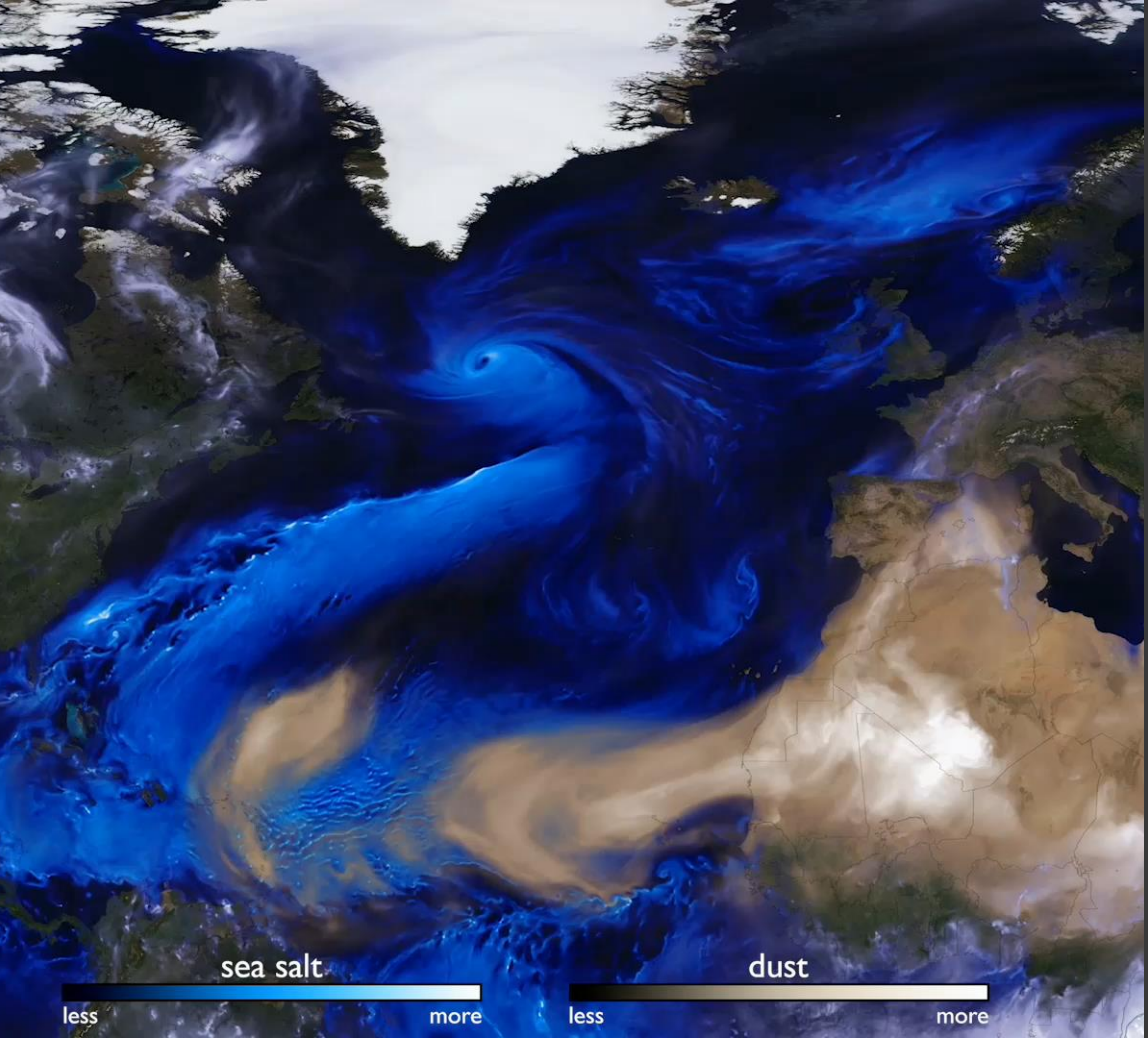

Reflections on Model and Satellite Integration

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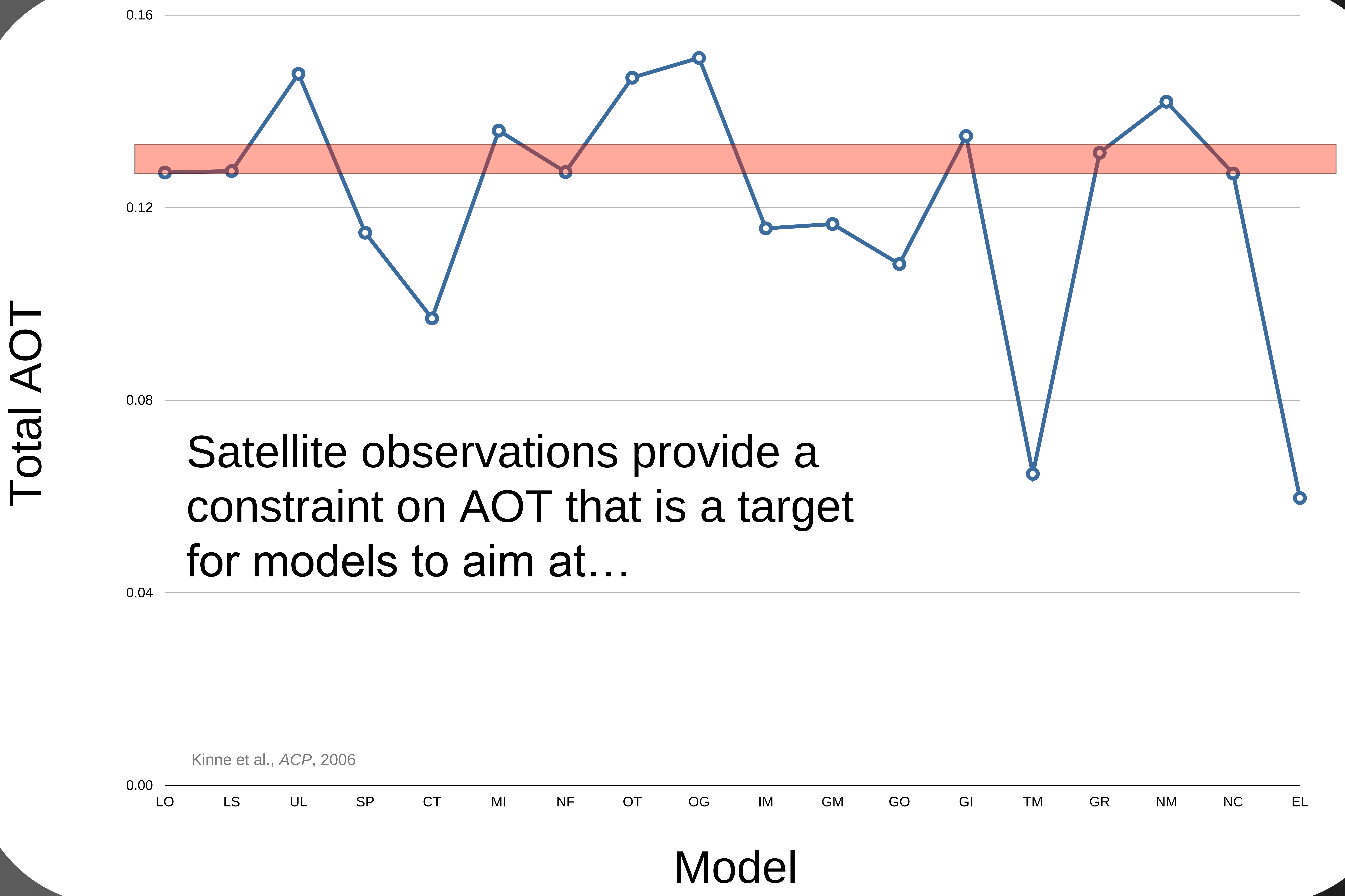
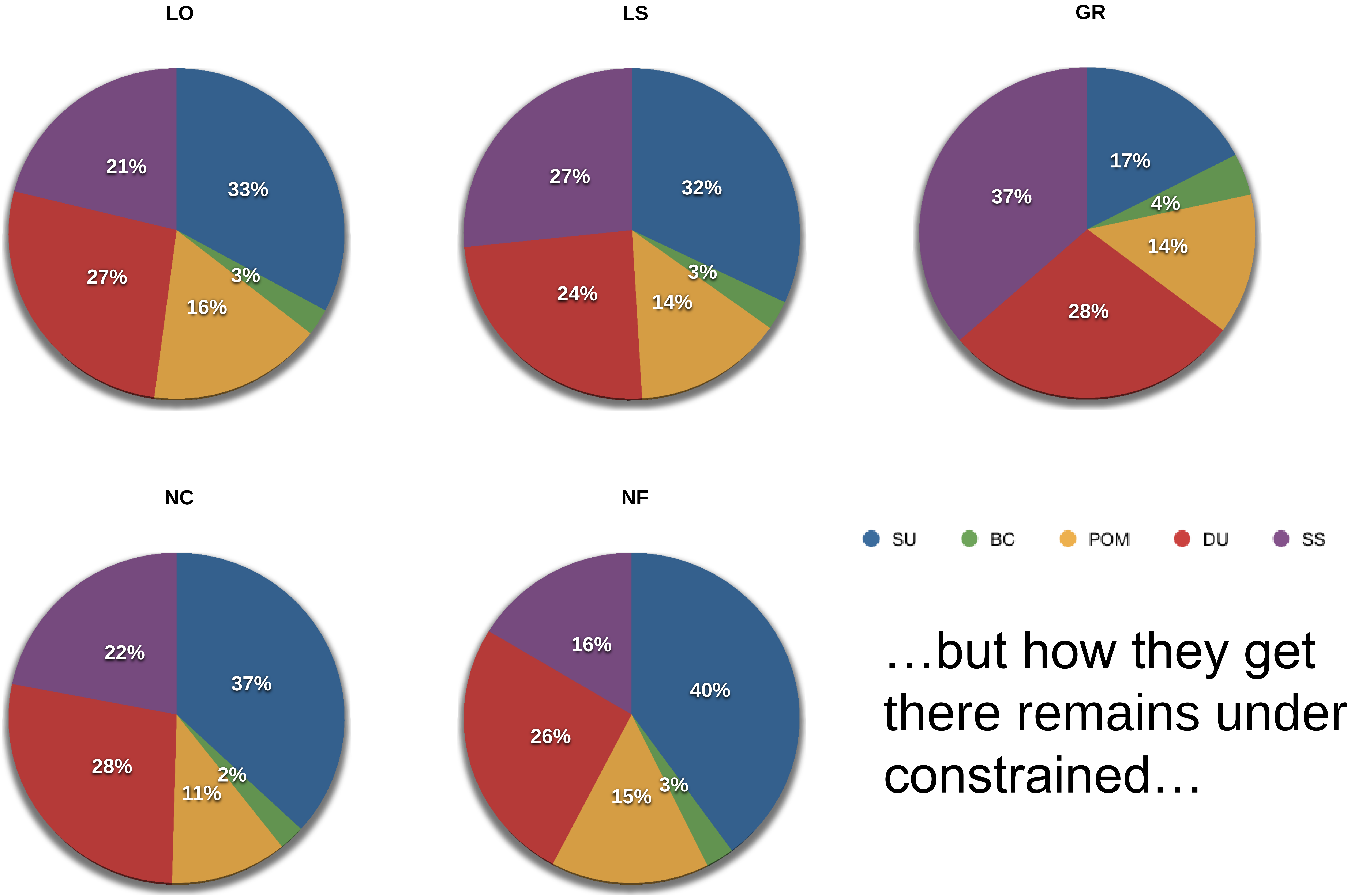
NASA GSFC, Code 614
Atmospheric Chemistry and Dynamics Laboratory

