Understanding aerosol feedbacks on atmospheric dynamics and impacts on NWP: a mineral dust example

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Dust aerosol particles are produced by wind erosion in arid and semi-arid surfaces. While dust distribution and dust effects are important at global scales, they strongly depend on dust emission, a threshold, sporadic and spatially heterogeneous phenomenon, that is locally controlled on small spatial and temporal scales.

Dust radiative effects on atmospheric dynamics and feedbacks upon dust emission within the Earth System span a wide range of spatial and temporal scales. In this contribution we will focus on recent achievements and current uncertainties in the assessment of direct radiative effects on atmospheric dynamics and feedbacks upon dust emission at short-term scales.

Perlwitz et al. (2001) and Miller et al. (2004a, 2004b) interactively coupled a dust aerosol module and a general circulation model. Over dust sources, it was found that the negative net surface forcing during the day was mainly balanced by the reduction of the turbulent sensible heat flux to the atmosphere, which in turn decreases turbulent mixing within the PBL and consequently the downward transport of momentum to the surface, generally resulting in a decrease of dust emission (Miller et al., 2004a; Pérez et al., 2006). On the global average, estimates of this effect are of 15% emission reduction (Miller et al., 2004a). On the other side, dust surface radiative cooling over high concentration areas suppresses convection and increases subsidence creating a positive surface pressure perturbation, whereas compensating negative pressure perturbations are created over nearby ambient areas (Pérez et al., 2006; Ahn et al., 2007; Heinold et al., 2008). This results in positive and negative feedbacks on surface wind velocity. All these effects are highly dependent on the magnitude of the event and the driving meteorological scenario.

Heinold et al. (2008) provides insight of these complex mechanisms for episodes driven by the formation and breakdown of low level jets (LLJ), concluding that local negative feedbacks upon dust emission could reach up to 40-70%, whereas positive feedbacks are encountered over ambient areas, partly compensating negative feedbacks at regional scale. Here, winds were lowered or increased in dependence on the atmospheric stratification and the degree of stabilization by mineral dust. Higher surface wind speeds occur in dust feedback simulations compared to the control run when momentum is mixed downwards to the ground by turbulence. Surface winds decrease when thermal stratification suppresses turbulent mixing more effectively. Under dust storms driven by synoptic scale low pressure systems, Pérez et al. (2006) and Ahn et al. (2007) found a strong AOD reduction (35–45% and 10-40%, respectively) with respect to the control run over the area covered by the main dust plume.

Several other studies recently suggested that the inclusion of mineral dust radiative effects would improve the radiation balance of numerical weather prediction (NWP) models and thus increase overall accuracy of the weather prediction itself. Most of current weather forecasting models use prespecified (climatological or other) ozone and CO_2 profiles in radiation calculations. Concerning the mineral aerosol and its impact on radiation, the situation is rather unsatisfactory. None of the operational NWP currently uses online predicted mineral aerosol concentration for radiation calculations. For example, the NCEP regional models use the solar constant reduced by 3% anywhere anytime to represent aerosol influence.

Pérez et al. (2006) showed that differences in 2-m temperature between feedback and control runs can reach as much as 6 K in some areas in North Africa. In fact, significant improvements of the atmospheric temperature and mean sea-level pressure forecasts can be obtained over dust-affected areas. In this example, PBL dust redistributes heat from the surface and near surface to higher levels of the atmosphere, considerably reducing both warm and cold temperature biases with respect to the control run. It should be noted that benefits in Numerical Weather Prediction by including on-line dust radiative effects can be achieved provided that the model is able to rather accurately predict the timing, position and strength of the dust plumes. This is usually the case for synoptic-scale driven dust storms as in Pérez et al. (2006). Some current limitations appear when regional atmospheric models are unable to accurately reproduce dust episodes over source regions under mesoscale systems such as gap winds, convective downbursts, downslope winds, etc.. From a weather forecast point of view, one of the main limitations in this sense is the lack of meteorological observations over source areas for data assimilation. On the other side, we should note that wind velocity is in general significantly underestimated over source regions by regional models and thus, negative feedbacks on wind velocity might increase the errors.

References

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