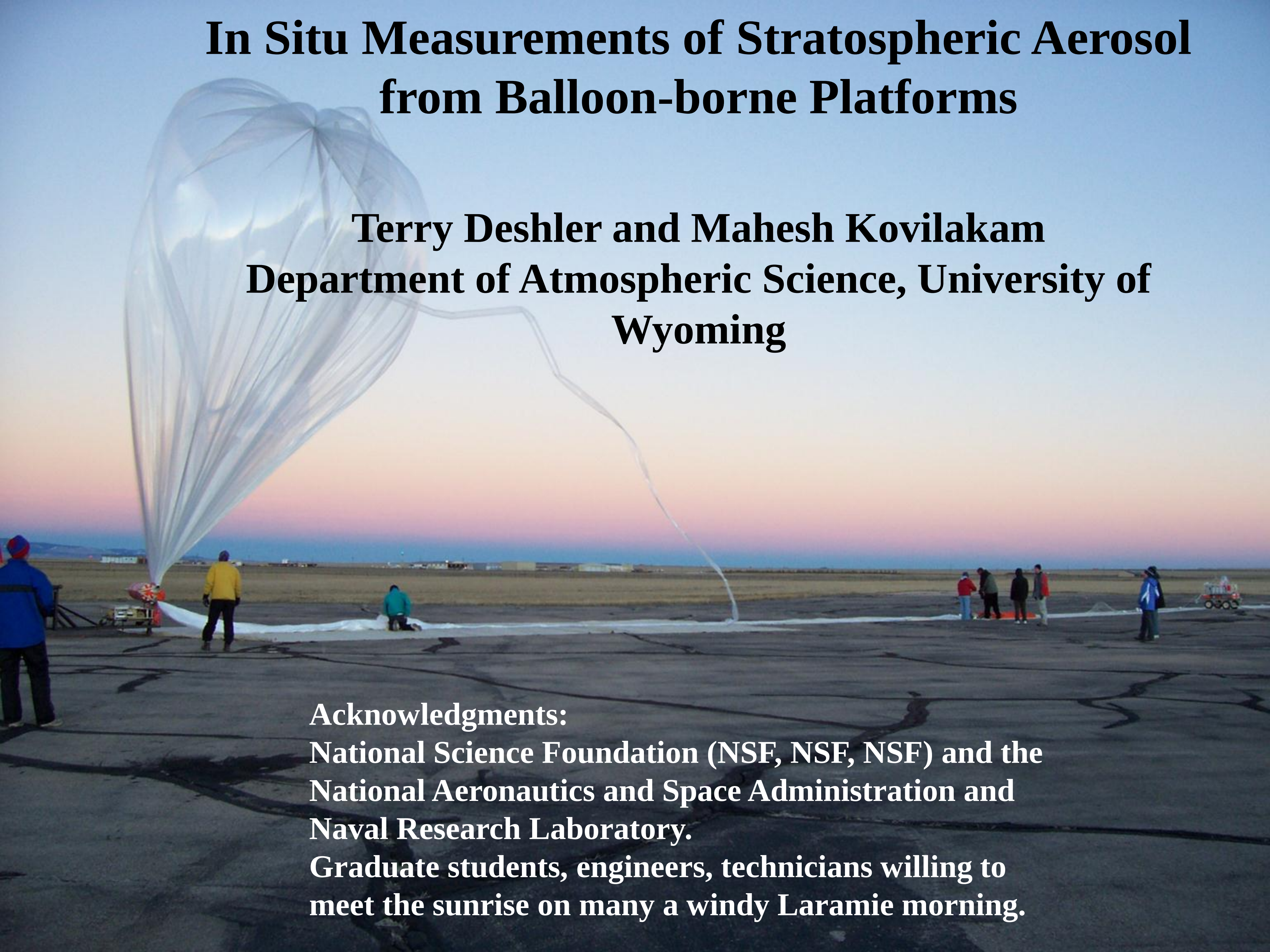
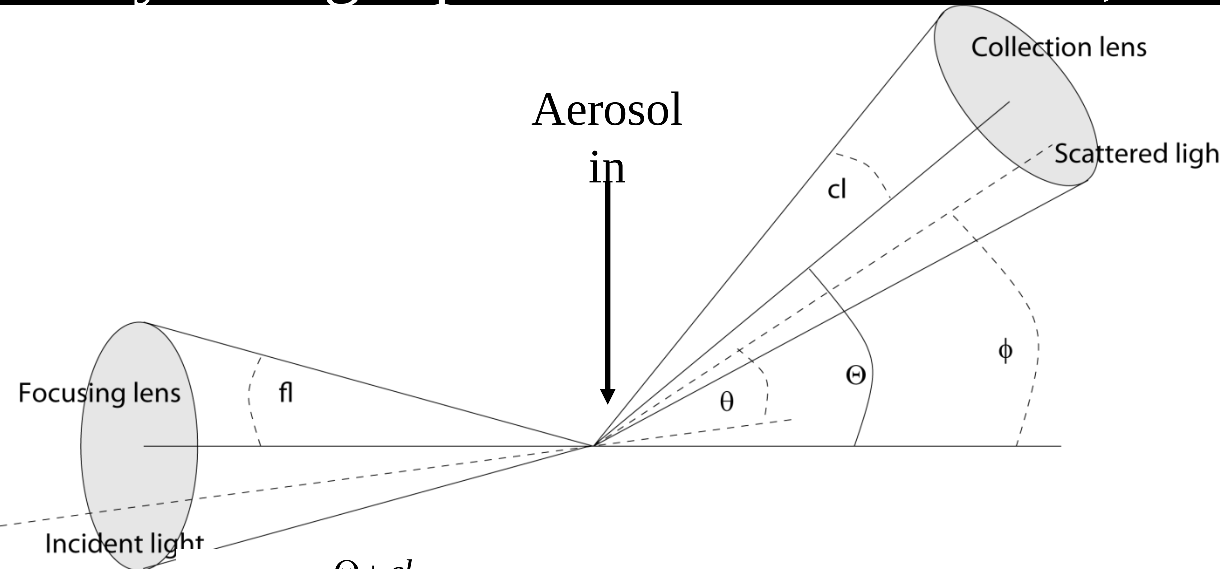


In Situ Measurements of Stratospheric Aerosol from Balloon-borne Platforms

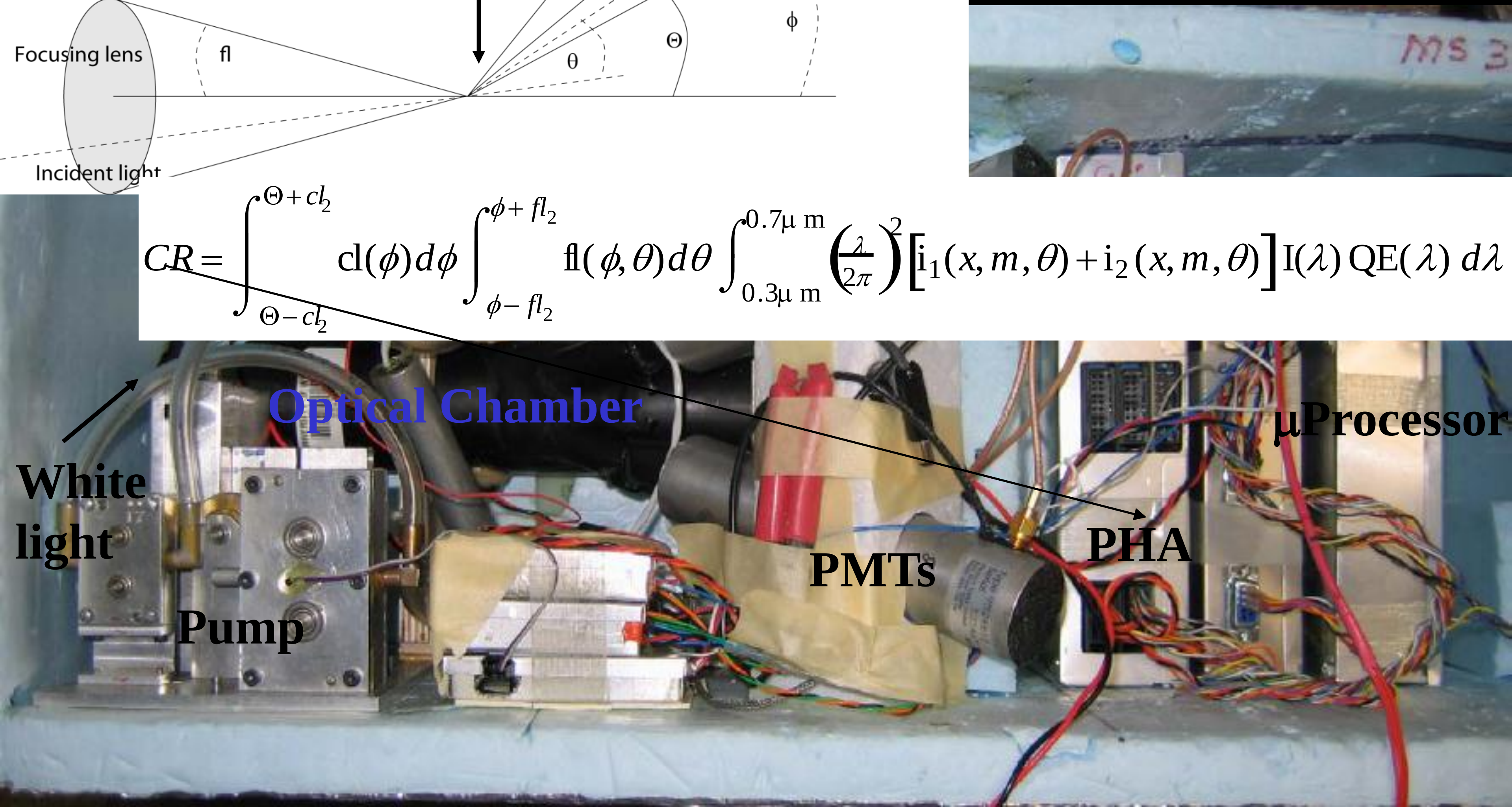
Terry Deshler and Mahesh Kovilakam
Department of Atmospheric Science, University of Wyoming

Acknowledgments:
National Science Foundation (NSF, NSF, NSF) and the National Aeronautics and Space Administration and Naval Research Laboratory.
Graduate students, engineers, technicians willing to meet the sunrise on many a windy Laramie morning.

Wyoming Optical Particle Counter, r > 0.2 - 10.0 μm



$$CR = \int_{\Theta - cl_2}^{\Theta + cl_2} \mathrm{cl}(\phi)\, d\phi \int_{\phi - fl_2}^{\phi + fl_2} \mathrm{fl}(\phi,\theta)\, d\theta \int_{0.3\mu\,\mathrm{m}}^{0.7\mu\,\mathrm{m}} \left(\frac{\lambda}{2\pi}\right)^2 \left[\mathrm{i}_1(x,m,\theta) + \mathrm{i}_2(x,m,\theta)\right] \mathrm{I}(\lambda)\, \mathrm{QE}(\lambda)\, d\lambda$$



Quantification of Sources of Error

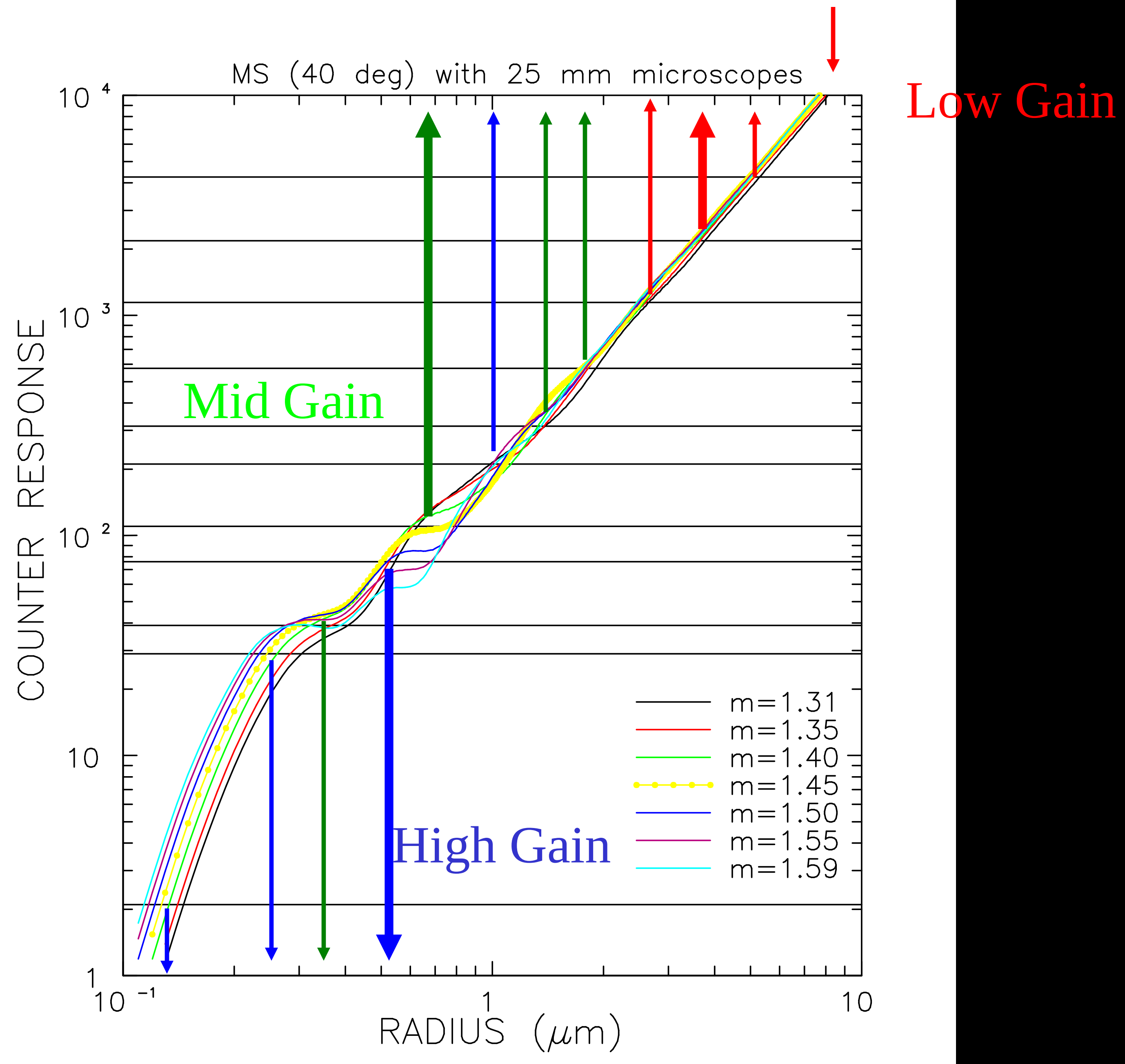
$$CR = \int_{\Theta - cl_2}^{\Theta + cl_2} \mathrm{cl}(\phi)\,d\phi \int_{\phi - fl_2}^{\phi + fl_2} \mathrm{fl}(\phi,\theta)\,d\theta \int_{0.3\mu\,\mathrm{m}}^{0.7\mu\,\mathrm{m}} \left(\frac{\lambda}{2\pi}\right)^2 \left[\mathrm{i}_1(x,m,\theta) + \mathrm{i}_2(x,m,\theta)\right] \mathrm{I}(\lambda)\,\mathrm{QE}(\lambda)\,d\lambda$$

