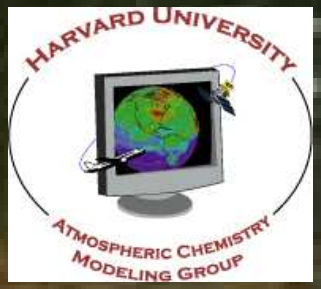
Fire smoke plume heights in North America: model validation using MISR and MODIS satellite observations

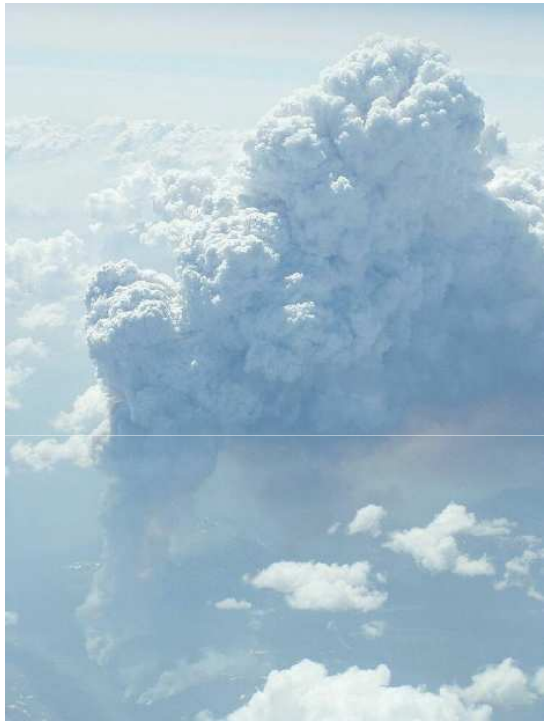
Maria Val Martin

J. Logan, R. Kahn, C. Ichoku and S. Freitas



Research funded by NSF and EPA

A little bit of history on plume heights….



Pyro-cumulonimbus observed at 10 km from a commercial airplane in Alaska, 27 June 2004 (Damoah et al, 2006)

1990: ABLE 3B. Identification of fire plumes from Alaskan and Siberian fires, 2-7 km (Wofsy et al., 1992)

Late 1990s: Boreal fire plumes transported over the southern U.S. seen during the Southern Oxidants Study (Wotawa and Trainer, 2000)

Late 1990s-2000s: Pyro-convective events transport aerosols to the stratosphere, seen in SAGE, POAM data (Fromm et al., 2004, 2005, Damoah et al, 2006).

2004-2007: Many studies of long-range transport from the 2004 fires in Alaska/Yukon (ICARTT)

2008-present: Studies of long-range transport from the 2008 boreal fires to the Arctic (ARCTAS)

…. and injection height modeling

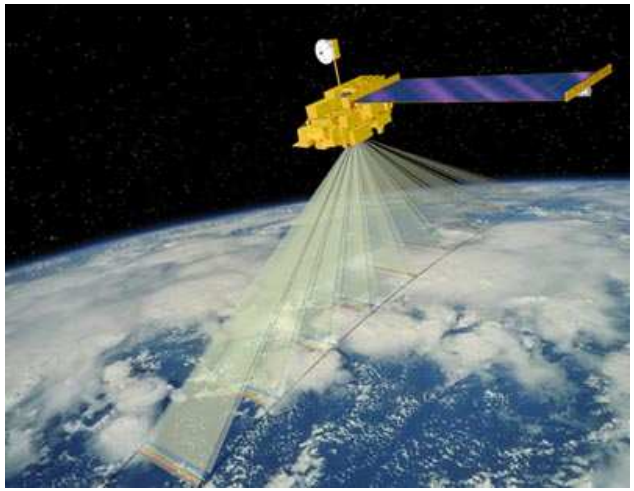
Until ~2005, most models released biomass burning emissions in the lowest model layer, or in the boundary layer.

For severe boreal fires, ~50% of emissions need to be released above the BL to match observations (e.g. Leung et al, 2008, Generoso et al., 2007, Hyer et al., 2007, Turquety et al., 2007)

Recently, satellite observations of plume heights (Chen et al., 2009) and subgrid plume-rise model schemes (Freitas et al., 2007; Guan et al., 2008, Rio et al., 2010) have been considered.

Many models use injection heights based on almost no data!

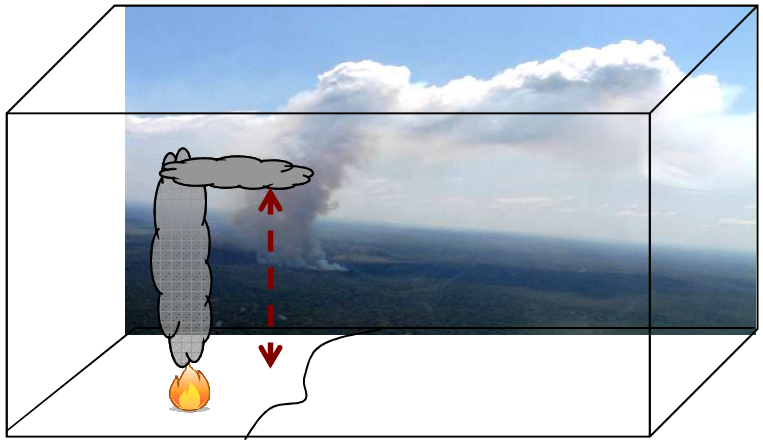
Objectives of this study



I. **To have a better understanding of injection heights over North America**

Analysis of MISR and MODIS data

Val Martin et al., ACP 2010



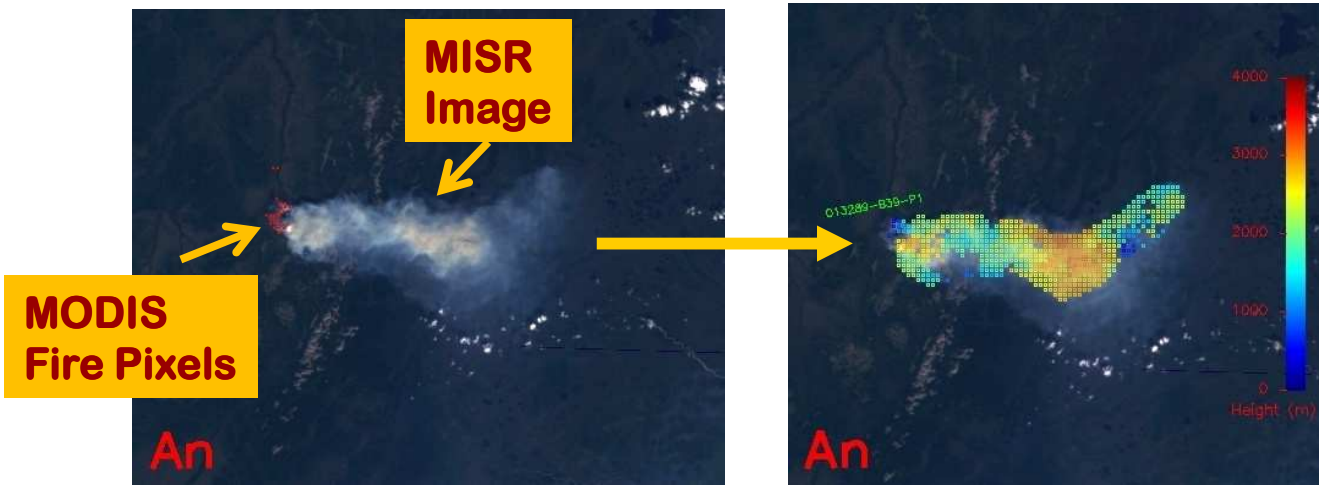
II. **To develop a parameterization of the injection heights of North American wildfire emissions**

