Regional Radiative and Climate Effects of Dust in MENA

Prof. Georgiy Stenchikov
King Abdullah University of Science and Technology
Kingdom of Saudi Arabia

Yoram Kaufman Memorial Symposium

1. Middle East Climate Mechanisms
2. Simulate Regional Climate Using Global Model
3. Simulate Fine-Scale Processes Using WRF-Chem
4. Dust radiative forcing: surface cooling and atmospheric warming
5. Observations at Kaust: Aeronet, MPLNET, MICROTOPS, dust deposition, dust composition
6. Dust impact on the Red Sea: Radiative cooling and nutrient deposition

Cairo
Gulf of Aqaba
Kuwait
مدينة الكويت
Al Kuwayt
Persian Gulf
Arabian Gulf
Qushm Island
Ad Dammam
Manama
Bahrain
مدينة بريدة
Buraydah
الدوحة
Doha
Gulf of Oman
ابو ظبي
Abu Dhabi
الرياض
Ar Riyad
المدينة المنورة
Al Madinah
United Arab Emirates
Saudi Arabia
Ash Sharqiyah
Jeddah Port
Jeddah Port
Jiddah Saudi Arabia
Makkah
Oman
Red Sea
Eritrea
Asmera
Yemen
Sana'a
© 2010 Europa Technologies
© 2010 LeadDog Consulting
US Dept of State Geographer
© 2010 Google
Gulf of Aden
Djibouti
©2010 Google
20°50'42.24" N 45°35'43.68" E elev 737 m
Eye alt 2188.29 km

Brown Booby at the Red Sea

Dust Storm Front Affecting the Saudi capital of Riyadh, Saudi Arabia, Tuesday, March 10, 2009

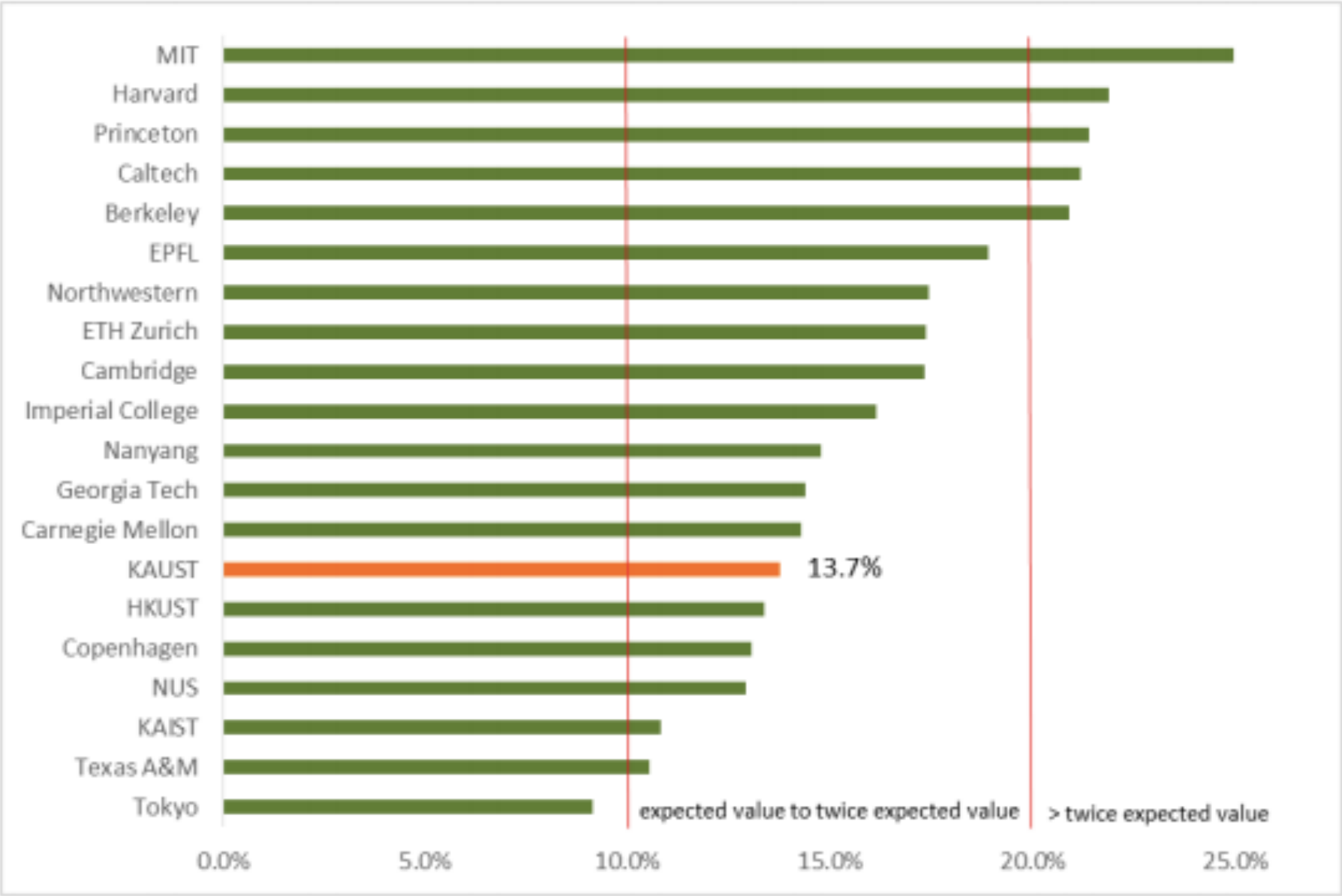
King Abdullah University of Science and Technology – founded in 2009

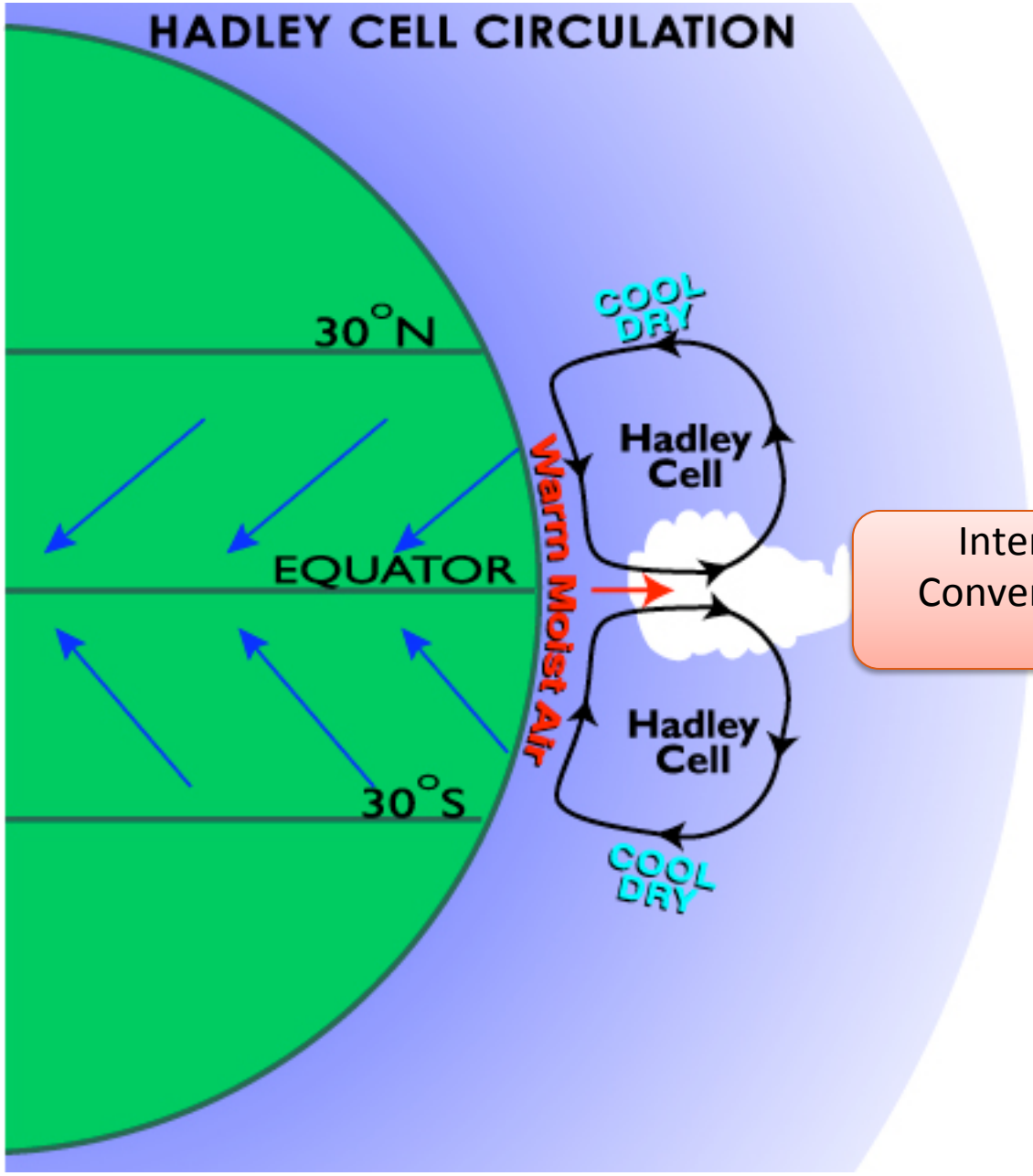
QS World University Rankings® 2015/16

http://www.topuniversities.com/university-rankings/world-university-rankings/2015#sorting=2453338+region=+country=+faculty=+stars=false+search=

RANK		UNIVERSITY	LOCATION	QS STARS ?
Citations per Faculty		Search for universities...		Show only
1	100.0	King Abdullah University of Science & Technology		
2	100.0	Gwangju Institute of Science and Technology (GIST)		
3	100.0	California Institute of Technology (Caltech)		
4	100.0	Princeton University		
5	100.0	University of California, Santa Barbara (UCSB)		
6	100.0	Pohang University of Science And Technology (POSTECH)		
7	100.0	Ecole normale supérieure, Paris		

On the 2016 CWTS Leiden Rankings Kaust is #84 on the indicator “Proportion of University’s Publications Belonging to the Top 10% of the World’s Most Frequently Cited”.





Inter-trorpical Convergence Zone (ITCZ)

Математические модели климате

Continuity equation

$$\frac{d\rho}{dt} = -\rho\, div\vec{V};$$

Momentum equation

$$\frac{d\vec{V}}{dt} = -2\omega\, \vec{k} \times \vec{V} - \frac{1}{\rho} gradP + \vec{g} + \vec{F};$$

Energy equation

$$Cp\frac{dT}{dt} = Q + \frac{1}{\rho}\frac{dP}{dt};$$

Radiative Transport

$$\frac{\partial I\nu}{\partial s} = -\chi_\nu \rho\,[I\nu - J\nu];$$

Spatial domain

$$0<\lambda<2\pi;\quad -\pi/2<\varphi<\pi/2;\quad z_s<z<z_{top}$$

Water vapor transport

$$\frac{dq}{dt} = S(q);$$

Boundary conditions

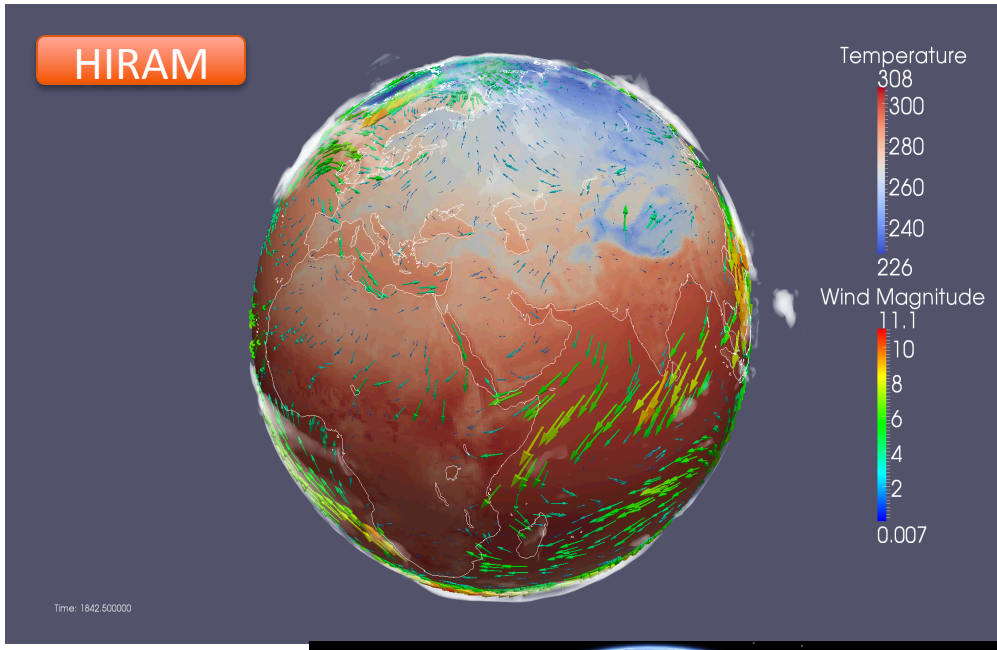
$$z=z_s:\quad v_n=0;\quad F^{\uparrow}=Fs$$

