Predicting time and location of melted dust in turbines

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Dust melting in turbines: emerging problem in aviation

- Over decades, there was only evidence on melted volcanic ash in turbines
- Recently, desert dust aso melted occasionally athough melting T(dust) >> melting T(volcanic ash). Why?
  - New generation of turbines increased working T for several hundreds deg (up to 1800-2000Cdeg)

Ash/dust melting conditions

.....

7000m

6000m

5000m

4000m

2000m

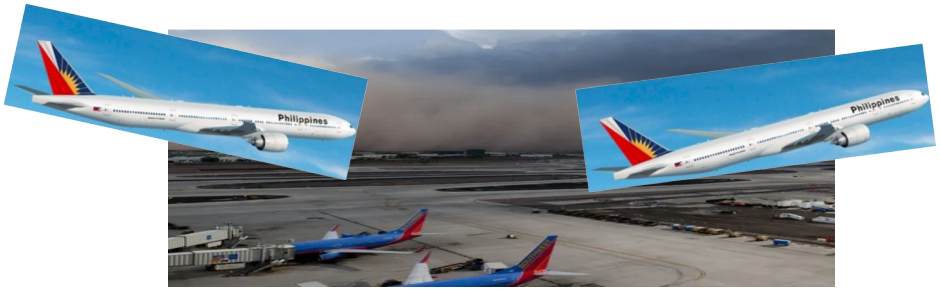
Volcanic ash:

- cruising phase
- high altitude
- low concentrations
- low melting T
- long-time exposure

Damaged turbine (Clarkson, 2016)

Dust storm:

- landing/takoff phase
- near-surface altitude
- extreme concentrations
- higher melting T
- short-time exposure



Volcanic ash impacts

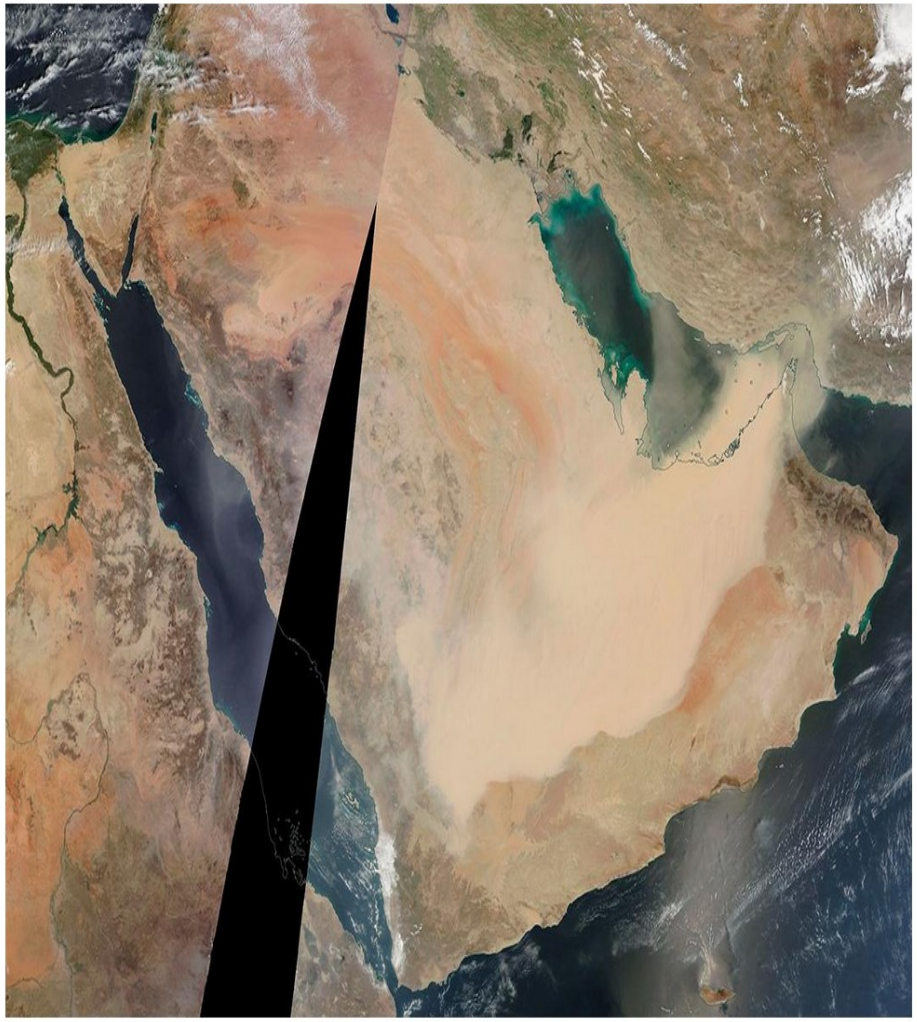
- **In the period 1953-2009:**
  - 94 incidents caused by volcanic ash;
  - out of it, in 26 cases there was serious damages in turbines
  - 9 cases with engines blackouts.

- **Eyjafjallajökull eruption 2010:**
  - ceased/disturbed aviation operations during 8 days
  - loose of 1.3 bil€

1-2 April 2015 Gulf dust storm: facts

- Selected as a test case in this study
- Massive dust storm originated in Iraq
- Fast moving towards SE along the Golf coastline
- Flight operations at several airports in the region adversly affected
- Indication that several aircafts experienced dust meting in turbines

1-2 April 2015 dust storm: local and large-scale picture



Dust travels across the Arabian Peninsula on Thursday, as seen from NASA's Terra satellite.

Sandstorm results in 354 traffic accidents

The eight-hour sandstorm also resulted in the disruption of incoming and outgoing flights from King Khaled International Airport (KKIA), which remained closed for more than seven hours. The airport cleared its runaway for landing only at 4 a.m. on Thursday.

