Observing Biomass Burning Emissions and Its Impacts: Everything you should know and probably don't want to hear.

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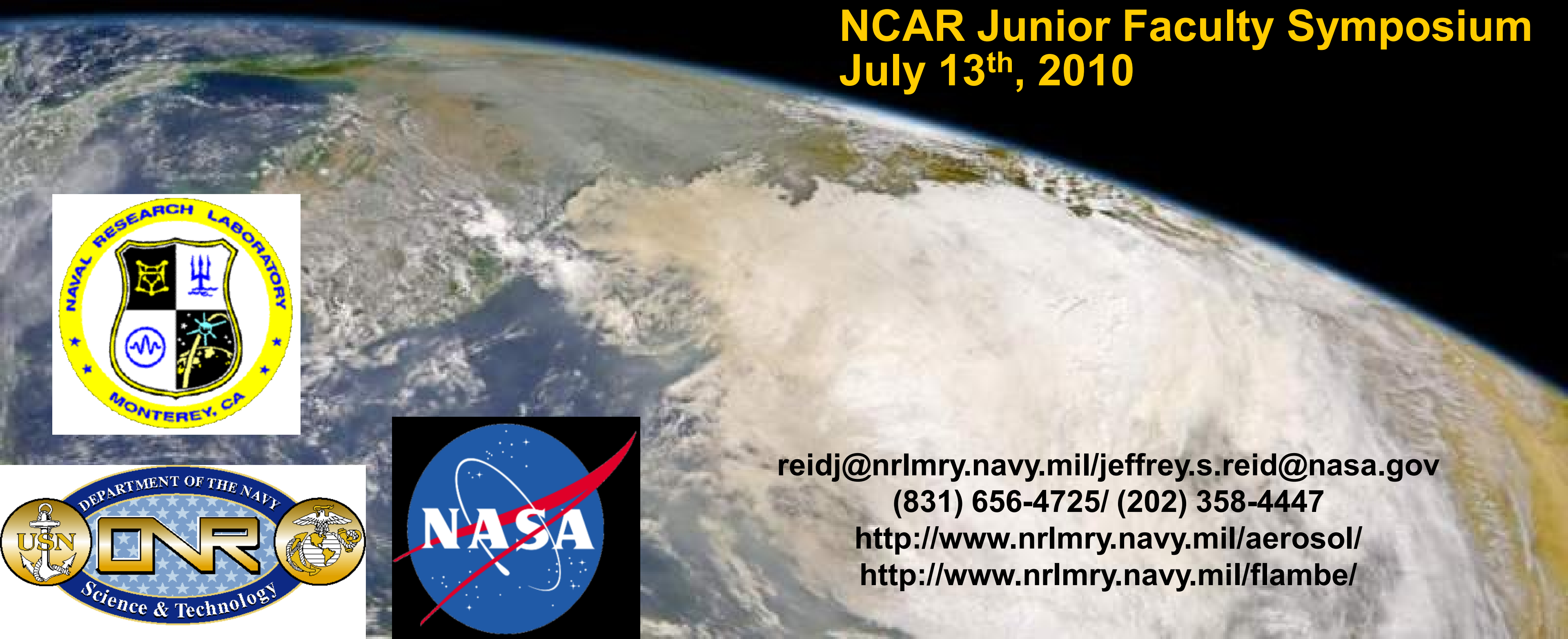

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First the bad news

- Biomass burning problems are massively underdetermined.
- Nearly all “measurements” you are making are not measuring what you think they are.
- What you really want to measure at the moment is not measurable, only inferred.
- There is typically an “observability wall” with diminishing returns for effort.
- Because scientists are a fairly focused lot, most miss the big picture and are not attempting to answer the relevant questions anyway (“What is?” versus “How does?”).
- Consequently, many papers yield to the pitfalls of measurement, contextual, aggregation, and cognitive biases.

Definitions: words matter, particularly for biomass burning.

(This may be my last chance at you)

- Aerosol: A colloidal suspension of particles or droplets in a gas. Smoke is an aerosol. Suspended particles are just that, or aerosol particles (versus aerosol medium).
- Particulate: It's an adjective, not a noun.
- Thermodynamics: It is not just water….
- Significant figure: any digit of a number that is known with *certainty*. Go back to your high school chemistry notes.
- Postulate: A self evident truth that forms the basis of a hypothesis or proof.

Congrats on picking biomass burning as your field: Lets begin….

So you want to study biomass burning?

Part 1: Emission
(even here there are tricks of the light)

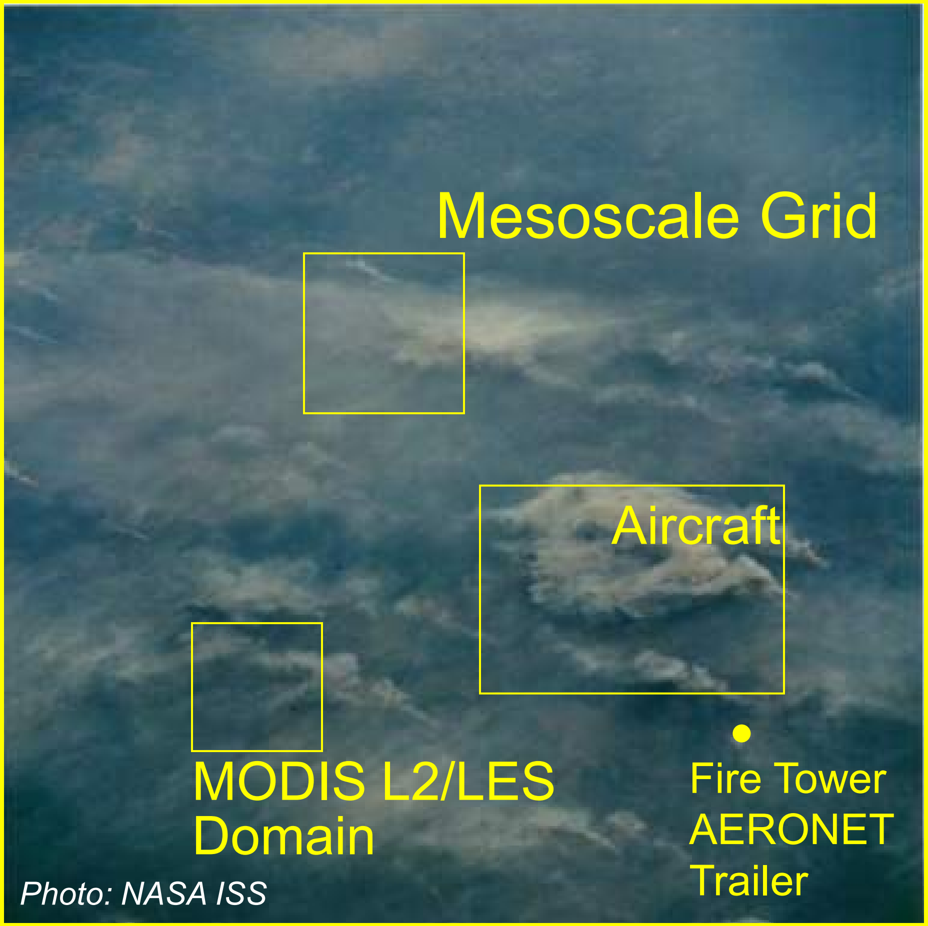
You can observe a lot by
just watching….
-Yogi Berra

So you want to study biomass burning?
Part 2: Receptor

Heterogeneity of the Biomass Burning System

Different tools and methods at different scales leads to scale bias in research and interpretational differences

The world is a non-linear place, and we need to know all of it.



Differences Between Regional and Global Research Requirements for Biomass Burning

	Domestic	Global
Fire Scale:	Kilometers	<10 degree
Temporal Scale:	Hourly to daily	Daily to seasonal
Transport Scale:	Mesoscale	Synoptic
Info on Source:	Moderate	Use class/CVFs
Ground Verification:	Networks/IOPs	Isolated IOPs/AERONET
Data Errors:	Direct propagation	RMS cancellation
Fire Model:	Sophisticated	Regression
Controlling Factor:	Point emissions	Meteorology
Analysis methods:	Auto & hand	Automated
Satellite technology:	Infancy	Commonplace

Bottom line: There are big differences in needs and scales, but the process and transcontinental science is the same. There is a good opportunity for joint work here.

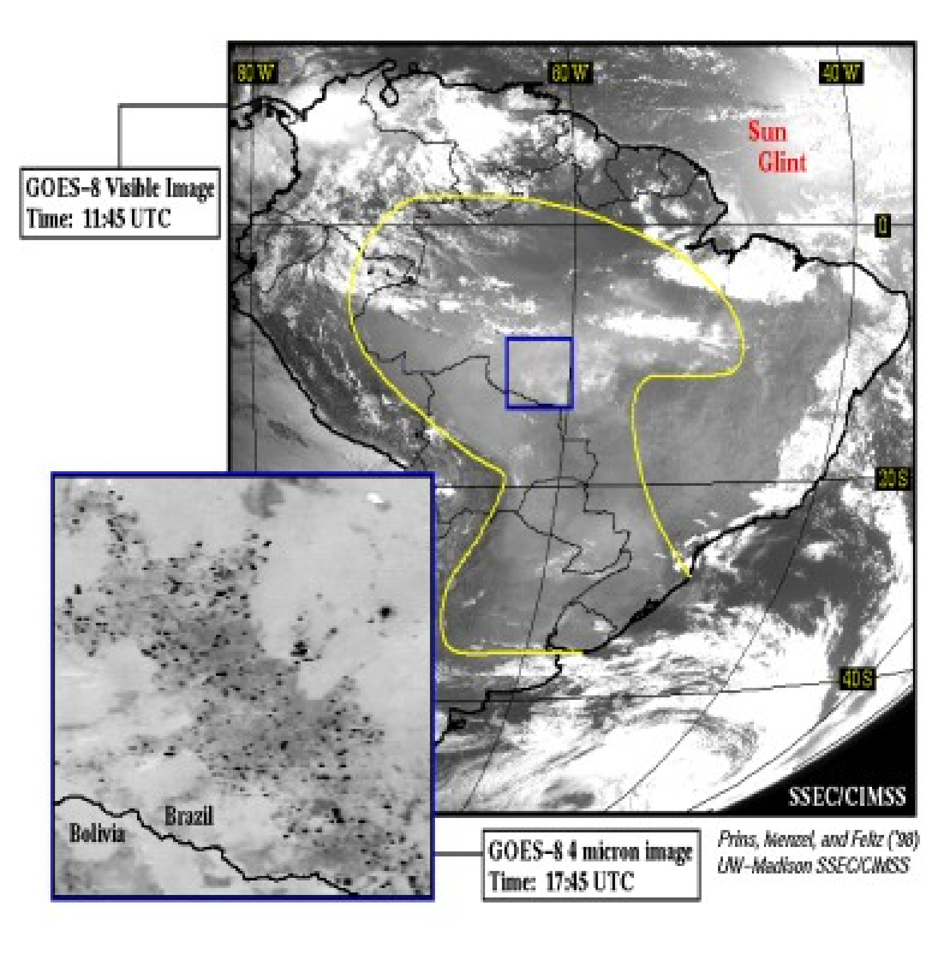
Temporal and Spatial Scales Of Concern

- Fuel conditions and fire propagation potential: Seasonal
- Ignition: Wild-Instantaneous/chaotic; prescribed-weeks to month.
- Particle formation: <1-3 seconds
- Condensation: seconds to ?
- Near field secondary production: seconds to hours?
- Long range transport and chemistry: days to weeks
- Scavenging: hours to weeks

