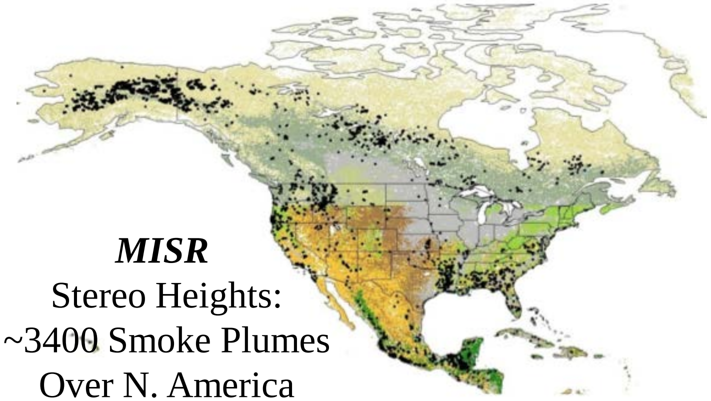
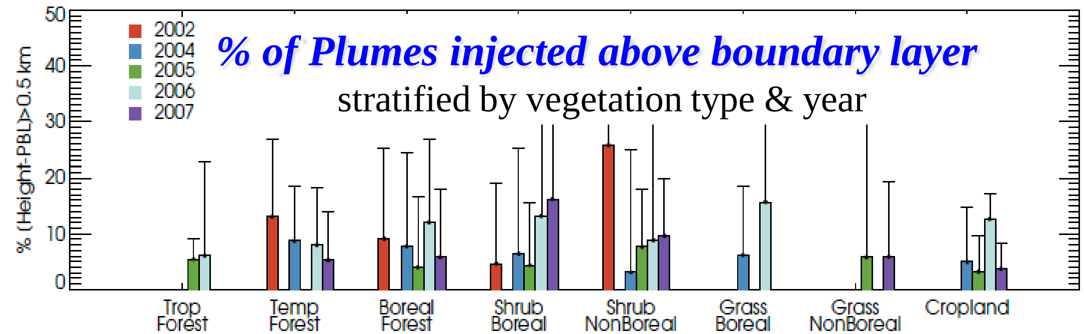
The AeroCom Biomass Burning Experiment

Mariya Petrenko, Maria Val Martin, Ralph Kahn, Mian Chin

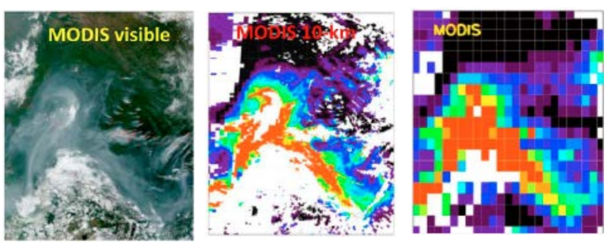
Wildfire Smoke *Injection Heights* & *Source Strengths*



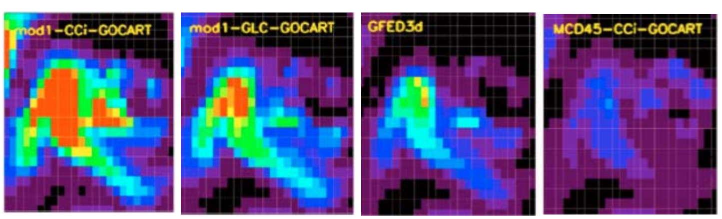
MISR
Stereo Heights:
~3400 Smoke Plumes
Over N. America



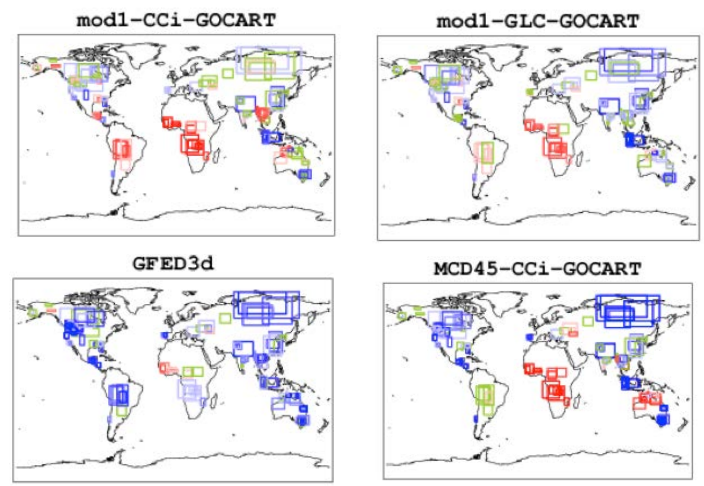
Val Martin et al. ACP 2010



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 et al., JGR 2012

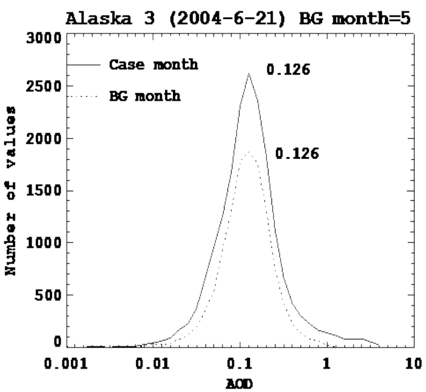
Source Strength
Refinements to the MODIS BB AOD Snapshot Dataset

(1) Expanded the ***Number of Fire Cases*** from 124 to over 900

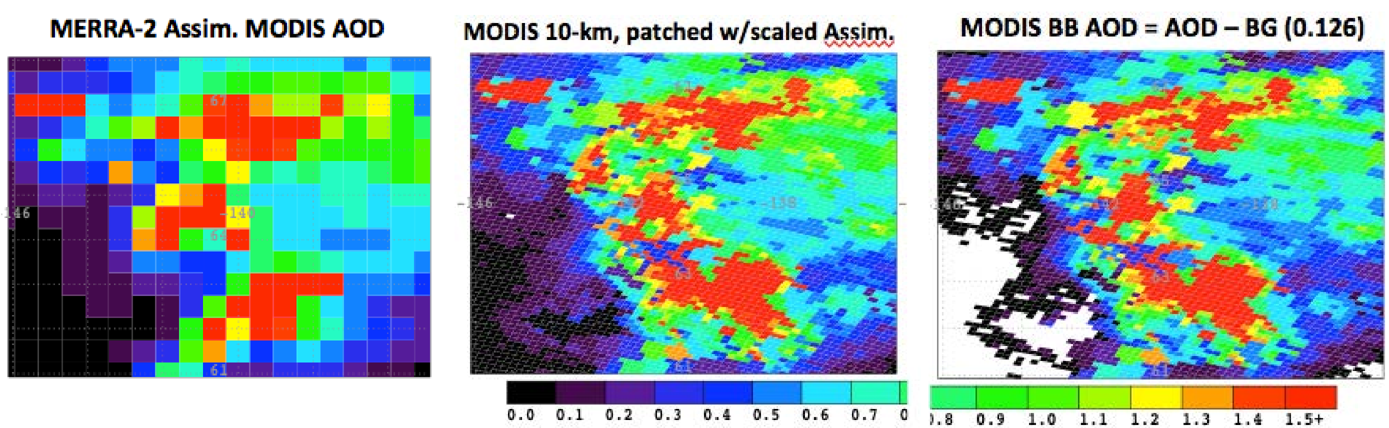
(2) Used scaled reanalysis-model simulations to ***Fill Missing AOD Retrievals*** in the MODIS observations

(3) ***Separated the BB Components*** of the total AOD from background aerosol in the near-source regions (*using pre-fire-season AOD statistics*)

(4) Included emissions from ***Small Fires*** that are not identified explicitly in the sate



Background AOD is the modal mean AOD for the month (BG month) at the beginning of, or just before, the burning season.

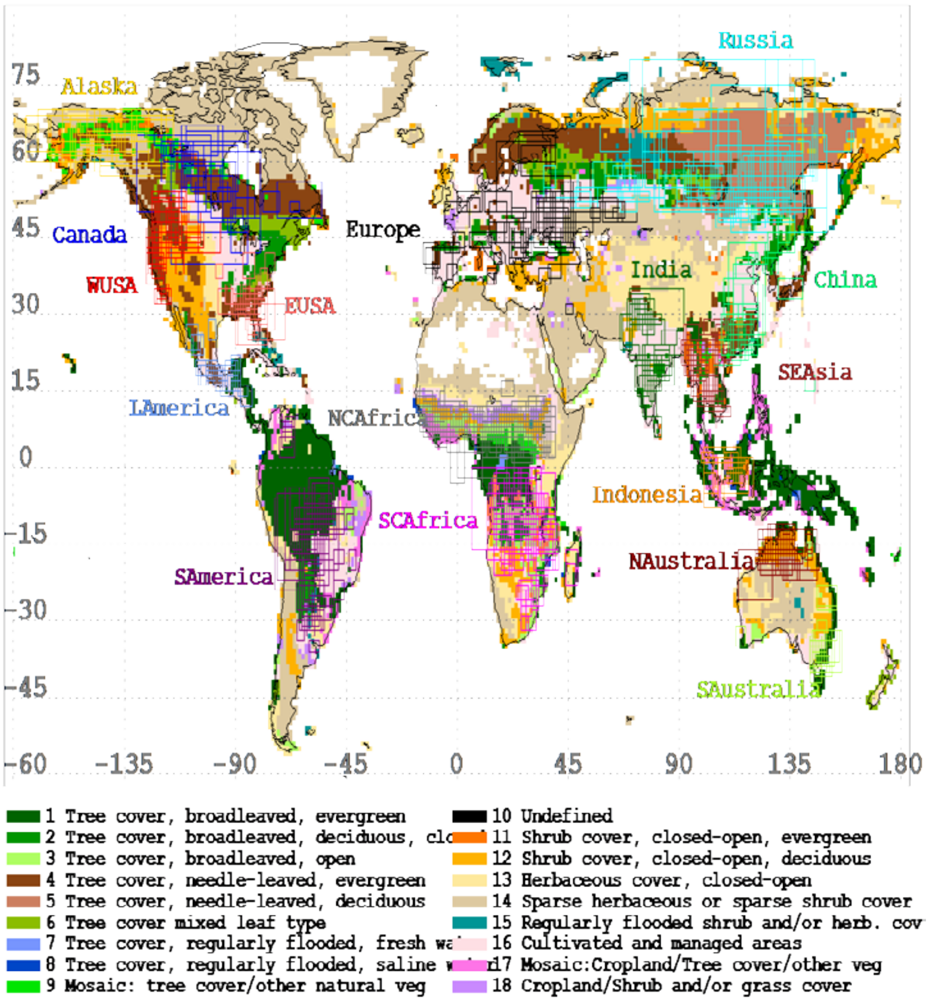


***MODIS BB AOD* = Plume $\mathbf{AOD_{tot}}$ – $\mathbf{AOD_{bkgnd}}$**

Petrenko et al., JGR 2017 in press

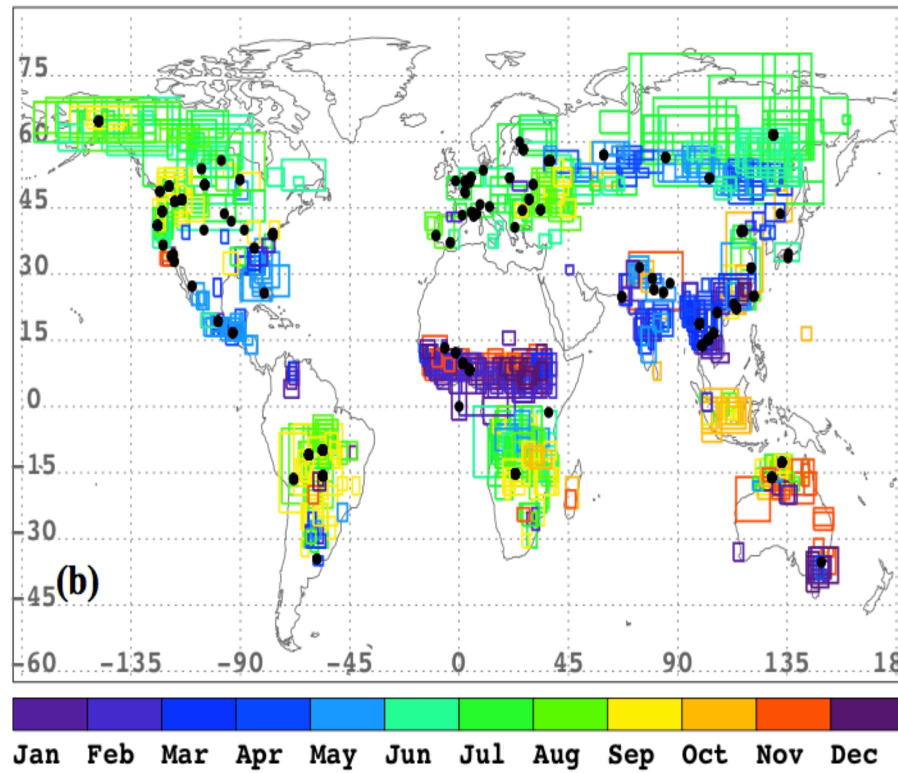
Source Strength
Satellite Reference Observational Dataset
2004, 2006-2008

