

Analysis of CLF Data for the Auger Observatory

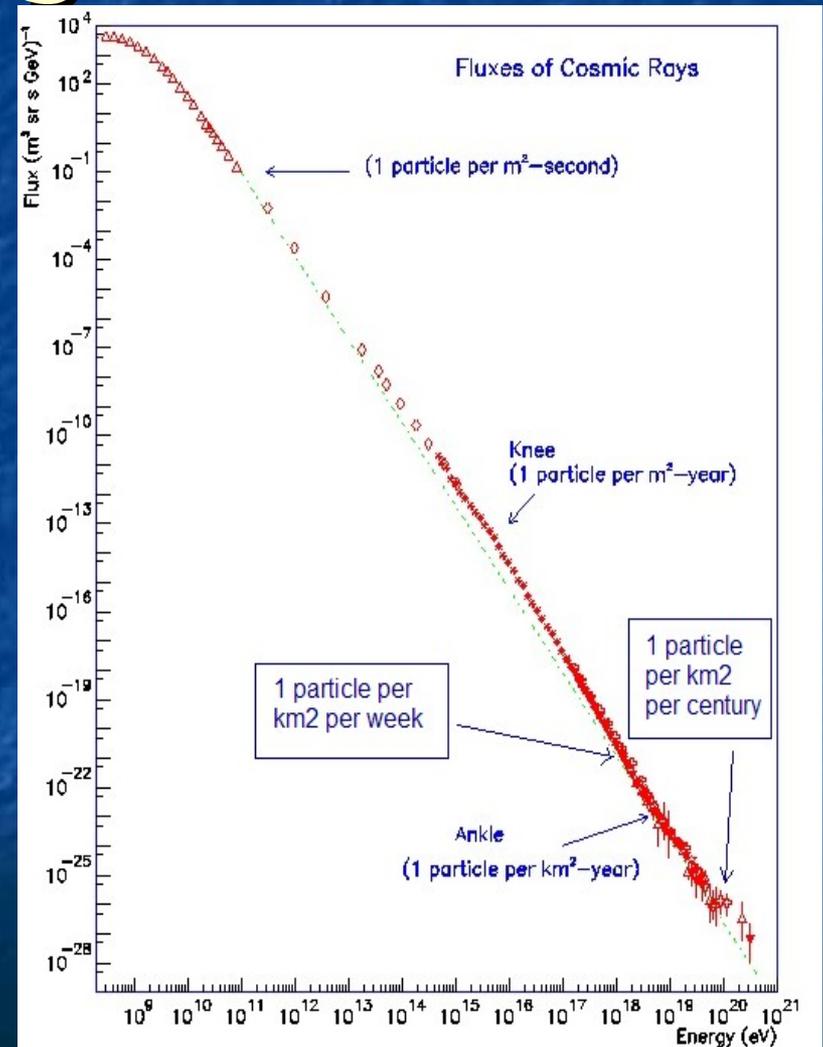
And Subsequent Correction of
Errors

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Columbia University REU, 2007

Ultra High Energy Cosmic Rays

- Low energy cosmic rays fall at about $200/\text{s}/\text{m}^2$
- Particles with energies $>10^{18}$ eV fall at rate of $1/\text{week}/\text{km}^2$
- Particles with energies $>10^{20}$ eV fall at rate of $1/\text{century}/\text{km}^2$
- What is the source

