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Dust-radiation interactions: from weather to climate

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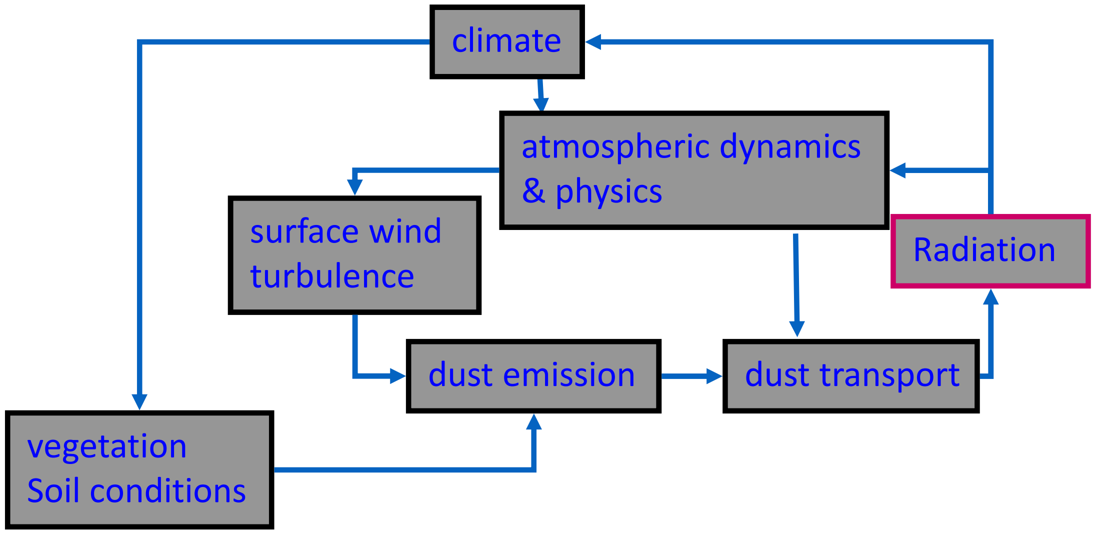
26/06/2017

9th ICAP Meeting, Lille France

Dust-radiation interactions

- Regional Short-term effects (NWP ?)
- Regional Climate / optical properties

History



Direct radiative forcing of dust (wide range of results)

Tegen and Lacis (1996)
Sokolik and Toon (1996)
Quijano *et al.* (2000)
Woodward (2001)
Myhre *et al*. (2003)
……

Dust has a recognizable Impact on large-scale dynamics

Geleyn and Tanré (1994)

AGCM (4º lat. x 5º lon.)

Miller and Tegen (1998) examined the radiative effect using prescribed dust distributions.
Perlwitz et al. (2001) and Miller et al. (2004) interactively coupled a dust-radiation in a GCM

Numerical Weather Prediction

Kischa et al. (2003); Haywood et al., (2005) suggest that inclusion of radiative effects of dust could improve weather prediction
Rodwell and Jung (2008) seasonal forecasting

Dust regional on-line models

Pérez et al. (2006): radiative forcing, NWP and feedbacks
Helmert et al., (2007): Radiative forcing
Ahn et al (2007) and Park et al. (2008): Radiaitve forcing and Feedbacks
Heinold et al. (2008): Radiaitve forcing and Feedbacks
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Pérez et al. (2006, JGR)

Interactive dust-radiation modeling: a step to improve weather forecasts

Following the idea of improving weather forecasts

Incorporate dust-radiation
2-way interaction into Eta/DREAM
for solar and terrestrial wavelengths

Atmosphere → Dust → Radiation → Atmosphere

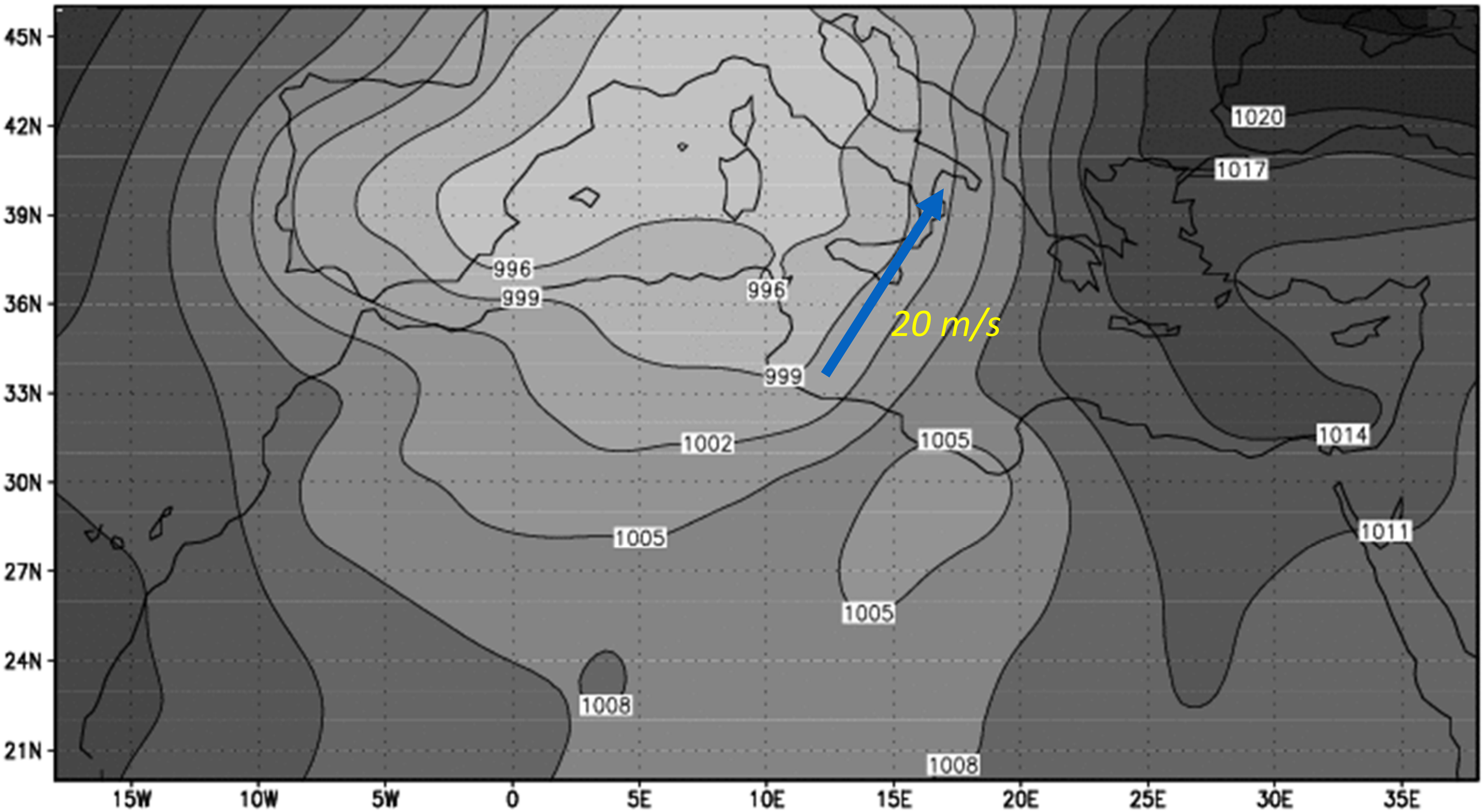
Perform study case of April 2002
major dust storm over the Mediterranean

1. CAN WE IMPROVE THE WEATHER FORECAST ??

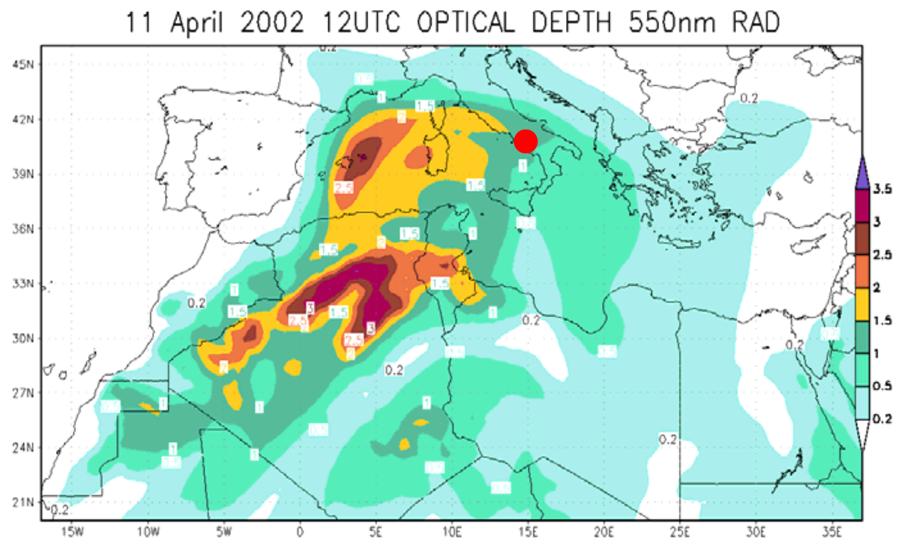
2. Mineral dust feedbacks?