972 Cases in 16 Colored *Ecosystems* (497 in 2008)



The colored squares represent ecosystems

***Month* when case was observed by MODIS**



Petrenko et al., 2017 in press

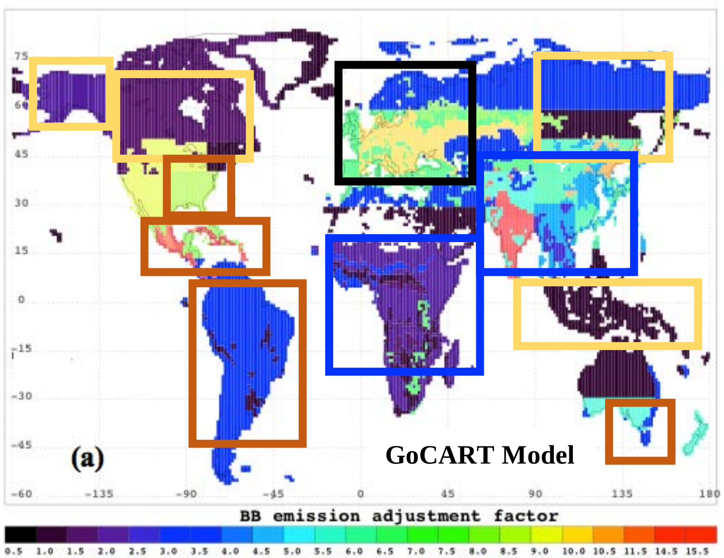
Source Strength
Adjustment Factor Situational Groupings

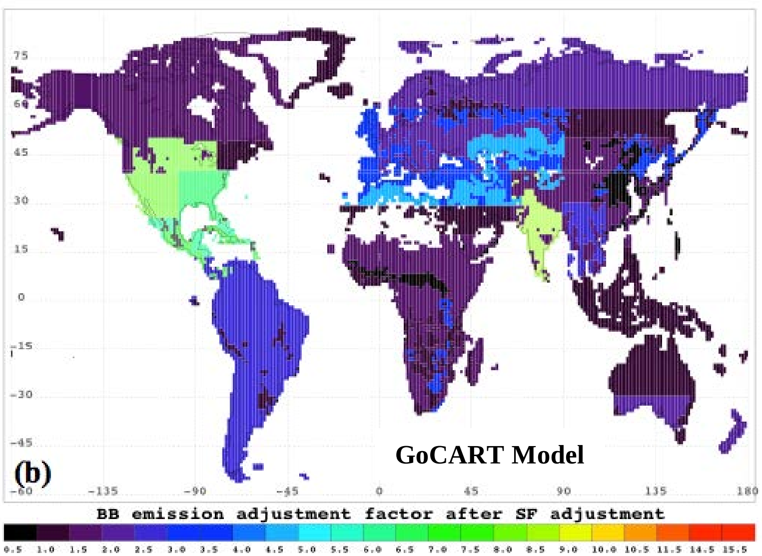
Group 1 –***Discrete, Strong Smoke Plumes*** dominate, minimal adjustment needed

Group 2 – Smoke source ***Adjustments Resolve most AOD Discrepancies***

Group 3 – ***Background AOD High & Comparable*** to or larger than smoke AOD

Group 4 – ***Background AOD Low but Comparable*** to smoke AOD





Petrenko et al., 2017 in press

Group 1 – ***Alaska, Canada, Indonesia, Eastern Siberia***

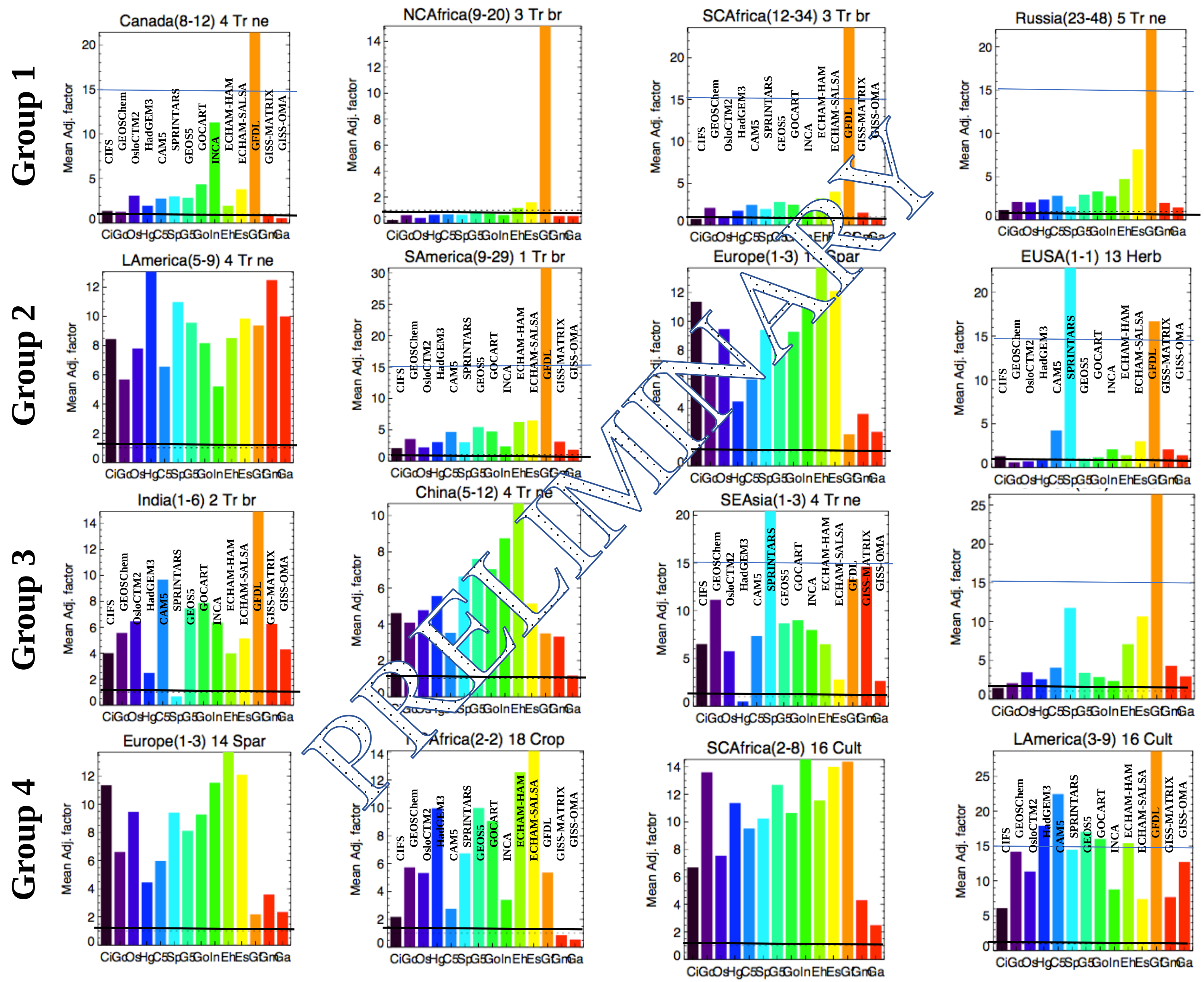
Group 2 – ***South Australia, Eastern USA, South America, Latin America*** *(with SF)*

Group 3 – ***India, China, Southeast Asia, North & South-Central Africa***

Group 4 – ***Europe***, + ***Crop, Cultivated*** *ecosystems almost everywhere*, ***& some Shrub***

Source Strength

AOD_{BB} Ratio Multi-Model/MODIS (2008)



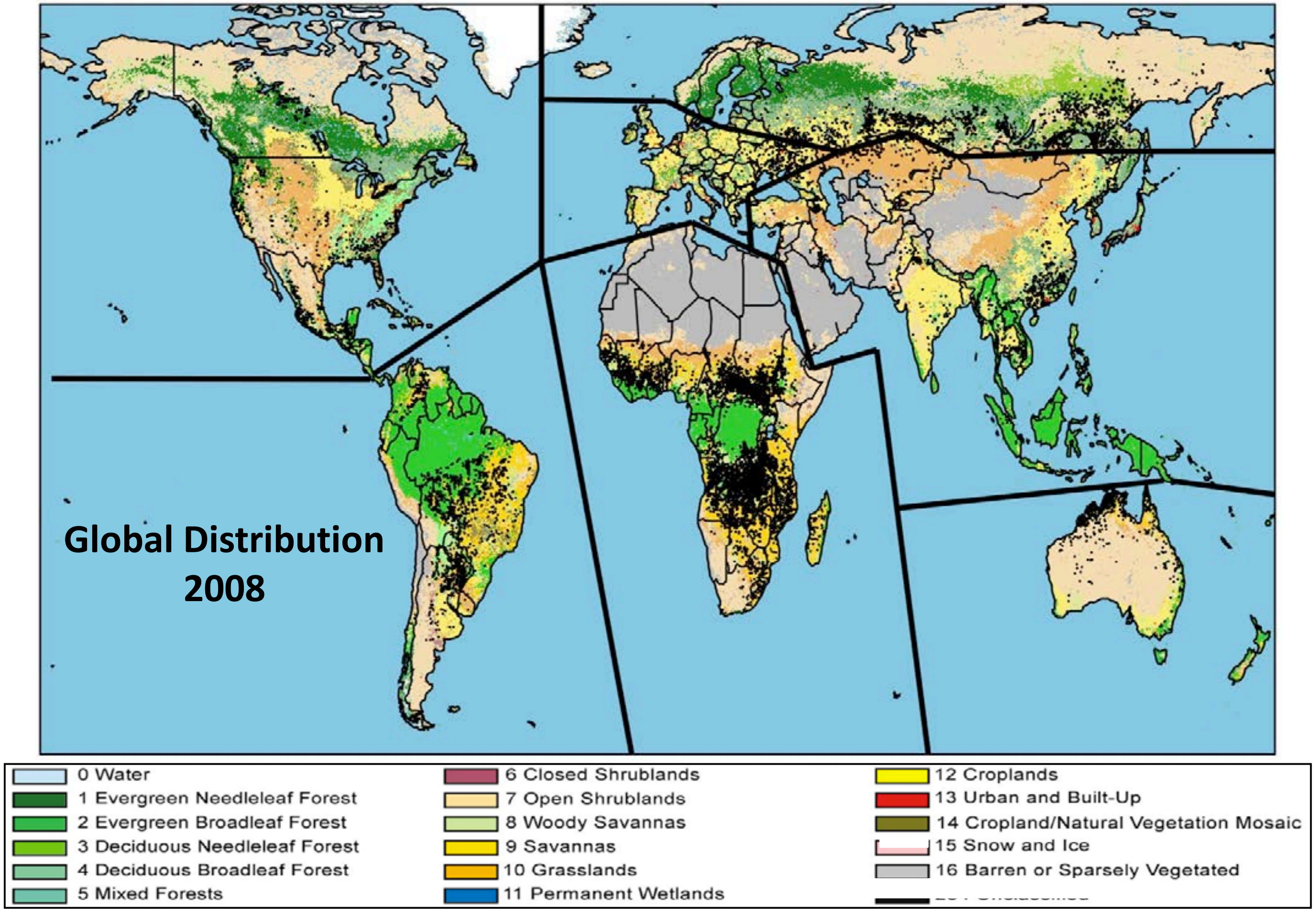
Organizing model runs into groups for which source-strength approach works differently, so we can:

- **Define adjustment factors** where they help
- Characterize **situations with large uncertainties**
- **Separate inventory from model-specific** issues

CAMS-GFED3-gd8b	GEOS5
GEOSCHEM-v902	GOCART
OsloCTM2	INCA
HadGEM3	ECHAM6.1-HAM2.2
CAM5	ECHAM6-SALSA
SPRINTARS	GFDL-AM3p10
	GISS-MATRIX
	GISS-OMA

Petrenko et al., 2017 in prep.

