Recent developments in aerosol forecasting at the Met Office

Yaswant Pradhan, Bruce Ingleby, Malcolm Brooks, Jane Mulcahy, Roger Saunders

Met Office, Exeter, UK

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This presentation covers the following areas

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- Summary

Recap

Dust in the Met Office NWP

Progress timeline

	ICAP-Monterey (2010)	ICAP-Frascati (2012)
Area	Limited area (South-Asia CAM)	Global
Resolution	~12km	~25km
Forecast lead time	6 days	6 days
Dust Scheme	6-bin (0.0316-0.1µm, 0.1-0.316µm, 0.316-1µm, 1-3.16µm,3.16-10µm, 10-31.6µm) version of Woodward (2001) scheme used in the HadGEM climate model Undergoes advection & deposition (wet & dry); Includes direct radiative effect	2-bin (0.1-2 µm, 2-10µm) version after Woodward (2001,2011) Undergoes advection & deposition but no interaction with radiation (comes from dust climatology)
Data Assimilation	3D-Var; SEVIRI dust AOD (over land, Pradhan & Saunders 2009, Brindley & Russell 2009): Obs variable: AOD; Control variable: Dust MMR (after Benedetti et al 2009)	No assimilation (expected in 2013)

Since then…

Dust in the Met Office NWP
Progress timeline

Late 2012 – early 2013: ***Global 4D-Var*** version

- Forecast has 2 size bins (6 for LAMs), analysis uses total dust
- OPS/VAR code more generic/robust
- MODIS/Aqua processing included (SATAOD)
- minor improvements to AOD observation operator
- new background error covariance statistics
- Trials:
  - Summer trial (JunJul'11) with MSGAOD only
  - Winter trial (Dec'11Jan12): MSGAOD + SATAOD (over land)

2013: Operational global 4D-Var (in April PS32)

Background
AOD observation operator (in OPS)

AOD derived from 2-bin (0.1-2 and 2-10 μm) model dust mass mixing ratio:

$$\tau(x,y,z) = \int_{z_b}^{z_t} \rho(x,y,z) \sum_i r_i(x,y,z) k_{\mathrm{ext},i}\, dz$$

$$= -\frac{1}{g} \sum_{j=1}^{N} (p_{j+1} - p_j) \sum_i r_i(x,y,z) k_{\mathrm{ext},i}$$

τ dust AOD (at 550nm)

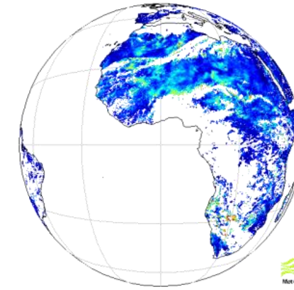
r_i dust mass mixing ratio for i_{th} size bin

$k_{\mathrm{ext},i}$ extinction coefficient (700.36,141.45 at 550nm, Balkanski et al 2007)

ρ density of model layer

p_j pressure at theta layer boundaries

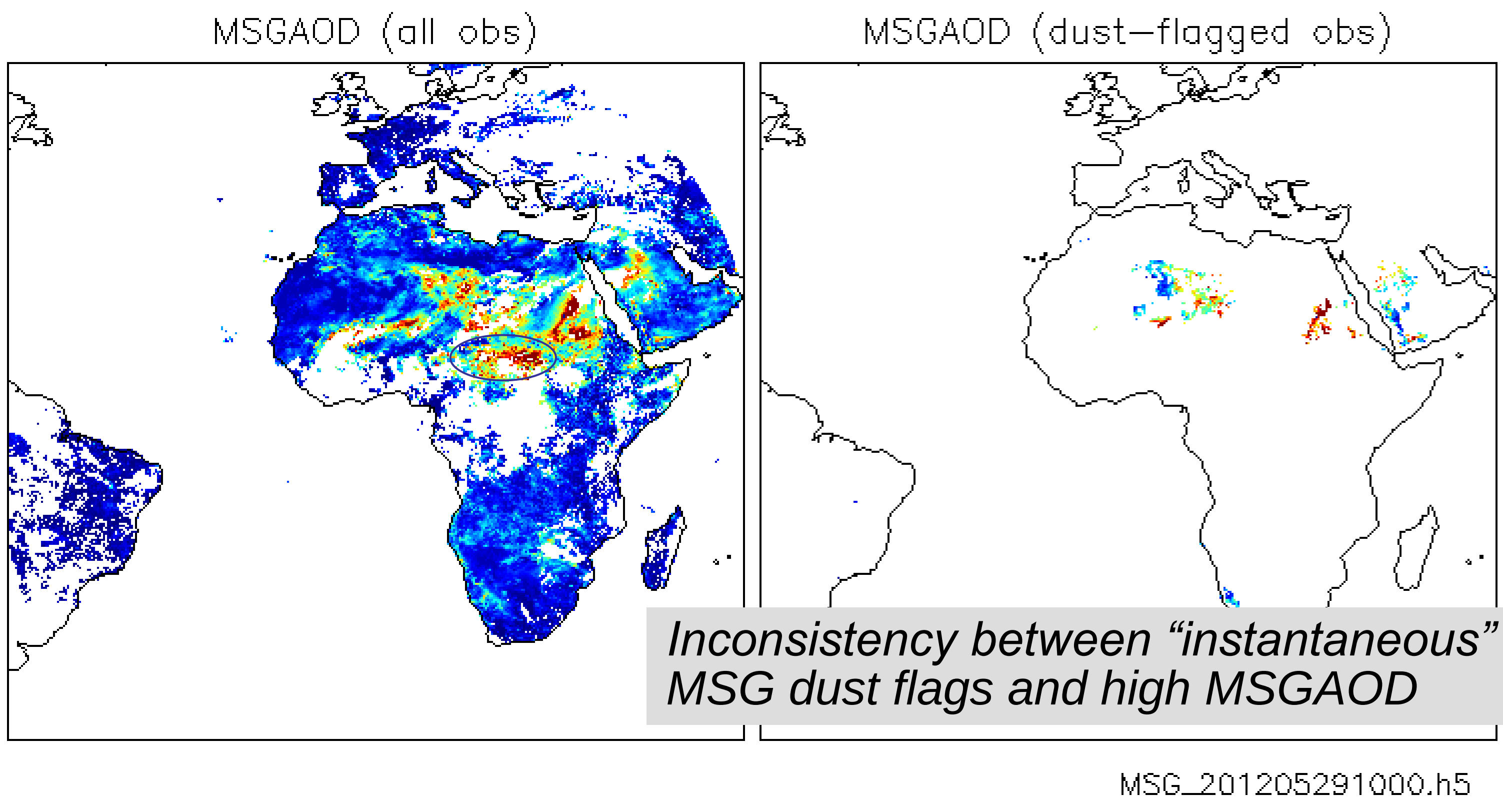
Observations – MSGAOD
(based on IR obs)



Reject obs where (VZA > 70°) and (SZA > 80°)

Fixed global RMSE 0.37; AOD range [0,5]

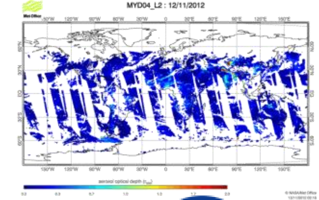
4x4 sub-sampled



Inconsistency between "instantaneous" MSG dust flags and high MSGAOD

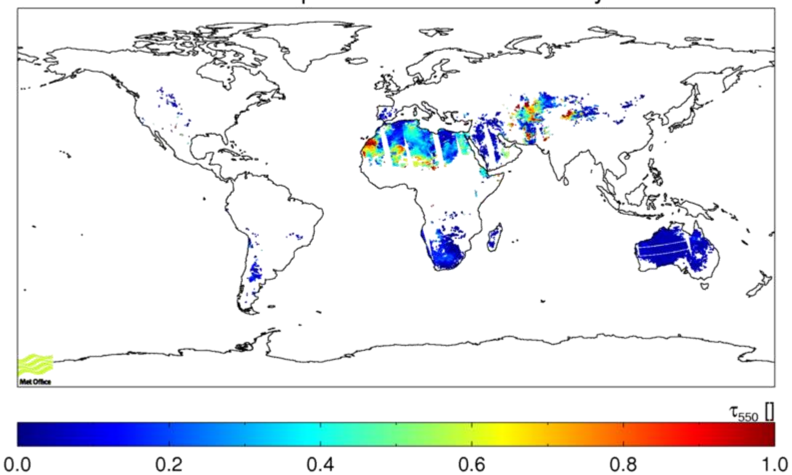
Observations – SATAOD

L2 MODIS/Aqua Collection 5.1

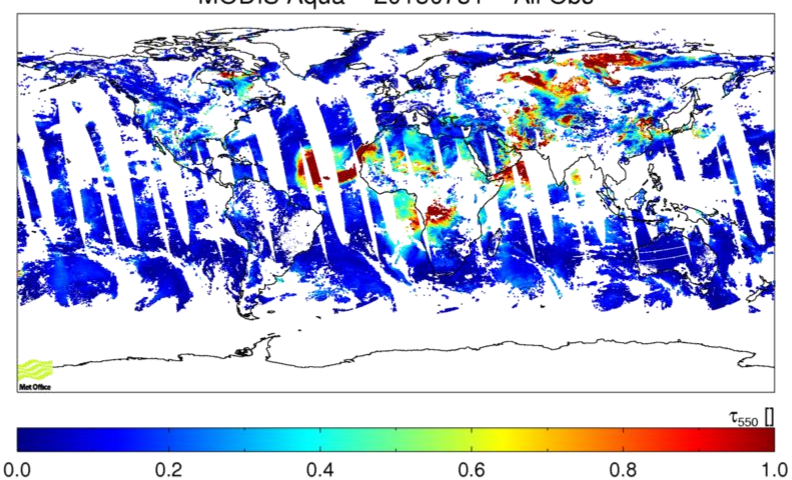


LANCE-MODIS

MODIS Aqua – 20130731 – Dust only



MODIS Aqua – 20130731 – All Obs



Allow all Deep Blue retrievals and DT-Land AOD qualifying “dust” flags;

AOD range [-0.05,5]; Fixed global RMSE 0.222 (Salustro *et al*, 2010)

No data thinning

Flagging issues

Inconsistent flagging across DT and BT products (no flags over ocean)

Dust-only – too patchy (not effective with DT-AOD)

Dust/Biomass discrimination ambiguous (sometimes)

Dust+Mixed – better option (better represented in MODIS Collection 6?)

