Impact of smoke from the Alaska 2004 wildfires on radiation and cloud microphyscics using WRF-Chem

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Overview

- WRF-Chem and the inclusion of wildfires
- Comparison of model runs with and without wildfires (also different physics options)
- Future work and other ongoing developments with respect to air quality forecasting

WRF-Chem: Community “online” modeling system

- Based on the Weather Research and Forecast model (WRF)
- Global to Large Eddy Simulation (LES) scale, non-hydrostatic
- Many physics options
- Many chemistry options, including a choice of aerosol modules and interactions of aerosols with radiation and microphysics

Grell et al (2005), Fast et al. (2006), Gustafson et al. (2007)

Ability to handle wildfires: A 1D cloud resolving model to calculate plumerise, injection heights

dynamics

$$\frac{\partial w}{\partial t} + w\frac{\partial w}{\partial z} = \gamma g B - \frac{2\alpha}{R} w^2 \quad \begin{cases} \gamma = \dfrac{1}{1+0.5} & \textit{Simpson\&Wiggert, 1968} \\ \gamma = \dfrac{1}{1-2\mu} & \textit{Siebesma et al, subm. JAS} \end{cases}$$

thermodynamics

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

water vapor conservation

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

cloud water conservation

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

rain/ice conservation

$$\frac{\partial r_{ice,rain}}{\partial t} + w\frac{\partial r_{ice,rain}}{\partial z} = -\frac{2\alpha}{R}|w| r_{ice,rain} + \left(\frac{\partial r_{ice,rain}}{\partial t}\right)_{microphysics} + \mathrm{sedim}$$

bulk microphysics

$$\left(\frac{\partial \xi}{\partial t}\right)_{microphysics} \quad (\xi = T, r_v, r_c, r_{rain}, r_{ice}), \quad \mathrm{sedim} \begin{cases} \textit{bulk microphysics:} \\ \textit{Kessler, 1969} \\ \textit{Ogura \& Takahashi,1971} \\ \textit{Berry,1967} \end{cases}$$

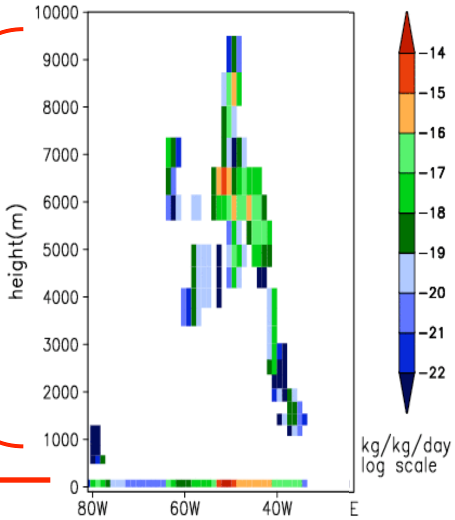
Including emission in the model

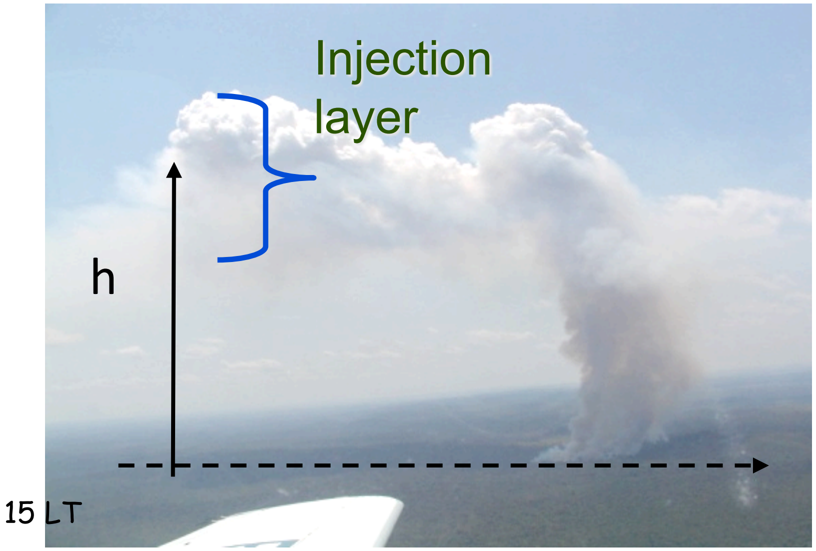
Smoldering : mostly surface emission

Flaming: mostly direct injection in the PBL,
free troposphere or stratosphere.

flaming
emission

smoldering
emission





Prep-Chem-Sources pre-processor

Biomass burning sources

–Brazilian Biomass Burning Emission Model (Freitas et al., 2005; Longo et al., 2007): plume rise mechanism, daily and model resolution.

–GFEDv2 (van der Werf et al., 2006): 8days/monthly – 1x1 degree.

–Emission Factors from Andreae and Merlet (2001), Ward et al 1992, Yokelson et al (200X)

110 species

Biomes: TropFor, ExtratropF, Savanna,
Pasture, charcoal, waste, lab

CO2
CO
CH4
NHMC
C2H2
C2H4
C2H6
C3H4
C3H6
C3H8
1_butene
i-butene
tr_2_butene
cis_2_butene
butadiene

n_butane
i-butane
1_pentene
2_pentene
n_pentane
2_Me_Butene
2_Me_butane
pentadienes
Isoprene
cyclopentene
cyclopentadiene
4_me_1_pentene
2_me_1_pentene
1_hexene
hexadienes

n_hexane
isohexanes
heptane
octenes
terpenes
benzene
toluene
xylenes
ethylbenzene
styrene
PAH
Methanol
Ethanol
1_Propanol
2_propanol

Butanols
cyclopentanol
phenol
Formaldehyde
Acetald
Hydroxyacetaldehyde
Acrolein
Propanal
Butanals
Hexanals
Heptanals
Acetone
2_Butanone
2_3_Butanedione
Pentanones
Hexanones

Heptanones
Octanones
Benzaldehyde
Furan
2_Me_Furan
3_Me_Furan
2_ethylfuran
2_4_dime_furan
2_5_Dime_furan
Tetrahydrofuran
2_3_dihydrofuran
benzofuran
Furfural
Me_format
Me_Acetate
Acetonitrile
Acrylonitrile
Propionitrile
pyrrole
trimethylpyrazole
methylamine
dimethylamine

ethylamine
trimethylamine
n_pentylamine
2_me_1_butylamine
HFo
HAc
Propanoic
H2
NOx
NOy
EF_N2O
EF_NH3
EF_HCN
cyanogen
SO2
DMS
COS
CH3Cl
CH3Br
CH3I
Hg
PM25
TPM
TC ,OC ,BC

Aerosol direct and indirect effect

In WRF-Chem

- The modal (MADE/SORGAM) and sectional (MOSAIC) schemes are coupled to both, atmospheric radiation and cloud microphysics (as originally introduced in WRF-Chem by *Fast et al. (2006), and Gustafson et al. (2007)*
- Bulk scheme (GOCART modules) only coupled to radiation (as of now)

WRF-Chem: Model setup for Alaska 2004 wild fire simulations

- 2 domains, 1-way nesting
  - Large domain with dx=10km
    - YSU PBL,
    - Grell-Devenyi improved convective parameterization to allow to spread subsidence in neighboring grid cells
    - RADM2 Chemistry coupled with modal aerosol scheme
    - Aqueous phase chemistry and Lin et al. microphysics (expanded to include prognostic equation for cloud droplet number)
    - Wet and dry deposition, anthropogenic and biogenic emissions, Fast-j photolysis, wildfire plumerise

