ICAP 4th Workshop, 14-17 May 2012, ESRIN, Frascati, Italy

The MACC/ECMWF aerosol analysis and forecast system: Recent results

Jean-Jacques Morcrette
ECMWF, Reading UK

Angela Benedetti,	aerosol analysis
Johannes W. Kaiser,	everything fire-related
Luke Jones,	AERONET, CALIPSO visualisation and some more diagnostics
Miha Razinger,	MACC web site and some other diagnostics
Martin Suttie	data acquisition and preparation

The MACC / ECMWF aerosol analysis and forecast system

- ECMWF for its operational analyses and forecasts ingest gigabytes of observational data every day and produces weather forecasts 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 those of reactive gases, greenhouse gases, and aerosols. Near Real Time forecasts started in Sep.'08.

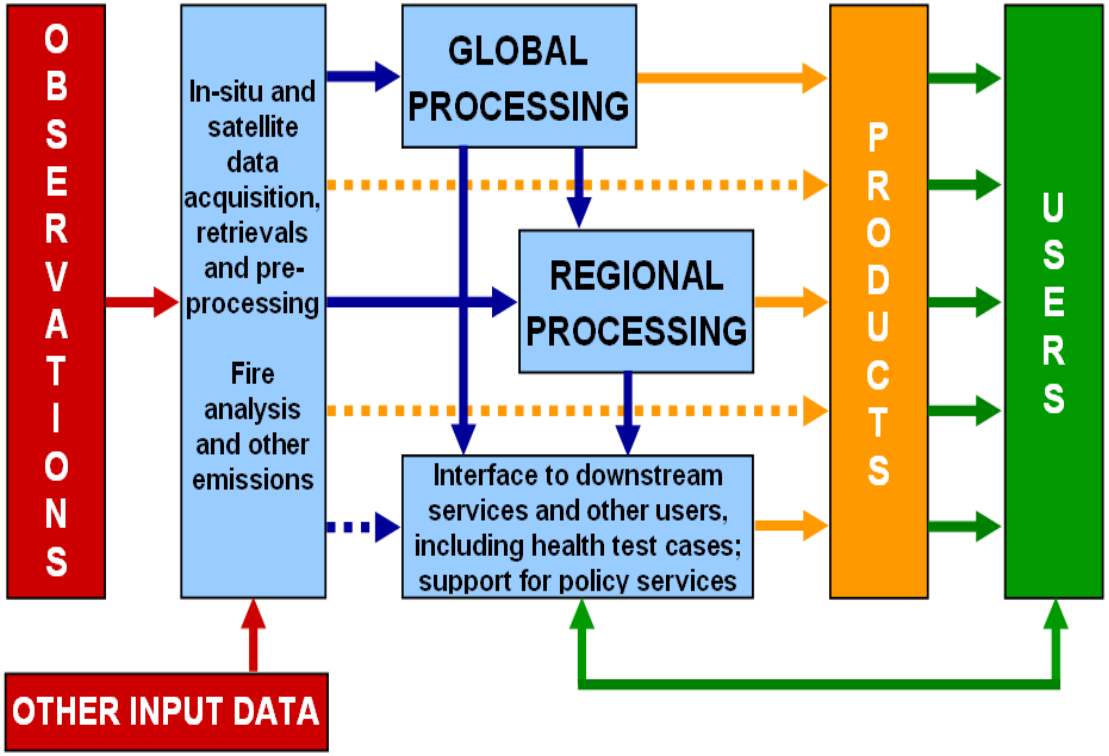
- **GEMS** produced a 2003-2008 reanalysis of GHG, RG and **AER**; **MACC** produced another reanalysis based on a more recent meteorological model and upgraded GHG, RG and AER system for 2003-2010. **MACC II** has been running since Nov.'11, and aim at introducing a further improved GHG, RG and **AER** system into operations by the end of 2014.

- This presentation will give a quick overview of the MACC **aerosol** system, then will briefly address recent model developments related to:
  - Desert dust
  - Volcanic aerosols
  - Progress in aerosol analysis (using the fine mode information, and preliminary work on assimilating CALIPSO backscatter)

Conclusions and perspectives

MACC – Monitoring Atmospheric Composition and Climate

- Integrates space-based and in-situ observations of atmospheric composition with state-of-the art atmospheric modelling provided by the ECMWF IFS
- Provides monitoring and forecasting services
- Helps Europe to respond to climate change and poor air quality



http://www.gmes-atmosphere.eu

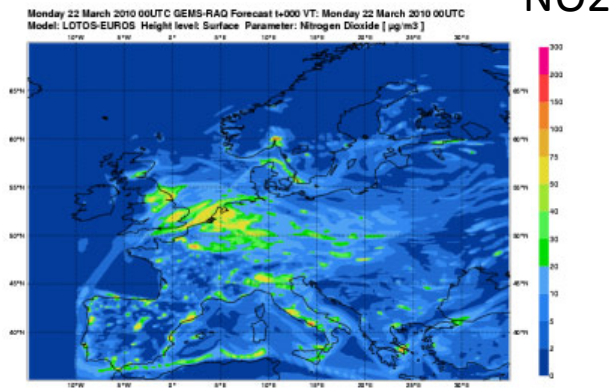
Since Nov'11, MACC II follow-up project

MACC Daily Service Provision

http://www.gmes-atmosphere.eu

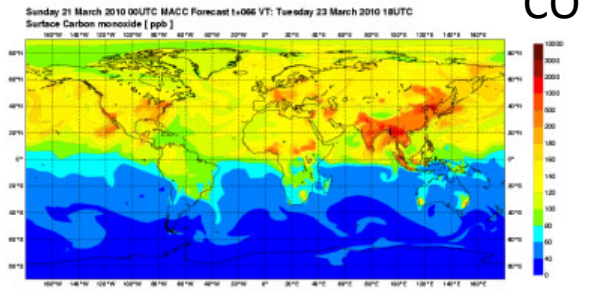
Air quality

NO2



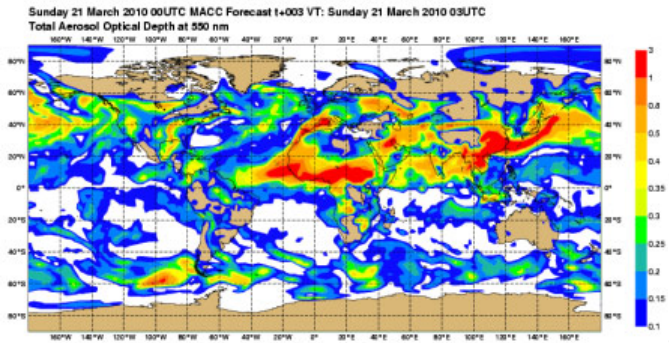
Global Pollution

CO

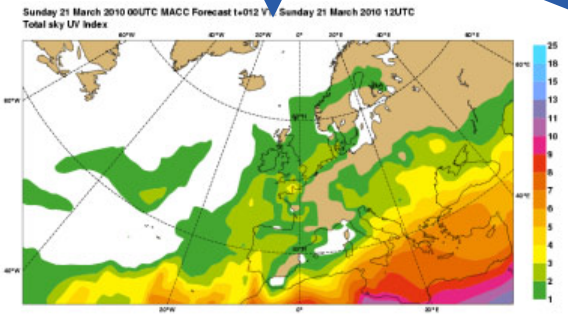


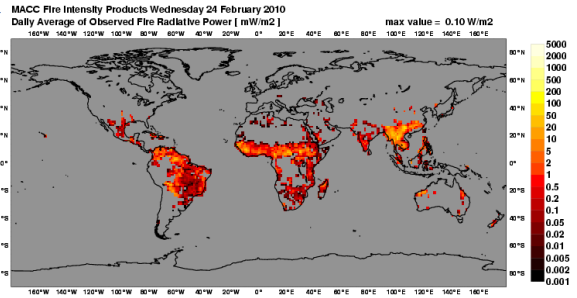
Biomass burning

Aerosol



UV index





NRT since September 2008

Quick overview of the MACC/ECMWF aerosol analysis and forecasting 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, DU, 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).

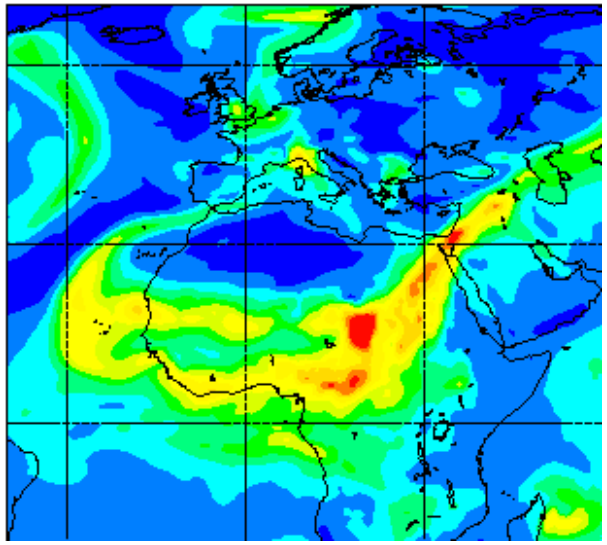
Assimilated observations are the MODIS Aerosol Optical Depths (AODs) at 550nm over land and ocean. Observation errors, originally prescribed, are now provided as part of the variational bias correction.

Benedetti et al., 2009, JGR

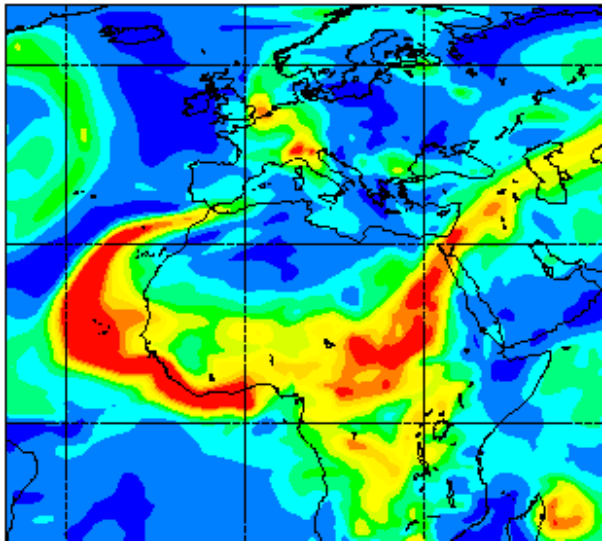
Evaluation with MODIS/SEVERI and AERONET

Saharan dust outbreak: 6 March 2004

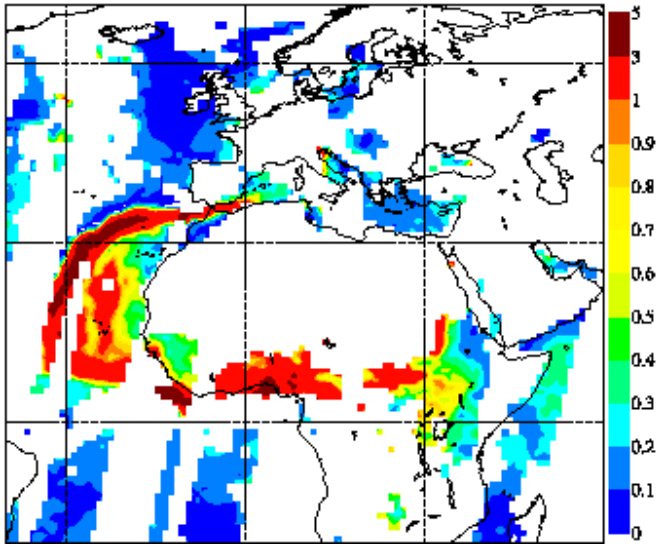
Model simulation



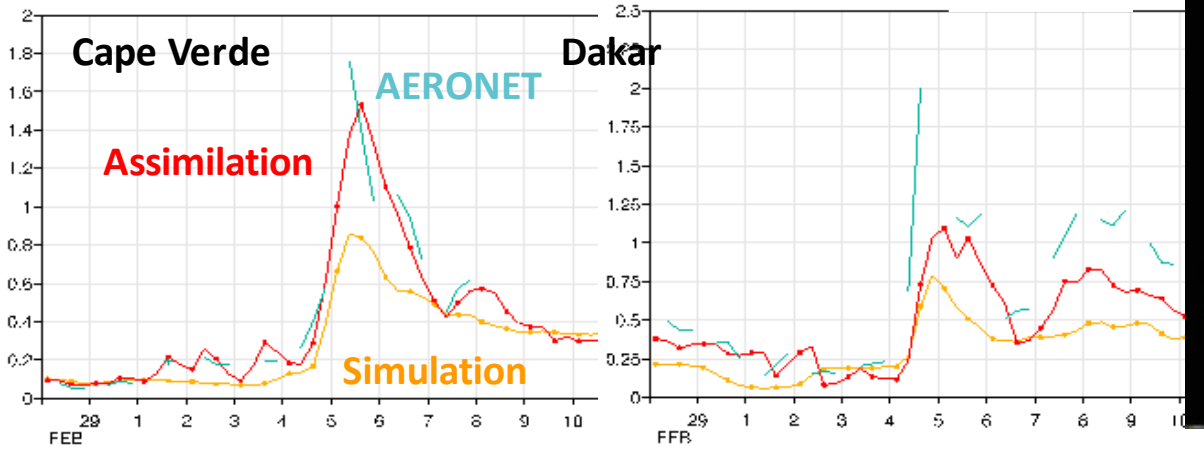
Assimilation

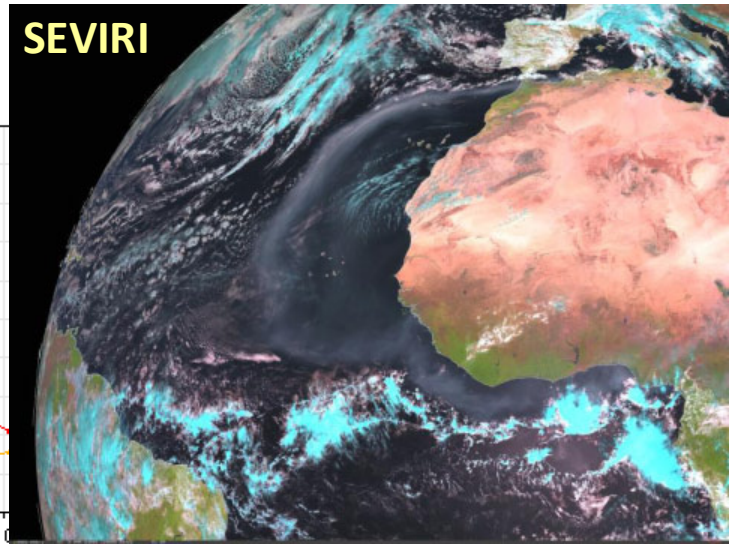


MODIS



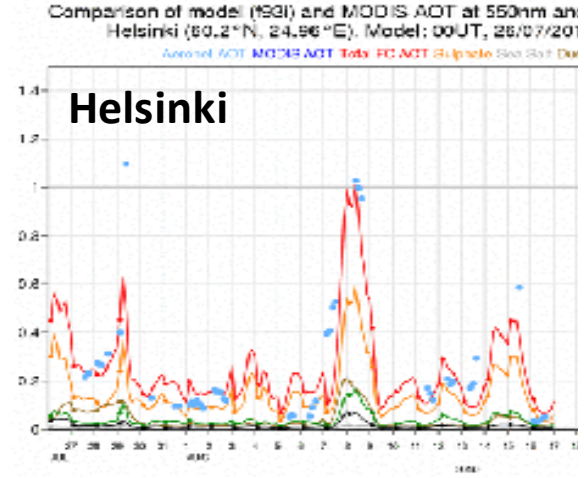
Aerosol optical depth at 550nm (upper) and 670/675nm (lower)

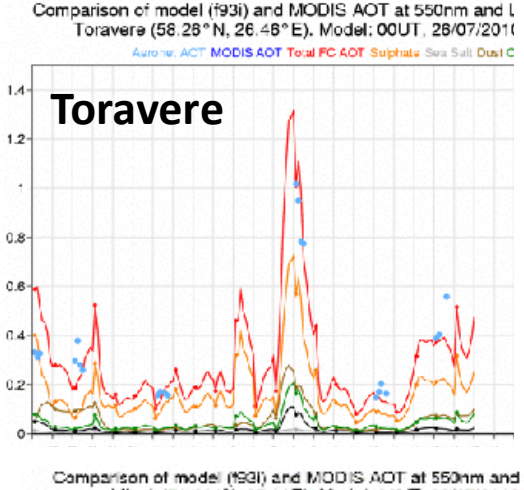


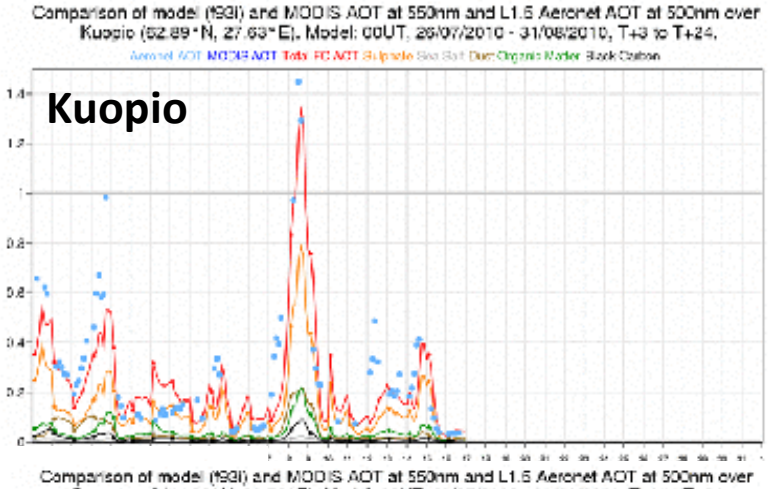


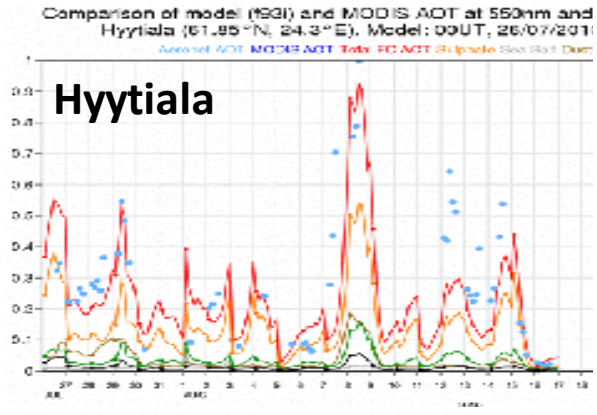
Morcrette et al., 2009; Benedetti et al., 2009