Observations - Limitations

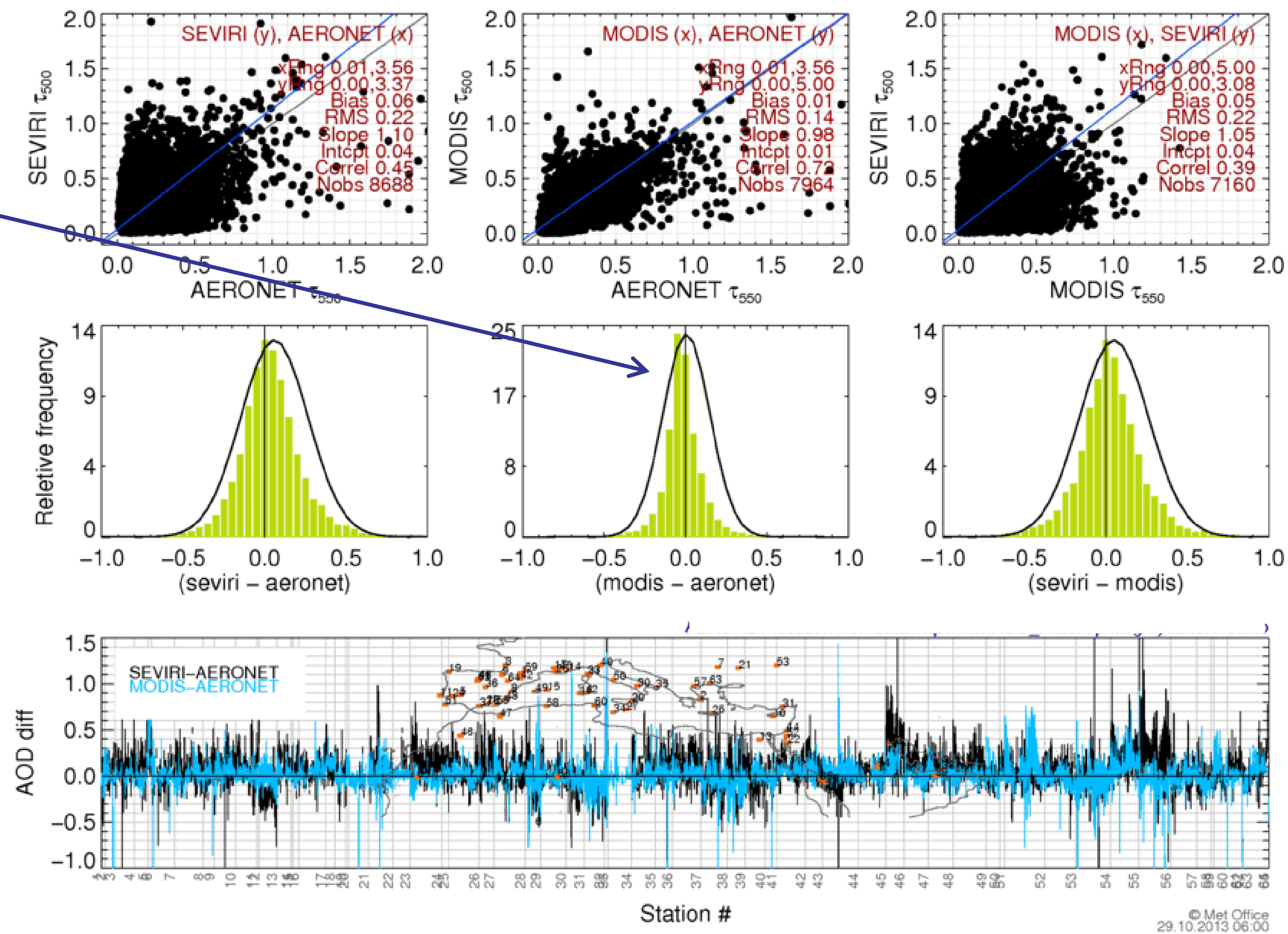
MSGAOD

- No information on vertical distribution, optical properties, shape and size distribution of aerosol
- Some level of cloud contamination
- Unrealistic assumption of constant T_{skin} over 28 days (retrieval window)
  - AOD retrieval is sensitive to ΔBT in the order: $\pm$1K (ΔBT) → 0.15 (τ)
- Failed retrieval when dust layer very close to the ground
- Night time retrieval accuracy has not been assessed

SATAOD

- No information on vertical distribution, Optical (absorption)/Chemical properties
- Sharp gradients across land-ocean boundaries
- MxDAODHD product will be ideal for DA (no option for aerosol partitioning yet)

Over Northern Africa, Southern Europe and Middle East: 20120627 – 20131026



MODIS AOD better than MSGAOD

However, MSGAOD performs better for prominent dust events

Assimilation

Bruce Ingleby

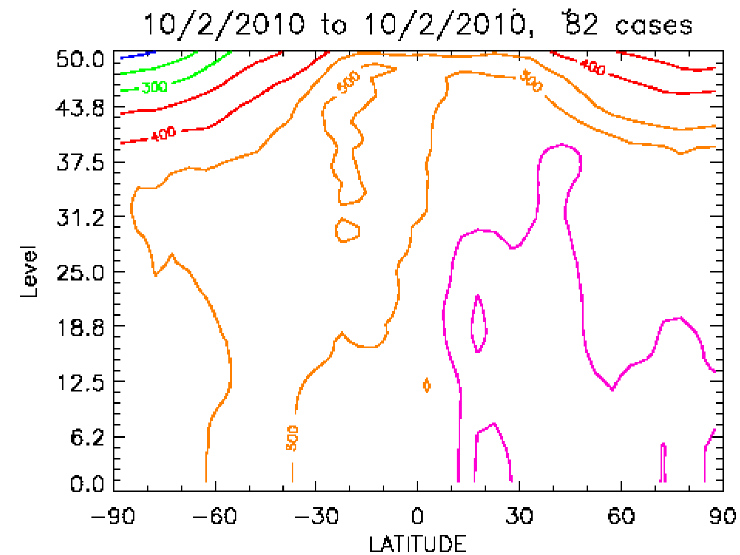
- Dust in the UM
  - Dust mixing ratio is stored for (2 -6) size bins (full 3D fields, but most dust in lower troposphere)
  - Sources depend on soil type, wetness and wind speed, sinks are wet and dry deposition.
  - AOD is a <u>linear</u> function of dust (recall obs operator)
- In DA have to split AOD to get increments to mixing ratio *r*; the split is proportional to background *r*
- 4D-Var (total dust added to PF model) dust inc advection ON, but not used to update u, v (i.e. dust observation don't affect other control variables)

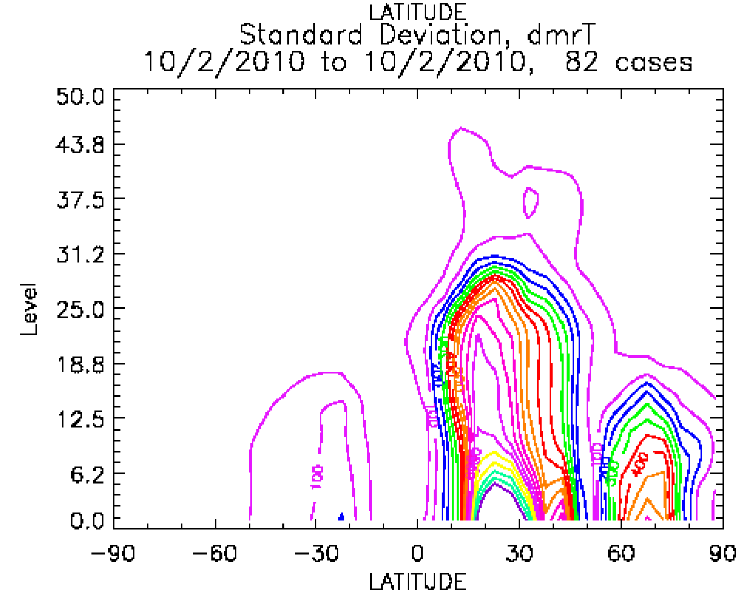
Observation error estimates

- σ_o (including representivity error) is taken as:
  - 0.37 for MSGAOD
  - 0.222 for SATAOD (MODIS)
- Higher σ_o at higher AOD values (?) not represented
- AOD reports are very high resolution (~10km) where present – thus less sensitivity to background error estimates

Background error estimates

- T+30 – T+6fc difference used
- Top: log(dust) – test (arbitrary min value)
- Bottom: dust – used max 20-30° N at low levels (patched into operational COV file)





Summer 2011 trials

UM at N320, VAR at N108 (~120 km)

MSGAOD only (daytime, cloud-free, land) with various options:

- Only reports with AOD>0.5
- No AOD threshold
- No AOD threshold and hscale reduced

Initial restriction was intended to include only reports that we are fairly sure are mainly dust – but gave biased sampling: some improvements but analysis AOD too high.

