Understanding mineral dust radiative feedbacks upon atmospheric dynamics and impacts on NWP at regional scales

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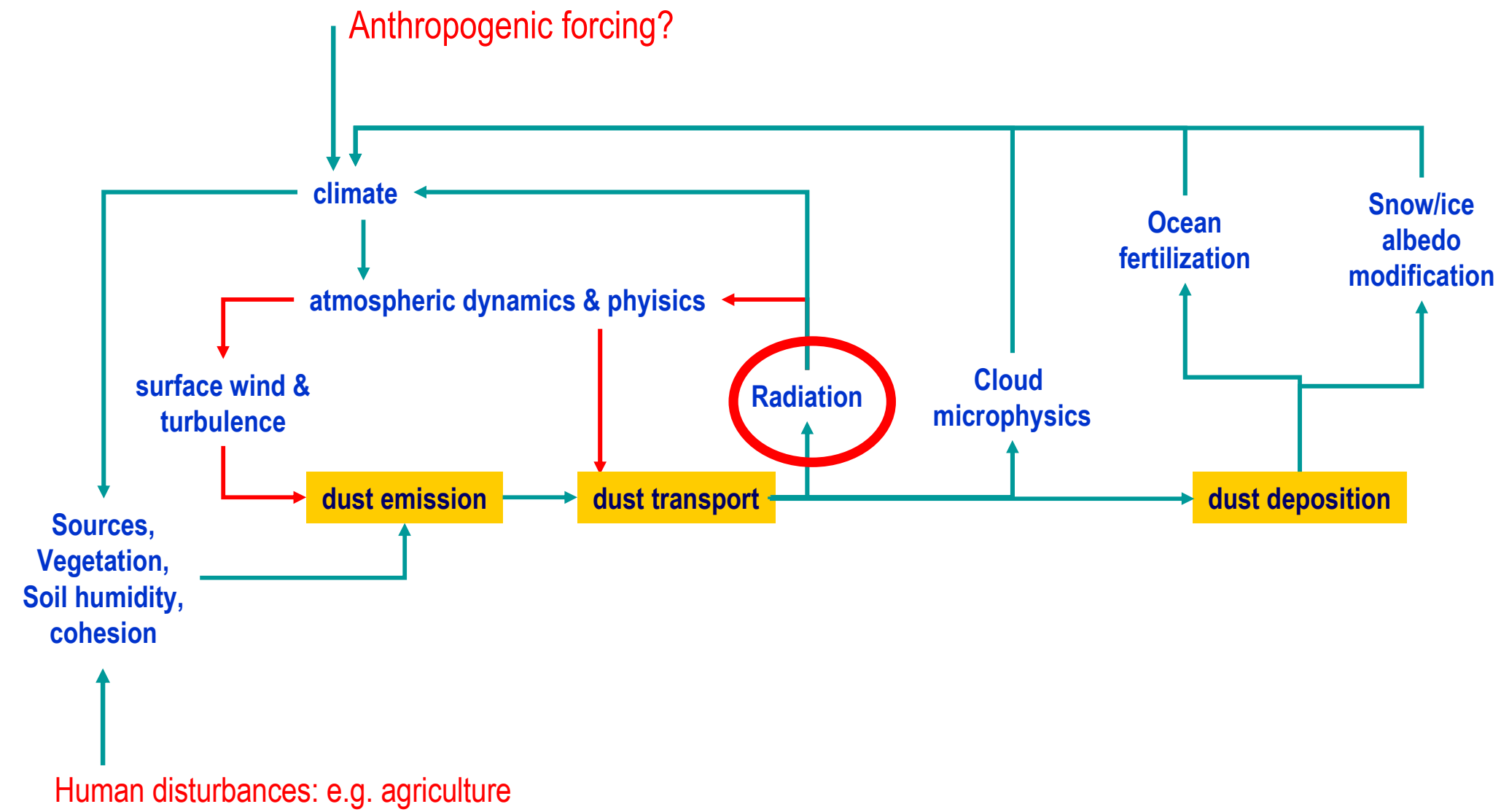
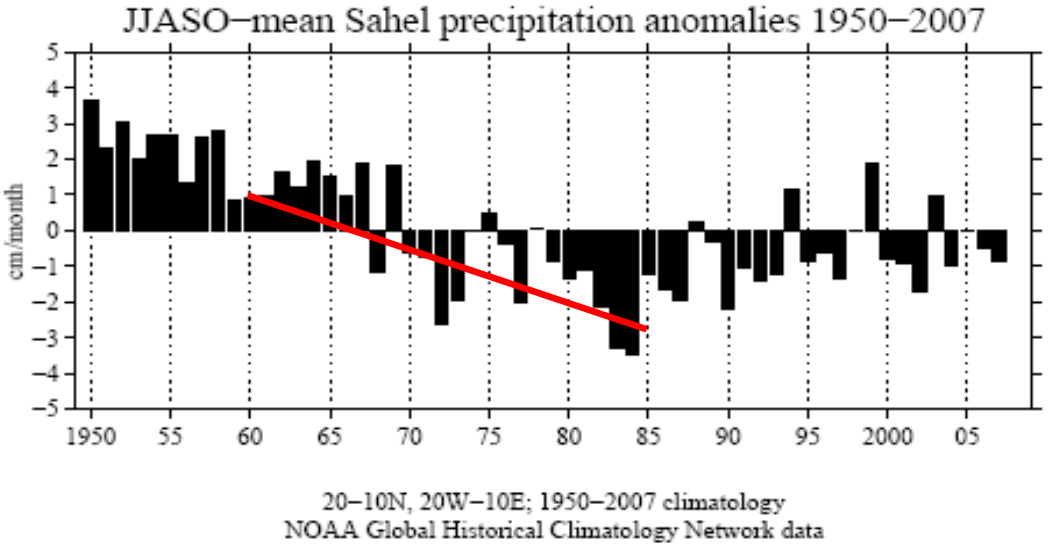
- Radiative feedbacks upon dust emission
- Dust radiative impacts on regional numerical weather prediction
- Next steps with the NMMb/BSC-Dust model

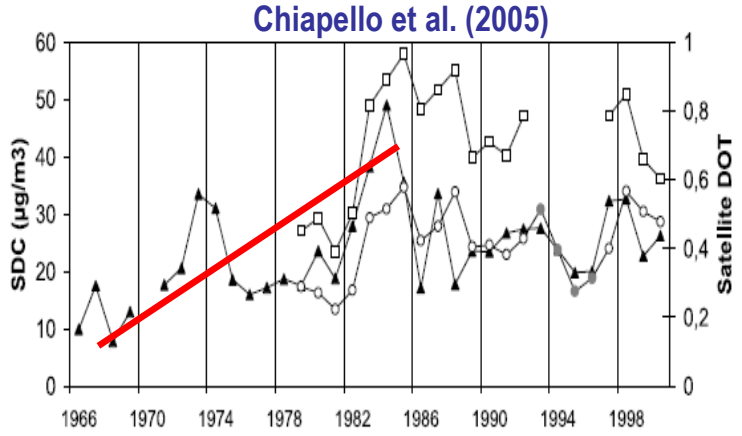
Mineral dust interactions with meteorology and climate



Barbados long term record of dust concentrations



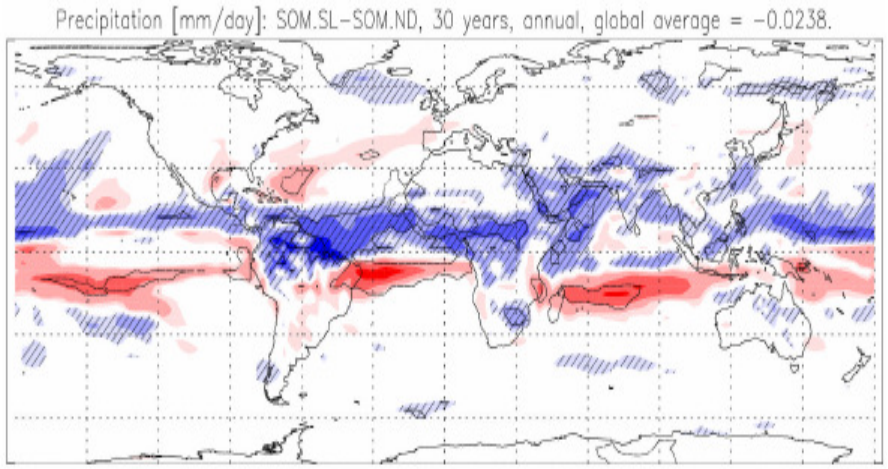
- **Droughts** since the 70s are severe **affecting the entire region** at the same time
- Tends to continue for many years or even decades



- A **4-fold increase** has been observed in **surface concentration** in Barbados from the 60s to 80s which is **negatively correlated with Sahel rainfall anomaly** of the previous year

Interactions between dust and sahel climate/precipitation

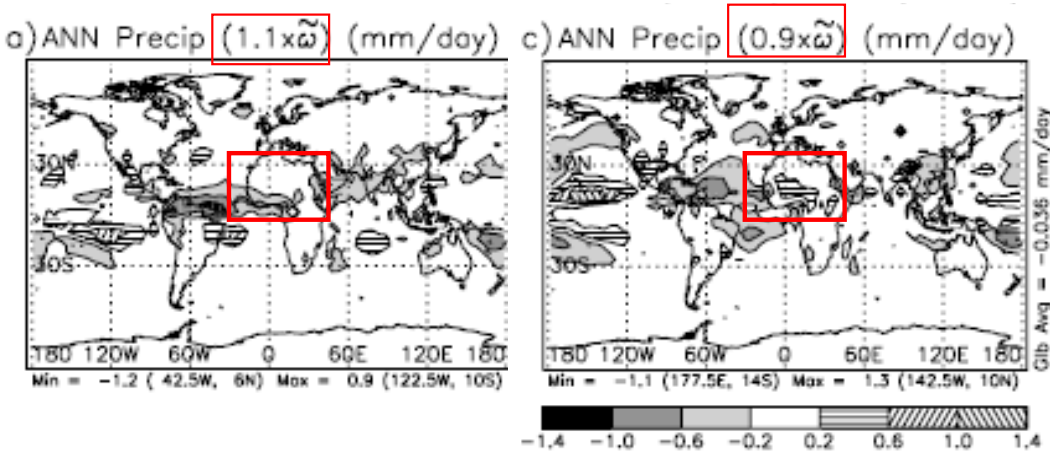
Yoshioka et al., 2007



➢ **Direct radiative forcing** by the increase of North African dust can explain up to **30% of the observed precipitation reduction** in the Sahel between wet and dry periods.

➢ **Atmospheric forcing of dust appears as the main impact in comparison to SST cooling**

Miller et al., 2004a



➢ Precipitation changes **highly sensitive to single scattering albedo** which is very uncertain for dust

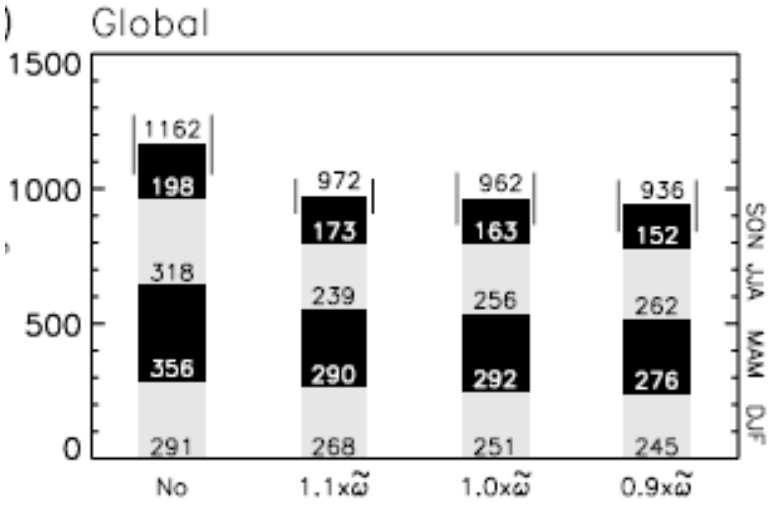
➢ **Global evaporation and precipitation are reduced**

……

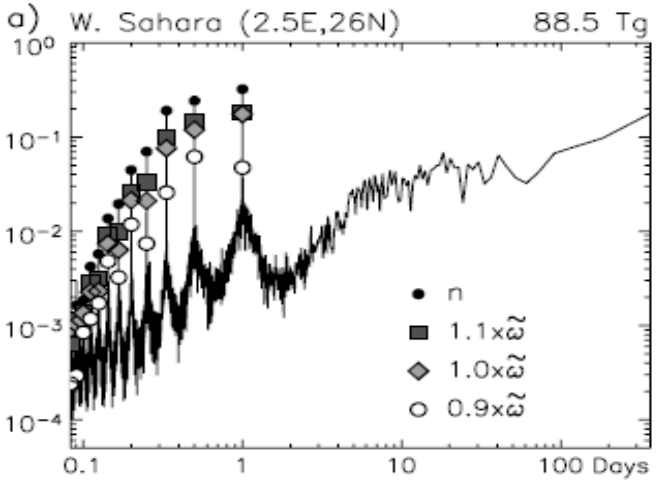
➢ **But can increase locally over desert regions, so that dust emission can act as a negative feedback to desertification**

Miller et al. (2004b)

Feedback upon dust emission by dust radiative forcing through the PBL
AGCM 31 years simulations.



- **Negative feedback** upon dust emission of about **15 % globally**
- **Dependence** of reduction upon **particle absorption** varies regionally
- Average reduction of emission is insensitive to the average forcing

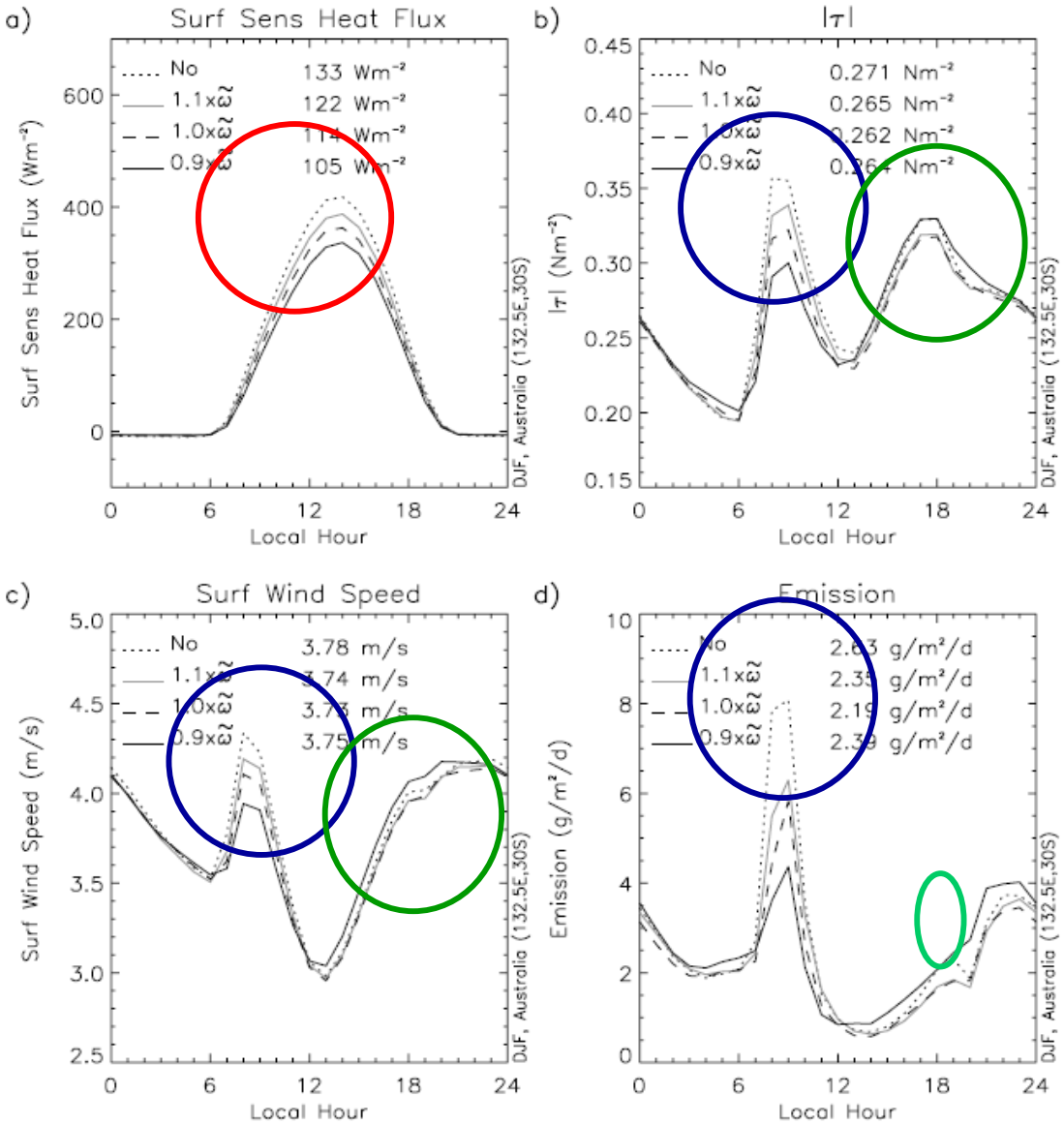


- Power spectrum of 10 years of hourly emission shows that distinctive time scales are the annual and diurnal cycles
- **Dust radiative forcing** reduces the spectral power **at diurnal harmonics**
- Reduction increases with the magnitude of the surface forcing by dust

Miller et al. (2004b)

Feedback upon dust emission by dust radiative forcing through the PBL

AGCM 31 years simulations.