So what/how much is burning? A multitude of top down and bottom up methods are tuned for each purpose

Possible feedbacks and assumptions: Location, area burned, fuel load/type, flaming/smoldering partition, emission factors, longevity, etc…

- **Near Real Time/Forecasting**
  - Satellite Hotspot (Geo+Polar)
    - Frequency
    - Subpixel Fire Characterization
  - Inverse/Data Assimilation (Polar)
  - Aircraft Survey
  - Manual/hand analysis
- **Retrospective/Apportionment/Inventory**
  - Satellite Burn Scar (Polar)
  - Post Fire Survey and Reporting
  - Integrated Hotspot
  - Inverse/Data Assimilation (Polar)



Lets Talk Evolution: Size

Source and Aging Impacts Mass Scattering Efficiency and Mass

Quebec Fire Smoke
O'Neill et al. (2004)

Aerosol Particle Volume Median Diameter (μm)

0.20 | 0.30 | 0.40 | 0.50 | 0.60 | 0.7+

Flaming-Smoldering

"Typical" Near-Source

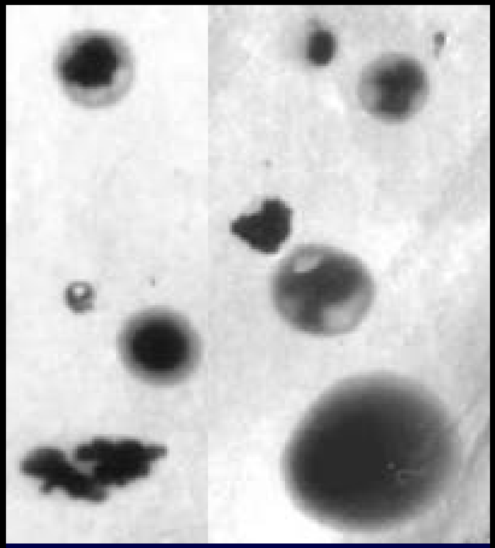
"Uncommonly Large" or Intercontinental

Largest "Inverted"
Moldova Smoke event
Eck et al., [2004]

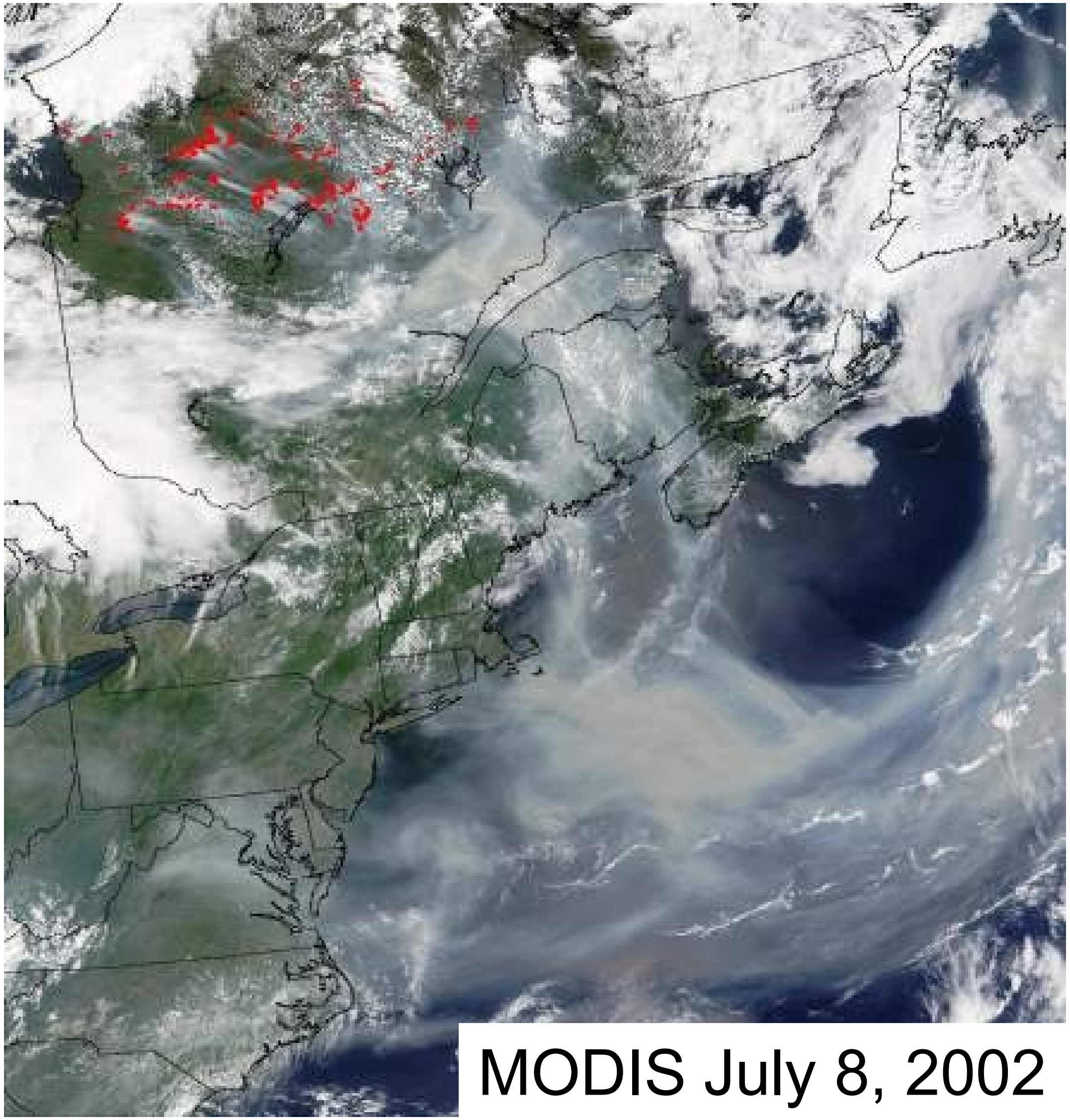
"Typical" Regional

Largest "Measured"
Canadian Smoke in the Mediterranean
Formenti et al., [2002]

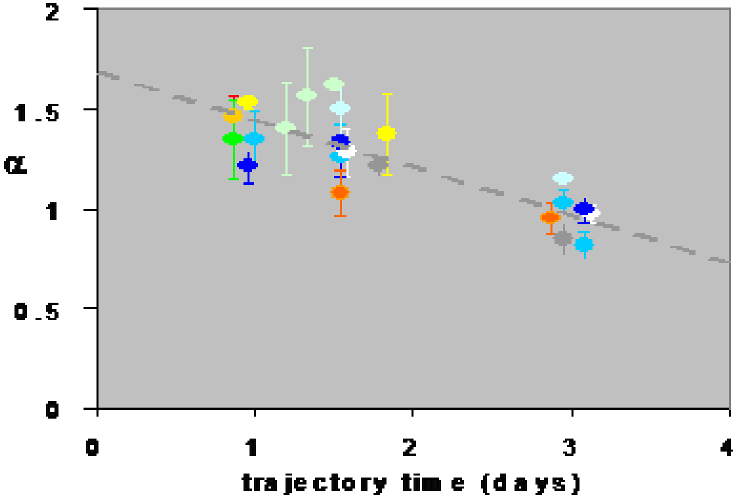
"Blue Moon"
Canadian Smoke Observed In England.
Robert Wilson, 1950

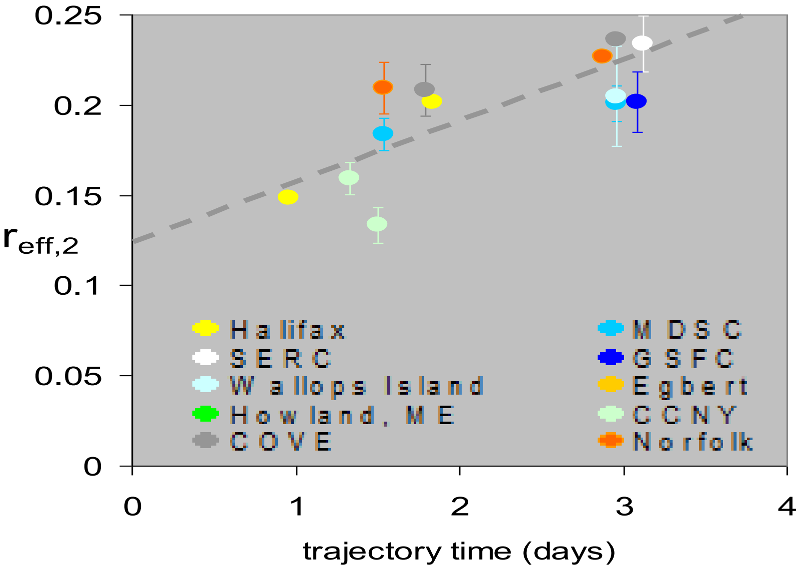


Example of Regional Change: 2002 Quebec Fires
O'Neill et al., [2004]



