Ensemble Kalman filter assimilation of MODIS AOT in a non-hydrostatic icosahedral aerosol transport model

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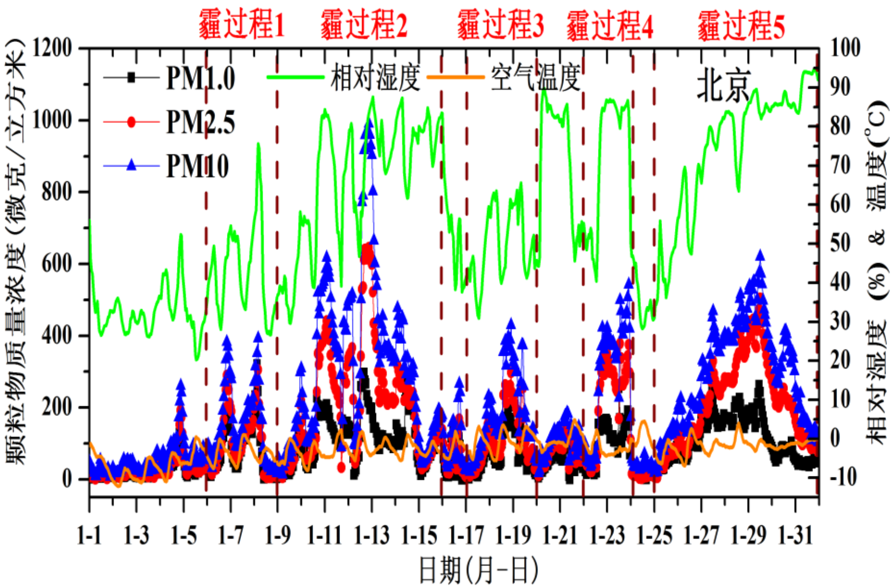
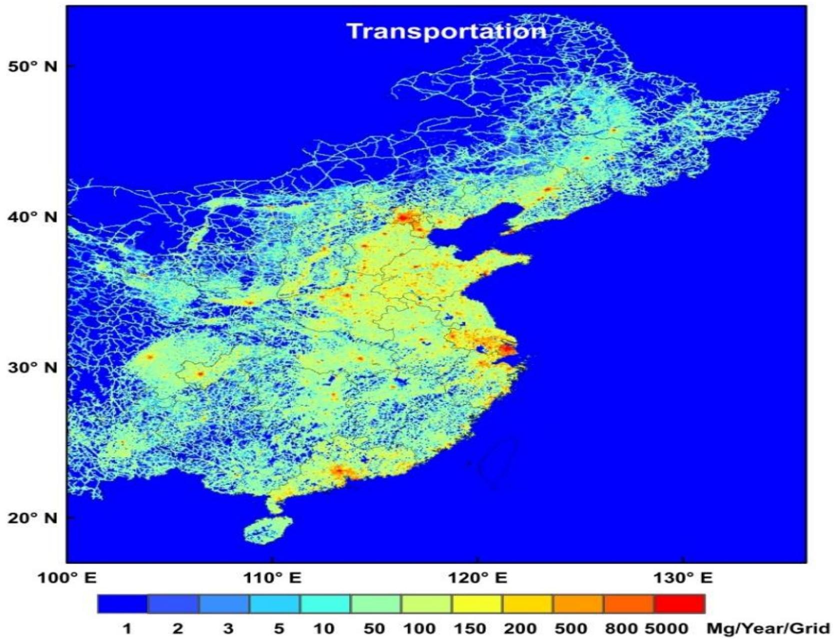
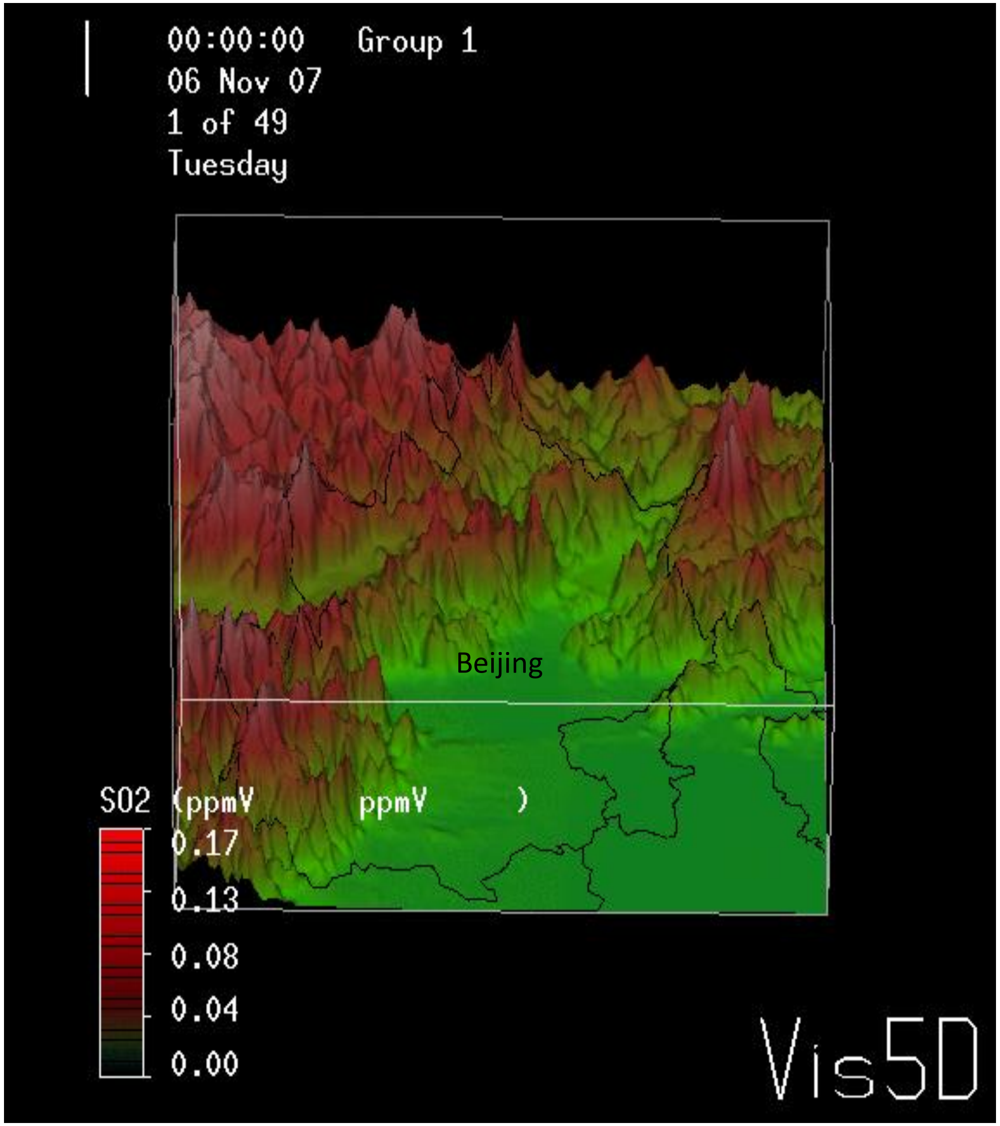
2013 January Haze pollutions in Beijing

