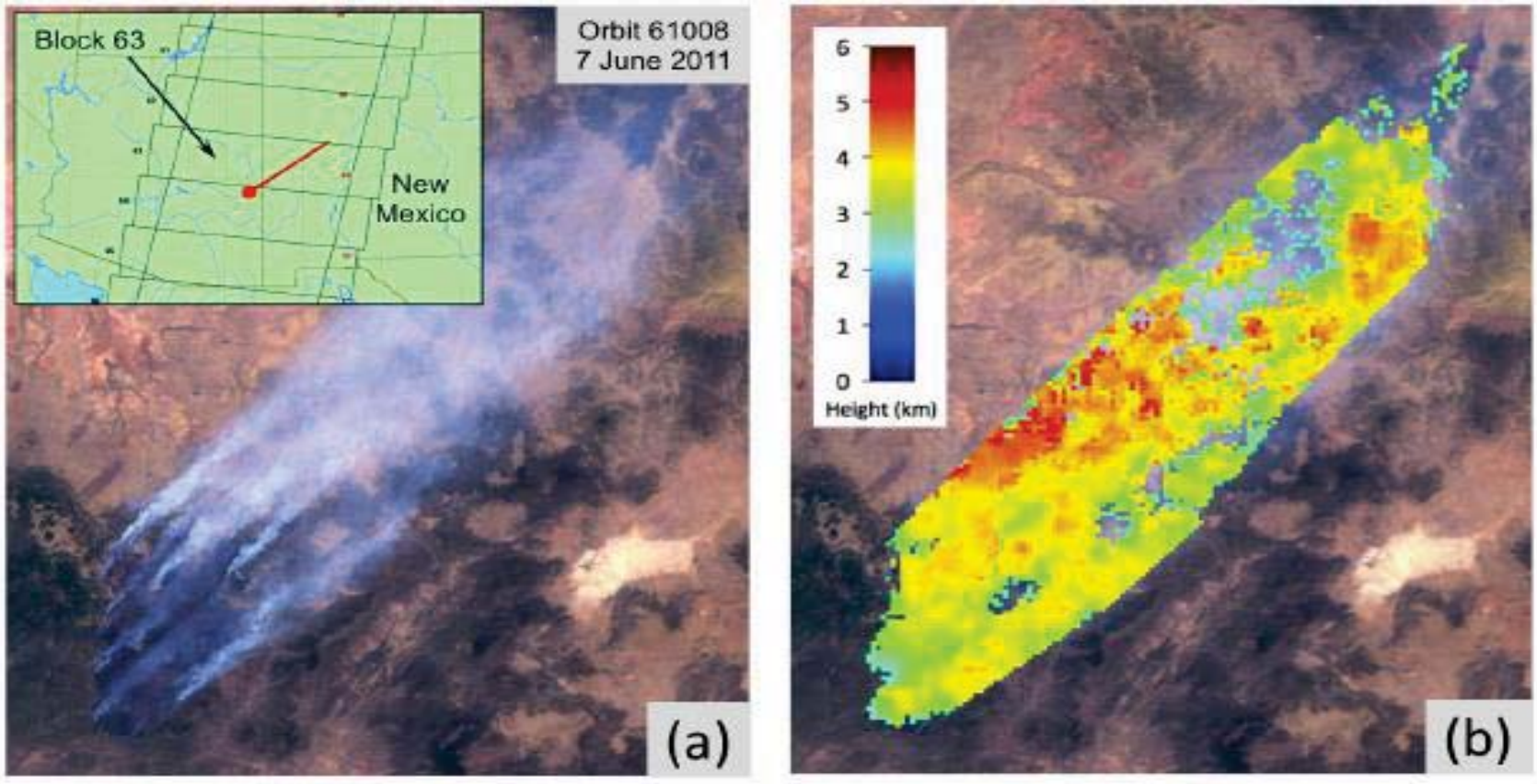
# Constraints on smoke injection height, source strength, and transports from MISR and MODIS

***Ralph Kahn***

**NASA Goddard Space Flight Center**

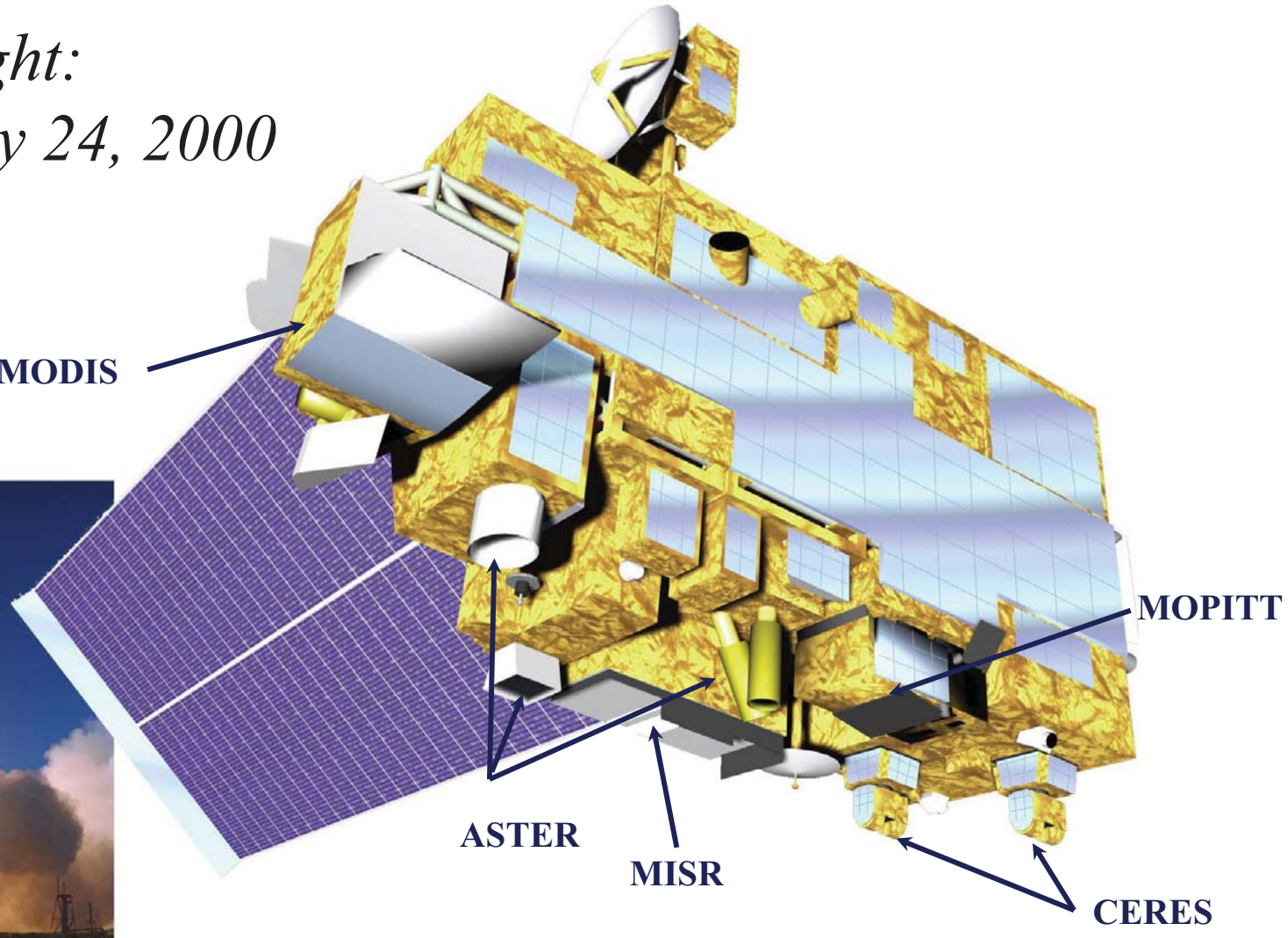
**Mariya Petrenko, Maria Val Martin, Mian Chin**




*Nelson et al., Remt. Sens*. 2013

# The NASA Earth Observing System's Terra Satellite

*First Light:*
*February 24, 2000*




Source: Terra Project Office / NASA Goddard Space Flight Center

# Multi-angle Imaging SpectroRadiometer

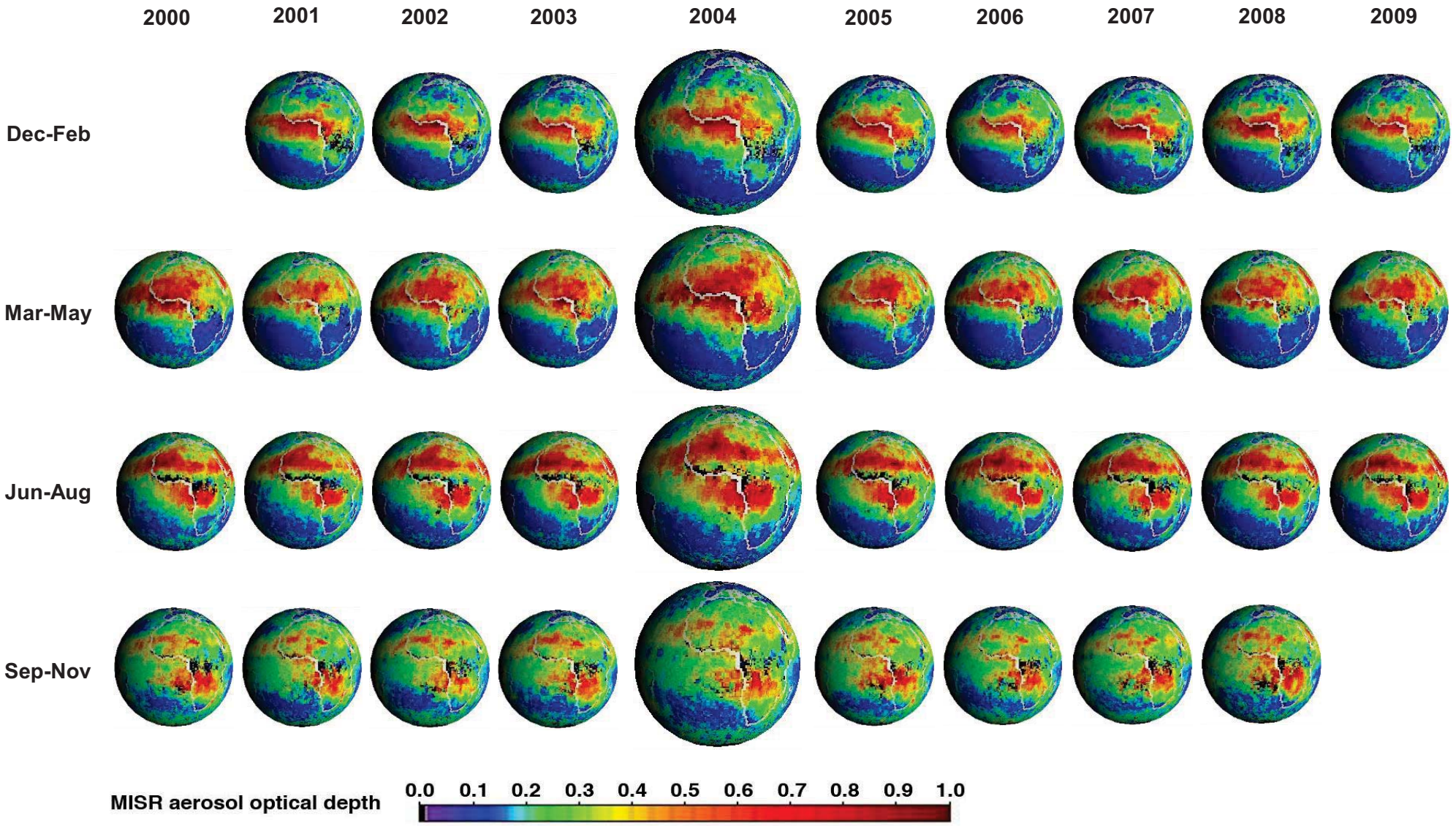
MISR


http://www-misr.jpl.nasa.gov

http://eosweb.larc.nasa.gov

- Nine CCD push-broom cameras
- Nine view angles at Earth surface: 70.5º forward to 70.5º aft
- Four spectral bands at each angle: 446, 558, 672, 866 nm
- Studies *Aerosols*, *Clouds*, & *Surface*

