Inclusion of Aerosol Impacts on Medium-Range Forecasts of Weather and Air Quality in the Flow-Following Finite Volume Icosahedral Model (FIM) Global Model

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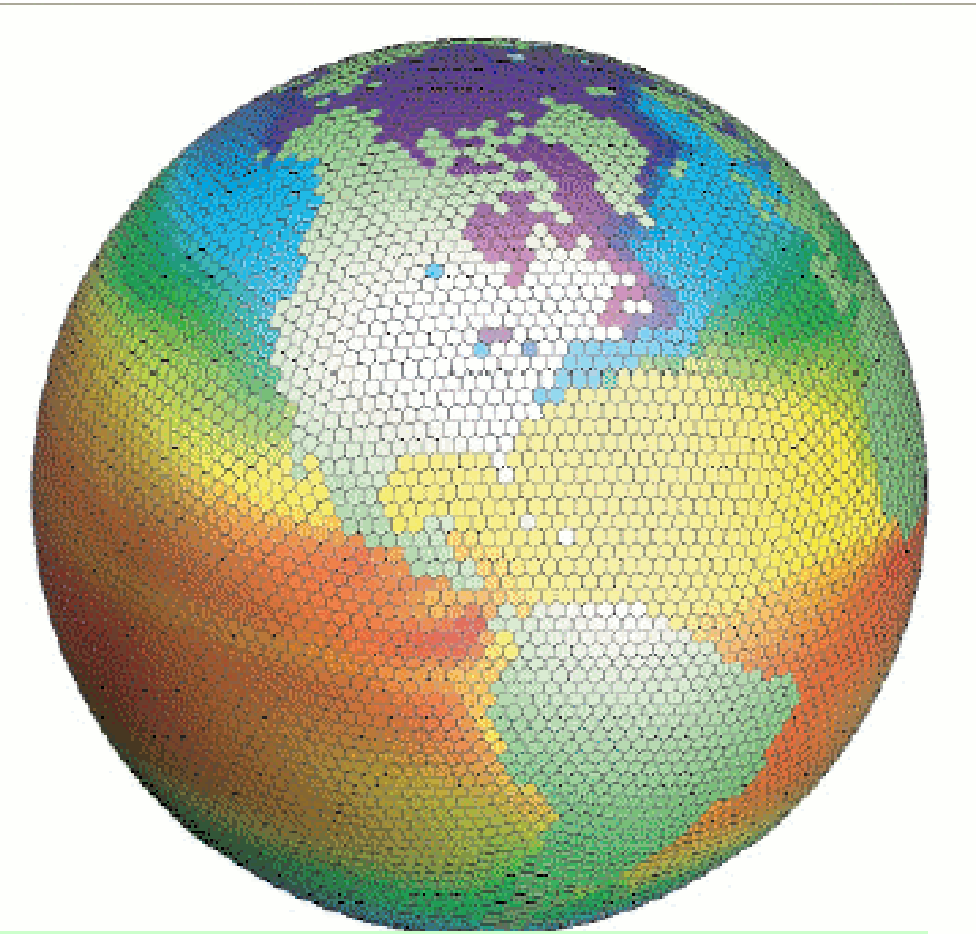
Overview

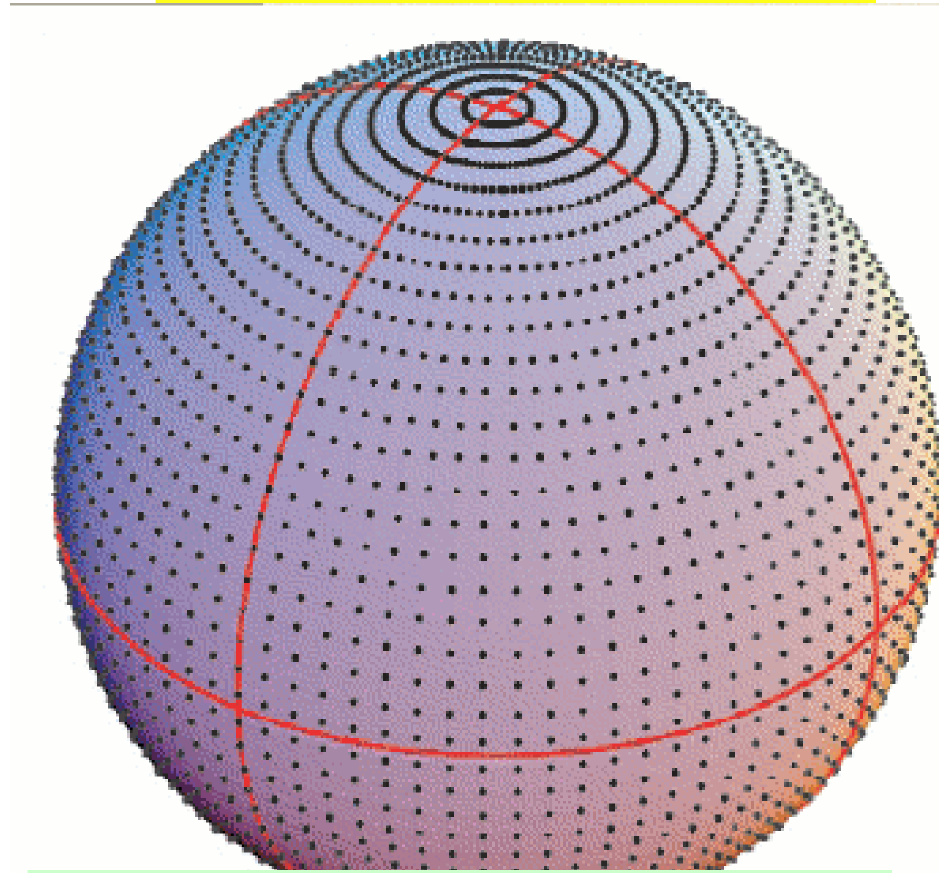
1. What is the FIM
2. What is the FIM-Chem
3. Case study: Impact of biomass burning and dust on weather forecasts
4. Today's 120hr real-time forecasts of chemistry and volcanic ash: *Possible airport closures*

