Observations and modeling of aerosol and cloud properties
for climate studies
Paris, France, 12-14 September 2011

The MACC/ECMWF aerosol analysis and forecast system: Some recent results

J.-J. Morcrette, A. Benedetti, L. Jones, J.W. Kaiser, M. Razinger, M. Suttie
M. Janiskova, O. Stiller, A.J. Simmons

ECMWF, Reading, UK

The MACC/ECMWF aerosol analysis and forecast

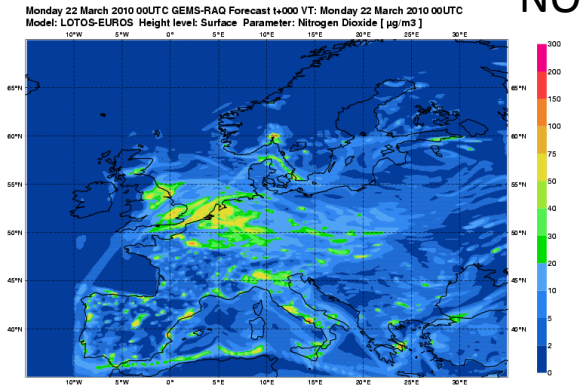
- ECMWF for its operational analyses and forecasts ingest gigabytes of observational data every day and produces weather forecast(s) of temperature, humidity, wind, ..
- Since 2006, with the EU FP7 **GEMS** then **MACC** projects, ECMWF has been producing experimental analyses and forecasts of the same meteorological parameters PLUS reactive gases, greenhouse gases, and aerosols. Near Real Time forecasts started in September 2008.
- This presentation **quickly** surveys some recent and ongoing work dedicated to **aerosols**:
  - Introduction
  - Prognostic aerosols in the IFS
  - Some aerosol events
  - On-going work

MACC Daily Service Provision

http://www.gmes-atmosphere.eu

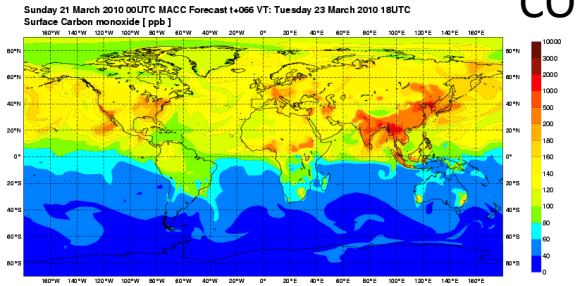
Air quality

NO2



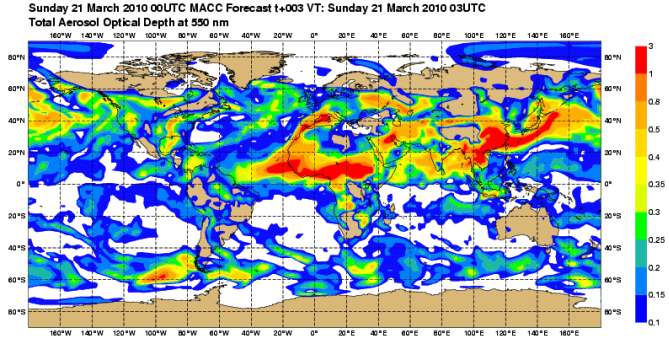
Global Pollution

CO

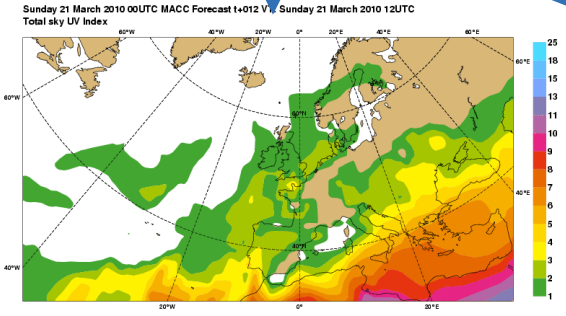


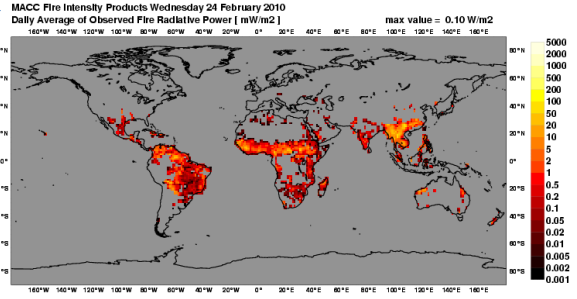
Biomass burning

Aerosol



UV index





NRT since September 2008

Quick overview of the MACC/ECMWF aerosol analysis and forecasting (original) system

Forward model

12 aerosol-related prognostic variables added to the existing prognostic variables (T, wind, q, O3, Ps)
* 3 bins of sea-salt (0.03 – 0.5 – 0.9 – 20 μm)
* 3 bins of dust (0.03 – 0.55 – 0.9 – 20 μm)
* Black carbon (hydrophilic and –phobic)
* Organic carbon (hydrophilic and –phobic)
* SO_2 -> SO_4

Physical processes include:

•emission sources (some of which updated in NRT, i.e.fires),
•horizontal and vertical advection by dynamics
•vertical advection by vertical diffusion and convection
•aerosol specific parameterizations for dry deposition, sedimentation, wet deposition by large-scale and convective precipitation (SS, OM, BC, SU) and hygroscopicity (SS, OM, BC, SU).

Morcrette et al., 2009, JGR

Analysis

Integrated in the ECMWF incremental 4D-Var

Control variable is formulated in terms of the total aerosol mixing ratio. Soon to come: fine and coarse mode. Increments in total mass are repartitioned into the single species according to their fractional contribution to the total.

Background error statistics have been computed using forecasts errors as in the NMC method (48h-24h forecast differences).

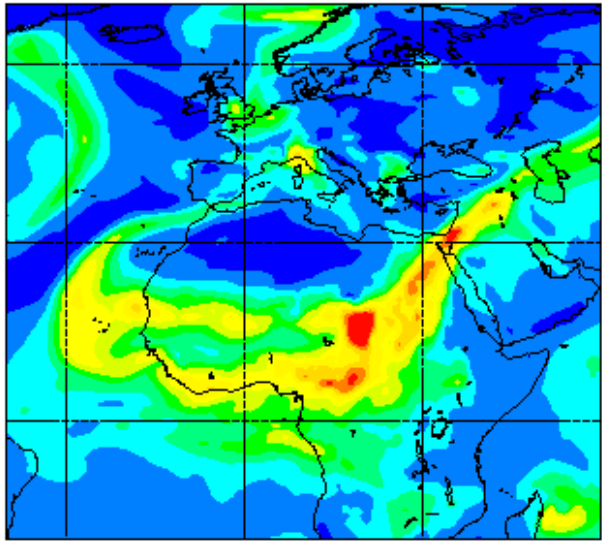
Assimilated observations are the MODIS Aerosol Optical Depths (AODs) at 550 nm over land and ocean. Observation errors are prescribed fixed values as a result of investigation to implement the variational bias correction (not active).

Benedetti et al., 2009, JGR

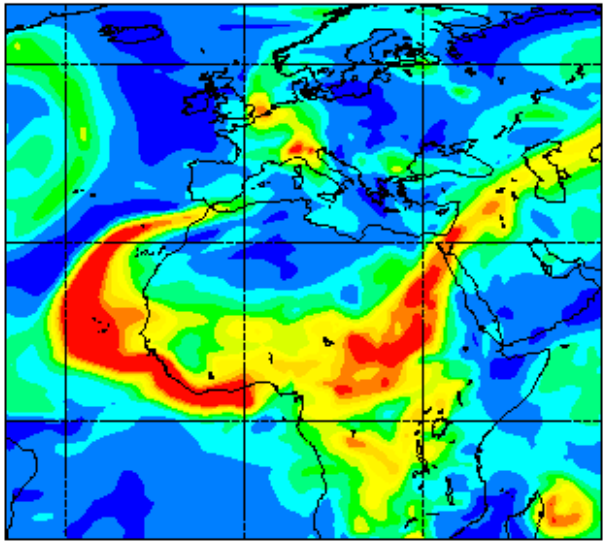
Evaluation with MODIS/SEVERI and AERONET

Saharan dust outbreak: 6 March 2004

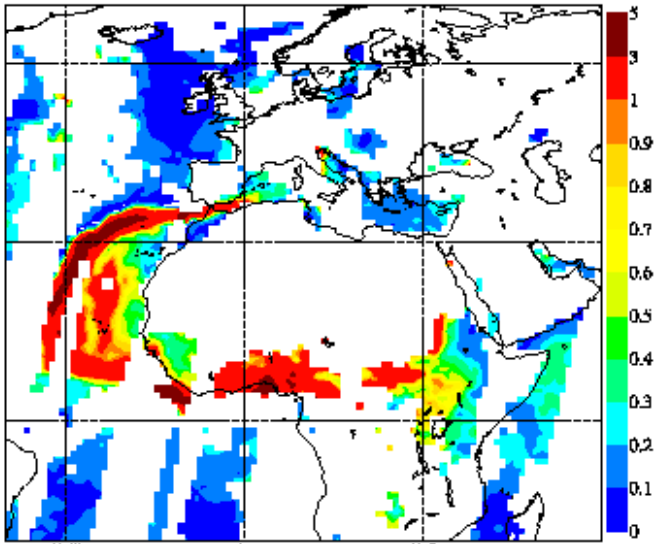
Model simulation



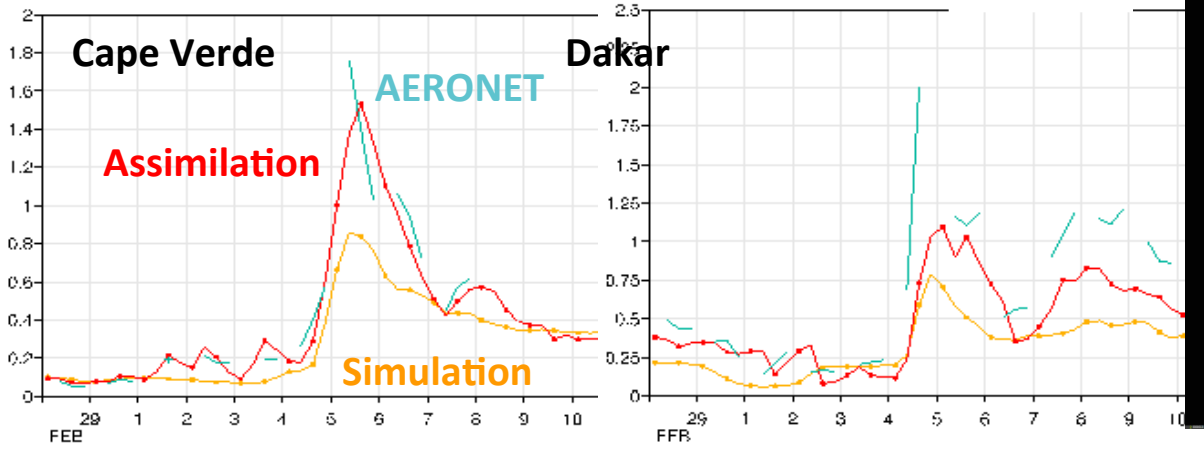
Assimilation

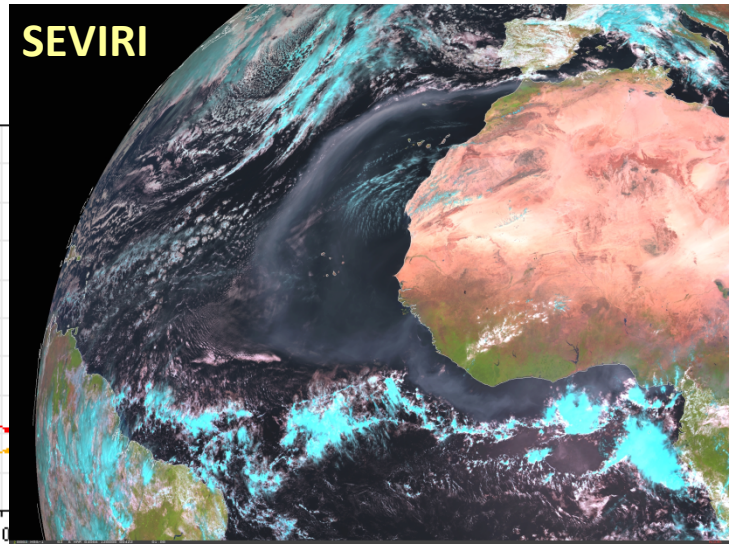


MODIS



Aerosol optical depth at 550nm (upper) and 670/675nm (lower)

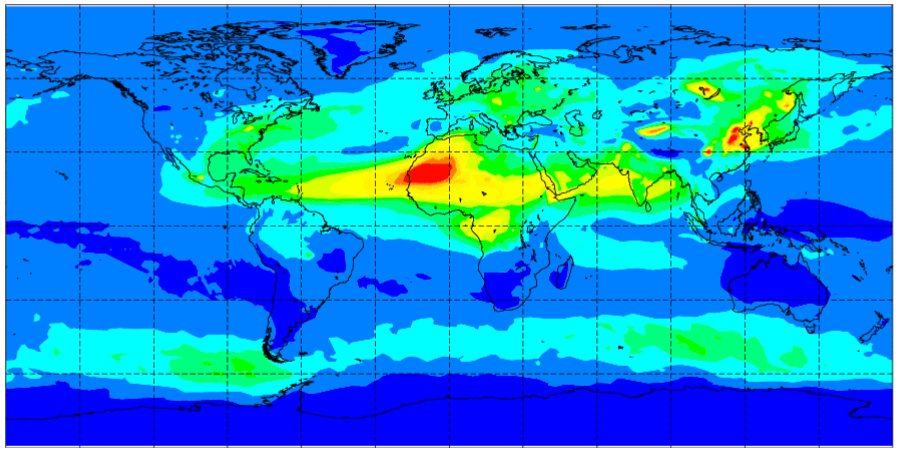




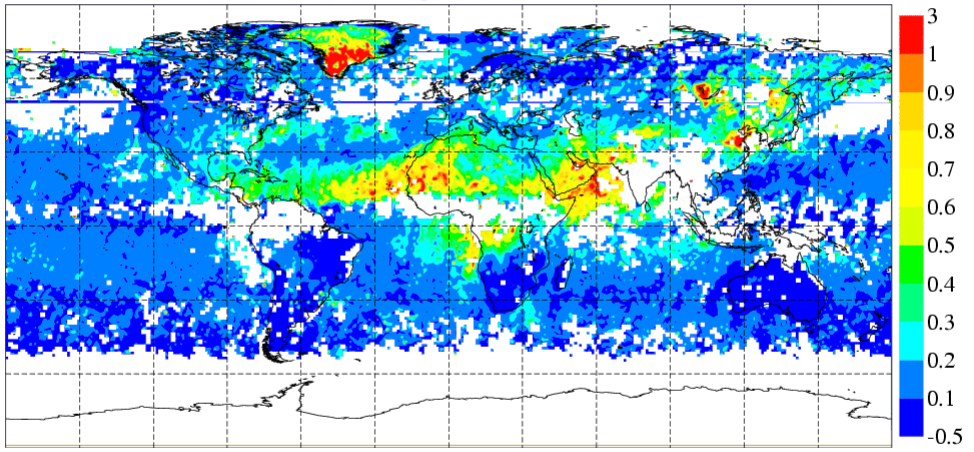
Morcrette et al., 2009; Benedetti et al., 2009

Comparison of GEMS simulated and analysed aerosol optical depth with MODIS and MISR for July 2003

