Recent (and near-Future) Developments in Aerosol Modelling and Assimilation at NOAA

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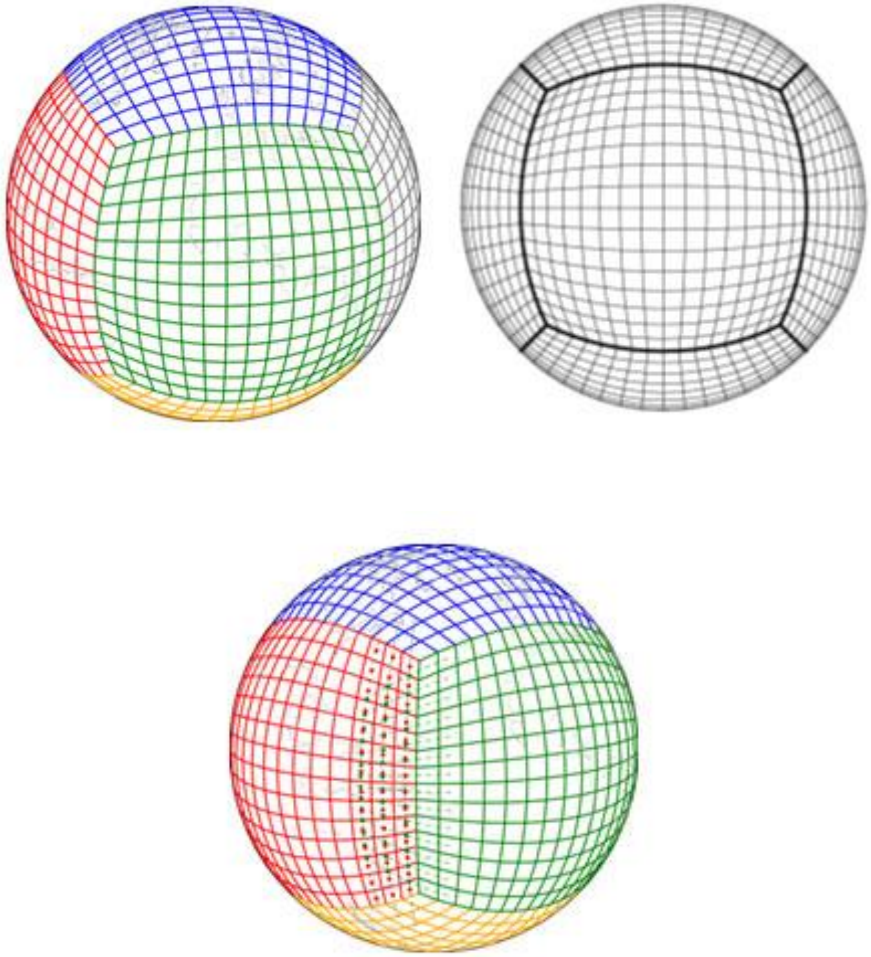
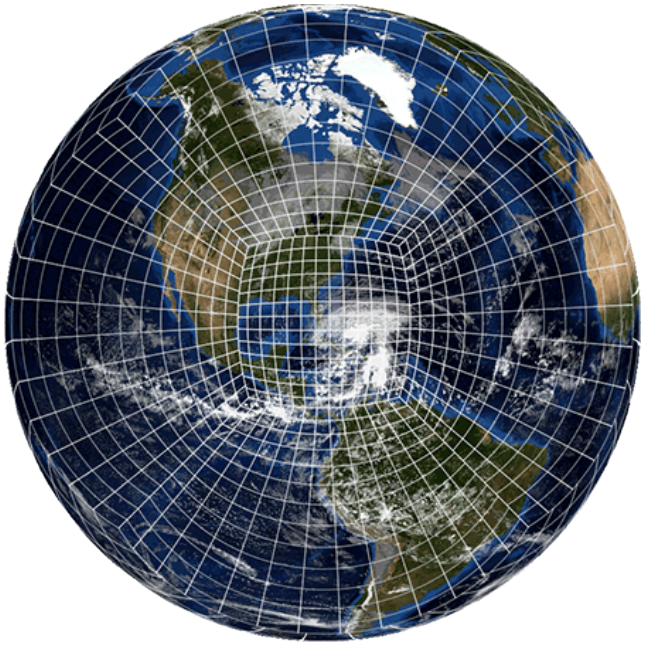
Also with contributions from B. Scherllin-Pirscher (ZAMG), B. Johnson (JCSDA), A. da Silva (NASA/GMAO).

