A Regional Desert Dust Forecast and Assimilation System

Yaswant Pradhan (Satellite Applications)

Keith Ngan (Data Assimilation & Ensembles)

Contents

This presentation covers the following areas

- Observation
  - SEVIRI dust optical thickness
  - comparison with MODIS and AERONET
- Dust assimilation
  - preliminary results

SEVIRI dust optical thickness

Y. Pradhan[1], H. Brindley[2] & R. Saunders[1]

[1] Met Office, [2] Imperial College

SEVIRI overview

Spinning Enhanced Visible and Infrared Imager

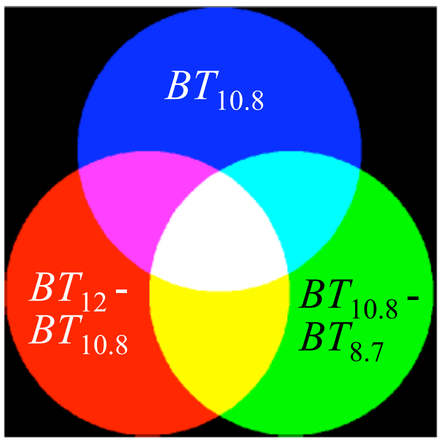
Channel no.		Characteristics of spectral band (µm)			Main gaseous absorber or window
		λ_{cen}	λ_{min}	λ_{max}	
1	VIS0.6	0.635	0.56	0.71	Window
2	VIS0.8	0.81	0.74	0.88	Window
3	NIR1.6	1.64	1.50	1.78	Window
4	IR3.9	3.90	3.48	4.36	Window
5	WV6.2	6.25	5.35	7.15	Water vapor
6	WV7.3	7.35	6.85	7.85	Water vapor
7	IR8.7	8.70	8.30	9.10	Window
8	IR9.7	9.66	9.38	9.94	Ozone
9	IR10.8	10.80	9.80	11.80	Window
10	IR12.0	12.00	11.00	13.00	Window
11	IR13.4	13.40	12.40	14.40	Carbon dioxide
12	HRV	Broadband (about 0.4 – 1.1)			Window/water vapor

Onboard MSG
Sampling frequency
15 min
Spatial resolution (ex HRV)
3km @nadir
Dust/Aerosol

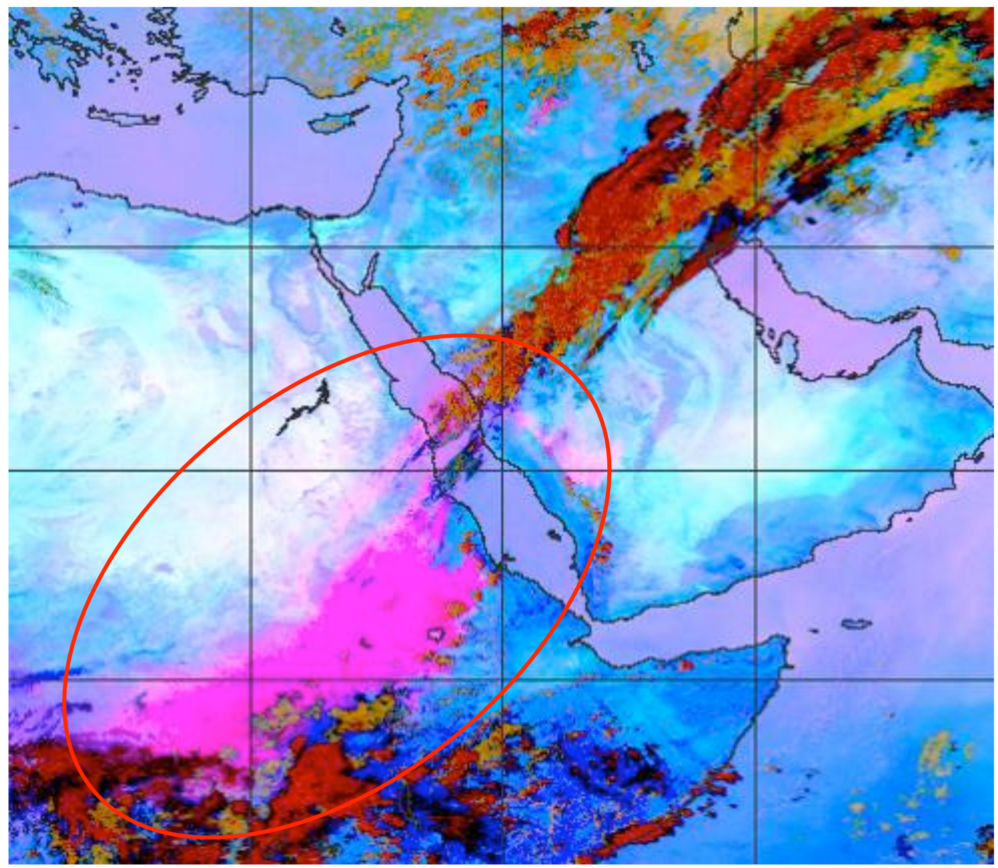
Schmetz et al., BAMS 2002

Dust detection using thermal channels (1)