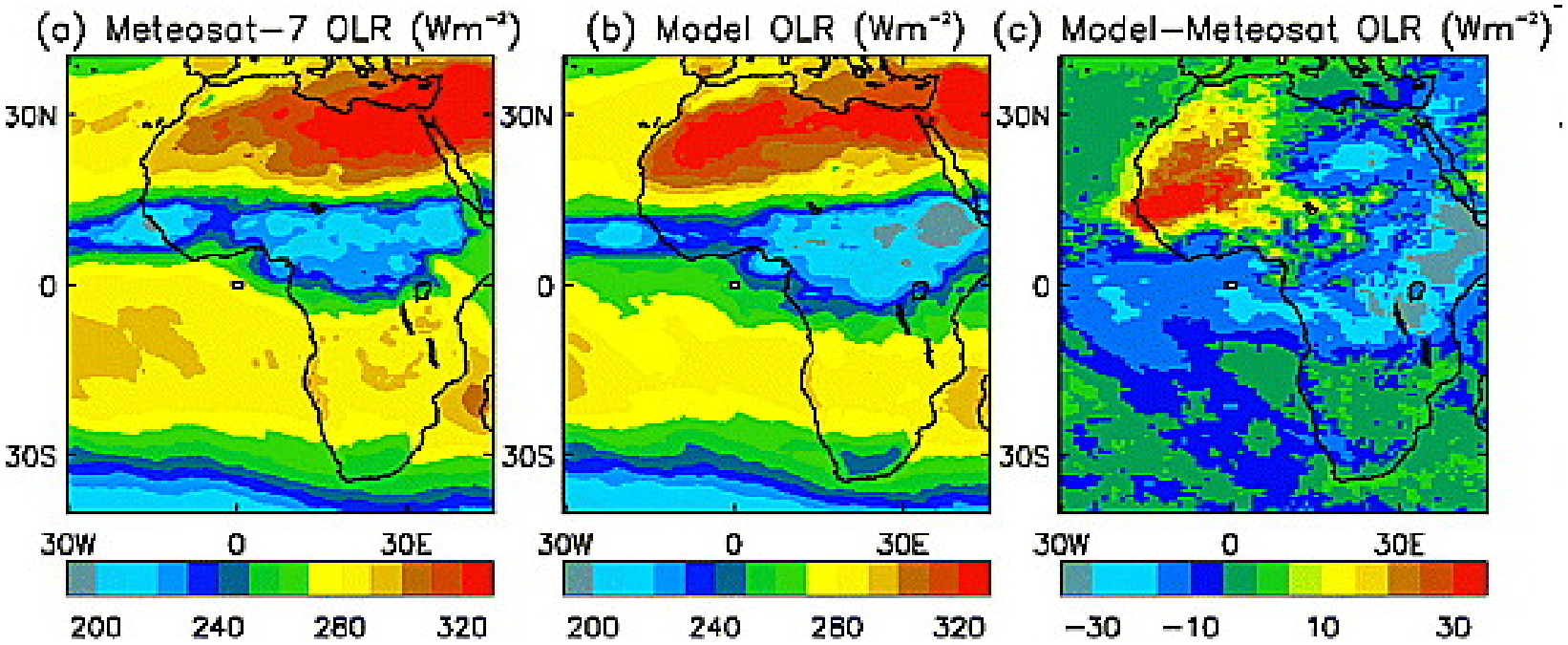
- **Reduction** of surface **sensible heat flux** depending on the forcing

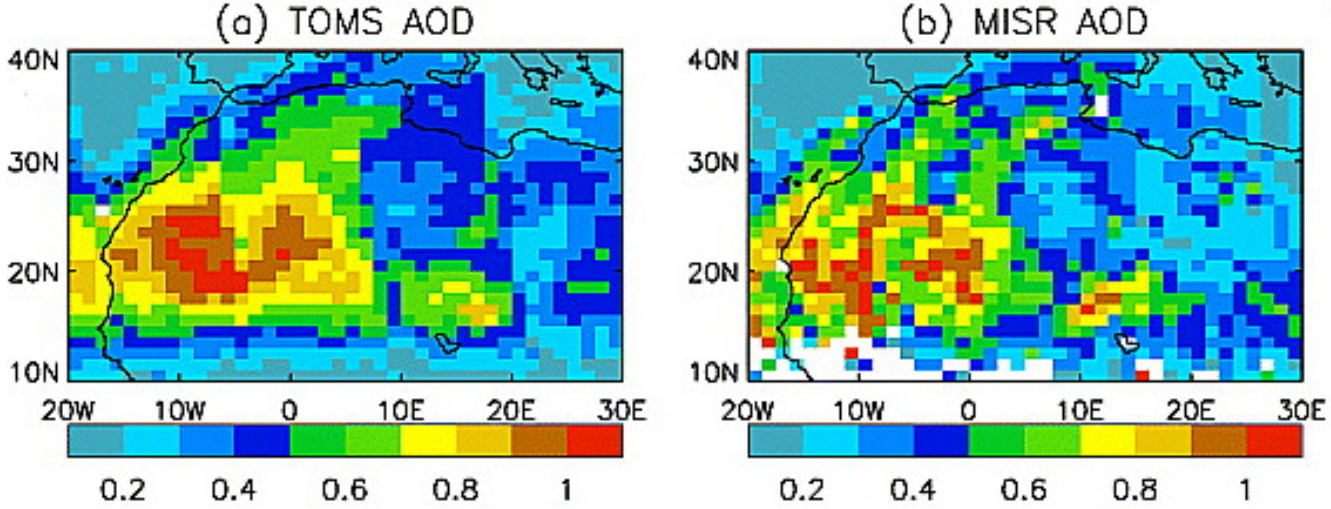
- In general during the **morning** peak, strong **reduction of surface wind stress and surface wind speed and emission** depending on the forcing

- **Afternoon, small increase of wind stress, wind speed and emission in the high absorption run**

Haywood et al., 2005

Can desert dust explain the outgoing longwave radiation anomaly over the Sahara during July 2003?





Can we improve the weather forecast?
How important are the feedbacks upon dust emission? Mechanisms?

8-15 April 2002 major dust outbreak over the Mediterranean

2 sensitivity experiments

CTR

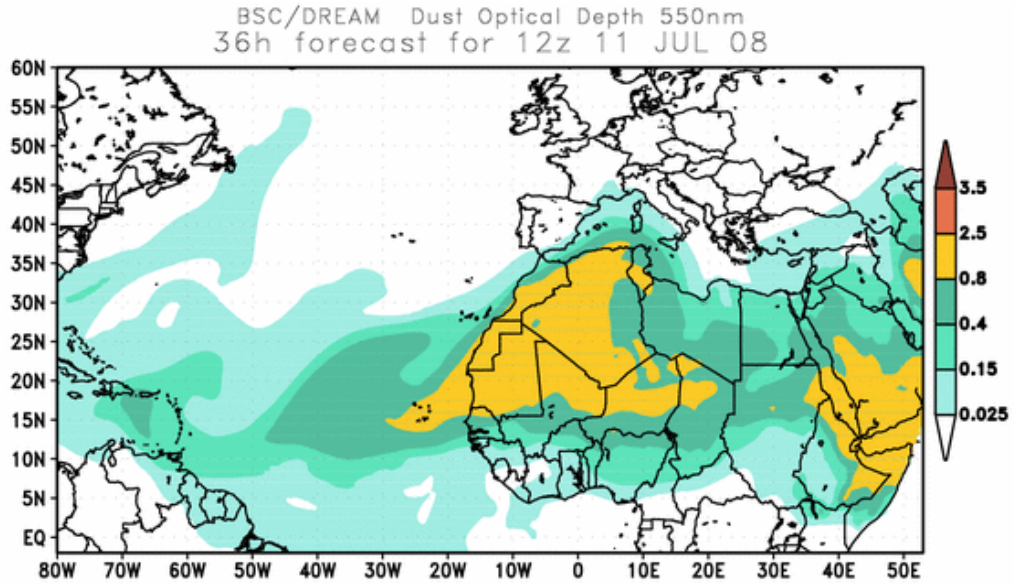
dust is considered as a dynamic tracer without interaction with atmospheric radiation

RAD

interaction between short- and long-wave radiation and dust is included

BSC/DREAM

http://www.bsc.es/projects/earthscience/DREAM/



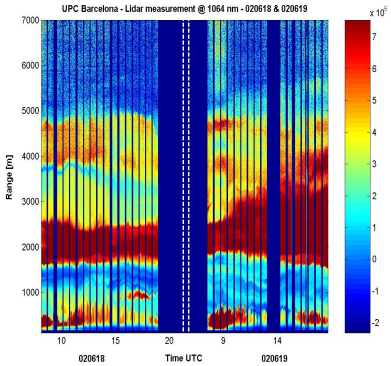
Embeded on-line into the NCEP/Eta model

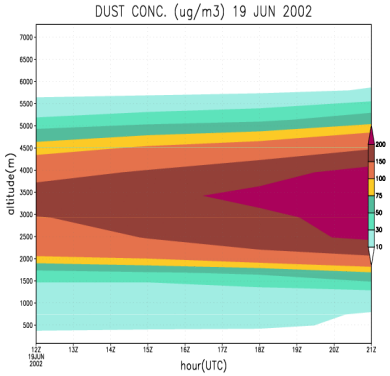
BSC/DREAM version features

- Dust production scheme with introduced viscous sub-layer (Shao et al., 1993; Janjic, 1994)
- USGS 1km vegetation and FAO 4km soil texture data
- 8 particle size bin distribution. Sub-bin log normal distribution (Zender et al, 2003, D'Almeida 1987)
- Soil wetness effects on dust production (Fecan et al., 1999)
- Dry deposition (Georgi, 1986) and simple below cloud scavenging (corrected)
- Horizontal and vertical advection, turbulent and lateral diffusion (Janjic, 2001; 1997) represented as for other scalars in the Eta/NCEP model
- Dust radiative feedbacks on meteorology (Pérez et al., 2006)

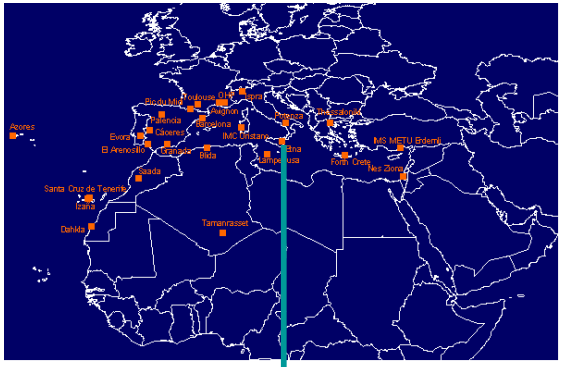
Dust forecast and daily evaluation
http://www.bsc.es/projects/earthscience/DREAM/

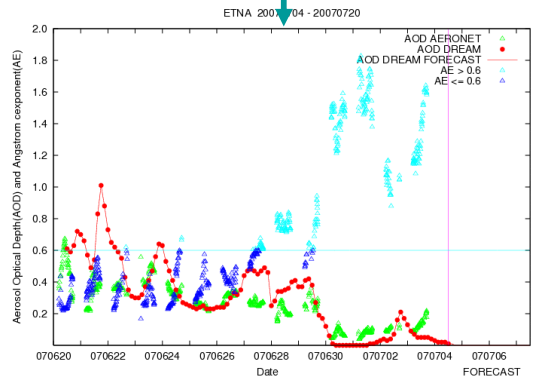
Lidars - EARLINET



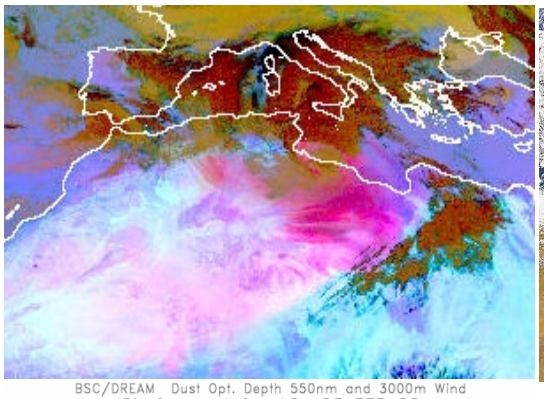


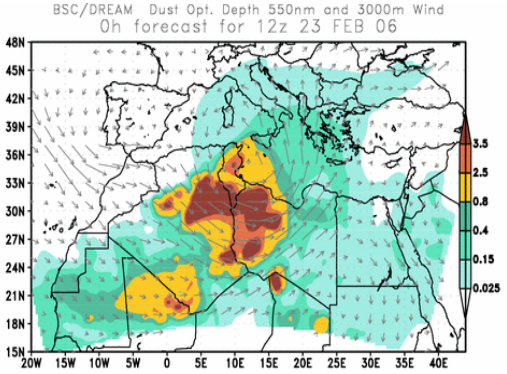
AERONET - ONLINE



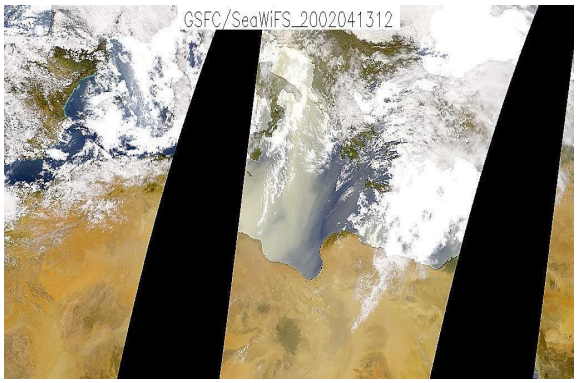


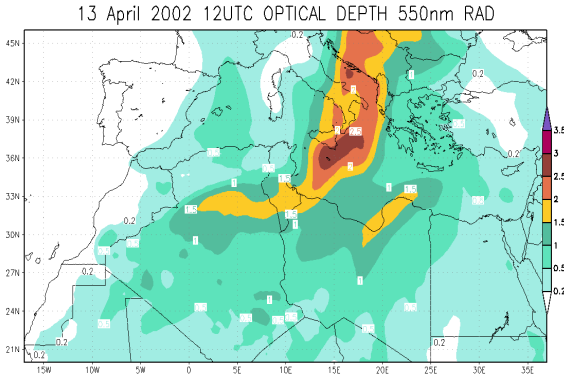
Meteosat Second Generation





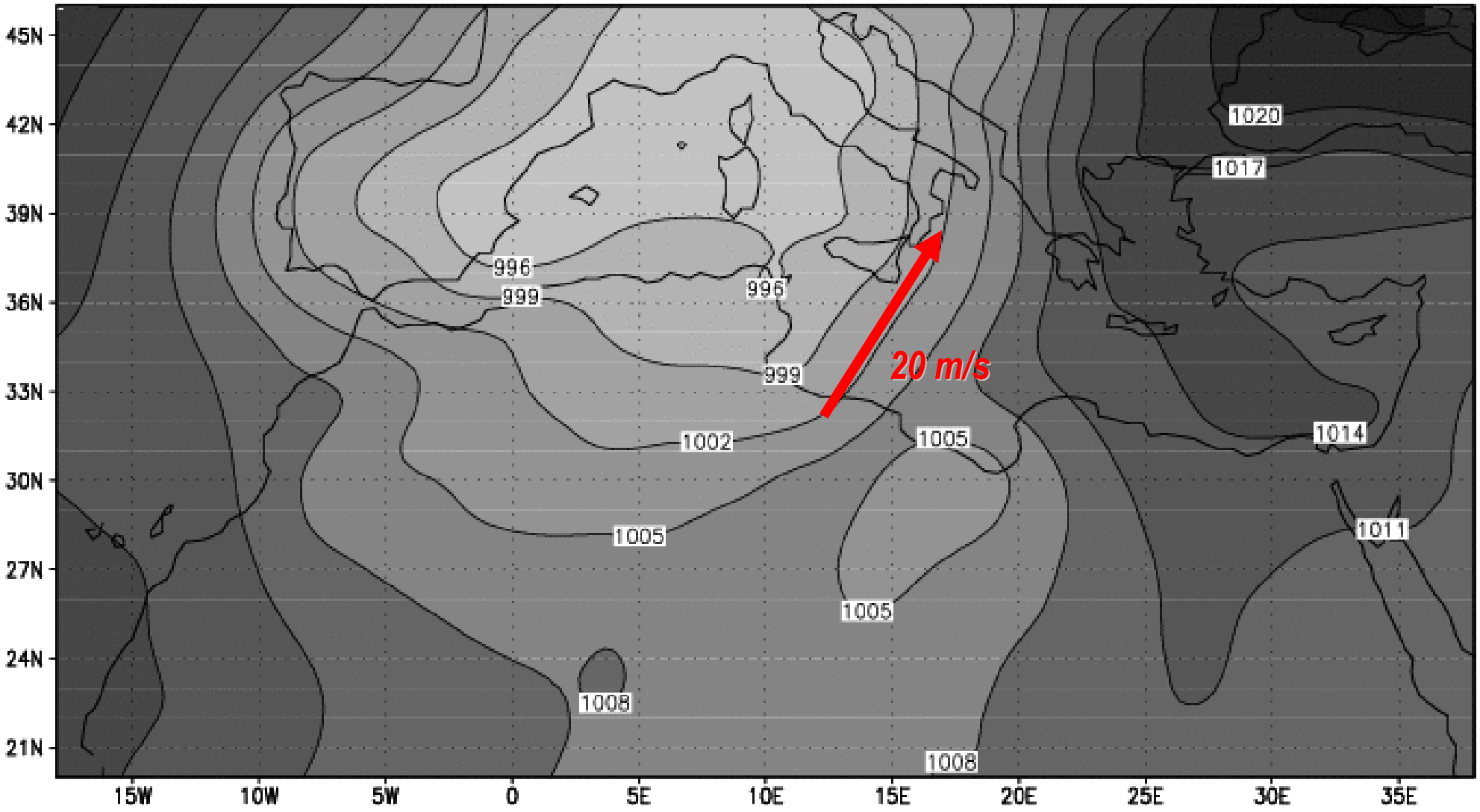
SeaWIFS



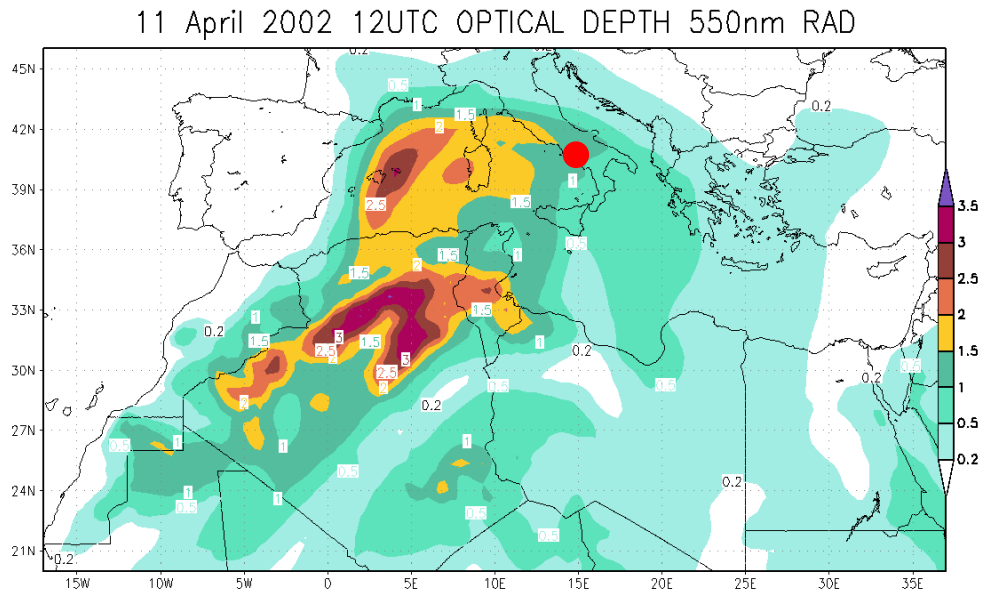


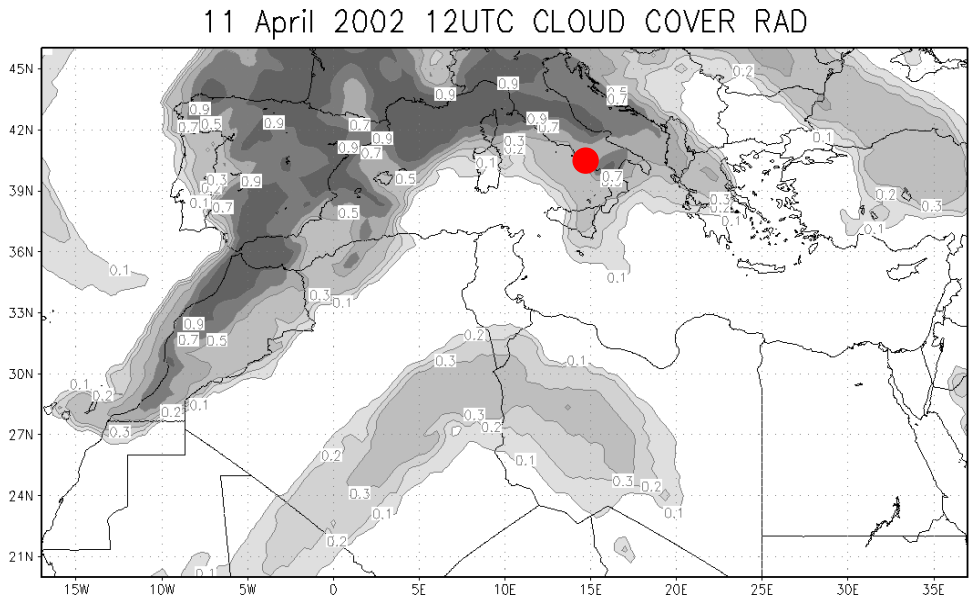
Model has shown good agreement with observations in a number of studies of single events (e.g., *Ansmann et al.*, 2003, *Papayannis et al.*, 2005; Balis et al., 2006; *Pérez et al.*, 2006a;b; *Jiménez et al*, 2006 ….)

