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

Betsy Andrews  Co-I’s:  Michael Schulz, Markus Fiebig
Lauren Schmeisser  Paul Zieger, Gloria Titos, HC
John Ogren  Hanssson, Martine Collaud Coen

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

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
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)*

[Graphs showing plots of RH vs. f(RH,550nm) for Jungfraujoch: Background and Saharan dust.]

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

<table>
<thead>
<tr>
<th></th>
<th>NOAA &amp; GAW Surface Networks</th>
<th>Aircraft Campaigns</th>
<th>AERONET</th>
<th>Satellite</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length of dataset</strong></td>
<td>Long-term</td>
<td>Short-term</td>
<td>Long-term</td>
<td>Long-term</td>
</tr>
<tr>
<td><strong>Temporal continuity</strong></td>
<td>Continuous</td>
<td>Variable</td>
<td>Intermittent</td>
<td>Intermittent</td>
</tr>
<tr>
<td><strong>Geographical Coverage</strong></td>
<td>Sparse</td>
<td>Sparse</td>
<td>Medium Sparse</td>
<td>Global</td>
</tr>
<tr>
<td><strong>Vertical Resolution</strong></td>
<td>Surface only, Vertically</td>
<td>Vertically resolved</td>
<td>Column only</td>
<td>Column (mostly)</td>
</tr>
<tr>
<td><strong>Aerosol optical properties</strong></td>
<td>Complete RFE suite; @ low RH</td>
<td>Various</td>
<td>Complete RFE suite (at high loading); @ ambient RH</td>
<td>Various</td>
</tr>
</tbody>
</table>

→ 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

Aerosol light scattering
- $3\lambda$ 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

Mauna Loa aerosol rack
• 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)

<table>
<thead>
<tr>
<th>IN-SITU</th>
<th>MODEL OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absorption</td>
<td>😞 abs550daryaer</td>
</tr>
<tr>
<td>Scattering</td>
<td>😞 f(abs550daryaer, ec550daryaer)</td>
</tr>
<tr>
<td>Extinction</td>
<td>😞 ec550daryaer</td>
</tr>
<tr>
<td>Single scattering albedo</td>
<td>😞 f(abs550daryaer, ec550daryaer)</td>
</tr>
<tr>
<td>Scattering Ångström exponent</td>
<td>★ f(ec440daryaer, ec550daryaer)</td>
</tr>
<tr>
<td>Absorption Ångström exponent</td>
<td>★ f(abs440daryaer, abs550daryaer)</td>
</tr>
<tr>
<td>Phase function parameterization</td>
<td>★ asydaryaer</td>
</tr>
<tr>
<td>Fine mode fraction</td>
<td>★ f(ec550daryaer, ec550daryaer1)</td>
</tr>
</tbody>
</table>

Description of data request can be found at: https://wiki.met.no/_media/aerocom/INSITU_AeroComPIII_description.pdf
## AeroCom Models Used in this Analysis

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

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...

<table>
<thead>
<tr>
<th><strong>Climatology</strong></th>
<th>Tells us how well the model is doing at given locations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Characteristics &amp; Behavior</strong></td>
<td>Tells us how well the model is simulating aerosol aging processes, chemistry, sources, transport, etc.</td>
</tr>
<tr>
<td><strong>??</strong></td>
<td>What other diagnostics should we consider to analyze the models?</td>
</tr>
</tbody>
</table>
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)
• General pattern of absorption similar for models and in-situ
• Biggest differences may be observed for some high altitude and marine sites
• Arctic is complex aerosol environment
• Models tend to under-estimate absorption relative to Arctic in-situ observations
Models tend to predict lower SSA than in-situ observations

No obvious dependence on model grid size

- Models see darker aerosol
- In-situ sees darker aerosol
Aerosol Climatology: Absorption and Extinction

Percent difference (model-insitu)/insitu

Absorption

Extinction

Insitu sees more

Model sees more
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
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
• 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.

Scattering at t=t₀+Δt

Lag is the time between measurements being compared (Δt)
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)
Various other methods exist for scoring model/measurement comparisons (e.g., Glackler et al., 2008; Murphy and Epstein, 1989).

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.
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...

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
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!

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

Plot shows stations with simultaneous scattering and absorption data*

*Data may not be in EBAS database
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
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?)

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

\[ y = 0.999x + 0.071, \quad R^2 = 0.97 \]

Preliminary analyses suggest properly corrected aethalometer data are in good agreement with better characterized aerosol absorption instruments.
Differences in lag-autocorrelation amongst models may be due to grid size, grid boundaries, differences in atmospheric processes and/or some combination.

GOCART is amazing in Arctic!

All models have difficulties with KPS (Hungary)

All models look good at CPR (Caribbean) and WLG (China)
Can we relate modelled aerosol water to Quinn in-situ parameterization?

Hygroscopic growth factor

\[ \gamma = \frac{OC}{OC + SO_4} \]

More H₂O uptake

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?