Development of a dust assimilation system for NMM-DREAM model based on MSG-SEVIRI satellite observations

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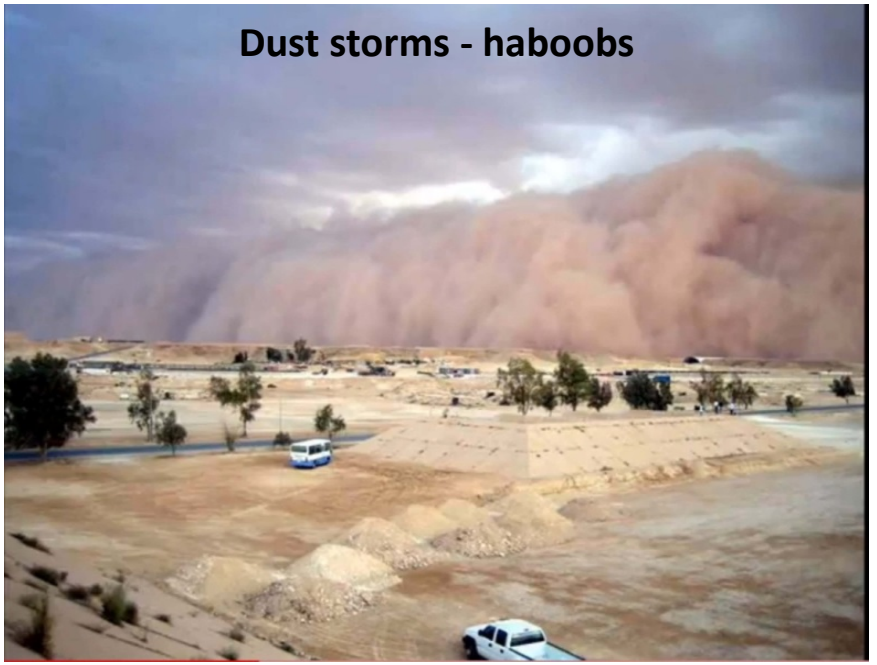
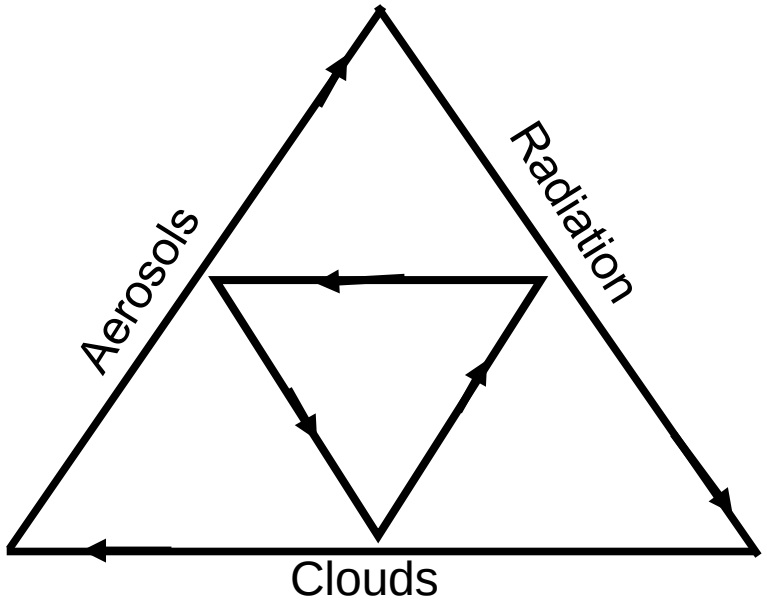
13th International Conference on
Meteorology, Climatology and Atmospheric Physics
COMECAP Thessaloniki, 19-21 September 2016

Why we care about dust aerosols?

1. **Natural Hazards** (dust storms, aerosol invigorated floods and cyclones, human health implications, visibility issues, aviation safety, etc.)
2. **Climate change** (Important scientific questions regarding the role of aerosols as weather and climate regulators).



Dust– meteorology interactions



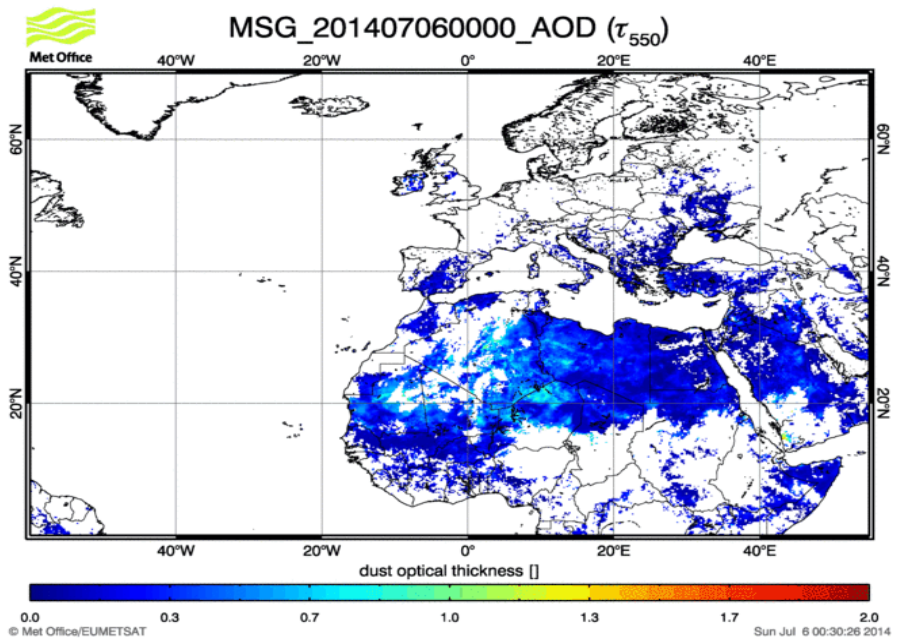
Small inaccuracies in modeled dust concentration may lead in big errors for radiative transfer and CCN/IN computations

