ATMOSPHERIC DISPERSION OF ALASKA WILDFIRE POLLUTANTS AS PREDICTED BY THE WRF-CHEM MODEL AND OBSERVATIONS

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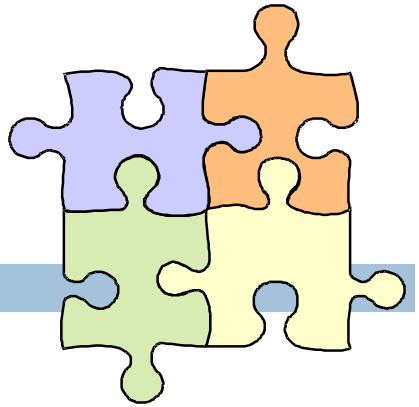
4: BRAZIL CENTER FOR WEATHER FORECASTING AND CLIMATE STUDIES
5: GEOGRAPHIC INFORMATION NETWORK OF ALASKA (GINA), UAF

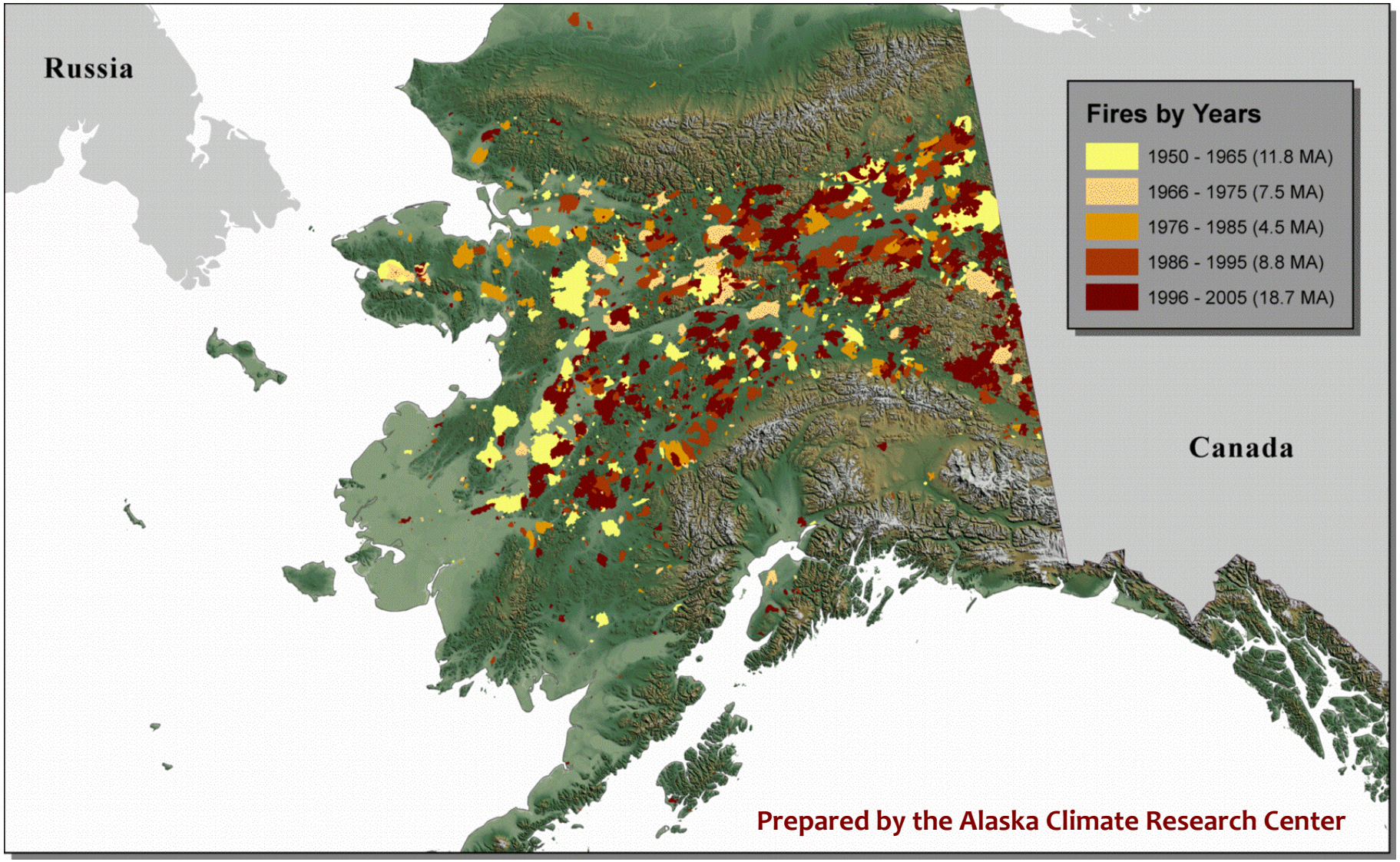
Fire Science Workshop – Fairbanks, Oct 11 & 12

OUTLINE



- Background
- Resources to Date – Weather Research Forecast Model
- Case Studies
- Validation and Operational Tool Development Status
- The Way Forward

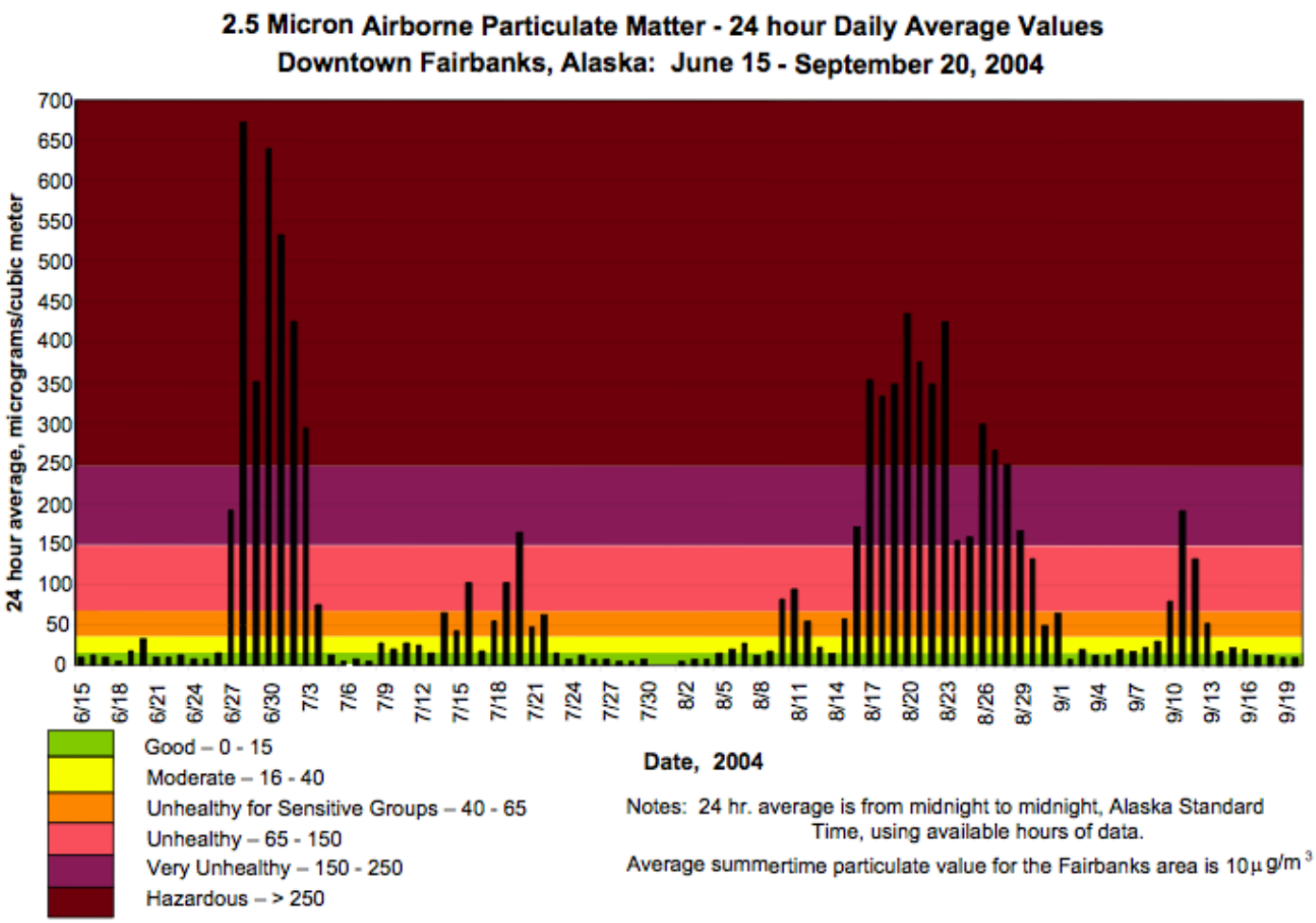
BACKGROUND


Russia
Canada
Fires by Years
1950 - 1965 (11.8 MA)
1966 - 1975 (7.5 MA)
1976 - 1985 (4.5 MA)
1986 - 1995 (8.8 MA)
1996 - 2005 (18.7 MA)
Prepared by the Alaska Climate Research Center