AeroCom/AeroSat, October 18, 2018



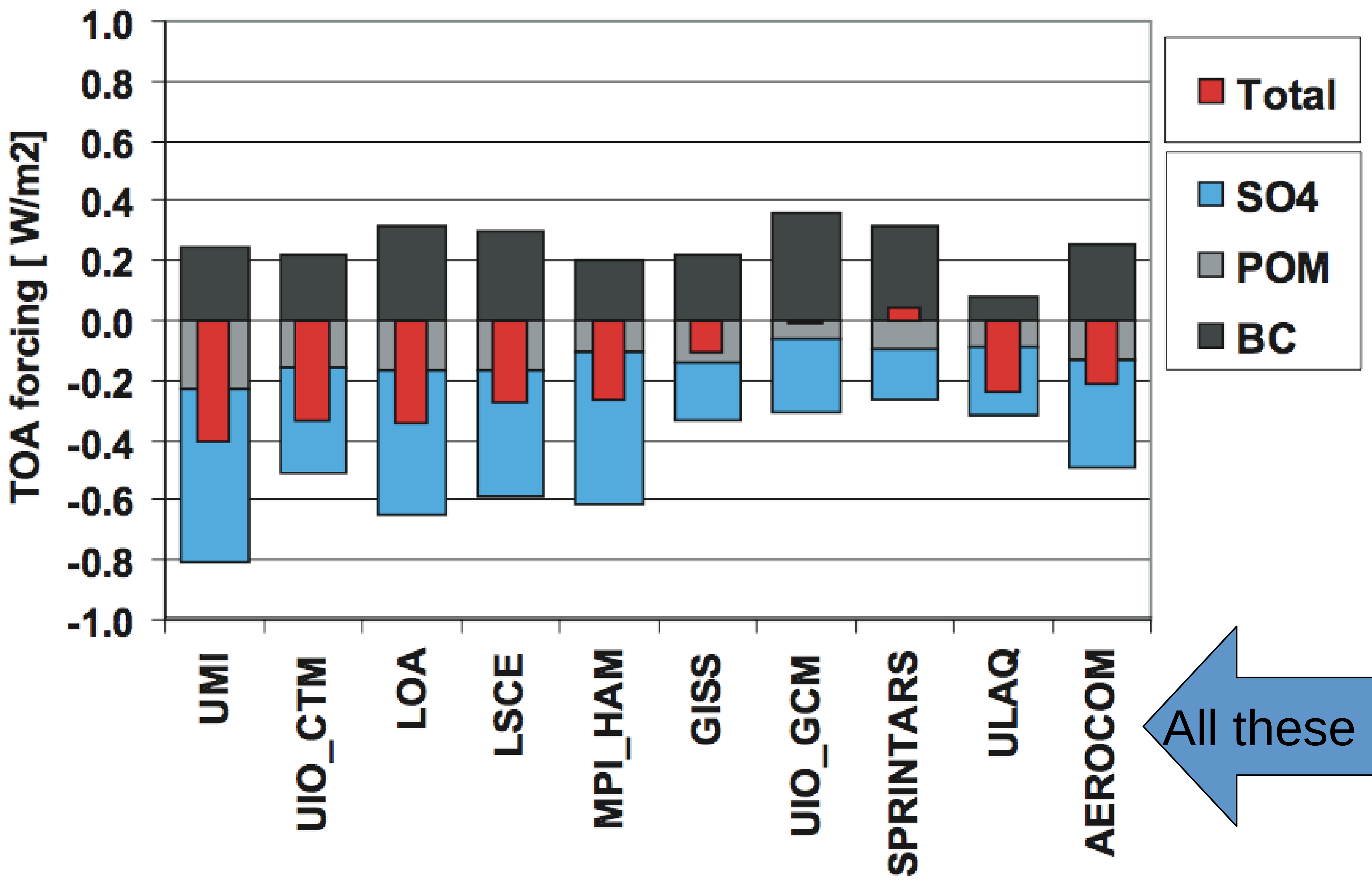
Satellite observations provide a constraint on AOT that is a target for models to aim at…

