Global LIDAR Remote Sensing of Stratospheric Aerosols and Comparison with WACCM/CARMA: The Need For Meteoritic Dust In The Stratosphere

CESM Whole Atmosphere Working Group Meeting 23 June 2011 Breckenridge, Colorado

Acknowledge: Dr. Michael Mills and Jason English for basis of current working model.

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Variability of stratospheric aerosol has an impact on the global radiation budget
Research Questions

Goal: Understand Variability in Stratospheric Aerosol

Seasonal cycles?  Long-term trends?

How will I answer these:

Observations:
- Lidar

Modeling:
- WACCM/CARMA

Pleiades Supercomputer (NASA AMES)

Boulder Lidar (R. Neely III)
Lidar Datasets

Lauder

Mauna Loa

Boulder

Altitude (km)

Year

Backscatter (km⁻¹ sr⁻¹)

Year

Altitude (km)

Year

Backscatter (km⁻¹ sr⁻¹)
Sources of Stratospheric Aerosols

Mesosphere

Meteoritic Dust

Stratosphere

Stratospheric Aerosol Layer

Troposphere

Volcanic

Terrestrial

Biomass Burning

Industrial

Marine

Surface

Volcanic

Terrestrial

Biomass Burning

Industrial

Marine
WACCM Setup

- NCAR’s WACCM version 3.1.9
- 4x5 degree resolution
- 66 vertical levels
- Model top near 140 km
- Vertical spacing of 1-1.75 km in the stratosphere
- 3D chemical transport Model for OZone And Related chemical Tracers (MOZART) (Horowitz et al. 2003)
- Sulfur chemistry includes seven sulfur species: SO$_2$, SO$_3$, SO, H$_2$SO$_4$, CS$_2$ and OCS (English et al., 2011 (ACPDP))
- 25 year run, using last 10 years for comparison to observations.
Sulfur Emissions Setup

Total SO$_2$ in Bottom Level of Model During January

- SO$_2$ Emission data representative of background aerosol period (Smith et al. (2010) and English et al., 2011 (ACPD)).
- OCS field is a lower boundary condition of 510 pptv.
CARMA Setup

- Aerosol Size Distributions created by thirty-six bins (dry radii from 0.2 nm to 1100 nm) each for:
  - Pure sulfates (English et al., in prep, 2011)
  - Meteoritic dust (Bardeen et al. 2008)
  - Mixed sulfates (sulfate aerosols with dust cores)
The cluster analysis uses all peaks from mass 1 to 220 to find spectra that are similar to each other. The centers of the clusters are defined as the average of similar spectra. For the great majority of the mass spectra, the correlation coefficient between an individual spectrum and its cluster is greater than 0.85. The meteoric cluster is especially tight.

Figure 4 shows the vertical profiles of the relative abundances of these types of particles. Particles with meteoric material and relatively pure sulfuric acid particles increase in frequency above the tropopause. The frequency of particles that contain meteoric material at the highest points on Figure 4 (about 19 km) may be compared to the volatility measurements of Curtius et al. [2005]. Their data, which extend to smaller particles than those measured by PALMS, found about 67% of particles within and 24% outside the polar vortex had nonvolatile cores. The smaller fraction of meteoric particles in Pre-AVE is probably due to those flights being further south than the WAM flights. The relatively pure sulfuric acid particles during all missions may have been due to growth of particles originally formed near the tropical tropopause [Brock et al., 1995].

