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Amplification of South Asian haze by water vapour–aerosol interactions

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Model validation:

The meteorological and aerosol parameters modeled using RegCM4 are further compared with the various dataset available over the Indian region.

Comparison of PM2.5 data collected at various city centers by Central Pollution Control Board (CPCB) with model simulated values. In general, the model underestimates PM2.5 values, especially at Delhi, Muzaffarpur, Gaya, Thiruvananthapuram, Lucknow, Varanasi, Agra and Guwahati. Since CPCB measurements are carried out at the urban hotspots and close to the city pollution, models simulations at coarse spatial resolution (50km) may not simulate the magnitude of city pollution accurately.

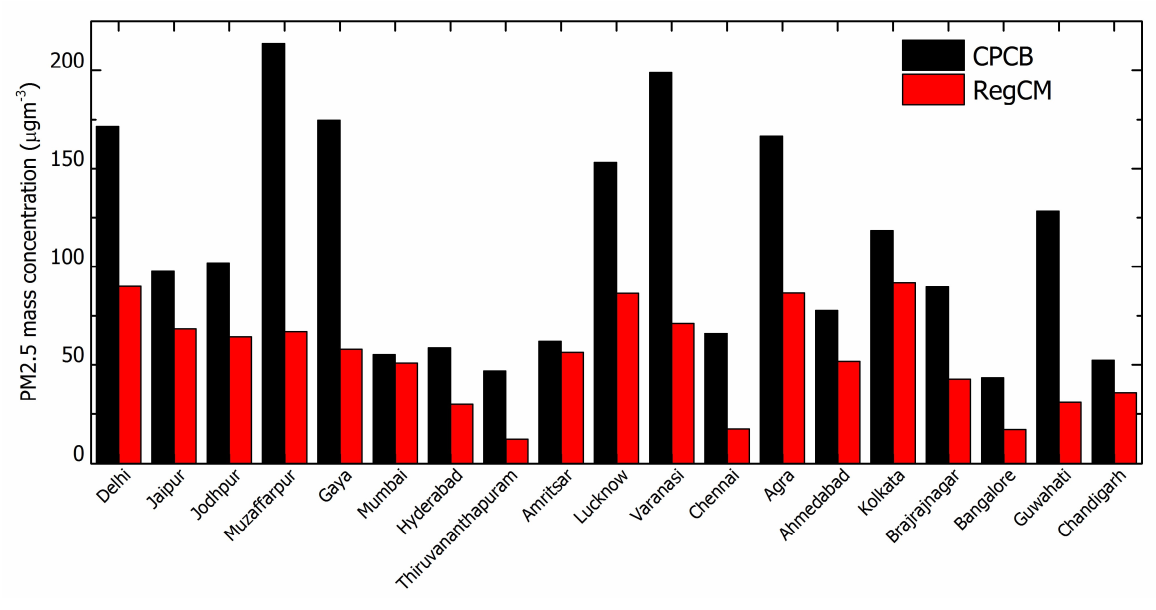

Figure S1: *Inter-comparison of PM2.5 simulated using RegCM4 with measurements from 19 stations maintained by Central Pollution Control Board (CPCB) India (www.cpcb.nic.in).*

The aerosol optical depth (AOD) measured using multiwavelength Radiometers installed at various locations under the ARFI project is used for the validation of modelled AOD. The figure below shows the RegCM4 and MWR AOD at mid visible wavelength Agartala, Varanasi, Gorakhpur and Udaipur from December 2015 to February 2016. In general, the model is able to simulate the magnitude of the aerosol loading over the Indian region accurately.

