A perspective on biomass burning research

DOE ASR/ARM

Sedlacek, Yokelson, et al.

Radiative Forcing Contribution of Biomass Burn (BB) Aerosols

Scientific Challenge:

To understand and quantify the role of BB in aerosol forcing (heating/cooling)

- Investigate the **evolution** of chemical, hydroscopic, microphysical, and optical properties of biomass burn aerosols in the near field

What is the **minimum knowledge** needed to accurately parameterize the contribution of biomass burn aerosols to radiative forcing?

Laboratory scale | Near-field scale | Meso scale

Current DOE Research

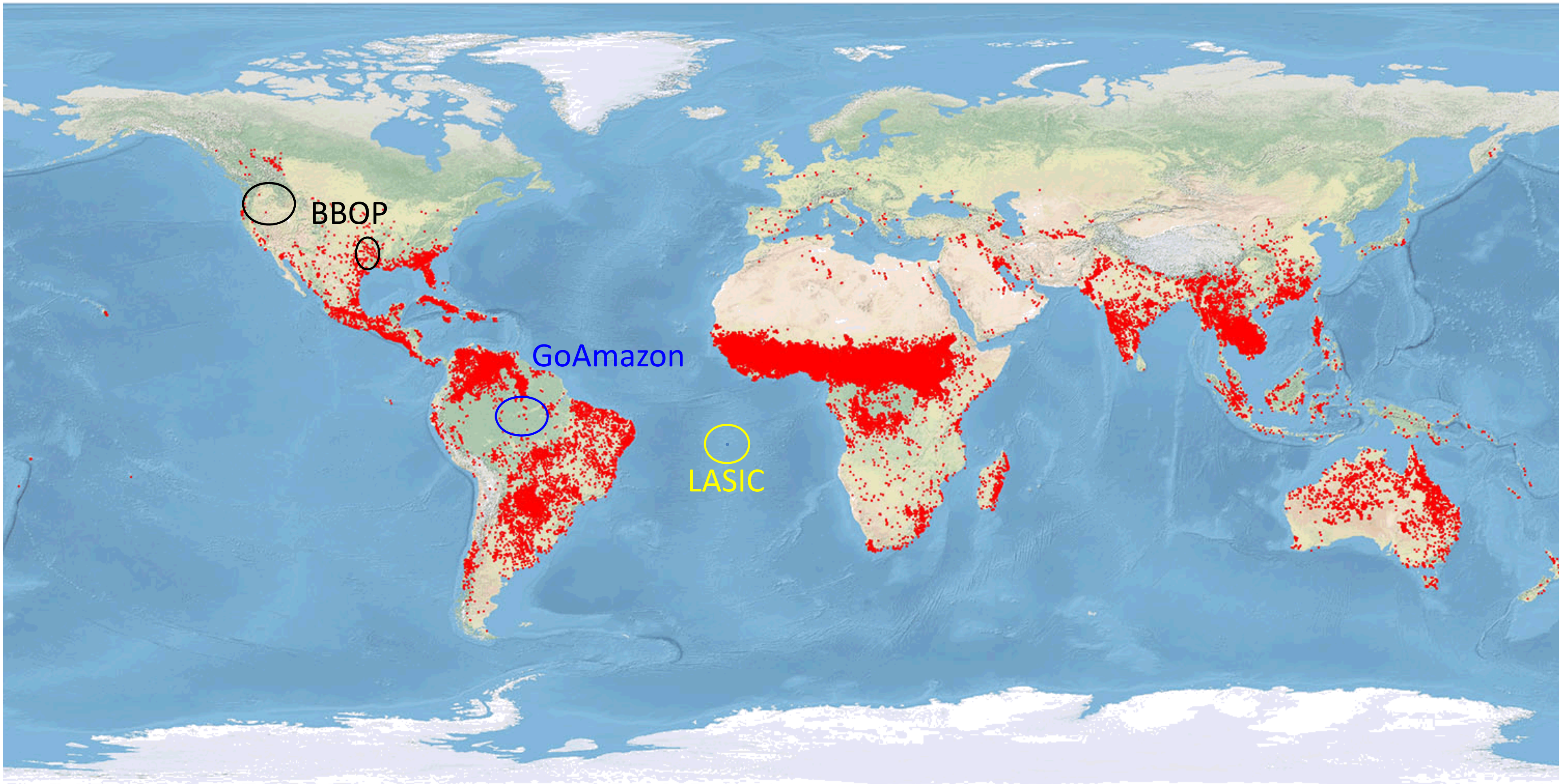
(incomplete….)

- Field
  - Biomass Burning Observation Project (BBOP)
    - Characterizing near-field biomass burning emission
  - Layered Atlantic Smoke Interactions with Clouds (LASIC)
    - Studying biomass burning emissions interactions with clouds
  - Green Ocean Amazon (GOAmazon)
    - Dry season offers targets of opportunity to study BB in rainforest
- Laboratory
  - Tar balls
- Modeling

Current State of the Science…

Biomass burning is a global issue with poorly characterized sources that effects human health, ecosystems, visibility (air quality), & climate.

2013 MODIS Active Fire Detections from the Aqua and Terra satellites



January February March April May June July August September October November December

Active fires, shown in red, are detected using MODIS data from the Aqua and Terra satellites.
Source: NASA Fire Information for Resource Management System (FIRMS) https://earthdata.nasa.gov/firms

Global Emissions Tg per year

Source	Total C	gas-phase NMOC		Primary PM2.5	
		VOC	SVOC	BC	OC
FF (Total)	7000	200		3	2
BB (Total)	4600 (6300)	200 (365)	200 (365)	5 (5.7)	32 (53)
Biogenic	1000	800	200		7

Sources: Akagi et al 2011; Bond et al 2013; Guenther et al 2006; 2012; Heald et al 2009