FV3 - the Future NOAA's Weather Model





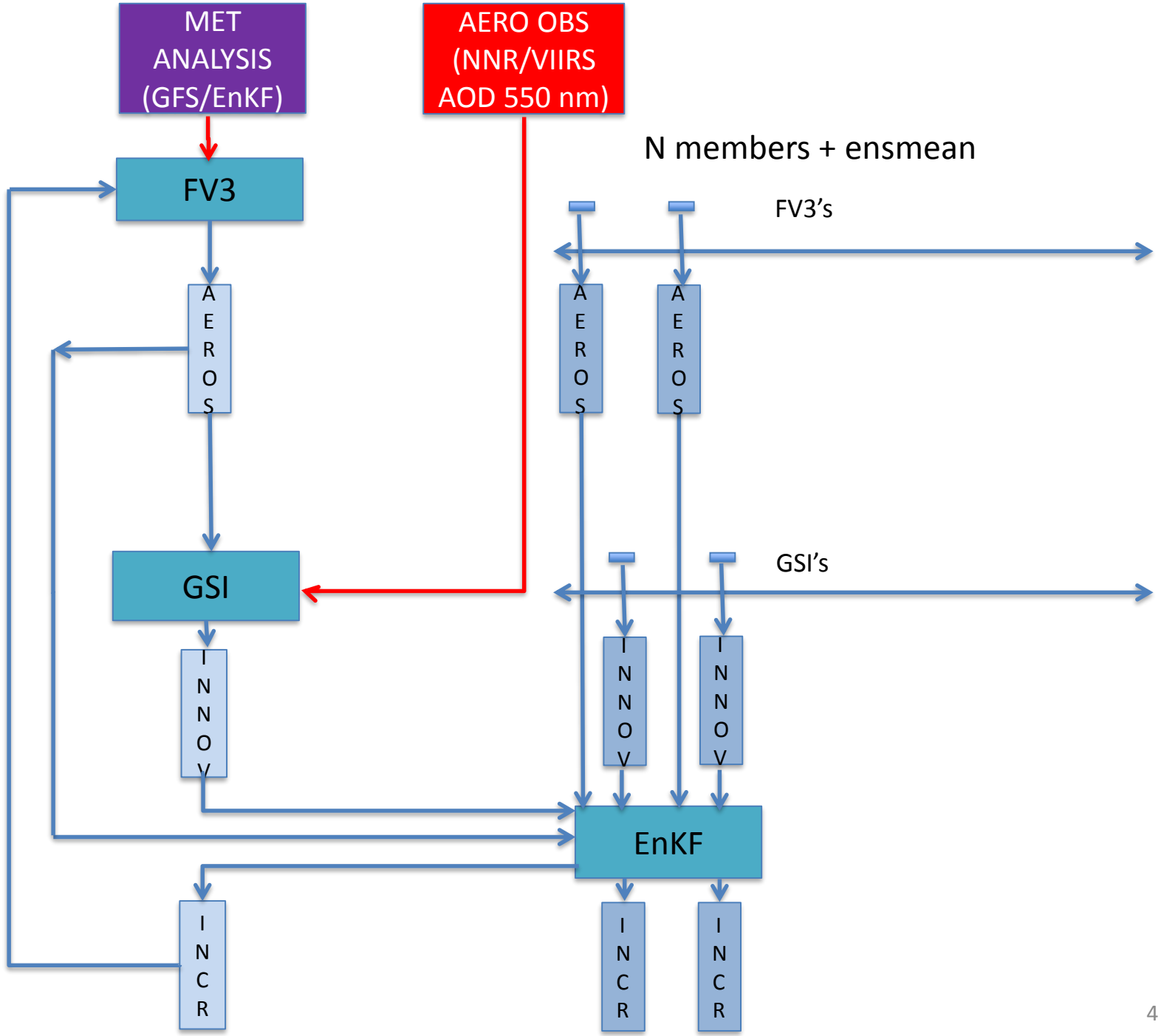
from https://www.gfdl.noaa.gov/fv3/

Developed by S.J. Lin et al. at GFDL. Finite Volume scheme with emphasis on mass/tracer conservation, over the years used in weather and climate models (notably GEOS)

GOCART and its on-line implementation in FV3

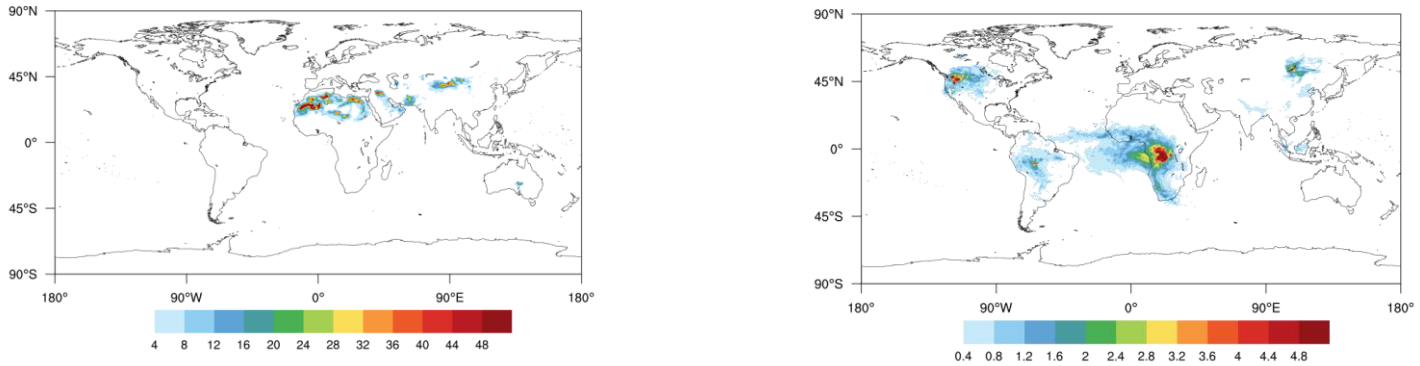
- Based on Chin, Ginoux et al.,
- 15 aerosol species: BC (hydrophobic/phillic), OC (hydrophobic/phillic), sulfate, five dust bins, four sea salt bins, plus unspecified P25.
- 3 gas species: SO_2, DMS, MSA plus climatological backgrounds of H_2O_2, OH, NO_3.
- Emissions:
  - anthropogenic based on EDGAR-HTAP inventory:
    - flat, monthly, no temporal factors, 0.1 deg resolution,
    - BC, OC, sulfate, SO_2, $PM_{2.5}$, PM_{10}, other not relevant for GOCART: NO_x, NH_3, CO, NMVOC
  - biomass burning and plume rise:
    - MODIS, about 4 km resolution, from CPTEC/Brasil, WRF-Chem,
  - dust:
    - AFWA scheme (Jones et al.), erodibility data @ 0.75 deg, and sand/clay data @ 0.08 deg, from WRF-Chem,
  - sea salt:
    - Gong et al., from NASA/NGAC.

- Chemistry: hydrophobic -> hydrophillic carbon by aging plus sulfate production – applied on chemical time step (e.g. 30 mins).
- Physics (mostly GFS defaults with some exceptions due to tracers) – applied on physical time step (e.g. 450 secs at ~ 50 km model):
  - mixing (PBL similarity based, non-local for heat, moisture though not tracers, required some additions including dry deposition and surface and plume emissions, implicit for numerical stability, ALL TRACERS), from GFS,
  - hygroscopic growth of some particles + gravitational settling (AEROSOLS), from NASA/NGAC,
  - Chikira-Sugiyama convective transport (ALL TRACERS) and scavenging (HYDROPHILLIC AEROSOLS), from GFS,
  - wet scavenging by resolved precipitation (HYDROPHILLIC AEROSOLS), from WRF-Chem,


MET ANALYSIS (GFS/EnKF)
AERO OBS (NNR/VIIRS AOD 550 nm)
N members + ensmean
FV3
FV3's
AEROS
AEROS
AEROS
GSI
GSI's
INNOV
INNOV
INNOV
EnKF
INCR
INCR
INCR

Data Assimilation

- NASA's NNR AOD 550 nm (combines MODIS and AERONET) or VIIRS AOD 550 nm retrieval;
- Community Radiative Transfer Model CRTM (JCSDA);
- Gridpoint Statistical Interpolation (GSI, NCEP)
  - forward model on the Gaussian grid - requires interpolation and reformatting C192 (NetCDF) ←→ T382 (NEMSIO),
  - 6-hr cycle with 3-hr window and FGAT;
- Need for source (state) dependent model error:
  - Ensemble Kalman Filter (NCEP operational, Whitaker and Hamill, 2003):
    - 20 members,
    - currently only perturbations to meteorology;

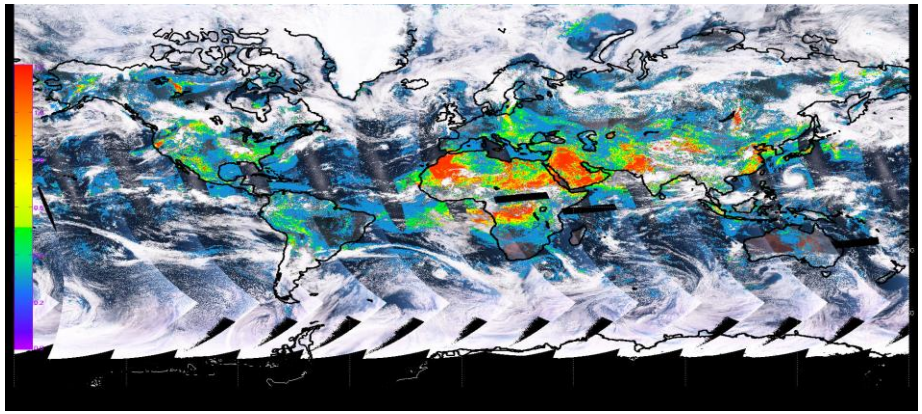


Model standard error deviation of mixing ratios [ug/kg] of fine dust (left) and secondary organic carbon (right) at the bottom level derived from month-long simulations in August 2015 using the NMC method (fcst_24hr-fcst_12hr).