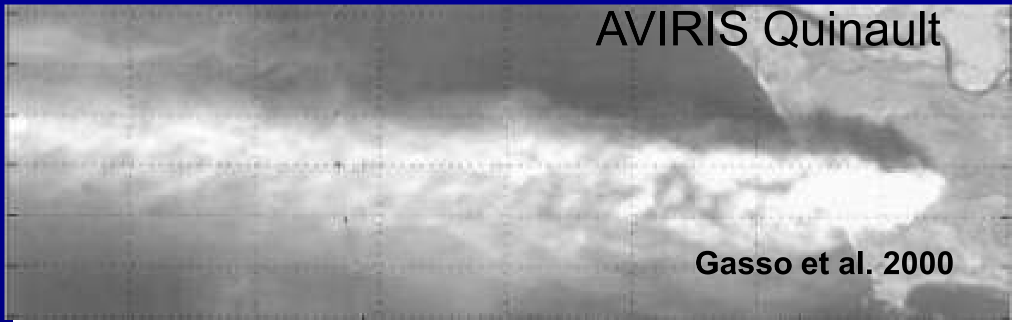
MODIS July 8, 2002

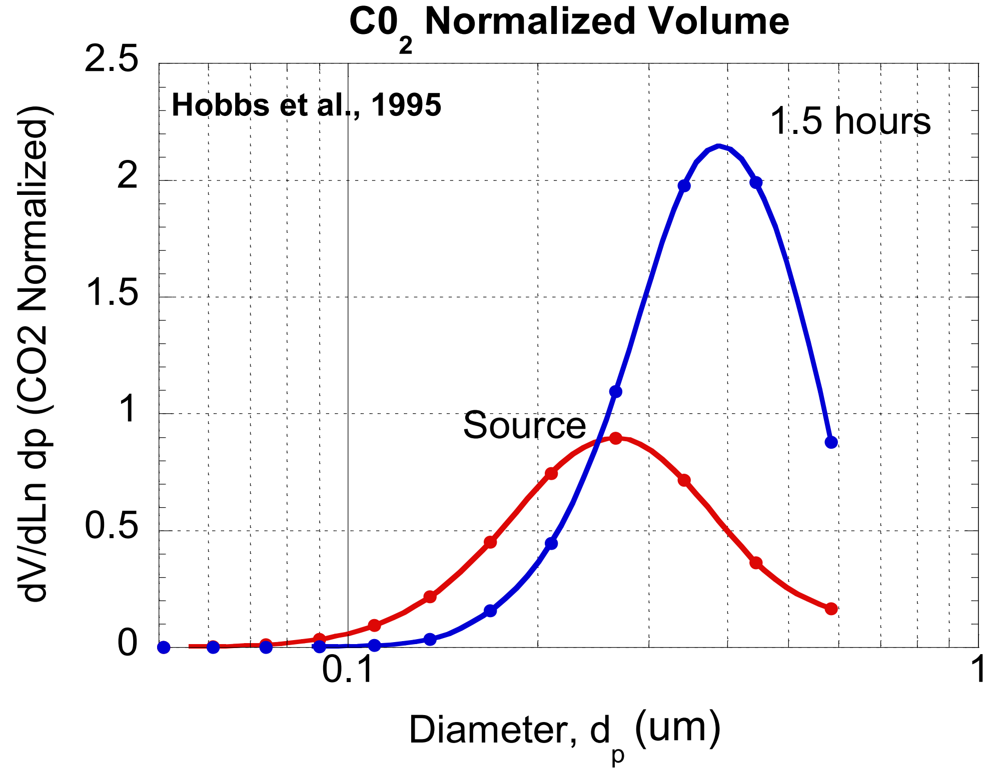




Particle Growth-Near Field: Condensation and rapid chemistry

- Particle formation essentially a condensational process. Material may still condense for ~ an hour after emission.
- Particle mass growth on the order of 20-40% observed directly and through receptor analysis. But still not certain.
- Not easily predictable, probably a bigger factor in forest rather than dried grasses.
- Because of d^3, not as big an issue for size, but strong impact on interpretation of mass extinction efficiency.
- Emission factors may need to be adjusted from the beginning and receptor modeling is hence tricky.





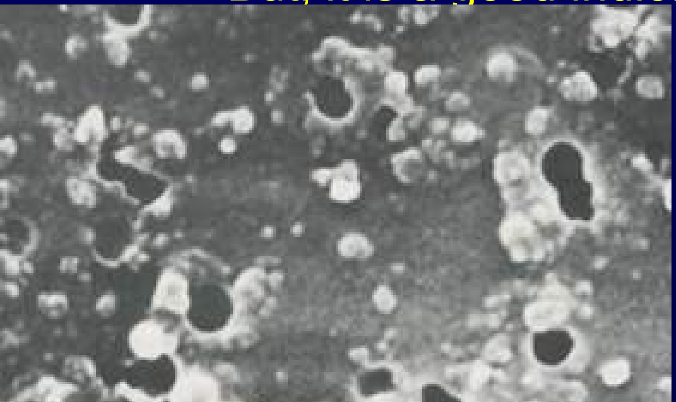
Evolution: Coagulation and Compression

Coagulation long studies and well defined

Active time scales highly dependent on nature of the plume minutes to weeks.
dN/dt goes as N^2, but dVMD/dt goes as N.
Sigma and two sigma sizes likely due to this mechanism alone.
Errors in size growth are moderate WRT model resolution. Low resolution models need to account fo sub-pixel plume variability.

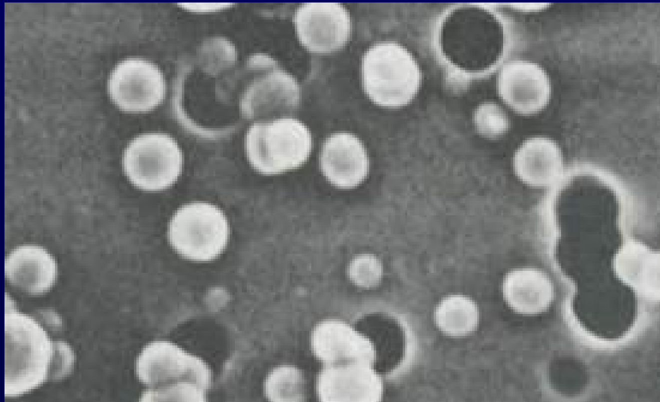
Compression also fairly well understood

Asymmetric and chain aggregates are not uncommon from flaming combustion
But most particles become spherical in a matter of hours [Martins et al., 1996].
Asymmetry and compression unlikely to effect ω_o [Abel et al., 2003].
But, it is a good indicator of what is going on.



Martins et al., [1996]

3 hours



Semi-volitiles and Evaporation????

If secondary particle mass can be produced and condense, can they evaporate?

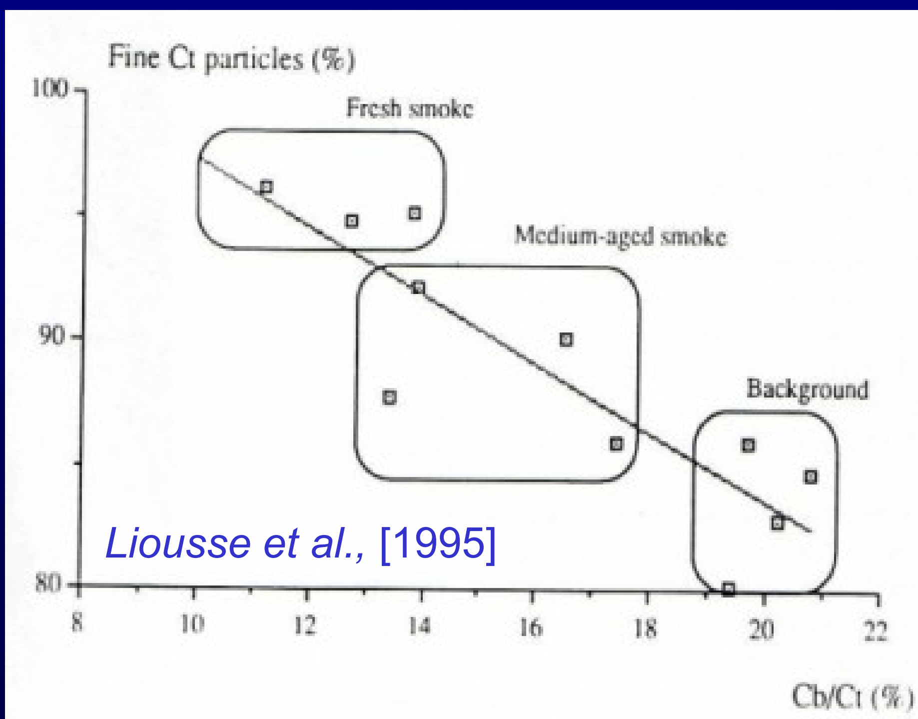
Two papers report evaporation:

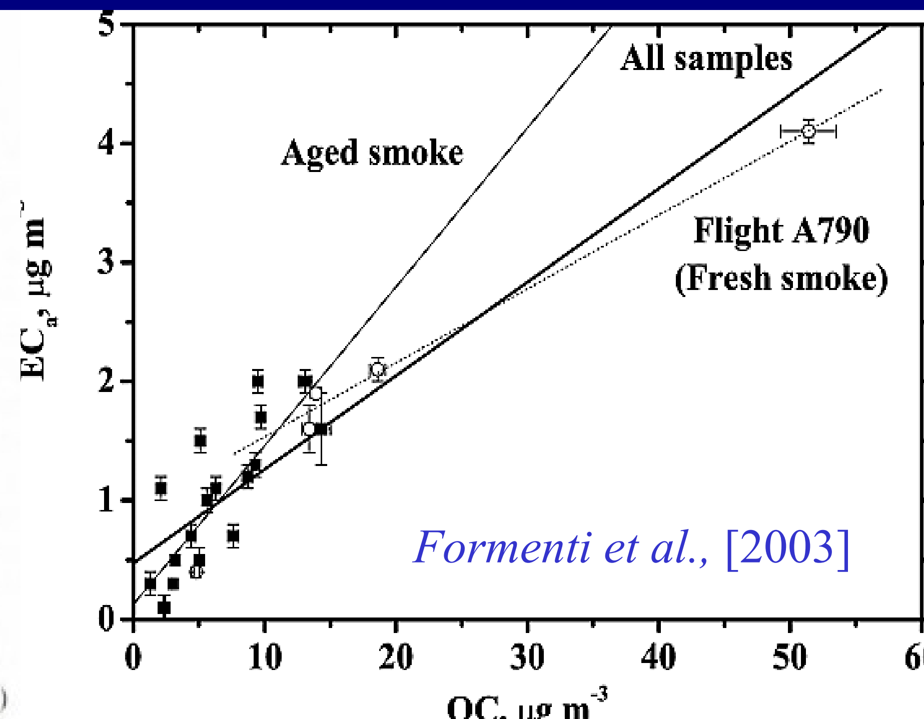
Liousse et al., [1996] and *Formenti, et al.*, [2004]

Both in Africa from grass fires

Both observed a net increase in particle size attributed to coagulation

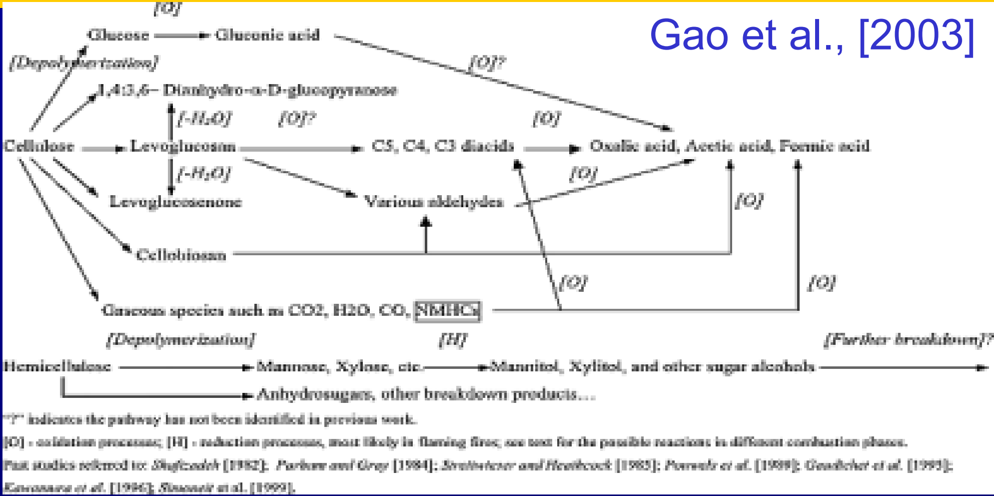
But, both inferred from EGA/TE techniques, not gravimetry.