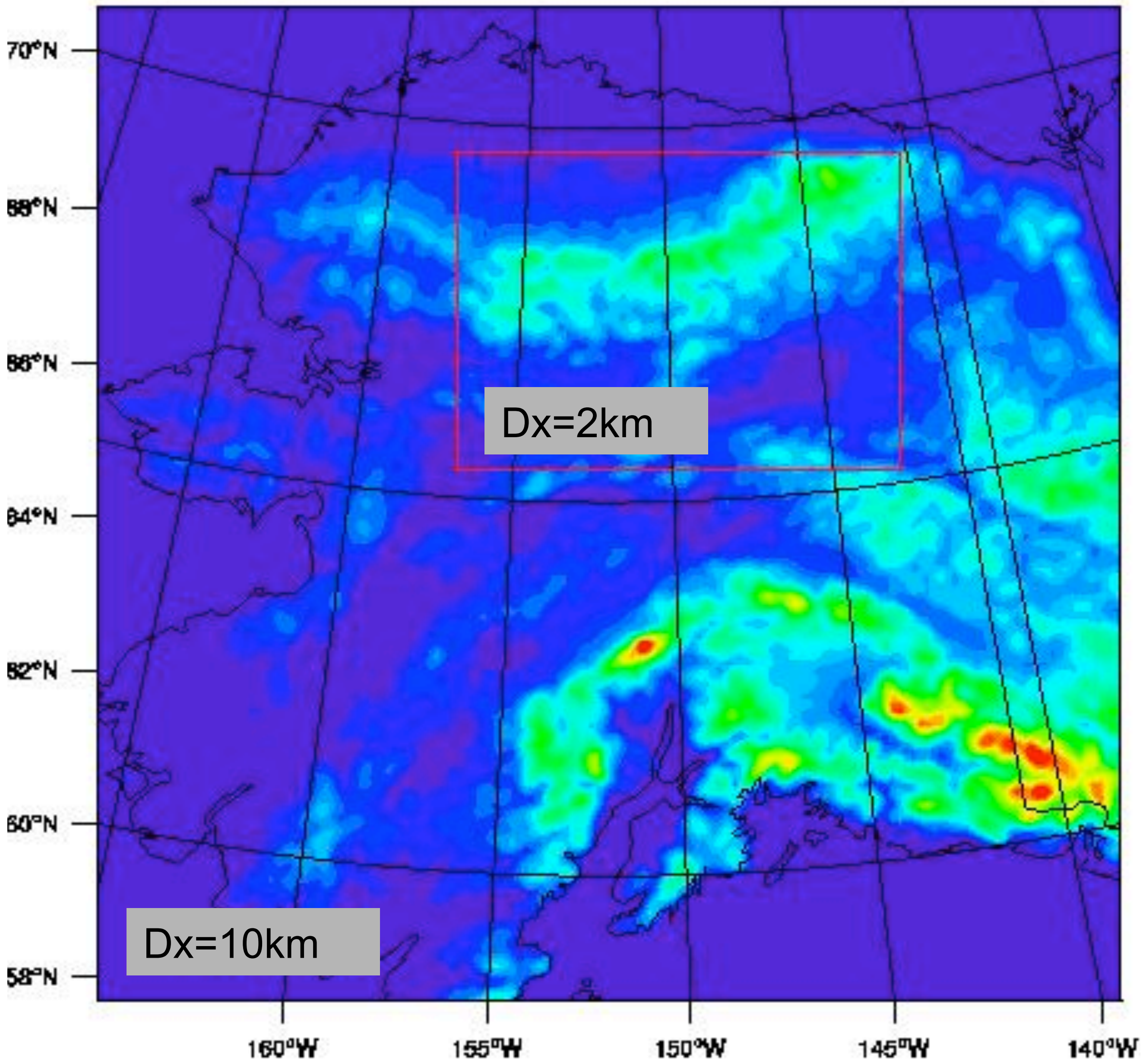
WRF-Chem, the cloud resolving domain:

- Dx=2km, 326x236 gridpoints
- Same physics and chemistry as coarse resolution domain, except no convective parameterization

Experimental setup

1) Run coarser domain for 10 days with and without fires (10 -24hr simulations, each simulation initialized with meteorological analysis, and previous 24hr chemistry forecast)
2) High resolution simulation starting on July 3, 2004 for 2 days, with and without fires. Initial and boundary conditions from (1)
3) Fires initialized using WF-ABBA, MODIS, as well as aerial and ground observations, but corrected for firesize