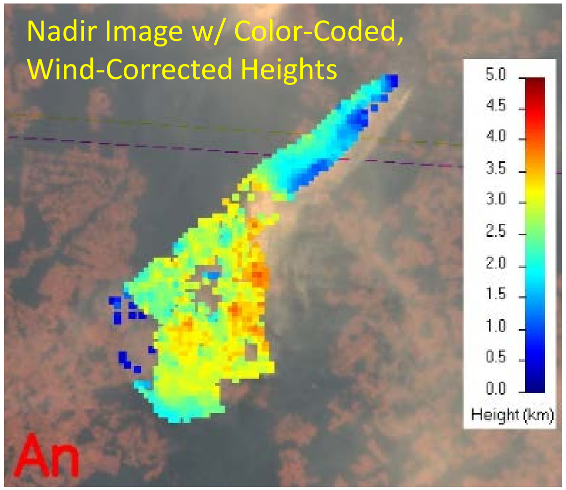
Biomass Burning Experiment *PHASE 2*: *Fire Emission Injection Heights*

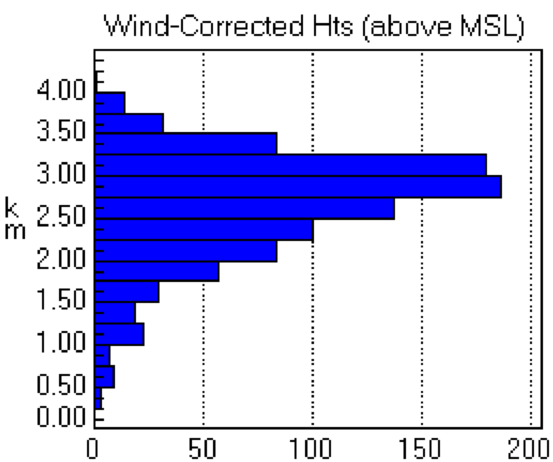


- About ***50,000 smoke plumes*** digitized 2008-2010 (~16,000 for 2008)
- Each plume is Operator-Processed using ***MINXv4.0***, and Quality Controlled
- For N America, about ***18% - 20%*** of plumes are injected above the PBL
- Raw, graphics and summary files, and documentation are ***available on-line:***

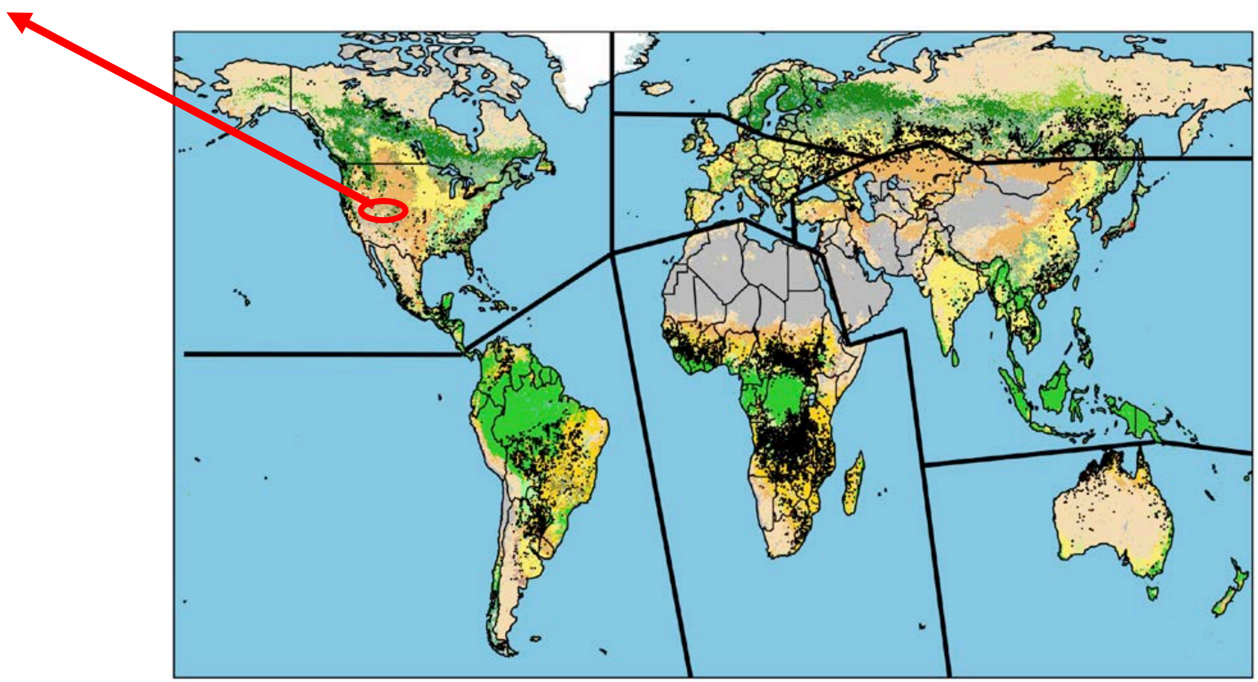
https://misr.jpl.nasa.gov/getData/accessData/MisrMinxPlumes2/ *Val Martin et al., 2017 in prep.*

Biomass Burning Experiment *PHASE 2*: *Fire Emission Injection Heights*



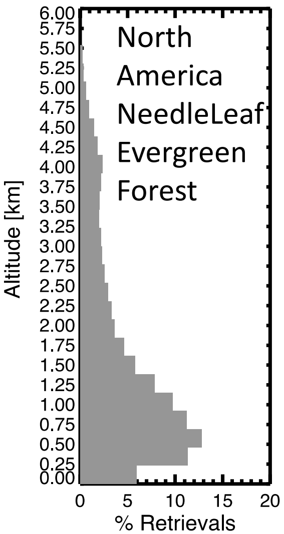


- Heights at ***1.1 km Horizontal*** res., ***~250-500 m Vertical*** res.
- Keyed to the ***Elevation of Maximum Spatial Contrast***
- Parallax is corrected for proper motion (***Wind Correction***)
- Height histogram gives some ***Indication of Vertical Extent***

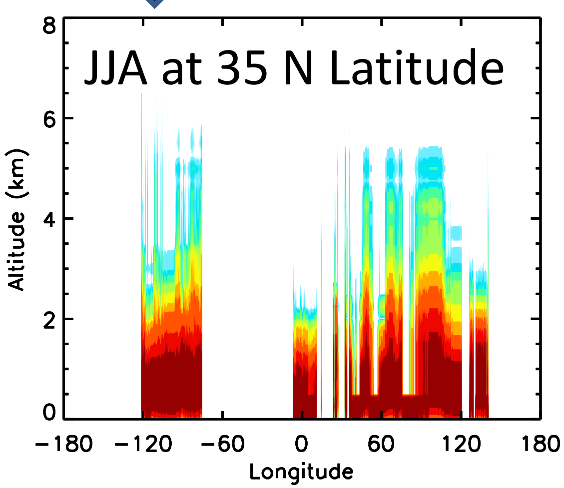


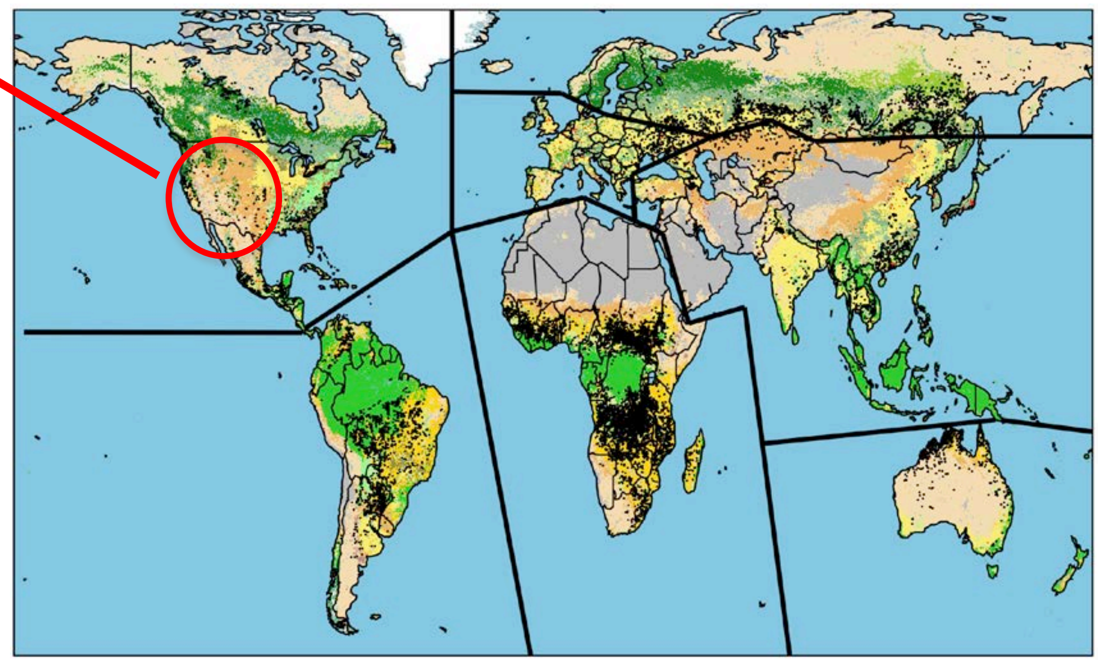
Val Martin et al., 2017 in prep.

