Sensitivity Study of Cross-Atlantic Dust Transport to Dust Emissions, Chemical Aging and Removal Processes

Comparison with Ground and Satellite Data

A3.2

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Acknowledgment

Ph.D. Thesis, M. Abdelkader

MODELING OF THE DUST CYCLE AND AGING IN AN EARTH SYSTEM MODEL

Dust–air pollution dynamics over the eastern Mediterranean

M. Abdelkader, S. Metzger, R. E. Mamouri, M. Astitha, L. Barrie, Z. Levin, and J. Lelieveld, Atmos. Chem. Phys., 15, 9173–9189, doi:10.5194/acp-15-9173-2015, 2015.

Dust chemical aging during transatlantic dust transport

M. Abdelkader, S. Metzger, B. Steil, K. Klingmüller, H. Tost, A. Pozzer, G. Stenchikov, L. Barrie, and J. Lelieveld; ready for submission to ACPD.

Modeling Framework

EMAC (ECHAM5/MESSy 2.5.0) climate model

T106L31 ($\approx$ 110km globally), nudged meteorology (ECWMF), state-of-the-art emissions, anthropogenic & online calculation of sea salt and dust in feedback with meteo (soil moisture).

Chemical speciation of natural aerosol emission fluxes

e.g., calcium ($\mathbf{Ca^{2+}}$) as a proxy for the chemical reactivity of mineral dust, potassium ($\mathbf{K^{+}}$) as a proxy for the chemical reactivity of biomass burning aerosols (resolved sea salt composition).

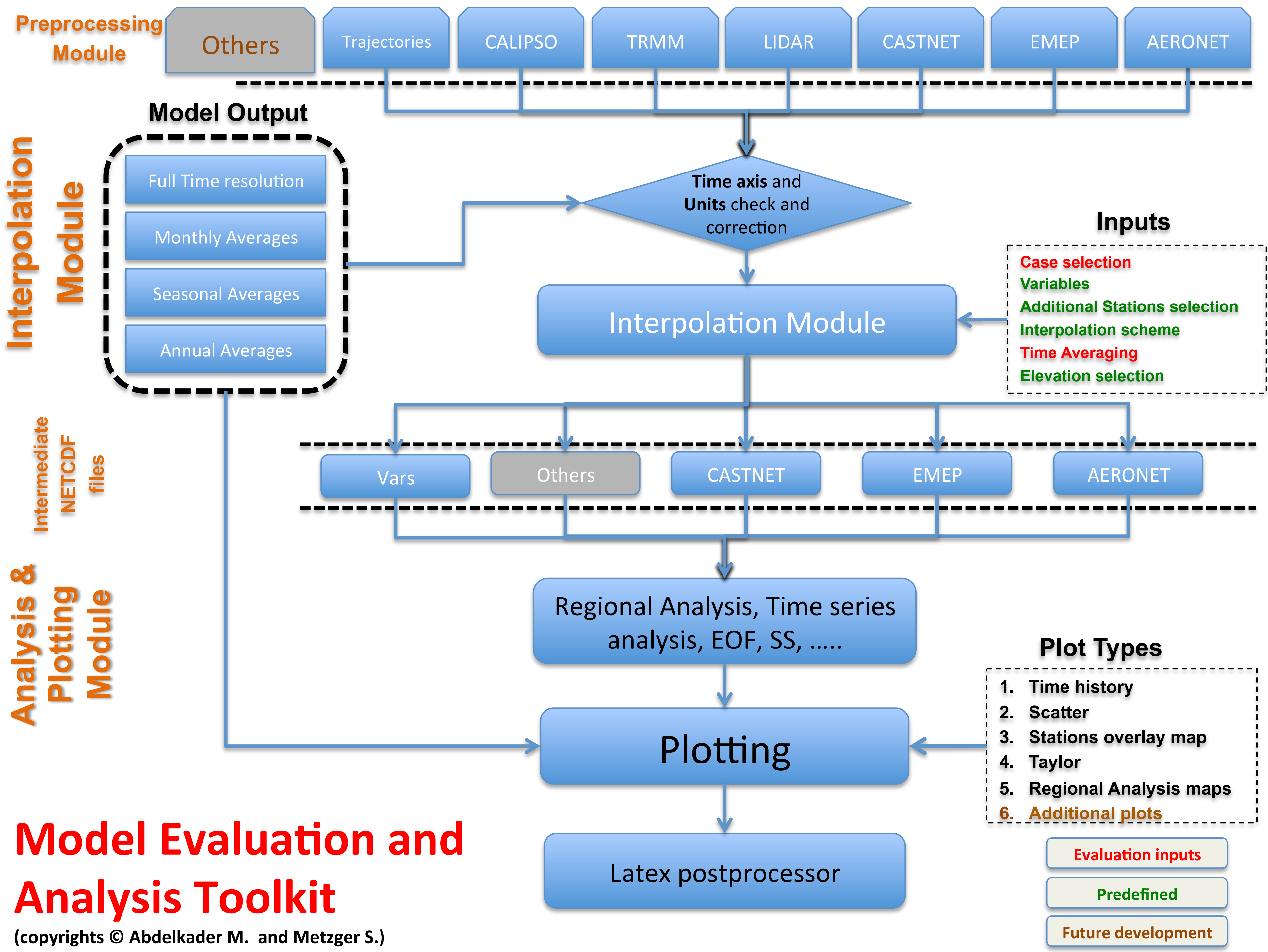
Gas-liquid-solid aerosol partitioning and radiation coupling

MECCA gas phase chemistry, aerosol thermodynamics (ISORROPIA II) considering major inorganic cations ($\mathbf{Na^{+}, Ca^{2+}, K^{+}, Mg^{2+}}$), anions ($\mathbf{SO_4^{2-}, HSO_4^{-}, NO_3^{-}, Cl^{-}}$), and acids ($\mathbf{H_2SO_4, HNO_3, HCl}$), including the associated uptake of water vapor ($\mathbf{H_2O}$).

Dust chemical aging – interaction with air pollution

Air-pollution loadings determine dust hygroscopicity and water uptake of calcium salts:
– water uptake is **low** in case of sulfate salts ($\mathbf{CaSO_4}$), – **high** in case of nitrates ($\mathbf{Ca(NO_3)_2}$),
– but **highest** in case of calcium chloride salts ($\mathbf{Ca(Cl)_2}$).