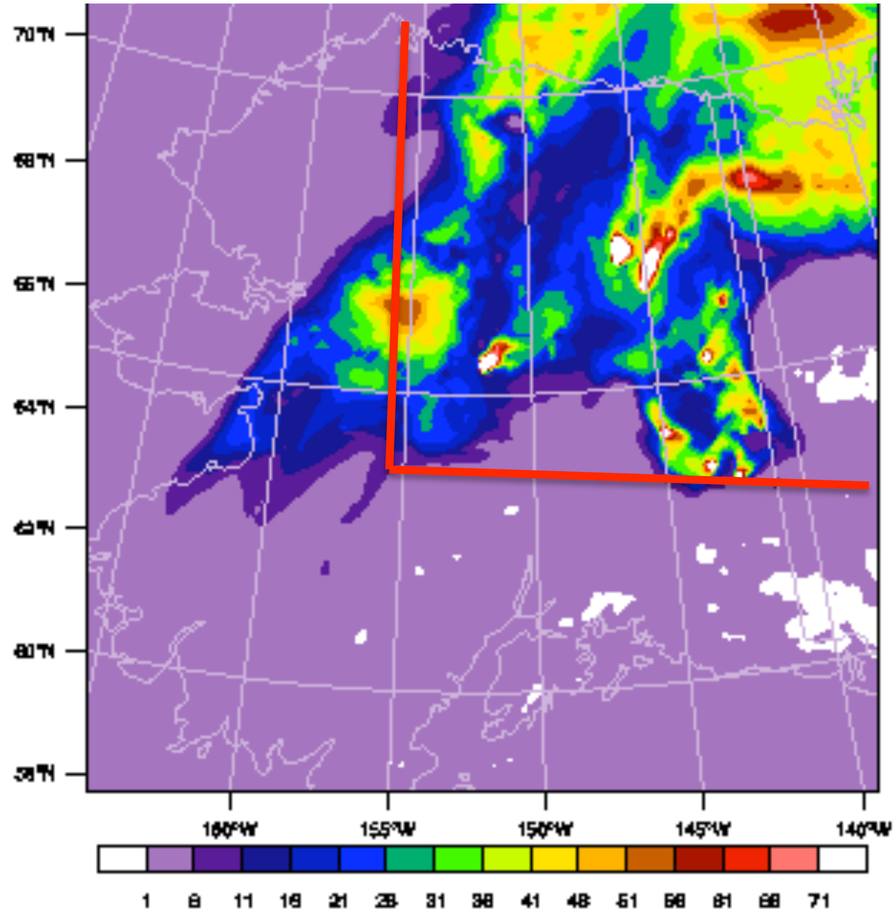
Domain setup


Dx=2km

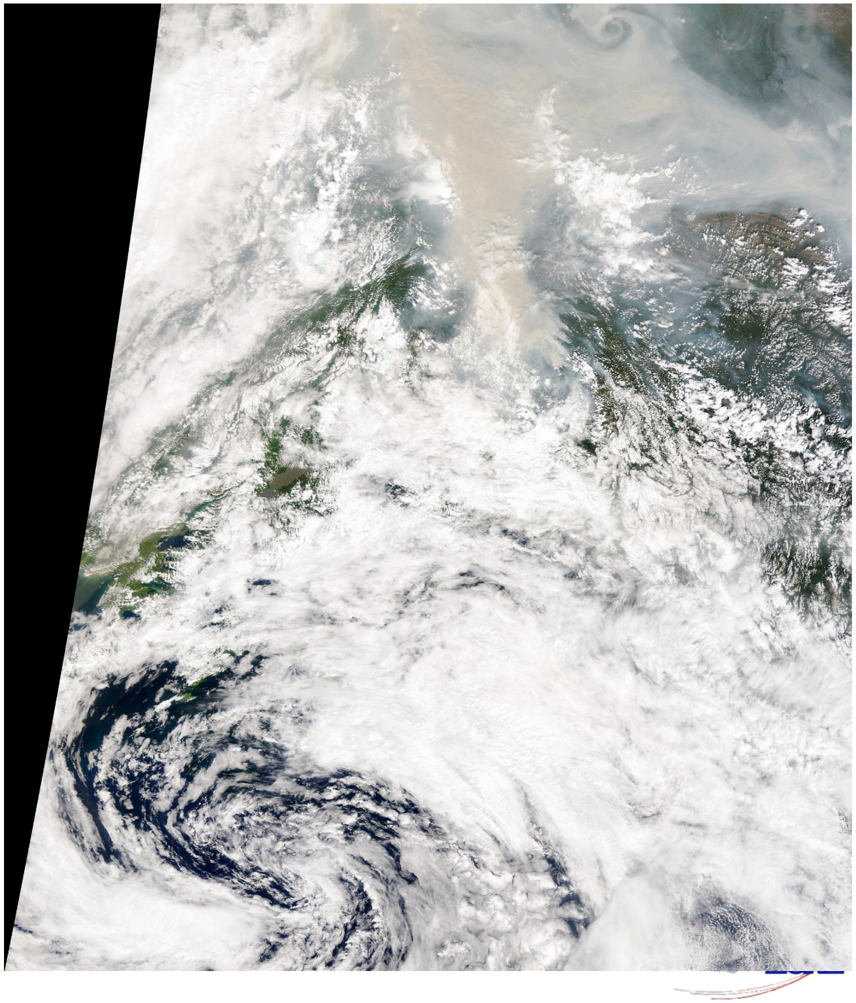
Dx=10km

Domain 1

Integrated PM2.5 for July 4, 18Z



July 4, 2025Z

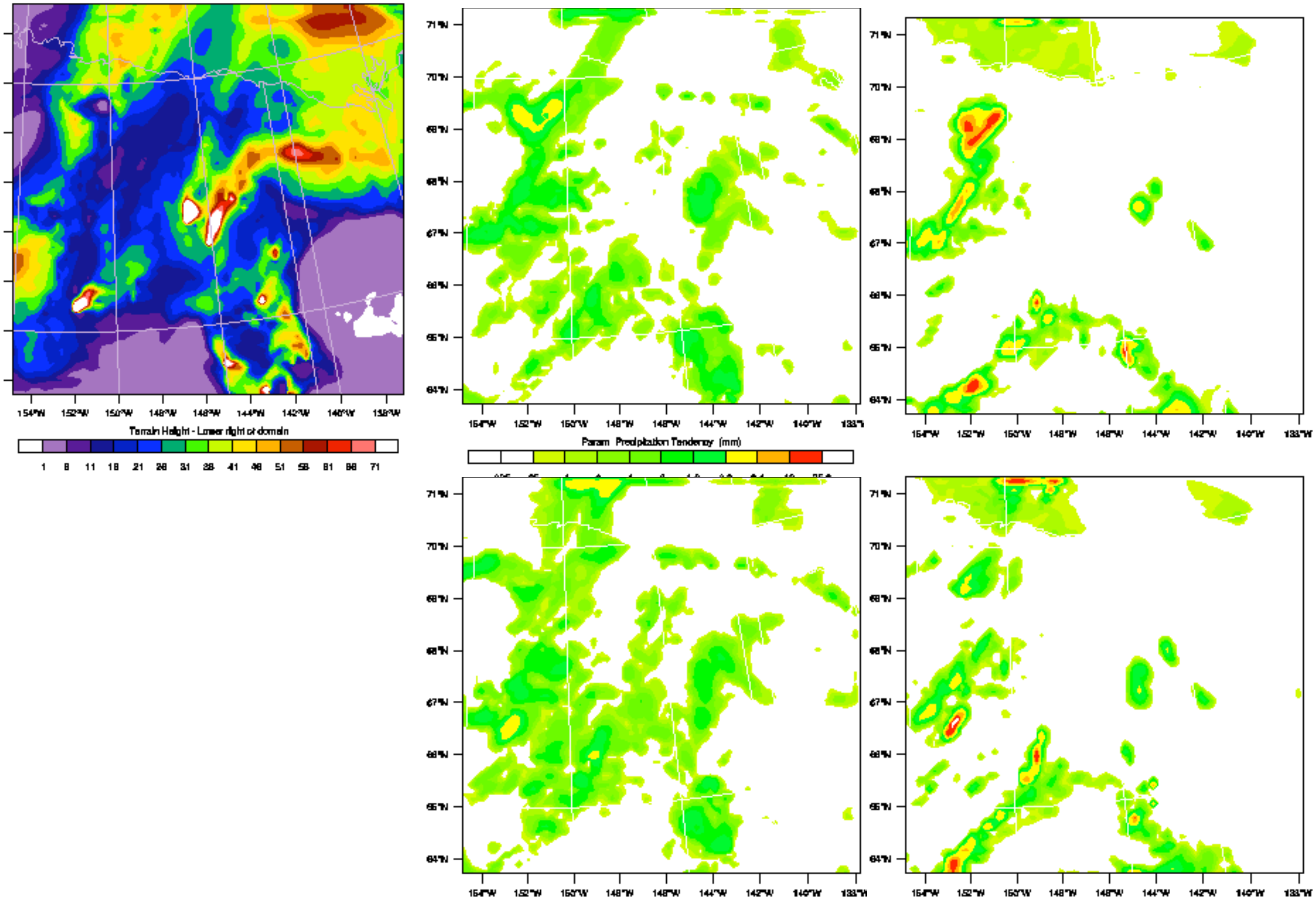


Non-resolved rain

Resolved rain

With fires

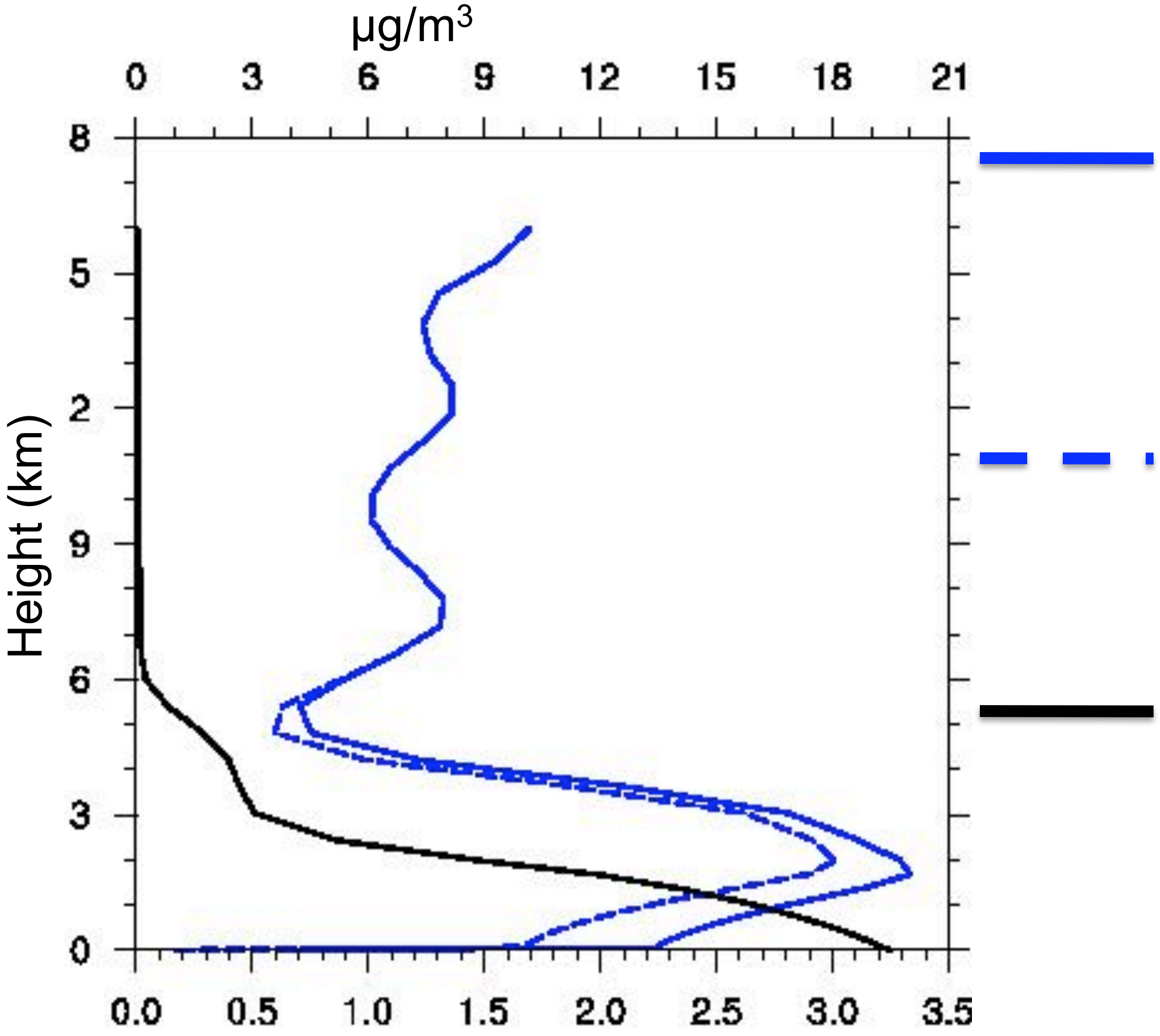
no fires



D2 – The cloud resolving domain

- Day 1: Much more undisturbed conditions
- Day 2: Disturbed weather moving through the area, active convection, much more interesting for microphysics interactions