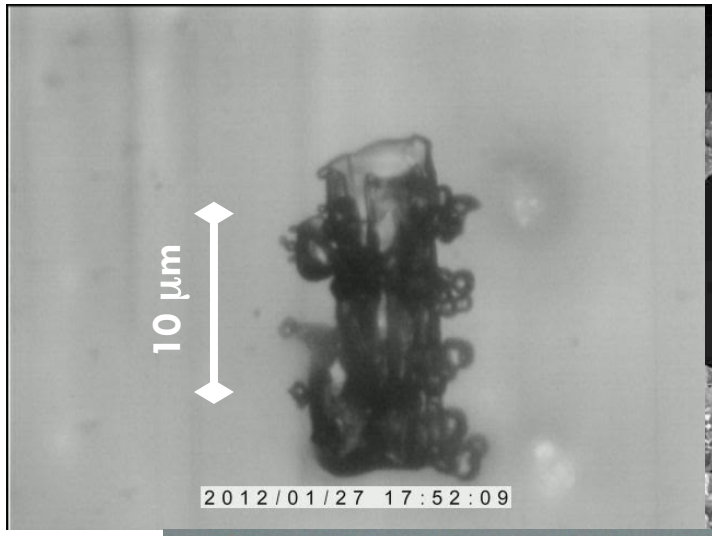
BACKGROUND

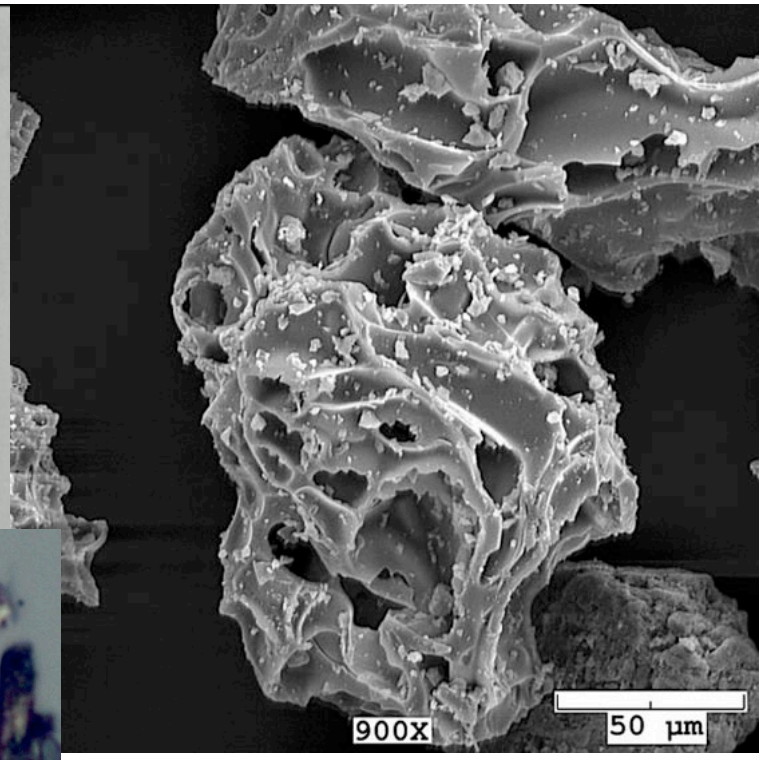
Prepared by DEC Division of Air Quality
http://www.dec.state.ak.us/air/

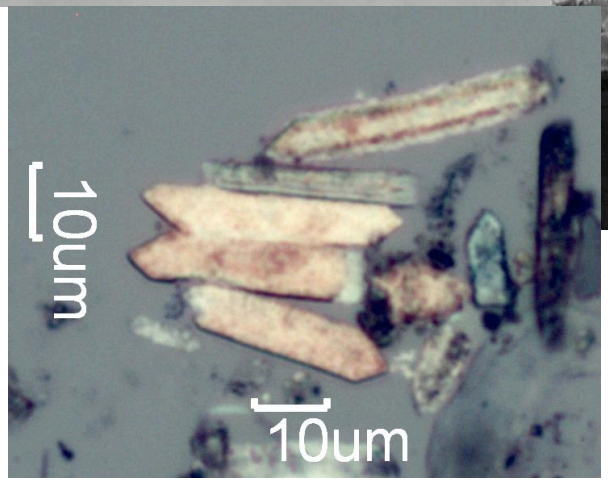
Summer 2004:
⇒ **41 days unhealthy to hazardous** in Fairbanks
⇒ **16 (of the 41) days clearly hazardous**



BACKGROUND –AEROSOL TYPES







BACKGROUND

- Health: Alaska wildfires have strong impact on air pollution on regional and even hemispheric scales. Biomass burning has especially strong impact on FNSB air quality during Interior Alaska fire seasons.
- Climate: Air pollution feedback to atmosphere.
- Traffic: Polluted air is dangerous for aviation, also impact due to visibility restrictions.

The following transmissions took place between Anchorage Center, the air traffic control facility for that region, and KLM 867:

Pilot — "KLM 867 heavy is reaching level 250 heading 140"
Anchorage Center— "Okay, Do you have good sight on the ash plume at this time?"
Pilot — "Yea, it's just cloudy it could be ashes. It's just a little browner than the normal cloud."
Pilot — "We have to go left now. . . it's smoky in the cockpit at the moment, sir."
Anchorage Center— "KLM 867 heavy, roger, left at your discretion."
Pilot — "Climbing to level 390, we're in a black cloud, heading 130."
Pilot — "KLM 867 we have flame out all engines and we are descending now!"
Anchorage Center— "KLM 867 heavy, Anchorage?
Pilot — "KLM 867 heavy, we are descending now. . . we are in a fall!"
Pilot — "KLM 867, we need all the assistance you have, sir. Give us radar vectors please!"

HOW DESCRIBE EMISSIONS => MODELING APPROACH

1. Wildfire source data: => ‘exact’ location and area?
2. What is burning (fuel, type, condition of surface, moisture)?
3. Status of wildfire: => burning or smoldering?
4. For forecasting: fire spread
5. Quantification of pollutants emitted from wildfires
6. Smoke plume estimate: => how high, what concentration?
7. Meteorological feedback at appropriate scales
8. Computing power

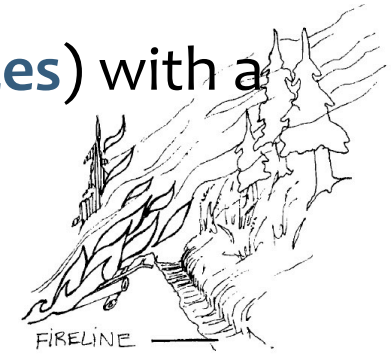
WRF: Weather Research Forecast Model

- Used for both **research** and **operational** forecasting
- "**Community model**"; distributed development and centralized support
- Its development is led by NCAR, NOAA/ ESRL and NOAA/NCEP/ EMC with partnerships at AFWA, FAA, and collaborations with universities and other government agencies in the US and overseas

WRF-Chem

- Applied for studies of **atmospheric pollution**.
- **Online (versus offline): Chemistry** is **completely embedded** within the WRF core.
- **Consistent:** All transport is done by the meteorological model
  - **No** location nor time **interpolation**: same coordinates, same time steps.
  - **Same physics** parameterization for subgrid scale transport.
- Easy **data handling**.
- Ideally suited to **study air quality** at various scales.
- Data source generator package (**Prep_Chem_Sources**) with a suite of **background data**.

Grell et al., 2005



Emission data generator

Prep_chem_sources developed by **Saulo Freitas and Karla Longo**, Brazil Center for Weather Forecasting and Climate Studies, implemented into WRF/Chem.
Gridded daily emissions fluxes (kg/m^2) using several types of map projection (currently polar stereographic, Gaussian, lambert conformal, regular lat/lon) with flexible resolution.

Biomass burning / wildfire emissions

Brazilian Biomass Burning Emission Model (Freitas et al. 2005; Longo et al., 2007)
Emission Factors from Andrae and Merlet, 2001, 110 chemical species, 6 types of biomass
GFEDv2: Global Fire Emissions Database (van der Werf et al., 2006): 8 days/monthly - 1° x1°

Anthropogenic sources

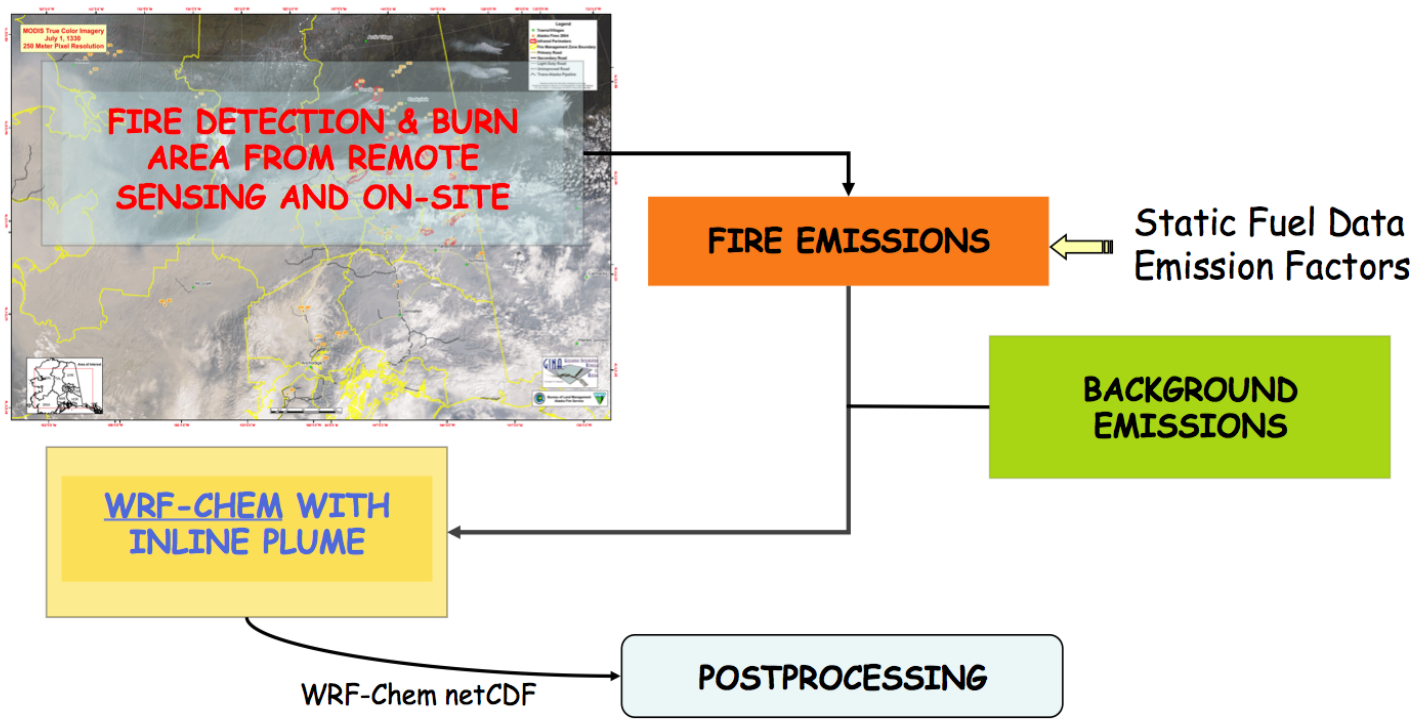
RETRO: REanalysis of the **TRO**pospheric chemical composition over the past 40 years, global, 0.5° x 0.5°, monthly
EDGAR: Emission Database for Global Atmospheric Research, global, 1° x 1°, annually
NEI 2005: Point Sources for Alaska

Biogenic sources

GEIA: Global Emissions Inventory Activity, 1° x 1°

GOCART: Goddard Chemistry Aerosol Radiation and Transport model

WRF-Chem Modeling Scheme



- Hybrid fire source data
- Gridded hourly fire emissions vertically distributed with the plume rise model inline in WRF/Chem.

