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The NMMB/BSC-CTM: a multiscale online chemical weather prediction system

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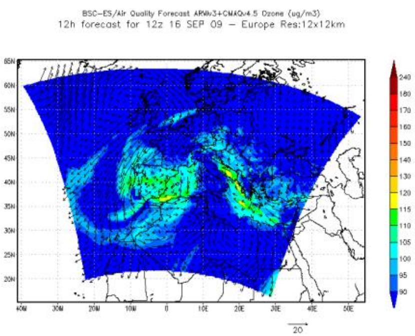
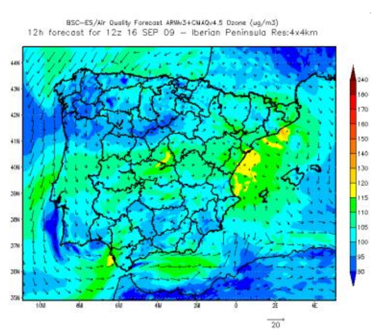
Kos Island, Greece, 2-6 October 2011

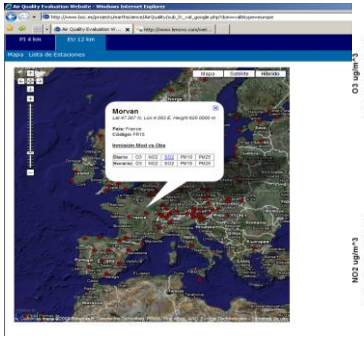
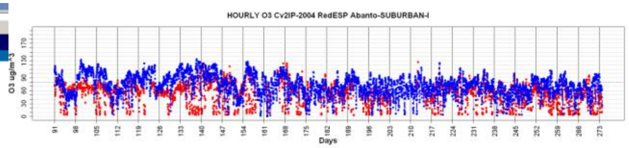
BSC air quality modeling activities

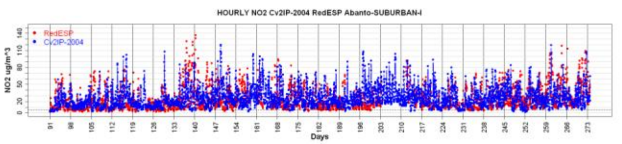
- CALIOPE daily experimental forecast and verification

✓ Daily experimental forecasts for meteorology and air quality (12 km for Europe and 4 km for the Iberian Peninsula) (http://www.bsc.es/caliope).



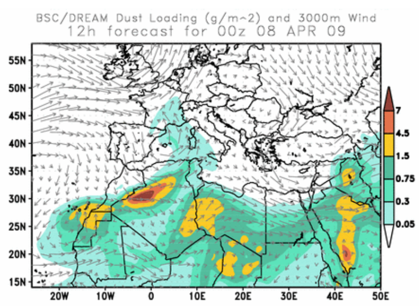


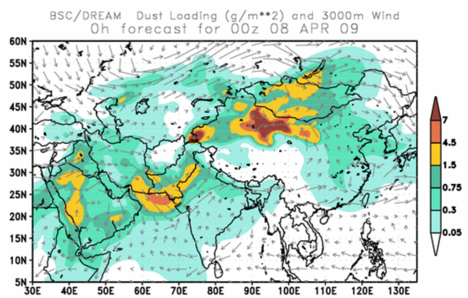



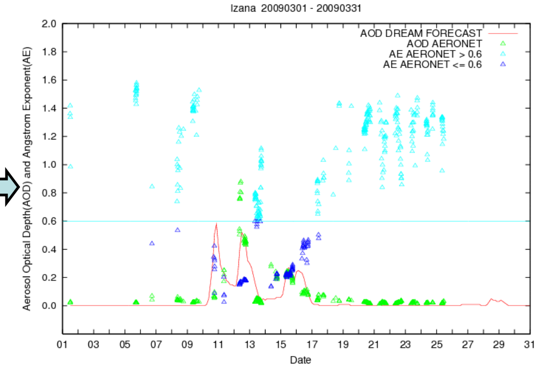


- BSC-DREAM8b daily forecast and verification

North Africa/Mediterranean - 1/3 x 1/3 degree resolution
Asia domain - 1/2 x 1/2 degree resolution





→ **http://www.bsc.es/projects/earthscience/DREAM**

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NMMB/BSC project

- Memorandum of understanding NCEP – BSC on the use and development of air quality and meteorological modules within the new NMMB NWP model

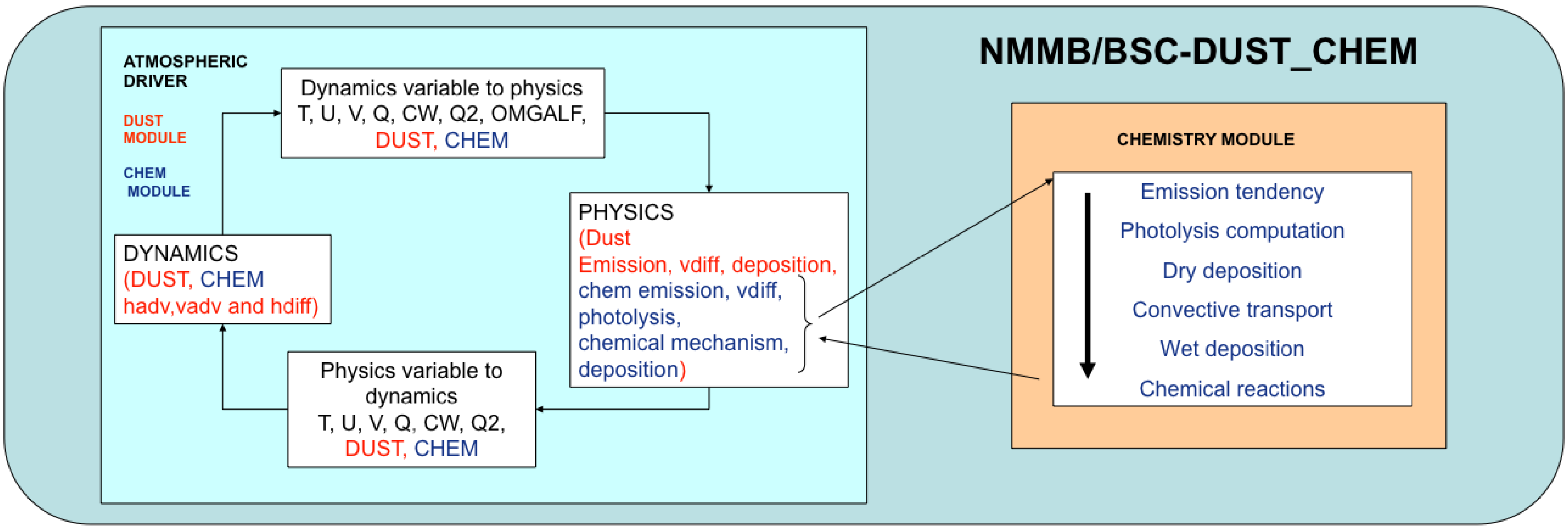
- Funded by national research projects:
  - Improvement of the Dust Regional Atmospheric Model (BSC-DREAM8b) for prediction of Saharan dust events in the Mediterranean and the Canary Islands [CICYT CGL2006-11879].
  - Coupling of a fully online chemical mechanism within the atmosperic global-regional umo/dream model [CICYT CGL2008-02818].
  - Coupling of a fully online multi-component aerosol module within the atmosperic global-regional NMMB model [CICYT CGL2010-19652].

