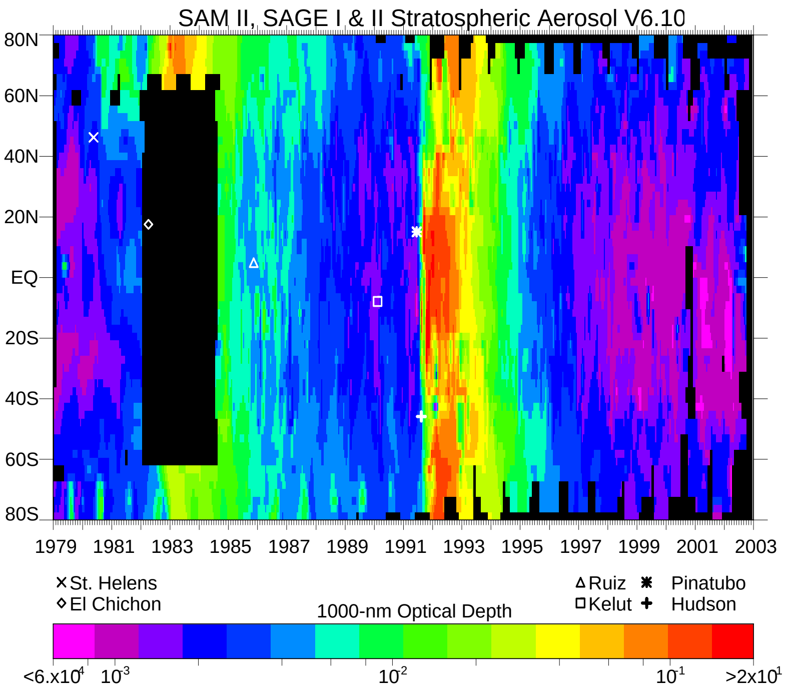
Spaced-Based Measurements of Stratospheric Aerosols

Larry W. Thomason
NASA Langley Research Center
Hampton, Virginia USA

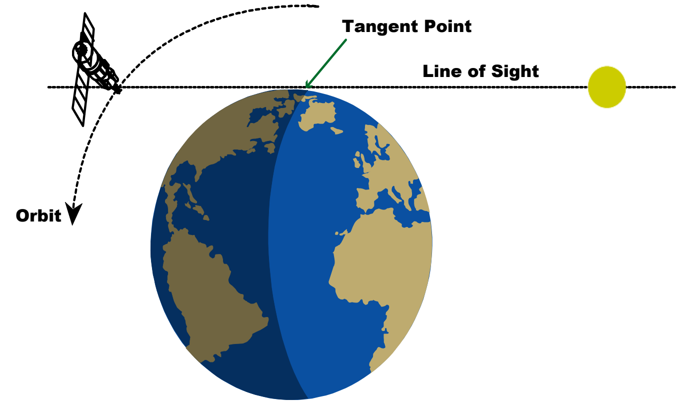
Measurement by Extinction of Solar Radiation

- Stratospheric aerosols are highly variable (10^2) on the decadal time scale
- Since 1978, variability has been dominated by a few significant volcanic events
- Loading in 2002 was at the lowest levels ever observed
- Focus of the presentation:
  - How are stratospheric aerosol measured from space?
  - What are the strengths and limitations of these measurements?

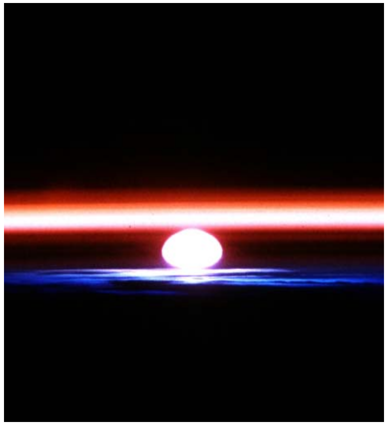


Solar Occultation Measurement Strategy

- Measure line-of-sight transmission during each sunrise/sunset encountered by space craft
- Use exo-atmospheric measurements to normalize measurements
- Use wavelength dependence to infer vertical profiles of target species
- Good dynamic range (>1000) & vertical resolution (down to 0.7 km)
- Subject to 'saturation' effects during extreme events

