Naval Research Lab Update: Toward Improved Predictions of Extreme Fire Spread, Pyroconvection, and Smoke Plume Altitude

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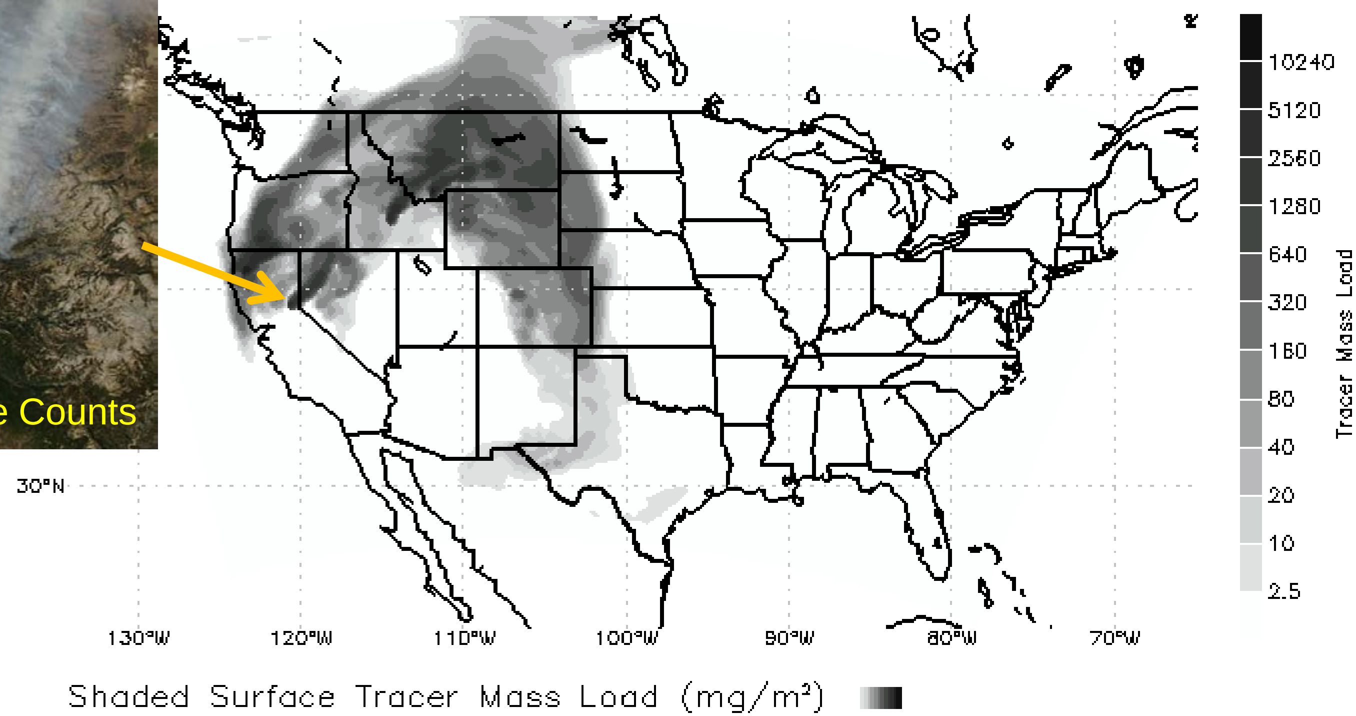
TFRSAC Meeting, 30 April 2014, NASA-Ames

Current Limitations: Smoke Transport Modeling

1. Satellite fire data quality?
2. Short-term changes in fire size?
3. Smoke injection altitude?

NRL COAMPS–OS® Seac4rsT2c 15.0km
Valid Time: 00:00Z 17 AUG 2013 Analysis: 00:00
Base Time: 00:00Z 17 AUG 2013

Rim Fire

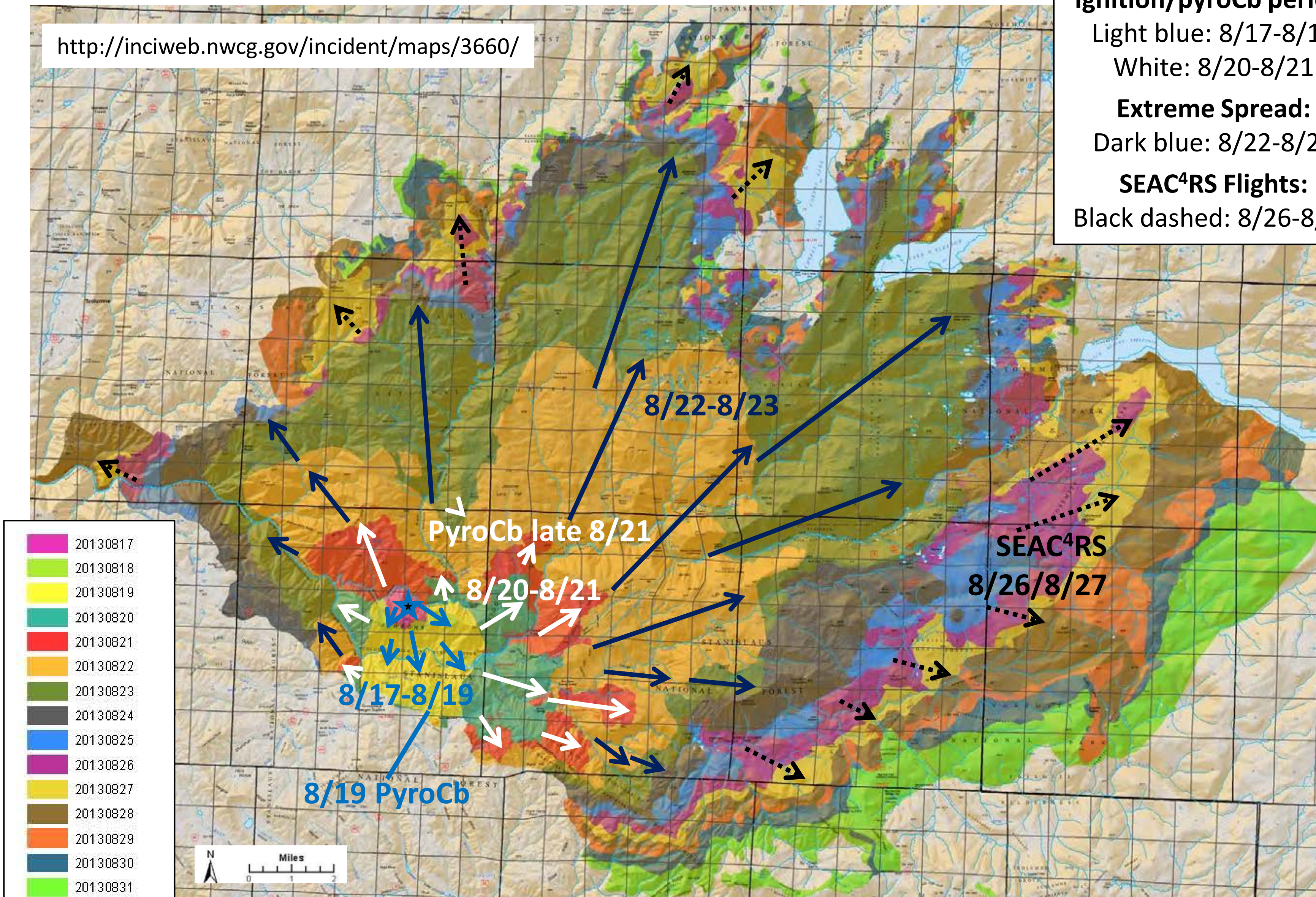


Goal: Global prediction of smoke emissions!

The Rim Fire's Extreme Fire Spread and PyroCbs

USFS Fire Progression Map: 8/17 (Ignition) – 8/31

Arrow Color:
Ignition/pyroCb period:
Light blue: 8/17-8/19
White: 8/20-8/21
Extreme Spread:
Dark blue: 8/22-8/23
SEAC4RS Flights:
Black dashed: 8/26-8/27



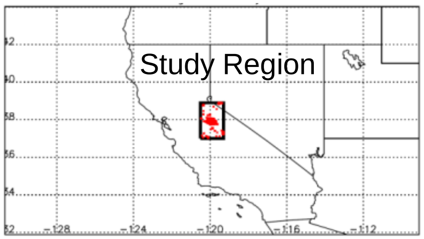
Rim Fire Time Series

Two periods of extreme spread!

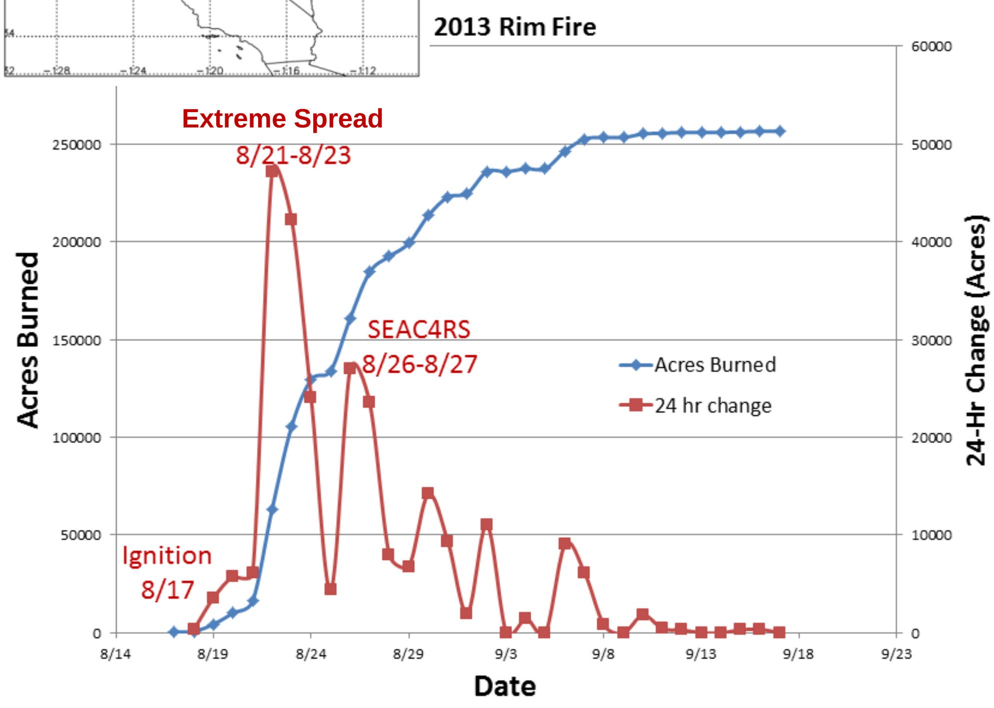
Forecast smoke emissions were underestimated!

Should we use fire counts or fire radiative power (FRP)?

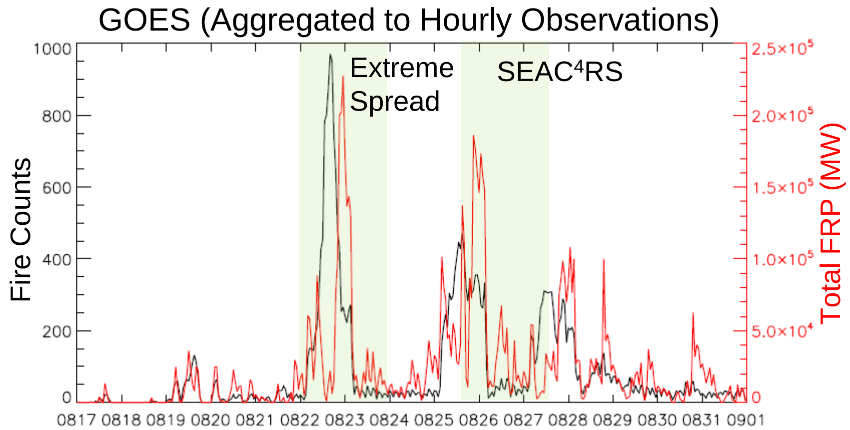
Many models are based on fire counts!

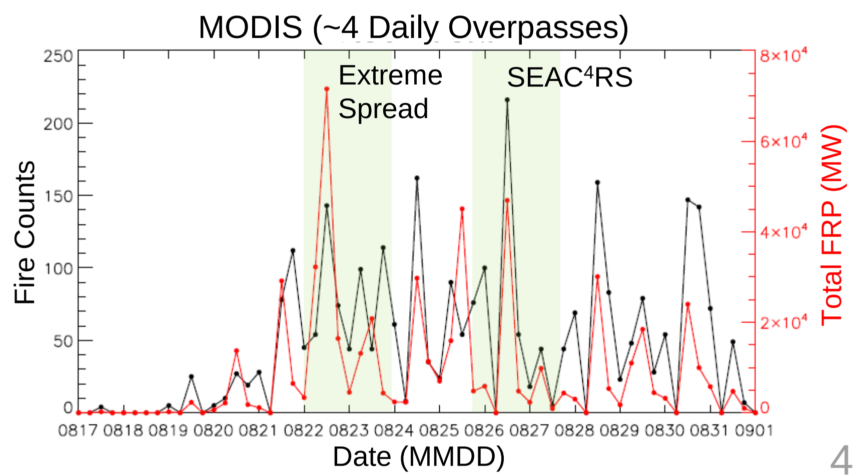


USFS Observations



http://inciweb.nwcg.gov/incident/news/3660/

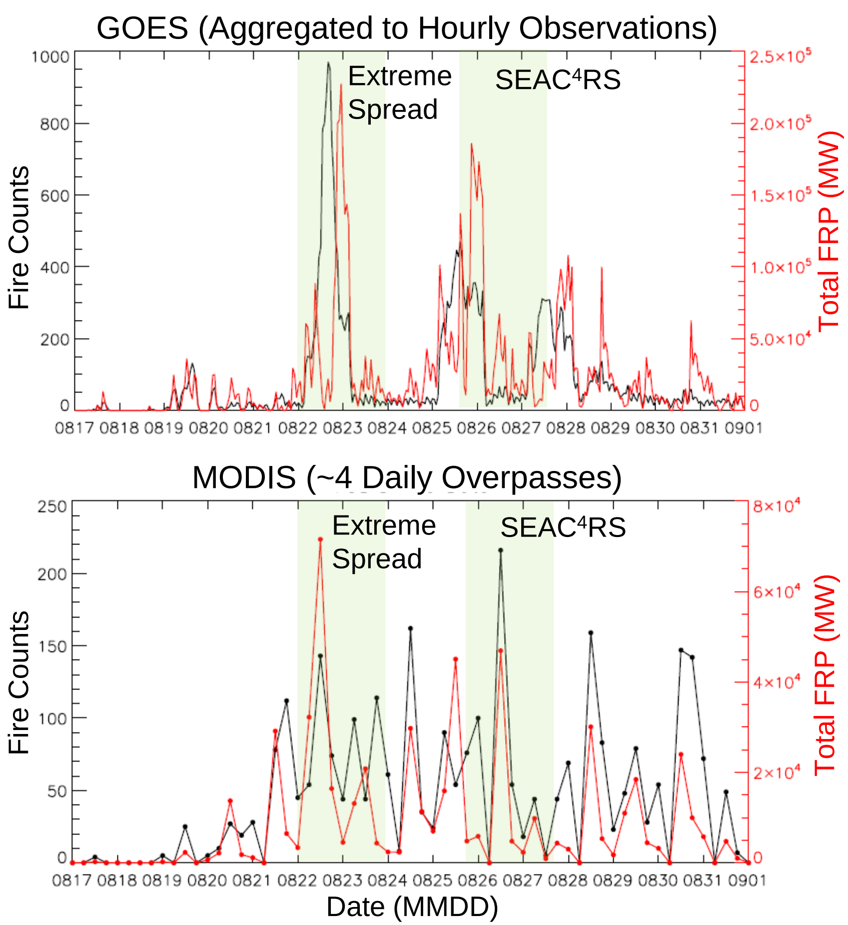




MODIS Time Series Riddled with Artifacts

Many artifacts can be corrected!

