Harvard University
Atmospheric Chemistry Modeling Group

Investigation of the Effects of Changing Climate on Fires and the Consequences for U.S. Air Quality, Using a Hierarchy of Chemistry and Climate Models

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JPL

Research funded by EPA
Fire, Climate, and Air Quality (RFA 2004-STAR-L1)

The Hayman fire, Colorado

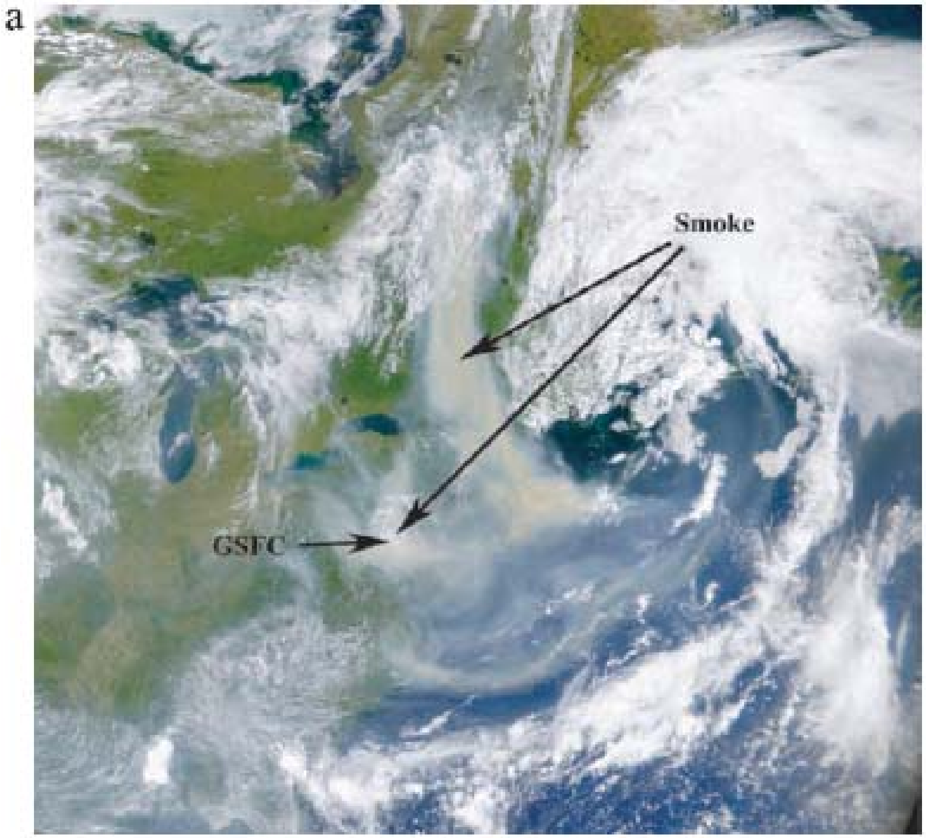
- 56000 ha, June 8-22, 2002
- 20 miles from Denver and Colorado Springs
- Air quality was the worst on record, in terms of smoke

Figure 8. Photos showing the Hayman fire's impact on Denver air quality on June 8 (left) and June 9 (right) 2002.

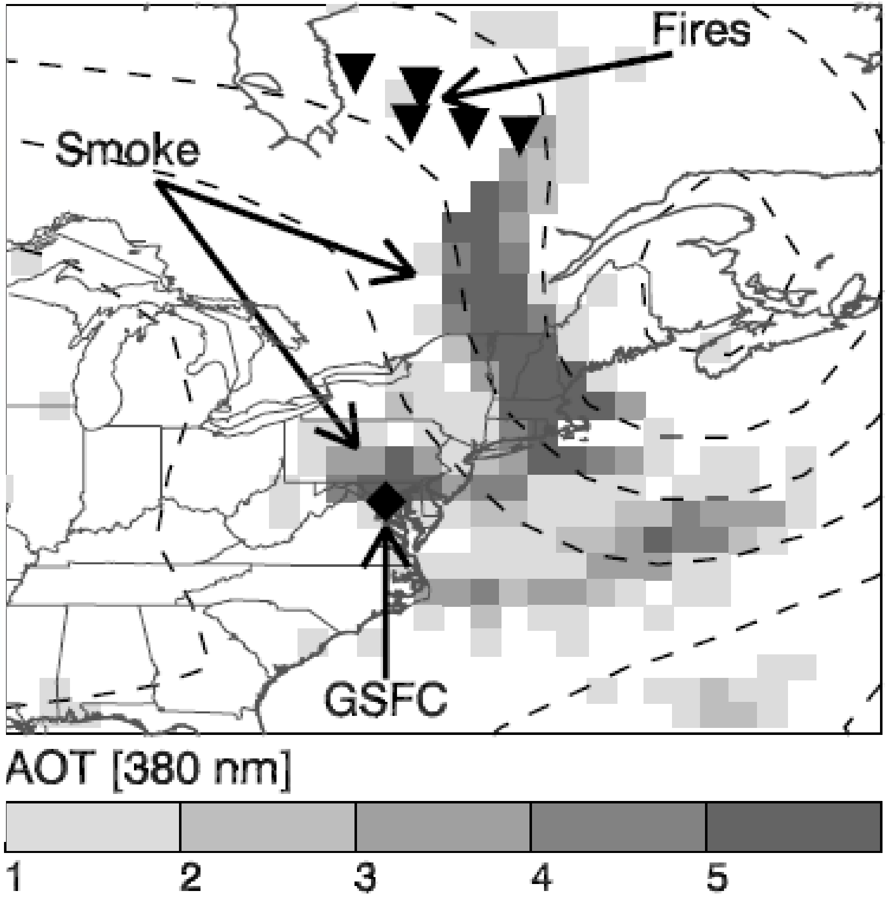
Fires in Quebec in July, 2002

Smoke from these fires impacted air quality over the N.E. United States, as the smoke plumes descended to the surface