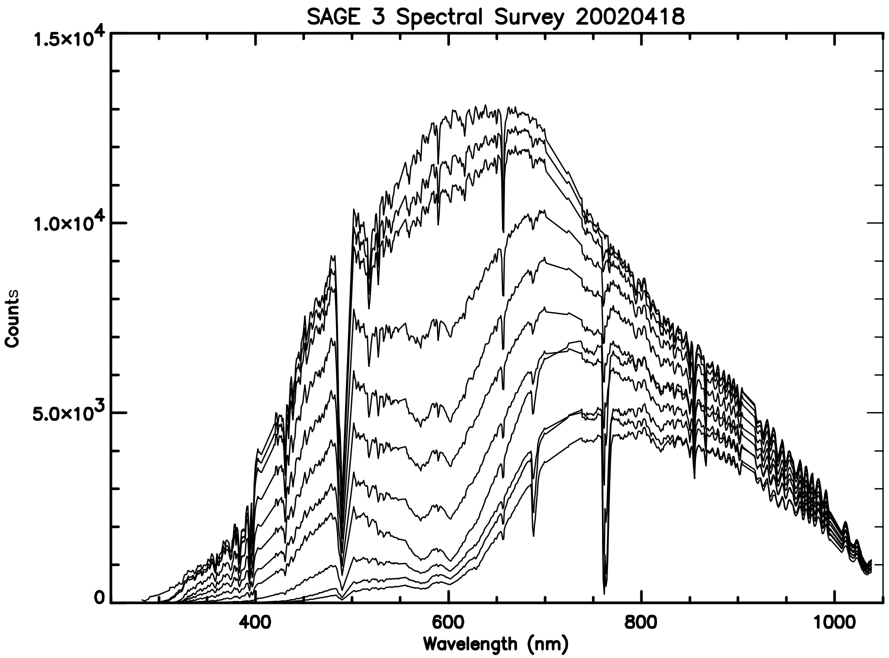


Solar Occultation Geometry



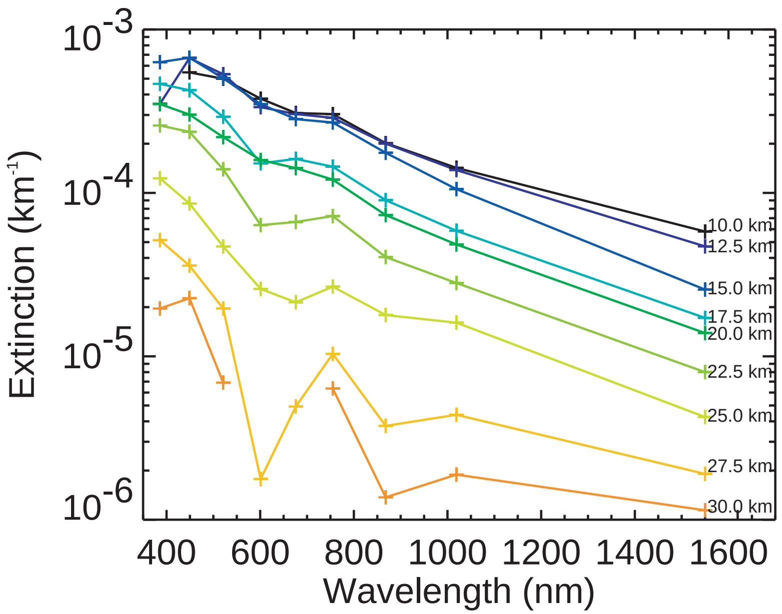
Retrieval Strategy

- Gas species retrieved based on their spectral variations using a variety of techniques (MLR, OE, LS, etc.)
- Aerosol can be derived as a residual or using a model to constrain its spectral shape



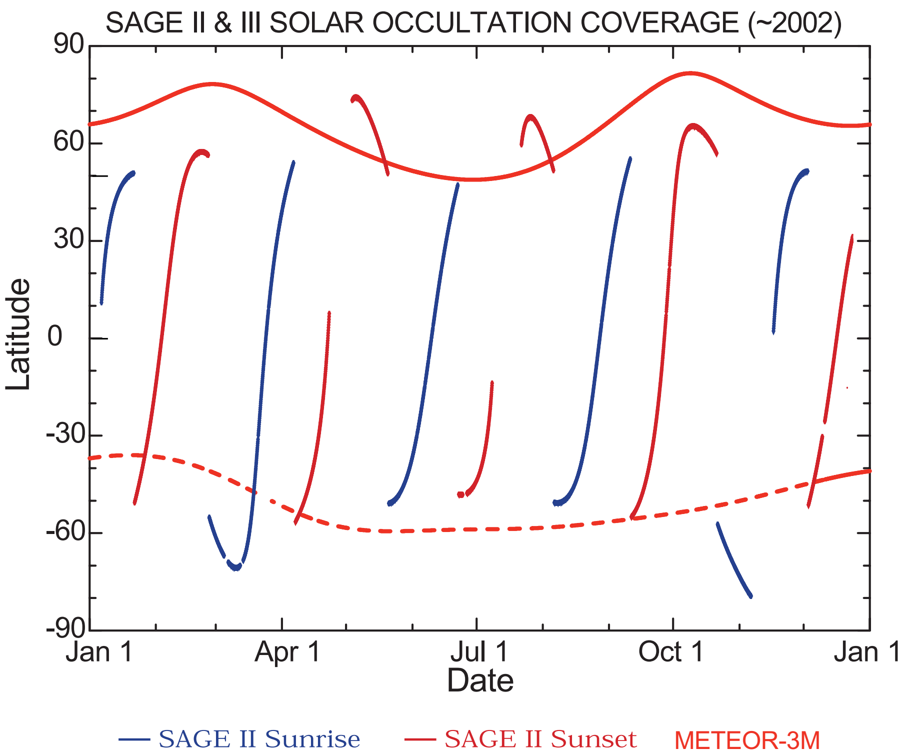
Aerosol Spectra (Vis)