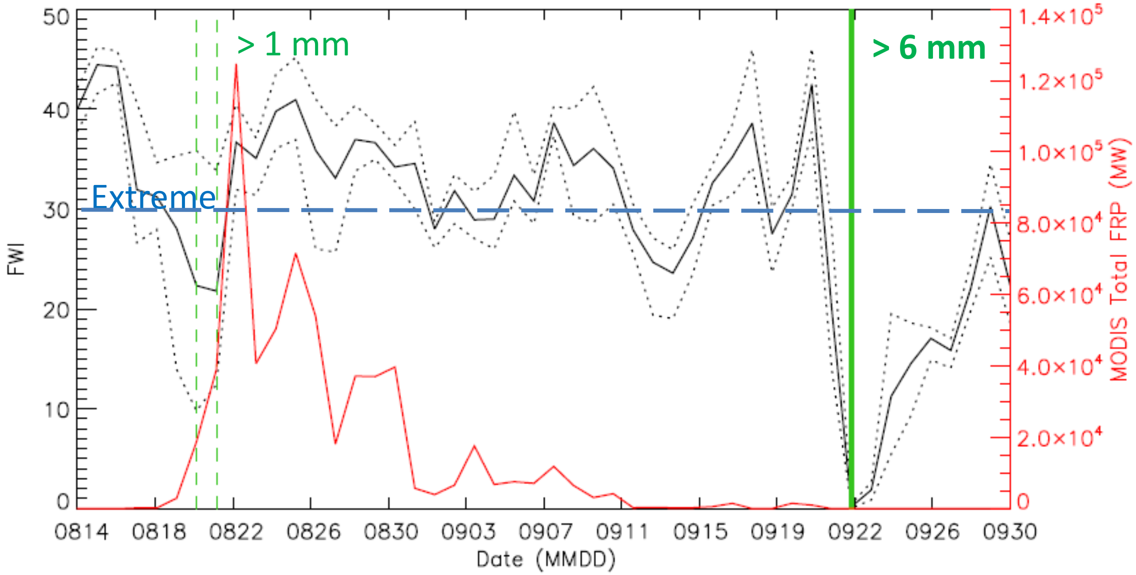
- Fire growth has strong day-to-day variability
- Satellite time series reflect that variability, and also:
  - Orbital pattern
  - Cloud cover
  - Scan angle
  - Time(s) of observation (diurnal)
- **These factors need to be considered when interpreting daily MODIS fire counts and FRP**
- NRL is developing a process to correct for all of these effects
  - Substantial improvement in MODIS-vs-GOES correlation
  - Works best at broad scales



Toward Building a Fire Prediction Model

1. How can we use weather information to make automated short-term forecasts of emissions for AQ models?
2. Do fire observations contain information to identify potential for high smoke injection and extreme fire spread?
3. How can we use weather information to improve smoke emission estimates in near-real-time and retrospectively?

Fire Weather Index (FWI)
Using the North American Regional Reanalysis (NARR, 32 km)



See Peterson et al., 2013, Atmos. Env.

Limitations of Fire Weather Indices

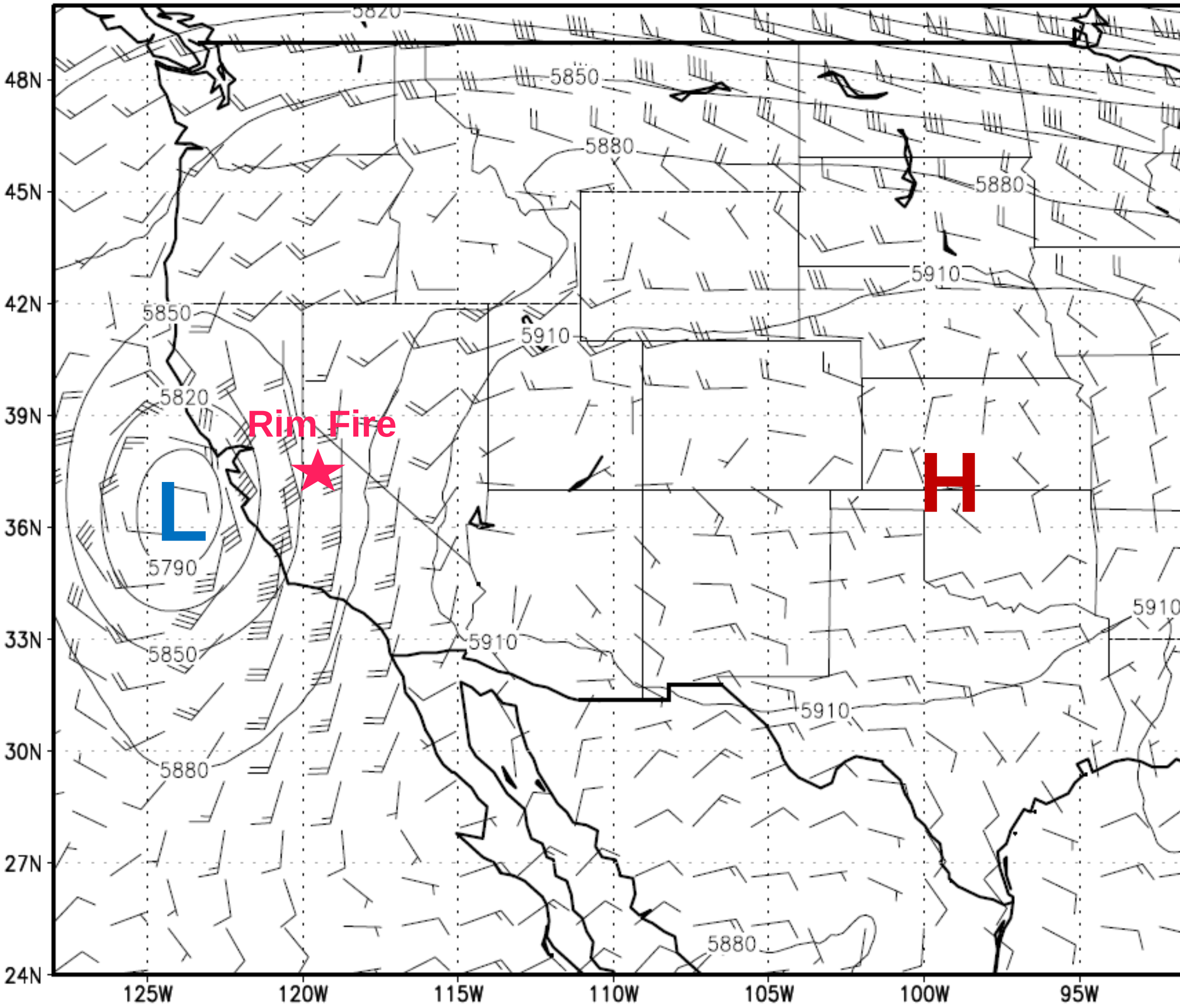
- Extreme fire danger during majority of Rim Fire
- Representativeness error near small-scale precip
- Lack upper-level meteorology!

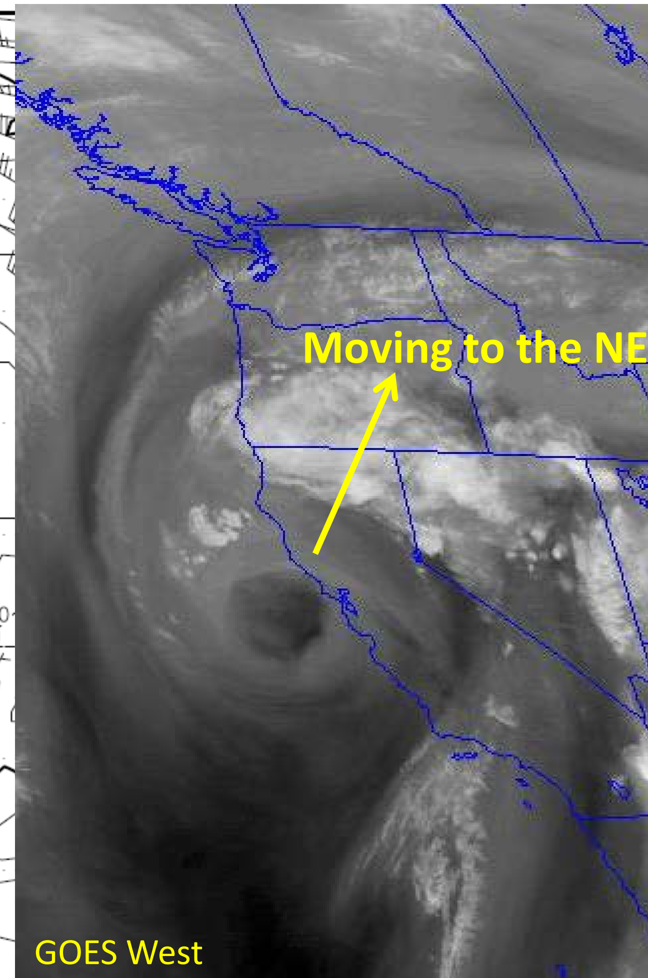
Green: daily precipitation
Red: MODIS FRP
Solid black: mean
Dashed Black: max or min

Impacts from Upper-Level Disturbances

Can we use upper-air analyses to forecast extreme spread & pyroconvection?

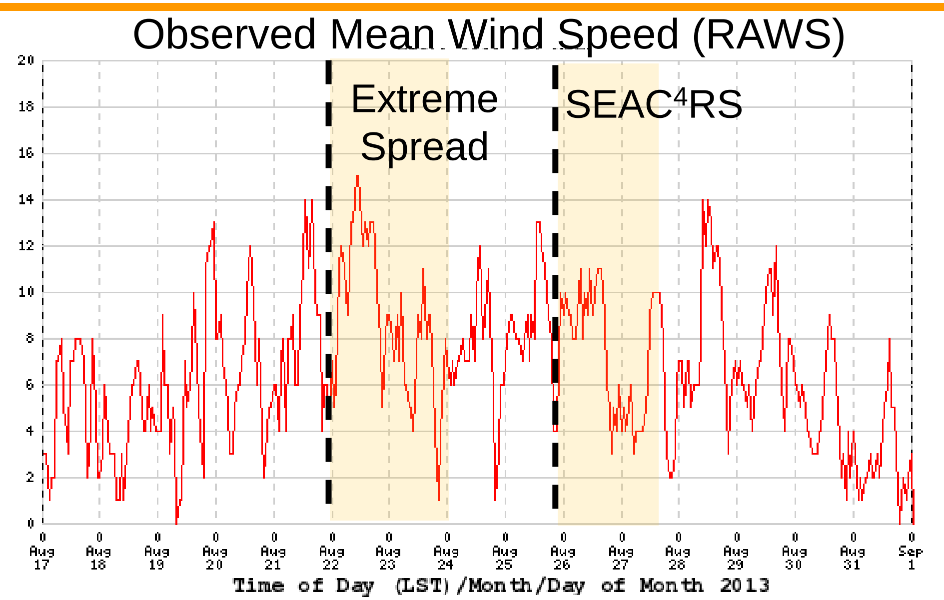
NARR 500 hPa Heights & Wind Barbs, 22 August 2013, 00Z (5 PM PDT, 21 August)

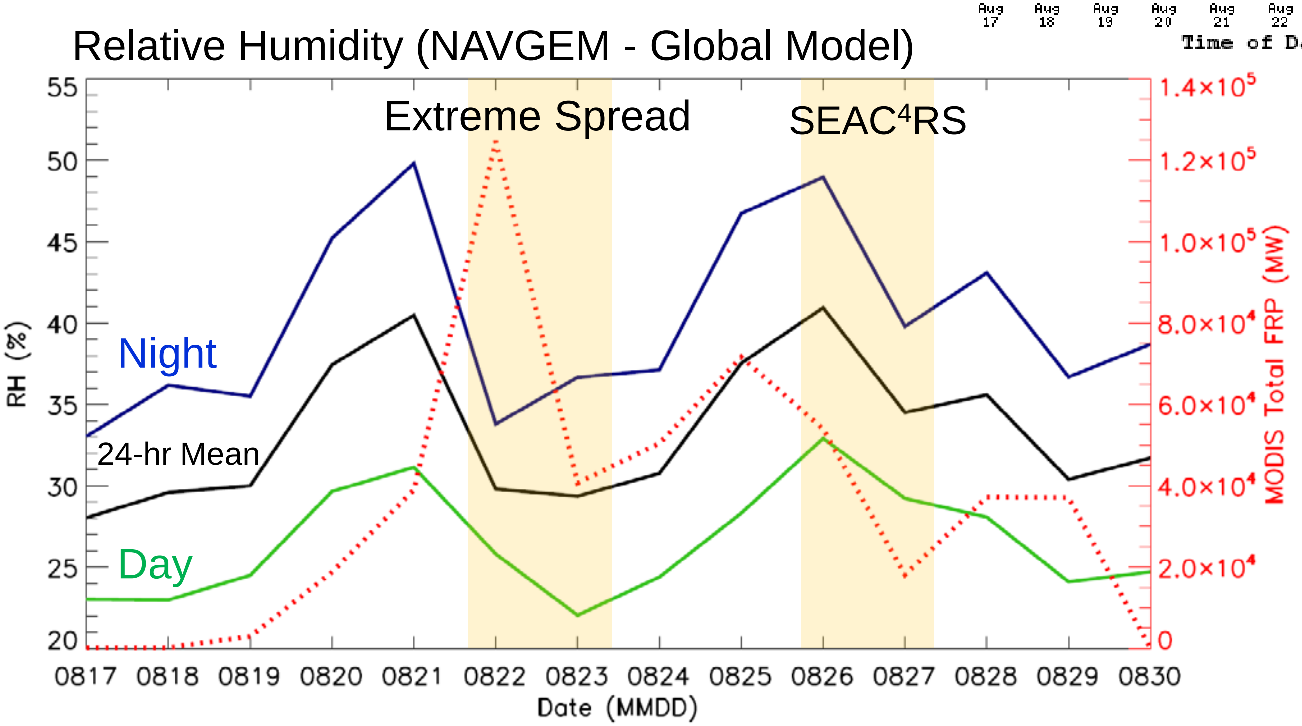




Identifying Extreme Fire Spread: Rim Fire

- Spread events driven by upper-levels!
- Higher NWP accuracy at upper-levels?
- Strong surface wind speed overnight!
- Wind direction relative to topography?
- Effect of NWP resolution on surface wind information?

