Influence of Land Surface Parameterization on Desert Dust Aerosols Emission within regional climate model

A.S. Zakey[1,*], A. ElAwady[1], M. Wahab[2]

(1) The Egyptian Meteorological Authority (ashzakey@gmail.com)
(2) Cairo University, faculty of science, meteorological department

Introduction

- Sever Dust Storms (SDS) have a major impact on the air quality and climate of North Africa (NA) and Western Asia (WA). *We must find a solution to reduce the impacts of dust storm on the society and environment*. May be the land use change is the best solution for dust mitigation ???
- In general, the arid and semi-arid area of NA and WA the SDS are occurs frequently. In this study we address the following scientific question: *What is the impacts of land-use change on SDS frequencies and intensities?*
- As well, the detection of the dust source region and monitoring of the dust plume from its primary outflow to final deposition will be taken into accounts.
- The main idea of integrated dust storm monitoring and modeling system should be described as a key research areas, including new dust modules (*More understandable Processes*) and techniques in satellite remote sensing and system integration.

What Controls Dust Emissions

MODELED NATURAL EMISSIONS:

- Preferential sources
- Vegetation cover / type
- Surface wind speed
- Soil particle size
- Soil moisture

HUMAN IMPACTS:

- Soil surfaces
  - Cultivation
  - Overgrazing
  - Deforestation
  - Roads, construction, military activity
- Climate
  - Meteorology (winds, precip)
  - Natural vegetation

Dust Emission Concepts

- dust emission is an indirect process: most particulates are emitted by a sand blasting process due to saltation (Gillette and Passi 1988; Shao et al. 1993)

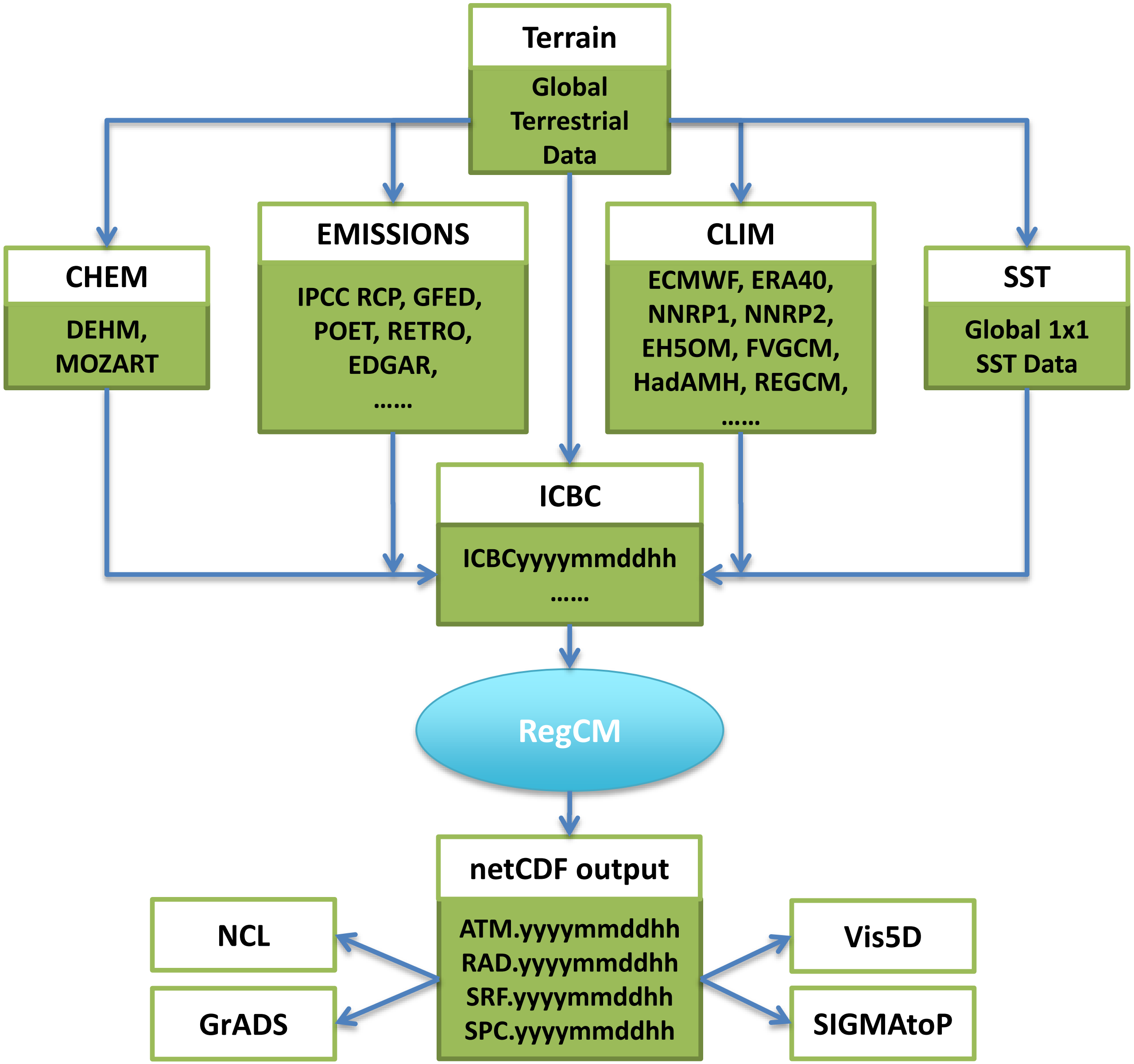
- Saltating particles must overcome binding energy between surface grains (Shao et al. 1993; Alfaro et al. 1997)

- The vertical dust flux (F) is proportional to the horizontal sand flux (q) for a given site (Gillette and Passi 1988 ; Alfaro et al. 2000)

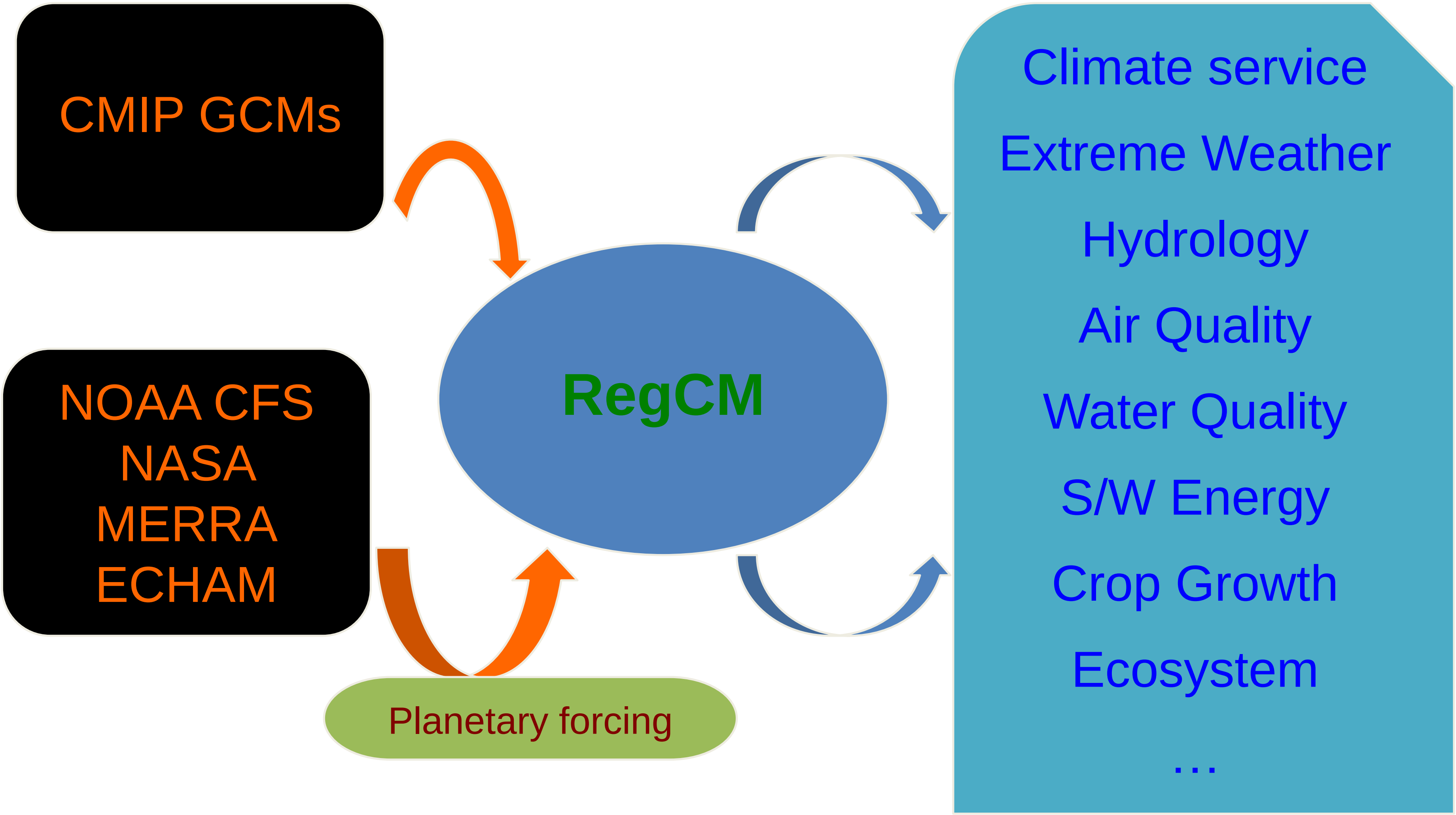
ENVIRONMENTAL CLIMATE MODEL

RegCM

RegCM: Modeling System Flow Chart



RegCM on regional-local predications



Dust Scheme in RegCM

Key question :

- Dust climatic forcing and impacts are still uncertain (IPCC).
- Environmental impacts of dust on society still open question
- Potential importance of dust for weather forecast
- Global climatic impact of dust on SST variability, Paleoclimate
- Dust aerosol and regional climatic response are still difficult to represent in GCM and RCM.

Aerosols in RegCM

- **General approach** ⟺ Tracer model / RegCM

$$\frac{\partial\chi}{\partial t} = -\overline{V}\cdot\nabla\chi + F_H + F_V + T_{CUM} + S_\chi - R_{w,ls} - R_{w,cum} - D_{dep} + \sum Q_p - Q_l$$

Transport ($-\overline{V}\cdot\nabla\chi + F_H + F_V + T_{CUM}$)

Primary Emissions (S_χ)

Removal terms ($R_{w,ls}$, $R_{w,cum}$, D_{dep})

Physico – chemical transformations ($\sum Q_p - Q_l$)

Strongly dependent on the nature of the tracer (Primary Emissions, Removal terms, Physico – chemical transformations)

- **Particles and chemical species considered.**

SO_2 ⟺ SO_4^{--}	**BC** (soot)		**OC** (total organic carbon)		**DUST** (4 bins)			
Aqueous and gazeous conversion (Qian et al., 2001)	*Hydrophilic (20% at emission)*	*Hydrophobic* (80%at emission)	*Hydrophilic (50%at emission)*	*Hydrophobic(50%at emission)*	0.01-1 µm	1-2.5 µm	2.5-5 µm	5-20 µm

Aerosol dust source and deposition parameterization in RegCM

Input parameters

Soil texture (12 types, USDA)

Soil erodible dry agregates distribution

Land surface properties (BATS)

(roughness, soil humidity, cover fractions)

Regcm atmospheric variables

(surface wind, air temperature, air density)

DUST emission scheme

Saltation (Marticorena et al. 1995)

Roughness and humidity correction

Sand-blasting (Alfaro et al., 1997, 2001)

Dust flux distribution

(3 log-normal emission modes)