FIM design: Global discretization for models

Icosahedral grid

Lat-lon representation
- Basis for GFS, ECMWF, others





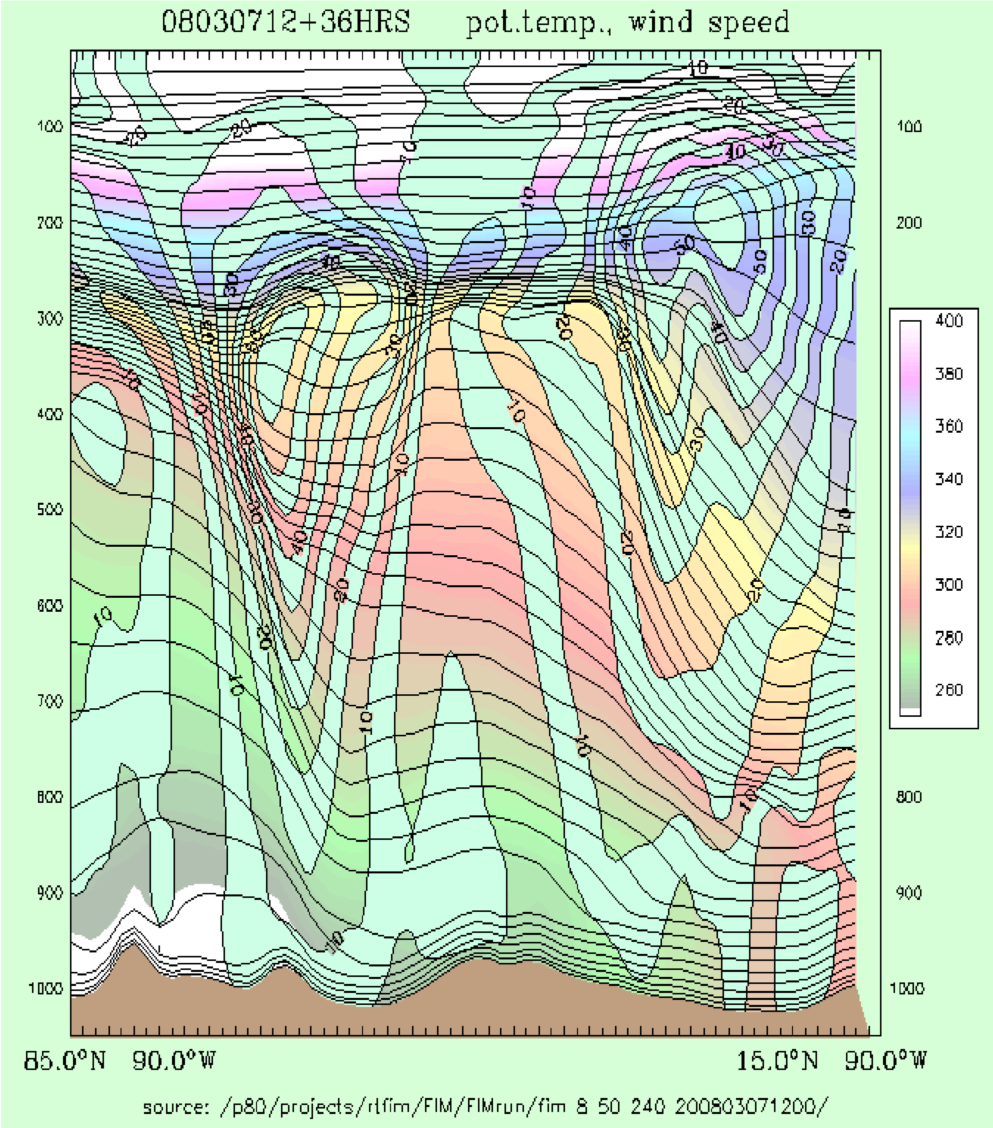
Nearly equal size of grid volumes, including near poles

- Singularities near poles
- Requires extra diffusion, longer time steps

FIM design – vertical coordinate

Hybrid (sigma / isentropic) vertical coordinate

- Improved conservation using quasi-material surfaces, reduced vertical dispersion. improved stratospheric/tropospheric exchange



Initial Physics in FIM

From GFS as of about 2006

Why GFS physics?

- Immediate goal for FIM is contributing dynamical-core diversity to NCEP Global Ensemble Forecast System
- Need to show that FIM is at least comparable in skill to GFS
- Use of GFS physics allows evaluation of differences between global spectral model and FIM dynamical core.

Chemistry in FIM

- FIM-Chem is an “online” model
  - Chemistry and meteorology integrated together
  - Feedback from Chemistry to Meteorology is allowed through atmospheric radiation
- FIM-Chem can use chemistry from WRF-Chem
  - Various choices for chemical mechanisms as well as aerosol modules
  - Biogenic emissions modules, fire plumerise, anthropogenic emissions based on RETRO/EDGAR
- Effect of volcanoes also was recently included

In future the online approach should also open doors for significant improvements in data assimilation

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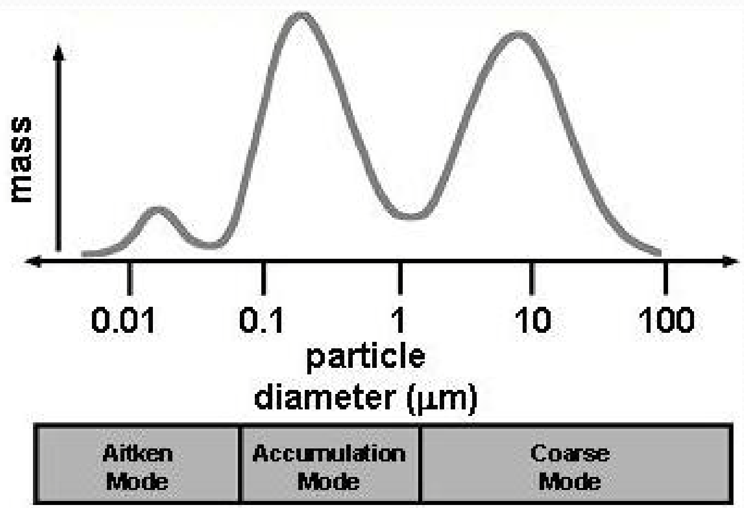
Available Aerosols modules

