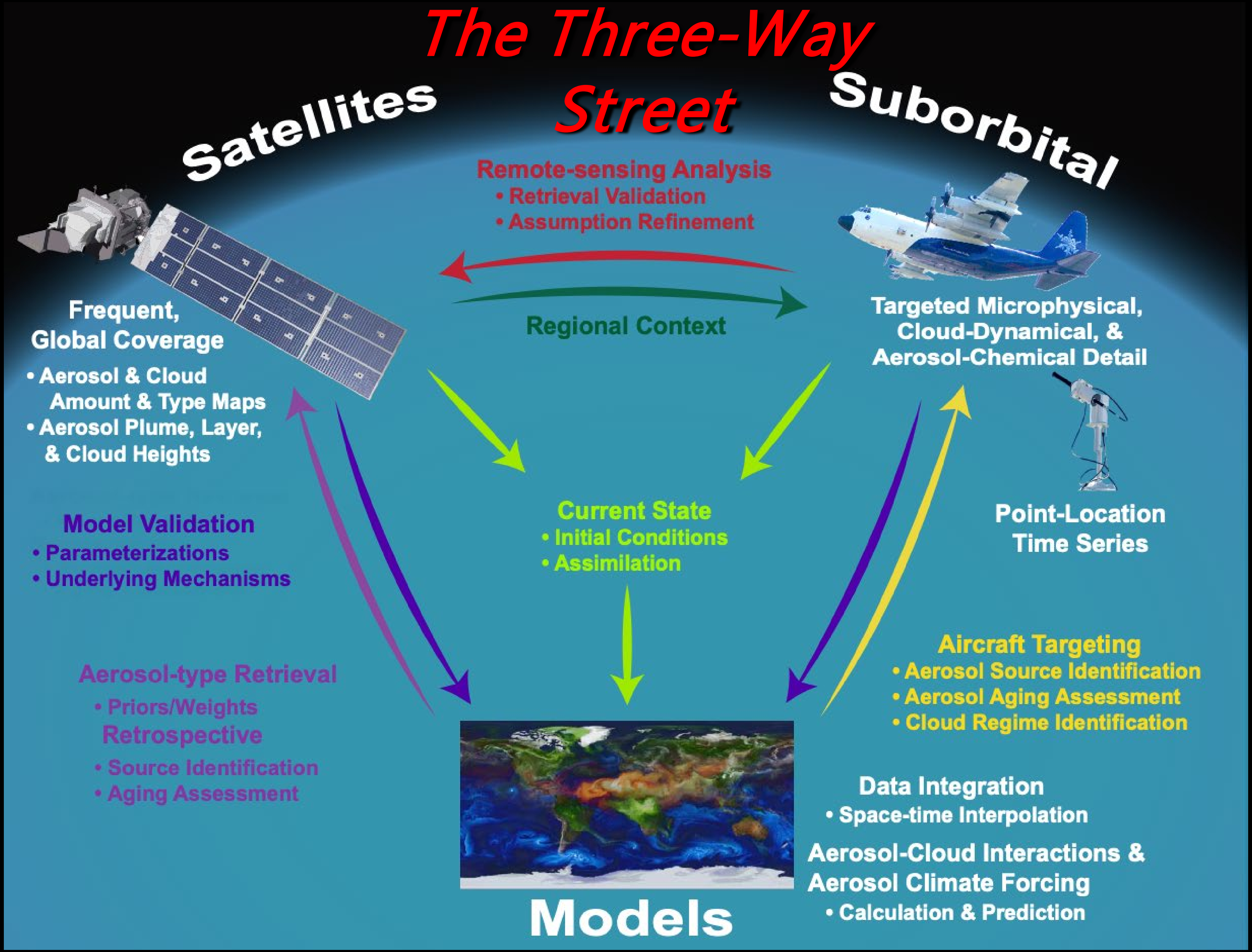
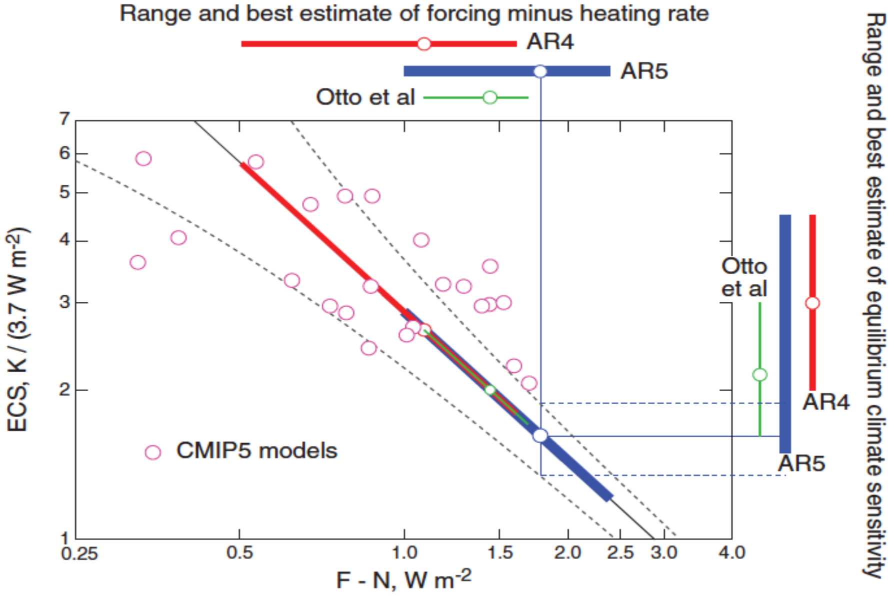


Kahn et al., Rev. Geophys. 2023

Climate Forcing – Aerosol Effects Produce the Biggest Prediction Uncertainties
→ *Aerosol-Cloud Interaction* and *Particle Microphysical Property Assumption Uncertainties Dominate; Trace-gas Distributions also matter*

