Learning about Earth from Space-based, Multi-angle Imaging

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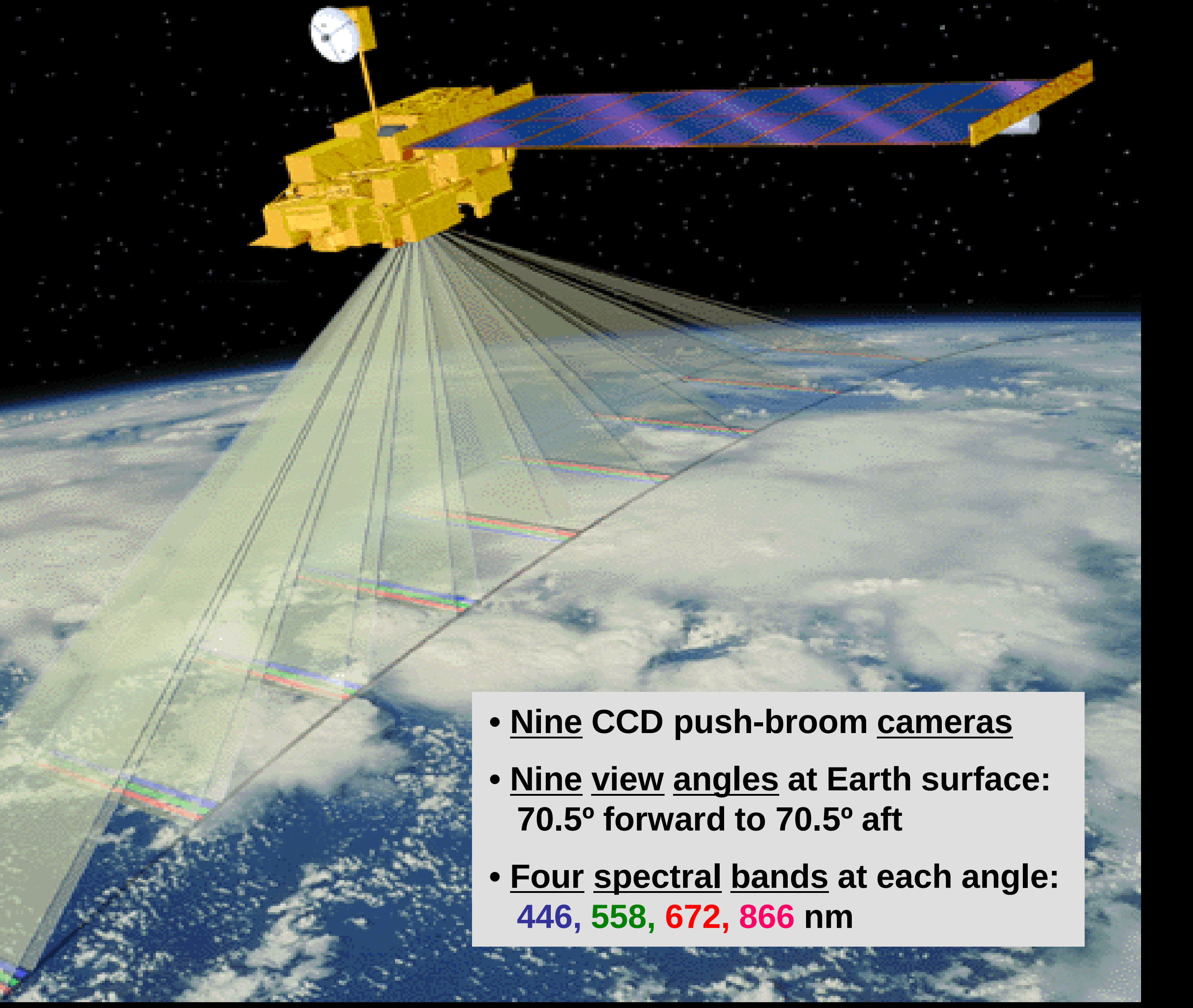
NASA Goddard Space Flight Center



- **Nine CCD push-broom cameras**
- **Nine view angles at Earth surface: 70.5º forward to 70.5º aft**
- **Four spectral bands at each angle: 446, 558, 672, 866 nm**

Current GSFC **MISR** Team Activities*

Climate

MISR Aerosol Type

Research algorithm ***& calibration***
Limbacher/Kahn
Production Code | Limbacher/Kahn
SAM-CAAM | Kahn/S-C Team

Air Quality

Friberg/Kahn
deSouza/Kahn/MIT

Plume/Layer Height

MISR Stereo- MINX, CALIPSO
Val Martin/Kahn
Active Dust/Smoke/Volcanoes
Kahn/Canty -- AAP/UMD
Junghenn/Kahn/Li/UMD

Volcano Studies

Flower/Kahn

IPCC

AeroCom **model constraints, assessment**

Aerosol-cloud Interactions

Zamora/Kahn

Aerosol Amount

Plume source strength
Petrenko/Kahn/Chin/JPL

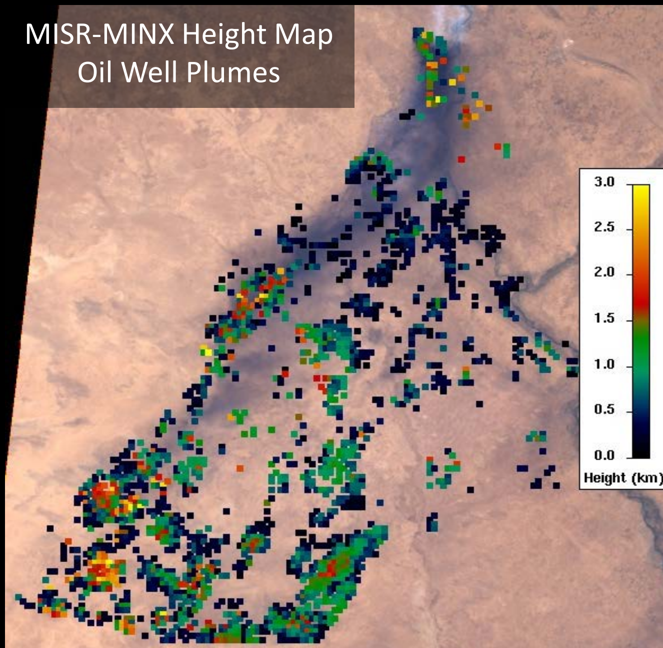
***Additional activities**

ACPC – iLEAPS/GEWEX
ACTRIS-2/EC
ACE/NASA
COSPAR
AeroSat/AeroCom
PUMAS
NPP/NASA post-docs

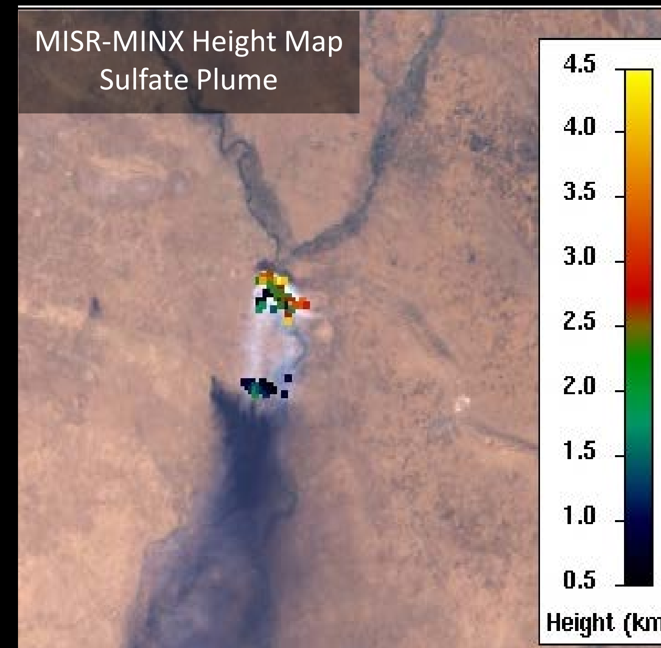
June 2018

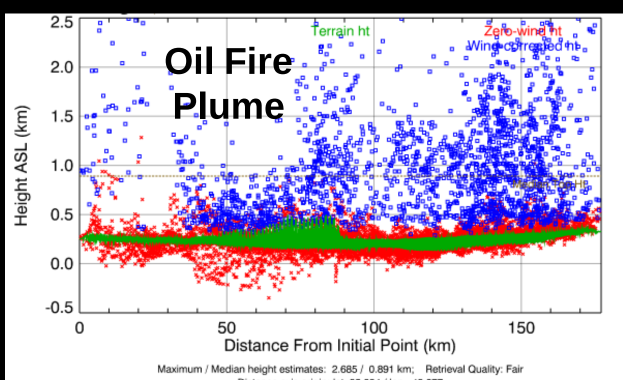
Iraq's Mishraq Sulfur Plant and Oil Well Smoke Plume Heights

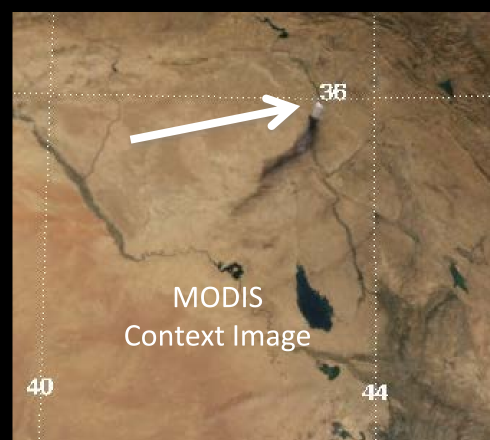
MISR Active Aerosol Plume-Height (AAP) Project 21 October 2016

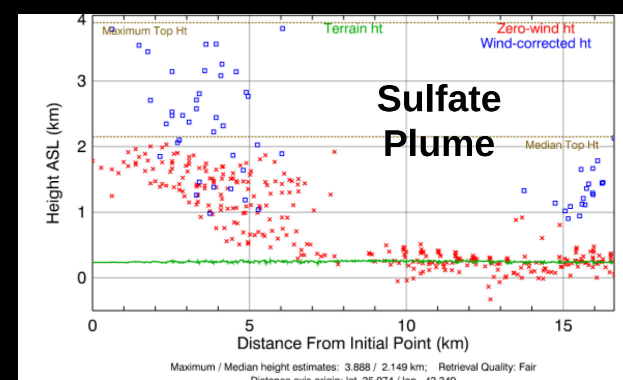


Black smoke emanates from oil-well fires and white smoke from a burning sulfate plant, during the recapture of Mosul in northern Iraq in October 2016. The sulfate plume remained within the near-surface boundary layer, whereas some of the oil-fire plumes might have escaped into the free troposphere, and traveled much further downwind.