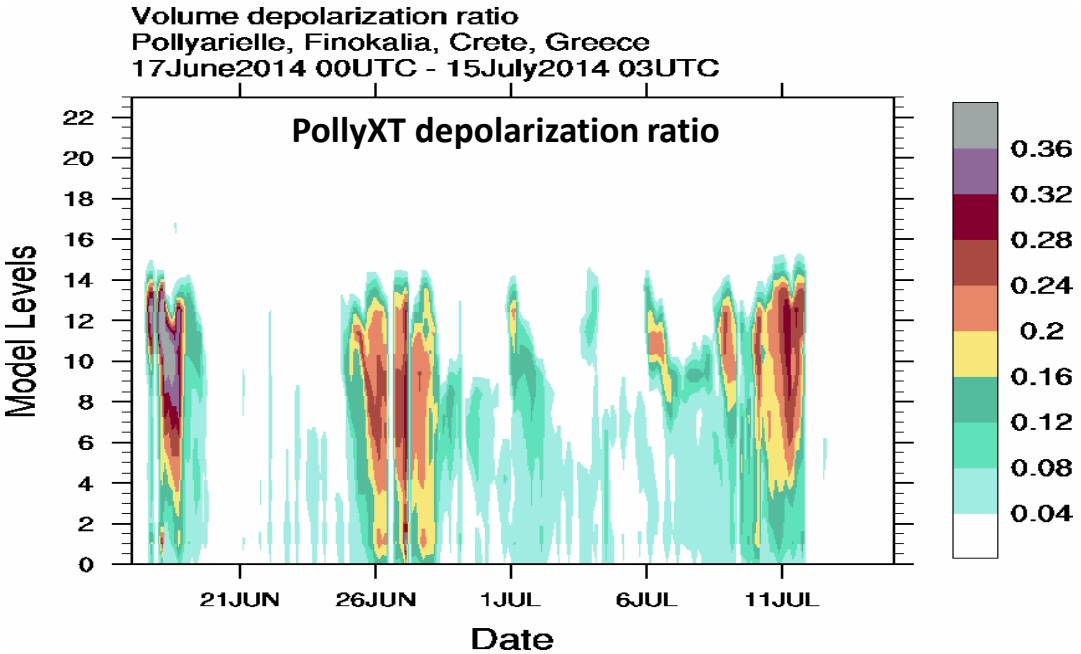
Dust modeling considerations – satellite assimilation

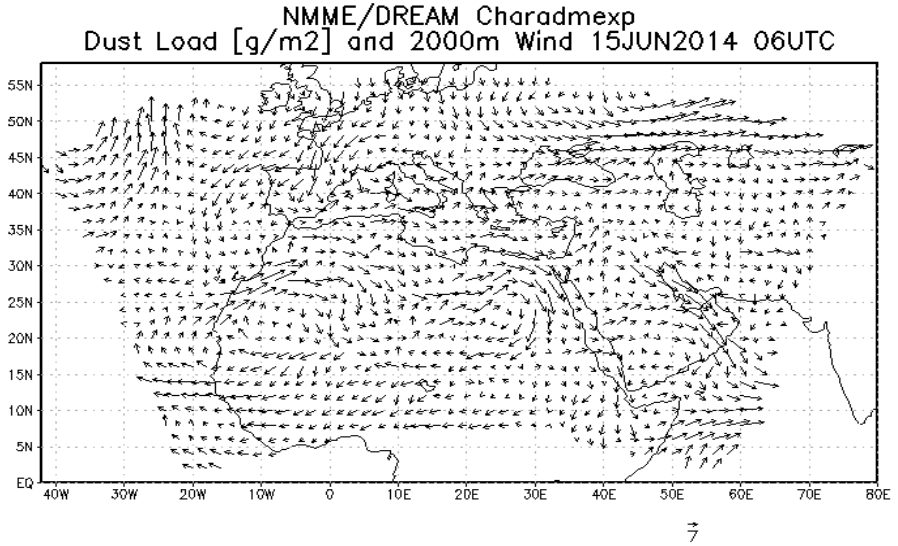
- **Atmospheric dust models rely on their own forecasts for initial and boundary conditions (warm start)**
- **Even at the idealized case of a perfect model run this methodology would imply error propagation from numerical diffusion itself**
- **The use of satellite assimilation to constrain the models is shown to improve forecast skill (e.g. Benedetti et al., 2009, JGR)**

CHARADMExp Campaign in Crete (June-July 2014)

Characterization of Aerosol mixtures of Dust And Marine origin

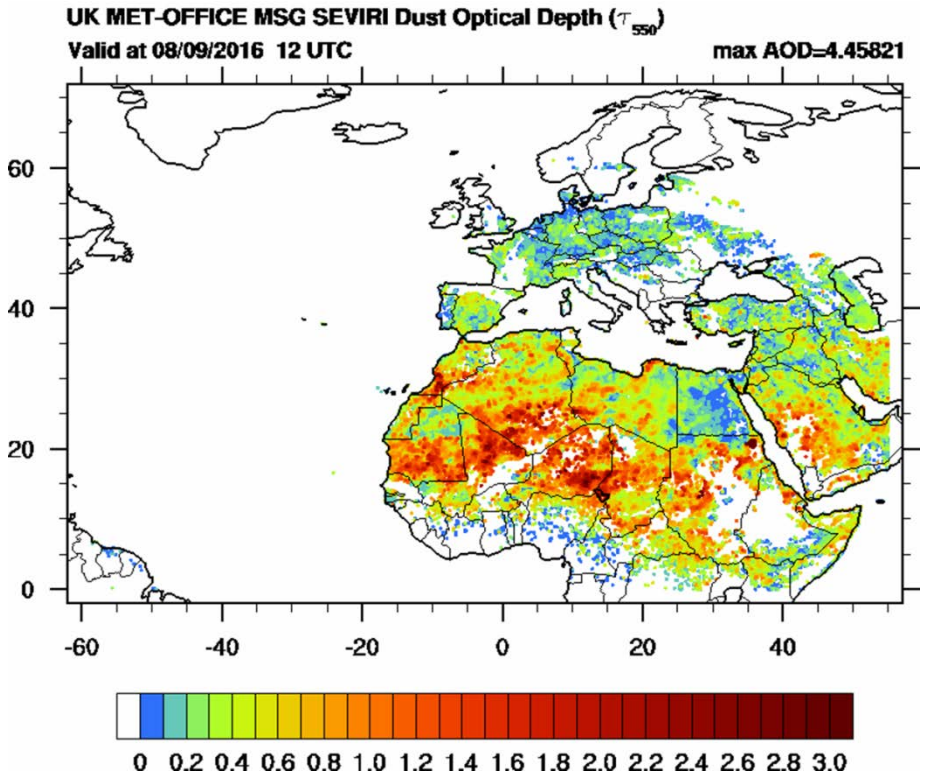






- The U.K. Met Office MSG dust product shows an estimation of the dust optical thickness retrieved from SEVIRI *(Brindley, H. E., and J. E. Russell (2009), JGR)*
- PollyXT lidar system operates 8 channels (3 backscatter, 2 Raman extinction, 2 depolarization and 1 water–vapor sensitive at 407 nm).
- NMME-DREAM dust model with MSG-SEVIRI dust assimilation

UK Met Office MSG dust product



Dust Optical Depth from the UK Met Office SEVIRI retrieval algorithm, 8 September 2016

