Republic Hydrometeorological Service of Serbia (establishted 1888, WMO member since 1947)

SEEVCCC

Atmospheric dust modeling
A way to better understand the Earth system

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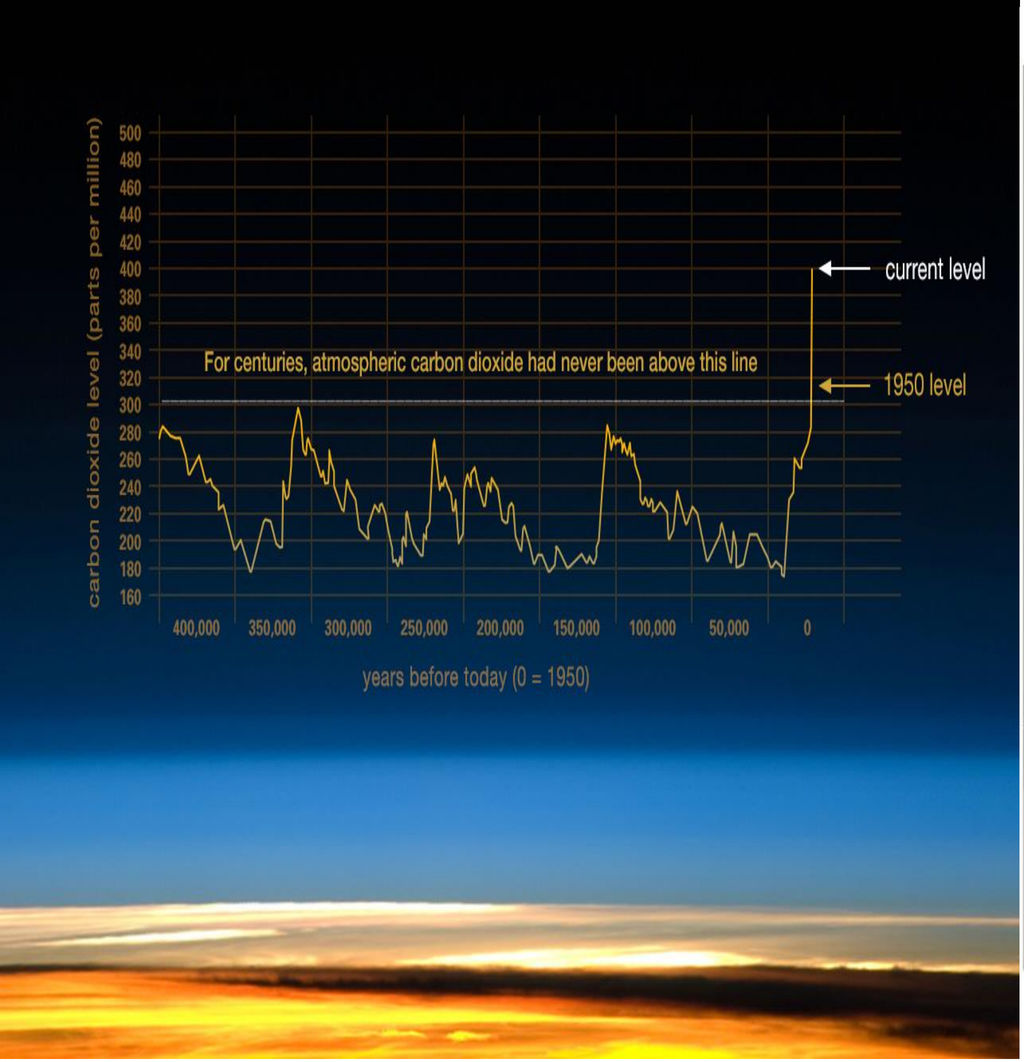
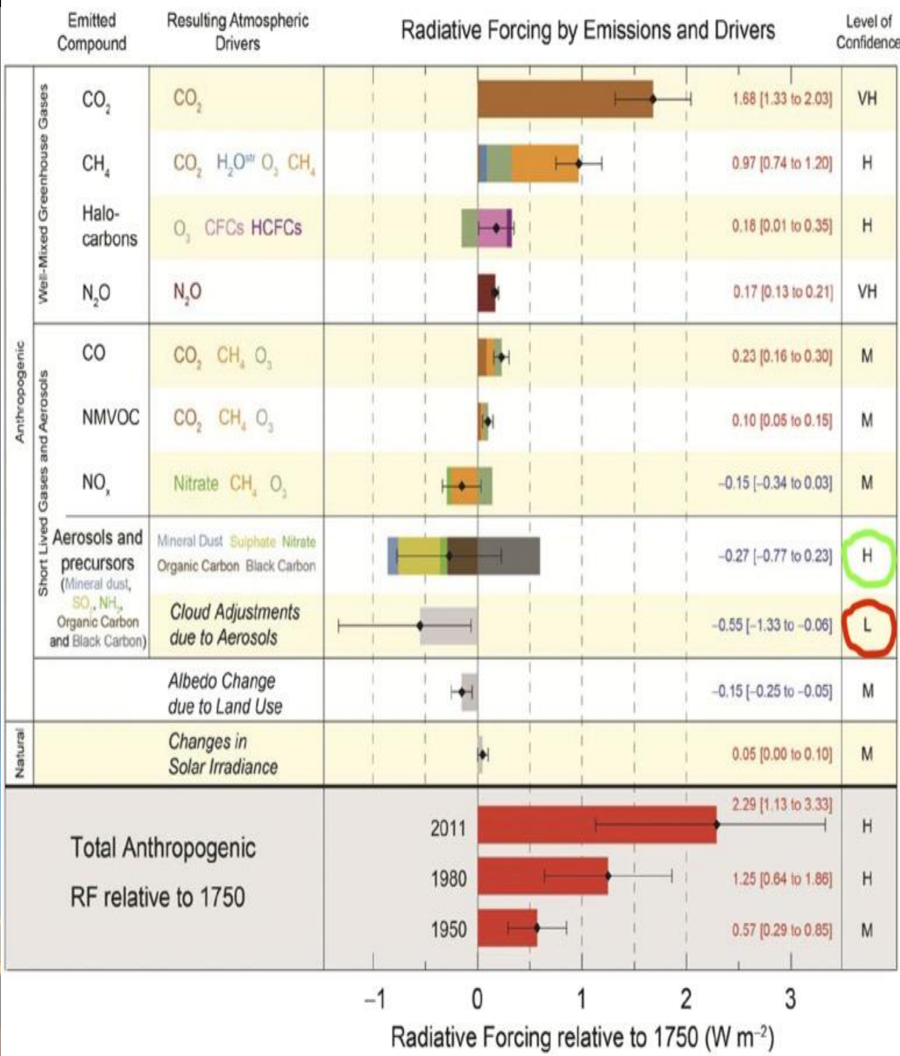




- The error bars in the greenhouse gas forcing are very small. The biggest uncertainty in defining radiative forcing comes from aerosols, especially from the mineral dust.

- Large uncertainties in evaluation of the atmospheric dust transport interactions with the environment and its roll in the climate system (IPCC 2013) motivate the researchers to sophisticate the knowledge, based on the empirical and experimental experience, and to improve the numerical modeling of the dust cycle, since the models are the most promising tool in understanding and in quantifying the roll of the atmospheric dust cycle in the climate system.

DUST CYCLE INTEFEERS WITH OTHER COMPONENTS OF THE CLIMATE SYSTEM

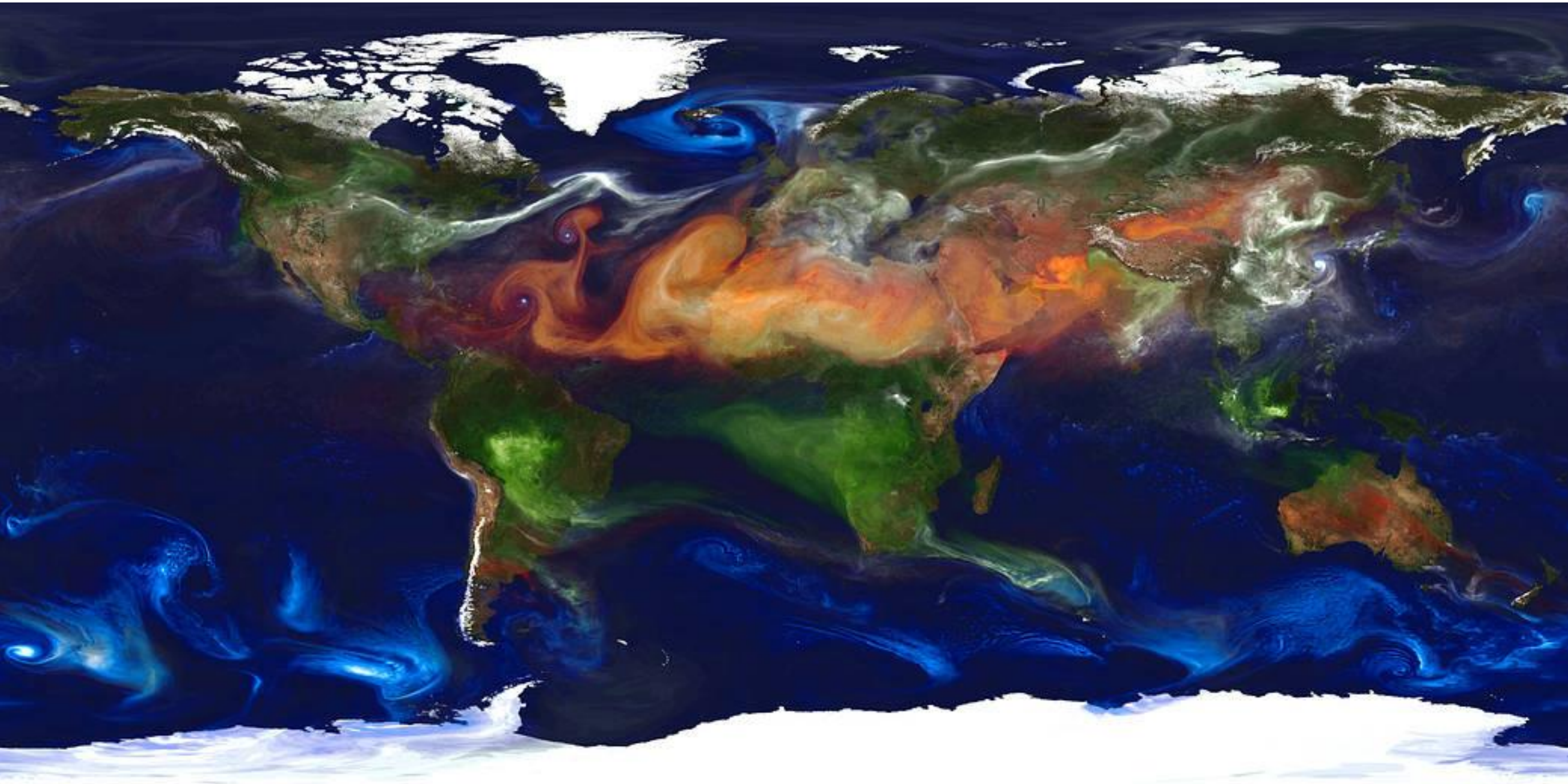
DRIVING CYCLES ON WIDE RANGE OF TIME AND SPACE SCALES

- DUST CYCLE
- ENERGY CYCLE
- WATER CYCLE
- CARBON CYCLE

The research focus – INTERACTION OF MINERAL DUST PARTICLES WITH THE ATMOSPHERE AND OCEANS

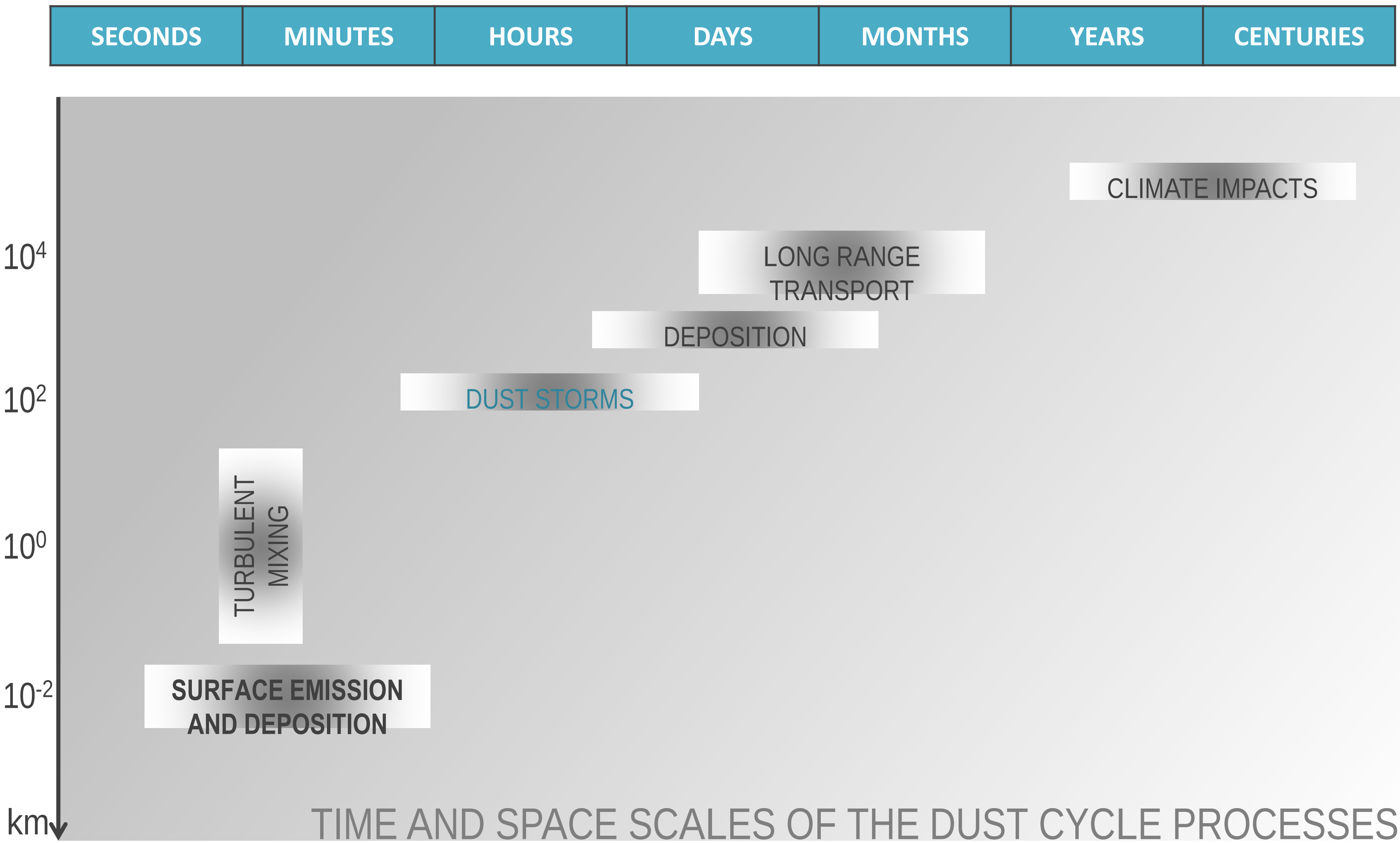
Sources and transport of atmospheric aerosols

Aerosol optical thickness of black and organic carbon (green), dust (red-orange), sulfates (white), and sea salt (blue) from a 10 km resolution GEOS-5 using the GOCART model - The Goddard Chemistry Aerosol Radiation and Transport (GOCART)



Dust picked up by winds from the Sahara and other North African deserts is often carried to the Caribbean Sea and the Americas. In fact, dust events deliver about **40 million tons of dust each year** from the Sahara to the Amazon River Basin alone. Research has shown that part of the reason the Amazon region is so fertile is because of the vast mineral nutrients carried on the winds from Africa.

To understand and model dust aerosol transport and its role within the Earth system, processes ranged from micro to global scales must be considered, which explains complexity of the problem.



