The Three-Way Street

Satellites

- Frequent, Global Coverage
  - Aerosol & Cloud Amount & Type Maps
  - Aerosol Plume, Layer, & Cloud Heights

- Model Validation
  - Parameterizations
  - Underlying Mechanisms

- Aerosol-type Retrieval
  - Priors/Weights Retrospective
  - Source Identification
  - Aging Assessment

Remote-sensing Analysis
- Retrieval Validation
- Assumption Refinement

Regional Context

Suborbital

- Targeted Microphysical, Cloud-Dynamical, & Aerosol-Chemical Detail

- Point-Location Time Series

Aircraft Targeting
- Aerosol Source Identification
- Aerosol Aging Assessment
- Cloud Regime Identification

Models

- Current State
  - Initial Conditions
  - Assimilation

- Data Integration
  - Space-time Interpolation

- Aerosol-Cloud Interactions & Aerosol Climate Forcing
  - Calculation & Prediction

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

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

\[ (F - N) \times S = \Delta T \]

Effective Forcing \hspace{1cm} Ocean Heat Content \hspace{1cm} Climate Sensitivity \hspace{1cm} Climate Response

Schwartz et al., Earth’s Future 2014

IPCC AR5, 2013
The Three-Way Street

Satellites

Frequent, Global Coverage
- Aerosol & Cloud Amount & Type Maps
- Aerosol Plume, Layer, & Cloud Heights

Remote-sensing Analysis
- Retrieval Validation
- Assumption Refinement

Regional Context

Current State
- Initial Conditions
- Assimilation

Models

Aerosol-type Retrieval
- Priors/Weights Retrospective
- Source Identification
- Aging Assessment

Suborbital

Targeted Microphysical, Cloud-Dynamical, & Aerosol-Chemical Detail

Point-Location Time Series

Aircraft Targeting
- Aerosol Source Identification
- Aerosol Aging Assessment
- Cloud Regime Identification

Data Integration
- Space-time Interpolation

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.

% of Plumes injected above boundary layer stratified by vegetation type & year

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.
• 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/
MISR Wildfire Smoke *Injection Height Climatology*

- 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/](https://misr.jpl.nasa.gov/getData/accessData/MisrMinxPlumes2/)
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
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*
- 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**
Grouping BB regions for source-strength estimation

- 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

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

**ANG**

\[
\text{Diff}_{\text{ANG}} = |\alpha_{\text{MISR}} - \alpha_{\text{GoCART}}| \leq \varepsilon_{\text{ANG}}
\]

We rank the \( \varepsilon_{\text{ANG}} \), \( \varepsilon_{\text{AAOD}} \) and select the common or the lowest mixtures.

**AAOD**

\[
\text{Diff}_{\text{AAOD}} = |\text{Fraction}_{\text{MISR, AAOD}} - \text{Fraction}_{\text{GoCART, AAOD}}| \leq \varepsilon_{\text{AAOD}}
\]

Fraction_{MISR, AAOD} is the absorbing fraction of total AOD.

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

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

Remote-sensing Analysis
- Retrieval Validation
- Assumption Refinement

Satellites
- Frequent, Global Coverage
  - Aerosol & Cloud Amount & Type Maps
  - Aerosol Plume, Layer, & Cloud Heights
- Model Validation
  - Parameterizations
  - Underlying Mechanisms
- Aerosol-type Retrieval
  - Priors/Weights Retrospective
  - Source Identification
  - Aging Assessment

Suborbital
- Targeted Microphysical, Cloud-Dynamical, & Aerosol-Chemical Detail
- Point-Location Time Series
- Aircraft Targeting
  - Aerosol Source Identification
  - Aerosol Aging Assessment
  - Cloud Regime Identification

Models
- Current State
  - Initial Conditions
  - Assimilation
- Data Integration
  - Space-time Interpolation
- Aerosol-Cloud Interactions & Aerosol Climate Forcing
  - Calculation & Prediction

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