Comparison of aerosol optical properties from in-situ surface measurements and model simulations

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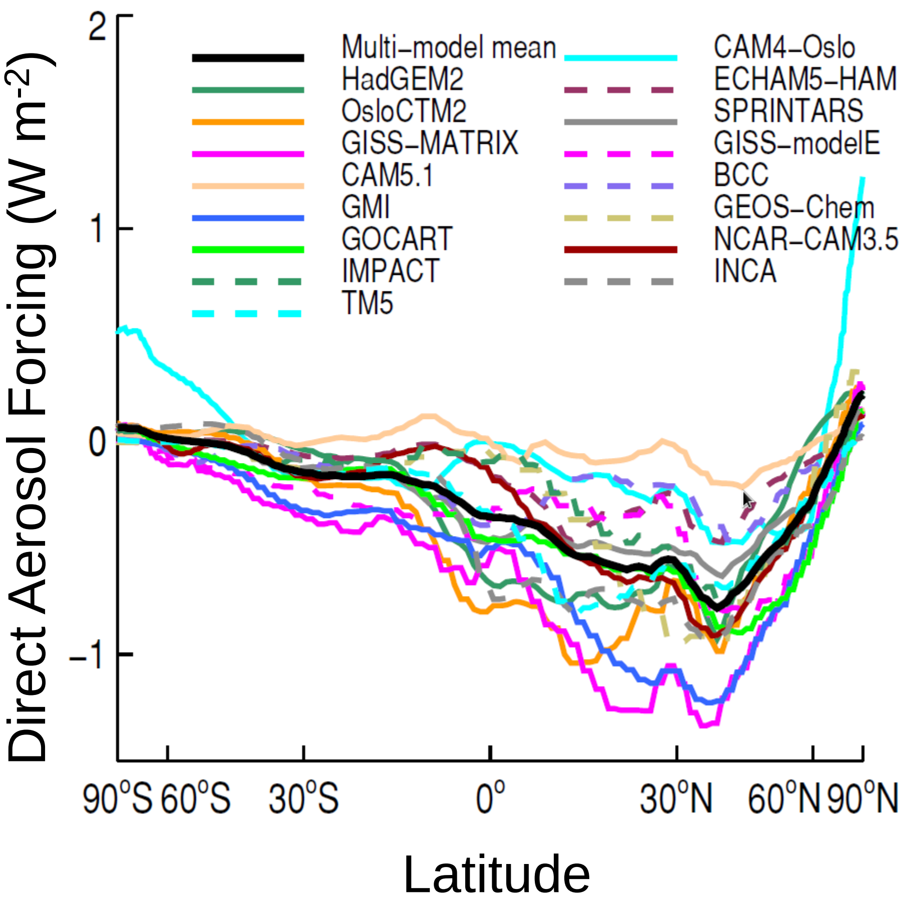
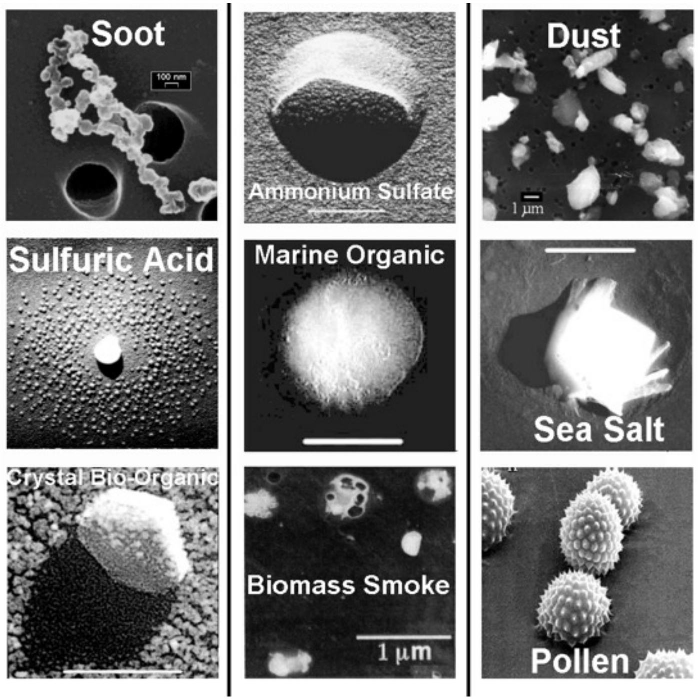
The AeroCom modelling community, and
GAW in-situ measurement community

Why evaluate models?

- Models are used to predict climate forcing
- Models parameterize complex aerosol processes
- Aerosol particles are large source of model uncertainty



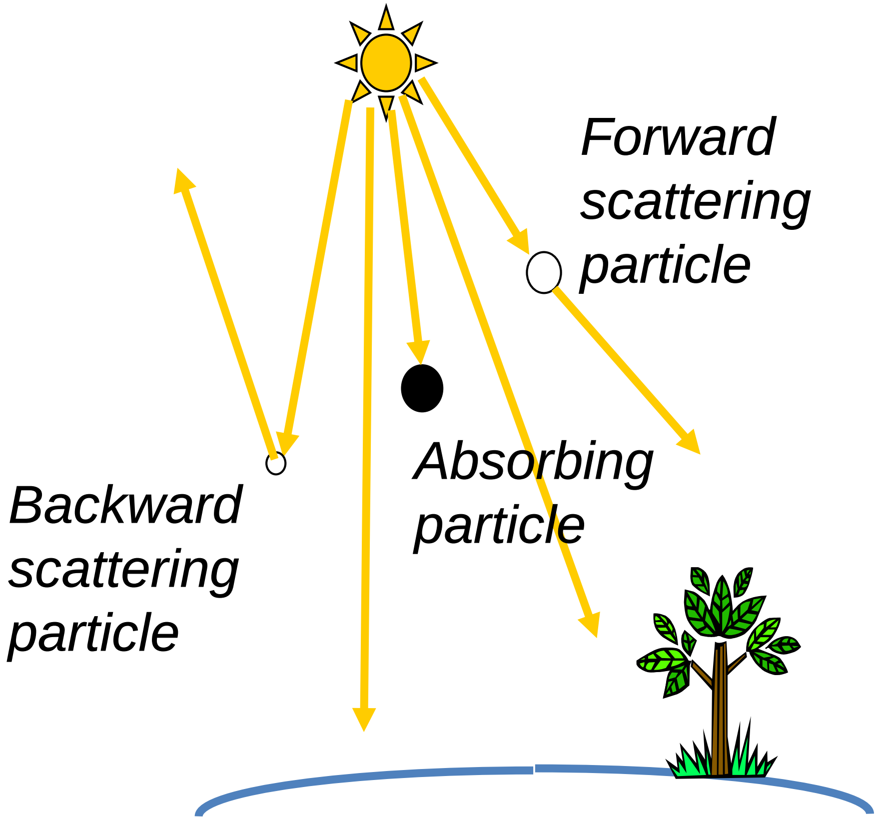
(from Myhre et al., 2013)



Evaluate AeroCom model simulations of aerosol optical properties using long-term, in-situ surface aerosol measurements

Direct Aerosol Effect on Climate

- *Surface cooling:* sunlight is prevented from reaching the Earth's surface
- *Atmospheric warming:* energy is transferred as heat by absorbing particles.



Measured and derived aerosol optical properties

Measured

Aerosol light scattering
Aerosol light absorption

} *f(amount, wavelength, size, composition)*

Derived

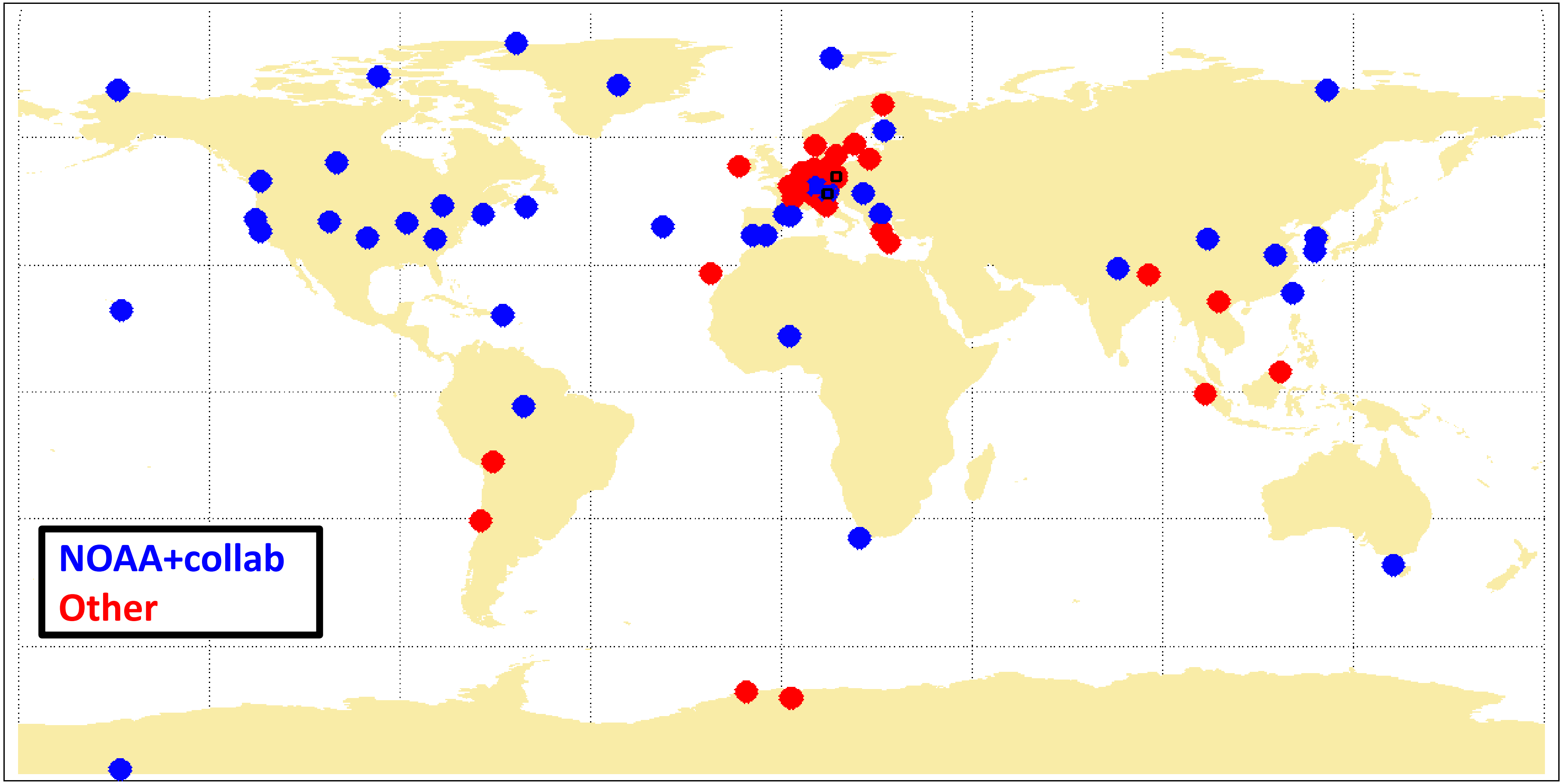
- DON'T depend on amount of particles – dimensionless
- Additional hints about particle 'nature' (chemistry/microphysics)