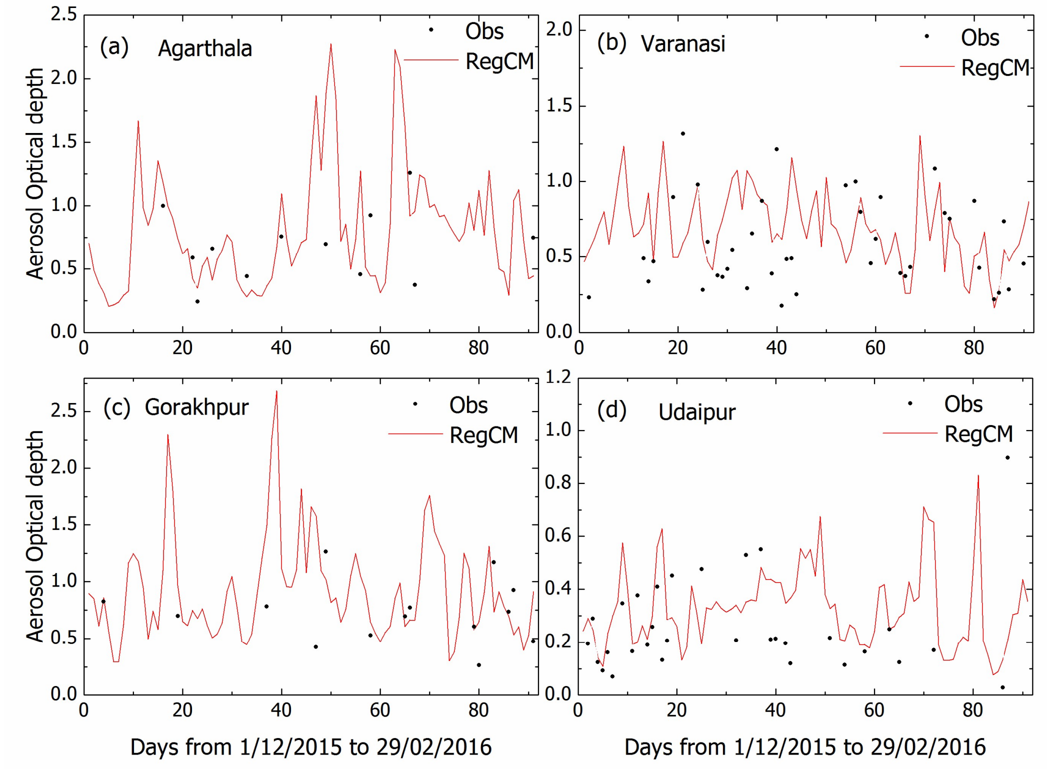

Figure S2: *Variation of aerosol optical depth measured using multi-wavelength radiometer installed as a part of Aerosol Radiative Forcing over India Project (ARFINET) and modeled using RegCM4 from December 2015 to February 2016.*

Similarly, inter-comparison of black carbon (BC) mass concentration over Agra, Jaisalmer, Udaipur and Hyderabad is shown in Figure S3.