Dust RGB



Dust
Convective cells
anvils
Low clouds
Thin mid/low clouds

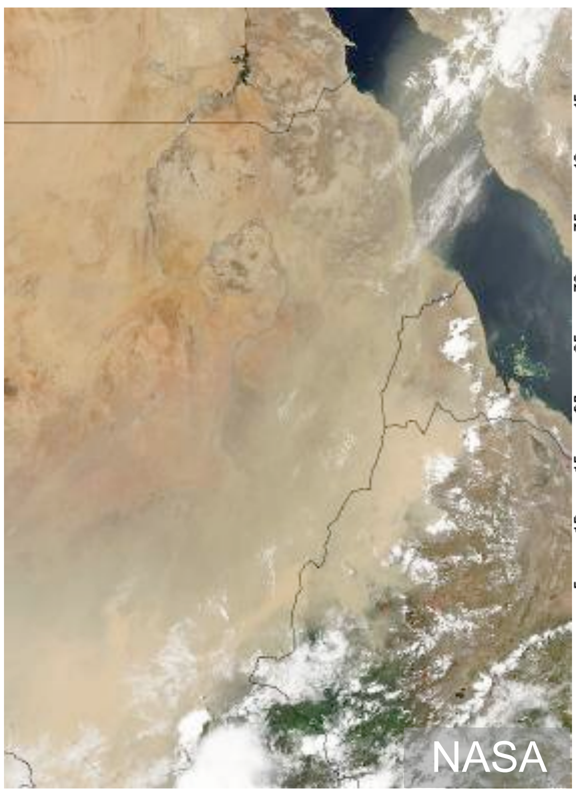


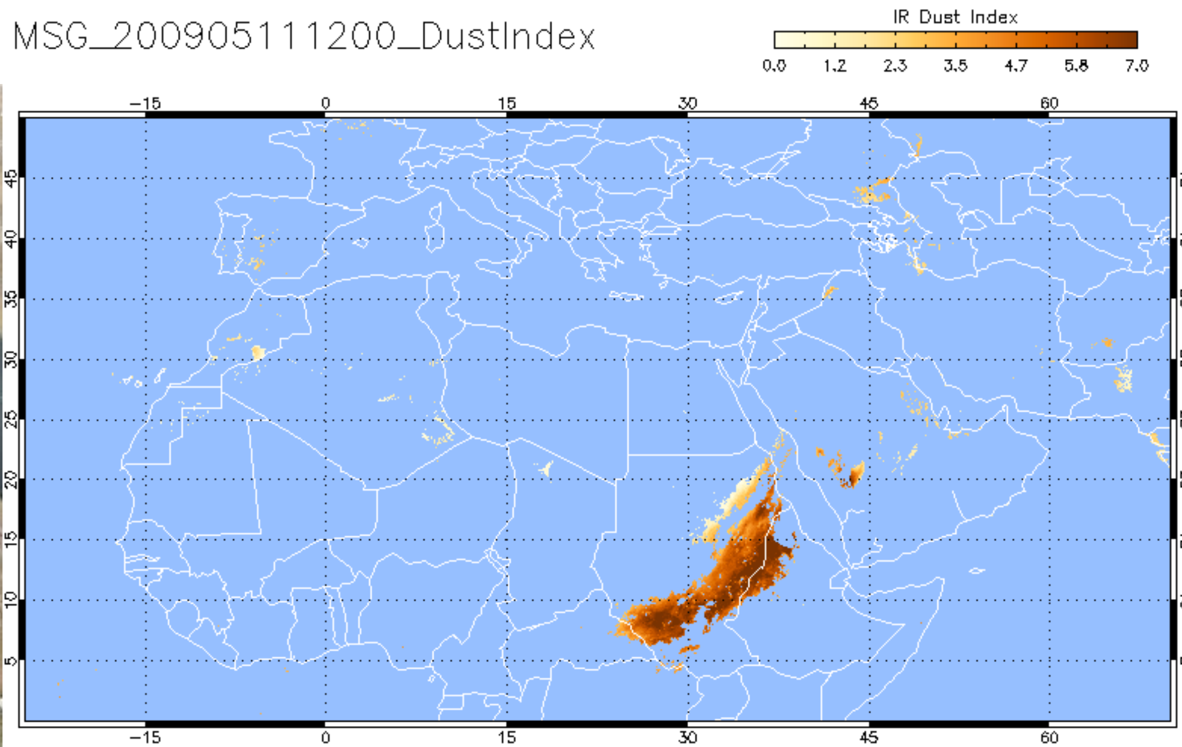
Courtesy: Pete Francis

Dust detection using thermal channels (2)

IR Dust index

MODIS true colour





$$DustIndex = (BT_{10.8}^{forecast} - BT_{10.8}^{observed}) - (BT_{12.0}^{forecast} - BT_{12.0}^{observed})$$

Quantification of AOD over land

- Based on the IDDI method of Legrand *et al.* (2001)
- relies on dust's strong absorption in the 10.8µm channel
- uses the dust optical properties described in Volz (1973).
- AOD and the change in $BT_{10.8}$ can be expressed as (Brindley and Russell, 2009)

$$AOD_{550} = c_1(\theta_v).c_2(\theta_v)^{\Delta BT_{10.8}} + c_3(\theta_v)$$

$c_{1,2,3}$ fitted coefficients as a function of viewing zenith angle θv

Simulation criteria AOD: 0-5, Surface type: (semi) arid, TCWV: 2-20kg/m^2, Ts: 300-330K, θv: 0-70º

Quantification of AOD over land – application to SEVIRI

- Met Office operational cloud mask with dust-flags was used to screen out cloud-only pixels
- A 16-day window is considered to obtain a reference (clear-sky) $BT_{10.8}$
  - corrections were applied to account for the change due to the change in meteorology
- $\Delta BT_{10.8}$ was then obtained by subtracting observed BT from the reference BT

Limitations

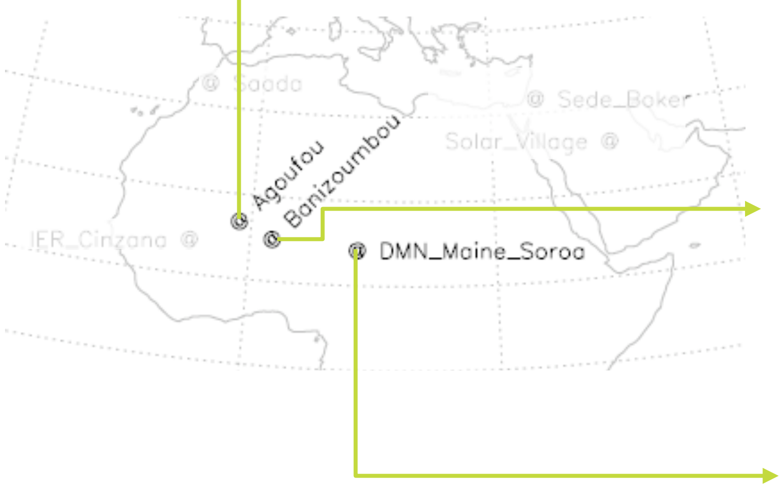
- relies on accurate discrimination of dust from cloud