SAE → Scattering Ångström exponent } *Size*

AAE → Absorption Ångström exponent } *Composition*

SSA → Single scattering albedo } *Composition*

In-situ Measurement Sites



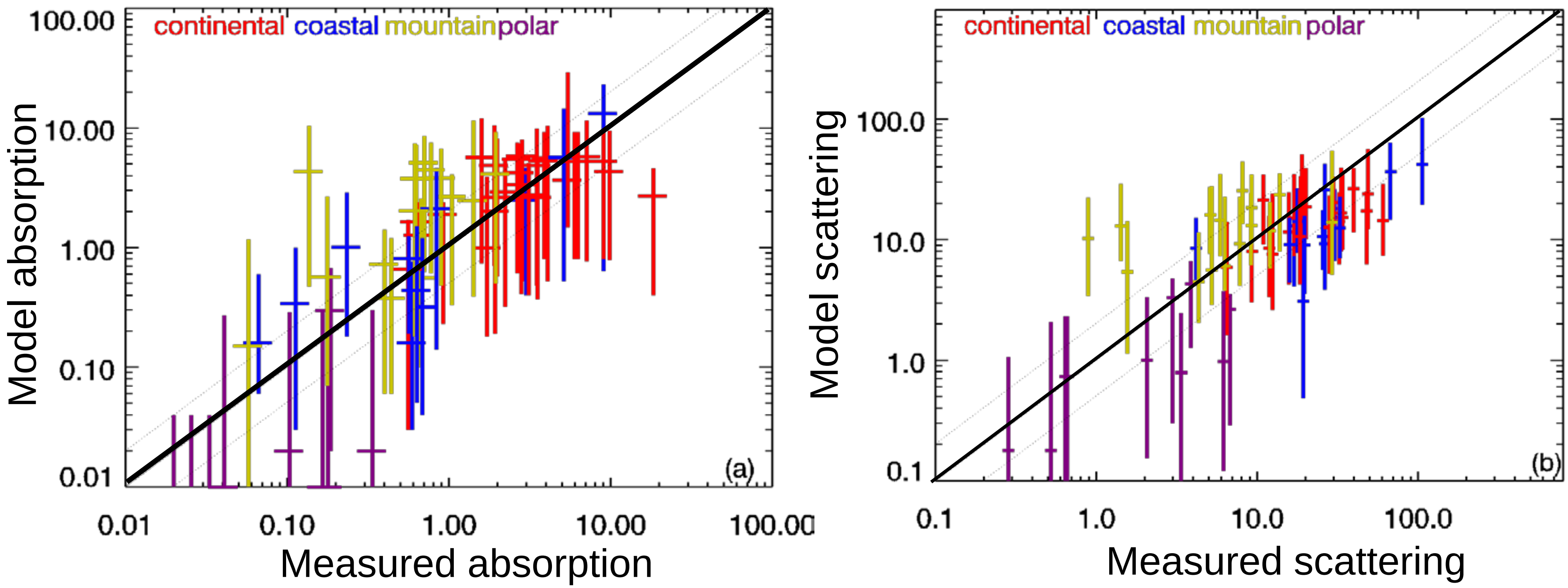
- Sites with aerosol light scattering and/or absorption (~70 locations)
  - Primarily GAW sites
  - Outside of Europe, NOAA's Federated Aerosol Network (NFAN) dominates
- Gaps in S. America, Africa, Middle East, Russia, Asia

Models Used in this Analysis

Model name	Grid size	Output Yr
TM5	3.0° x 2.0°	2010
GEOS-Chem	2.4° x 2.0°	2010
CAM5	2.4° x 1.9°	2010
ECHAM6-SALSA	1.8° x 1.9°	2010
GEOS5-Globase	1.25° x 1°	2010
GEOS5-MERRAero	0.6° x 0.5°	2010
OsloCAM5	1° x 1°	2010
EMEP	0.5° x 0.5°	2010
OsloCTM2	2.8° x 2.8°	2008
GOCART	2.5° x 2.0°	2006*
MPIHAM	1.8° x 0.9°	2006*
SPRINTARS	1.1° x 1.1°	2006*

Models provide simulated dry optical properties at the surface at several wavelengths.
Model groups are all participants in 'AeroCom' project (http://aerocom.met.no/)

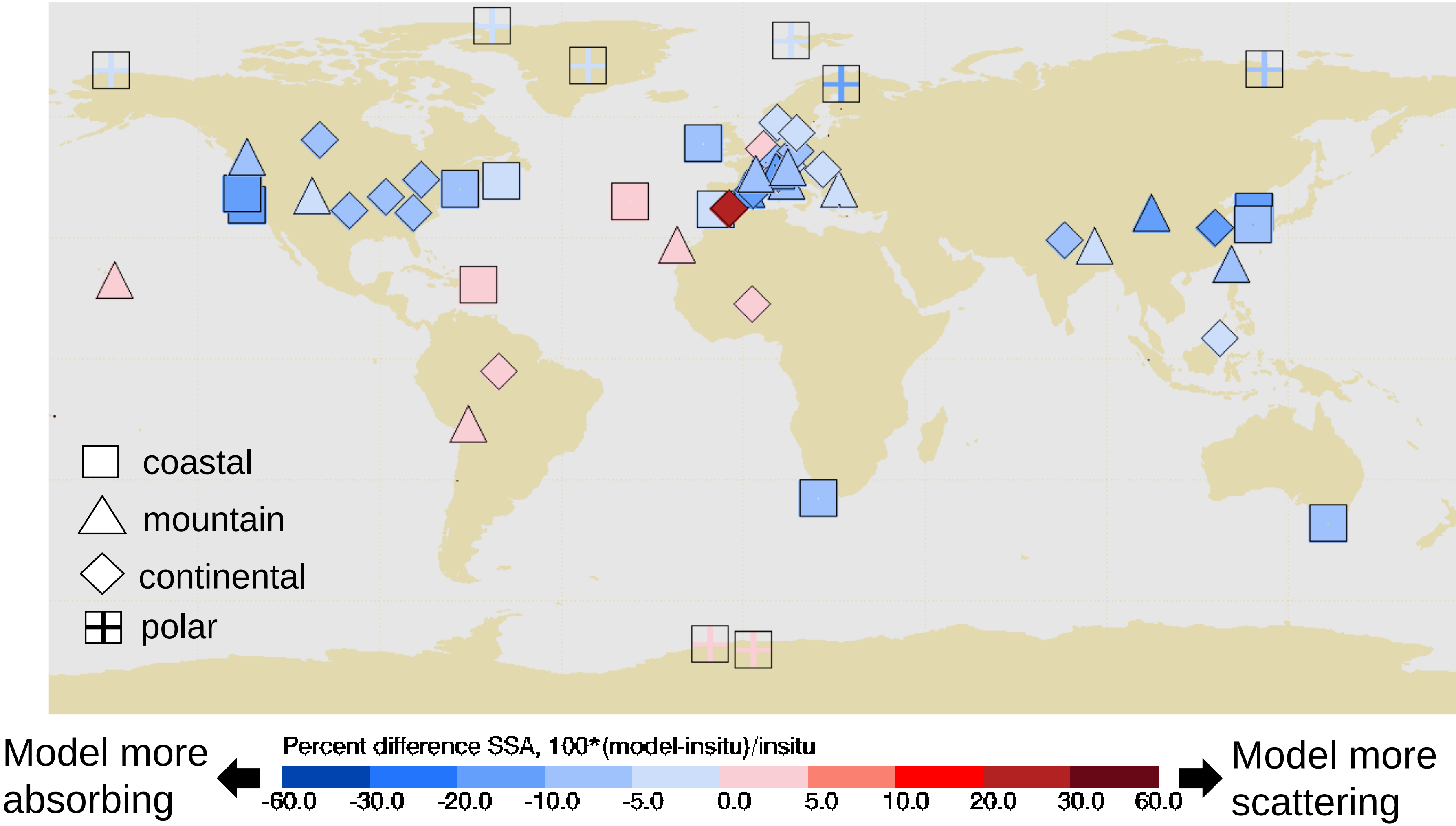
Model Evaluation – Absorption and Scattering



- Models tend to over-predict absorption and scattering at mountain sites
- Modeled absorption tends to be over-predicted
- Scattering tends to be under-predicted
- More model diversity in absorption than scattering