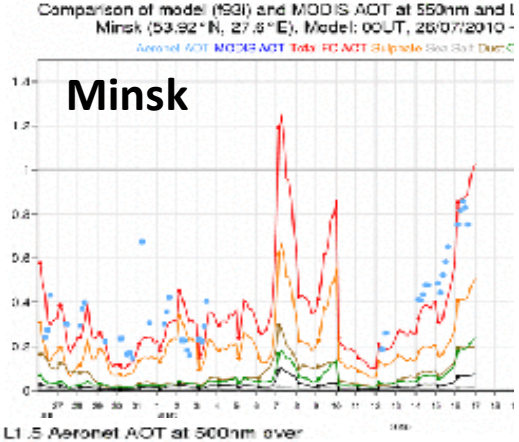
Russian fires, August 2010

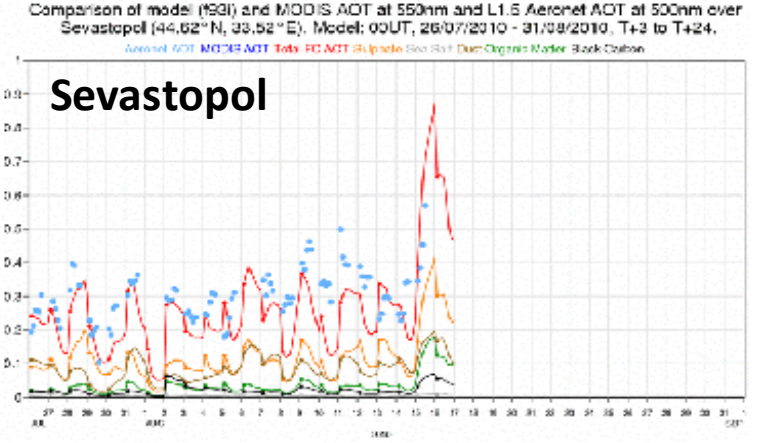








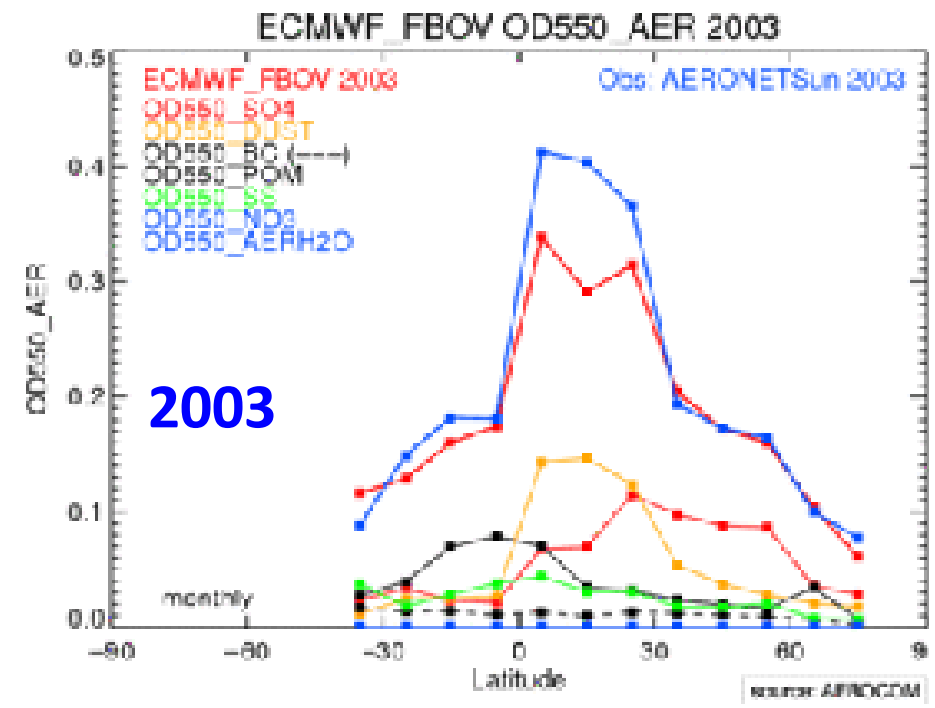


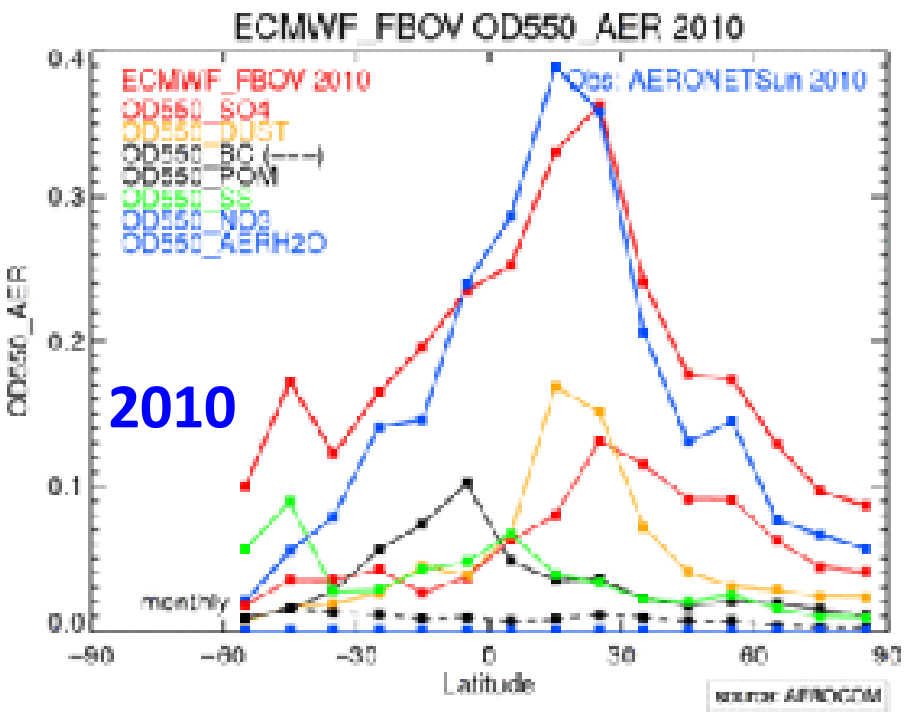


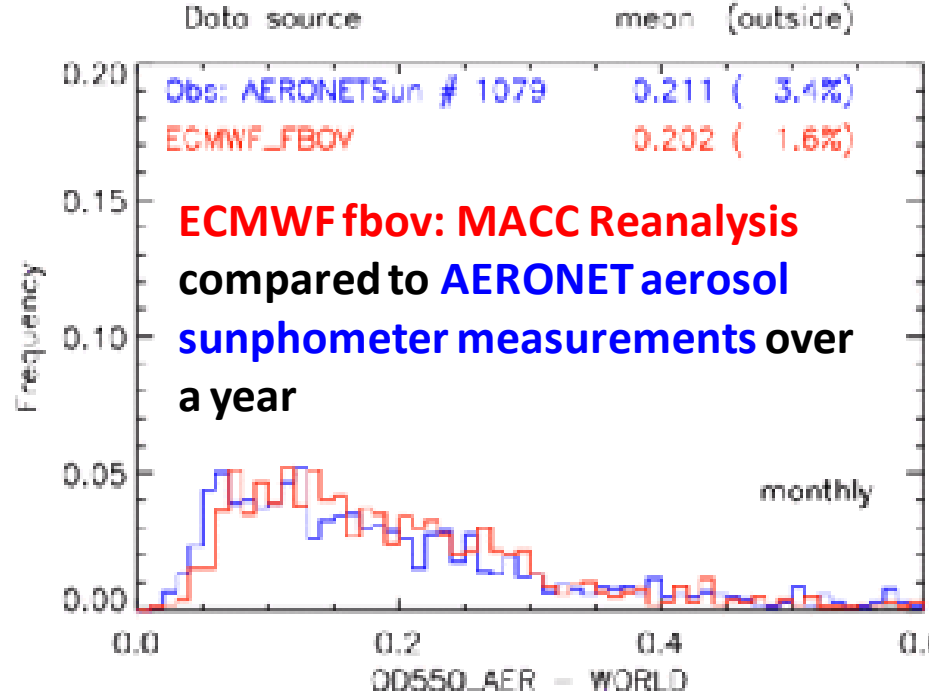
The MACC-AERosol system, assimilating MODIS tau550 allowed a good description of the impact of the Russian fires in mid-August 2010 over North-Eastern Europe

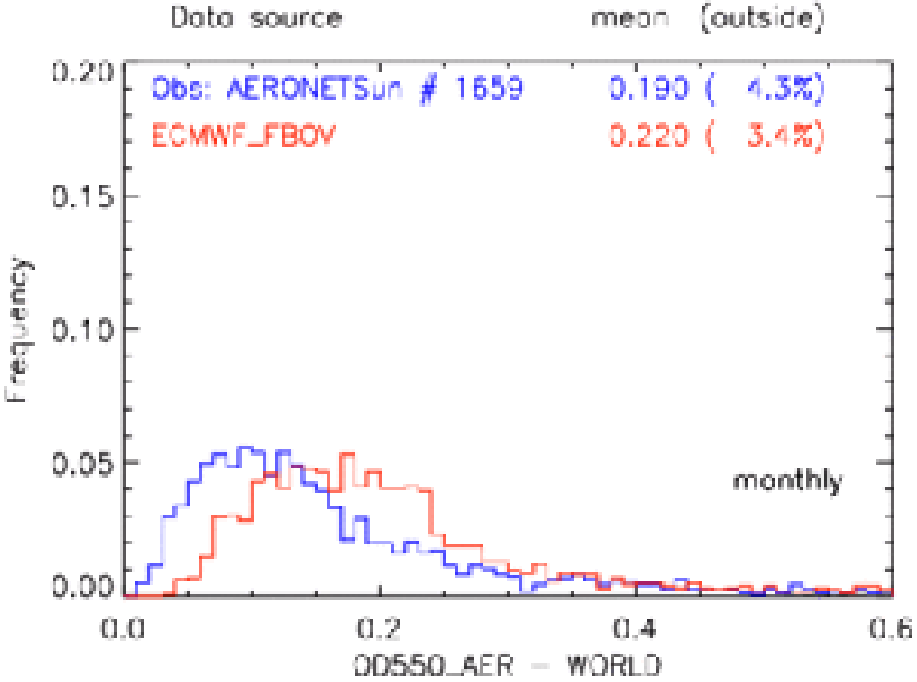
More on fires from J. Kaiser on Wednesday

How good (or otherwise) is the MACC/ECMWF aerosol system?



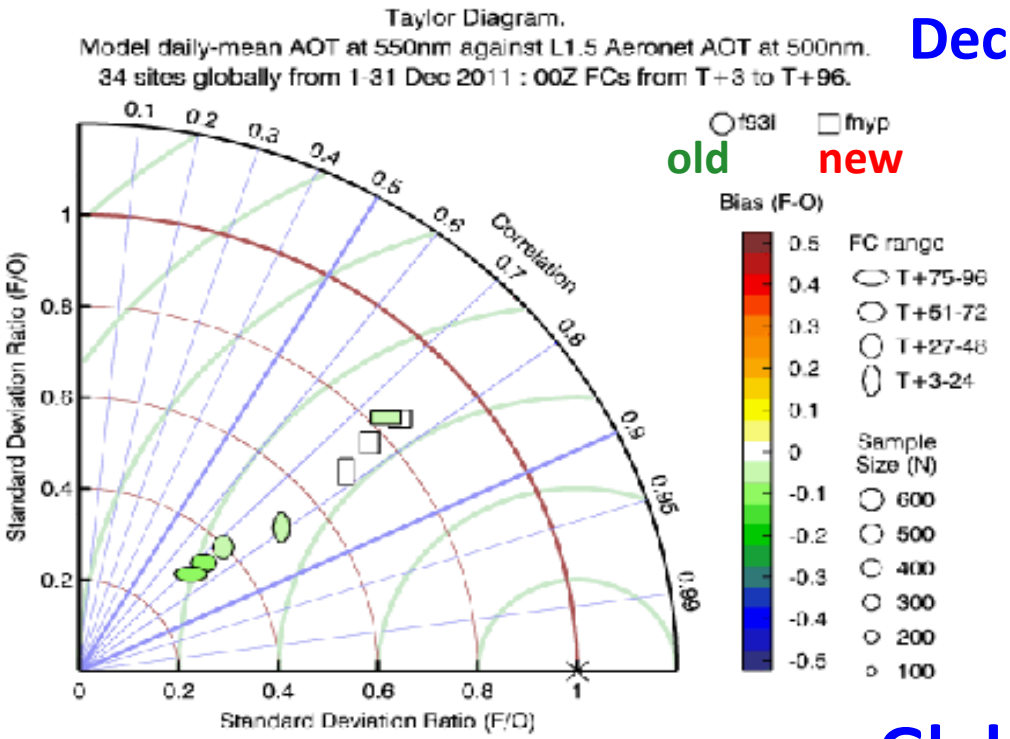


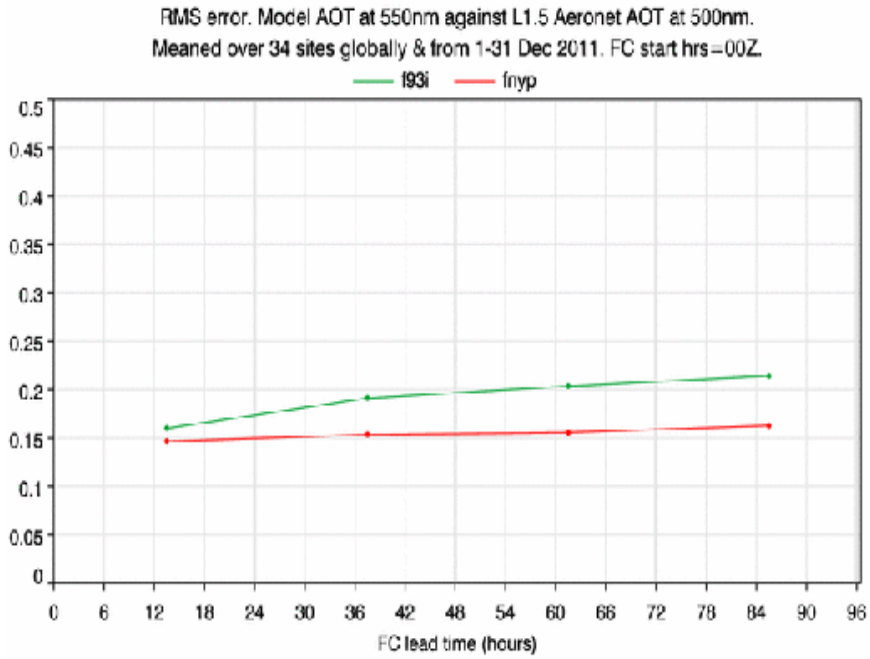




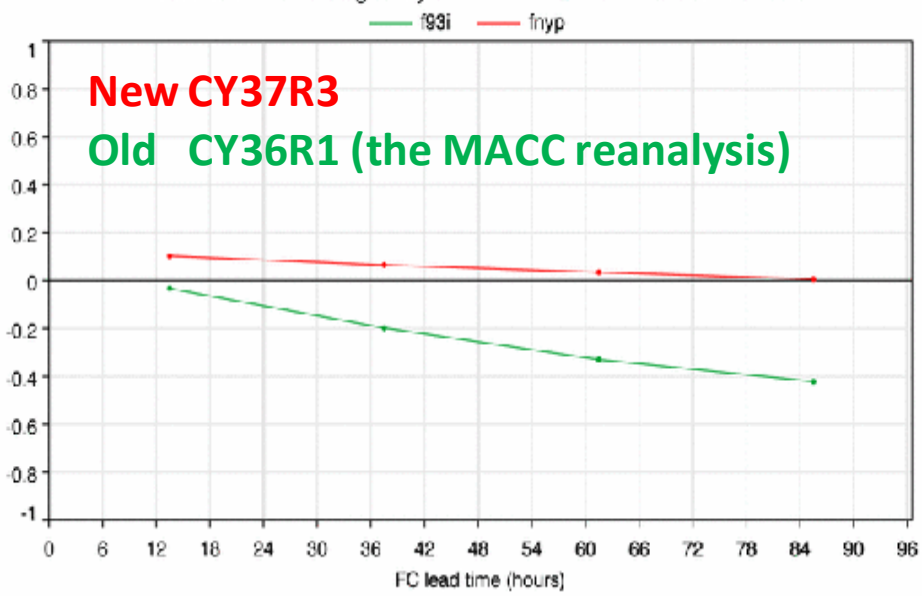
ECMWF fbov: MACC Reanalysis compared to AERONET aerosol sunphometer measurements over a year