1-2 April 2015 dust storm - facts

Disaster Medicine and Public Health Preparedness VOL. 11/NO. 2

Health System Response and Adaptation to the Largest Sandstorm in the Middle East

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ABSTRACT

The State of Qatar experienced a sandstorm on the night of April 1, 2015, lasting approximately 12 hours, with winds of more than 100 km/h and average particulate matter of approximately 10 μm in diameter. The emergency department (ED) of the main tertiary hospital in Qatar managed 62% of the

the current storm readings (on multiple instruments around Doha) exceeded 1,000,000 $\mu g/m^3$. This was the highest reading ever seen by

Technologies new, problems with SDS remained

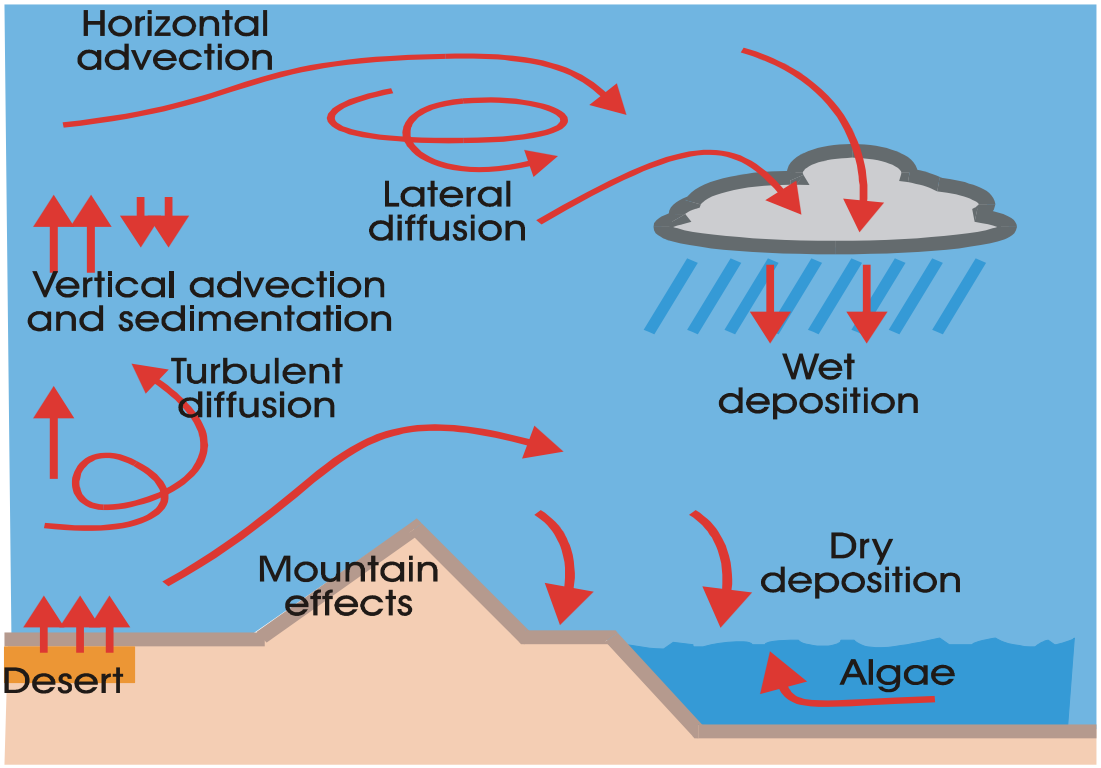
- ***Do we have today better means to mitigate SDS effects rather than than just praying?***

Dust storm in Sahara, painted by George Francis Lyon

George Francis Lyon (1795-1832) - Lyon (1821):A Narrative of Travels in North Africa in the years 1818, 1819, and 1820,

Numerical dust prediction models: Potentially useful tool to assist aviation operations