Size

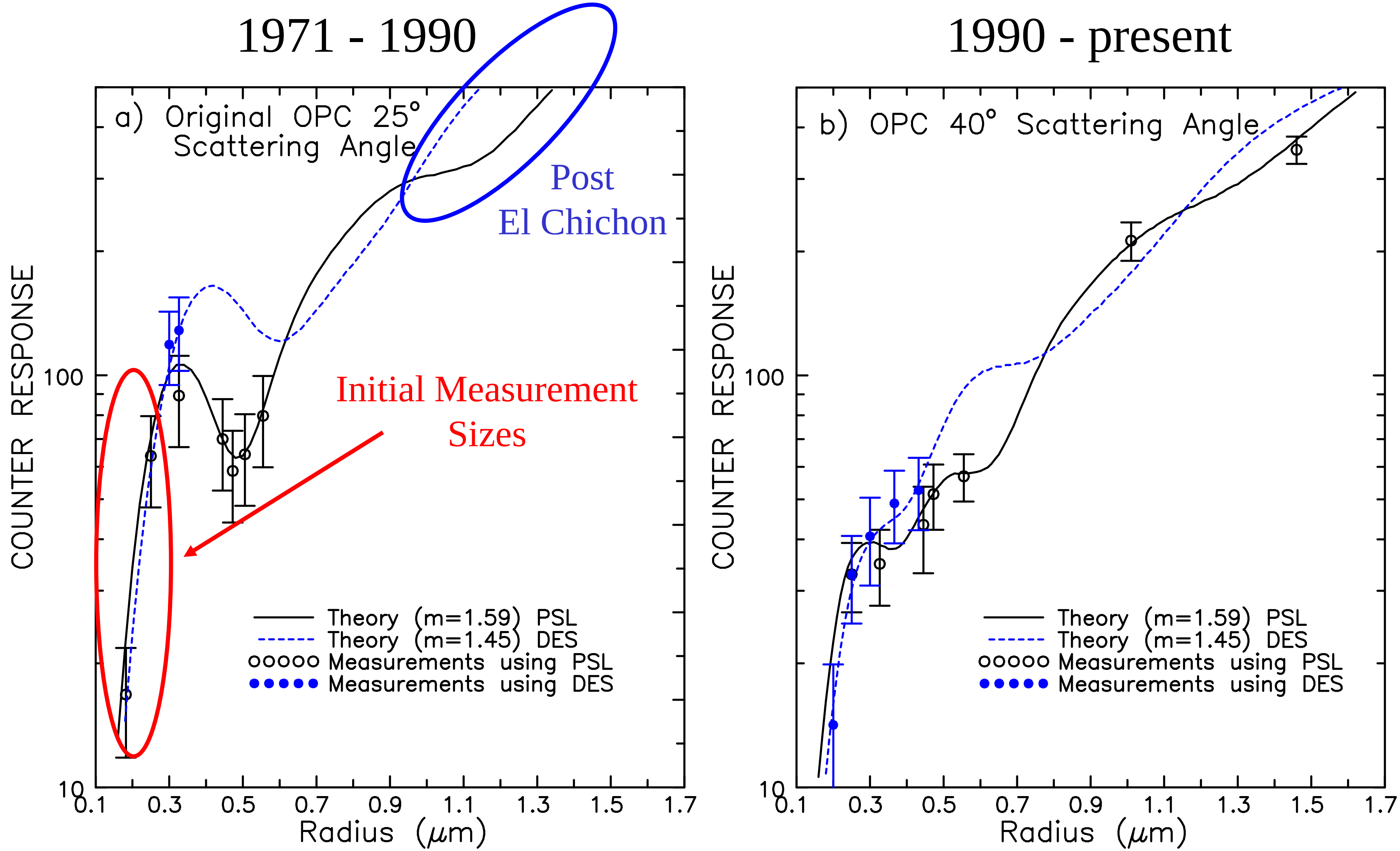
- Aerosol index of refraction and shape [< 10%]
- Uniformity of illumination [< few %]
- **PMT response – pulse width broadening**
  - **[±30% (r <~ 0.7 µm) to (±10% (r > 1.0 µm)]**

Number concentration

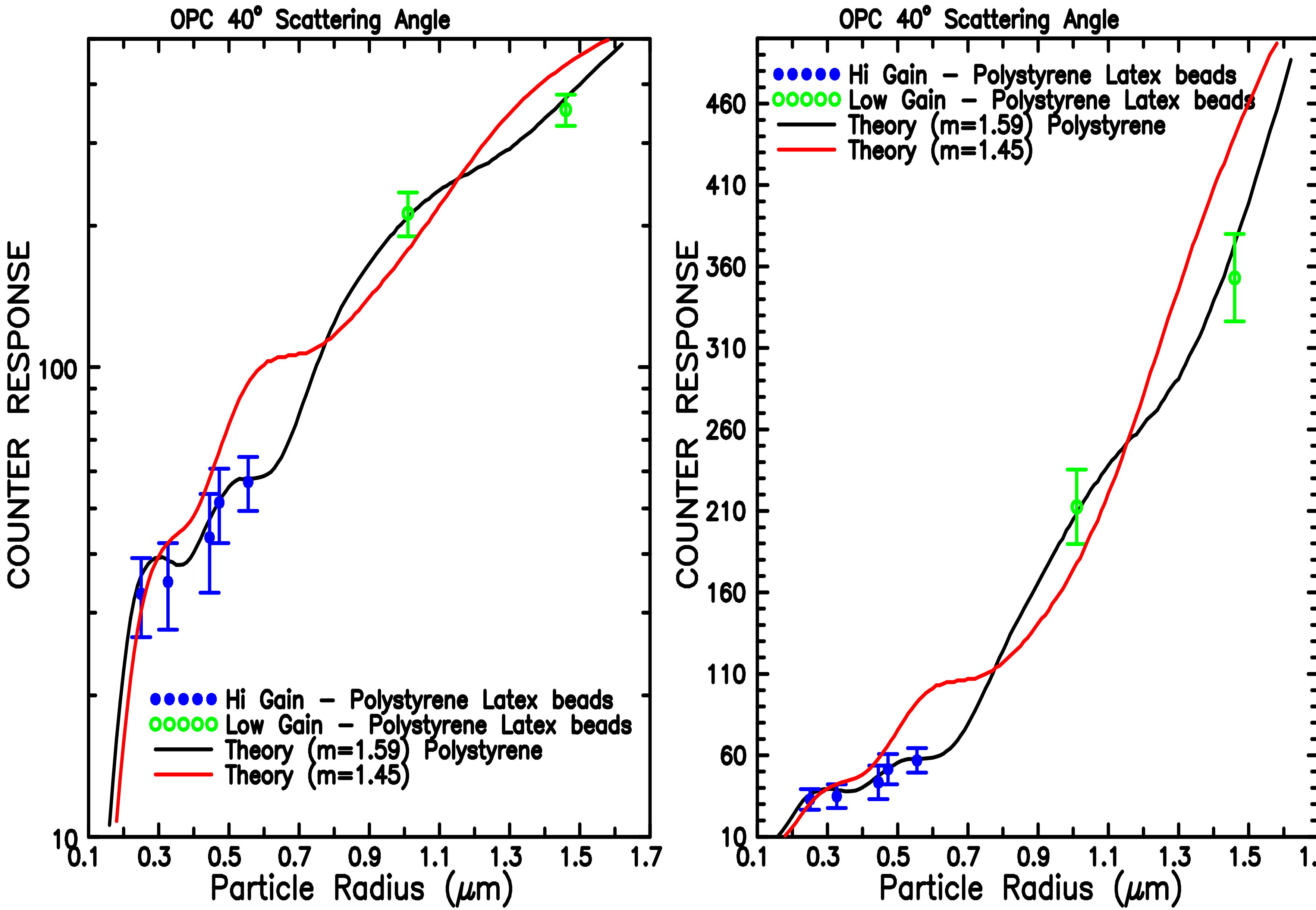
- Flow rate (3% at 30 hPa to 10% at 5 hPa)
- Coincidence (negligible, N(r) < 30 cm-3)
- Reproducibility from two identical instruments (±10%)
- **Poisson counting uncertainty**
  - **(±80 to ±8% for N(r) of 0.001, 0.01, 0.1 cm-3**

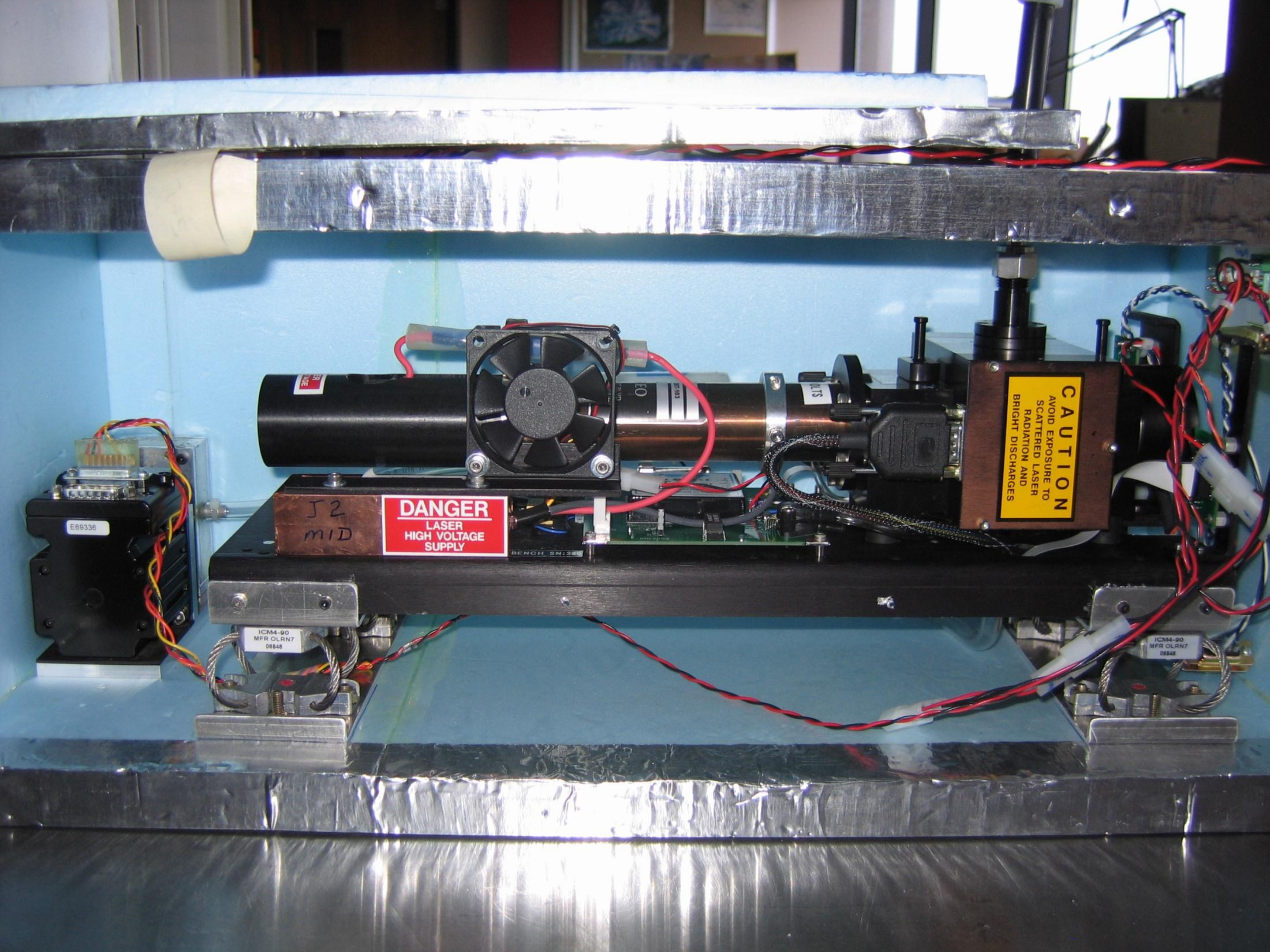


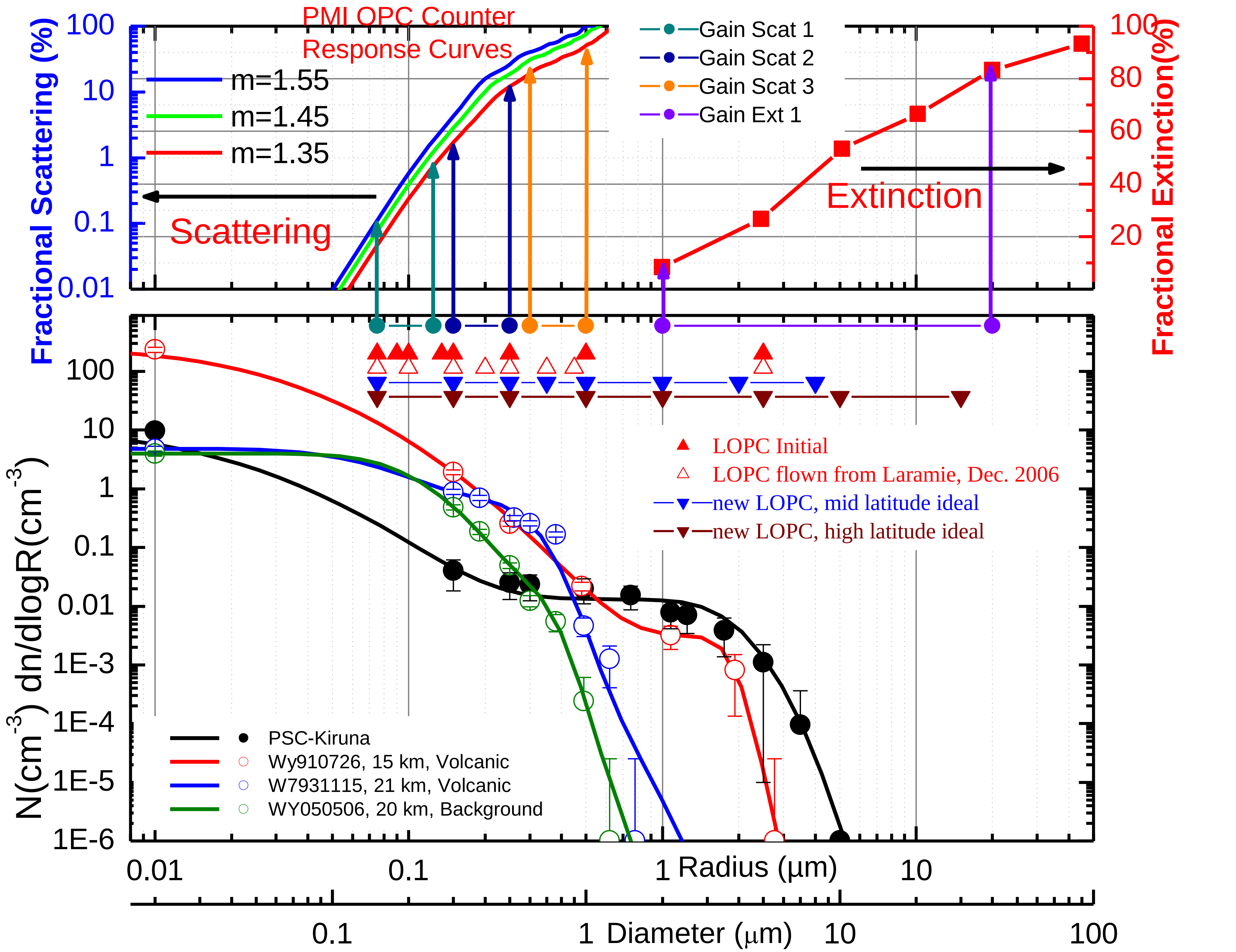
MS (40 deg) with 25 mm microscopes
Low Gain
Mid Gain
High Gain
COUNTER RESPONSE
RADIUS (μm)
m=1.31
m=1.35
m=1.40
m=1.45
m=1.50
m=1.55
m=1.59



1971 - 1990
1990 - present
a) Original OPC 25° Scattering Angle
Post El Chichon
Initial Measurement Sizes
COUNTER RESPONSE
100
10
0.1 0.3 0.5 0.7 0.9 1.1 1.3 1.5 1.7
Radius (μm)
Theory (m=1.59) PSL
Theory (m=1.45) DES
ooooo Measurements using PSL
●●●●● Measurements using DES
b) OPC 40° Scattering Angle
COUNTER RESPONSE
100
10
0.1 0.3 0.5 0.7 0.9 1.1 1.3 1.5 1.7
Radius (μm)
Theory (m=1.59) PSL
Theory (m=1.45) DES
ooooo Measurements using PSL
●●●●● Measurements using DES


OPC 40° Scattering Angle
COUNTER RESPONSE
100
10
0.1
0.3
0.5
0.7
0.9
1.1
1.3
1.5
1.7
Particle Radius (μm)
Hi Gain – Polystyrene Latex beads
Low Gain – Polystyrene Latex beads
Theory (m=1.59) Polystyrene
Theory (m=1.45)
OPC 40° Scattering Angle
COUNTER RESPONSE
460
410
360
310
260
210
160
110
60
10
0.1
0.3
0.5
0.7
0.9
1.1
1.3
1.5
1.7
Particle Radius (μm)
Hi Gain – Polystyrene Latex beads
Low Gain – Polystyrene Latex beads
Theory (m=1.59) Polystyrene
Theory (m=1.45)

