CMIP6 Stratospheric Aerosol Forcing Data Set

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CMIP6 Stratospheric Aerosol Forcing Data Set (Part I)

- Similar form (CCMI, ASAP, etc.) but addresses some long term issues associated with the data set
  - Monthly, latitude/altitude grids of aerosol properties including aerosol surface area density, extinction, etc.
- Previous incarnations include:
  - a SAGE II-only set with limited filling (e.g., Thomason et al., 1997)
  - ASAP (SPARC 2006) which introduced ‘gap-free’ goal
  - SAGE 4λ data set (Arfeuille et al., 2012)
  - CCMI expanded time frame to pre-satellite era and into the post-SAGE period; uses SAGE 4λ methodlogy; includes direct radiative properties customize for various CCMs

CMIP6 Stratospheric Aerosol Forcing Data Set (Part II)

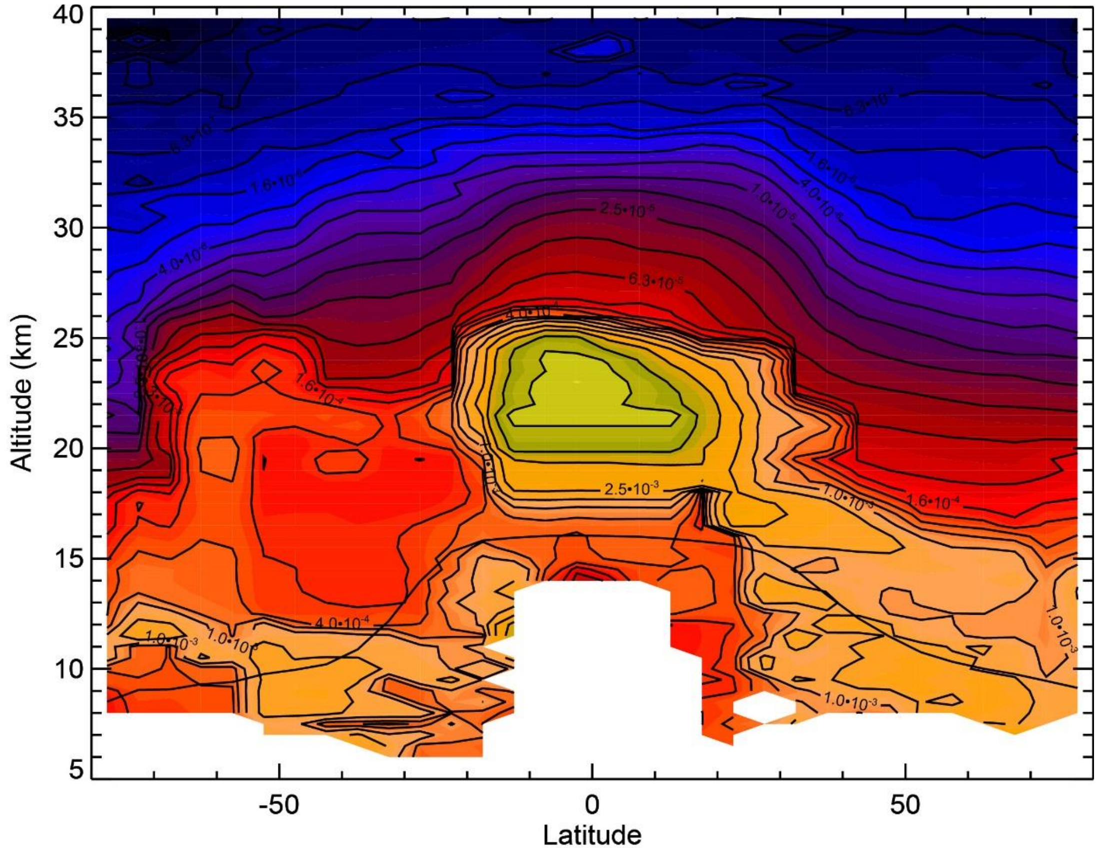
- For CMIP6 (and beyond) the process has been split into aerosol optical property climatology (GloSSAC) and s.d./bulk properties (ETH)
- The Global Space=based Stratospheric Aerosol Climatolgoy (1979-2016) adds CLAES, HALOE, OSIRiS and improved usage of CALIPSO to SAGE series of instruments; improved gap-filling
- GloSSAC paper submitted to ESSD: August 2017. Available as eosweb.nasa.gov (look for GloSSAC, doi: 10.5067/GloSSAC-L3-V1.0
- ETH uses GloSSAC to produce aerosol size distributions and bulk properties from SAD to radiative parameters required by CCMs

The Pinatubo eruption and early inhomogeneity in the stratosphere

Is it possible to produce a meaningful global aerosol data set for the summer months of 1991?

Probably not…

CMIP6 Analysis for July 1991

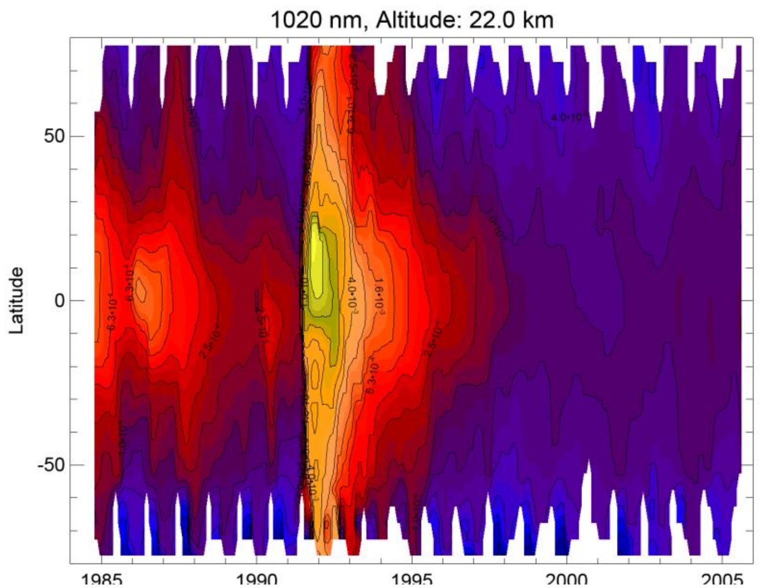


Latitude

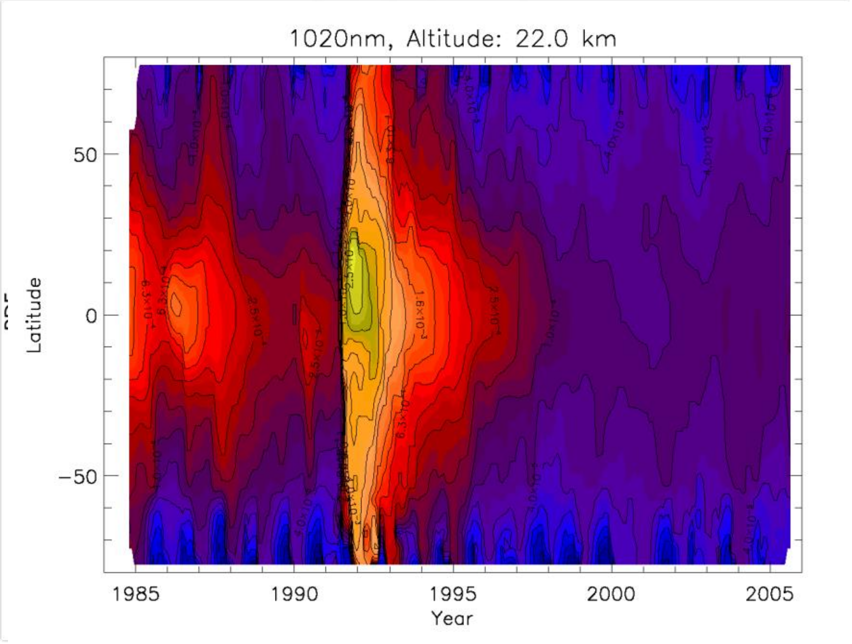
From NASA LaRC Airborne lidar
Winker and Osborn ,1992