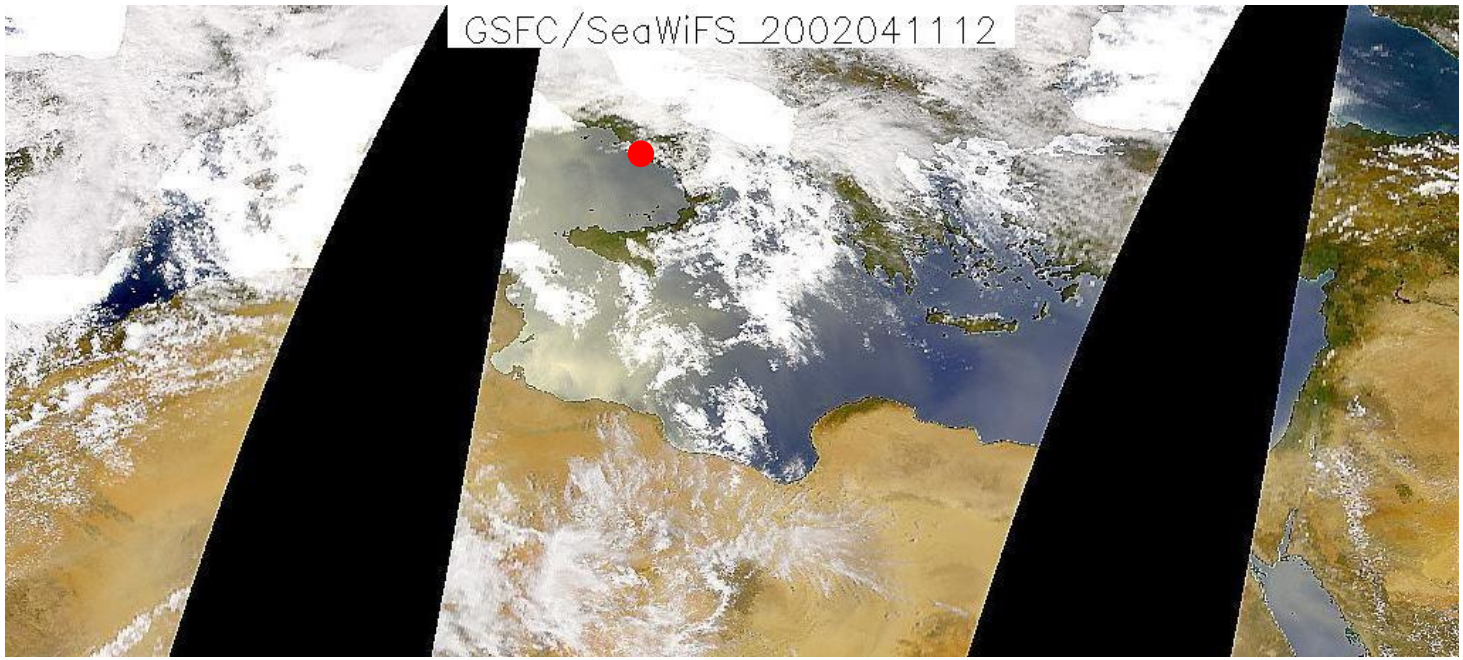
MSL pressure 12 April at 12 UTC

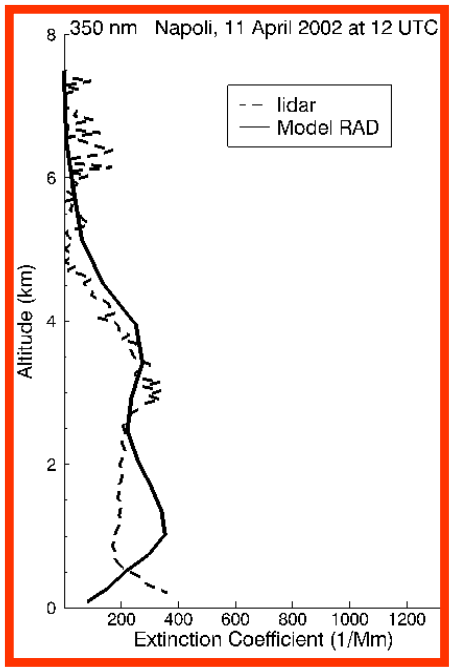


11 April 2002



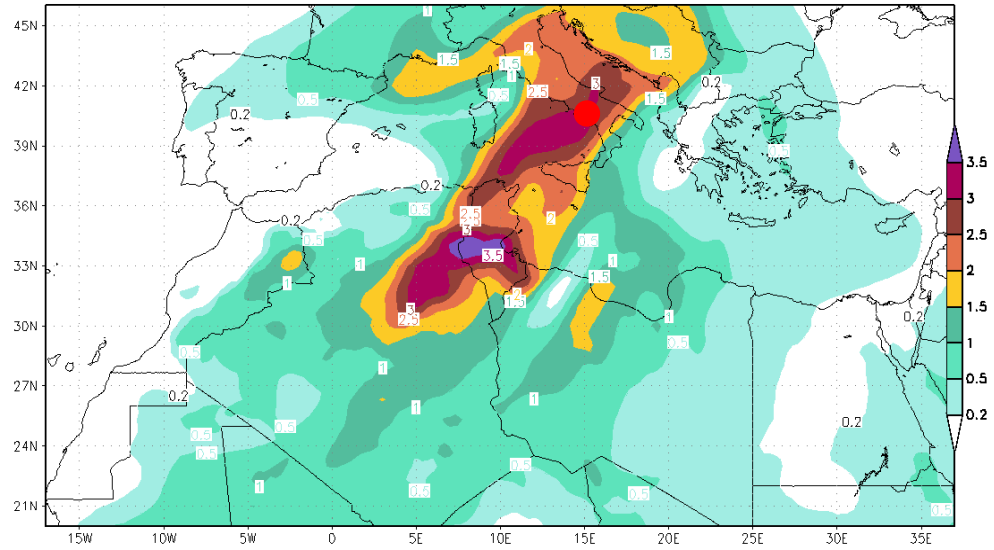


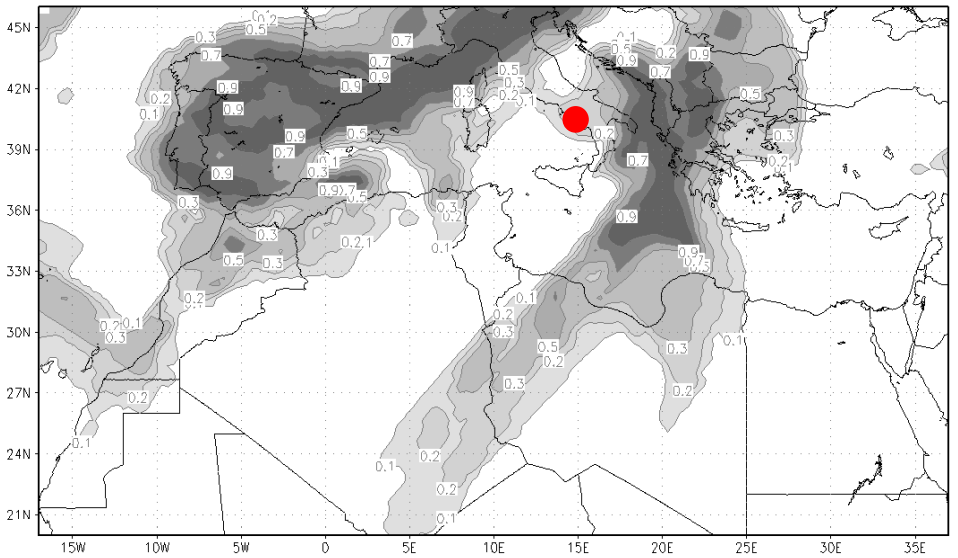


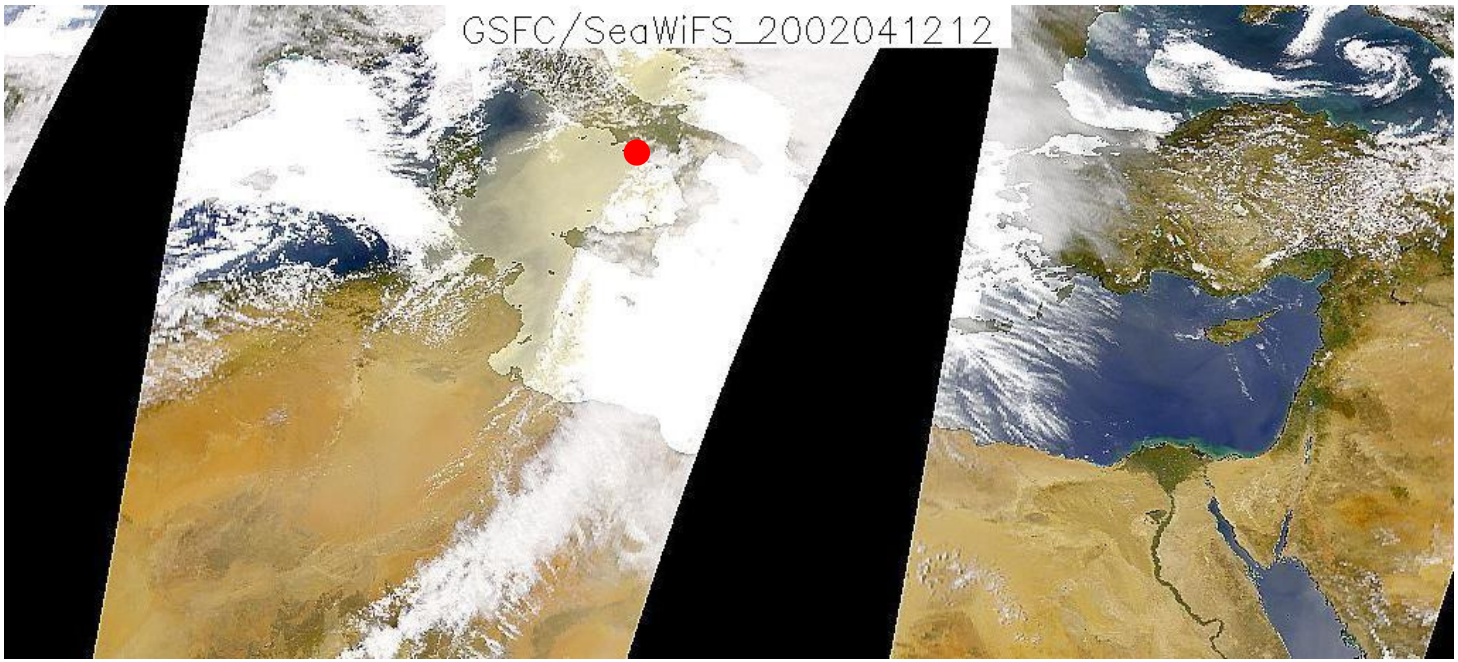


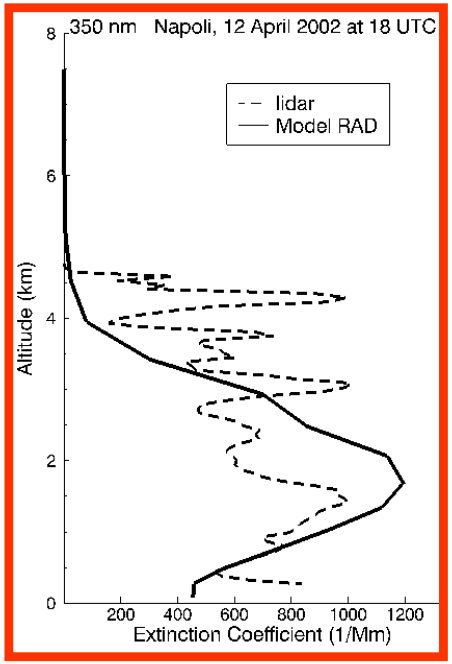
● *Napoli Raman Lidar*

12 April 2002



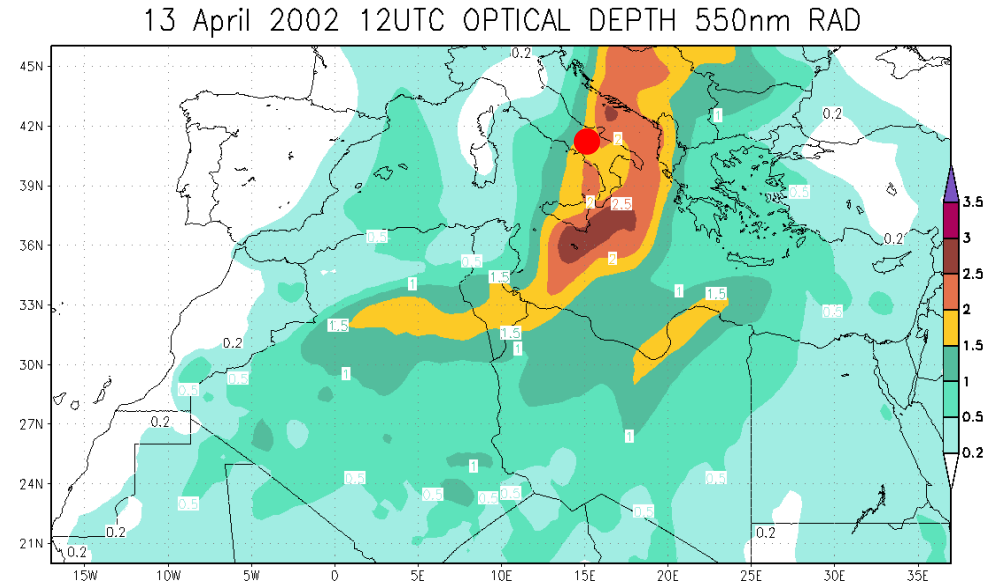


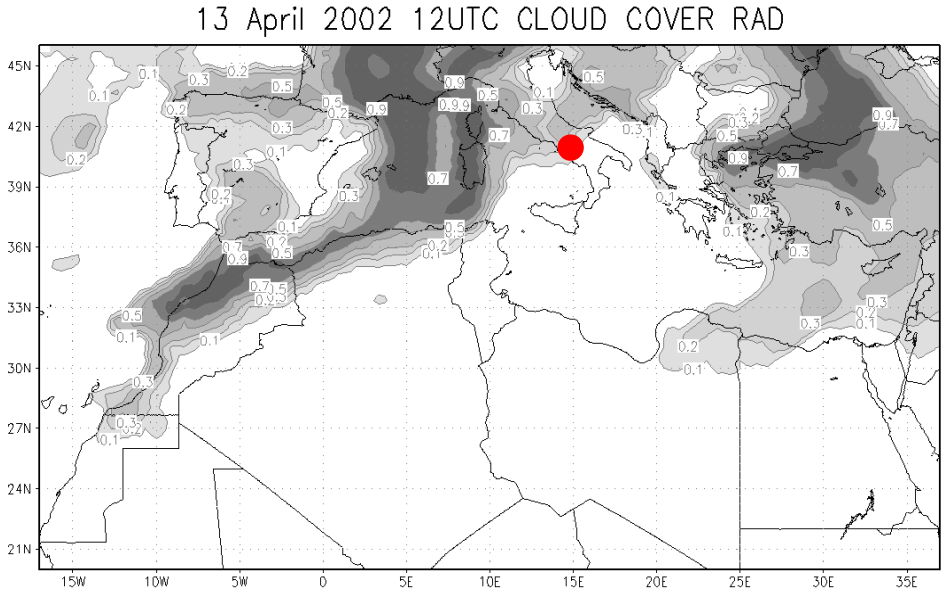


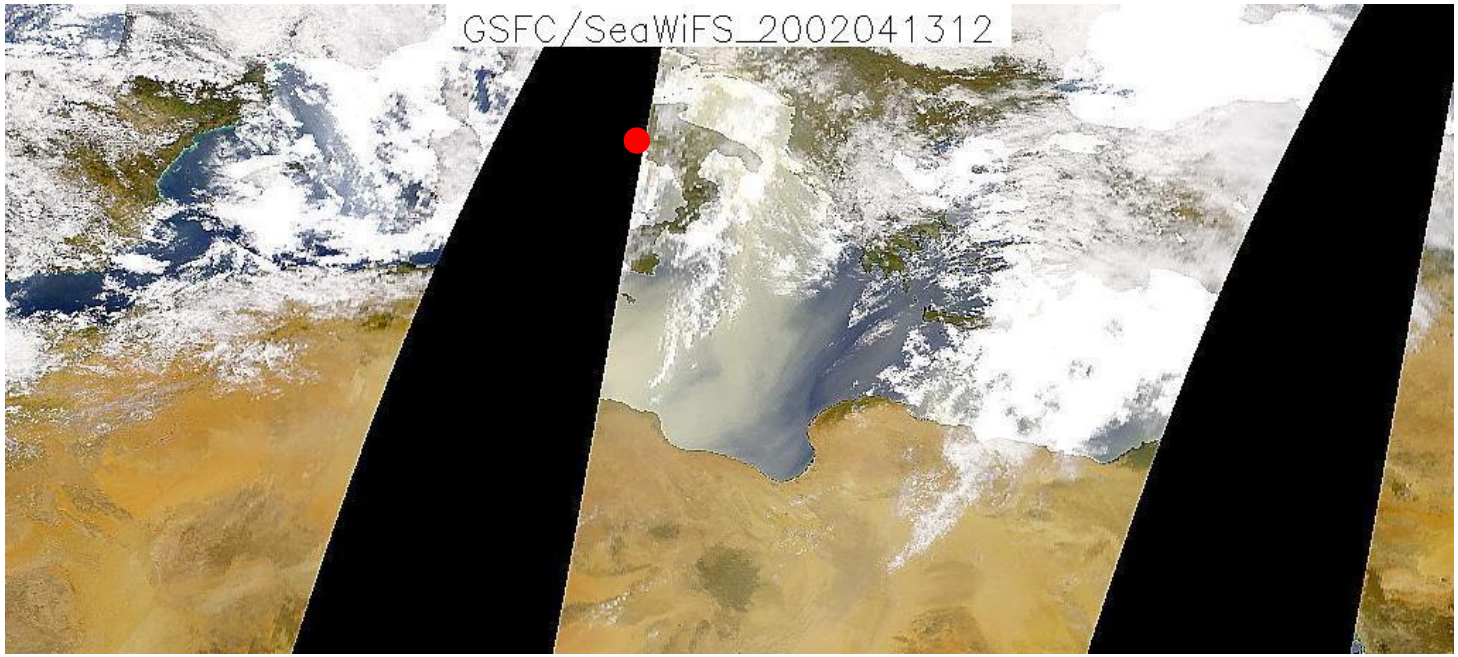


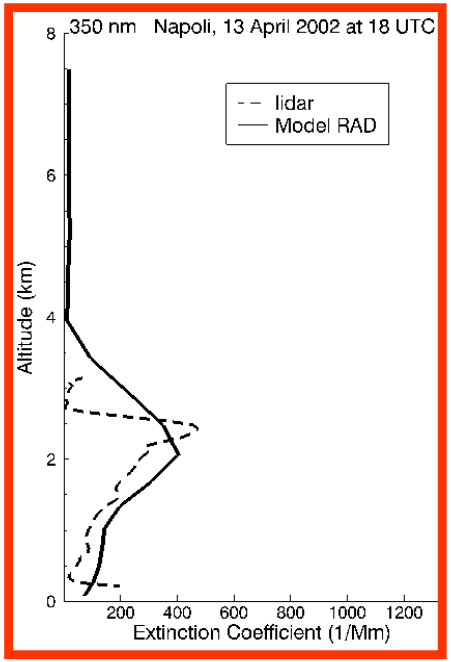
- *Napoli Raman Lidar*

13 April 2002