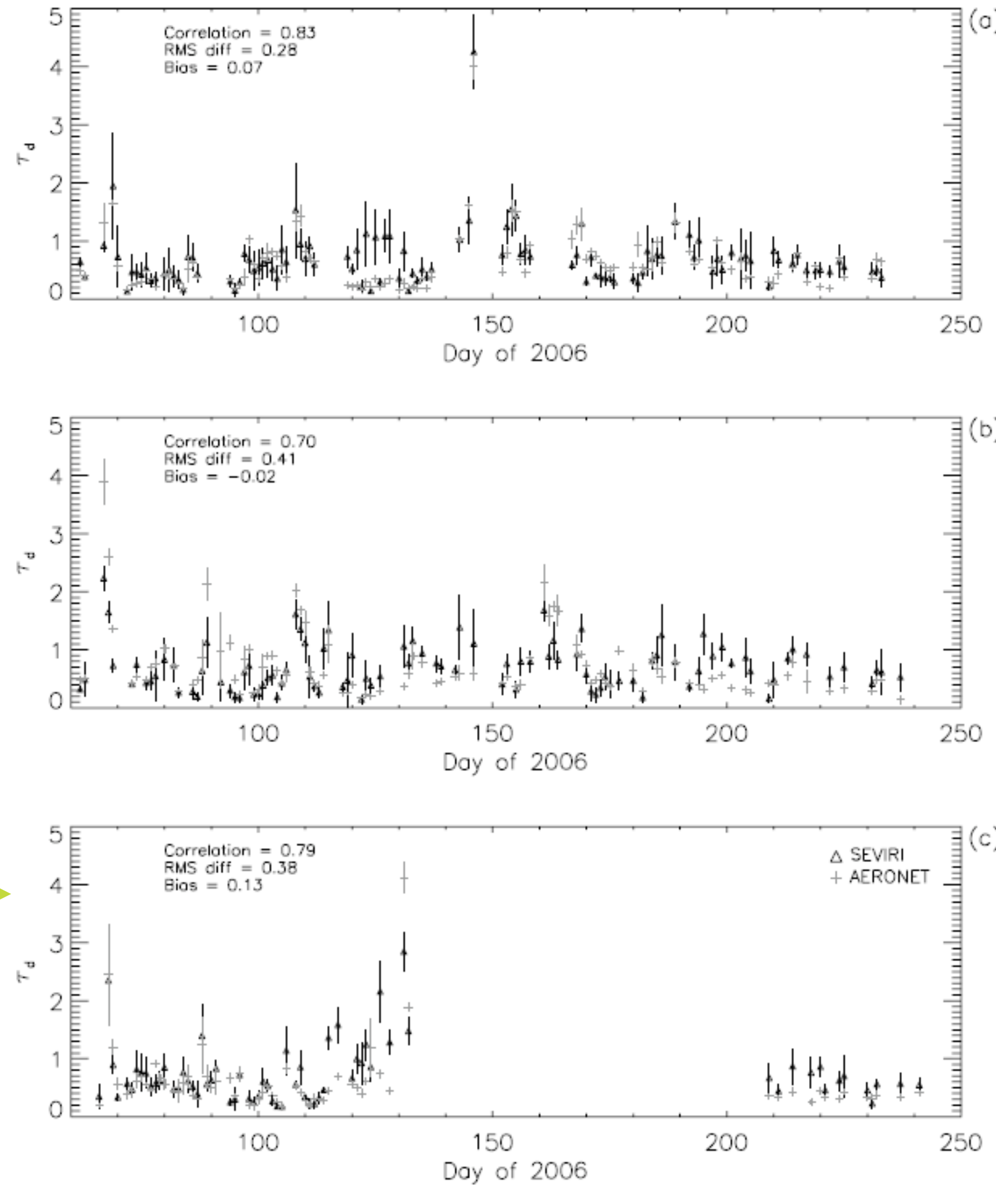
- some level of background dust loading is always present in reality

- signals from the dust layer are difficult to separate when very close to the ground

- may have a reverse effect on BT during non-sunlit period

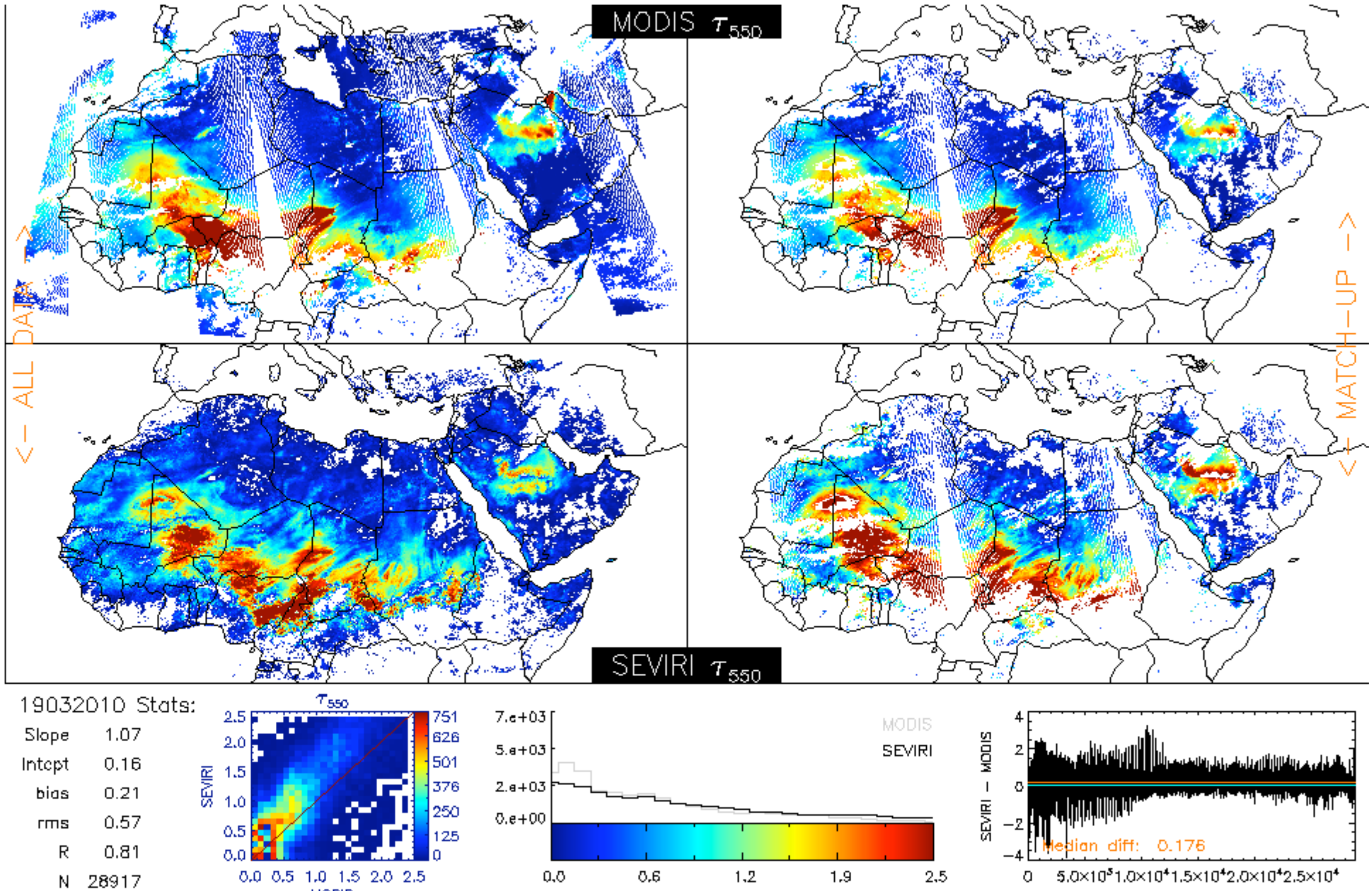
Comparison with AERONET





Comparison with data from 7 AERONET locations show an overall rms difference of 0.37 and bias 0.01

Comparison with Aqua/MODIS
daily, near real time



Summary

- semi-operational hourly SEVIRI τ_{550} at near-real-time with a pre-assessed rms ±0.37
- capable to detect and quantify major dust events

Scope for improvement

- dust detection (very thick layers) needs further improvement
- address the impact of dust layer height on the retrieval