- PM advection, transport, emissions and deposition only
- Bulk approach (GOCART)
- Modal approach (MADE/SORGAM)
- Sectional approach (MOSAIC)

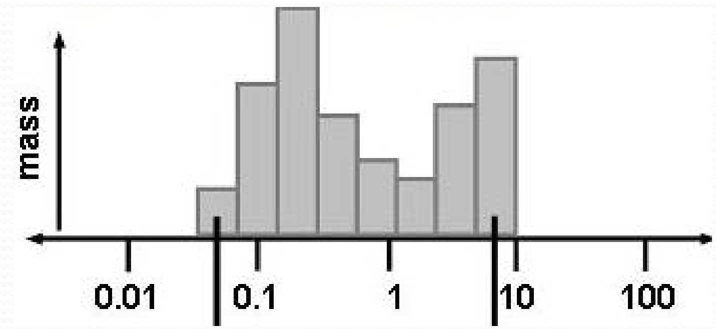
Aerosol modules comparison

(1) Modal



(2)

composition
sulfate
nitrate
ammonium
chloride
carbonate
sodium
calcium
other inorganics
organic carbon
elemental carbon



(3) GOCART: Sections for dust and sea salt, otherwise total mass only

Bulk scheme – GOCART (Currently used in FIM-Chem

- Much simpler than the sectional and model schemes
  - Calculates only with the total mass of the aerosol components
  - Provides no information on
    - Particle size
    - Particle concentration
  - E.g., when particles grow, the aerosol mass increases but we don't know how their size/number changes
- Numerically very efficient
- Coupled with radiation (Mie scattering and extinction calculations as implemented in WRF-Chem by Fast et al., PNNL)

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Important sources for aerosols: Fires and Volcanoes

Collaboration with Martin Stuefer (UAF), Saulo Freitas (CPTEC), and Peter Webley (UAF)

The 1D cloud model:
including the environmental wind effect on cloud scale dilution- governing equations

dynamics for W

$$\frac{\partial w}{\partial t} + w\frac{\partial w}{\partial z} = \gamma g B - \frac{2\alpha}{R} w^2 \ - \delta_{entr} w$$

dynamics for U

$$\frac{\partial u}{\partial t} + w\frac{\partial u}{\partial z} = -\frac{2\alpha}{R}|w|(u - u_e) - \delta_{entr}(u - u_e)$$

thermo-dynamics

$$\frac{\partial T}{\partial t} + w\frac{\partial T}{\partial z} = -w\frac{g}{c_p} - \frac{2\alpha}{R}|w|(T - T_e) + \left(\frac{\partial T}{\partial t}\right)_{micro-physics} - \delta_{entr}(T - T_e)$$

water_vapor_ conservation

$$\frac{\partial r_v}{\partial t} + w\frac{\partial r_v}{\partial z} = -\frac{2\alpha}{R}|w|(r_v - r_{ve}) + \left(\frac{\partial r_v}{\partial t}\right)_{micro-physics} - \delta_{entr}(r_v - r_{ve})$$

cloud water conservation

$$\frac{\partial r_c}{\partial t} + w\frac{\partial r_c}{\partial z} = -\frac{2\alpha}{R}|w| r_c + \left(\frac{\partial r_c}{\partial t}\right)_{micro-physics} - \delta_{entr} r_c$$

rain/ice conservation

$$\frac{\partial r_{ice,rain}}{\partial t} + w\frac{\partial r_{ice,rain}}{\partial z} = -\frac{2\alpha}{R}|w| r_{ice,rain} + \left(\frac{\partial r_{ice,rain}}{\partial t}\right)_{micro-physics} + \text{sedim} - \delta_{entr} r_{ice,rain}$$

dynamic entrainment

$$\delta_{entr} = \frac{2}{\pi R}|u_e - u|$$

equation for radius size

$$\frac{\partial R}{\partial t} + w\frac{\partial R}{\partial z} = +\frac{6\alpha}{5R}|w| R + \frac{1}{2}\delta_{entr} R$$

bulk microphysics

$$\left(\frac{\partial \xi}{\partial t}\right)_{micro-physics} (\xi = T, r_v, r_c, r_{rain}, r_{ice}),\ \text{sedim}$$

bulk microphysics:
Kessler, 1969; Berry,1967
Ogura & Takahashi,1971

See Freitas et al. (2010 ACPD) for 1d cloud model comparisons with fully 3D ATHAM simulations

Volcanoes: new module for emissions preprocessor code

1. New fortran module that contains the Mastin etal. dataset (more than 1500 Volcanoes)
2. Provides collocation of the volcano to the nearest model grid box

Can be used for

- Historic cases
- Real-time predictions

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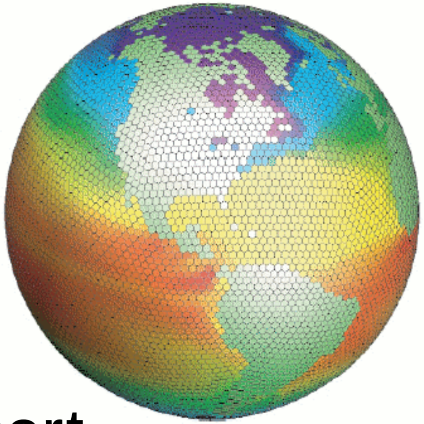
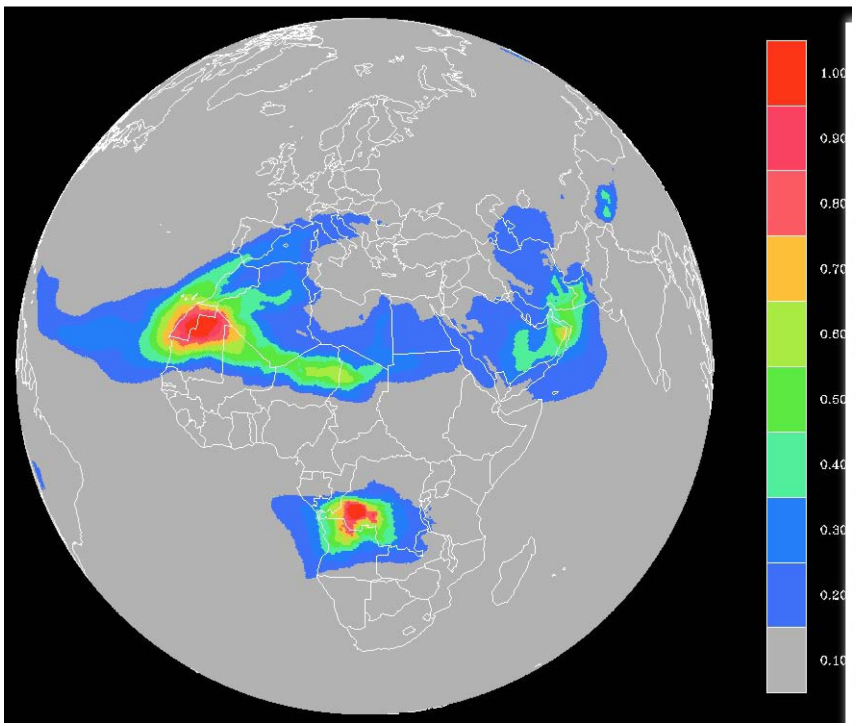
Results using FIM-Chem



