Aerosol Modelling at ECMWF

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ECMWF

with contributions from:

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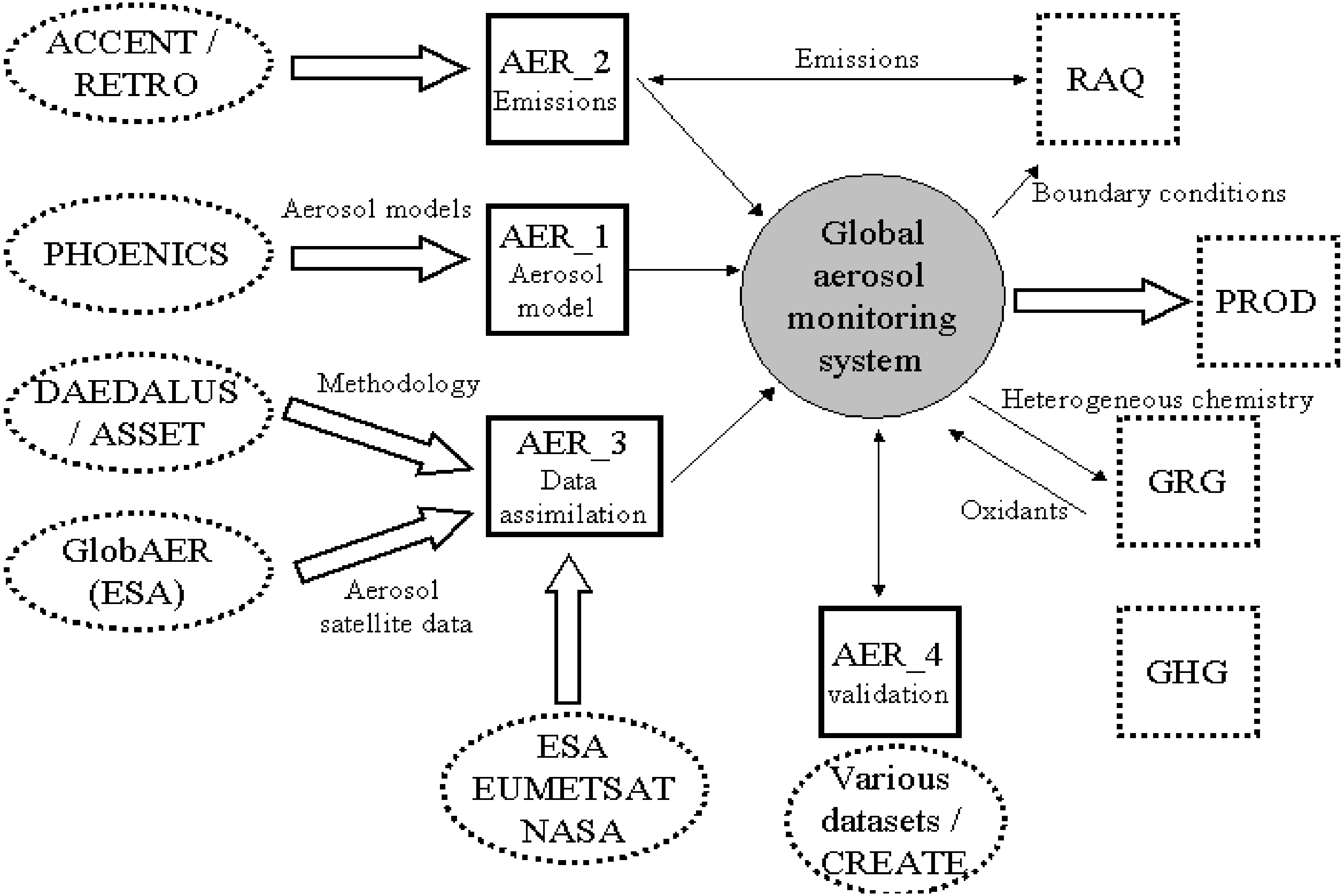
Soumia Serrar, Agathe Untch

GEMS AEROSOL Global Monitoring System

Leader: O. Boucher



GEMS Aerosols

- **AER_1**: Implementation of the direct physical aerosol model in the ECMWF model
  - **> implementation of parametrisations for tropospheric aerosols**
  - **> implementation of parametrisations for stratospheric aerosols**
  - **> implementation of new emission inventories**
  - **> implementation of aerosol optical properties**
  - **> production of test simulations**

HC-MO, MPI-M, CEA-LSCE, ECMWF, SA-UPMC

- **AER_3**: Aerosol data assimilation
  - > **adaptation of RT codes for SW and LW radiances in nadir geometry**
  - > preparation and harmonisation of aerosol satellite data sets
  - > error covariance matrices
  - > test of a 1D-Var system using aerosol products
  - > test of a 1D-Var system using aerosol radiances

ECMWF, CEA-LSCE, HC-MO, SA-UPMC

GEMS Aerosols: products @ end of contract (03/2008)

- Analysis of aerosol-related observations at ERA40 resolution (T_L159 L60 [1.125 deg]^2 or better) twice a day
- Total optical thickness at ~0.55 μm OCEAN
- Angstrom coefficient (or τ at~ 0.865μm) "
- Total optical thickness at ~0.55 μm LAND

- From model 12-hour forecasts used in assimilation cycle

  -> Up to 15 mixing ratio profiles of aerosols, every 3 hours

  sea salt 3 bins — 1st stage

  desert dust 3 bins

  organic 2 bins — 2nd stage

  black carbon, carbonaceous 2bins

  sulfate

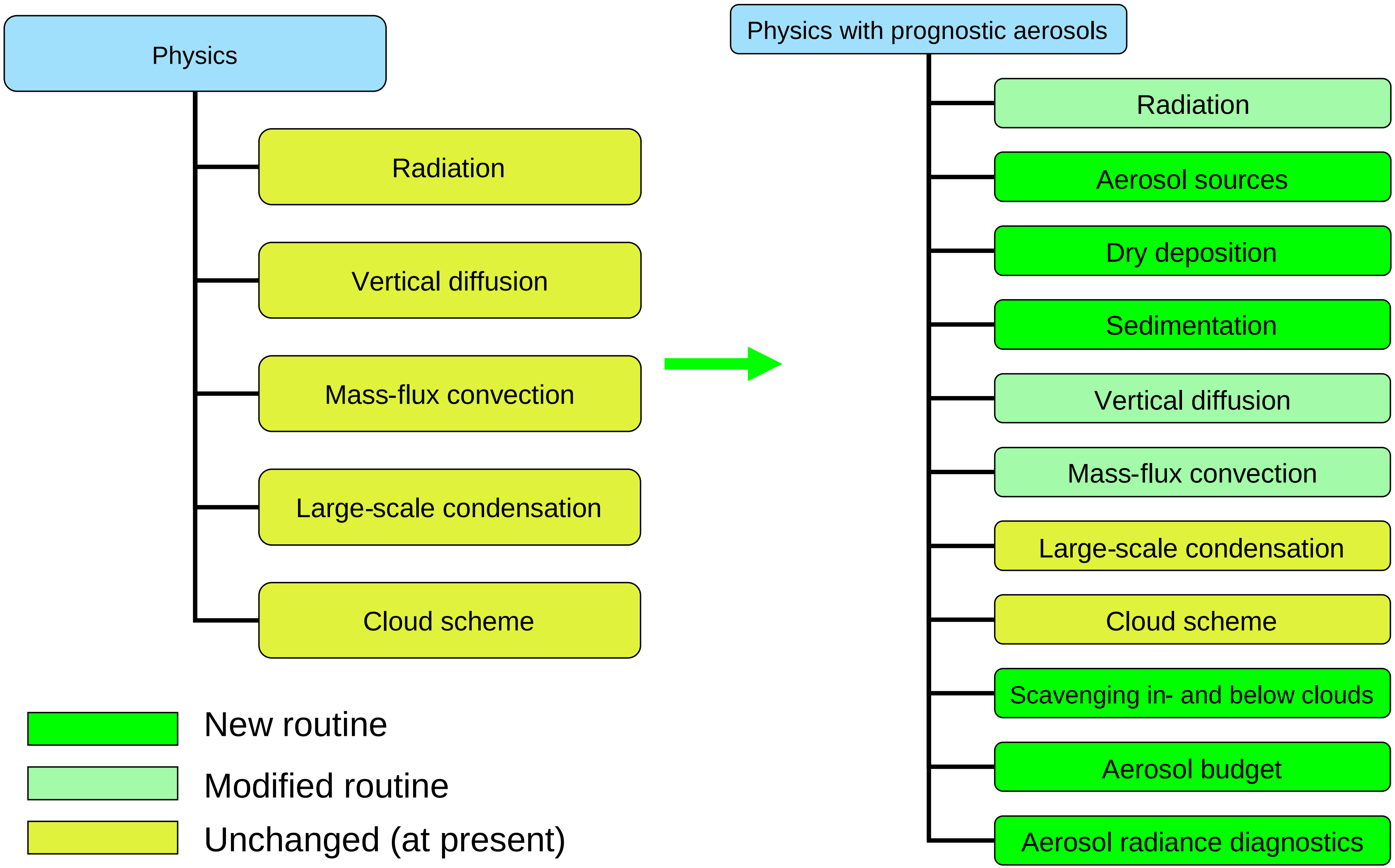
  fly ash

  stratospheric

Likely to be changed if a modal representation or the 4-variable representation is shown to be better

->Corresponding 2D-fields for sources and sinks

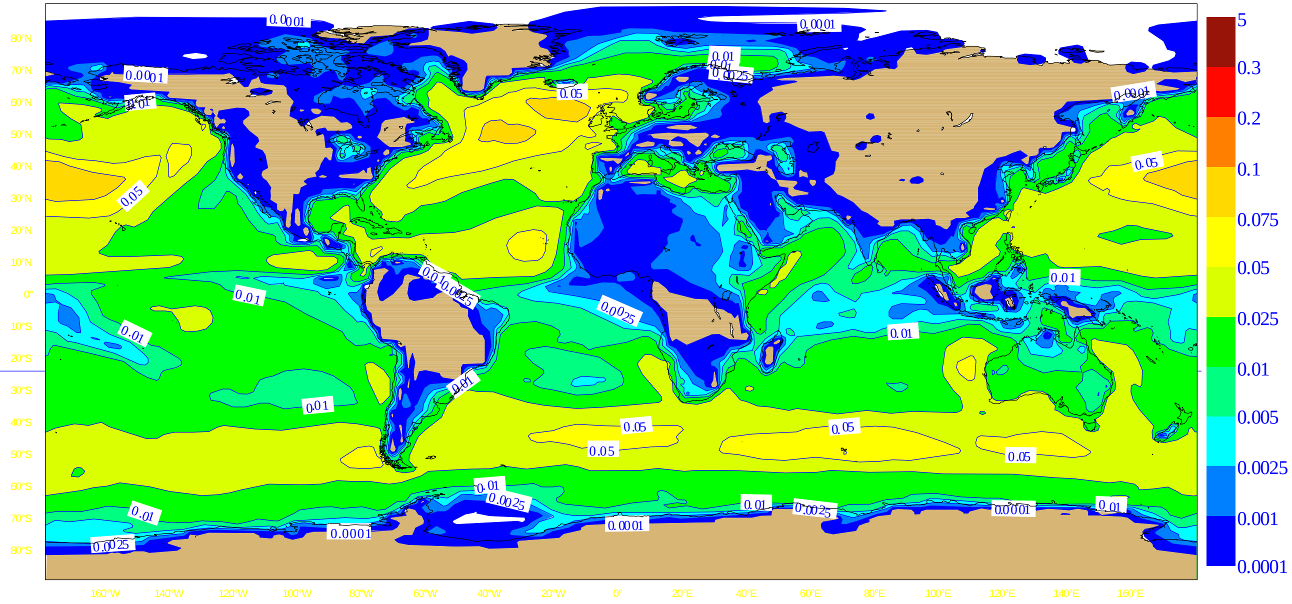
AER_1.1: Development of a prognostic aerosol package in the ECMWF model



