Chemical Weather Predictions and Sensitivity of Dust Emissions to Aerosols Using a Global Online Coupled Modeling System

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Motivation

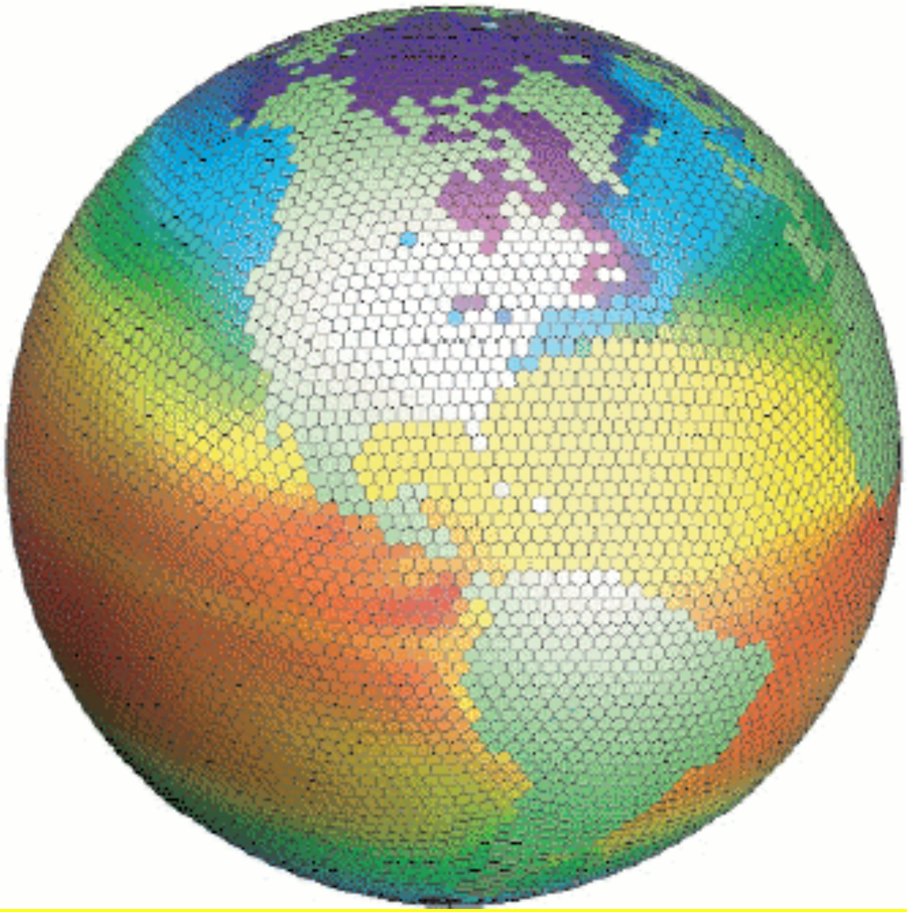
Development of chemical weather forecast

Raise concerns about the impacts of more complex chemistry on weather forecast and climate

Evaluate the chemical weather forecast and estimate the sensitivities of dust emissions to aerosol feedback using global weather prediction model online coupled with aerosol and gas-phase chemistry schemes of different complexity.

FIM: Flow-following- finite-volume Icosahedral Model

soccer-ball like icosahedral horizontal grid



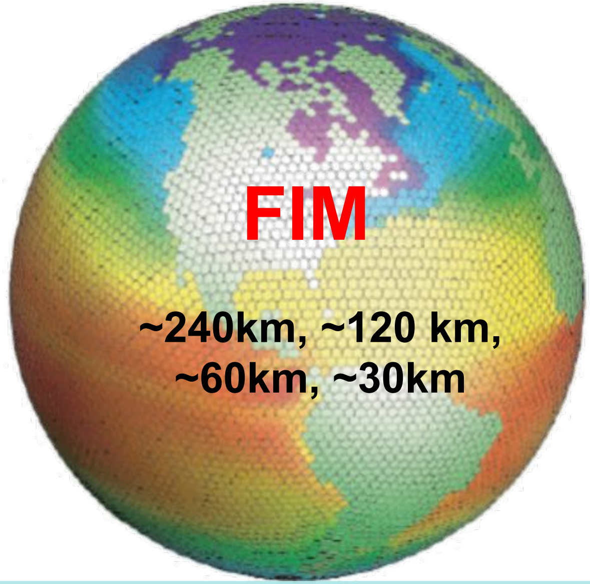
A unique combination of three numerical design features

- **Icosahedral horizontal grid, mostly hexagons except for 12 pentagons ("I" in FIM)**
- **Isentropic-sigma hybrid vertical coordinate, adaptive, concentrates around frontal zones, tropopause, similar to RUC model ("F" for Flow-following in FIM)**
- **Finite-volume horizontal transport (Also under "F", for "finite-volume" in FIM)**

FIM will be replaced with FV3, non-hydrostatic finite volume (NGGPS selected dynamic core)

Current Modeling System (FIM-Chem)

Meteorological fields (P, T, U, V, Q etc.), dynamic core and GFS physics package



Aerosols direct and semi direct feedback, that impact on changing the meteorological fields

Online coupled

Short-term chemical weather forecast and long-term simulation

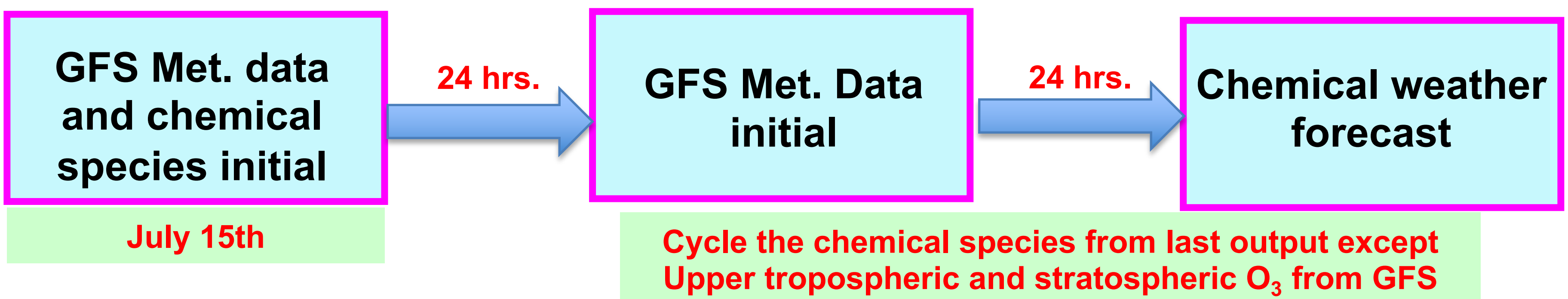
Coupled chemistry suites!

Simplest aerosol modules are from the GOCART model that includes only simplified sulfur chemistry.	**Photochemical gas-phase mechanism RACM included to determine the impact of the additional complexity on the aerosols simulations.**	**More sophisticated aerosol modules include secondary organic aerosols (SOA) based on the VBS approach.**	**Operational CMAQ EPA modules in progress (CB05, AERO), NGGPS/EPA project**
GOCART	GOCART-RACM	RACM-SOA-VBS	

FIM to be replaced with NGGPS core (FV3) as early as this summer

Model Chemical Weather Forecast

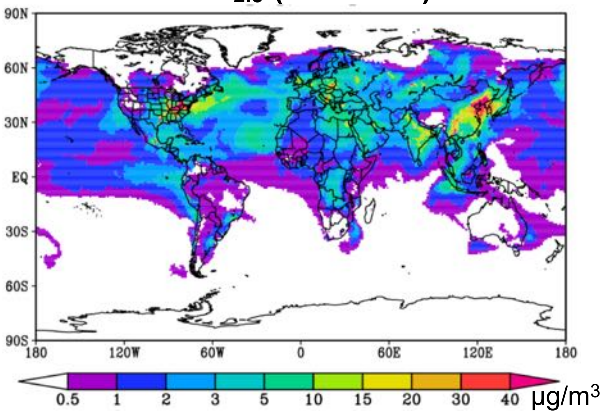
- Initial Met. fields: Global forecast system (GFS) provide the meteorological initial.
- Chemistry: Deposition and atmospheric chemistry routines are from WRF-Chem. GOCART, GOCART-RACM, RACM-SOA-VBS.
- Emission: HTAP anthropogenic emission. 3BEM fires globally and replaced by WFABBA for the America, plumerise for wildfires. MEGAN biogenic emissions. Volcanic ash.
- AFWA Dust Scheme : Five dust size bins; Marticorena and Bergametti scheme provide bulk vertical dust flux; Particle size distribution is based on Kok 2010 (PNAS), the brittle material fragmentation theory.
- FENGSHA Dust Scheme: can also be made available (initial results are as promising as tuned AFWA module, easily implementable module now available and running in HRRR)