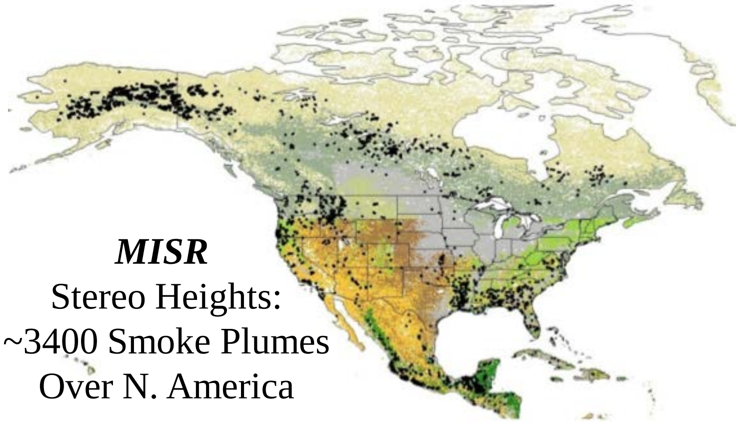


Zero-wind & Wind-Corrected
MISR Height Profiles
Downwind from Near-source

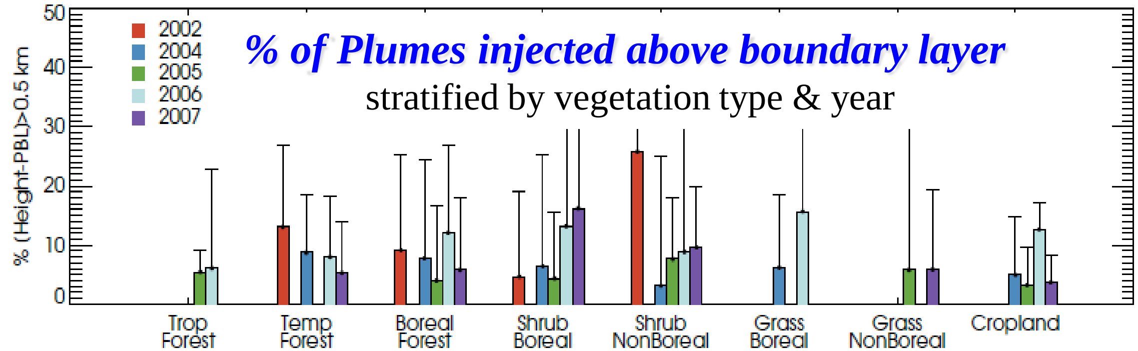
***R. Kahn*, T. Kucsera / NASA GSFC**
T. Canty, R. Bolt, CJ Vernon / U. Maryland

Wildfire Smoke *Injection Heights* & *Source Strengths*

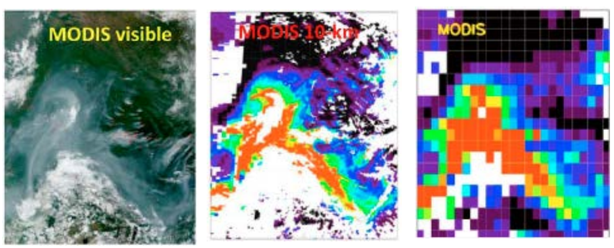
[These are *the two key parameters* representing aerosol sources in climate models]



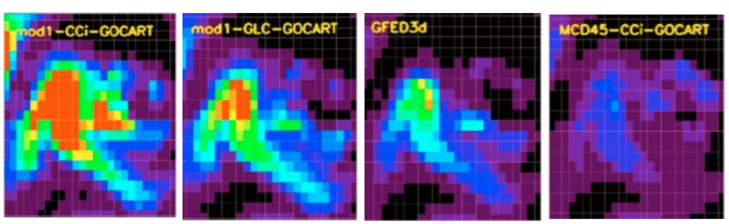
MISR
Stereo Heights:
~3400 Smoke Plumes
Over N. America



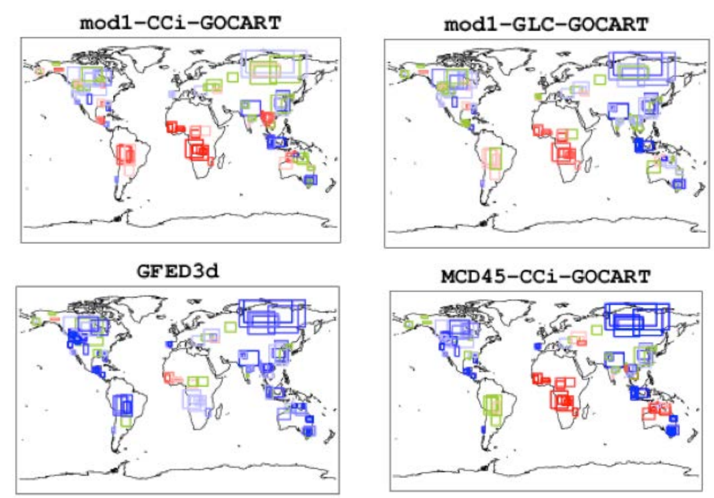
Val Martin et al. ACP 2010



MODIS Smoke Plume Image & Aerosol Amount Snapshots



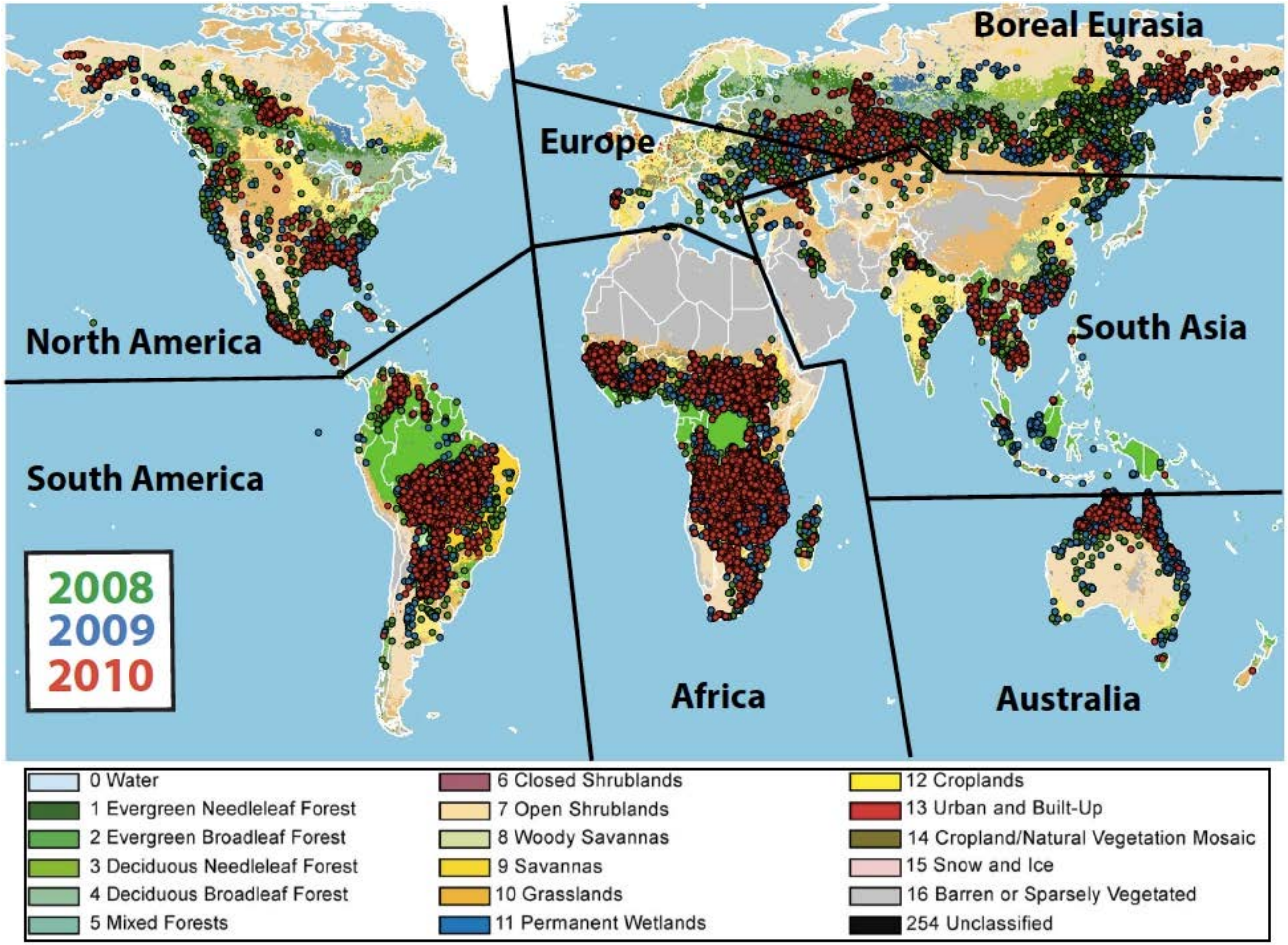
GoCART Model-Simulated Aerosol Amount Snapshots
for *Different Assumed Source Strengths*



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

Petrenko et al., JGR 2012

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

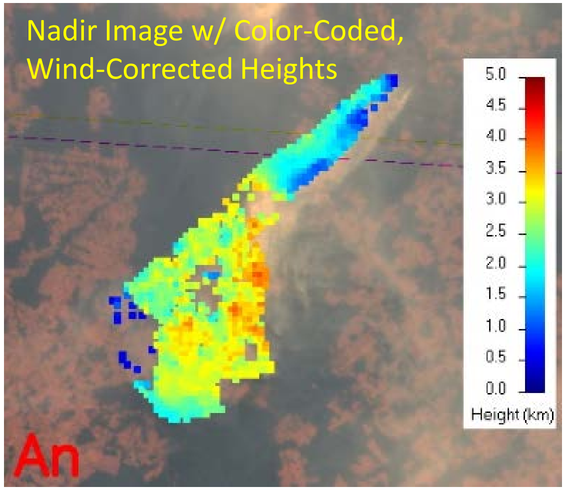


- About ***23,000 smoke plumes*** digitized 2008-2010 (~13,000 for 2008)
- Each plume is Operator-Processed using ***MINXv4.0***, and Quality Controlled
- For N America, ≥ ***4% - 12%*** of plumes are injected above the PBL; Boreal Forest **18%**
- Raw, graphics and summary files, and documentation are ***available on-line:***

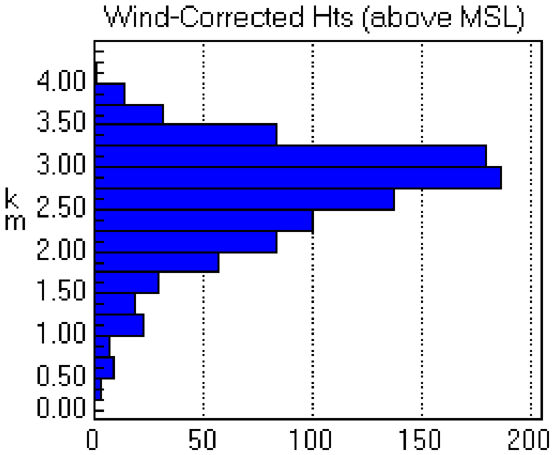
https://misr.jpl.nasa.gov/getData/accessData/MisrMinxPlumes2/