Evaluation of a 1-D plume-rise model, using MISR plume data as a constraint

Val Martin et al., in prep. ACPD

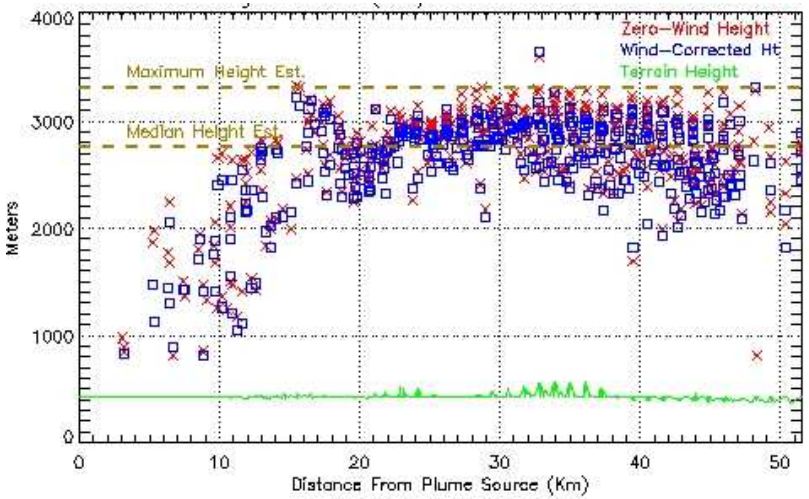
MISR Plumes: Overview of the MINX Tool (MINX = MIsr Interactive eXplorer)

Smoke plume over central Alaska in June 2002

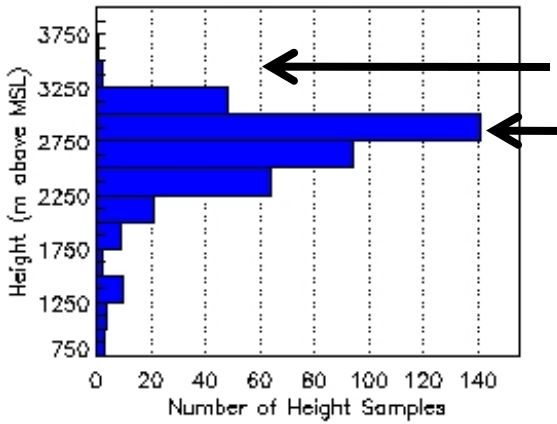


From MODIS:
Fire Radiative Power = 2500 MW;
Area = 50 ha

Cross-section of heights vs. distance from plume source (0-50 km)



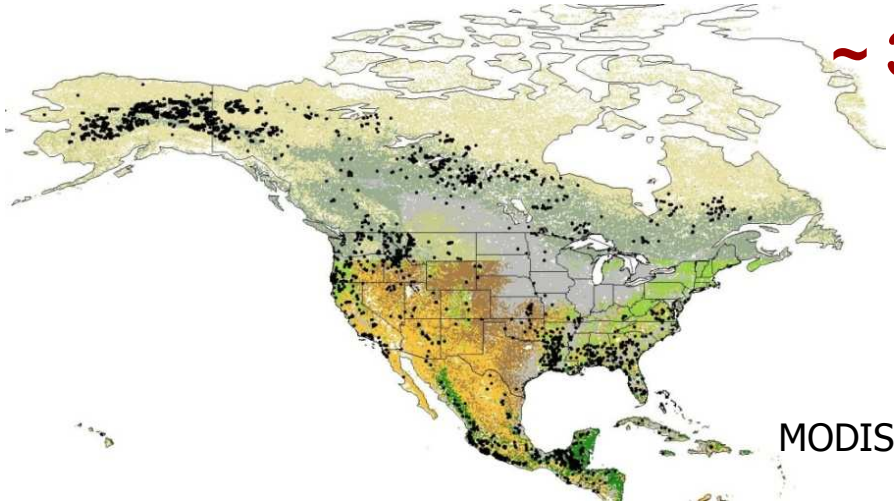
Histogram of heights



Max Height

Median Height

North America Plume Climatology

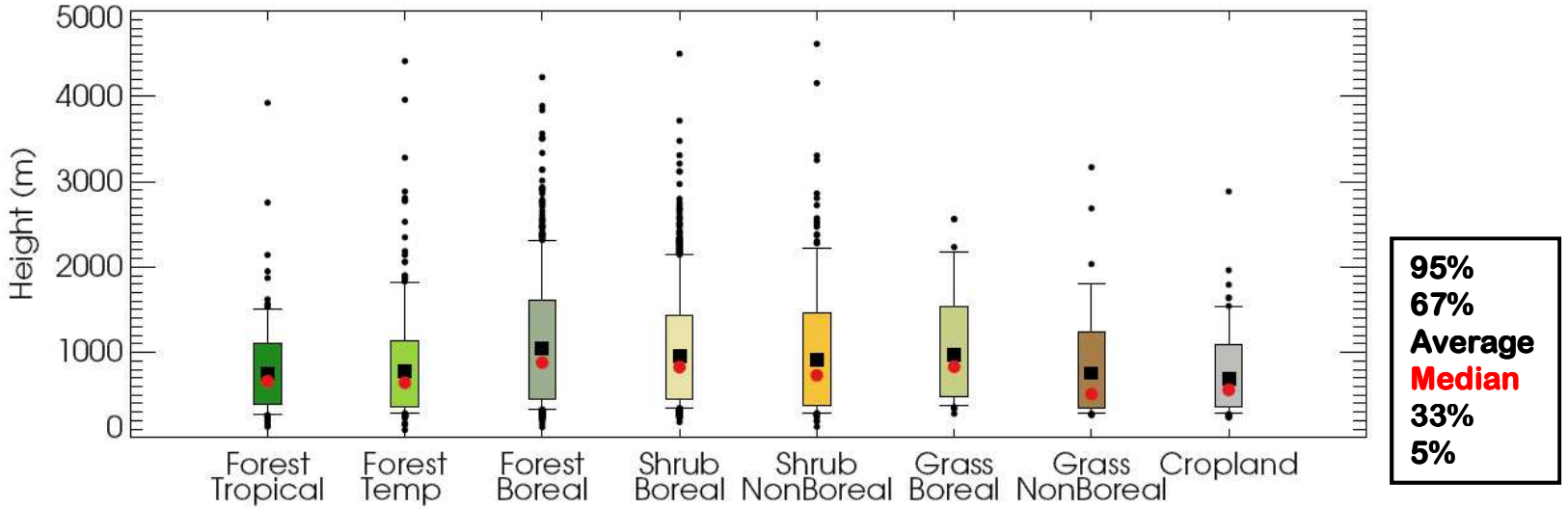


MODIS IGBP land cover map
(1x1 Km res)