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

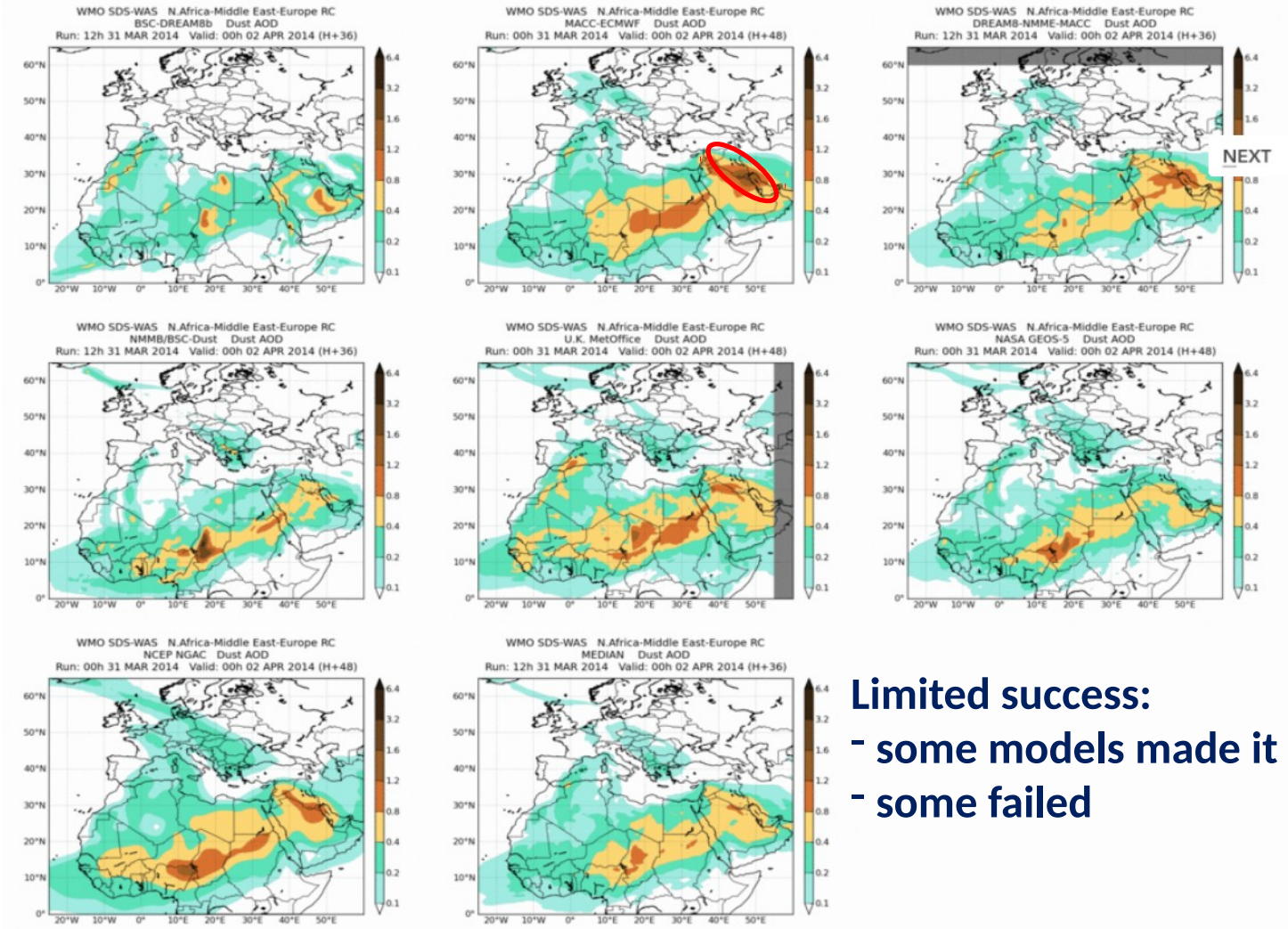


Concept of DREAM (Dust Regional Atmospheric Model)

Nickovic et al., 2001; Nickovic et al., 2016)

Could current dust models predict storms of the April 2015 type?

WMO SDS-WAS AOD predictions valid for 18:00UTC

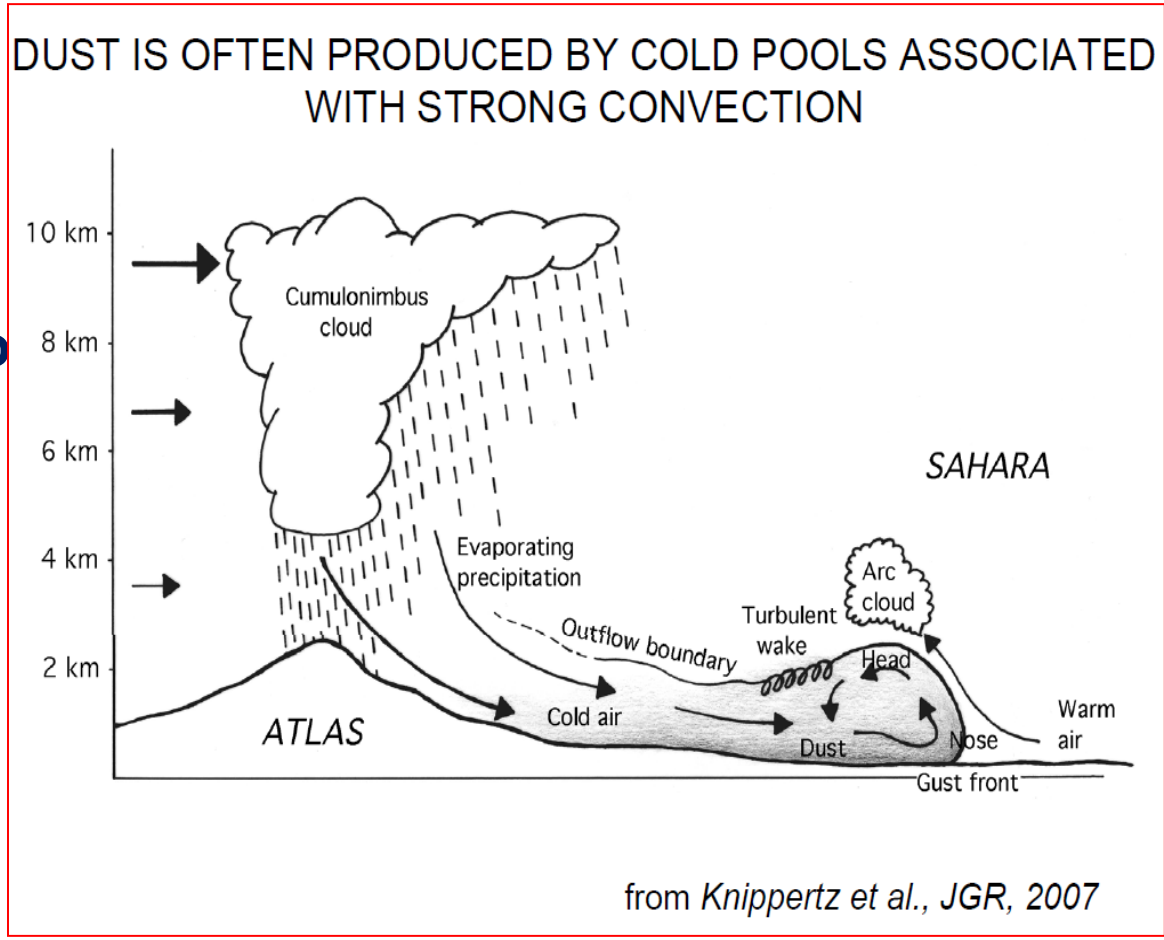


Limited success:

- **some models made it**
- **some failed**

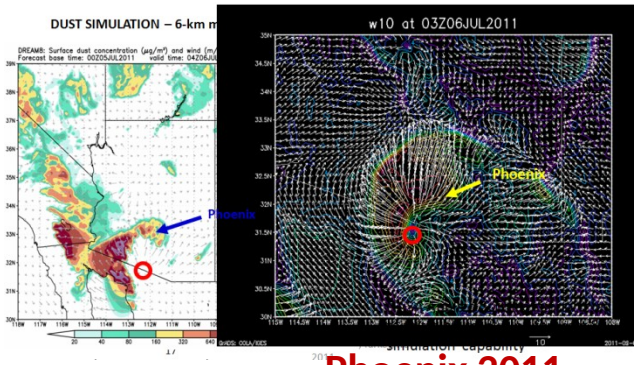
Apart of the large-scale SDS (e.g. April 2015), there is another SDS type: small-scale haboobs, also badly affecting aviation