Emission Rates

- Bottom-Up Approach: Mass *E* of the emitted tracer species *i* is calculated according to:

$$E_i = a * b * CE * e_i,$$

  - *a*: burning area
  - *b*: fuel loading
  - *CE*: combustion efficiency (above-ground biomass available for burning)
  - e_i: emission factor

- emission factors were comprised in order to relate various fuel-load types involved in **biomass burning to emissions.**

Plume Model

inline in **WRF/Chem** : PLUMP => one-dimensional plume model including parameterized cloud physics has been implemented

Inaccuracies are avoided due to otherwise necessary parameterization because of the small scale characteristics of the plume rise.

The one-dimensional fire plume rise model (PLUMP, Latham, 1994) estimates the vertical displacement of fire emissions mainly due to the heat emitted from fires.

Freitas et al. , 2009

$$\Delta h = \left(\left(\frac{3 r_0 x^2}{4 \beta^2 F^2 K^3} \right) + \left(\frac{r_0}{\beta} \right)^3 \right)^{\frac{1}{3}} - \frac{r_0}{\beta}$$

$$F = \left(\frac{w_0^2 \rho_a}{2 \Delta \rho g} \right)^{\frac{1}{2}}$$

$$w_0 = \frac{8.8 \times 10^{-6} Q_h T_P}{g (T_P - T_a) r_P^{\,2}}$$

Δh : the plume rise of fire plume, m
x: the downward distance,
r_0: fire radius, m
K: the velocity ratio
U: 10-m wind speed, m/s
β : the entrainment coefficient (β=0.6)
F : the Froude number
w_0 : the initial vertical velocity, m/s
ρ_a: ambient density, kg/m3
$\Delta\rho$: the initial density difference between ambient air and the fire plume. (ρ_a-ρ_p)

T_P, T_a : temperature of plume and ambient respectively, K
r_P: the radius of fire, m
Q_h: the heat release rate, J/s

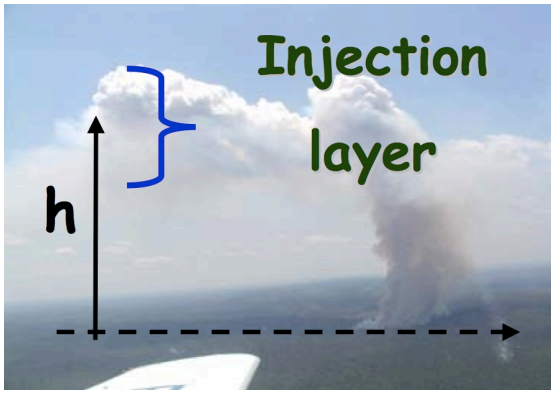
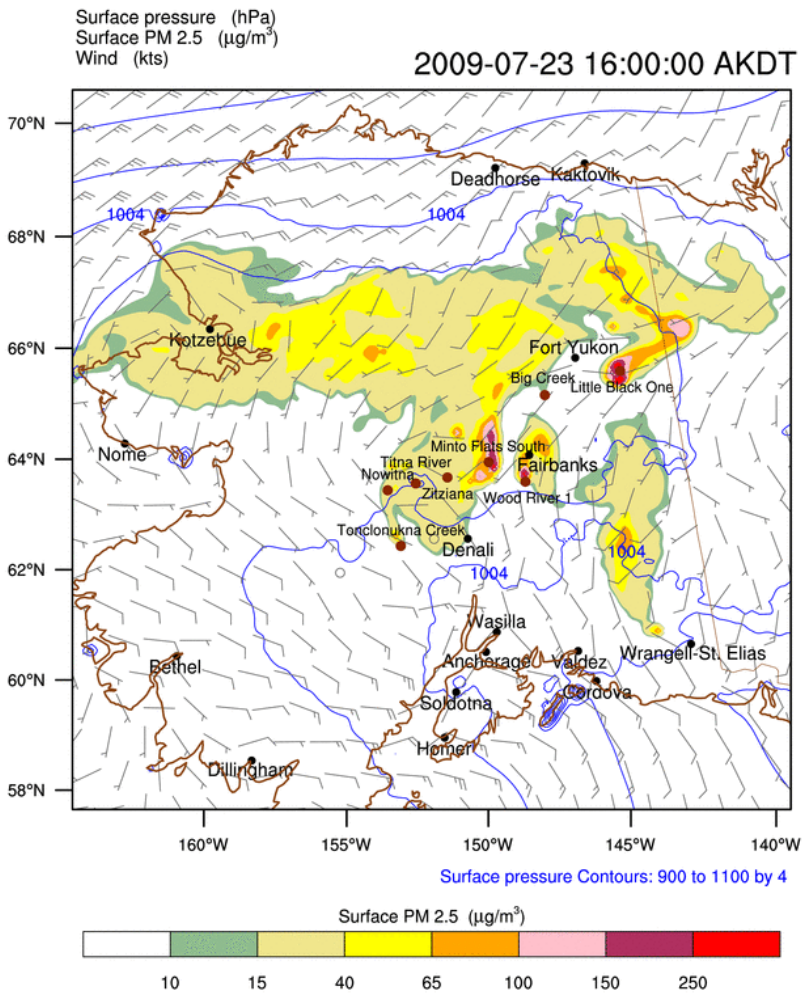