(2 performed better and 3 slightly better again.)

Winter 2011 trials

UM at N512, VAR at N216 (~60 km)

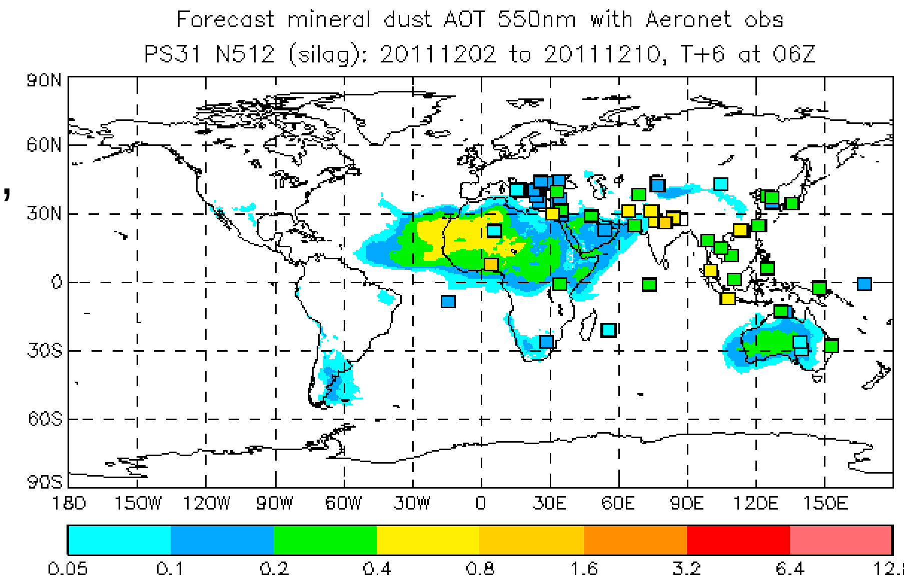
MSGAOD and MODIS

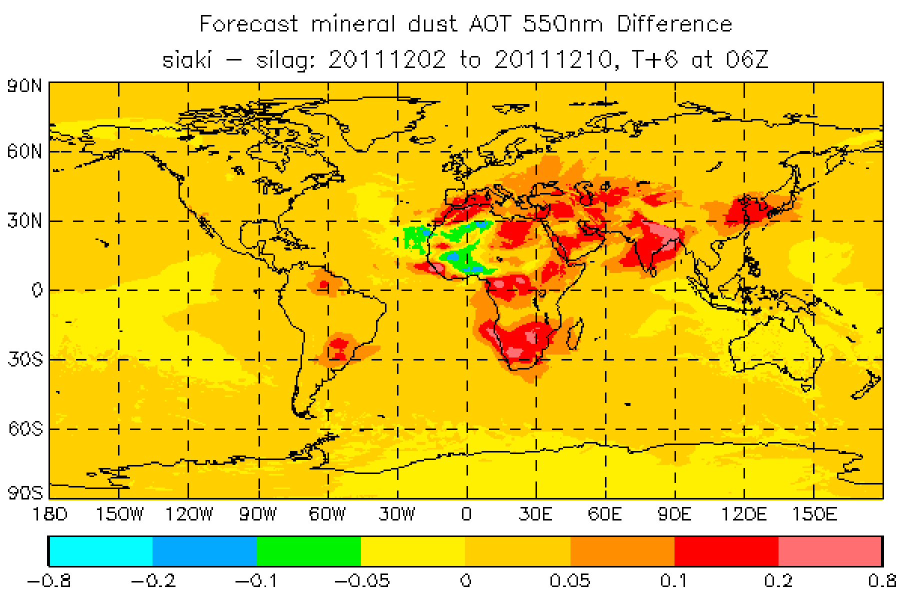
- AOD assimilation trial
- Seasonal vegetation control (as PS31)
- AOD assimilation with “SeasVeg”, no MSGAOD over South America
- AOD assimilation as above excluding MSGAOD
- As above but homogeneous dust covariances

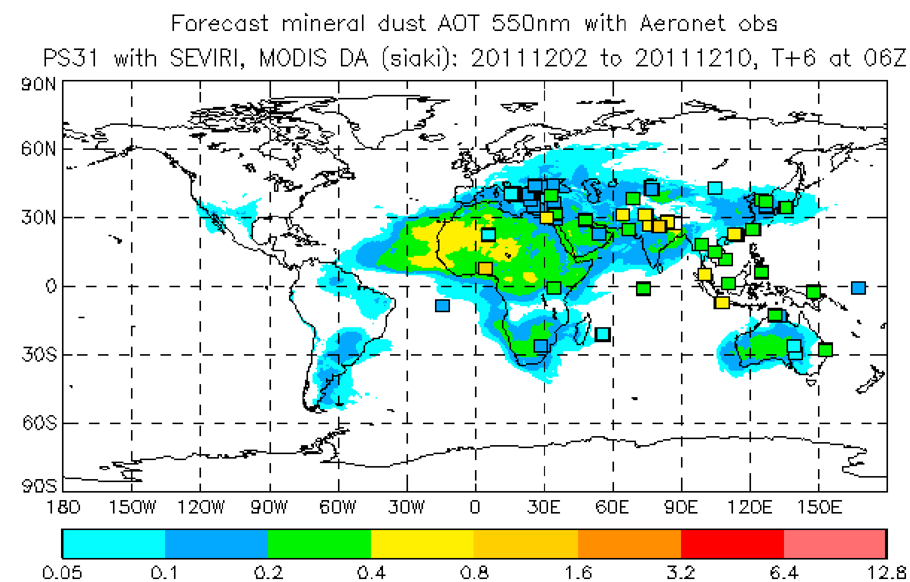
Seasonal vegetation gives small improvement

Winter 2011 trial (1)

- Assimilation mainly adding dust, except over Sahara
- Better fit to AERONET
- India, China: part dust part pollution?

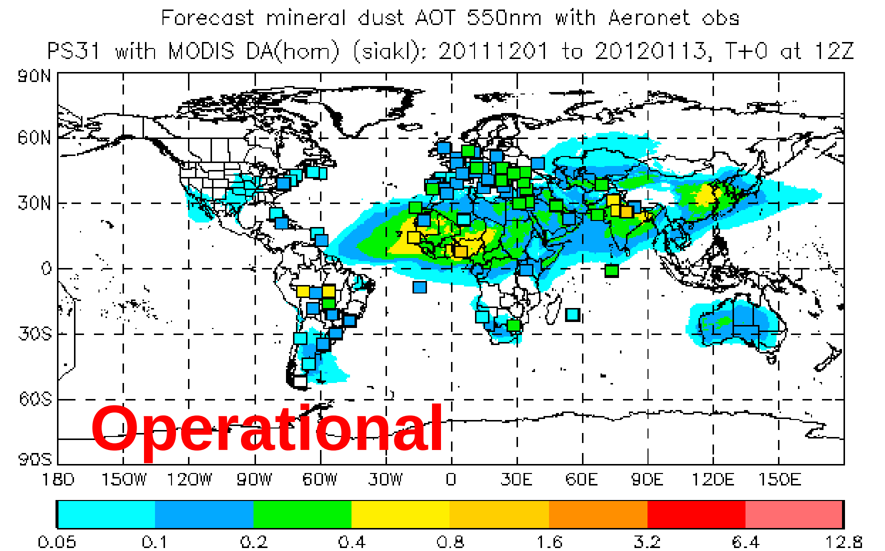


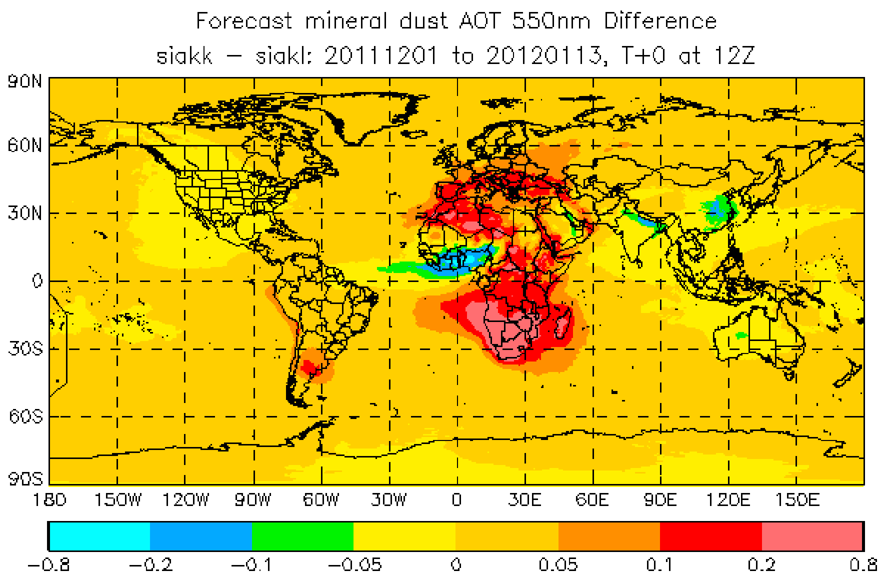


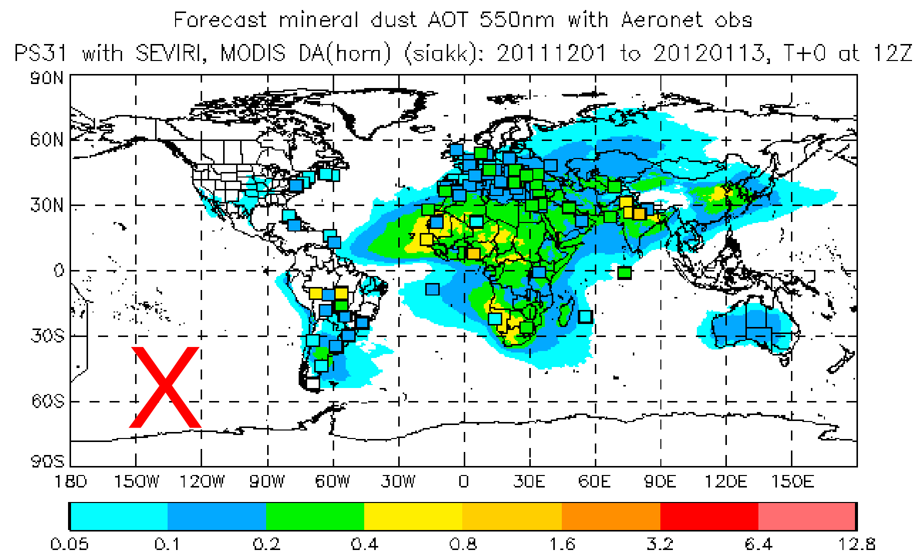


Winter 2011 trial (2)

Adding MSGAOD gives more dust over most of Africa (map below).