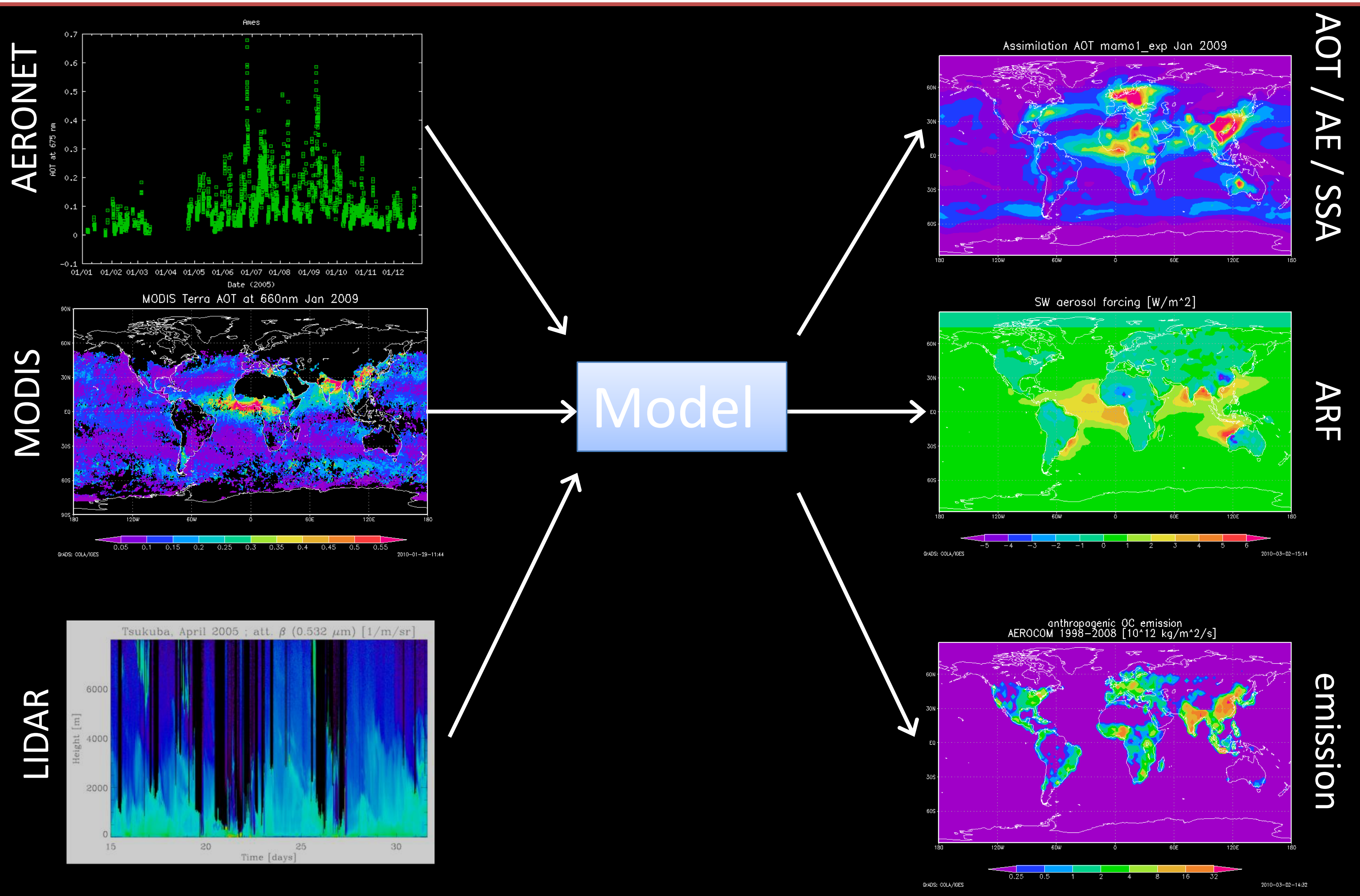






(From IAP annual meeting)

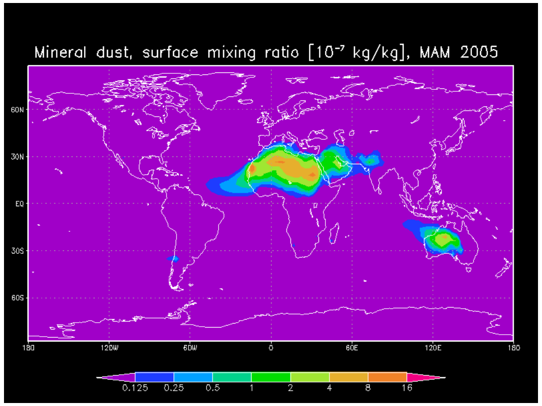
Assimilation: combining model & observation to obtain the best estimate of the truth.

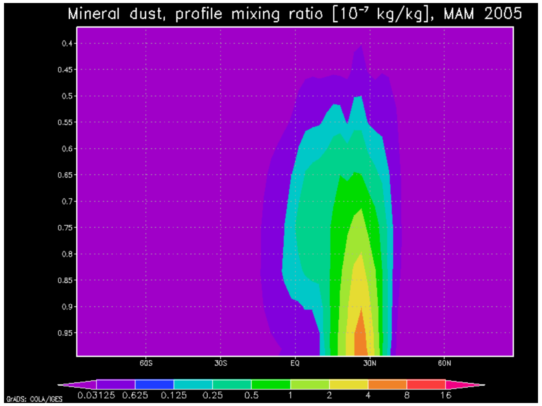


S P R I N T A R S

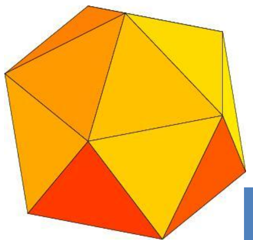
model description (Takemura et al., 2000, 2002, 2005, 2009, Goto et al., 2011)

- Aerosol module
  - Mineral dust
  - Carbons (pure OC & BC, mixed)
  - Seasalt
  - Sulfate
- Sources, transports and sinks
  - Emission inventories (carbons, sulfate)
  - Emission parameterize (dust, seasalt)
- Wet & dry deposition & grav. Settling
- MIROC AGCM
  - T42 or T106
  - NCEP or JMA meteorology



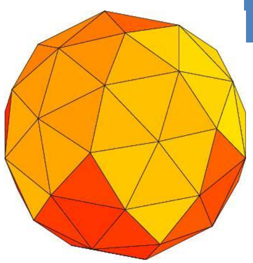


NICAM is the Nonhydrostatic icosahedral atmospheric model for global cloud resolving simulation, which is a new type of ultra-high resolution and the next generation atmospheric model (Satoh, et al, 2008)



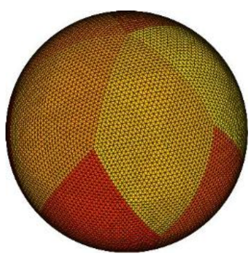
glevel 0
7141 km

g: glevel
number of rhomboses = 10×4^g
S: Earth Surface [m^2]
resolution ~ sqrt [$S / (10 \times 4^g)$]



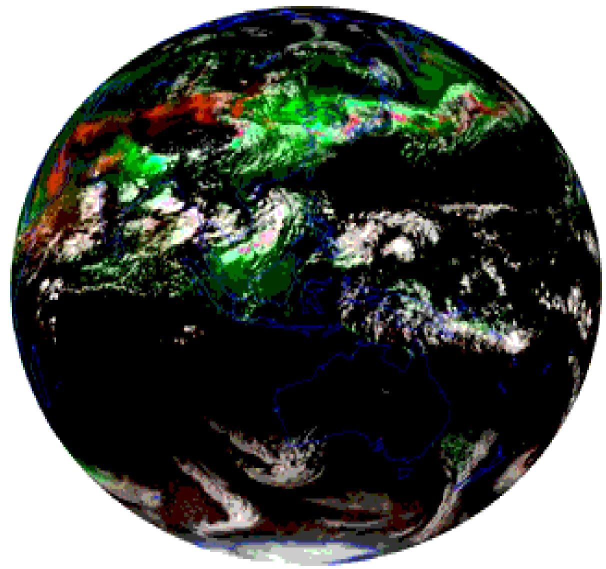
glevel 1
3570 km

...



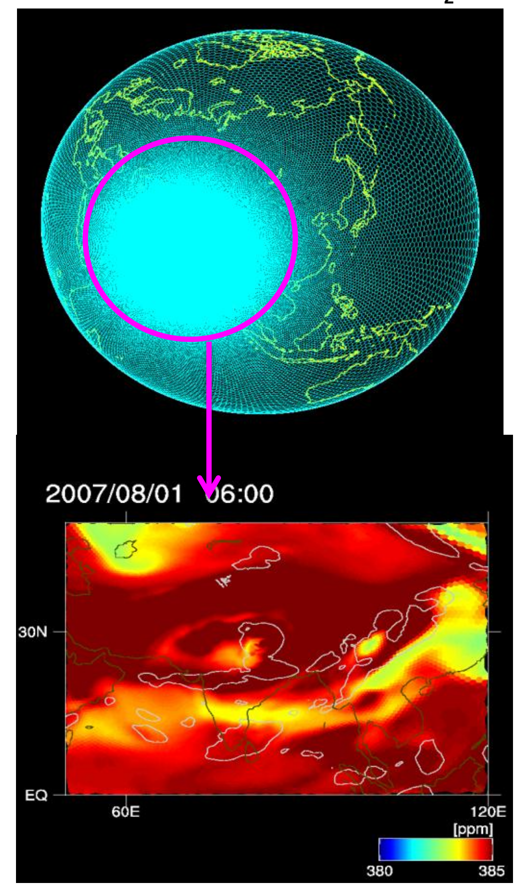
glevel	resolution
6	112 km
7	56 km
8	28 km
9	14 km
10	7 km
11	3.5 km

glevel 5
223 km



NICAM 7km global simulation: cloud (white), mineral dust (red), man-made aerosols (green)