ATMOSPHERIC DUST MODELLING

Depending on the research goals, considering nowadays computer resources, dust models evolution is divided in:

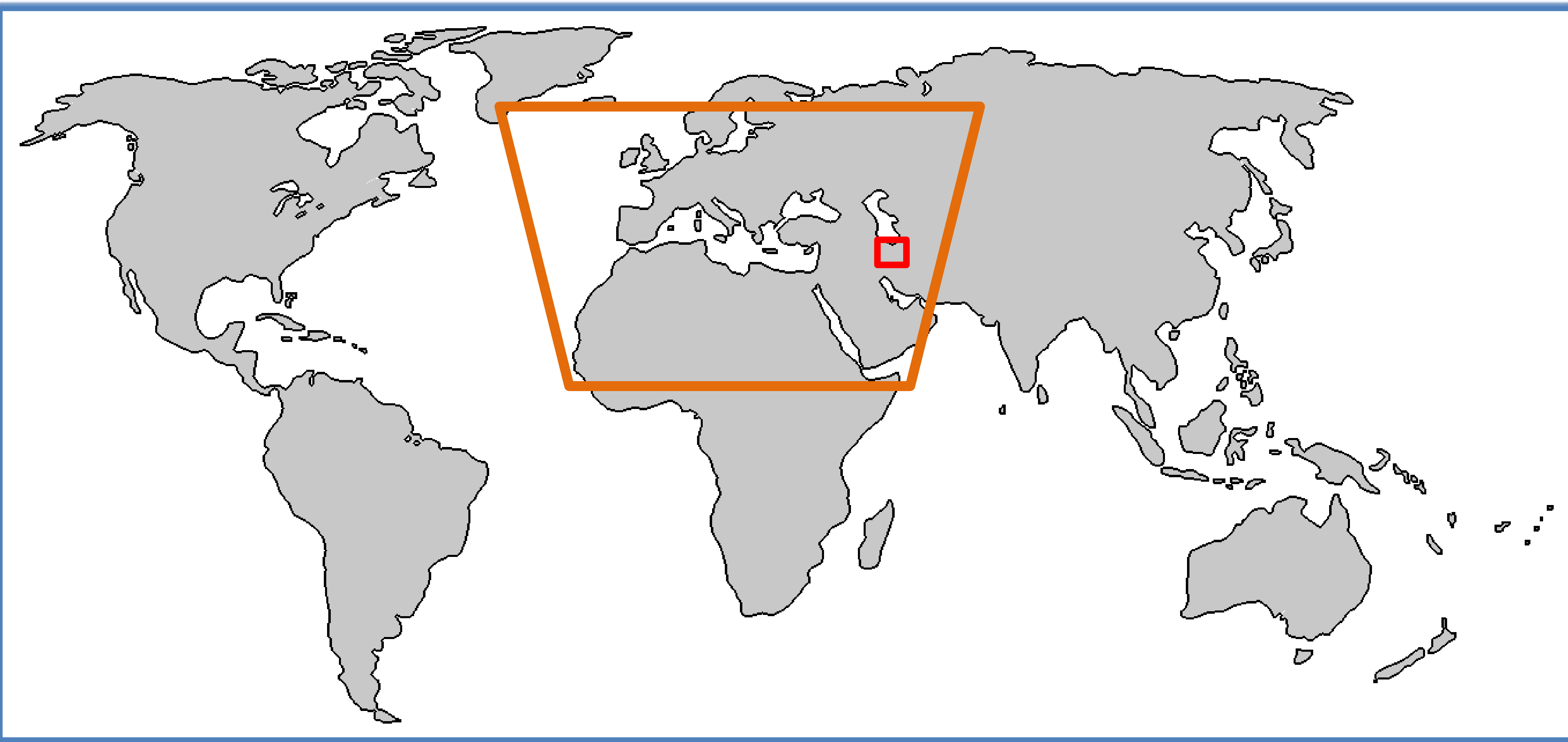
(1) modelling of the long range transport (global with resolutions ~100km)

(2) modelling of the intense dust storms (regional of several tens of km)

LONG RANGE TRANSPORT:
Global and regional models
Coarse resolution (several 10km to ~100km)

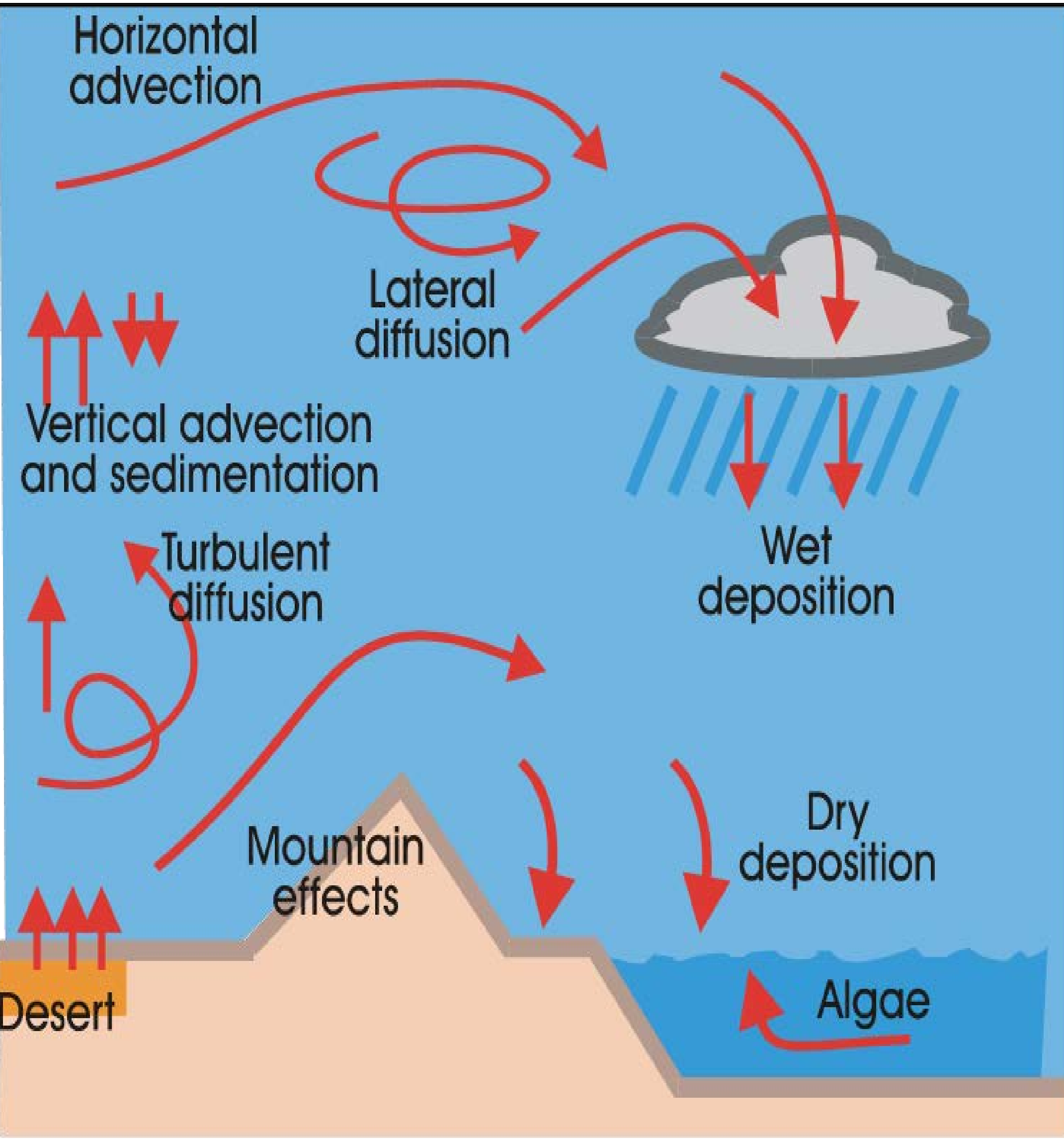
SHORT RANGE TRANSPORT:
Nonhydrostatic regional models
High resolution (several km)
Forecast of the dust storms

GLOBAL MODELS **REGIONAL MODELS** **NONHYDROSTATIC MODELS**



Dust Regional Atmospheric Model (DREAM)

$$\frac{\partial C_k}{\partial t} = -u\frac{\partial C_k}{\partial x} - v\frac{\partial C_k}{\partial y} - (w - v_{gk})\frac{\partial C_k}{\partial z} - \nabla(K_H \nabla C_k) - \frac{\partial}{\partial z}\left(K_Z \frac{\partial C_k}{\partial z}\right) + \left(\frac{\partial C_k}{\partial t}\right)_{SOURCE} - \left(\frac{\partial C_k}{\partial t}\right)_{SINK}$$



- Driven by the non-hydrostatic atmospheric model NCEP NMME
- Simulates all major processes of the atmospheric dust cycle
- Includes 8 different dust particle bins
- Includes different dust mineral fractions
- Simulates ice nuclei concentration

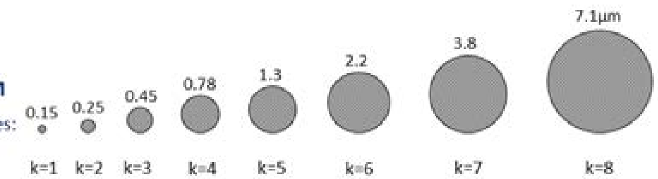
Dust Regional Atmospheric Model (DREAM) workflow

Dust model is coupled with atmospheric model (Eta, NMME, NMMB…)

- Preprocessing: Very important is to define dust sources using land cover and soil texture data bases or other source of information, depending on area of interest ➔ prepare dust mask on model grid

Particles are assumed to be spherical.
Particles are divided in categories by size.
Number of categories different among models.
Concentration of particles is calculated for each category in each model grid point.

Example for DREAM
8 particle size categories:



Kernel of dust modeling – to solve equation:

$$\frac{\partial C_k}{\partial t} = -u\frac{\partial C_k}{\partial x} - v\frac{\partial C_k}{\partial y} - (w - v_{gk})\frac{\partial C_k}{\partial z} - \nabla(K_H \nabla C_k) - \frac{\partial}{\partial z}\left(K_Z \frac{\partial C_k}{\partial z}\right) + \left(\frac{\partial C_k}{\partial t}\right) - \left(\frac{\partial C_k}{\partial t}\right)$$

horizontal advection | vertical advection | horizontal turbulent mixing | vertical turbulent mixing | source | sink

update of dust concentration in every model time step and in every model point and level (same as atmospheric parameters)

using updated values of soil moisture and friction velocity calculate dust emission for each of 8 bins

loss through dry (gravitational settling) and wet (washed down by precipitation) deposition

(Nickovic et al., 2001)

C is calculated for each particle size category C_k(k=1,…,8) at each model grid point in every time step!

Dust storm forecast: Nonhydrostatic high resolution simulation of intense dust event (Vukovic et al. 2014)

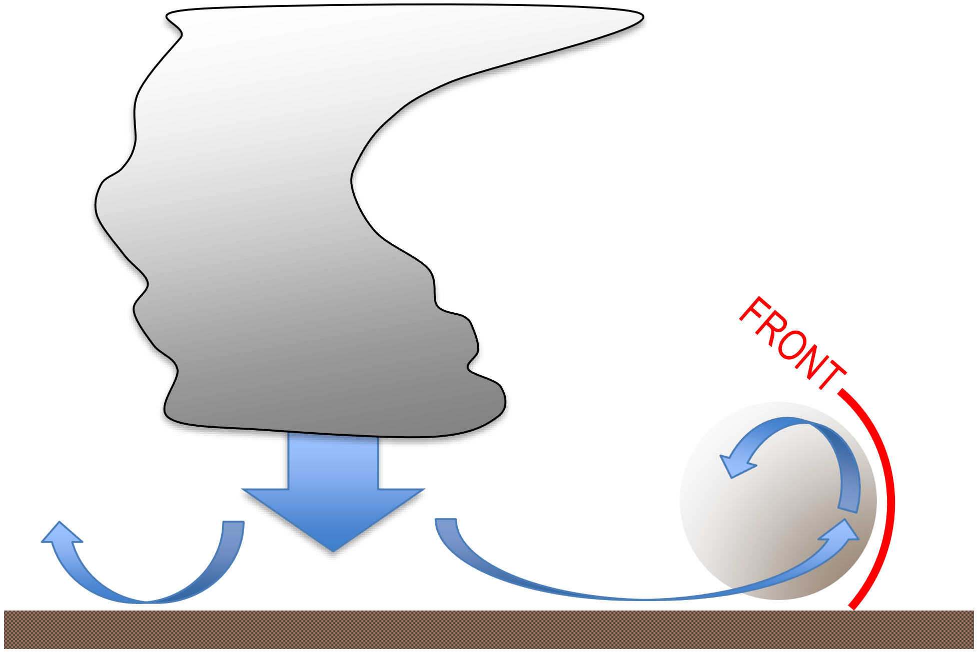
Haboob: cold downdraft from supercell clouds forms strong surface winds, intensive dust uplift, forms wall of dust; temperature drops, humidity rises, pressure rises.

Problem for modeling: mapping position and strength of dust sources!

Problem with verification methods, *DOUBLE PENNALTY PROBLEM*!

Study case: 5 JULY 2011 Phoenix (Arizona); model simulation 4km resolution

- Tucson – Phoenix; Front wide ~150km; travelled distance ~250km; Dust wall height ~1500-2000m
- 02UTC 6. JULY reached SE Phoenix; 02-04 UTC cross over Phoenix



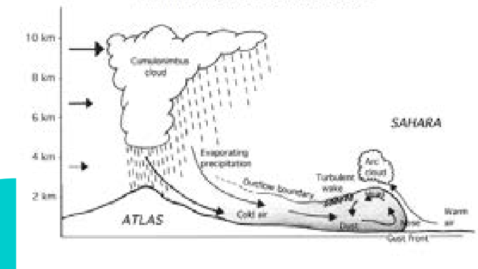
Successful simulation of the Phoenix haboob 6th July 2011 (Ana Vukovic, Mirjam Vujadinovic Mandic …)

Atmos. Chem. Phys., 14, 3211–3230, 2014
www.atmos-chem-phys.net/14/3211/2014/
doi:10.5194/acp-14-3211-2014

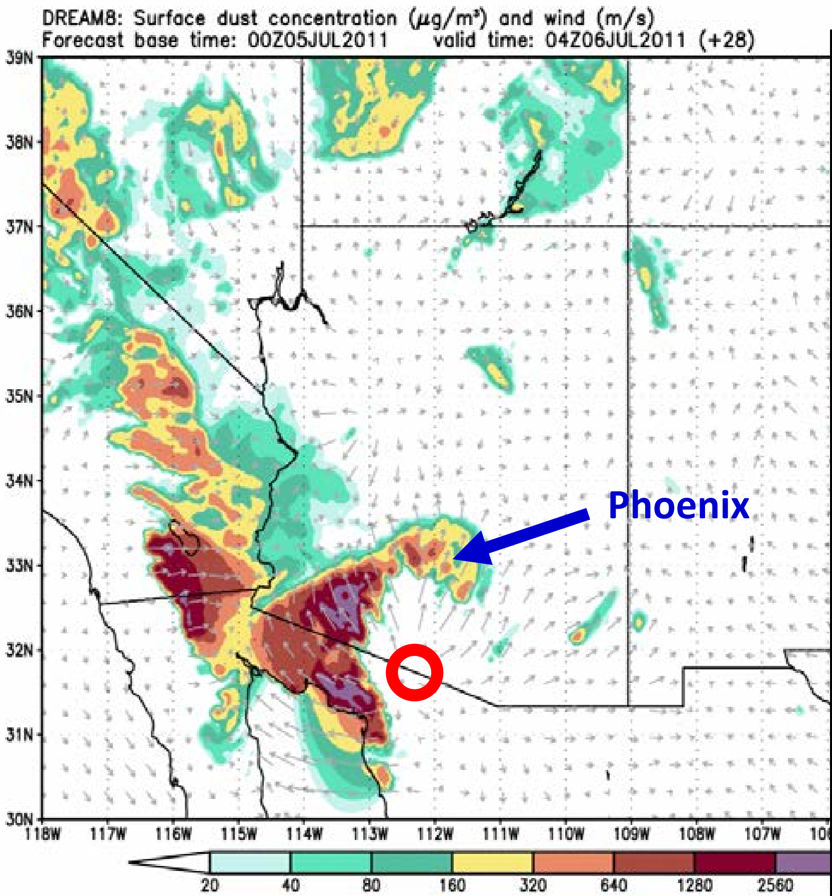
Atmospheric Chemistry and Physics
Open Access