Forcing uncertainty translates into prediction uncertainty

Equilibrium Climate Sensitivity

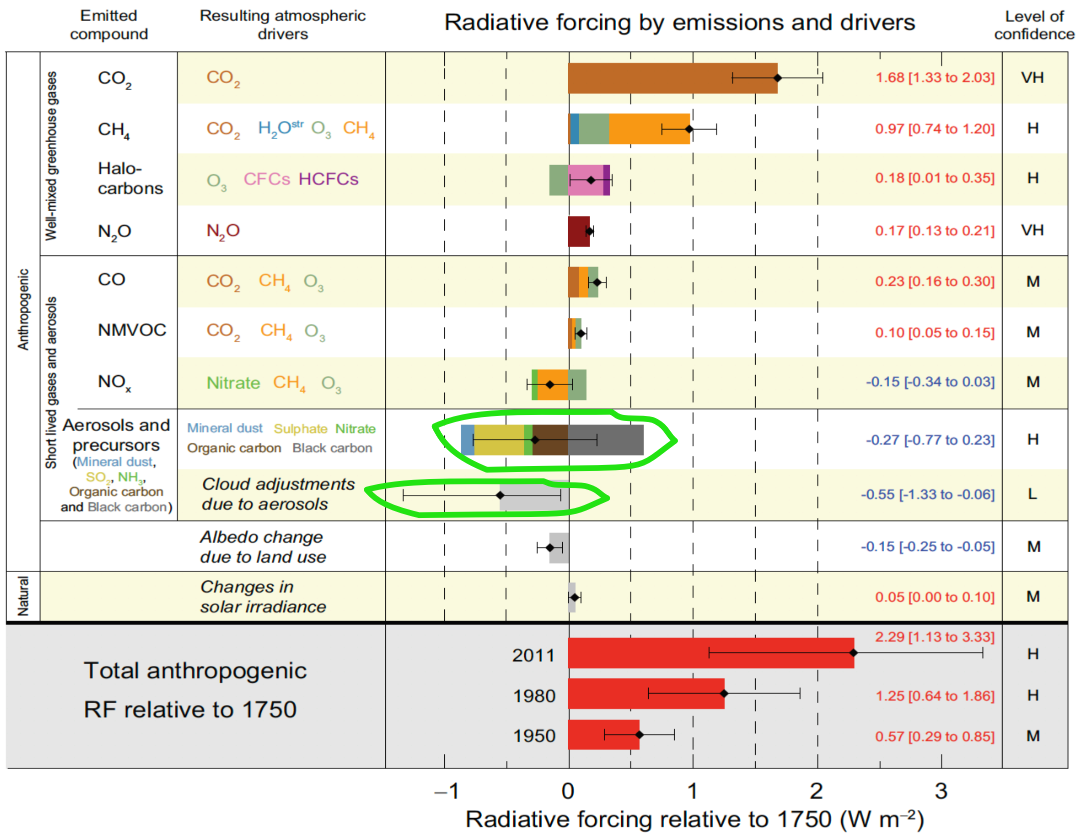


Schwartz et al., Earth's Future 2014

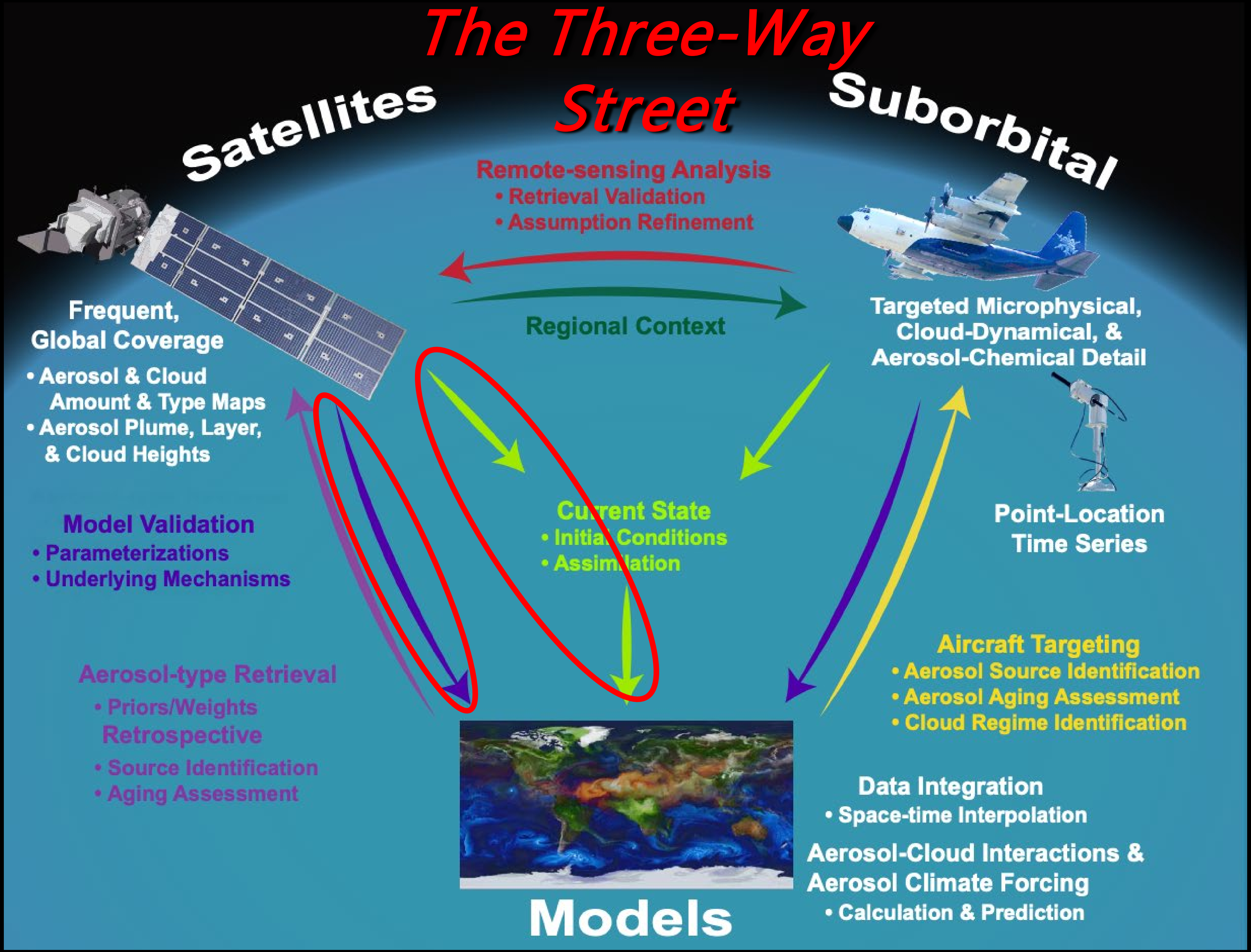
$$(F - N) \times S = \Delta T$$

Effective Forcing | Ocean Heat Content | Climate Sensitivity | Response

Aerosol-related forcing uncertainties need to be reduced to enable climate predictions



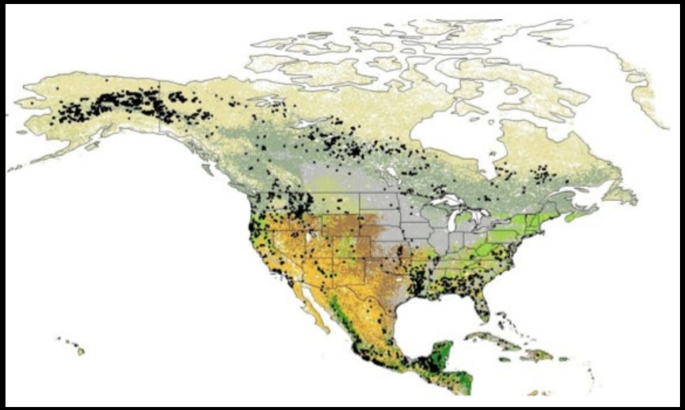
IPCC AR5, 2013

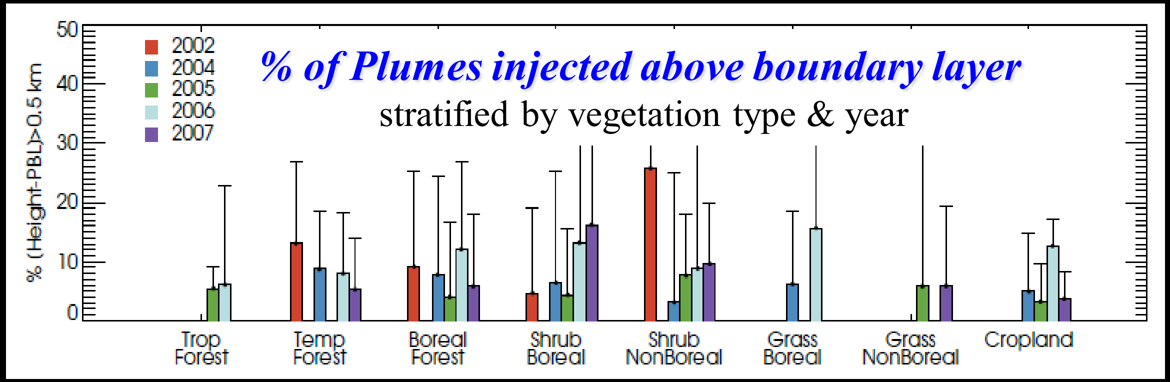


Kahn et al., Rev. Geophys. 2023

Wildfire Smoke *Injection Heights & Source Strengths*

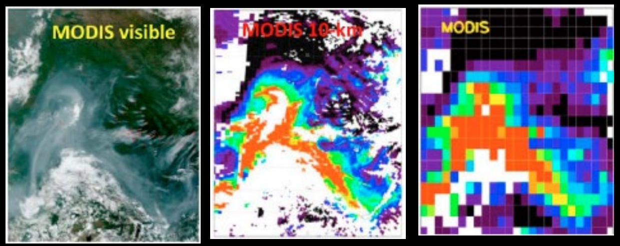
[These are *the two key parameters* representing aerosol sources in climate models]



