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# BSC UPDATE


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**Earth Sciences Department**

**Barcelona Supercomputing Center**


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**9th ICAP Meeting, Lille France**

# Development of MONARCH

**M**ultiscale **O**nline **N**on-hydrostatic **A**tmosphe**R**e **CH**emistry model

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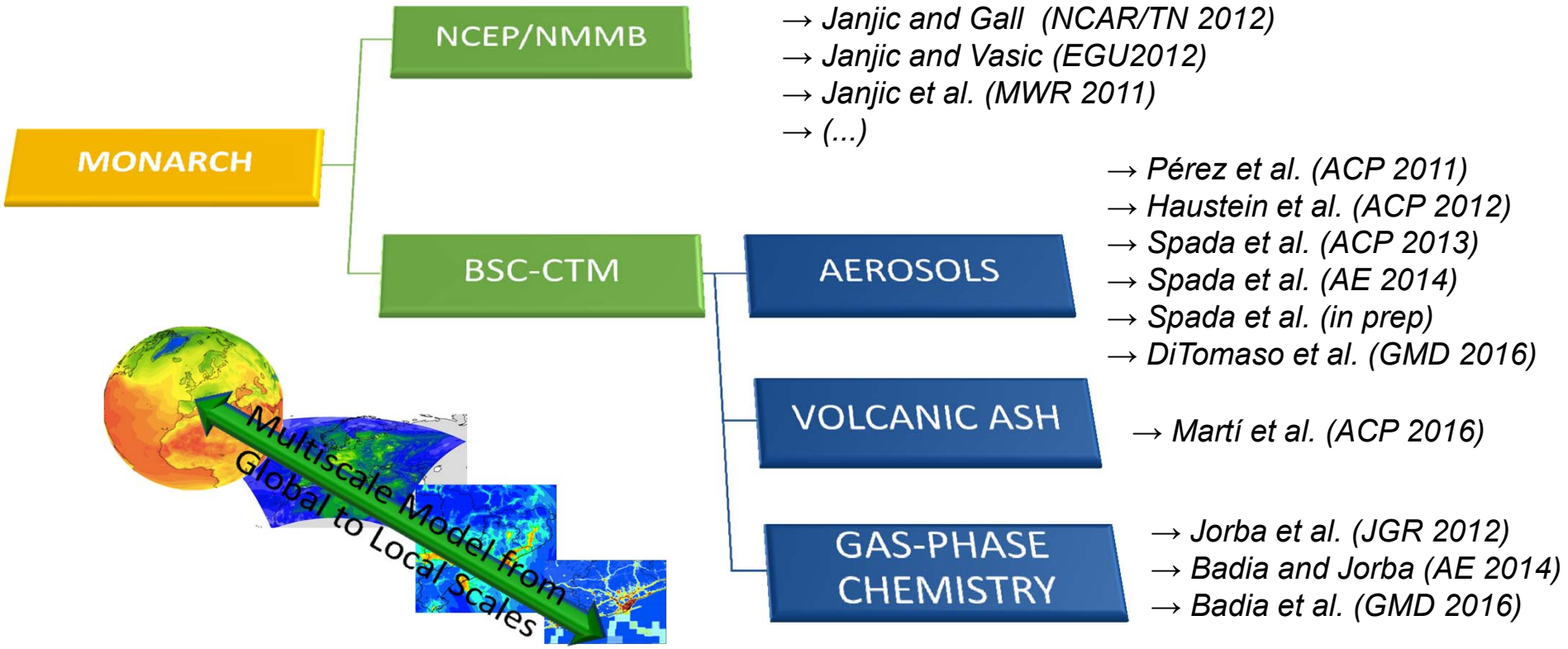
**Multiscale**: global to regional scales allowed (nesting capabilities)
**Non-hydrostatic** dynamical core: single digit kilometre resolution allowed
**On-line** coupling: weather-chemistry feedback processes allowed
**Ensemble-based data assimilation** system for aerosols



# NMMB

## Model features

- Non-hydrostatic Multiscale Model NMMB (Janjic et al., 2004)
- Arakawa B grid (Arakawa and Lamb, 1977)
- Vertical hybrid $\sigma$-pressure coordinate system (Simmons and Burridge, 1981)
- A rotated longitude-latitude coordinated system is used for regional simulations

## Physics schemes

- Radiation: RRTMG
- Convection: Betts-Miller-Janjic (BMJ) (Betts, 1986)
- Clouds and microphysics: Ferrier (Ferrier et al., 2002)
- Turbulence: Mellor-Yamada-Janjic (MYJ) (Janjic, 2001)
- Land model: NCEP NOAH (Eck et al., 2003) and LISS

# BSC Current forecasts and plans

CURRENT FORECASTING – DEVELOPED/AVAILABLE – UNDER DEVELOPMENT - PLANNED

| DOMAIN | GLOBAL (ICAP) | REGIONAL North Africa, Middle East and Europe (SDS-WAS) | REGIONAL Europe/Iberian Peninsula/Urban Areas (CALIOPE) |
|---|---|---|---|
| Model | MONARCH | MONARCH | CMAQ (DREAM for dust)<br>MONARCH |
| Status | QO | O | O |
| Meteorology | Inline: NMMB | Inline: NMMB | Offline: WRF-ARW<br>Inline: NMMB nesting |
| Resolution | 1.4x1 deg<br>0.7x0.5 deg | 0.1x0.1 deg<br>0.03x0.03 deg | 0.1x0.1 / 0.04x0.04 / 0.01 x0.01 |
| levels | 24<br>48 | 40<br>60-70 | 30<br>60-70 |
| DA | LETKF | LETKF | NA<br>LETKF |
| Assimilated Obs | MODIS DT+DB (DU)<br>MODIS DT+DB (ALL) | MODIS DT+DB (DU) | NA<br>MODIS DT+DB (ALL) |
| Aerosol Species | DU, SS, BC, POA, SOA bio, SOA anthro, SU, NI | DU | CMAQ (AERO5)<br>MONARCH aerosols |
| Gas phase chemistry | CBM-IV<br>CB05<br>ONLINE and CLIMATOLOGY | | CB05<br>CB05 |
| Emissions | HERMES 3.0 (HTAP v2)<br>MEGAN ONLINE | | EMEP, MEGAN / HERMES, MEGAN/ HERMES MEGAN |
| Bio. Burn. Emissions | GFAS<br>NRT | | NA<br>NRT |

# MONARCH: Aerosols

**Sectional**

dust (DU)

sea-salt (SS)


**Bulk**

Black Carbon (BC)


Organic Aerosols (OA)


Primary Organic Aerosols (POA)

Secondary organic aerosols (SOA)

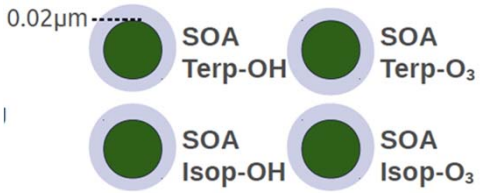
4 gaseous tracers (OH, O3, TERP, ISOP). Online emission (MEGAN)

4 aerosol-phase hydrophilic tracers

2-product scheme of Tsigaridis and Kanakidou (2007)

Oxidation by OH and O3 and gas-particle partitioning

Anthropogenic SOA from Toluene and Xylene under development



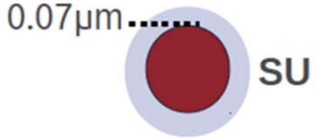

Sulfate (SU):

4 additional prognostic tracers (SO2, DMS, H2O2, H2SO4)

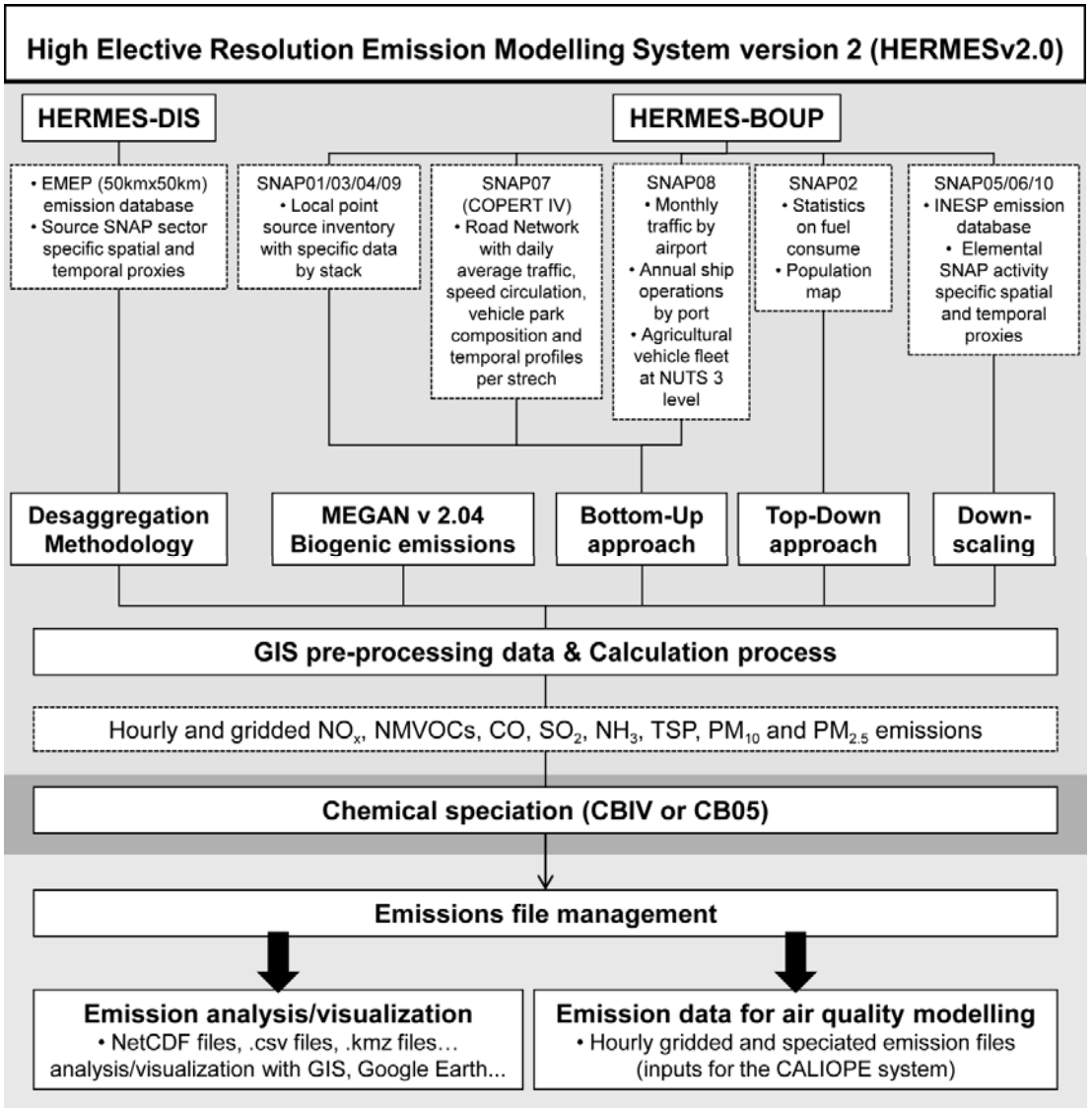
3 online or climatological oxidants (OH, O3, HO2)

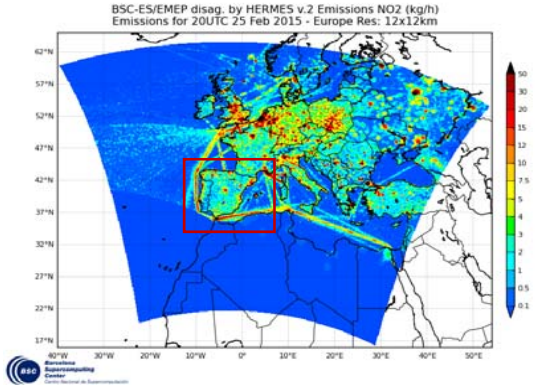
gas-phase oxidation of SO2, DMS and H202 by OH

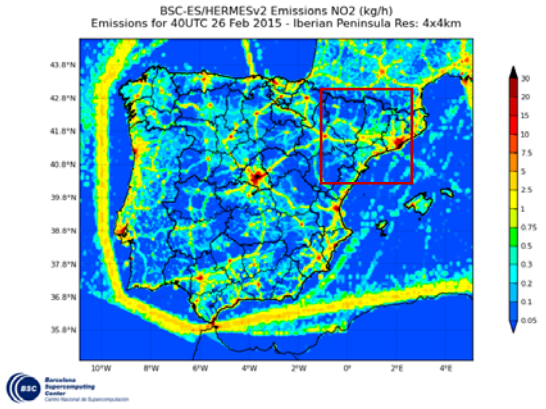
aqueous-phase oxidation by H202 and O3

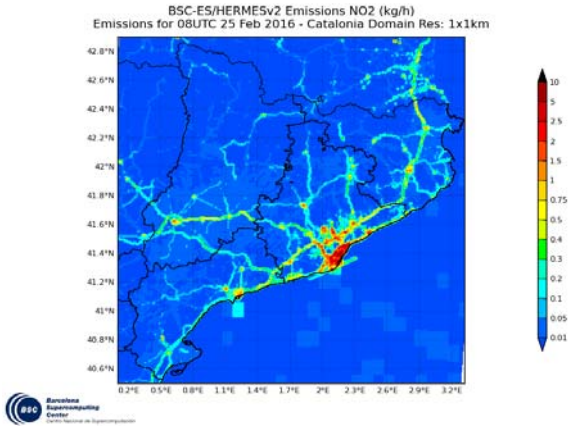


# HERMESv2.0:
# An emission model for Europe and Spain



# HERMESv3.0:
# A multiscale emission modeling framework

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- A **stand-alone tool** for simulating **emissions** on a **user-defined grid for global, regional and urban** air quality models.
- Users can **select, combine and scale multiple inventories** through a flexible configuration file to obtain **hourly gridded emissions**.

