<u>**Response to Reviewer's Comments**</u>

<u>**Reviewer #2**</u>

We thank the reviewer for careful evaluation of the manuscript. Below we give a detailed response to each of the concerns raised by the reviewer. Reviewer's comments are in regular font and our replies are in bold font characters.

The paper investigates the radiative impact of a pre-monsoon dust storm event. A small impact was found, certainly because the nudging imposed to the thermodynamics fields over the whole depth of the atmosphere. It is very unusual and does not permit the PBL to evolve freely. This strongly constrains the surface wind, therefore the dust emissions. At least, the reasons for this choice should be given. It is recommended to investigate the nudging effect on the dust emission by letting the thermodynamics to evolve freely within the PBL.

We agree that the radiative perturbation numbers given in the abstract indicate a small impact but that is because they represent the values averaged over the entire domain and 6 days (17-22 April 2010) period. Now, we have replaced these numbers with those over a subregion (70^o-80^{o}E, 25^o-30^{o}N) affected significantly by the dust storm and added information about simulated highest instantaneous cooling (please see response to first reviewer's second comment for details). The reason for nudging the whole atmosphere is given below in reply to your specific comments. We agree that application of nudging directly affects the dust emissions as it reduces wind speed over the model domain. However, we have compensated the effect of the nudging-induced reduction in wind speed by increasing the value of C factor. The tuning of C factor associated with nudging was already mentioned in the manuscript (Page 21844, Lines 10-17).

Specific Comments

Introduction

Page 21838, first paragraph. The dust also impacts on the dynamics of the atmosphere through radiative effects. There is a growing number of papers on that topic. For example, Tompkins et al. (2005) have shown that a revision of the aerosol climatology in the forecasting system at ECMWF significantly improved the ECMWF 5-day forecasts of the African Easterly Jet, the central dynamical feature over West Africa. Chaboureau et al. (2011) did a study of sensitivity to the radiative effect of dust that showed a better prediction of precipitation whane a dust prognostic scheme was used rather than climatology or when dust effects were ignored. Stanelle et al. (2010) have shown that the temperature changes caused by the mineral dust modified near surface winds. Further, they found a feedback on total emission fluxes with an increase of 25% during the dust episode under scrutiny.

Thanks for bringing these studies to our knowledge. These references are now cited in the introduction of the paper.

Section 2 The WRF-Chem Model

Page 21841, line 17. "….at a spatial resolution of 30x30 km2". This is the grid mesh size. What about the effective resolution.

The effective resolution of WRF model for kinetic energy spectrum is estimated as about about 7 times the grid spacing (Skamarock, 2004). Therefore, effective resolution of the model for a grid spacing of 30 km will be about 210 km. Now, we have changed "spatial resolution" to "grid spacing" in the manuscript.

Page 21843, line 16. The choice to nudge the thermodynamical fields over the whole troposphere needs to be explained and justified.

The analysis nudging is used to limit the errors in simulated meteorology and obtain an aerosol distribution as accurate as possible. The choice of nudging the whole depth of the model atmosphere was inspired by the study of Deng et al. (2006) who showed that the WRF model with nudging at all the levels performs better in simulating the meteorological variables (temperature, water vapor, wind speed and direction) as compared to without nudging in the planetary boundary layer (PBL). To examine the advantage of nudging in our study, we conducted two sensitivity runs: (a) without nudging in the PBL (NoPBL-Nudging) and (b) No Nudging at any level (No-Nudging). These sensitivity runs are compared to the run with nudging at all the model levels (Full-Nudging) in terms of correlation coefficients between the model and observations for AOD at all AERONET sites. Results are shown in the Table below. It is clear that the "Full-Nudging" run leads to higher values of r at all the sites except at EVK2-CNR where r value decreased due to nudging.

Table: Correlation coefficient (r) between the model and observations at AERONET sites in three different model configurations.

Site	Full-Nudging	No-Nudging	NoPBL-Nudging
Kanpur	0.78	0.59	0.66
Nainital	0.68	0.25	0.64
Jaipur	0.62	0.23	0.47
Lahore	0.58	0.06	0.51
Kathmandu	0.80	-0.37	0.07
EVK2-CNR	-0.04	0.45	0.20
Pokhara	-0.16	-0.31	-0.25

An explanation of why we chose to nudge the whole depth of atmosphere is now included in Section 2.

Page 21844, line 4. Is the C value dependent on the grid spacing?

C is an empirical constant and does not have any direct relation with the grid spacing. However, it may depend indirectly on grid spacing as change in grid spacing may lead to change in wind speed and a different C value may be required to obtain the same amount of dust emissions in model runs with different grid spacing.