Kinne et al., *ACP*, 2006



…but how they get there remains under constrained…

Kinne et al., *ACP*, 2006



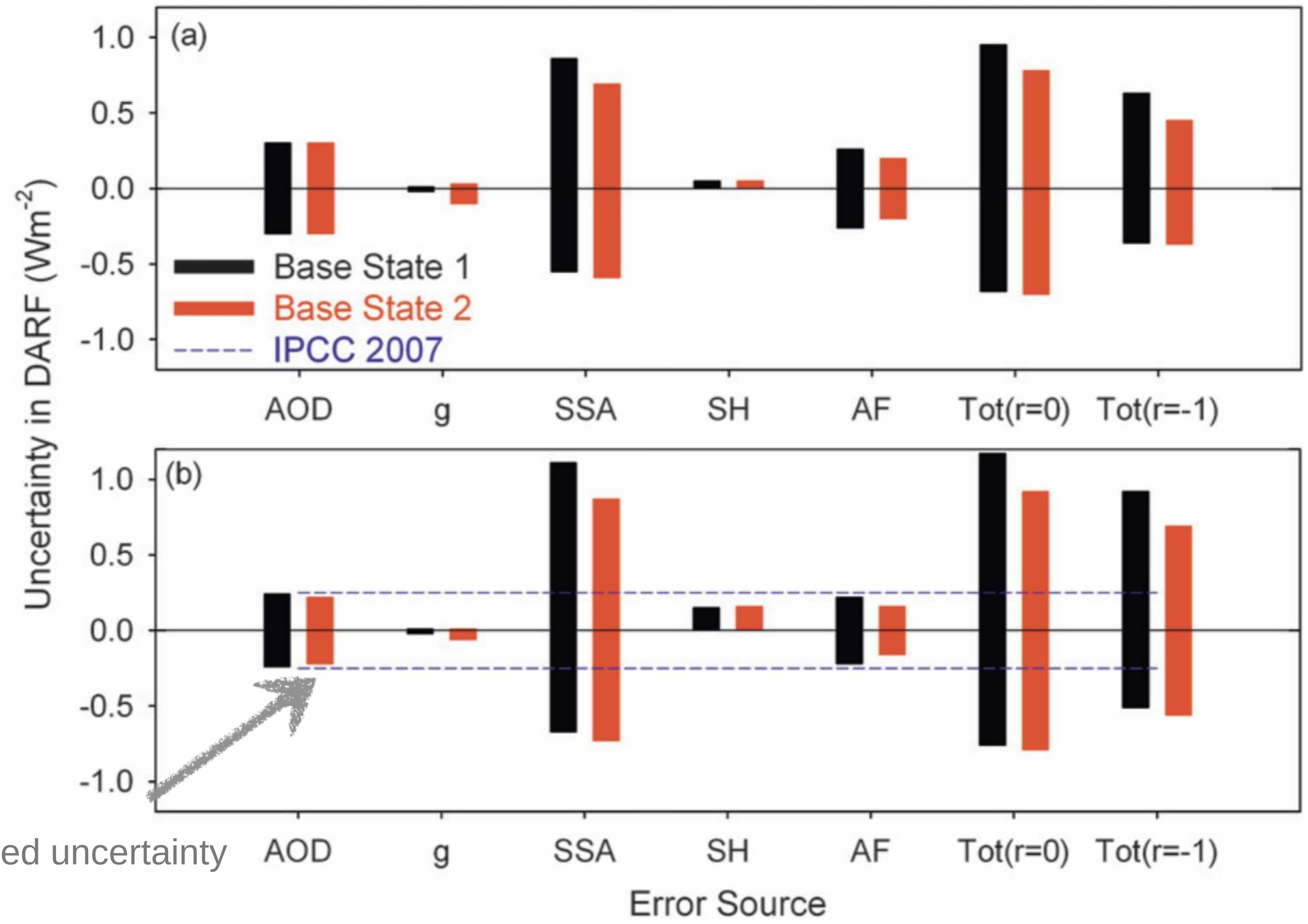
Model Δ

burdens (M_{SO4} = 0.6 - 1.8 Tg)
lifetimes (τ_{SO4} = 2.3 - 5.1 days)
optics (β_{ext} = 4.5 - 12.3 $m^2 g^{-1}$)
Improvements require better characterization of surface reflectance and aerosol scattering properties

All these models have same emissions

…and process-level uncertainties (lifetimes, MEE, …) remain large (still) so that we have residual uncertainty in forcing.

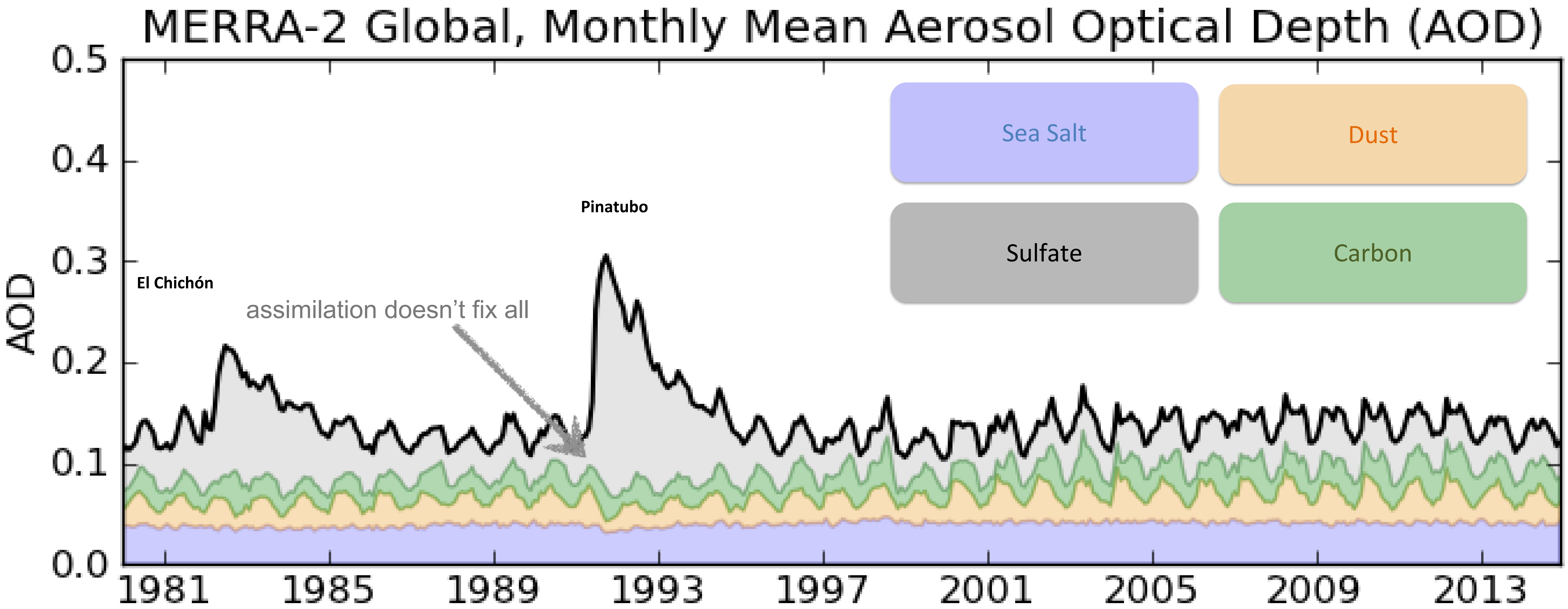
Schulz et al., *ACP*, 2006



IPCC FAR stated uncertainty

FIG. 1. DARF uncertainty associated with different aerosol parameters for (a) clear- and (b) all-sky conditions. The dashed line corresponds to the DARF uncertainty in Solomon et al. (2007).

Loeb and Su, *J. Clim.*, 2010



assimilation doesn't fix all

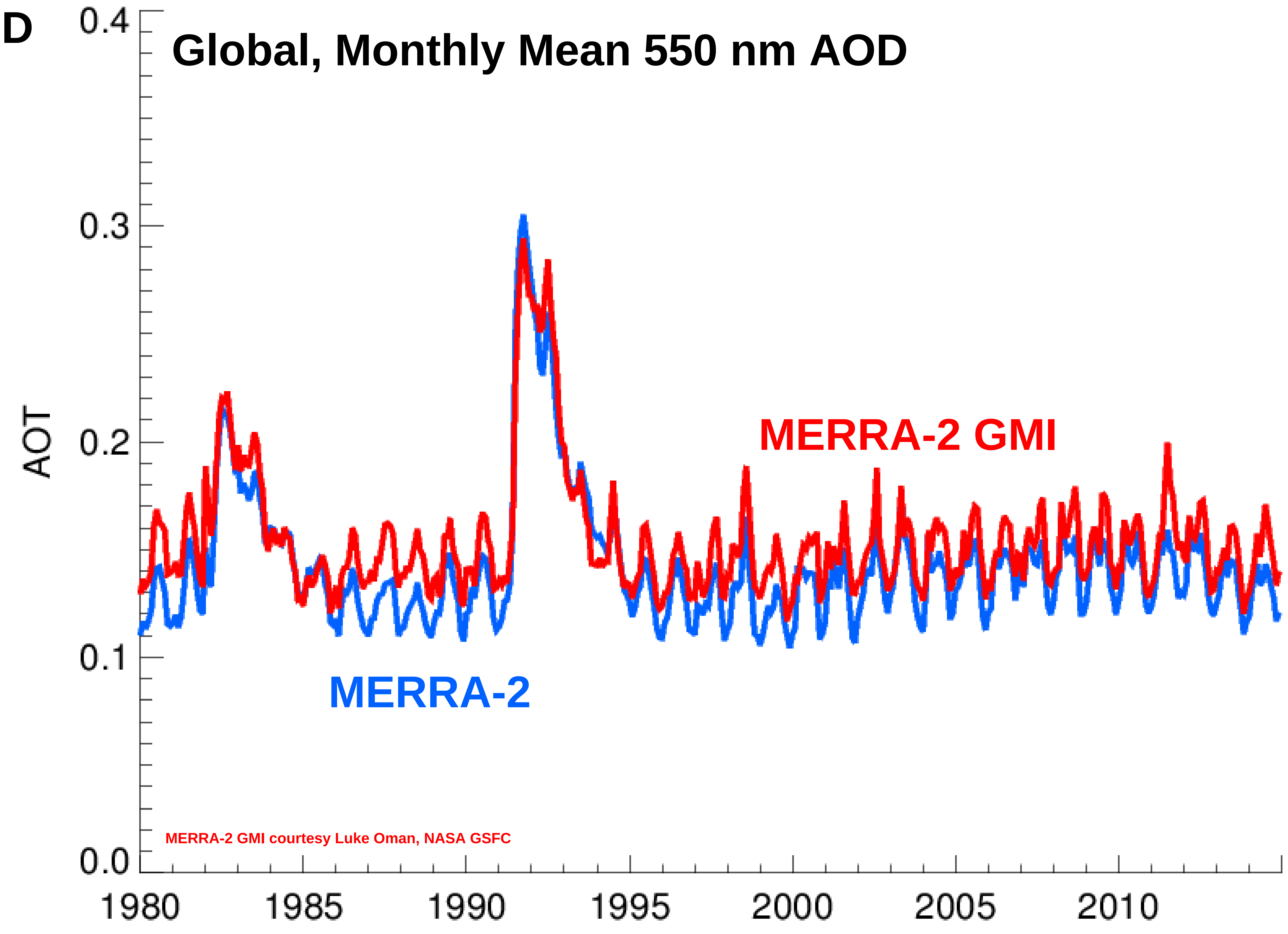
Randles et al., *J. Clim.*, 2017

Two realizations of the global mean AOD

- same model
- same meteorology (MERRA-2)
- same resolution (~50 km)
- same aerosol module* (GOCART)
- same emissions
- same optical properties
- aerosol data assimilation
- **no** aerosol data assimilation