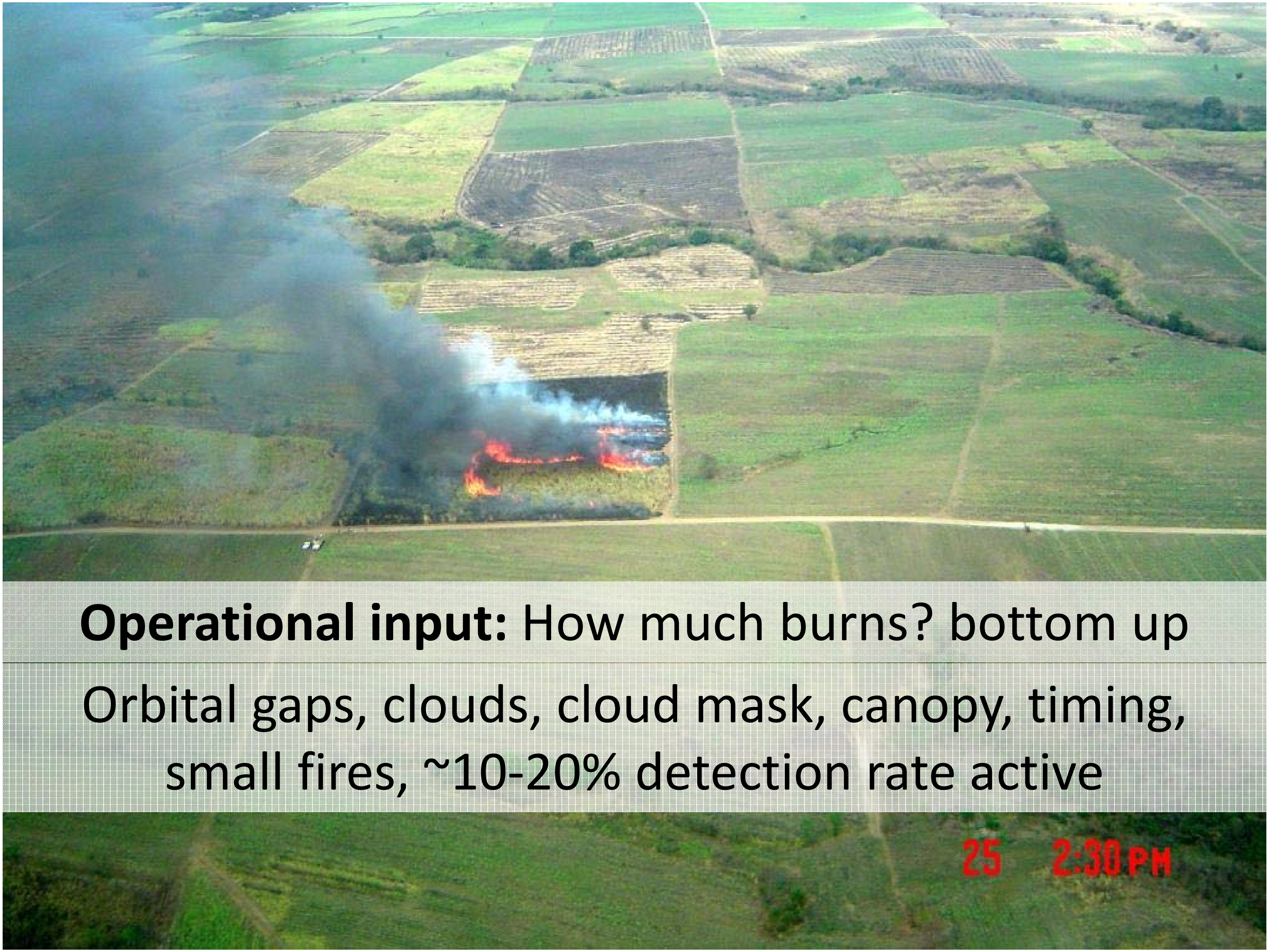
Science focus areas

1. Quantifying BB emissions (wildfire & agricultural burn) including bottom-up and top-down approaches
2. Quantify BB emissions during nighttime
3. Represent the highly variable spatially and temporally components of emissions and understand fresh plume dynamics
4. Characterize chemistry of emissions and understand chemical evolution and SOA in downwind plume
5. Understand smoke – cloud interactions

Quantifying BB emissions (wildfire & Agricultural burn) including bottom-up & top-down approaches

Under Sampling of BB Emissions

- Until recently, very few measurements of the emissions from wildfires and crop-residue burning in the US
- This is starting to change as biomass burning becomes more of a science focus
  - **2013 DOE ARM BBOP**
  - 2013 NASA SEAC4RS
  - 2016-2019 NOAA FIREX
  - 2019 NASA FIRECHEM
  - 2018-2021 Joint Fire Science Program (JFSP), DoD, and ESTCP sponsored FASMEE studies

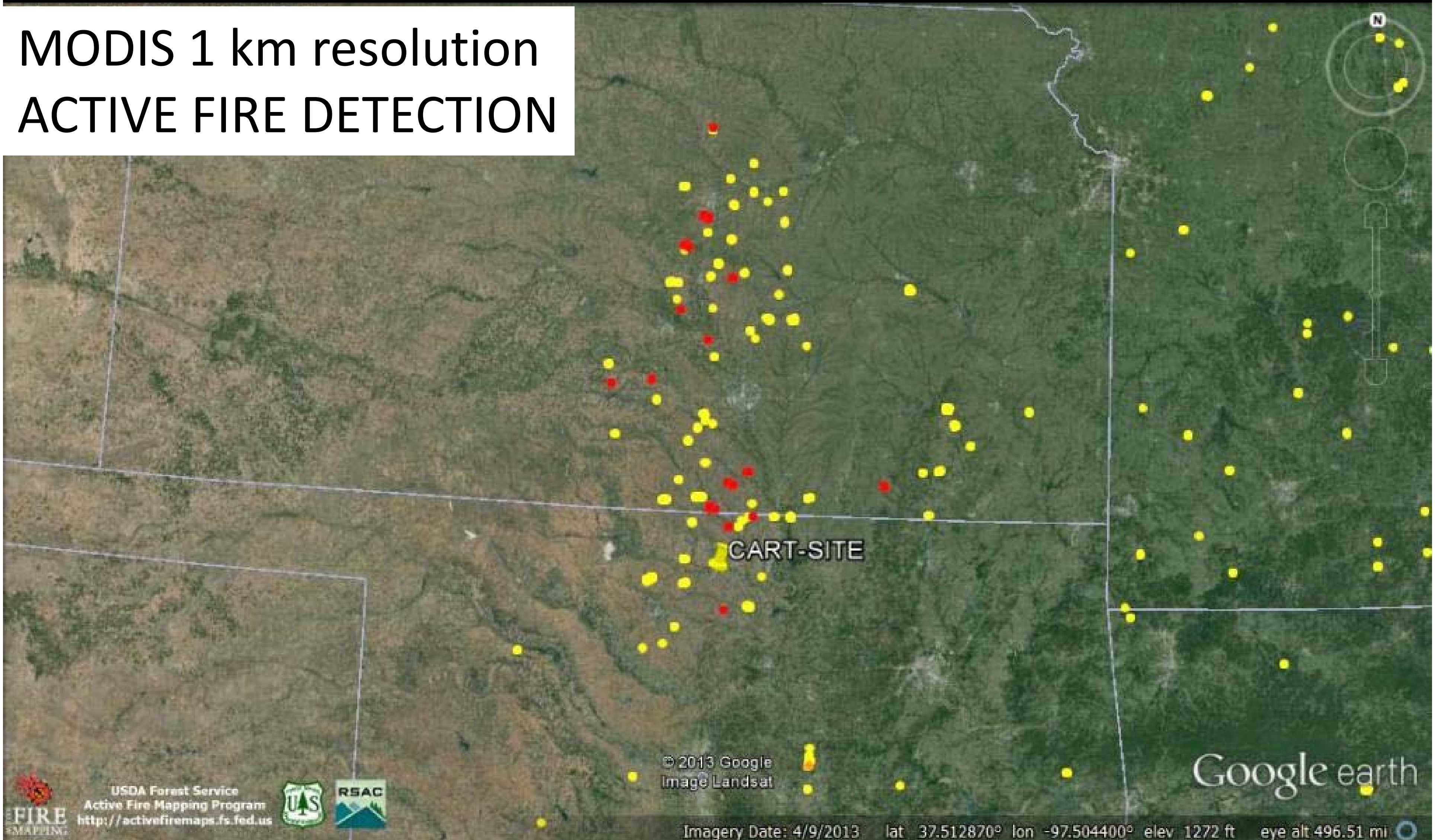


Operational input: How much burns? bottom up

Orbital gaps, clouds, cloud mask, canopy, timing, small fires, ~10-20% detection rate active