Evaluation Toolkit



Temporal and spatial collocation of model and observational data

Long-term Evaluation

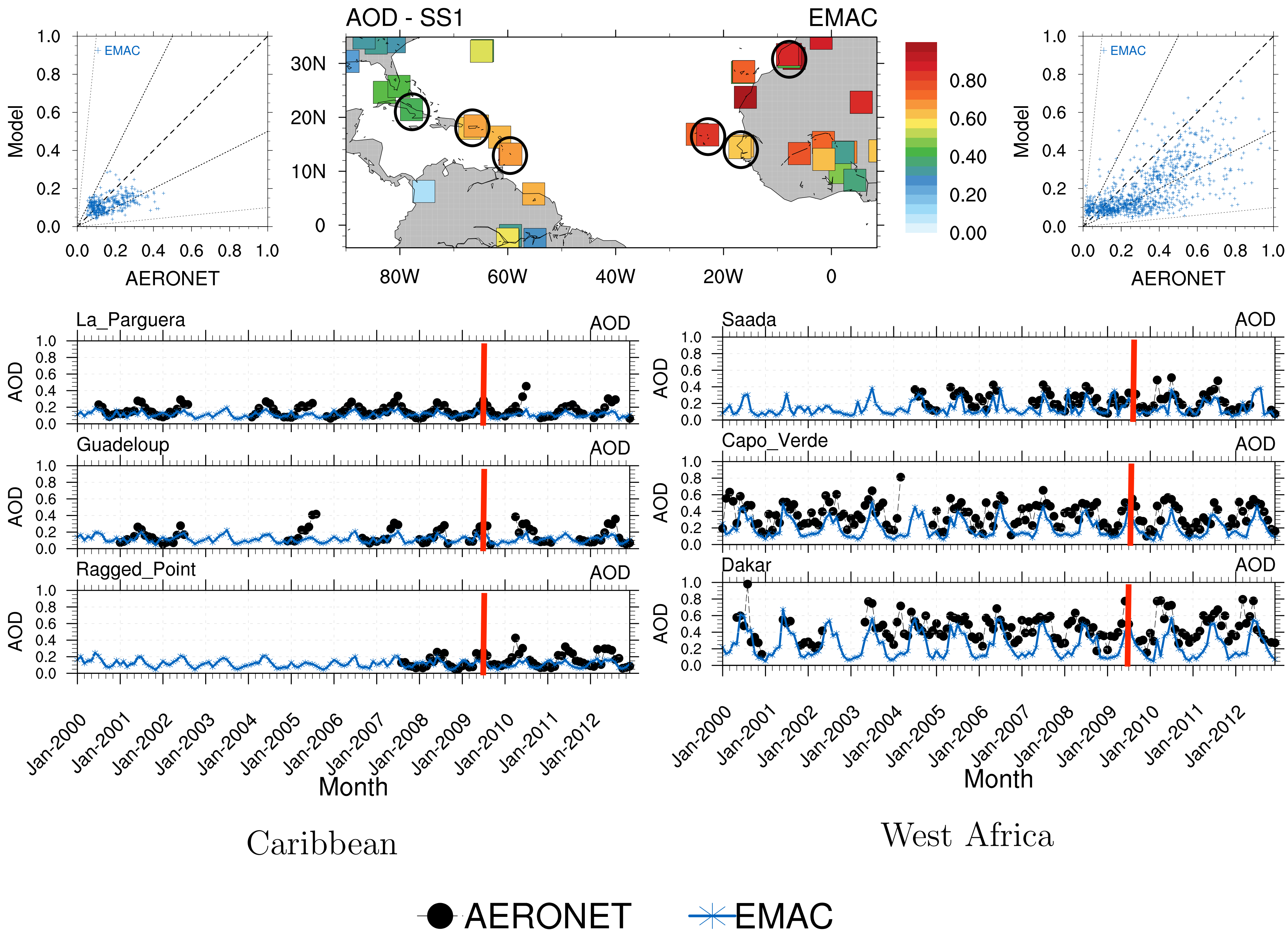


Figure: *Long-term evaluation of the AOD (2000-2012) for the Caribbean and West Africa: (Top panel) scatter plot (left, Caribbean; right, West Africa) and (middle) skill score (SS1); (Lower panels) time series for the key AERONET stations in both regions (monthly means).*

Climatology of dust burden and precipitation

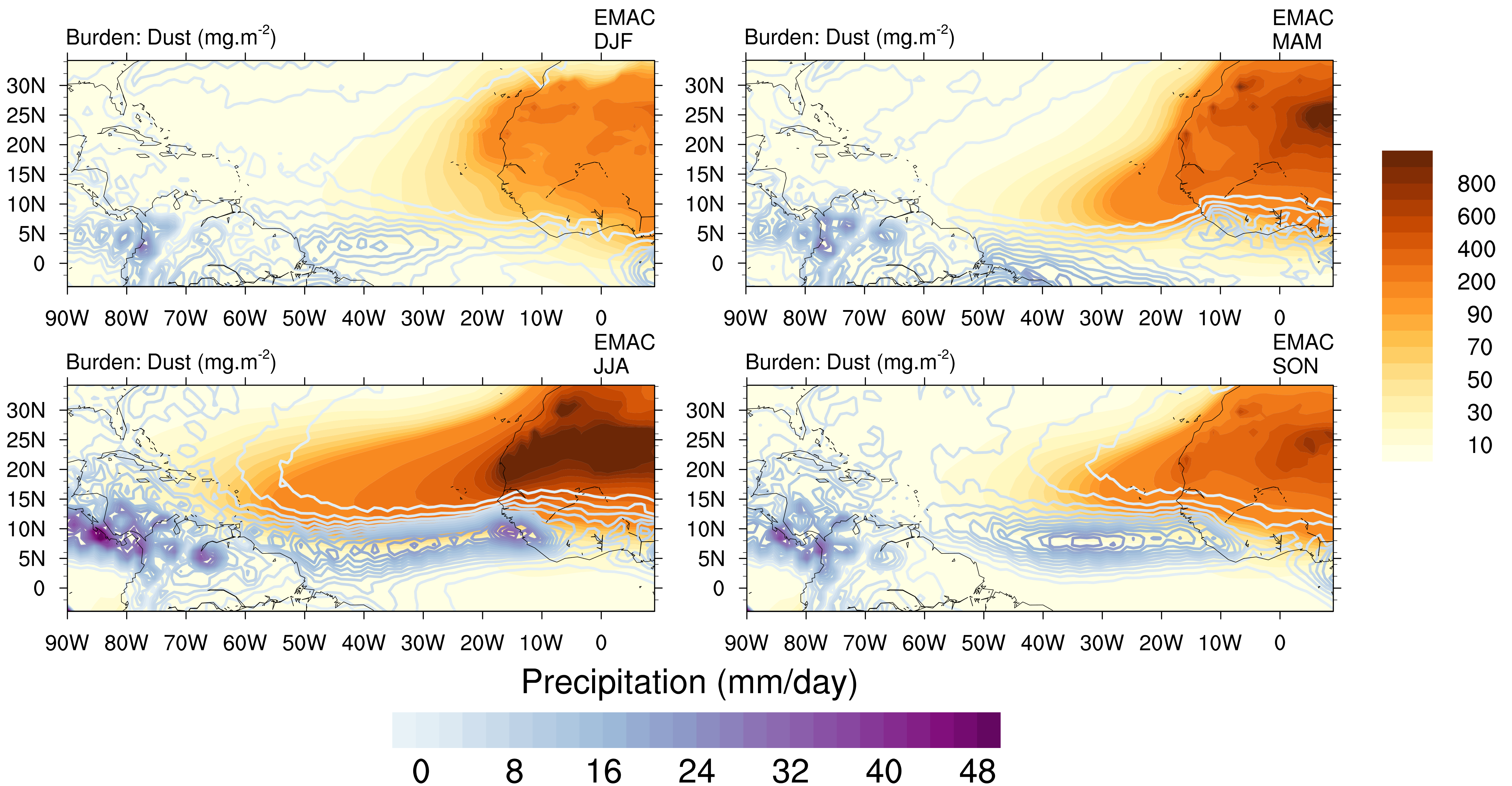


Figure: *Seasonal averages for the dust burden and precipitation representing the transatlantic dust outflow for the entire model evaluation period (2000-2012). Dust burden and precipitation depict a maximum during boreal summer and a minimum during the respective winter.*