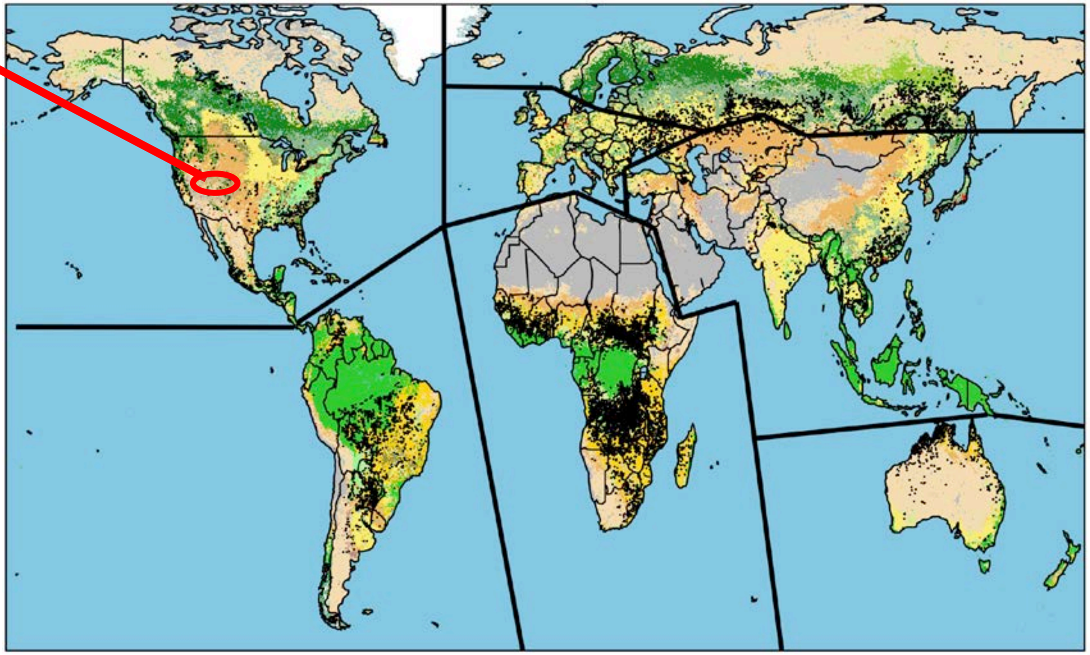
Val Martin et al., Remt. Sens.2018

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



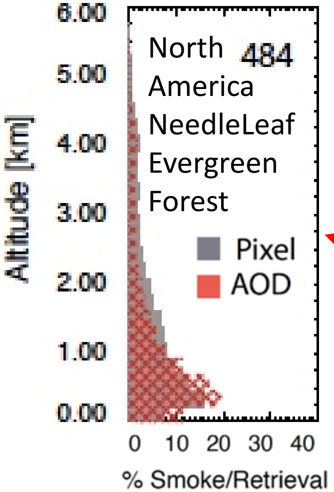
- Heights at ***1.1 km Horizontal*** res., ***~250-500 m Vertical*** res.
- Keyed to the ***Elevation of Maximum Spatial Contrast***
- Parallax is corrected for proper motion (***Wind Correction***)
- Missing AOD filled w/ ***max***; missing height w/***statistical dist***.
- Both ***Pixel-weighted*** and ***AOD-weighted*** profiles derived
- Height histogram gives some ***Indication of Vertical Extent***

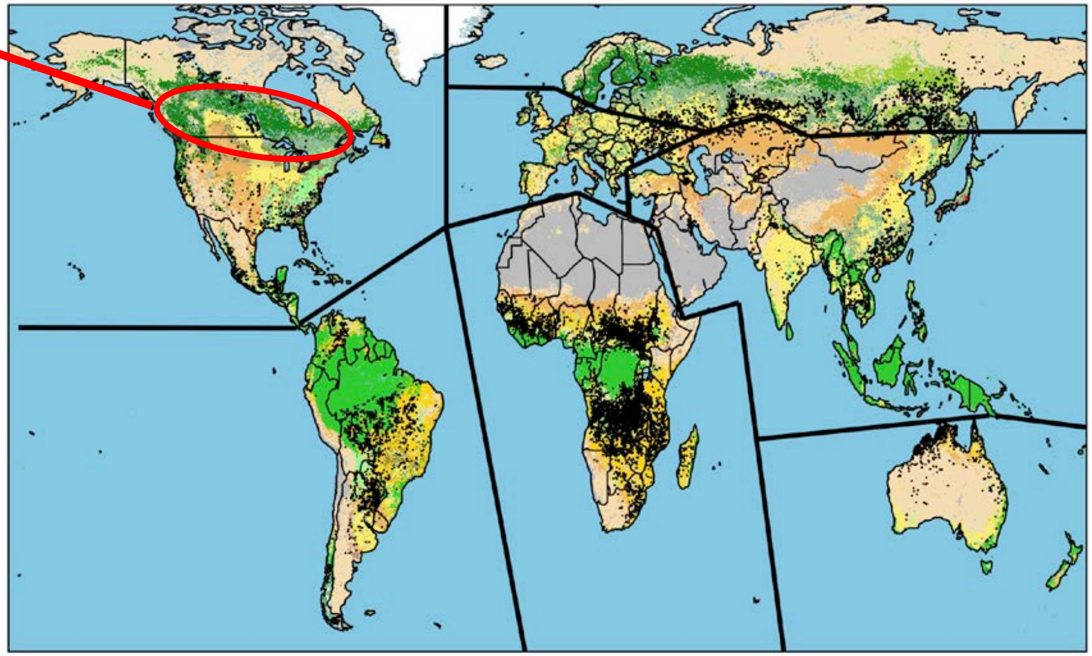


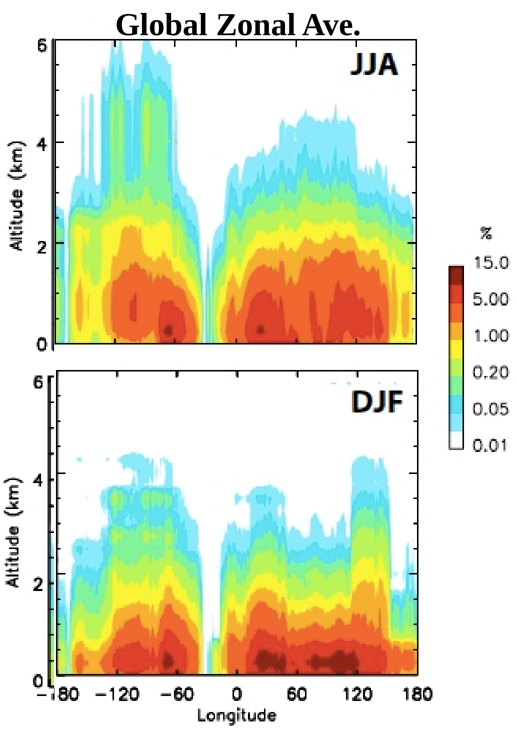


Val Martin et al., Remt. Sens. 2018

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





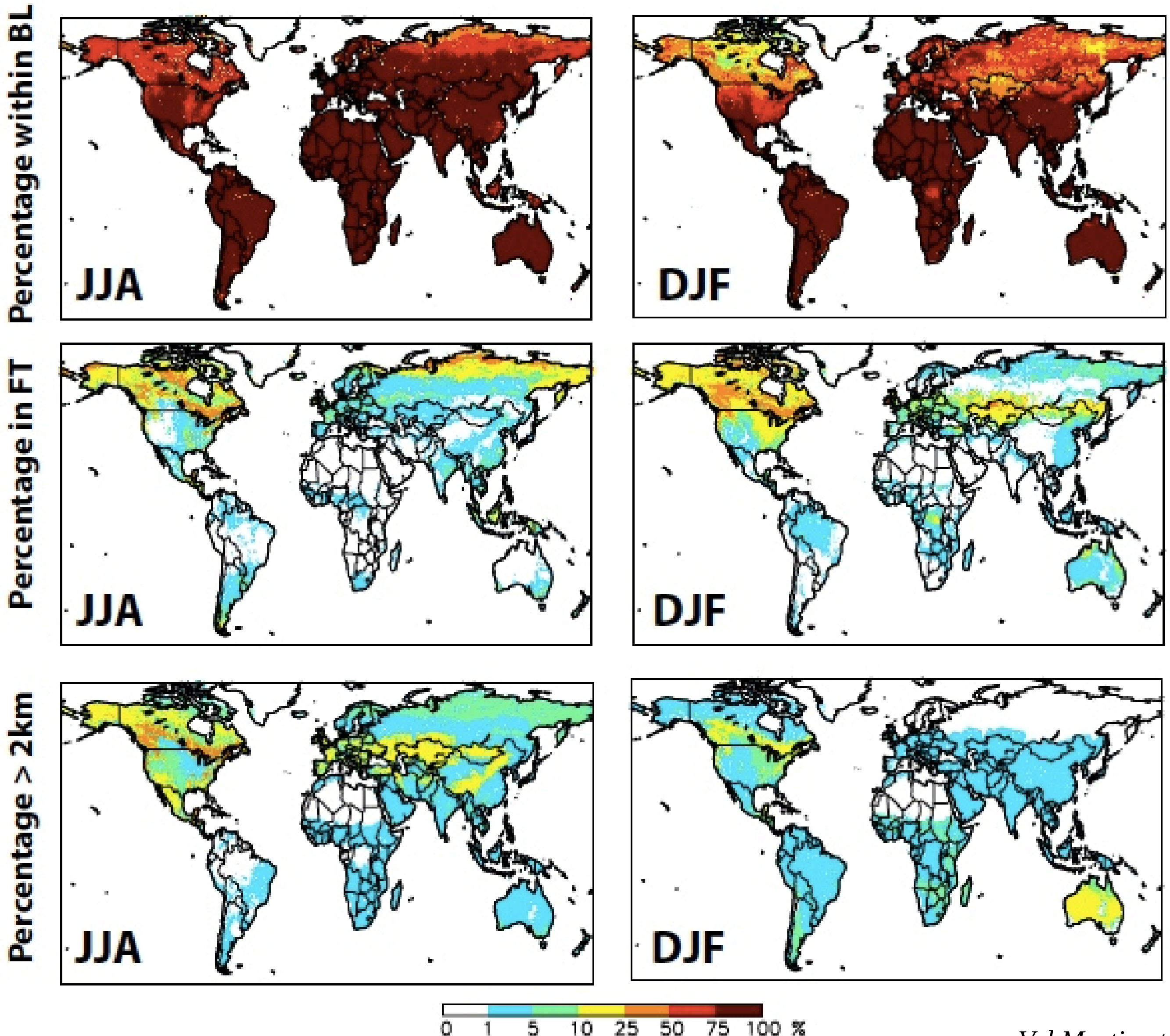


- Fire emissions are ***Stratified by Altitude***, ***Region***, ***Ecosystem***, & ***Season***
- The cases in each stratum are ***Averaged*** to produce a statistical summary
- Inter-annual and/or sub-seasonal ***temporal resolution*** might be needed in some cases; requires detailed, regional study (e.g., Amazon)