## Emission data library

- Multiple **global and regional emission inventories**
- **Online emissions:**
- Biogenic (MEGAN), lightning, ocean
- Spanish bottom- up emission inventory (street level emissions)

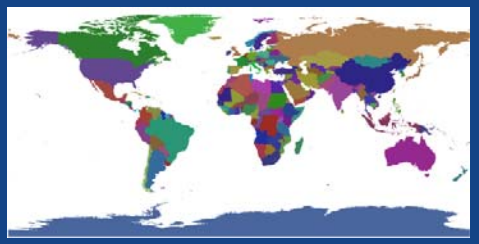
EDGAR · macc City · Convention on Long-range Transboundary Air Pollution emep · Atmosphere Monitoring Service · TNO innovation for life · (…)

## Conservative regridding

- **User-defined grid:**

- Regular lat-lon
- Rotated lat-lon
- LCC

- **Masking and scaling factors to combine and update emission inventories**



ESMF

## Vertical, temporal, speciation

- **Vertical profiles:**

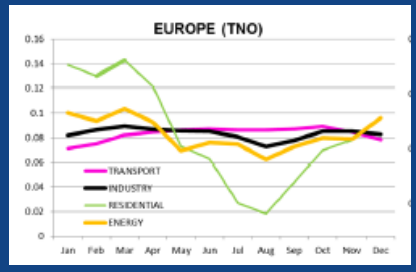
- Point sources, biomass burning, air traffic

- **Temporal profiles:**

- Monthly, weekly and daily factors per sector

- **VOC and PM2.5 speciation**:

- CB05, SAPRC99, AERO5, AERO6



# HERMESv3.0 Configuration for ICAP

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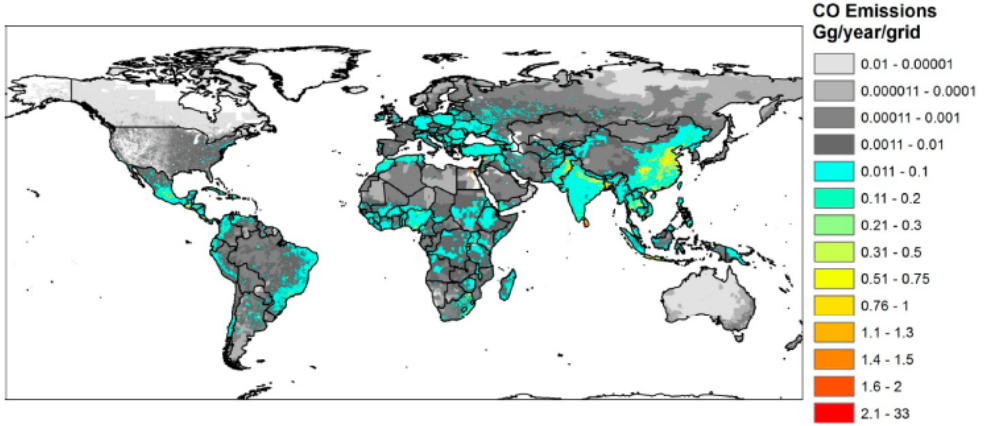
| EI | Sector | Year | Pollutants | Vertical | Temporal |
|---|---|---|---|---|---|
| GFASv1.2 Kaiser et al. (2012) | Biomass burning | 2015 | oc, bc(*), so2, pm25,c2h6s | Plume top = Sofiev et al. (2012) Distribution=50 % top 50% uniform below | Daily |
| HTAPv2.2 Janssens-Maenhout et al. (2015) | energy | 2010 | oc,bc,so2, pm25,pm10 | 218-724 m (Bieser et al., 2011) | Monthly |
| | industry | | | 72-292 m (Bieser et al., 2011) | |
| | residential | | | First layer | |
| | transport | | | First layer | |
| | air_lto | | | 0 – 1 km | Yearly (monthly flat profile) |
| | air_cds | | | 1 – 9 km | |
| | air_crs | | | 9 – 12 km | |
| | ships | | | First layer | |
| Wiedinmyer el al. (2014) | Residential trash burning | | | First layer | |
| MOZART Horowitz et al. (2013) | Ocean | 2000 | c2h6s | First layer | Monthly |

(*) Scaling factors applied: bc → 6.1 and oc → 3.1 (Rémy et al., 2017)

# Residential waste burning

- **Residential waste burning emissions** have a significant contribution to **global OC**. These emissions are mainly occurring in **developing and poor countries**

| species | open waste burning | total reported anthropogenic | ref |
|---|---|---|---|
| ammonia ($NH_3$) | 1.1 Tg | 47 Tg | HTAP v2 for 2008[c] |
| sulfur dioxide ($SO_2$) | 486 Gg | 109 Tg | HTAP v2 for 2008[c] |
| nitrogen oxides ($NO_x$ as NO) | 3.6 Tg | 113 Tg | HTAP v2 for 2008[c] |
| $PM_{2.5}$ | 10 Tg | 34 Tg | HTAP v2 for 2008[c] |
| $PM_{10}$ | 12 Tg | 51 Tg | HTAP v2 for 2008[c] |
| BC | 632 Gg | 5.5 Tg | HTAP v2 for 2008[c] |
| OC | 5.1 Tg | 12 Tg | HTAP v2 for 2008[c] |

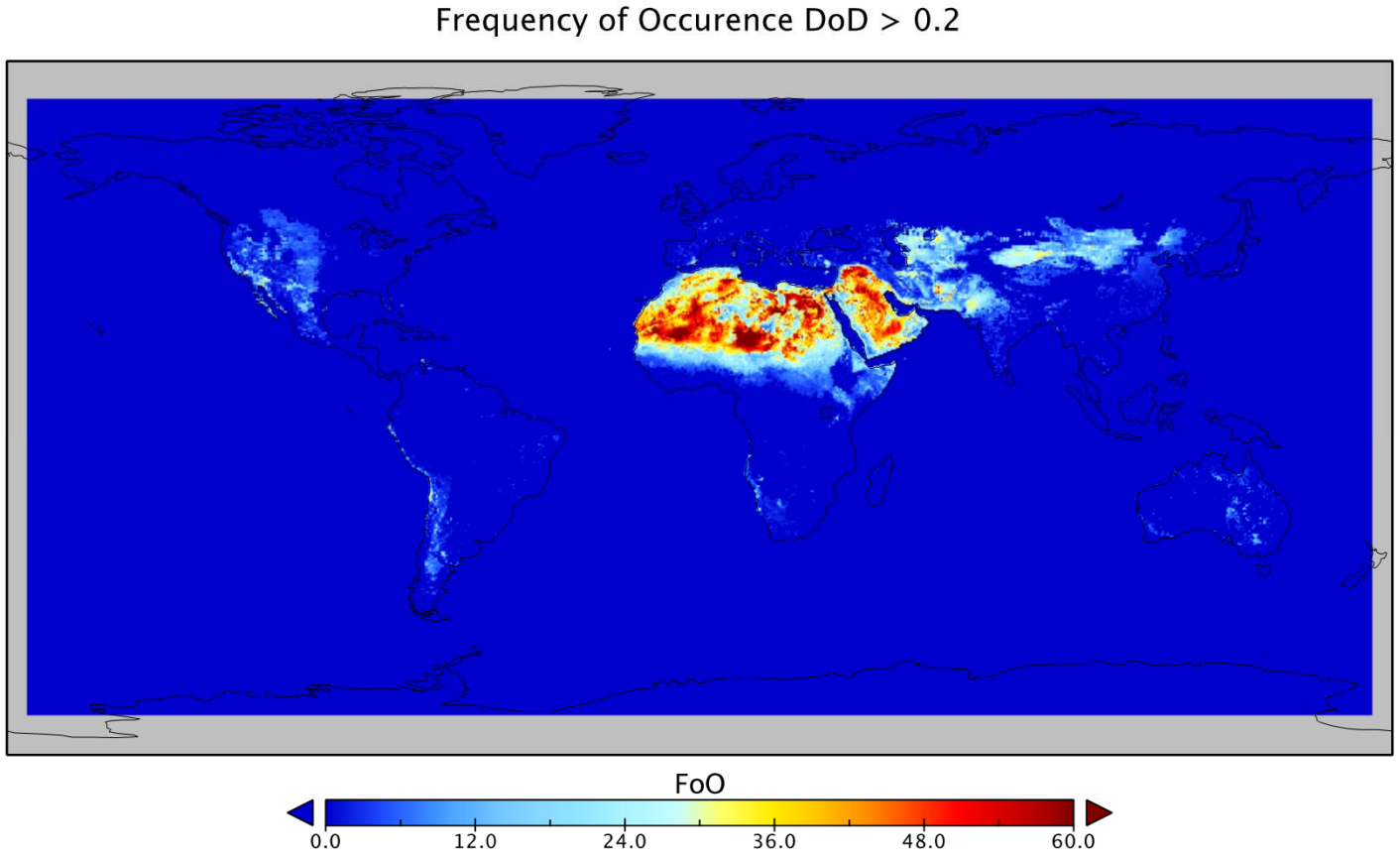



Wiedinmyer et al. (2014)

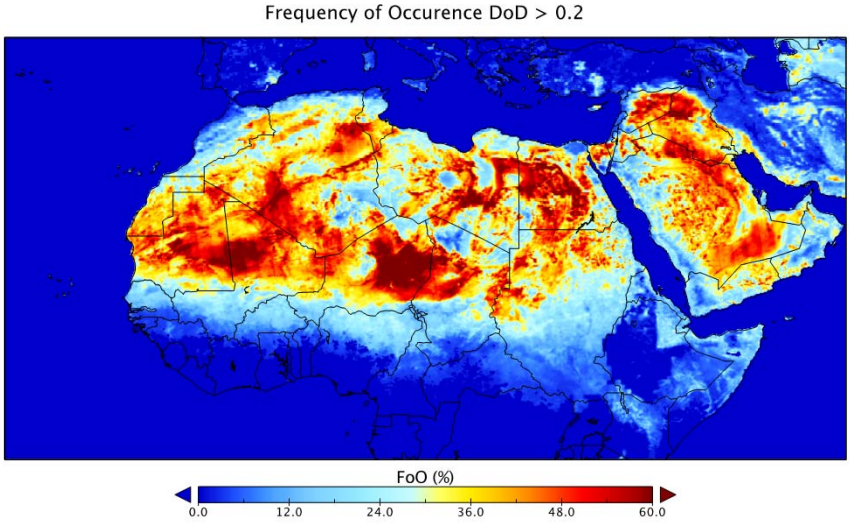
**For this sector, PM2.5-BC-OC accounts for 42.7% of total PM2.5.**
**All PM2.5-BC-OC is considered PMFINE**

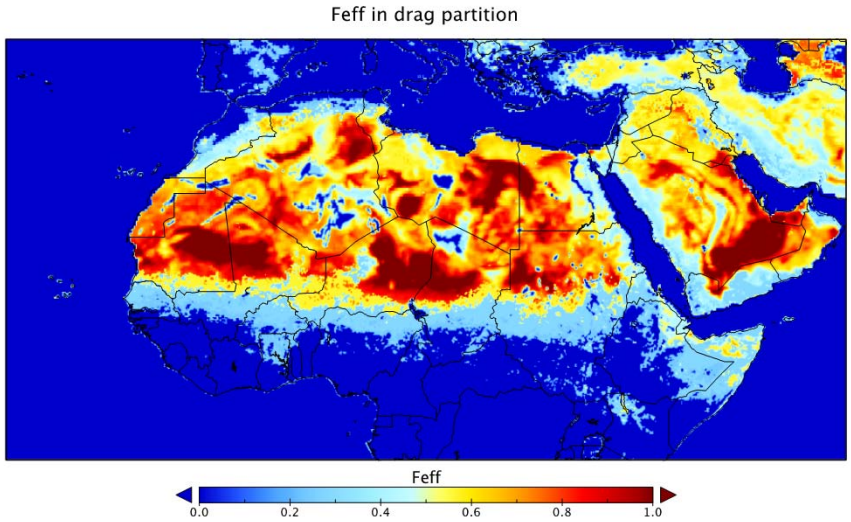
# Natural aerosol emissions

- Sea-salt: Jaeglé et al. (2011) wind and sst
- Dust:  source location based on MODIS DB, vertical flux scaled with the topographic source of Ginoux - 2001



# Natural aerosol emissions




- 3 emission schemes with drag partition:

NMMB original (~Maticorena based scheme)
GOCART scheme
New Kok scheme (Kok et al., 2014)

$$U*t = \frac{U*ts}{feff} \qquad feff = 1 - \frac{\ln(z0/z0s)}{\ln(0.7(X/z0s)^{0.8})}$$

z0 based on satellite static roughness + monthly vegetation (LAI) from MODIS

# AOD Evaluation 2015

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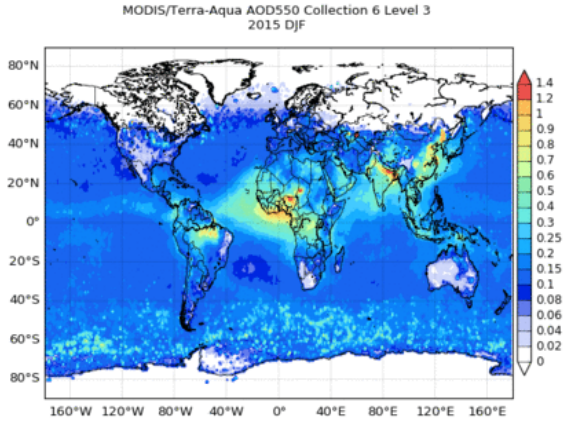
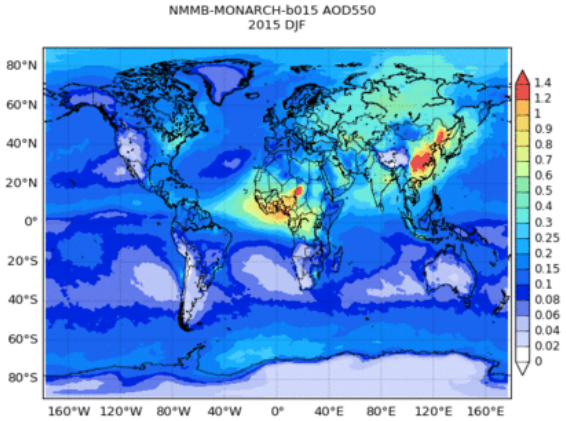
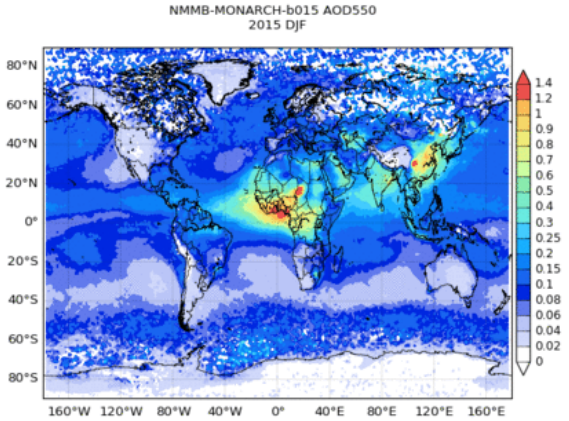
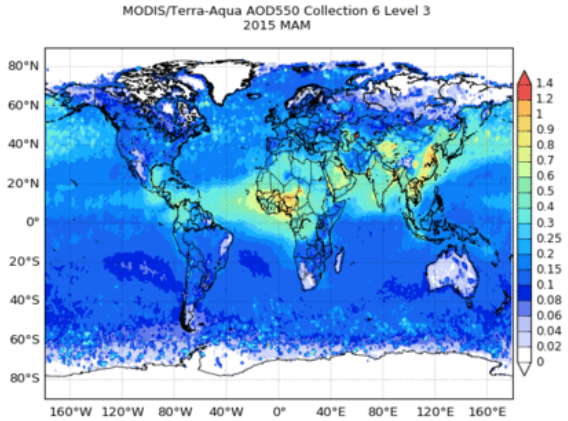
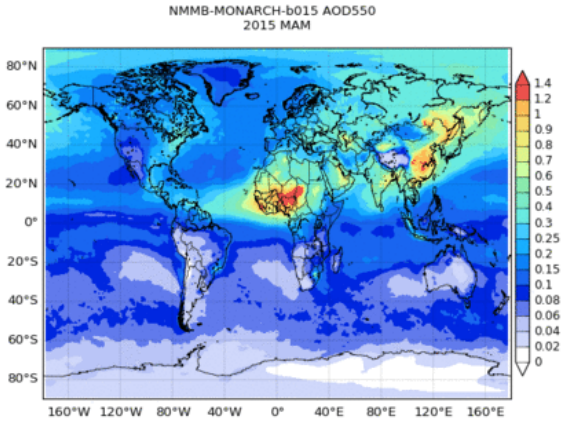
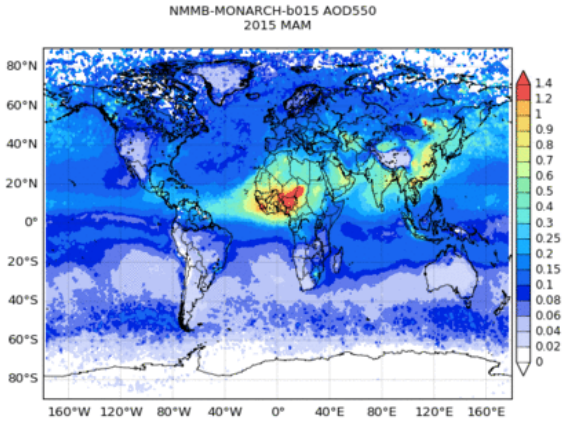
| | MODIS C6 Level 3 | MONARCH All Sky | MONARCH Clear Sky |
|---|---|---|---|
| DJF |   |   |   |
| MAM |   |   |   |

