Global Aerosol Modeling at the BSC: Activities and developments

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The Earth Sciences Department is devoted to the development and implementation of regional and global state-of-the-art models for air quality, meteorology and climate applications.
Earth Sciences Activities

Research lines:
- Air Quality
- Mineral Dust
- Atmospheric Modeling
- Climate Modeling

New on-line Chemistry-Meteorology model:
- NMMB/BSC-CTM

Dust daily forecast:
- BSC-DREAM8b
- NMMB/BSC-Dust:
- Mineral dust database: Files download
NMMB/BSC-Chemical Transport Model (Overview)

- fully on-line access coupling: feedback processes allowed
- multiscale: global to regional scales allowed

**Nonhydrostatic Multiscale Model on the B-grid (NMMB)**

- meteo variables/parameters

**NMMB/BSC-CTM**

**BSC Chemical Transport Model**

- (gas/aerosol variables: mass mixing ratios)

- GAS-PHASE CHEM (52 species)
  → Jorba et al. (JGR 2012)
  → Badia and Jorba (AE 2014)

- DUST (8 bins)
  → Pérez et al. (ACP 2011)
  → Haustein et al. (ACP 2012)
  → Spada et al. (ACP 2013)

- SEA-SALT (8 bins)

- BC/OM/SO4
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), nesting capabilities (1-way, 2-way, moving nest)
- 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 became the next-generation NCEP mesoscale model for operational weather forecasting in 2011
NMMB/BSC-DUST is embedded into the NMMB model and solves the mass balance equation for dust taking into account the following processes:

- Dust generation/emission by surface wind
- Horizontal and vertical advection
- Vertical transport/diffusion by turbulence and convection
- Dry deposition and gravitational settling
- Wet removal including in-cloud and below-cloud scavenging
- RRTM SW/LW dust radiative feedback

Evolution from Nickovic et al. (2001) Pérez et al. (2006ab)
EMISSION SCHEME

- Source function: includes update land databases (vegetation fraction, land textures, soil types and albedo) and a preferential “topographic” source mask

- Physically-based emission scheme which includes saltation and sandblasting

DAILY OPERATIONAL DUST FORECAST AT BSC

http://www.bsc.es/earth-sciences/mineral-dust/nmmbbsc-dust-forecast/
Evaluation methods

- Column-integrated AOD at 550 nm from AERONET Level 2.0
- Spectral Deconvolution Algorithm providing AODfine and AODcoarse
- Filter applied to the AERONET observations
  - AE<0.75 is considered in the calculations
  - AE>=0.75 not dust contribution, not considered for calculations
- RMSE, MB, correlation
Improvement of Global dust calibration factor

Exp. Global standard calibration factor of Pérez et al. (2011)

Exp. Global Corrected calibration factor same as Regional NAMEE domain

<table>
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<th>NMEEM</th>
<th>Exp. Glob.</th>
<th>Exp. Glob. Corrected</th>
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<tr>
<td>Global</td>
<td>45306</td>
<td>0.65</td>
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</table>
- Clear improvement of the bias near the sources, Sahel-Banizoumbou station, and Dakar-Atlantic.

- The model reproduces the annual cycle, and the daily variability.

- The strong decrease in dust AOD from end of August to October is under investigation. It could be related with the meteorological IC from NCEP/GFS analysis.
AERONET comparison

- Now the expected underestimation is present with the new calibration. In regions affected by other aerosols, the dust contribution has been reduced.

- East Asia maximums during Spring well reproduced.

- Australia maximums during fall-winter well reproduced.

- South America during summer well reproduced.
ICAP models with DA

Current global systems with data assimilation for aerosols

Working to include this capability in NMMB/BSC-CTM

= data assimilation
Data Assimilation for NMMB/BSC-CTM: Mineral Dust

- Enhancement of NMMB/BSC-CTM model with data assimilation using an ensemble technique: the **Local Ensemble Transform Kalman Filter** (LETKF)
  - it is particularly suited to high-performance computing applications: it allows a parallel computation of the analysis;
  - it uses flow-dependent background errors: the background error covariance is generated and propagated by the filter, using model dynamics;
  - it is easy to code: it does not require the development of adjoint code.

- Using a smoothed localisation of the observations:
  - observation influence decays gradually towards zero as their distance from analysis location increases.

- Testing the assimilation of NRL MODIS AOD:
  - a Level 3 filtered, corrected, and aggregated product, with a retrieval error also provided.

- The following preliminary tests are focused on mineral dust and on low resolution runs of our global model.

\[
F_k = C S (1 - V) \alpha H \sum_{i=0}^{3} m_i M_{i,k} \quad k = 1, \ldots, 8
\]
Data Assimilation Flow

Hybrid 4D DA approach – Model-Obs in 4 time slots

12 members

Log-normal perturbation of emission factor

Experiments use a spin-up of 1 month w/o DA
Validation against independent observations

- **Short-range transport**
- **Near sources**
- **Long-range transport**

AERONET stations
Black dot → dust AOD AE<=0.75 ;
Grey dots → uncertain type of AOD with 0.75<AE<1.3
Quality control on the observations

6 hour NRL MODIS AOD are selected according to:

**land:**
- \(AE < 0.75\) from daily MODIS Aqua or Terra products
- \(Al > 1.5\) from daily OMI product

**sea:**
- if \(AOD > 0.2\), \(FF < 0.5\) from 6 hour NRL MODIS
- if \(AOD \leq 0.2\), \(0.4 < FF < 0.5\) from 6 hour NRL MODIS
- \(Al > 1.5\) from daily OMI product

Mean observations (NRL MODIS)

The quality of the observations.