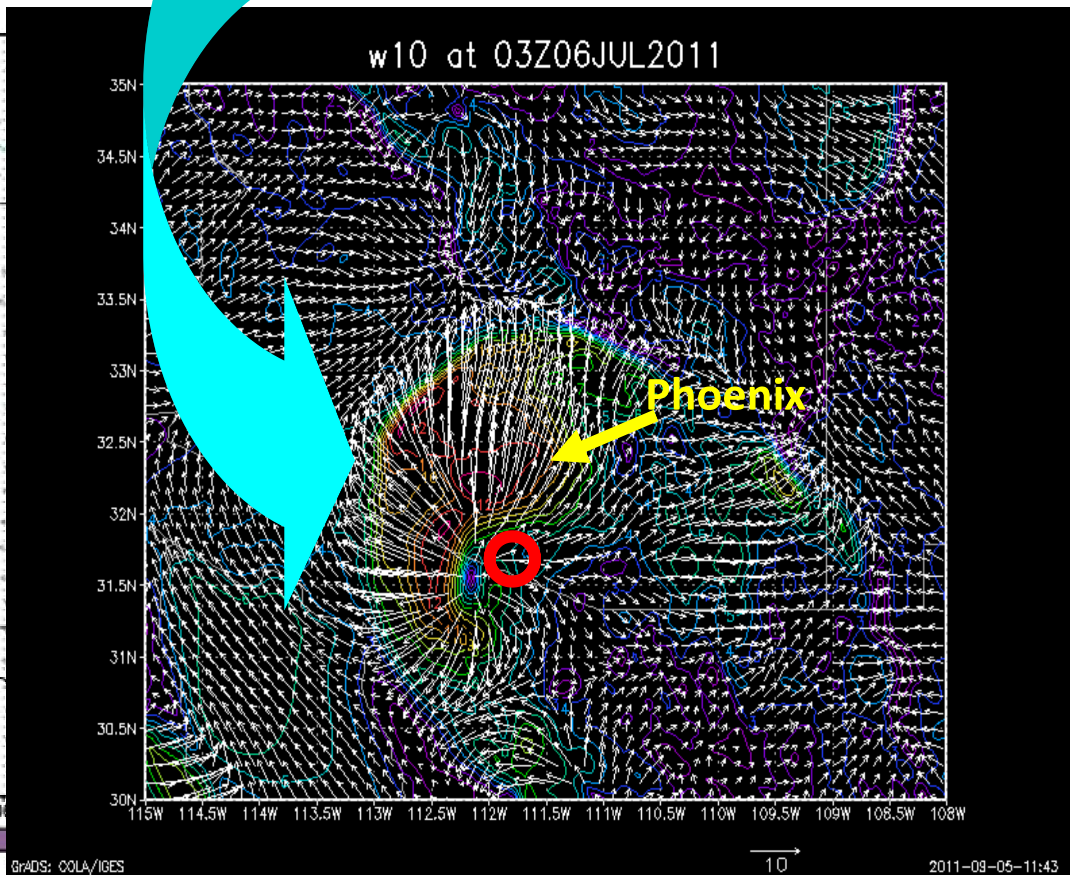
Numerical simulation of "an American haboob"

A. Vukovic[1,2], M. Vujadinovic[1,2], G. Pejanovic[2], J. Andric[3], M. R. Kumjian[4], V. Djurdjevic[2,5], M. Dacic[2], A. K. Prasad[6], H. M. El-Askary[6,7], B. C. Paris[8], S. Petkovic[2], S. Nickovic[9,10], and W. A. Sprigg[11,12]



10m WIND MAGNITUDE





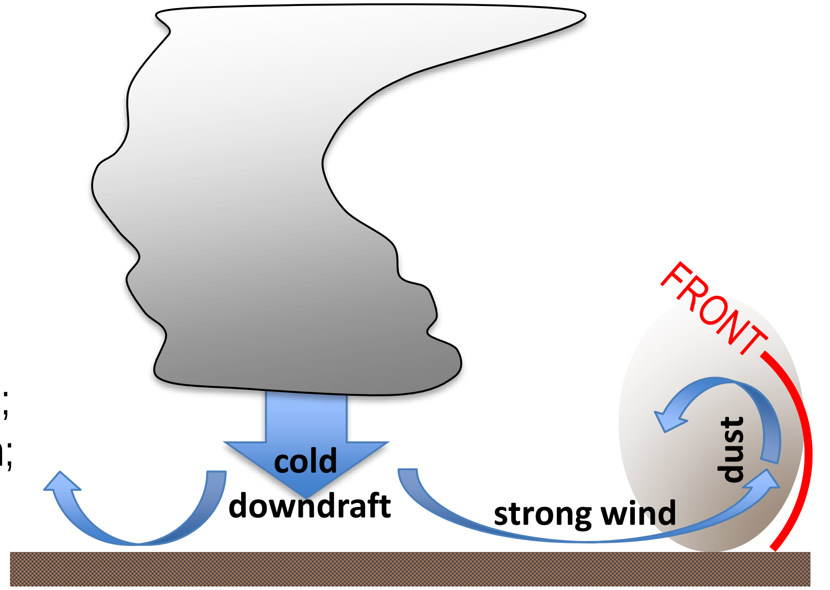
NASA Applied Science support led to this high-resolution forecast and simulation capability

STUDY CASE: TEHRAN DUST STORM 2ND JUNE 2014

Simulation of small scale (local; several 100km), intense (several 1000ug/m3 PM10) & short lived (few hours) dust storms

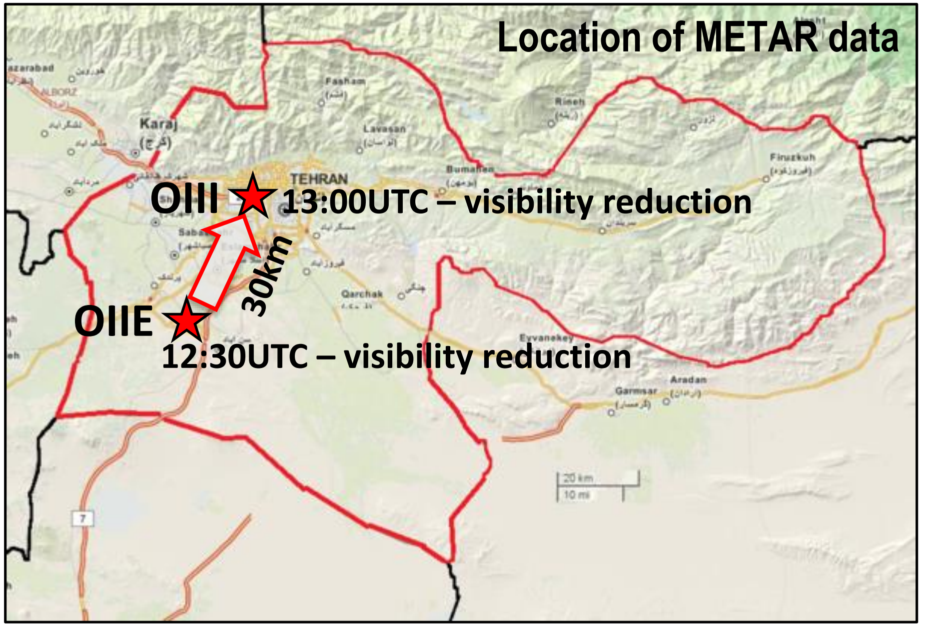
Information from reports

- reached city at 04:50 p.m. local time;
- passing of the sand storm over the fixed site lasted about 15min;
- storm duration less than 2h;
- reduction of visibility to ~10m; wind velocity reached 110 km/h;
- temperature dropped from 33C to 18C in several min;
- at least 5 deaths, 82 injured; multiple vehicle collision;
- 50 000 residential units lost power.



Theory

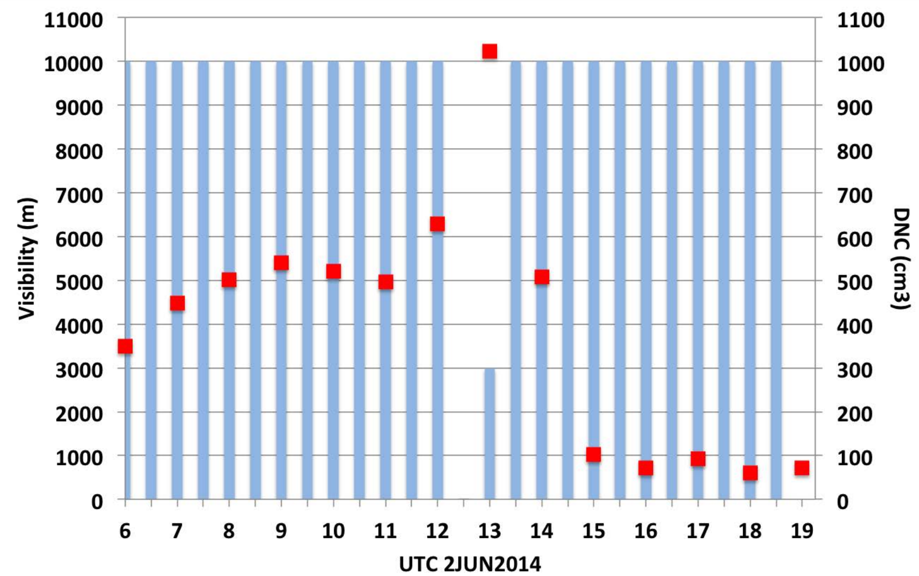
- Intensive cold downbursts from convective cells produced high velocity surface wind, creating cold front which was lifting, mixing and pushing dust towards the city;
- Expected: high wind speed, drop in temperature, rise in humidity, rise in pressure, reduction of visibility.

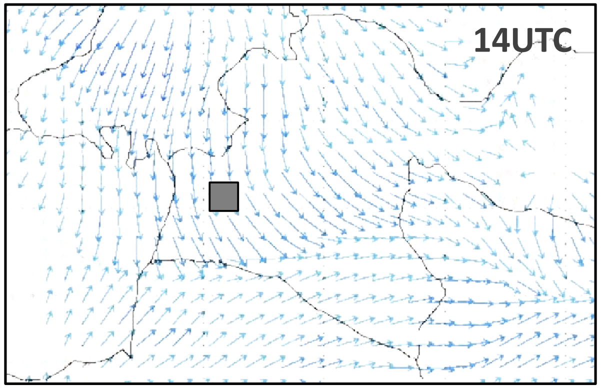


Imam Khomeini airport OIIE

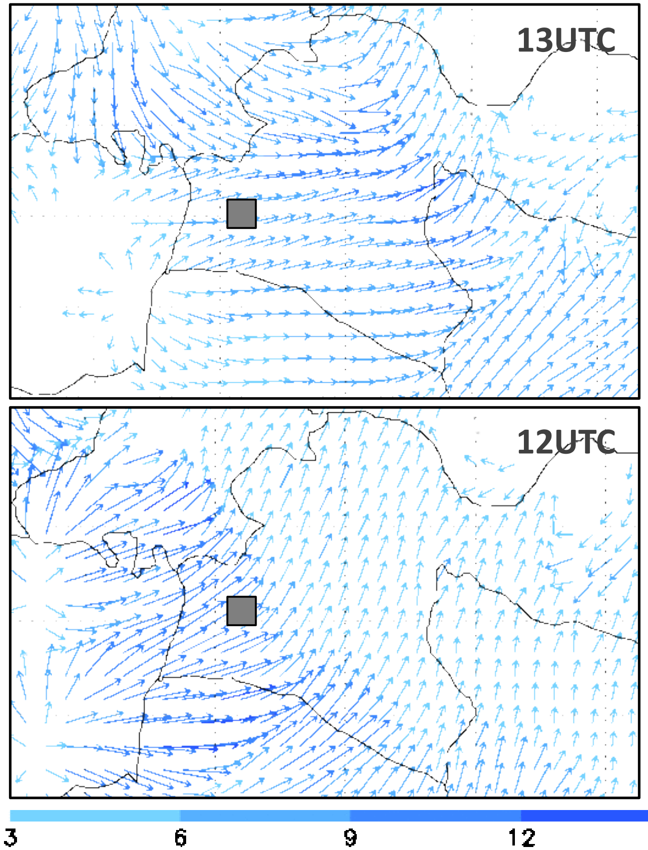
Visibility reduced to 20m at 12:30UTC.
Model output data available on 1h.

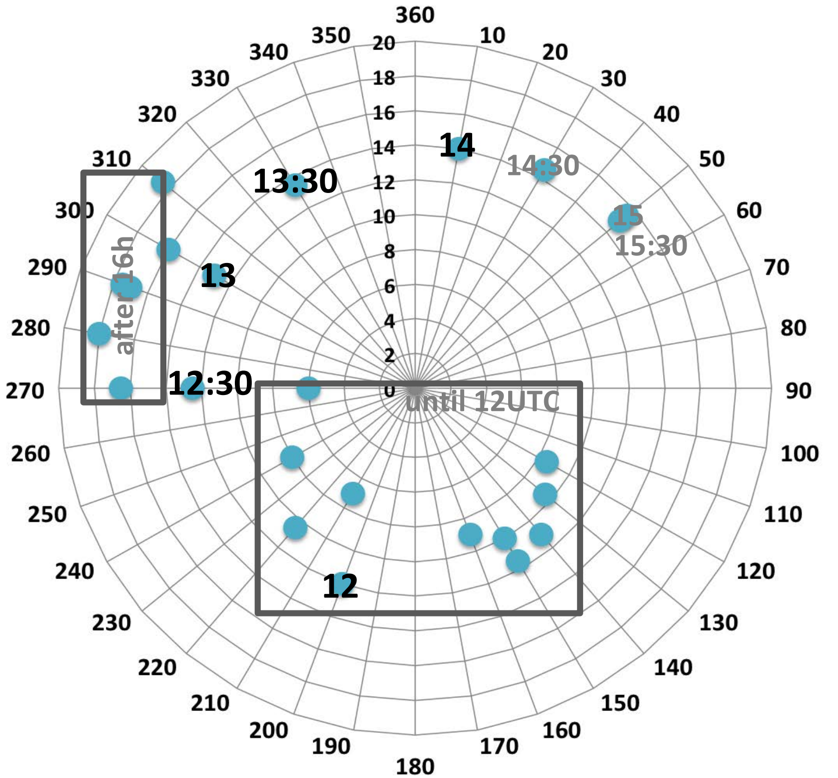
Observed visibility & model DNC





Observed wind direction & model wind

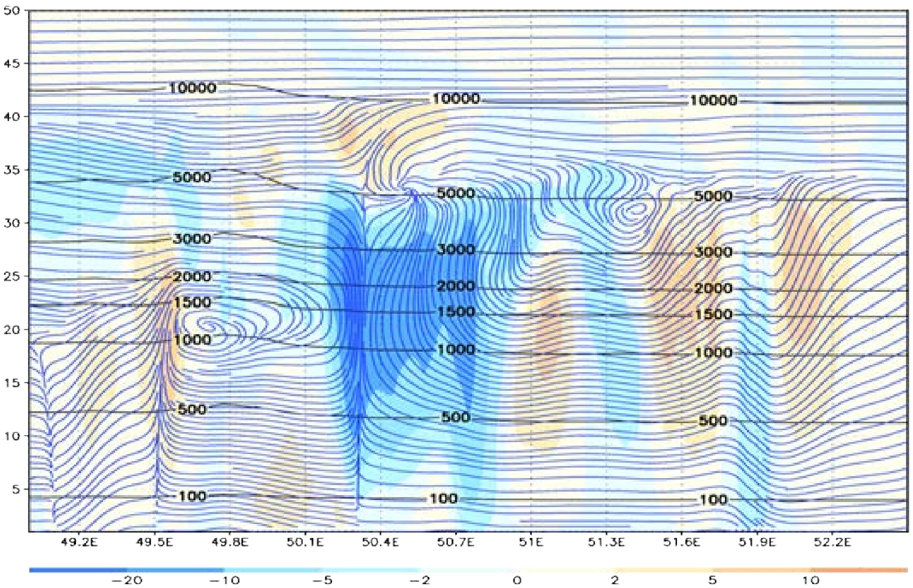




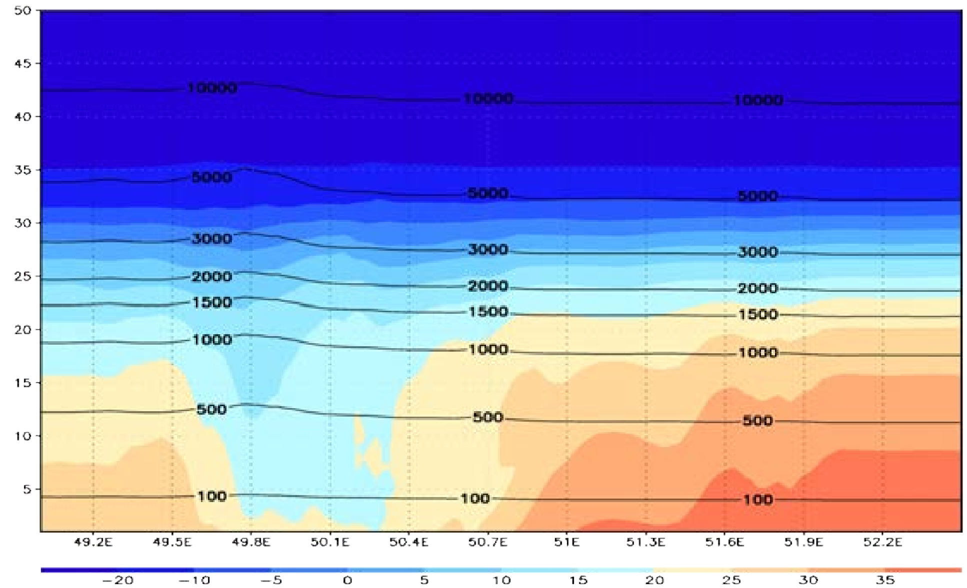
Vertical cross section along 35N

Values are on model levels, altitude of model levels are in black lines.