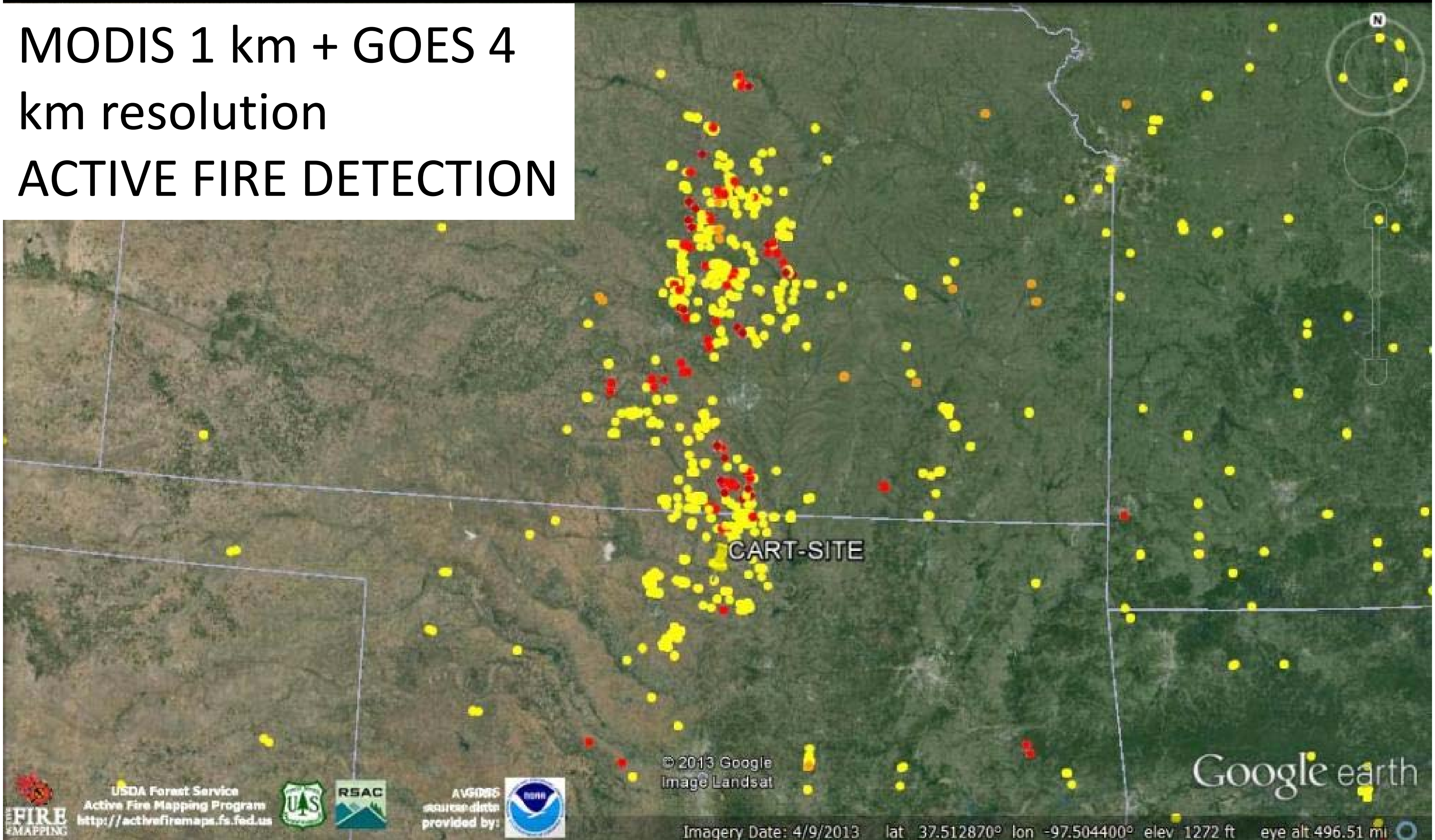
Operational input: How much burns? bottom up

MODIS 1 km resolution
ACTIVE FIRE DETECTION



Operational input: How much burns? bottom up

MODIS 1 km + GOES 4 km resolution
ACTIVE FIRE DETECTION

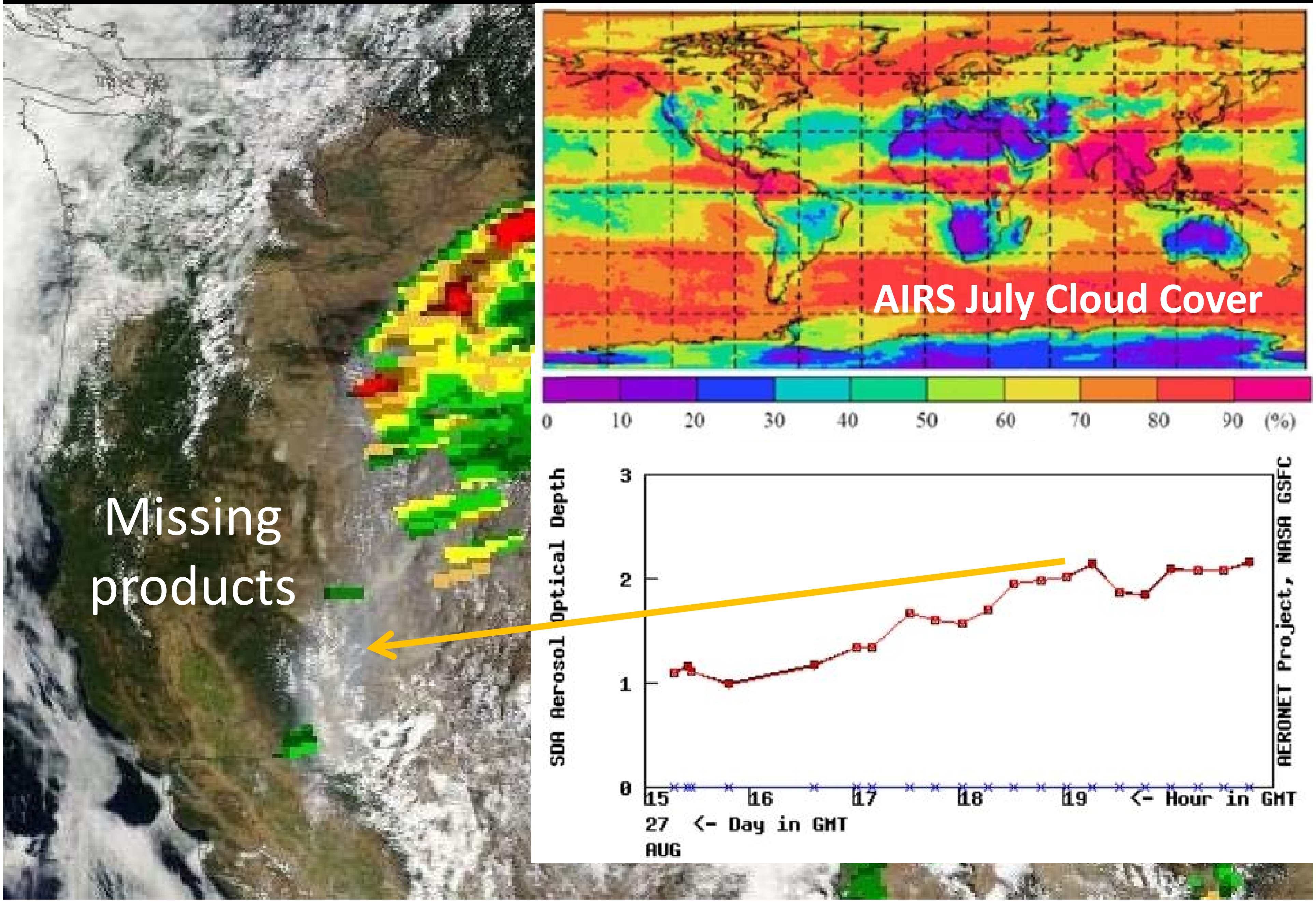


Look more, see more, limits of “persistence”

Operational input: *a-priori* scaling factors in inversions

Study	**"scaling factor"**	**What/where**
Kopacz et al (2010)	2	CO/ SE-Asia, Africa, +
Bond et al (2013)	4	BC absorption/ Southern Hemi
Van der Werf et al (2010)	19	Ag-fires/ CONUS
Lu and Sokolik (2013)	10	AOD/ Canada
Reddington et al (2016)	1.5 (FINN)	AOD, Surface PM/Brazil, Thailand

Operational input: How much burns? Top down



Operational input: major uncertainties

Summary: smoke amount, chemical and optical props of both fresh and aged, evolution, mapping.