# *Ten* Years of Seasonally Averaged Mid-visible Aerosol Optical Depth from MISR

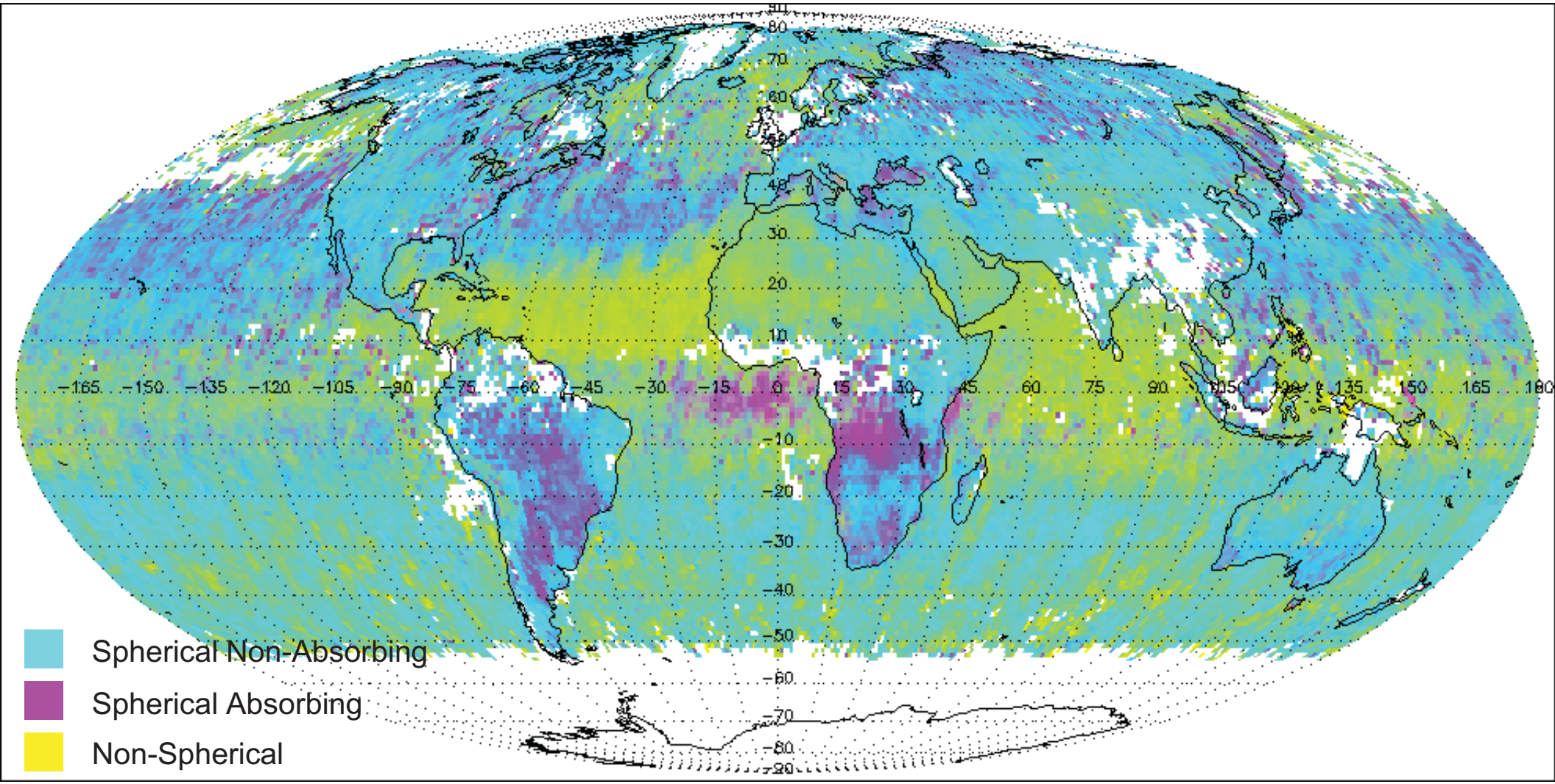



***…includes bright desert dust source regions***

*MISR Team,* JPL and GSFC

# MISR *Aerosol Type* Distribution

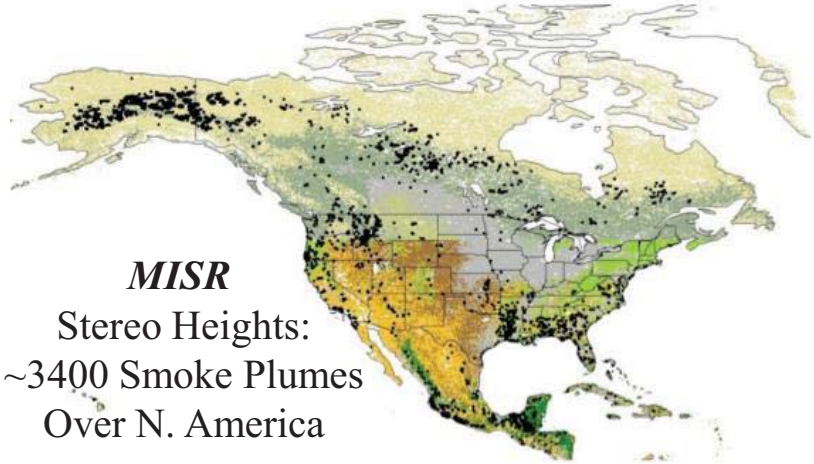
**MISR Version 22, July 2007**



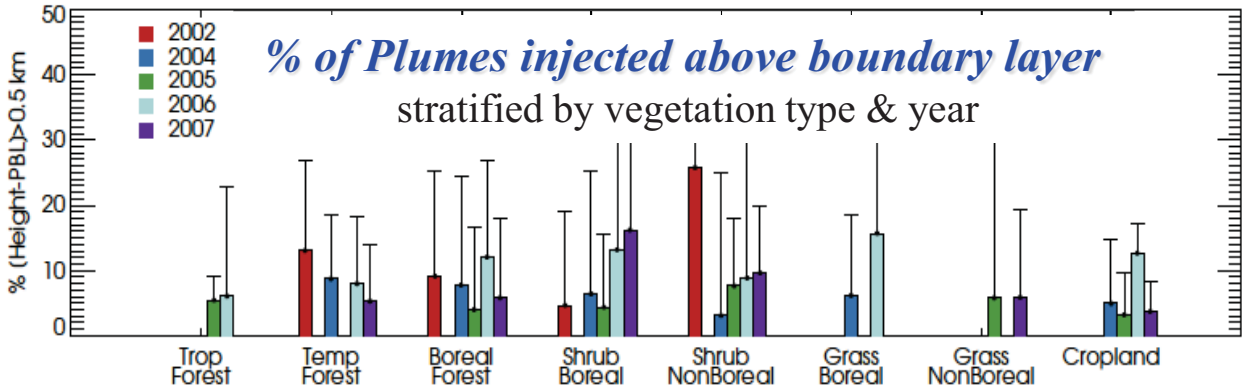

*Kahn, Gaitley, Garay, et al., JGR 2010*

# Wildfire Smoke *Injection Heights* & *Source Strengths*

**[These are *the two key parameters* representing aerosol sources in climate models]**

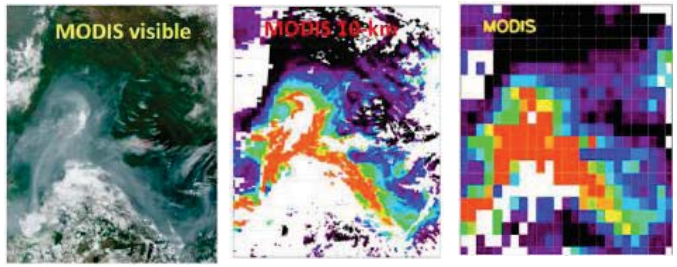


***MISR***
Stereo Heights:
~3400 Smoke Plumes
Over N. America

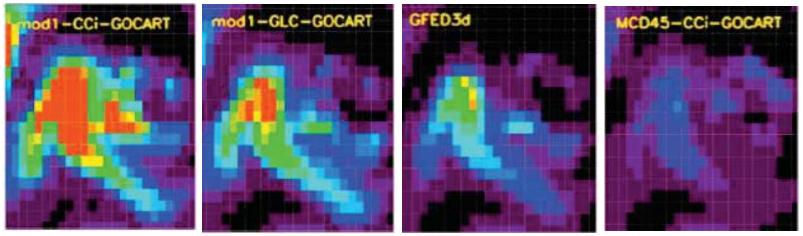



***% of Plumes injected above boundary layer***
stratified by vegetation type & year

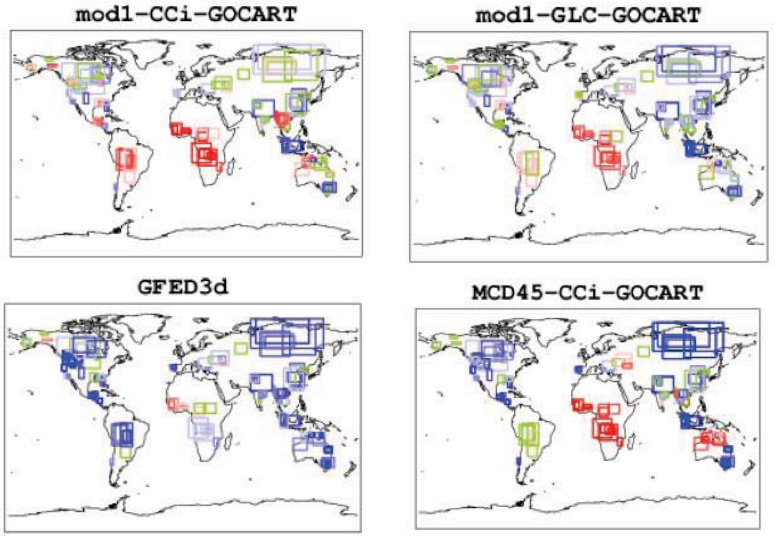
*Val Martin et al. ACP 2010*




***MODIS*** Smoke Plume Image & Aerosol Amount Snapshots

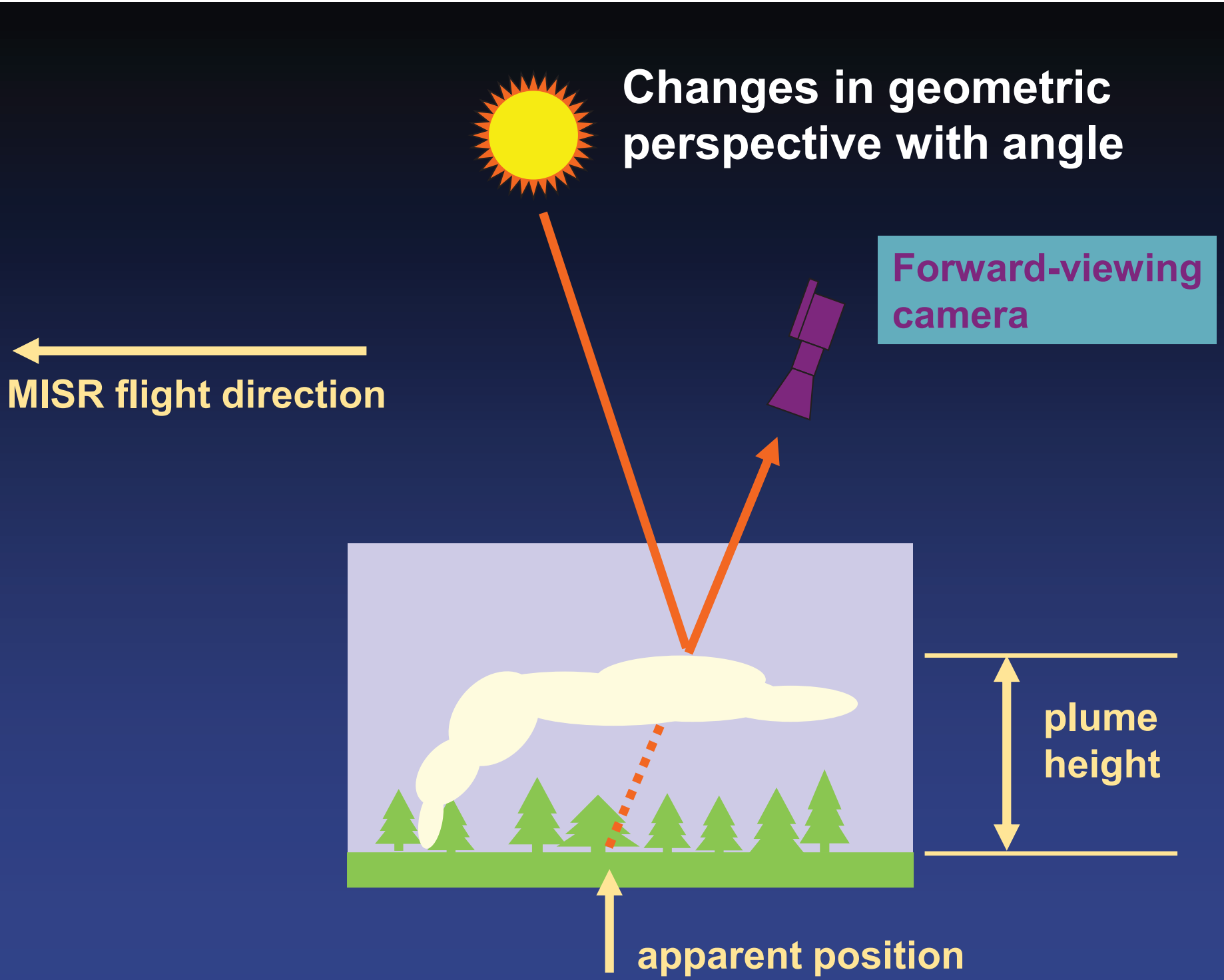



***GoCART Model-Simulated*** Aerosol Amount Snapshots
for *Different Assumed Source Strengths*

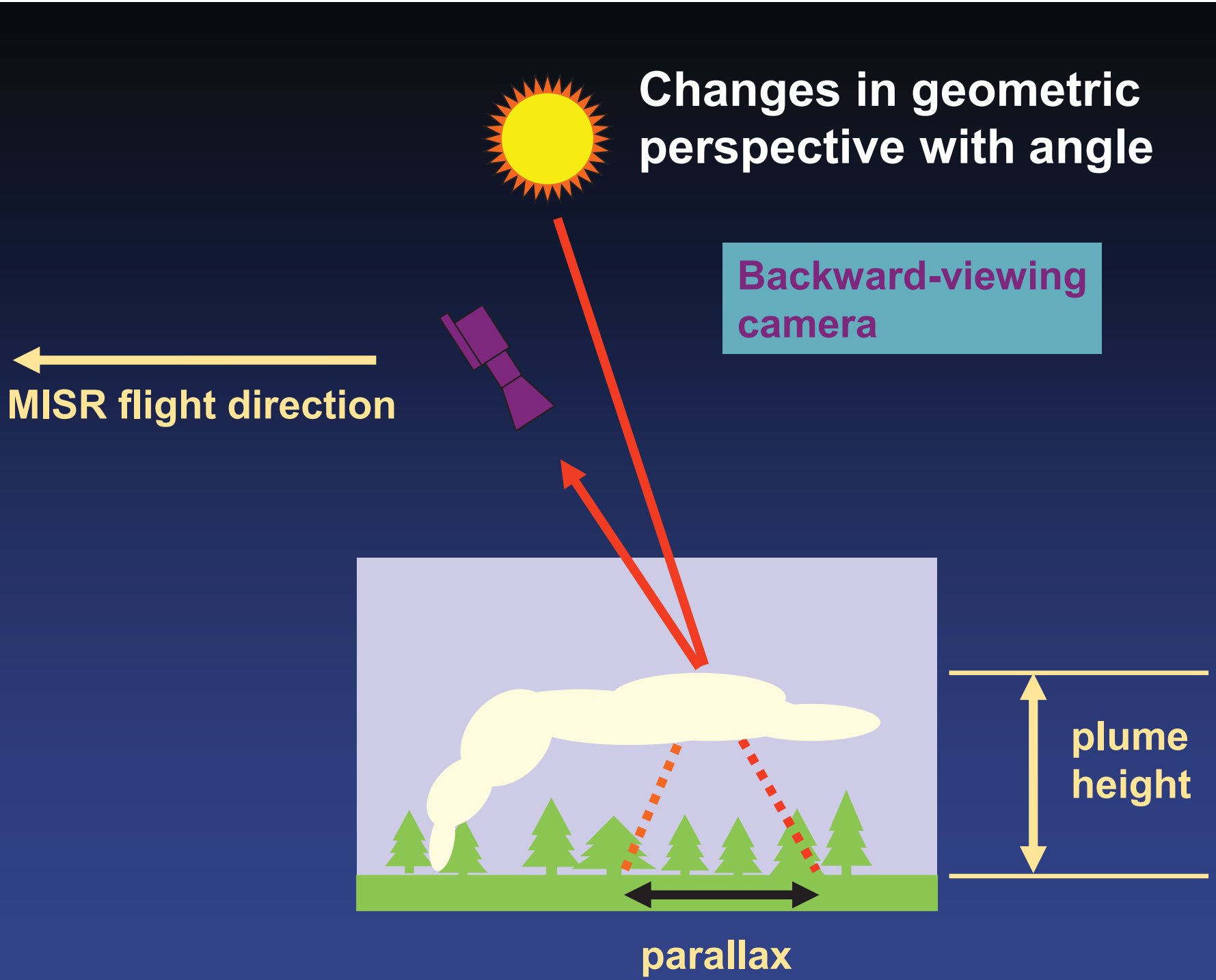



Different Techniques for *Assuming Model Source Strength*
***Overestimate*** or ***Underestimate*** Observation
***Systematically*** in Different Regions

*Petrenko et al., JGR 2012*


Changes in geometric perspective with angle
Forward-viewing camera
MISR flight direction
plume height
apparent position

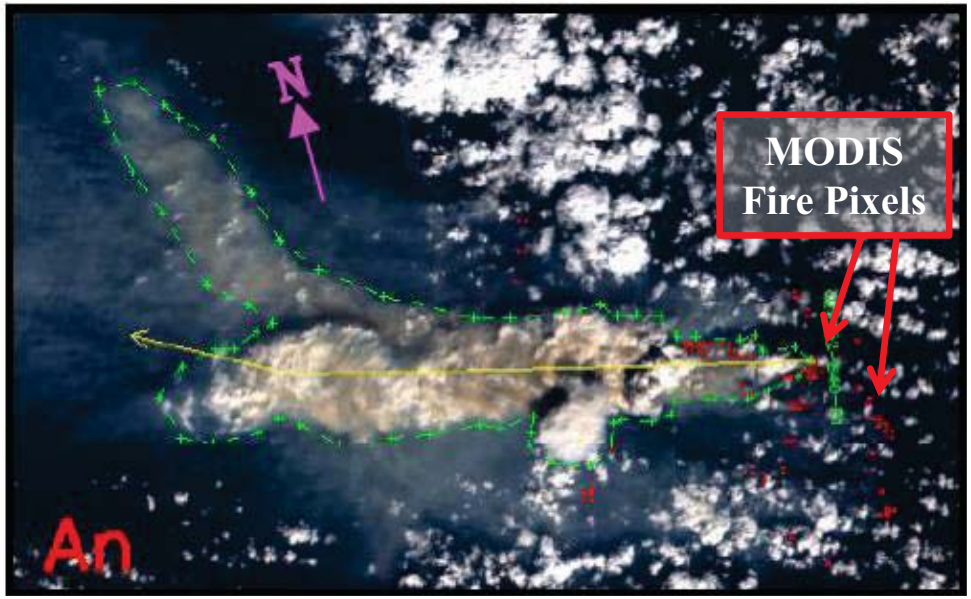
Diner et al.