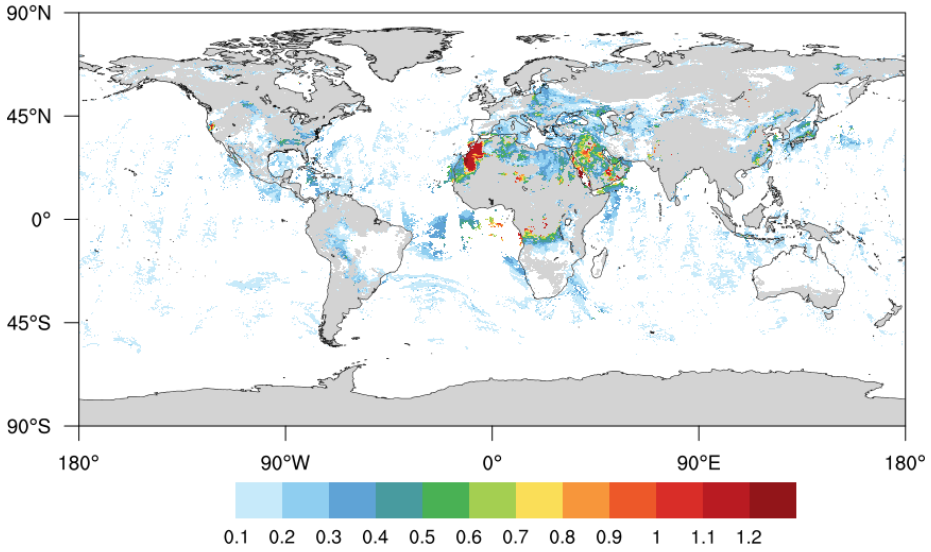
- Realistic for NRT:
  - 9-hr forecast on 96 processors on NOAA's Theia supercomputer less than 10 mins,
  - GSI/EnKF/interpolations in comparable time.