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

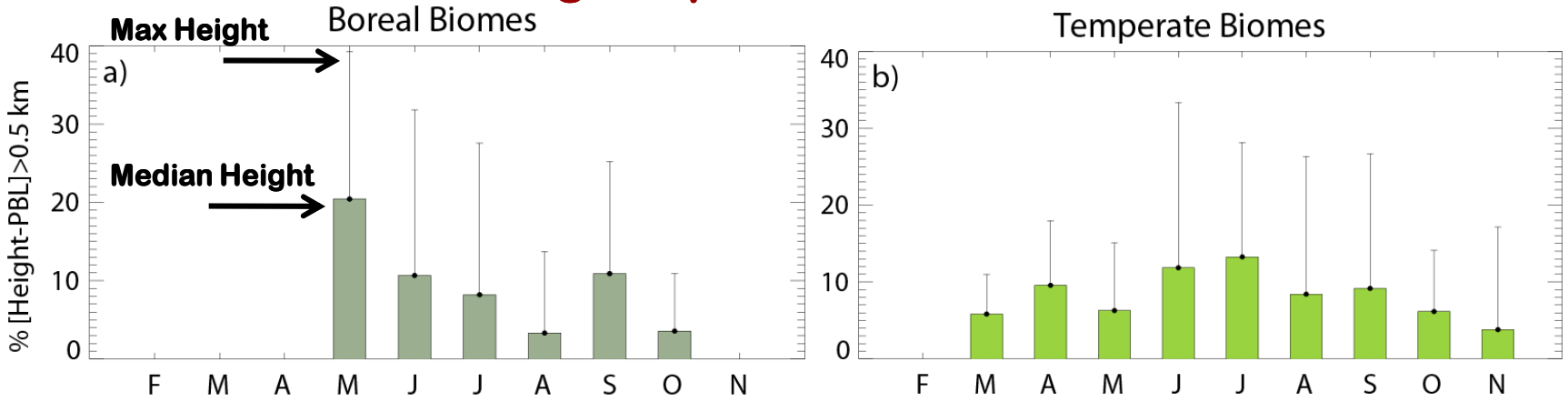
- Tropical Forest
- Temperate Forest
- Boreal Forest
- Boreal Shrubland
- Non-Boreal Shrubland
- Boreal Grassland
- Non-Boreal Grassland
- Cropland

MISR Plume Median Heights

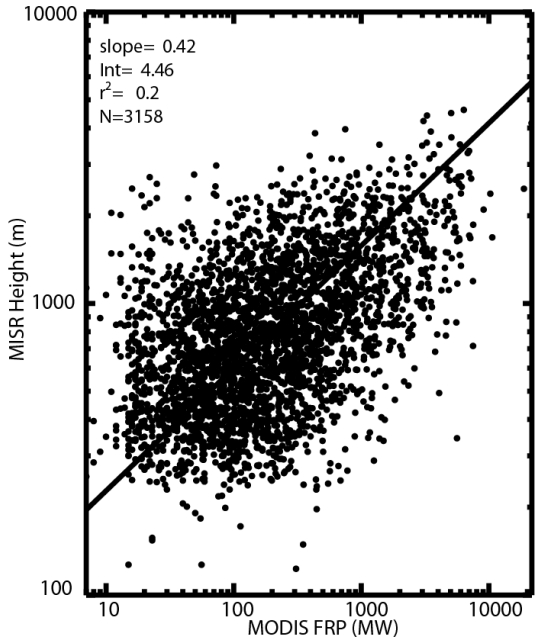


Plume heights depend on atmospheric stability and fire intensity

Percentage of plumes above the BL



MISR height versus MODIS FRP

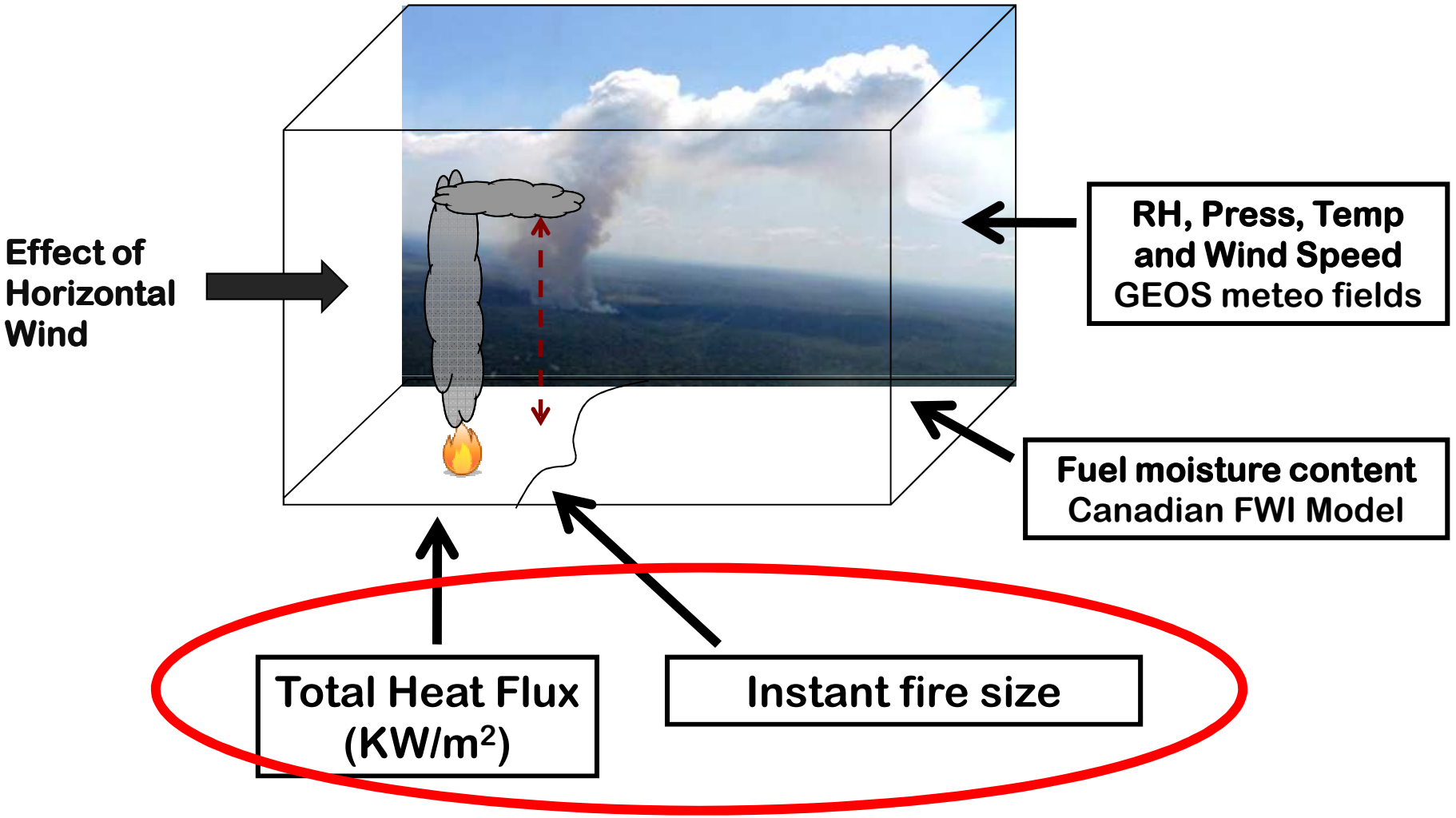


- 10-20% plumes in FT at the fire season peak
- Plumes above the BL tend to get trapped in stable layers
- Plumes without stable layers get more dispersed in the FT

- There is a connection between height and fire intensity

Val Martin et al., ACP 2010

Fire smoke heights with a 1-D plume-rise model



Model description in Freitas et al., 2006, 2007, 2009

Testing different fire characteristics approaches

Instant fire size

MODIS pixel

1 pixel=0.625 km^2

(FLAMBE, Reid et al,2009)

