Does horizontal resolution produce better dust predictions? Evaluation of the NMMB/BSC-Dust model for northern Africa, the Middle East and Europe

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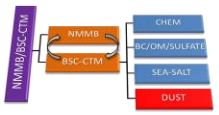
Introduction

NMMB/BSC-Dust is the mineral dust module of the Chemical Transport Model, **NMMB/BSC-CTM** (Pérez et al., 2011; Jorba et al., 2012; Spada et al., 2013; http://www.bsc.es/earth-sciences/nmmbbsc-project), which is developed and operated in the Earth Sciences Department of the Barcelona Supercomputing Center (ES-BSC). The model is online embedded into the meteorological Non-hydrostatic Multiscale Model on the B grid (**NMMB**) and is able to simulate from global to regional scales. NMMB/BSC-Dust is the operational model of the WMO Barcelona dust forecast center (http://dust.aemet.es/), the first regional specialized meteorological center with activity specialization on atmospheric dust forecast



NMMB/BSC-CTM modules

Objective: Sensitivity of the NMMB/BSC-Dust model to horizontal resolutions in terms of wind and dust

Model Evaluation: We evaluate three annual simulations using a set of observational data and computing classical statistics

Common model configuration
- *Temporal period: Annual (2011)*
- *Study domain: Northern Africa, the Middle East and Europe (NAMEE) [25°W-65°E and 0°-65°N]*
- *Forecast: 24h*
- *Temporal resolution (outputs): 3h*
- *Vertical resolution: 40-layers up to 50 hPa*
- *Cold start without data assimilation*
- *Initial conditions from NCEP/FNL meteorological analysis (1°x1°) at 00 UTC and boundary conditions every 6 h*

Model setup three configurations
- *Global:*
  - *Horizontal resolution: 1.4°x1°*
  - *Fundamental time step: 180s*
- *Regional [25°W-65°E and 0°-65°N]:*
  - *Horizontal resolution: 0.25 °x0.25°*
  - *Fundamental time step: 40s*
- *Regional [25°W-65°E and 0°-65°N]:*
  - *Horizontal resolution: 0.1°x0.1°*
  - *Fundamental time step: 25s*

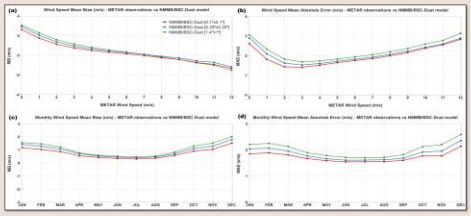
Observational datasets:
- ***Dust observations:***
  - ***Seasonal Aqua-MODIS [Deep Blue + Dark Target]***
    - *Variable: Aerosol optical depth 550 nm (AOD)*
  - ***50 AERONET sites (grouped in nine regions)***
    - *Variable: Dust optical depth 550 nm (DOD)*
    - *Temporal resolution: 3h*
  - ***3 AMMA sites (Sahel):***
    - *Variable: Particulate matter 10 μm (PM10)*
    - *Temporal resolution : 3h*
- ***Meteorological observations:***
  - ***628 ground-based METAR sites***
  - *Variables:*
    - *Wind speed 10m (WS)*
    - *Wind direction 10m (WD)*
  - *Temporal resolution: 3h*

Statistics :
- *Correlation coefficient (r)*
- *Mean bias (MB)*
- *Mean absolute error (MAE)*
- *Root mean square error (RMSE)*

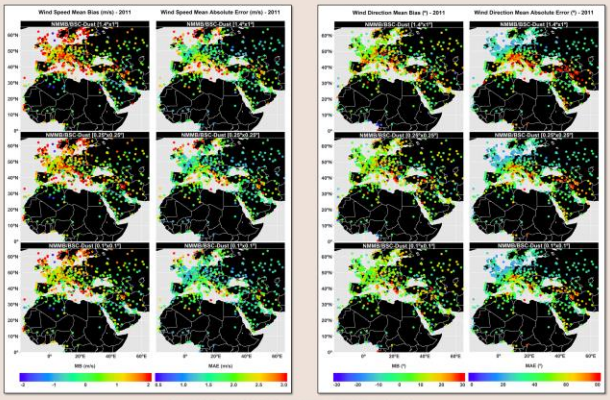
Wind evaluation

Wind is a key parameter in the **dust emission process** which is a non-linear function of surface **wind speed** . Dust emission occurs when a given threshold value (dependent on soil parameters) is exceeded

Domain	Parameter	1.4°x1°	0.25°x0.25°	0.1°x0.1°
NAMEE (628 sites) (Wind Speed)	MB (m/s)	1.09	0.96	0.76
	MAE (m/s)	2.02	1.87	1.73
NAMEE (628 sites) (Wind Speed 8m/s)	MB (m/s)	-1.00	-0.81	-0.95
	MAE (m/s)	2.75	2.61	2.55
NAMEE (628 sites) (Wind Speed 4m/s)	MB (m/s)	1.68	1.48	1.24
	MAE (m/s)	2.01	1.83	1.64
Middle East (121 sites) (Wind Speed)	MB (m/s)	0.42	0.44	0.25
	MAE (m/s)	2.07	1.95	1.83
Middle East (#sites MB<0) (Wind Speed)	#sites; MB (m/s)	48 (-0.78)	41 (-0.75)	49 (-0.68)
	#sites; MAE (m/s)	48 (1.93)	41 (1.86)	49 (1.96)
NAMEE (628 sites) (Wind Direction)	MB (°)	10.35	8.47	7.12
	MAE (°)	44.86	40.93	39.12
NAMEE (352 sites) (Station height < 100m)	MB (°)	10.60	8.25	6.88
	MAE (°)	42.59	38.27	36.40
NAMEE (42 sites) (Station height > 800 m	MB (°)	6.65	7.00	6.13
	MAE (°)	69.41	64.96	61.71



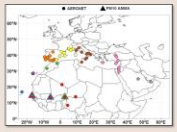
The annual model (a) MB and (b) MAE for discrete intervals of WS from 0 to 12 m/s and monthly model (c) MB and (d) MAE with respect to observed WS of the METAR sites. Each plot contains the values for three horizontal resolutions, differentiated by colours.



