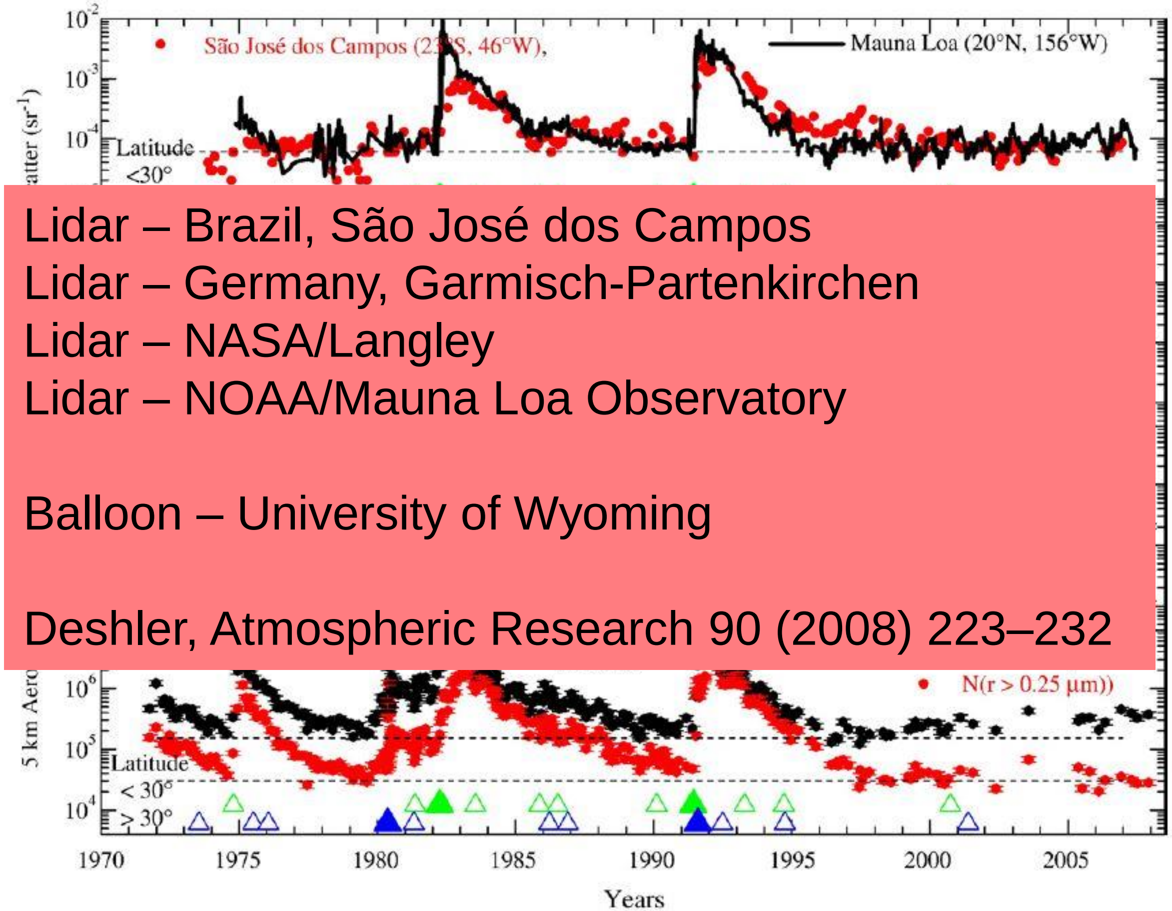
ESRL/Global Monitoring Division
Boulder, Colorado

Mauna Loa Observatory
Hawaii

Early regular measurements of the stratospheric aerosol layer started in 1970's



Lidar – Brazil, São José dos Campos
Lidar – Germany, Garmisch-Partenkirchen
Lidar – NASA/Langley
Lidar – NOAA/Mauna Loa Observatory

Balloon – University of Wyoming

Deshler, Atmospheric Research 90 (2008) 223–232

Fig. 1. History (1970–2007) of SA from two tropical lidar sites (São José dos Campos, Brazil and Mauna Loa, Hawaii, USA), two mid latitude lidar sites (Hampton, Virginia, USA, and Garmisch, Germany) and one set of mid latitude in situ measurements. The lidar measurements are presented as integrated SA backscatter above the tropopause at each site. The in situ data are presented as integral columns of number between 15–20 and 20–25 km at two sizes. The time of volcanic eruptions for VEI=4 (open triangle) and VEI=5 (closed triangle) and for latitudes <30° and >30° are shown in the bottom of the top and bottom panels. A complete description of each of these instruments is provided by Deshler et al. (2006). Recent data from São José dos Campos were provided by Dale Simonich and Barclay Clemesha, from Mauna Loa by John Barnes, and from Garmisch by Thomas Trickl. The Hampton measurements have been discontinued.

Lidar Equation

$$Sig(z) = Const * \exp(-Up) * \exp(-Down) * \frac{(Molecular + Aerosol)}{z^2}$$

Basic lidar quantity is backscatter (per km per steradian) with ~5% error

exp(-Up) and exp(-Down): Corrections for molecular extinction (well known) and aerosol extinction

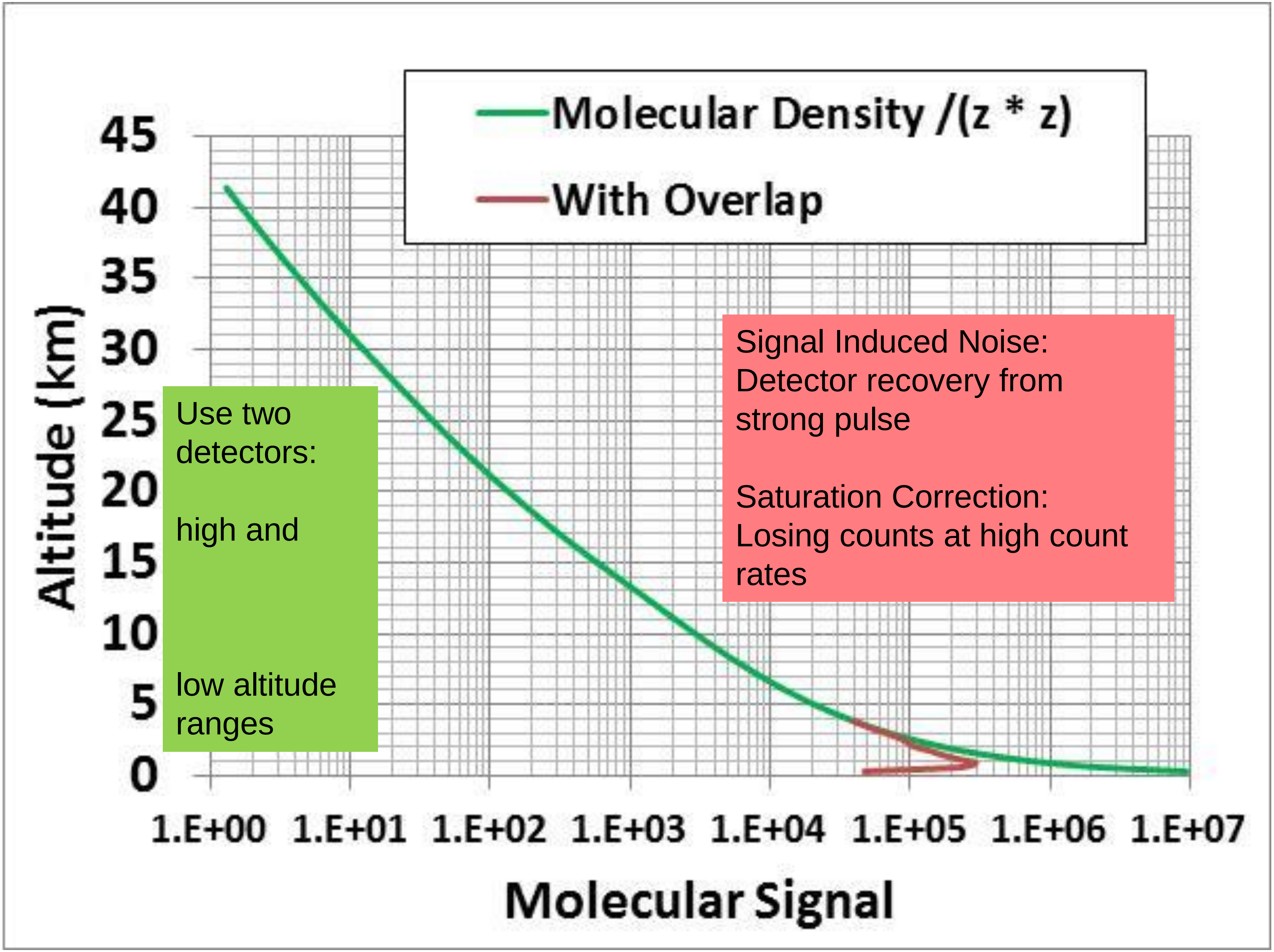
Aerosol extinction depends on “Lidar Ratio” = Ext/Backscatter (?)
And Aerosol(z) which you are trying to measure

Stratospheric extinction is small during background conditions, small effect

Multiplying backscatter by Lidar Ratio to get extinction can introduce large error

