

Interactive comment on “Air quality in the Kathmandu Valley: WRF and WRF-Chem simulations of meteorology and black carbon concentrations” by Andrea Mues et al.

Andrea Mues et al.

axel.lauer@dlr.de

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Below we reply to the anonymous referee #3's comments and questions on our GMDD manuscript "Air quality in the Kathmandu Valley: WRF and WRF-Chem simulations of meteorology and black carbon concentrations". We would like to thank the reviewer for the constructive comments helping us to improve the paper. We have listed all reviewer comments below and answers are provided in [blue](#). A "track changes" version of the revised manuscript is provided as a supplement with all changes to the manuscript highlighted.

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Specific comments

I have three specific comments listed below.

First, I was surprised to see large differences between WRF and ERA-Interim wind fields (Figure 2) because WRF is driven by the ERA-Interim itself. Since the model runs are a month long, I think WRF is drifting away significantly from the large-scale forcing provided by the ERA-Interim. Thus, I suggest the authors to conduct a model experiment by nudging the WRF meteorological fields towards the ERA-Interim above the planetary boundary layer, and examine if that helps in reducing the bias. In case, the authors are not aware of the nudging option in WRF, here are the steps to run analysis nudging in WRF (http://www2.mmm.ucar.edu/wrf/users/wrfv2/How_to_run_grid_fdda.html). In addition to this, I think the authors also need to examine the sensitivity of model results to land use in WRF. The USGS land-use category used here is representative of 1994 and Kathmandu Valley has changed dramatically since then. Thus, I suggest conducting a WRF simulation with MODIS land-use. MODIS land-use is representative of 2003 but this experiment should still help us understand the sensitivity of model results to land-use representation.

Following the reviewer's suggestions, we performed two additional sensitivity simulations, one in which the meteorological fields were nudged above the boundary layer, and one that involved the use of MODIS land use data. We have summarized our findings in a new subsection:



”3.1.7 Sensitivities of main meteorological parameters to nudging technique and land use data

In order to test that the simulated large-scale circulation does not drift or deviate from the observed synoptic condition, a sensitivity simulation in which a grid nudging technique was employed for horizontal winds, temperature and water vapor above boundary layer has been performed. In this simulation, we obtained similar results as in the reference simulation, for example the RMSE of temperature is 3.0 K using the nudging approach compared to 3.1 K in the reference run. The model performance for wind speed does not change. In the upper troposphere the differences in the simulated meteorological variables in the reference and the sensitivity runs were statistically insignificant, suggesting that the WRF model results in this altitude range are mostly driven by the prescribed boundary conditions. In a second sensitivity simulation we have analyzed the impact using of MODIS land use data instead of the default USGS dataset. In this simulation the impact of using the MODIS data together with applying the nudging technique on WRF results is tested for temperature and wind speed parameters. As in the first sensitivity simulation, the RMSE of temperature does not deviate much from the one obtained from the reference simulation, i.e. using USGS land use data and no nudging, leading to a RMSE of 2.9 K compared with 3 K in the WRF_ref_D02 simulation. In contrast to temperature, the model performance for wind speed worsens with a RMSE of 3.2 m s^{-1} and an average correlation coefficient of 0.21. Since the relative small number of measurement stations in the evaluation domain might not be representative for the whole domain, we have also compared the results from the sensitivity simulations with the reference simulation. When applying the nudging technique the domain averaged mean bias between the sensitivity and the reference simulation -0.03 K for temperature and 0.08 m s^{-1} for wind speed. For the MODIS land use sensitivity simulation the domain averaged mean bias when compared to the reference simulation is 0.08 K for temperature and 0.2 m s^{-1} for wind speed. This suggests that the changes in temperature and wind speed when applying

the nudging technique and using the MODIS land use dataset are rather small and not expected to be important factors in explaining the differences between the model results and observations found.”

Second, I think section 3.2.3 needs further detailed investigation. I believe that this event is potentially driven by open burning of agricultural crop residue in northern part of India and forest fires in Himalayas. The failure of the model to capture this event should not be attributed only to the anthropogenic emissions in Kathmandu Valley. It is important to understand the relative importance of local vs. non-local sources in this event as well as uncertainties in biomass-burning emissions. I realize that such an exercise can be time-consuming and can lead to another paper in itself. Thus, I recommend deleting this section. However, I suggest the authors to include a discussion about the potential impact of uncertainties in open biomass burning emissions and long-range transport on black carbon mass concentrations in the Kathmandu Valley.

Following the reviewer’s suggestion, we deleted section 3.2.3 (Case study: the episodes 2-5 May and 6-8 May 2013).

The biomass burning emissions in the model are calculated from satellite observations of fires and land cover using average emission factors (Fire Inventory from the National Center for Atmospheric Research (NCAR) version 1: FINN, Wiedinmyer et al., 2011). We think that anything beyond the rather general uncertainty analysis given in Wiedinmyer et al. (2006 and 2011) would not only be beyond the scope of this study but also beyond our expertise.

Third, I recommend the authors to quantitatively assess the model performance by comparing their statistical metrics for temperature and wind speed against the benchmarks by Emery (2001). This is important for this paper as the focus is on

evaluating the meteorological parameters that are highly relevant to air quality.

Following the recommendation of the reviewer, we have included the benchmark proposed by Emery et al. (2001) in the discussions of the model performance in sections 2.4 (evaluation metrics), 3.1.3 (2m temperature) and 3.1.4 (10m wind speed and direction).

Minor Comments:

1. Page 1, Line 20: Change "long-term" to "extensive" because 6 months is not long-term.

Changed as suggested.

2. Page 3, Line 8: I think it is important to state how different regional and global models have performed in simulating BC mass concentrations in South Asia. This will nicely connect the present study to literature. Here are few studies that employed regional and global models to simulate black carbon mass concentrations in South Asia [e.g., Ganguly et al., 2009; Nair et al., 2012; Moorthy et al., 2013; Pan et al., 2015; Kumar et al., 2015a, 2015b, Goverdhan et al., 2016]

As suggested, we added a paragraph to the introduction linking this work to studies with different regional and global models including references to Goverdhan et al. (2016), Nair et al. (2012), Pan et al. (2015) and Moorthy et al. (2013).

3. Page 9, Line 28: This is probably a typo here because there is no panel corre-

sponding to station "1206" in Figure 5.

Thanks for spotting this. The typo was actually not in the text but in the caption of figure 5 (and figure 6). We corrected "6480" to "1206" in both cases.

4. Section 3.1.6: I suggest adding a map of the WRF and TRMM precipitation for February and May so that readers can visualize if the model is able to simulate the precipitation in right places.

As suggested, we added a figure comparing the precipitation from WRF and TRMM in February and May (new figure 11). The discussion in section 3.1.6 (precipitation) has been extended with a brief discussion of the new figure.

5. Table 1: Please name the inventory used to represent biomass burning emissions.

For biomass burning emissions, the Fire Inventory from the National Center for Atmospheric Research (NCAR) version 1 (FINN, Wiedinmyer et al., 2011) is used. This has been added to table 1.

6. Figure 12: Should the last legend read as "WRFchem_BC_min/max"?

The legend has been corrected in the revised version of figure 12.