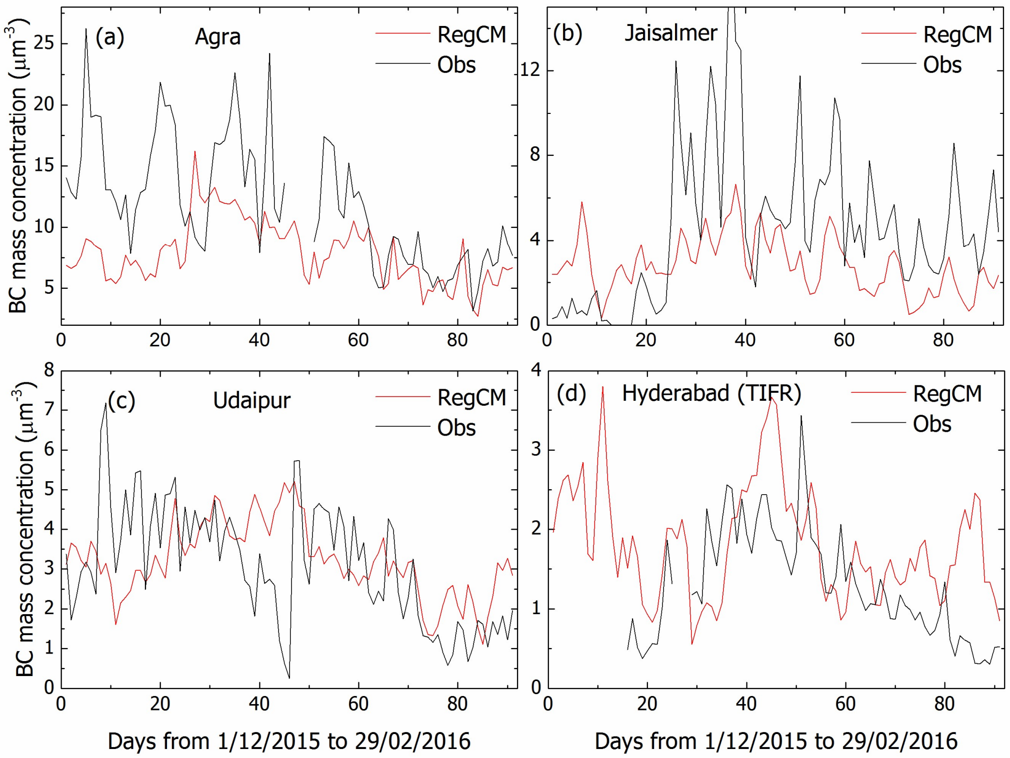

Figure S3: *Temporal variation of BC mass loading measured at 4 ARFINET stations and modeled using RegCM4 over Agra, Jaisalmer, Udaipur and Hyderabad from December 2015 to February 2016.*

It is interesting to that aerosol loading and clear-sky radiative forcing showed very high values over the eastern IGP. In contrast, the change in surface temperature and relative humidity due to aerosol induced surface dimming was high over central IGP with a moderate change over eastern IGP. To further understand this, the change in solar radiation reaching at the surface for with and without aerosol conditions is shown in the figure below. Though the AOD and aerosol direct radiative forcing (clear sky) are high values over the eastern IGP, the presence of relatively high cloud fraction over the eastern IGP mask the aerosol effects (limit the availability of radiation for interaction) significantly. So, the change in surface temperature did not show a similar pattern as that of AOD. Whereas the change in shortwave flux at the surface (due to clouds and aerosols together) showed an almost similar pattern as that of change in temperature and humidity.