Smoke production ***bottom up:***

- Burned area uncertainty
- Misassigned fuel consumption per unit area
- Unknown emission factors
- Emission ratios (ER)

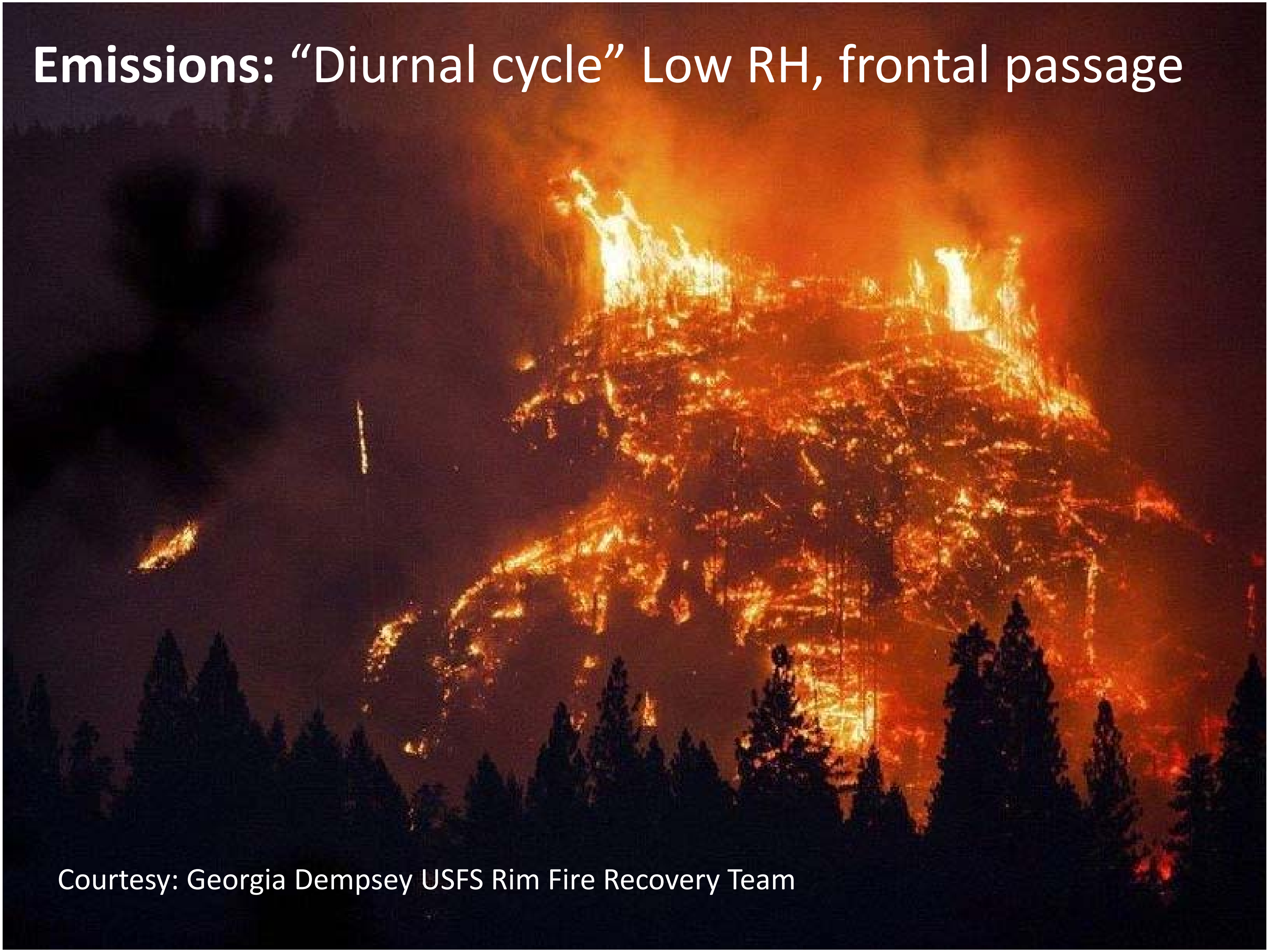
Operational input: major uncertainties (continued)

*Smoke production **top-down:***

- Missing fires (cloud masking)
- Missing products (clouds, gaps, AND limited species that can be measured)
- Variable injection altitude
- Meteorology: dispersion and mixing effects
- Variable/unknown evolution of measured and unmeasured species
- Misassigned product sources (e.g. haze due to multiple sources)

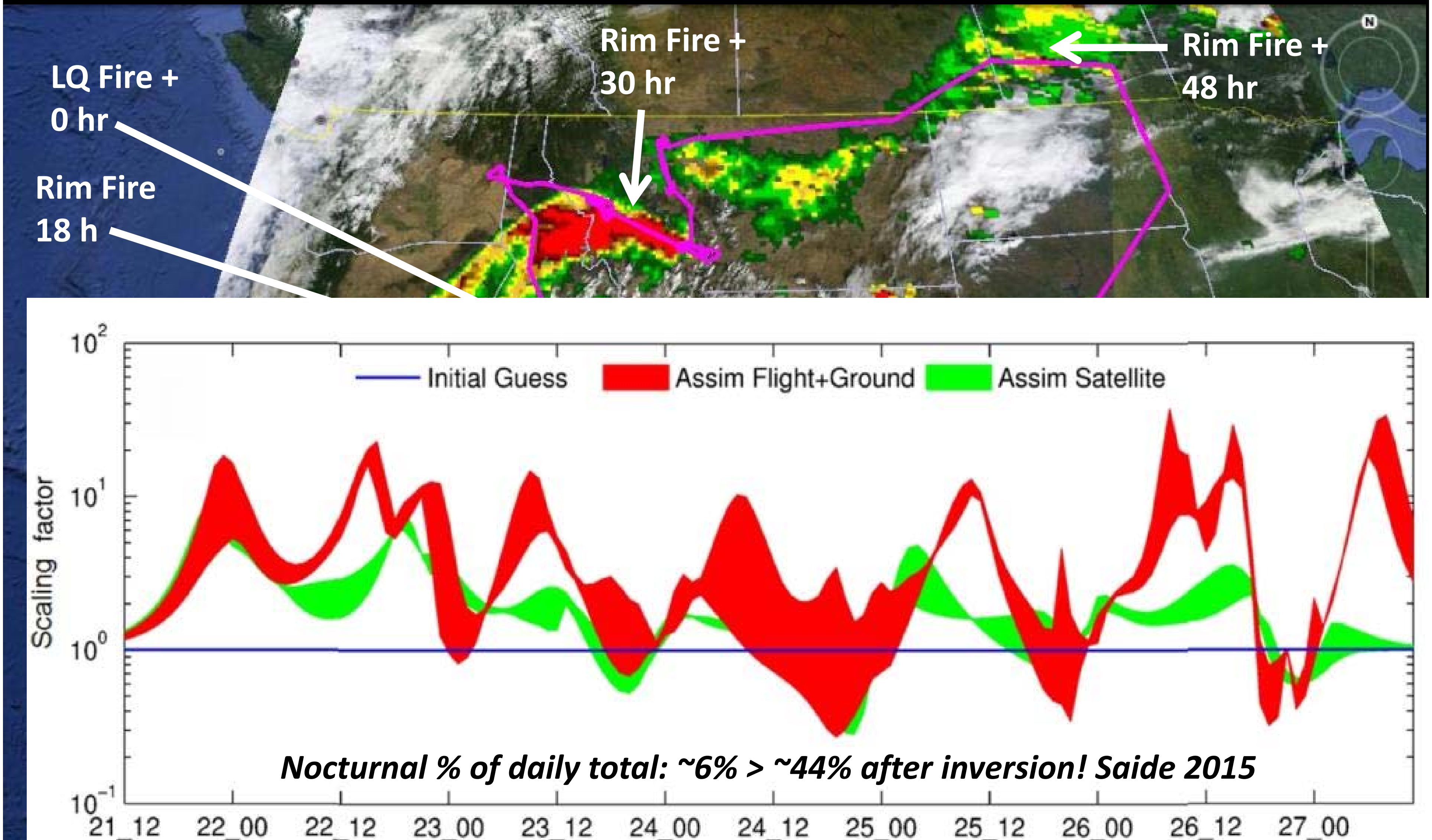
Quantify biomass burning emissions during nighttime

Emissions: “Diurnal cycle” Low RH, frontal passage



Courtesy: Georgia Dempsey USFS Rim Fire Recovery Team

Emissions: air plus ground evaluation of usual constraints DC-8 flight tracks and 2013-08-27 TERRA/AOD