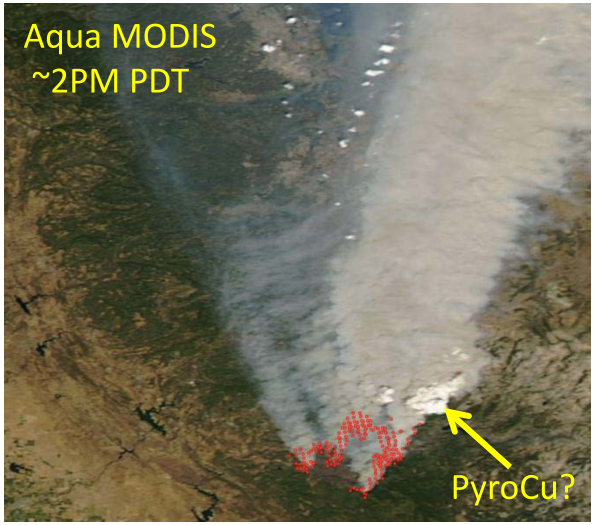




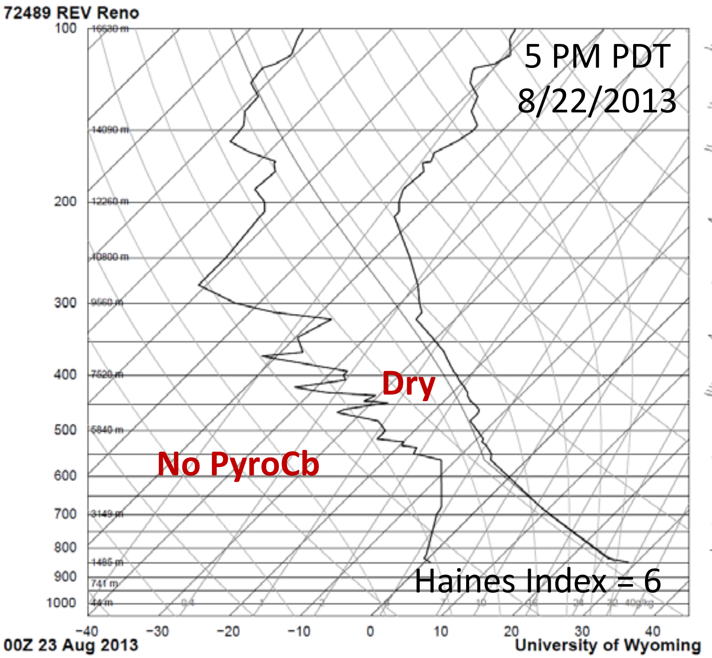
- RH remains low overnight
- NAVGEM (1/3 degree) captures this effect!
- Day/night & upper-level info not included in fire weather indices!

Pyroconvection During Extreme Fire Spread?

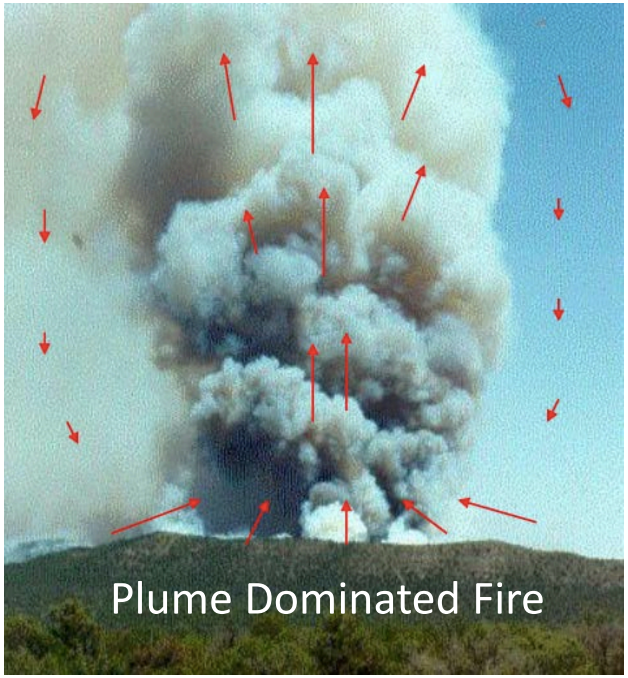
8/22/2013 (Extreme Spread)



- Extreme FRP, but atmospheric column was dry
- Only a few capping pyroCu were observed
- Unstable lower-atmosphere (Haines Index = 6)
- Produces a positive feedback loop for spread
- Enhanced by upper-level/nighttime conditions!



SLAT	39.56
SLON	
SELV	1516.
SHOW	-9999
LIFT	0.61
LFTV	0.29
SWET	-9999
KINX	-9999
CTOT	-9999
VTOT	-9999
TOTL	-9999
CAPE	0.00
CAPV	10.02
CINS	0.00
CINV	-43.7
EQLV	-9999
EQTV	480.4
LFCT	-9999
LFCV	483.6
BRCH	0.00
BRCV	0.57
LCLT	267.3
LCLP	564.8
MLTH	314.7
MLMR	4.44
THCK	5796.
PWAT	12.78



Rim Fire Smoke Plume Altitude: Extreme Fire Spread

- DIAL lidar sampled smoke emitted over 48-50 hrs (24-26 Aug.)
  - Mixing with Idaho smoke?
  - Idaho fires were decaying
- Despite extreme FRP and pyroCu, nearly all smoke is below 6 km!
- High enough for long distance transport.

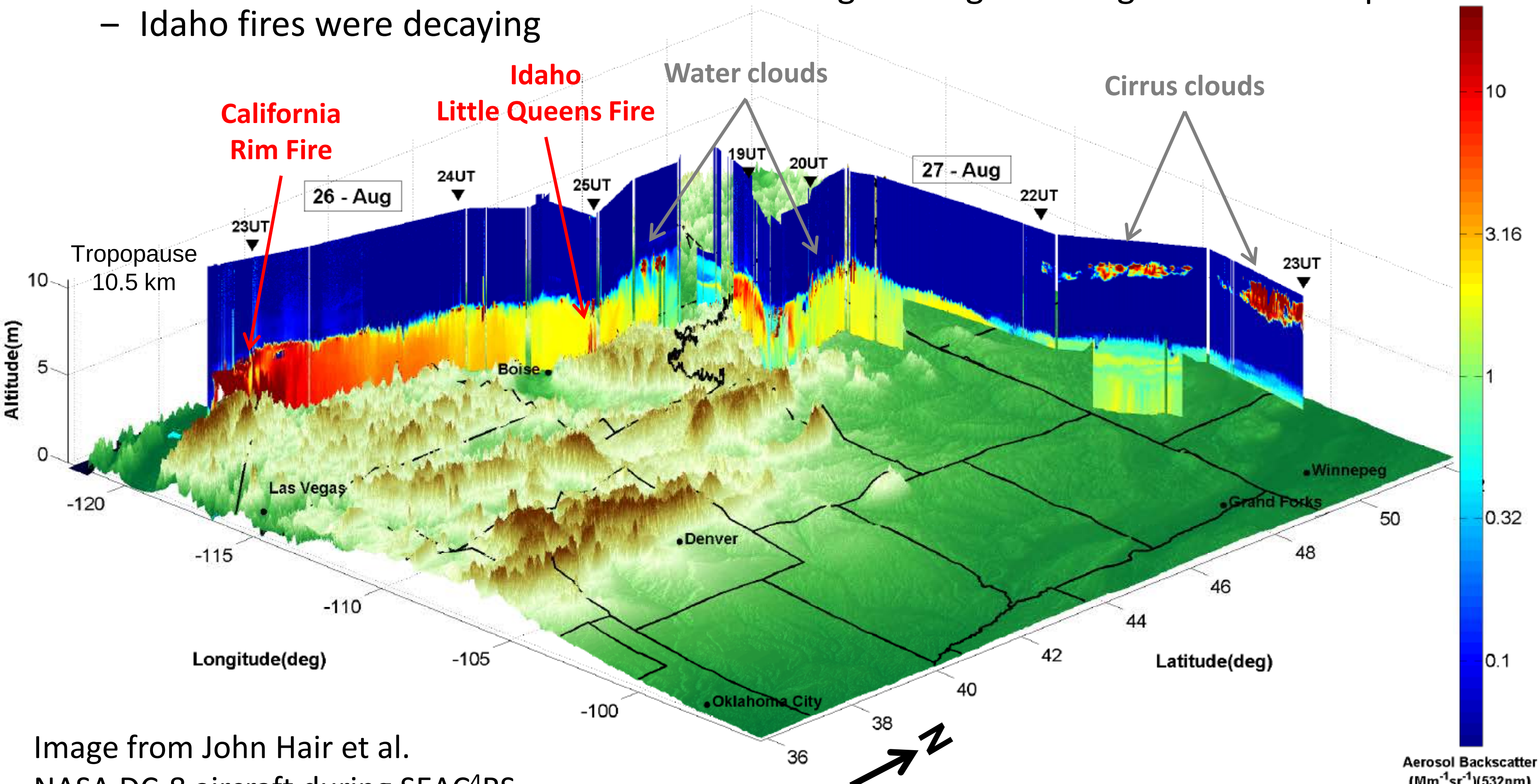
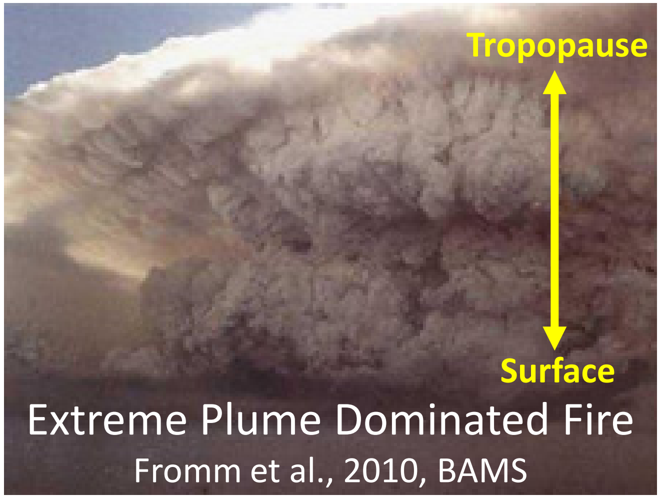
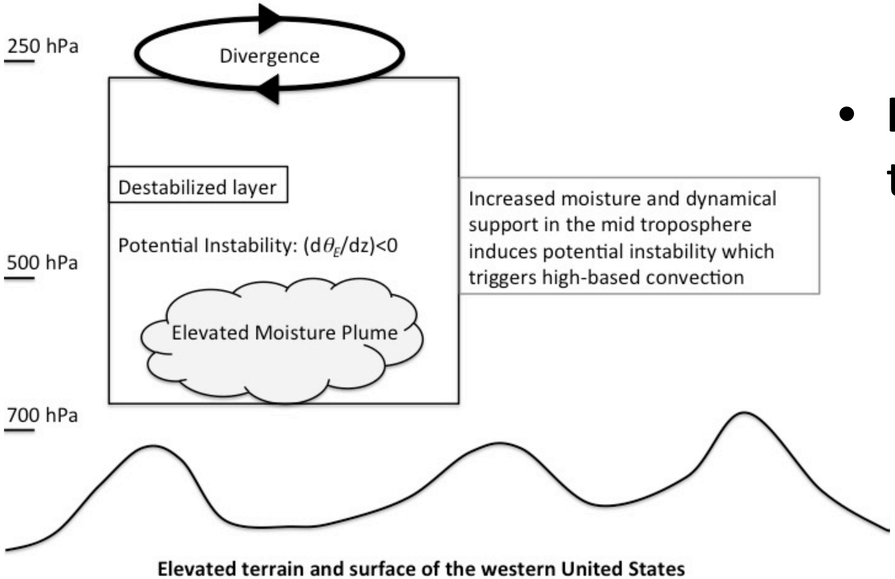


Image from John Hair et al.
NASA DC-8 aircraft during SEAC^{4}RS

Toward the Prediction of PyroCbs



Dry Thunderstorm Schematic



e.g. Rorig and Ferguson, 1999; Nauslar et al., 2013

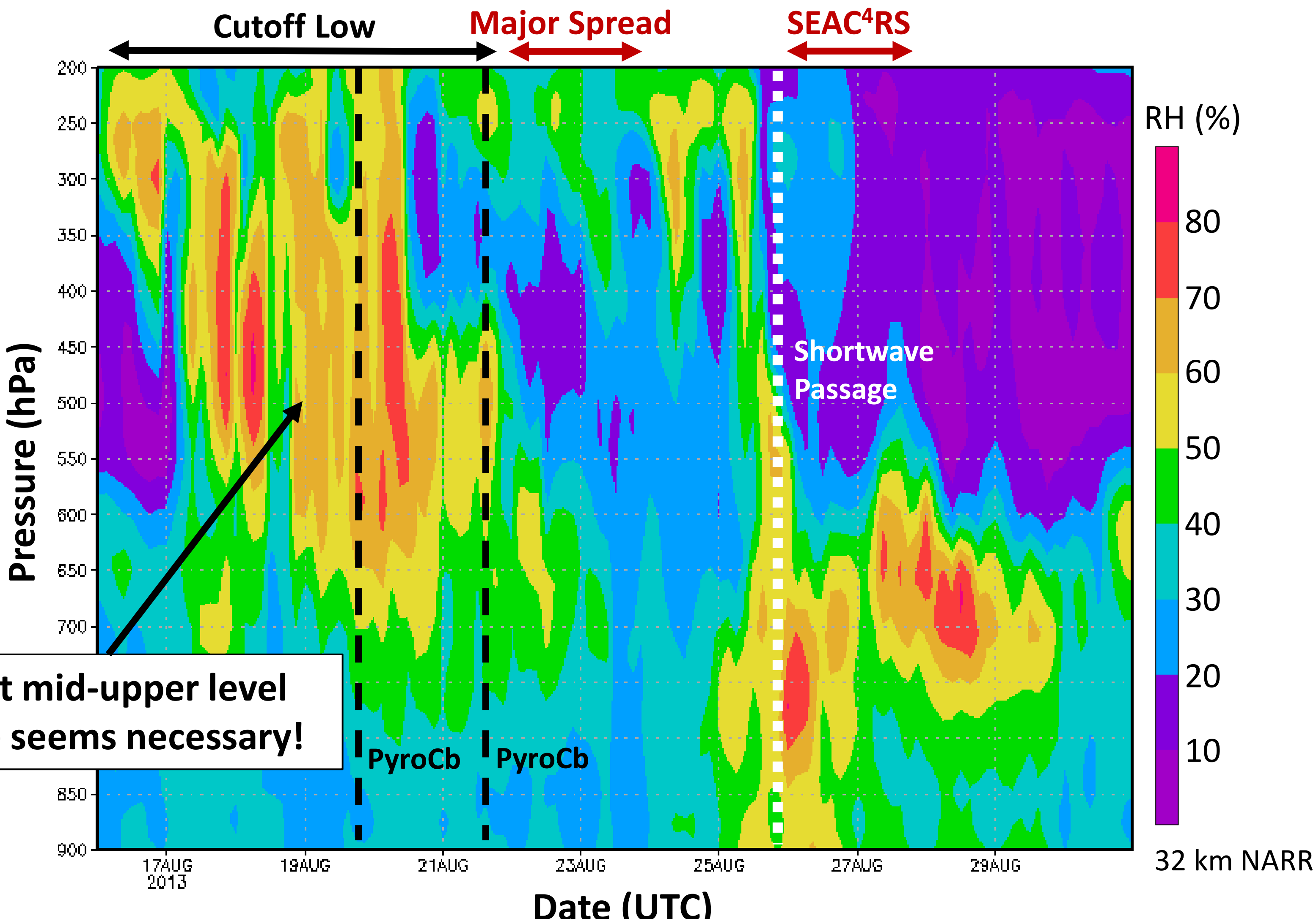
Pyrocumulonimbus (PyroCb) Development

- How much FRP?
- Low-level instability (Haines Index = 6)
- Moisture/latent heat release is required!
- What is the primary moisture source?
  - Combustion
  - Ambient atmosphere
- Recent modeling studies disagree!