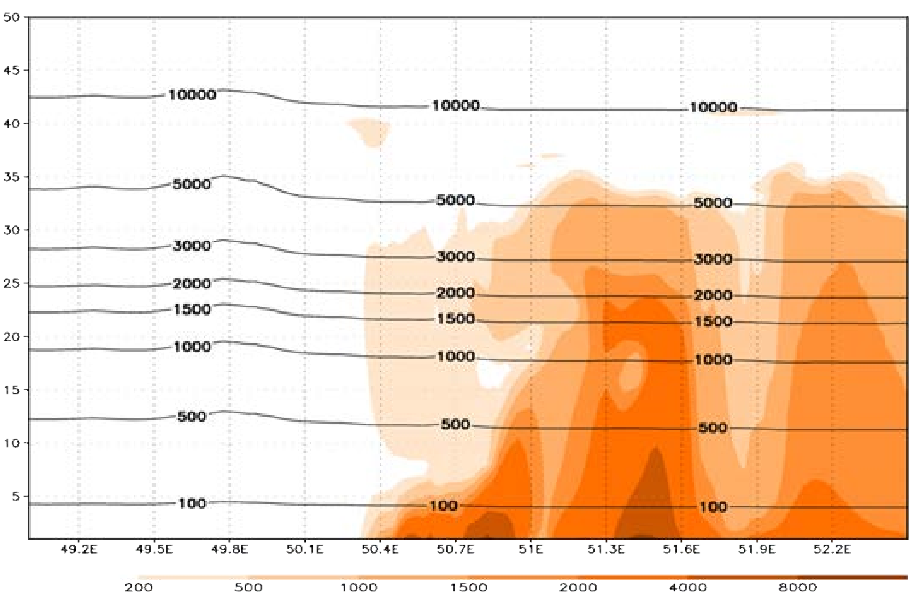
Streamlines (u,w) and vertical wind velocity



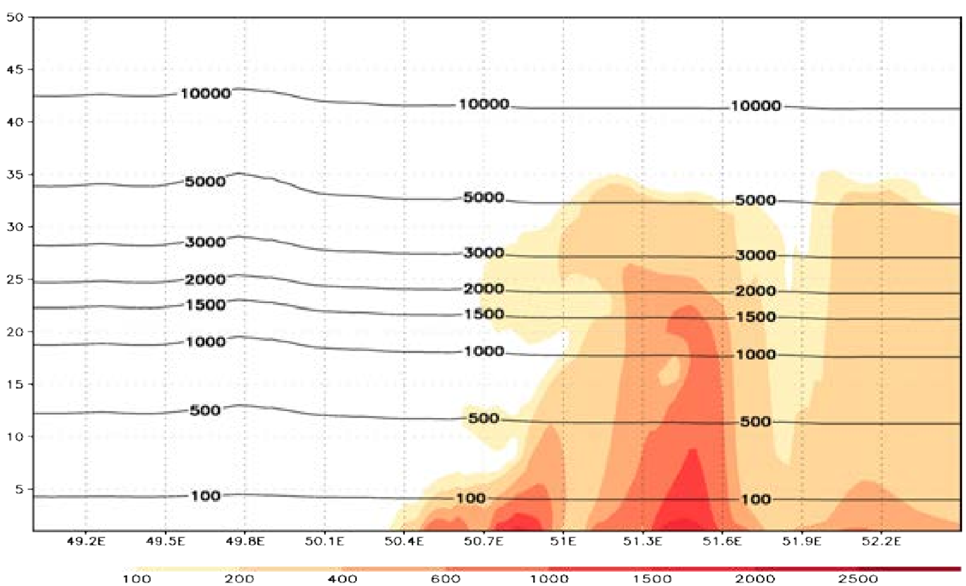
Temperature



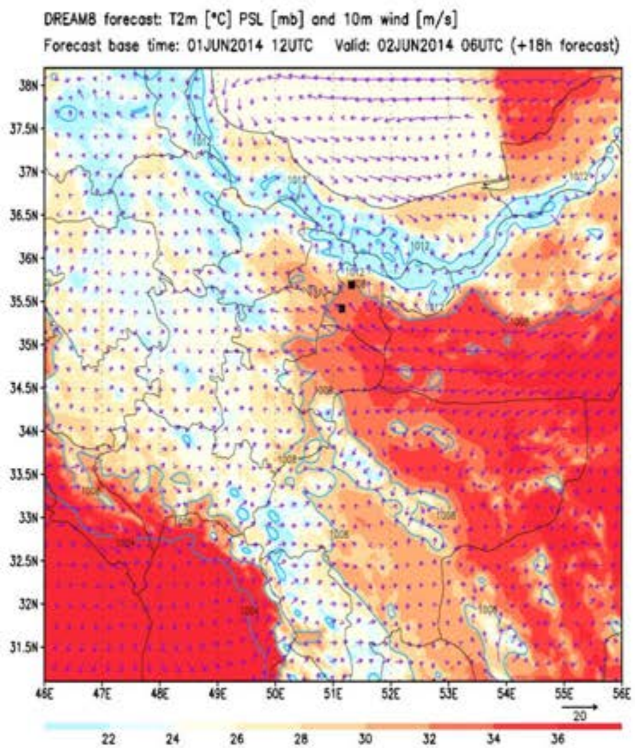
Dust PM10 concentration

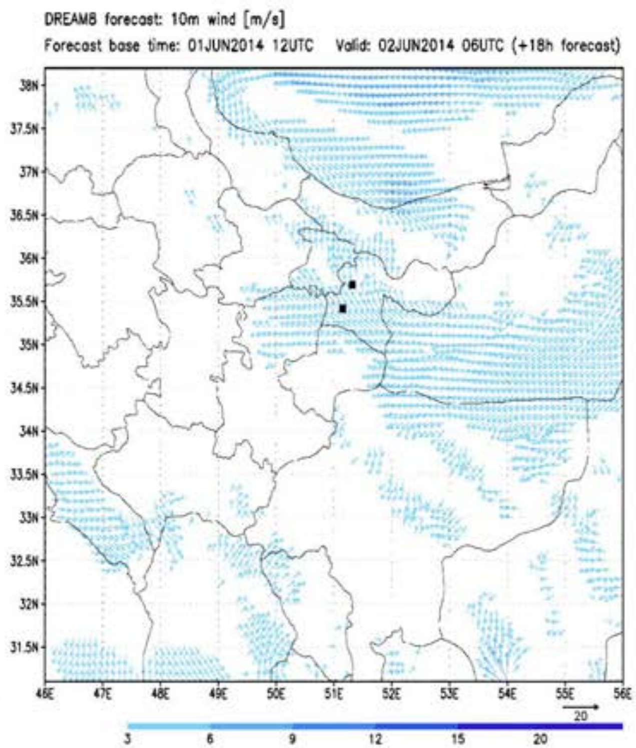


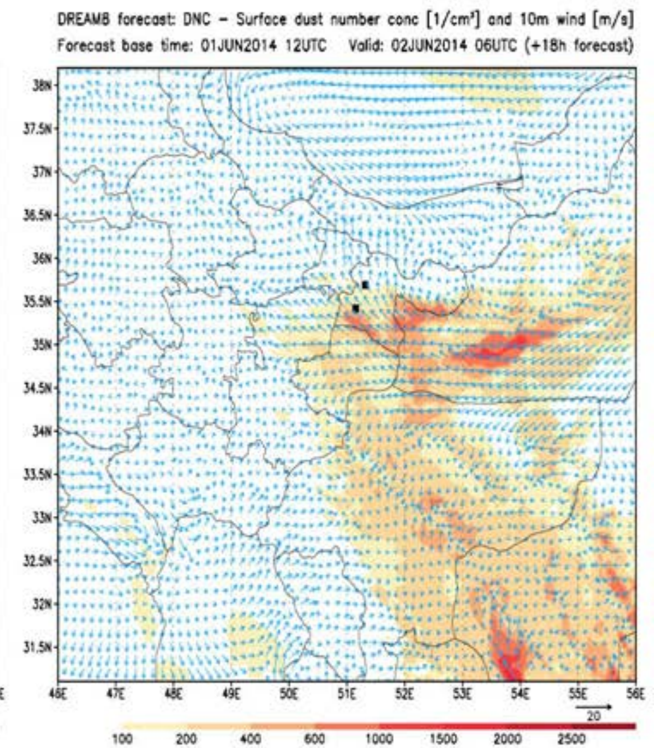
DNC – dust number concentration



NMME-DREAM (SEEVCCC) simulation results for the period June 2nd 2014 06-20 UTC

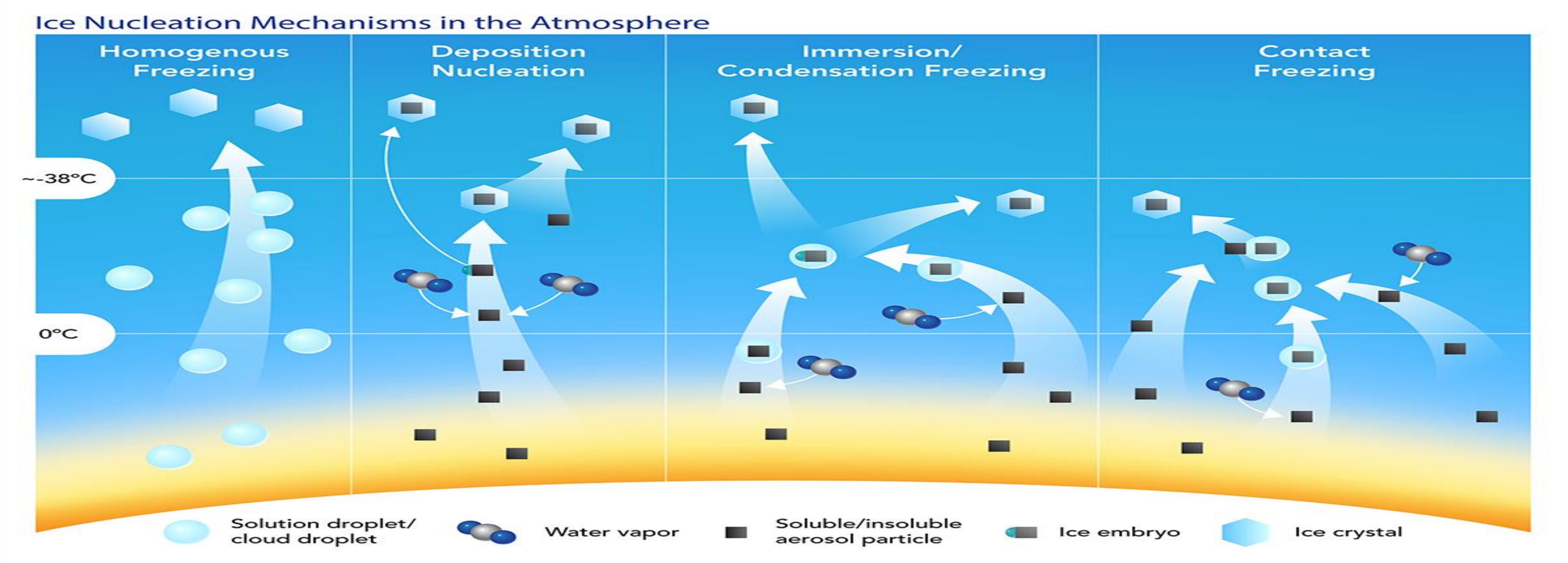


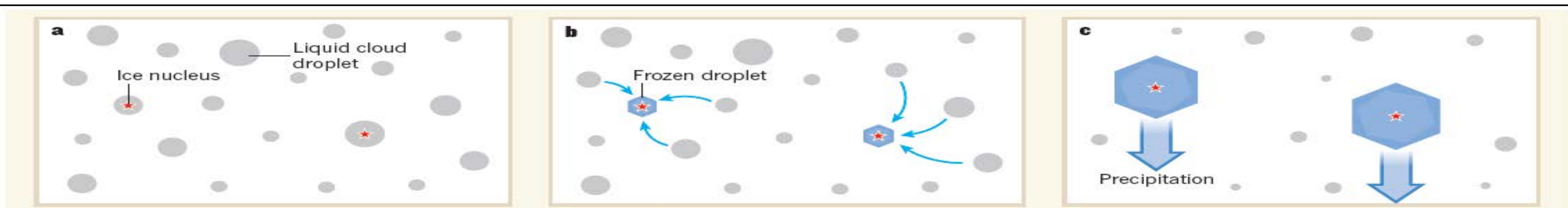




Heterogeneous cold clouds formation

- Mineral dust particles act as efficient heterogeneous ice nuclei in the tropospheric cold and mixed-phase clouds
- Dust particles lifted to the cold cloud layer effectively glaciate supercooled cloud water





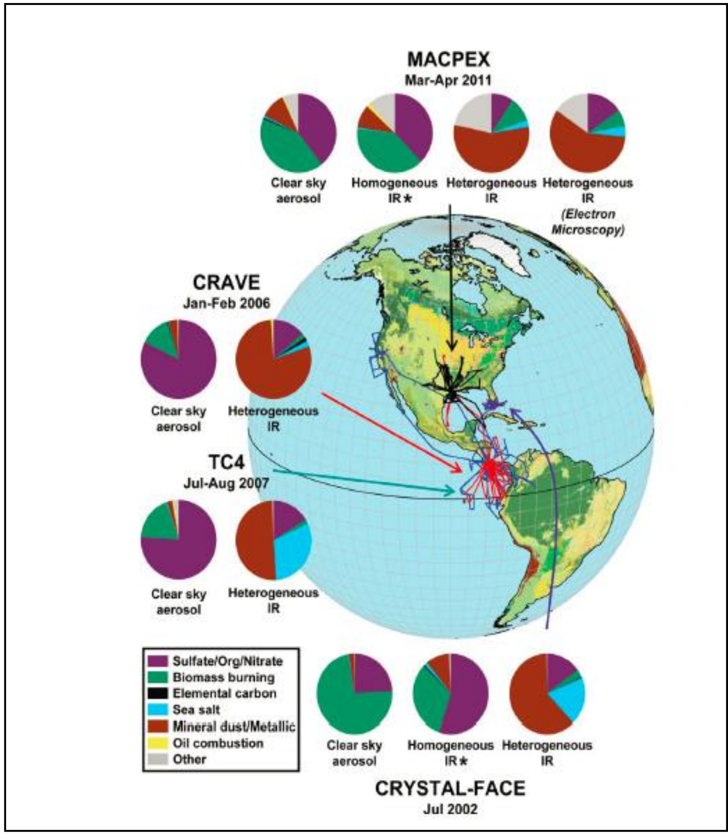
Ice formation and precipitation

Koop and Mahowald, Nature, 2013

Recent findings from observations (Ice Nuclei in ice crystals)

Cziczo at al., Science (2013)

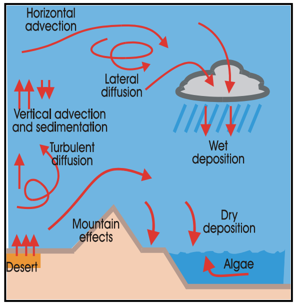
- 2/3 of residues in ice crystals from high clouds are dust+dust metallic oxides particles
- Small dust concentration needed to trigger the process
- Heterogeneous freezing is dominant process
- Minimal surface coating (no dust aging observed)
- Dust as ice nuclei found far from any of major desert sources (Asian, Saharan) !