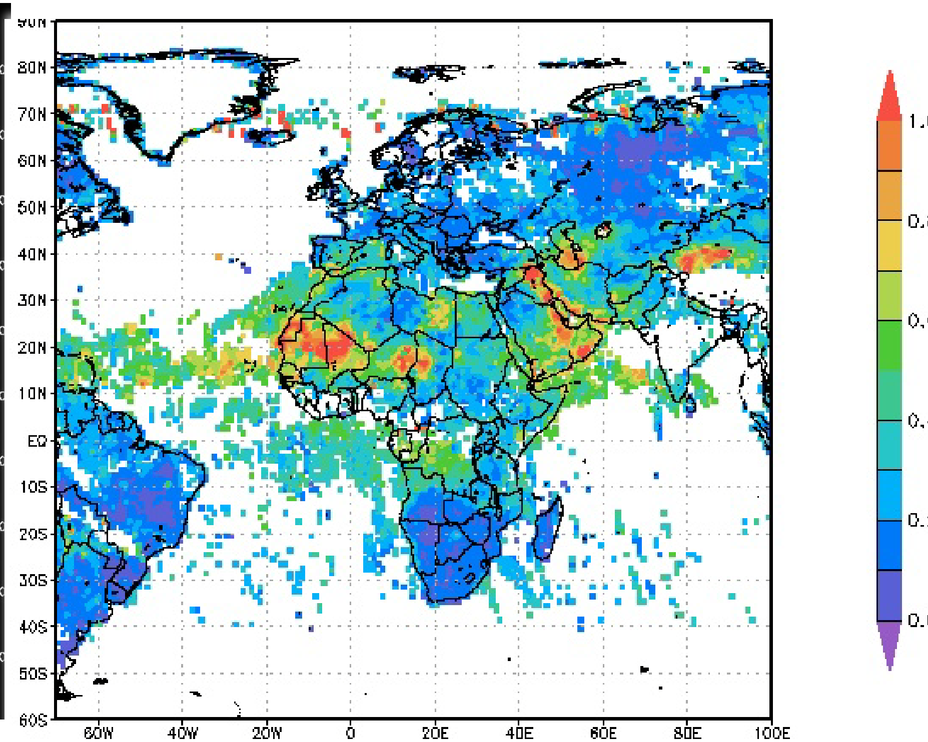
- Resolution: G8 (dx~30km), 50 levels
- Chemistry: GOCART, optical routines, deposition, emissions, plumerise for wildfires, sub-grid transport from WRF, 4 size bins for volcanic ash
- Fire data from WFABBA for the America's, Brazilian info for South America added, TERRA and AQUA MODIS for the rest of the world
- 2 examples:
  1. 5-day run from July 21 2009. Used as case for effects of wild-fires and dust on weather forecasts
  2. Real-time prediction from today (Includes volcanic ash)

Aerosol Optical Depth (AOD) comparisons of FIM-Chem simulations with Satellite observations

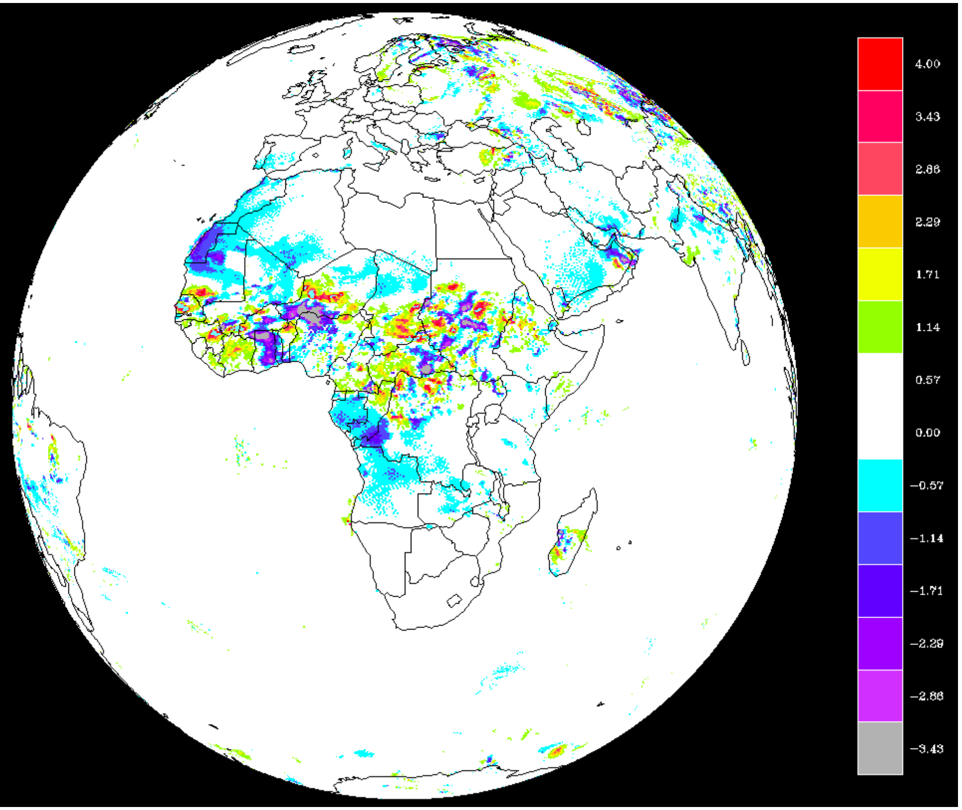
Time averaged FIM-Chem AOD predictions, July 21 – July 25