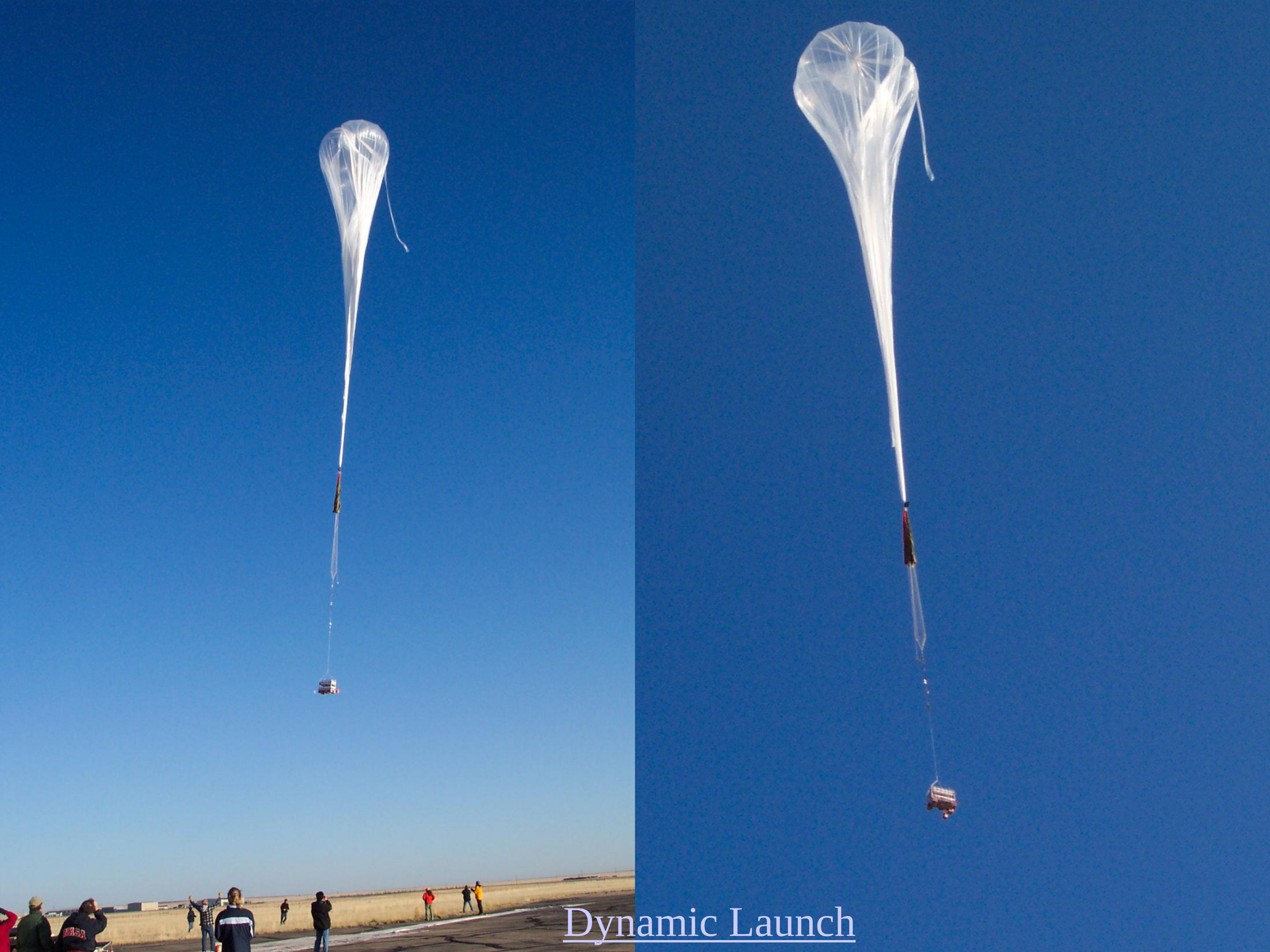

DANGER
LASER
HIGH VOLTAGE
SUPPLY
J2
MID
CAUTION
AVOID EXPOSURE TO
SCATTERED LASER
RADIATION AND
BRIGHT DISCHARGES
E69336



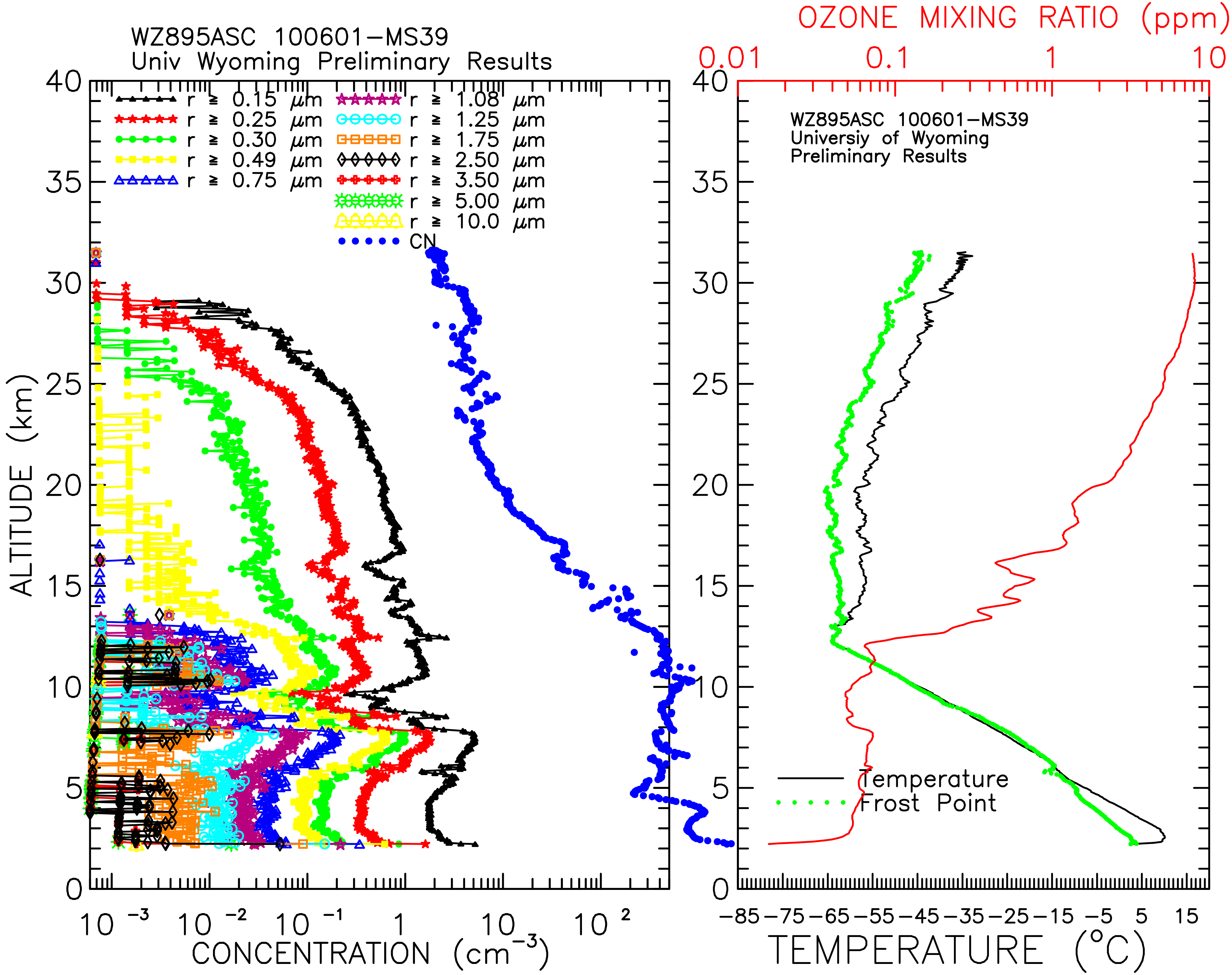
PMI OPC Counter
Response Curves
Fractional Scattering (%)
100
10
1
0.1
0.01
m=1.55
m=1.45
m=1.35
Scattering
Gain Scat 1
Gain Scat 2
Gain Scat 3
Gain Ext 1
Extinction
Fractional Extinction(%)
100
80
60
40
20
LOPC Initial
LOPC flown from Laramie, Dec. 2006
new LOPC, mid latitude ideal
new LOPC, high latitude ideal
N(cm-3) dn/dlogR(cm-3)
100
10
1
0.1
0.01
1E-3
1E-4
1E-5
1E-6
PSC-Kiruna
Wy910726, 15 km, Volcanic
W7931115, 21 km, Volcanic
WY050506, 20 km, Background
0.01
0.1
1
Radius (µm)
10
0.1
1
Diameter (µm)
10
100

History of sizes measured by balloon-borne in situ optical particle counters at Laramie Wyoming:

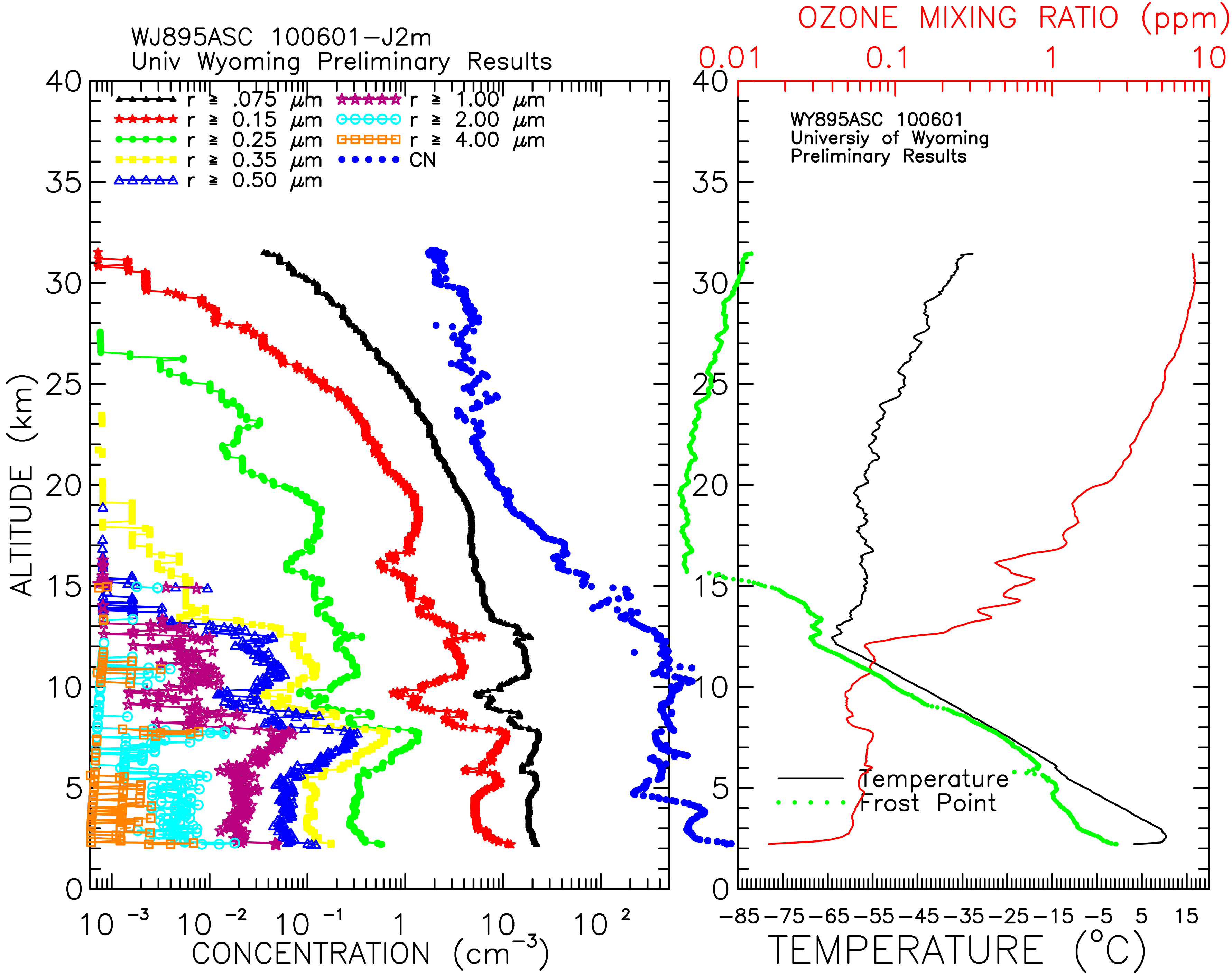
	Aerosol radii (μm)
Oct 71 - Jun 82	0.15 0.25
Jun 82 - Dec 87	0.15 0.25 0.95 1.20 1.80
Jan 88 - Apr 89	0.15 0.25
May 89 - Nov 89	0.15 0.25 0.5 1.0 2.0 3.0 5.0 10.0
Dec 89 - Feb 90	0.15 0.25
Mar 90 - Aug 90	0.15 0.25 0.5 1.0 2.0 3.0 5.0 10.0
Sep 90 - Mar 91	0.15 0.25
Mar 91 - Apr 92	0.15 0.25 0.5 1.0 2.0 3.0 5.0 10.0
May 92 - Nov 93	0.15 0.25 0.5 0.75 1.0 1.08 1.45 2.0
Nov 93 - Present	0.15 0.19 0.25 0.30 0.38 0.49 0.62 0.78 1.08 1.25 1.58 2.00
Jul 07 – Present	0.075 0.15 0.25 0.35 0.5 1.0 2.0 4.0