SeaWIFS Image



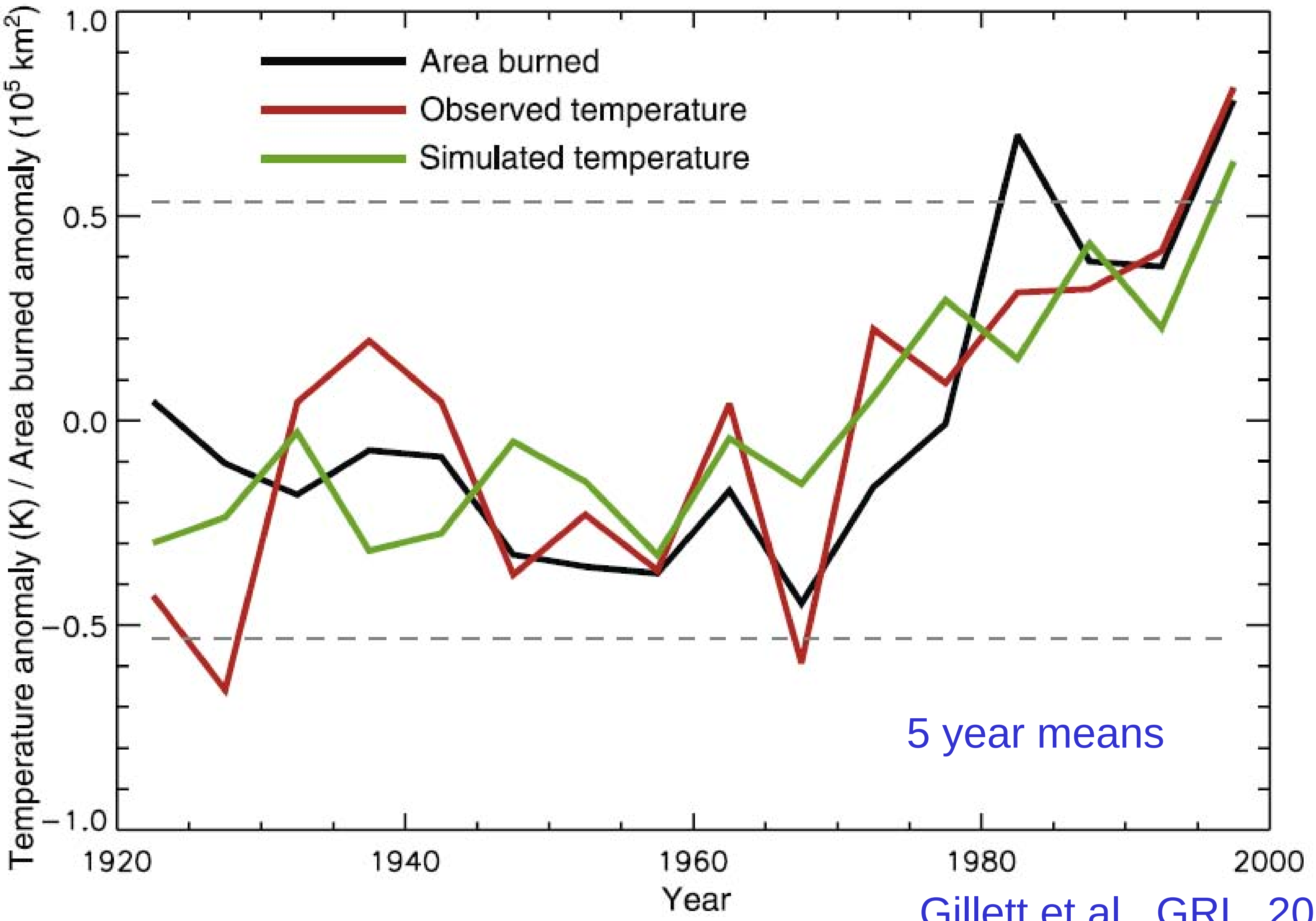
Aerosol Optical thickness from TOMS



Source: Colarco et al., JGR, 2004

An unusual event

Area burned in Canada has increased since the 1960s

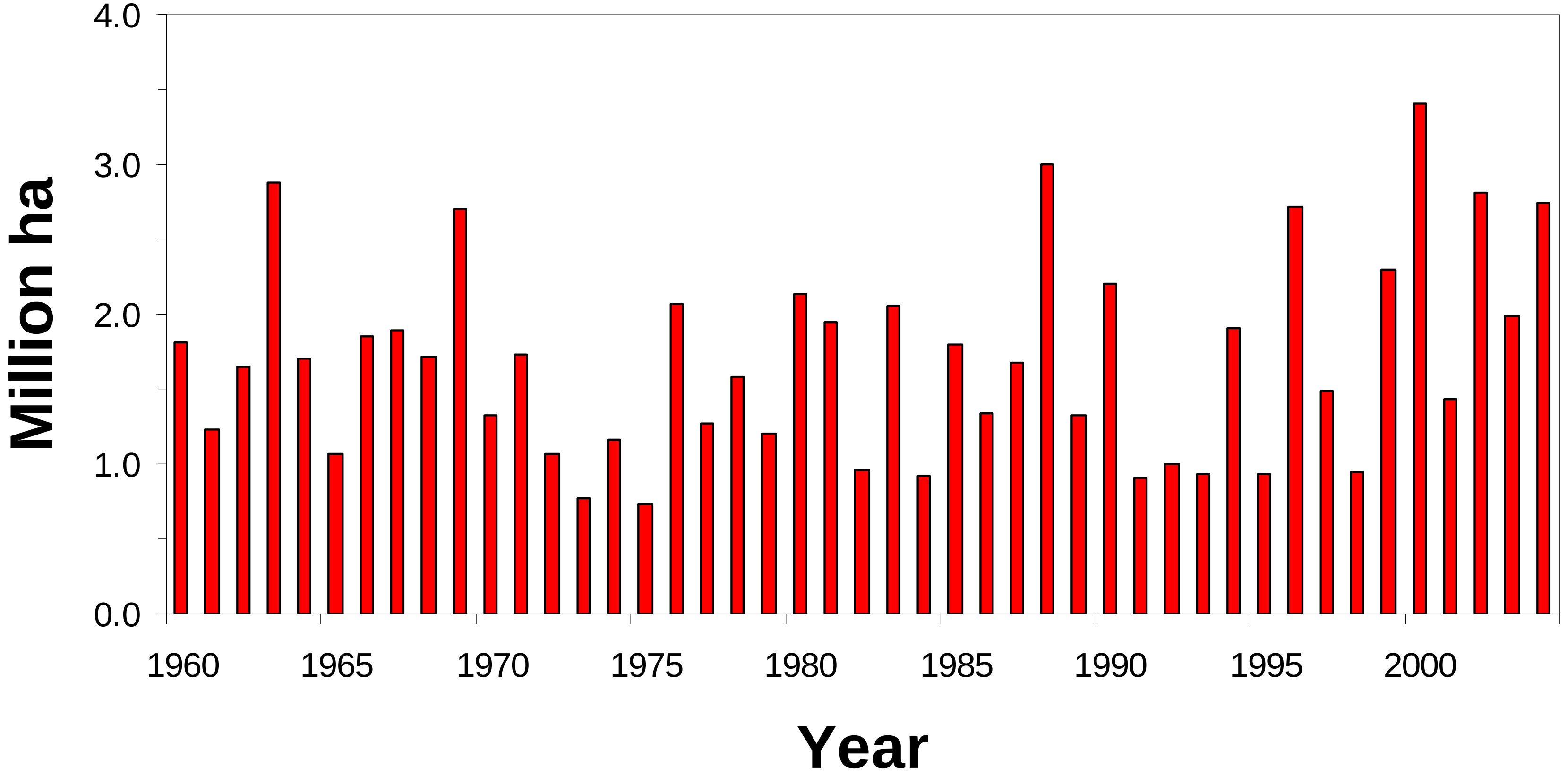


5 year means

Gillett et al., GRL, 2004

Area burned in the U.S. 1960-2004

Less year-to-year variation than in Canada, less indication of an increase



www.nifc.gov

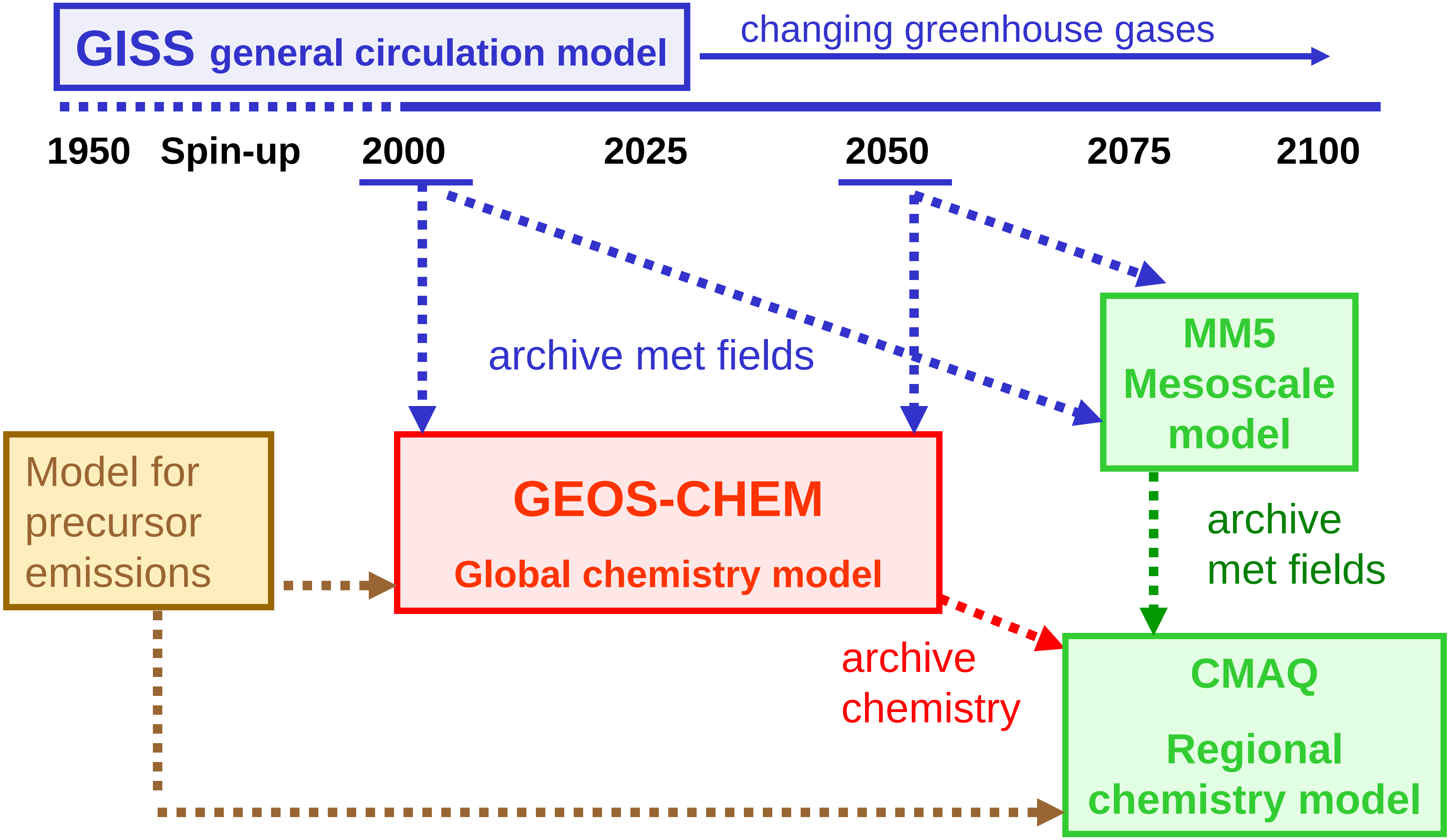
Objectives

Provide an integrated assessment of the effects of fires in a future climate on ozone and PM air quality in the United States:

- **Explore relationship between climate and frequency/ magnitude of wildfires in N. America**
- **Develop scenarios for future fires**
- **Analyze plume heights from forest fires from MISR data for 2000-2004**
- **Quantify the dependence of air quality on height at which emissions are released**
- **Quantify the effect of present day fires on air quality in the U.S.**
- **Examine how different scenarios for future fires will affect air quality in a future climate**
- **Assess uncertainty in results**

This project builds on the Global Change and Air Pollution (GCAP) project, D. Jacob (P.I.)

Blueprint for GCAP: 5 models working together to provide information on climate change impacts



GISS **general circulation model**

changing greenhouse gases

1950 **Spin-up** **2000** **2025** **2050** **2075** **2100**

archive met fields

MM5
Mesoscale
model

Model for
precursor
emissions

GEOS-CHEM

Global chemistry model

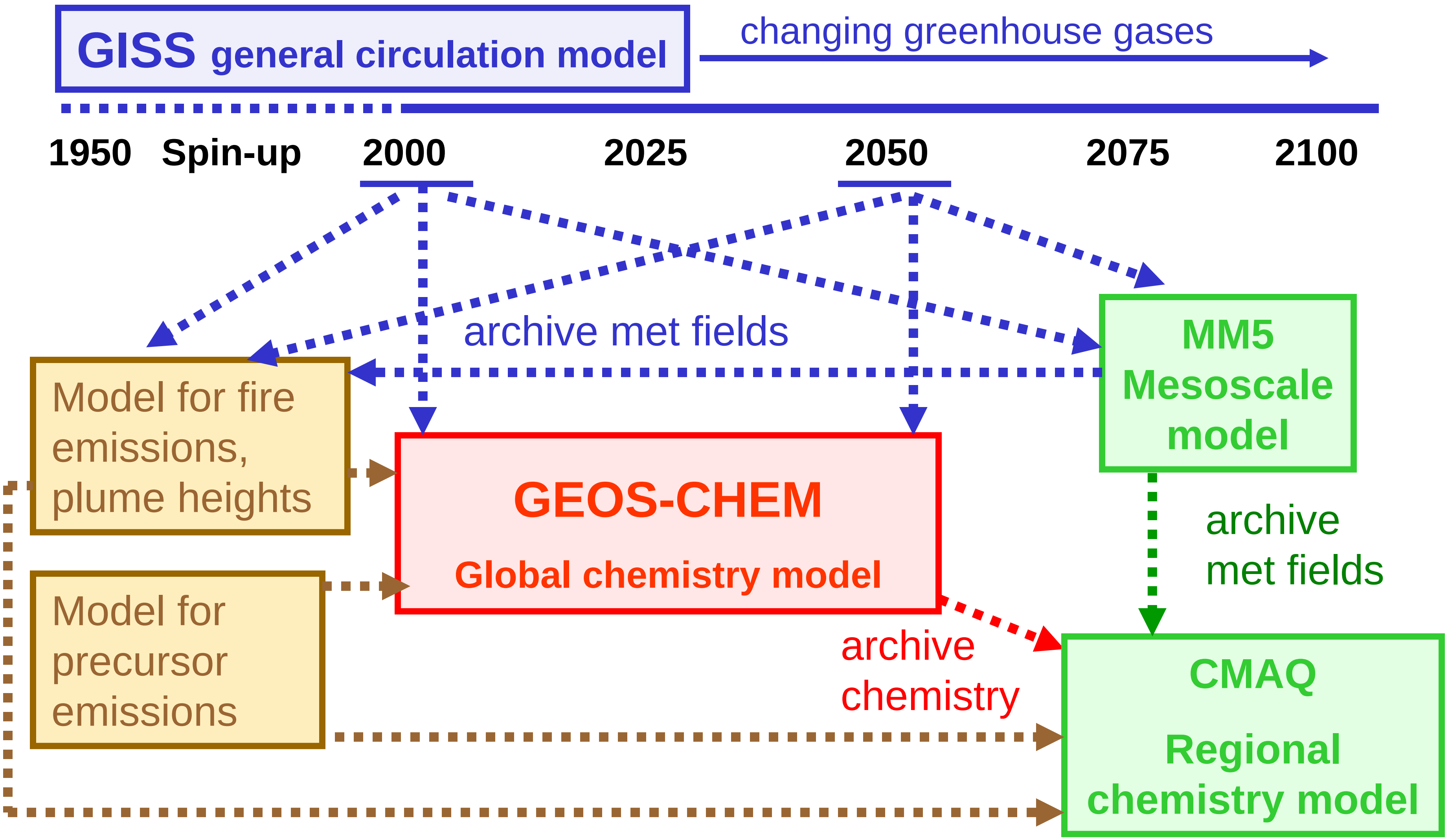
archive
met fields

archive
chemistry

CMAQ

Regional
chemistry model

<u>Revised blueprint</u>, allowing for fire emissions, with fire model driven by meteorological data for a future climate



GISS general circulation model

changing greenhouse gases

1950 Spin-up 2000 2025 2050 2075 2100

archive met fields

Model for fire emissions, plume heights

Model for precursor emissions

GEOS-CHEM

Global chemistry model

MM5 Mesoscale model

archive met fields

archive chemistry

CMAQ

Regional chemistry model

The strategy and the people

Harvard University

- Develop fire scenarios for a future climate - **Dominick Spracklen**
- Climate simulations - **Loretta Mickley**
- Effects of 2004 fires on U.S. air quality (GEOS-Chem) - **Rokjin Park**
- Analyze and interpret plume height data - **Jennifer Logan**
- GEOS-Chem simulations for future climate, air pollution, fires

University of Houston

- Implement GISS output as IC/BC in MM5 - **H.C. Kim, C.-K. Song**
- MM5 simulations with GISS output
- CMAQ simulations with MM5 output