Biomass Burning Experiment *PHASE 2*: *Fire Emission Injection Heights*



- Fire emissions are ***Stratified by Altitude***, ***Region***, ***Ecosystem***, & ***Season***
- Inter-annual and/or sub-seasonal ***temporal resolution*** might be required in some cases
- The cases in each stratum are ***Averaged*** to produce a statistical summary

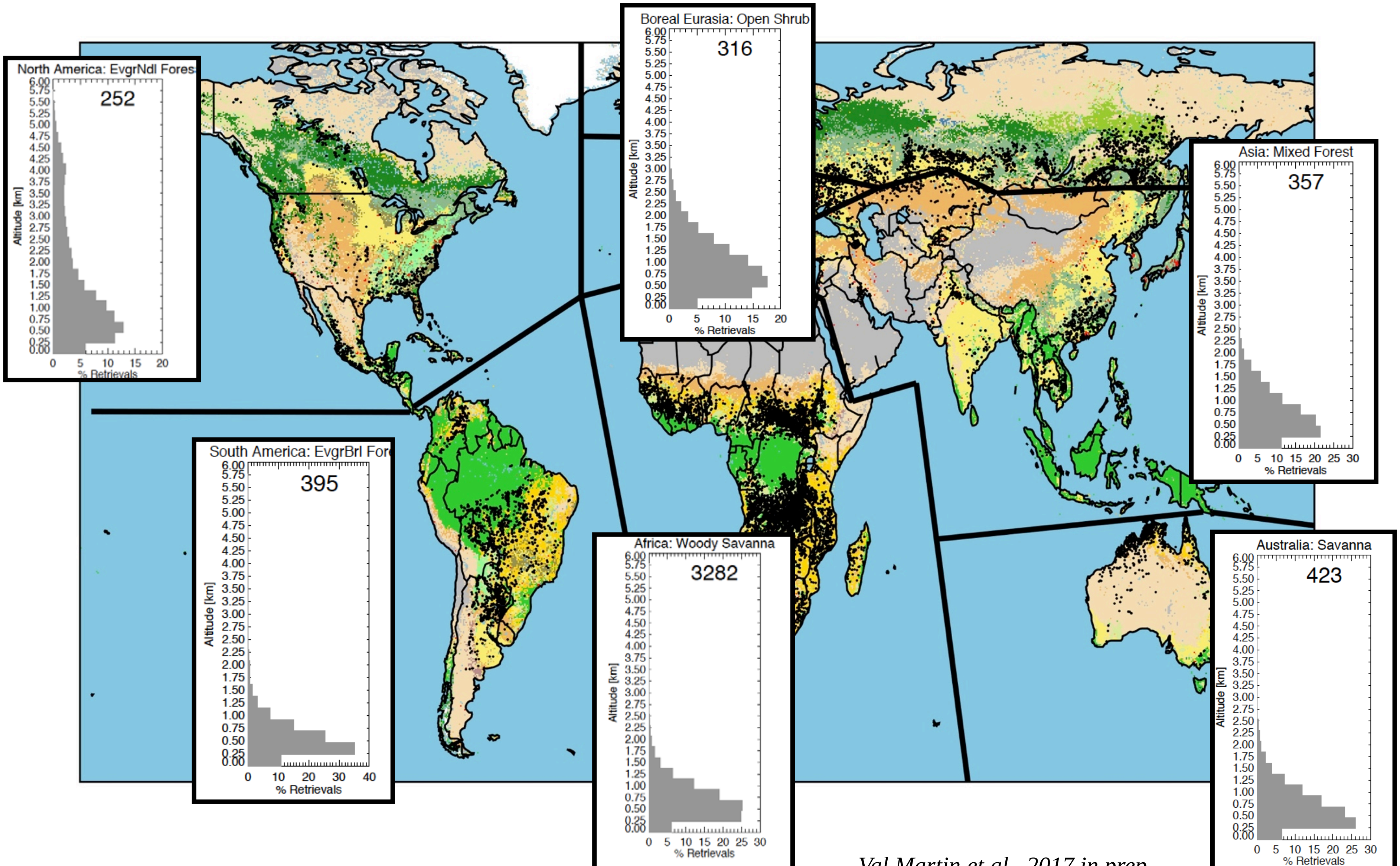




Val Martin et al., 2017 in prep.

Example *Injection Height Vertical Distributions*

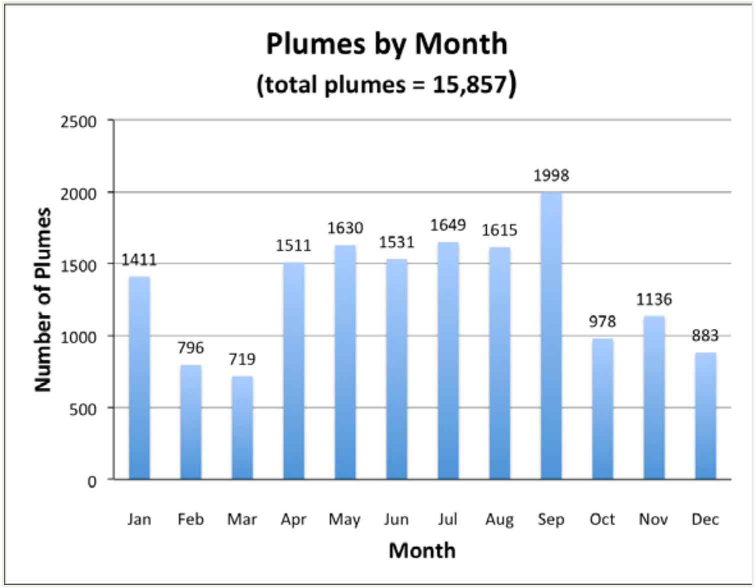
Stratified by Region and Biome

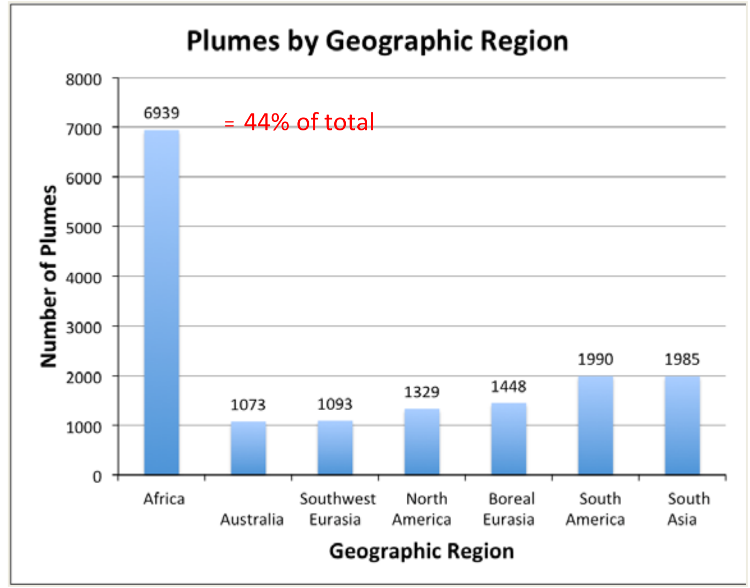


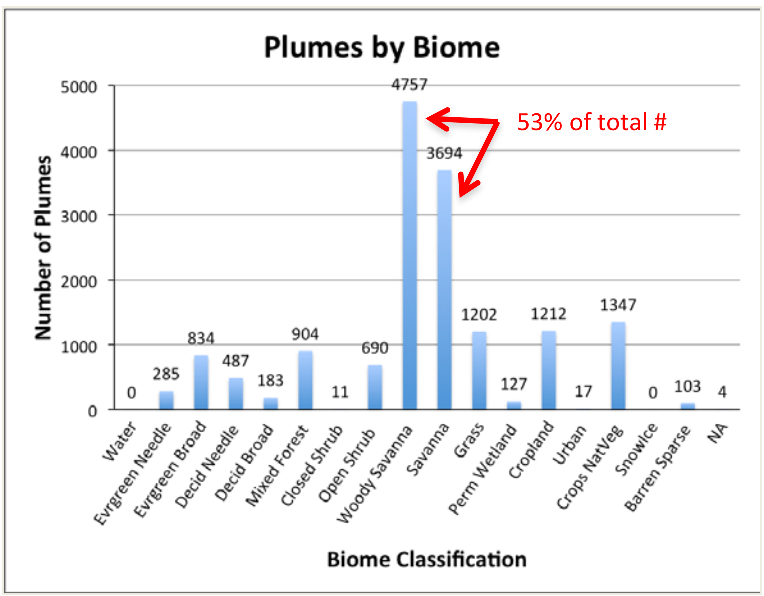
Val Martin et al., 2017 in prep.

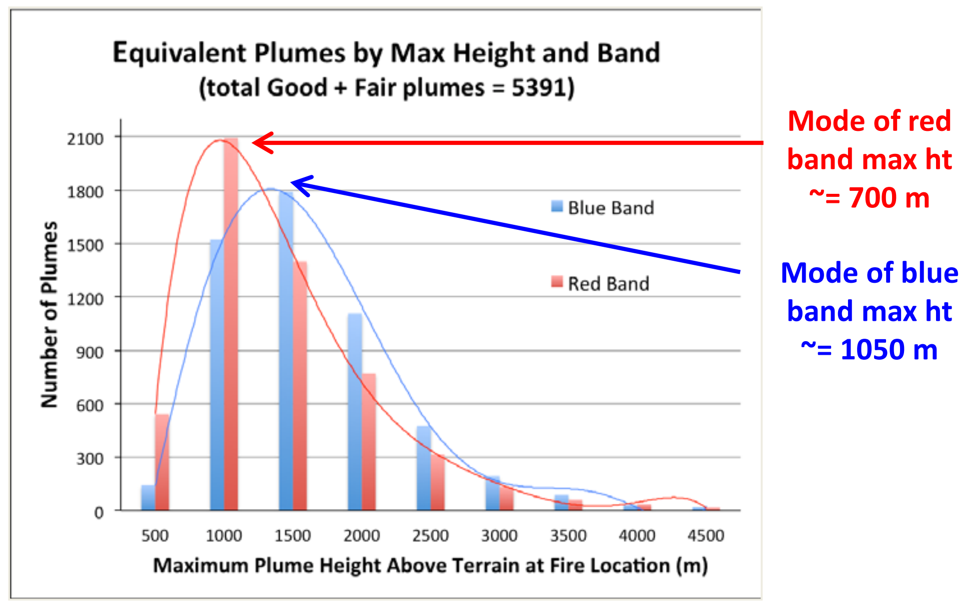
Biomass Burning Experiment *PHASE 2*:

Global Statistics for 2008









Val Martin et al., 2017 in prep.

Eyjafjallajokull Volcano, Iceland

May 07, 2010 Eruption *NOAA HySPLIT Model*

Baseline HYSPLIT Simulation

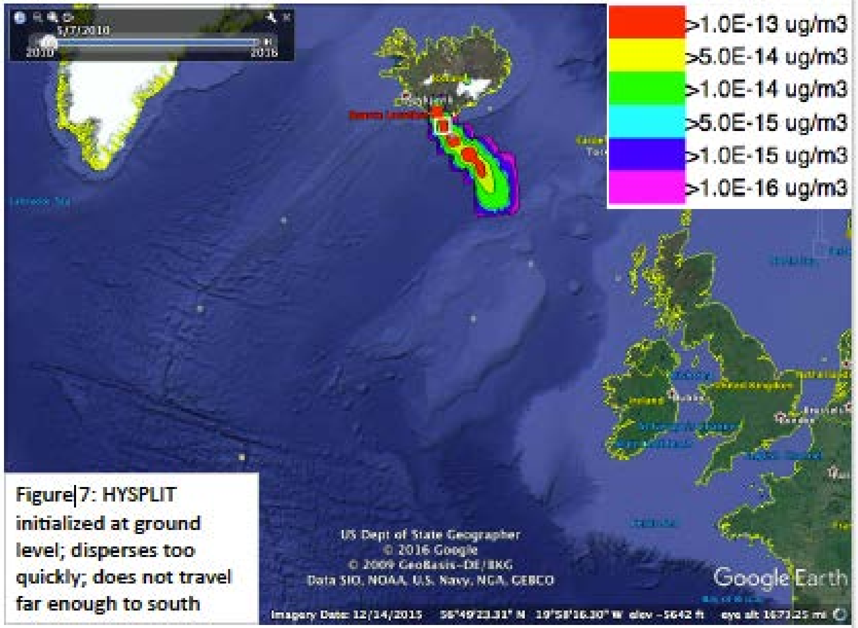


Figure 7: HYSPLIT initialized at ground level; disperses too quickly; does not travel far enough to south