Modeling the transatlantic dust transport

- The area within the yellow lines show the **DOAO** zone: Dust Outflow over the Atlantic Ocean – deposition dominated by dry removal processes.
- The area within the blue line represents the Dust-ITCZ relaxation zone **DIRZ** – deposition dominated by scavenging processes.
- The regions are defined according to the predominant dust removal mechanism.

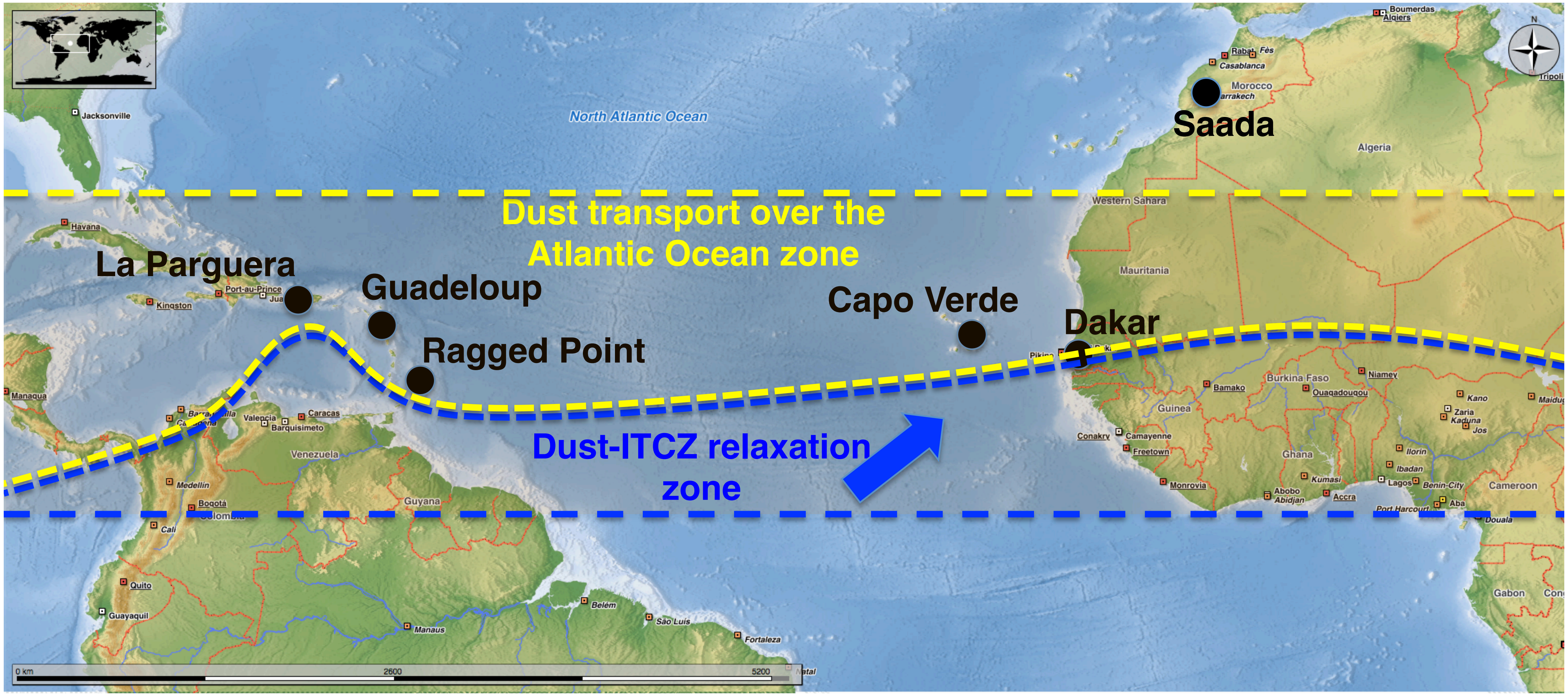


Figure: *Location of selected AERONET stations used in the TADT study.*

Dust removal during long-range transport

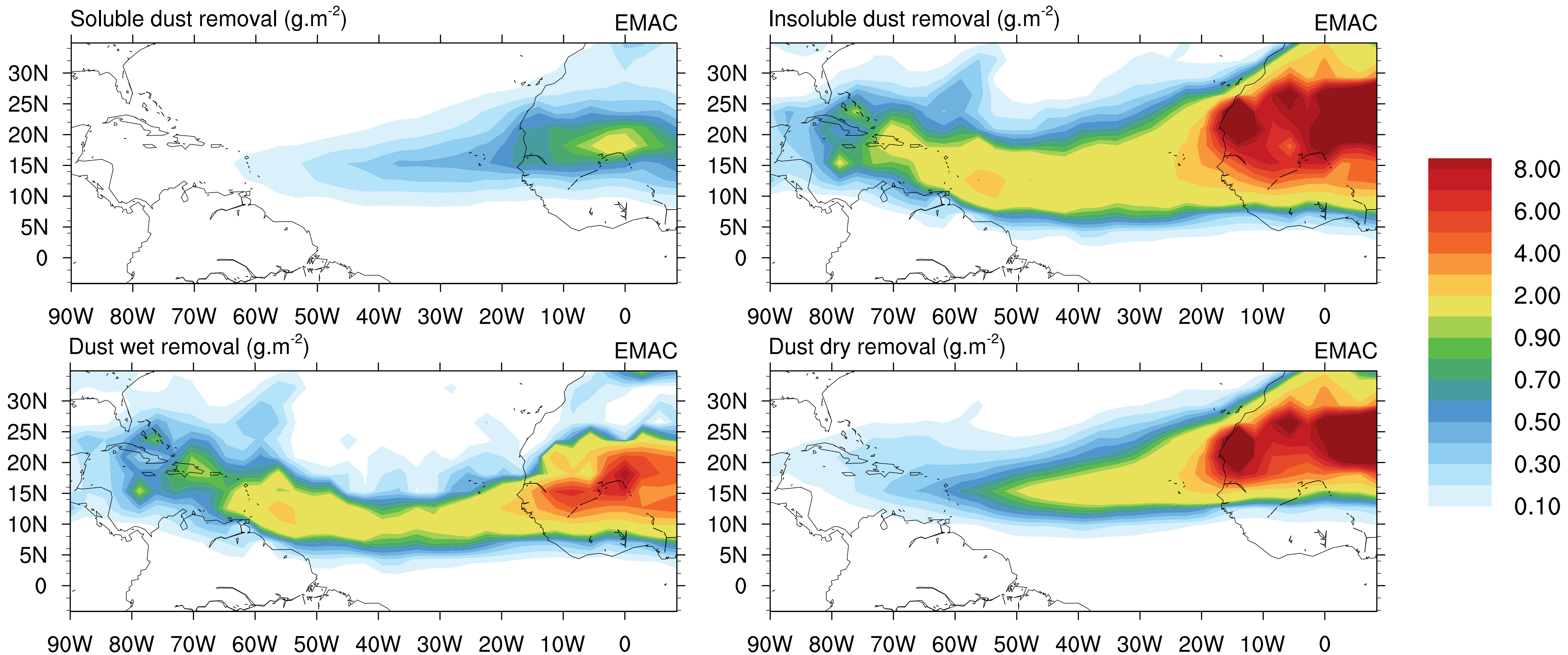


Figure: *Monthly averages (July 2009). Dust removal during TADT: (top) total removal for soluble and insoluble modes; (bottom) wet removal (left) and dry removal (right).*

- Majority of insoluble dust is removed over the Sahara.
- Dry removal dominates the northern part of the dust outflow domain.
- Wet removal is most significant in the Dust–ITCZ interaction zone.

Comparison with CALIPSO observations

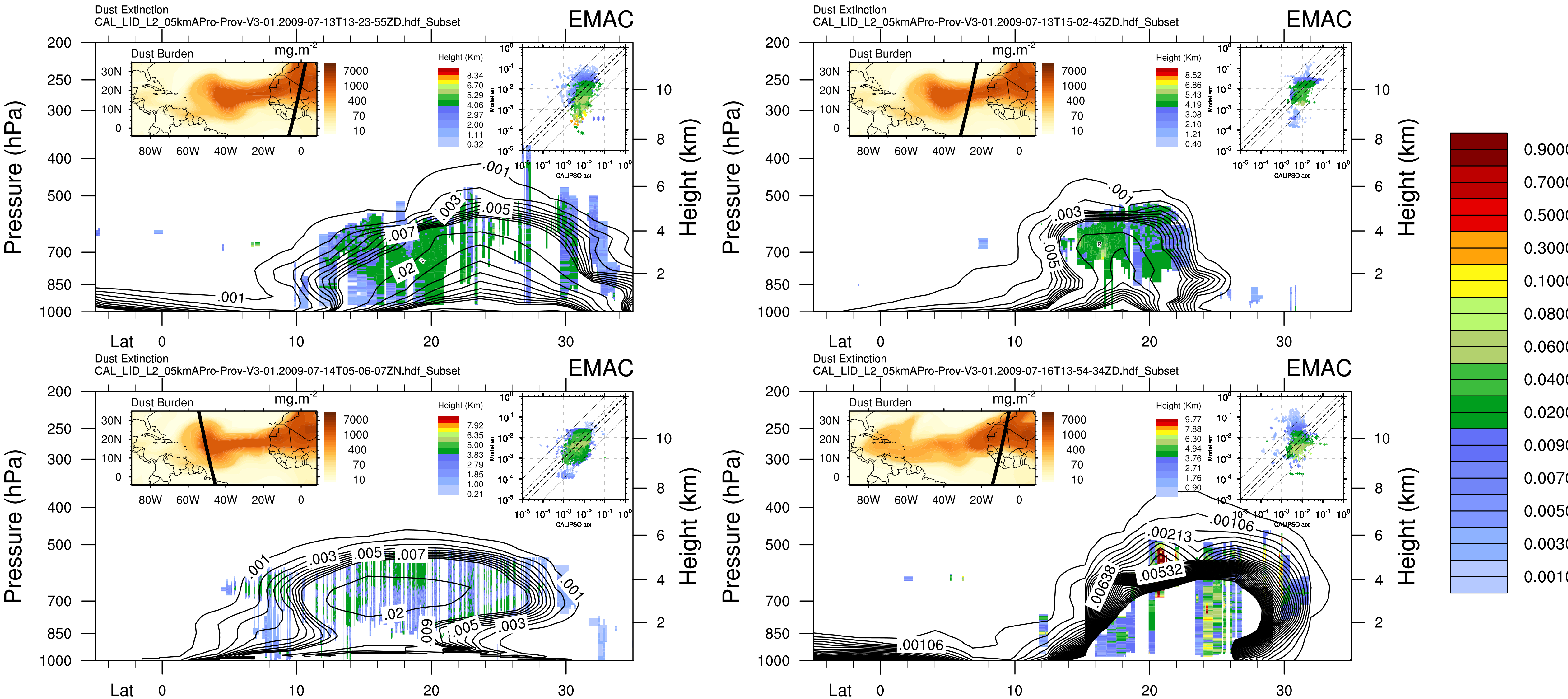


Figure: *Collocated EMAC and CALIPSO observations of dust extinction and burden.*