NICAM-Stretch simulation of CO_2



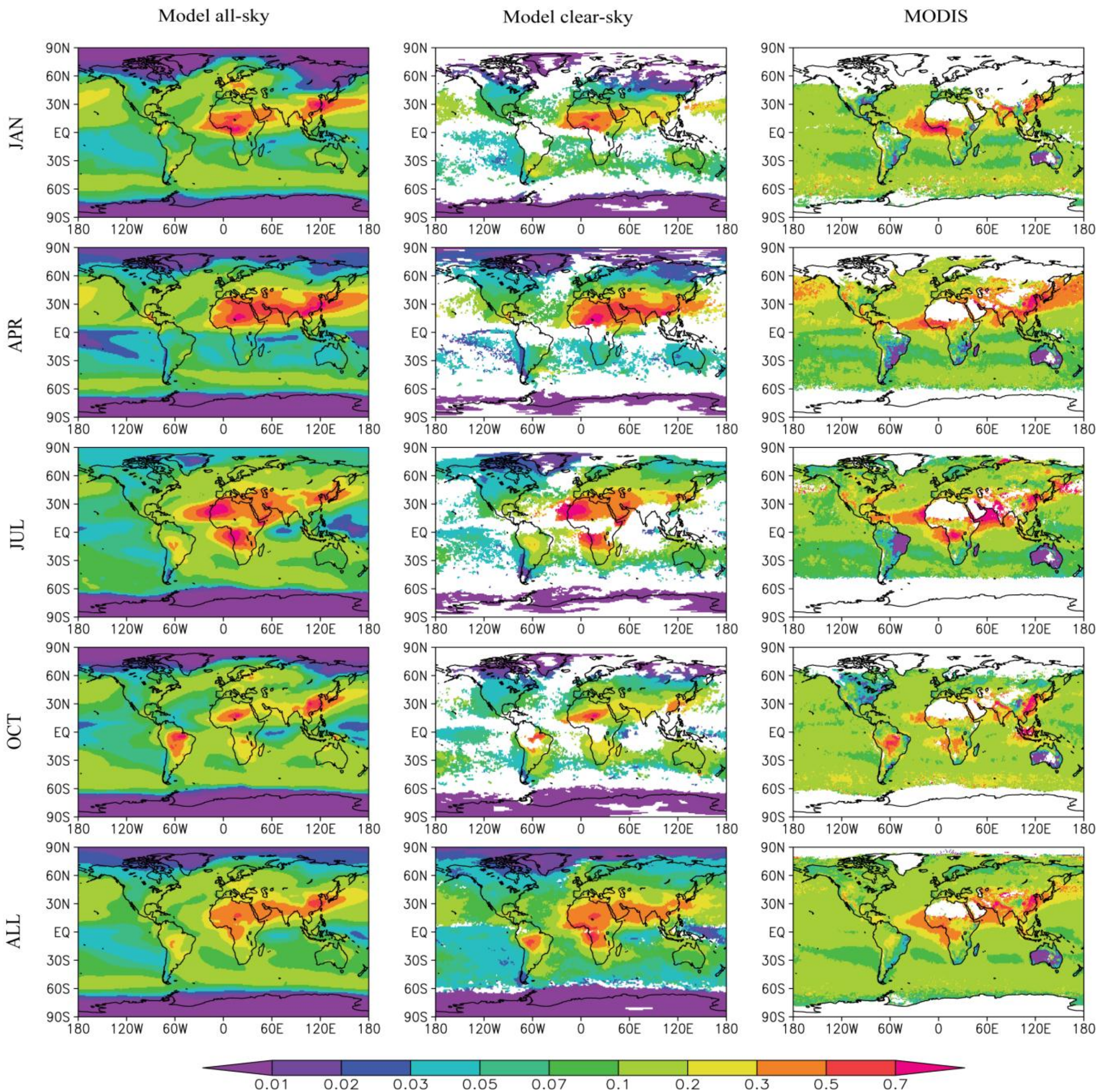
Figures from http://www.ccsr.u-tokyo.ac.jp/~satoh/nicam/ico.html

Aerosol-coupled version of NICAM: NICAM-SPRINTARS (Suzuki, 2008, 2011)

General setting of the simulation using NICAM+SPRINTARS

1. horizontal resolution of about 224 km (Glevel-5, total number of grid points is 10242)
2. 40 vertical layers with the top of model about 40 km
3. k-distribution radiation scheme (Nakajima et al., 2000; Sekiguchi and Nakajima, 2008),
4. the prognostic Arakawa-Schubert type cumulus convection scheme (Arakawa and Schubert, 1974; Pan and Randall, 1998; Emori et al., 2001)
5. MATSIRO land surface scheme (Takata et al., 2003)
6. The emission inventories of aerosol (primary OC and BC) and aerosol precursors (SO_2) emitted from anthropogenic sources, including fossil fuel combustion and biomass burning, are based on the AeroCom Phase-II dataset (Diehl et al., 2012)
7. The emission flux of soil dust aerosols depends on the near-surface wind speed, vegetation, leaf area index (LAI), soil moisture, and amount of snow (Takemura et al., 2009).
8. Sea salt emissions depend on the near-surface wind speed, and emissions are not possible over areas covered by sea ice (Takemura et al., 2009)
9. the modeled winds, water vapor, pressure and temperature fields are also nudged to the NCEP FNL analysis data with a time-scale of six hours

General pattern of the simulated AOD and compared with MODIS data (2006-2008)