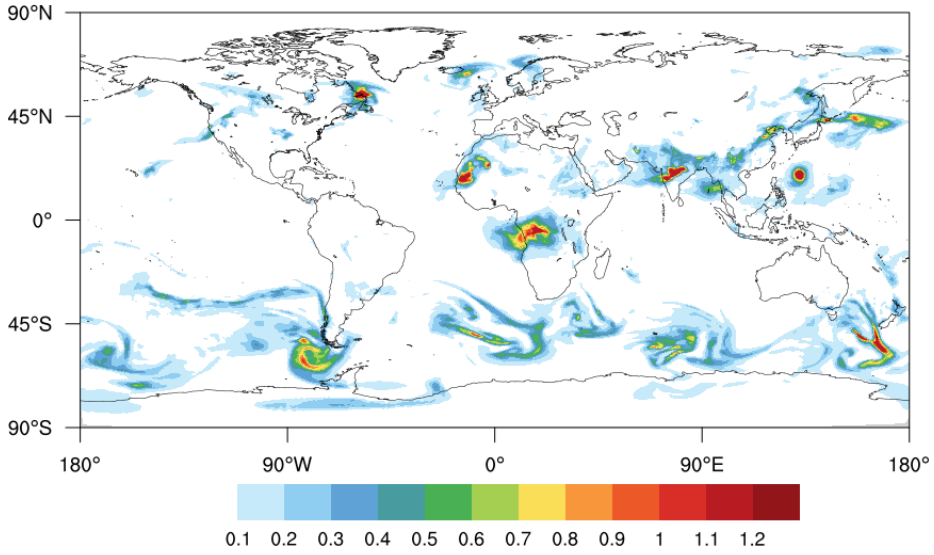
Example: AOD 550 nm 20150805

VIIRS

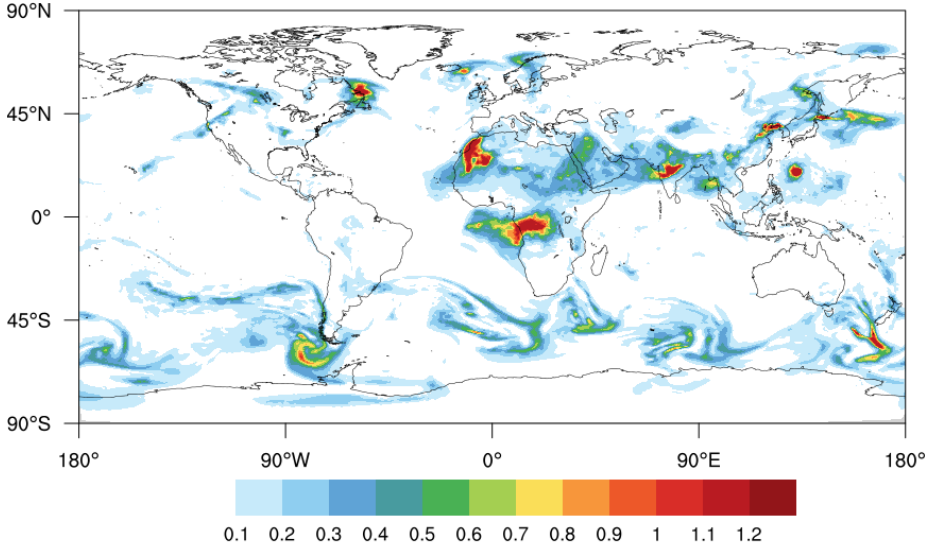


MODIS NNR





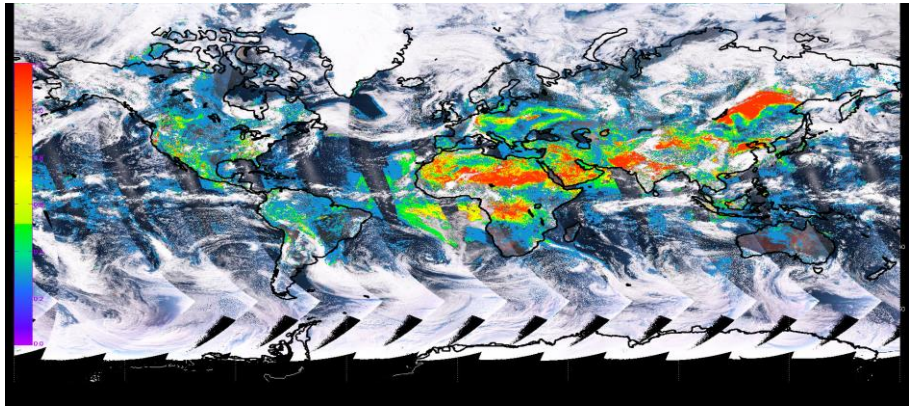
Free-run forecast 12 UTC



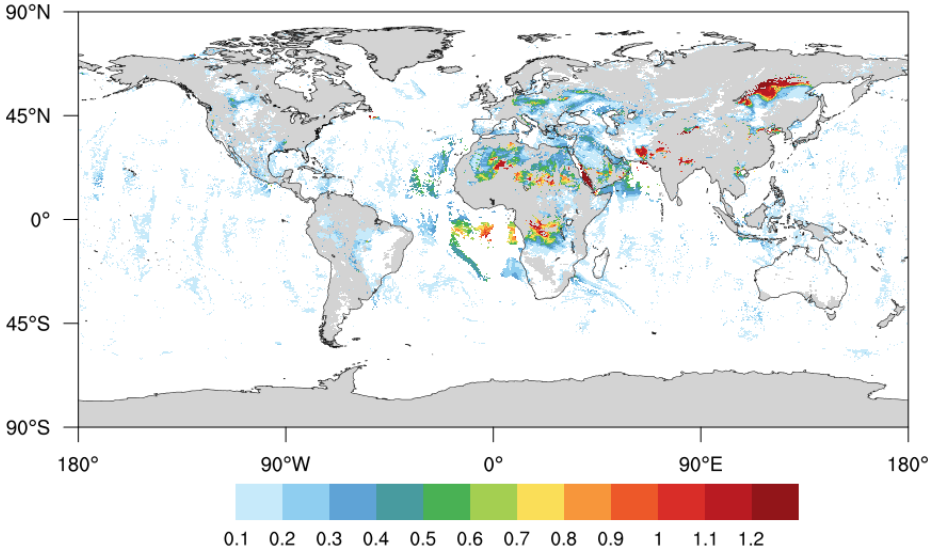
Analysis 12 UTC

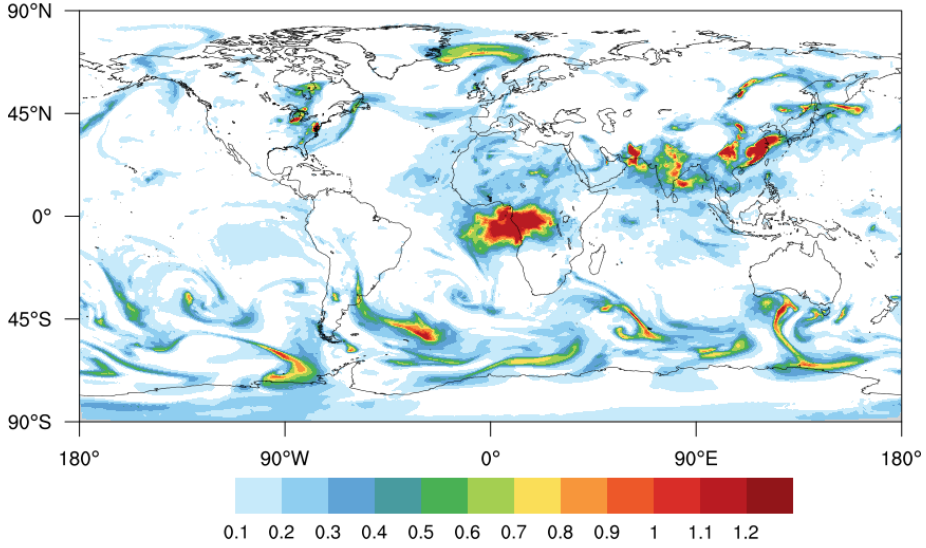
Example: AOD 550 nm 20150810

VIIRS

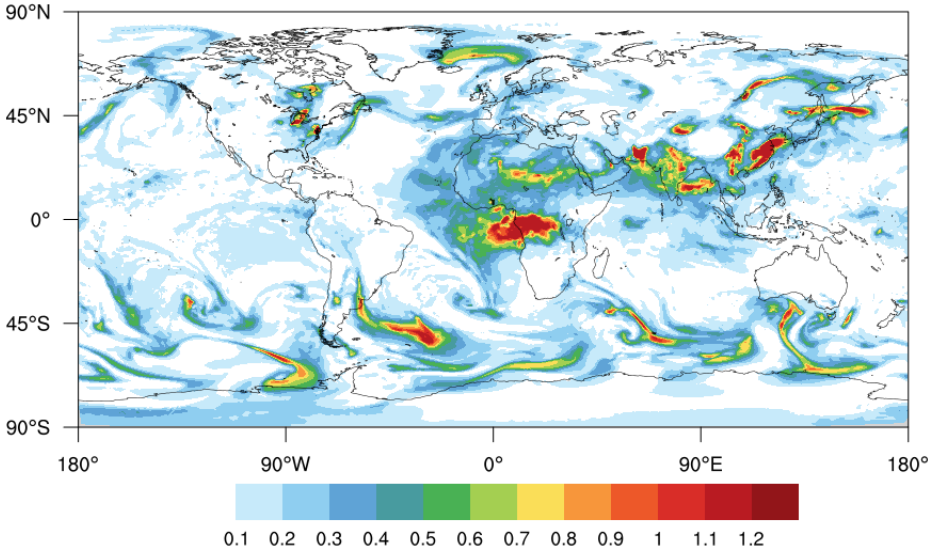