Val Martin et al., 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

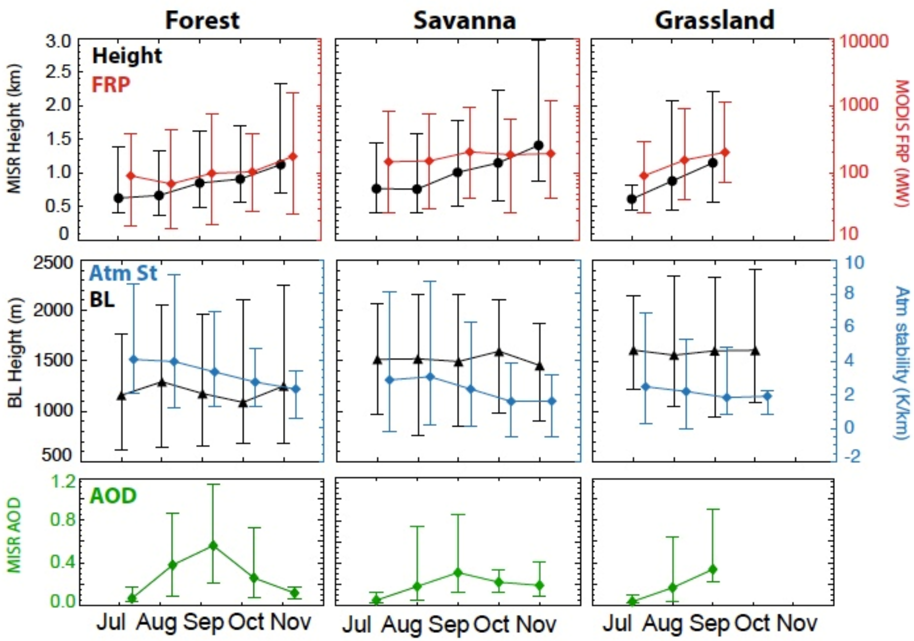
[PBL from MERRA-2}

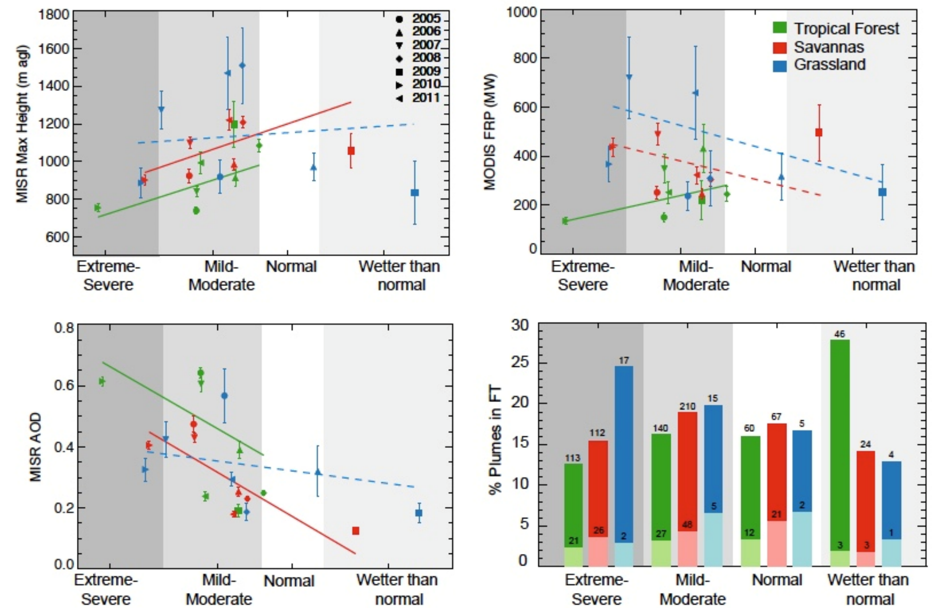
2 km threshold avoids dependence on PBL height estimate

Val Martin et al., Remt. Sens. 2018

Amazon Plume-Height Climatology

2005-2012





Seasonal Cycle of 5 parameters, stratified by ***Vegetation Type***

MISR Plume Height, MODIS FRP, Model BL Height & Atm. Stability MISR AOD

Interannual patterns of 4 parameters, stratified by ***Drought Index***

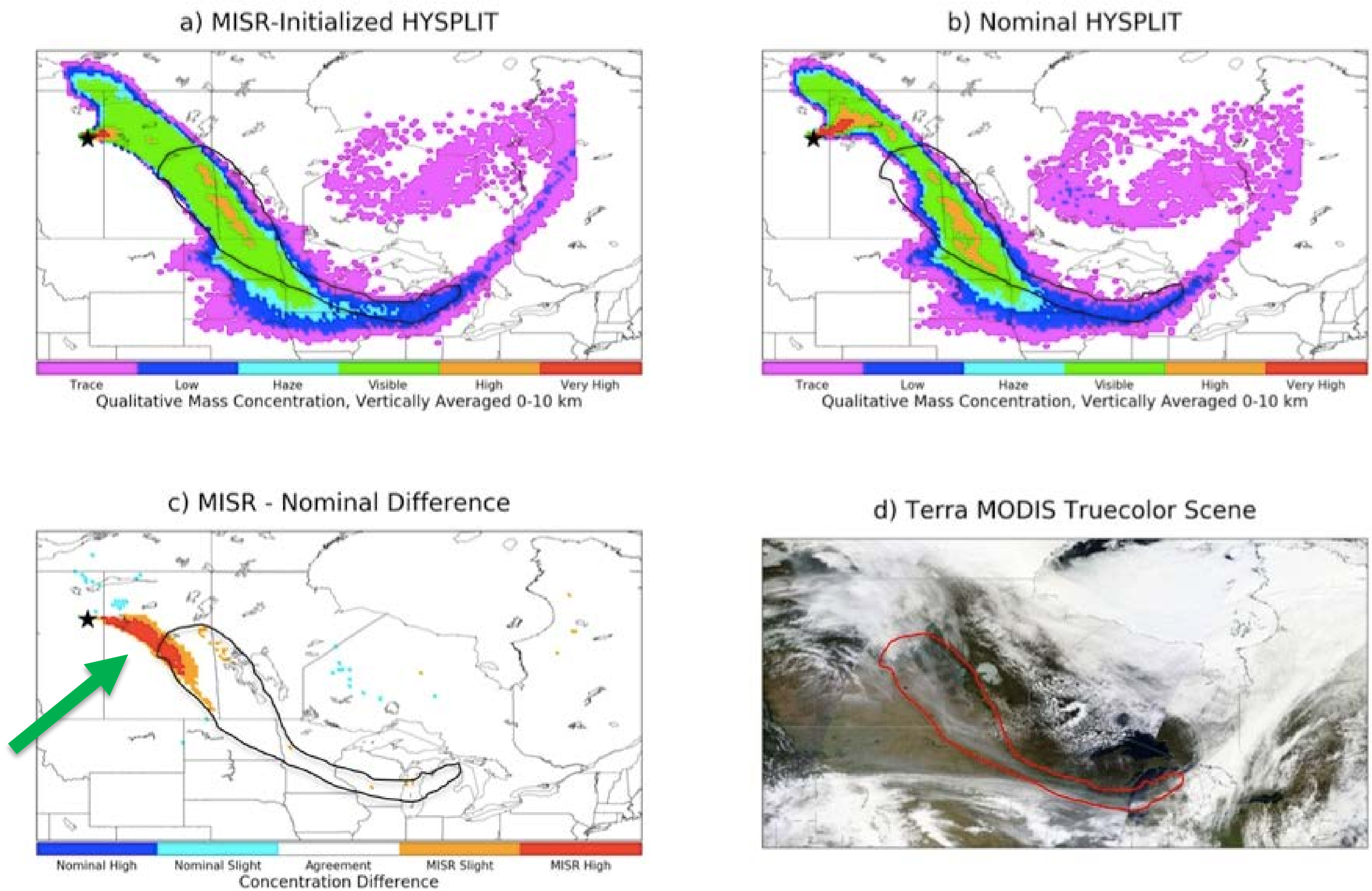
MISR Plume Height, MODIS FRP, MISR AOD, % in Free Troposphere

- ***FRP*** **and** ***Height*** **tend to** ***increase*** **as the fire season progresses, for all major Amazon biomes**
- ***AOD*** **tends to** ***increase***, ***Height*** **tends to** ***decrease*** **for forest & savannah in drought years**