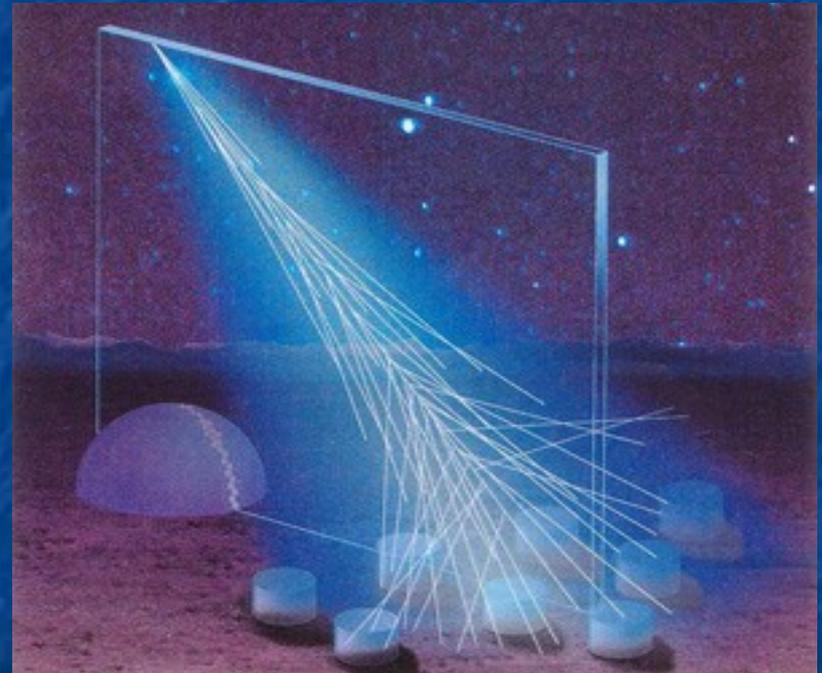


Possible Sources Ultra High Energy Cosmic Rays

- GZK cutoff – expectation that particles cannot be accelerated above 6×10^{19} eV
 - Collisions with CMB would decrease energy of cosmic rays from far distances
 - Thus, source cannot be farther than 50 Mpc
 - Cannot find a source within this distance
- Proposed Sources
 - Collapse of topological defects
 - Active Galactic Nuclei jets
 - Radio Galaxy hot spots

Pierre Auger Observatory

- Hybrid Detector
 - 1600 Surface Detectors
 - 4 Fluorescence Detectors
- Seeks to study high energy cosmic rays by reconstructing air showers in atmosphere.
- Ultimately wants to understand cosmic rays with energies $> 10^{20}$ eV



Central Laser Facility

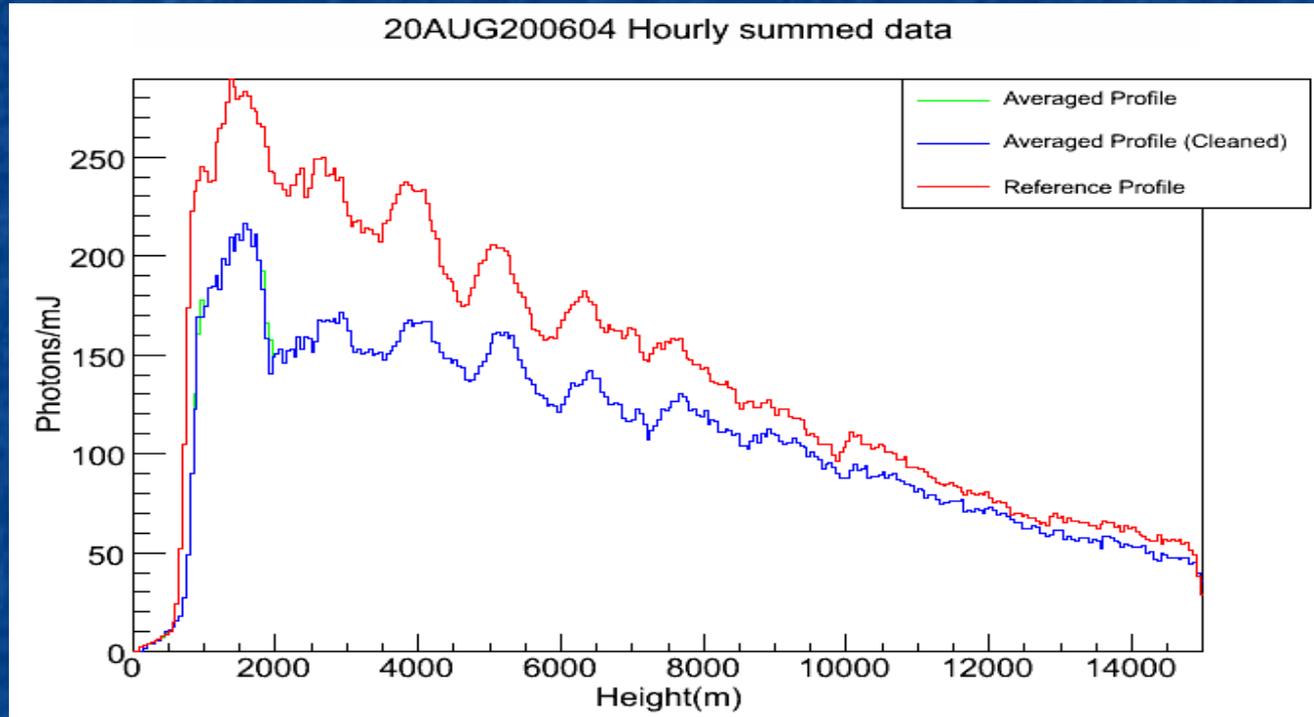
- UV laser is pulsed every 15 minutes into the sky
- Light scatters off of particles in atmosphere
- FD then detects and profiles



