AeroCom INSITU Project: Comparing modeled and measured aerosol optical properties

E. Andrews, L. Schmeisser, P. Zeiger, G. Titos, M. Schulz, M. Fiebig, J. Ogren, H. Bian, M. Chin, G. Curci, R. Easter, S. Ghan, H. Kokkola, A. Laakso, G. Myhre, C. Randles, A. da Silva, P. Stier, R. Skeie, T. Takemura, T. van Noije, K. Zhang

Acknowledgements:
Derek Hageman (programmer extraordinaire) and in-situ data providers, particularly: AMY, ARN, BKT, CES, GSN, HYY, LLN MSY, PYR, WLG and US DOE.

https://wiki.met.no/aerocom/phase3-experiments#in-situ_measurement_comparison

OBJECTIVE

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

DESCRIPTION

Three-tiered project:

I. Evaluation of dry, surface aerosol optical parameters (this talk)
II. Trend analysis of dry, surface aerosol optical properties
III. Evaluation of hygroscopicity of aerosol scattering (posters)

https://wiki.met.no/aerocom/phase3-experiments#in-situ_measurement_comparison

PROCESS

- Acquire and review in-situ surface aerosol optical data – EBAS data archive
- Obtain high frequency model output consistent from AeroCom community
  - →dry, spectral extinction and absorption at surface
  - →consistent with in-situ data
- Sample model output at station locations
- Compare model output with in-situ measurements:
  - →Scattering
  - →Absorption
  - →Scattering and Absorption Ångström exponent (SAE)
  - →Single scattering albedo (SSA)

https://wiki.met.no/aerocom/phase3-experiments#in-situ_measurement_comparison

In-situ Aerosol Optical Properties

Mauna Loa aerosol rack

Aerosol light scattering

- Nephelometer (TSI or Ecotech)

Aerosol light absorption

- Instruments: MAAP, PSAP, or CLAP

Data Collection

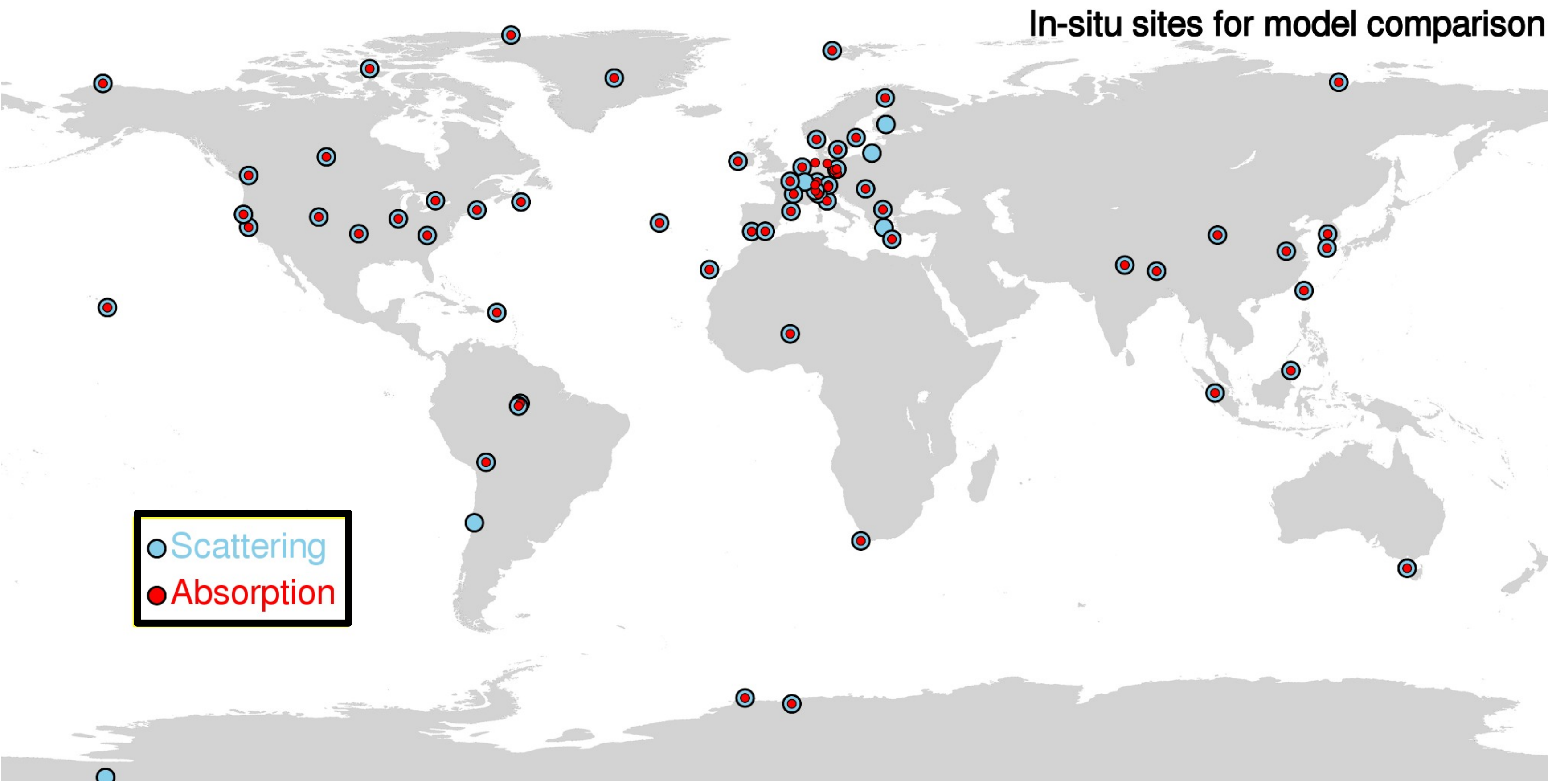
- Low RH (<40% RH)
- 1 min resolution (typically)
- 1 & 10 um size cuts (at some sites)
- CONTINUOUS!

Data Processing

- QC'd and corrected
- Averaged (H, D, M, Y),
- Absorption and scattering reported at STP

Data are primarily from the EBAS data archive

In-situ Measurement Sites

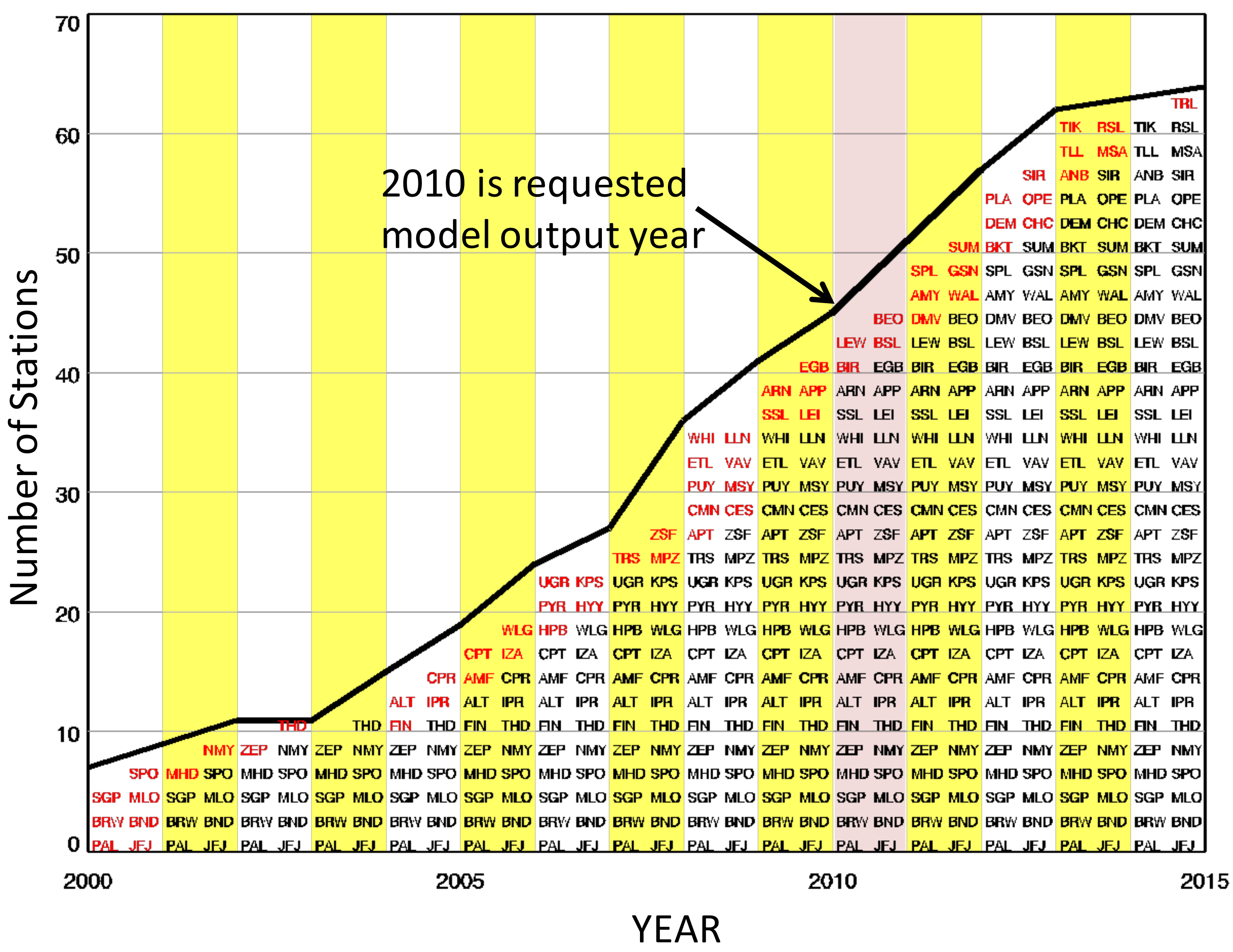


- Sites with aerosol light scattering and/or absorption (~65 sites)
- Fewer sites than AERONET
- Gaps in S. America, Africa, Middle East, Russia, Asia

→In-situ data have been acquired and reviewed
→Working on generating consistent format - 'benchmark data files'

When are in-situ data available?

Stations with absorption and/or scattering data between 2000 and 2015



- Number of stations increasing by ~5/year
- Data for more than 60 sites by 2015
- ~45 sites in 2010 for time-matched model-measurement comparisons

AeroCom Models Used in this Analysis

Model name	Gridbox size	Output Year
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
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*

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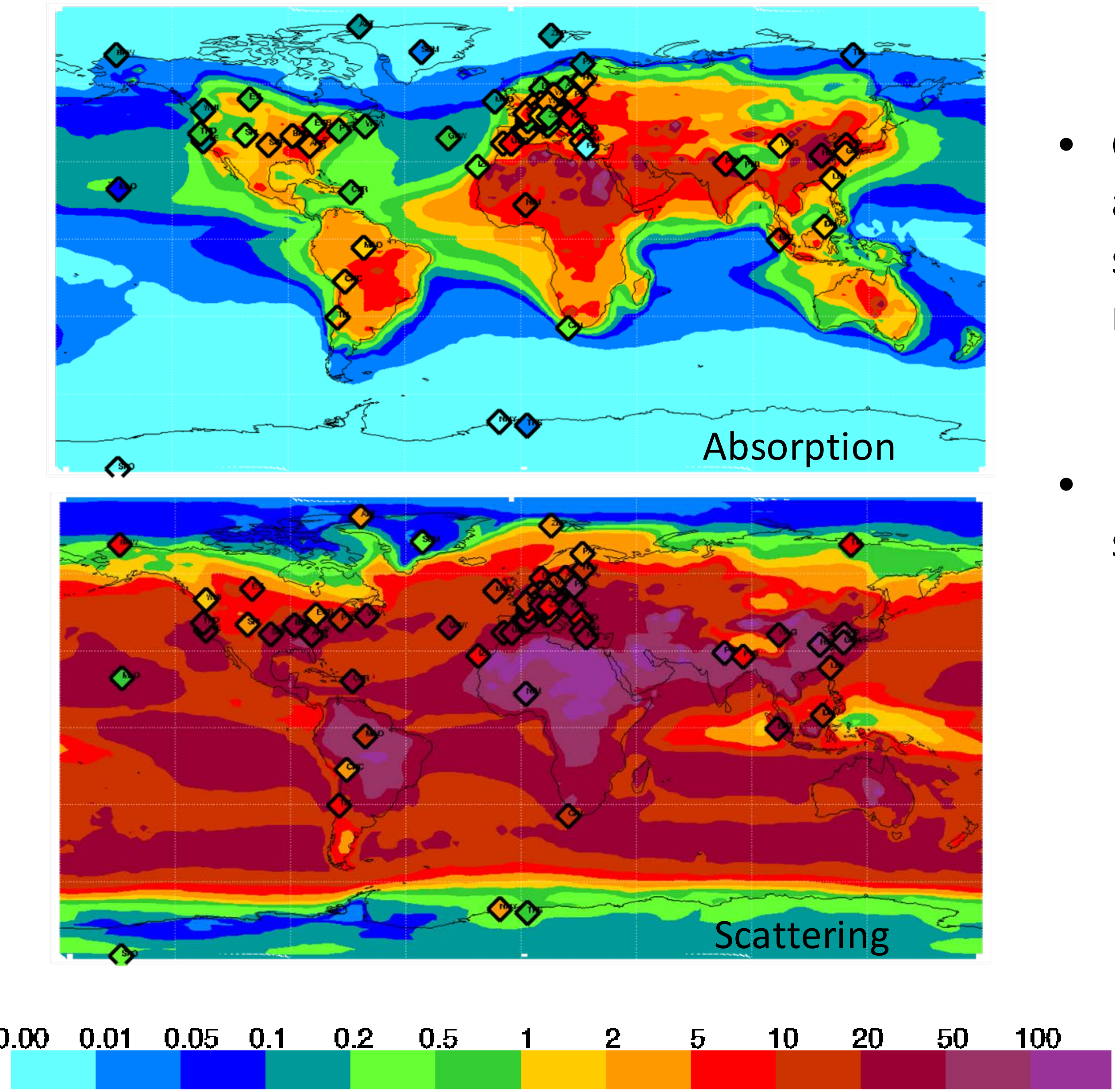
Comparisons

Compare models/measurements from two perspectives…

CLIMATOLOGY	Tells us how well the model is doing at given locations

CHARACTERISTICS & BEHAVIOR	Information about how well the model is simulating aerosol processing, transport, etc.