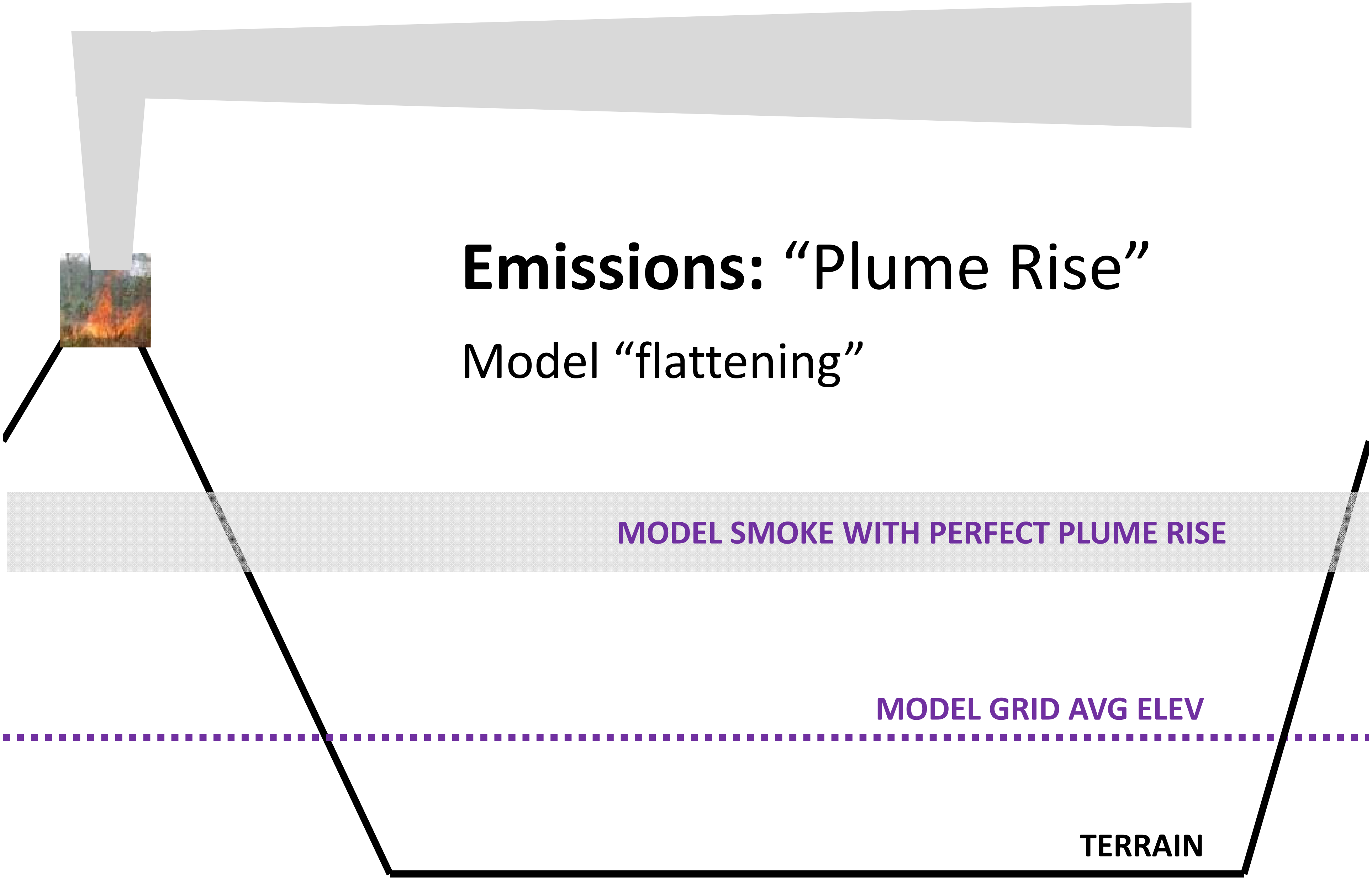


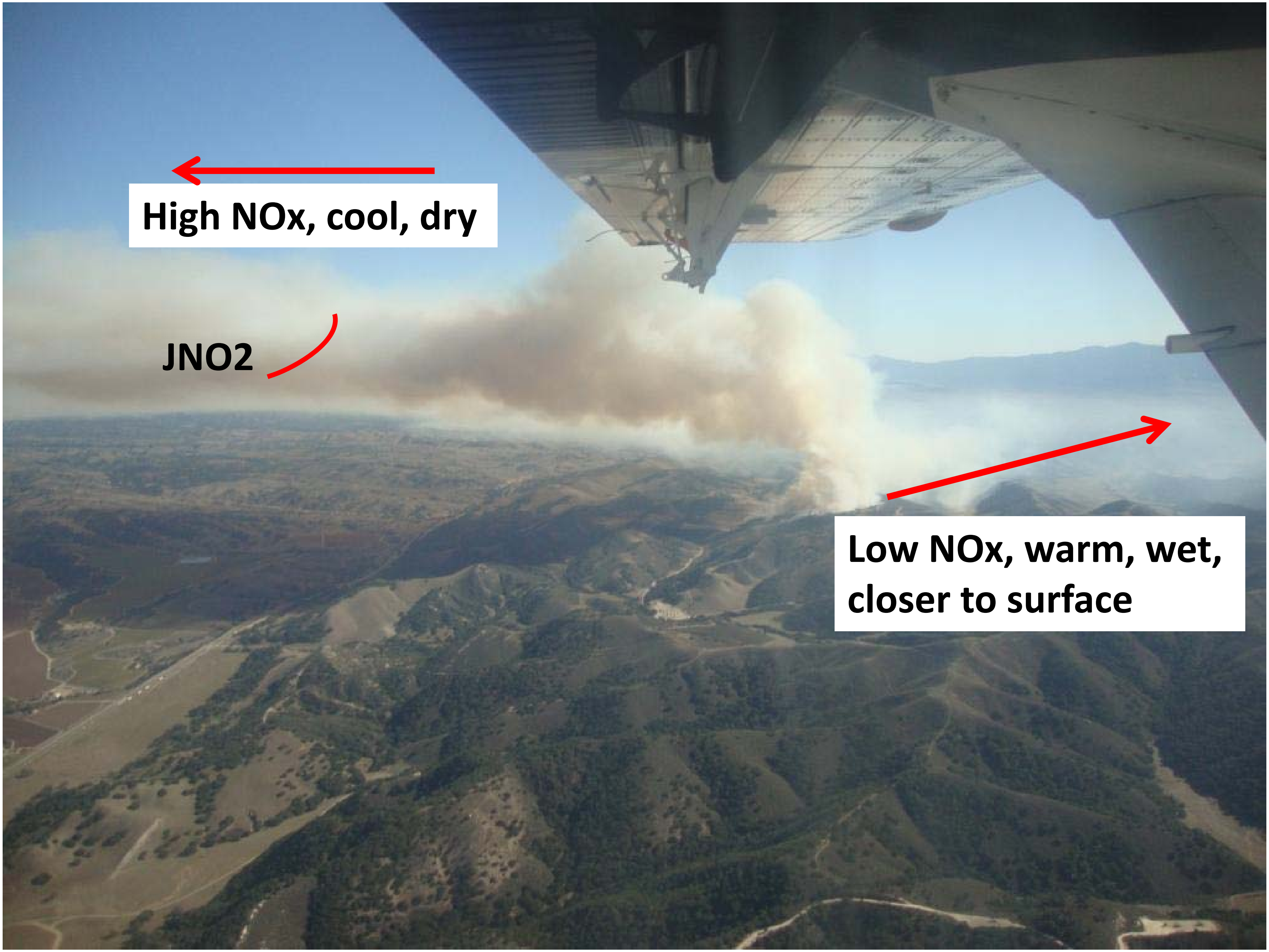
Represent the highly variable spatially and temporally components of emissions and understand fresh plume dynamics


Emissions: “pyrodiversity” includes evolving spatial pattern

Emissions: "Plume Rise"

Model "flattening"




High NOx, cool, dry
JNO2
Low NOx, warm, wet,
closer to surface

Residual smoldering combustion (RSC) AKA "post-frontal combustion"

- Definition: ~ "combustion with products not initially "significantly lofted" by flame-induced convection
- 90% of total emissions from a crown fire in Alaska
- Extreme PM per unit fuel consumption (volatile), major AQ issue!