EMAC simulations

	Case	Description
Emission	EMAC	Reference simulation
	B1E1	Redistribution of dust between accumulation and coarse modes
	B1E2	As EMAC, accumulation fraction incased by a factor of 2.61
	B1E3	As EMAC, the coarse mode increased by a factor of 5.3
	B1E4	As EMAC, the accumulation mode increased by a factor of 5.3
	B1E5	As EMAC, the accumulation mode increased by a factor of 10.6
	B1E6	As EMAC, the accumulation and coarse modes increased by a factor of 10.6 and 2.61 respectively
	B1E7	As EMAC, the accumulation and the coarse modes increased by a factor of 2.61
	B1E8	As EMAC, factor=2.61 in the horizontal flux
Convection	EMAC	Reference simulation; TIEDTKE convection with NORDENG closure
	B1T2	TIEDTKE convection with TIEDTKE closure (Tiedtke, 1989)
	B1T3	TIEDTKE convection with HYBRID closure (Tiedtke, 1989)
	B1T4	ECMWF operational convection scheme (Bechtold et al., 2004) with the shallow convection closure of Grant and Brown (1999)
	B1T5	ECMWF operational convection scheme (Bechtold et al., 2004)
	B1T6	Zhang-Hack-McFarlane convection scheme (Zhang and McFarlane, 1995; Hack, 1994)