- **Hypothesis**: pyroCb environment similar to traditional high-based dry thunderstorms?
  - Ahead of approaching disturbance
  - Mid-level moisture advection
  - Upper-tropospheric lapse rate (UTLR) > 7.5 ^{o}C/km
  - Divergence at 250 hPa
  - What about CAPE?

Presence of Mid-Level Moisture: 2013 Rim Fire

Primary Burning Period (17-31 August) Relative Humidity

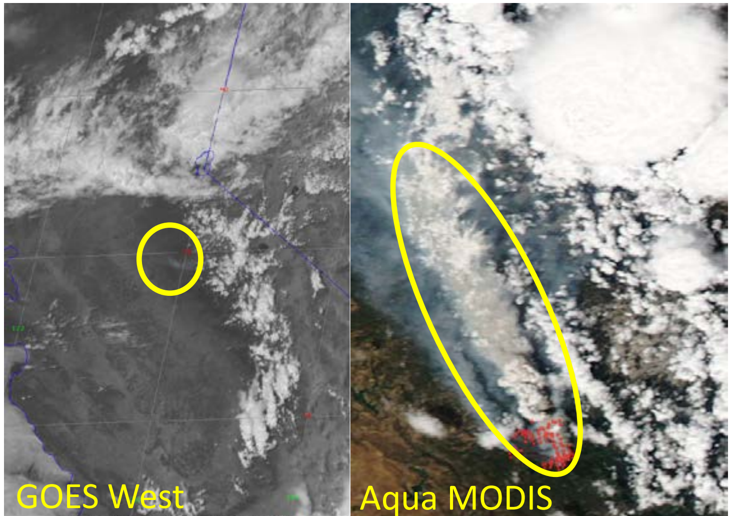


Ambient mid-upper level moisture seems necessary!

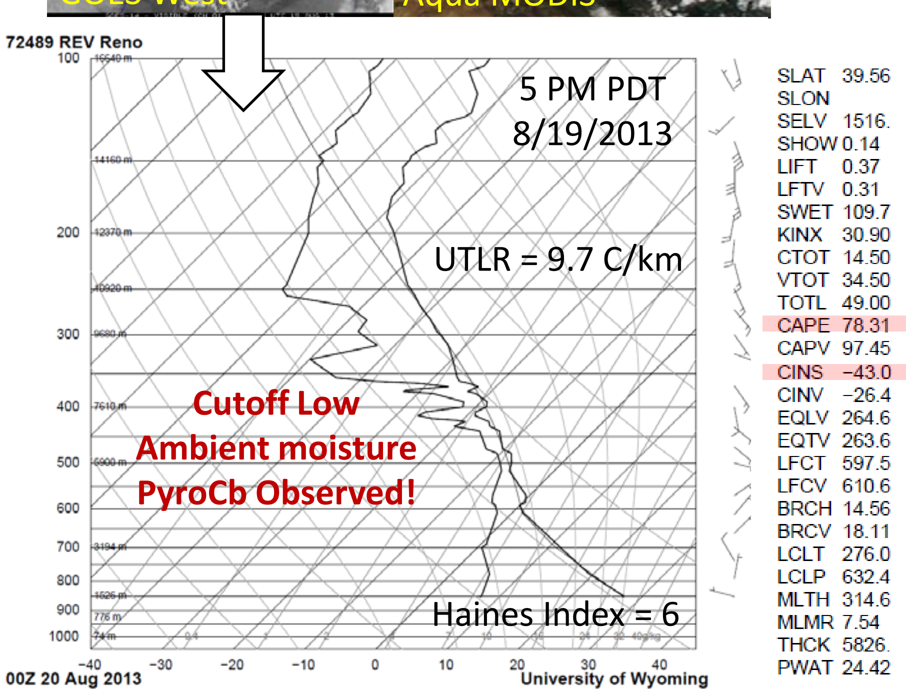
http://nomads.ncdc.noaa.gov/#narr_datasets

Favorable Meteorology for PyroCb Development

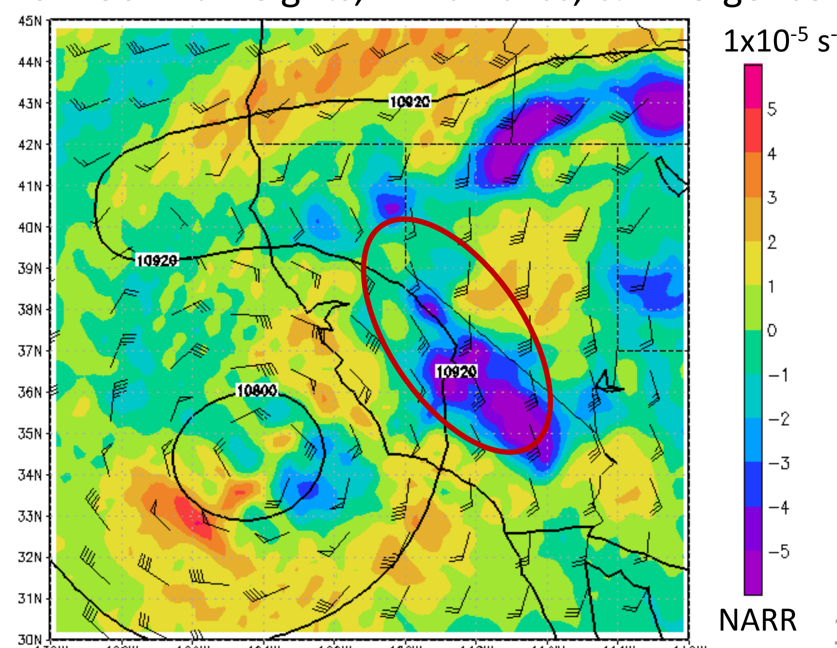
8/19/2013 8/21/2013



- Located well ahead of approaching cutoff low
- Unstable/moist mid-upper troposphere
- In the vicinity of traditional dry T-storms
- Divergence at 250 hPa



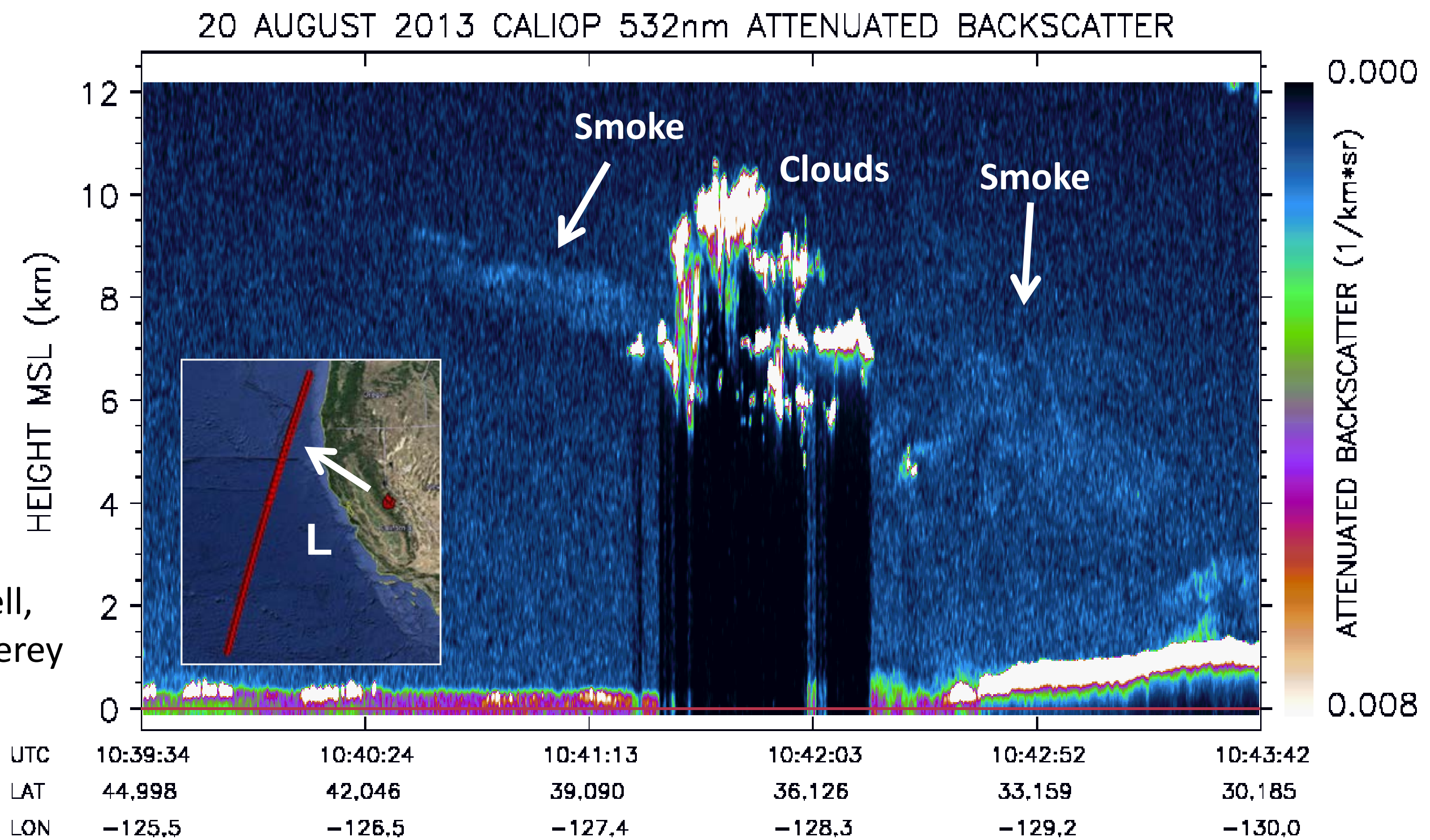
8/19: 250 hPa Heights, Wind Barbs, & Divergence



PyroCb Impact on Smoke Altitude

- Most efficient avenue for lofting smoke
  - Aided by latent heat release
- Less important for extreme fire spread
- Upper-level meteorology is key!

Observation	PyroCb	Spread
Smoke Altitude	> 8 km	< 6 km
FRP	Mod/High	Extreme
Haines Index	6	6



J. Campbell, NRL - Monterey

Characterizing Smoke Plume Altitude using MOD14

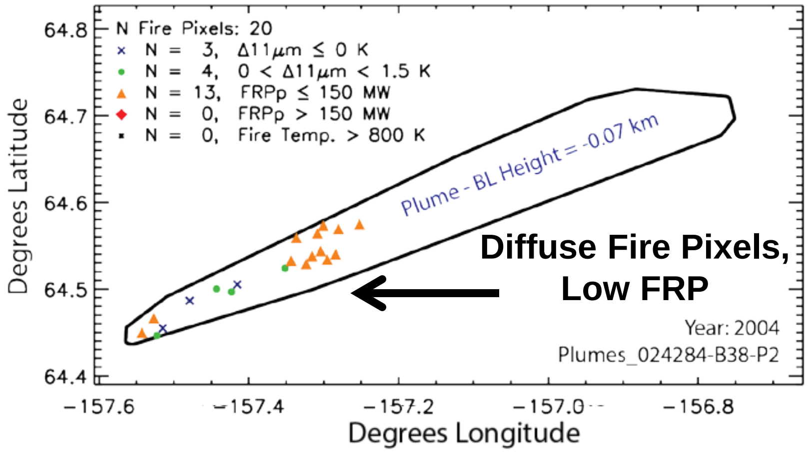
Peterson et al. (*in press, JGR*)

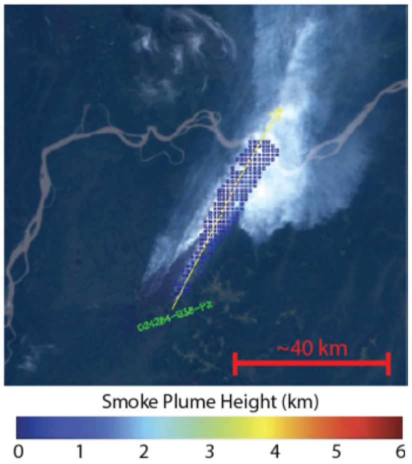
Low FRPp, Low-Altitude Injection

BL_{500} Injection Probability: 50%

Total FRPp: 954 MW
FRPf Flux: 8.8 kW/m^2

Mean Fire Temp: 647 K
Total Fire Area: 0.09 km^2



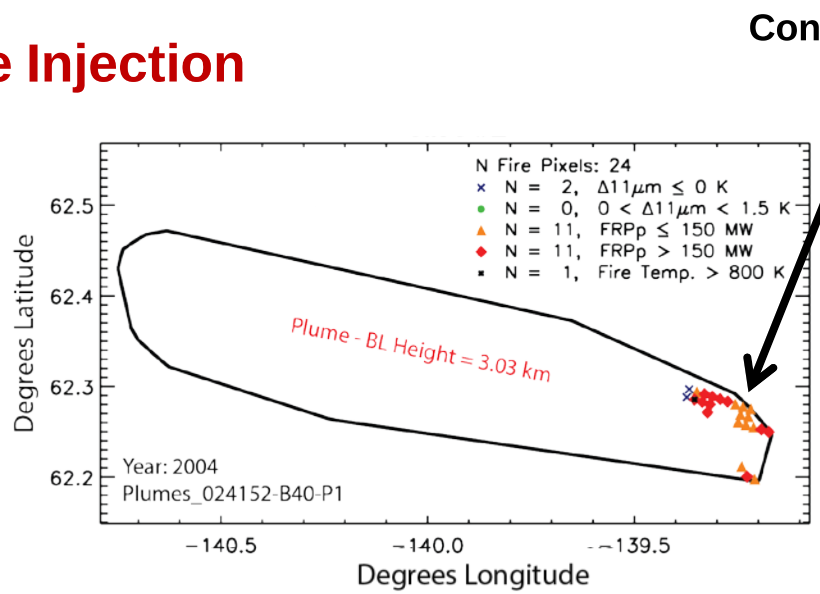


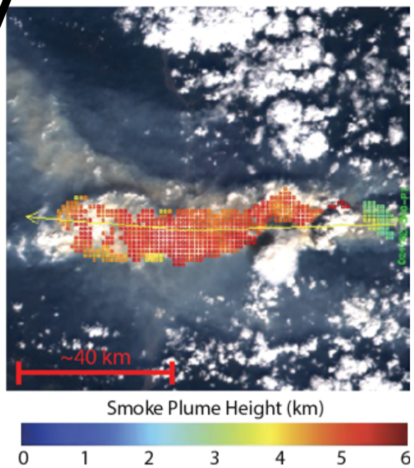
High FRPp, High-Altitude Injection

BL_{500} Injection Probability: 90%

Total FRPp: 5793 MW
FRPf Flux: 11.4 kW/m^2

Mean Fire Temp: 643 K
Total Fire Area: 0.54 km^2





Characterizing Smoke Plume Altitude using MOD14

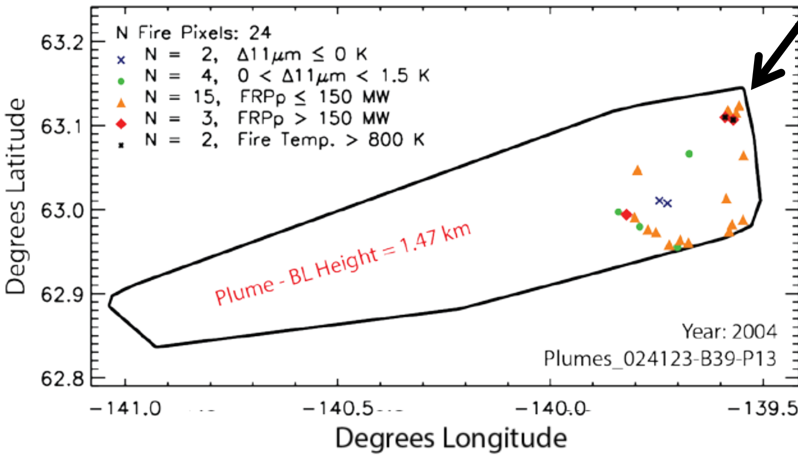
Peterson et al. (*in press, JGR*)