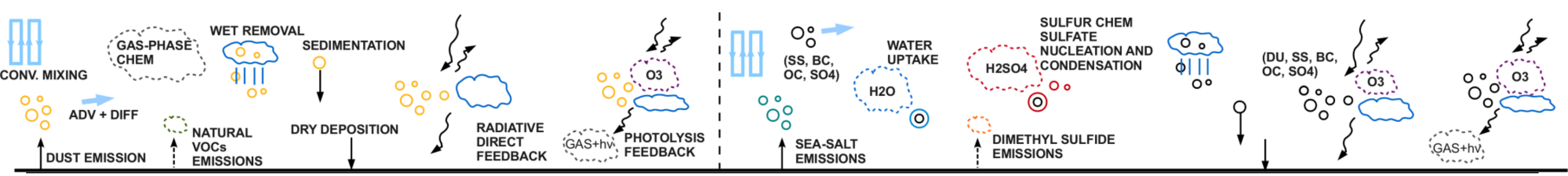
- Development under a collaborative framework with several research institutions

- Experimental research regional and global air quality modelling system

NMMB/BSC-Chemical Transport Model

Embedding dust and chemistry processes within the meteorological core driver NMMB





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NMMB – Nonhydrostatic Multiscale Model on the B grid – Main characteristics
Under development at NCEP (Janjic, 2005; Janjic, 2007; Janjic, 2009)

Unified nonhydrostatic dynamical core (list of features is not exhaustive)

✓ Wide range of spatial and temporal scales (from meso to global)

✓ Regional and global domains (just a simple switch)

✓ Evolutionary approach,built on NWP experience by relaxing hydrostatic approximation
- ➢Favorable features of the hydrostatic formulation preserved

✓ The nonhydrostatic option as an add–on nonhydrostatic module

✓ No problems with weak stability on mesoscales

✓ Conservation of important properties of the continuous system

✓Arakawa B grid (in contrast to the WRF-NMM E grid)

✓Pressure-sigma hybrid

✓Improved tracer advection: Eulerian, positive definite, mass conservative and monotonic

✓NMMB regional will become the next-generation NCEP mesoscale model for operational weather forecasting in 2011

NMMB/BSC-DUST: a new online mineral dust model

- Evolution of the BSC-DREAM8b model [Nickovic et al., 2001; Pérez et al., 2006]

- NMMB introduction
  - The NCEP-ETA weather forecast model is replaced by a state-of-the-art regional/global NWP model with improved dynamics and physics:

    → ***NCEP-NMMB*** [Janjic, 2005, 2007, 2009, 2010, 2011]

- New NMMB/BSC-Dust model [Pérez et al., 2008,2011; Haustein et al., 2011]

  - Implementation of all common **on-line dust modules** for global and regional simulations
  - Nested regional domains at very high resolution are available
  - The current DREAM dust emission scheme is upgraded to a physically based scheme → ***explicitly accounting for saltation and sandblasting***
  - New high resolution database for soil textures and vegetation fraction is included
  - Dust direct radiative effect implemented

NMMB/BSC-CTM: gas-phase chemistry

- Implementing the gas-phase chemistry within NMMB/BSC-DUST model.

- Fully on-line modeling system

- NEW NMMB/BSC-CTM [Jorba et al., 2009, 2010, 2011]
  - Wide range of application from global to sub-synoptic scales.
  - Modular implementation within NMMB. Chemistry solved after NMMB physics with the same timestep.
  - The advection, horizontal and vertical diffusion solved using the NMMB numerical schemes.
  - Dust processes of NMMB/BSC-DUST included and feedback interactions allowed.
  - Several gas-phase processes implemented, such as on-line natural emissions from MEGAN model, transport, dry deposition, clouds scavenging and wet deposition.

Tropospheric gas-phase chemistry processes (Jorba et al., 2009-2011; Badia and Jorba, 2011)

Photolysis scheme

- On-line Fast-J scheme (Wild et al., 2000)
- Coupled with physics of each model layer (e.g., aerosols, clouds). Planned to couple with NMMb/BSC-DUST aerosols.
- Considers NMMB grid-scale clouds and NMMB/BSC-CHEM O3 or climatology
- 7 bins wave-length (quick version)

$$J_i = \int_{\lambda_1}^{\lambda_2} F(\lambda)\,\sigma_i(\lambda)\,\phi_i(\lambda)\,d\lambda$$

$F(\lambda)$: actinic flux

$\sigma_i(\lambda)$: absorption cross section

$\Phi_i(\lambda)$: quantum yield of phot. react.

- Tables of $\sigma_i(\lambda)$ and $\Phi_i(\lambda)$ to be updated from Prather Fast-JX.