- Driven by concective circulations
- Cold air downdraft – generator of a dust storm
- **Coud current models also predict such SDS?**

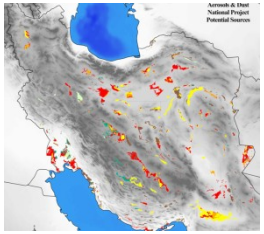


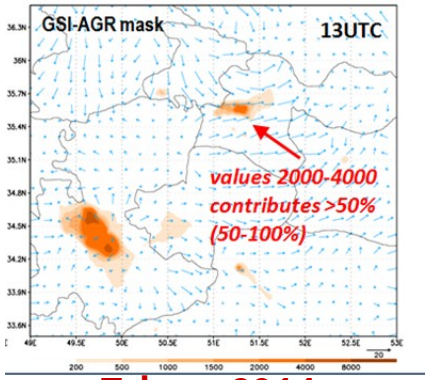
DREAM examples with haboob-like storms

- Downscaling the model to at least 3-5 km horiz. resolution
- Convective systems resolved
- Non-hydrostatic effects included (high vertical velocities)
- DREAM tests for selected haboobs
  - **Phoenix 2011;**
  - **Tehran 2014;**
  - **Turkey 2018**
- New approach to consider small-scale hot-spot dust sources :
  - **land cover (static) and NDVI (dynamic)**
  - **Re-definition of the Ginoux source function for vary-small scales**
  - **Local data on**
    - clay/silt fractions
    - identified sources not existing in other data bases (agricultural sources, etc…)

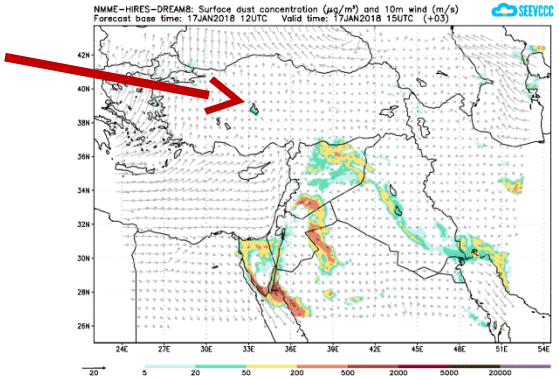


Phoenix 2011





Tehran 2014



Turkey 2018

Tools to reduce dust melting impacts and to understand the process

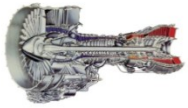
Ground-based controlled engine testing

National Aeronautics and Space Administration

Vehicle Integrated Propulsion (VIPR) Engine Test Program

- VIPR is a series of ground-based on-wing engine demonstrations to mature aircraft engine health management technologies
- Test vehicle is a U.S. Air Force C-17 aircraft equipped with Pratt & Whitney F117 engines
- VIPR partners include NASA, U.S. Air Force and other external organizations
- VIPR test schedule
  - VIPR1 (2011)
  - VIPR2 (2013)
  - VIPR3 (2015)
- VIPR3 testing covered in this presentation:
  - Gas Path Diagnostics (GPD): A series of nominal and faulted engine test cases
  - Volcanic Ash Environment (VAE): Low concentration engine ash ingestion testing

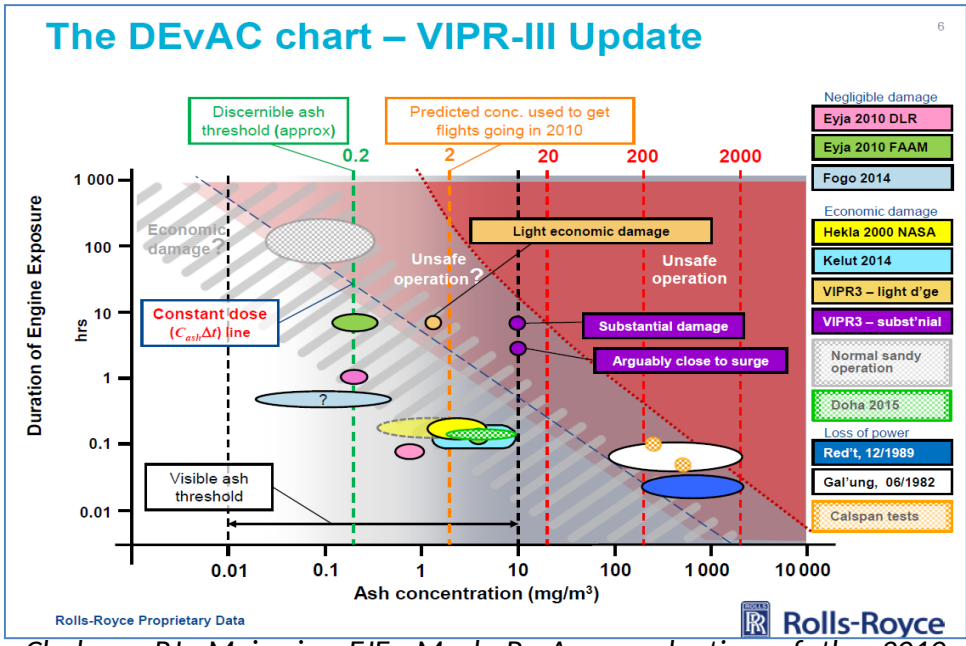
Boeing C-17 Globemaster III



Pratt & Whitney F117 Turbofan Engine

Vehicle Integrated Propulsion Research (VIPR) Gas Path Diagnostics and Volcanic Ash Ingestion Test Results Donald L. Simon et al,. 5th NASA GRC Propulsion Control and Diagnostics (PCD) Workshop September 16 -17, 2015Cleveland, Ohio

Diagnostic phenomenological model [concentration vs. duration vs. exposure]