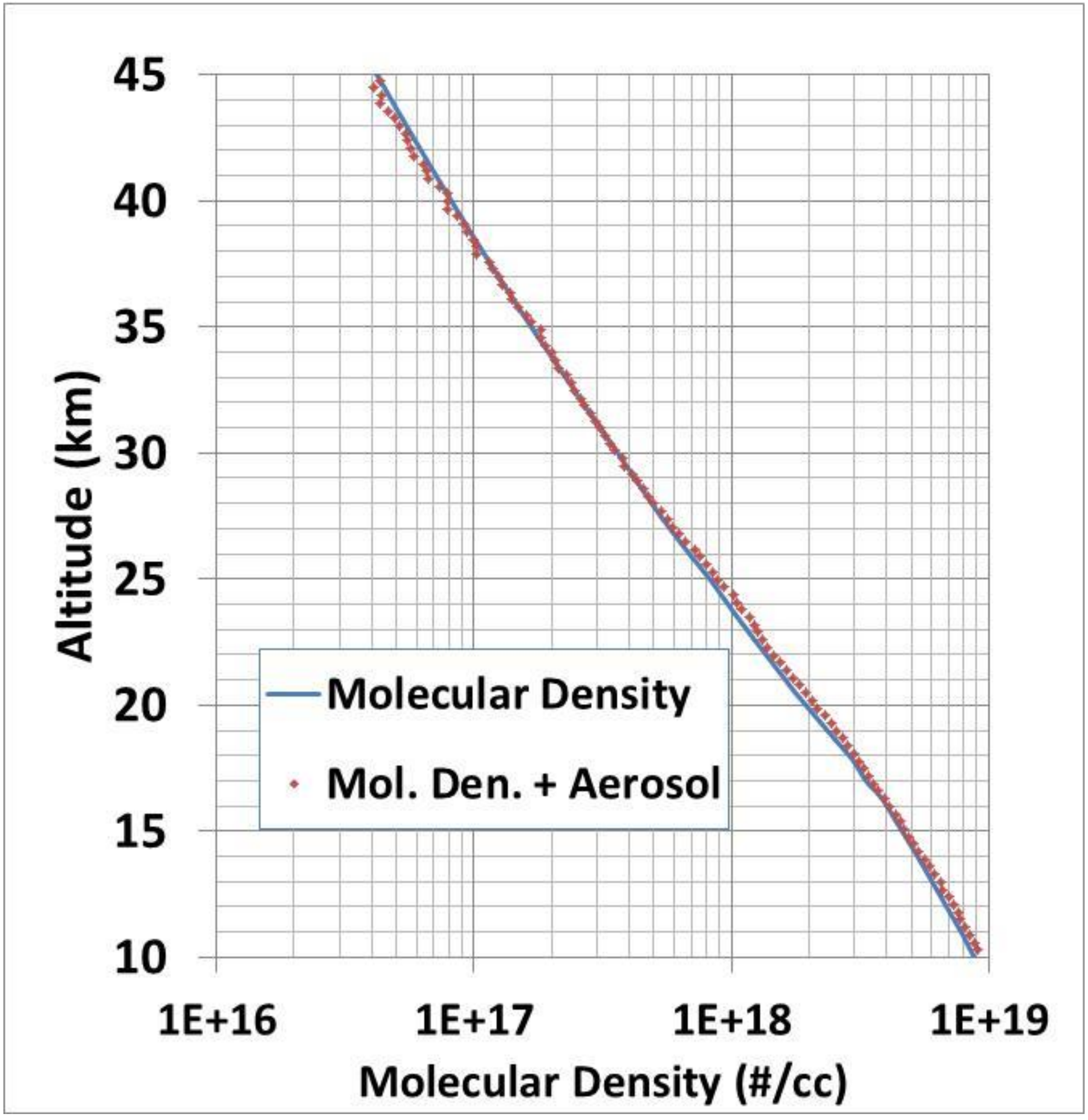
e. g. CALIPSO/CALIOP Troposphere Lidar Ratio is 20 – 70 steradian

e. g. Lidar Ratio for stratosphere at 532 nm is 45 – 50 steradian

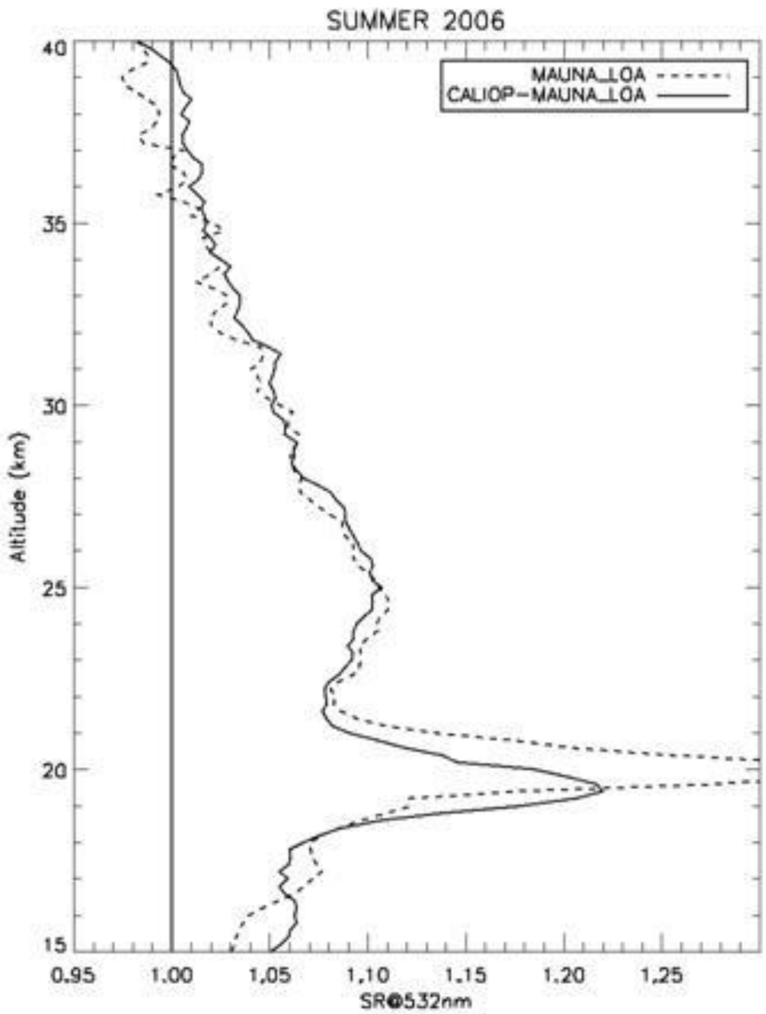


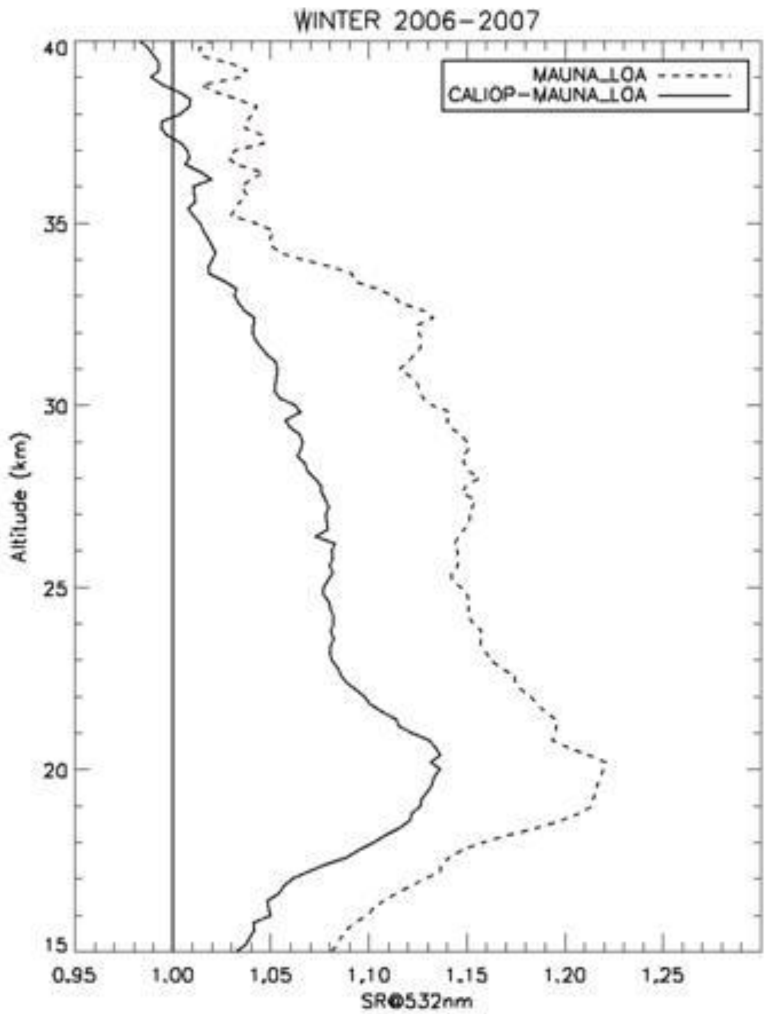
Molecular Density /(z * z)
With Overlap
Altitude (km)
45
40
35
30
25
20
15
10
5
0
1.E+00
1.E+01
1.E+02
1.E+03
1.E+04
1.E+05
1.E+06
1.E+07
Molecular Signal
Use two detectors:
high and
low altitude ranges
Signal Induced Noise:
Detector recovery from strong pulse
Saturation Correction:
Losing counts at high count rates

Example of lidar - normalization of signal to clean air (pure molecular)