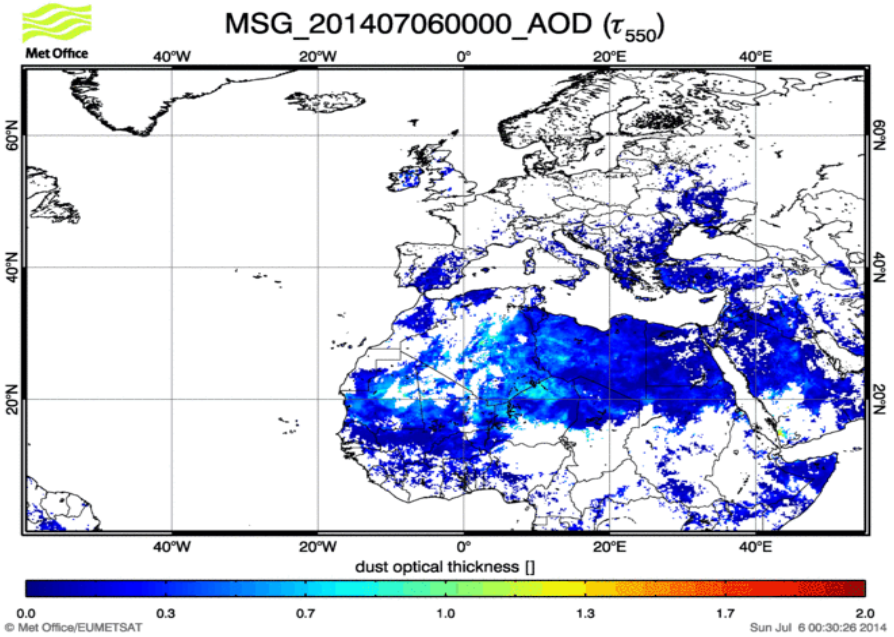
- The U.K. Met Office MSG dust product shows an estimation of the dust optical thickness retrieved from empirical relationship between SEVIRI infrared (10.8 μm) radiance and aerosol optical depth at 550nm.
- It is generated by transforming original retrievals to regularly-spaced grids (0.18 degree) using simple average methods.

Brindley, H. E., and J. E. Russell (2009), JGR

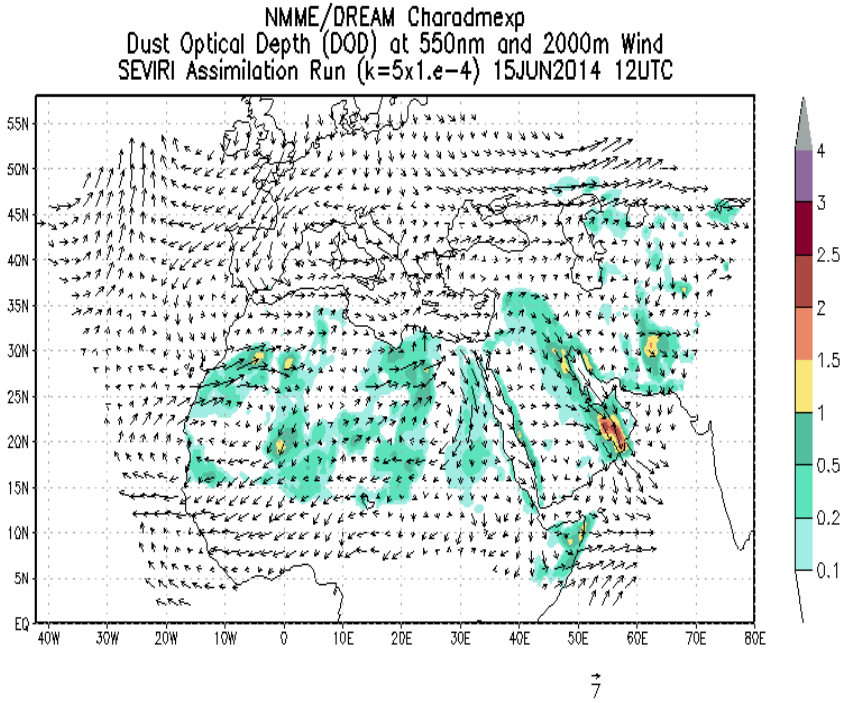
Possible issues for the assimilation of MSGDOD in NMME-DREAM

- Cloud contamination over the Sahel and southern latitudes
- Caspian sea dust
- Validation with campaign data
- DOD over sea
- Define observational error covariance