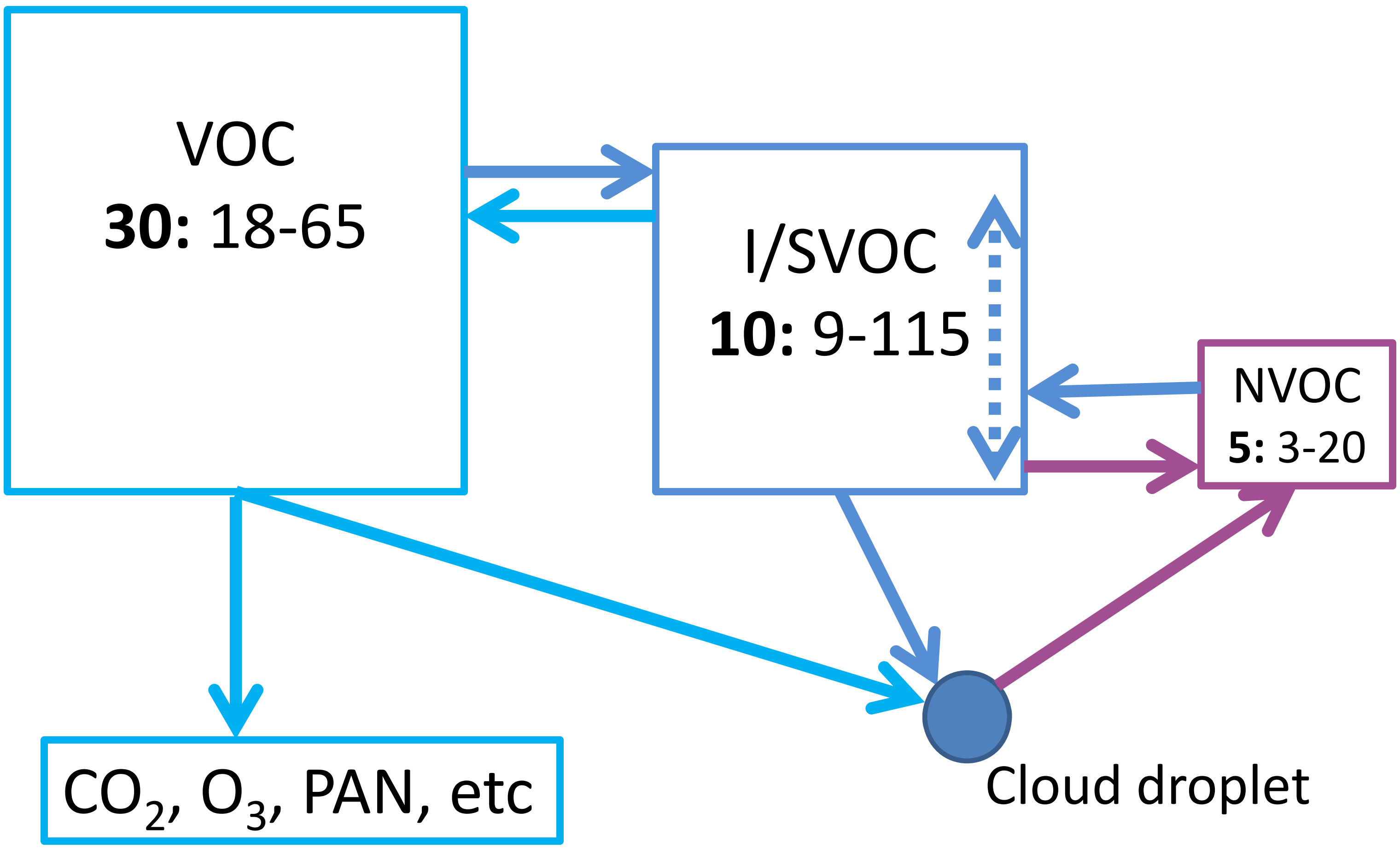
Characterize chemistry of emissions and understand chemical evolution and SOA in downwind plume

Emissions: Undersampled chemistry: e.g. non-methane organic gases especially SVOC precursors

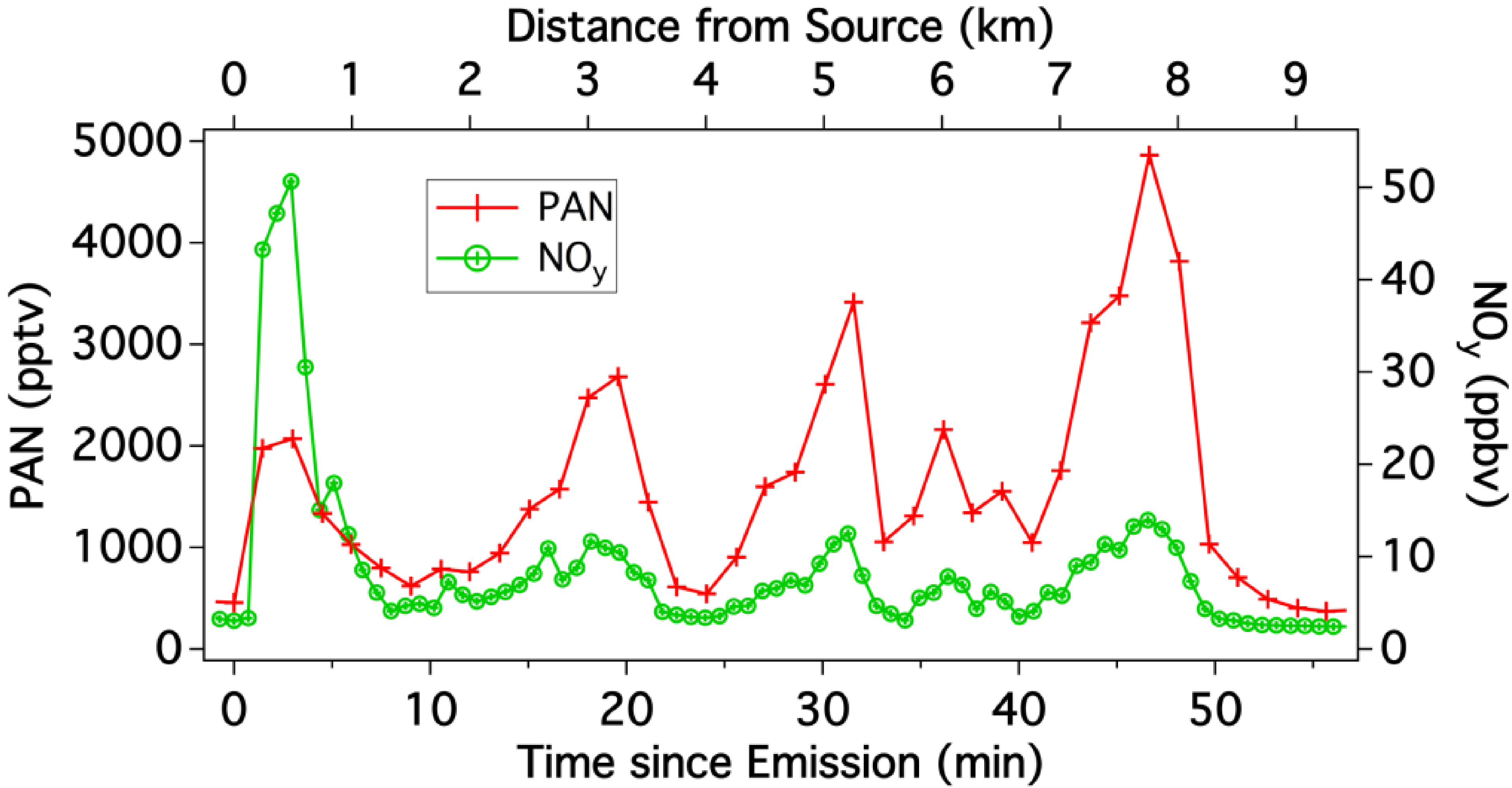
Percent of unidentified NMOG mass in lab smoke				
Year	Chaparral	Coniferous	Peat	Avg-all
2009 w/NOAA	31	47	72	45
2012 FLAME-4	7-15	7-17	20-37	8-19
2016 FIREX				