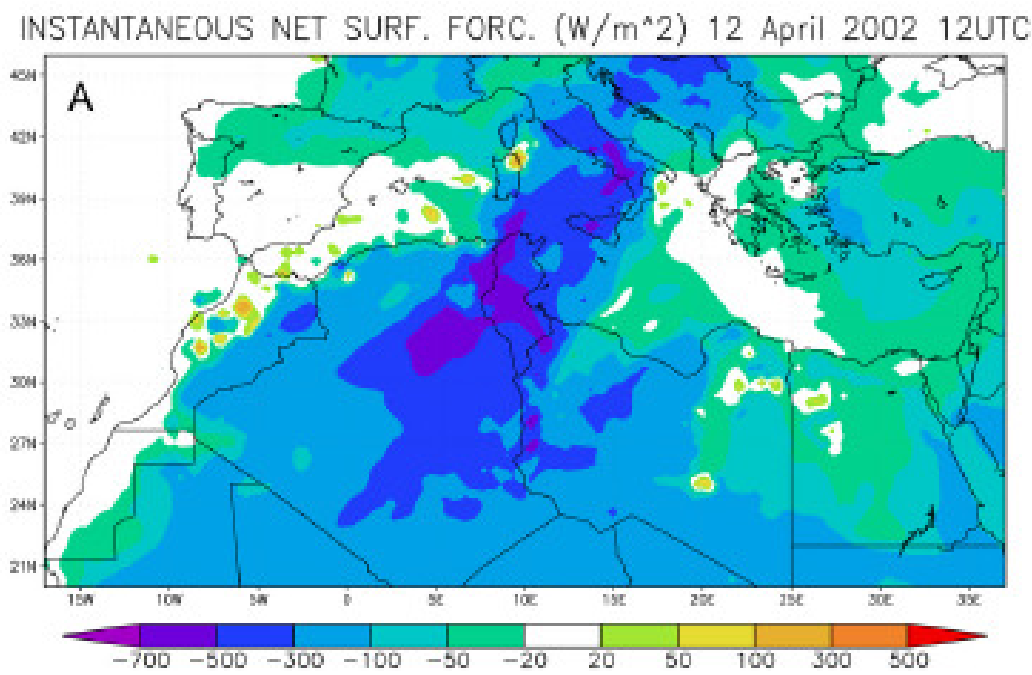


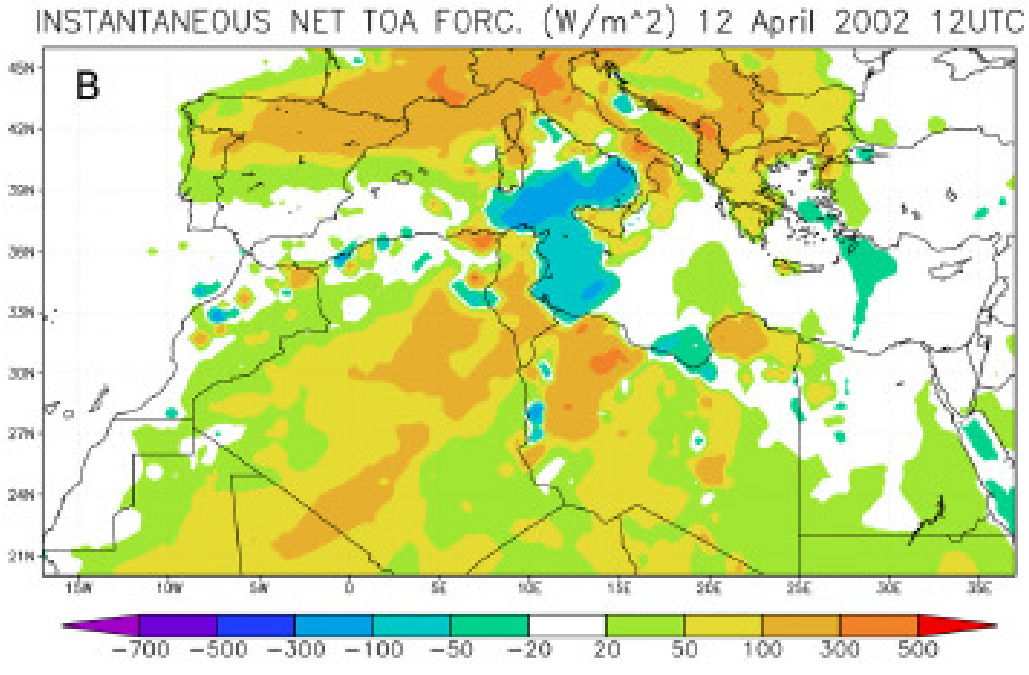


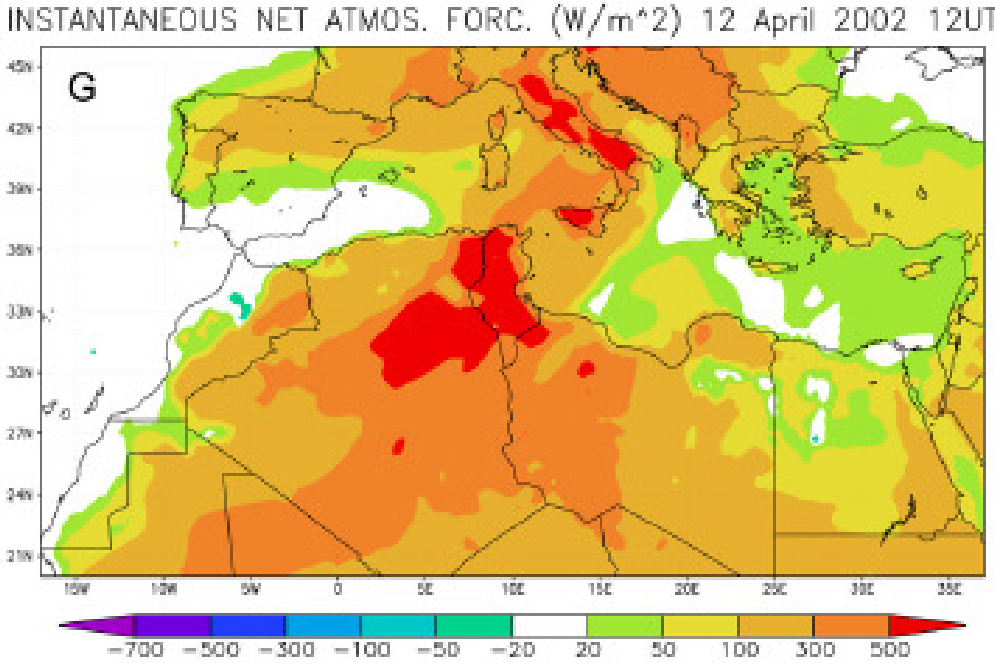


● *Napoli Raman Lidar*

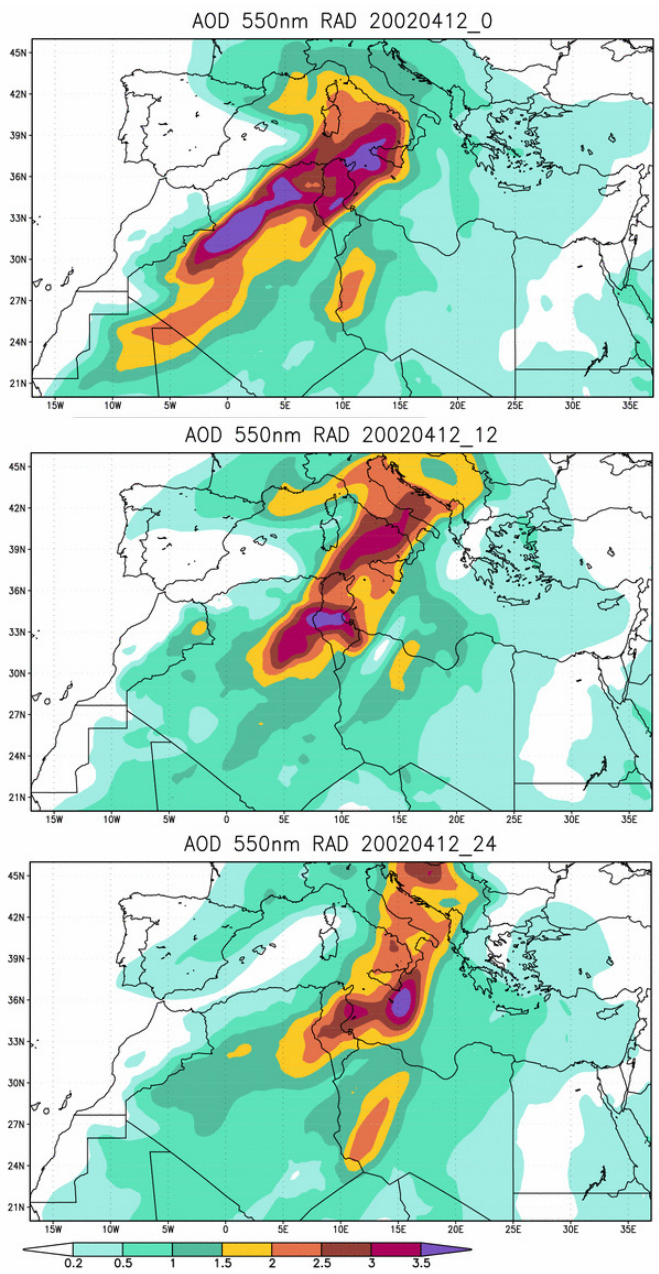
INSTANTANEOUS RADIATIVE FORCING AT 12 UTC

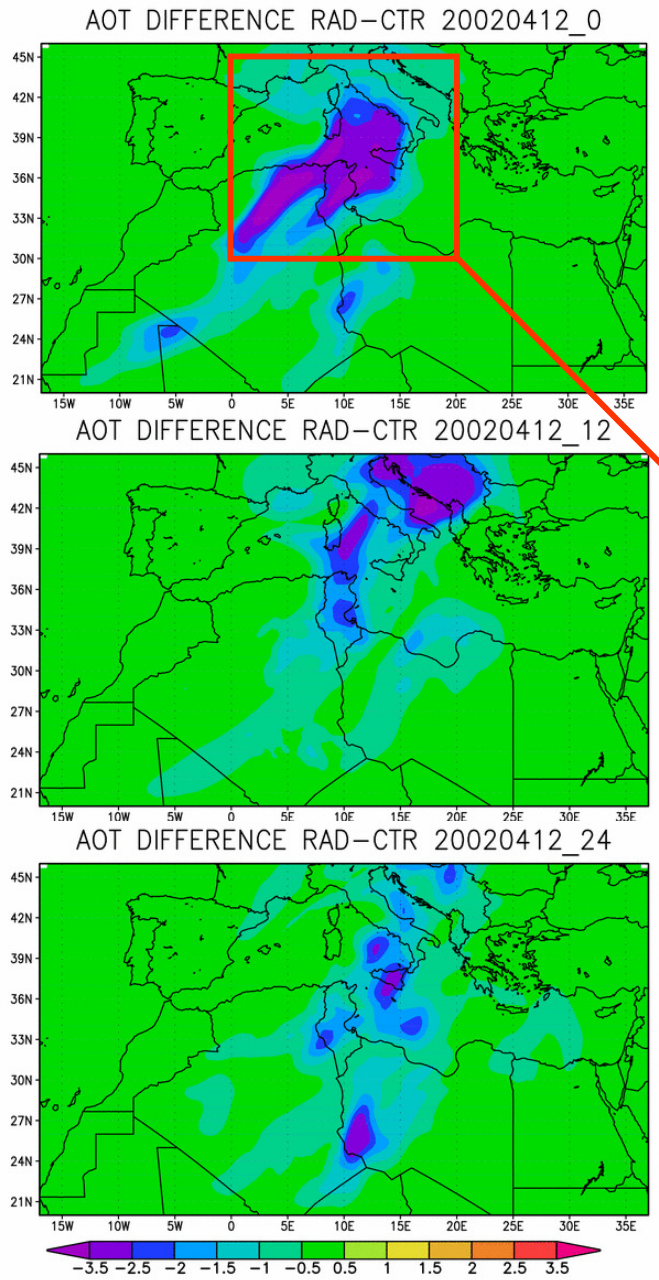




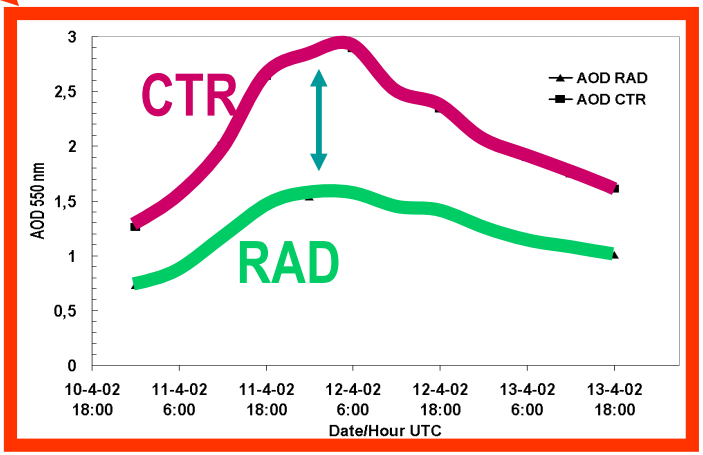


Feedbacks upon dust emission

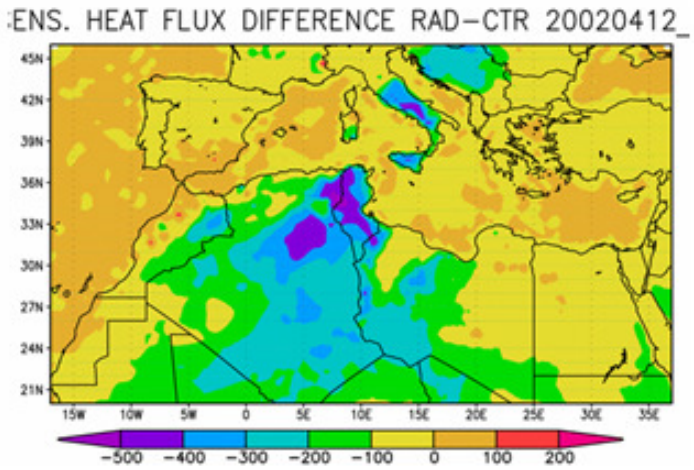


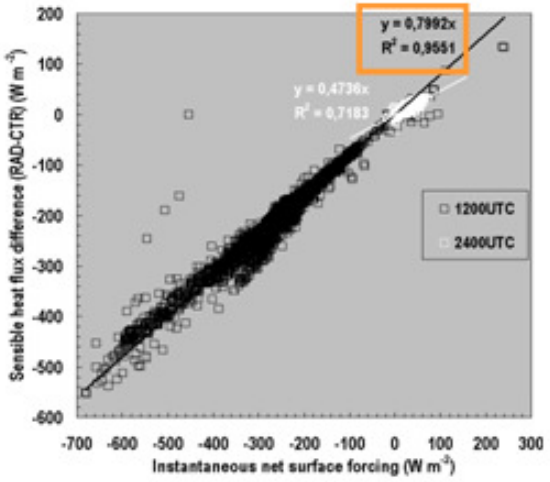


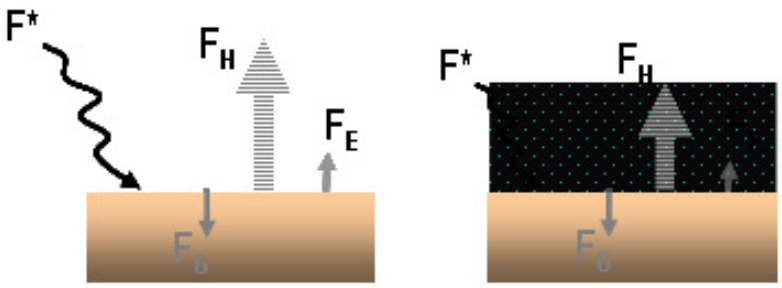
- 35-45 % reduction of the average AOD over the area covered by the main dust plume



