Radiative forcing of Sahara dust and its impacts on the hydrological cycle in the West African monsoon system

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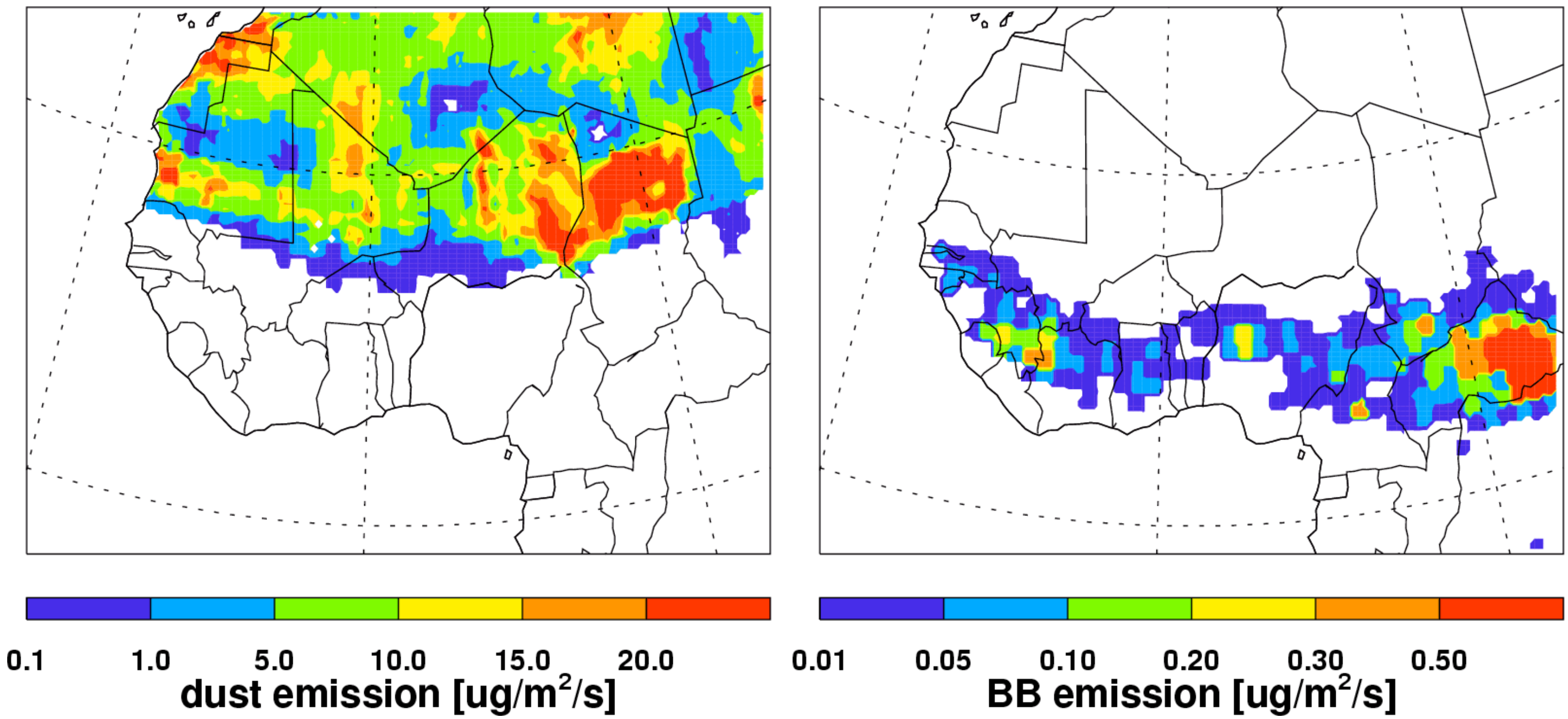
Impact of Sahara dust

- The Sahara desert is the largest source of dust in the world and thus plays an important role in climate change at both regional and global scales [e.g., Sokolik et al., 1998; Mahowald et al., 2002], by
  - Modifying the hydrologic cycle over North Africa [e.g., Miller et al., 2004; Lau et al., 2009]
  - Modulating tropical North Atlantic temperature [Evan et al., 2009]
  - Being transported northward to central and northern Europe, or westward across the Atlantic ocean to occasionally reach the eastern coasts of the United States [Moulin et al., 1997; Chin et al., 2007].