Low FRPp, High-Altitude Injection

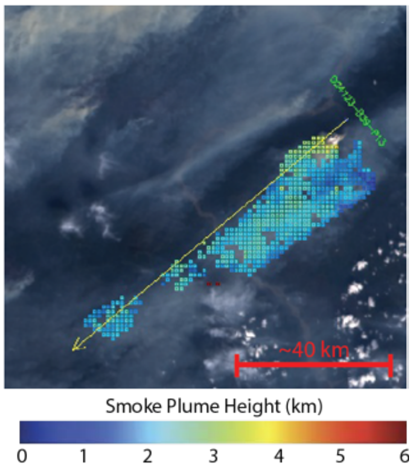
BL_{500} Injection Probability: 60%

Total FRPp: 2424 MW
FRPf Flux: 14.6 kW/m^2

Mean Fire Temp: 663 K
Total Fire Area: 0.17 km^2



High FRP pixels near base of plume…



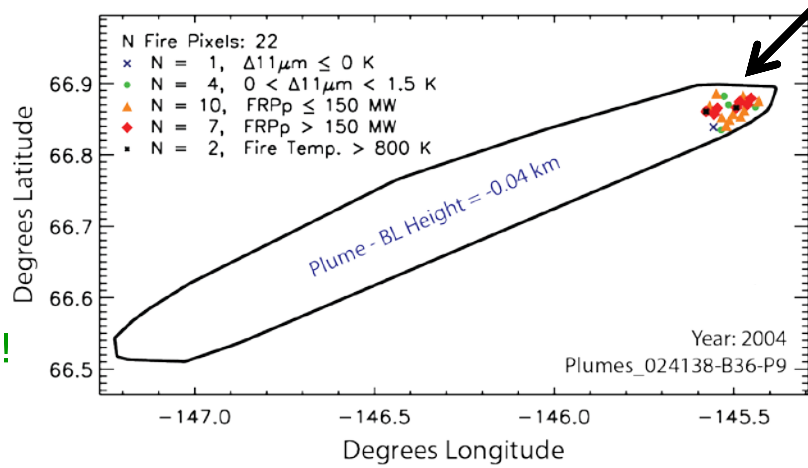
High FRPp, Low-Altitude Injection

BL_{500} Injection Probability: 65%

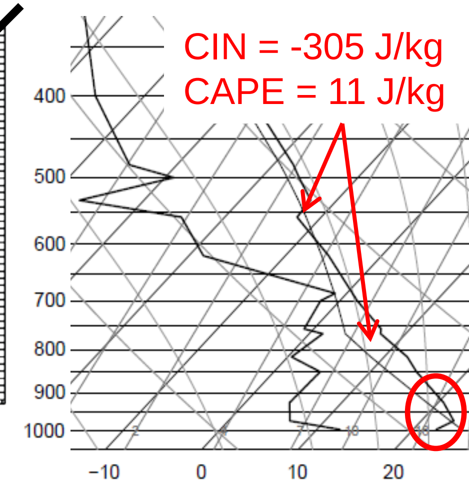
Total FRPp: 3517 MW
FRPf Flux: 14.4 kW/m^2

Mean Fire Temp: 702 K
Total Fire Area: 0.25 km^2

Meteorology must be considered!
Kahn et al. (2007)
Val Martin et al. (2010, 2012)



Concentrated Fire Pixels, High FRP, but INVERSION & STABLE!



Conclusions and Future Work

Extreme Fire Spread

- Initiated by the passage of an upper-level disturbance (e.g. cutoff/shortwave)
- Effect on nighttime wind speed and relative humidity is key!
- Likely corresponds to highest FRP

PyroCb Hypotheses

- Meteorological environment is similar to high-based dry thunderstorms
- More important for lofting of smoke particles, less important for fire spread

Signal of Plume Height in MODIS Fire Observations

- All retrieved fire properties (pixel and sub-pixel) correlate with plume height
- Combining pixel and sub-pixel fire data may improve plume height characterization for lower FRPp events!

Improving fire time series with MODIS and GEO satellite data

- Systematic production of MODIS observation quality data and graphics to interpret MODIS fire observations
- Construction of corrected smoke release time series from MODIS and GEO.

Future Goal: Produce a global fire and smoke altitude prediction tool that can be used for operational smoke emissions modeling (e.g. NRL's FLAMBE).

Thank You!

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Acknowledgements and Related Publications

National Research Council Postdoctoral Fellowship
NASA Earth and Space Science Fellowship
Naval Research Enterprise Intern Program

Peterson, D., Hyer, E., & Wang. J.: Quantifying the Potential for High-Altitude Smoke Injection in the North American Boreal Forest using the Standard MODIS Fire Products and Sub-Pixel-Based Methods, ***Journal of Geophysical Research***, in press.

Peterson, D., Hyer, E., & Wang. J.: A short-term predictor of satellite-observed fire activity in the North American boreal forest: toward improving the prediction of smoke emissions, ***Atmospheric Environment***, 71, 304-310, 2013.

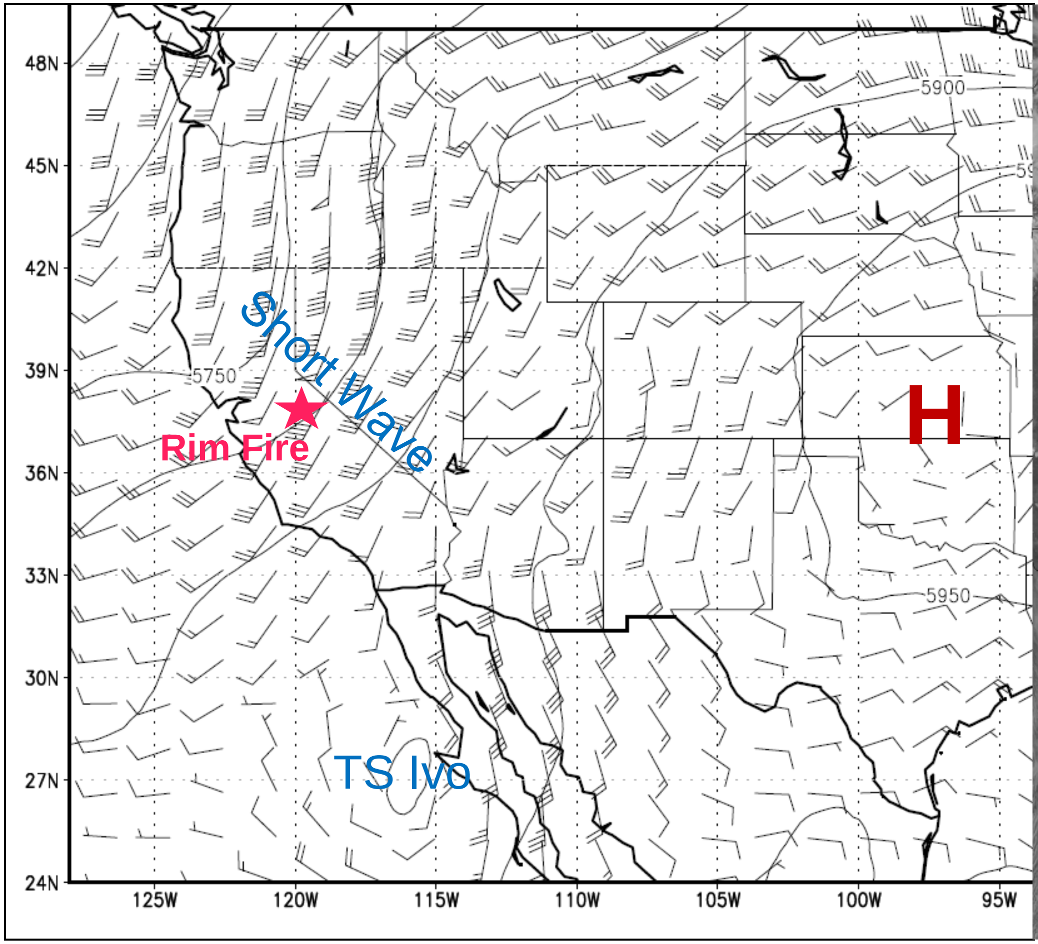
Peterson, D., Wang, J., Ichoku, C., Hyer, E., & Ambrosia, V.: A sub-pixel-based calculation of fire radiative power from MODIS observations: 1. Algorithm development and initial assessment, ***Remote Sensing of Environment***, 129, 262-279, 2013.

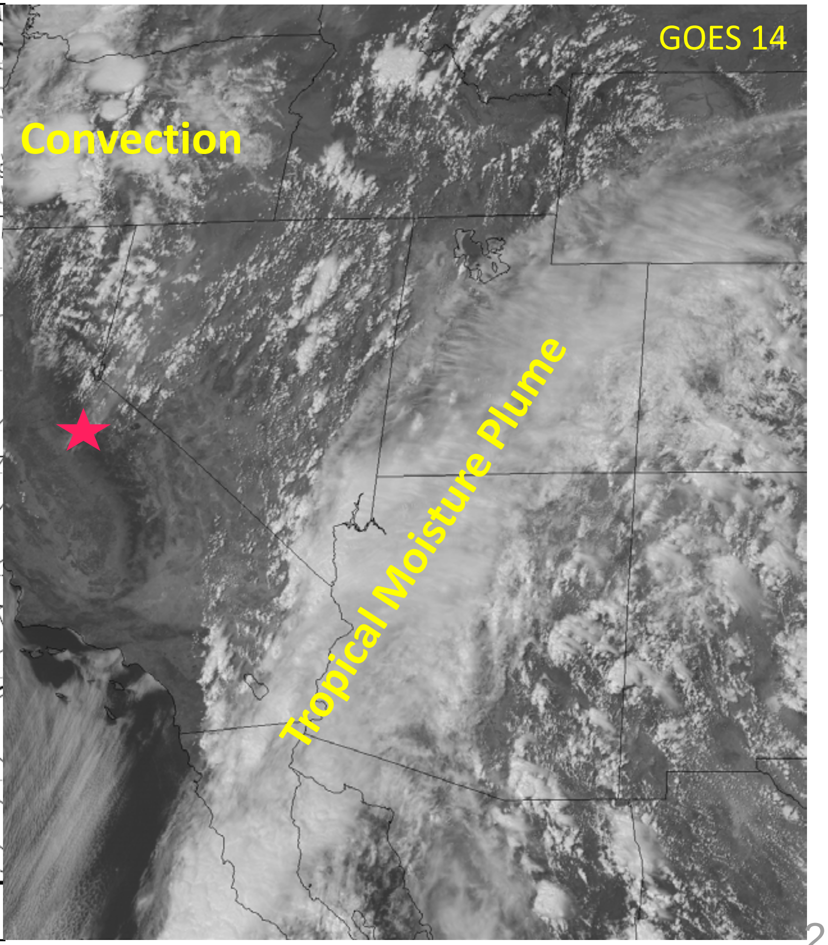
Upper-Level Impacts: SEAC^{4}RS

Periods of extreme fire spread initiated by an upper-level disturbance

SEAC^{4}RS flights preceded by a shortwave trough…

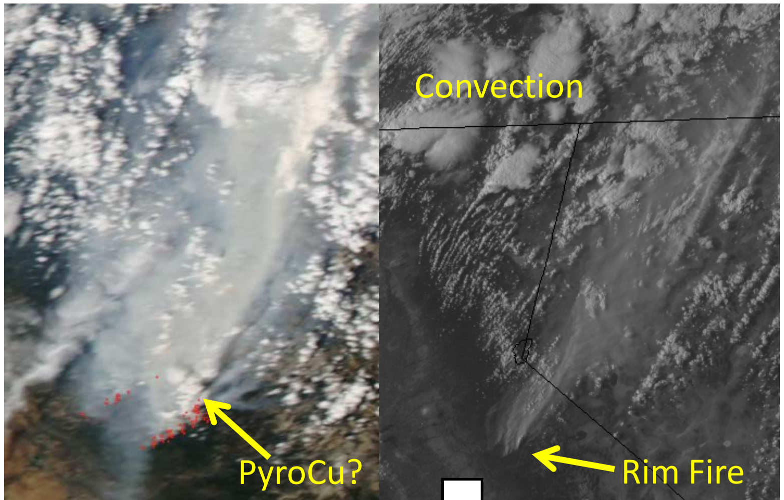
NARR 500 hPa Heights & Wind Barbs, 25 August 2013, 21Z (2 PM PDT)

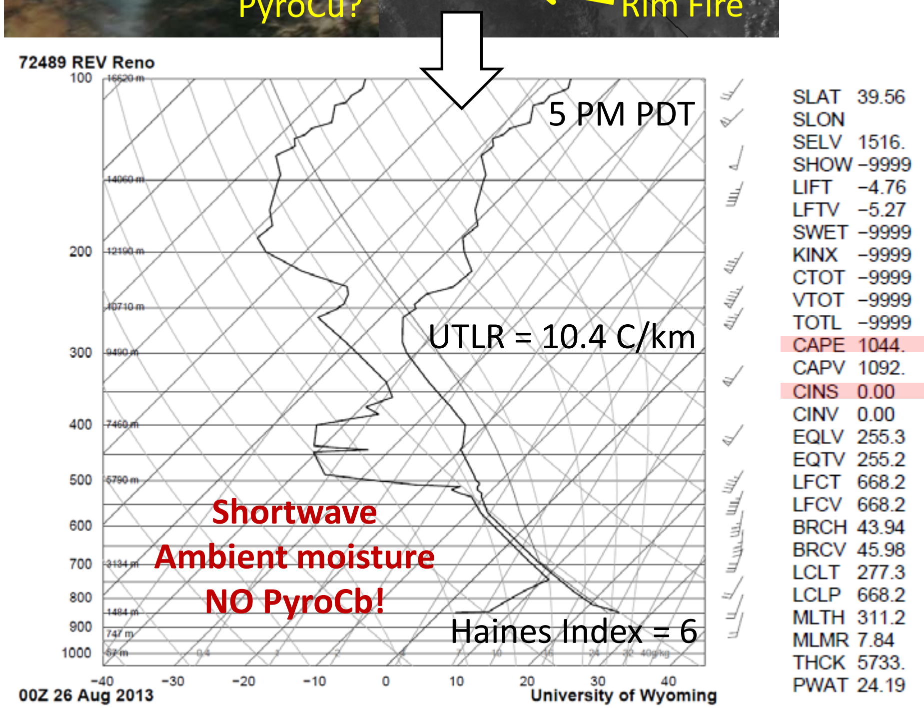




No PyroCb on 25 August?