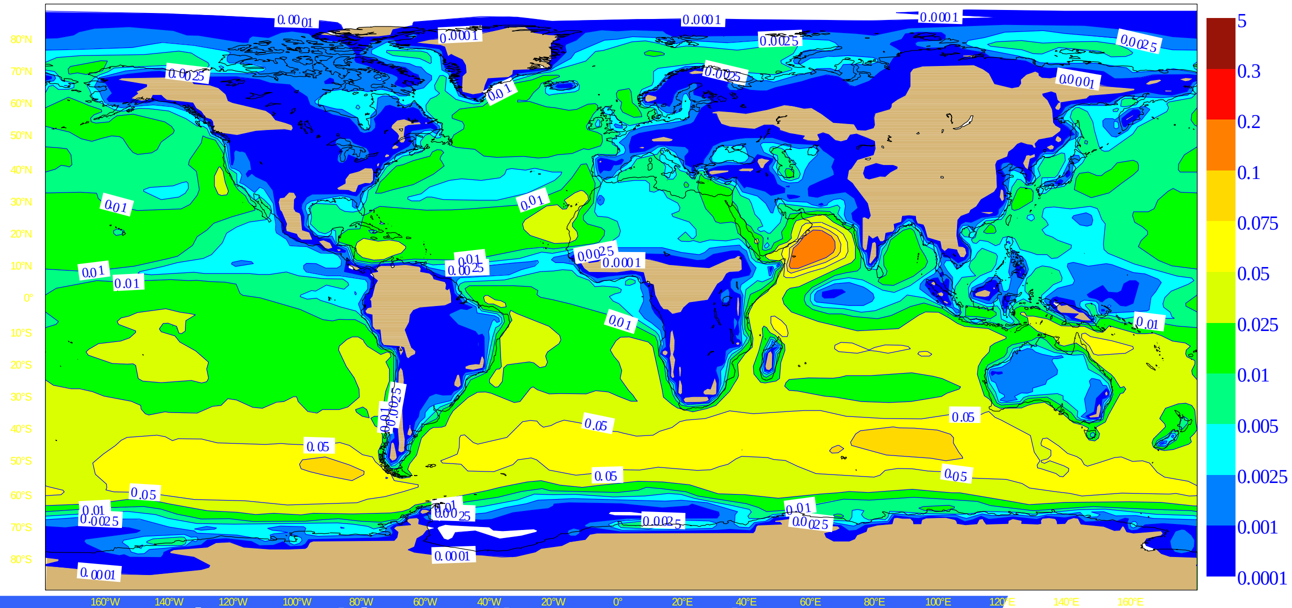
Development of a prognostic aerosol package in the ECMWF model

- A 3-bin representation for both sea-salt and desert dust aerosols, borrowed from the aerosol physics of the LMDZ model (sources, sedimentation, dry and wet deposition, optical properties), was introduced into the ECMWF model (O.Boucher)
- It is connected to the ECMWF model dynamics (A.Untch) and to the vertical diffusion and convection parametrisations of the physics package (A. Beljaars, P. Bechtold)
- Preliminary studies of the sensitivity to both horizontal and vertical resolutions showed the aerosols to have a similar behaviour to other fields in the model (q, clouds), complicated by the representation of surface fluxes. Generally, the dependency to horizontal resolution is weak, that to vertical resolution is much stronger.
- A first annual simulation (Dec’2002-Jan’2004) with this 3-bin representation for both sea-salt and desert dust was performed and presented at the GEMS Seminar (Sep’2005).
- This simulation was made available to the external partners (Sep’2005).

Wednesday 1 January 2003 00UTC ECMWF Forecast t+12 VT: Wednesday 1 January 2003 12UTC Surface: **
"ep97: Tau550: Sum 3bins: SS: TL159L60"

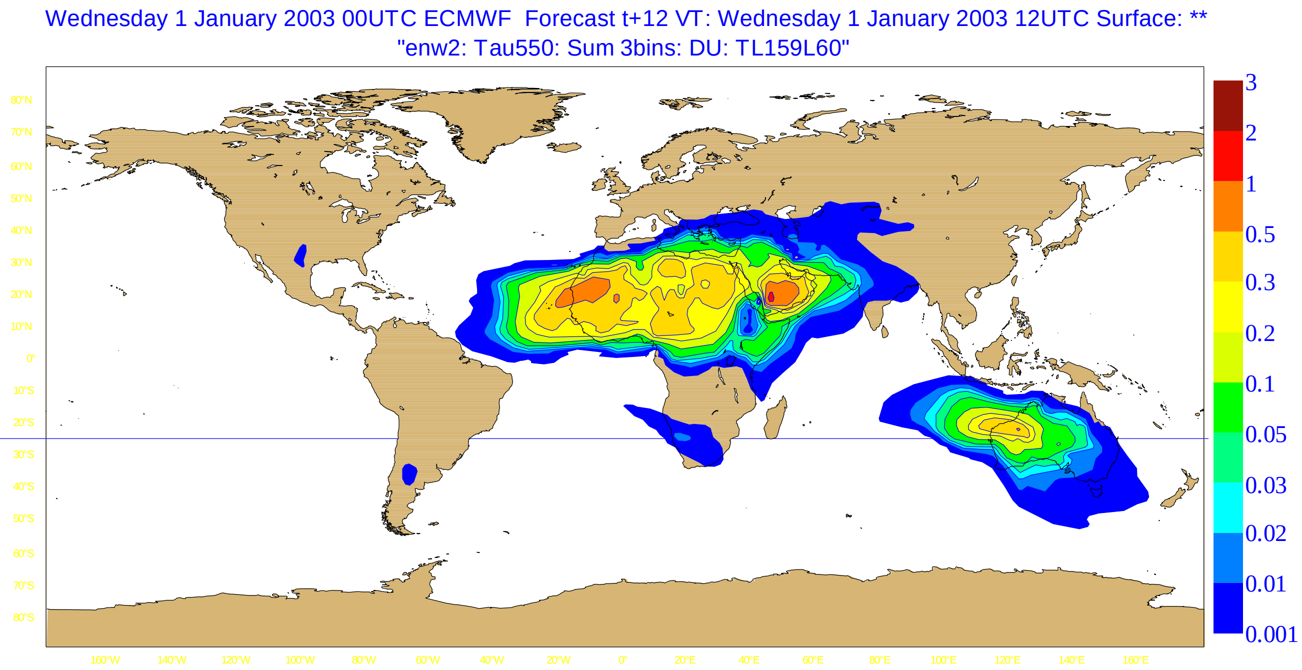


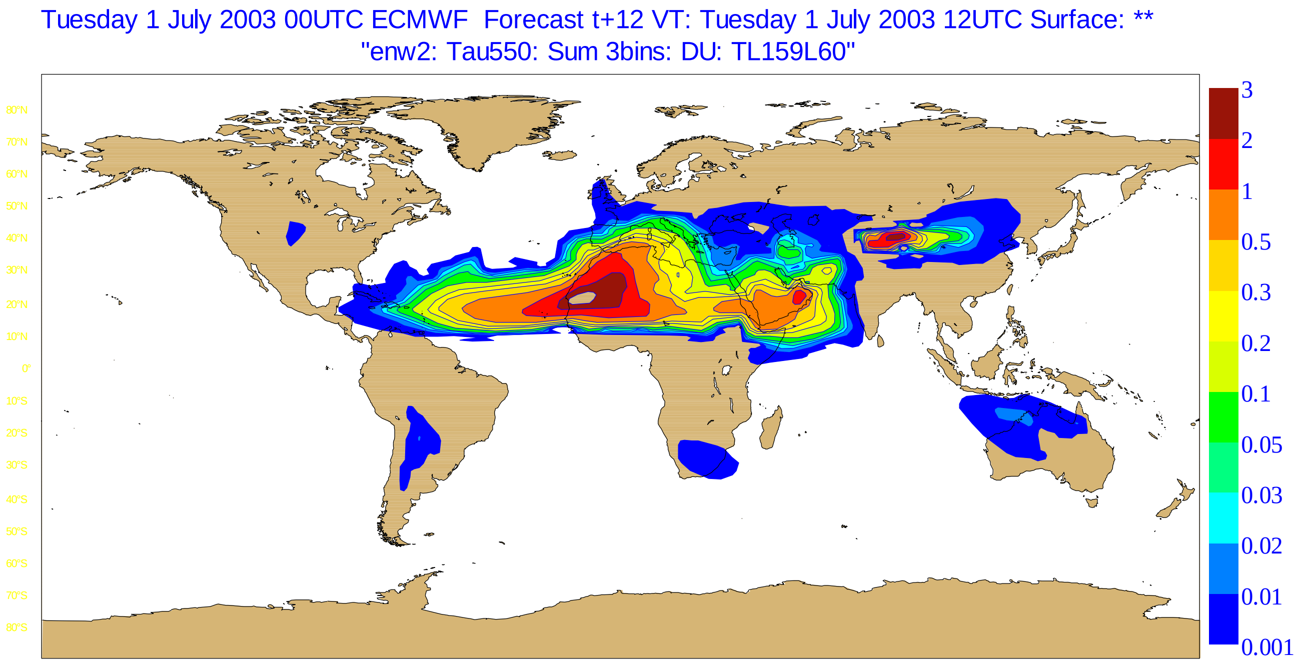
Tuesday 1 July 2003 00UTC ECMWF Forecast t+12 VT: Tuesday 1 July 2003 12UTC Surface: **
"enw2: Tau550: Sum 3bins: SS: TL159L60"