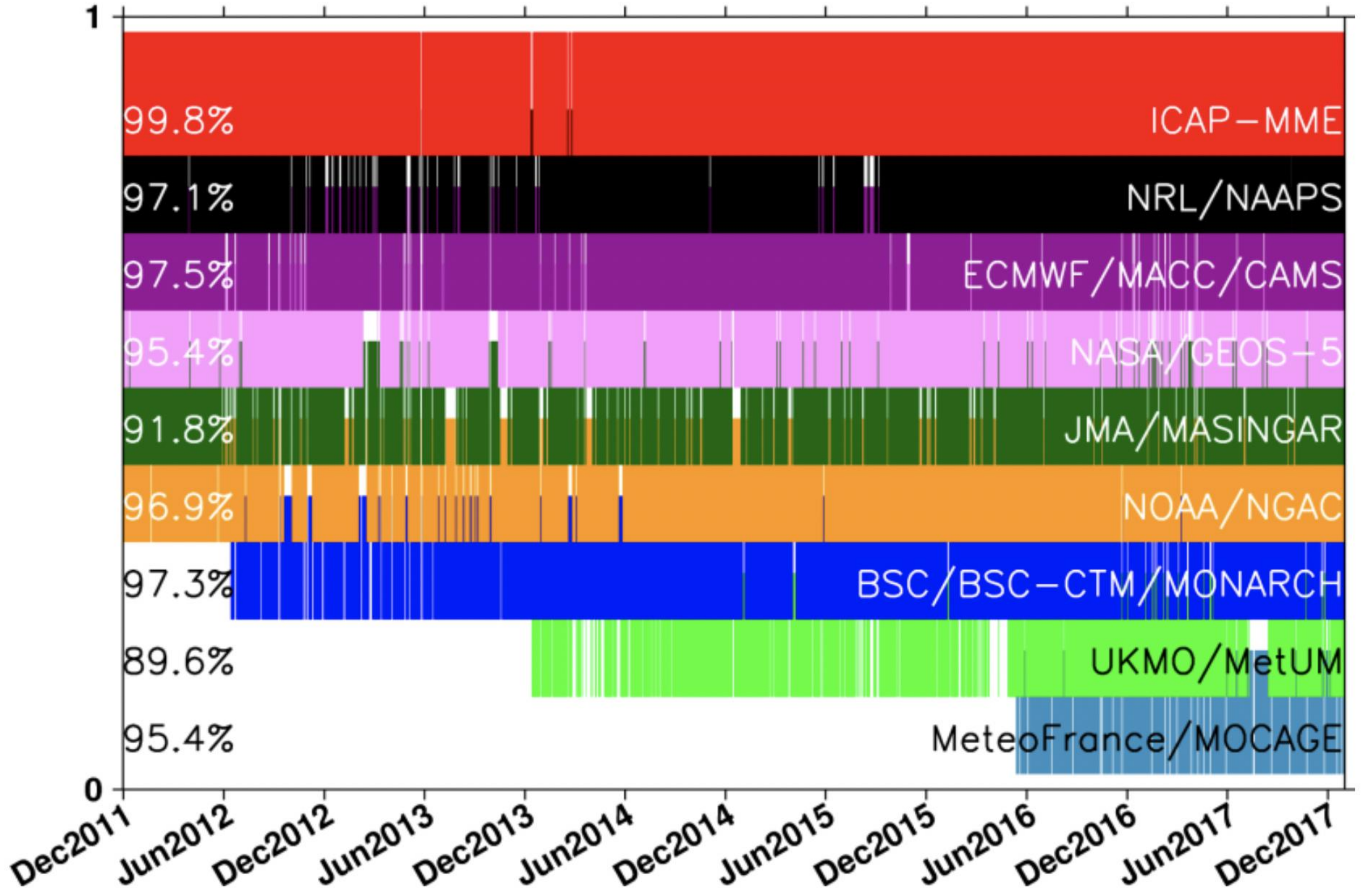
* MERRA-2 GMI includes full GMI chemistry (coupled oxidants) and new nitrate module

Different applications…

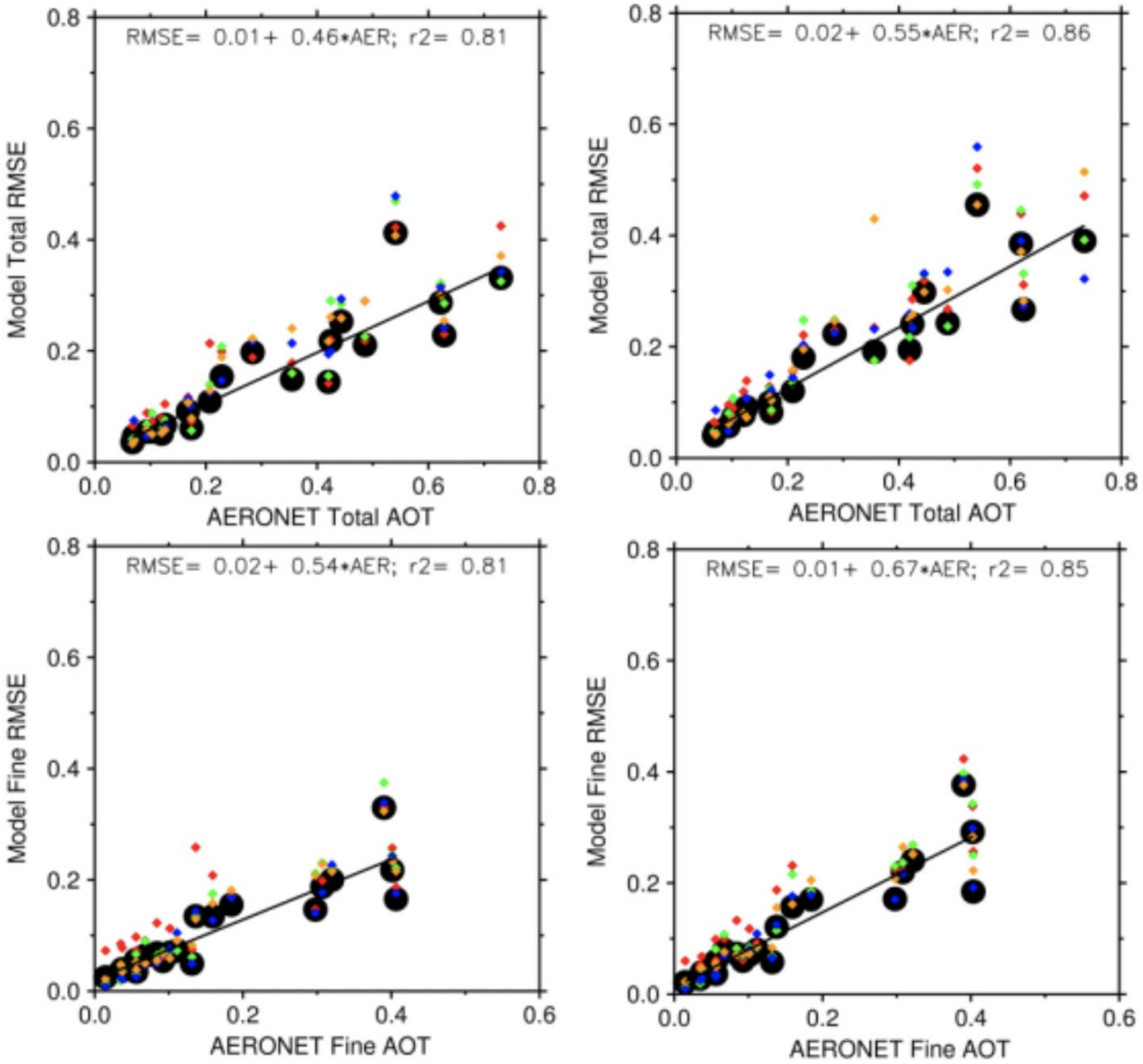


ICAP: International Cooperative for Aerosol Prediction

- Complementary community to AeroCom/AeroSat, but focused on near-real time prediction issues
- ICAP Multi-Model Ensemble



Xian et al., *QJRMS, 2018*



This is probably where I’m supposed to say those 5 things that modelers want…

…but of course we want it all.