Chemical mechanism

- CBM-IV and CB05 mechanisms implemented (Gery et al., 1989; Yarwood, 2005)
- Coupled with Fast-J photolysis scheme
- Mechanism implemented through KPP kinetic pre-procesor (Damian et al., 2002)
- KPP coupling allows a straightforward modification of chemistry kinetics and reactions. Suitable for sensitivity studies.
- Implemented an EBI solver for CB05

Dry deposition

- Wesely et al. (1986, 1989) implemented to compute deposition velocities
- Simple scheme coupled with surface model layer physics (e.g., skin temperature, incoming shortwave radiation, friction velocity, …)
- Solve dry deposition in chemistry module independently from vertical diffusion. Considering to solve dry depositoin and vertical diffusion at first model level at same time.

$$dC_i(z_{ref})/dt = -V_g(z_{ref}) \times C_i(z_{ref})/\Delta z$$

$$V_d = (R_a + R_b + R_c)^{-1}$$

Cloud chemistry

- Cloud chemistry includes: **scavenging, mixing, wet deposition** and aqueous chemistry
- Scavenging and wet deposition implemented for gridscale and sub-gridscale clouds following Byun and Ching (1999)
  - Sub-grid + gridscale:

$$\left.\frac{\partial \overline{m}_i}{\partial t}\right|_{cld} = \left.\frac{\partial \overline{m}_i}{\partial t}\right|_{subcld} + \left.\frac{\partial \overline{m}_i}{\partial t}\right|_{rescld}$$

Scavenging:

$$\left.\frac{\partial \overline{m}_i^{cld}}{\partial t}\right|_{scav} = \overline{m}_i^{cld}\left(\frac{e^{-\alpha_i \tau_{cld}} - 1}{\tau_{cld}}\right)$$

$$\alpha_i = \frac{1}{\tau_{washout}\left(1 + \frac{TWF}{H_i}\right)} \qquad \tau_{washout} = \frac{\overline{W}_T \Delta z_{cld}}{\rho_{H_2O} P_r}$$

  - Wet deposition:

$$wdep_i = \int_0^{\tau_{cld}} \overline{m}_i^{cld} P_r\,dt \qquad TWF = \frac{\rho_{H_2O}}{\overline{W}_T R T}$$

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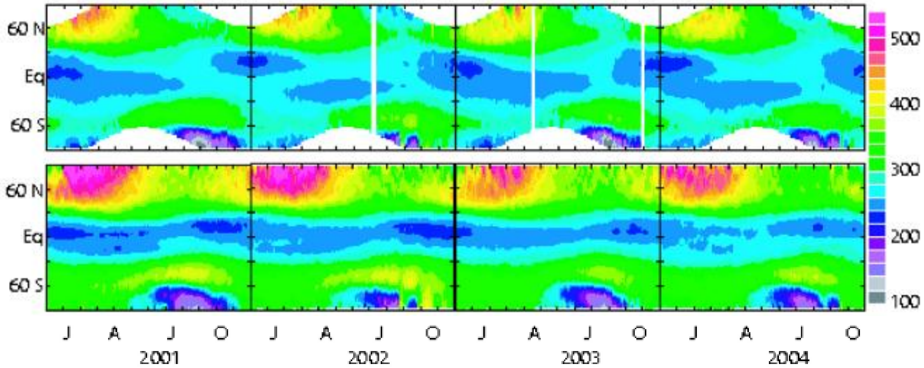
Stratospheric ozone chemistry

- Proper treatment of STE, improve the balance of tropospheric ozone and specify upper boundary condition for tropospheric ozone
- Implementation of the Cariolle and Teyssèdre (2007) linear model from the tropopause to the model top

$$dr_{O_3}/dt = A_1 + A_2(r_{O_3} - A_3) + A_4(T - A_5) + A_6(\Sigma - A_7) + A_8 r_{O_3}$$

$A_1=(P-L)$: Production and loss rate
$A_2=\partial(P-L)/\partial r_{O_3}$
$A_3=r_{O_3}$: ozone mixing ratio
$A_4=\partial(P-L)/\partial T$
$A_5=T$: temperature
$A_6=\partial(P-L)/\partial\Sigma$
$A_7=\Sigma$: ozone column



(Cariolle and Teyssèdre, 2007)

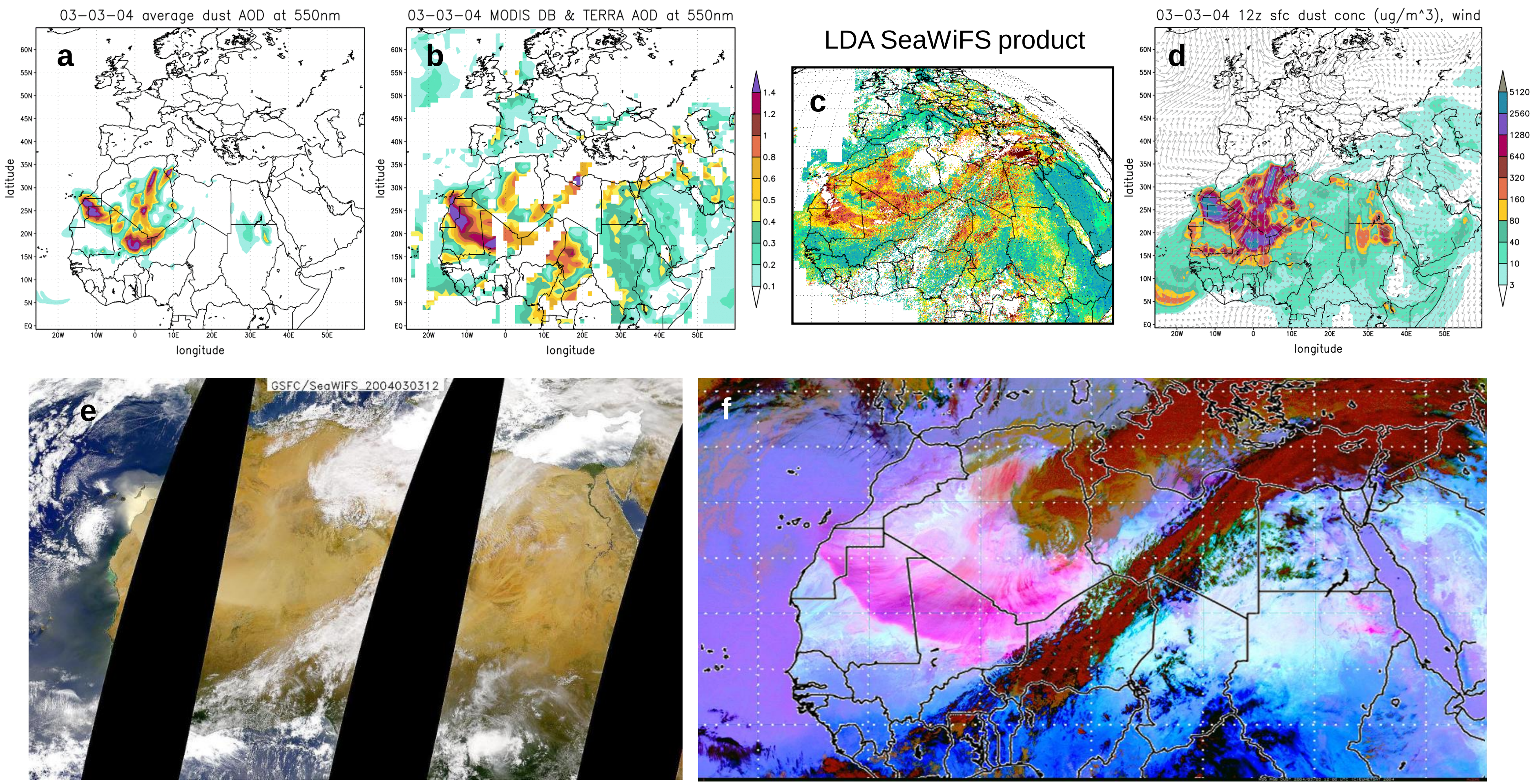
Ai coefficients are monthly averages calculated with the MOBIDIC 2D model (Cariolle and Brard, 1984)