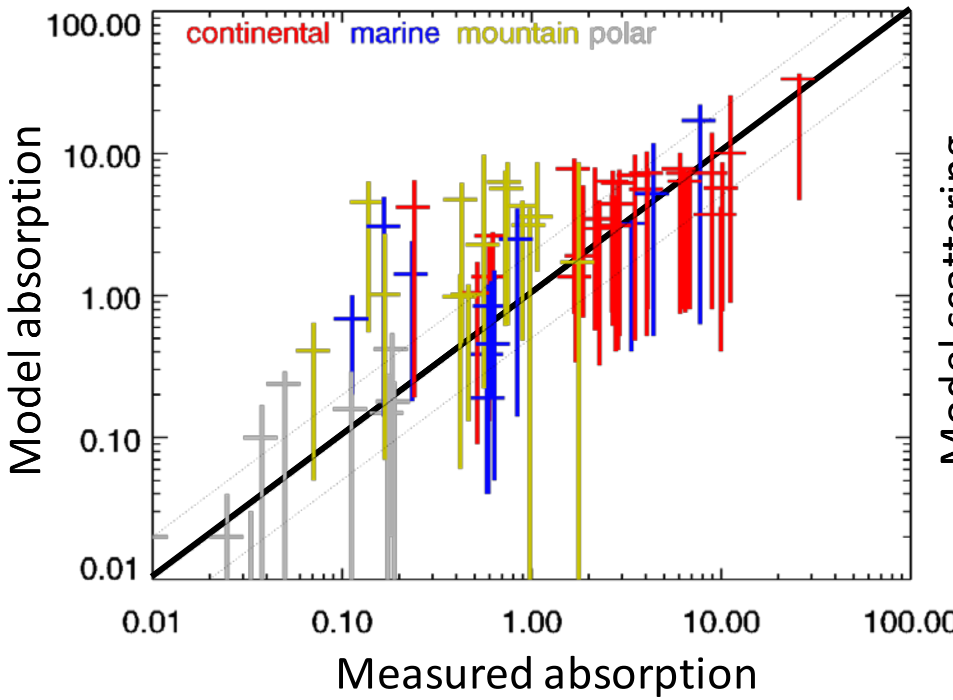
Aerosol Climatology: **Big Picture**

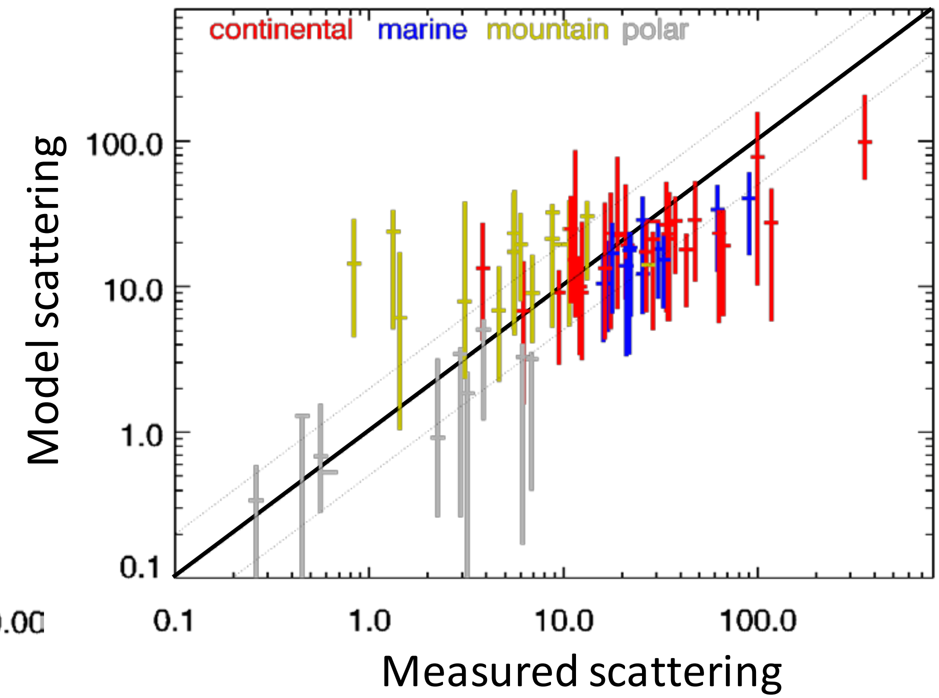


CAM5 output for AEROCOM P3 INSITU project

- General pattern of absorption and scattering similar for models and in-situ measurements
- Differences are observed for some sites

Aerosol Annual Climatology: **Absorption and Scattering**

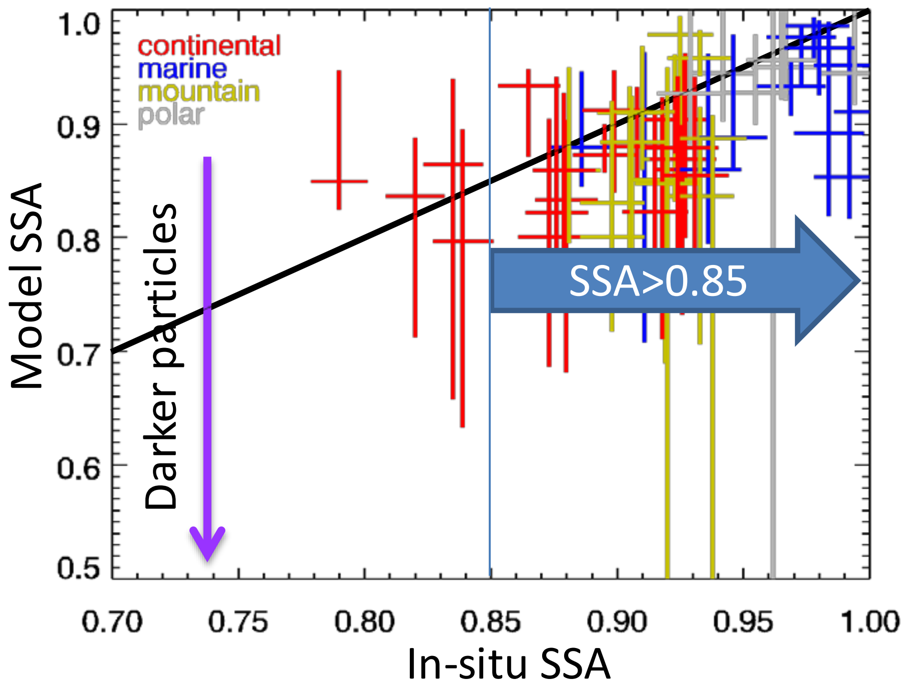


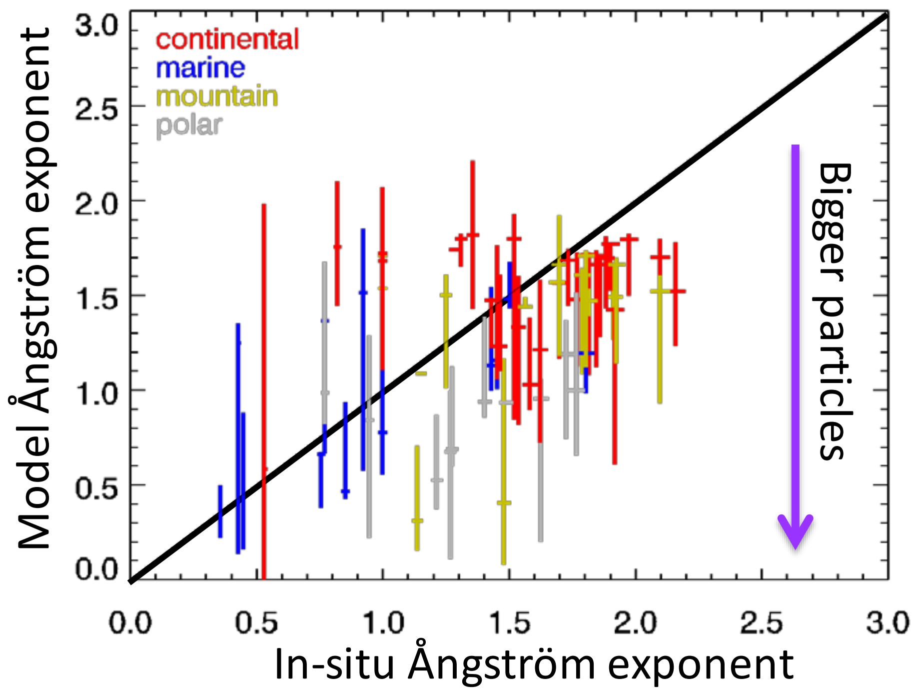


- Models tend to over-predict absorption and scattering at mountain sites
- Modelled absorption tends to be over-predicted
- Scattering tends to be under-predicted at other site types
- More range (relatively) in model prediction of absorption than scattering

Vertical bar shows range of model medians, horizontal bar is measurement uncertainty based on Sherman et al. (2015), only 2010 model output (CAM5, ECHAM6-SALSA, GLOBASE, GEOS-CHEM, MERRAERO, TM5)

Aerosol Annual Climatology: SSA and Ångström exponent



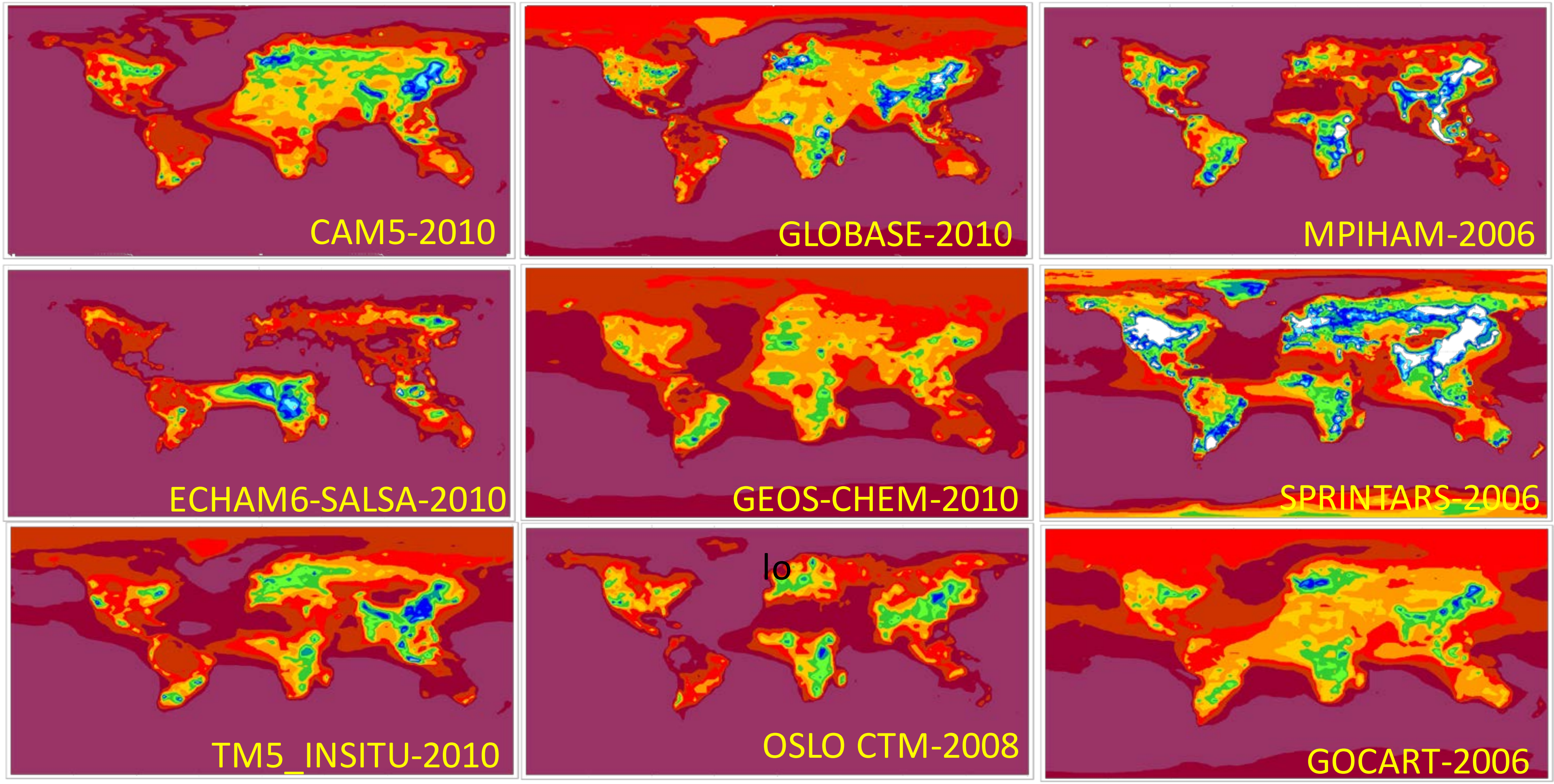


- Model SSA tends to be lower (more absorbing) than in-situ SSA
  → partly driven by model under-prediction of scattering

- Modelled Ångström exponents suggest larger particles than observed by in-situ measurements

Vertical bar shows range of model medians, horizontal bar is measurement uncertainty based on Sherman et al. (2015), only 2010 model output (CAM5, ECHAM6-SALSA, GLOBASE, GEOS-CHEM, MERRAERO, TM5)

Aerosol Annual Climatology: Single Scattering Albedo

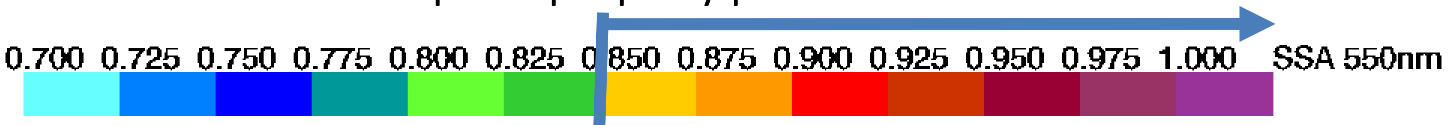


In-situ observations: SSA > 0.85; Models see much darker aerosol in some source regions

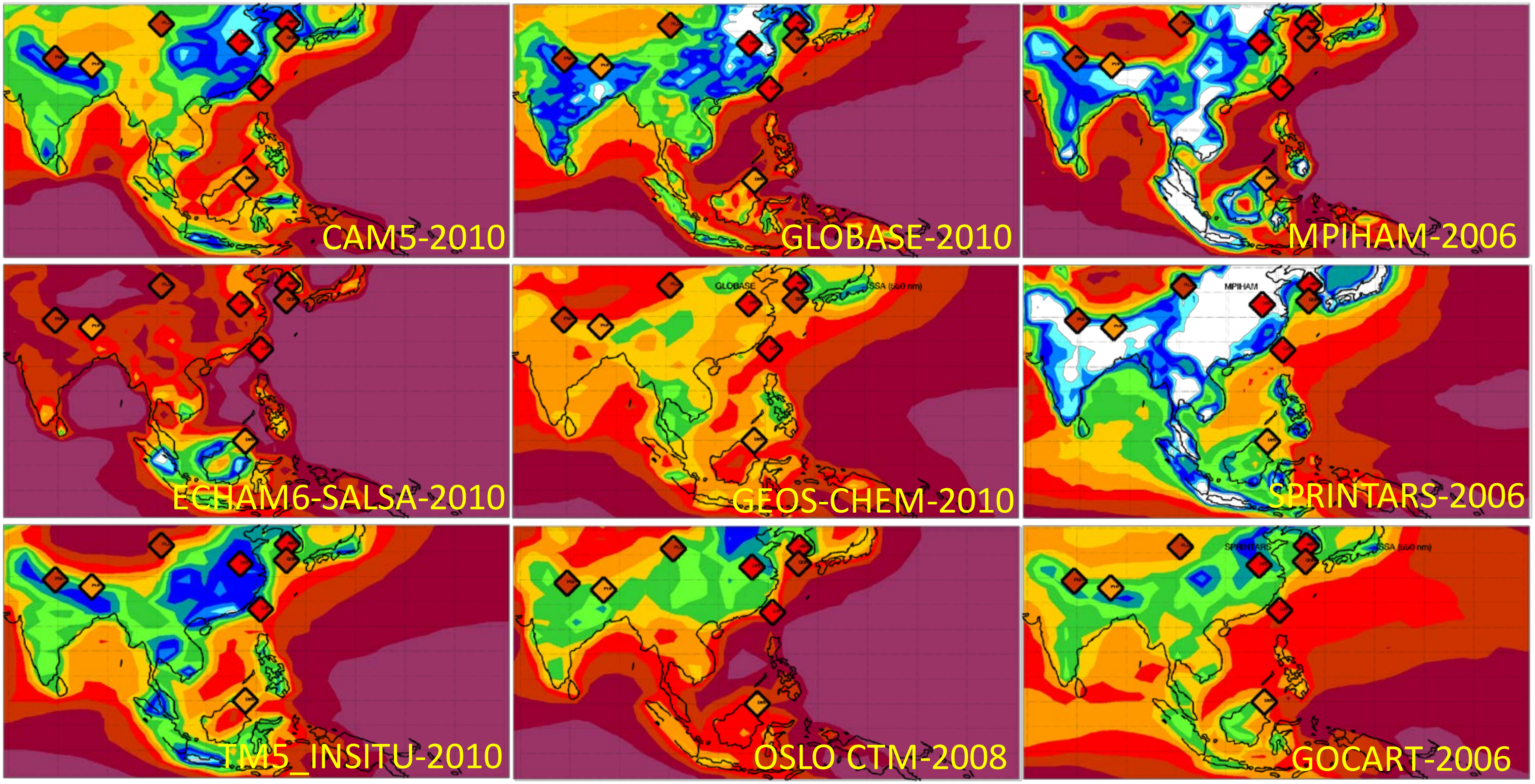
→ Sampling location limitations?

→ Model emissions/processing of black carbon?