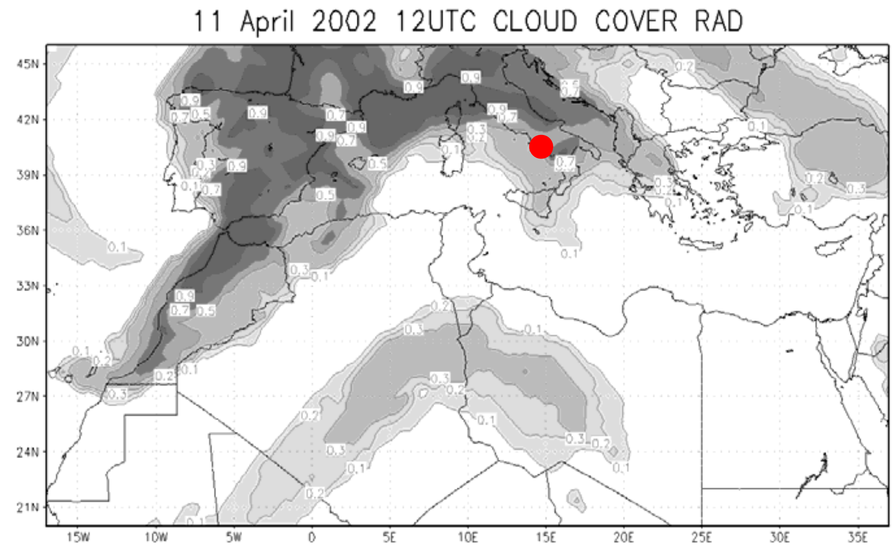
APRIL 2002 DUST OUTBREAK

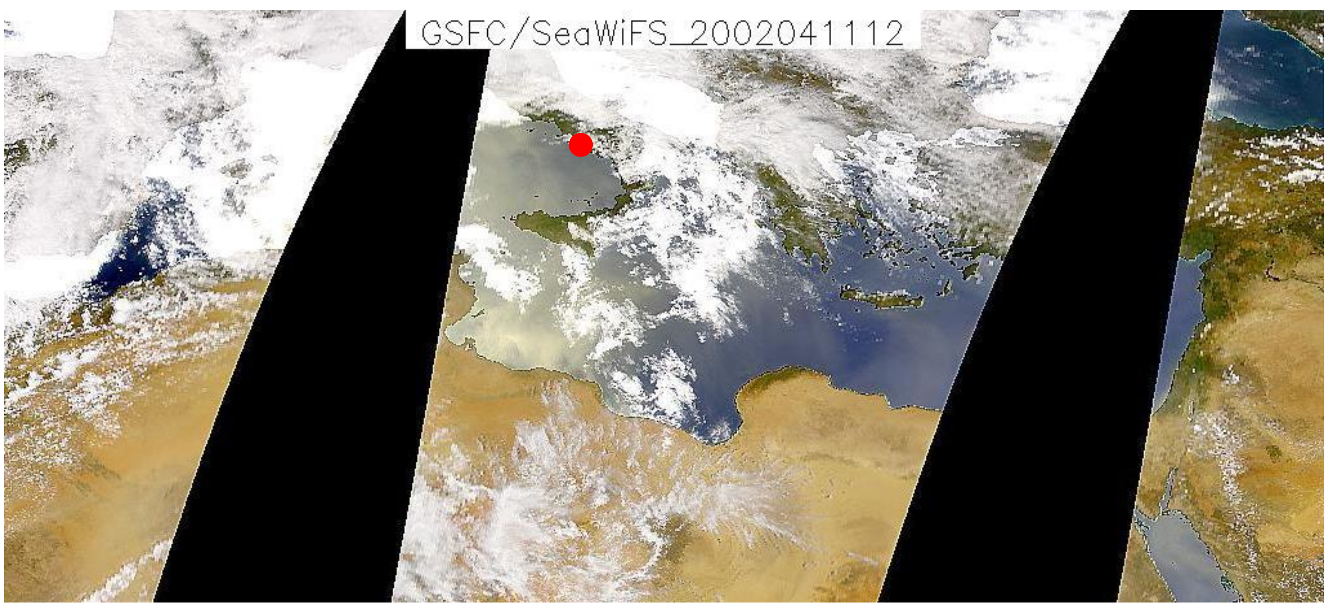
MSL pressure 12 April at 12 UTC

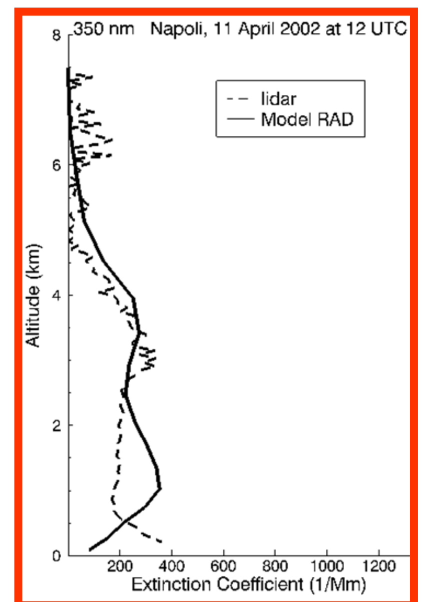


11 April 2002



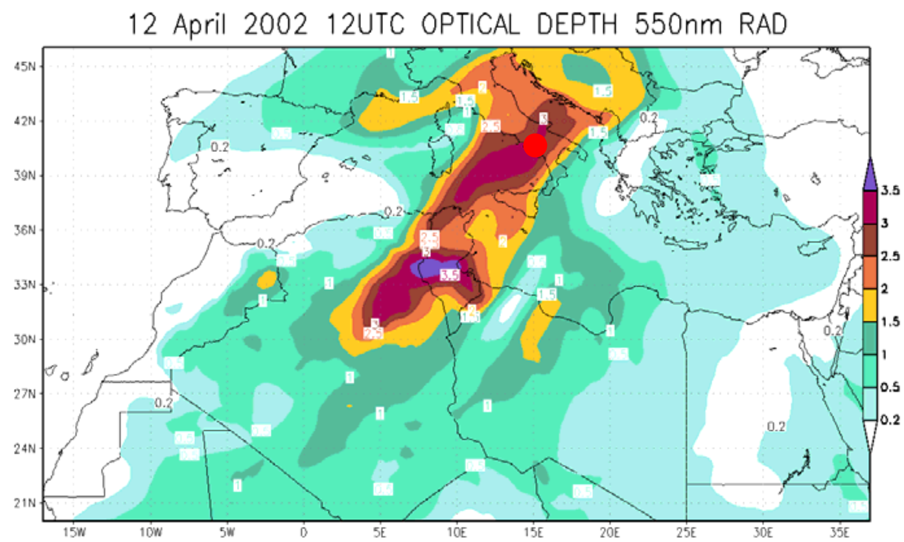


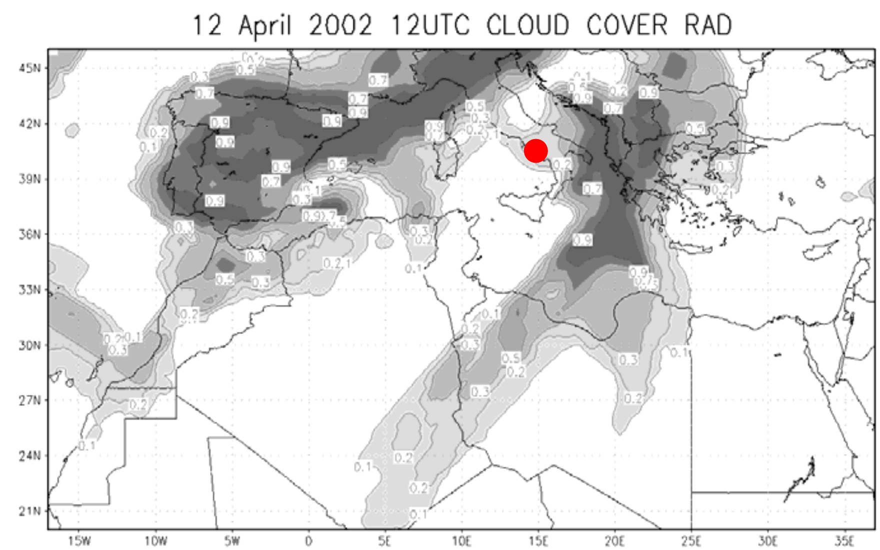


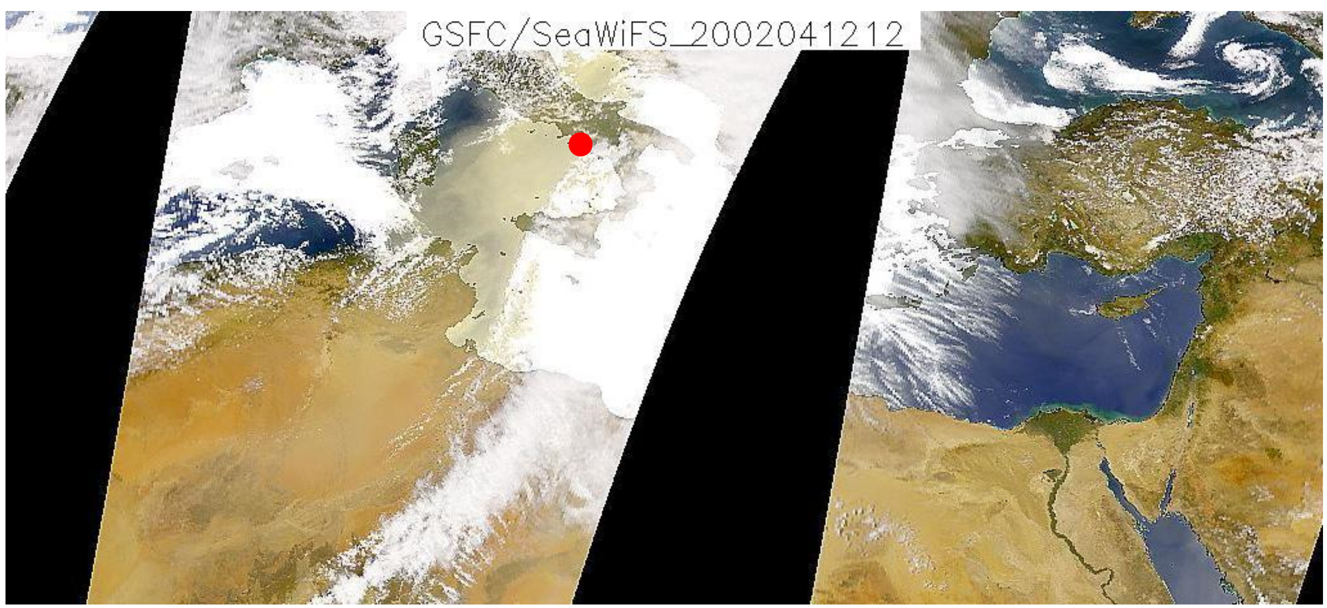


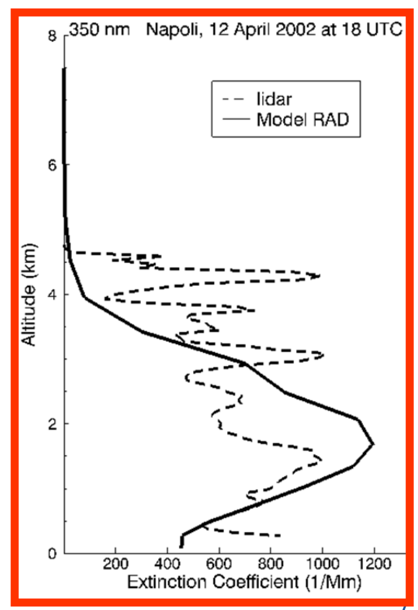
● *Napoli Raman Lidar*

12 April 2002



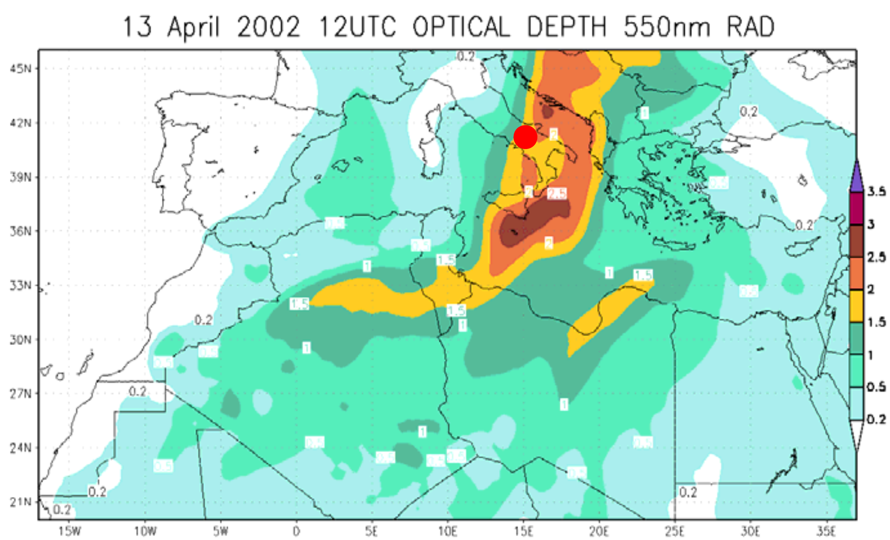


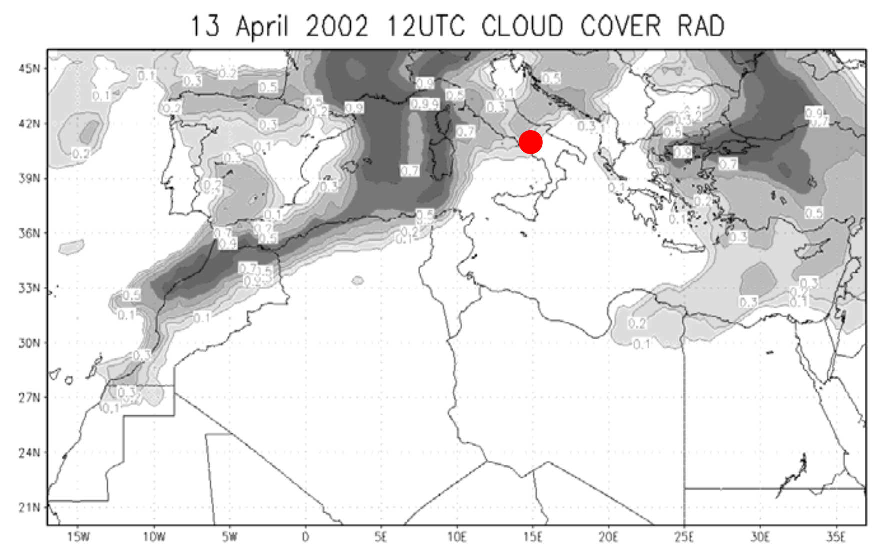


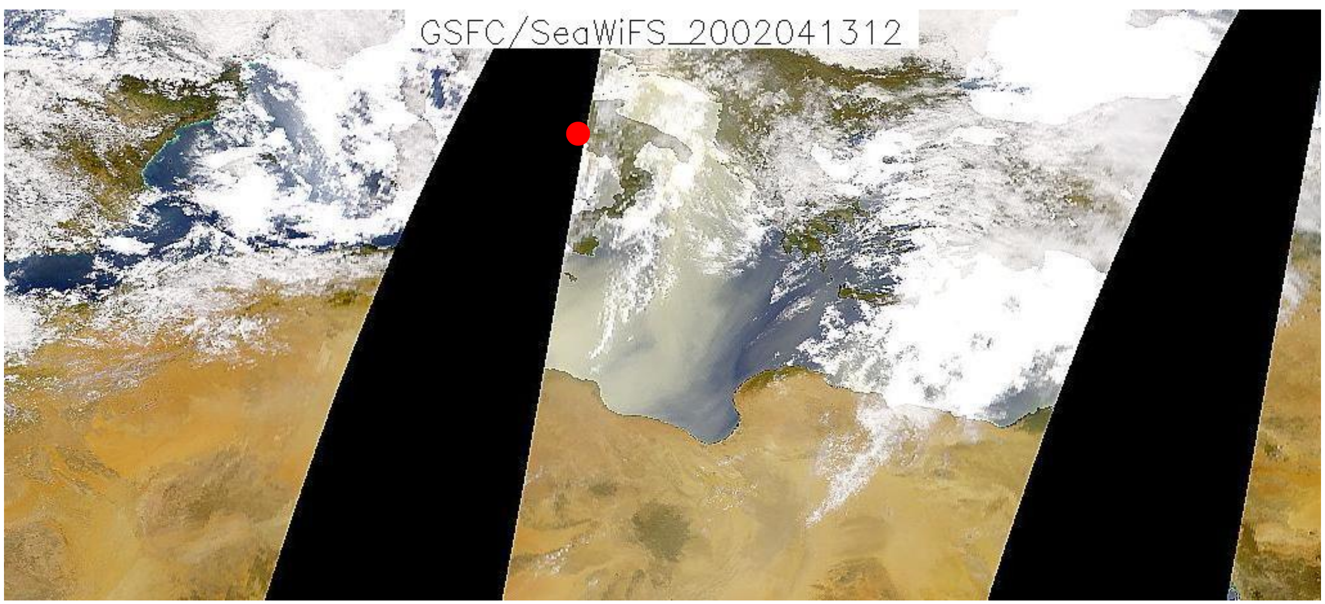


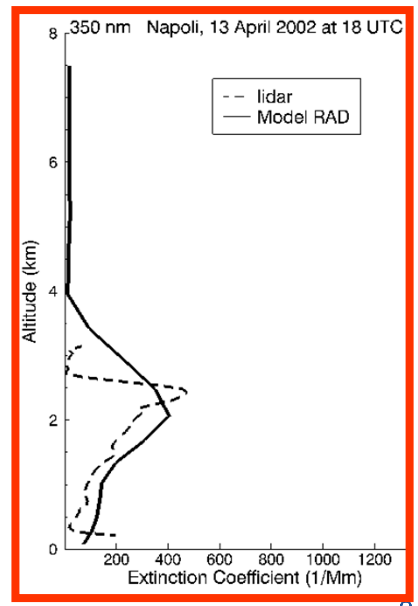
● *Napoli Raman Lidar*

13 April 2002





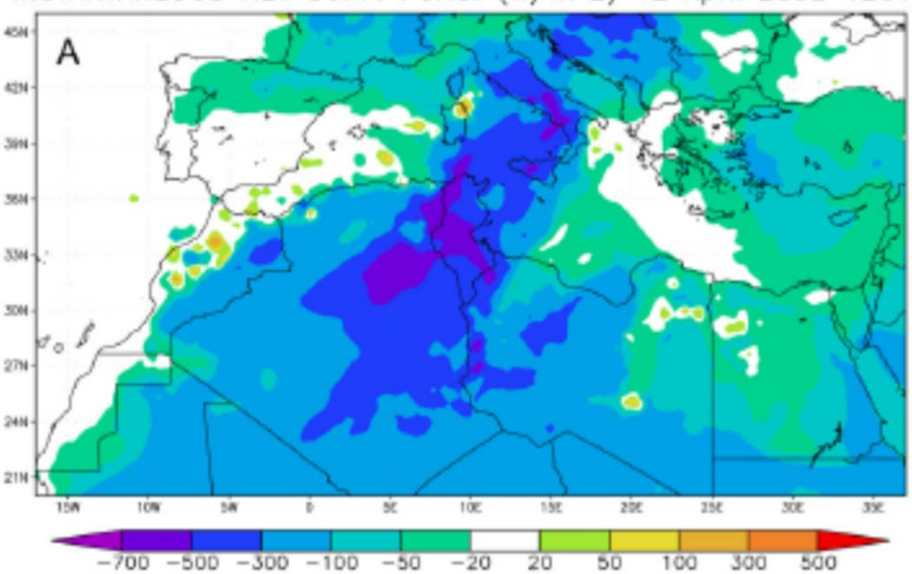




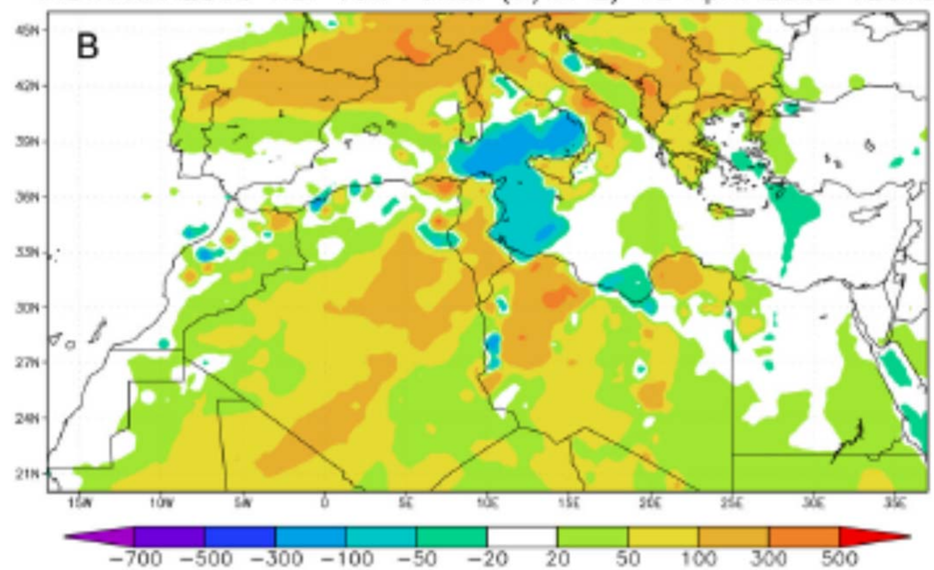
● *Napoli Raman Lidar*

INSTANTANEOUS RADIATIVE FORCING AT 12 UTC

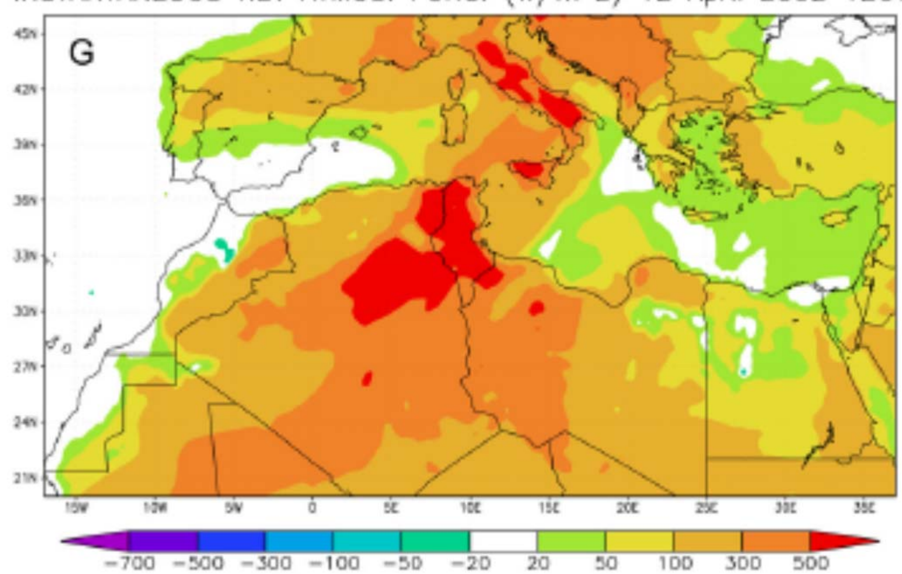
INSTANTANEOUS NET SURF. FORC. (W/m^2) 12 April 2002 12UTC



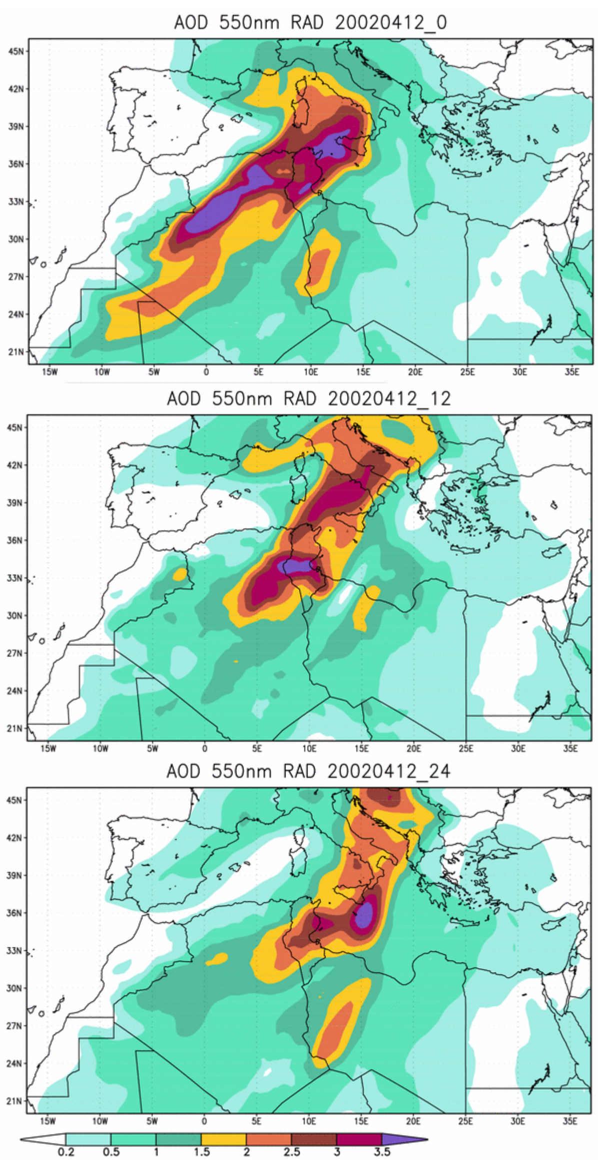
INSTANTANEOUS NET TOA FORC. (W/m^2) 12 April 2002 12UTC