Flight tracks of ice cloud residual measurements for four aircraft campaigns spanning a range of geographic regions and seasons

Improving precipitation forecast

'Cooking' cold clouds: our recipe



DREAM model

NMM model

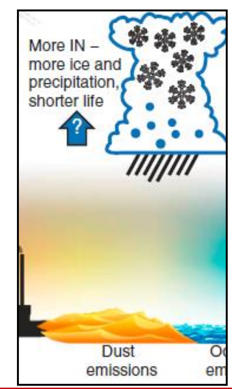
Dust C → **T, RH**

Parameterization of IN in DREAM

-55 °C	DEPOSITION Steinke et al. 2015: $n_{IN} = pS_{dust}exp^{(-q(T-273.16)+(rRH_{ice}-100))}$
-35 °C	IMMERSION DeMott al. 2015: $n_{IN} = C(n_{dust})^{(\alpha(273.16-T)+\beta)}exp^{(\gamma(273.16-T)+\delta)}$
-20 °C	IMMERSION DeMott al. 2015 (out of the scheme validity): $n_{IN} = C(n_{dust})^{(\alpha(273.16-T)+\beta)}exp^{(\gamma(273.16-T)+\delta)}$
-5 °C	

n_{IN} → **NMMB Thompson dust-friendly cold cloud micrphysics**

- Empirical parameterizations for immersion and deposition ice nucleation, which include dust concentration as a dependent variable for cloud glaciation process, are implemented in NMM/DREAM. Ice nucleation concentration is calculated as a prognostic parameter depending on dust and atmospheric thermodynamic conditions.
- Instead of a predefined IN typically used in cloud mycrophysics we predict IN
- **NOTE: IN is fraction of aerosol capable to glaciate cloud water!**



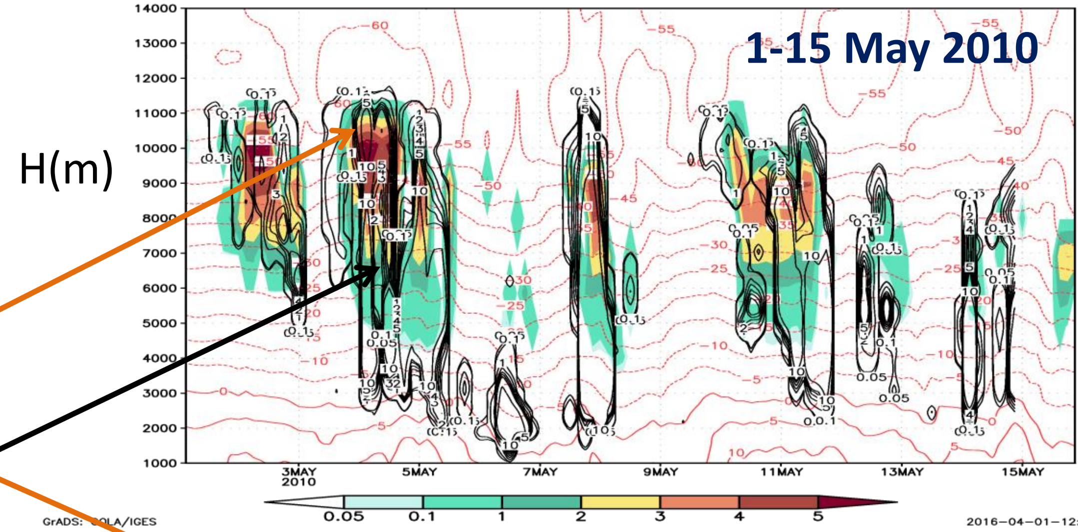
Nickovic et al, 2016, Atmos. Chem. Phys., 16, 11367–11378

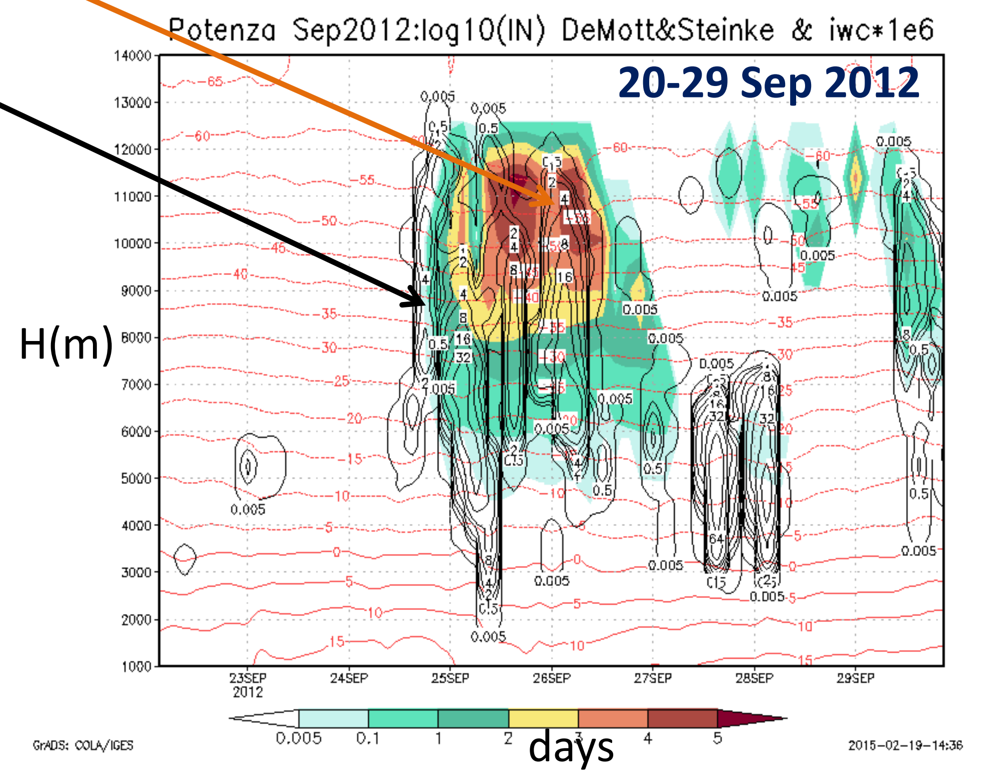
Model well reproduced timing, duration and position of #IN

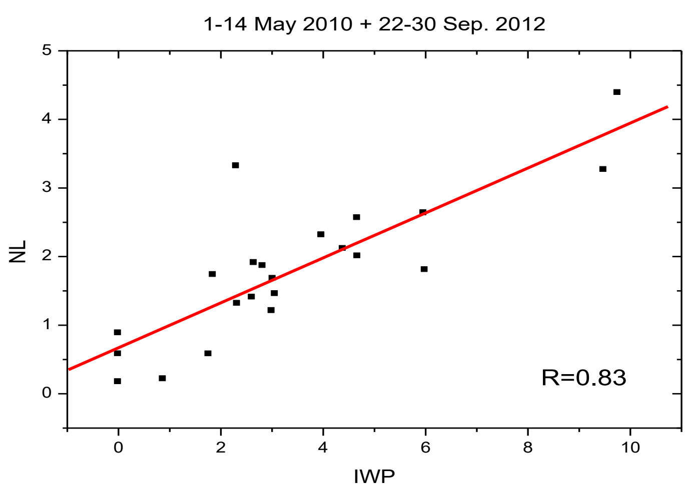
Vertical distribution
Data for model validation:
Lidar and cloud radar
CNR-IMAA Atmospheric
Observatory CIAO, Potenza, Italy

- Model #IN (shaded)

- MIRA55 Ice Cloud Water (black contours)



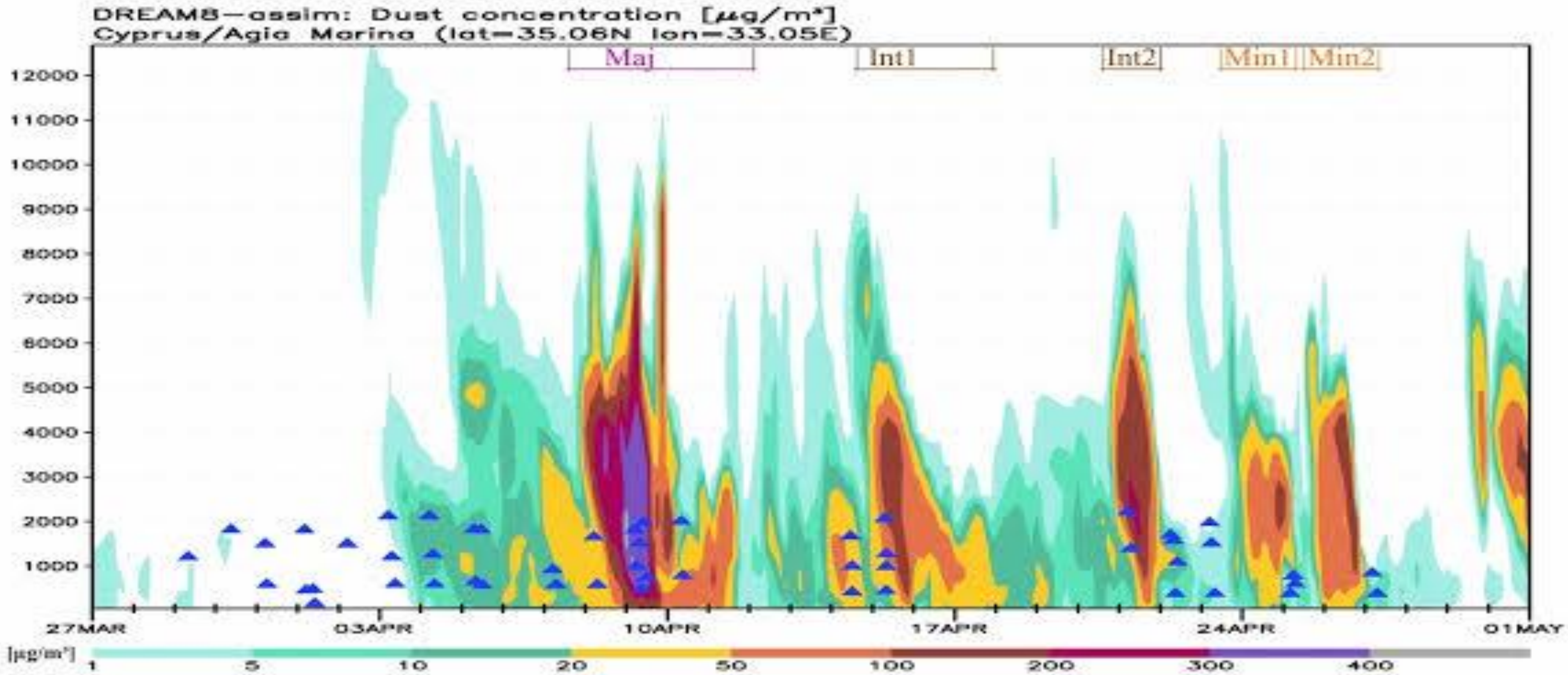




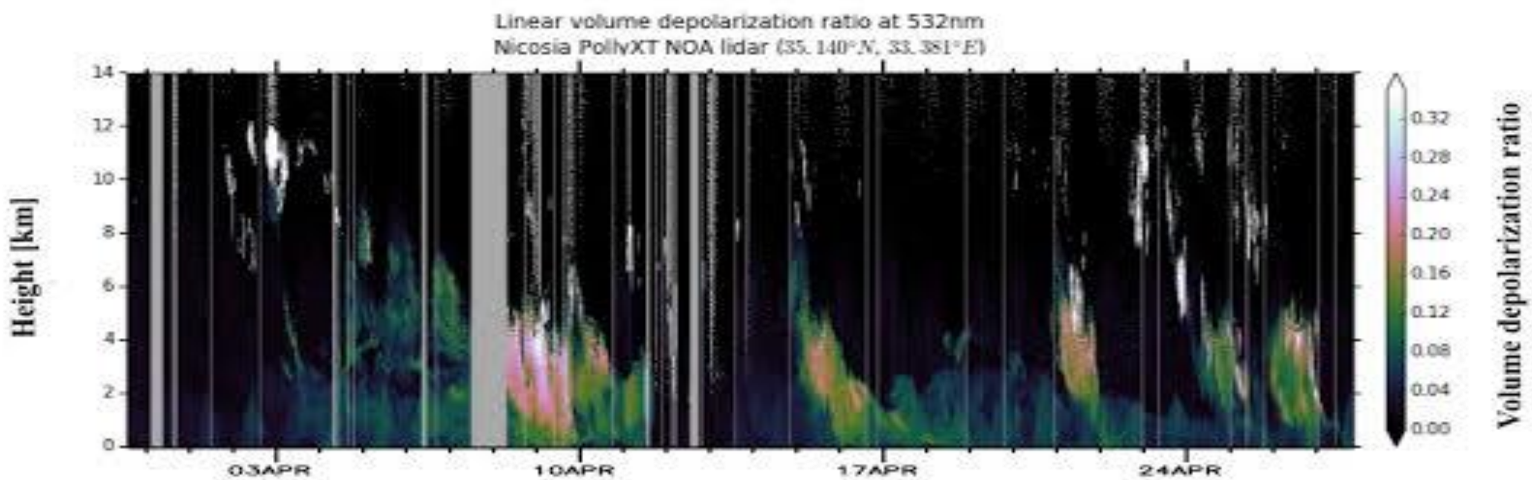
Daily averaged vertical loads
Potenza , May 2010 & Sep 2012

MODEL vs LIDAR – Cyprus, April 2016
BACCHUS-INUIT-ACTRIS field campaign

a)

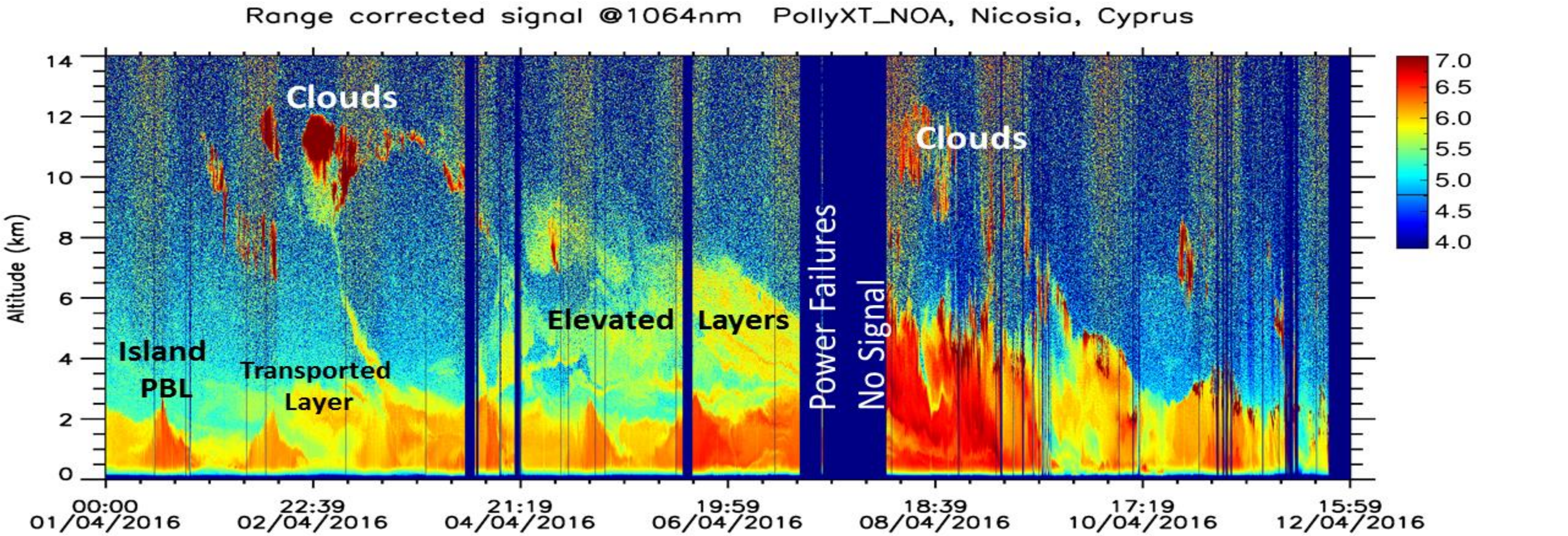


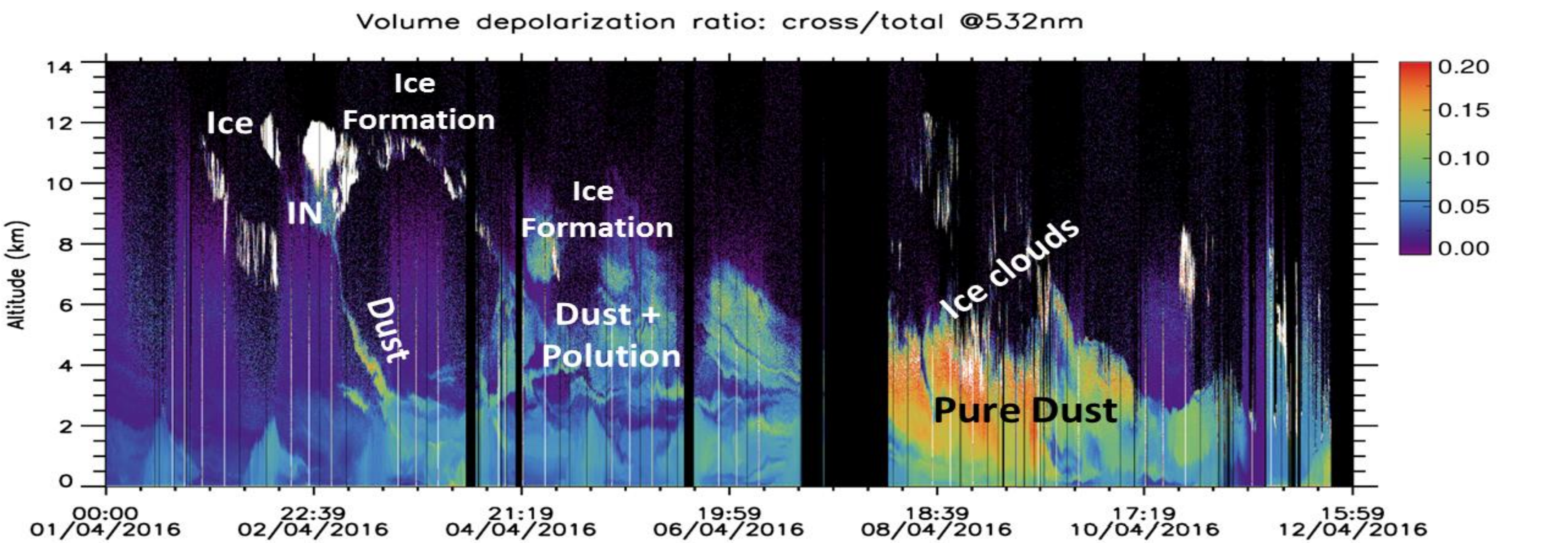
b)