A fix for missing wintertime high latitude data

Construct high latitude winter analysis using equivalent latitude-based analyses

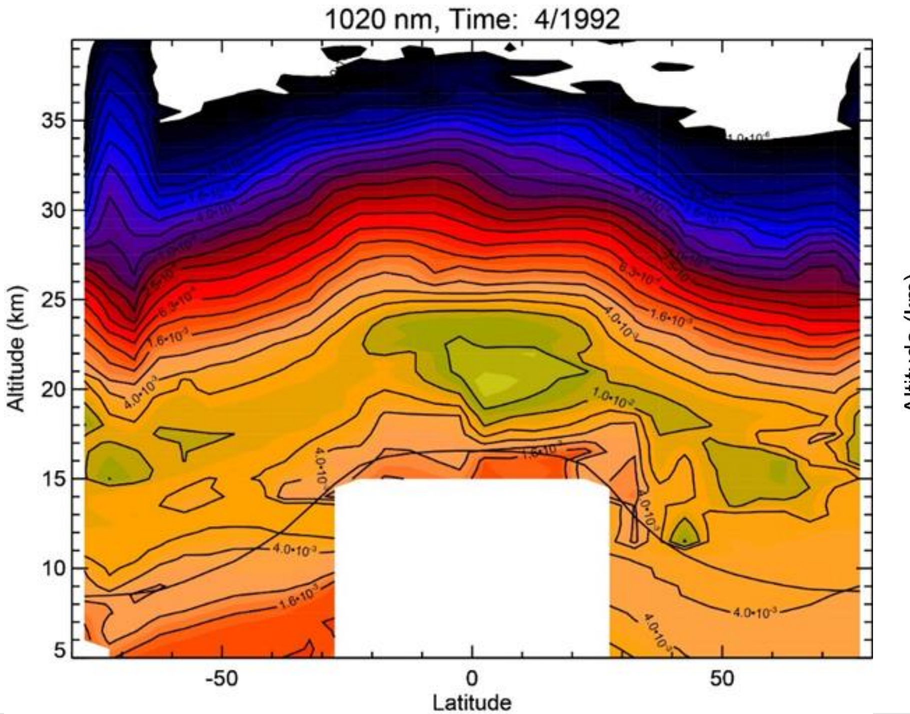


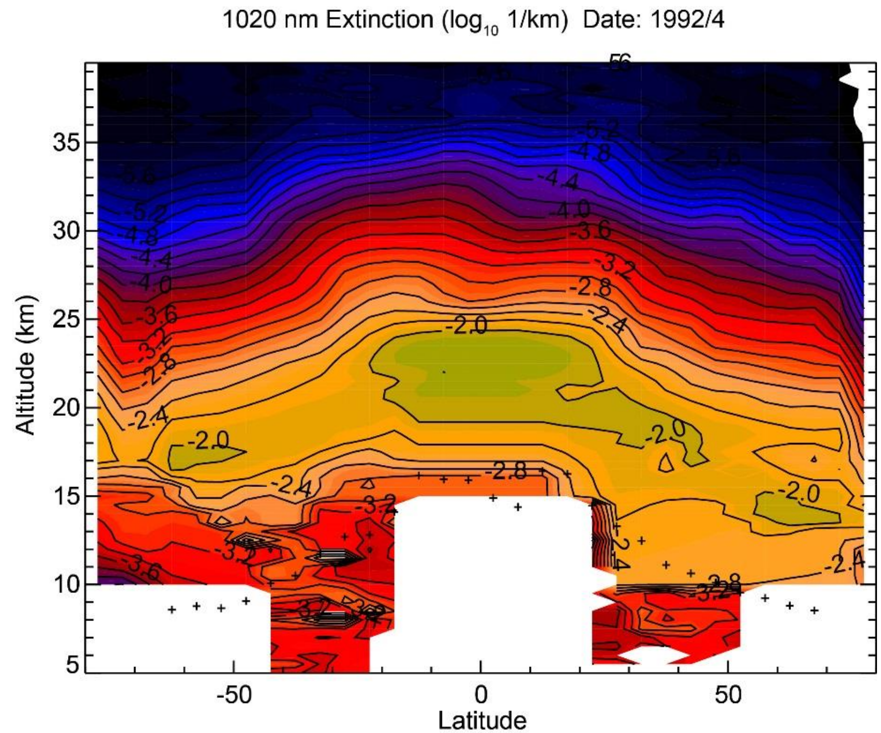
Extinction coefficient at 22 km using Standard interpolation for filling



Extinction coefficient at 22 km after estimating extinction at high latitudes from eq. lat. analyses and pdfs