Mean observations that pass the quality test.

Observation departures. Still some residual bias in some locations strongly affected by other types of aerosols.
Impact of calibration factors per bin

Vertical mass flux of dust into a transport bin $k$

$$F_k = \mathcal{C} S (1 - V) \alpha H \sum_{i=0}^{3} m_i M_{i,k} \quad k = 1, \ldots, 8$$
SEA SALT AEROSOL MODULE
\[
dF/dr = f(r, \xi)
\]

- **M86** → \( \xi = U_{10} \) (bubbles)
- **G03** → \( \xi = U_{10} \) (bubbles, spume?)
- **M86/SM93** → \( \xi = U_{10}, U_T=9\text{m/s} \) (bubbles, spume)
- **M86/SM93/MA03** → \( \xi = (U_{10}, U_T, \text{SST}) \) (bubb., sp.)
- **J11** → \( \xi = (U_{10}, \text{SST}) \) (bubb., sp.)

**criteria:**
- whitecap method
- simplest (low number of parameters)
- bubbles and spume mechanisms

(M86, G03 and J11 extended up to 15µm)

→ strong differences
  for \( r_d > 5\mu m \) (spume)
  and for \( 0.1\mu m < r_d < 1\mu m \) (bubbles)

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Gong et al. (GBC 2003)
Smith et al. (RMS/QJ 1993)
Martensson et al. (JGR 2003)
Jaegle et al. (ACP 2011)
SSA evaluation: sconc and AOD

→ Surface monthly mean concentrations from U. Miami network

→ 2002-2006 runs with dust+ssa

→ Monthly mean AOD

→ 2002-2006 runs with dust+ssa

→ Best agreement J11
BC/OM/SULFATE MODULE
previous version (until 2014):
- DUST (8 mass bins) ← Perez et al., 2011 (ACP)
- SEA-SALT (8 mass bins) ← Spada et al., 2013 (ACP)

new implementations (2014):
- BC (2 mass bins, phob/phil)
- POM (2 mass bins, phob/phil)
- SOA (4 mass bins → 2-product mechanism OR 1 bin → prescribed production, all phil)
- SO4 (1 mass bin, all phil)

related gases:
- SO2, DMS, H2O2, ISOP, TERP, ISOP-P1, ISOP-P2, TERP-P1, TERP-P2 (transported)
- OH, O3, HO2 (off-line climatologies from NMMB/BSC-CTM full gas-phase simulations)

emissions:
- anthro: AEROCOM-ACCMIP emissions ← Lamarque et al., 2010 (ACP)
- DMS: AEROCOM EXP-I ← Dentener et al., 2006 (ACP)
- volcanic: AEROCOM-HC ← T. Diehl
- fires' injection height: under investigation...

AOD calculation (we have a total AOD now):
- GADS optical properties
- water-uptake depending on RH
transported gases:
- ISOP-P1, TERP-P1
- ISOP-P2, TERP-P2

clim gases:
- OH
- O3

emi phob/phil=0.8/0.2
emi phob/phil=0.5/0.5

phob-to-phil conv 1.2 days
OM/OC=1.6
phob-to-phil conv 1.2 days

MEGAN online emissions
2-products SOA mech
← Tsigaridis and Kanakidou, 2003 (ACP)

SO2, DMS, H2O2
OH, O3, HO2

Sulfur chem (gas and aqueous phases) from MECCA mech (simplified)
← Sander et al., 2011 (GMD)
Preliminary RESULTS

JANUARY 2006 SCONC (monthly means)

NMMB/BSC-CTM

GOCART (AEROCOM EXP-II)

Note: scales are not exactly the same
Preliminary RESULTS

JANUARY 2006 SCONC (monthly means)

NMMB/BSC-CTM (2-PRODUCTS SOA)

NMMB/BSC-CTM (DENTENER SOA)

GOCART (AEROCOM EXP-II)

Note: scales are not exactly the same
Future NMMB/BSC-CTM updates in ICAP

- Recalibration of the dust module
- Sea salt scheme based on Jaegle et al. (2011)
- Data assimilation of MODIS AOD L3 product for mineral dust analysis
- Extending to all aerosol components (BC/OM/Sulfate) to provide smoke and sulfate components
BSC aerosol forecasting collaborations

- Mineral dust forecasts for SDS-WAS North Africa, Middle East and Europe portal
  
  http://sds-was.aemet.es/

- Participate in the ICAP global-model intercomparison initiative

- Participate in the Charmex Chemistry-Aerosol Mediterranean experiment

- Participate in the AQMEII on-line Air Quality model intercomparison project
Next Aerosol events

Symposium on Coupled Chemistry-Meteorology/Climate Modelling
Status and Relevance for Numerical Weather Prediction, Air Quality and Climate Research
WMO Headquarters, Geneva, Switzerland
23-25 February 2015

1st Announcement

Key Dates
- Deadline for Abstracts: 10th Nov. 2014
- Registration (max. 100 participants): http://eumetchem.info/
- Abstract Submission (<1 page): http://eumetchem.info/

Topics
- Coupled chemistry-meteorology (weather and climate) modelling (CCMM): approaches and requirements;
- Key processes of chemistry-meteorology interactions and their descriptions;
- Aerosol effects on meteorological processes and NWP;
- CCMM for air quality and atmospheric composition;
- CCMM for regional and global climate modelling;
- Model validation and evaluation;
- Data requirements, use of observations and data assimilation;
- Outlook and future challenges.

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Venue
The CCMM Symposium will take place at the WMO Headquarters in Geneva. The airport and main train are in easy reach by public transport and offer excellent traffic links to the whole world.

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