Optical depth at 550nm of the sea salt aerosol for January and July 2003

Optical depth at 550nm of the desert dust aerosol for January and July 2003

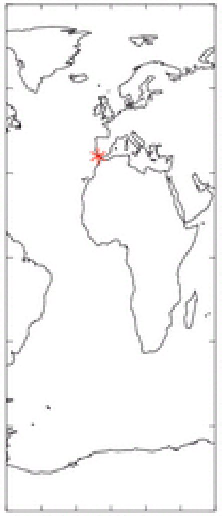


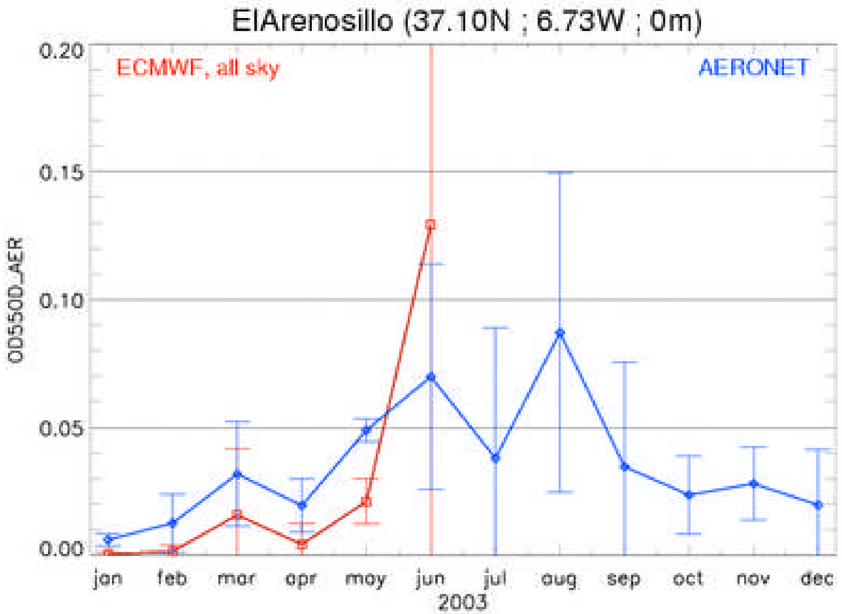


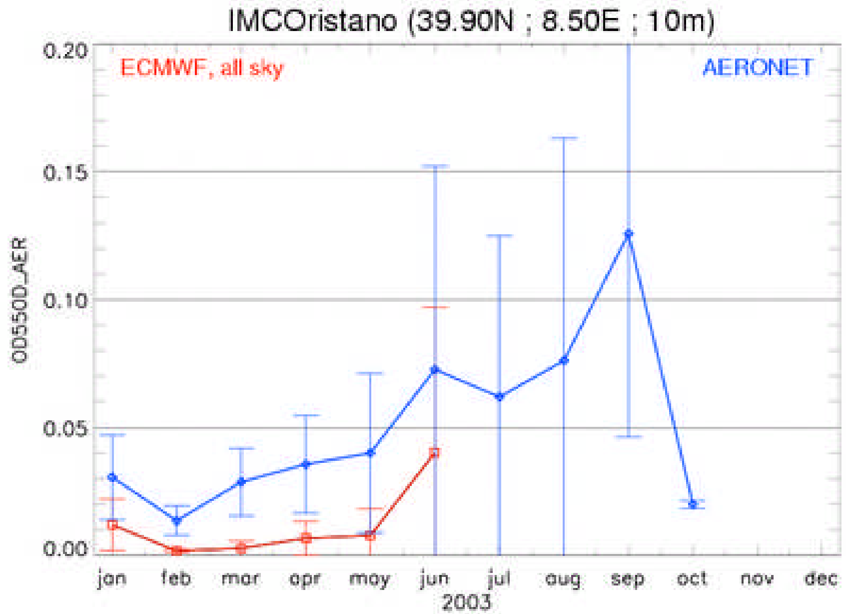
ECMWF

Development of a prognostic aerosol package in the ECMWF model

- Comparisons with measurements (S. Kinne/M. Schulz for AEROCOM, H. Flentje for GAW) show the model aerosol optical thickness to be usually systematically low.
- A 10-bin representation for sea-salt and desert dust was recently tested. It provides slightly better larger τ for sea salt and larger τ for desert dust, through reduction of sedimentation and deposition.



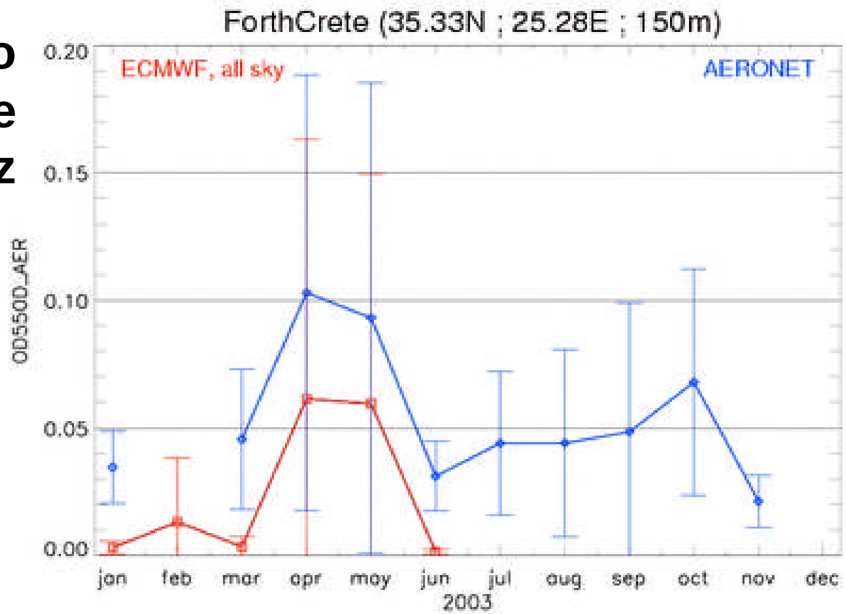


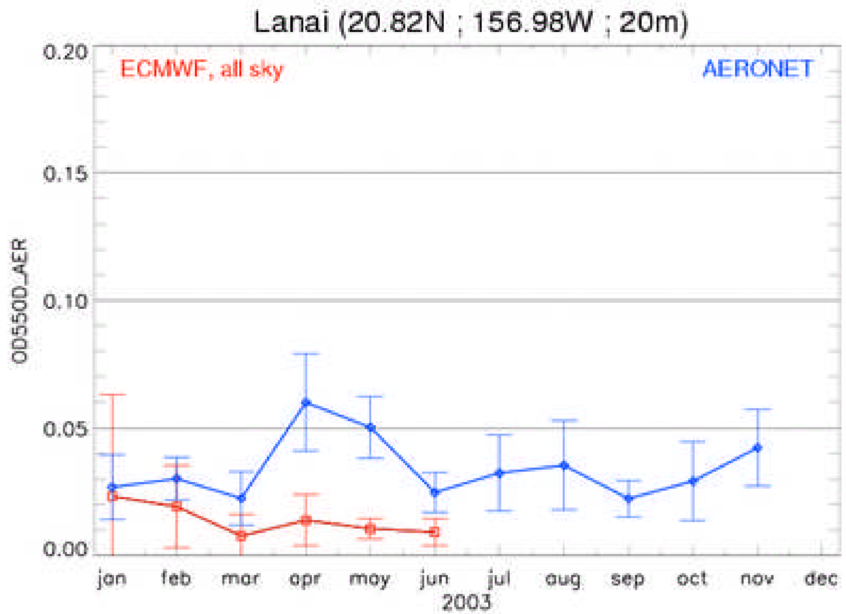


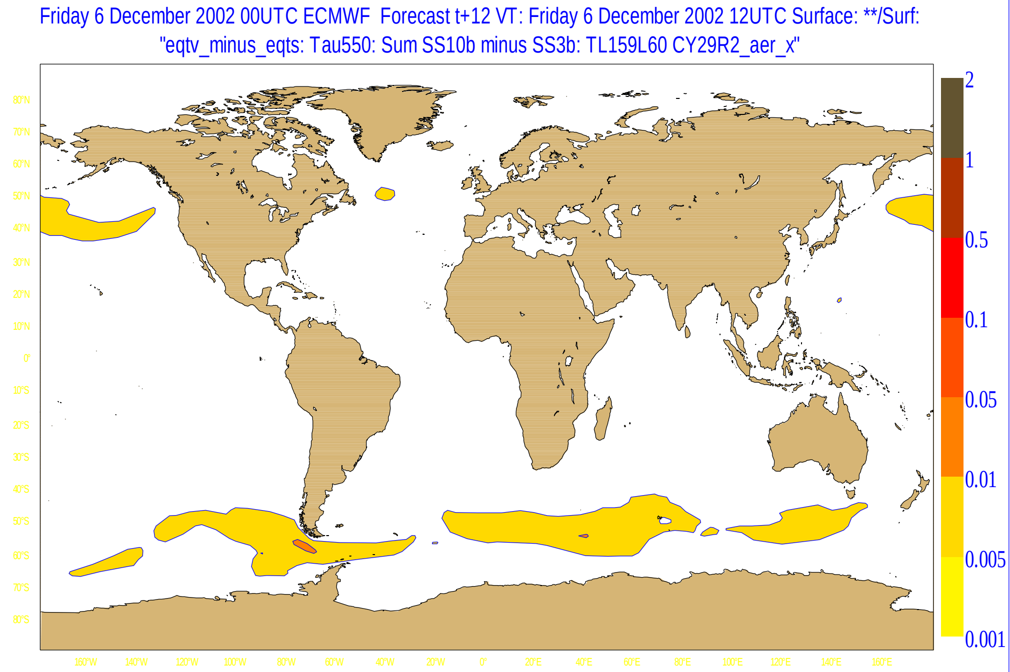
Graph | Data source | Species | Parameter
SERIES | ECMWF | AER | OD550D
ForthCrete | an2003 | m ALLYEAR

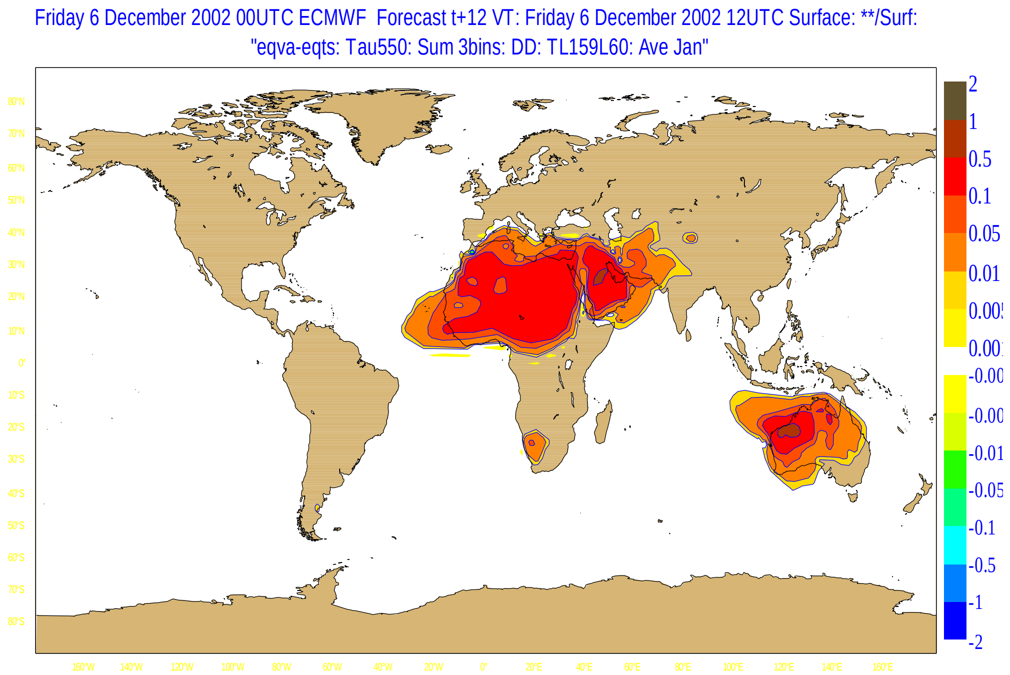
Graph | Data source | Species | Parameter
SERIES | ECMWF | AER | OD550D
Lanai | an2003 | m ALLYEAR

Thanks to
Stefan Kinne
Michael Schulz









Replacing a 3-bin by a 10-bin representation of aerosols

Sea-Salt from 0.03-0.5-5-20

Desert Dust from 0.03-0.55-0.9-20

To 0.03-0.06-0.12-0.24-0.48-0.96-1.92-3.84-7.68-15.36-30.72

Sea-Salt: +8 to 15%

Desert Dust: +30 to 50%

ECMWF

Development of a prognostic aerosol package in the ECMWF model (months 13-30)

- Future work will include the calibration of size-sensitive parameters of the 3-bin representation using results from the 10-bin experiments.