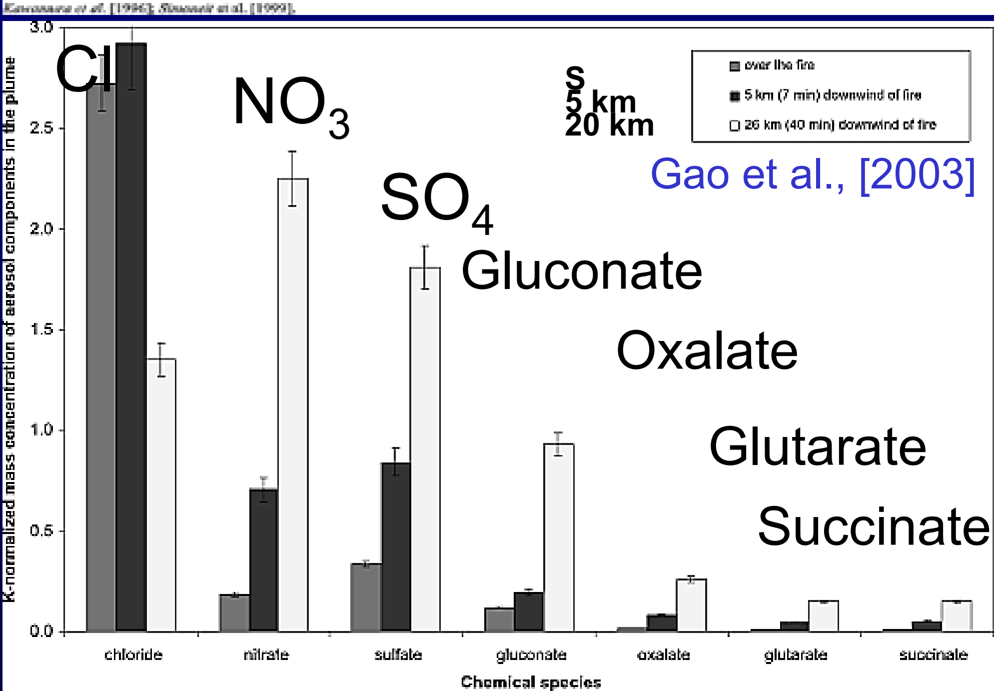




Secondary Production and Photochemisty

- •Organic acids are likely 25-45% of particle mass: Commonly measured include Acetate, Formate, Oxalate.
- •Gluconate probably the dominant species [Gao et al., 2003].
- •Levoglucosan a perennial tracer favorite, but it is less stable than many think. K evolution?
- •CM folks suggest oxidation of aromatics the key. But, my gut says oxygenates are also likely important.
- •Organic acid production clearly identifiable in evolving plumes. But probably leads to only ~10-20% mass growth.
- •Inorganics have a potential for ~10-15% mass growth.
- •Cloud processing a key reaction pathway? Gao et al., [2003] found rapid sulfate production in dry dirty air.

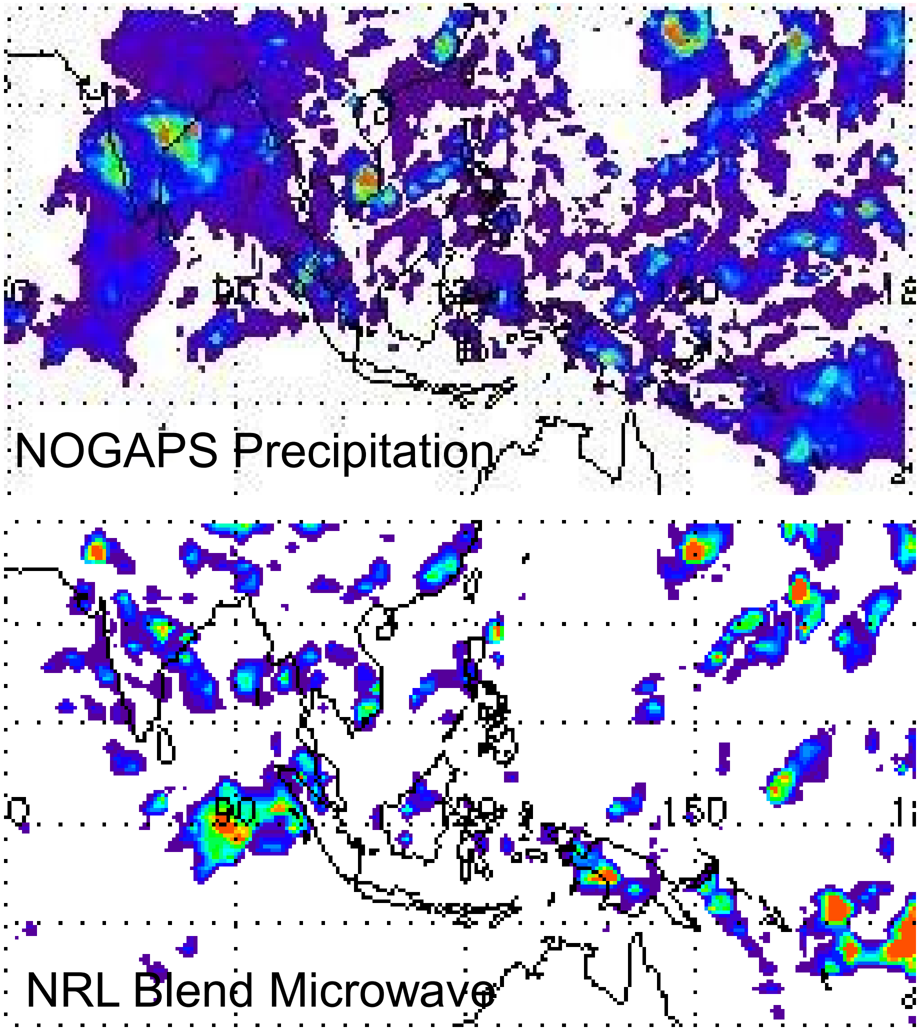




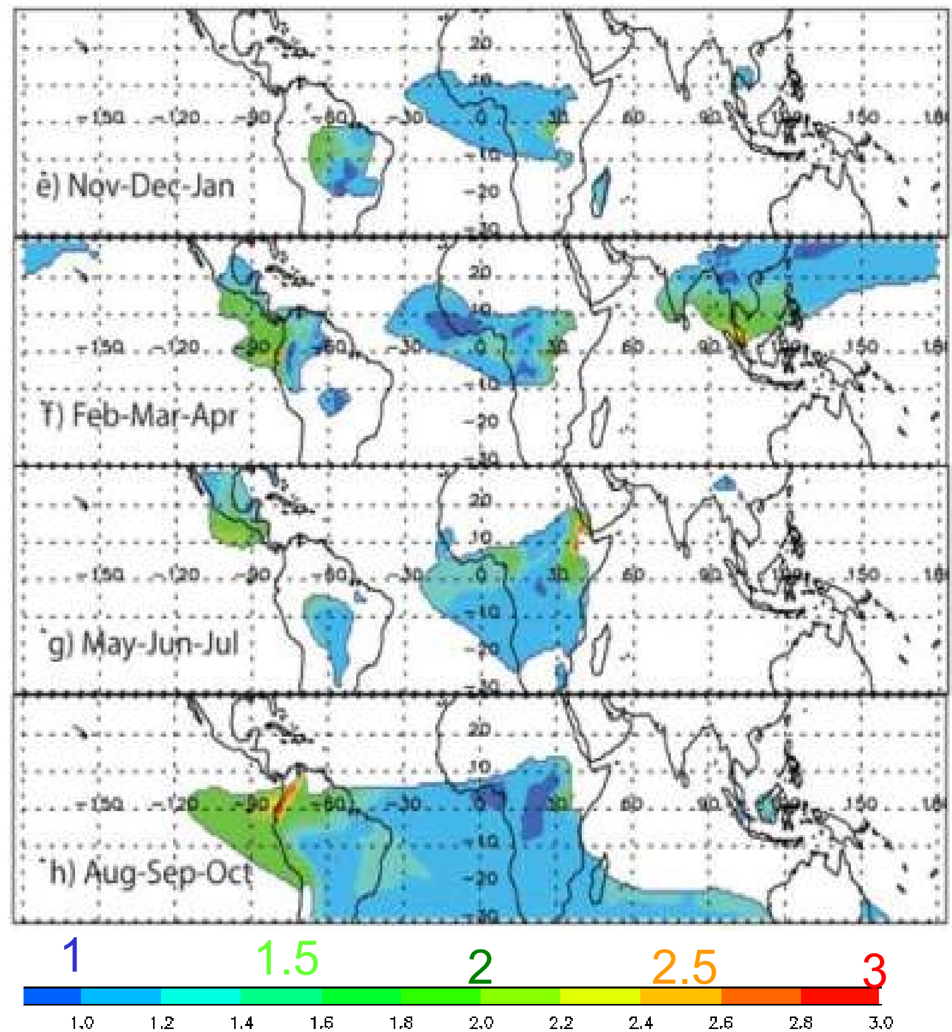
After Transport: Scavenging

Models have difficulty with convective precip. Example of merged Aerosol Model and Satellite Precipitation (Xian et al., 2009)