MODIS FRP-scaled pixel

Max FRP = 1 km^2

(Charles Ichoku personal communication)

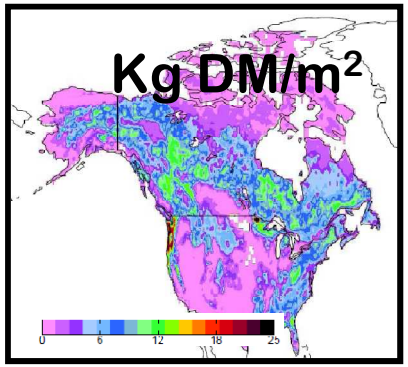
Total Heat Flux

Total MODIS FRP x 10 (Wooster et al., 2005; Freeborn et al.,2008)

Reported total heat fluxes (Freitas et al, 2006)

Biome type	Lower Limit, kW m^{-2}	Upper Limit, kW m^{-2}
Tropical forest	30.	80.
Woody savanna - cerrado	4.4	23.
Grassland - pasture - cropland	3.3	

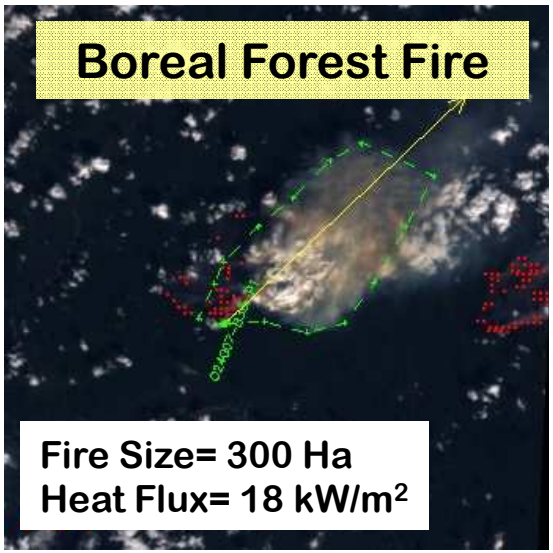
Fuel combustion

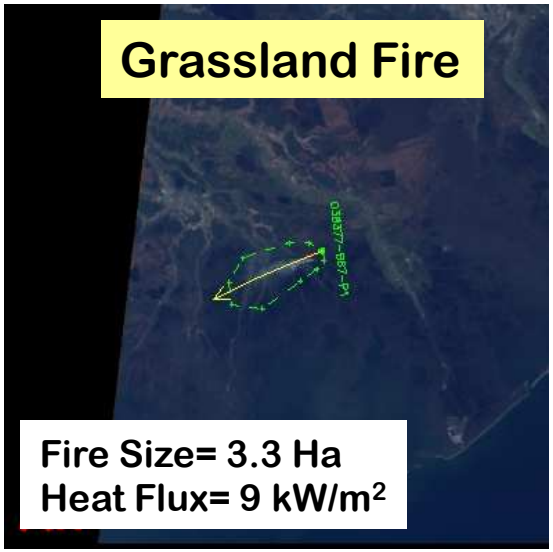


→ **KW/m²**

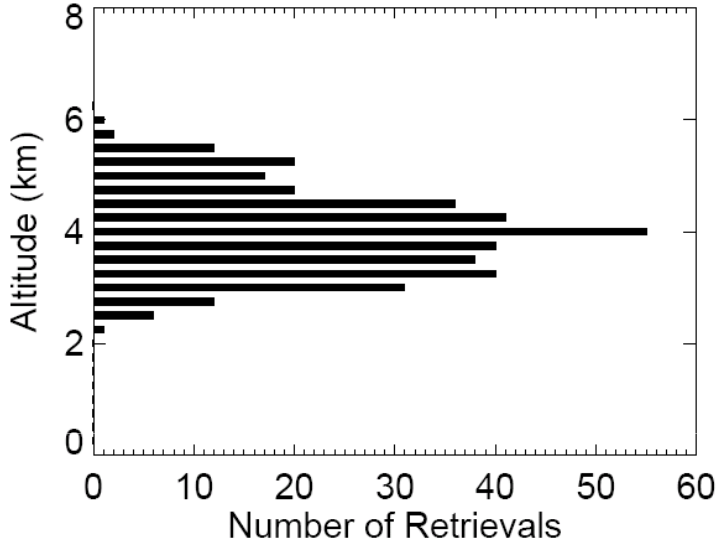
Example of smoke plume simulations: Boreal and grassland fires