Gonzalez-Alonso et al., ACPD 2018

Ft. McMurray Wildfire, Alberta Canada

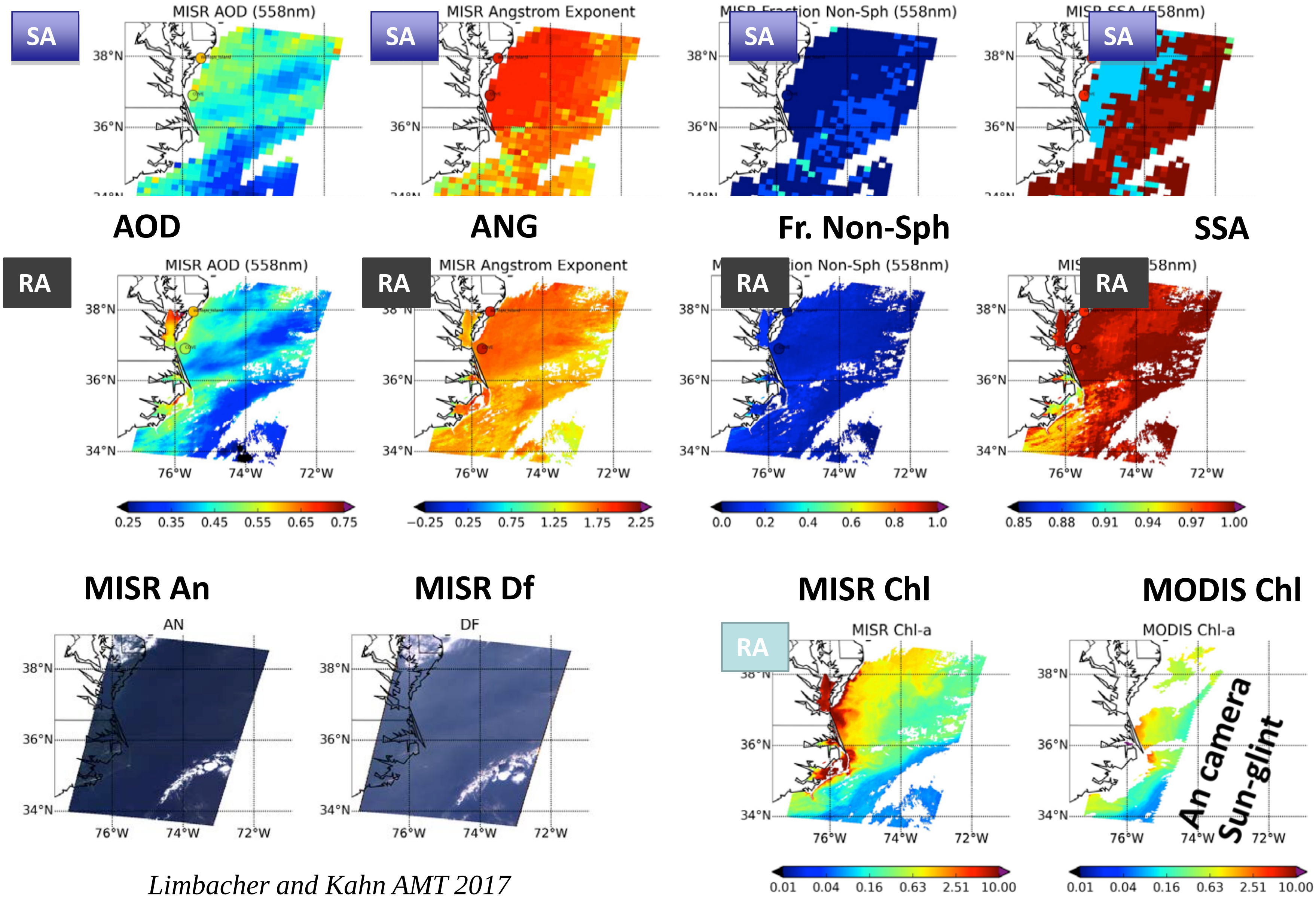
May 07, 2016 (Day 2) NOAA HySPLIT Model



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

Vernon et al., AMT 2018

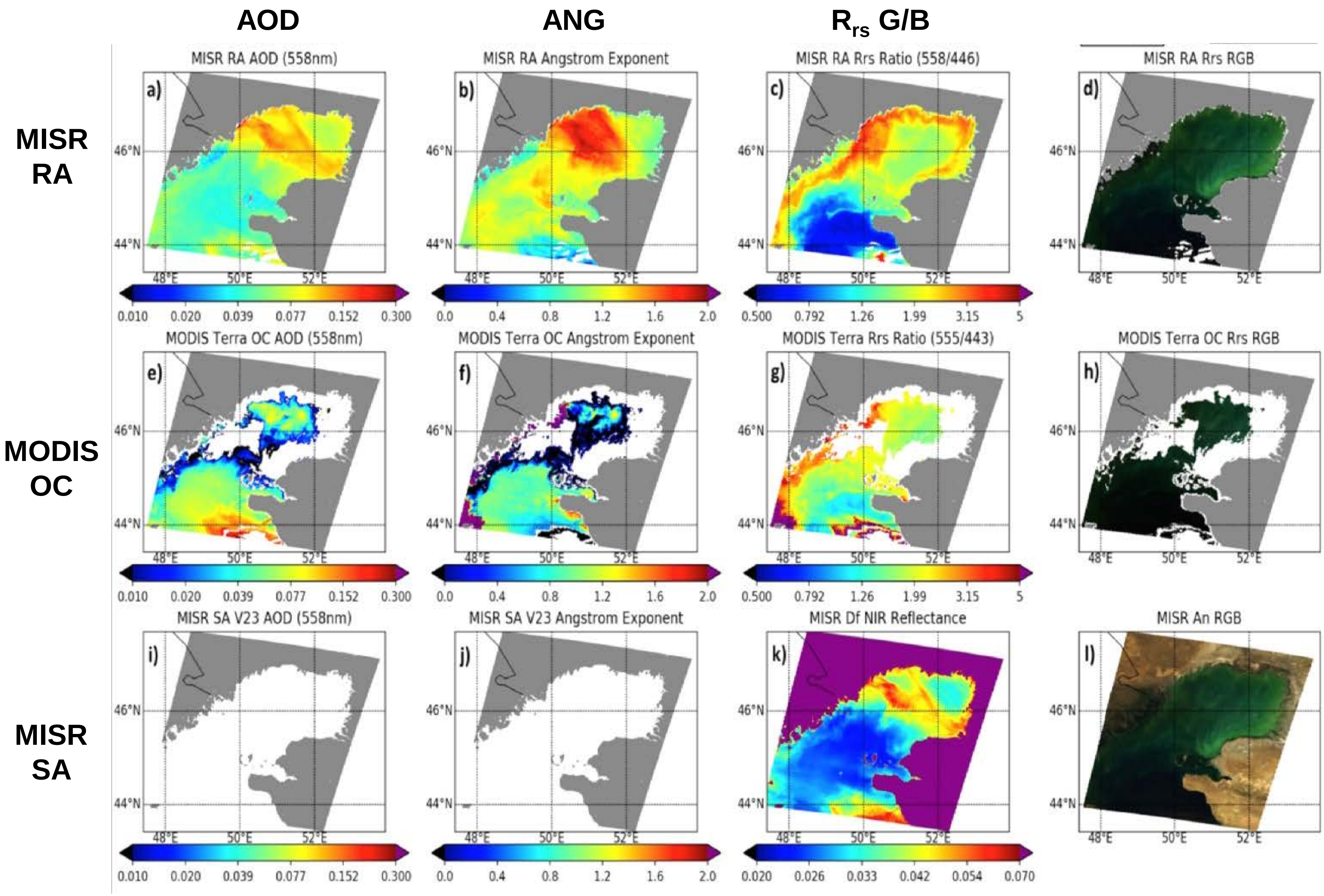
MISR *Research Algorithm* With Self-consistent Ocean Surface Retrieval



Limbacher and Kahn AMT 2017

MISR *Research* Retrievals Over *Shallow, Turbid, & Eutrophic* Water

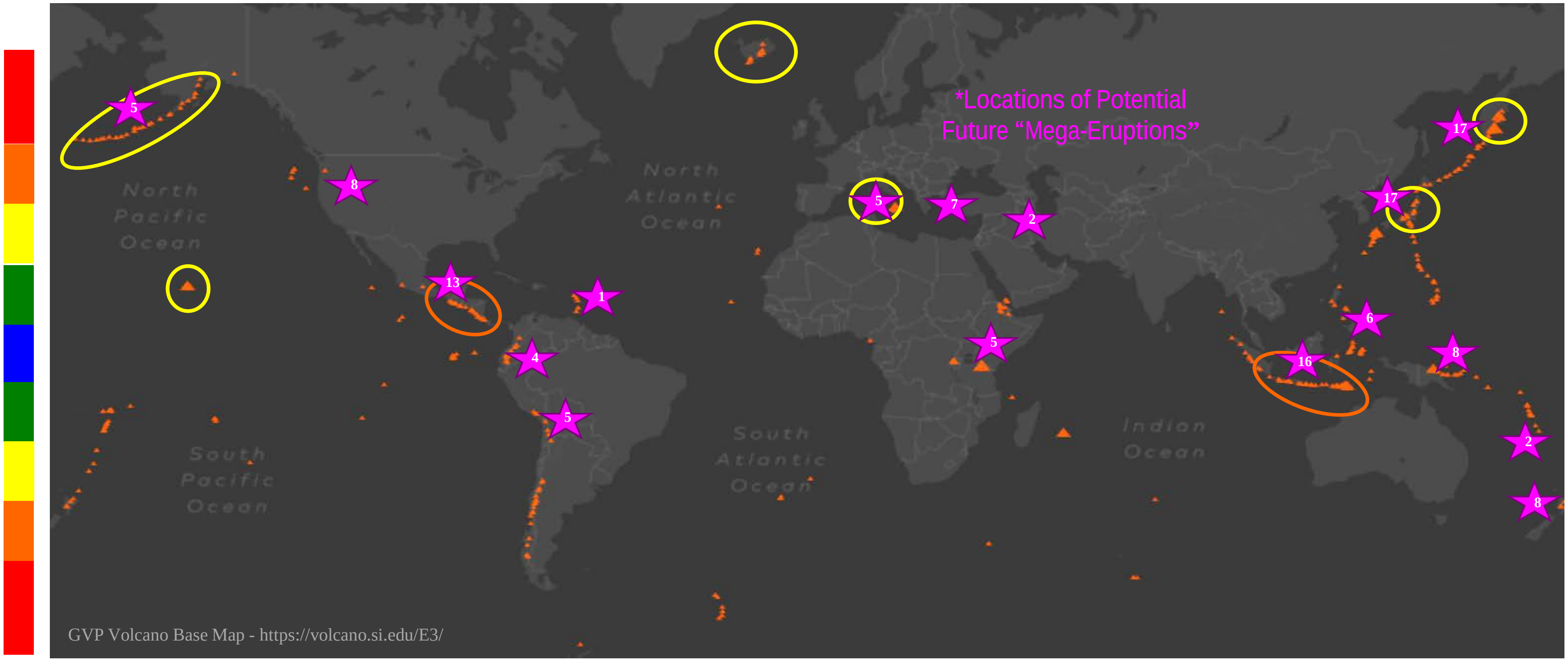
Bay of Bengal 01/29/2015 (*Turbid*)



Limbacher & Kahn, AMT 2018

Volcanology from Space

MISR latitude-dependent observation regions



MISR latitude-dependent observations/month

- ~15
- ~11
- ~9
- ~6
- ~4

Suborbital Monitoring Networks

- Well-monitored
- Partially-monitored

Global Active Volcanism (1960-2017)

- VEI 0
- VEI 1
- VEI 2
- VEI 3
- VEI 4

*VEI – Volcanic Explosivity Index

Key Information from Global Volcano Monitoring

Aviation and downwind environmental ***hazard response***

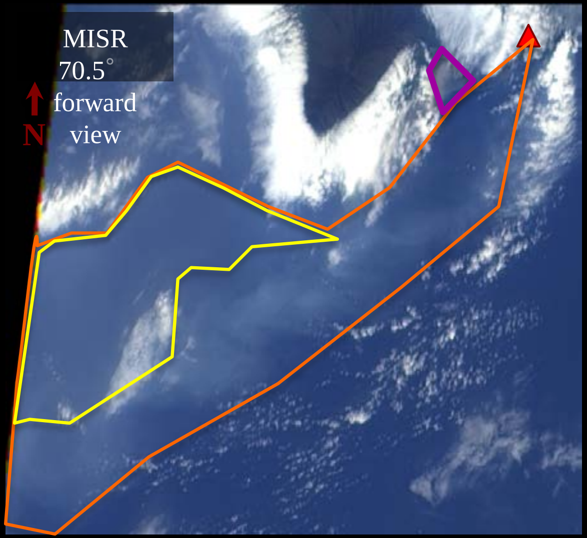
Constraints on ***air quality and climate modeling***

*Surface and subsurface **geology implications***

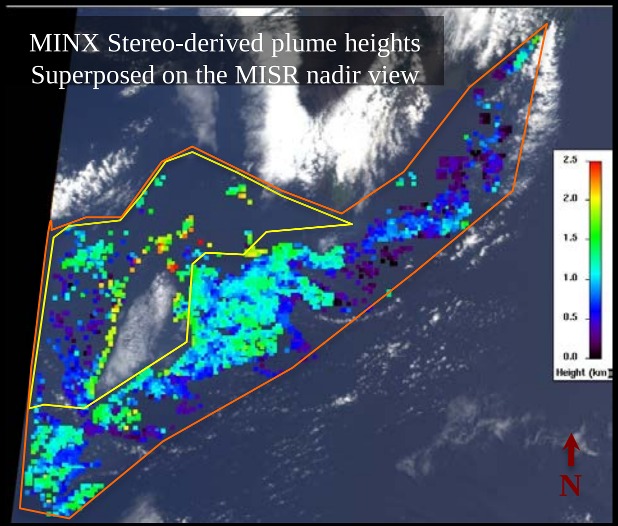
Flower & Kahn 2017-2019

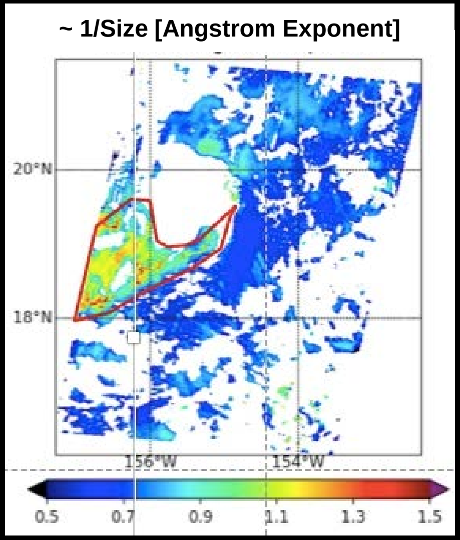
Volcanic eruption plume from *Kilauea Volcano*, Hawaii