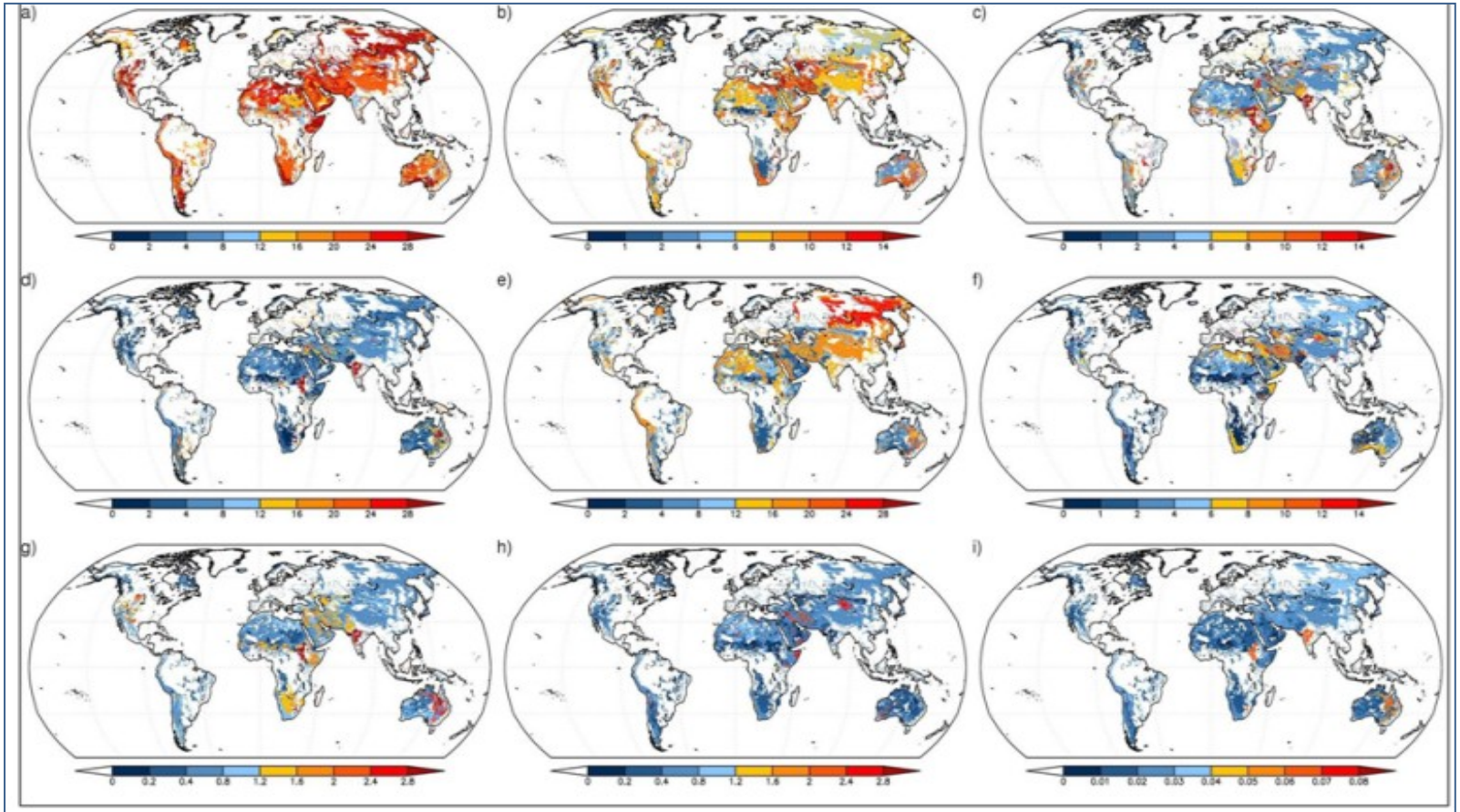
Clarkson RJ, Majewicz EJE, Mack P: A re-evaluation of the 2010 quantitative understanding of the effects volcanic ash has on gas turbine engines. Proc IMechE Part G: Journal of Aerospace Engineering, DOI: 10.1177/0954410015623372, 2016.

Dust melting prediction

How to predict dust melting in turbines?

- **New approach: DREAM-MELT** specifically designed to predict time/location of posible dust melting in turbines
  - Melting depends on
    - Time on dust exposure
    - Concentration level
    - Dust mineralogy (melting point)
    - Aircraft turbine performances

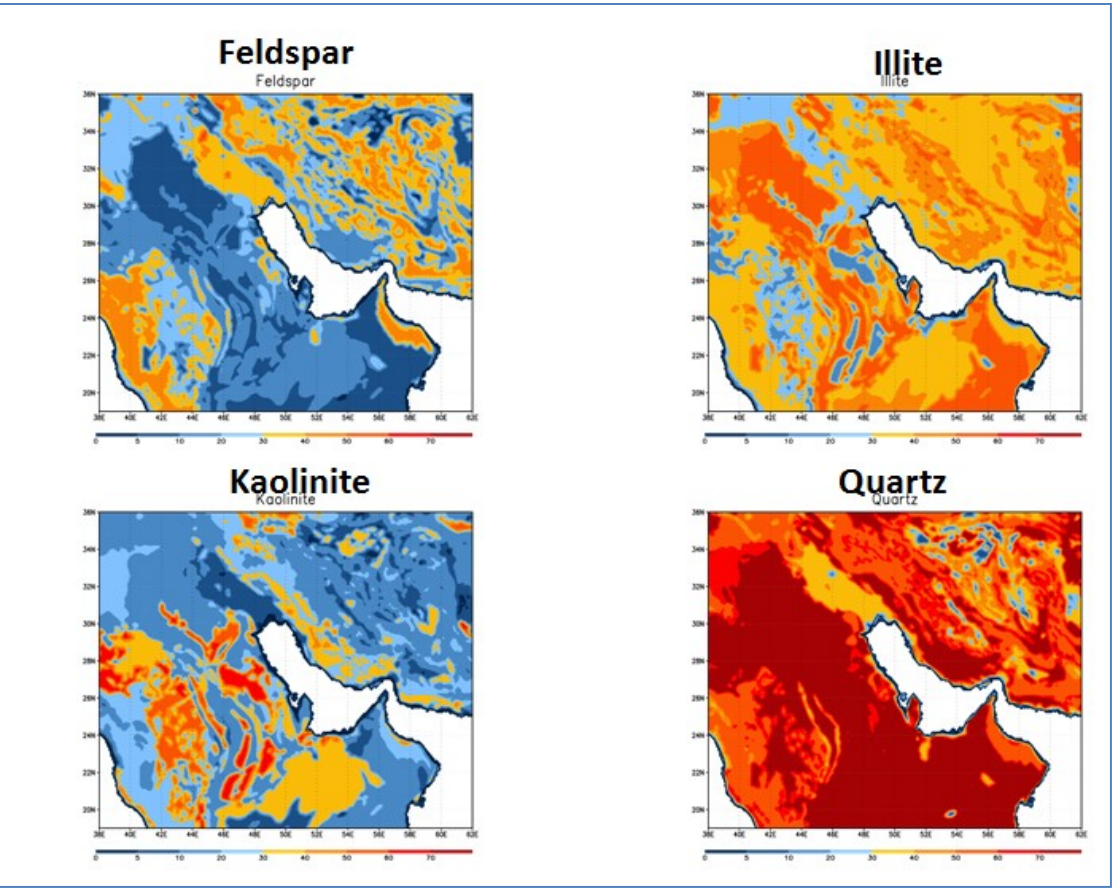
Dust mineralogy:
key for estimating melting of the dust mineral mixture