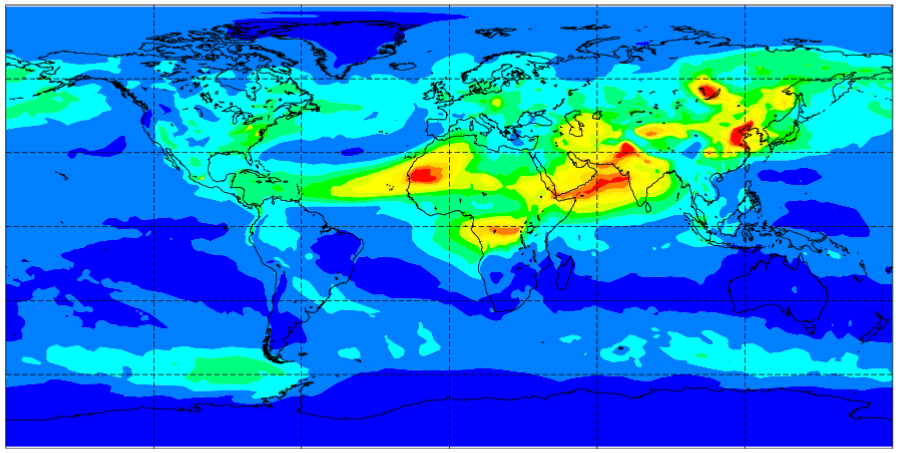
Aerosol Optical Depth at 550 nm from Unconstrained Model Run
July 2003



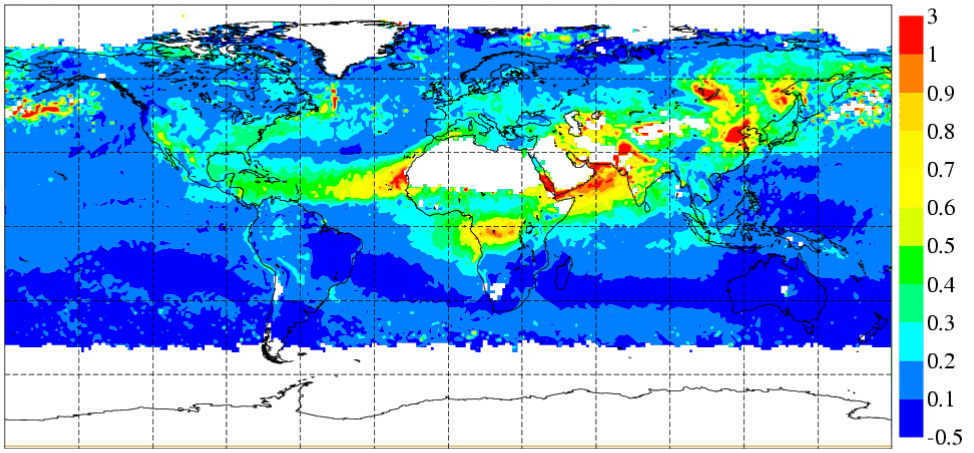
MISR Terra Aerosol Optical Depth at 557.5 nm [unitless]
July 2003



Aerosol Optical Depth at 550 nm for Reanalysis using MODIS AOD
July 2003

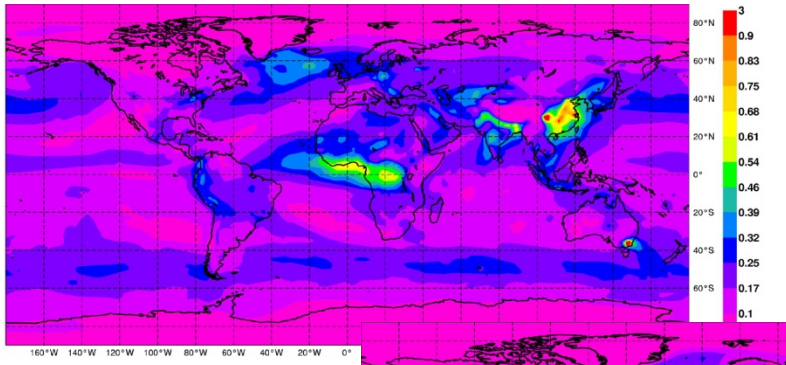


MODIS Terra MOD08-M3.005 Aerosol Optical Depth at 550 nm [unitless]
July 2003



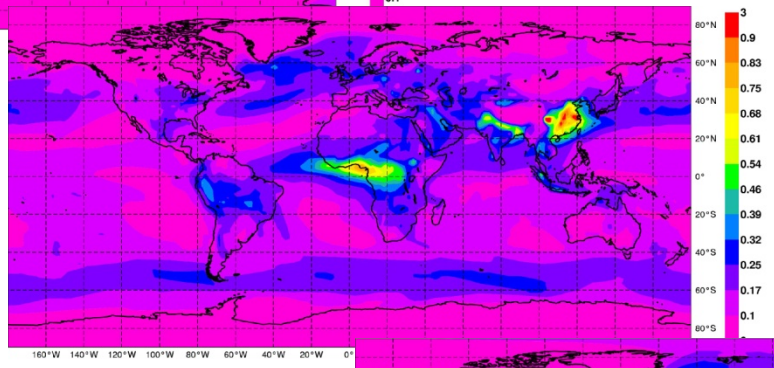
Morcrette et al., 2009; Benedetti et al., 2009

Total aerosol optical depth

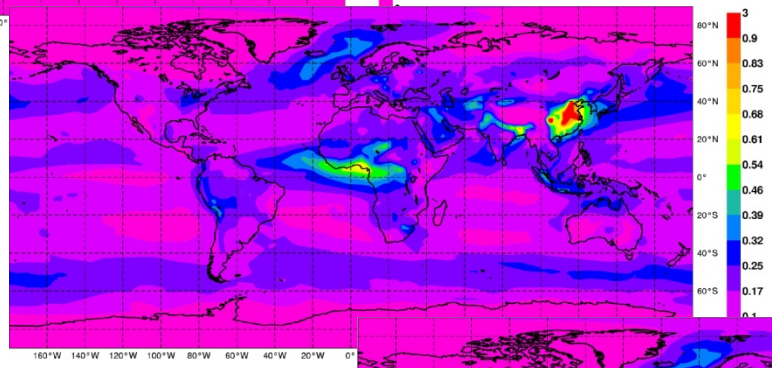


January 2003

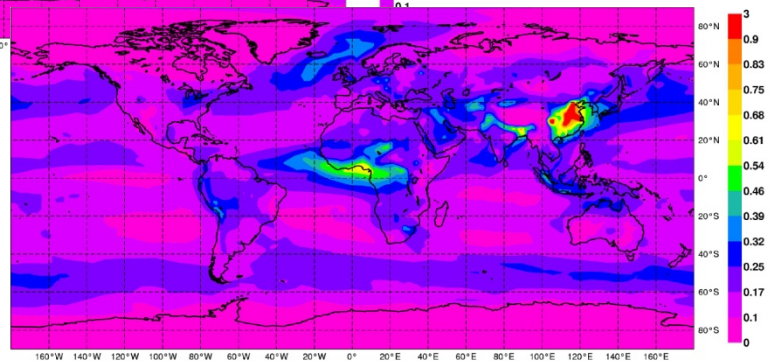
- January 2003: increased AOD over south-eastern Australia as a result of bush fires



2004



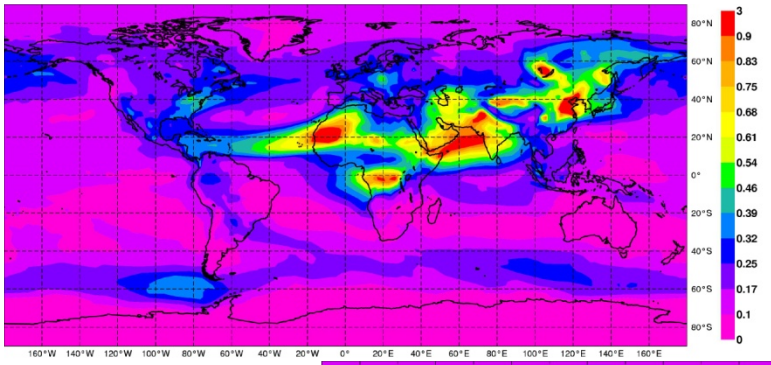
2005



2006

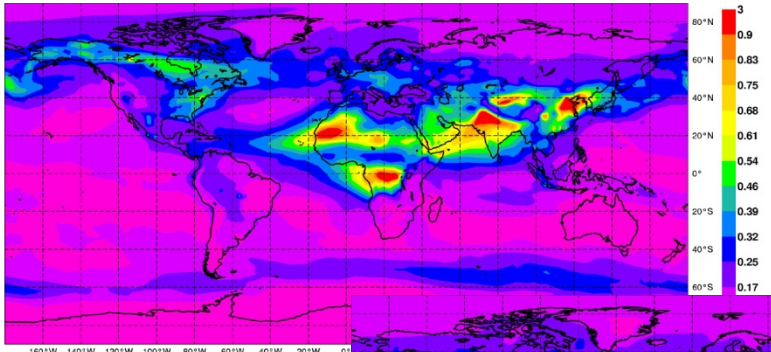
- Low AOD-month with just a few hot spots (India, China and West Africa).
- Strip of large AOD at the foot of the Himalaya is a constant feature, due to trapped pollution coming from the Indian sub-continent.
- Large values of AOD with little seasonal and inter-annual variability over China, associated with anthropogenic pollution.
- Winter AOD maximum of varying inter-annual strength off the coast of West Africa at the Equator associated with biomass burning of the tropical savannah

Total aerosol optical depth

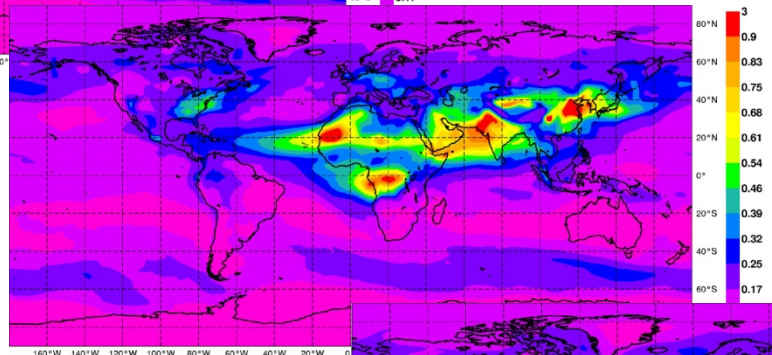


- July 2003: AOD maxima over Siberia associated with wild fires. This signature is also present in the CO field which is independently analyzed.
- July 2004: presence of a large aerosol load in the North-West of America connected with pollution transport from East Asia.

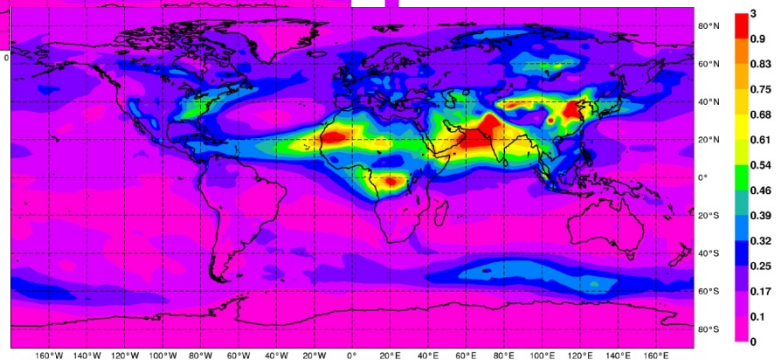
July 2003



2004



2005



2006

- Biomass burning over West Africa and desert dust emissions from the Sahara are the main “constant” features
- Aerosol load in the Indian Ocean associated to strength of the monsoon
- The winter hemisphere usually presents larger values of AOD over the oceans connected to more intense circulation and increased production of maritime aerosols with inter-annual variability dependent on that of wind intensity at the ocean surface.

Sydney dust storm, 23-09-09

BBC Low graphics | Help

NEWS LIVE BBC NEWS CHANNEL

News Front Page

Page last updated at 10:42 GMT, Wednesday, 23 September

Desert dust storm chokes Sydney

Sydney's red dust has been blown from the outback

A large stretch of Australia's east coast, including the largest city Sydney, has been shrouded in red dust blown in from the desert outback.

Visibility in Sydney was so bad that flights were diverted and harbour ferry traffic disrupted.

ABC News

NewsRadio Now playing

Video

News Home | Just In | Australia | World | Business | Entertainment | Weather

DUST STORM Video, your pics and comments

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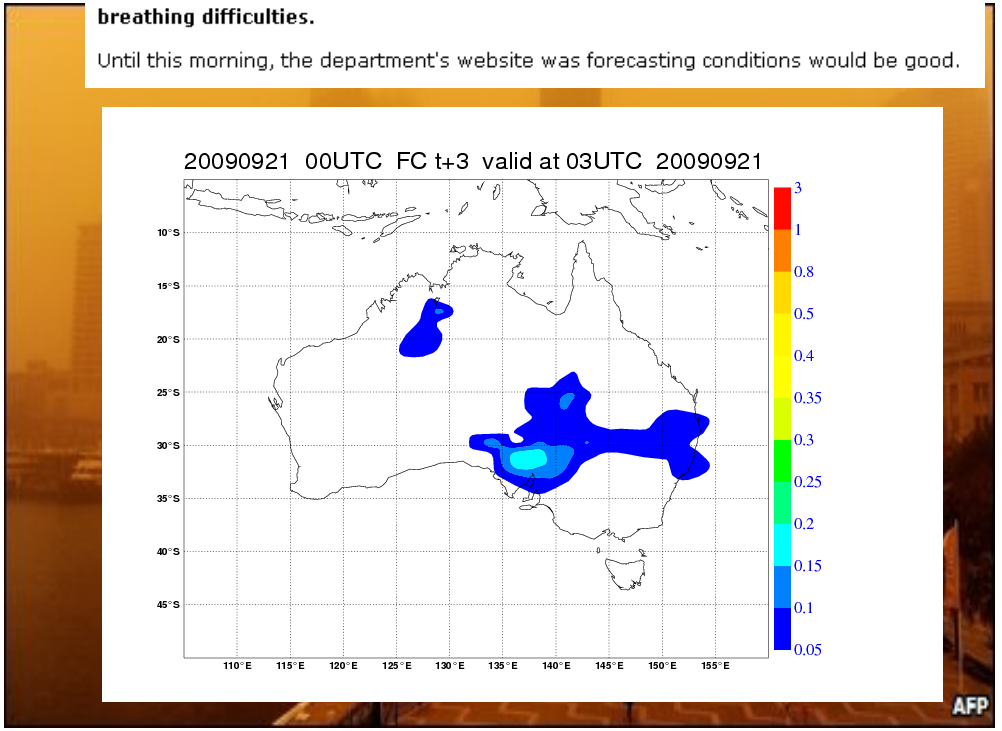
Dept admits error in air quality forecast

Posted 11 hours 54 minutes ago
Updated 11 hours 51 minutes ago

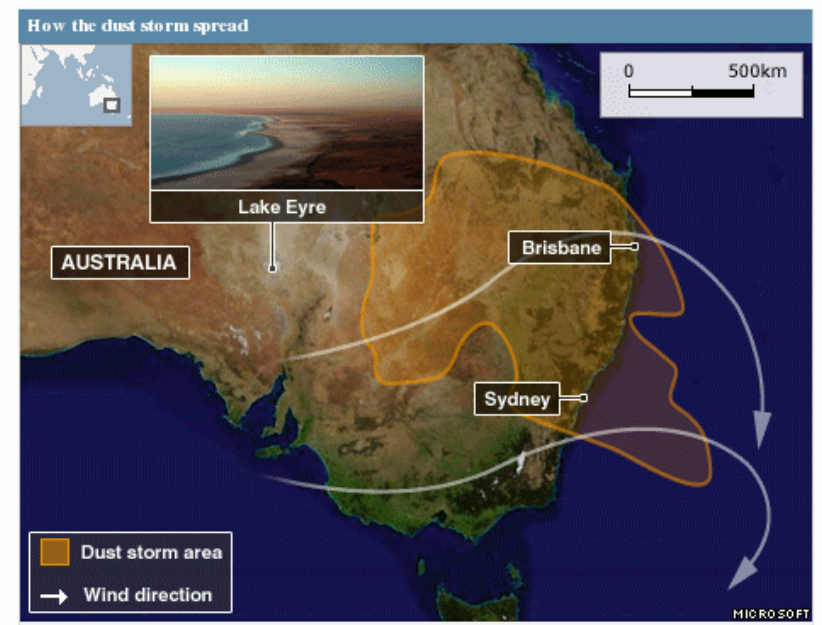
The New South Wales Environment Department has admitted its forecast for air quality in Sydney today was wildly wrong after a dust storm prompted hundreds of emergency calls due to breathing difficulties.