Section 4.1 General Meteorology

Page 21848, How do you define the PBL height?

The PBL height is available as a standard variable in WRF model output. The determination of PBL height differs among PBL schemes available in WRF and is defined as the level of minimum entrainment flux in the PBL scheme (YSU) used in this study. This is now noted on Page 21848 (Lines 23-24).

Section 4.2 Spatial and vertical distribution of dust

Page 21848, line 24. Figure 4. It is not clear whether the two images cover the same domain or not. If yes, the spatial patterns differ between the simulation and the observation.

Yes, both the images cover the same spatial extent which is now stated in the Figure caption. We agree that there are some differences in the spatial pattern but model does fairly well in capturing the structure of the dust plume, i.e. northward transport along Indo-Pak border, changing direction just west of the Himalayas and then moving along the Indo-Gangetic Plain region. However, we do not expect the model to exactly reproduce the MODIS observed spatial pattern considering the relatively coarser grid spacing and inherent uncertainties in parameterization of different physical processes.

Page 21851, line 12. Plotting the mean vertical profile of extinction would provide a more quantitative comparison between retrievals and simulation. The CALIPSO retrieval shows extinction value at 3 km altitude larger than those simulated. Is it a nudging effect that damps the PBL development.

The latitudinal coverage (18^o-32^oN) of CALIPSO in our domain (Figure 1) covers different environments including the urban and rural regions, desert region and high altitude mountains. Averaging the extinction coefficient along the CALIPSO track will not only hide the spatial variability but will also make it difficult to interpret the variability in the resulting mean profile as that would represent a combination of features from different regions. For this reason, we did not plot the mean profile. Regarding the underestimation of extinction coefficient at 3 km, the differences cannot be attributed to PBL development

alone as anthropogenic emissions of aerosols are also reported to be highly uncertain in India (e.g. Nair et al., 2012; Cherian et al., 2012). A comparison between CALIPSO and WRF-Chem in No-Nudging configuration showed that underestimation of extinction coefficient is even larger if nudging is not applied to the meteorological fields (see Figure below). This could be due to faster dilution of dust plumes as the model without nudging produces higher wind speed.

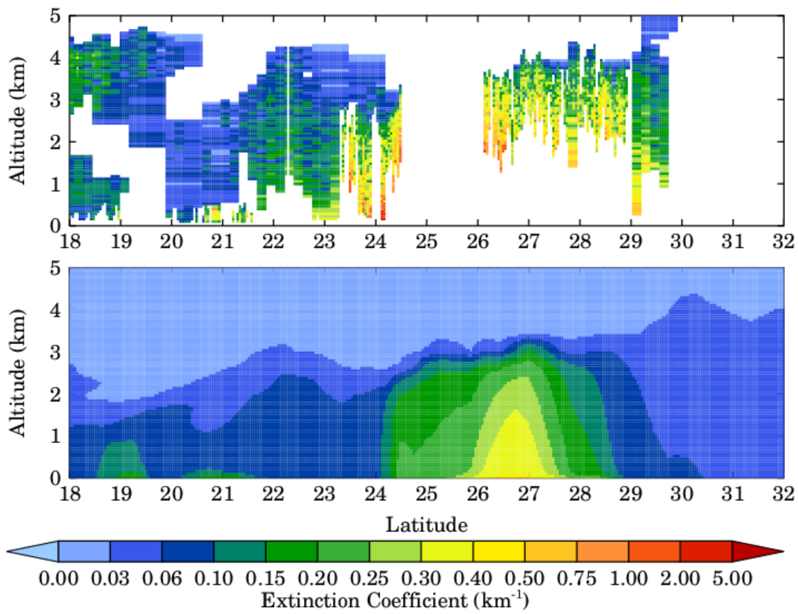

Figure: Comparison of CALIPSO retrieved extinction coefficient at 532 nm (top panel) with WRF-Chem ("No-Nudging" configuration) simulated extinction coefficient at 550 nm (lower panel) on 20 April 2010.

Section 4.4 Impact of dust storm on radiation budget

Page 21856, line 4. It should be recalled that radiative forcing computed here is limited by the nudging effect. The feedback on dynamics was not taken into account.

We have added a sentence in the revised manuscript.

References

Skamarock, W. C.: Evaluating Mesoscale NWP Models Using Kinetic Energy Spectra, *Mon. Wea. Rev.*, 132, 3019–3032. doi: http://dx.doi.org/10.1175/MWR2830.1, 2004.