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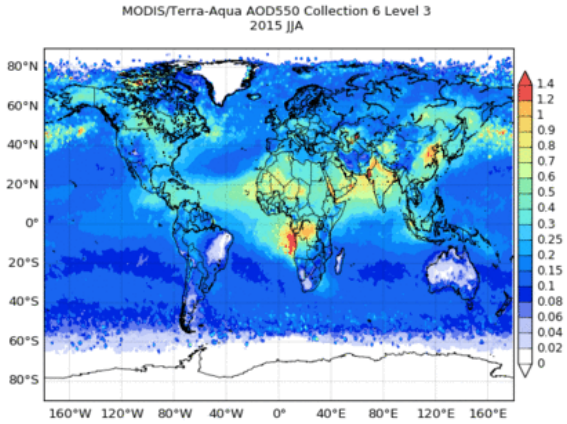
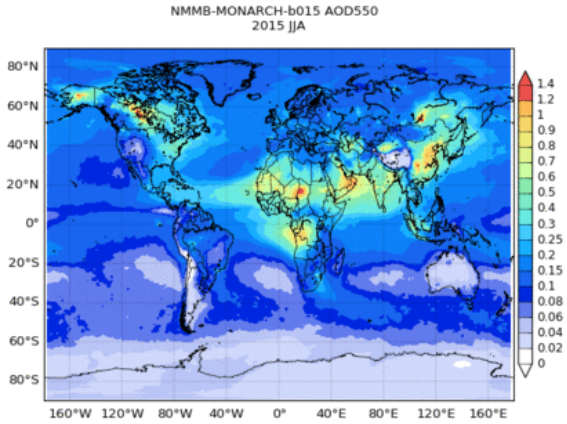
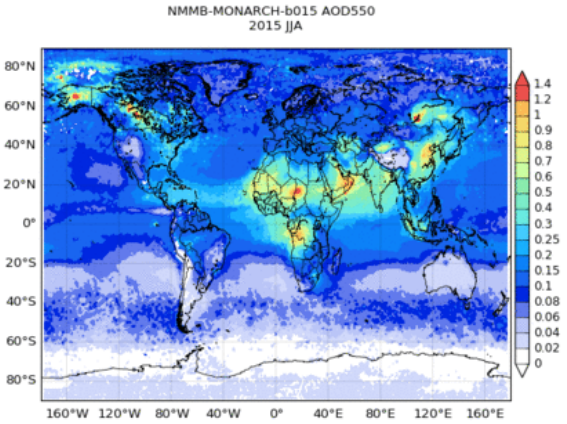
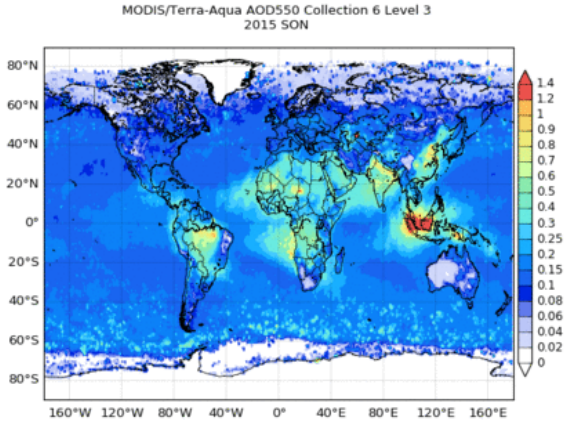
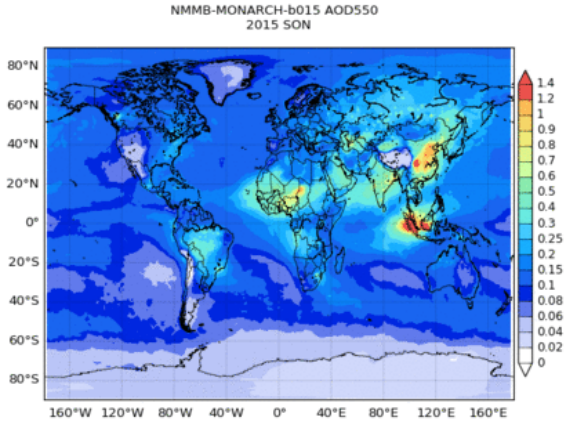
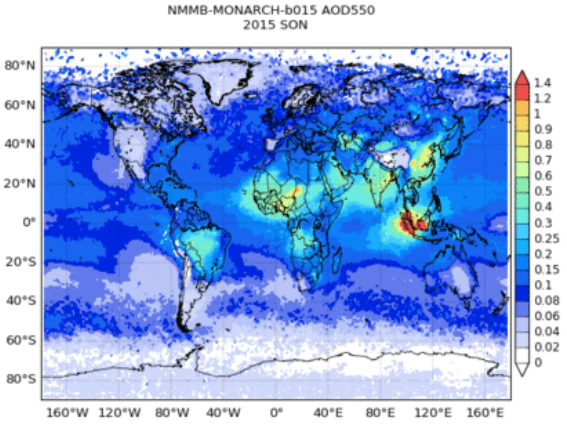
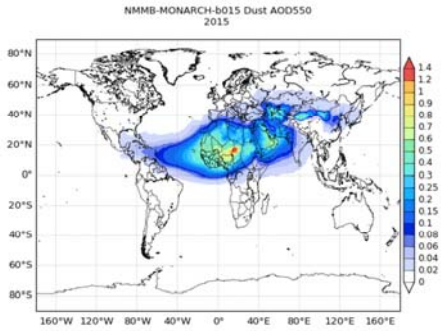
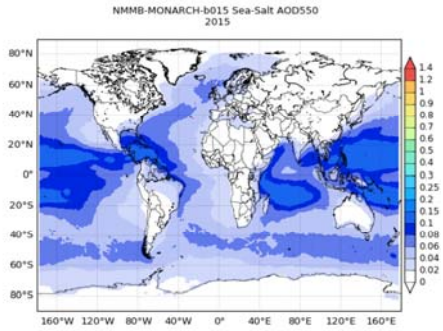
| | MODIS C6 Level 3 | MONARCH All Sky | MONARCH Clear Sky |
|---|---|---|---|
| JJA |  |  |  |
| SON |  |  |  |

# AOD components

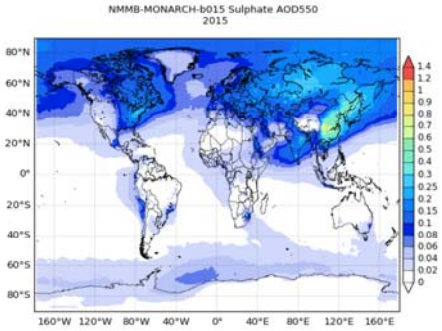
Dust



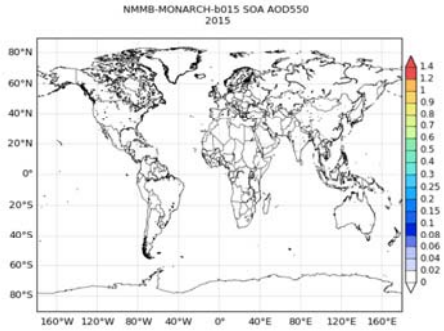

SS

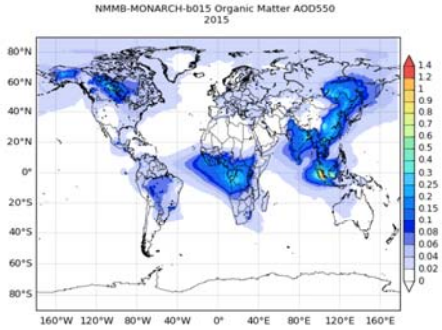


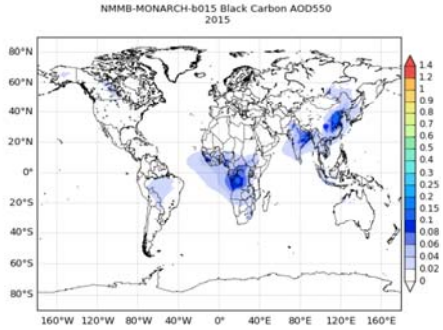

SU

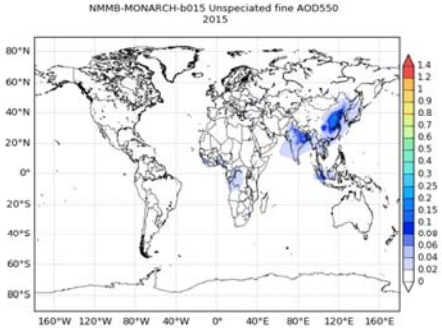


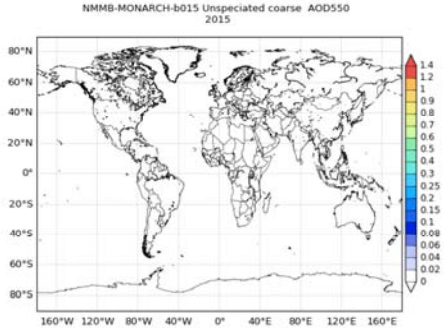

SOA



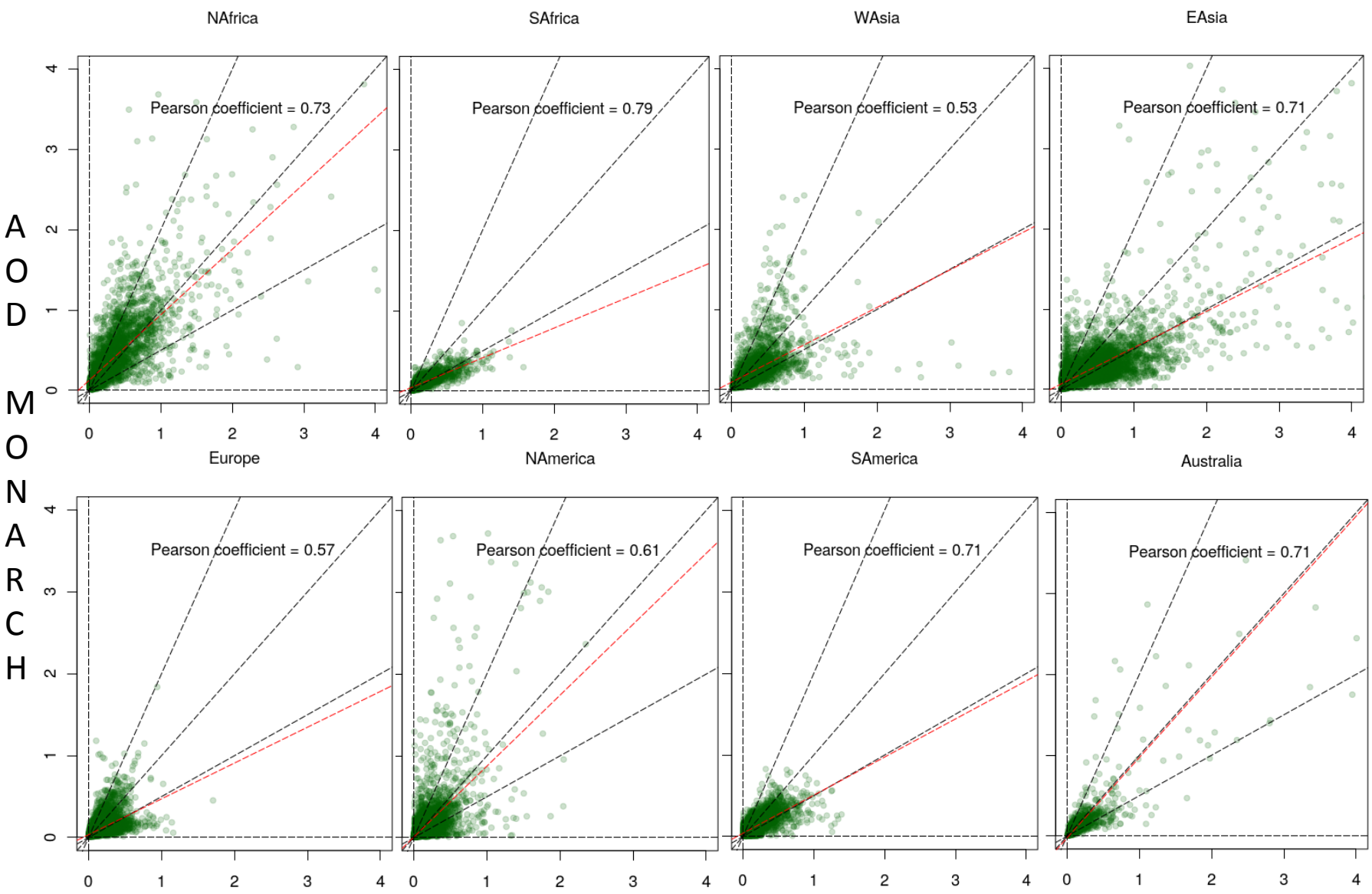

OM

BC

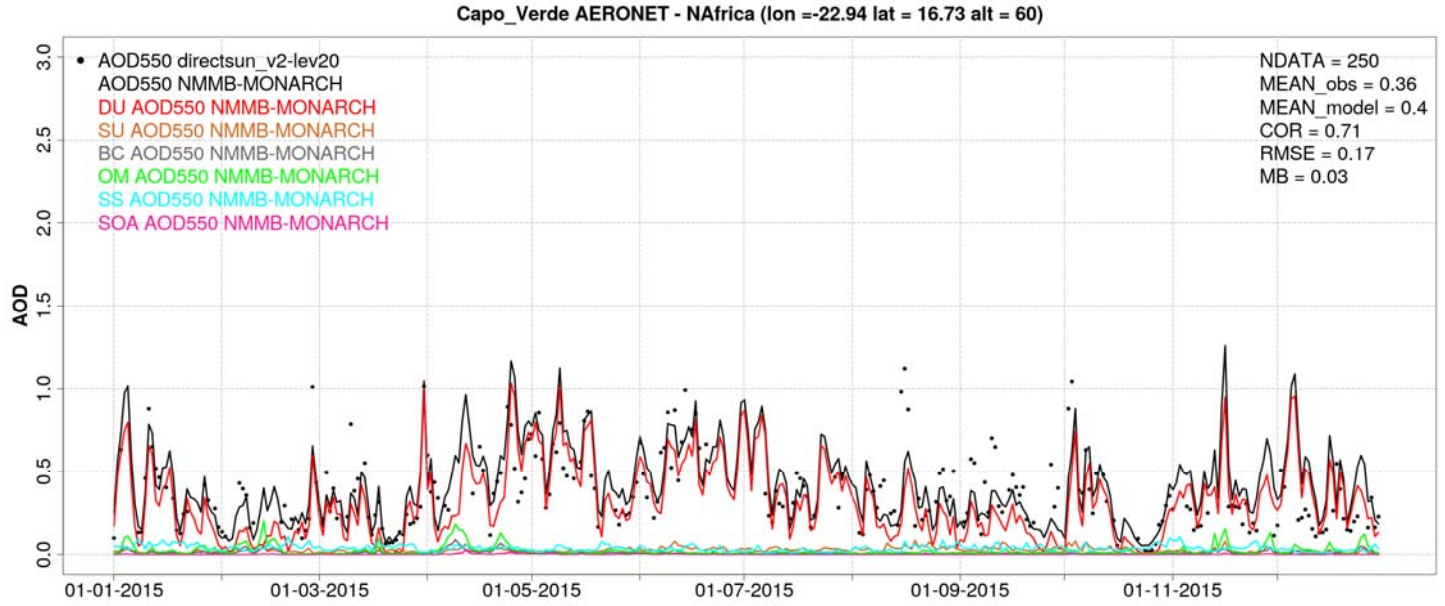
Fine (unspec.)

