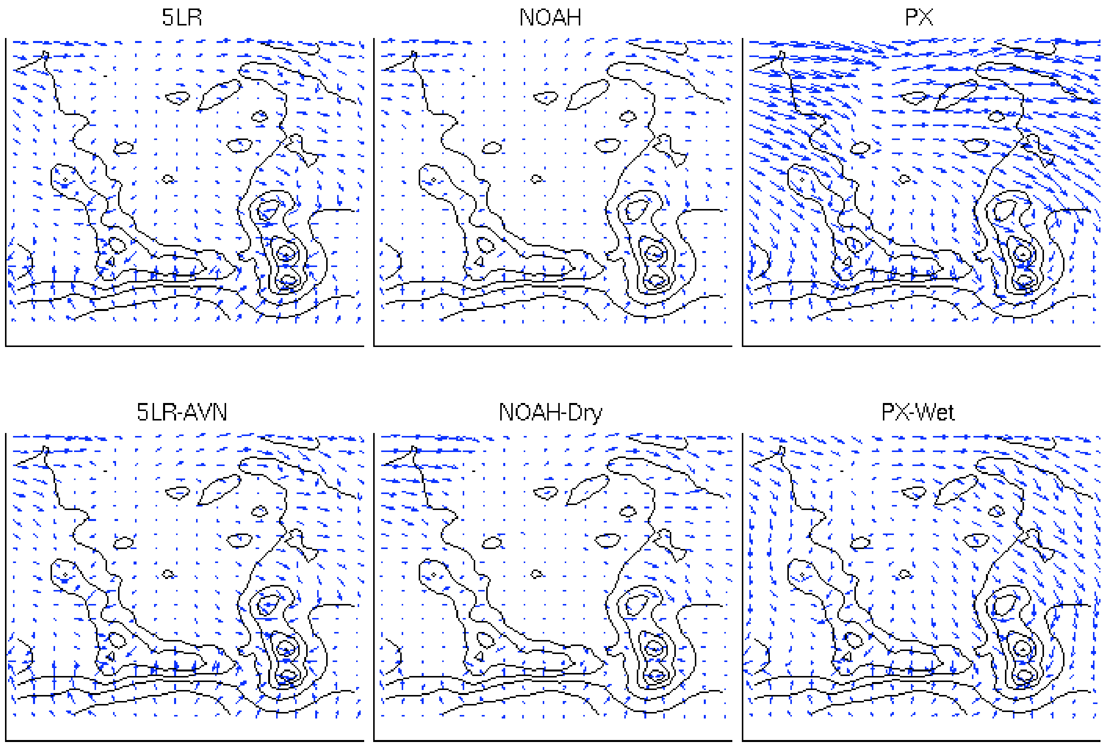

Fig. 6. Surface Wind Vectors on 11:00 CDT 15 April 2003 for 6 different runs.

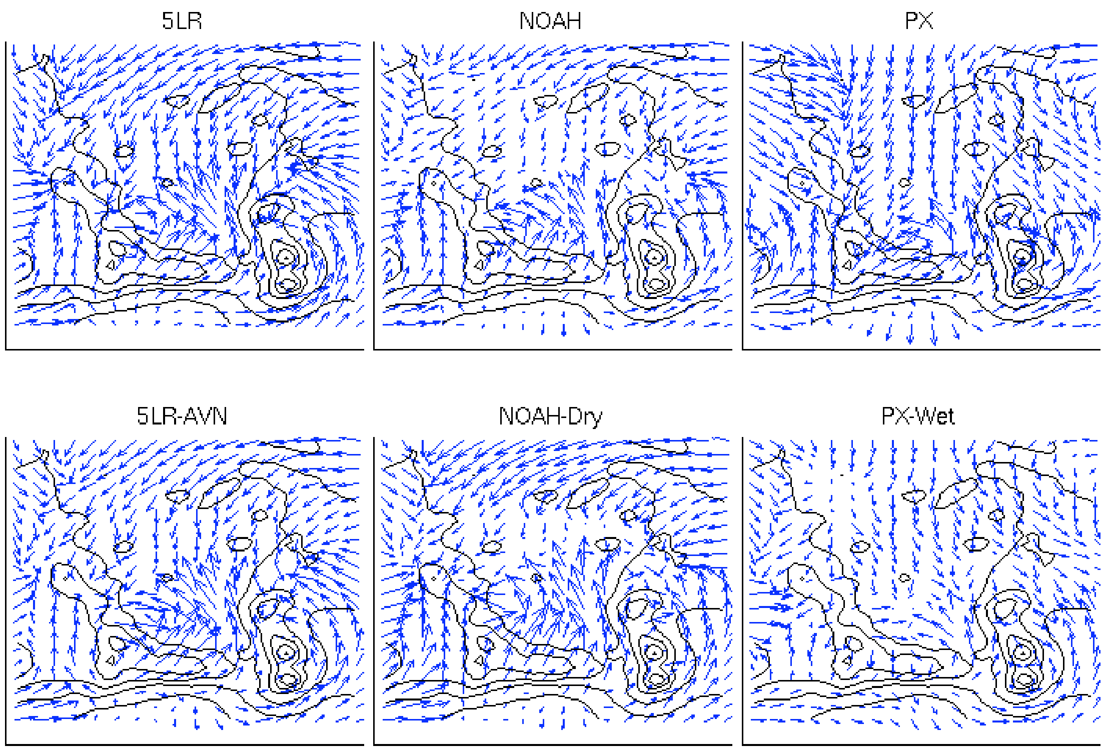

Fig. 7. Surface Wind Vectors on 19:00 CDT 15 April 2003 for 6 different runs.