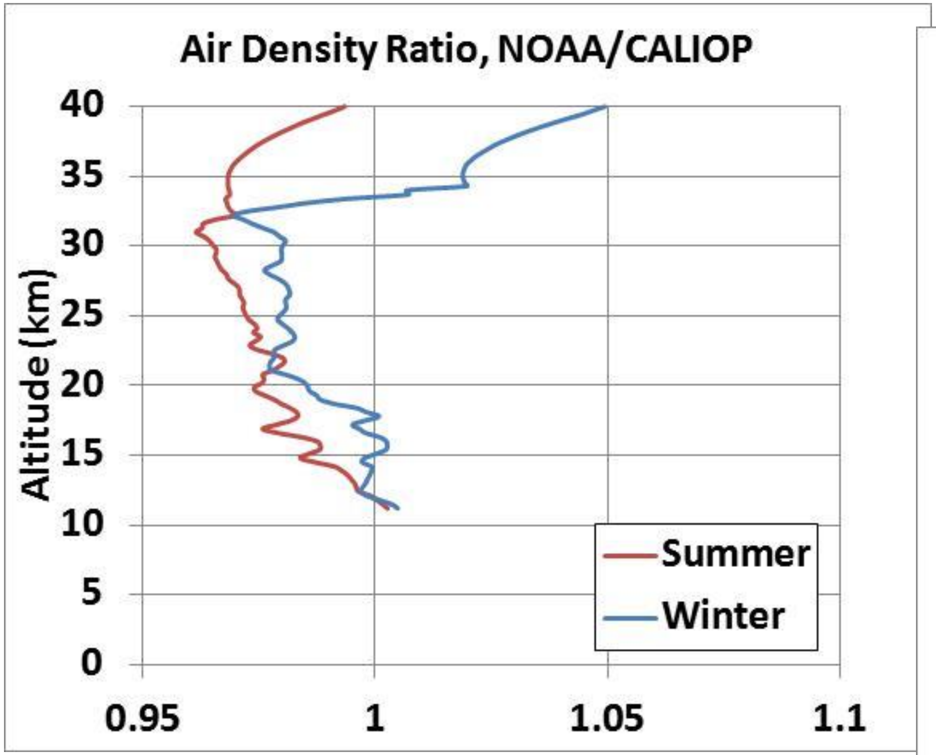


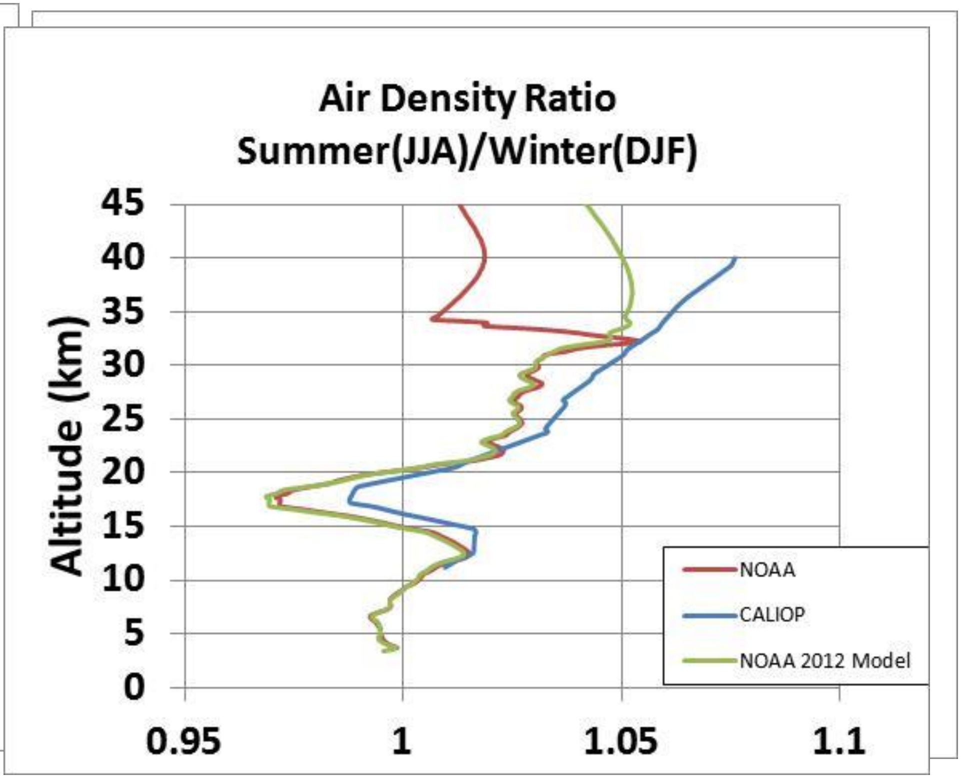
Comparison of NOAA/MLO lidar with NASA/CALIOP Space Lidar Vernier et. al, in preparation





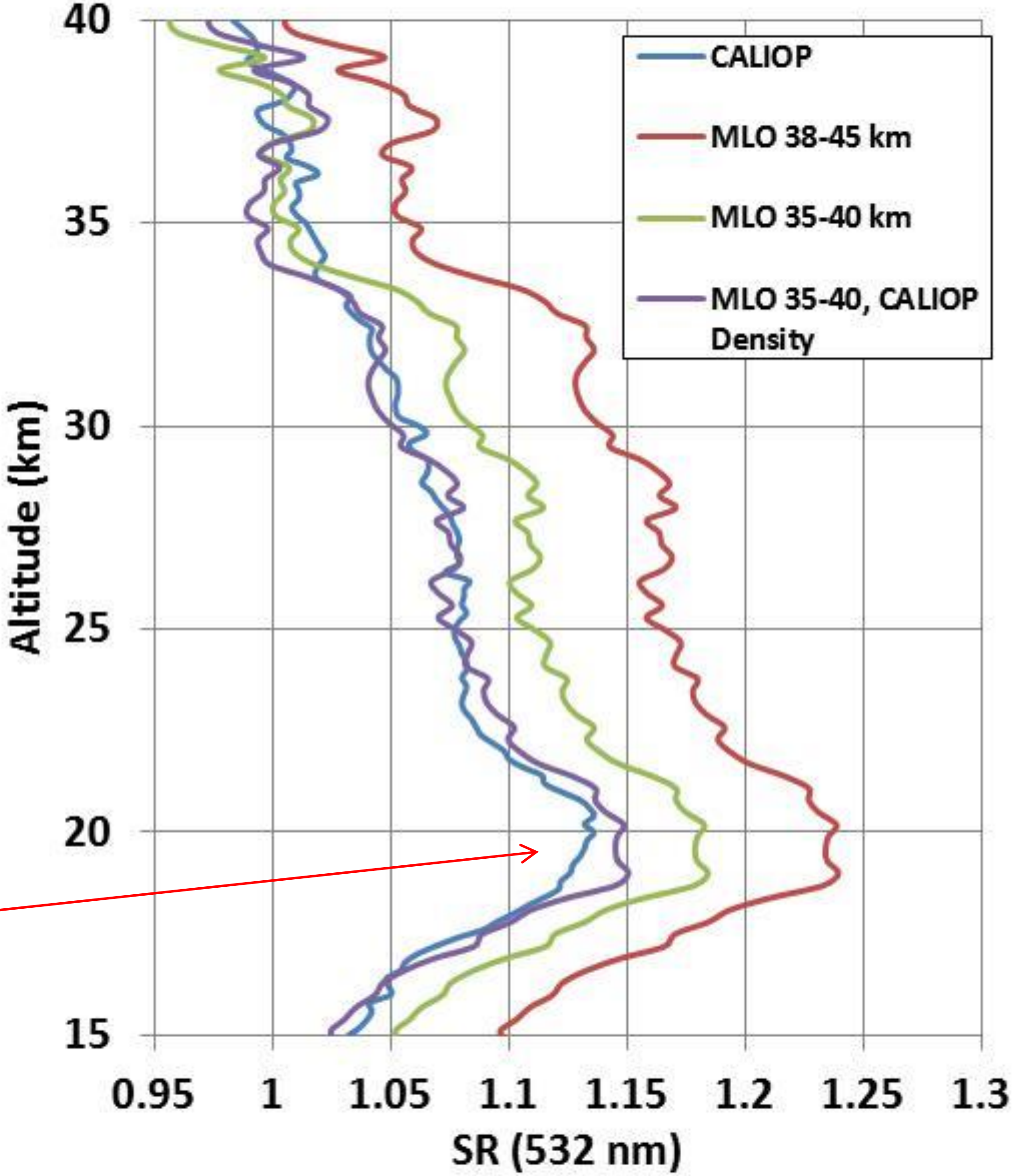
NOAA/MLO sources for molecular density profile
Hilo, HI Radiosondes for 0 to 35 km
MSIS model above 35 km





Comparison of NOAA/MLO lidar with NASA/CALIOP Space Lidar

Winter, 2006-2007



Soufrie`re Hills eruption in Monserrat Island

Measurement of stratospheric aerosols with lidar

- Advantages

- Relatively cheap aerosol profiles
- Continuous measurements (many per night/day)
- High time and altitude resolution
- Multiple wavelengths and polarization

- Disadvantages

- Measures aerosol/mol ratio of backscattered light, not extinction
- Conversion to extinction introduces major error
- Lidars have a bias towards clear conditions
- Use of multiple wavelengths to constrain particle properties limited

- Considerations

- Normalization of profile very important during background times
- Saturation correction and signal-induced-noise must be handled appropriately