Photo courtesy:
S. Freitas

Operational WRF-Chem Smoke Runs for Alaska



⇒ **72 hour** Smoke WX

⇒ GFS meteorological initial and boundary conditions

⇒ **daily** during the fire season

⇒ Forecast graphics at

http://smoke.arsc.edu

=> Chemistry: GOCART simple aerosol scheme, no O_3

⇒ WSM 5-class scheme microphysics

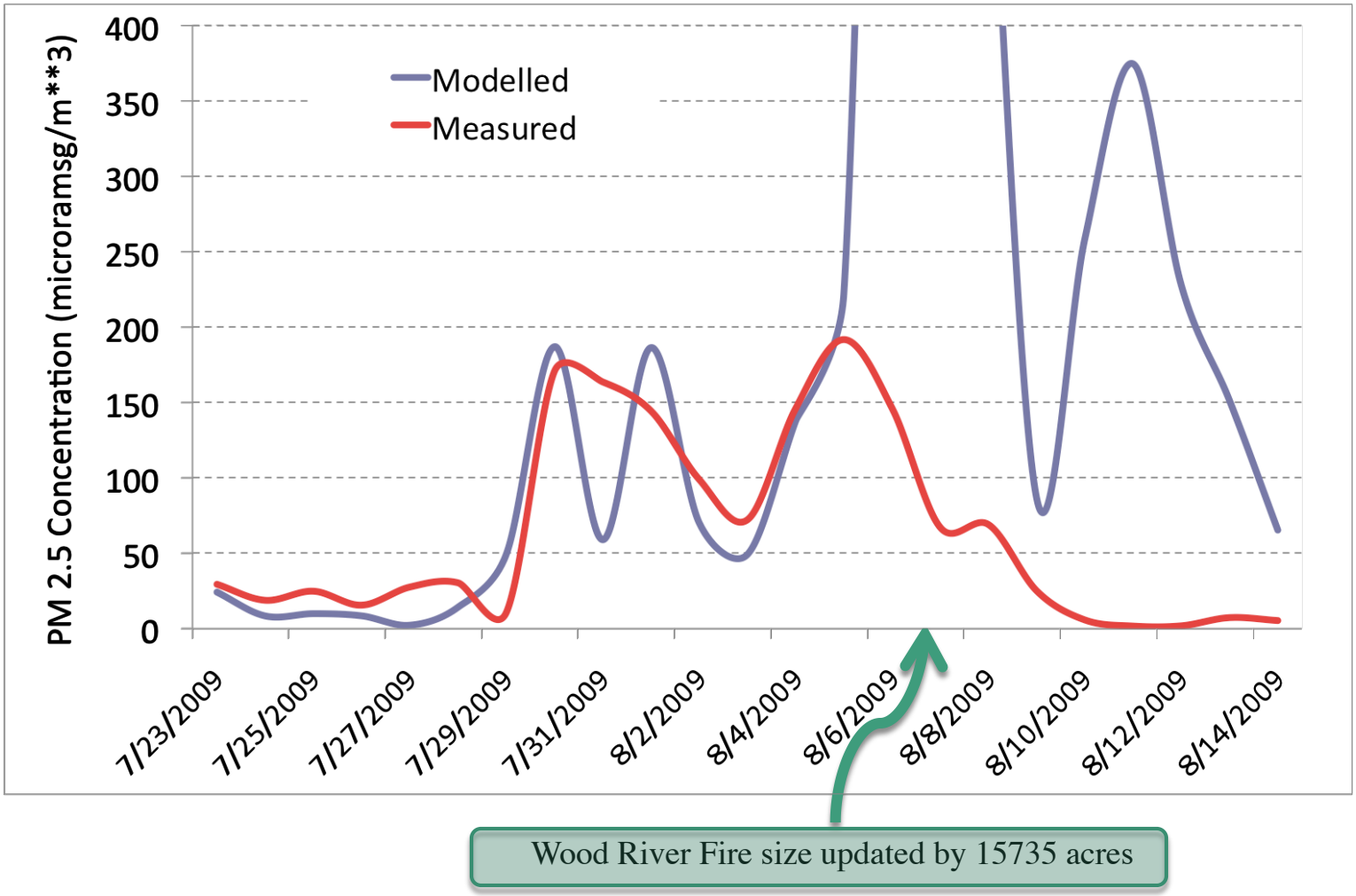
⇒ RRTM longwave

⇒ Dudhia shortwave

⇒ YSU boundary layer scheme

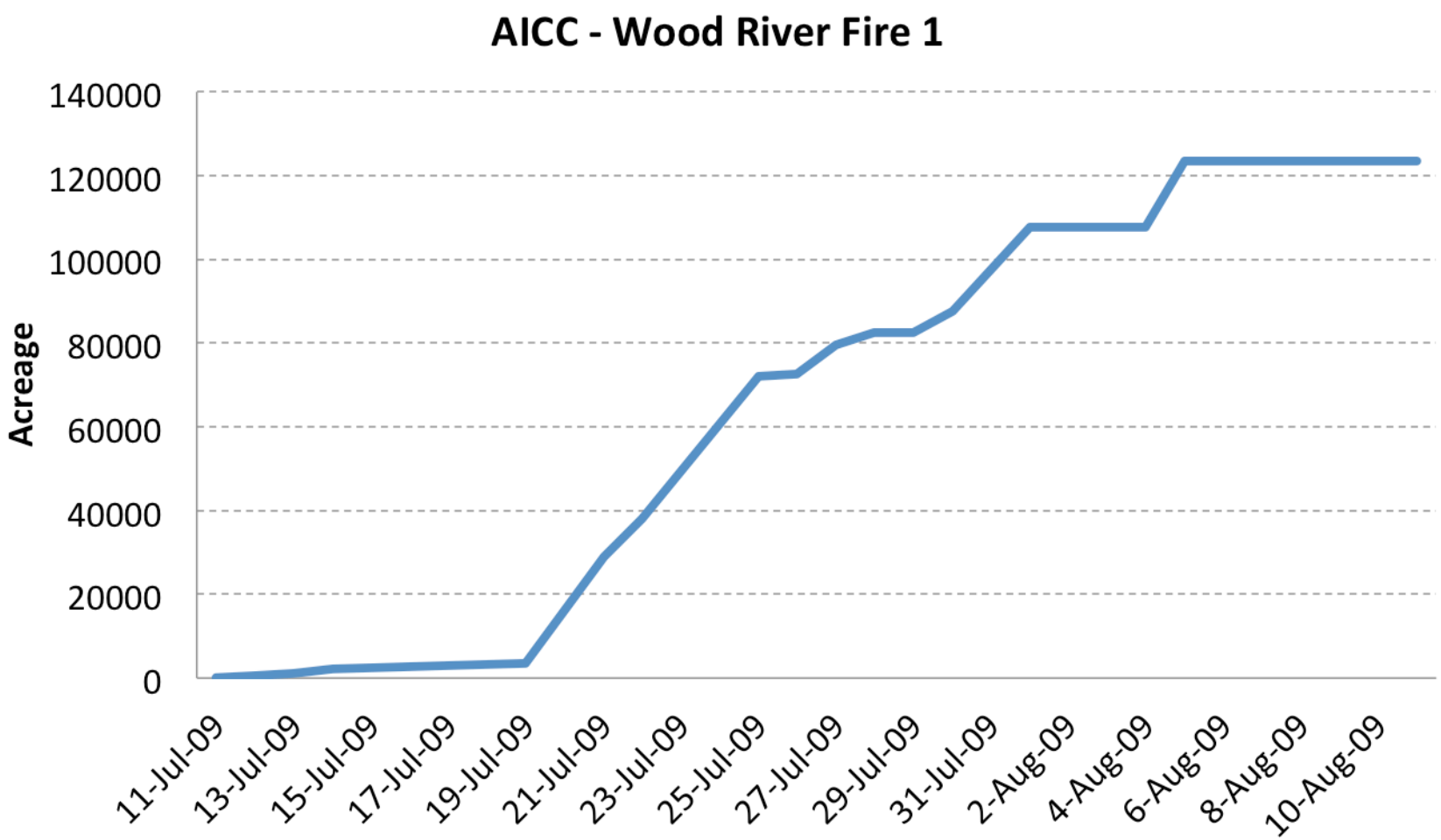
⇒ AICC and MOD14 fire source data

PM2.5 Comparison

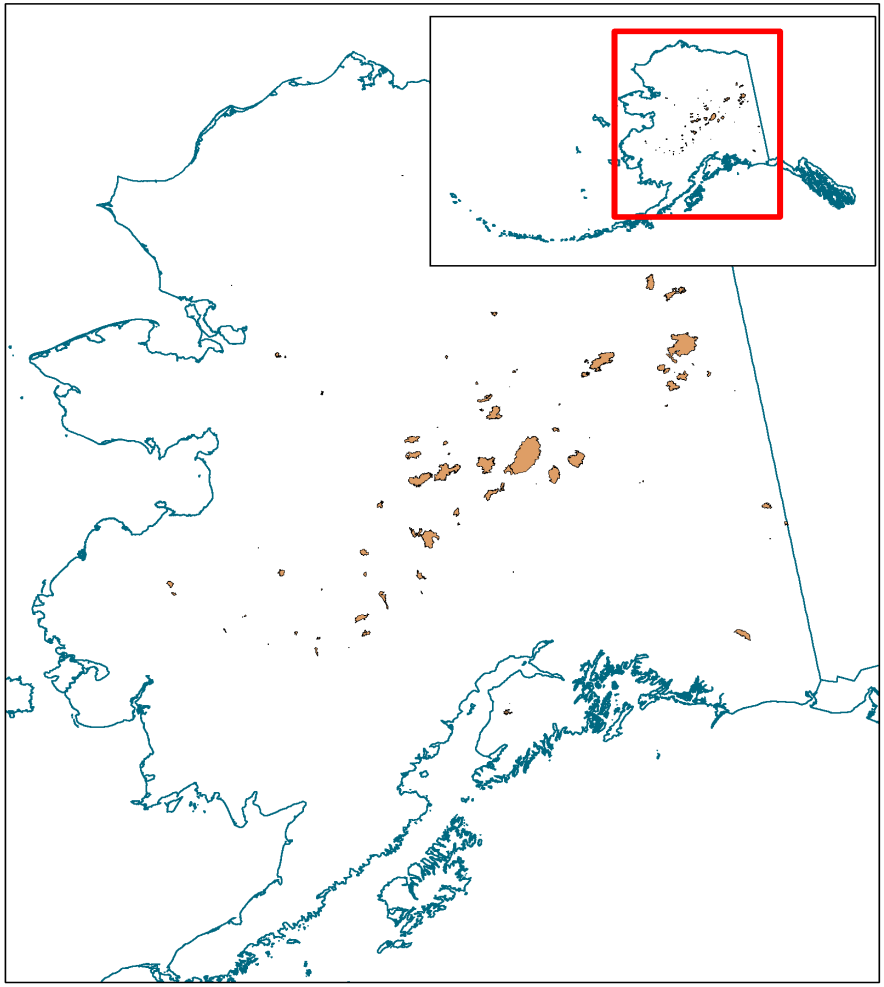


Measurement Source: Jim Conner, Fairbanks North Star Borough

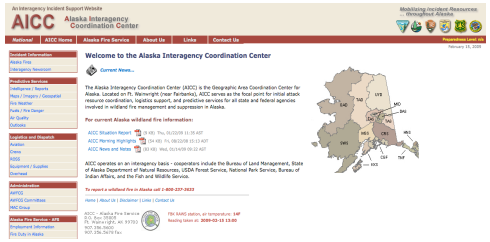
Challenge: Fire Source



Various Fire Sources as Hybrid



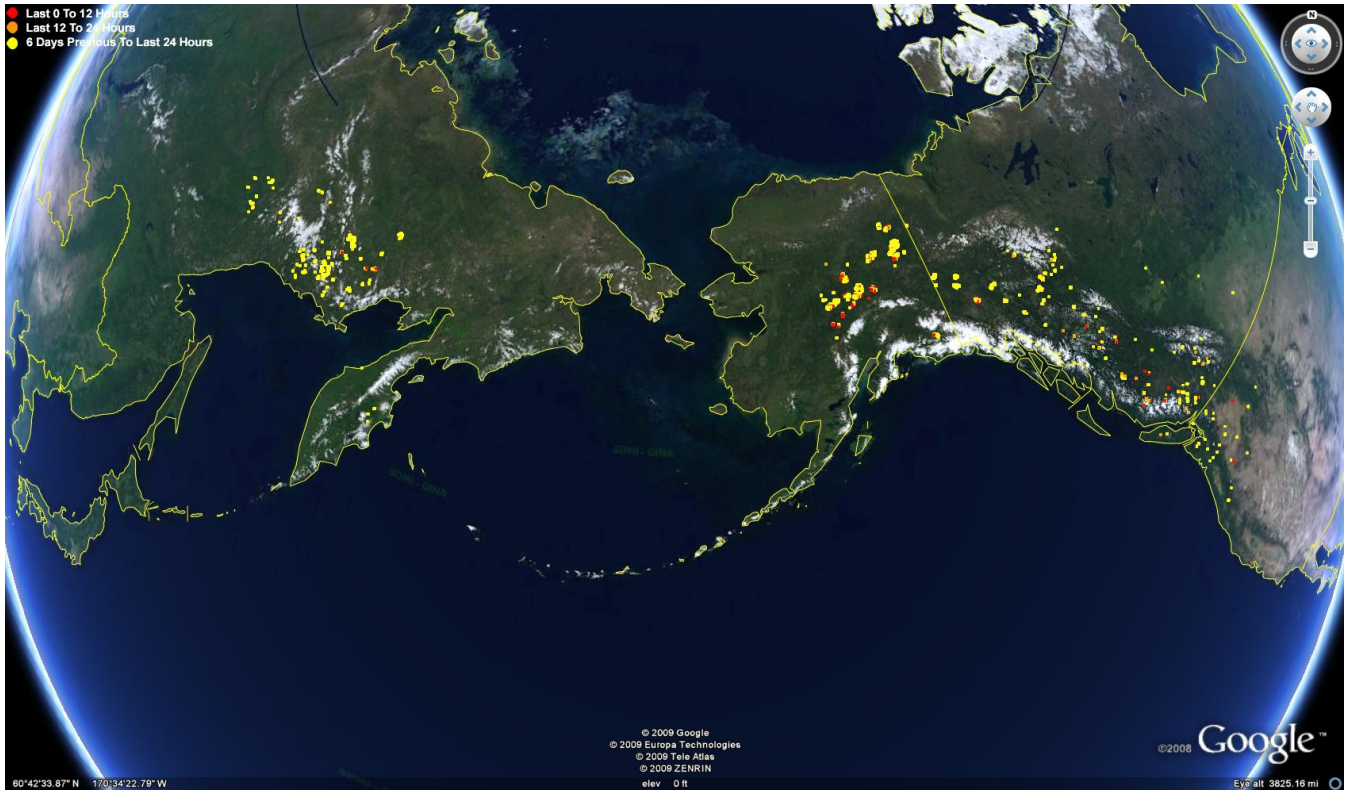
Wildfire extents (July 1 - Aug 15, 2009)



AICC FIRE SOURCE

The **fire information** products may be **combined** using a **filter algorithm** to avoid double count of the same fire, by eliminating additional fires within a circle of 1 km radius. The fire detection maps are merged with 1 km resolution fuel load to provide the associated emission factor, combustion factor and carbon density.