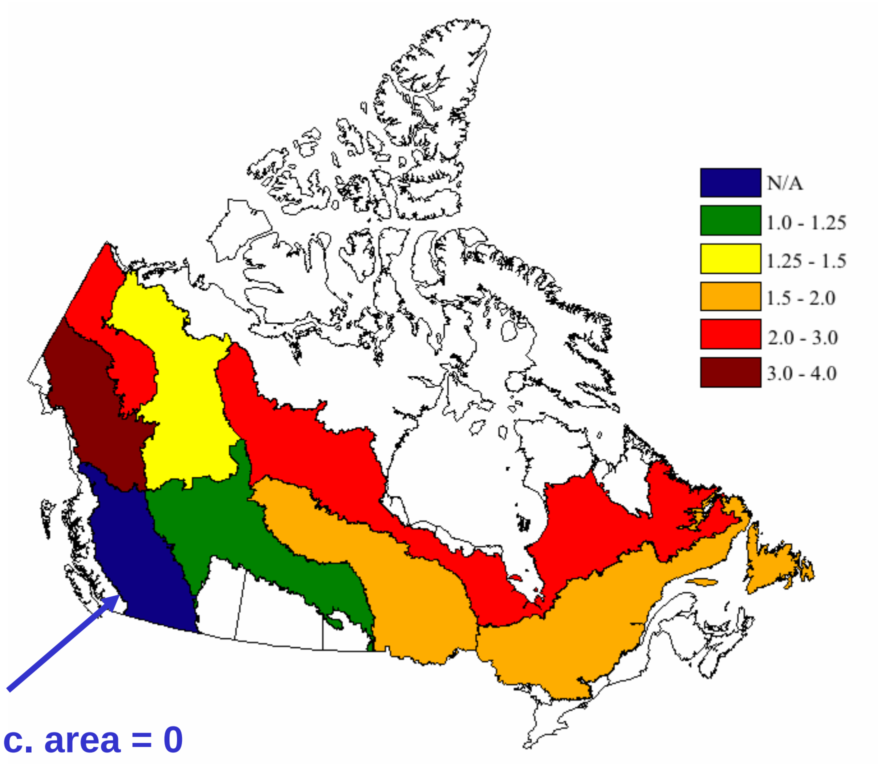
JPL

- Derive plume heights from MISR - **Dominic Mazzoni**
- Collaborate on analysis of plume height data

Fire scenarios - we are building on prior efforts for Canada

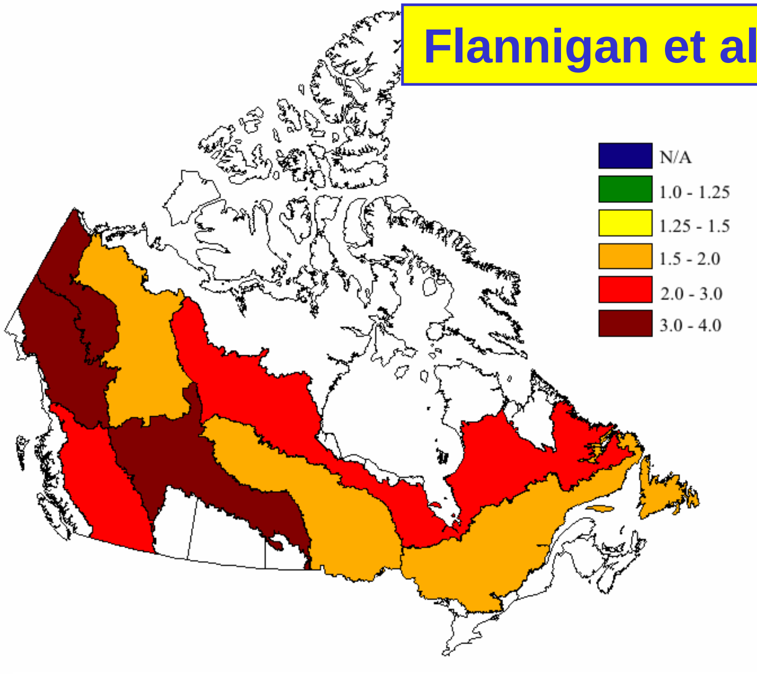
Ratio of Area Burned for $3xCO_2:1xCO_2$ (20 yr simulations)

Flannigan et al., 2006



Calc. area = 0

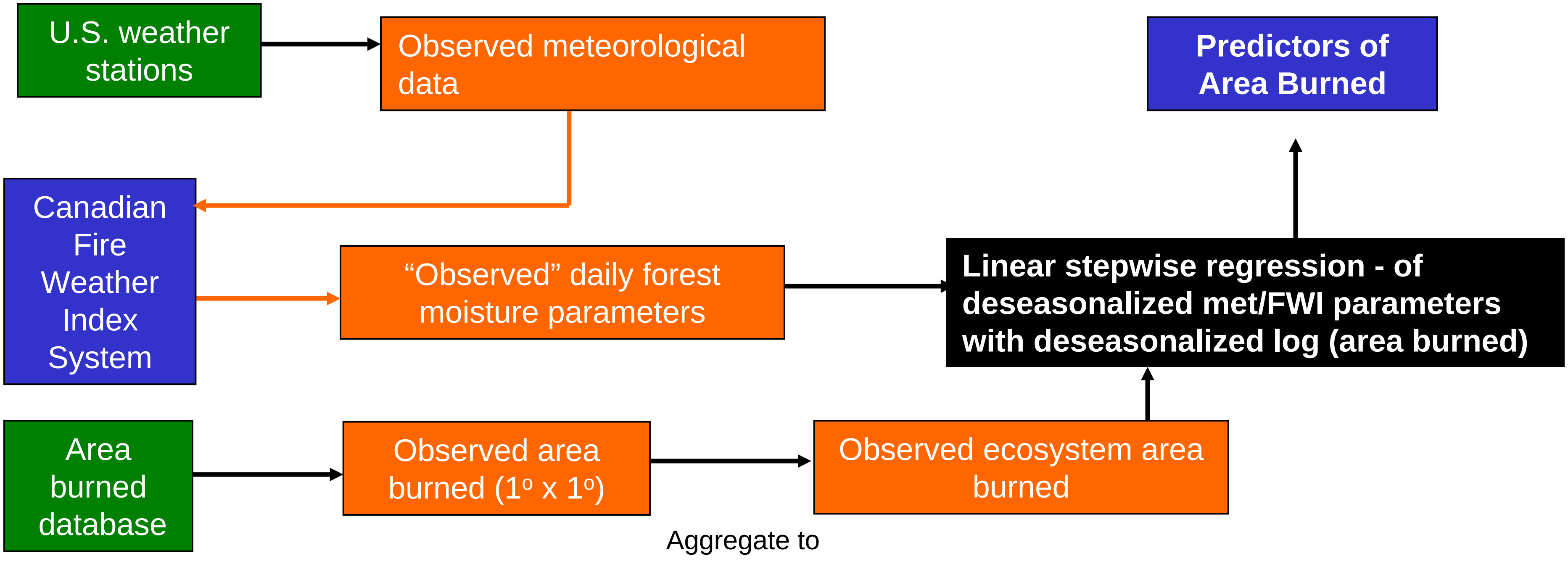
Canadian GCM
Overall ratio = 1.74



Hadley GCM
Overall ratio = 2.2

Most prior work focused on fire severity, not area burned

Predicting forest fire area burned in a future climate



U.S. weather stations

Observed meteorological data

Canadian Fire Weather Index System

"Observed" daily forest moisture parameters

Linear stepwise regression - of deseasonalized met/FWI parameters with deseasonalized log (area burned)

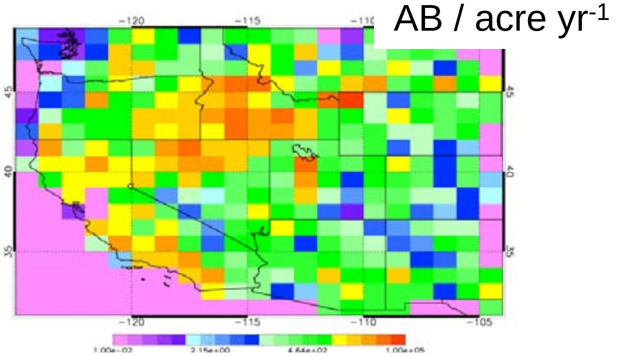
Predictors of Area Burned

Area burned database

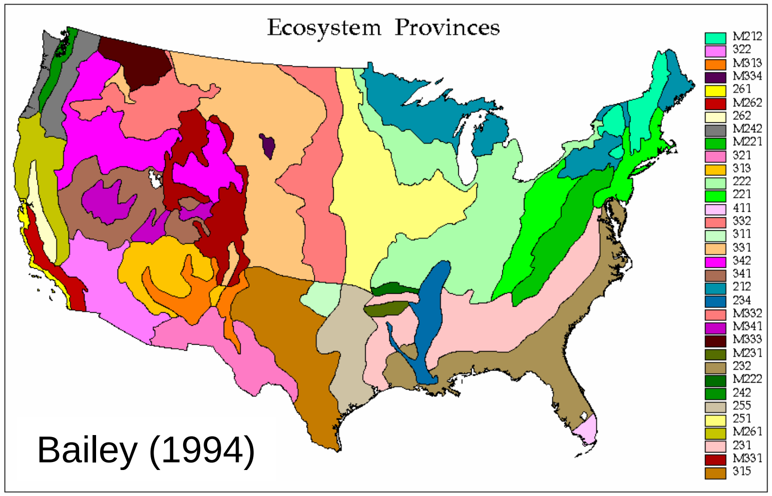
Observed area burned ($1^o \times 1^o$)

Observed ecosystem area burned

Aggregate to ecosystem province



Annual area burned (AB) on $1^o \times 1^o$ [Westerling et al., 2002]



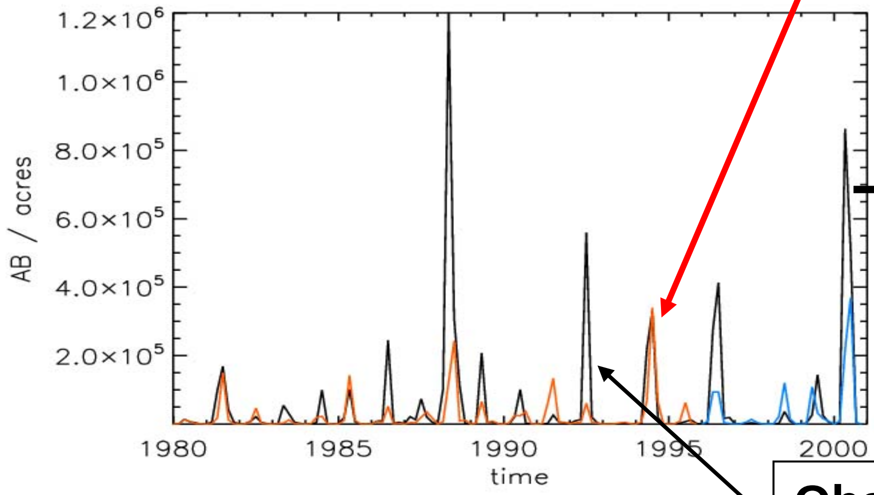
Bailey (1994)

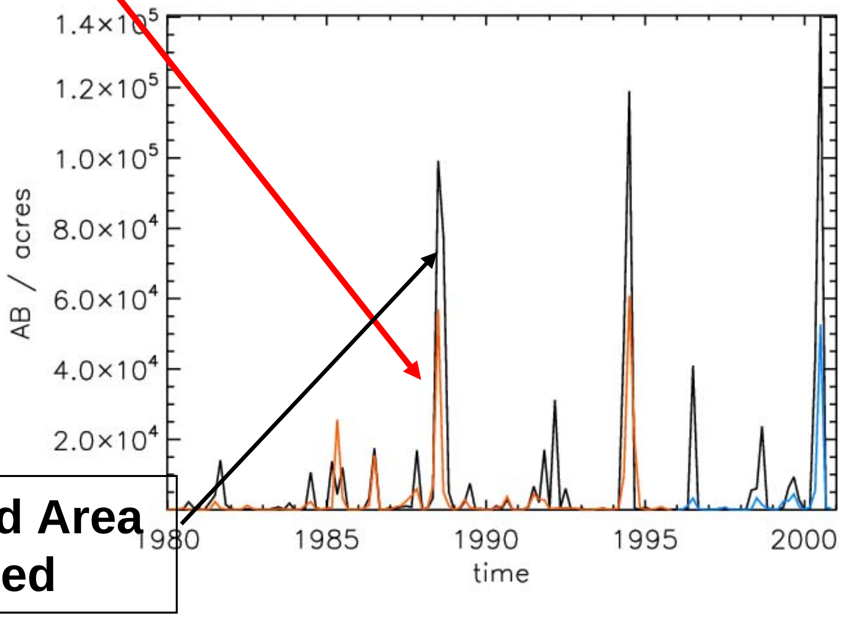
Predictions of Area Burned

M332 – Middle Rocky Mountain Steppe

Predicted Area Burned

M333 – Northern Rocky Mountain Forest, Steppe, Coniferous Woodland





Observed Area Burned

Development data (used to build regression)

Independent data (used to test regression)

Large fire seasons are often under-predicted - same result as for Canada

Ecosystem provinces, observed and calculated area burned (AB) and best predictors.