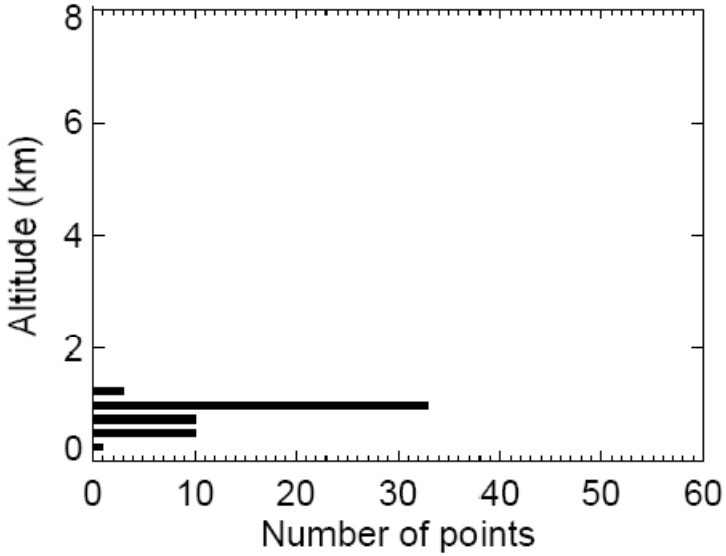
MISR Smoke Plume



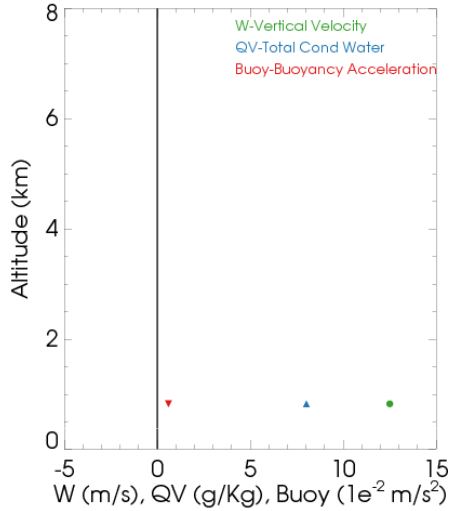


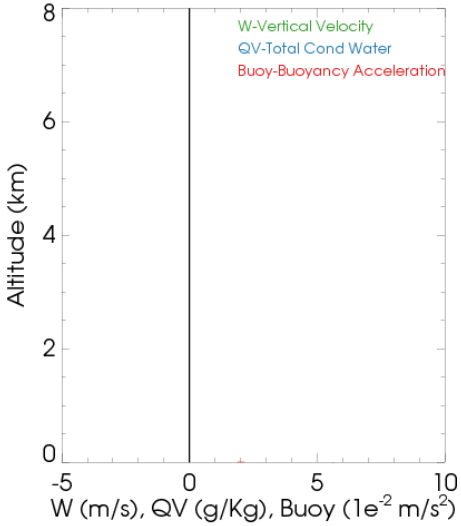
MISR Retrieved Heights





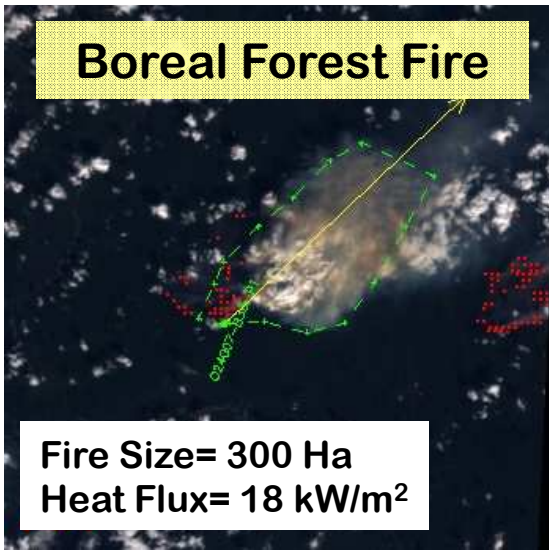
1D Plume-rise Model

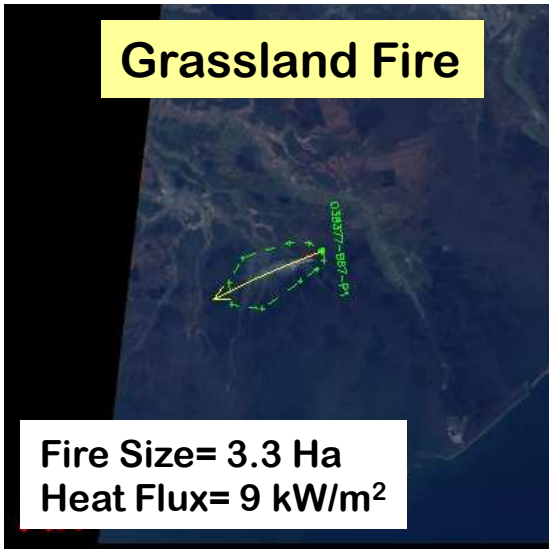




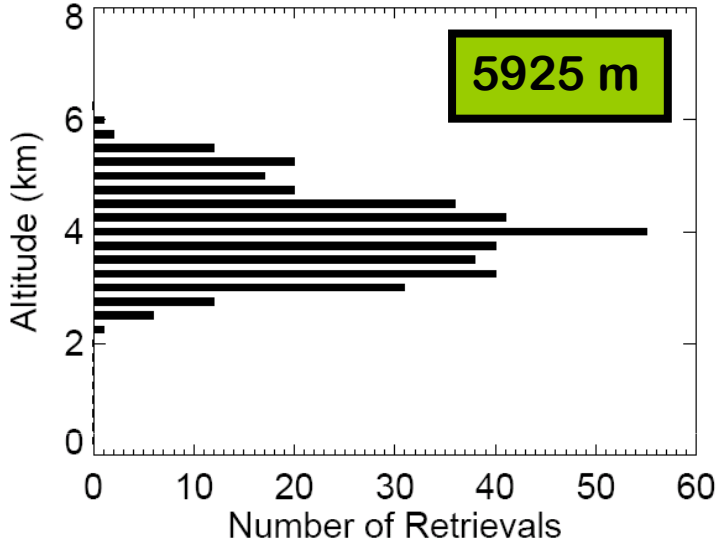
Example of smoke plume simulations: Boreal and grassland fires