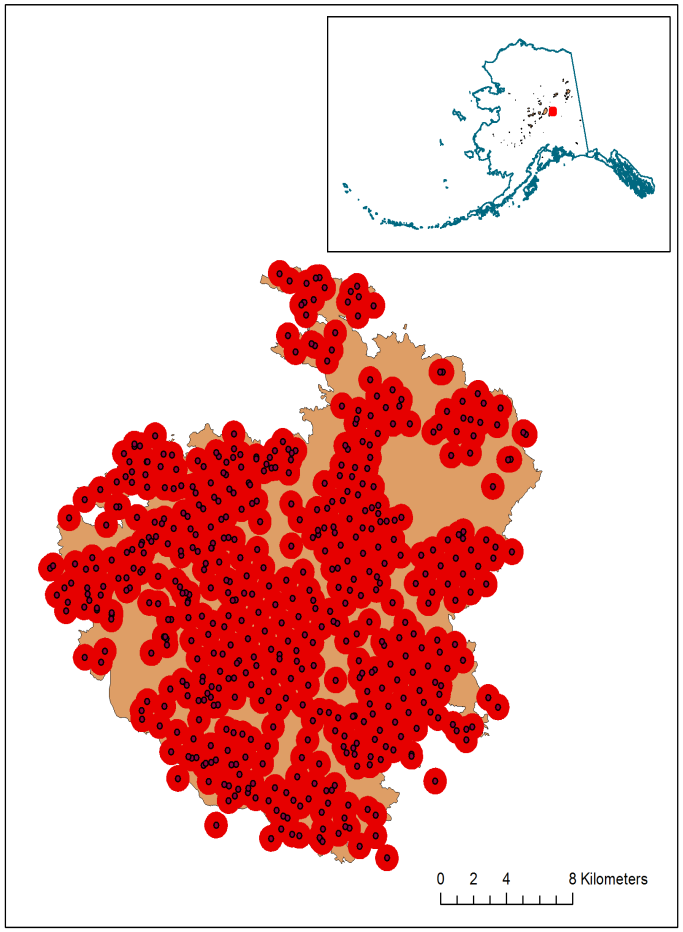
MODIS (MOD 14) Thermal Anomalies



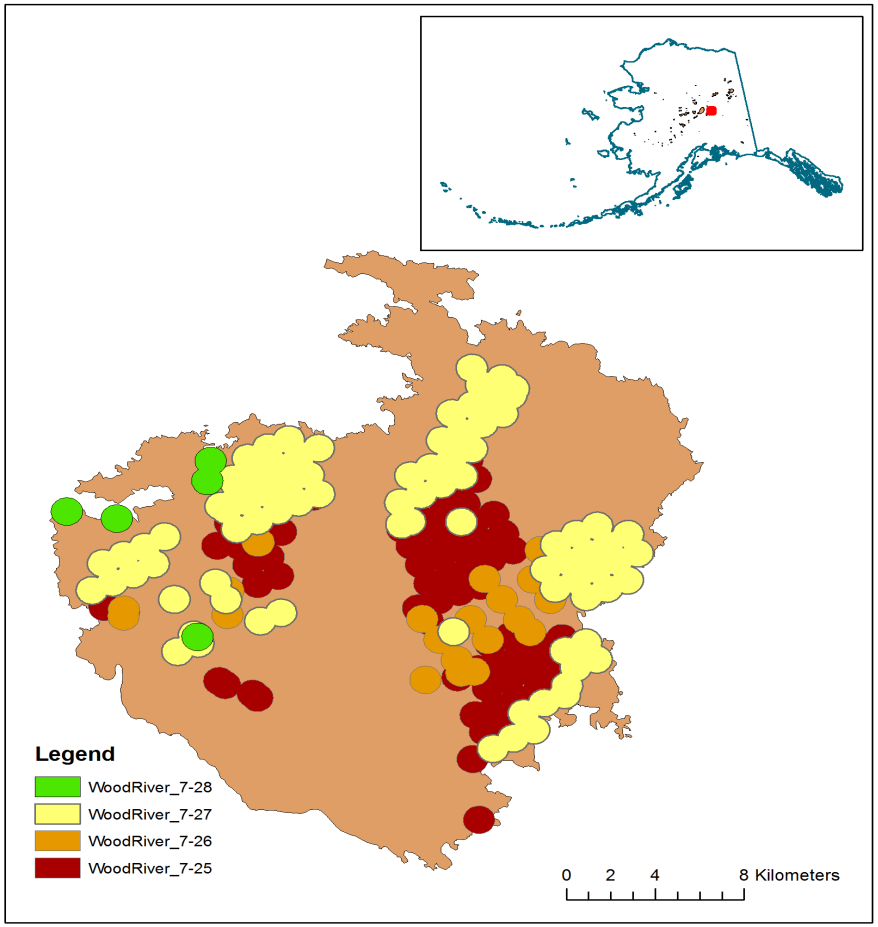
A MODIS hotspot/active fire location represents the center of a 1km (approx.) pixel flagged as containing one or more actively burning hotspots/fires. The hotspots/fires are detected using data from the MODIS (or Moderate Resolution Imaging Spectroradiometer) instrument, on board NASA's Aqua and Terra satellites. In most cases, MODIS hotspots are vegetation fires.

It is **not** recommended to use hotspot/active fire locations to estimate burned area due to spatial and temporal sampling issues.

Hotspots ⇔ AICC burned Area



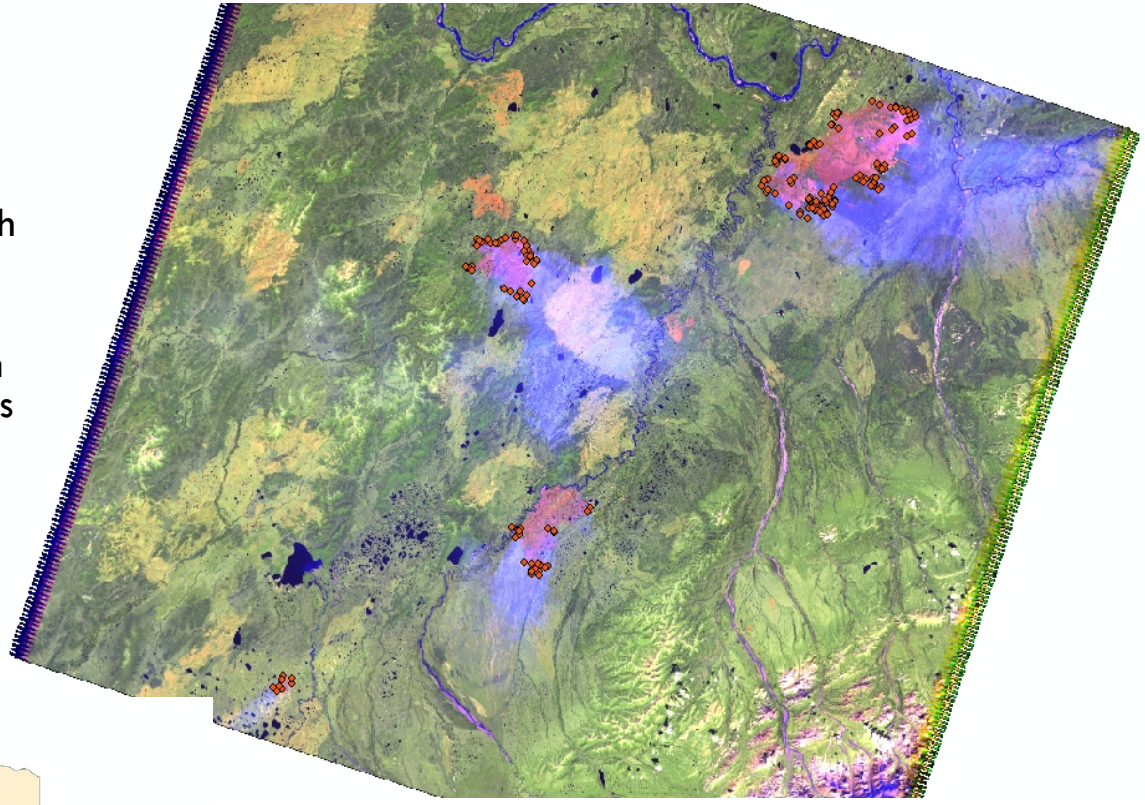
Buffered hotspots from the Wood River Fire

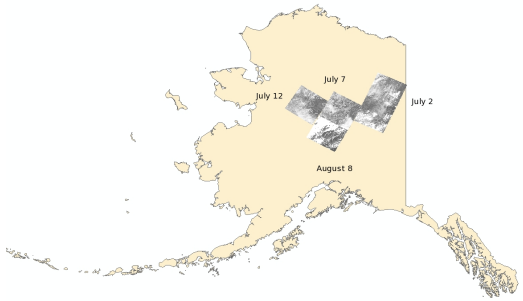


Fire extent for a sample of dates.

Supplemental Fire Data

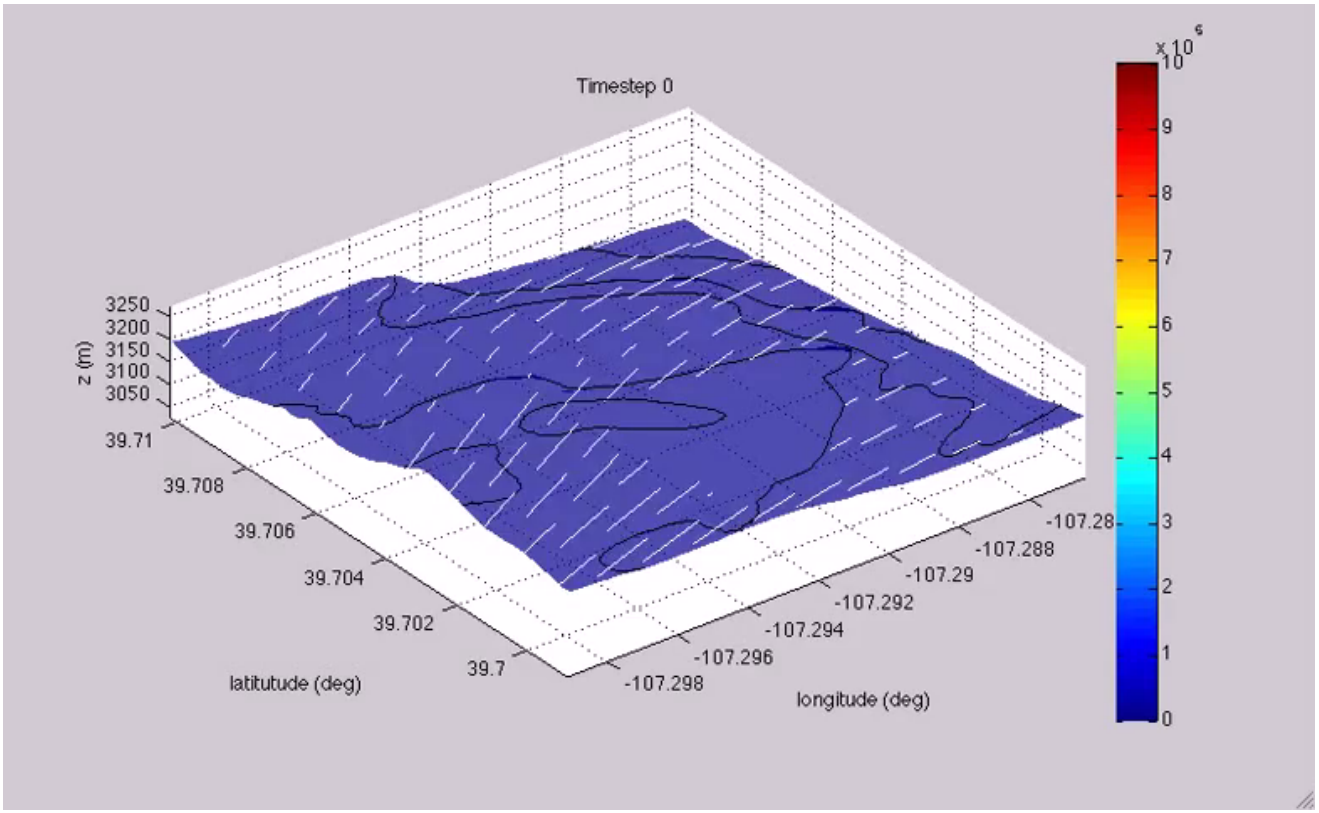
- Hybrid of AICC data and MOD-14 hotspots
- Additional Landsat Thematic Mapper (TM) sensor data, which include a middle infrared channel (2.08-2.35 μm).
- => 30 m high spatial resolution sensor, which permits active fires to be detected. A 700 K fire that occupies 20% of the 30 m pixel will saturate the middle infrared TM channel.
- => A single Landsat TM scenes covers typically areas of about 150 times 150 miles.