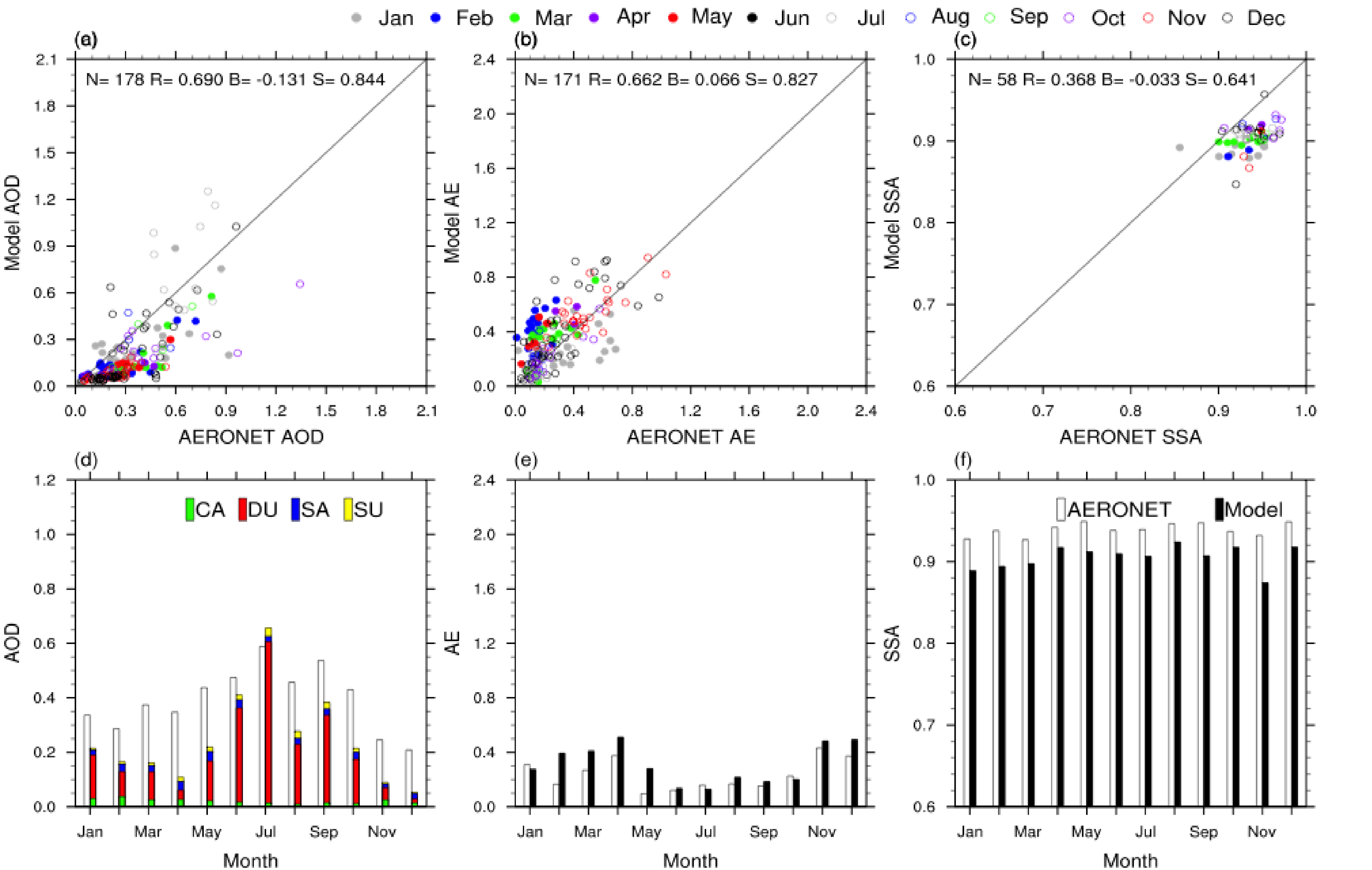


1.simulated results of AOT generally reproduce the MODIS retrieved results well

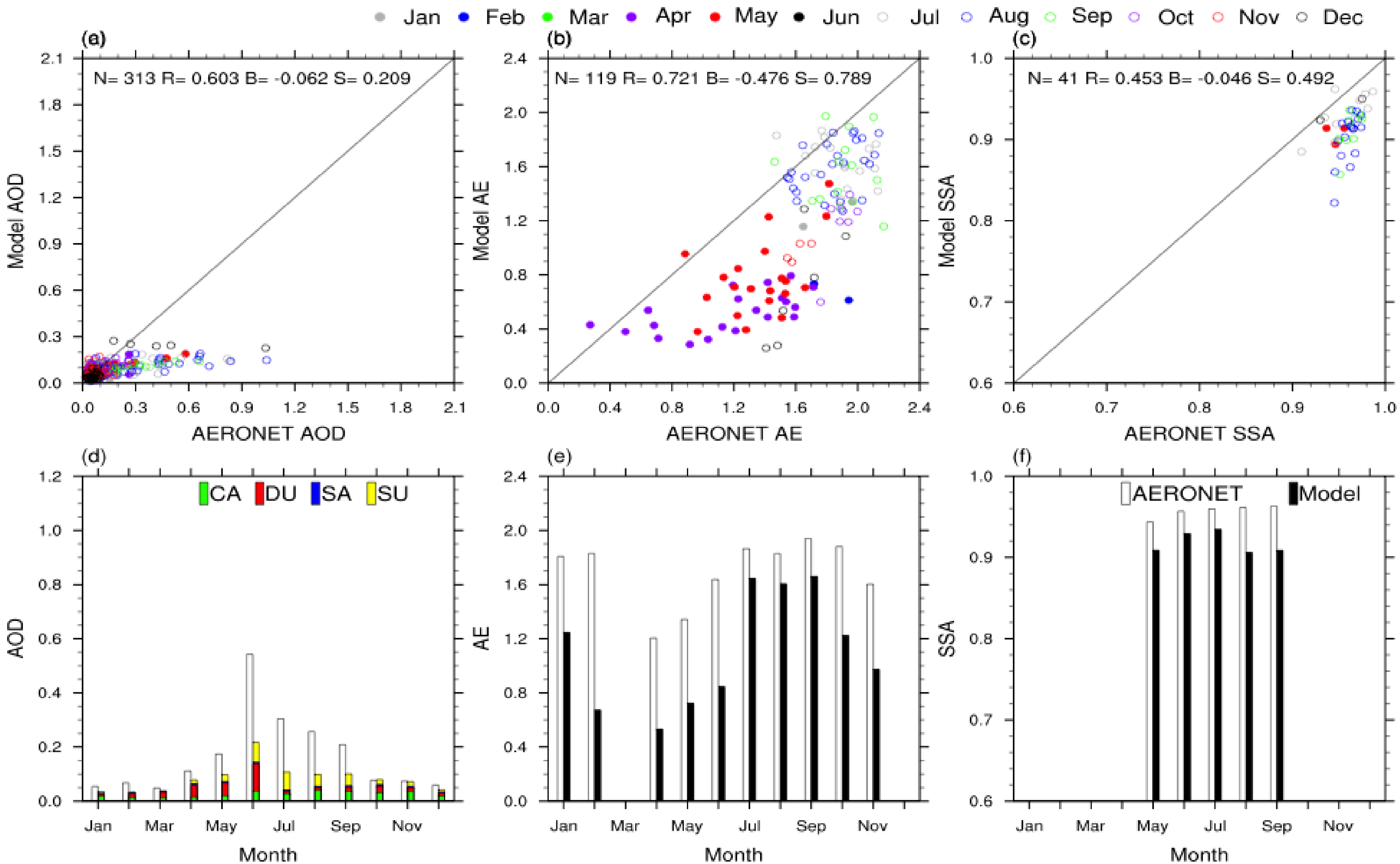
2. High AOT values are found over the Saharan, Arabian and Asian regions

3. The simulated seasonal variations of AOT in the northern hemisphere mostly regulated by the dust aerosol and in the Congo and Amazon basins caused by a strong seasonal cycle of biomass burning are consistent with MODIS products

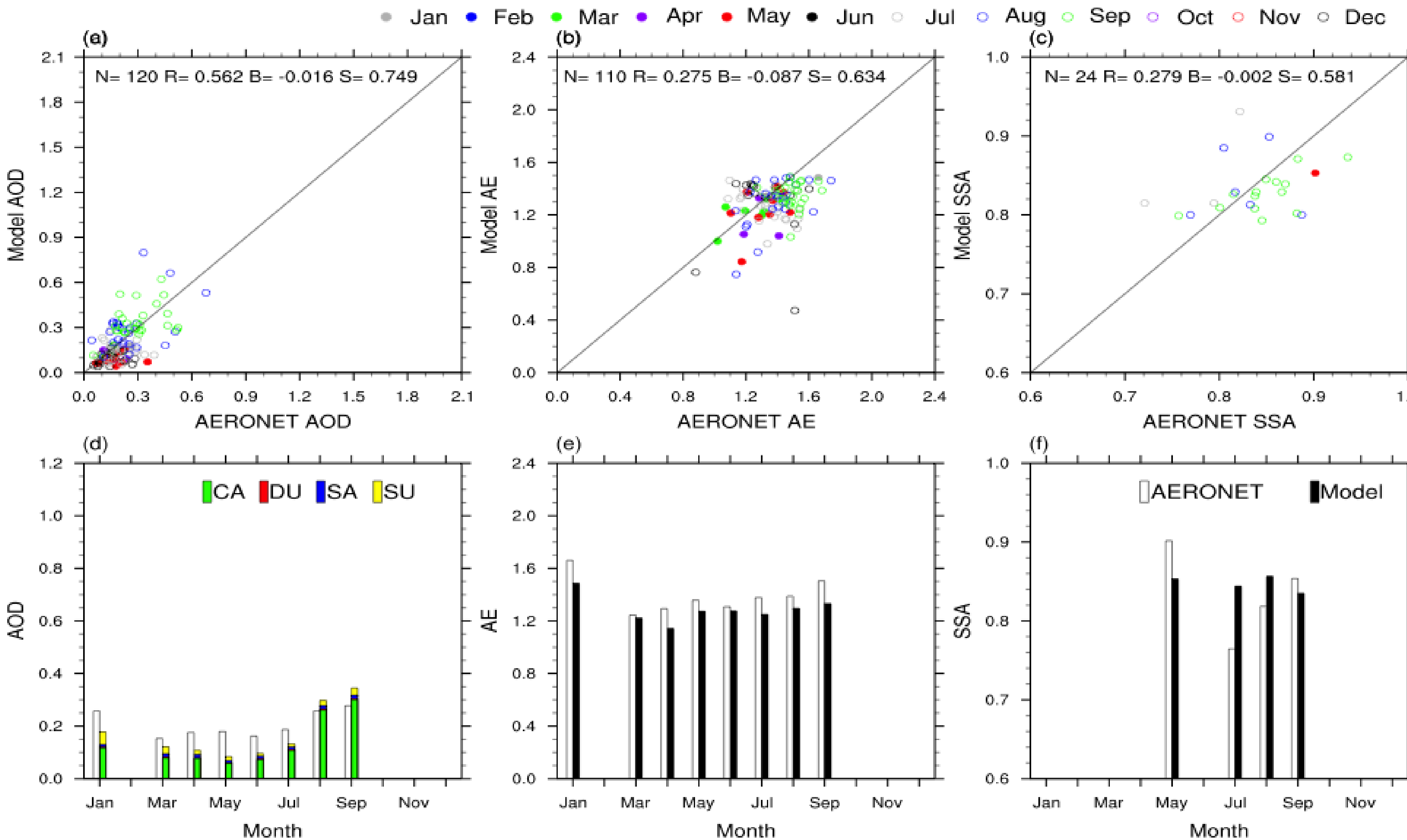
Evaluation of simulated key optical properties over Sahara dust outflow region (AERONET Capo_verde site)