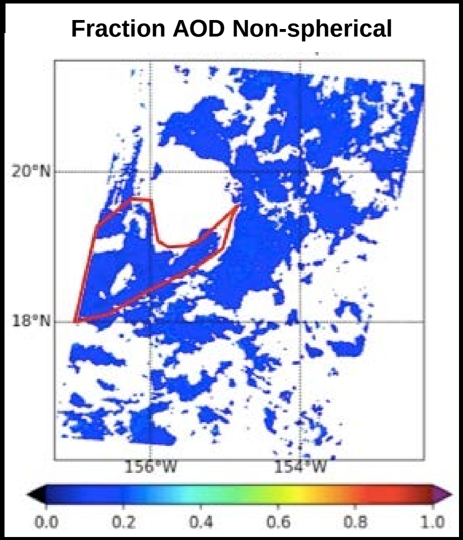
MISR Active Aerosol Plume-Height (AAP) Project 22 May 2018

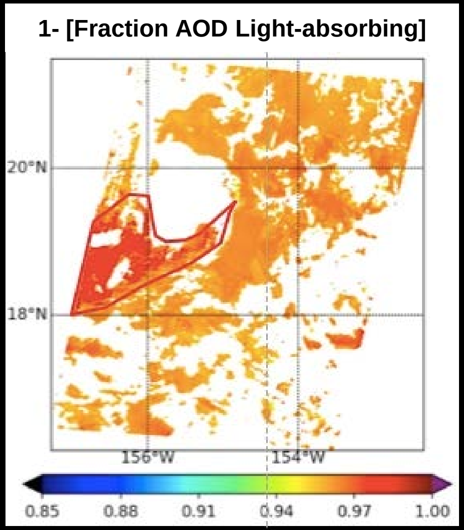


The *core* and *diffuse* plumes concentrate at ~1±0.5 km above the *ocean*, dispersing to the west. A *small summit plume* is elevated ~1 km above the *terrain*.









The particles are spherical, smaller and brighter than background – sulfate, not ash dominated.

V. Flower, R. Kahn, J. Limbacher/ NASA GSFC

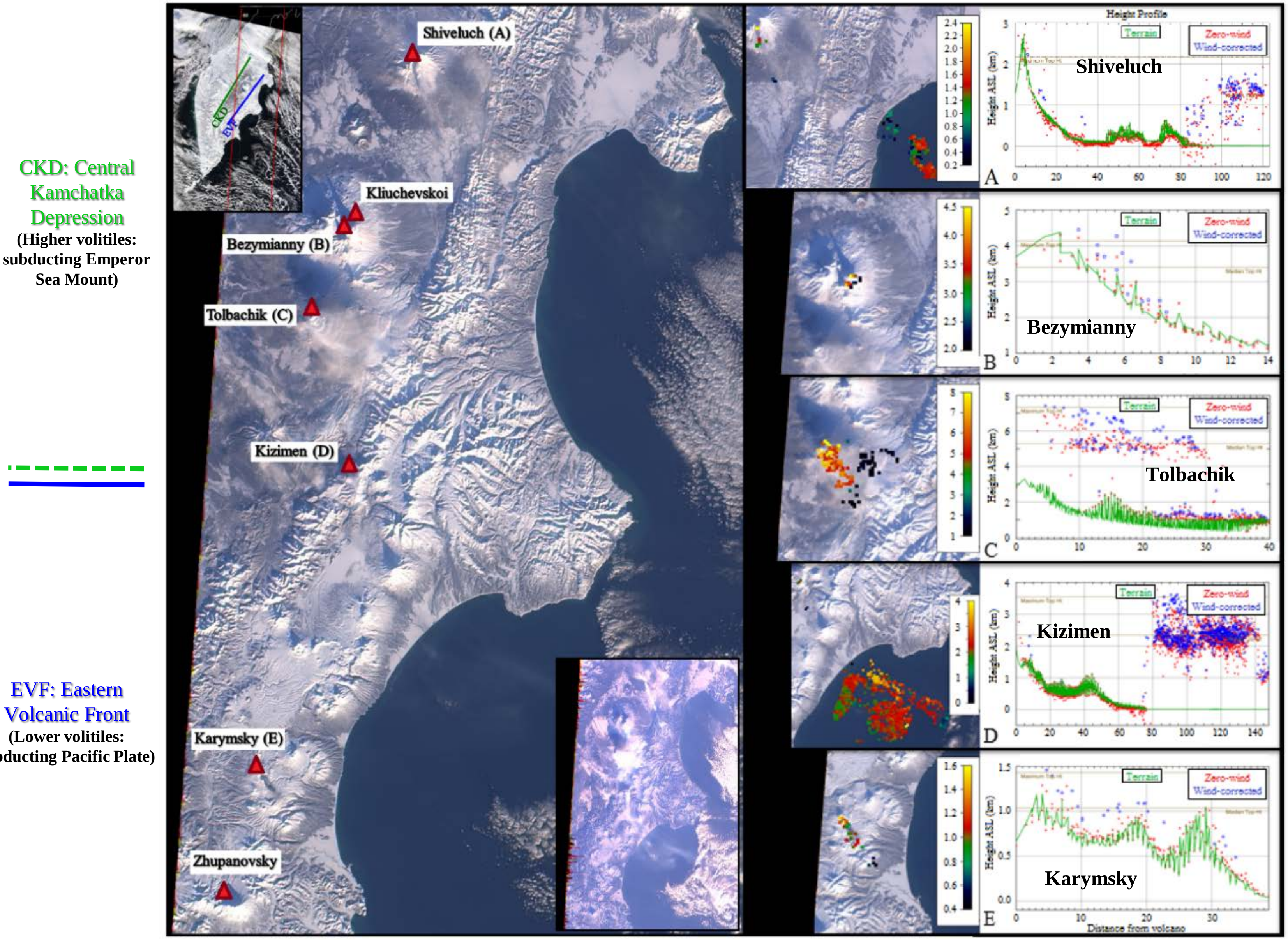
Five *Kamchatka Volcano Plumes* *06 January 2013*

CKD: Central Kamchatka Depression

(Higher volitiles: subducting Emperor Sea Mount)

EVF: Eastern Volcanic Front

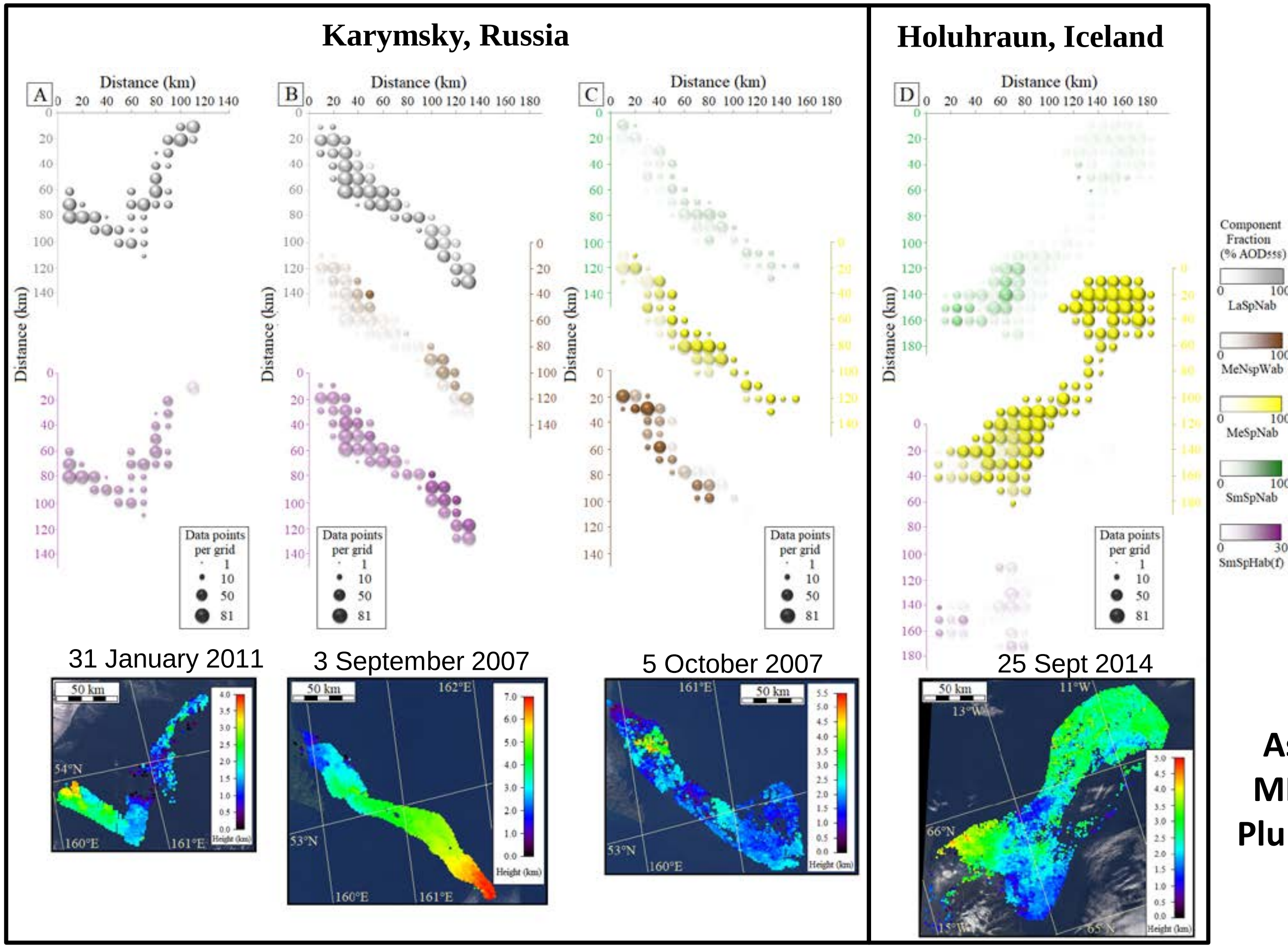
(Lower volitiles: subducting Pacific Plate)



Flower & Kahn J. Volc., 2017a

MISR *Research* Aerosol Retrieval Algorithm Particle Types

[Constraints on particle size, shape, light-absorption properties]