Landsat TM from July 7, 2009 showing fires south of Galena.

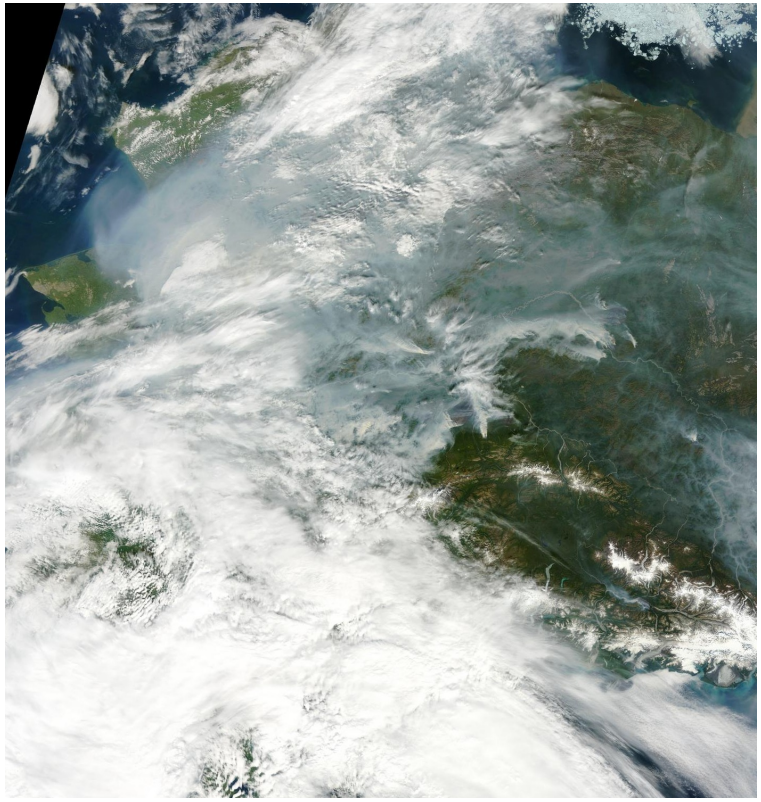
WRF-Fire



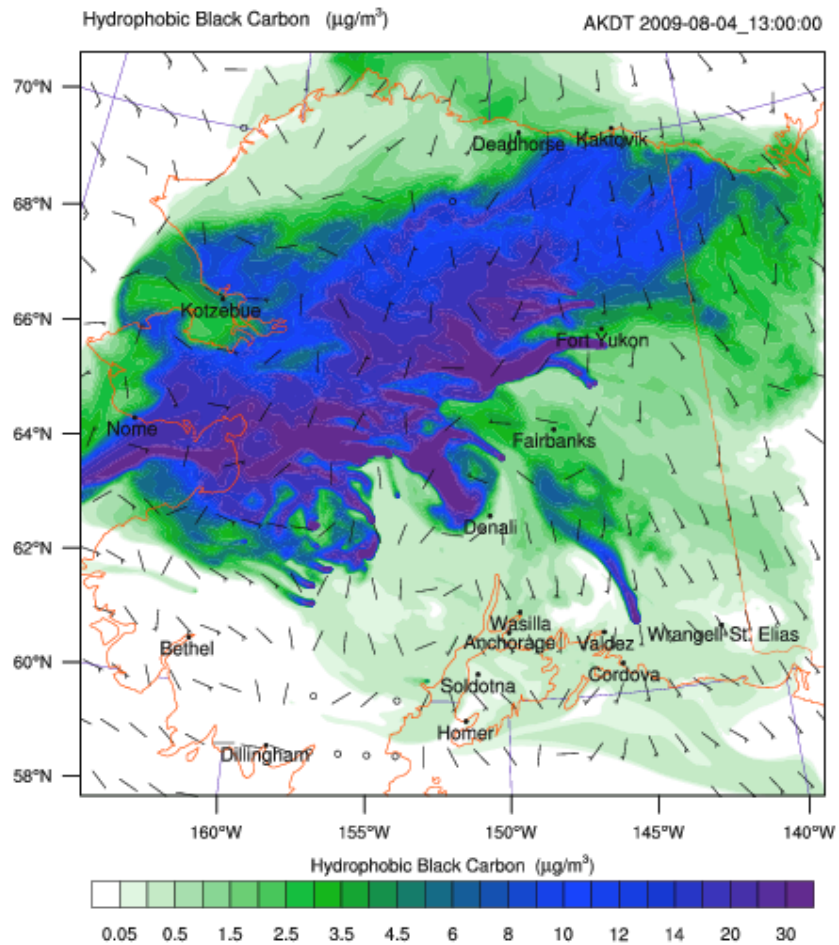
Development led by NCAR and the University of Colorado Denver, University of Utah, Washington State University

WRF wildland fire behavior module: Coupled weather-*fire* simulation using real weather data => Progress to apply model for Alaska (C. Waigl)

2009: Forecast Comparison with MODIS

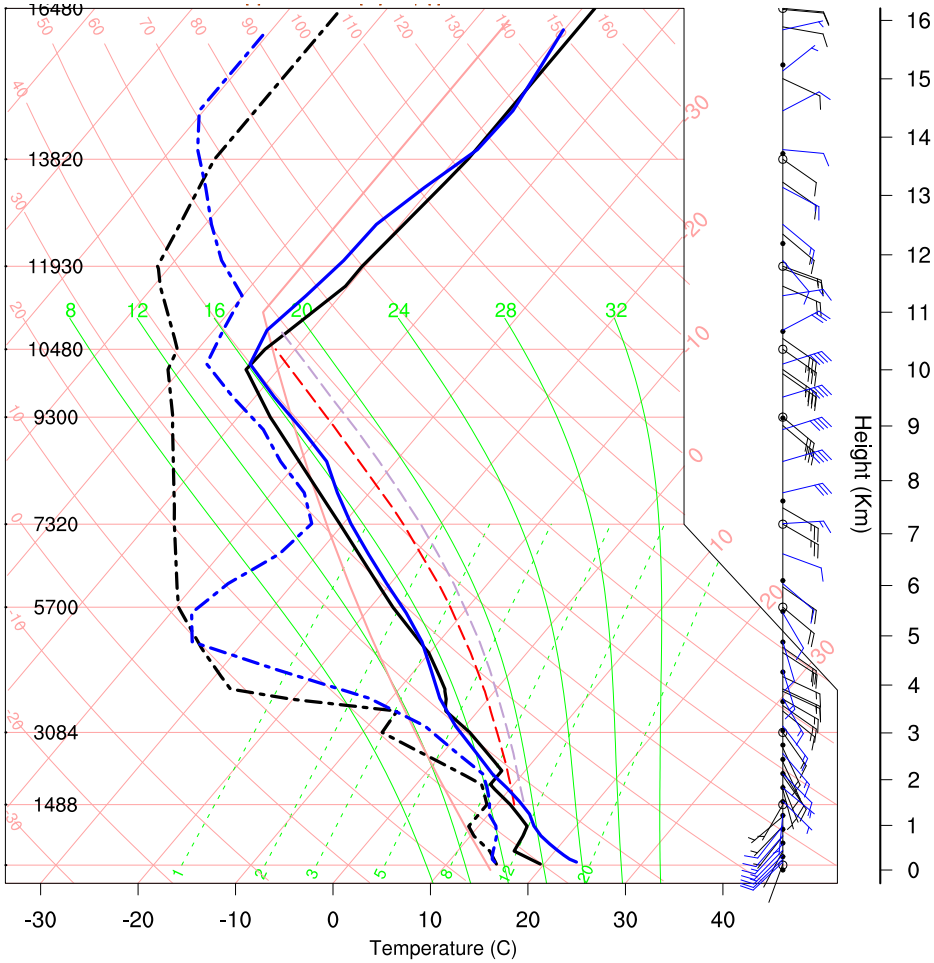


MODIS - TERRA 4.Aug.2009 01:14 PM AKDT
Data courtesy Geographic Information Network of Alaska