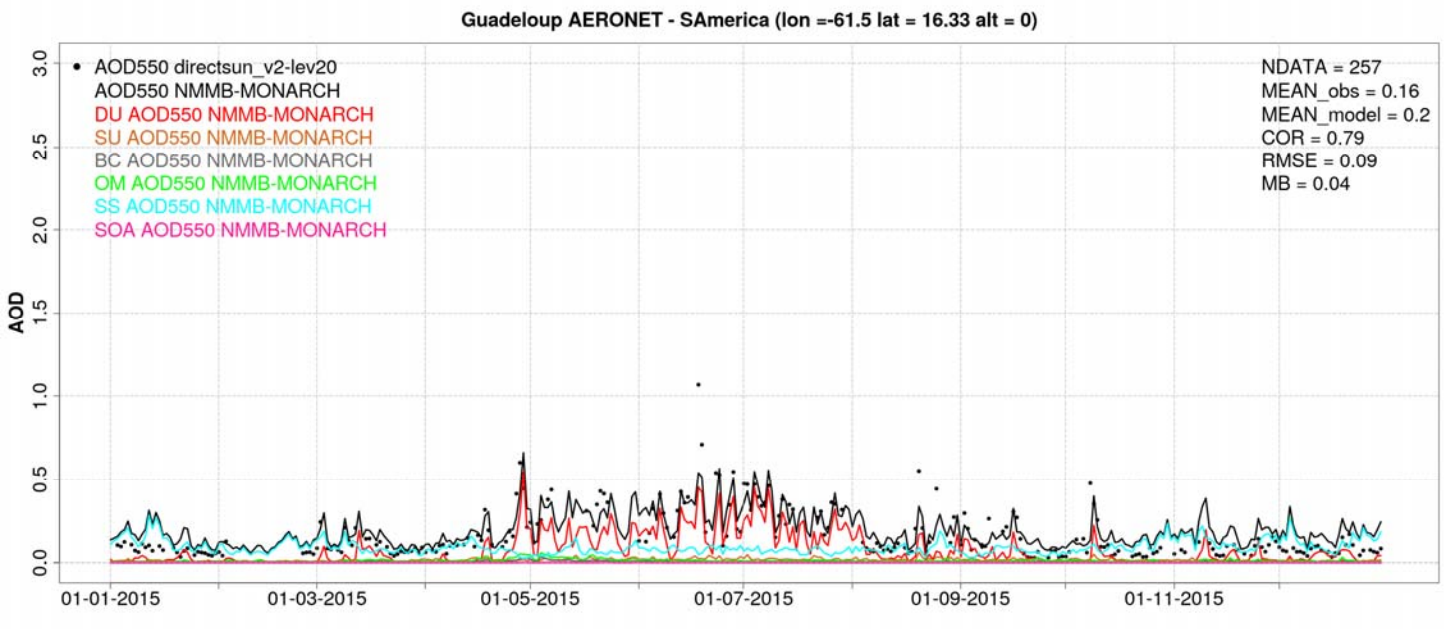
Coarse (unspec.)

# AOD Evaluation 2015

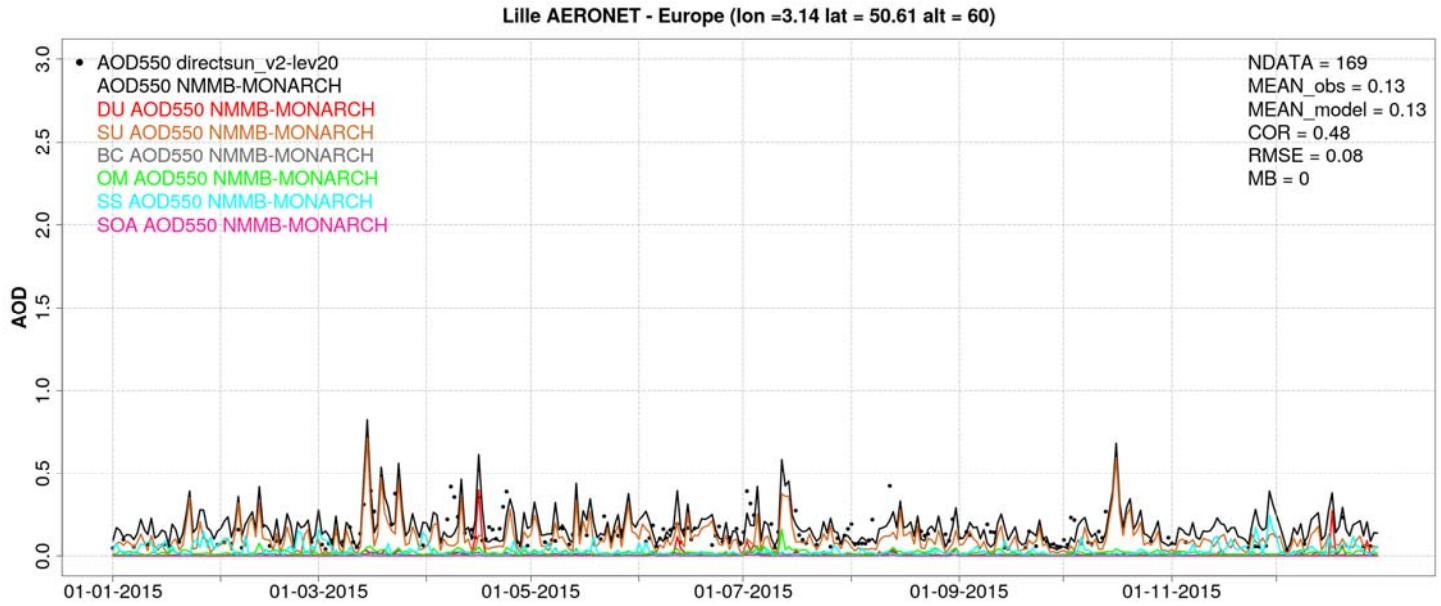


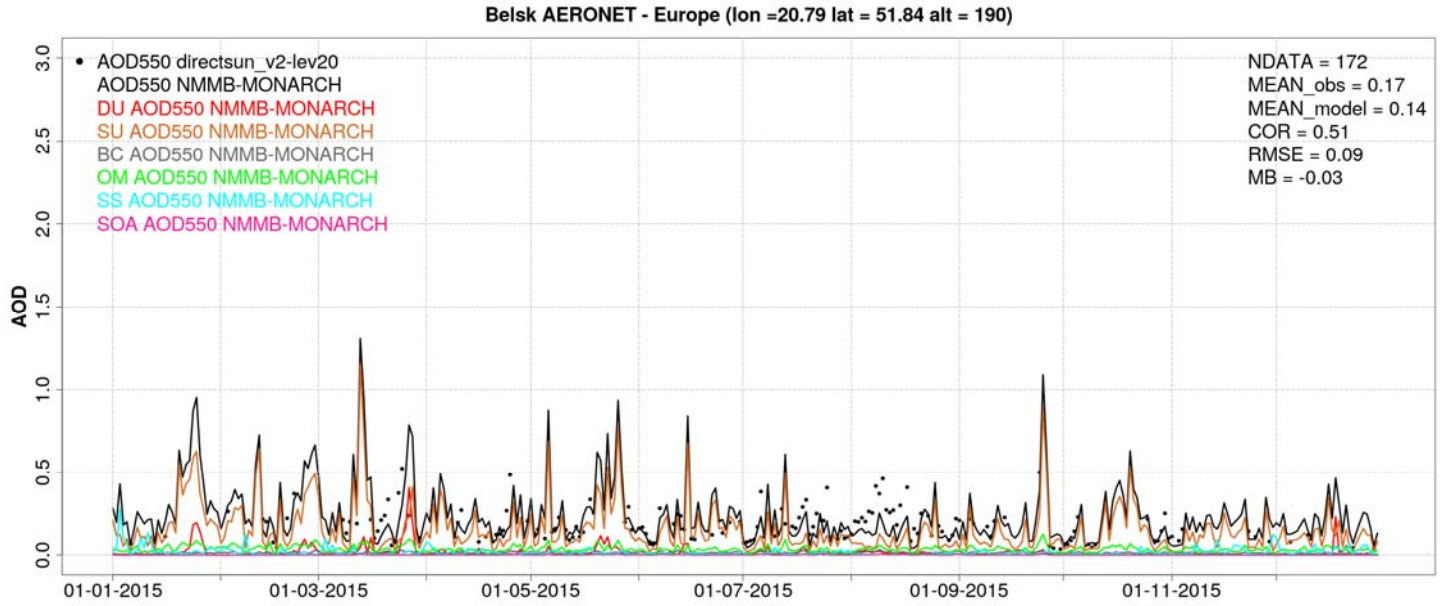
# Dust Atlantic Transport



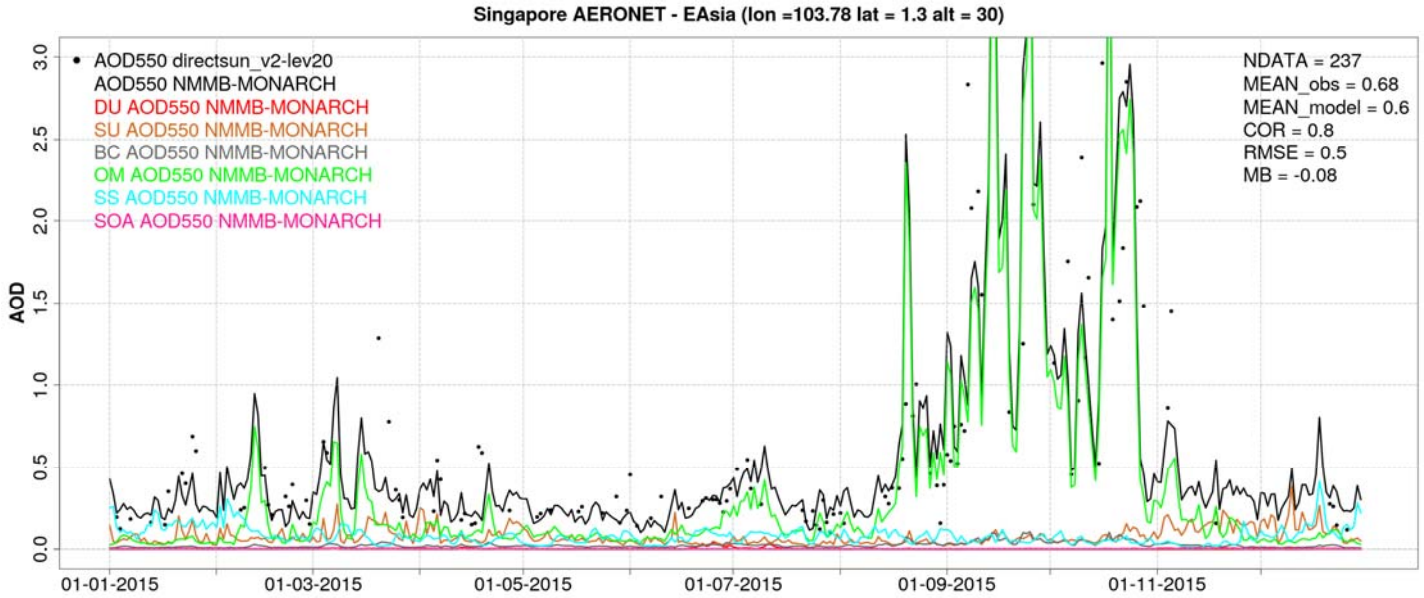



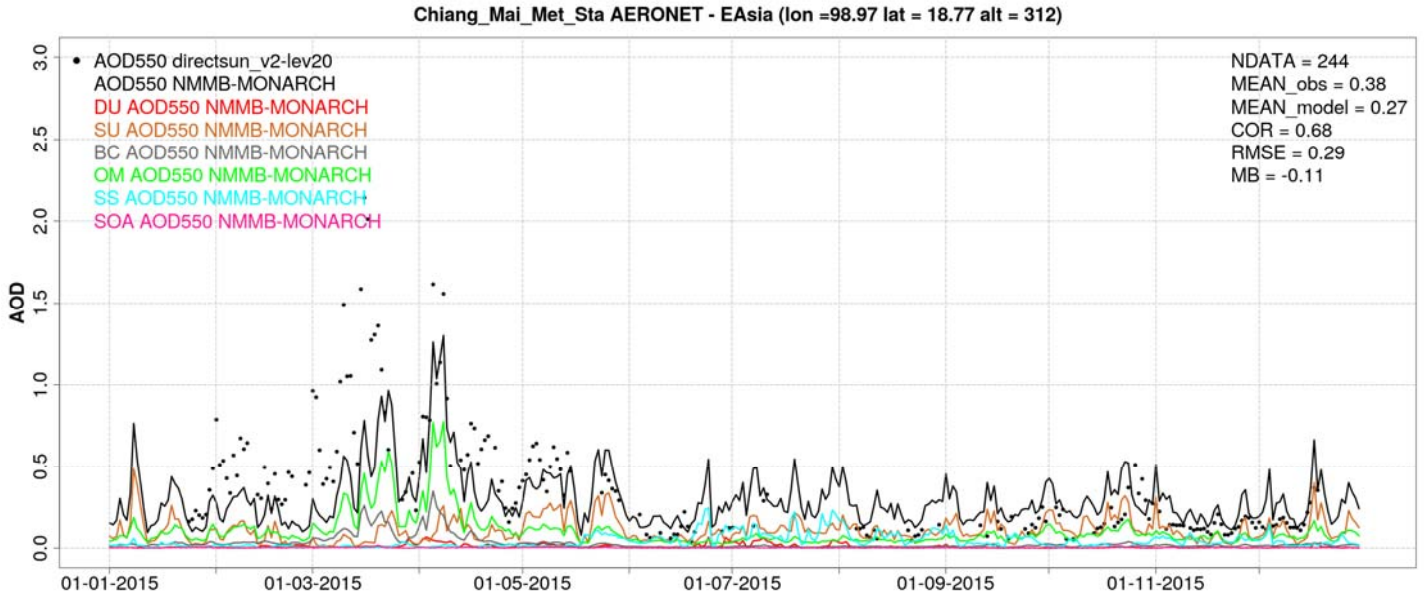
# Europe


Lille AERONET - Europe (lon =3.14 lat = 50.61 alt = 60)
AOD550 directsun_v2-lev20
AOD550 NMMB-MONARCH
DU AOD550 NMMB-MONARCH
SU AOD550 NMMB-MONARCH
BC AOD550 NMMB-MONARCH
OM AOD550 NMMB-MONARCH
SS AOD550 NMMB-MONARCH
SOA AOD550 NMMB-MONARCH
NDATA = 169
MEAN_obs = 0.13
MEAN_model = 0.13
COR = 0.48
RMSE = 0.08
MB = 0
AOD
0.0
0.5
1.0
1.5
2.0
2.5
3.0
01-01-2015
01-03-2015
01-05-2015
01-07-2015
01-09-2015
01-11-2015

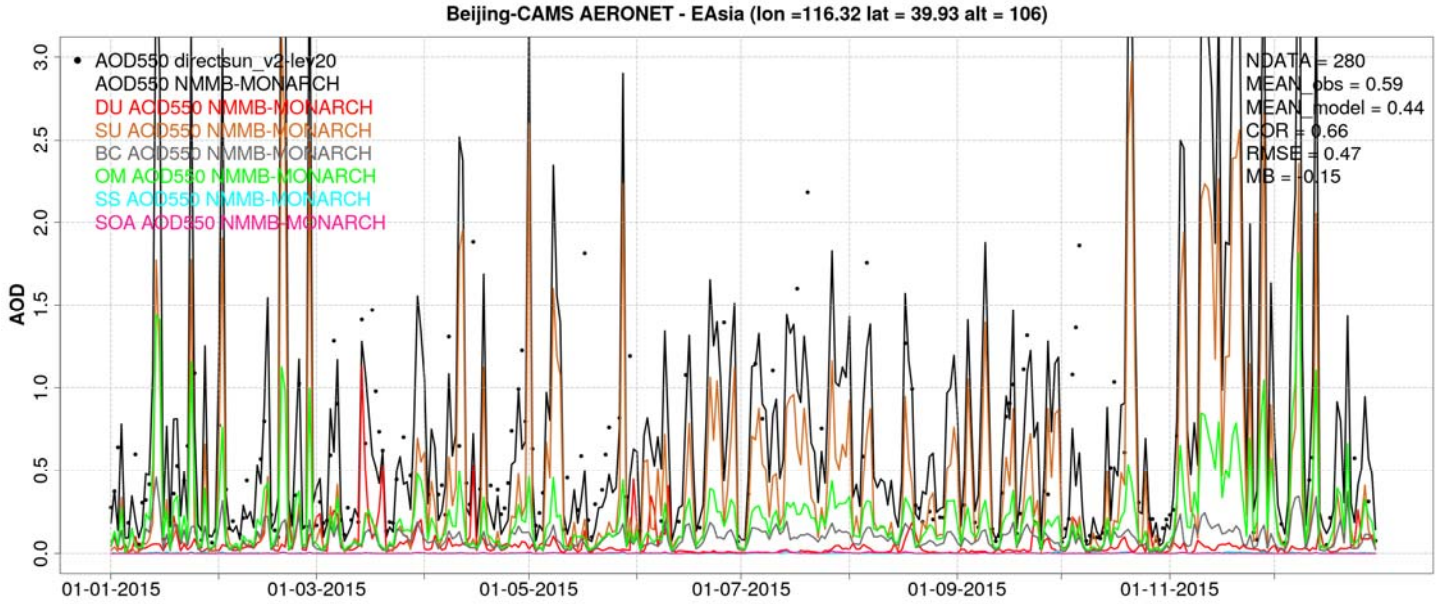

Belsk AERONET - Europe (lon =20.79 lat = 51.84 alt = 190)
AOD550 directsun_v2-lev20
AOD550 NMMB-MONARCH
DU AOD550 NMMB-MONARCH
SU AOD550 NMMB-MONARCH
BC AOD550 NMMB-MONARCH
OM AOD550 NMMB-MONARCH
SS AOD550 NMMB-MONARCH
SOA AOD550 NMMB-MONARCH
NDATA = 172
MEAN_obs = 0.17
MEAN_model = 0.14
COR = 0.51
RMSE = 0.09
MB = -0.03
AOD
0.0
0.5
1.0
1.5
2.0
2.5
3.0
01-01-2015
01-03-2015
01-05-2015
01-07-2015
01-09-2015
01-11-2015