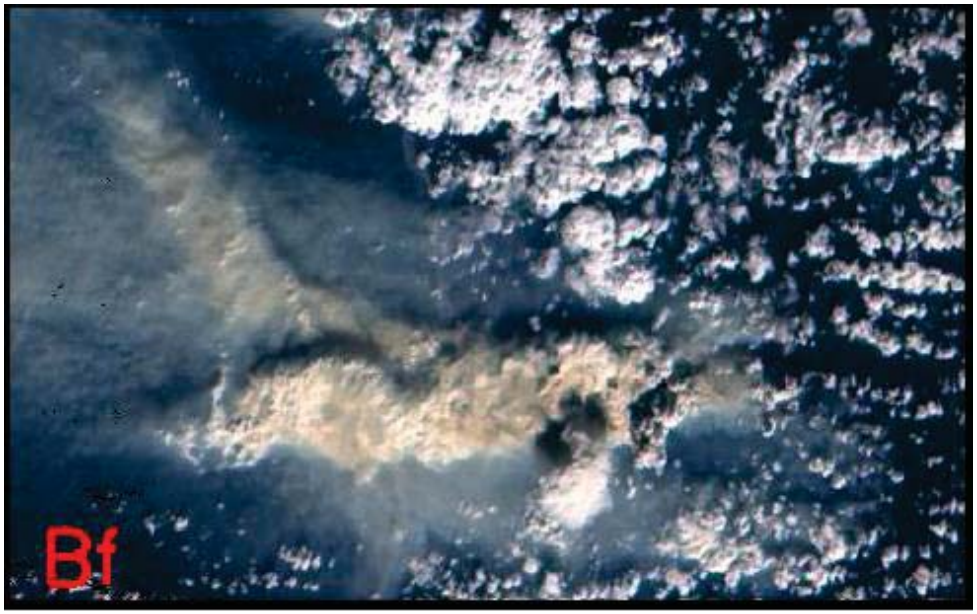

Changes in geometric perspective with angle
Backward-viewing camera
MISR flight direction
plume height
parallax

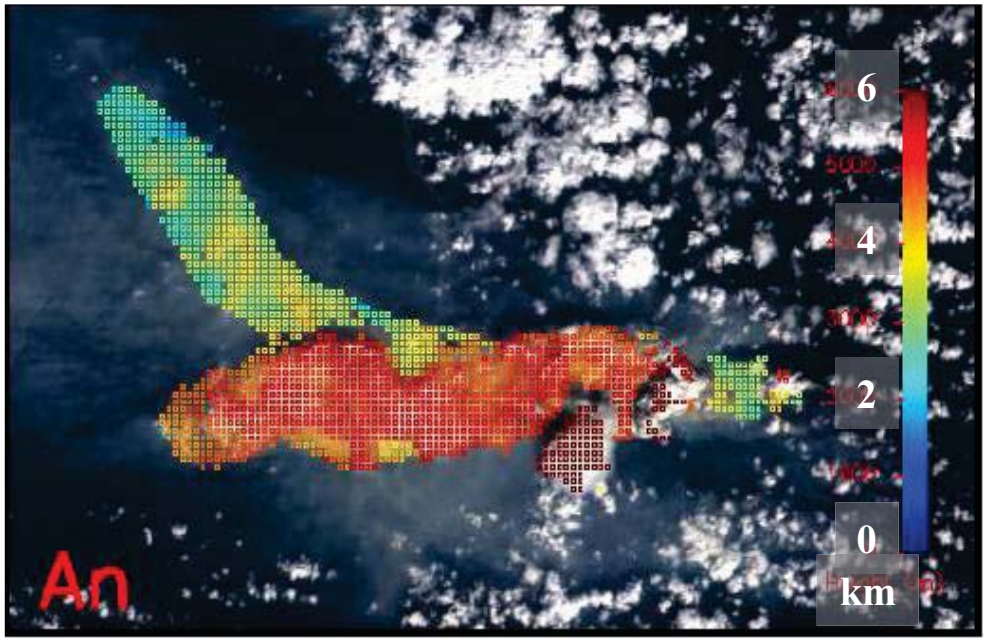
Diner et al.

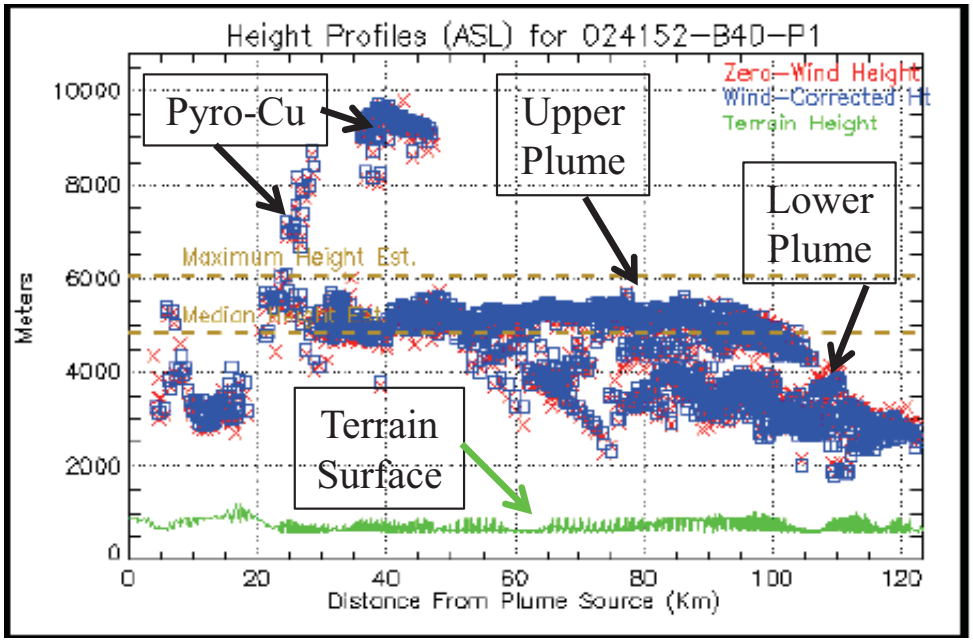
# MISR *Smoke Plume Height* Mapping

July 2, 2004, Canada near Alaska border



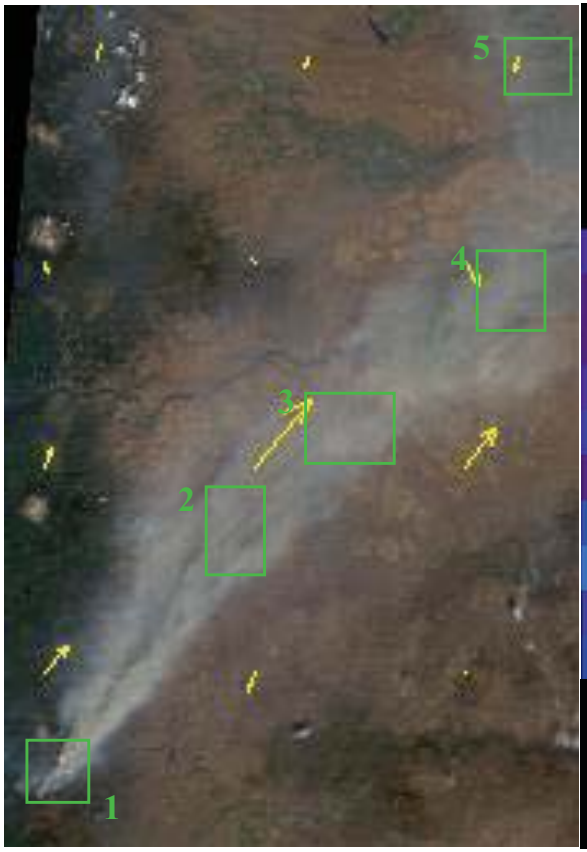



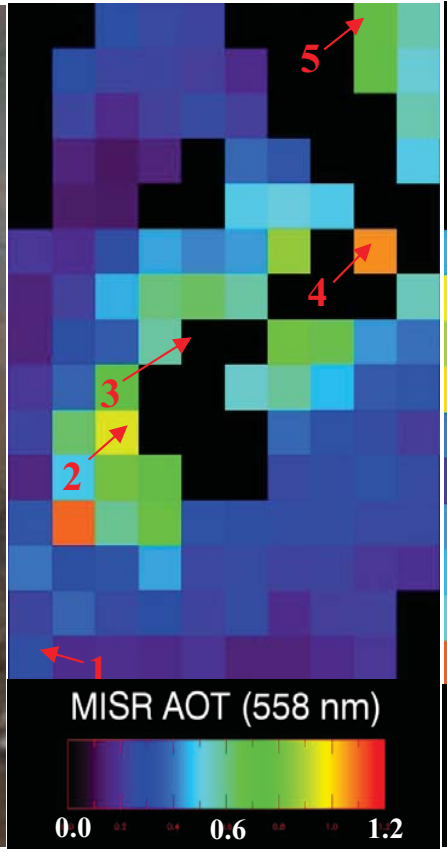



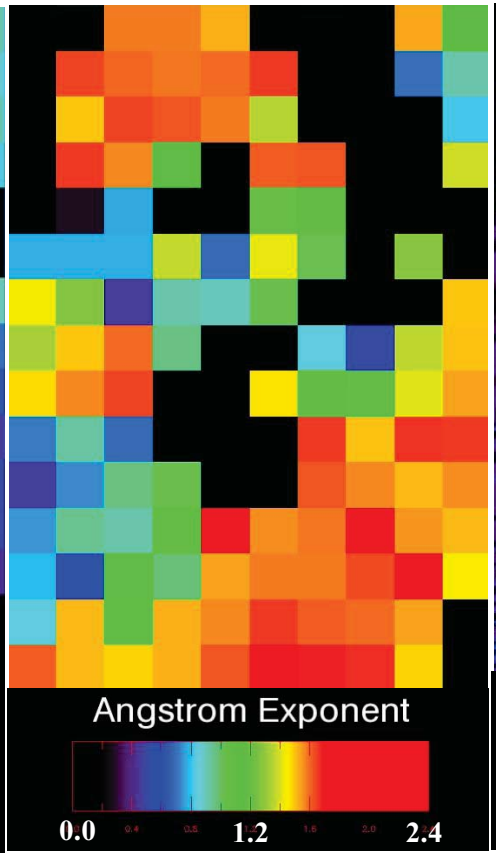

*Nelson, et al., Proc. SPIE 2008*

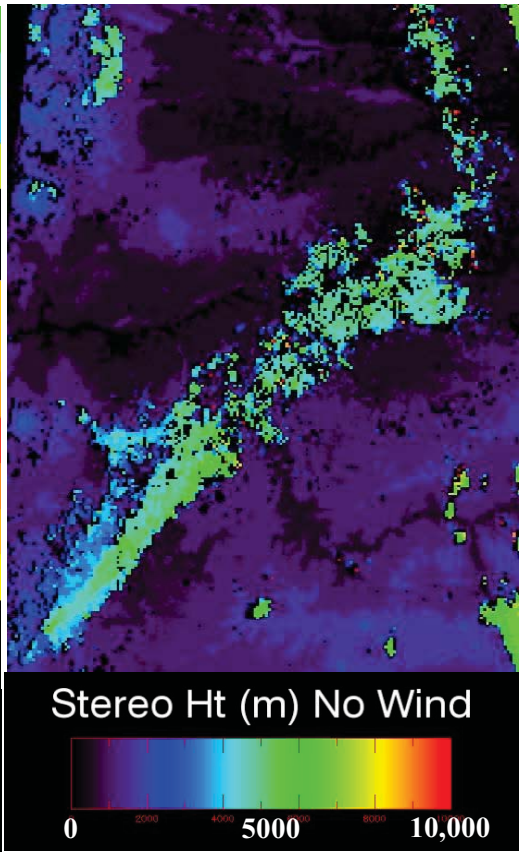
# Oregon Fire Sept 04 2003

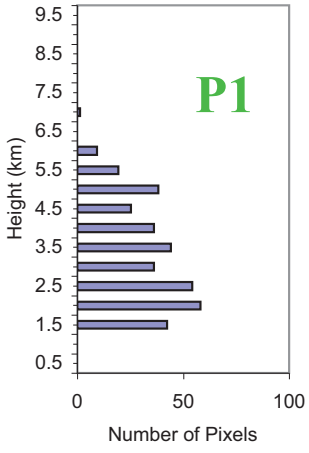
## Orbit 19753 Blks 53-55 MISR Aerosols V17, Heights V13 (no winds)