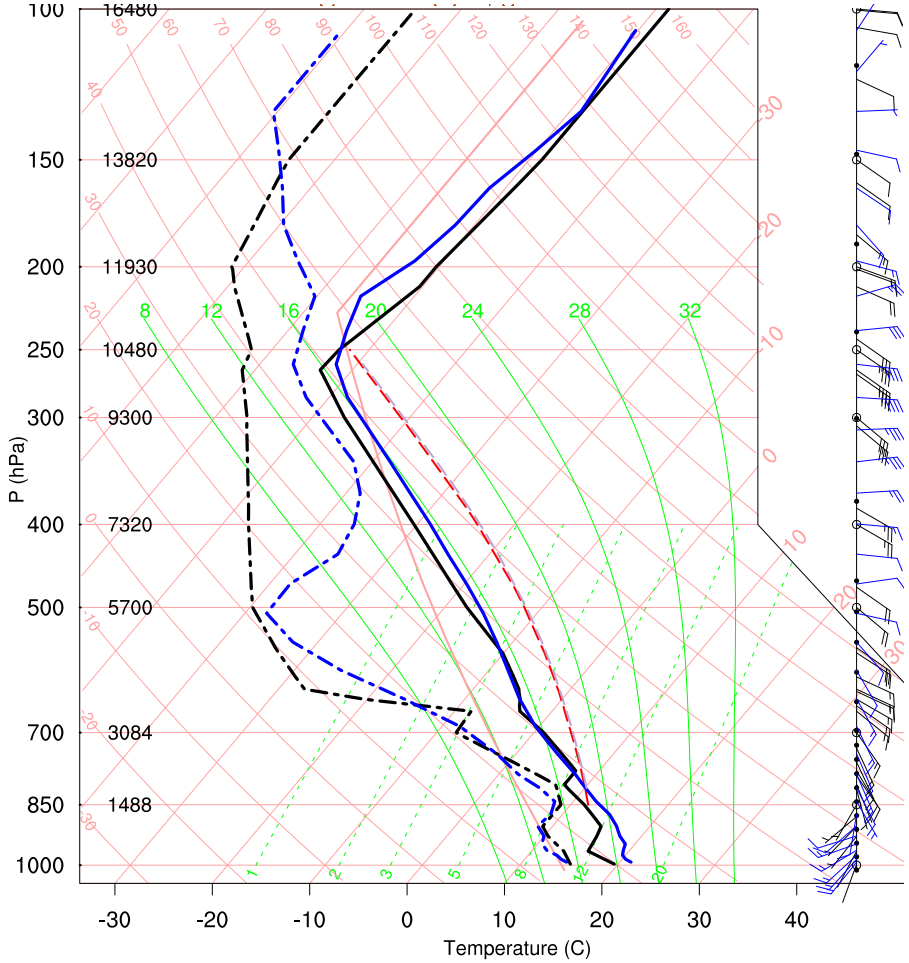


How is the meteorological forecast affected by the smoke? => Direct and Semi-Direct effect using WRF-Chem

Without Fires



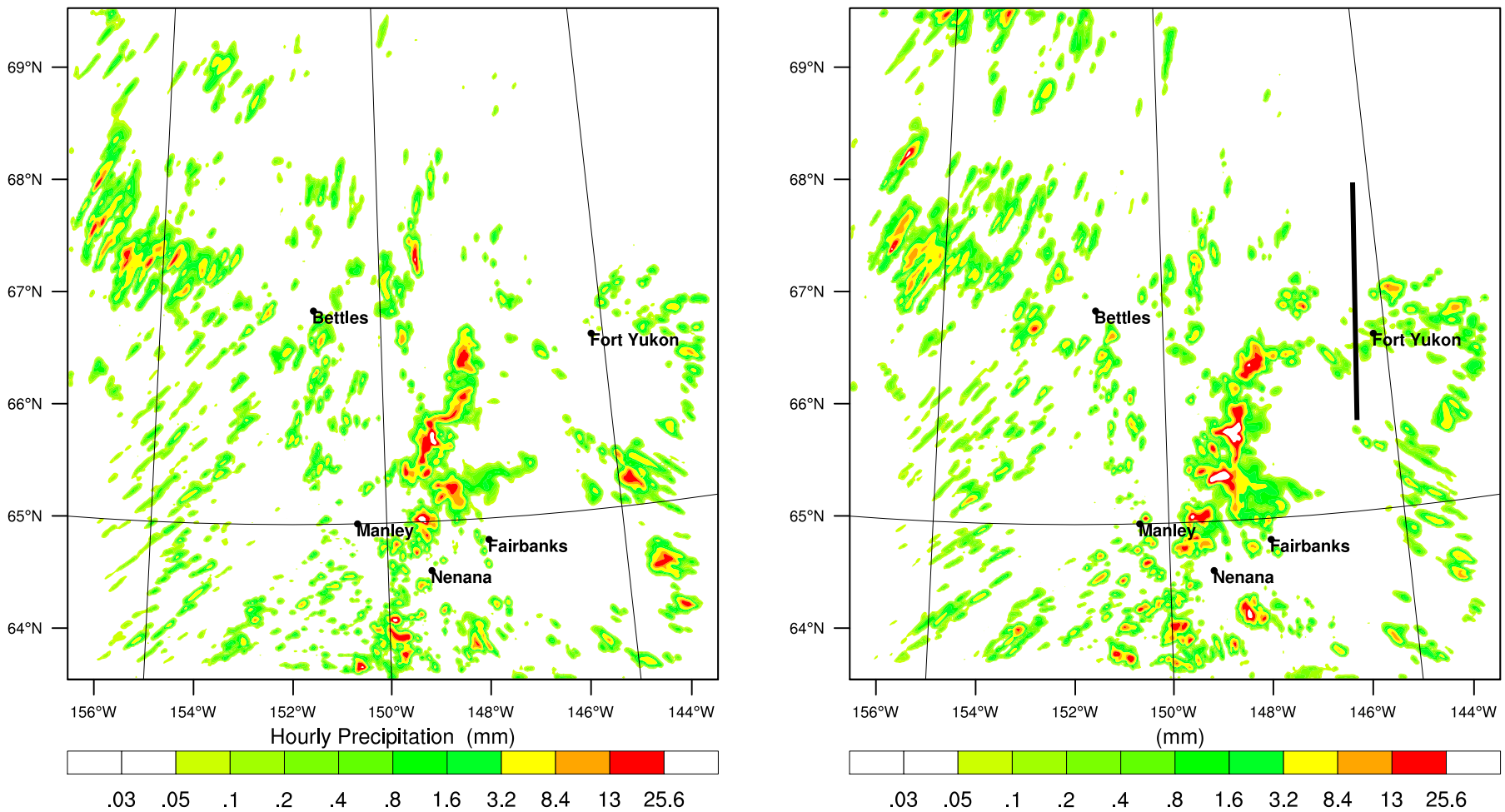
With Fires



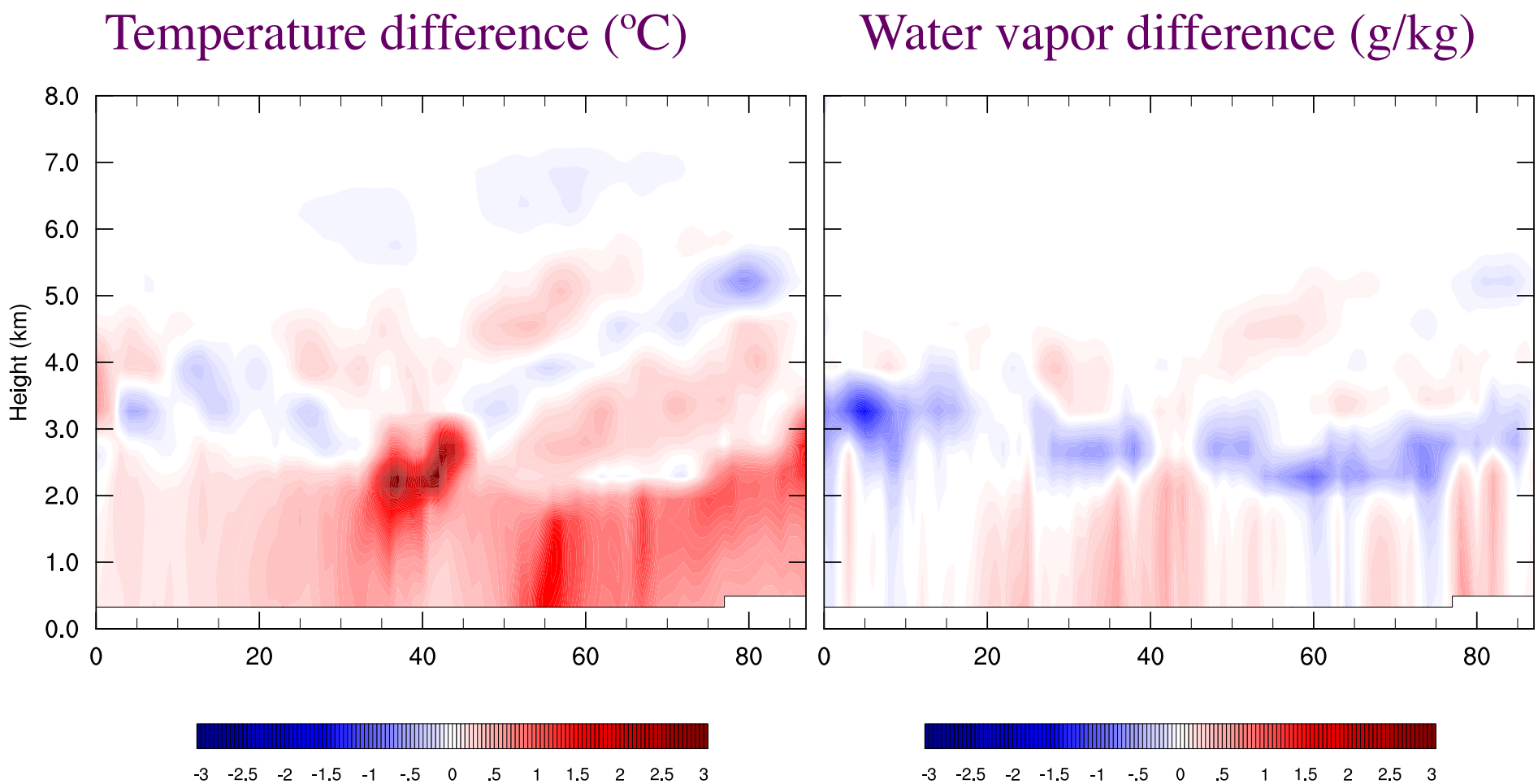
24 hr cloud-resolving forecast (**blue**) and observed (**black**) sounding for Fairbanks, 4 July 2004 00UTC

Hourly Precipitation

Without Fires 0000UTC, July 4, 2004 With Fires



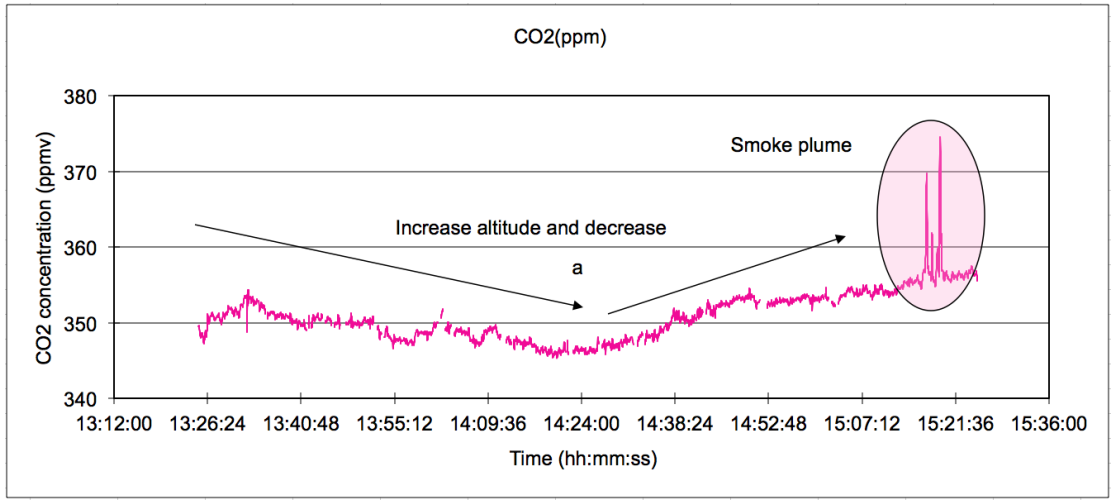
WRF-Chem simulation on fire effects on weather