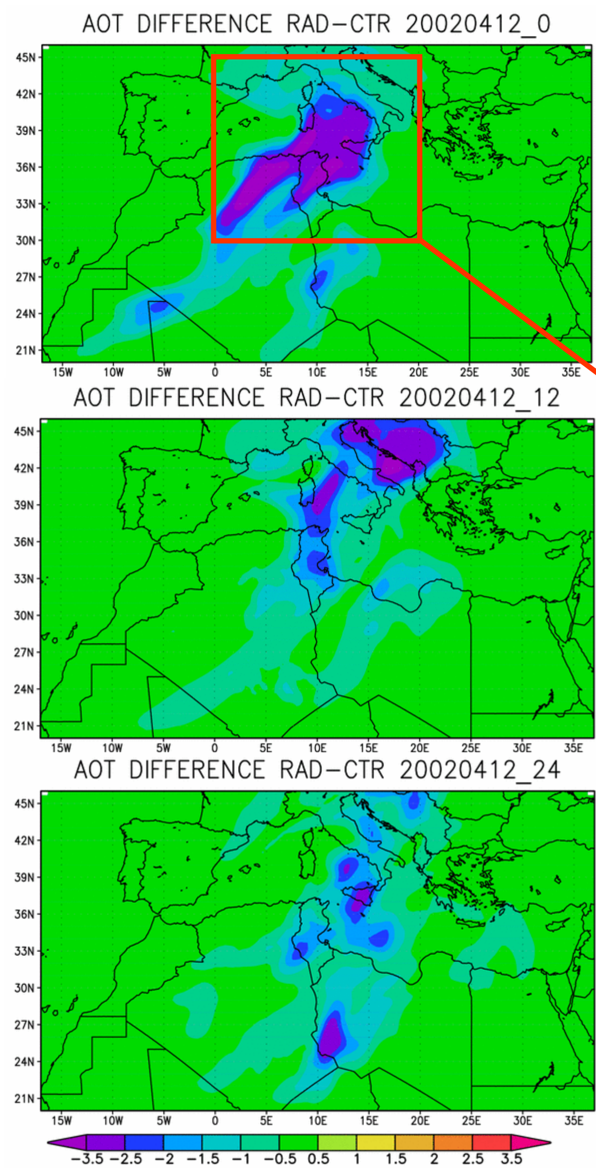


INSTANTANEOUS NET ATMOS. FORC. (W/m^2) 12 April 2002 12UTC

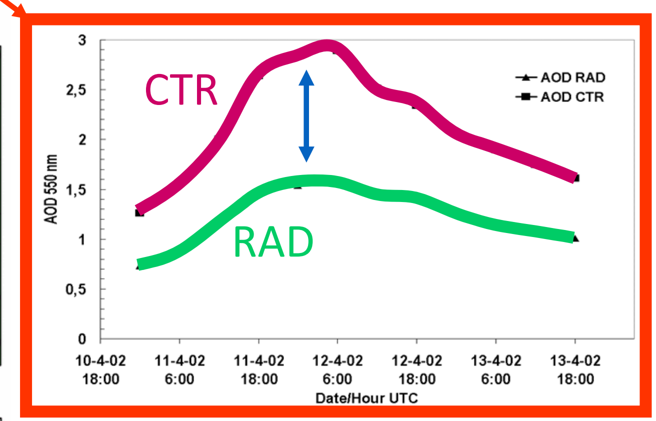


FEEDBACKS UPON EMISSION AND AOD



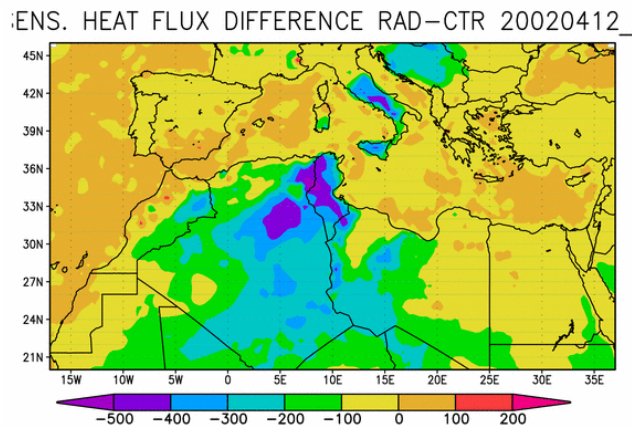


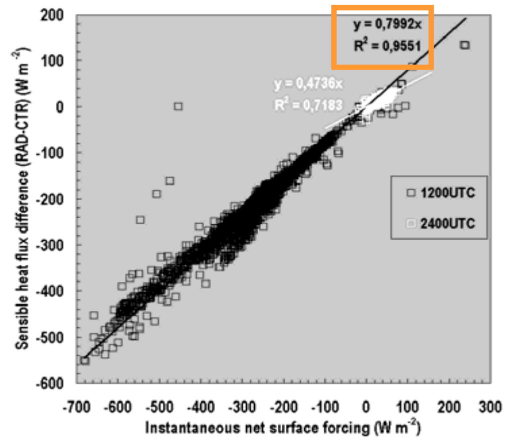
- 35-45 % reduction of the average AOD over the area covered by the main dust plume



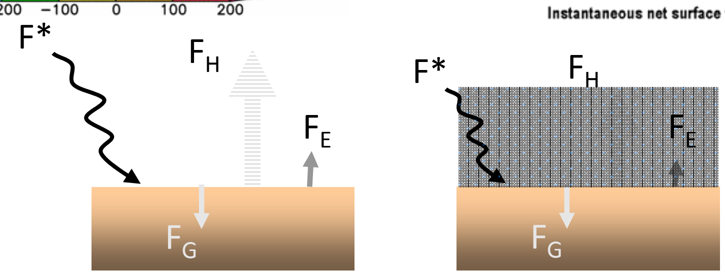
- Strong average negative feedback upon dust emission by dust radiative forcing

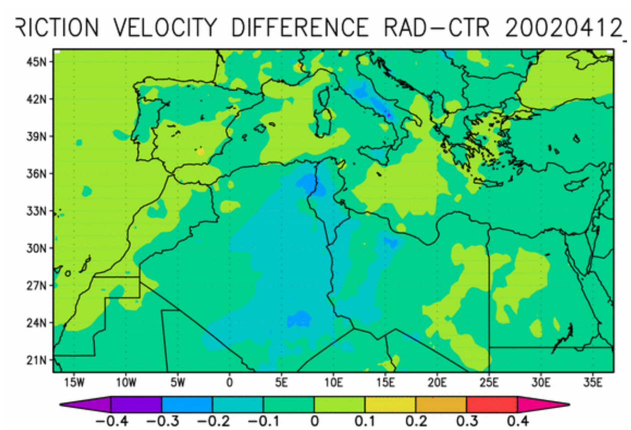
12 April at 12 UTC

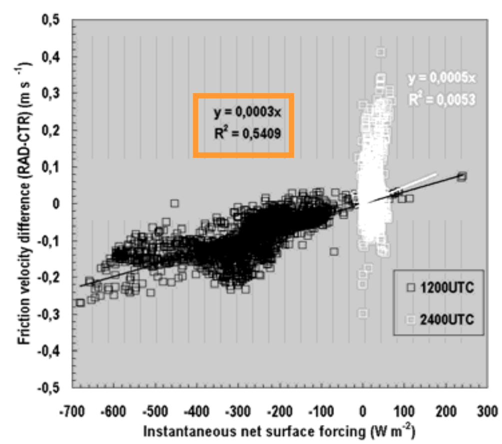




- Negative surface forcing mainly balanced by reduction in turbulent sensible heat flux into the atmosphere



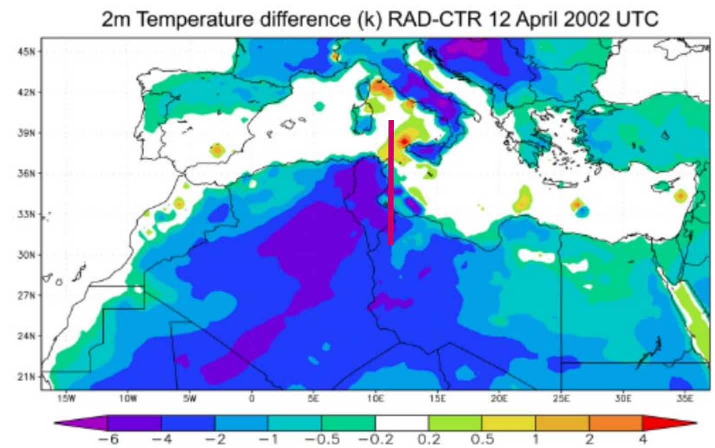


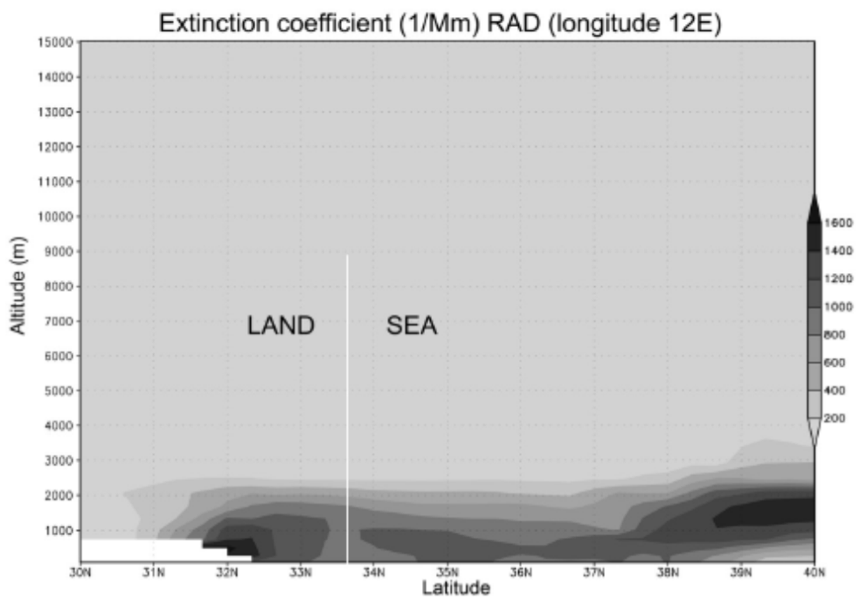


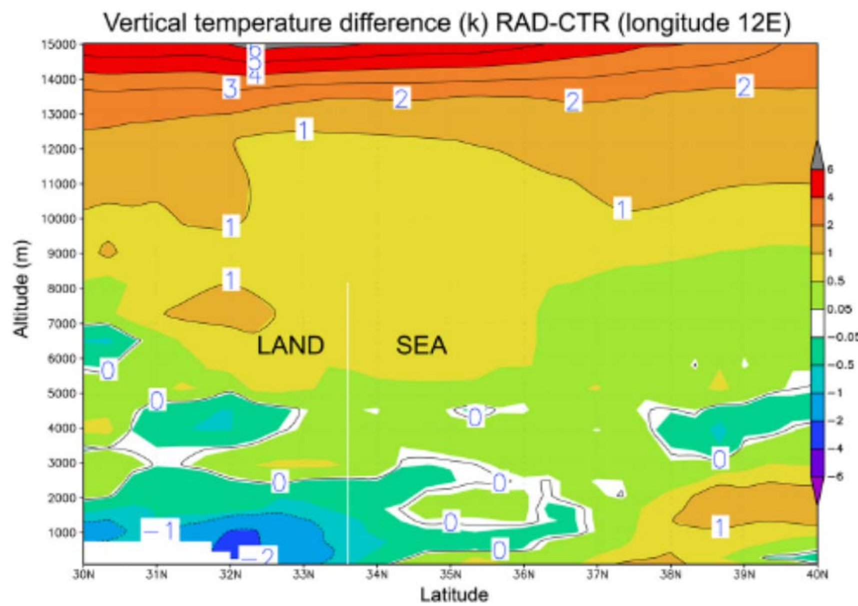
-In RAD mixing is reduced (more stability) and downward momentum is reduced

- Friction velocity significantly correlates with surface forcing during the day

Effects on temperature

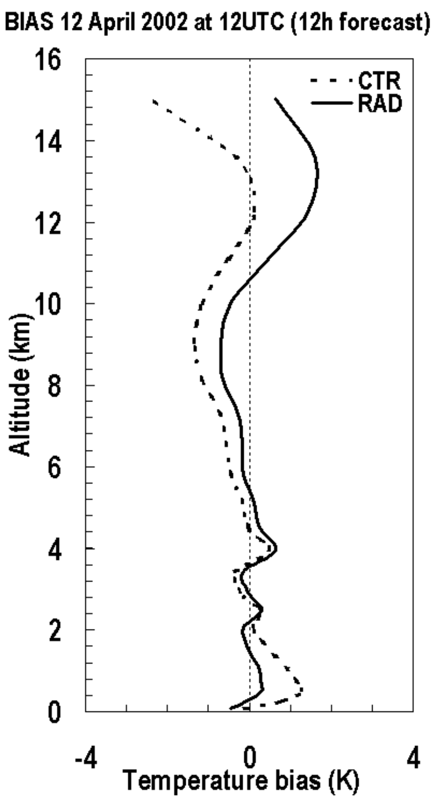




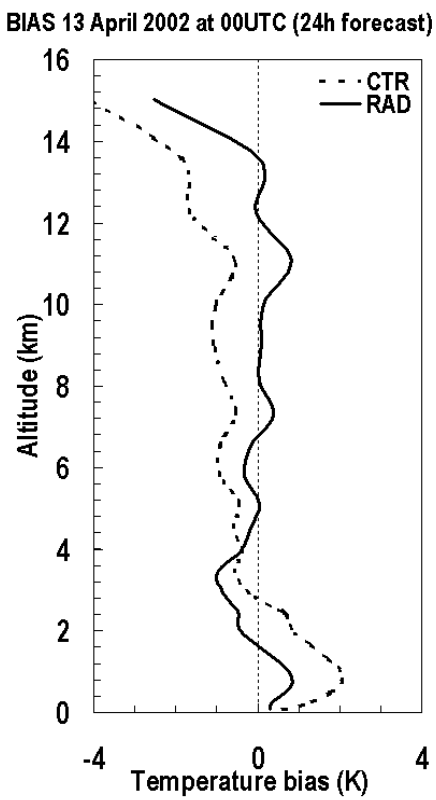


NUMERICAL WEATHER PREDICTION
Can we improve it?

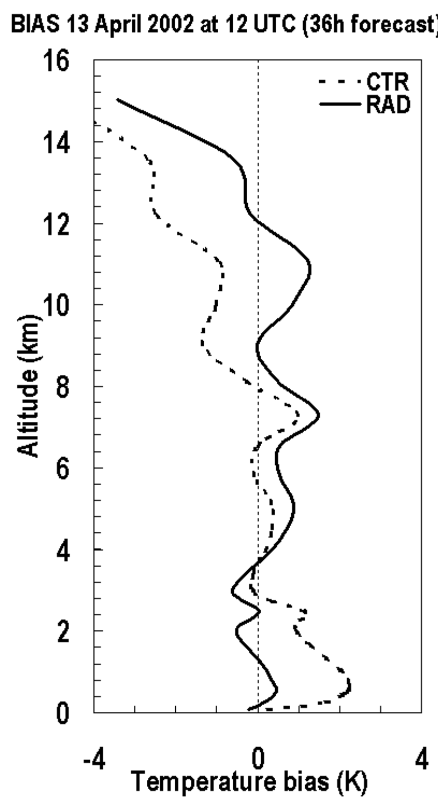
Atmospheric temperature forecasts
RAD and CTR evaluated against objective analysis data