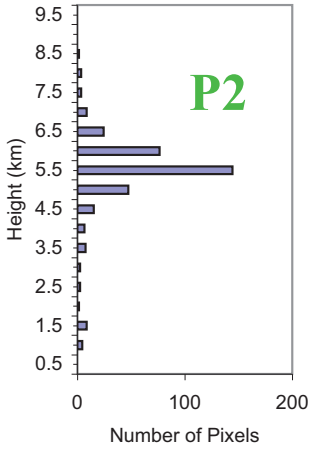


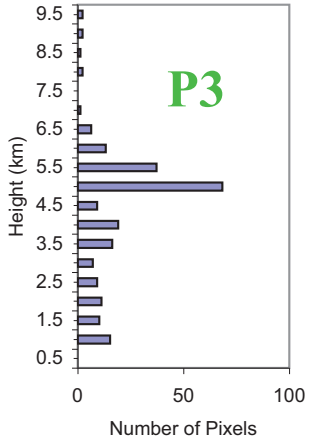



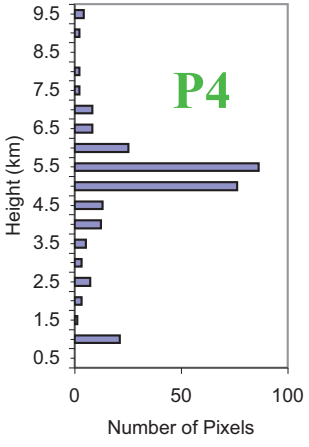



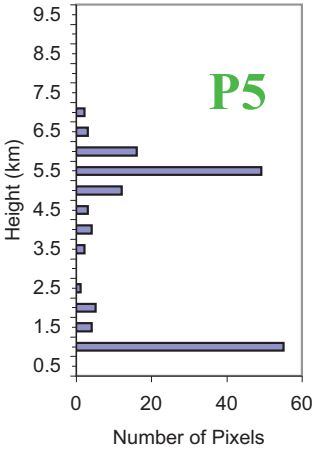



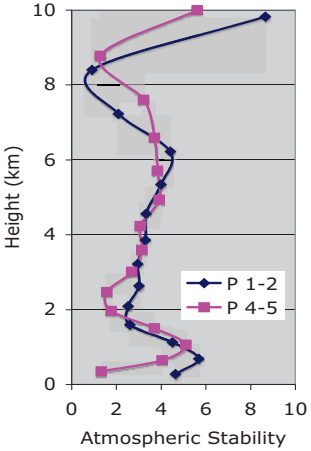



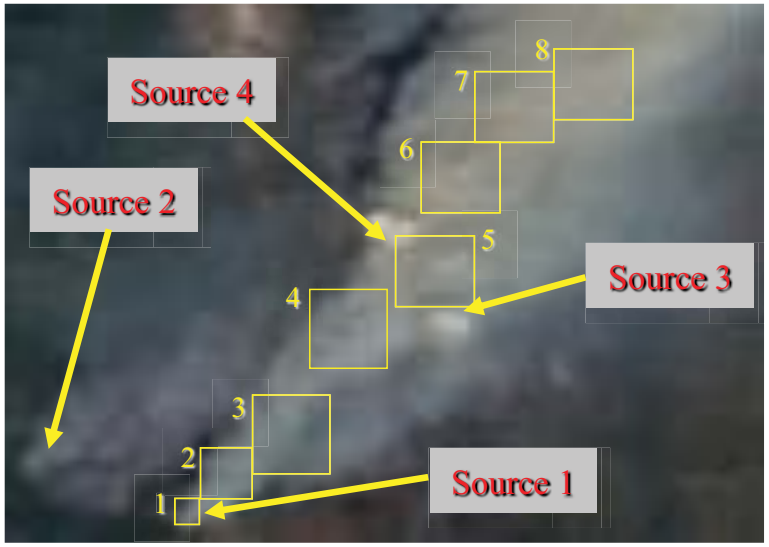



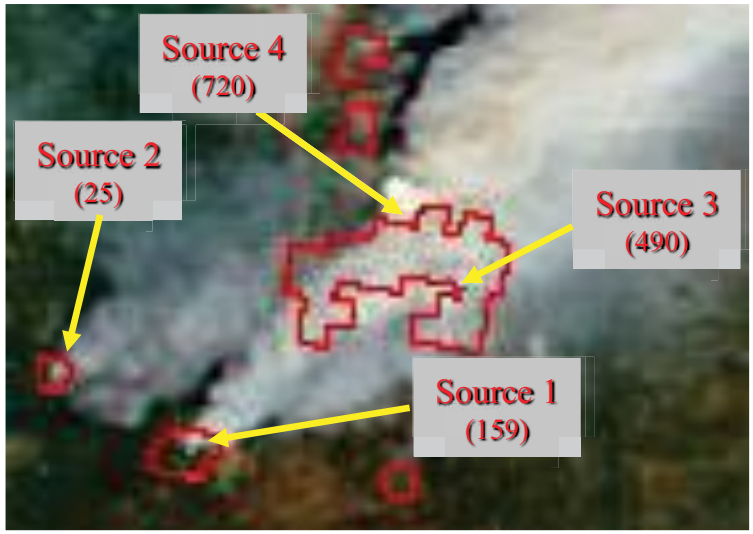

*Kahn, et al.*, JGR 2007

# Detail of Wildfire Source Region

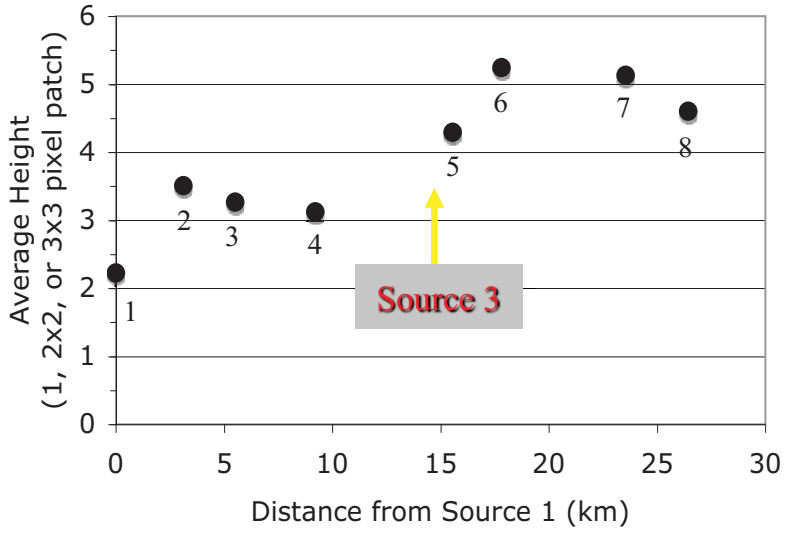
## Oregon Fire Sept 04 2003



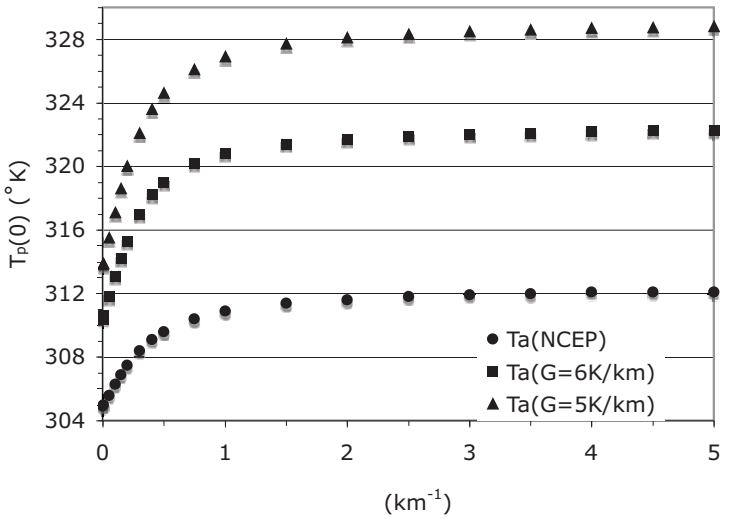

MISR Nadir **275 m** Image




MODIS Image + **Fire Power**



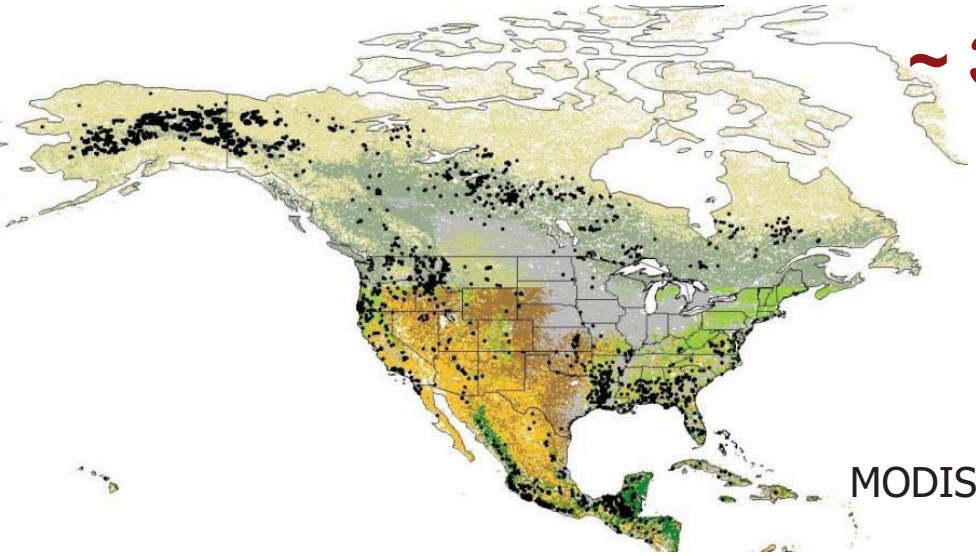

MISR **Plume Heights** for Sub-patches




Very Simple Plume Parcel Model

→ ***Broad swath + high spatial resolution*** needed to characterize sources

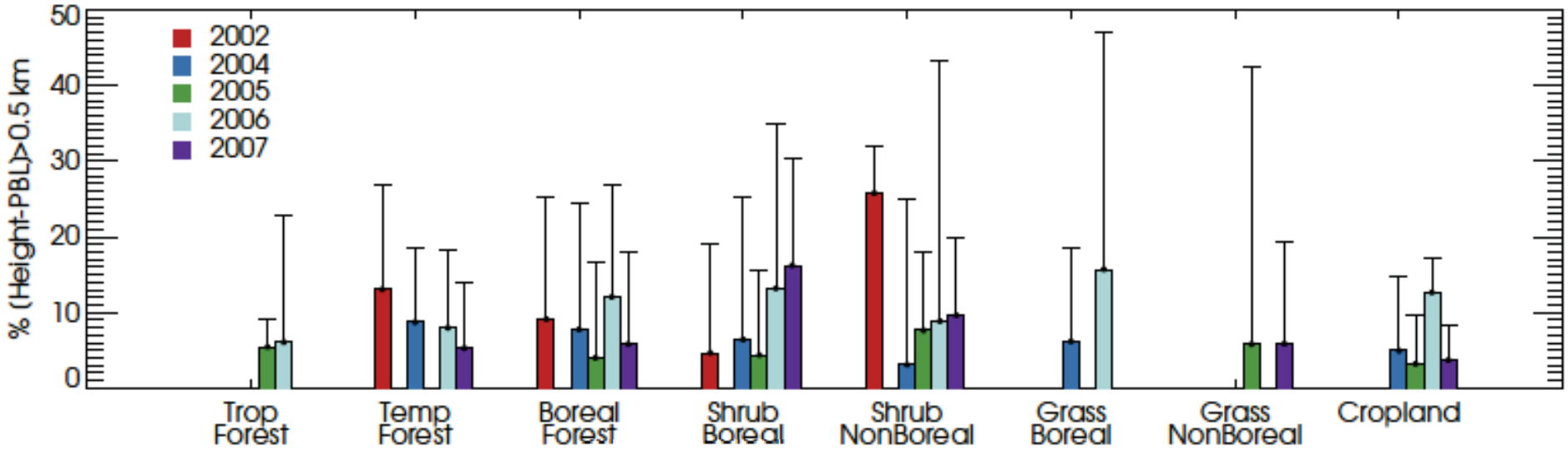
# N. America Plume *Injection Height* Climatology



MODIS IGBP land cover map
(1x1 Km res)

**~ 3400 plumes digitized over North America for 2002, 2004-2007**

- Tropical Forest
- Temperate Forest
- Boreal Forest
- Boreal Shrubland
- Non-Boreal Shrubland
- Boreal Grassland
- Non-Boreal Grassland
- Cropland




Percent of plumes >0.5 km ***above BL***, stratified by year and vegetation type

*Val Martin et al. ACP 2010*

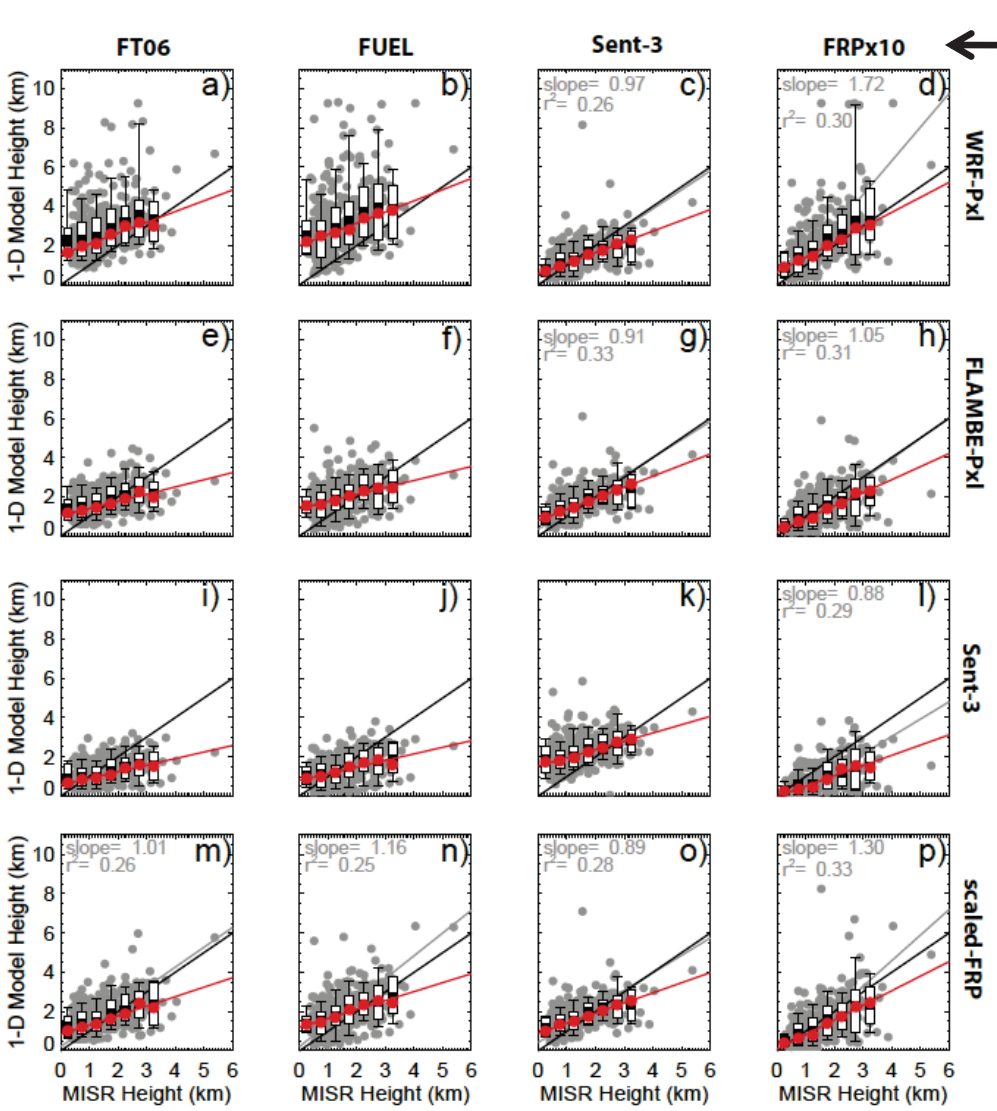
# Evaluation of a 1D plume-rise model: Towards a parameterization of smoke *injection heights*

***To Constrain models:***

Need to assess the

***Parameterizations***

actually used

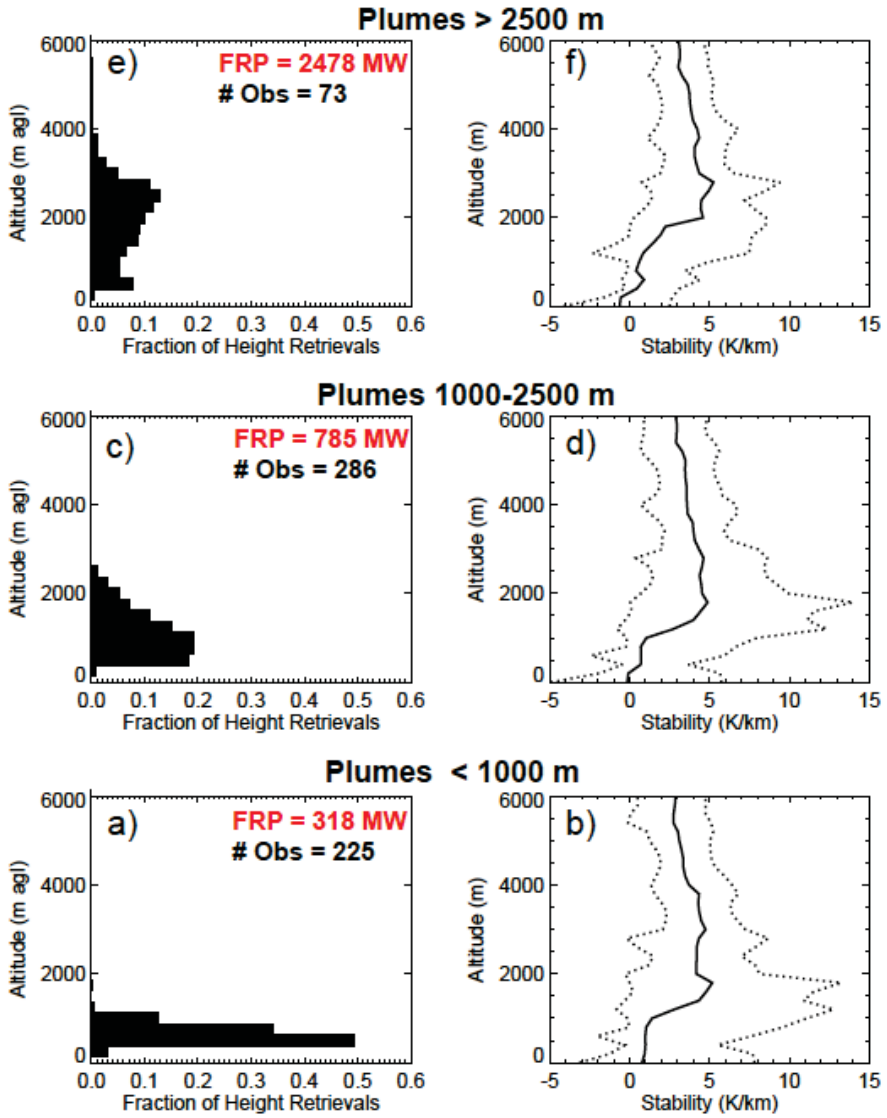



**1-D Plume-rise model heights** vs. **MISR-observed max. plume heights**

-- Plume-rise calculations have ***lower dynamic range than observed***, but very variable

*Val Martin et al., JGR 2012*

# Evaluation of a 1D plume-rise model: Towards a parameterization of smoke *injection heights*



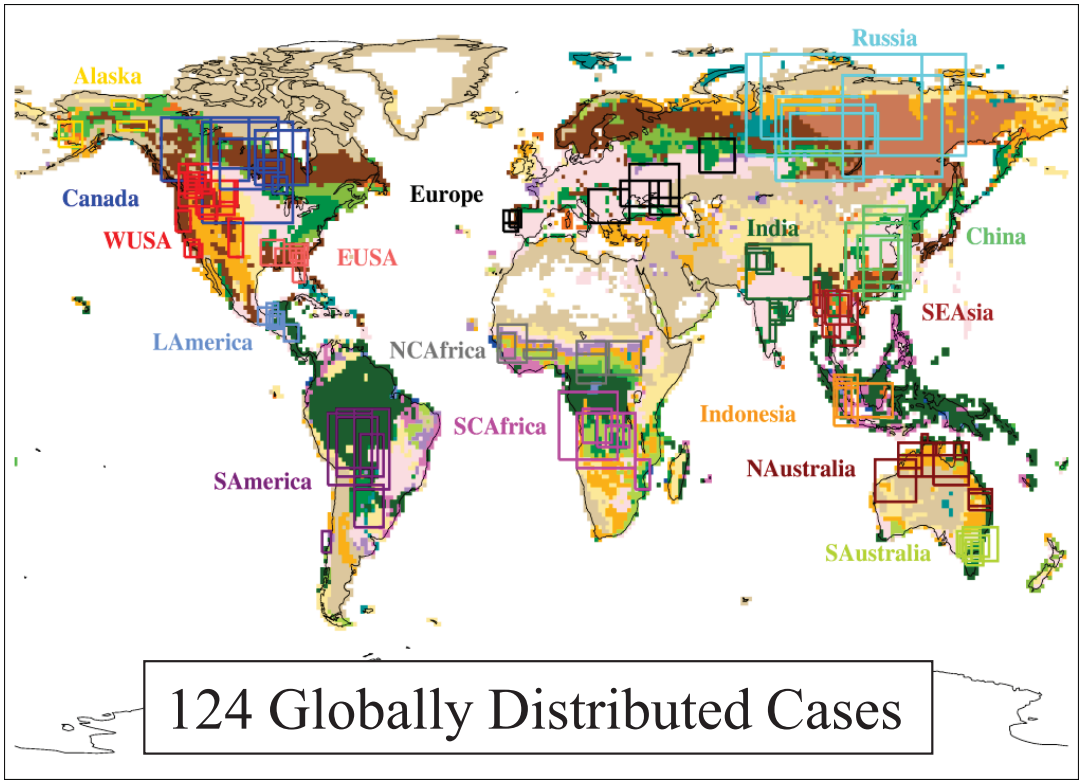

The key factors:

- ***Fire Energy***
  (fire area; heat flux, FRP)
- ***Atmospheric Stability***
- ***Entrainment***

Plume height increases systematically as ***FRP*** increases and ***Atmospheric Stability*** decreases