MODIS NNR



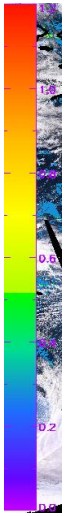


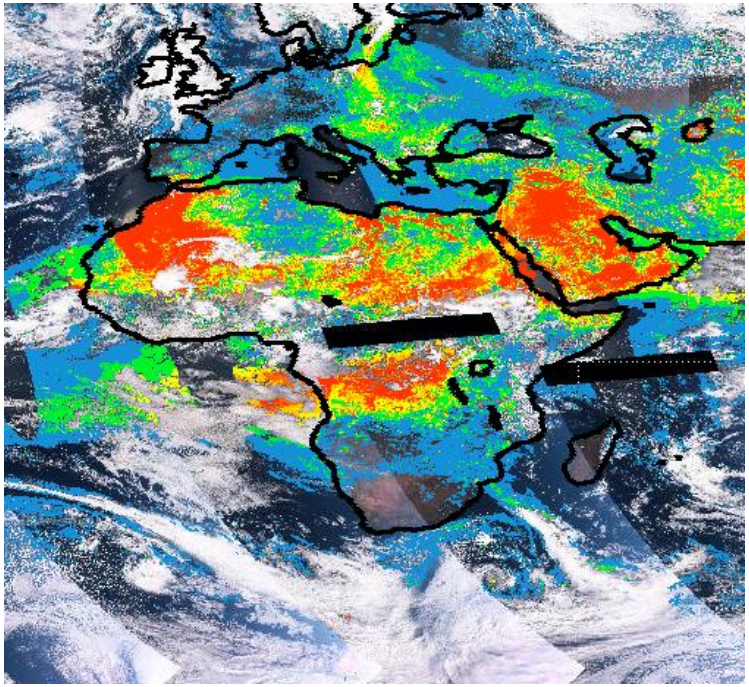
Free-run forecast 12 UTC

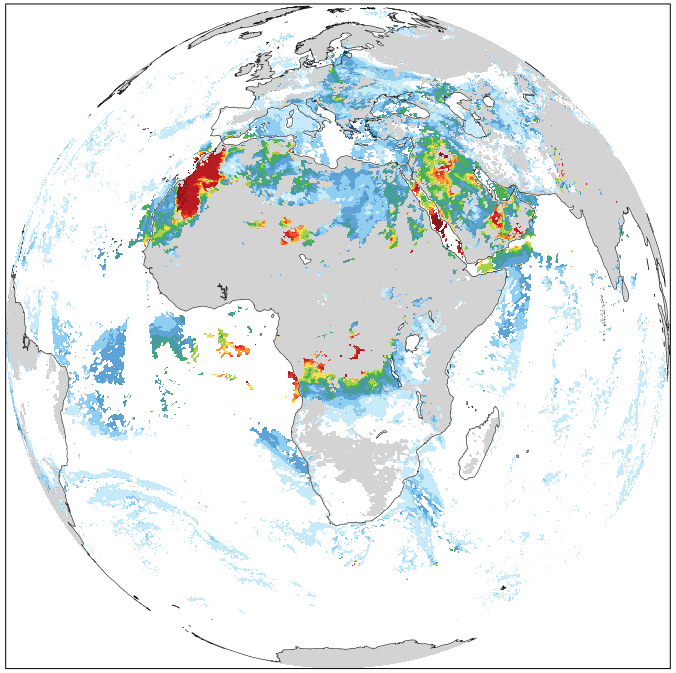


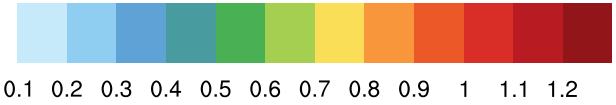
Analysis 12 UTC

VIIRS vs. NNR 20150805



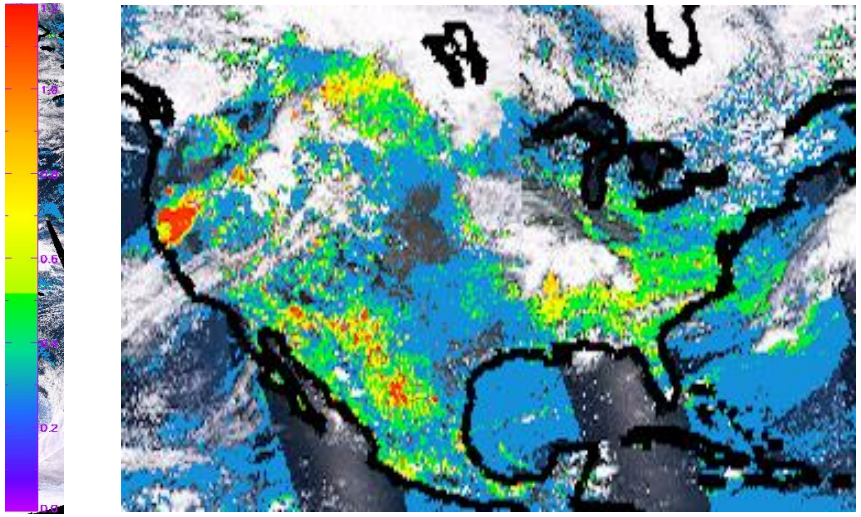


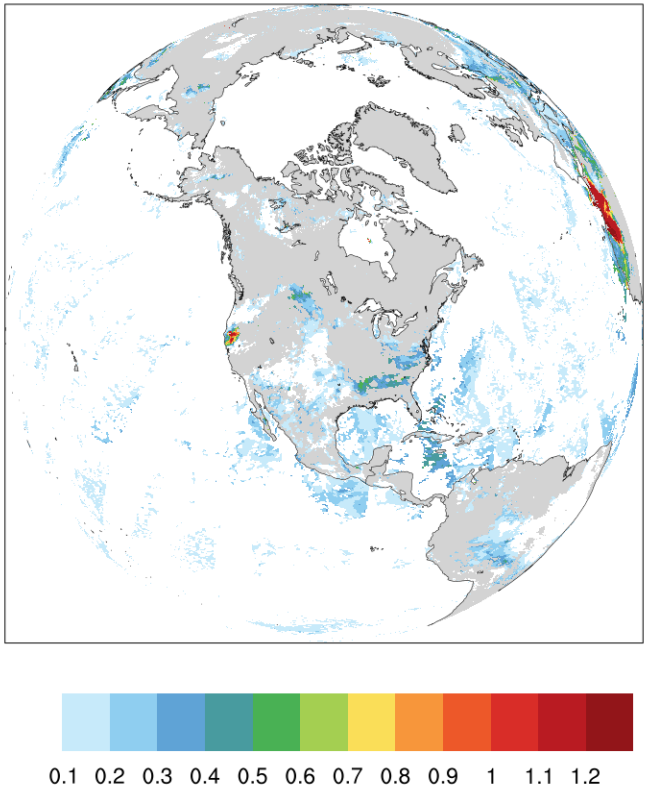




What is real?