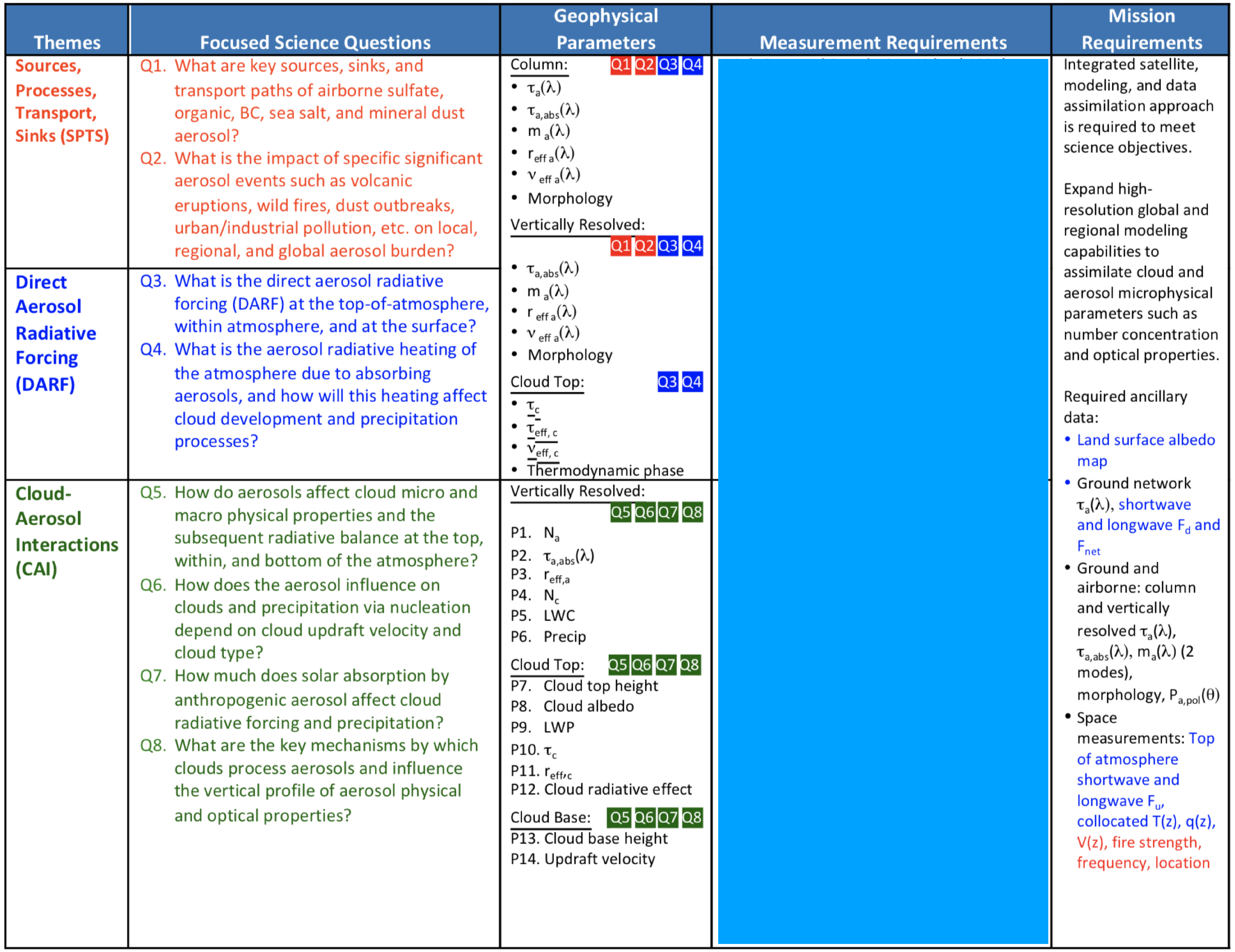
Forecasting and data assimilation:

- high frequency, low latency, coverage
- well characterized errors

Reanalysis and climate:

- consistent, harmonized records
- long time series

These are framed in terms of needed constraints on models or else as “coverage” constraints where models have difficulty



Themes	Focused Science Questions	Geophysical Parameters	Measurement Requirements	Mission Requirements
Sources, Processes, Transport, Sinks (SPTS)	Q1. What are key sources, sinks, and transport paths of airborne sulfate, organic, BC, sea salt, and mineral dust aerosol? Q2. What is the impact of specific significant aerosol events such as volcanic eruptions, wild fires, dust outbreaks, urban/industrial pollution, etc. on local, regional, and global aerosol burden?	Column: Q1 Q2 Q3 Q4 • $\tau_a(\lambda)$ • $\tau_{a,abs}(\lambda)$ • $m_a(\lambda)$ • $r_{eff\ a}(\lambda)$ • $\nu_{eff\ a}(\lambda)$ • Morphology Vertically Resolved: Q1 Q2 Q3 Q4 • $\tau_{a,abs}(\lambda)$ • $m_a(\lambda)$ • $r_{eff\ a}(\lambda)$ • $\nu_{eff\ a}(\lambda)$ • Morphology		Integrated satellite, modeling, and data assimilation approach is required to meet science objectives. Expand high-resolution global and regional modeling capabilities to assimilate cloud and aerosol microphysical parameters such as number concentration and optical properties. Required ancillary data: • Land surface albedo map • Ground network $\tau_a(\lambda)$, shortwave and longwave F_d and F_{net} • Ground and airborne: column and vertically resolved $\tau_a(\lambda)$, $\tau_{a,abs}(\lambda)$, $m_a(\lambda)$ (2 modes), morphology, $P_{a,pol}(\theta)$ • Space measurements: Top of atmosphere shortwave and longwave F_u, collocated T(z), q(z), V(z), fire strength, frequency, location
Direct Aerosol Radiative Forcing (DARF)	Q3. What is the direct aerosol radiative forcing (DARF) at the top-of-atmosphere, within atmosphere, and at the surface? Q4. What is the aerosol radiative heating of the atmosphere due to absorbing aerosols, and how will this heating affect cloud development and precipitation processes?	Cloud Top: Q3 Q4 • τ_c • $\tau_{eff,\ c}$ • $\nu_{eff,\ c}$ • Thermodynamic phase		
Cloud-Aerosol Interactions (CAI)	Q5. How do aerosols affect cloud micro and macro physical properties and the subsequent radiative balance at the top, within, and bottom of the atmosphere? Q6. How does the aerosol influence on clouds and precipitation via nucleation depend on cloud updraft velocity and cloud type? Q7. How much does solar absorption by anthropogenic aerosol affect cloud radiative forcing and precipitation? Q8. What are the key mechanisms by which clouds process aerosols and influence the vertical profile of aerosol physical and optical properties?	Vertically Resolved: Q5 Q6 Q7 Q8 P1. N_a P2. $\tau_{a,abs}(\lambda)$ P3. $r_{eff,a}$ P4. N_c P5. LWC P6. Precip Cloud Top: Q5 Q6 Q7 Q8 P7. Cloud top height P8. Cloud albedo P9. LWP P10. τ_c P11. $r_{eff,c}$ P12. Cloud radiative effect Cloud Base: Q5 Q6 Q7 Q8 P13. Cloud base height P14. Updraft velocity		

ACE 2011-2015 Progress Report and Future Outlook (2016)

Instrument simulation as a means to harmonize models and observations

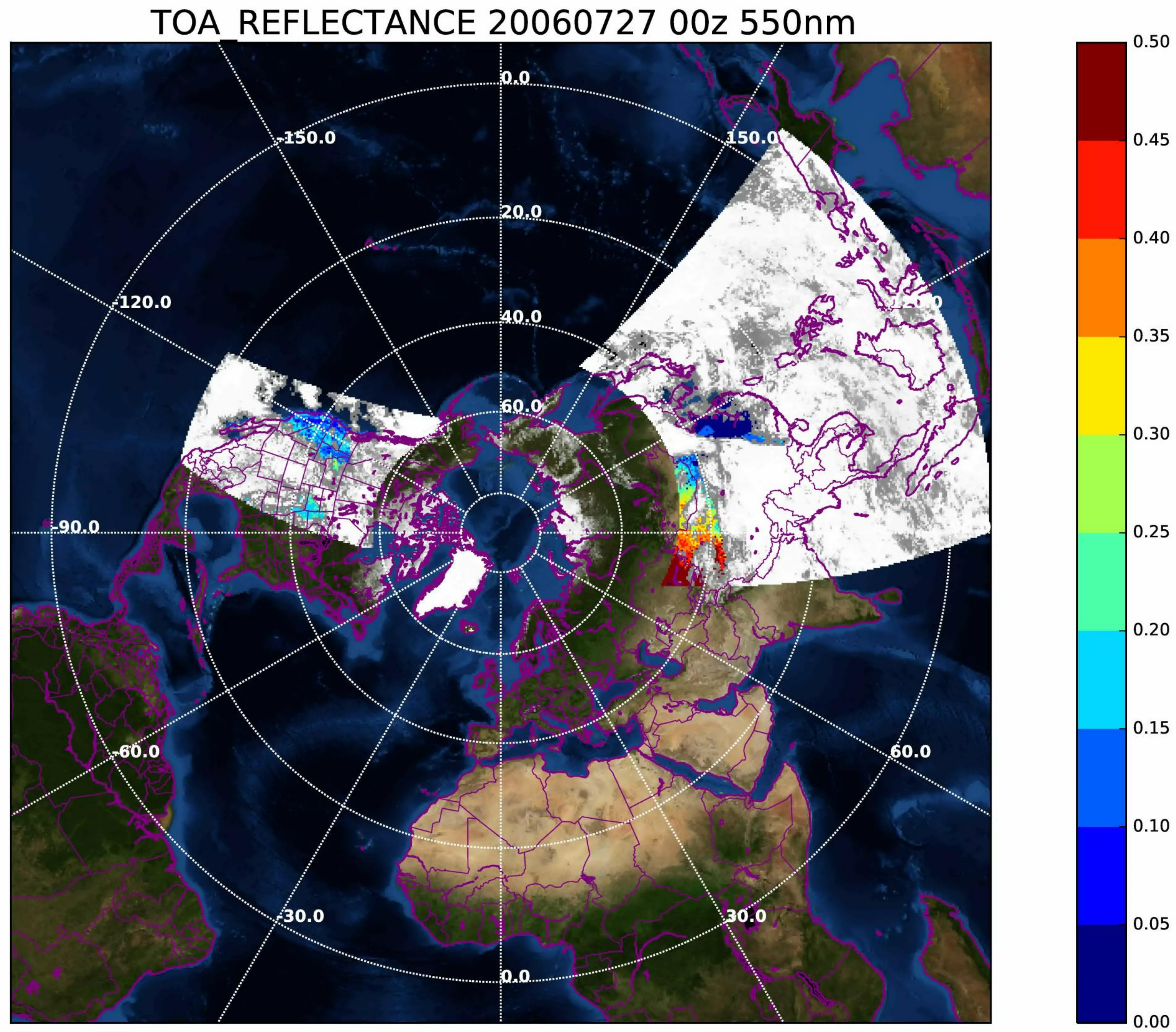
Models and retrievals are not (never will?) converge on what they mean by, e.g., aerosol type