Evolution: mass transfer between initial volatility pools, g/kg avg: range

Muller (2016) fast airborne PTR-MS tracks C-pools

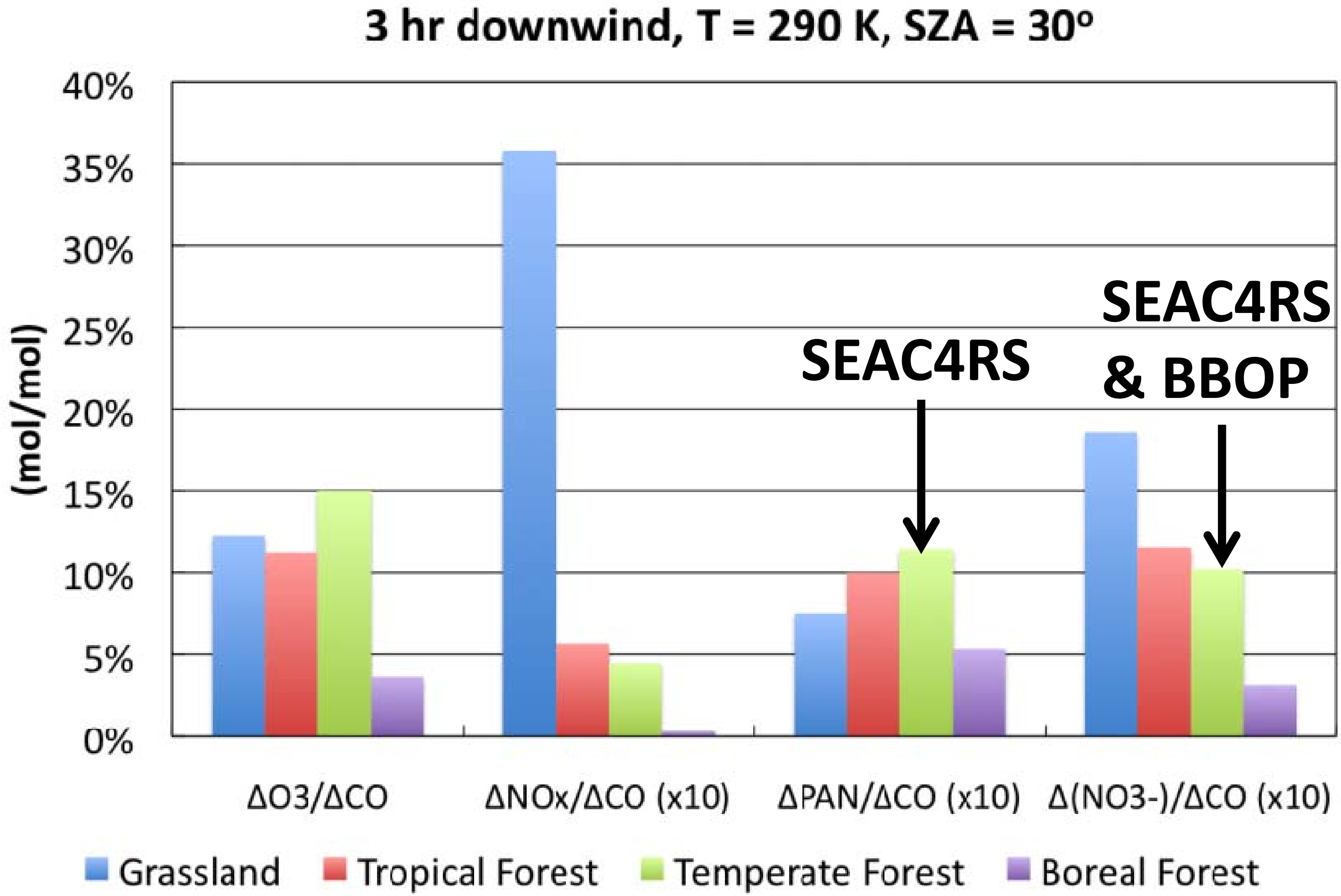


SEAC[4]RS PAN formation: space, time, subgrid?



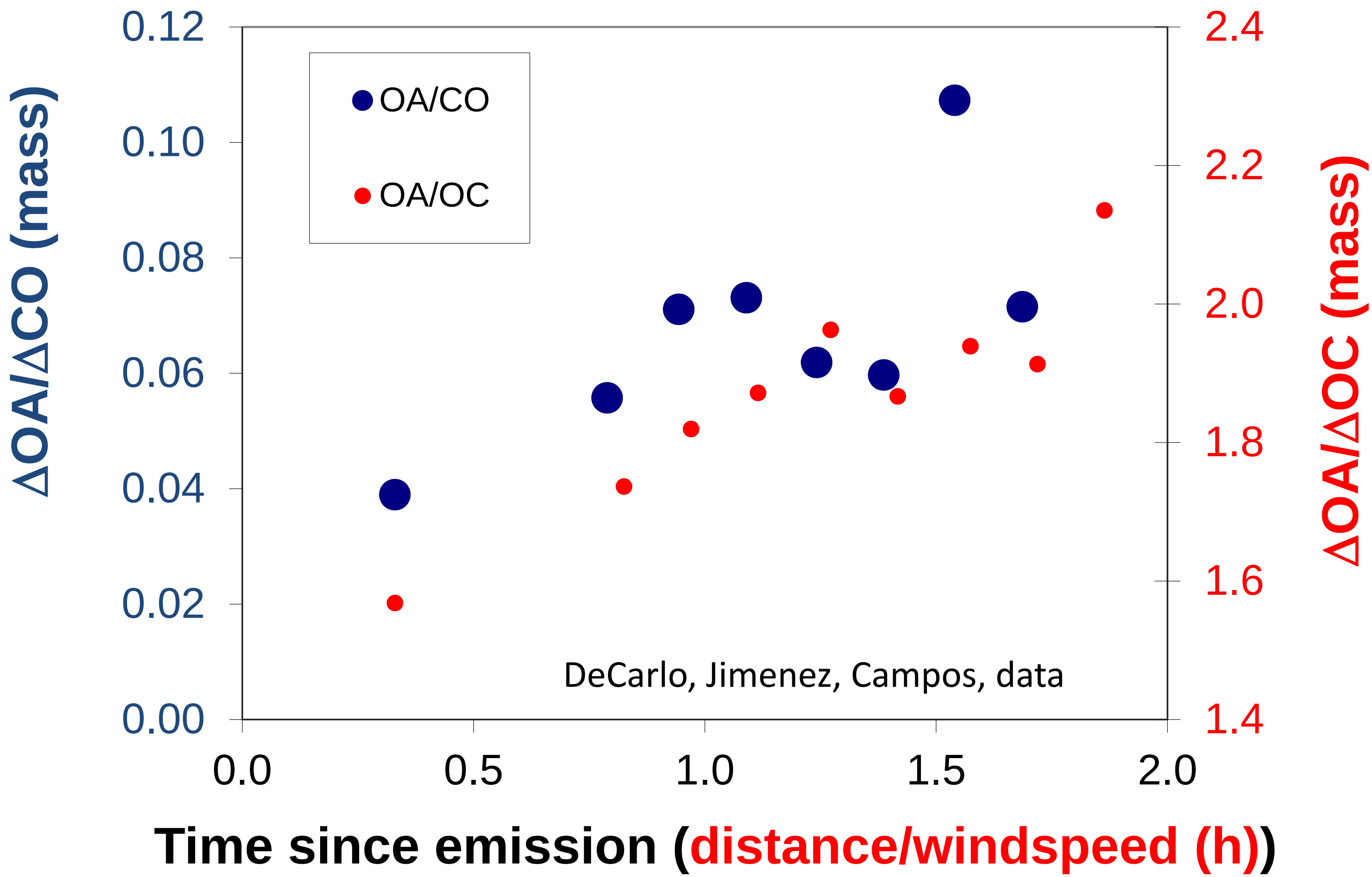
PAN: Xiaoxi Liu, Greg Huey, Dave Tanner GA Tech. NOy: Tom Ryerson NOAA.