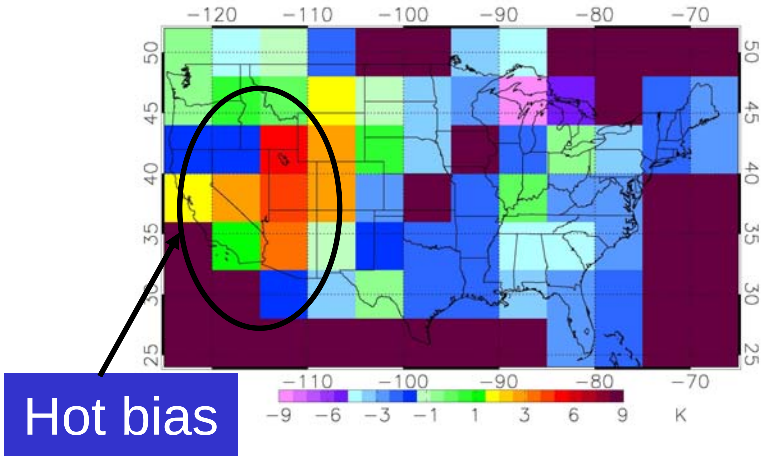
Ecosystem	Area Burned 1980-2001 acres x10^6	Explained variance (R^2)	Fraction of observed total AB captured by regression	Best Predictors meteorological and FWI parameters)
M332 (Middle Rocky Mountain Forest)	6.81	0.40	0.47	Initial Spread Index (ISI), Temperature (T)
M333 (Northern Rocky Mountain Forest)	0.83	0.46	0.41	Relative Humidity (RH), Palmer Drought Severity Index (PDSI), Drought Code
M331(Southern Rocky Mountain Forest)	2.39	0.25	0.23	RH, PDSI, ISI
M261 (Sierra Coniferous Forest)	3.37	0.41	0.28	Drought Severity Rating, PDSI (March of fire season), FFMC

The regressions underestimate areas burned.
We will scale future AB by observed/predicted AB for the present

Same approach as Flannigan et al.

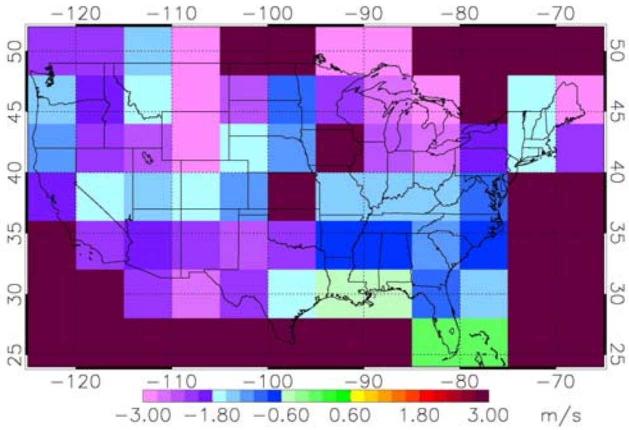
Difference between GISS met fields and observations (August)

Temperature

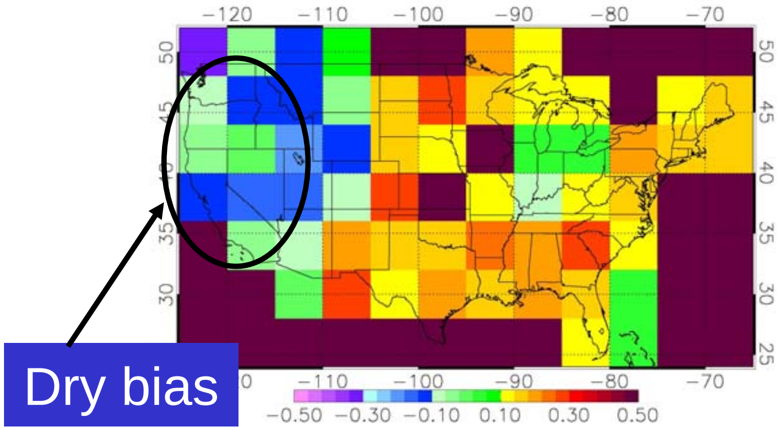


Hot bias

Wind speed



Relative humidity



Dry bias

- GISS wind speeds are slow.
- In S.W. US (Jul, Aug) GISS is too hot and dry as has been seen by others (e.g., Schmidt, 2006).

GCMs often have deficiencies at this level of detail, including the Hadley and Canadian GCMs

Approaches to solving the problems with model meteorology

1. Apply bias corrections to GISS parameters

2. Use meteorological output from MM5 driven by GISS input

   Downscaling of GISS data should improve met. data. as MM5 has finer resolution of surface properties, etc.

   Initial results show cooler temperatures in MM5

Daewon Byun's group have interfaced MM5 with GISS meteorological output.

We held a meeting with them on March 27/28 to discuss scientific and technical issues, and plan future work.

GISS-MM5 interface

Regridding

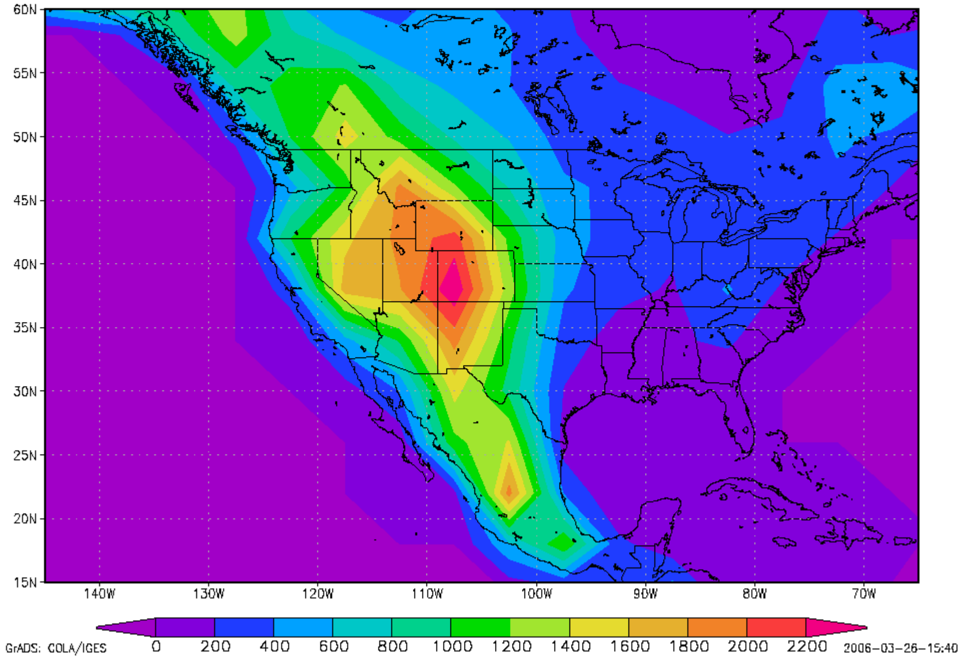
- U. Houston modified REGRID, one of preprocessors of MM5 to deal with GISS output .
- GISS2MM5 performs interpolation, extrapolation and some diagnosis with GISS output to fit them into MM5 domain, resolution and file format.

Downscaling Issue:

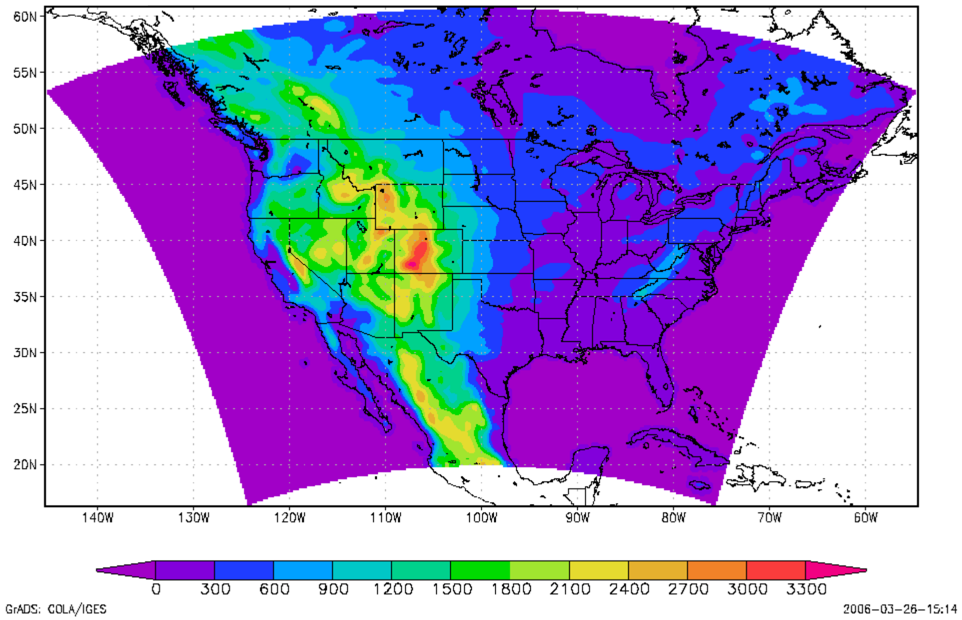
- GISS grid resolution is too coarse to downscale directly into 36 km MM5.
- Our solution : 108 km MM5 run with GISS BC and IC
  ==> 36 km MM5 run with BC and IC from 108 km run

TOPOGRAPHY

GISS, 4° x 5°

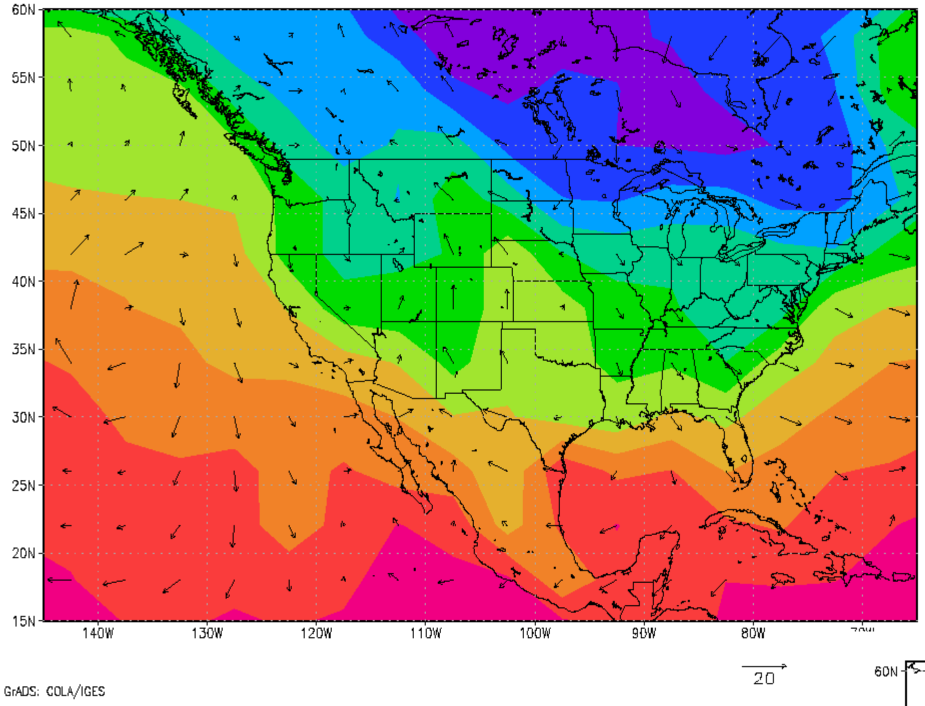


MM5, 36 km grid



Surface wind and temperature (03 UTC, January 1st, 2000)

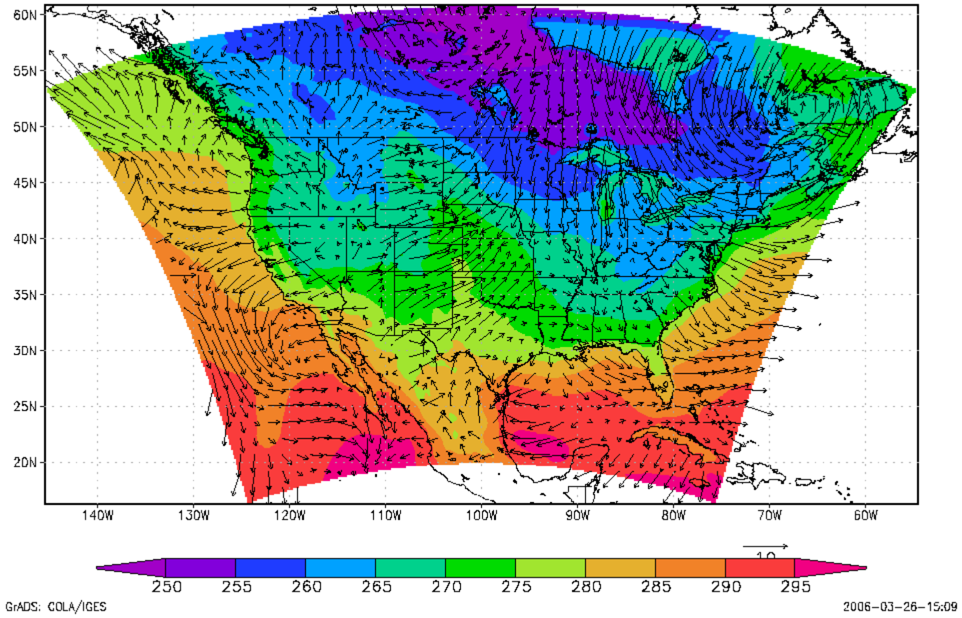
GISS, 4° x 5°



MM5 is “nudged” with data from GISS.