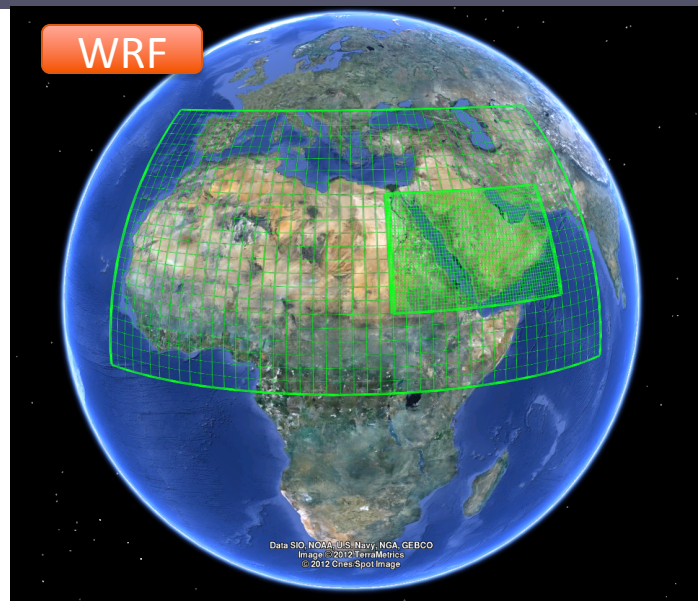
$$z=z_{top}:$$

Equation of state

$$P=\rho RT;$$

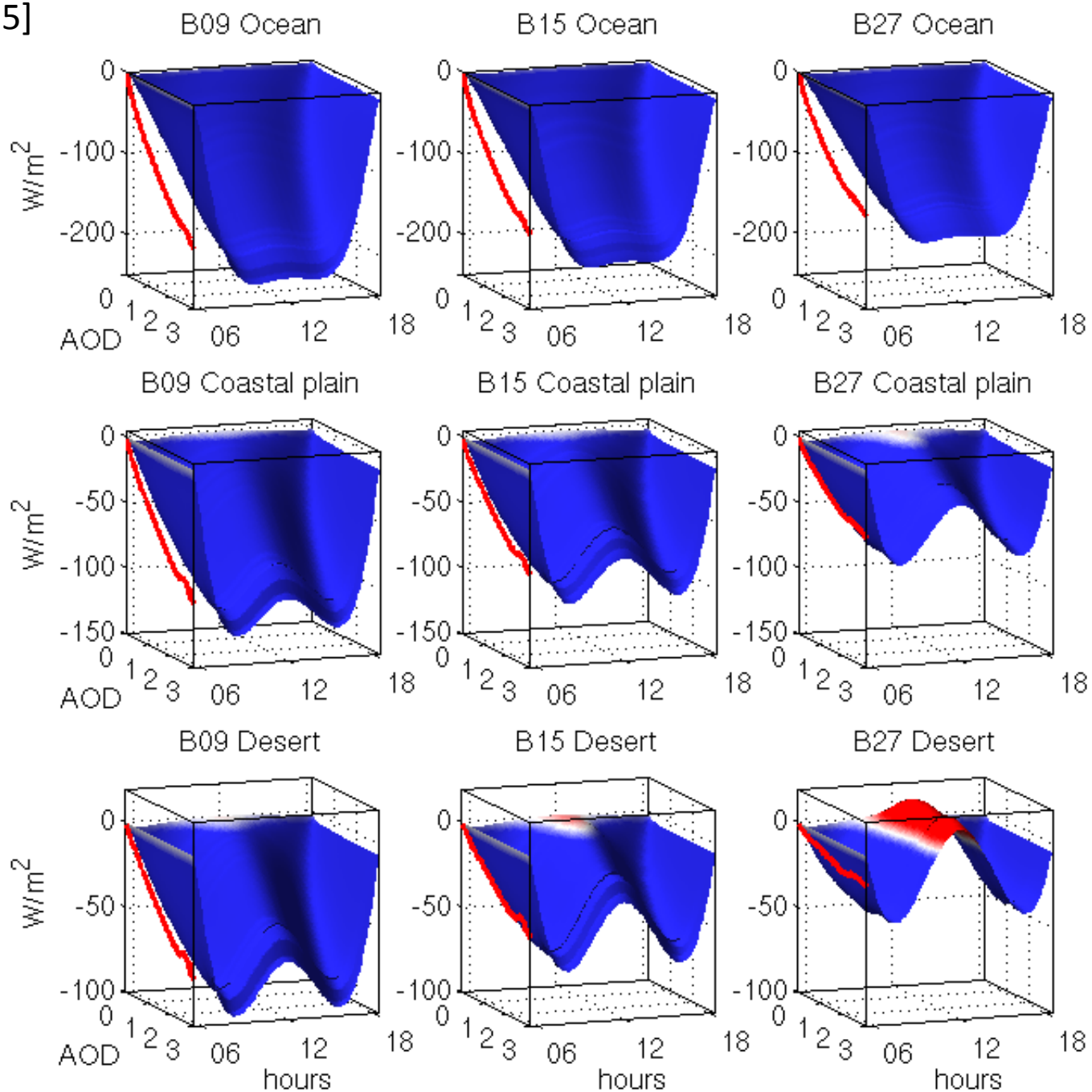
$$w=\frac{\partial z_{top}}{\partial t} + u\frac{\partial z_{top}}{(a\cos\varphi)\partial\lambda} + v\frac{\partial z_{top}}{a\partial\varphi};\quad F^{\downarrow}=S_0\cos\varsigma$$



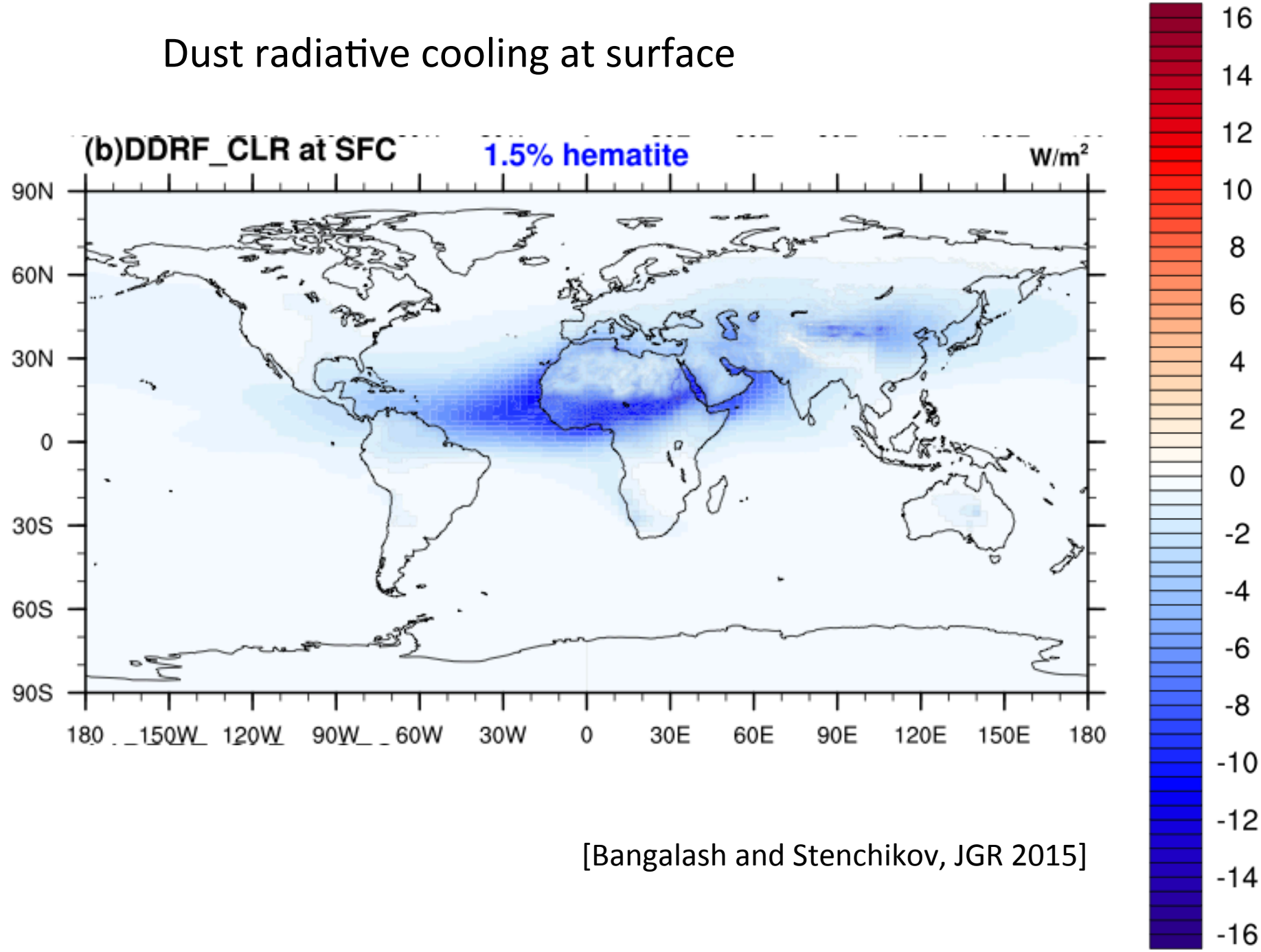


[Osipov et al., ACP 2015]