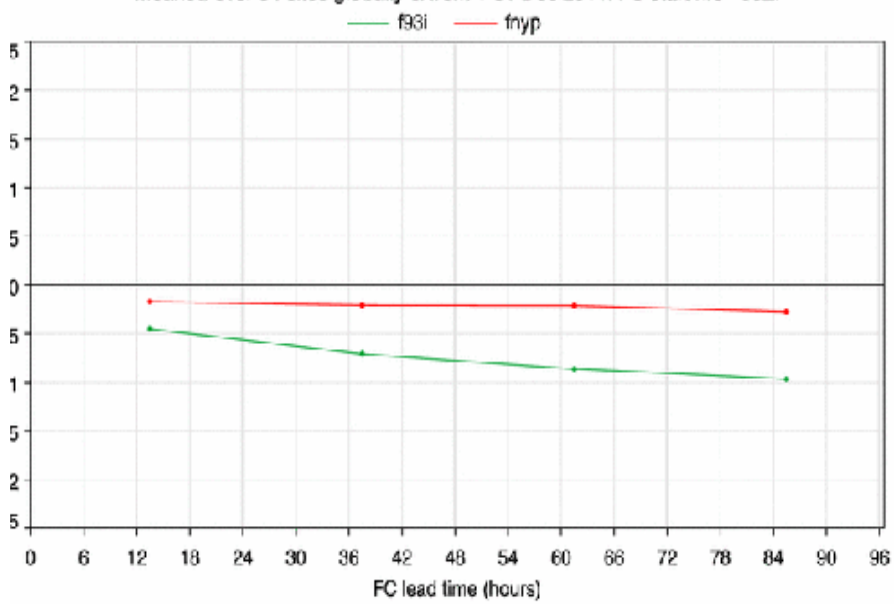
Dec.'11



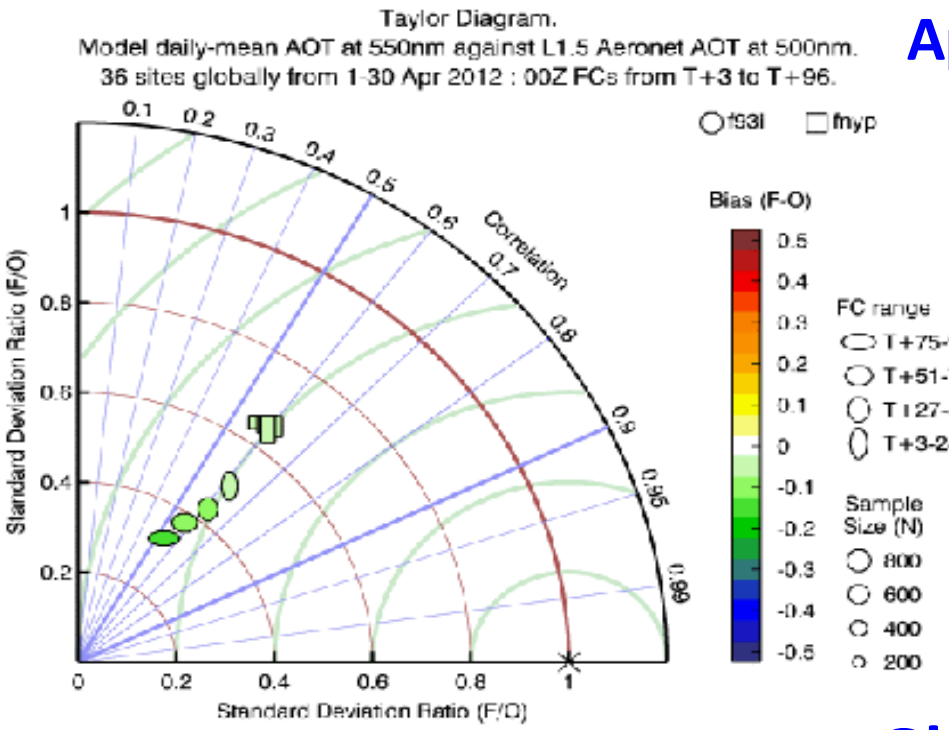


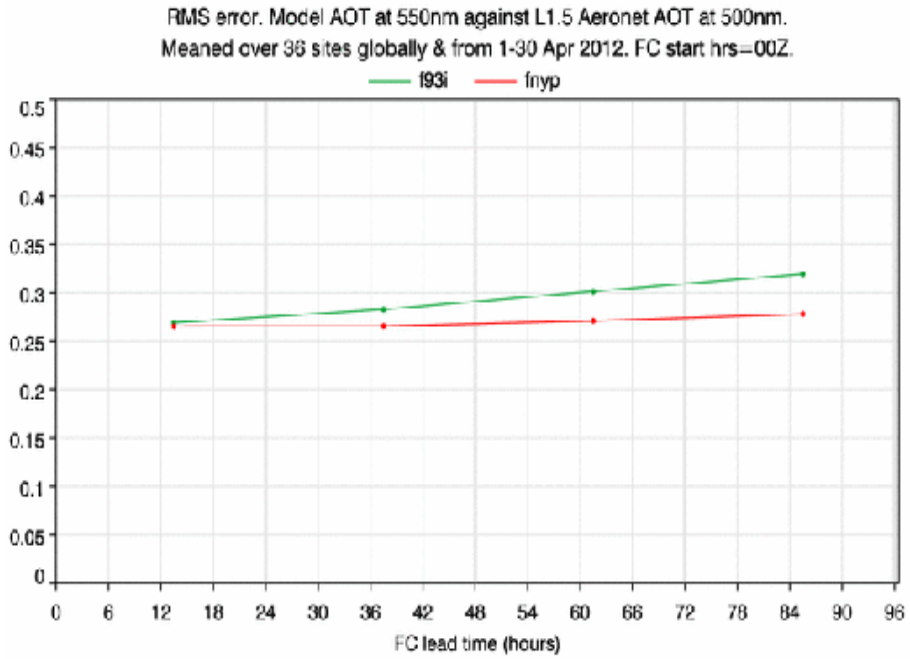
Global



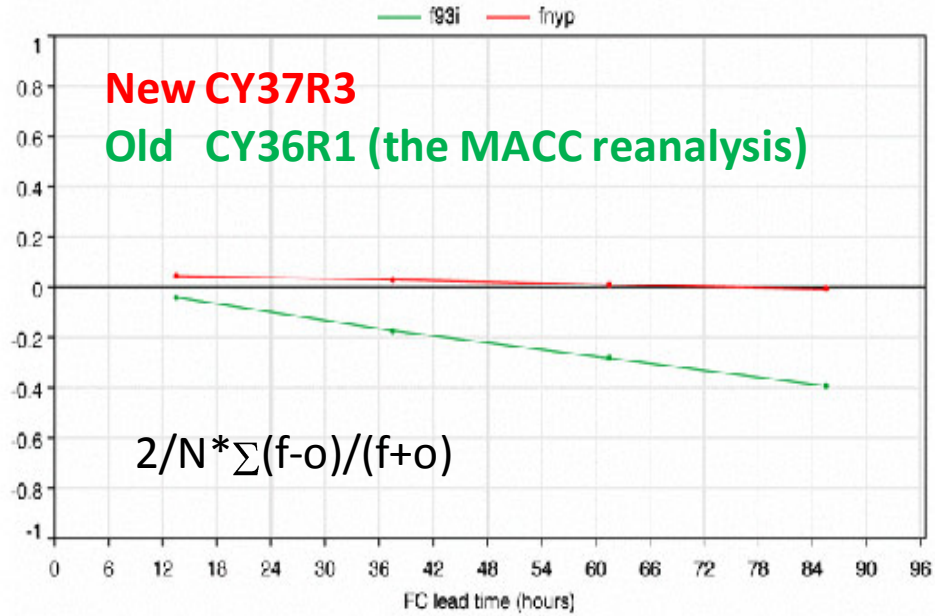


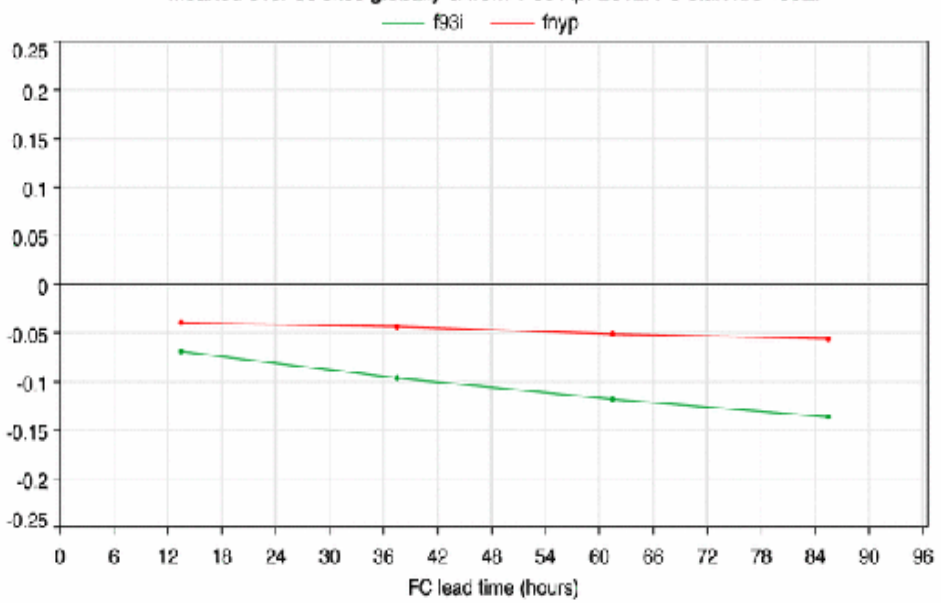
April '12



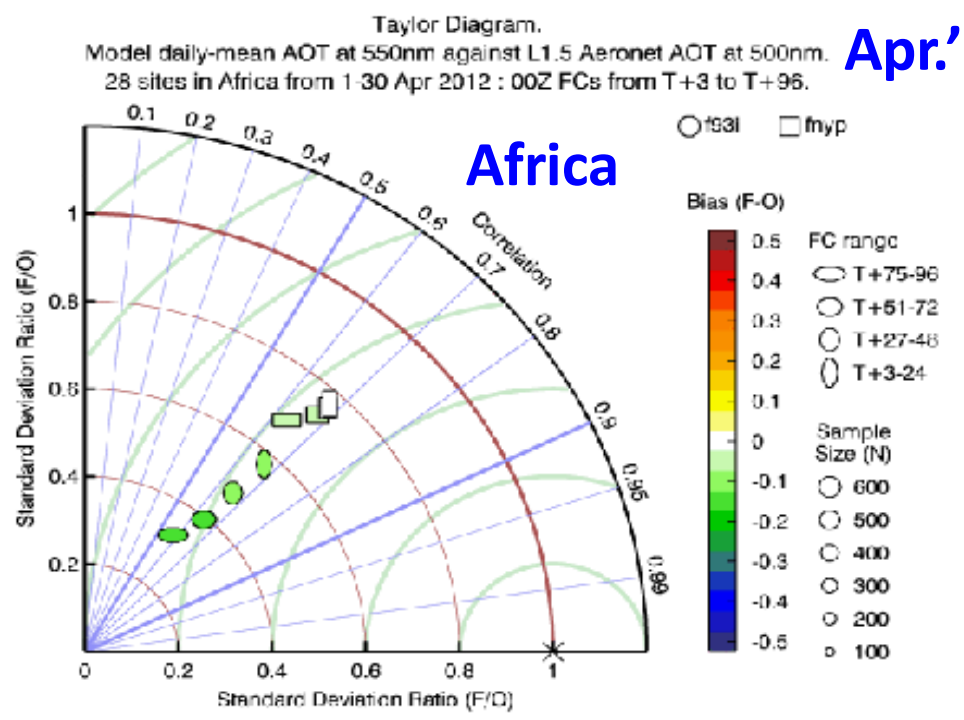


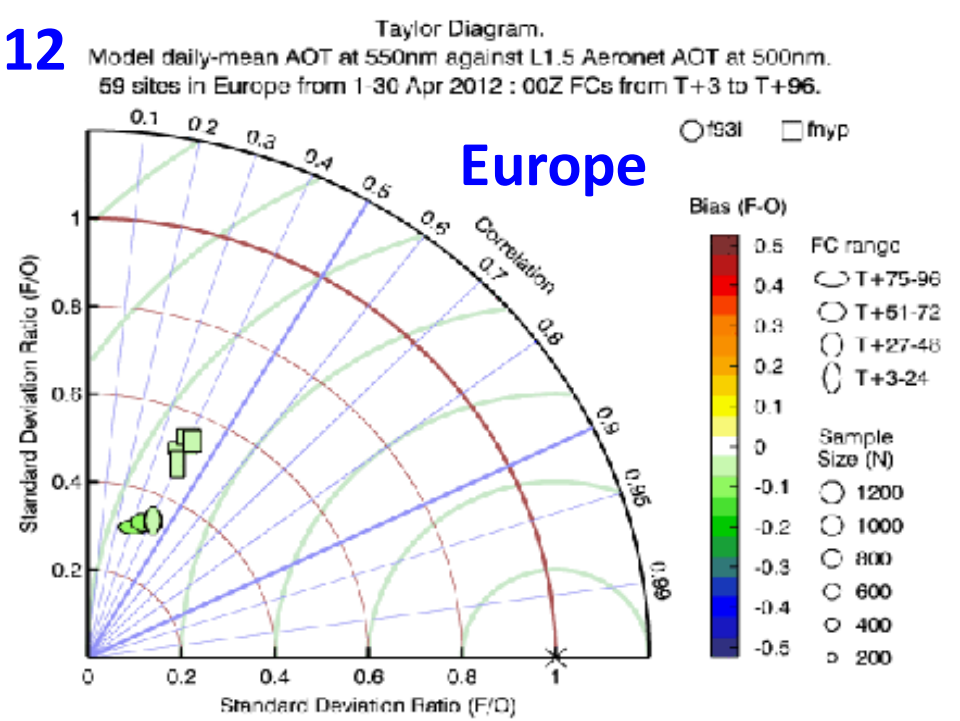
Global

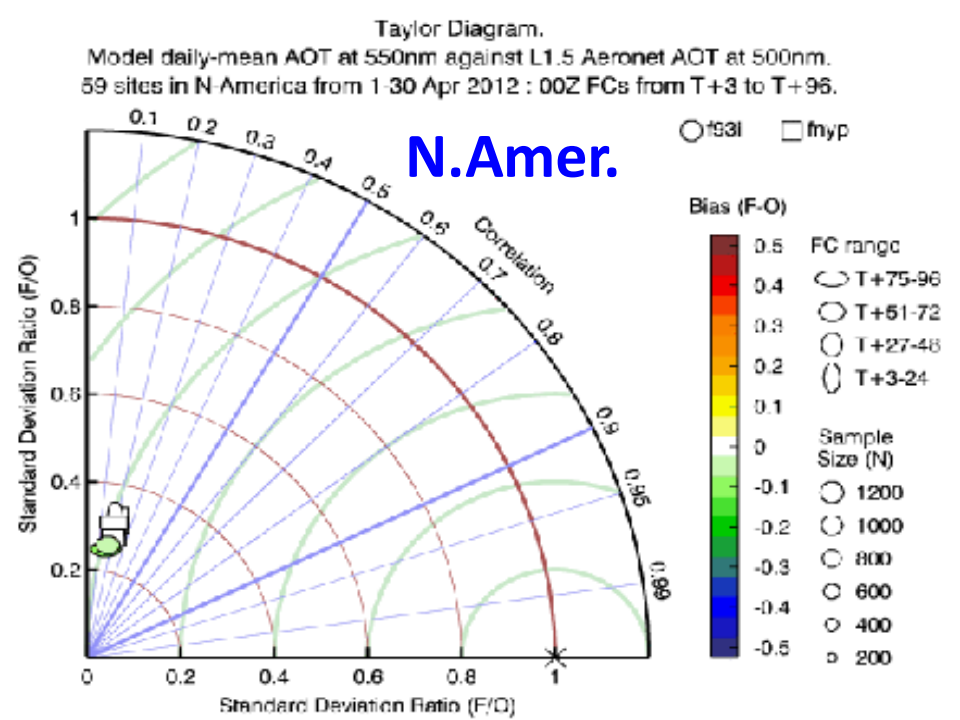




Apr.'12


Taylor Diagram.
Model daily-mean AOT at 550nm against L1.5 Aeronet AOT at 500nm.
28 sites in Africa from 1-30 Apr 2012 : 00Z FCs from T+3 to T+96.
Africa
f93l
fnyp
Bias (F-O)
FC range
T+75-96
T+51-72
T+27-48
T+3-24
Sample Size (N)
600
500
400
300
200
100
Correlation
Standard Deviation Ratio (F/O)
Standard Deviation Ratio (F/O)


Taylor Diagram.
Model daily-mean AOT at 550nm against L1.5 Aeronet AOT at 500nm.
59 sites in Europe from 1-30 Apr 2012 : 00Z FCs from T+3 to T+96.
Europe
f93l
fnyp
Bias (F-O)
FC range
T+75-96
T+51-72
T+27-48
T+3-24
Sample Size (N)
1200
1000
800
600
400
200
Correlation
Standard Deviation Ratio (F/O)
Standard Deviation Ratio (F/O)


Taylor Diagram.
Model daily-mean AOT at 550nm against L1.5 Aeronet AOT at 500nm.
59 sites in N.America from 1-30 Apr 2012 : 00Z FCs from T+3 to T+96.
N.Amer.
f93l
fnyp
Bias (F-O)
FC range
T+75-96
T+51-72
T+27-48
T+3-24
Sample Size (N)
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800
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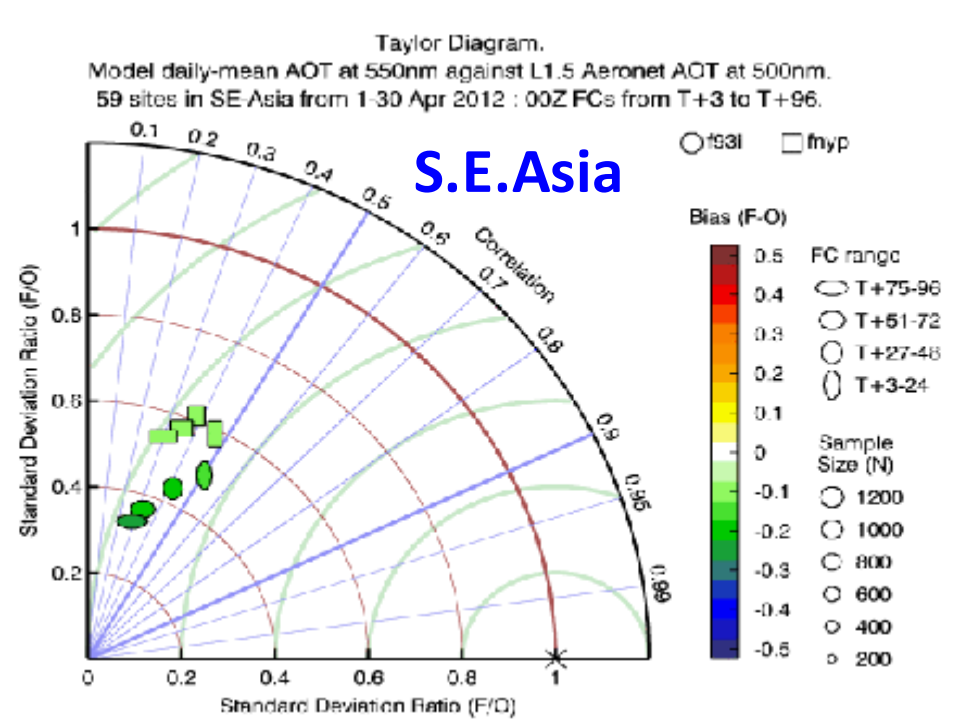
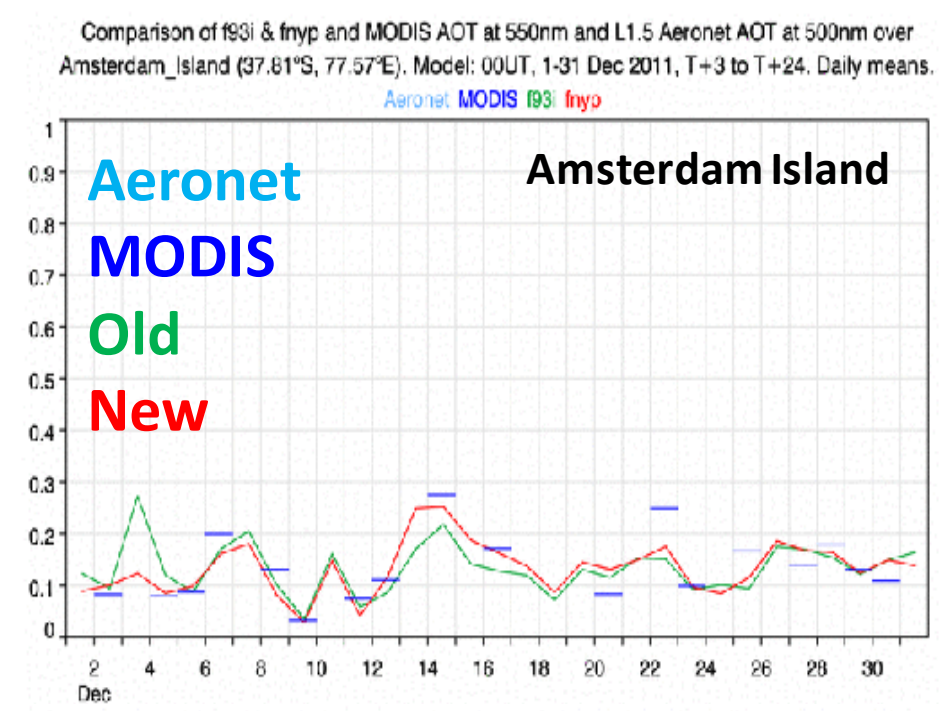
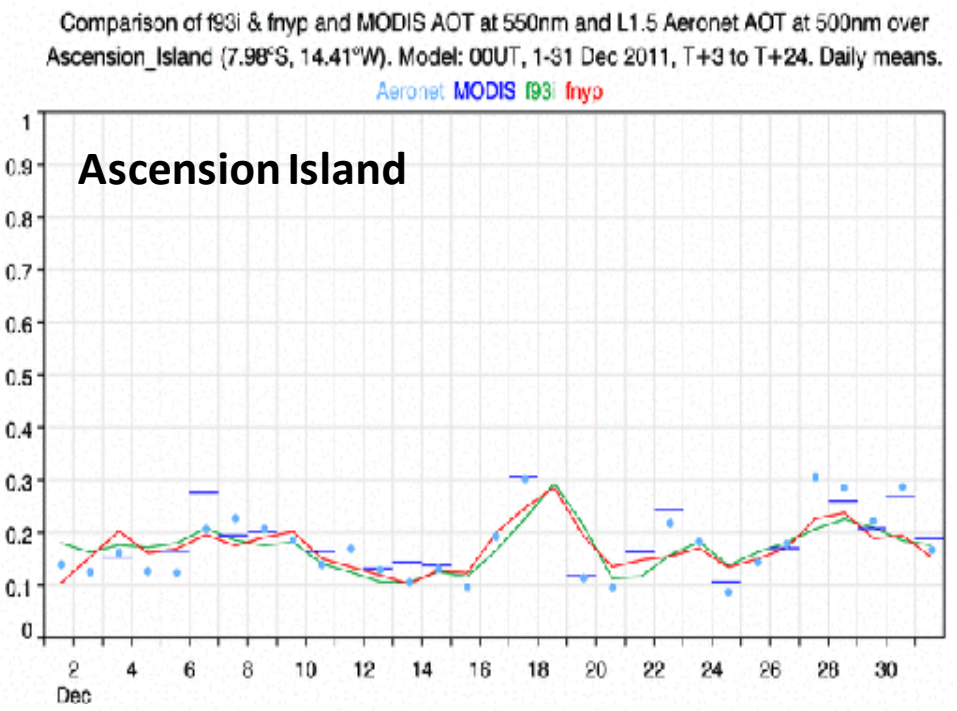
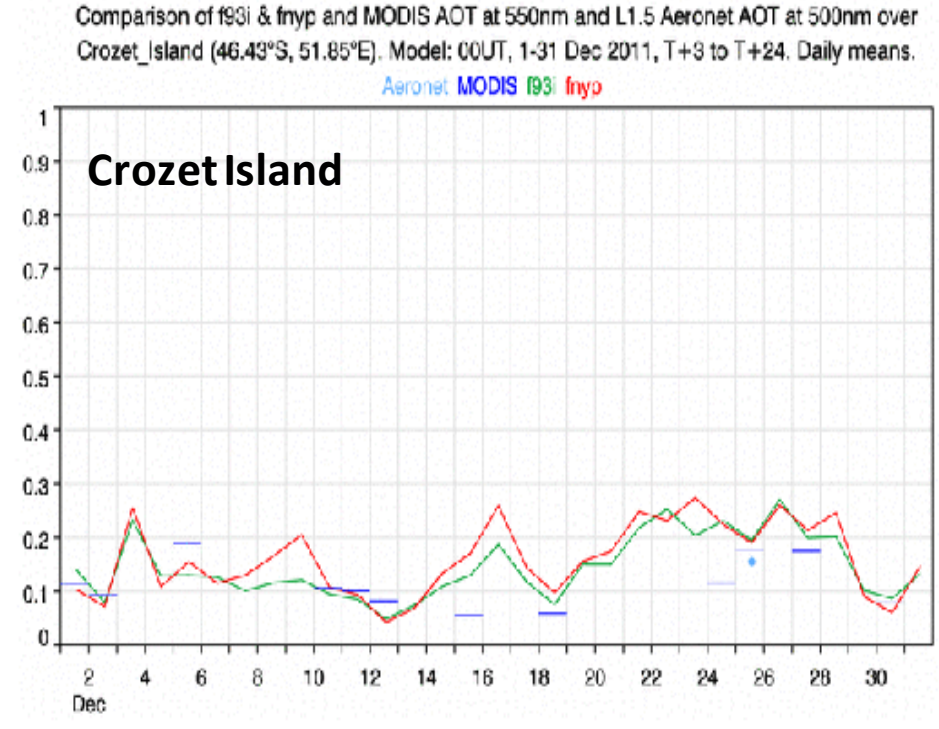
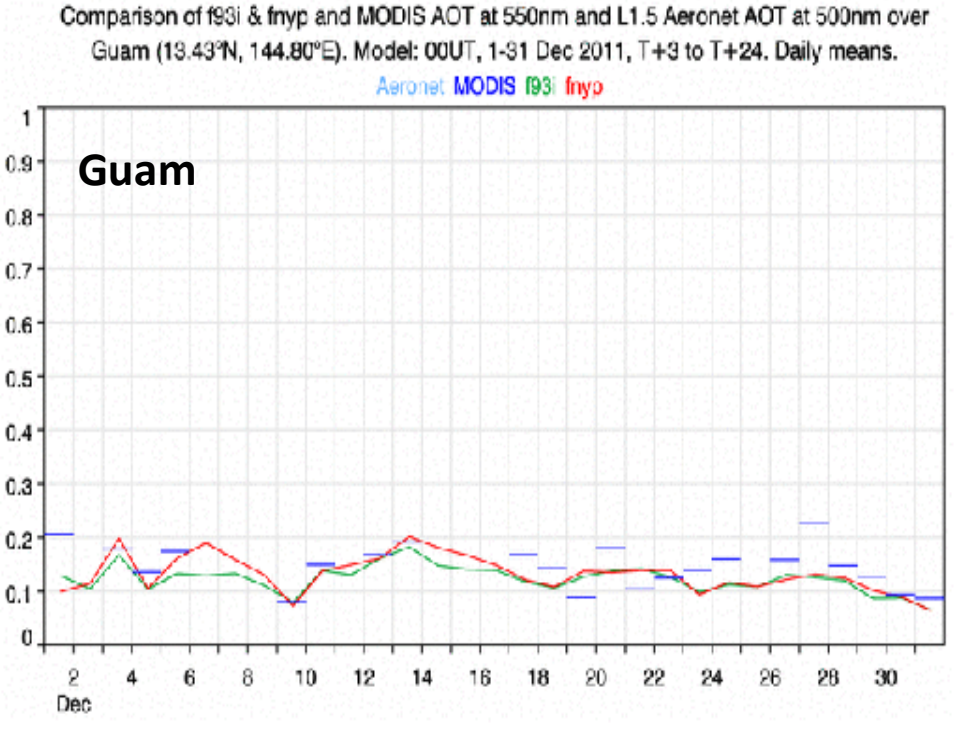
400
200
Correlation
Standard Deviation Ratio (F/O)
Standard Deviation Ratio (F/O)