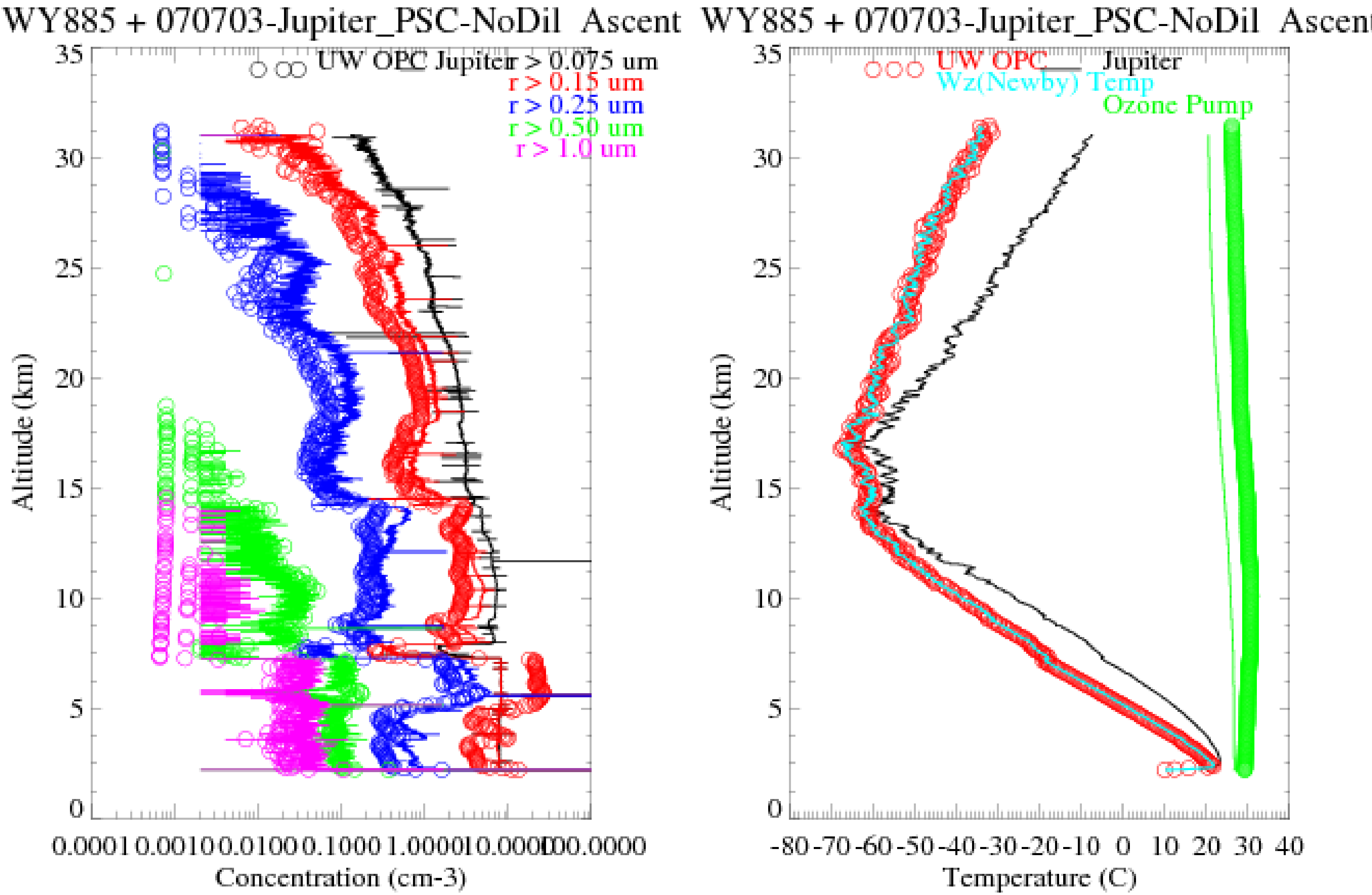
Dynamic Launch



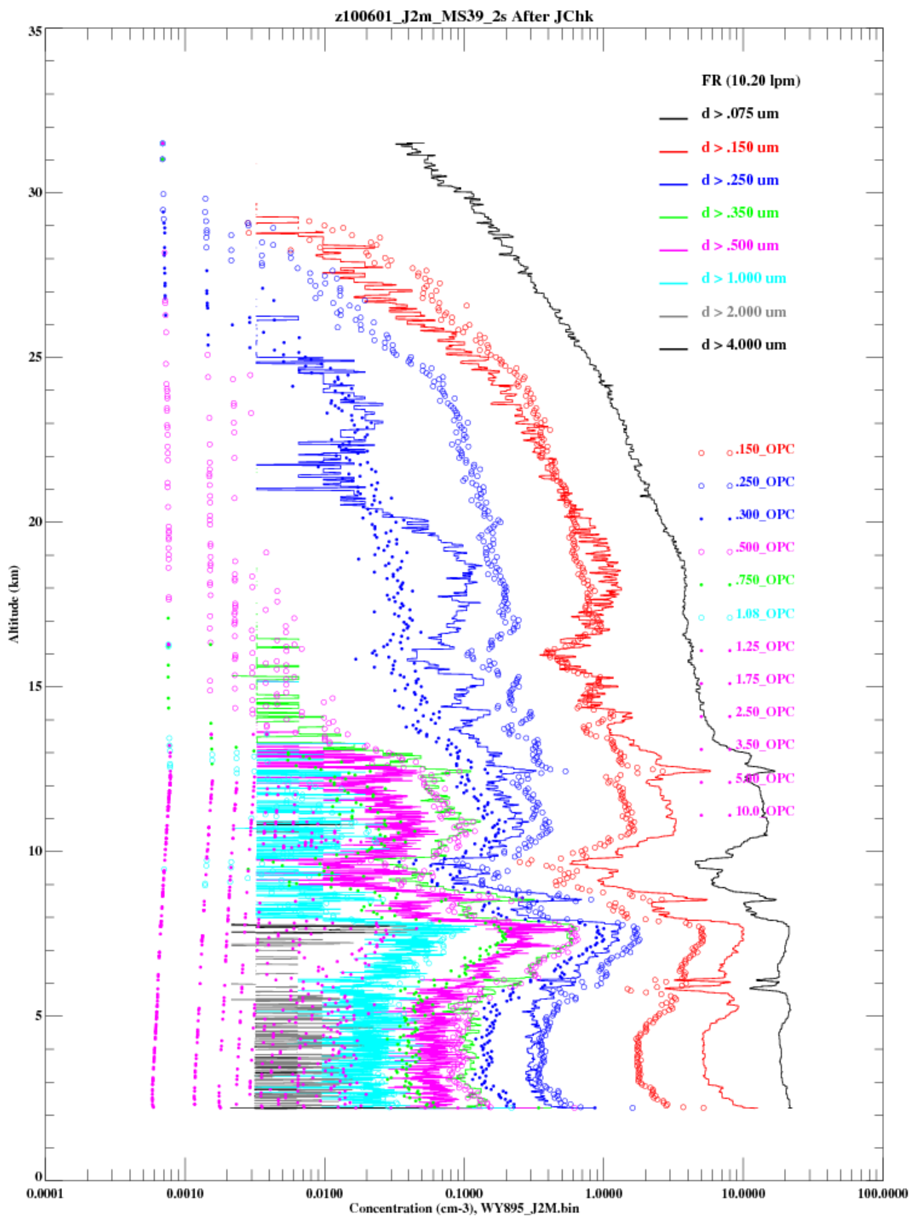
WZ895ASC 100601-MS39
Univ Wyoming Preliminary Results
r ≥ 0.15 μm
r ≥ 0.25 μm
r ≥ 0.30 μm
r ≥ 0.49 μm
r ≥ 0.75 μm
r ≥ 1.08 μm
r ≥ 1.25 μm
r ≥ 1.75 μm
r ≥ 2.50 μm
r ≥ 3.50 μm
r ≥ 5.00 μm
r ≥ 10.0 μm
CN
ALTITUDE (km)
CONCENTRATION (cm⁻³)
OZONE MIXING RATIO (ppm)
WZ895ASC 100601-MS39
Universiy of Wyoming
Preliminary Results
Temperature
Frost Point
TEMPERATURE (°C)

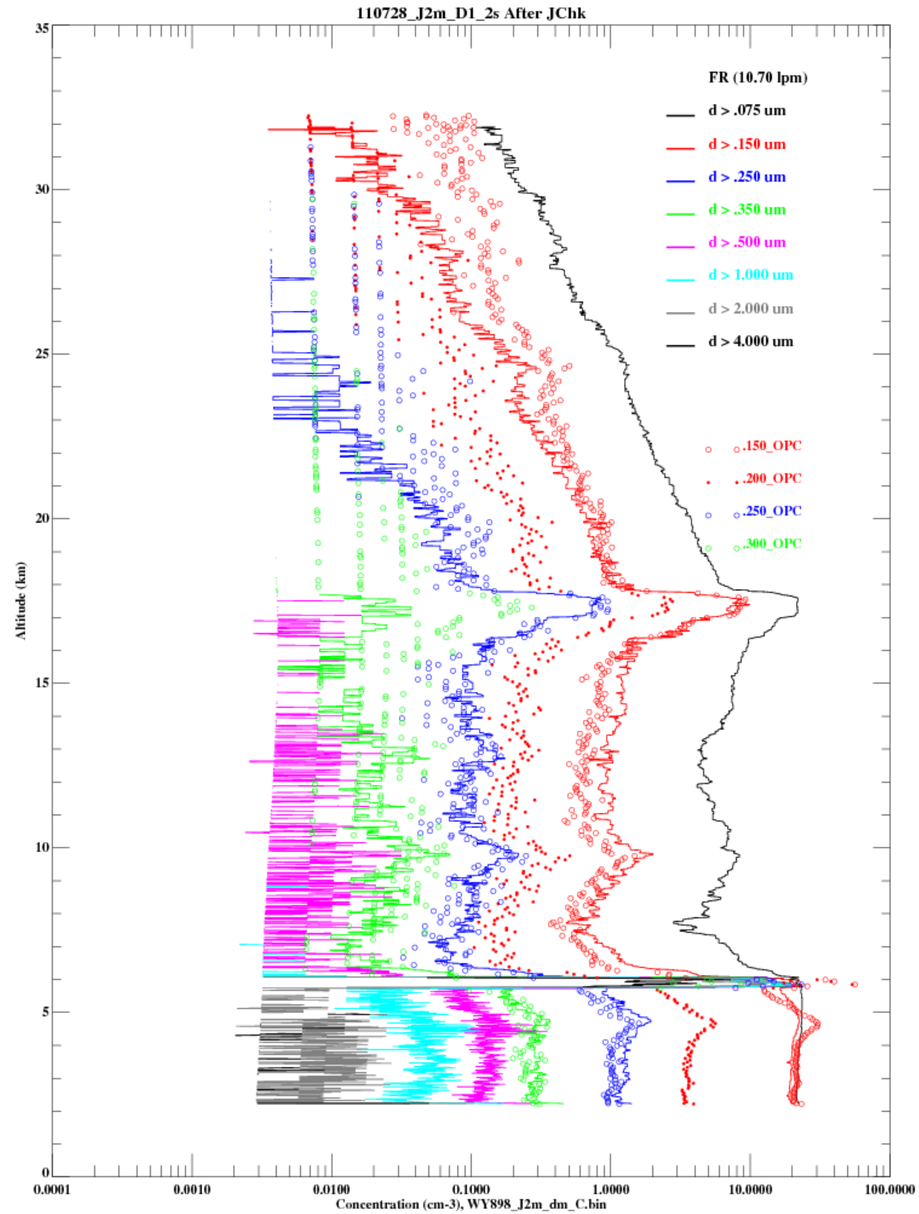


WJ895ASC 100601–J2m
Univ Wyoming Preliminary Results
r ≥ .075 µm
r ≥ 0.15 µm
r ≥ 0.25 µm
r ≥ 0.35 µm
r ≥ 0.50 µm
r ≥ 1.00 µm
r ≥ 2.00 µm
r ≥ 4.00 µm
CN
ALTITUDE (km)
CONCENTRATION (cm⁻³)
OZONE MIXING RATIO (ppm)
WY895ASC 100601
Universiy of Wyoming
Preliminary Results
Temperature
Frost Point
TEMPERATURE (°C)



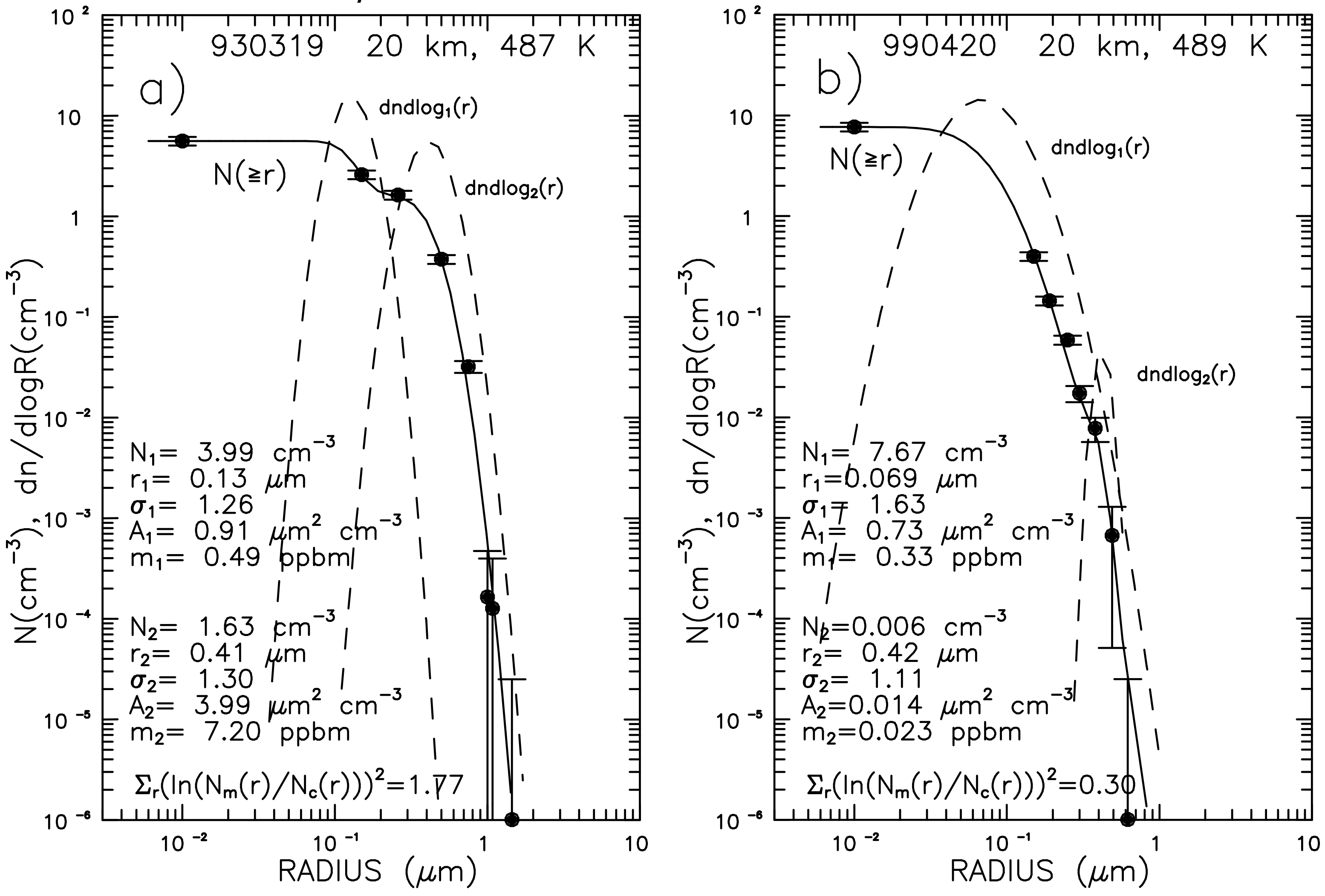
WY885 + 070703-Jupiter_PSC-NoDil Ascent
UW OPC Jupiter r > 0.075 um
r > 0.15 um
r > 0.25 um
r > 0.50 um
r > 1.0 um
Altitude (km)
Concentration (cm-3)
0.0001
0.0010
0.0100
0.1000
1.0000
10.0000
100.0000
WY885 + 070703-Jupiter_PSC-NoDil Ascent
UW OPC
Jupiter
Wz(Newby) Temp
Ozone Pump
Altitude (km)
Temperature (C)


z100601_J2m_MS39_2s After JChk
FR (10.20 lpm)
d > .075 um
d > .150 um
d > .250 um
d > .350 um
d > .500 um
d > 1.000 um
d > 2.000 um
d > 4.000 um
.150_OPC
.250_OPC
.300_OPC
.500_OPC
.750_OPC
1.08_OPC
1.25_OPC
1.75_OPC
2.50_OPC
3.50_OPC
10.0_OPC
Altitude (km)
Concentration (cm-3), WY895_J2M.bin

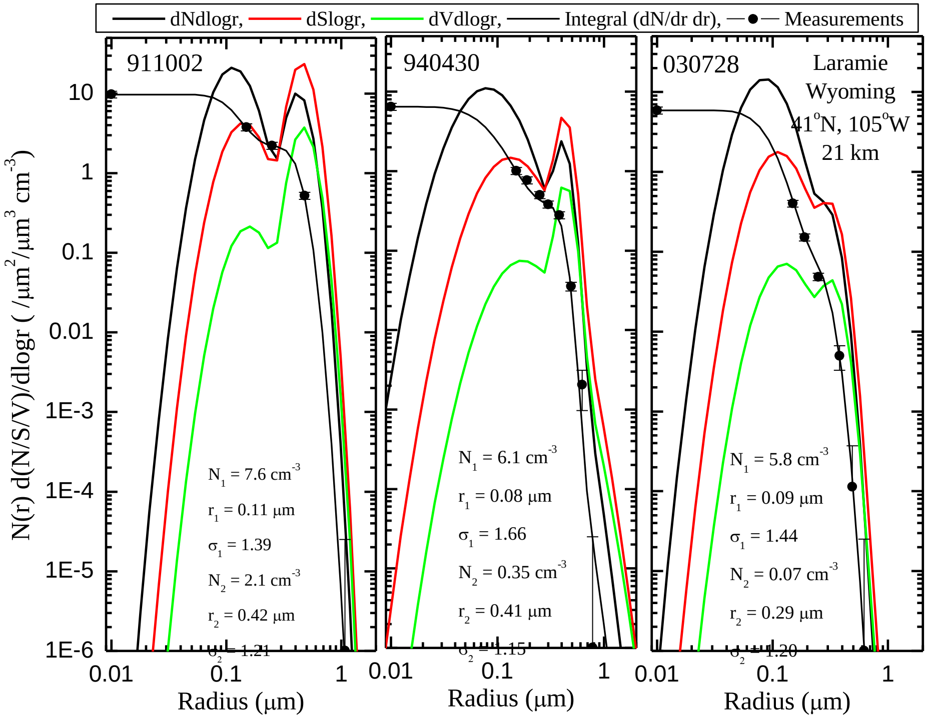

110728_J2m_D1_2s After JChk
FR (10.70 lpm)
d > .075 um
d > .150 um
d > .250 um
d > .350 um
d > .500 um
d > 1.000 um
d > 2.000 um
d > 4.000 um
.150_OPC
.200_OPC
.250_OPC
.300_OPC
Altitude (km)
Concentration (cm-3), WY898_J2m_dm_C.bin

Aerosol Size distributions

$$N(>r) = \sum_i \int_r^\infty \frac{N_i}{\sqrt{2\pi}\ln\sigma_i} \exp\left(\frac{-\ln^2[a/r_i]}{2\ln^2\sigma_i}\right) d\ln a$$