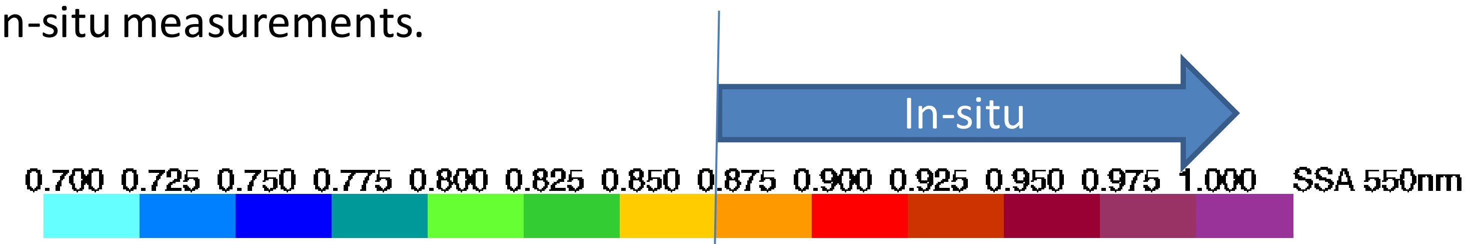
→ Aerosol mass to optical property parameterization?



Aerosol Annual Climatology: **Single Scattering Albedo**

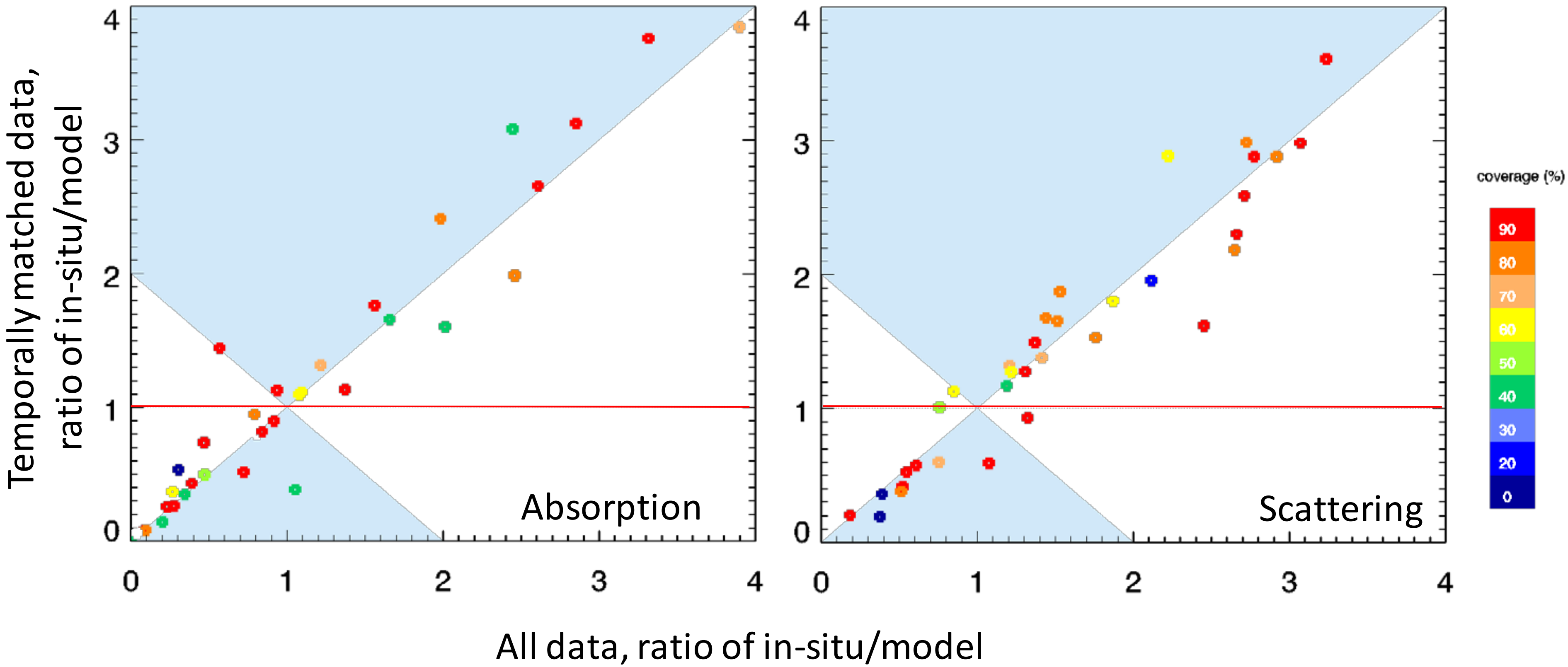


At most sites in Asia, most models simulate darker aerosol (lower SSA) than is observed by the in-situ measurements.



Aerosol Annual Climatology: **Temporal Matching**

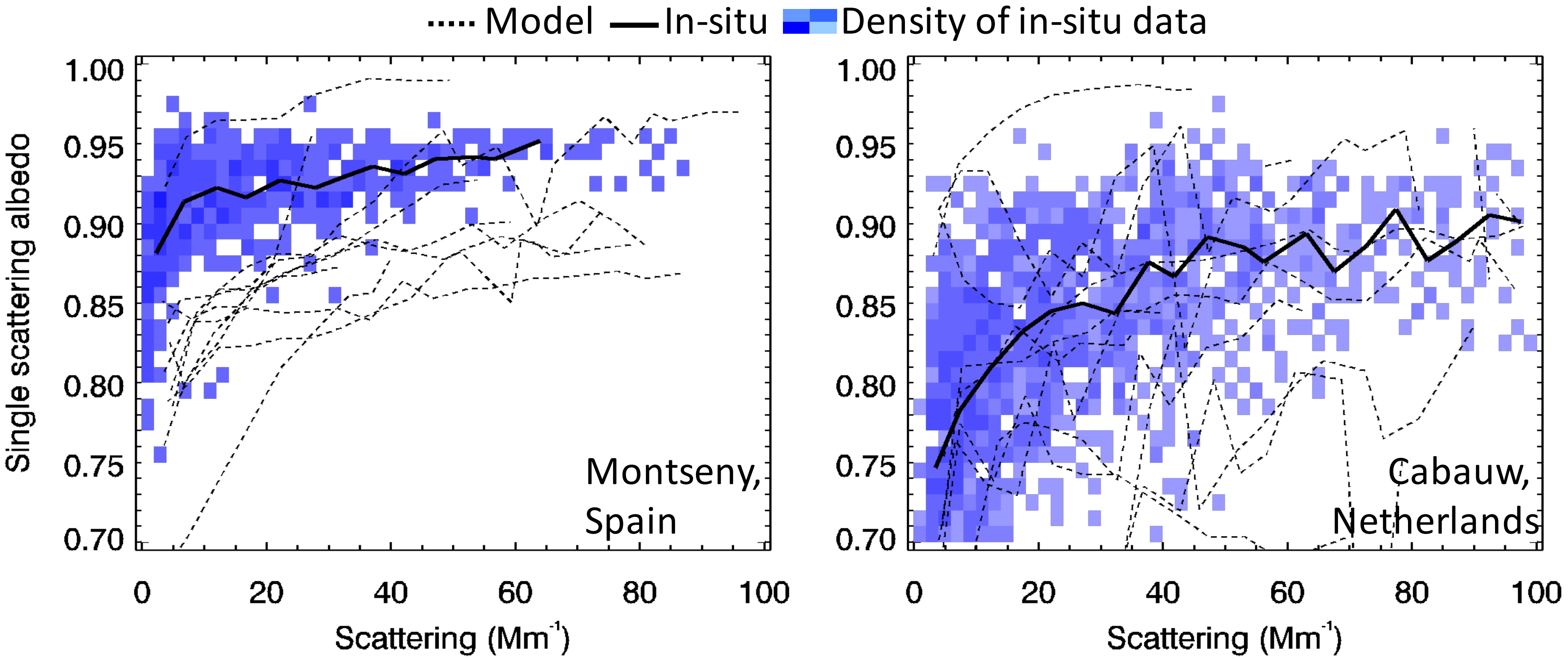
Schutgens et al. (2016) demonstrated the importance of temporal matching – i.e., sampling the model at the same times that measurements exist.



- Most ratios don't change too much
- Depending on site may see improvement or worsening of insitu/model comparison

Results shown for GLOBASE; similar results for all 2010 models. Used daily averages to calc. annual median

Aerosol Behavior: **Systematic Variability**

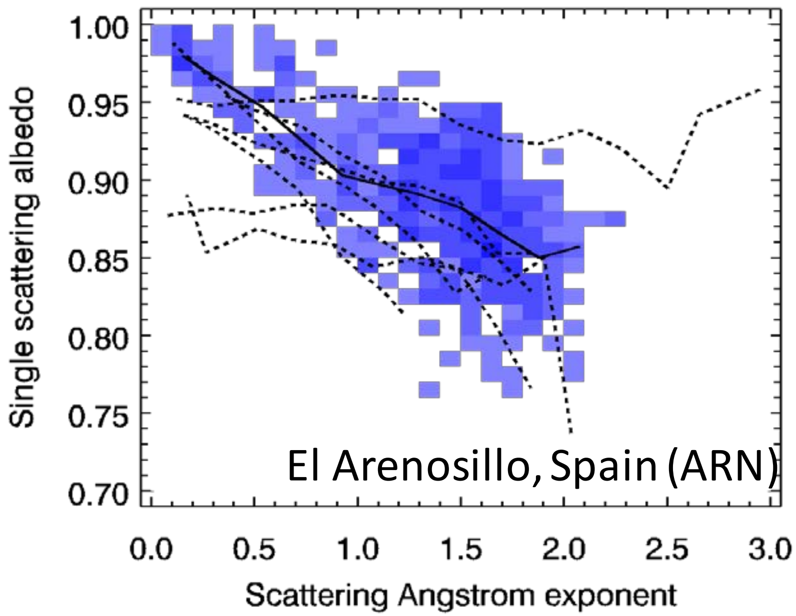


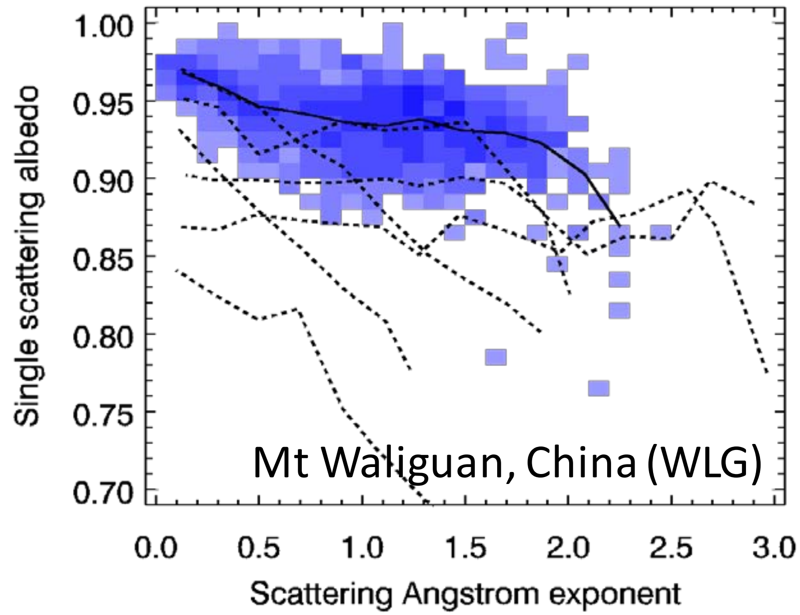
- Lower loading corresponds to darker (and smaller) particles

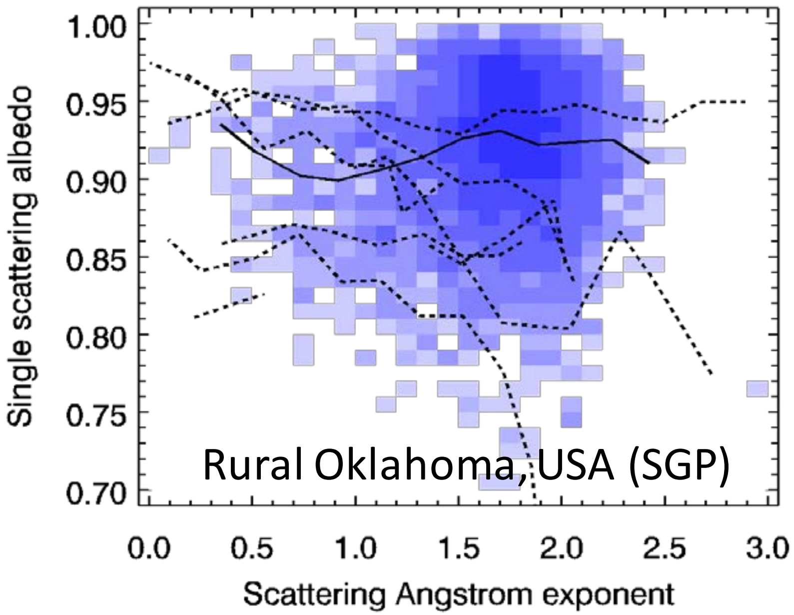
→ preferential scavenging of large, scattering aerosol by clouds/precipitation?

The co-variance observed between SSA and scattering for in-situ data is not necessarily reproduced by model output

Aerosol Behavior: Systematic Variability

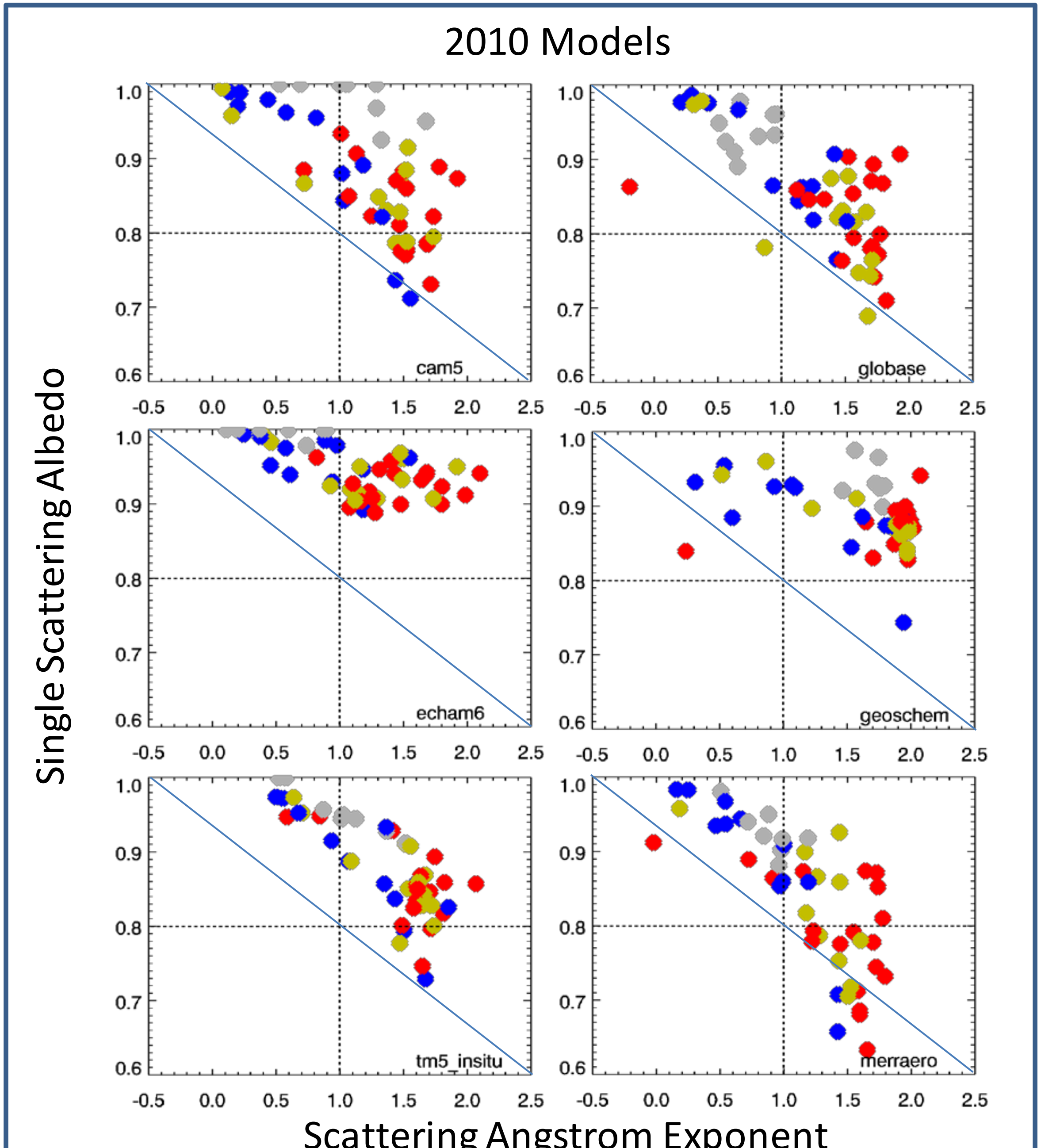


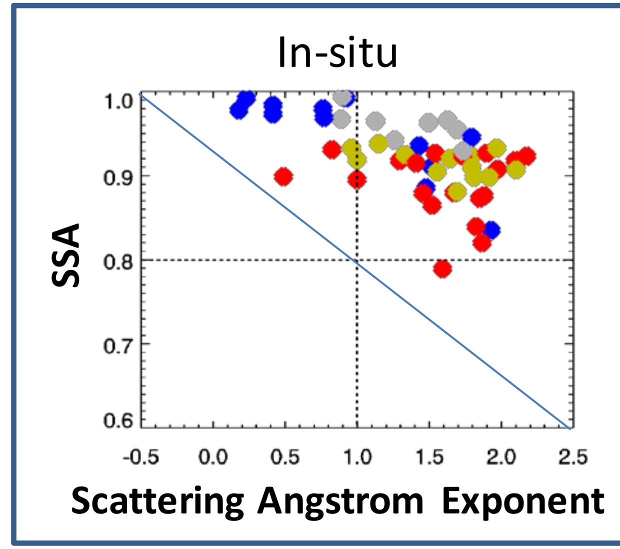




- Models and in-situ tend to agree at coastal sites (ARN)
- Models tend to be darker than in-situ in Asia (WLG)
- Mid-continental, rural sites may be hard to characterize this way (SGP)