Different dust emissions

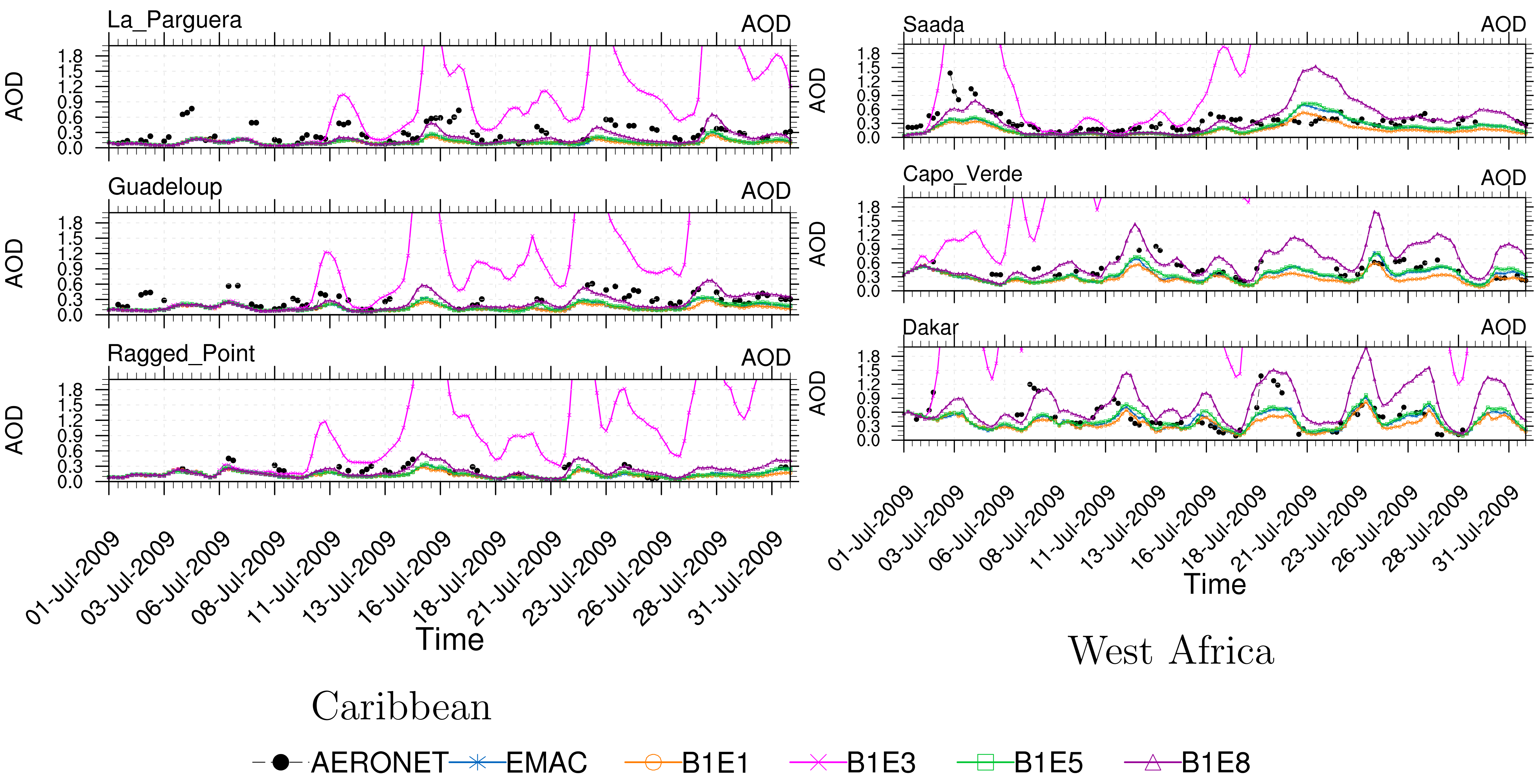


Figure: *EMAC and AERONET AOD for the Caribbean sites (left) and western Africa (right).*

Different convection scheme

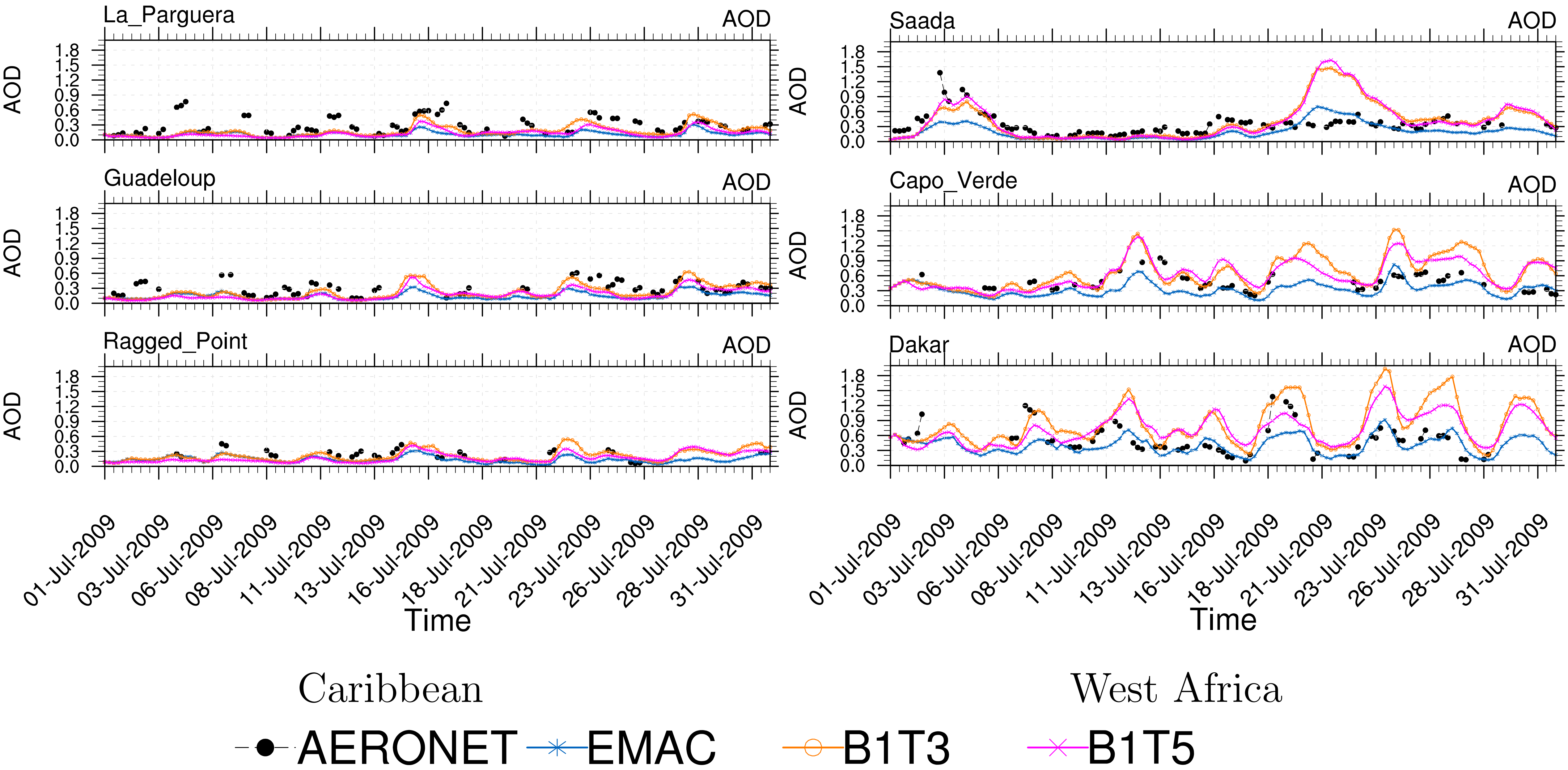


Figure: *EMAC and AERONET AOD for the Caribbean sites (left) and western Africa (right).*