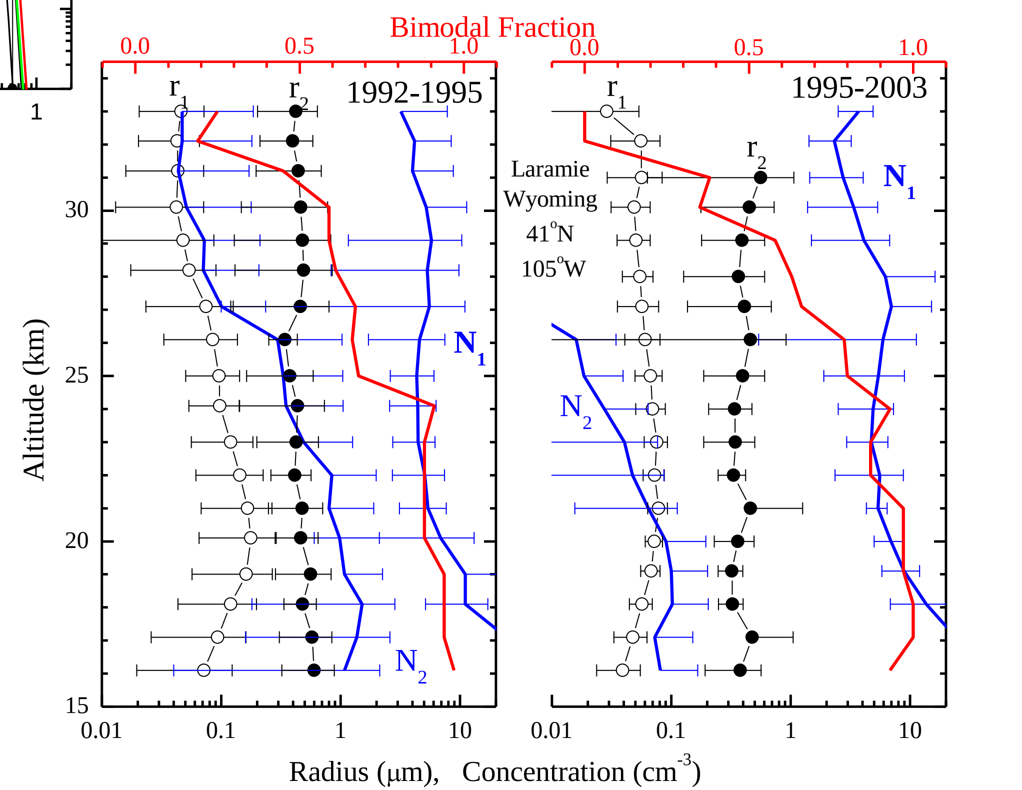


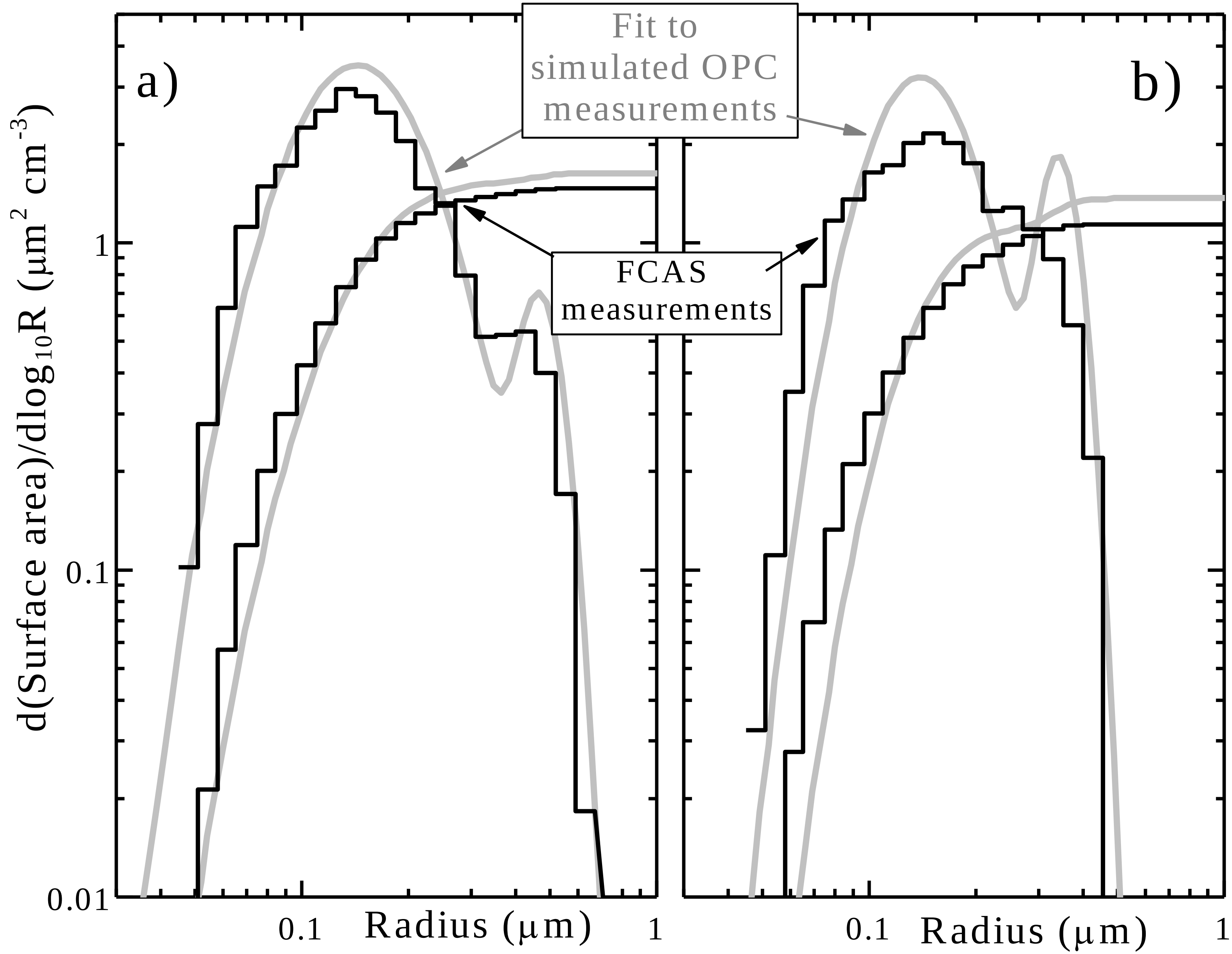
Evolution Pinatubo Aerosol



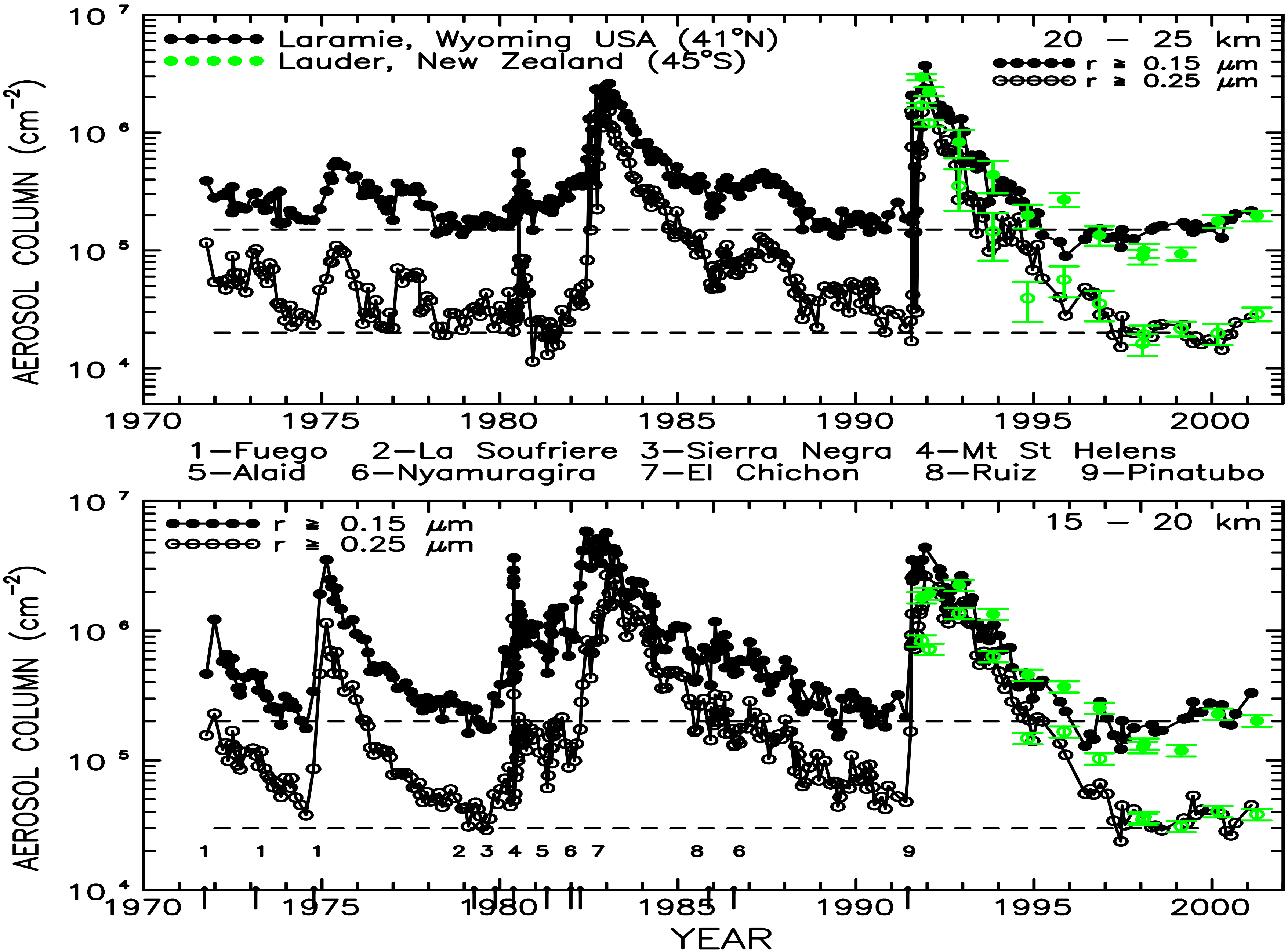
$$N(>r) = \sum_i \int_r^{\infty} \frac{N_i}{\sqrt{2\pi}\,\ln\sigma_i} \exp\left(\frac{-\ln^2[a/r_i]}{2\ln^2\sigma_i}\right) d\ \ln a,$$

Monte Carlo simulations using Poisson counting uncertainty and pulse width broadening lead to uncertainties of 20% for distribution width, 30% for median radii and 40% for surface area and volume.

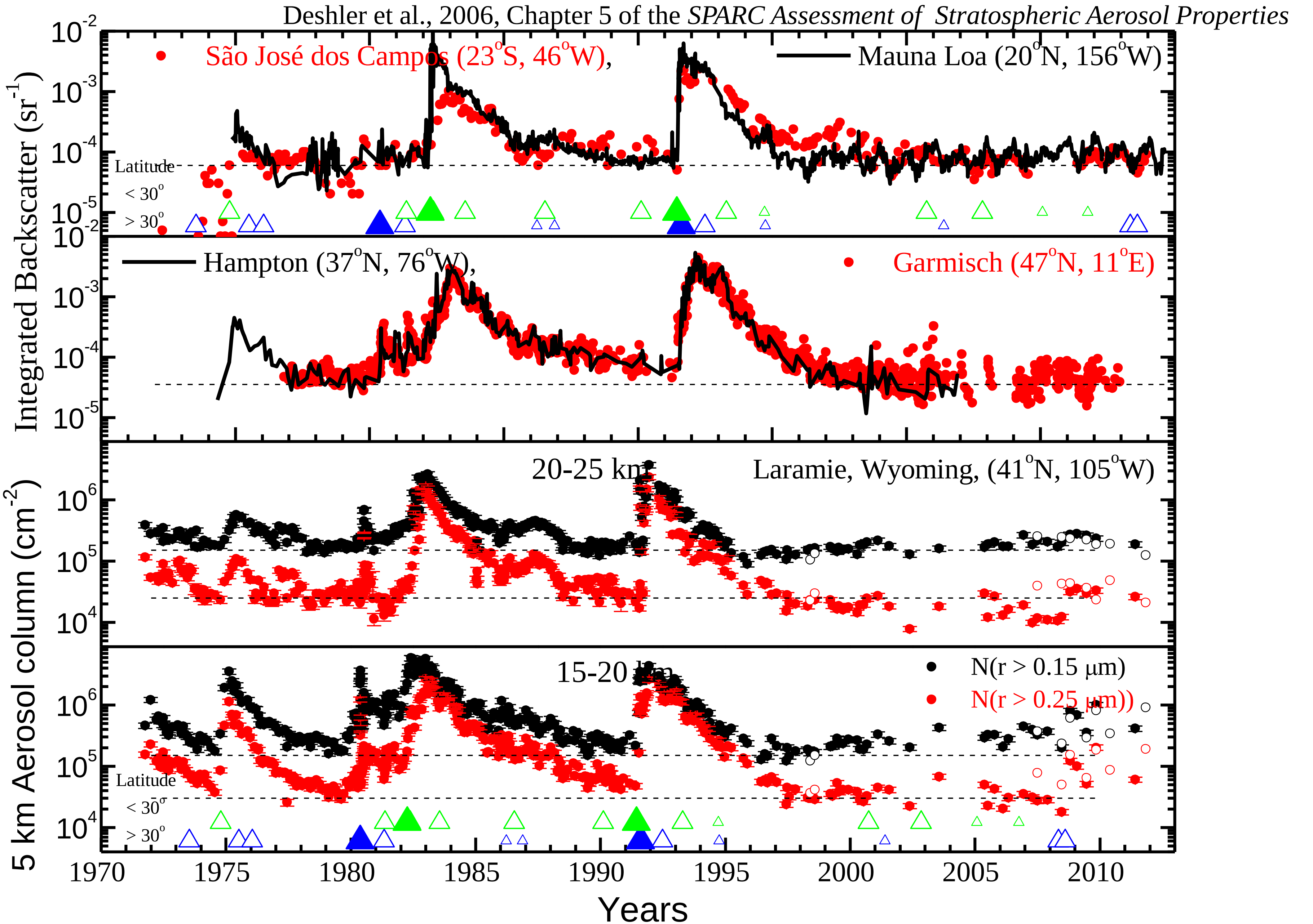




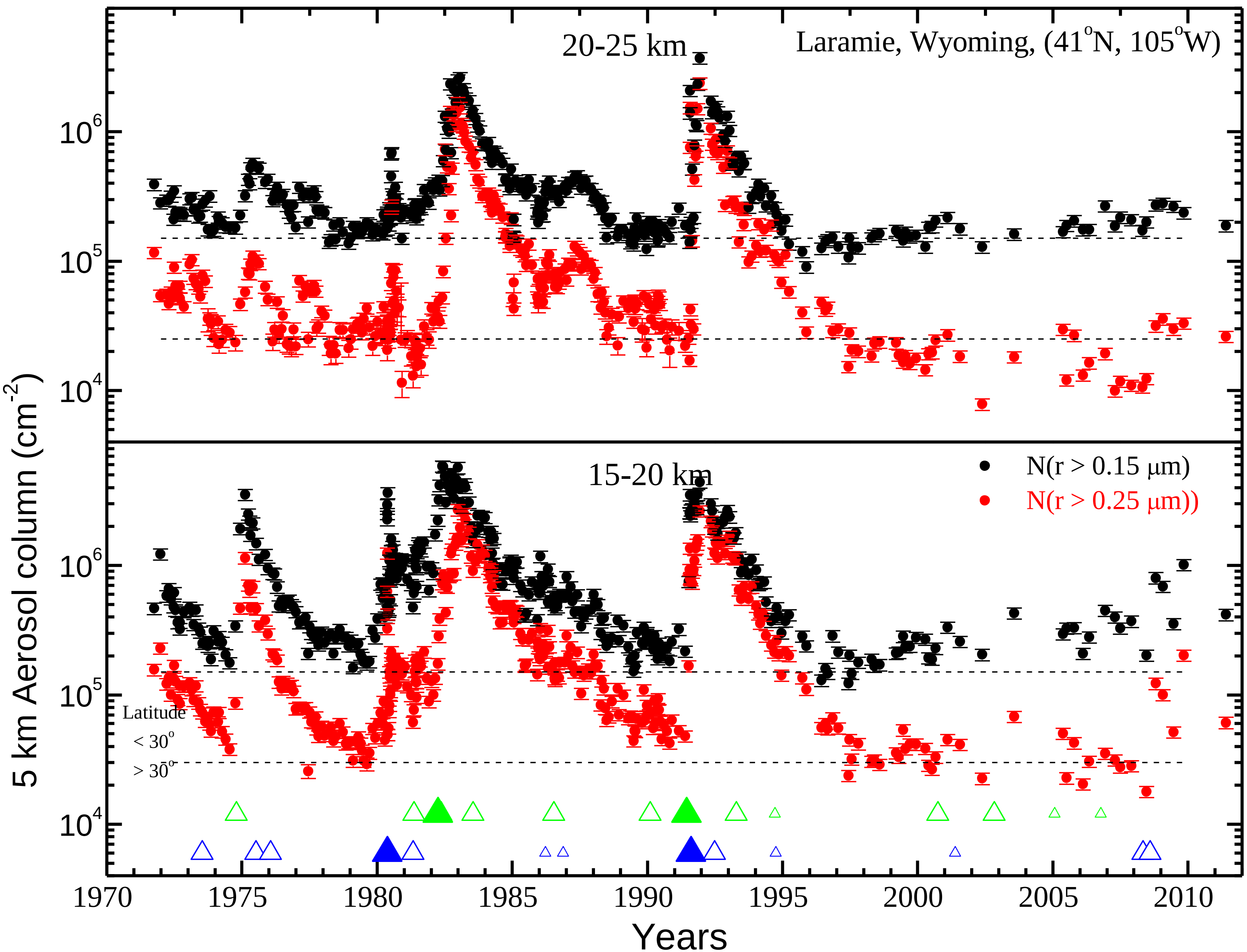
Deshler et al., 2006, Chapter 5 of the *SPARC Assessment of Stratospheric Aerosol Properties*