Domain 2, dx=2km, Box averages (90x90 grid points) over fairly dry and very smoky areas at July 3, 21Z

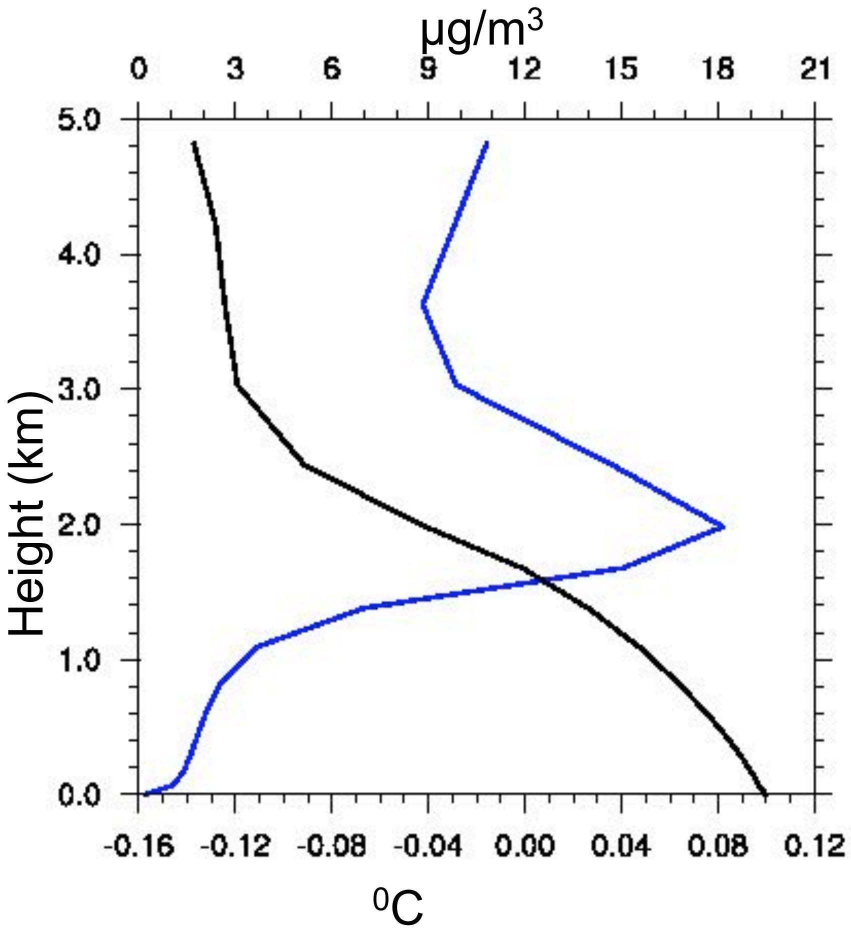


Short wave radiation tendency with fires

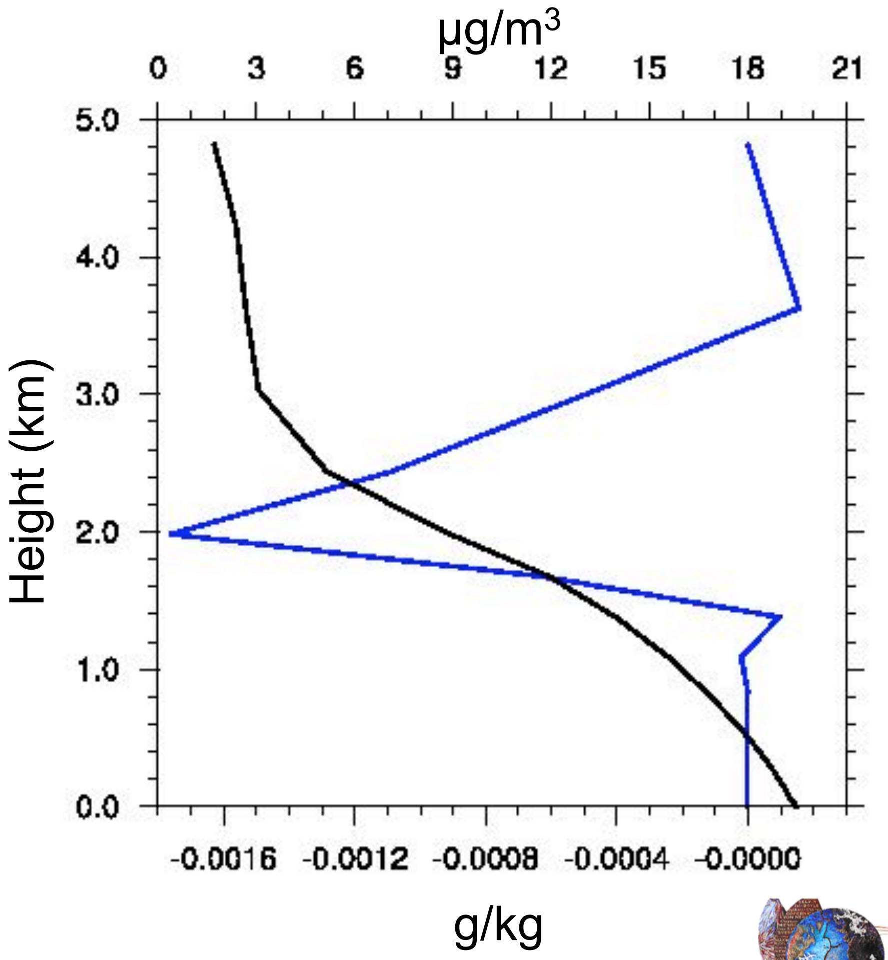
Short wave radiation tendency without fires

PM2.5 concentration (ug/m^3)

Box averaged
Temperature difference
(blue) and PM2.5 (black)