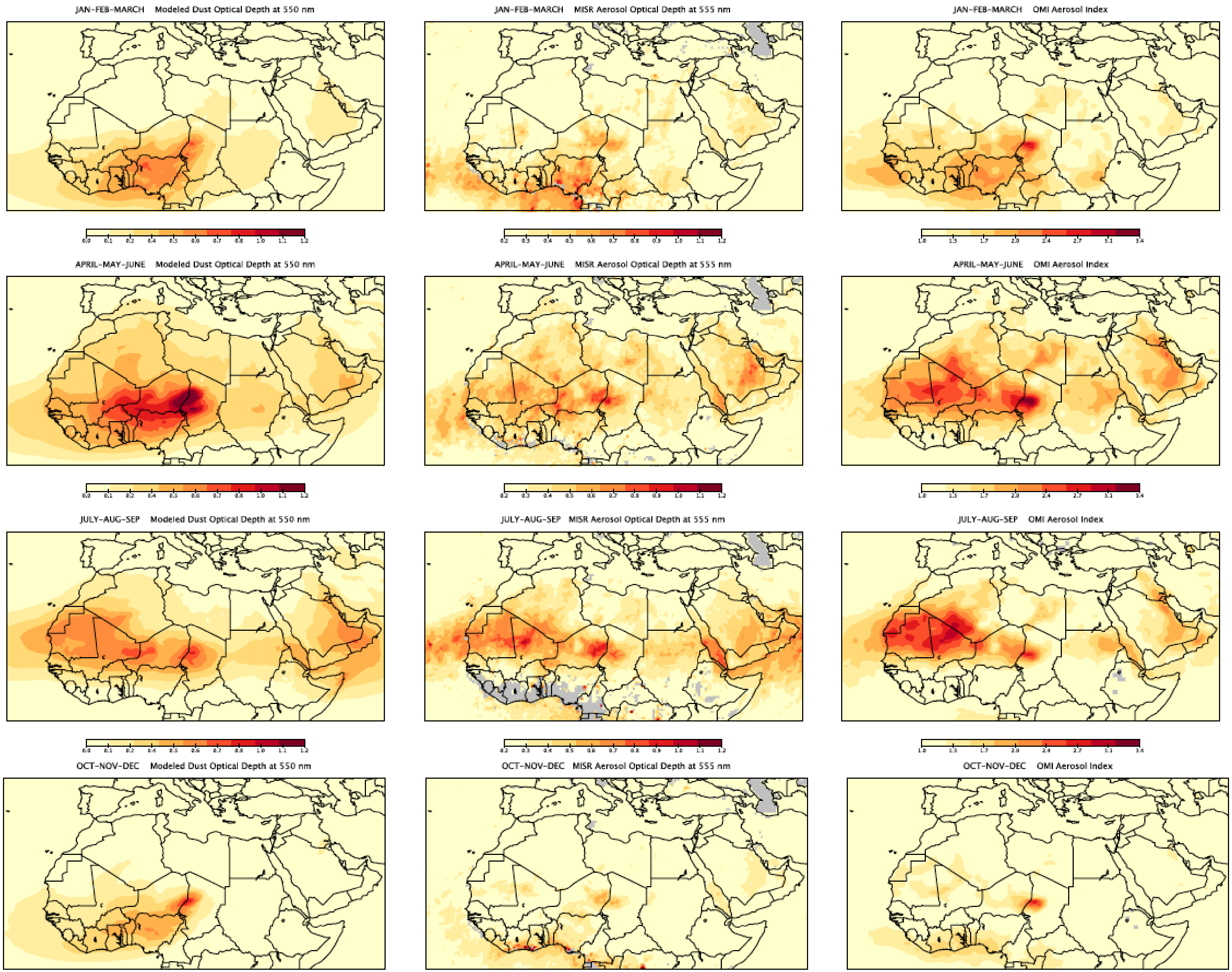
Cariolle, D. and H. Teyssèdre (2007). A revised linear ozone photochemistry parameterization for use in transport and general circulation models: multi-annual simulations. Atmos. Chem. Phys., 7, 2183–2196, 2007.