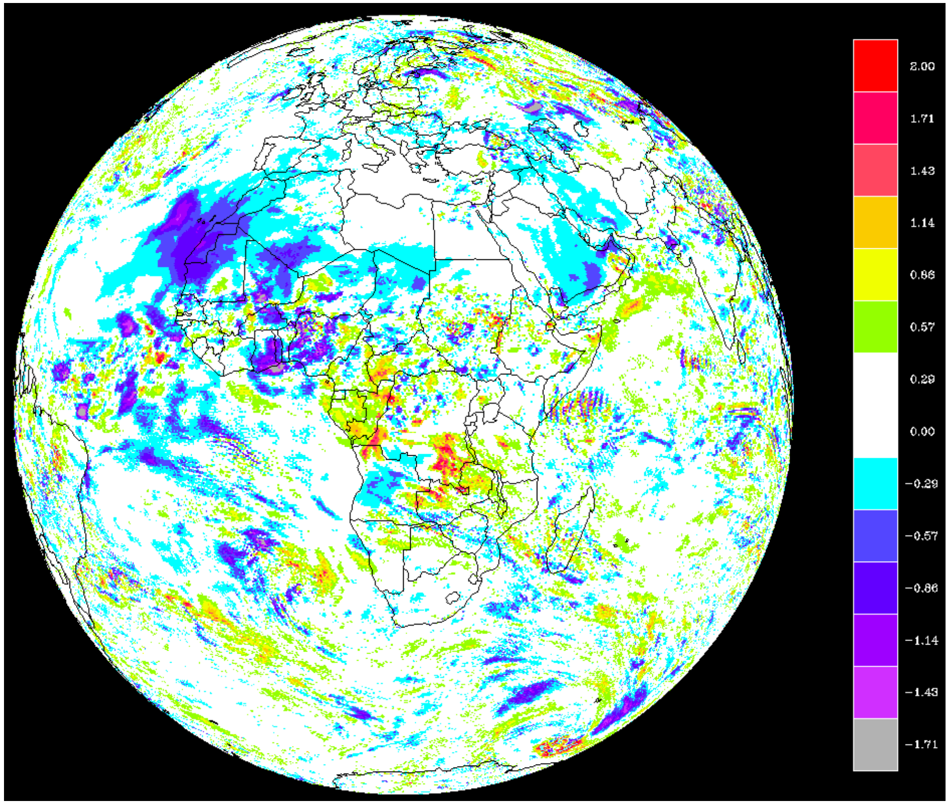
Time averaged AOD Satellite observations from OMI