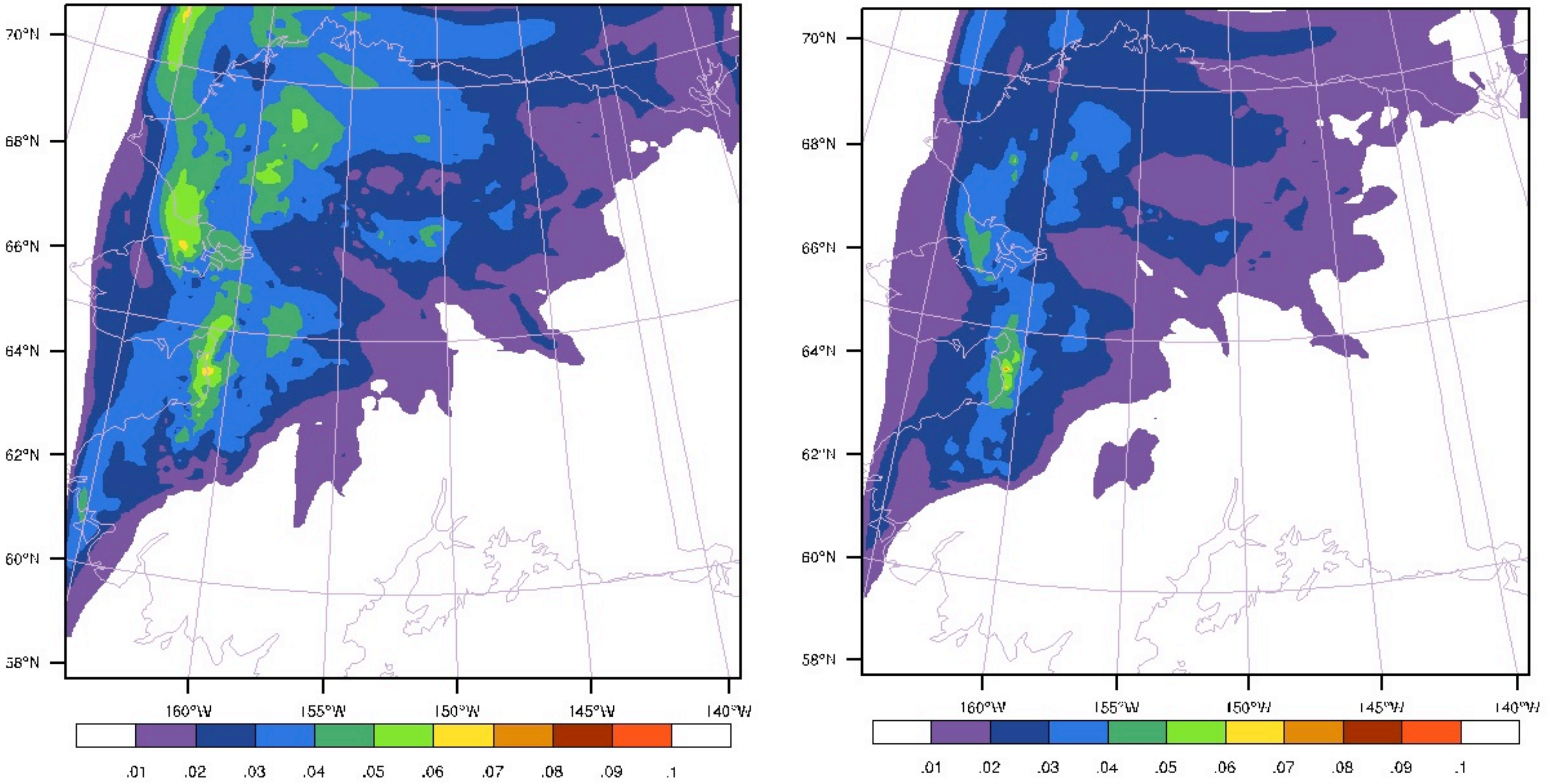


Box averaged cloud
water difference (blue)
and PM2.5 (black)



If it is the semi-direct effect, then will we see it with a very simple approach that is not coupled to microphysics?

Compare results to a simulation without any indirect effect:
Using GOCART bulk scheme

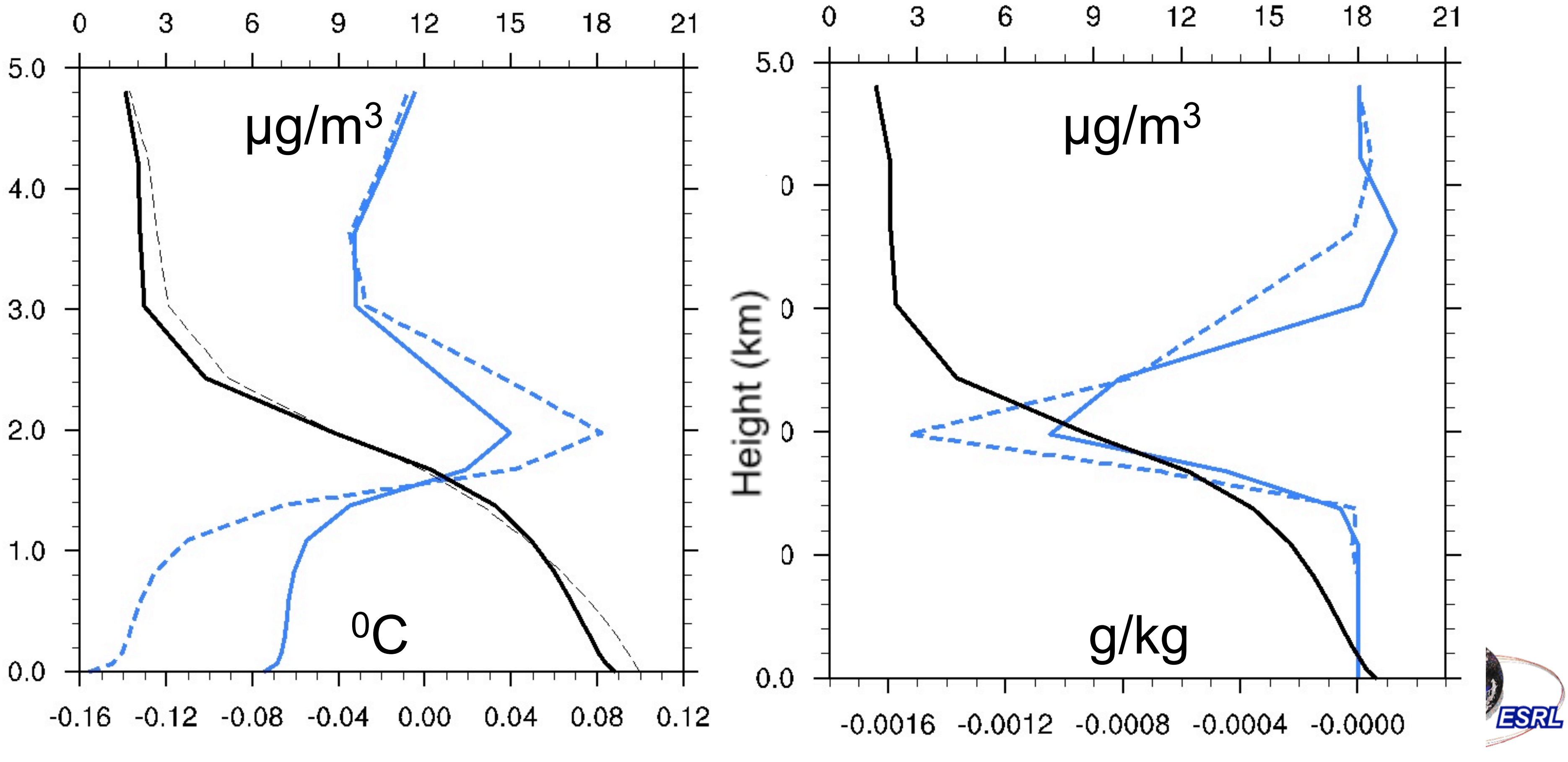


Full Chemistry, > 100 extra variables

GOCART with 9 extra variables

Comparison of integrated extinction coefficients (at .55um) when using bulk aerosol module (GOCART modules): a little smaller than in full chemistry run (a little less aerosol in the air)