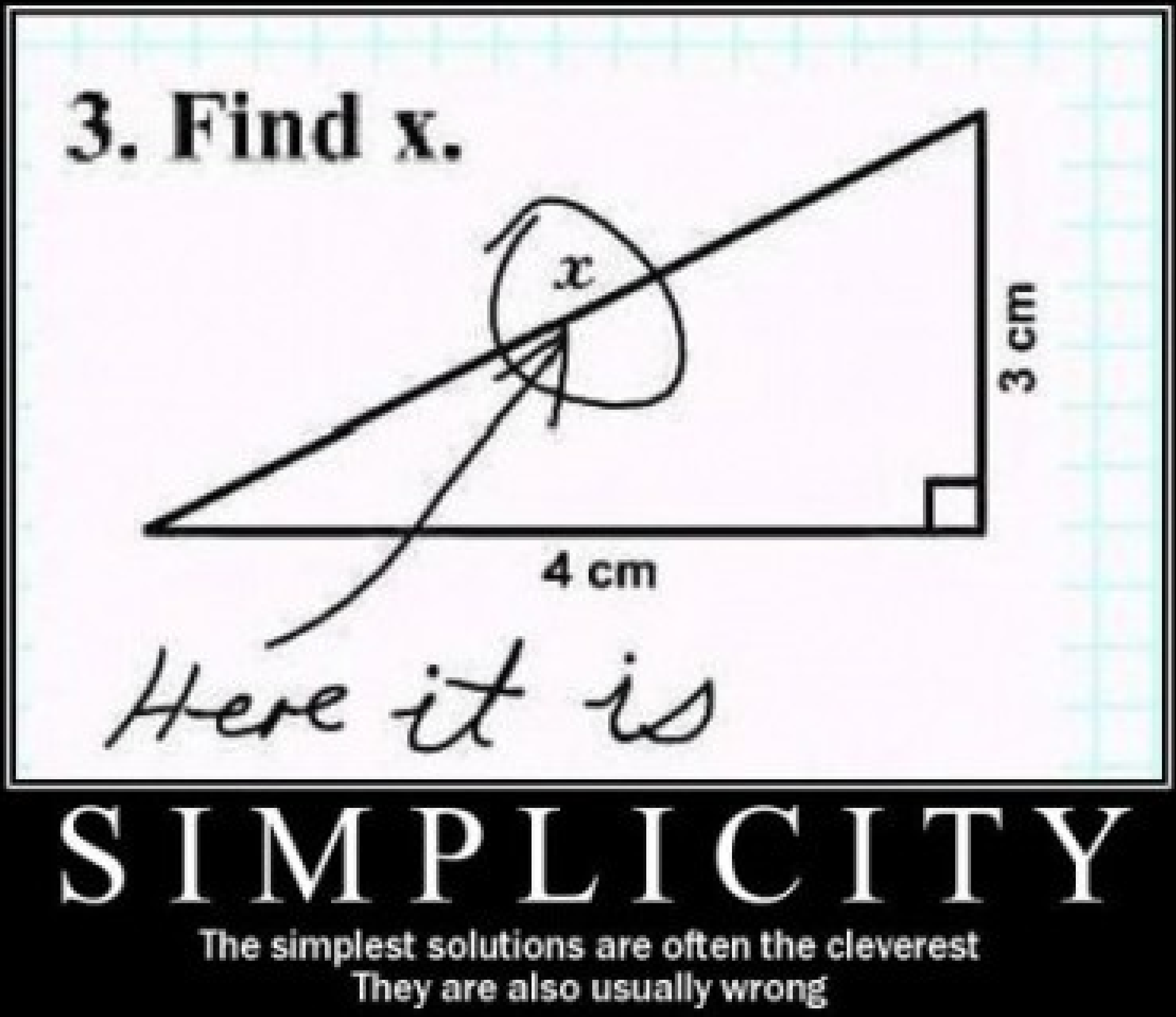
Sept 1, 2007: Precipitation Fields



AOD Ratio After Sat Precip. AODs>0.05

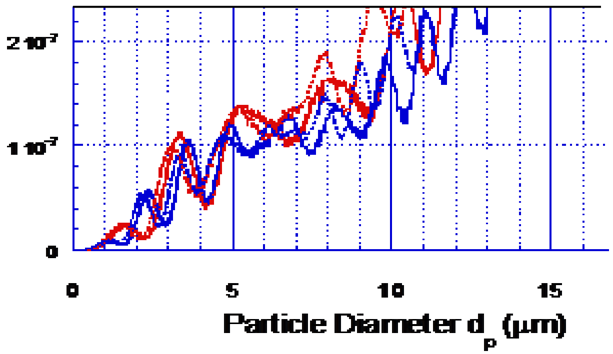


So what are we measuring?



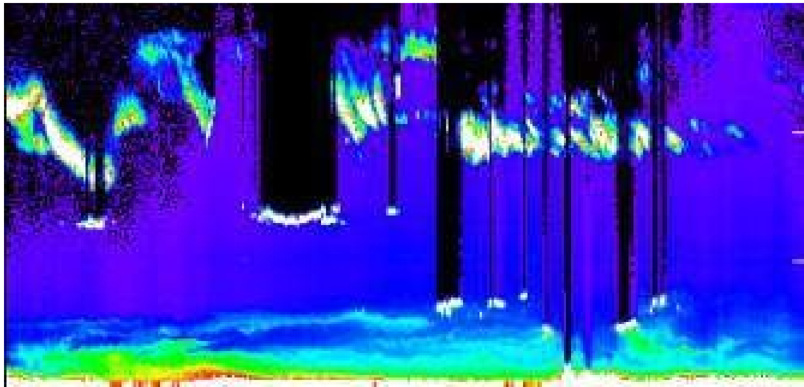
Important considerations for "measurement"

• **Representativeness:** From lab to field experiments does your measurement reflect what is in the environment?



•**Instrument Transfer Functions:** What is it that your instrument really measures? Likely a physical quantity related to what you want, if at all….

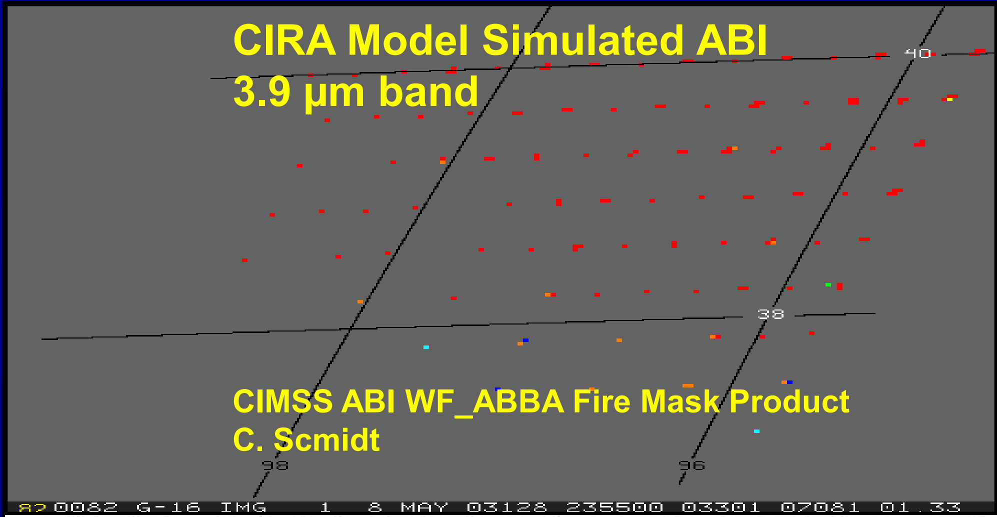
•**Environmental or Model Transfer Functions:** What is it that your model really needs? Likely you need to propagate error across multiple instrument and model parameters.

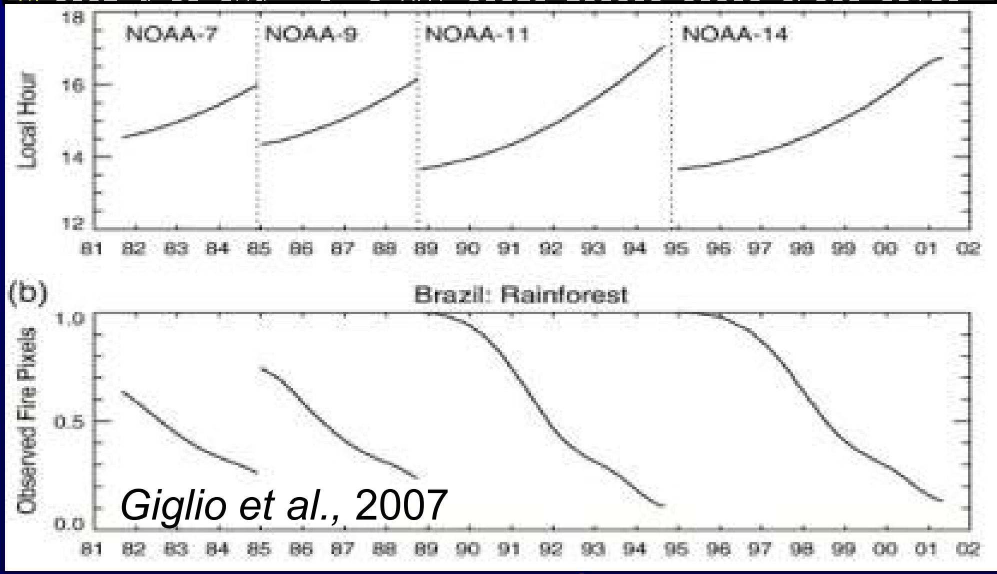


Globally, Satellite products are one of our best tools. But what are they telling us?

Considerations for both active and scar fire products

- Sensor characteristics: Resolution, geometry, navigation, saturation, calibration, point spread function etc…
- Diurnal cycle: Fire ignition probability, overpass time/viewing geometry
- Obscurant: Cloud cover, forest upper story, terrain.
- Ignition/burning practice/land lifecycle: Fuel stacking, residual fuel from conversion