DIURNAL CYCLE of AEROSOL TOA RADIATVE FORCING over DIFFERENT SURFACES as a FUNCTION of AOD

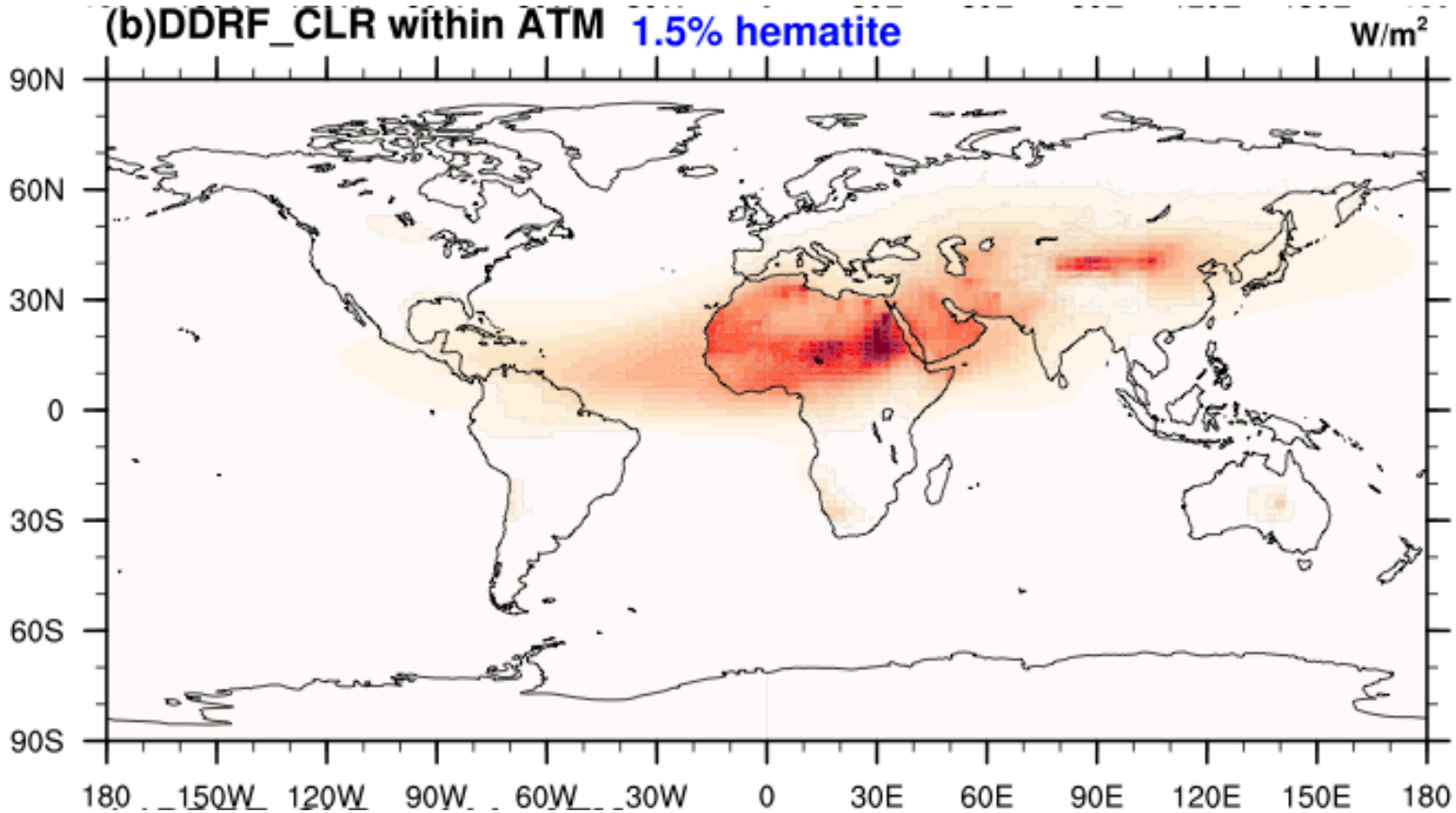


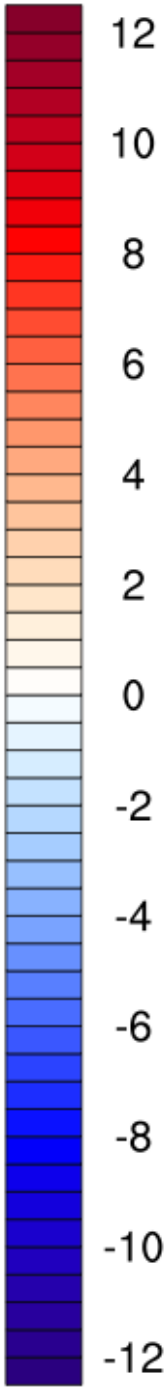
Dust radiative cooling at surface



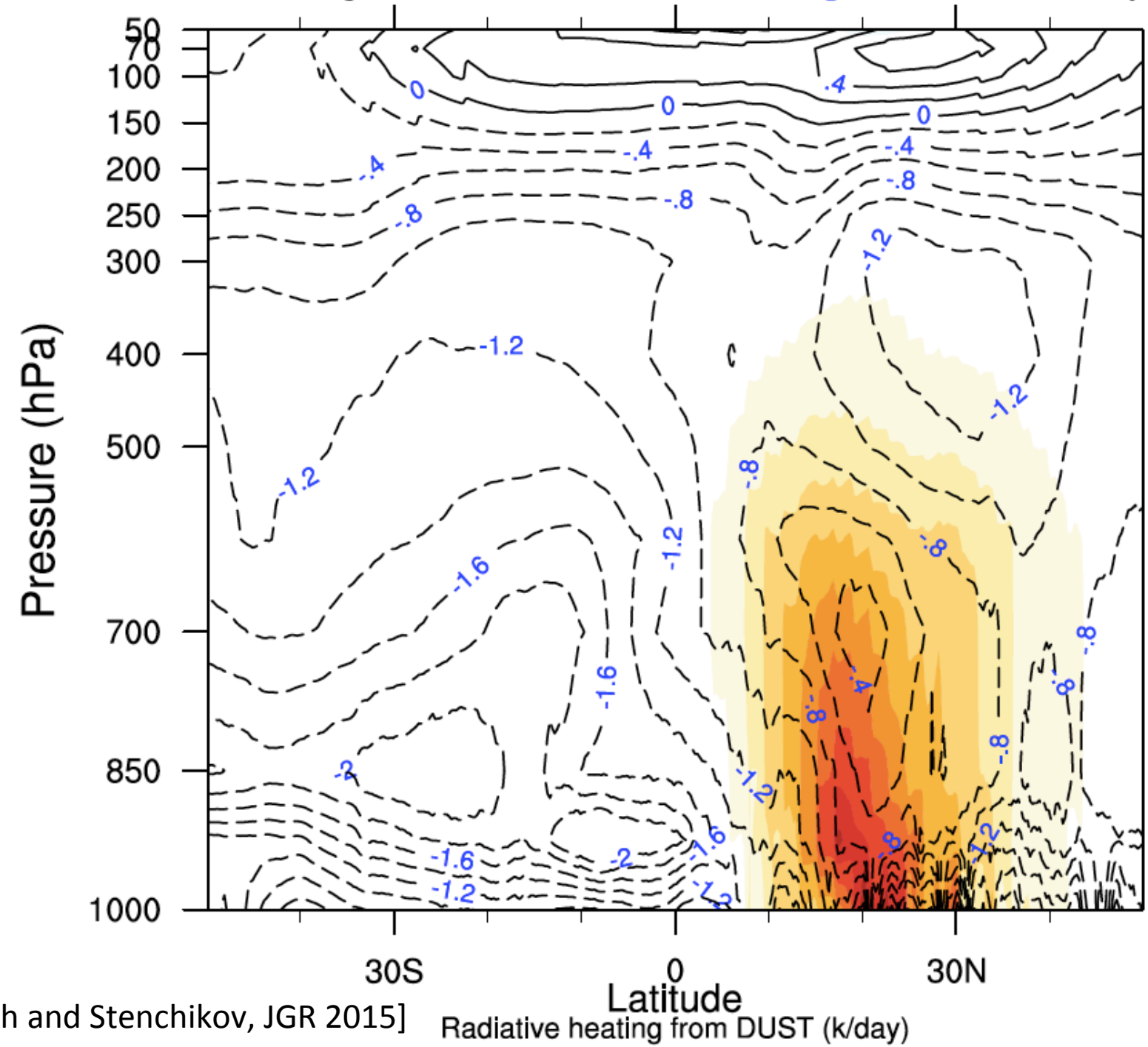
[Bangalash and Stenchikov, JGR 2015]

Dust atmospheric heating

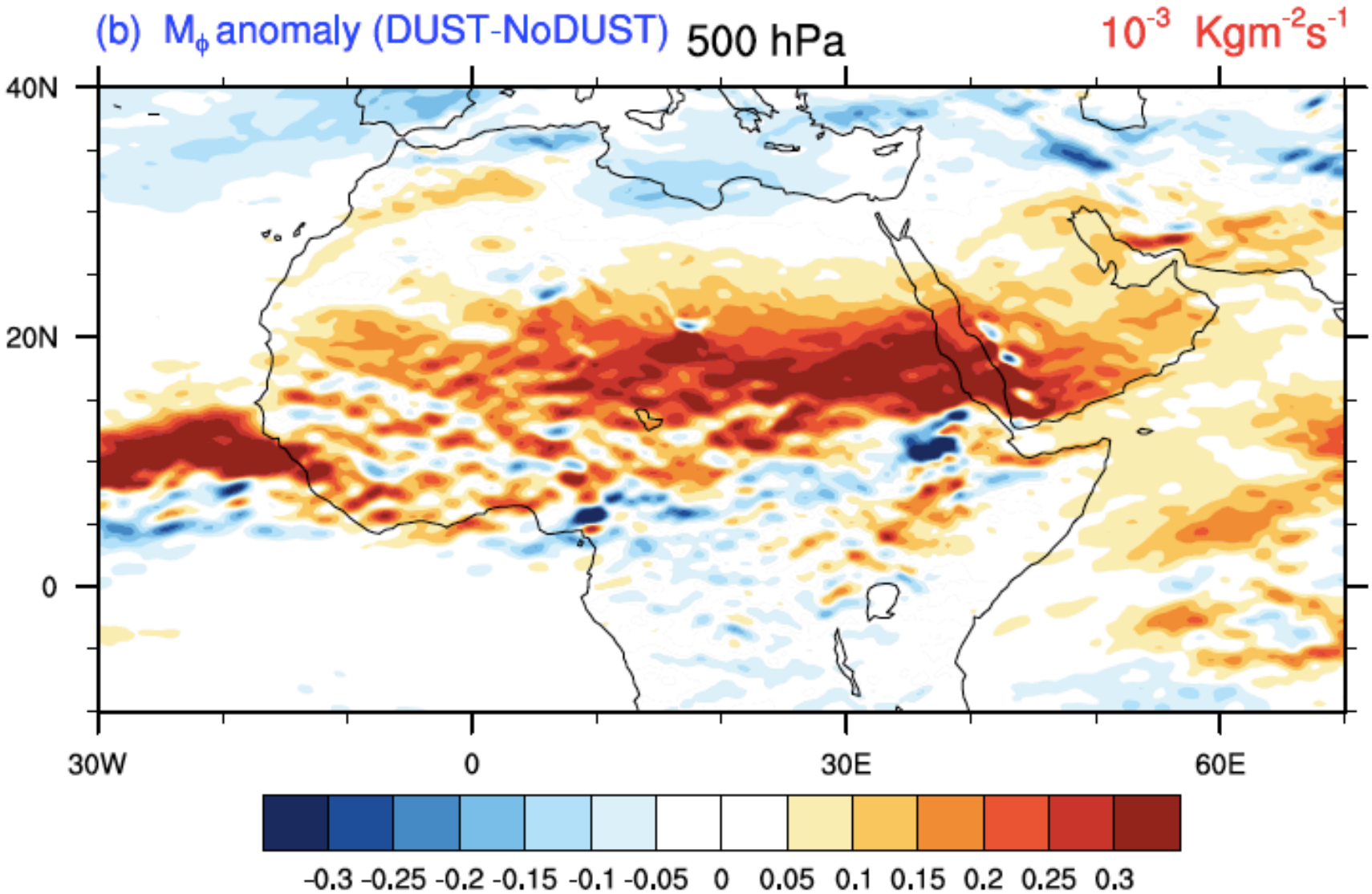




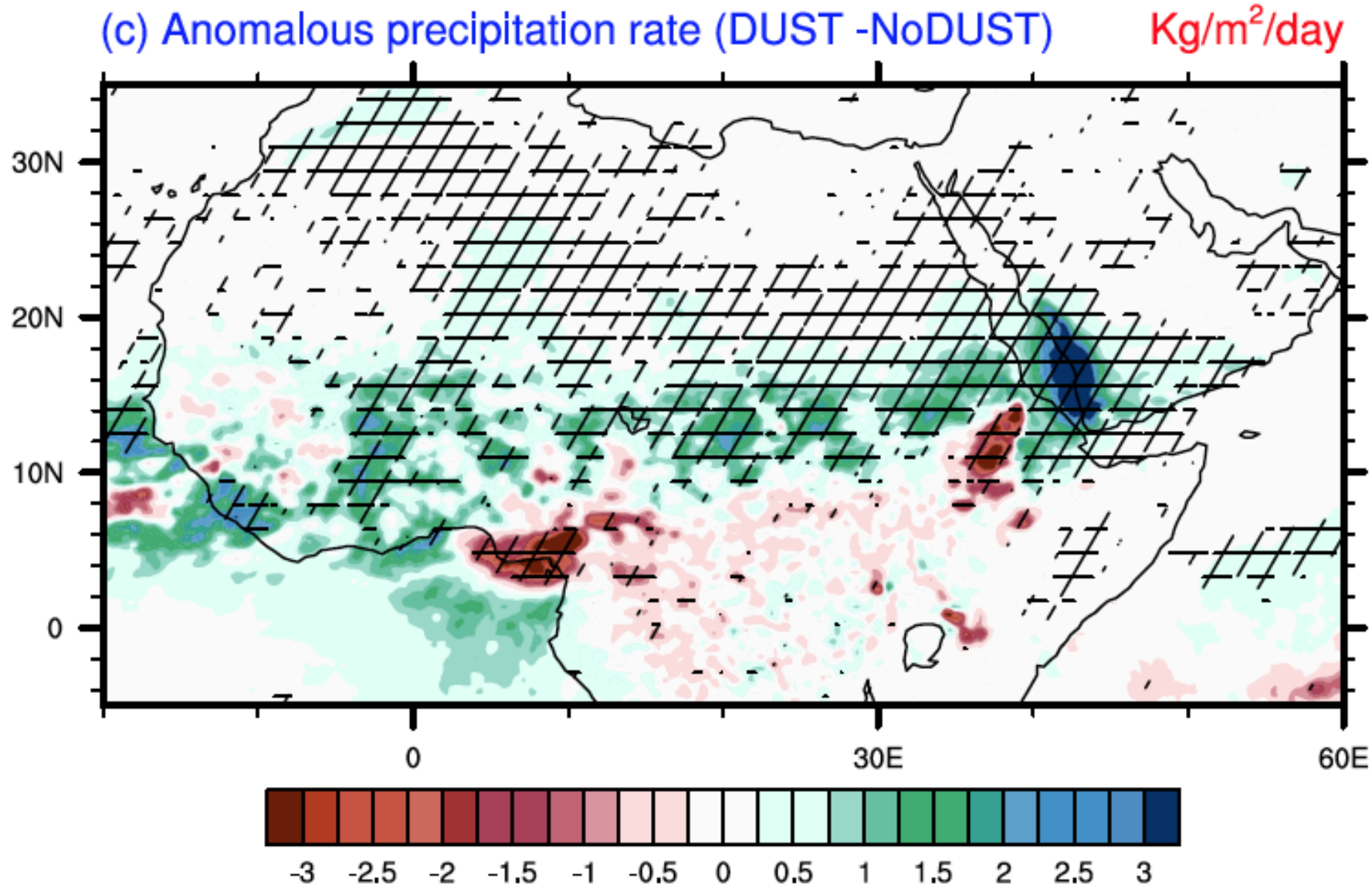
[Bangalash and Stenchikov, JGR 2015]



[Bangalash and Stenchikov, JGR 2015]

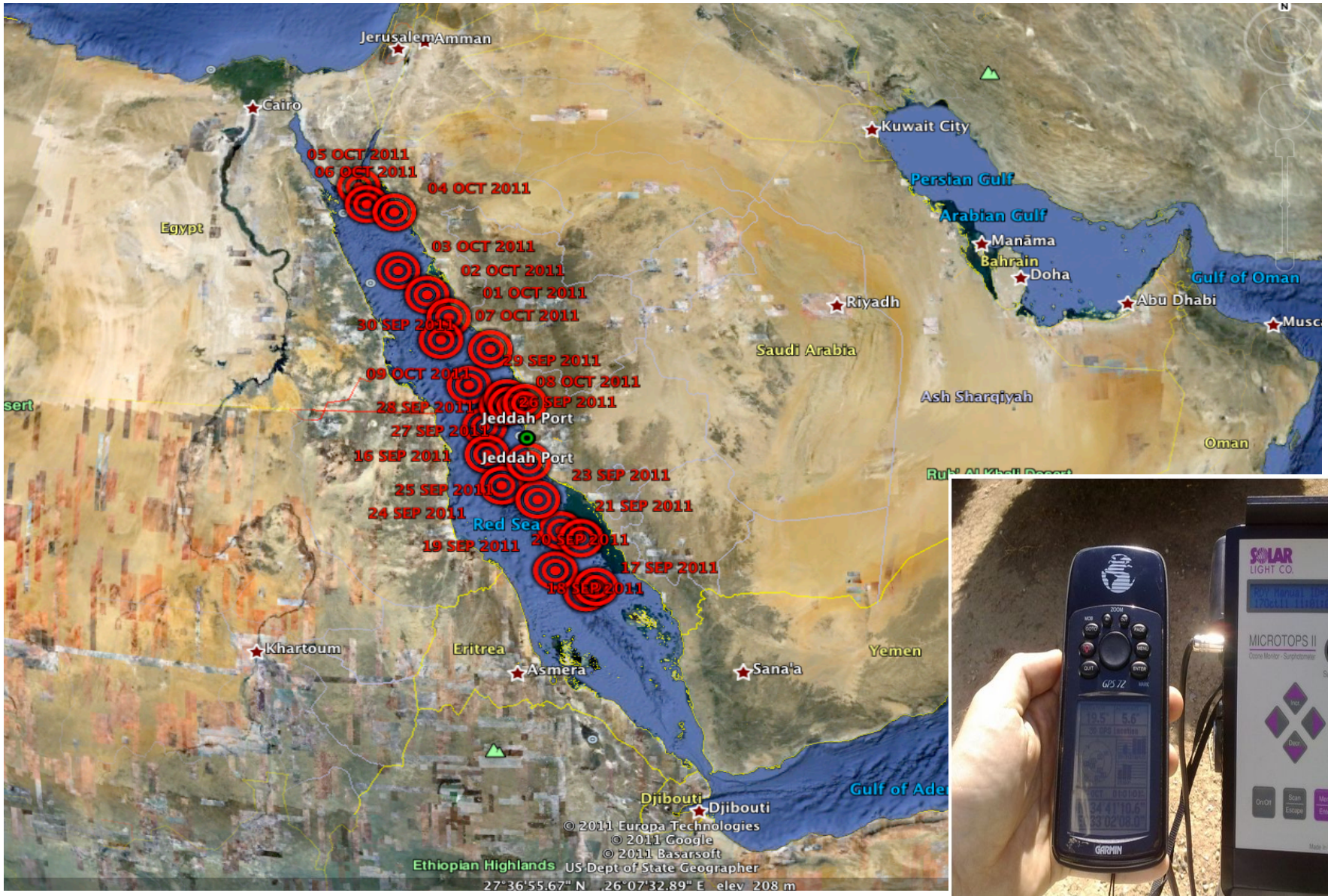


[Bangalash and Stenchikov, JGR 2015]