- SAGE II/III algorithms derive aerosol as a residual
- Spectra are not constrained to fit a predetermined shape
- Spectral artifacts are possible where measurement modeling is deficient



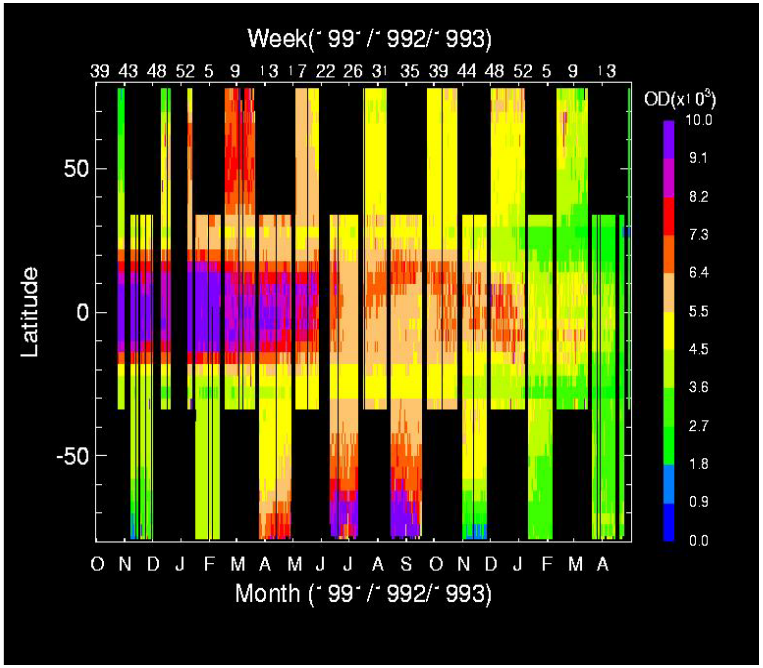
Occultation Coverage

- Occultation events occur twice an orbit or about 30/day (data rates are low)
- Latitude coverage orbit dependent
  - Sun-Synchronous orbits yield high latitude measurements
  - Mid-inclination orbits cover low and latitudes (30-40 day period)