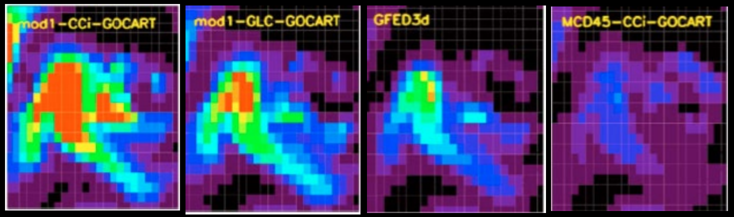


Val Martin et al. ACP 2010; 2012, 2018;m Pan et al., in preparation

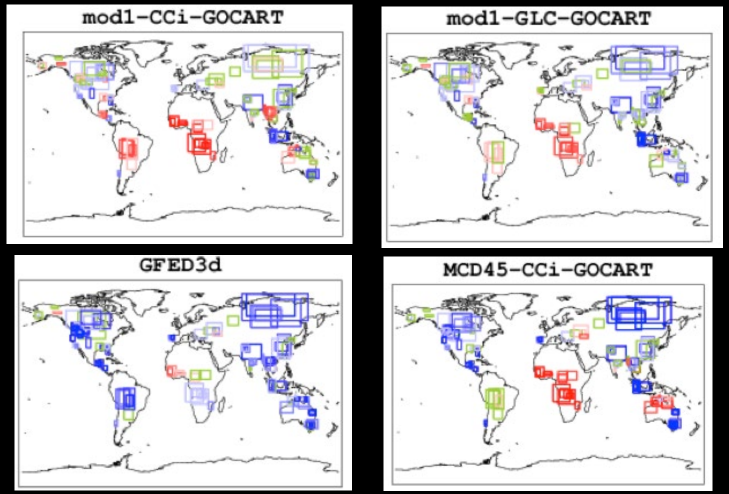
These two projects are the subjects of current AeroCom/AeroSat Experiments



MODIS Smoke Plume Image & Aerosol Amount Snapshots



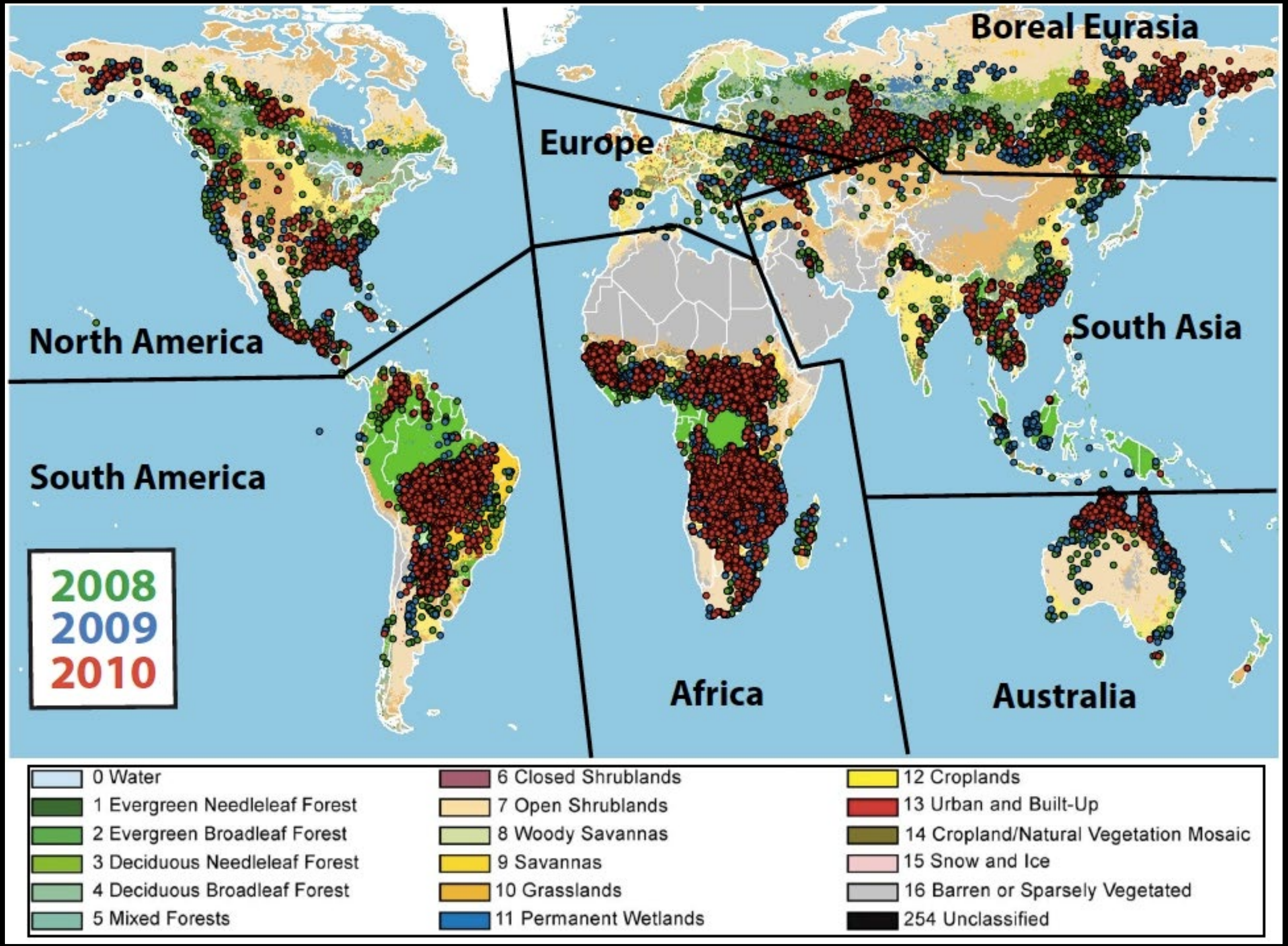
GoCART Model-Simulated Aerosol Amount Snapshots
for *Different Assumed Source Strengths*



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

Petrenko, Kahn, et al., JGR 2012; 2017; 2023 in prep.

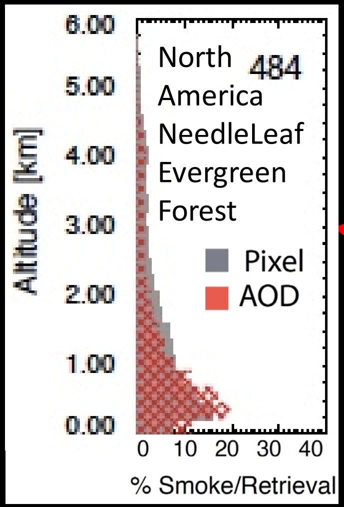
Global Climatology of Smoke-Plume Injection Heights