Development of an MSG-SEVIRI dust assimilation scheme in NMME-DREAM



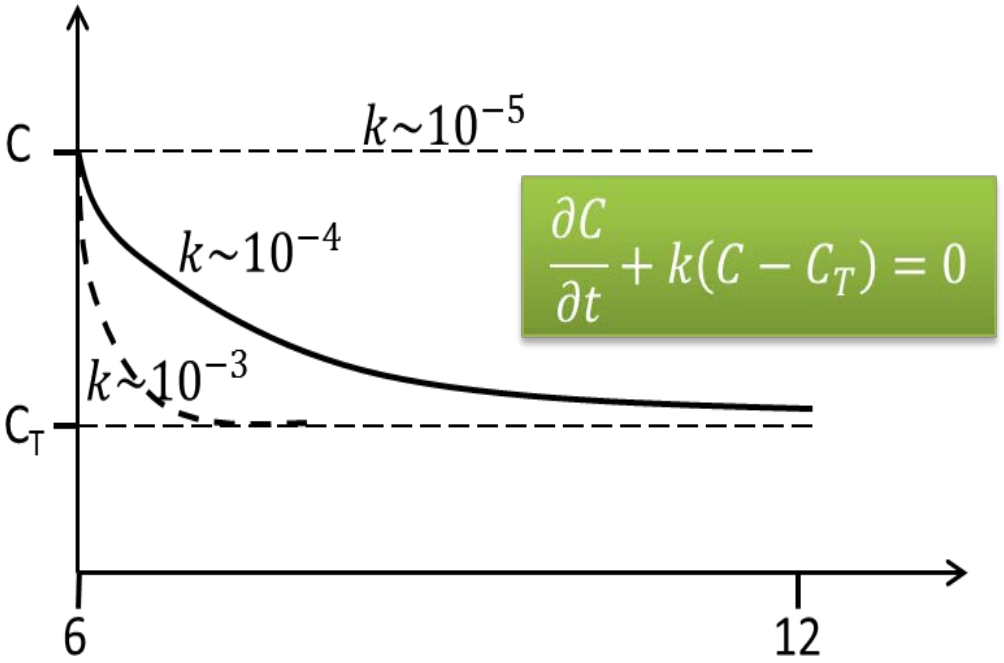
Dust assimilation



U.K. Met Office MSG dust optical thickness

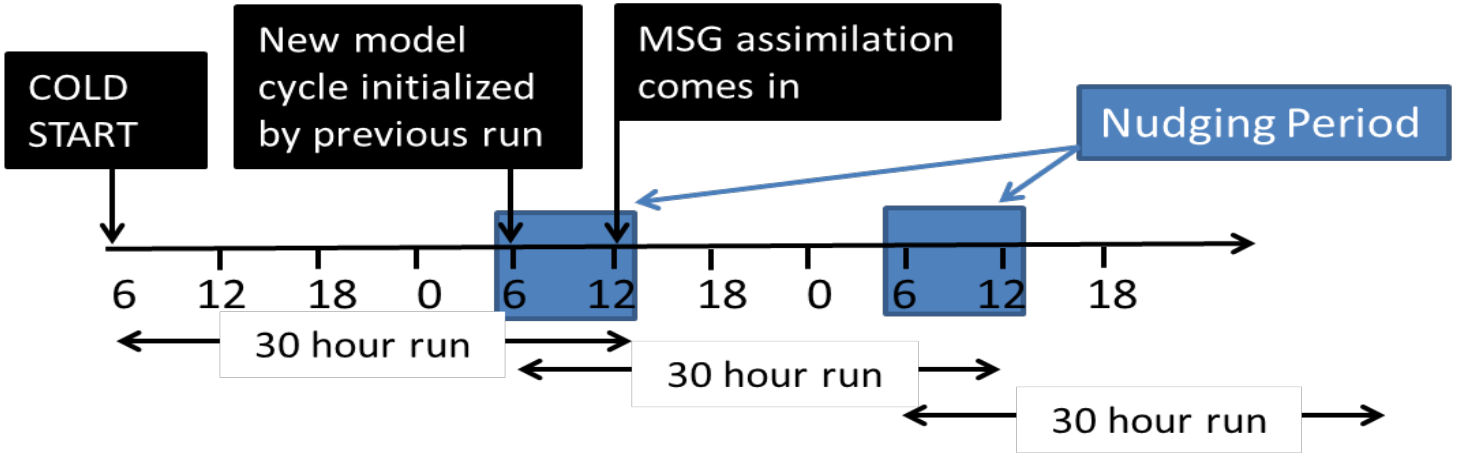
NMME-DREAM Dustload [g/m^2] with dust assimilation

Assimilation of MSG/SEVIRI dust in NMME-DREAM



$$\frac{\partial C}{\partial t} + k(C - C_T) = 0$$

- Newtonian Relaxation method to assimilate the UK Met Office MSG/SEVIRI dust product in NMME/DREAM
- Methodology first used at Serbia Met Service (SEEVCCC) to assimilate the ECMWF MODIS dust product in DREAM model *(Pejanovic et al.,2010 ; AGU)*
- Nudging strength coefficient (k) must be fine tuned



Assimilation of MSG/SEVIRI dust in NMME-DREAM

1. **What about areas without satellite data (e.g. sea)?**

We merge model forecast fields and satellite data to produce continuous (no-gap) target assimilation fields

$$\boldsymbol{DOD_T = a \times DOD_M + b \times DOD_{MSG}}$$

IF MSG dust exists at grid point THEN a=0.2 b=0.8 (test values!!)
ELSE a=1. b=0. (i.e. we use the dust value from the previous model run)

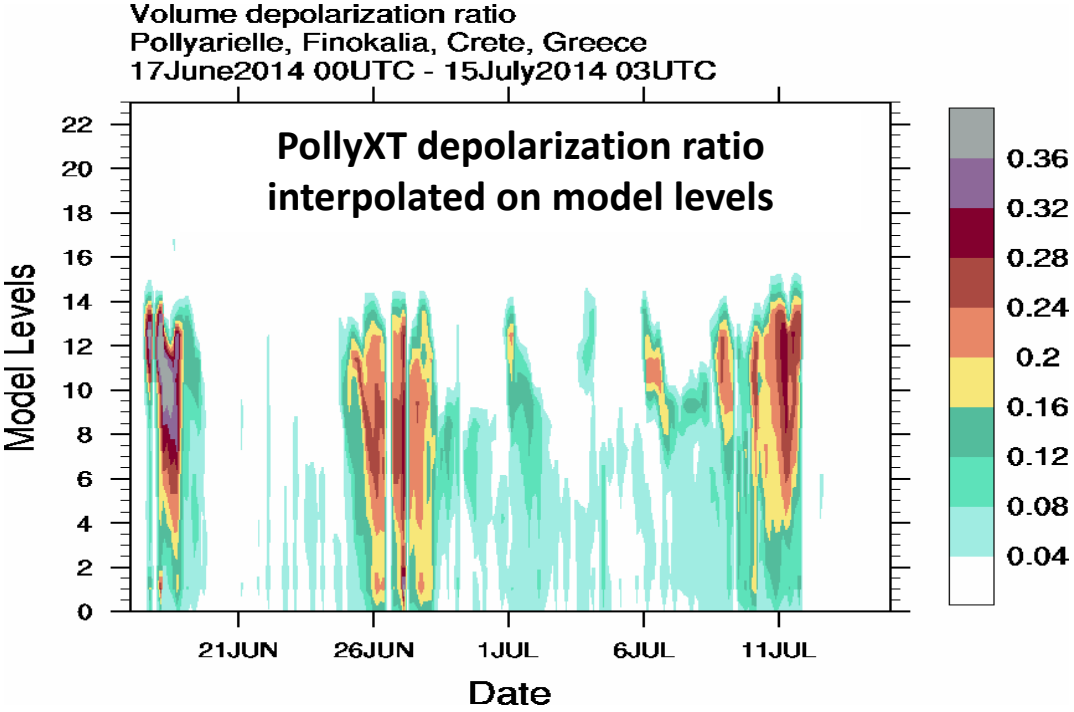
2. **We assimilate AOD . What about the vertical dust distribution?**

We assume that the modeled and the new target fields will have the same vertical structure (so the ratios of level dust to total column dust should be equal)

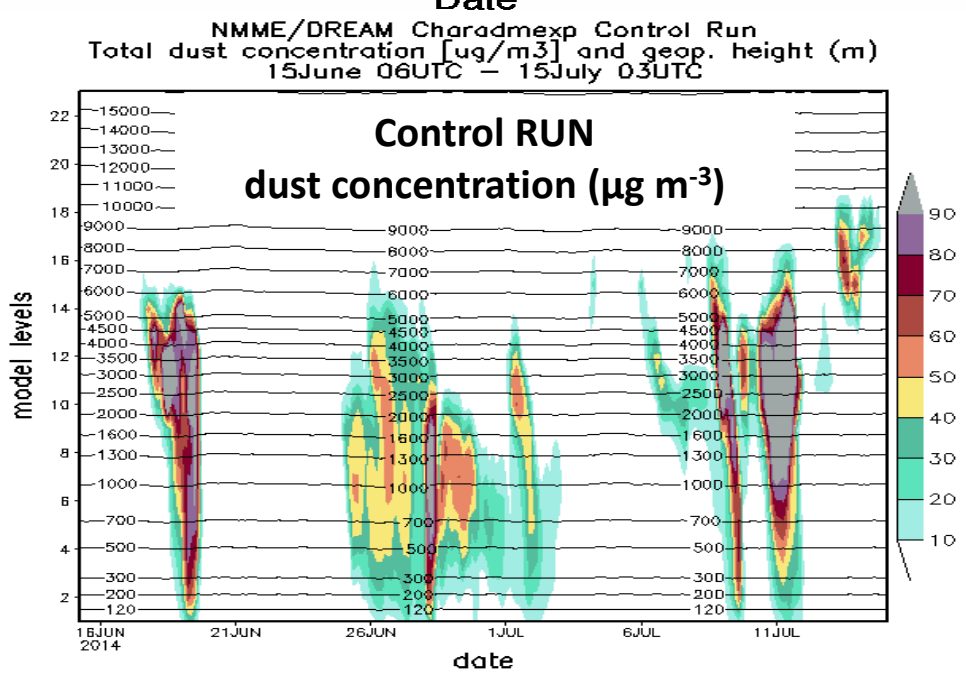
$$\frac{\boldsymbol{C_T}}{\boldsymbol{DOD_T}} = \frac{\boldsymbol{C_M}}{\boldsymbol{DOD_M}} \Rightarrow \boldsymbol{C_T = C_M \times \frac{DOD_T}{DOD_M}}$$