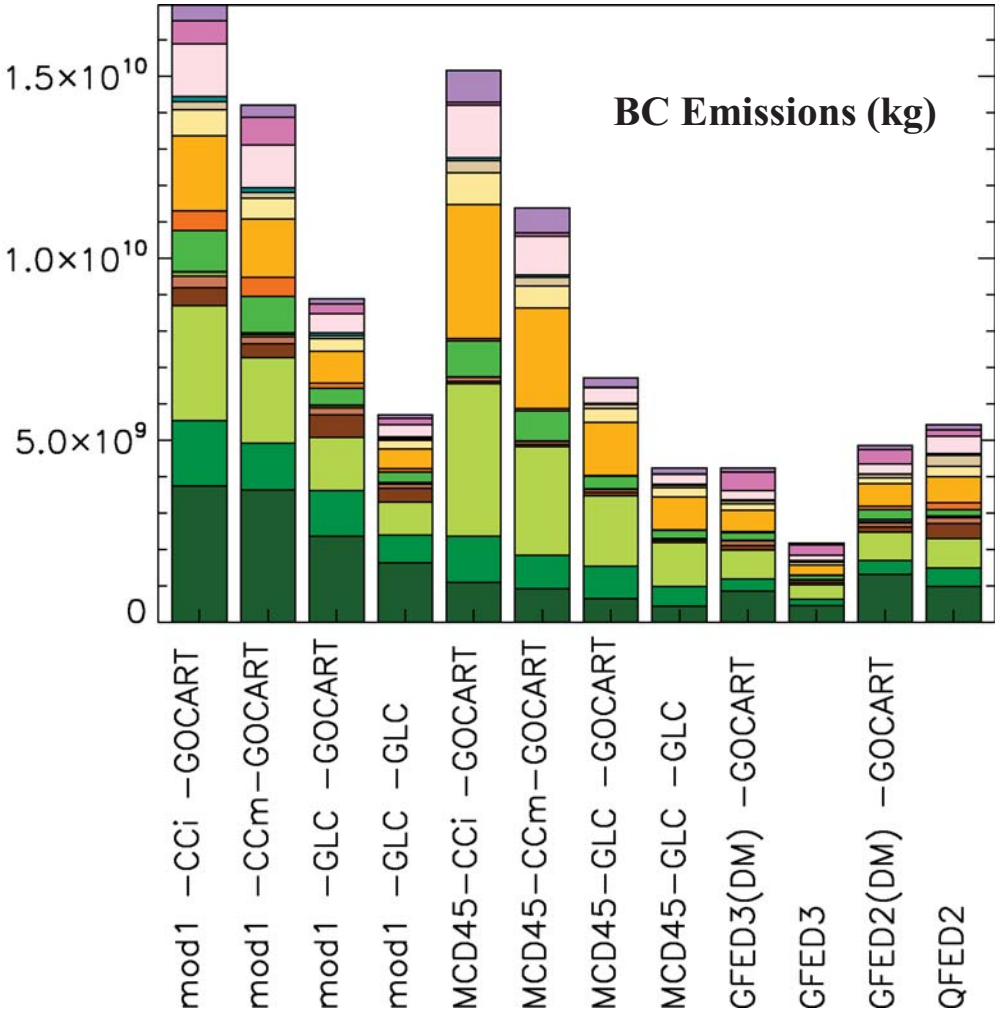
*Val Martin et al., JGR 2012*

# Satellite AOD snapshots to constrain Biomass Burning Emissions *Source Strength*




124 Globally Distributed Cases

1 Tree cover, broadleaved, evergreen
2 Tree cover, broadleaved, deciduous, closed
3 Tree cover, broadleaved, open
4 Tree cover, needle-leaved, evergreen
5 Tree cover, needle-leaved, deciduous
6 Tree cover mixed leaf type
7 Tree cover, regularly flooded, fresh water
8 Tree cover, regularly flooded, saline water
9 Mosaic: tree cover / other natural vegetation
10 Undefined
11 Shrub cover, closed-open, evergreen
12 Shrub cover, closed-open, deciduous
13 Herbaceous cover, closed-open
14 Sparse herbaceous or sparse shrub cover
15 Regularly flooded shrub and/or herbaceous cover
16 Cultivated and managed areas
17 Mosaic:Cropland/Tree cover/other natural veg
18 Cropland/Shrub and/or grass cover

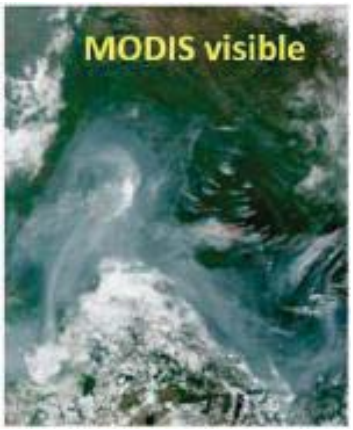


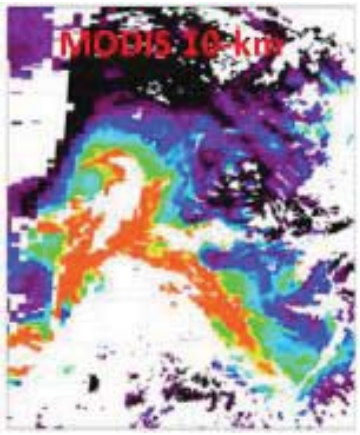

13 Smoke Emission Estimates

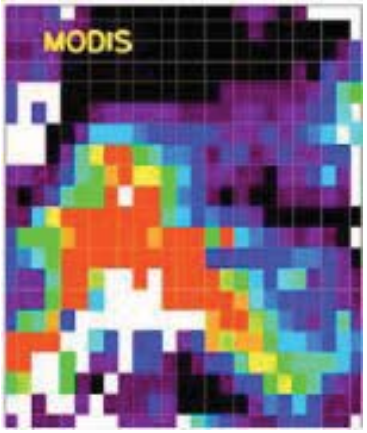
*Petrenko, Kahn, Chin, et al., JGR 2012*

# MODIS-GoCART Total Column AOD Comparisons

## Sample Case: Siberia July 20 2006




**Goddard Chemistry Aerosol Radiation and Transport (GOCART) model runs**

3-hourly output

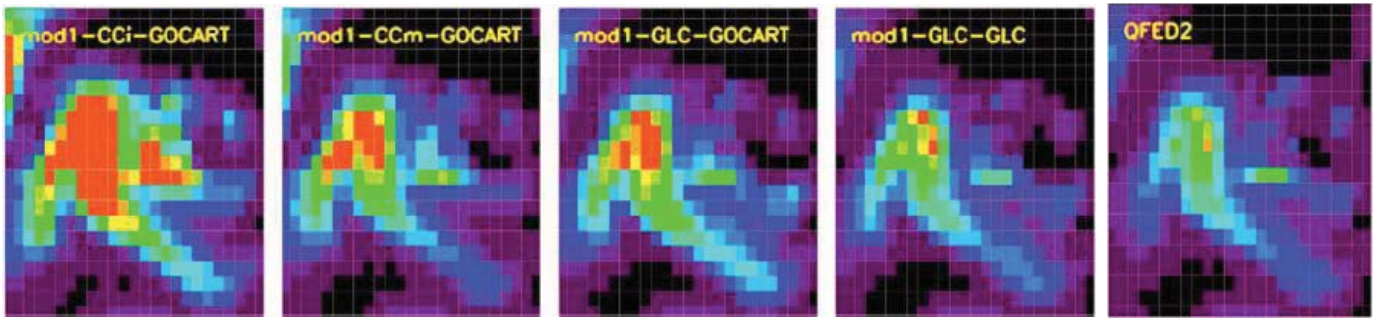
**Resolution:** 1°(lat) x 1.25°(lon) x 30 vert. layers

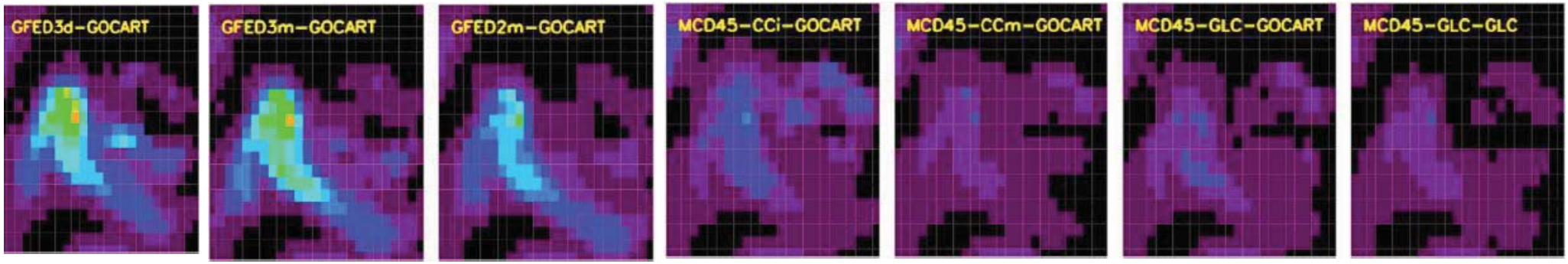
**Meteorological fields** GEOS DAS Version 4

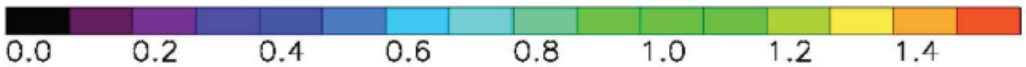
**Emissions** include: dust, sea salt, anthropogenic, sulfate & precursors, BB