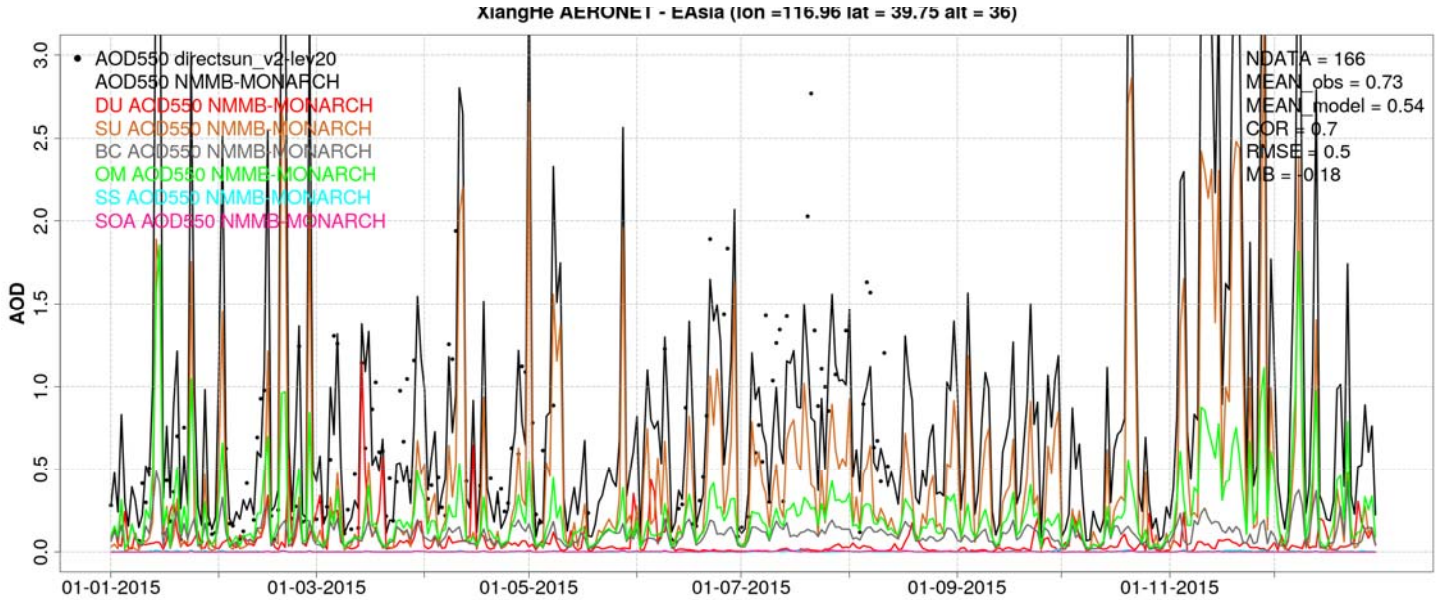
# Biomass Burning



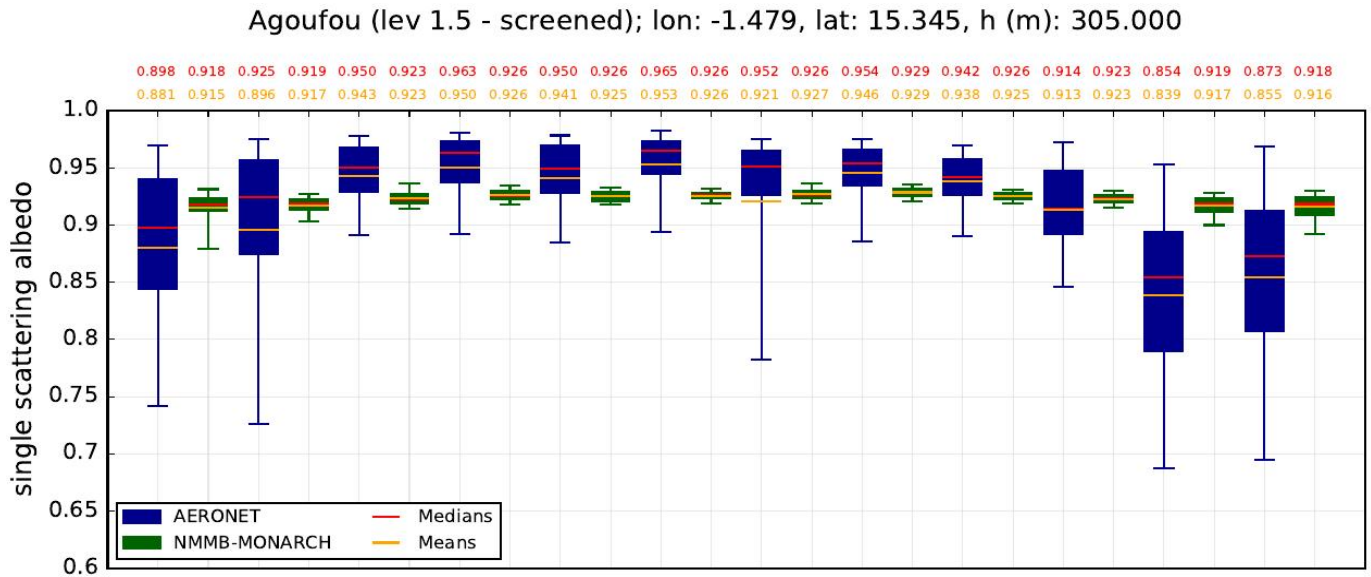
# China

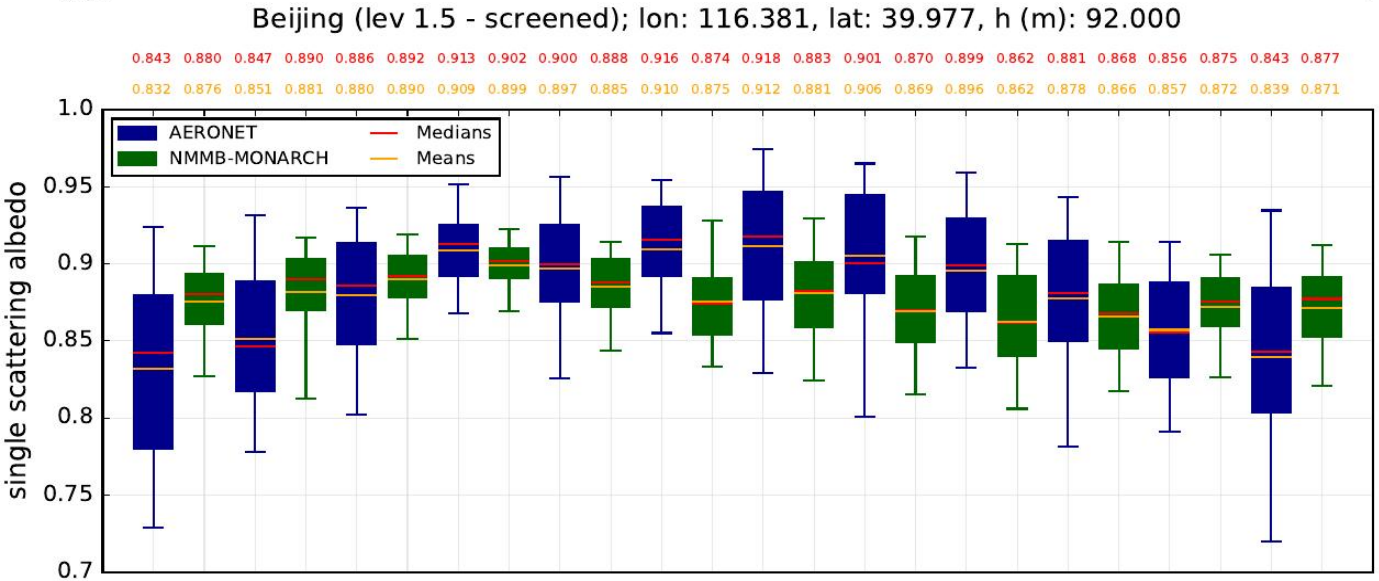

Beijing-CAMS AERONET - EAsia (lon =116.32 lat = 39.93 alt = 106)
AOD550 directsun_v2-lev20
AOD550 NMMB-MONARCH
DU AOD550 NMMB-MONARCH
SU AOD550 NMMB-MONARCH
BC AOD550 NMMB-MONARCH
OM AOD550 NMMB-MONARCH
SS AOD550 NMMB-MONARCH
SOA AOD350 NMMB-MONARCH
NDATA = 280
MEAN_obs = 0.59
MEAN_model = 0.44
COR = 0.66
RMSE = 0.47
MB = -0.15
AOD
0.0
0.5
1.0
1.5
2.0
2.5
3.0
01-01-2015
01-03-2015
01-05-2015
01-07-2015
01-09-2015
01-11-2015


XiangHe AERONET - EAsia (lon =116.96 lat = 39.75 alt = 36)
AOD550 directsun_v2-lev20
AOD550 NMMB-MONARCH
DU AOD550 NMMB-MONARCH
SU AOD550 NMMB-MONARCH
BC AOD550 NMMB-MONARCH
OM AOD550 NMMB-MONARCH
SS AOD550 NMMB-MONARCH
SOA AOD350 NMMB-MONARCH
NDATA = 166
MEAN_obs = 0.73
MEAN_model = 0.54
COR = 0.7
RMSE = 0.5
MB = -0.18
AOD
0.0
0.5
1.0
1.5
2.0
2.5
3.0
01-01-2015
01-03-2015
01-05-2015
01-07-2015
01-09-2015
01-11-2015

# Intensive Optical Properties in MONARCH

- Preliminary results of evaluation against AERONET of aerosol single scattering albedo simulated by the MONARCH:




*i)* AERONET level 1.5 data with all screening 2.0 filters applied except AOD > 0,4

*ii)* Monthly data collected over 5 years (2002-2006): # measures > 30 for each month

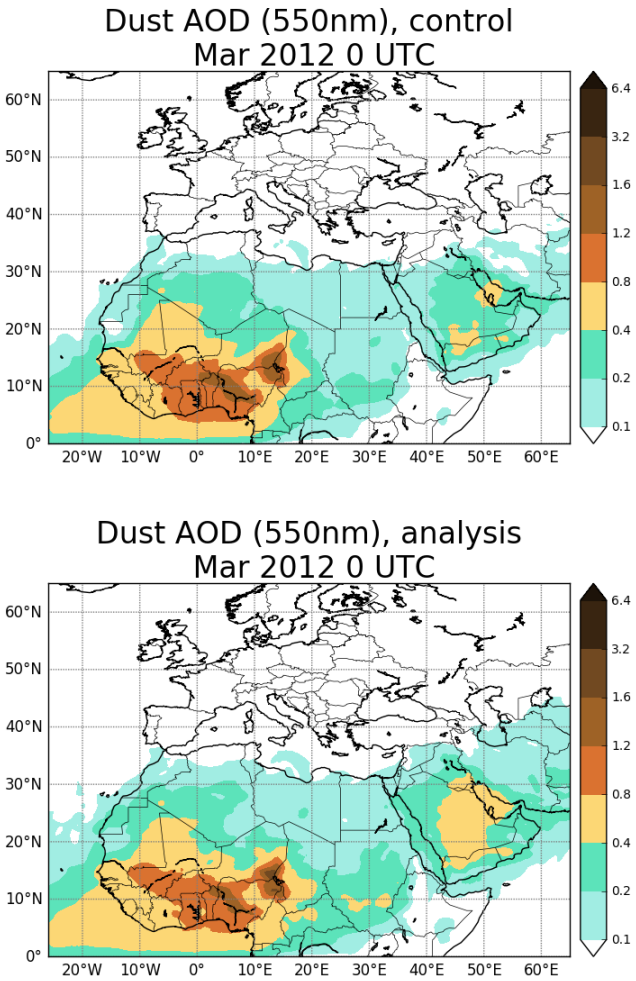
# Data assimilation updates at BSC

- **Testing new observational datasets (MODIS coarse DB, IASI dust AOD)**
- **Vertical observational constraint (assimilation of extinction profiles)**
- **Multi-scale capability (coping with a limited area domain and rotated coordinate system, e.g. used by the BDFC)**
- **Adapting the DA scheme to model developments (MONARCH v2.0)**

# MODIS Deep Blue coarse DoD

Assimilation of 0.1x0.1 deg MODIS Deep Blue coarse DOD based on Ginoux et al., 2012

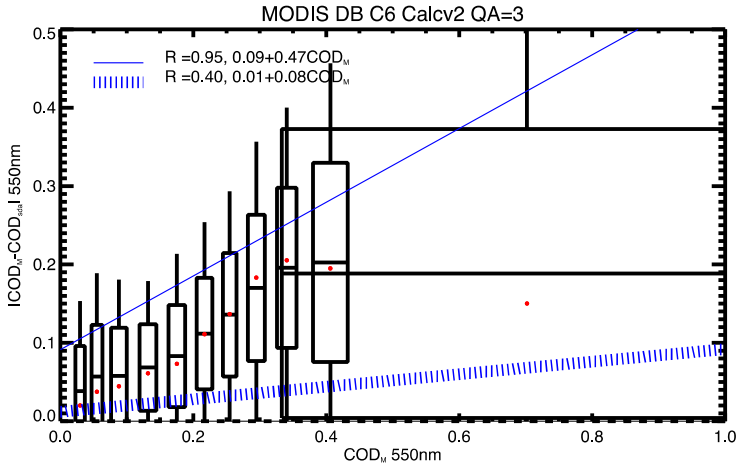
First assimilation tests with MONARCH at 0.3x0.3 deg resolution

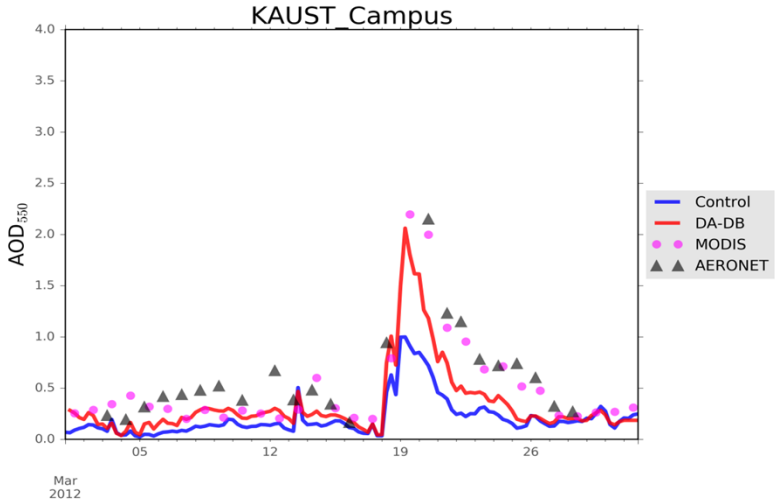






Error estimates: collocated comparison of DOD over N Africa (5 to 35N,-20 to 60E) with AERONET data between 2003 and 2015