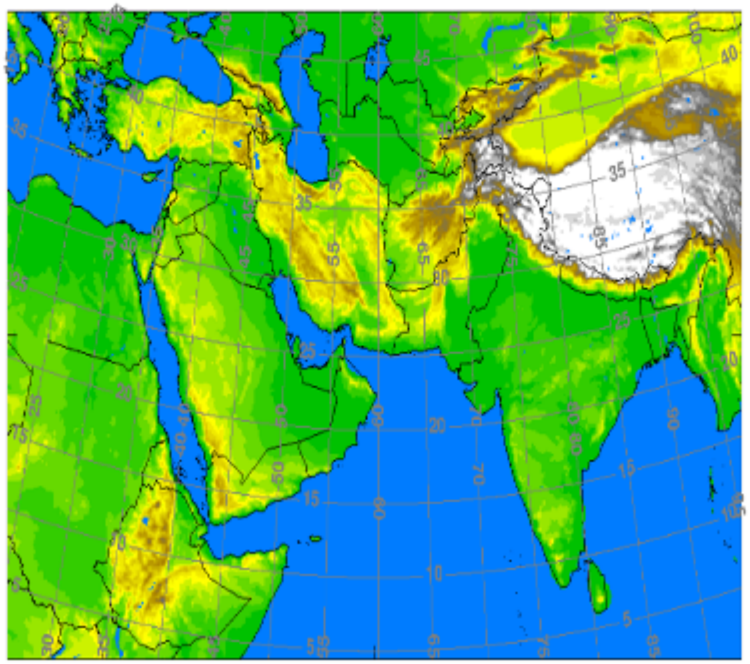
Dust assimilation

K. Ngan, Y. Pradhan, M. Brooks, D. Walters & D. Jackson

Aerosol / dust forecasting

- Numerical Model
- Dust scheme
- Observations
- Assimilation trials

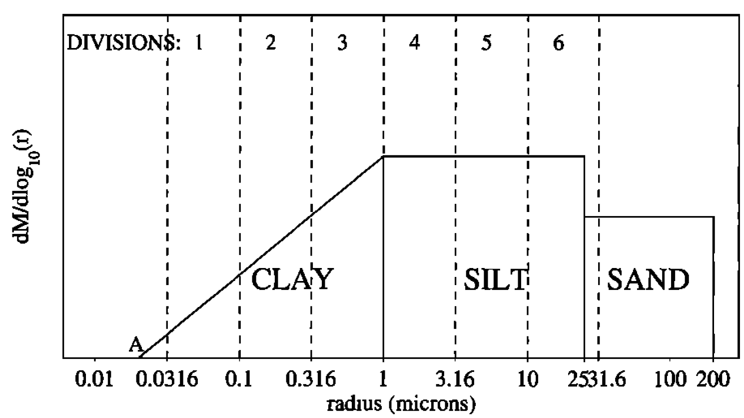
South Asia Model (SAM)



- Limited area NWP configuration of MetUM introduced in Apr 2008
- Grid 648x400x70 (Mar 2010)
- Horizontal Resolution 12 km
- Vertical lid 80 km
- LBCs and covariance statistics are derived from the global model

Dust scheme

Since dust particles vary widely in size, a discrete representation is necessary. The Met Office scheme (Woodward 2001) uses 6 bins.



Division number	1	2	3	4	5	6
Lower bound (μm)	0.0316	0.1	0.316	1.0	3.16	10.0
Upper bound (μm)	0.1	0.316	1.0	3.16	10.0	31.6

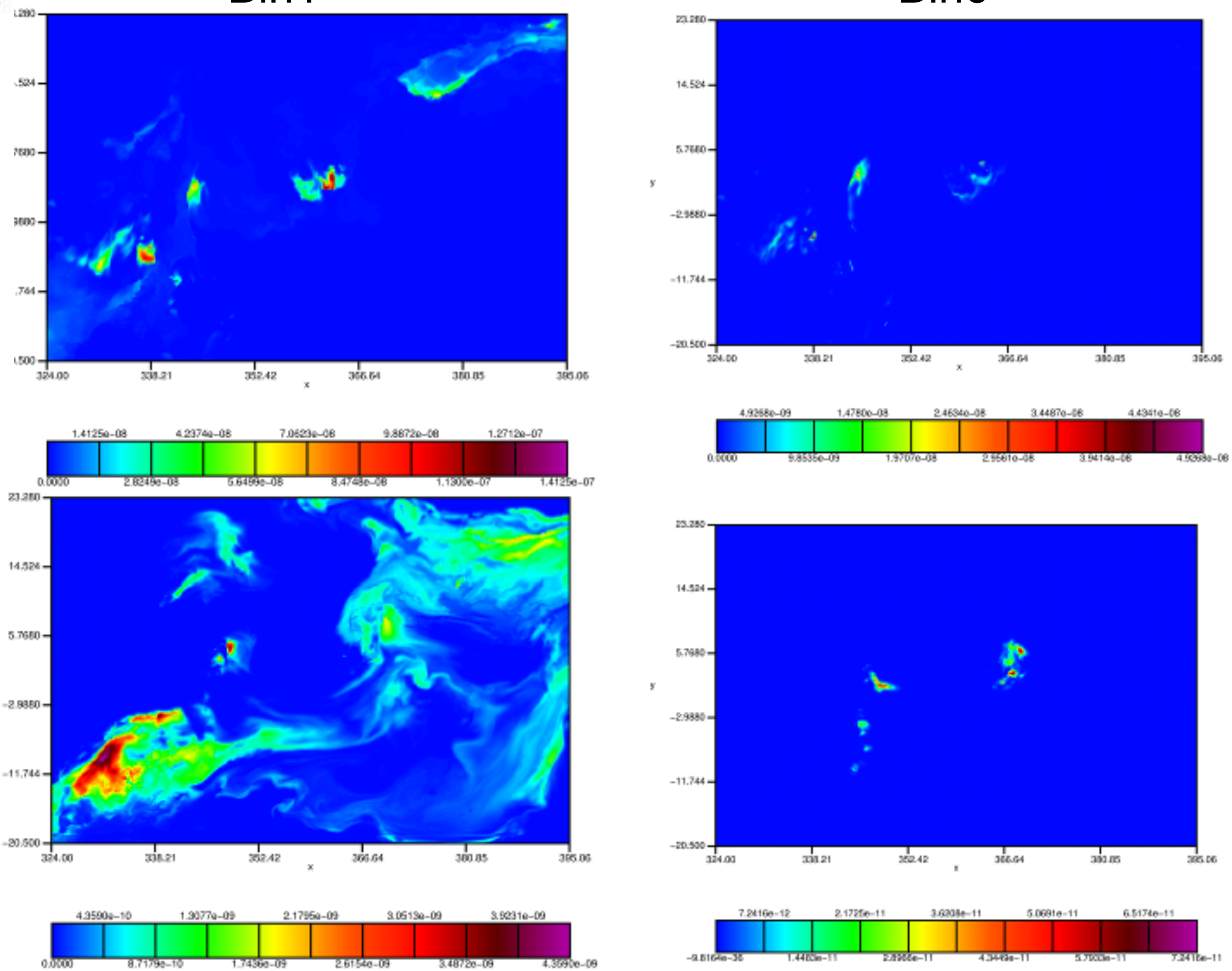
- Emission is parameterised using density and relative mass of each size bin.
- Both wet and dry deposition are included.
- Direct radiative effect is included

Model fields (dust mixing ratio)