- Test a simplified stratospheric aerosol model, based on climatological aerosols, then advected.

- Get and implement:
  - - the aerosol modal representation of stratospheric aerosols from SA
  - - the aerosol modal representation of tropospheric aerosols from MPI-Hamburg

  - Possibly, introduce the organic (2 bins), sulphate (2bins), black carbon (2 bins), fly ash (1 bin) from LMDZ model
  - Or the 4-parameter representation (Huneeus & Boucher) presently tested in LMDZ.

AER_3.1: Simulating the SW radiances

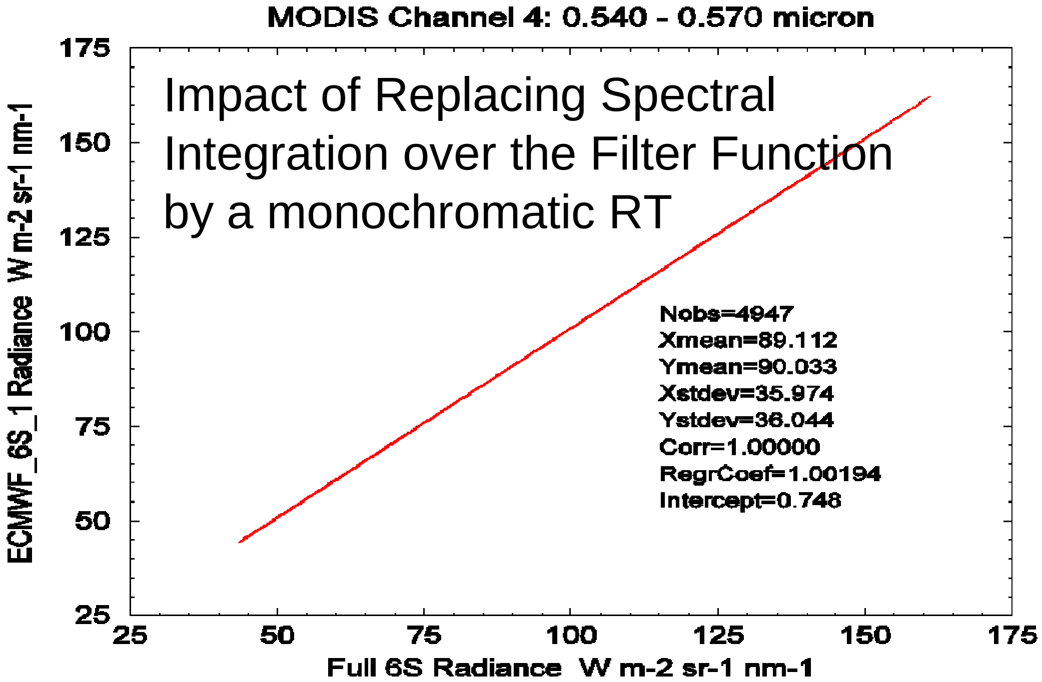
- 6S: Second Simulation of the Satellite Signal in the Solar Spectrum: Vermote et al., 1997, version 4.1
  - allows the computation of radiances in the shortwave channels of most of the present satellites: AVHRR, GOES, HRV_spot, METEOSAT, MODIS, POLDER, TM_landsat
  - under the proper satellite/sun/target geometry
  - and various specifications of the surface
    - ➔ homogeneous vs. inhomogeneous
    - ➔ without and with directional effect
    - ➔ with possibly different target and environment characteristics
    - ➔ with different surface representations: Hapke, Verstraete et al., Roujean et al., Walthall et al., Minnaert, Iaquinta and Pinty, Rahman et al., Kuusk allowing sophisticated descriptions of the surface including structural parameters for the canopy.

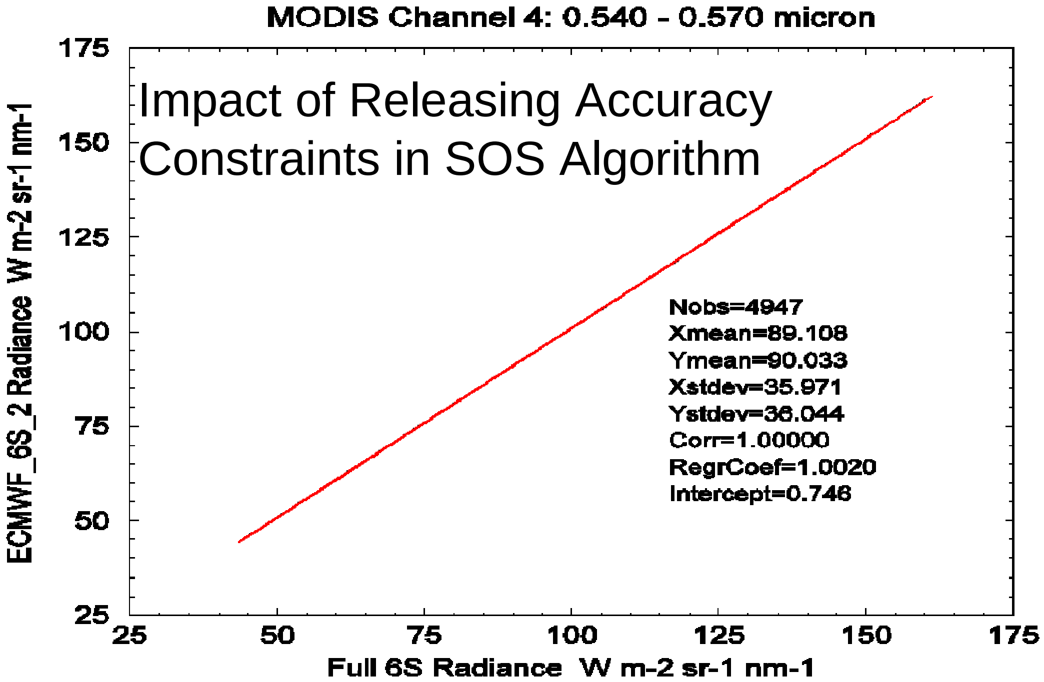
Simulating the SW radiances

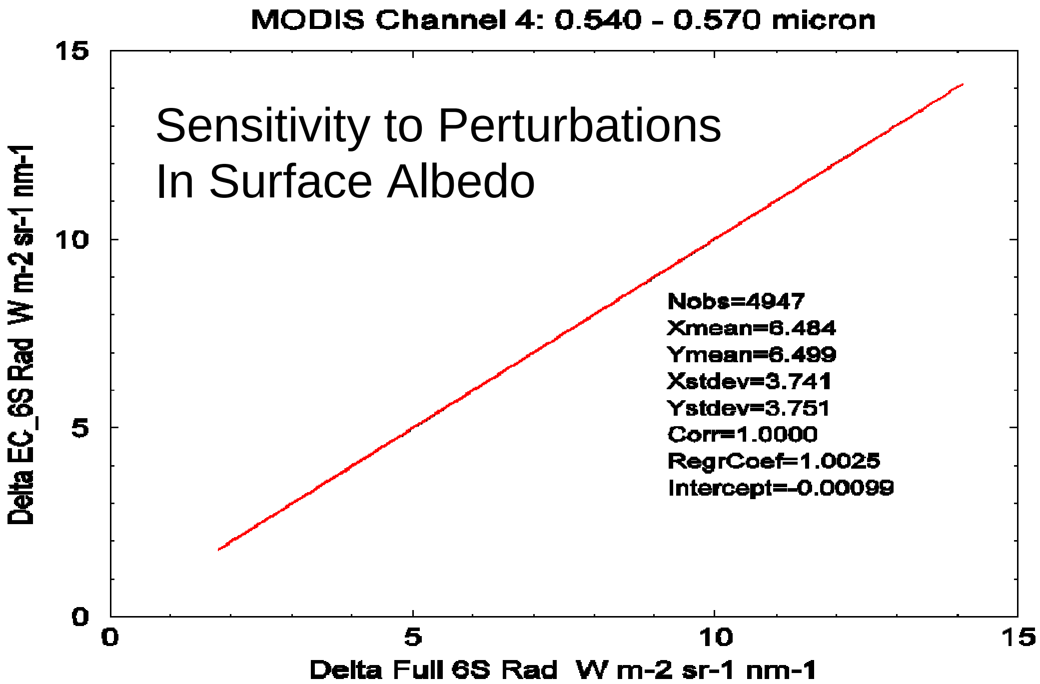
- 6S_ECMWF: optimized
  - by choosing one wavelength (instead of between 10 and 30) to represent the radiative transfer in a given satellite channel.
  - by releasing some accuracy constraints for convergence in the SOS algorithm