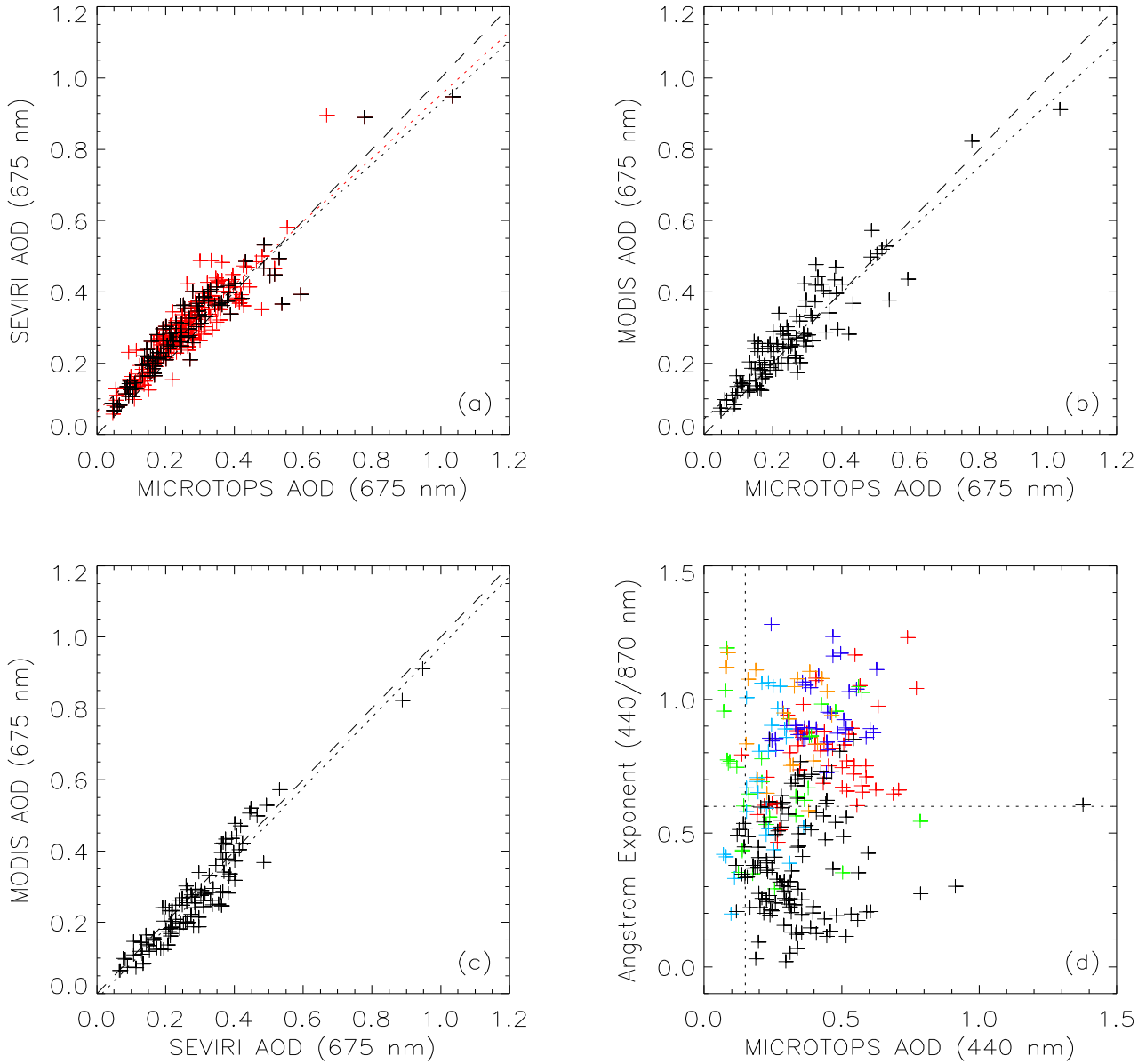


[Bangalash and Stenchikov, JGR 2015]

Red Sea Cruise Aerosol Observations by Multispectral Sunphotometer provided to NASA Maritime Network (A. Smirnov)