Audio: Respiratory expert Dr Christine Jenkins speaks to ABC Local Radio (ABC News)

Until this morning, the department's website was forecasting conditions would be good.

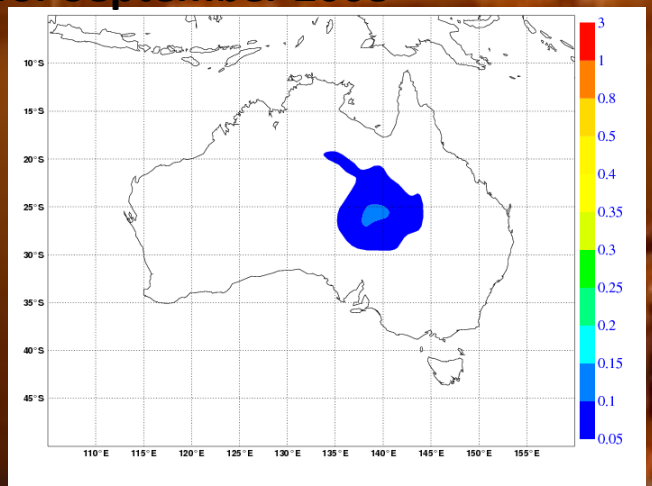


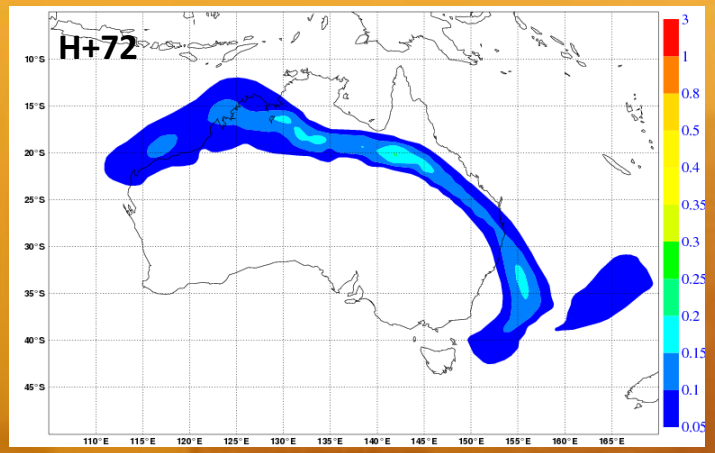
Sydney dust storm, 23-09-09

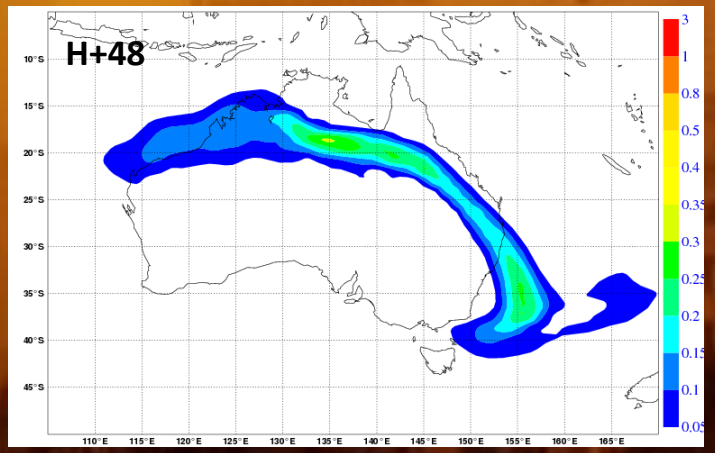


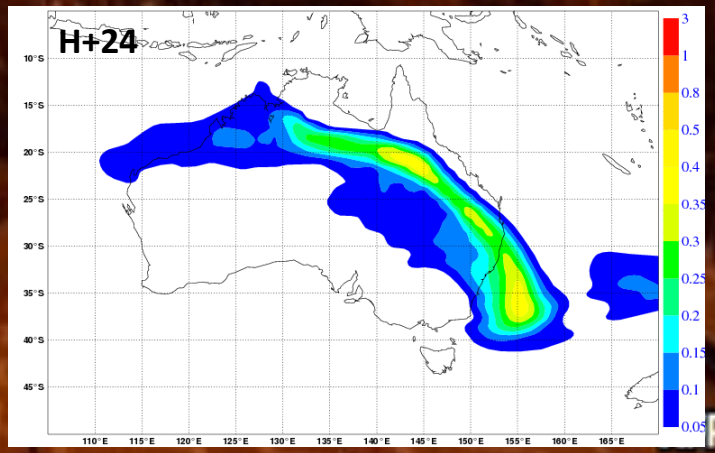
- A cold front combined with strong winds whipped up topsoil from the dried-out Lake Eyre basin and swept across New South Wales spreading about 600km along the east coast

Aerosol optical depth for desert dust: monthly average for September 2008

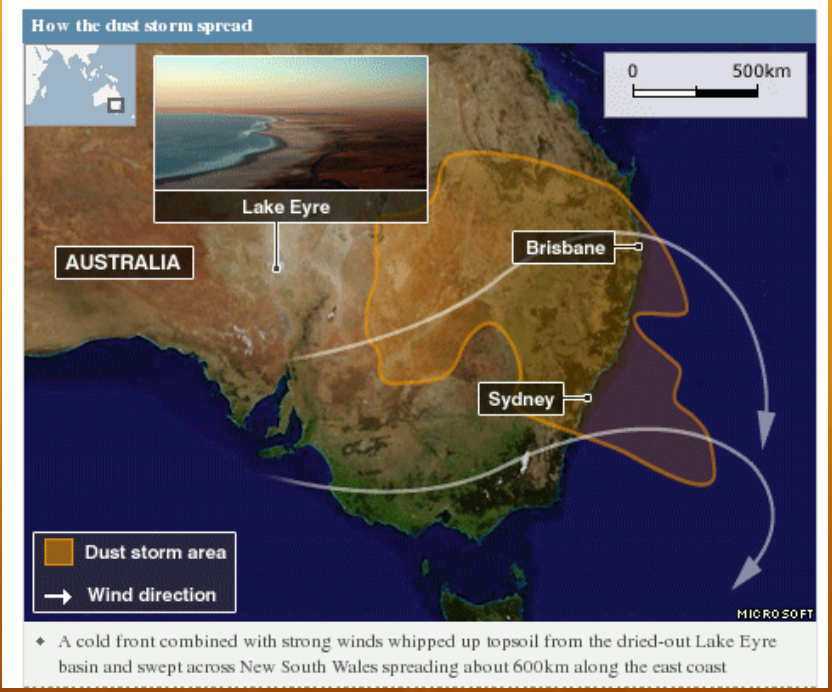






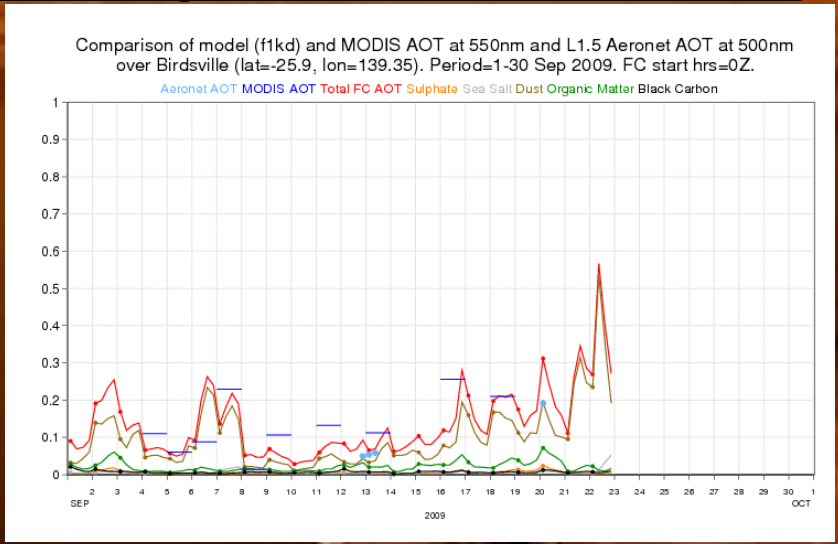


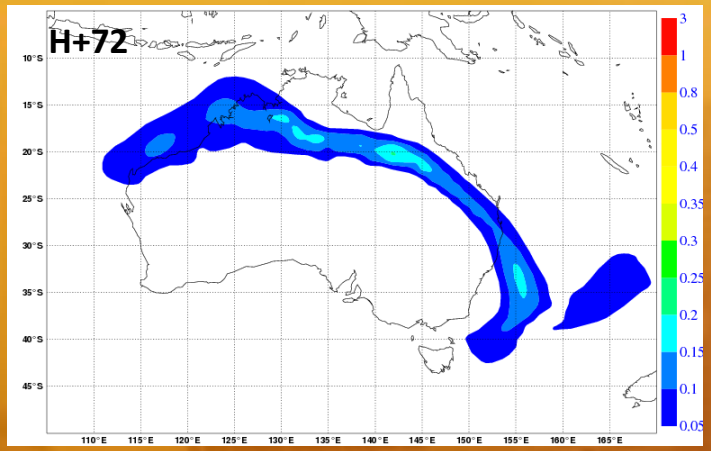
Sydney dust storm, 23-09-09

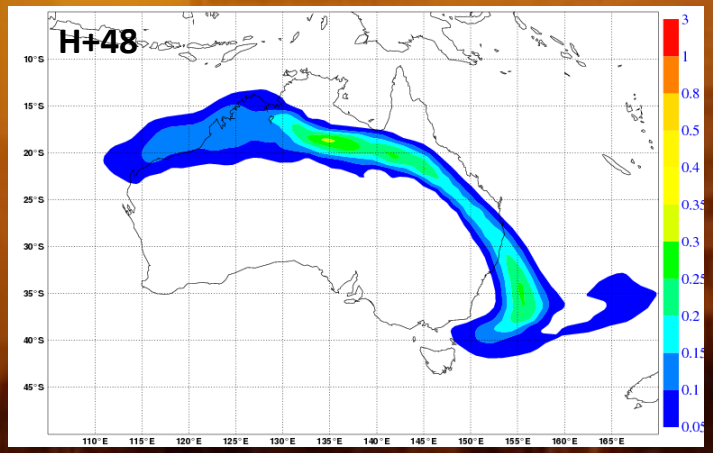


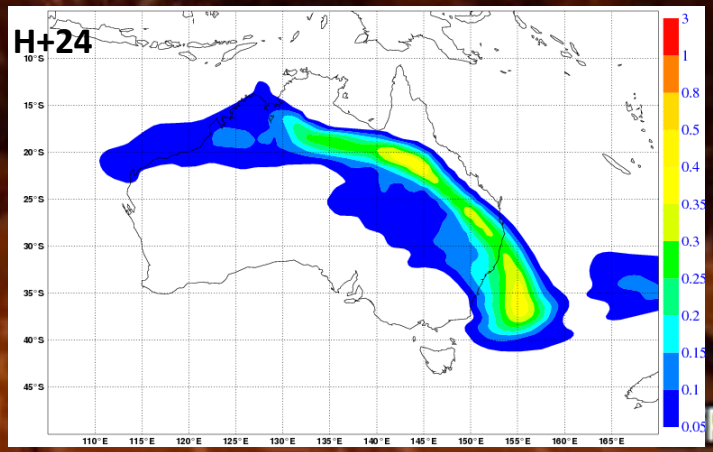
- A cold front combined with strong winds whipped up topsoil from the dried-out Lake Eyre basin and swept across New South Wales spreading about 600km along the east coast

Verification using AERONET data from Birdsville

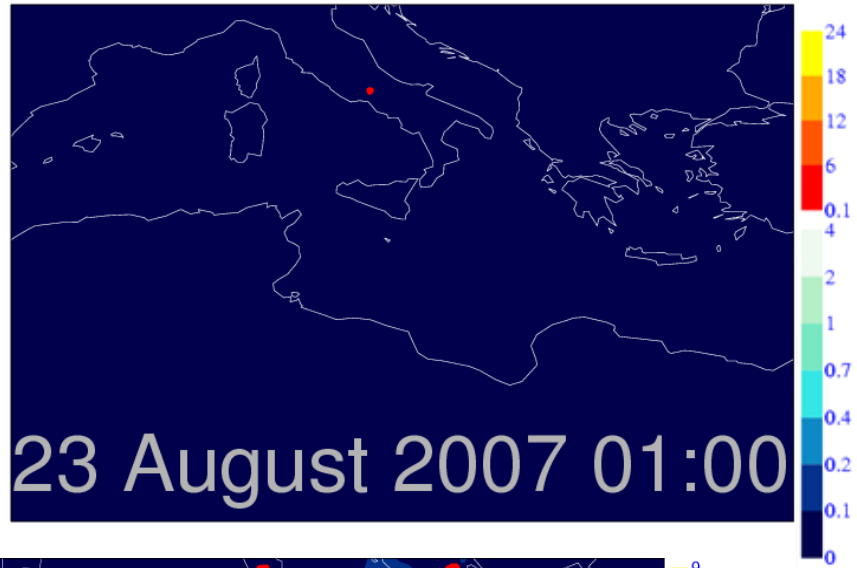








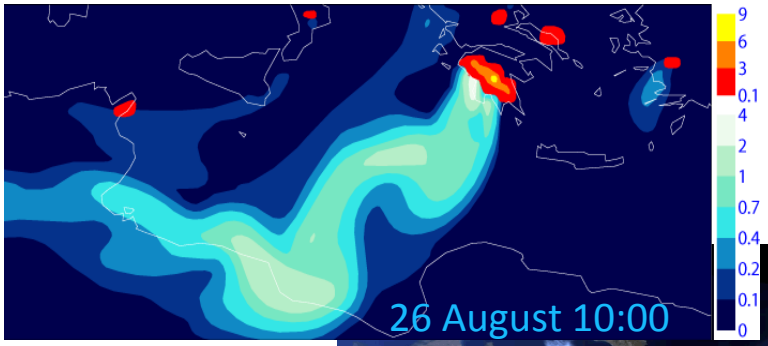
Evaluation with SEVIRI - Case study: Fire emissions in August 2007

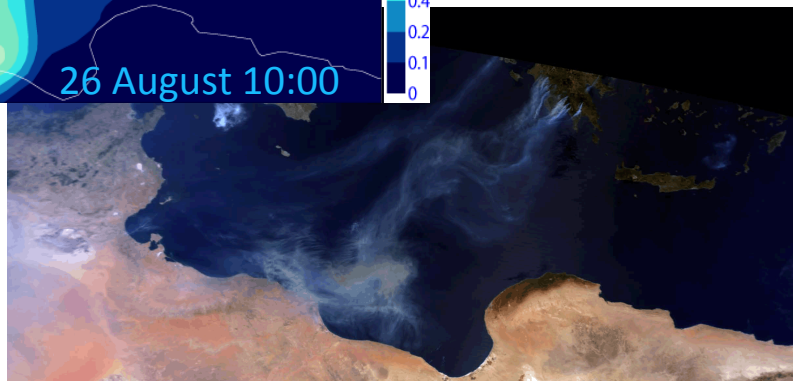


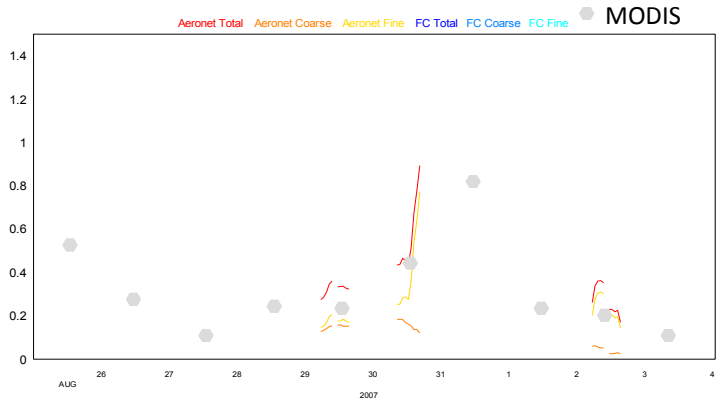
Observed Fire Radiative Power (from SEVIRI on Meteosat) is converted to emitted aerosol.