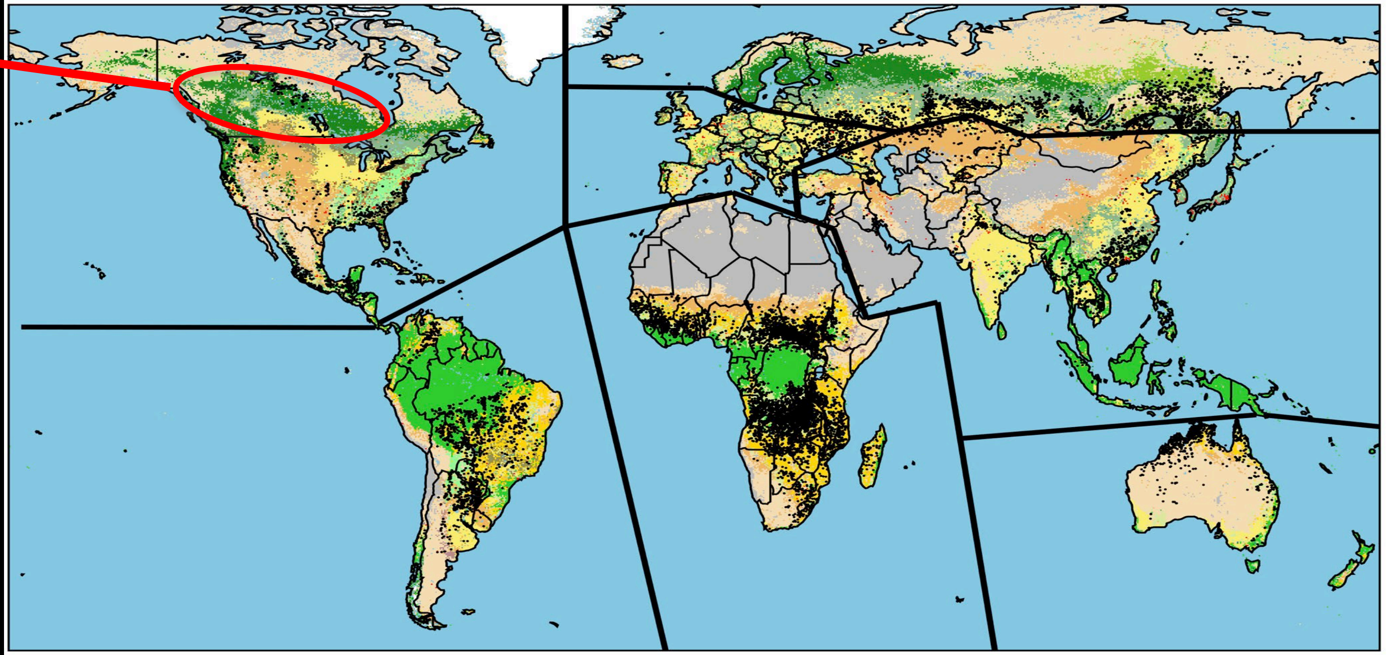


- About ***23,000 smoke plumes*** digitized 2008-2010 (~13,000 for 2008); ***overpass ~10:30 AM*** local time
- Each plume is Operator-Processed using ***MINXv4.0***, and Quality Controlled
- ***Available on-line: https://misr.jpl.nasa.gov/getData/accessData/MisrMinxPlumes2/***

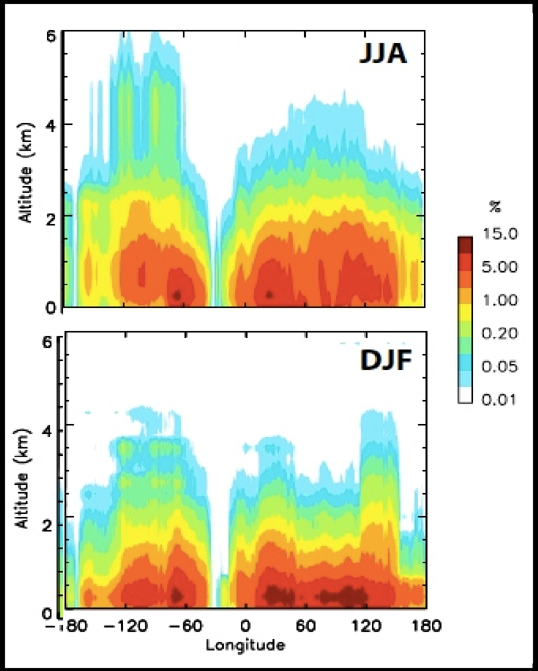
Val Martin, Kahn & Tosca; Remt. Sens. 2018

MISR Wildfire Smoke *Injection Height Climatology*





Global Zonal Ave.



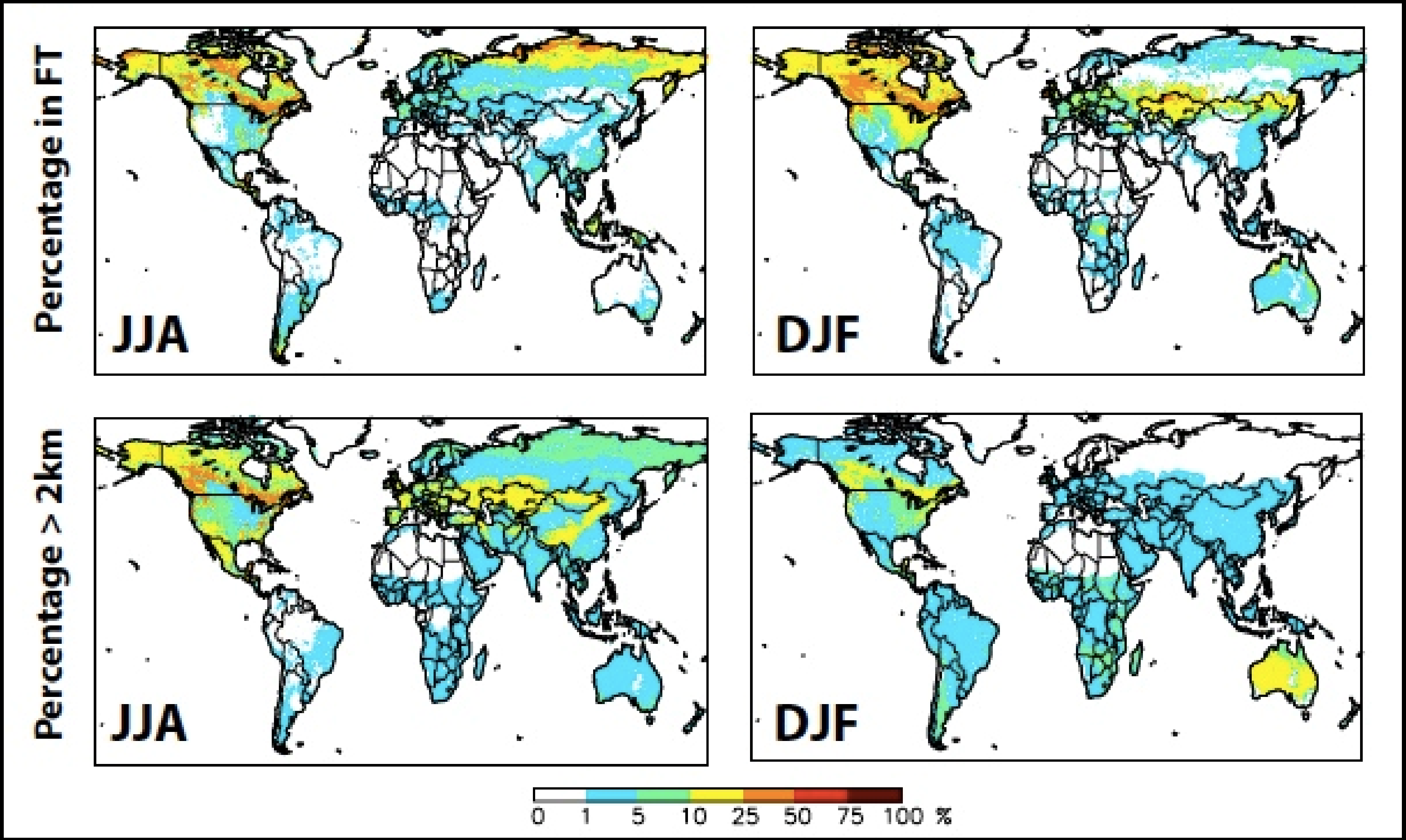
- Individual Heights at ***1.1 km Horizontal*** res., ***~250-500 m Vertical*** res.
- Both ***Pixel-weighted*** and ***AOD-weighted*** profiles derived
- Fire emissions are ***Stratified by Altitude***, ***Region***, ***Ecosystem***, & ***Season***
- The cases in each stratum are ***Averaged*** to produce a statistical summary
- Inter-annual and/or sub-seasonal ***temporal resolution*** might be needed in some cases; requires detailed, regional study (e.g., Amazon)