**13 BB emission options** in separate model runs

**Study period**: June 2006-June 2007



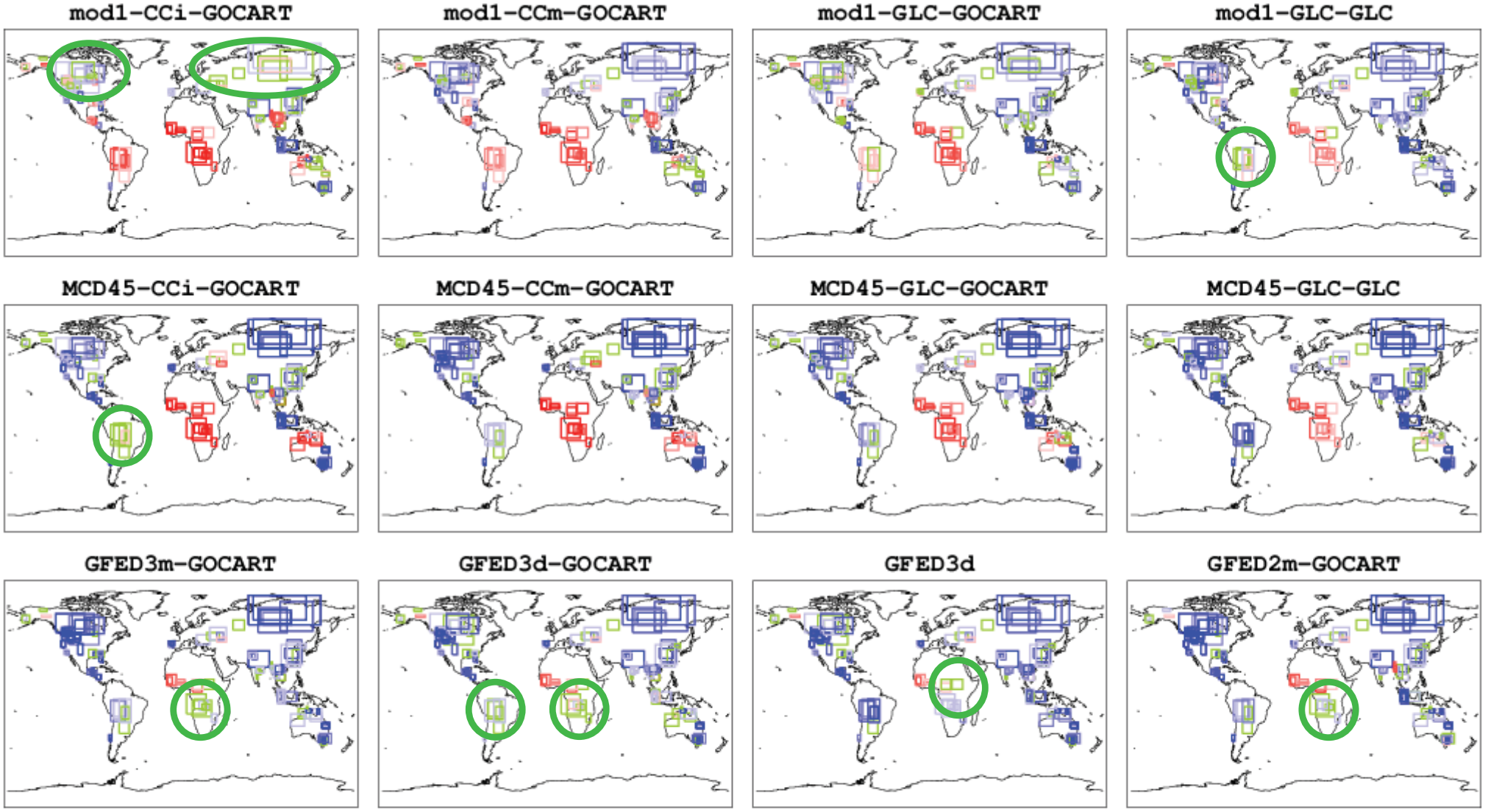




**AOD (550nm)**

*Petrenko et al., JGR, 2012*

# Ratio of GOCART to MODIS average AOD

## For each case, for 12 emission estimates



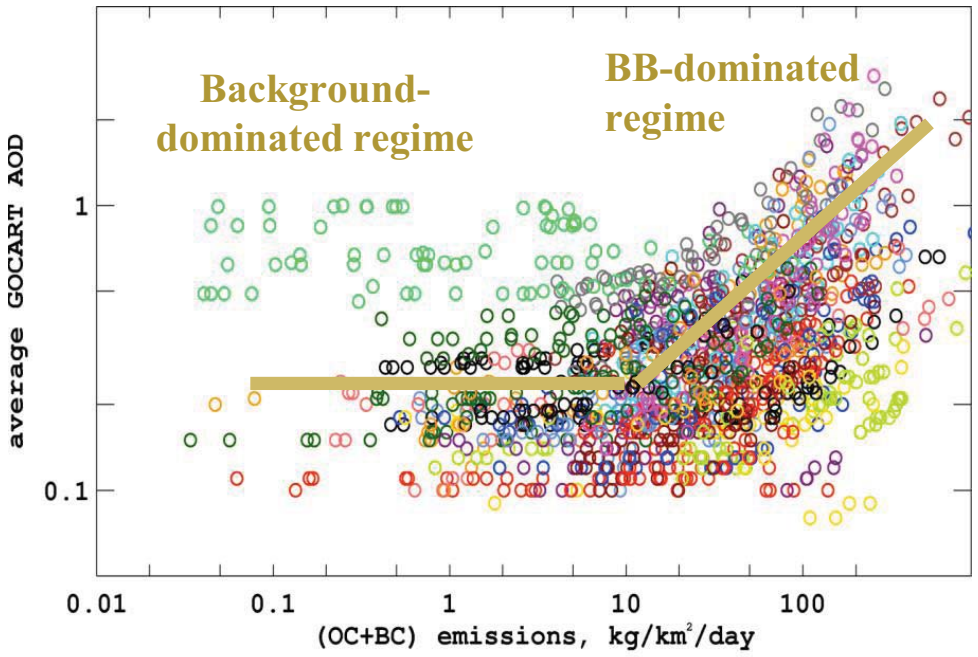

**Systematic regional patterns; some emissions work better in certain regions**

# *Quantitative* Relationship Between Smoke Emission and AOD

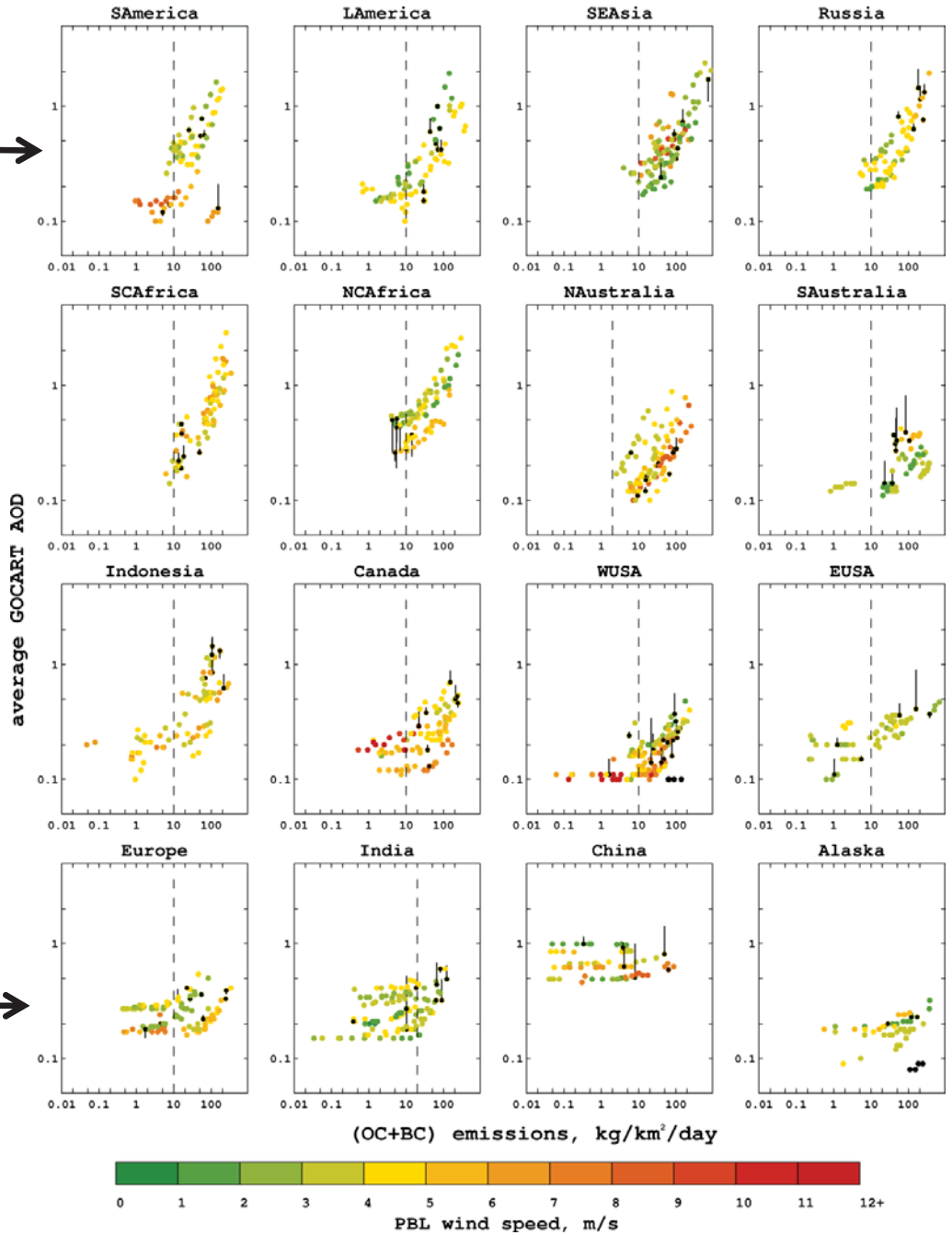
***Depends On***

- ***Wind Speed at source***
- ***Background AOD***

Steeper slope ~
Lower wind speed →



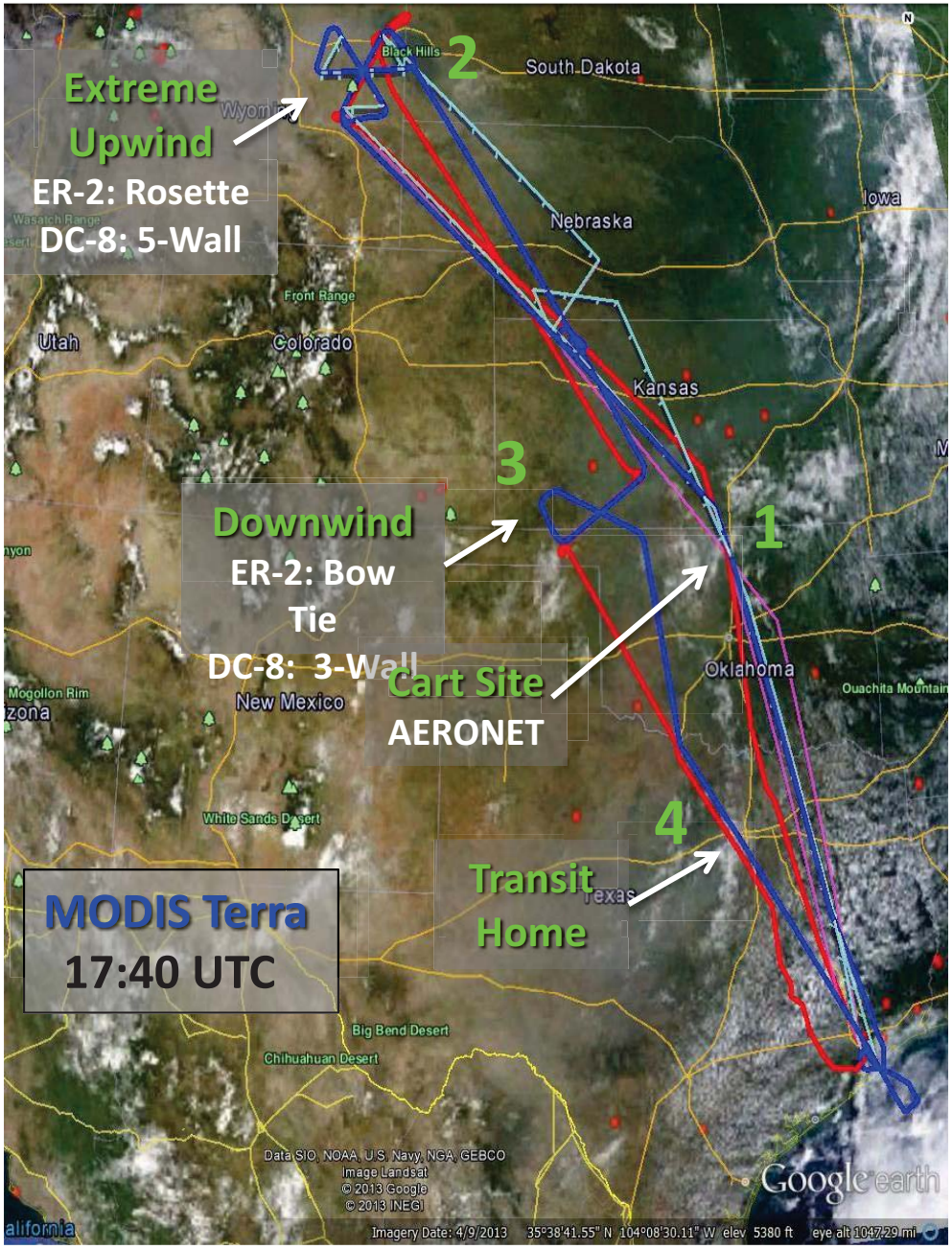

High background AOD ~
Smoke plume insignificant →

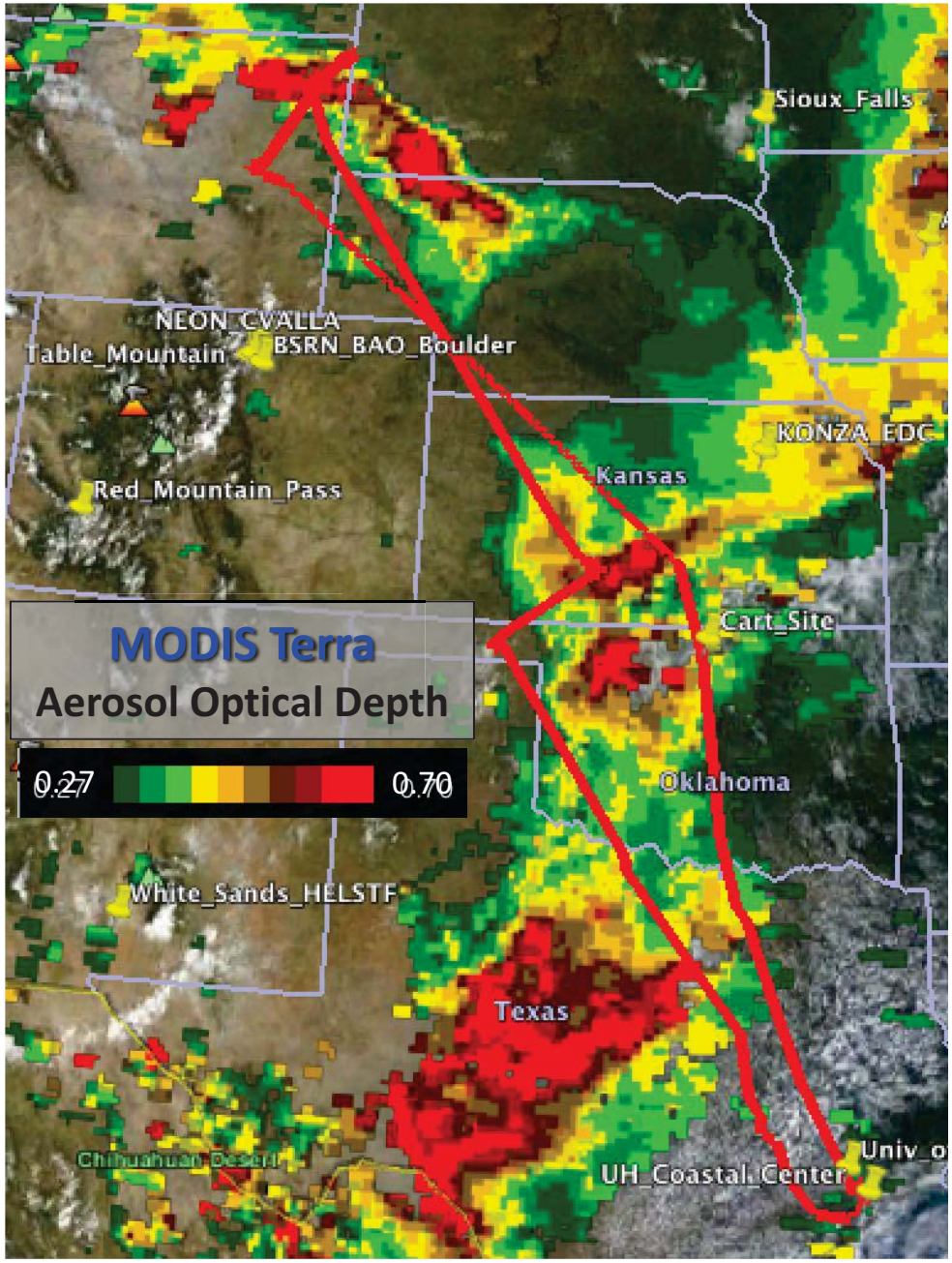



*Petrenko et al., JGR 2012*

# SEAC4RS Field Campaign

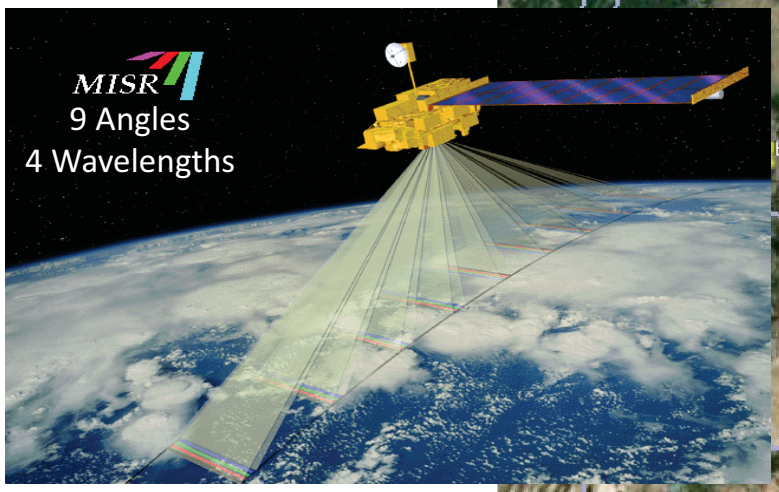
## DC-8 and ER-2 Flights Monday, 19 August 2013