We will explore nudging above the boundary layer only

MM5. 36 km grid



Plume heights from MISR

(Multi-angle Imaging SpectroRadiometer)

MISR facts

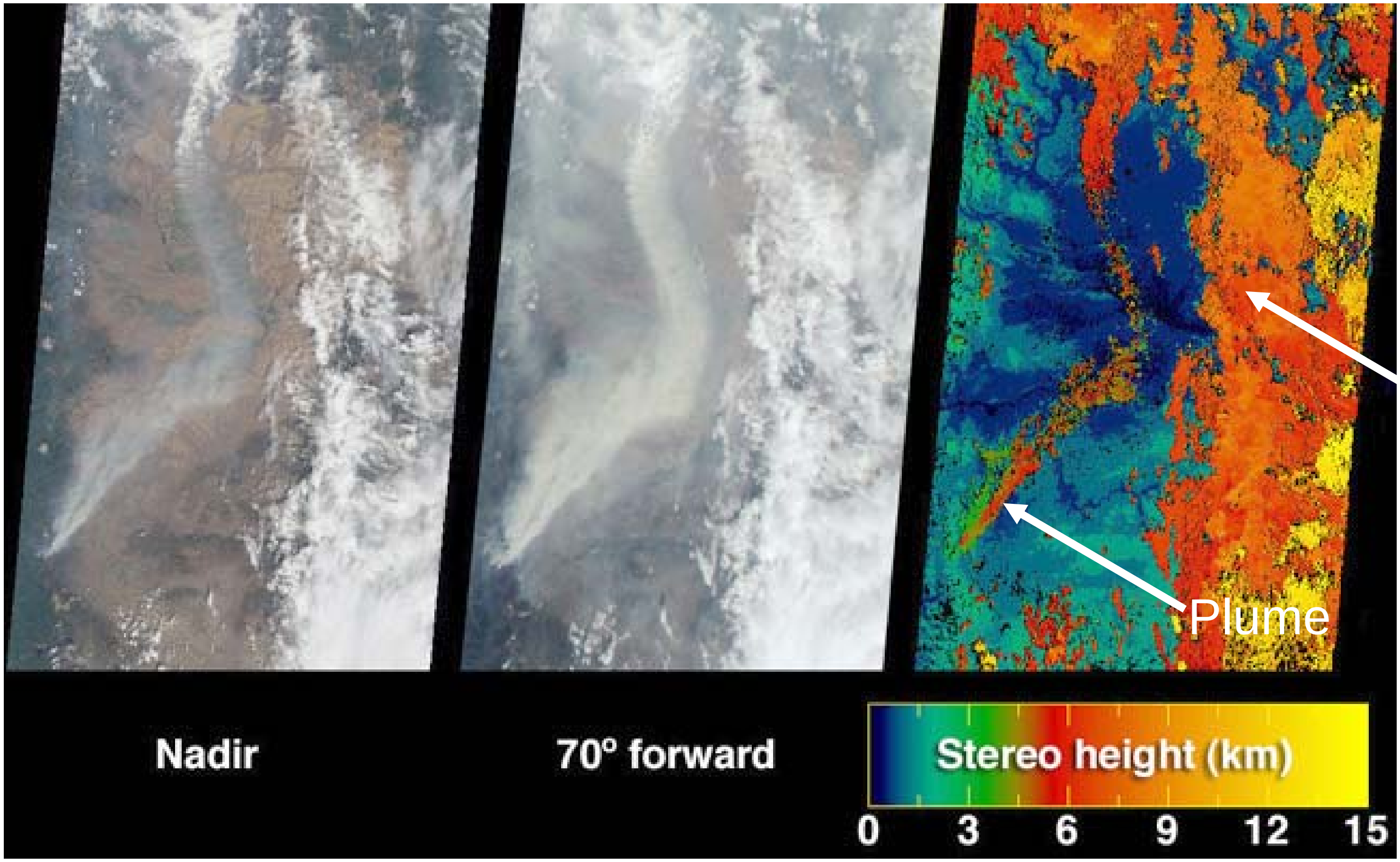
- MISR collects data at 9 angles, 4 wavelengths, with 1 km resolution
- 380 km swath, global cover in 9 days, 4-5 days at high altitudes
- can distinguish smoke from clouds or other aerosols
- heights accurate to ±500 m

Automatic Derivation of Plume Heights

- Fires identified from MODIS thermal anomalies (“hot spots”)
- Identify smoke in MISR data using machine learning techniques
- Find wedge shaped smoke with a tip within 16 km of a MODIS hot spot
- For these, determine if it is a long thin plume
- Determine maximum height of plume

MISR

Fires in Oregon as viewed by MISR on 9/4/2002
The Booth and Near Butte fires had burned 30,000 ha in 16 days

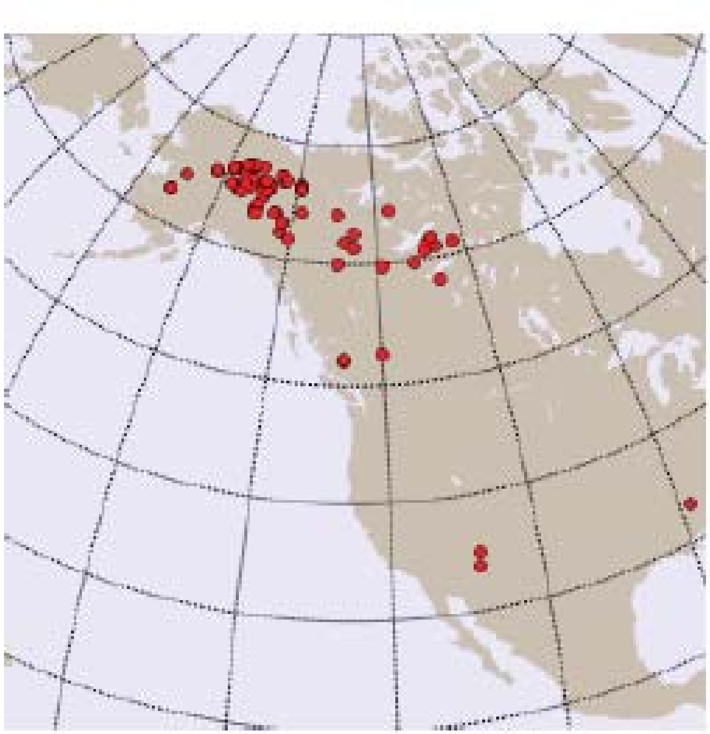


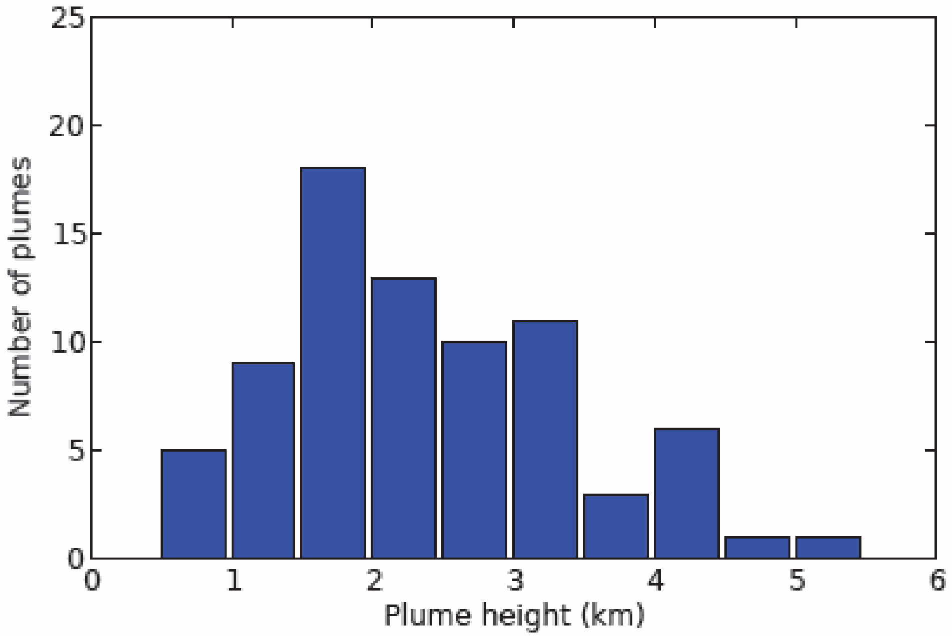
Source: D. Diner, JPL

The plume heights reach 6-7 km

Plumes heights derived from MISR for June-Sept., 2004. A record fire year in Alaska and the Yukon Territory

325 candidate plumes found, 187 were false positives, 61 had inconclusive height data => 77 plumes





From: A data mining approach to associating MISR smoke plume heights with MODIS fire measurements, Mazzoni et al., submitted to Remote Sens. Environ.