https://misr.jpl.nasa.gov/getData/accessData/MisrMinxPlumes2/

Val Martin, Kahn & Tosca; Remt. Sens. 2018

Global Distribution of Percent Injected Within/Above the PBL

Based on MERRA-2 Hourly PBL 10:00-13:00 LT



Accounting for uncertainty
FT = PBL + 500 m

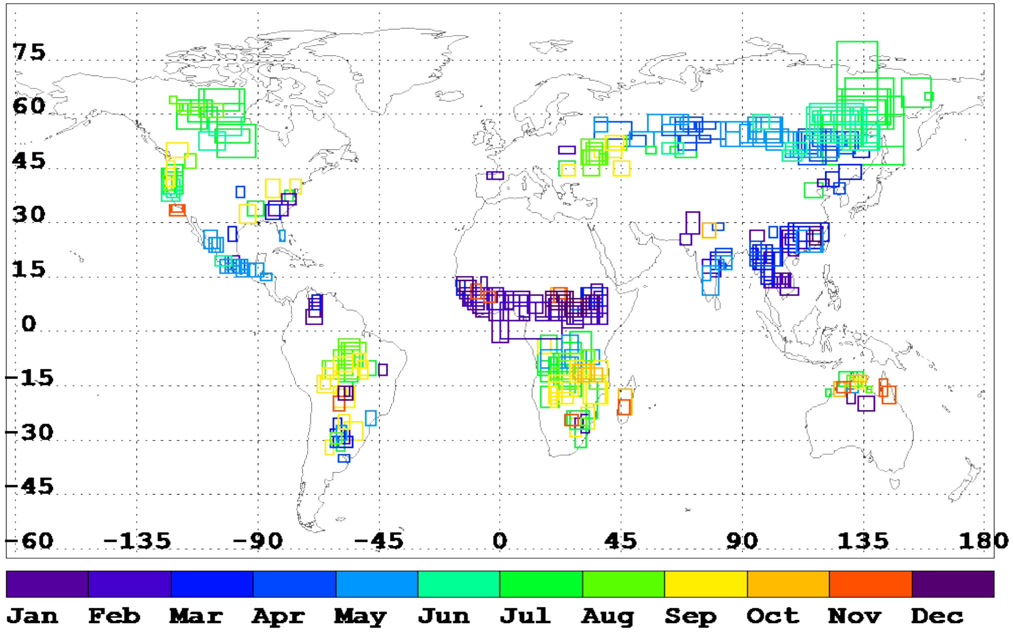
[PBL from MERRA-2]

2 km threshold avoids dependence on PBL height estimate

Val Martin, Kahn & Tosca; Remt. Sens. 2018

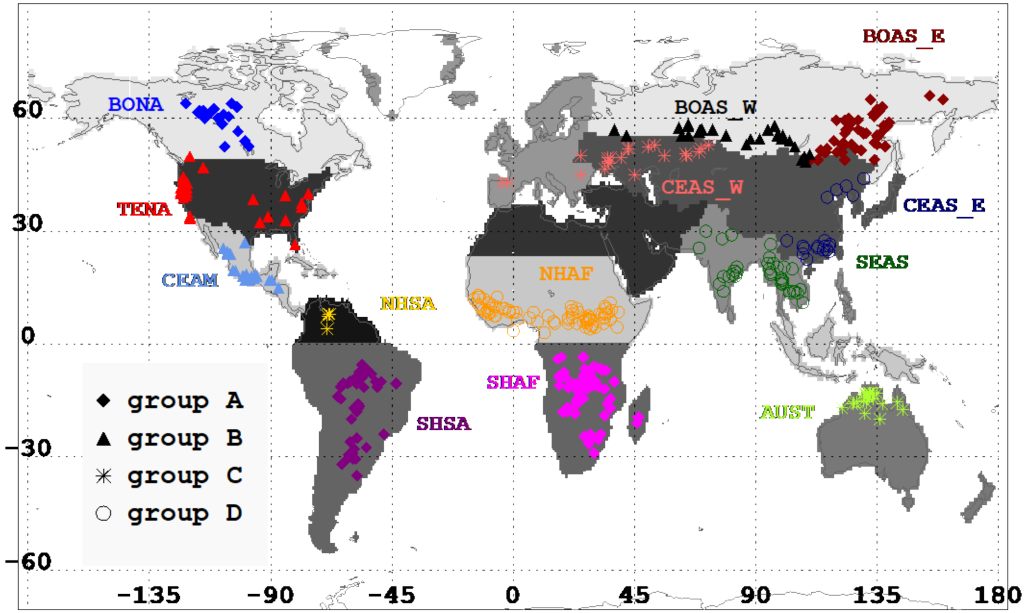
Constraining Source Strength Using Satellite AOD and Forward Modeling

447 satellite **snapshots provide instantaneous constraint** on a source strength



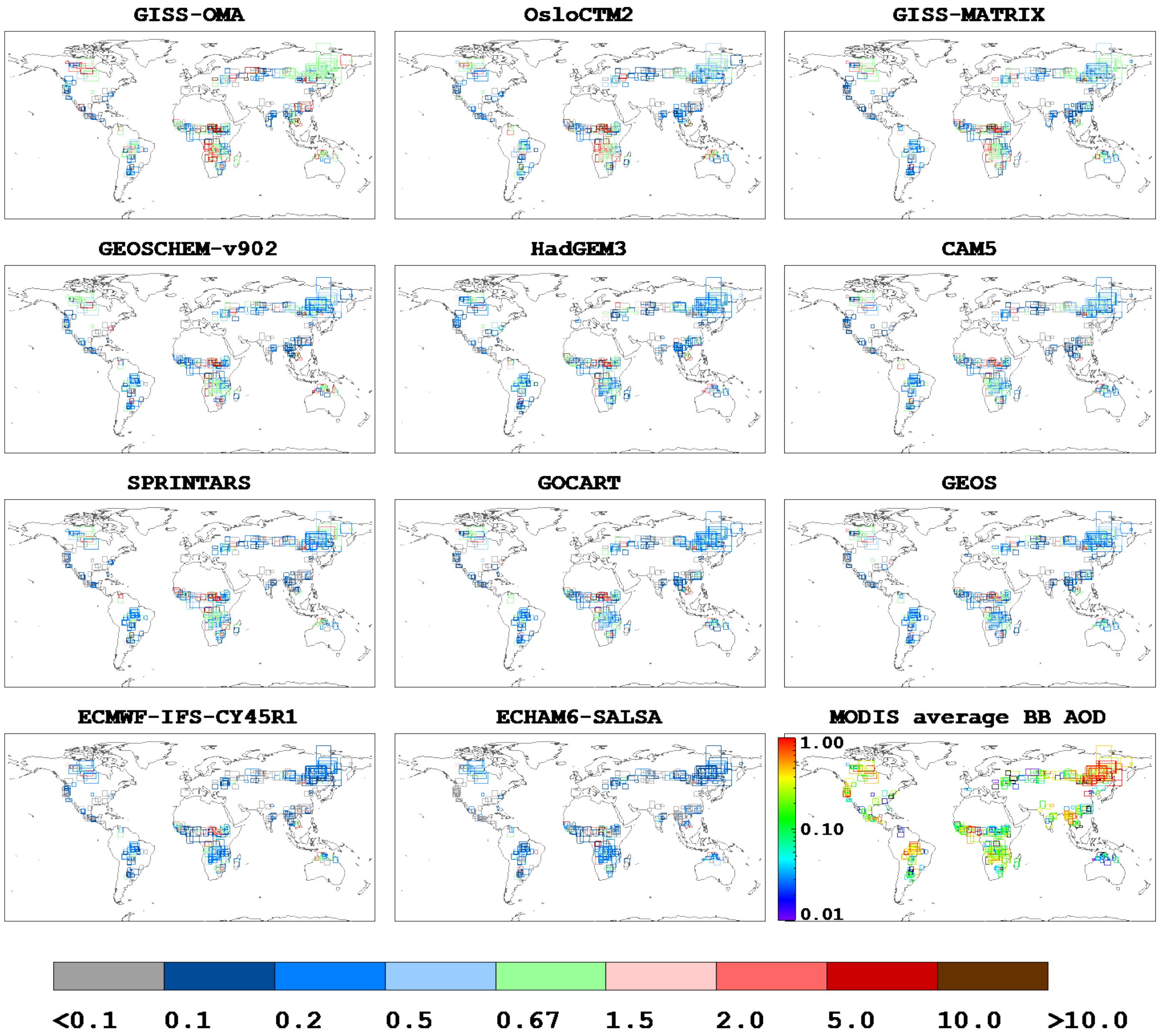
Fire cases for *Petrenko et al.* source-strength studies
(1) plumes with at least one linear dimension of **100 km**, to be useful for global modeling studies with fairly coarse resolution of 1° or larger
(2) a coordinated pattern of **elevated AOD**,
(3) a **visible smoke plume** in the satellite imagery, and
(4) a **fire signal** in the MODIS thermal anomalies product (MOD14)

