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

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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](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

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 atmospheric global-regional umo/dream model [CICYT CGL2008-02818].
  - Coupling of a fully online multi-component aerosol module within the atmospheric 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
Embedding dust and chemistry processes within the meteorological core driver NMMB
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
NMNB/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:

- 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
NMNB/BSC-CTM: gas-phase chemistry

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

- Fully on-line modeling system

- NEW NMNB/BSC-CTM [Jorba et al., 2009, 2010, 2011]
  - Wide range of application from global to sub-synoptic scales.
  - Modular implementation within NMNB. Chemistry solved after NMNB physics with the same timestep.
  - The advection, horizontal and vertical diffusion solved using the NMNB numerical schemes.
  - Dust processes of NMNB/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 NMME/BSC-DUST aerosols.
- Considers NMME grid-scale clouds and NMME/BSC-CHEM O3 or climatology
- 7 bins wave-length (quick version)
  - $J_i = \int_{\lambda_1}^{\lambda_2} F(\lambda) \sigma_i(\lambda) \Phi_i(\lambda) d\lambda$
  - $\sigma_i(\lambda)$: 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.

**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: Scavenging:
    - $\frac{\partial m_i^{\text{old}}}{\partial t} = \frac{\partial m_i^{\text{old}}}{\partial t} + \frac{\partial m_i^{\text{old}}}{\partial t}^{\text{subgrid}}$
    - $\frac{\partial m_i^{\text{old}}}{\partial t} = m_i^{\text{old}} \left( e^{-\alpha \tau_{\text{old}}} - 1 \right)$
    - $\alpha = \frac{1}{\tau_{\text{subgrid}} \left( 1 + \frac{IWF}{H_i} \right)}$
    - $\tau_{\text{subgrid}} = \frac{W_i \Delta z_{\text{old}}}{\rho_{H,i} P_i}$
    - $IWF = \frac{P_{H,O}}{W_i RT}$
  - Wet deposition:
    - $w dep_i = \int_0^{t_{\text{old}}} m_i P_i dt$

**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 preprocessor (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 deposition and vertical diffusion at first model level at same time.

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

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

\[
d\rho_3/dt = A_1 + A_2(r_3 - A_3) + A_4(T - A_5) + A_6(\Sigma - A_7) + A_9r_3
\]

\[A_1=(P-L): \text{Production and loss rate}\]
\[A_2=\partial(P-L)/\partial r_3\]
\[A_3=r_3: \text{ozone mixing ratio}\]
\[A_4=\partial(P-L)/\partial T\]
\[A_5=T: \text{temperature}\]
\[A_6=\partial(P-L)/\partial \Sigma\]
\[A_7=\Sigma: \text{ozone column}\]

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

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; Haustein et al., 2011
Aerosol optical depth on an annual cycle
Aerosol optical depth near emission sources

Pérez et al., 2011 – ACPD
Results: Gas-phase chemistry

● Model setup:

→ Global domain
→ Non-hydrostatic physics
→ 1.4° x 1° horizontal resolution
→ 64 vertical (sigma-hybrid) layers
→ 1° x 1° 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

<table>
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<tr>
<th>GAS (ppbv)</th>
<th>Source</th>
<th>Nº stns</th>
<th>Obs. Mean</th>
<th>Sim. Mean</th>
<th>MB</th>
<th>RMSE</th>
<th>MNBE (%)</th>
<th>MNGE (%)</th>
<th>MFB (%)</th>
<th>MFE (%)</th>
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<td>EMEP</td>
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<td>31.73</td>
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Root Mean Square Error (ppbv) in every station (~100m) of Surface O3 (ppbv)

Root Mean Square Error (ppbv) in every station (~100m) of Surface NO2 (ppbv)

Root Mean Square Error (ppbv) in every station (~100m) of Surface CO (ppbv) - EMEP

Badia and Jorba, 2011 – EGU2011
Preliminary evaluation with surface and ozonesondes

Root Mean Square Error(ppbv) in every station (<1000m) of Surface O3 (ppbv)
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
THANK YOU FOR YOUR ATTENTION

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