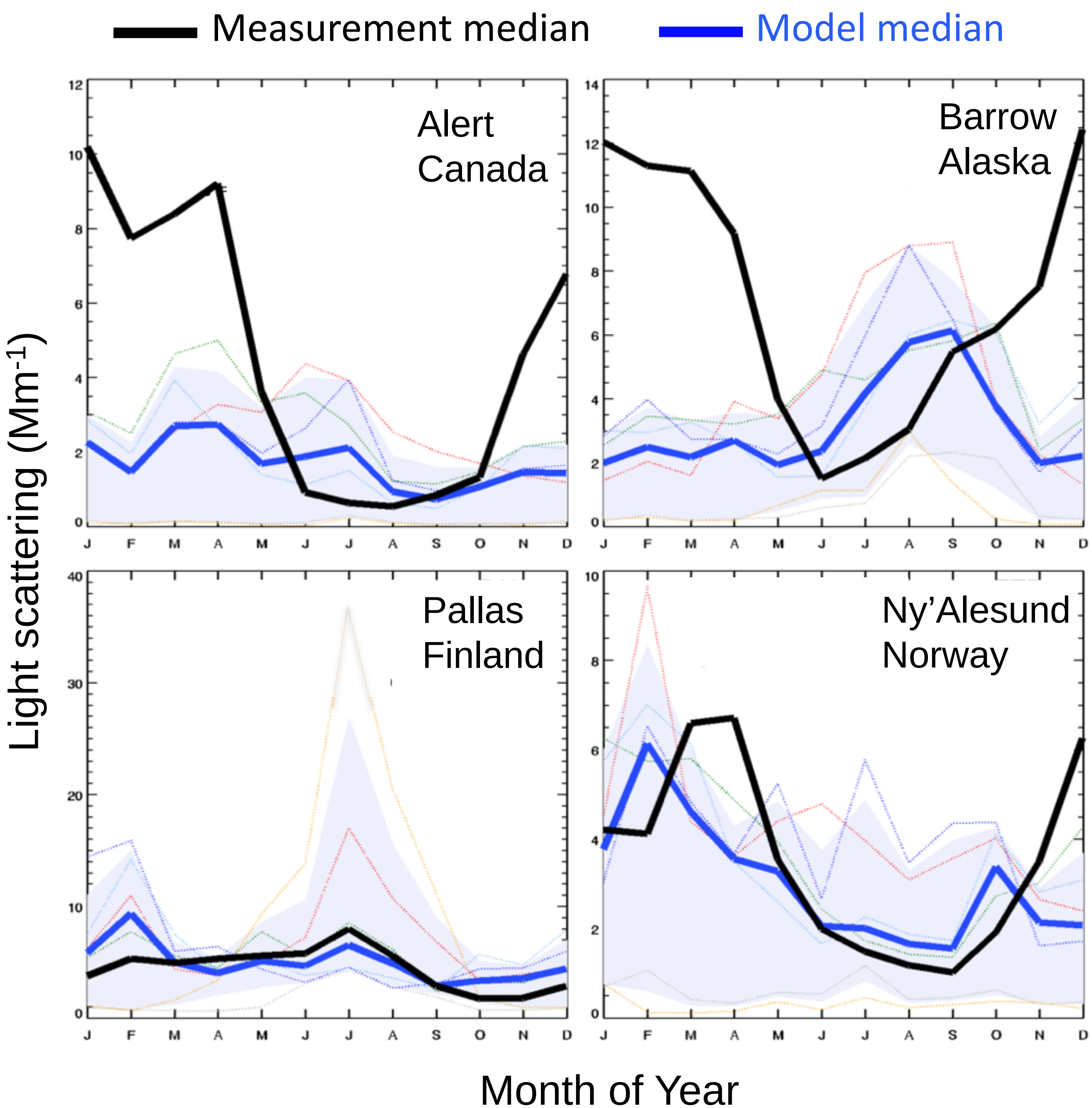
Vertical bar shows model diversity, horizontal bar is measurement uncertainty based on Sherman et al. (2015)

Model Evaluation – Single scattering albedo



- Models tend to predict more absorbing aerosol than is observed.
- Model SSA best at high latitudes

Model Evaluation – Arctic Sites



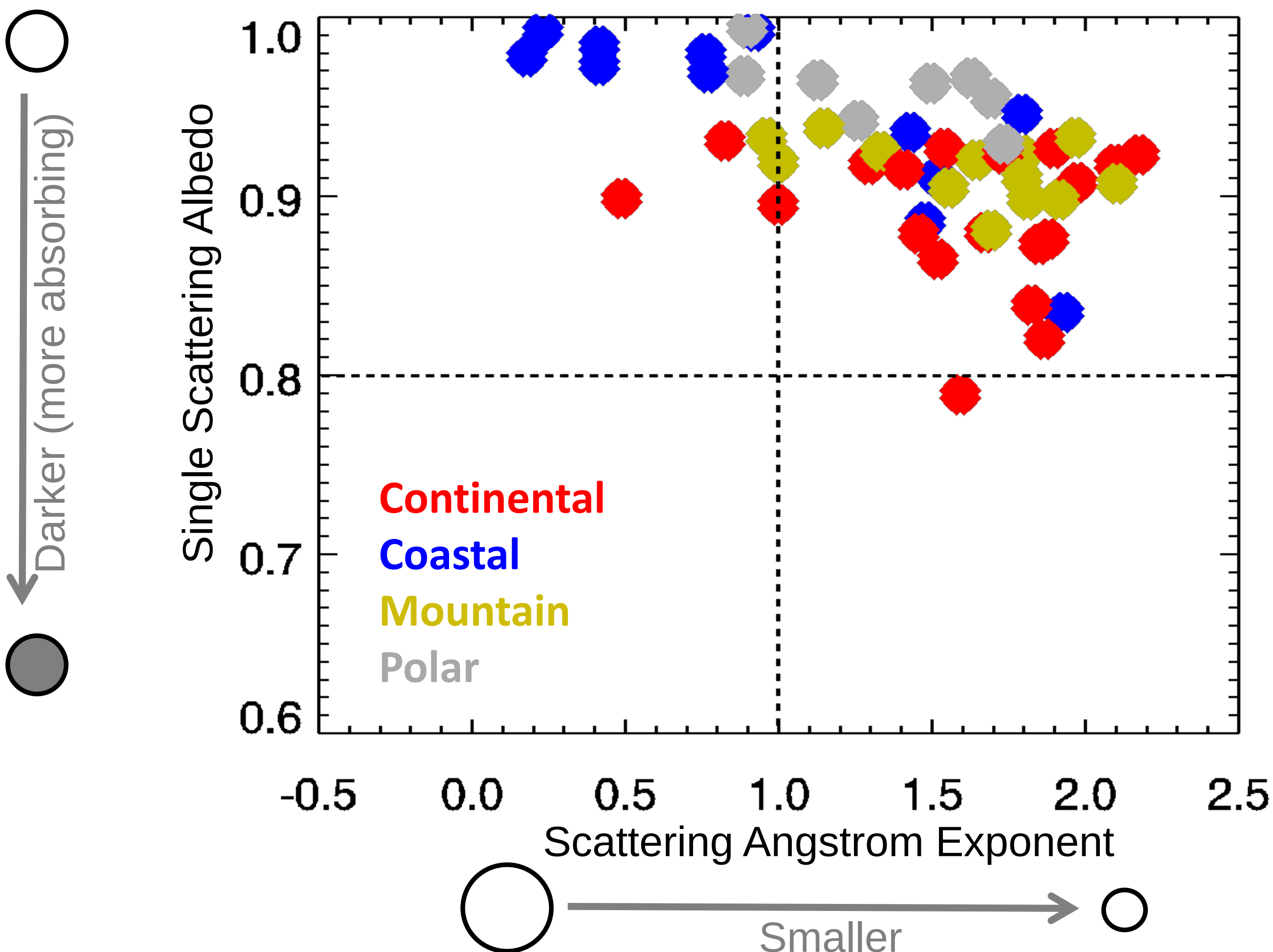
Model/measurement discrepancies can suggest model processes to focus on.

What causes the model peak in summer at Barrow?
→Overestimating forest fire emissions?
→Underestimating removal processes such as wet deposition?

Why is model/meas. agreement better in the European Arctic than the North American Arctic?

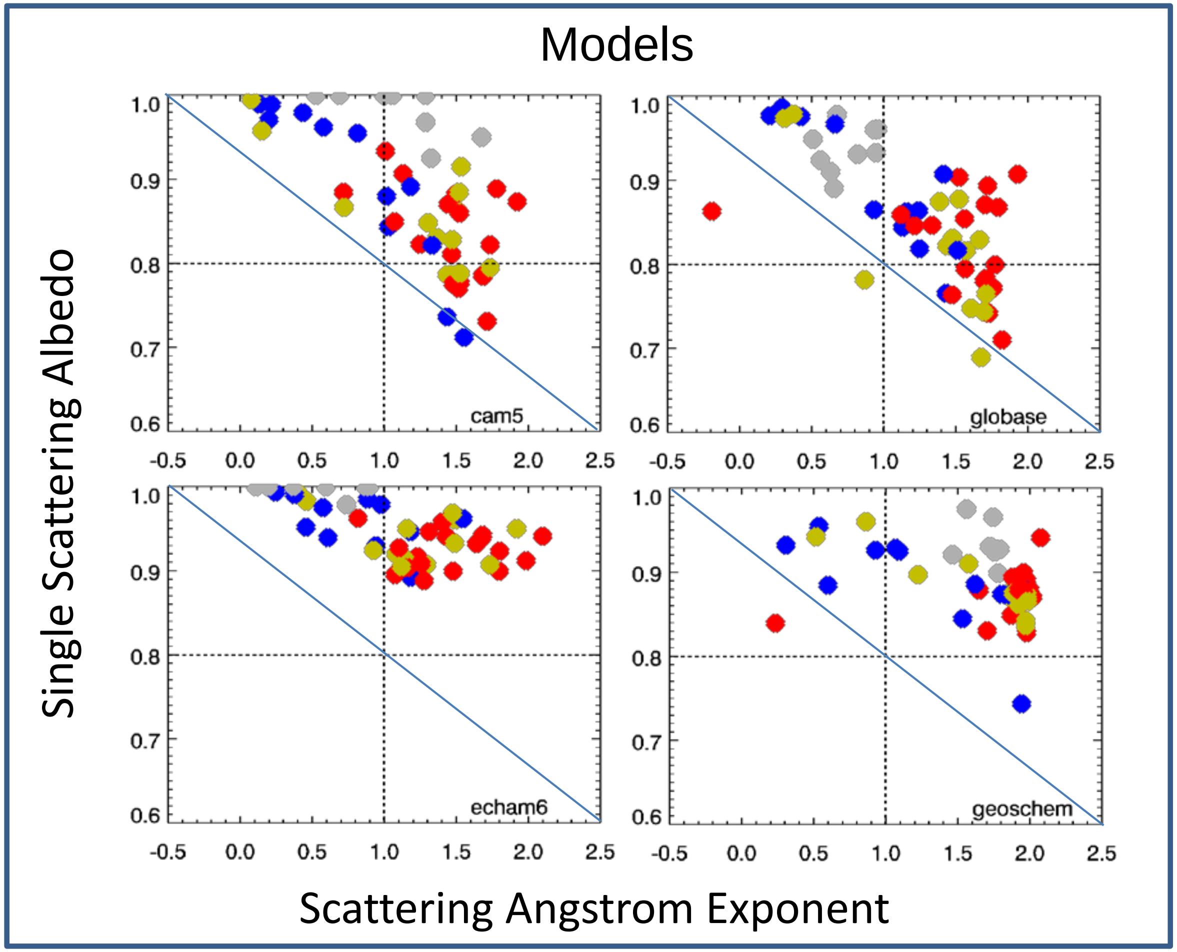
Model evaluation: Co-variance of aerosol properties

