Recent developments in aerosol forecasting at the Met Office

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

*Met Office, Exeter, UK*
Contents

This presentation covers the following areas

• Recap
  • Dust in Met Office NWP (LAM, Global)

• Ongoing activities
  • Operational global dust forecasting and DA (results from winter 2011 trial)
    • Model inter-comparison (SDS-WAS)
  • BBA in SAMBBA LAM
  • Upcoming changes (aerosol strategy for global NWP)

• Summary
Recap
## Dust in the Met Office NWP Progress timeline

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<tr>
<td><strong>Area</strong></td>
<td>Limited area (South-Asia CAM)</td>
<td>Global</td>
</tr>
<tr>
<td><strong>Resolution</strong></td>
<td>~12km</td>
<td>~25km</td>
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<td><strong>Forecast lead time</strong></td>
<td>6 days</td>
<td>6 days</td>
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<tr>
<td><strong>Dust Scheme</strong></td>
<td>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</td>
<td>2-bin (0.1-2 μm, 2-10μm) version after Woodward (2001,2011) Undergoes advection &amp; deposition but no interaction with radiation (comes from dust climatology)</td>
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<td></td>
<td>Undergoes advection &amp; deposition (wet &amp; dry); Includes direct radiative effect</td>
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<td><strong>Data Assimilation</strong></td>
<td>3D-Var; SEVIRI dust AOD (over land, Pradhan &amp; Saunders 2009, Brindley &amp; Russell 2009):</td>
<td>No assimilation (expected in 2013)</td>
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<td>Obs variable: AOD; Control variable: Dust MMR (after Benedetti et al 2009)</td>
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Since then…
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:

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

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

\(\tau\) dust AOD (at 550nm)

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

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

\(\rho\) density of model layer

\(p_j\) pressure at theta layer boundaries
Observations – MSGAOD (based on IR obs)

Reject obs where (VZA $> 70^\circ$) and (SZA $> 80^\circ$)

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

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 $T_{\text{skin}}$ over 28 days (retrieval window)
  - AOD retrieval is sensitive to $\Delta BT$ in the order: $\pm 1K (\Delta BT) \rightarrow 0.15 (\tau)$
- 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)
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 linear 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

- $\sigma_o$ (including representivity error) is taken as:
  - 0.37 for MSGAOD
  - 0.222 for SATAOD (MODIS)
- Higher $\sigma_o$ 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.

Negligible impact on NWP skill
Currently operational

MSGAOD: an independent source for verification
Verification: comparison w/ Synop obs

SYNOP dust reports in orange/red (smoke in light blue, haze in grey) 20111201

haze
Verification: Model inter-comparison (SDS-WAS)

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

- BSC_DREAM8b
- DREAM8-MACC
- NMMP-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](http://sds-was.aemet.es)
Model inter-comparison (SDS-WAS)

Data courtesy: WMO SDS-WAS http://sds-was.aemet.es
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 $\rightarrow$ 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.
• 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}

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.
AOD at Porto Vehlo

Observations, satellites, model and MACC 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.
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 GAS#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 GAS#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