Model and Measurements

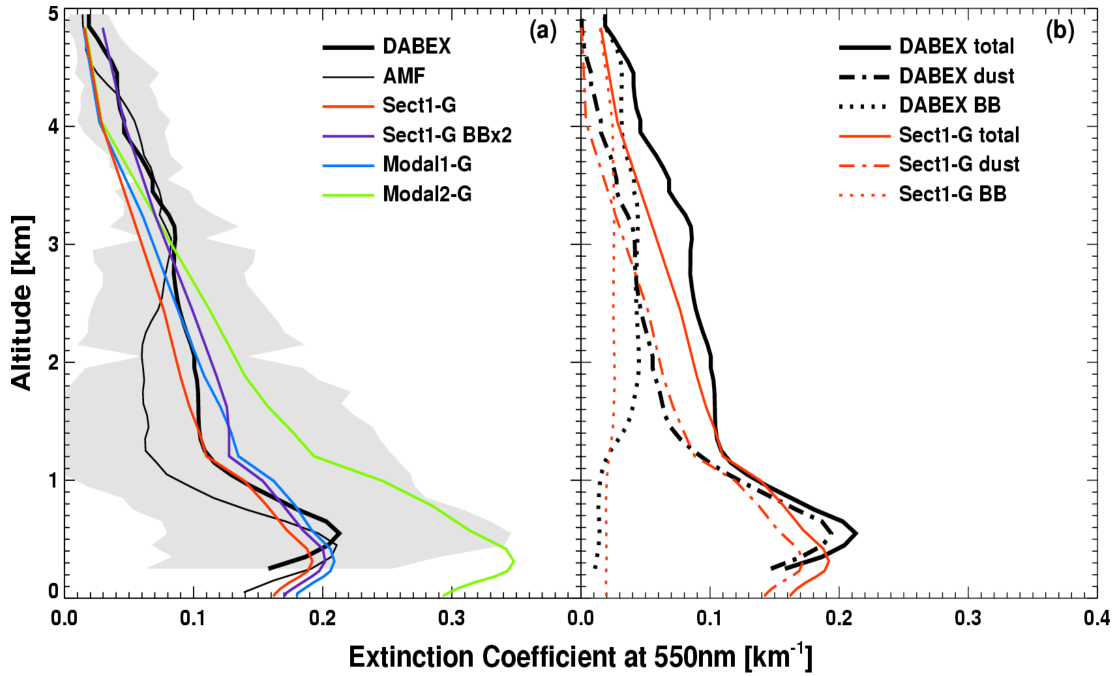
- WRF-Chem model
  - MADE/SORGAM aerosol scheme (Modal) and MOSAIC aerosol scheme (Sect) are used in this study. Both of them simulate the mass, number and size of aerosols.
  - Aerosol shortwave and longwave direct (RRTMG) and 1st and 2nd indirect effects (Lin microphysics) are included.
  - Dust emission scheme (GOCART) following Ginoux et al. [2001] is implemented into two aerosol schemes.
- Measurements
  - DABEX aircraft, AERONET, AMF, and satellite (MISR and MODIS) measurements during the AMMA 2006 campaign
  - GPCP and TRMM