NDACC lidar working group

NDACC lidar working group

LIDAR Aerosol

Last update: September 16, 2011

Results are in the public archive�

Instrument was operational��

	Filename	Wavelength		1991	1992	1993	1994	1995	1996
Eureka, Canada (80.1�N, 86.4�W)	euae*.ntl	532/1064 nm							
Eureka, Canada (80.1�N, 86.4�W)	euae*.cal	353 nm							
Ny �lesund, Spitsbergen (78.9�N, 11.9�E)	nyae*.nel	353/532 nm							
Thule, Greenland (76.5˚N, 68.7˚W)	thae*.fil	532 nm							
Garmisch, Germany (47.5˚N,� 11.1˚E)	gaae*.jal	532 nm							
Observatoire Haute Provence, France (43.9�N, 5.7�E)	ohae*.dal	532 nm							
Toronto, Canada (43.66�N, 79.40�W)	toae*.pal	532 nm							
Boulder, CO, USA (40.0˚N, 105.3˚W)	bdae*.5bl	532 nm							
Table Mountain, CA, USA (34.4�N, 117.7�W)	tma3*.mdl	353 nm	1989 <						
Mauna Loa, Hawaii (19.5�N, 155.6�W)	mlae*.6bl	694 nm	1974 <						
Mauna Loa, Hawaii (19.5�N, 155.6�W)	mlae*.5bl	532 nm							
Mauna Loa, Hawaii (19.5�N, 155.6�W)	mla3*.mdl	353 nm							
Lauder, New Zealand (45.0�S, 169.7�E)	laae*.uc1	532 nm							
Dumont d�Urville, Antarctica (66.7˚S, 140.0˚E)	duae*.dal	532 nm	1989<						
McMurdo Station, Antarctica (77.9˚S, 166.6˚E)	muae*.adl	532 nm	1990 <						

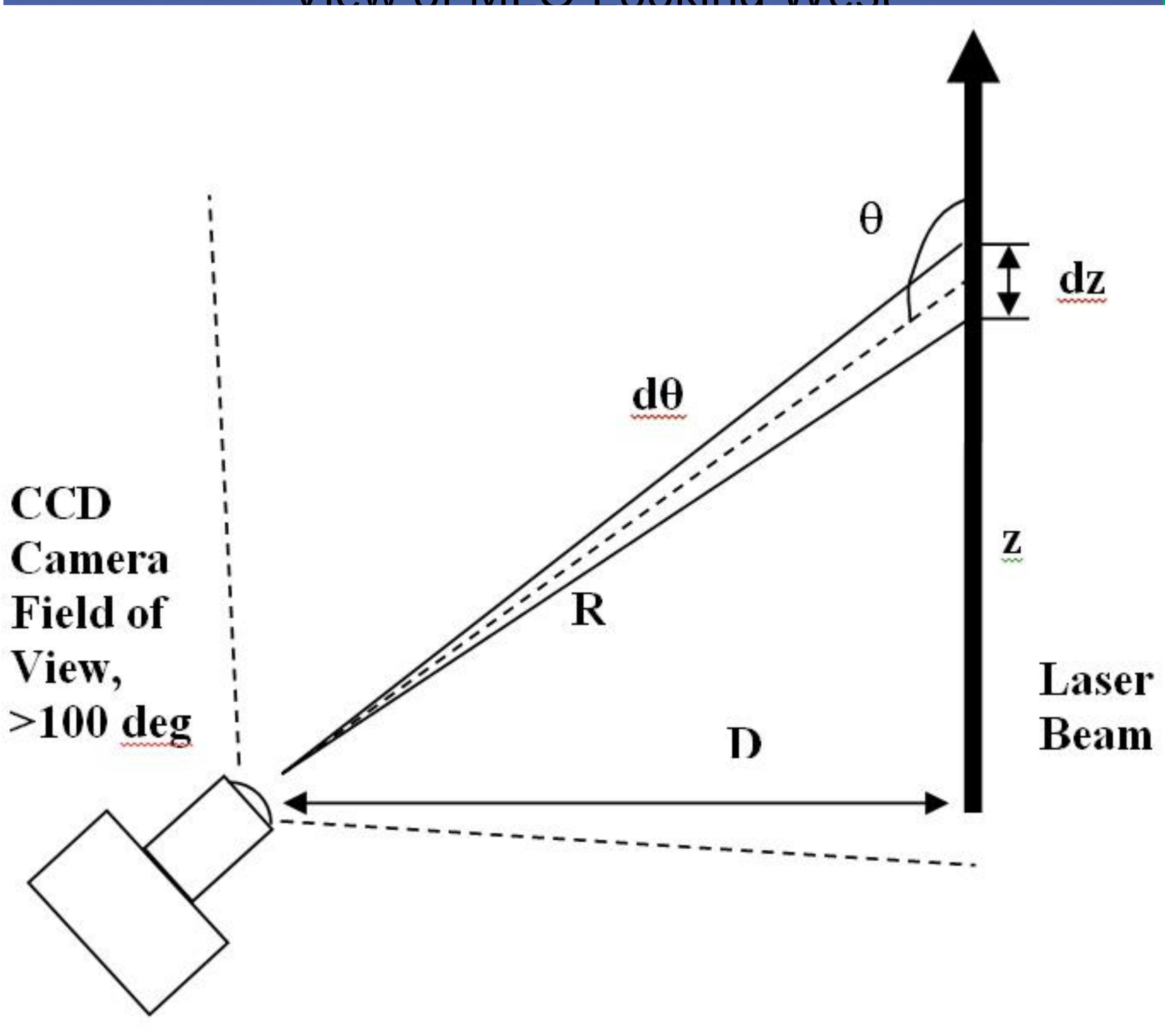
NDACC

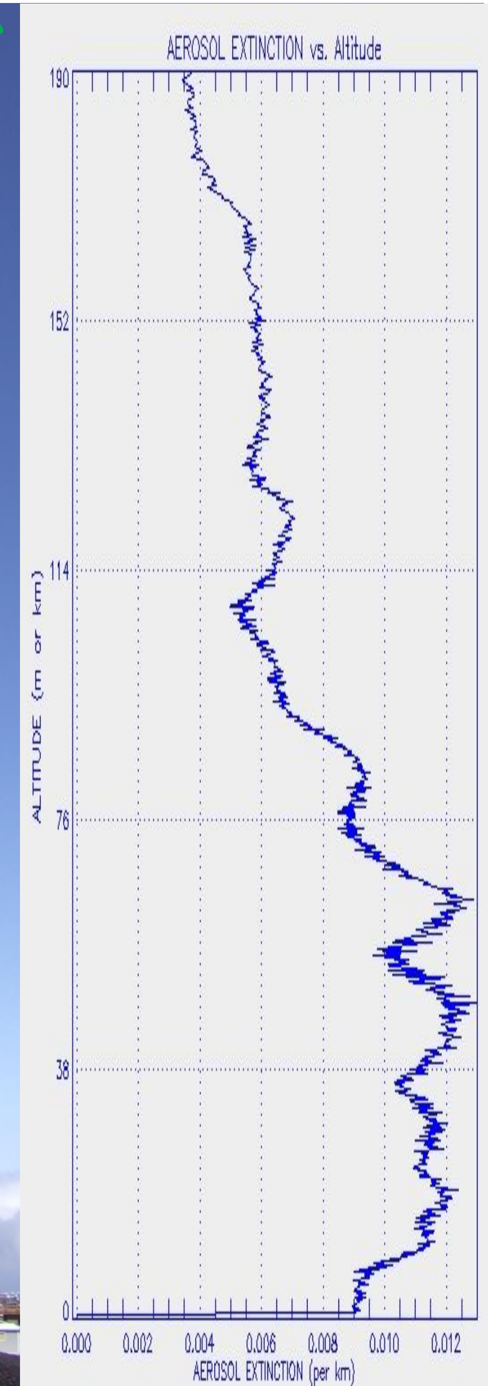
19 September 2016

Clidar (Camera Lidar) measurement of aerosol properties

View of MLO Looking West

190 m





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Multistatic aerosol–cloud lidar in space: A theoretical perspective

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[a] NASA Goddard Institute for Space Studies, 2880 Broadway, New York, NY 10025, USA

[b] Department of Applied Physics and Applied Mathematics, Columbia University, 2880 Broadway, New York, NY 10025, USA