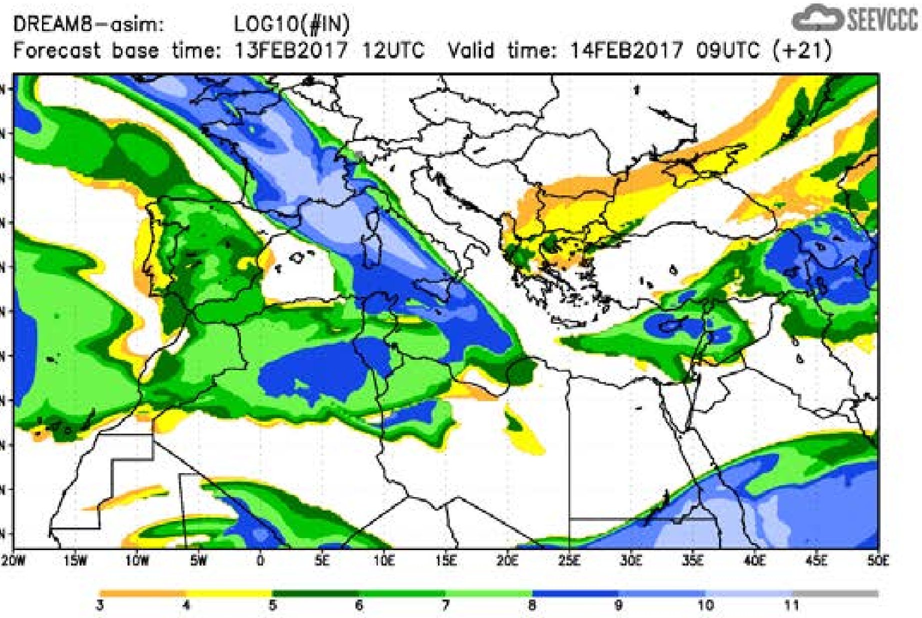
BACCHUS-INUIT-ACTRIS field campaign: April 2016

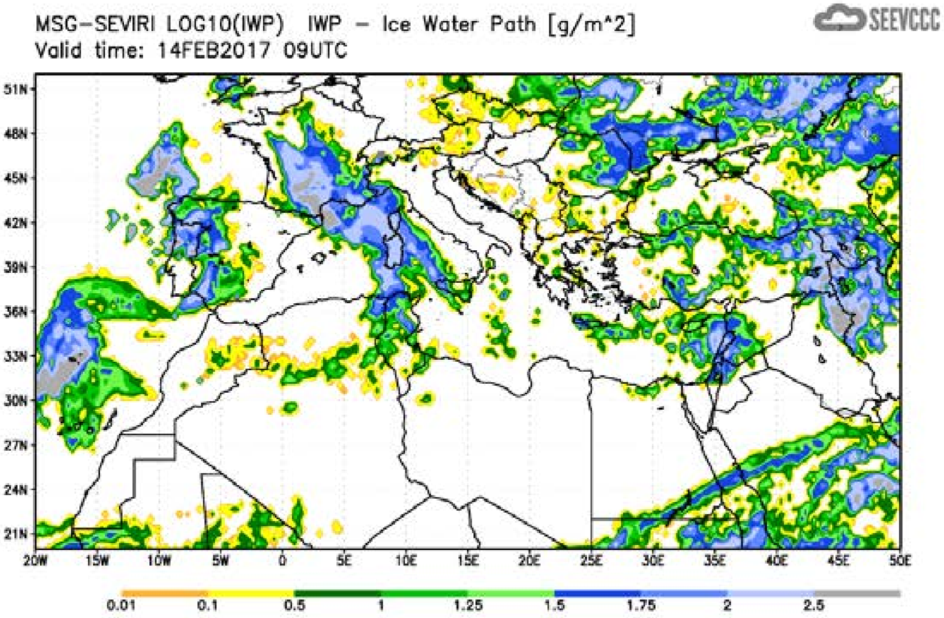
Remote sensing (LIDAR)

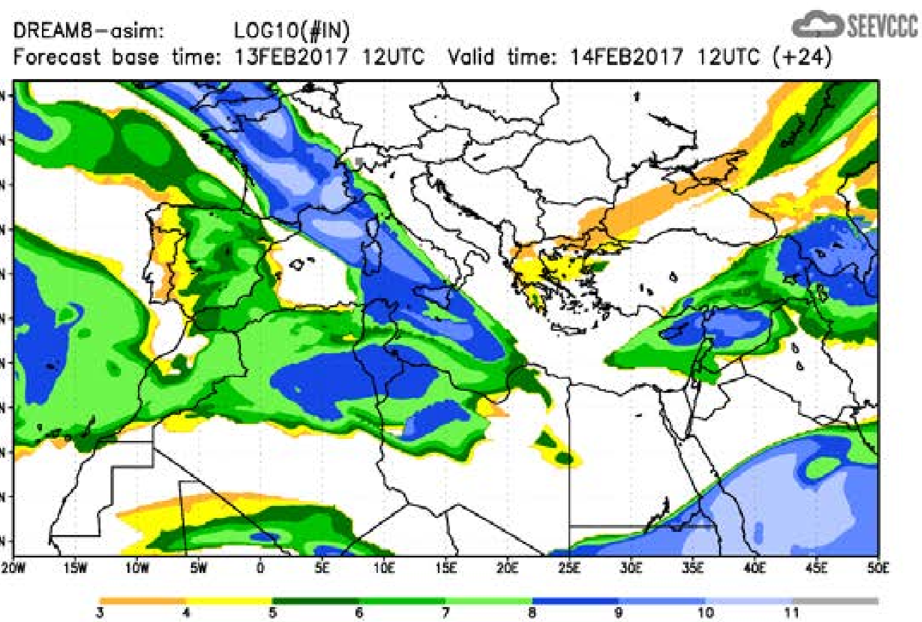


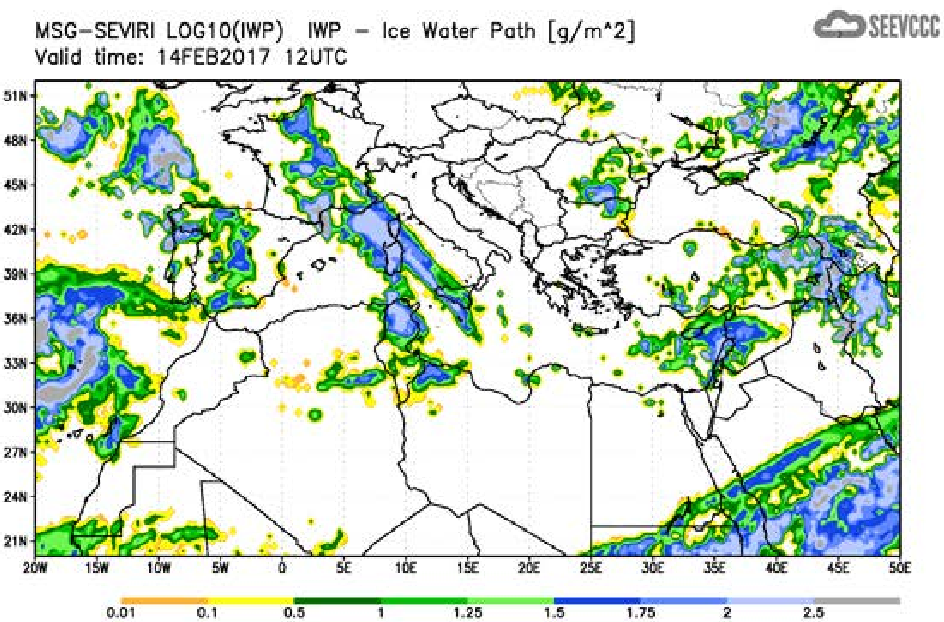


Model number of Ice nuclei load (left) vs MSG-SEVIRI satellite Ice water path (right)



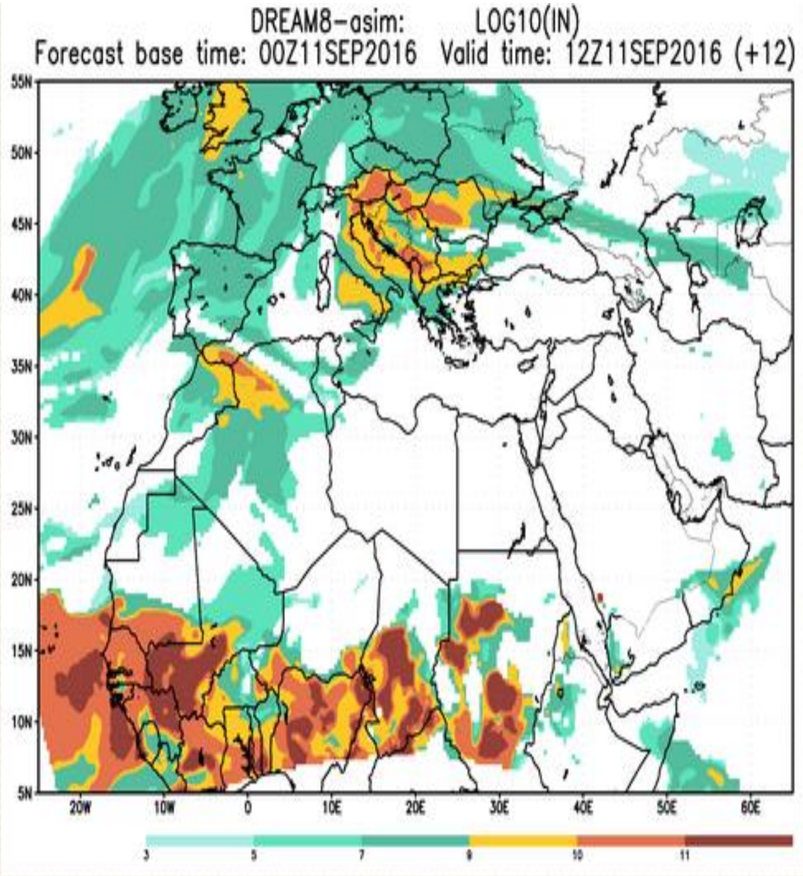


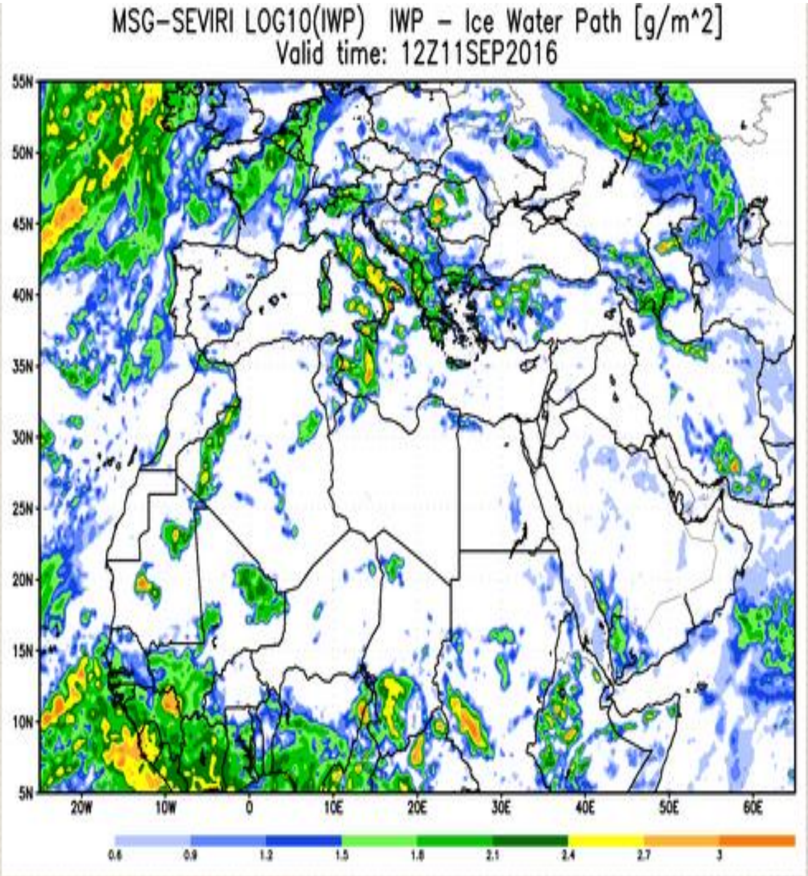




Daily IN maps

http://dream.ipb.ac.rs/ice_nucleation_forecast.html





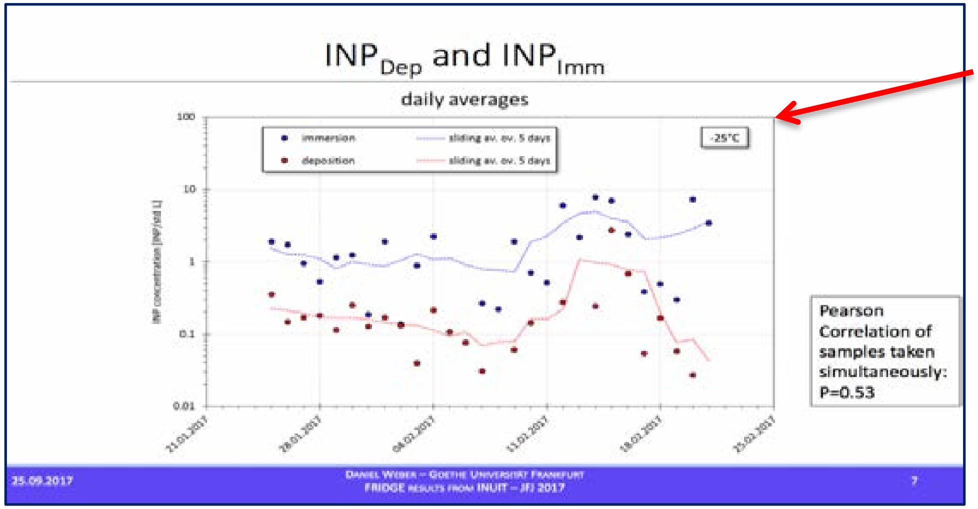
NWP groups interested to use daily #IN forecasts will soon have it available through the WMO SDS-WAS (dust) project

Is there any connection between these two pictures/locations?