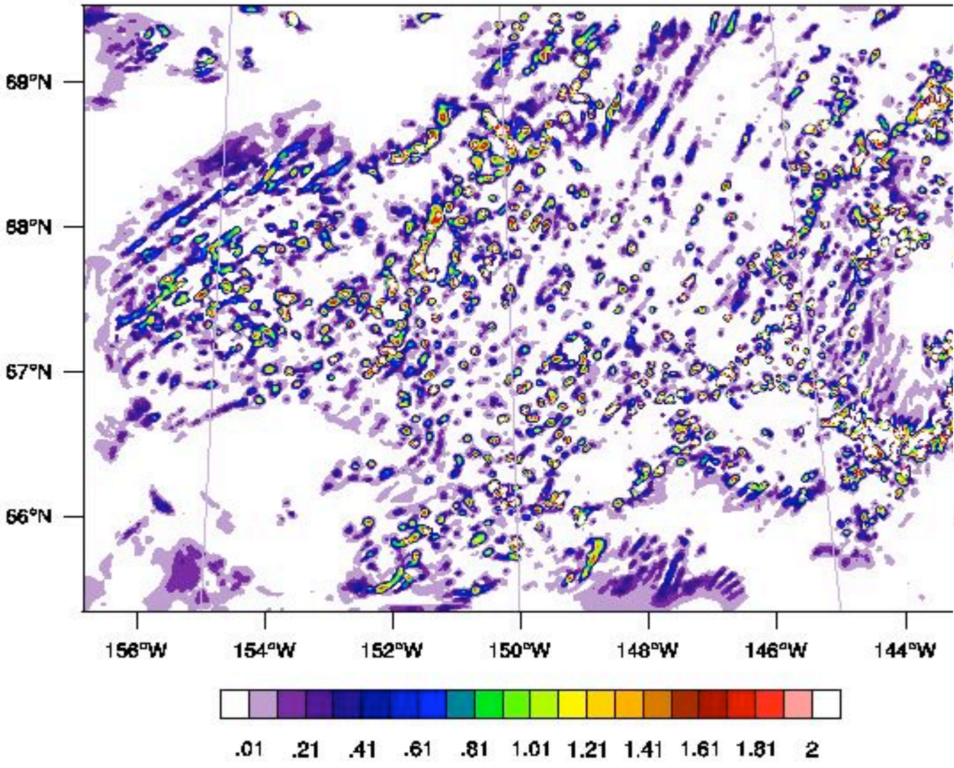
In black: PM2.5, solid is GOCART aerosols, dashed is full chemistry runs



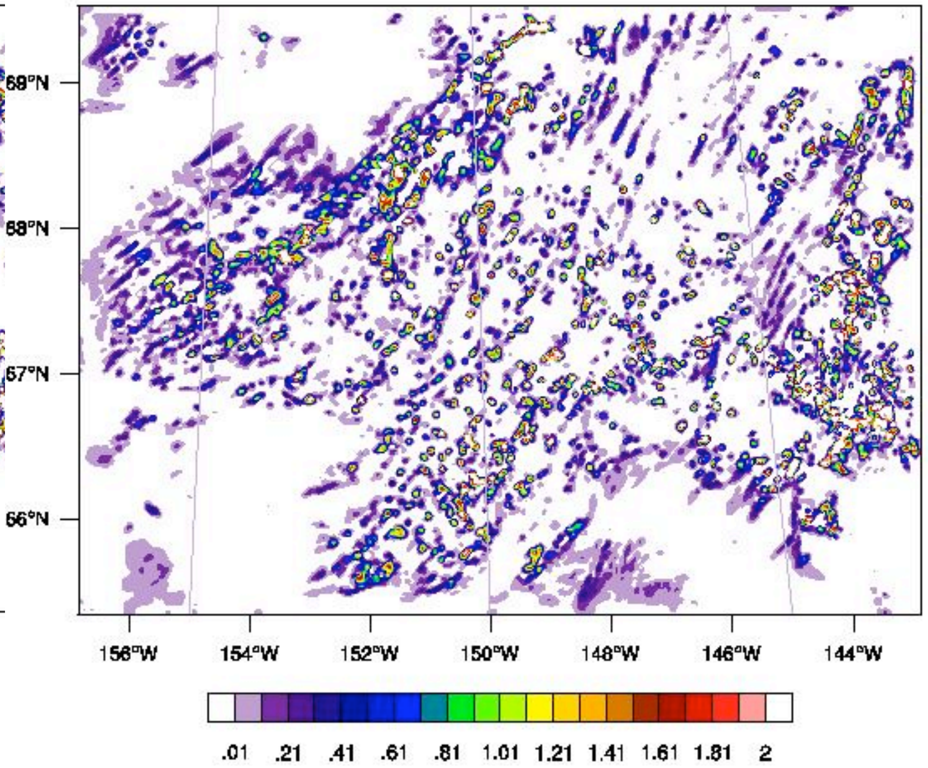
How about when microphysics get’s more involved?

Integrated cloud water for July 4, 2100UTC

With fires



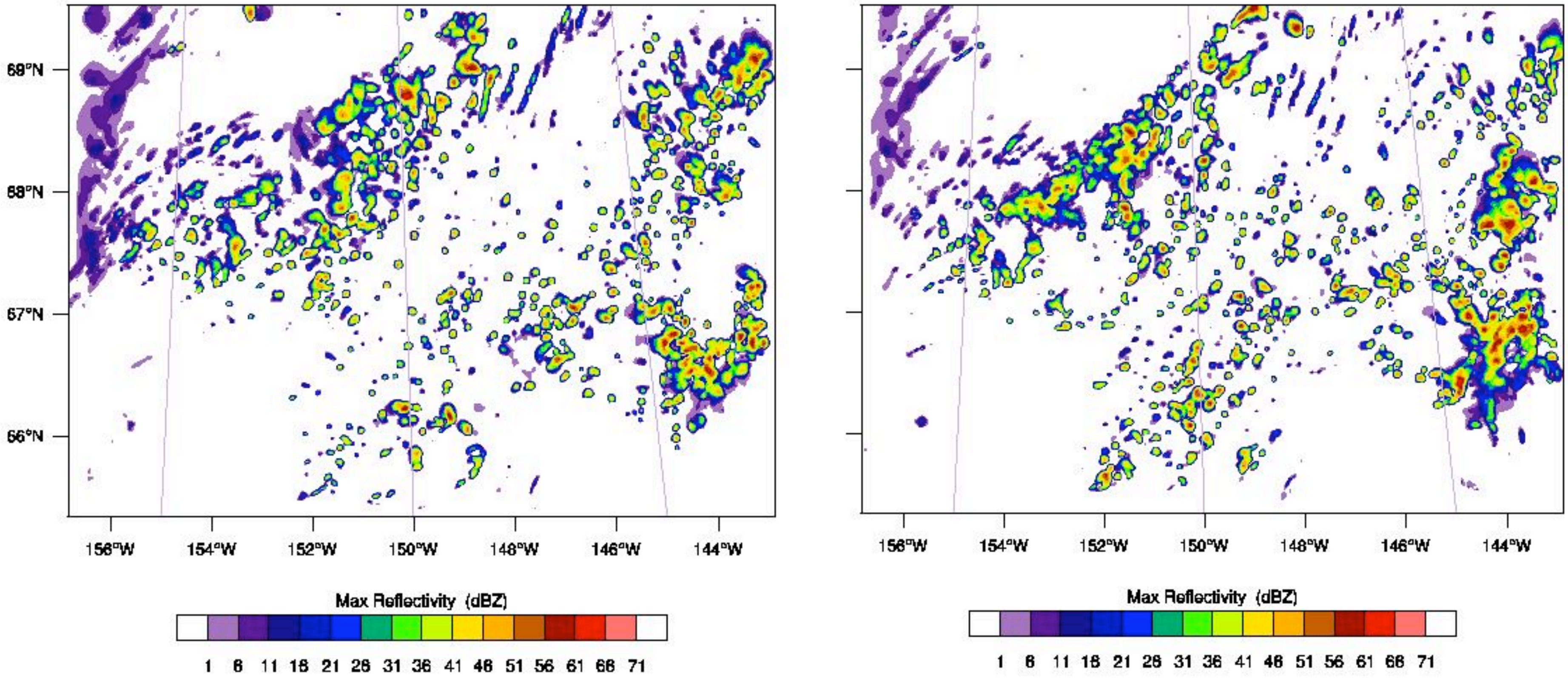
Without fires



Counting the number of grid points with Iclw > 0, more clouds when fires are included