MINX-Initialized Simulation

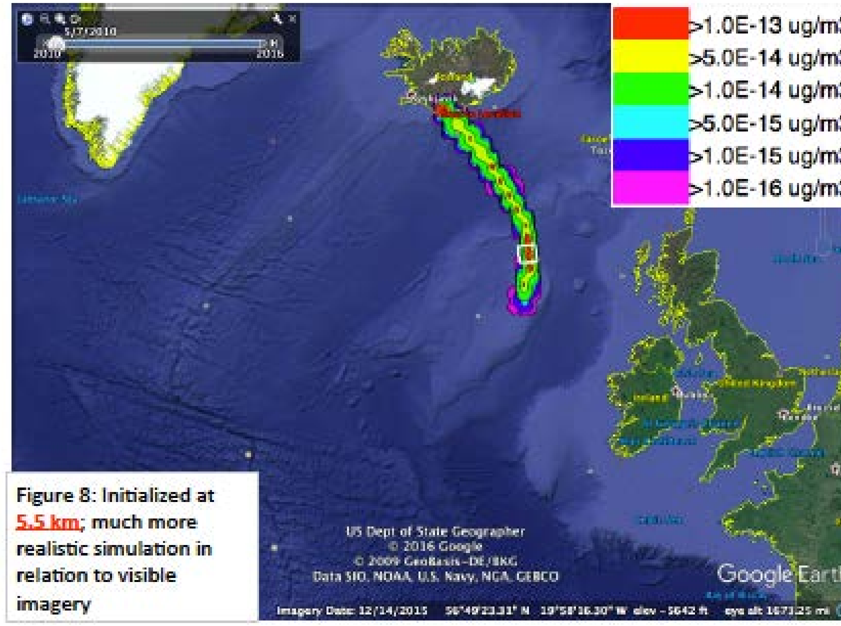


Figure 8: Initialized at 5.5 km; much more realistic simulation in relation to visible imagery

Conclusion:

When the injection height is above the PBL in regions with significant wind shear, MINX-initiated simulations better represent satellite observations.

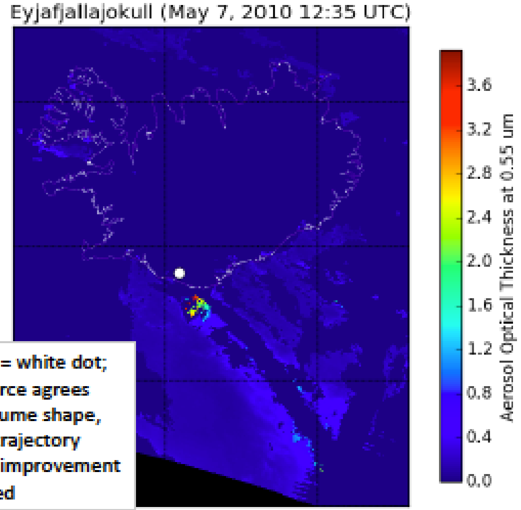


Figure 9: Source = white dot; AOD right at source agrees with baseline; plume shape, dispersion, and trajectory show significant improvement in MINX-initialized

We invite AeroCom participants to run their models considering these injection-height constraints.

How these data might be applied in models would be a topic for discussion at AeroCom, and as the study progresses

CJ Vernon et al., UMD Senior Project 2017

AEROSAT Perspectives
On Collaboration with Modelling

Thomas Popp / DLR
Ralph Kahn / NASA-GSFC

AEROSAT Goals (1)

- **Work with modelers to make satellite aerosol data as useful as possible for climate modeling (e.g., AeroCom)**
- **Achieve open and active exchange of information**
  - Retrievals and their strengths and limitations
  - Match requirements of users to technical capabilities with data
  - Share the latest technological advances
  - Work toward inter-operability (data formats, data standards)
- **Forum for satellite aerosol retrieval experts**
  - Learn from each other, collaborate as appropriate
  - Initiate new developments
  - Discuss harmonization

AEROSAT Goals (2)

- **Promote the use of satellite data**
  - As **complementary** to other sources of information
  - To better understand the role of aerosols in climate, climate change, air quality, and atmospheric processes
- **Forum includes satellite data users** (AEROCOM / CCMI models, ICAP forecasts) **and data providers** (AERONET reference, space agencies)
  - Listen to each others' needs and limitations
  - Discuss what is possible; Motivate new activities
  - Contribute to integration of satellite & suborbital observations
- AEROSAT is an unfunded network (like AEROCOM)

AeroSat in the First 3 Years

- **Joint Sessions with AEROCOM**
  - Needs of modelers ←→ Possibilities & limitations of data producers
  - Common understanding of definitions

- **Internal Retrieval Expert Discussions**
  - Principles, *consistent definitions*, strengths / limitations
  - Constraining *aerosol type* with satellite data
  - Deriving *pixel-level uncertainties*
  - Producing *long-term* satellite data records
  - Satellite capabilities / limitations for *air quality applications*

- **Summary (draft) outcomes**
  - Intensified dialogue (among retrieval experts & with modelers)
  - List of long-term datasets
  - List of inter-comparison studies
  - Inventory of aerosol-type products & definitions
  - Review of validation metrics (linear regression; confidence intervals, etc.)

Long-term Data Record Table 2015

AEROSAT Working Group on Climate Data Records

List of candidate aerosol CDRs currently available:

Satellite Instrument	*Algo*	*Main Retrieved Quantities*	*Time Span*	*Provider*	*Access*	*Reference*
NOAA-AVHRR	2-channel	AOD (ocean)	1981-2009	NOAA	NOAA CLASS	Heidinger et al., 2014: The Pathfinder Atmospheres–Extended AVHRR Climate Dataset. Bull. Amer. Meteor. Soc., 95, 909–922.
TOMS	near-UV	AOD, AAI	1979-2005[1]	NASA	ozoneaq.gsfc.nasa.gov	O. Torres, P. K. Bhartia, J. R. Herman, A. Sinyuk, Paul Ginoux, and Brent Holben, 2002: A Long-Term Record of Aerosol Optical Depth from TOMS Observations and Comparison to AERONET Measurements. *J. Atmos. Sci.*, **59**, 398–413.
SAGE	ver 7.0 (SAGE II) ver 4.0 (SAGE III)	Aerosol extinction coefficient profiles from cloud top to 40 km at 4 wavelengths in the UV-vis-NIR	1984-2005[2]	NASA LaRC eosweb.larc.nasa.gov	sage.nasa.gov	R. P. Damadeo, R. P., J. M. Zawodny, L. W. Thomason, and N. Iyer, SAGE Version 7.0 Algorithm: Application to SAGE II, Atmos. Meas. Tech., 6, 3539-3561, 2013 www.atmos-meas-tech.net/6/3539/2013/, doi:10.5194/amt-6-3539-2013 Thomason, L. W., James R. Moore, Michael C. Pitts, Joseph M. Zawodny, and Er-Woon Chiou, An Evaluation of the SAGE III Version 4 Aerosol Extinction Coefficient and Water Vapor Data Products, Atmos. Chem. Phys., 10, 2159-2173, 2010 www.atmos-chem-phys.net/10/2159/2010/

[1] TOMS data after 2001 should not be used for trend analysis. TOMS instruments were flown on the following satellites: Nimbus-7 (Nov 1978 - May 1993), Meteor-3 (Aug 1991 - Dec 1994), Earth Probe (July 1996 - Dec 2005), and ADEOS (Sep 1996 - June 1997)

[2] SAGE II (Oct 1984-Aug 2005), SAGE III-Meteor-3M (Feb 2002-Dec 2005). Older data sets from SAM II (1975-1978) and SAGE I (1979-1981) also exist.

Table collected from AEROSAT Participants

This is 1 of 6 pages

… Table needs updating

Aerosol Product Inter-Comparison Table (land) 2014

Publication	variables	method(s)	sensors: VIIRS	SeaWIFS	AVHRR	TOMS	MODIS	MISR	POLDER	AATSR	MERIS	SYNAER	OMI	AIRS	IASI	CALIOP	SEVIRI	period	region(s)	reference(s)
Kahn et al. (2011), JQSRT, 112:901–909. doi:10.1016/j.jqsrt.2009.11.003	AOD	L2 statistics					x	x										3 months 2006	Global	-
Liu, et al. (2014), JGR, 119, 3942–3962, doi:10.1002/2013JD020360.	AOD	L2 statistics	x				x											2012/13	global	AERONET, MAN
Kinne, et al. (2003), JGR, 108, 4634, doi:10.1029/2001JD001253	AOD	Monthly means			x	x	x												global	AERONET, AEROCOM
Kittaka et al. (2011), AMT, 4, 131–141, doi:10.5194/amt-4-131-2011	AOD	Collocated pairs, 5 deg					x									x		2006-2008	global	-
Sayer, et al. (2012), AMT, 5, 1761, doi:10.5194/amt-5-1761-2012	AOD	Lv3		x			x	x										Multi-year	global	AERONET
Redemann, et al. (2012), ACP 12, 3025-3043, doi:10.5194/acp-12-3025-2012, 2012	AOD	L2					x									x		4M 2007 & 2009	Global CALIOP tracks	-
Carlson and Lacis (2013), JGR, 118, 8640–8648, doi:10.1002/jgrd.50686	AOD	PCA analysis		x			x	x										2002-2010	Global ocean	-
Kahn,et al. (2009), TGARS 47, 4095-4111, doi: 10.1109/TGRS.2009.2023115	AOD, ANG	L2 statistics					x	x										2M of 2006	Global	-
Bréon,et al., (2011), RSE 115, 3102	AOD, ANG	L2 statistics					x		x		x					x	x	various,	global; sea/land	AERONET
de Leeuw, et al., RSE (2014) doi: 10.1016/j.rse.2013.04.023	AOD, ANG	Lv2 / L3 L3 scoring					x	x	x	x	x	x	various algorithms for one sensor					4M of 2008	global;,	AERONET
Holzer-Popp, et al., AMT, 6, 1919 - 1957, (2013) doi:10.5194/amt-6-1919-2013	AOD, ANG	L3 statistics algorithm experiment					x	x	x	x	x	x	various algorithms for one sensor					1M of 2008	Global; regions	AERONET
Kokhanovsky, et al. (2010), AMT, 3, 909-932, doi:10.5194/amt-3-909-2010	AOD, optical properties	Single cases					x	x	x	x	x		various algorithms for one sensor					Single cases	Single cases	Simulations

Table collected from AEROSAT Participants

2nd table over ocean

… Tables need updating

Overview of typing procedure

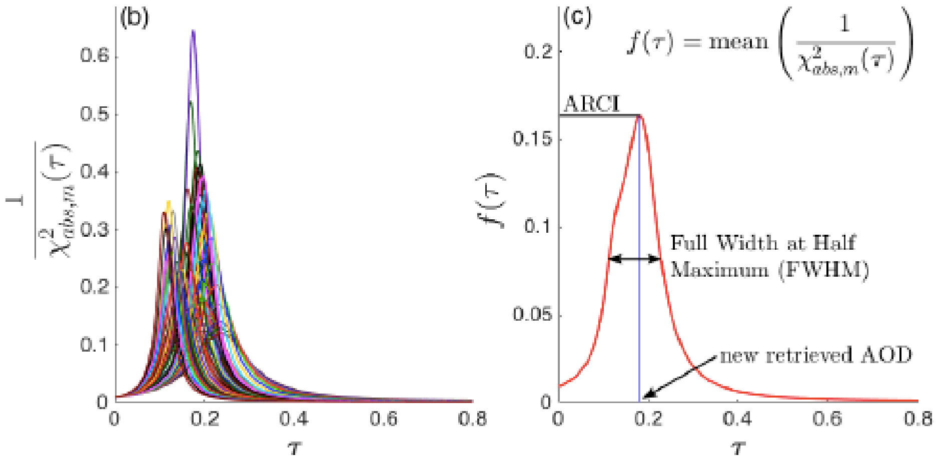
The nomenclature is very heterogeneous among different platforms.