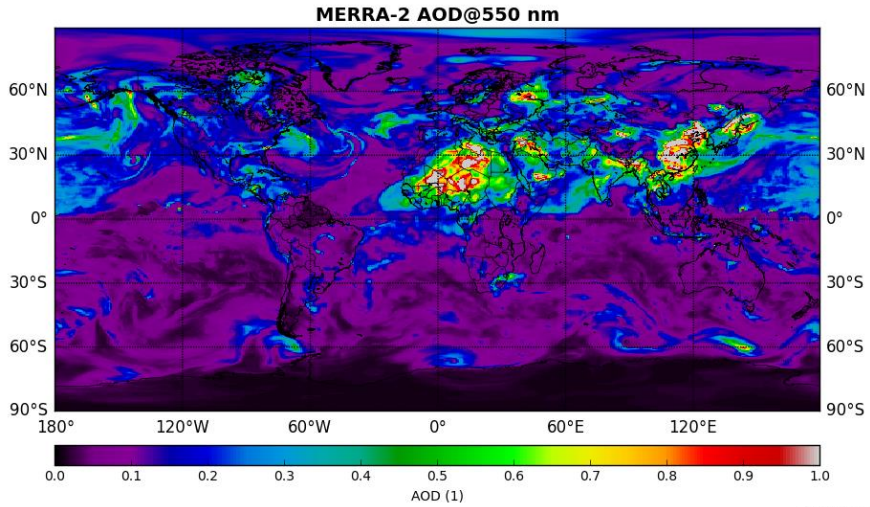
VIIRS vs. NNR 20150805

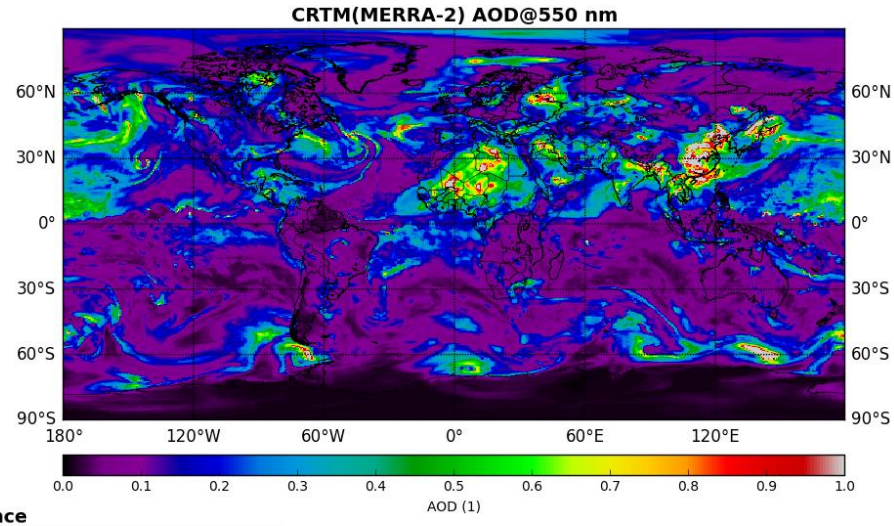


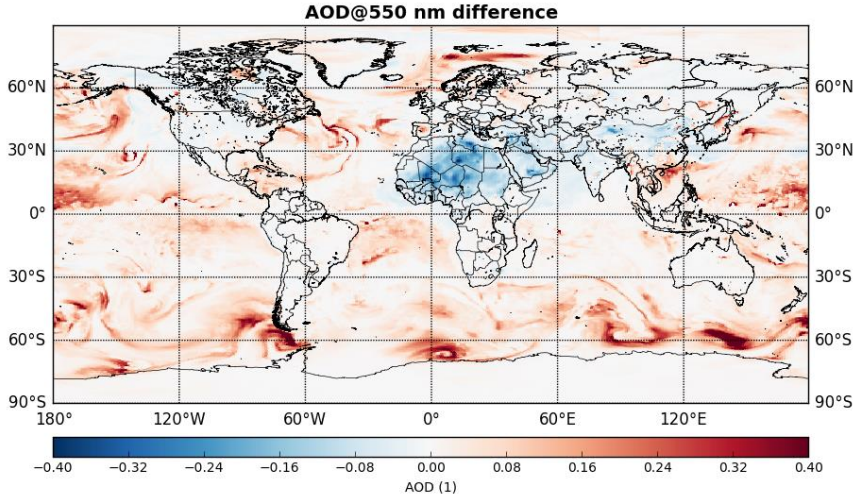


What is real?

MERRA -2 vs. CRTM(MERRA-2 species) 20100417







Possible differences:

- calculation of radii for sea-salt due to hygroscopic growth,
- non-spherical dust in MERRA-2.

What is real?

EnKF and its application to AOD 550 nm assimilation

$$t(\lambda) = \sum_{i=1}^{n} \sum_{k=1}^{ktop} E_{ext}\left(\lambda, n_{r_i}, r_{eff_i}\right) \cdot c_{ik} \cdot r_{d_k} \cdot d_k,$$

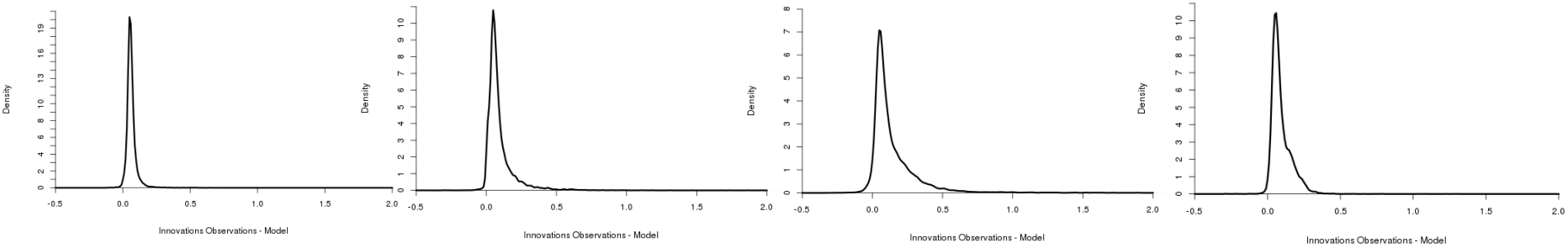
E_{ext} - the extinction coefficient (wavelength λ, refractive index n_r, and effective radius r_{eff}), c - aerosol mixing ratio, d - layer depth, i and k - aerosol species and model layers respectively

$$\Delta c_{ik} \sim \Delta\tau(\lambda)$$

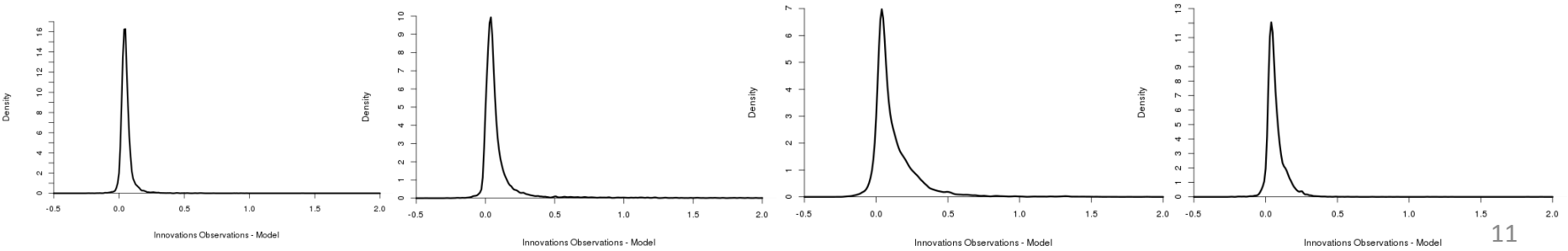
$$\Delta c_{ik} = \mathrm{K} \times [(\tau_O(\lambda) - \tau_M(\lambda)] = \mathrm{K} \times \Delta\tau(\lambda) \text{ and } \Delta\tau(\lambda) \sim \mathcal{N}(0, \sigma^2)$$

20150805

00 UTC | 06 UTC – CENTRAL ASIA | 12 UTC – AFRICA | 18 UTC – AMERICAS



20150810



EnKF and its application to AOD 550 nm assimilation

$$\mathrm{T} = \log(\tau + B)\,, \Delta\mathrm{T} = \Delta\tau/(\tau + B)$$

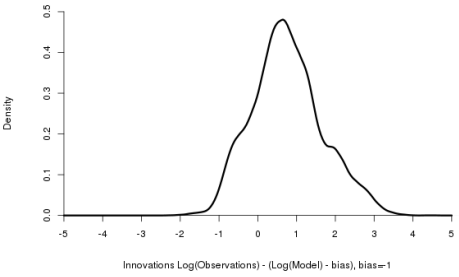
$$\Delta c = \mathrm{K} \times \Delta\tau = \mathrm{K} \times \Delta\mathrm{T} \times (\tau + B)$$

$$\Delta c/(\tau + B) = \mathrm{K} \times \Delta\mathrm{T}, \text{and } \Delta\mathrm{T} \sim \mathcal{N}(0, \sigma^2)$$

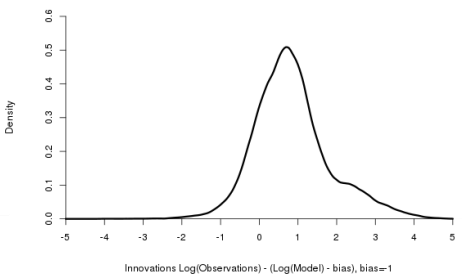
(May be problematic for other moments ?)