GFED-based Biomass Burning regions



The 13 regions with the BB cases in each region. BONA = Boreal North America, TENA = Temperate North America, CEAM = Central America, NHSA = Northern Hemisphere South America, SHSA = Southern Hemisphere South America, NHAF = Northern Hemisphere Africa, SHAF = Southern Hemisphere Africa, BOAS_W = Boreal Asia West, BOAS_E = Boreal Asia East, CEAS_W = Central Asia West, CEAS_E = Central Asia East, SEAS = Southeast Asia, AUST = Australia

Petrenko, Kahn, Chin et al. 2023

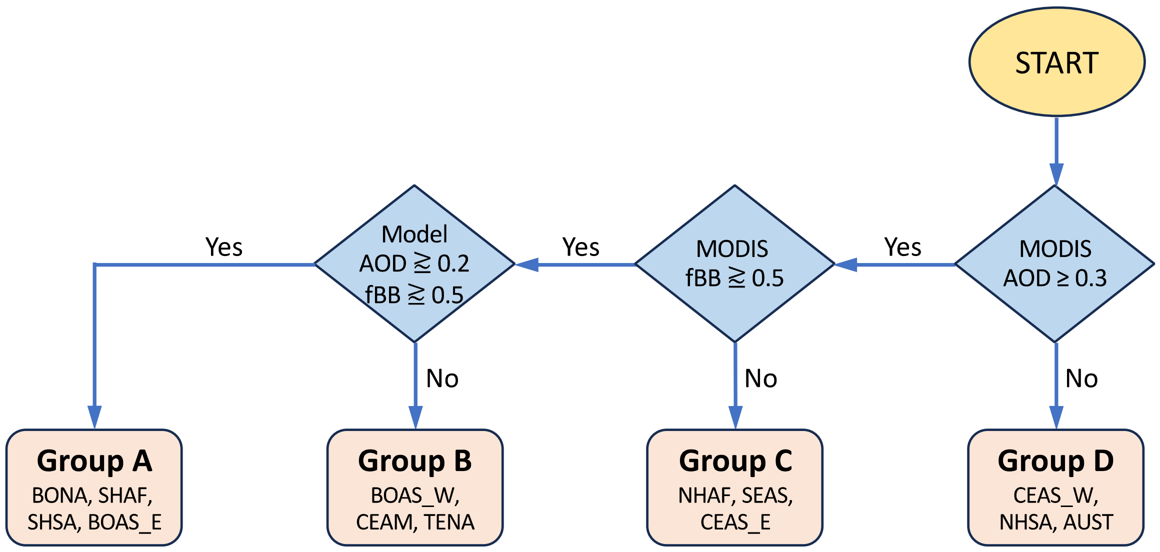


Ratio of model-simulated BB AOD (AOD_BB1 – AOD_BB0) to the BB AOD derived from MODIS for all individual fire cases.

- Models are ranked from highest to lowest overall model BB AOD
- Generally consistent model performance within individual BB regions
- In some regions, models all under- (USA, SEAsia) or overestimate (NCAfrica) BB AOD
- But there are also significant ***inter-model differences***

Petrenko, Kahn, Chin et al. 2023

Grouping BB regions for source-strength estimation



Using satellite observations to constrain BB aerosol simulations work best in regions

- With relatively high total MODIS AOD
- Low/uncomplicated background aerosol (BB aerosol dominates)

➢BB regions can be divided into **four groups** w.r.t. source-strength estimation method applicability:

➢A: ***High AOD, low background***, high BB AOD fraction, high confidence: boreal NH, woodlands of SH

➢B: ***Med AOD, low BG***, medium confidence, possibly missing emissions: cultivated lands

➢C: ***High AOD, high & complex background***, low confidence: NH Africa, SE Asia, China

➢D, ***Low total AOD, sporadic burning events***, low confidence: Europe Australia, LAmerica

➢**Several factors in addition to emissions input affect AOD calculations** in the model (all of which require their own constraints, and ***the required measurements are currently lacking***):

➢**OA/OC ratio**

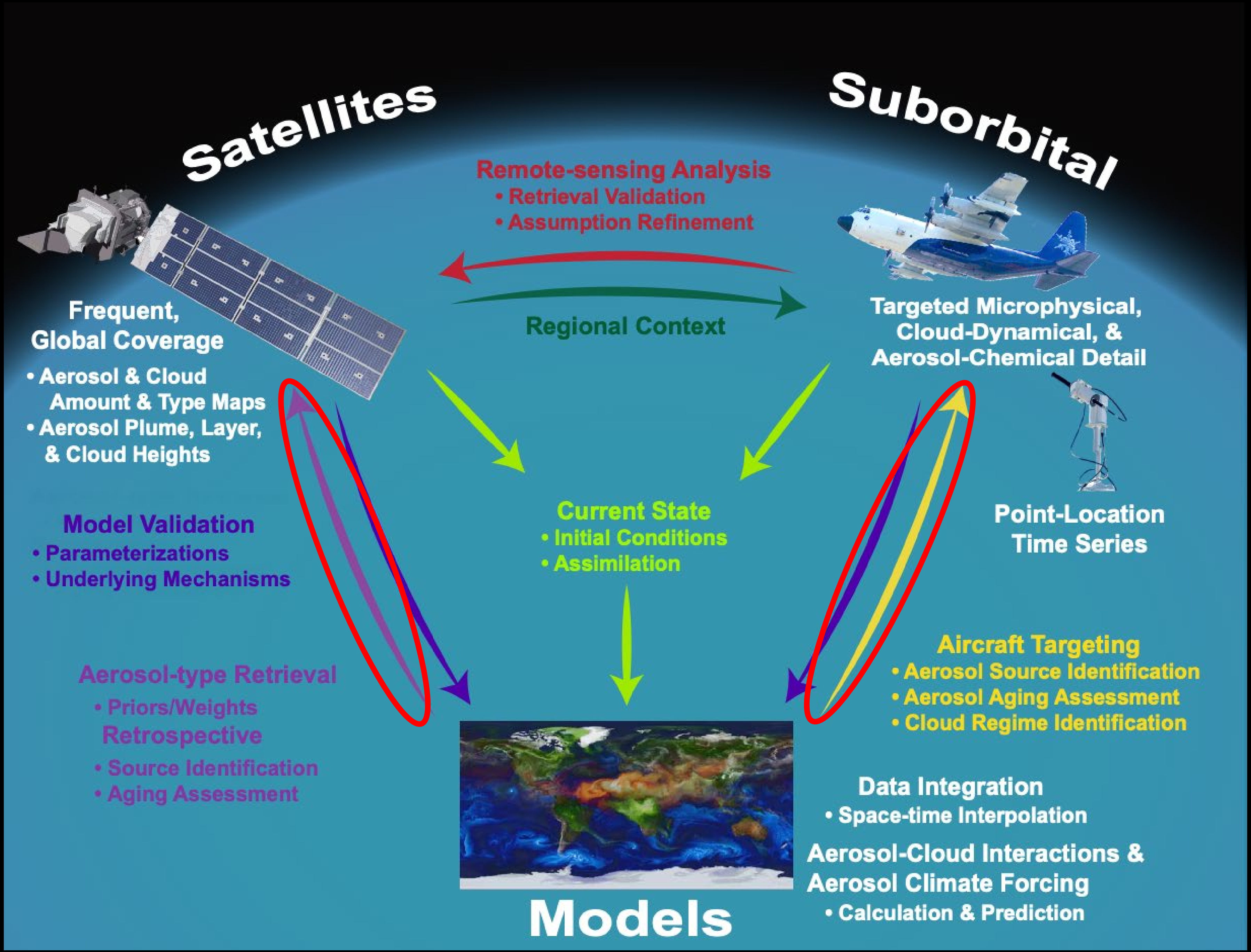
➢**Aerosol removal rates** (hence loads)