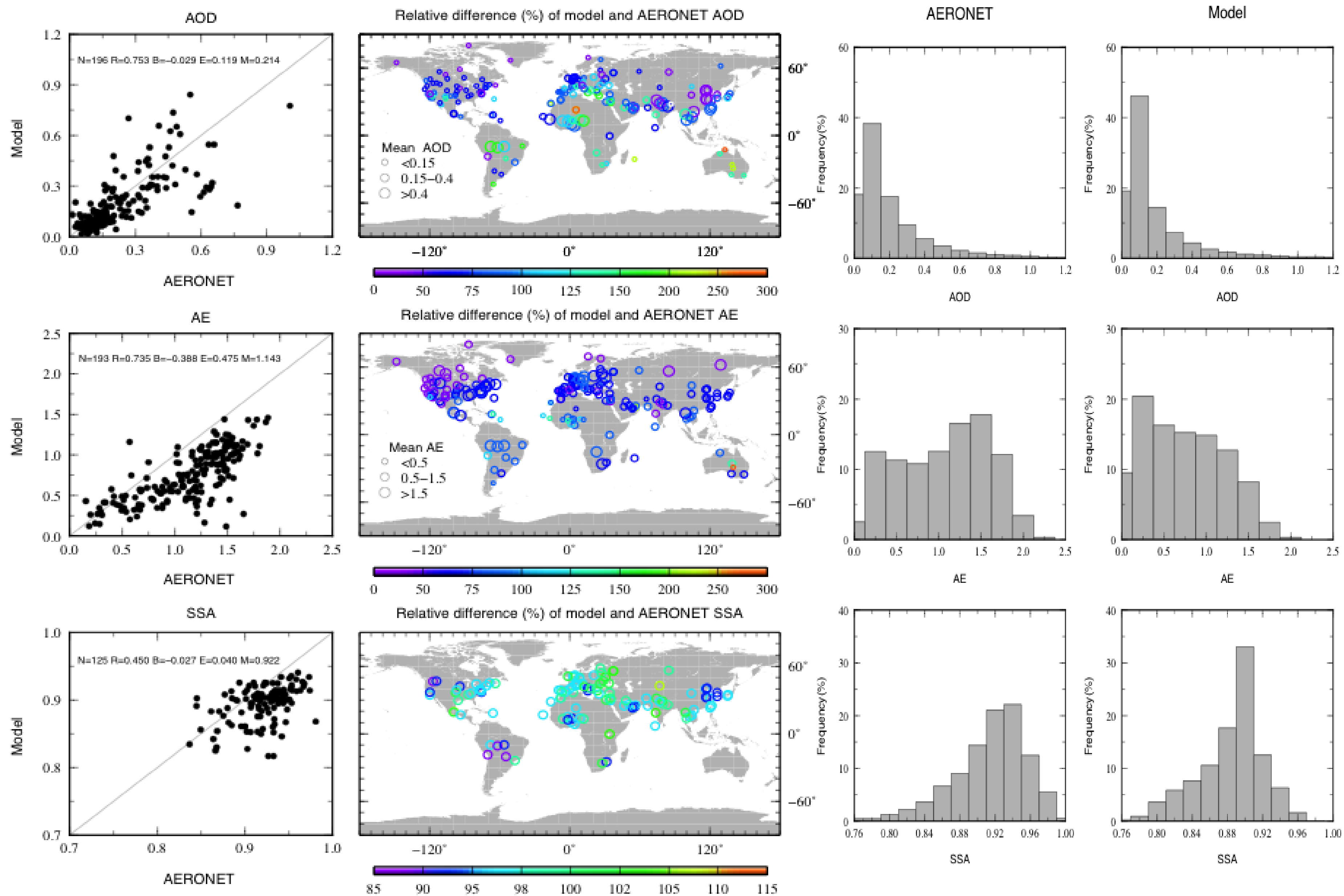
Evaluation of simulated key optical properties over Northern America
(AERONET GSFC site, USA)



Evaluation of simulated results over biomass burning region
(AERONET Sao Paulo site, Brazil)



General comparison of simulated key optical properties using AERONET observation



The Ensemble Kalman filter minimize the following cost function

$$\Psi(\mathbf{x}_a) = (\mathbf{y} - \mathbf{H}\mathbf{x}_a)^T \mathbf{R}^{-1} (\mathbf{y} - \mathbf{H}\mathbf{x}_a) + (\mathbf{x}_f - \mathbf{x}_a)^T \mathbf{P}^{-1} (\mathbf{x}_f - \mathbf{x}_a)$$

$\mathbf{x}_f$ Mixing ratio forecast → $\mathbf{x}_a$ Mixing ratio analysis

$\mathbf{y}$ Observations

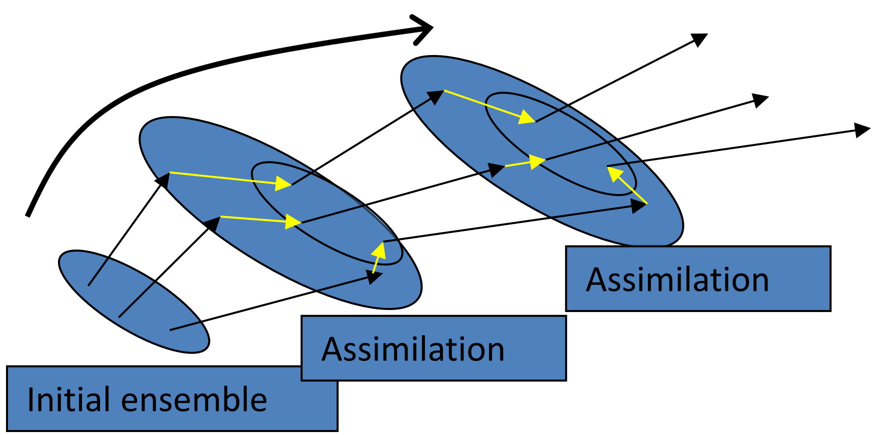
$\mathbf{H}\mathbf{x}_a$ Simulated observation

Disparate observations: AOT, AE, β, $PM_{2.5}$ etc.

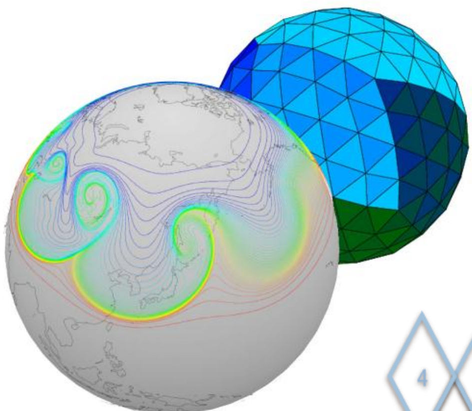
$\mathbf{R}$ Observational errors — Relative accuracy: e.g. MODIS vs AERONET

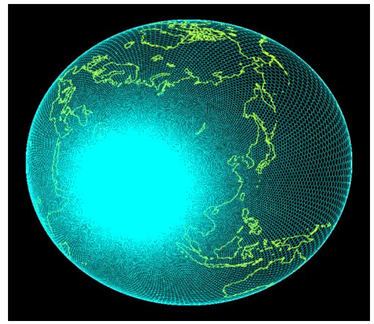
$\mathbf{P}$ Model prediction covariance — 'Spreading out' of information in observation

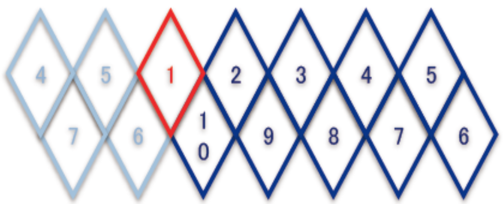
Relative accuracy: observations vs model