Sensitivity to the convection schemes

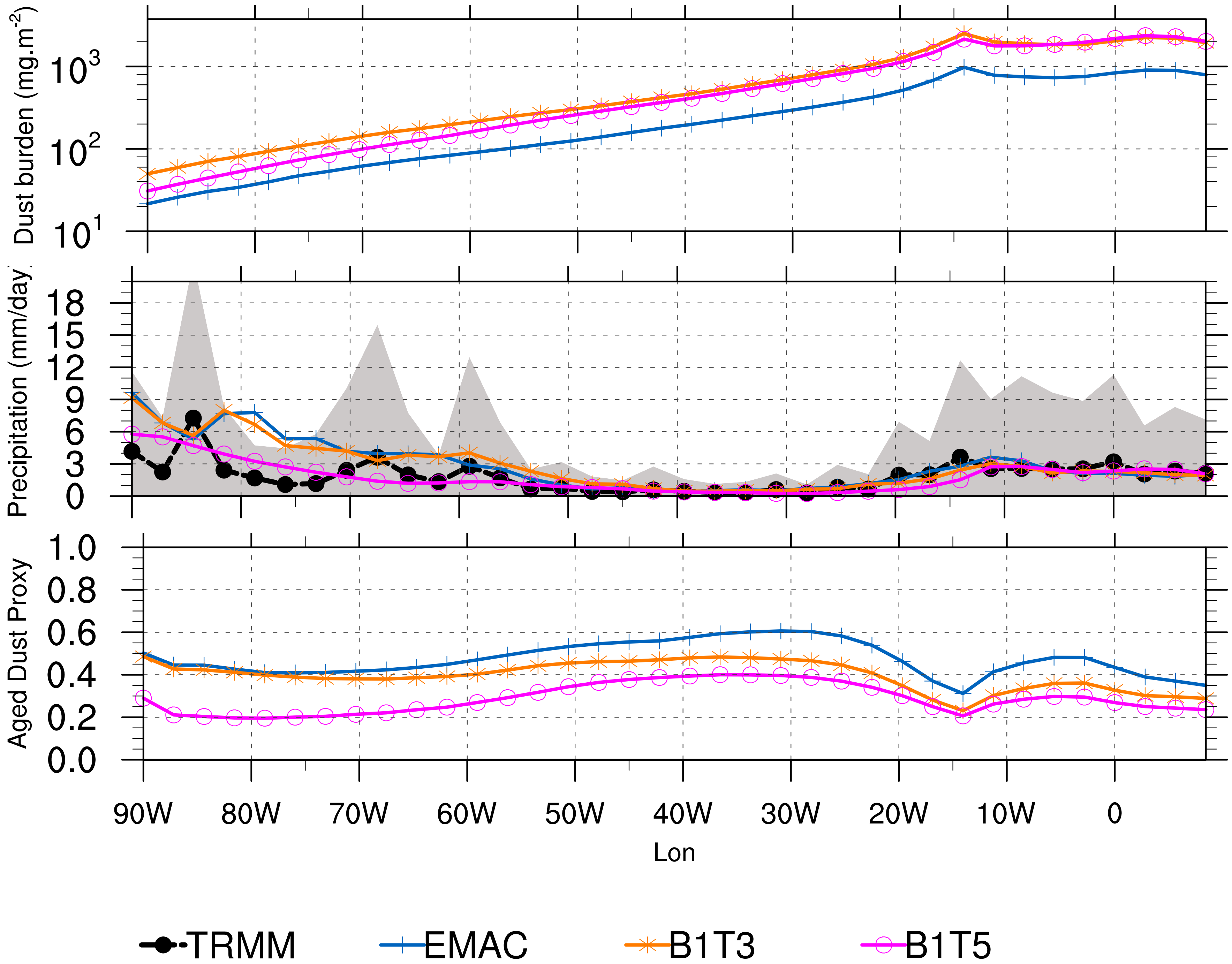


Figure: *Comparison of meridional means for the dust outflow for July 2009 (monthly mean): (Top) dust burden, (middle) precipitation, (bottom) aged dust proxy (tracer ratio DU_{cs}/DU_{ci}).*