Bin1 | Bin6

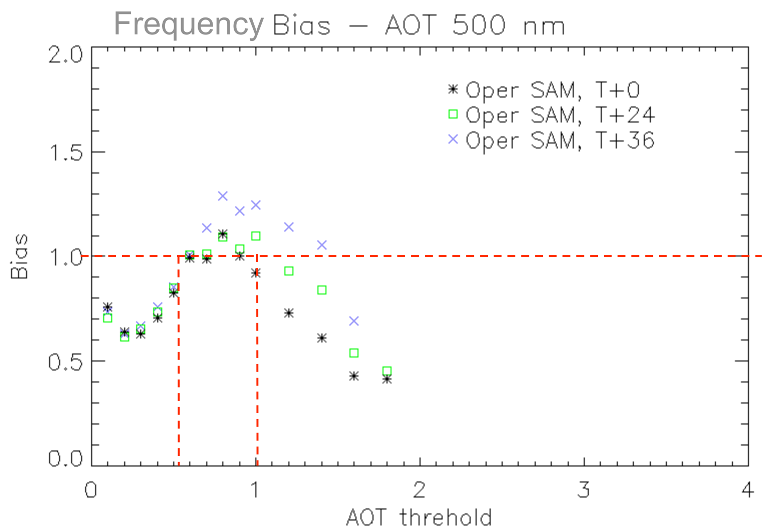
Ground

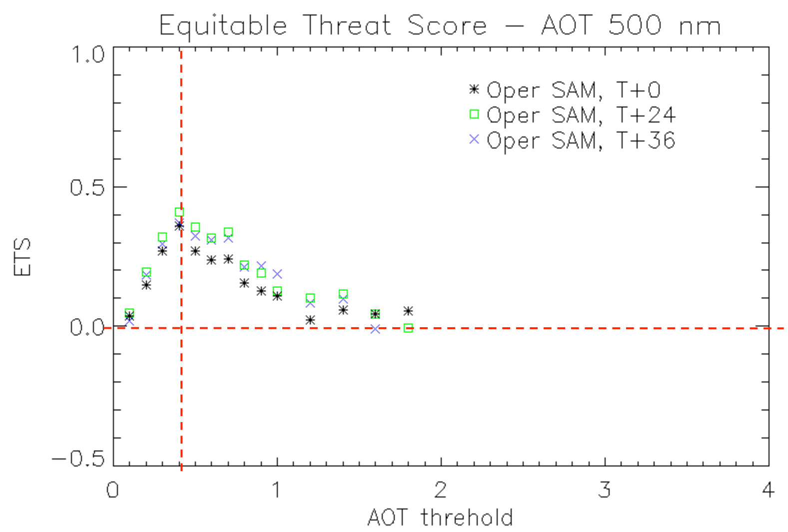
~5km



SAM forecast skill

March 2009-March 2010 (covering 10 AERONET locations over Middle-east and N. Africa)





SAM forecasts against AERONET (no assimilation)

- under-predict AOD at low thresholds (probably due to the absence of non-dust aerosols)
- relatively unbiased for 0.5<AOD<1
- most difficult to predict for larger AOD events

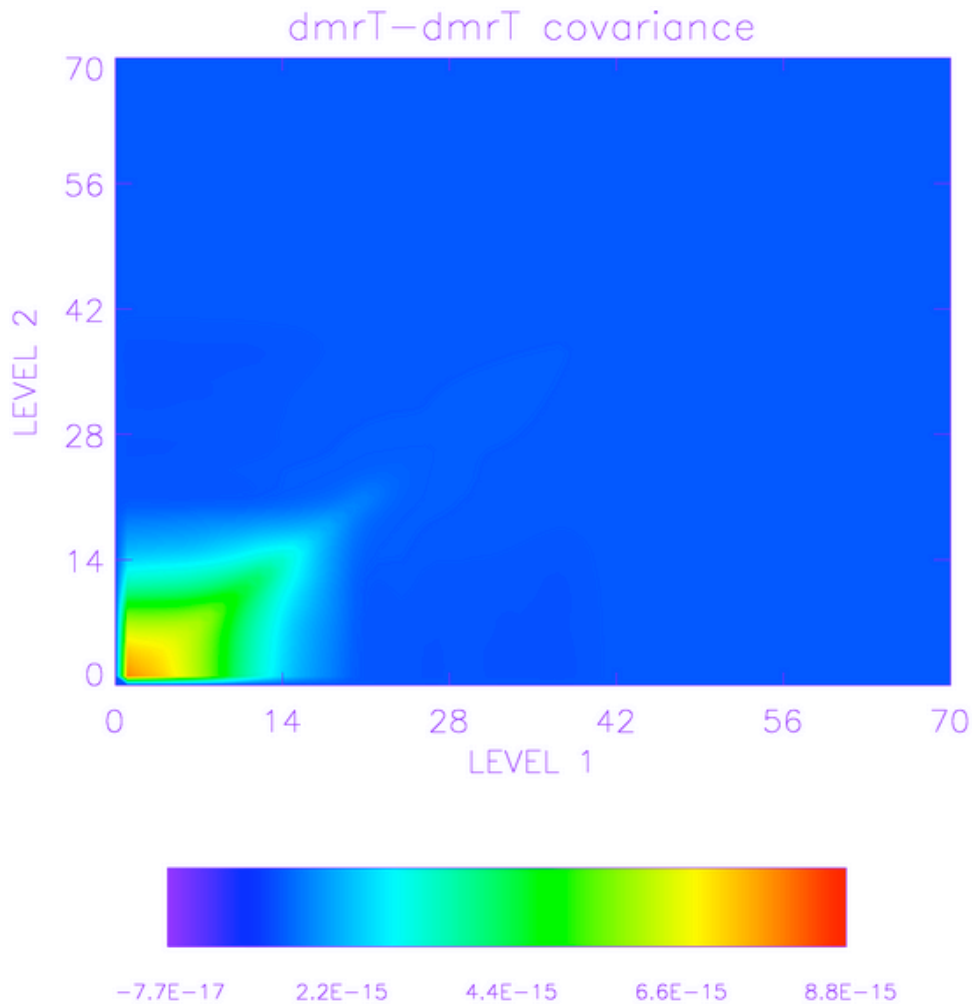
DA approach

Work within framework of existing incremental 3D-Var system.

Key elements

- Background statistics obtained via the NMC method
- Observation variable is aerosol optical depth
  - Obs err matrix (**R**) is assumed to be diagonal (rms error =0.37 from comparisons of SEVIRI with AERONET)
- Control variable is total dust mixing ratio (after Benedetti *et al.* 2009). Total dust is obtained by summing over all dust bins.