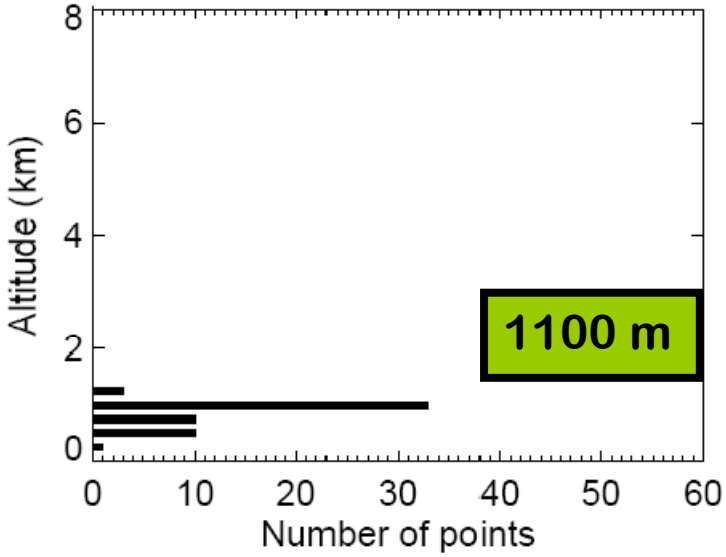
MISR Smoke Plume



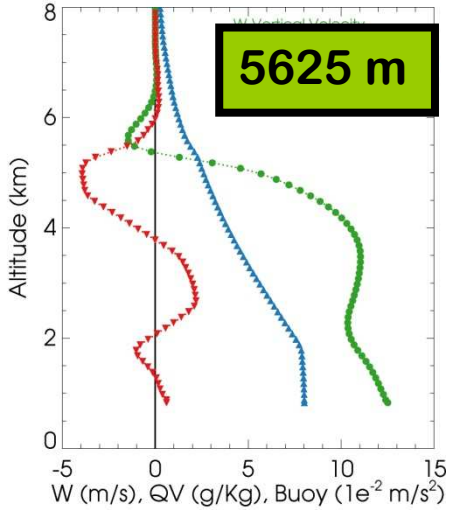


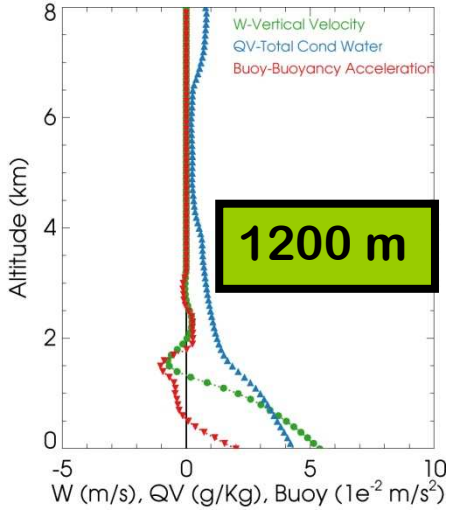
MISR Retrieved Heights





1D Plume-rise Model

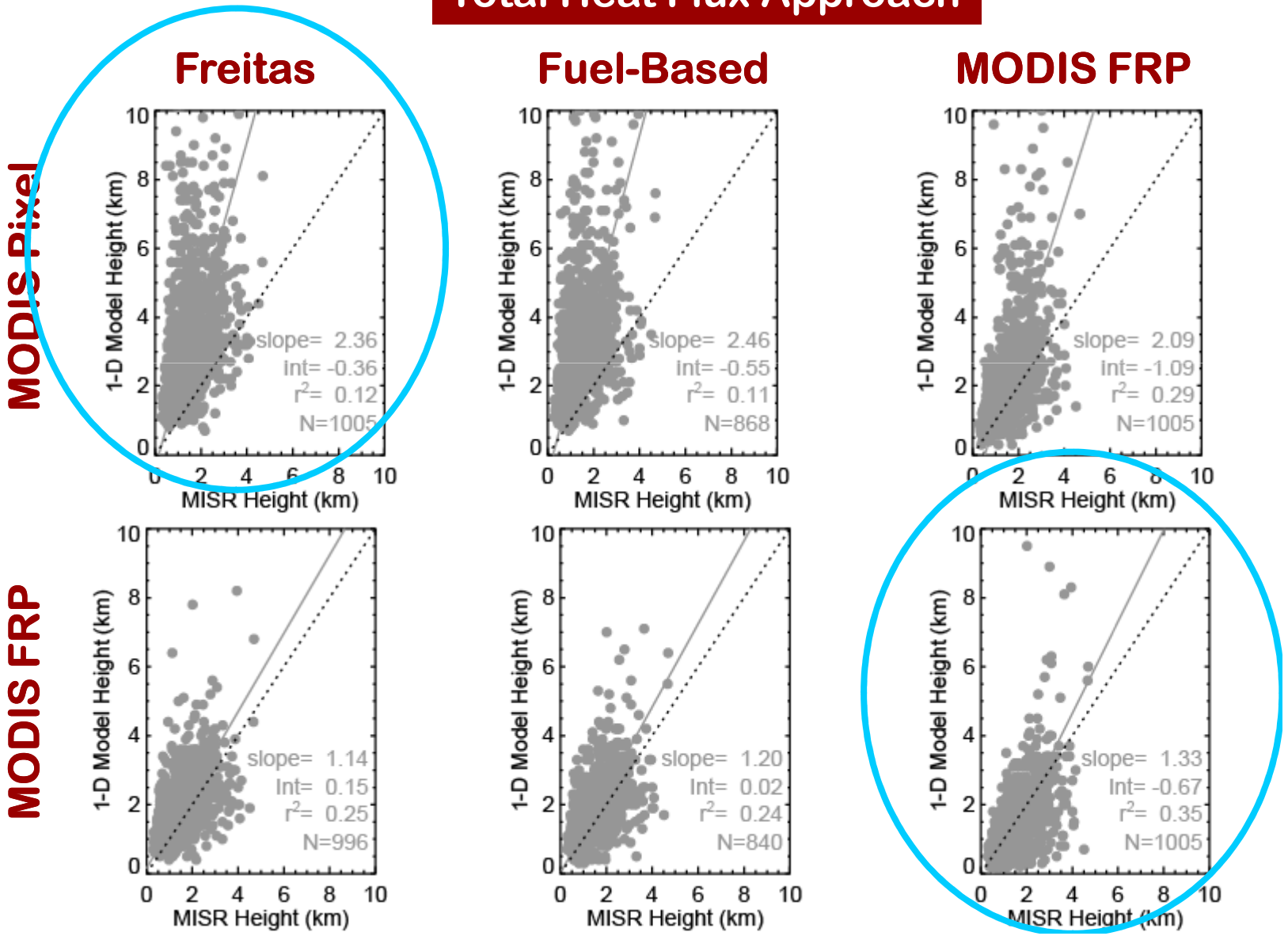




Evaluation of the 1-D plume-rise model

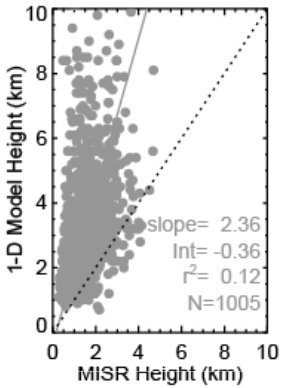
Total Heat Flux Approach

Instant Fire Size Approach

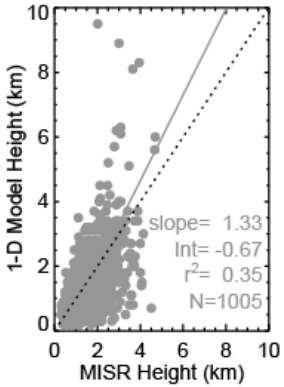


Evaluation of the 1-D plume-rise model

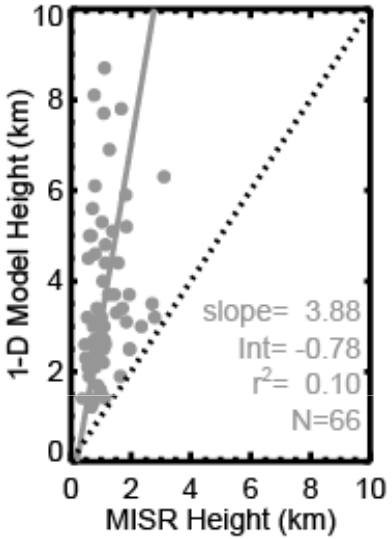
MODIS Pixel+Freitas

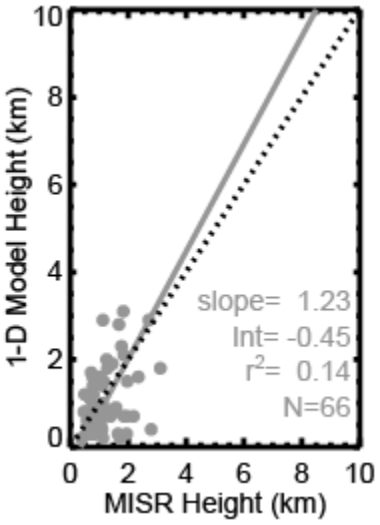


MODIS FRP+FRP

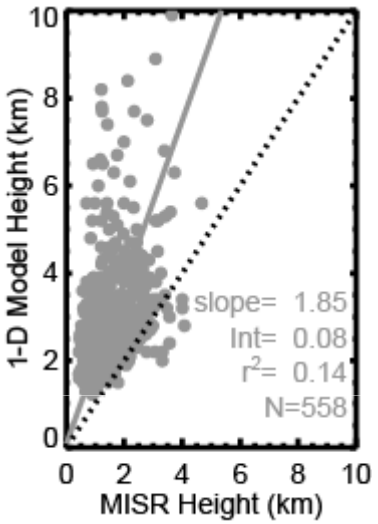


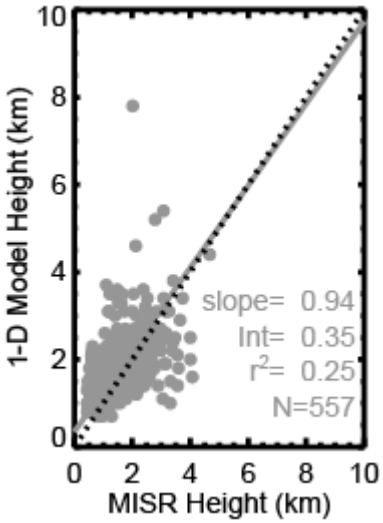
Temperate Forest



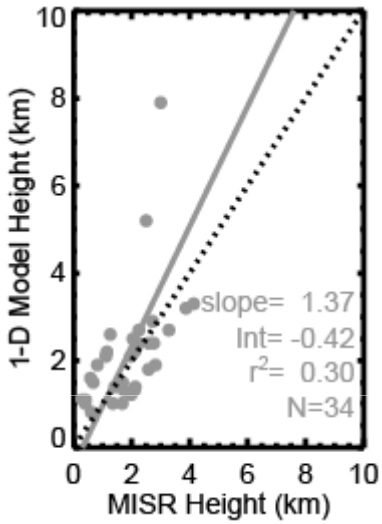


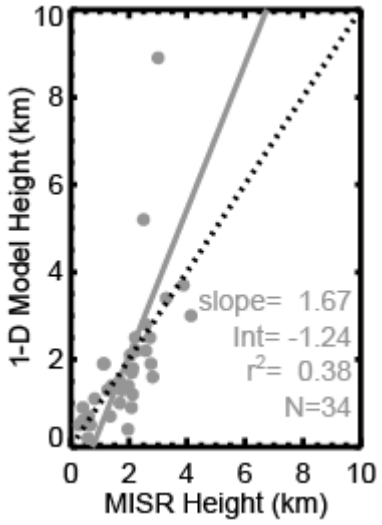