Evolution: look-up tables for GEOS-Chem

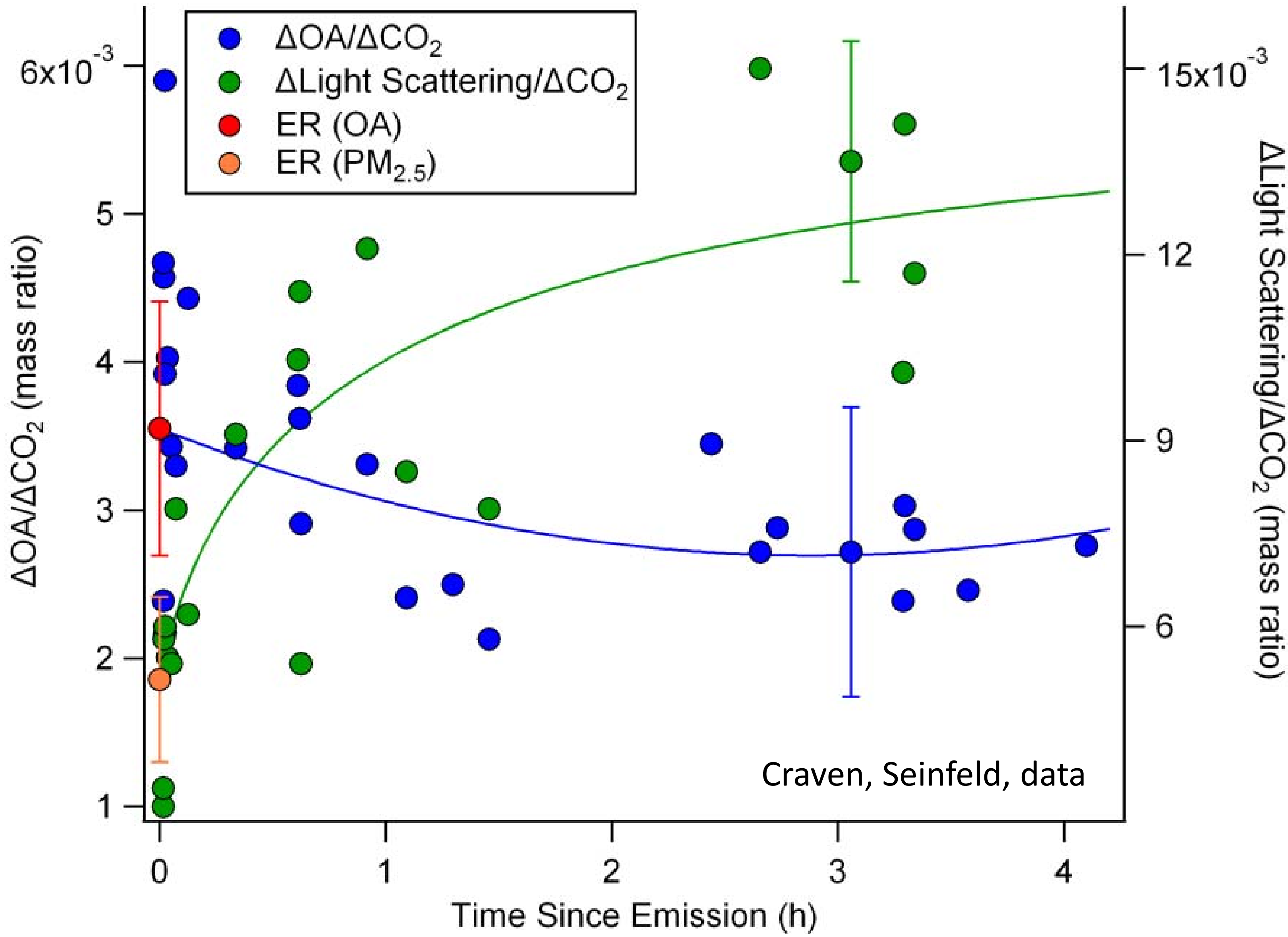


Courtesy: Matthew Alvarado, Atmospheric Environmental Research

Evolution: net secondary organic aerosol (SOA)

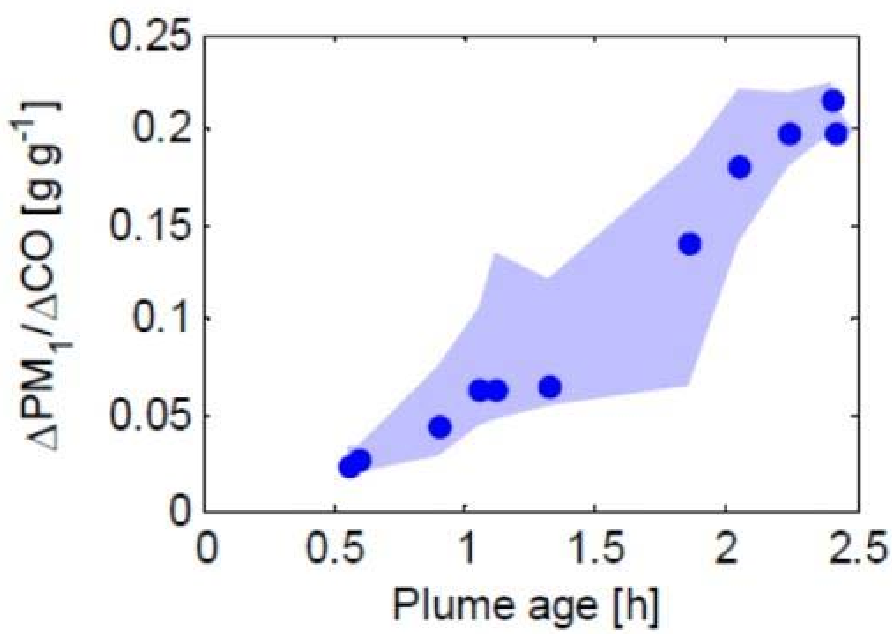


Evolution: no net SOA, but scattering increase



Evolution: SOA controls?

- Jolleys et al (2012) review of field campaigns concludes no net source of SOA in biomass burning plumes
- Controlling factors (precursors, RH, etc?) largely unknown
- What's normal?
- Aerosol evolves even when no enhancements occur (e.g. May et al differential evaporation).
- Small enhancements are significant!



Vakkari et al (2014) PM1 increase partly inorganic, often overlooked!

Understand smoke – cloud interactions

Evolution: Cloud processing of smoke

- Smoke and fairweather cumulus are like “milk and cereal”
- **DOE LASIC** (breakout session Wednesday 10:30)
- NASA ORACLES

Conclusions:

Emissions: First detailed emission factors for previously little-studied US wildfires and agricultural burning (BBOP/SEAC4RS). Top-down/bottom-up discrepancy

Evolution: New smoke evolution case studies at 1-40 hour time scales for wildfires and ag-burning.

Product/model validation: Evaluating operational input and model performance with aircraft data

These advances, especially in combination, will improve present and future atmospheric modeling of air quality, visibility, climate, etc

Operational input: improvements on horizon

1. *<u>More aircraft evaluation of inventories scaled with "usual" constraints</u>*
2. *<u>Better smoke chemistry, fresh and evolution</u>*
3. *<u>New products and sensor from space</u>*

MODIS smoke over cloud AOD, GOES, VIIRS aerosol, MISR validation

VIIRS 750 and 375 in orbit

Sees small fires better than MODIS, other

GOES-2016:

4X better spatial res, 5X better time res, 3X better spectral

TEMPO-2018 (Tropospheric **E**missions: **M**onitoring of **Po**llution**):**

High res gases, e.g. CO

Good timing for FIREX, Fire-Chem, C-130!