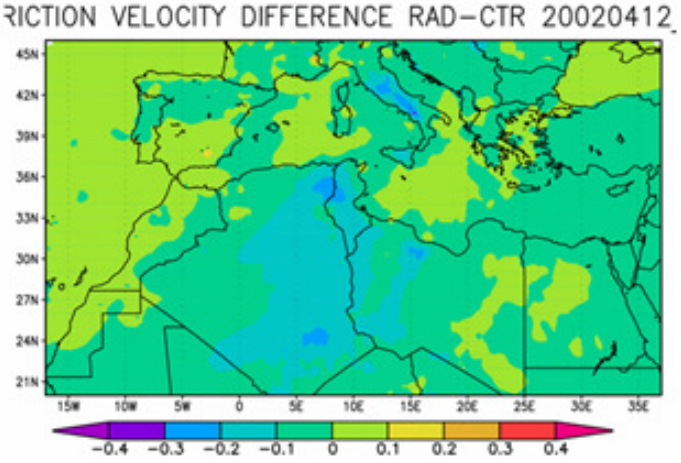
12 April at 12 UTC

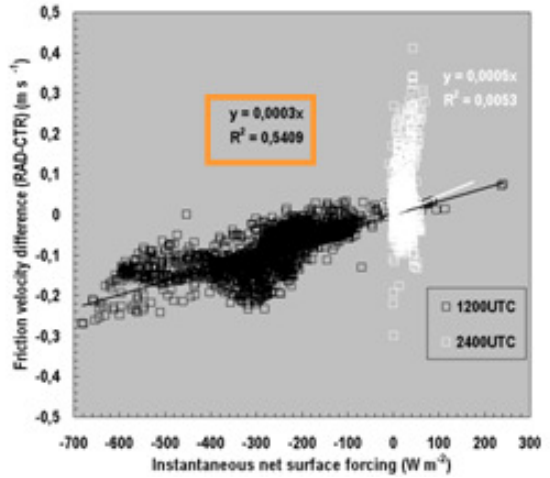






- Negative surface forcing mainly balanced by reduction in **turbulent sensible heat flux** into the atmosphere

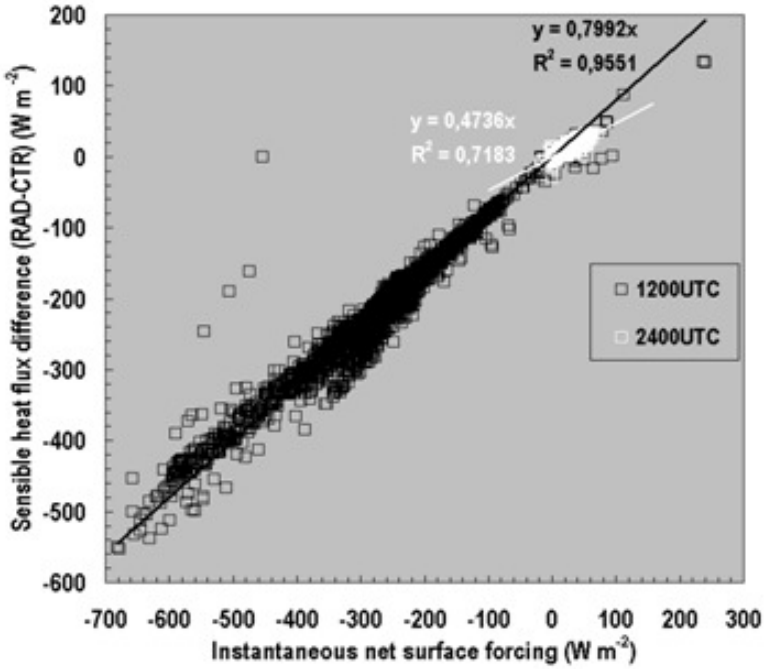


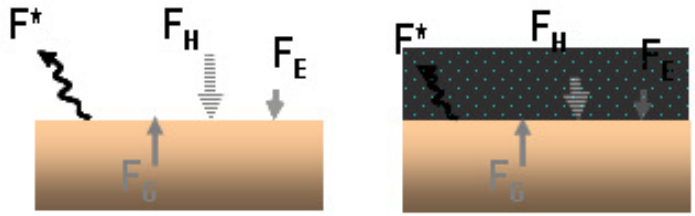


-In RAD mixing is reduced (more stability) and **downward momentum is reduced**

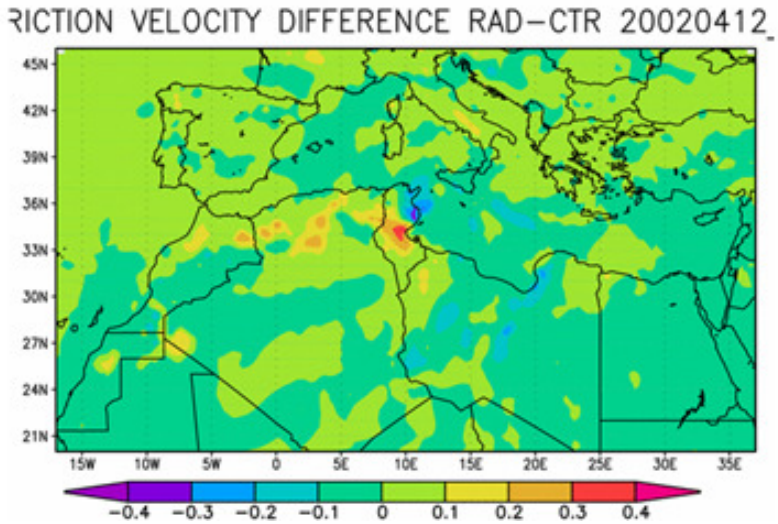
- **Friction velocity** significantly **correlates with surface forcing during the day**

13 April at 00 UTC

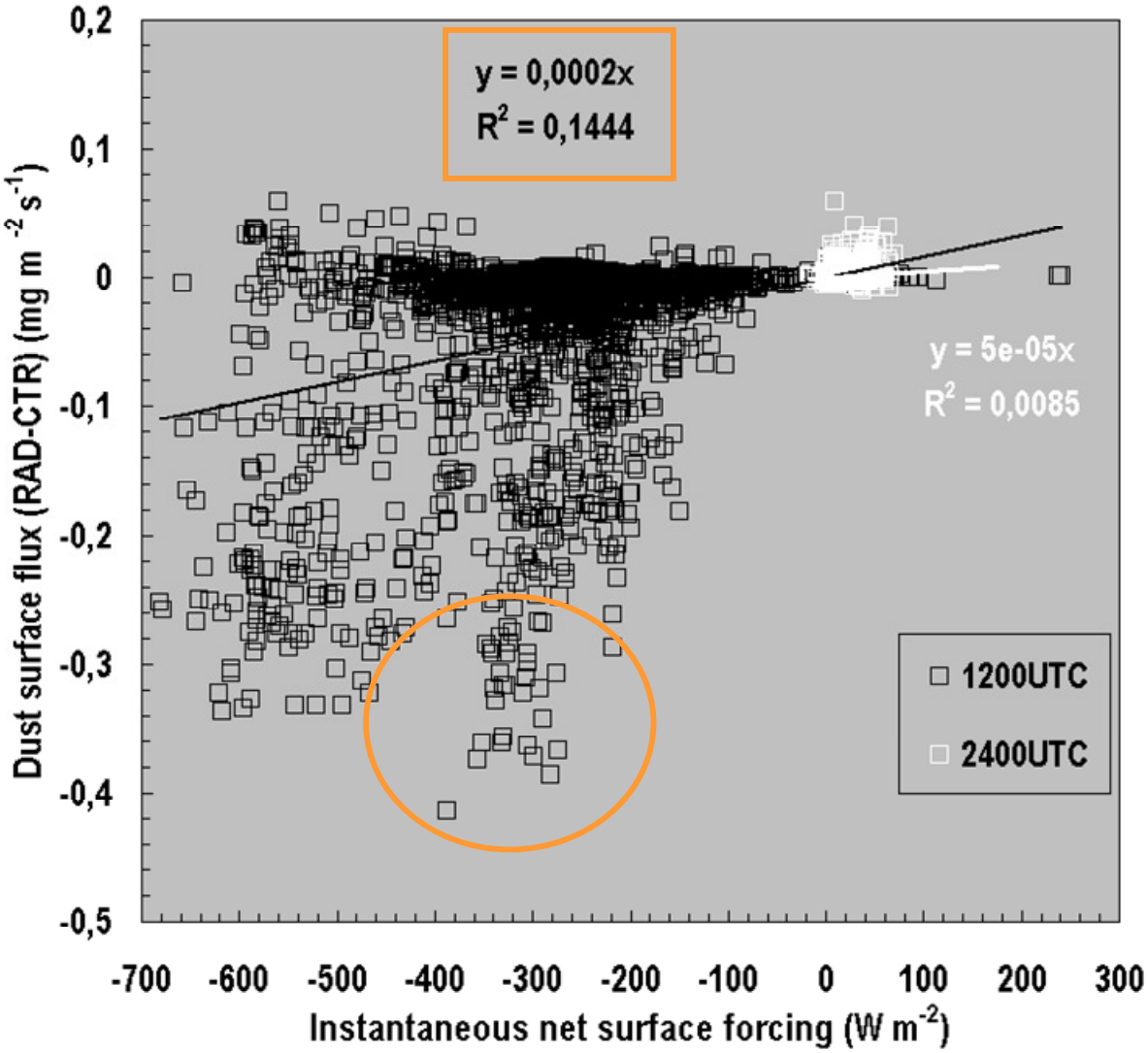




- In RAD absorption and reemission from the dust layer can delay surface cooling and increase mixing



Dust surface flux vs. Instantaneous net surface forcing



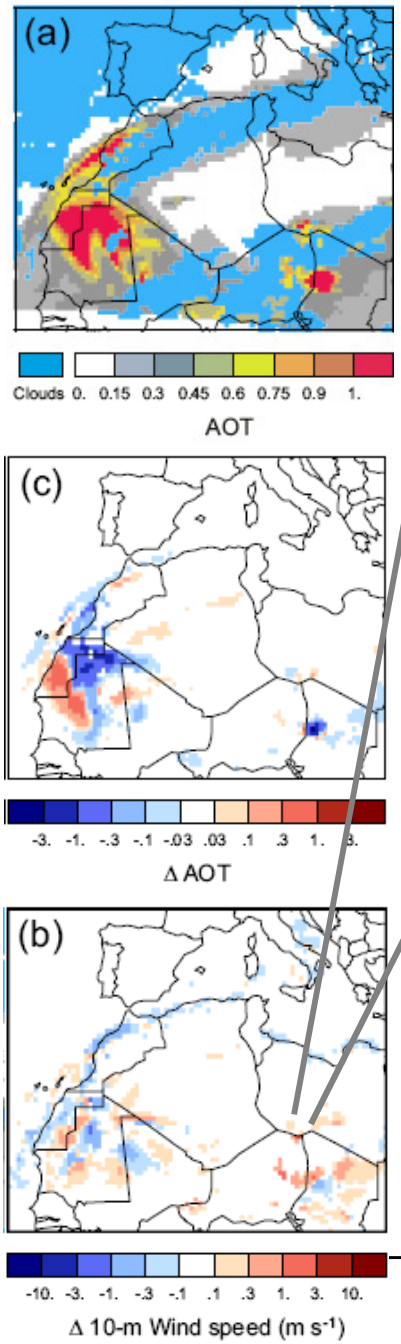
✓ **Highly non-linear function Threshold, power dependency**

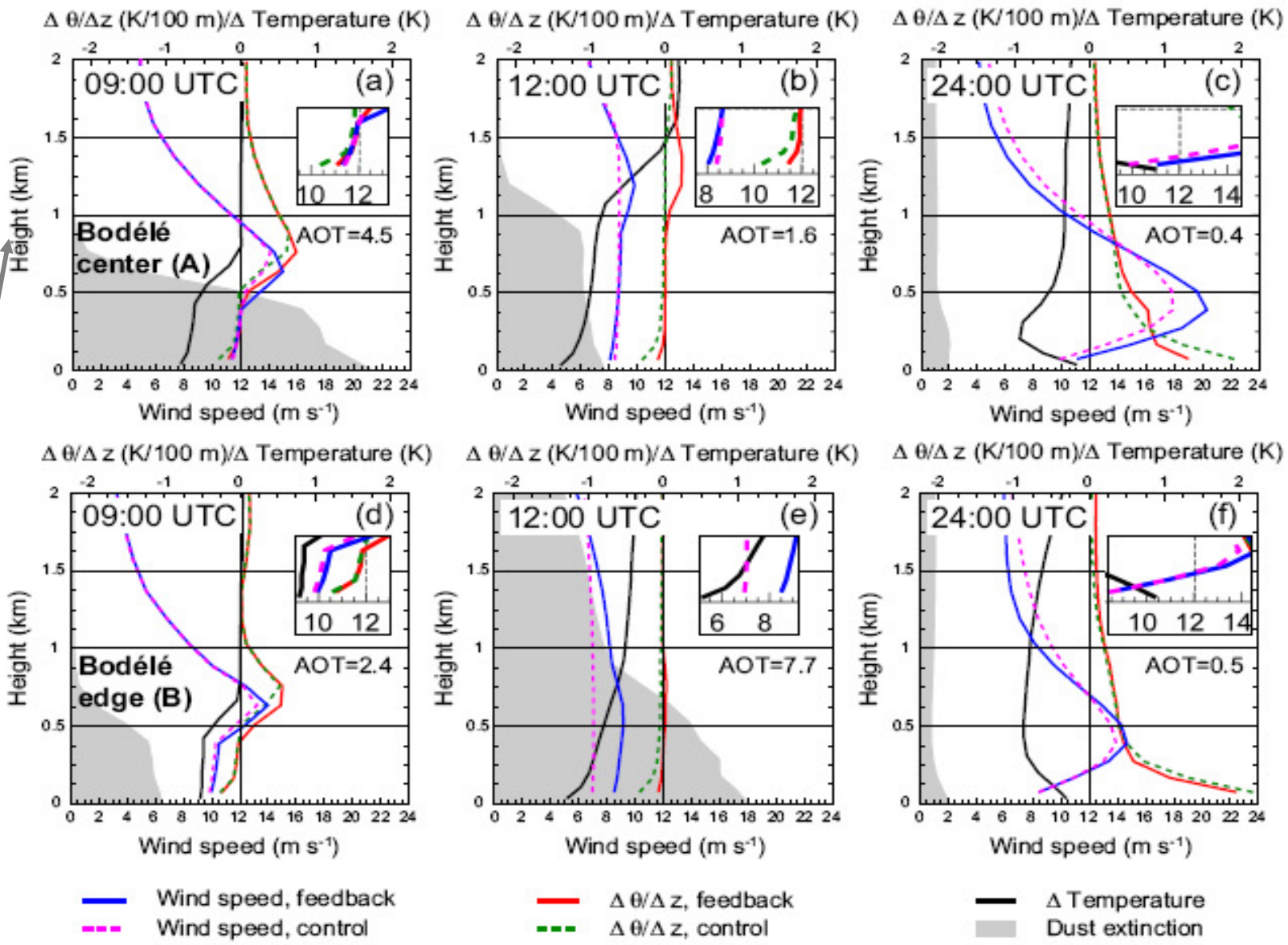
✓ **Very large reduction in some areas**

Heinold et al. (2008)

Dust radiative feedback on Saharan Boundary Layer Dynamics and Dust mobilization

Regional model (Low Level Jet in the Bodélé)



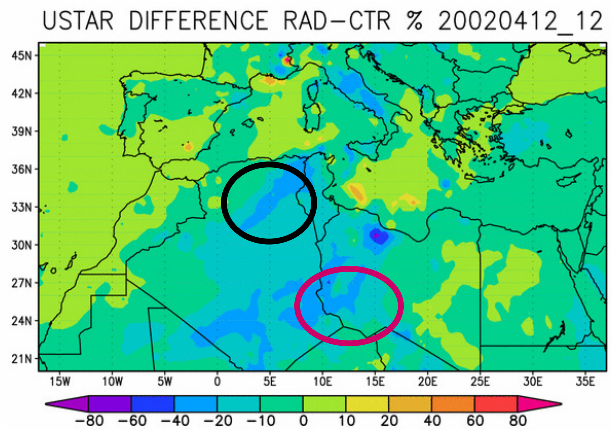


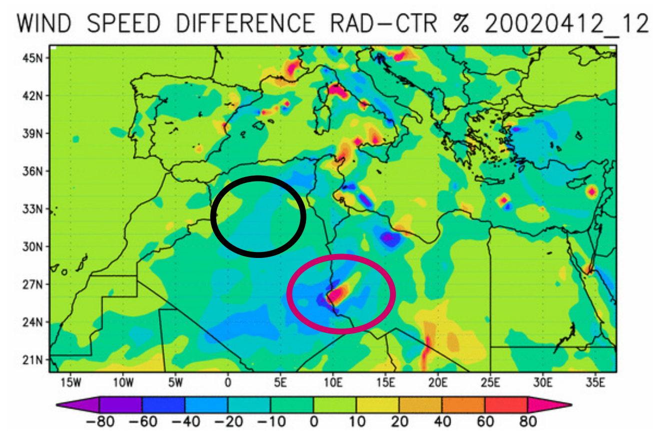
- AOD reduction: locally 40-70%, average reduction 3-11 %

Feedbacks upon surface wind speed and friction velocity

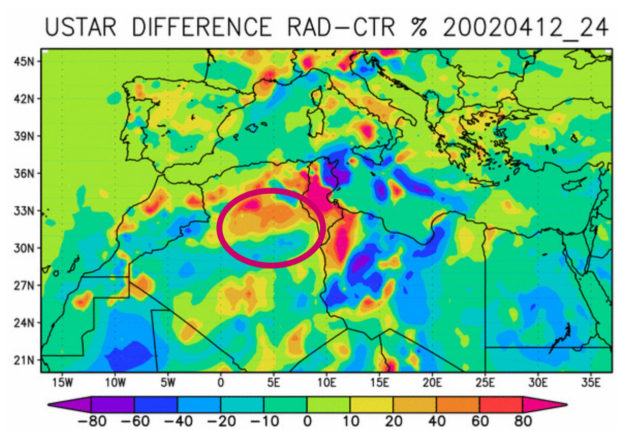
Feedback on dust emission model dependent!