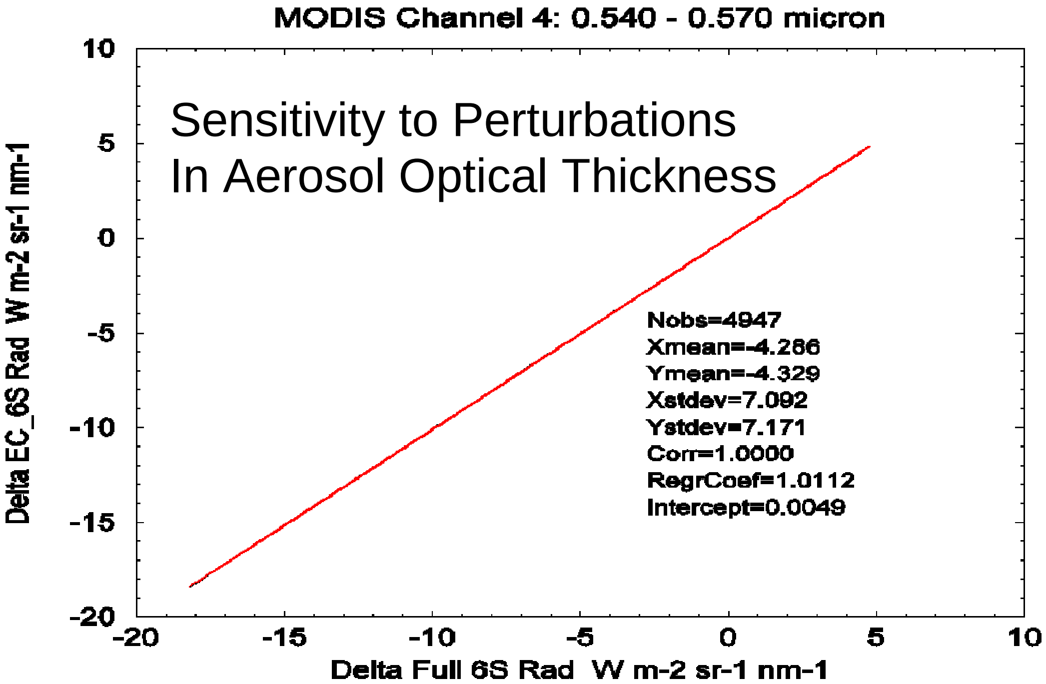
Sensitivity studies to perturbations in

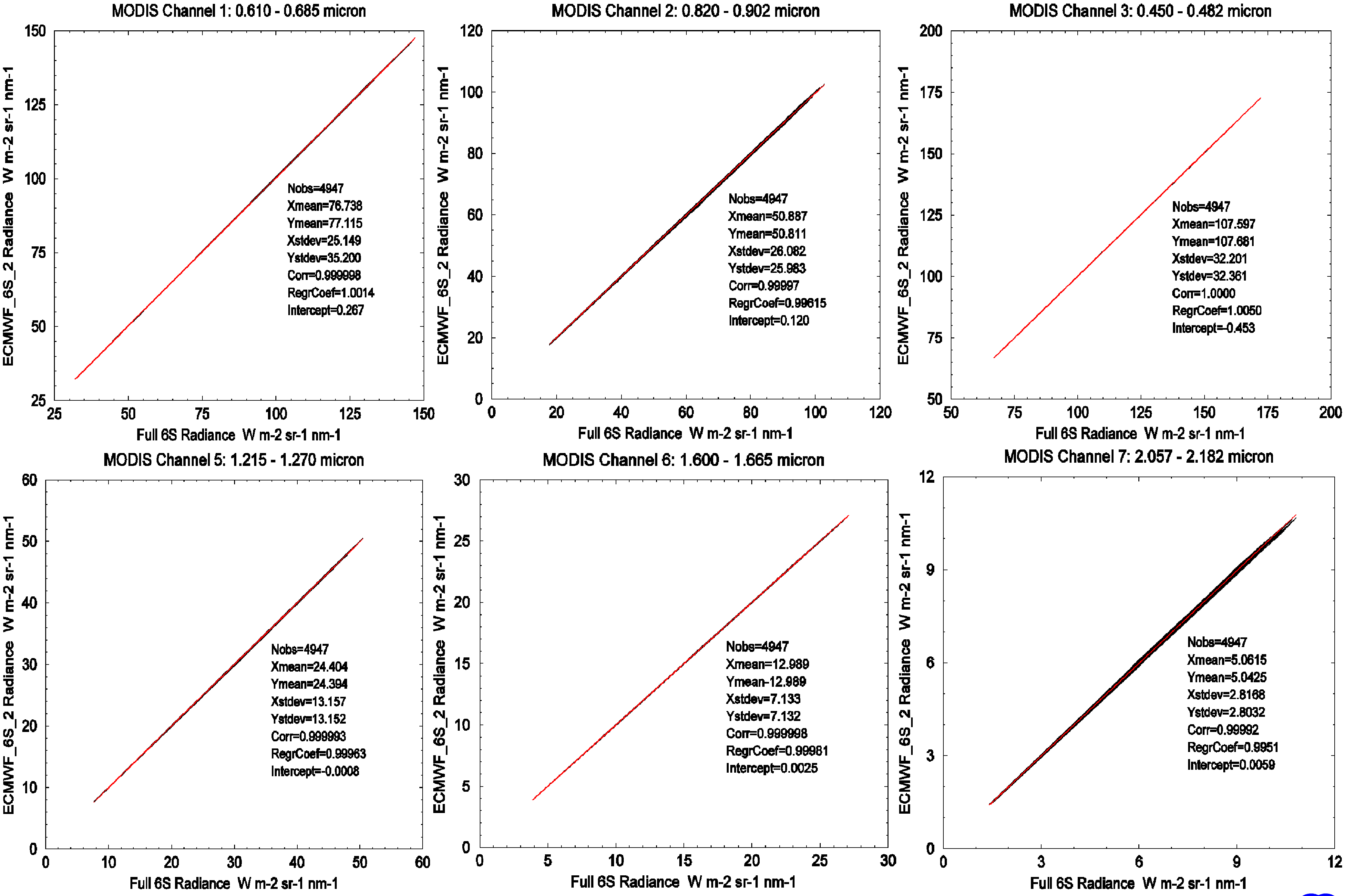
- Surface albedo
- Aerosol optical thickness


MODIS Channel 4: 0.540 - 0.570 micron
Impact of Replacing Spectral
Integration over the Filter Function
by a monochromatic RT
Nobs=4947
Xmean=89.112
Ymean=90.033
Xstdev=35.974
Ystdev=36.044
Corr=1.00000
RegrCoef=1.00194
Intercept=0.748
ECMWF_6S_1 Radiance W m-2 sr-1 nm-1
Full 6S Radiance W m-2 sr-1 nm-1
25
50
75
100
125
150
175


MODIS Channel 4: 0.540 - 0.570 micron
Impact of Releasing Accuracy
Constraints in SOS Algorithm
Nobs=4947
Xmean=89.108
Ymean=90.033
Xstdev=35.971
Ystdev=36.044
Corr=1.00000
RegrCoef=1.0020
Intercept=0.746
ECMWF_6S_2 Radiance W m-2 sr-1 nm-1
Full 6S Radiance W m-2 sr-1 nm-1
25
50
75
100
125
150
175


MODIS Channel 4: 0.540 - 0.570 micron
Sensitivity to Perturbations
In Surface Albedo
Nobs=4947
Xmean=6.484
Ymean=6.499
Xstdev=3.741
Ystdev=3.751
Corr=1.0000
RegrCoef=1.0025
Intercept=-0.00099
Delta EC_6S Rad W m-2 sr-1 nm-1
Delta Full 6S Rad W m-2 sr-1 nm-1
0
5
10
15


MODIS Channel 4: 0.540 - 0.570 micron
Sensitivity to Perturbations
In Aerosol Optical Thickness
Nobs=4947
Xmean=-4.286
Ymean=-4.329
Xstdev=7.092
Ystdev=7.171
Corr=1.0000
RegrCoef=1.0112
Intercept=0.0049
Delta EC_6S Rad W m-2 sr-1 nm-1
Delta Full 6S Rad W m-2 sr-1 nm-1
-20
-15
-10
-5
0
5
10


MODIS Channel 1: 0.610 - 0.685 micron
ECMWF_6S_2 Radiance W m-2 sr-1 nm-1
Full 6S Radiance W m-2 sr-1 nm-1
Nobs=4947
Xmean=76.738
Ymean=77.115
Xstdev=25.149
Ystdev=35.200
Corr=0.999998
RegrCoef=1.0014
Intercept=0.267
MODIS Channel 2: 0.820 - 0.902 micron
ECMWF_6S_2 Radiance W m-2 sr-1 nm-1
Full 6S Radiance W m-2 sr-1 nm-1
Nobs=4947
Xmean=50.887
Ymean=50.811
Xstdev=26.082
Ystdev=25.983
Corr=0.99997
RegrCoef=0.99615
Intercept=0.120
MODIS Channel 3: 0.450 - 0.482 micron
ECMWF_6S_2 Radiance W m-2 sr-1 nm-1
Full 6S Radiance W m-2 sr-1 nm-1
Nobs=4947
Xmean=107.597
Ymean=107.681
Xstdev=32.201
Ystdev=32.361
Corr=1.0000
RegrCoef=1.0050
Intercept=-0.453
MODIS Channel 5: 1.215 - 1.270 micron
ECMWF_6S_2 Radiance W m-2 sr-1 nm-1
Full 6S Radiance W m-2 sr-1 nm-1
Nobs=4947
Xmean=24.404
Ymean=24.394
Xstdev=13.157
Ystdev=13.152
Corr=0.999993
RegrCoef=0.99963
Intercept=-0.0008
MODIS Channel 6: 1.600 - 1.665 micron
ECMWF_6S_2 Radiance W m-2 sr-1 nm-1
Full 6S Radiance W m-2 sr-1 nm-1
Nobs=4947
Xmean=12.989
Ymean-12.989
Xstdev=7.133
Ystdev=7.132
Corr=0.999998
RegrCoef=0.99981
Intercept=0.0025
MODIS Channel 7: 2.057 - 2.182 micron
ECMWF_6S_2 Radiance W m-2 sr-1 nm-1
Full 6S Radiance W m-2 sr-1 nm-1
Nobs=4947
Xmean=5.0615
Ymean=5.0425
Xstdev=2.8168
Ystdev=2.8032
Corr=0.99992
RegrCoef=0.9951
Intercept=0.0059

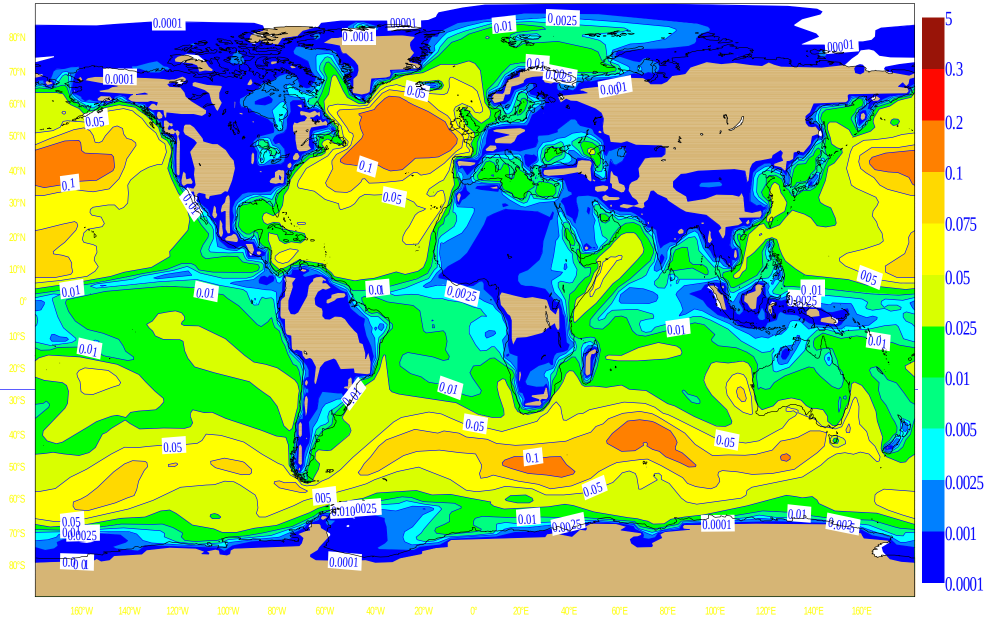
THE END

thank you for your attention!