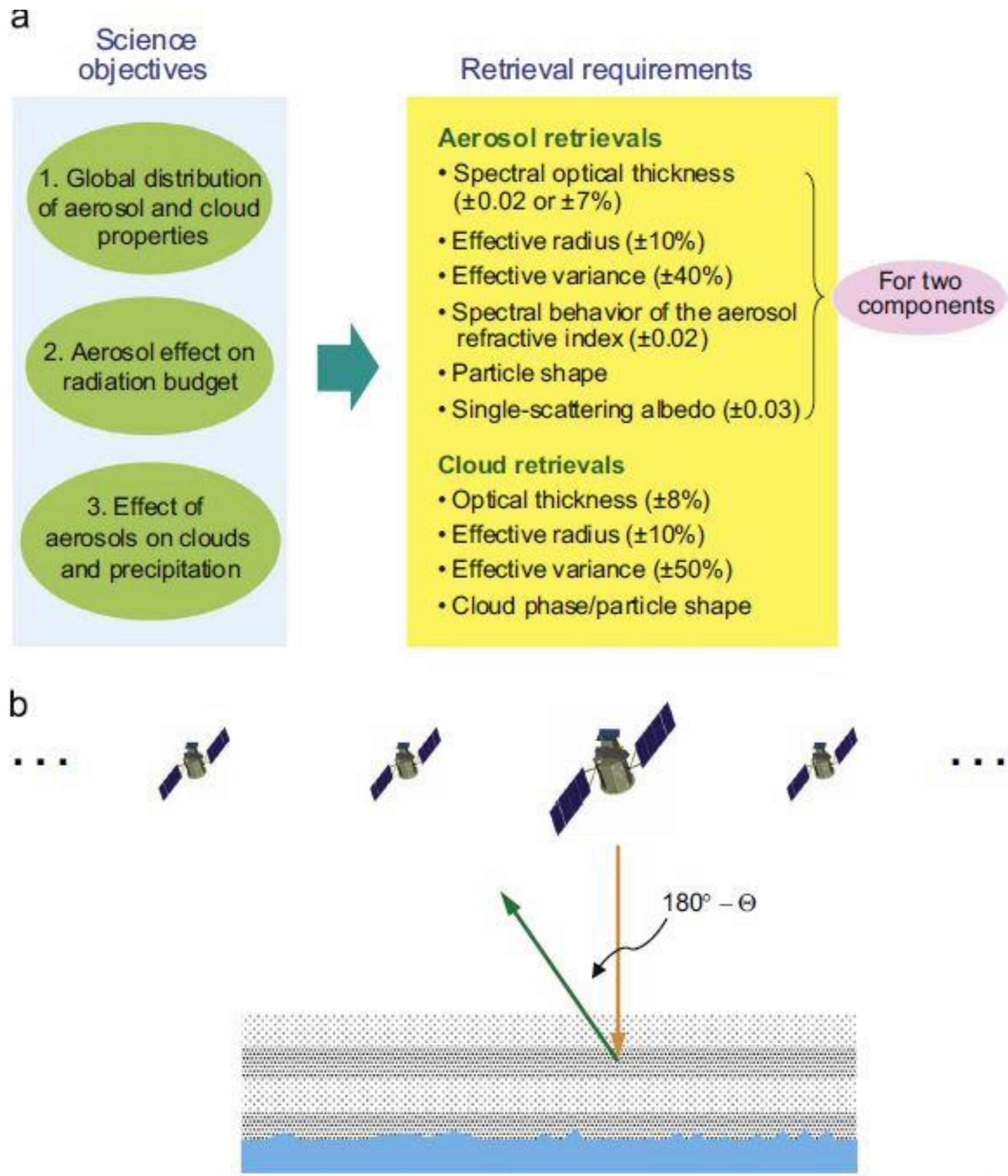
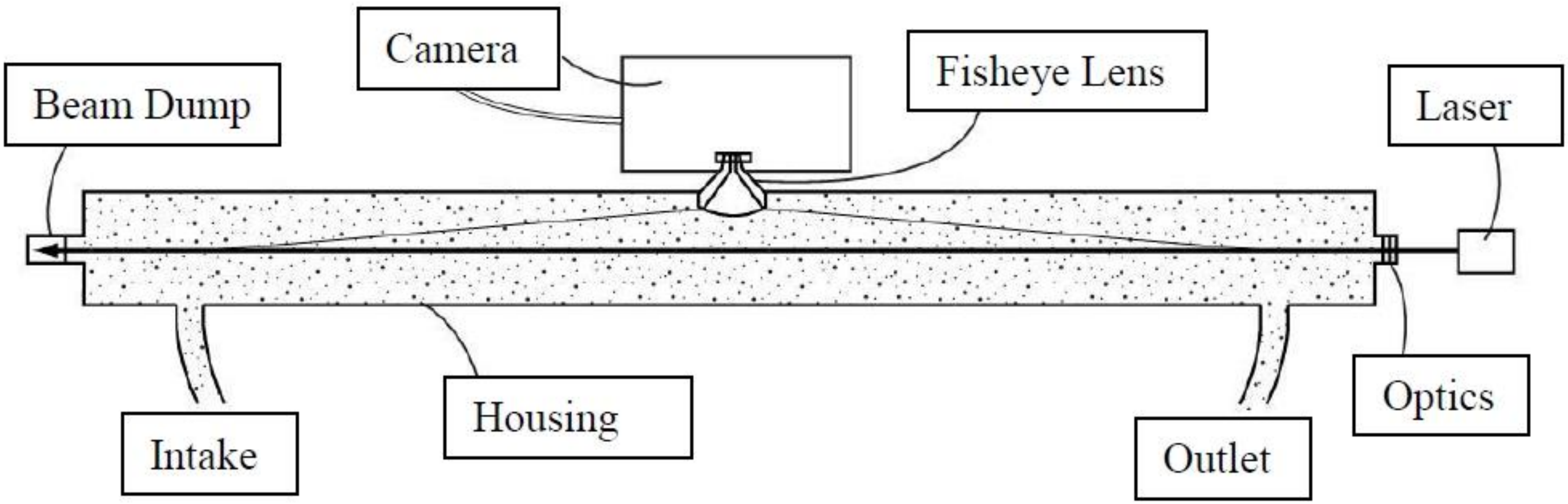
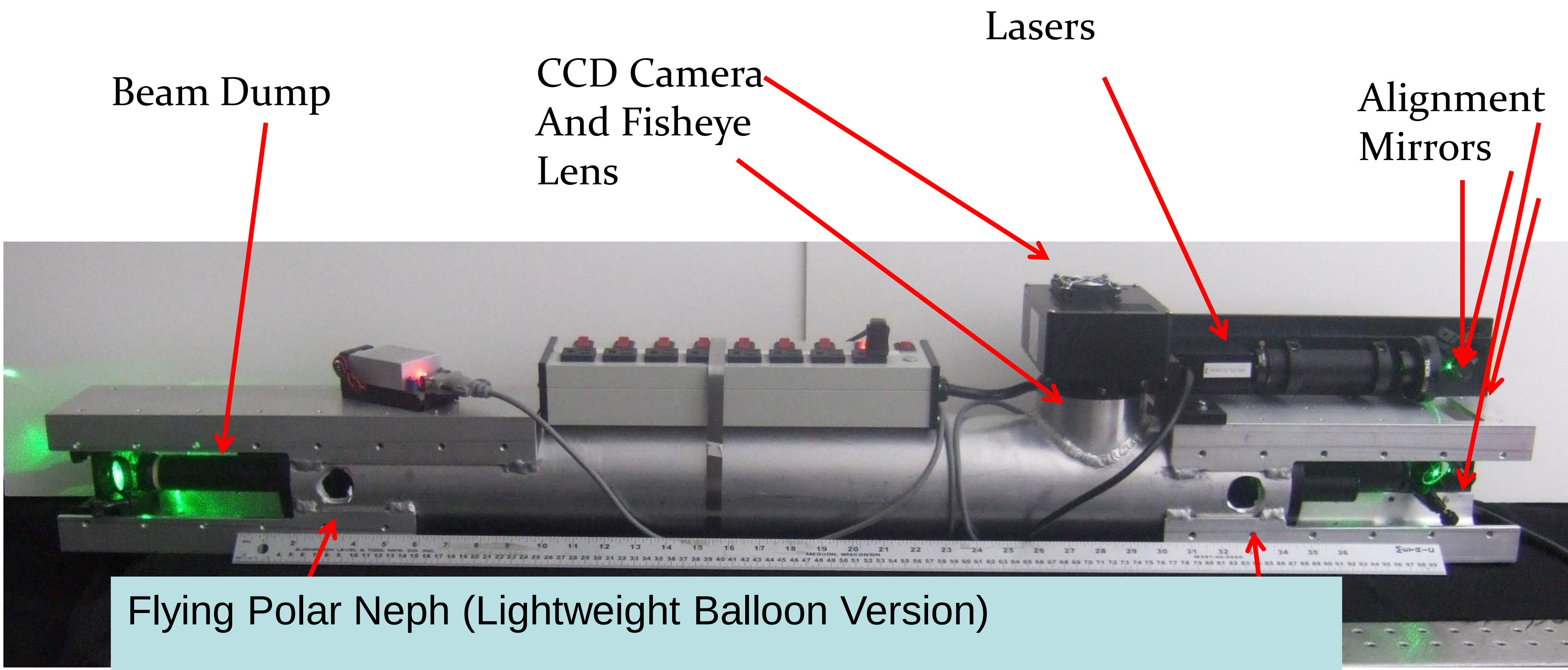


Fig. 1. (a) Aerosol and cloud retrieval requirements follow from the overarching science objectives. (b) Orbital multistatic lidar system. The primary satellite is equipped with a nadir-pointing backscattering lidar, while one or more secondary platforms carry additional receivers of scattered laser light. The scattering angle $\Theta \neq 180^{\circ}$ characterizes the bistatic configuration formed by the transmitted laser beam and the receiver on a secondary platform.

Imaging Polar Nephelometer
Measures Aerosol Phase Function P(θ)



Ground/Aircraft Based Polar Nephelometer



Flying Polar Neph (Lightweight Balloon Version)

Calibrated on ground

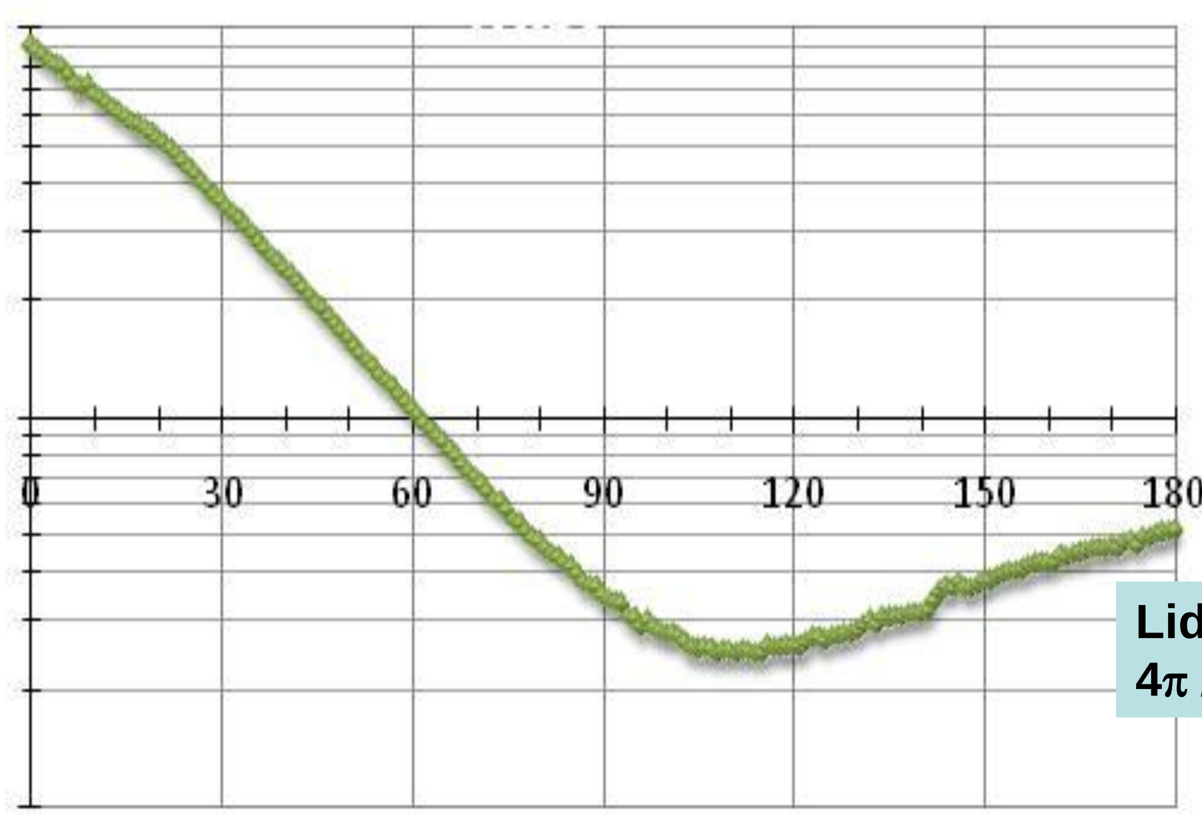
Estimates indicate reasonable accuracy at 30 km with
50 mWatt laser for 5 minute integration