Taylor Diagram.
Model daily-mean AOT at 550nm against L1.5 Aeronet AOT at 500nm.
59 sites in SE.Asia from 1-30 Apr 2012 : 00Z FCs from T+3 to T+96.
S.E.Asia
f93l
fnyp
Bias (F-O)
FC range
T+75-96
T+51-72
T+27-48
T+3-24
Sample Size (N)
1200
1000
800
600
400
200
Correlation
Standard Deviation Ratio (F/O)
Standard Deviation Ratio (F/O)


Comparison of f93i & fnyp and MODIS AOT at 550nm and L1.5 Aeronet AOT at 500nm over Amsterdam_Island (37.81°S, 77.57°E). Model: 00UT, 1-31 Dec 2011, T+3 to T+24. Daily means.
Aeronet MODIS f93i fnyp
Aeronet
MODIS
Old
New
Amsterdam Island
Dec

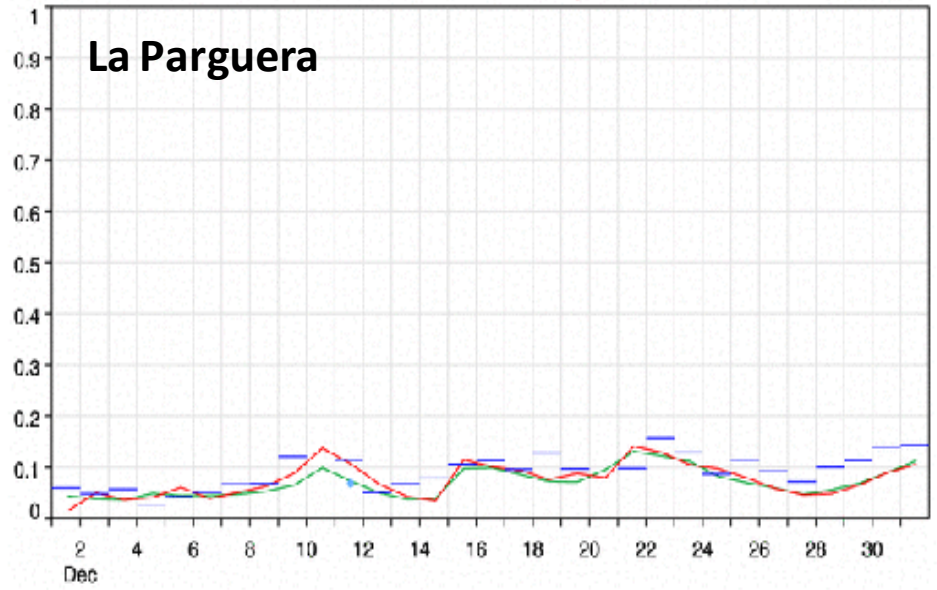

Comparison of f93i & fnyp and MODIS AOT at 550nm and L1.5 Aeronet AOT at 500nm over Ascension_Island (7.98°S, 14.41°W). Model: 00UT, 1-31 Dec 2011, T+3 to T+24. Daily means.
Aeronet MODIS f93i fnyp
Ascension Island
Dec


Comparison of f93i & fnyp and MODIS AOT at 550nm and L1.5 Aeronet AOT at 500nm over Crozet_Island (46.43°S, 51.85°E). Model: 00UT, 1-31 Dec 2011, T+3 to T+24. Daily means.
Aeronet MODIS f93i fnyp
Crozet Island
Dec


Comparison of f93i & fnyp and MODIS AOT at 550nm and L1.5 Aeronet AOT at 500nm over Guam (13.43°N, 144.80°E). Model: 00UT, 1-31 Dec 2011, T+3 to T+24. Daily means.
Aeronet MODIS f93i fnyp
Guam
Dec

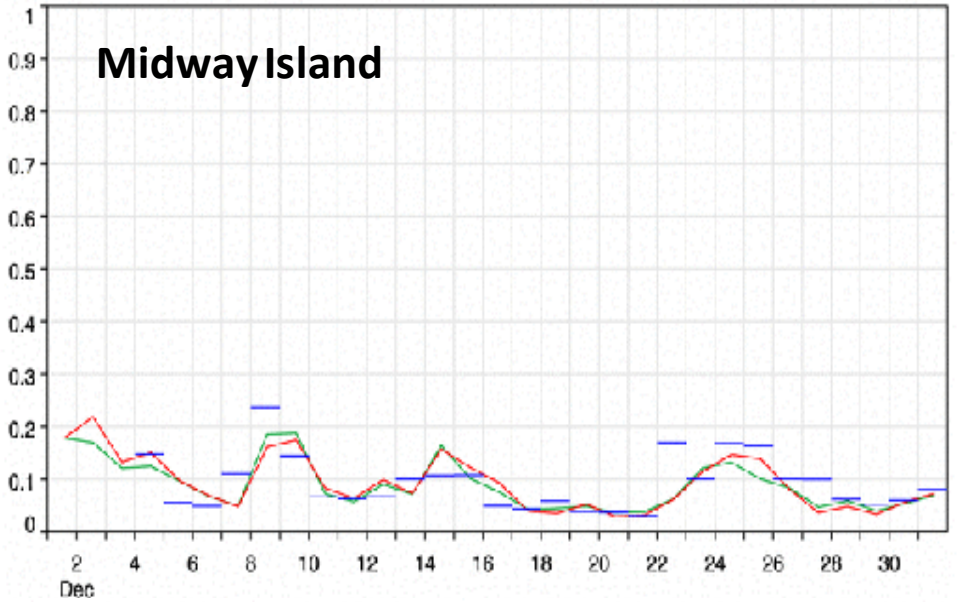
Comparison of f93i & fnyp and MODIS AOT at 550nm and L1.5 Aeronet AOT at 500nm over La_Parguera (17.97°N, 67.05°W). Model: 00UT, 1-31 Dec 2011, T+3 to T+24. Daily means.

Aeronet MODIS f93i fnyp



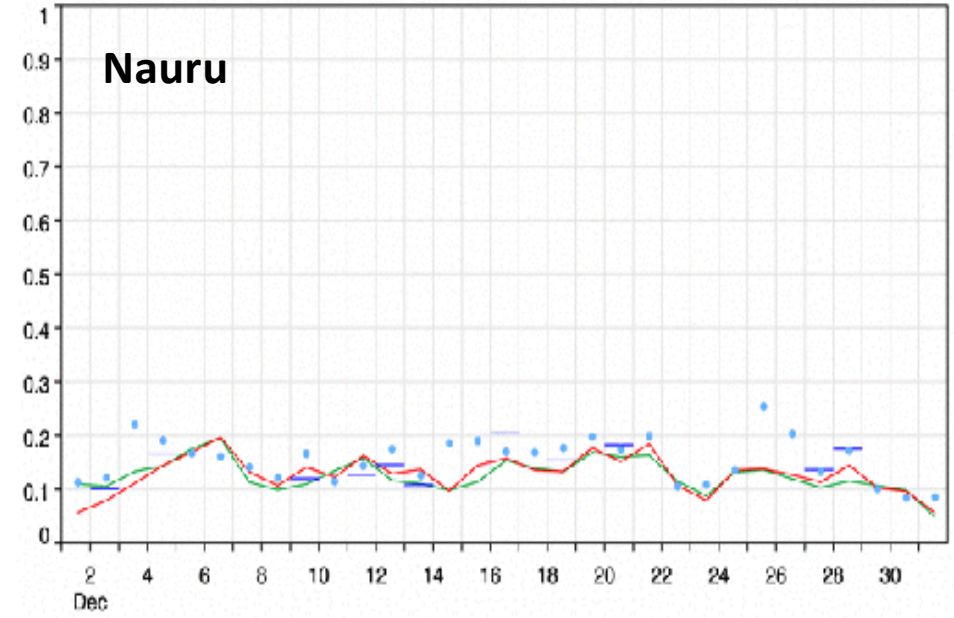
Comparison of f93i & fnyp and MODIS AOT at 550nm and L1.5 Aeronet AOT at 500nm over Midway_Island (28.21°N, 177.38°W). Model: 00UT, 1-31 Dec 2011, T+3 to T+24. Daily means.

Aeronet MODIS f93i fnyp



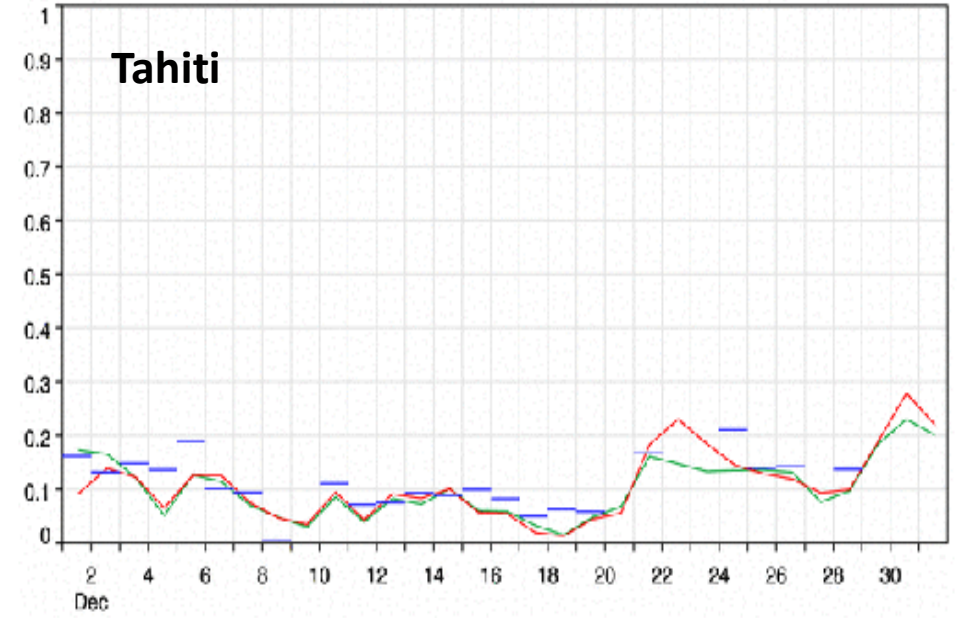
Comparison of f93i & fnyp and MODIS AOT at 550nm and L1.5 Aeronet AOT at 500nm over Nauru (0.52°S, 166.92°E). Model: 00UT, 1-31 Dec 2011, T+3 to T+24. Daily means.

Aeronet MODIS f93i fnyp



Comparison of f93i & fnyp and MODIS AOT at 550nm and L1.5 Aeronet AOT at 500nm over Tahiti (17.58°S, 149.61°W). Model: 00UT, 1-31 Dec 2011, T+3 to T+24. Daily means.