Optical Constraints vs. Compositional Inferences

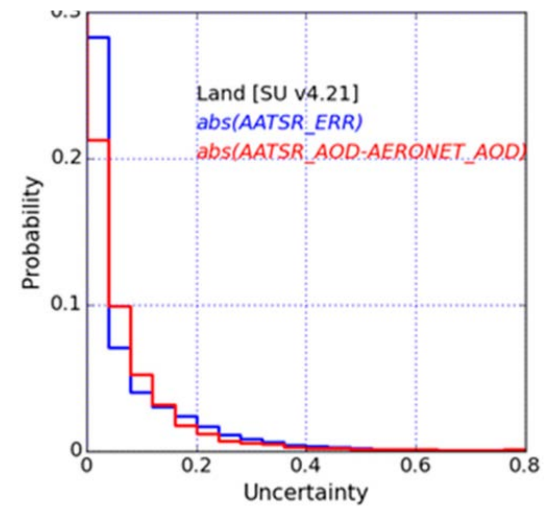
6 main classes could be identified grouping the different nomenclatures.

Useful validation metrics

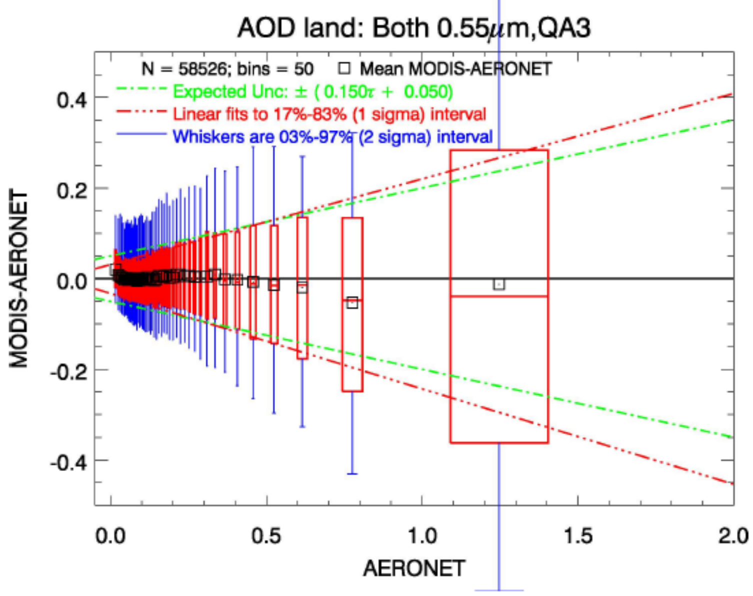
Inverse goodness-of-fit metric



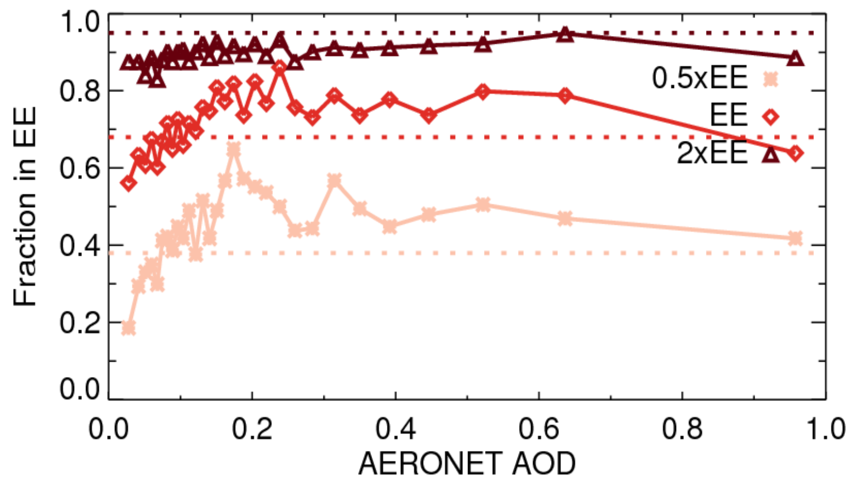
Compliance with uncertainty estimates



Error statistics as function of AOD



Fraction of pixels within error envelope



Modified from: Andrew Sayer, AEROSAT 2016 Beijing

AeroSat 2017

- **Continue *Presentation & Discussion* of Strengths & Limitations**
  - How to document added-value and guide product usage
  - AERONET new version
  - GRASP multi-sensor algorithm
  - SAT – MOD optics inter-comparison
  - Variables beyond AOD (ANG, Aerosol Type)
  - Validation of pixel-level uncertainties
  - …

- **Discuss new element: Possible AeroSat Experiments**
  - Study sensitivities / spread of results
  - Investigate approaches to ***constraining and/or validating models***
  - Investigate ways to ***add value to satellite products*** using models
  - Study scientific questions

- **Possibilities for contributing to aerosol-cloud interaction studies**

Perspectives on Collaboration with Modelers

- **Support model-satellite consistency**
  - Discuss + publish ***definition similarities & differences*** (Mod + Sat)
  - Provide ***aerosol typing information*** in a useful form
    -- Includes application of ***optical vs. compositional types***
  - Provide ***uncertainty characterization*** in a useful form

- **Guide the use of satellite datasets**
  - Provide a ***critical assessment*** of strengths and limitations
  - Provide harmonized ***quality statements***
  - Create ***data-record ensembles*** –> report spread / confidence

- **Experiments**
  - Involve modelling to tie evaluations to critical variables
  - Develop smart ways to integrate complementary information content

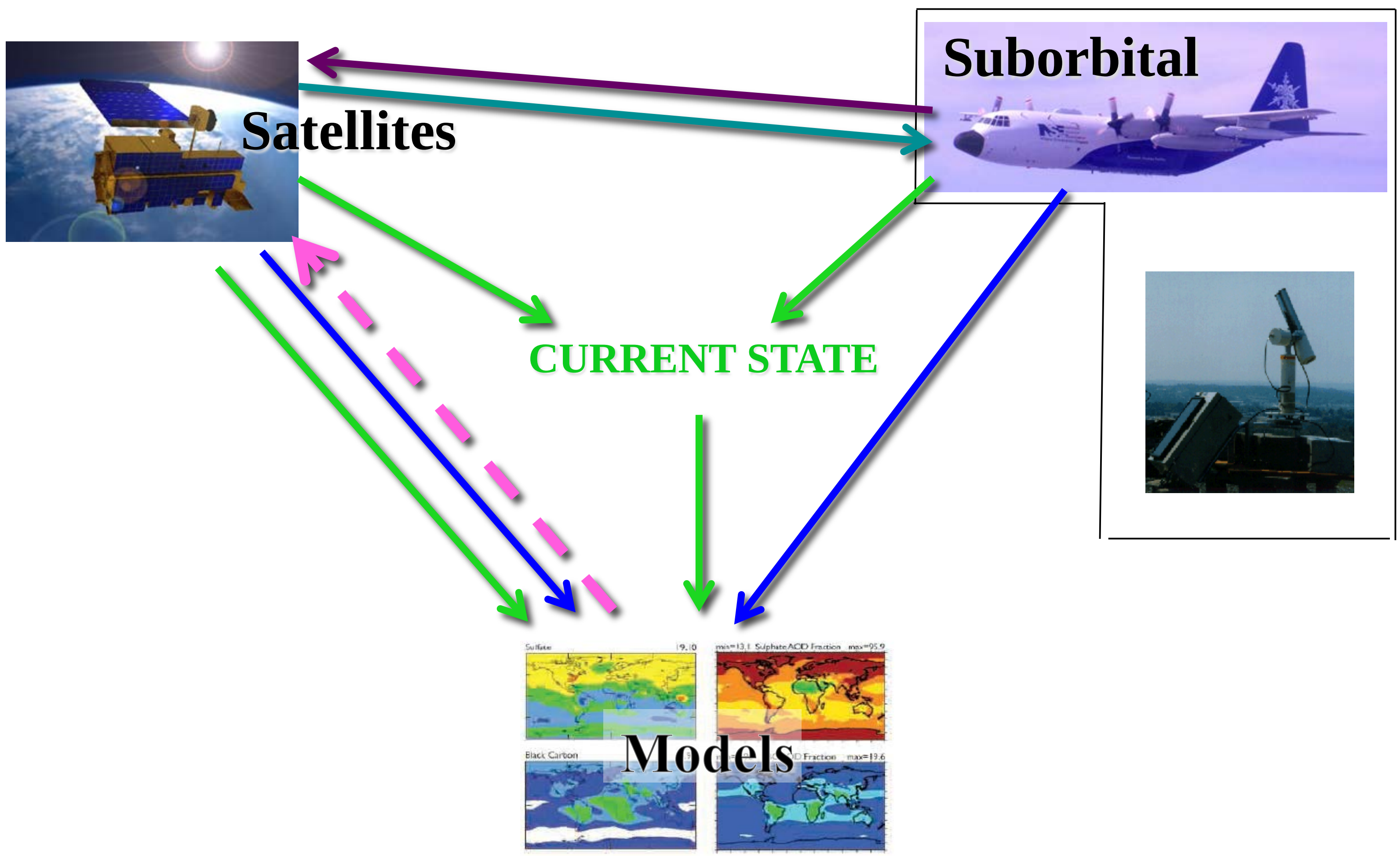
Session 13

Challenges for AeroSat – Remote-Sensing Perspective

Ralph Kahn / NASA-GSFC

- **Providing *Consistent, Global, 3-D Aerosol Amount and Type* products**
- **Providing *Quantitative, Credible Uncertainty Estimates* (*Level 2*; *Level 3*)**
- **Producing *Long-term* satellite data records**
- **Applying satellite datasets to *Constrain* and/or *Validate Models***
- ***Using Models* to supplement measured quantities**
- **Providing *"Deliverables"* (results) on zero budget...**

AeroSat Experiments
(Session 15)



Slide 1 – More Detail

Session 13

Challenges for AeroSat – Remote-Sensing Perspective

Ralph Kahn / NASA-GSFC

- Providing ***Consistent*** satellite ***AOD, ANG***
- Constraining ***Aerosol Type*** with satellite data
- Providing ***Consistent Aerosol Type*** satellite products
- Finding ***CNN proxies***
- Mapping aerosol ***Vertical Distribution***
- Deriving Level 2 & 3 ***Pixel-level Uncertainties***
- Producing ***Long-term*** satellite data records
- Applying individual satellite datasets to ***Models***
- Using ***Multiple Data Sources*** to constrain models
- Providing ***"Deliverables"*** (results) on zero budget...