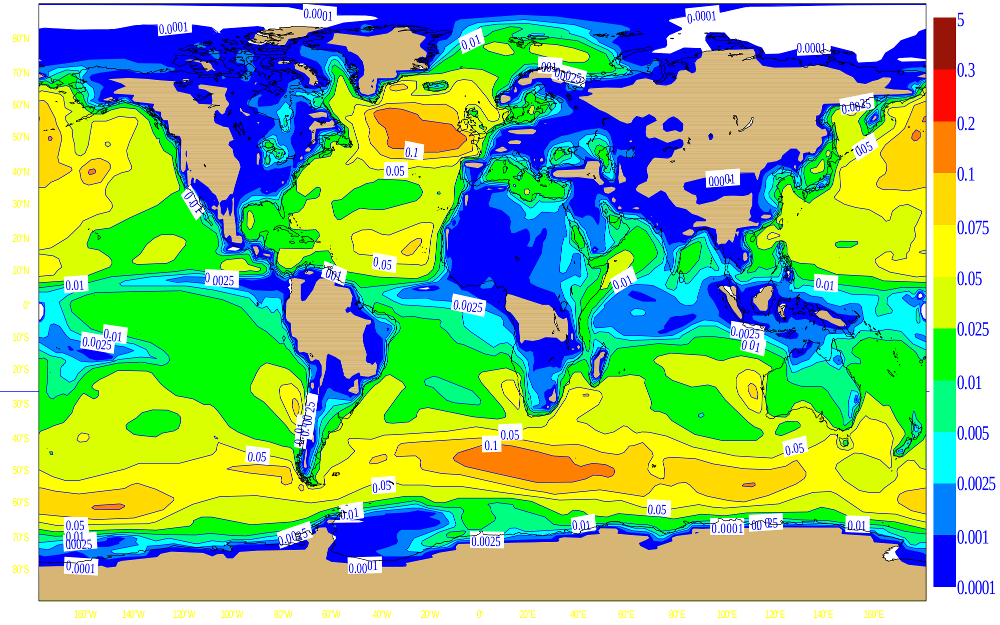
Sensitivity to model vertical resolution

- In all following results, aerosol processes are interactive with ECMWF model soil moisture, precipitation, …
- The ECMWF IFS model (cycle 29R2) is run with the previous description of aerosols at T_L159, and L19, L31, L60 and L91 vertical levels
- Comparisons are presented for one month (December 2002), for sea salt aerosols, and for:
  - surface sources
  - dry deposition
  - sedimentation
  - wet deposition (LSP+CP)
  - tau550
- Main modulators appear to be the 10m wind with subsequent impact on surface source, and precipitation (mainly large-scale) with impact on wet deposition.

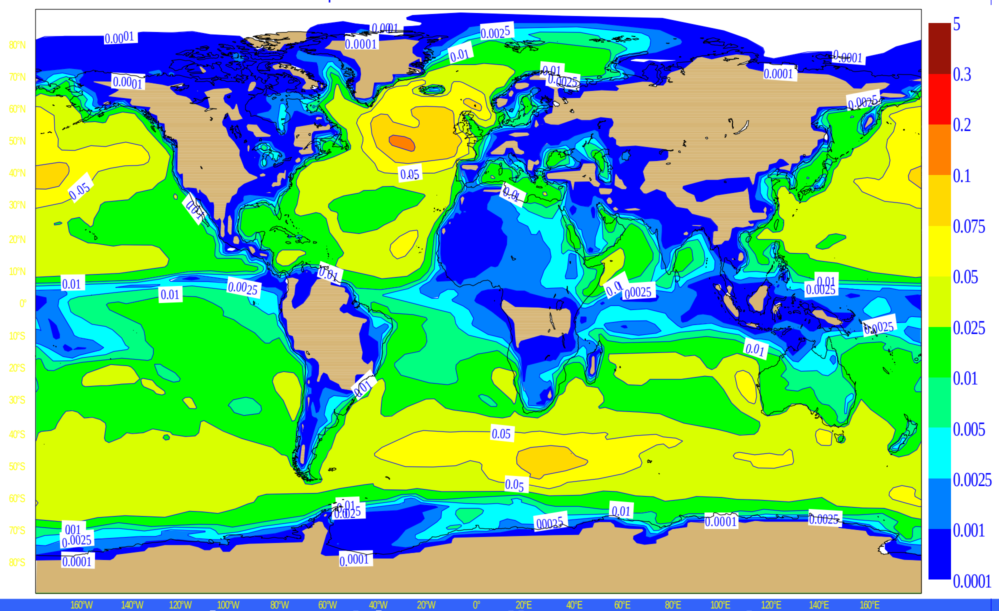
Friday 29 November 2002 00UTC ECMWF Forecast t+31 days VT: Monday 30 December 2002 00UTC Surface: **
"ep26: Tau550: Sum 3bins: SS: TL159L19"



Friday 29 November 2002 00UTC ECMWF Forecast t+31 days VT: Monday 30 December 2002 00UTC Surface: **
"ep27: Tau550: Sum 3bins: SS: TL159L31"



Friday 29 November 2002 00UTC ECMWF Forecast t+31 days VT: Monday 30 December 2002 00UTC Surface: **
"ep58: Tau550: Sum 3bins: SS: TL159L60"



Friday 29 November 2002 00UTC ECMWF Forecast t+31 days VT: Monday 30 December 2002 00UTC Surface: **
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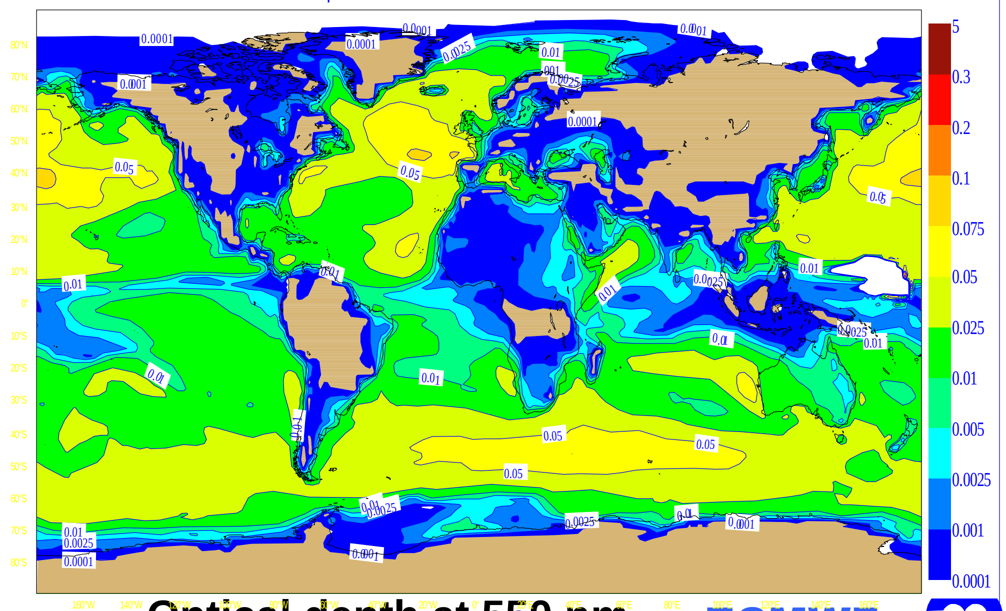

Optical depth at 550 nm

Optical depth at 550 nm: dust

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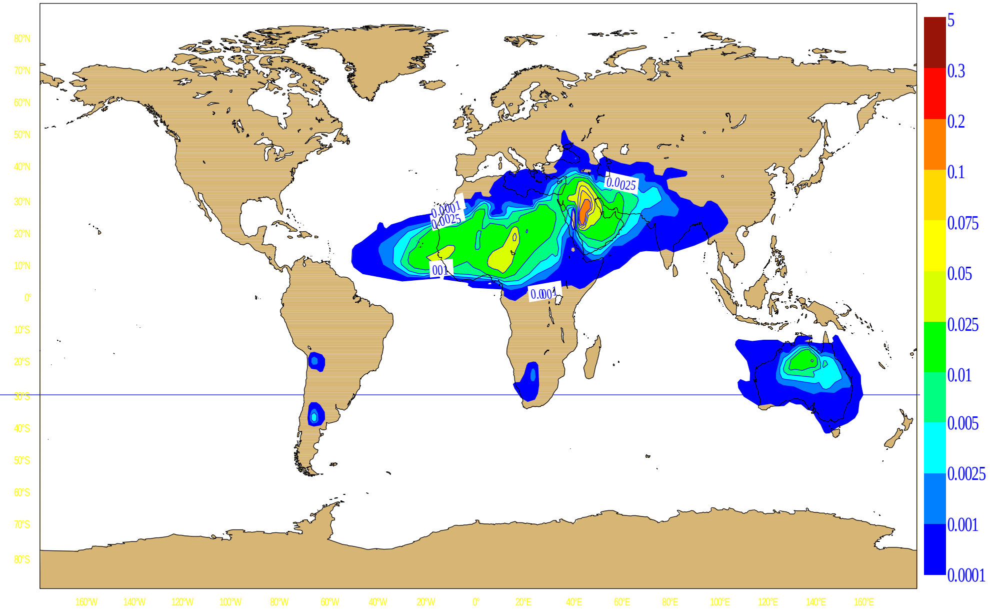