Run at 25km global resolution rather than 125km standard GEMS global resolution.

Joint work with FREEVAL project (M. Wooster, G. van der Werf, …).

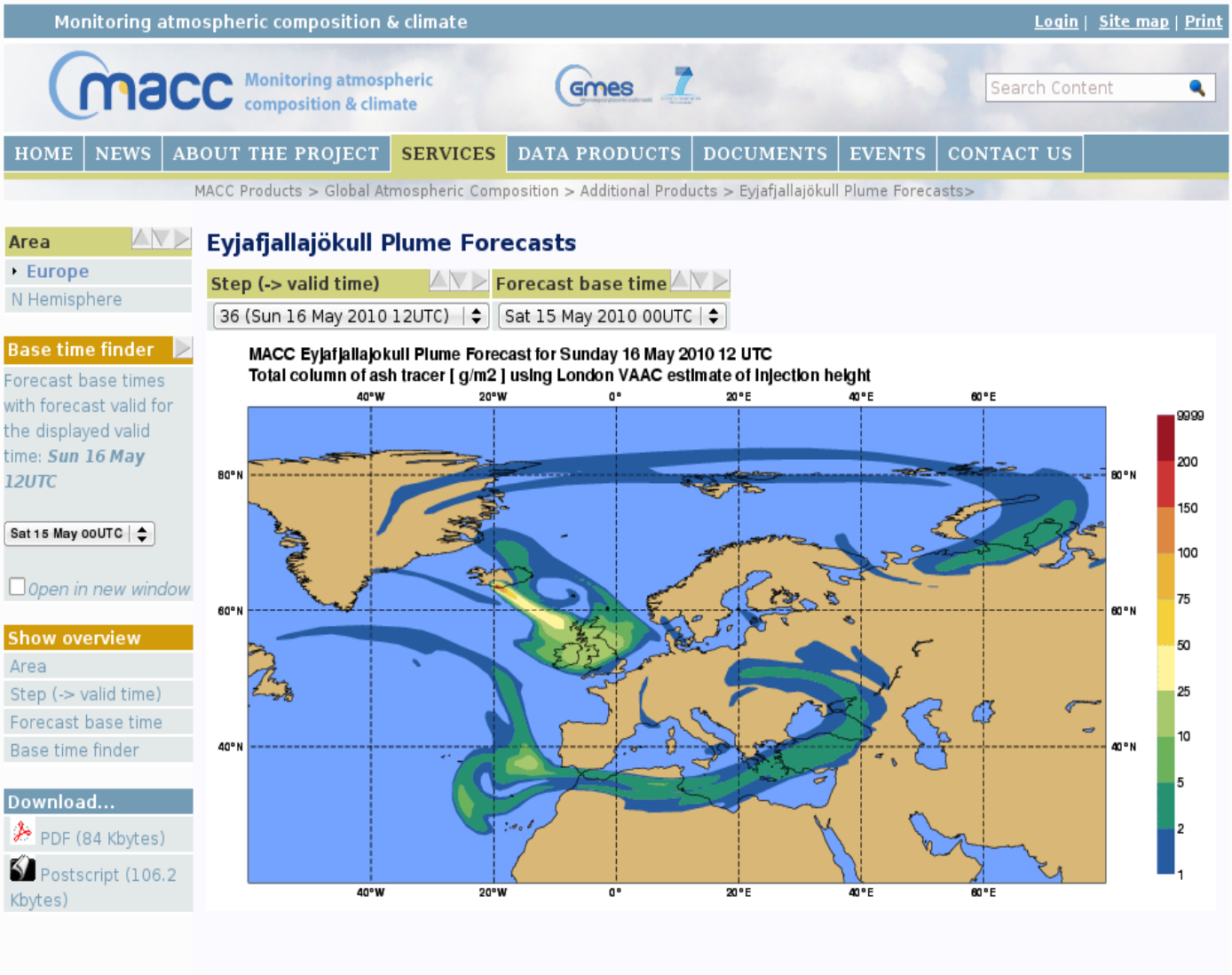






J.W. Kaiser et al., 2009

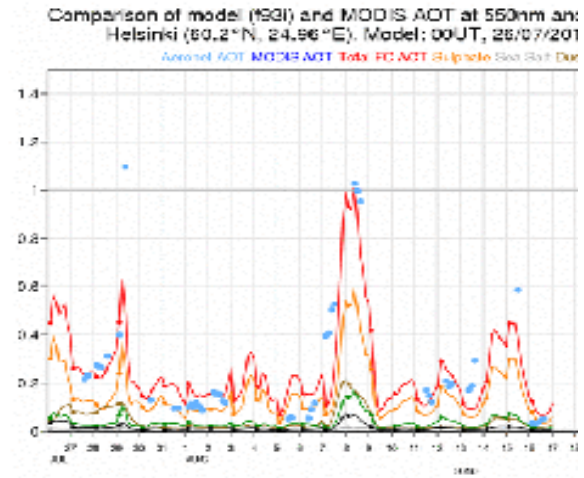
Daily MACC forecasts: Eyjafjallajökull eruption

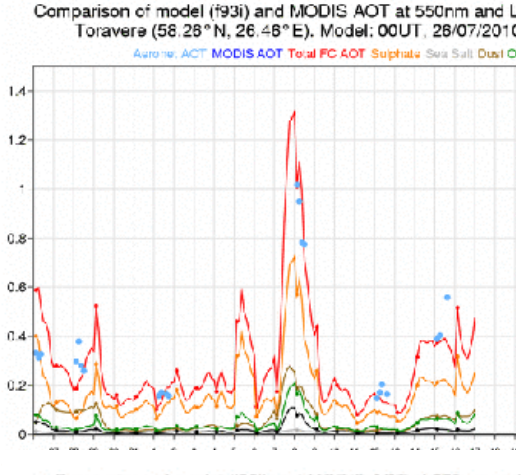


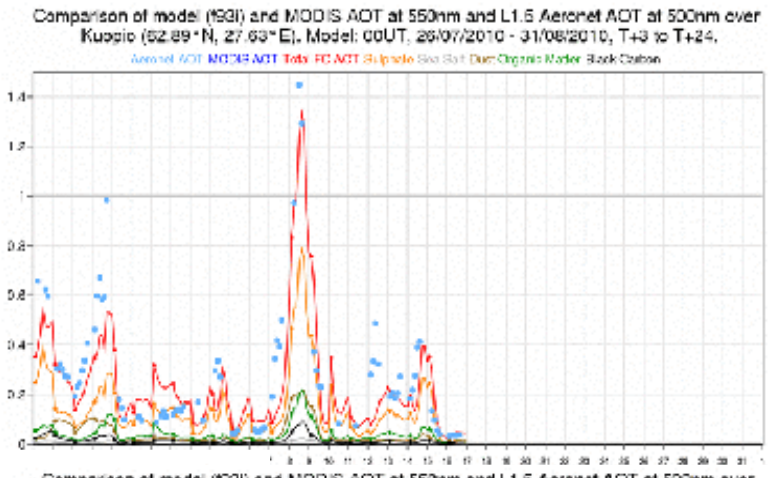
The global MACC system at ECMWF provided daily 4-day forecasts of the plume **shape** based on basic assumptions for the injection height and mass.

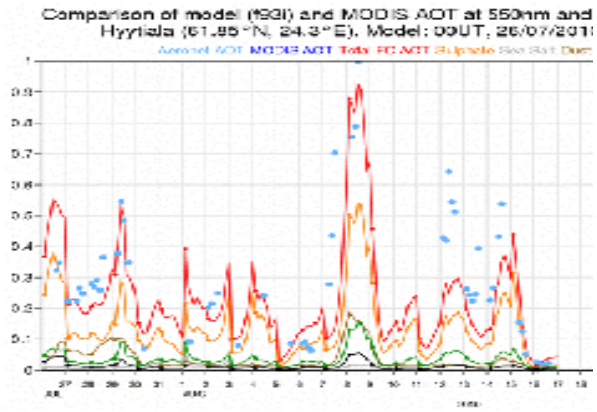
MACC is a Collaborative Project (2009-2011) funded by the European Union under the 7th Framework Programme.
It is coordinated by the European Centre for Medium-Range Weather Forecasts and operated by a 45-member consortium.