The positive and negative ion mass spectra provide complementary information about the carbonaceous material. The negative ion mass spectra are simpler and provide more consistent estimates of the overall carbonaceous content of the particles. For example, at lower altitudes the average area of the negative ion carbonaceous peaks was better correlated with independent measures of organics [Murphy et al., 2006] . However, the positive ion spectra are much better suited to study the sources and sinks of the carbonaceous material. The reason is that in the stratosphere the majority of the negative ion current is in one peak, HSO$_4$ and the other peaks are almost all either carbonaceous or sulfate. If one uses cluster analysis to select mass spectra with carbonaceous material, there is little additional information in the size of those peaks. That size is already determined by the choice of the categories. In contrast, in the positive ion spectra, the pattern of peaks is much richer and the cluster analysis can bring together similar spectra even if the carbonaceous and sulfate contents vary. The best example is the set of particles containing meteoric material. These particles are categorized mostly on their Fe, Mg, and Ni.

**Total Mass Fraction of Meteoritic Sulfate**


Dust Sulfate model and SOFIE agree within the model variability and measurement precision.

Pure Sulfate model (from English et al. (2011)) and Dust-Sulfate Model with No Dust agree within the model variability.

Dashed lines represent 90% Confidence Interval.
Lidar Comparison

Lauder, NZ

Model With Dust
\[ \beta_{\text{total}} = \beta_{\text{Pure Sulfate}} + \beta_{\text{Fixed Sulfate}} + \beta_{\text{Dust}} \]

WACCM
Lidar
SAGE II
Rayleigh

Model Without Dust
\[ \beta_{\text{total}} = \beta_{\text{Pure Sulfate}} + \beta_{\text{Fixed Sulfate}} \]
Lidar Comparison

Boulder, CO

Model With Dust

$\beta_{total} = \beta_{Pure \ Sulfate} + \beta_{fixed \ Sulfate} + \beta_{Dust}$

(Same as Results Shown Previously)

WACCM

Lidar

SAGE II

Rayleigh

Model Without Dust

$\beta_{total} = \beta_{Pure \ Sulfate} + \beta_{fixed \ Sulfate}$
Summary

• First global microphysical model of stratospheric aerosols to include current sulfur emissions and meteoritic dust

• Comparison to observations show:

1. Agreement within the natural variation of the observations in the lower aerosol layer that is dominated by sulfate aerosols.

2. Meteoritic dust is needed to fully characterize the upper aerosol layer.

3. Inclusion of meteoritic dust is needed within lidar retrievals

• Errors associated with the lidar retrievals need to be addressed before further comparison and analysis of trends can be made.

Observations⇒Modeling⇒Observations
Future Work: Trends?

Possible theories:

1. Anthropogenic emissions (Hofmann et al. 2009)?

2. Small episodic volcanic injections (Vernier et al. 2009)?

3. Strengthening of stratospheric circulation (Butchart et al., 2006; Niwano et al., 2009)?

![Graphs showing aerosol backscatter trends at Mauna Loa Observatory and Boulder, Colorado.](Image)

- **Mauna Loa**
  - Integrated backscatter for the 20–25 km altitude range at (a) Mauna Loa Observatory and (b) Boulder, Colorado.
  - Observations, Smoothed, Deseasonalized Trend, Average Trend = 4.8% yr⁻¹

- **Boulder**
  - Observations, Smoothed, Deseasonalized Trend, Average Trend = 6.3% yr⁻¹

Adapted from Hofmann et al. (2009)
Thank You
Adapted from Bates et al. 1992
**Lidar Retrieval Error**

**Derivable**

Boulder Retrieval Comparison

- Backscatter Ratio \([A+M]/M\]

- Altitude (km)

- Derivable Backscatter

- Rayleigh

**Backscatter**

Boulder Retrieval Comparison

- Backscatter \((1/\text{km}) (1/\text{sr})\)

- Altitude (km)

- Backscatter Ratio \([A+M]/M\]

- Calibration from 40–45 km
- Calibration from 35–40 km
- Calibration from 30–35 km
• Osiris =alt omi=how much
• Then put in if then logic in mo sad
• Get kathrine to do emission stuff
• Compiler switch
• Intro models
• Show comparison of models
• Show from ells calc that is is 1-2% and not radiatively that important
• Show sofie
• Show lidar and show how this small error can propagate using russel math