4 Transport bins

0.01 -1 µm

1 - 2.5 µm

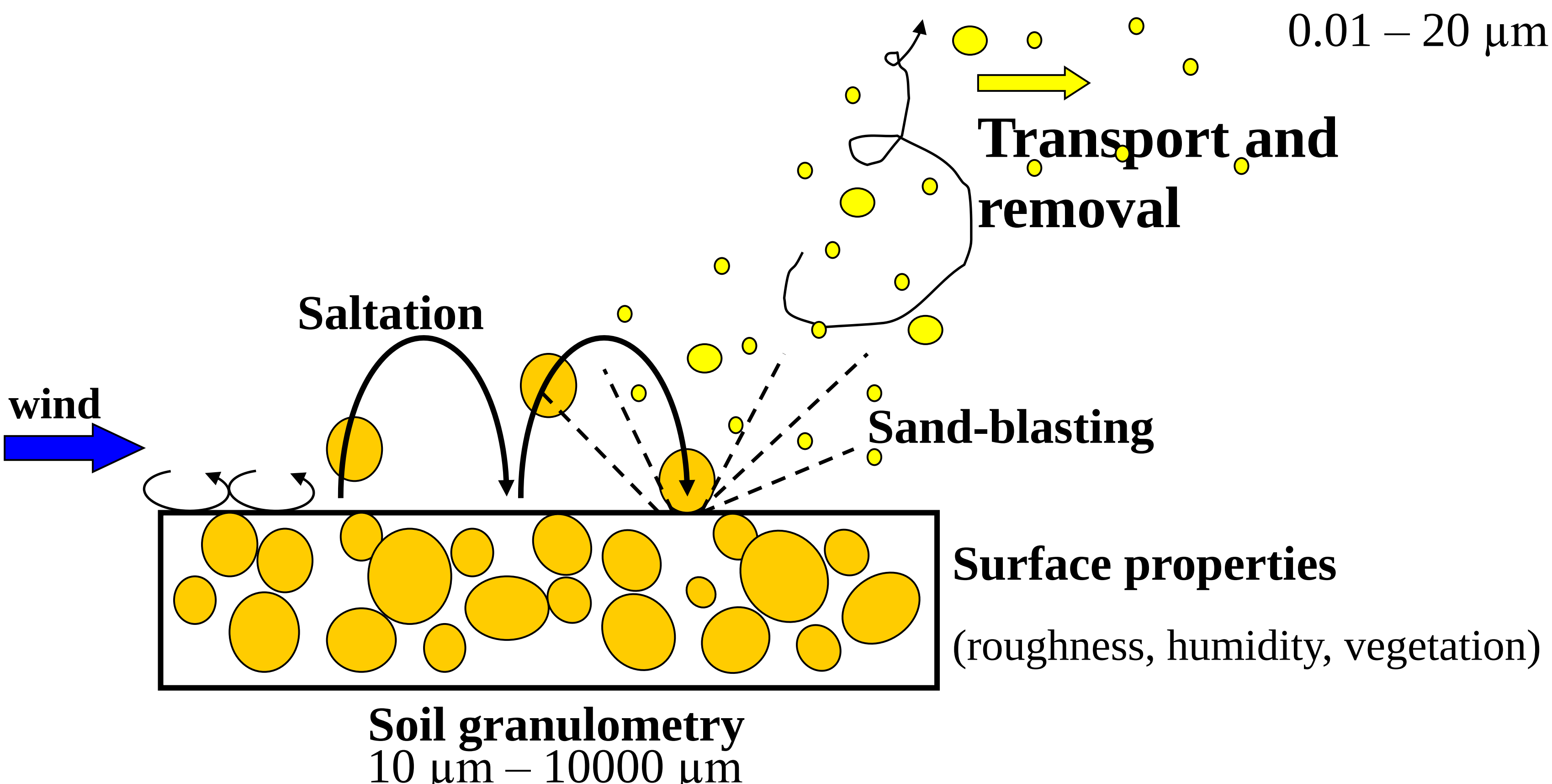
2.5 - 5µm

5 - 20 µm

AOP / radiation

Size dependant settling and surface déposition

Regional climate modelling approach



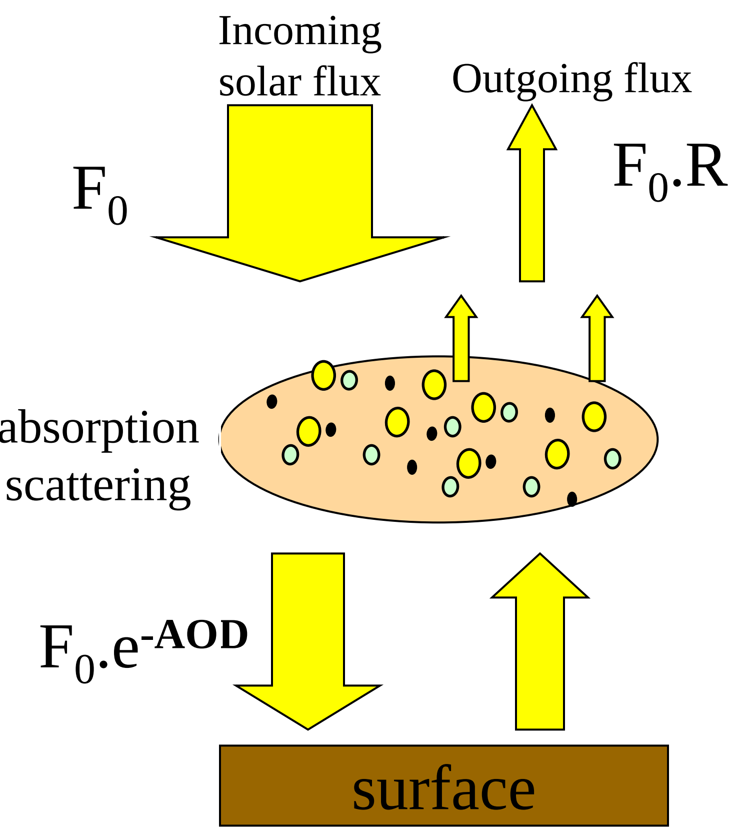
Zakey et al., 2006

RegCM

DUST (4 bins)			
0.01-1 µm	1-2.5 µm	2.5-5 µm	5-20 µm

Dust radiative forcing (aerosol direct effect)

SW (solar radiation)



LW (thermal radiation)

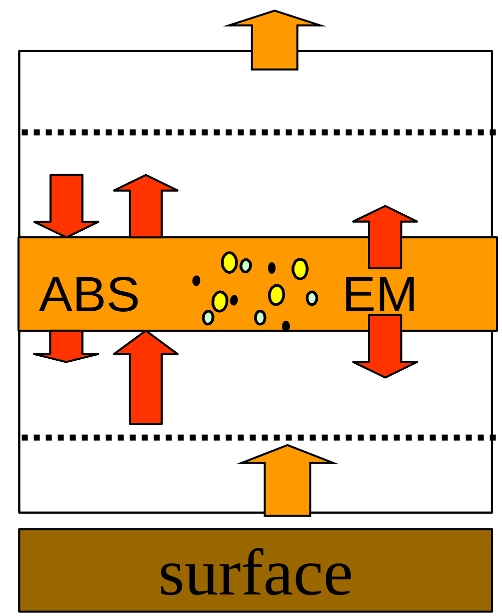
TOA forcing

(nodust - dust)

+ or -

ATM forcing

SRF forcing



LW absorption cross section

<u>Optical properties</u>

Extinction cross section

Single scattering albedo

Backscattering ratio

Regional Climatic response

Southern Hemisphere Dust Sources

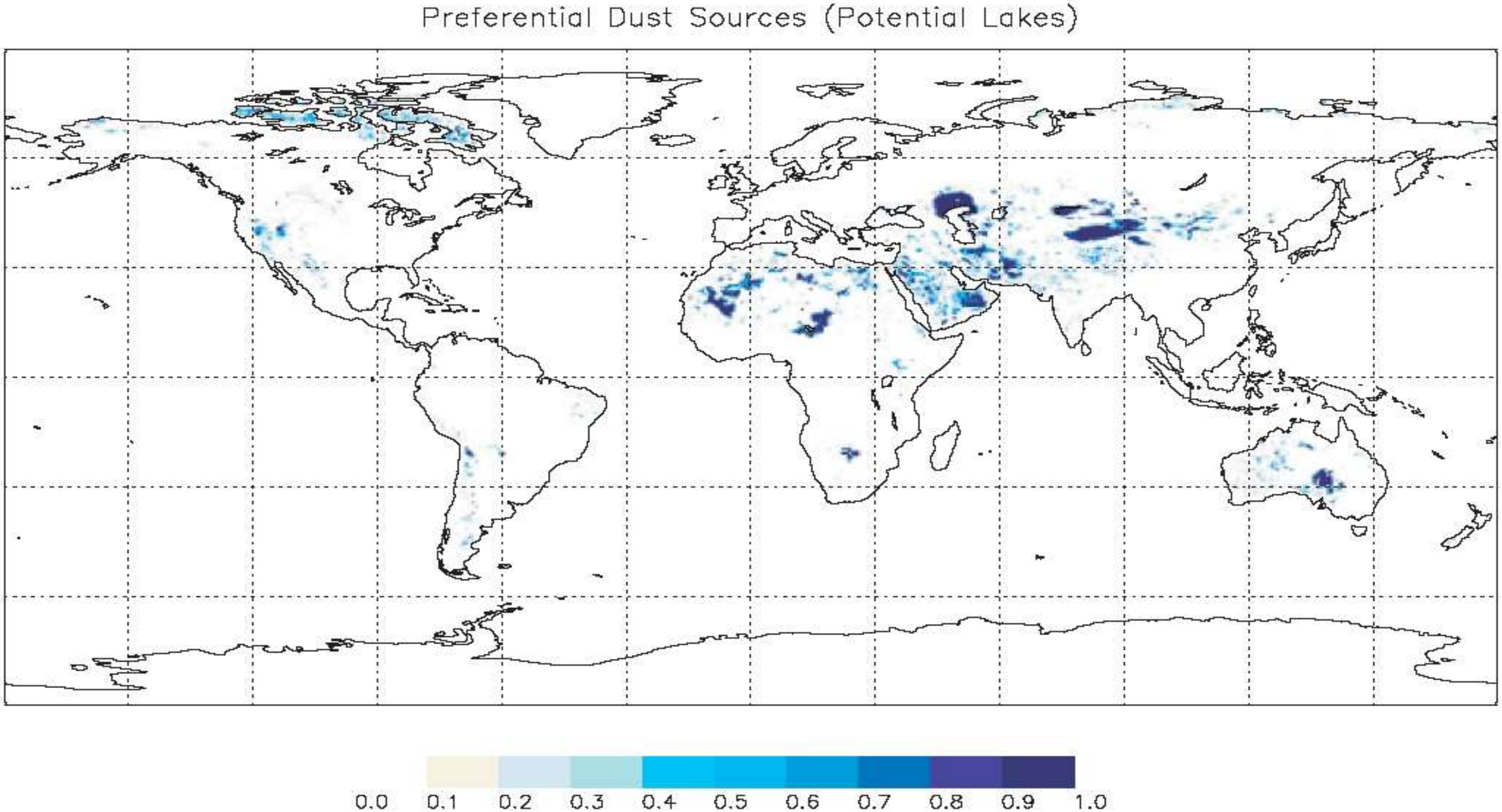
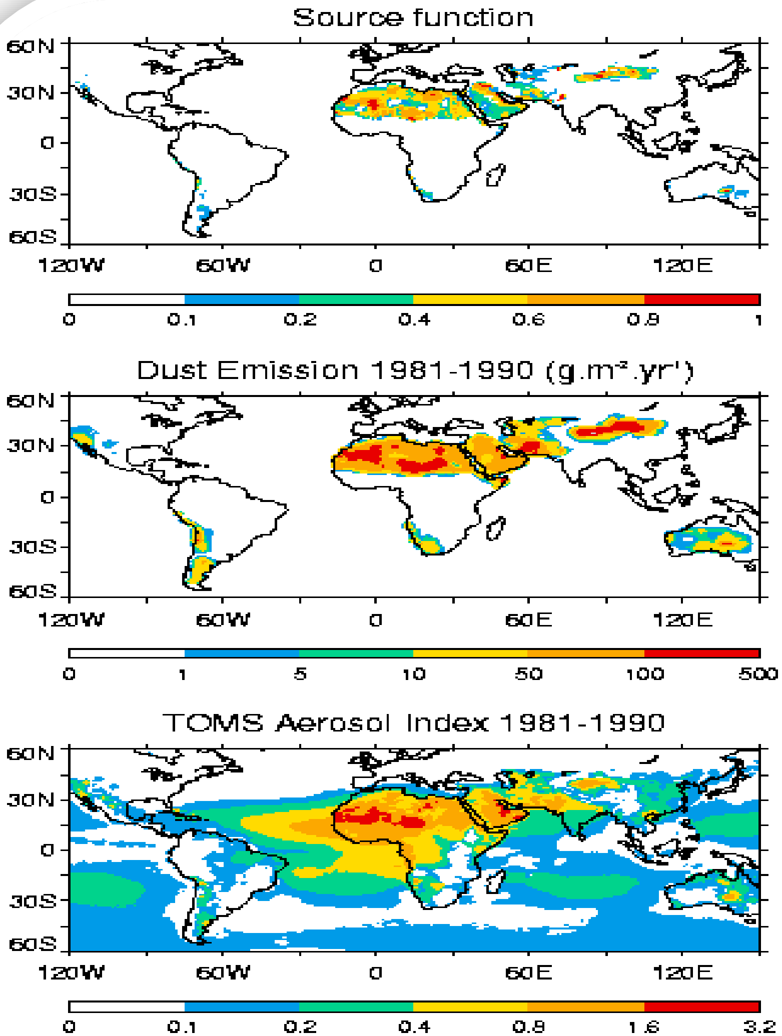


Fig. 4. Areal coverage of preferential dust sources, calculated from the extent of potential lake areas, excluding areas of actual lakes. Modified after Tegen et al. (2002).

Areal coverage of preferential dust sources, calculated from the extent of potential lake areas, excluding areas of actual lakes.

Modified after Tegen et al. (2002).

Mineral Dust Aerosols: Global dust sources



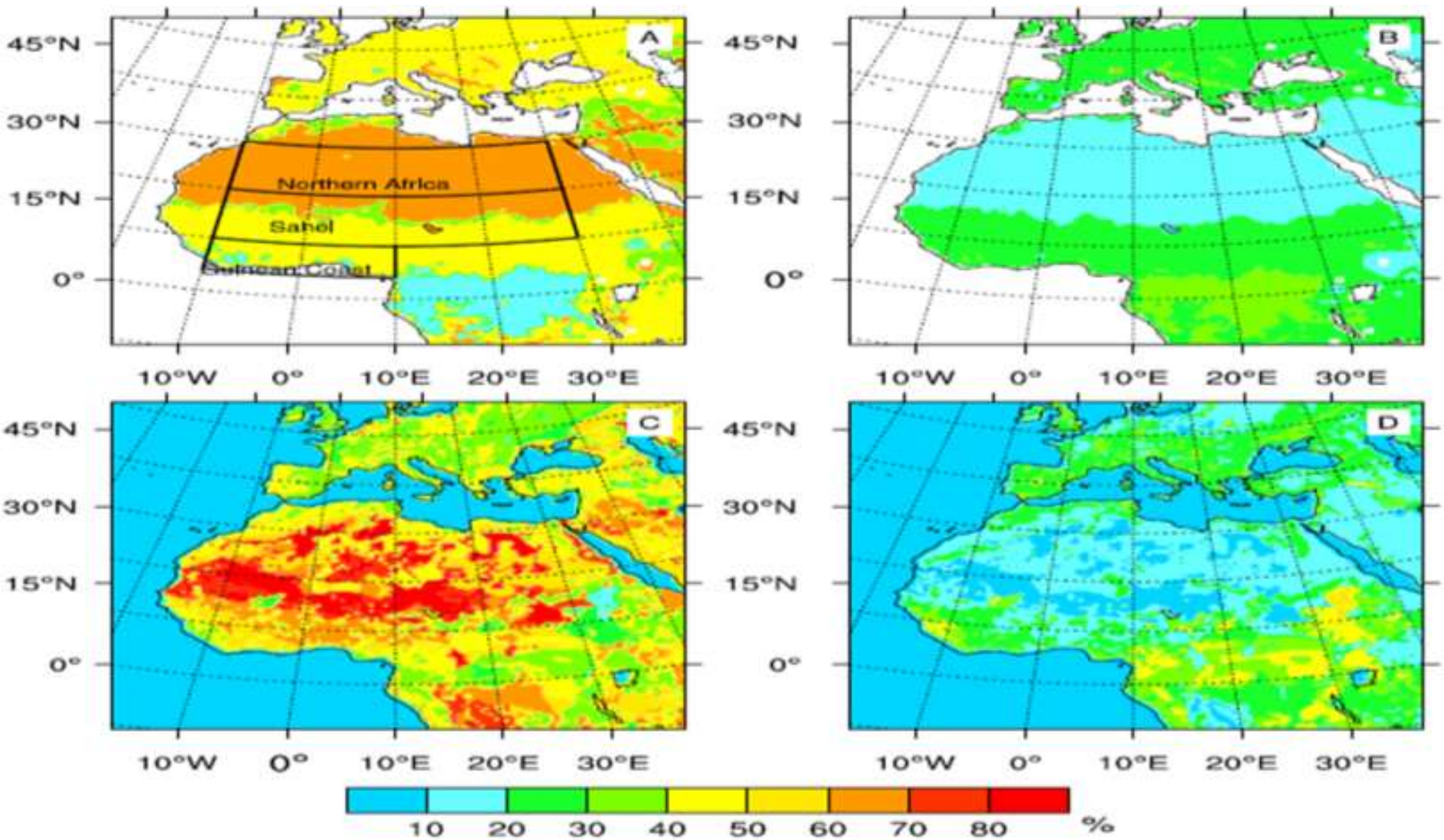
Ginoux et al. (2001) prescribed the dust sources based on topography

$$S = \left(\frac{z_{\max}^{10x10} - z}{z_{\max}^{10x10} - z_{\min}^{10x10}} \right)^{5}$$

and vegetation (bare surface from AVHRR 1x1 degree)

GOCART, GFDL models, KARMA, GEOS-CHEM, US Army, several regional models, IPCC 2001, AEROCOM.