Aerosol Behavior: **Systematic Variability**





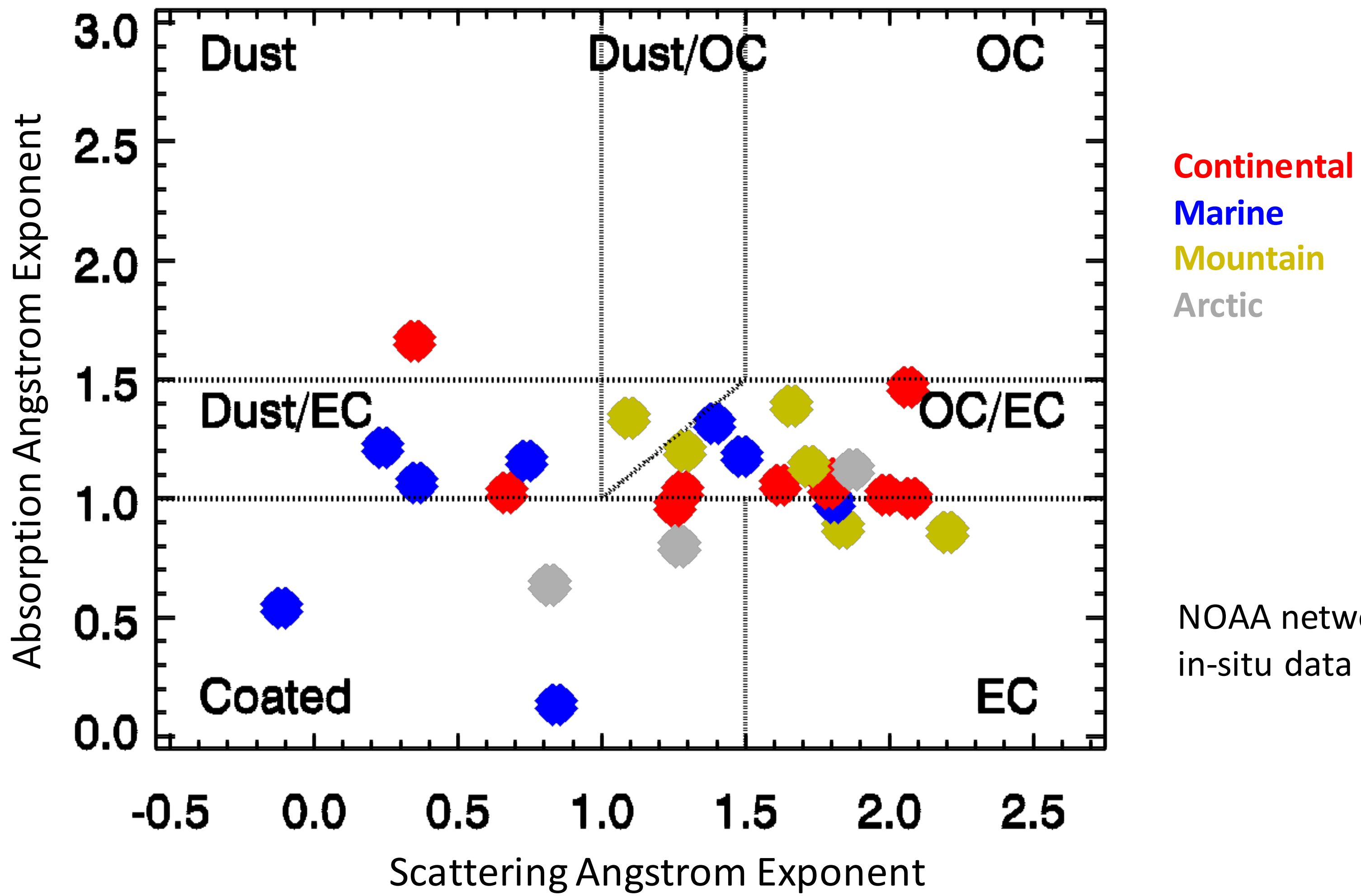
Model data exhibit similar overall relationships between SSA and SAE

→general pattern of decreasing SSA with increasing SAE

→models tend to have darker, larger particles

Continental
Marine
Mountain
Arctic

Aerosol Behavior: Systematic Variability

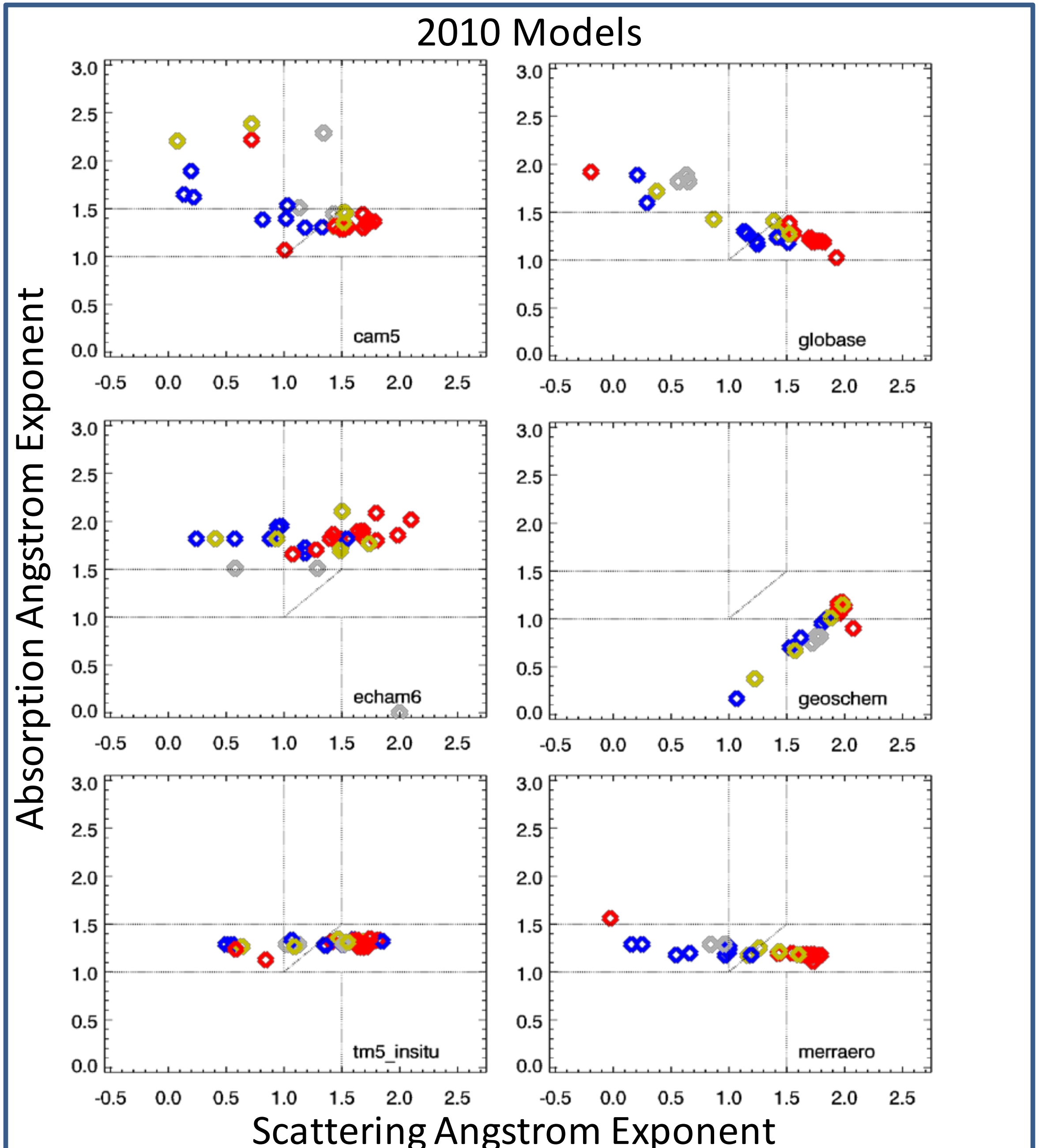


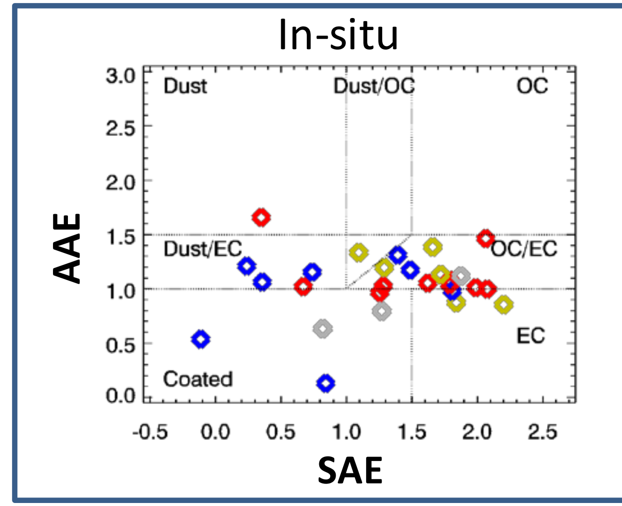
NOAA network
in-situ data only

Relationships between aerosol optical parameters may indicate aerosol type/composition.

Cazorla et al., 2013; Schmeisser et al. (to be submitted)

Aerosol Behavior: Systematic Variability





Model data exhibit very different relationships between AAE and SAE
→differences amongst models
→differences between models and insitu

Suggests very different aerosol types.

Hygroscopicity (Tier III)

Funding from US Dept. of Energy → PIs: E. Andrews, P. Zieger, G. Titos, M. Fiebig; Collab: K. Zhang

GOAL **Use in-situ measurements to evaluate model parameterizations of hygroscopicity**

- Process in-situ hygroscopicity data
- Compare in-situ observations and model simulations
- Evaluate in terms of model parameterizations, aerosol type, region…

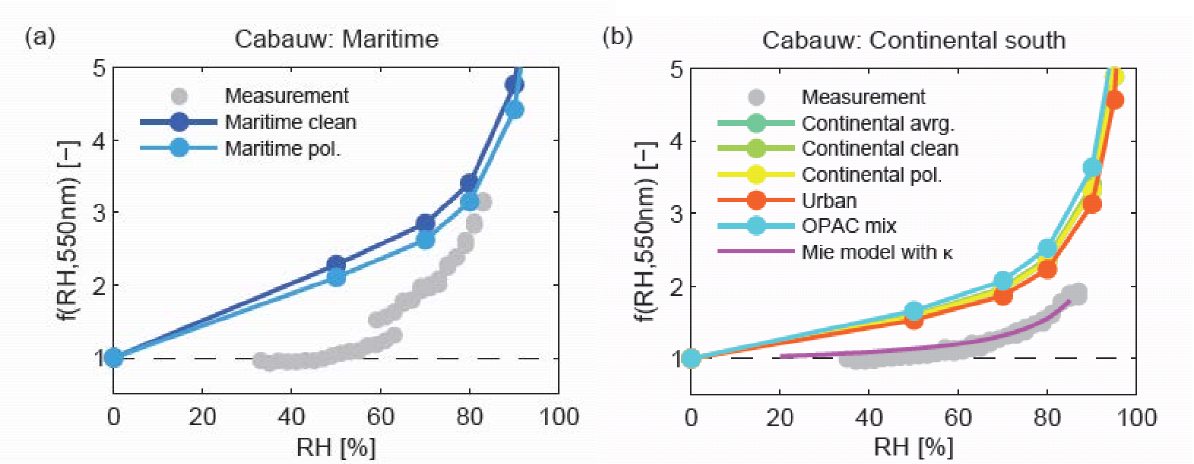
~30 sites with in-situ hygroscopicity data

See posters by Zieger et al. and Titos et al. for more details!

Please participate!!

https://wiki.met.no/aerocom/phase3-experiments#in-situ_measurement_comparison

Hygroscopicity (Tier III)



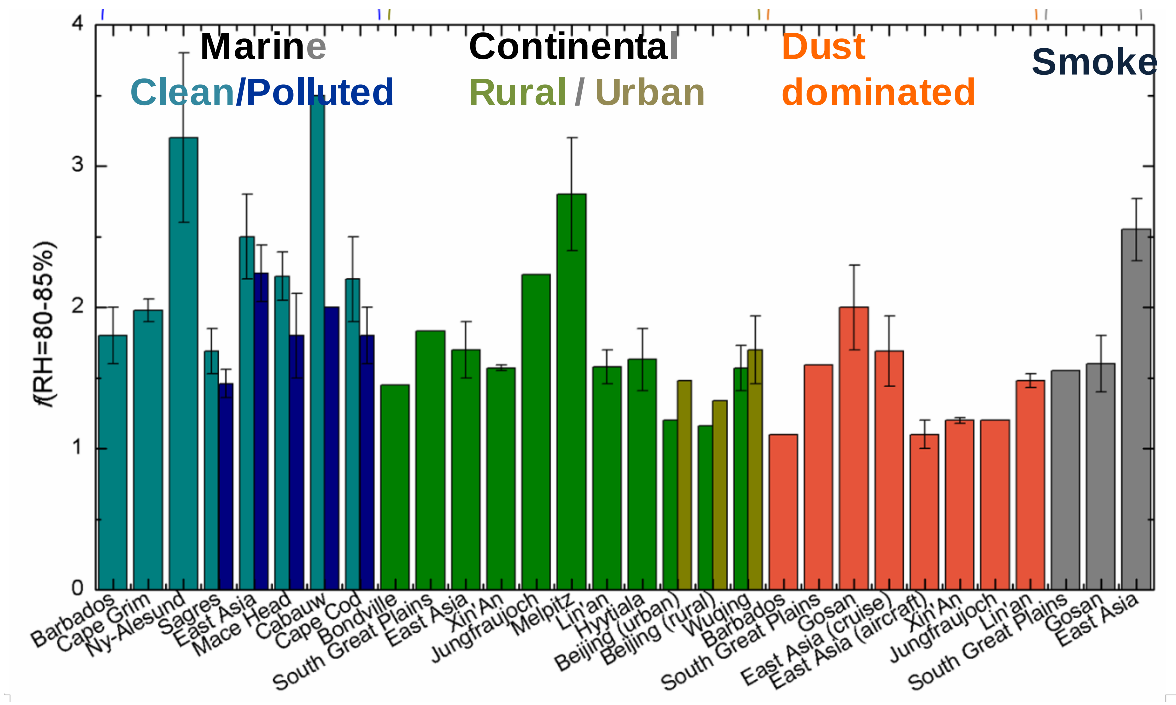
Colored dots are results based on OPAC; Grey dots are in-situ measurements

Zieger et al., ACP, 2013

→Reviews OPAC hygroscopicity estimates

→Systematic overestimate of f(RH)

See posters by Zieger et al. for more details!