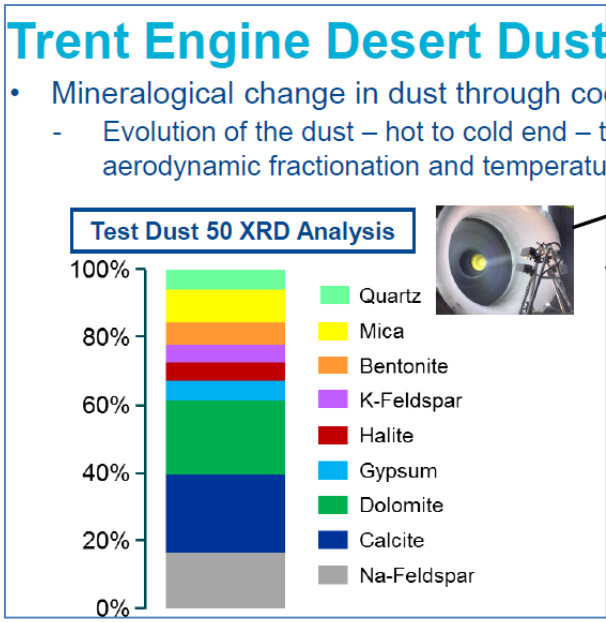
Geographic distribution of:
a) Quartz, b) Illite, c) Kaolinite, d) Smectite, e) Feldspar,
f) Calcite, g) Hematite, h) Gypsum and i) Phosphorus

Nickovic et al, 2011: GMINER 1km global mineralogy database

Closer look:
minerals in the region heterogeneously distributed



Interest of tubine producers on dust mineralogy



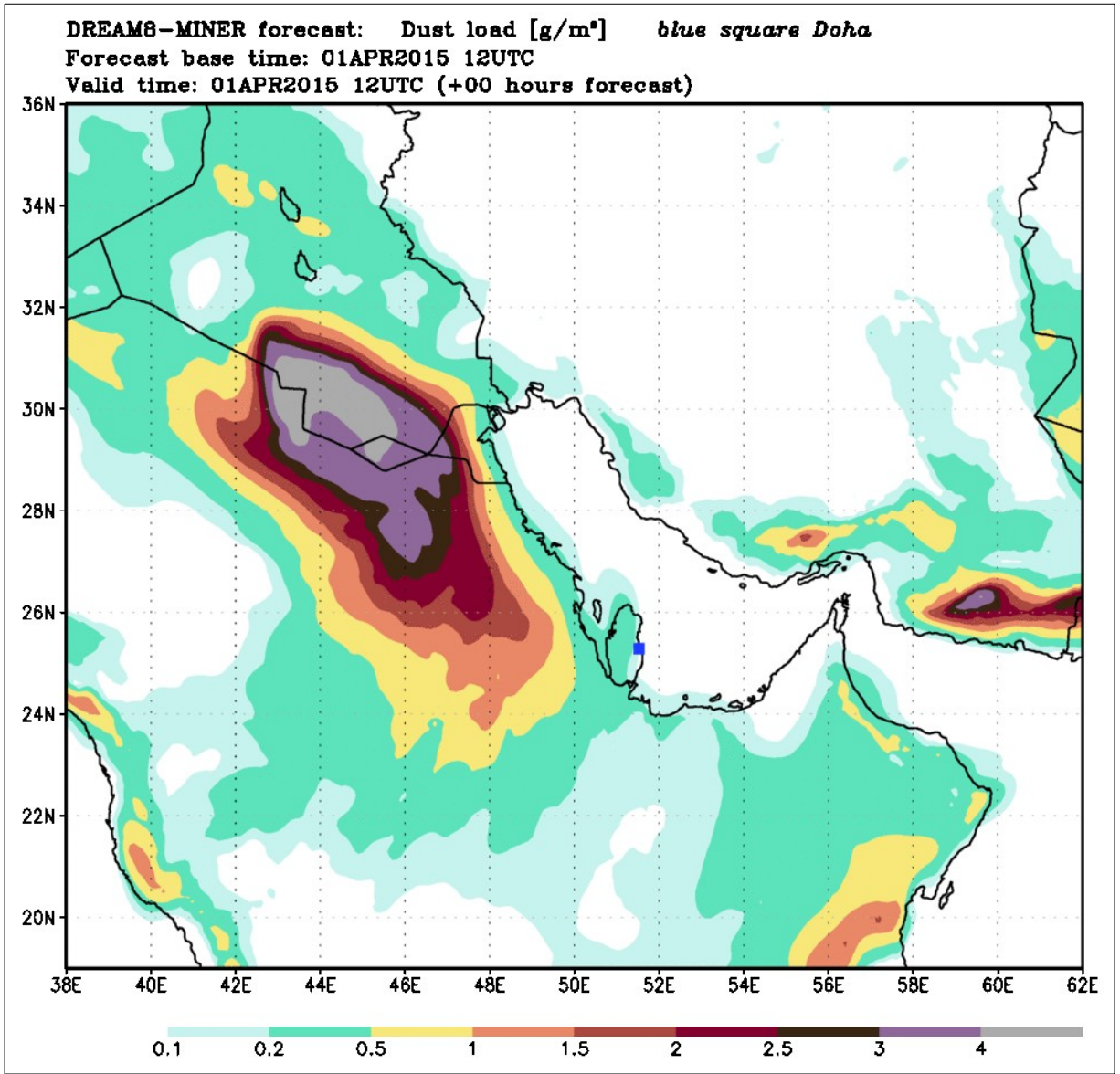
Identifying the minerals origin:
- Eulerian or trajectory approach?