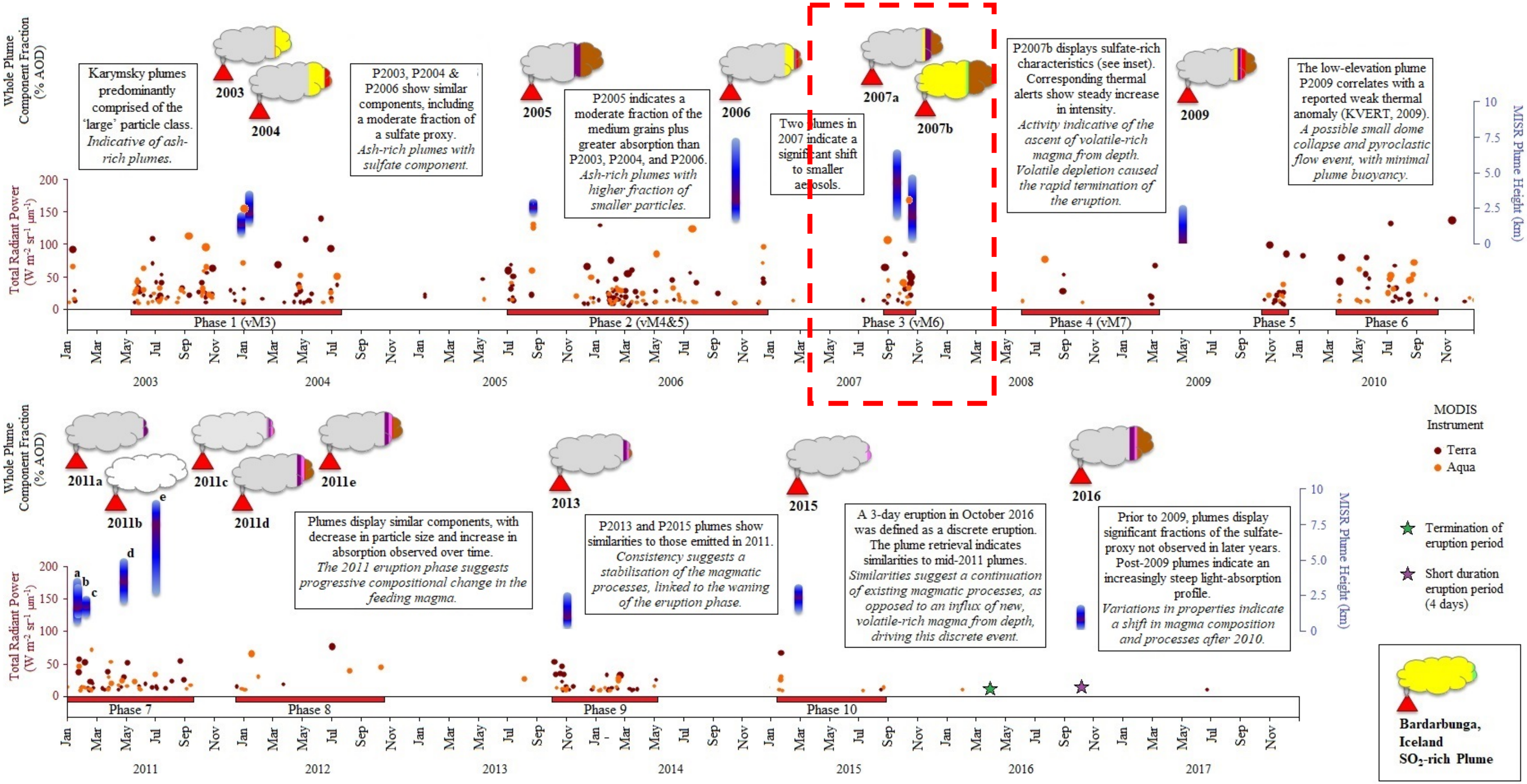
Associated MISR stereo Plume heights

Particle-property maps reflect *plume-to-plume (magma) differences* & *downwind particle evolution*

Grey=ash-proxy; Purple, Brown=light-absorbing; Green=spherical non-absorbing; Yellow=sulfate-proxy

Flower & Kahn ACP., 2018

Volcanology from Space

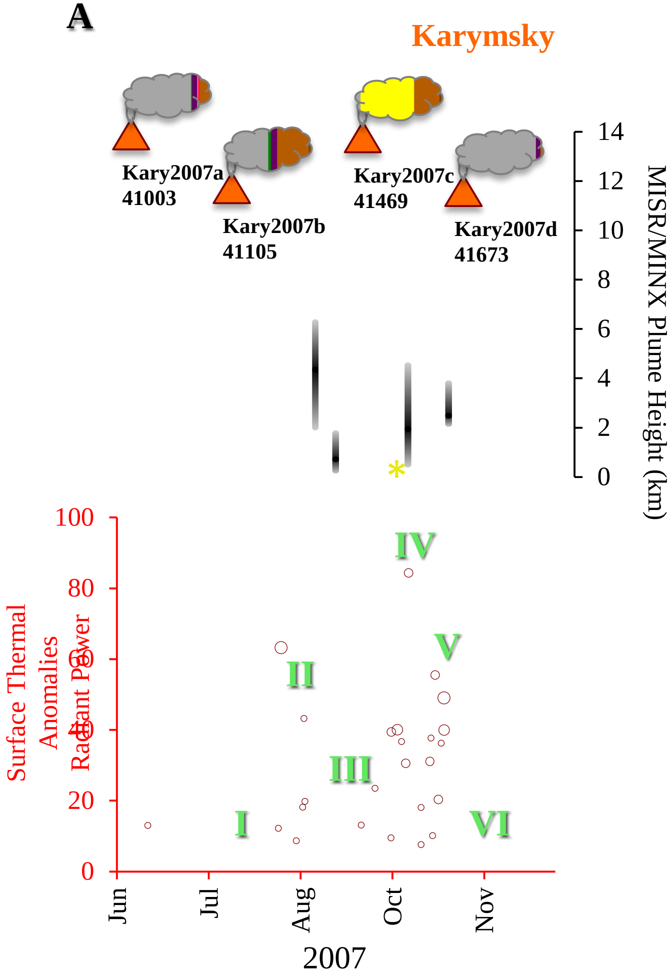


SmSpNab	Small (~0.06μm), spherical, non-absorbing
MdSpNab	Medium (~0.57μm), spherical, non-absorbing
LaSpNab	Large (~1.28μm), spherical, non-absorbing
SmSpHab(f)	Small (~0.12μm), spherical, highly absorbing ('flat' absorption profile)
SmSpHab(s)	Small (~0.12μm), spherical, highly absorbing ('steep' absorption profile)
SmSpMab(f)	Small (~0.12μm), spherical, moderately absorbing ('flat' absorption profile)
MdNspWab	Medium (~0.75μm), weakly-absorbing dust grains
LaSpdWab	Large (~2.4μm), weakly-absorbing coarse dust spheriods

Flower & Kahn, 2017c

Karymsky Volcano 2007 Eruptions – Geological Interpretation

A



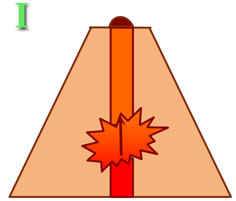
MISR Research Aerosol Retrieval (RA)

- Ash Particles
- Fine ash particles
- Spherical absorbing components
- Spherical non-absorbing components

* OMI SO_2 observation – 670t

B

I

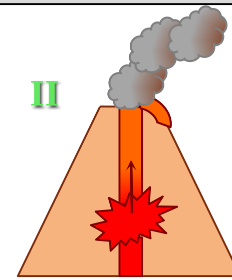


System is ***capped preventing lava flow*** development.

Minimizing the ***number and size*** of ***plumes***.

System put under ***strain*** by ***upwelling magma*** from depth.

II

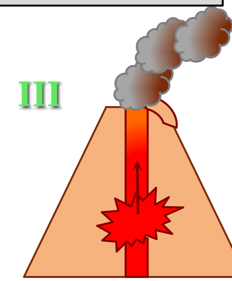


Pressure of upwelling magma ***overcomes cap*** causing ***explosive decompression*** of the system.

Fragmentation of the ***shallow, volatile poor magma*** generates ***ash rich plumes*** with ***large particles.***

Concurrent ***outflow of lava*** correspond to thermal anomaly detection.

III

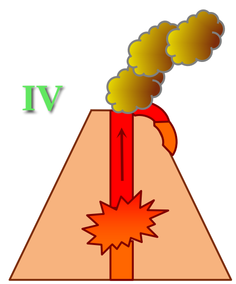


Influx of ***fresh magma*** combined with ***shallow, volatile poor magma***.

Generates ***ash rich plumes***, with ***smaller particle size.***

No thermal anomaly detection suggesting ***no surface lava flows***

IV

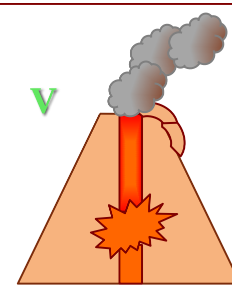


Decompression of the system draws ***volatile rich magma from depth***.

Generation of ***plumes*** with ***small ash particles*** and a ***higher fraction*** of ***sulfate and water***.

Lava flow extension corresponds to an increase in thermal anomalies.

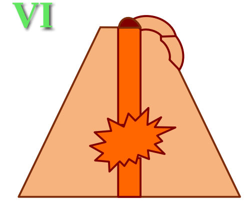
V



Decreasing influx of the ***volatile rich magma from depth*** corresponds to a shift back to ***ash rich plumes*** with minimal volatile components.

No thermal anomaly detection indicates ***cessation of lava flow extension.***

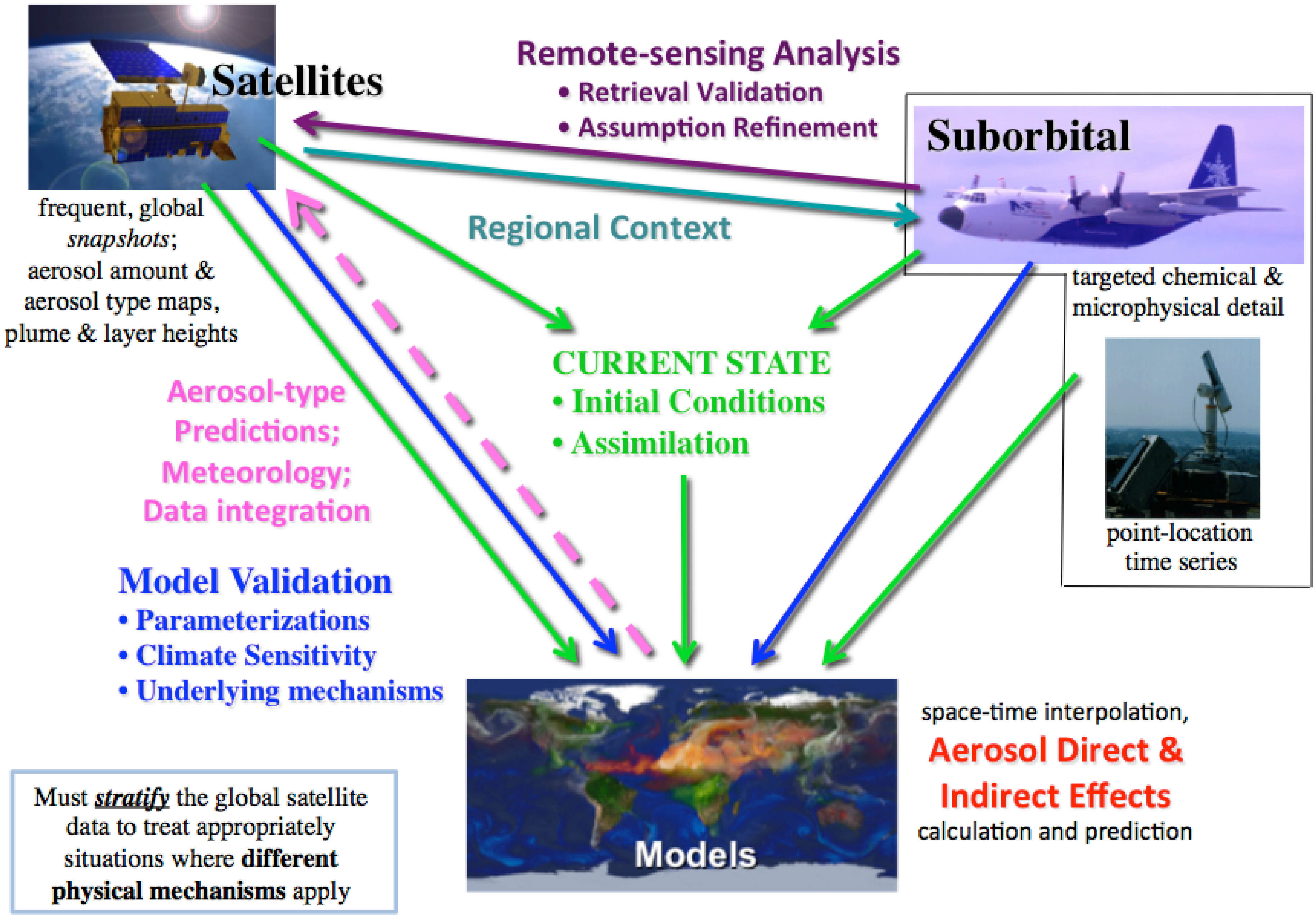
VI



Reduction in ***upwelling magma*** increases magma viscosity leading to the ***development of a cap.***

Small sulfate/water plumes tend to occur that are ***less conducive*** with MISR observations.