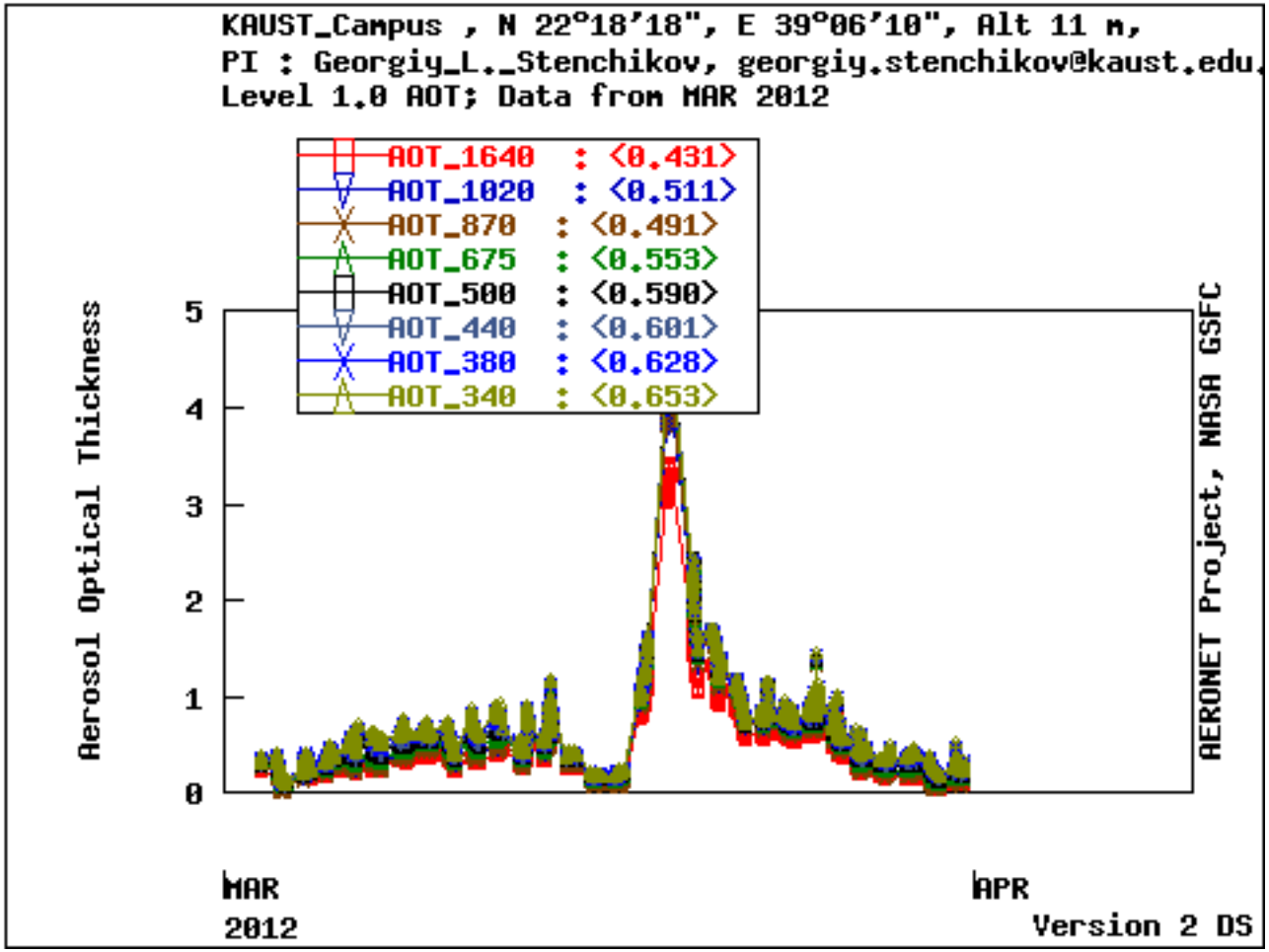


MODIS-SEVIRI-MICROTPS COMPARISON: Brindley et al., JGR 2015

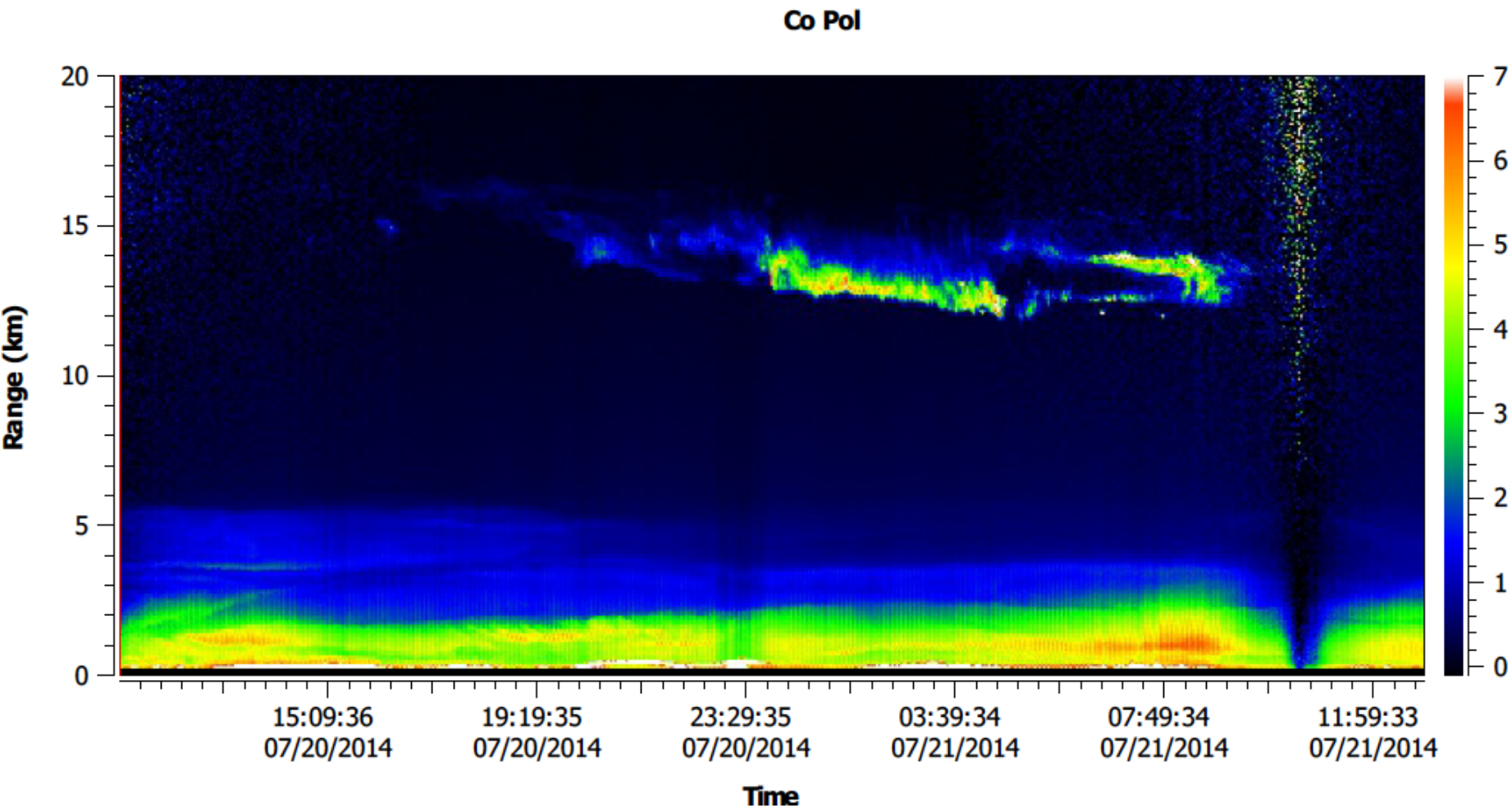


DUST MONITORING at KAUST: Cimel Robotic Sunphotometer, NASA AERONET

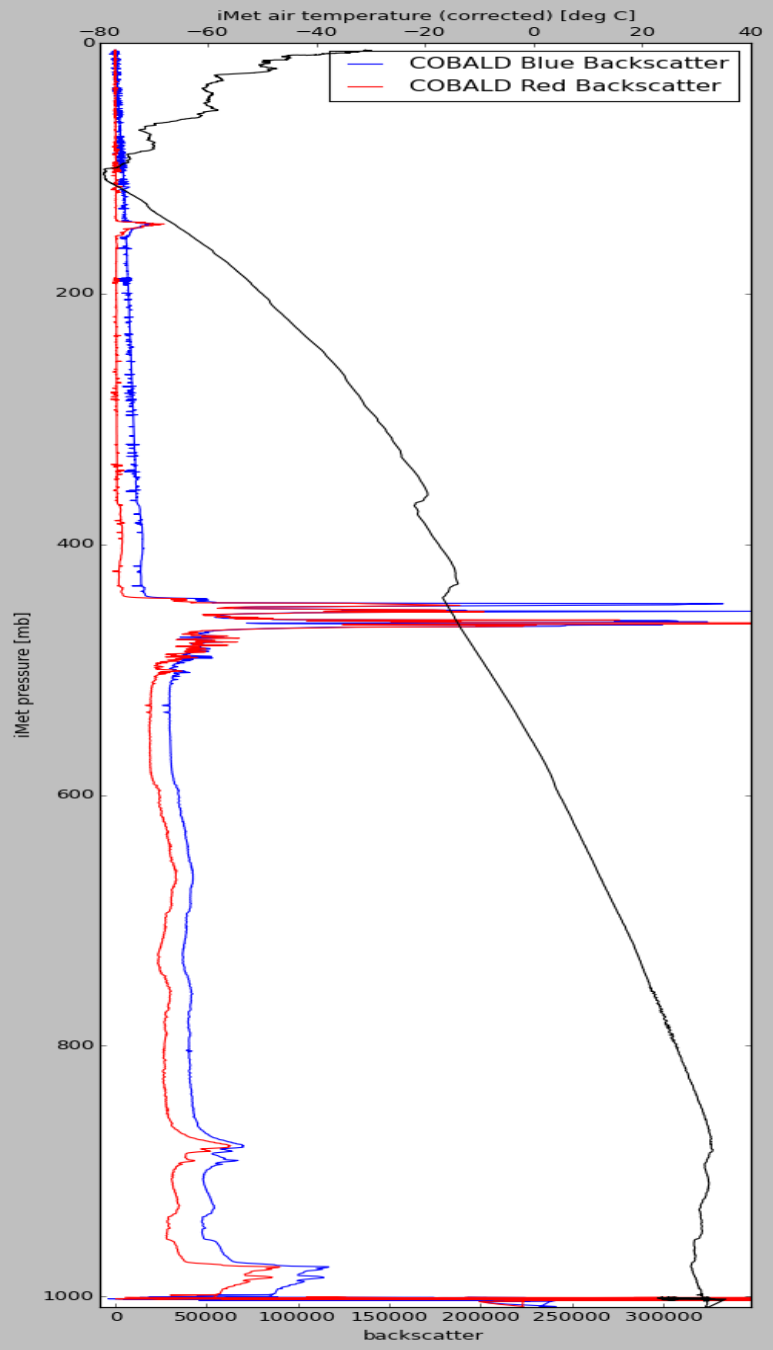
AEROSOL OPTCAL DEPTH MEASURED AT KAUST CAMPUS SITE IN MARCH 2012

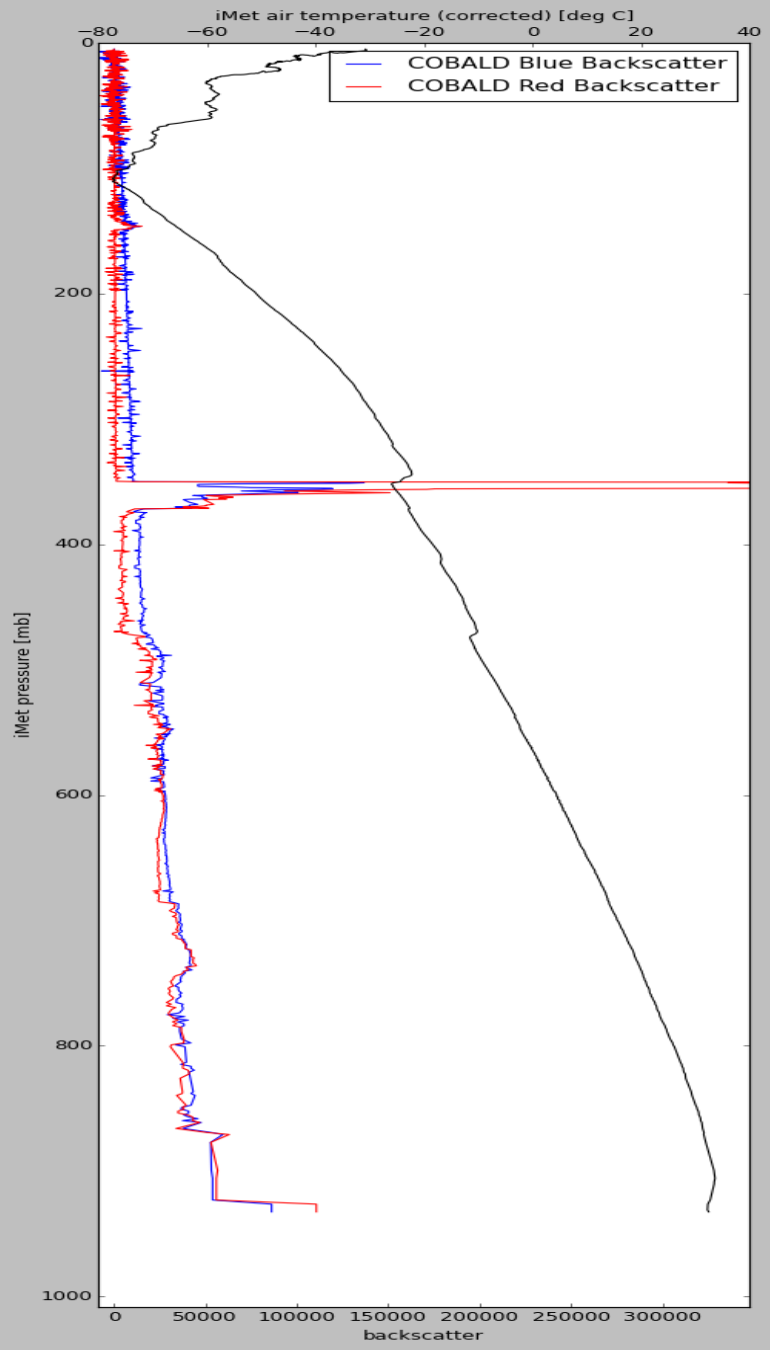


Micropulse lidar collocated with the Aeronet site


Co Pol
Range (km)
20
15
10
5
0
15:09:36
07/20/2014
19:19:35
07/20/2014
23:29:35
07/20/2014
03:39:34
07/21/2014
07:49:34
07/21/2014
11:59:33
07/21/2014
Time
7
6
5
4
3
2
1
0

NASA Langley Balloon campaign (BATAL) in August 2015


iMet air temperature (corrected) [deg C]
−80
−60
−40
−20
0
20
40
COBALD Blue Backscatter
COBALD Red Backscatter
iMet pressure [mb]
0
200
400
600
800
1000
0
50000
100000
150000
200000
250000
300000
backscatter

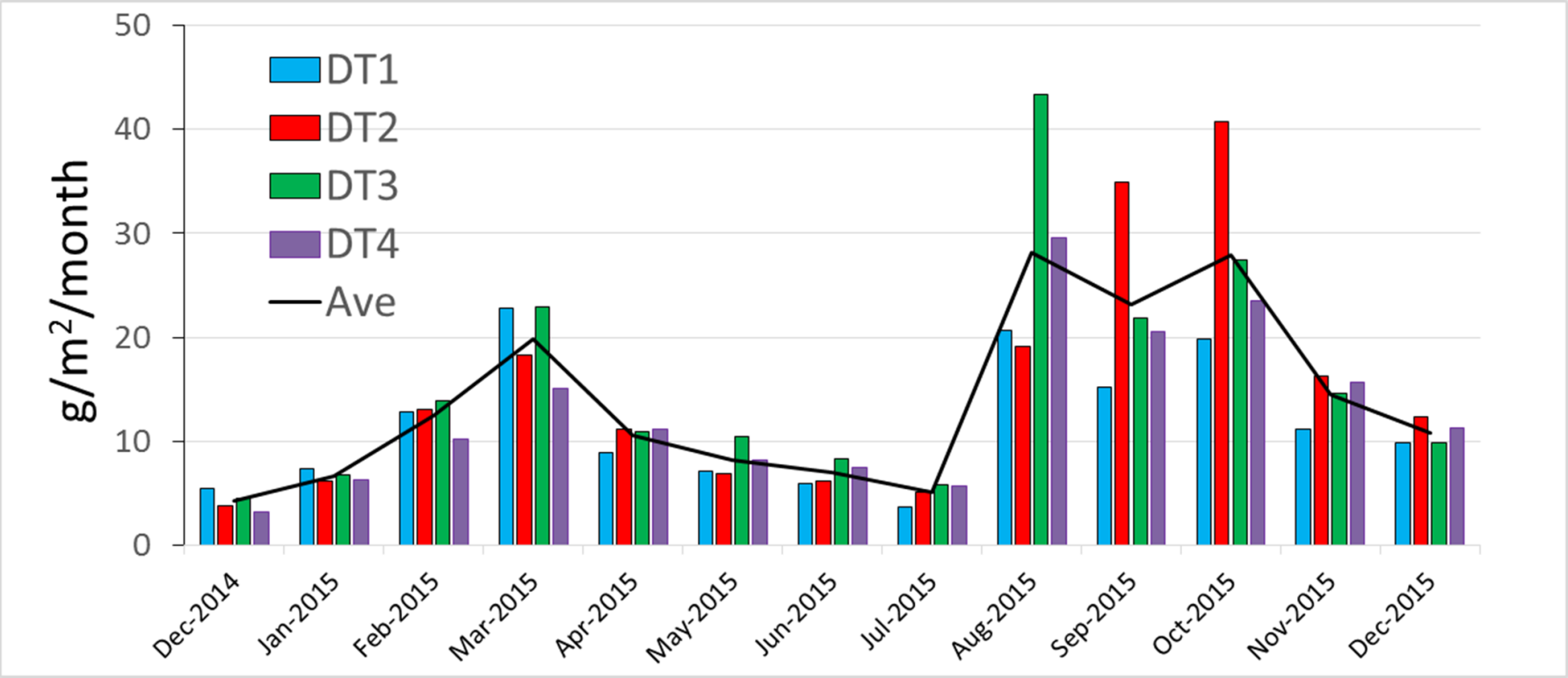

iMet air temperature (corrected) [deg C]
−80
−60
−40
−20
0
20
40
COBALD Blue Backscatter
COBALD Red Backscatter
iMet pressure [mb]
0
200
400
600
800
1000
0
50000
100000
150000
200000
250000
300000
backscatter

Dust deposition monitoring for closing dust mass balance

Prakash et al., ACP 2016

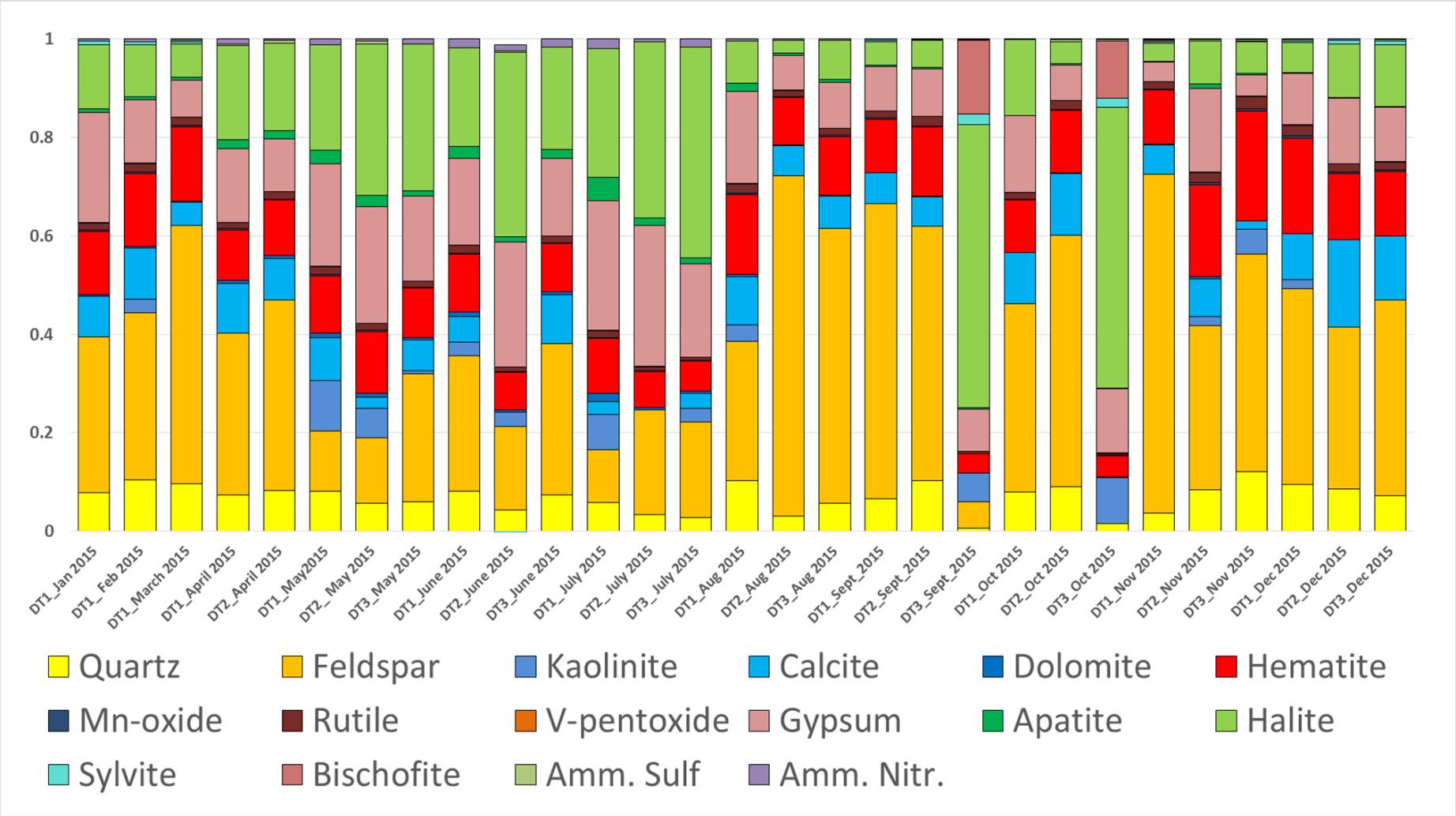
KAUST

KAUST – Deposition Rates for Frisbee Samplers at Four Campus Sites (DT1-residential, DT2-CMOR, DT3-NEO, DT4-NEO4)