FIM-Chem: The effect of online chemistry for weather forecasts

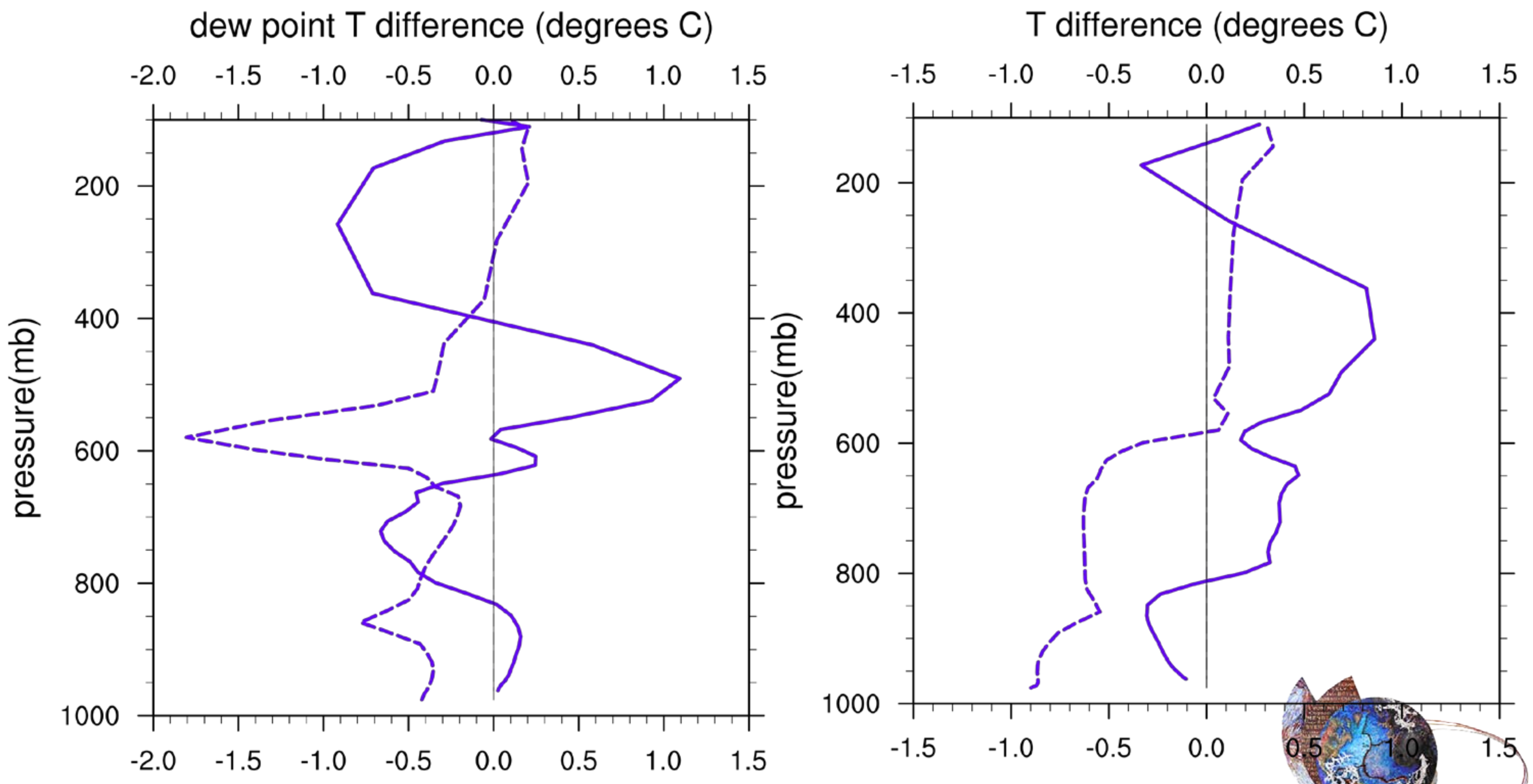


Surface Temperature differences caused by AOD (120hr)



700mb Temperature differences caused by AOD (120hr)

Area average vertical profiles of T and TD (120hr forecast) Solid is over Central Africa, dashed over NE Sahara (10x10) degree average)



Some initial conclusions

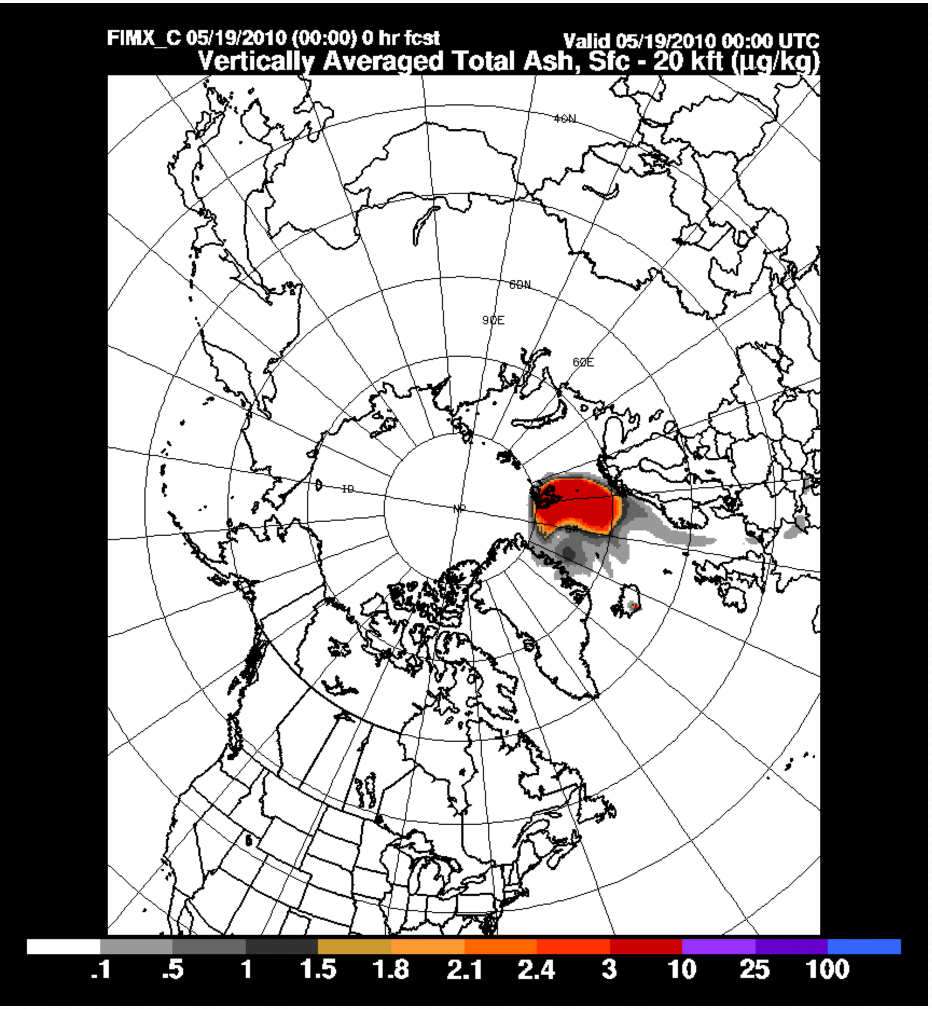
Direct and semi-direct effect maybe significant for weather forecasting even on a timescale of a few days

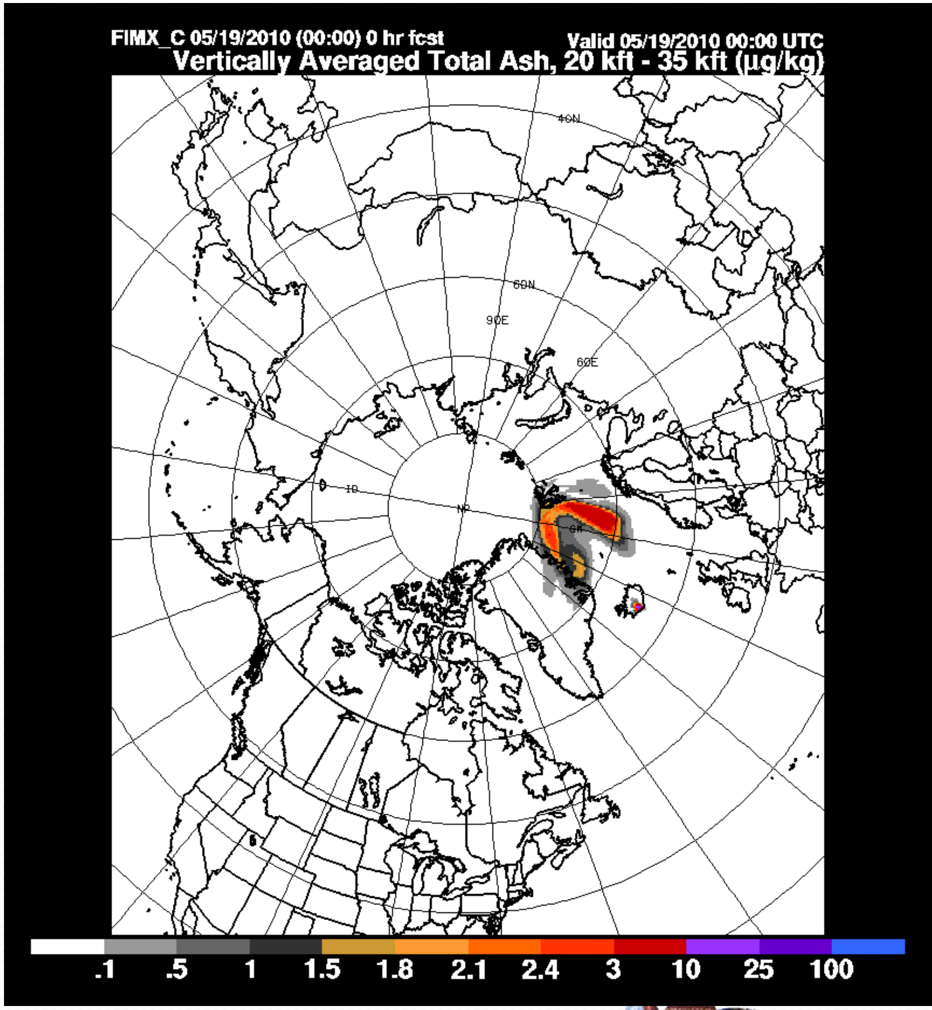
- The surface level itself is cooled
- Interaction of Black Carbon from biomass burning with atmospheric radiation leads to warming through absorption (above the BL)
- Semi-direct effect causes significant changes in the predicted precipitation pattern