Dust aging effects

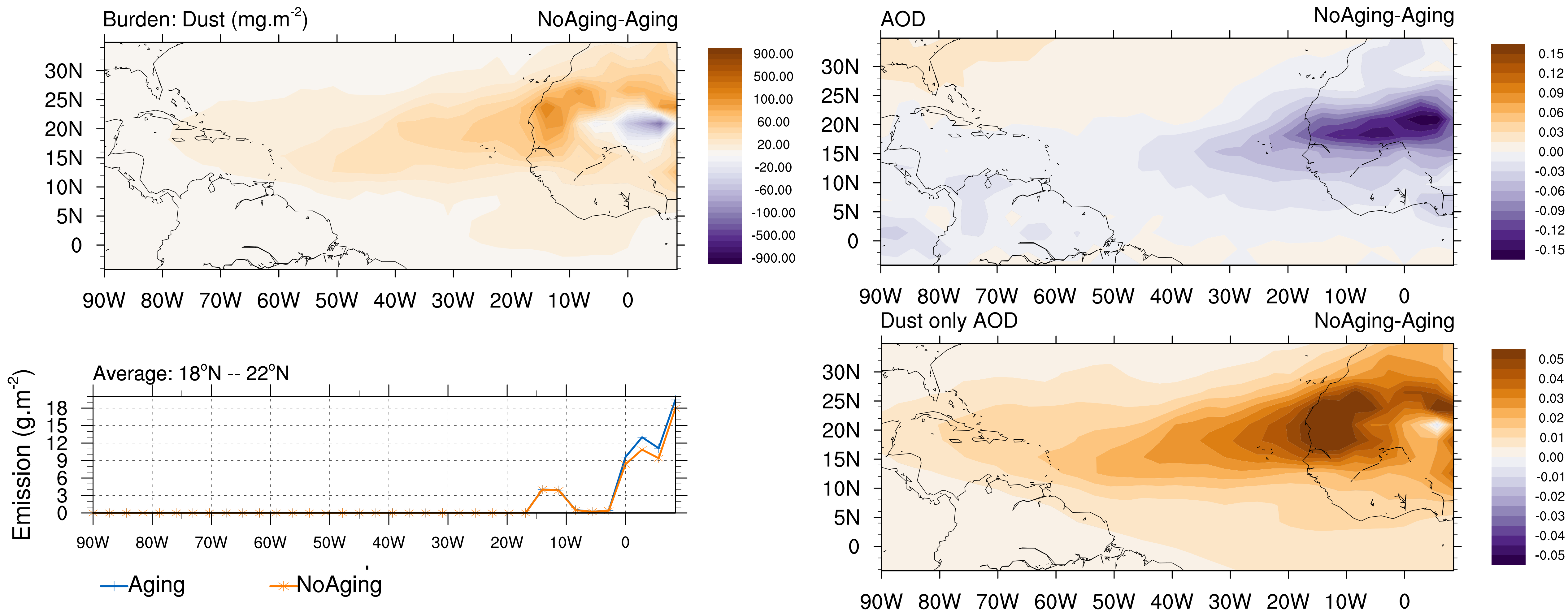


Figure: *EMAC results (monthly mean) for two simulations: "Aging" and "No aging". (UL) difference in dust burden, (UR) difference in AOD, (LL) dust emission averaged over the region from 18-22 N, (LR) difference in "dust only AOD".*

Dust aging effects

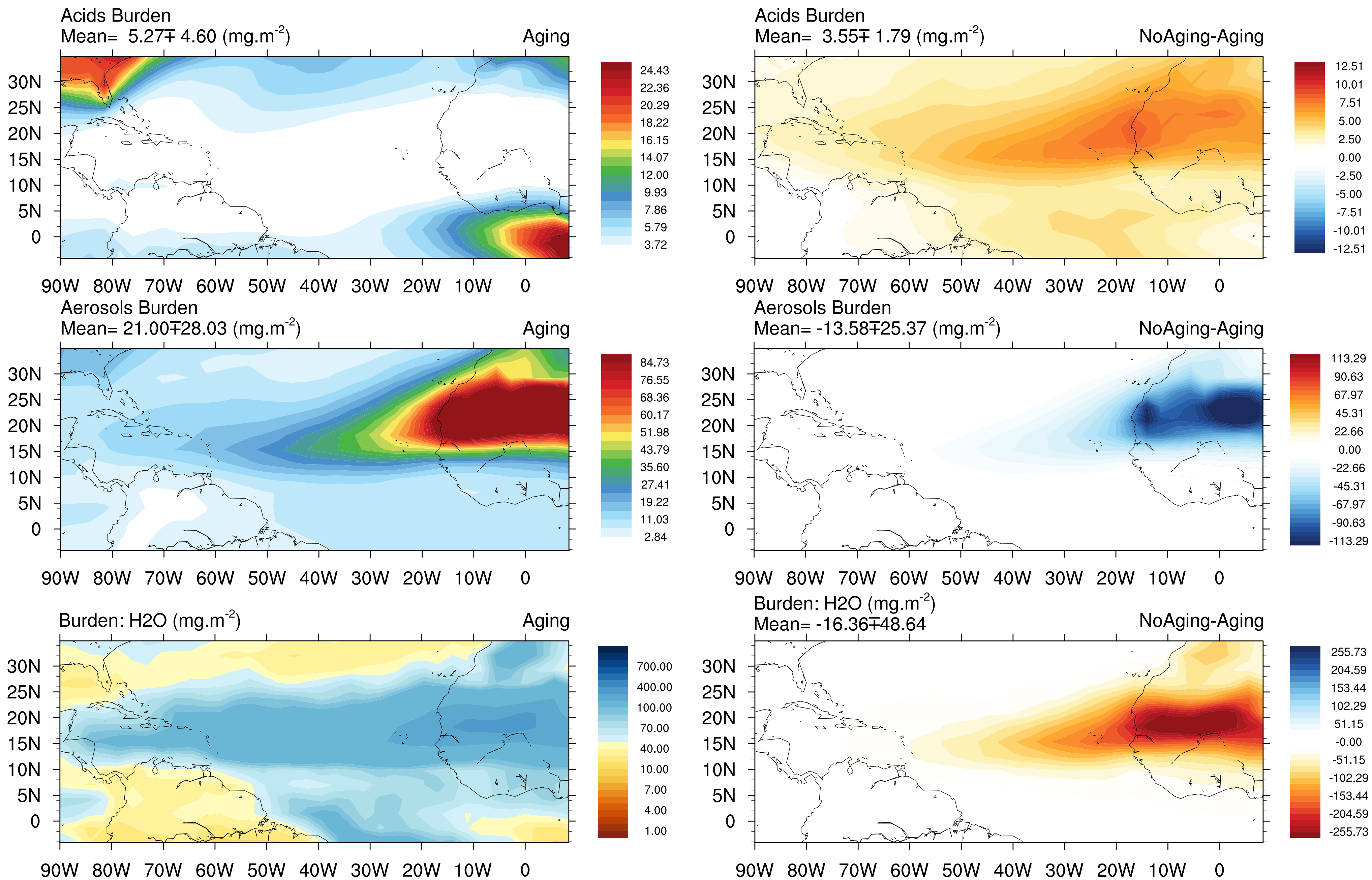


Figure: *(Top) burden of lumped inorganic acids (gas-phase), (middle) burden of lumped aerosols, (bottom) burden of aerosol associated water mass (monthly mean). (Left column) reference simulation (aging case), (right) difference between reference and "No Aging" case.*

Dust aging effects (long-term average)

