AeroCom INSITU Project: Comparison of aerosol optical properties from in-situ surface measurements and model simulations

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Model output providers:
CAM5 (Zhang et al.), ECHAM6-SALSA (Meilonen et al.), MERRAero (Randles et al.), OsloCTM2 (Myhre et al.), GOCART (Chin et al.), MPIHAM (Stier et al.), SPRINTARS (Takemura et al.), TM5 (Krol et al.)

Monitoring stations and in-situ data providers:
Environment Canada (ALT), Univ Puerto Rico (CPR), South African Weather Service (CPT), US Dept of Energy (SGP, GRW), Chinese Academy of Met Sciences (WLG), Finnish Met Institute (TIK), Stockholm Univ & INRASTES (ZEP), NOAA (BRW, MLO, BND), Applachian State Univ. (APP), Univ. Veszprem (KPS)

OBJECTIVE

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

MOTIVATION

Improve the predictive capability of global climate models

- Models often cannot reproduce surface aerosol trends or annual cycles (e.g., Shindell et al., 2008), but the models still are used for predicting atmospheric behavior/climate
- In-situ absorption measurements provide another opportunity for bounding black carbon estimates
- High temporal resolution, long-term in-situ measurements may be useful for evaluating model parameterizations of atmospheric processes

Description

Three-tiered project:

I. Evaluation of dry, in-situ optical parameters (this talk)

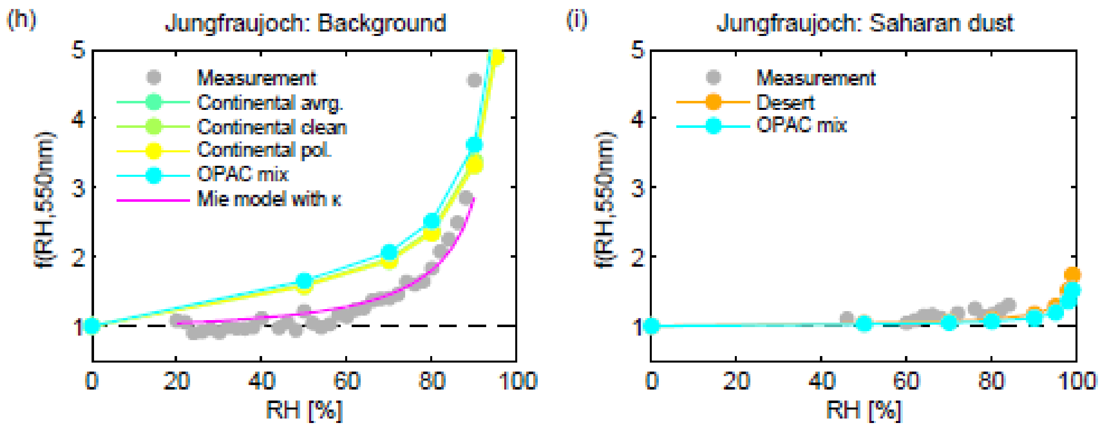
II. Trend analysis of dry optical properties

Extend in-situ trend analysis of Collaud Coen et al. (2011)

Compare with trends in model time series

III. Evaluation of hygroscopicity of aerosol scattering

Paul Zieger&HC Hansson (Stockholm U) and Gloria Titos (U of Granada)



From Zieger et al. (2013)

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

Process

- Request high frequency model output consistent with measured in-situ aerosol parameters

- Review and develop benchmark data sets for in-situ optical data
  → independent data review leads to improved data quality
  → modeler/data provider interaction is valuable

- Sample model output at station locations

- Compare model output and measurements

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

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.

Talk Outline

- In-situ data
  - → Measurements
  - → Locations
  - → Aerosol parameters
- Models
  - → Model output requested
  - → Model participation status
- Preliminary comparisons
  - → Aerosol Climatology
  - → Aerosol Characteristics and Behavior

- Where do we go from here?

In-situ Aerosol Optical Properties

Mauna Loa aerosol rack

Aerosol light scattering

- 3λ nephelometer (TSI or Ecotech)
- Total & hemispheric back-scattering

Aerosol light absorption

- Instruments: MAAP, PSAP, or CLAP
- Single and multi-wavelength

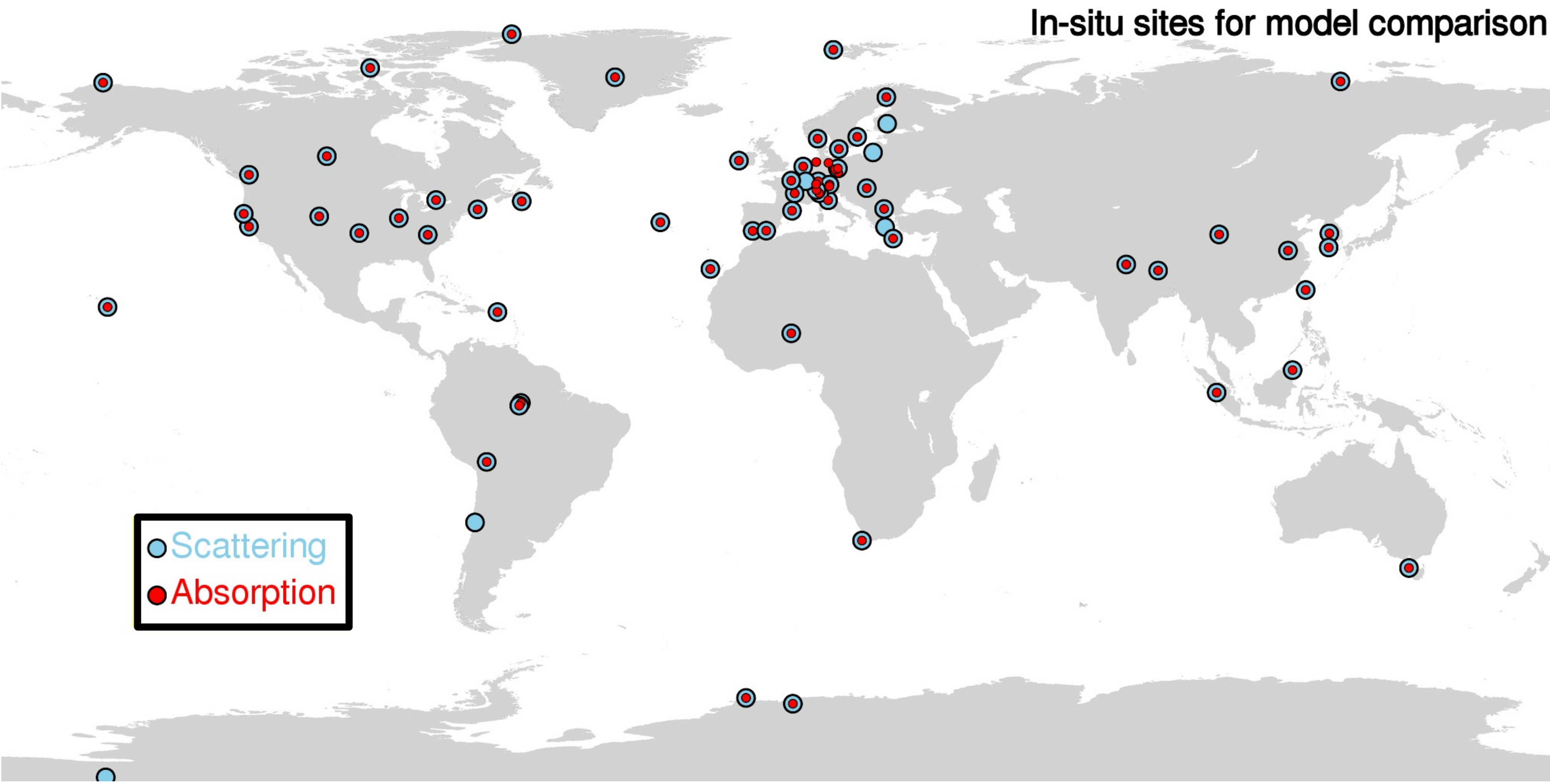
Data Collection

- Low RH (<40% RH)
- 1 min resolution (typically)
- 1 & 10 um size cuts (usually)

Data Processing

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

In-situ Measurements – All Years



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

→Currently working on getting data into consistent format – ‘benchmark datafiles’

Optical Parameters Available for Comparison

Low RH surface data from A2.CTRL runs in AeroCom database did not capture breadth of parameters available from in-situ measurements:

- Climatically important phase function parameterization (e.g. asymmetry parameter)
- Source characterization (Ångström exponents, fine mode fraction)

IN-SITU	MODEL OUTPUT
Absorption	☺ abs550dryaer
Scattering	☺ f(abs550dryaer, ec550dryaer)
Extinction	☺ ec550dryaer
Single scattering albedo	☺ f(abs550dryaer, ec550dryaer)
Scattering Ångström exponent	☆ f(ec440dryaer, ec550dryaer)
Absorption Ångström exponent	☆ f(abs440dryaer, abs550dryaer)
Phase function parameterization	☆ asydryaer
Fine mode fraction	☆ f(ec550dryaer, ec550dryaer1)

Description of data request can be found at:
https://wiki.met.no/_media/aerocom/INSITU_AeroComPIII_description.pdf

AeroCom Models Used in this Analysis

	Project	Highest freq	Gridbox size	Year(s)
CAM5	P3_INSITU	Hourly	2.4° x 0.9°	2010
ECHAM6-SALSA	P3_INSITU	Hourly	1.8° x 0.9°	2010
MERRAero	P3_INSITU	3-Hourly	0.6° x 0.3°	2010
OsloCTM2	P3_INSITU	Daily	2.8° x 2.8°	2008
GOCART	P3 (A2.CTRL)	Hourly	2.5° x 2.0°	2000-2007
MPIHAM	P3 (A2.CTRL)	Daily	1.8° x 0.9°	2006-2008
SPRINTARS	P3 (A2.CTRL)	Daily	1.1° x 1.1°	2000-2008
TM5	P3 (A2.CTRL)	Daily	3° x 2°	2000-2009

Models in waiting: GEOS-Chem, ULAQ-CCM, ECHAM-HAM, EMEP, NorESM2/CAM5-Oslo, ECHAM-HAMMOZ, HadGEM

Join us!!

Preliminary Comparisons

Can compare models/measurements from several perspectives…

CLIMATOLOGY	Tells us how well the model is doing at given locations
CHARACTERISTICS & BEHAVIOR	Tells us how well the model is simulating aerosol aging processes, chemistry, sources, transport, etc.
???	What other diagnostics should we consider to analyze the models?