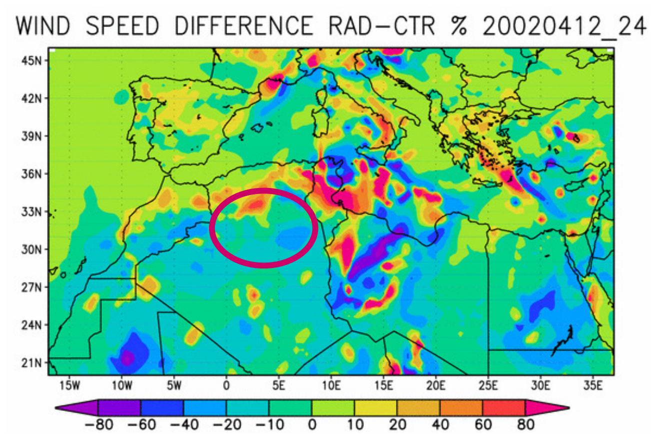
U* RAD-CTL (%) | **Wind speed RAD-CTL (%)**





day





night

Relative impact and sign between friction velocity and wind speed anomalies may strongly differ

Models use friction velocity or surface wind speed

$u^* = Vs\,\kappa \;/\; [\ln(zs / z0) - ym\,(zs / L)]$

Vs is the surface wind speed
κ is the von Karman constant,
z0 is the surface roughness
ym is the stability parameter for momentum
L is the Monin-Obukhov length.

Unstable: ym > 0 U* innreases
Neutral : ym = 0
Stable : ym > 0 U* indreases

Current situation of NWP models

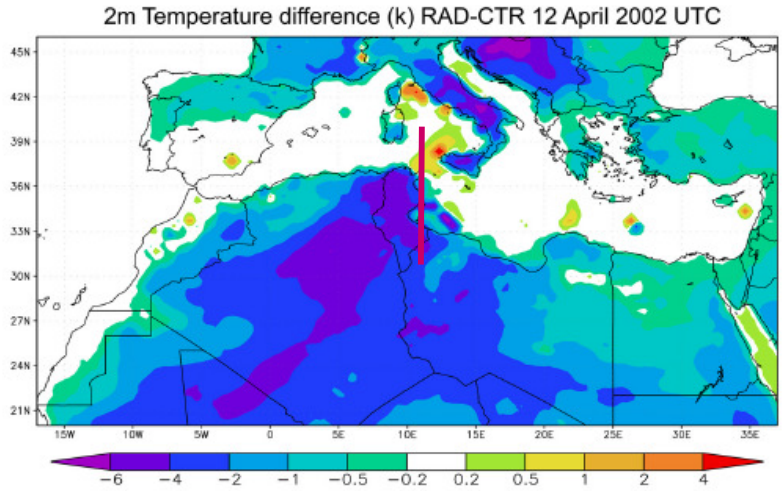
Use pre-specified O_3 and CO_2 profiles in radiation calculations

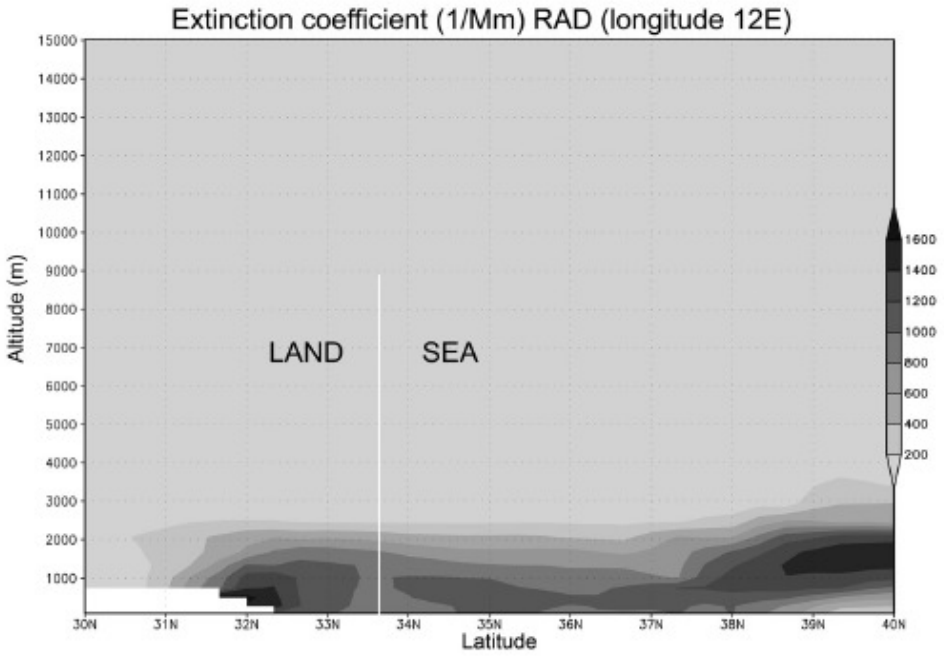
NCEP regional model use the solar constant reduced by 3% anywhere anytime to represent *aerosol influence*

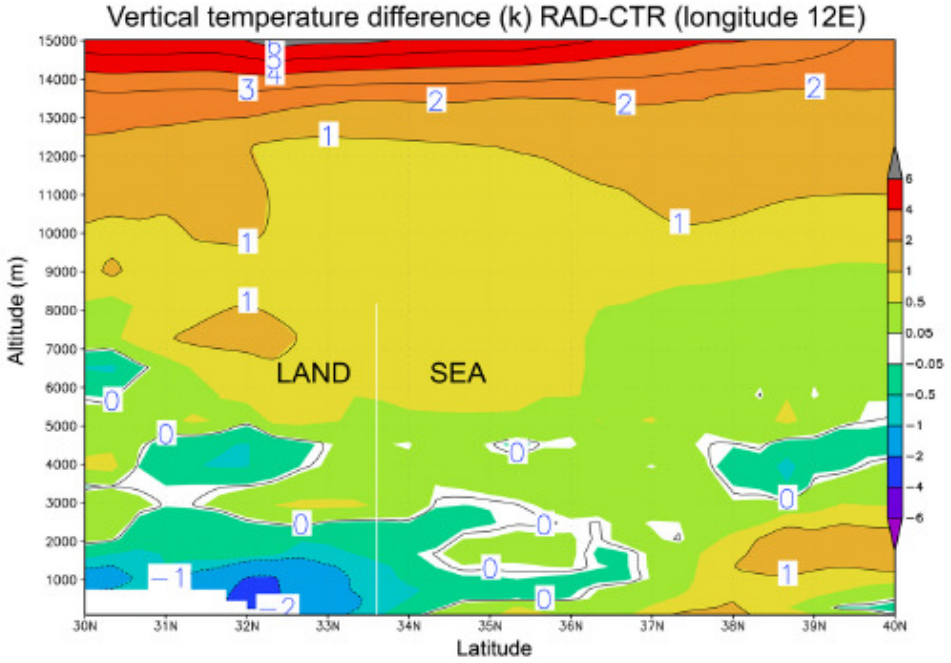
X None of the operational atmospheric models use online predicted mineral dust concentration for radiation calculations

IS IT IMPORTANT CLOSE TO DUST SOURCES FOR NWP?

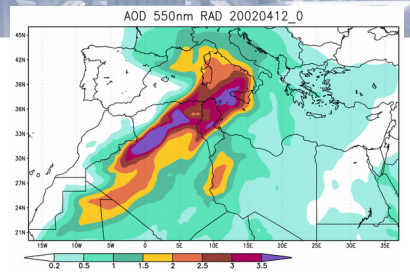
Effects on temperature



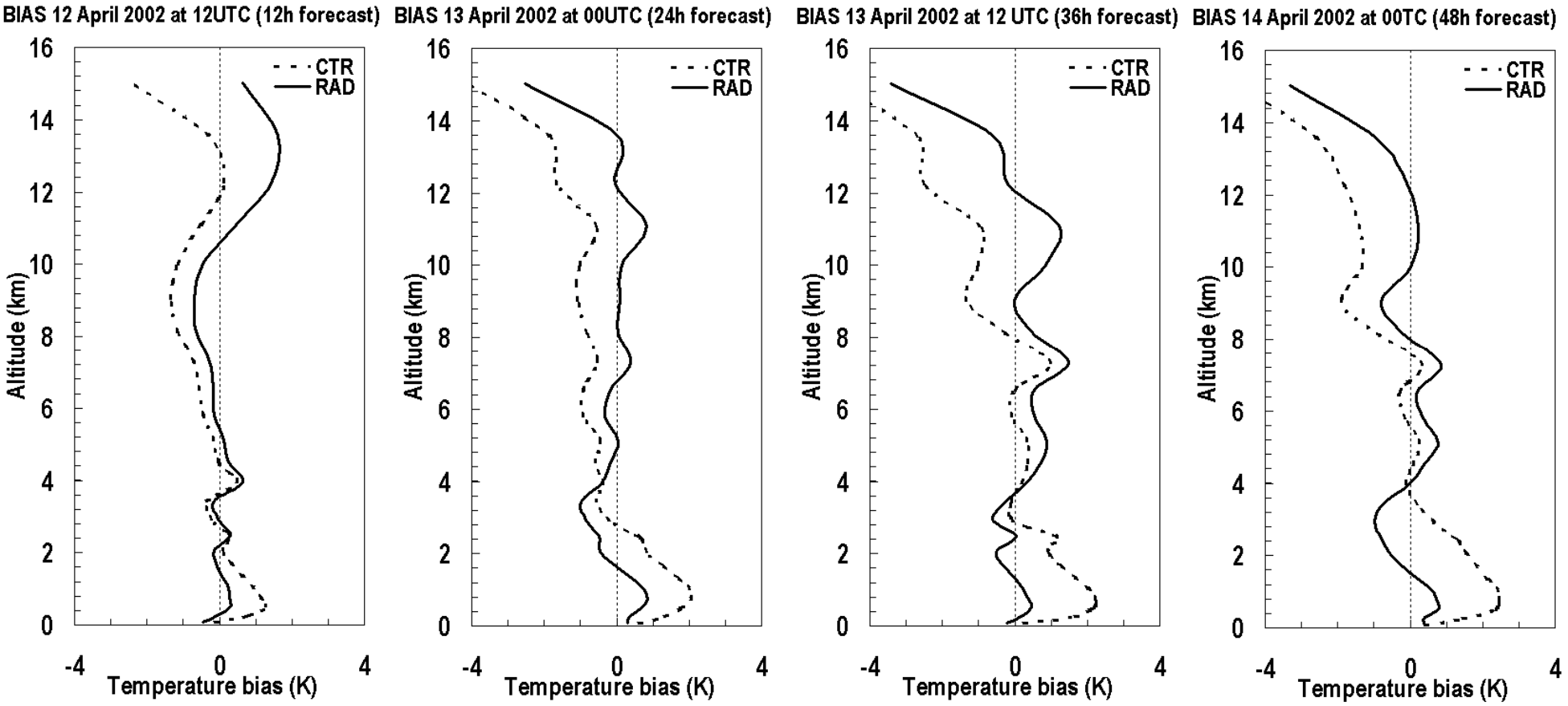




Interactive dust-radiation modeling: a step to improve weather forecasts,. Regional Model. Large scale dust storm Pérez et al. (2006)

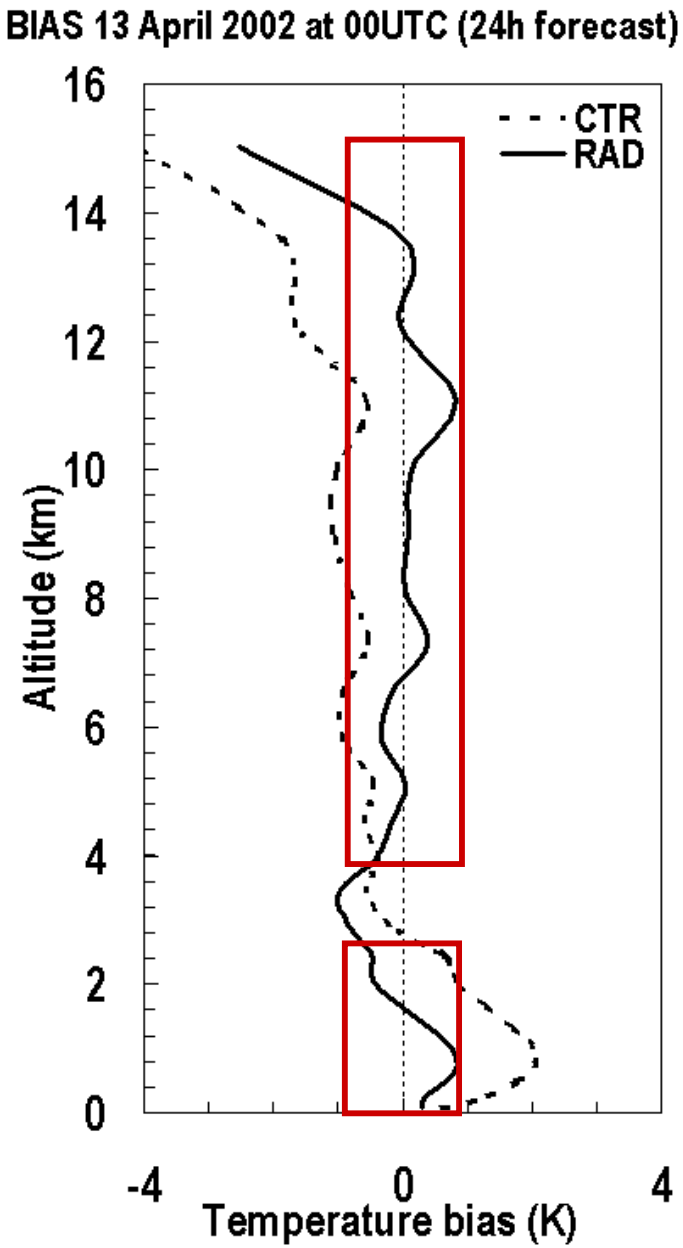


Atmospheric temperature forecasts
RAD and CTR evaluated against objective analysis data



12 h Forecast | 24 h Forecast | 36 h Forecast | 48 h Forecast

Interactive dust-radiation modeling: a step to improve weather forecasts,. Regional Model. Large scale dust storm Pérez et al. (2006)



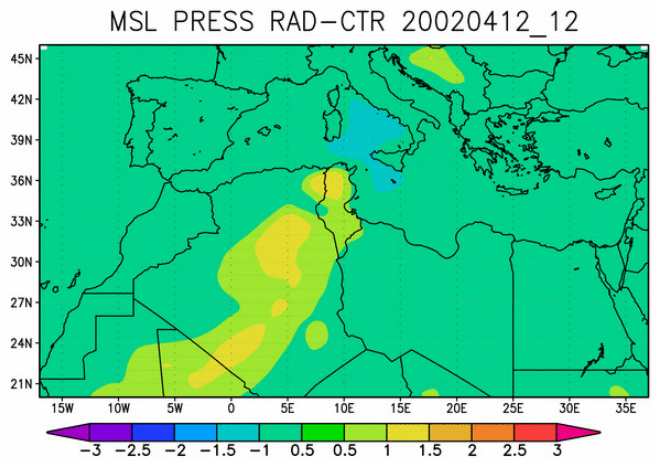
- ✓ RAD improves in most of the atmospheric layers
- ✓ Reduction of the low level warm bias
- ✓ Reduction of the upper level cold bias

Reduction of sensible heat flux reduces PBL temperature

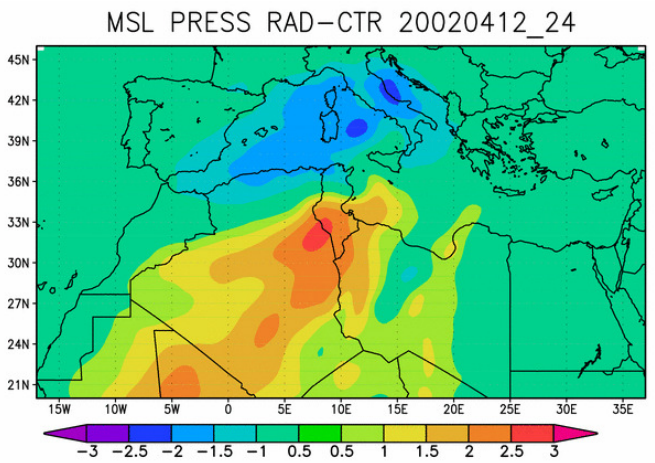
Dust redistributes heat from the surface and near surface to higher levels of the atmosphere

Sea-level pressure forecasts

00UTC +12h



00UTC +24h



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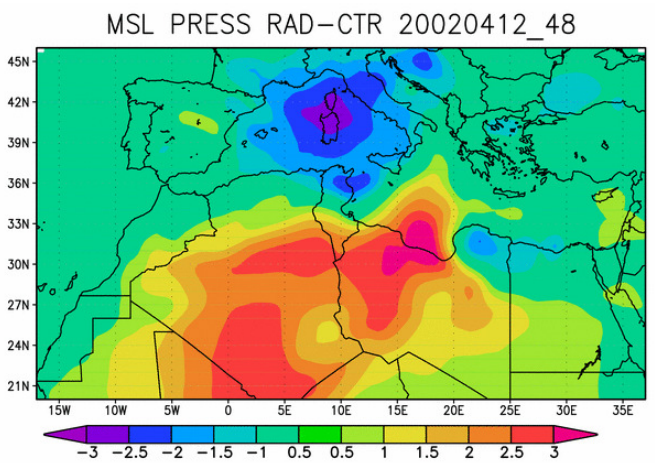


RAD and CTR evaluated against objective analysis data

Root mean square error

	Forecast time			
	12 h	**24 h**	**36 h**	**48 h**
RAD	1.93	1.52	2.29	1.76
CTR	1.95	1.83	2.73	2.09

Rodwell and Jung (2008)

Understanding the local and global impacts of model physics changes: An aerosol example

DUST AND SEASONAL FORECASTING: SIGNIFICANT IMRPOVEMENTS THROUGH DIRECT ATMOSPHERIC FORCING AND TELECONNECTIONS FOR HEIGHT, WIND AND PRECIPITATION

Seasonal integrations for 40 December–February and June–August seasons for the period 1962 to 2001.