- Results and evaluation works

Results: Dust model

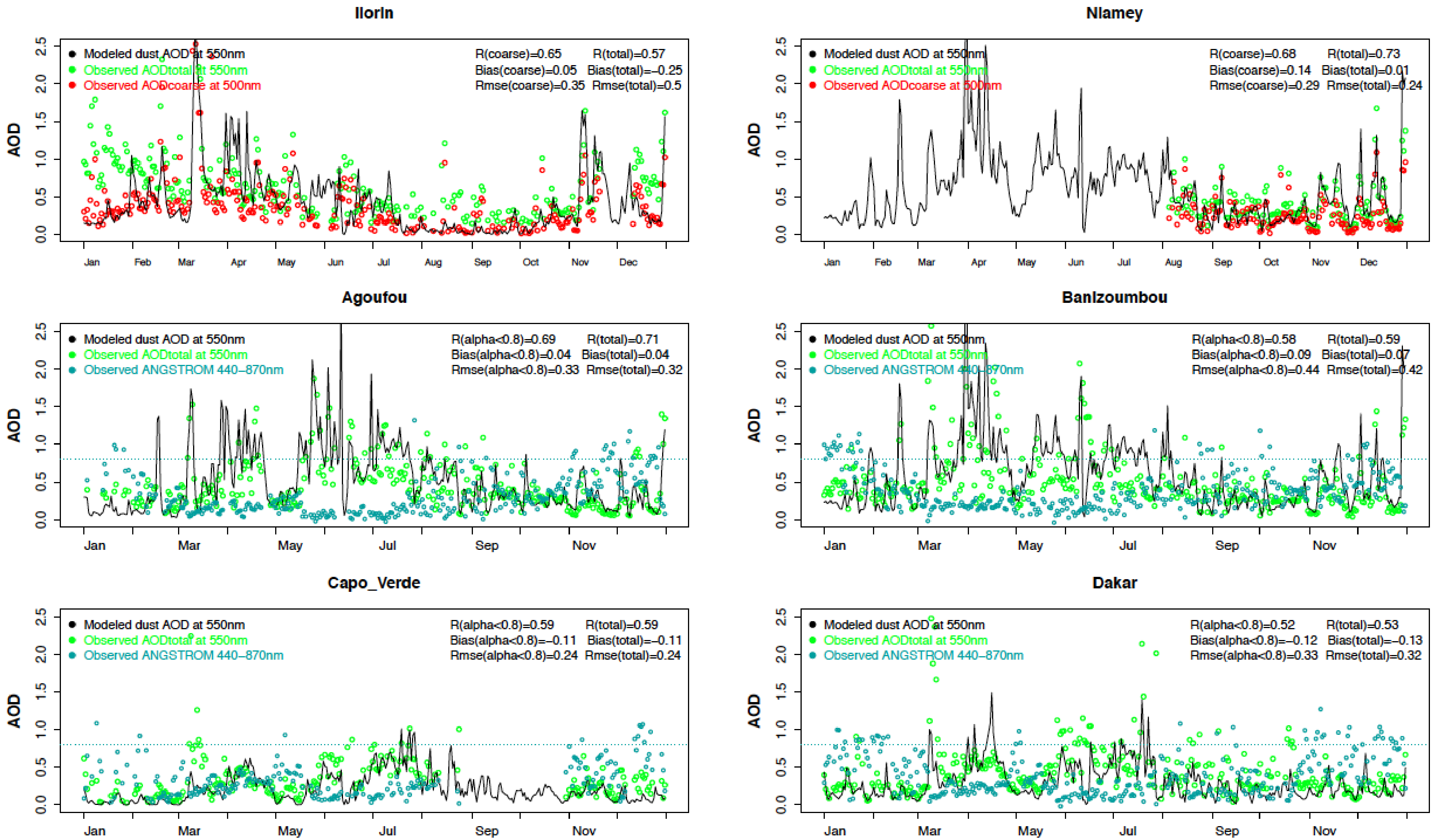
- Global and regional annual simulations evaluated with:
  - Aeronet sun-photometer networks
  - LIDAR vertical profiles
  - Several satellite products
  - Surface concentrations
  - Emission and deposition fluxes





Pérez et al., 2011 – ACPD

Aerosol optical depth on an annual cycle



Pérez et al., 2011 – ACPD

Aerosol optical depth near emission sources

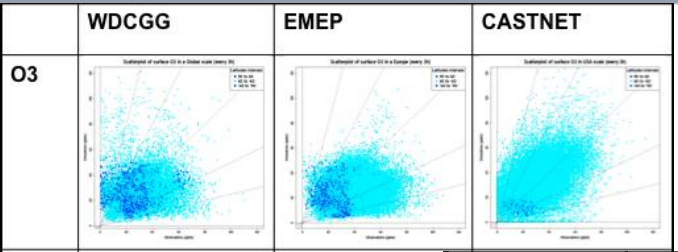
Results: Gas-phase chemistry

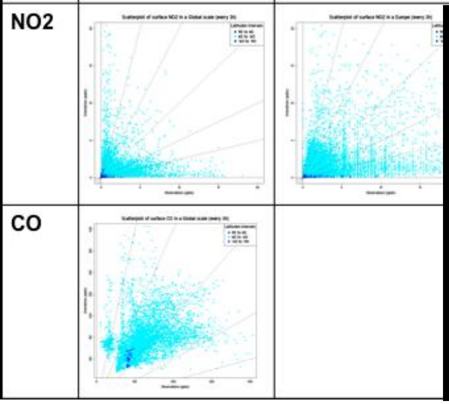
- Model setup:

→ Global domain
→ Non-hydrostatic physics
→ 1.4º x 1º horizontal resolution
→ 64 vertical (sigma-hybrid) layers
→ 1º x 1º NCEP/FNL analysis for meteorological initial conditions
→ Chemistry initial conditions from LMDz-INCA
→ Anthropogenic emissions: MOZART 2004
→ Biogenic emissions: MEGAN online model
→ No biomass burning emissions
→ Half-year spin-up
→ July – August 2004 simulation

→ All results are preliminary!