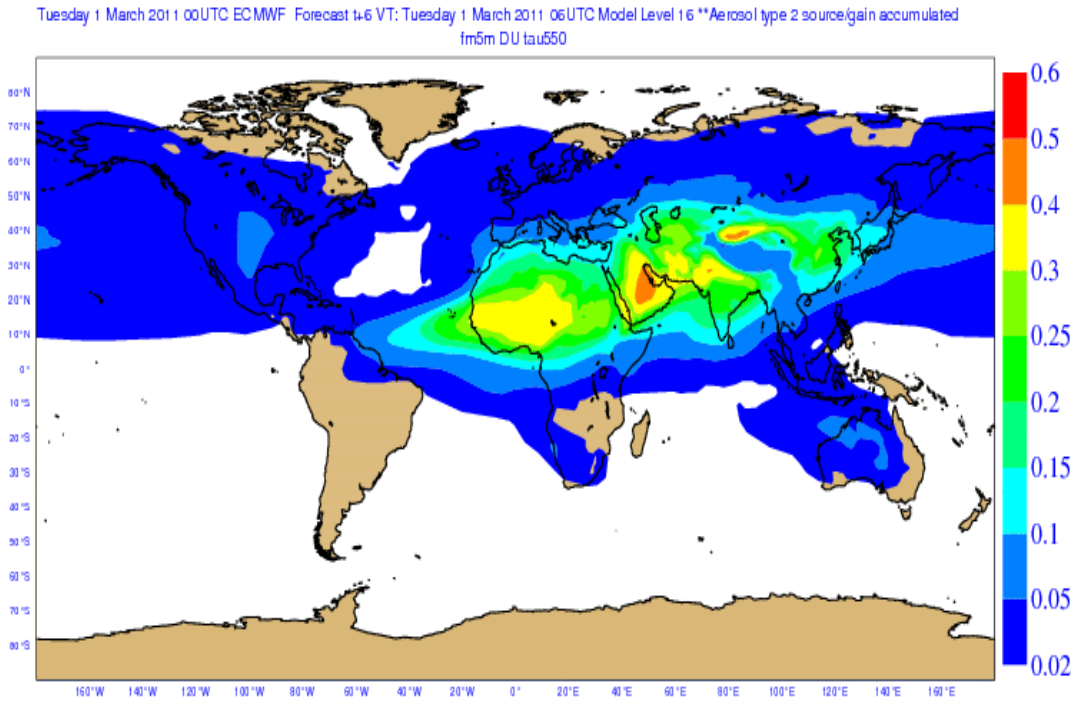
Aeronet MODIS f93i fnyp



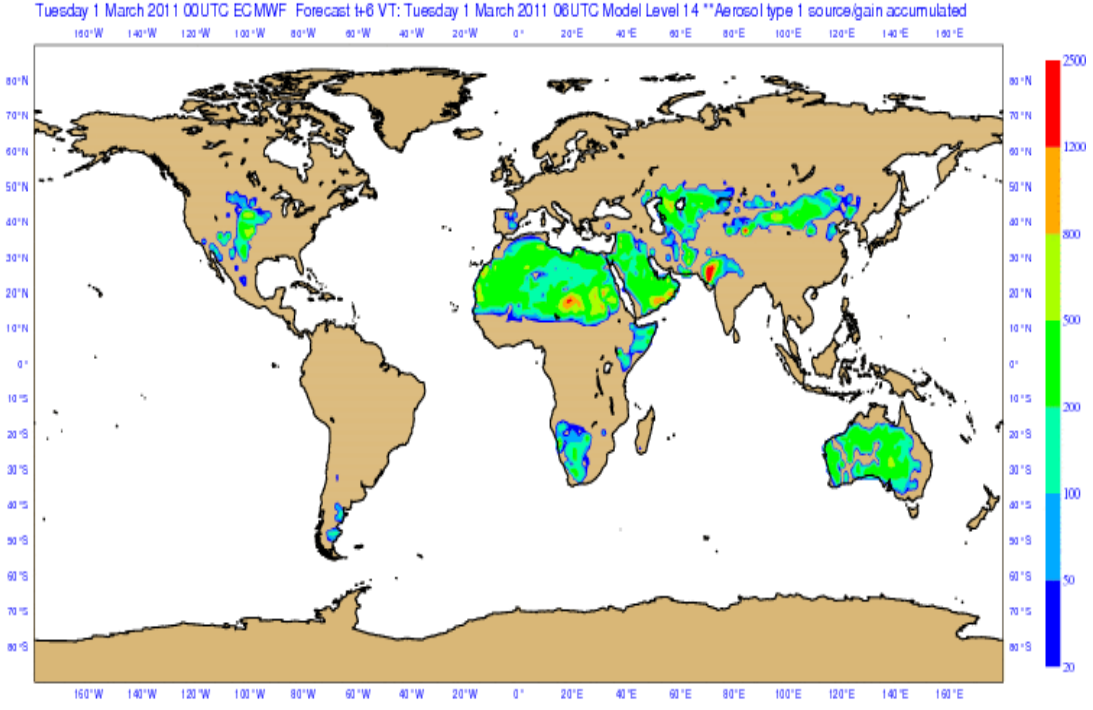
Dust only

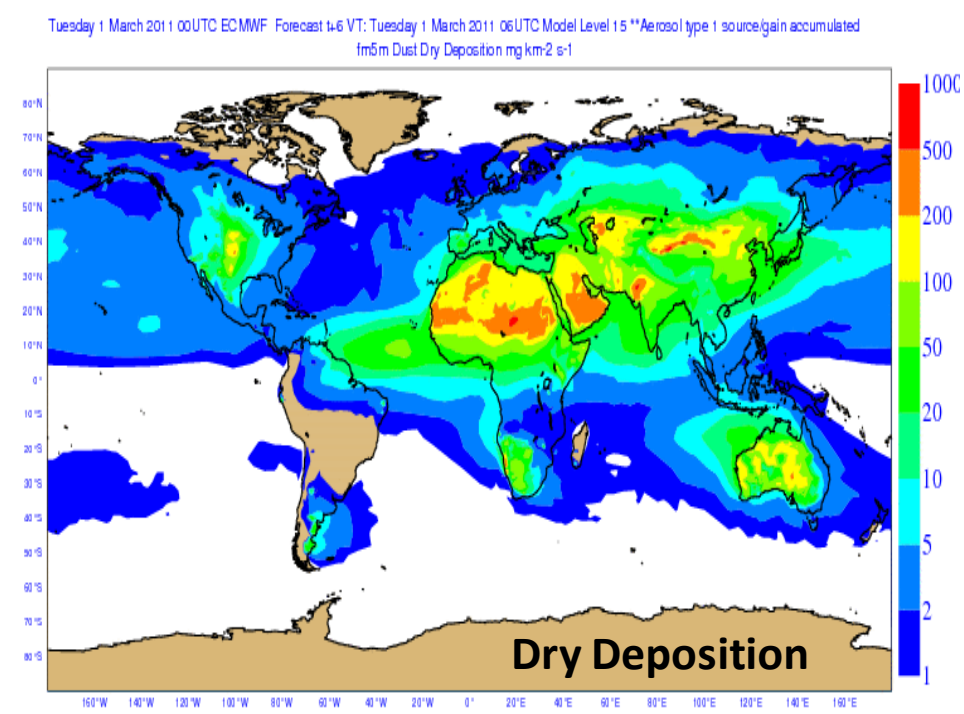
20110301-20110531

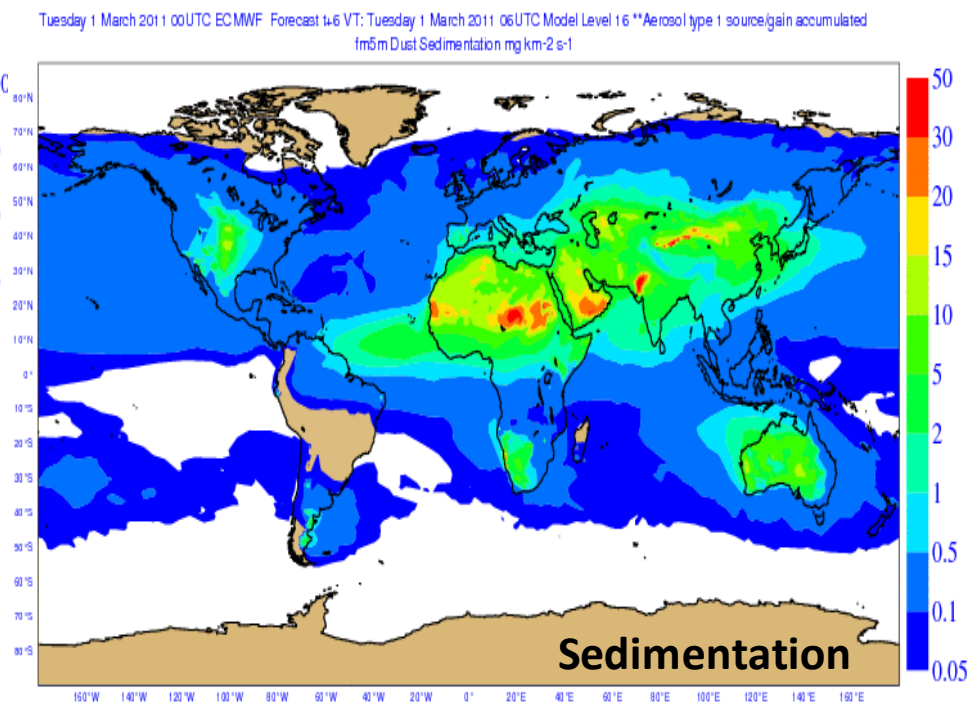
tau550

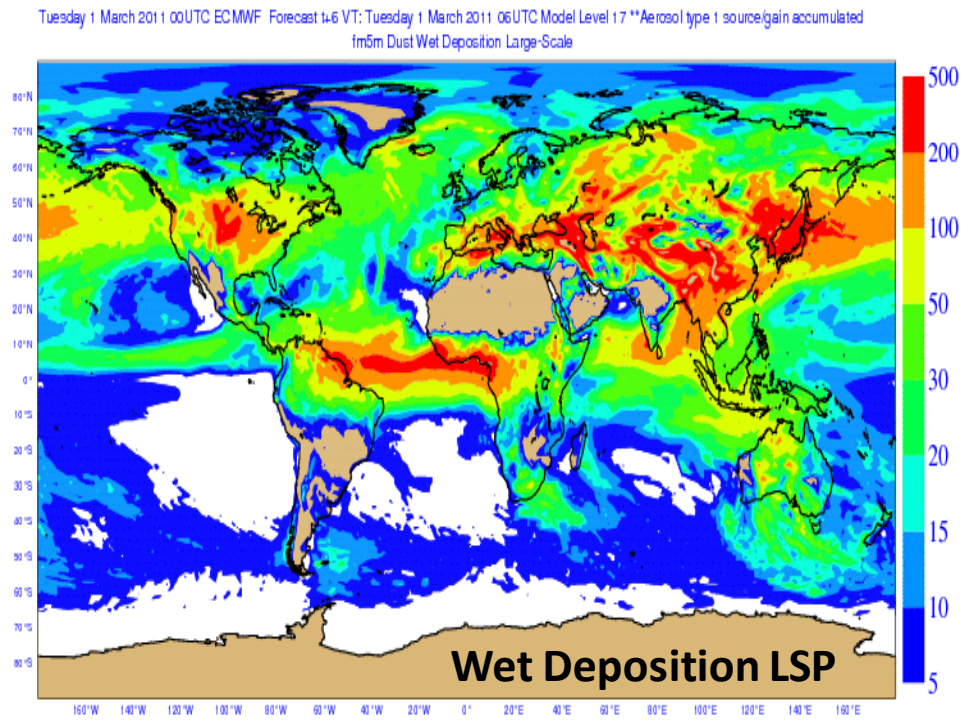


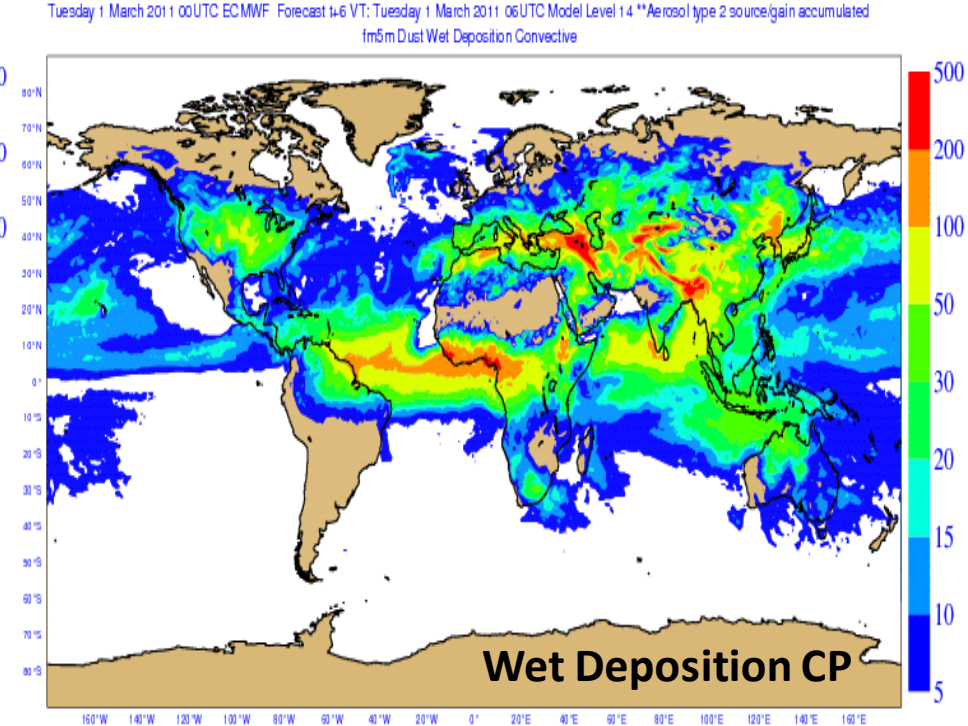
sources



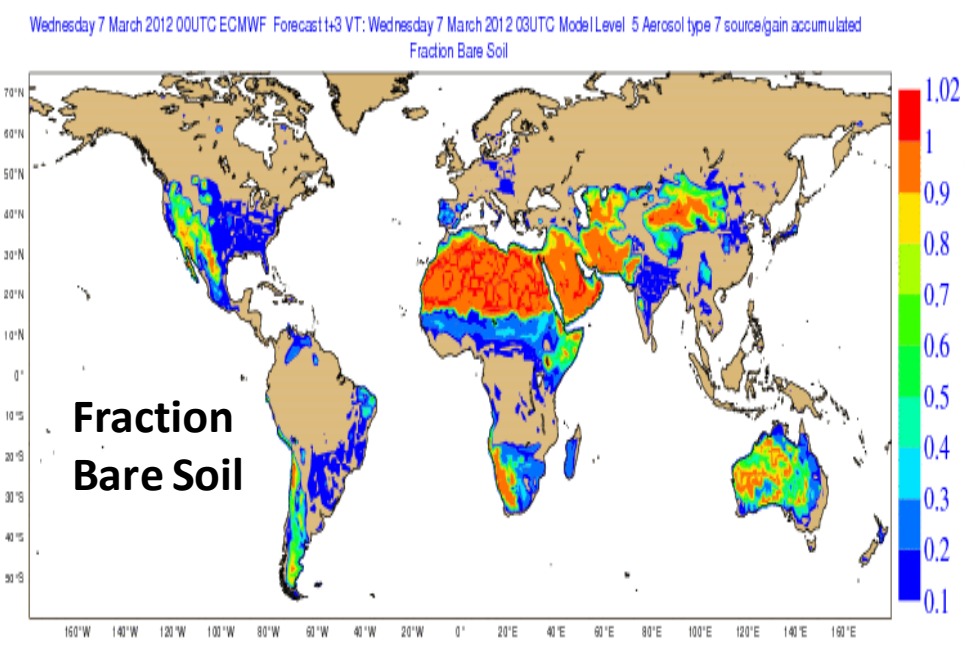

Tuesday 1 March 2011 00UTC ECMWF Forecast t+6 VT: Tuesday 1 March 2011 06UTC Model Level 15 **Aerosol type 1 source/gain accumulated
fm5m Dust Dry Deposition mg km-2 s-1
1000
500
200
100
50
20
10
5
2
1
Dry Deposition

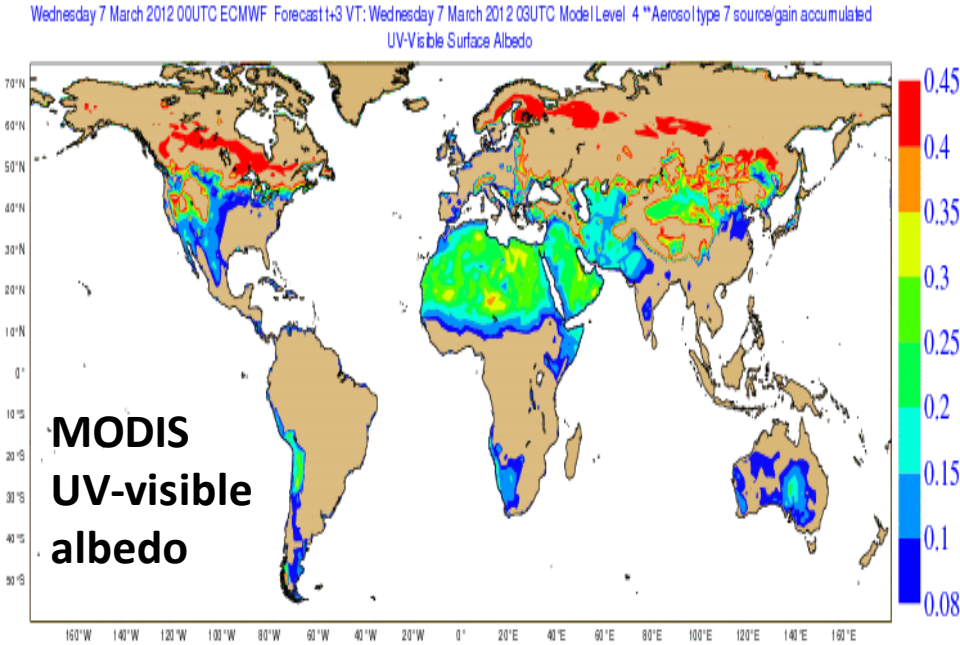

Tuesday 1 March 2011 00UTC ECMWF Forecast t+6 VT: Tuesday 1 March 2011 06UTC Model Level 16 **Aerosol type 1 source/gain accumulated
fm5m Dust Sedimentation mg km-2 s-1
50
30
20
15
10
5
2
1
0.5
0.1
0.05
Sedimentation

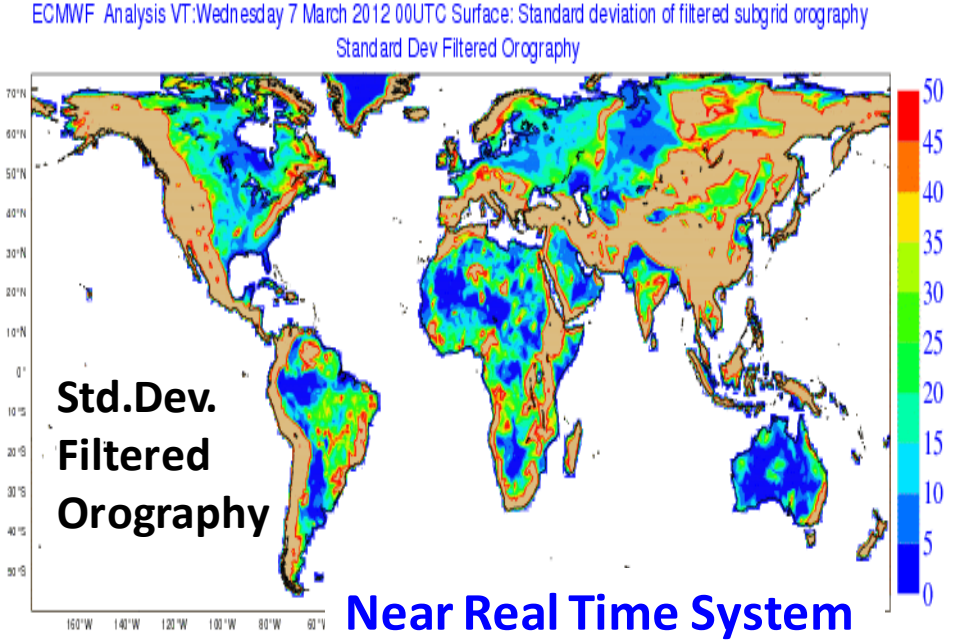

Tuesday 1 March 2011 00UTC ECMWF Forecast t+6 VT: Tuesday 1 March 2011 06UTC Model Level 17 **Aerosol type 1 source/gain accumulated
fm5m Dust Wet Deposition Large-Scale
500
200
100
50
30
20
15
10
5
Wet Deposition LSP

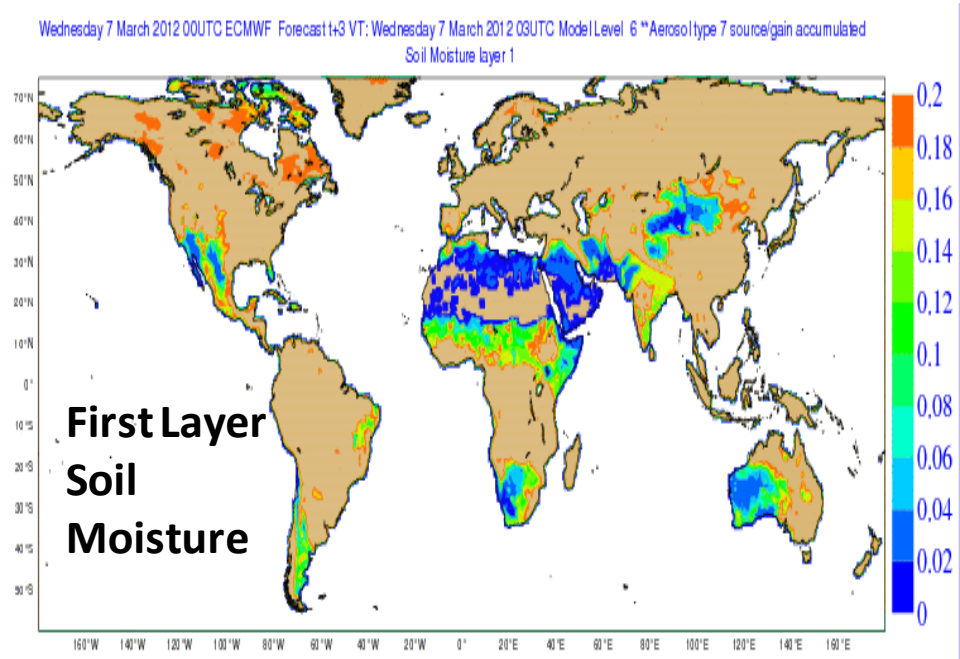

Tuesday 1 March 2011 00UTC ECMWF Forecast t+6 VT: Tuesday 1 March 2011 06UTC Model Level 14 **Aerosol type 2 source/gain accumulated
fm5m Dust Wet Deposition Convective
500
200
100
50
30
20
15
10
5
Wet Deposition CP