20150805

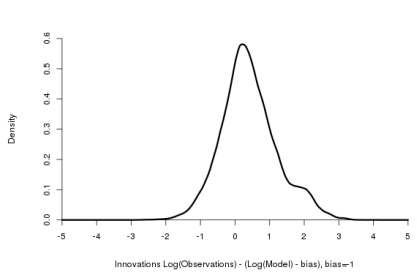
00 UTC



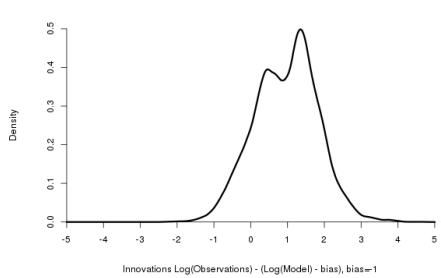
06 UTC – CENTRAL ASIA



12 UTC – AFRICA



18 UTC – AMERICAS



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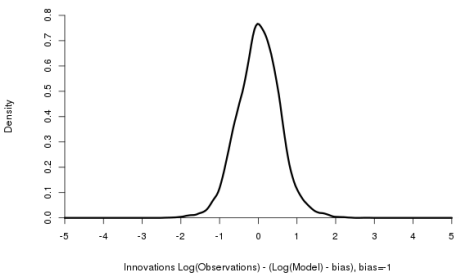
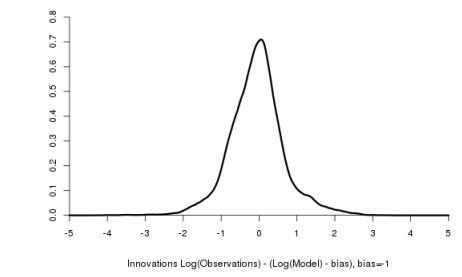
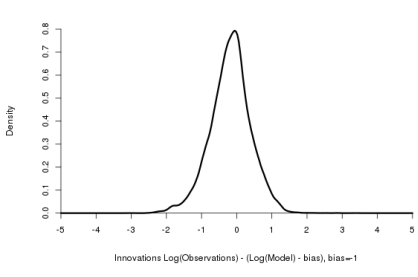
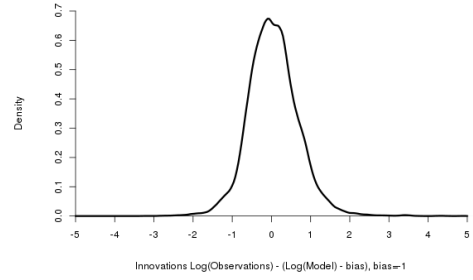






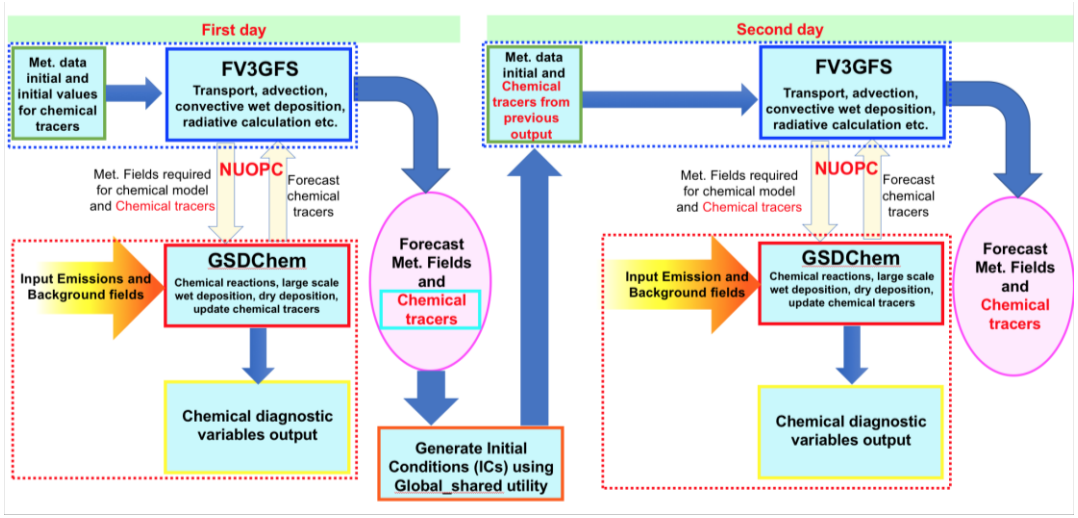


What are we doing now?

- Chemical model development
  - coupling aerosols/chemistry with meteorology via NUOPC interface;
  - various flavors of GOCART (incl. nitrate, brown carbon);
  - photochemical gas-phase mechanism RACM with GOCART;
  - RACM with secondary organic aerosols;
  - CMAQ.
- Data assimilation
  - addressing deficiencies of EnKF approach;
  - JEDI project;
  - enhancing aerosol radiative transfer model (CRTM):
    - flexible size distribution incl. variable modes, variance and mean,
    - flexible chemical composition,
    - non-spherical particle shapes,
    - coagulation (external vs. internal mixture),
    - UV;
  - aerosol reanalysis (joint with NASA/GMAO);
  - trace gases (CO, …).