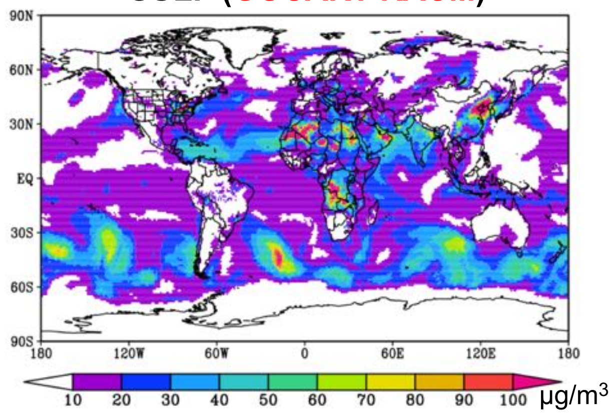
- Real-time prediction on the WEB will start to include gas-phase chemistry (http://fim.noaa.gov)
- Also, we are now starting to test FIM-Chem as “Earth-Analyser”: multidecadal simulations for CO2, CH4, and SF6

Chemical Weather Forecast using Different Aerosol and gas-phase chemistry, 06Z, 07/29/2016

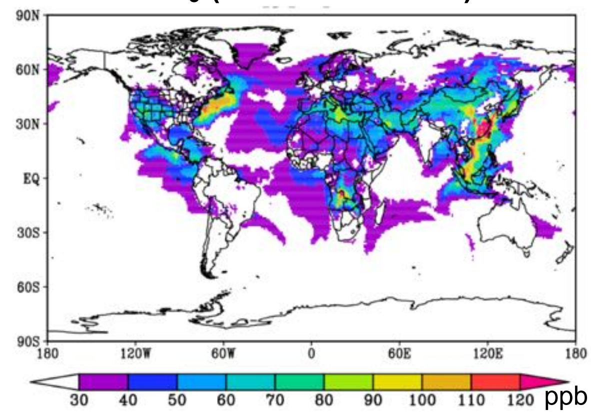
$PM_{2.5}$ (GOCART)



SULF (GOCART-RACM)

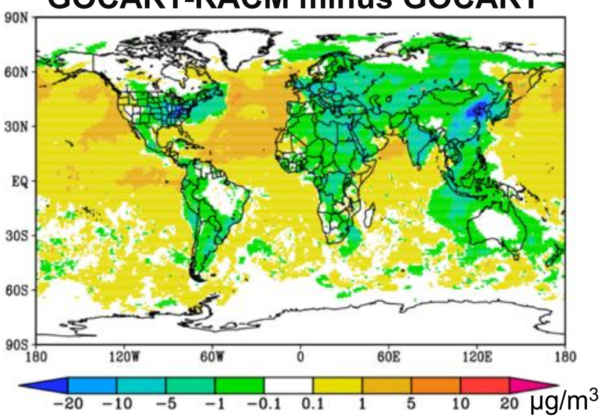


O_3 (GOCART-RACM)

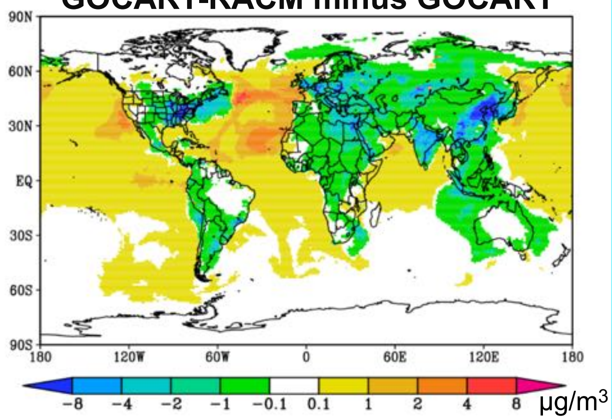


Differences

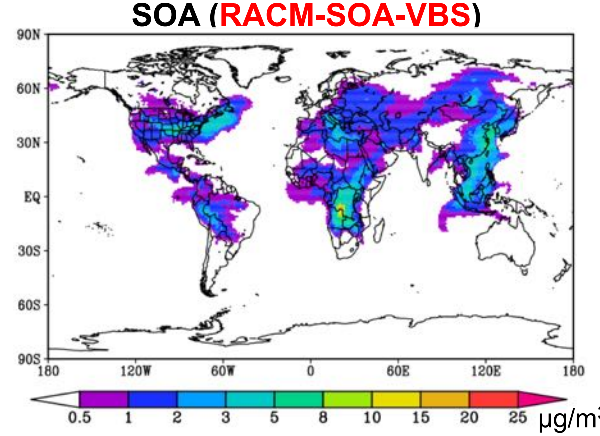
GOCART-RACM minus GOCART



GOCART-RACM minus GOCART



SOA (RACM-SOA-VBS)



About 10 μg/m³ decrease for sulfate and $PM_{2.5}$ in the southeast U.S. and more than 20 μg/m³ $PM_{2.5}$ decrease over Eastern China.

Computer cost: 160 cores, ~ 120 km:

- GOCART: 19 tracers, ~ 4 mins / 24 hrs
- GOCART_RACM: 66 tracers, ~19 mins / 24 hrs
- RACM_SOA_VBS: 103 tracers, ~22 mins / 24 hrs

ATom

The Atmospheric Tomography Mission (ATom) will study the impact of human-produced air pollution on greenhouse gases and on chemically reactive gases in the atmosphere. ATom deploys an extensive gas and aerosol payload on the NASA DC-8 aircraft for systematic, global-scale sampling of the atmosphere, profiling continuously from 0.2 to 12 km altitude.

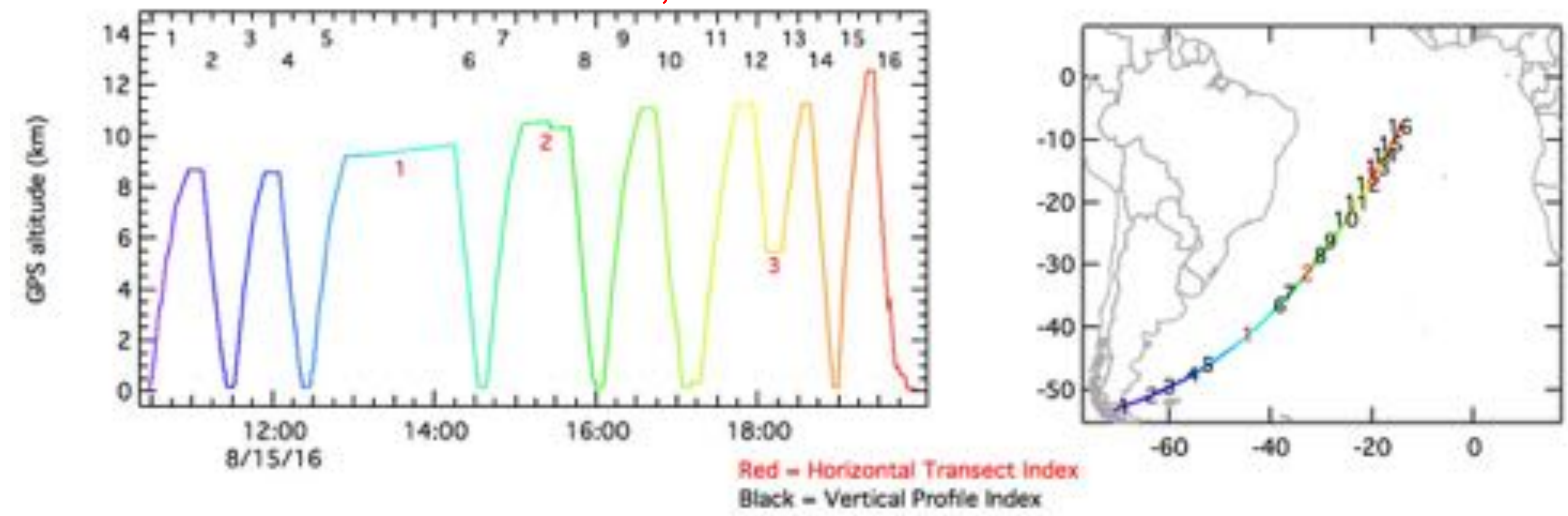
2 days of preliminary data are used here (ftp://ftpanon.al.noaa.gov/pickup)
Public release of ATom-1 data will be July, 2017 through NASA/Langley.