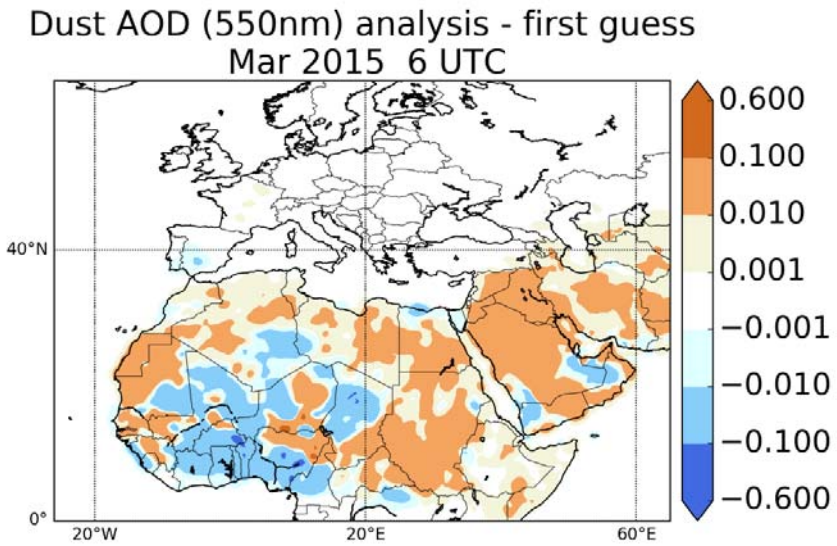


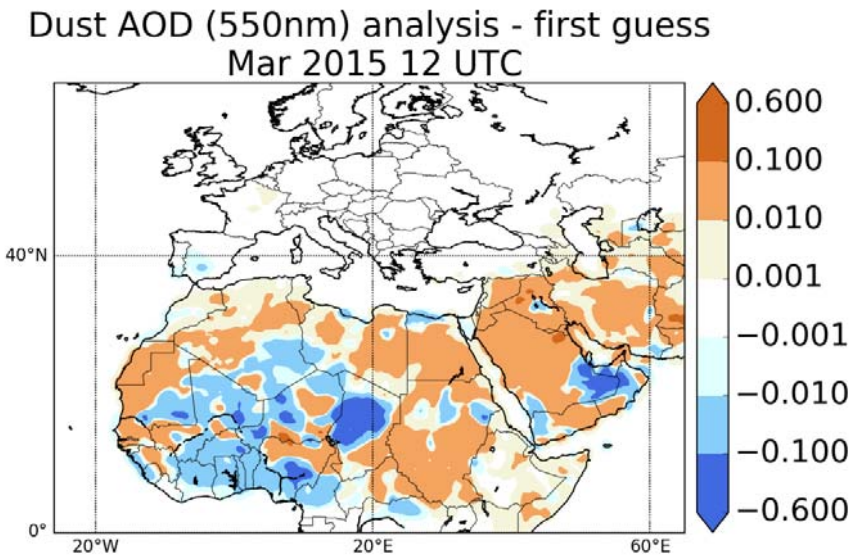



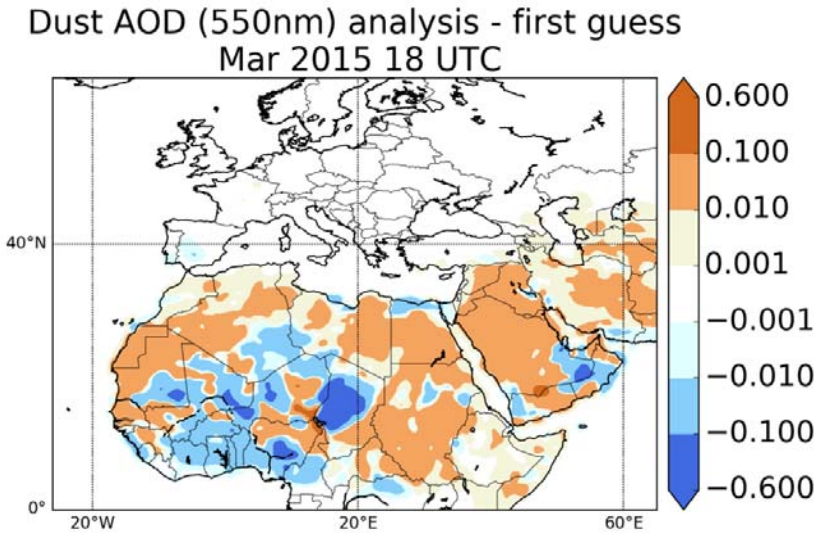
# Assimilation of MODIS coarse Deep Blue

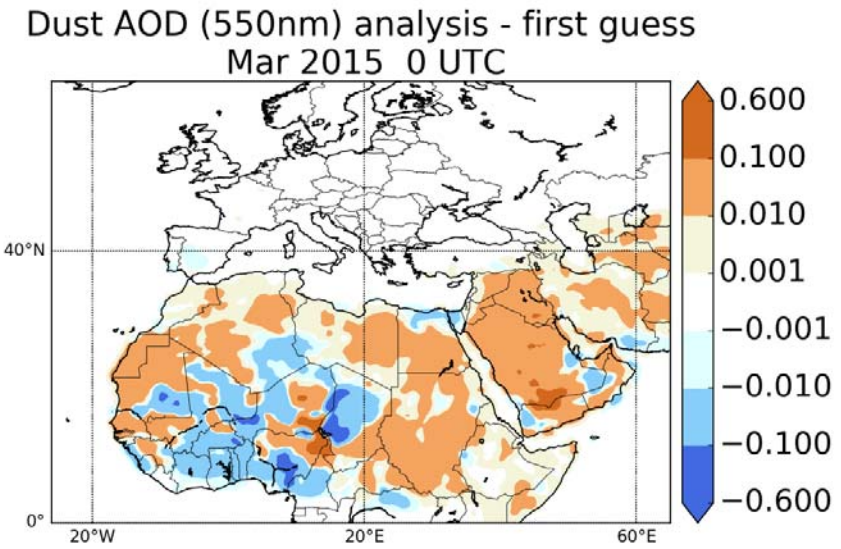
Barcelona Supercomputing Center
Centro Nacional de Supercomputación
EXCELENCIA SEVERO OCHOA

***Feedback from assimilation increments***



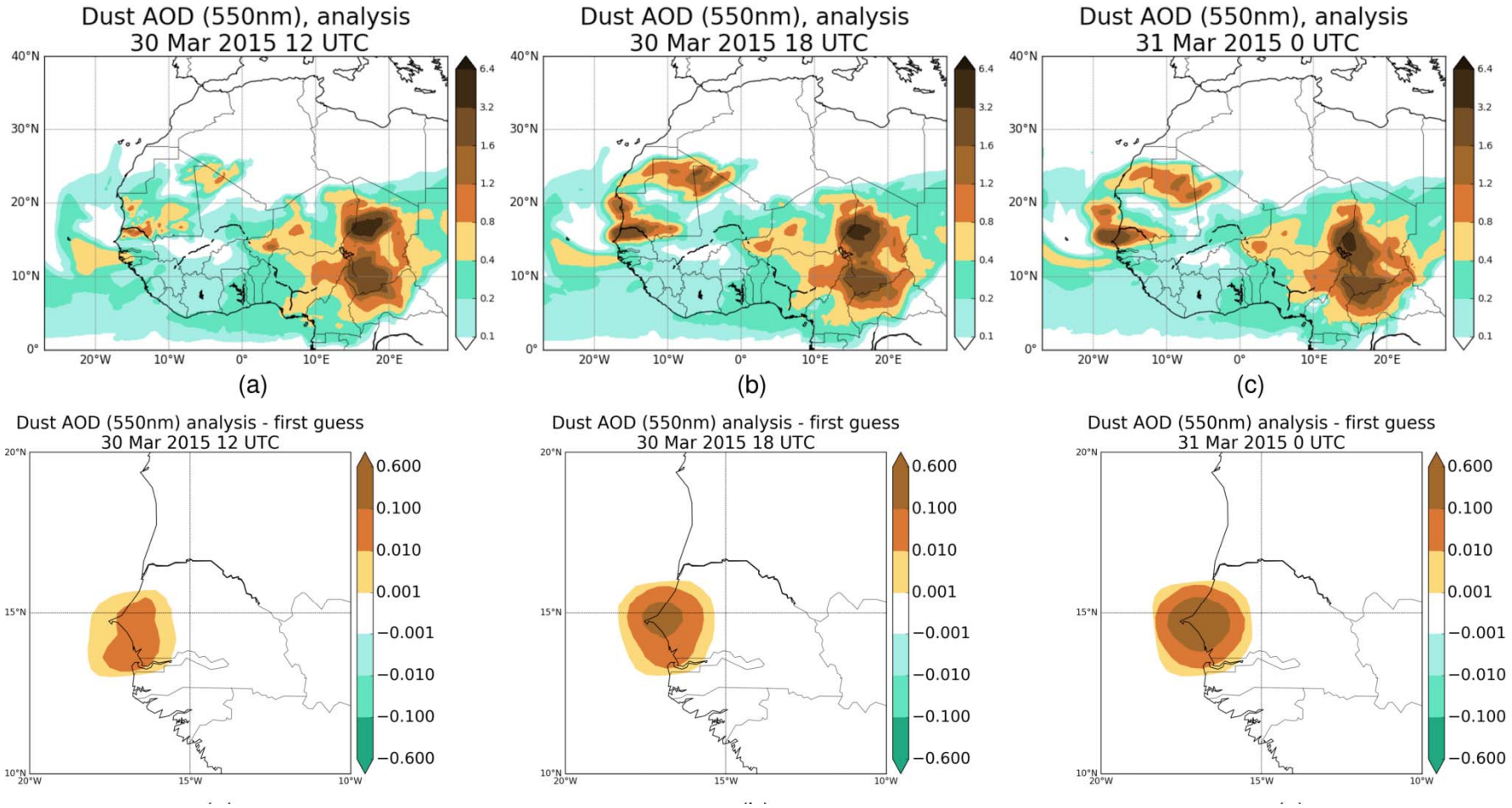
# ACTRIS-2 project Joint Research Activity on DA

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

EXCELENCIA SEVERO OCHOA

**Evaluating the potential of ACTRIS-2 data for assimilation through pilot dust case studies**

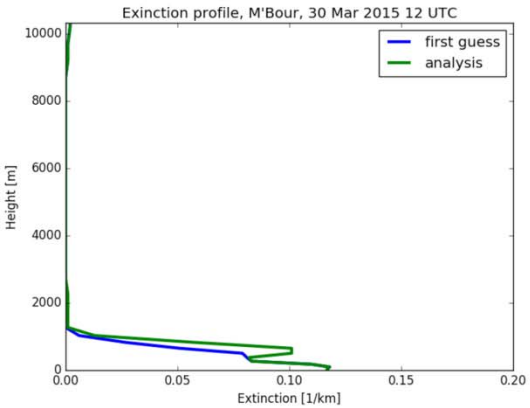
Multi-wavelength Mie-Raman lidar profile observations provided by the University of Lille for the M'bour site outside Dakar



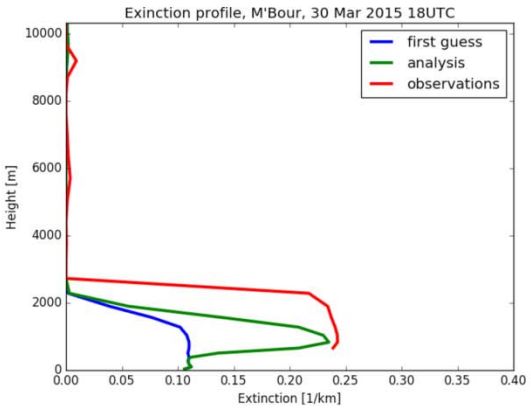
# ACTRIS-2 project Joint Research Activity on DA

Evaluating the potential of ACTRIS-2 data for assimilation through pilot dust case studies

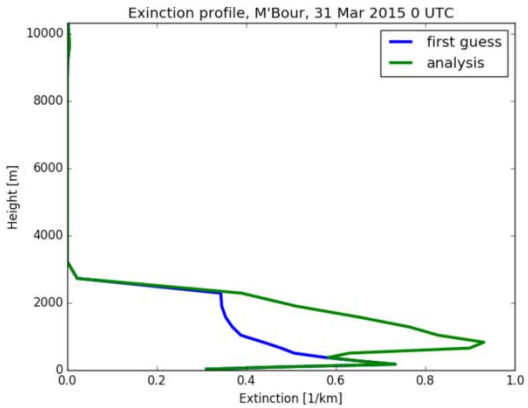
Observational impact through the whole assimilation window



(a)

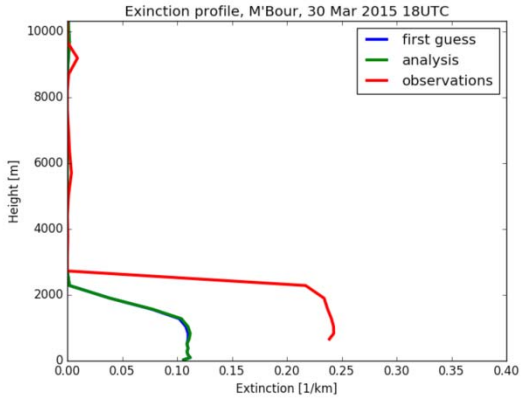


(b)



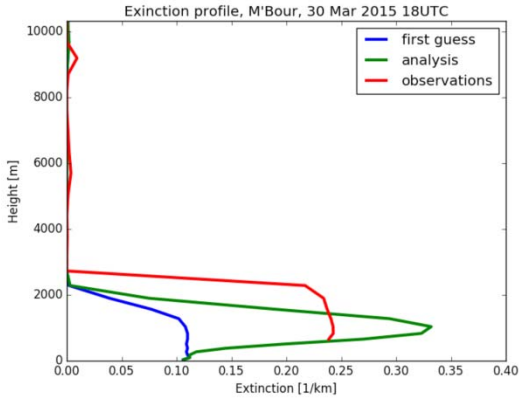
(c)

Higher observation uncertainty



(a)

Increasing the vertical localization factor

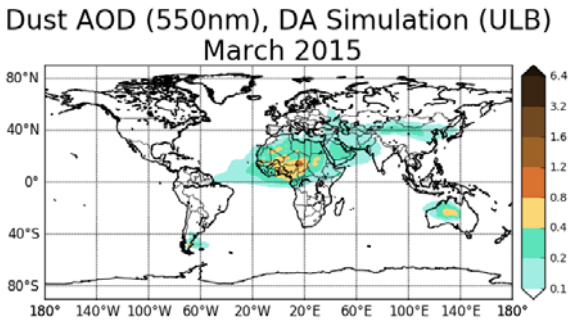


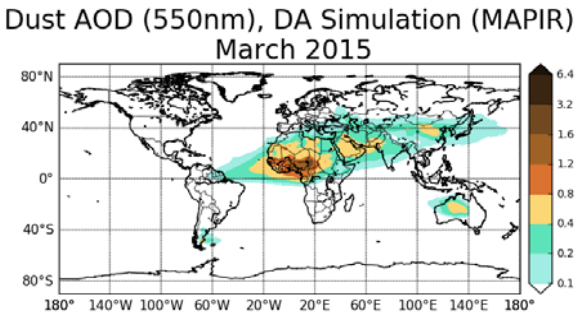
(b)

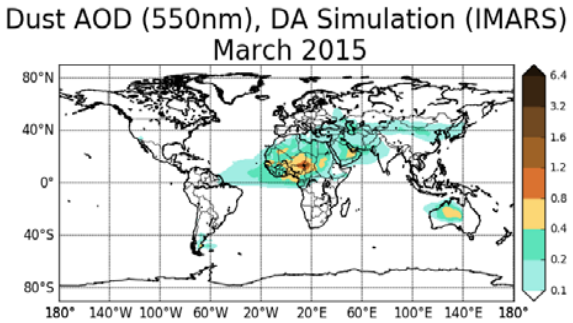
# Case Study
# ESA Climate Change Initiative