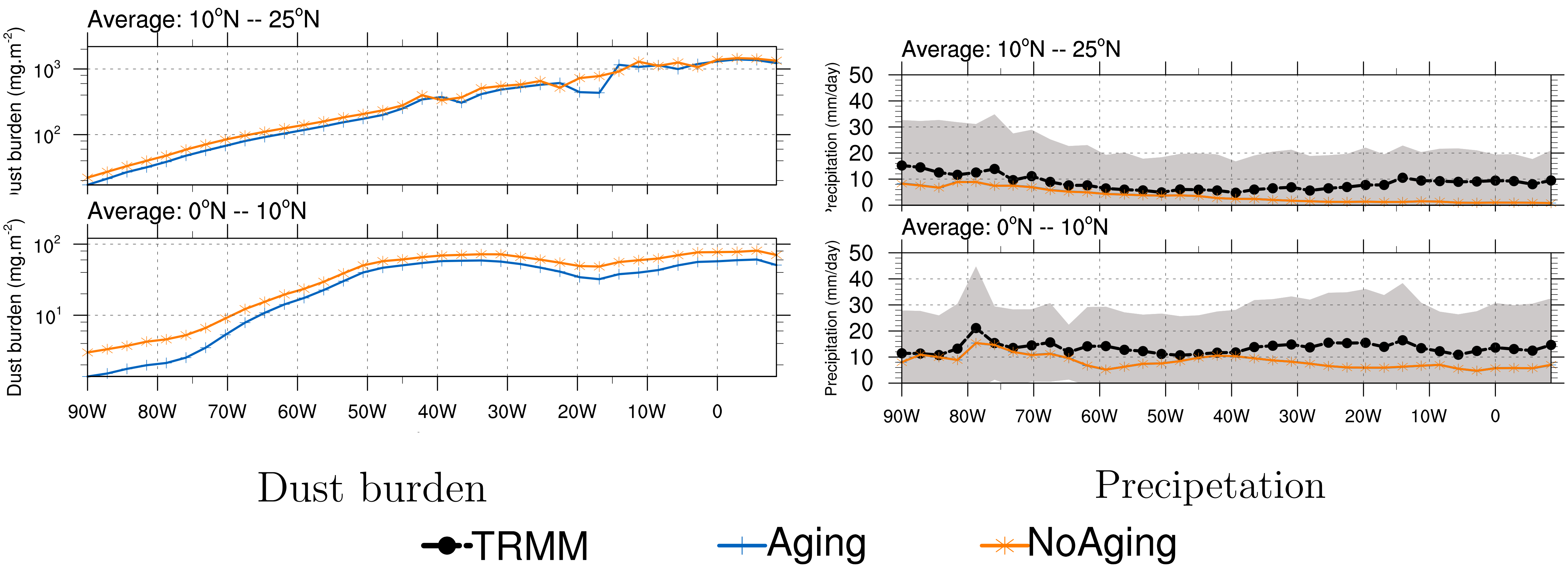
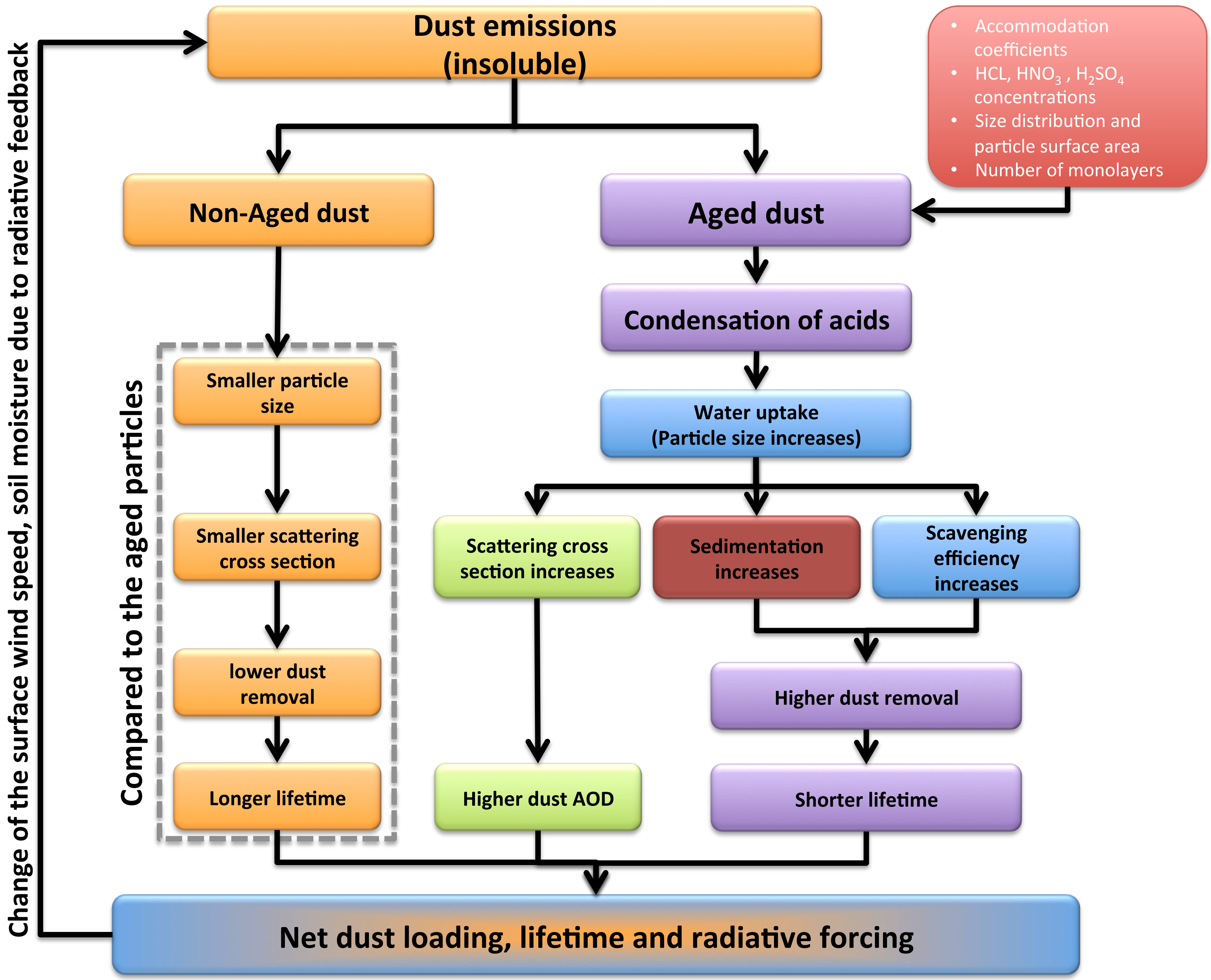


Figure: *(Left) Dust burden, (right) precipitation for the two different dust outflow regions: (Top) Dust transport over the northern Atlantic Ocean; (bottom) Dust-ITCZ relaxation zone. The shaded area represents one standard deviation of TRMM precipitation. The results show the impact of dust aging for the long-term average of the entire evaluation period 2000-2012.*

Dust Cycle & EMAC Model Feedbacks



Conclusions

Long-term evaluation

Transatlantic dust transport can be divided into two sub-regions: (1) The Dust-ITCZ relaxation zone and (2) the adjacent northern zone of the Dust Outflow over the Atlantic Ocean.

Sensitivity study

AOD is sensitive to the emission flux parameters but even more to choice of convection scheme.

Dust aging

Aged dust particles have a larger particle size and scatter therefore more light, while they are also more efficiently removed by dry and wet removal. Thus, we find two dust aging effects.

Direct effect of dust aging (on AOD)

Increase of AOD, mainly due to enhanced water uptake by calcium salts ($\mathbf{Ca(NO_3)_2}, \mathbf{Ca(Cl)_2}$).

Indirect effect of dust aging (on AOD)

Decrease of AOD due to higher removal of aged dust particles (larger particle size).


Thank you very much
for your attention