Titos et al., Atmos. Environ., 2016

→Historical review of measurements

→Evaluation of techniques

→Estimates of error and uncertainty

See poster by Titos et al. for more details!

Takeaways

- Climatological comparisons tell us how models are doing now and may identify regions of difficulty for models
  →models tend to see lower scattering than in-situ
  →models tend to see darker aerosol (lower SSA) than in-situ
  →models tend to see larger aerosol (lower Ångström exponent) than in-situ

- Behavioral comparisons may indicate discrepancies in aerosol modules in terms of atmospheric sources/processes
  →models have varying success in reproducing observed co-variance amongst aerosol optical properties

- Hygroscopicity evaluation is planned (Tier III of INSITU project)
  →Please join us!
  →Participate by providing simulation data over range of RH

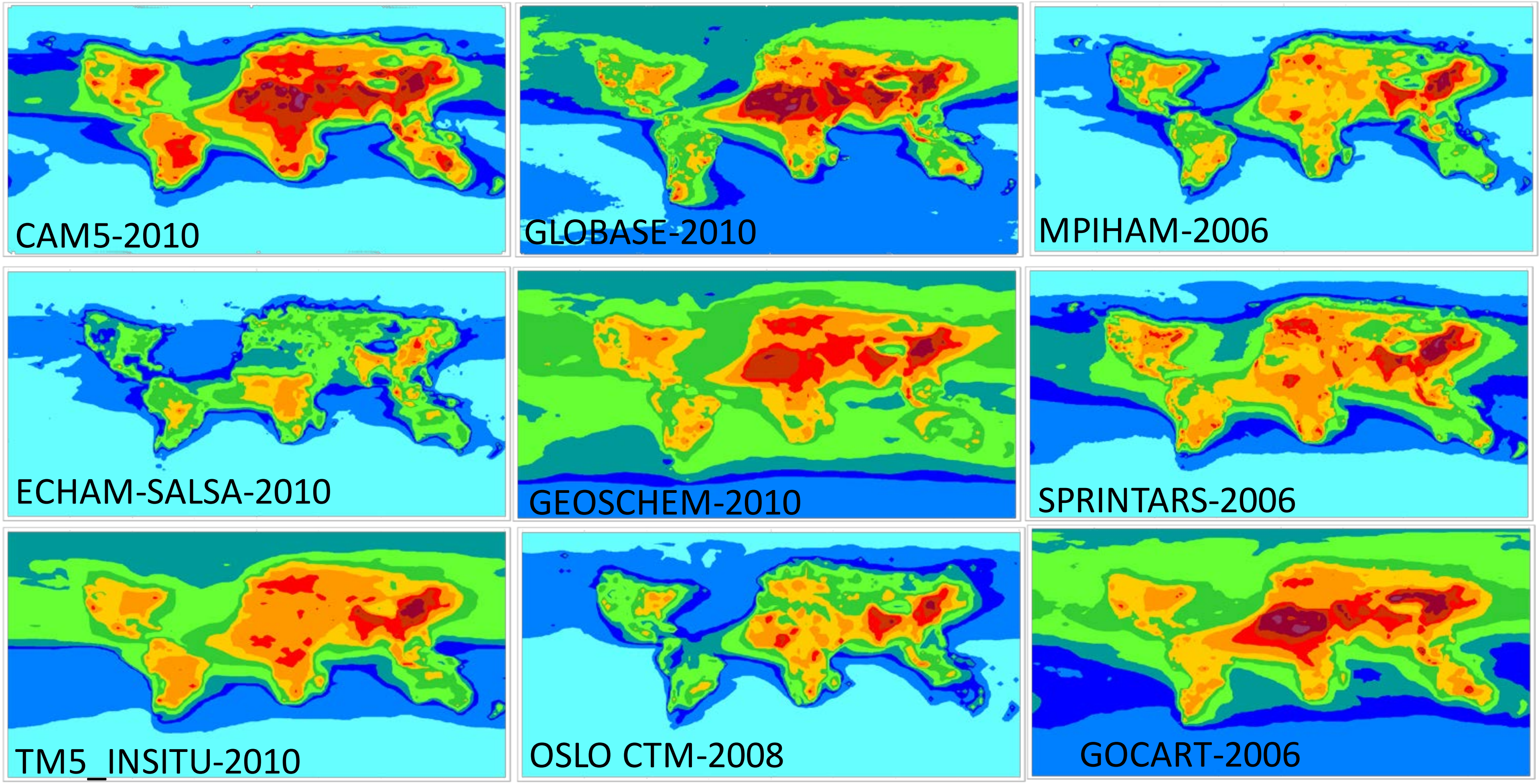
https://wiki.met.no/aerocom/phase3-experiments#in-situ_measurement_comparison

Extra slides

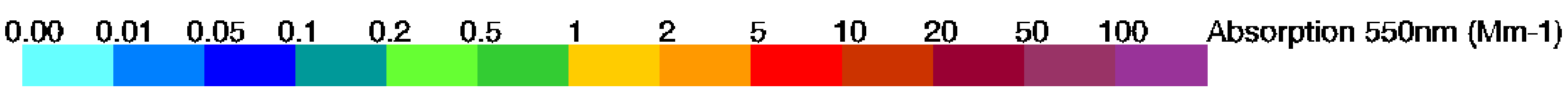
Why long-term, in-situ, surface aerosol optical data?

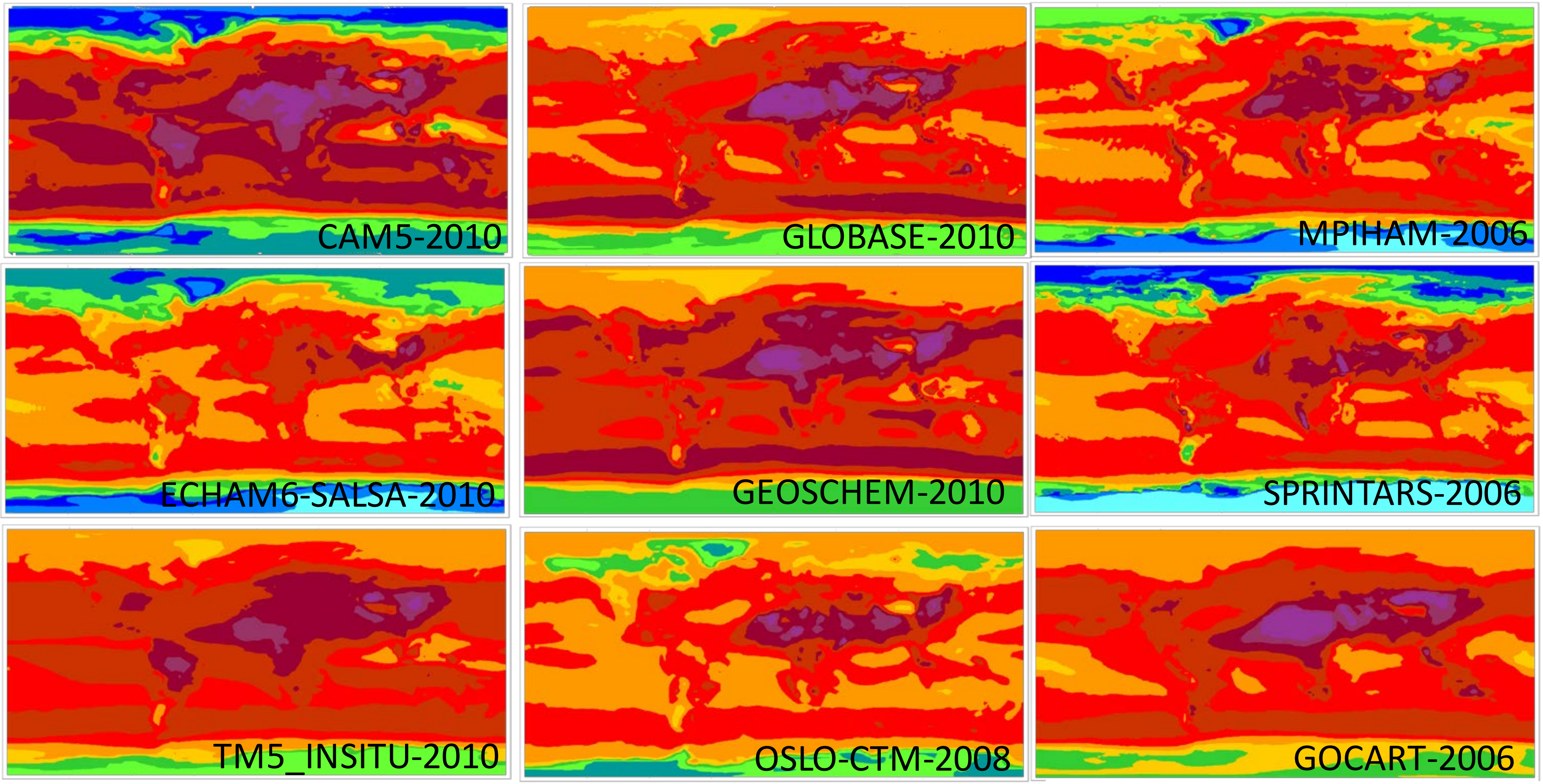
	NOAA & GAW Surface Networks	Aircraft Campaigns	AERONET	Satellite
Length of dataset	Long-term 🙂	Short-term ❌	Long-term 🙂	Long-term 🙂
Temporal continuity	Continuous 🙂	Variable ❌	Intermittent ❌	Intermittent ❌
Geographical Coverage	Sparse ❌	Sparse ❌	Medium Sparse 🙂	Global 🙂
Vertical Resolution	Surface only ❌	Vertically resolved 🙂	Column only ❌	Column (mostly) ❌ 🙂
Aerosol optical properties	Complete RFE suite; @ low RH 🙂	Various ❌ 🙂	Complete RFE suite (at high loading); @ ambient RH 🙂	Various ❌ 🙂

→There are advantages and disadvantages for each data set.

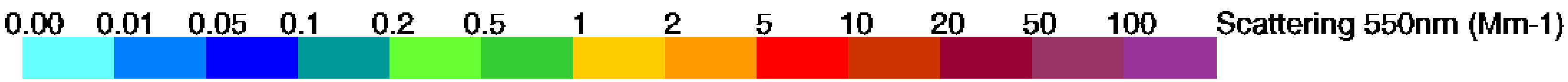


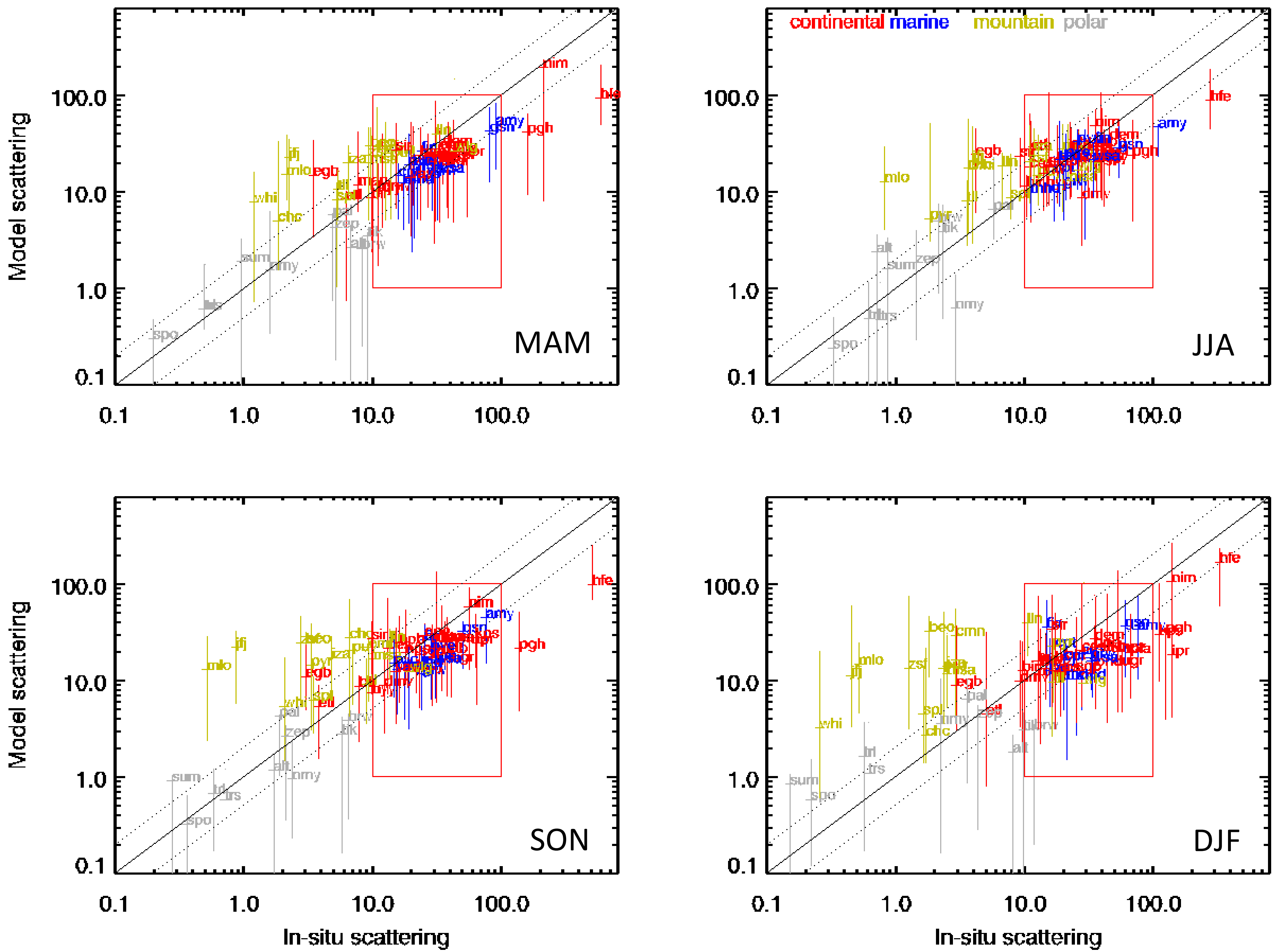
Annual Median Absorption (550 nm)