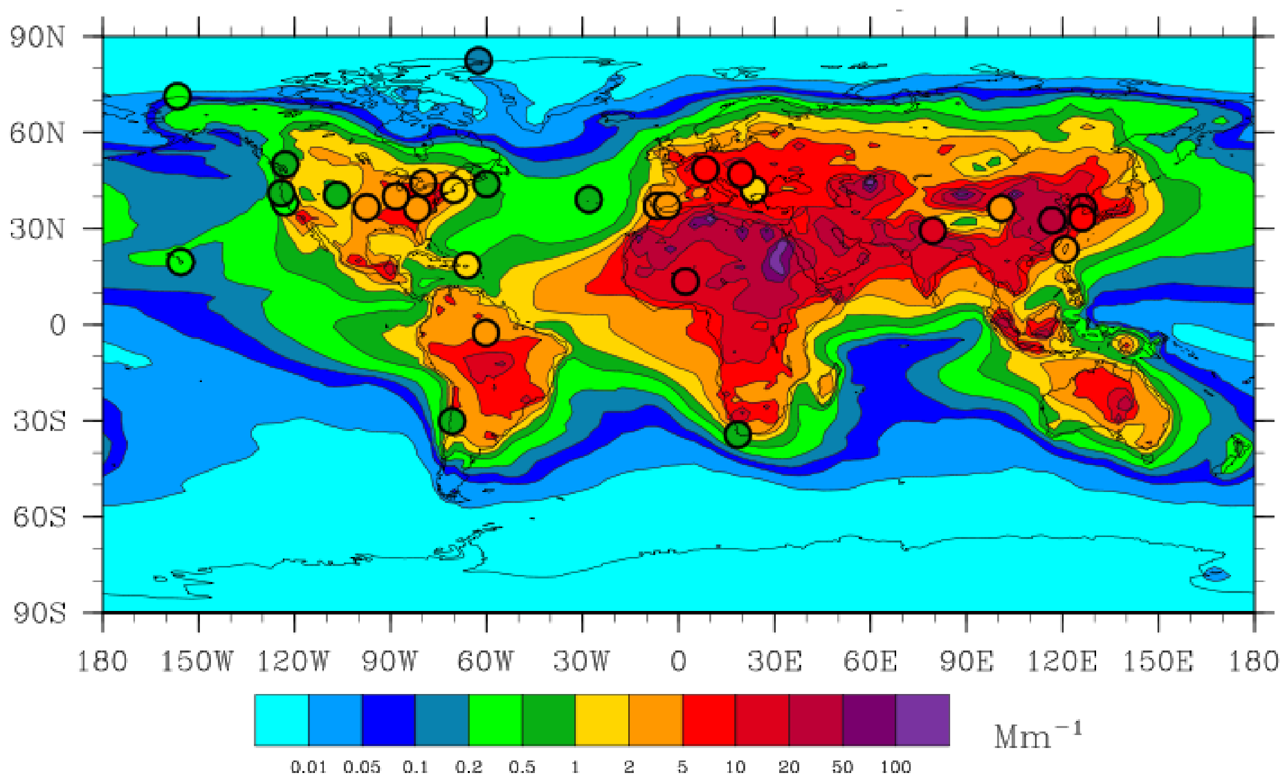
Comparisons of Aerosol Climatology

- *Annual means*
- *Seasonality*

Caveats!
PRELIMINARY:
Only showing results from some models, some measurements
Using all available in-situ data (currently not matching model data years)

Aerosol Climatology: **Annual Mean Absorption**

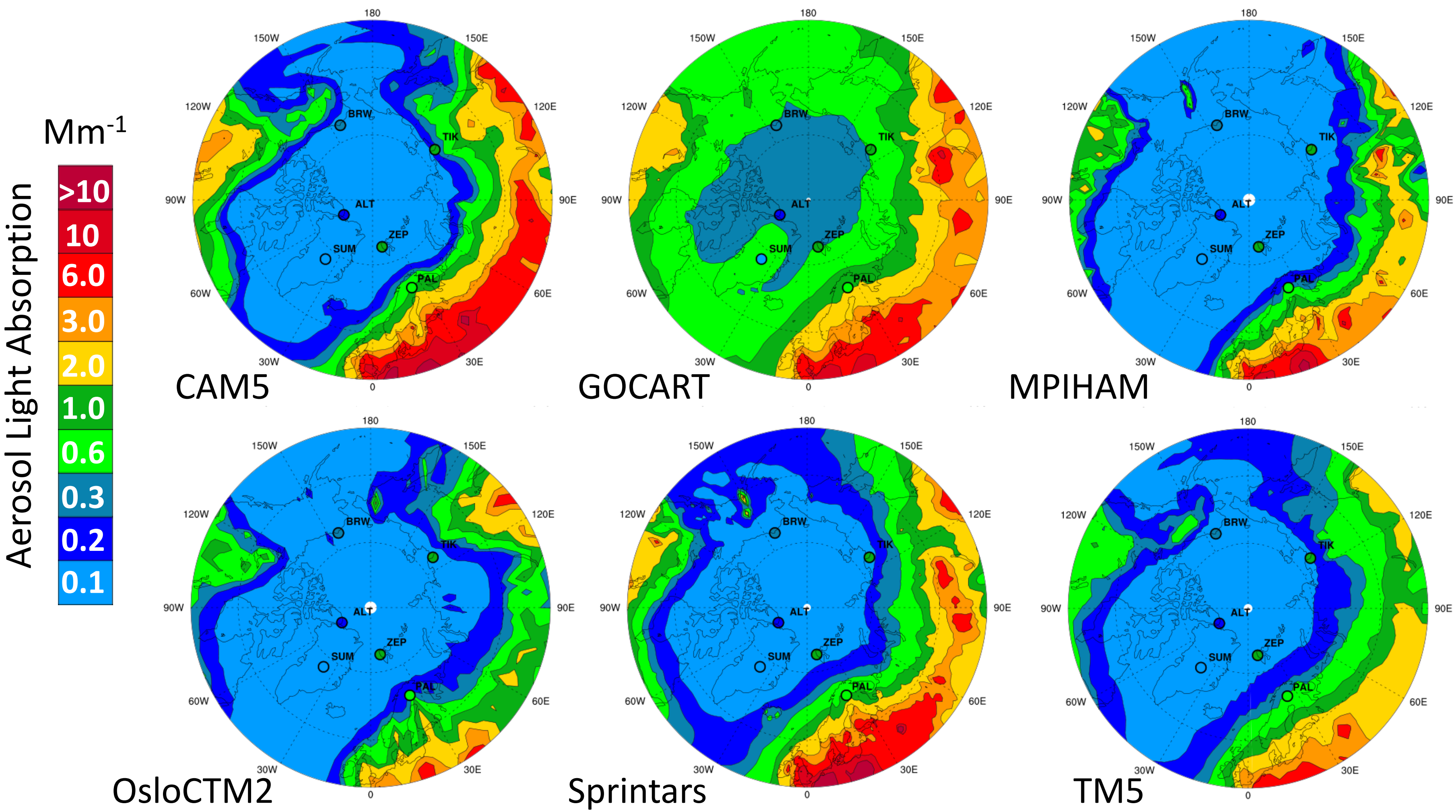
OsloCTM2



--NOAA collaborative network sites only
--Model = 2008
--In-situ = variable years
--Log color scale

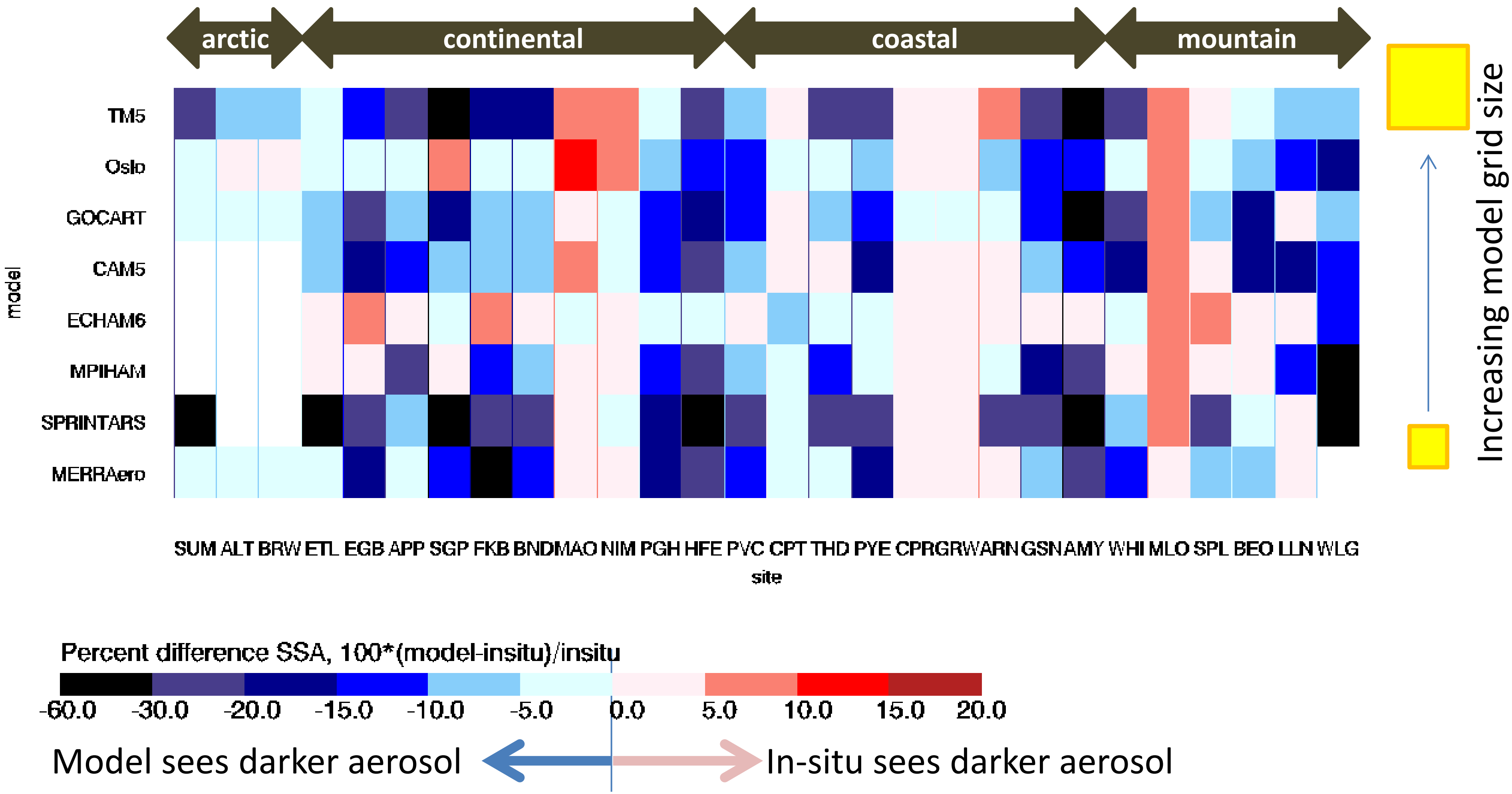
- General pattern of absorption similar for models and in-situ
- Biggest differences may be observed for some high altitude and marine sites

In-situ/Model absorption comparison – Arctic



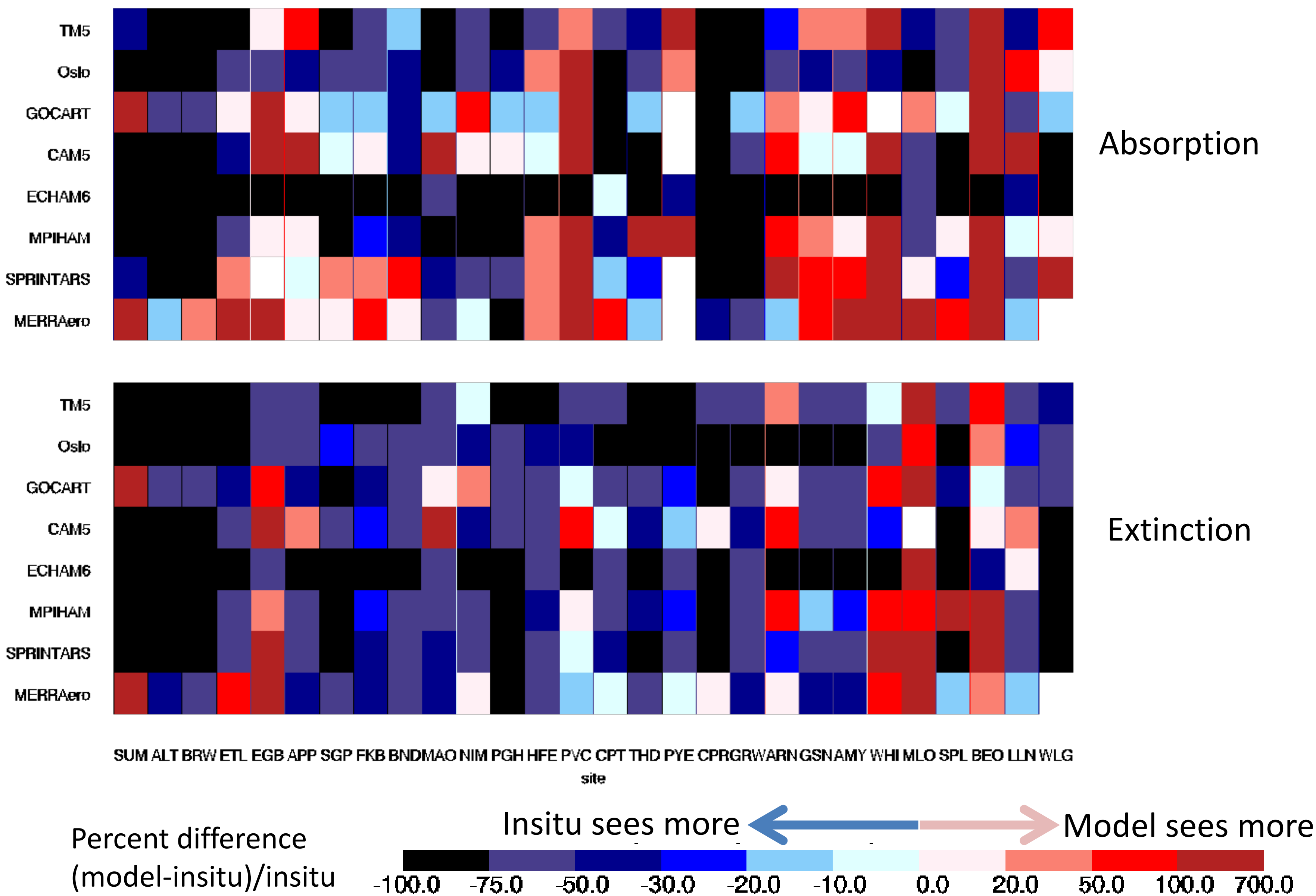
- Arctic is complex aerosol environment
- Models tend to under-estimate absorption relative to Arctic in-situ observations