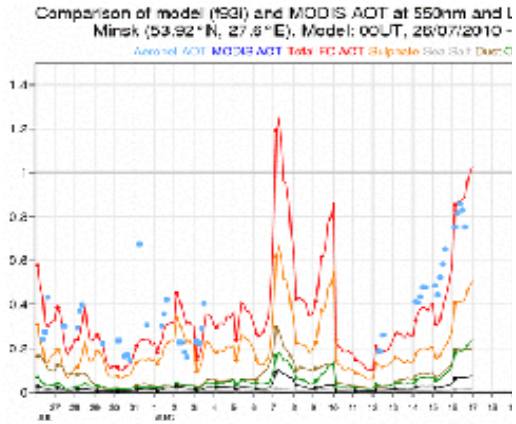
Russian fires, August 2010

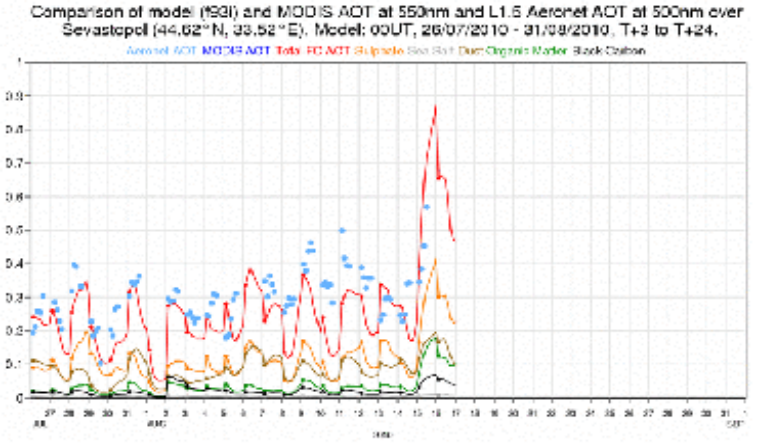


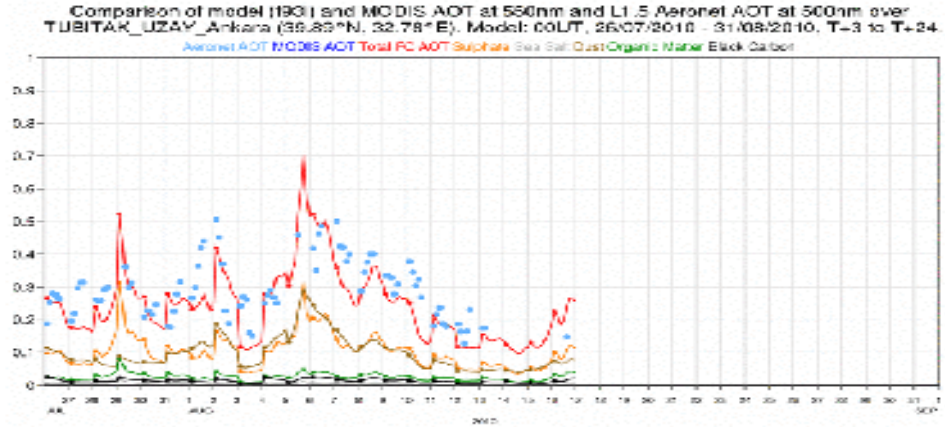




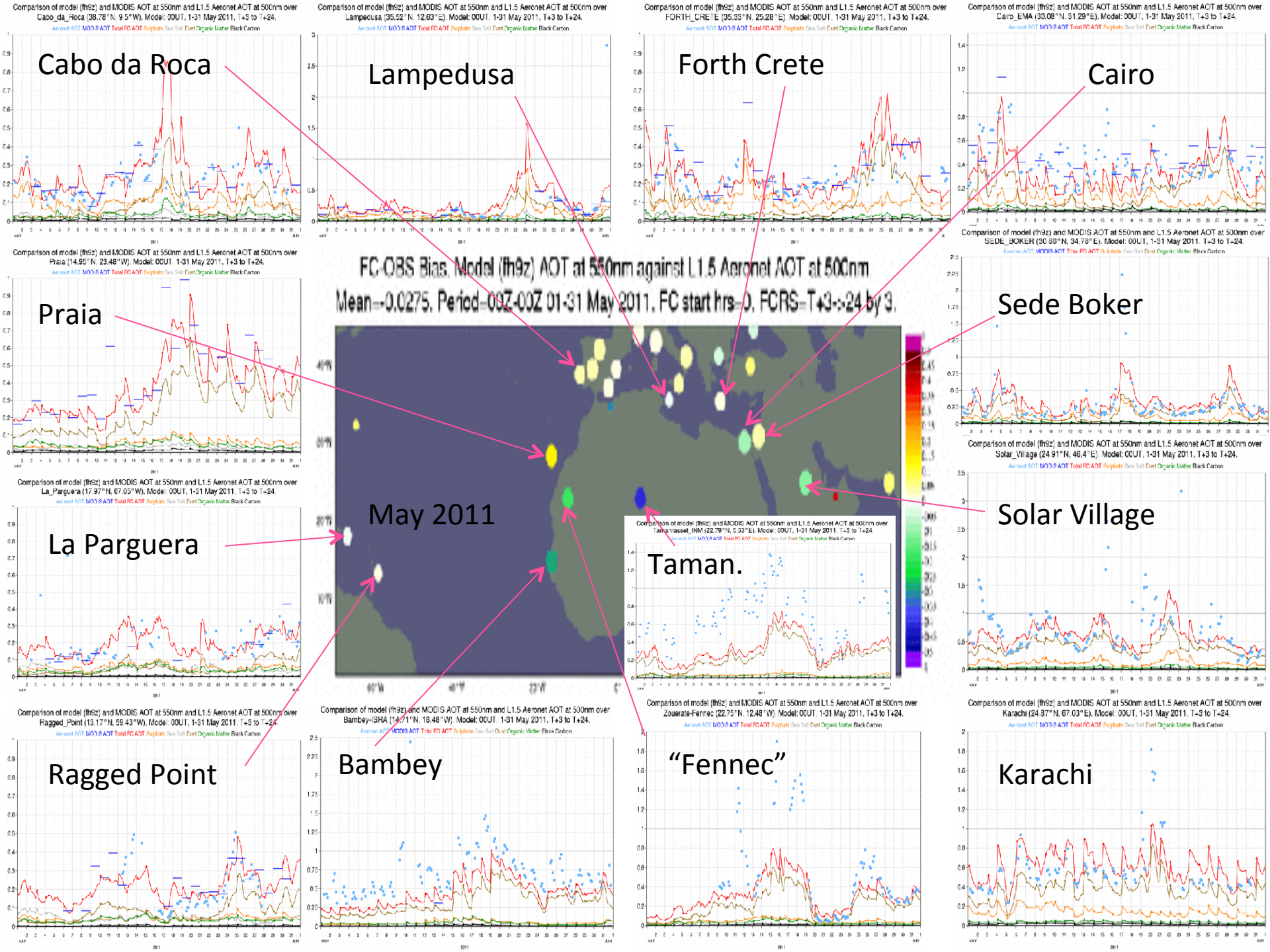




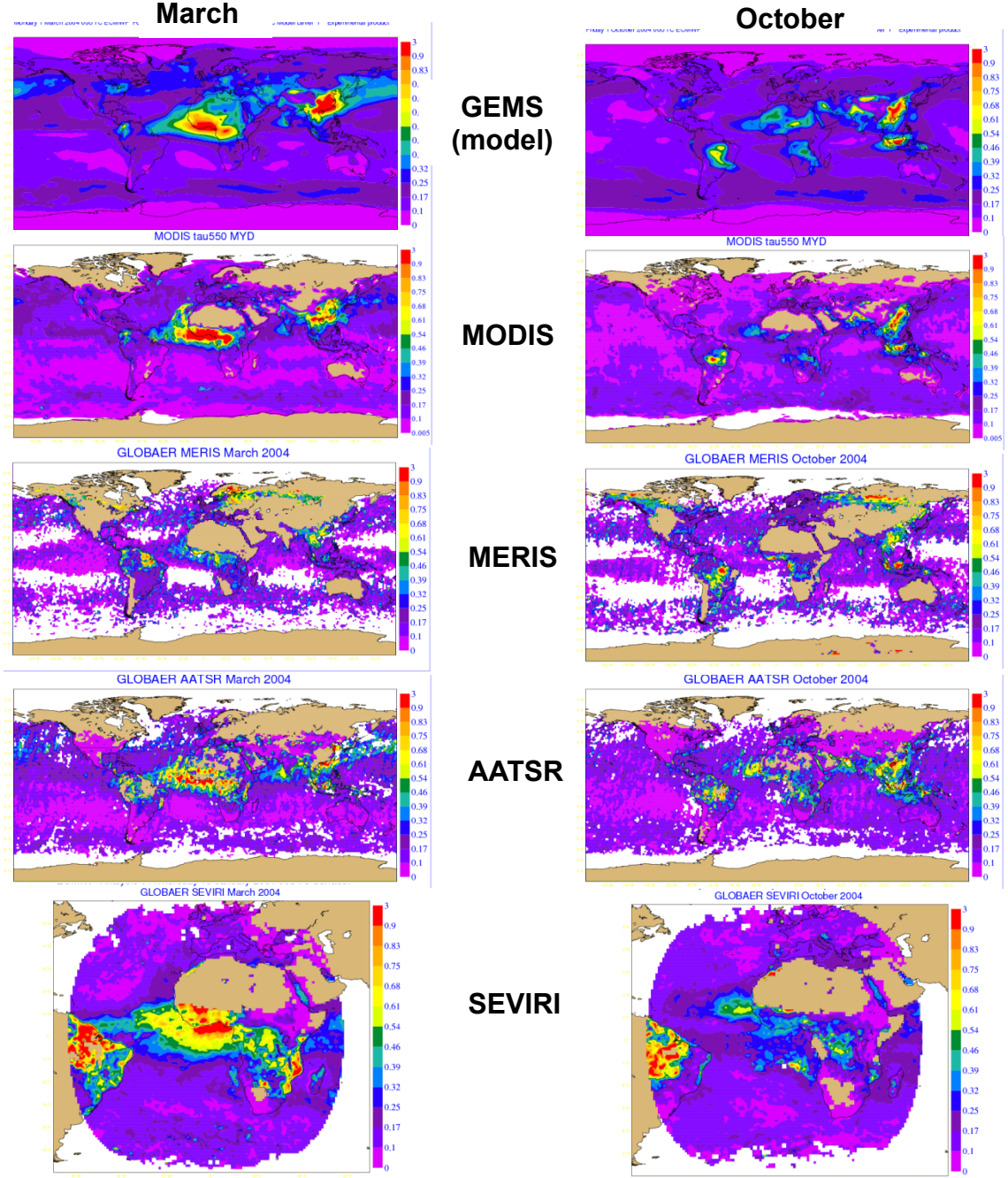




The MACC-AERosol system, assimilating MODIS tau550 allowed a very good description of the impact of the Russian fires In mid-August 2010 over North-Eastern Europe


Cabo da Roca
Lampedusa
Forth Crete
Cairo
Praia
Sede Boker
FC-OBS Bias. Model (fh9z) AOT at 550nm against L1.5 Aeronet AOT at 500nm
Mean=-0.0275. Period=09Z-09Z 01-31 May 2011. FC start hrs=0. FCRS=T+3-->24 by 3.
May 2011
La Parguera
Taman.
Solar Village
Ragged Point
Bambey
"Fennec"
Karachi

Validation of ESAGlobAEROSOL products: 550 nm Aerosol Optical Depths



-Large spread within the GlobAEROSOL product,

-MERIS presents the lowest values for the Saharian dust aerosols

-Large values over Brazil for SEVIRI (and MERIS) in March

-AATSR agrees the most of MODIS

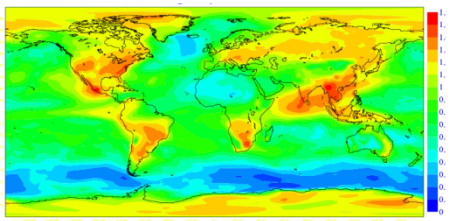
Validation of ESA GlobAEROSOL products:

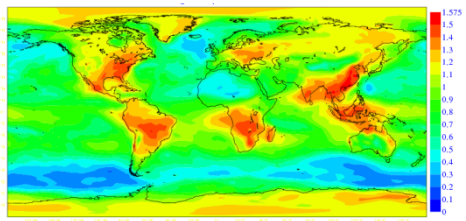
550-865 nm Angstrom exponents

March

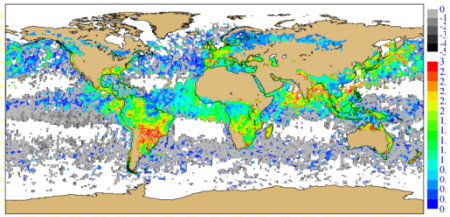
October

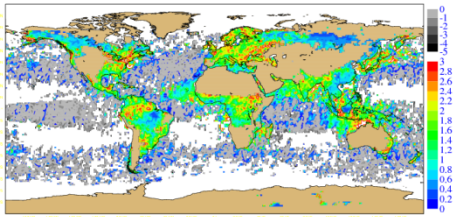
GEMS



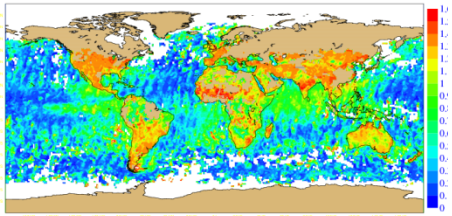


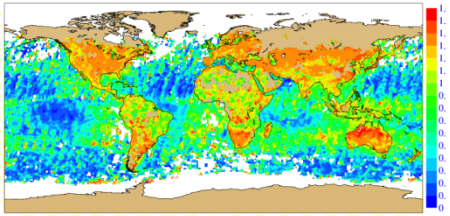
MERIS



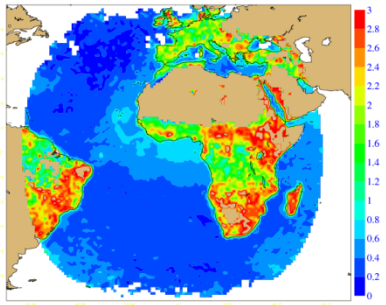


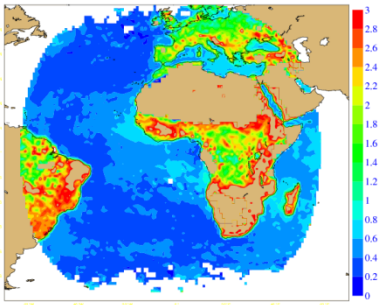
AATSR





SEVIRI





-Land/sea discontinuity in regions where continuity is known to exist (off coast west-Sahara and central Africa)

- Negative Angstrom exponent for MERIS

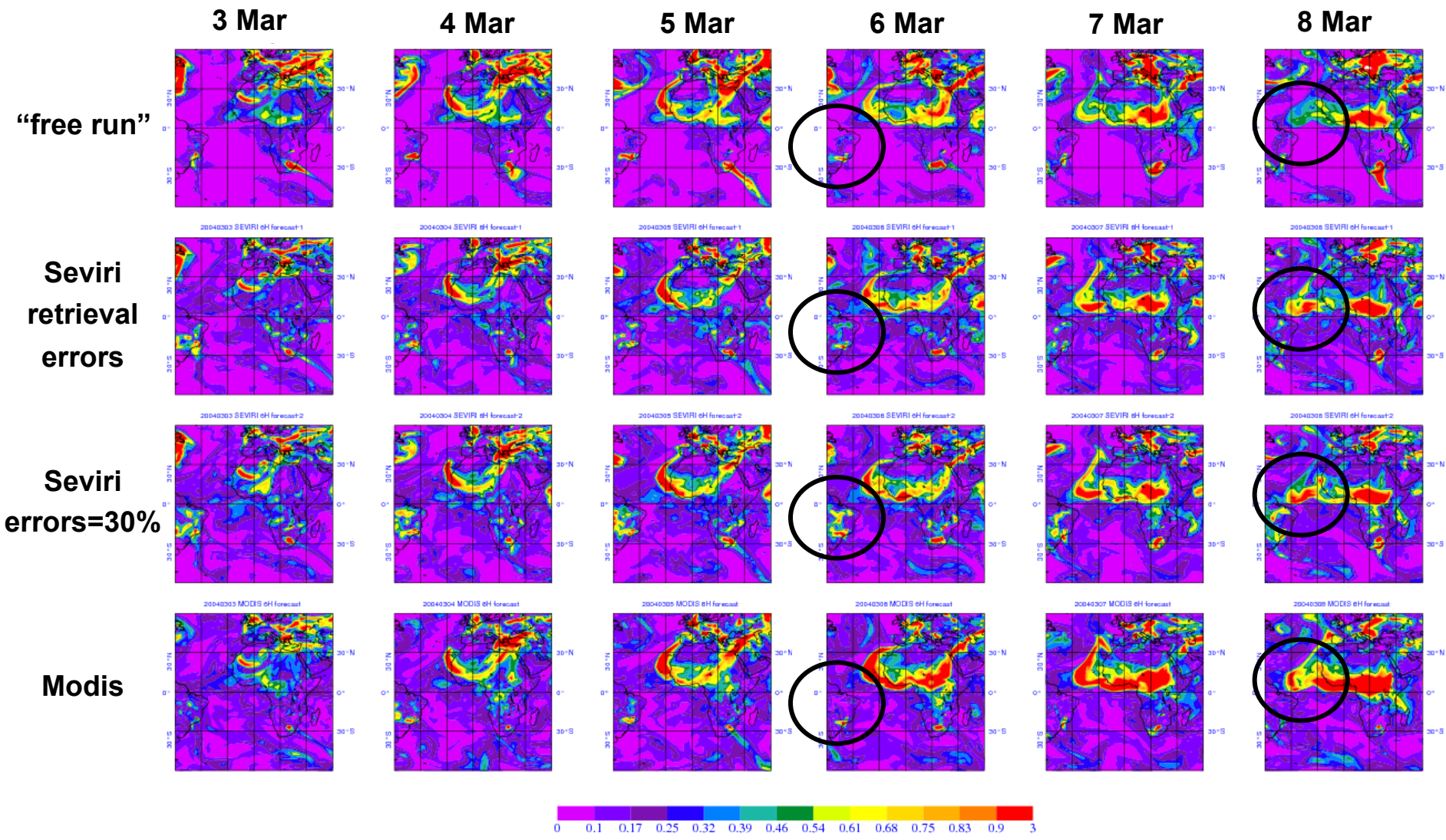
Good for assimilation?

→Can we relay on quality control and on the use of obs. errors fiom the retrievals to "clean" the data?

→Choice of SEVIRI to start with

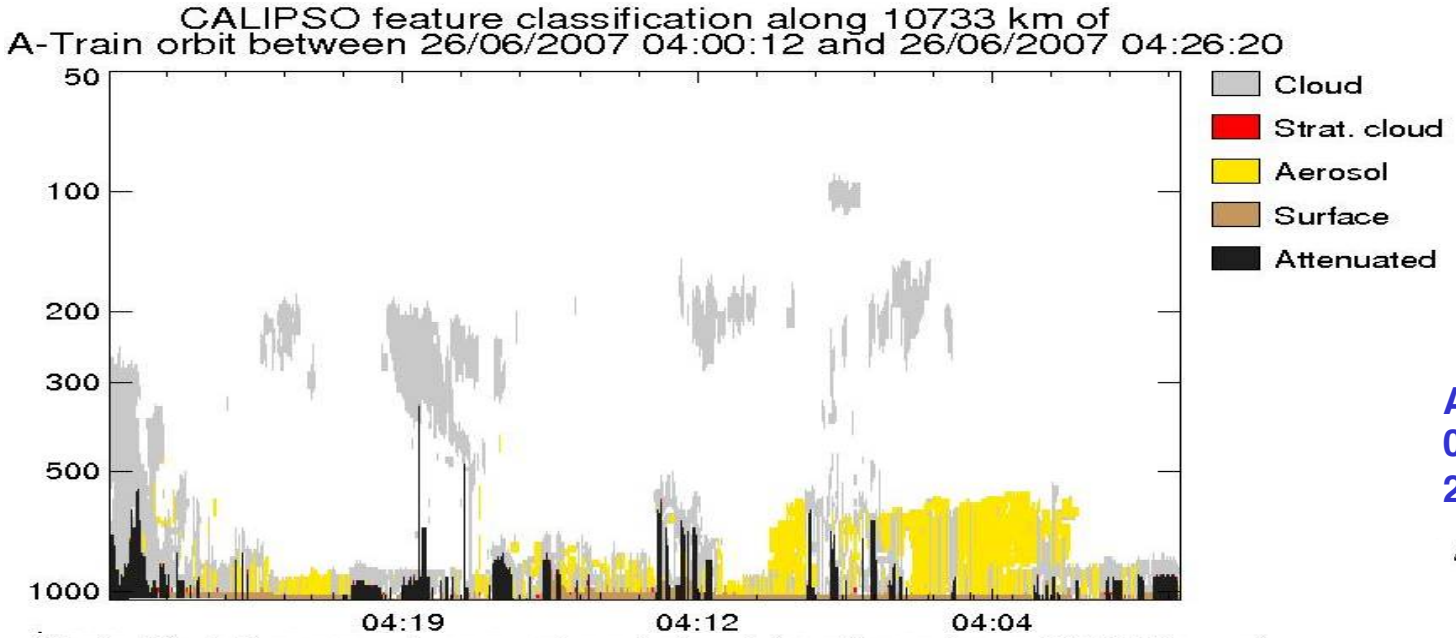
Assimilation of SEVIRI optical depths:

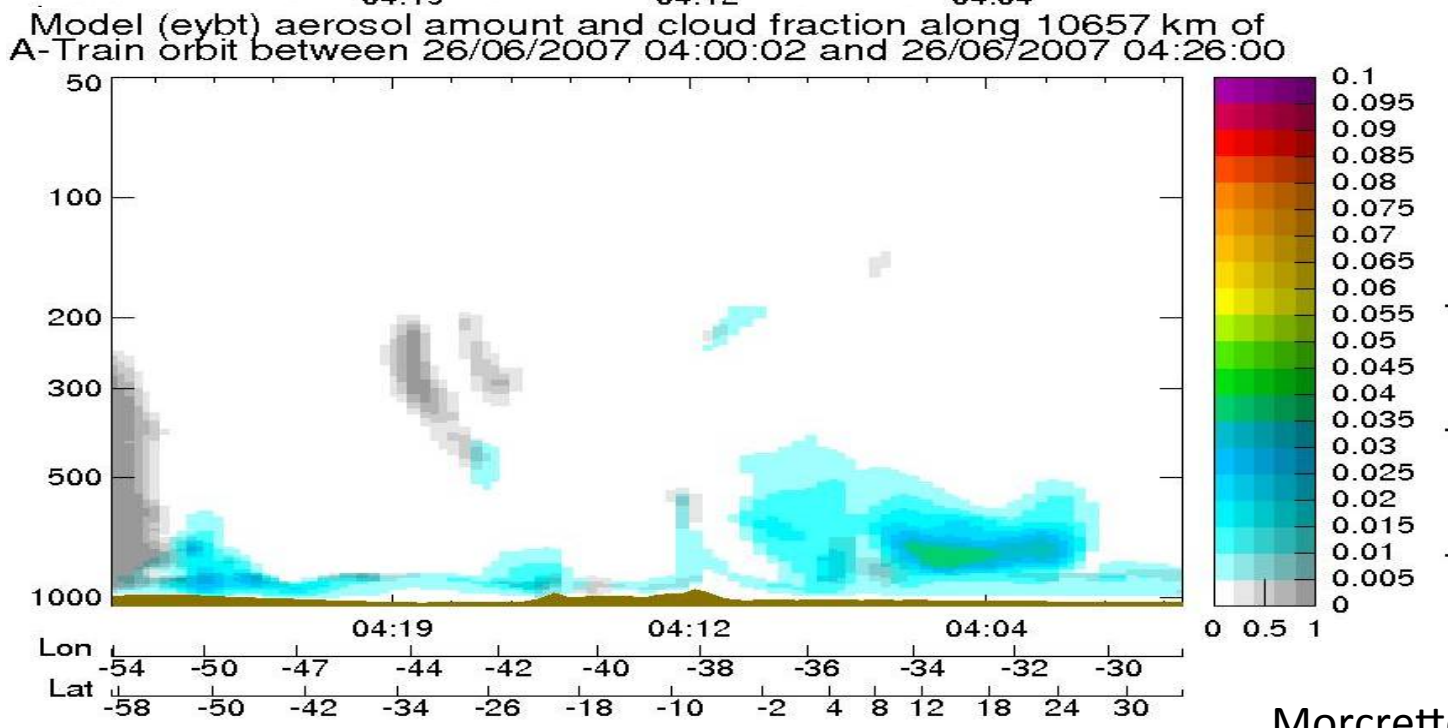
6hour-forecasts



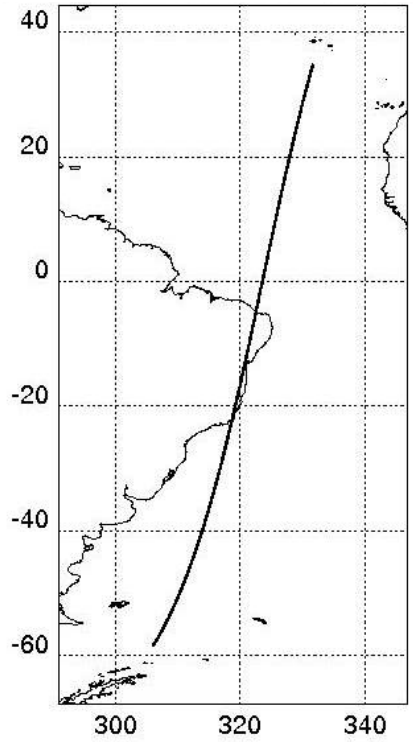
Comparison of aerosol with CALIPSO cloud/aerosol mask

- Validation of aerosol parametrization
  - Comparison of model aerosol vertical profiles with CALIPSO cloud/aerosol mask

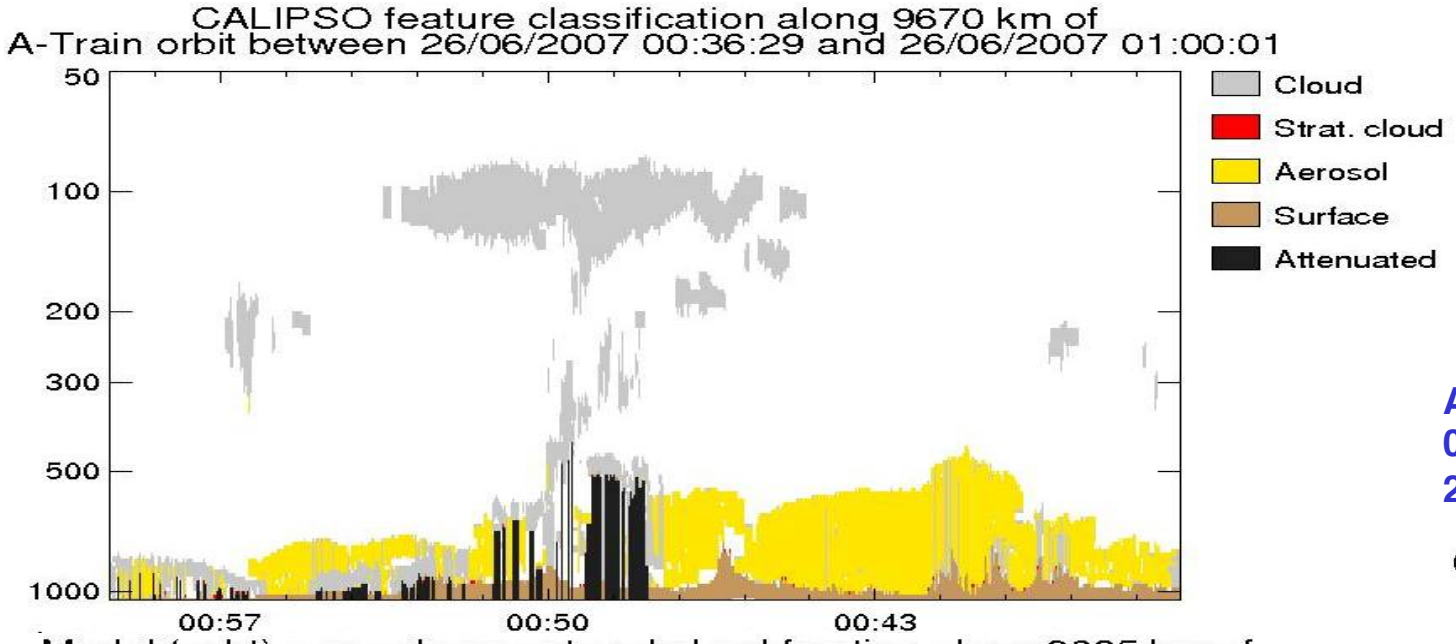


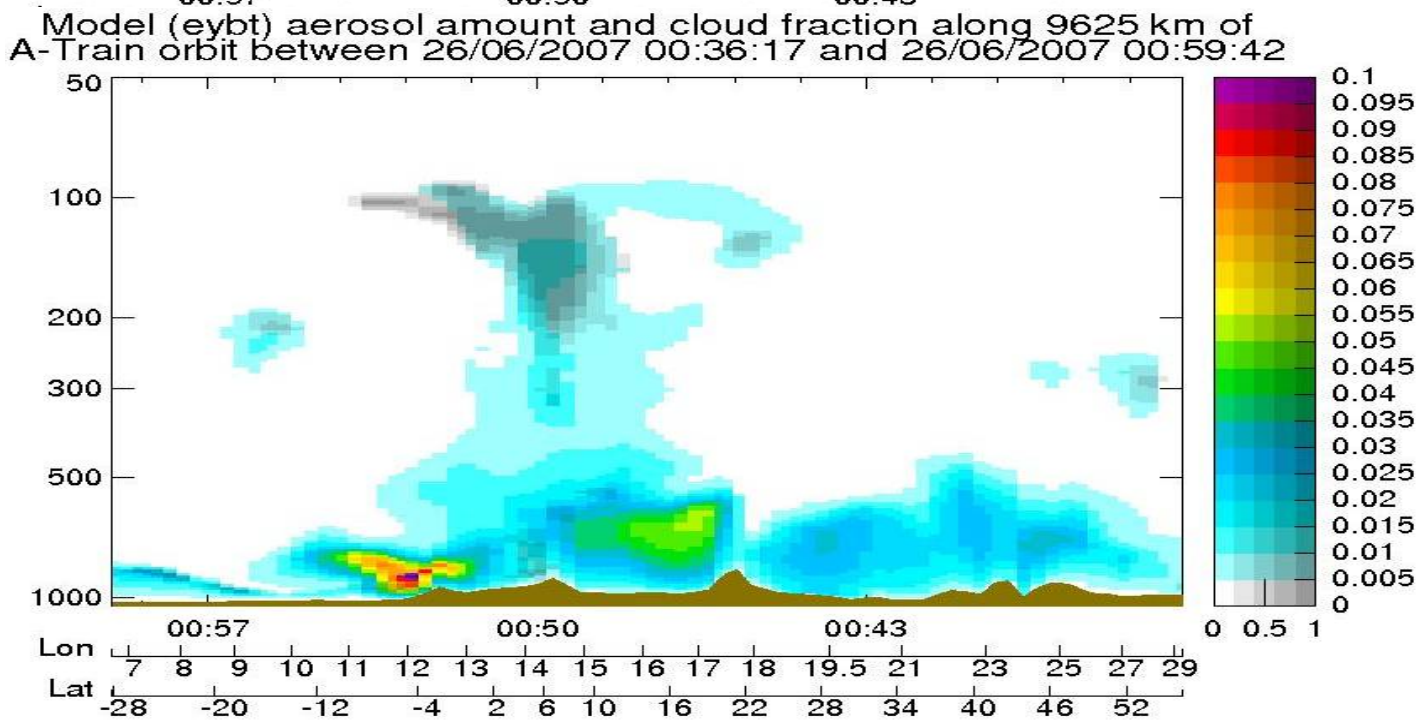


A-Train orbit between 04:00:12 and 04:26:20 26/06/2007

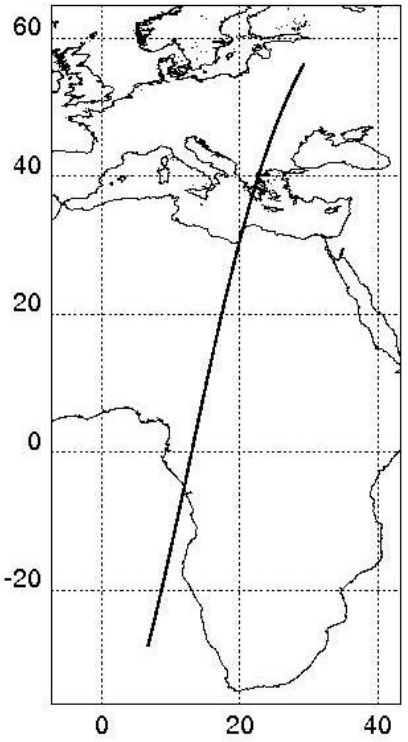


Morcrette and Jones, 2010





A-Train orbit between 00:36:29 and 01:00:01 26/06/2007



Comparison of aerosol with CALIPSO cloud/aerosol mask: Conclusions

- From this limited set of comparisons, the vertical distribution of the model aerosols appears reasonable (although maybe issue with convective transport)
- Deficiencies are often linked to limited knowledge of emissions of anthropogenic aerosols
- On the model side, the absence of a plume model for emission (for OM, BC, and SU) is likely to limit the extent of the area over which these aerosols might be simulated.
- CALIPSO cloud/aerosol mask is aerosol or cloud, whether model results often show aerosols within cloud layers

The lidar equation

$$LS(z,\lambda) = C_{LS}[\beta(\lambda)\omega(\lambda)\sigma(z,\lambda)]\exp[-2\int_{z}^{z_{TOA}}\sigma(z',\lambda)dz']$$

The lidar signal (LS) equation is given above, in which:

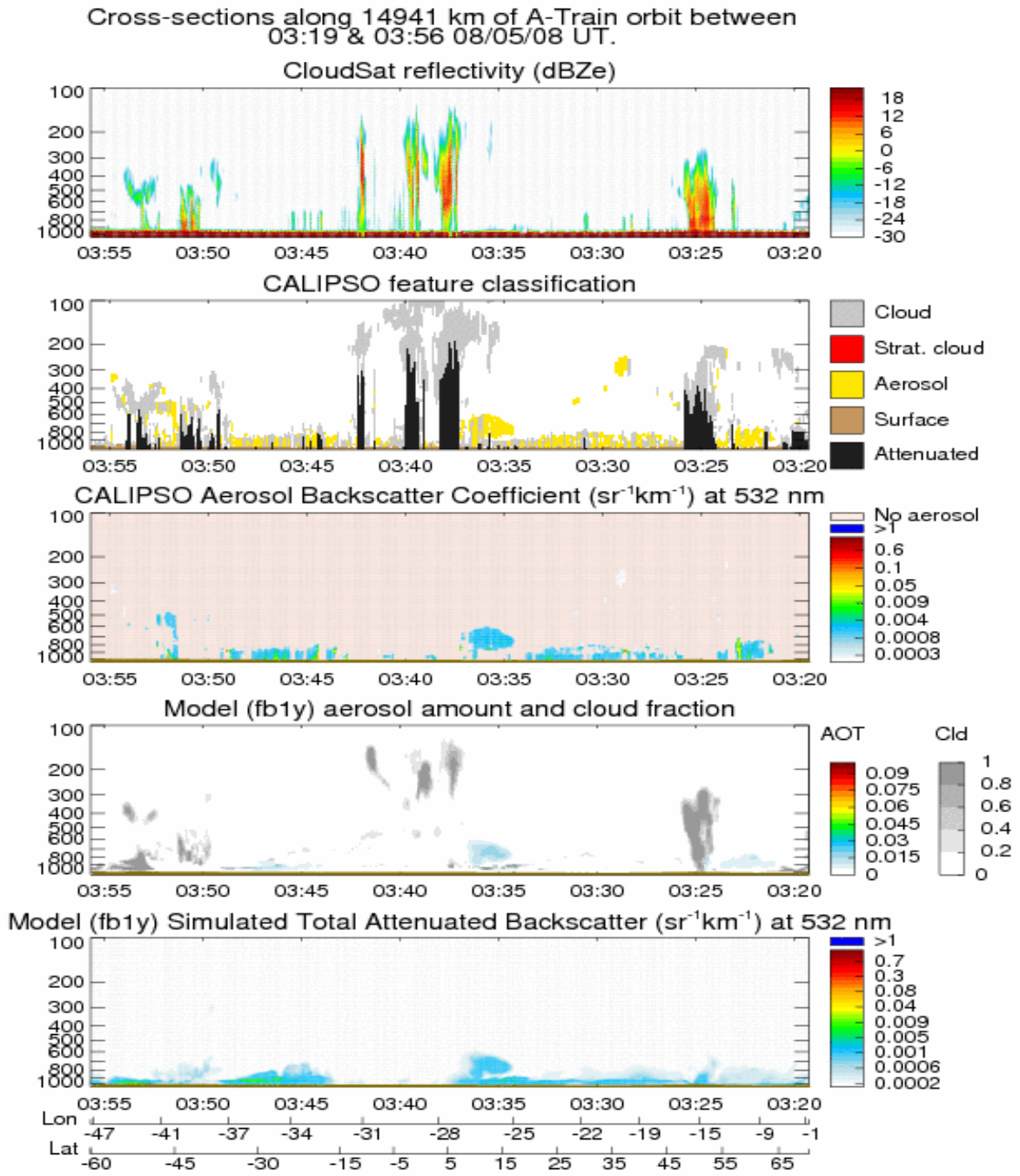
ω is the single scattering albedo, β is the phase function at 180°, σ the extinction coefficient, $\mathbf{C_{LS}}$ a calibration coefficient, **z** the height and λ the wavelength.

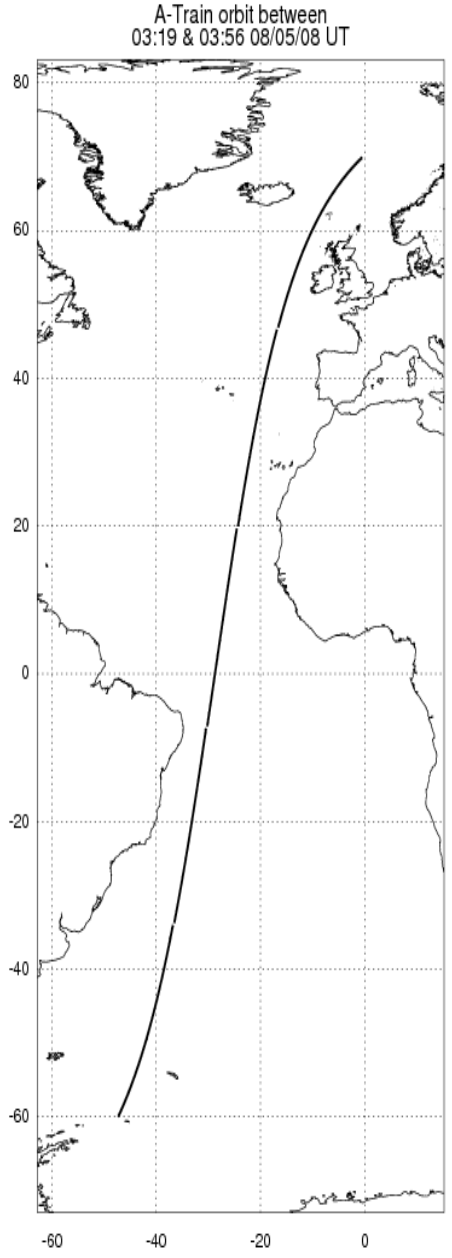
Processes to be accounted for are: Rayleigh scattering, and depending on λ, gaseous absorption by O_3, NO_2, O_2, CO_2 … and the absorption/scattering by aerosols in the observed volume and along the path.