NOAA/ESRL Measurements:

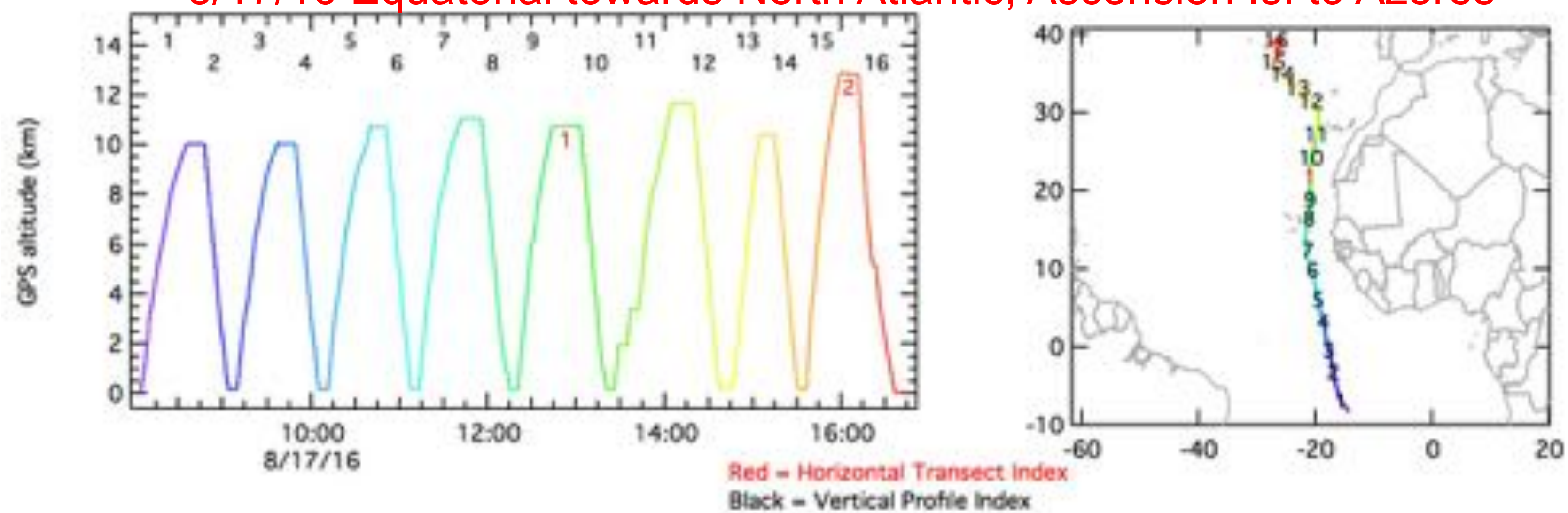
- SP2: The Single Particle Soot Photometer (SP2) uses laser-induced incandescence to measure the mass of individual black carbon particles in the atmosphere. The mass range of SP2 is 3-300 fg (0.15–0.7 mm volume equivalent diameter). EC
- PALMS: The Particle Analysis by Laser Mass Spectrometry (PALMS) instrument continuously measures the chemical composition (refractory and nonrefractory components including organics and salts) of atmospheric particles on a single-particle basis. Dust, Sea salt
- NOAA ESRL/CSD: O_3, NOAA ESRL/GMD: CO (Colm Sweeney and Kathy McClain)

ATom Flight Tracks

8/15/16 South Atlantic, Punta Arenas to Ascension Is.



8/17/16 Equatorial towards North Atlantic, Ascension Is. to Azores



Comparisons of Aerosols between FIM-Chem and ATom

8/15/2016 and 8/17/2016

Height Vs. Latitude

Dust

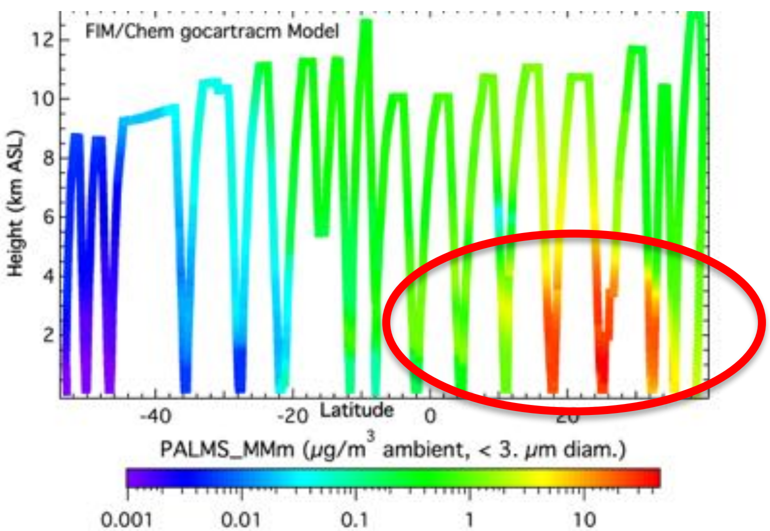
Preliminary data

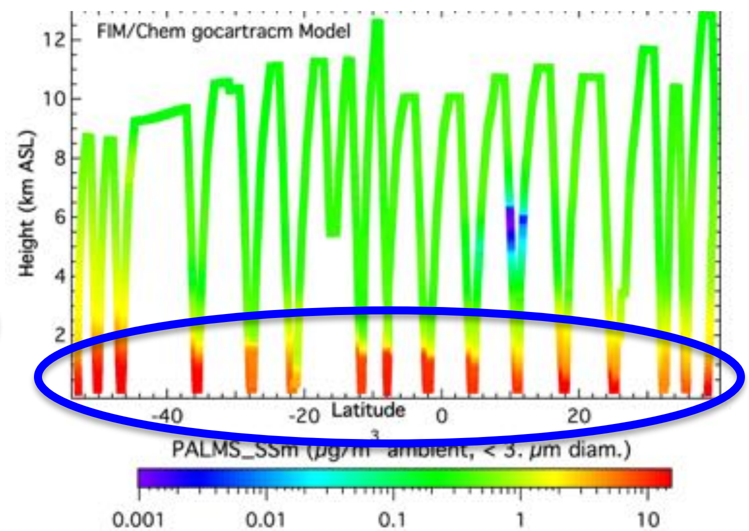
Sea salt

Preliminary data

ATom

GOCART_RACM





- Dust plumes are reproduce by the model but underestimate the wet removal at the upper level.
- GOCART sea salt algorithm is too high