This presents a fundamental challenge in using the two together (you all know this)

Another approach is direct observation simulation

- Level 1
  - Detailed radiative transfer calculation in the presence of clouds, aerosols, ice, etc.
  - Instrument characteristics
  - Observables: polarized radiances, backscatter
- Level 2
  - Retrieved quantities at observation location
  - Averaging kernels, error characteristics
- Level 3
  - Hourly to seasonal mean statistics sampled at the instrument footprint
- Level 4
  - Not necessarily at the model footprint

After Patricia Castellanos, GSFC



Simulate OMI radiances directly as means to evaluate and improve model

- From MERRA-2 aerosol fields we simulate the OMI observed TOA radiances (354 and 388 nm) using VLIDORT
- Comparison of the simulated and observed UV aerosol index provides complementary information to comparison of simulated and retrieved AAOD
- Result is improved confidence in simulated aerosol absorption, as well as refinement of assumed input aerosol optical properties (dust, organic carbon)

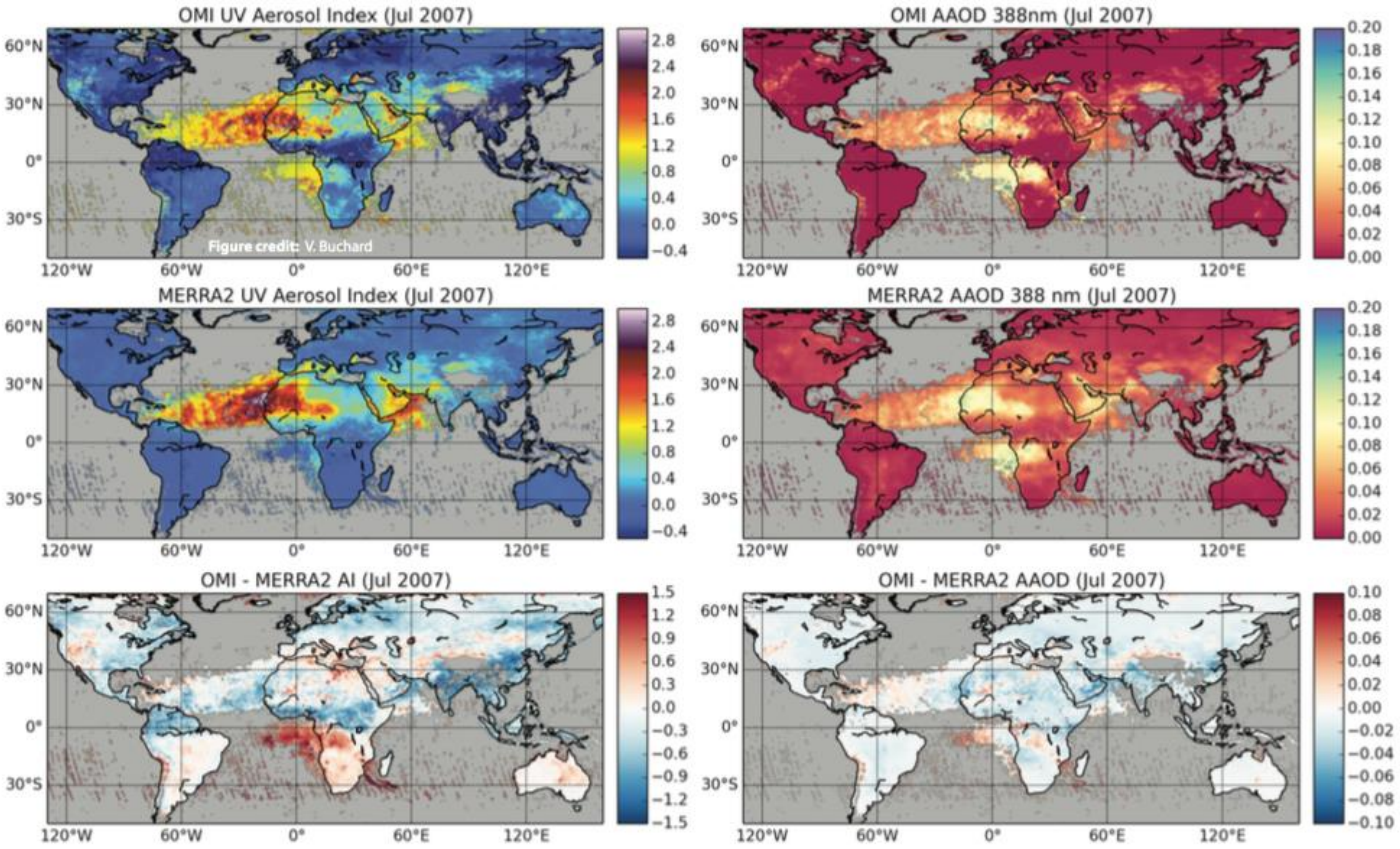
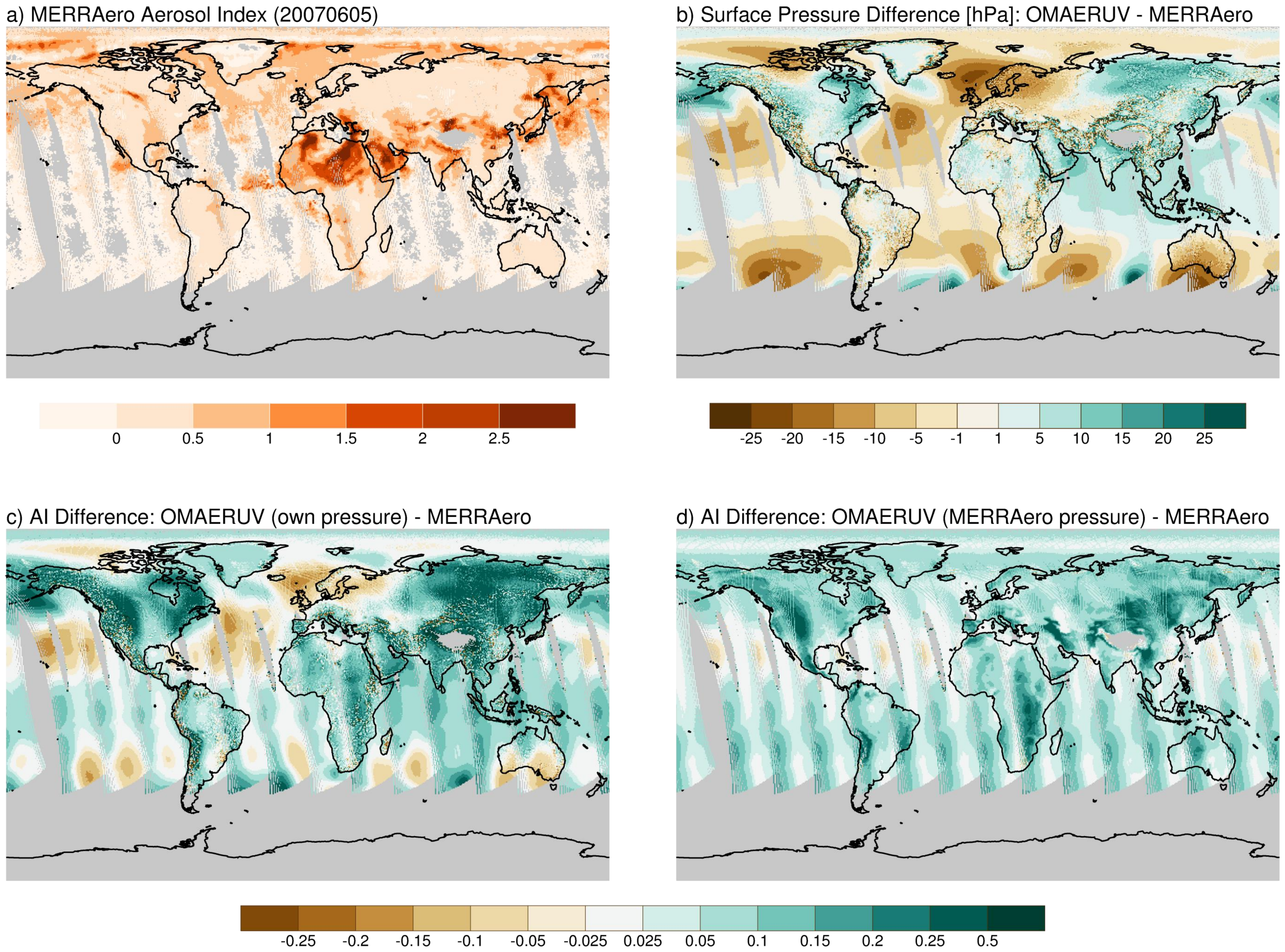