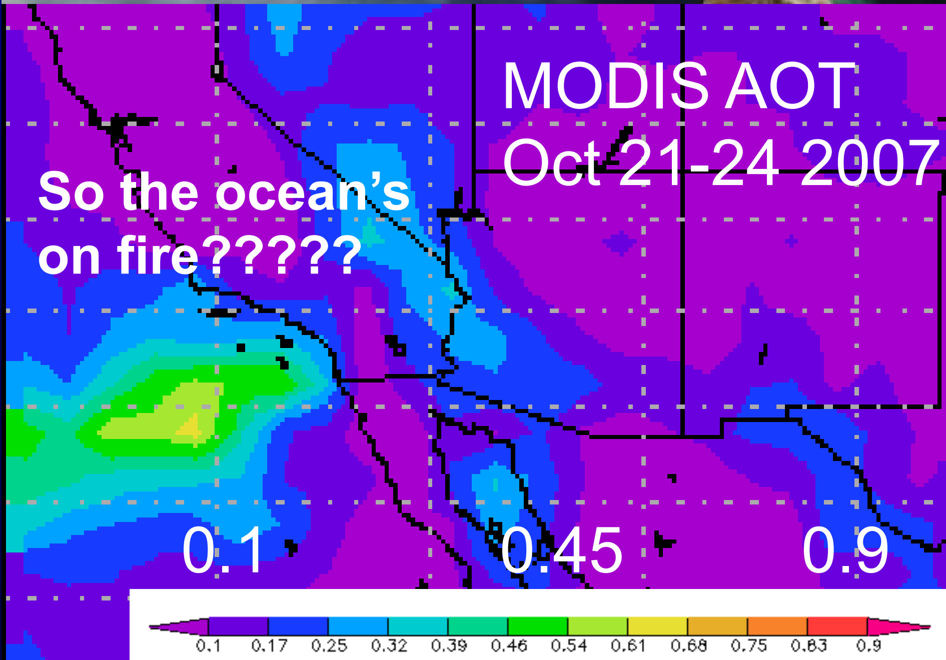




This leads to **hellish** direct propagation of error

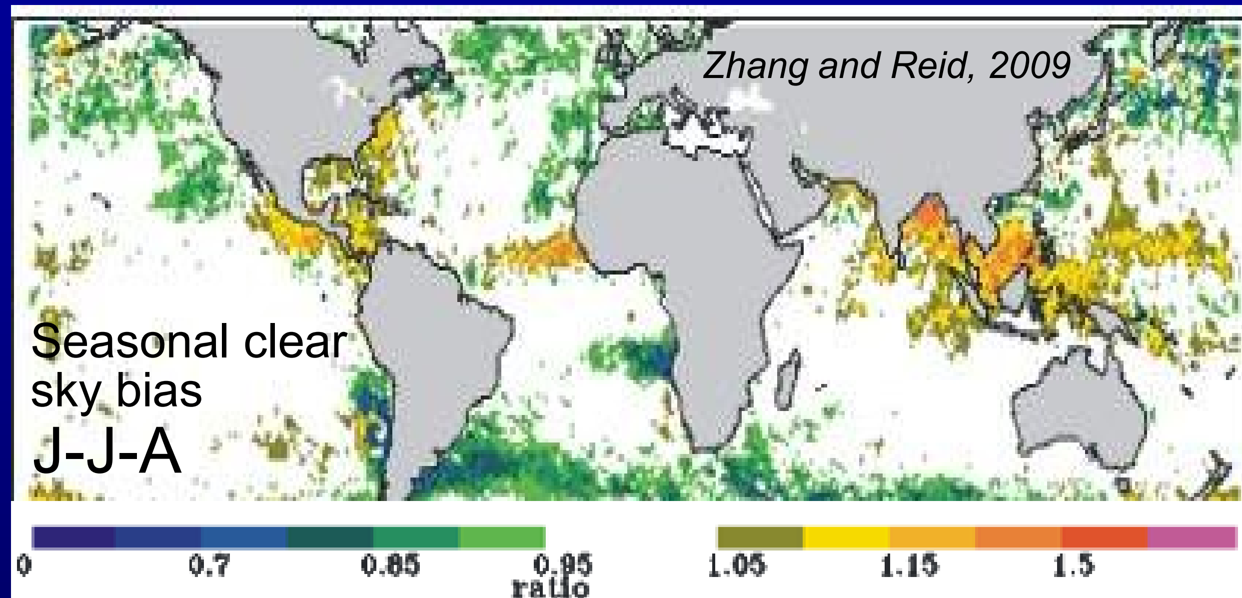
Next Question: So where is the smoke?

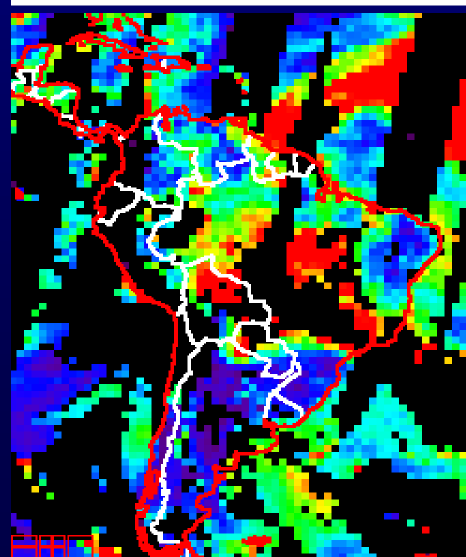
- Differences in approach between situational awareness, climatology, and assimilation.
- Satellite retrievals are underdetermined and there are integer factor differences between algorithms at the regional level.
- Need to consider retrieval and contextual biases in experiment/system design.
- Remember: Satellites and their products are ephemeral, with even yearly changes.

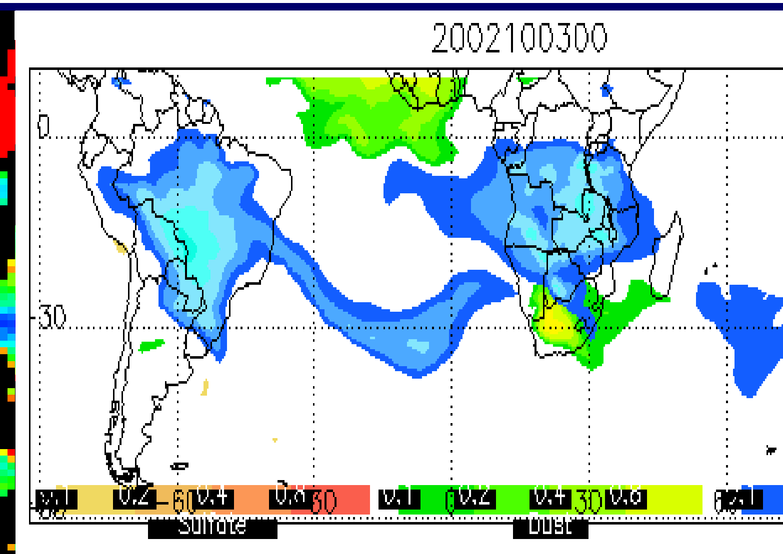


Tracking the smoke is not always easy: Controlling for contextual Bias

- •Sampling/Contextual Biases: Clear sky, Scale/Amplitude, Species, Land Surface, Dynamical
- •Analyses now require a number of “qualifiers” to describe what you are seeing.
- •For example: Clear sky bias for MODIS was calculated during 2 year data assimilation run by comparing 24 hour forecasts to that next days MODIS sampling.
- •As expected, positive clear sky biases in tropics, negative bias in the mid-latitude due to storm track (usually-see Pacific).
- •Individual events have bigger biases.