Comparisons of Aerosol and Gas Tracers between FIM-Chem and ATom

8/15/2016 and 8/17/2016

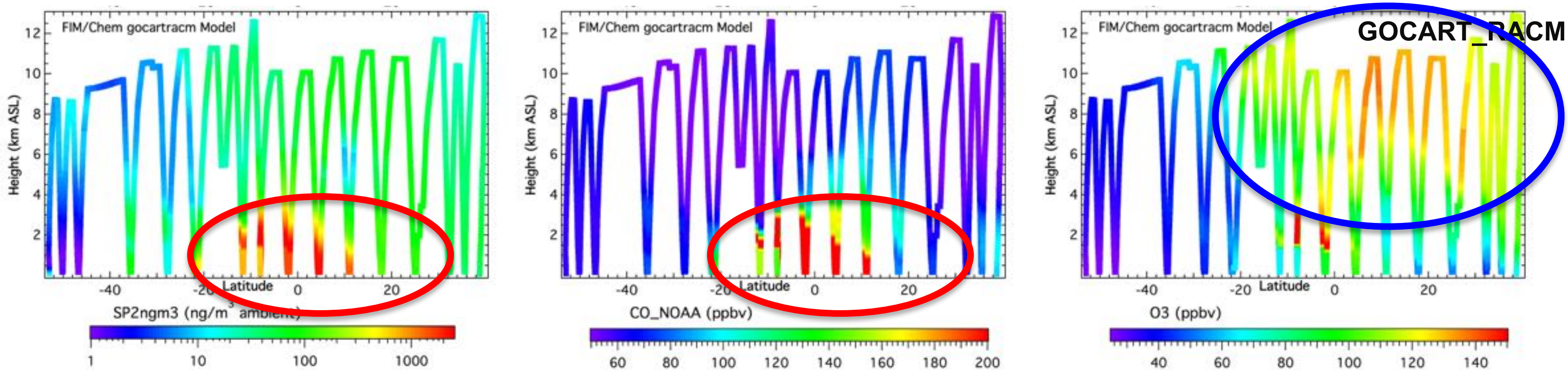
Height Vs. Latitude

EC Preliminary data

CO Preliminary data

O_3 Preliminary data

ATom

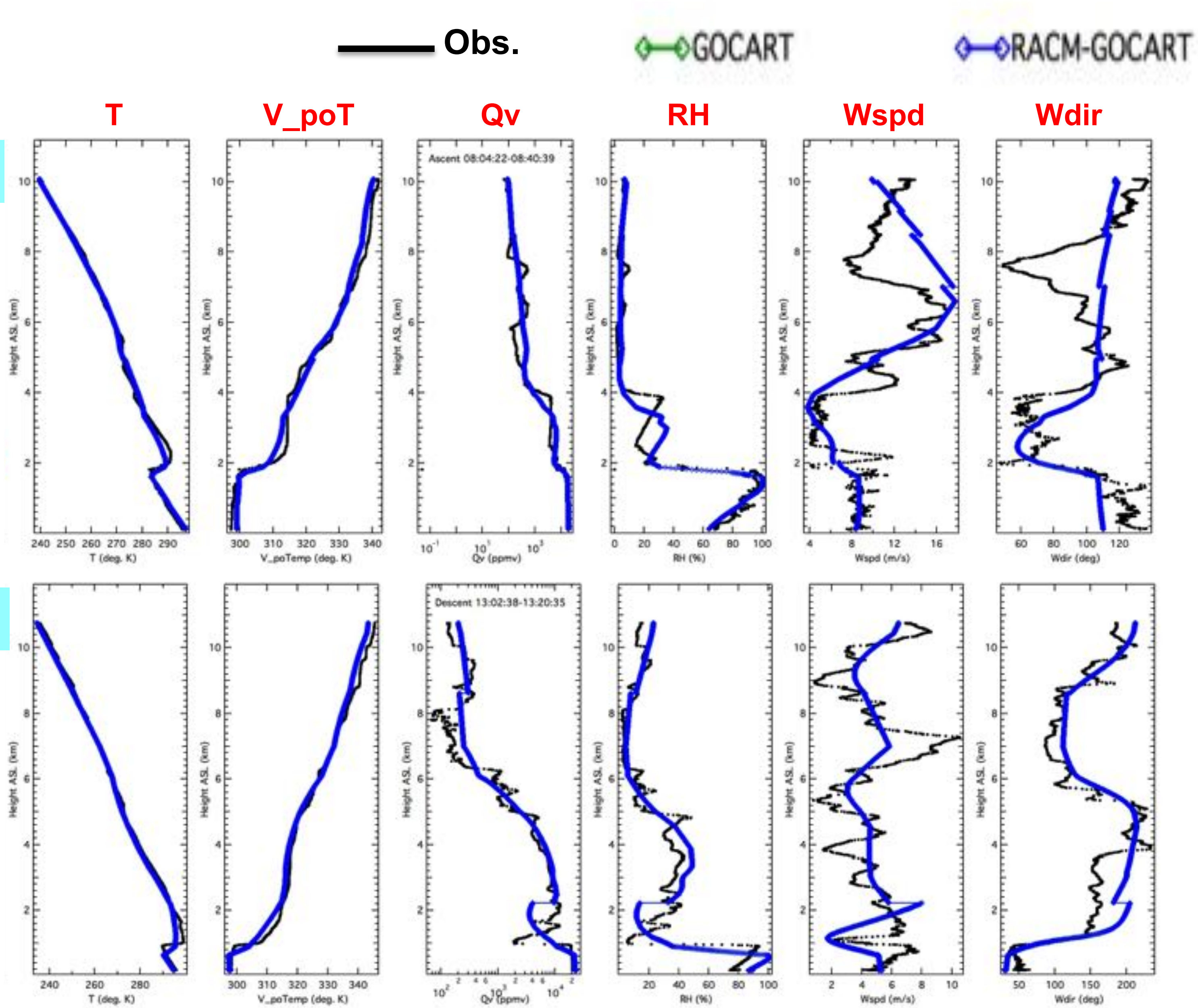


- The model shows good performance in reproducing the height-latitude profiles of EC and CO at the low altitude, especially capturing the biomass burning plumes.
- The big discrepancies between model predictions and measurements are mainly over the altitude above 4~5km. O_3 still have the common overestimating problems. Using the GFS analysis O_3 fields to drive upper-tropospheric O_3 may be the reason for the high O3 throughout the model troposphere.

Vertical Profiles of Met. Fields

8/17/2016, V1,

Biomass burning plume

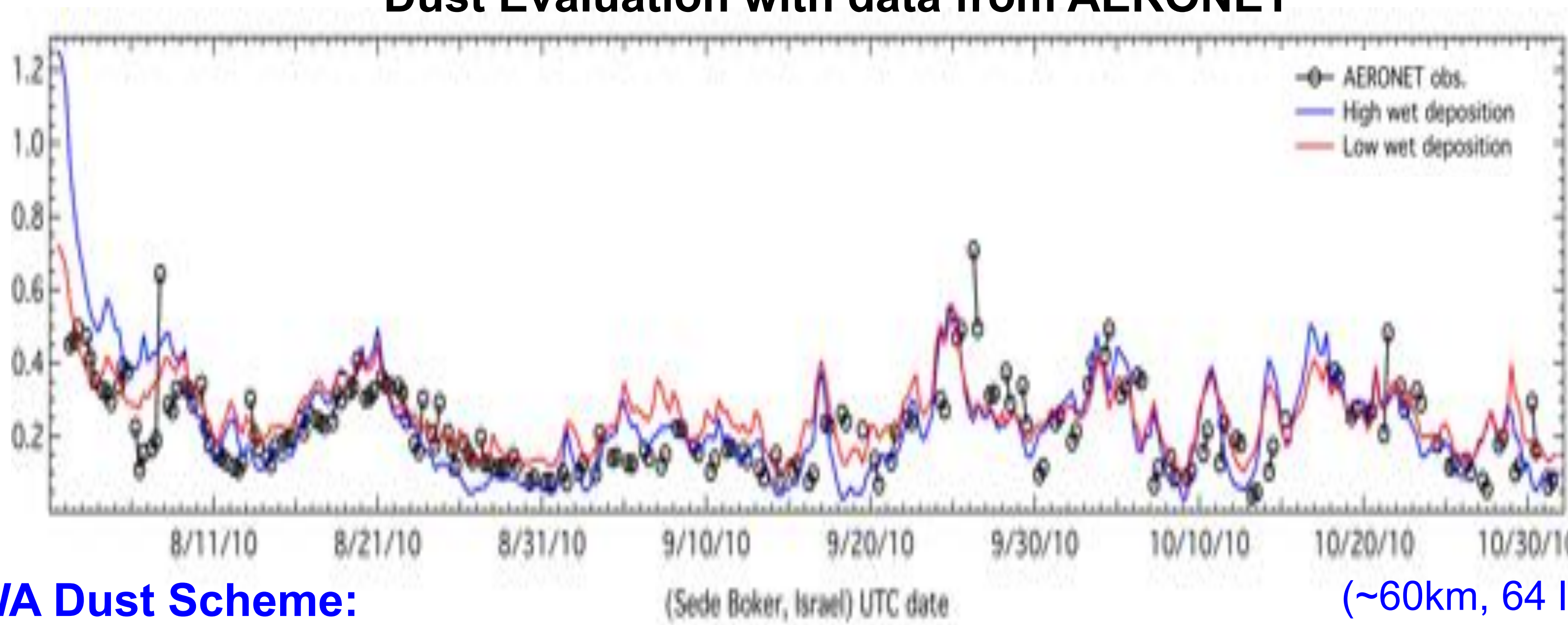


8/17/2016, V10

Saharan dust plume

Sensitivity of Dust Emissions to Aerosol Feedback using GOCART Scheme

Dust Evaluation with data from AERONET



AFWA Dust Scheme:

(~60km, 64 levels)

Saltation Flux Over Bare Soil (Kawamura, 1951):

friction velocity

$$H(D_p) = C\frac{\rho_a}{g}u_*^3\left(1+\frac{u_{*t}}{u_*}\right)\left(1-\frac{u_{*t}^2}{u_*^2}\right) \qquad G = \sum H(D_p)dS_{rel}(D_p)$$

- **Threshold Friction Velocity (Iversen & White, 1982)):**

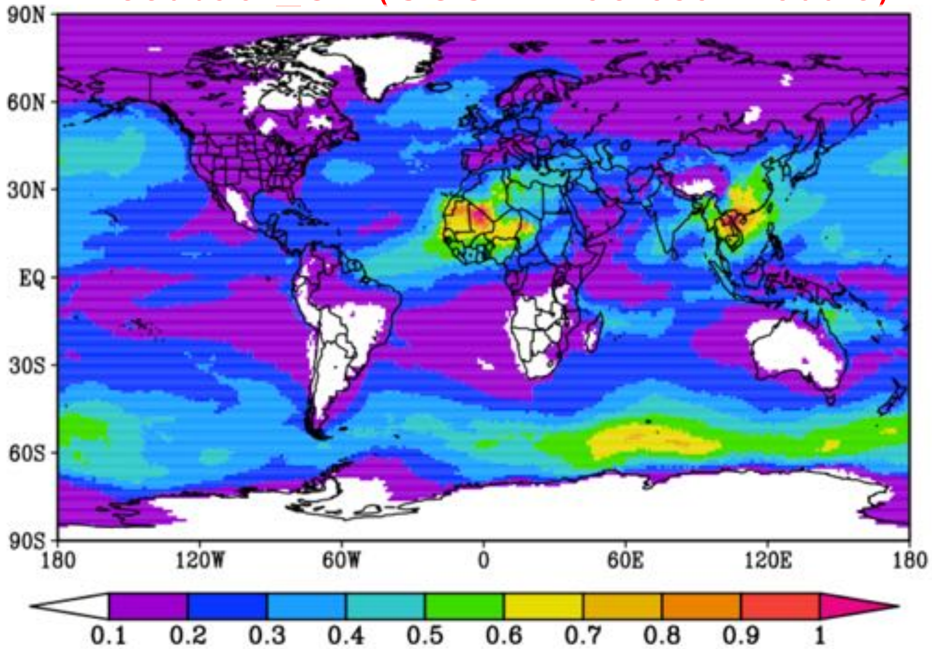
$$u_{*t}(D_p) = 0.129\frac{\left[\frac{\rho_p g D_p}{\rho_a}\right]^{0.5}\left[1+\frac{0.006}{\rho_p g D_p^{2.5}}\right]^{0.5}}{\left[1.928(aD_p^x+b)^{0.092}-1\right]^{0.5}} \qquad u_{*t} = u_{*t}(D_p)\frac{f(\text{moisture})}{f(\text{roughness})}$$

AOD Comparison between with and without Aerosol Feedback, April 2010

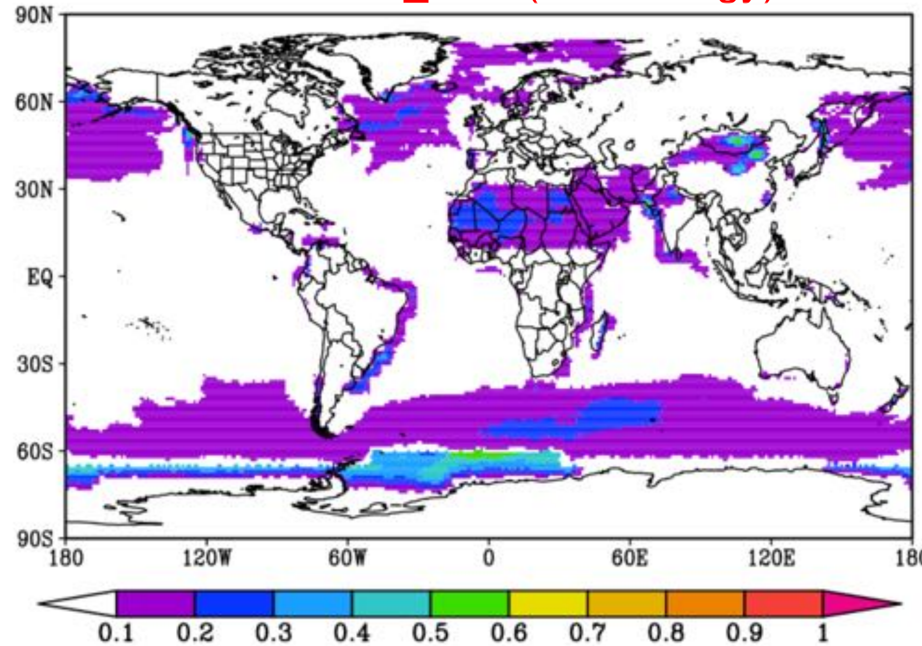
Feedback_OFF: turn off all aerosol feedback
Feedback_ON: turn on all aerosol feedback
Resolution: ~120km, 64 levels

Only GFS background AOD from operational system

Feedback_ON (GOCART aerosol Module)



Feedback_OFF (Climatology)

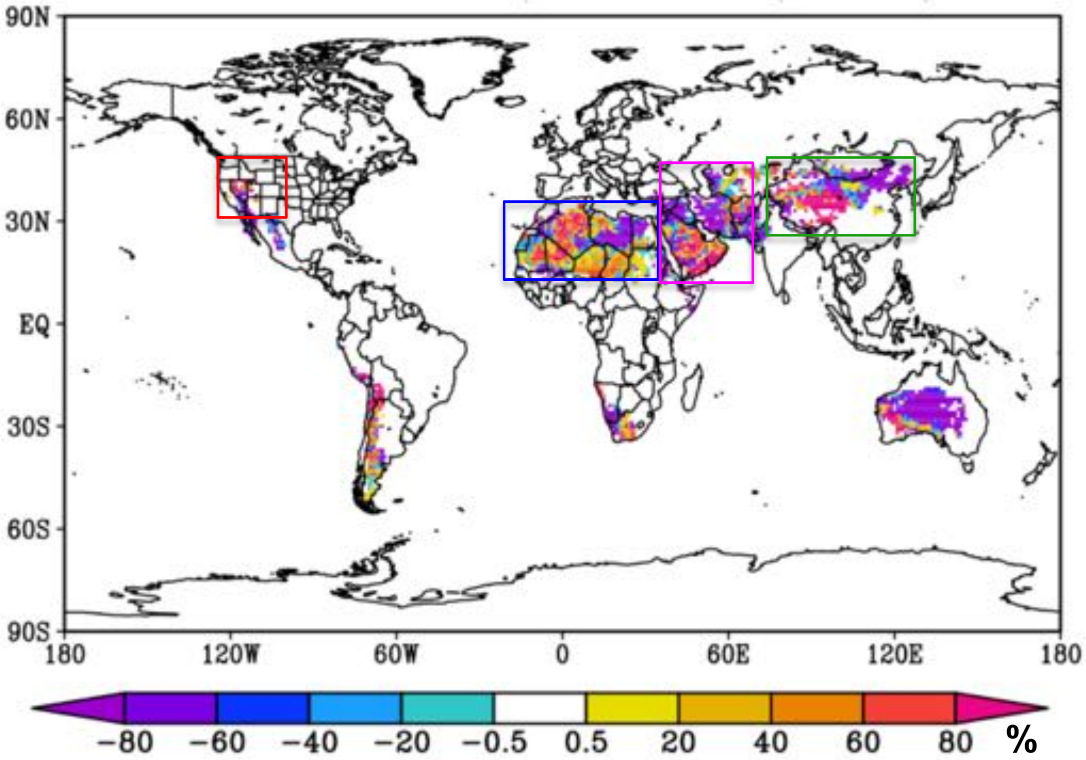


4 months integration without re-initialization

Significant enhancement of AOD has been shown over Africa and southeast Asia.