Filling the Pinatubo data gap (1991-1993) – The ASAP way



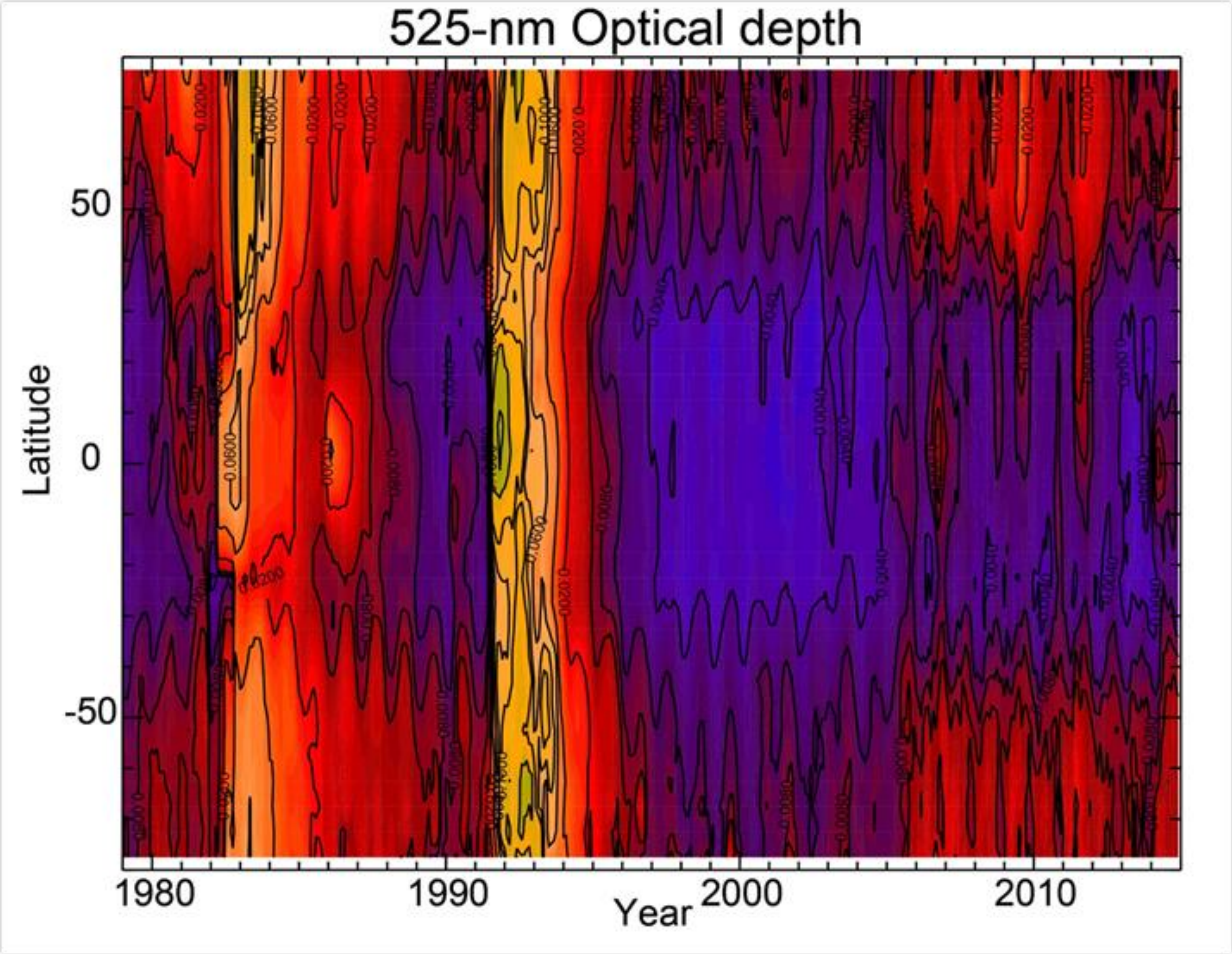


Using scaled CLAES data to fill missing SAGE II observations generally increases aerosol loading in the lower stratosphere particularly in the tropics.

Filled using composite lidar record from Mauna Loa and Camaguey (ASAP) (tropics and subtropics), ground-based lidar mid and high latitudes (CCMI)