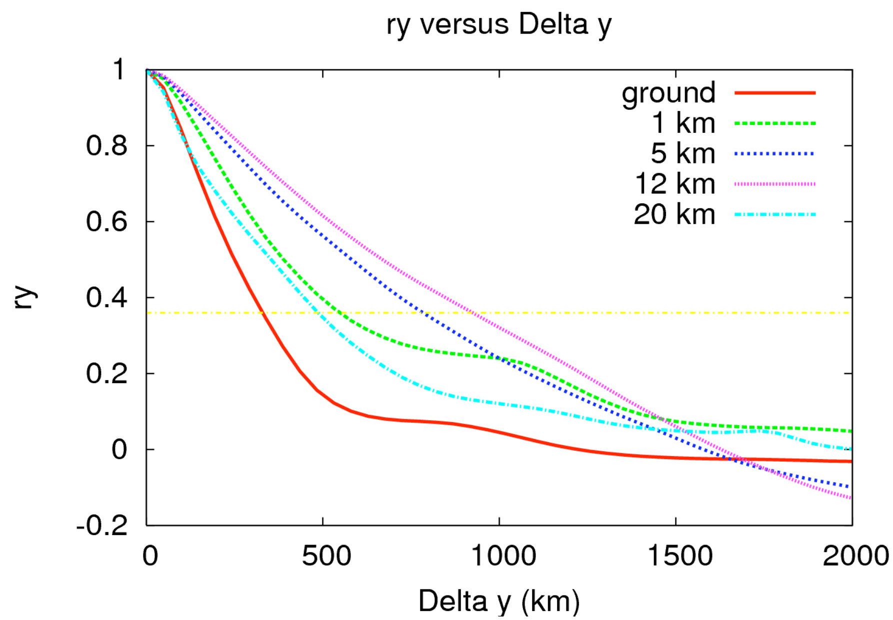
Background error covariance

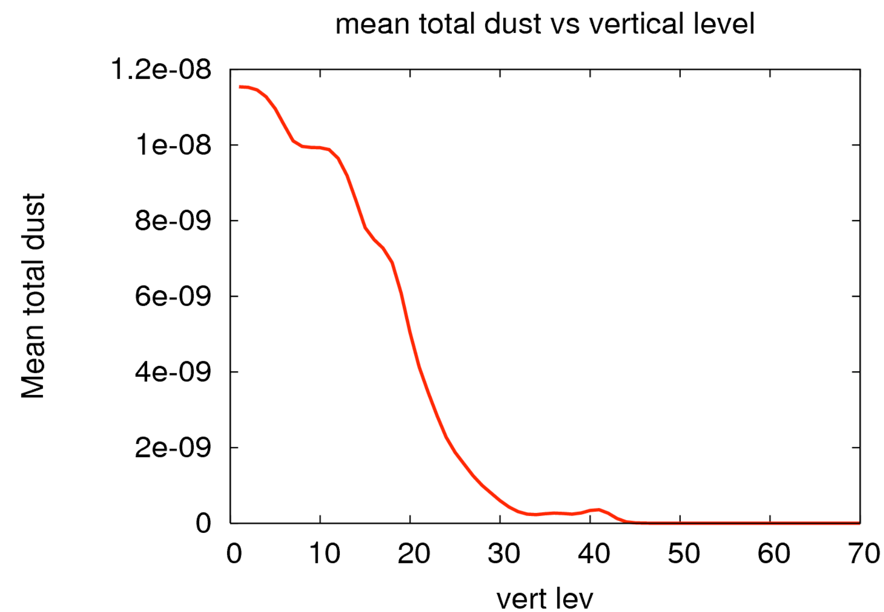


Vertical correlations extend throughout boundary layer (level 14 ~ 1.5 km).

Spatial autocorrelations

In limited-area mode, the Met Office variational system requires that a horizontal correlation length be prescribed for the control variable, i.e., total dust.

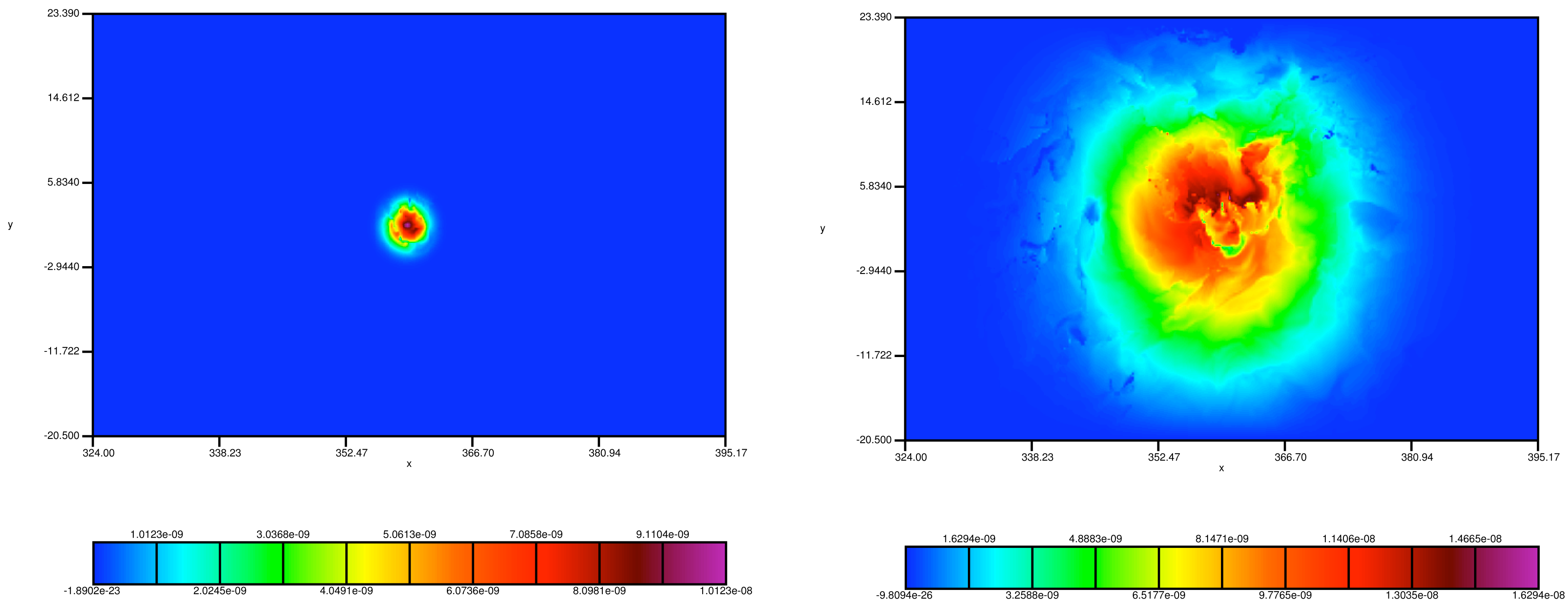




- Correlation lengthscale cannot be specified unambiguously.
- We use L_{td} = 300km. By default, L_{ψ} = 400km in the global model.