Boreal Shrubland





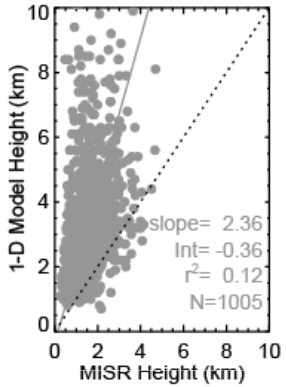
Grassland



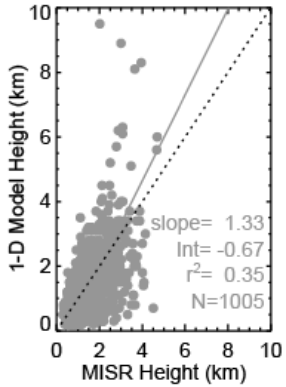


Evaluation of the 1-D plume-rise model

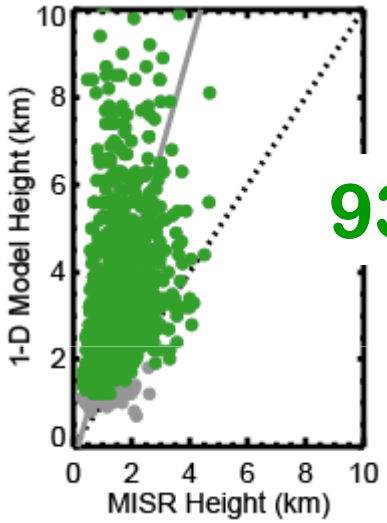
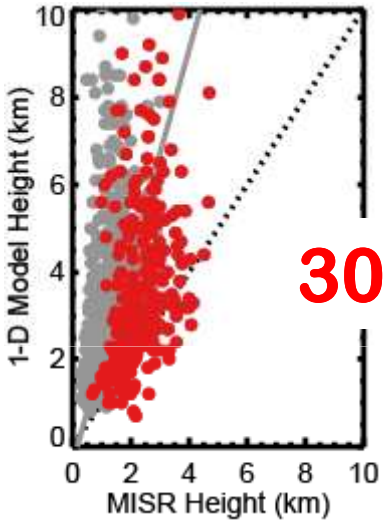
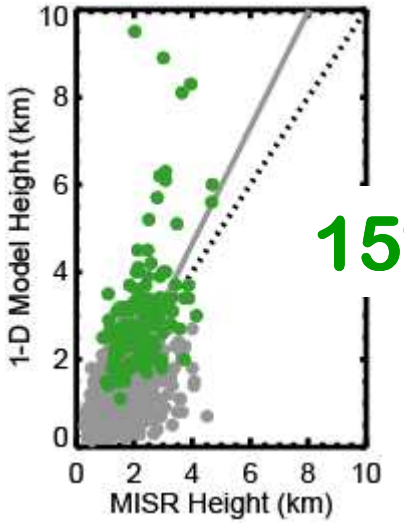
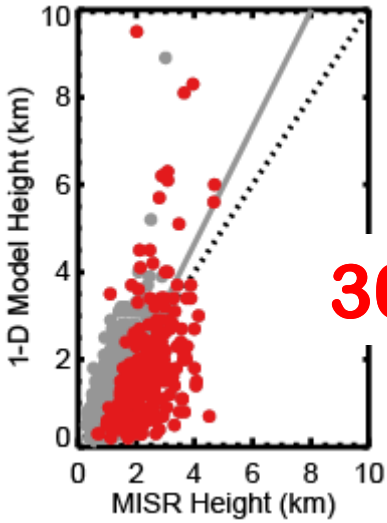
MODIS Pixel+Freitas



MODIS FRP+FRP



Plumes located in FT

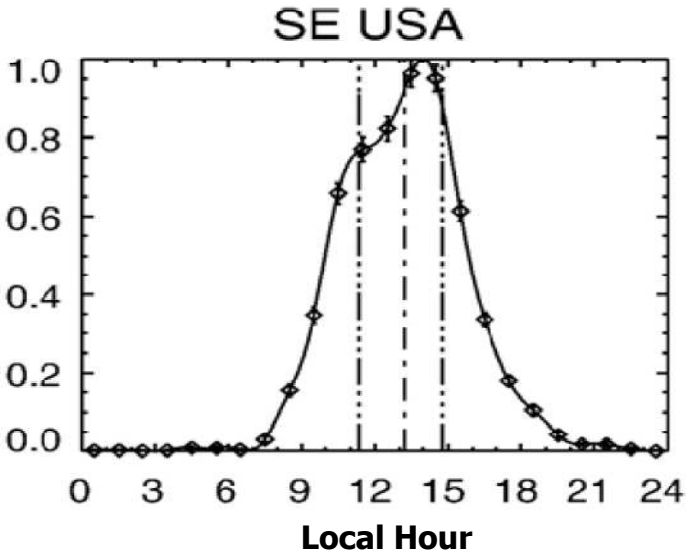
MODEL	MISR
 93%	 30%
 15%	 30%

Issues to consider when modeling injection heights

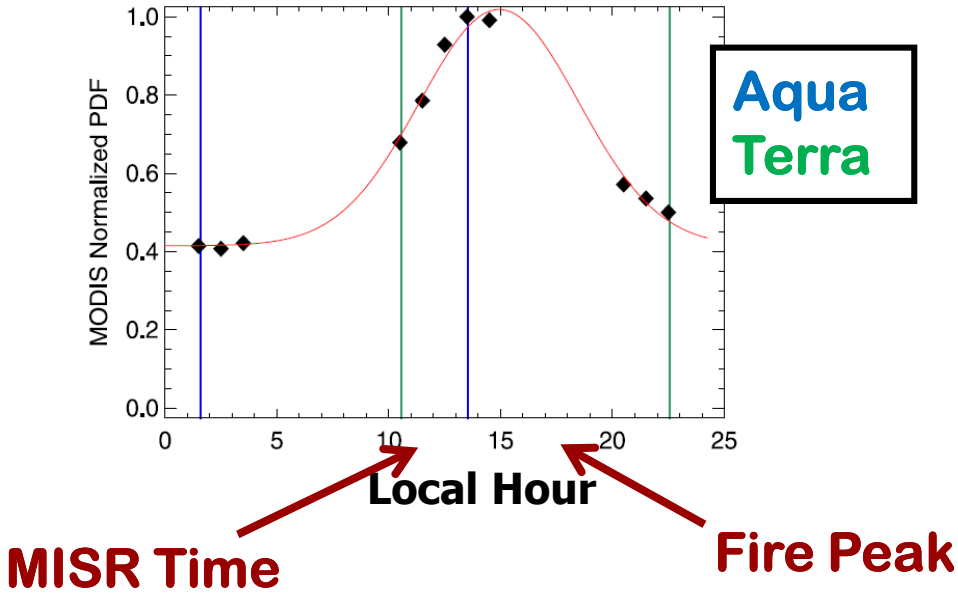
1) Diurnal variability

- Fire intensity increases during the afternoon
- Pyro-convective events usually occur later in the day

PDF of fire counts from VIRS (Giglio et al., 2007)