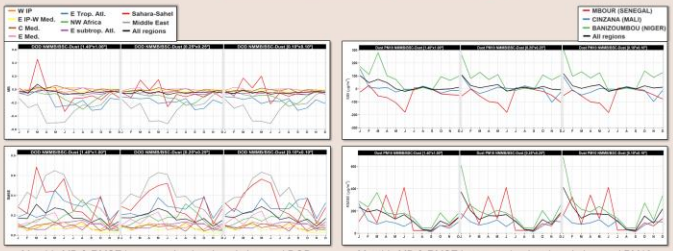
Annual MB and MAE of wind speed and direction 10m

- ***Wind performance improves among resolutions:***
  - ***Larger error reductions:*** *Winter, WS<4m/s, complex terrains and Europe*
  - ***Minor error reductions:*** *Summer, WS>4m/s, northern Africa and the Middle East*
- ***WS underestimations are found for the three configurations in the Middle East and in some Saharan sites, partly linked with the input global meteorological data (i.e. NCEP/FNL)***
- ***WS overestimations are produced under low wind speeds and in complex terrain regions***
- ***WD tends to present positive MB (wind vectors tend to the right (clockwise) with respect to observations)***

Dust evaluation

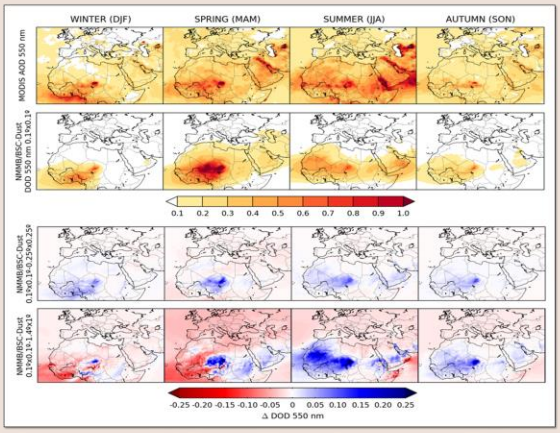


Domain	Parameter	1.4°x1°	0.25°x0.25°	0.1°x0.1°
NAMEE (DOD) (50 AERONET sites)	r	0.70	0.75	0.73
	MB	-0.03	-0.05	-0.05
	RMSE	0.20	0.19	0.20
Sahara-Sahel (DOD) (5 AERONET sites)	r	0.54	0.58	0.56
	MB	-0.03	-0.05	-0.01
	RMSE	0.40	0.35	0.38
Middle East (DOD) (2 AERONET sites)	r	0.37	0.37	0.34
	MB	-0.31	-0.30	-0.29
	RMSE	0.43	0.43	0.44
Transport regions (DOD; 42 AERONET sites)	r	0.73	0.79	0.77
	MB	-0.02	-0.04	-0.04
	RMSE	0.13	0.12	0.13
Sahel PM10 (3 AMMA sites)	r	0.54	0.68	0.66
	MB (μg/m³)	38	25	31
	RMSE (μg/m³)	170	208	235



Monthly MB & RMSE between simulated and observed DOD

Monthly MB & RMSE between simulated and observed PM10



Seasonal averaged Aqua-MODIS AOD, simulated DOD at 0.1°x0.1° horizontal resolution, and DOD differences between 1.4°x1° and 0.1°x0.1° and between 0.25°x0.25° and 0.1°x0.1°

- ***The model is able to reproduce the dust annual cycle (spatio-temporal seasonal variability) , although with underestimations in summer over the Sahara***
- ***The correlation is higher in dust transport regions (r>0.7) than in dust source regions (r<0.6)***
- ***Model limitations are found on the reproduction of mesoscale convective systems that cause dust underestimations over desert dust source regions (i.e. Middle East and Sahara)***
- ***The preferential source approach misrepresents some sources such as omitting the Mali/Mauritania border***

Conclusions

The wind model performance improves at higher resolutions. In terms of dust parameters, 0.1ºx0.1º and 0.25ºx0.25º horizontal resolutions more closely agree with observations than at 1.4x1º. Both higher resolutions generally present no significant differences, although 0.25ºx0.25º shows slightly better skill scores. Part of these improvements at higher resolutions are linked to a better representation of sea/land interfaces, the orography and the mesoscale circulations. Wind biases are partly due to the meteorological initial conditions (i.e. NCEP/FNL) which causes a decline of dust emissions. Model limitations in dust production are focused on the representation of mesoscale convective systems and in the misrepresentation of some sources by the model source mask.

References

Pérez et al., 2011: *Atmospheric dust modeling from meso to global scales with the online NMMB/BSC-dust model part 1: model description, annual simulations and evaluation Atmos. Chem. Phys., 11 (2011), pp. 13001–13027*
Jorba et al., 2012: *Potential significance of photoexcited NO2 on global air quality with the NMMB/BSC chemical transport model. J. Geophys. Res. Atmos., 117 (2012)*
Spada et al., 2013: *Modeling and evaluation of the global sea-salt aerosol distribution: sensitivity to size-resolved and sea-surface temperature dependent emission schemes Atmos. Chem. Phys., 13 (2013), pp. 11735–11755*

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