Parameters governing dust emissions

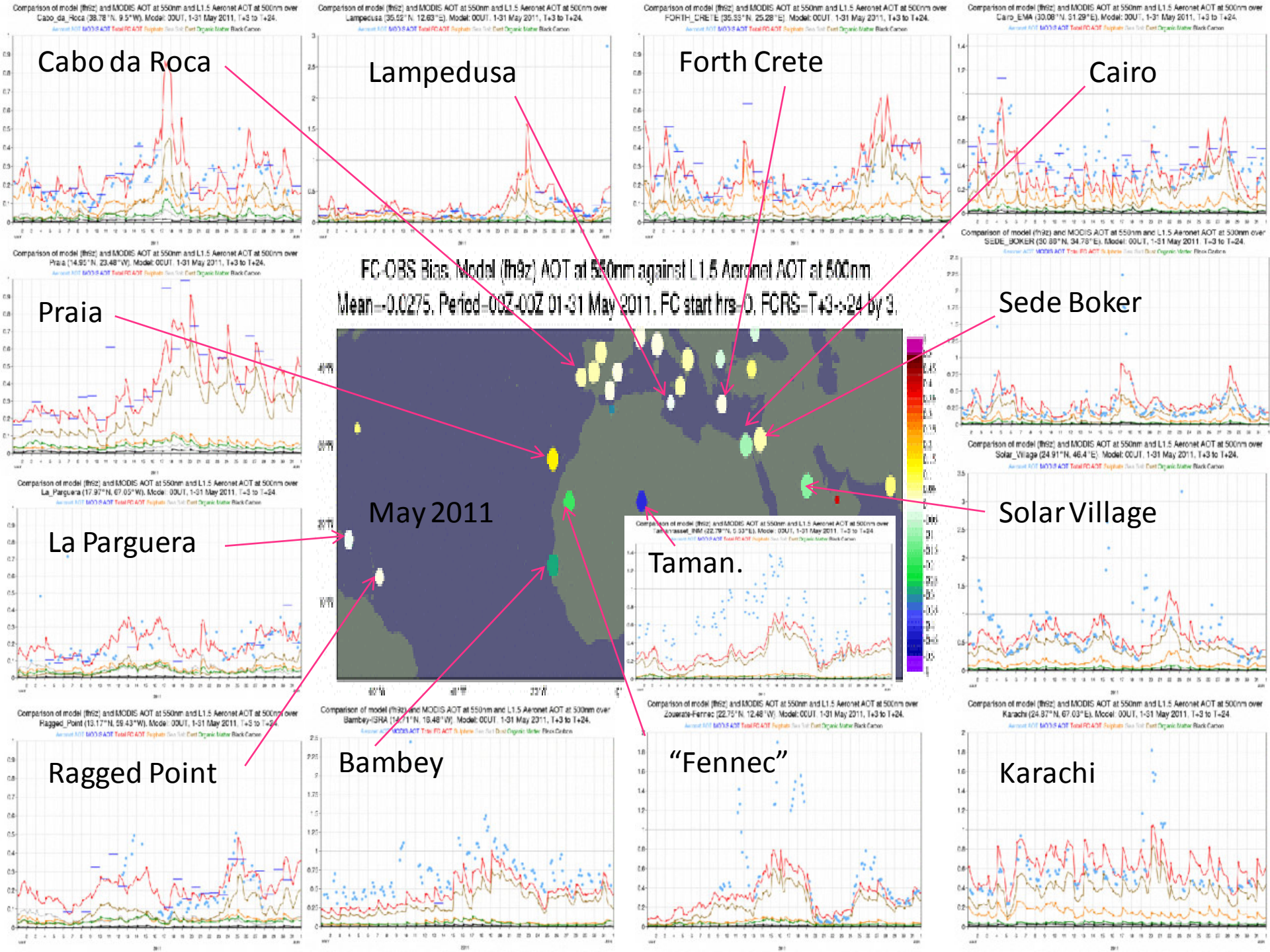


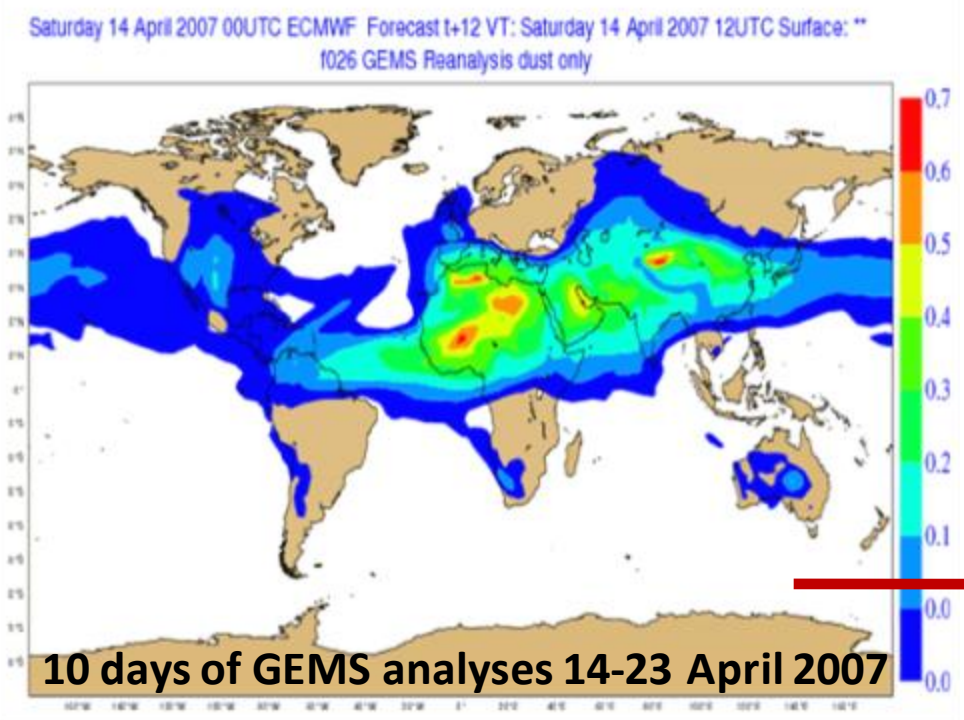


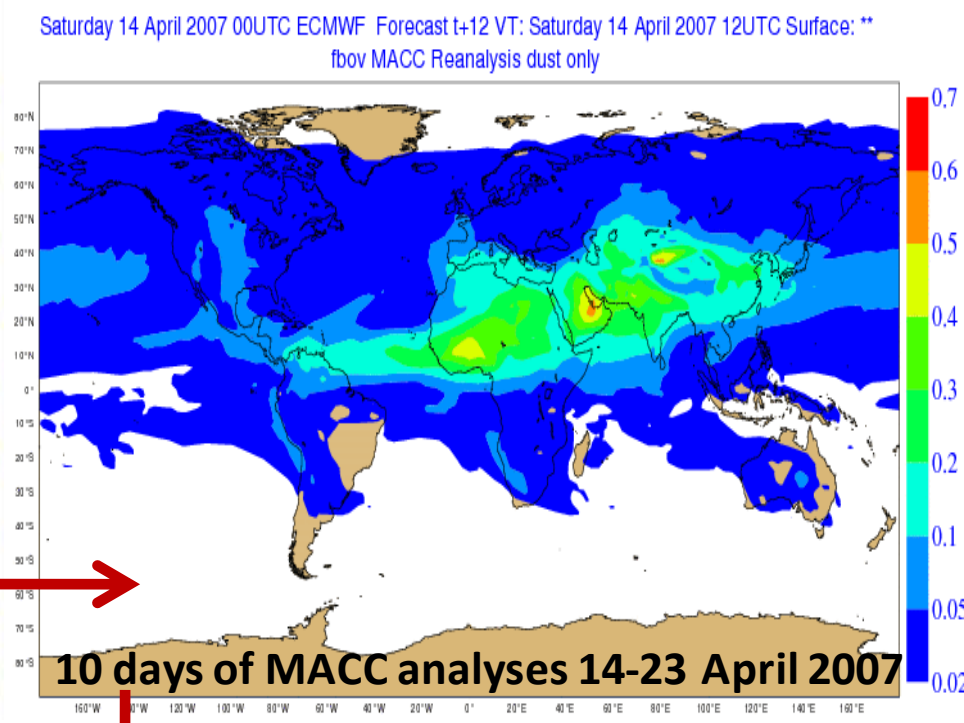


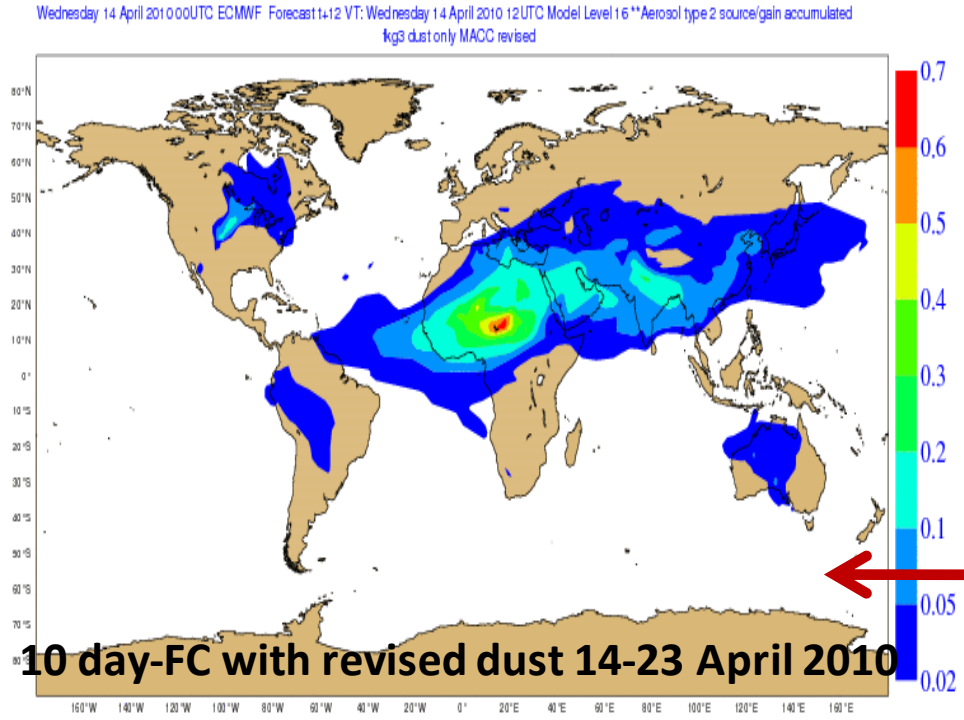


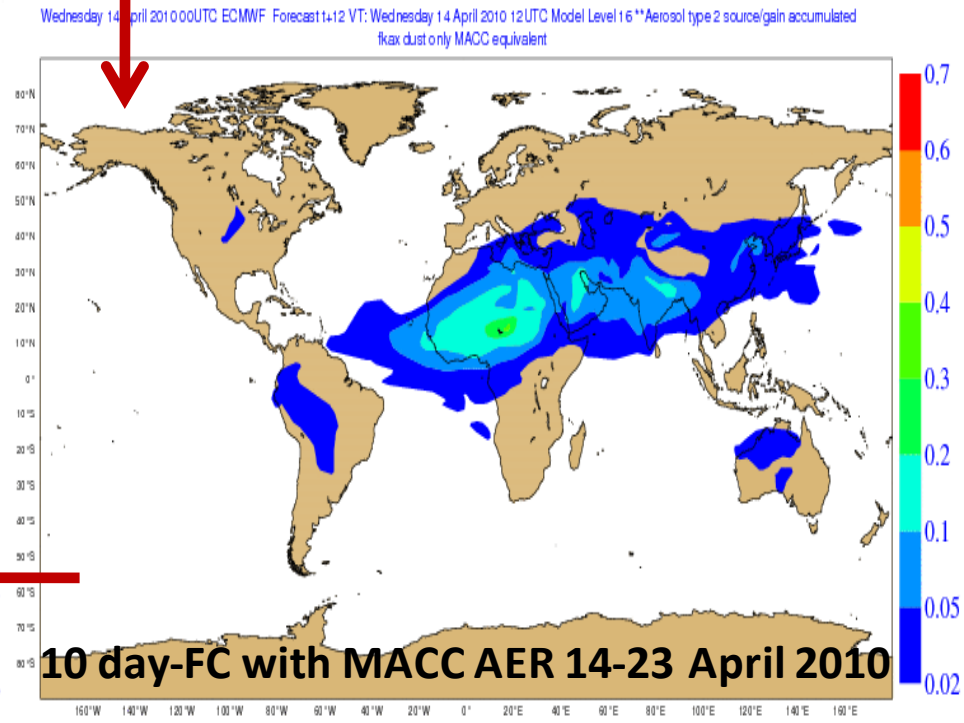
Near Real Time System


Cabo da Roca
Lampedusa
Forth Crete
Cairo
Praia
FC-OBS Bias: Model (fh9z) AOT at 550nm against L1.5 Aeronet AOT at 500nm
Mean=-0.0275, Period=00Z-00Z 01-31 May 2011, FC start hrs=0, FCRS=T+3-:-24 by 3.
Sede Boker
May 2011
Solar Village
La Parguera
Taman.
Ragged Point
Bambey
"Fennec"
Karachi

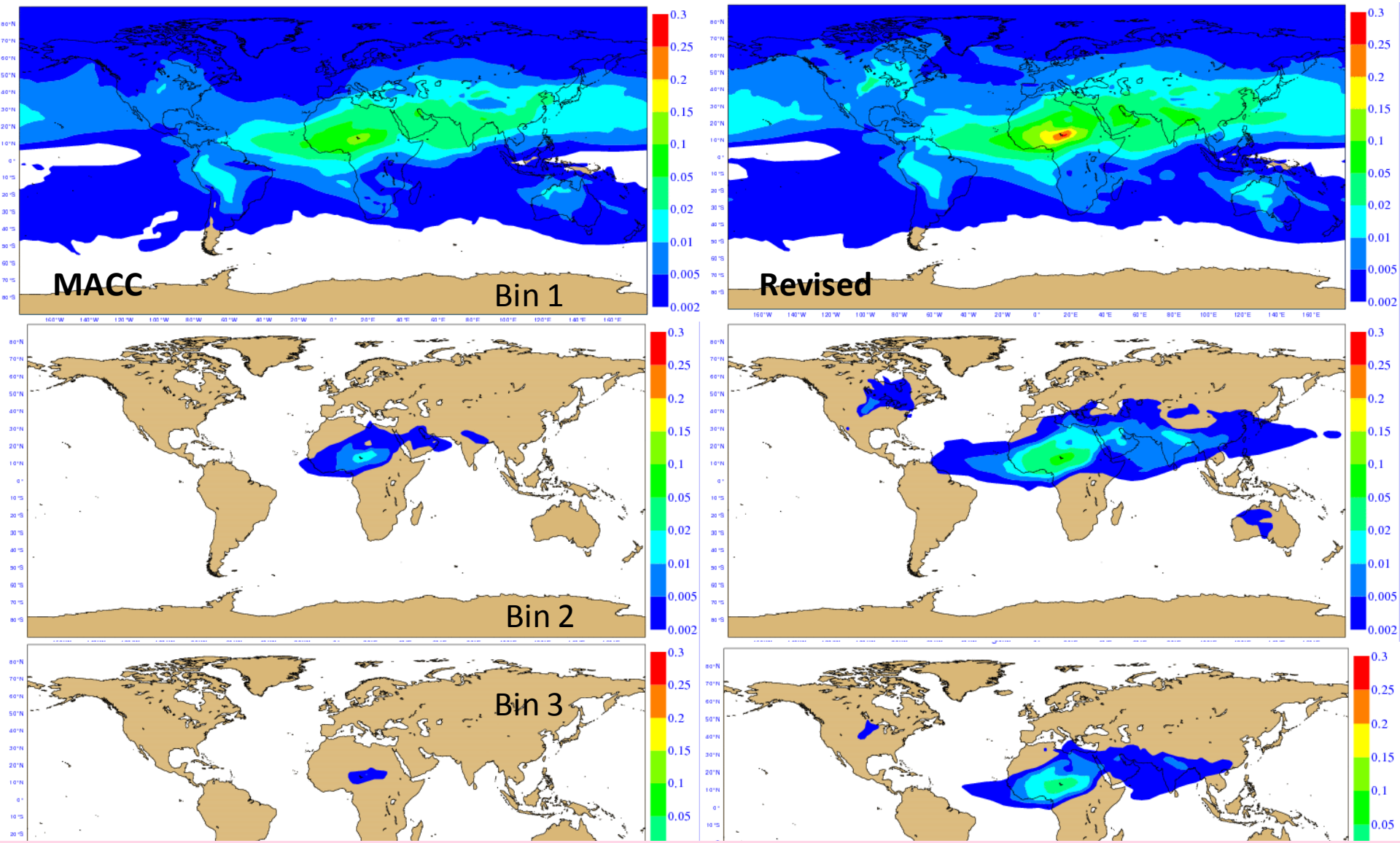

Saturday 14 April 2007 00UTC ECMWF Forecast t+12 VT: Saturday 14 April 2007 12UTC Surface: **
f026 GEMS Reanalysis dust only
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0
10 days of GEMS analyses 14-23 April 2007


Saturday 14 April 2007 00UTC ECMWF Forecast t+12 VT: Saturday 14 April 2007 12UTC Surface: **
fbov MACC Reanalysis dust only
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.05
0.02
10 days of MACC analyses 14-23 April 2007

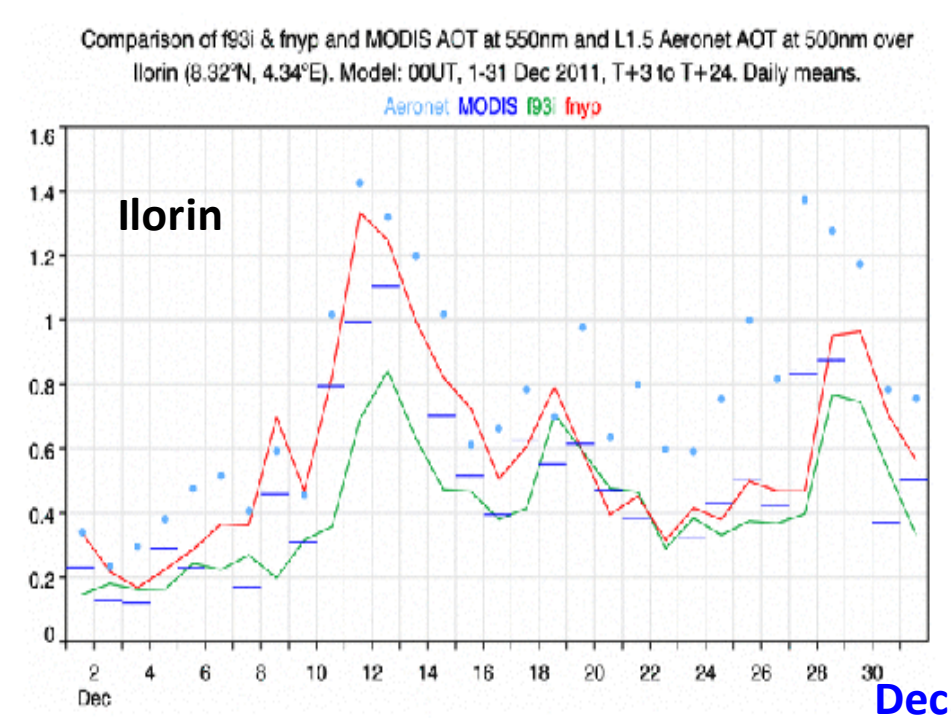

Wednesday 14 April 2010 00UTC ECMWF Forecast t+12 VT: Wednesday 14 April 2010 12UTC Model Level 16 **Aerosol type 2 source/gain accumulated
fkg3 dust only MACC revised
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.05
0.02
10 day-FC with revised dust 14-23 April 2010

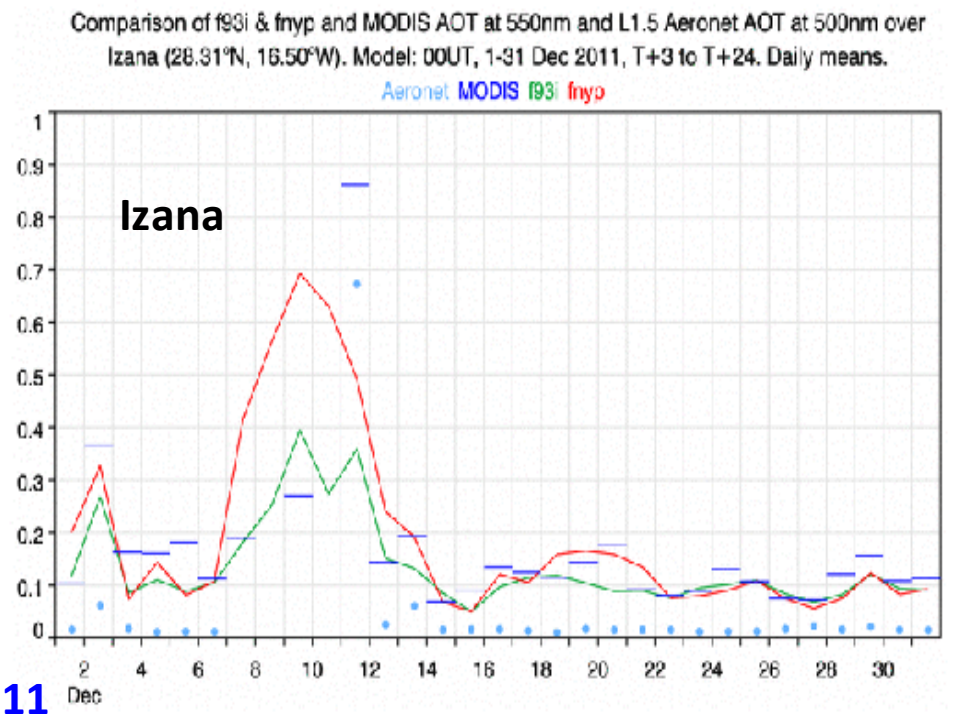

Wednesday 14 April 2010 00UTC ECMWF Forecast t+12 VT: Wednesday 14 April 2010 12UTC Model Level 16 **Aerosol type 2 source/gain accumulated
fkax dust only MACC equivalent
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.05
0.02
10 day-FC with MACC AER 14-23 April 2010

Revisions to the GEMS/MACC Aerosol Model

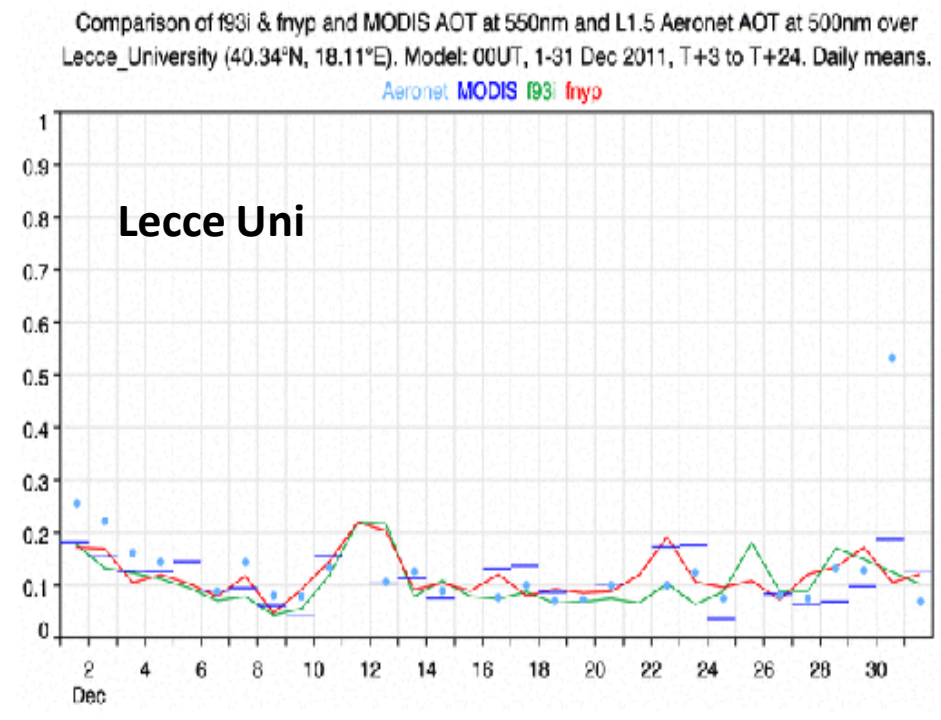


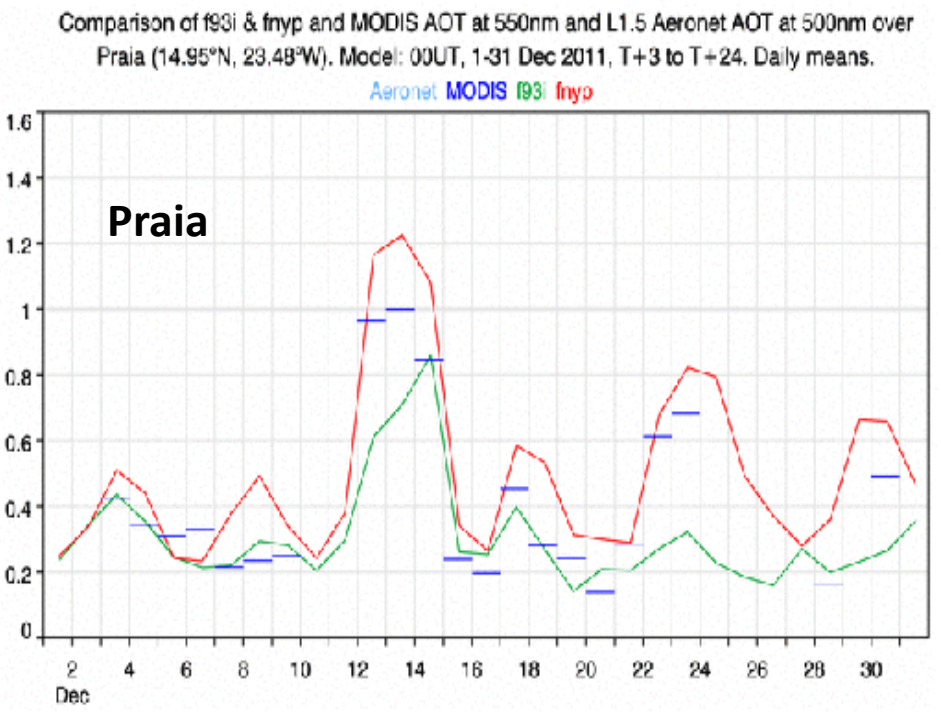
One deficiency in the original GEMS model was the large dust load, mainly constituted of fine (0.03-0.55 um particles. The amount produced was revised for MACC, with no real impact on the size distribution. A recent revision of the source formulation has markedly improved this aspect of the model.