Preliminary evaluation with surface and ozonesondes

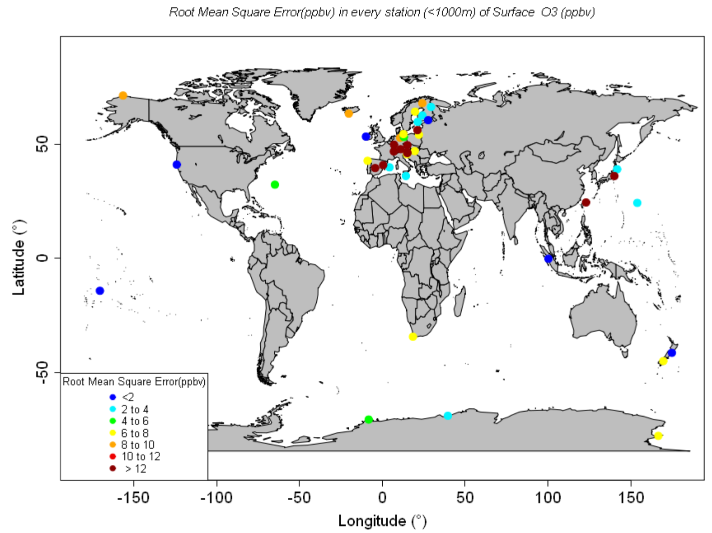


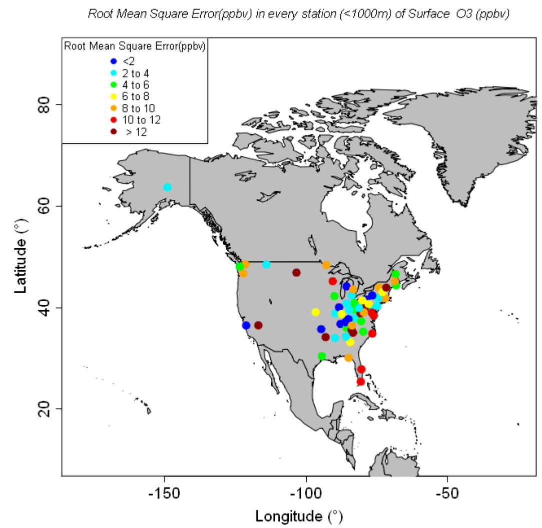


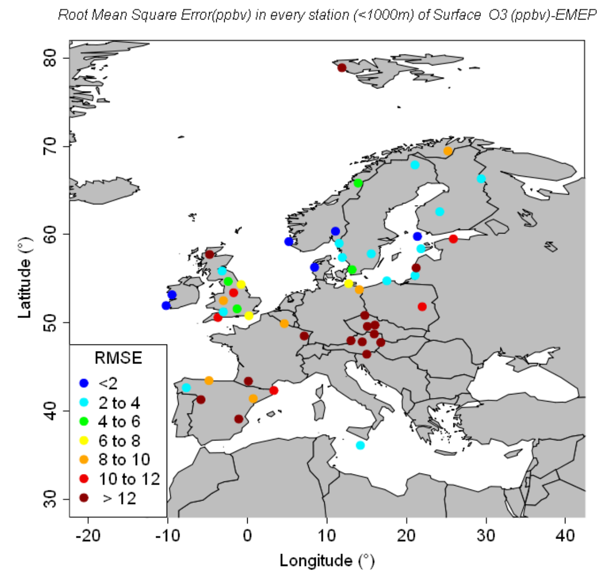
Evaluation against background surface from WDCGG, EMEP and CASTNET networks

Evaluation from 3-hourly simulations

GAS (ppbv)	Source	Nº stns	Obs. Mean	Sim. Mean	MB	RMSE	MNBE (%)	MNGE (%)	MFB (%)	MFE (%)
O3	WDCGG	41	31.69	27.35	-4.34	11.2	-7.87	25.49	-13.45	26.83
	EMEP	70	38.25	27.25	-11	15.77	24.22	30.38	32.21	37.5
	CASTNET	63	31.73	33.86	2.37	2.21	11.57	22.67	7.58	20.56
NO2	WDCGG	12	1.94	1.23	-0.71	2.04	29.37	102.26	-30.49	80.74
	EMEP	21	3.9	1.8	-2.1	3.36	-38.85	56.58	-64.45	77.2
CO	WDCGG	14	121.51	145.32	23.82	51.51	43.28	50.14	22.06	29.93