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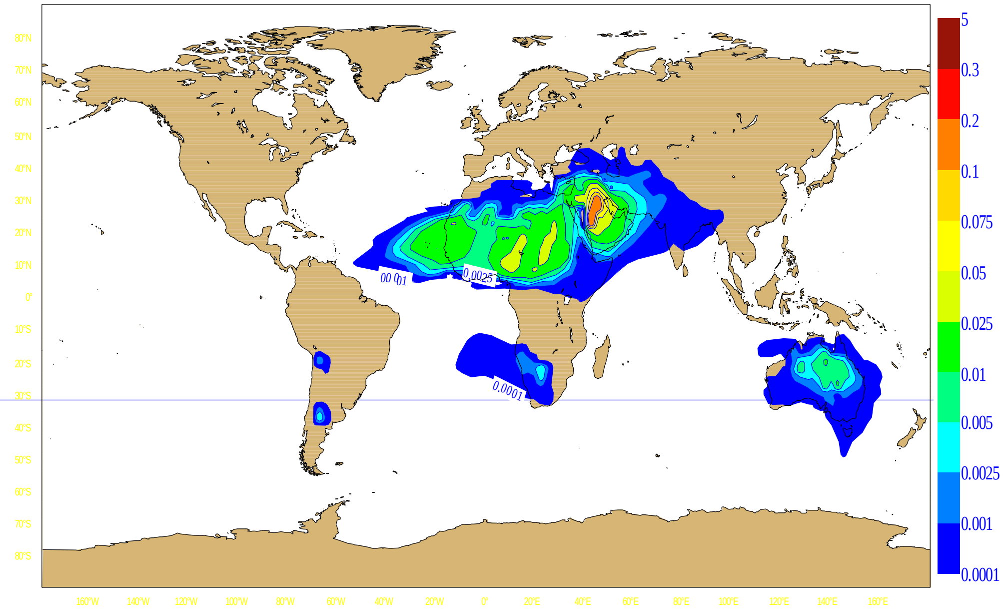

Friday 29 November 2002 00UTC ECMWF Forecast t+31 days VT: Monday 30 December 2002 00UTC Surface: **
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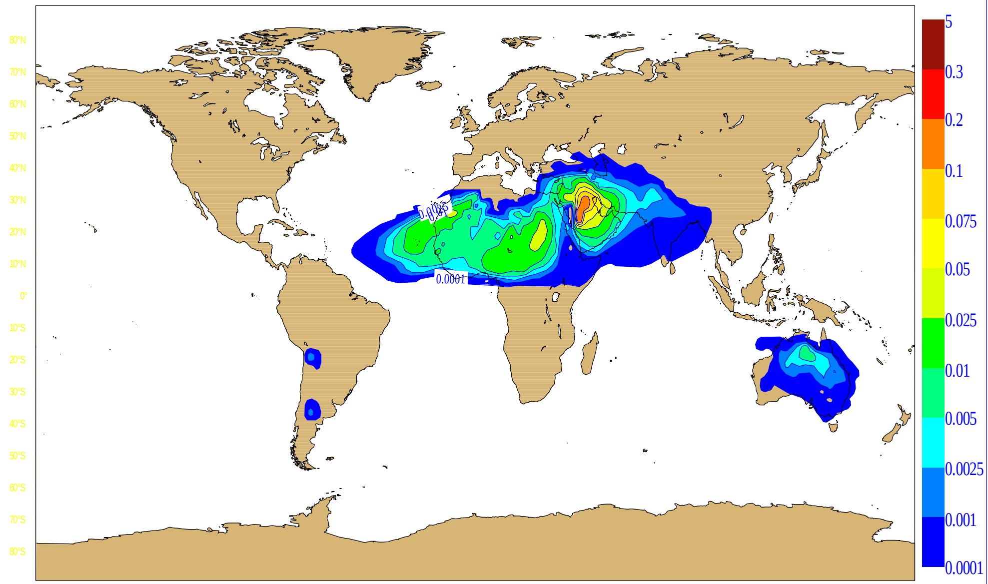

Friday 29 November 2002 00UTC ECMWF Forecast t+31 days VT: Monday 30 December 2002 00UTC Surface: **
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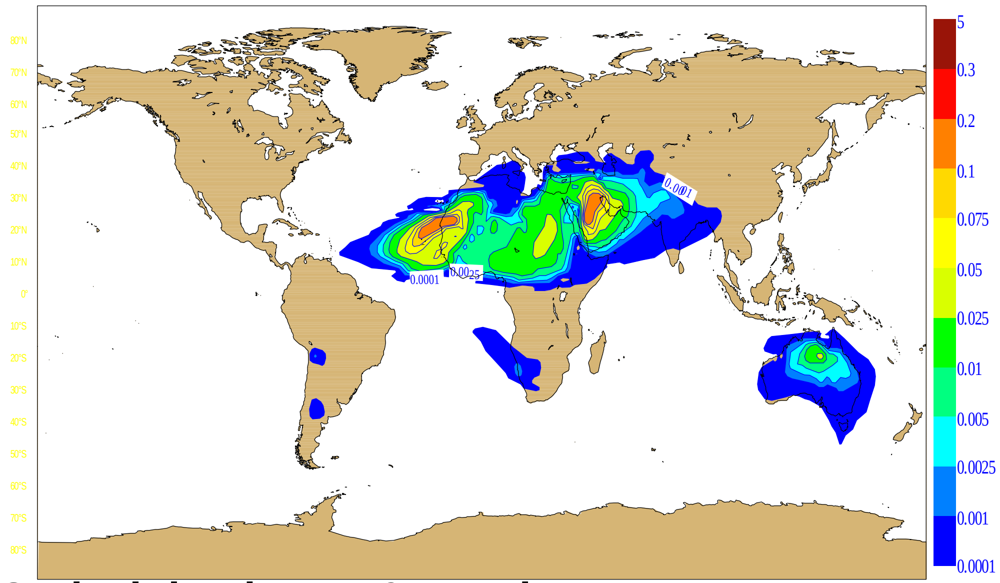


Sensitivity to vertical resolution: Conclusions

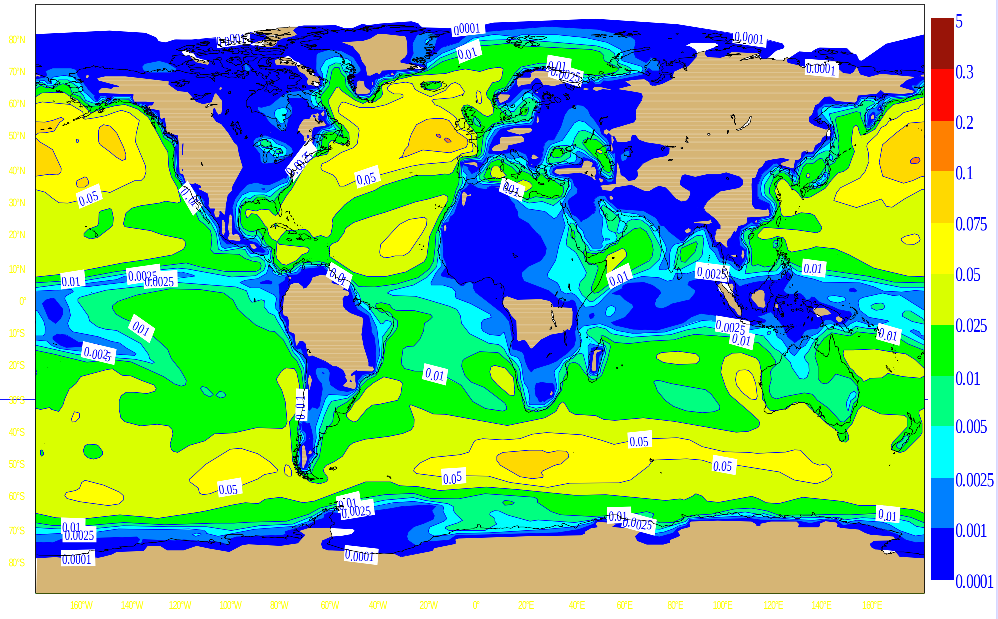
- The aerosols are sensitive to the model vertical resolution, through the dependencies “built-in” within the representation of source fluxes, dry deposition, sedimentation, wet deposition.
- The aerosol parametrisations mainly reflect the “usual” vertical dependence of governing fields (10m wind, precipitation).
- For desert dust, the picture is further complicated by change in orography (surface temperature, soil moisture)

Sensitivity to model horizontal resolution

- The ECMWF IFS model (cycle 29R2) is run with the previous description of aerosols at T_L95, T_L159 and T_L319, all L60 vertical levels
  - $T_L95 = (1.875deg)^2$, $T_L159 = (1.125deg)^2$, $T_L319 = (\sim 0.56deg)^2$
- Comparisons were for one month (December 2002), and all source and sink terms checked:
  - surface sources
  - dry deposition
  - sedimentation
  - wet deposition (LSP+CP)
  - tau550 (shown)

Friday 29 November 2002 00UTC ECMWF Forecast t+31 days VT: Monday 30 December 2002 00UTC Surface: **
"ep21: Tau550: Sum 3bins: SS: TL95L60"

95



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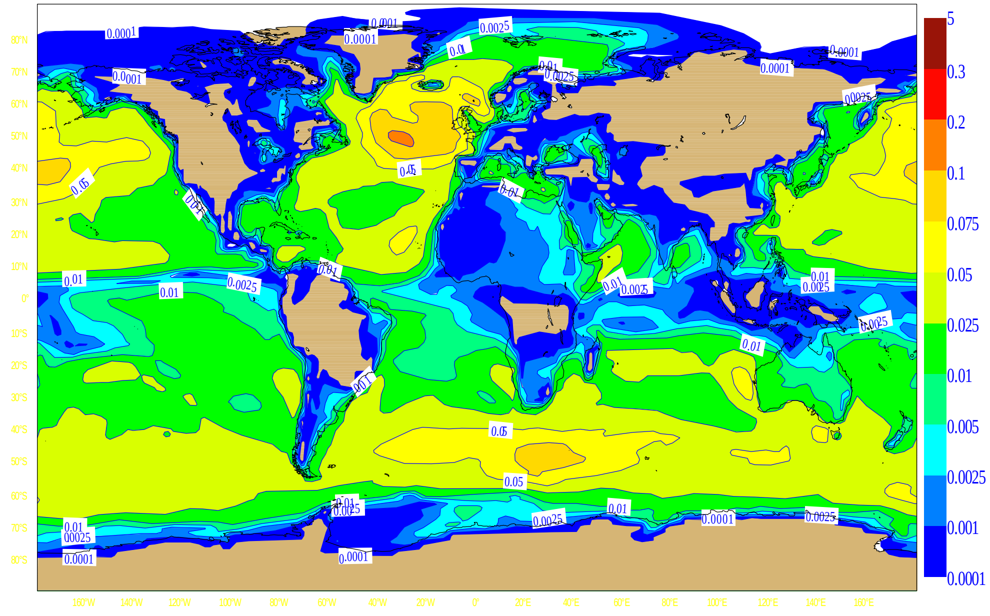
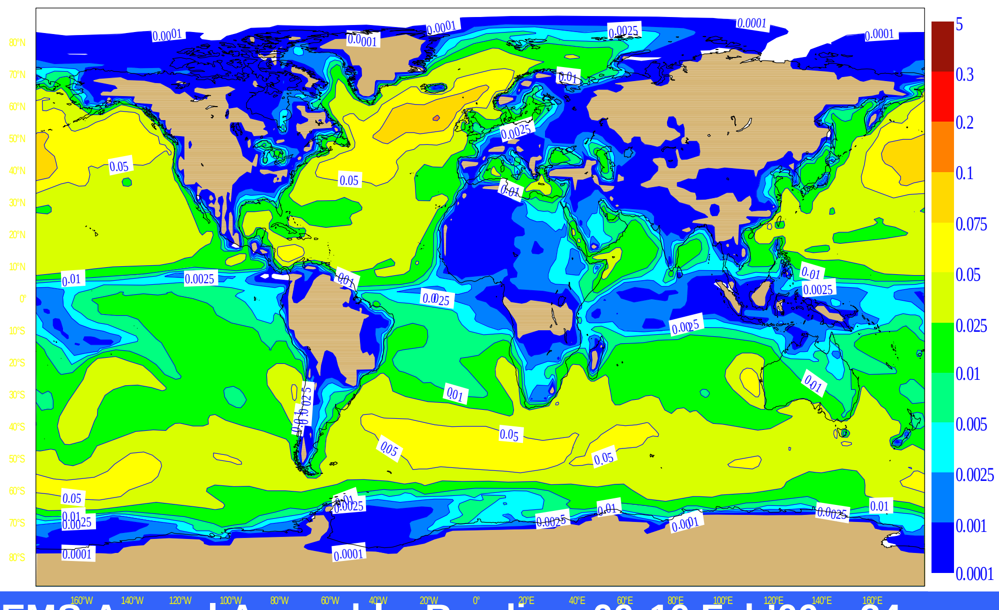
159