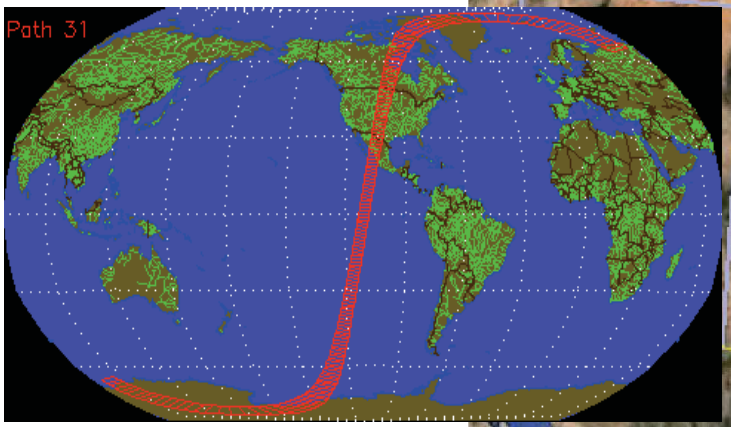


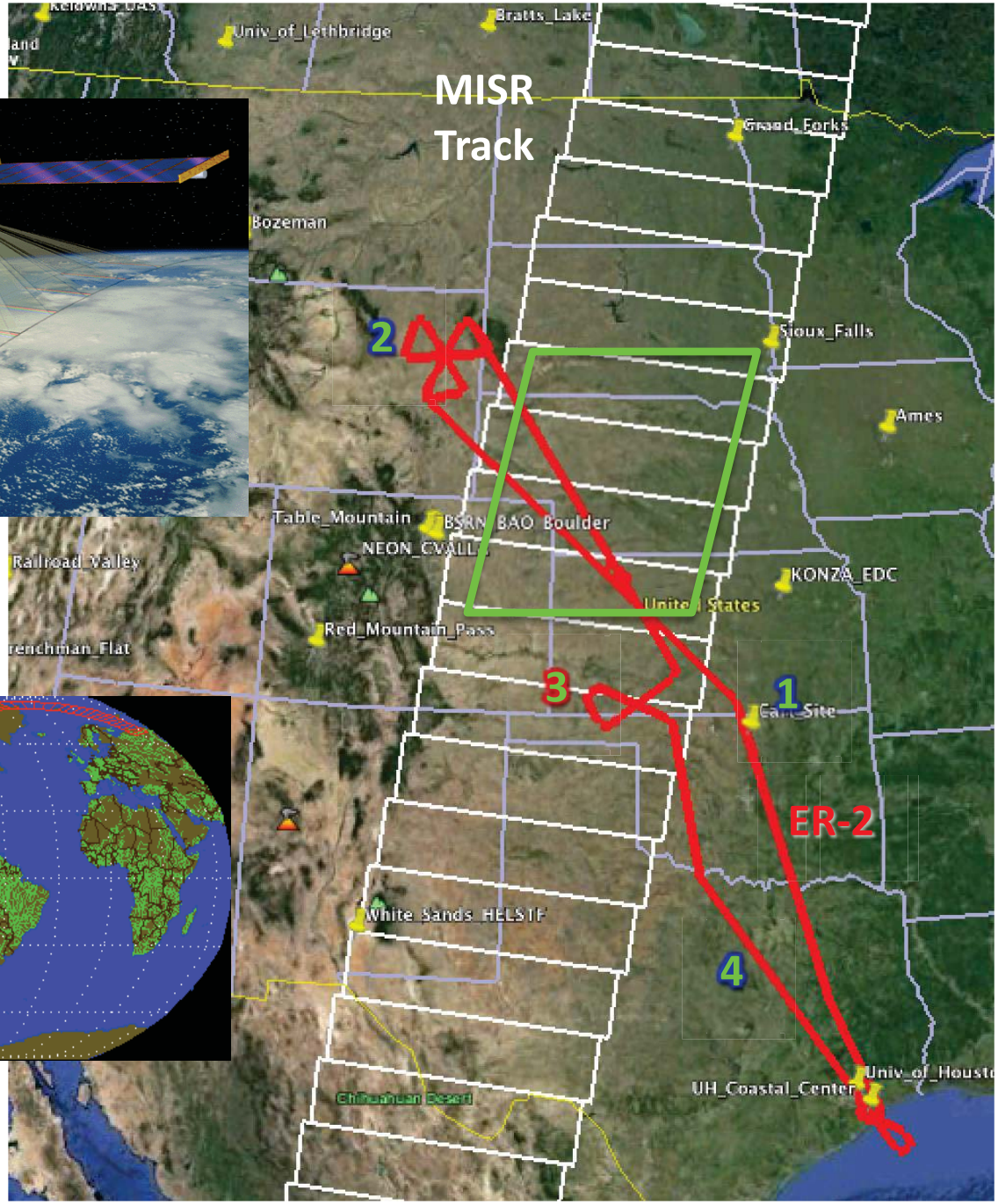



# MISR (Multi-angle Imaging SpectroRadiometer) Overpass

## Monday, 19 August 2013 17:40 UTC




**17:40 UTC**
Path 031
Orbit 72716

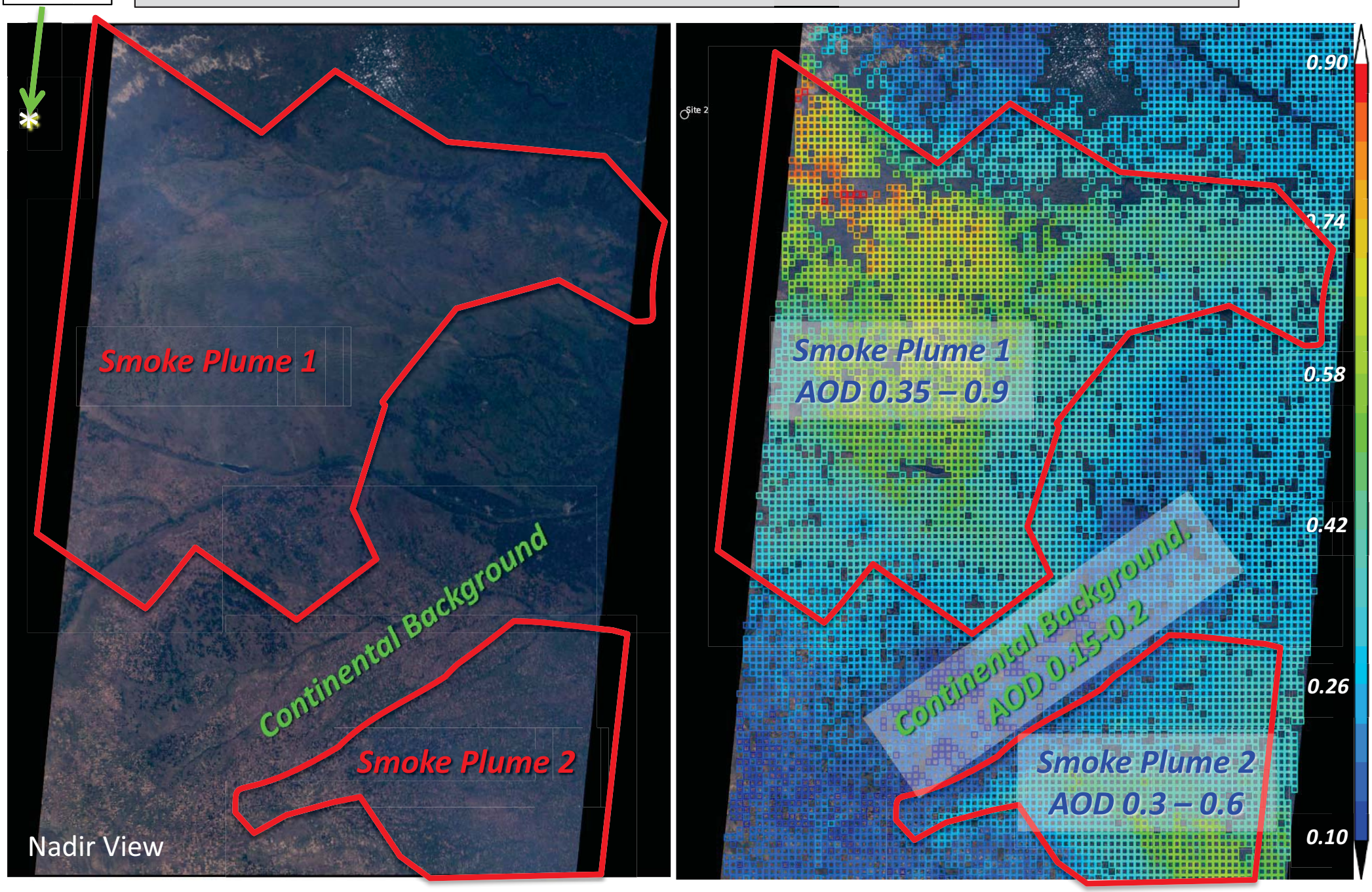
**South Dakota**

**Nebraska**

**Kansas**

# MISR Aerosol Optical Depth (Research Algorithm)

19 August 2013



# MISR Aerosol Type (Research Algorithm)

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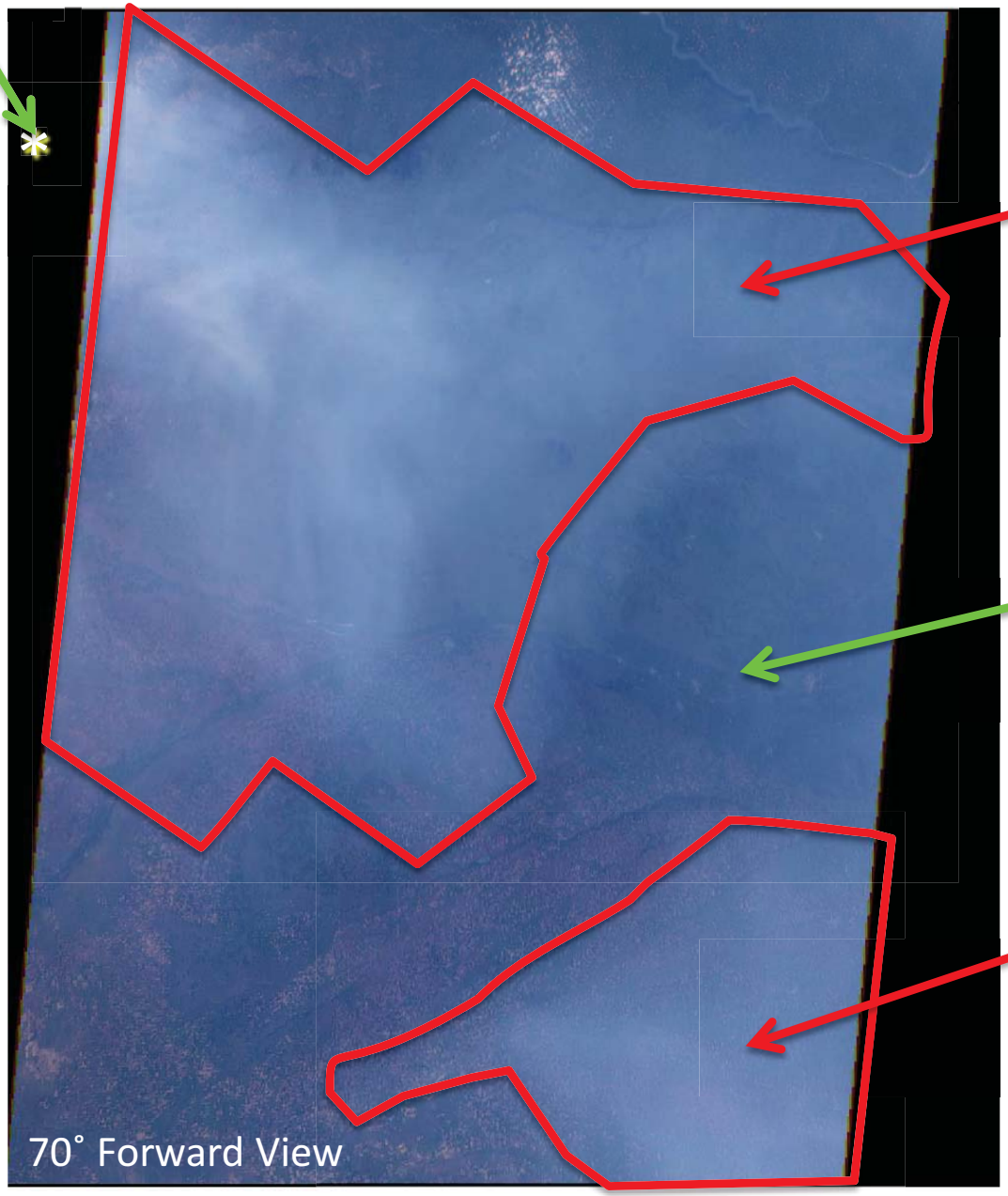
Site 2




**Smoke Plume 1**
**AOD 0.35-0.9**
*ANG 1.5-1.9 (**small**)*
*SSA 0.94-0.98 (**absorbing**)*
*FrNon-Sph 0-0.2 (**mostly spherical**)*

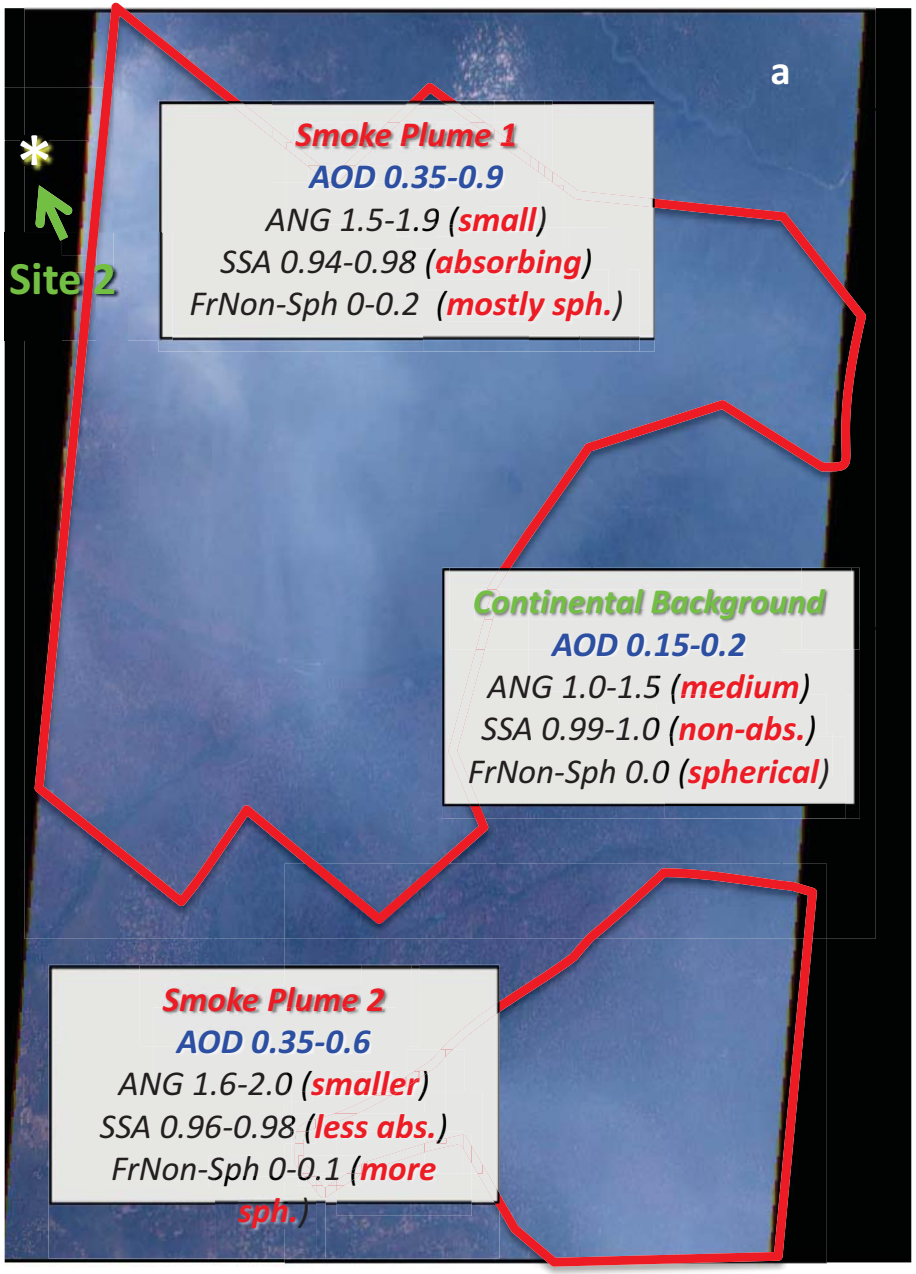
**Continental Background**
**AOD 0.15-0.2**
*ANG 1.0-1.5 (**medium**)*
*SSA 0.99-1.0 (**non-absorbing**)*
*FrNon-Sph 0.0 (**spherical**)*

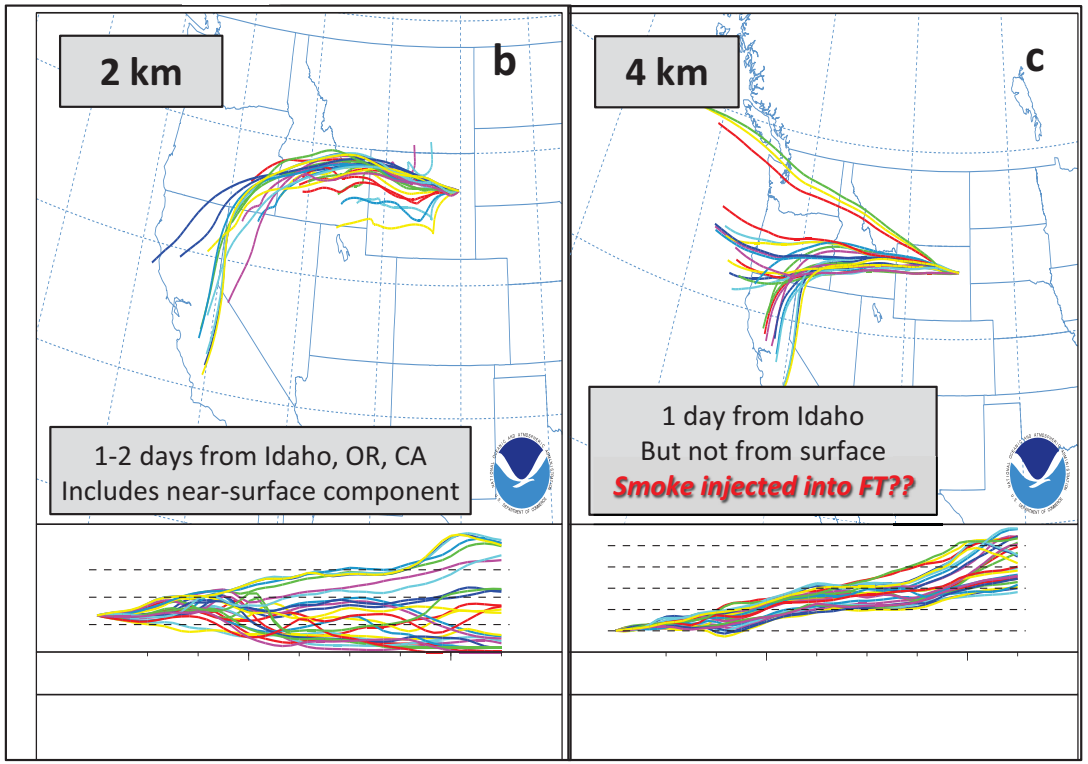
**Smoke Plume 2**
**AOD 0.35-0.6**
*ANG 1.6-2.0 (**smaller**)*
*SSA 0.96-0.98 (**less absorbing**)*
*FrNon-Sph 0-0.1 (**more spherical**)*

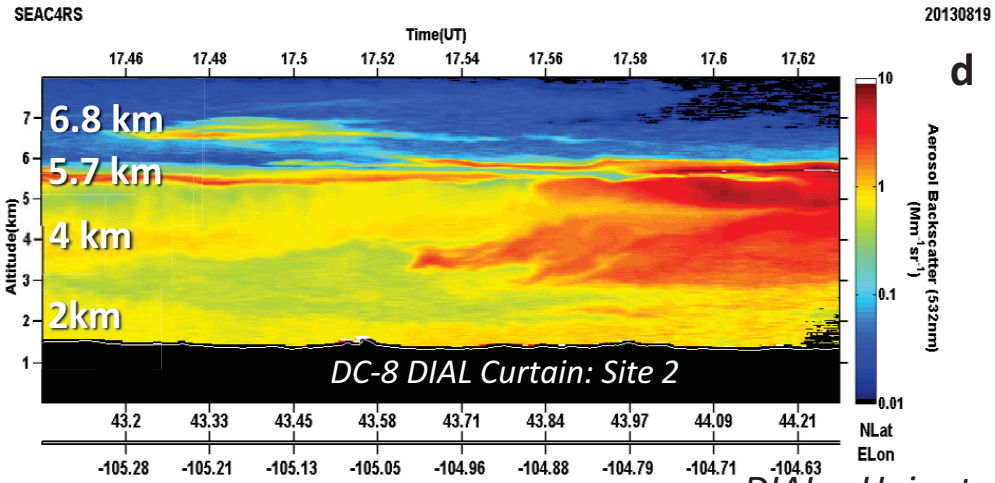
Passive-remote-sensing ***Aerosol Type*** is a ***Total-Column-Effective***, ***Categorical*** variable!!