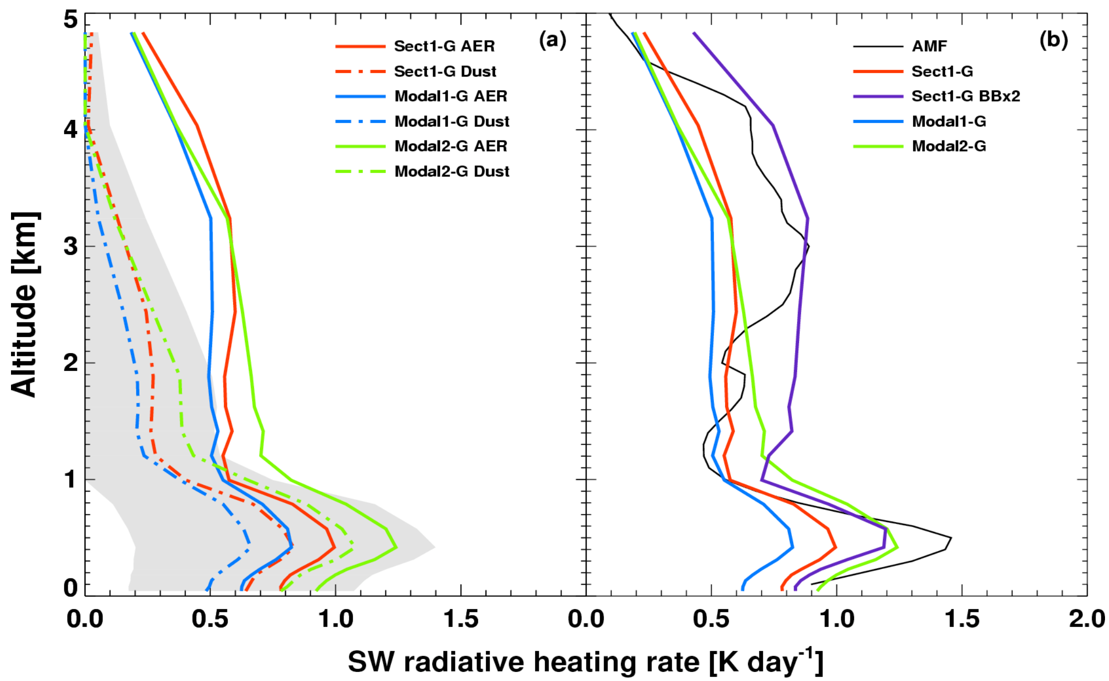


- Domain is set up with 200x150 grids of 36 km horizontal resolution centering at Niamey (Niger) and 35 vertical layers to 10 hPa.

- NCAR/NCEP Reanalysis data are used for meteorological boundary and initial conditions.