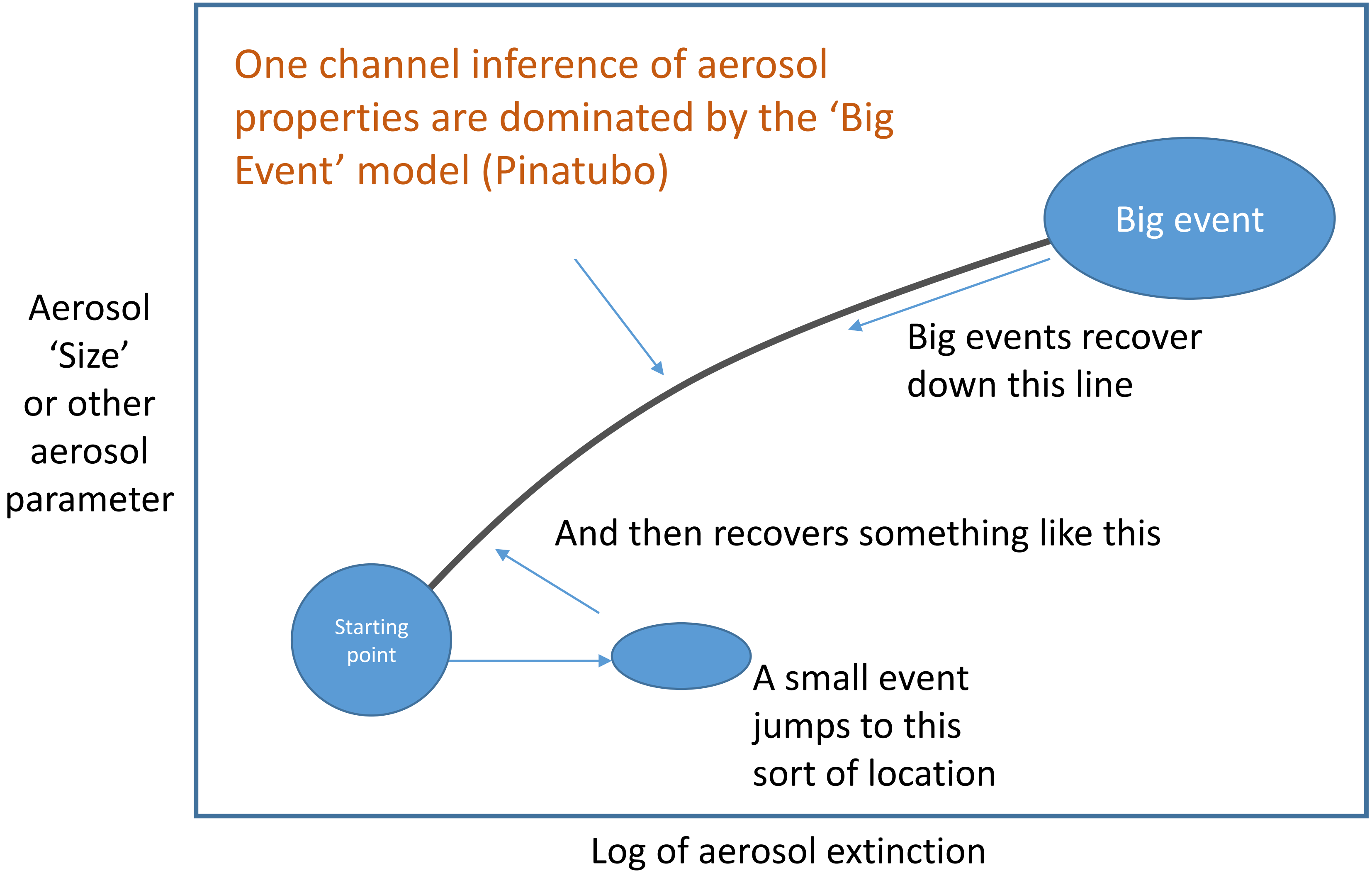
CALIPSO/OSIRIS Era

Challenges from the transition from the SAGE Era



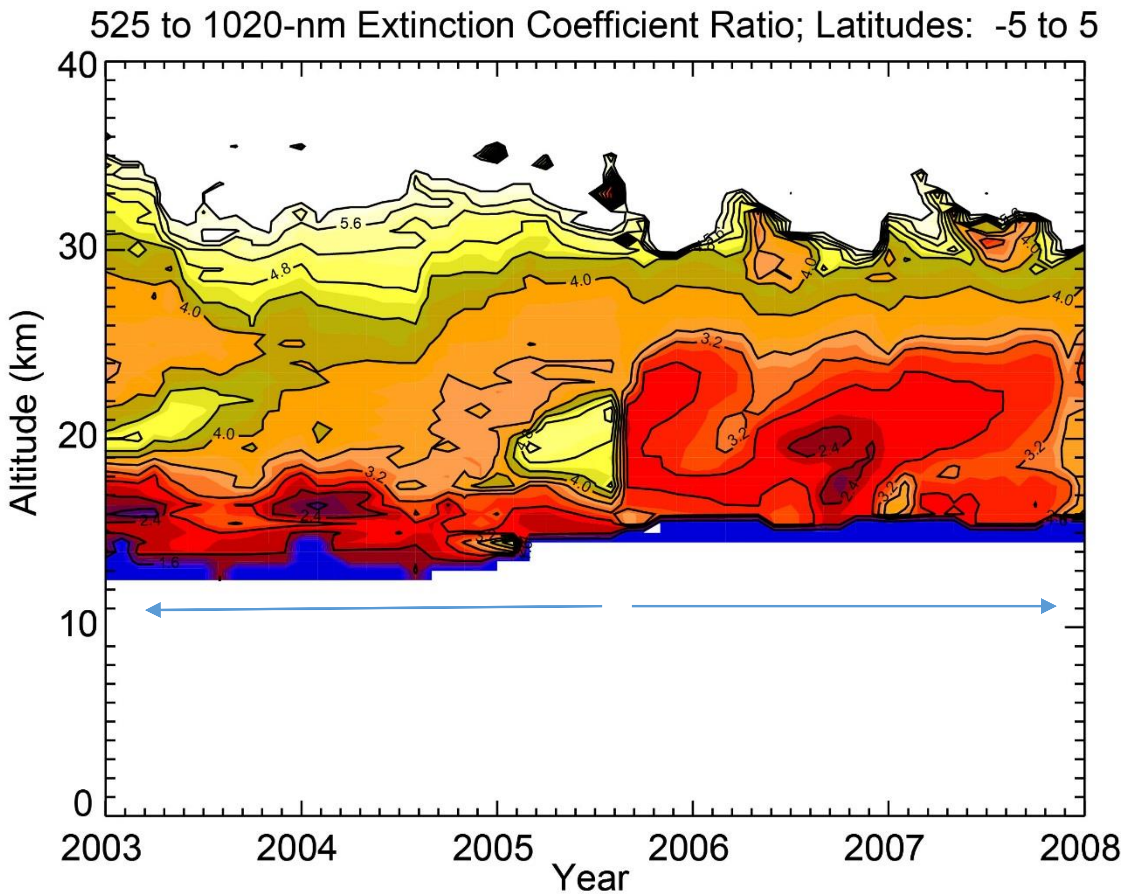
Big Volcano vs Small Volcano

The One-Wavelength Problem



Small Volcano Impact

Why does it matter?

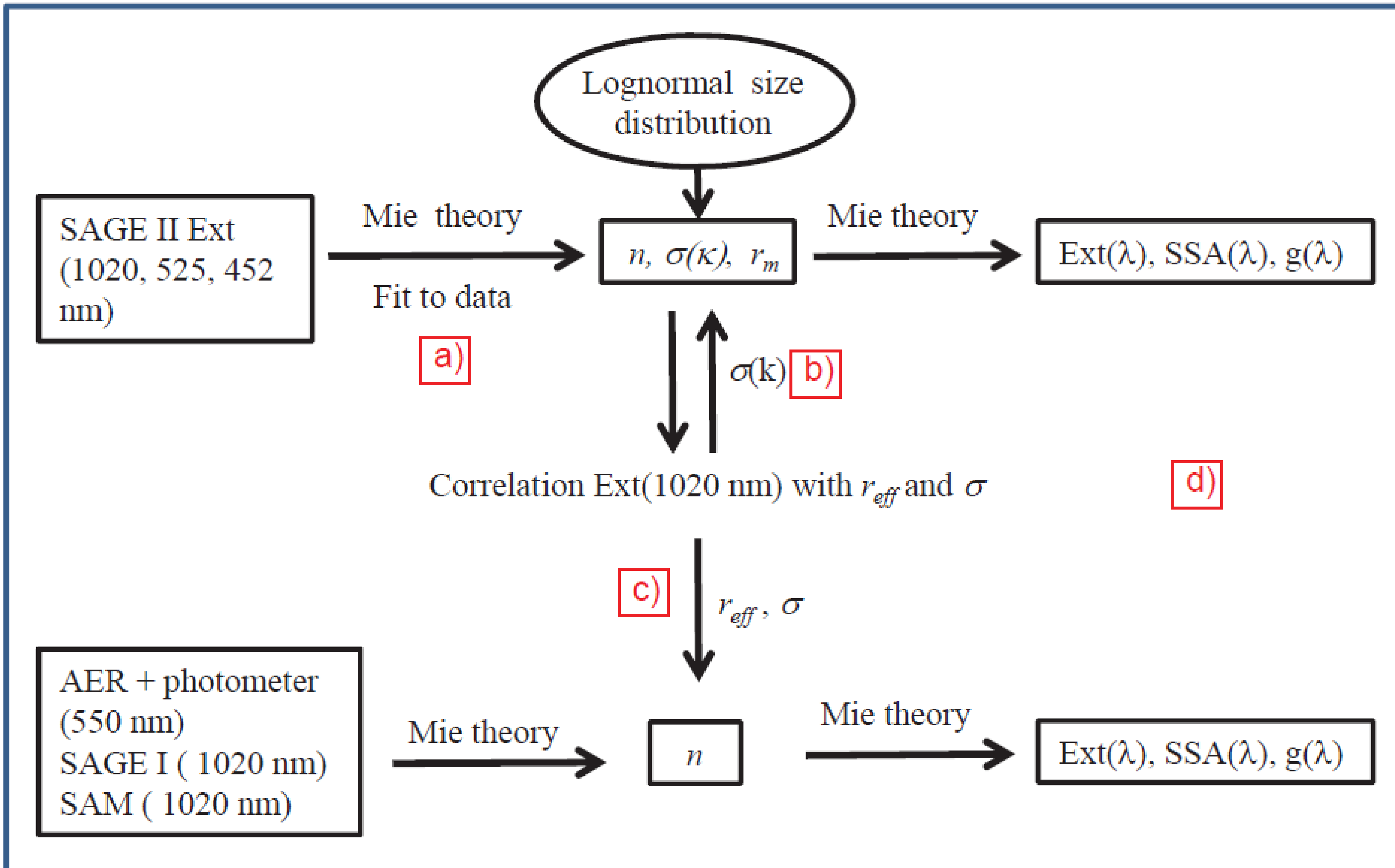


It is clear that it is an issue for the Manam eruption of 2005 and may be an issue for some or all of the events after 2005.

Estimates of aerosol ‘size’ directly impact inferences of other parameters like SAD.

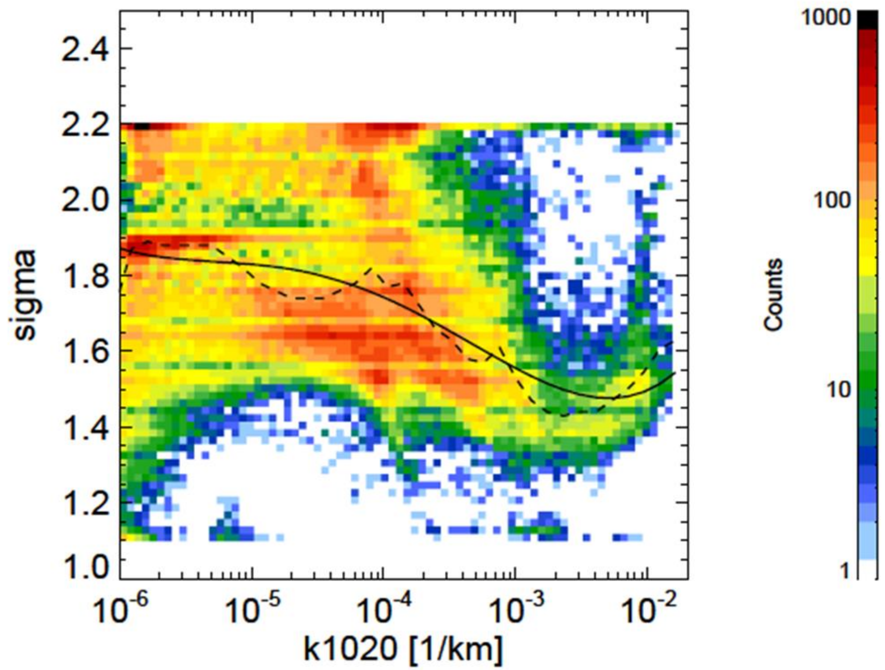
May lead to underestimates of SAD for small volcanic events.