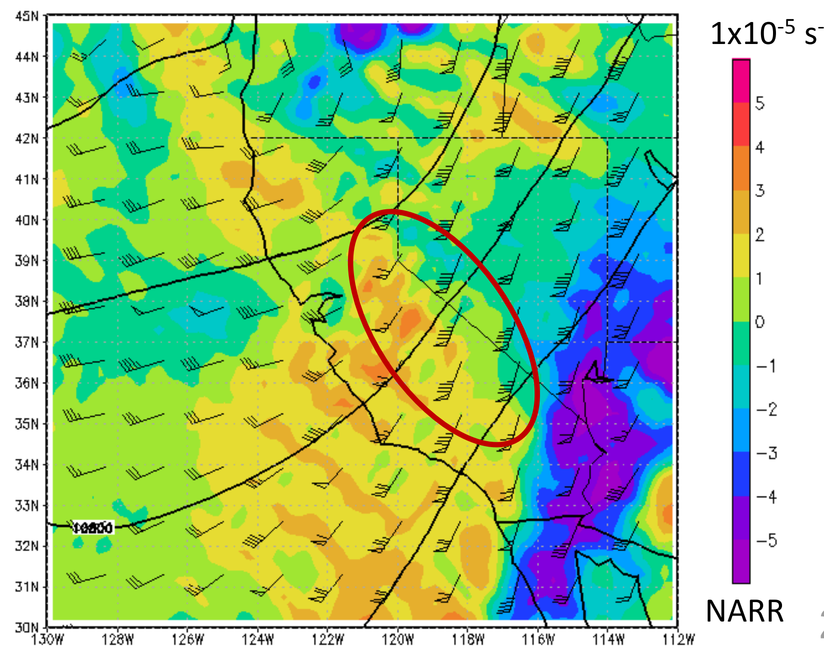
Aqua MODIS: 2 PM PDT GOES 14: 5 PM PDT





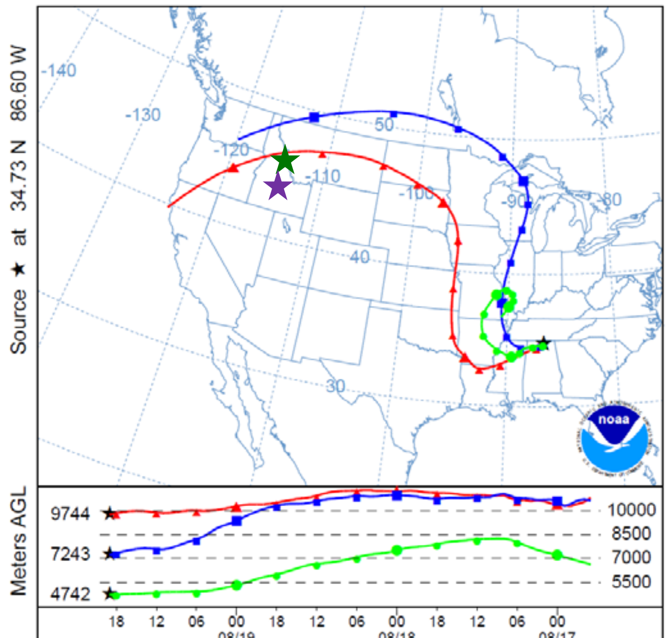
- Located in vicinity of approaching short wave
- Unstable/moist mid-upper troposphere
- Devoid of traditional dry T-storms
- Convergence at 250 hPa

250 hPa Heights, Wind Barbs, & Divergence



Additional PyroCbs & High-Altitude Smoke During SEAC⁴RS

HYSPLIT Backward Trajectories



From Mike Fromm, NRL - DC

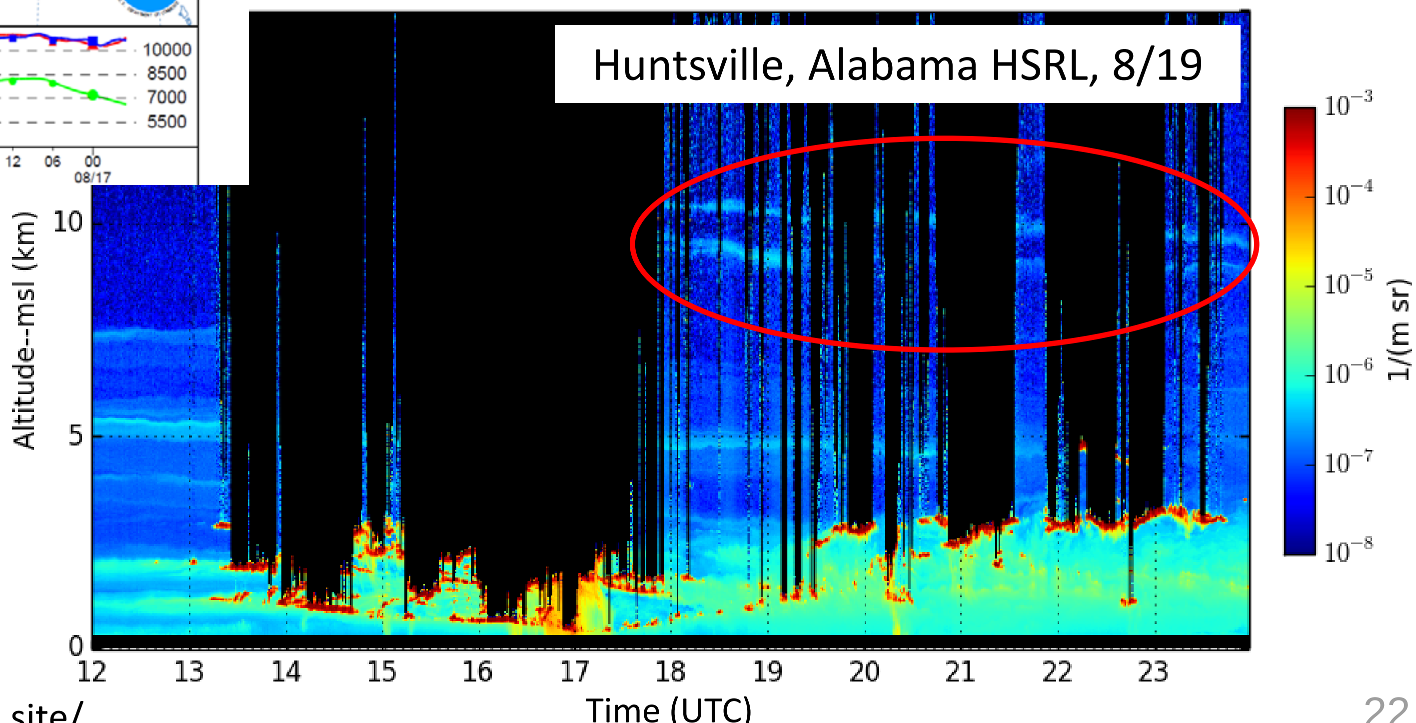
Date (2013)	Fire	State
8/8	Beaver Creek	Idaho
8/8	McCan	Idaho
8/9	Pony, Elk?	Idaho
8/10	Elk	Idaho
8/10	NA	Canada?
8/12	Pony	Idaho
8/13	Pony	Idaho

Selected PyroCbs

★ **8/16 Gold Pan**

★ **8/16 Beaver Creek**

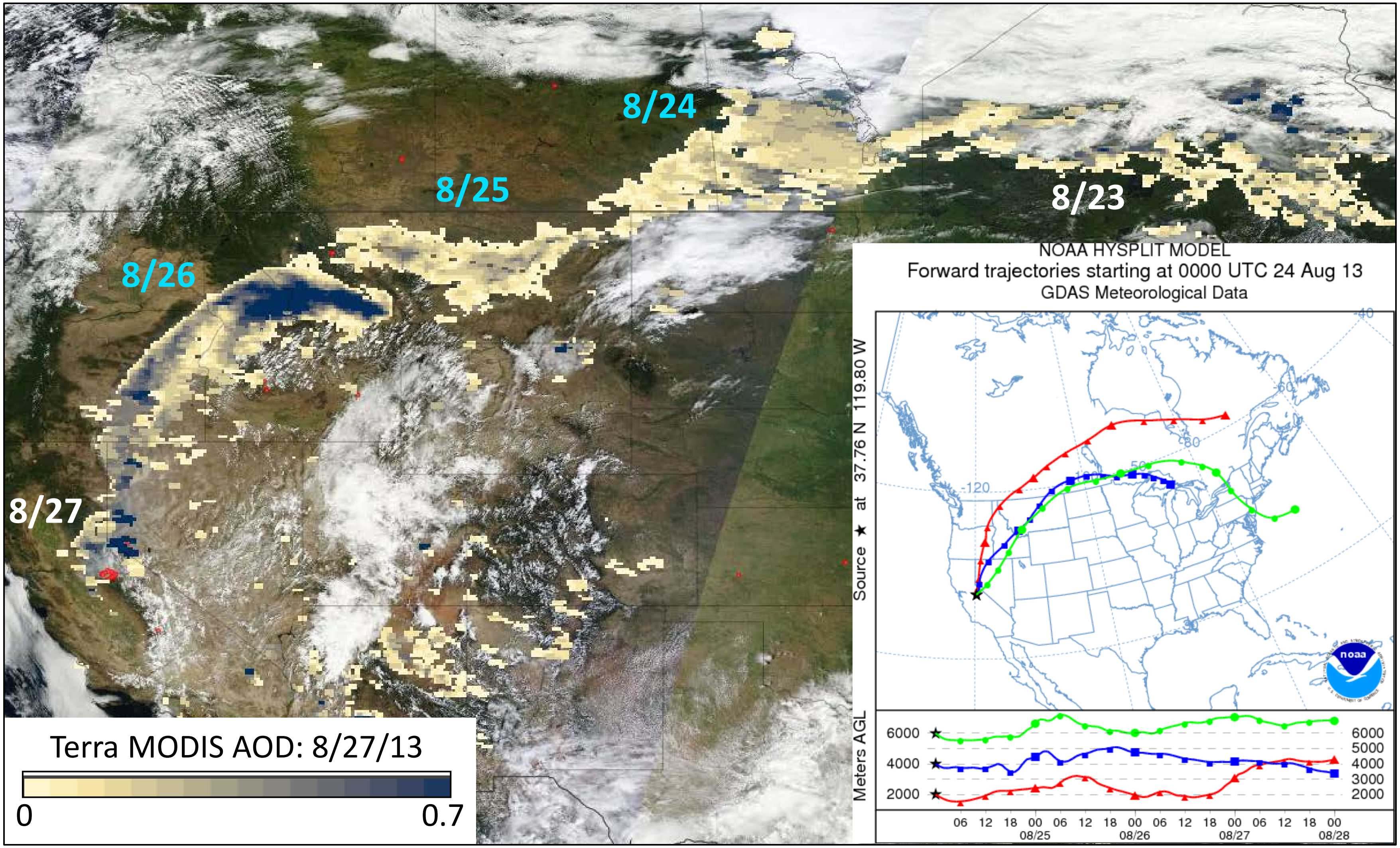
PyroCb impact on smoke properties?



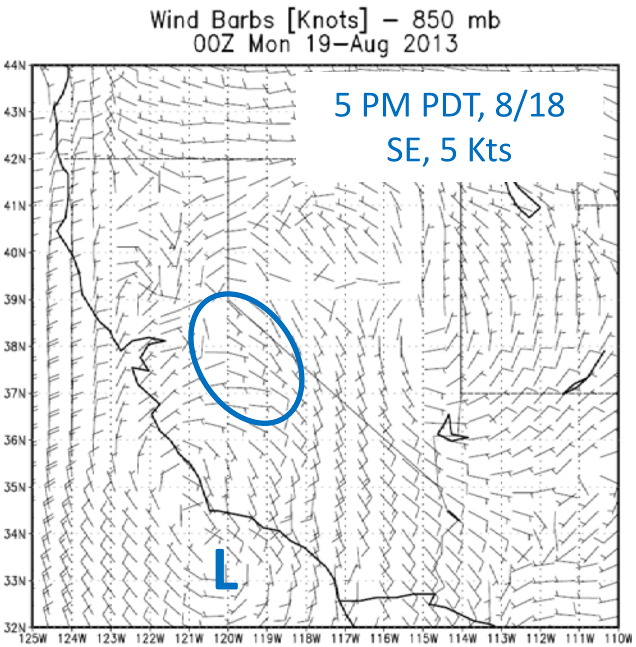
http://hsrl.ssec.wisc.edu/by_site/

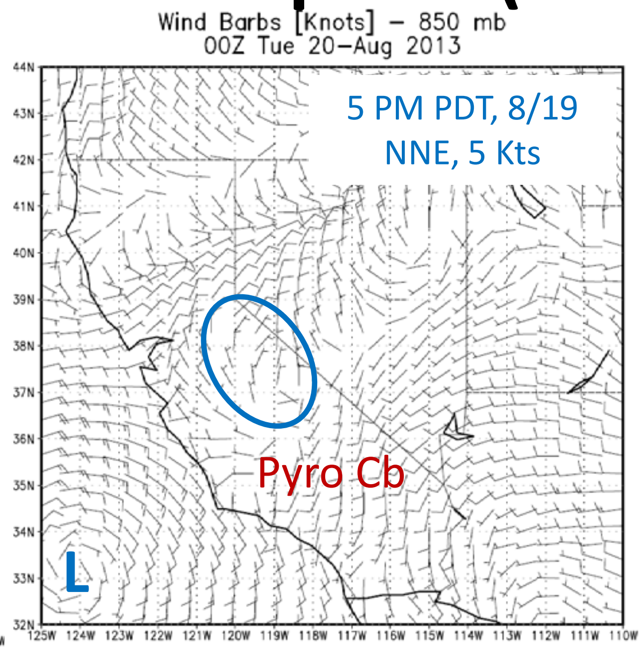
Rim Fire Smoke Plume Map (8/27)