- Dust emission mainly in north and biomass burning emission in south

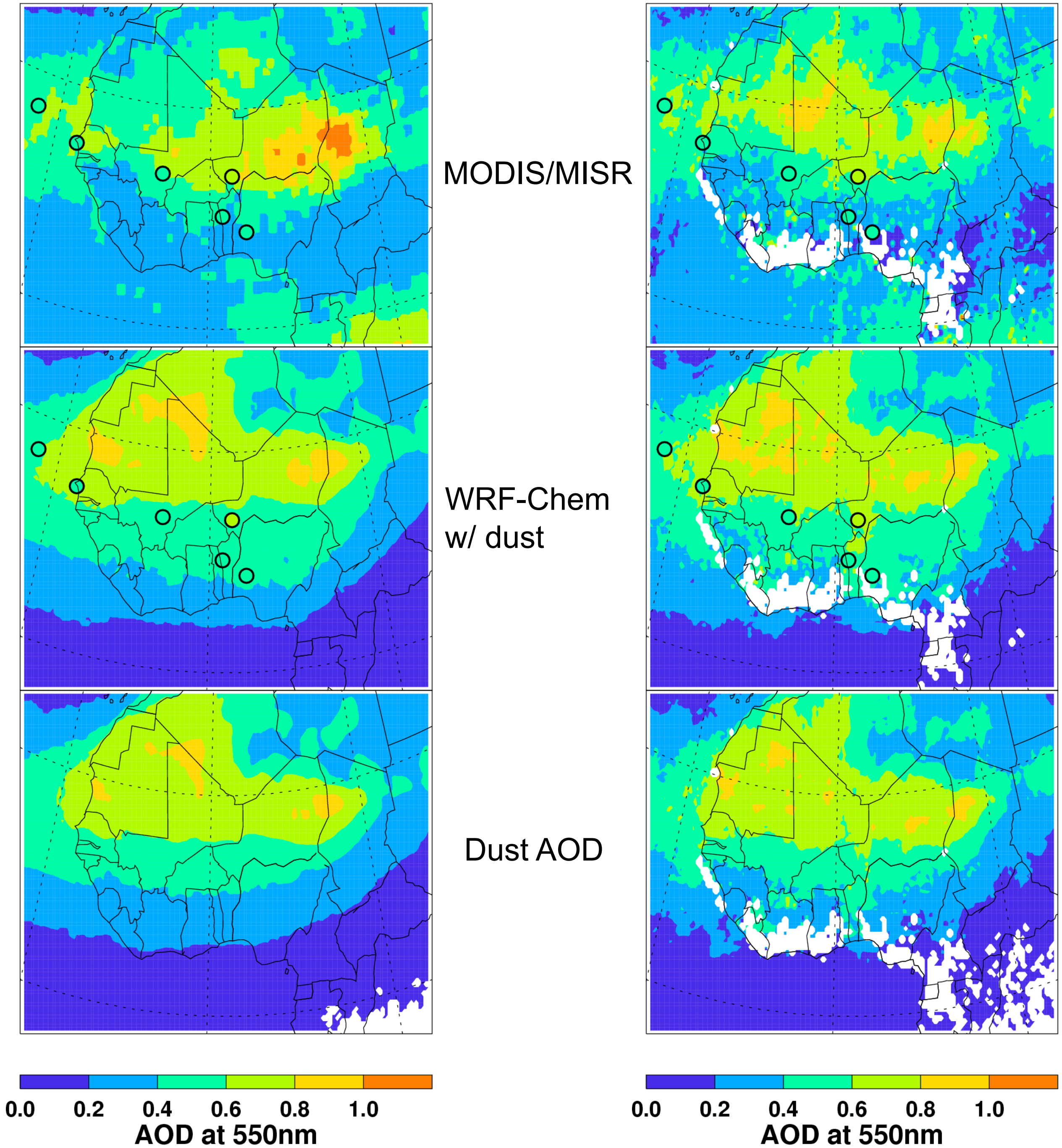




- WRF-Chem (Sect1-G) captures the measured aerosol extinction profile and its dust and BB aerosol components in the vicinity of Niamey

- WRF-Chem captures the measured aerosol SW heating profile with doubling biomass burning emissions; Dust results in SW heating with a rate of 0.8±0.5 K/day at 12UTC below 2 km in the vicinity of Niamey for January 2006.

- Initial dust size distribution and aerosol size treatments result in different dust extinction and SW heating profiles below 2 km.



Zhao et al. (ACPD., 10, 9753-9799, 2010)

- WRF-Chem can simulate spatial distribution of AOD reasonably well when compared with satellite measurements.
- WRF-Chem generally captures the AERONET measured AOD.
- Dust significantly contributes to the AOD near the dust source region

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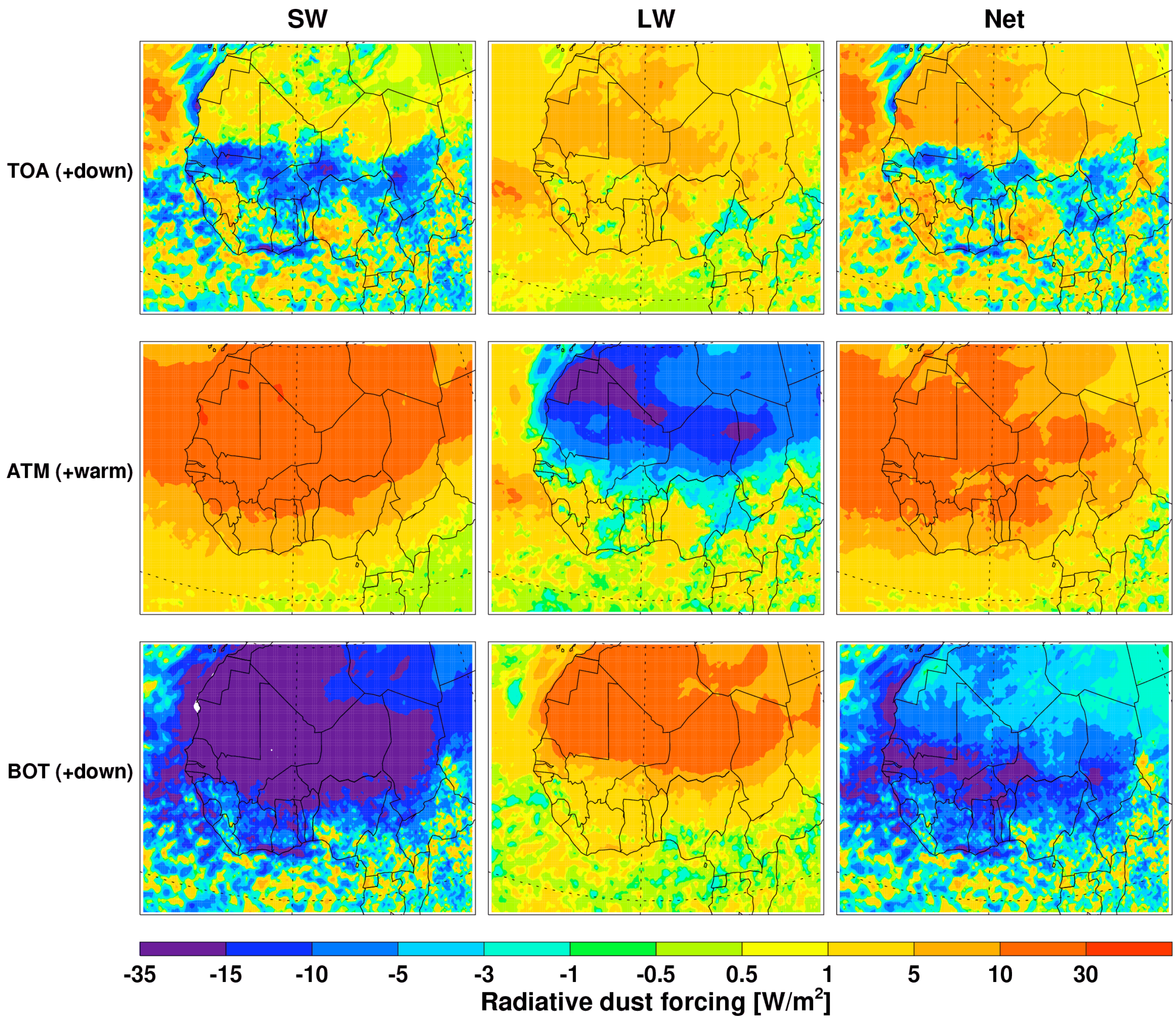