Microphysical retrieval algorithm of data (ETH)



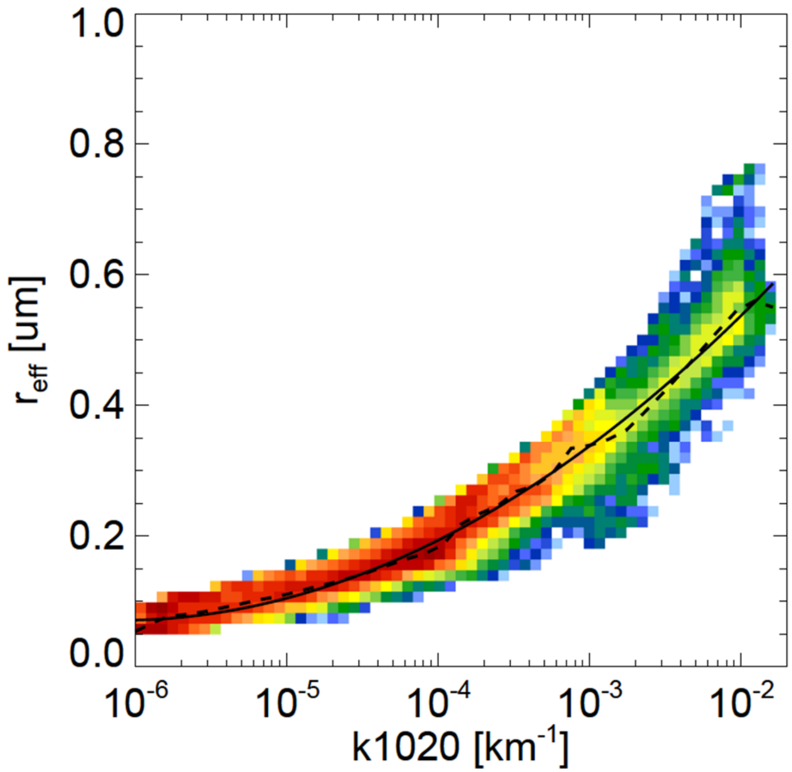
3-λ SMLN width as inferred from SAGE II data

- Distribution of SMLN width as a function of 1020-nm extinction coefficient
- Solid line is use to estimate effective radius when only one wavelength is available



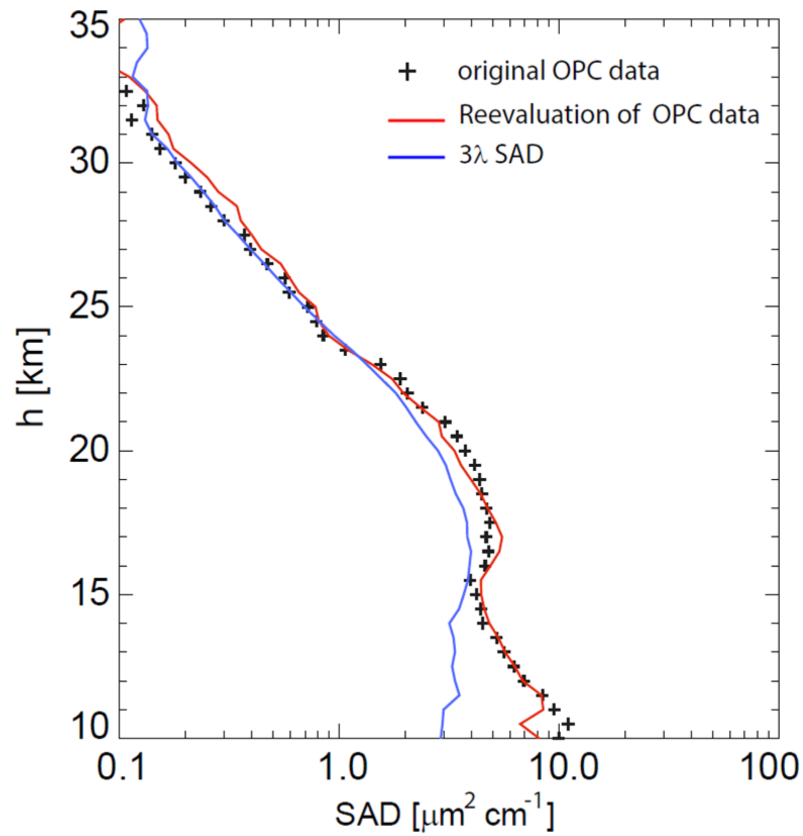
Correlation between r_{eff} and extinction

- Distribution of effective radius as a function of 1020-nm extinction coefficient
- Solid line is use to estimate effective radius when only one wavelength is available

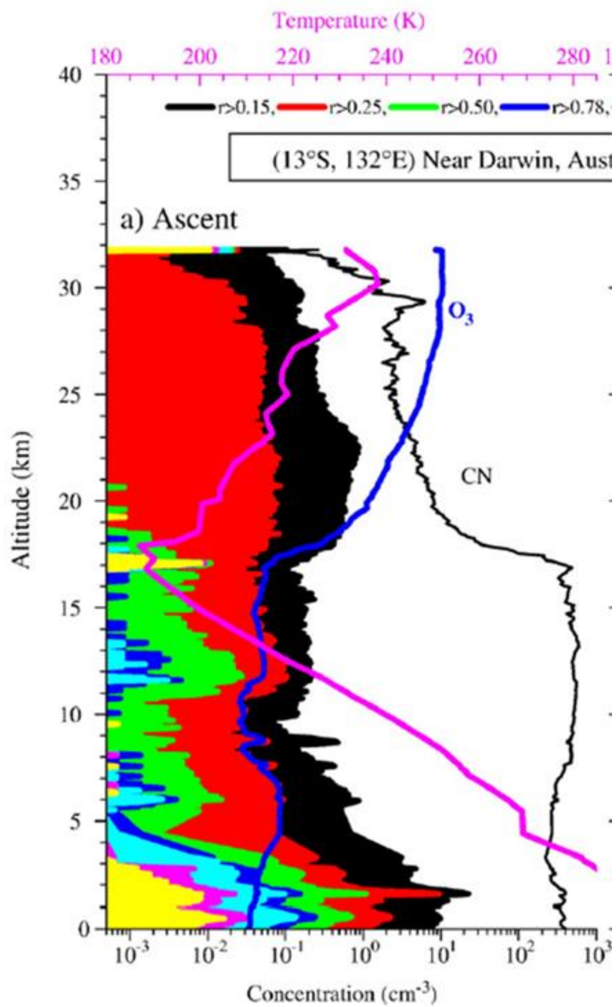


Comparison of ‘pure’ 3-λ SAD with UW OPC values

- SAGE 3-λ SAD agrees well with OPC data above 20 km but arge deviation in the lower stratosphere remain
- SMLN underestimates (incapable) aerosol number density for small particles (~<0.1μm)



For instance…



- Extinction is dominated by large particles and is insensitive to small particles which can contribute to SAD significantly
- A SMLN inferred from vis/nir extinction cannot reflect these smaller particles
- For CMIP6, small particles in the vicinity of the aerosol are added to the inferred SMLN

Deshler 2008

What does it all mean?