Aerosol Climatology: Annual Mean SSA



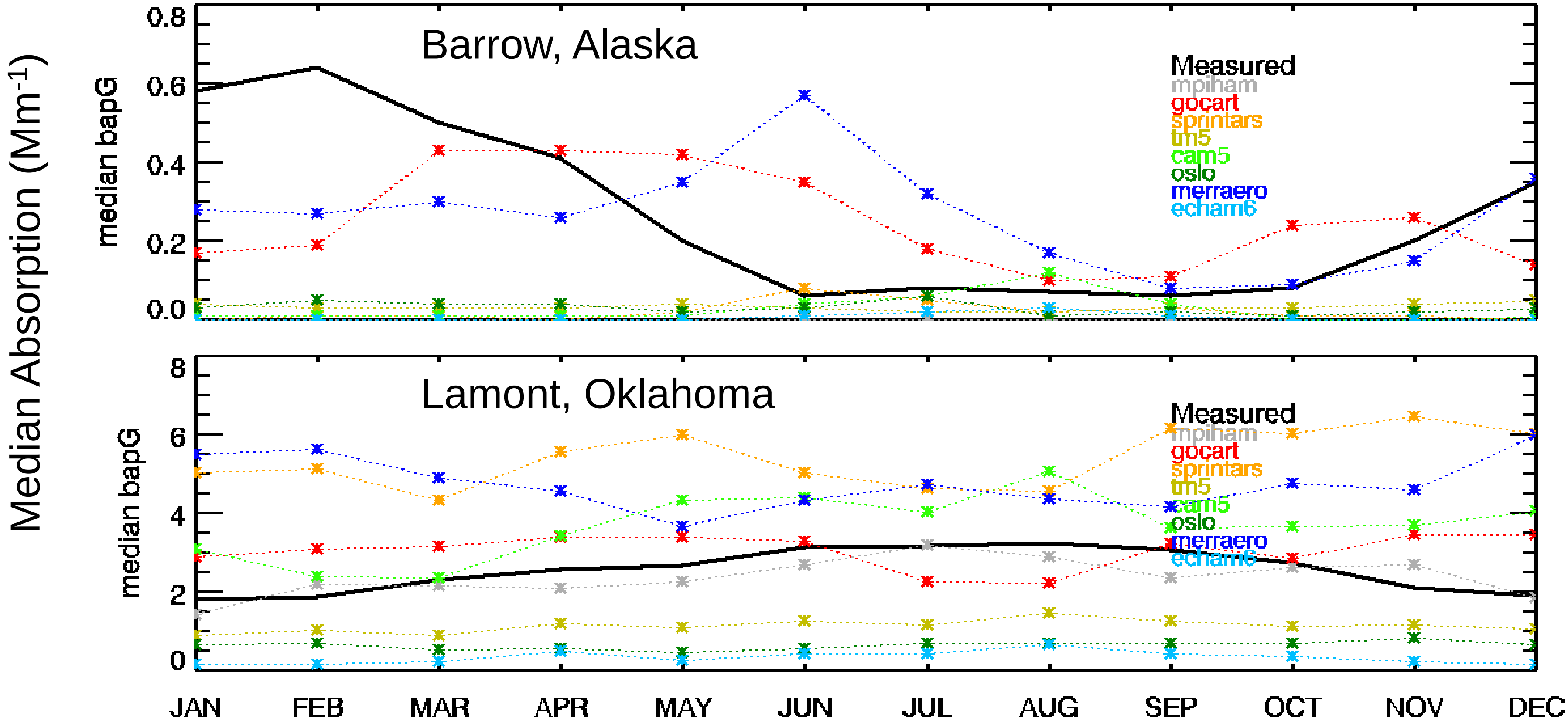
- Models tend to predict lower SSA than in-situ observations
- No obvious dependence on model grid size

Aerosol Climatology: Absorption and Extinction



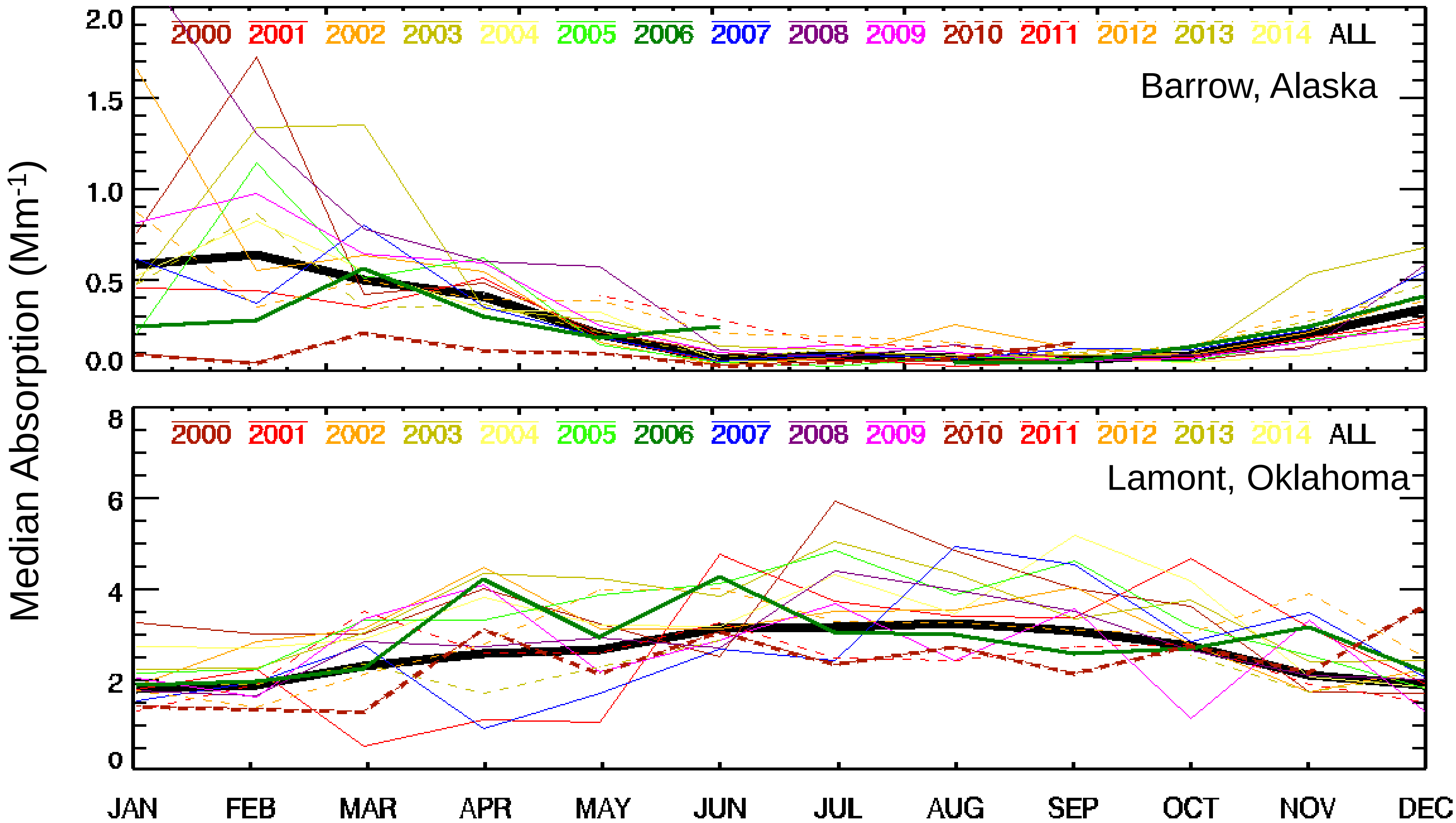
Aerosol Climatology: **Seasonality**

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 Climatology: Inter-annual Variability



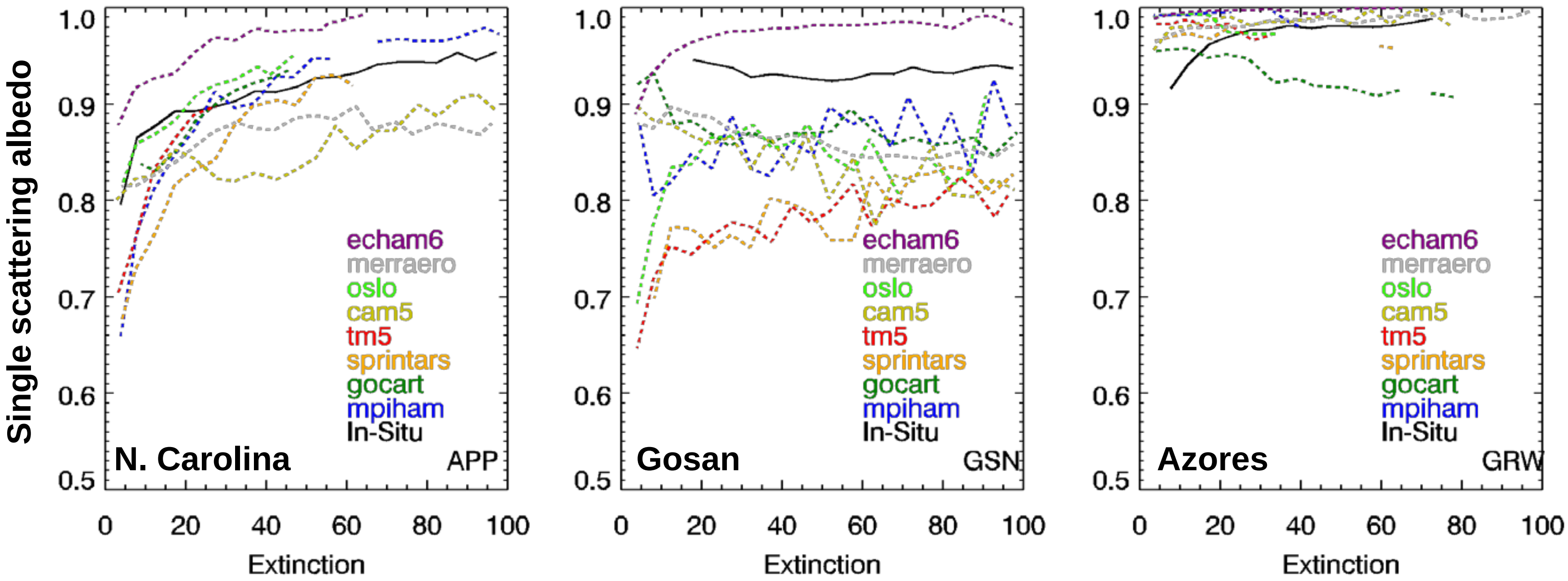
Plot shows only in-situ data for two sites with long term records
Thick black lines are 'in-situ' lines from previous slide.
→inter-annual variability is very site dependent