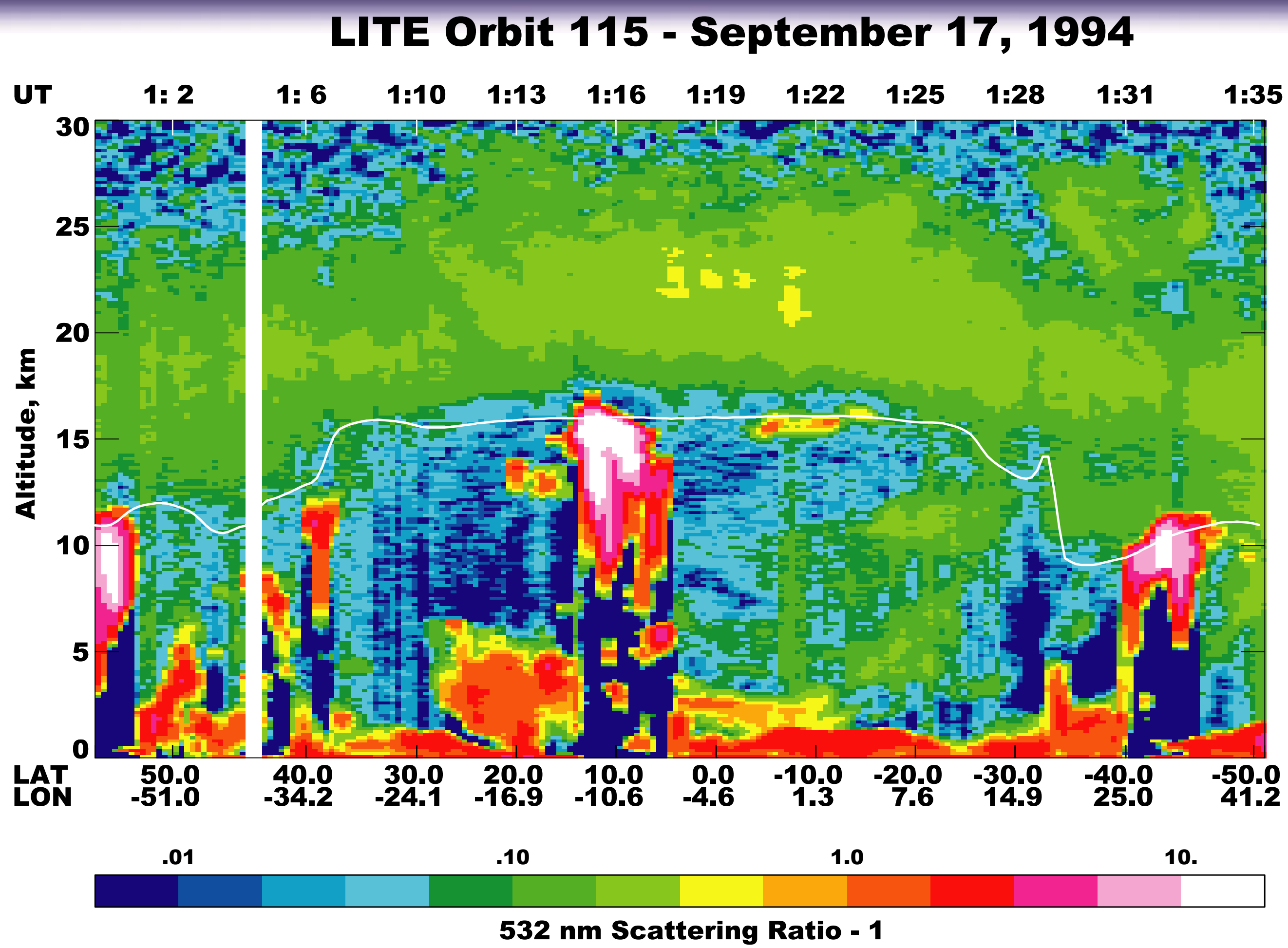


Measurement by Limb Emission (CLAES/HRDLS)

- Aerosol measured by IR emission observed through the Earth's limb
- Measured continuously through an orbit
- 'Saturation' effects are about the same as for solar transmission measurements.



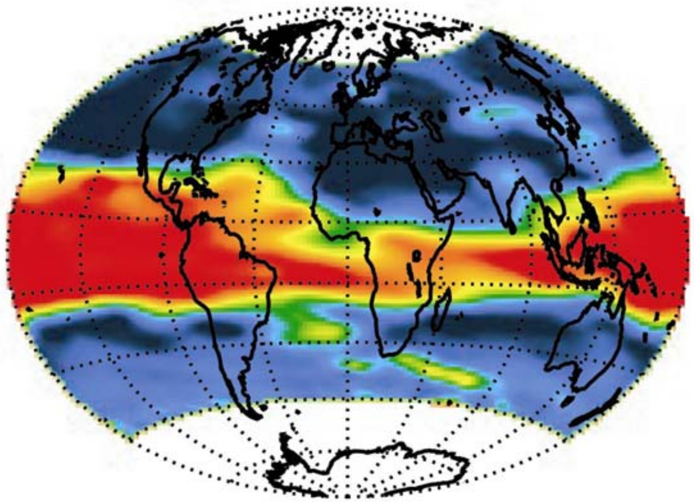
Lidar Observations of Stratospheric Aerosol



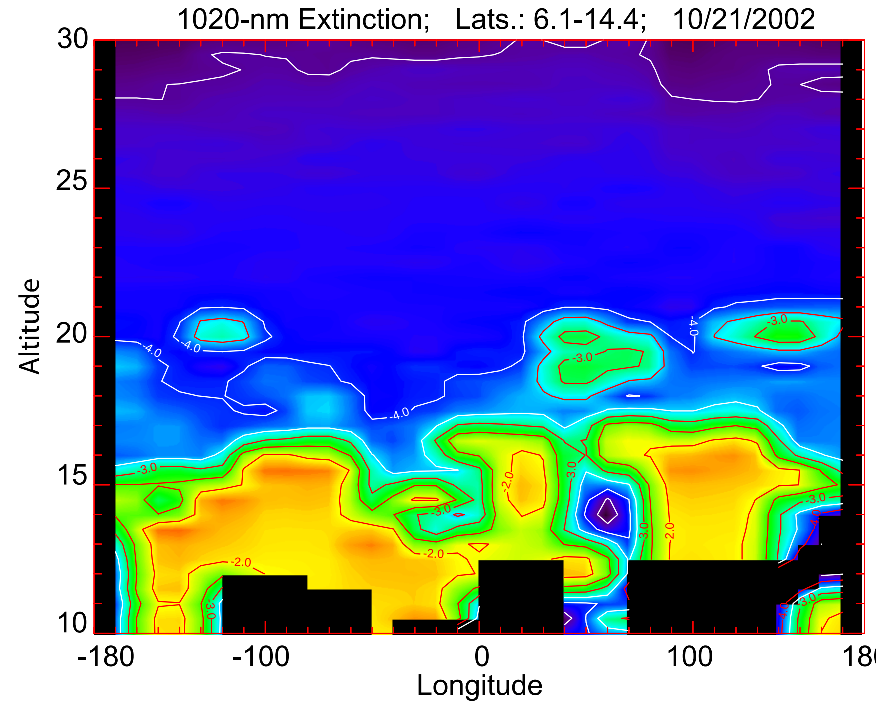
Modeling Stratospheric Aerosol

- Is a *fairly* well-behaved parameter
  - Tends to behave well in θ–potential vorticity space as aerosol extinction ratio (relative to Rayleigh)
  - Composed primarily of sulfate
- Complicating factors
  - Measured quantities are often not the most important
  - Condensates (e.g., PSCs)
  - Second order humidity/temperature effects
  - Irreversible processes
    - Post-volcanic aerosol sedimentation
    - PSC formation and sedimentation