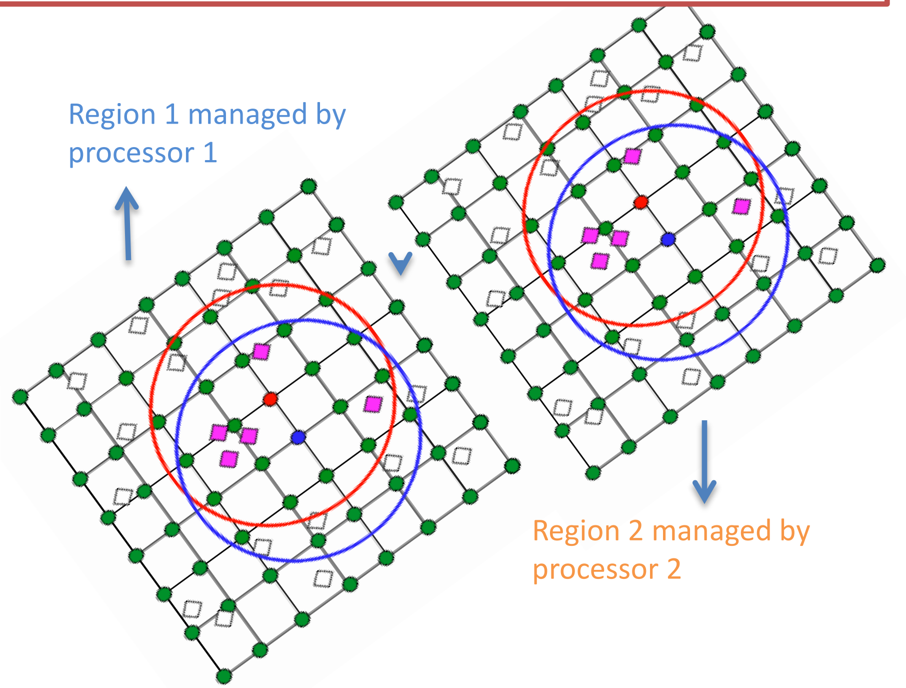
Applying Local Ensemble Transform Kalman Filter (LETKF, Ott et al.2004, Hunt et al., 2007) to NICAM Model







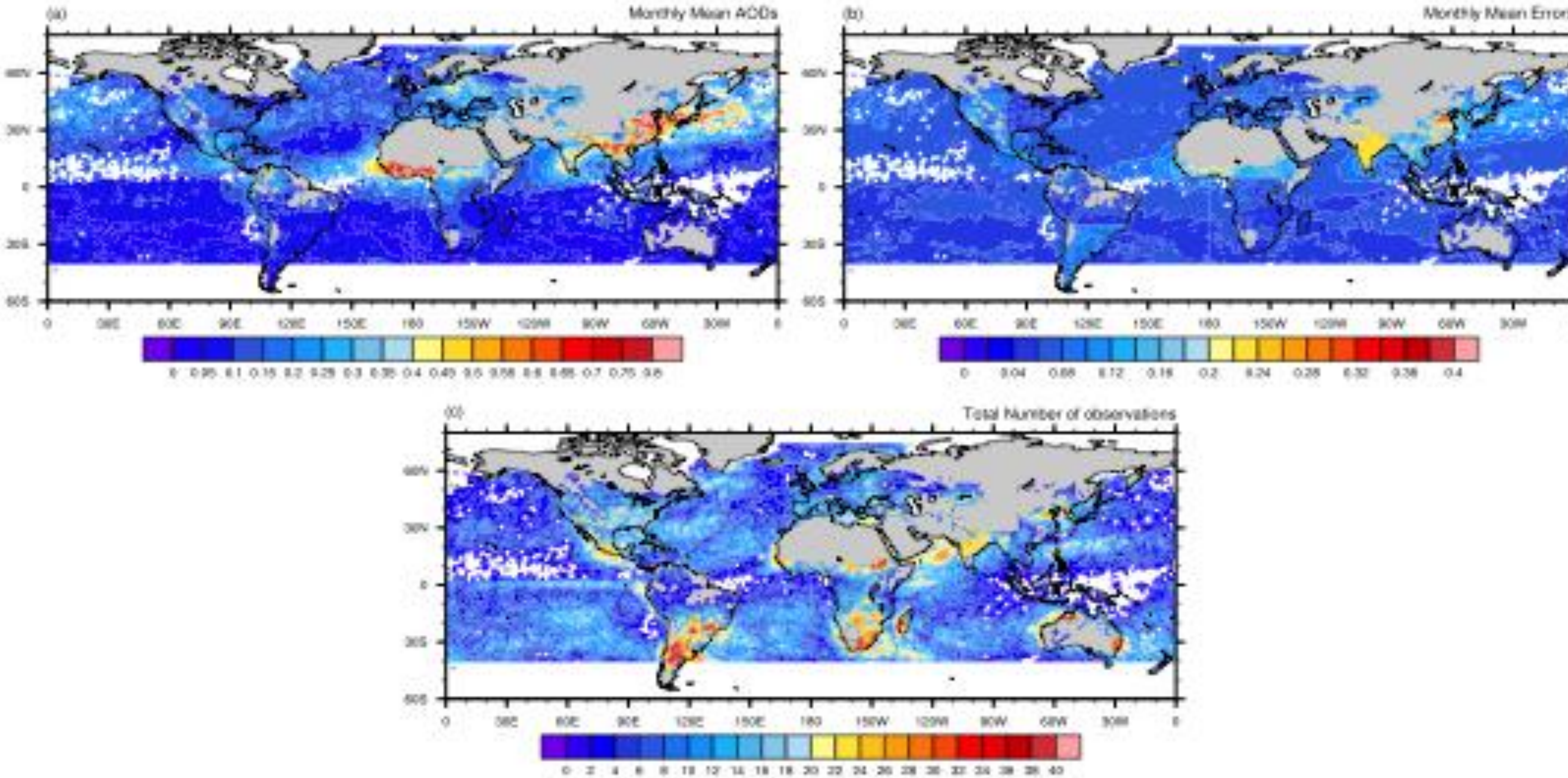
Diamond Cutoff



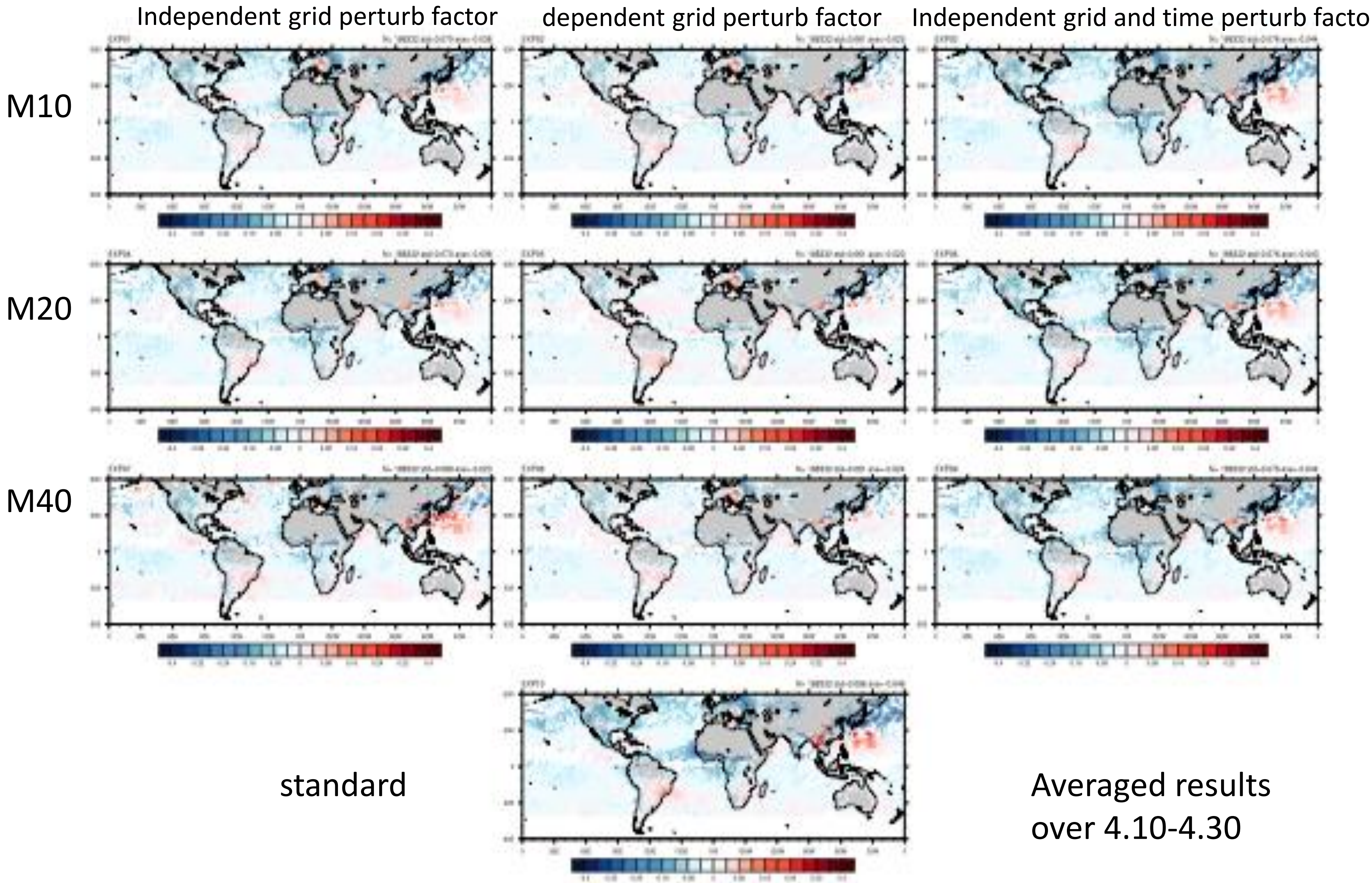
1. The assimilation system uses the some grid and regional system as the forward model (NICAM-SPRINTARS), so it is convenient to use the forward model (including standard, stretched, diamond NICAM) forecast variables.
2. To avoid defining the horizontal boundaries conditions for the LETKF system, the parallelization in our assimilation system was achieved by storing the global assimilated and modeled observations in each processor .
3. In every grid point, each processor assimilate the useful observation based on the distance between the observation site and the grid point.
4. Output the analysis results for the next forward calculation.