➢**Hygroscopic properties** and chemical and physical **interactions**

➢**Optical properties** (e.g., mass extinction efficiency)

➢***Additional measurements*** and methodology development needed to separate BB signal in satellite data

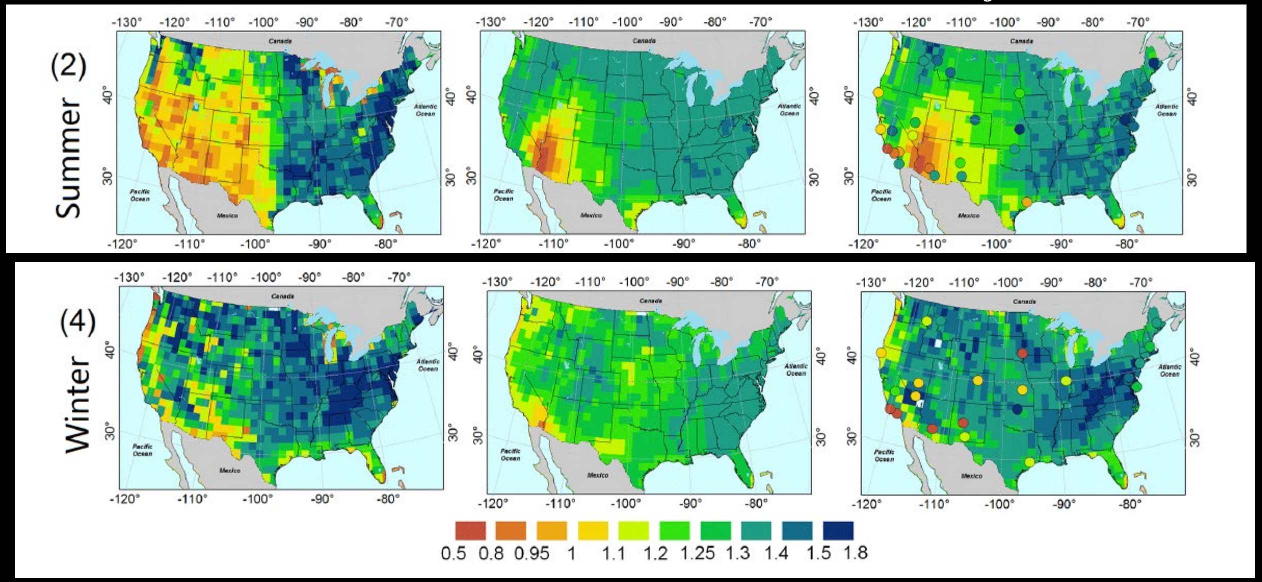
Petrenko, Kahn, Chin et al. 2023



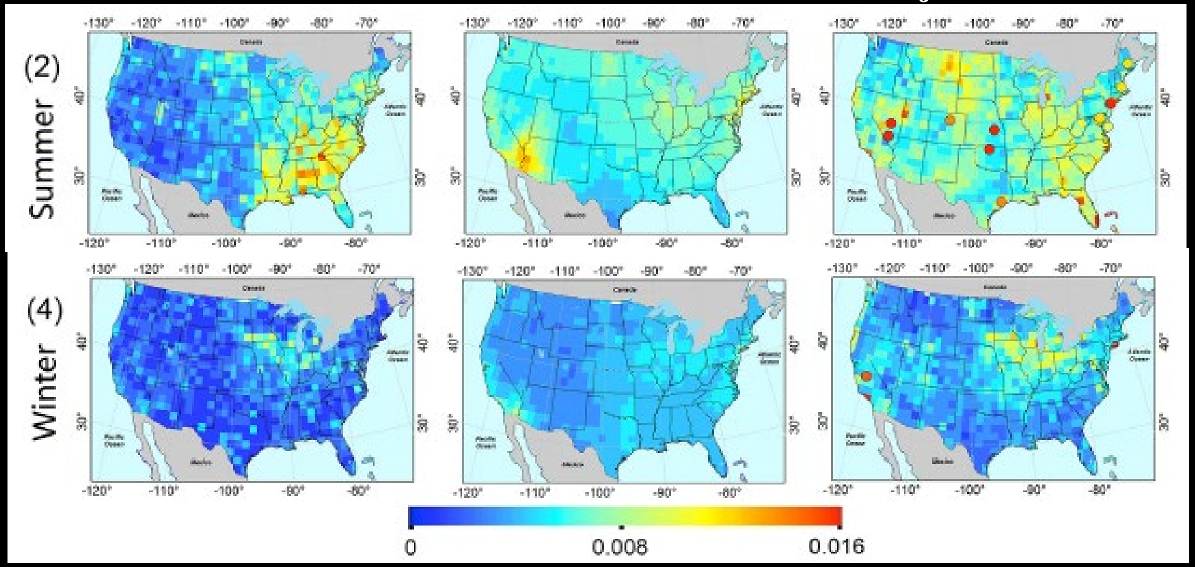
Kahn et al., Rev. Geophys. 2023

MISR *ANG*, *AAOD* Results *Constrained by GoCART Model*

MISR GoCART Adj. MISR



MISR GoCART Adj. MISR



Shenshen Li, R. Kahn, et al. AMT 2015

ANG

Four years of data (2006-2009)
Seasonally averaged

$$\mathrm{Diff}_{\mathrm{ANG}} = |\alpha_{\mathrm{MISR}} - \alpha_{\mathrm{GOCART}}| \leq \varepsilon_{\mathrm{ANG}}$$

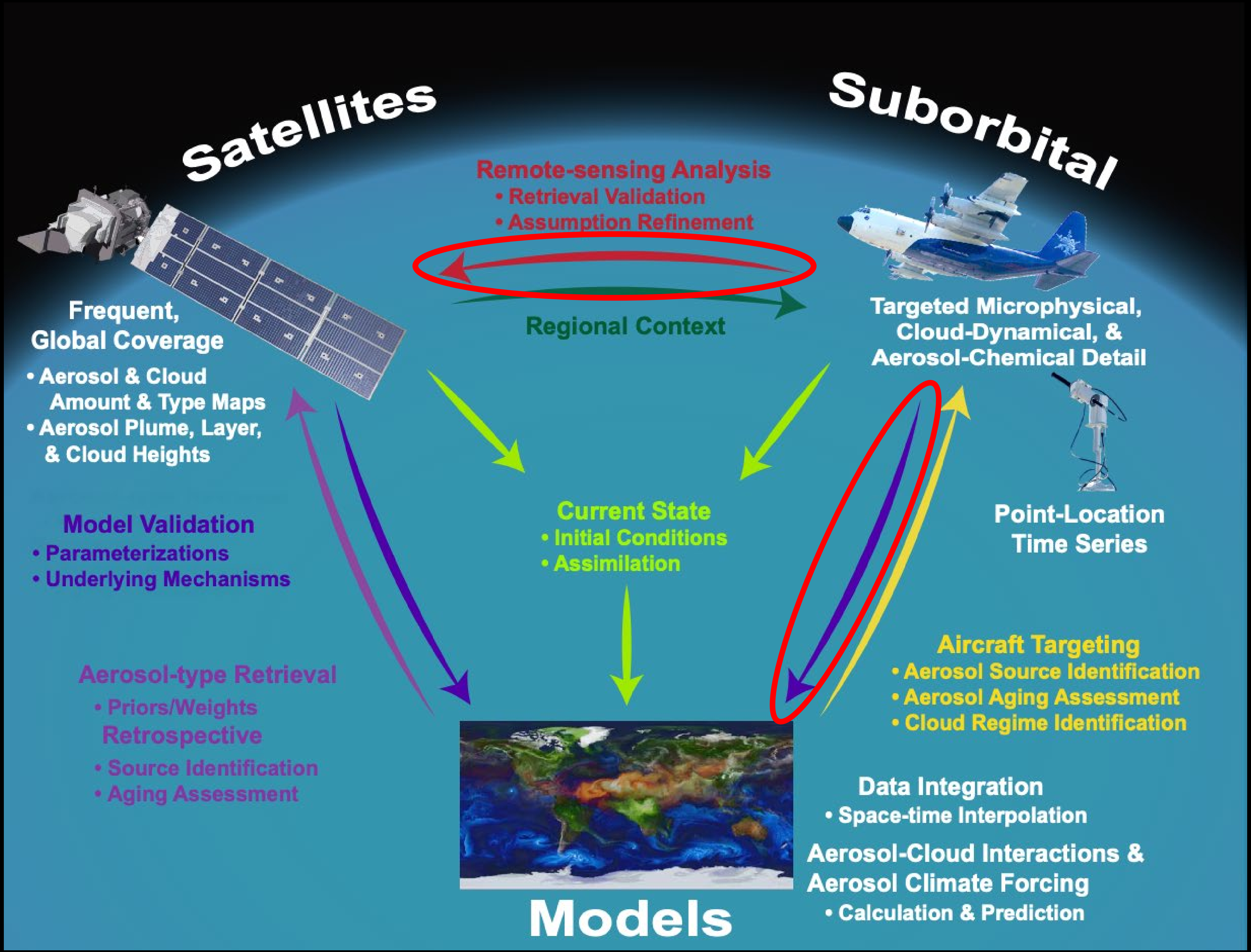
We rank the ε_{ANG}, ε_{AAOD} and select the common or the lowest mixtures