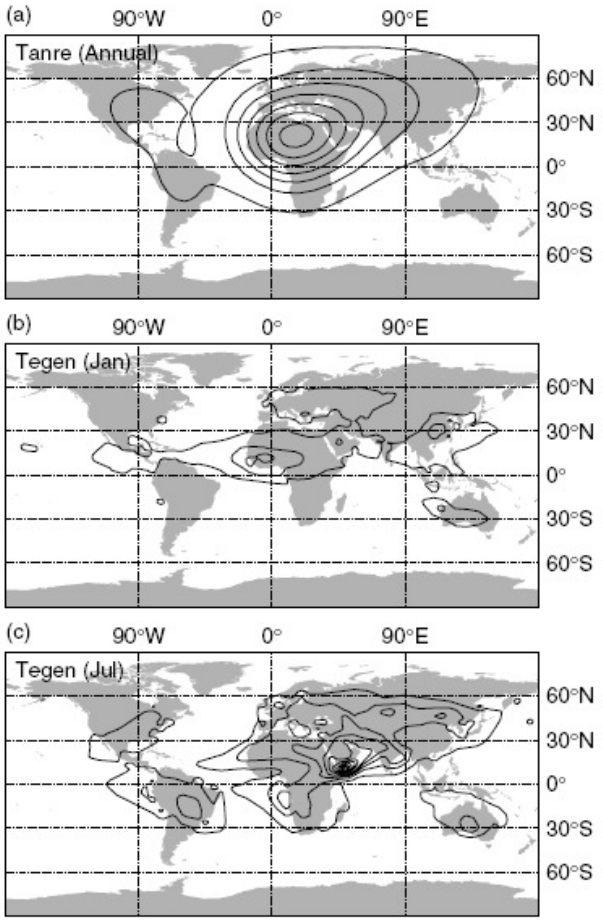


Figure 1. Optical depths at 550 nm associated with the model aerosol climatology. (a) The 'old' annually-fixed climatology of Tanré *et al.* (1984), (b) the 'new' January climatology of Tegen *et al.* (1997), (c) the 'new' July climatology of Tegen *et al.* (1997). The smallest contour is 0.1 and the contour interval is 0.1.

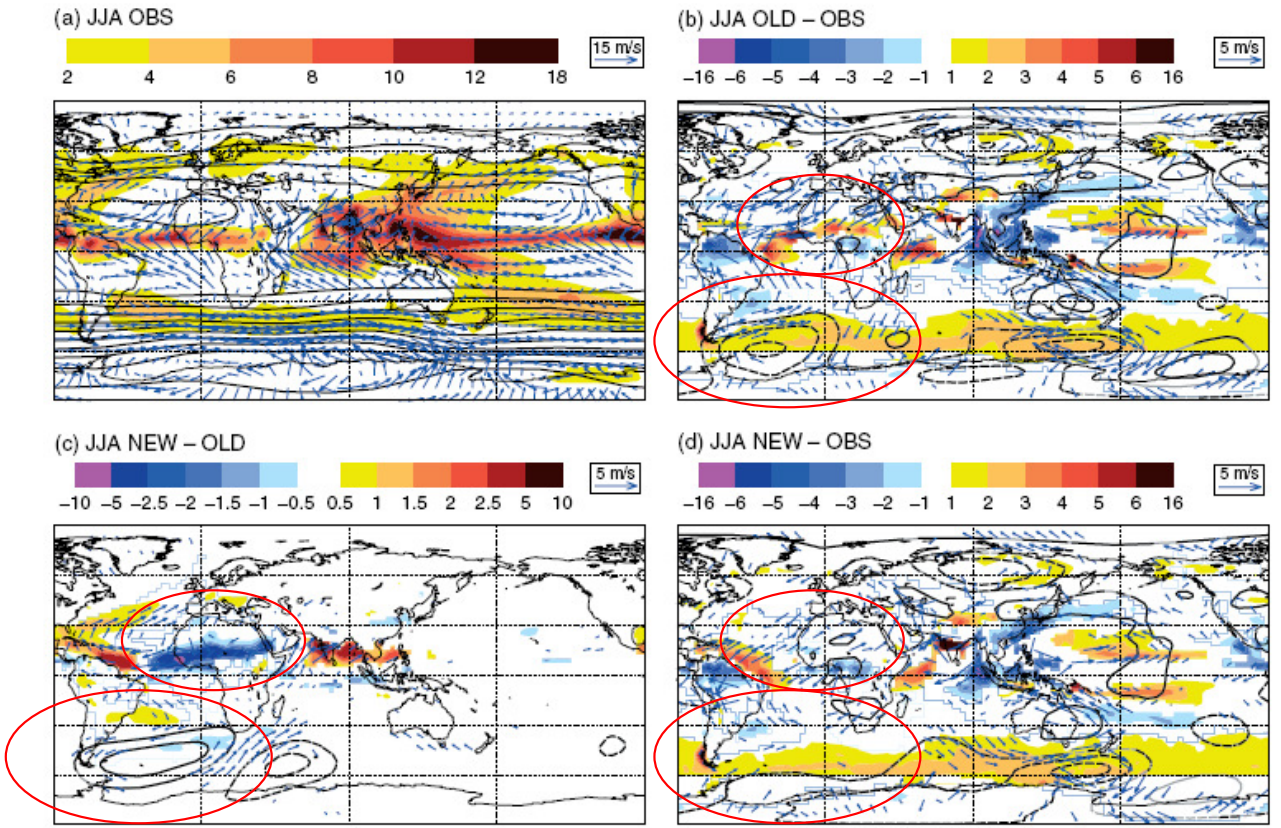


Figure 2. Diagnostics of June–August seasonal-mean total precipitation (shading; mm day^{-1}), 925 hPa horizontal wind vectors (see scaling vectors) and 500 hPa geopotential heights (see below for contour interval). Observational data come from Xie and Arkin (1997) for precipitation over the period 1980–1999 and from ERA-40 for the other fields over the period 1962–2001. Forecast data come from the 'seasonal integrations' covering the same period as for the observations (see text for details). (a) Mean observed, (b) mean model error with the 'old' aerosol, (c) mean difference: model with 'new' aerosol minus model with 'old' aerosol (note the change in shading interval for precipitation), and (d) mean model error with the 'new' aerosol. Precipitation and wind differences are only plotted where seasonal-mean differences are statistically significant at the 10% level. Height differences are contoured solid for positive, dashed for negative, grey where not significant and with contour interval of 10 dam in (a) and 2 dam in (b)–(d).

SUMMARY AND RECOMMENDATIONS
Regional models and feedbacks

- Uncertainties related to dust optical properties !!

- Need for more regional model sensivity studies to understand complex interactions:
  - Under different types of events
  - Taking into account the range of uncertainty in optical properties
  - Multi-model approach: different emission, turbulence and surface layer schemes, e.g. assumptions in friction velocity calculation.
  - New opportunities as more and more sofisticated weather models are being on-line coupled with dust

- Need for regional multi-model estimates of the feedback integrated over larger time scales (seasonally, yearly) to complement AGCM study of Miller et al. (2004)

- Effect of larger particles on longwave radiation

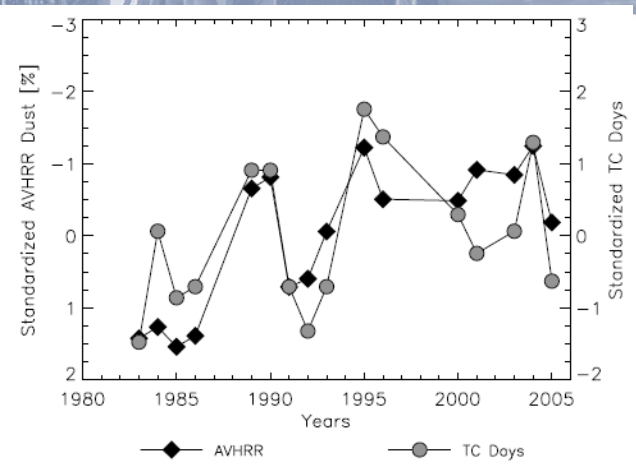
- Explore combined and relative impacts of dust direct, semi direct *(and indirect effects)* in regional climate mode integrations

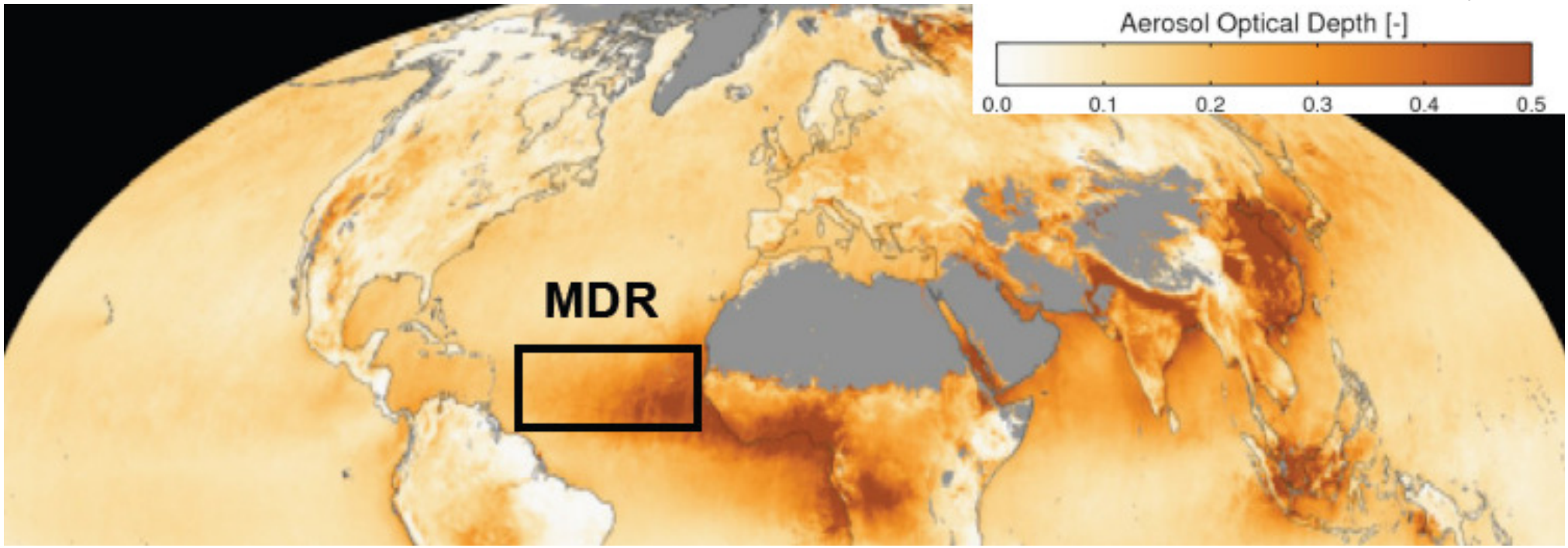
- Dust-radiation benefits on numerical weather prediction should be further assesed and progressively operationally implemented.

- Need for numerical experiments of hurricanes with on-line regional dust models

Mineral dust and Atlantic hurricane activity

Various studies have shown that there is an anti-correlation between the year-to-year variability of integral measures for seasonal hurricane intensity and dust activity over the main development region (MDR; 10°–20°N, 20°–65°W; *Evan et al. 2006*).





Does mineral dust influence hurricane activity? What are the time-scales of interaction? Synoptic, seasonal, decadal?

Mineral dust and Atlantic hurricane activity

CURRENT HYPOTHESES

1: Non-causal relationship due to „external“ processes Interannual–decadal

1a) Atlantic Meridional Mode (AMM)

1b) El Niño/Southern Oscillation (ENSO)

2: Causal relationship mediated through SST changes (Seasonal–decadal)

3: Direct causal relationship through SAL impact on hurricane dynamics (Synoptic–seasonal)

4: Modification of H2 & H3 through cloud-microphysical processes

NMMb/BSC-DUST (Perez et al., 2009)

- The NCEP-ETA weather forecast model is replaced by a state-of-the-art regional/global model with improved dynamics and physics:

→ ***NCEP-NMMb***

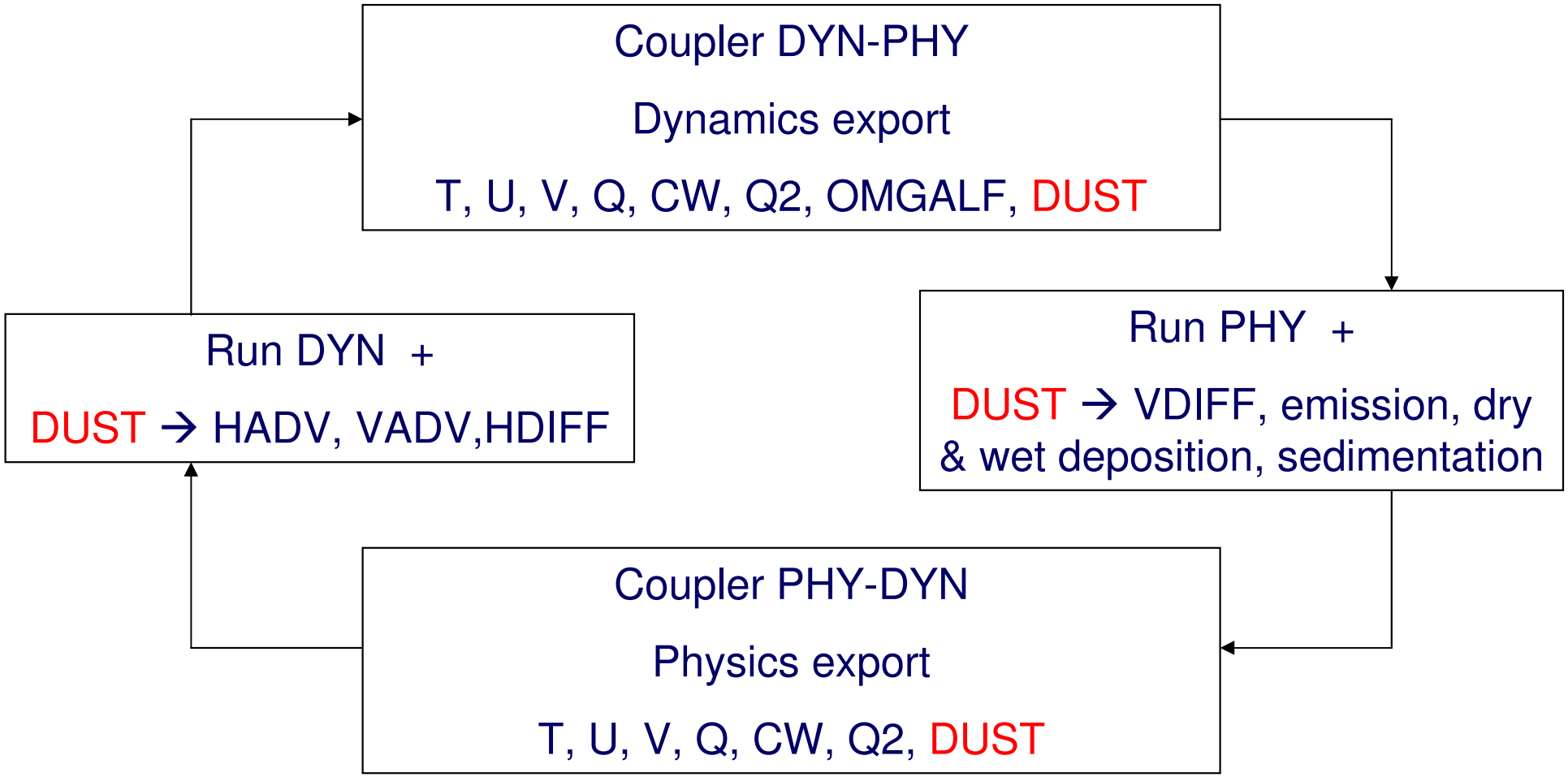
- ***Under development at NCEP*** [Janjic, 2007]
- Evolution of ETA model with updated meteorological core
- Built on NWP experience by relaxing hydrostatic approximation
- Unified model with **regional and global domain** (simple switch)
- The **nonhydrostatic** option as an add–on module
- Arakawa B grid and pressure-sigma hybrid coordinate [Arakawa and Lamb, 1977]
- Adams-Bashforth/Crank-Nicholson for horizontal/vertical advection
- NMMb regional will become the next-generation NCEP mesoscale model for ***operational weather forecasting in 2010***

→ ***NMMb/BSC-DUST***

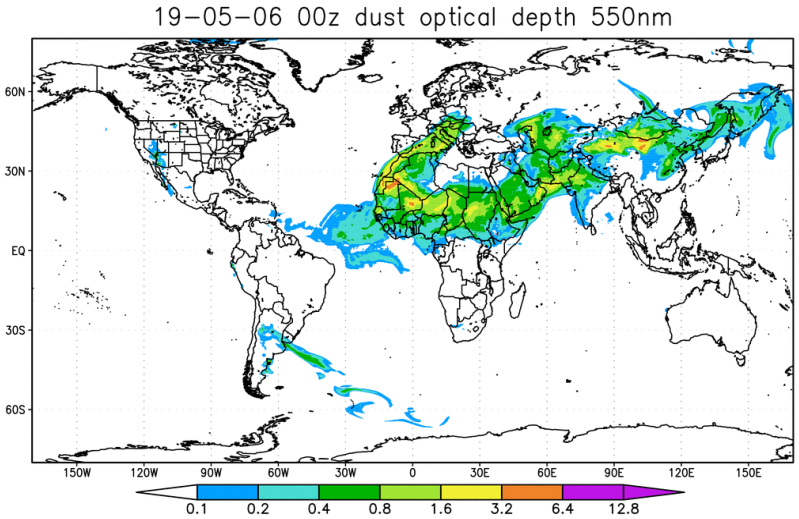
- Implementation of all common **on-line dust modules** for regional/global simulations
- **Nested regional domains at very high resolution**
- The current DREAM dust emission scheme is upgraded to a physically based scheme
- new high resolution database for soil textures and vegetation fraction is included
- **Radiative feedbacks on meteorology**

- NMMb ESMF

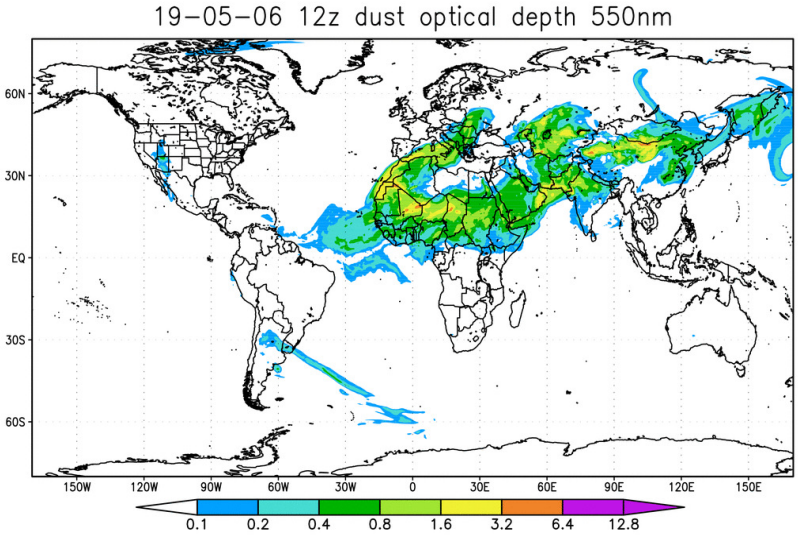
The atmospheric part of the ESMF superstructure
(Earth System Modeling Framework)