- Dust results in surface shortwave cooling and longwave warming.
- Dust results in atmosphere shortwave warming and longwave cooling.
- Dust reduces the net downward radiation (SW+LW) at the surface but warms the atmosphere.

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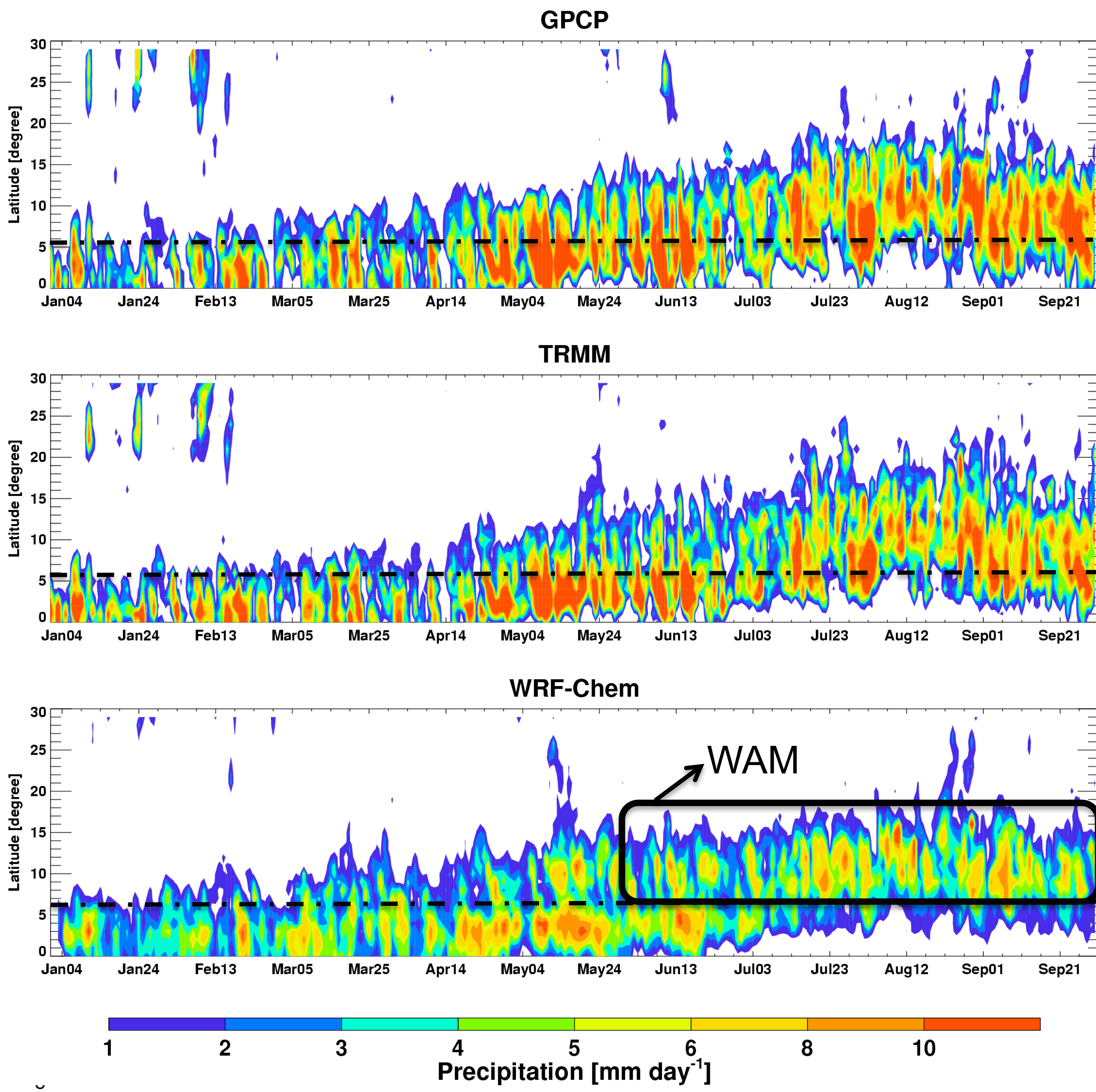