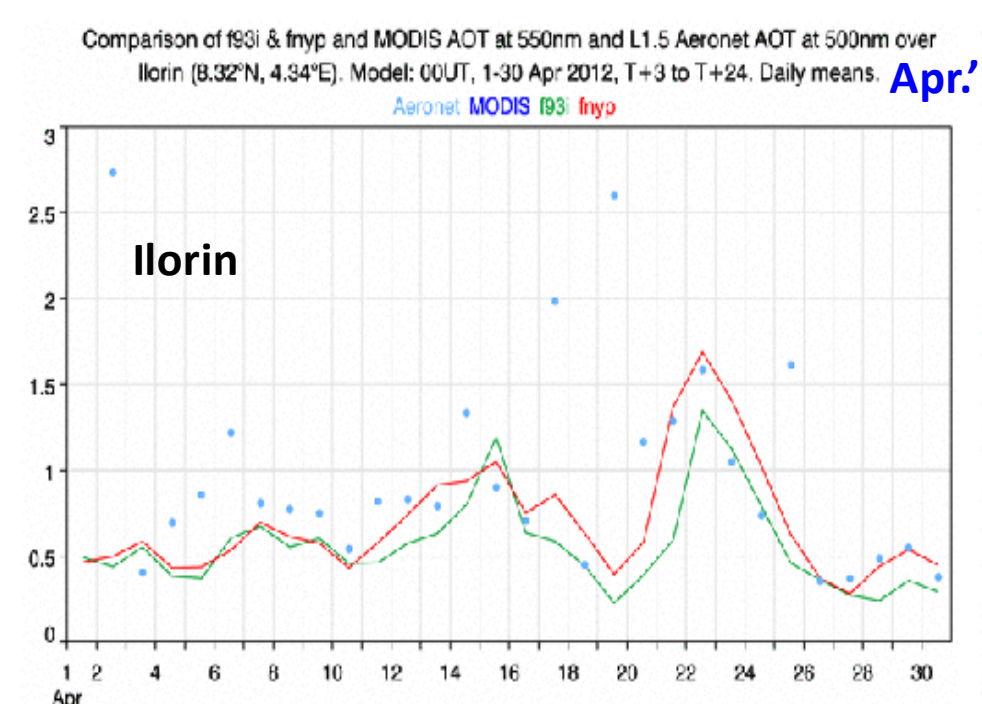

Comparison of f93i & fnyp and MODIS AOT at 550nm and L1.5 Aeronet AOT at 500nm over
Ilorin (8.32°N, 4.34°E). Model: 00UT, 1-31 Dec 2011, T+3 to T+24. Daily means.
Aeronet MODIS f93i fnyp
Ilorin
Dec


Comparison of f93i & fnyp and MODIS AOT at 550nm and L1.5 Aeronet AOT at 500nm over
Izana (28.31°N, 16.50°W). Model: 00UT, 1-31 Dec 2011, T+3 to T+24. Daily means.
Aeronet MODIS f93i fnyp
Izana
Dec

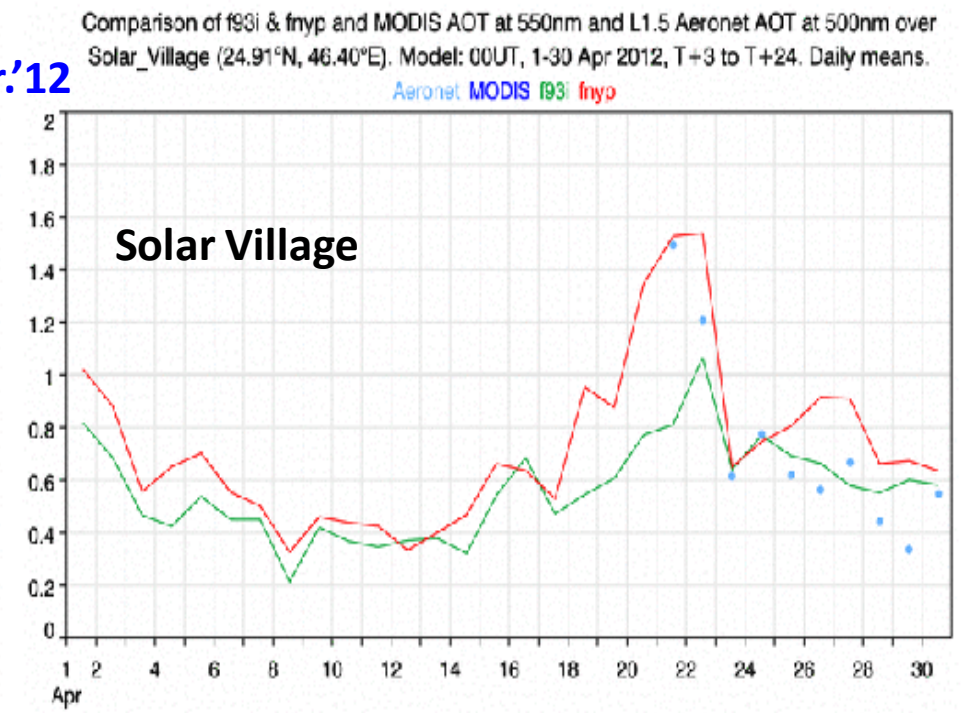
Dec.'11

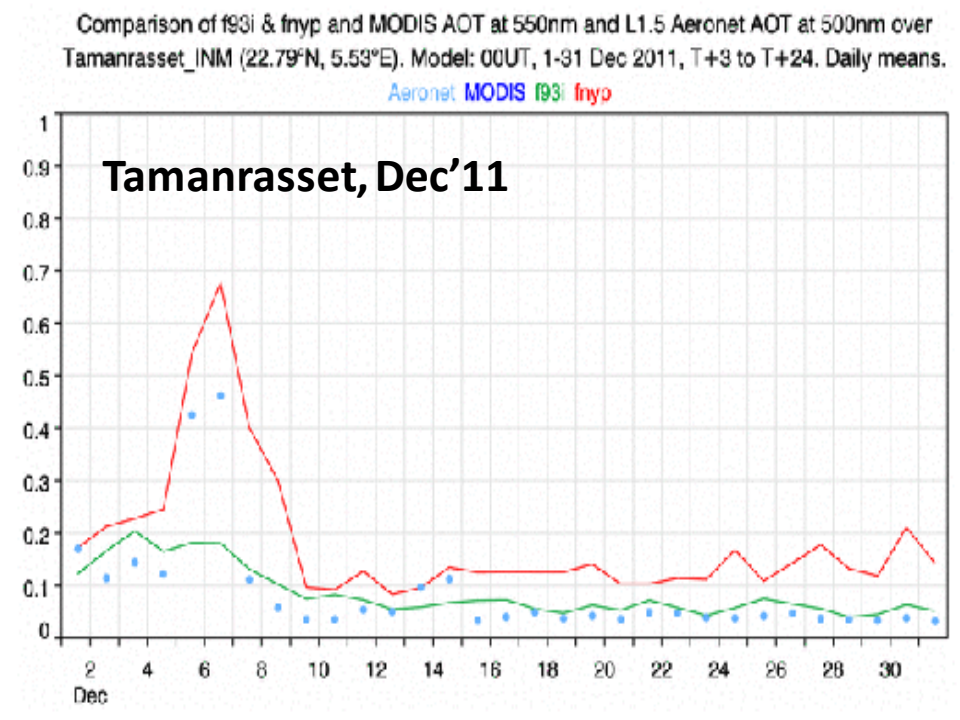

Comparison of f93i & fnyp and MODIS AOT at 550nm and L1.5 Aeronet AOT at 500nm over
Lecce_University (40.34°N, 18.11°E). Model: 00UT, 1-31 Dec 2011, T+3 to T+24. Daily means.
Aeronet MODIS f93i fnyp
Lecce Uni
Dec

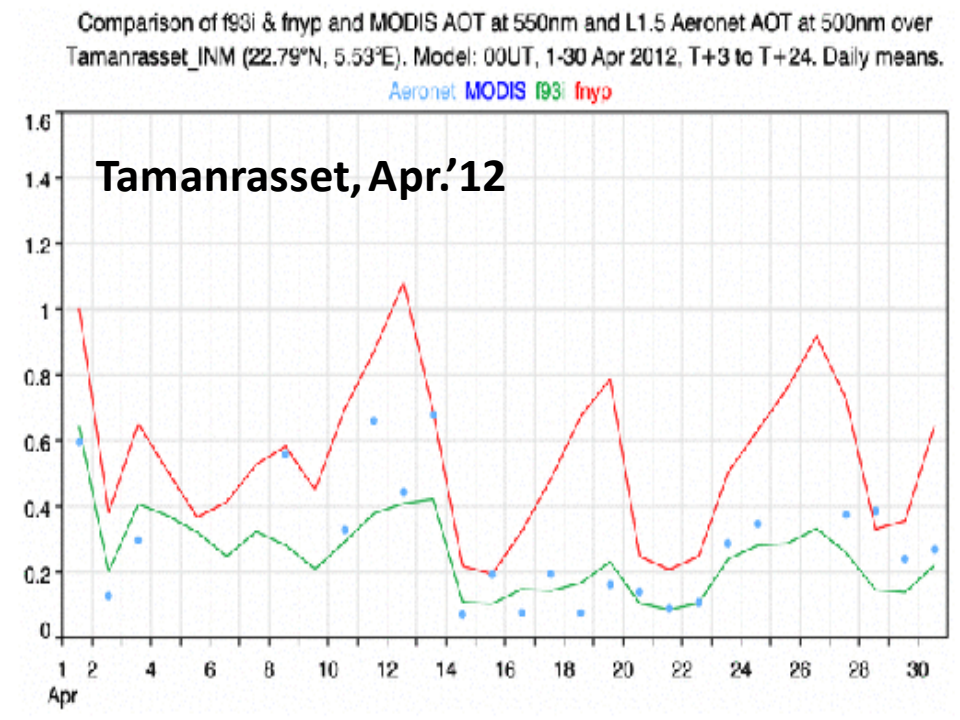

Comparison of f93i & fnyp and MODIS AOT at 550nm and L1.5 Aeronet AOT at 500nm over
Praia (14.95°N, 23.48°W). Model: 00UT, 1-31 Dec 2011, T+3 to T+24. Daily means.
Aeronet MODIS f93i fnyp
Praia
Dec


Comparison of f93i & fnyp and MODIS AOT at 550nm and L1.5 Aeronet AOT at 500nm over Ilorin (8.32°N, 4.34°E). Model: 00UT, 1-30 Apr 2012, T+3 to T+24. Daily means.
Aeronet MODIS f93i fnyp
Ilorin
Apr

Apr.'12


Comparison of f93i & fnyp and MODIS AOT at 550nm and L1.5 Aeronet AOT at 500nm over Solar_Village (24.91°N, 46.40°E). Model: 00UT, 1-30 Apr 2012, T+3 to T+24. Daily means.
Aeronet MODIS f93i fnyp
Solar Village
Apr


Comparison of f93i & fnyp and MODIS AOT at 550nm and L1.5 Aeronet AOT at 500nm over Tamanrasset_INM (22.79°N, 5.53°E). Model: 00UT, 1-31 Dec 2011, T+3 to T+24. Daily means.
Aeronet MODIS f93i fnyp
Tamanrasset, Dec'11
Dec


Comparison of f93i & fnyp and MODIS AOT at 550nm and L1.5 Aeronet AOT at 500nm over Tamanrasset_INM (22.79°N, 5.53°E). Model: 00UT, 1-30 Apr 2012, T+3 to T+24. Daily means.
Aeronet MODIS f93i fnyp
Tamanrasset, Apr.'12
Apr

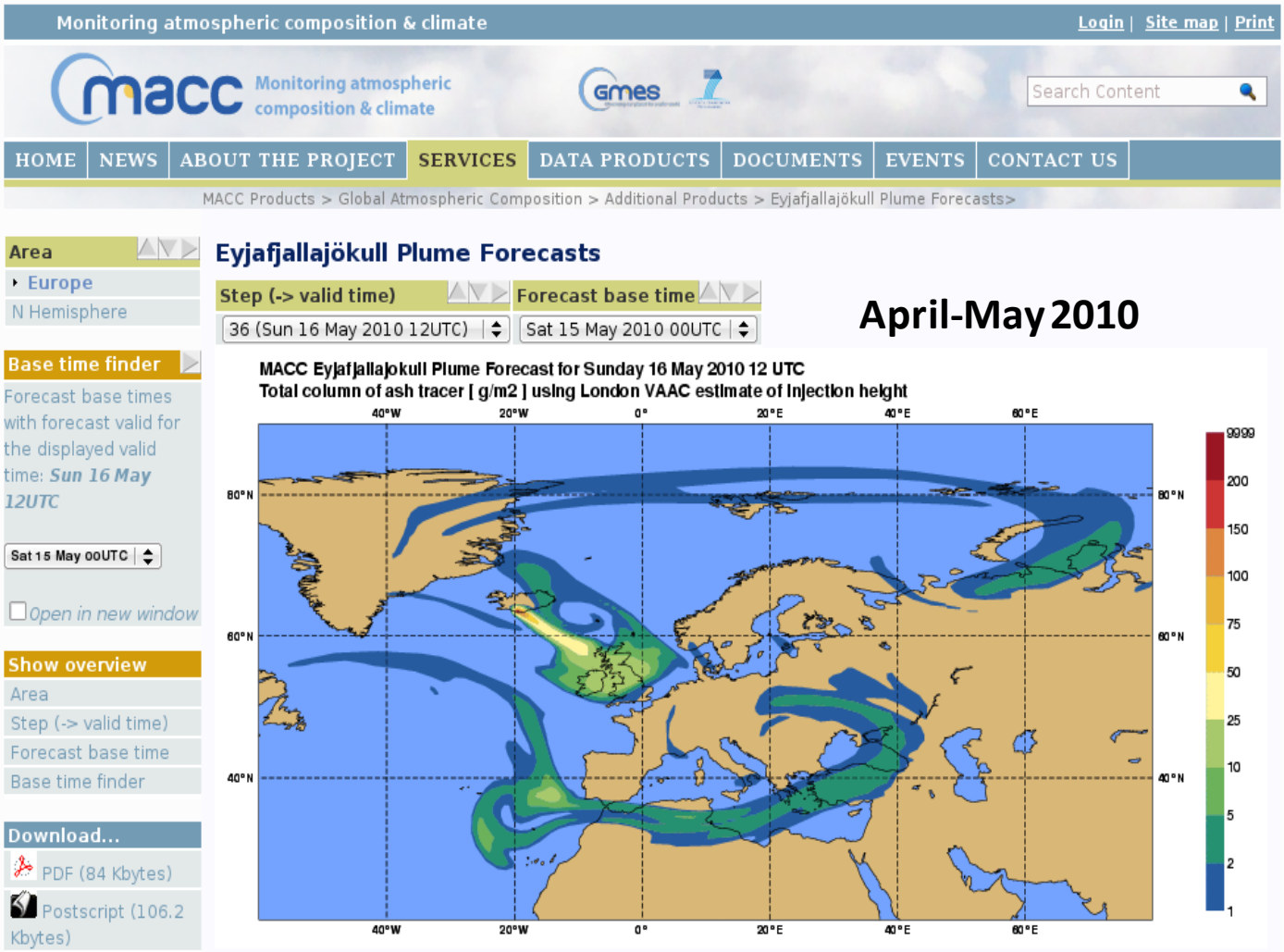
Other revisions to the GEMS/MACC aerosol model

- Additional sets of optical properties have been computed for radiation diagnostics/direct effect using refractive indices from Bond &Bergstrom (2006) or Stier et al. (2007) for BC; Woodward et al. (2001) or Highwood et al. (2009) for DU.