WRF-Chem simulation, dx=2km, July 4, 2100UTC,

Simulated max reflectivity



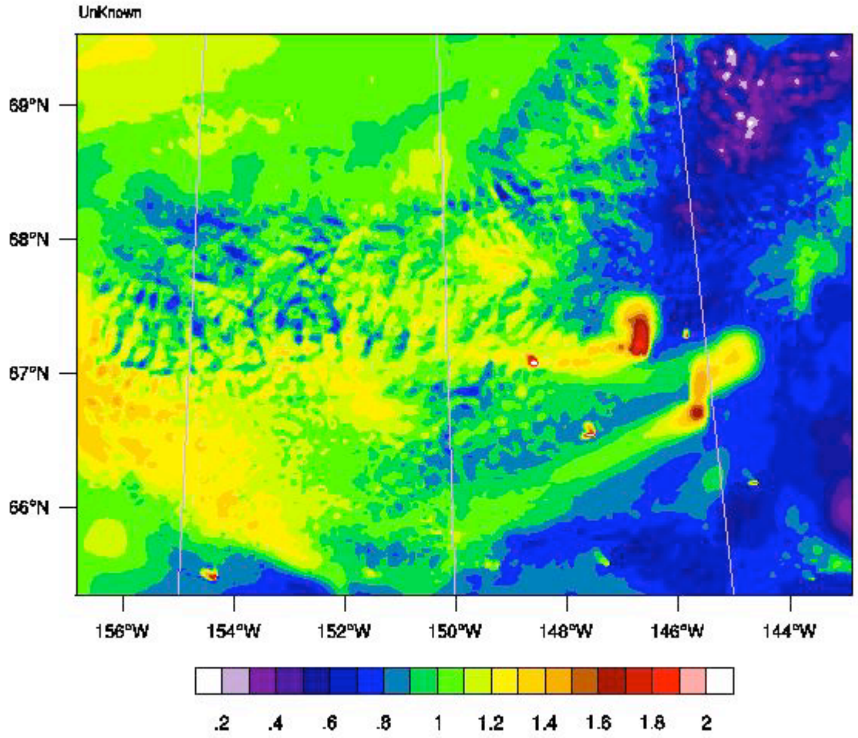
With fires

Without fires

More precipitation coverage when fires are not included

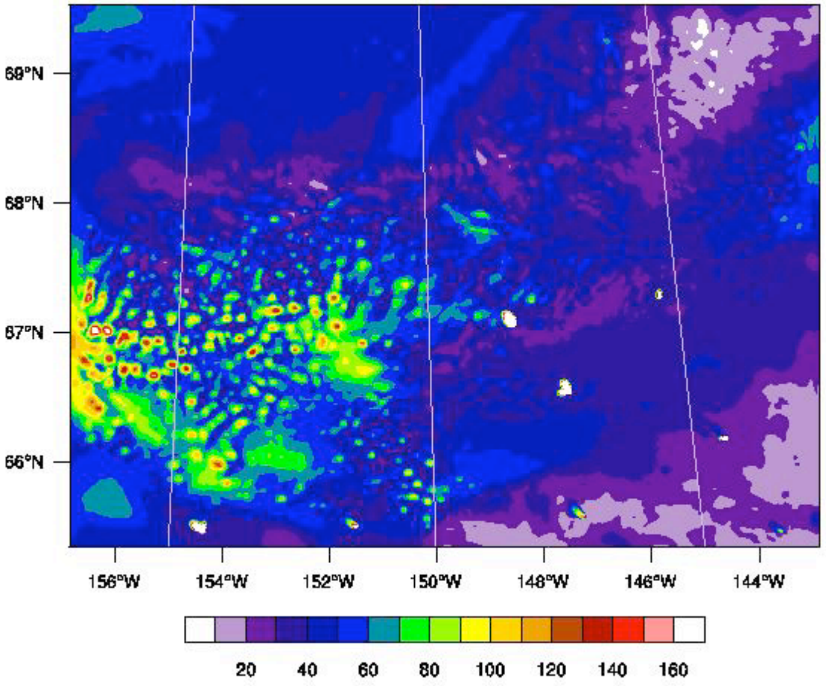
Domain 2, with fires, comparison of CCN and PM2.5

Vertically Integrated PM2.5



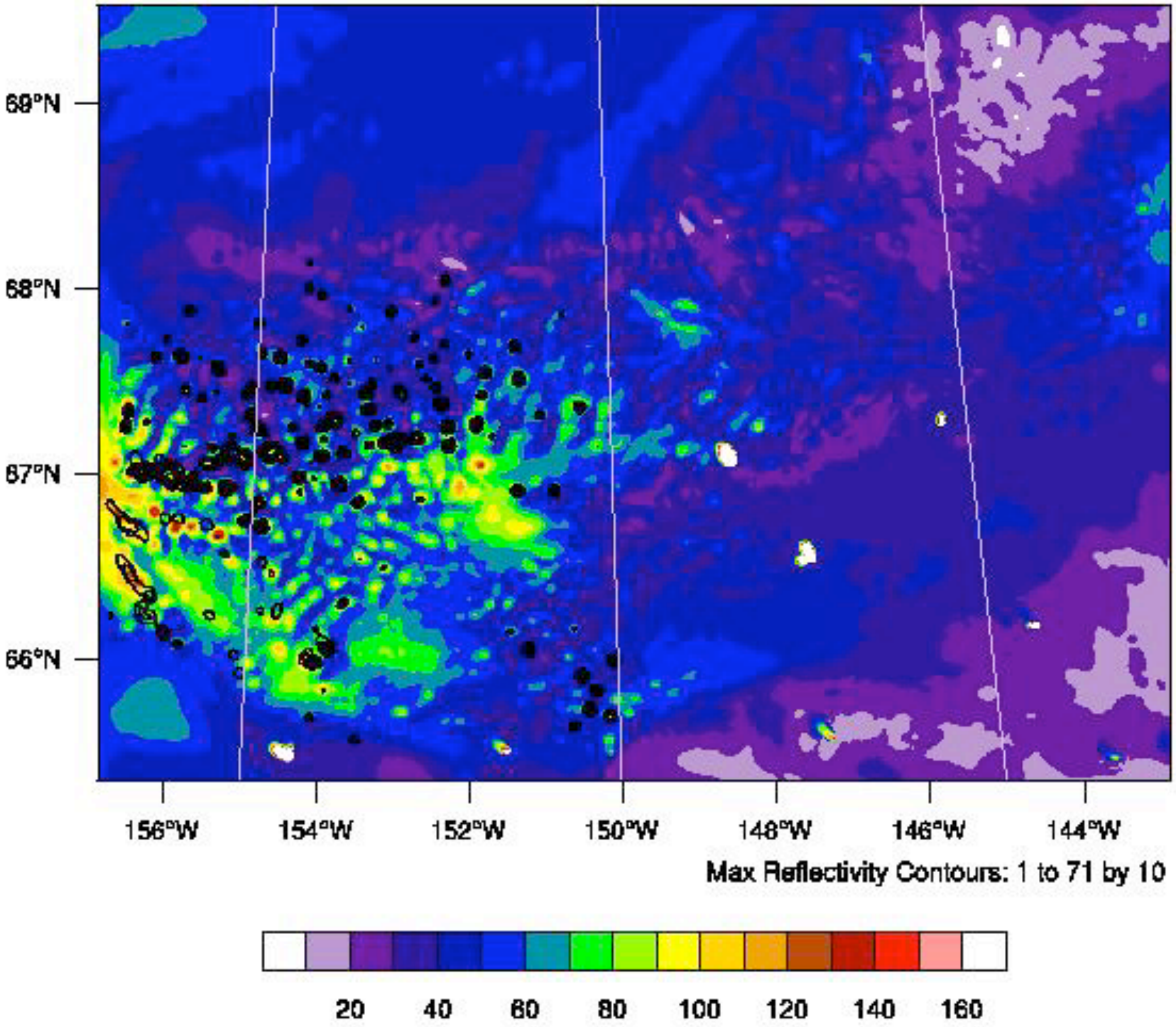
OUTPUT FROM WRF V3.1.1 MODEL
WE = 326 ; SN = 236 ; Levels = 35 ; Dis = 2km ; Phys Opt = 2 ; PBL Opt = 1 ; Cu Opt = 0

Vertically Integrated CCN at .05% super saturation



OUTPUT FROM WRF V3.1.1 MODEL
WE = 326 ; SN = 236 ; Levels = 35 ; Dis = 2km ; Phys Opt = 2 ; PBL Opt = 1 ; Cu Opt = 0

Vertically Integrated CCN at .05% super saturation, dbz overlaid in black contours