1. The domain of the study area with dust source fraction and soil percentage for CLM and BATS



A brief comparison between the two land surface parameterization schemes

Category	BATS	CLM
Land cover/vegetation classes	20 vegetation types	24 vegetation types
Surface representation	One vegetation layer, a surface soil layer, a snow layer	One vegetation layer with a canopy photosynthesis-conductance model, 10 unevenly spaced soil layers, five snow layers with an additional representation of trace snow
Soil temperatures calculation	Uses a two-layer force-restore model	Soil temperature is calculated explicitly by a10-layer soil model
Treatment of vegetation canopy	Treats all vegetation within the canopy in the same manner	The canopy is divided into sunlit and shaded fractions as a function of LAI
Calculation of stomatal conductance and photosynthesis rate	No individual calculation is made for sunlit and shaded fractions. It does not compute photosynthetic rates	Stomatal conductance is calculated for sunlit and shaded fractions. Calculation of photo synthetic rates is done in this scheme
Treatment of heat and roughness length	Heat and water vapor roughness lengths are constant	Updates these values over bare soil and snow with values from the stability functions
Albedo treatment	Uses prescribed values for vegetation albedo for both short- and longwave components	Uses a modified two stream approach that reduces the complexity of a full two-stream albedo treatment

Abstract

In this study we used the updated version of the regional climate model (RegCM4.5) which is characterized by two online coupled land-surface schemes. The purpose here is using the two land-surface schemes to perform sensitivity study on the modeling of dust emission over North Africa and the Middle East (MENA) area. The aerosol optical depth (AOD) of desert dust is re-produced and compared using both of the Biosphere Atmosphere Transfer Scheme (BATS) and Community Land Model (CLM) schemes. Two 11-years simulations (2000–2010) are performed for both of RegCM-BATS (ReBAT) and RegCM-CLM (ReCLM) over Middle East and North Africa (MENA) region. Both of the spatial and temporal distributions of the Aerosol optical depth (AOD) derived from the model simulations are compared to the available observations from the Aerosol Robotic Network (AERONET) program and satellites data from MODIS (Moderate Resolution Imaging Spectroradiometer), MISR (Multi-angle Imaging SpectroRadiometer) and SeaWIFS (Sea-Viewing Wide Field-of-View Sensor). The result shows that ReBAT is re-produced desert aerosol AOD values consistent with those observed from MODIS, MISR, and AERONET AOD while ReCLM produce higher AOD values. The average difference of AOD between ReBAT simulation and AERONET is less than the average difference of AOD between ReCLM simulation and AERONET. The results illustrate increases in the frequencies of dust storm activities over the region with extreme AOD >1 events of dust emission. The relation between AOD from AERONET and ReBAT simulation shows correlation coefficient ranging from -0.35 to 0.90, while the relation between AOD from AERONET and ReCLM simulation shows correlation coefficients ranging from -0.41 to 0.64 .

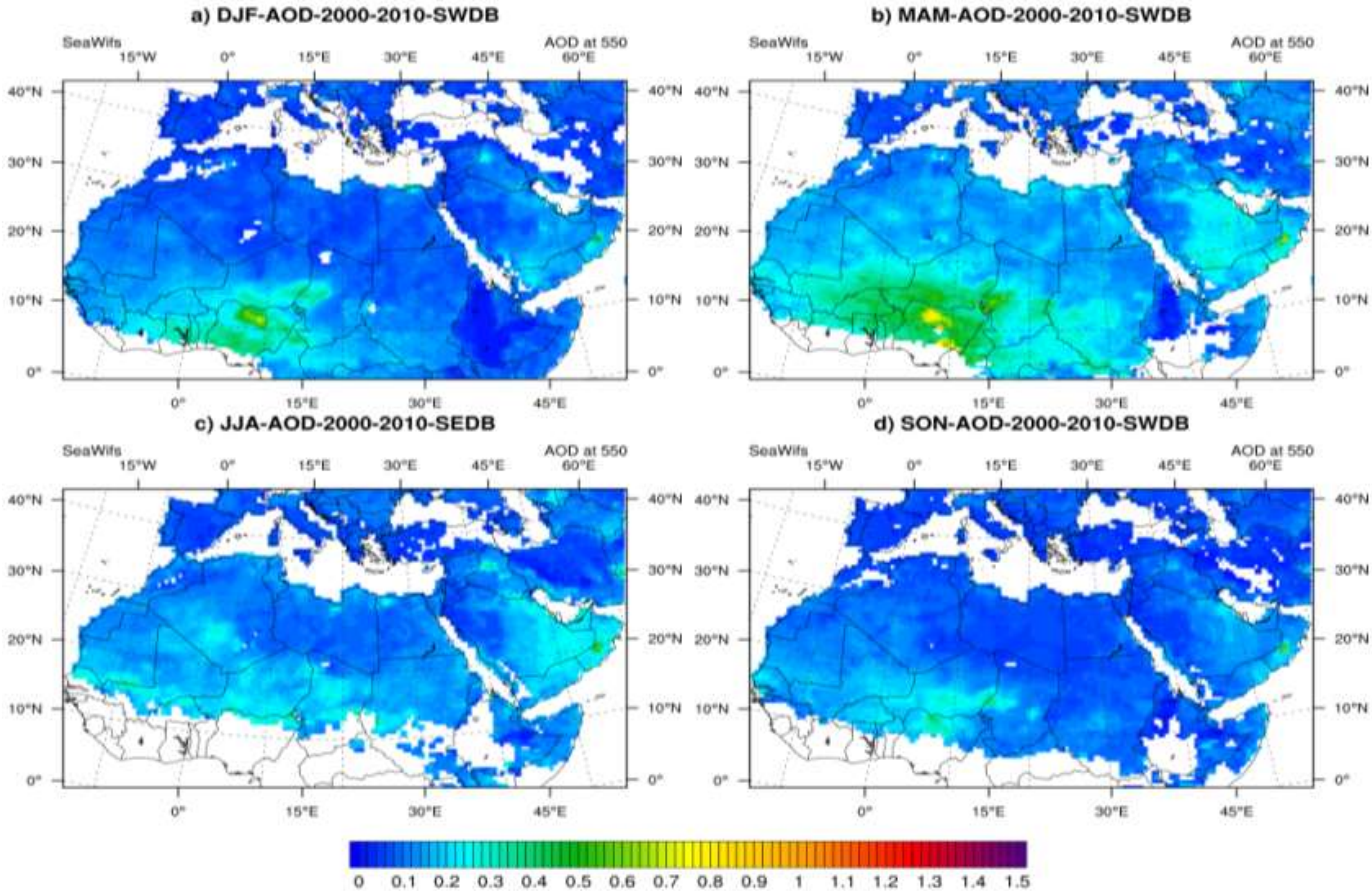
Model Configuration

M	**Model** Configuration	
1	Dynamics	Hydrostatic
2	Main prognostic variables	*u*,*v* *t*, *q* and *p*
3	Model domain	2S-42º N, 10W-55º E; res. = 50 km
4	Map projection	Lambert conformal mapping
5	Vertical coordinate	Terrain-following sigma coordinate 18 sigma levels (five levels in PBL)
6	Cumulus parameterization	Grell with Fritch & Chappell closure
7	Land surface models	Biosphere-atmosphere transfer scheme (BATS)and Community Land Model (CLM)
8	Radiation parameterization	NCAR/CCM3 radiation scheme
9	PBL parameterization	Holtslag

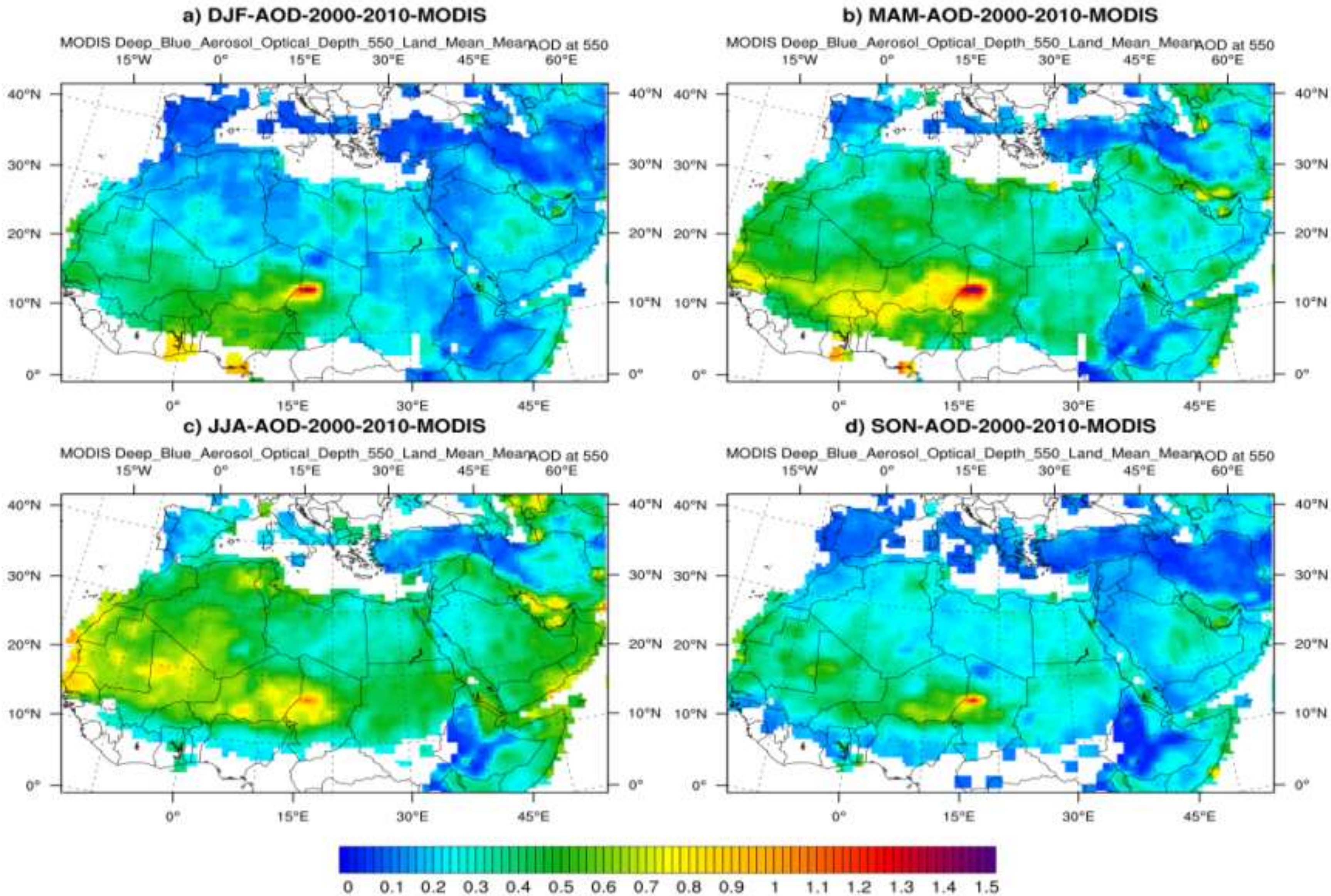
Long-term AOD from satellite measurements including (SeaWiFS, MODIS and MISR)

Figure (2) shows the monthly average of AOD from SeaWiFS. The highest AOD is noticed in spring season in the Sahel region and central Africa. Depicts dust immediately off the coast of West Africa and also an extended plume transport over the Atlantic, captured by SeaWiFS as shown in Figure (2). SeaWiFS has better coverage of the North African desert comparing to MODIS Dark Target that cannot measure over bright surface as shown in figure (3). Strong upward trends are also found over the adjoining Persian Gulf. Thus, it is likely that the increasing aerosol load over the Arabian Peninsula, together with the increase over the northern Arabian Sea, has contributed to upward trends in AOD over surrounding oceanic regions largely associated with the spring and summer-time dust outflow.