Pseudo-observations

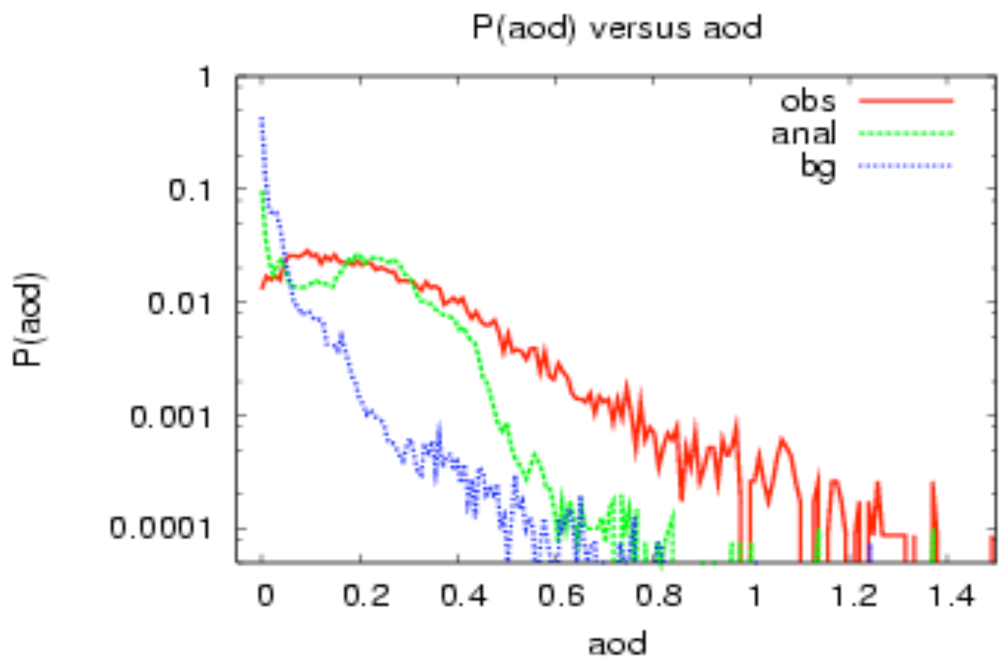
Increment to dust bin 1 at ground

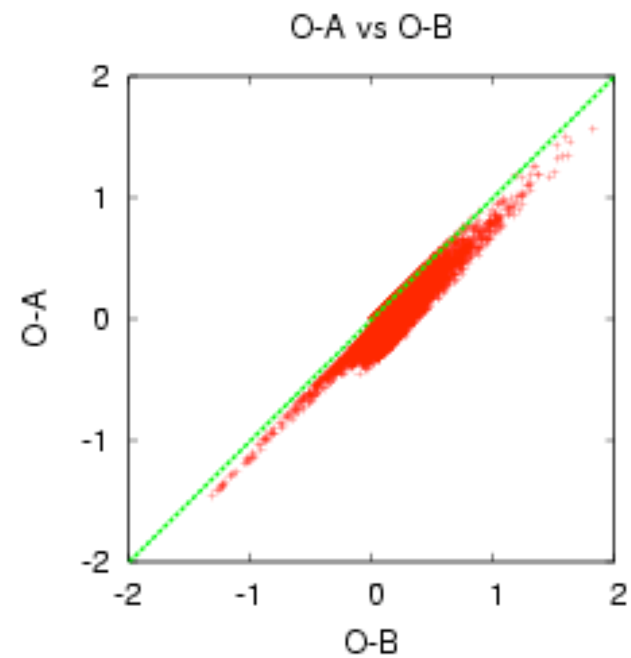


•Horizontal structure is a product of the isotropic horizontal correlations and the anisotropic background.