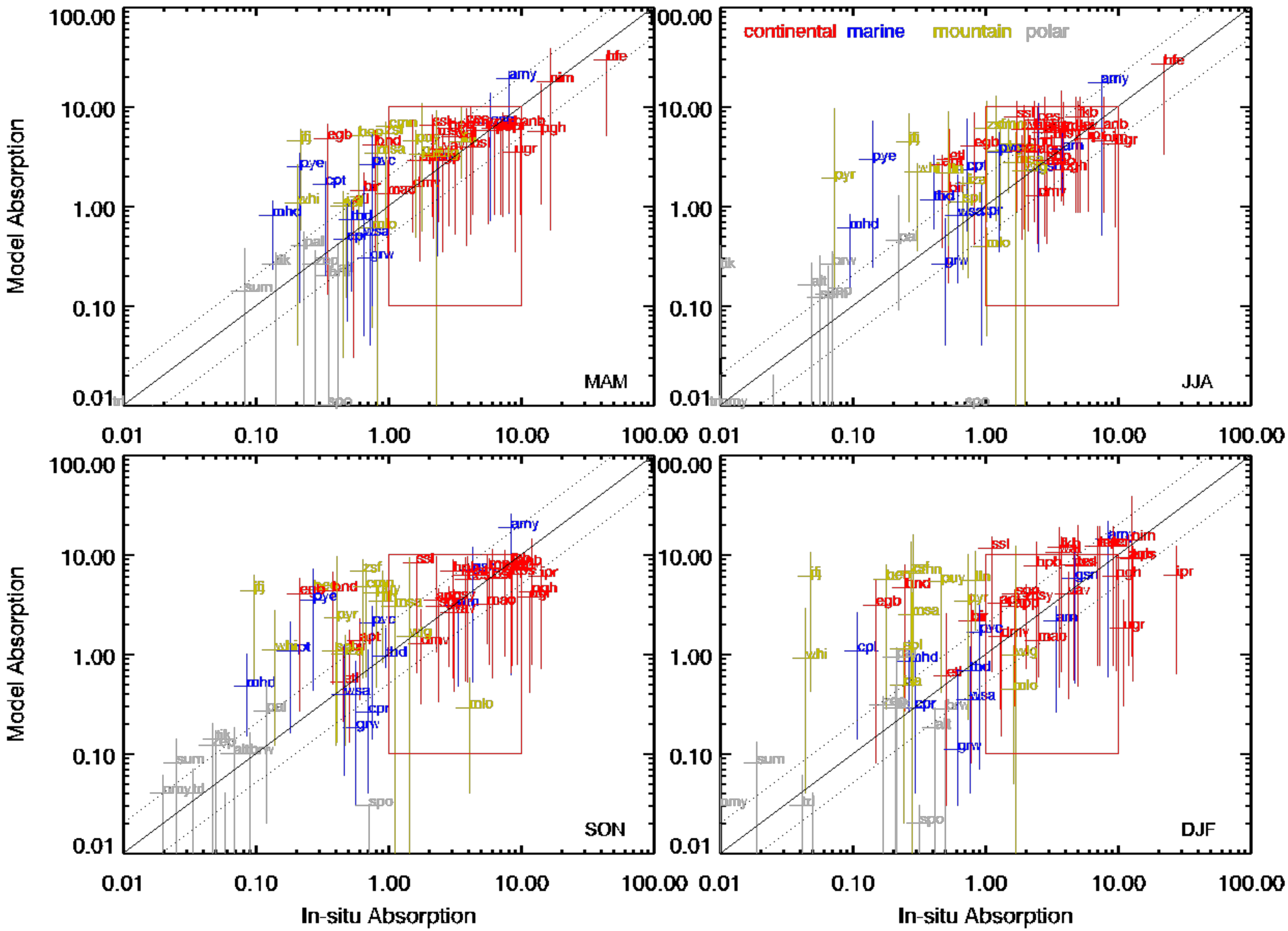




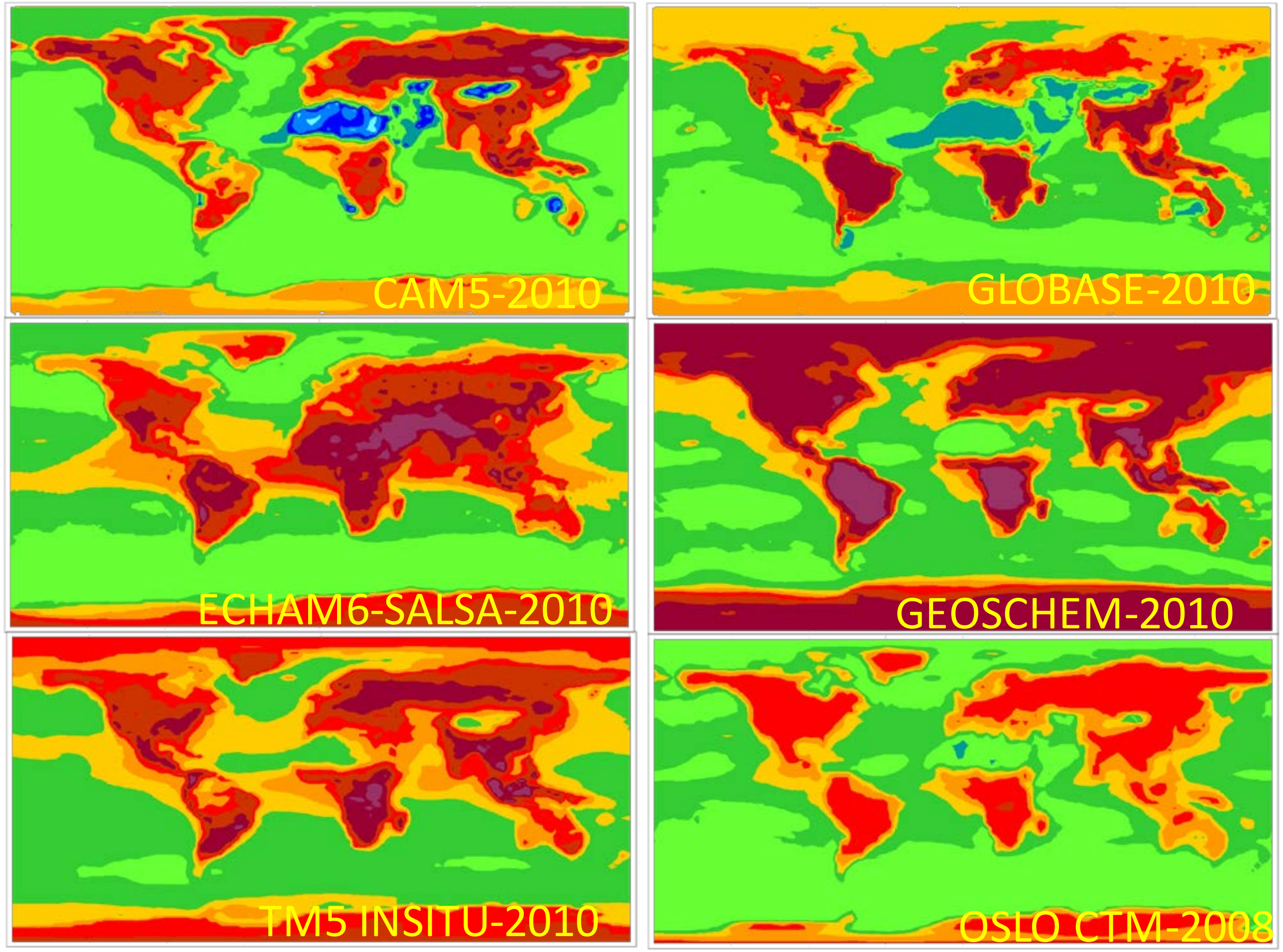
Annual Median Scattering (550 nm)




continental marine mountain polar
Model scattering
In-situ scattering
0.1
1.0
10.0
100.0
MAM
JJA
SON
DJF



Next slide zooms in on redbox and can see LEW and LEI

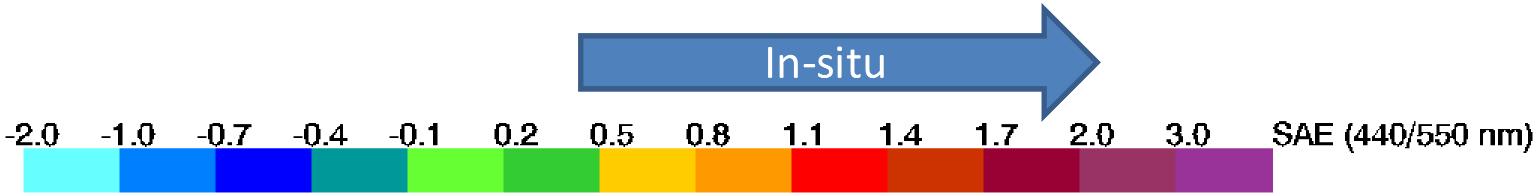


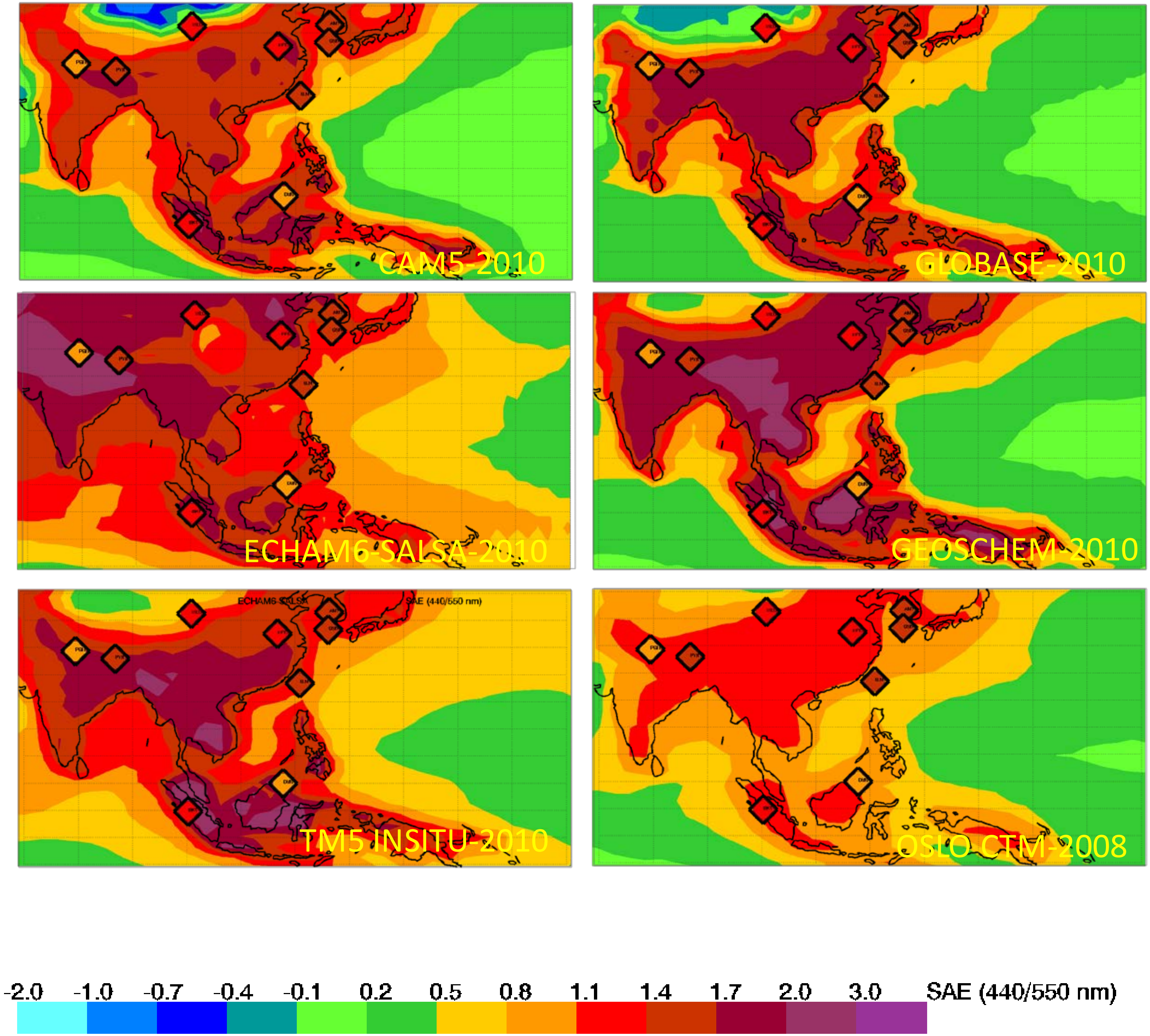
Annual Median Scattering Angstrom Exponent (440/550 nm wavelength pair)

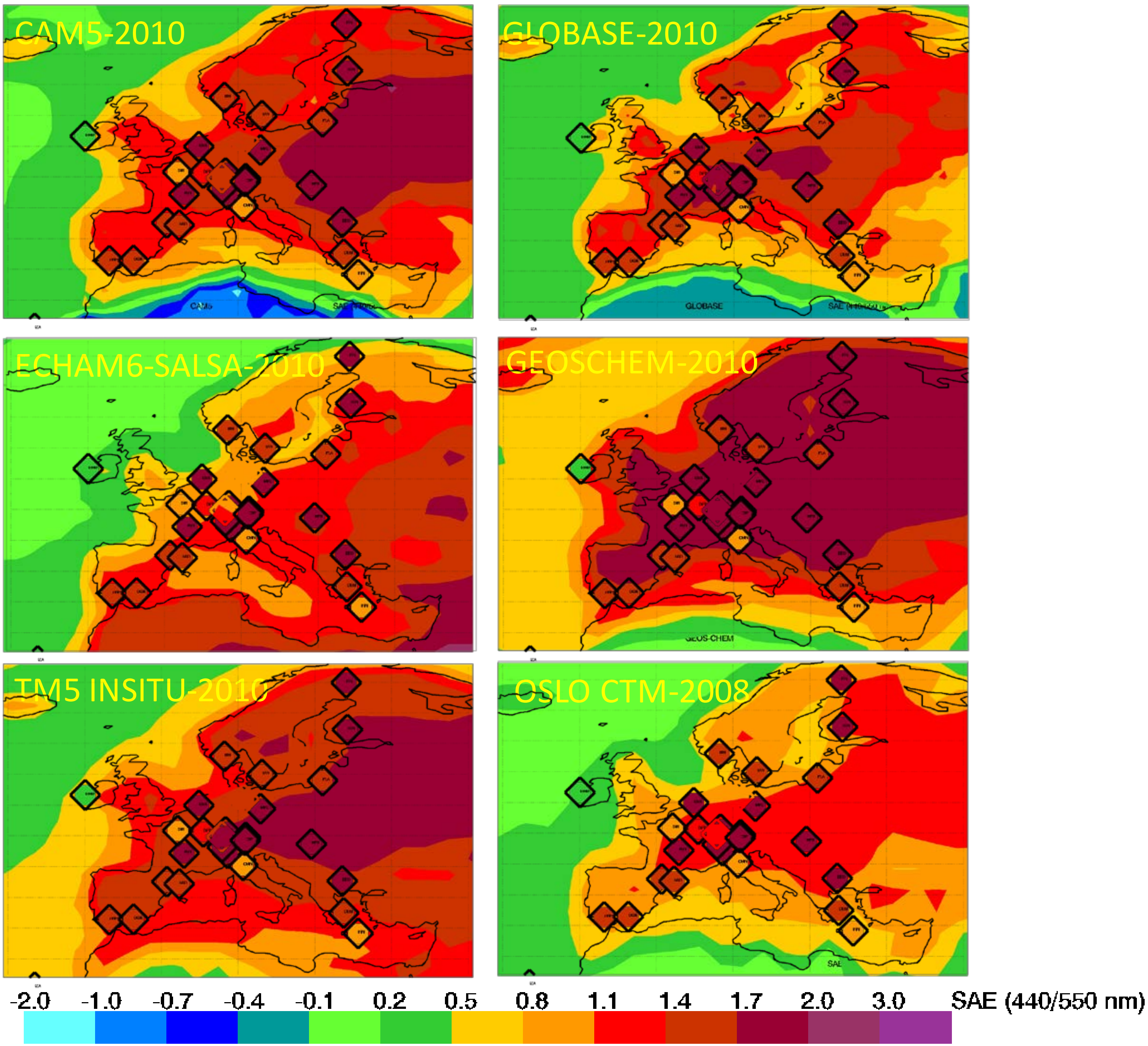
In-situ observations: SAE > 0.5; Models see much larger aerosol in some regions

→ Sampling location limitations?

→ Emissions issue? Assumptions about size issue?