AAOD

$$\mathrm{Diff}_{\mathrm{AAOD}} = \left|\mathrm{Fraction}_{\mathrm{MISR\_AAOD}} - \mathrm{Fraction}_{\mathrm{GOCART\_AAOD}}\right| \leq \varepsilon_{\mathrm{AAOD}}$$

$\mathrm{Fraction}_{MISR\_AAOD}$ is the absorbing fraction of total AOD

Where remote-sensing data are ambiguous, can ***use a model to weight the options***



Kahn et al., Rev. Geophys. 2023

SAM-CAAM *Concept*

[Systematic Aircraft Measurements to Characterize Aerosol Air Masses]

Primary Goal: [This is currently a ***concept-development effort***, not yet a project]

- ***Characterize statistically particle properties*** **for major aerosol types globally, to provide detail unobtainable from space, adding value to models & satellite aerosol data, offering** *improved aerosol property assumptions for:*

  -- ***Modeling*** **aerosol direct forcing and aerosol-cloud interactions**

  -- ***Satellite retrieval algorithm*** **climatology options or priors**

Plus: More robust ***translation between satellite-retrieved aerosol optical properties and*** **species-specific aerosol mass and size tracked in** ***aerosol transport, climate, & air quality models***

Substantially reduce model uncertainty & enhance the value of 23+ years of satellite aerosol retrieval products

Kahn et al., BAMS 2017

Suborbital *In Situ* Required for PDFs of Particle Microphysical Properties

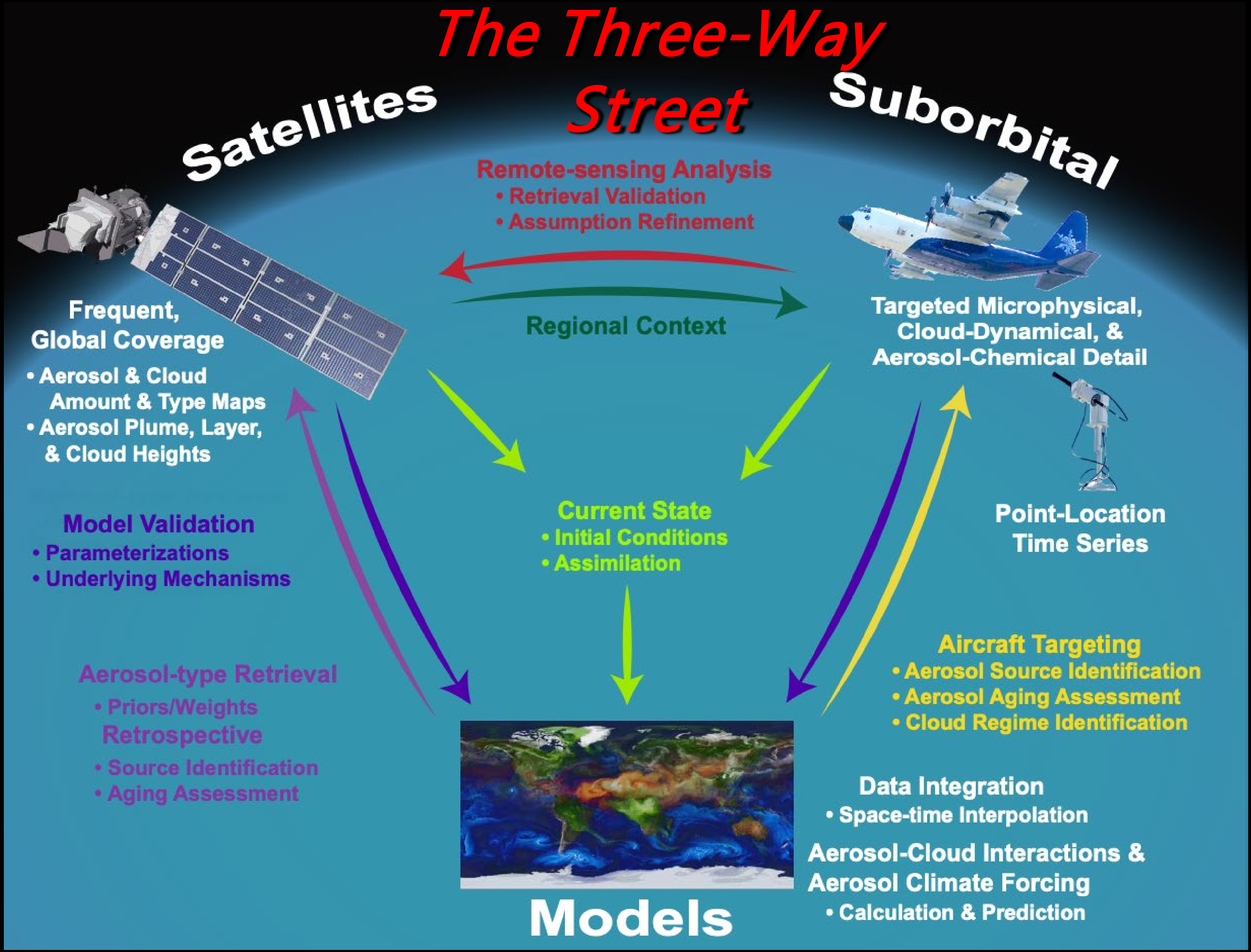
Aerosol intensive properties required for key aerosol science objectives, but ***cannot be retrieved adequately*** or are ***entirely unobtainable from remote sensing***

- ***Hygroscopicity**** – Ambient ***particle hydration***, ***aerosol-cloud interactions***
- ***Mass Extinction Efficiency*** – Translate between retrieved ***optical properties*** from remote sensing ***& aerosol mass*** book-kept in models
- ***Spectral Light-Absorption*** – Aerosol ***direct & semi-direct forcing***, atmospheric stability structure & circulation
- ***CCN Properties**** – At least part of the CCN size spectrum is ***too small to be retrieved*** by remote-sensing

Acquiring such data is feasible because:
Unlike aerosol amount, ***aerosol microphysical properties tend to be repeatable*** from year to year, for a given source in a given season

Kahn et al., BAMS 2017

*Under special conditions, hygroscopicity (*Dawson et al. 2020*) and CCN # (*Rosenfeld et al. 2016*) can be derived from remote sensing; however: (*Stier*, ACP 2016)



- SAM-CAAM
- ACI Suborbital
- 3-Way Street Research Program

Kahn et al., Rev. Geophys. 2023