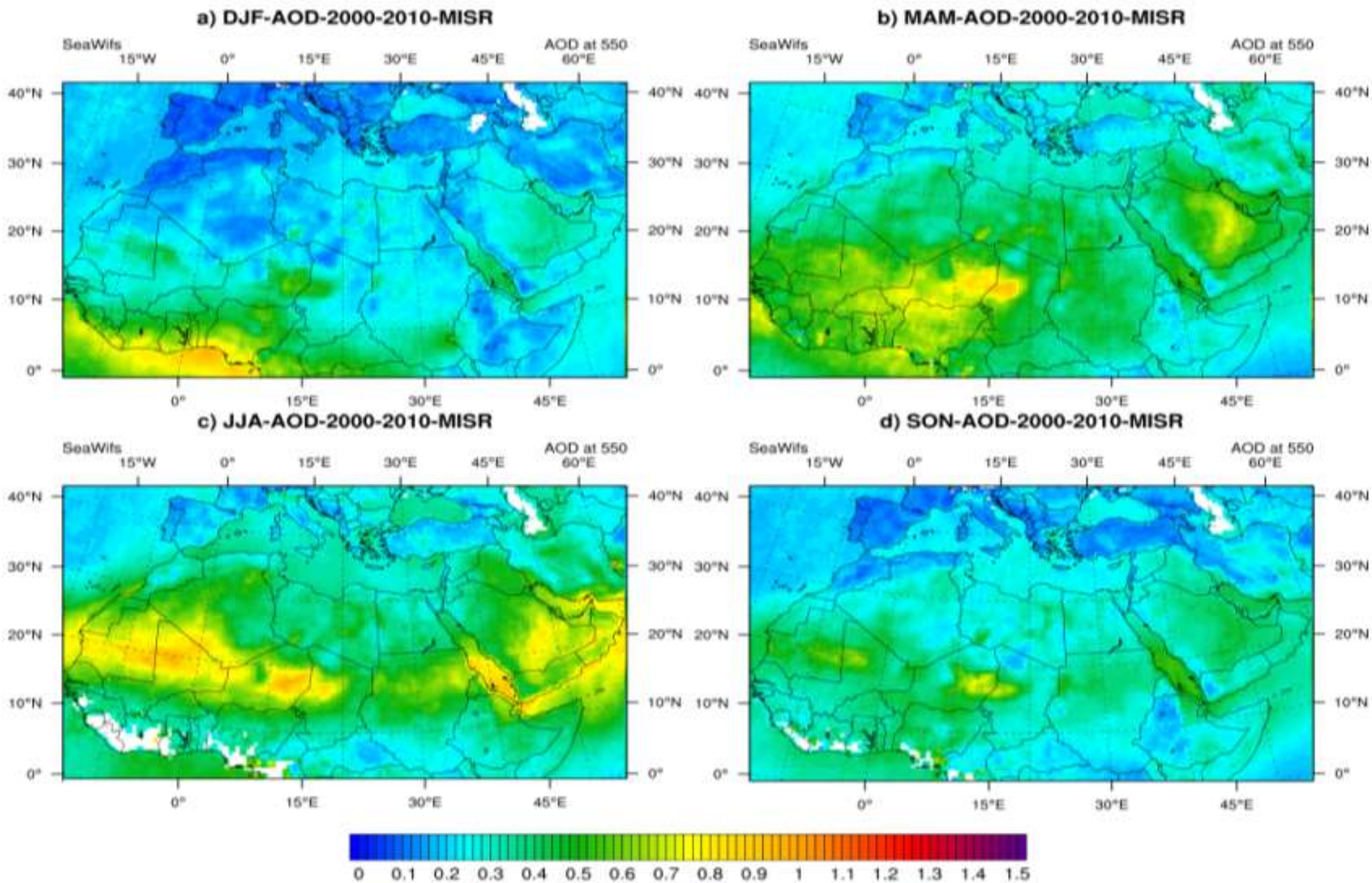
2. AOD monthly average of eleven years 2000-2010 of SeaWifs observations



3. AOD monthly average of eleven years 2000-2010 of MODIS observations



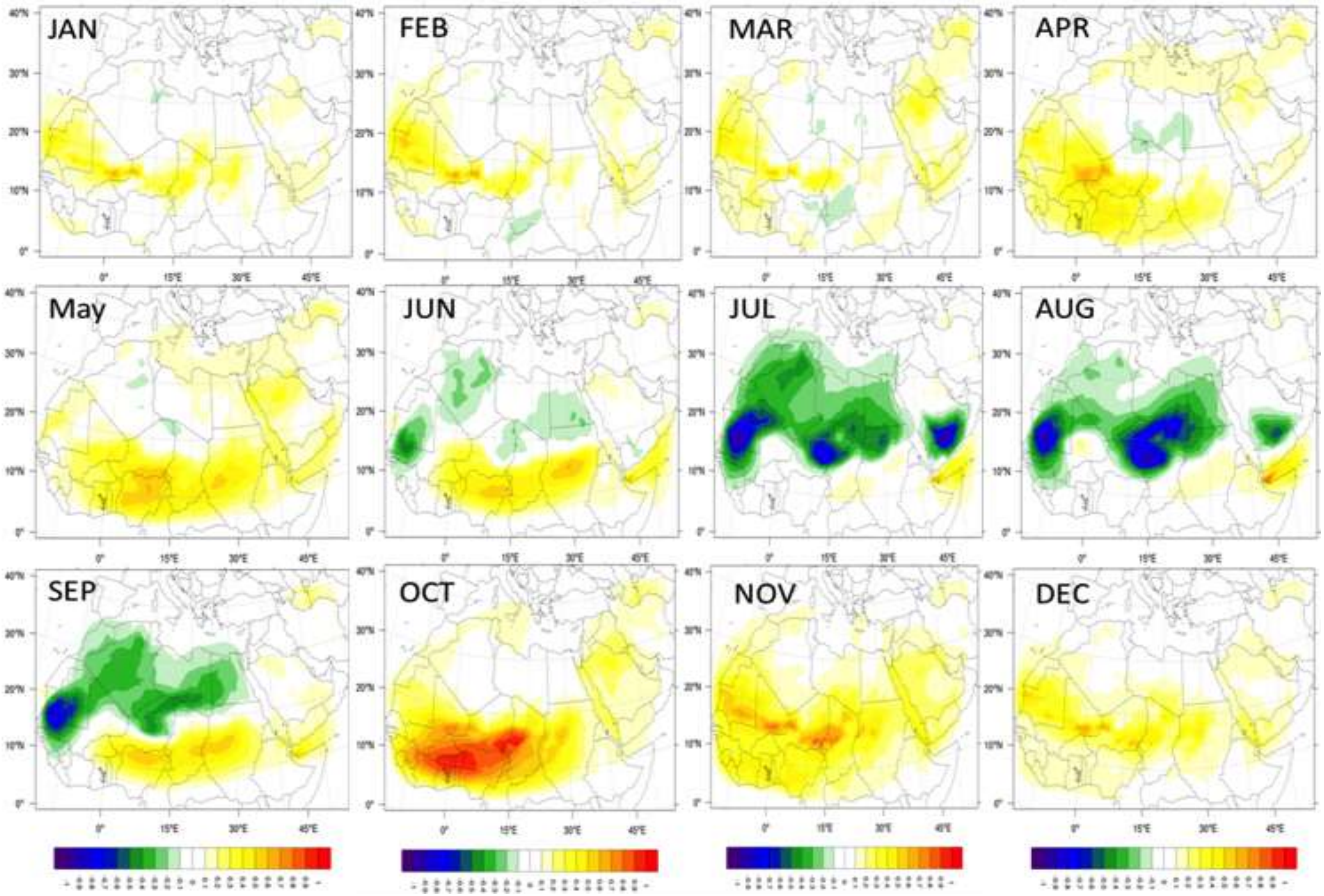
4. AOD monthly average of eleven years 2000-2010 of MISR observations



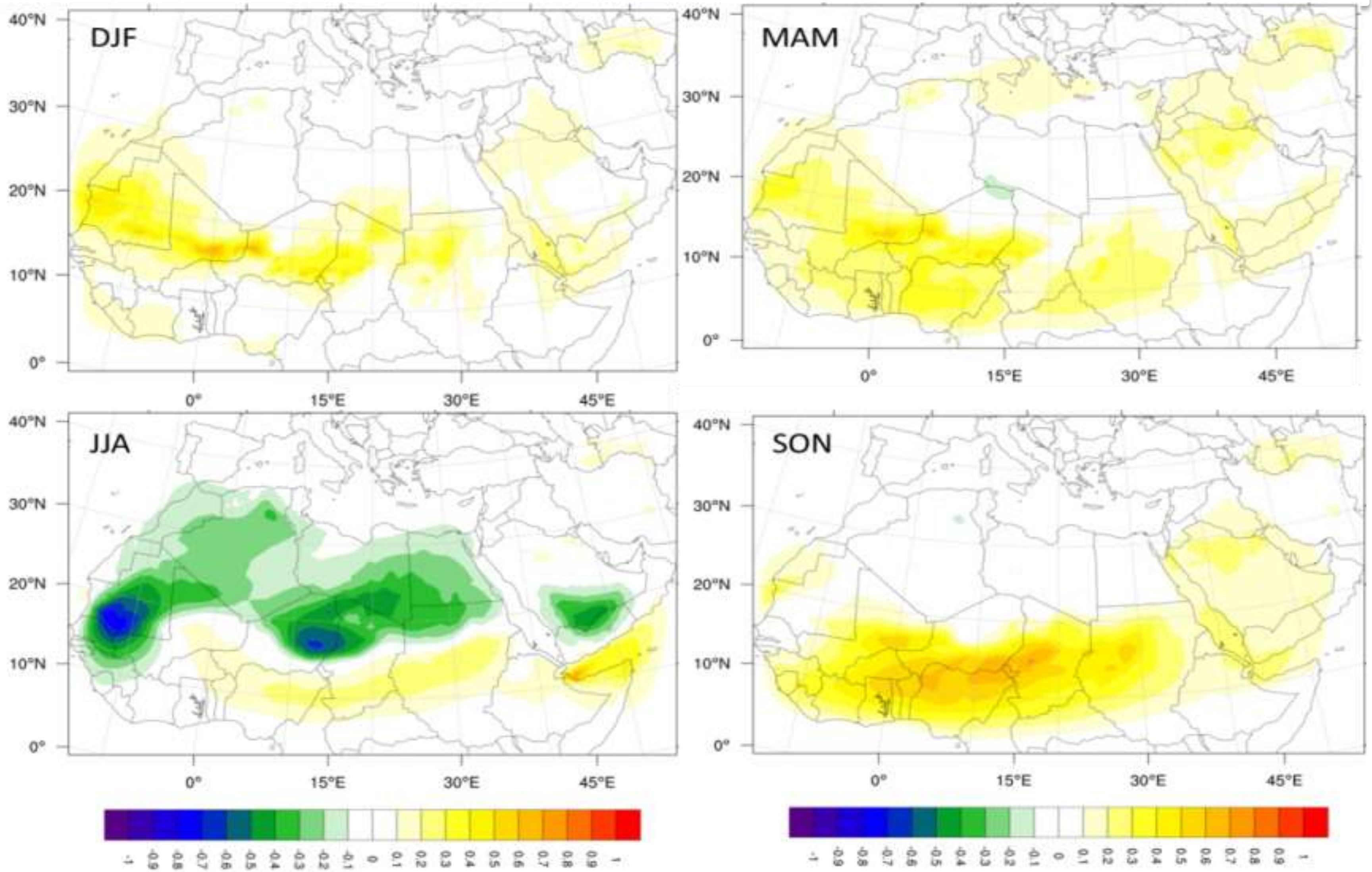
Spatial and temporal variation of Aerosols Optical Depth

From January-May the ReCLM has recoded higher AOD in central and western Africa, which could extend to the Arabian Peninsula region. Over Egypt and North Africa the difference almost zero expect at the Egyptian-Libyan border in April where the ReBAT recoded slight higher AOD due to the main dryness of the dust source in this region. From Jun-September, the ReBAT simulation shows more dust over the entire region except in September. From October to December, the ReCLM has recoded higher AOD over the entire region as shown in figure 5. The overall seasonal-spatial pattern shows that winter, spring and autumn facing positive AOD differences due to the effective role of CLM parameterizations and producing more dust from ReCLM model as shown in figure 6.

5. Monthly aerosol optical depth differences between from ReCLM and ReBAT simulations



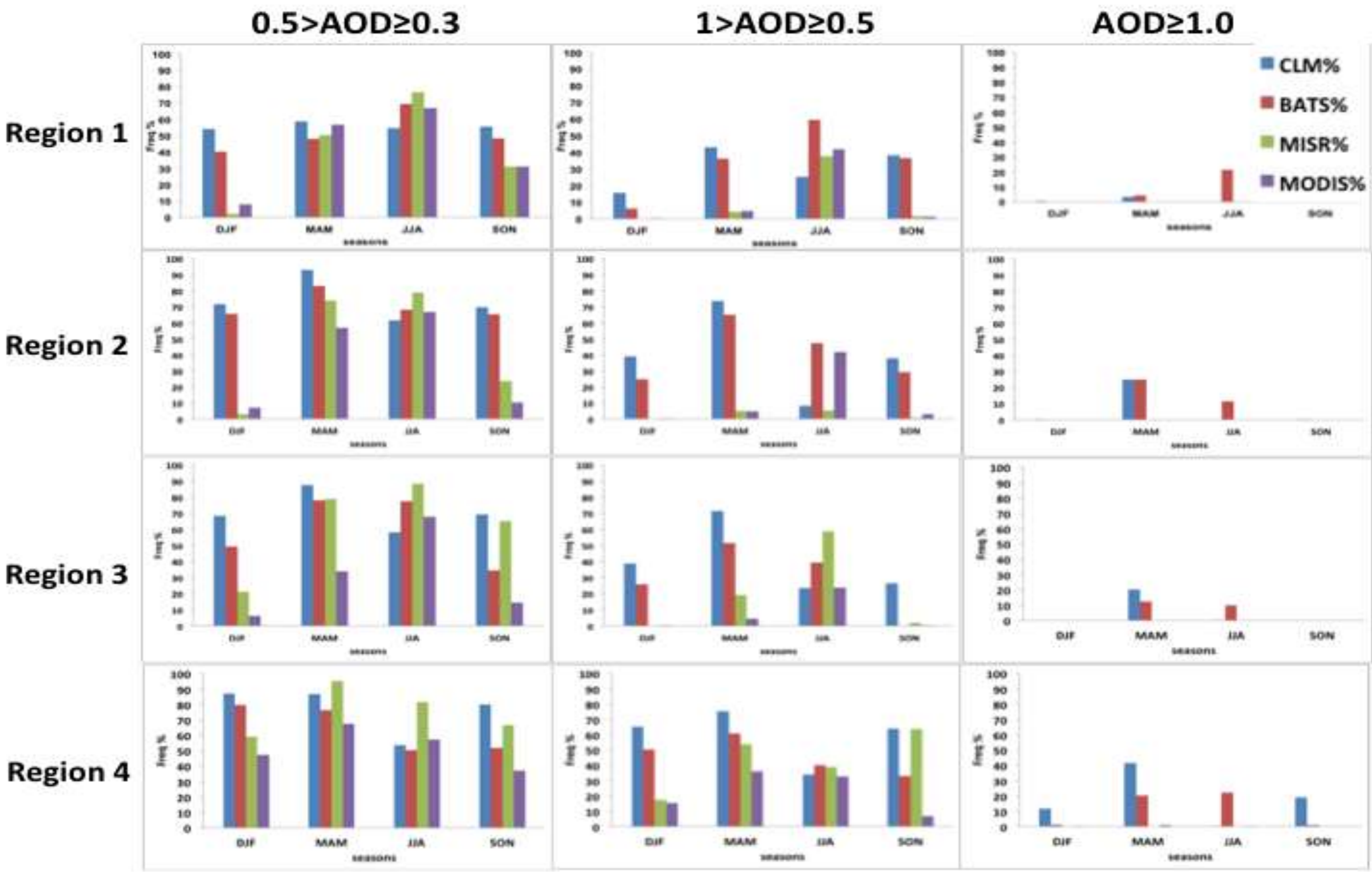
6. seasonal aerosol optical depth differences between ReCLM and ReBAT simulations