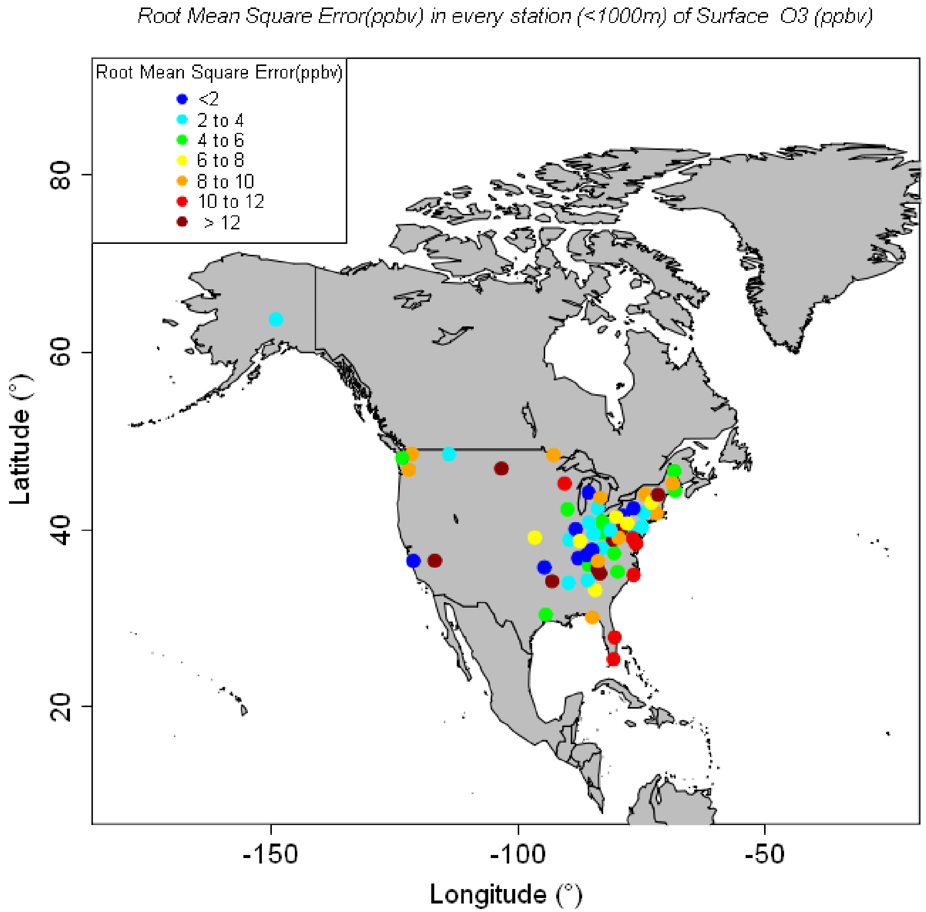


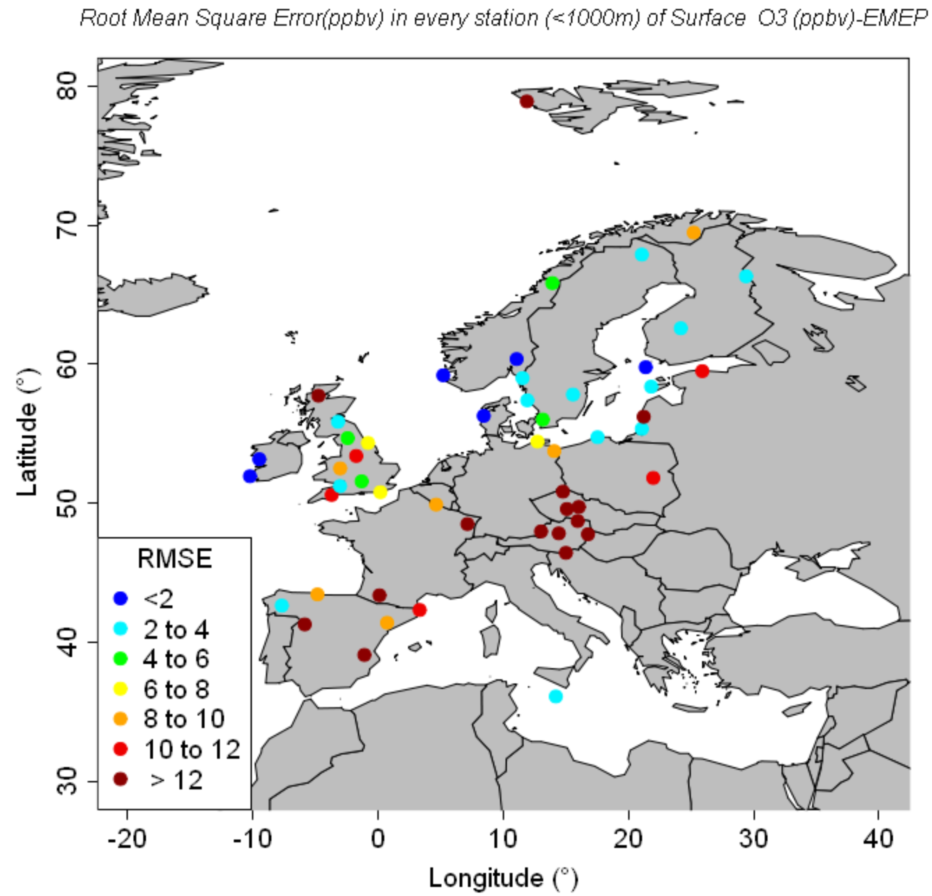


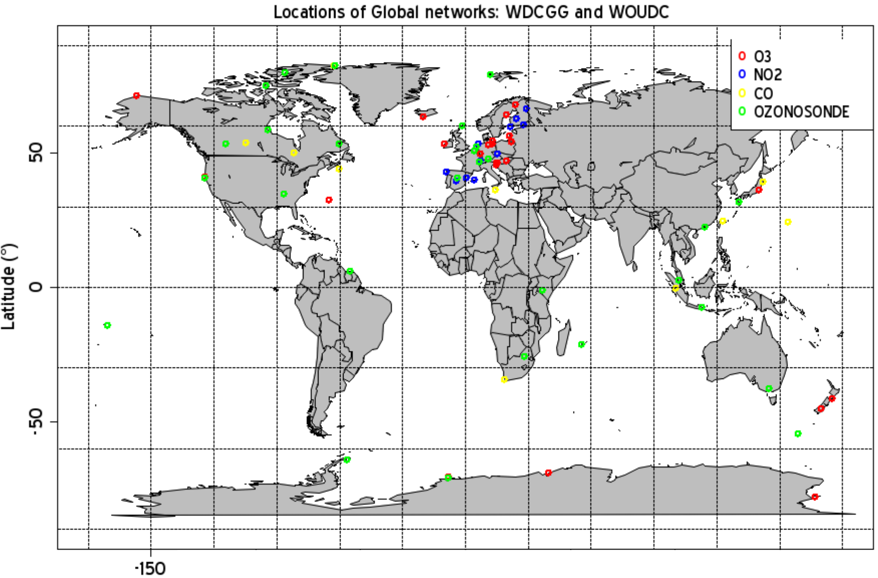


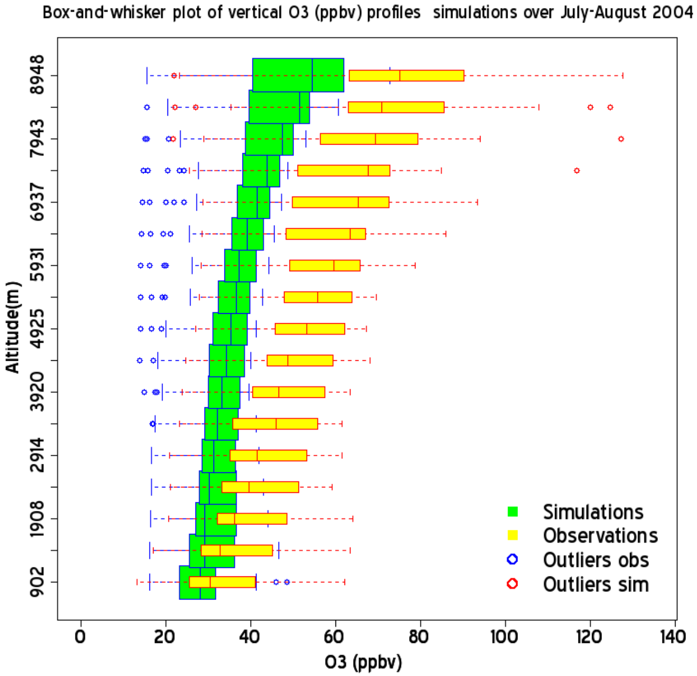
Badia and Jorba, 2011 – EGU2011

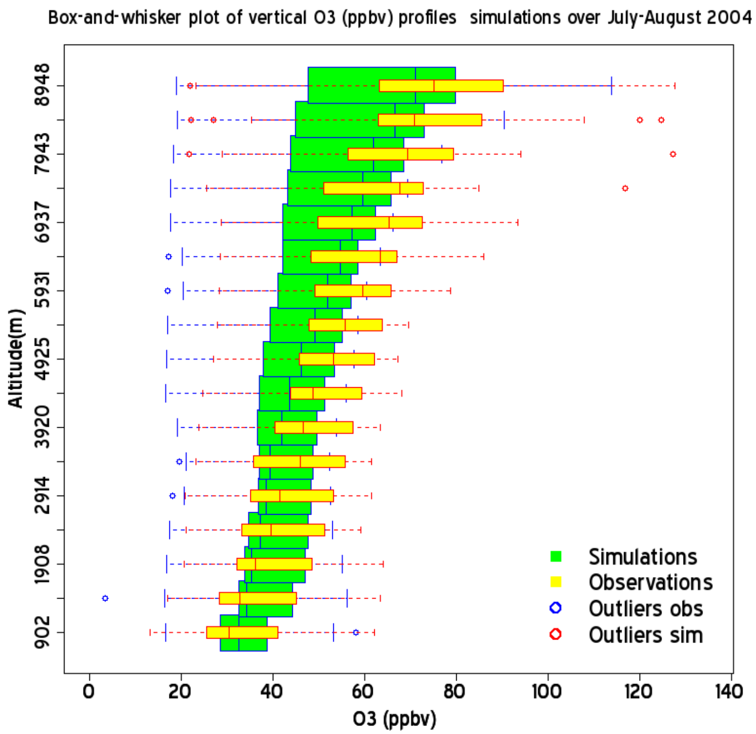
Preliminary evaluation with surface and ozonesondes







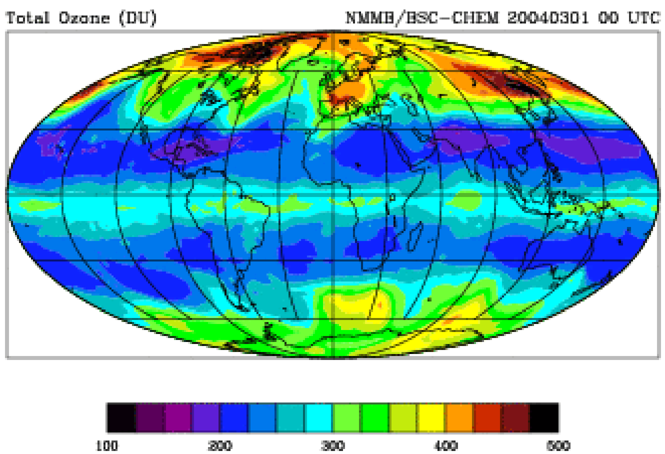


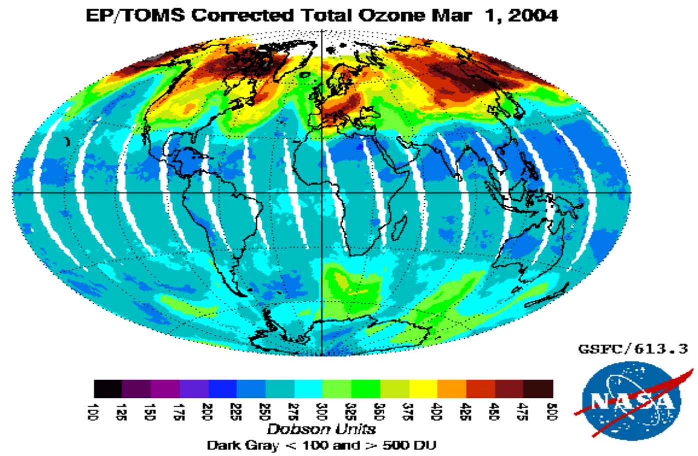


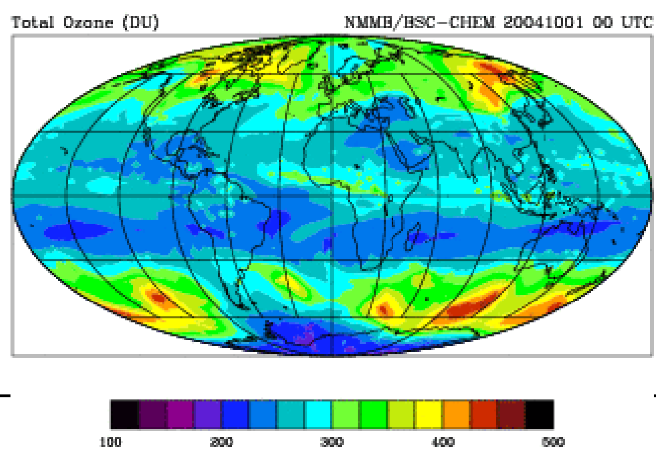
Inclusion of the stratospheric O3 linear model

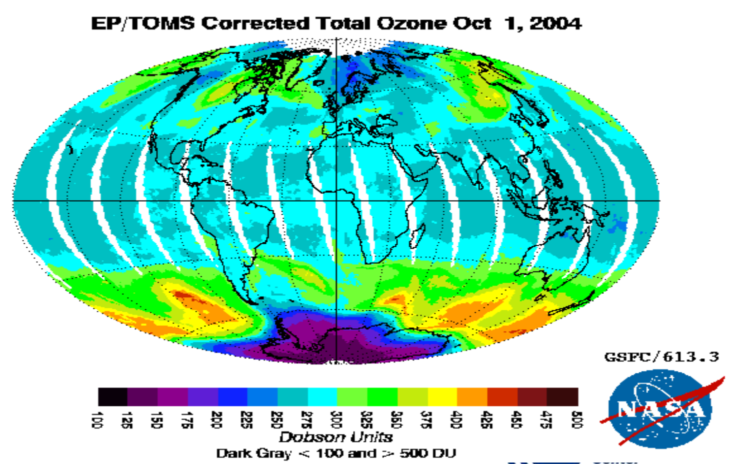
Stratospheric ozone

- Implementation of the Cariolle and Teyssèdre (2007) linear model
- It improve the ozone balance within the troposphere









- Future developments

Future developments (I/II)

- Improvement and evaluation of the chemistry part of the model.
- Implementation of the other global relevant aerosol species, i.e. sea-salt (SS), black (BC) and organic carbon (OC), and sulfate (SO4), in addition to dust (DU).

- It is planned to couple the radiative scheme with all the considered aerosol species to simulate the direct aerosol radiative effect.
- It is planned to couple the model ozone prediction with the radiative scheme of NMMB.
- It is panned to couple the photolysis scheme with the model clouds, ozone, and aerosol species (DU, SS, BC, OC, SO4).

Future developments (II/II)

- Implementation of secondary aerosol schemes (SIA, new SOA parameterizations) for LAM applications at high-resolutions

- Evaluation of the gas-phase chemistry on regional domains

- Experimental dust forecasts on global and regional domains to replace BSC-DREAM8b forecasts

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