General setting of the assimilation experiment

Observations : NRL MODIS L3 AOD data (1degree x 1degree)
Period: 2006.4.1-4.30 from the same initial conditions
Ensemble members: created by taking the standard aerosol emission inventories and modified by the same random factor drawn from a log-normal distribution. The mean and spread of this distribution are both chosen to be 1.

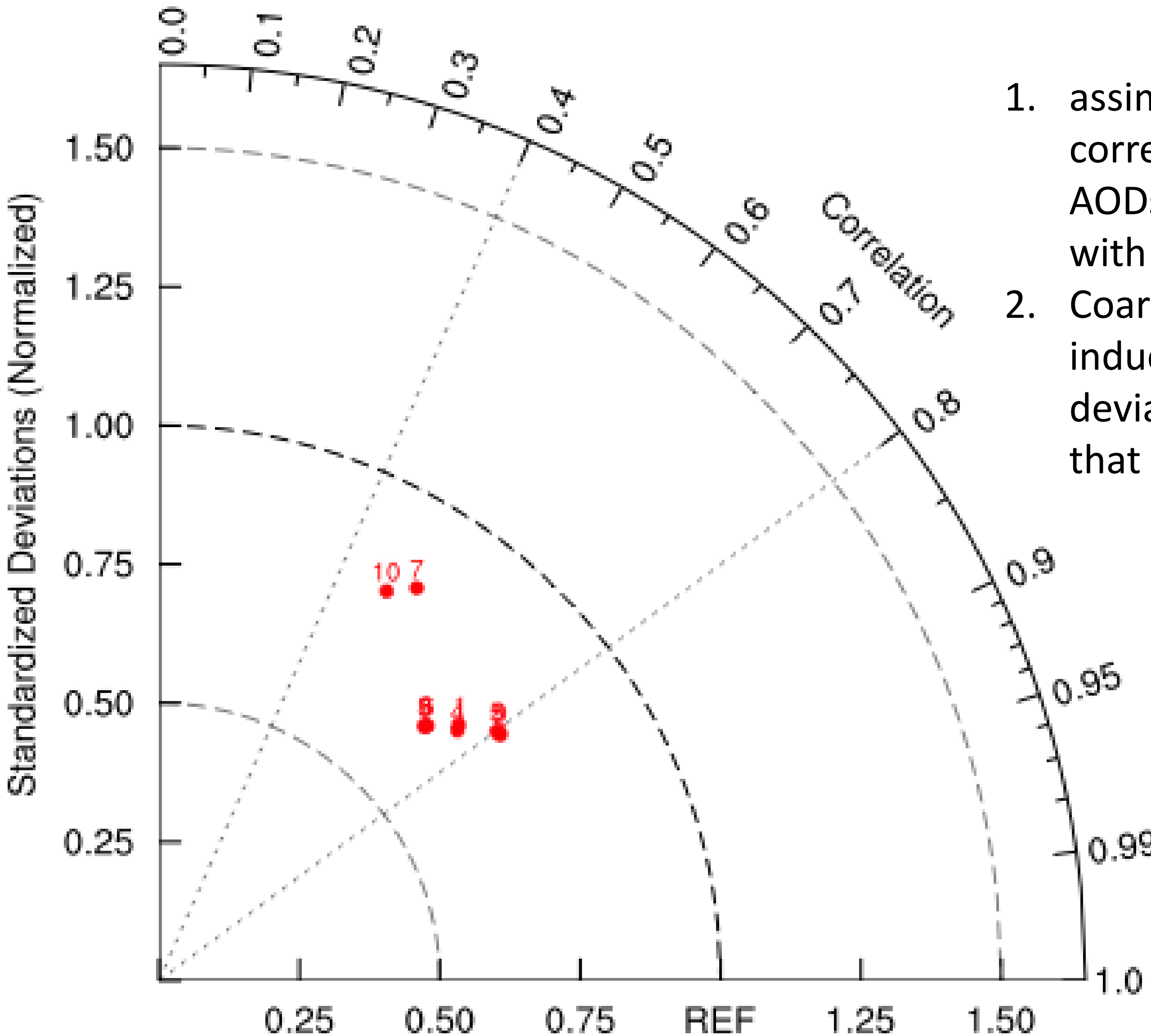


Influence of model spread on the assimilation efficiency



Difference between the simulated AOD and that of MODIS observation

Taylor diagram of the model spread sensitivity study



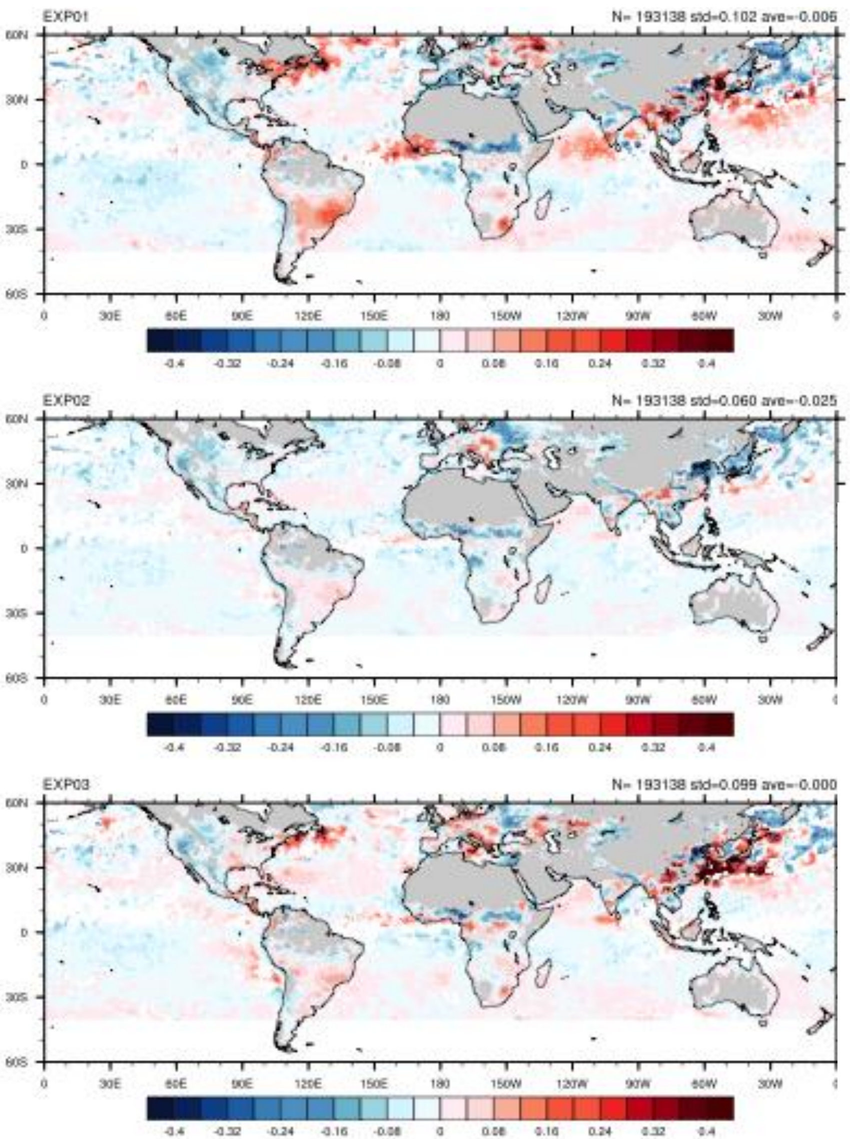
1. assimilation system correctly adjusts modeled AODs to better agreement with the MODIS AODs
2. Coarse model resolution induces the model standard deviation bias lower than that of MODIS