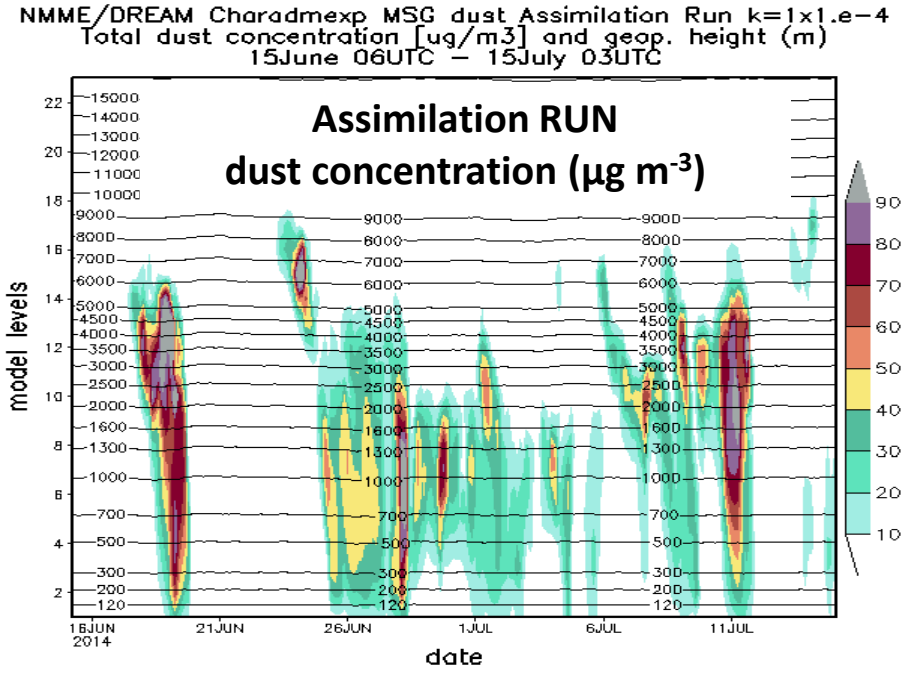
$C_T = Target\ Dust\ Concentration$
$C_M = Model\ Dust\ Concentration$
$DOD_T = Target\ (MSG) Dust\ Optical\ Depth$
$DOD_M = Model\ Dust$ Optical Depth
$DOD_{MSG} = MSG\ Dust$ Optical Depth

NMME-DREAM with MSG-SEVIRI dust assimilation comparison with Finokalia lidar

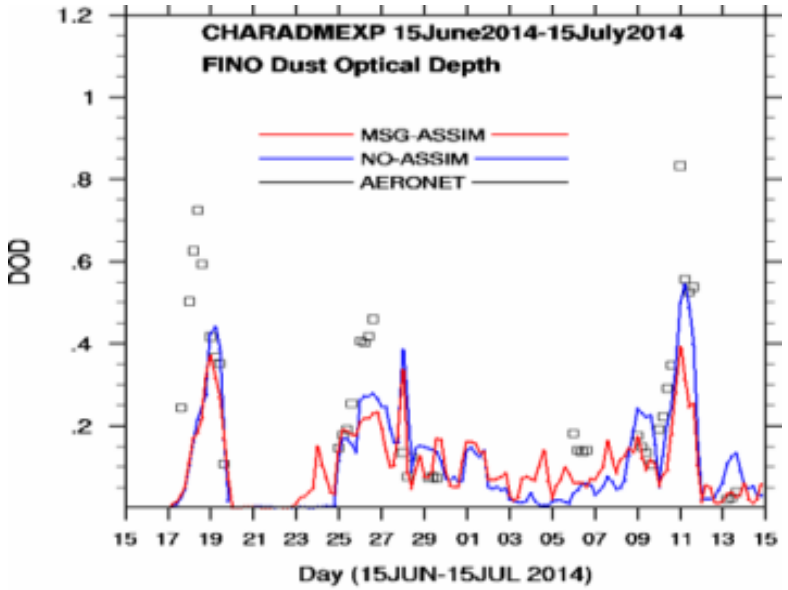


- The model reproduces the spatiotemporal structure of dust layers over Finokalia lidar station
- Succesful implementation of the new development
- Quantification of dust remains an issue