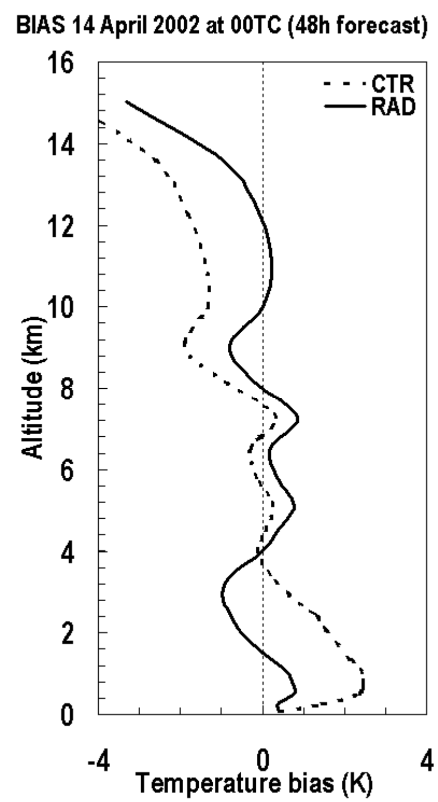
12 h Forecast



24 h Forecast

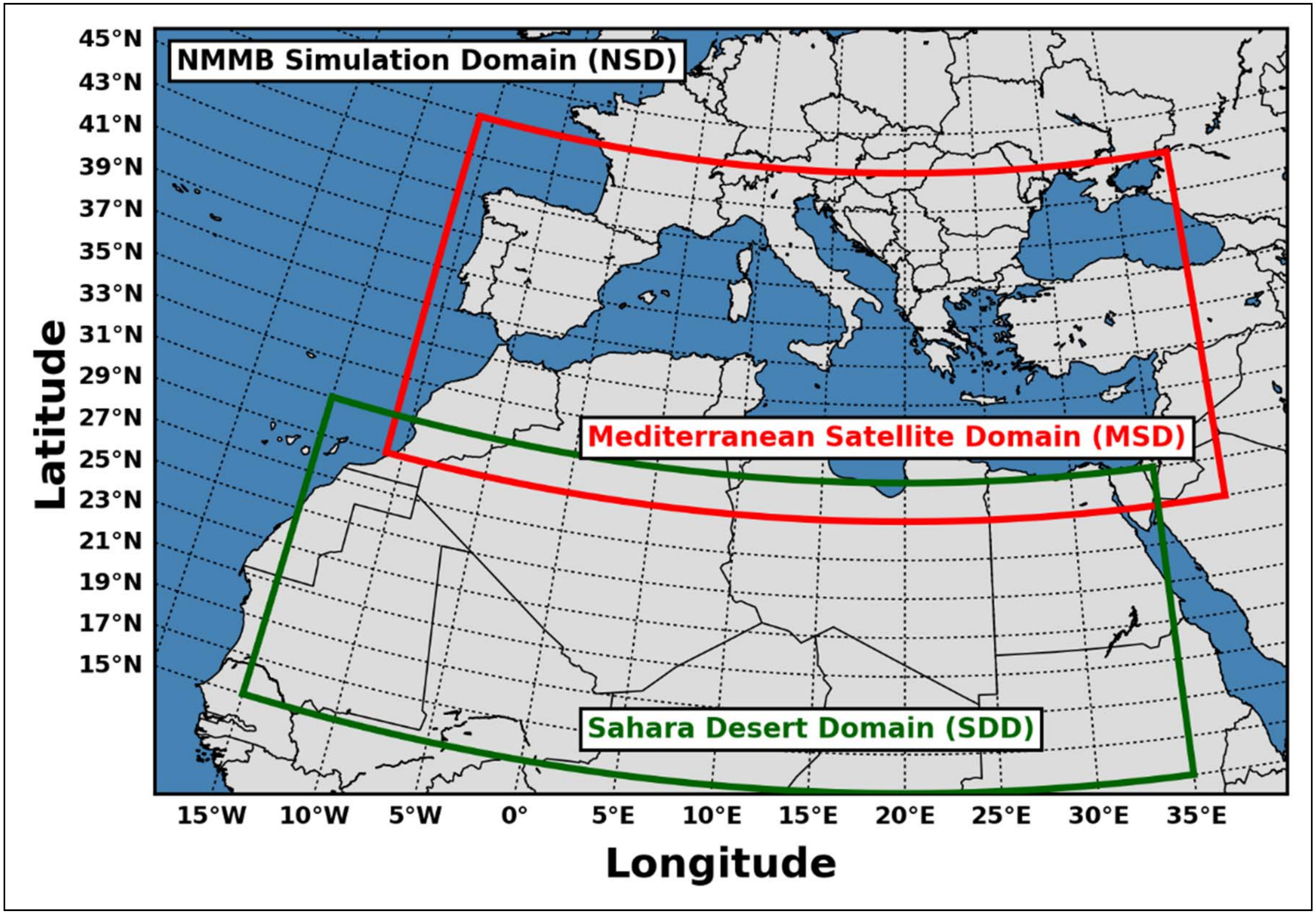


36 h Forecast



48 h Forecast

Gkikas et al., in prep



NSD: NMMB/BSC-Dust short-term (84 h) forecasts
MSD: Identification of desert dust outbreaks

Selection of desert dust outbreaks at regional level (MSD domain)

Selection criteria

- Days where at least 30 pixel-level DD episodes (either strong or extreme) have been identified by the satellite algorithm (Gkikas et al., 2012; 2015)
- Calculation of the mean regional AOD considering only pixels undergoing a DD episode
- Ranking of days based on dust outbreaks' intensity (MODIS-Terra regional AOD)
- 20 widespread and intense Mediterranean desert dust outbreaks are analyzed

Statistics

	Dust outbreaks	Percentage (%)	MSD Sector
Winter	5	25%	Eastern – Central
Spring	11	55%	Central – Eastern
Summer	4	20%	Western
Autumn	0	0%	-
Total	20	100%	

Intensity of dust outbreaks: 0.74 (31/7/2001) – 2.96 (2/3/2005)

Identification of desert dust (DD) episodes

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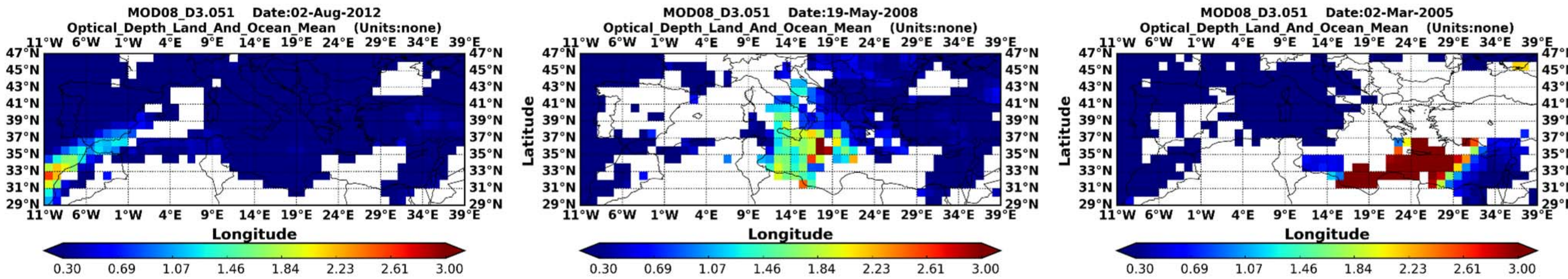
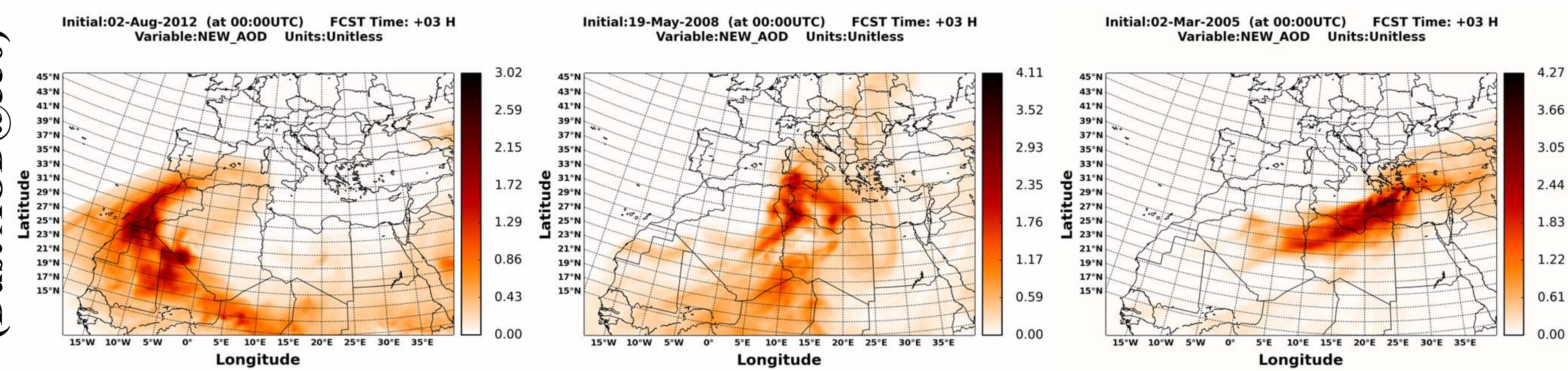
2 August 2012 **19 May 2008** **2 March 2005**

MODIS-Terra (AOD@550)



Satellite observations of the desert dust outbreaks

NMMB (Dust AOD@550)



NMMB short-term (84 hours) regional simulations initialized at 00 UTC of the desert dust outbreak day

Regional DREs
(20 desert dust outbreaks)

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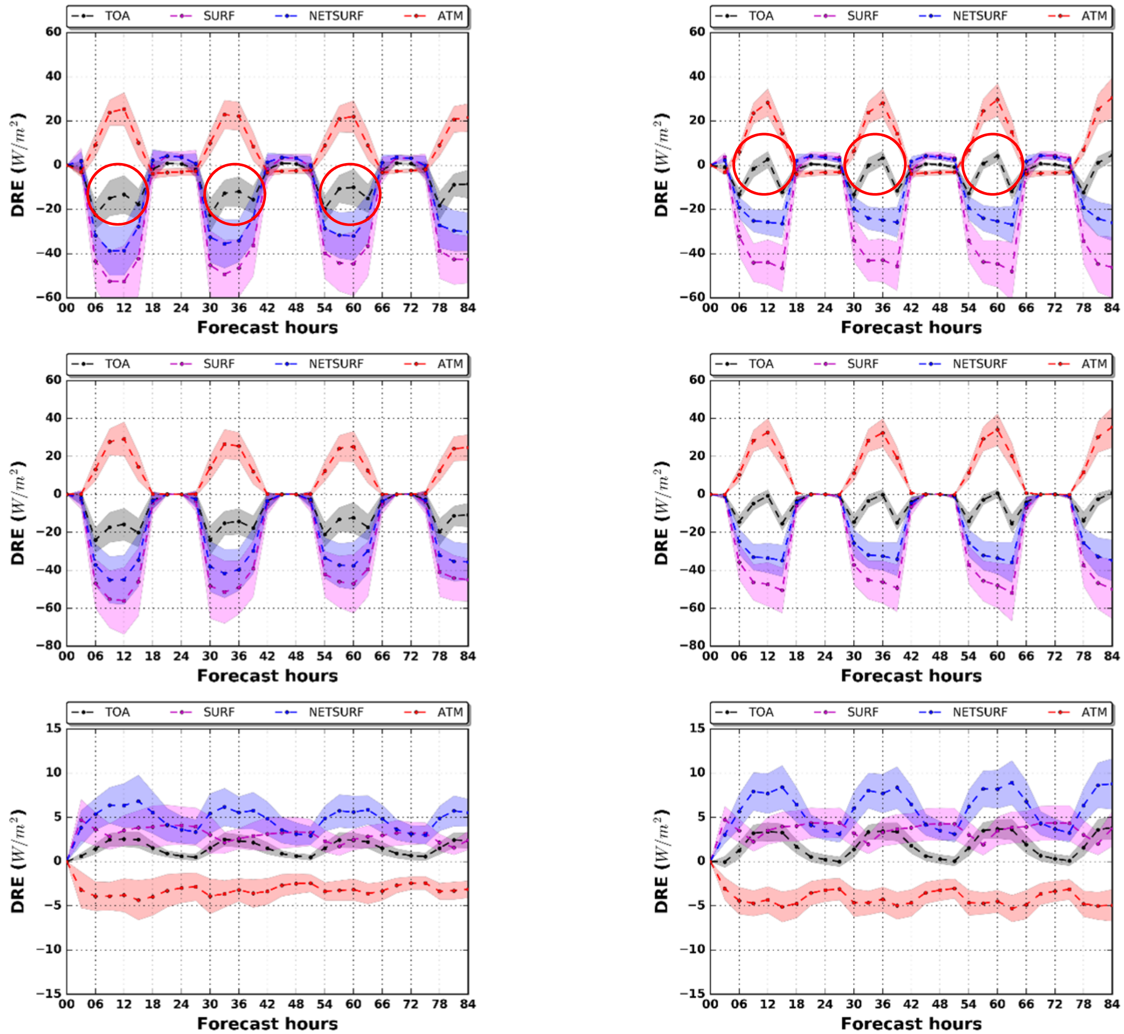
MSD **SDD**

NET (SW+LW)

SW

LW



Surface **cooling**
(up to 60 W/m^2)
Atmospheric **warming**
(up to 30 W/m^2)
Planetary **cooling**
(up to 20 W/m^2)

Slightly **higher** SW DREs compared to NET DREs

Reverse LW effects of **lower** magnitude compared to SW ones

Predominance of SW effects

Impact on temperature at 2 meters: 2nd August 2012

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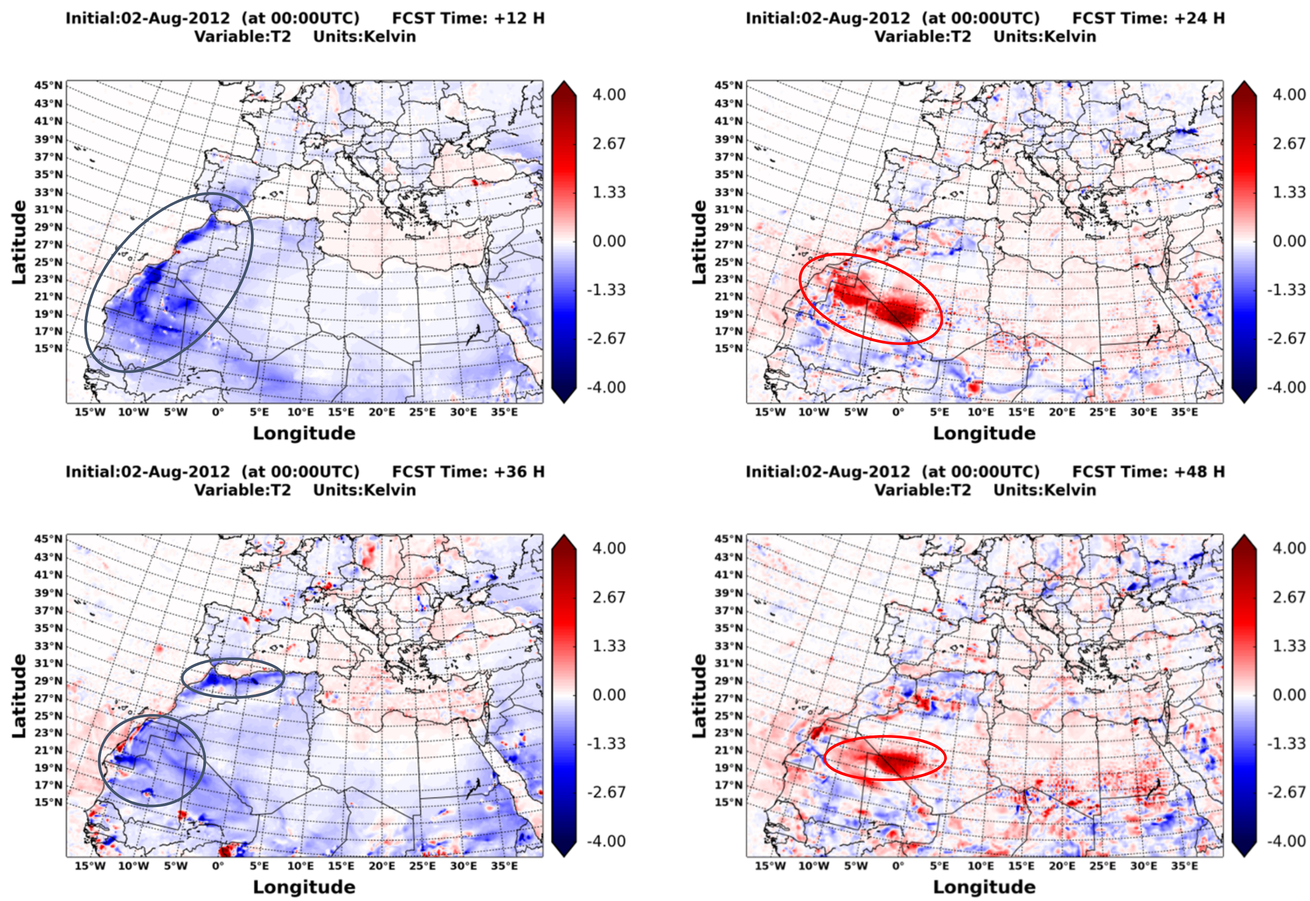
Daytime | **Nighttime**