# Site 2 Smoke Transports

**19 August 2013**



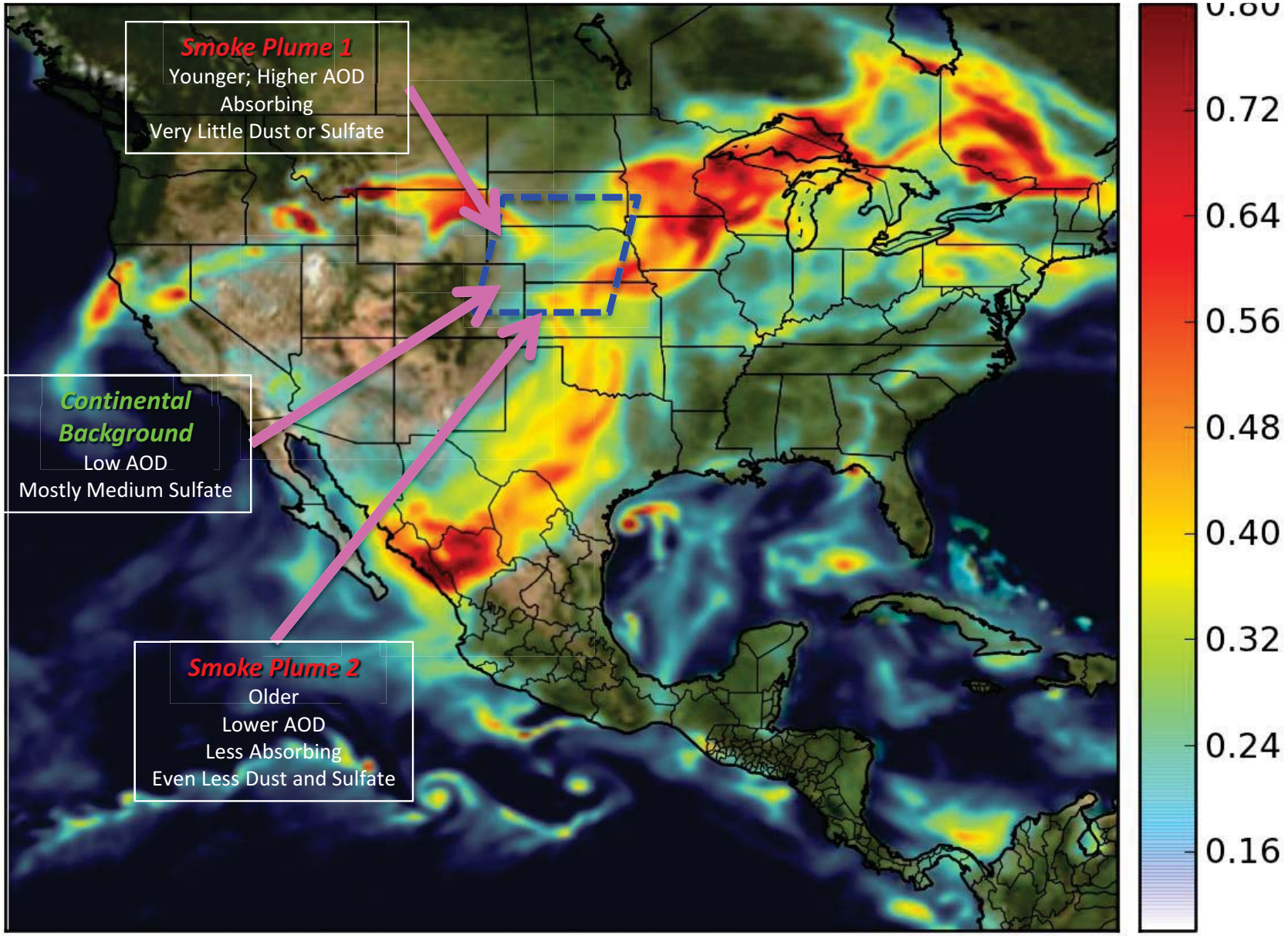




*DIAL – Hair et al.*

# GEOS-5 MODEL Aerosol Optical Depth

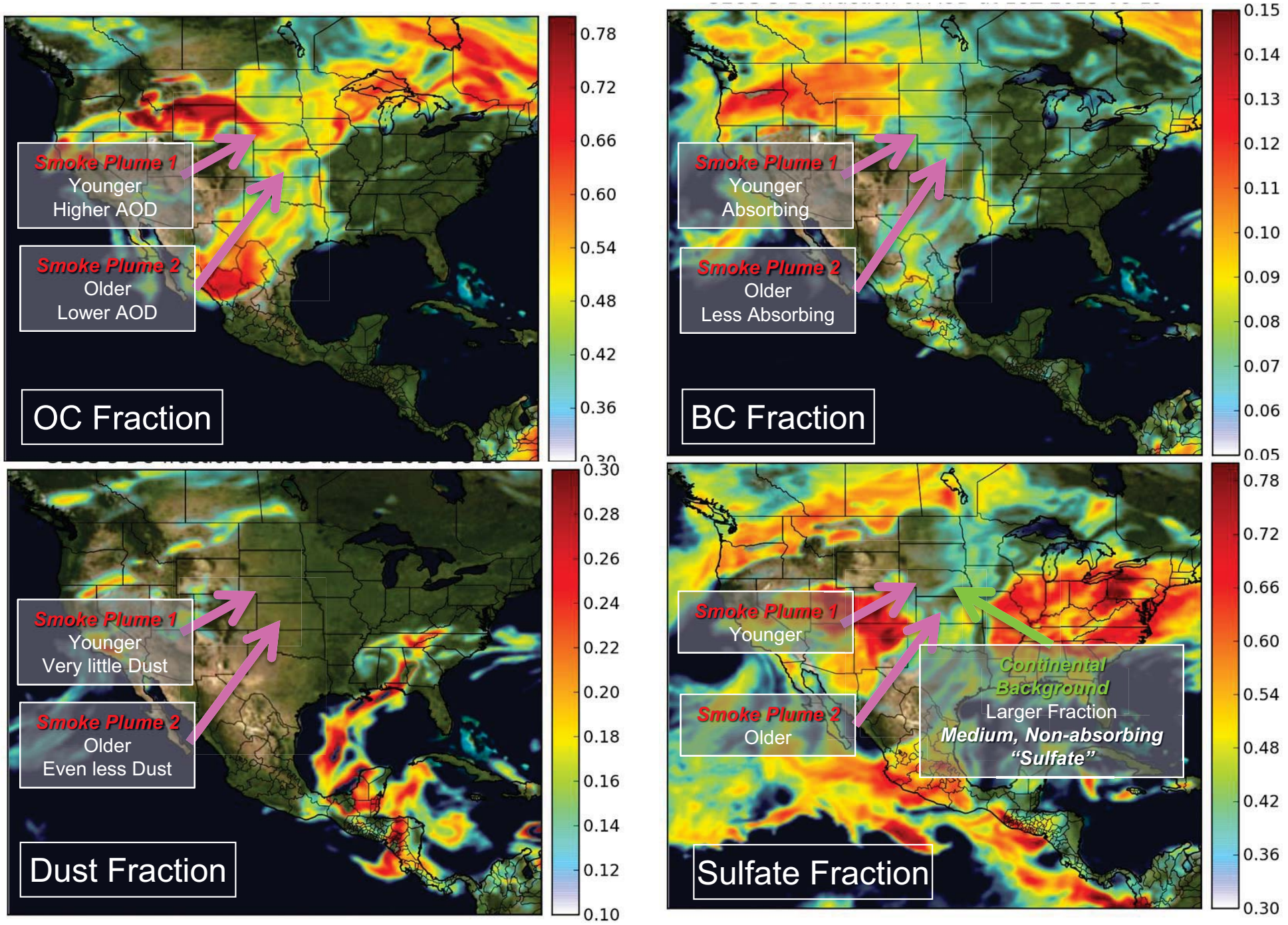
**19 August 2013 18 UTC**



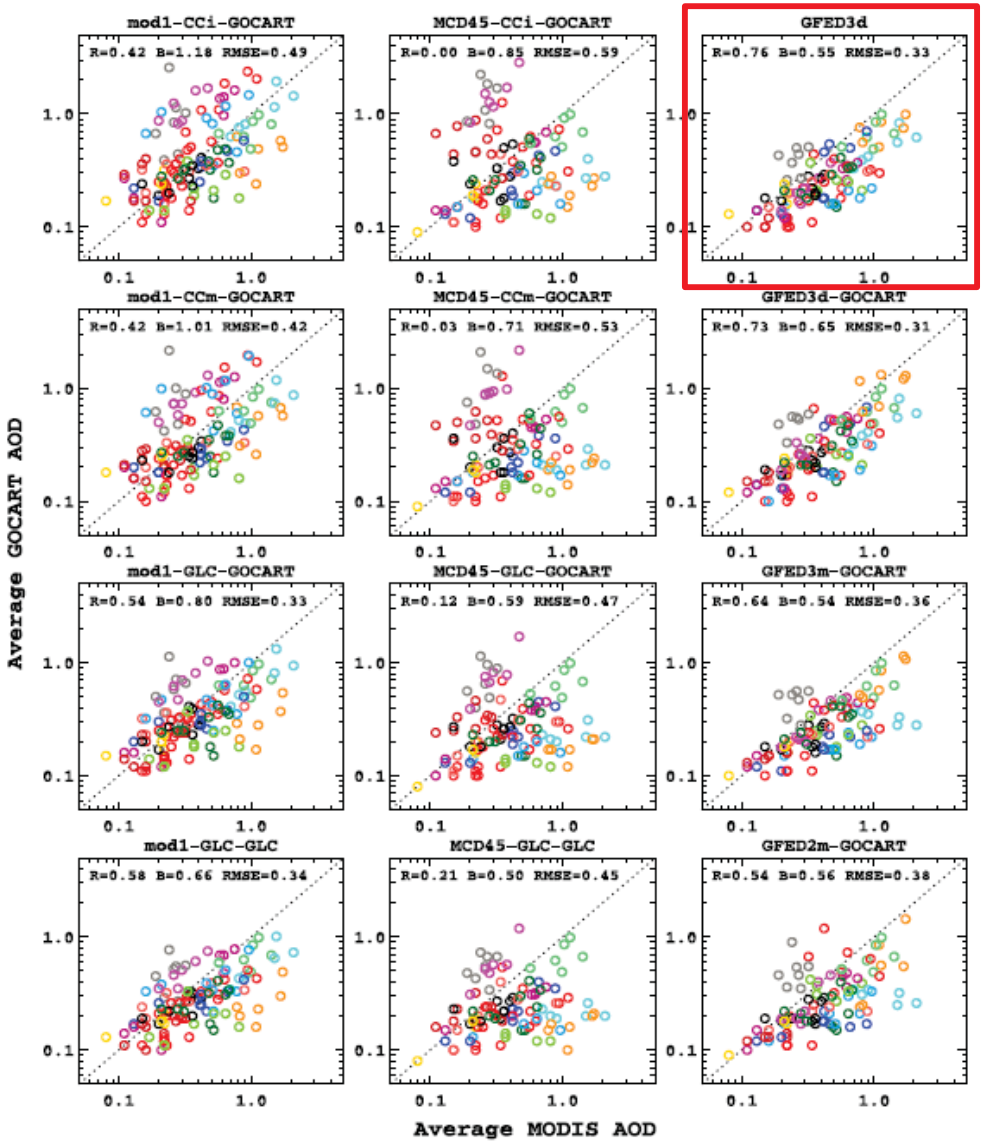

*GEOS-5 Team – DaSilva & Randles*

# GEOS-5 MODEL Aerosol Type

19 August 2013 18 UTC



# AeroCom BB Experiment AOD – *Motivation*




- We have a substantial set of ***satellite wildfire plume AOD snapshots and injection heights*** to help calibrate model/inventory performance
- We are: (1) adding ***more fire source-strength cases***, (2) using MISR to ***improve the AOD constraints*** and (3) adding ***2008 global injection heights***
- We selected ***GFED3-daily*** due to good overall source strength performance, but ***any inventory can be tested***
- Joint effort, to ***test multiple, global models*** to draw robust BB injection height & emission strength conclusions

***We provide: Satellite-based injection height and smoke plume AOD climatologies***

# Experiment Design

| | Exp. | BB Daily emission | Injection height |
|---|---|---|---|
| | BB0 | ***No BB emission*** | |
| Control → | **BB1** | **GFED v3** | Boundary layer |
| | BB2 | **GFED v3 x 0.5** | Boundary layer |
| | BB3 | **GFED v3 x 2** | Boundary layer |
| | BB4 | **GFED v3 x 5** | Boundary layer |
| Stage 2 → | BB5 | **GFED v3** | From MISR plume ht. |
| | BB6 | **GFED v3 x 5** | From MISR plume ht. |

***Requested output:***

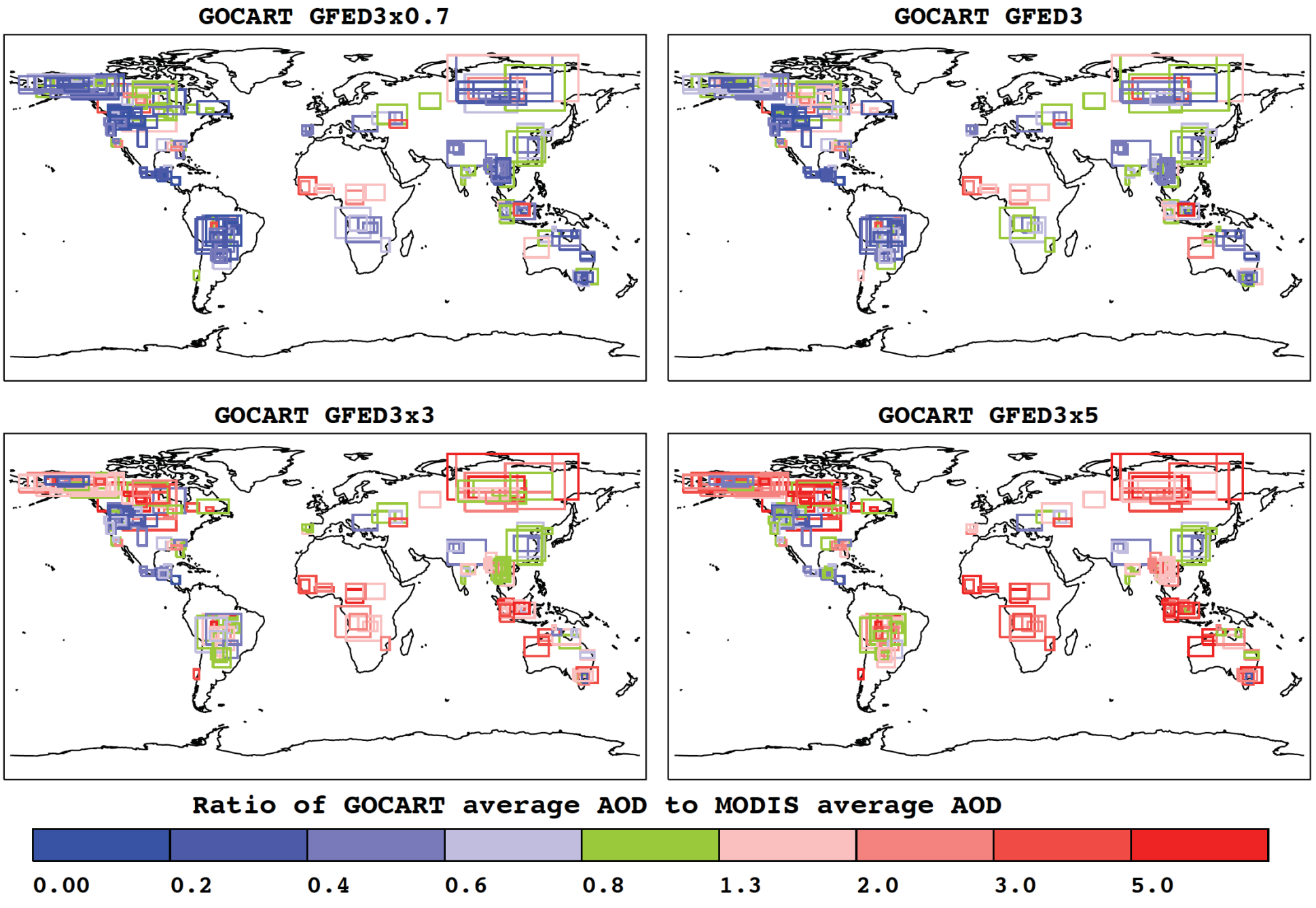
***2-D, 3-hourly, instantaneous***

- Total column ***550 nm AOD***
- ***Biomass burning AOD***, if available (or AOD's of individual aerosol species)
- ***Wind speeds*** in the middle of emission injection height
  [e.g., if all smoke is distributed within PBL, output mid-PBL winds]
- **PBL height**

***3-D [3-hourly]***

- Aerosol ***species concentrations***
- Aerosol 550 nm ***extinction***

# With *Source Strength* Perturbation Factors: 0.7, 1, 3 & 5




*Petrenko et al., 2014, in preparation*

## Satellites

frequent, global *snapshots*; aerosol amount & aerosol type maps, plume & layer heights

## Remote-sensing Analysis

- Retrieval Validation
- Assumption Refinement

## Suborbital

targeted chemical & microphysical detail

point-location time series

## Regional Context

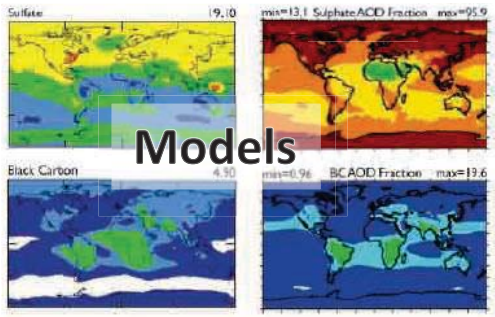
## Aerosol-type Predictions

## CURRENT STATE

- Initial Conditions
- Assimilation

## Model Validation

- Parameterizations
- Climate Sensitivity
- Underlying mechanisms




## Models

space-time interpolation,

## DARF & Anthropogenic Component

calculation and prediction

*Kahn, Survy. Geophys. 2012*