Figure credit: V. Buchard

Buchard et al., *ACP*, 2015; Buchard et al., *J. Clim.*, 2017

Observation Simulation to Interrogate Algorithms

- Use reanalysis aerosol and atmosphere fields to simulate the OMI radiances and aerosol index
- Give the simulated radiances to the OMAERUV algorithms and have them retrieve aerosol index (and possibly other aerosol quantities…)
- Comparison of AI from OMAERUV algorithms to AI from direct simulation shows where assumptions of satellite algorithms come into play
  - Surface pressure assumptions
  - Interpolation of radiative transfer results



a) MERRAero Aerosol Index (20070605)

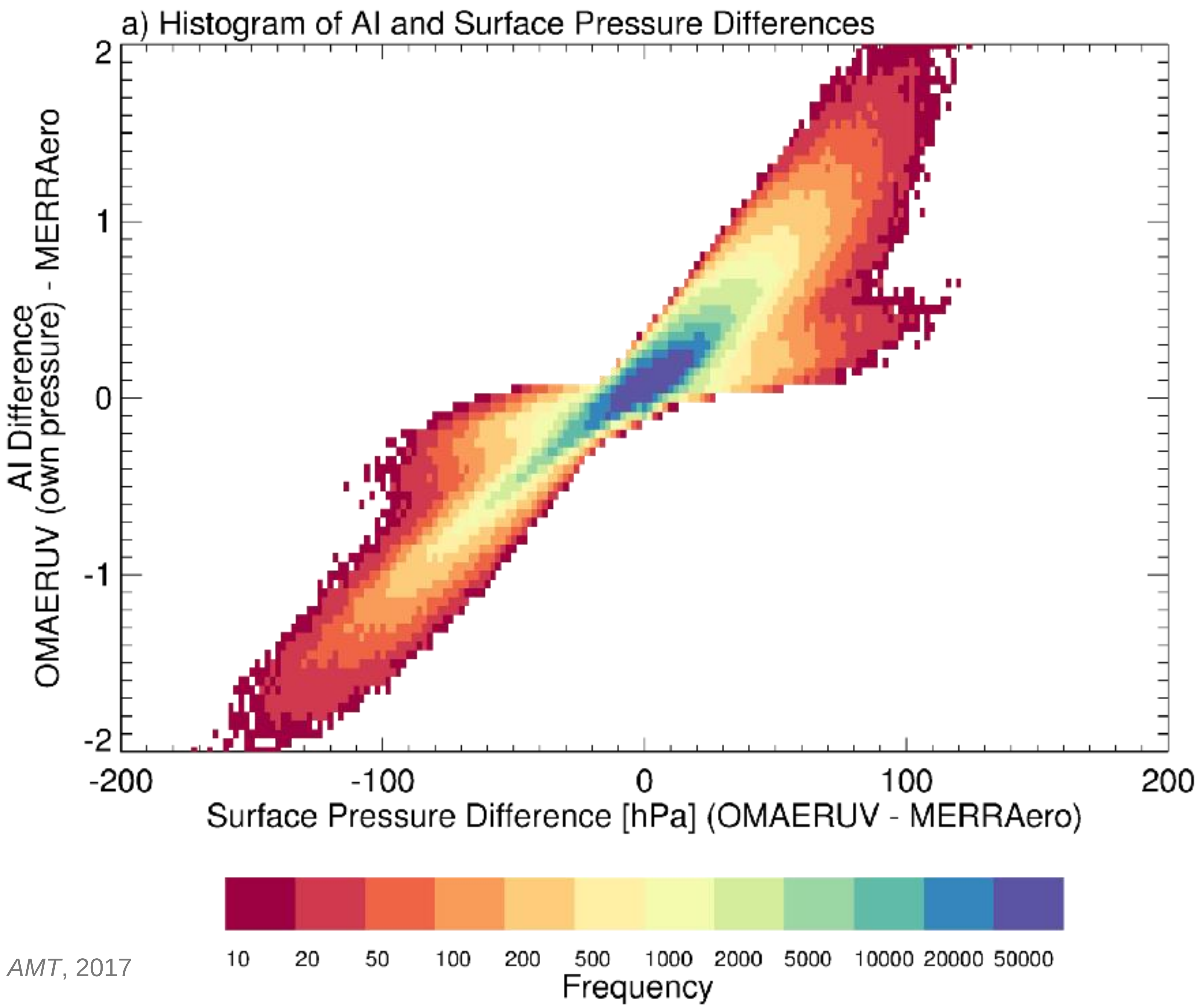
b) Surface Pressure Difference [hPa]: OMAERUV - MERRAero

c) AI Difference: OMAERUV (own pressure) - MERRAero

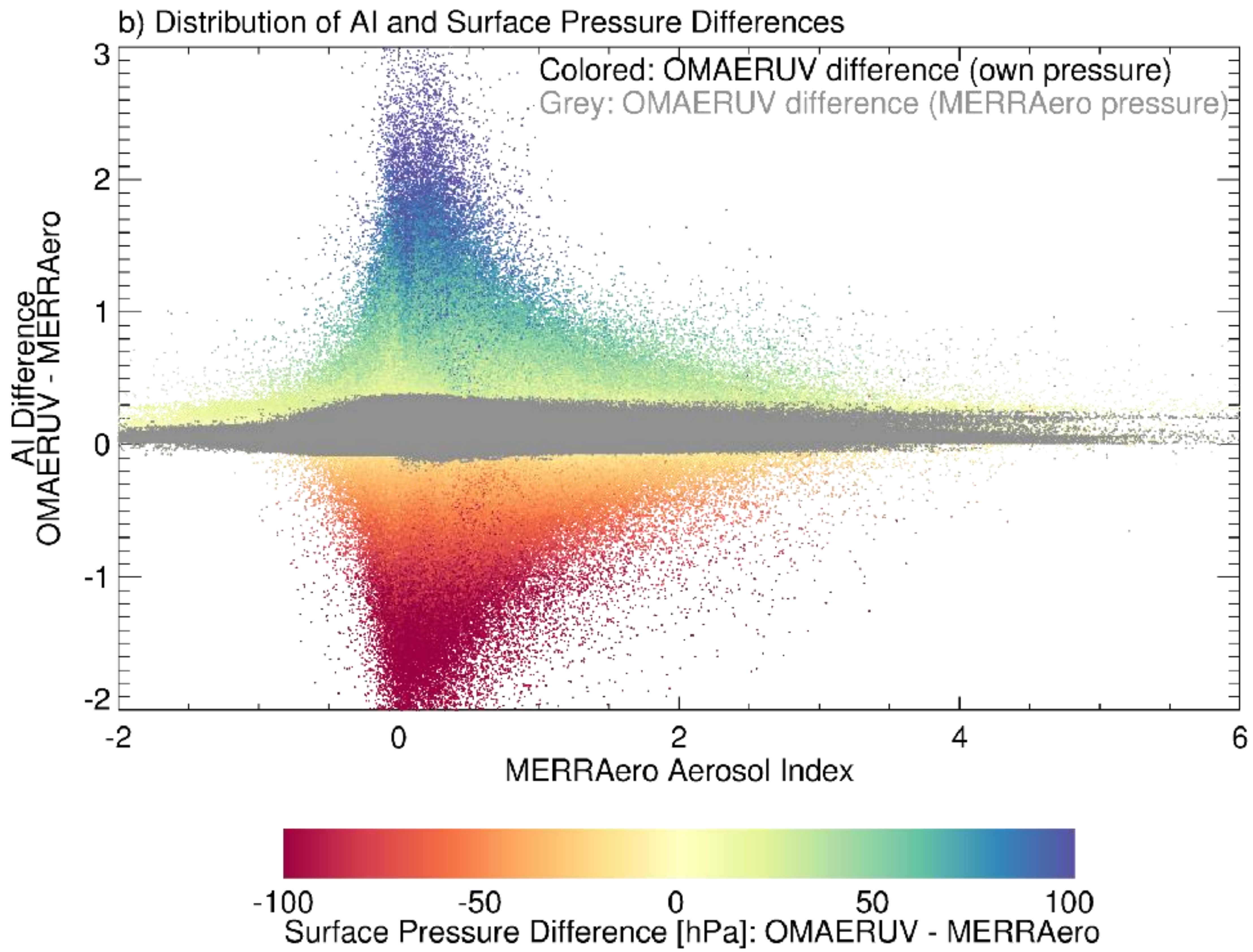
d) AI Difference: OMAERUV (MERRAero pressure) - MERRAero