KAUST

Mineralogy of monthly deposition samples



Aerosol optical depth calibration

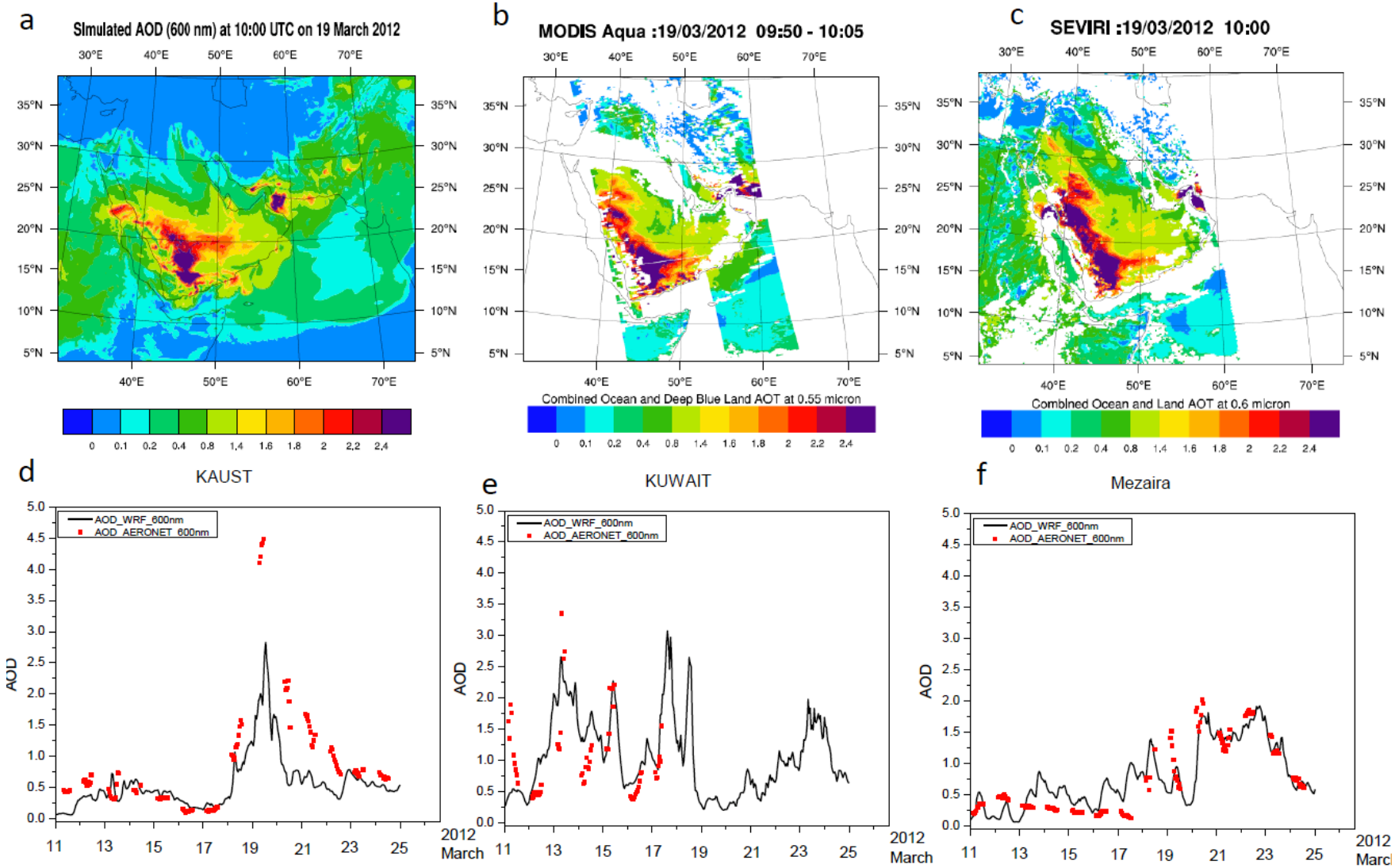
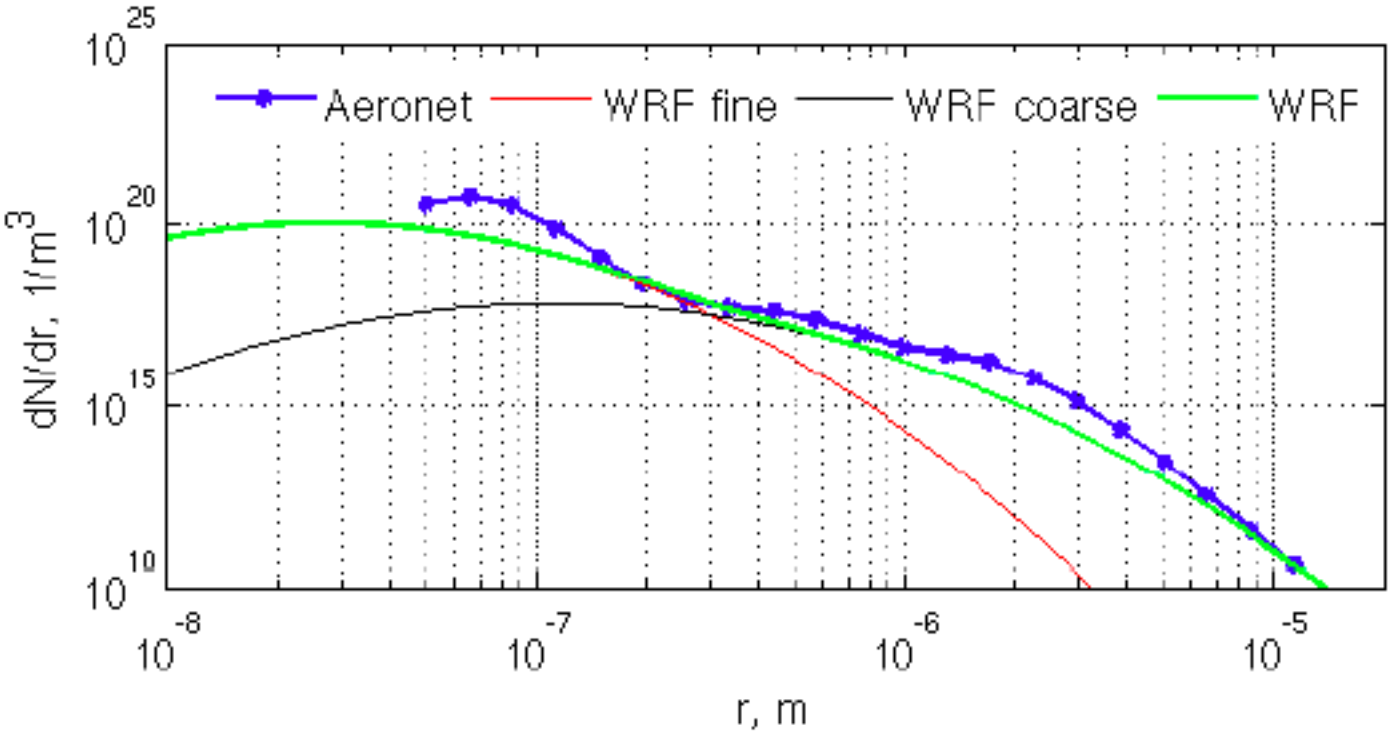


Figure 10. (a) Simulated spatial distribution of AOD (600 nm) at 1000 UTC 19 March (b) AOD obtained from MODIS (standard ocean and Deep blue products) at 0950-1005 UTC March 19 (c) AOD obtained from SIVIRI(Product description) at 1000 UTC March 19 (d) Time series of simulated AOD (600 nm) and AERONET Sun photometer AOD(red dots) for KAUST Campus (22.30° N 39.10° E) (e) Same as 9d, but for Kuwait University (29.32° N, 47.97° E) and (g) Same as 9d, but for Mezaira (23.14° N, 53.77° E).

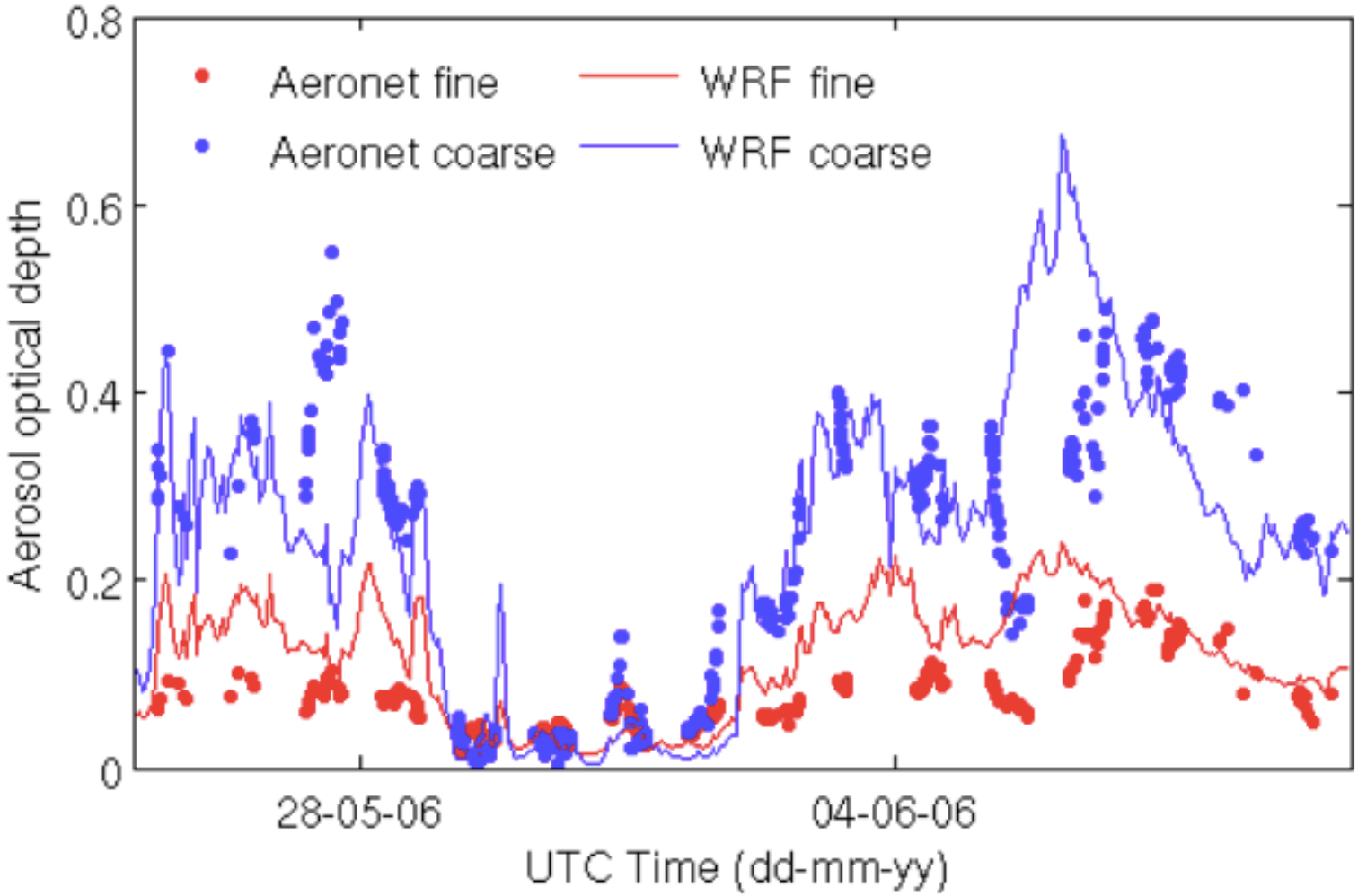
[Prakash et al., ACP 2015]

Aerosol size distribution



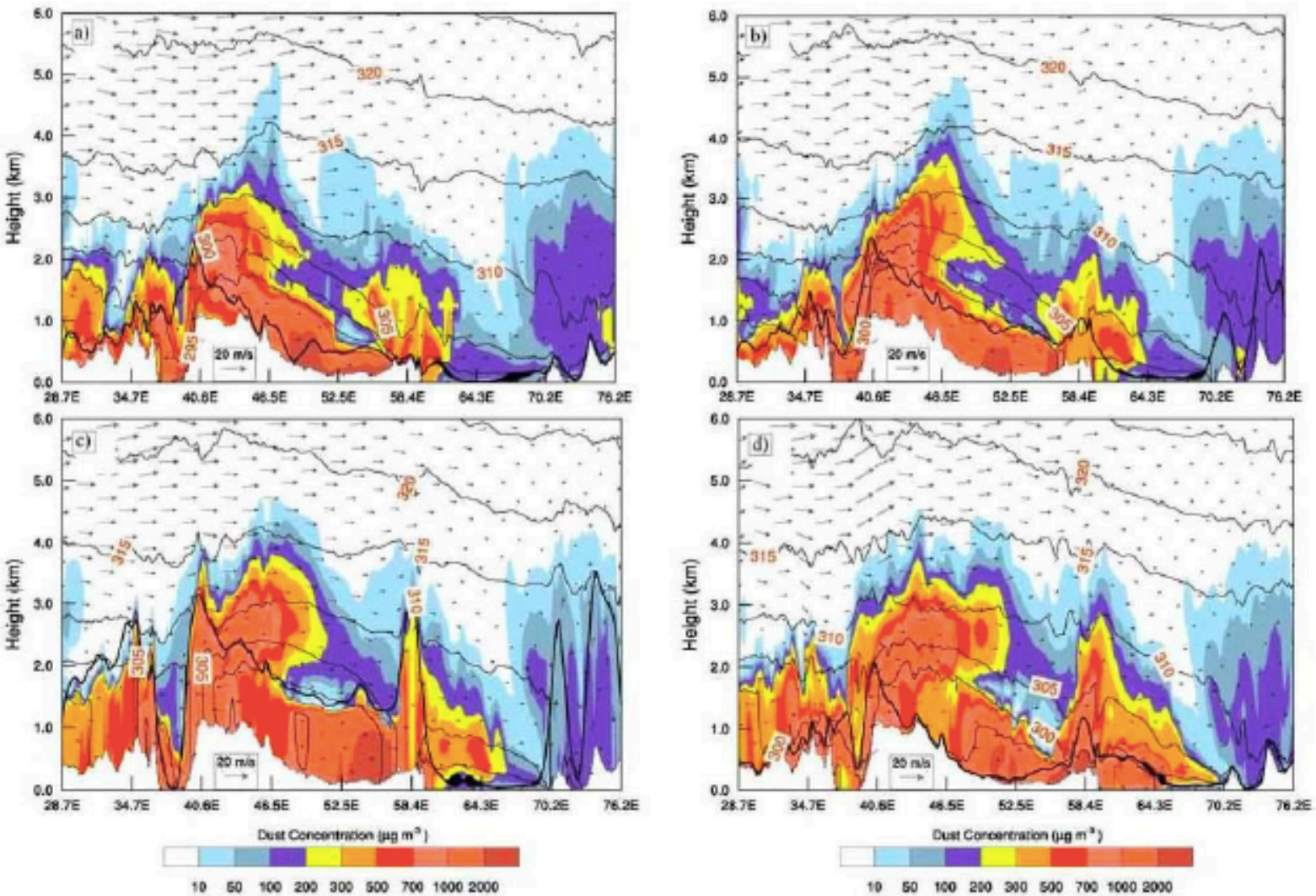
[Khan et al., Tellus-B, 2015]