Observing Volcanic Effects - Initial

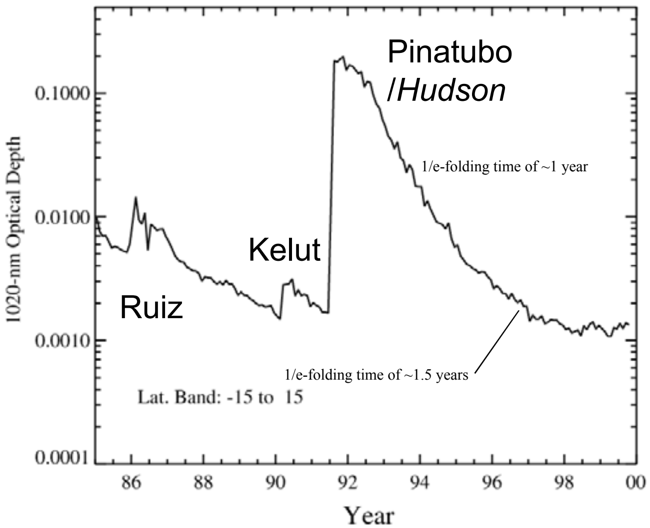


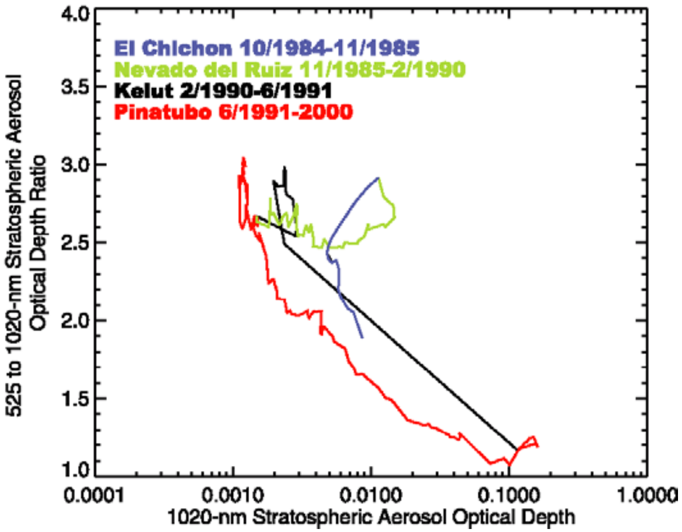
15 June to 25 July 1991



- Initial dispersion as a tracer of transport
- Observations of small volcanic events

Observing Volcanic Effects - Long Term

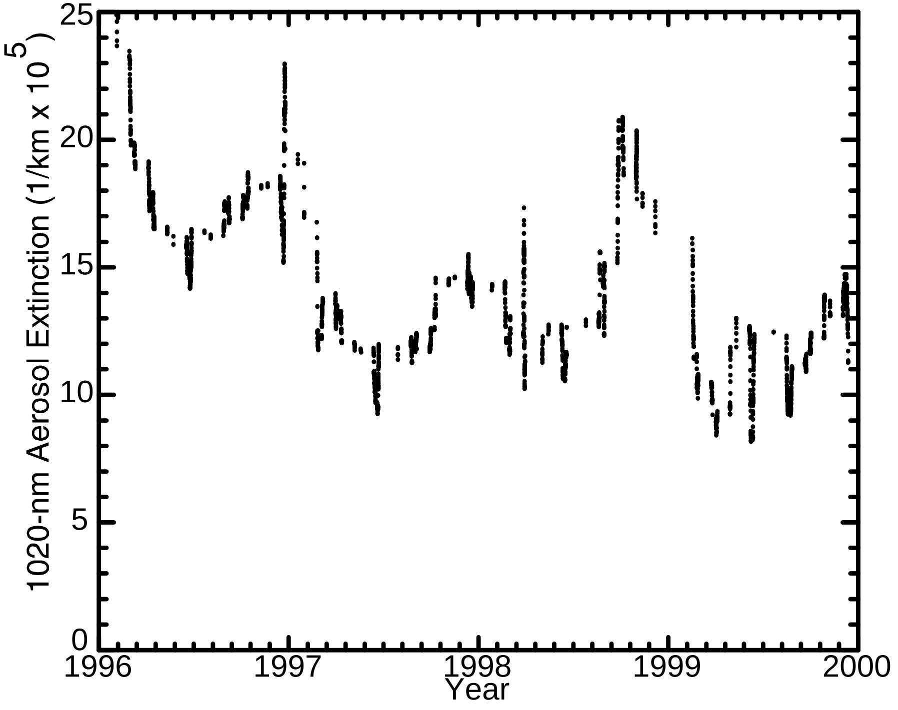




- Events are rare (5 in SAGE II record; 4 in SAM II/SAGE)
- Effects persist for many years (Pinatubo ~10 years; El Chichon/Ruiz ~8 years)
- Aerosol 'size' appears to maintain persistent memory of volcanic events
  - Processes that control aerosol s. d. must be slow