CAM5-2010
GLOBASE-2010
ECHAM6-SALSA-2010
GEOSCHEM-2010
ECHAM6-SALSA
SAE (440/550 nm)
TM5 INSITU-2010
OSLO-CTM-2008
-2.0
-1.0
-0.7
-0.4
-0.1
0.2
0.5
0.8
1.1
1.4
1.7
2.0
3.0
SAE (440/550 nm)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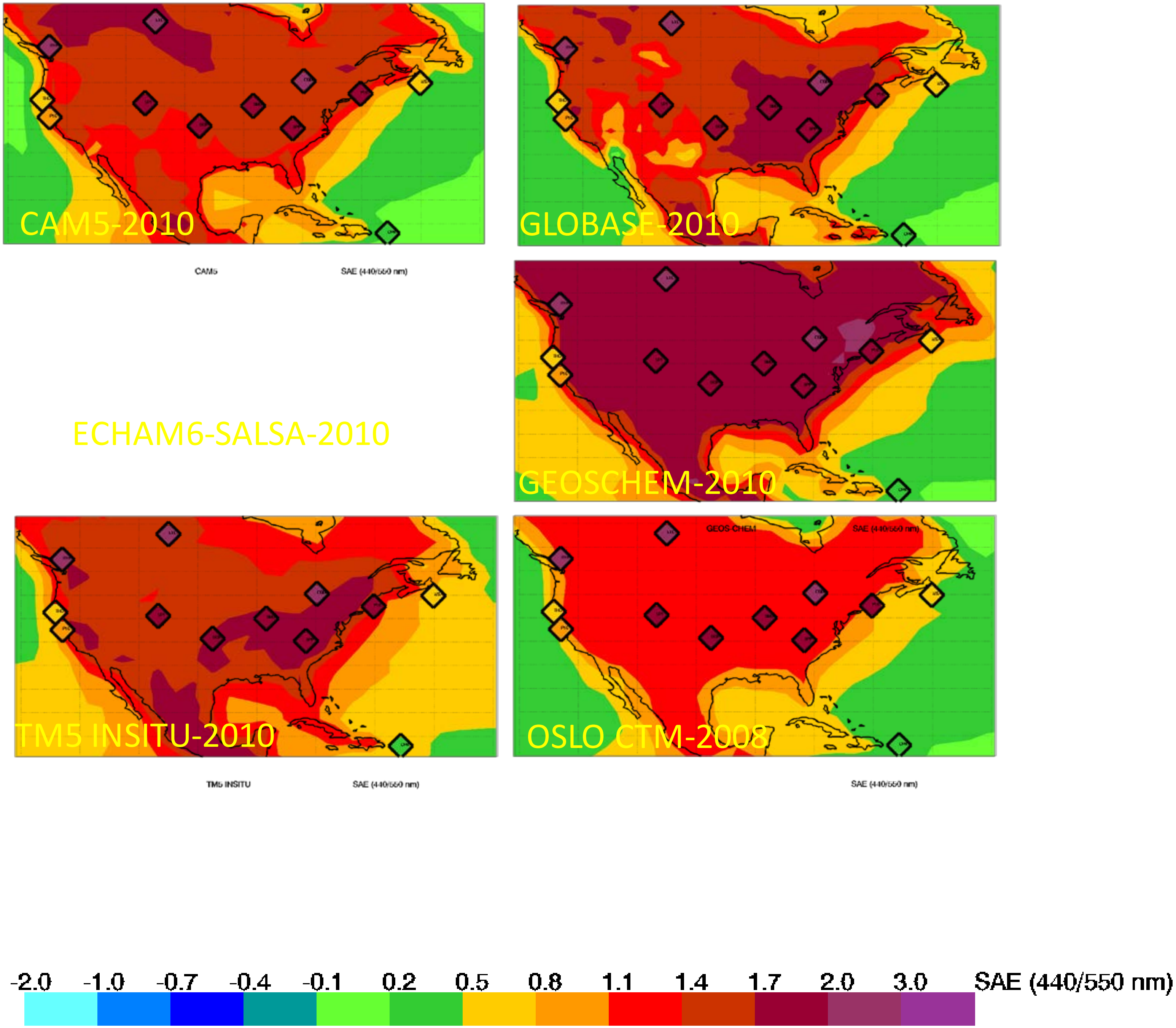
SAE (440/550 nm)


CAM5-2010
GLOBASE-2010
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SAE (440/550 nm)
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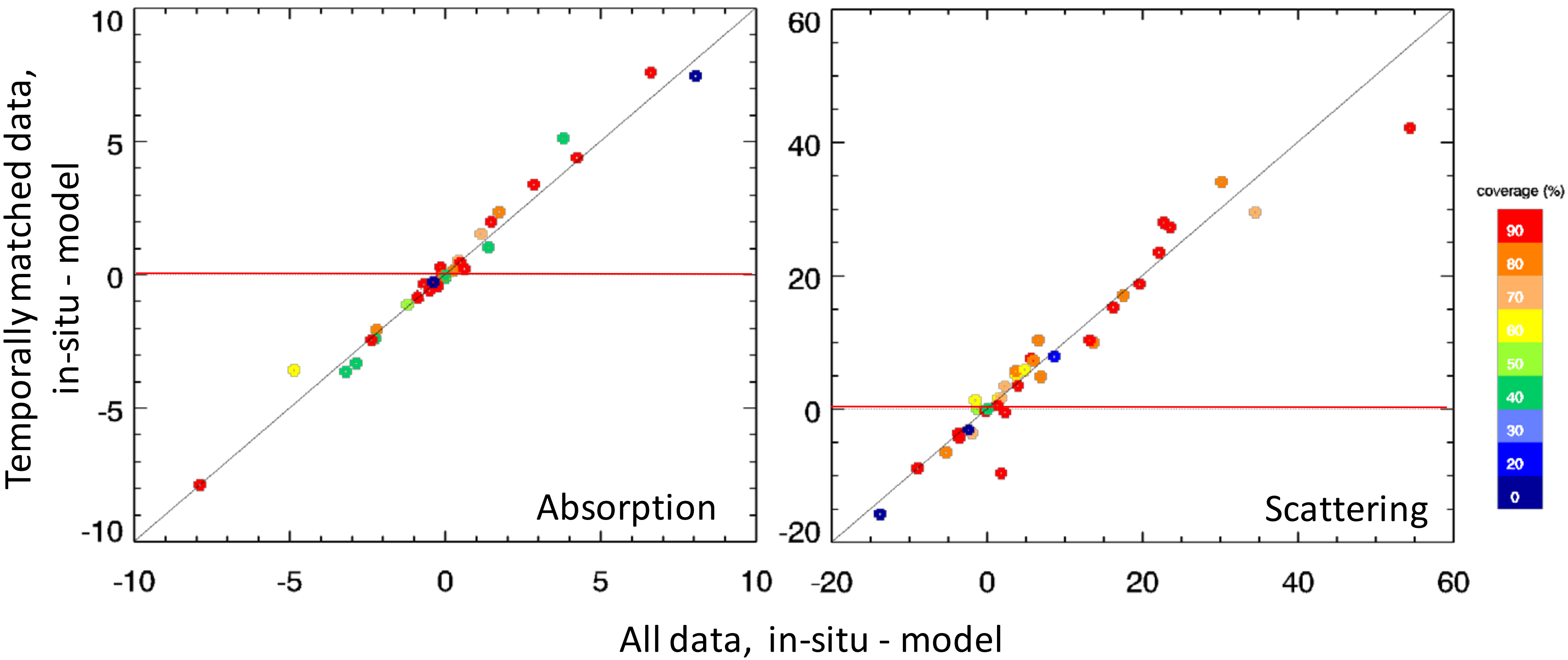
SAE (440/550 nm)

Aerosol Annual Climatology: **Temporal Matching**

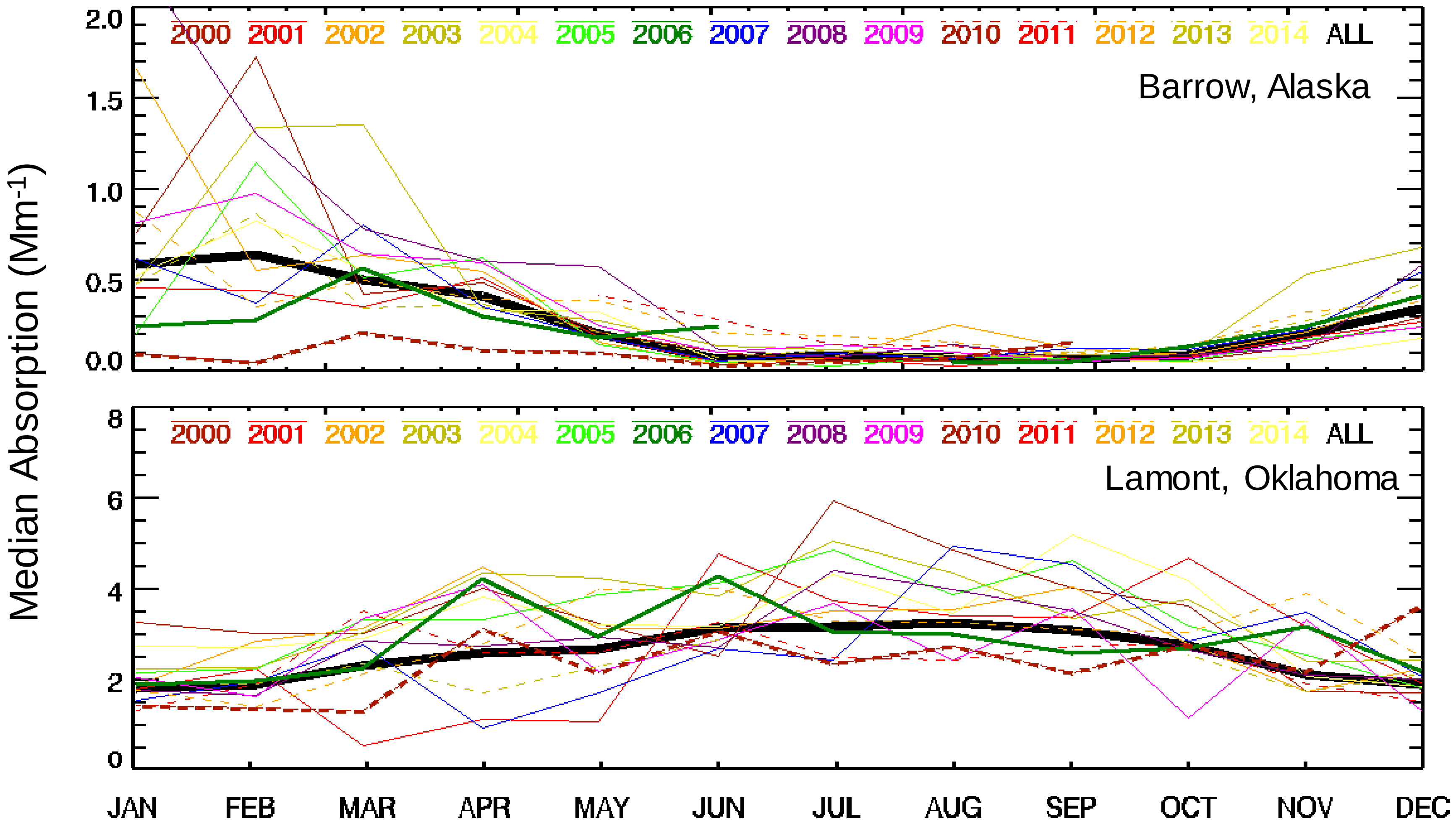
Schutgens et al. (2016) demonstrated the importance of temporal matching – i.e., sampling the model at the same times that measurements exist.



- Most ratios don't change too much
- Depending on site may see improvement or worsening of model/insitu comparison

Results shown for GLOBASE; similar results for all 2010 models. Used daily averages to calc. annual median

Aerosol Climatology: Inter-annual Variability



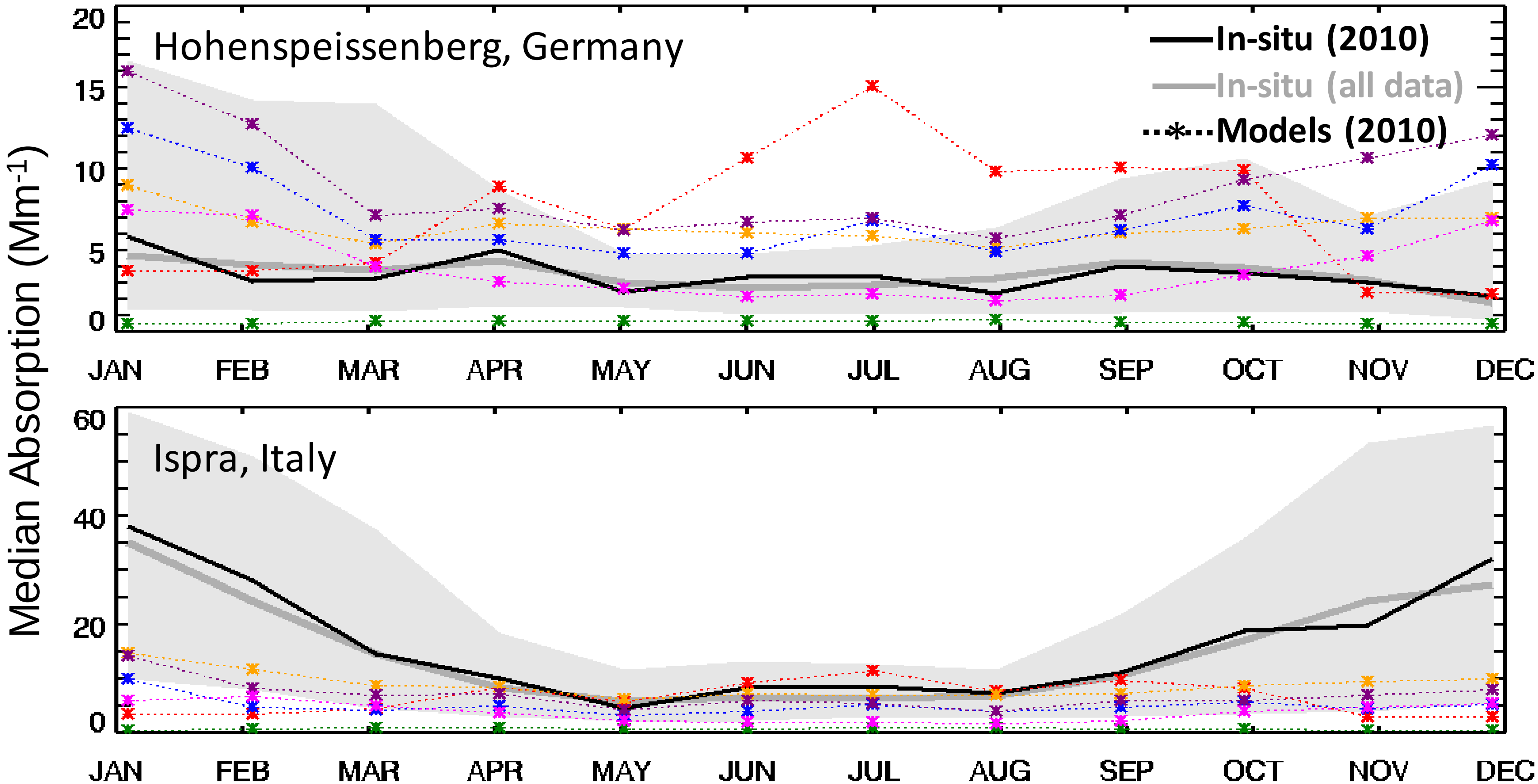
Plot shows only in-situ data for two sites with long term records

Thick black lines are 'in-situ' lines from previous slide.