Fine and Coarse aerosol modes



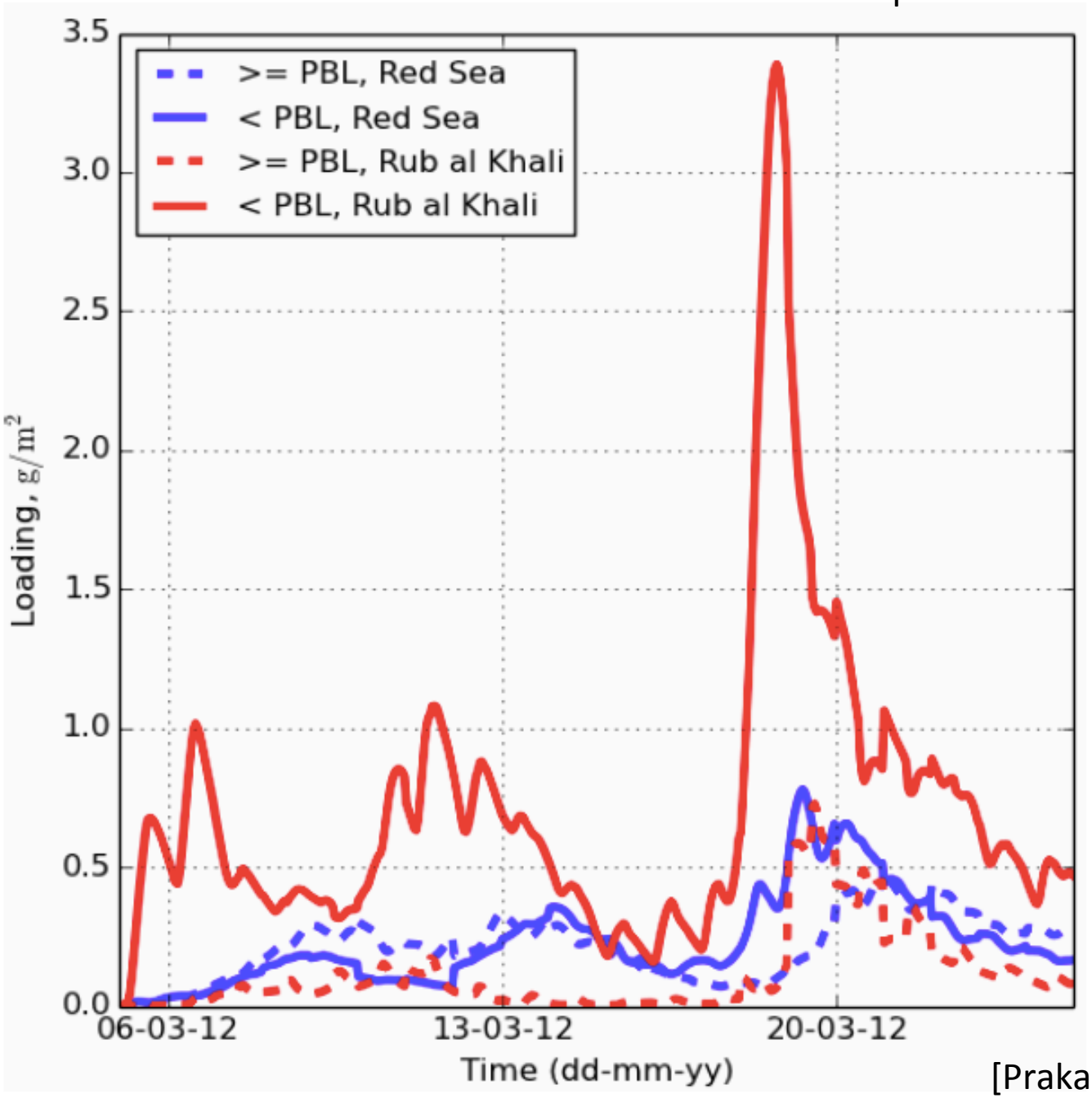
[Khan et al., Tellus-B, 2015]

Mechanisms of Aerosol Mixing into the Free Troposphere



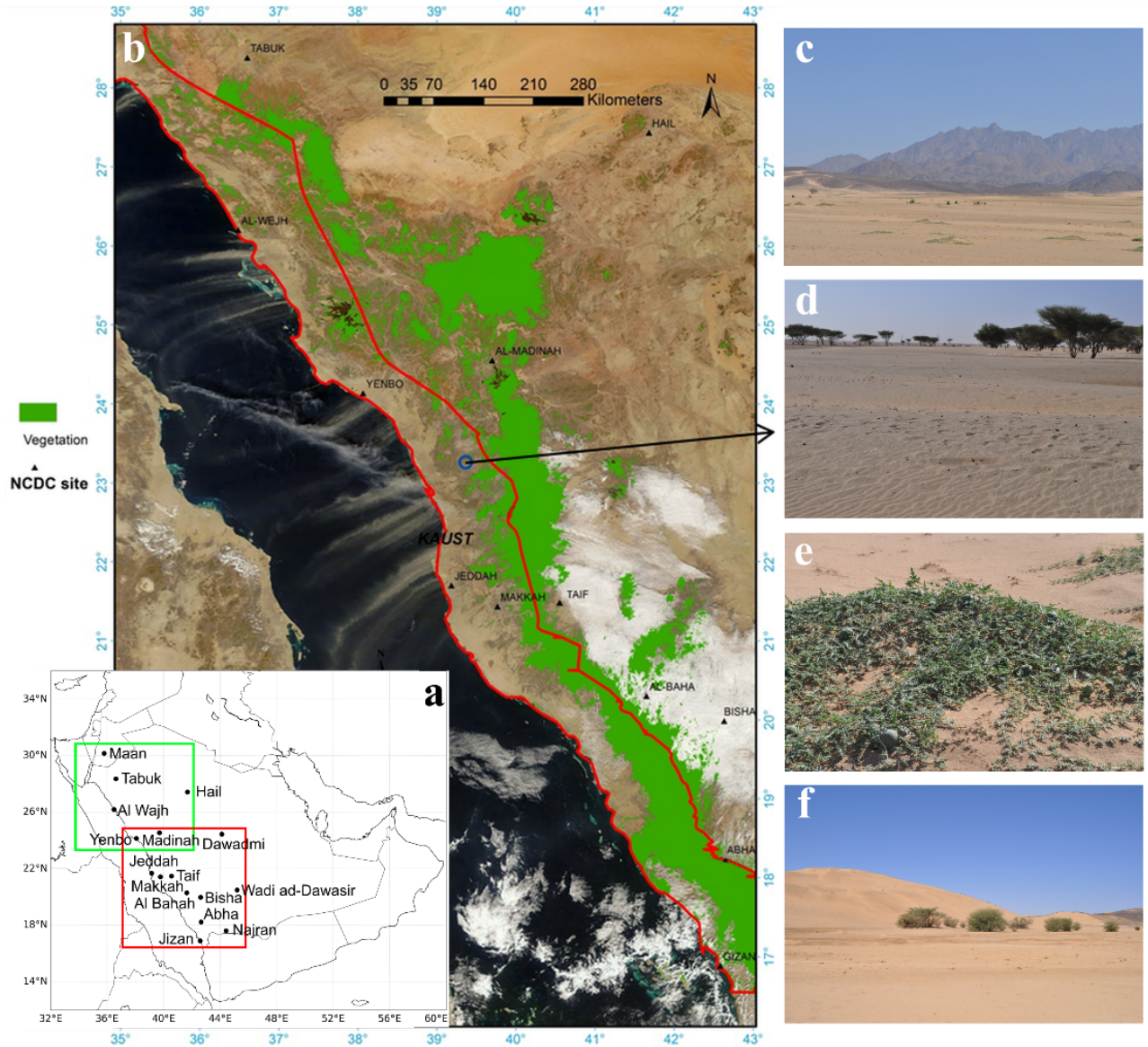
[Prakash et al., ACP 2015]

Amount of dust above and below PBL top



[Prakash et al., ACP 2015]

Arabian coastal plane is an important dust source in winter

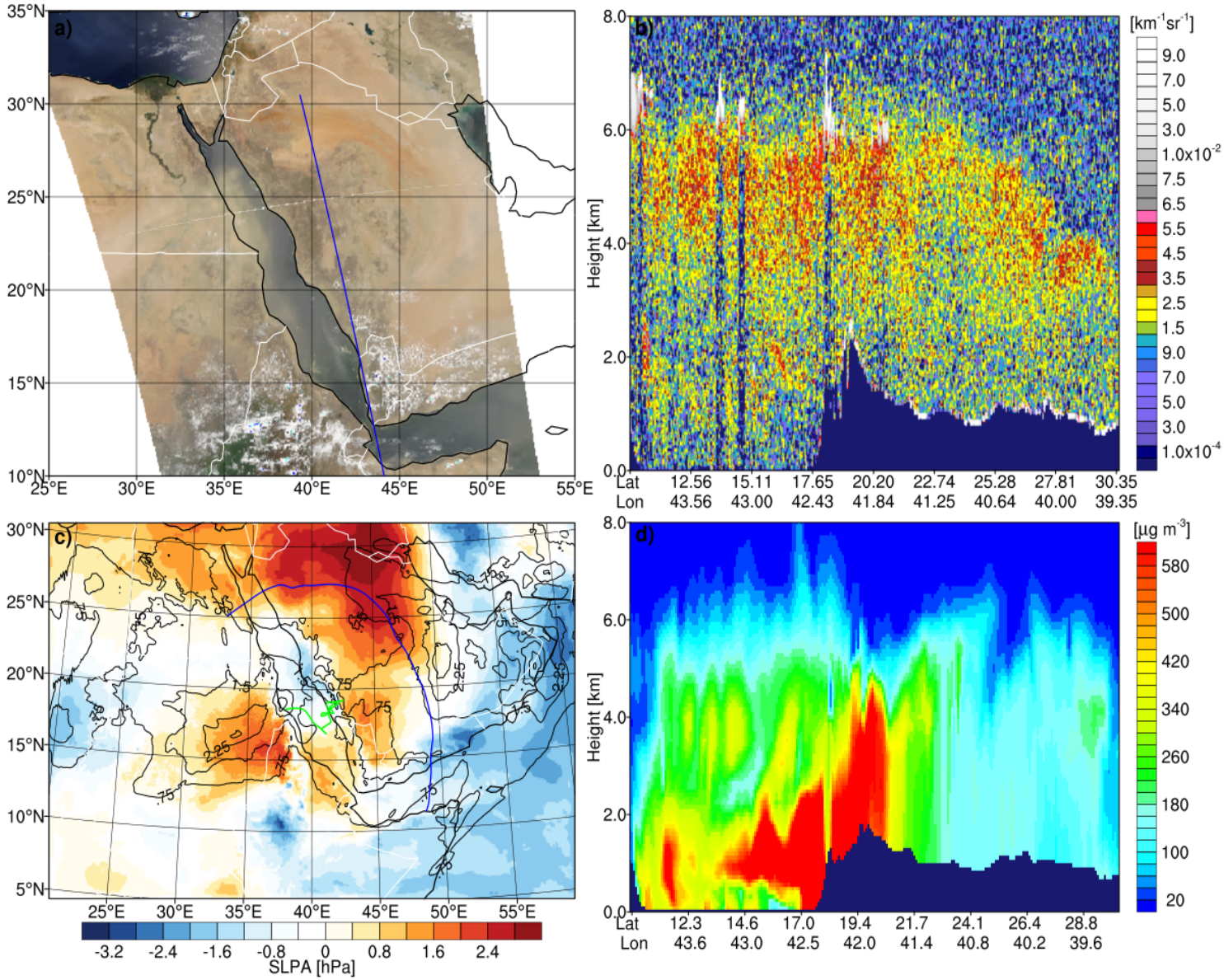


Anisimov et al., 2016]