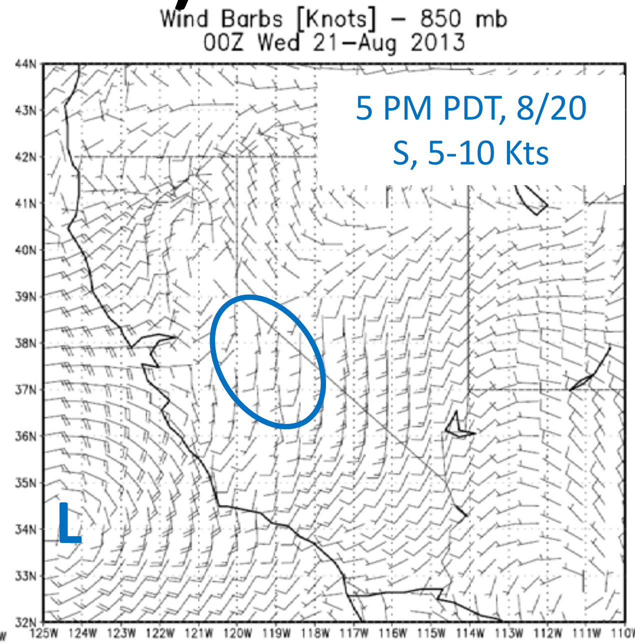
Map contains smoke emitted over 4-5 days (23-27 August)
SEAC[4]RS likely sampled 2-3 days of smoke (~24-26 August)

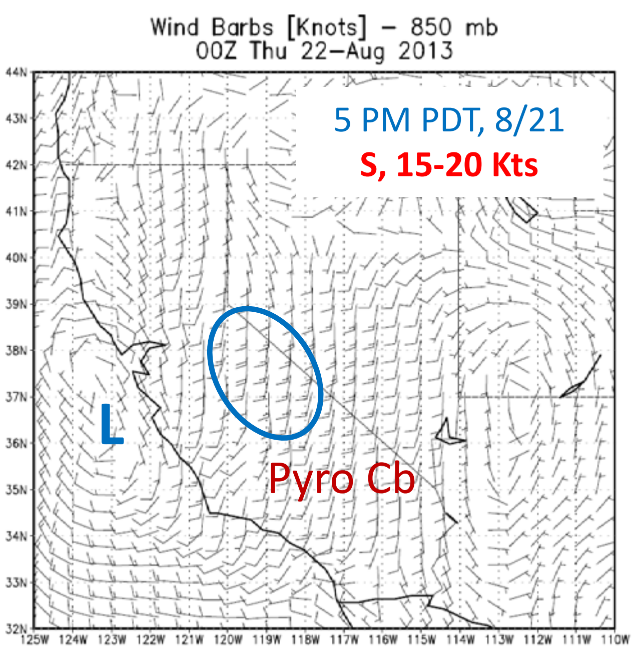


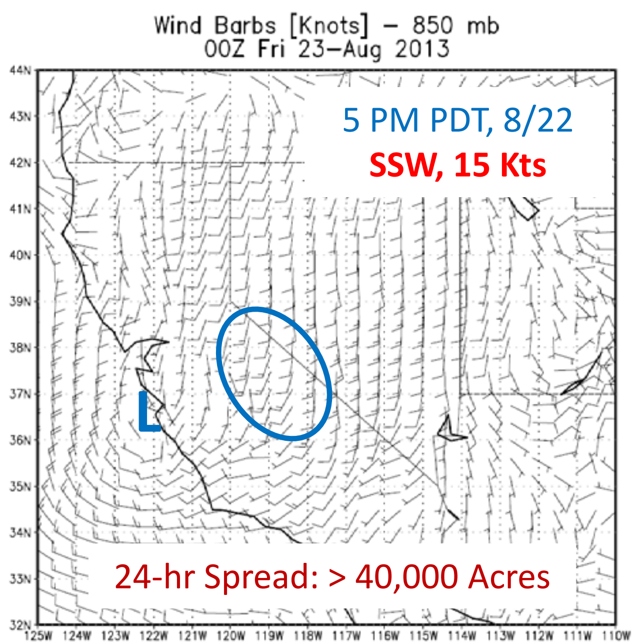
Low-Level Impacts (850 hPa)

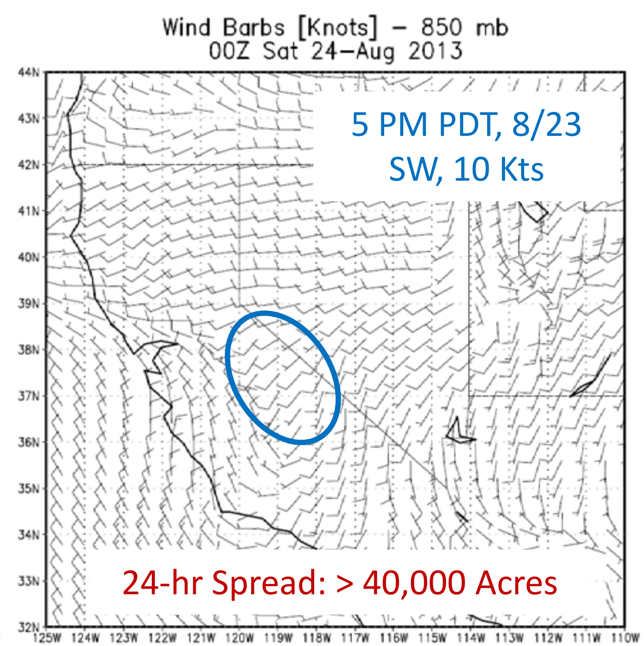




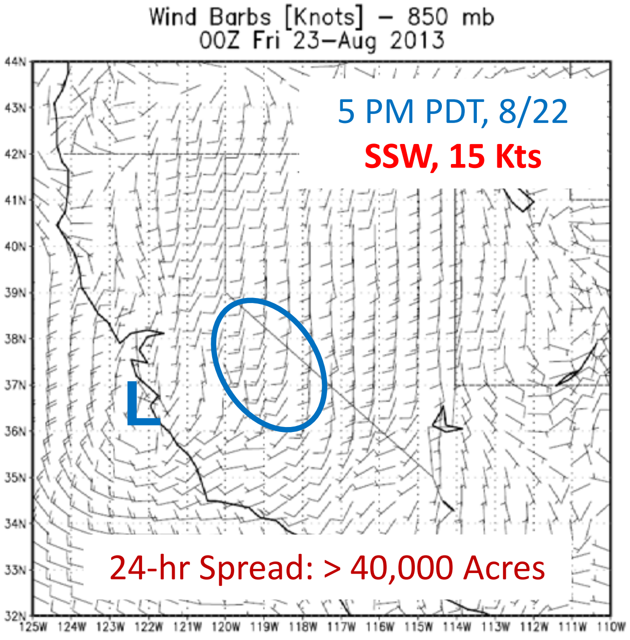


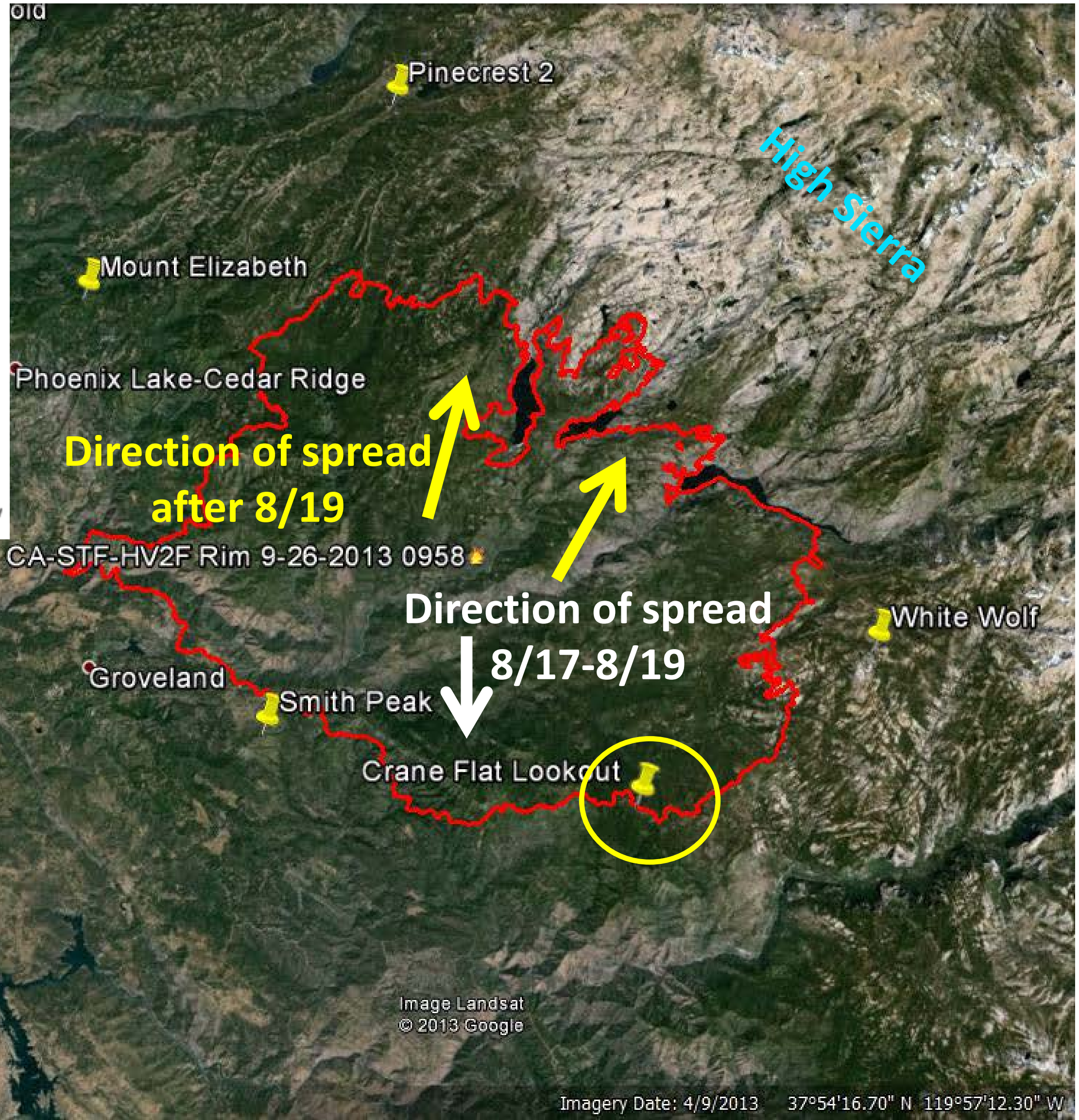






Wind Direction Relative to Topography

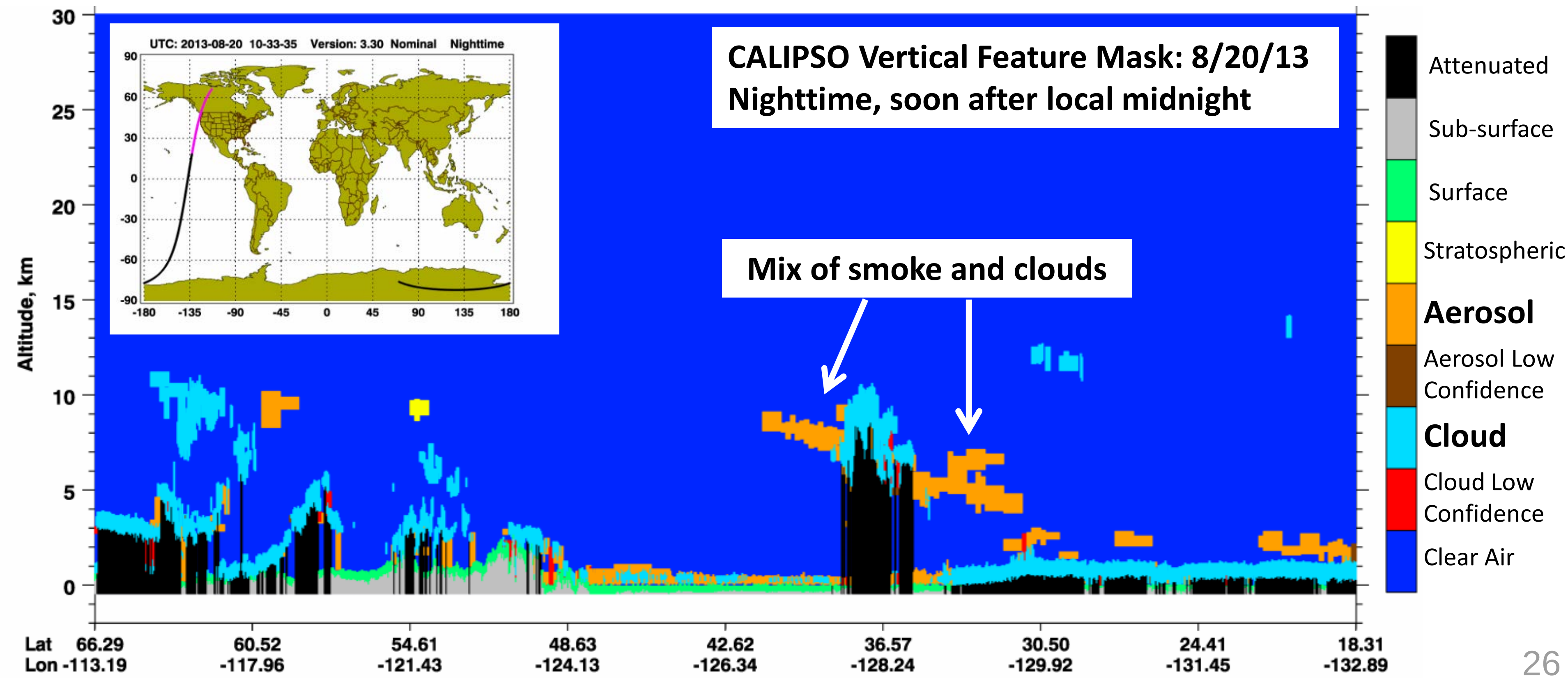




PyroCb Impact on Smoke Altitude

- Prediction of pyroCbs important for plume height!
- Less important for extreme fire spread
- Upper-level meteorology is key!