Comparisons of Aerosol Characteristics & Behavior

- *Systematic Relationships*
- *Lag-Autocorrelation/Persistence*

Aerosol Behavior: Systematic Variability

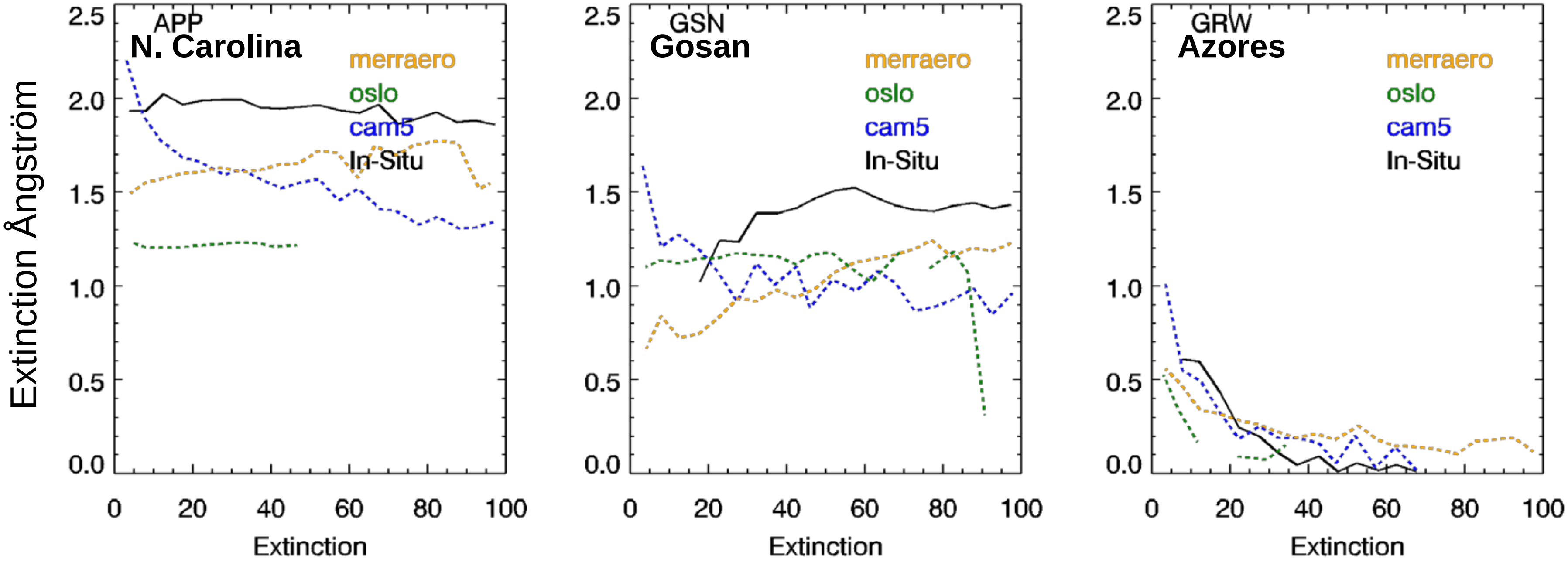
Systematic variability can provide information about aerosol processes and sources



Lower loading corresponds to darker (and smaller) particles
→ preferential scavenging of large, scattering aerosol by clouds/precipitation?

- Models tend to underestimate SSA (i.e., darker aerosol than in-situ)
- The co-variance observed between SSA and extinction for in-situ data is not necessarily reproduced by model output

Aerosol Behavior: **Systematic Variability**

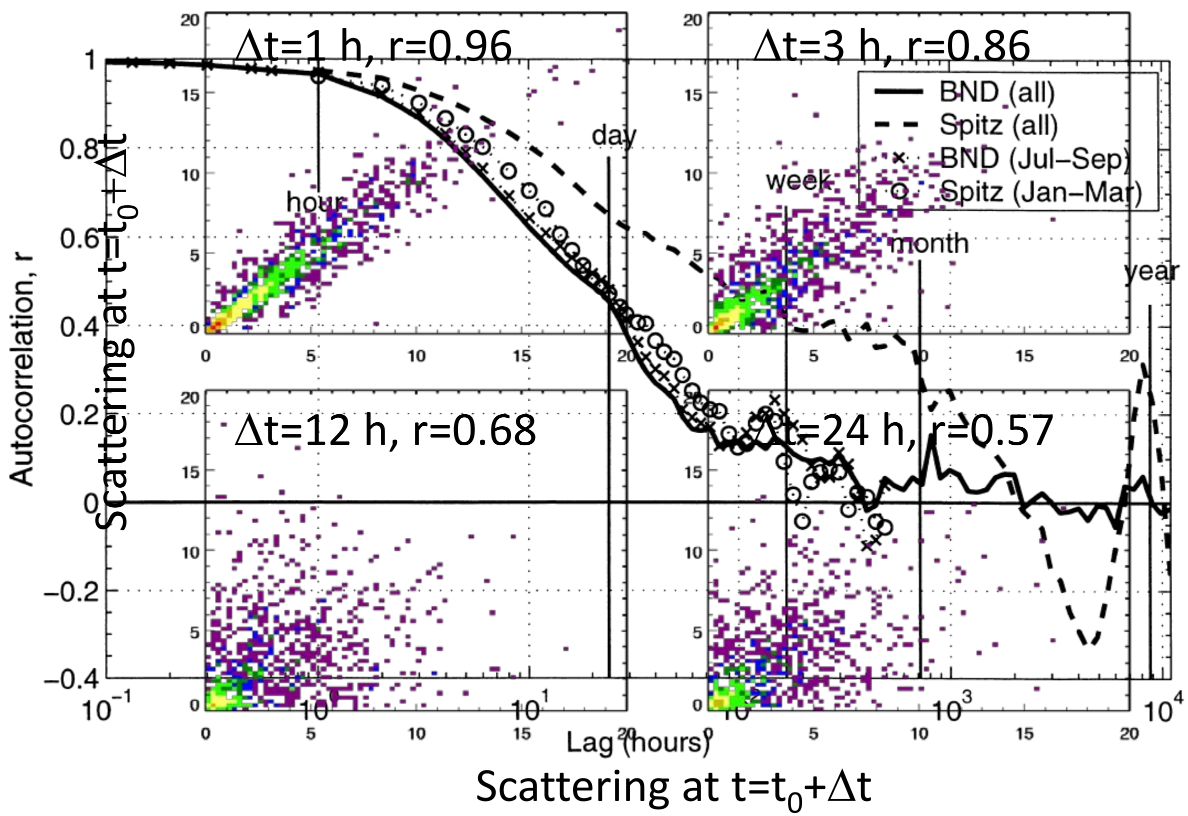


Relationship between aerosol loading and aerosol size distribution changes with location (i.e., aerosol type)

- Models tend to underestimate Ångström exponent (i.e., models predict larger aerosol than in-situ observes)
- Systematic relationships observed between Ångström exponent and extinction for in-situ data are not necessarily reproduced by model output

Aerosol Behavior: **Lag-Autocorrelation**

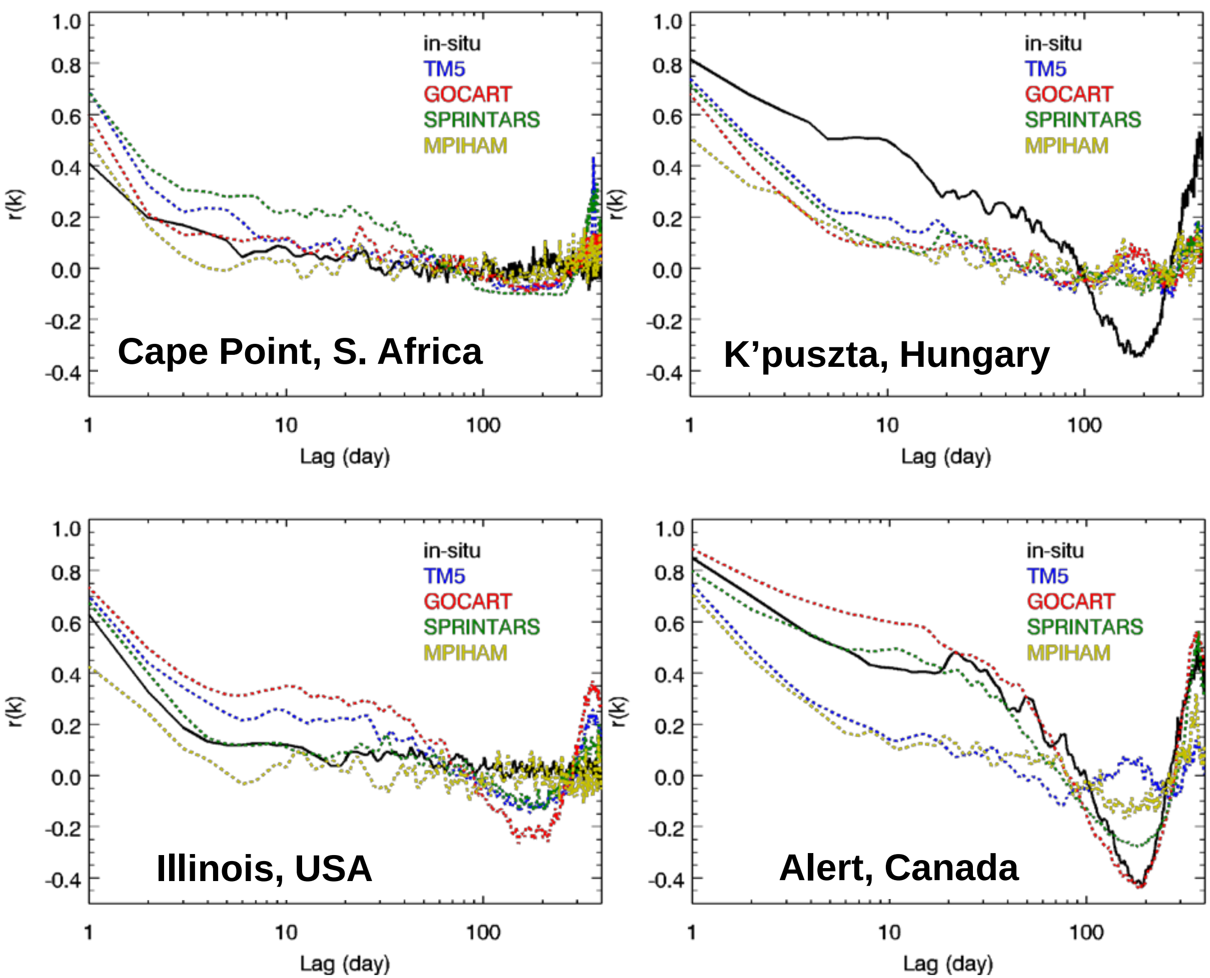
- Constrain comparisons by identification of expected 'best case' agreement between data sources with different temporal/spatial resolution
- Provides information about atmospheric processes, especially for higher frequency data (e.g., NPF, uplope/downslope…)



Lag is the time between measurements being compared (Δt)
'r' is the lag autocorrelation statistic.