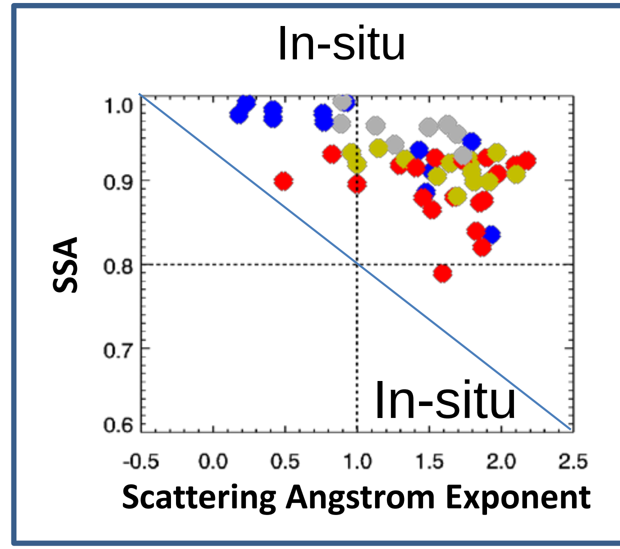
- Co-variance can provide info about air mass types and atmospheric processes
- Useful metric for constraining parameter space in models



Each point represents annual median for 1 site

Model Evaluation – Aerosol property co-variance





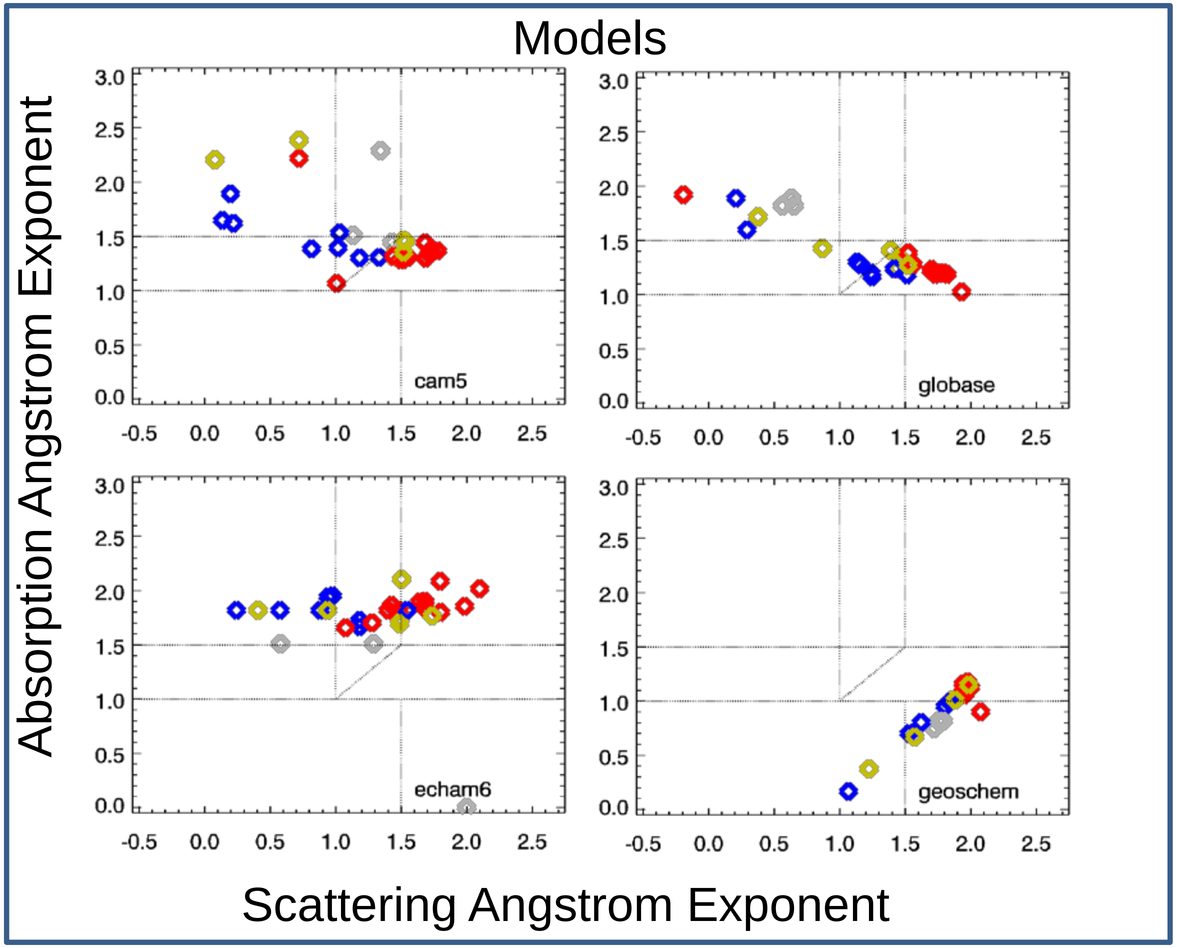
Continental
Coastal
Mountain
Polar

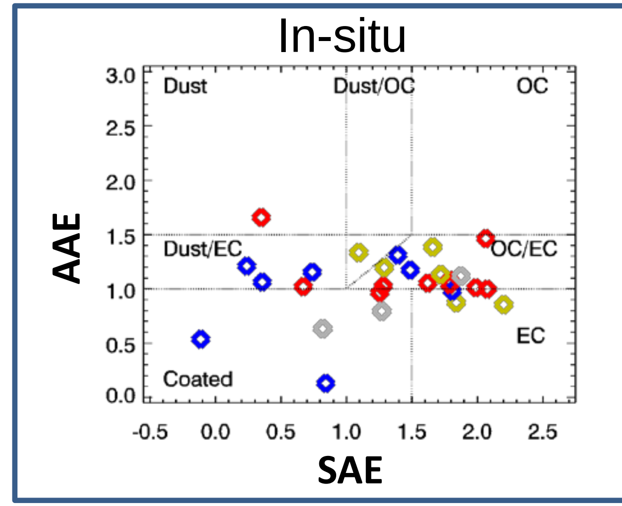
Similar model/measurement relationships between SSA (chem) and SAE (size)

→general pattern of decreasing SSA with increasing SAE

→models tend to simulate darker, larger particles than are measured

Model Evaluation – Aerosol property co-variance





Each point

NFAN makes up ~90% of sites submitting spectral aerosol absorption to WDCA.

Many different relationships between absorption and scattering Angstrom exponent

→differences amongst models

→differences between models and in-situ

Conclusions

Long-term, high quality surface measurements are being used to evaluate global model simulations of aerosol optical properties