Non-Volcanic Aerosol Processes

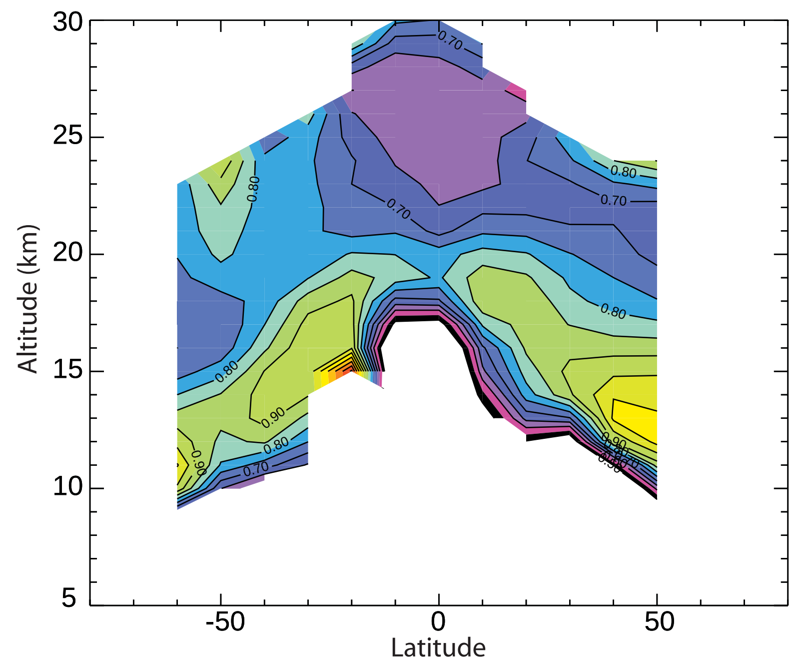
- Annual cycle in aerosol observed between 16 and 20 km. The differences in the phasing between 525 and 1020 nm extinction suggests that the cycle reflects the introduction of small aerosol.
- Also, PSC-related preferential loss of large aerosol



Long-Term Trends in the Stratospheric Background

- Stratospheric record has several 'clean' periods: 1979, 1989, 1998-present
- Relative to the nominal 1979 'background' period, the current period is ~30% lower except in the vicinity of the tropopause

SAGE II 1020 nm aerosol in Spring 2000 relate to SAGE 1000 nm in Spring 1979



Inferring Non-Measured Properties

- Most Desirable Properties:
  - Integral properties
    - Surface area density (SAD)
    - Volume density or mass
    - Effective radius
    - Full aerosol extinction spectra
  - Size distribution
  - Composition
- Estimation of non-measured properties of aerosol generally requires a non-linear retrieval algorithm