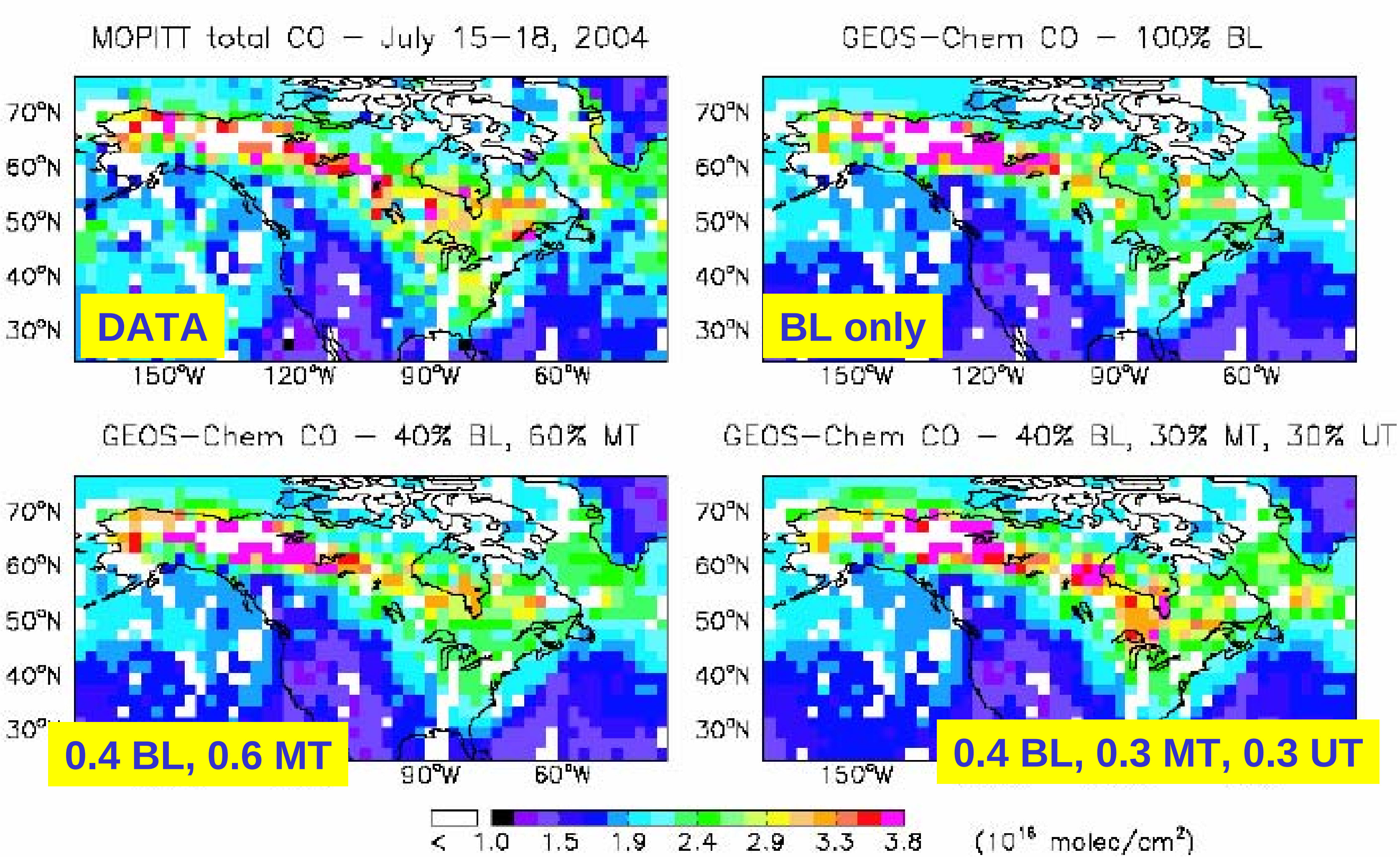
Planned Analysis of Plume Height Data

- Relationship to fuel consumption rate, using Canadian model
- Alaskan data base on daily fire descriptions
- Analysis of meteorology
  - boundary layer height
  - static stability
  - ....

Plumes heights for 2000-2003 to come from JPL

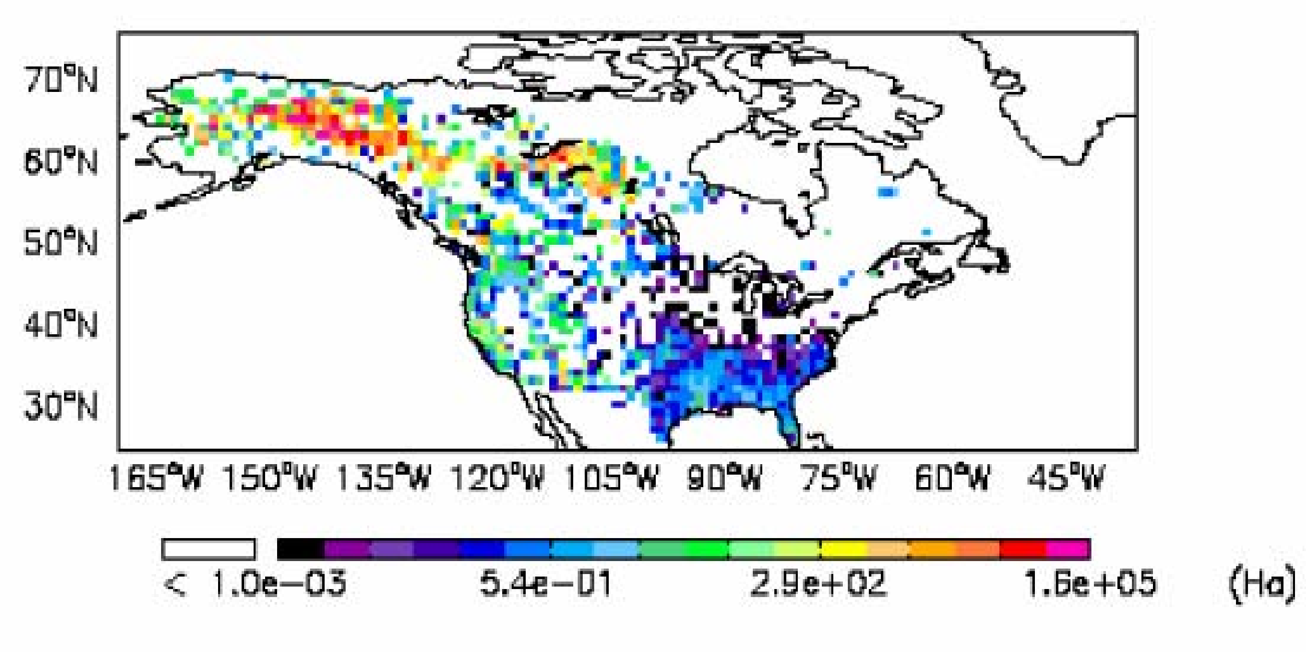
- 2002 was a high fire year in the lower 48 states

Effect of injection altitude on the CO column during an episode of long-range transport, July 2004



Turquety et al., 2006, JGR, submitted

Area burned in June-August, 2004



Daily area burned was derived from:

- **daily reports of areas by region for the US and Canada by the Forest Service etc.**
- **MODIS fire count data**

Turquety et al., 2006, JGR, submitted

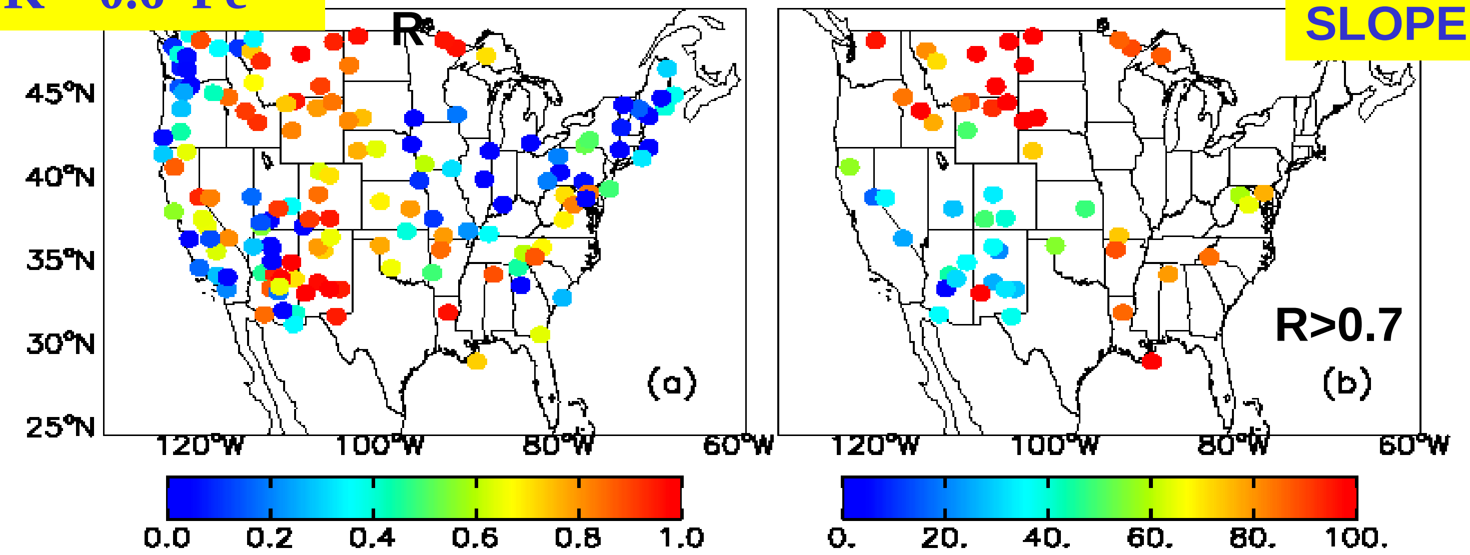
ANALYSIS OF THE EFFECTS OF PRESENT DAY WILDFIRES ON U.S. AIR QUALITY

Rokjin Park

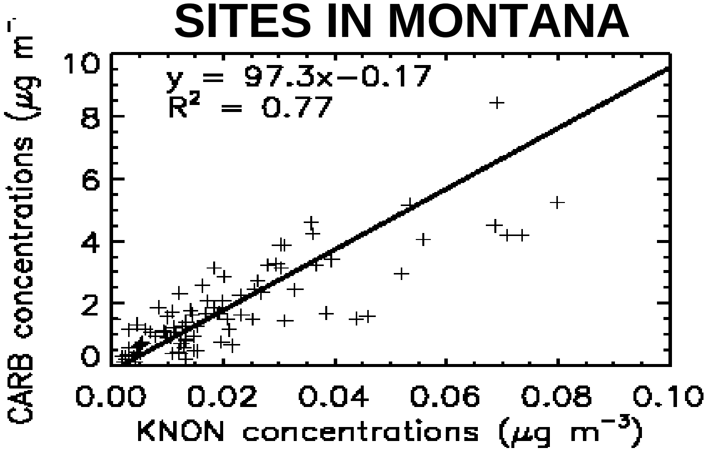
- Use daily IMPROVE observations to determine wildfire contributions to U.S. aerosol concentrations in surface air
- Use the GEOS-Chem model to quantify the enhancements of CO, ozone, and aerosol concentrations in the United States caused by wildfires in Alaska and Canada in 2004
- Study facilitated by the daily inventory developed by Turquety et al. 2006

RELATIONSHIP BETWEEN CARBONACEOUS AEROSOLS AND NON-SOIL POTASSIUM (K_{NON}): IMPROVE (July-August, 2004)