Colarco et al., *AMT*, 2017

Observation Simulation to Interrogate Algorithms



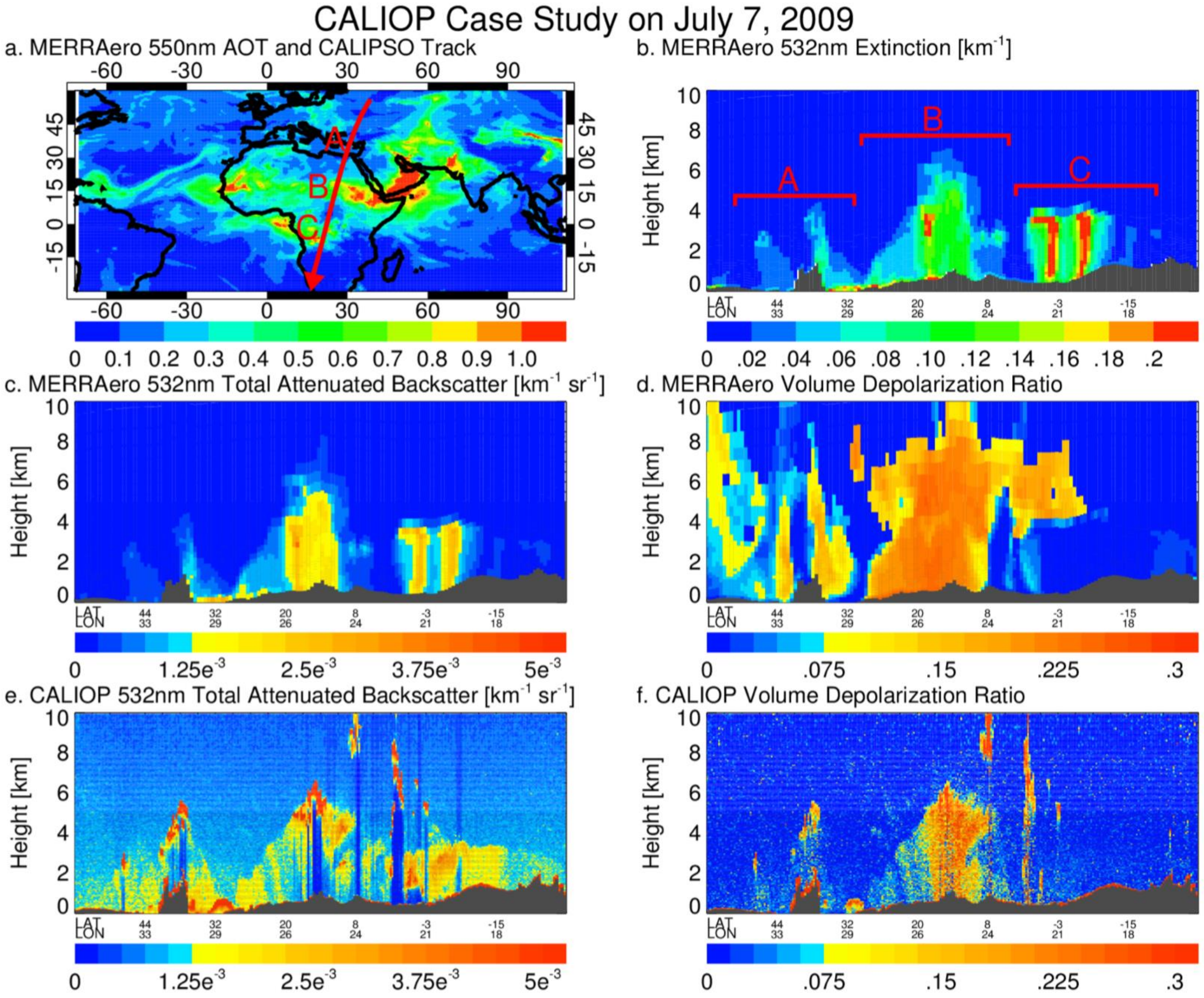
Colarco et al., *AMT*, 2017



- Systematic error introduced to standard OMI aerosol products because of assumption of fixed (time invariant) surface pressure (pressure profile affects molecular scattering profile needed for radiative transfer calculations)
- Forcing OMI algorithms to use consistent pressure profile with actual meteorology corrects this error
- Most of remaining residual is attributable to OMAERUV interpolation of pre-computed radiative transfer calculations (use more nodes in interpolation)

Observation Simulation to Interrogate Algorithms

- From MERRAero aerosol fields we simulate the CALIOP 532 nm attenuated backscatter and depolarization ratio
- Simulation of depolarization ratio is possible through inclusion of non-spherical dust optical properties (other species in development)
- Level 2 CALIOP simulator: by simulating the observables we can feed these as inputs to CALIOP VFM algorithm and evaluate aerosol typing
- Level 3 CALIOP simulator: a complementary typing analysis can be performed by using aerosol speciation from MERRAero



CALIOP Case Study on July 7, 2009

a. MERRAero 550nm AOT and CALIPSO Track

b. MERRAero 532nm Extinction [km^{-1}]

c. MERRAero 532nm Total Attenuated Backscatter [km^{-1} sr^{-1}]

d. MERRAero Volume Depolarization Ratio

e. CALIOP 532nm Total Attenuated Backscatter [km^{-1} sr^{-1}]

f. CALIOP Volume Depolarization Ratio

Nowottnick et al., *AMT*, 2015

Observation Simulation to Interrogate Algorithms

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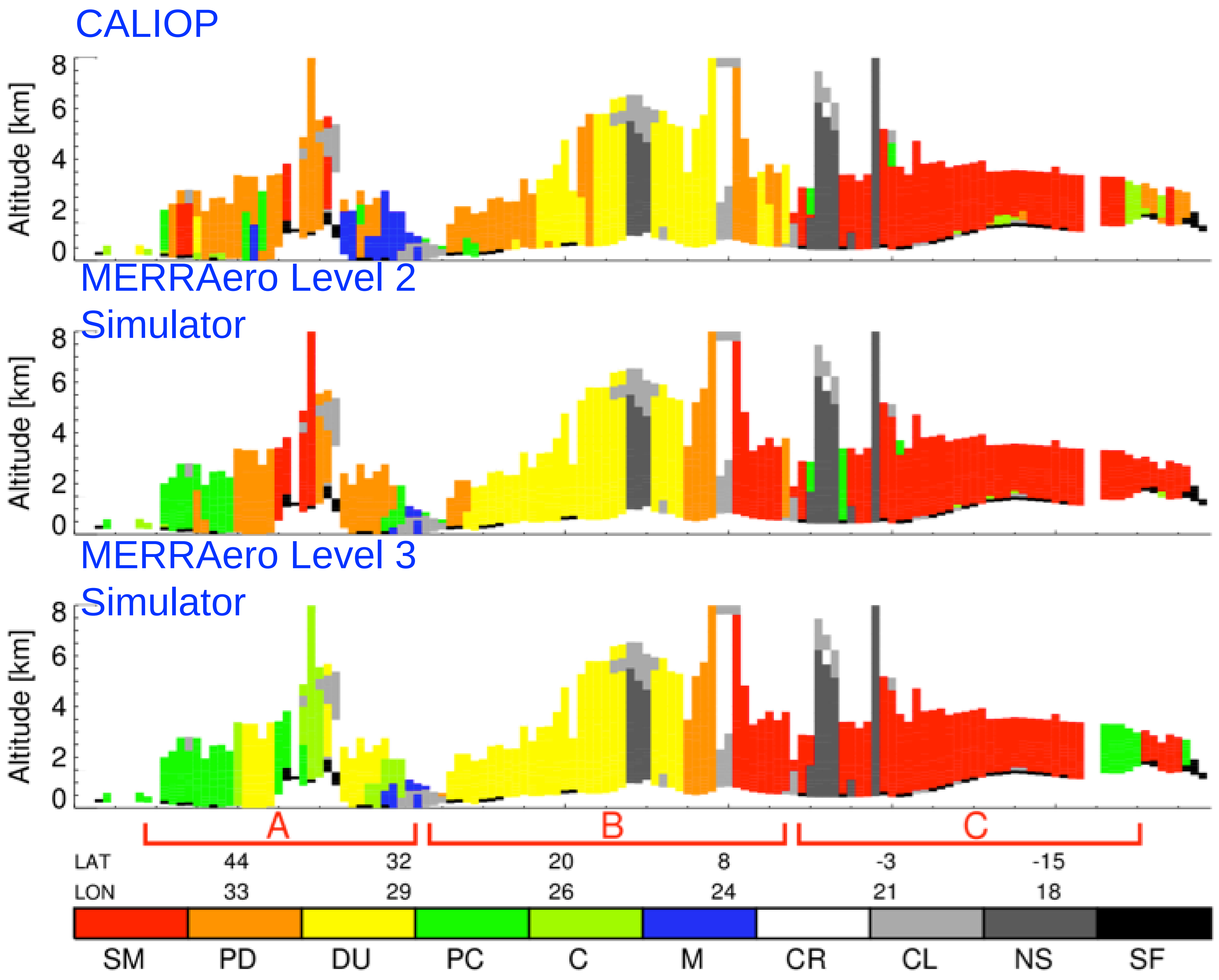

Nowottnick et al., *AMT*, 2015

Summary

- Our remote sensing observational data sets provide enormous quantities of information with which to understand our problems and constrain our models, but clearly some things remain challengingly under constrained
- Even if models can hit the target on total aerosol optical thickness, how they get there can remain a free parameter to “fix” the model’s problems (absorption, mass extinction efficiency, lifetime)
- Some progress on remaining issues can be made by including some component of more sophisticated observation simulation in your analysis
- Objective is *not to replace traditional retrieval products*, but the approach outlined is complementary and helps put those observations in context
- Added bonus: development of these capabilities will help design the next instruments (coverage, channels, …)