All relevant coefficients have been computed for the 11 aerosol types of the GEMS-AER configuration (SS3b, DU3b, 2OM, 2BC, 1SO4) using a standard Mie code.

The new model routine simulates the back-scattering coefficient of the GEMS aerosols (for a clear-sky atmosphere) observed by a lidar at 355$, 532* and 1064* nm at TOA and surface (for comparison with EARLINET observations?)

$: wavelength of future EarthCare lidar; *: wavelengths of CALIPSO (practically only 532 nm); Lidars parts of EARLINET (European Aerosol Research Lidar Network) have data from the surface over various subsets of the three wavelengths.





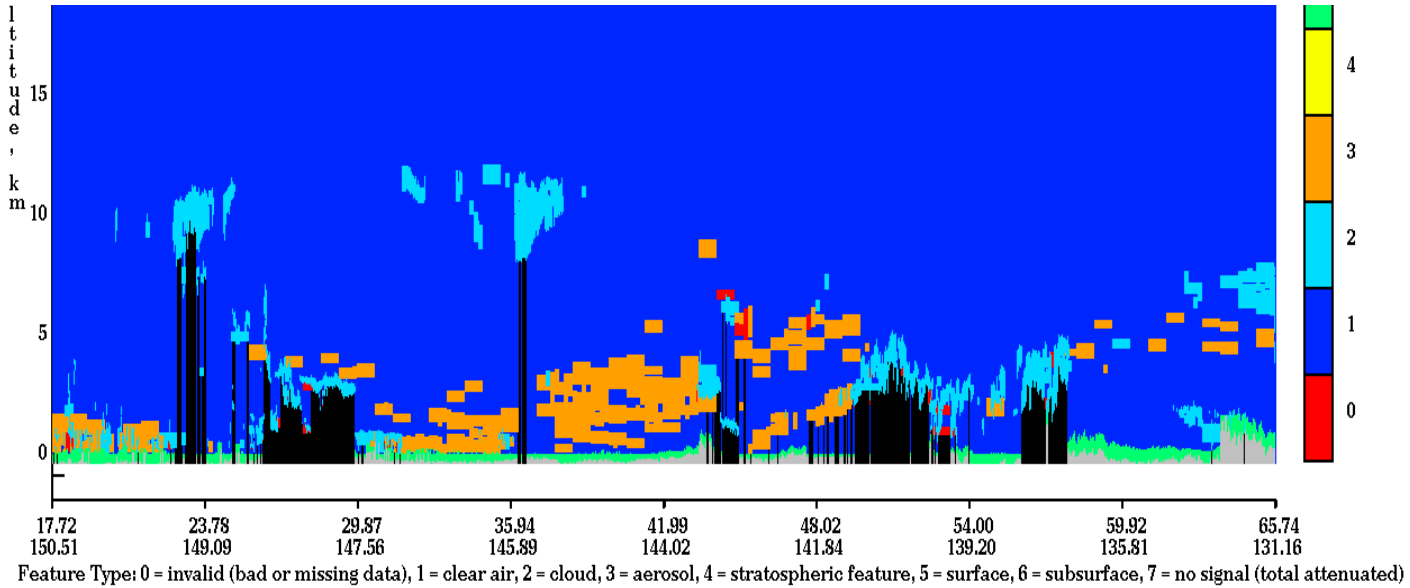
Graphics by Luke Jones

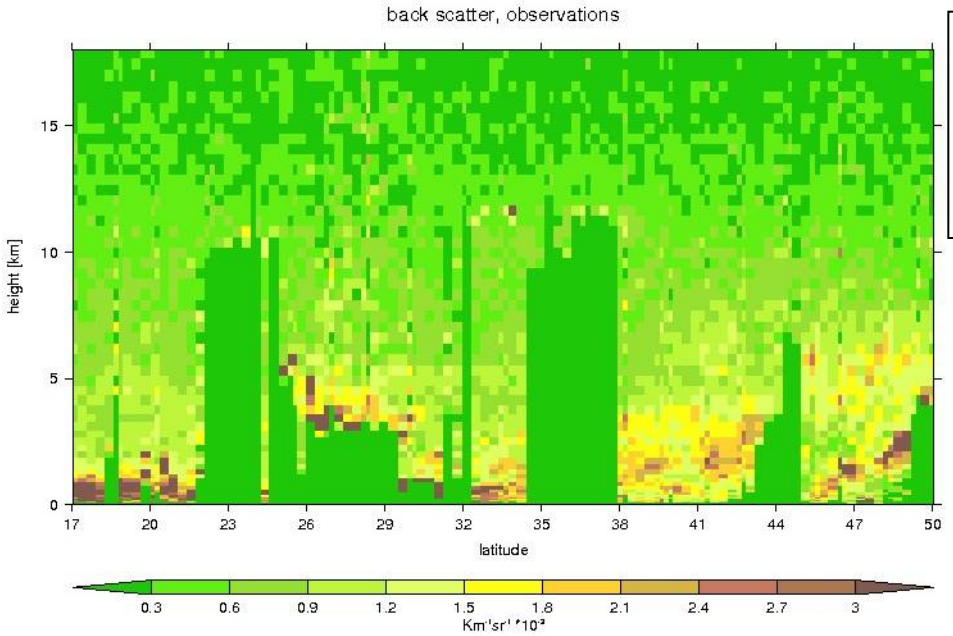
1D-Var for CALIPSO aerosol observations
Janiskova, Stiller, 2010

- assimilation of CALIPSO backscatter data restricted to updating only the aerosol fields, other fields left unchanged by the analysis procedure
- 11 aerosol species represented in the forecast model, but only one observed field to be assimilated

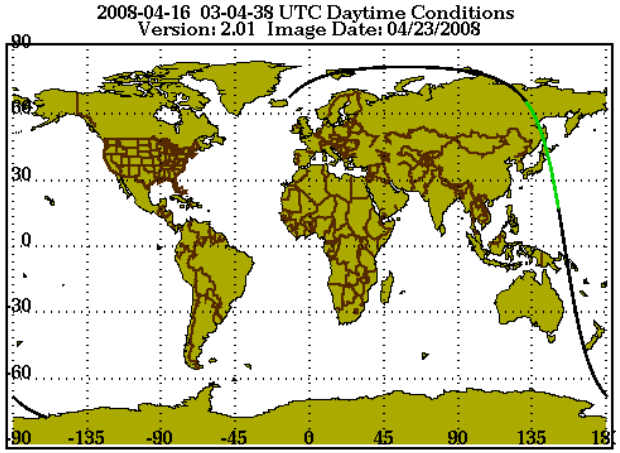
  - only the total mixing ratio is incremented and the fractional contribution of each species is kept constant at the value given by the model background *(Benedetti et al. 2009)*

CALIPSO observations and cloud screening





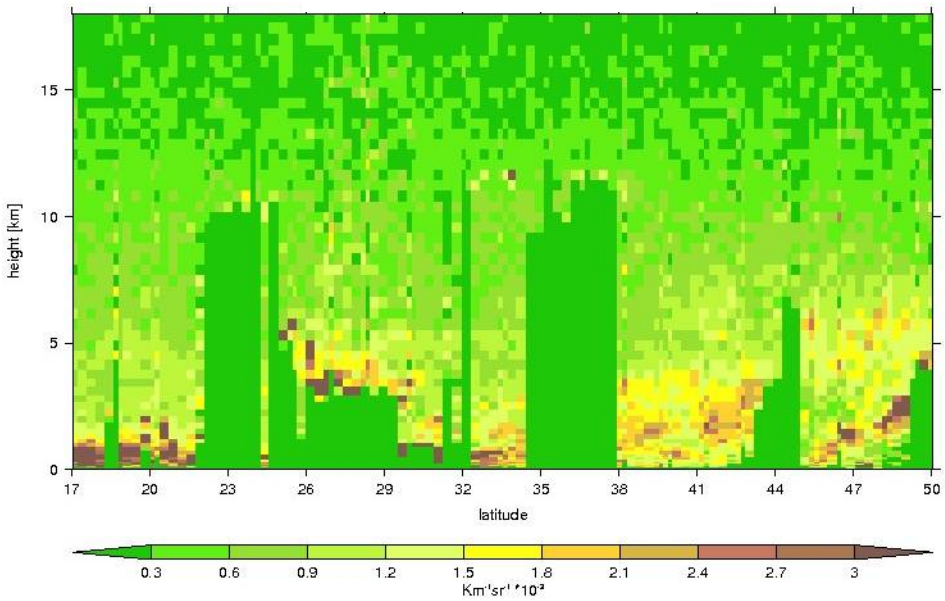
Cloud screening: 5km product



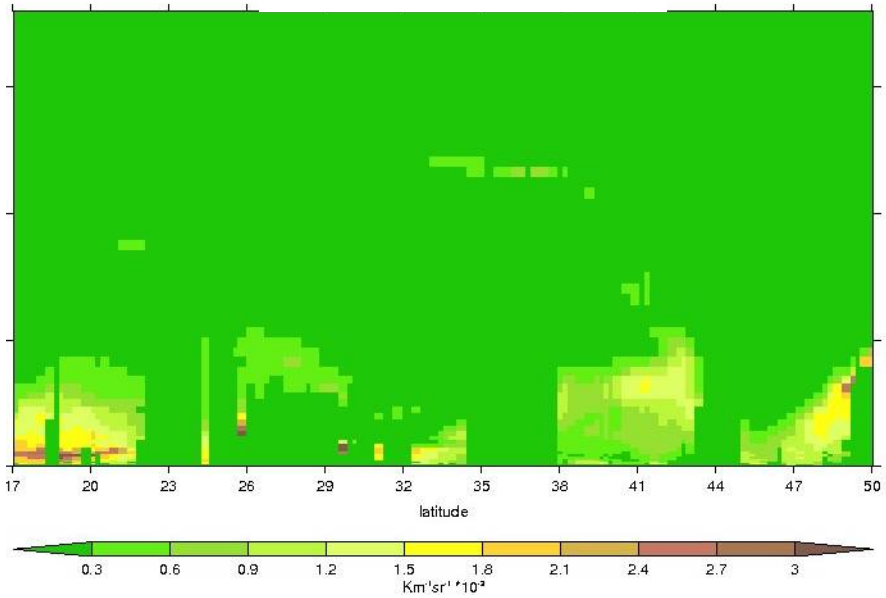
Case 20080416

1D-Var for CALIPSO aerosol observations – FG vs. AN

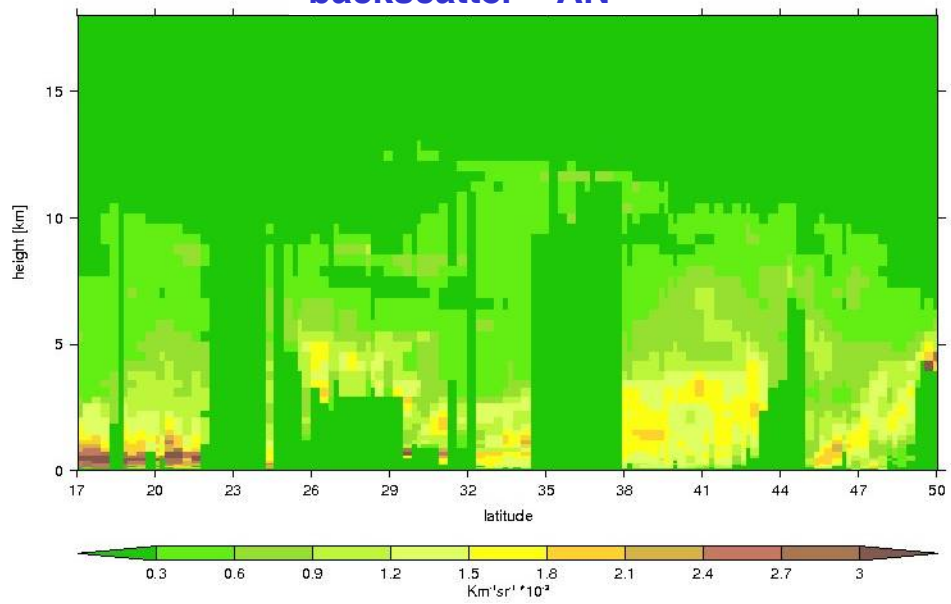
backscatter – OBS

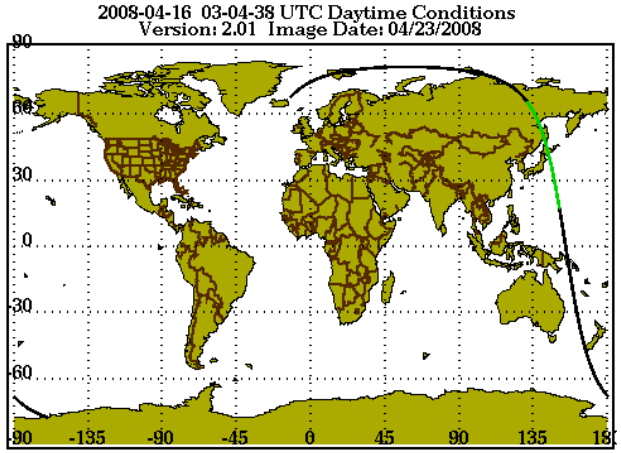


backscatter – FG



backscatter – AN





Case 20080416

Janiskova & Stiller, 2010

Summary of 1D-Var experiments for aerosol observations

- A major technical and scientific development towards the assimilation of aerosol information from CALIPSO has been implemented

- Main outcomes from 1D-Var experimentation:
  - model equivalent aerosol observations are substantially driven towards CALIPSO backscatter data
  - model aerosols are strongly incremented
  - encouraging results suggest there is a potential of using these observations in the ECMWF aerosol system
  - GMES/MACC could also benefit from technical foundations laid by this project
  - further use in assimilation studies would require improved observation errors, more targeted cloud screening, …
  - exciting perspectives for air quality monitoring and forecasting