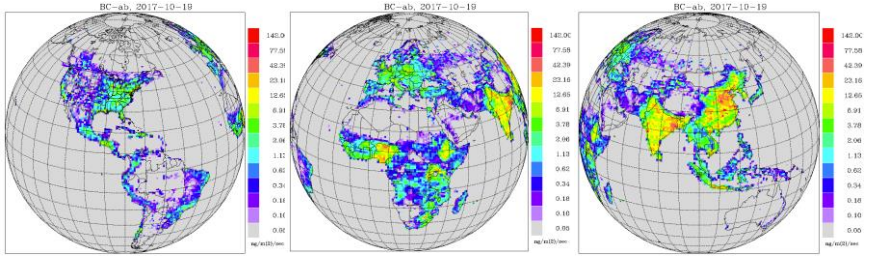
Chemical model development

FV3-Chem coupled structure

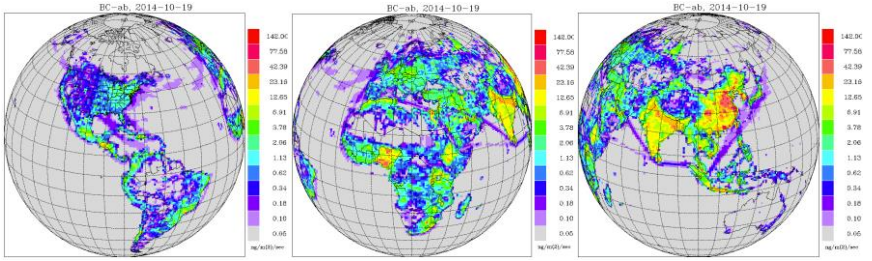


Anthropogenic emission sources based on new emission inventories

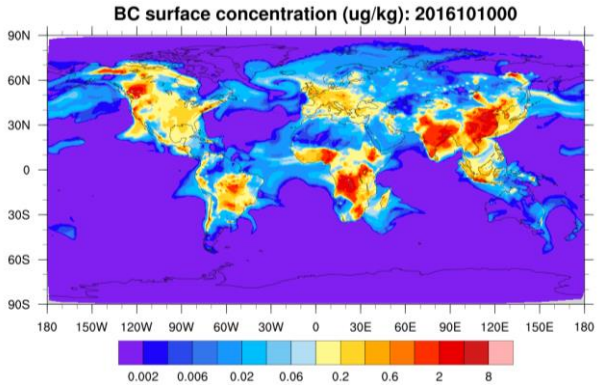
Black Carbon
HTAP 2010

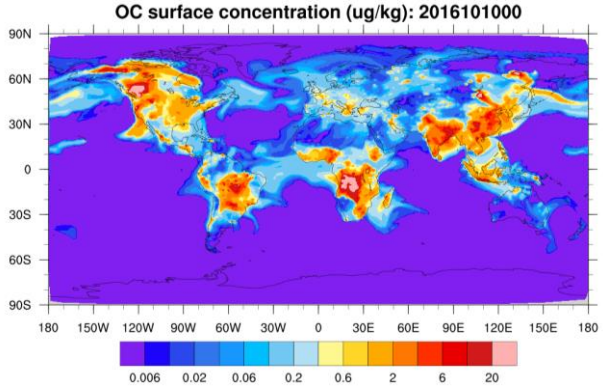


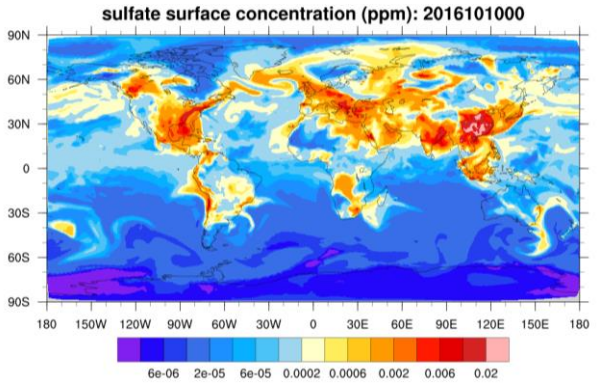
Black Carbon
CEDS 2014

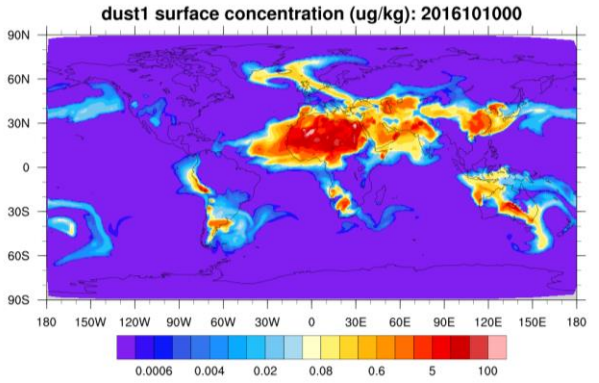


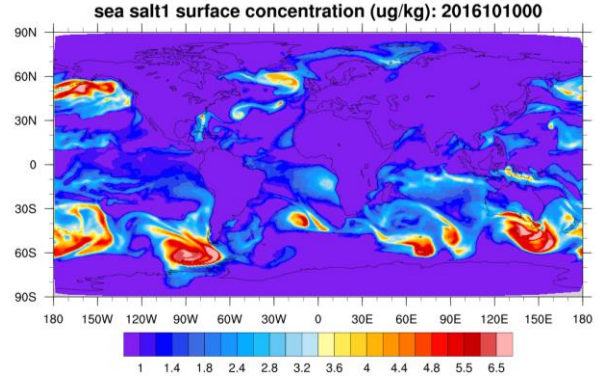
FV3-Chem

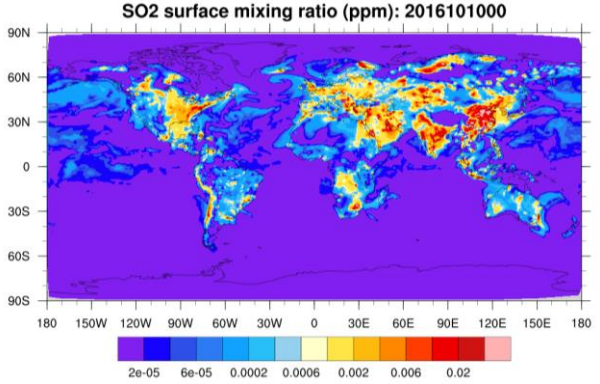








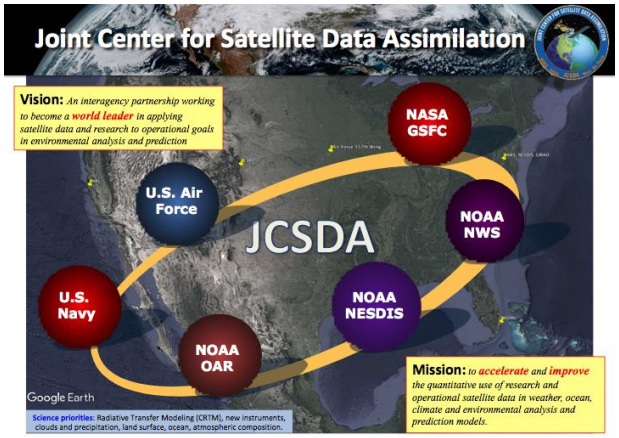




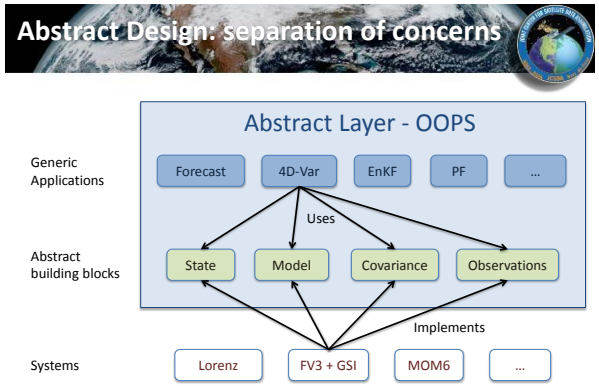
Seven-day forecast at 2016101000

Data Assimilation

JEDI (Joint Effort for Data Assimilation Integration)



From T. Auligne's and Y. Tremolet's presentations at May 2018 JCSDA meeting



Abstract interfaces are the most important aspect of the design

- AOD operator coded using CRTM in UFO (United Forward Operator);
- CALIPSO and ground lidar backscatter (B. Scherllin-Pirscher, ZAMG, and B. Johnson, JCSDA);
- 3D/4D-EnsVar with FV3-GOCART available in a year (or sooner).