→inter-annual variability is very site dependent

Aerosol Climatology: **Seasonality**

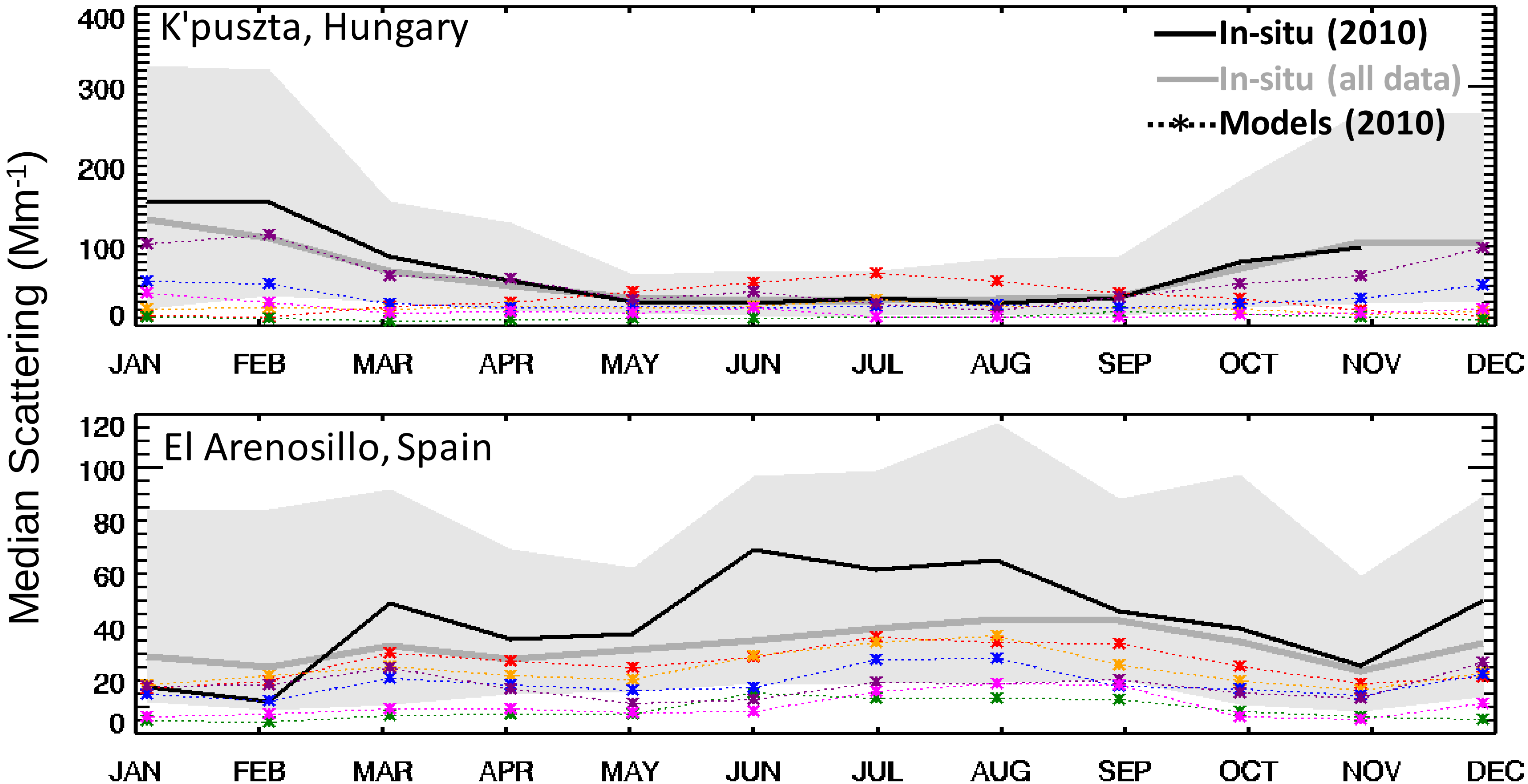
Discrepancies in seasonality may help identify issues with model emissions, transport and/or atmospheric processing



In-situ (all data) and in-situ (2010) tend to be closer to each other than to model 2010 data
→reasonable to do monthly statistical comparisons (ignoring year)

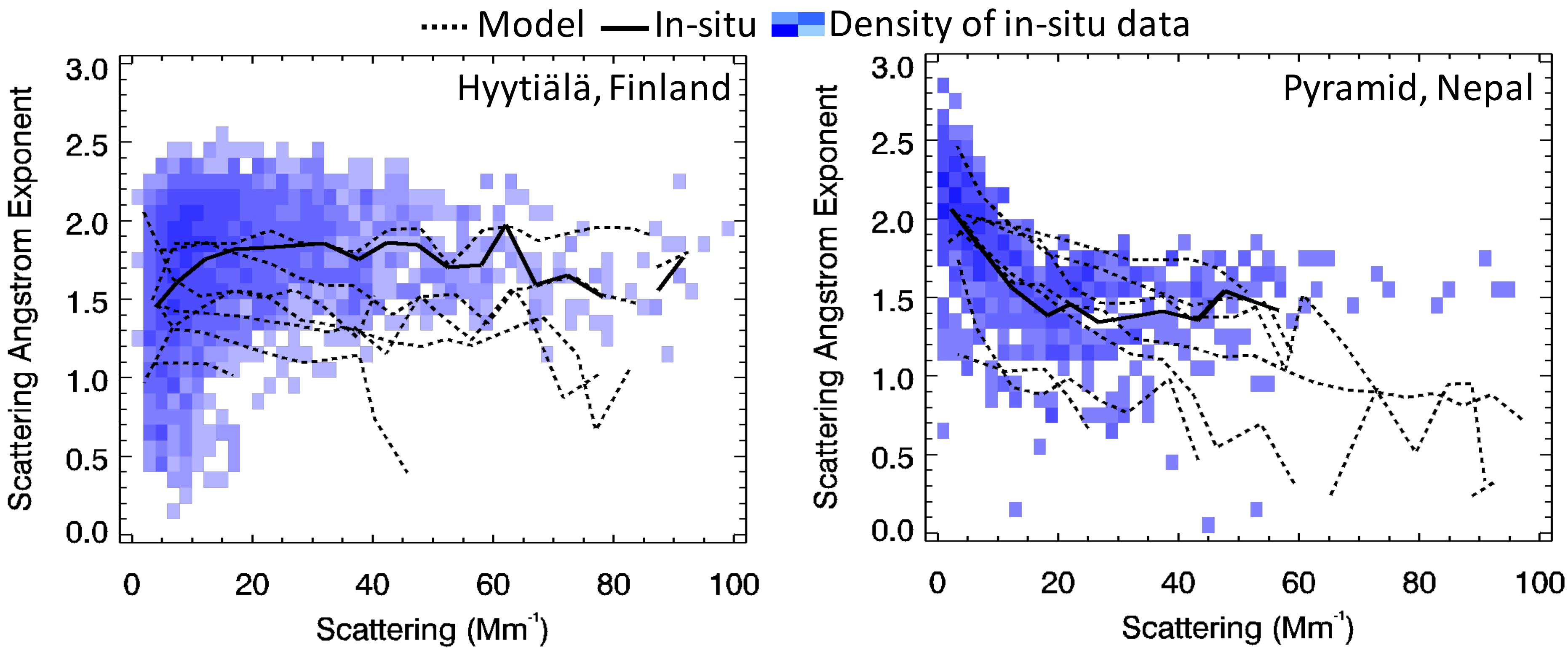
Aerosol Climatology: **Seasonality**

Discrepancies in seasonality may help identify issues with model emissions, transport and/or atmospheric processing



- Models can get observed seasonality right at one location and not at another,
- Models can capture seasonality well, but not magnitude
- Seasonality at one location can be totally different among models

Aerosol Behavior: **Systematic Variability**



- Relationship between aerosol loading and aerosol size distribution changes with location (i.e., aerosol type)
- The co-variance observed between Ångström exponent and scattering for in-situ data is not necessarily reproduced by model output

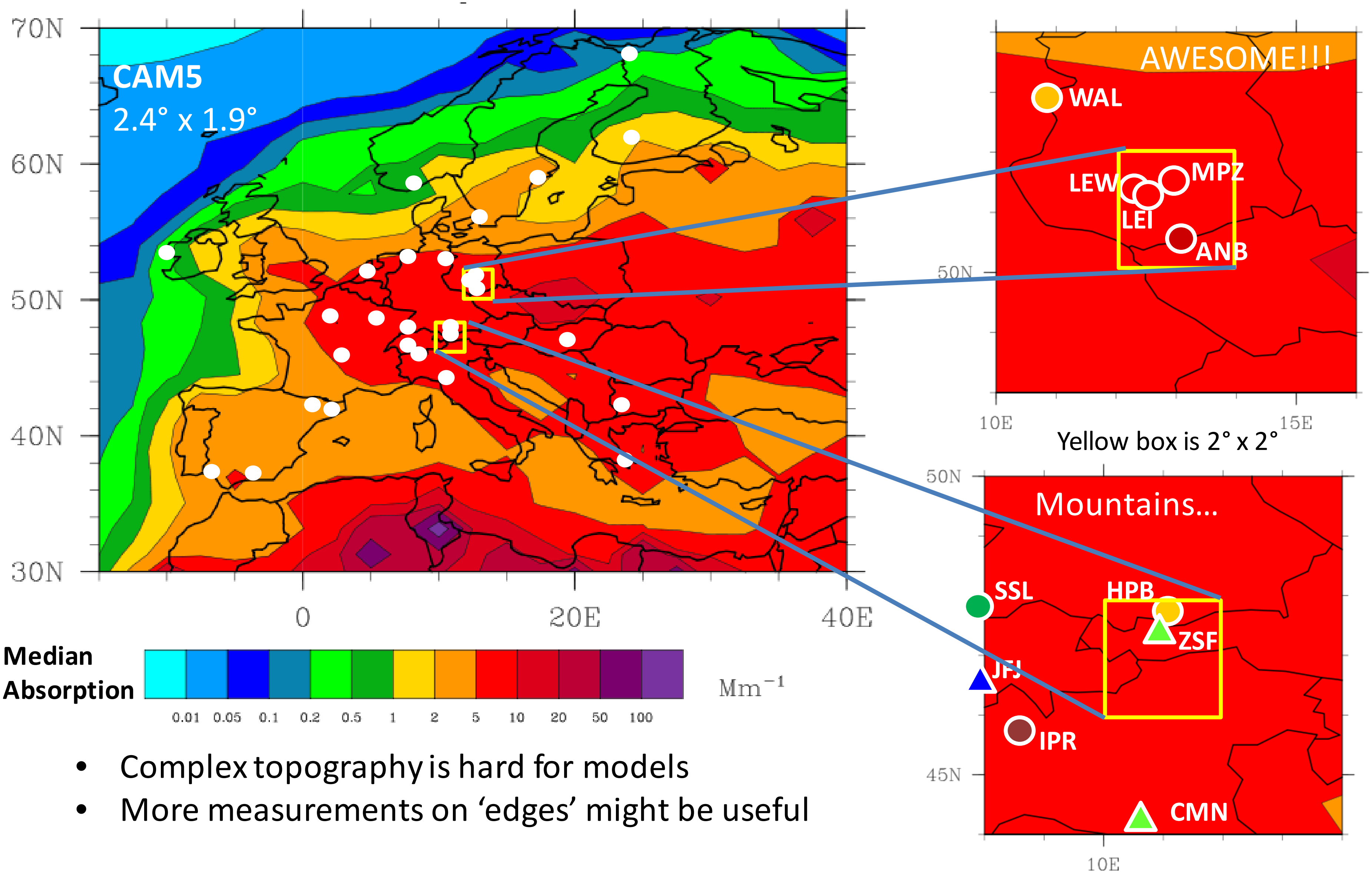
Potential Issues for In-situ/Model Comparisons

- **Point measurement vs Area prediction**
  - *"…sites dominated by local pollution or sites near mountains are expected to introduce unwanted biases with respect to the regional average" (Kinne et al., 2006)*

- **Meteorological adjustments**
  - *e.g., Measurement to ambient conditions (T, P) or model to STP*

- **Averaging**
  - *In-situ daily: 0 UTC-24 UTC, time=start of average*
  - *Model daily: ??*

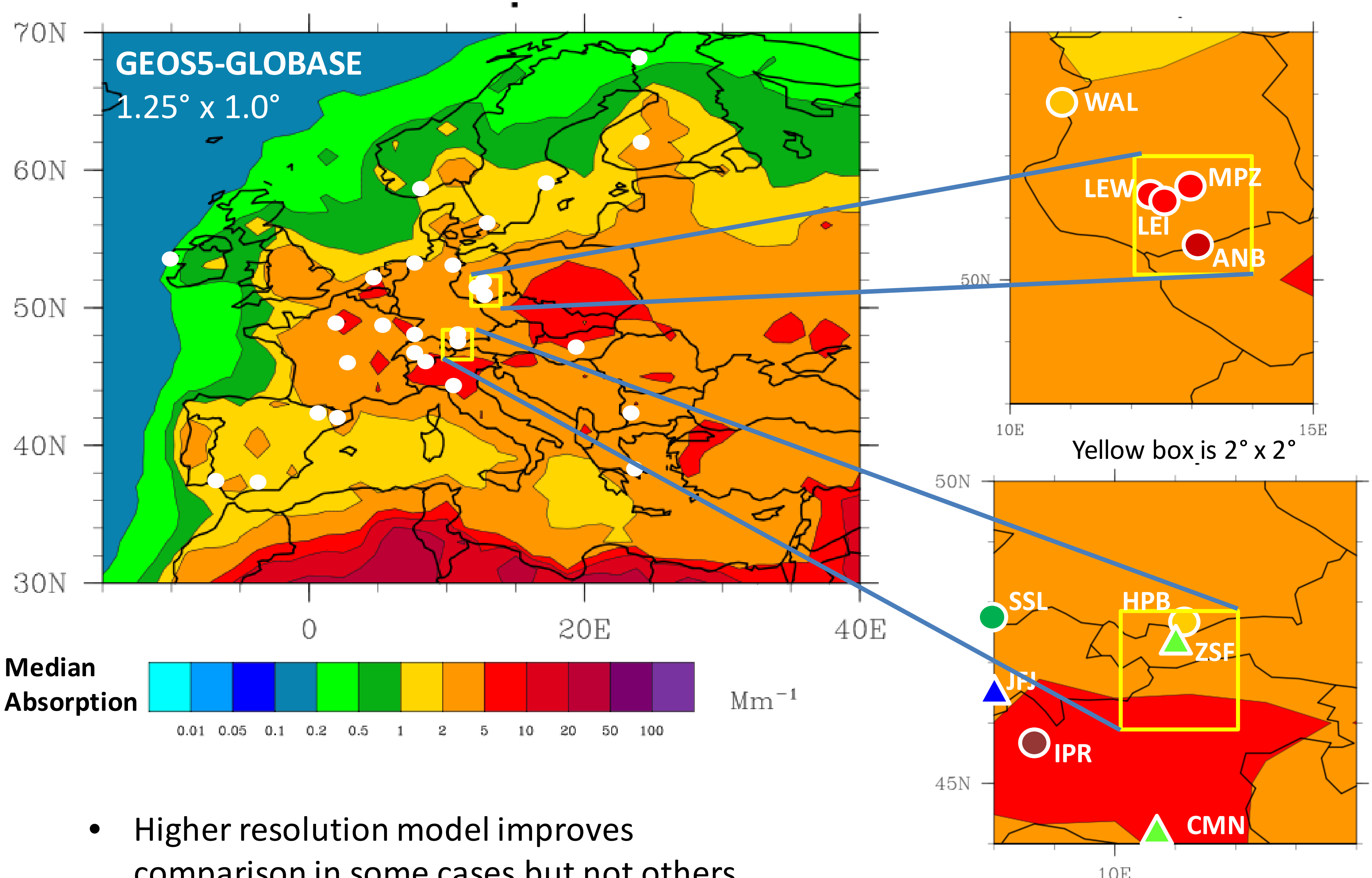
Aerosol Climatology: Sub-grid variability



- Complex topography is hard for models
- More measurements on 'edges' might be useful

Note: Only Europe has high enough density of in-situ measurements to look at sub-grid variability.

Aerosol Climatology: **Sub-grid variability**

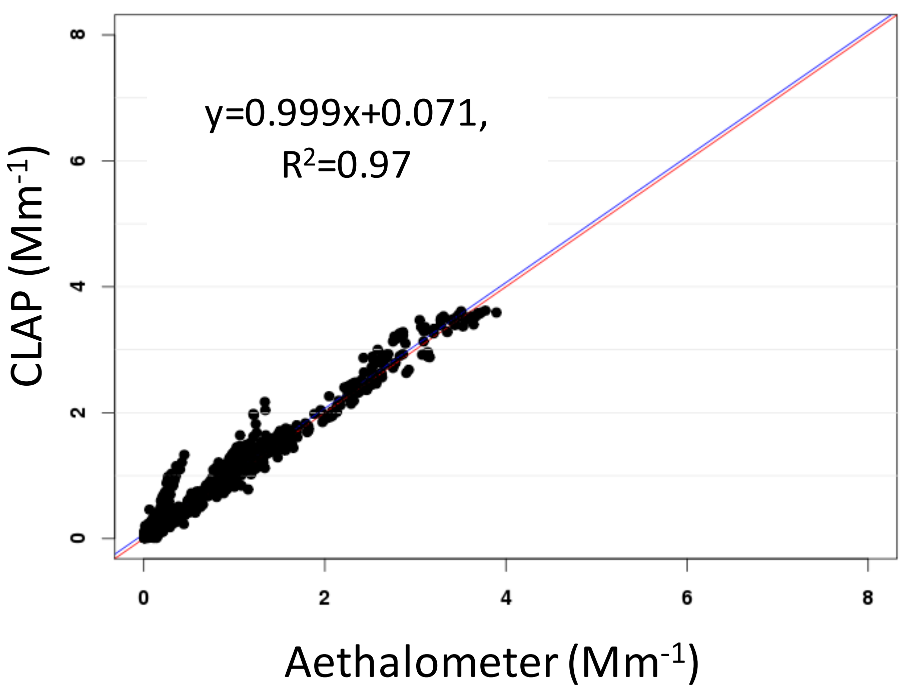


- Higher resolution model improves comparison in some cases but not others…
- Topography is still an issue.

Aethalometers

- Currently, have not included aethalometer data sets due to correction scheme issues
- Including aethalometer data increases number of sites with in-situ absorption data

Barrow, Alaska



Preliminary analyses suggest properly corrected aethalometer data are in good agreement with better characterized aerosol absorption instruments.