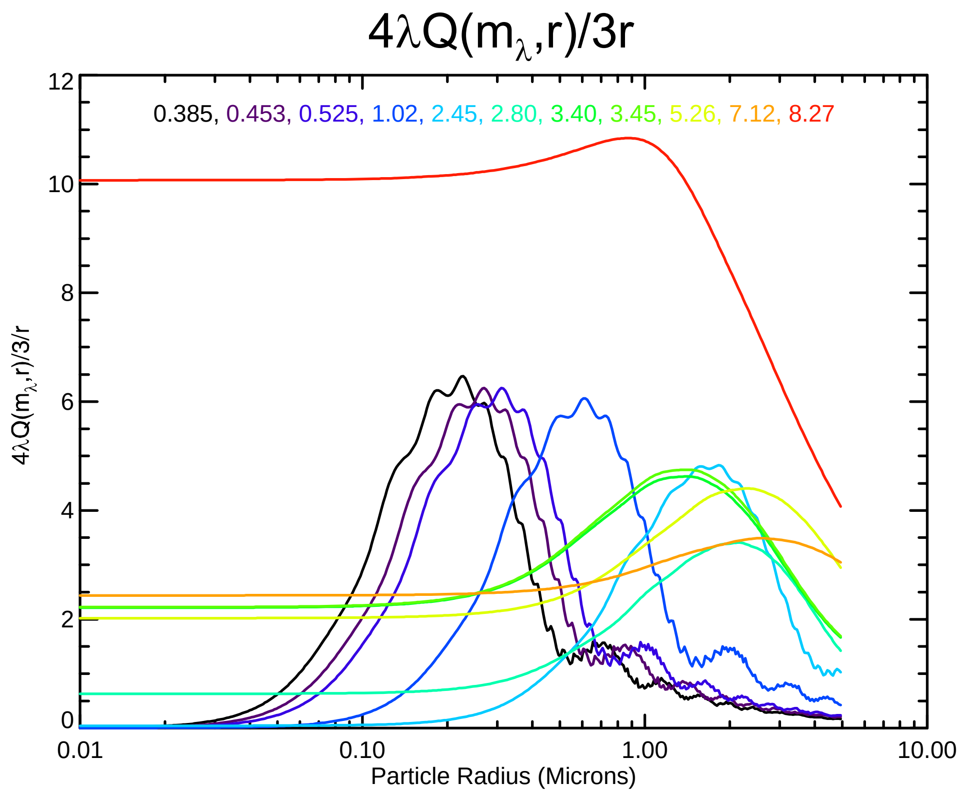
The Extinction Measurement

$$k_\lambda = \int_0^\infty \pi r^2 Q(m_\lambda, r) \frac{dn(r)}{dr} dr$$

or

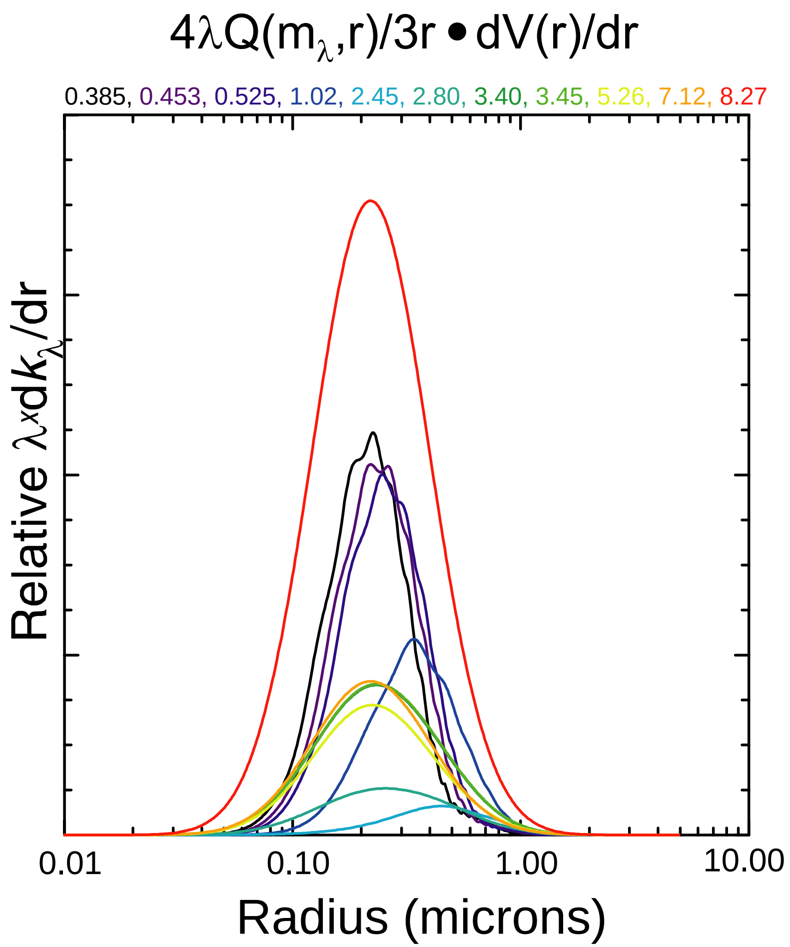
$$k_\lambda = \int_0^\infty \frac{3Q(m_\lambda, r)}{4r} \frac{dV(r)}{dr} dr$$

k - extinction
r - radius
Q() - Extinction kernel
dn(r)/dr - aerosol size distribution by number
dV(r)/dr - aerosol size distribution by volume