→General consistency between measurements and models for annual loading

**Models simulate more aerosol absorption than observed

**Models simulate less aerosol scattering than observed

→Model ability to simulate observed aerosol seasonality varies by site

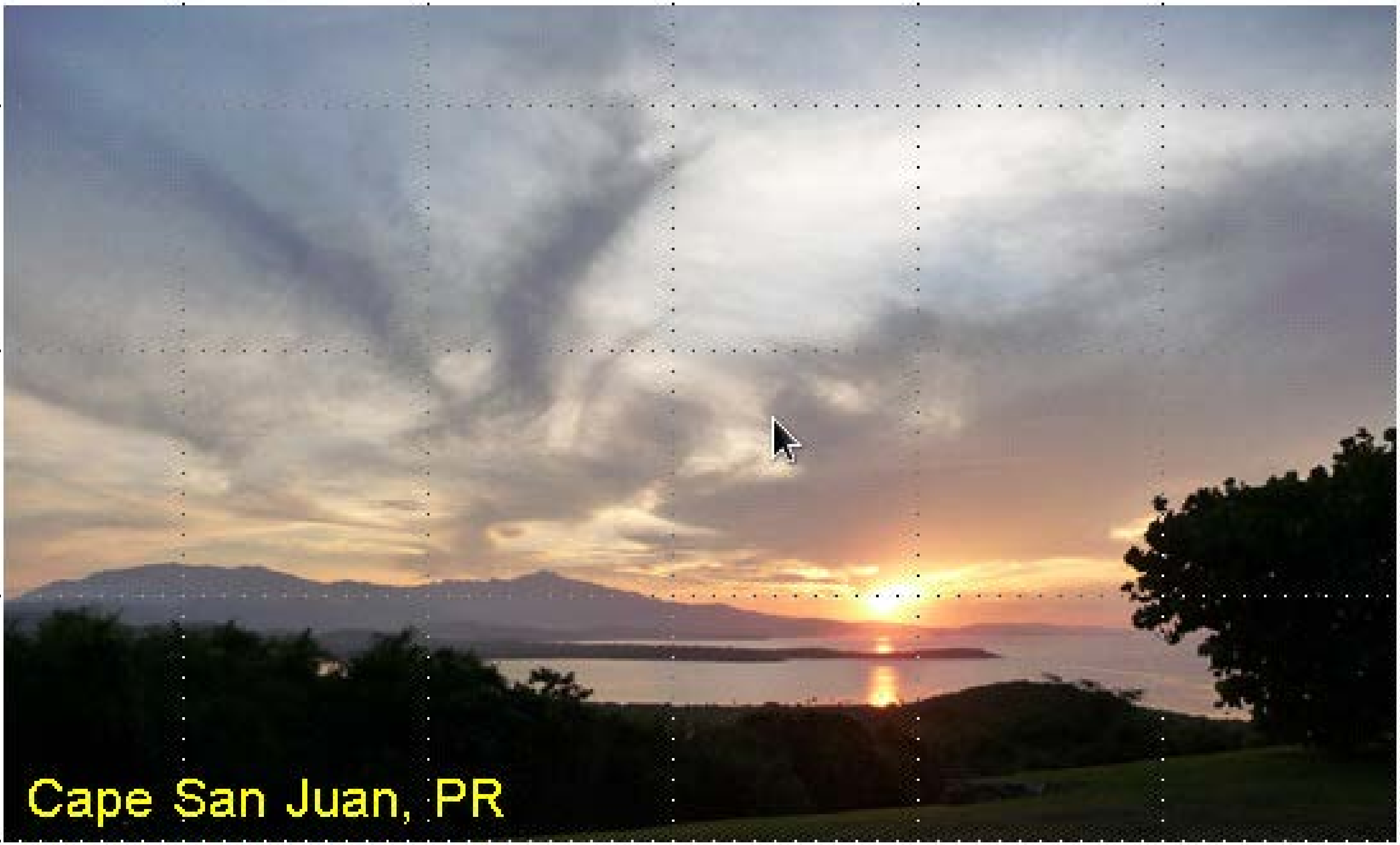
→Models have issues simulating observed co-variance of aerosol properties

Future work

This is part of a three-tiered project

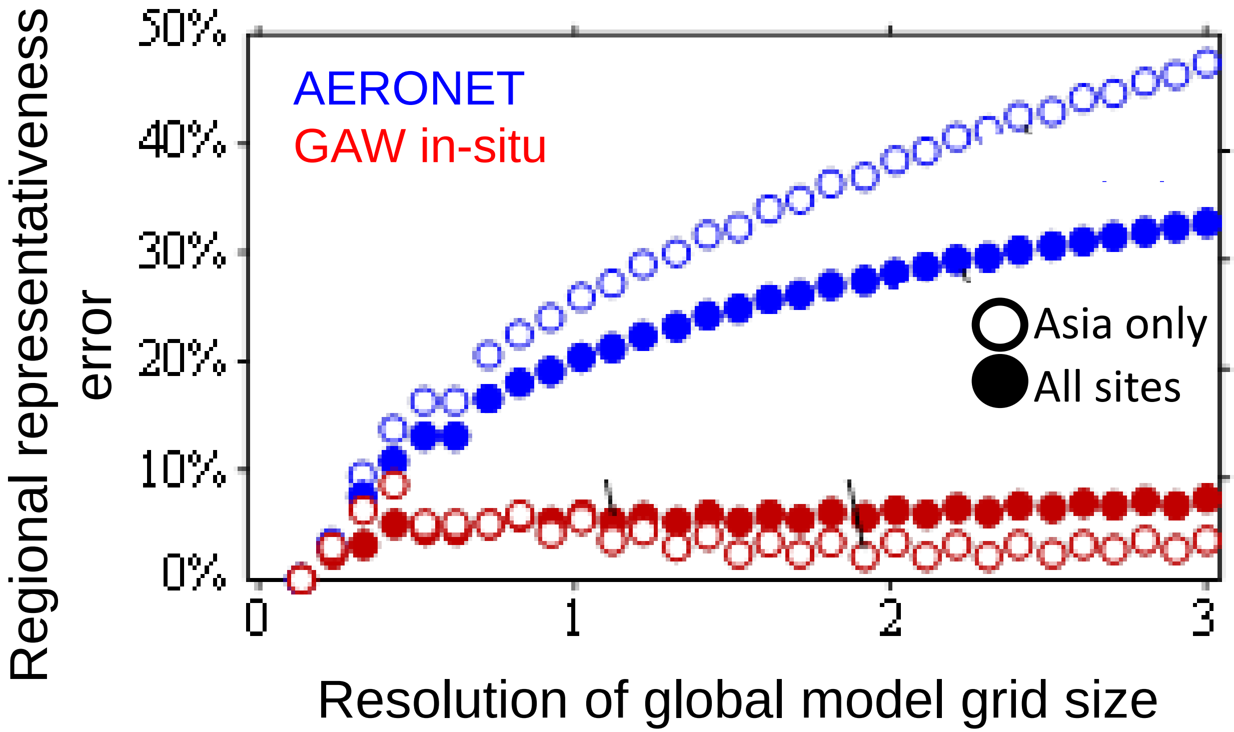
I. Dry aerosol evaluation
II. Long-term trends evaluation
III. Aerosol hygroscopicity evaluation

THANK YOU!



NFAN Side note – Air mass representativeness

The NOAA network (subset of GAW) is quite good at measuring regionally representative air masses on global model scales.



From Wang et al, accepted, 2018

Global models are frequently evaluated against remote sensing measurements such as AERONET.

Note: ~Half of the GAW sites used in this study are NFAN sites

Introduction – Aerosol Group

Objective:

- Characterize the means, variabilities, and trends of climate-forcing properties of atmospheric aerosols
- To understand the factors that control these properties.

Our approach:

→Standardized suite of measurements and protocols

→Standardized software

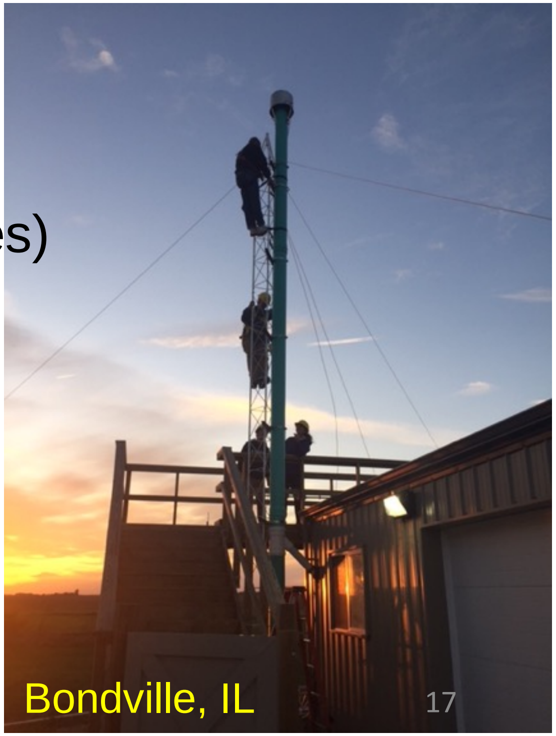
→Long-term permanent sites

→Globally distributed network (pristine and polluted sites)

→Collaborate collaborate collaborate!

Applications:

- Context for field campaigns and aerosol 'events'
- Ground truth for remote sensing (e.g., satellites)
- Evaluate/constrain global models