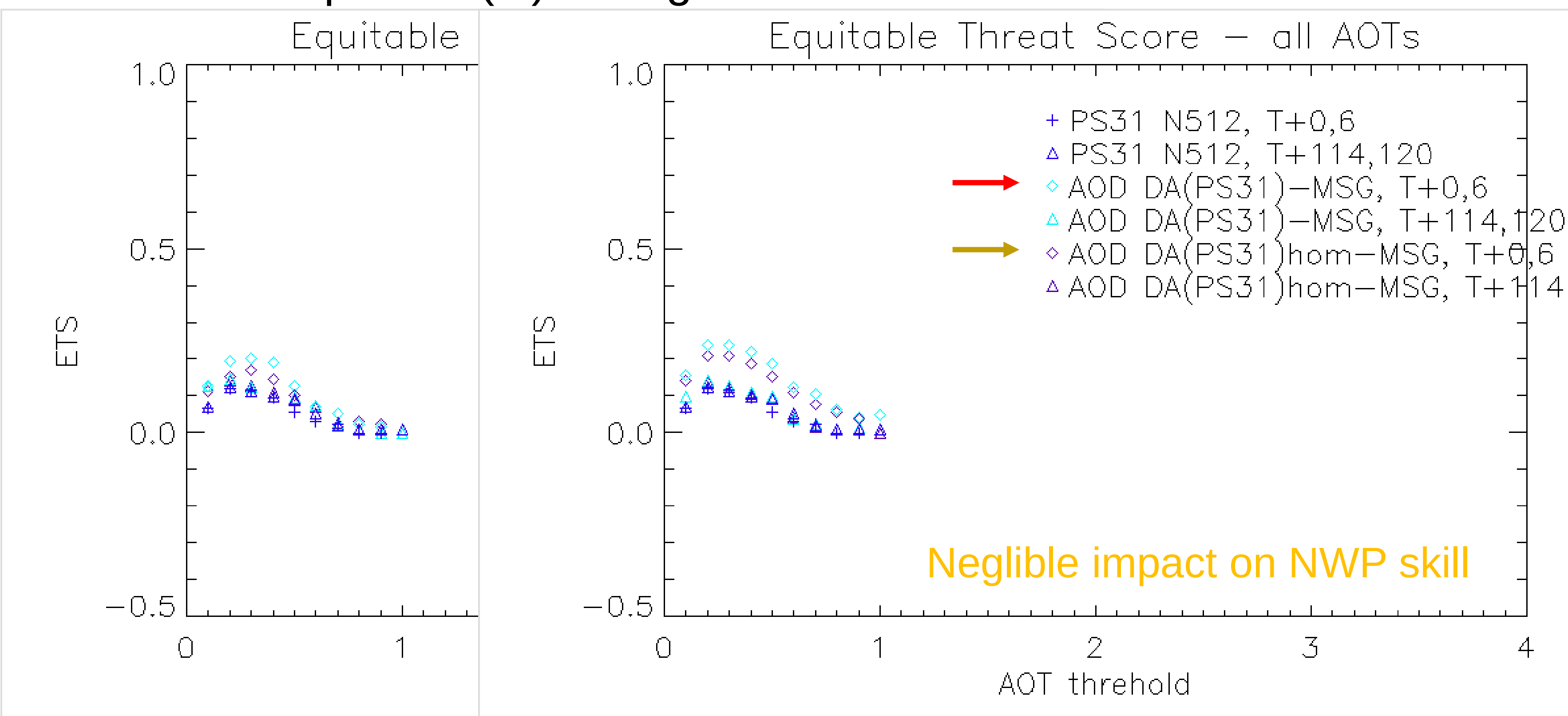
Winter 2011 trial (3) Forecast vs. AERONET

Left (Right): Global scores with (without) MSGAOD

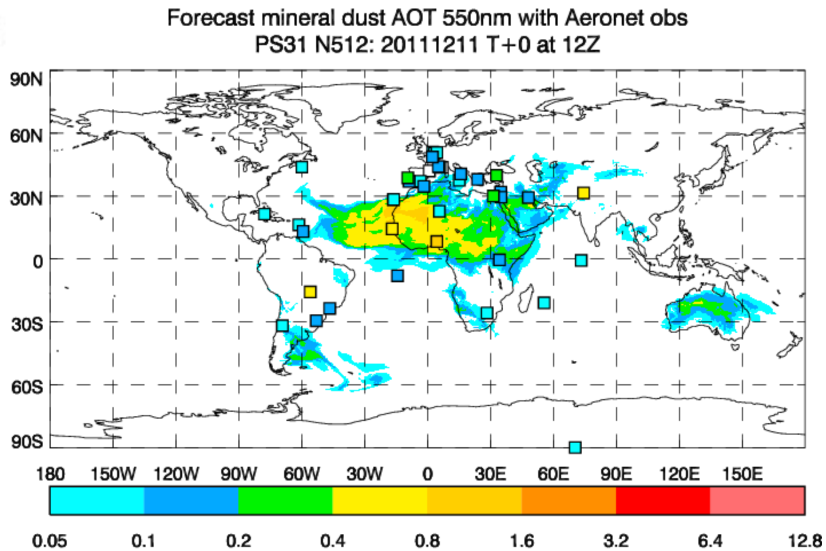
ETS scores (T+0,6) better/higher without MSG,

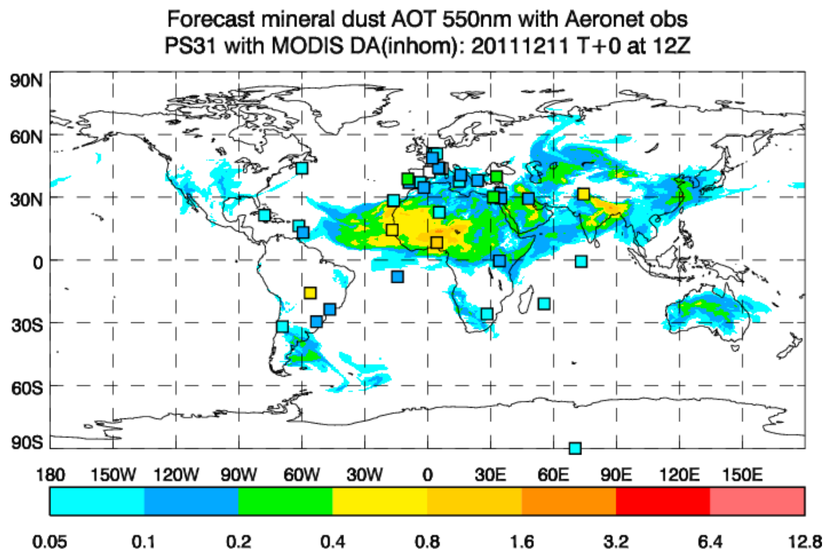
also true for regional scores (and coarse-mode)

Little impact of (in)homogeneous covariances.