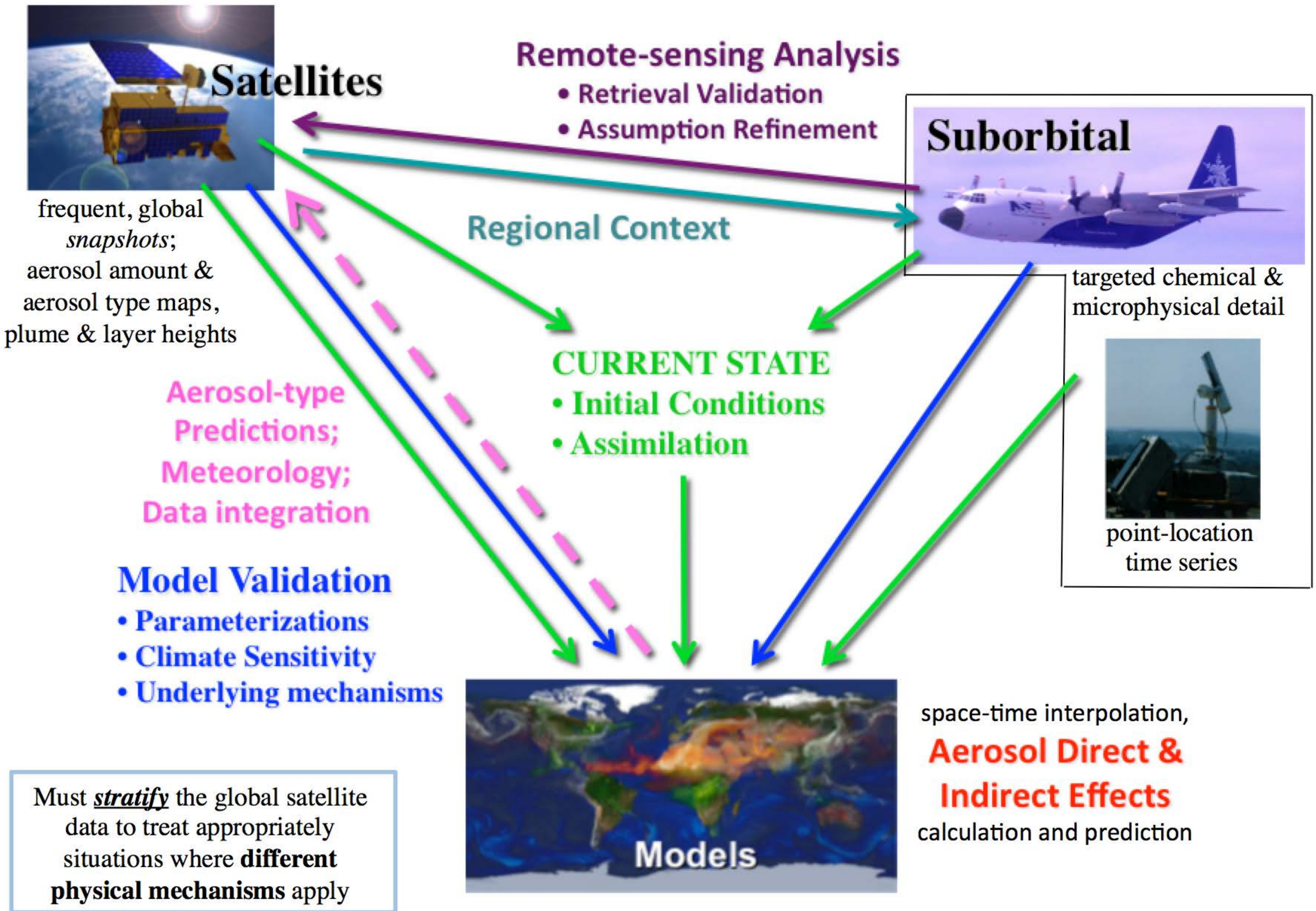
Session 15
Working Group on AeroSat Experiments

Chair: *Ralph Kahn* / NASA-GSFC
Notes: *Olga Kalashnikova* / JPL-Caltech

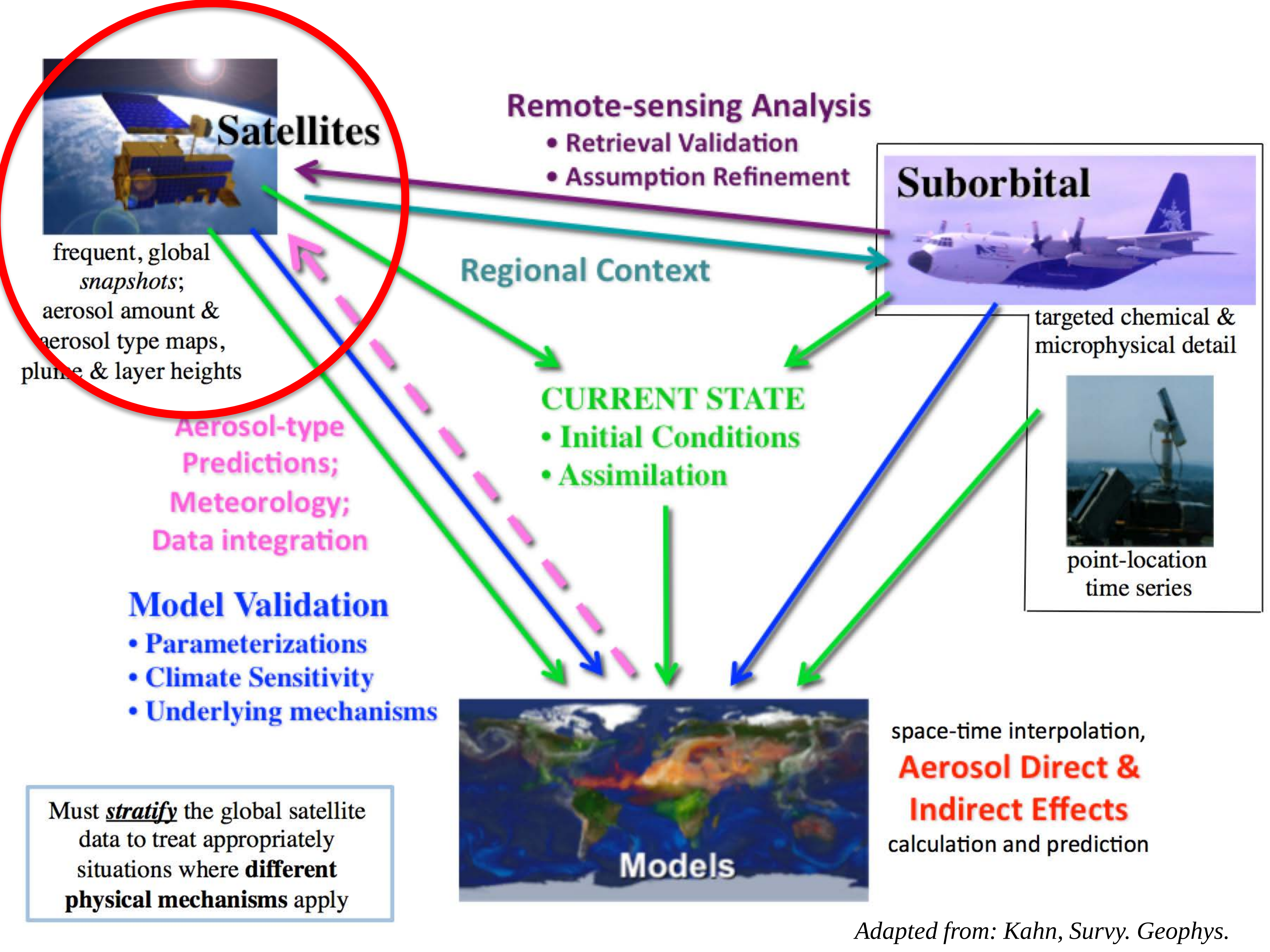
Objective: **Identify Possible AeroSat Experiments**

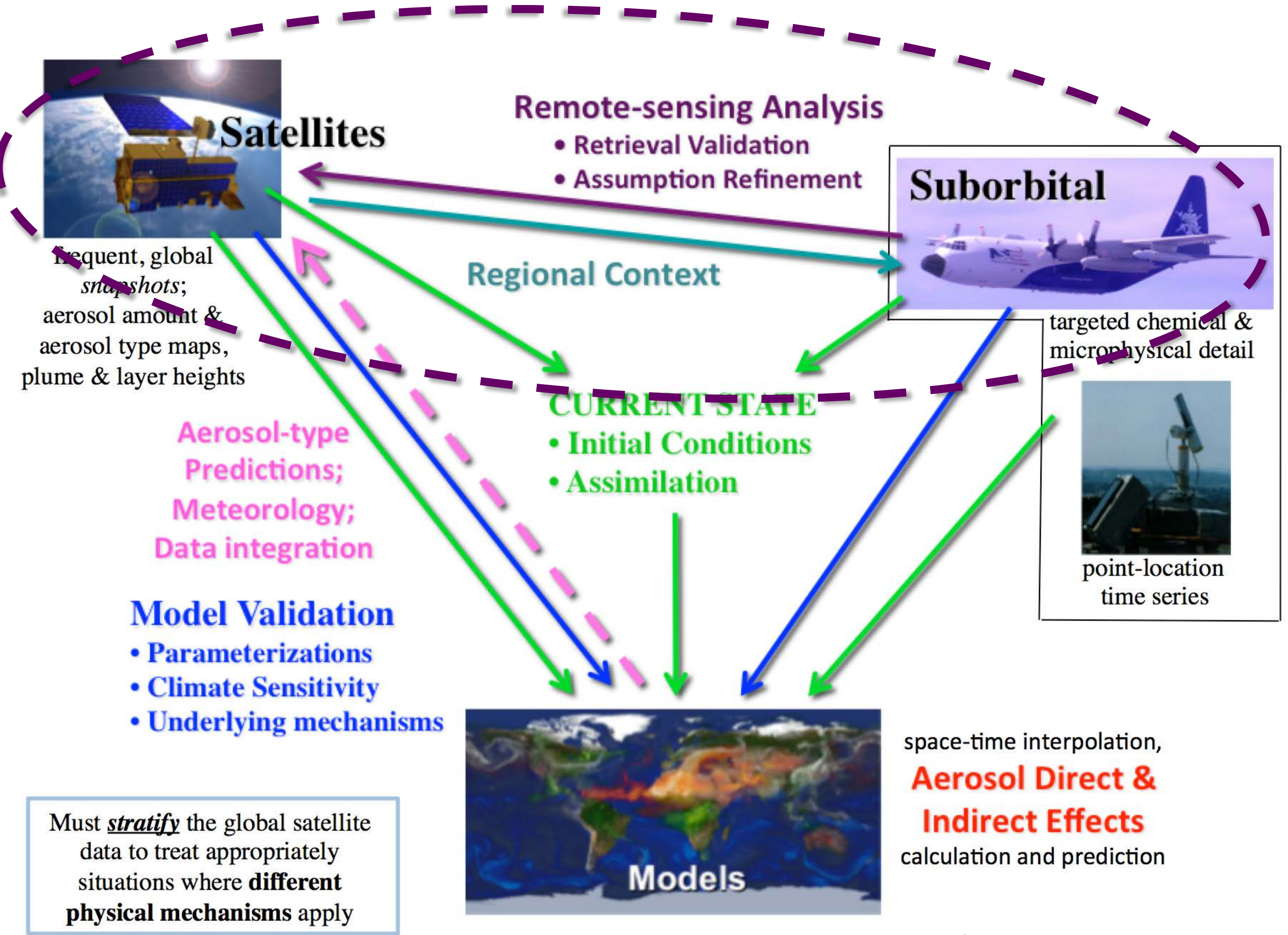
-- Studies ***Among Aerosol Products***
-- Studies About ***Using Satellite Data*** to Constrain and/or Validate Models
-- Studies About ***Using Models*** to Add Value to Satellite Data

Could be small (bilateral) or larger (multi-lateral) efforts



Adapted from: Kahn, Survy. Geophys.


Satellites
frequent, global snapshots; aerosol amount & aerosol type maps, plume & layer heights
Remote-sensing Analysis
• Retrieval Validation
• Assumption Refinement
Suborbital
targeted chemical & microphysical detail
Regional Context
CURRENT STATE
• Initial Conditions
• Assimilation
point-location time series
Aerosol-type Predictions; Meteorology; Data integration
Model Validation
• Parameterizations
• Climate Sensitivity
• Underlying mechanisms
Models
space-time interpolation,
Aerosol Direct & Indirect Effects
calculation and prediction
Must stratify the global satellite data to treat appropriately situations where different physical mechanisms apply
Adapted from: Kahn, Survy. Geophys.



Adapted from: Kahn, Survy. Geophys.