Aerosol Behavior: **Lag-Autocorrelation**

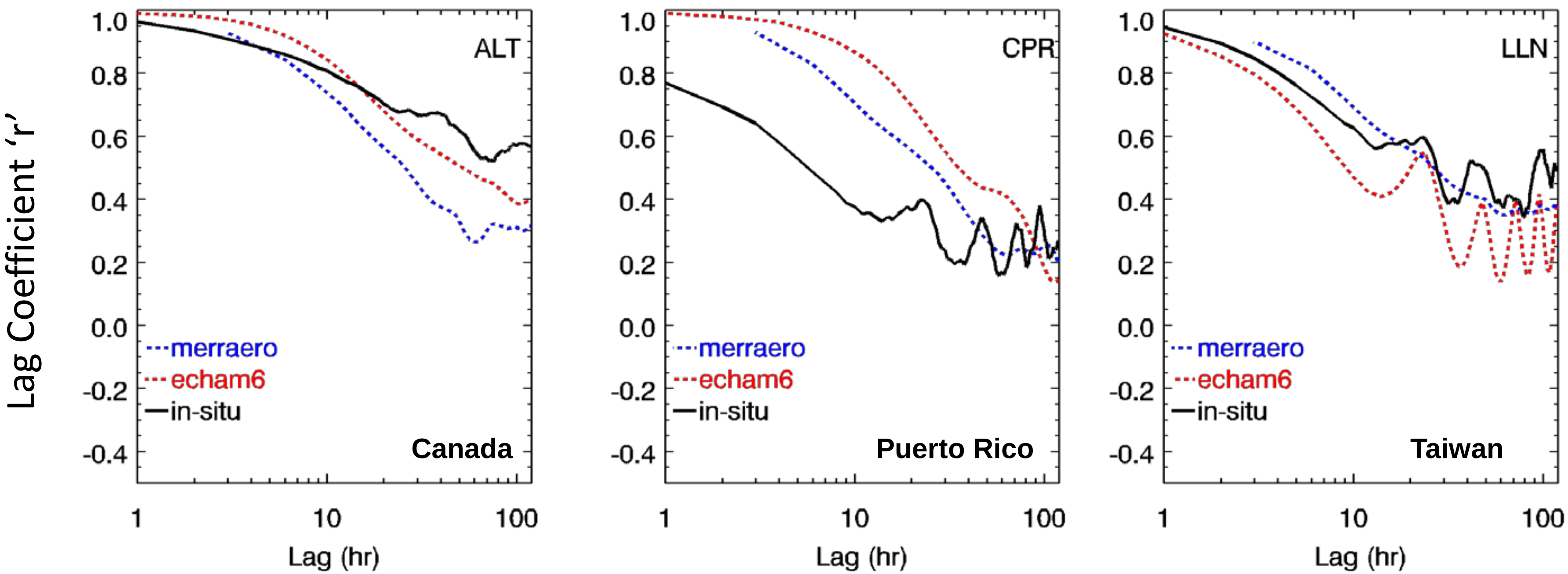
Lag-autocorrelation will vary from site to site as a function of sources, processes and transport affecting the aerosol at that location



- Plots show lag-autocorrelation for dry aerosol extinction
- No consistent pattern relating model/in-situ lag-autocorrelation

Aerosol Behavior: **Lag-Autocorrelation in Absorption**

High frequency data + parameter co-variance can highlight atmospheric processes



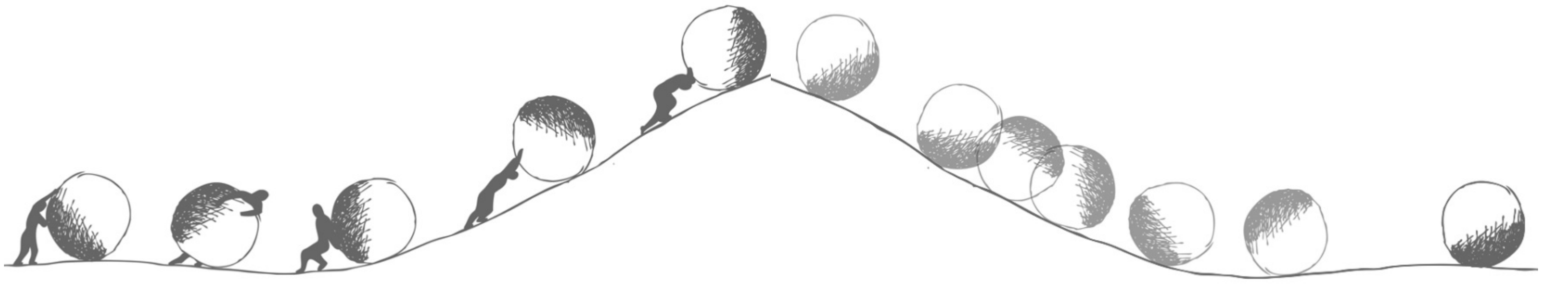
Plots show lag-autocorrelation for dry aerosol absorption

ALT – models and in-situ quite similar

CPR – models miss diurnal cycle observed in in-situ data (on shore/off shore?)

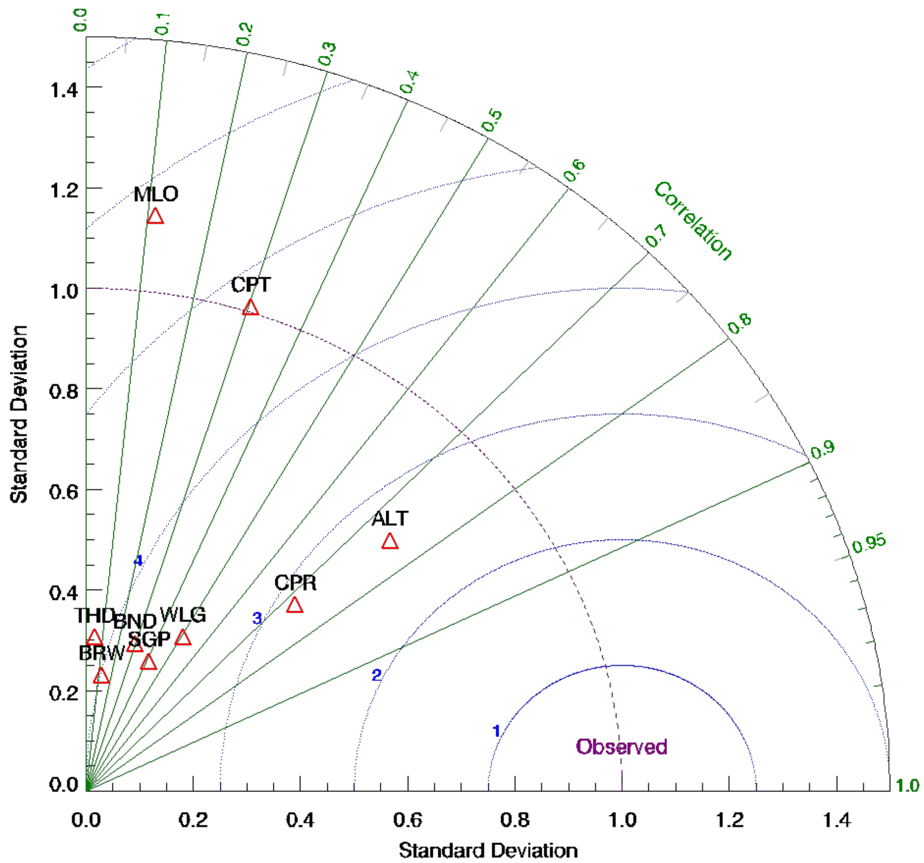
LLN – models behave differently

Where do we go from here?



Follow project progress at https://wiki.met.no/aerocom/phase3-experiments
(there's a link to a google doc under In-situ Measurement Comparison)

Quantifying Model/Measurement Agreement



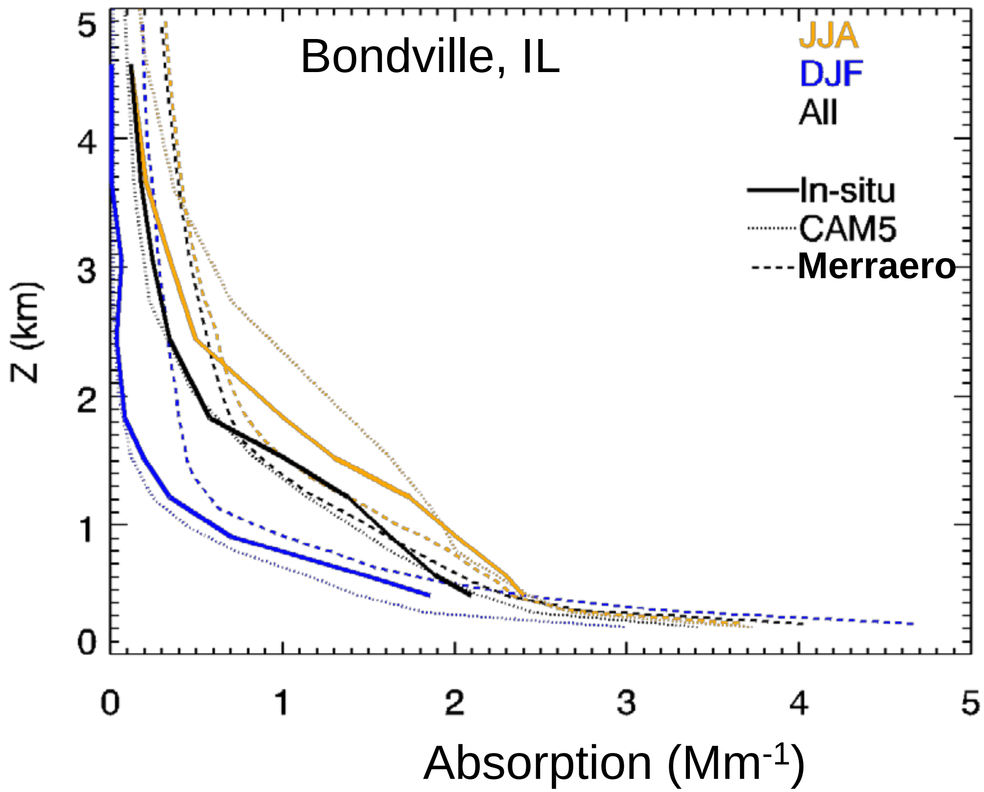
Taylor diagrams provide a way of graphically summarizing how closely a model matches observations.

- Correlation (R)
- Root-mean-square difference
- Standard deviation

Modelled daily scattering (GOCART) tends to under-predict observed 2006 scattering variability at several sites. R<0.8 for all sites.

Various other methods exist for scoring model/measurement comparisons (e.g., Glackler et al., 2008; Murphy and Epstein, 1989).

Beyond surface observations …



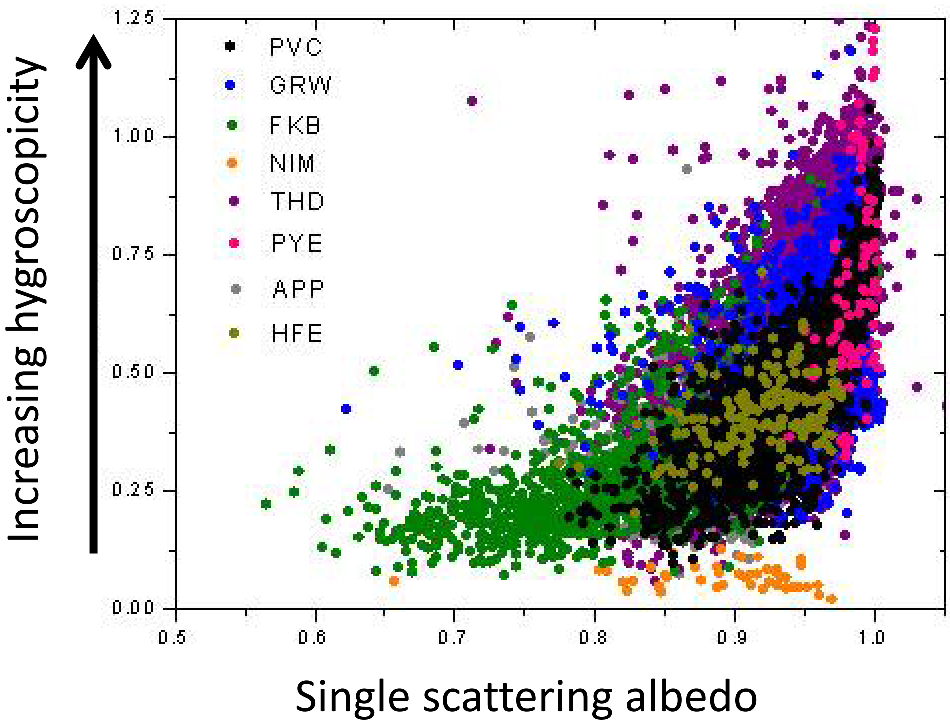
Vertical profile comparisons

- Two sites in central US with long-term vertical profile measurements of in-situ aerosol absorption and scattering.
- Approximately 700 flights over ~program time period
- Stairstep profile from 4.5 km down to 0.5 km agl

→General agreement in terms of seasonality and profile shape

→Biggest model/in-situ discrepancy at surface

Beyond dry observations…



From Titos et al. (2014)
(EGU presentation)

- How well do model simulations of aerosol hygroscopicity compare with measurements?
- Do models reproduce observed relationships between aerosol optical properties and hygroscopicity ?
- How well do models agree amongst themselves in terms of aerosol hygroscopicity?
- How well does ambient RH (or dewpoint) agree amongst models and measurements?