- Model generally well captures the migration of the monsoon system, and the seasonal change of the precipitation over the WAM region (15^{o}W-10^{o}E), but underestimates the heavy precipitation events during the monsoon season.

- In terms of daily precipitation, dust effect is negligible.

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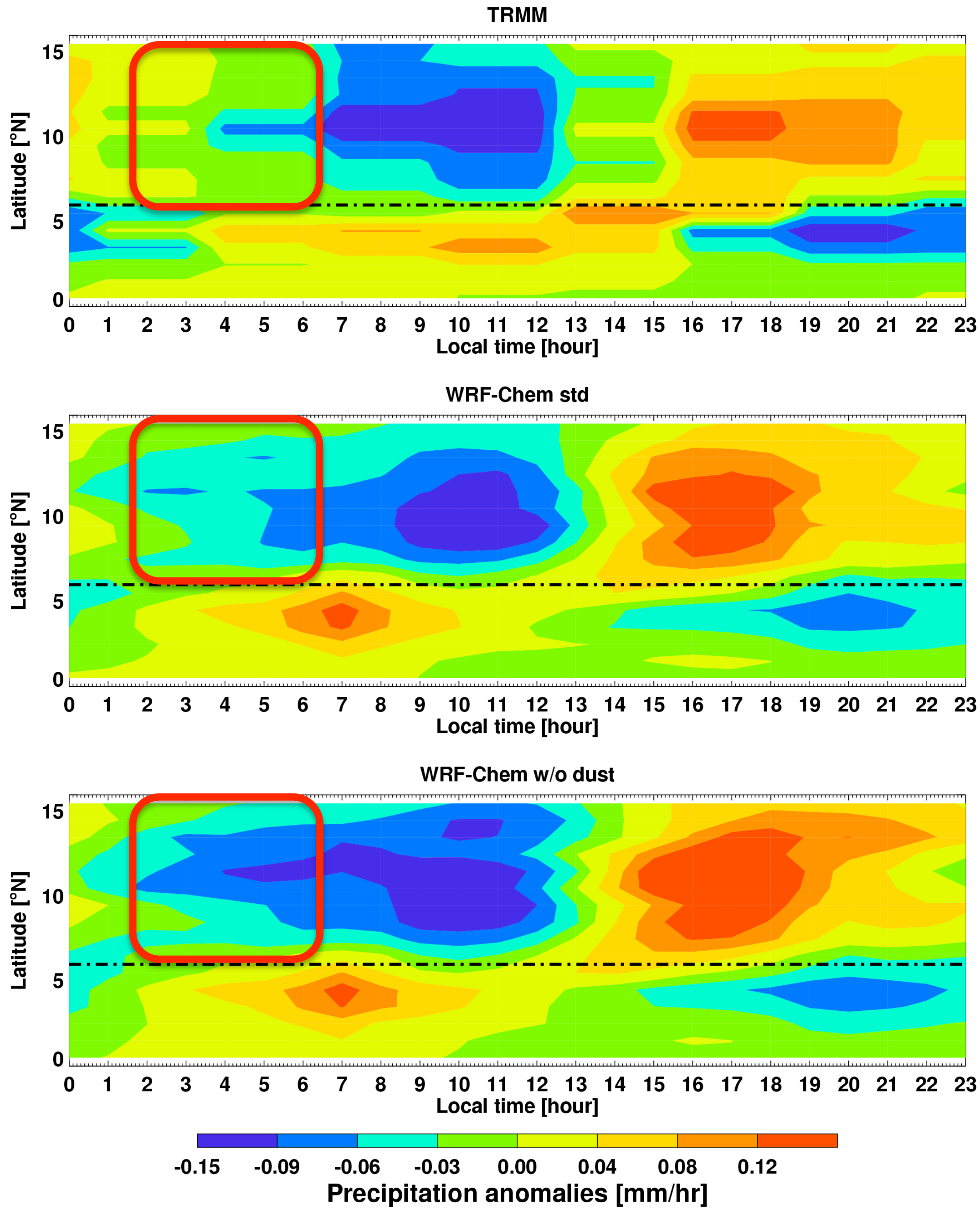
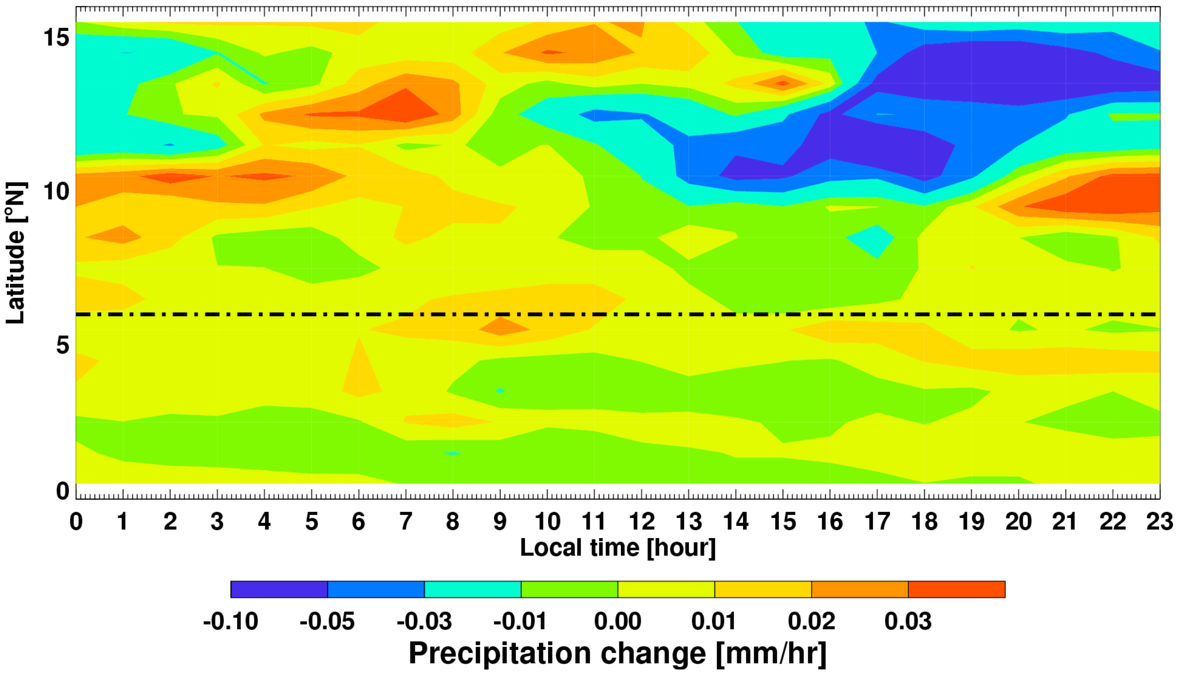
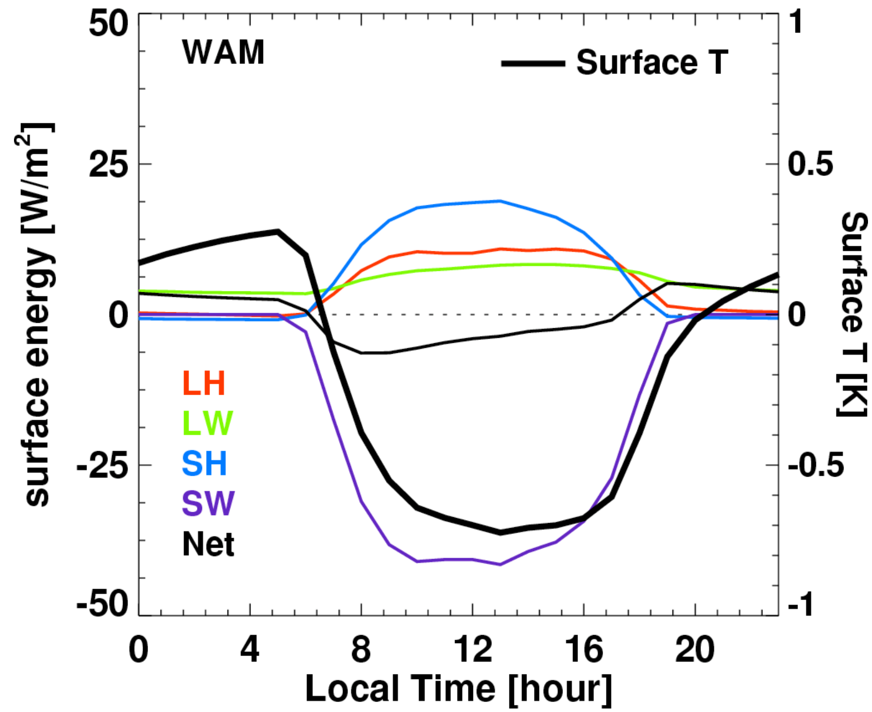