+12H | +24H

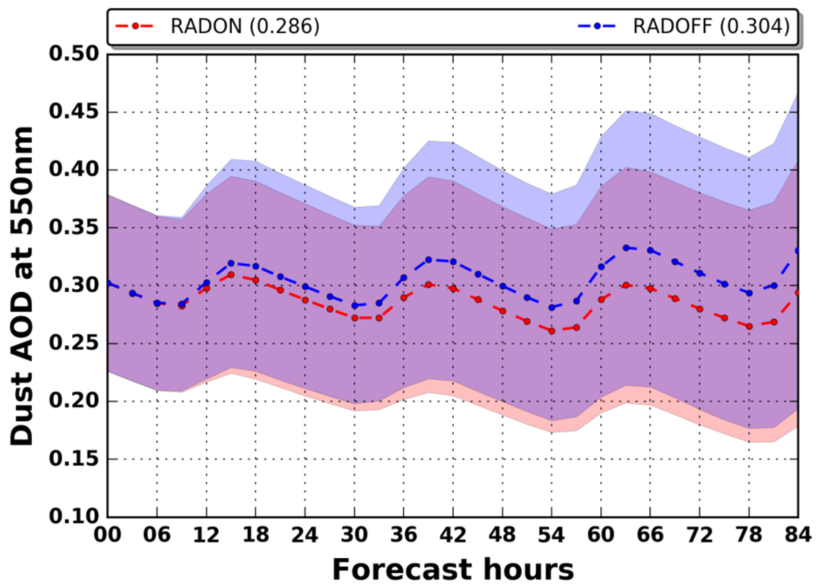
+36H | +48H



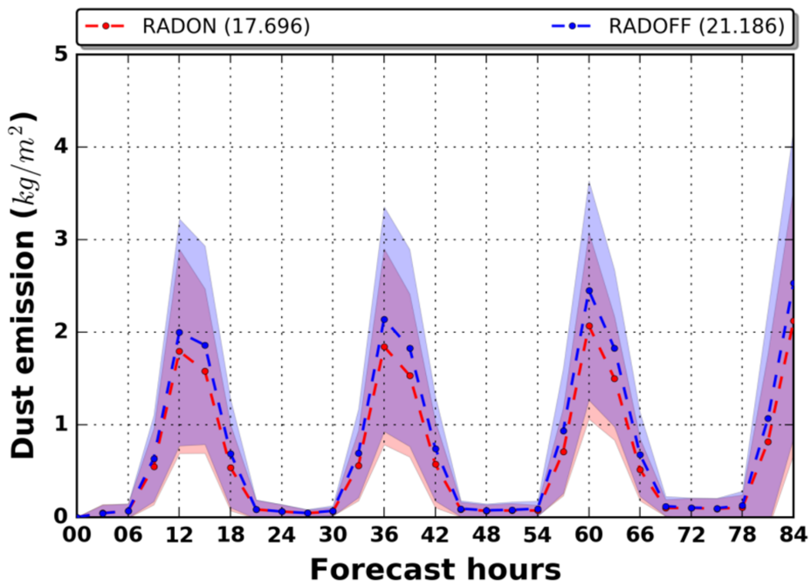
- SW DREs ➔ **Reduction** of temperature at 2 meters (up to 4 ºC) during daytime
- LW DREs ➔ **Increase** of temperature at 2 meters (up to 3-4 ºC) during nighttime
- Reduction of the diurnal temperature range

Feedbacks on dust AOD and dust emission (NSD)

Dust AOD@550



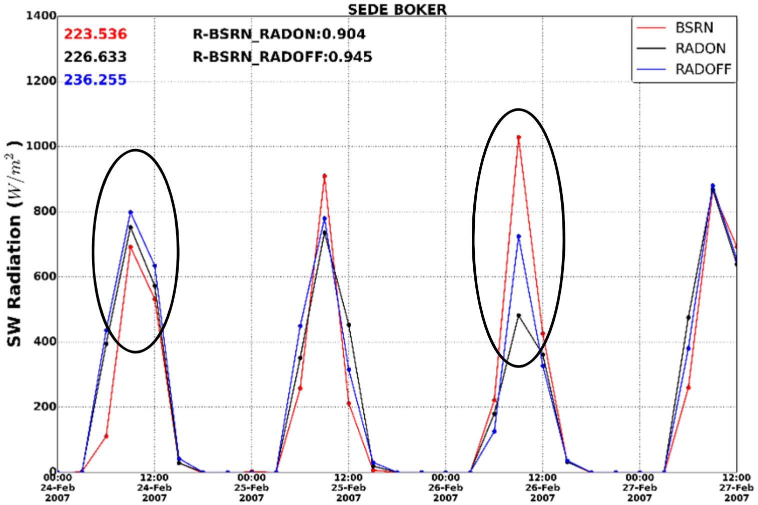
Dust emission



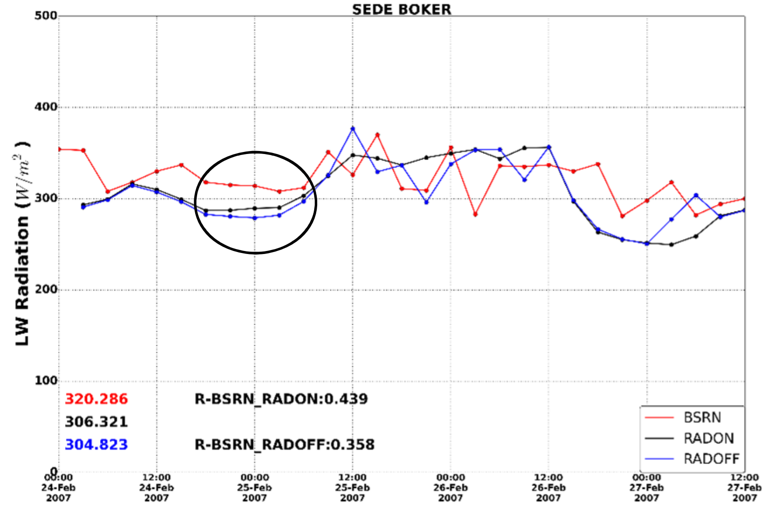
- Reduction of dust emission at noon-late noon for the RADON simulation
- Reduced outgoing surface sensible heat flux from the ground
- **Reduction by 19.7%** of the regional (NSD) dust emission over the forecast cycle (84 hours)

Downwelling SW and LW radiation: Comparison NMMB – BSRN

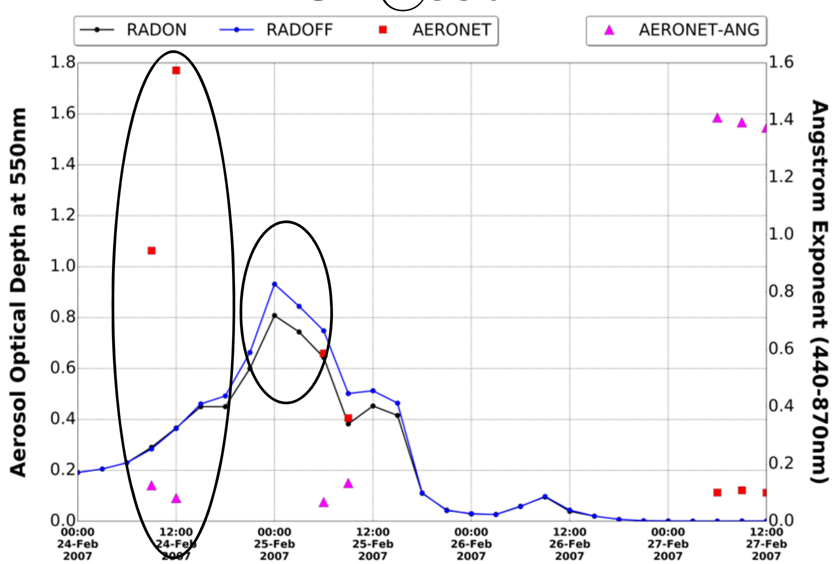
SW radiation



LW radiation



AOD@550nm



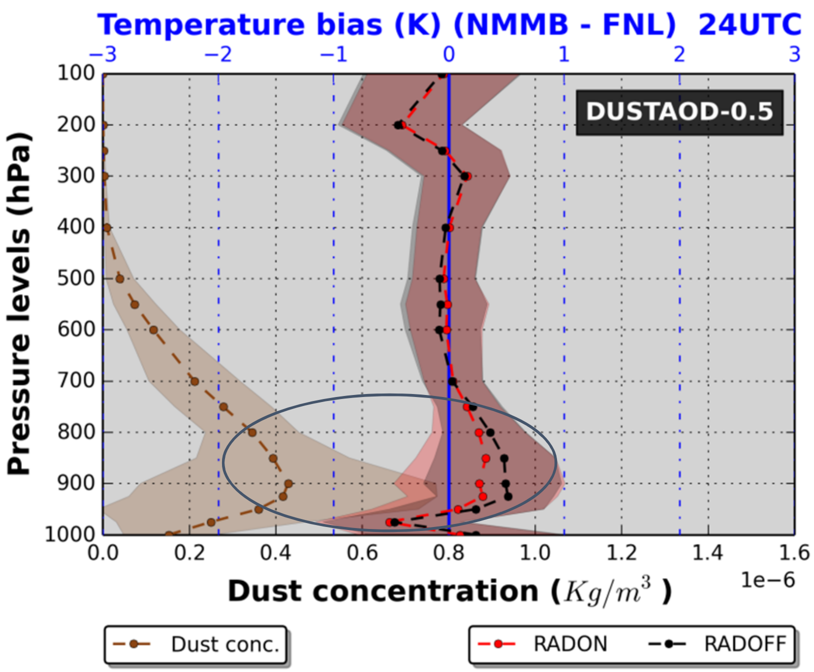
Sede Boker (Israel) | 24 Feb. 2007

- Misrepresentation of the dust outbreak by the model ➔ Overestimation (by 30-40 Wm^{-2}) of the SW radiation
- LW effect ➔ Reduction (by 20-30 Wm^{-2}) of the LW underestimation by the model (RADON)
- Underestimation (by 300-600 Wm^{-2}) of the SW radiation by the model ➔ Development of low clouds based on model simulations

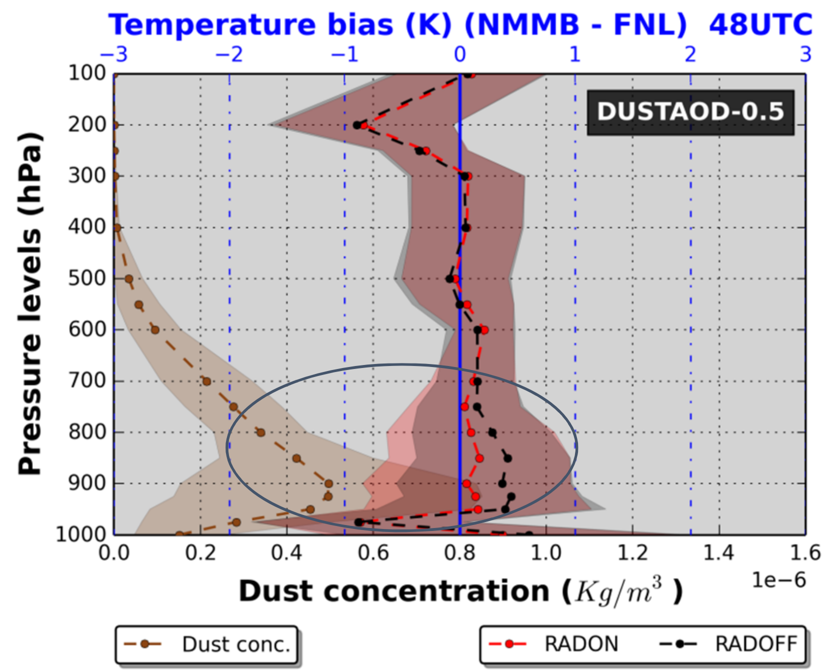
Reduction of NMMB-BSRN differences for the RADON simulation

Temperature vertical profiles: NMMB-FNL (NSD)

+24H



+48H



Dust AOD ≥ 0.5

LW effect → Reduction by 0.2-0.3 ºC, for the RADON simulation, of the model warm biases during nighttime