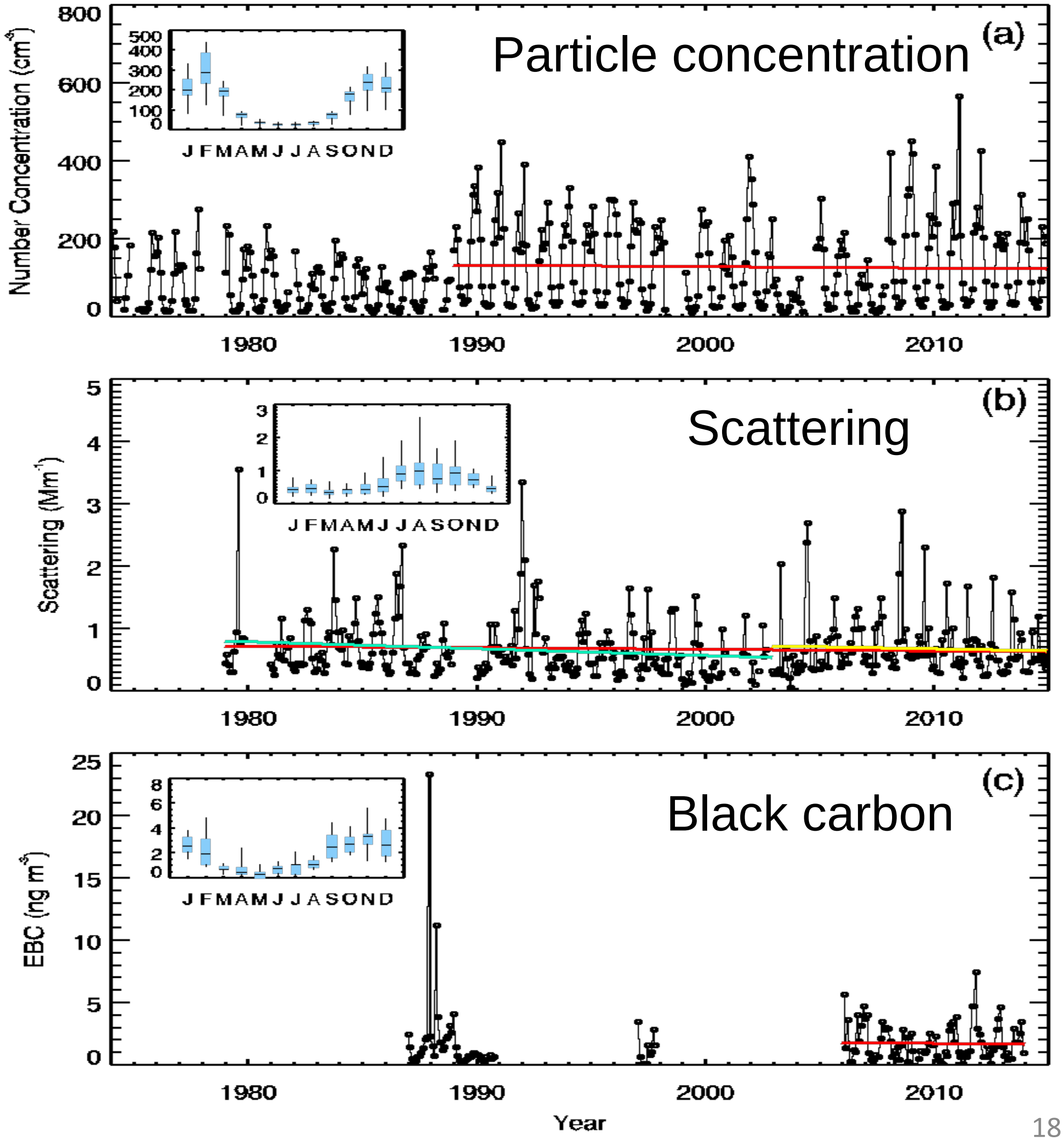


Climatology and Trends – South Pole: 1974 - 2014

- No statistically significant trends

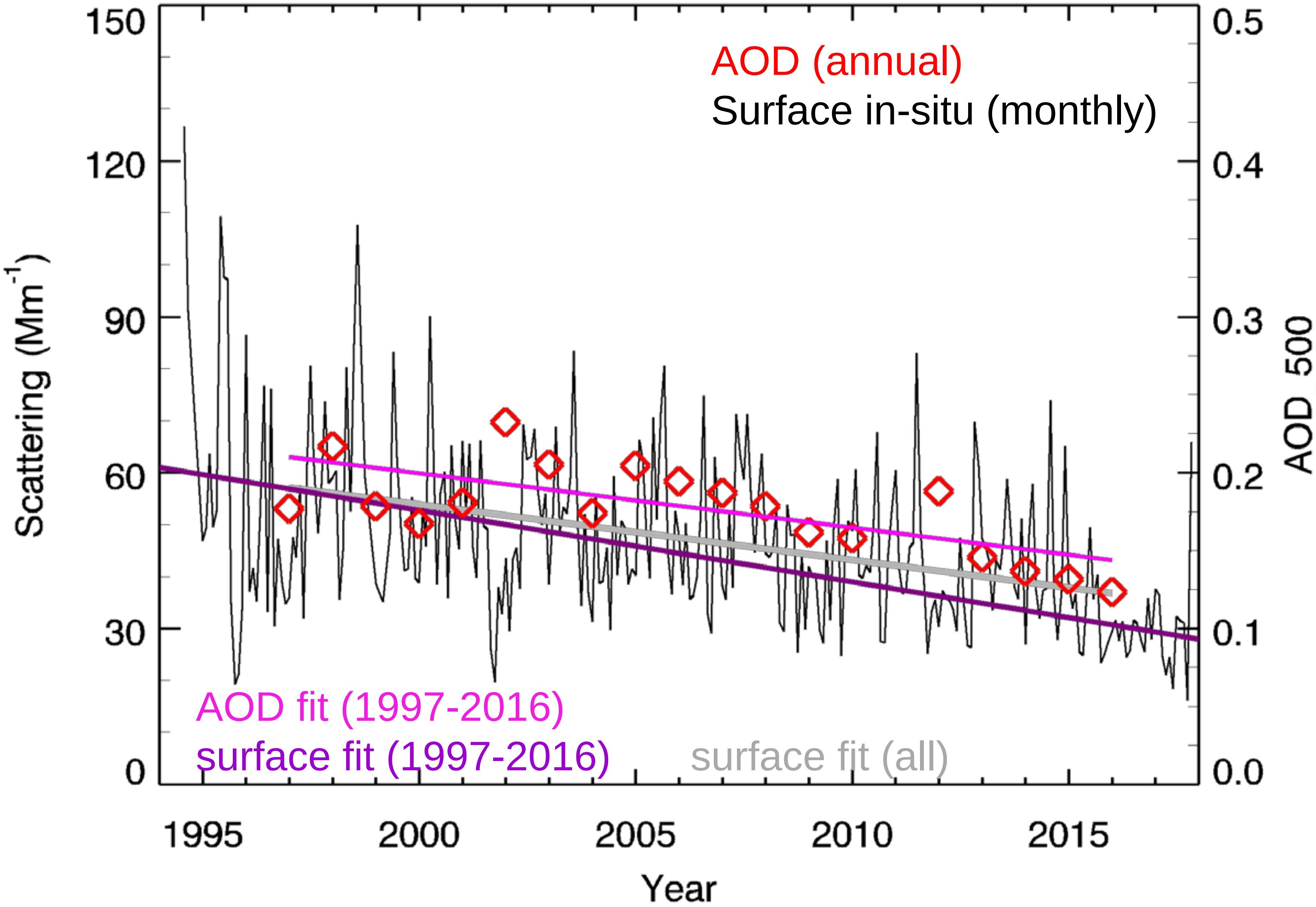
- Annual cycle in the different aerosol properties

- Different parameters have different annual cycles → different sources/types of particles??



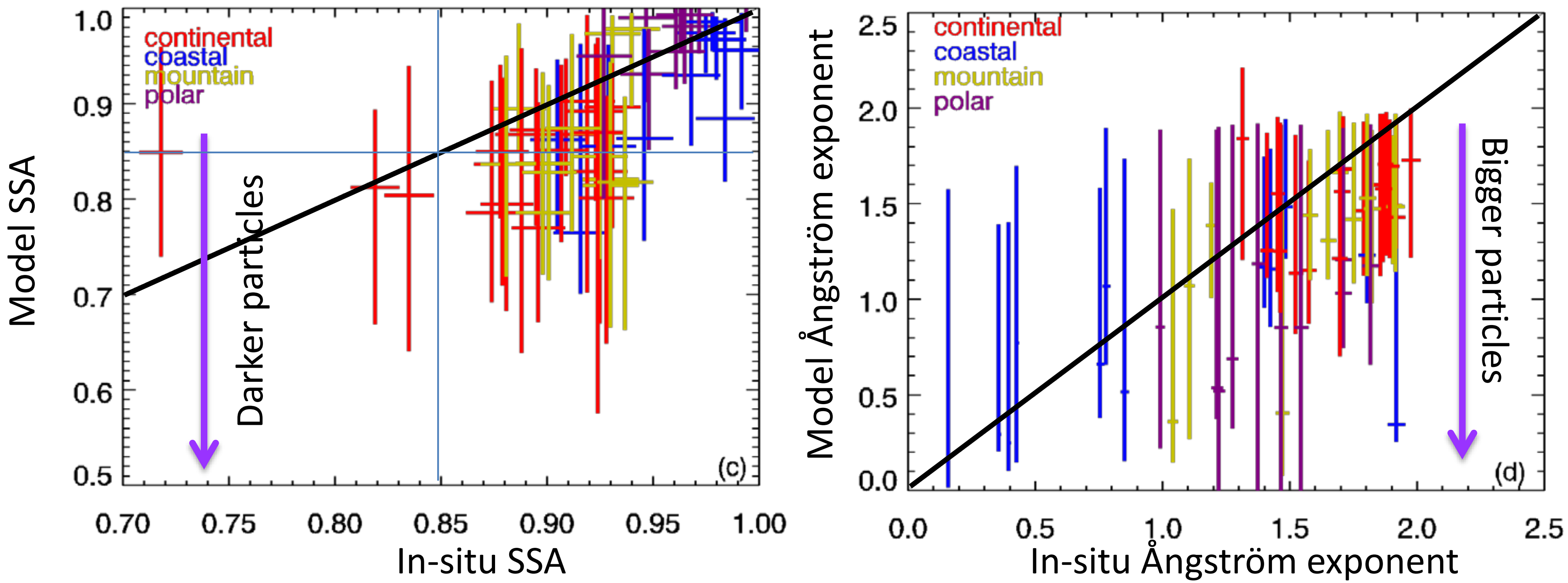
From Sheridan et al., 2015

Climatology and Trends – Bondville 1994-2017



Bondville aerosol data exhibits similar decreasing trends in surface in-situ scattering and aerosol optical depth (from G-RAD)