DREAM-MELT

- Consists of
  - DREAM Dust Regional Atmospheric Model (Nickovic et al, 2001; Nickovic et al, 2012; Vukovic et al, 2014): dust concentration prediction
    - DREAM driven by the NCEP/WRF-NMM atmospheric NWP model
  - DREAM-MINER (extended DREAM): mineral dust fractions added as prognostic parameters
  - Specification of a melting point for predicted mineral mixture
  - Newly introduced Melting Index (MI) – a parameter predicting level of potential dust melting conditions for a particular aircraft turbine (**intelectual protection process pending**)

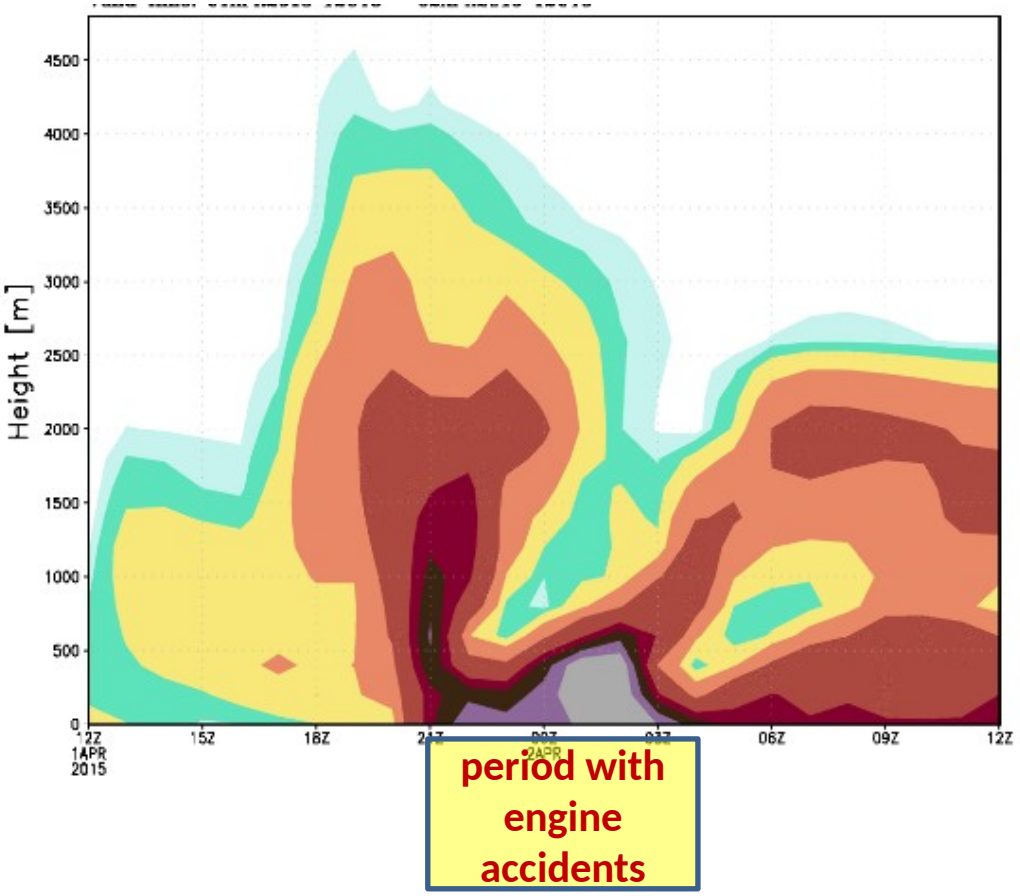
Vertically integrated dust - dust load

(animation)



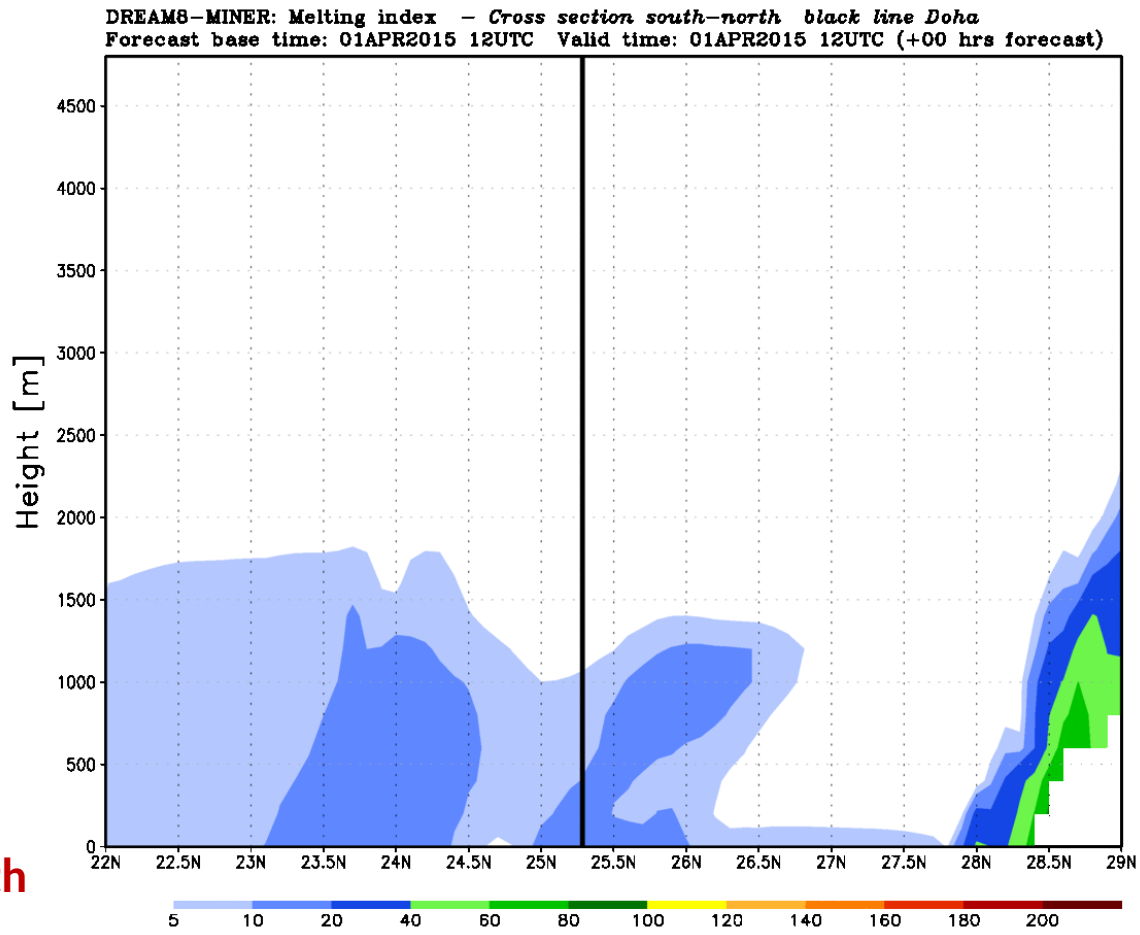
Melting Index (MI) predicted for the April Golf dust case