All aerosol-induced Percentage Changes of Dust Emissions, April 2010

(Feedback_ON-Feedback_OFF)/Feedback_ON

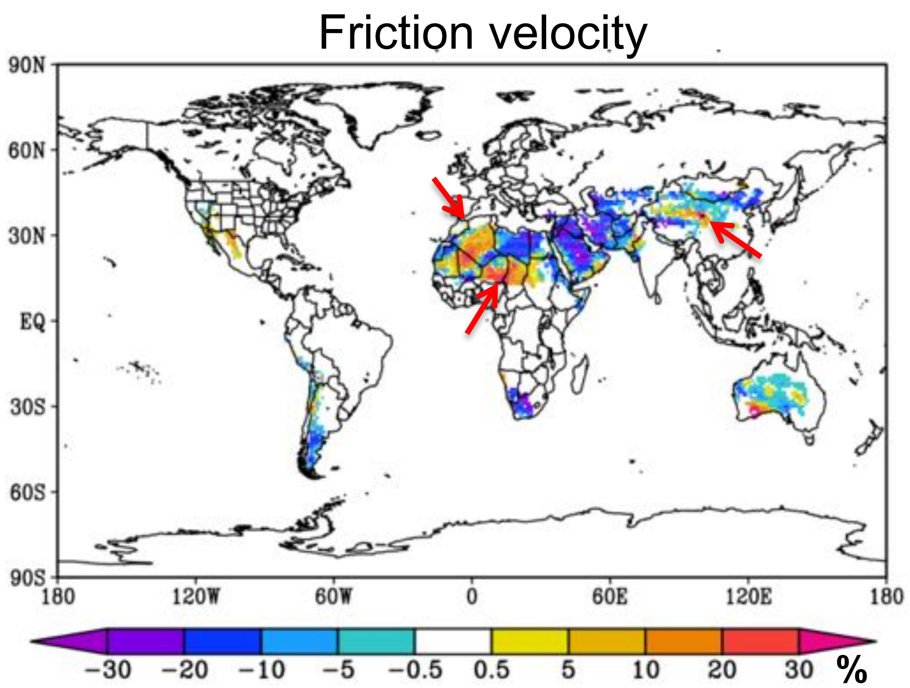


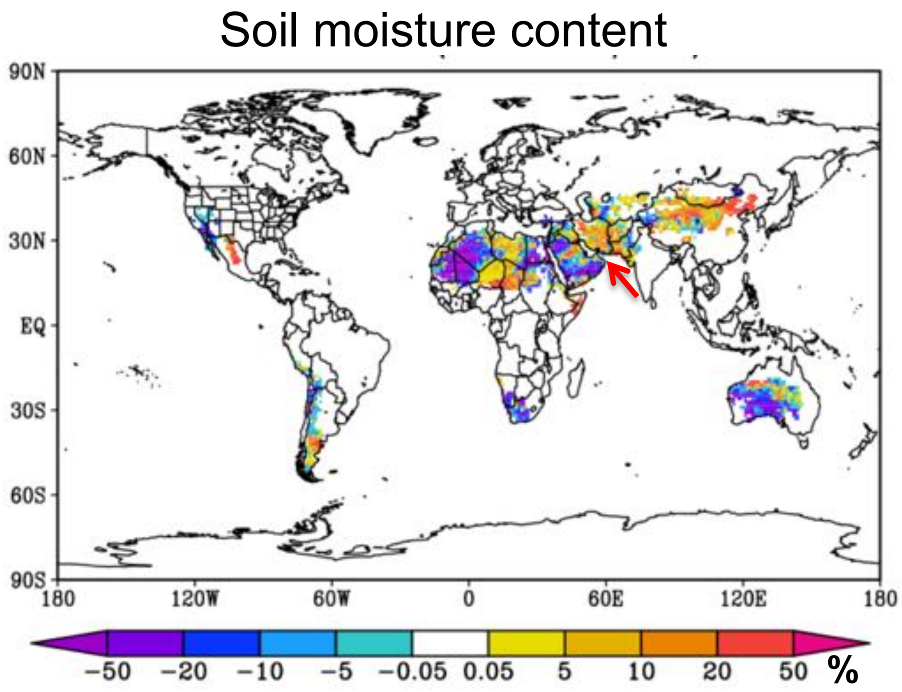
- **North America**: **−0.57 Tg**
- **Africa**: **26.15 Tg**
- **East Asia**: **−0.53 Tg**
- **Middle East**: **−19.5 Tg**

Without aerosols feedback: **265.6 Tg**
With all aerosols feedback **including fire** emissions: **250.5 Tg**
Contributions of **all aerosol**: **−15.1 Tg** (reduce about ~6%)
non-fire aerosol: **−45.4 Tg** (reduce about ~18%)
fire aerosols: **30.4 Tg** (enhance about **~12%**)

All Aerosol-induced Percentage Changes of Friction Velocity and Soil Moisture Content, April 2010

(Feedback_ON-Feedback_OFF)/Feedback_ON %

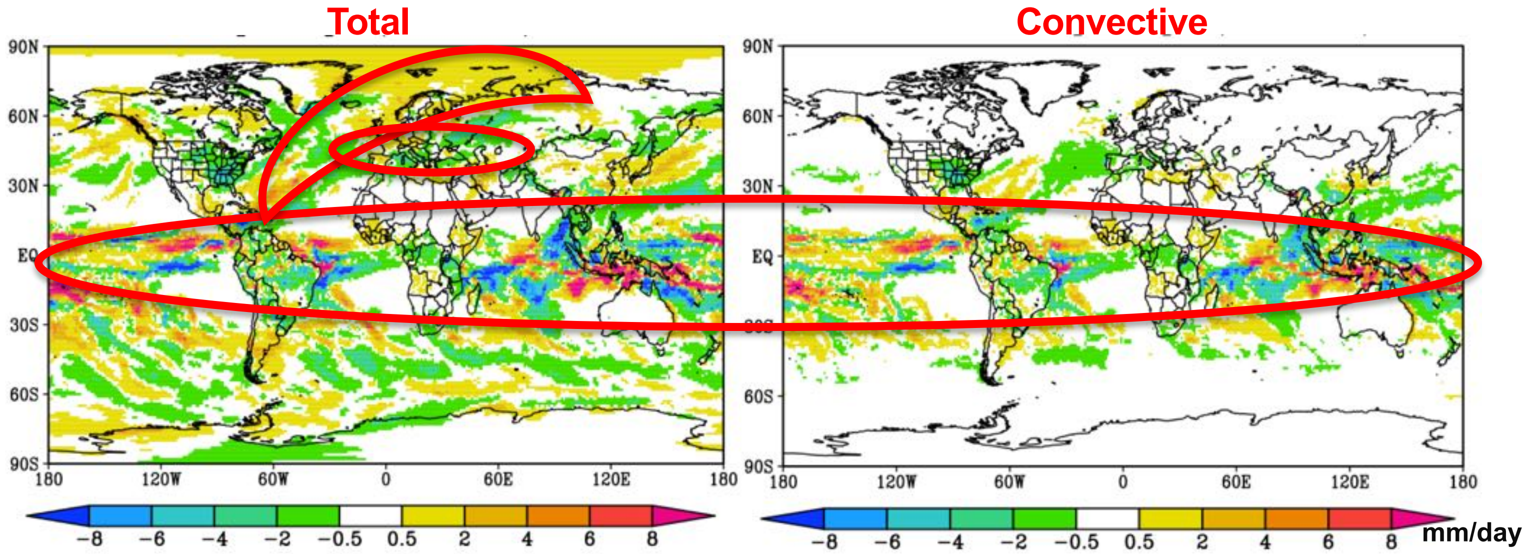




- The increasing dust emissions over western Africa are mainly due to the aerosol-induced increasing friction velocity and decreasing soil moisture content.
- The decreasing dust emissions over Middle East is associated with the significant reduction of friction velocity and enhancement of soil moisture content.