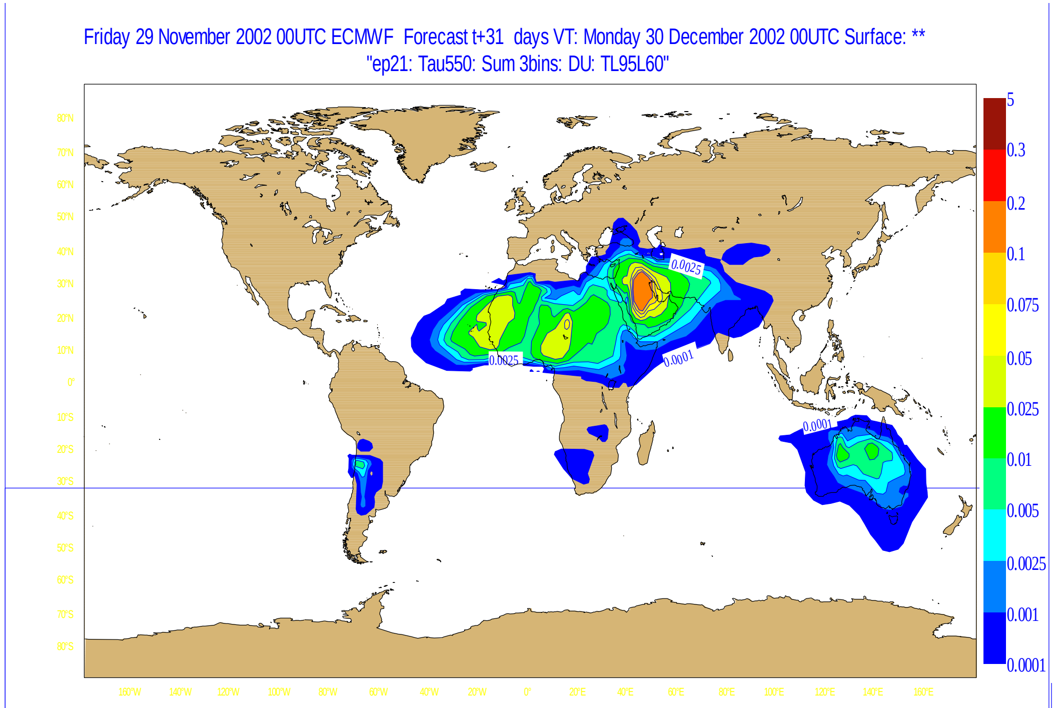


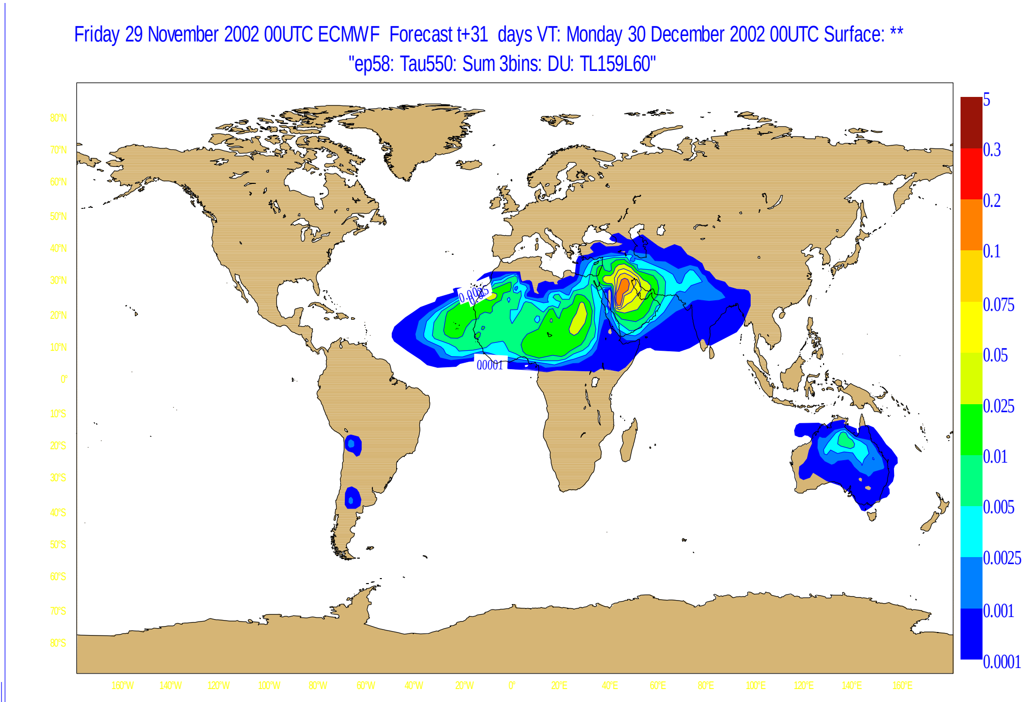
Friday 29 November 2002 00UTC ECMWF Forecast t+31 days VT: Monday 30 December 2002 00UTC Surface: **
"ep22: Tau550: Sum 3bins: SS: TL319L60"

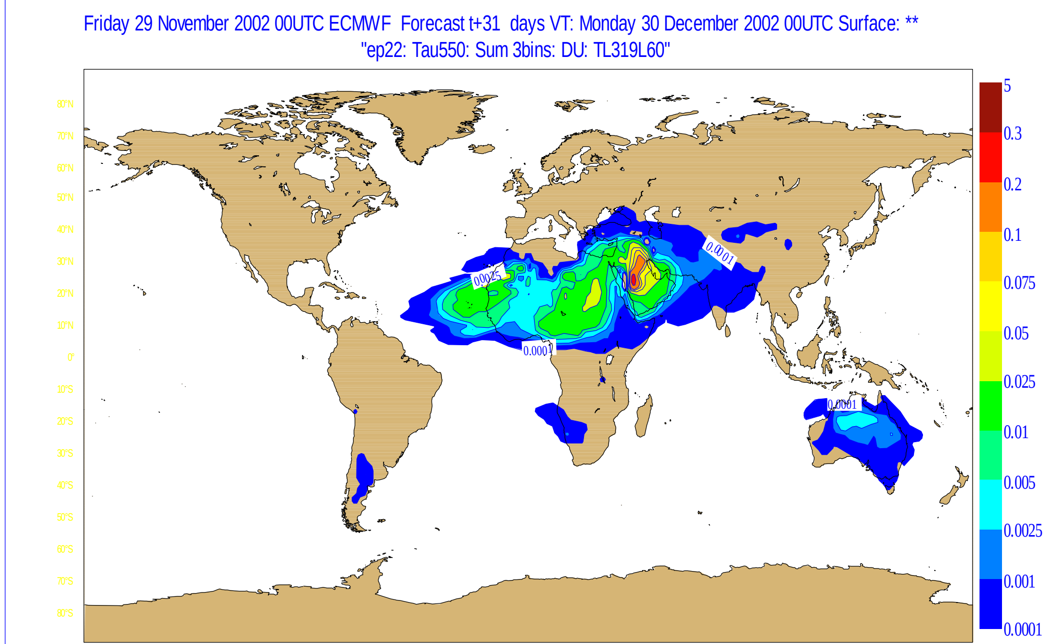
319



Optical depth at 550 nm







Optical depth at 550 nm: dust

ECMWF

Model Resolution	159L19	159L31	95L60 159L60 319L60	159L91
Source: g m^{-2} yr^{-1}	3.832	3.718	2.953 2.912 3.074	2.761
Dry sinks: Dry deposition+Sedimentation g m^{-2} yr^{-1}	1.385	1.358	1.185 1.147 1.179	1.087
Wet Deposition sinks: Large-scale + Convective precipitation g m^{-2} yr^{-1}	2.482	2.357	1.738 1.736 1.874	1.509
Optical depth at 550 nm	0.0251	0.0228	0.0177 0.0171 0.0175	0.0143

Sea Salt Aerosols

Sensitivity to model resolution: Conclusions

- Sea salt aerosol fields are less sensitive to the model horizontal- than to its vertical resolution.
- With the ad hoc formulation used here for dust emission, the dust aerosols show similar sensitivities to horizontal and vertical resolutions.
- The aerosol budget (Source-Sinks-Atmospheric Loading) is not strictly closed:
  - Within 1.5% over a month, without "negative aerosol fixer"
  - Likely causes from by increasing order of importance
    - ➔ Semi-Lagrangian dynamics (a +ve field is always kept +ve)
    - ➔ Small instabilities in convective transport resulting in small negative aerosol concentrations (if no aerosol fixer is used)
    - ➔ Build-up of temporary spuriously large aerosol mass mixing ratios in upper layers close to steep orography (Andes, Himalaya), getting worse with increasing resolution?

Summary and perspectives: 1

- Earlier studies without aerosols, or with two different climatologies show the ECMWF model to be sensitive to the representation of the aerosols.
- A more realistic aerosol climatology (desert dust) improves both the circulation and some temperature biases over Africa.

- These are early days for prognostic aerosols in the ECMWF model. However the model appears able to
  - provide realistic horizontal patterns of sea salt and desert dust
  - simulate realistic dust aerosol events.
- There is a need for extensive validation:
  - Intercomparison with other models as part of AEROCOM
  - Comparison with AERONET optical thicknesses for stations where sea-salt and desert dust are the dominant aerosols
  - Comparison with lidar measurements (EARLINET) to check the vertical distribution of these modelled aerosols

Summary and perspectives: 2

- **The aerosols display the usual model dependency on vertical resolution, but show relatively small sensitivity to horizontal resolution.**
- **When aerosol assimilation is ready, the ECMWF IFS will allow an improved knowledge of the temporal and horizontal distributions of the aerosols represented by the system. Major effort (and new observations: CALIPSO) will be required to validate their vertical distributions.**