Model Output Wish List

- Spectral scattering and absorption (dry, surface aerosol)
- Indicator of phase function (e.g., asymmetry parameter, backscatter fraction or upscatter fraction) for dry, surface aerosol
- Submicron scattering and absorption (dry surface aerosol)
- RH (only some models output daily specific humidity)
- Output for specific locations (i.e., GAW sites)
- Higher frequency (hourly!) data

Please join us!
Description of data request can be found at:

https://wiki.met.no/_media/aerocom/INSITU_AeroComPIII_description.pdf

Takeaways

- Potential for lots of measurement/model comparisons
- Climatological comparisons tell us how models are doing now and may identify regions of difficulty for models
  - →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 processing
- Looking forward to a long and fruitful collaboration…

Questions?

Comments?

Let's Discuss!

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

Extra slides

To do:

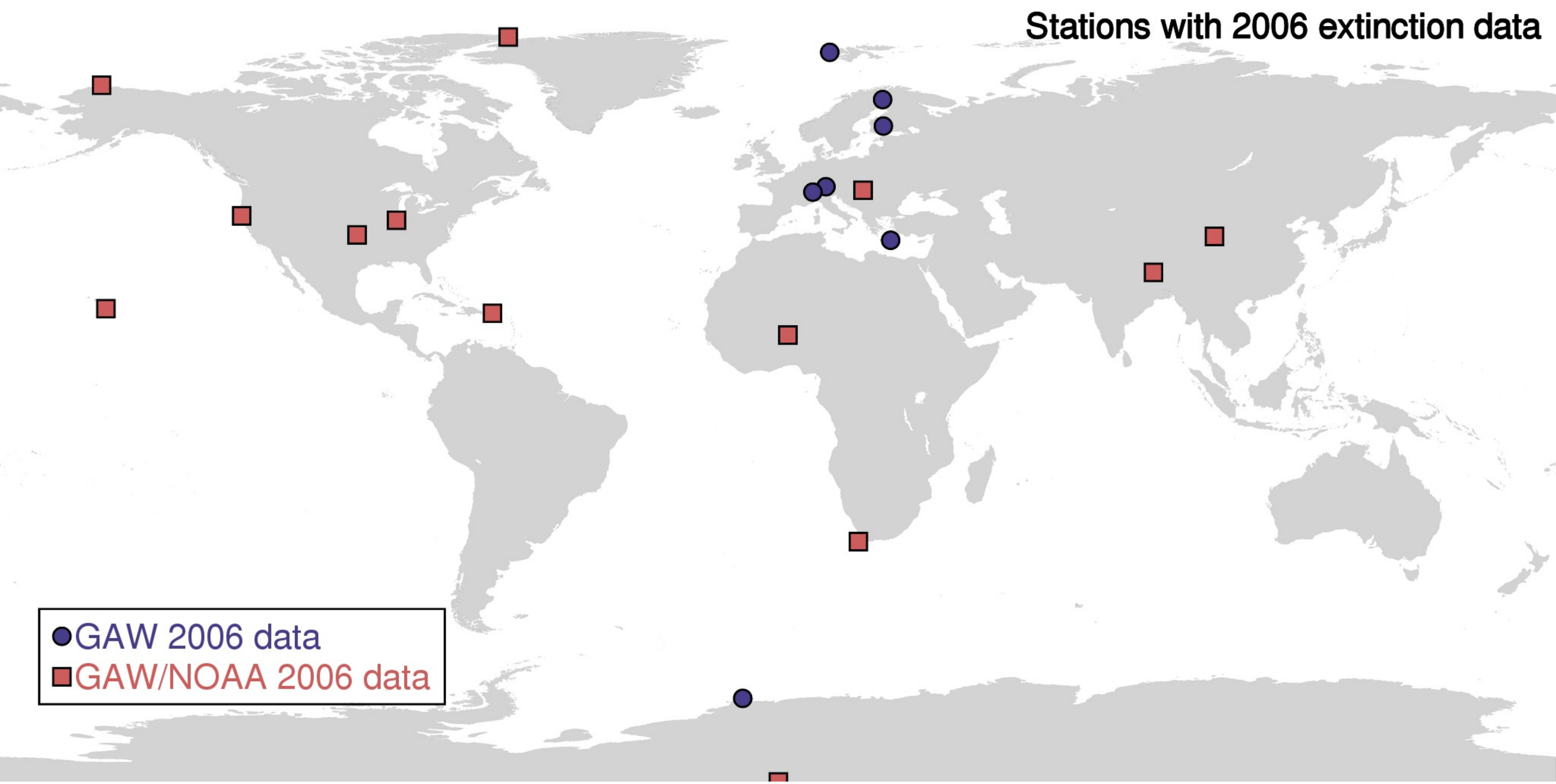
Incorporate additional ~40 stations into analysis

Incorporate additional model output

Evaluate sub-micron fraction, absorption angstrom asymmetry

More interaction with modelers!

In-situ Measurements – 2006



- Sites with both scattering AND absorption measurements in 2006
- Data may not be in EBAS database

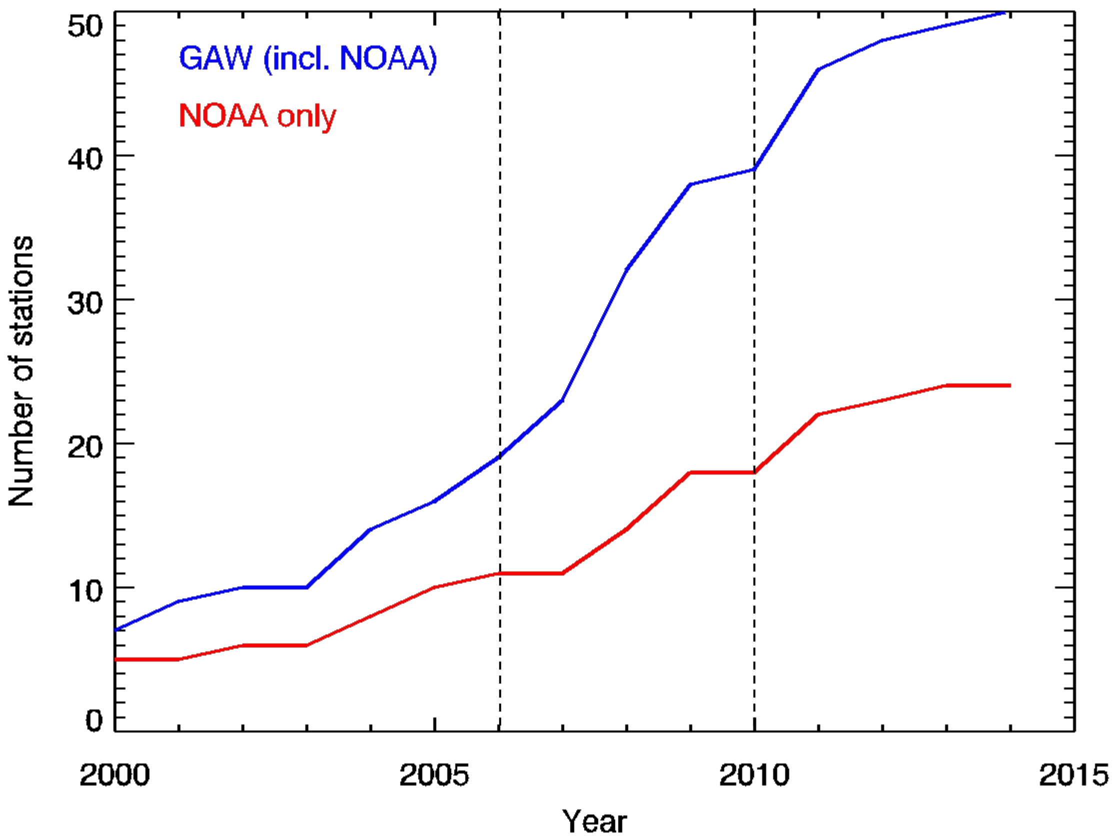
Potential Issues for In-situ/Model Comparisons

- **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, RH)*

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

Number of Monitoring Stations is Growing!