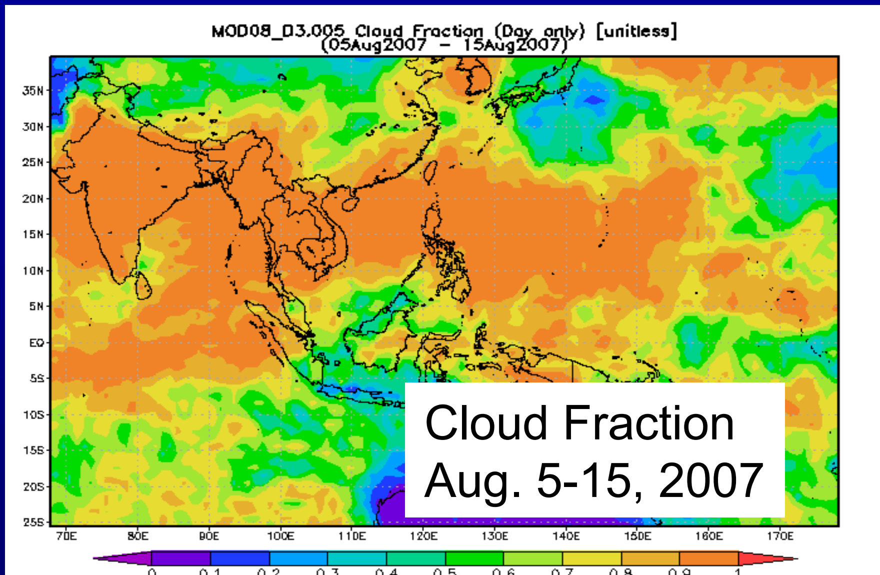


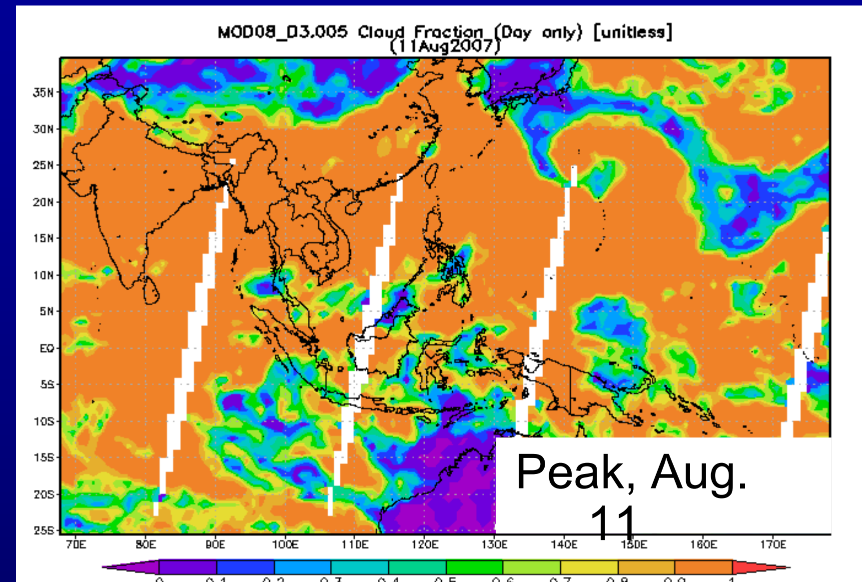


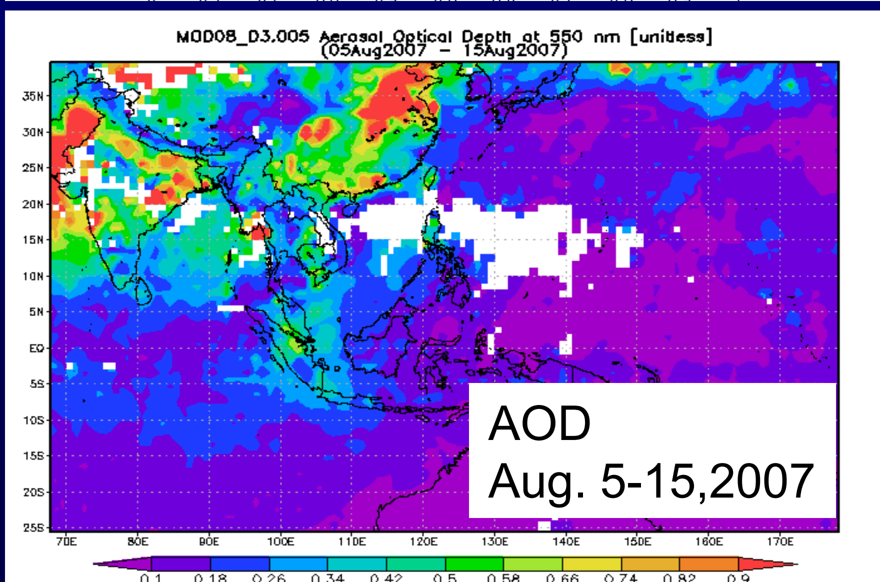
SE Asia and the Observability Problem

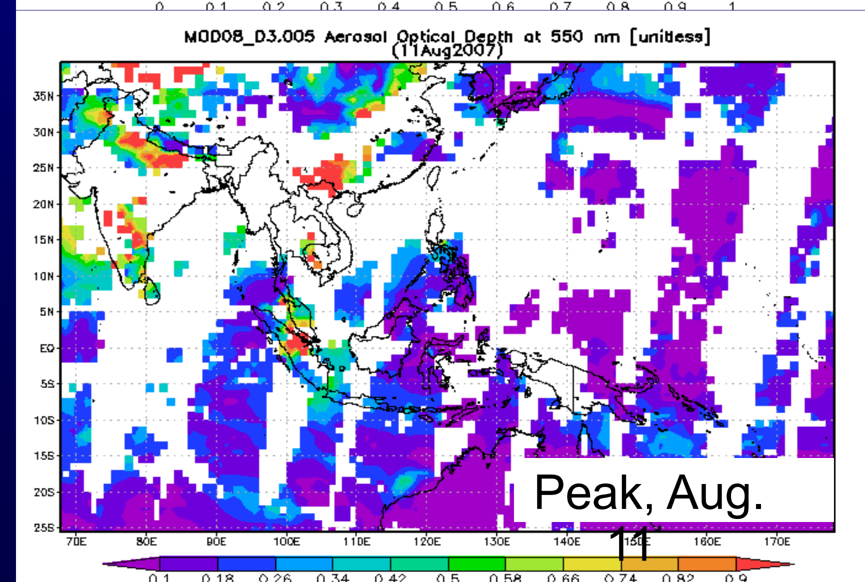
VBBE Example: Not much to go on during an event

(From NASA GIOVANNI-MODIS TERRA)



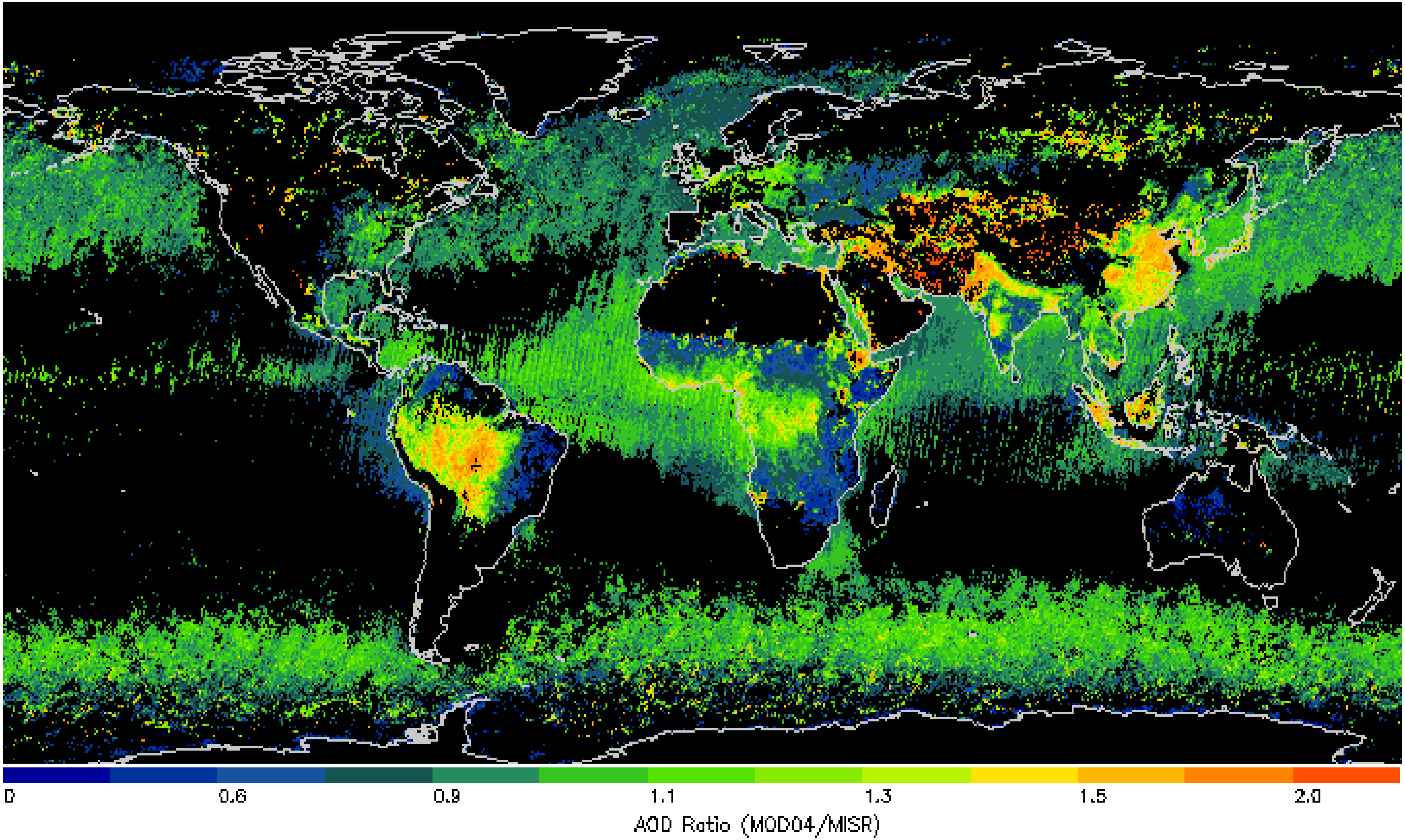






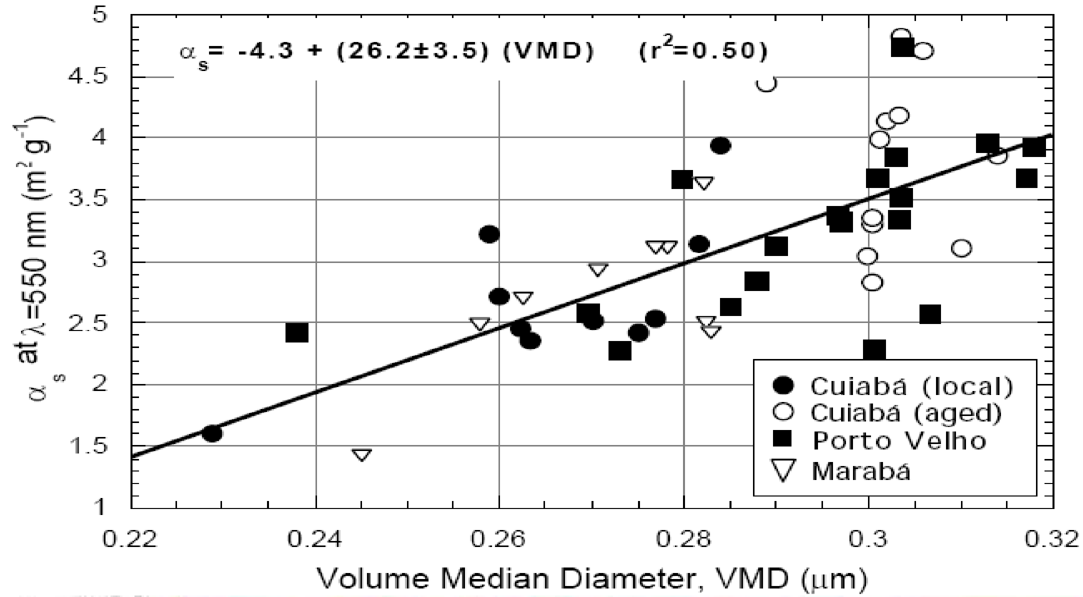
How quantitative can you be on smoke AOD?

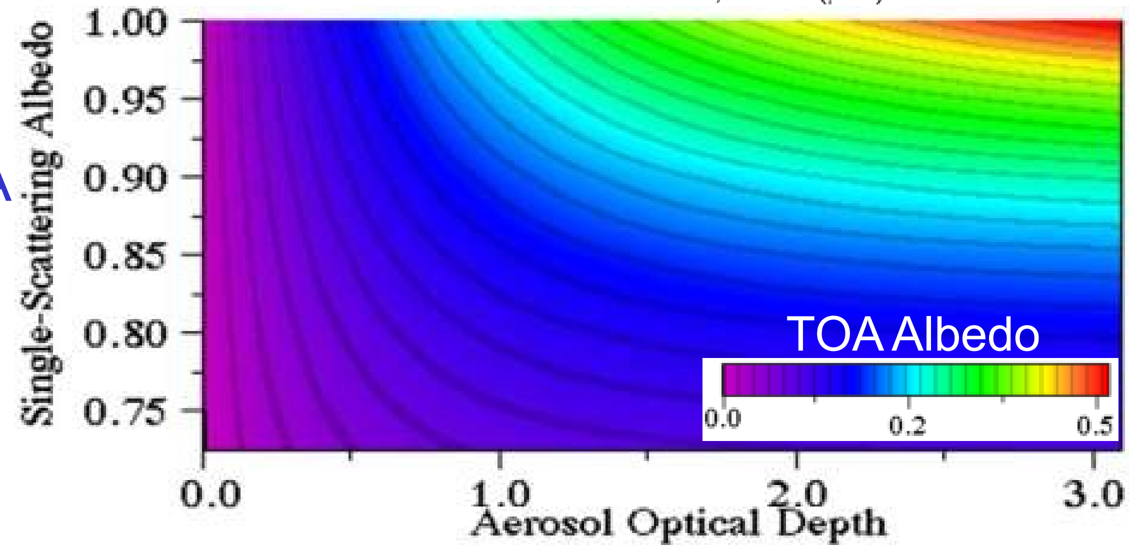
Ratio of MODIS to MISR for AOD>0.15 shows regions of correlated error (Courtesy Jianglong Zhang).