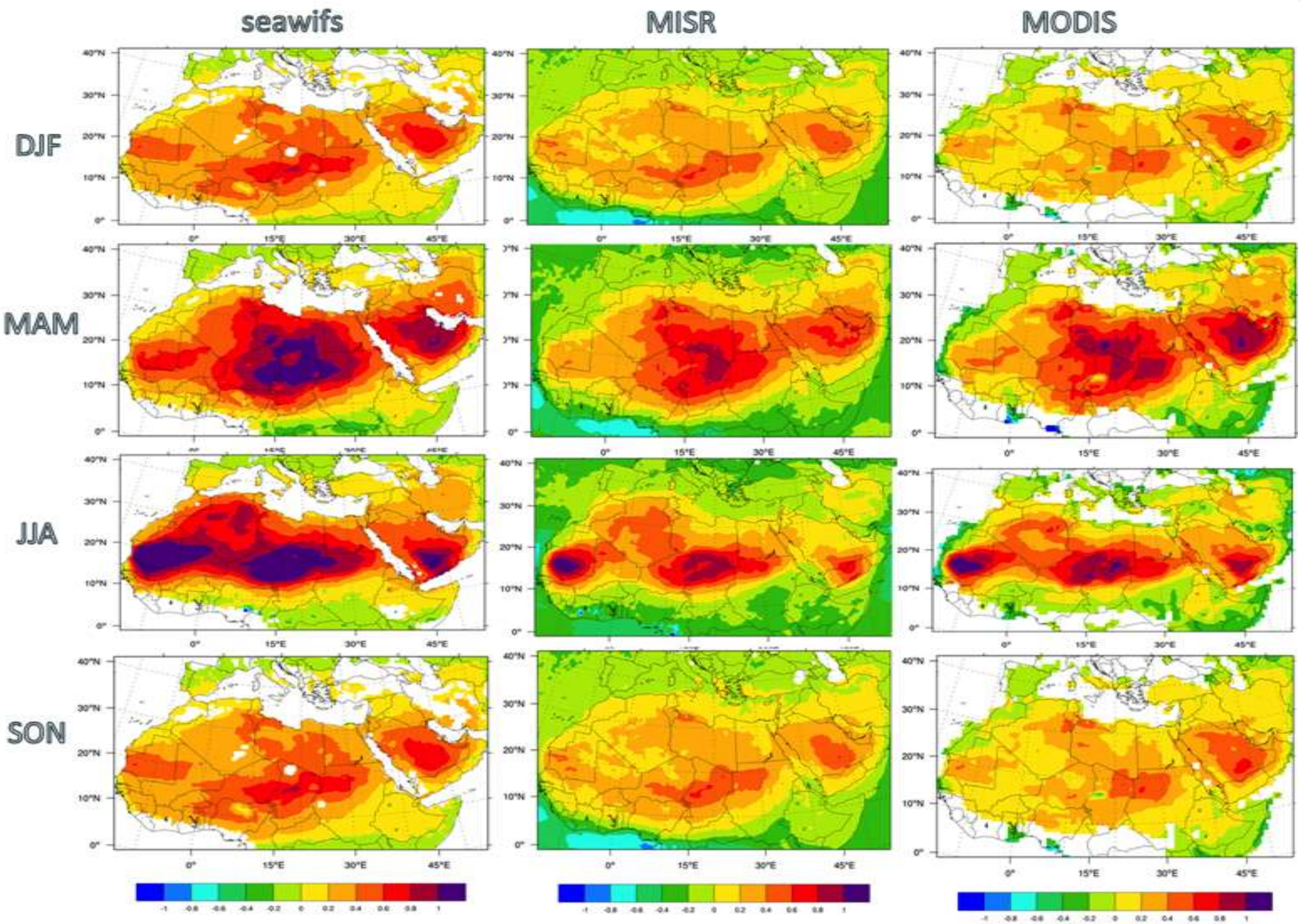
The percentage of seasonal distribution of the aerosol optical depth from ReCLM, ReBAT, MODIS and MISR

Figure (7) shows the percentage of seasonal distribution of the aerosol optical depth from ReCLM, ReBAT, MODIS and MISR for three AOD categories 1) 0.5>AOD≥0.3, 2) 1>AOD≥0.5, and 3) AOD≥1.0 in a four regions: REGION1 [latitude (20 - 40), Longitude (-20 -10)], REGION2 [latitude (20 - 40), Longitude (10 - 40)], REGION3 [latitude (10 - 40), Longitude (40 - 60)], and REGION4 [latitude (5 - 20), Longitude (-20 - 40)], respectively. The result indicate that the most predominate AOD category is located in the range 0.5>AOD≥0.3 in all the regions. It is noticed that the AOD from ReBAT is higher than ReCLM in summer season, while in spring season AOD from ReCLM is higher than ReBAT. The third categories of aerosol optical depth [AOD≥1.0] illustrate the extreme dust events which are more frequent in region-4. Regions-2, 3, and 4 shows maximum springtime AOD frequencies in the range [0.5>AOD≥0.3] with ReCLM simulation that could reach about 90%. Both of spring and summertime African Sahel zone is more frequent of AOD in the range [AOD≥1.0], while areas further north and northeast have less numbers of AOD. More AOD frequencies are also detected over southern areas of Algeria and Libya in springtime. At the same time fewer events are detected along the northern coast of Libya. This pattern strongly suggests a southward displacement of wind maxima along the margins of the Saharan heat low.

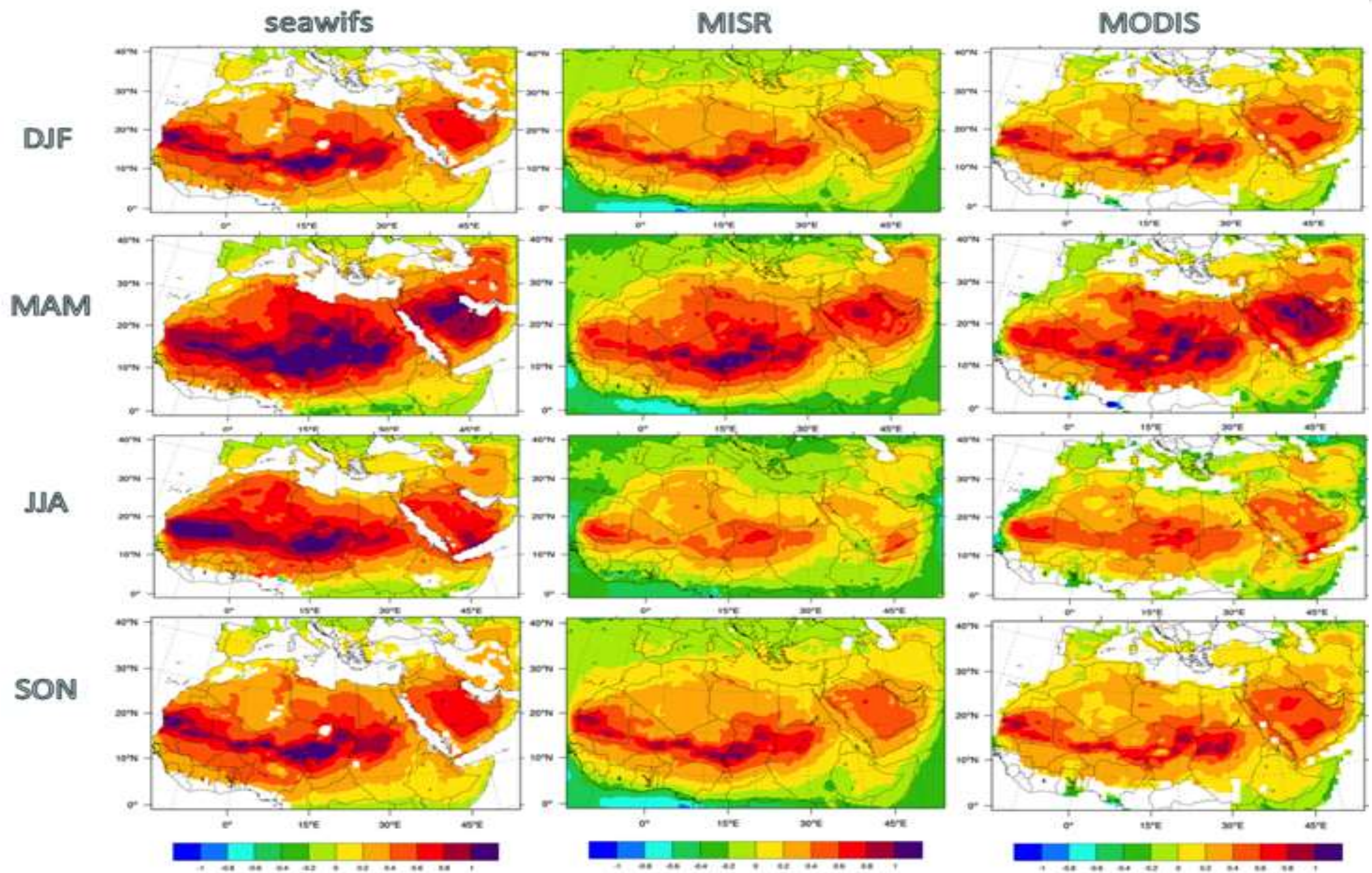
7. The percentage of seasonal distribution of the aerosol optical depth for the three AOD categories 1) 0.5>AOD≥0.3, 2) 1>AOD≥0.5, and 3) AOD≥1.0 at the four regions



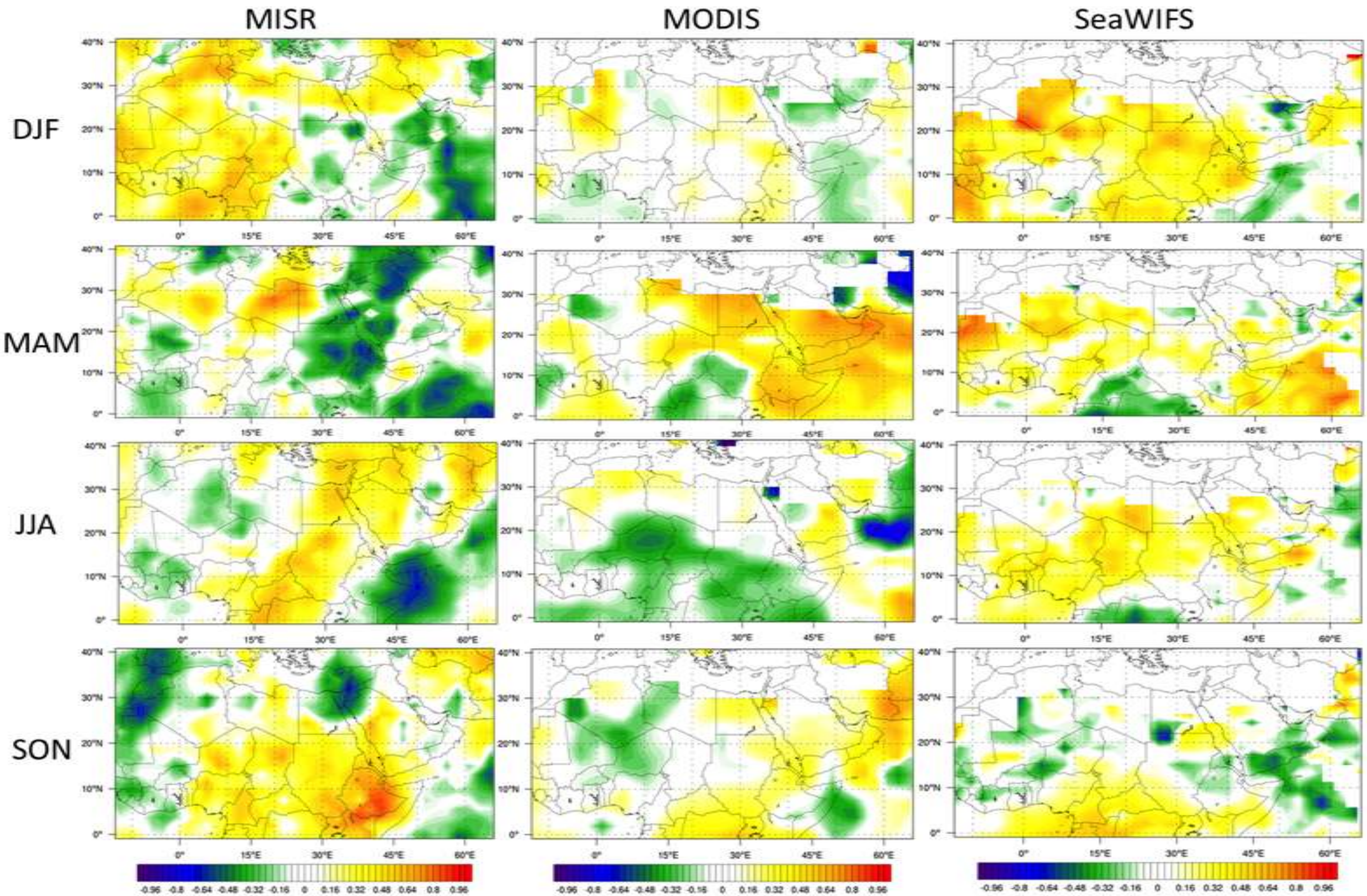
8. Seasonal AOD bias between ReBAT simulation and AOD from different satellite observations (MODIS, MISR and seawifs) for the eleven years 2000-2010