SAM-CAAM

[Systematic Aircraft Measurements to Characterize Aerosol Air Masses]

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

***Primary Objectives*:**

• **Interpret and *enhance ~17 years of satellite aerosol retrieval* products**

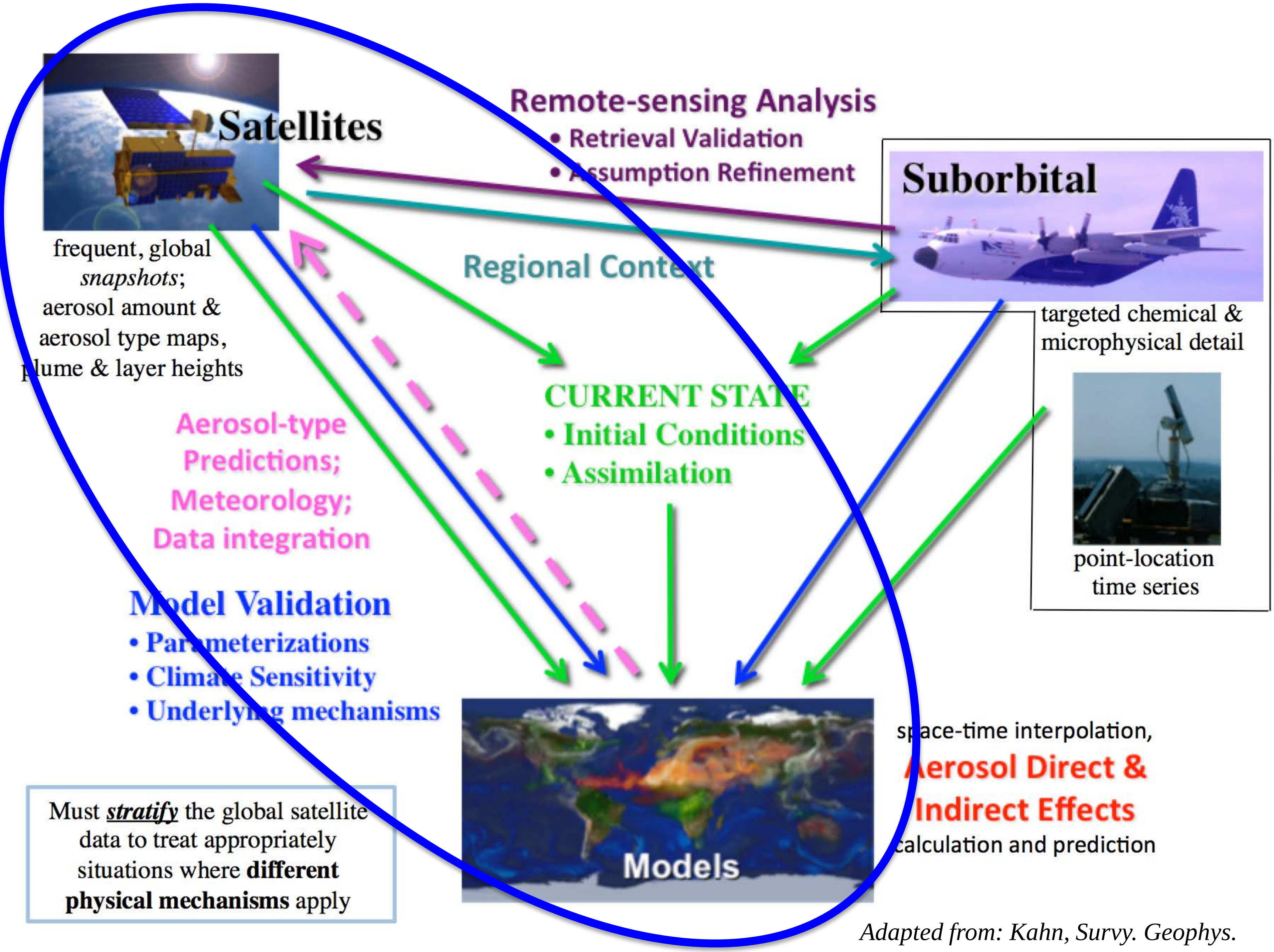
• ***Characterize statistically particle properties* for major aerosol types globally,**

to provide detail unobtainable from space, but needed to *improve*:

-- Satellite aerosol *retrieval algorithms*

-- The *translation between satellite-retrieved aerosol optical properties*

Kahn et al., BAMS 2017


Satellites
frequent, global *snapshots*; aerosol amount & aerosol type maps, plume & layer heights
Remote-sensing Analysis
• Retrieval Validation
• Assumption Refinement
Suborbital
Regional Context
targeted chemical & microphysical detail
CURRENT STATE
• Initial Conditions
• Assimilation
Aerosol-type Predictions; Meteorology; Data integration
point-location time series
Model Validation
• Parameterizations
• Climate Sensitivity
• Underlying mechanisms
Models
space-time interpolation,
Aerosol Direct & Indirect Effects
calculation and prediction
Must ***stratify*** the global satellite data to treat appropriately situations where **different physical mechanisms** apply
Adapted from: Kahn, Survy. Geophys.

Session 15

Working Group on AeroSat Experiments

Some Initial Ideas

- A general ***Aerosol Retrieval Comparison*** for a recent year (e.g. 2016 and 2017) [AOD; AOD & AAOD by size mode; dust as a component, maybe smoke; ***Chin***; ***Kinne*** – requests gridded, daily data in netcdf or ascii]

- ***Joint Remote-Sensing AOD and Type*** products (e.g., IASI + POLDER; MISR + OMI AAOD, etc.) [***Kinne***, ***others***]

- Aerosol retrievals over the ***Congo Region*** in the absence of AERONET [***Kinne***, ***Dubovik***, ***Lang***]

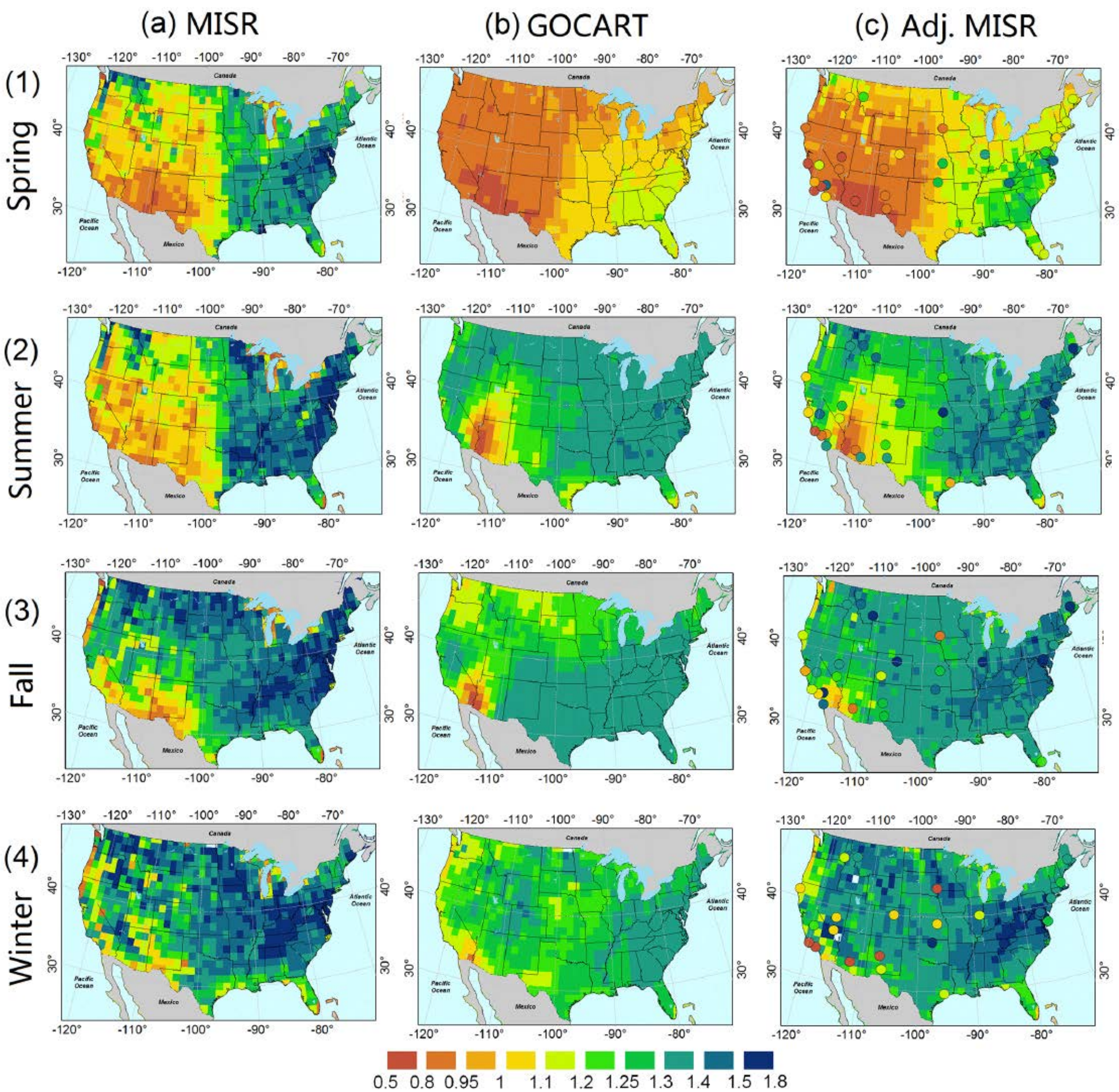
- Connecting retrieved optical constraints ***(Aerosol Type) with Inferred Composition*** [***Mona***, ***Kahn***]

- Constraining ***Aerosol Vertical Distribution*** [MISR upwind, CALIPSO downwind, model between; ***Kahn***]

- Use ***Model to Constrain Type*** in satellite product (e.g., when AOD is low)

- ***Level 3 Pixel-level uncertainties*** (Counts, STD, + Sampling: Diurnal?, Day-to-day?, Within grid-box?; Aggregated?)

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



ANG

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

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

Four years of data (2006-2009)
Seasonally averaged

Shenshen Li et al. AMT 2015

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

Session 15

Working Group on AeroSat Experiments

AEROSAT experiments template

Version 2, 20 July 2017 (Thomas Popp and Ralph Kahn)

AEROSAT experiments aim at strengthening the use of aerosol satellite data for climate research. They can either inter-compare data records, assess algorithm sensitivities or analyze a scientific problem with significant use of satellite data.

To be accepted in AEROSAT, an experiment needs

a) a clear question or objective and a detailed description of steps to be taken
b) support by at least 3 independent satellite groups with independent satellite datasets / algorithms (may be for the same set of sensors)
c) interest and/or direct involvement of a user or user group (e.g. modelers; *in situ* measurement teams; surface networks)

The roles of participants should be identified at the beginning (independent work, if appropriate) inter-comparisons, evaluation or analysis of results. The intended outcome of an experiment should be a study paper to be submitted to the scientific literature to share the findings with the community.

An AEROSAT experiment should be presented to AEROSAT (at annual meetings) and should be open for further participants; its status / results should be summarized at subsequent AEROSAT meetings. AEROSAT will grow in substance with such concrete activities and therefore experiment suggestions are encouraged. "Formal" acceptance by AeroSat will be based on community interest after the brief pitch at the annual meeting, and the degree to which conditions a) – c) are met.

Name of experiment		
Objective of experiment		
Type of experiment	Retrieval inter-comparison	
	Retrieval sensitivity	
	Scientific problem; other	
Size of experiment	Case study	
	Large-scale study	
	other	
Responsible coordinator / presenter		
Satellite groups who commit to participate	Group / contact name	Dataset / algorithm contribution
User (group) involvement	Group / contact name	Role
AeroSat evaluation		
Parameters / variables needed		
Reference data needed		
Region, period, resolution		
Any other comments		