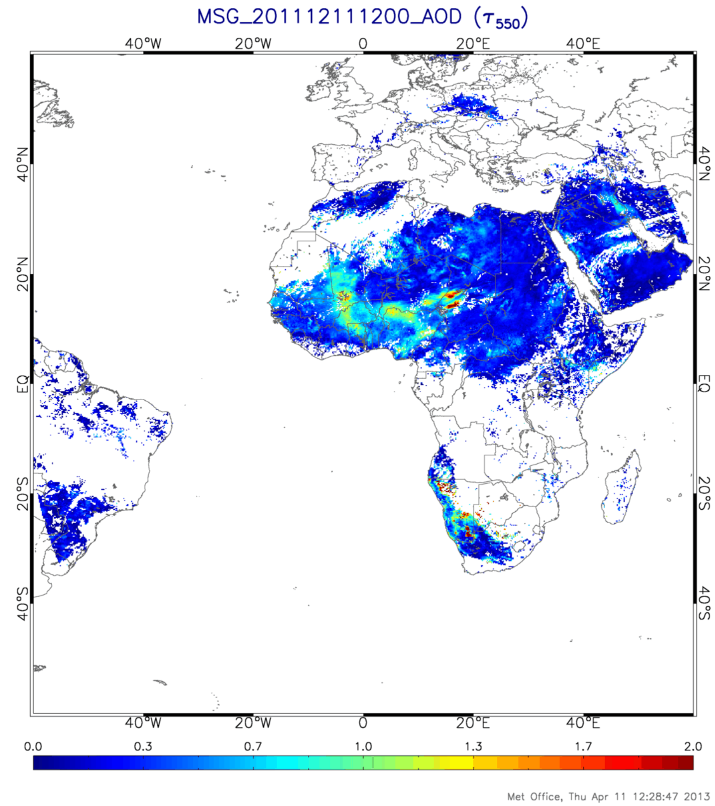


Currently operational

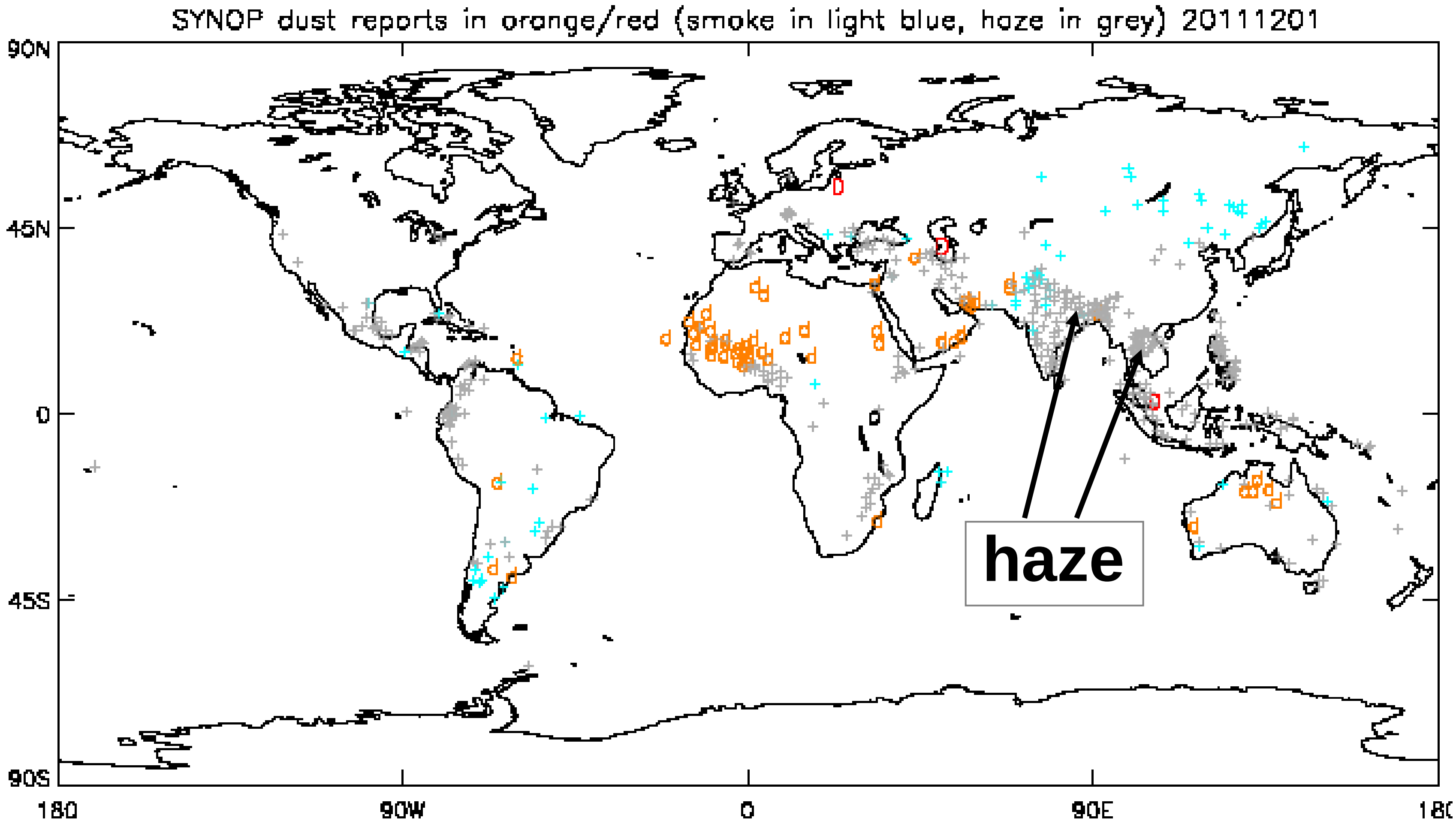




MSGAOD: an independent source for verification



Verification: comparison w/ Synop obs



Verification: Model inter-comparison (SDS-WAS)

against AERONET AOD (α<0.6) over
N Africa/Europe, Mediterranean, and Middle East

BSC_DREAM8b
DREAM8-MACC
NMMB-BSC
1/3 x 1/3 deg

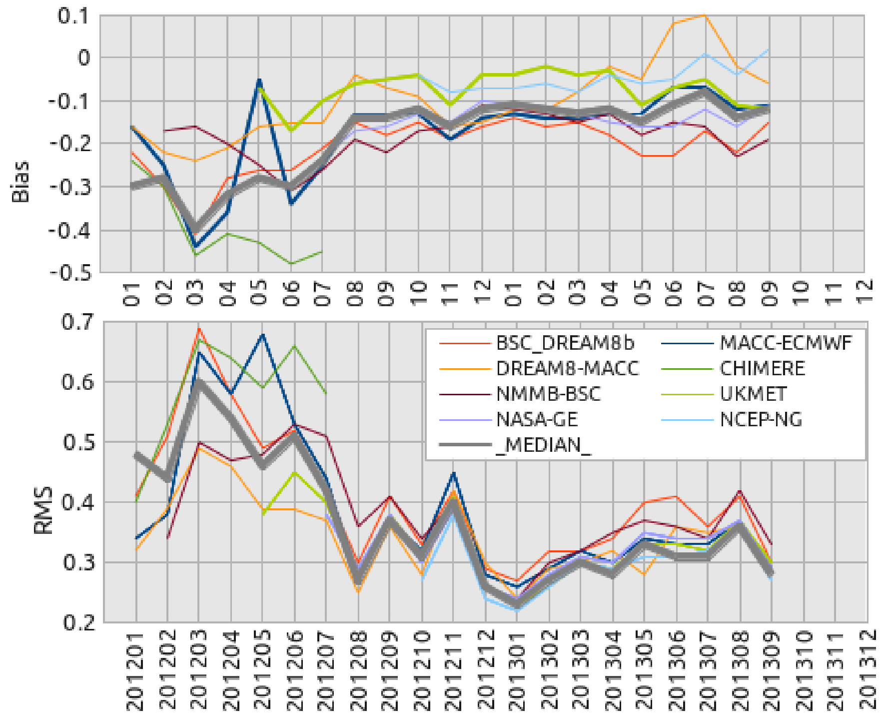
CHEMERE
1 x 1

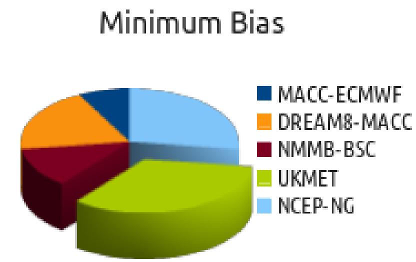
MACC-ECMWF
1 x 1

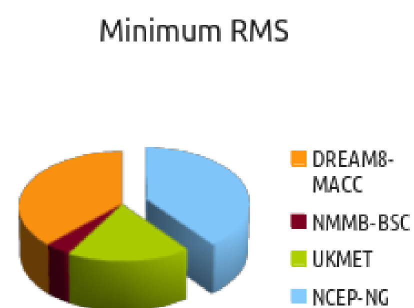
UKMET
0.35 x 0.23

NASA-GE
0.25 x 0.31

NCEP-NG
~1 x 1

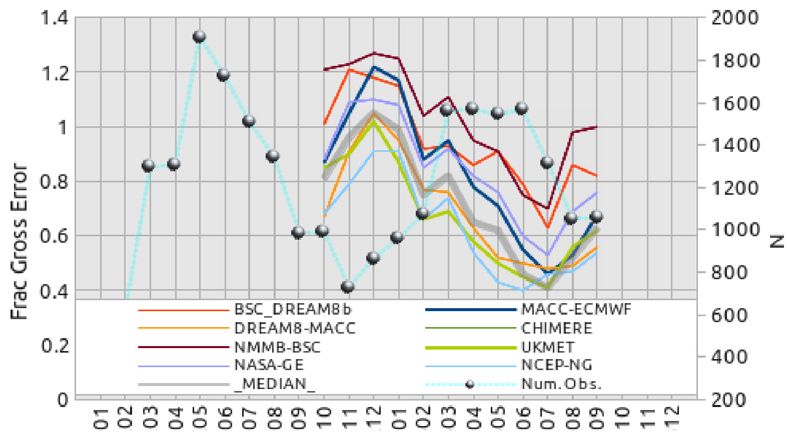


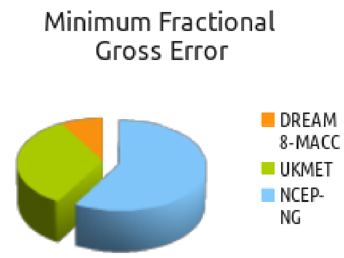




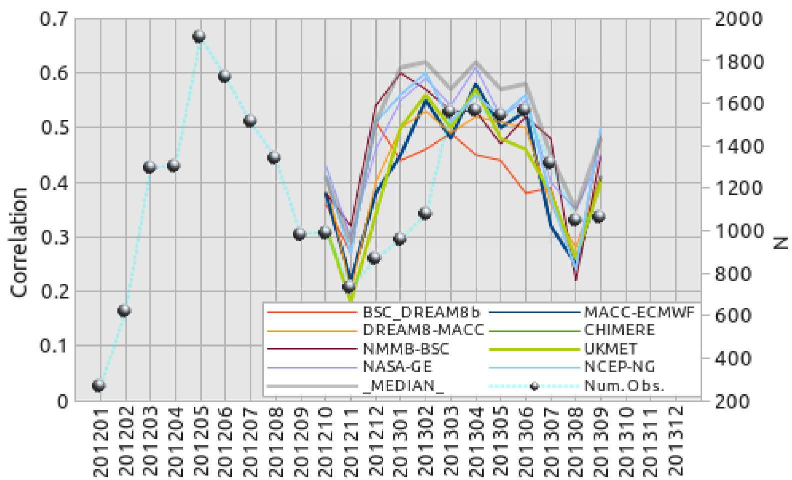
Data and model details at: WMO SDS-WAS http://sds-was.aemet.es

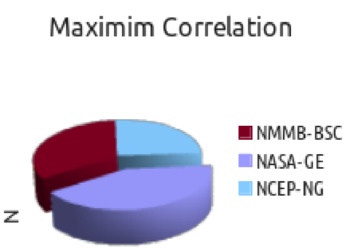
Model inter-comparison (SDS-WAS)





Stats biased with Num obs.?