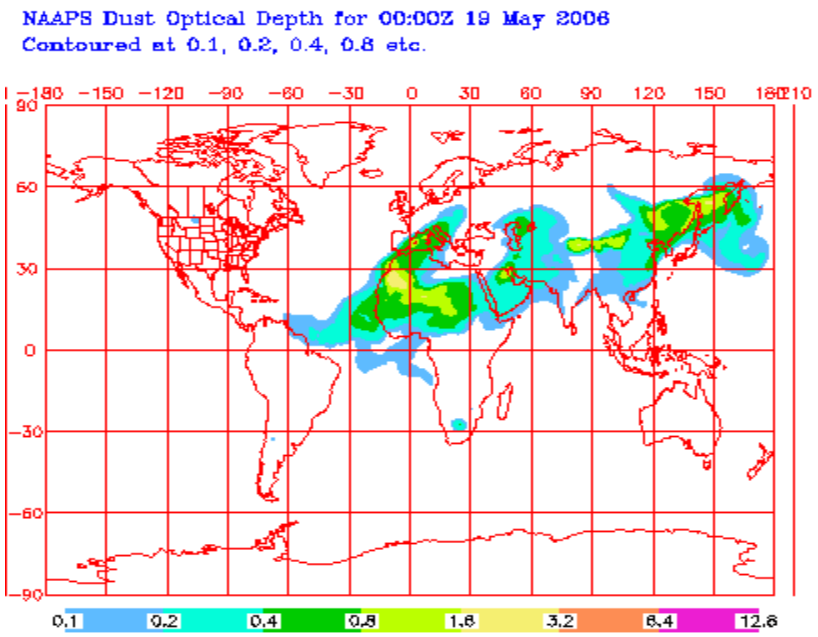


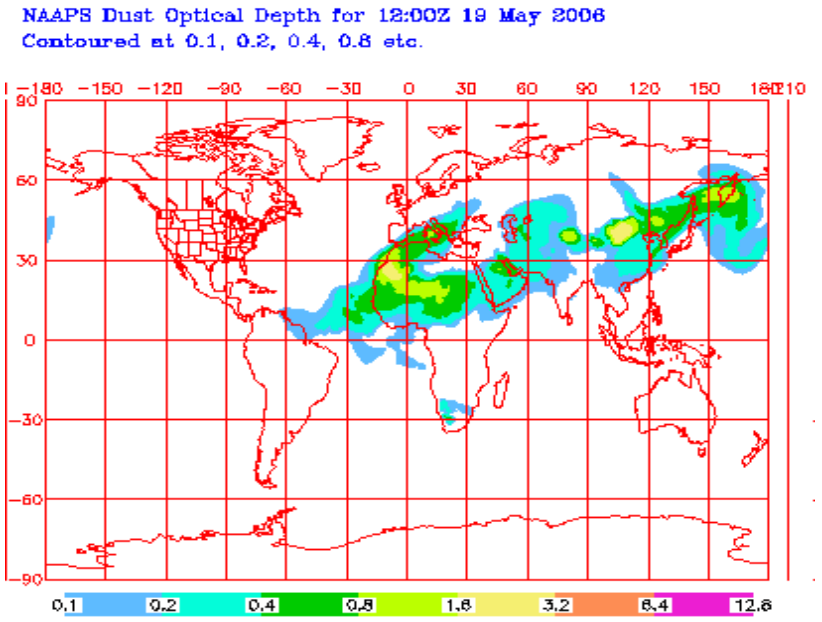
- NMMb first results



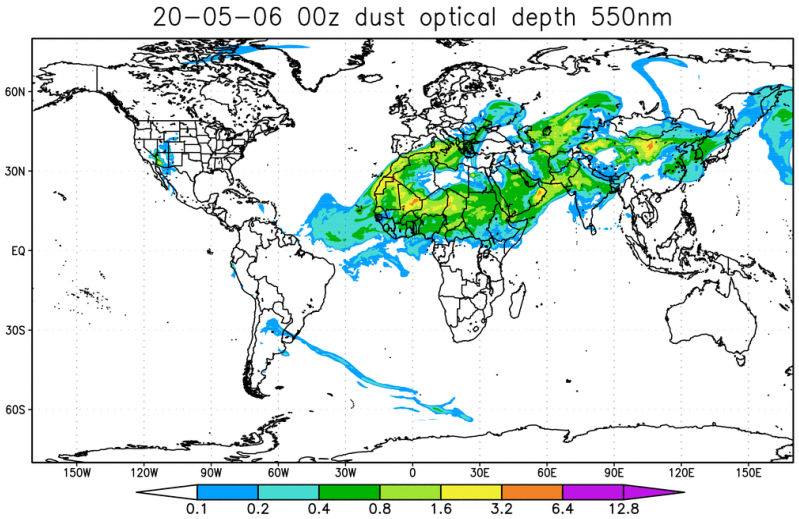
NMMb-DUST vs. NAAPS AOD



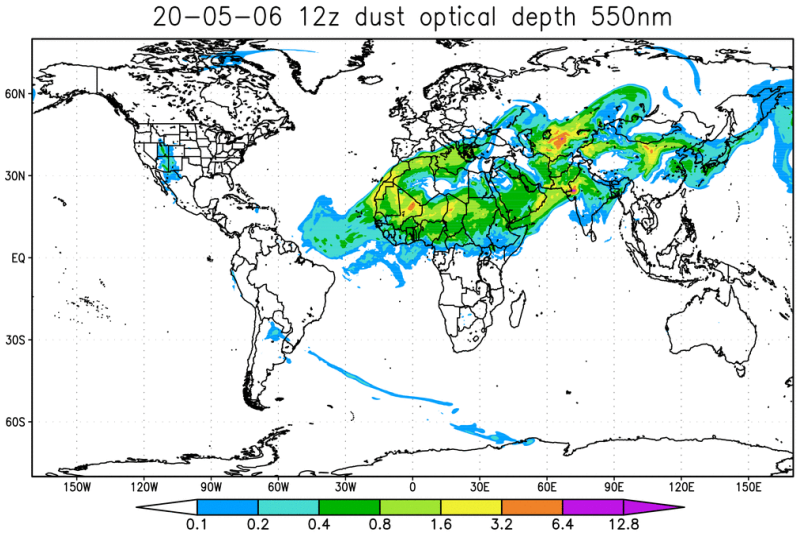


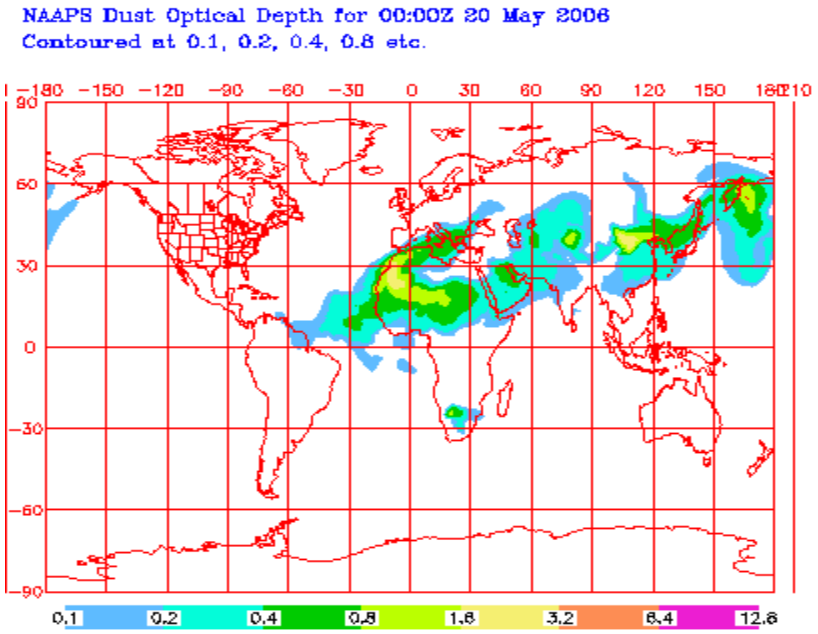


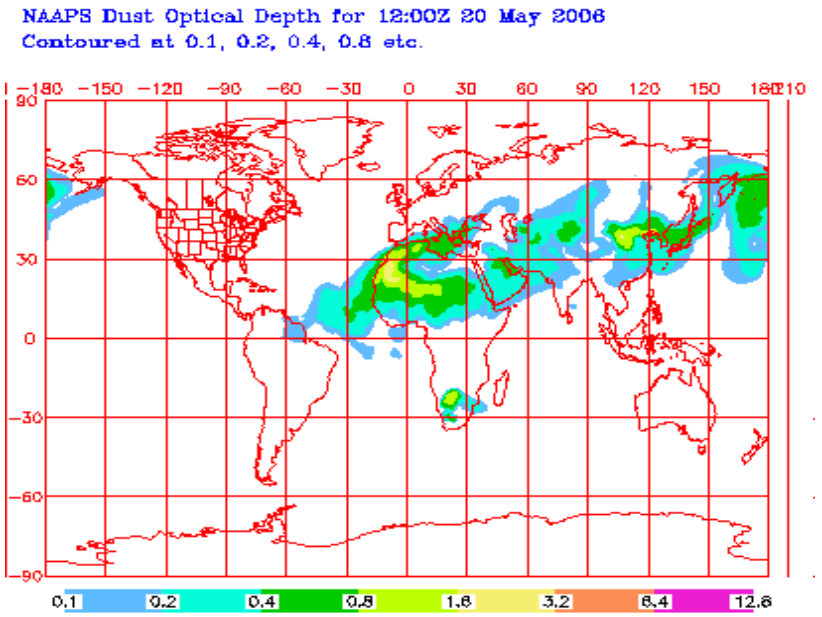
- NMMb first results



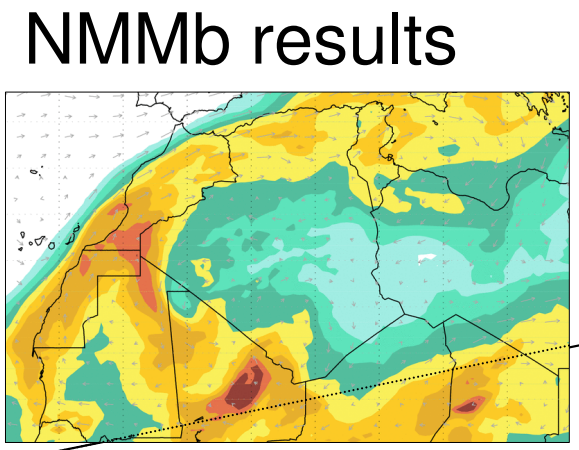
NMMb-DUST vs. NAAPS AOD

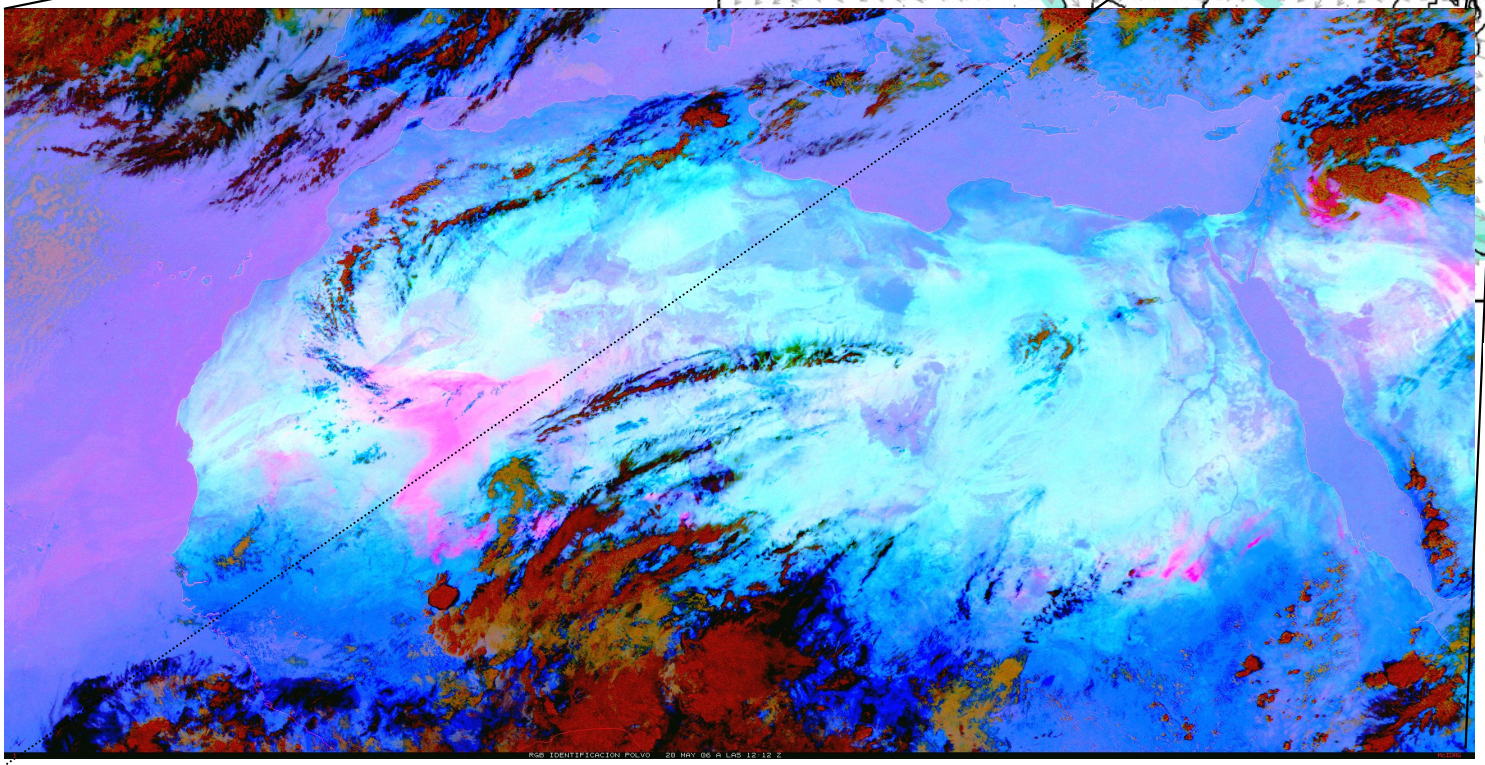


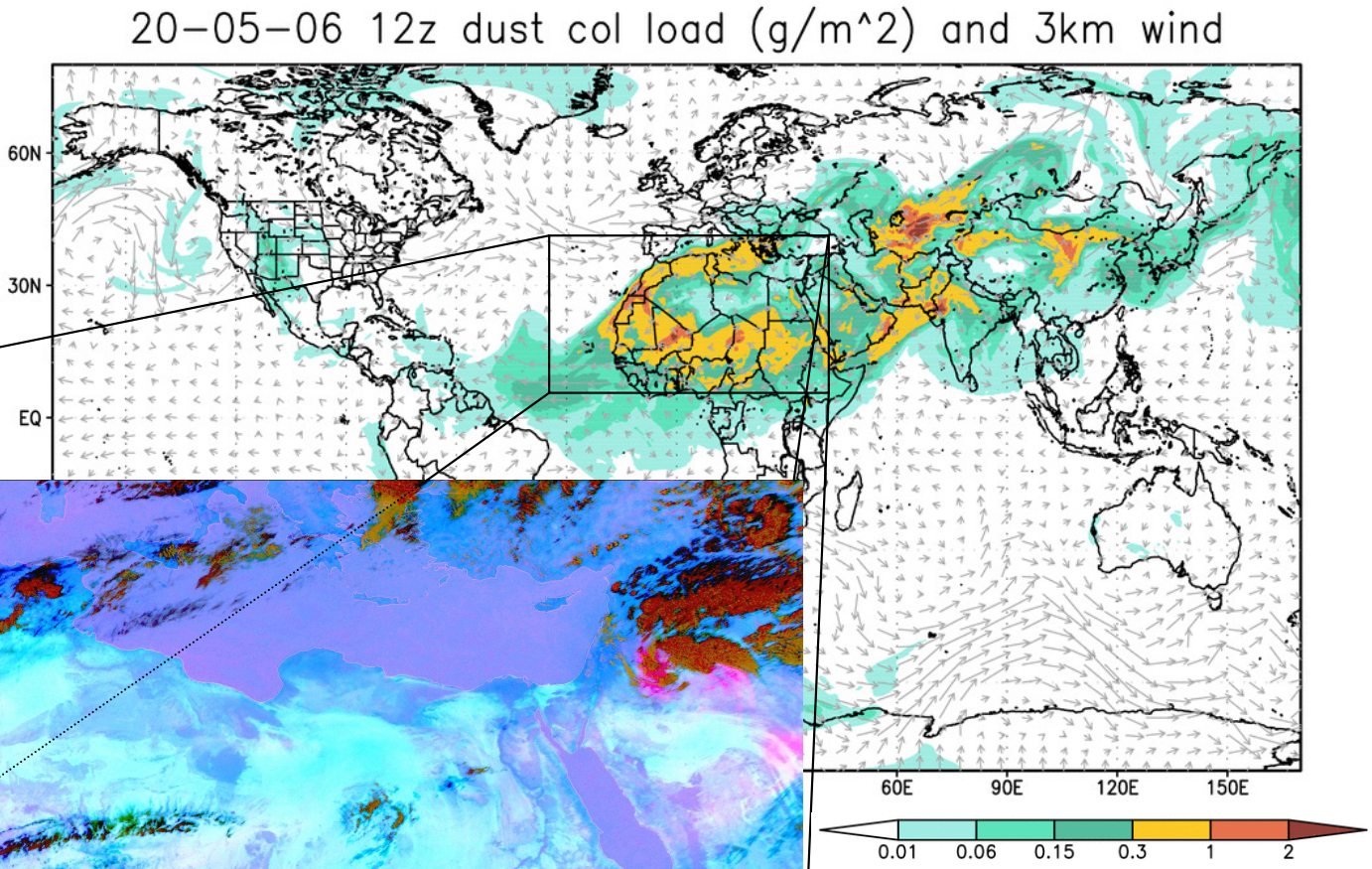




- NMMb results







MSG dust image
20-05-06 12z

THANK YOU

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