Future work

- More on evaluation (AERONET and Satellite AOD)
- Look at indirect effect
- Seasonal forecasts – possibly also hind casts with large volcanic eruptions

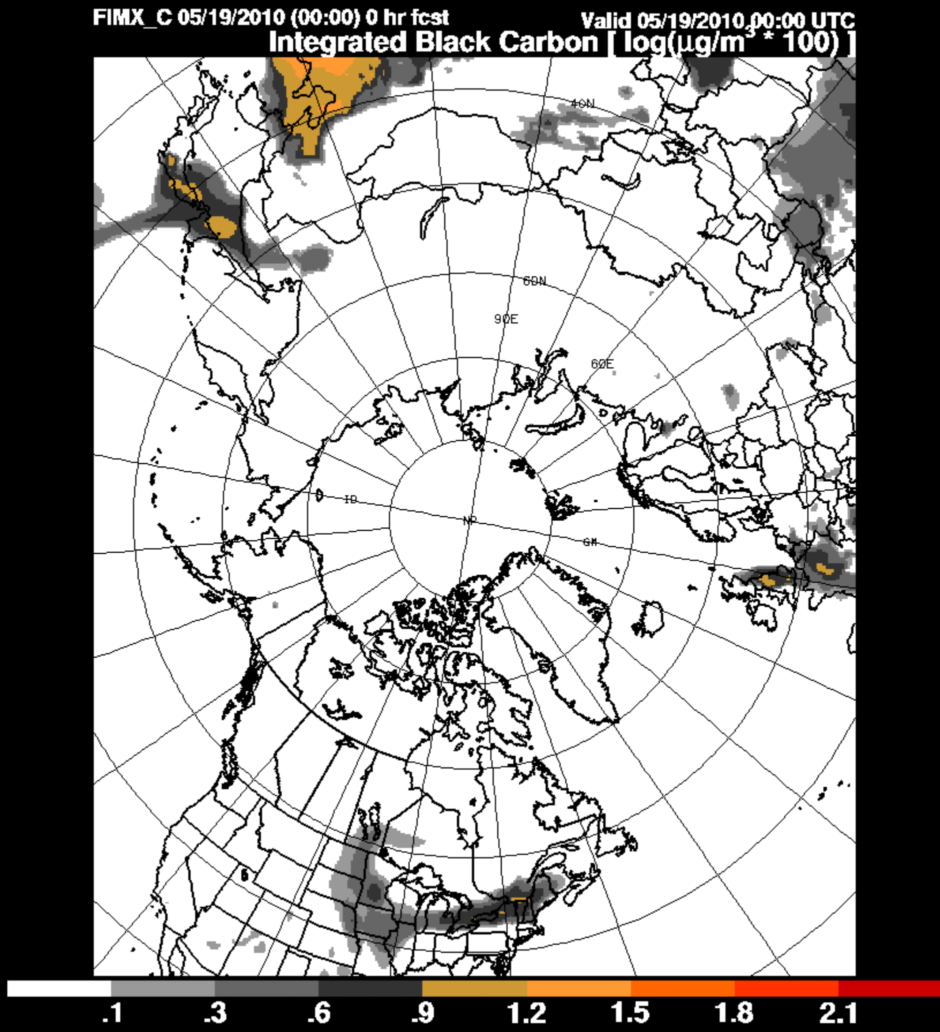
120hr real-time predictions from 19May 2010, 0000UTC : volcanic ash