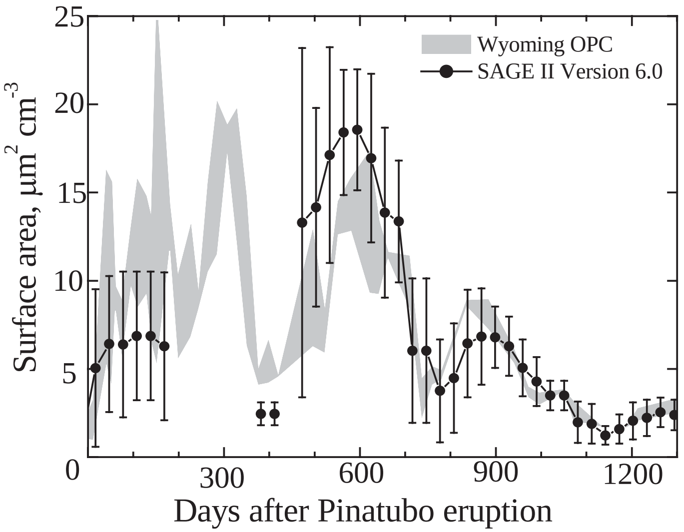


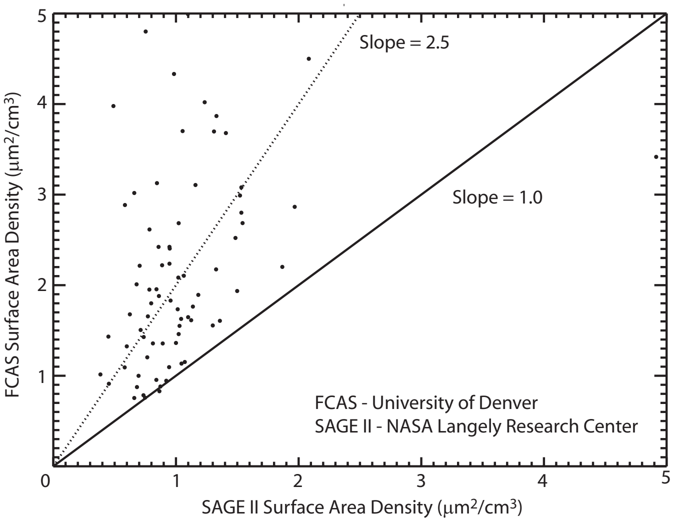
Size/Composition Sensitivity

- Visible wavelength aerosol is ~10 times larger than that in the IR
- Infrared measurements tend to scale with composition and total volume but have little sensitivity to size
- Visible measurements tend to be more size sensitive but very insensitive to composition and aerosol with radii less than 0.1 μm.
- A system with both IR and visible extinction measurements would be a considerably stronger measurement suite than either wavelength set alone



Problems in Computing SAD

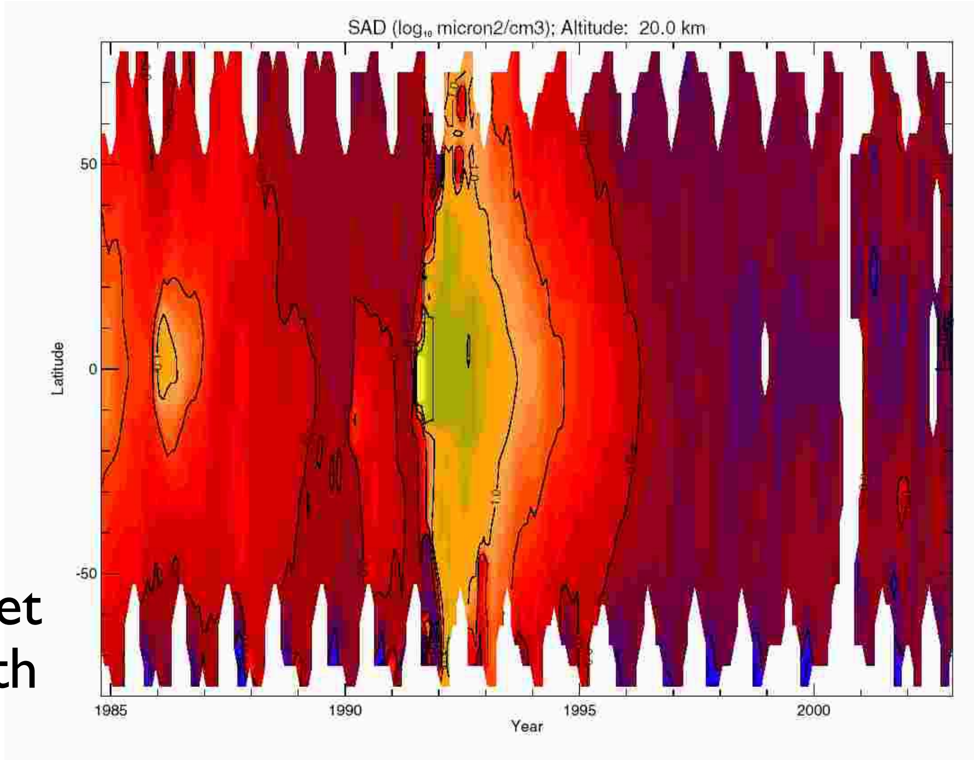




- SAGE II, OPC, HALOE SAD values usually agree with 20-30%
- Agreement with in situ systems with high size discrimination for smaller (e.g., FCAS) can be rather poor.
- Many retrieval processes are dependent on assumed size distributions (e.g., log-normal) that can have an enormous impact on retrieval results

Stratospheric Aerosol Climatologies

- Extensive data sets for extinction, and some integral properties are available
- Data sets are mostly instrument-based
- Data sets are not spatially/temporally continuous
- Need for combined data set with data gap filling for both El Chichon and Pinatubo
  - Lidar data sets
  - SME



Assessment of Stratospheric Aerosol Properties (ASAP)

- ASAP is an on-going SPARC examination of stratospheric aerosols
- Topics include:
  - Aerosol precursors
  - Measurements & climatologies
    - 'Filled' data set for 1979-present
  - "Trends"
  - Modeling

Reconstruction of NH aerosol extinction at 1020 nm during El Chichon from NASA LaRC 48-inch lidar system