- Overall quality of the data set continues to improve but should not be confused with ‘truth’
- Outstanding issues:
  - Artistry: Some manual repair of unreasonable ‘looking’ data is still necessary.
  - An increase in the lower stratosphere at high latitudes at the 2005 is a concern
  - SAD estimates in the ‘clean’ post-SAGE period may be too low
  - How do we improve S.D. estimates?

Fin

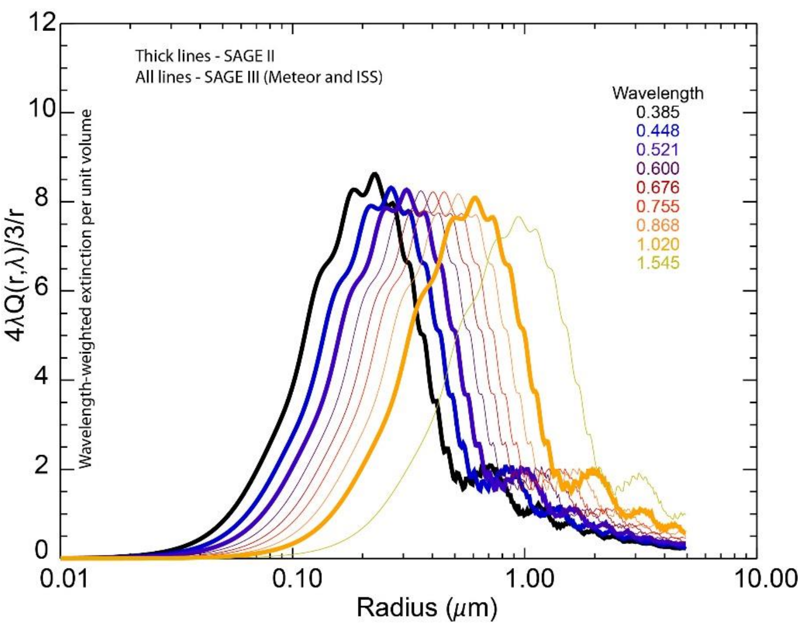
CMIP6: improving the CCMI retrieval

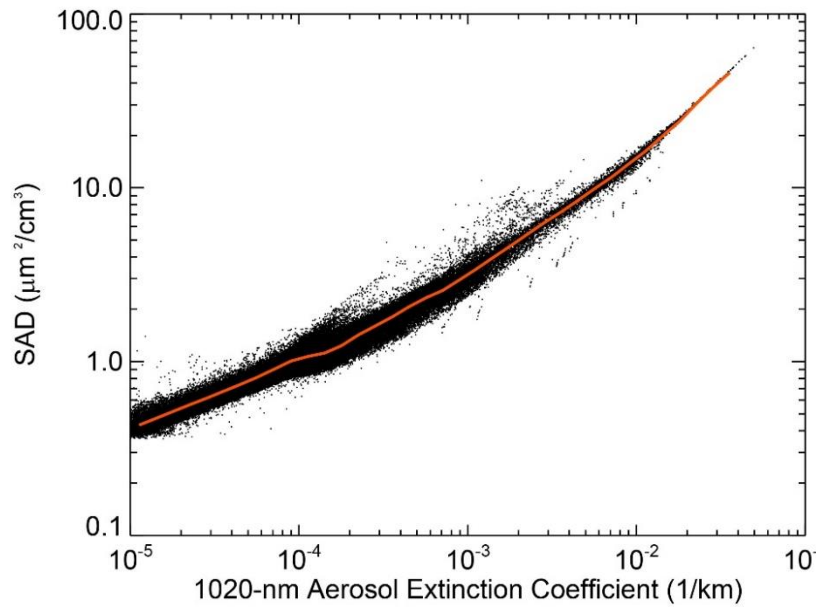
- Use only SAGE at 1020 nm, 525 nm, 452 nm
- Refrain from using SAGE at 386 nm, i.e. 3λ instead 4λ
- Improve gap-filling by using CLAES instead of ground-based lidar
- Include OSIRIS data together with CALIPSO
- Use HALOE only for validation
- Apply correlation for distribution width $\sigma(k)$ instead $r_{\mathrm{eff}}(k)$ for SAGE II data
- Extend from 1960-2011 to 1850-2015

Derived Aerosol Product Issues

The quality of the inference of aerosol properties from SAGE II measurements is limited by the information content of the measurements. Retrievals are dependent on the assumptions made about the underlying size distribution.

Periods where only one optical parameter available (CLAES, OSIRIS/CALIPSO) infer aerosol properties based on observed relationships during the multi-wavelength (SAGE II) period; a period dominated by recovery from large volcanic eruptions.