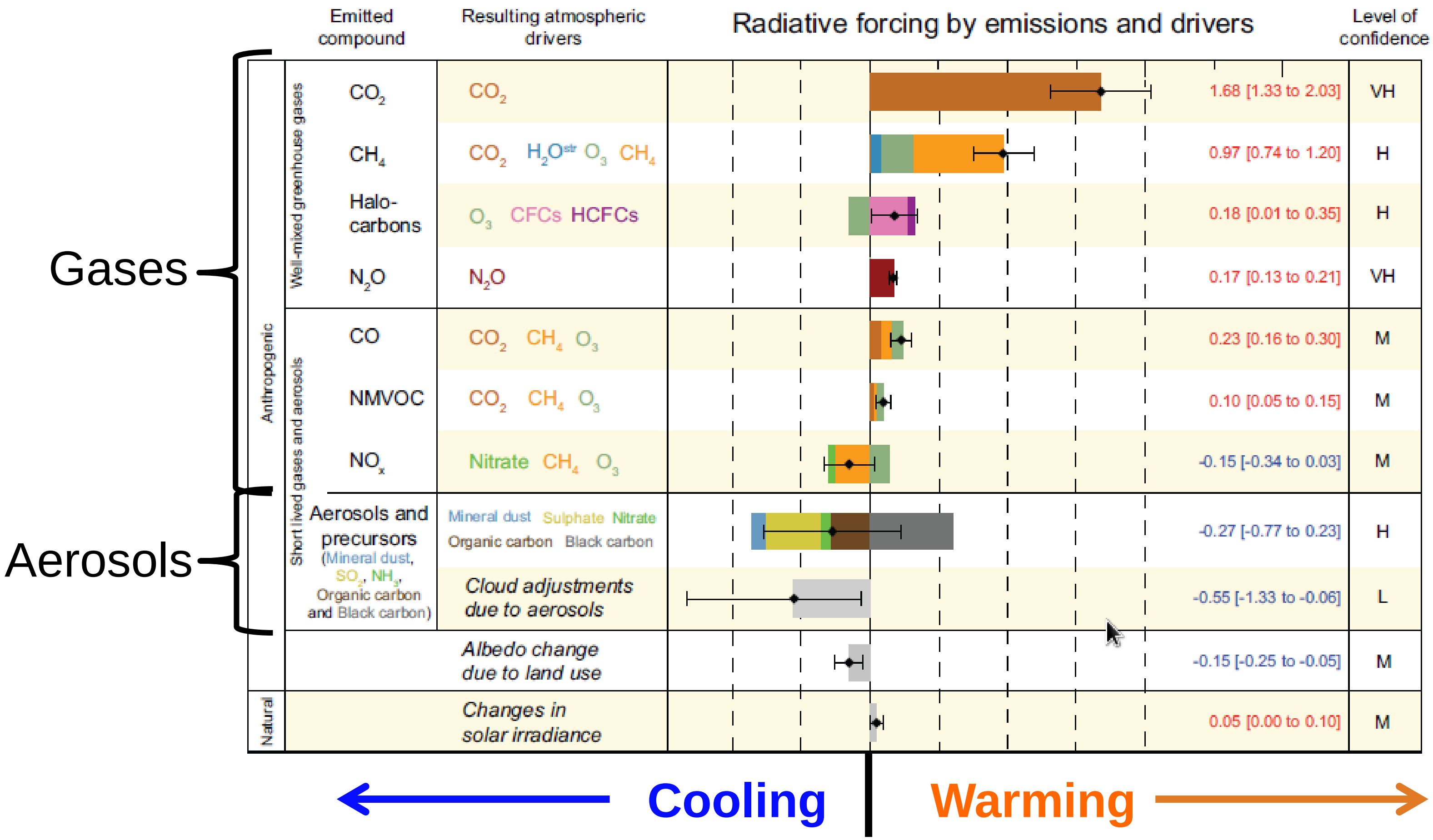
Model Evaluation – SSA and Ångström exponent



- Model SSA tends to be lower (more absorbing) than in-situ SSA → partly driven by model under-prediction of scattering
- Modelled Ångström exponents suggest larger particles than observed by in-situ measurements

Vertical bar shows model diversity, horizontal bar is measurement uncertainty based on Sherman et al. (2015)

Factors influencing climate change

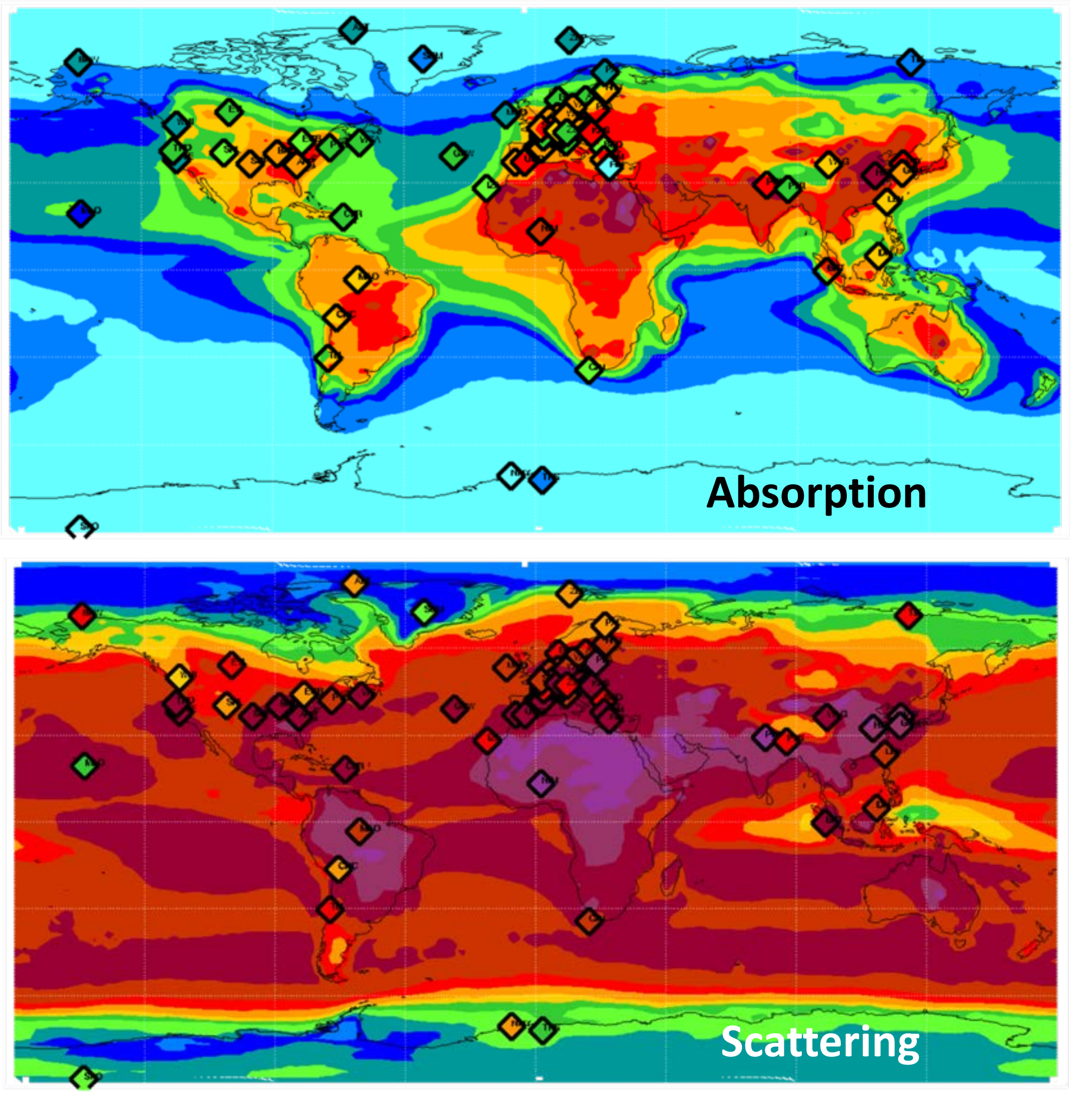


GMD
GHG
O3
Rad
Aero

From IPCC, 2013

Global averages based on models, **measurements** and theory.
Aerosols ‘contribute the largest uncertainty to the total radiative forcing estimate’.

Model comparisons: **Big Picture**



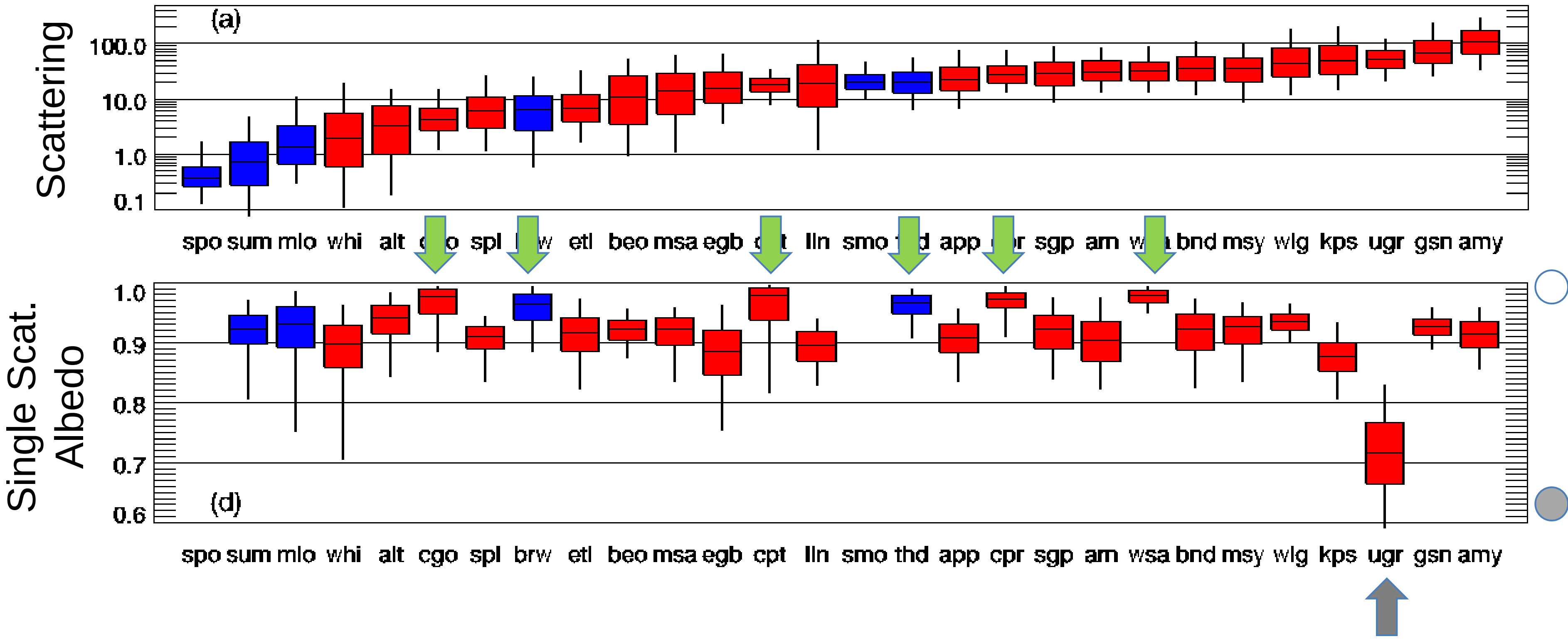
Diamonds represent in-situ surface measurements