Goncalves et al., in prep

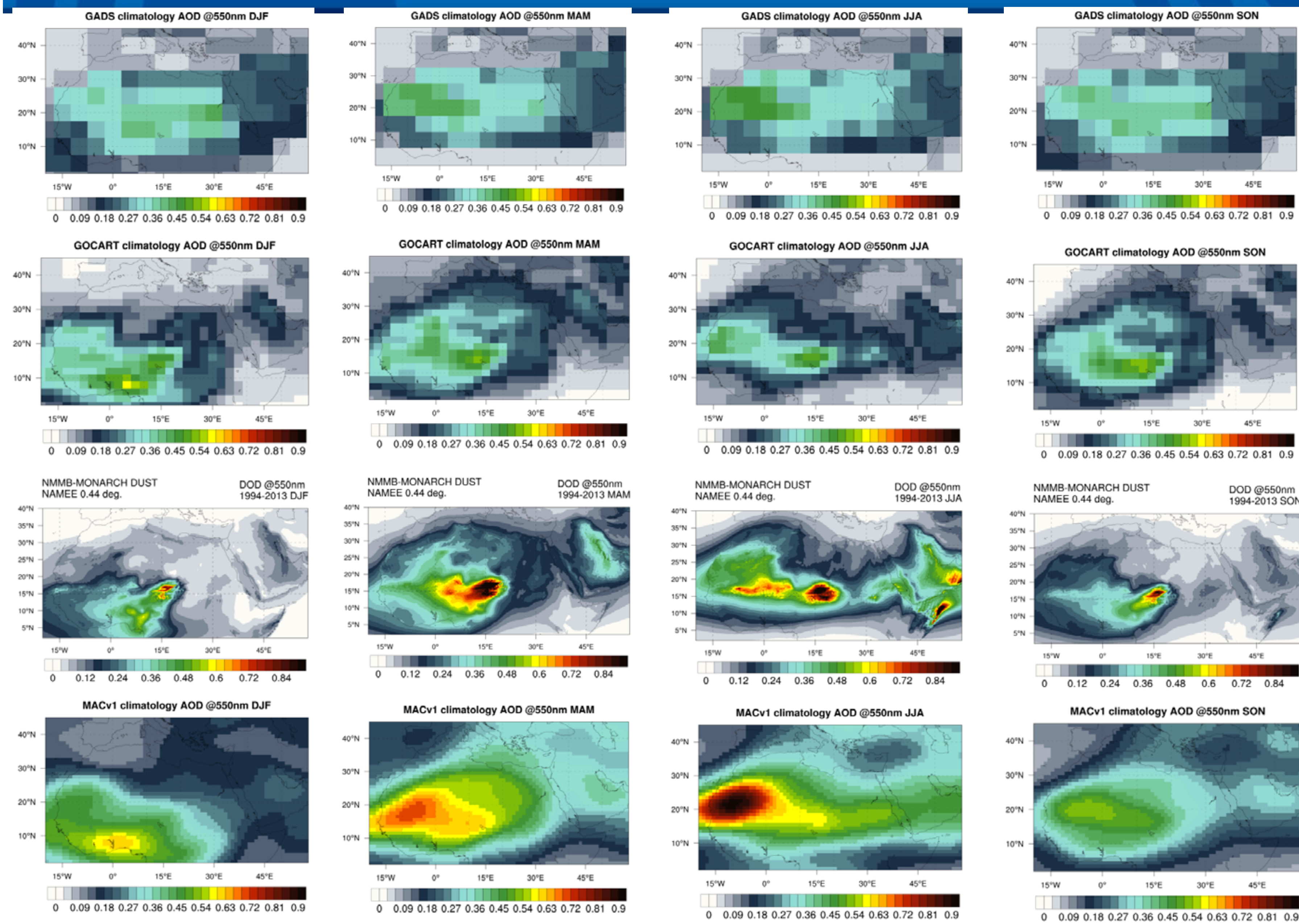
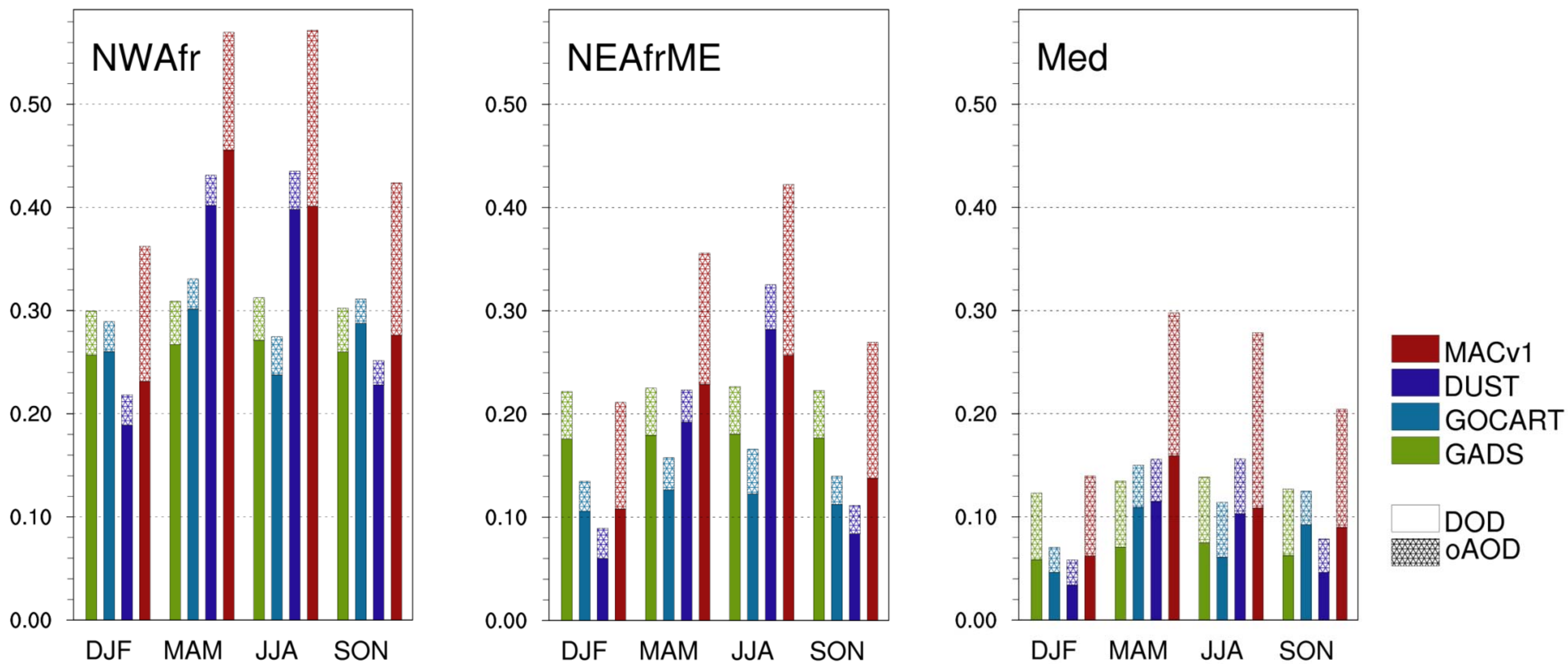
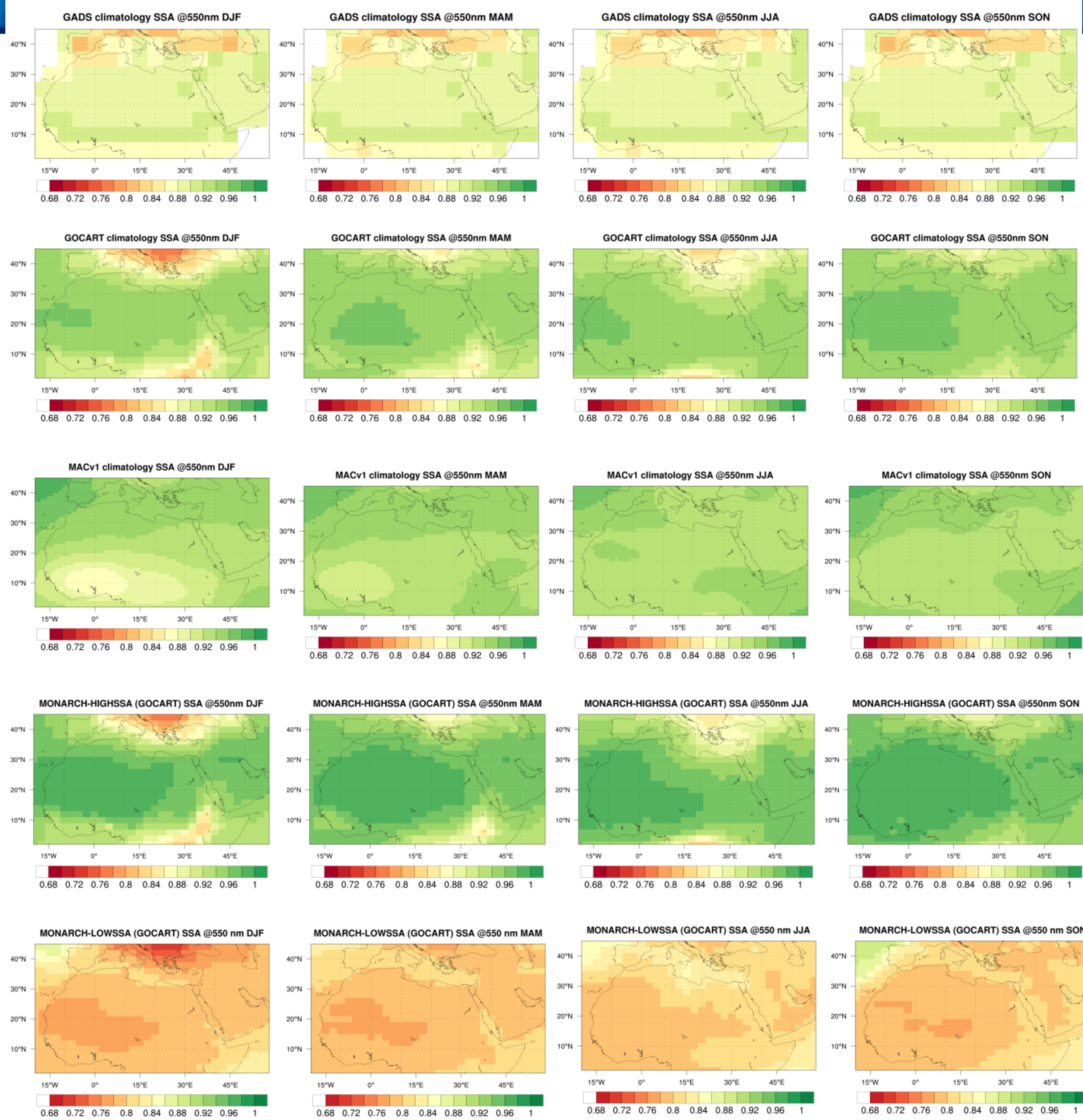
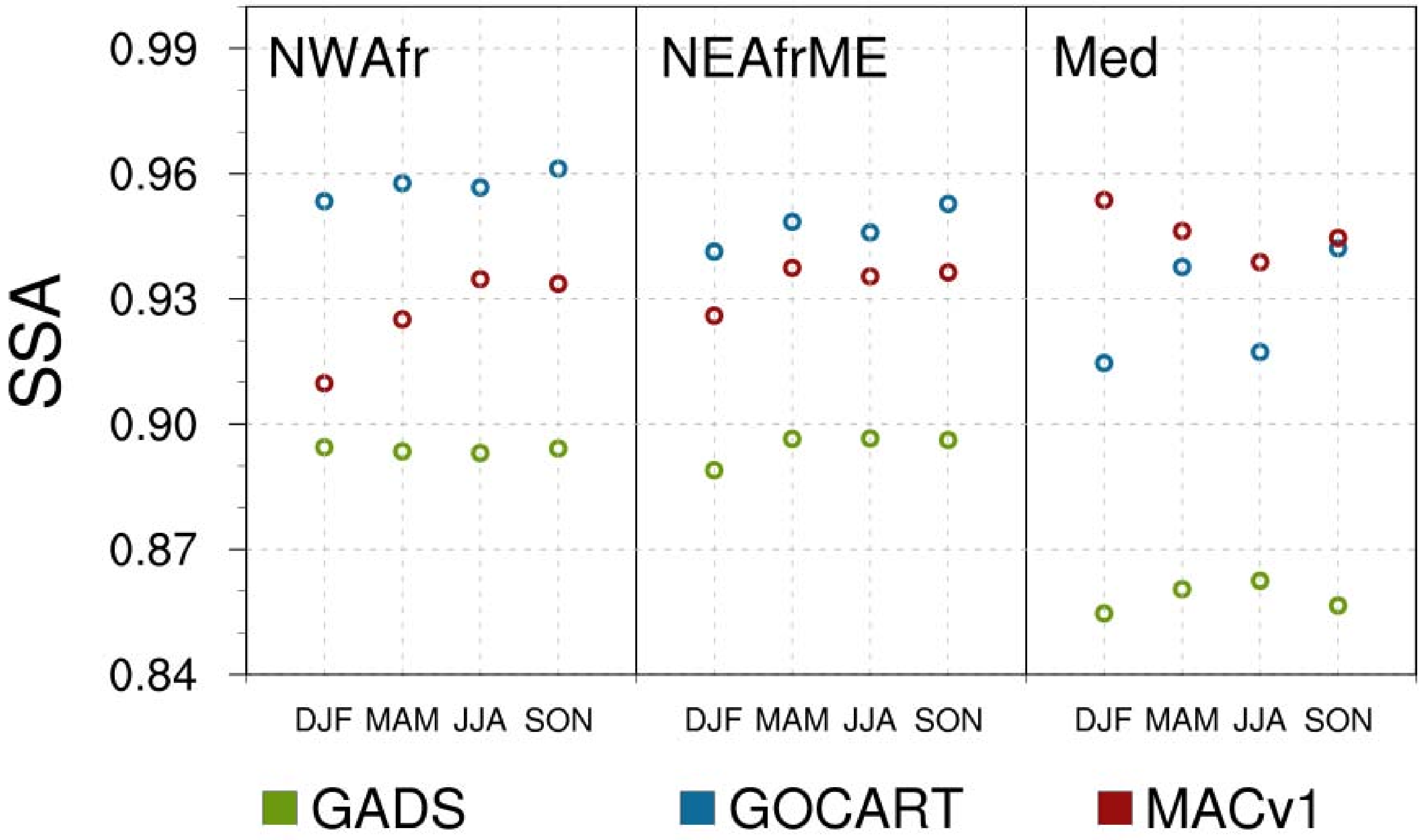


Figure 3. Seasonal mean AOD at 550 nm over NWAfr, NEAfrME, and Med, as defined in the GADS, GOCART, and MACv1 climatologies, as well as the NM-DUST case. MACv1 climatology is included as a reference. Filled boxes represent the mineral dust fraction (DOD), except for MACv1, where they represent all coarse aerosols (dust and sea salt components). NM-DUST DOD considers the seasonal average for the 1994-2013 period, while other AOD (oAOD) is derived from GOCART values.



SSA


GADS climatology SSA @550nm DJF
GADS climatology SSA @550nm MAM
GADS climatology SSA @550nm JJA
GADS climatology SSA @550nm SON
GOCART climatology SSA @550nm DJF
GOCART climatology SSA @550nm MAM
GOCART climatology SSA @550nm JJA
GOCART climatology SSA @550nm SON
MACv1 climatology SSA @550nm DJF
MACv1 climatology SSA @550nm MAM
MACv1 climatology SSA @550nm JJA
MACv1 climatology SSA @550nm SON
MONARCH-HIGHSSA (GOCART) SSA @550nm DJF
MONARCH-HIGHSSA (GOCART) SSA @550nm MAM
MONARCH-HIGHSSA (GOCART) SSA @550nm JJA
MONARCH-HIGHSSA (GOCART) SSA @550nm SON
MONARCH-LOWSSA (GOCART) SSA @550 nm DJF
MONARCH-LOWSSA (GOCART) SSA @550 nm MAM
MONARCH-LOWSSA (GOCART) SSA @550 nm JJA
MONARCH-LOWSSA (GOCART) SSA @550 nm SON
0.68 0.72 0.76 0.8 0.84 0.88 0.92 0.96 1



SSA
0.99
0.96
0.93
0.90
0.87
0.84
NWAfr
NEAfrME
Med
DJF MAM JJA SON
DJF MAM JJA SON
DJF MAM JJA SON
GADS
GOCART
MACv1

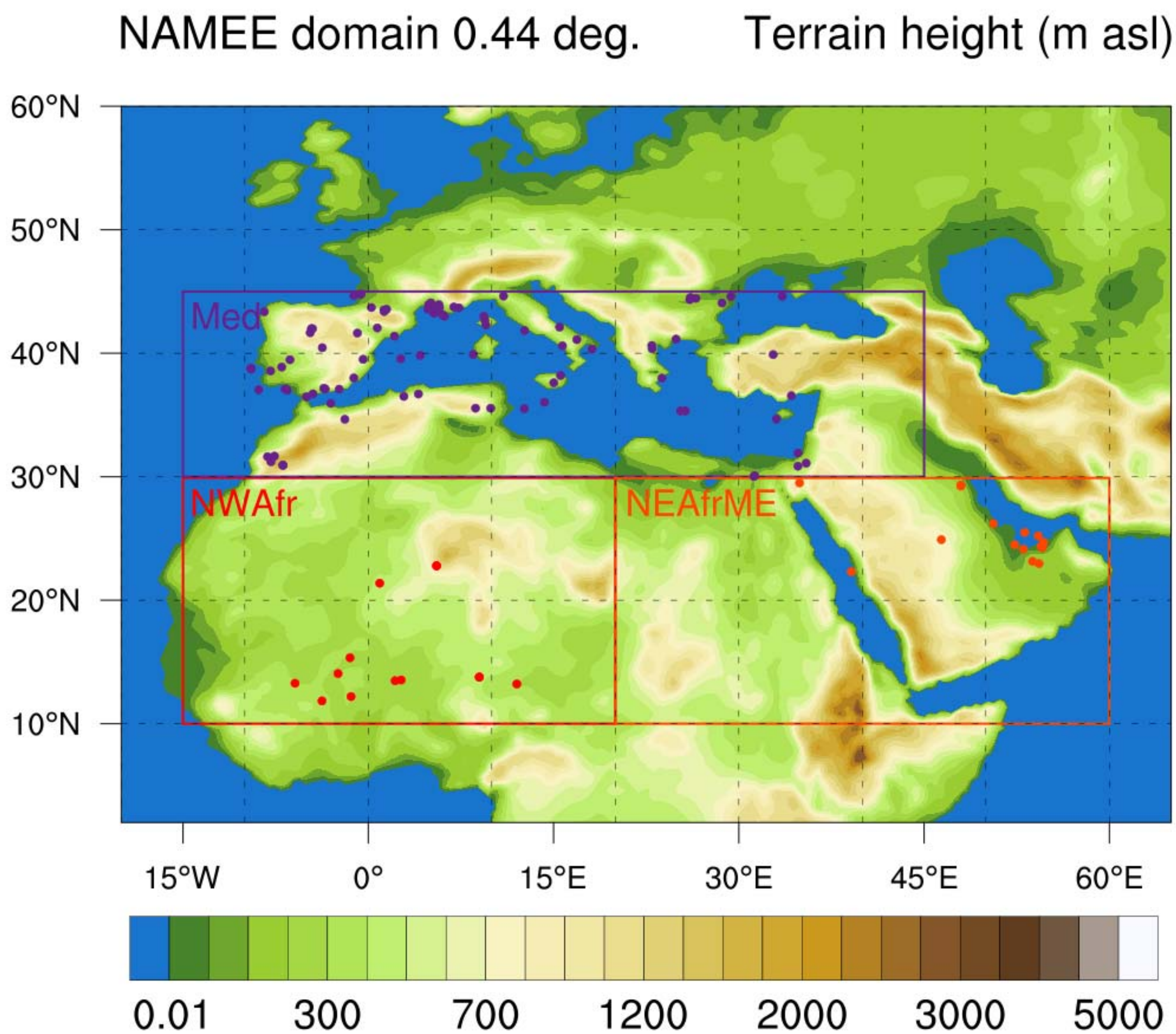
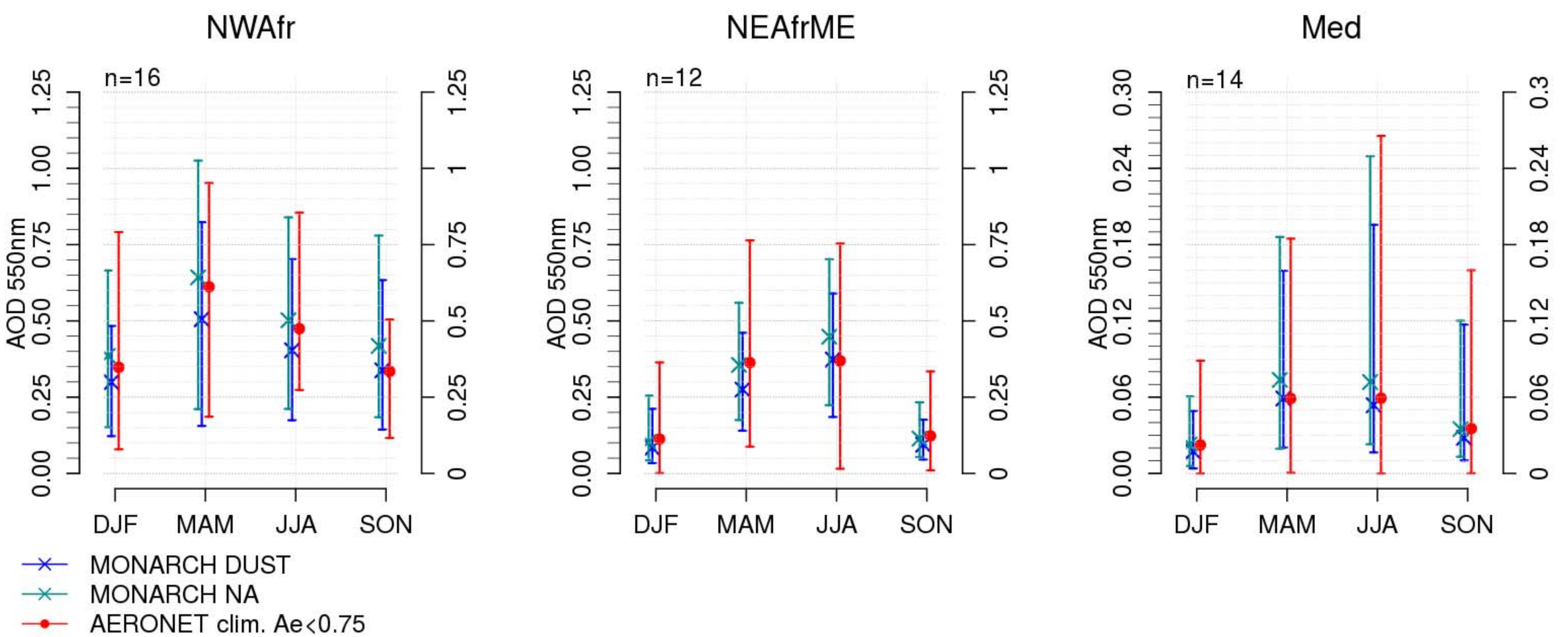
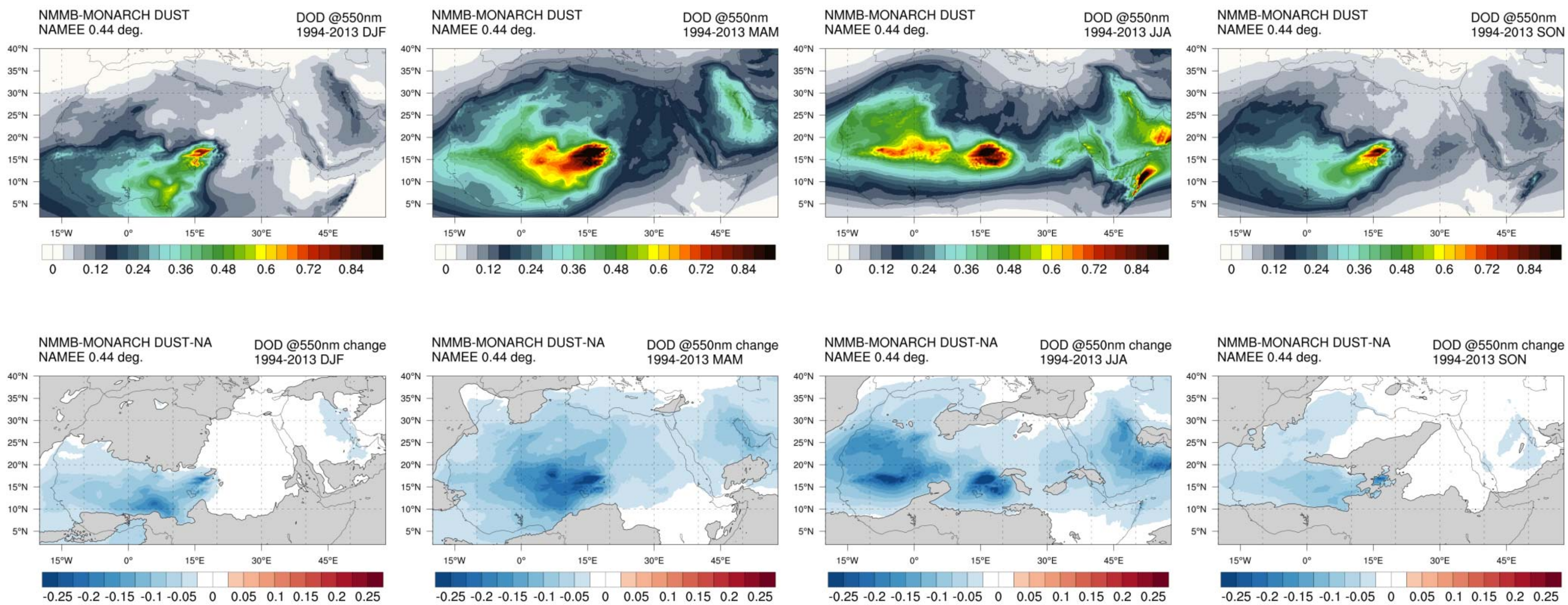