- Lidar simulator at 355, 532, and 1064 nm has been developed (used in comparisons with CALIPSO, and for work on assimilation of lidar backscatter profiles)

- Following what is done in the M7 model:
  - Coefficients for dry deposition have been made function of the underlying surface type (ocean, ice/snow, land)
  - Coefficients for wet deposition, sedimentation have been adapted from M7

Daily MACC forecasts: Eyjafjallajökull eruption

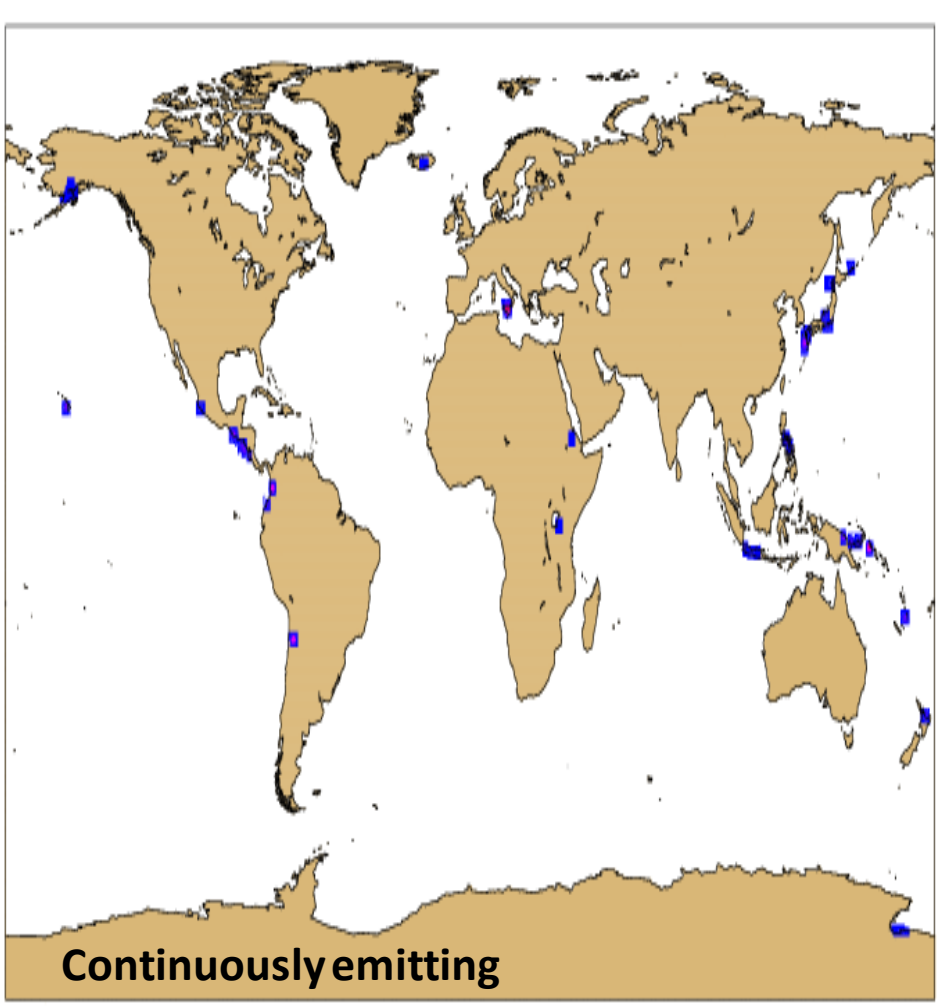


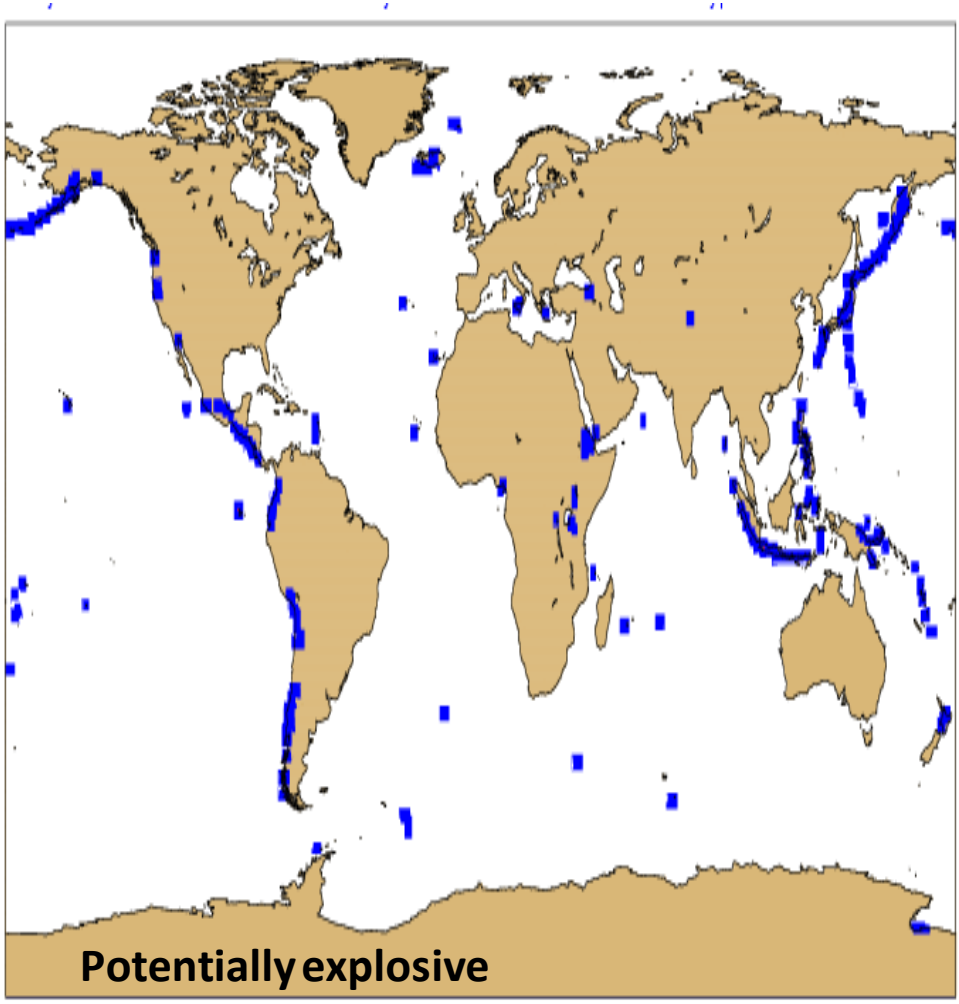
The global MACC system at ECMWF provided daily 4-day forecasts of the plume **shape** based on basic assumptions for the injection height and mass.

But the original GEMS aerosol system was analysing the increased optical depth from the volcanic plume and was affecting it as an increased amount of the dominant aerosol in this region, i.e., sea salt aerosol

Recent work on Volcanic aerosols in ECMWF/MACC

- **A new prognostic variable has been added to represent volcanic aerosols**, and the code reorganised to allow volcanoes to be "switched on or off", with namelist or file definition of the emitted mass and boundaries of the plume.
- Simulations of the 2010/04 Icelandic volcano have been performed (and a few others ...)
- Sensitivity to optical properties given to volcanic aerosols (passive, SO4, BC, DU3)
- Sensitivity to efficiency of gravitational deposition (sedimentation)
- Sensitivity to vertical distribution of ejecta
- Sensitivity of details of the profile of ejecta
- 10-day forecast vs. cycling forecast forced every 12 hours by analysis





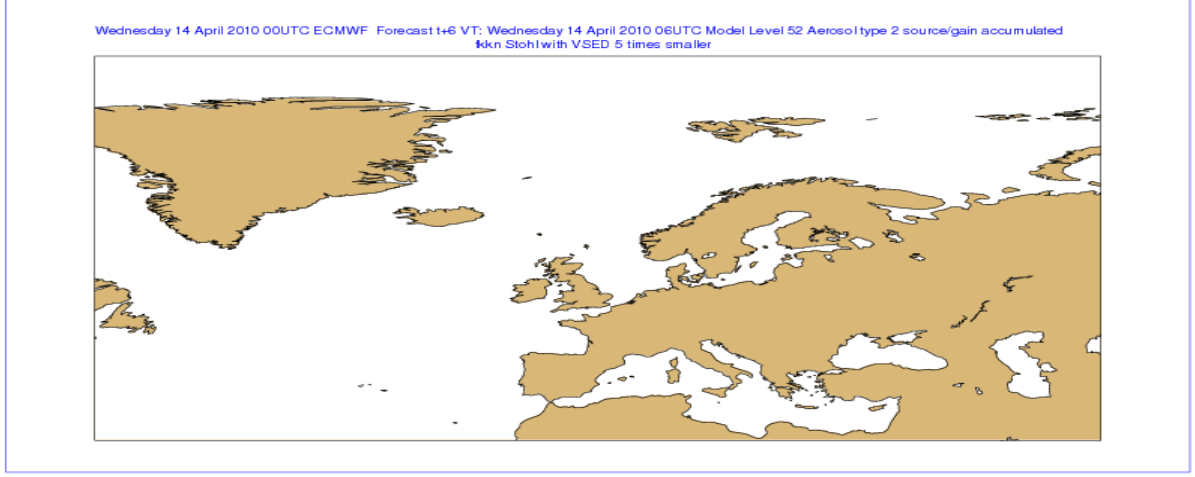
Wednesday 14 April 2010 00UTC ECMWF Forecast t+6 VT: Wednesday 14 April 2010 06UTC Model Level 52 Aerosol type 2 source/gain accumulated
fkgo: Stohl et al's emission, 10-day FC from MACC analysis 0n 20100414 00UTC

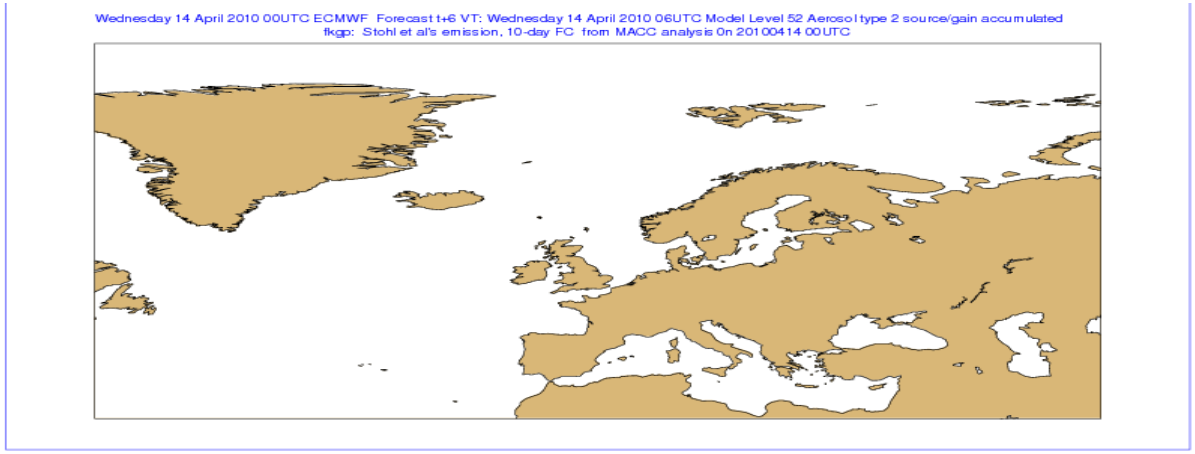
Wednesday 14 April 2010 00UTC ECMWF Forecast t+6 VT: Wednesday 14 April 2010 06UTC Model Level 52 Aerosol type 2 source/gain accumulated
fkkf: Stohl et al's emission, 10-day FC from MACC analysis 0n 20100414 00UTC, dierct effect on, volc as SO4

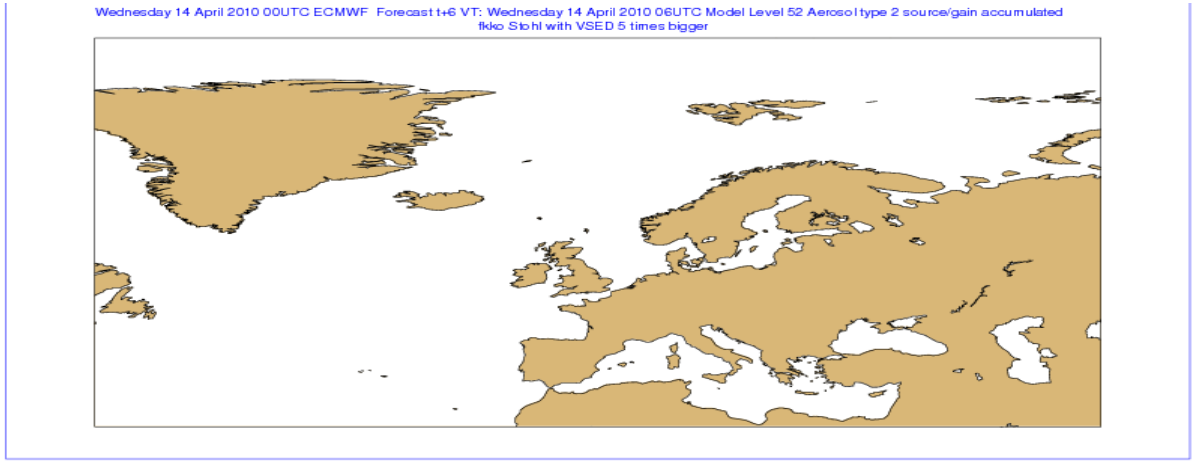
Wednesday 14 April 2010 00UTC ECMWF Forecast t+6 VT: Wednesday 14 April 2010 06UTC Model Level 52 Aerosol type 2 source/gain accumulated
fkkg: Stohl et al's emission, 10-day FC from MACC analysis 0n 20100414 00UTC, dierct effect on, volc as BC

Wednesday 14 April 2010 00UTC ECMWF Forecast t+6 VT: Wednesday 14 April 2010 06UTC Model Level 52 Aerosol type 2 source/gain accumulated
fkkh: Stohl et al's emission, 10-day FC from MACC analysis 0n 20100414 00UTC, dierct effect on, volc as DU3

UL:passive; UR: SO4; LL: BC; LR: DU3





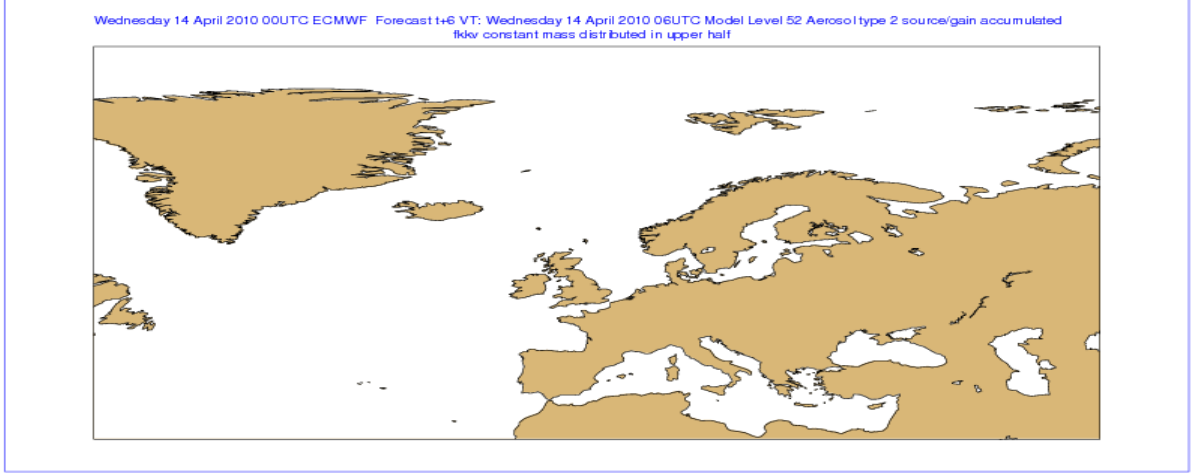


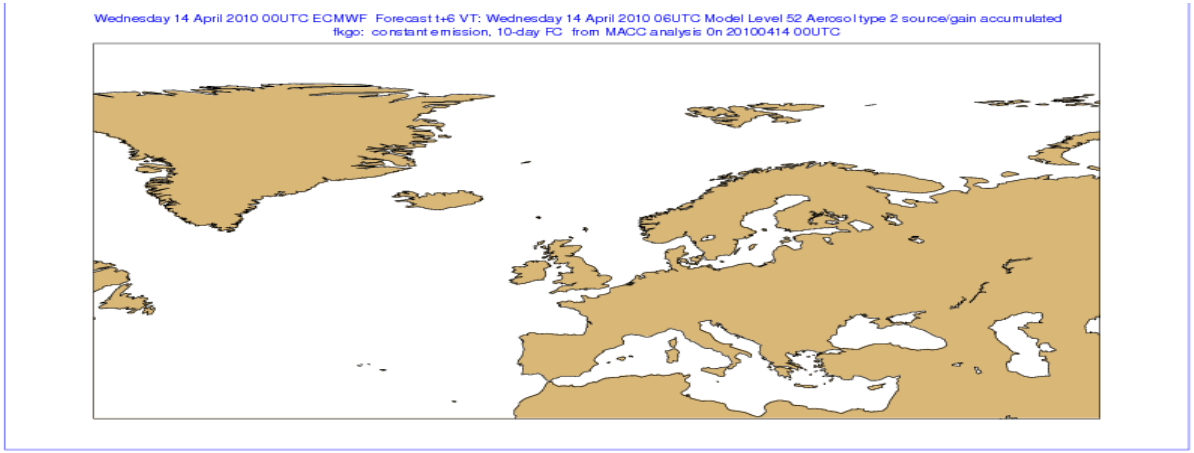
Sensitivity to gravitational sedimentation:

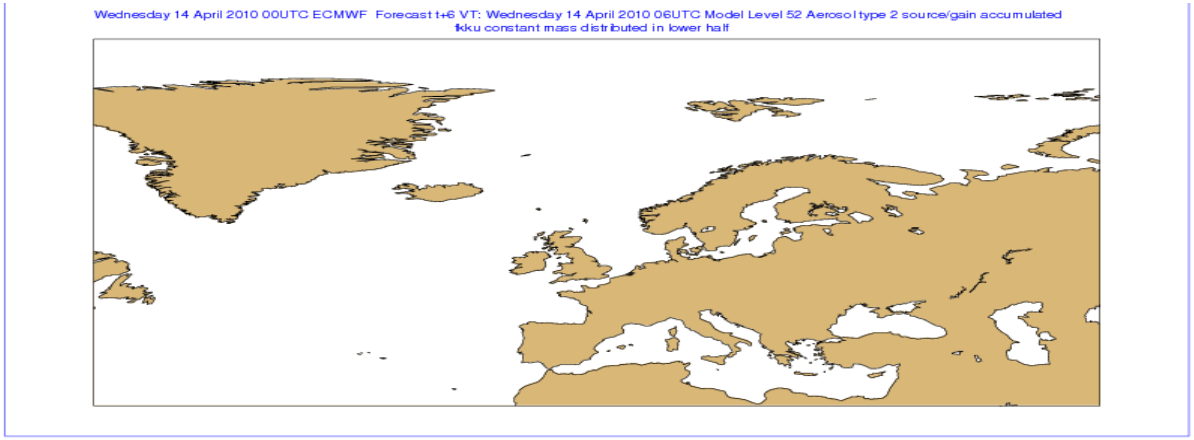
Top is coefficient / 5

Middle is reference coefficient

Bottom is coefficient * 5







Sensitivity to vertical distribution of homogeneously distributed ejecta:

Top: upper half: 3350-6000 m

Middle: full layer: 700-6000 m

Bottom: lower half: 700-3350 m

Wednesday 14 April 2010 00UTC ECMWF Forecast t+6 VT: Wednesday 14 April 2010 06UTC Model Level 52 Aerosol type 2 source/gain accumulated
fkgp: Stohl et al's emission, 10-day FC from MACC analysis 0n 20100414 00UTC

Wednesday 14 April 2010 00UTC ECMWF Forecast t+6 VT: Wednesday 14 April 2010 06UTC Model Level 52 Aerosol type 2 source/gain accumulated
fkgo: constant emission, 10-day FC from MACC analysis 0n 20100414 00UTC

Wednesday 14 April 2010 00UTC ECMWF Forecast t+6 VT: Wednesday 14 April 2010 06UTC Model Level 52 Aerosol type 2 source/gain accumulated
fkgm: Stohl et al's emission, cycling from MACC analysis every 12 hours

Wednesday 14 April 2010 00UTC ECMWF Forecast t+6 VT: Wednesday 14 April 2010 06UTC Model Level 52 Aerosol type 2 source/gain accumulated
fkgl: constant emission, cycling from MACC analysis every 12 hours

UL: Stohl FC; UR: constant FC; LL: Stohl cycling; LR: constant cycling

Preliminary conclusions on the volcanic aerosol modelling work

- Each volcano is obviously different and the behaviour of the aerosol plume depends on “N” parameters!

- Over a few days (~ 2-3), dynamics govern the dispersion, sedimentation is important, optical properties are not.

- For a future operational MACC-type system (for which profile information is not likely to be available in NRT), it appears better to have a “volcano” system with only a few parameters that could be adjusted to give a reasonable agreement with MODIS-type observations of optical depth.

Summary

- From the meteorological model point of view, the new aerosol system benefits from a better cloud scheme (5 progn.variables) and other modifications to the physics package.

- A revision of the dust source formulation has corrected the strong bias on small dust particles seen before, and improved the steadiness of the aerosol load during the forecasts.

Future aerosol modelling work

- “Back-burner” work on direct/indirect effects of GEMS/MACC aerosols to (possibly) improve the FCs.
- Making volcanoes “go” at the turning of a LOGICAL
- At part of MACC II, finalise the introduction of UKCA_GLOMAP_MODE in the IFS.
- Comparison between IFS-GLOMAP and GEMS/MACC aerosols in analysis and forecast modes against observational datasets (AERONET, GAW, CALIOP, MISR, …)

Prospective/Perspectives

- In forecast mode, the present (simple) prognostic aerosol system at ECMWF adds 85% extra time and 200% extra memory to the operational configuration.
- An operational configuration therefore can only be run at relatively low resolution (presently T255 L60 vs. T1279 L91).
- Presently, aerosols are analyzed with assimilation of MODIS tau550, but the aerosol analysis does not affect the rest of the analysis (T,q, winds, O3).
- Having the aerosols affecting the full analysis system requires the development of the TL/AD of the aerosol model.
- In this case, is a more sophisticated (and potentially better) modal aerosol model affordable?
- Figure out and thoroughly test a viable (affordable) configuration of the ECMWF IFS allowing aerosol analysis and forecast to become operational (Present is TL255 L60) in 2014, for post-MACC II activities.

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, 11, 7781-7816

- TM653: Simulations of volcanic plumes with the ECMWF/MACC aerosol system
- TM659: Prognostic aerosols: MACC vs. GEMS
- TM660: Aerosol-Cloud-Radiation Interactions in the ECMWF/MACC forecasts

Submitted

* **Benedetti et al., 2012: BAMS, 93, State of the Climate 2011**
* **Morcrette et al., 2012: JGR, direct/indirect aerosol effects**

http://www.gmes-atmosphere.eu the MACC/MACC II web site

http://www.ecmwf.int/publications/library/do/references/list/14