- General pattern of absorption and scattering similar for models and in-situ measurements

CAM5 output for AEROCOM P3 INSITU project

Annual climatology from NOAA Collaborative Network

- Wide range in aerosol amount
- No relationship between amount and "nature" of aerosol



Granada is impacted by agricultural burning and home heating – low SSA
Clean marine sites have highest SSA
SSA tends to be >0.85

In prep for BAMS

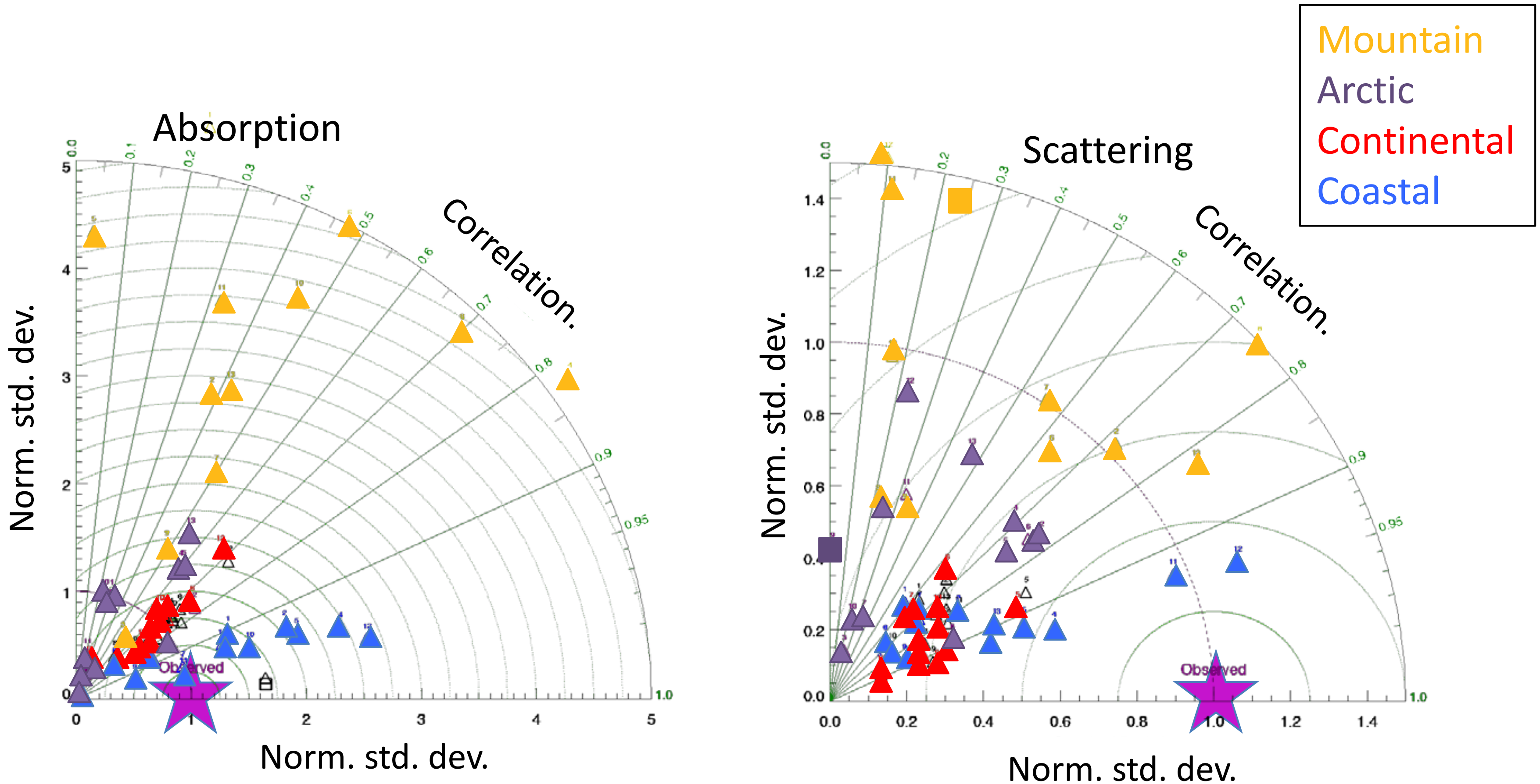
Model Patterns: **Taylor diagram analysis**

Taylor diagrams provide a visual statistical summary of how well patterns match each other in terms of:

(a) correlation

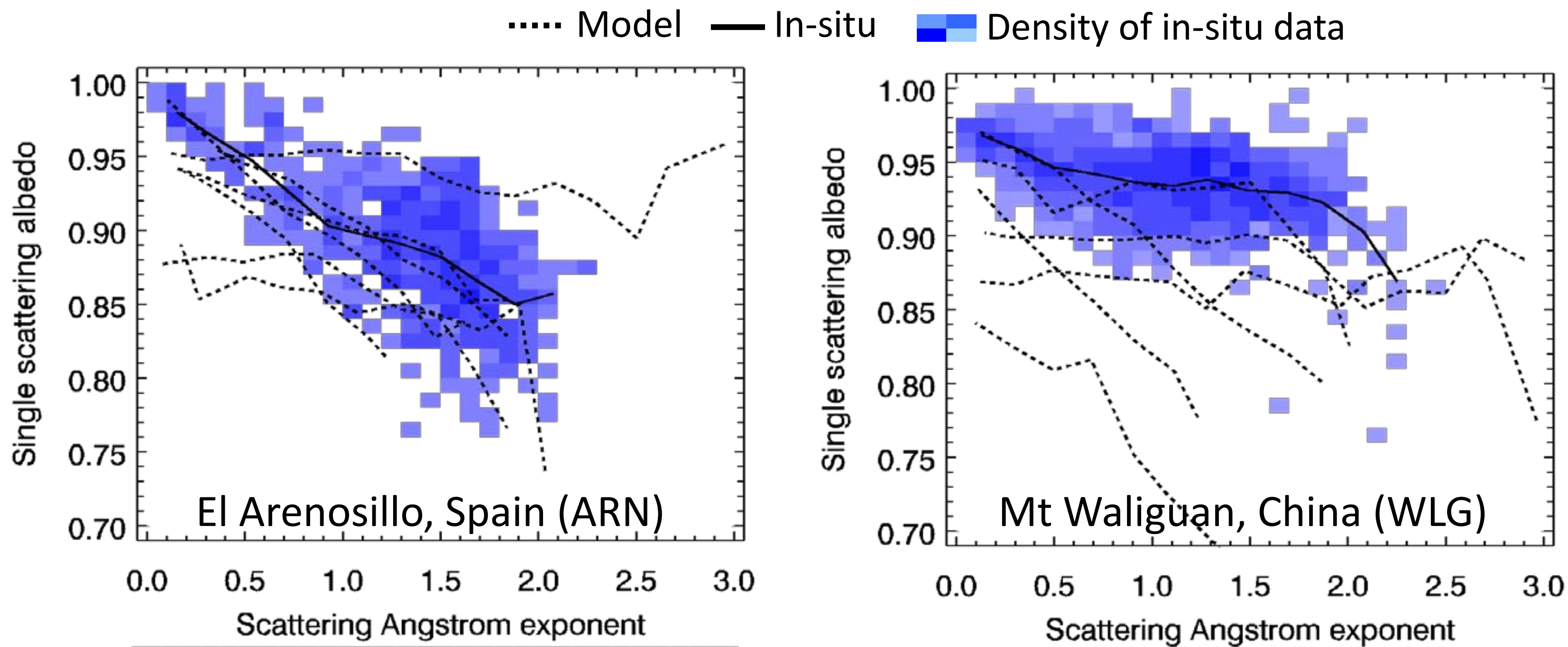
(b) root-mean-square difference

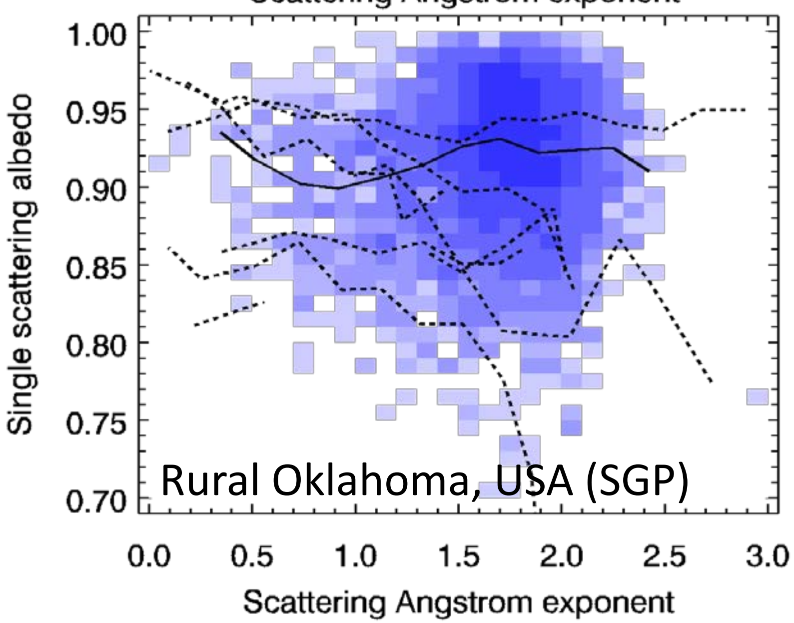
(c) the ratio of their variances (standard deviation)



- Taylor diagrams suggest that models are most successful at simulating coastal site observations.
- Models appear to be better at simulating absorption in spring and summer than in fall and winter

Aerosol Behavior: **Systematic Variability**





- Models and in-situ tend to agree at coastal sites (ARN)
- Models tend to be darker than in-situ in Asia (WLG)
- Mid-continental, rural sites may be hard to characterize this way (SGP)