Data courtesy: WMO SDS-WAS http://sds-was.aemet.es

SAMBBA 2012

South American Biomass Burning Analysis

Widespread seasonal burning of vegetation impacts:

- Visibility
- Air quality

Direct and Indirect Effects of BBA impacts:

- Radiation budget, clouds
- Surface temperatures
- Sensible & latent heat fluxes
- BL development, convection, precipitation

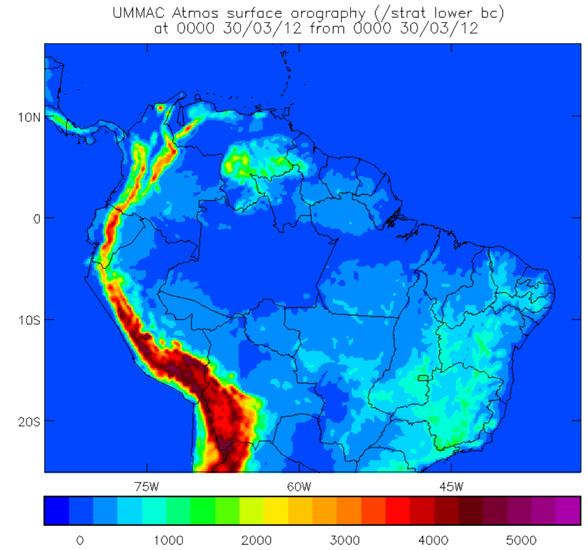
Changes in diffuse radiation → plant productivity

- Campaign Objective: Improve our understanding of the direct and indirect impacts of biomass burning aerosols for climate and NWP.
- 2 week field campaign (aircraft & ground-based) in Brazil, Sept/Oct 2012.

SAMBBA LAM

Jane Mulcahy

- 12km limited area model set-up over Brazil
- Initialised via 3D-Var
- Global model (25km) 3 hourly LBC's
- Prognostic biomass burning scheme
- 00Z → T+48; 18Z → T+120



Biomass Burning Scheme (CLASSIC, Bellouin et al 2011):

- BB = BBBC + BBOC components
- 3 modes: fresh, aged and in-cloud
- Aging from fresh (hydrophobic) to aged (hydrophillic) with a 6 hr e-folding timescale
- Condensation of VOCs: Mass x 1.62 → aged
- No interaction with radiation during campaign (*radiative impacts from climatology*)
- **Emissions**: GFAS v1.1 (MODIS-FRP) daily product (Kaiser et al 2012), 0.1° resolution

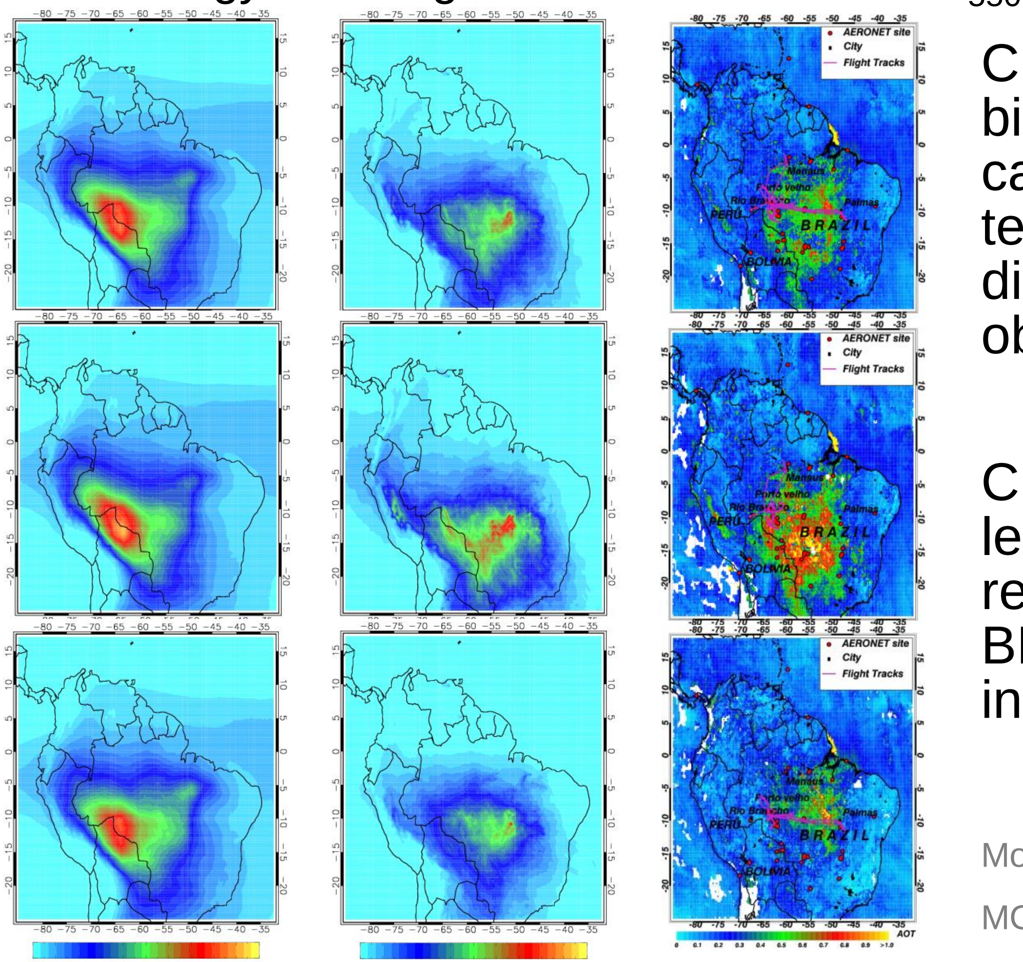
CLASSIC vs. NWP BBA Climatology

	NWP Climatology	CLASSIC Prognostic	MODIS AOD_{550}

14 Sep - 03 Oct Campaign avg.

14 – 22 Sep

23 Sep – 03 Oct



CLASSIC prognostic biomass scheme captures the temporal and spatial distribution of observed AOD.

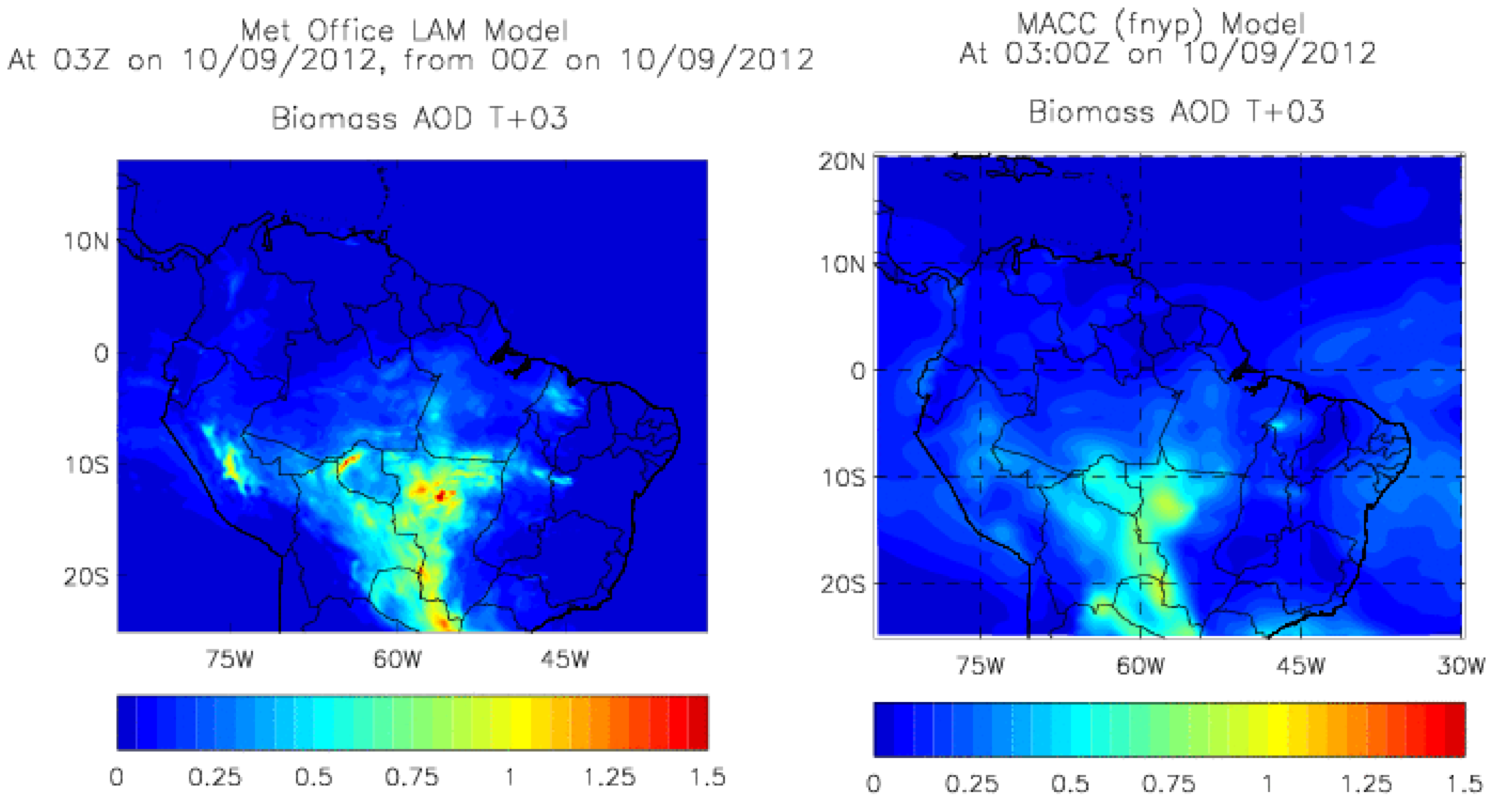
Climatology gives a less realistic representation of BBA – more aerosol in western Brazil.