- Model generally well captures the diurnal cycle of the precipitation during monsoon season. Model simulates the "opposite" features of the diurnal cycle over the WAM region and the ocean.
- Over WAM, model simulation with dust improves the comparison.



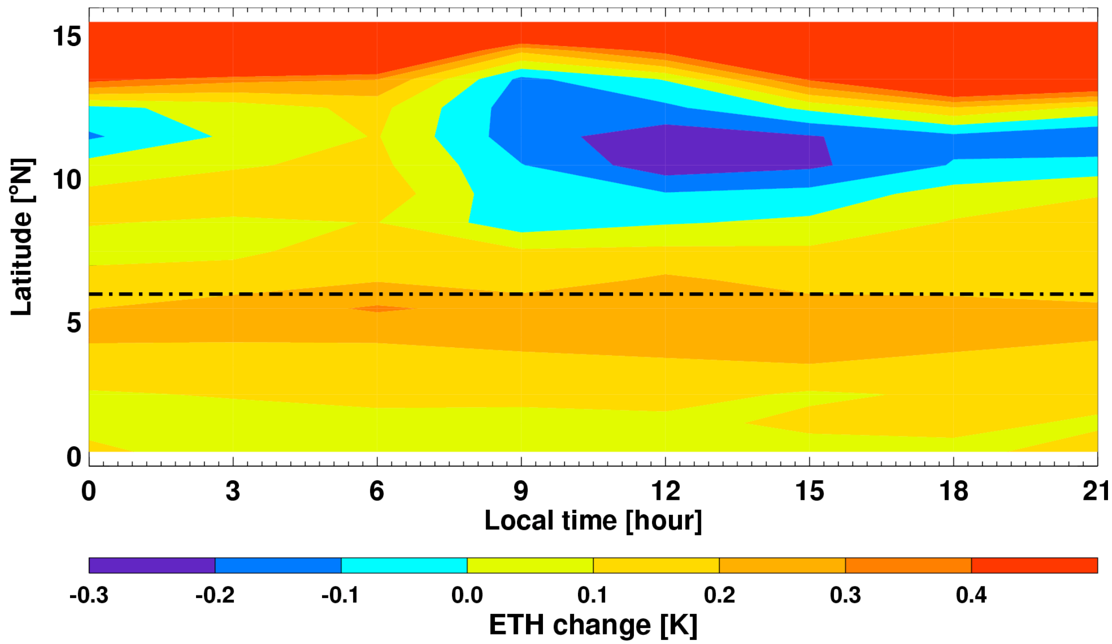
- Dust tends to increase the precipitation in the morning but reduce the precipitation in the afternoon and hence reduce the diurnal variation over WAM during the monsoon season.

- Dust modifies the surface energy budget, resulting in surface cooling effect in the afternoon but warming effect in the early morning over WAM, making atmosphere more stable in the afternoon but less stable in the early morning.



Summary

- WRF-Chem successfully captures the features of measured size and spatial distribution and radiative properties of mineral dust over West Africa, although the results are sensitive to the differences in size distributions of emitted dust and the underlying aerosol size treatments.
- Dust is a dominant contributor to AOD near the dust source regions, reduces the downward shortwave radiation but increases the downward longwave radiation at the surface, and results in the shortwave heating and longwave cooling in the atmosphere over WAM during the monsoon season.
- Dust modifies the energy budget at the surface through the interactions among the changes of radiation, LH, and SH fluxes, and results in large surface cooling effect in the afternoon but warming effect in the early morning over WAM during the monsoon season.
- The dust-driven change of the stability of atmosphere reduces the diurnal variation over WAM during the monsoon season.



- Dust reduces surface equivalent potential temperature (ETH) in the afternoon but increases it in the early morning over WAM.

- Dust modifies the vertical profiles of the ETH, and hence the stability of the atmosphere, making air more stable in the afternoon and less stable in the early morning.