Jungfraujoch Swiss Alps

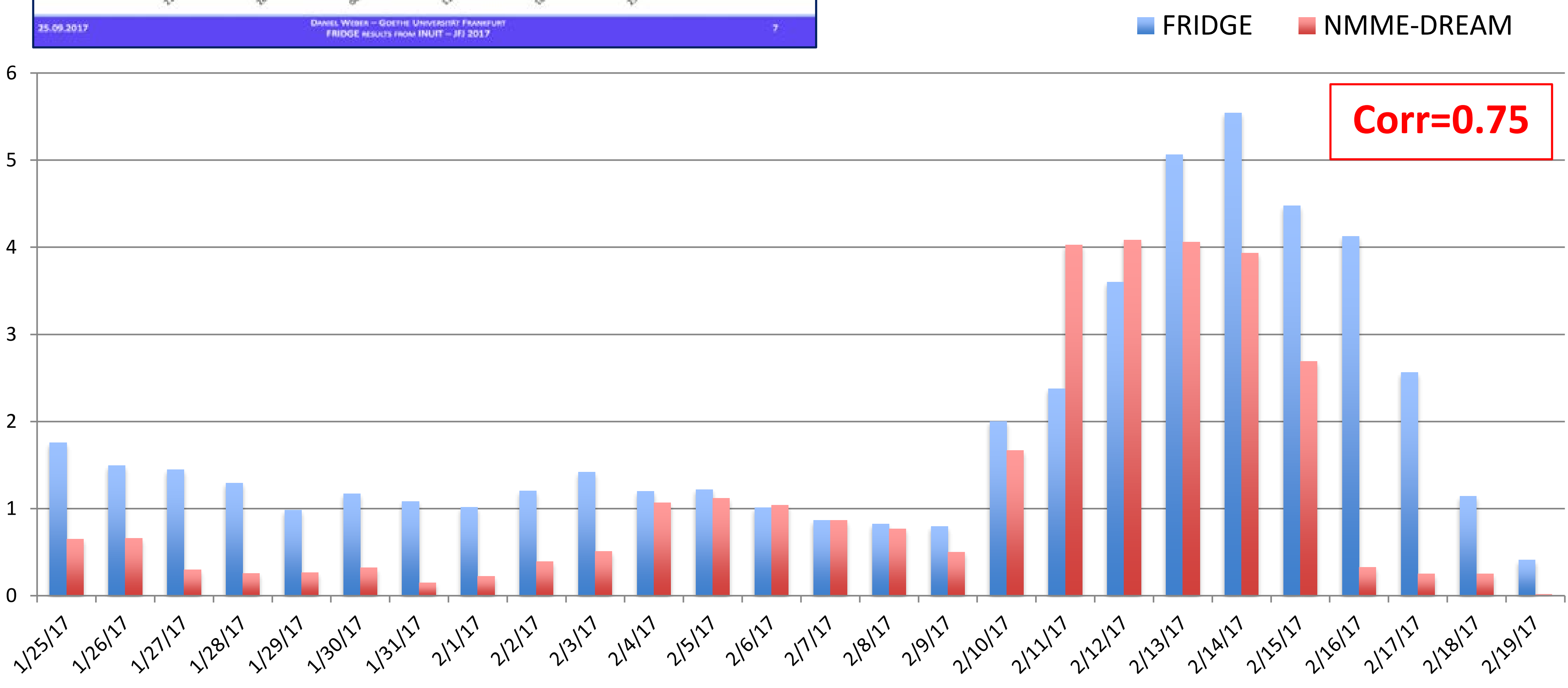

Sahara desert

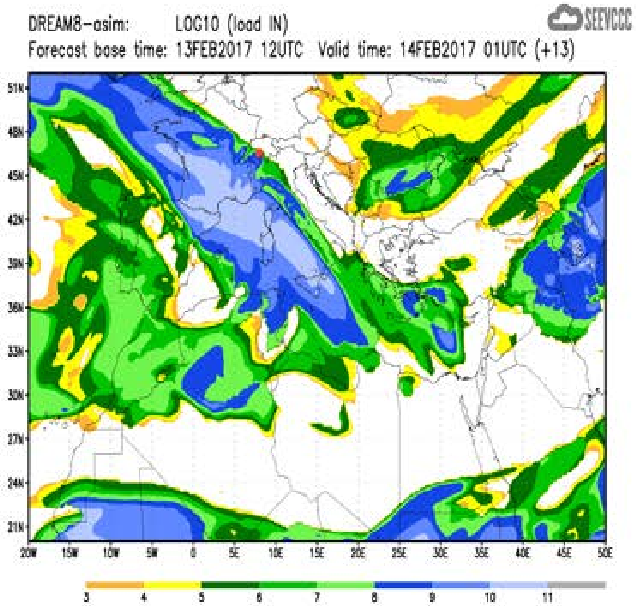
FRIDGE INP concentration [INP/std L] and NMME-DREAM const x LOG_{10}(load IN) sliding average over five days

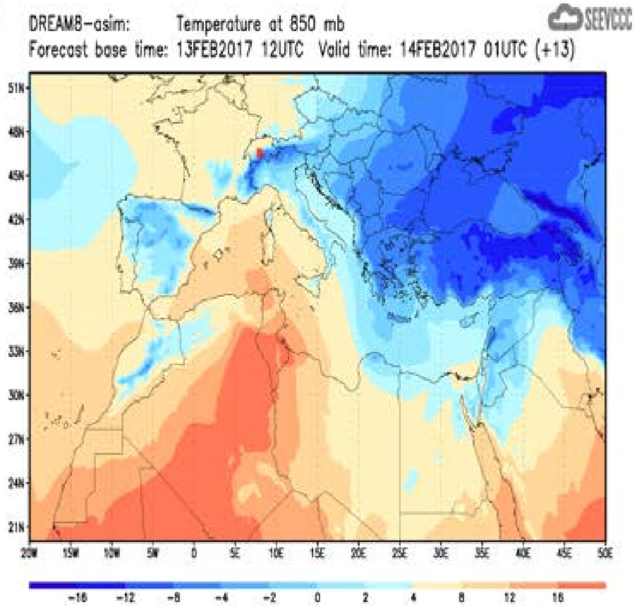


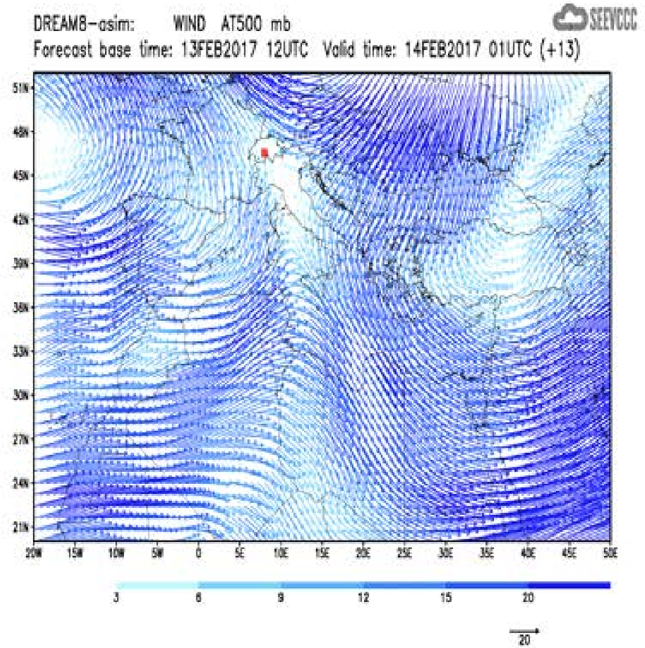
Note constant temperature -25C and constant RH=101%

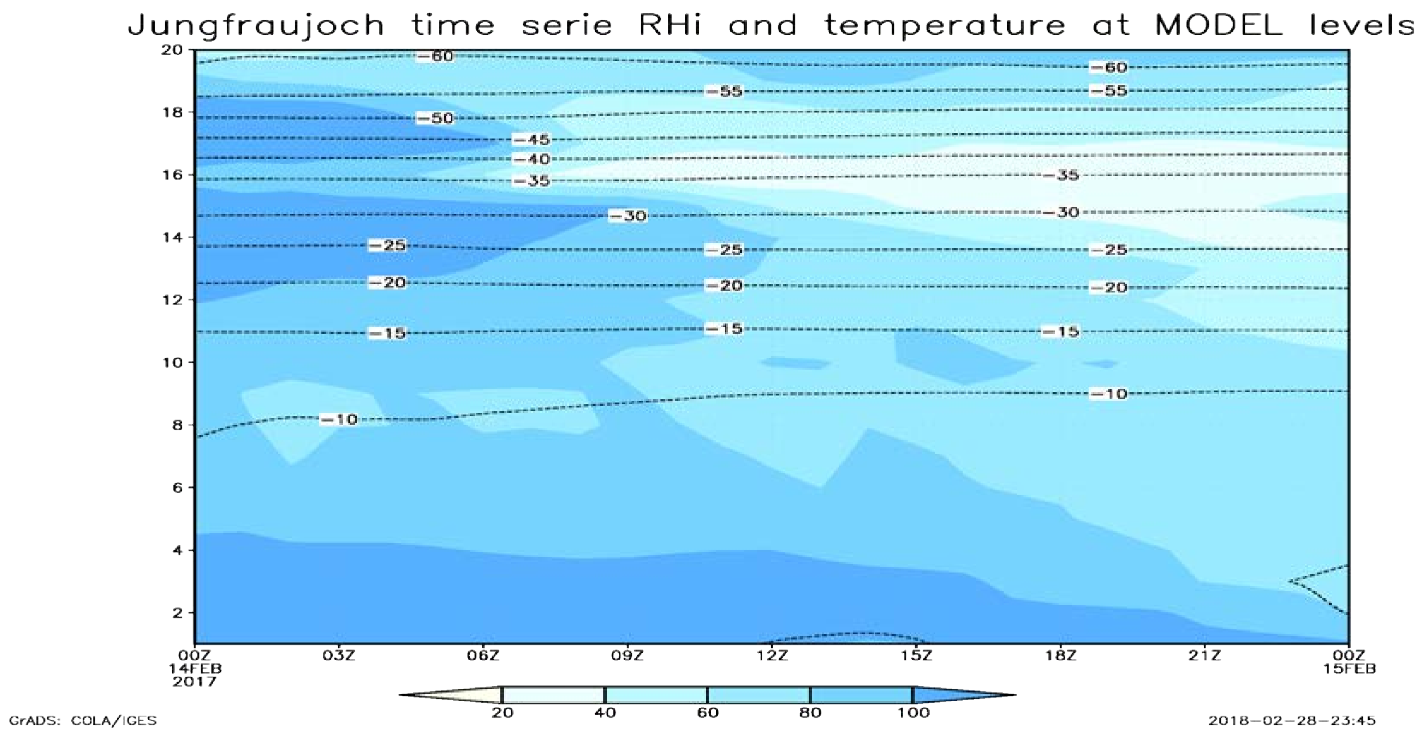
Jungfraujoch INUIT campaign January – February 2017




DREAM8-asim: LOG10 (load IN)
Forecast base time: 13FEB2017 12UTC Valid time: 14FEB2017 01UTC (+13)
SEEVCCC
3 4 5 6 7 8 9 10 11


DREAM8-asim: Temperature at 850 mb
Forecast base time: 13FEB2017 12UTC Valid time: 14FEB2017 01UTC (+13)
SEEVCCC
-16 -12 -8 -4 -2 0 2 4 8 12 16


DREAM8-asim: WIND AT500 mb
Forecast base time: 13FEB2017 12UTC Valid time: 14FEB2017 01UTC (+13)
SEEVCCC
3 6 9 12 15 20
20


Jungfraujoch time serie RHi and temperature at MODEL levels
00Z 14FEB 2017
03Z
06Z
09Z
12Z
15Z
18Z
21Z
00Z 15FEB
20 40 60 80 100
GrADS: COLA/IGES
2018-02-28-23:45

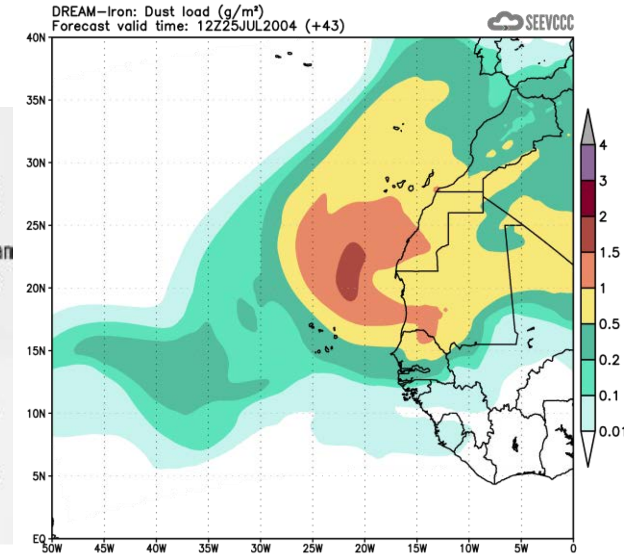
Atmospheric iron transport modeling

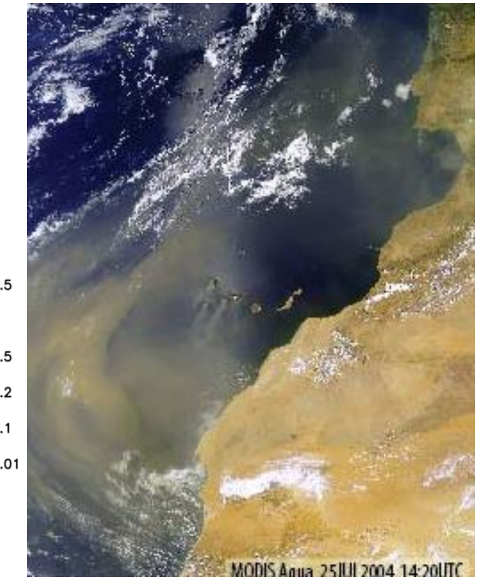
Example of mineral database application

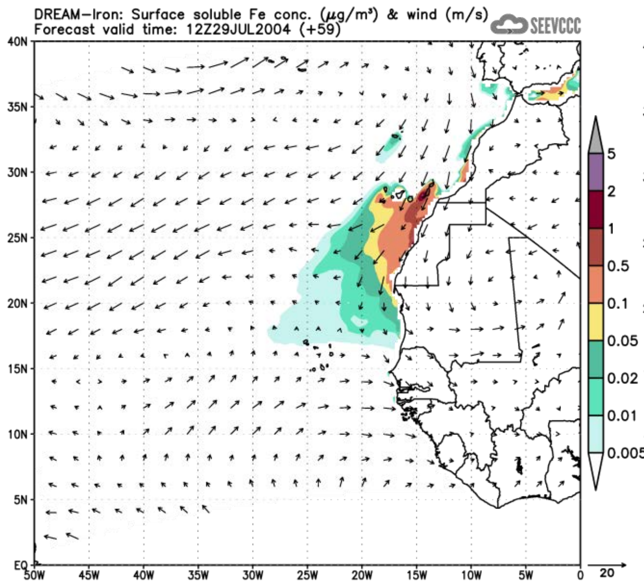
CASE STUDY

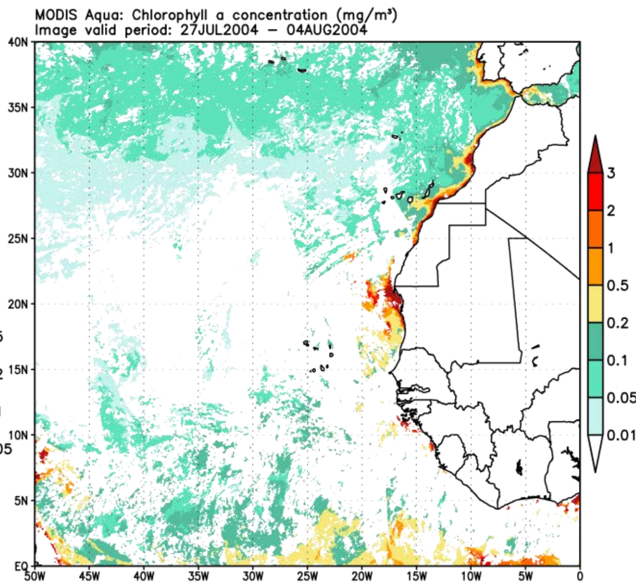
Dust storm induced chlorophyll bloom near Canary Islands, July 2004

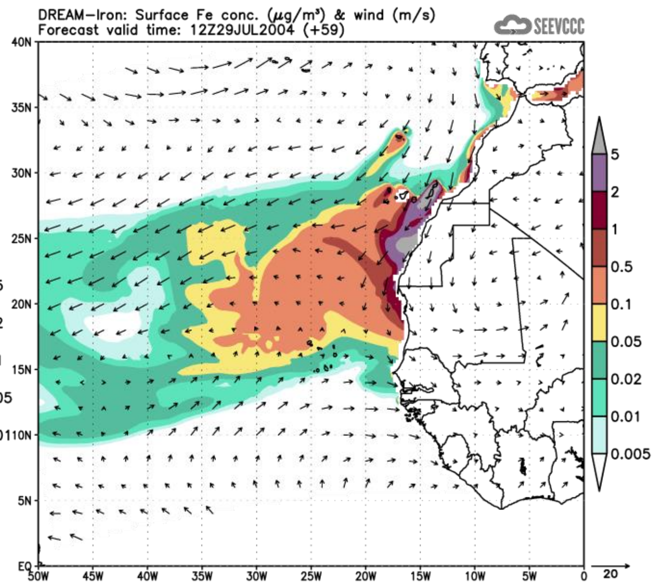
During July and August 2004, numerous dust storms occurred in northwestern part of Africa during which Saharan dust was blown towards the Atlantic ocean. Mineral rich dust aerosol was deposited mainly along the northwest African shelf, supplying the ocean with nutrient necessary for phytoplankton growth. During August, a massive occurrence of cyanobacteria was reported near Canary Islands (Ramos et al., 2005).
According to the iron hypothesis (Martin, 1994), the deposition of iron, along with dust aerosol, might increase biological productivity of the ocean and might enhance chlorophyll concentration. Therefore, we simulated this event using DREAM-Iron. The integration covers the period between 15th and 31st of July. Here we present preliminary results for dust load and iron deposition and surface concentration which is in good agreement with observed pattern of chlorophyll a concentration, observed with MODIS Aqua satellite.