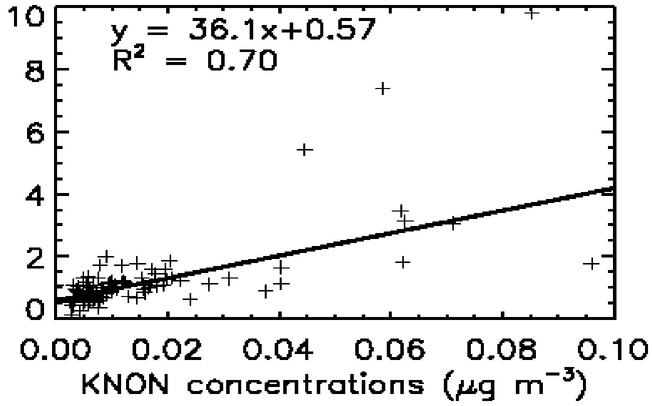
$K_{NON} \equiv K - 0.6*Fe$



SITES IN MONTANA



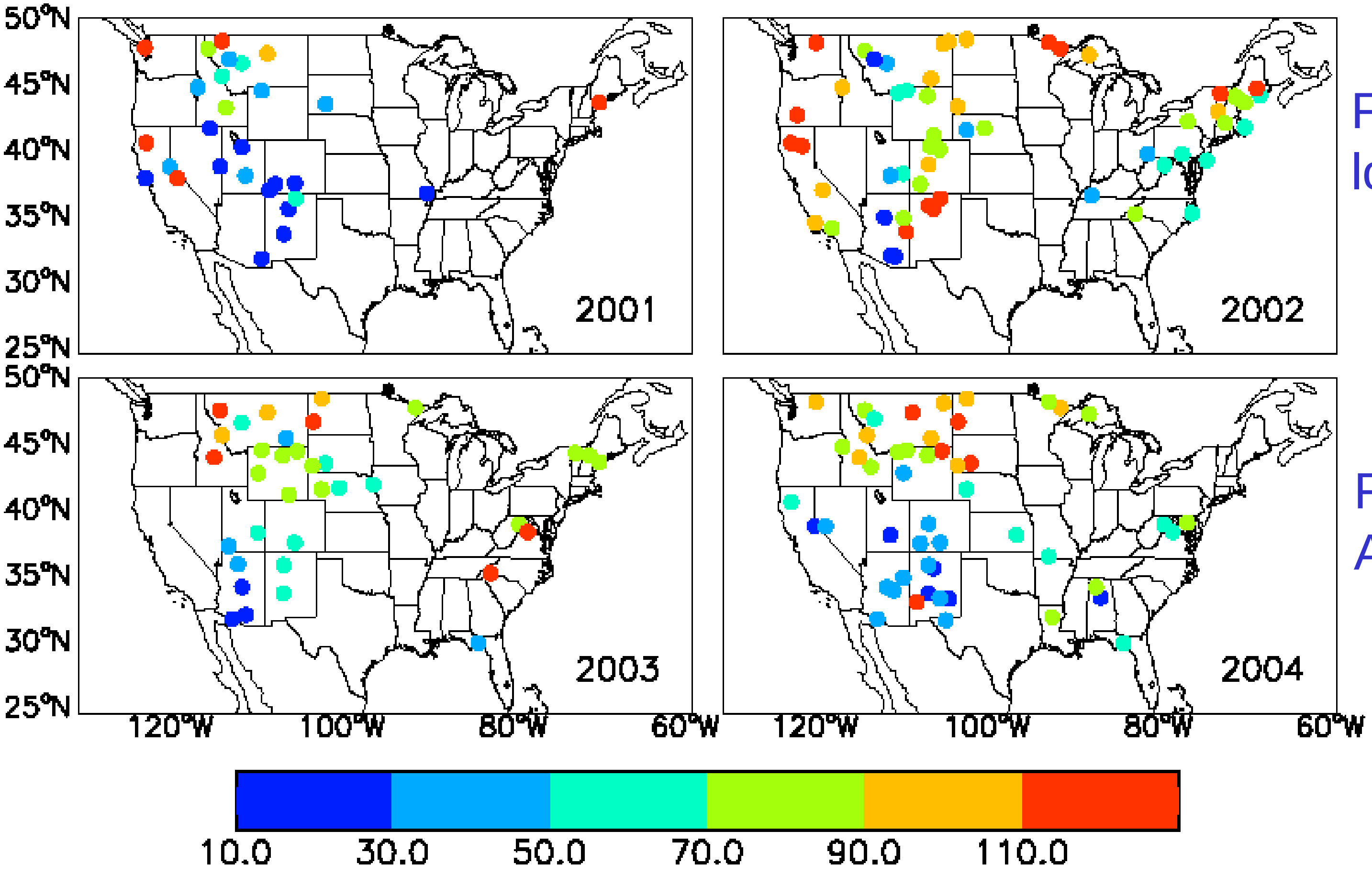
SITES IN NEW MEXICO



HIGH SLOPE INDICATES SIGNIFICANT BOREAL WILDFIRE INFLUENCE

REGRESSION SLOPES BETWEEN CARBONACEOUS AEROSOLS AND NON-SOIL POTASSIUM (K_{NON}) IN SUMMER: IMPROVE (2001-2004)

SITES WITH R > 0.7

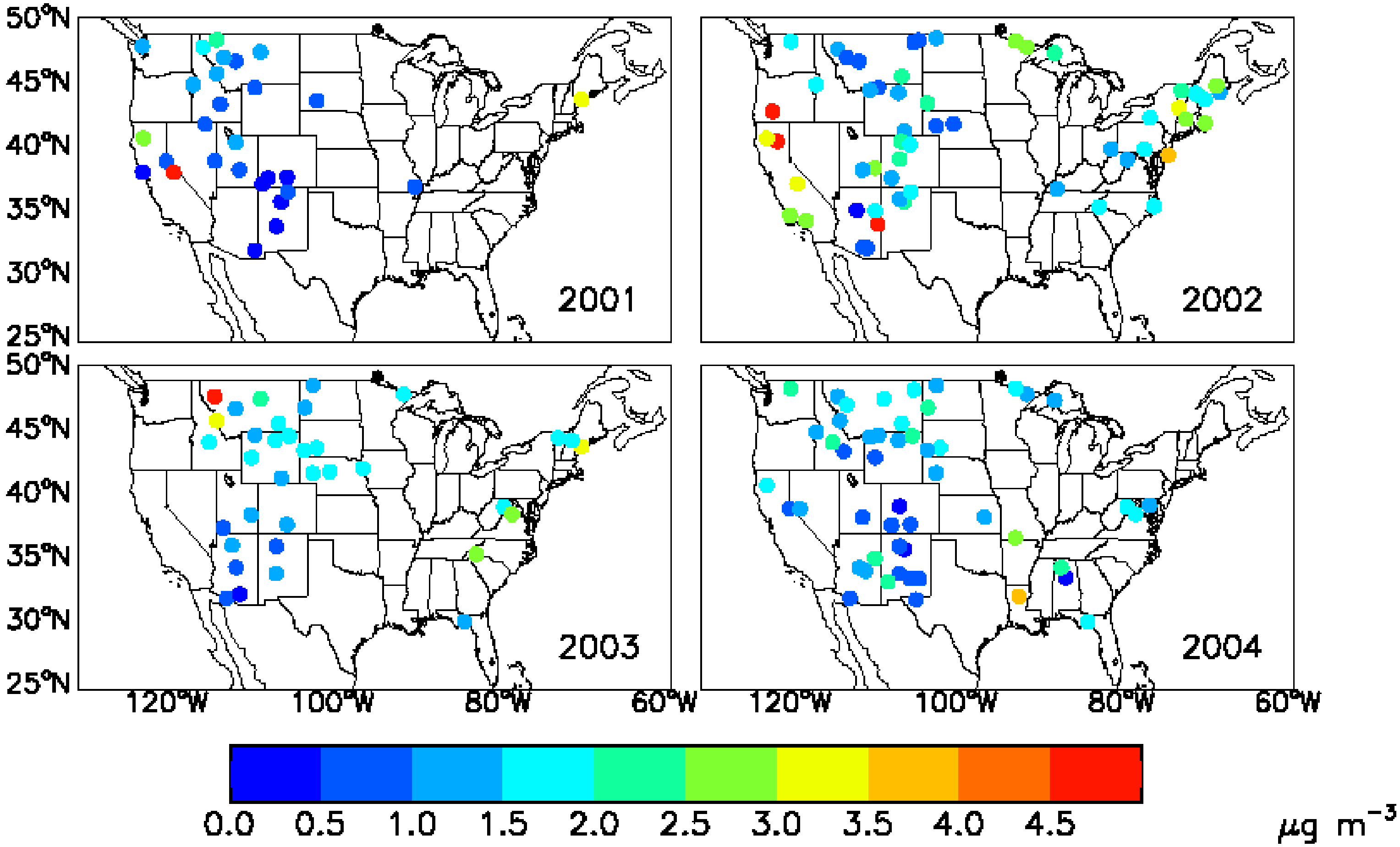


Fires mostly in lower 48 states

Fires mostly in Alaska, Canada

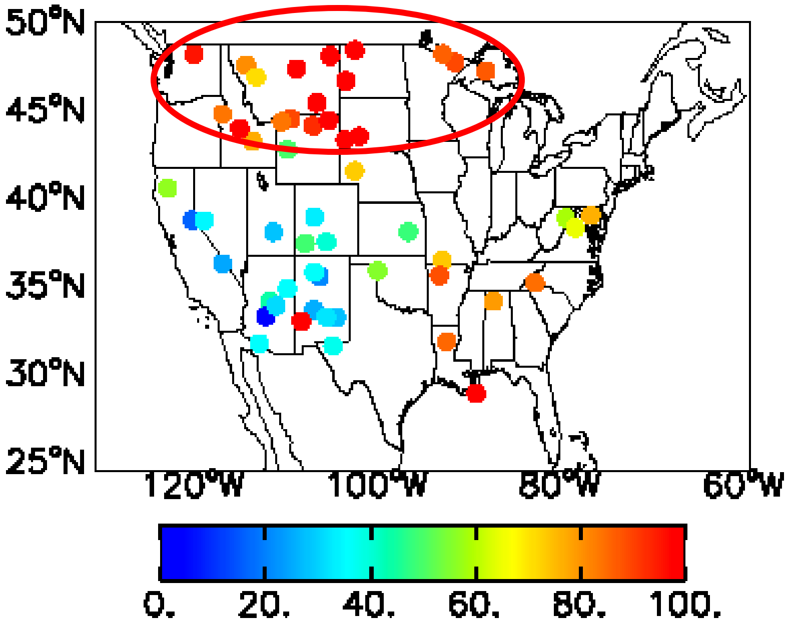
BIOMASS BURNING CONTRIBUTIONS TO CARBONACEOUS AEROSOL IN SUMMER OVER THE U.S.

SITES WITH R > 0.7

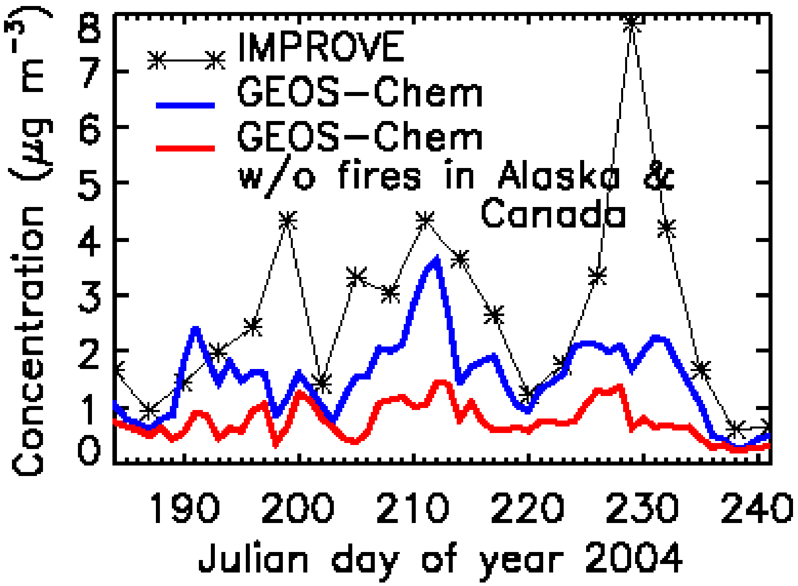


INFLUENCE of WILDFIRES in ALASKA AND CANADA on CARBONACEOUS AEROSOL in the U.S. in 2004: IMPROVE vs. GEOS-Chem