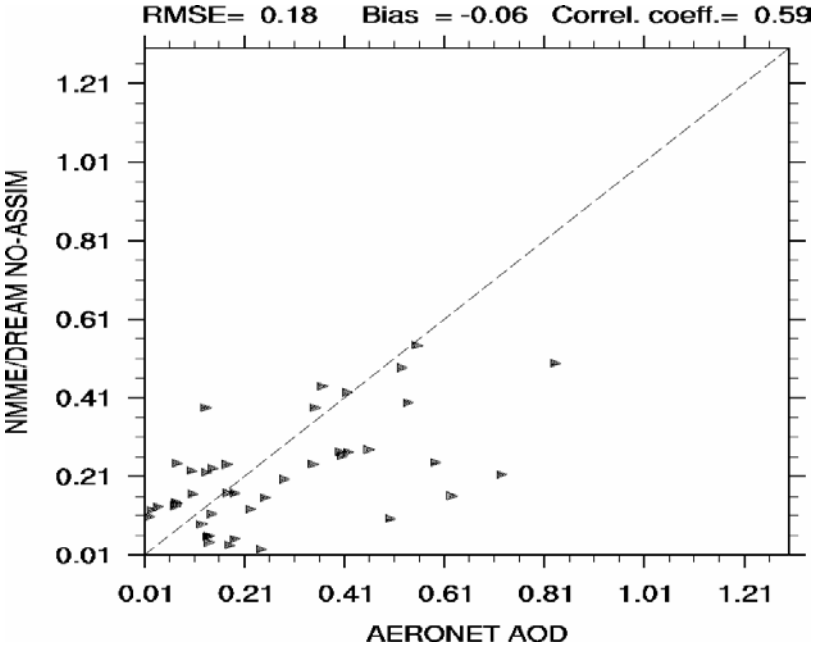


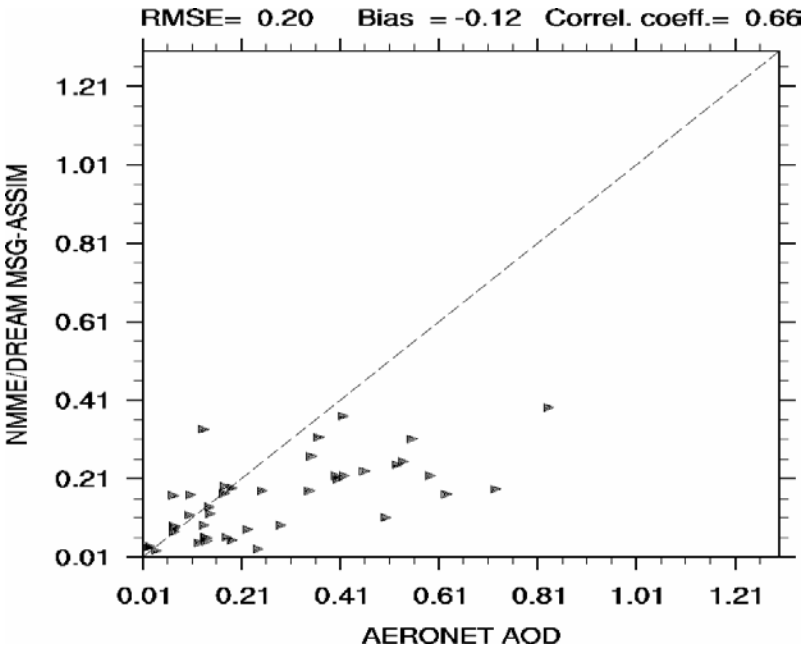


NMME-DREAM with MSG-SEVIRI dust assimilation comparison with Finokalia AERONET CIMEL photometer



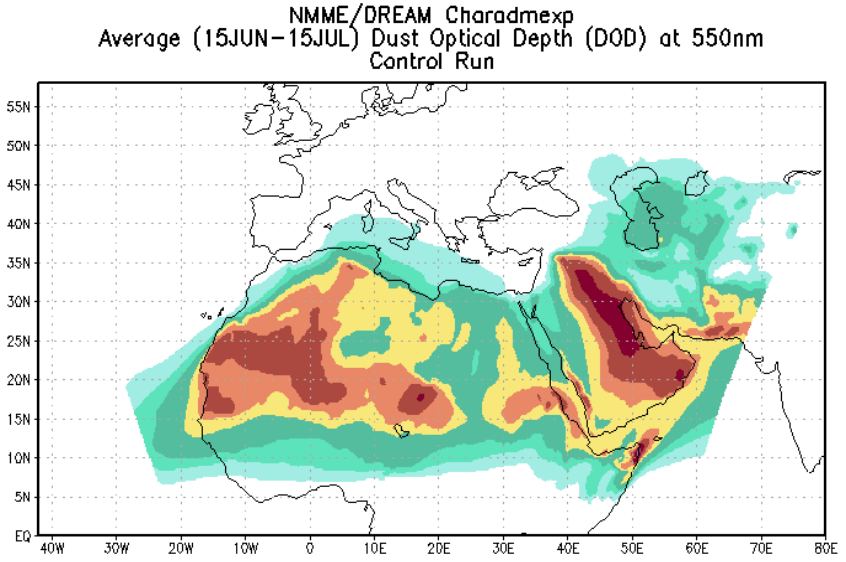
- Not very impressive differences
- Correlation is improved
- RMSE and Bias are bigger in the assimilation run
- A detailed evaluation with ground-based sun-photometers (AERONET) and lidar measurements for a longer period is necessary

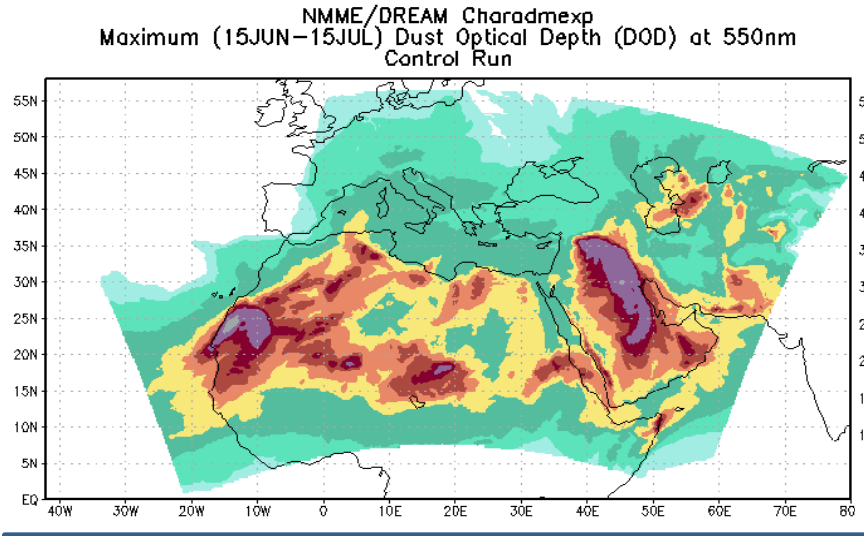




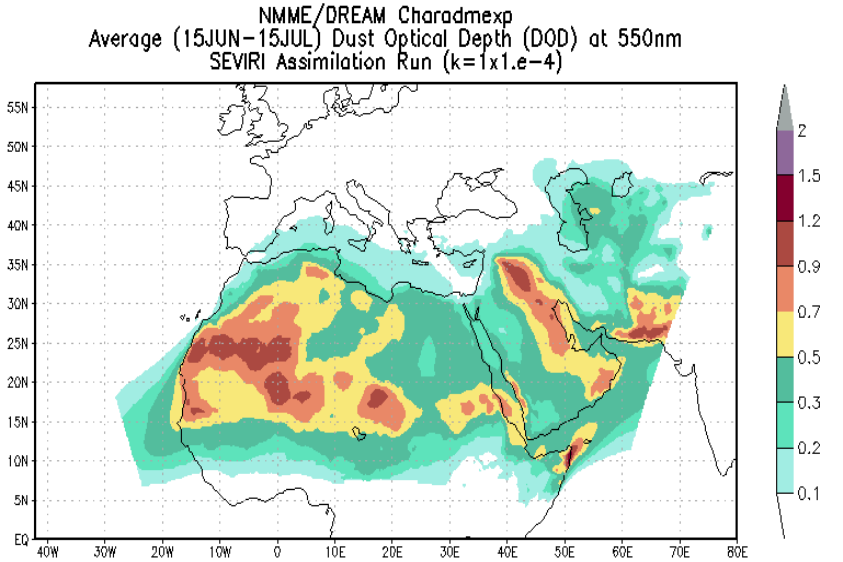
Assimilation of MSG/SEVIRI dust in NMME-DREAM