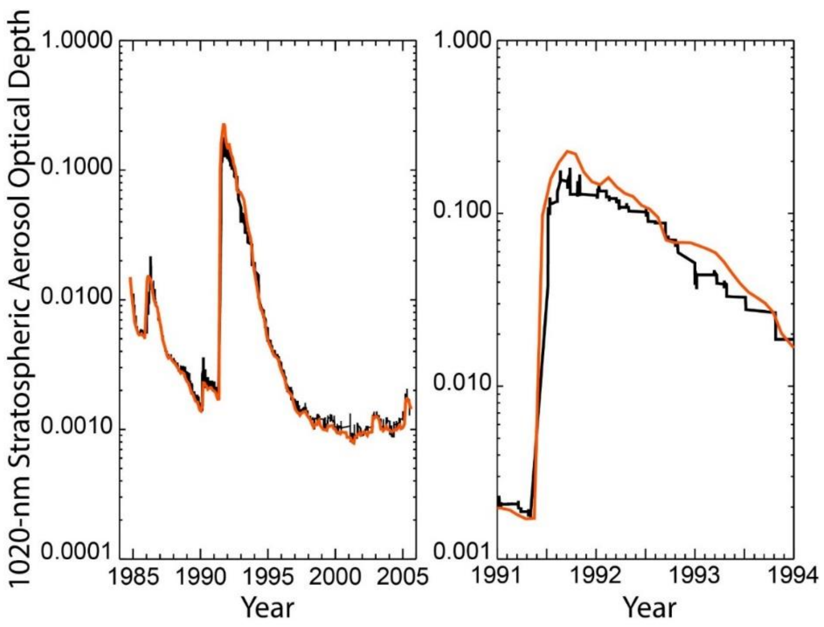




Things that tend to get ignored

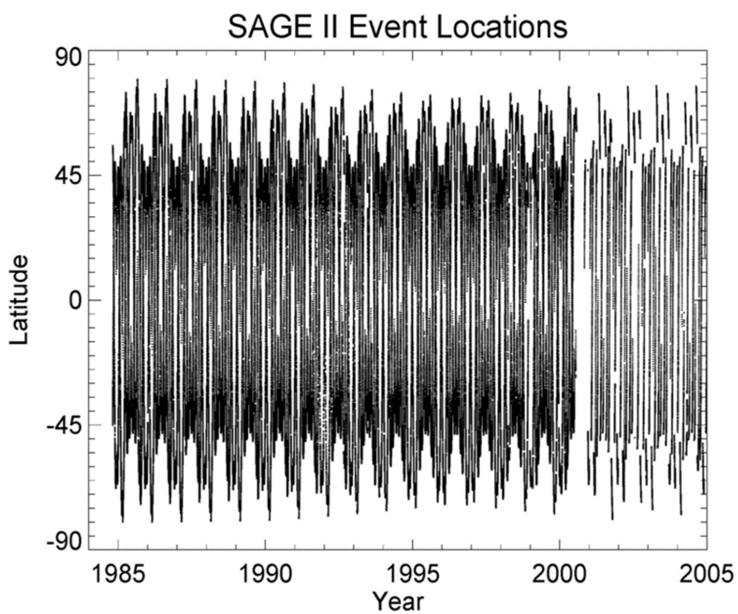
- Uncertainty in the derivation of inferred quantities (SAD, etc.) because it is due to more than measurement noise (e.g., imposition of a model)
- Inhomogeneity following volcanic events
- Composition Issues
  - Many sulfate stratospheric aerosol have solid or dissolved inclusions (metal, salts, etc.) with possible impact on optical properties and things derived from them
  - Above the main aerosol layer, the partitioning of sulfur changes from primarily as sulfate aerosol to primarily gases; this change is currently ignored
  - Organic-sulfate aerosol certainly exist in the UTLS (see above)
  - Non-ice PSCs

Optical Depth Changes from CCMI to CMIP6 Revision



Change in filling leads to generally larger optical depths in the early Pinatubo period particularly at low latitudes

Solar Occultation Impact on a 'Gap Free' stratospheric aerosol data set

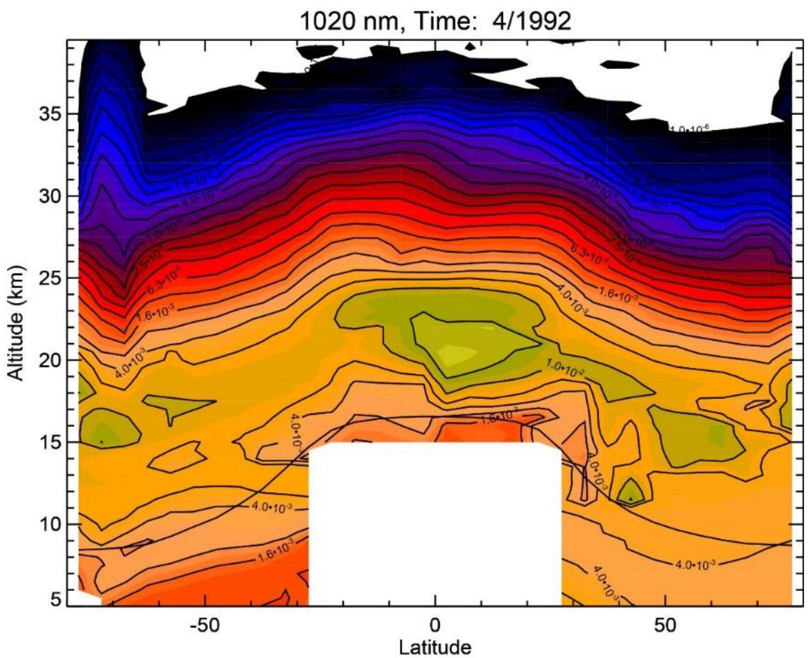


- About 160,000 profiles over 21 years
- Sampling is a bit thin at low latitudes
- **No high latitude measurements in winter**
- No data in September to November 2000
- Data rate drops to 50% in December 2000

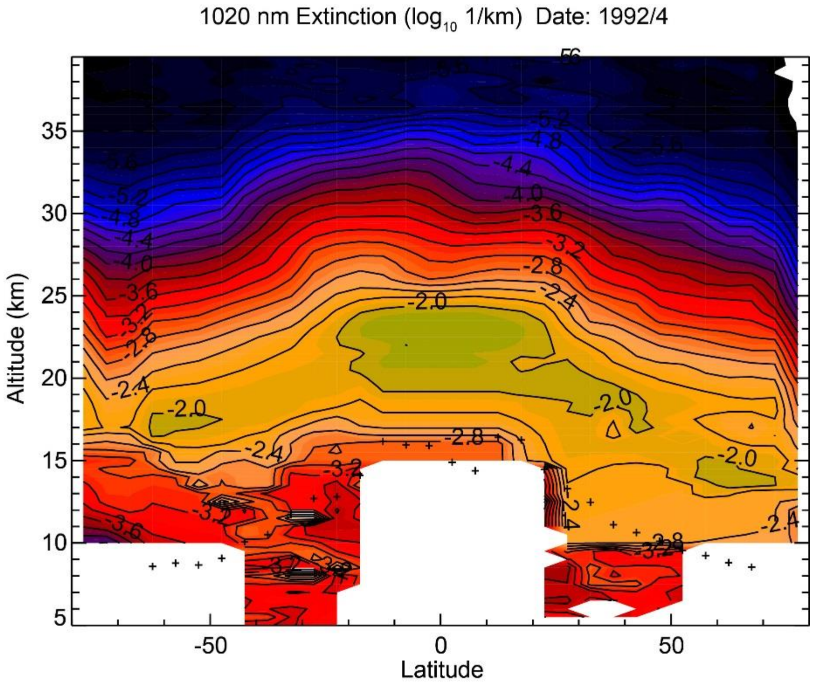
Changes for CMIP6

- The basic approach has not changed from that described in the ASAP approach
- Basic paradigm:
  - SAGE II (now v7.0 vs v6.2) is used exclusively used when it is available; homogeneity is preferred when possible
  - The extinction-to-derived products methodology has also been change. Derived products are based on the ETH 4λ approach
  - Reported uncertainties are measurement noise/zonal inhomogeneity and not algorithmic.
  - Interpolation is used for gaps of up to 2 months except at higher latitudes and in the data gap period in 2000
  - When gap data is used, it is used stand-alone so discontinuities in the data set may occur when SAGE II and gap data are not fully consistent

Improving the Pinatubo Period (1991-1993)



Filled using scaled CLAES Data

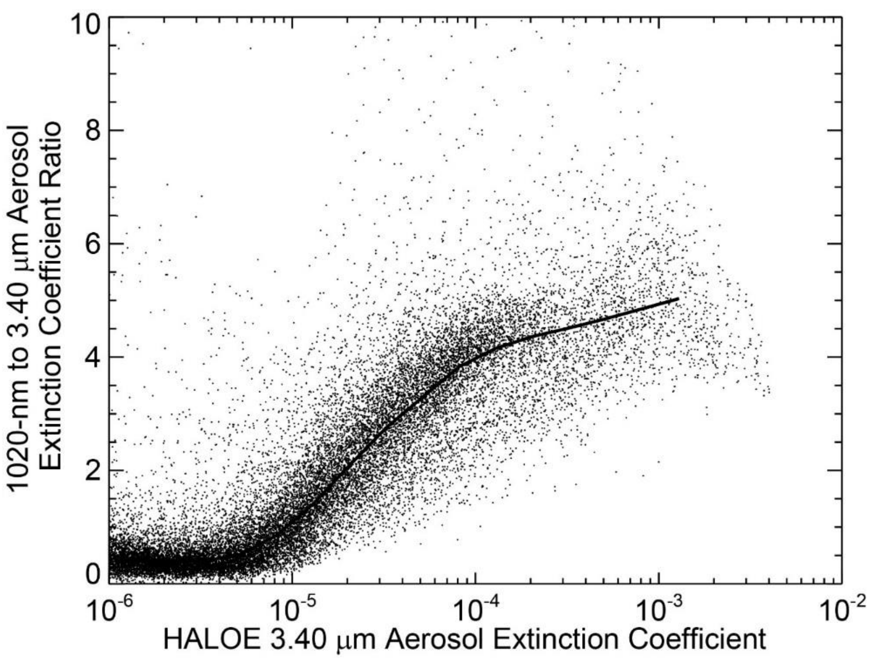


Filled using composite lidar record from Mauna Loa and Camaguey (ASAP)