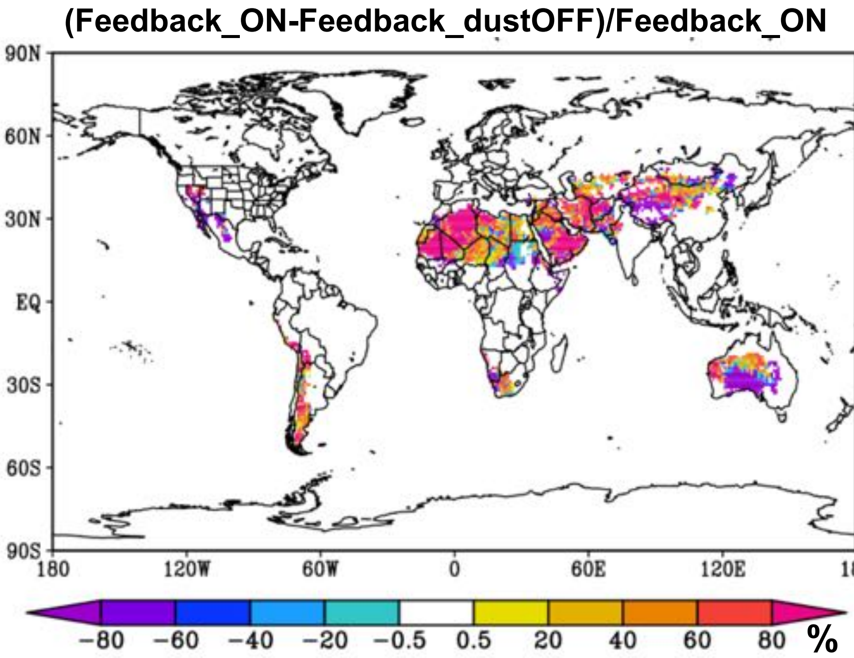
All Aerosol-induced Changes of Precipitations, April 2010

4 months integration without re-initialization



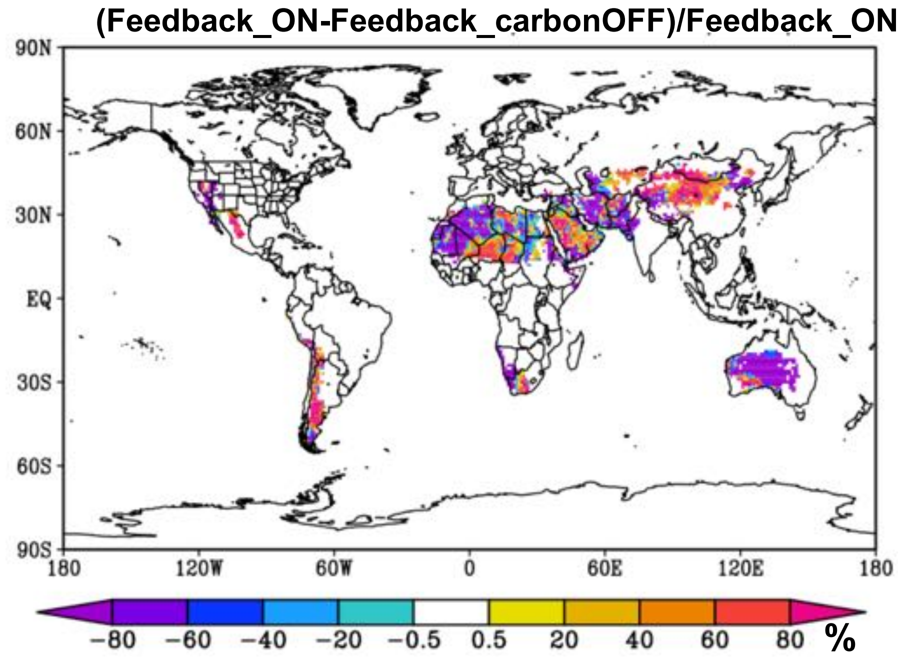
- **Largest changes in tropics due to changes in non resolved precipitation**
- **Some increase in precipitation (FOR THIS RUN) in northern mid-high latitudes**
- **Some decrease in precipitation (FOR THIS RUN) in Mediterranean area**

Dust and Carbonaceous aerosol-induced Percentage Changes of Dust Emissions, April 2010



- **North America**: **−0.50 Tg**
- **Africa: 86.68 Tg**
- **East Asia: 0.76 Tg**
- **Middle East: 12.38 Tg**

Dust feedback: **103 Tg** (enhance about **~41 %**, which is about **a factor of 7** of the all aerosol feedback contributions)



- **North America: −0.76 Tg**
- **Africa: −27.94 Tg**
- **East Asia: 1.15 Tg**
- **Middle East: −10.18 Tg**

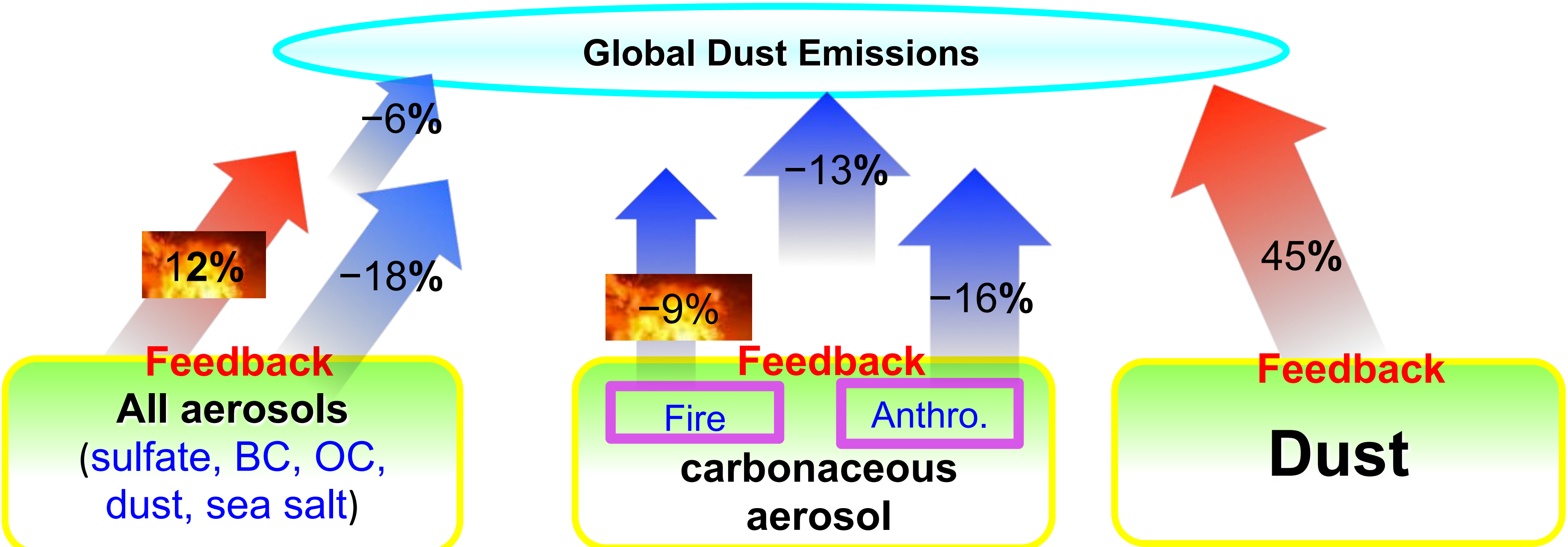
Carbonaceous aerosol feedback: **−32.7 Tg** (reduce about **~13%**, which is about **a factor of 2** of all aerosol feedback contributions)

Summary and Discussions

Chemical weather forecast:

- The predicted vertical profiles of biomass burning plumes and dust off western Africa are reproduced reasonably well. GOCART sea salt algorithm is too high; the vertical profiles of the meteorological fields are also well represented by the model.
- Model predictions are much better at the low altitude and overestimate soluble species above 5 km, probably due to an underestimation of wet scavenging on this day.