NAMEE domain 0.44 deg.
Terrain height (m asl)
60°N
50°N
40°N
30°N
20°N
10°N
Med
NWAfr
NEAfrME
15°W
0°
15°E
30°E
45°E
60°E
0.01
300
700
1200
2000
3000
5000

Figure 6. Seasonal mean DOD at 550 nm as derived from NM-DUST (coupled to radiation) and NM-NA (not coupled) on the locations of selected AERONET stations averaged over NWAfr, NEAfrME and Med, compared to the corresponding coarse filtered AERONET AOD at 550 nm (Angstrom exponent below 0.75). Error bars represent the 5 and 95 percentiles of the seasonal mean AOD for the stations included in the subdomain. n represents the average number of months included in the calculation of the seasonal means.



Negative feedback upon dust emission



Not statistically significant differences, as assessed by a
two-tailed student’s t-test at a 95% confidence level, are shaded (grey).

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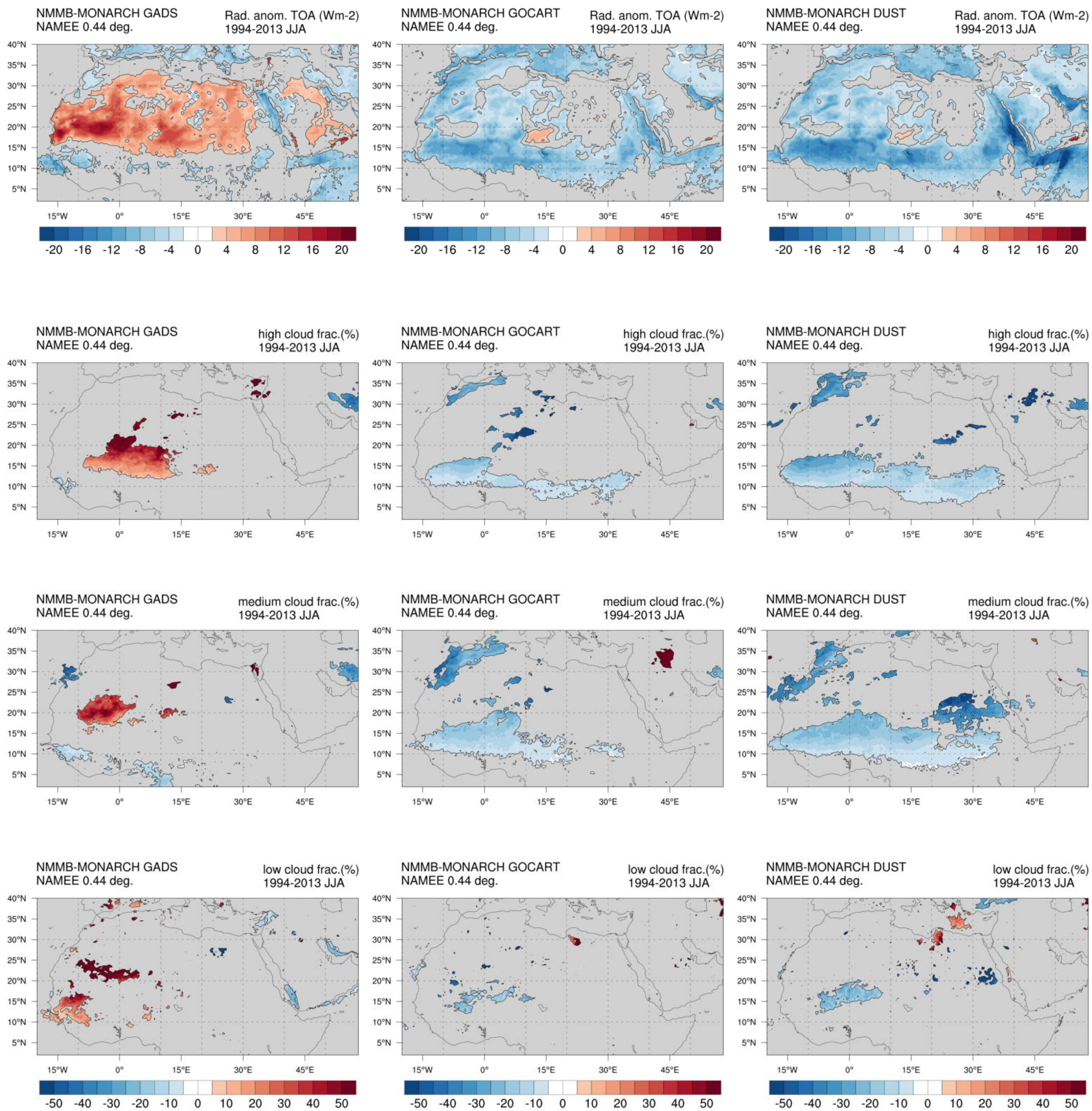


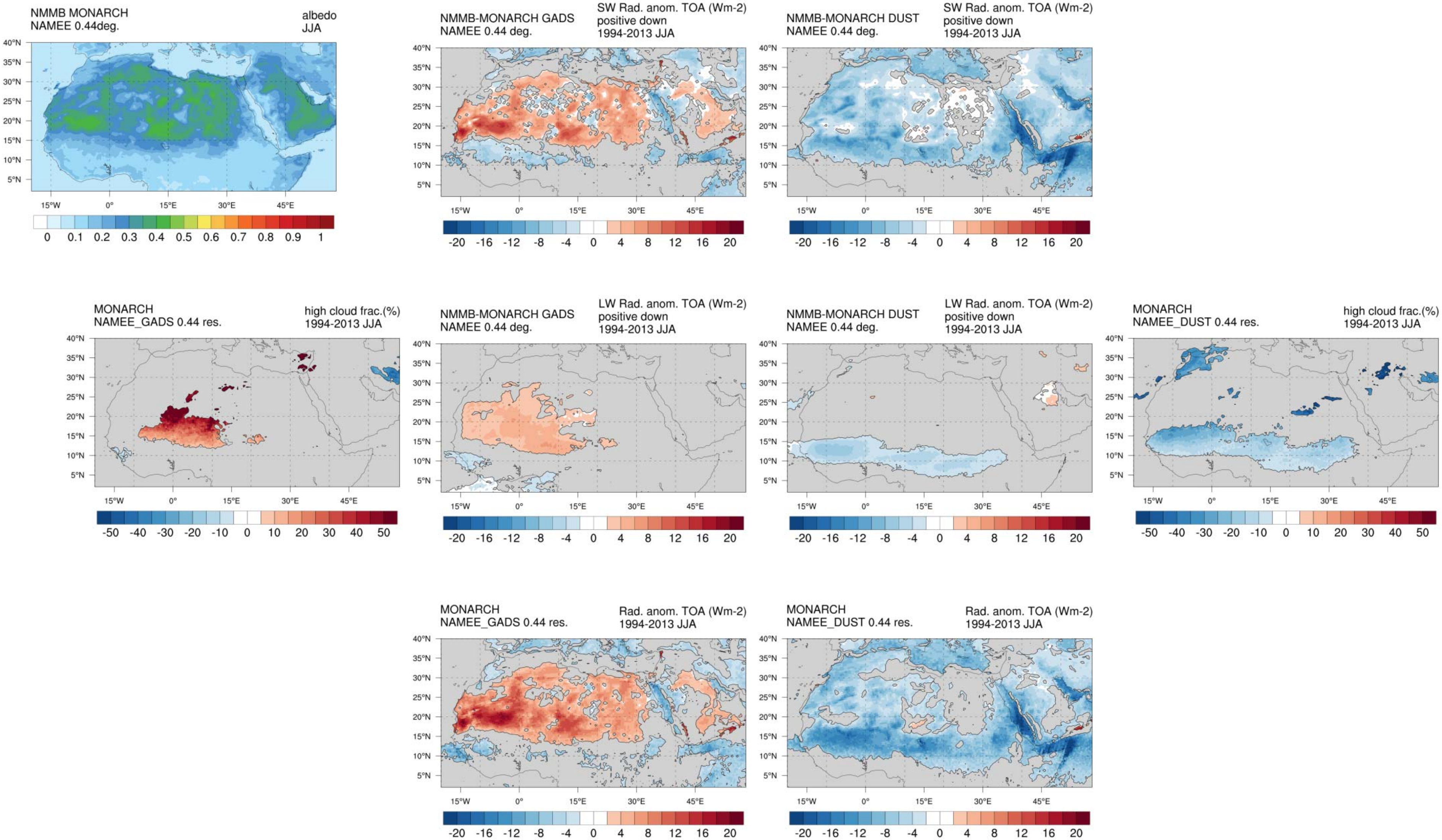
Change in JJA all-sky radiative anomaly at TOA (Wm-2),

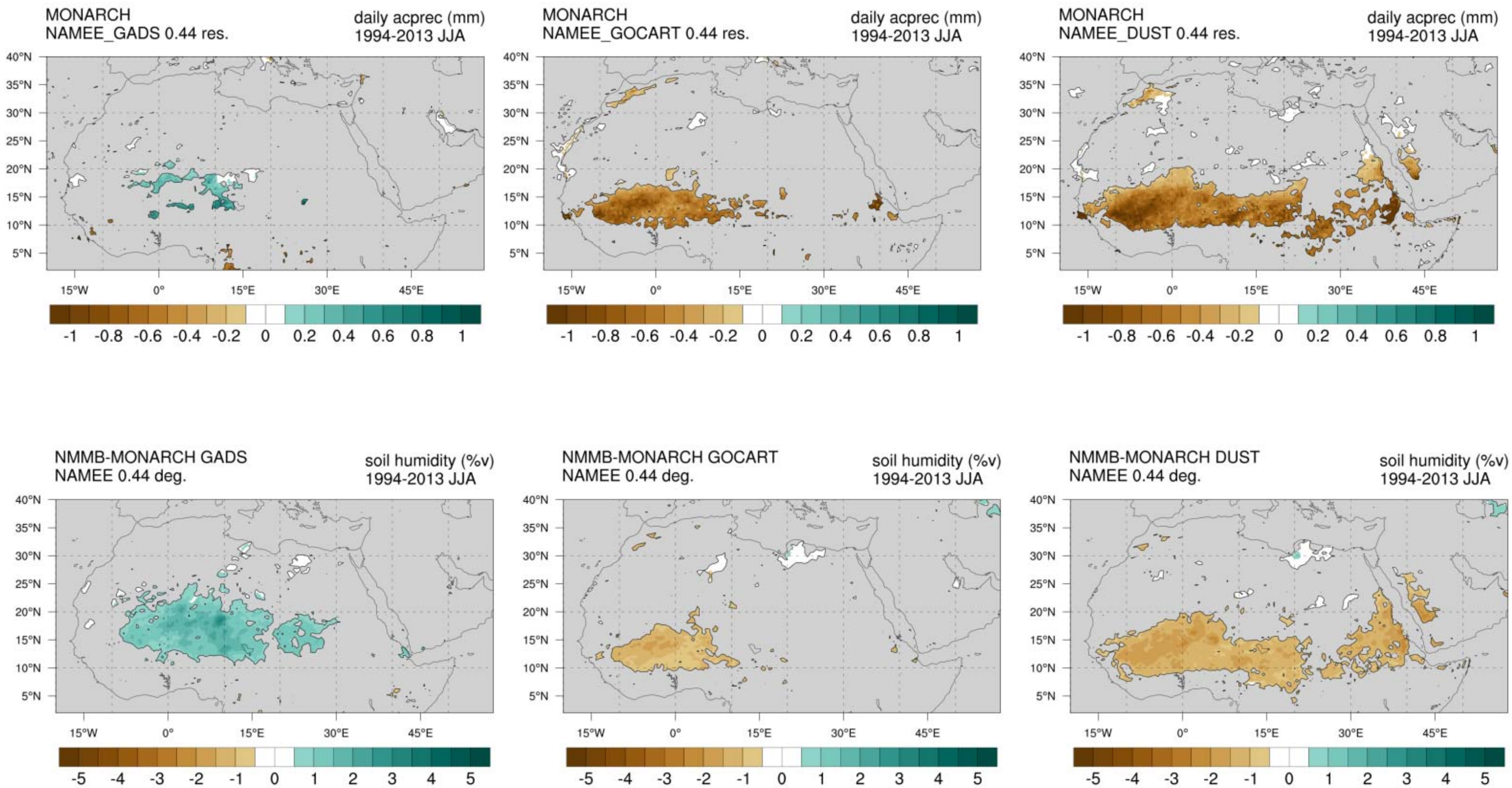
high level cloud fraction

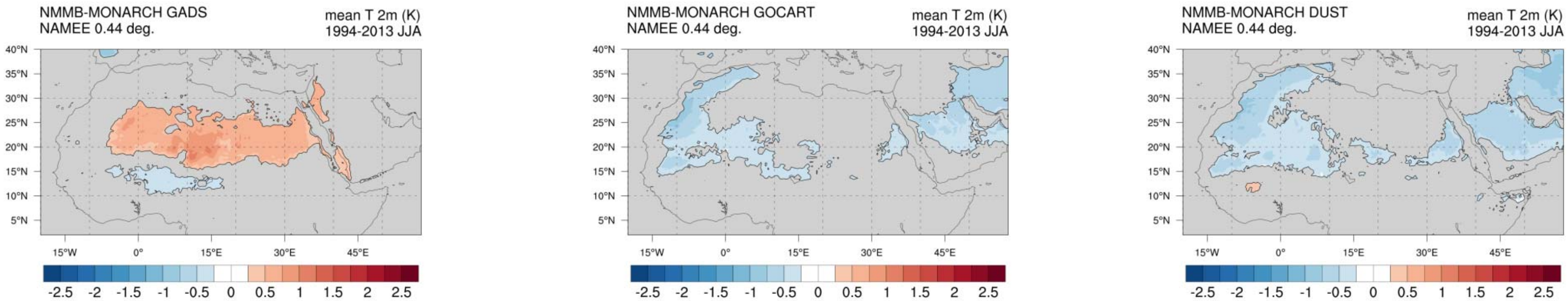
medium level cloud fraction

low level cloud fraction (%),

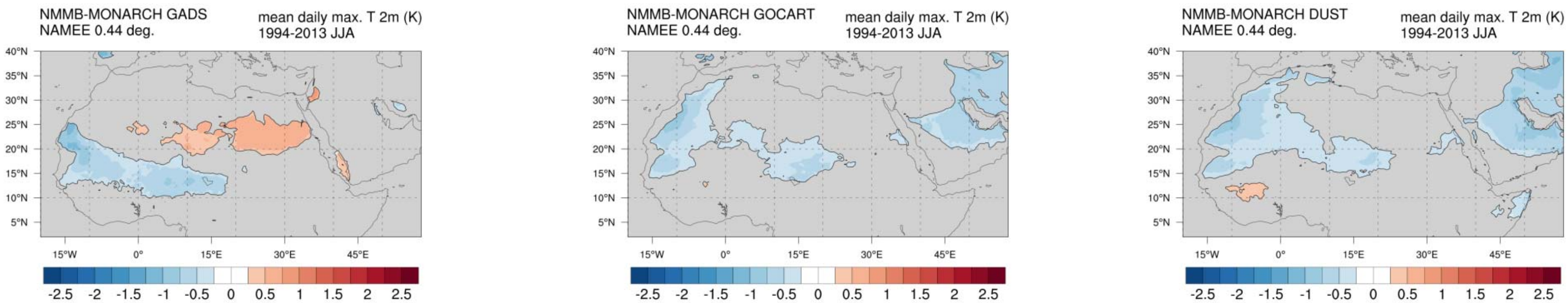
All sky SW and LW and total anomalies at TOA for GADS and DUST simulations (JJA, 1994-2013), together with average albedo and high level cloud cover changes.