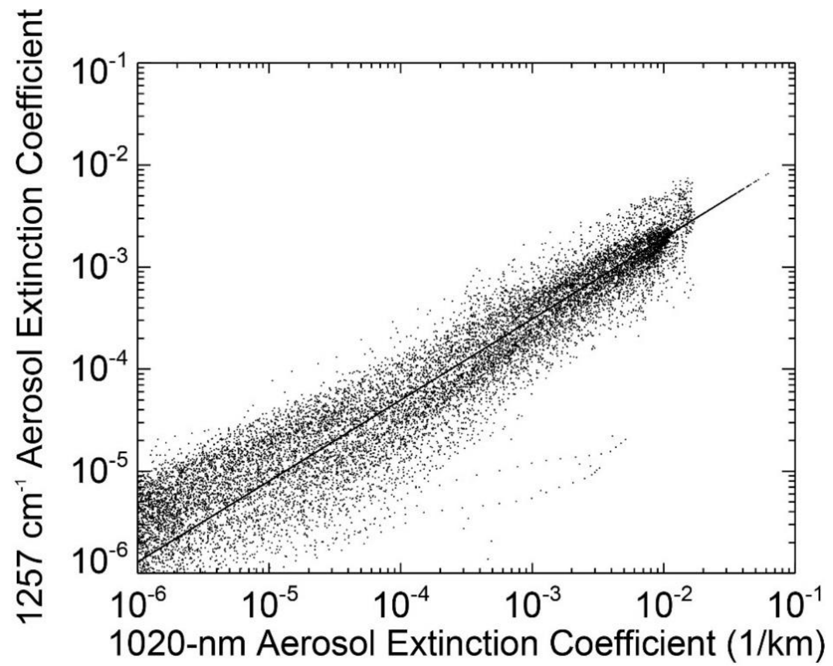
- Replace subtropical lidar data used in previous version with 1020-nm extinction empirically derived from CLAES and HALOE; there are still issues with the early months (if any sensible monthly mean is possible)

Empirical fits for CLAES and HALOE for the Pinatubo Gap period

HALOE-SAGE II Linkage



CLAES-SAGE II Linkage



No compensation for differences in vertical resolution

Using equivalent latitude statistics to reconstruct a latitude-based analysis

Steps:

- Compile aerosol statistics on an equivalent latitude/time grid. This has been done before and is straightforward. Since SAGE II uses MERRA data, this is what I would use for the Eq. Lats. So this distribution is: $f(\theta_e,t)$
- Using the full MERRA product (not just that associated with SAGE II observations) compute the density of equivalent latitudes as a function of latitude for winter hemispheres. This would be like for latitudes of 60 to 65N, 8% of the time equivalent latitude is between 50 and 55N, 17% of the time it is between 55 and 60N, 43% of the time it is between 60 and 65N, and so on. This function is $p(\theta|\theta_e)$
- Compute the distribution of aerosol properties on a latitude grid, k', using:

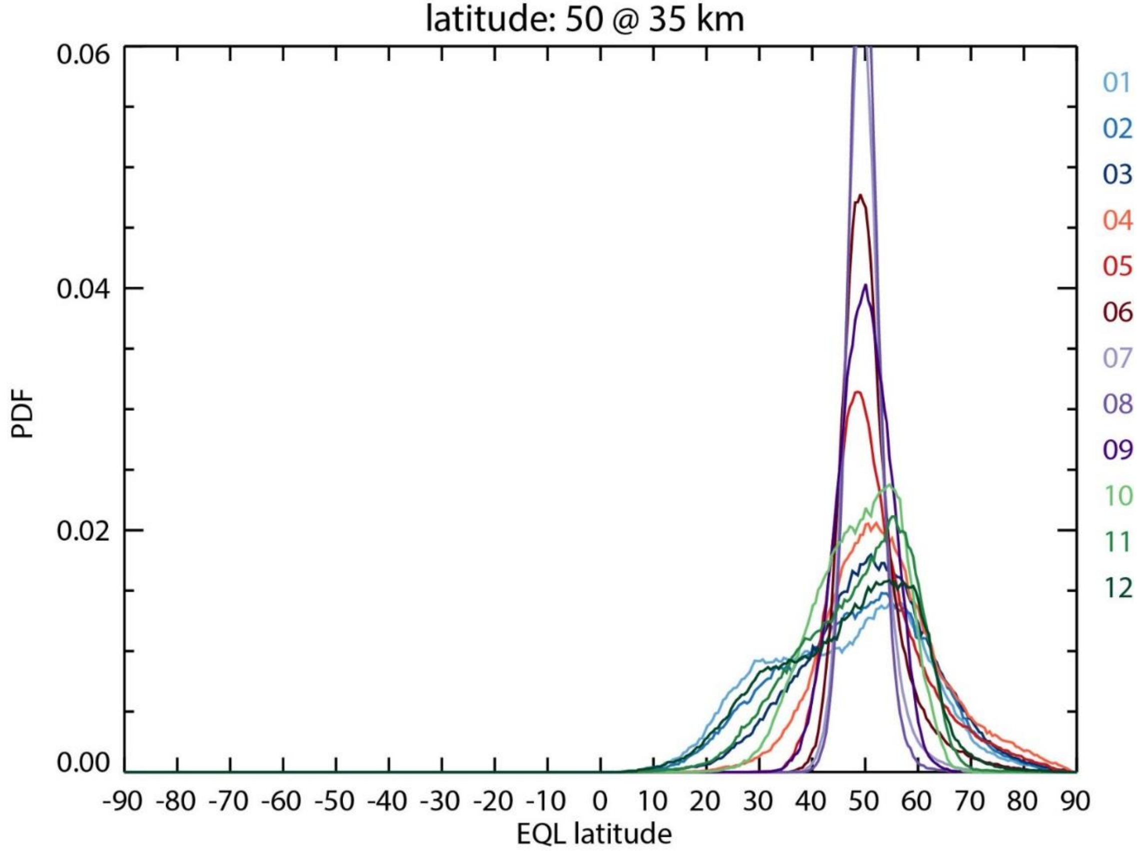
$$k'(\theta_j) = \Sigma k(\theta_{je})p(\theta_j|\theta_{ei})$$

where the j subscript is for latitude bin 'j', and the 'i' subscript is for equivalent latitude bin i.

(Apologies for the bad math form)

- I think this would fill in most of the high latitude bins to at least the point that further interpolation would not yield the silly stuff that the current approach produces.

PDFs of Equivalent Latitude



Climatological Values from Luis Millan (NASA JPL)