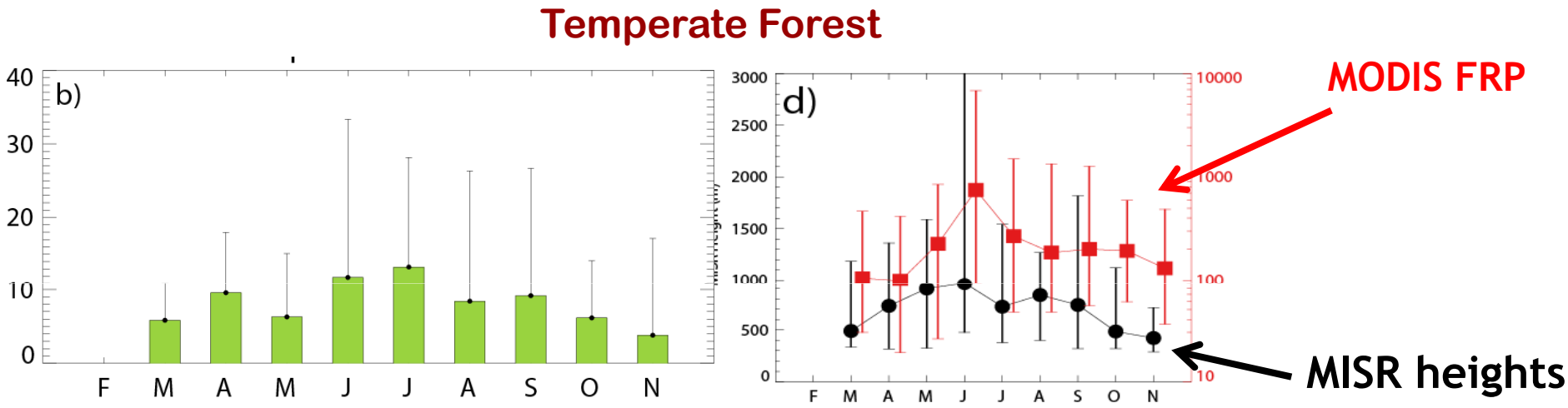


PDF of MODIS FRP in the boreal region (Vermote et al., 2009, Ellicott et al, 2009)



Issues to consider when modeling injection heights

2) Seasonal variability



Val Martin et al., ACP 2010

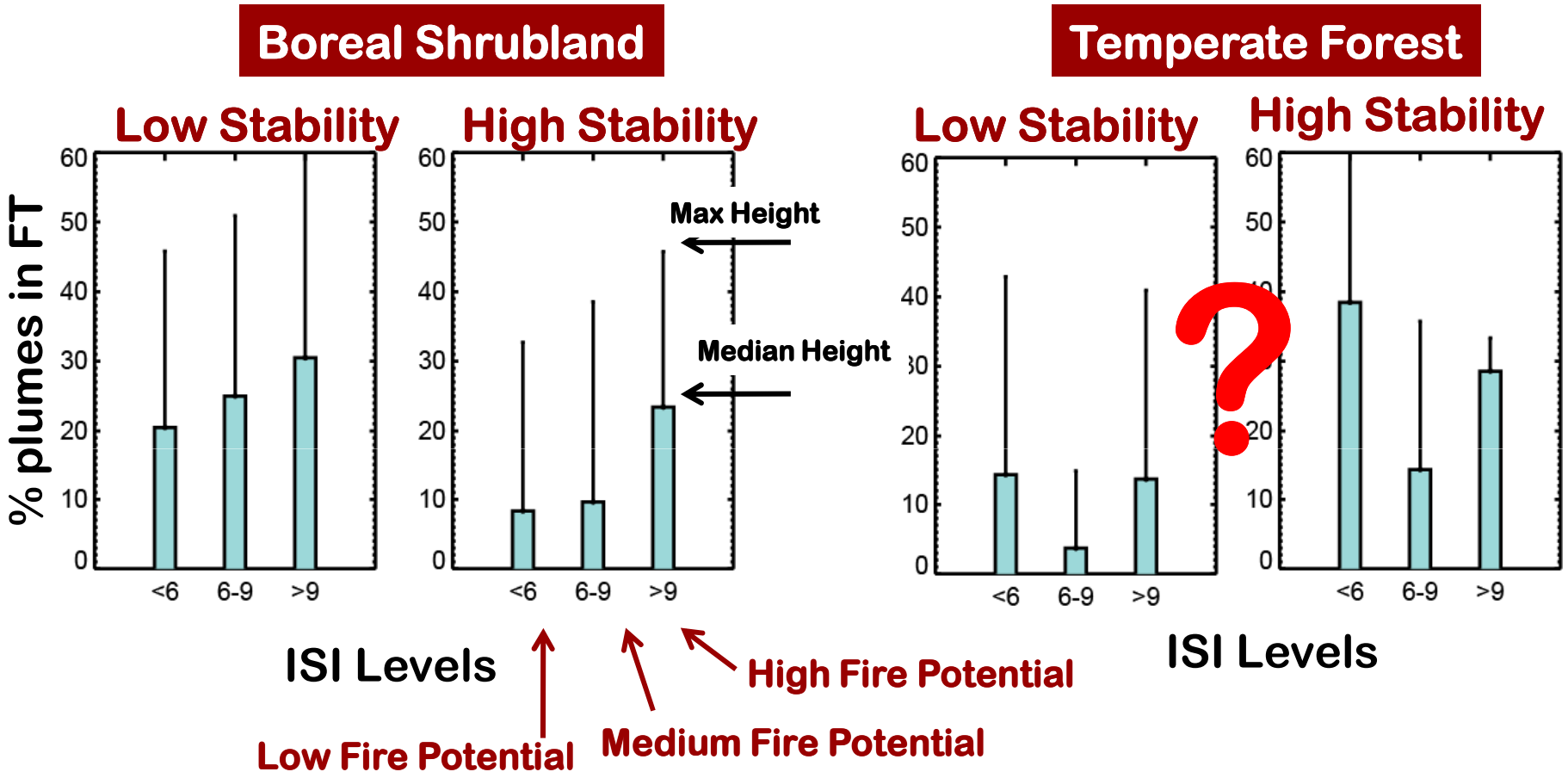
3) MODIS limitations

- Obscuration of MODIS fire pixels by dense smoke and clouds
- Different fire emissivity (smoldering vs flaming)

4) Model assumptions

- Entrainment coefficient?

Towards an empirical approach



$$\text{Stability} = \frac{d\vartheta}{dz}, \text{ where } \vartheta = \mathrm{T}\left(\frac{\mathrm{P}_0}{\mathrm{P}}\right)^{R/c_p}$$

Initial Spread Index (ISI) = f (wind speed, fine fuel layer moisture)

A quick summary

1. About 5-20% of plumes inject smoke above the BL over North America at 11:00-14:00.
2. Plume heights are variable, and depend on atmospheric stability and fire intensity.
3. Caution is needed when using 1D plume-rise models to simulate injection heights.

    The "MODIS pixel - Freitas" scenario significantly overestimates injection heights, whereas the "MODIS FRP-FRP" scenario underestimates injection heights.

4. On-going work: empirical parameterization of injection heights.

For more information

Val Martin et al., Smoke injection heights from fires in North America: Analysis of 5 years of satellite observations, ACP, 2010.

The MISR tool can be downloaded from:
http://www.openchannelsoftware.org

Also see Nelson et al. (SPIE, 2008)

The North American plume data base is available from:
www-misr2.jpl.nasa.gov/EPA-Plumes

Thank you to the JPL summer students that digitized the North America plumes