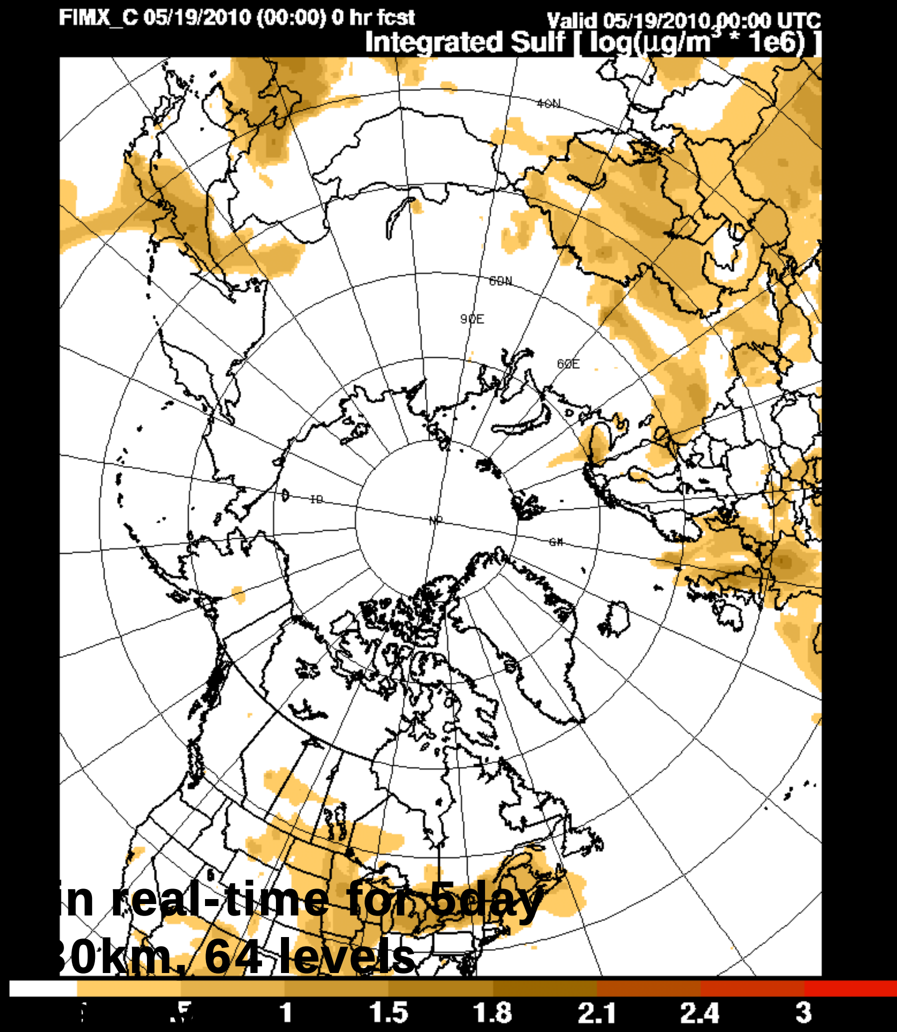




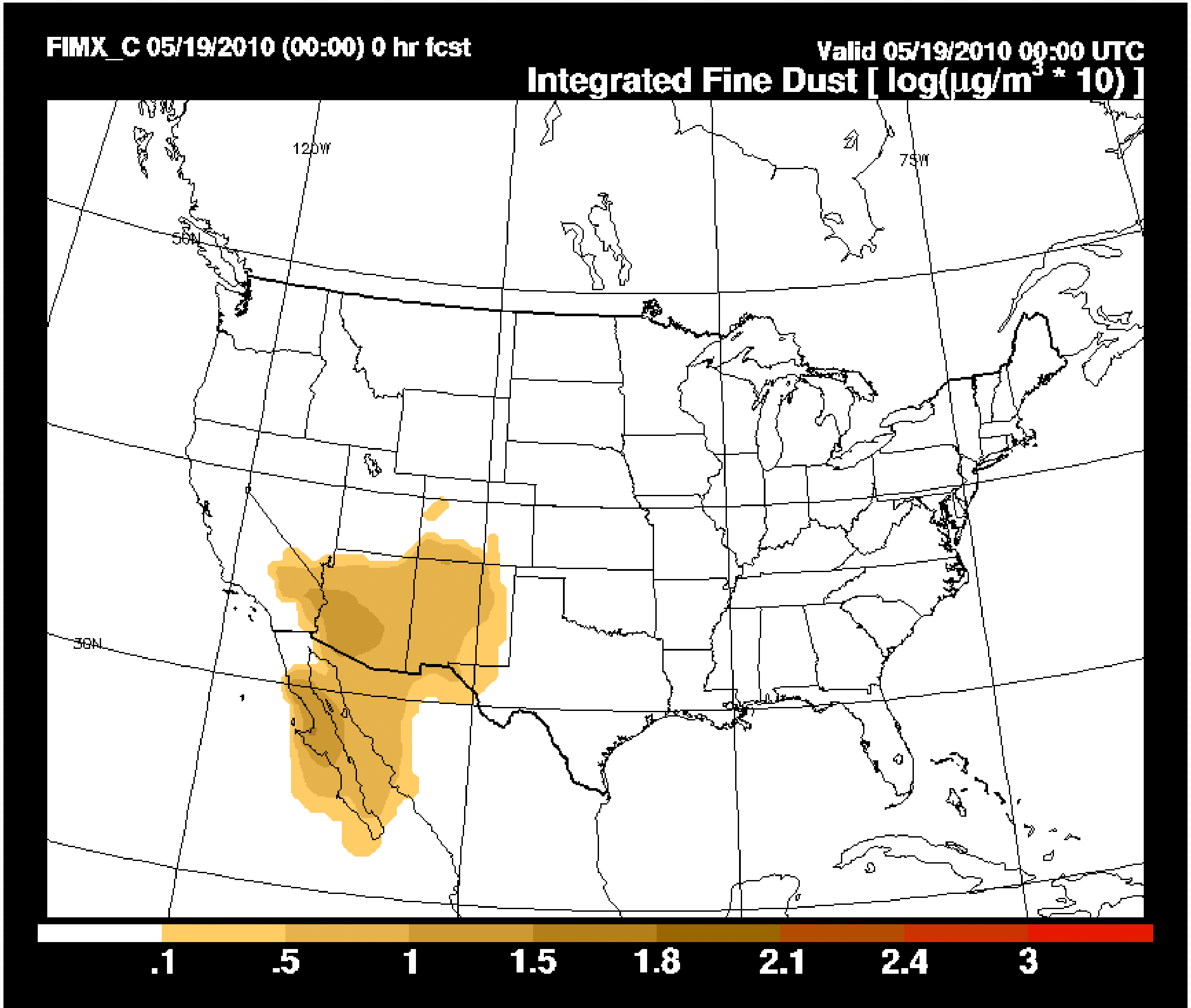
FIM-Chem (FIMX) now runs in real-time for 5day forecasts at ESRL, dx=30km, 64 levels
http://fim.noaa.gov

120hr real-time predictions from 19May 2010, 0000UTC : volcanic ash





120hr real-time predictions from 19May 2010, 0000UTC : Dust



Thank you!