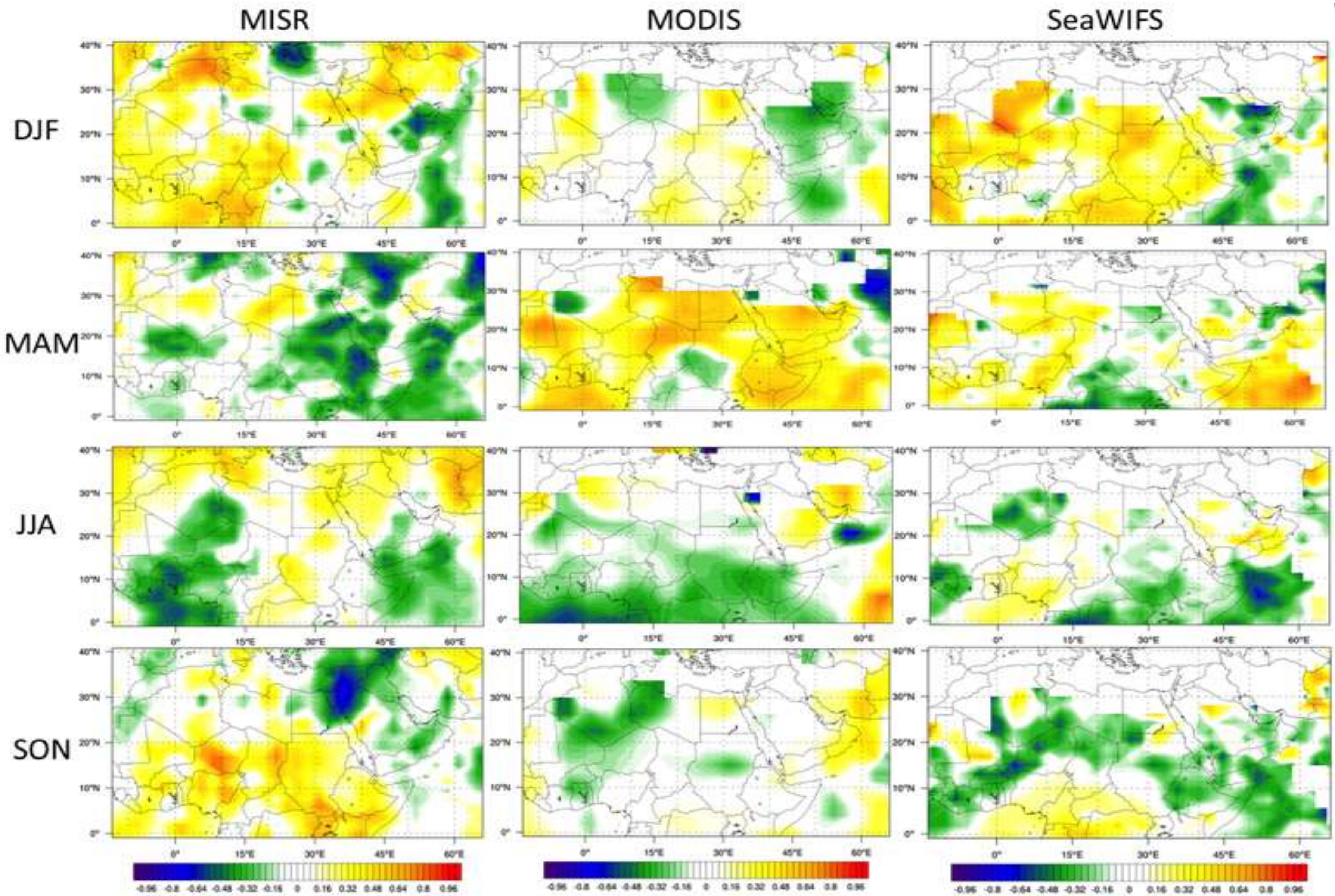
9. Seasonal AOD bias between ReCLM simulation and AOD from different satellite observations (MODIS, MISR and seawifs) for the eleven years 2000-2010



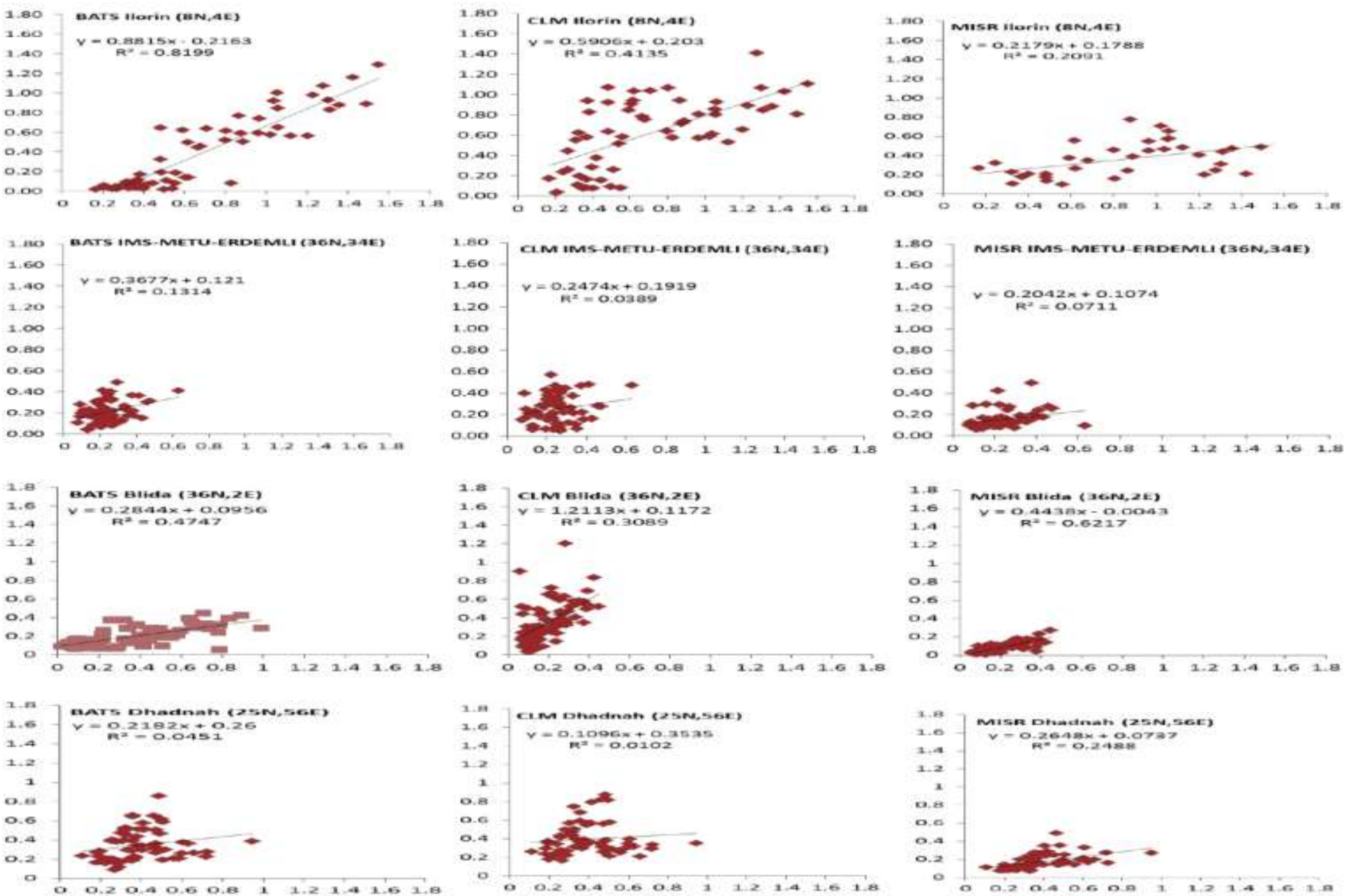
10. Seasonal AOD correlation coefficient between ReBAT simulations with MISR, MODIS and SeaWiFS



11. Seasonal AOD correlation coefficient between ReCLM simulations with MISR, MODIS and SeaWiFS



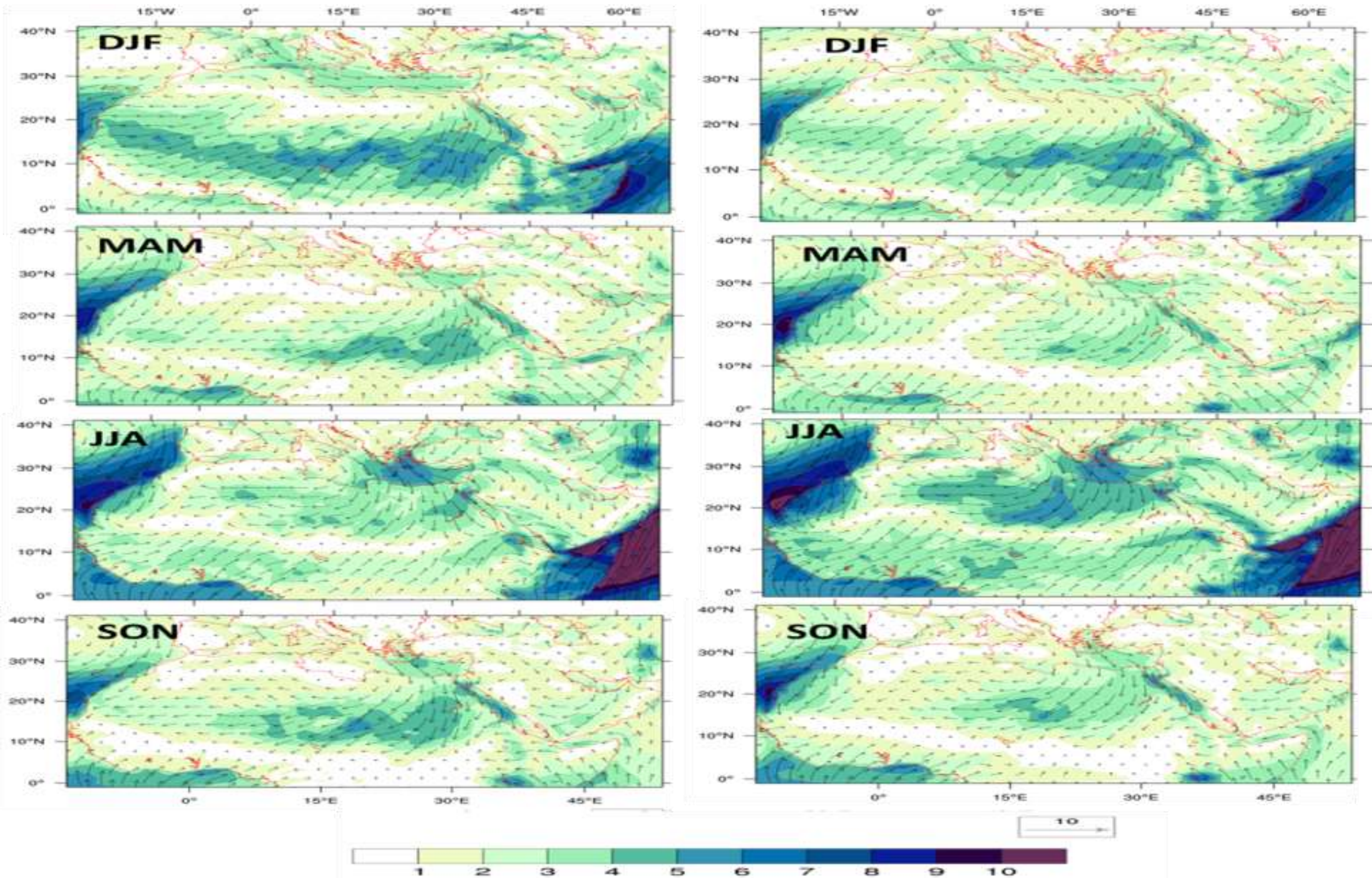
Model validation at several AERONET stations and comparison of AERONET with MISR



correlation coefficients of AOD between ReBAT, ReCLM simulations and AERONET

Station name	MISR-AERONET	ReCLM-AERONET	ReBAT-AERONET
ATHENS-NOA (37N,23E)	-0.03000809	-0.273105142	-0.304030859
Bahrain (26N,50E)	0.43628152	-0.257004934	-0.286509639
Blida (36N,2E)	**0.78847568**	0.555751684	**0.689000553**
Burjassot (39N,0W)	0.2812488	0.361953203	**0.765138453**
Cabo_da_Roca (38N,9W)	**0.74066147**	0.068876215	-0.352493907
Caceres (39N,6W)	0.71463983	0.009275776	0.214642186
Dakar (14N,16W)	0.72596218	0.101410731	0.401505105
Dhadnah (25N,56E)	0.49881726	0.100826173	0.212332843
Eilat (29N,34E)	0.55371476	0.495210845	0.546012645
El_Arenosillo (37N,6W)	0.55856857	0.182177333	0.399779574
Evora (38N,7W)	0.27822634	-0.415432391	0.222821983
Granada (37N,3W)	0.66101312	0.602943589	0.658689494
IER_Cinzana (13N,5W)	0.53061268	0.415008201	0.616468899
Ilorin (8N,4E)	**0.80436683**	**0.643055357**	**0.905480352**
IMAA_Potenza (40N,15E)	0.22499718	-0.00683289	0.129728774
IMS-METU-ERDEMLI (36N,34E)	0.26661164	0.197283292	0.362542532
Izana (28N,16W)	0.5706059	0.216284223	0.315833503
Lecce_University (40N,18E)	0.70215018	-0.202978694	-0.108177885
Mezaira (23N,53E)	0.75214766	0.061091242	0.484373999
Nes_Ziona (31N,34E)	0.32741981	0.329673153	0.50619101
Santa_Cruz_Tenerife (28N,16W)	0.37697742	0.164010592	0.249800985
SEDE_BOKER (30N,34E)	0.56472434	0.437439554	0.491328784
Solar_Village (24N,46E)	**0.8385373**	0.278721762	0.320278857

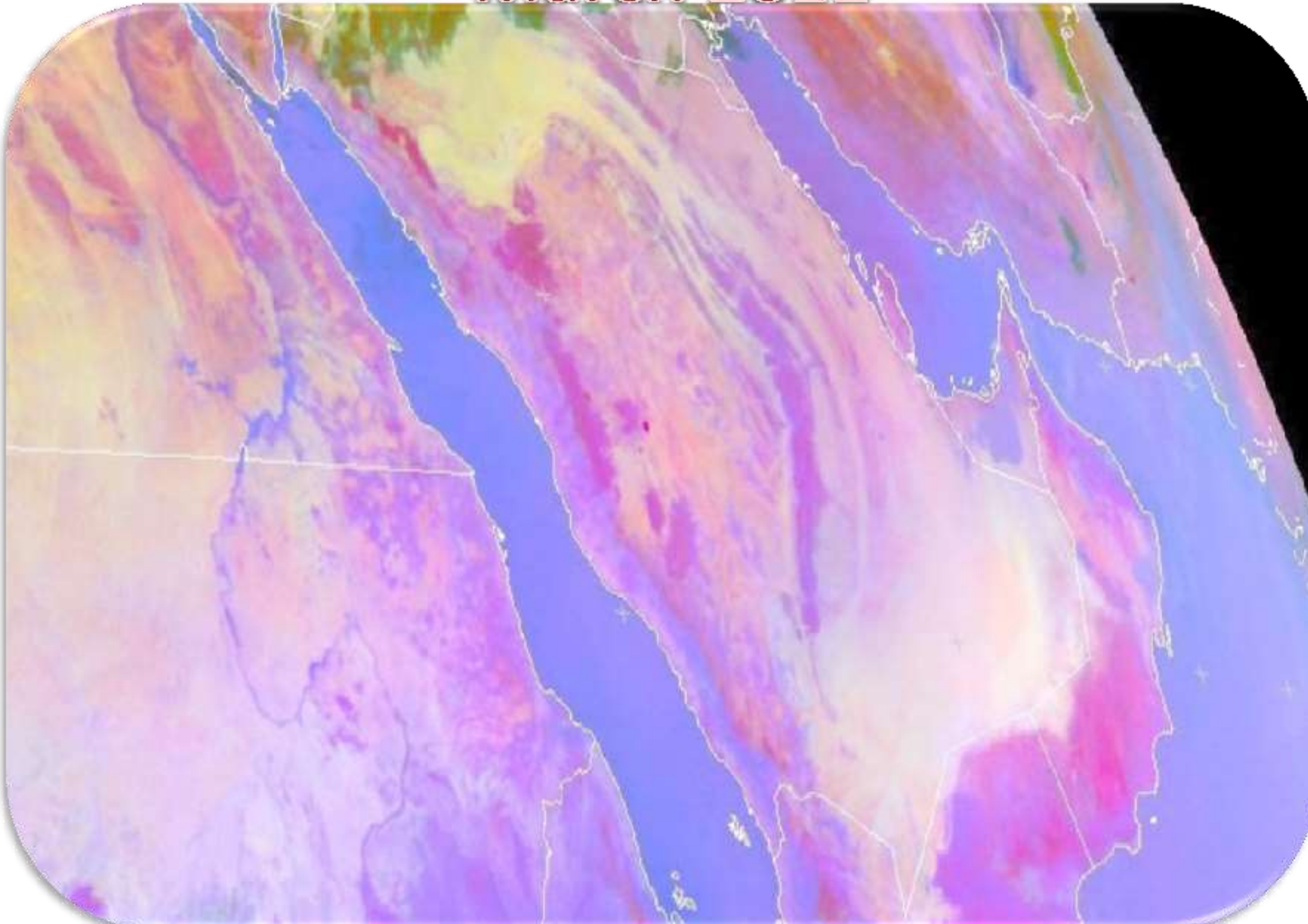
seasonal 10-m wind speed from ReBAT and ReCLM simulation