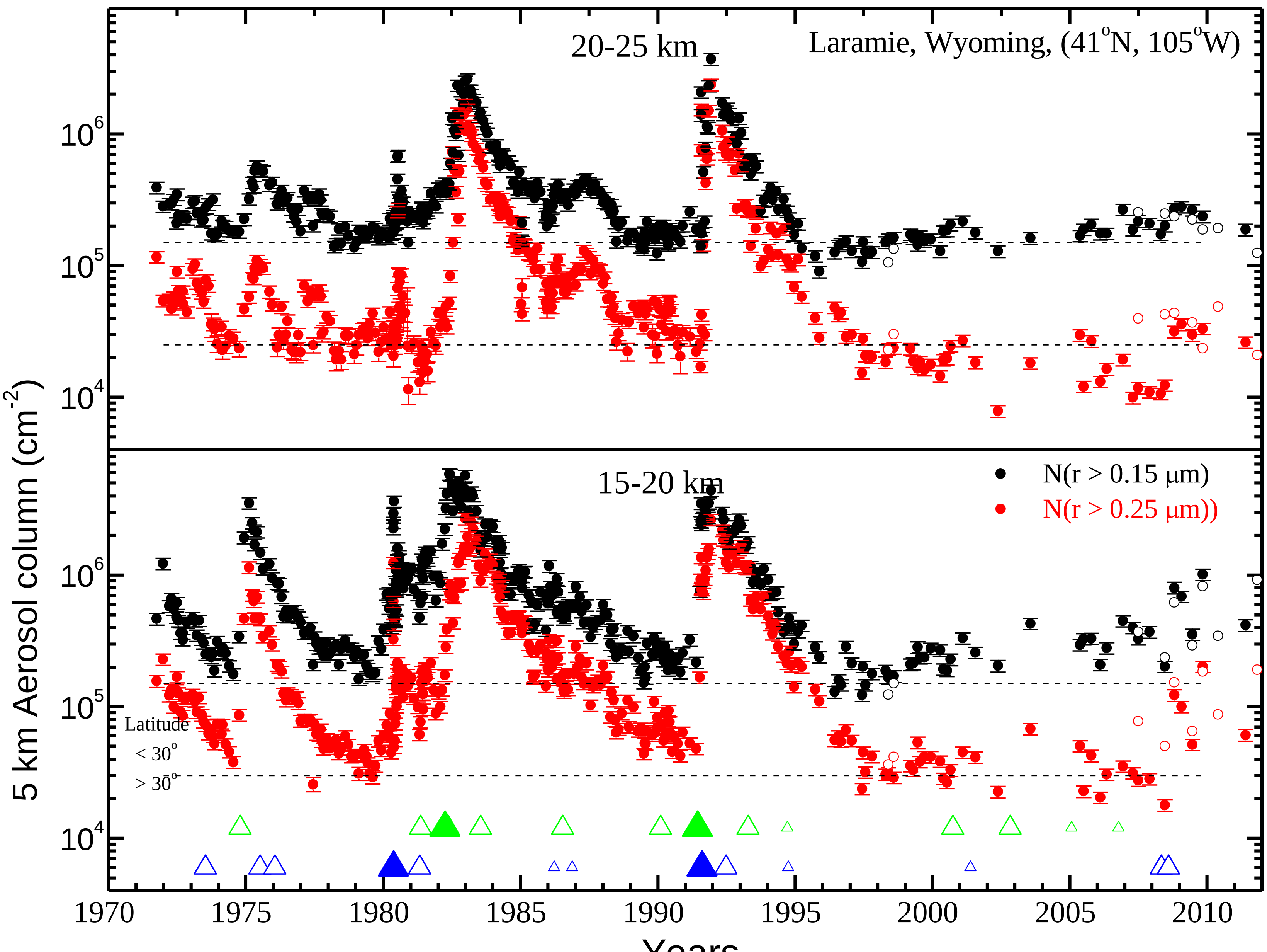


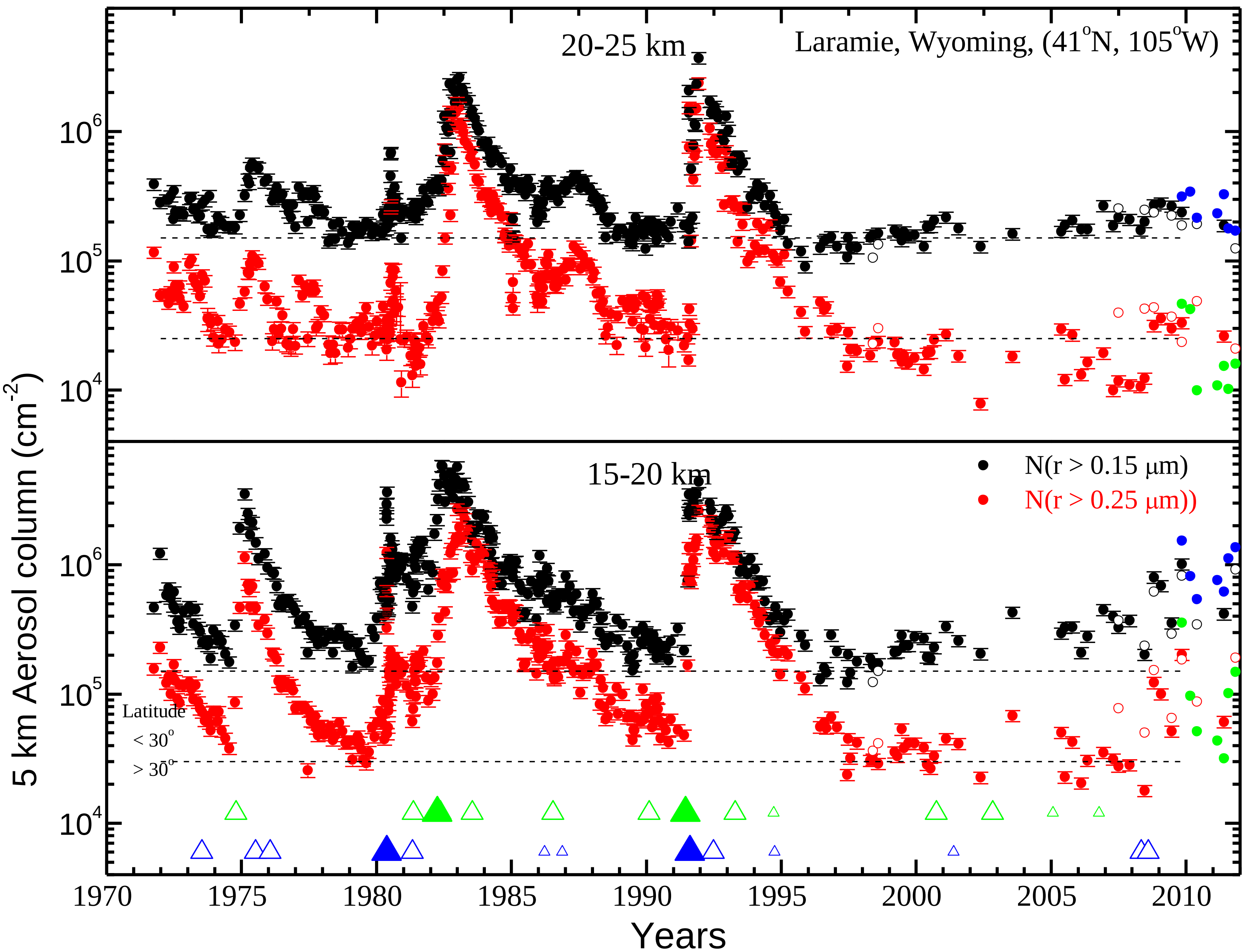
Deshler et al., 1993, JGR



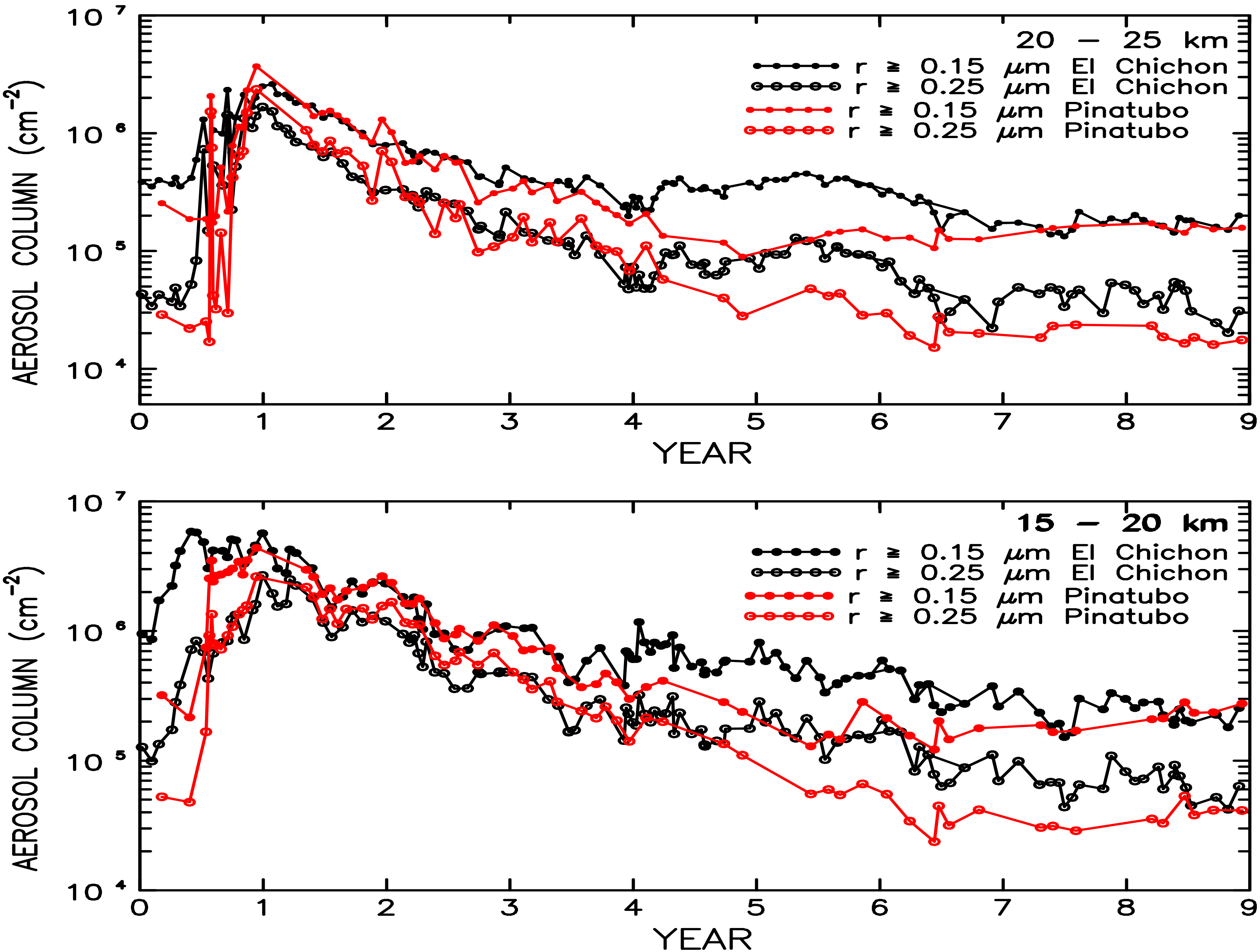
Acknowledgments for recent data to:
John Barnes, National Oceanic & Atmospheric Administration , USA,
Barclay Clemesha, Dale Simonich, Instituto Nacional de Pesquisas Espaciais,Brazil
Thomas Trickl IMK-IFU, Forschungszentrum Karlsruhe, Germany

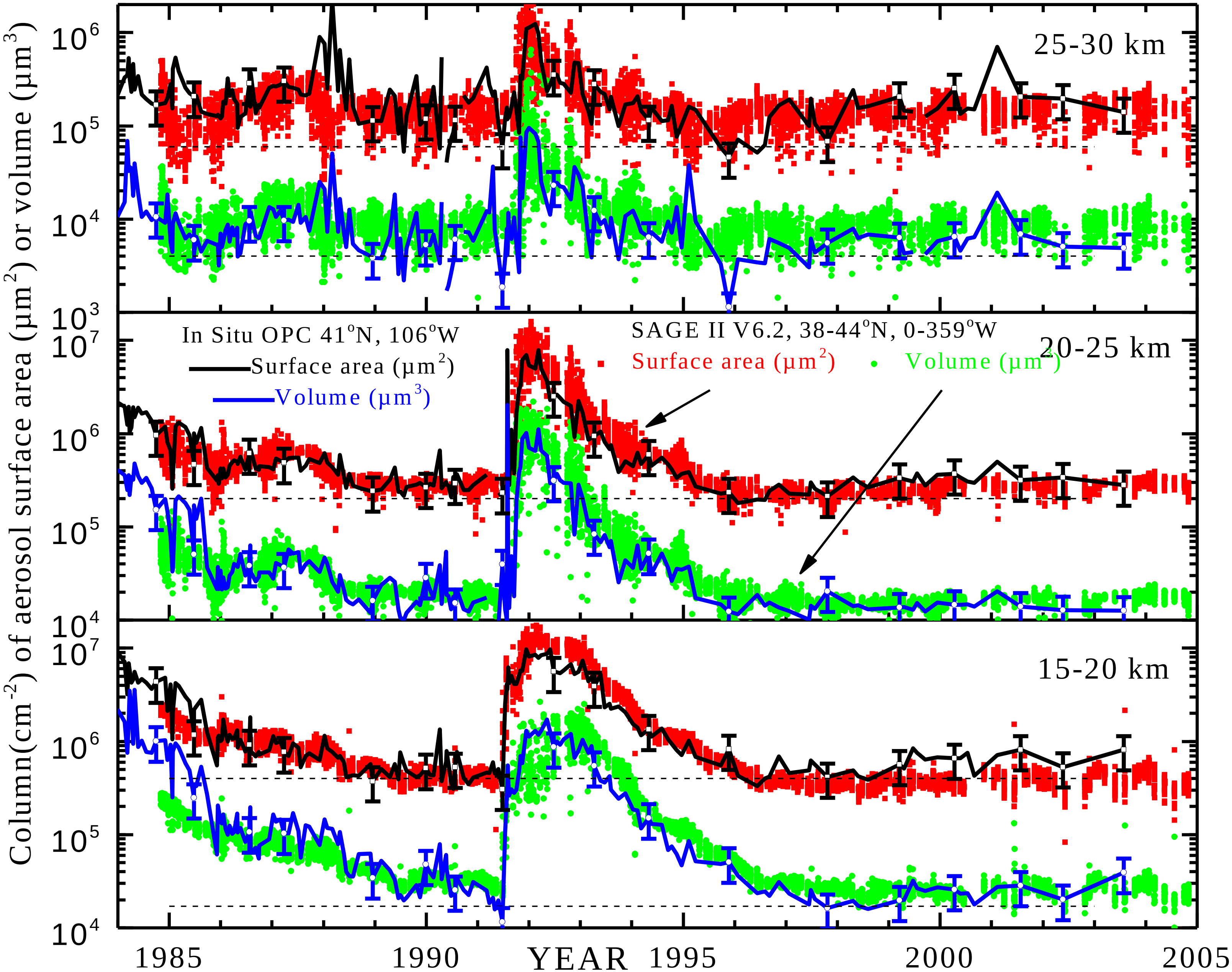

20-25 km
Laramie, Wyoming, (41°N, 105°W)
15-20 km
N(r > 0.15 μm)
N(r > 0.25 μm))
Latitude
< 30°
> 30°
5 km Aerosol column (cm^-2)
Years
1970
1975
1980
1985
1990
1995
2000
2005
2010


20-25 km
Laramie, Wyoming, (41°N, 105°W)
15-20 km
N(r > 0.15 μm)
N(r > 0.25 μm))
Latitude
< 30°
> 30°
5 km Aerosol column (cm⁻²)
Years