- **Time range:**
  - 1 Apr 12UTC – 2 Apr 12UTC 2015
- **Location:**
  - Doha, Qatar



Predicted Melting Index (MI) for Doha (Qatar)

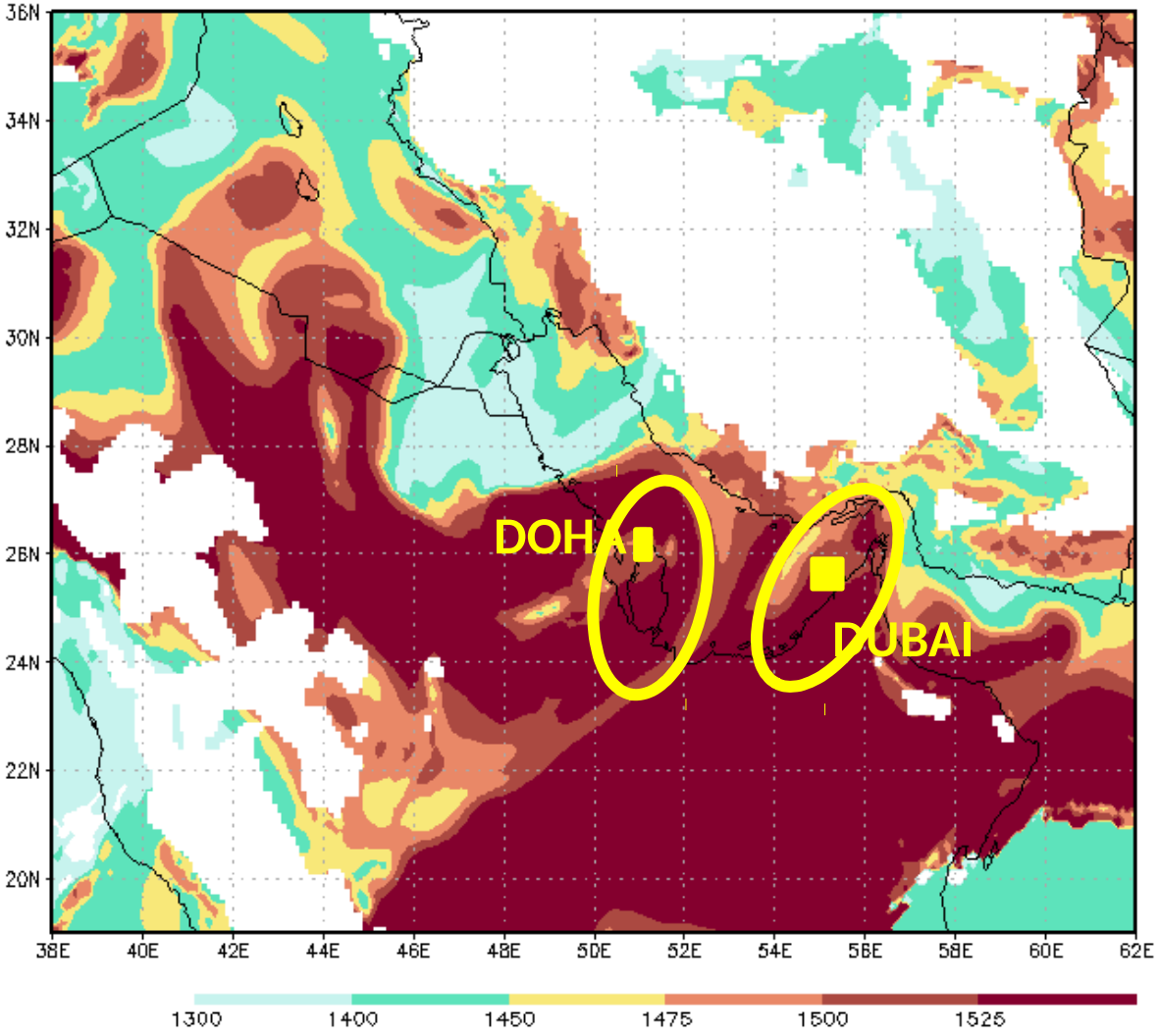
MI valid for the period 1 April 12:00 to 2 April 12:00 2015



South **North**

Predicted Melting T of the dust mixture

T(melting) at 800m asl valid for 1 April 2015 at 22UTC



Future plans:
Transferring the dust melting application to the newly developed global DREAM

4-day dust AOD valid for 9 April at 12UTC