SLOPE: CARB VS. K_{NON}



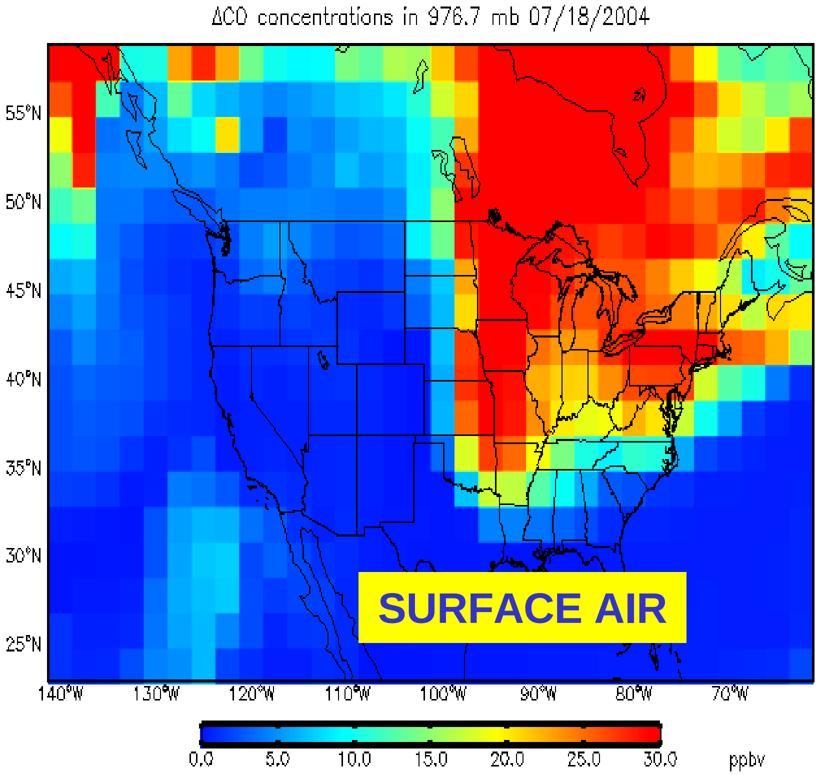
CARBONACEOUS AEROSOL



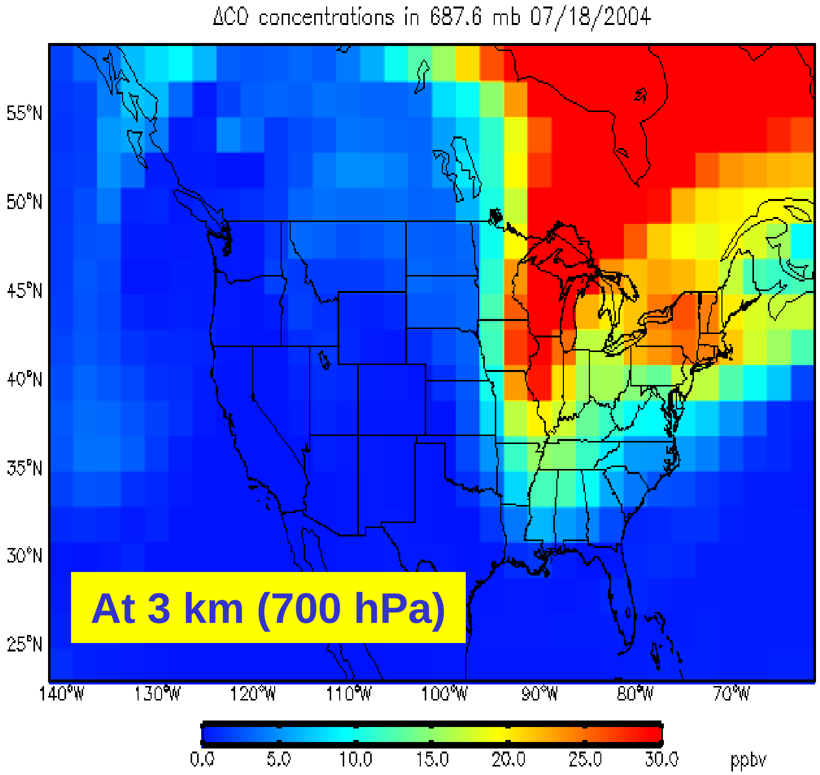
MODEL HAS SOME SUCCESS IN SIMULATING THE TIMING OF HIGH CARB. AEROSOL FROM WILDFIRES IN ALASKA AND CANADA BUT UNDERESTIMATES THEIR MAGNITUDE IN LATE AUGUST.

CO ANIMATION FOR JULY 18-21, 2004

DAILY CO ENHANCEMENTS DUE TO WILDFIRES IN CANADA AND ALASKA



ΔCO concentrations in 976.7 mb 07/18/2004

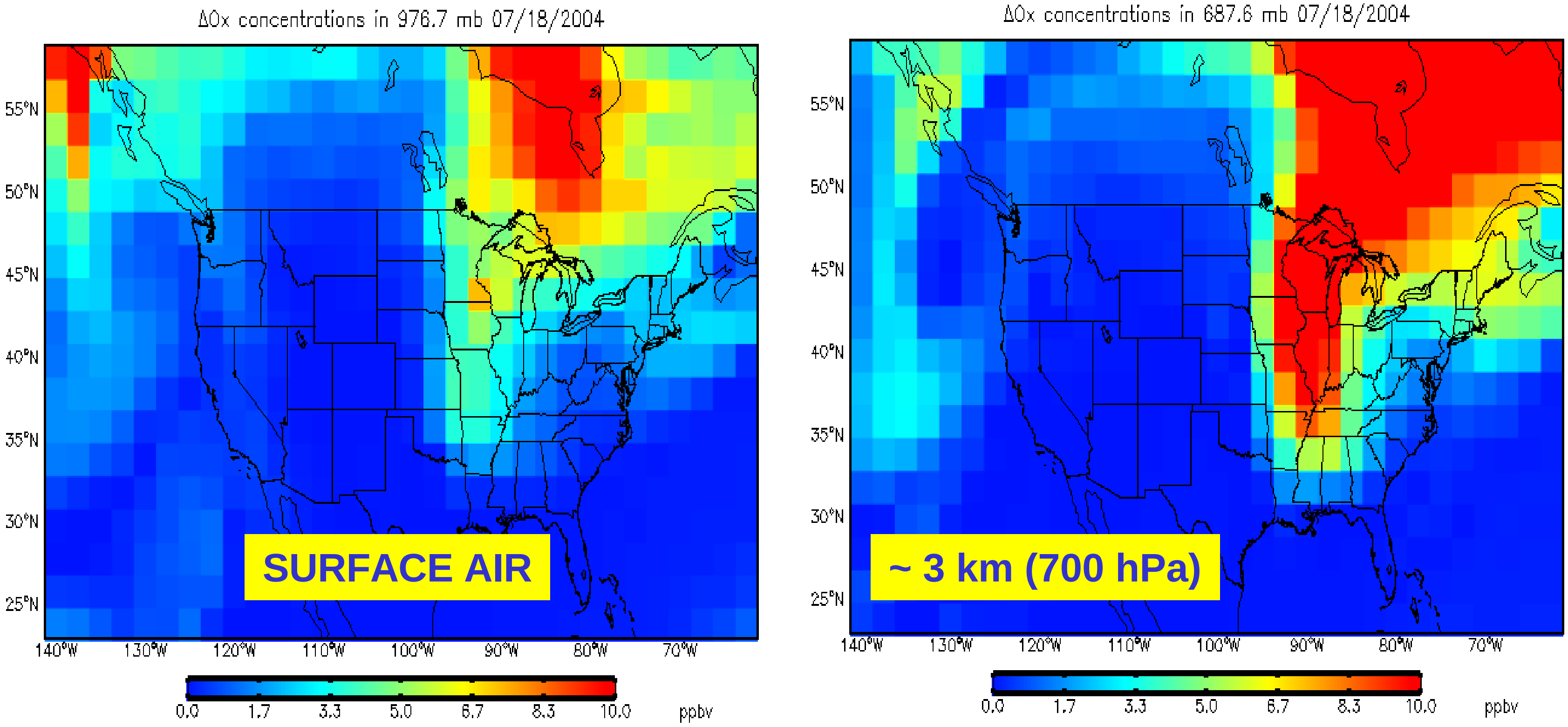


ΔCO concentrations in 687.6 mb 07/18/2004

Enhanced ozone over Houston was ascribed to transport from boreal fires (Morris et al., 2006).
GEOS-Chem simulates CO enhancements, but the transport is too far east to reach to Houston, TX.

Ox ANIMATION FOR JULY 18-21, 2004

DAILY Ox ENHANCEMENTS FROM WILDFIRES IN CANADA AND ALASKA



GEOS-Chem has Ox enhancements from wildfires in Canada and Alaska but with too small a magnitude.

Summary

- Fire prediction scheme under development
- Analysis of GISS met. data in progress

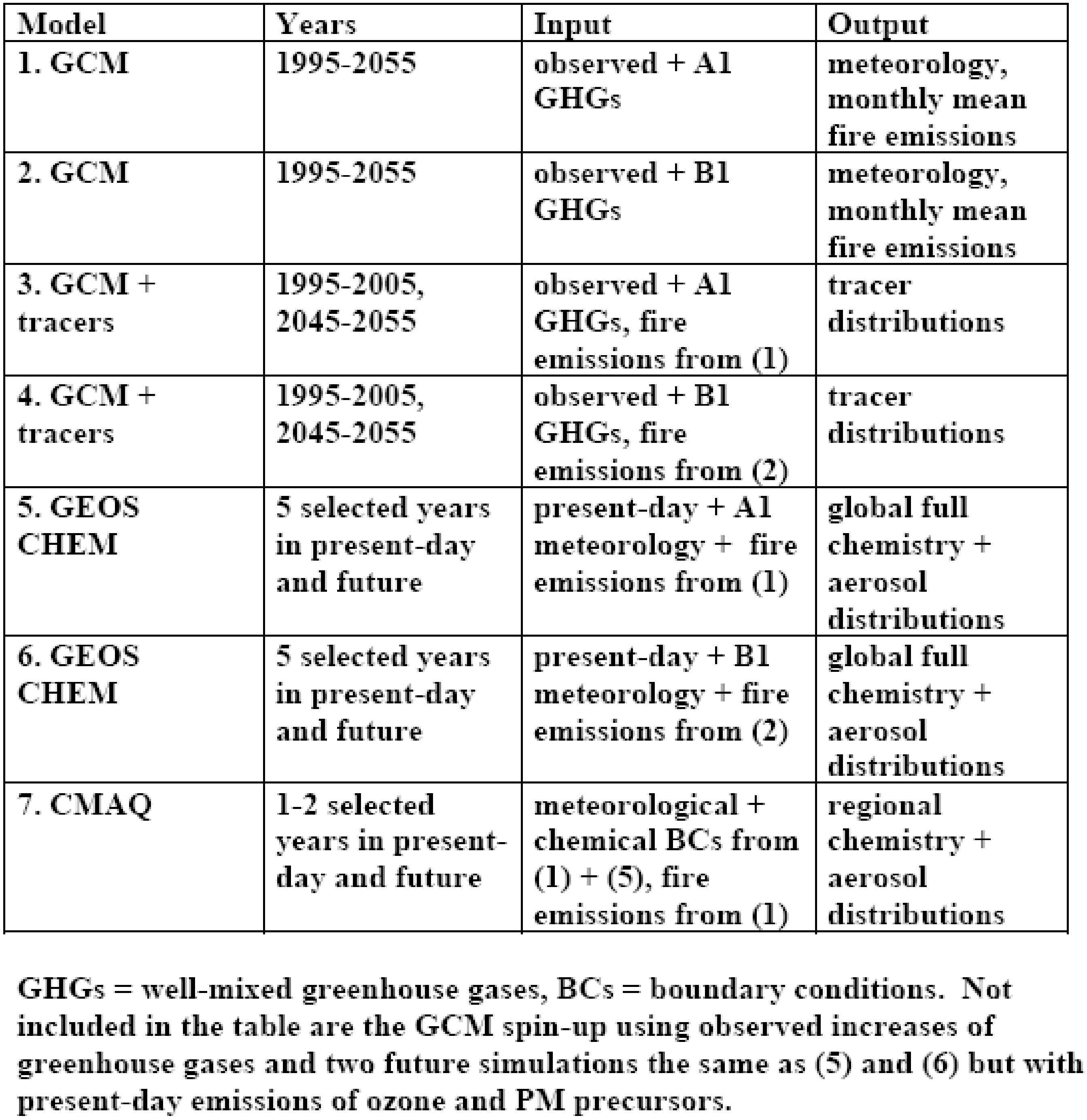
- Interface of GISS data with MM5 done
- On-going work with how to use GISS data in MM5

- Plume height data available for 2004
- Analysis of plume height data in progress

- Analysis of the effects of the 2004 fires on surface air quality in progress, promising first results

- Updated version of GISS model will be delivered soon.
- Future climate runs in progress at Harvard with present version

Planned Simulations



Model	Years	Input	Output
1. GCM	1995-2055	observed + A1 GHGs	meteorology, monthly mean fire emissions
2. GCM	1995-2055	observed + B1 GHGs	meteorology, monthly mean fire emissions
3. GCM + tracers	1995-2005, 2045-2055	observed + A1 GHGs, fire emissions from (1)	tracer distributions
4. GCM + tracers	1995-2005, 2045-2055	observed + B1 GHGs, fire emissions from (2)	tracer distributions
5. GEOS CHEM	5 selected years in present-day and future	present-day + A1 meteorology + fire emissions from (1)	global full chemistry + aerosol distributions
6. GEOS CHEM	5 selected years in present-day and future	present-day + B1 meteorology + fire emissions from (2)	global full chemistry + aerosol distributions
7. CMAQ	1-2 selected years in present-day and future	meteorological + chemical BCs from (1) + (5), fire emissions from (1)	regional chemistry + aerosol distributions

GHGs = well-mixed greenhouse gases, BCs = boundary conditions. Not included in the table are the GCM spin-up using observed increases of greenhouse gases and two future simulations the same as (5) and (6) but with present-day emissions of ozone and PM precursors.