Camera, lens, computer, laser, batteries < 6 lbs

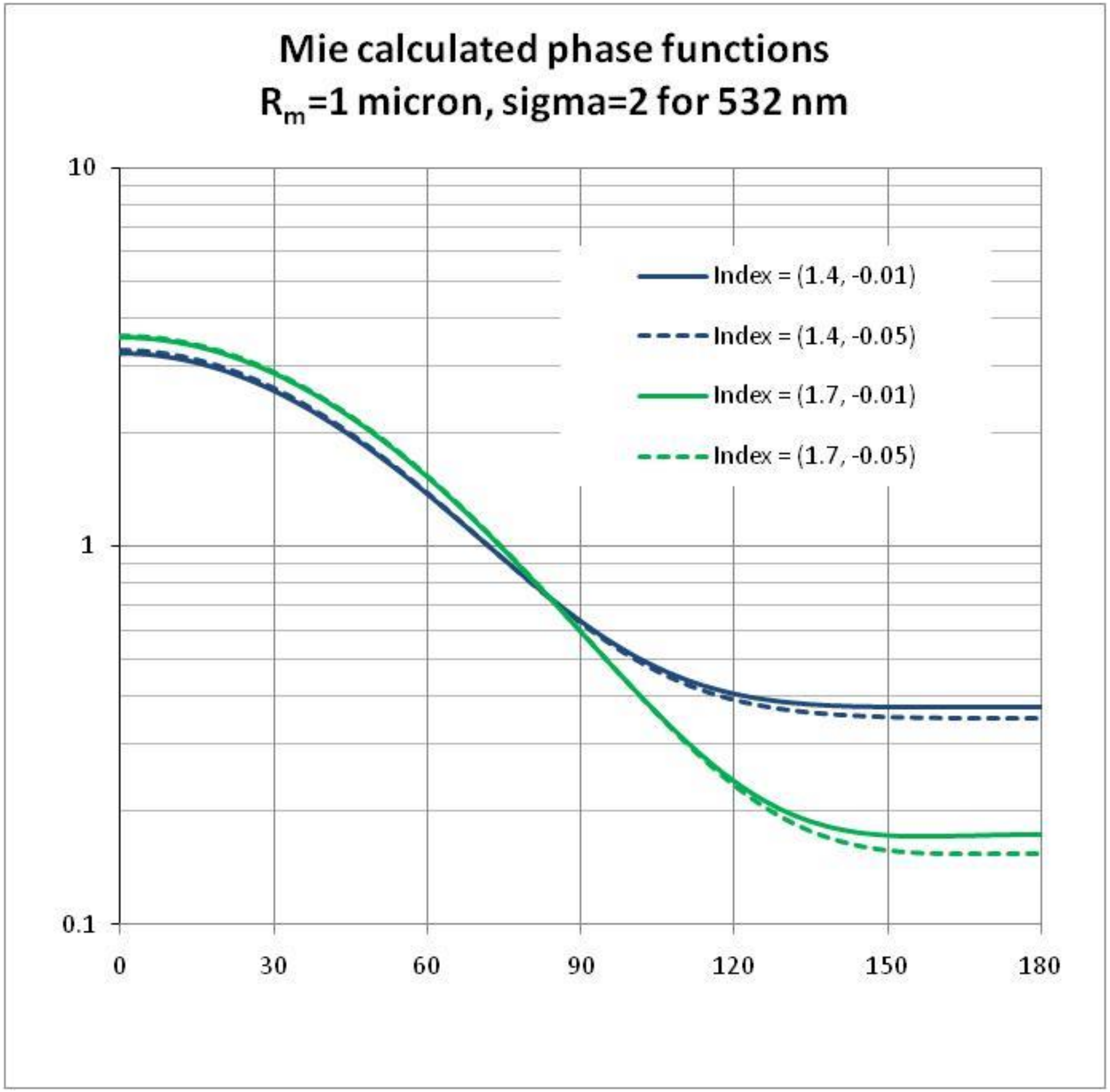
Example: Scattered light from mist generator

5 to 175 degrees measured
Absolutely Calibrated to Molecular Scatter

Asymmetry parameter and Lidar Ratio directly measured



Lidar Ratio
4π / P(180)



Best fit of Mie calculations for:

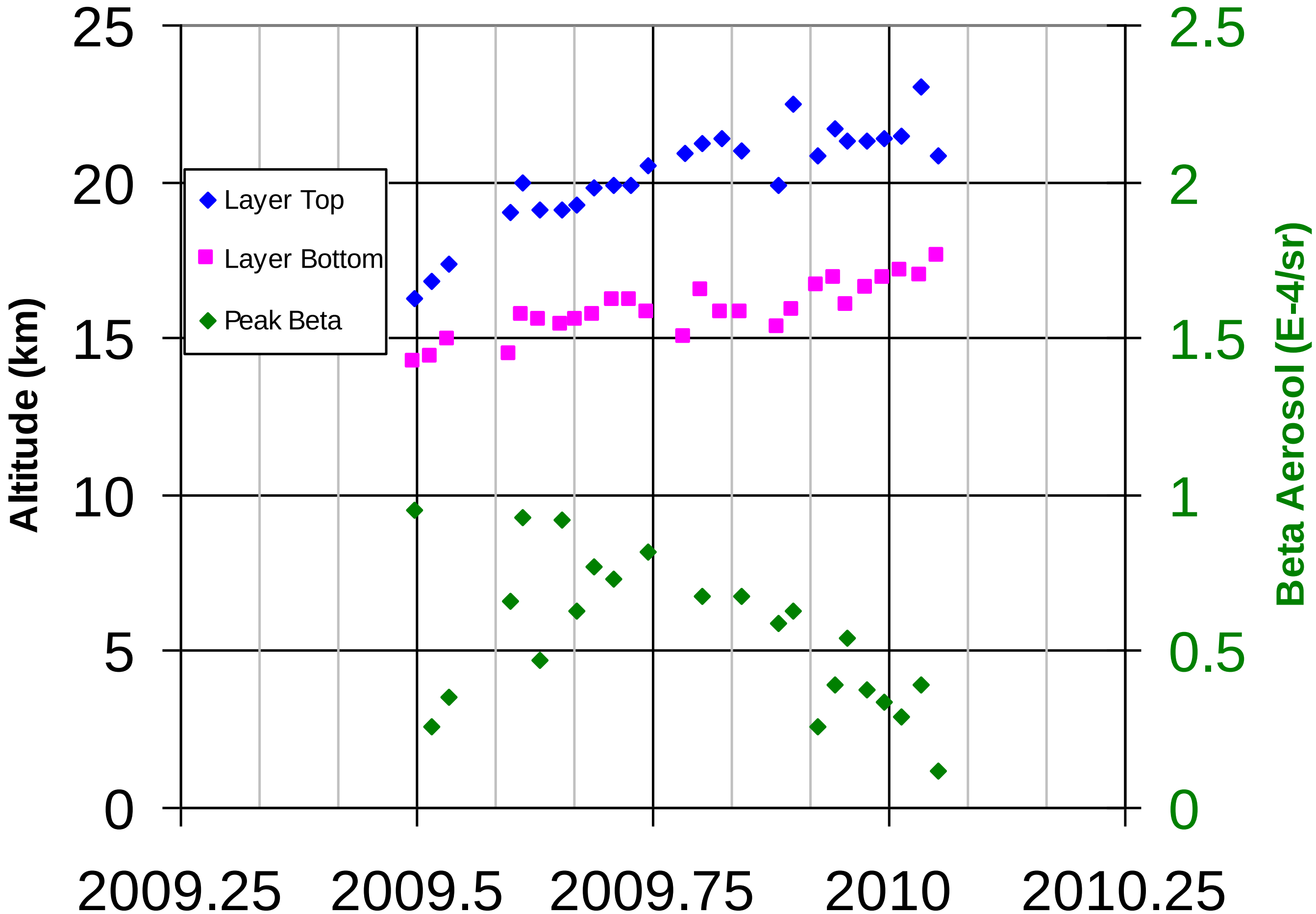
Particle size distribution,

Index of refraction

The 2009 Sarychev Eruption (48 deg N) on 6/12 was first observed at Mauna Loa (20 deg N) on 7/1.

The plot tracks the top and bottom altitudes (left axis),

and total backscatter (right axis) while the layer could be distinguished from the background.