Influence of Local Patch size on the assimilation efficiency

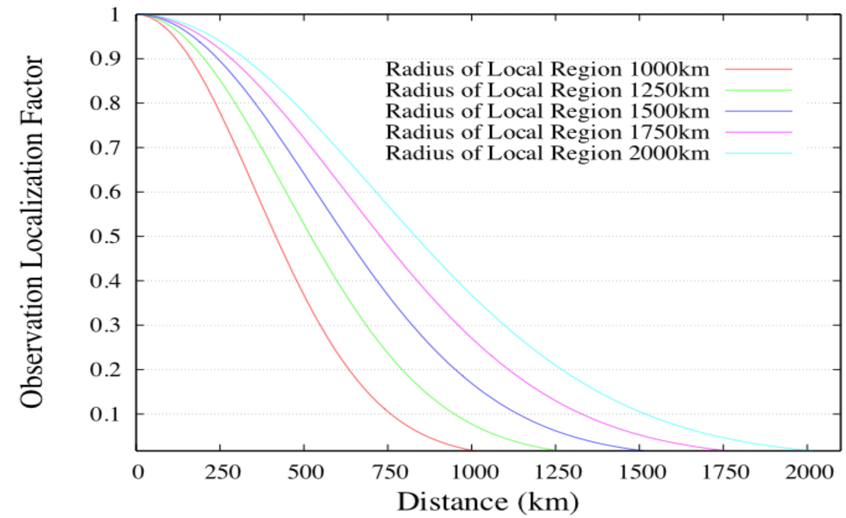
1000km

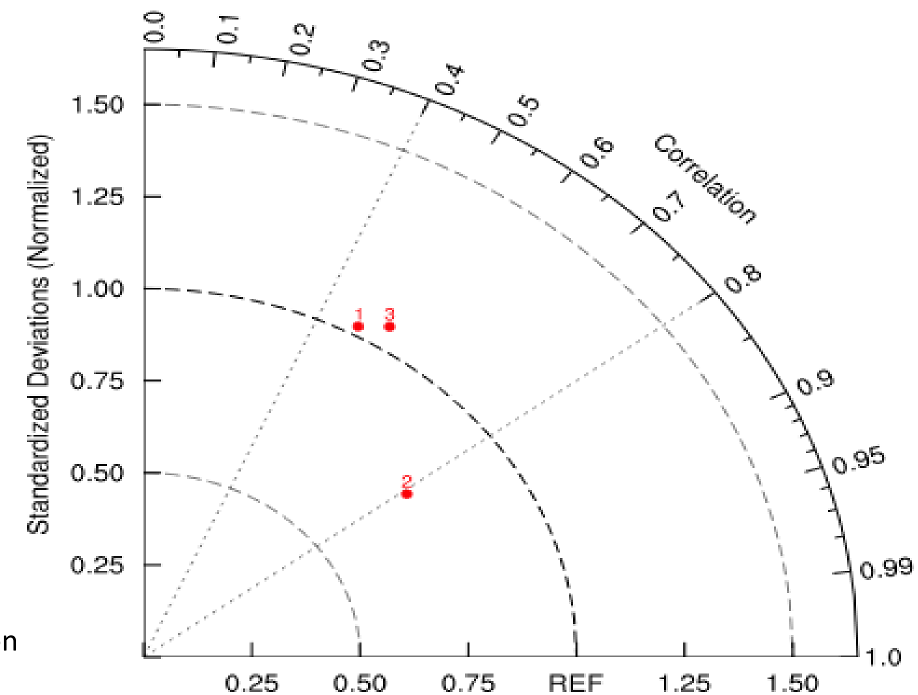
1500km

2000km

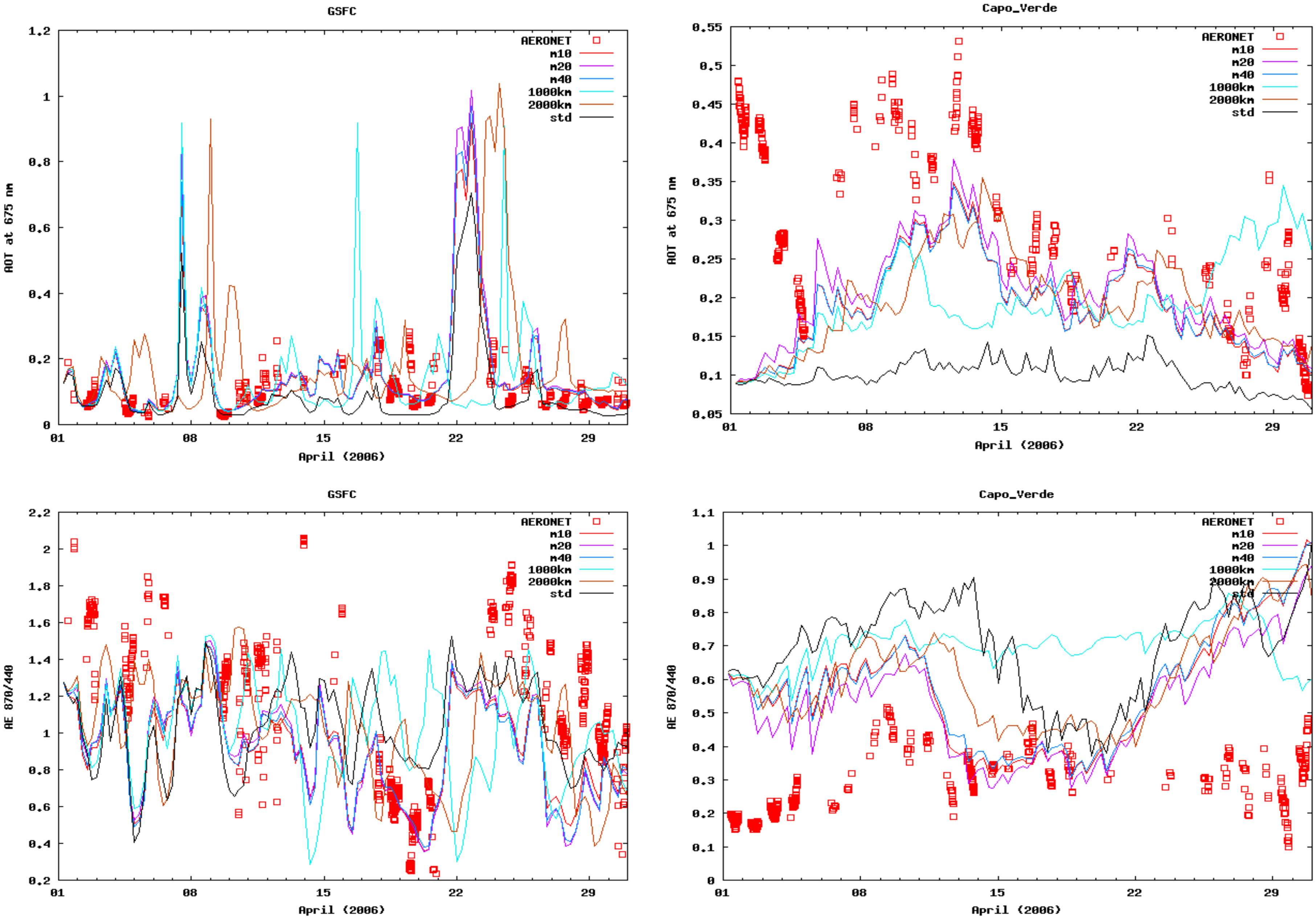


Difference between the simulated AOD and that of MODIS observation





Validation the assimilation results using independent AERONET observation



Summary

1. We implemented an aerosol assimilation system for the cloud-resolving model NICAM with SPRINTARS aerosol module. To avoid defining the horizontal boundaries conditions for the LETKF system, the parallelization in our assimilation system was achieved by storing the global assimilated and modeled observations in each processor
2. Validation experiment shows that the assimilation system correctly adjusts modeled AODs to better agreement with the MODIS AODs, and the assimilation system are lesser sensitive to the ensemble members than the local patch size. It looks 10 ensemble members and local patch size about 1500km with dependent perturb factors could achieve best assimilation results.
3. The comparison with globally distributed independent AERONET observations further illustrated the significantly improved both modeled AODs and AEs by the assimilation.

Thanks for your attention!