Janiskova & Stiller, 2010

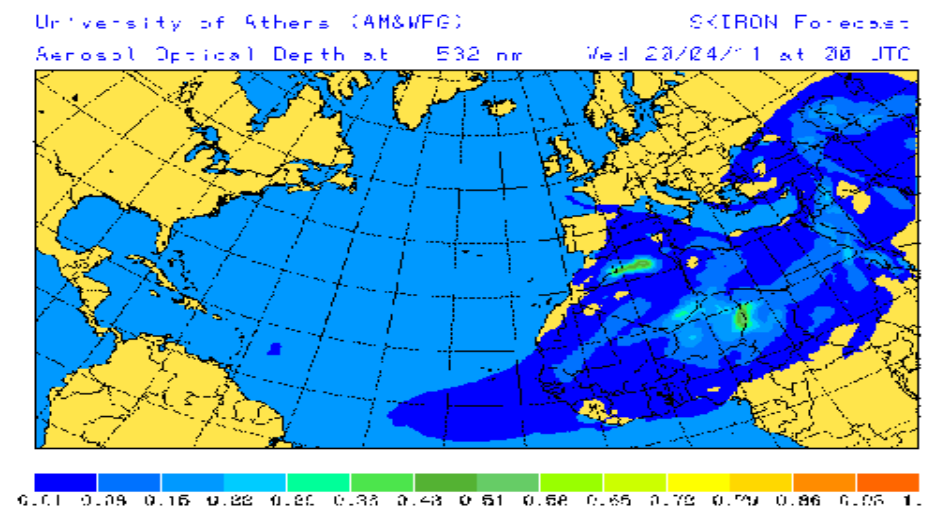
As a matter of conclusions

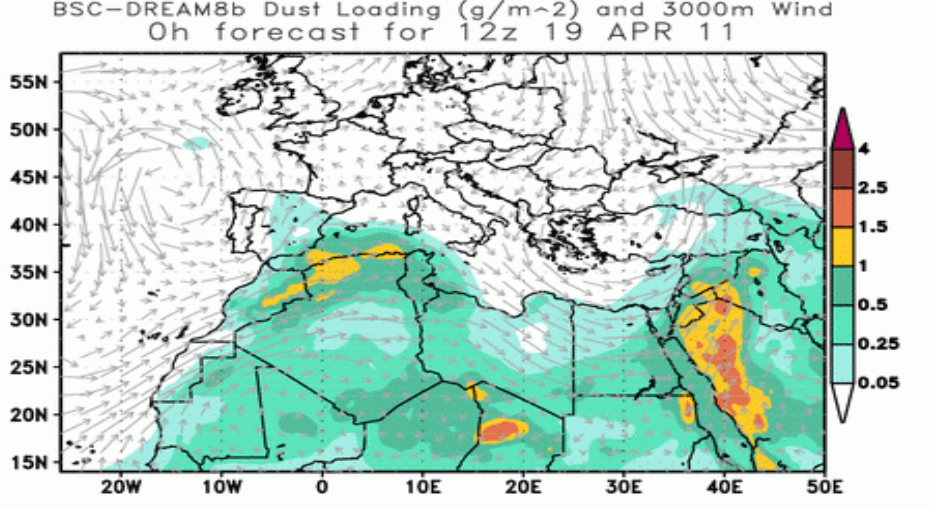
- Over the last six years, as part of first the GEMS, then the MACC projects, the development, validation and pre-operational provision of aerosol analyses and forecasts by the ECMWF IFS have relied heavily on the satellite data provided by MODIS and the surface measurements at the AERONET stations. MODIS fine mode tau550 is currently being tested for assimilation. CALIPSO backscatter measurements are the next measurements to be assimilated in the near future. SEVIRI is also considered for the future.
- Six years of aerosol daily analyses (2003-2008) followed by 3-day forecasts were produced by GEMS. Eight years of aerosol daily analyses (2003-2010) followed by 5-day forecasts are being repeated by MACC. All these are publicly available on request (EU FP project policy). Near real time analyses and forecasts have been produced daily since September 2008.
- These products are being refined through further aerosol and model developments, and will continue to depend on the near-real time provision of such satellite (and surface) measurements.
- A lot is going on in terms of “oper”, “pre-oper”, or “quasi-operational” aerosol modelling in various academic and operational meteorological institutions (WMO-SDS, ICAP).

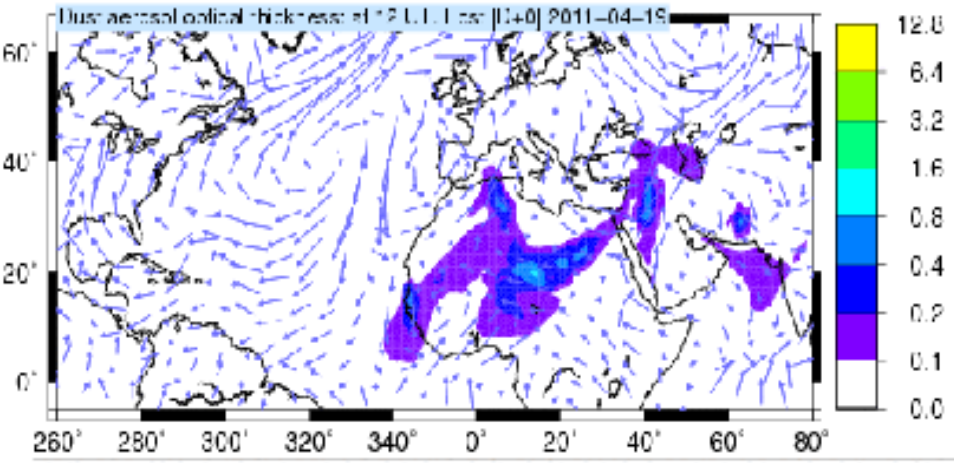
- **Thank you**

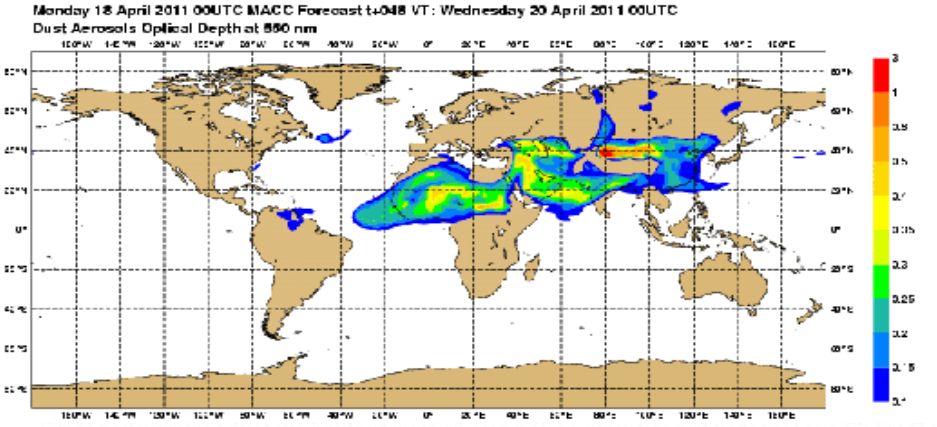
Present state of the prognostic aerosols in the ECMWF IFS

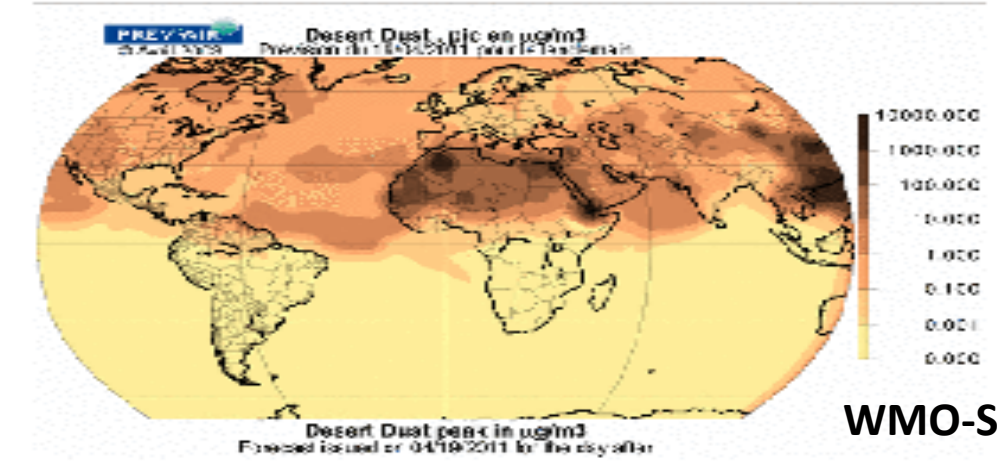
- Benedetti et al., 2009: JGR, 114, D13205
- Morcrette et al., 2008: GRL, 35, L24813
- Morcrette et al., 2009: JGR, 114, D06206
- Mangold et al., 2011: JGR, 116, D03302
- Kaiser et al., 2009: AIP CP, 1100
- Kaiser et al., 2010: BAMS, 91, SC2009
- Kaiser & Goldammer, 2010: BAMS, 91, SC2009
- Benedetti et al., 2011: BAMS, 92, SC2010
- Huneeus et al., 2011: ACPD

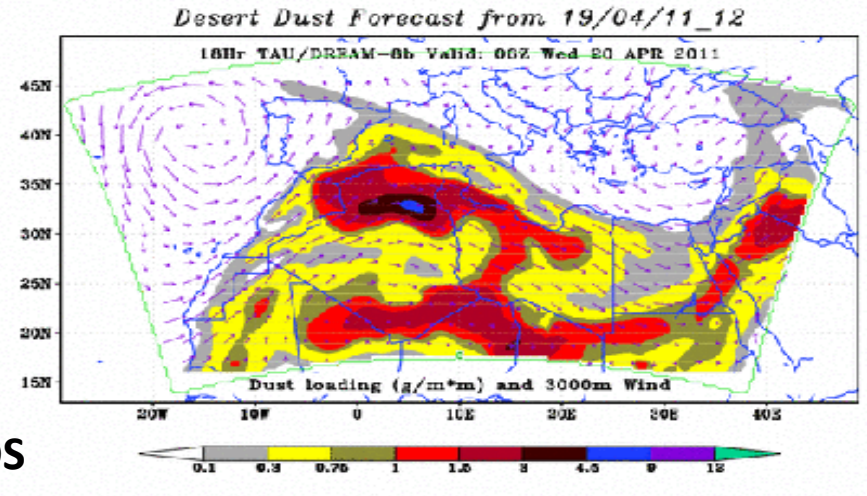

University of Athens (AM&WFG)
SKIRON Forecast
Aerosol Optical Depth at 532 nm
Wed 20/04/11 at 00 UTC


BSC-DREAM8b Dust Loading (g/m^2) and 3000m Wind
0h forecast for 12z 19 APR 11
55N
50N
45N
40N
35N
30N
25N
20N
15N
20W
10W
0
10E
20E
30E
40E
50E
4
2.5
1.5
1
0.5
0.25
0.05


60°
40°
20°
0°
260°
280°
300°
320°
340°
0°
20°
40°
60°
80°
12.8
6.4
3.2
1.6
0.8
0.4
0.2
0.1
0.0

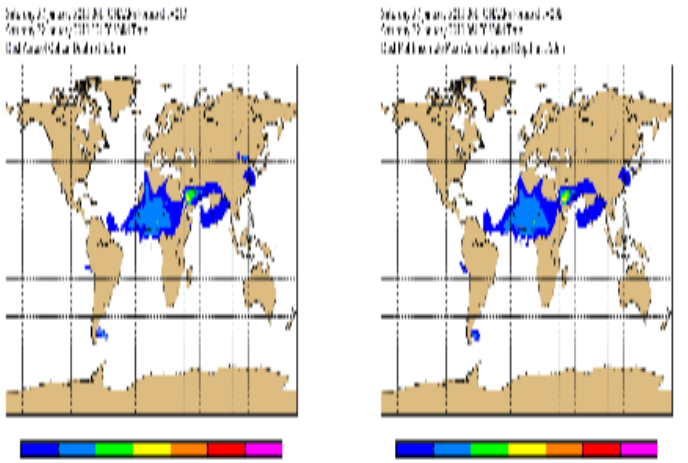

Monday 18 April 2011 00UTC MACC Forecast t+048 VT: Wednesday 20 April 2011 00UTC
Dust Aerosols Optical Depth at 550 nm


Desert Dust, µic en µg/m3
Desert Dust peak in µg/m3

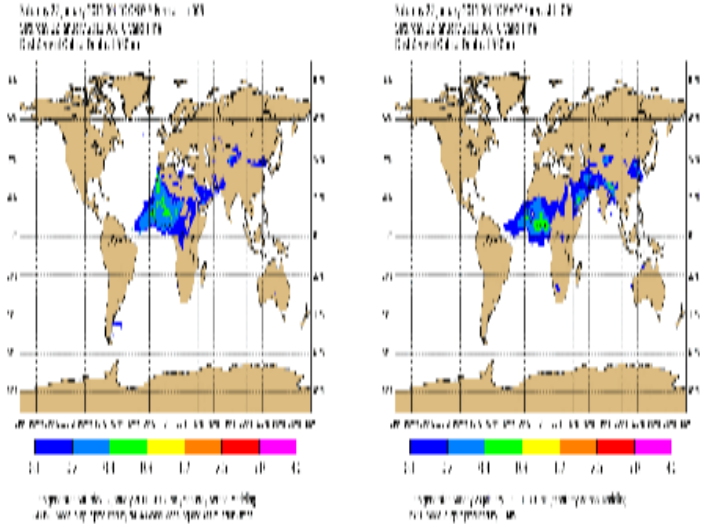

Desert Dust Forecast from 19/04/11_12
18Hr TAU/DREAM-8b Valid: 00Z Wed 20 APR 2011
Dust loading (g/m*m) and 3000m Wind
45N
40N
35N
30N
25N
20N
15N
20W
10W
0
10E
20E
30E
40E
0.1
0.3
0.75
1
1.5
3
4.5
9
15

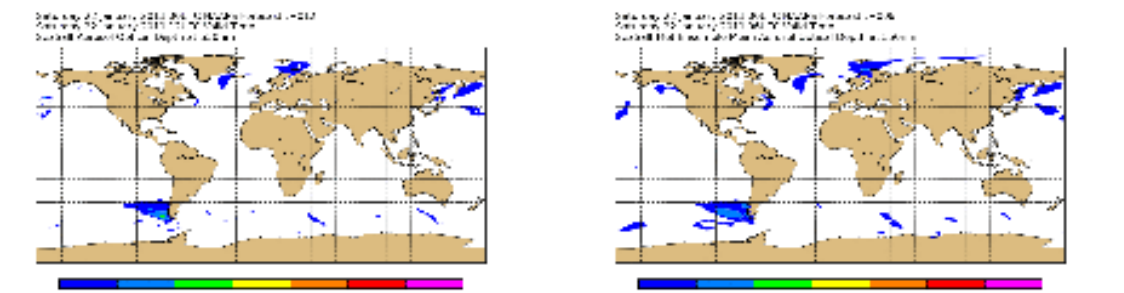
WMO-SDS

International Comparison of Aerosol Prediction: NRL, NRL-EPS, GMAO, ECMWF, soon NCEP

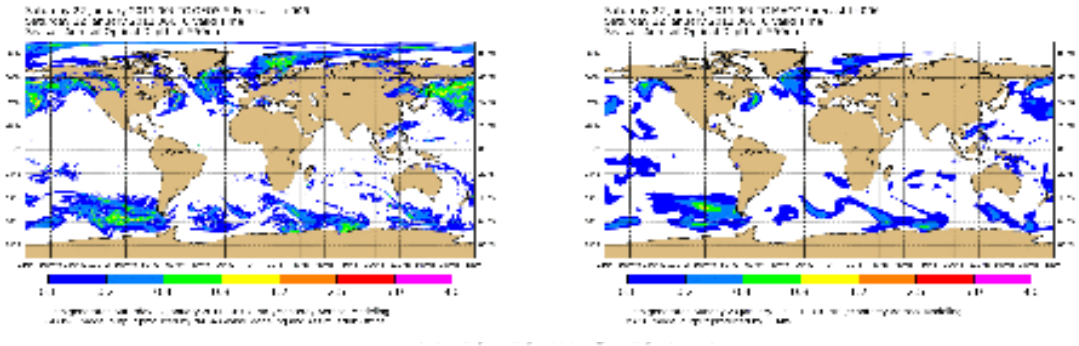


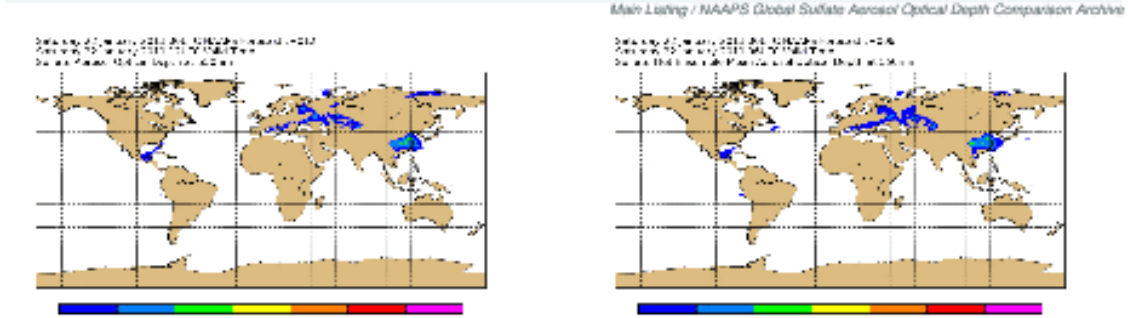
Dust





Sea salt





Sulphate