Sensitivity of dust emissions to aerosol feedback:

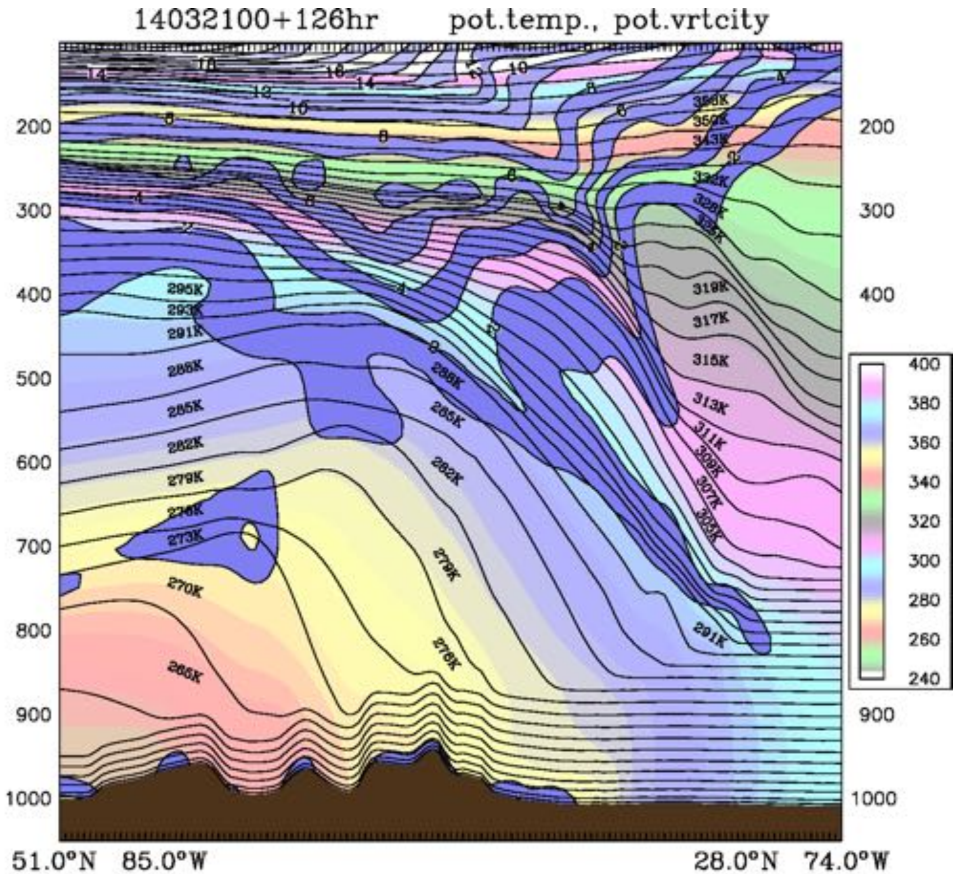


Future Work Planned Collaboration with ESRL/CSD, ARL, and EPA

- Switch to NGGPS core, FV3.
- CMAQ/EPA module inclusion.
- Currently our runs are with GFS physics suite (GBPHYS + GF convection).
- Inclusion of more physics options or suites (through coupling with Interoperable Physics Driver (IPD), or direct inclusion into GBPHYS) – possibly focused on GFS future advanced physics suites.
- Feedback to NWP also with microphysics:
  - In addition to GFS physics, this will also run with HRRR physics, which includes Thompson aerosol aware microphysics.


Thank you!

FIM design – vertical coordinate

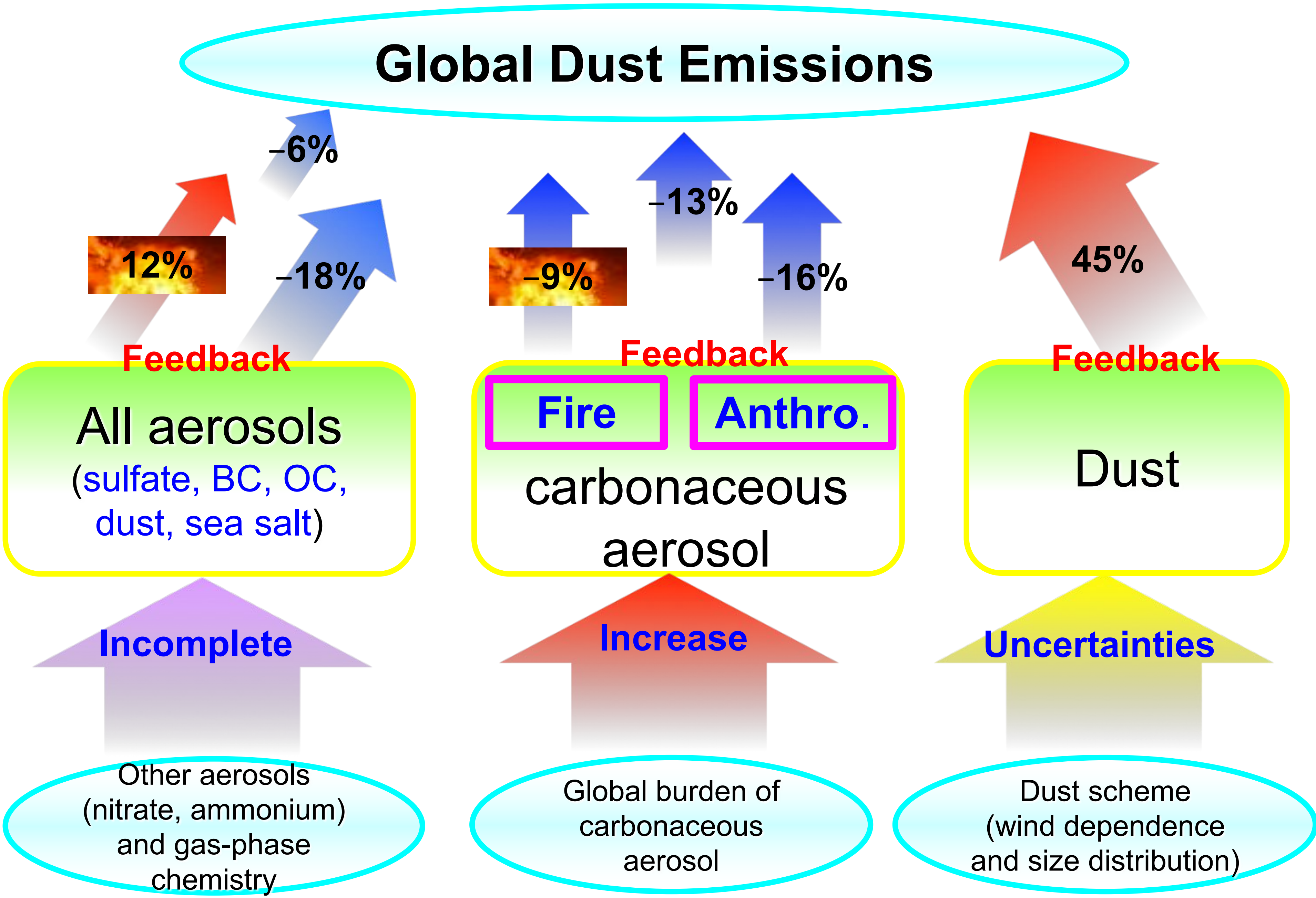


FIM vertical section

- **Heavy black lines:** coordinate surfaces.
- **Colored field:** potential temperature (K).
- **Shaded contours:** potential vorticity.

Hybrid (sigma/ isentropic) vertical coordinate

- The primary purpose of using a near-isentropic vertical coordinate in a circulation model is to assure that momentum and mass field constituents (potential temperature, moisture, chemical compounds,...) are dispersed in the model in a manner emulating reality, namely, along neutrally buoyant surfaces.
- Physics parameterizations: GFS for NCEP
- Improved conservation using quasi-material surfaces, reduced vertical dispersion. Improved stratospheric/tropospheric exchange


Global Dust Emissions
−6%
12%
−18%
−9%
−13%
−16%
45%
Feedback
All aerosols
(sulfate, BC, OC, dust, sea salt)
Feedback
Fire
Anthro.
carbonaceous aerosol
Feedback
Dust
Incomplete
Increase
Uncertainties
Other aerosols (nitrate, ammonium) and gas-phase chemistry
Global burden of carbonaceous aerosol
Dust scheme (wind dependence and size distribution)