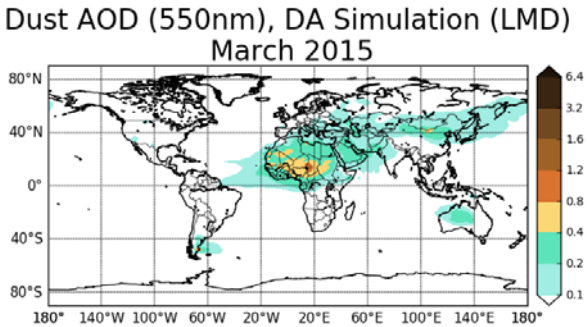
Barcelona Supercomputing Center
Centro Nacional de Supercomputación
EXCELENCIA SEVERO OCHOA

***IASI dust reanalyses (MetOp-A  IASI in the thermal IR)***




Level 3 mineral dust AOD datasets

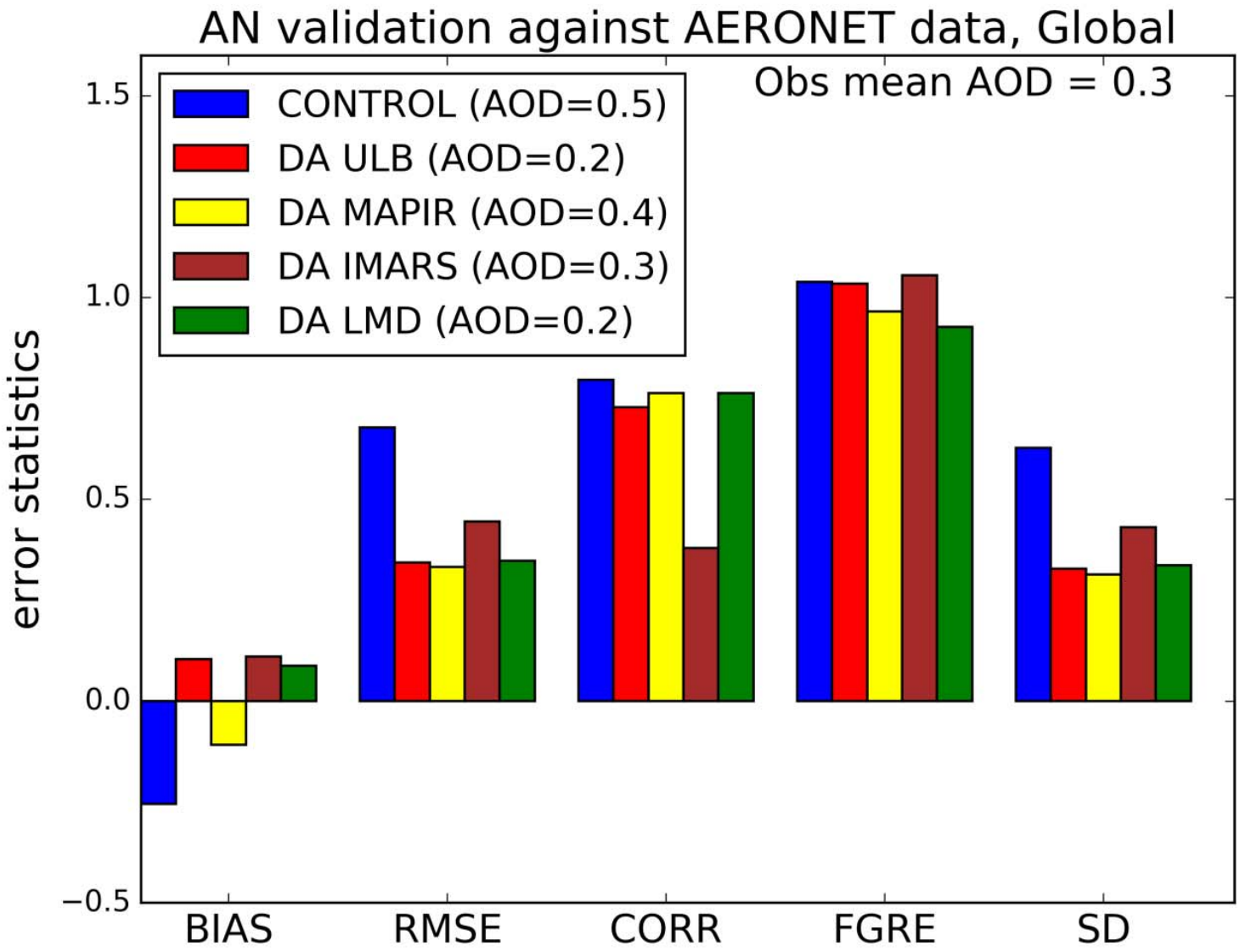
- retrieved from MetOp-A  IASI in the thermal IR
- uncertainty estimation
- converted to 550nm
- sub-daily set mineral dust retrievals (6h)
- spatially aggregated (1x1)
- screened for AOD (>0.15)

4 different retrieval algorithms

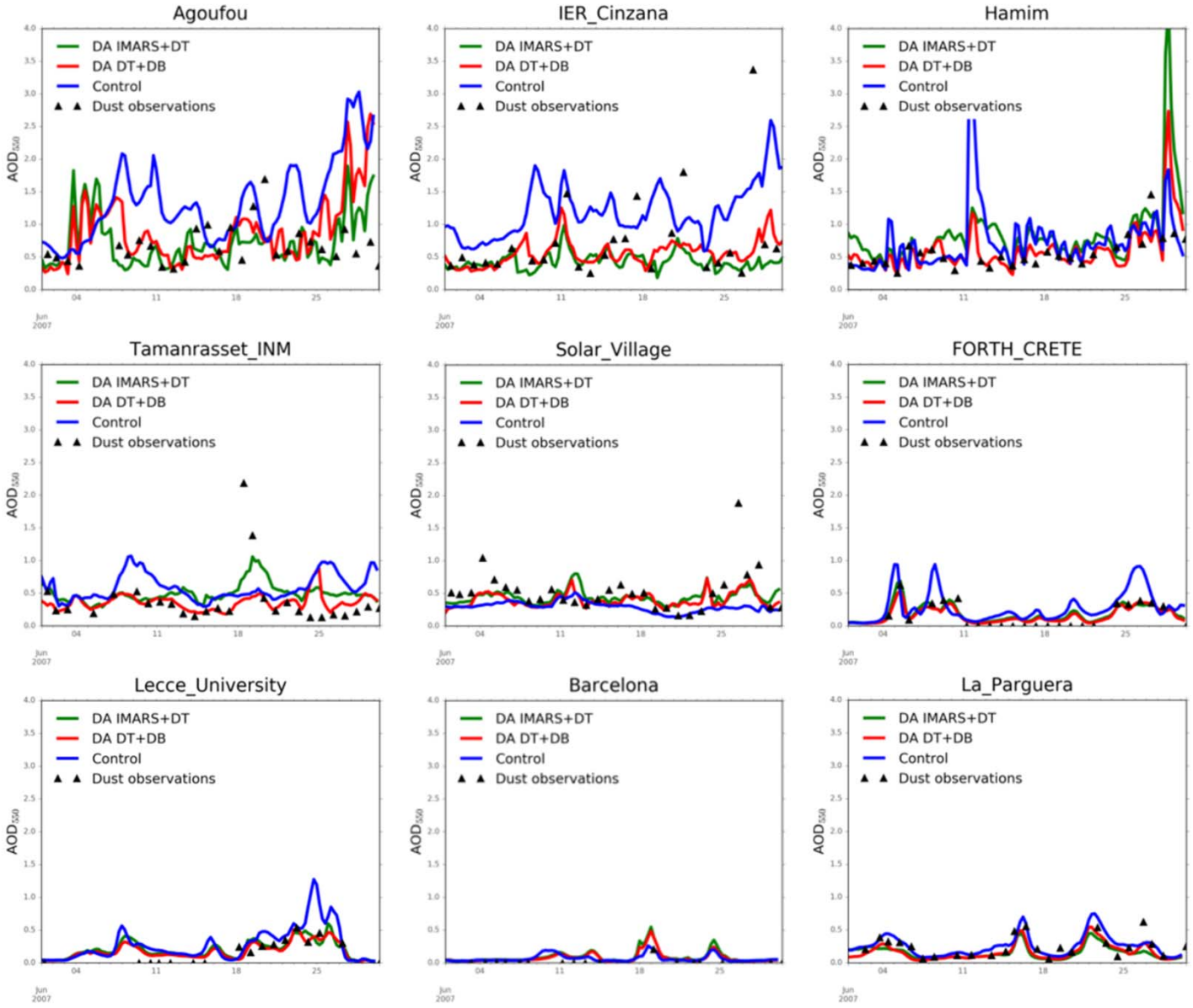
- ULB  v7, Universite Libre de Bruxelles
- MAPIR v3.5, BIRA-IASB
- LMD v2.1
- IMARS v5.2, DLR


26

# Case Study
# ESA Climate Change Initiative

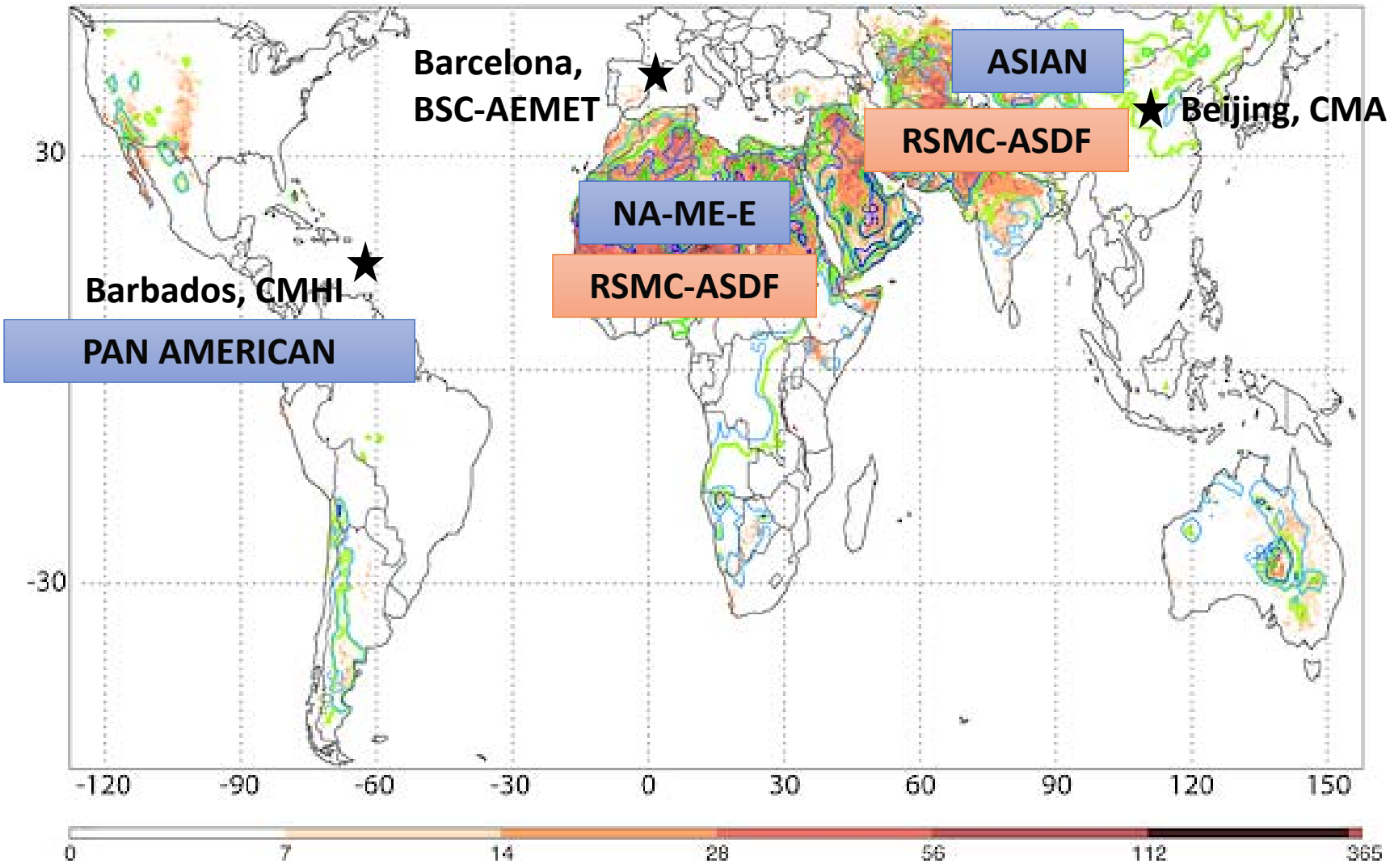


# Case Study
# ESA Climate Change Initiative




IMARS_QC
+
DT

# WMO Dust Regional Centers



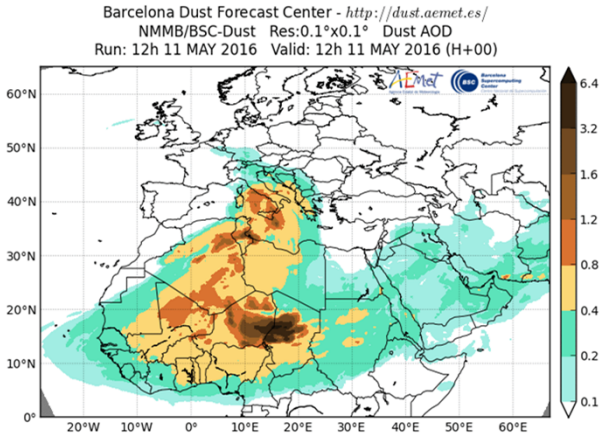

*Extracted from Ginoux et al. (2012, Rev. Geophys.)*

# WMO Dust Centers in BCN

***SDS-WAS. North Africa, Middle East and Europe Regional Center*** - *Research*
*Started in 2010*

*http://sds-was.aemet.es*

***Barcelona Dust Forecast Center*** - *Operations*
*First specialized WMO Center for mineral dust prediction. Started in 2014*




***http://dust.aemet.es*** ***@Dust_Barcelona***

# SDS-WAS NAMEE: Dust observations

Barcelona Supercomputing Center
Centro Nacional de Supercomputación

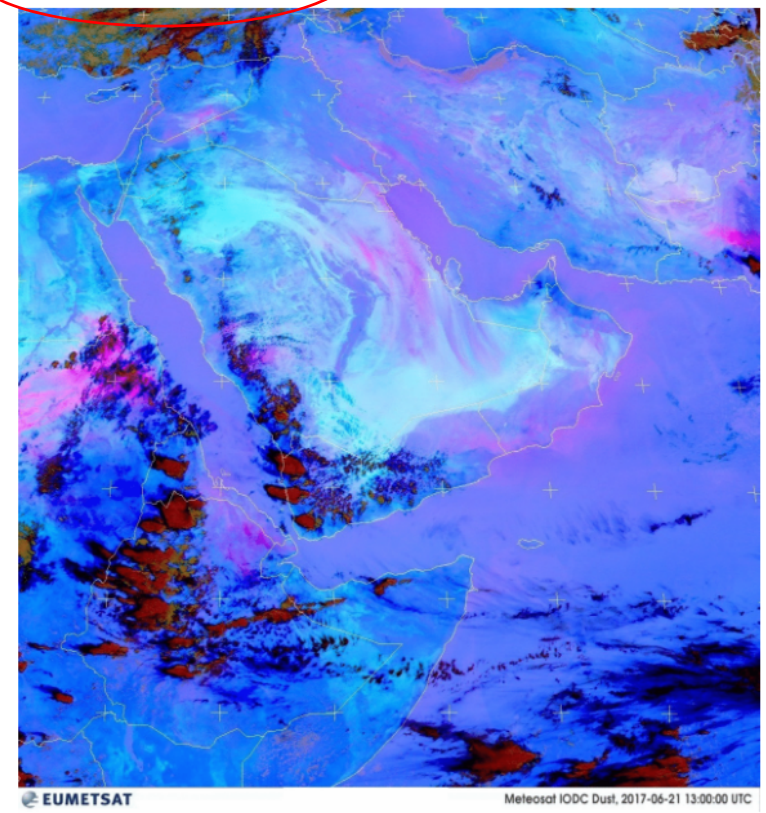
EXCELENCIA SEVERO OCHOA

AEMet Agencia Estatal de Meteorología

**MSG – EUMETSAT Middle East**

by Francesco Benincasa — last modified Mar 17, 2017 11:32 AM

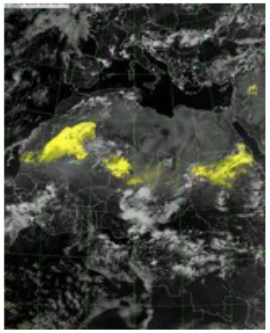
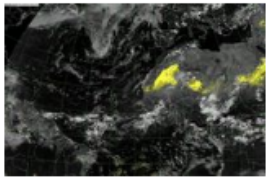
Date: 2017-06-21 anim ▾ Archive