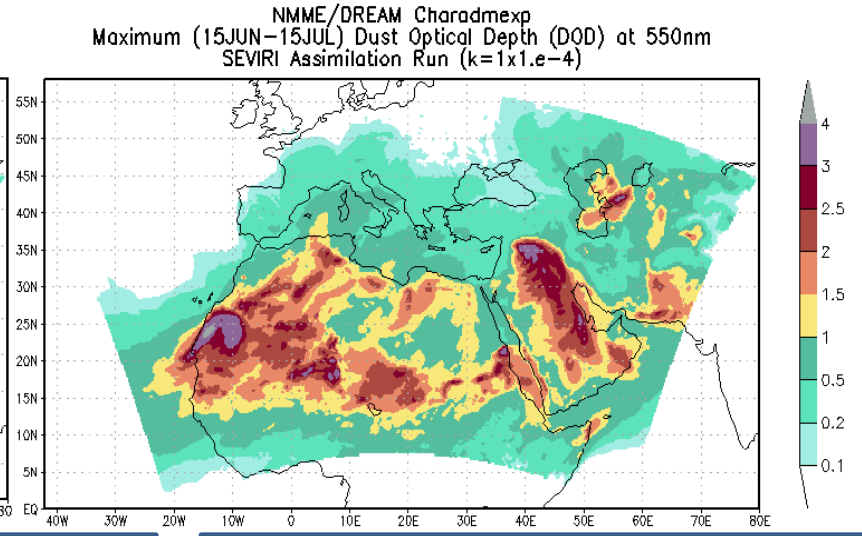
NO ASSIMILATION





WITH MSG ASSIMILATION





Assimilation Effects

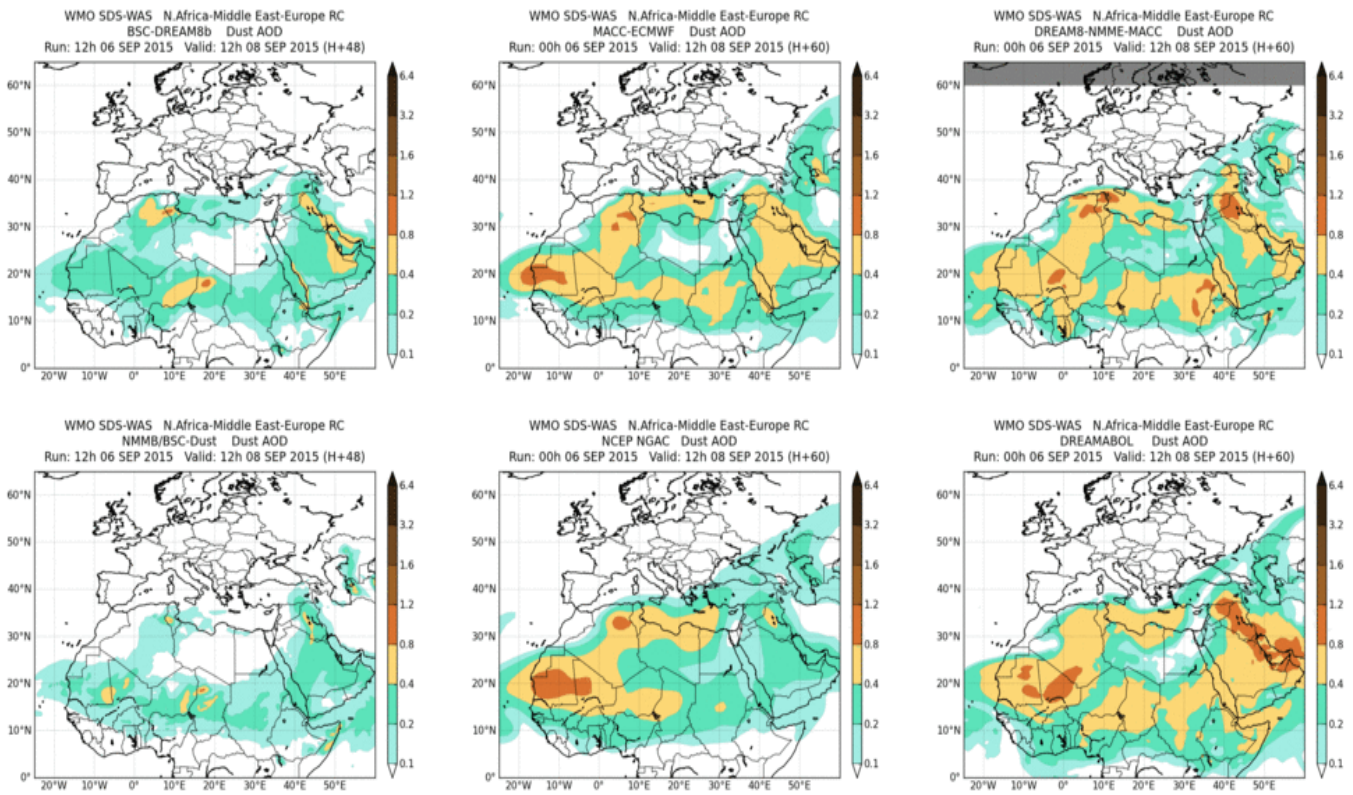
- Cuts dust production over Arabian Peninsula
- Saharan dust sources are represented in finer detail
- Sahel sources may be too strong

- Geostationary assimilation is promising for the accurate description of diurnal dust emissions
- Spatial distributions of model error can be defined and explained

- **Assimilation is promising but it is not a panacea to all our dust modeling problems (e.g. haboobs, LLJ)**
- **The contribution of haboobs to the total dust emissions is estimated up to 30% (Pope et al., 2016, GRL)**

A Middle East haboob 6-13 September 2015

Dust Operational Models (SDS-WAS)