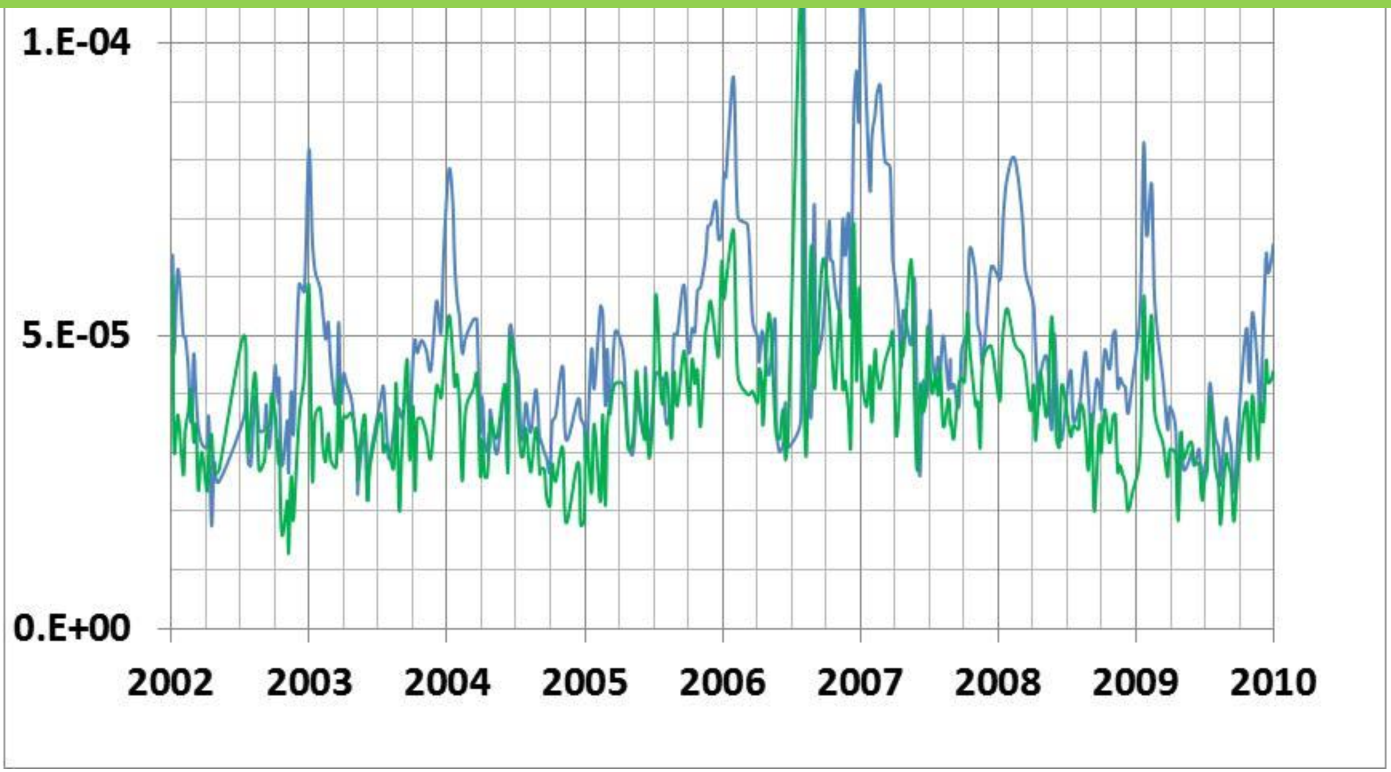
<u>Increase in Stratospheric Aerosol, ~2002 to ~ 2007</u>

Kuhl, Kulkarni, Ramachandran, Kumar, Rao, Krishnaiah, JGR, 2008

Hofmann, Barnes, O'Neill, Trudeau, Neely, GRL, 2009

Nagai, Liley, Sakai, Shibata, Uchino, SOLA, 2010

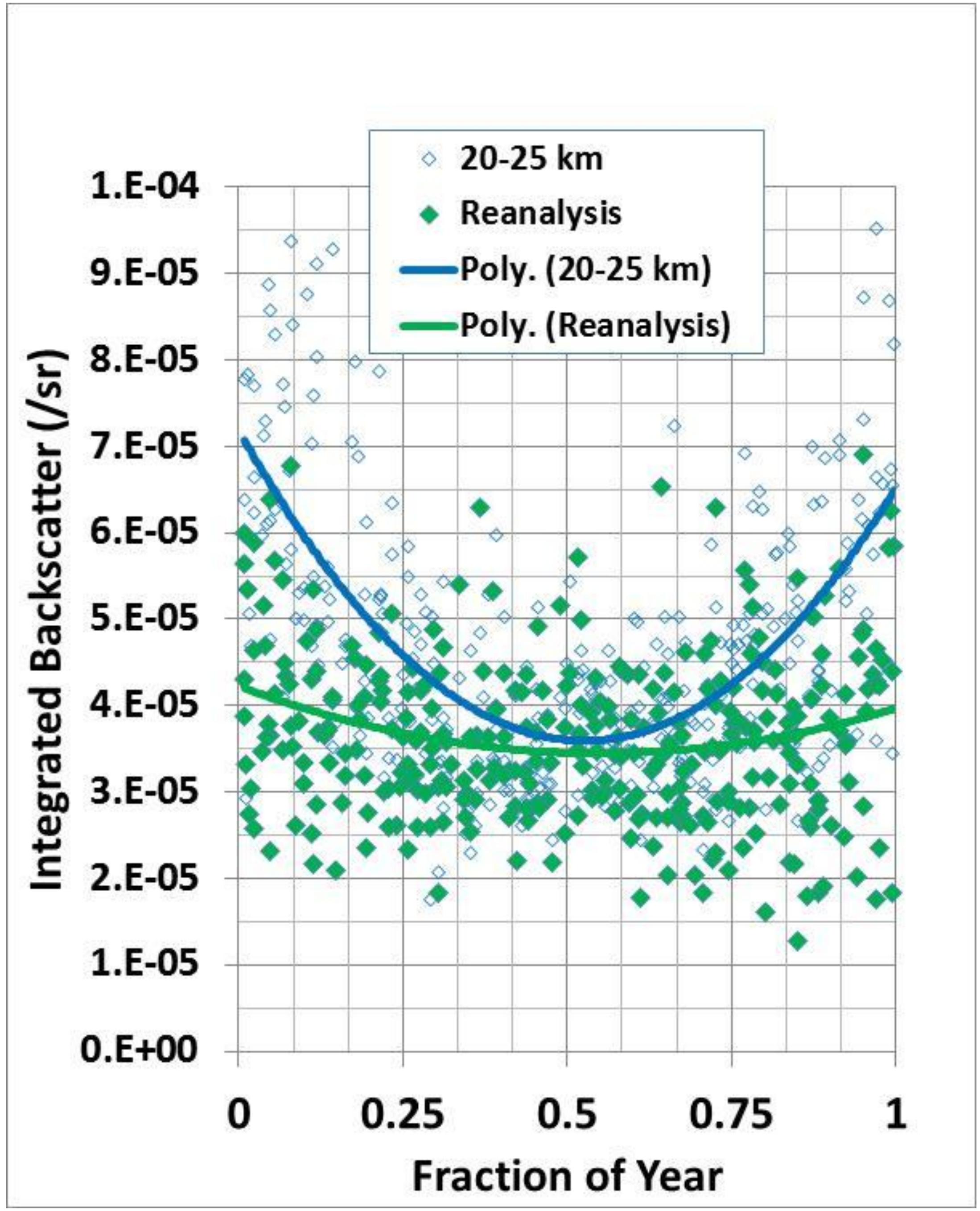
Vernier, Thomason, Pommereau, Bourassa, Pelon, Garnier, Hauchecorne, Blanot, Trepte, Degenstein, F. Vargas, GRL, 2011