Model Plots: Caroline Dunning

MODIS Plots: Sundar Christopher

LAM vs. MACC

The MACC aerosol forecasting system assimilates AOD using MODIS total AOD at 550nm.

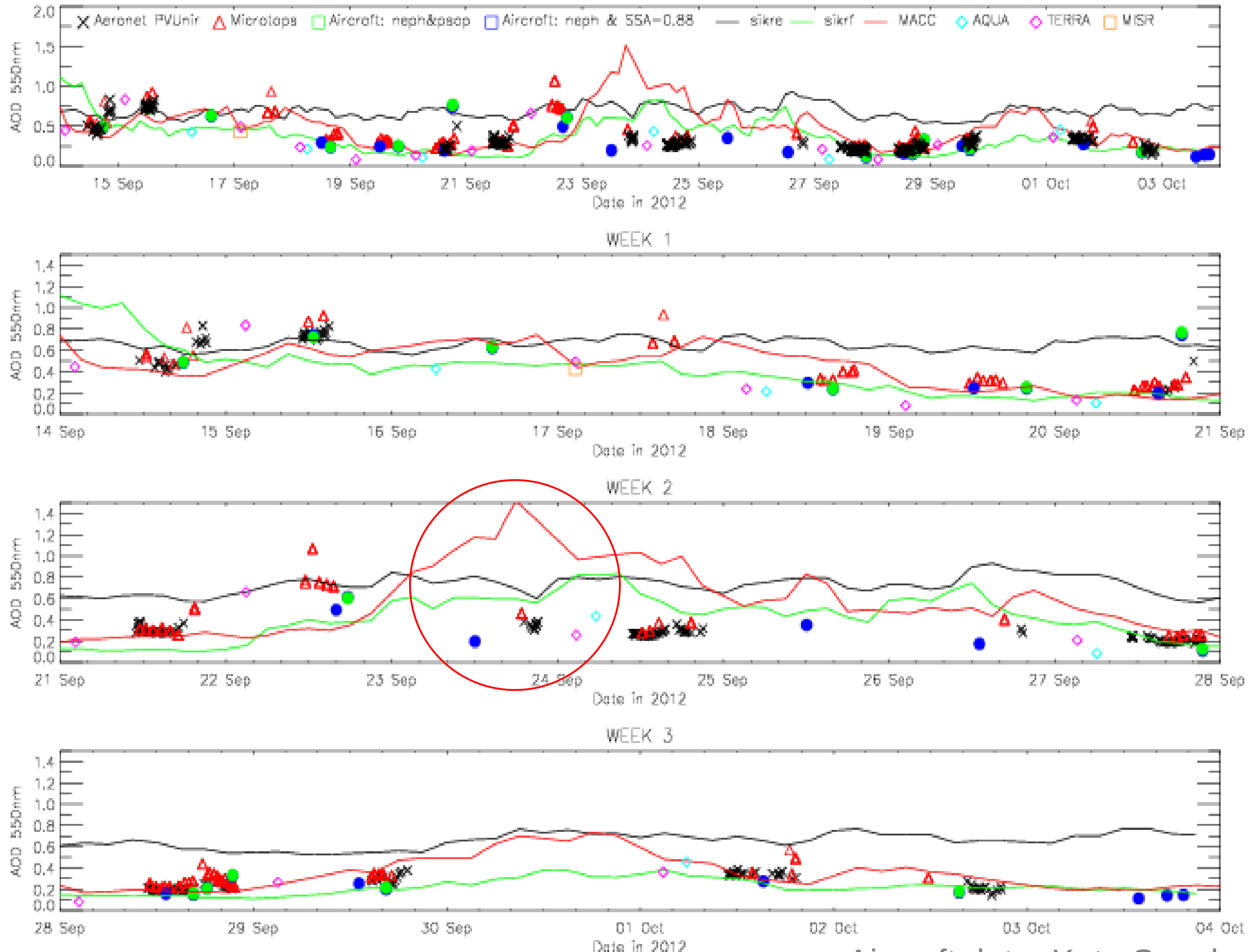


macc Monitoring atmospheric composition & climate GMES

AOD at Porto Vehlo

- Climatology not good representation, when compared against MACC or obs.
- Generally good agreement between MACC, CLASSIC and obs.
- Large variation 23-24 September, obs support CLASSIC over MACC.

Observations, satellites, model and MACC at Porto Vehlo



Aircraft data: Kate Szpek
Plots: Caroline Dunning

Upcoming model changes

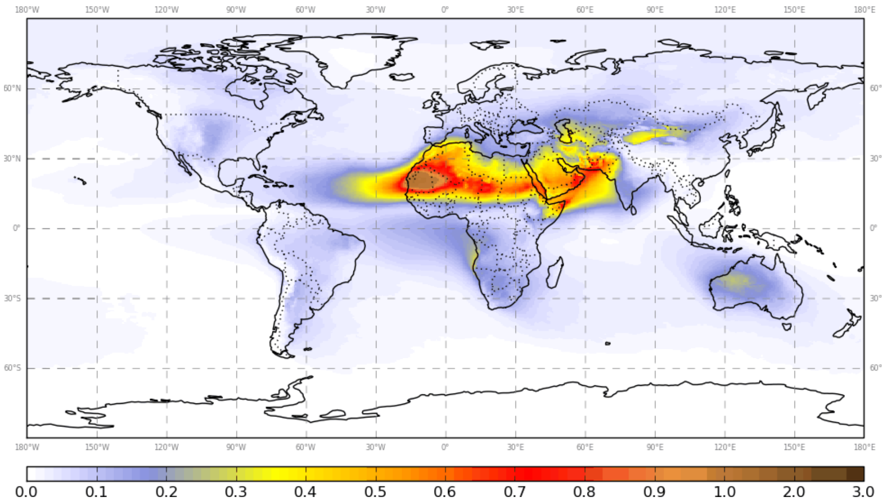
GA3.1 (N512 ~25km) current operational configuration

GA5.0 (N768 ~17km) configuration with ENDGame dynamics and a bunch of physics upgrades/changes

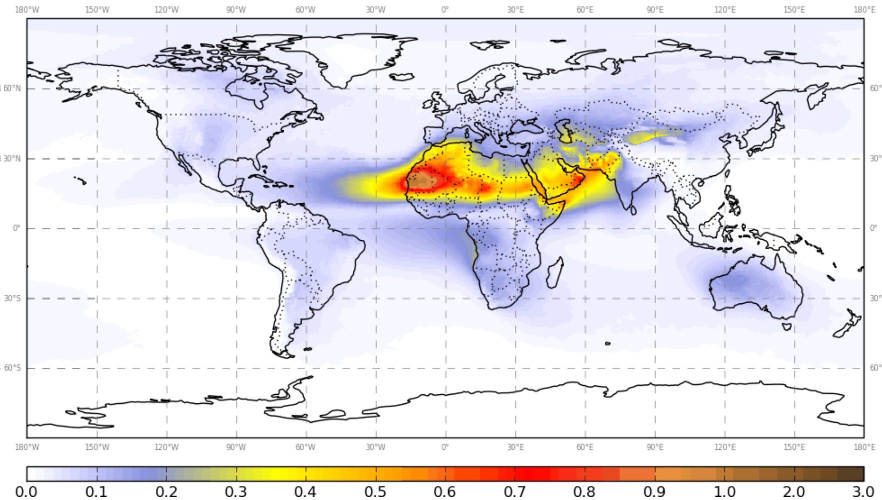
Impact of model changes

Malcolm Brooks

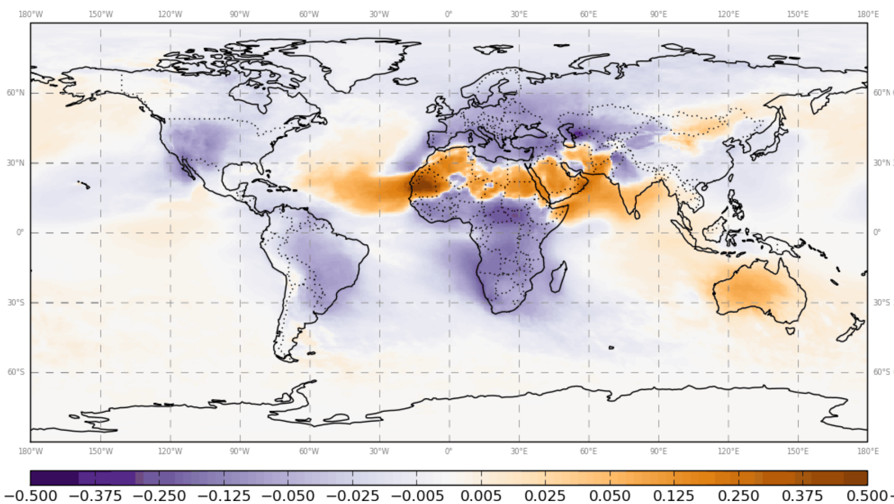
N512 GA3.1 Dust AOD at 550nm
Time mean 2012/07/04 12Z to 2012/09/20 12Z at T+120