Single-cycle Analysis and Background

23-Jan-2010



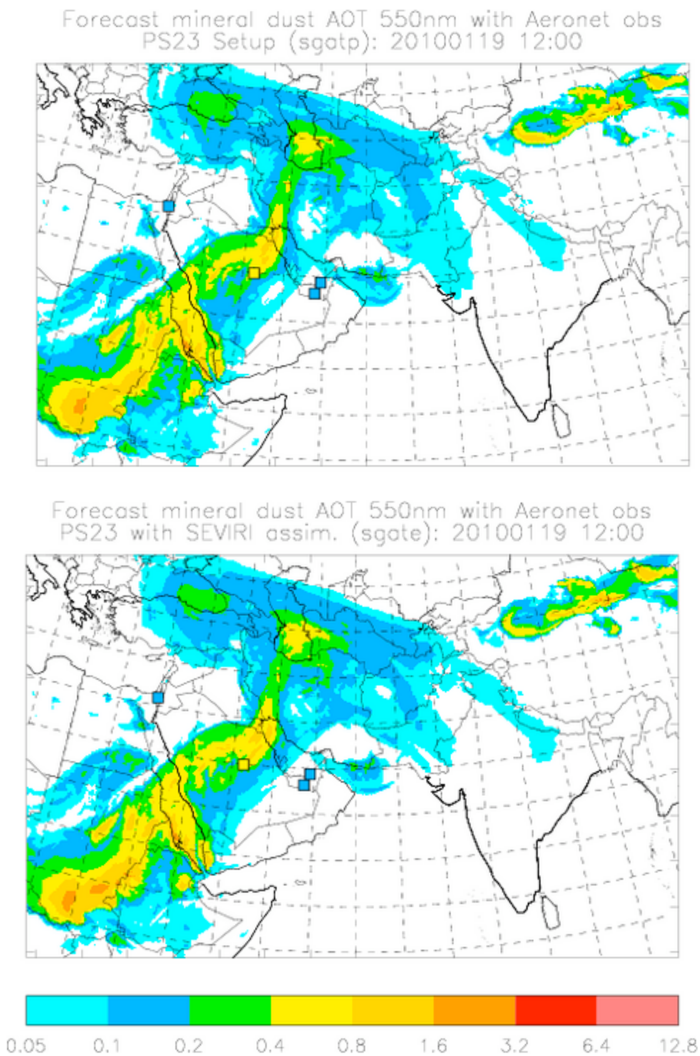


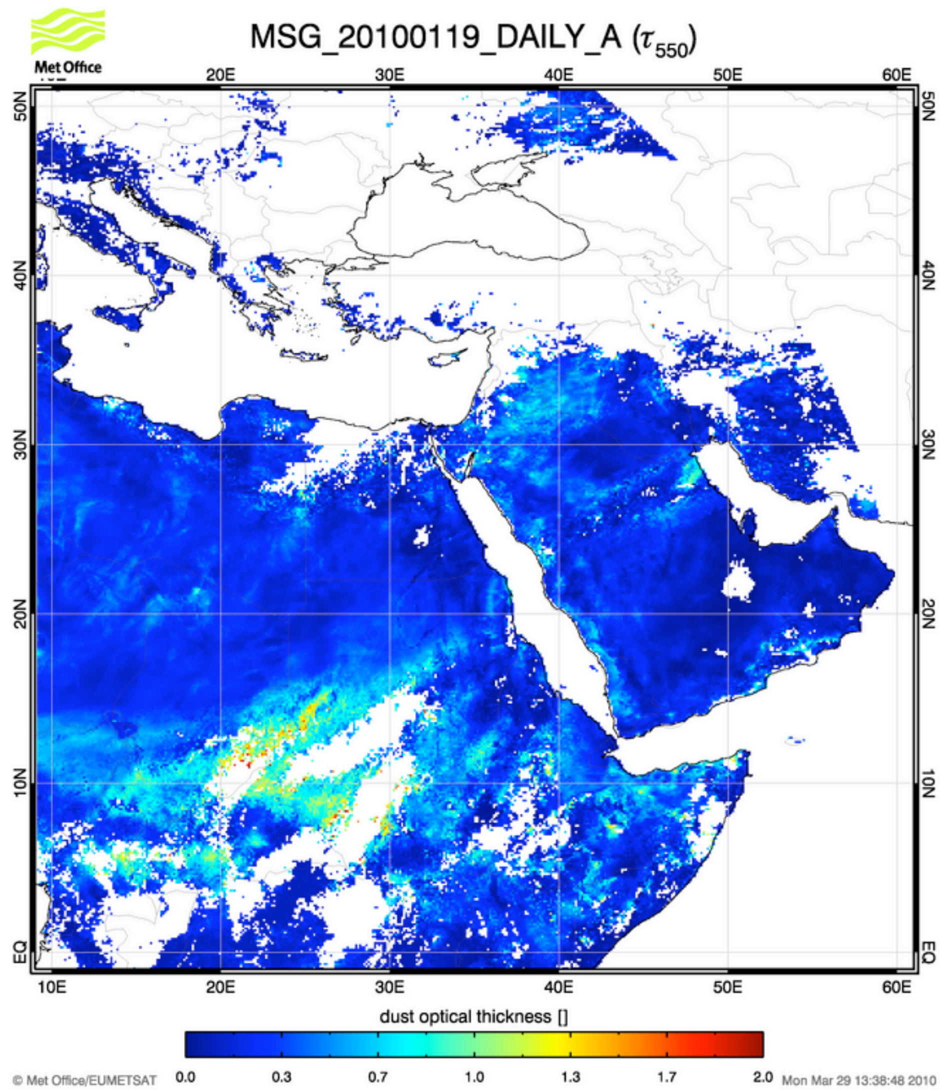
- Analysed pdf is intermediate between analysed and observed pdfs.
- fails to capture long tail

- Analysis error is smaller than background error for O-B>0

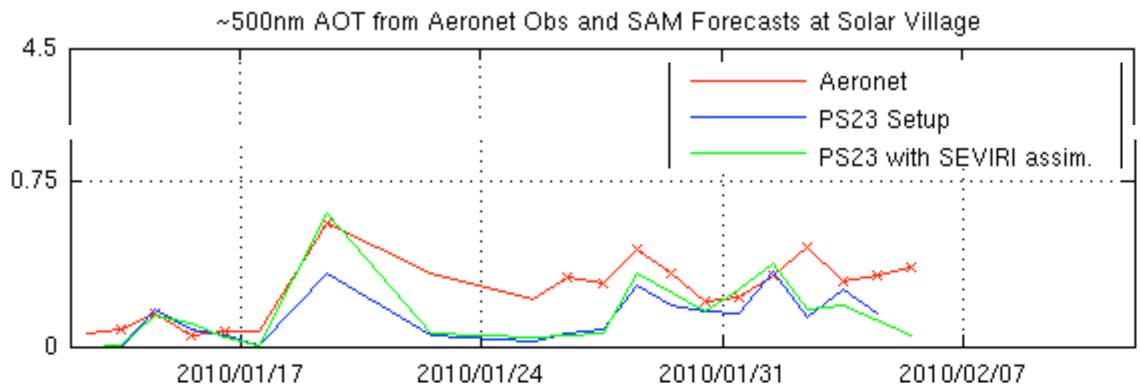
Trial results (1)

Trial period: 10 Jan’10 – 10 Feb’10

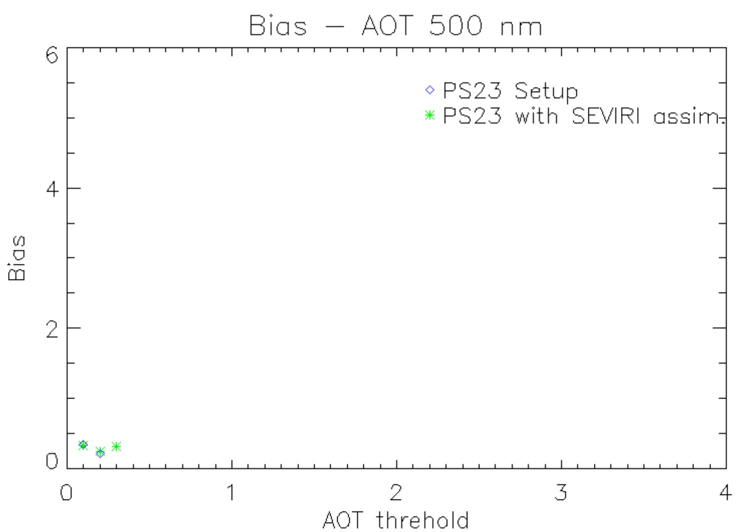


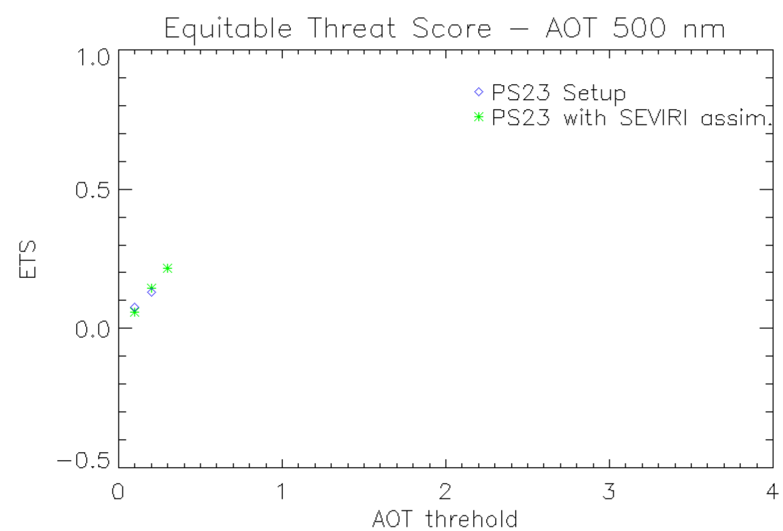


Trial results (2)



Captured the dust event over Solar Village; Timeseries over other AERONET locations shows little or no improvement





Future Work

Short term

- 4d-Var
- More extensive trialling: major dust events

Longer term

- Alternative control variables
- Alternative data sources (e.g. MODIS/VIIRS)
- Volcanic ash assimilation (?)

Questions and answers

Control variable and adjoint

Variational systems minimise the control-variable cost function using adjoint equations.

- Assumptions (Benedetti et al. 2009):
  - Total dust mixing ratio, r_T = constant
  - Fractional mixing ratio $f_i = \boldsymbol{r_i}/r_T$ = constant
- Tangent-linear equations

$$\begin{pmatrix} \tilde{r}'_T \\ \tilde{\boldsymbol{r}}'_i \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ \boldsymbol{f}_i & 0 \end{pmatrix} \begin{pmatrix} r'_T \\ \boldsymbol{r}'_i \end{pmatrix}$$

- Adjoint equations follow immediately. For real variables, the adjoint operator is equivalent to the transpose.