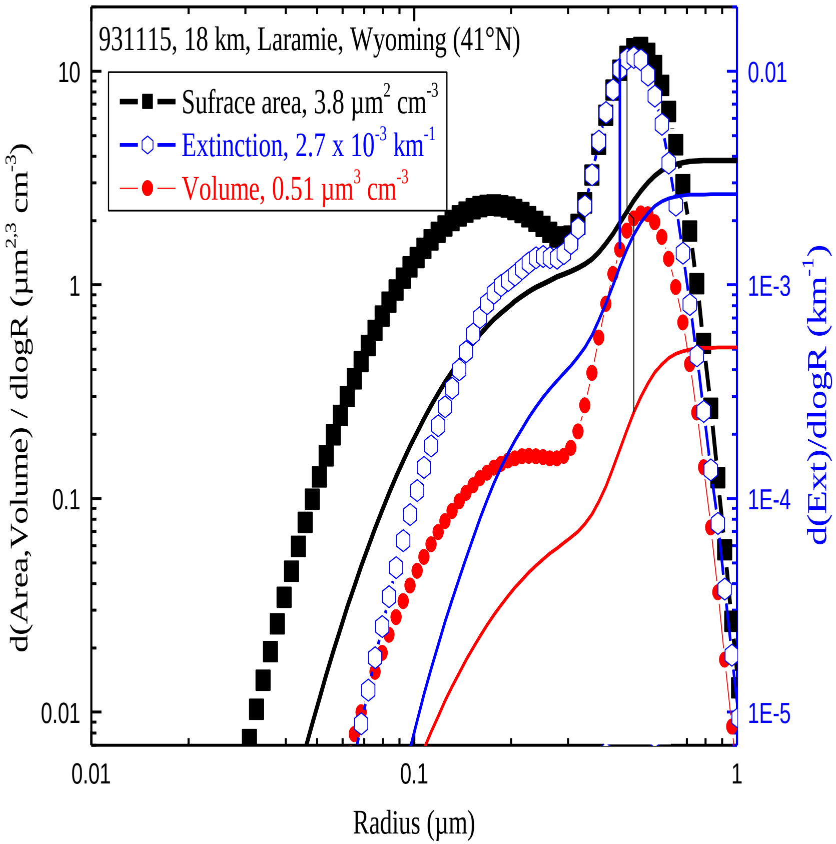
20-25 km
Laramie, Wyoming, (41°N, 105°W)
15-20 km
N(r > 0.15 μm)
N(r > 0.25 μm))
Latitude
< 30°
> 30°
5 km Aerosol column (cm⁻²)
Years
1970
1975
1980
1985
1990
1995
2000
2005
2010

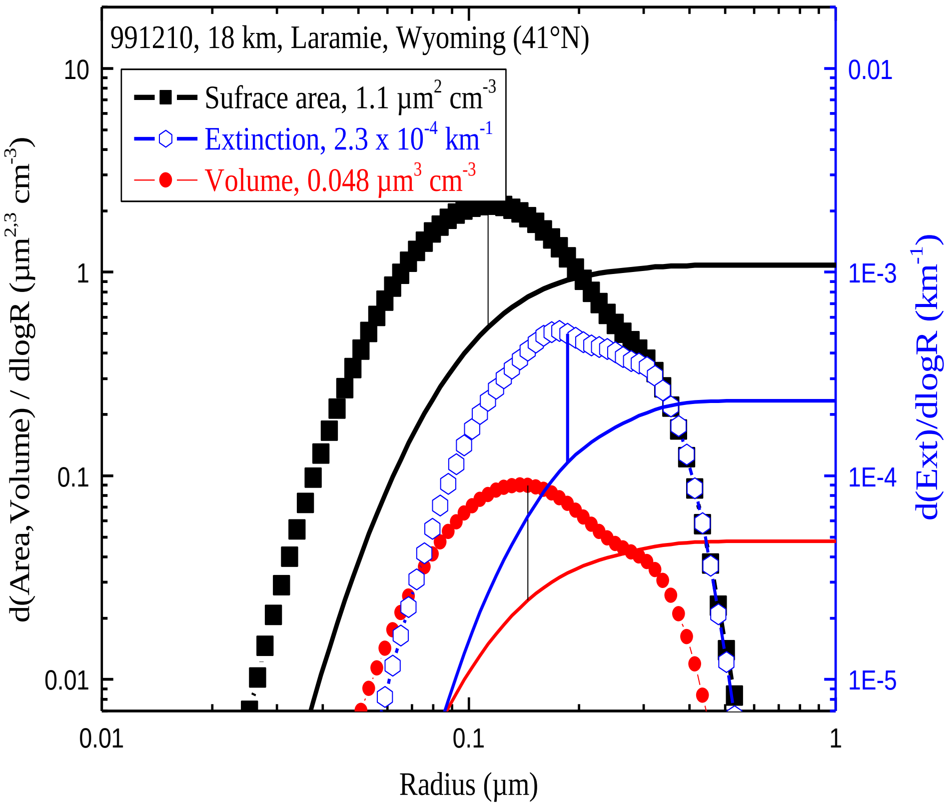

20 – 25 km
r ≥ 0.15 μm El Chichon
r ≥ 0.25 μm El Chichon
r ≥ 0.15 μm Pinatubo
r ≥ 0.25 μm Pinatubo
AEROSOL COLUMN (cm^{-2})
YEAR
15 – 20 km
r ≥ 0.15 μm El Chichon
r ≥ 0.25 μm El Chichon
r ≥ 0.15 μm Pinatubo
r ≥ 0.25 μm Pinatubo
AEROSOL COLUMN (cm^{-2})
YEAR



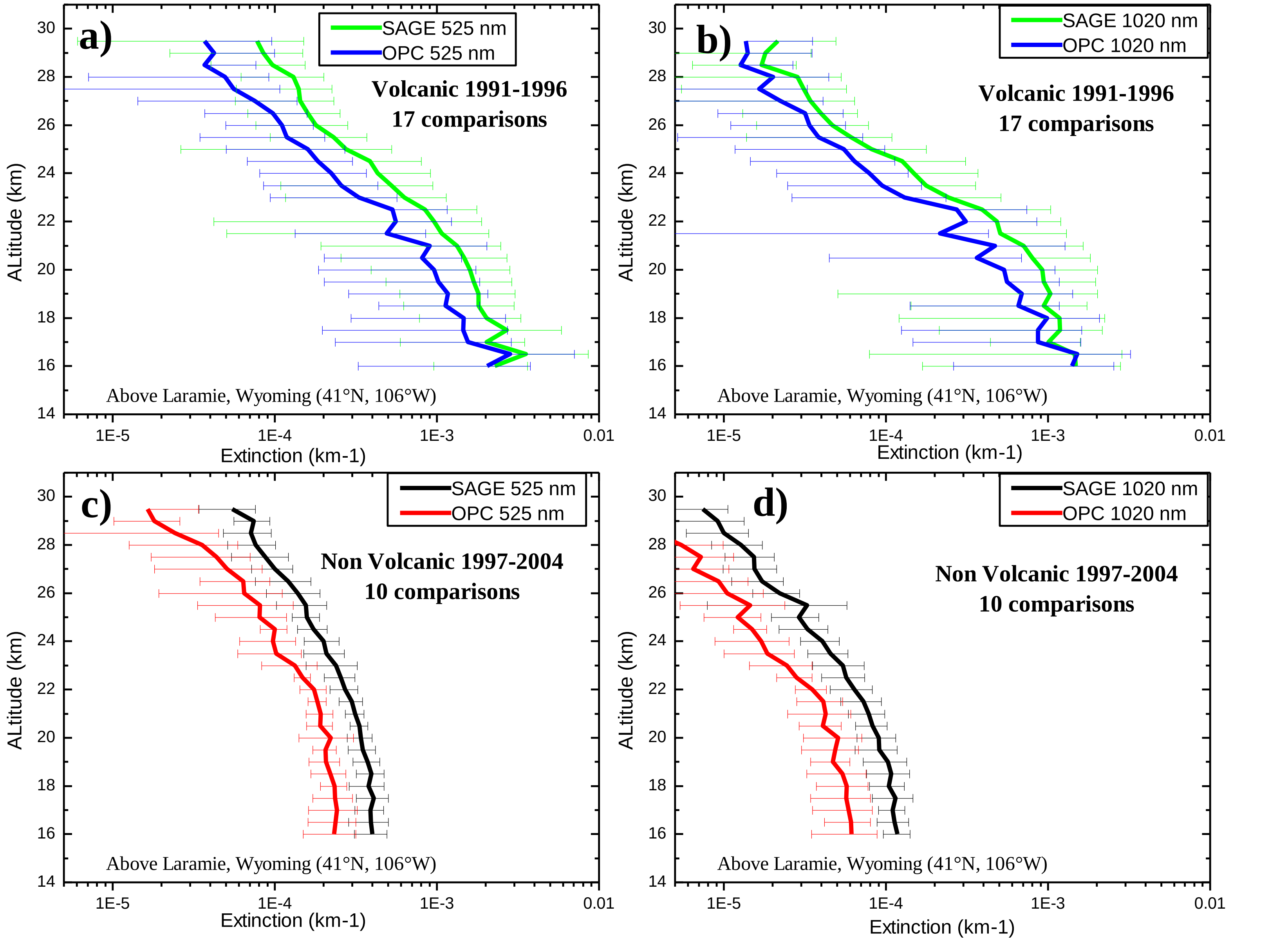
Deshler et al., 2006, Chapter 5 of the *SPARC Assessment of Stratospheric Aerosol Properties*

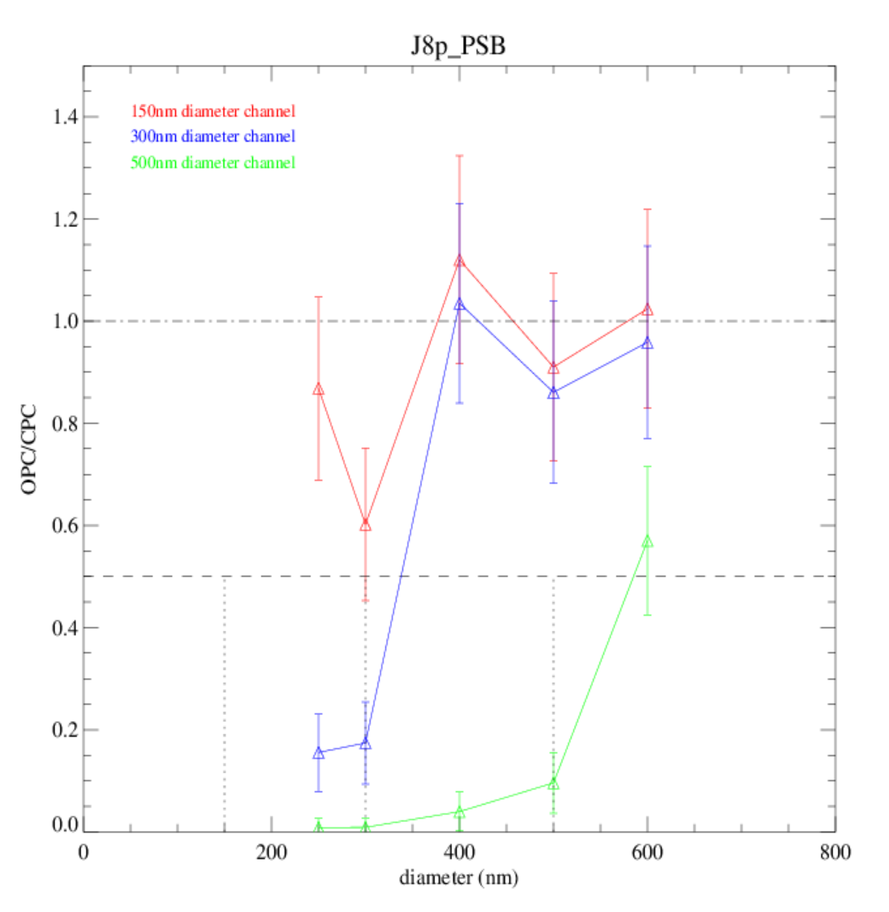
Estimates of differential surface area ($\mu m^2\ cm^{-3}$), , and volume ($\mu m^3\ cm^{-3}$) for in situ measurements in 1993 and 1999

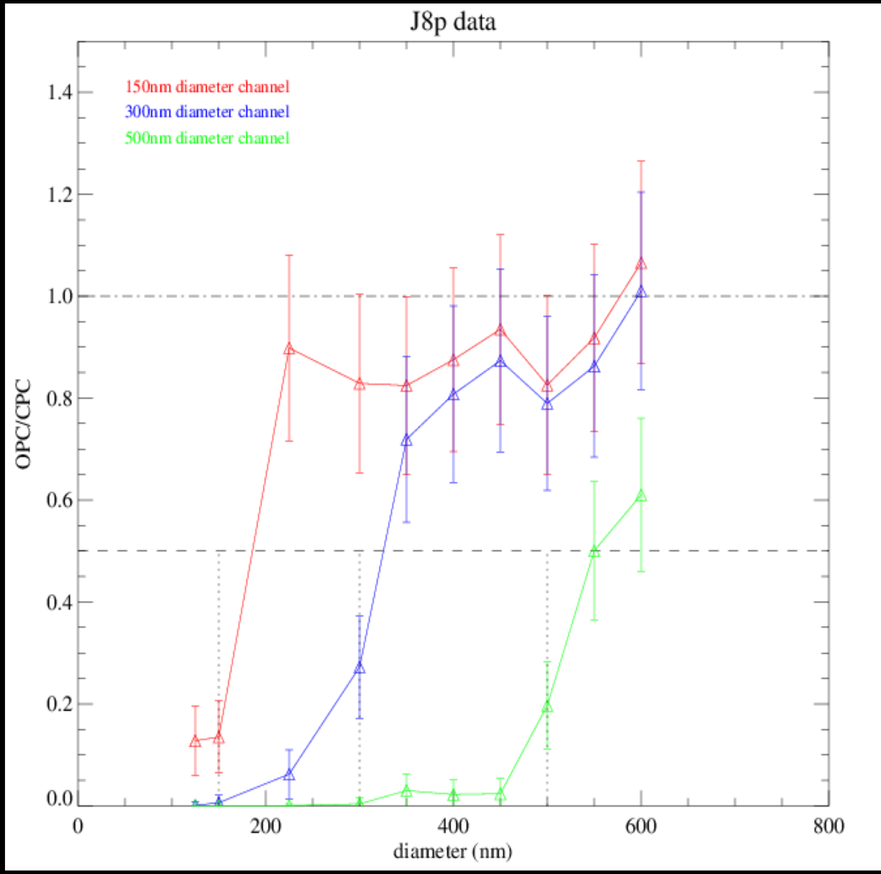




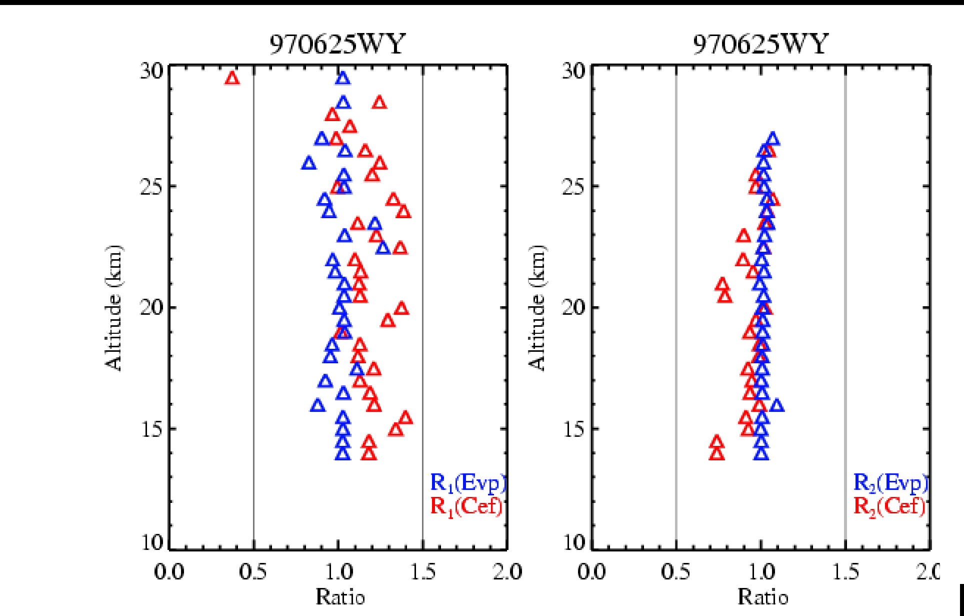
Evolution of Pinatubo Aerosol

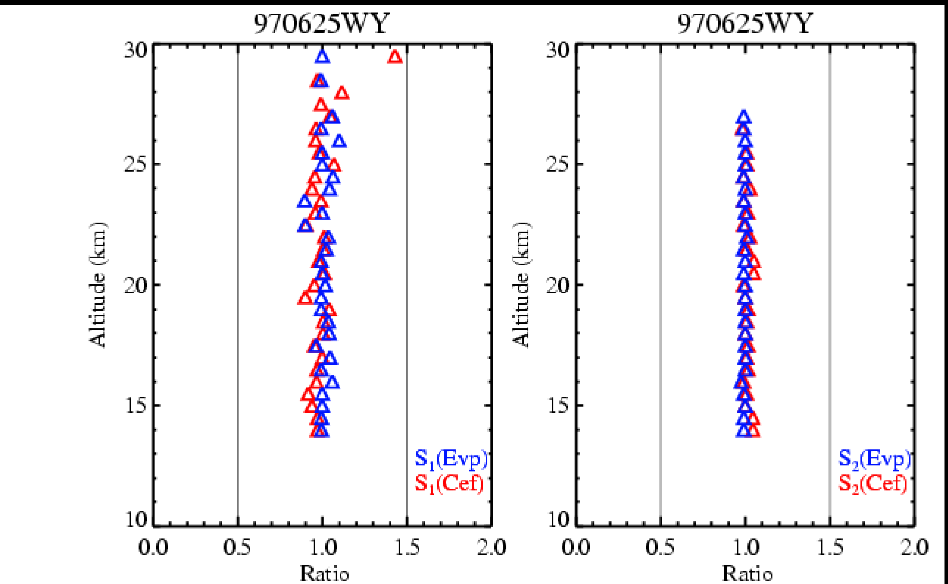

a)
SAGE 525 nm
OPC 525 nm
Volcanic 1991-1996
17 comparisons
Above Laramie, Wyoming (41°N, 106°W)
ALtitude (km)
Extinction (km-1)
b)
SAGE 1020 nm
OPC 1020 nm
Volcanic 1991-1996
17 comparisons
Above Laramie, Wyoming (41°N, 106°W)
ALtitude (km)
Extinction (km-1)
c)
SAGE 525 nm
OPC 525 nm
Non Volcanic 1997-2004
10 comparisons
Above Laramie, Wyoming (41°N, 106°W)
ALtitude (km)
Extinction (km-1)
d)
SAGE 1020 nm
OPC 1020 nm
Non Volcanic 1997-2004
10 comparisons
Above Laramie, Wyoming (41°N, 106°W)
ALtitude (km)
Extinction (km-1)
1E-5
1E-4
1E-3
0.01