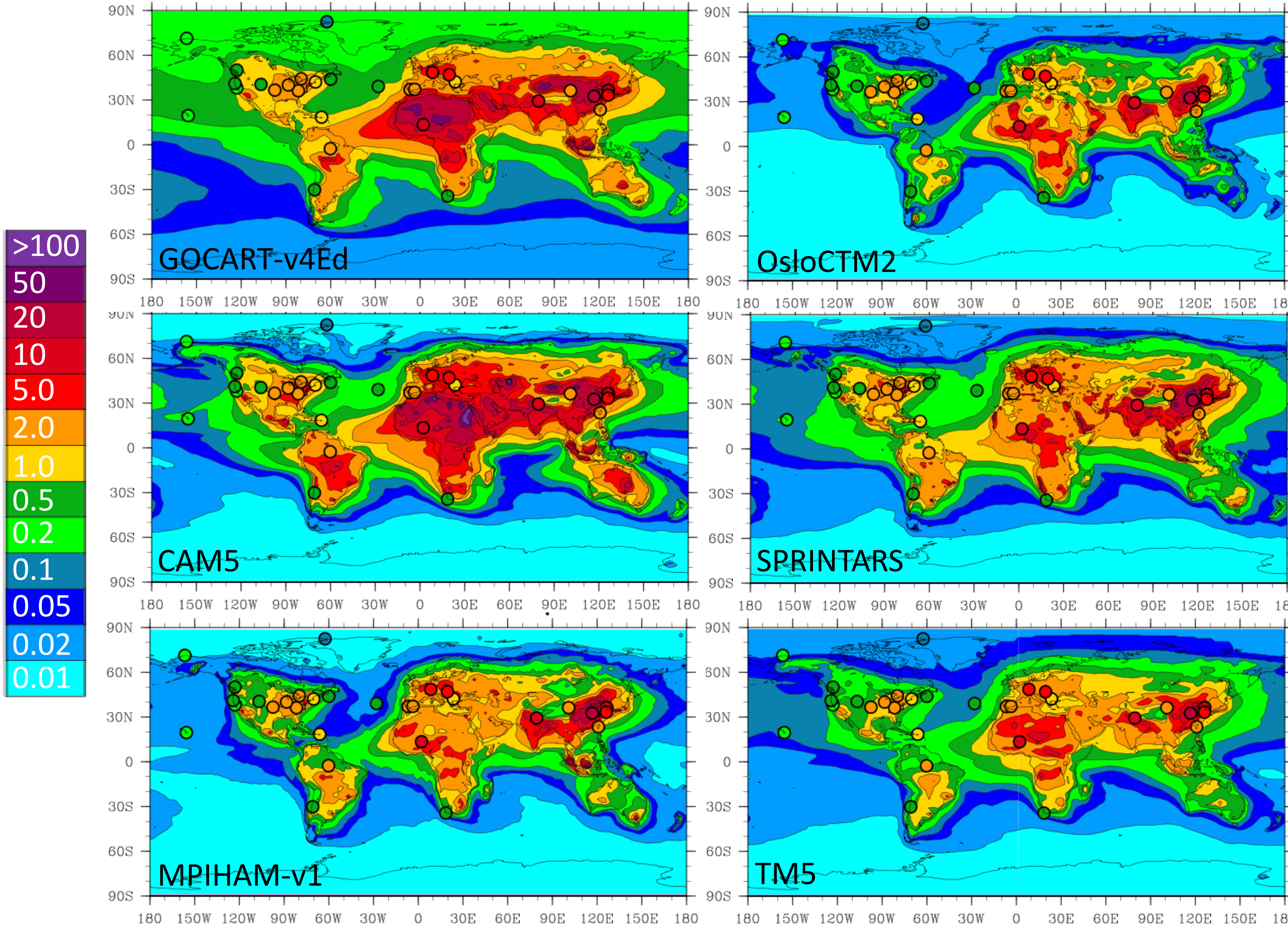


Plot shows stations with simultaneous scattering and absorption data*

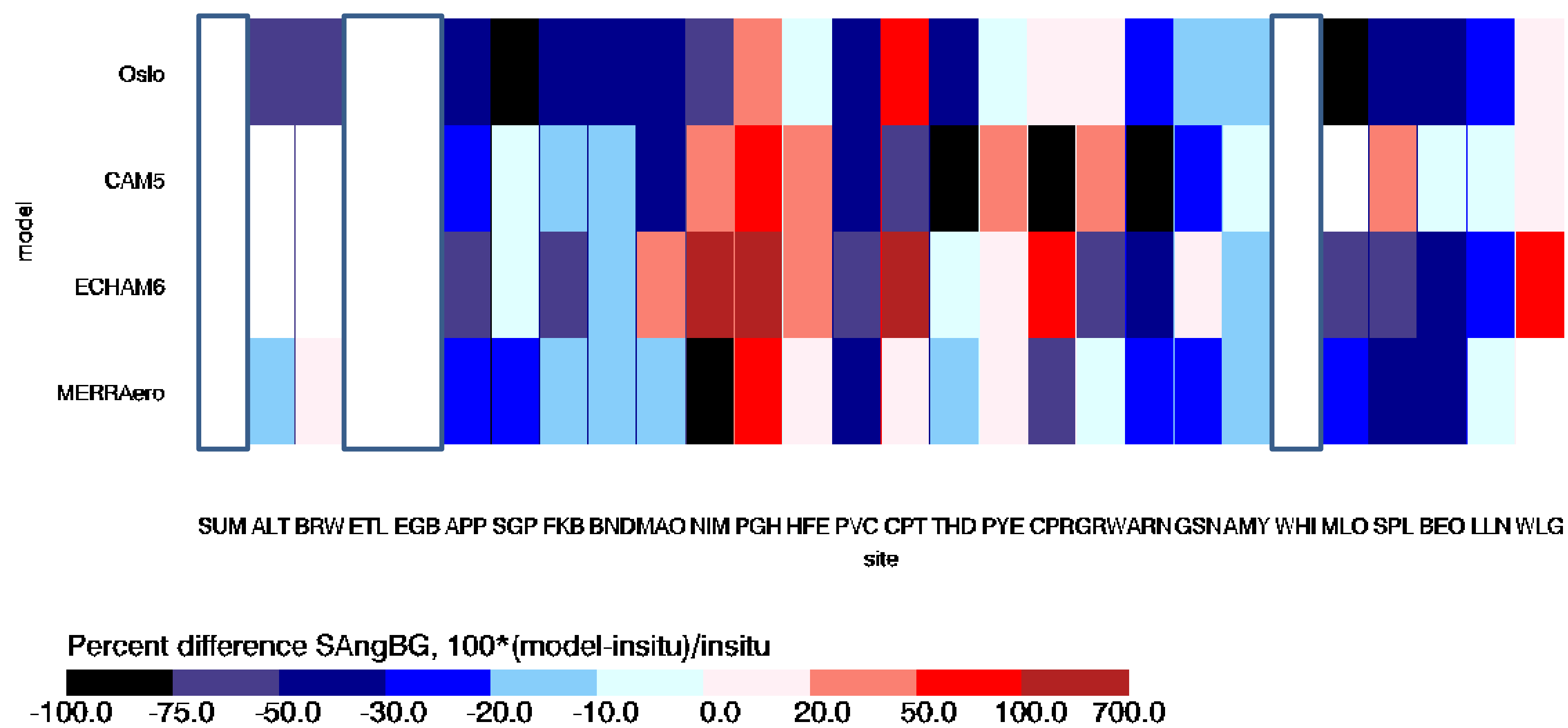
*Data may not be in EBAS database

- Number of stations almost doubled from 2006 to 2009
- 2006 is not ideal for model/in-situ measurement comparison

In-situ/Model absorption comparison – Global



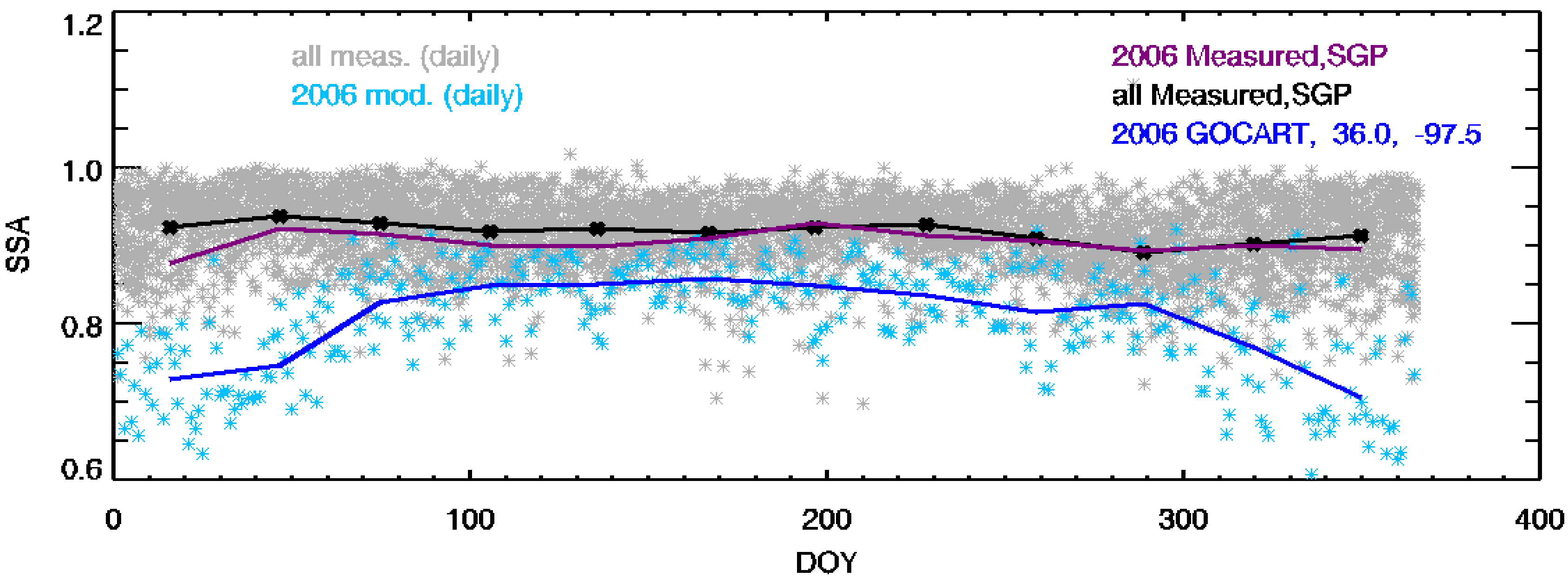
Quilt plot for scattering Angstrom exponent (blue/green)



Blue →model sees bigger particles
Red →in-situ sees bigger particles

Aerosol Climatology: **Seasonality**

Much AeroCom model output focuses on 2006; many in-situ sites start after 2006

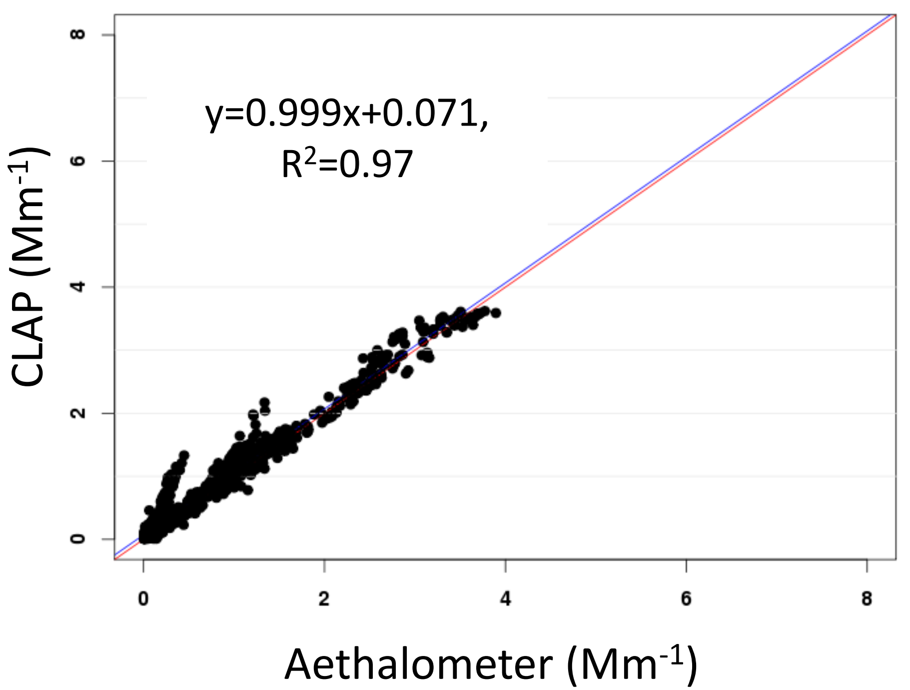


- Model predicts darker aerosol (lower SSA) than suggested by in-situ observations
- Model predicts seasonal variation which is not observed by in-situ measurements
- Compare 2006 model output with in-situ data for different years (for SSA only?)

Aethalometers

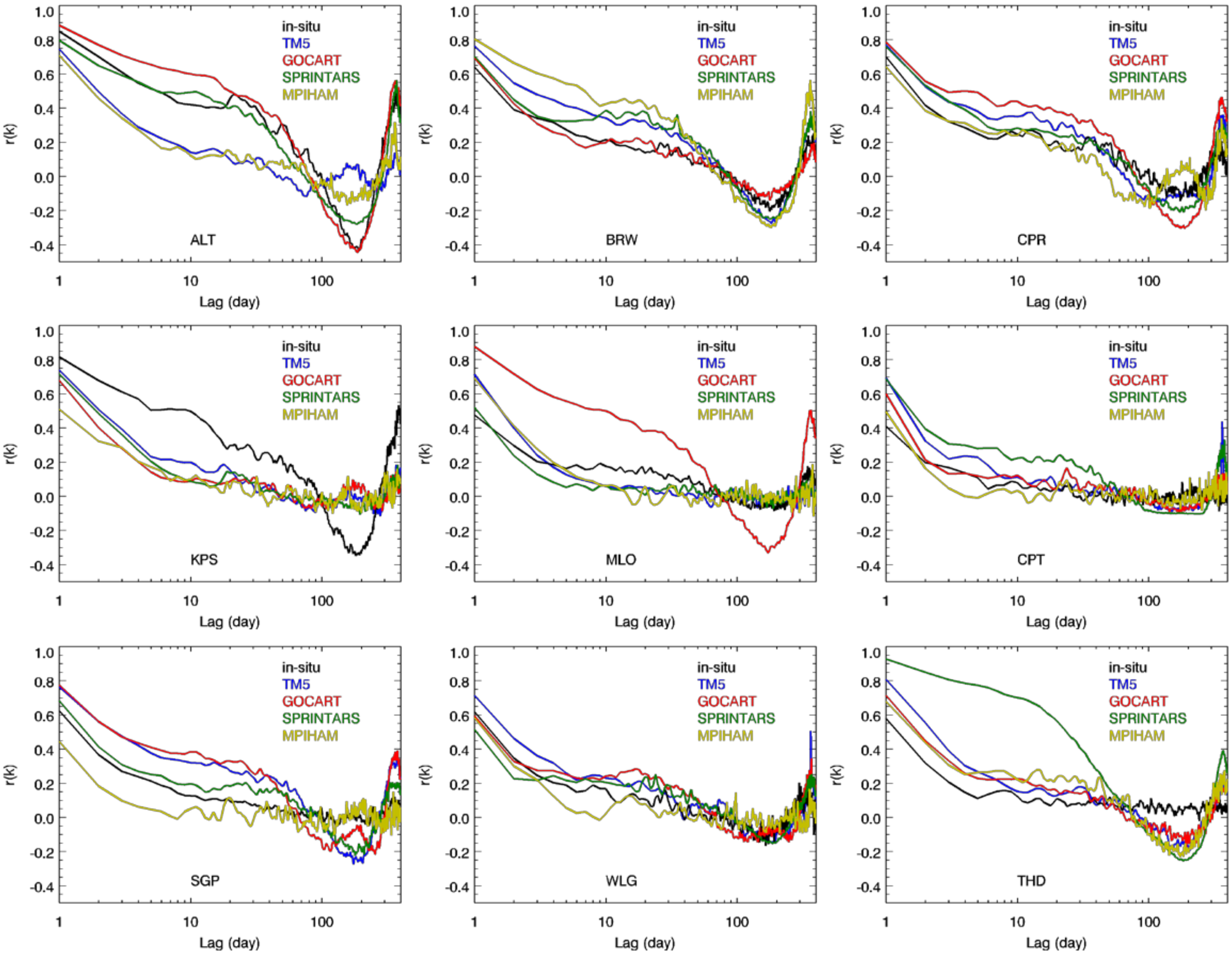
- Currently, have not included aethalometer data sets due to correction scheme issues
- Including aethalometer data increases number of sites with in-situ absorption data