Cross section: July 4, 2004

Verification

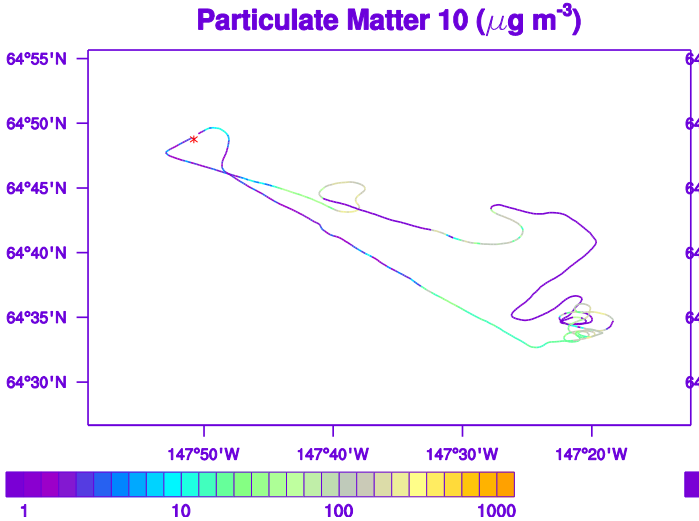
- Airborne optical particle counter (Grimm Particle Spectrometer) and CO_2 measurements.



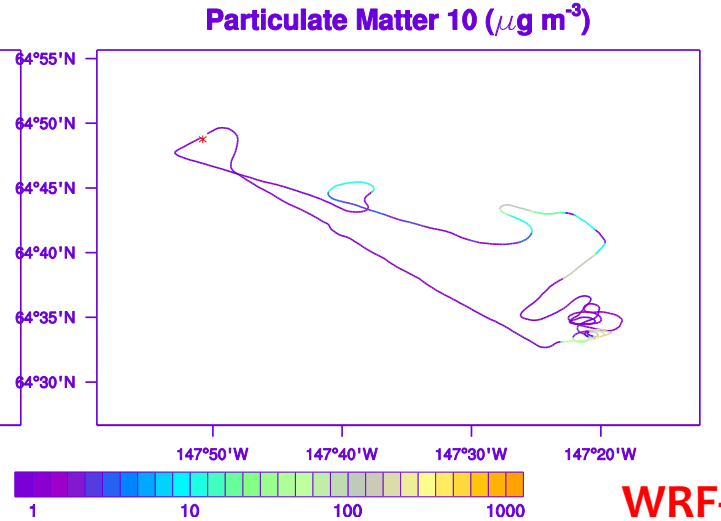
Measurements – Dry Creek Fire 2012

Measurements – Dry Creek Fire 2012

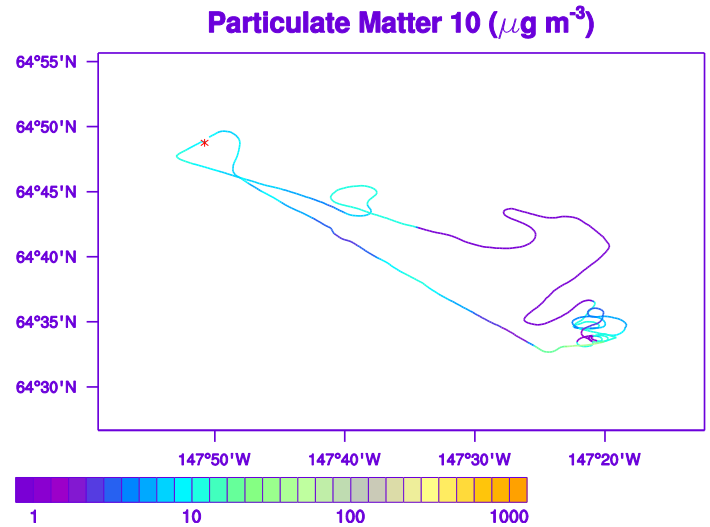
OBSERVED



WRF-CHEM -- MADE/SORGAM

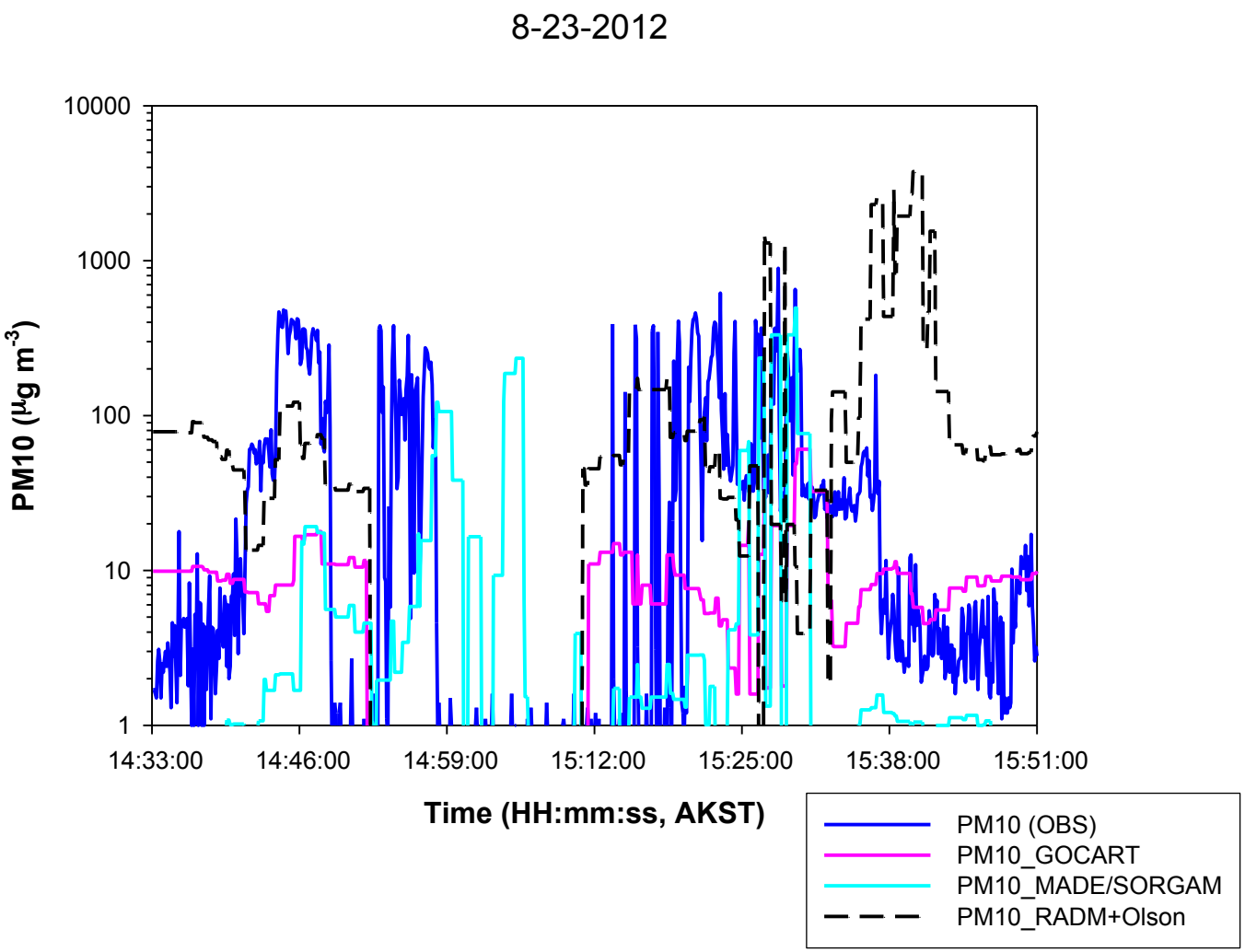


WRF-CHEM -- GOCART



Simulation with two types of aerosol modules: the results are different between two.

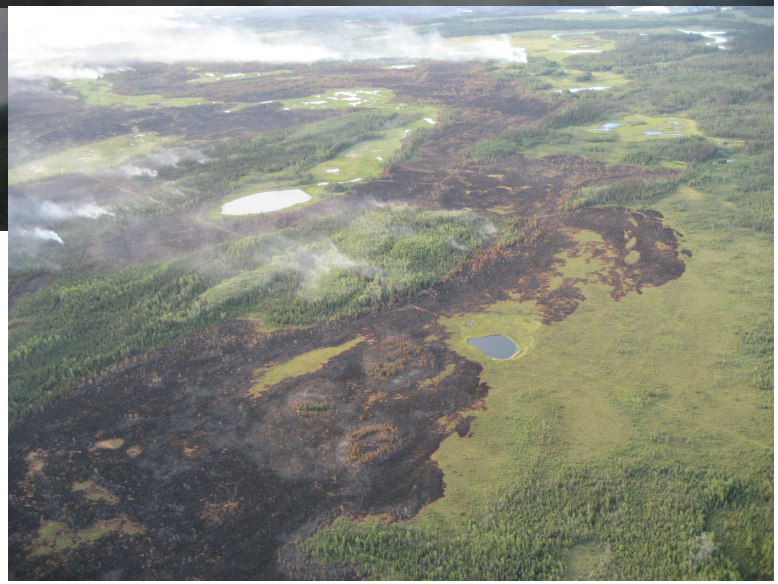
Measurements – Dry Creek Fire 2012



Time series of PM10 from observation and simulation with several options.

Future Updates

- Horizontal wind field in plume model
- Fire plume rise verification with LIDAR measurements (CALIPSO, airborne Spectrometer data)
- Improved Fire Source Data
- Operational wildfire smoke emission runs with improved graphics and visibility.
  http://smoke.arsc.edu/



"Railbelt" Wildfire
South-West of Fairbanks
Photos July 21, 2009
(Martin Stuefer)