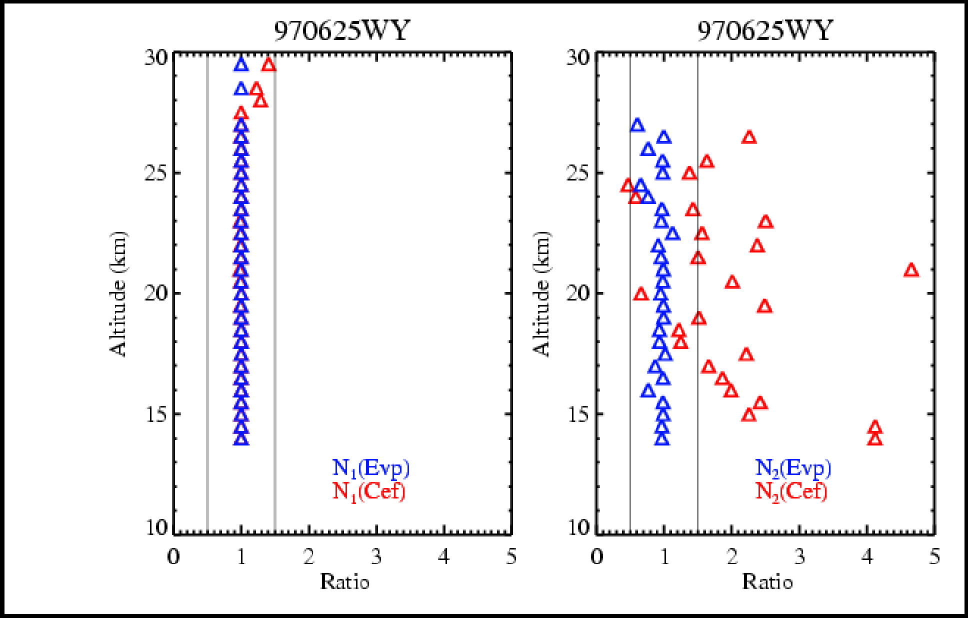

J8p_PSB
150nm diameter channel
300nm diameter channel
500nm diameter channel
OPC/CPC
diameter (nm)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
0
200
400
600
800


J8p data
150nm diameter channel
300nm diameter channel
500nm diameter channel
OPC/CPC
diameter (nm)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
0
200
400
600
800

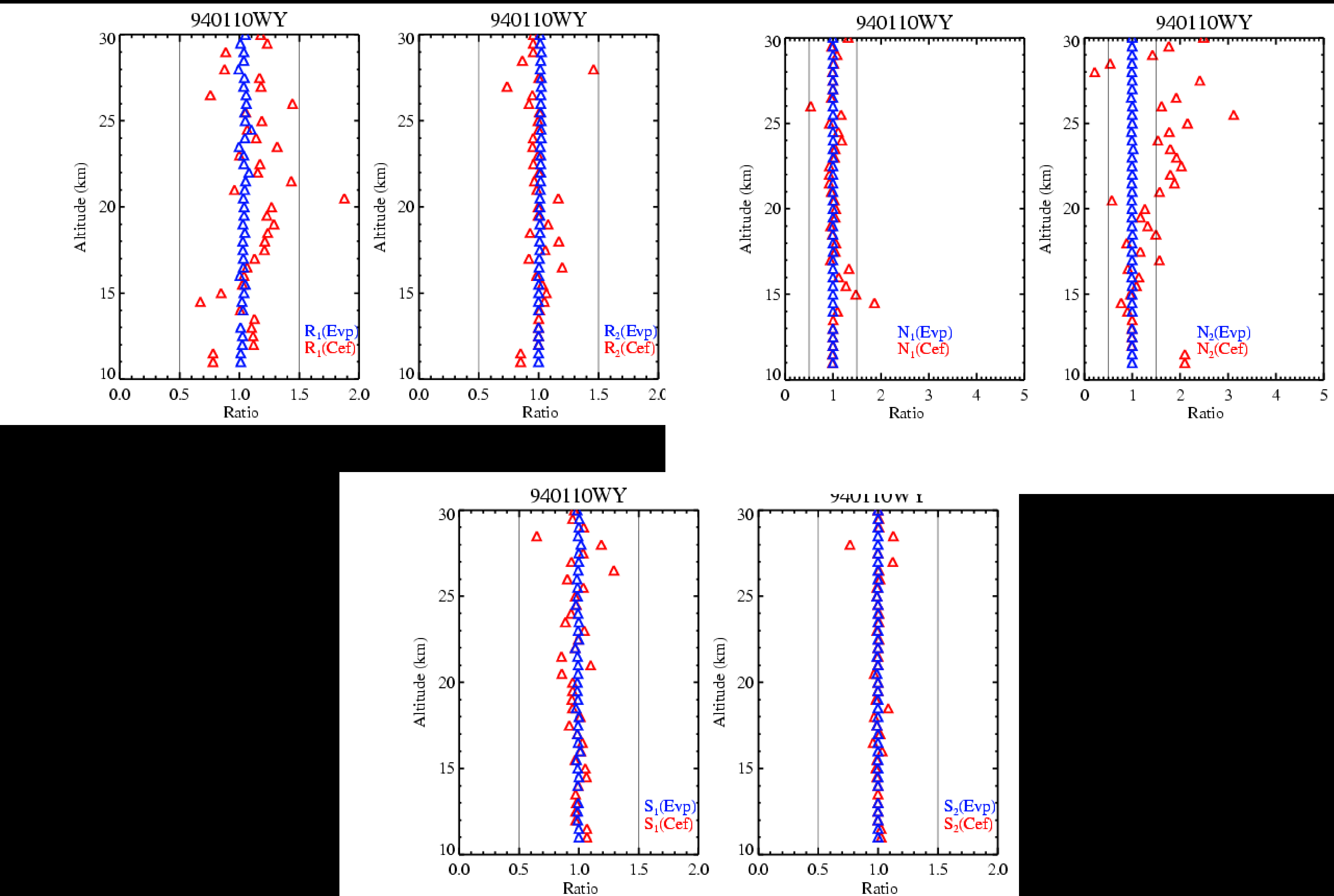
Non-volcanic profile- size distribution parameters comparison

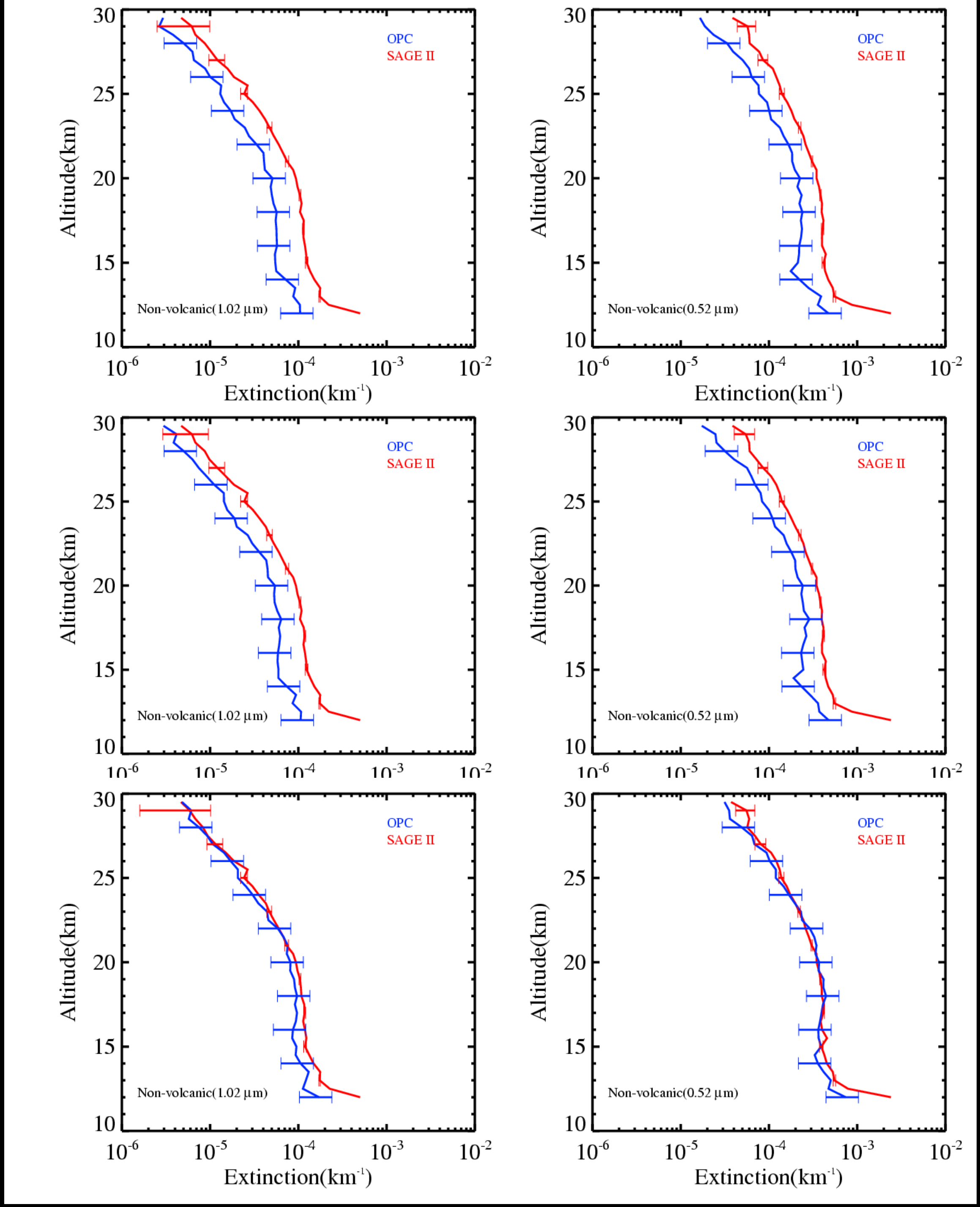






Volcanic profile- size distribution parameters comparison



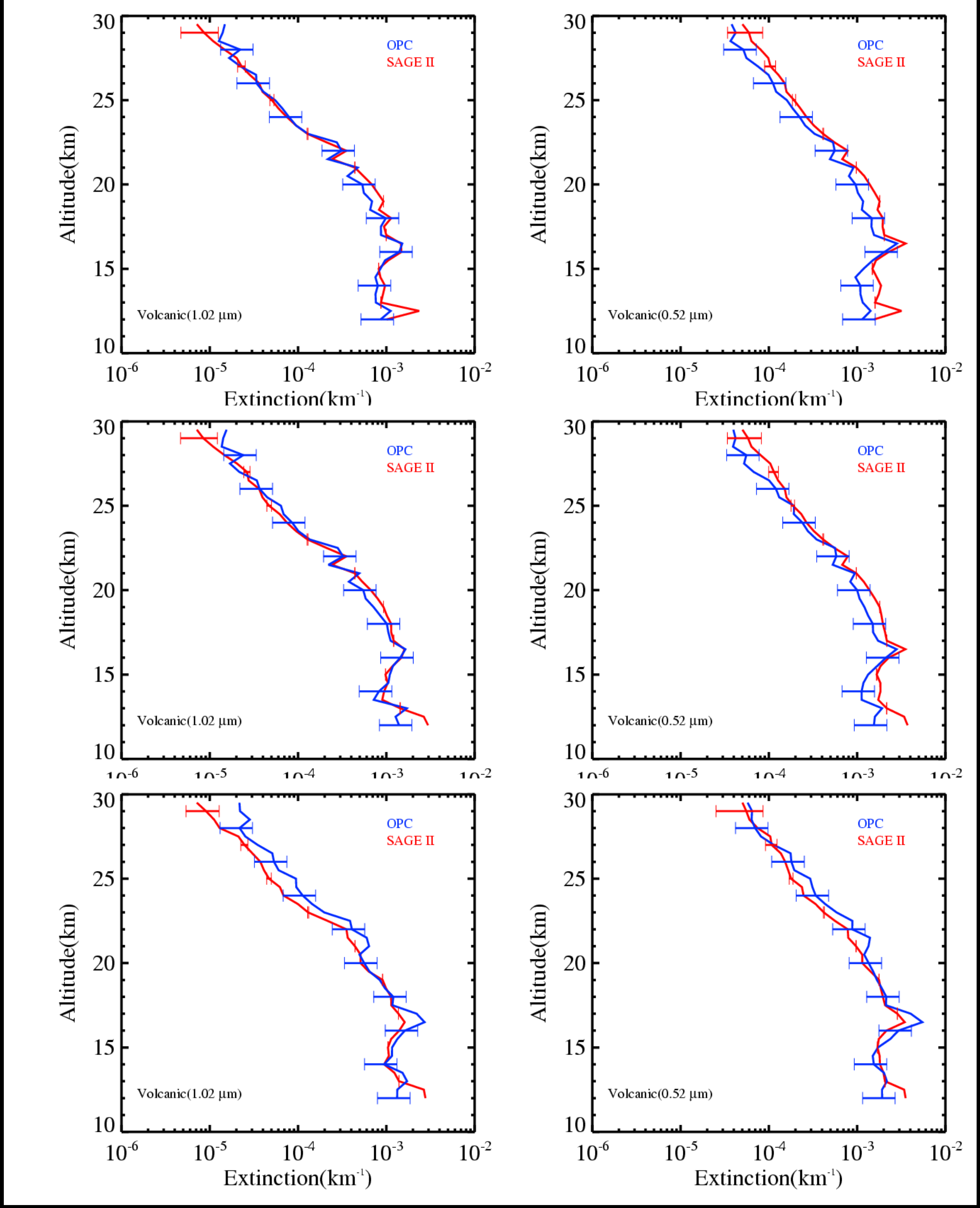


Non-
Volcanic profiles

No Correction

Corrected
for Evaporation

And
Counting
Efficiency



Volcanic profiles

No Correction

Corrected
for Evaporation

And
Counting
Efficiency

Conclusions

- The measurements at Laramie (41°N) provide a measure of the evolution of stratospheric aerosol over the past 40 years illustrating the stratospheric impact of a number of volcanoes in particular: Fuego (1974), El Chichon (1982), Pinatubo (1991), and recent low level activity.
- The capability is somewhat portable, but the instruments are large enough to require clearance through air traffic control.
- Measurements have been made from: Antarctica, Sweden, New Zealand, Brazil, Niger, Australia.
- In situ errors are dominated by pulse width broadening and Poisson counting statistics leading to errors of ~ ±30-40% on any distribution moment.
- New instruments seek to expand the size range and provide replacement to the current instruments.
- Differences between Wyoming in situ estimates of extinction, and SAGE II measured extinctions are close to being resolved, but will lead to larger discrepancies between in situ and remote surface area estimates under low aerosol loading conditions.