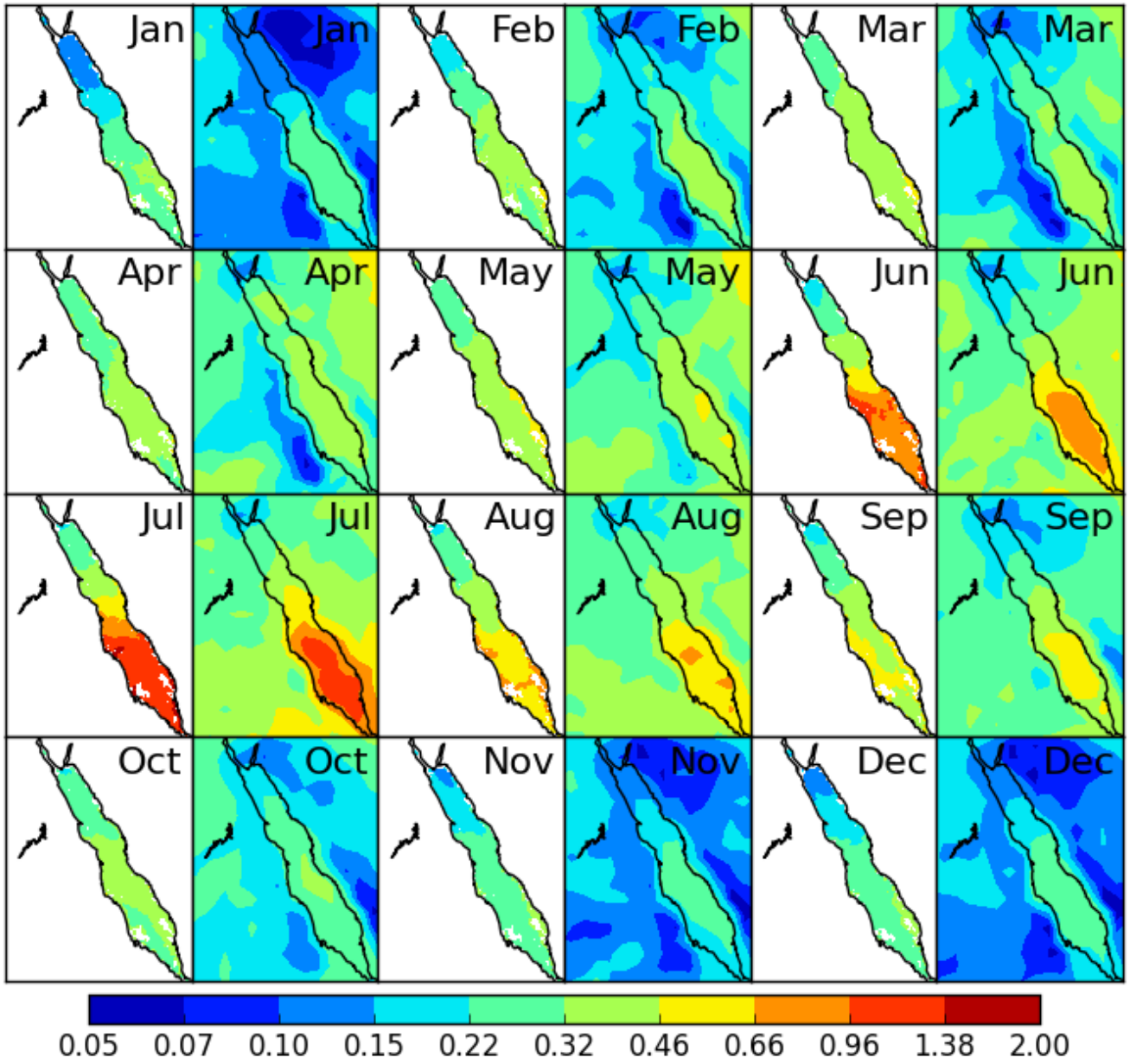
NASA Image of the Month

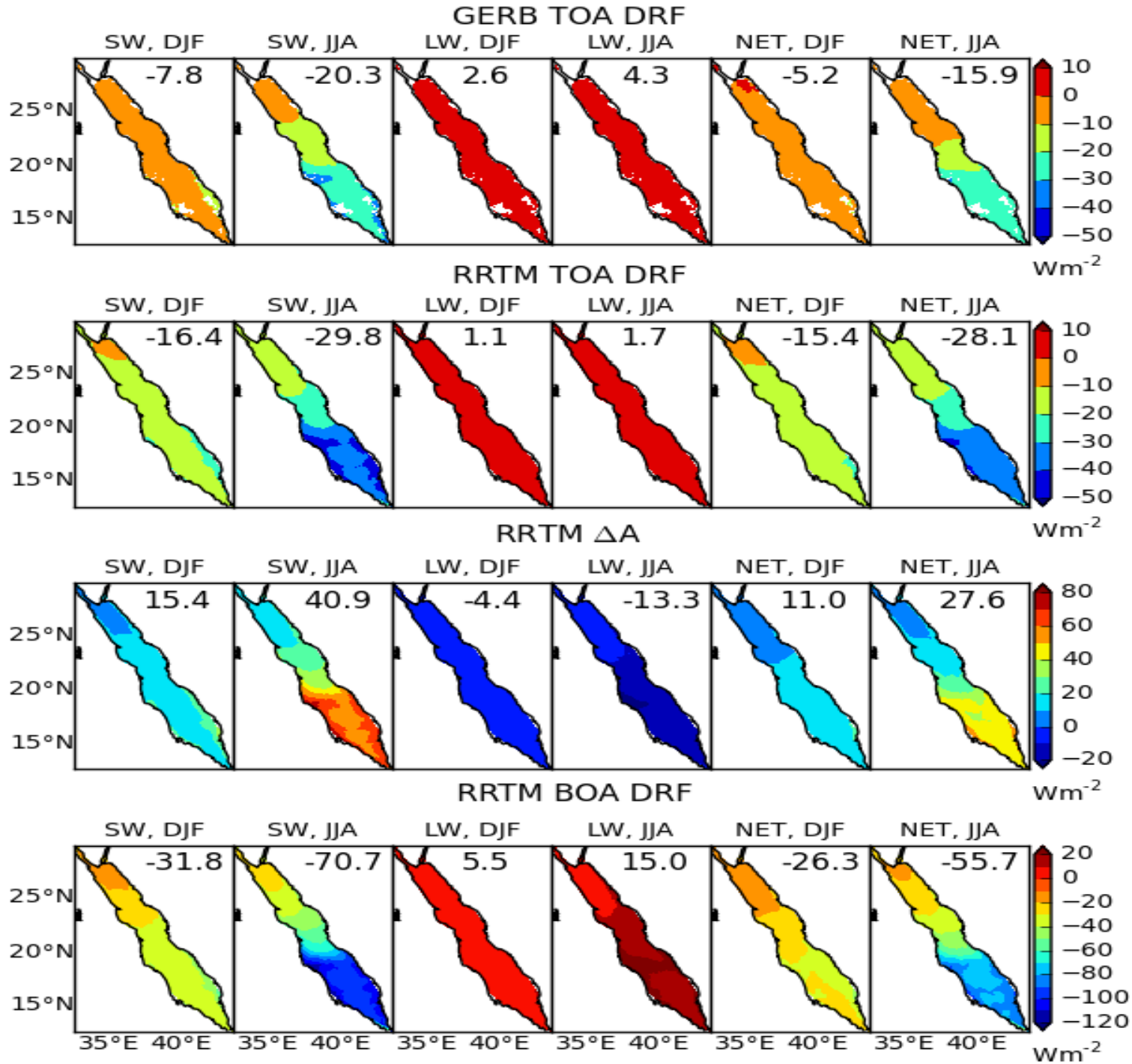
Observed transport through Tokar gap

Simulated transport through Tokar gap: Kalenderski and Stenchikov, JGR 2016



SEVIRI and MODIS AOD over the Red Sea




GERB TOA DRF
SW, DJF
SW, JJA
LW, DJF
LW, JJA
NET, DJF
NET, JJA
-7.8
-20.3
2.6
4.3
-5.2
-15.9
10
0
−10
−20
−30
−40
−50
Wm-2
RRTM TOA DRF
-16.4
-29.8
1.1
1.7
-15.4
-28.1
RRTM ΔA
15.4
40.9
-4.4
-13.3
11.0
27.6
80
60
40
20
0
−20
RRTM BOA DRF
-31.8
-70.7
5.5
15.0
-26.3
-55.7
20
0
−20
−40
−60
−80
−100
−120
25°N
20°N
15°N
35°E 40°E

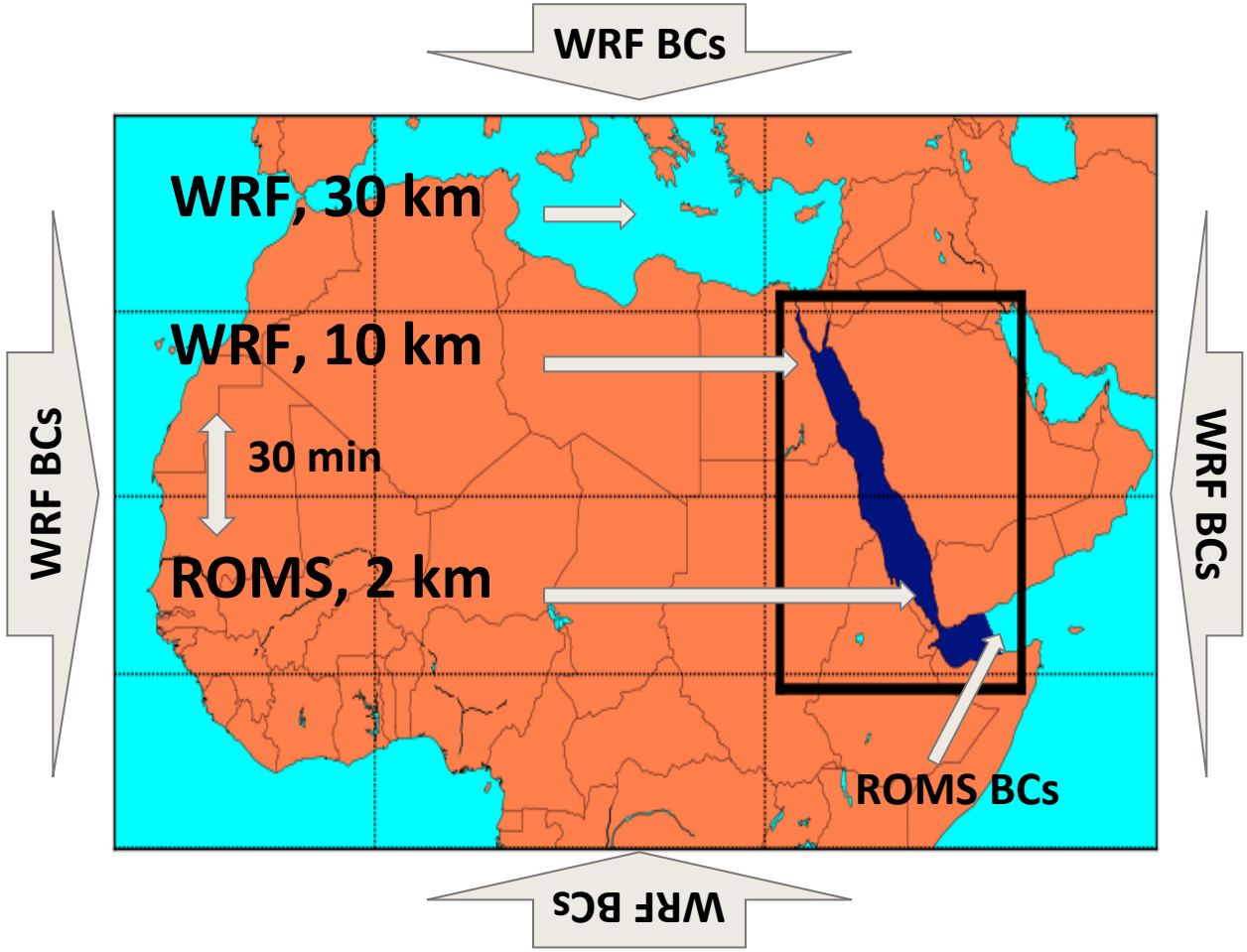
Dust climatology is prescribed. Spectral optical properties of dust aerosols are computed using Mie. RRTMG radiative transfer code is used.

Boundary conditions impose “observed” large scale circulation from ERA-Interim reanalysic

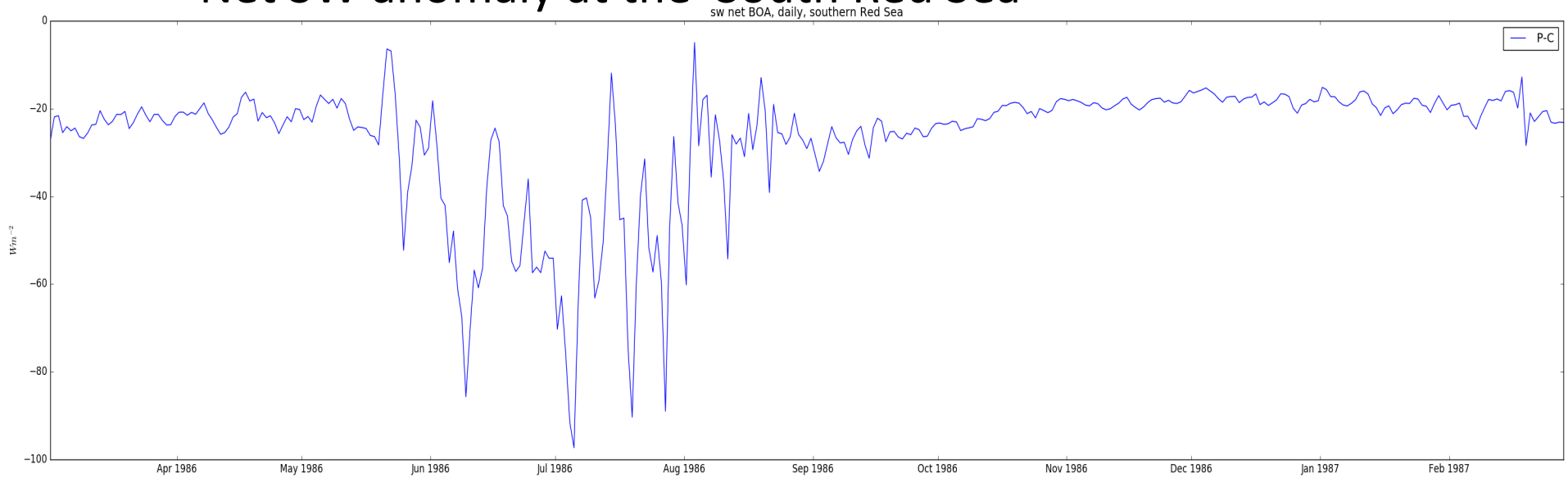
Framework:
A Coupled Ocean Atmosphere Wave Sediment Transport Modeling System (COAWST)

Atmosphere:
Weather Research and Forecasting Model (WRF)

Ocean:
Regional Ocean Modeling system
(ROMS)



Net SW anomaly at the South Red Sea



SST anomaly at the South Red Sea

APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB

SUMMARY

- NASA aerosol observations open a new horizon in understanding of dust role in climate system. Yoram's contribution in this is invaluable
- Dust forcing in the source regions on regional level is extremely high
- Dust is very effective in causing circulation anomalies
- Dust effect on the Red Sea is huge and is not accounted in any model
- Regional climate studies do not account for aerosol effect
- Dust mass balance is poorly known; observations of dust deposition and emission are required
- Dust radiative, biological, and medical effects are crucially dependent from dust chemical composition; observations of dust mineralogy and chemical composition are required