Barrow, Alaska



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

Lag-Autocorrelation



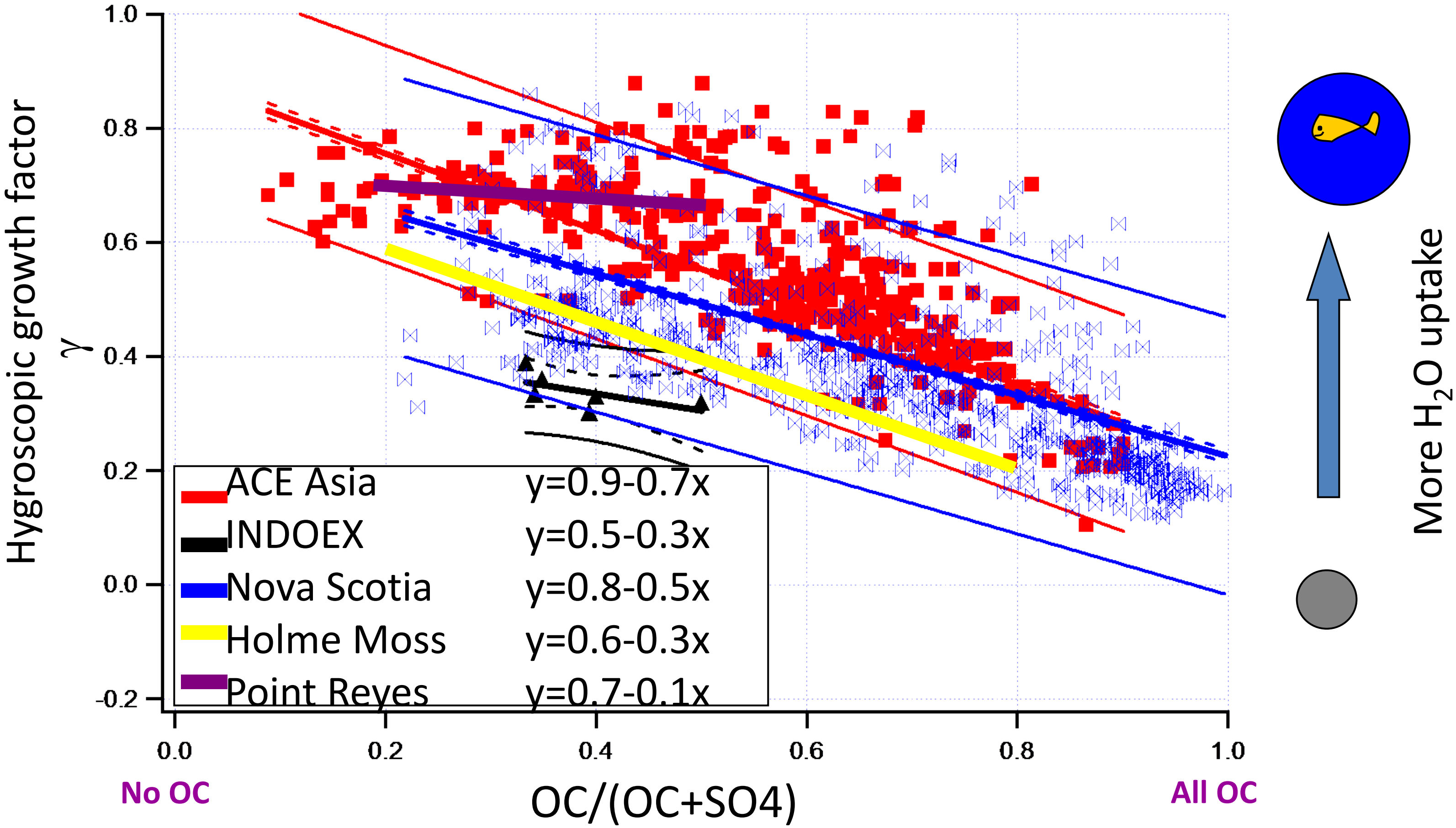
GOCART is amazing in Arctic!

All models have difficulties with KPS (Hungary)

All models look good at CPR (Caribbean) and WLG (China)

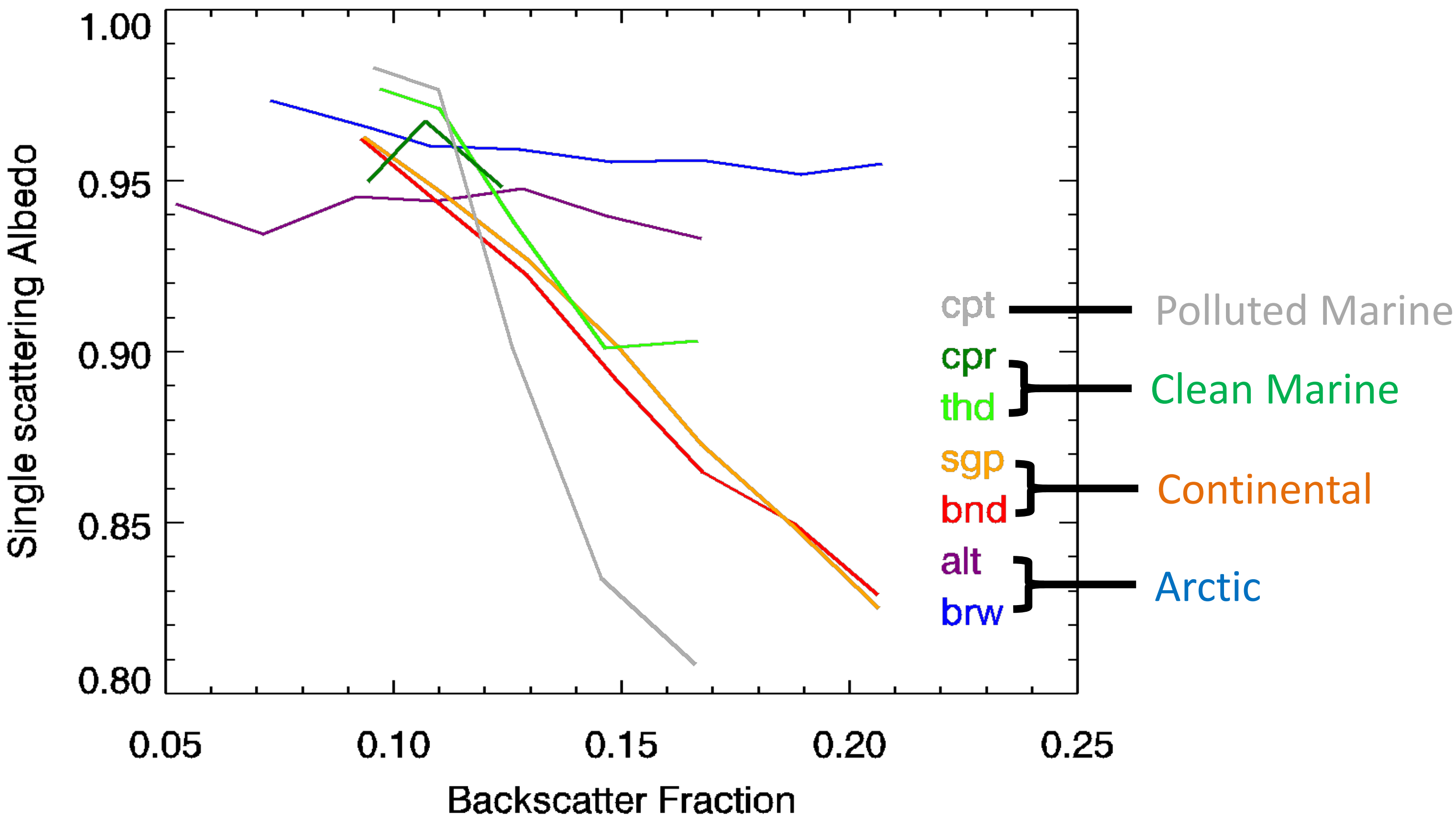
Differences in lag-autocorrelation amongst models may be due to grid size, grid boundaries, differences in atmospheric processes and/or some combination.

Can we relate modelled aerosol water to Quinn in-situ parameterization?



Quinn et al., GRL, 2005

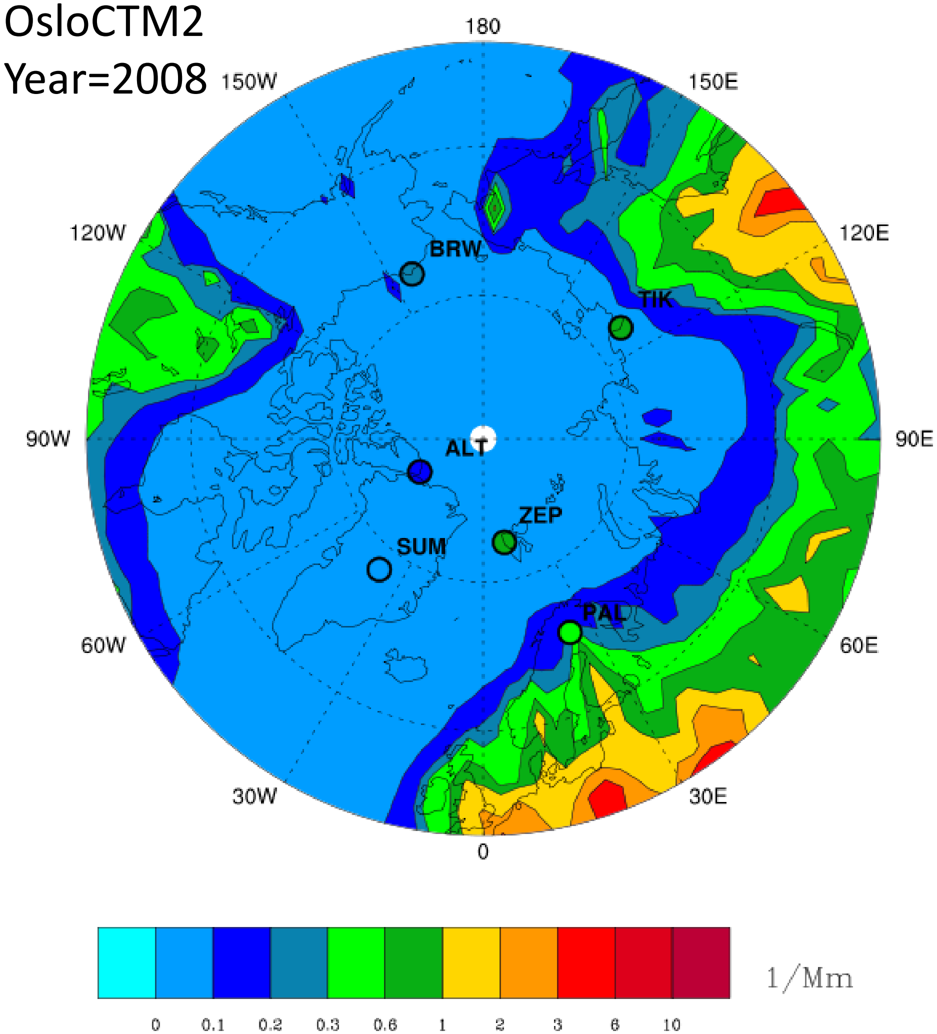
Aerosol Behavior: **Systematic Variability**



- Relationship between aerosol loading and aerosol size distribution changes with location
- Currently no model output to evaluate this sort of systematic variability for surface, low RH conditions

Aerosol Climatology: Annual Mean Absorption

OsloCTM2
Year=2008



Focus on the Arctic

Leave in or take out? What else say?