Some conclusions

- Interaction of aerosols from biomass burning with atmospheric radiation leads to warming through absorption (in and just above the BL), causing the semi-direct effect
- The surface level itself is cooled
- Semi-direct effect appears to play a role in suppressing clouds especially when general meteorological situation is somewhat suppressed, but low level clouds still exist

Direct and semi-direct effect maybe significant for weather forecasting even on 1 -2 day timescale

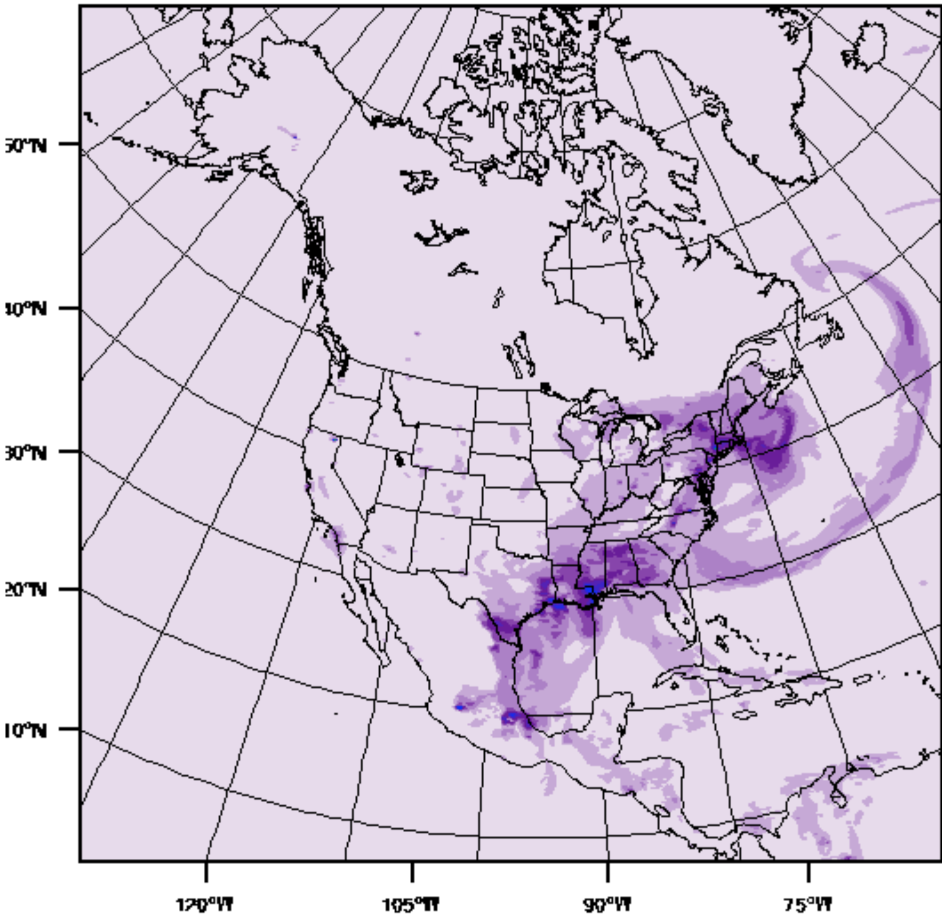
- During periods of stronger precipitation activity, cloud coverage is similar, but dbz echoes have smaller area coverage
- Strong echoes can become stronger and longer lived

Droplets are smaller when fires are included: usually less precipitation except for some intense storms that are longer lasting

Some current and ongoing activities relating to air quality forecasting

- Chemical data assimilation (talk by Mariusz Pagowski) for Ozone and PM2.5
- Rapid Refresh (RR, dx=13km) and High Resolution Rapid Refresh (HRRR, dx=3km) are run with GOCART aerosol modules, RR will use meteorological and chemical data assimilation (poster by Steven Peckham)
- Volcanic eruptions have been implemented for ash fall predictions as well as SO2 emissions
- Chemistry from WRF-Chem is now also available in ESRL's global model, the Flow-following finite volume Icosahedral Model (FIM)

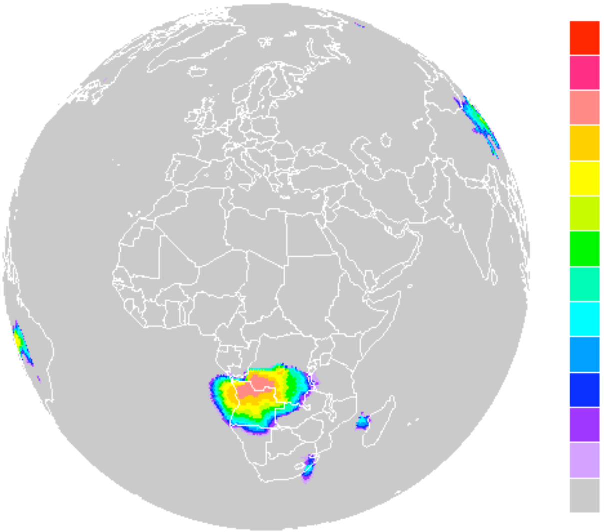
Some current and ongoing activities relating to air quality forecasting



RR-Chem, currently out to 48hr forecasts to collect data for chemical data assimilation (background error statistics). Maybe ideal tool to test sensitivity of meteorological data assimilation to online chemistry

Some current and ongoing activities relating to air quality forecasting

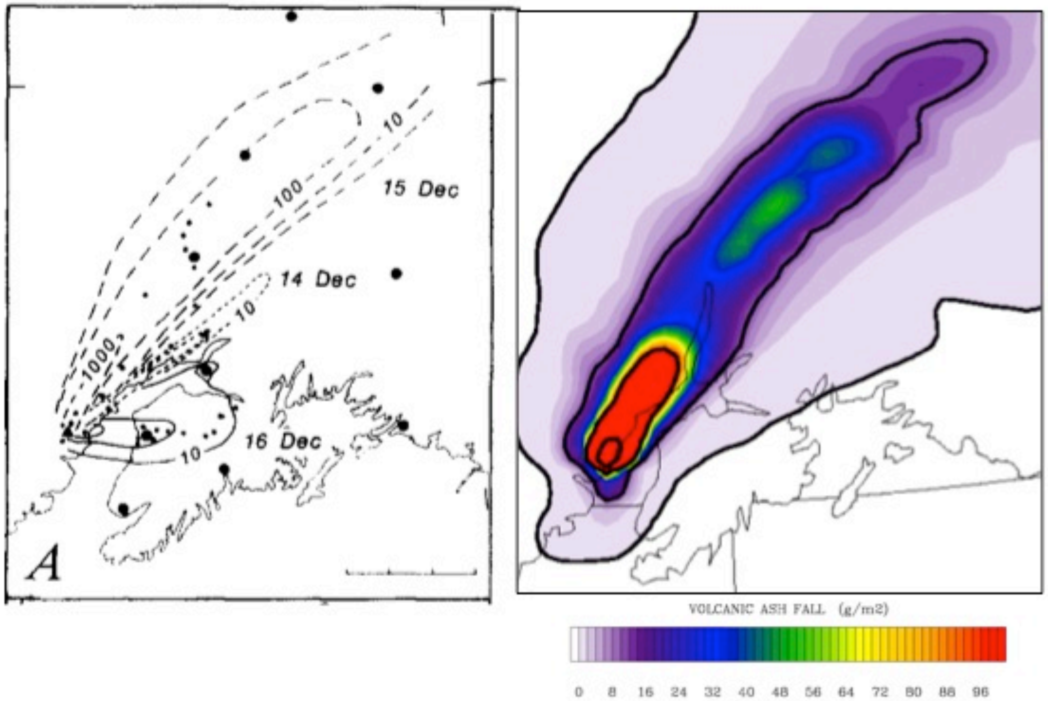
15 day hydrophillic carbon
prediction, July 1 – July 15, 2009
Dx about 60km



FIM-Chem, can use physics and chemistry from WRF-Chem

Some current and ongoing activities relating to air quality forecasting

Tephra-fall deposits (g/m²)
Redoubt Volcano, south-central Alaska
December 15, 1989



Observed

Predicted by WRF-Chem

Ash-Fall predictions using 10 size bins