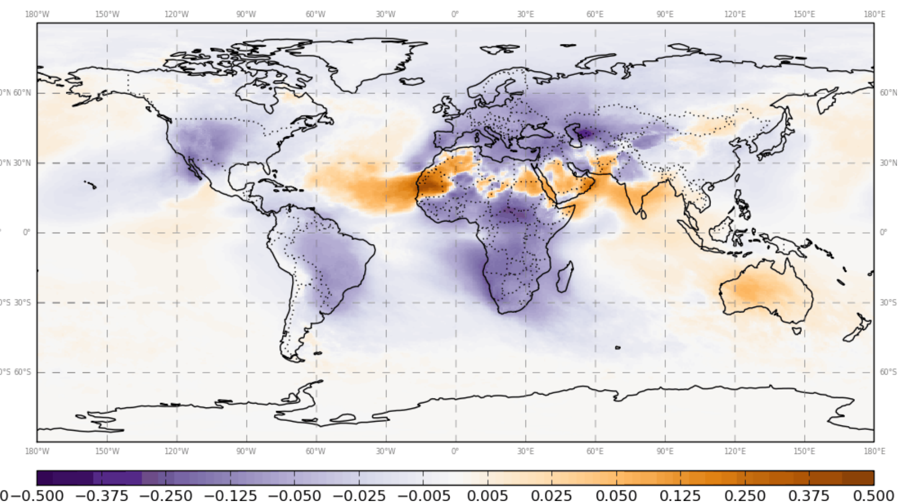
N768 GA5#99.2 Dust AOD at 550nm
Time mean 2012/07/04 12Z to 2012/09/20 12Z at T+120



N512 GA3.1 difference from T+0 Dust AOD at 550nm
Time mean 2012/07/04 12Z to 2012/09/20 12Z at T+120



N768 GA5#99.2 difference from T+0 Dust AOD at 550nm
Time mean 2012/07/04 12Z to 2012/09/20 12Z at T+120

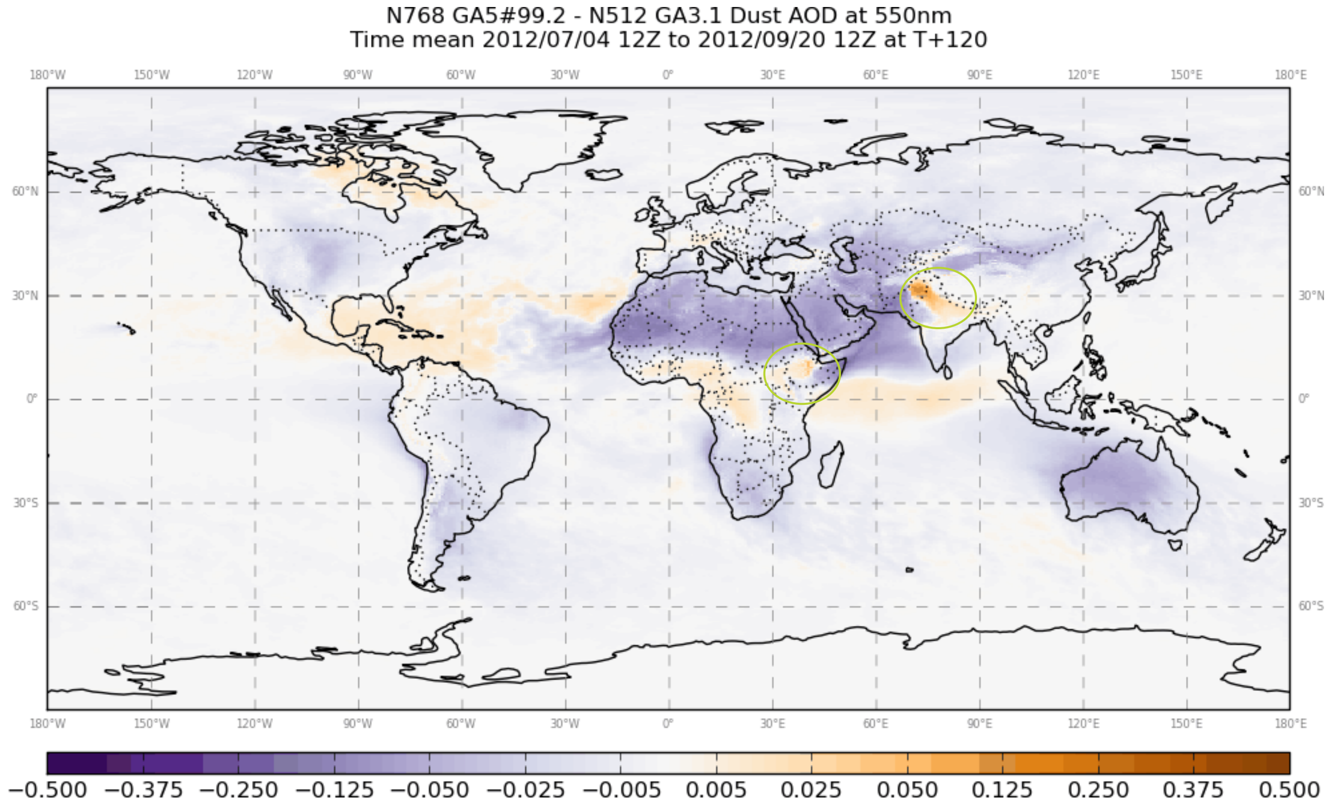


GA5 – GA3.1

Negligible differences – no further tuning required!

New dynamics,
Flow around
orography

Model wind

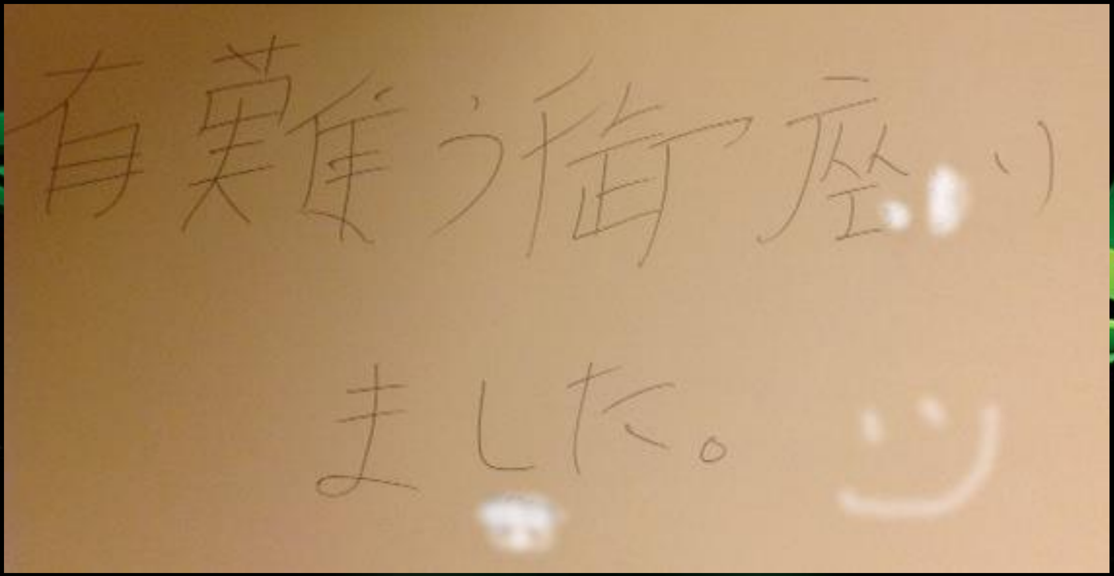


Summary & Future Plans

- *Global dust forecasting with MODIS assimilation is now operational – encouraging results (AERONET and model comparison); negligible impact on NWP index*
- Rooms for improvement:
  - Improvement to MSGAOD: 1DVar approach (Francis et al 2012)
  - More satellite obs: MODIS over ocean, MODIS Land selection and QC, VIIRS, other..
  - Look at diurnal cycle (MSGAOD), bias correction
  - Data thinning/superobbing?
  - Model: use of UKCA-MODE and more aerosols – sea salt, biomass burning
  - Evaluation of satellite and AERONET AOD needs some standardisation/ tools in house

Summary & Future Plans

- *Initial implementation and evaluation of BBA scheme in LAM is very promising and motivates further testing in "global" NWP model*
  - Started looking at radiative impacts of BBA in LAM (U. Leeds)
  - Internal aim to implement new aerosol scheme GLOMAP-MODE in next ESM has slowed further work involving CLASSIC with possible simplified GLOMAP-MODE scheme being investigated in the future
- *Dust forecasting trials with new model changes (GA5.0) comparable to the existing suite (or better to some extent)*



Questions and answers