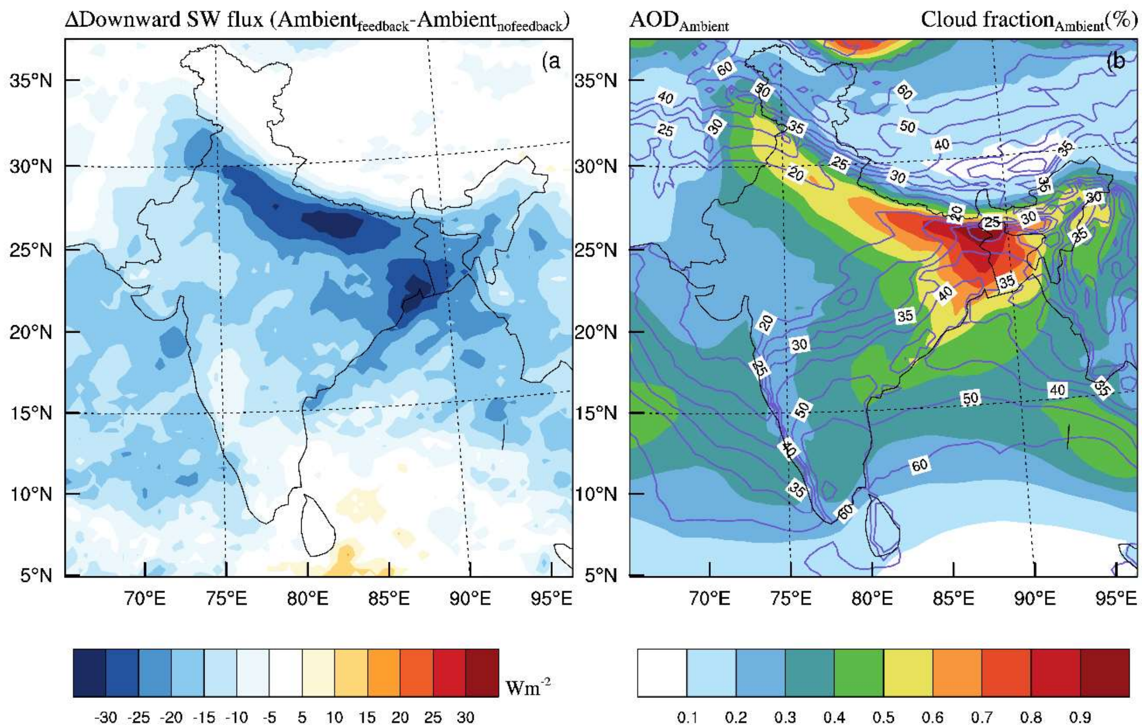

Figure S4: *(a) Spatial variation of change in surface-reaching solar radiation for with and without aerosol conditions. (b) variation of AOD (color) and cloud fraction (line contour) for aerosol feedback simulation.*

Change in specific humidity for radiative effects of total aerosols and due to hygroscopic growth is shown below. Similar to relative humidity, specific humidity also showed an increase in the boundary layer and a decrease in the lower free troposphere.

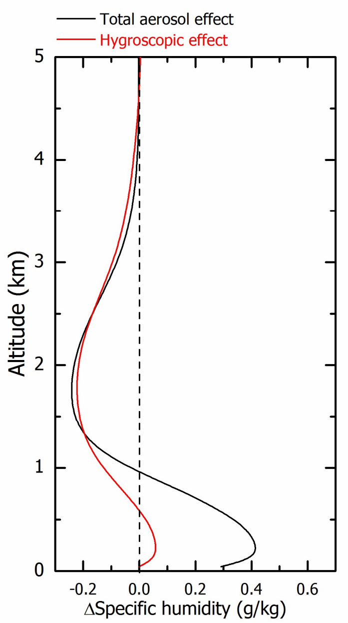

Figure S5: *Vertical profiles of change in specific humidity due to the total aerosol effect (Ambient$_{feedback}$ -Ambient$_{nofeedback}$) (black line) and only due to hygroscopic growth of aerosols (Ambient$_{feedback}$ - dry$_{feedback}$) (red line).*

The diurnal evolution of the planetary boundary layer (PBL) is primarily driven by the sensible and latent heat flux from the surface. When the surface reaching solar radiation is blocked by the aerosols, it reduces the sensible and latent heat flux resulting in the suppression of the PBL height. The figure S6a shows the reduction in the noontime PBL height due to the aerosol hygroscopic growth which shows a reduction up to 100 m and the total aerosol effect reduces the PBL height further up to 200 m. As discussed before, the prevailing meteorology of the wintertime IGP consists of weak near-surface winds which is further weakened by the reduced temperature and suppressed PBL.