Published Annual Cycle
winter/summer ~ 2.0

Reanalyzed Annual Cycle

winter/summer~1.2



Lidar (Extinction/backscatter) Ratio from XXX Eruption

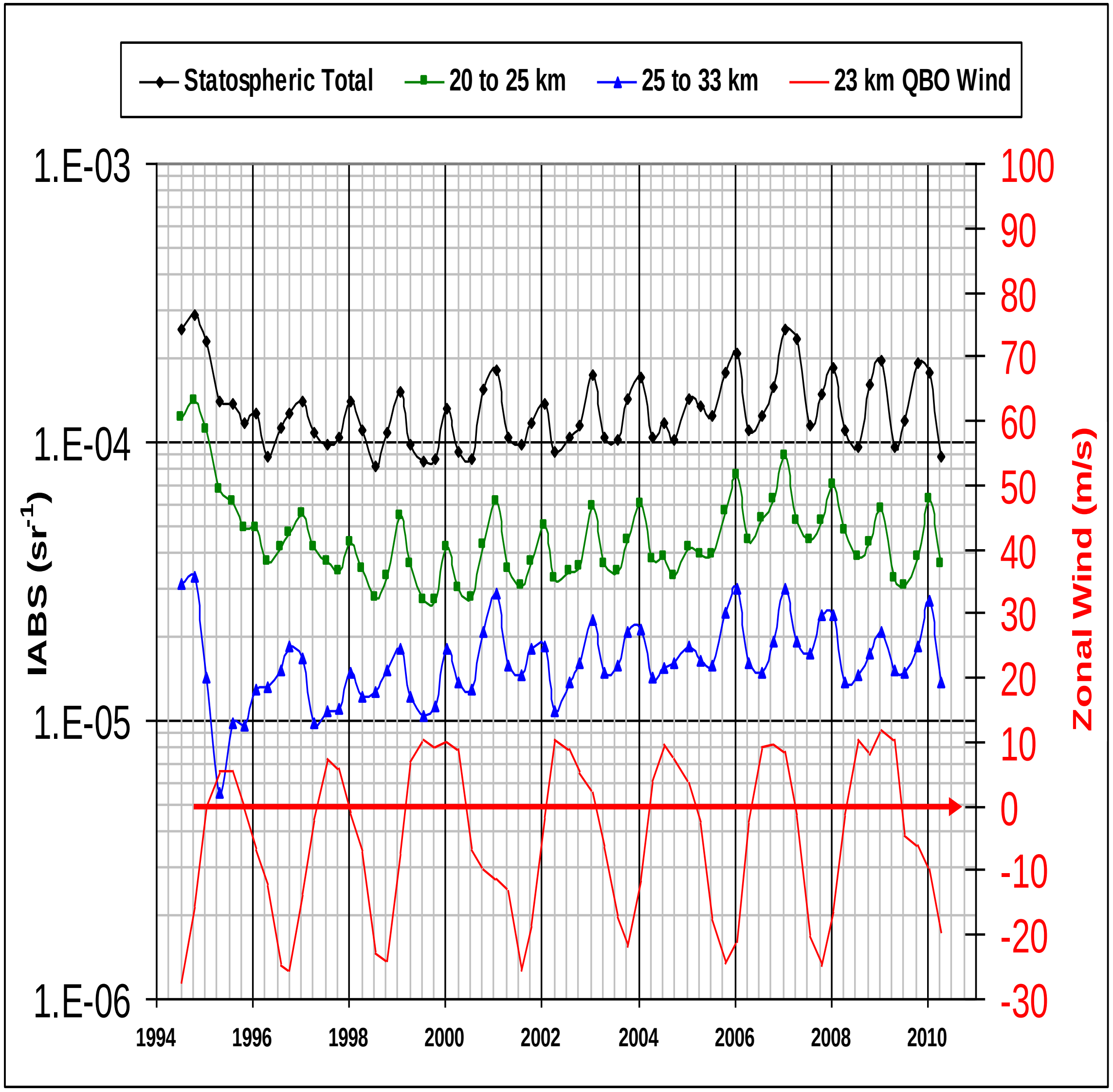
Increase in Stratospheric Aerosol

Between 2000 and 2007 a significant increase (~5%/yr) in stratospheric aerosol was observed both in total and in altitude layers (top 3 plots - left axis).

Hofmann, Barnes et al. (GRL, 2009) suggested increased coal burning could be the cause.

The trend has not continued since 2007.

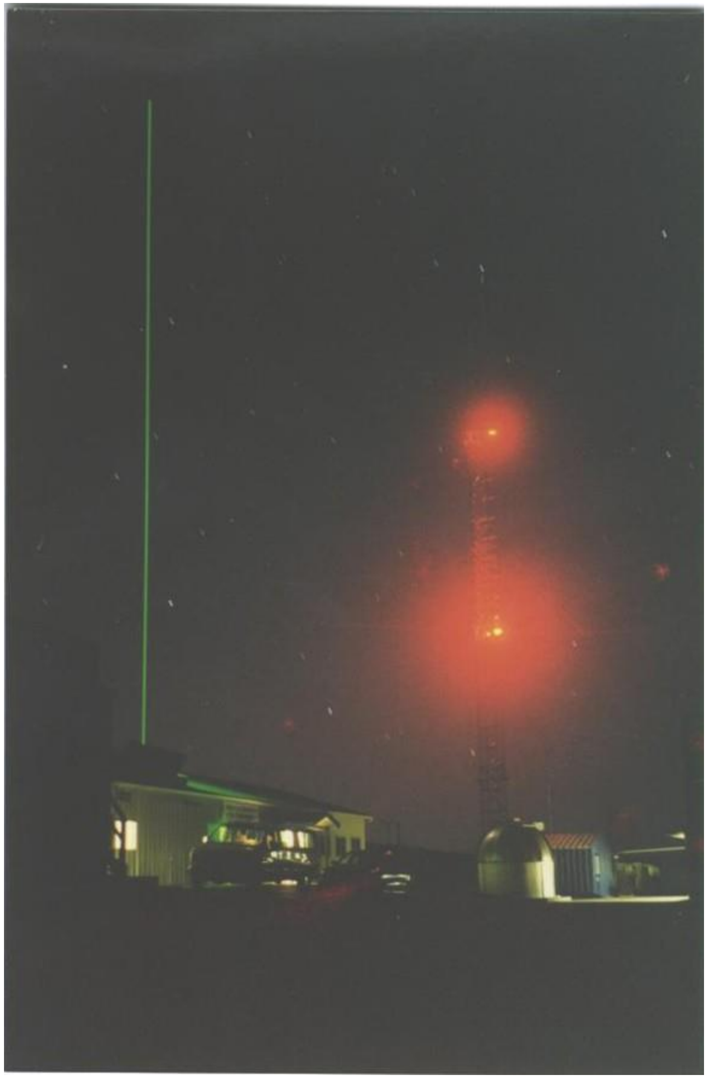
Recent work suggests a few small eruptions during the period can also explain the increase.

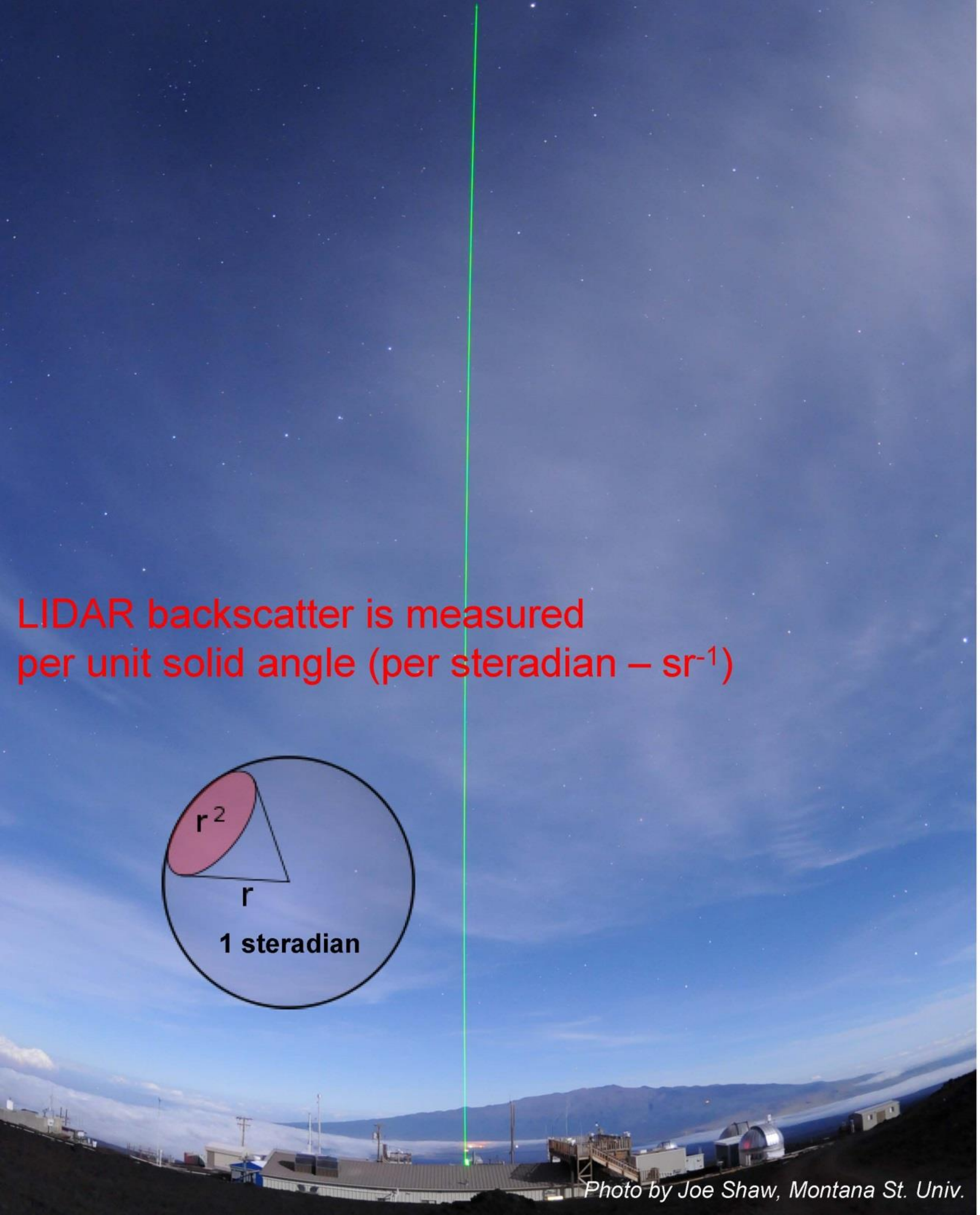


NDACC NOAA/Mauna Loa Observatory lidar,

- **Observations of stratospheric aerosol have been made since 1972 beginning with a Ruby (694 nm) laser**

- **The Nd:YAG (532 nm) based lidar currently measures stratospheric aerosol and temperature, and tropospheric aerosol, and water vapor.**





Mauna Loa Observatory Nd:YAG LIDAR

- Nd:YAG* LIDARs (532 & 1064 nm) are used to detect the stratospheric aerosol layer at Mauna Loa Observatory in Hawaii and Boulder, Colorado.

- Since the eruption of the volcano Pinatubo in June 1991, there have been no major eruptions capable of perturbing the global stratosphere above 20 km. This has provided an unprecedented opportunity to study the background aerosol, free of volcanic effects.

*Nd:YAG = neodymium-doped yttrium aluminum garnet: Nd:$Y_3Al_5O_{12}$ emits at 1064 nm, doubled freq. gives 532 nm

NOAA Stratospheric Aerosols (Particulates)