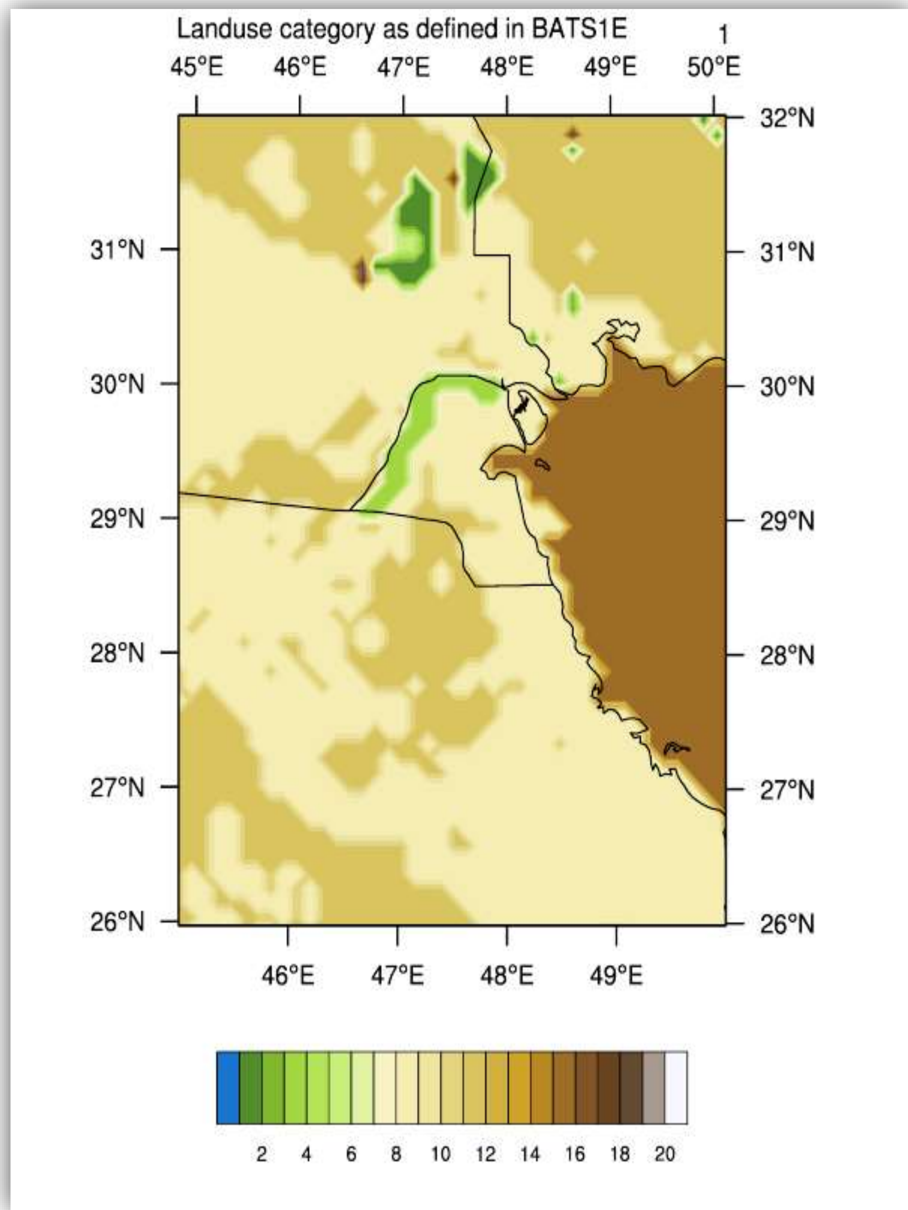
Green belt experiment
Land Use change

Case Study 25 March 2011

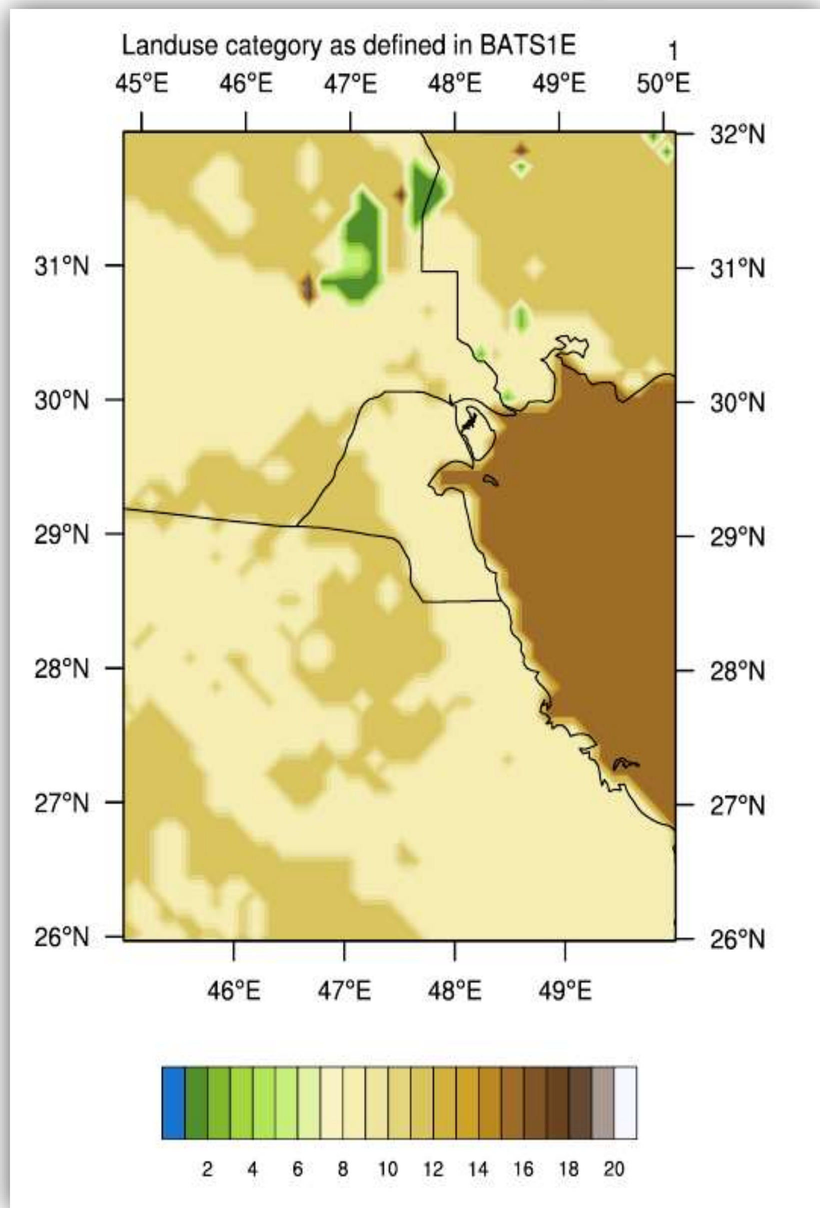
March 2011



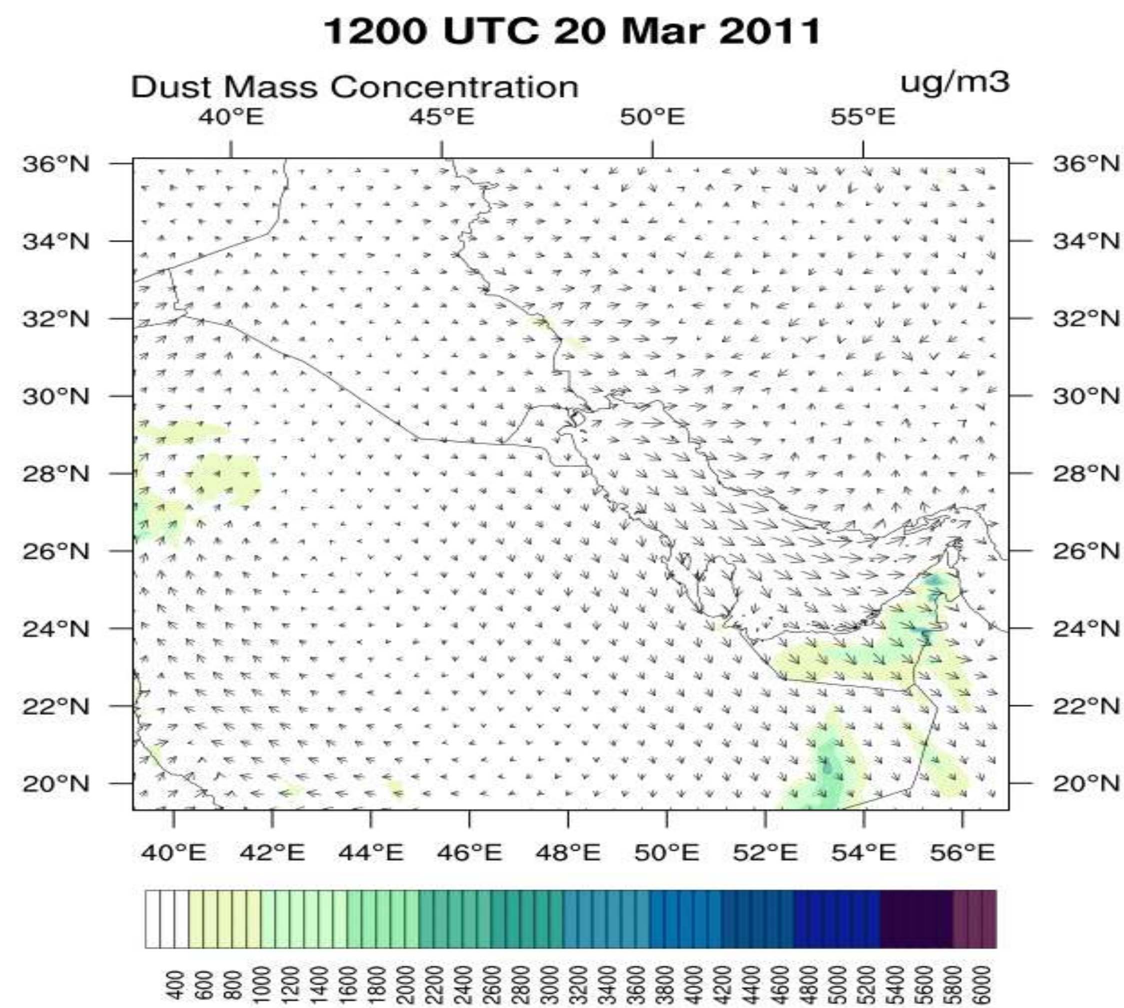
After Land-Use Change



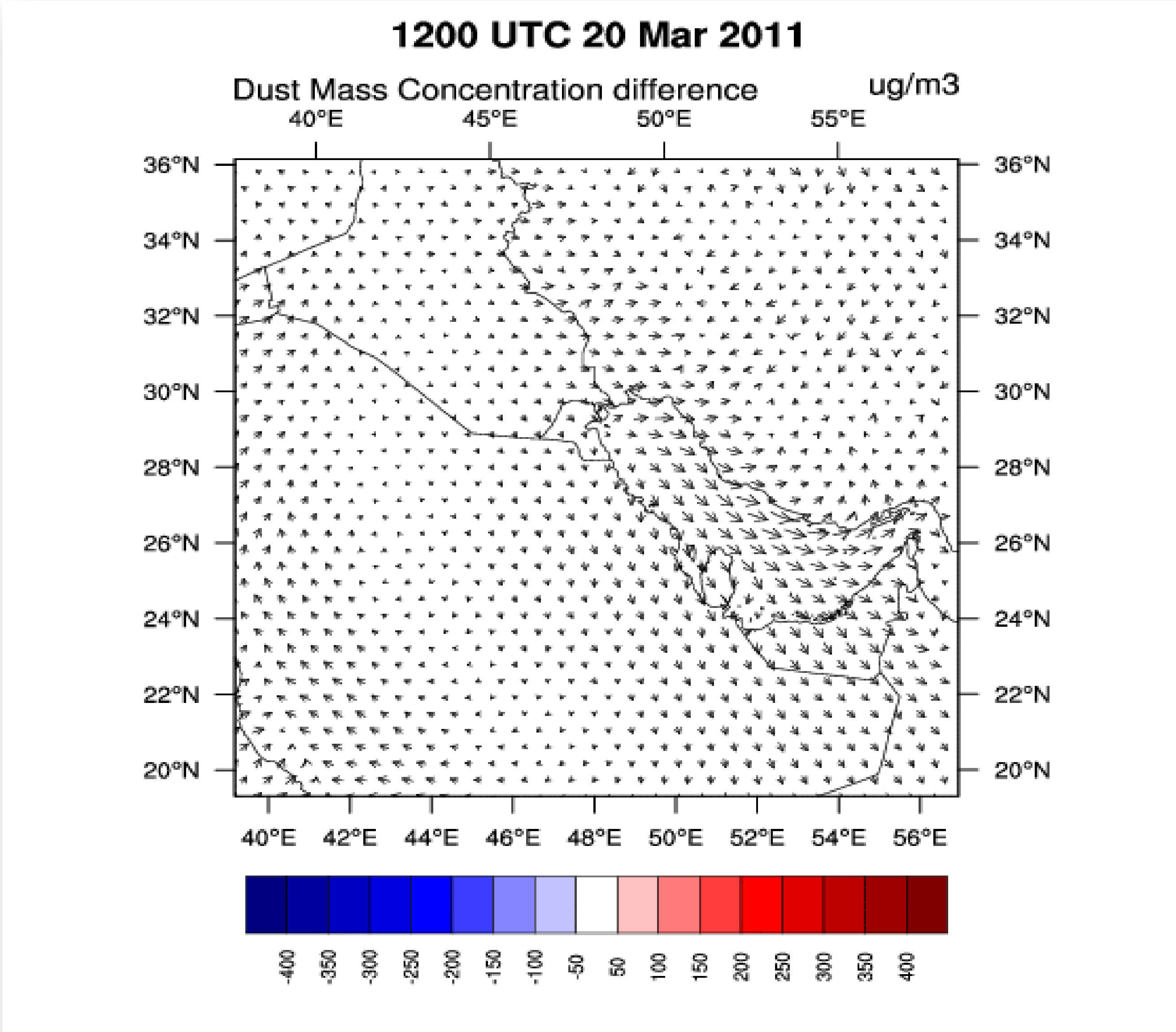
Before Land-Use Change



Dust Storm Case study 20-30 March 2011

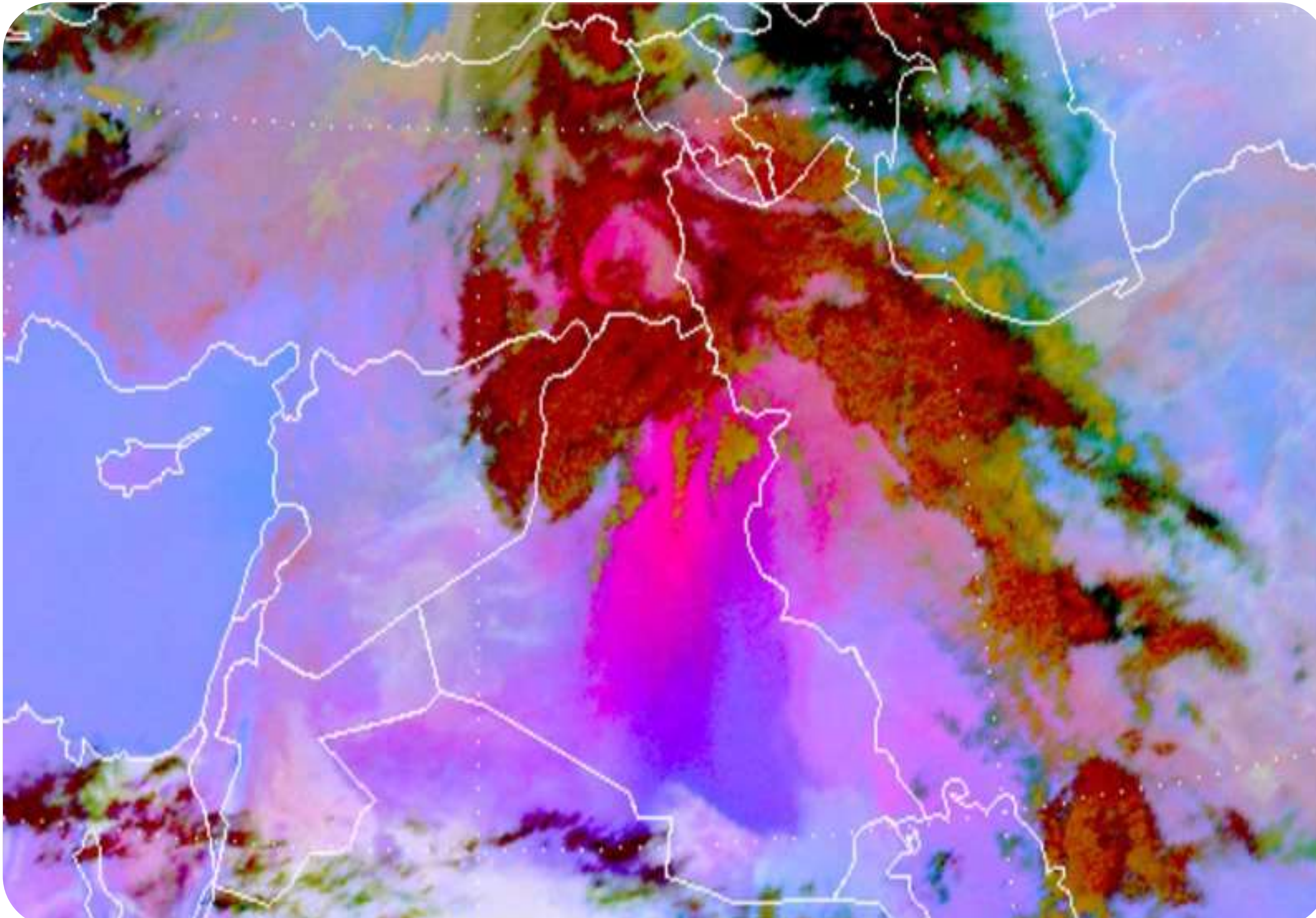


Dust difference due to land use changes

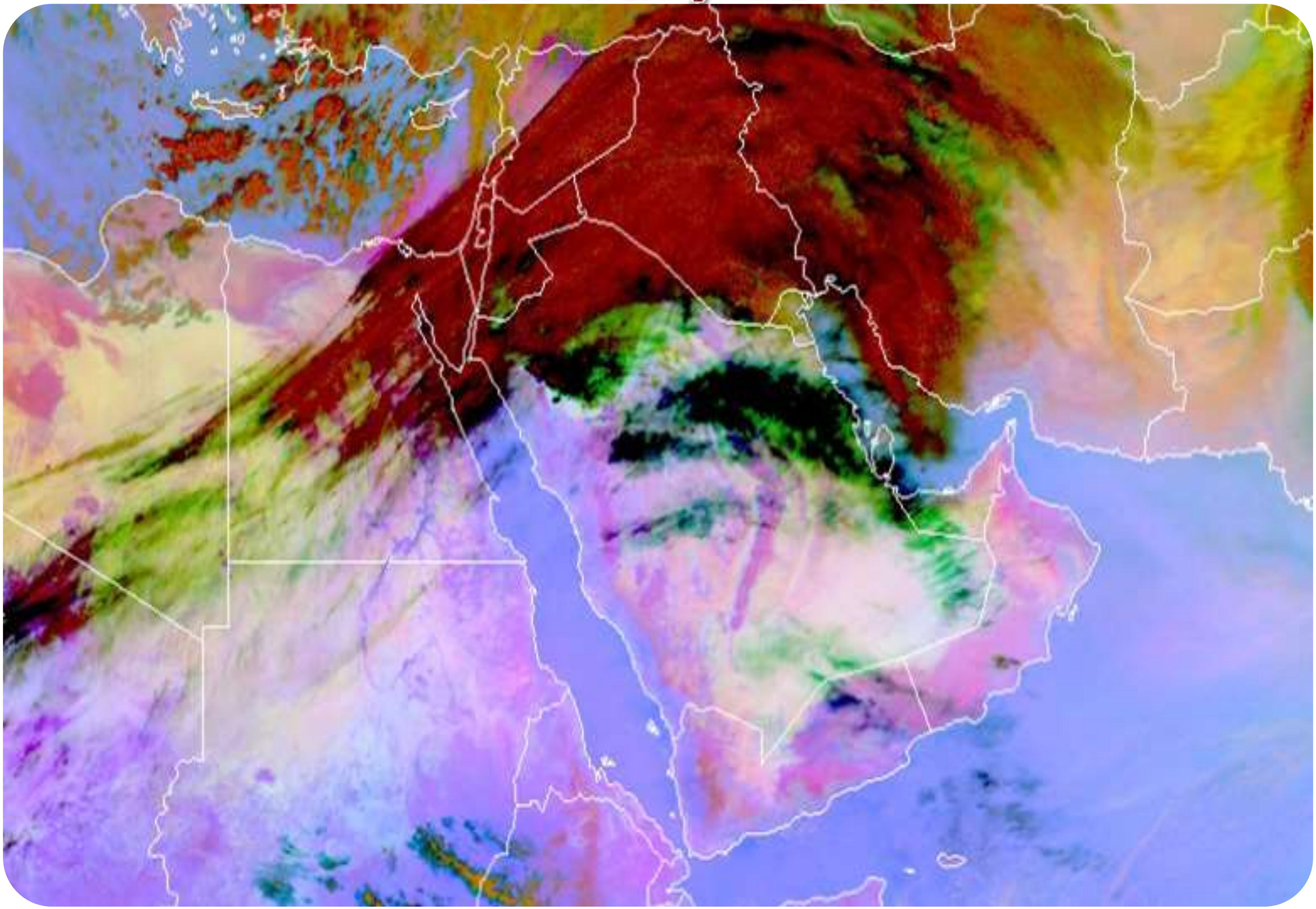


More …… extreme events of dust activities on West Asia

June 2009



February 2009



Summary: Controls on Dust Emissions

Precipitation and Inflow

- Direct control on soil moisture (which percentage can off dust emissions?),
- Direct control on surface roughness and roughness change
- Control on vegetation– (important role on dust emission according to the vegetation type)

negative dust anomalies

Wind

- Exerts a variable control;
  - **Thresholds can be attenuated by soil moisture.**
  - **Wind can dry sediment surface and reduce threshold**

positive or negative dust anomalies

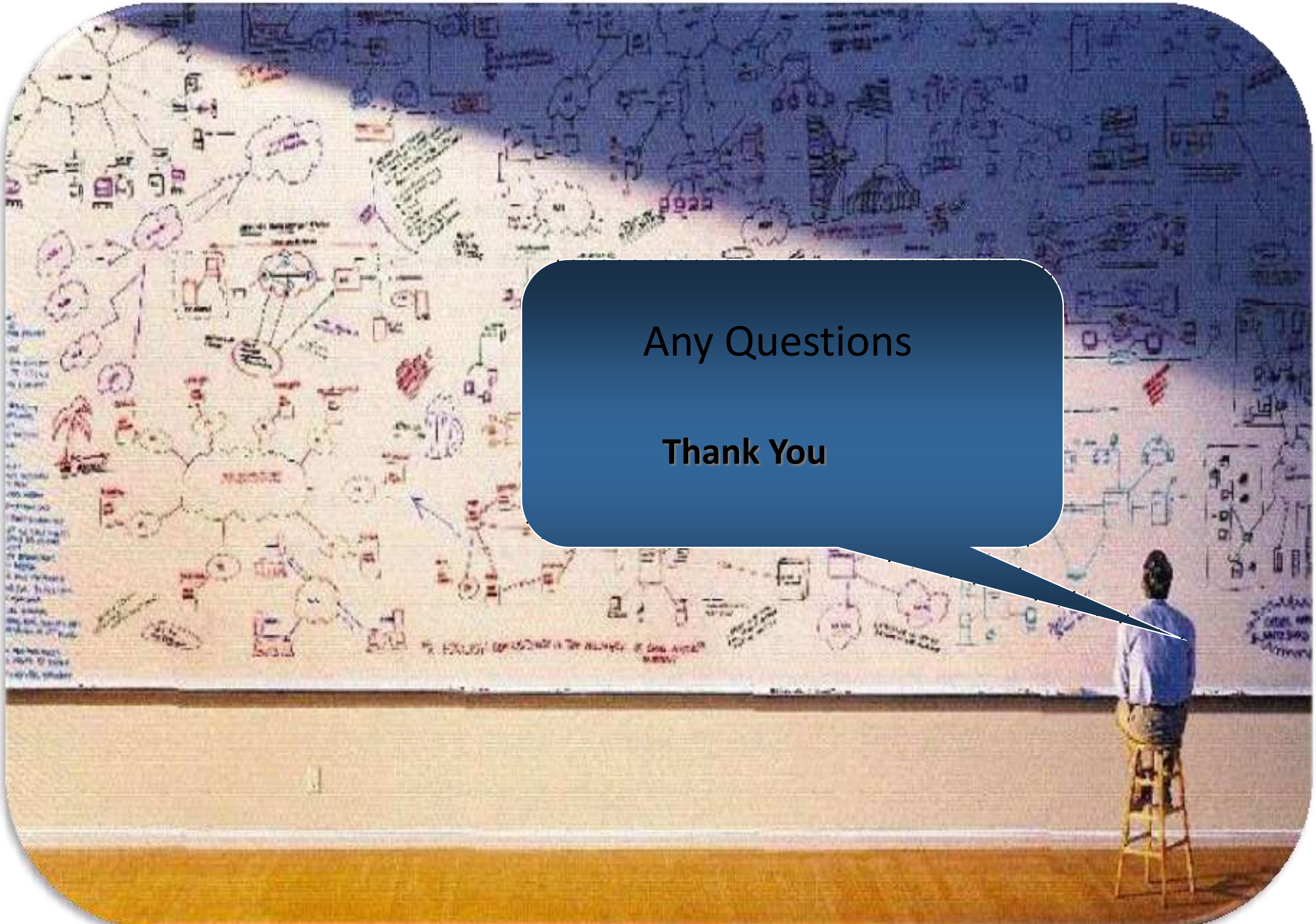
Sediment supply (clay, silt + sand)

- Not really known, but…….
  - **Inflow of water often means significant inflow of fine sediment**
  - **Sediment availability controlled by surface crusting ? – dry lake can often mean well developed, rough crusts**

positive or negative dust anomalies

Conclusions

- In this study the important land surface features with respect to desert dust aerosol modeling is considered for eleven-year simulation using the regional climate model RegCM that is coupled with both of CLM and BATS. Significant influence of land surface parameterization on desert aerosols emission with regional climate model is detected. The surface processes conditions online coupled with Regional Climate Model RegCM are demonstrate their impacts to increase 10-m wind speed that in turn demonstrated their ability to increase the desert dust emission and aerosol optical depth.
- The result shows that in spring and summer, ReBAT shows the largest aerosol optical depth which are simulated over MENA region and southern fringes of the Saharan desert and parts of West Africa with seasonally 0.5 -1.5. These areas continue being active in the remaining months of the year, although peak AOD decrease per season in most areas. In comparison with the satellite aerosol optical depth it is noticed that the largest systematic discrepancy is found between ReCLM and SeaWiFS in all seasons and with MISR and MODIS in spring season, due simply to the use of different calibrations and may be the role of cloud. In addition to the satellite AOD differences, the raised differences from CLM and BATS parameterization on AOD from both simulations.


Any Questions
Thank You