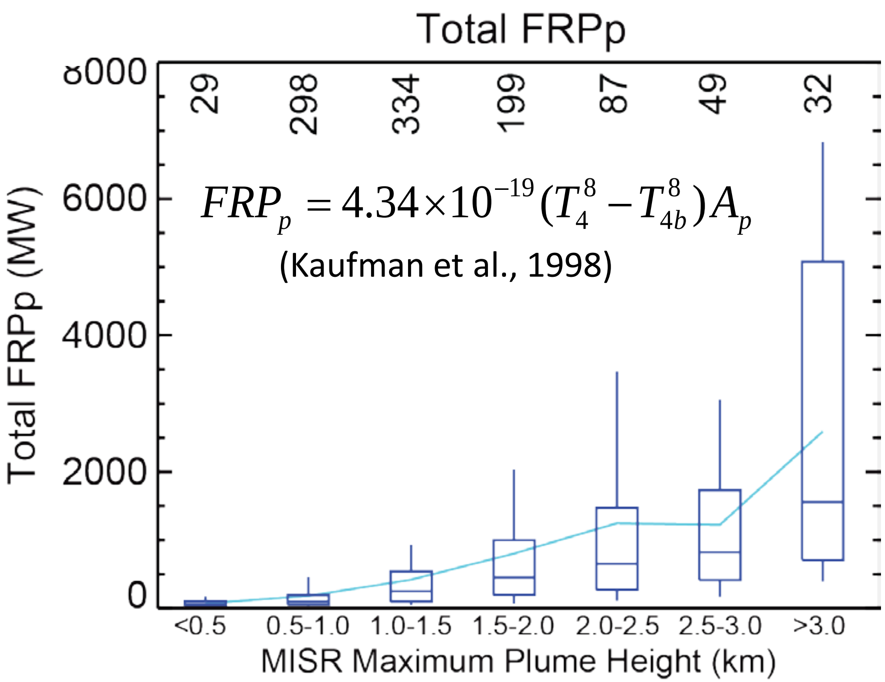
Observation	PyroCb	Spread
Smoke Altitude	> 8 km	< 6 km
FRP	Mod/High	Extreme
Haines Index	6	6

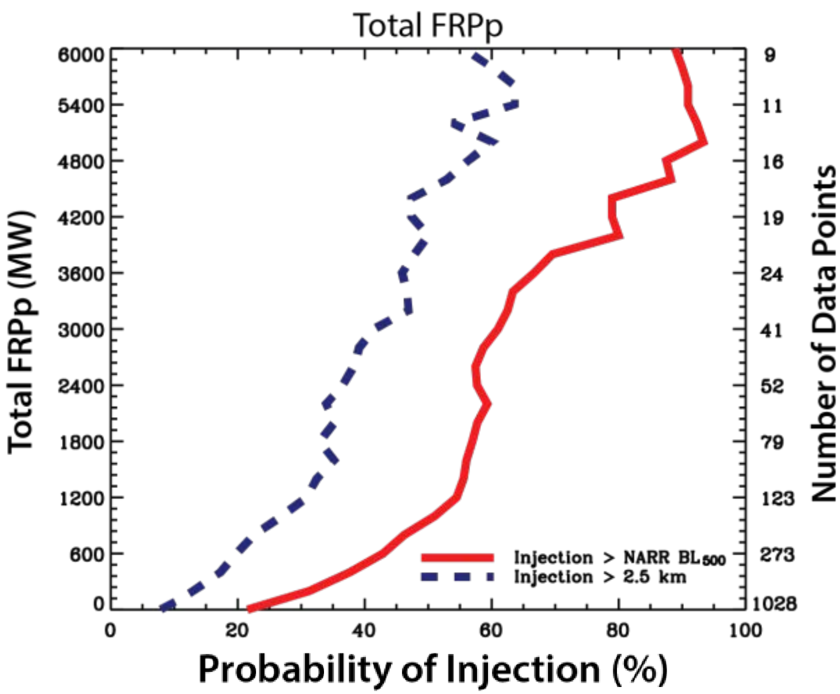


Signal of Plume Height in Pixel-Level MOD14 Data

Standard MOD14 data includes the number of fire pixels (fire counts) and FRPp

N = 1028, Alaska and Canada, 2004-2005

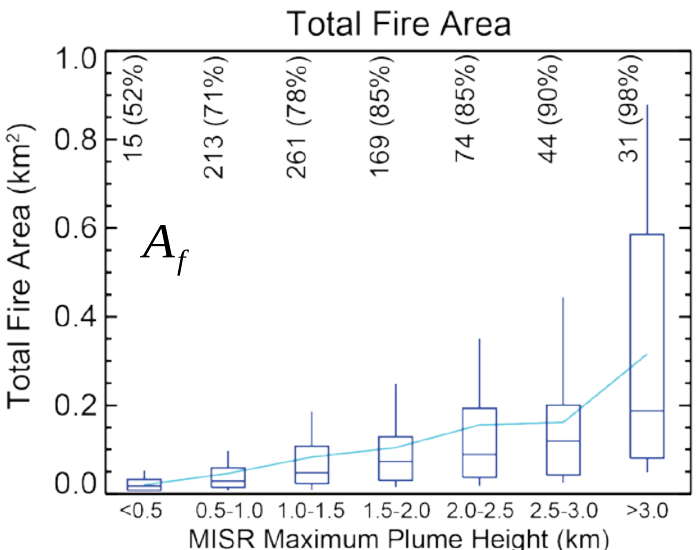


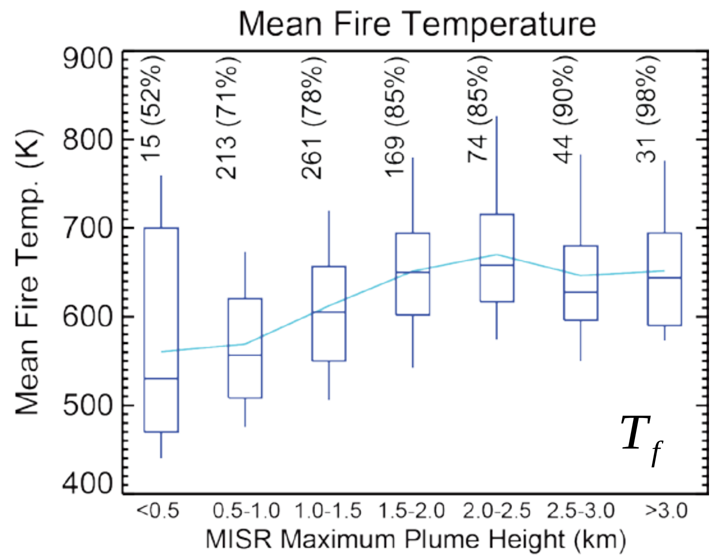


High injections generally correspond to the largest and most intense fire events!
Similar results have been shown in earlier studies (e.g. Val Martin et al., 2010).

Signal of Plume Height in MODIS Sub-Pixel Outputs

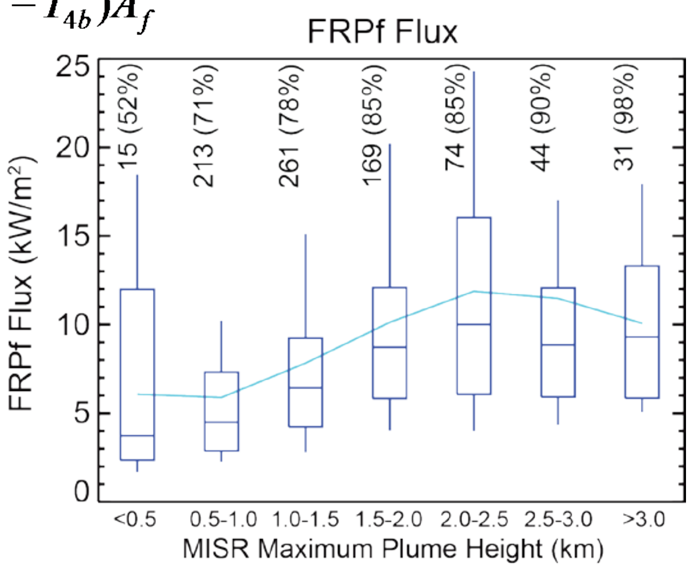
There is signal in the filtered sub-pixel data! Filtering primarily removes low injection cases!





$$FRP_f = \sigma(T_f^4 - T_{4b}^4)A_f$$

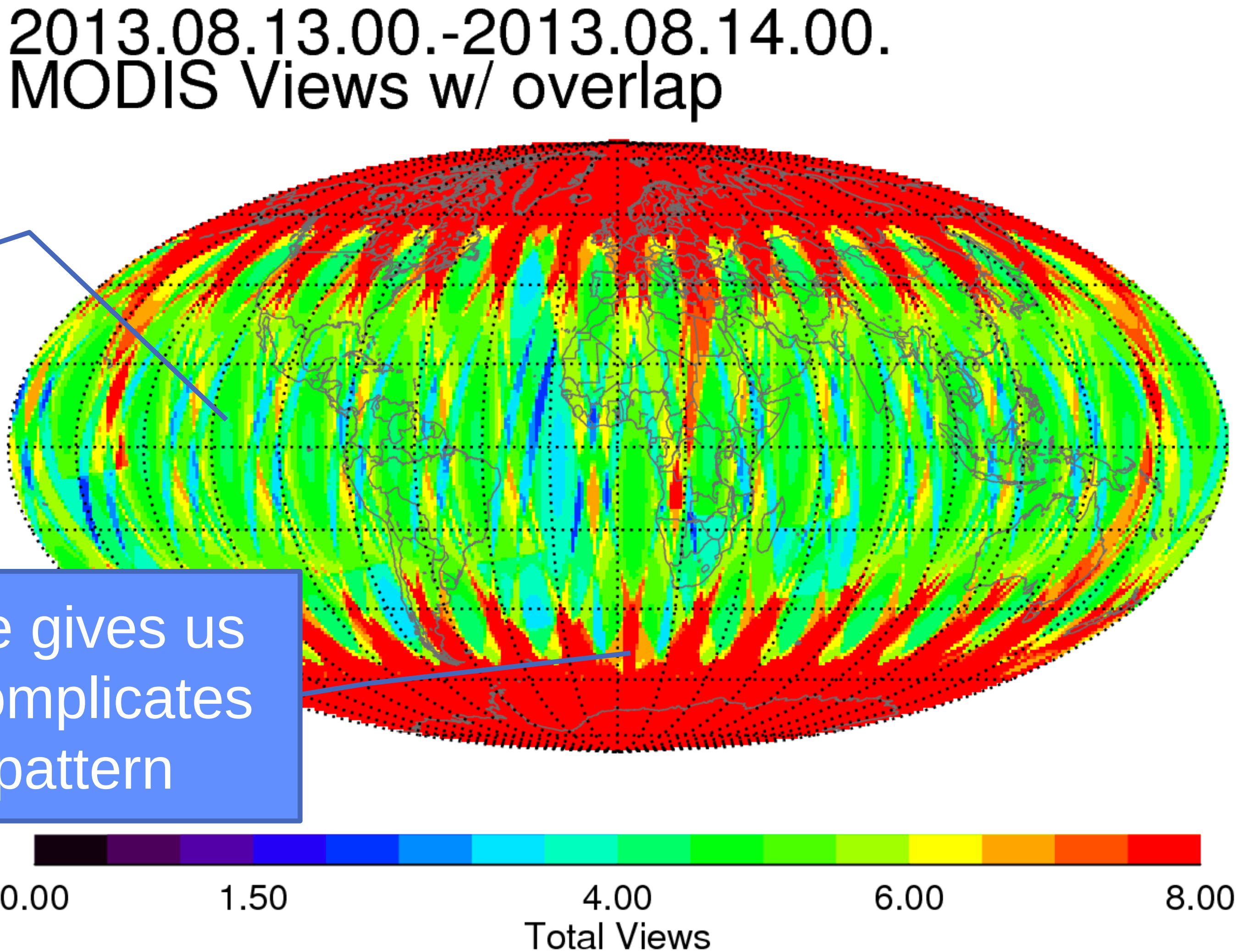
$$\frac{\sum_{i=1}^{n} FRP_{f_i}}{\sum_{i=1}^{n} A_{f_i}}$$



- Using a bi-spectral (4 and 11 μm) retrieval of sub-pixel fire area and temp. (Peterson et al., 2013; Peterson & Wang, 2013, RSE)
- **FRP_f flux**: closer approximation to fire line intensity!
  - Related to plume buoyancy!

Peterson et al., in press, JGR

Diagnosing MODIS time series: Coverage for one day

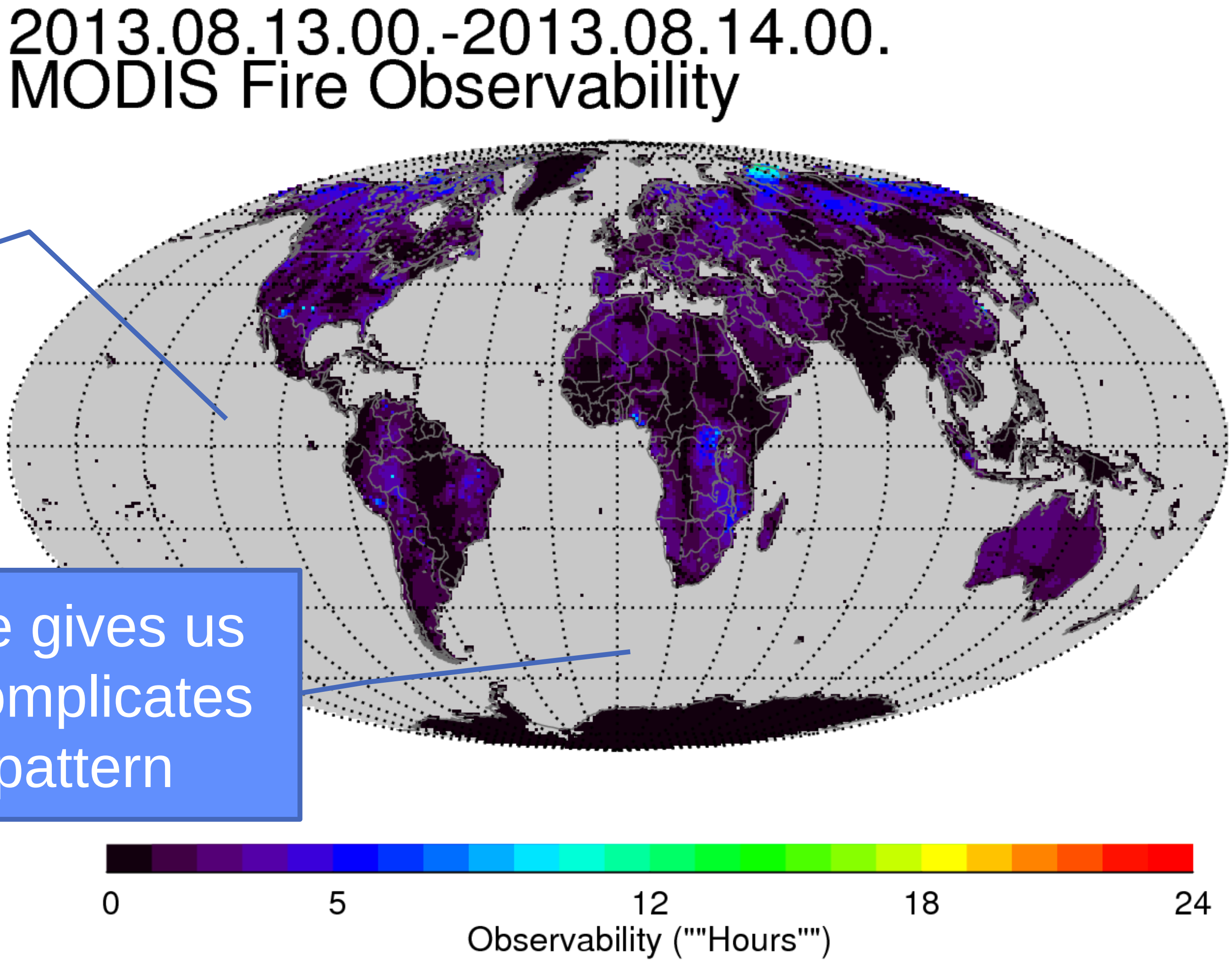


Over most of 50S-50N, we get 4 scenes/day: nominal MODIS coverage

MODIS bowtie gives us extra looks, complicates the spatial pattern

Diagnosing MODIS time series: Fire observability

Over most of 50S-50N, we get 4 scenes/day: nominal MODIS coverage



MODIS bowtie gives us extra looks, complicates the spatial pattern