The Mass Scattering-Absorption Transfer Function: Linking Satellite Observations to the Model

- Mass scattering efficiency is linear in VMD.
- α_s also increases with decreasing σ_{gv}.
- α_a is a complicated function of assumed composition, size, mixing and refractive index.
- Consequently, you can easily justifv and combination of α_s and α_a you want.
- This is a bad thing, as ω_o is the driving force for smoke TOA radiance (think retrieval), particle direct and semi-direct effects.
- Bigger issues at higher AODs=contextual bias

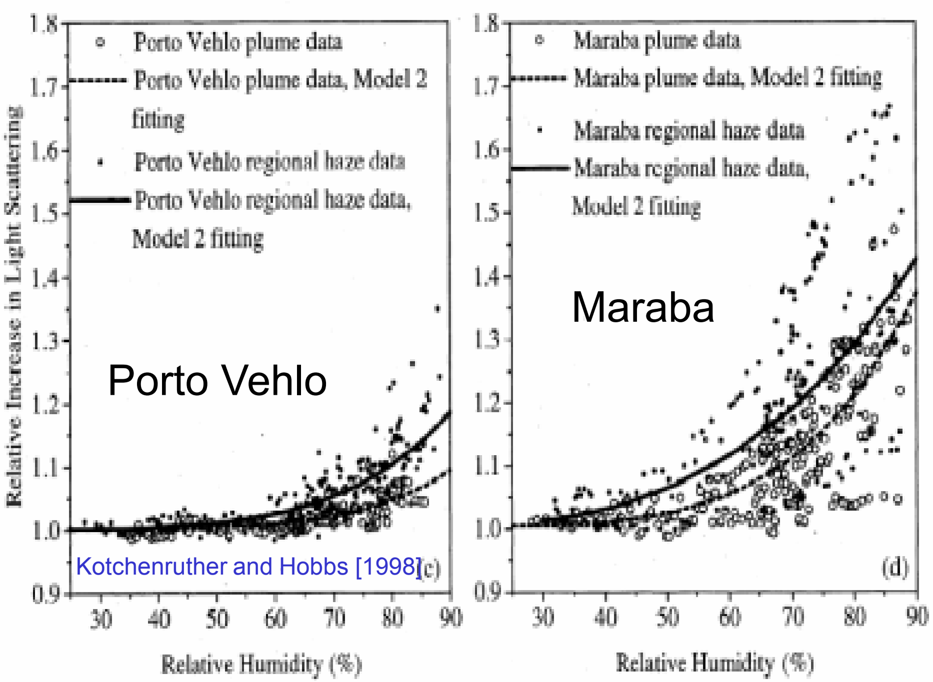


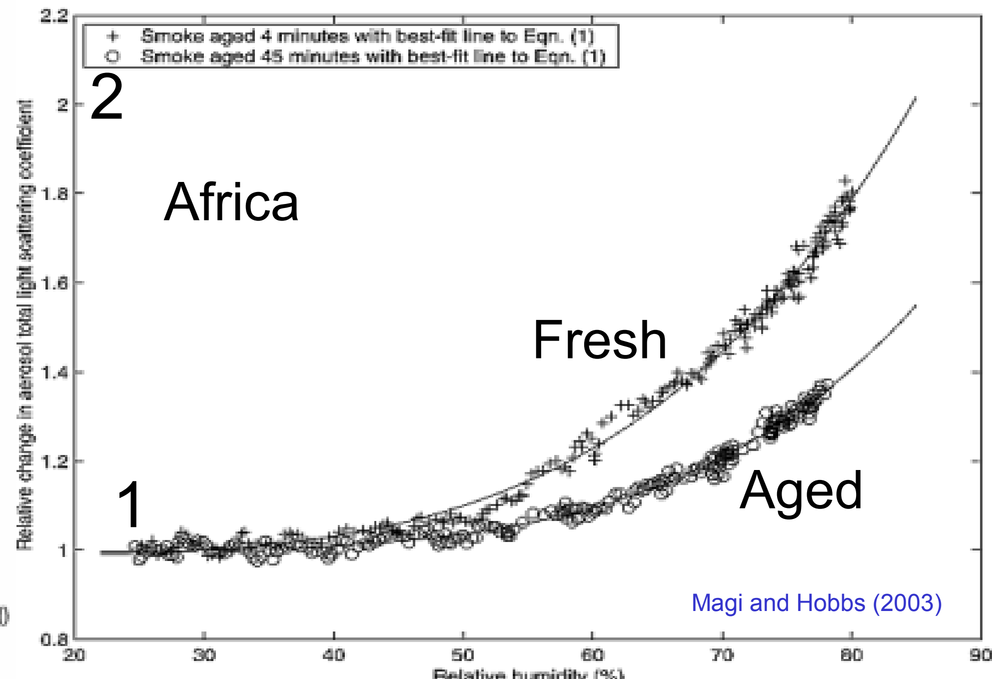


Hygroscopicity: *f*(RH)

Most uncertain of bulk properties with highly non-linear impacts on mass-scattering transfer function in models

- Smoke particle f(RH) changes by fuel type, phase, and age. *f*(80%) ranges from 1.1(fresh Brazilian smoke) -2 (aged high-sulfate peat).
- Progression: Kotchenruther et al., (1998); Gras et al., (1999); Magi and Hobbs (2003), Carrico et al., (2005); Chang et al., (2005); Day et al. (2006)-*no clear systematic findings other than inorganic fraction*
- Nonlinearity in f(RH) makes uncertainty propagation difficult, especially in the context of weather model uncertainties.





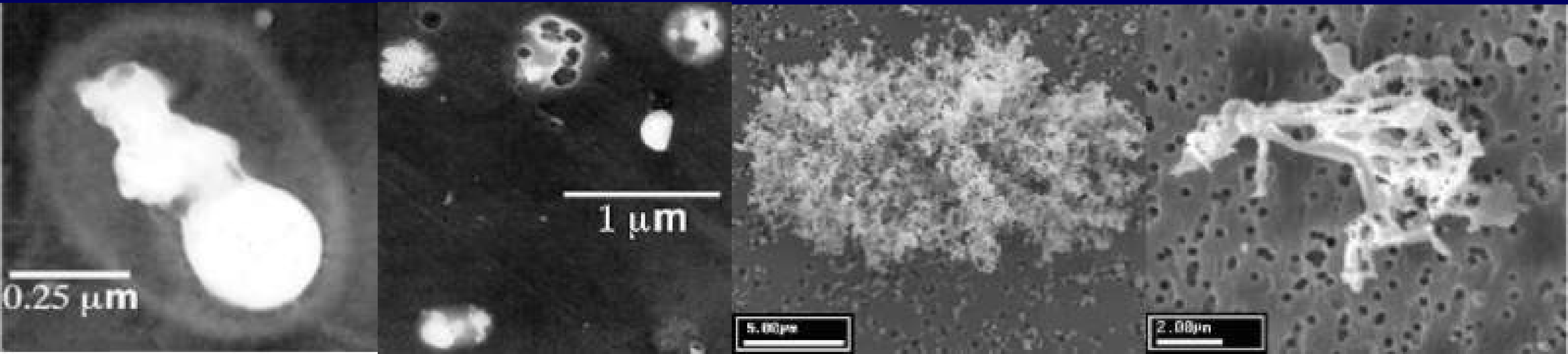
Black Carbon and Absorption

Key to RT, Retrievals, and Apportionment

- Black carbon is an ill defined quantity, and is more of a thermal diagnostic than anything else. Absorption measurements of BC are just that, absorption, not BC.
- Chemically, it is loosely defined as a highly absorbing species with a graphitic like structure.
- You can't "measure" BC with absorption techniques, and for BB you can't readily infer absorption with a BC number.
- There is a lot of circular citation and tautology problems with BC microphysics in the literature. See Bond's papers for summaries.
- Dozens of intercomparison and closure papers have been written, all with the same conclusion: people's numbers don't match.
- Spectral ω_o is another kettle of fish entirely. Don't forget $\omega_o=\sigma_s/\sigma_e$. A 0.03 difference can mean a factor of 2 difference in σ_a.
- Brown carbon is something different entirely. You don't need soot to absorb. Look at fresh motor oil….

Particle Size

- There are no direct measurements of particle size. Rather you relate some measureable quantity to size.
- Common diameters include, aerodynamic, mobility, flavors of optical, and oh yeah, geometric. Typically the transfer functions of these size parameterizations are not straightforward.
- There are a variety of diameters, such as equivalent volume, equivalent mass, equivalent surface area etc. Radiation folks like effective radius…
- No easy way to deal with particle heterogeneity and core/shell stratification.
- By the way, most ambient aerosol size distributions are not really lognormal. Often number and volume distributions are decoupled.
- Typically the measurement process modifies the size, particularly SEM/TEM.



Particle Mass and Chemistry

- Particle chemistry is much more complicated than size.
- We know the rough proportions of OC/BC/POM/inorganics, but every fire is different. So how big does N need to be?
- Semi-volatiles are tricky, and are in rapid equilibrium with their environment. TEOMS are known to have difficulty.
- Typically analytical methods begin to diverge as speciation become more complicated.

How are you feeling?

Know where you fit on the chart

Experimental and Theory

Goal: Determine the fundamental physical properties of the environment

Issues: Limited observations and extreme environmental conditions

Example problems: Evolution, semi-volitles, source-receptor linkage, boots on the ground

?

Remote Sensing

Goal: Spatial and temporal monitoring

Issue: Tends to be underdetermined. Complicated microphysics and boundary conditions, clouds

Example problems: Bayesian emissions models, inversions, comprehensive v&v

Data Assimilation

Describing and predicting the environment

Issue: Error characterization and physical constraints

?

?

Modeling

Goal: Temporal/spatial extrapolation and physical inference

Issue: The world is a complicated place and is not easy to parameterize. Lack of physical constraints. Non-lineararities.

Example problems: Look outside….

Knowledge of the Ancients

- 30 years ago, scientists had the same problems. They did not have the variety of instruments, but they knew the tools that they had really well.
- Some of these older papers are hard to get a hold of (or even search for). It will require some library gumshoe skills.
- Because computers were not there, they did a lot of hand analyses. This gave them insight.
- This does not mean that they were always (or even mostly) right. You should challenge commonly held beliefs and assumptions.
- Even if they were wrong, or missed some important physics, it is helpful to understand how the field has evolved.

Know your Tools

- Take the time to really understand what your instrument and/or model is doing. Smoke is an extreme condition and is not considered by most manufacturers or developers.
- Real craftsmanship requires good hand tools, rather than mass production. Sometimes simpler is better.
- Aerosol instruments never measure what they output.
- Modelers grabbing products off the shelf leads to cognitive dissonance: Let's just ignore unpleasant information. "It's the only product out there…"
- Work with product/instrument developers, not against them

Now the good news !

OK, there is no good news, but here is some good advice for junior faculty

- Don't be intimidated by the complexity of the world, but you do need a healthy respect for it. If this were easy, you would be out of a job…..
- Don't be foolish, use the library. Just because you had an epiphany does not mean that Ward or Radke did not write about it 30 years ago.
- Don't follow rules. Understand where rules come from. Mother nature does not have to do anything….
- Ask the right question. You can gain ground if you sequester uncertainty by working the right hypothesis.
- Identify your customer. You need to clearly understand why someone would care about your work-and I don't mean flashing the IPCC forcing chart.
- Know your tools: Most instruments and models are not geared for biomass burning and are not measuring/simulating what you think they are.
- Biomass burning is inherently interdisciplinary. Come into the field as an expert in your part, but don't think you can do it all. Make friends.

Questions?

THINK

Do you really think you can fly if you flap your arms really fast?