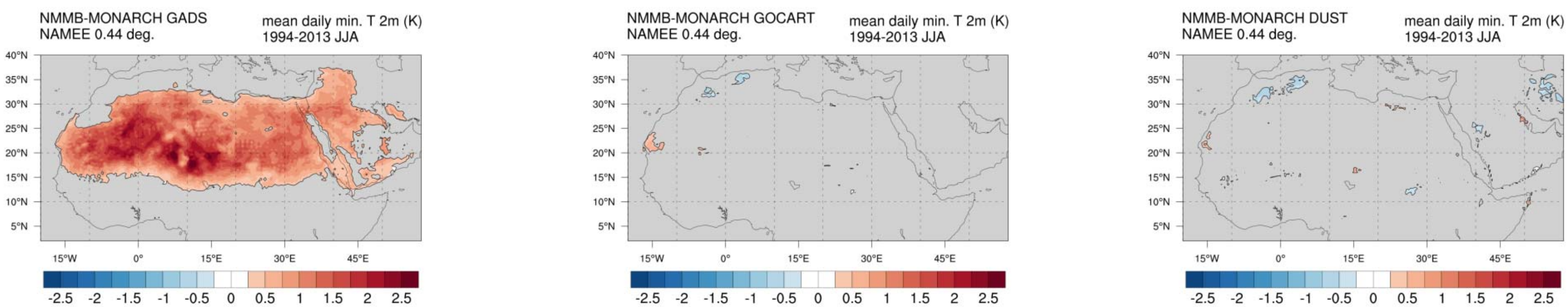

MONARCH
NAMEE_GADS 0.44 res.
daily acprec (mm)
1994-2013 JJA
MONARCH
NAMEE_GOCART 0.44 res.
daily acprec (mm)
1994-2013 JJA
MONARCH
NAMEE_DUST 0.44 res.
daily acprec (mm)
1994-2013 JJA
40°N 35°N 30°N 25°N 20°N 15°N 10°N 5°N
15°W 0° 15°E 30°E 45°E
-1 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1
NMMB-MONARCH GADS
NAMEE 0.44 deg.
soil humidity (%v)
1994-2013 JJA
NMMB-MONARCH GOCART
NAMEE 0.44 deg.
soil humidity (%v)
1994-2013 JJA
NMMB-MONARCH DUST
NAMEE 0.44 deg.
soil humidity (%v)
1994-2013 JJA
-5 -4 -3 -2 -1 0 1 2 3 4 5



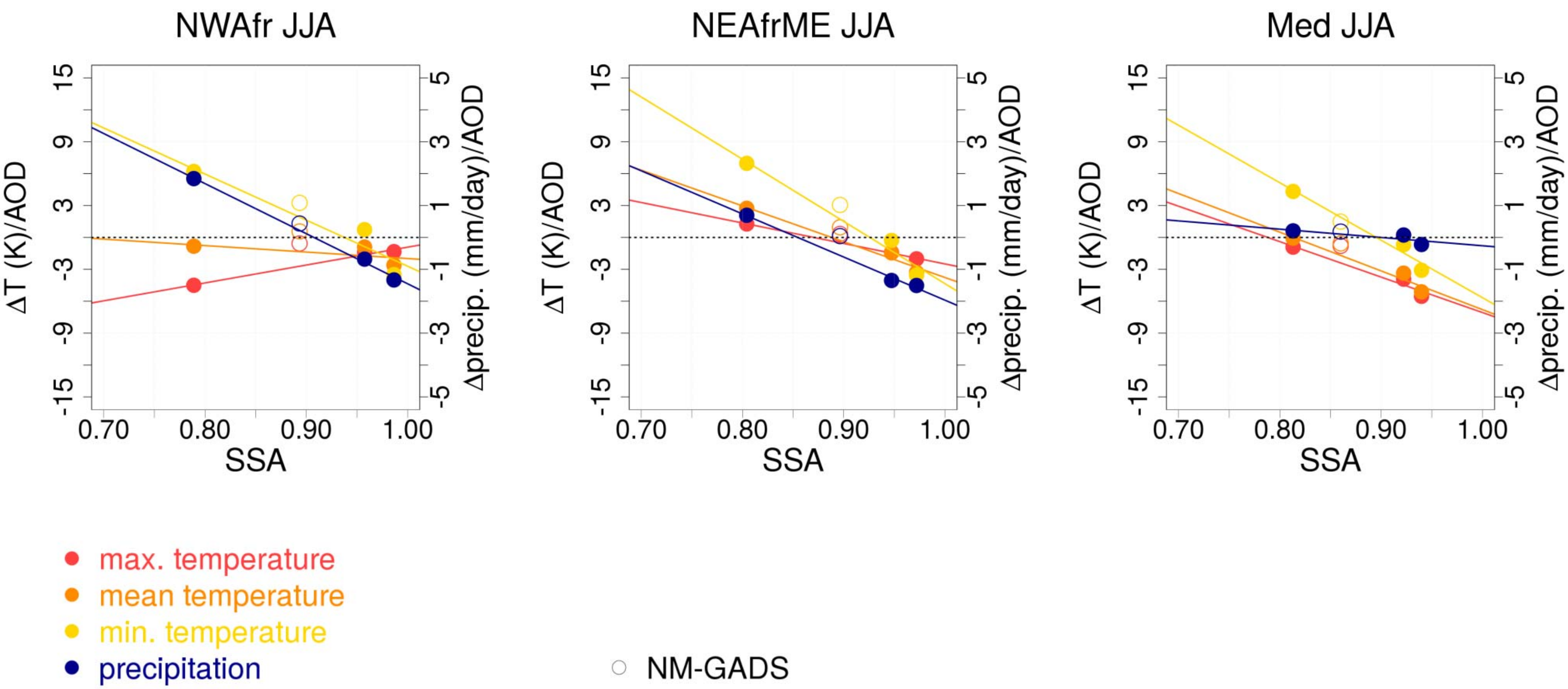
Mean t2



Max t2

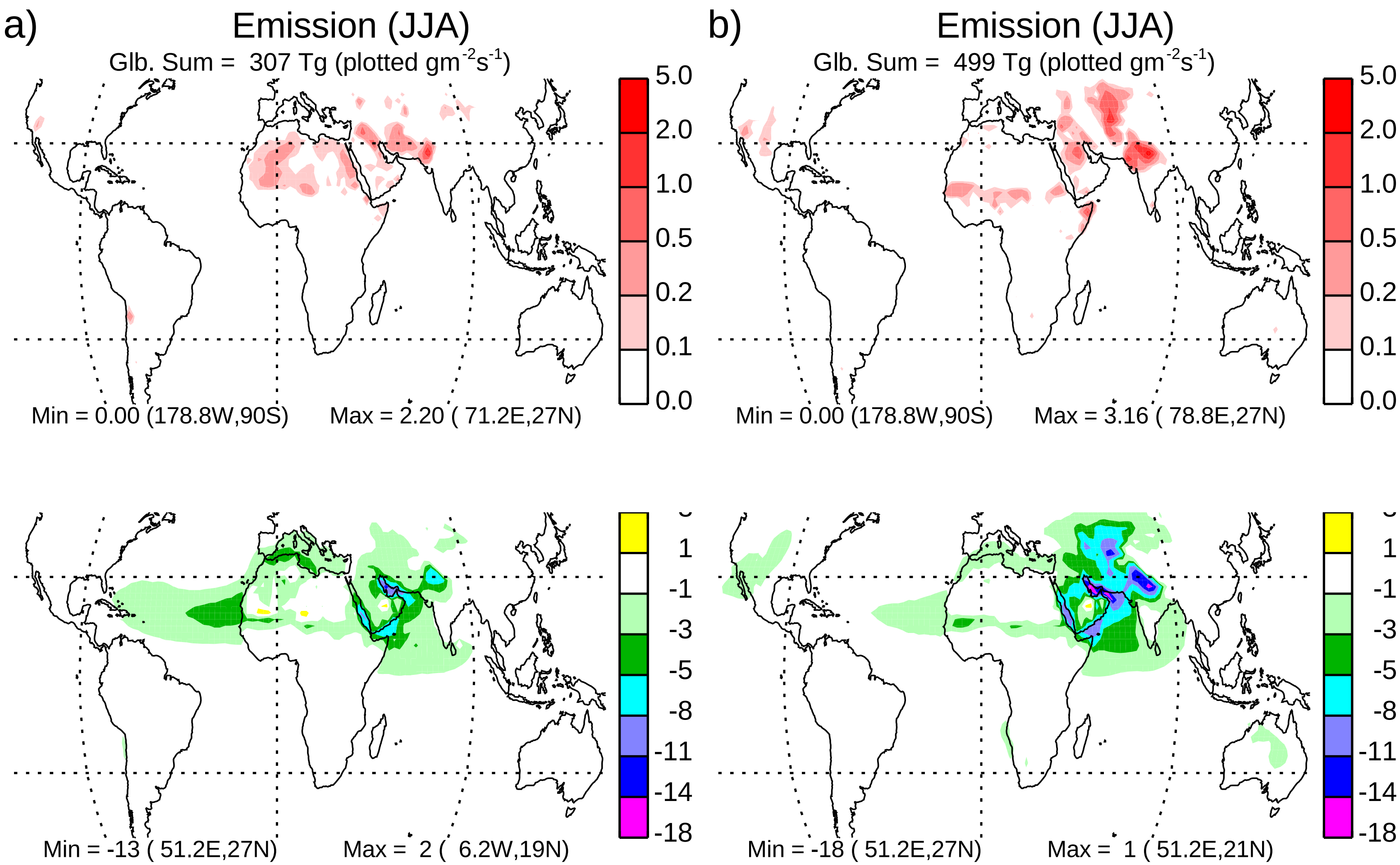


min t2


NWAfr JJA
NEAfrME JJA
Med JJA
ΔT (K)/AOD
Δprecip. (mm/day)/AOD
-15
-9
-3
3
9
15
-5
-3
-1
1
3
5
0.70
0.80
0.90
1.00
SSA
max. temperature
mean temperature
min. temperature
precipitation
NM-GADS

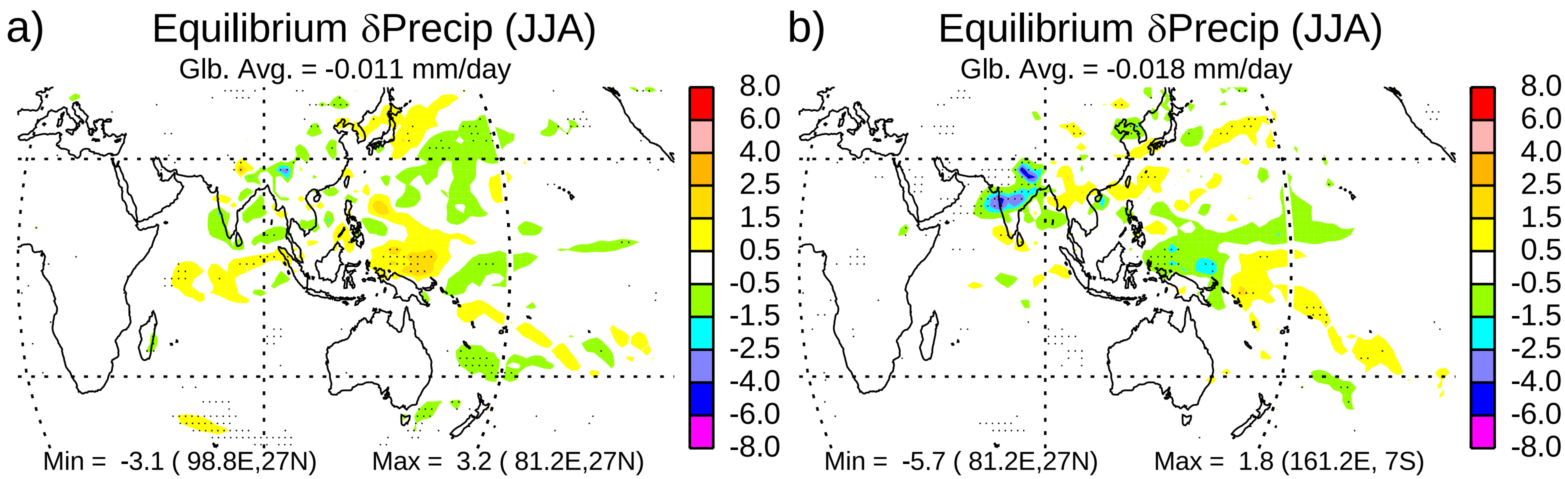
Miller et al. in prep

Natural Sources **Anthro Sources**



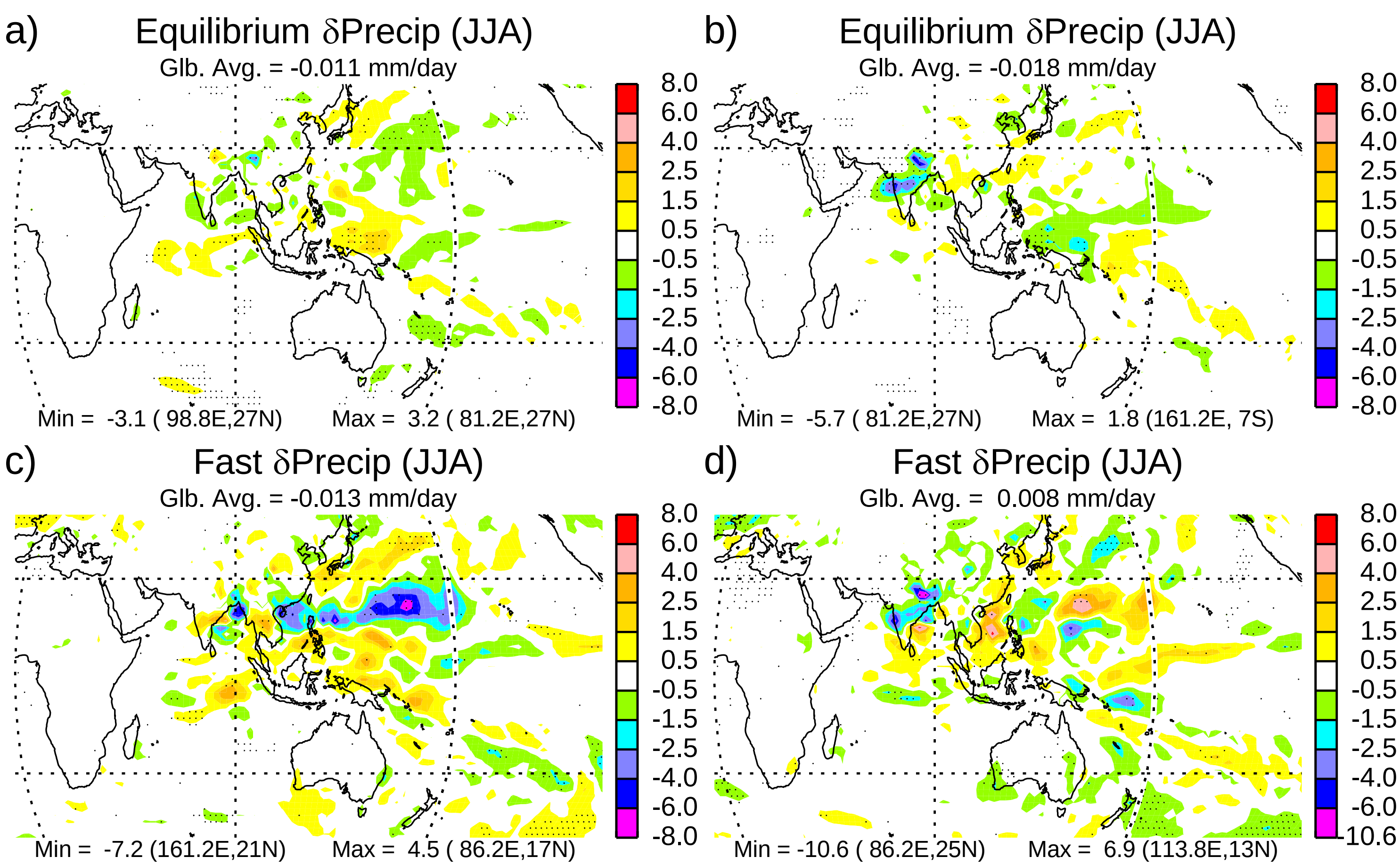
Natural Sources

Anthro Sources



- Anthropogenic dust leads to a reduction of precipitation over the Indian subcontinent up to a few mm per day. (For comparison, typical rainfall rates within the ITCZ are on the order of 10 mm per day.)
- There is also a weaker reduction of precipitation over the West Pacific (that is offset by an increase due to natural sources).

Natural Sources | **Anthro Sources**



Lower panels show the 'fast' response shortly after an increase in dust, but before the ocean mixed layer has come into balance with the forcing (which requires a few decades.)

Key points

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Strong well localized events -> positive impacts on forecasts
-> 1st order error

Moderate events -> 2nd order error ?
model dependent / other 1st order biases more important

Online vs climatology -> no statistical differences on the averaged effects
-> SW vs LW ?
-> pending to check diurnal cycles

Long term simulations are key to infer robust signal from aerosol radiative forcing

Absorption is key -> changes the sign of the Sahel precipitation response which is controlled by TOA forcing