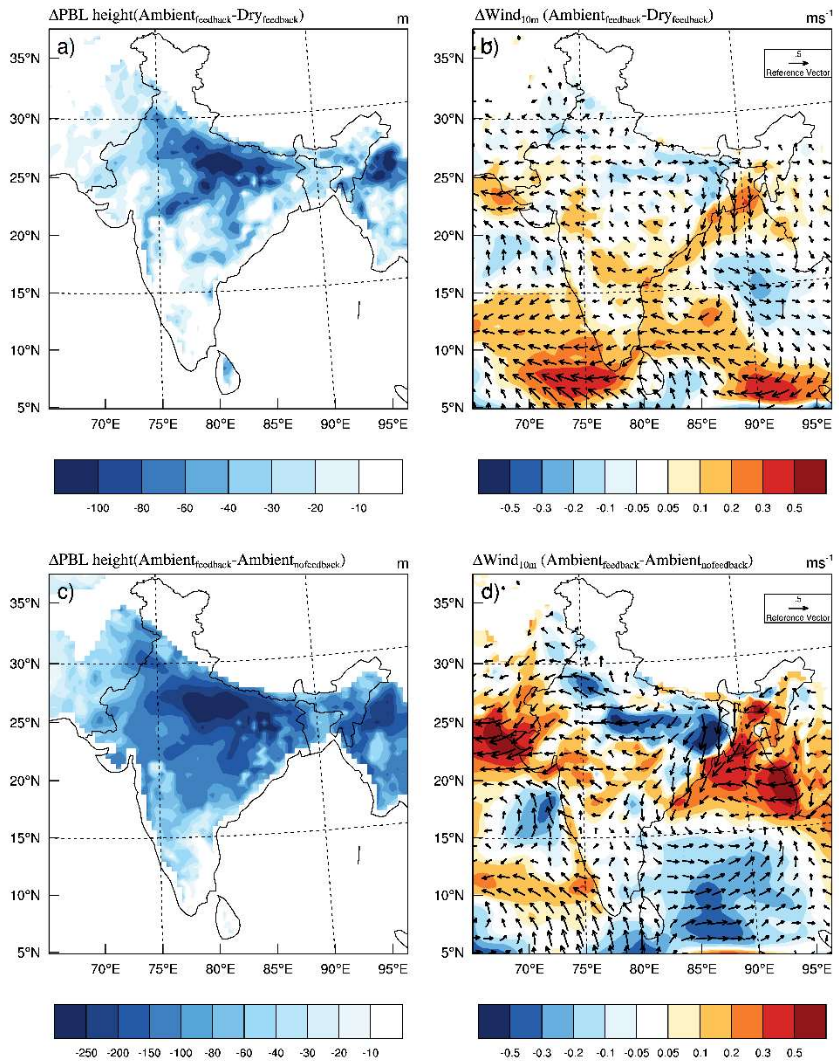

Figure S6: *Change in (a) boundary layer height and (b) wind due to hygroscopic growth and meteorological feedback of aerosols. (c) and (d) are similar to figure (a) and (b) but for the total effect of aerosols.*

Figure shows the frequency distribution of the daily mean visibility estimated from the aerosol extinction coefficient averaged over the Indo-Gangetic Plain. When hygroscopic growth of aerosol is activated, the distribution peak shifts toward the lower value to a large extent, which means that there is an increase in the occurrence of the days with lower visibility. This underlines the role of the hygroscopic growth of aerosols in the degradation of the air quality over Indo-Gangetic Plains.

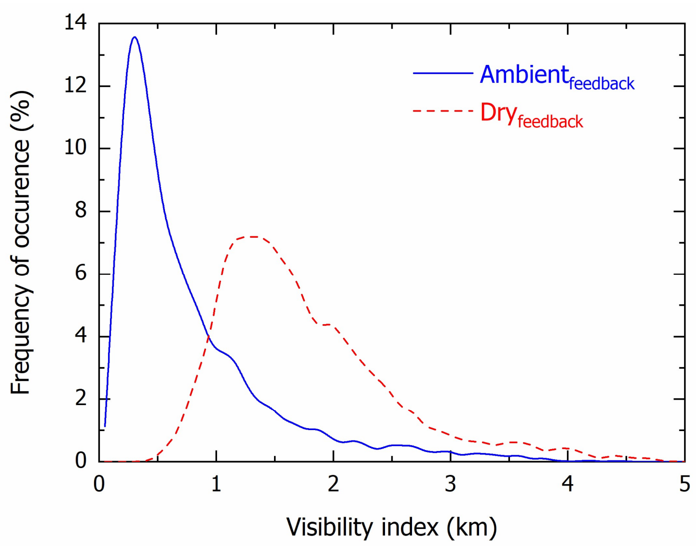

Figure S7: Fr*equency distribution of spatially averaged visibility over Indo Gangetic Plain for Ambient*$_{feedback}$ *and Dry*$_{feedback}$ *simulations.*