Lava flow development ceases.



Adapted from: Kahn, Survy. Geophys. 2012

SAM-CAAM *Concept*

[Systematic Aircraft Measurements to Characterize Aerosol Air Masses]

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

Primary Goals:

- Interpret and *enhance ~19 years of satellite aerosol retrieval* products
- *Characterize statistically particle properties* for major aerosol types globally, to provide detail unobtainable from space, adding value to all satellite aerosol data:

-- Improved aerosol property assumptions/initialization in satellite *retrieval algorithms*

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

Kahn et al., BAMS 2017

SAM-CAAM *Objective*

[Systematic Aircraft Measurements to Characterize Aerosol Air Masses]

Obtain ***aerosol intensive property PDFs*** required for key aerosol science objectives, but cannot be retrieved with adequate precision, or are ***entirely unobtainable***, ***from remote sensing******

- ***Hygroscopicity****** – Particle ambient 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

SAM-CAAM 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

AeroCom Model *Mass Extinction Efficiencies*

Table 3.3

Model – **Sulfate**	Mass load ($mg\ m^{-2}$)	MEE ($m^2\ g^{-1}$)	AOD at 550 nm	TOA Forcing ($W\ m^{-2}$)	Forcing/AOD ($W\ m^{-2}$)	Forcing/mass ($W\ g^{-1}$)
AeroCom: Identical emissions used for year 2000 and 1750						
M UMI	2.64	7.6	0.02	-0.58	-29	-220
N UIO-CTM	1.70	11.2	0.019	-0.36	-19	-212
O LOA	3.64	9.6	0.035	-0.49	-14	-135
P LSCE	3.01	7.6	0.023	-0.42	-18	-140
Q ECHAM5-HAM	2.47	6.5	0.016	-0.46	-29	-186
R GISS**	1.34	4.5	0.006	-0.19	-32	-142
S UIO-GCM	1.72	7.0	0.012	-0.25	-21	-145
T SPRINTARS	1.19	10.9	0.013	-0.16	-12	-134
U ULAQ	1.62	12.3	0.02	-0.22	-11	-136

MEE values for aerosol species are **uncertain by *factors* of 3 or more**

Table 3.4

Model	POM						BC					
	Mass load ($mg\ m^{-2}$)	MEE ($m^2\ g^{-1}$)	AOD at 550 nm	TOA Forcing ($W\ m^{-2}$)	Forcing/AOD ($W\ m^{-2}$)	Forcing/mass ($W\ g^{-1}$)	Mass load ($mg\ m^{-2}$)	MEE ($m^2\ g^{-1}$)	AOD at 550 nm x1000	TOA Forcing ($W\ m^{-2}$)	Forcing/AOD ($W\ m^{-2}$)	Forcing/mass ($W\ g^{-1}$)
AeroCom: Identical emissions for year 2000 & 1750												
L UMI	1.16	5.2	0.0060	-0.23	-38	-198	0.19	6.8	1.29	0.25	194	1316
M UIO-CTM	1.12	5.2	0.0058	-0.16	-28	-143	0.19	7.1	1.34	0.22	164	1158
N LOA	1.41	6.0	0.0085	-0.16	-19	-113	0.25	7.9	1.98	0.32	162	1280
O LSCE	1.50	5.3	0.0079	-0.17	-22	-113	0.25	4.4	1.11	0.30	270	1200
P ECHAM5-HAM	1.00	7.7	0.0077	-0.10	-13	-100	0.16	7.7	1.23	0.20	163	1250
Q GISS**	1.22	4.9	0.0060	-0.14	-23	-115	0.24	7.6	1.83	0.22	120	917
R UIO-GCM	0.88	5.2	0.0046	-0.06	-13	-68	0.19	10.3	1.95	0.36	185	1895
S SPRINTARS	1.84	10.9	0.0200	-0.10	-5	-54	0.37	9.5	3.50	0.32	91	865
T ULAQ	1.71	4.4	0.0075	-0.09	-12	-53	0.38	7.6	2.90	0.08	28	211

Similar situation for particle:

- ***Hygroscopicity***
- ***Light Absorption***

CCSP 2009

SAM-CAAM *Implementation*

[Systematic Aircraft Measurements to Characterize Aerosol Air Masses]

- ***Dedicated Operational Aircraft*** – routine flights, 2-3 x/week, on a continuing basis
- ***Sample Aerosol Air Masses*** accessible from a given base-of-operations, then move; project science team to determine schedule, possible field campaign participation
- ***Process Data Routinely*** at central site; instrument PIs develop & deliver algorithms, upgrade as needed; data distributed via central web site, ***as with EOS data***
- Parallels the relationship between ***AERONET and MODIS / MISR*** during EOS era
- Fills gaps in satellite remote-sensing as ***IceBridge*** did for cryosphere
- Peer-reviewed paper with notional payload ***demonstrating feasibility***; subsequent selections based on agency buy-in and available resources

SAM-CAAM 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

Practical Uses of Math And Science

The On-Line Journal of Math and Science Examples for Pre-College Education

pumas.nasa.gov

Ralph Kahn, Editor & Founder ***Susannah Pierce***, Web Developer

Backup Slides

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Implementation of MISR BB Injection Height in *GEOS-Chem* Model

MINX-derived global plume height database in 2008
Val Martin et al. (2018)

↓

Statistically derived profiles (%) based on altitude, land cover unit, region, and season

↓

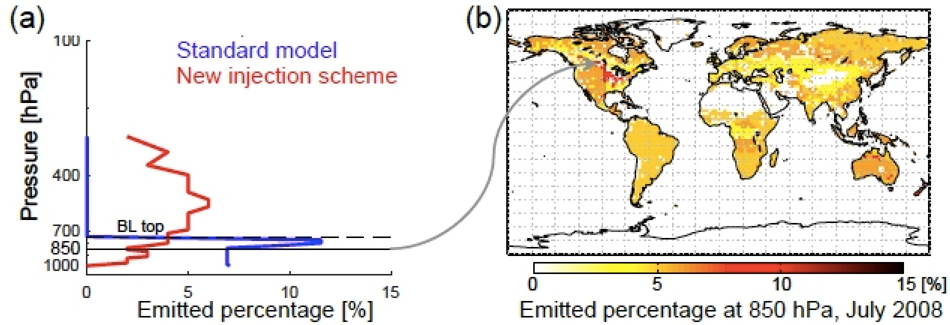
Map native MISR injection altitude distribution (0–8 km, 250 m) to GMAO 47-layer reduced vertical grid (hPa)

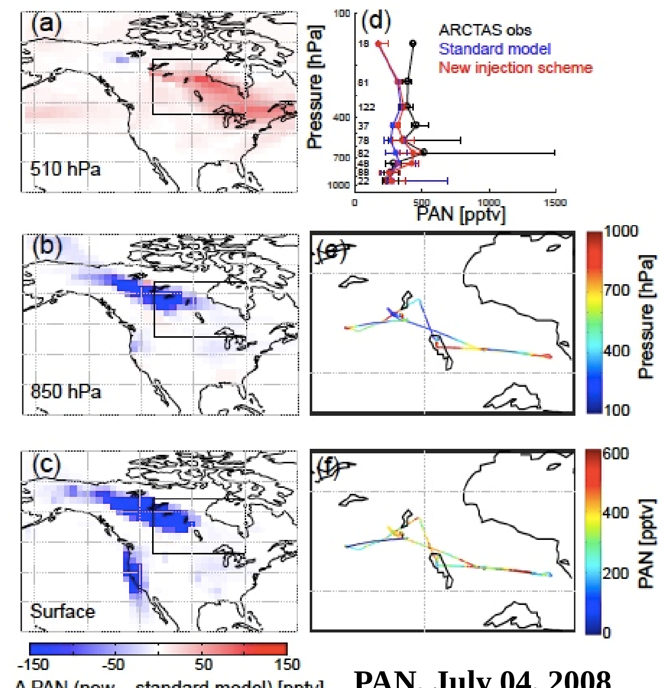
↓

Assign a smoke injection height altitude distribution to GEOS-Chem grid box (2° latitude x 2.5° longitude)

↓

Modify setemis.F in GEOS-Chem (v9.01.01) to distribute biomass burning emissions according to 3-D matrix





PAN, July 04, 2008

Better PAN and CO agreement with ARCTAS aircraft observations using MISR injection heights

Zhu et al., Geosci. Mdl. Dev. 2018

SAM-CAAM *15 Required Variables*

[Systematic Aircraft Measurements to Characterize Aerosol Air Masses]

1. AEROSOL PROPERTIES FROM *IN SITU* MEASUREMENTS & INTEGRATED ANALYSIS

	Abbrev.	Required Variable
1	EXT	Spectral Extinction
2	ABS	Spectral Absorption
3	GRO	Hygroscopic Growth
4	SIZ	Particle Size
5	CMP	Particle Type (a composition constraint)
6	PHA	Single-scattering Phase Function
7	MEE	Mass Extinction Efficiency
8	RRI	Real Refractive Index

Kahn et al., BAMS 2017

SAM-CAAM *15 Required Variables*

[Systematic Aircraft Measurements to Characterize Aerosol Air Masses]

2. METEOROLOGICAL CONTEXT

	Abbrev.	Required Variable
9	CO	Ambient Gases (CO + O_3 + NO_2)
10	T; P; RH	Standard Ambient Meteorological Variables
11	LOC	Geographic Location

3. AMBIENT REMOTE-SENSING CONTEXT

	Abbrev.	Required Variable
12	A-EXT & A-ABS	Ambient Spectral Extinction & Absorption
13	A-PHA	Ambient Particle Phase Function
14	A-CLD	Ambient Cloud & Large-Particle Size/Type
15	HTS	Aerosol Layer Heights

Kahn et al., BAMS 2017

SAM-CAAM

A Concept for Acquiring Systematic Aircraft Measurements to Characterize Aerosol Air Masses

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SAM-CAAM aims to characterize particle properties statistically with systematic, aircraft in situ measurements of major aerosol air masses, to refine satellite data products and to improve climate and air quality modeling.