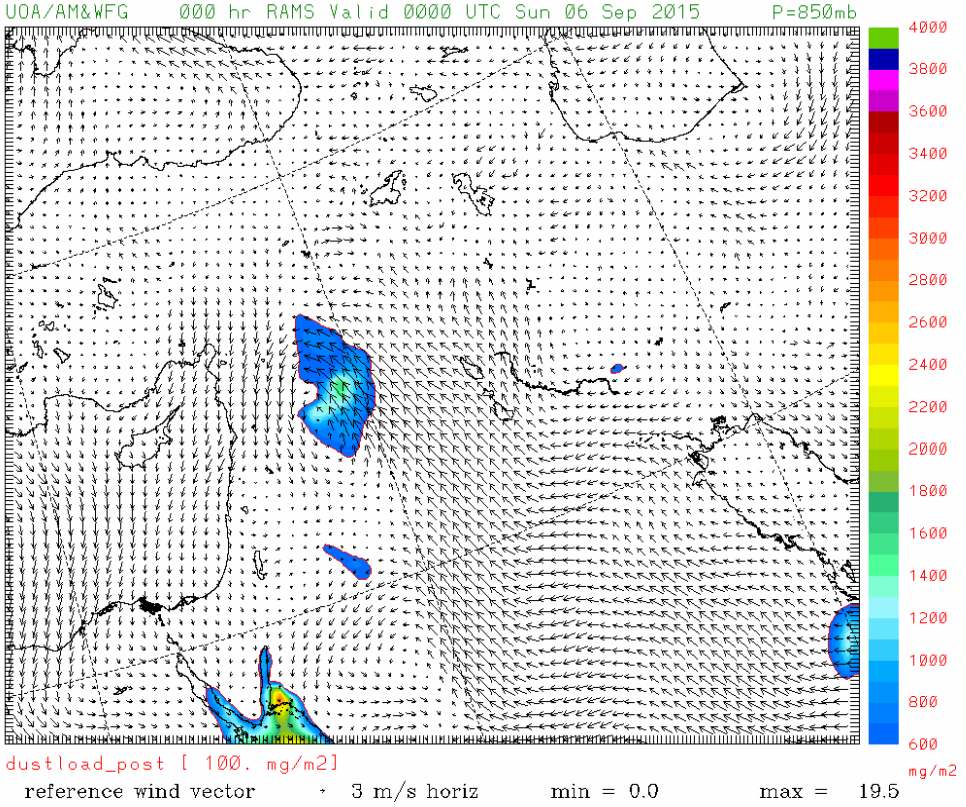
Convective downdrafts over the mountainous areas of East Turkey and North Iran result in mobilization of dust over Middle East and East Mediterranean and extreme record concentrations on Cyprus.

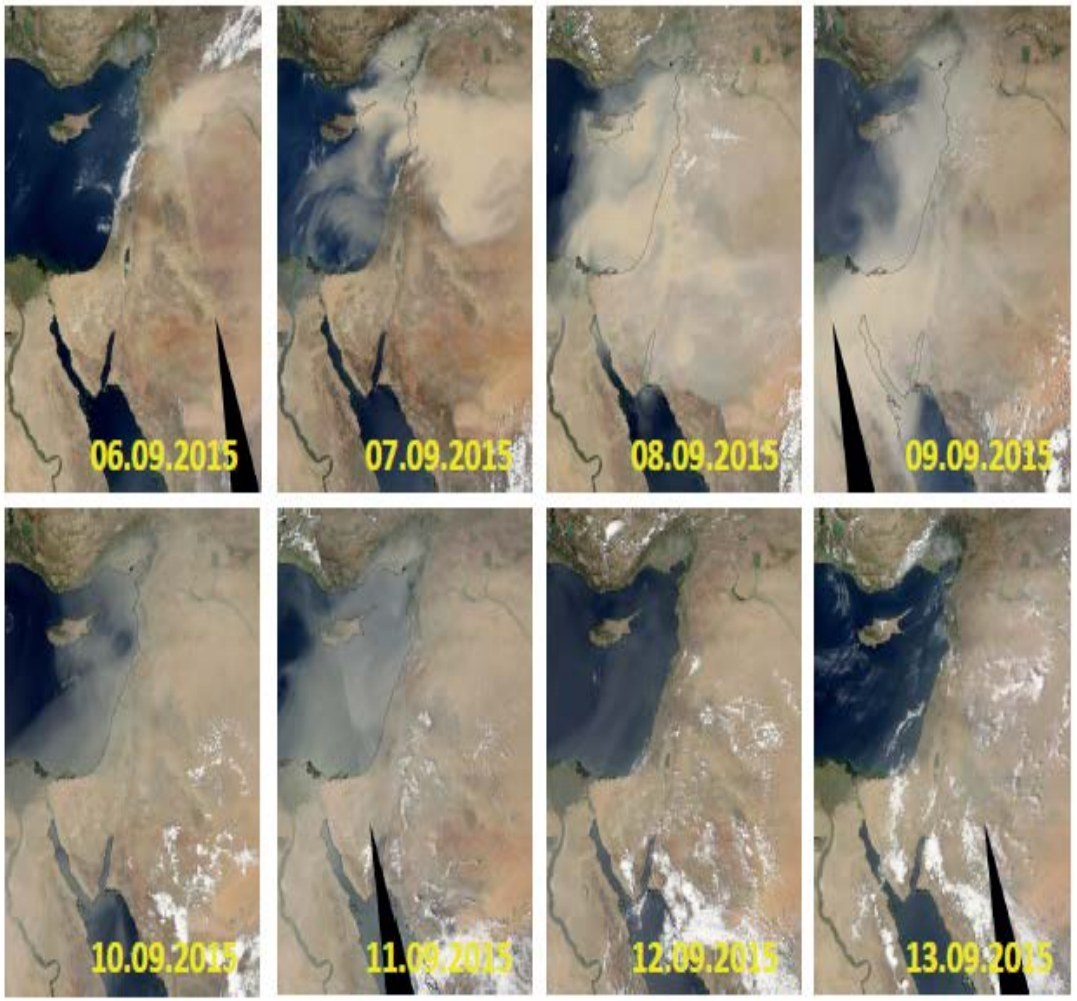
AOD in Cyprus exceeded 5. Mesoscale operational models even with satellite assimilation cannot reproduce the strength of such events.

Mamouri et al., 2016, ACPD

A Middle East haboob 6-13 September 2015

RAMS simulation and MODIS images





Simulations with the RAMS-ICLAMS limited area model with the use of advanced explicit microphysics and a high resolution (4×4 km) nested grid show the complexity of atmospheric processes that led in this extreme dust-storm

Solomos et al., 2016, in prep. for ACP

Conclusions & Discussion

- We developed a modeling scheme to assimilate the UK Met Office MSG-SEVIRI satellite dust product in NMME-DREAM
- First results indicate a reasonable response of the model to this additional forcing and some promising improvements
- Arabian dust seems to be more realistic in the assimilation run. This is also an indication of the natural variability between Saharan and Arabian sources that are currently treated in a similar way in numerical models
- The satellite retrieval algorithm will be extended to include also the DOD over the ocean
- Evaluation of modeled fields against the AERONET photometer network for a longer time period is needed
- Assimilation by itself cannot solve all our dust modeling problems – We must improve model physics & resolution

Thank You !

BEYOND

SEVENTH FRAMEWORK PROGRAMME

GEO CRADLE

HORIZON 2020