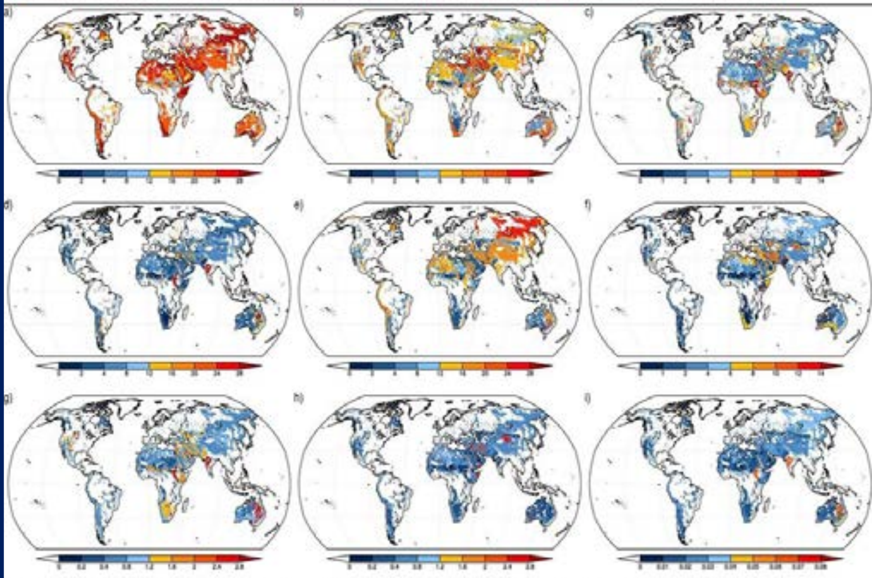






Soil sources of mineral fractions in DREAM

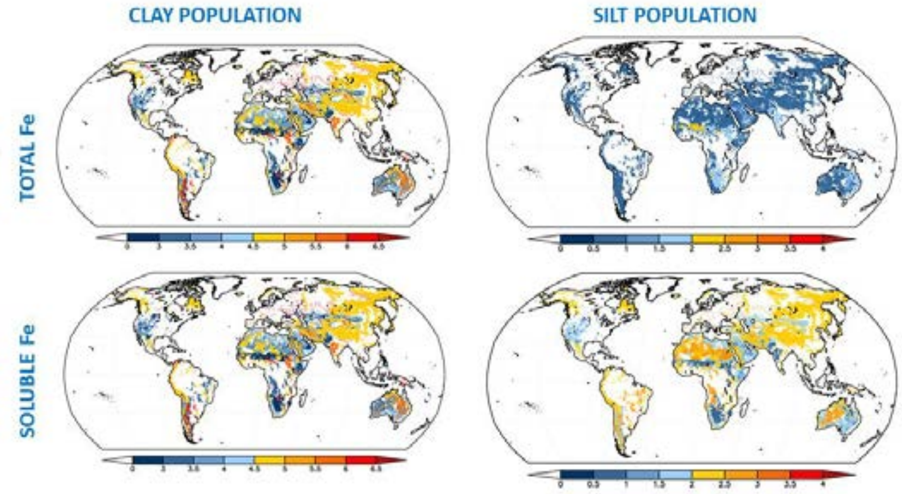
[Nickovic S., A. Vukovic, M. Vujadinovic, G. Pejanovic, V. Djurdjevic and M. Dacic 2010]



Geographic distribution of: a) quartz, b) illite, c) kaolinite, d) smectite, e) feldspar, f) calcite, g) hematite, h) gypsum and i) phosphorus

- using mineralogy data we calculated fraction of total and soluble Fe in clay and silt

-information on Fe percentage combine with land cover data provides information on how much Fe is available to uptake DREAM-IRON



OLD APPROACH

- Fe total~ 3.6 % CONST
- K (decay rate) is ONLY function of cloud interaction, effects and pollution

NEW APPROACH

- Fe spatially distributed (source map)
- K depends also on Fe mineralogy
- Free iron fraction
- Solubility

$$\frac{\partial C_k}{\partial t} + \Delta[C_k] = \left(\frac{\partial C_k}{\partial t}\right)_{\text{SOURCE}}$$ Dust concentration

$$\frac{\partial T_k}{\partial t} + \Delta[T_k] = \left(\frac{\partial T_k}{\partial t}\right)_{\text{SOURCE}}$$ Total Fe concentration

$$\frac{\partial F_k}{\partial t} + \Delta[F_k] = \left(\frac{\partial F_k}{\partial t}\right)_{\text{SOURCE}}$$ Free Fe concentration

Atmos. Chem. Phys. Discuss., 13, 2695–2723, 2013
www.atmos-chem-phys-discuss.net/13/2695/2013/
doi:10.5194/acpd-13-2695-2013

$$\left(\frac{dS}{dt}\right) + K(S - T) = 0$$

S - Soluble Fe concentration

f - $\frac{\text{FREE IRON}}{\text{TOTAL IRON}}$ ratio

K parameterized as a function of soil mineralogy

$$K = \frac{1}{\tau}\left[\alpha_C + \alpha_R - \ln\left(1 - \frac{-22.1 \times f + 15.8}{100}\right)\right]$$

Why to deal with the Icelandic volcanic dust?

- **Scientific callengies**
  - Specifics:
    - sources,
    - emission,
    - mineralogy,
    - particle properties,
    - seasonality

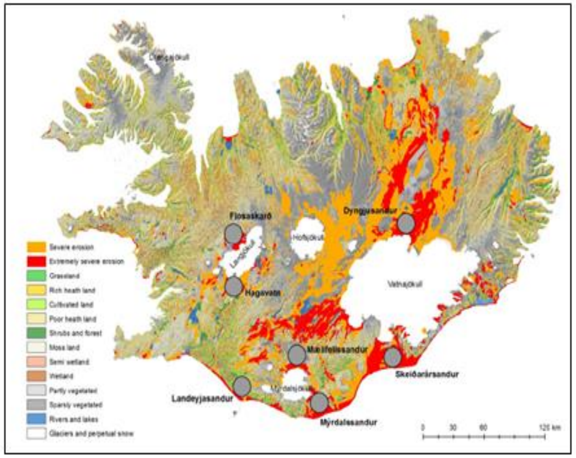
  ... quite different features from other desert particles

- **Practical effects**
  - Impacts on:
    - marine envronment
    - climate
    - flight safety
    - human health

NEW HIGH LATITUDE DUST FORECAST – NMME-DREAM-Iceland

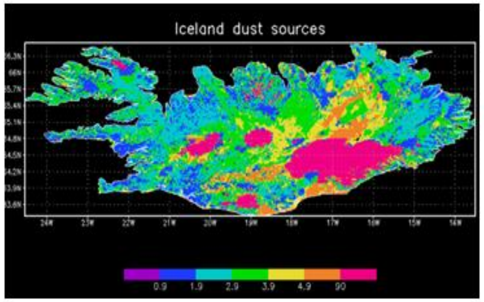
Operational products available daily at http://www.seevccc.rs/?p=8

Dust sources re-mapped from the Arnalds (2010) soil erodibility map to the DREAM numerical grid



Intensity of soil erosion based on Arnalds (2010)

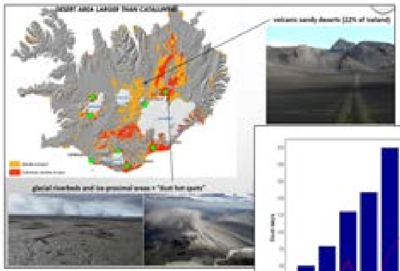
re-mapping



Dust sources in DREAM

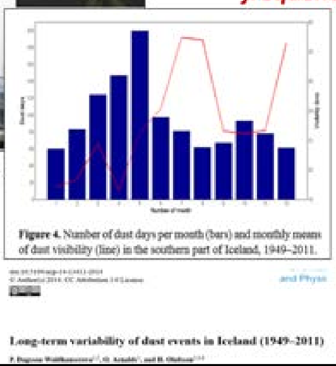
Icelandic volcanic dust

sources

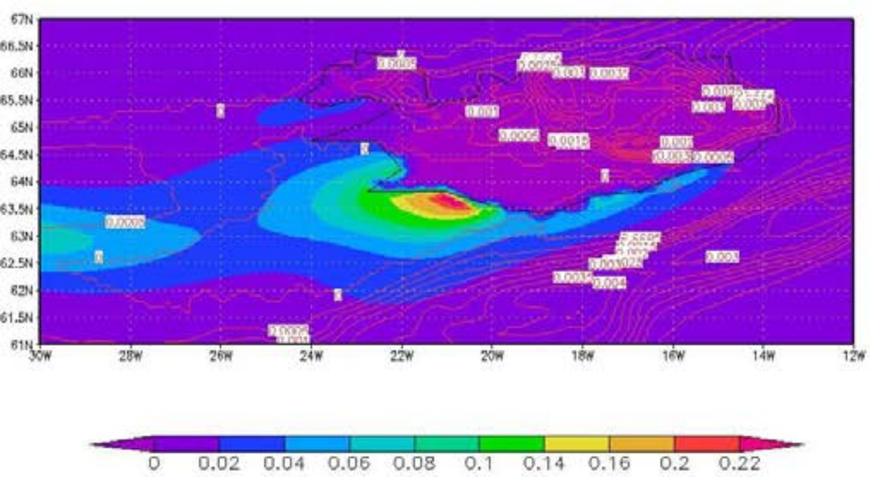


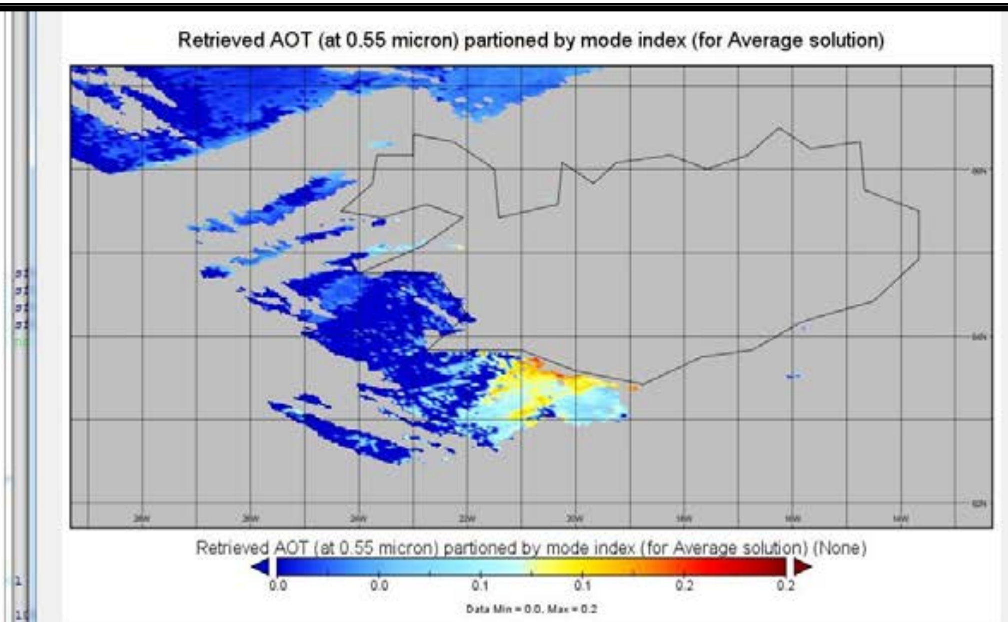
P. Dagsson-Waldhauserova et al (2018), WMO SDS-WAS webinar

frequency



NMME—DREAM-Iceland vs MODIS AOT (Aerosol Optical Thickness)





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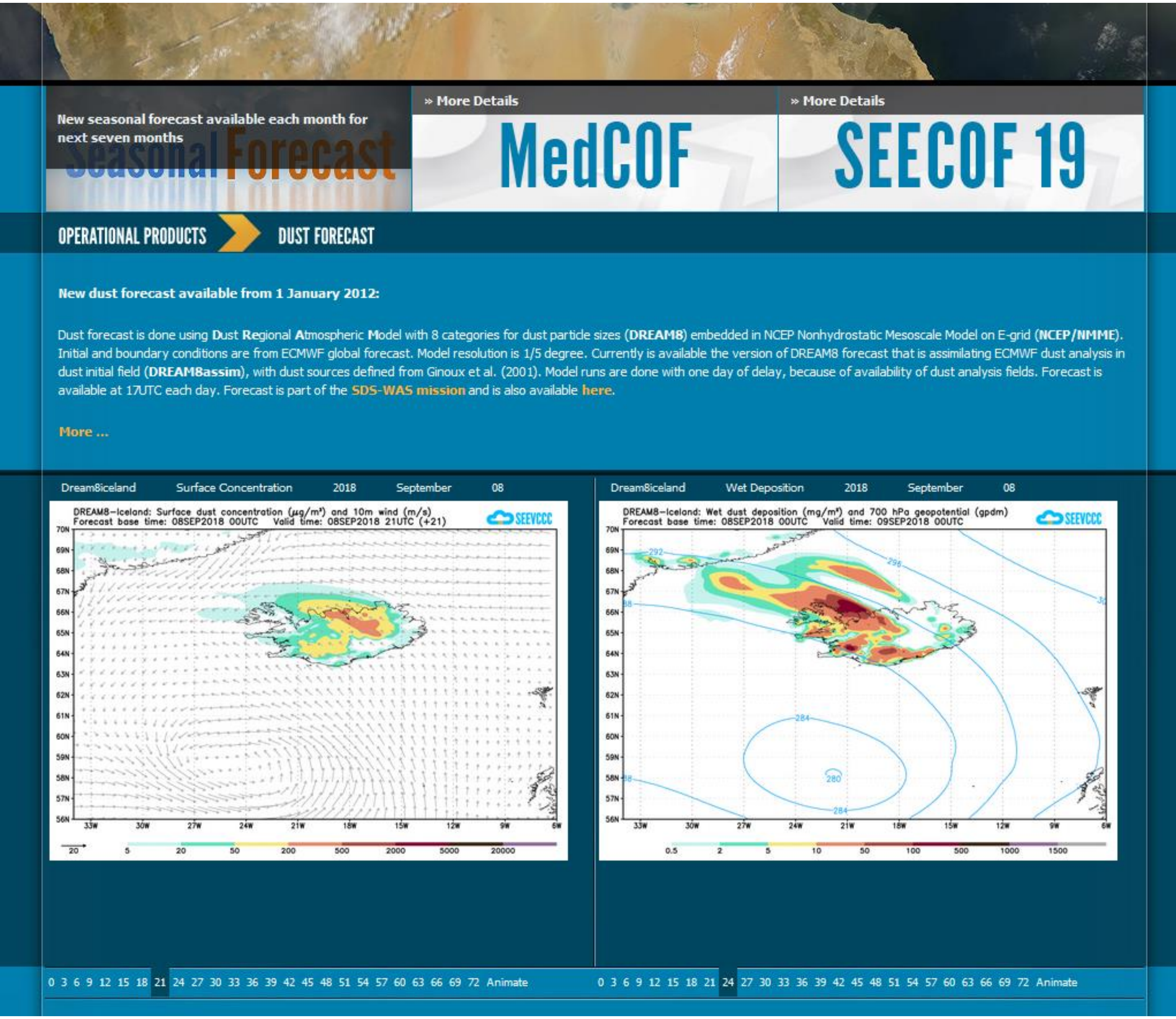

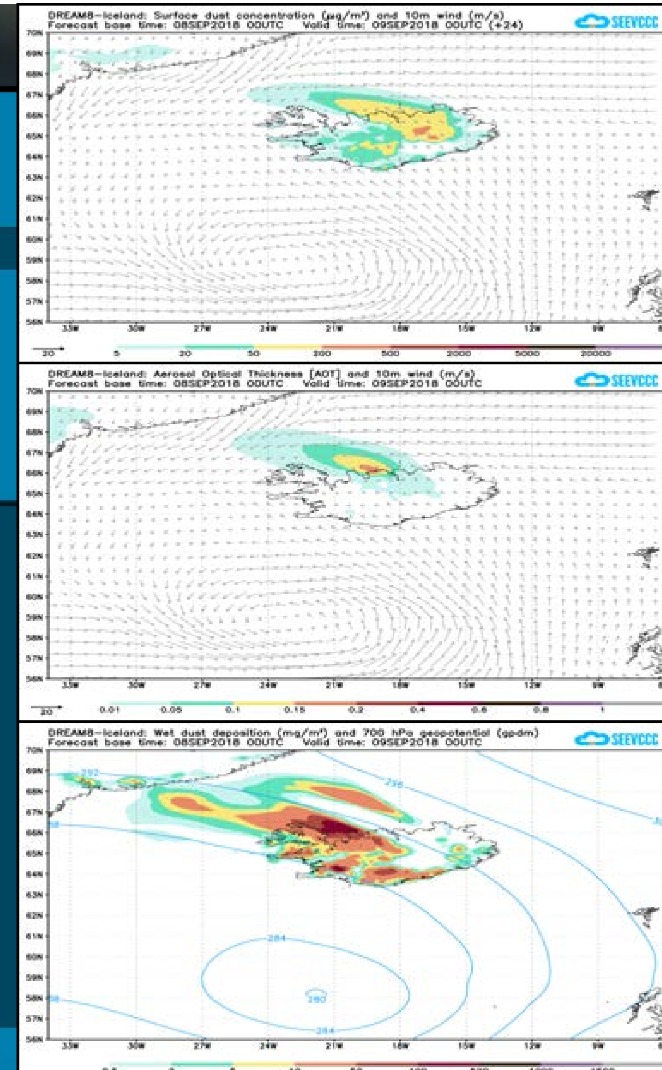

Thank you kindly for your attention!