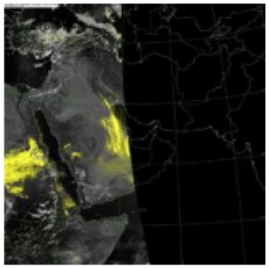



Download full image

**DEBRA-Dust**

by Enric Terradellas — last modified Mar 22, 2017 03:30 PM

| MSG - Africa | | | MSG - Atlantic | |
|---|---|---|---|---|
|  | Latest image<br>5-hour loop<br>4-week archive | RAMMB<br>NOAA<br>CIRA |  | Latest image<br>5-hour loop<br>4-week archive |

| Suomi NPP VIIRS - West Asia | | |
|---|---|---|
|  | Latest image<br>3-day loop<br>4-week archive | RAMMB<br>NOAA<br>CIRA |

EUMETSAT

*http://sds-was.aemet.es/*

# SDS-WAS NAMEE: Towards NRT Evaluation profiles

## OBSERVATIONS

***Extinction profiles at 12UTC***
*available in a window of 24 hours*


***3 ceilometers***
***1 lidar***

## SDS-WAS MODELS

- **BSC-DREAM8b**
- **NMMB/BSC-Dust**
- **CAMS**
- **DREAM8-NMME**
- ….

```
2016040512_3H_BSC_DREAM8B_profiles {
dimensions:
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        lon:long_name = "longitude" ;
        lon:units = "positive degrees East" ;
    double lat(station) ;
        lat:long_name = "latitude" ;
        lat:units = "positive degrees North" ;
    char station_name(station, strlen) ;
```

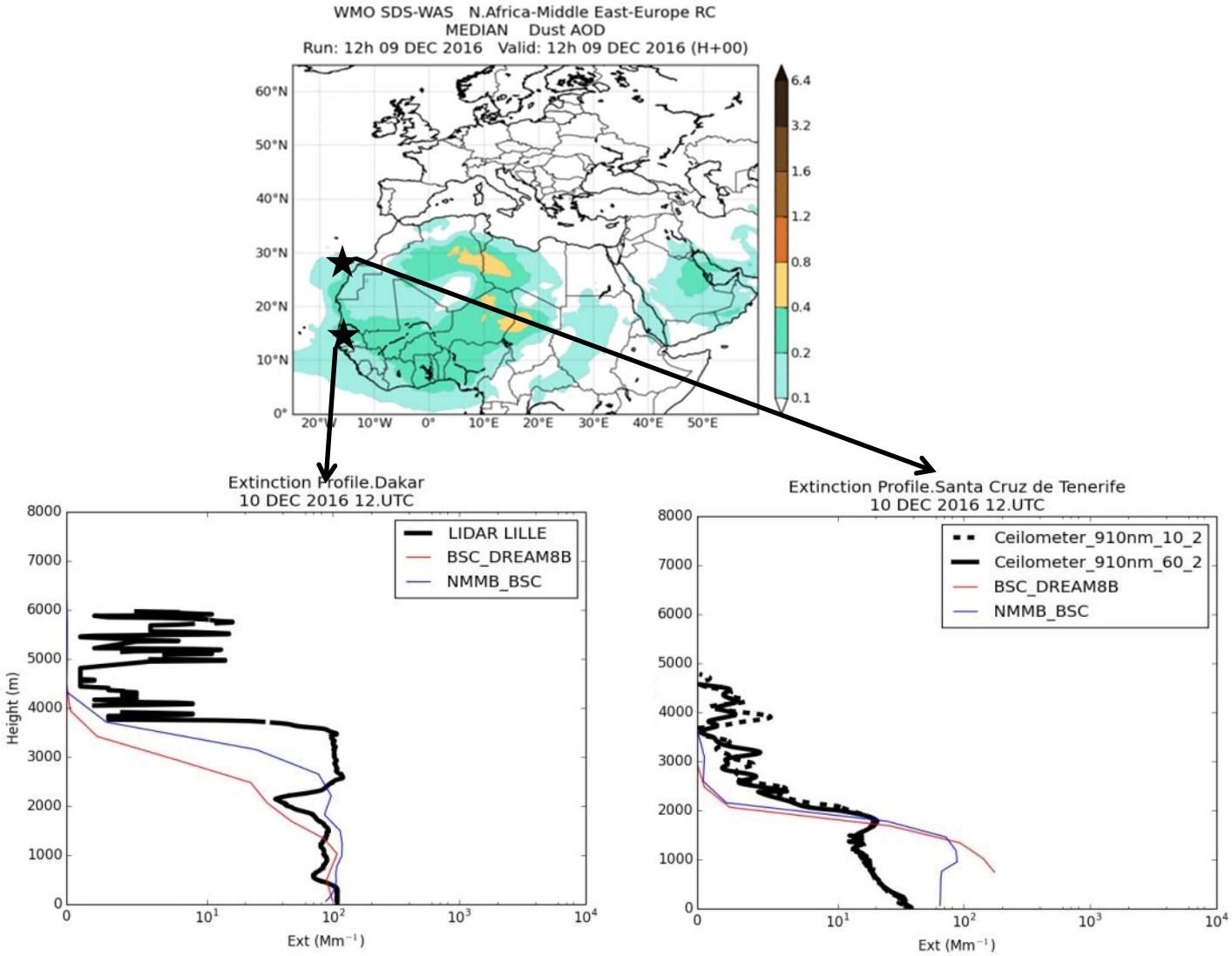
***Data format***
*Exchange operational protocol includes 72 hours forecasts*

*http://sds-was.aemet.es/projects-research/evaluation-of-model-derived-dust-vertical-profiles*

# SDS-WAS NAMEE: NRT Evaluation profiles

Barcelona Supercomputing Center
Centro Nacional de Supercomputación
EXCELENCIA SEVERO OCHOA

## Atlantic dust event: 9 - 12 December 2016



# SDS-WAS NAMEE: Daily Dust Forecasts

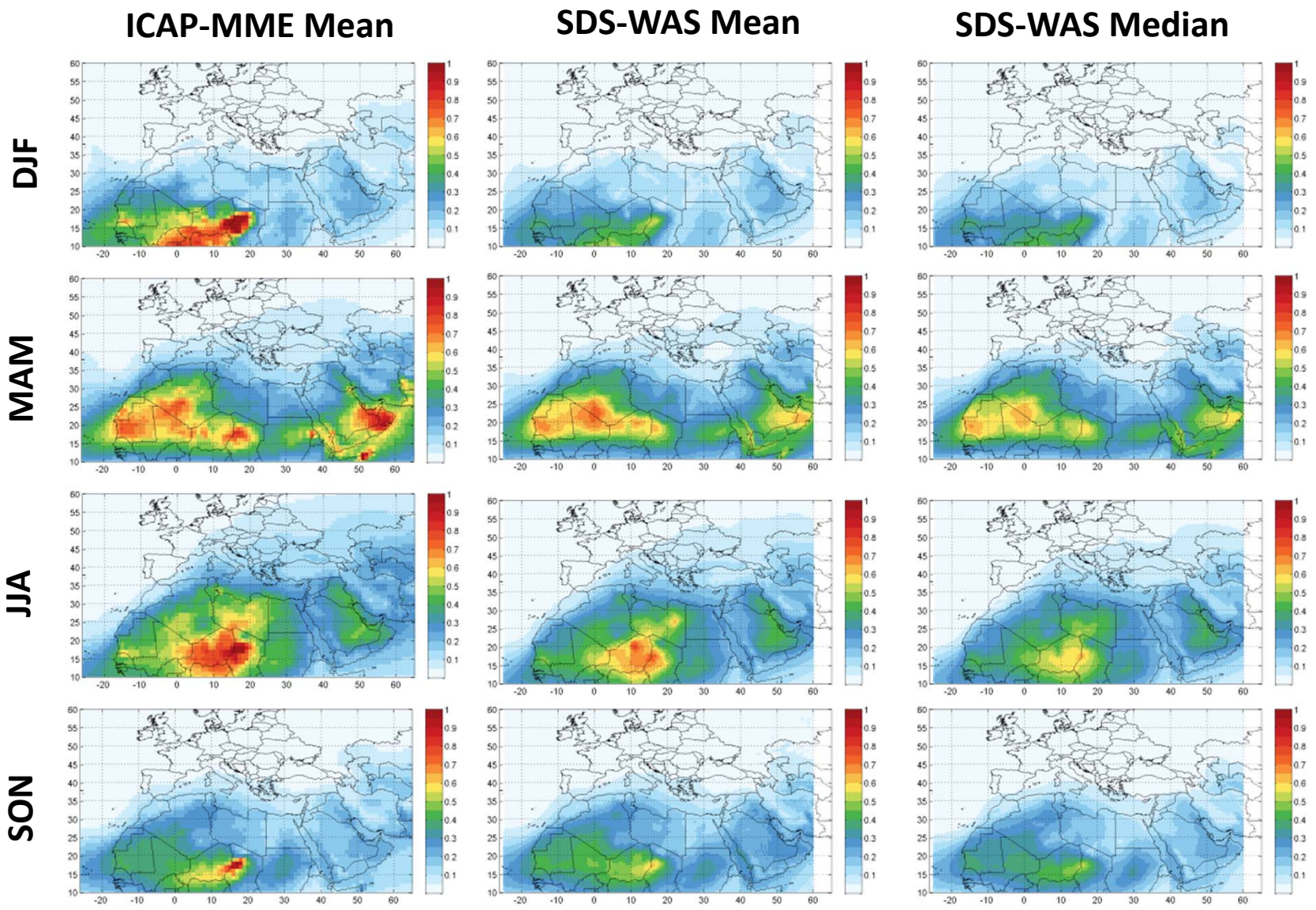
Dust prediction models provide 72 hours (at 3-hourly basis) of dust forecast (AOD at 550nm and surface concentration) covering NAMEE

| MODEL | RUN TIME | DOMAIN | DATA ASSIMILATION |
|---|---|---|---|
| BSC-DREAM8b | 12 | Regional | No |
| CAMS ECMWF | 00 | Global | MODIS AOD |
| DREAM8-NMME | 00 | Regional | CAMS analysis |
| NMMB/BSC-Dust | 00 | Regional | No |
| MetUM | 12 | Global | MODIS AOD |
| GEOS-5 | 00 | Global | MODIS reflectances |
| NGAC | 00 | Global | No |
| RegCM4 EMA | 00 | Global | No |
| DREAMABOL | 12 | Regional | No |
| WRF-CHEM NOA | 12 | Regional | No |
| SILAM | 12 | Regional | No |
| LOTOS-EUROS | 12 | Regional | No |

***http://sds-was.aemet.es/***

# ICAP-MME vs SDS-WAS: Results 2016

Barcelona Supercomputing Center
Centro Nacional de Supercomputación
EXCELENCIA SEVERO OCHOA



# ICAP-MME vs SDS-WAS: Results 2016

## DOD AERONET Direct-sun Version 3 Level 1.5 comparison

### Statistics ICAP-MME Mean

| | NDATA | MEAN_obs | MEAN_model | SD_obs | SD_model | COR | RMSE | MB | MNBE | MNGE | MFB | MFE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NAfrica | 4137 | 0.43 | 0.43 | 0.36 | 0.33 | 0.79 | 0.22 | 0.00 | 0.08 | 0.37 | 0.02 | 0.38 |
| Middle East | 755 | 0.33 | 0.30 | 0.28 | 0.21 | 0.60 | 0.23 | -0.04 | -0.06 | 0.39 | 0.20 | 0.67 |
| Mediterranean | 4932 | 0.09 | 0.10 | 0.15 | 0.14 | 0.85 | 0.08 | 0.01 | -0.14 | 0.43 | 1.04 | 1.39 |
| all_selected_sites | 10016 | 0.25 | 0.25 | 0.31 | 0.29 | 0.85 | 0.17 | 0.00 | 0.00 | 0.39 | 0.55 | 0.91 |

### Statistics SDS-WAS Mean

| | NDATA | MEAN_obs | MEAN_model | SD_obs | SD_model | COR | RMSE | MB | MNBE | MNGE | MFB | MFE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NAfrica | 4428 | 0.42 | 0.34 | 0.35 | 0.23 | 0.74 | 0.25 | -0.08 | -0.08 | 0.36 | -0.14 | 0.43 |
| Middle East | 802 | 0.34 | 0.30 | 0.28 | 0.23 | 0.38 | 0.29 | -0.03 | -0.08 | 0.36 | 0.18 | 0.65 |
| Mediterranean | 5279 | 0.09 | 0.08 | 0.15 | 0.12 | 0.84 | 0.08 | 0.00 | -0.27 | 0.46 | 0.99 | 1.44 |
| all_selected_sites | 10716 | 0.24 | 0.20 | 0.31 | 0.22 | 0.80 | 0.19 | -0.04 | -0.14 | 0.39 | 0.45 | 0.96 |

### Statistics SDS-WAS Median

| | NDATA | MEAN_obs | MEAN_model | SD_obs | SD_model | COR | RMSE | MB | MNBE | MNGE | MFB | MFE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NAfrica | 4440 | 0.42 | 0.31 | 0.35 | 0.20 | 0.79 | 0.26 | -0.12 | -0.20 | 0.36 | -0.27 | 0.48 |
| Middle East | 809 | 0.33 | 0.26 | 0.28 | 0.14 | 0.64 | 0.23 | -0.08 | -0.19 | 0.35 | 0.09 | 0.68 |
| Mediterranean | 5293 | 0.09 | 0.07 | 0.15 | 0.11 | 0.86 | 0.08 | -0.02 | -0.38 | 0.50 | 0.91 | 1.49 |
| all_selected_sites | 10750 | 0.24 | 0.18 | 0.31 | 0.19 | 0.85 | 0.19 | -0.06 | -0.26 | 0.40 | 0.35 | 1.01 |

# Near future Operational Updates

CURRENT FORECASTING – DEVELOPED/AVAILABLE – UNDER DEVELOPMENT - PLANNED

| DOMAIN | GLOBAL (ICAP) |
|---|---|
| Model | MONARCH |
| Status | QO |
| Meteorology | Inline: NMMB |
| Resolution | 1.4x1 deg<br>0.7x0.5 deg |
| levels | 24<br>48 |
| DA | LETKF |
| Assimilated Obs | MODIS DT+DB (DU)<br>MODIS DT+DB (ALL) |
| Aerosol Species | DU, SS, BC,<br>POA, SOA bio,<br>SOA anthro, SU, NI |
| Gas phase chemistry | CBM-IV<br>CB05<br>ONLINE and CLIMATOLOGY |
| Emissions | HERMES 3.0 (HTAP v2)<br>MEGAN ONLINE |
| Bio. Burn. Emissions | GFAS<br>NRT |

2017: New Marenostrum up in July
Full model into ICAP ensemble

Scalability tests and setting final resolution

Further tuning of
- emissions by region,
- wet scavenging
- optical properties

2018 Q2: Data assimilation with full aerosol model
Autosubmit workflow

Regional forecasts for Europe and Spain