Scattering in Atmosphere

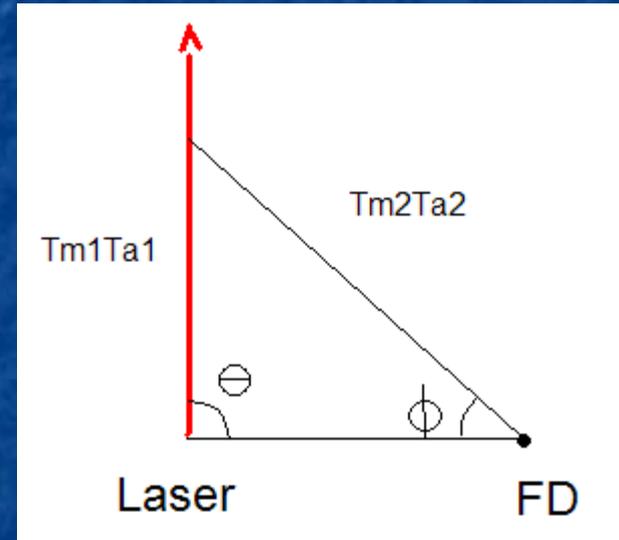
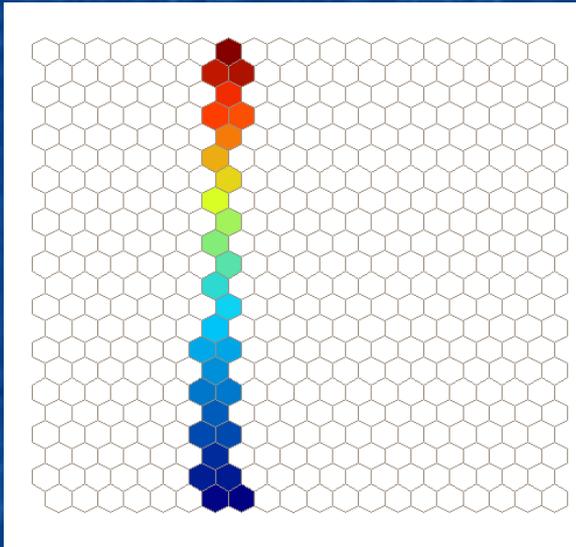
- Two Types of Scattering
 - Molecular (Rayleigh) – due to nitrogen, oxygen particles in atmosphere
 - Aerosol – due to presence of particulate matter due to dust, fog, et cetera.
- Reference profile – recalibrated every 4 months to an extremely clear day
- Measured profiles are then compared to reference

Example Profile



- Red is the clean reference night.
- Blue is measured profile.
- Light is attenuated in “dirty” atmosphere.

Example Setup



- Track from CLF event display program

- Theta is used in calc. of VAOD

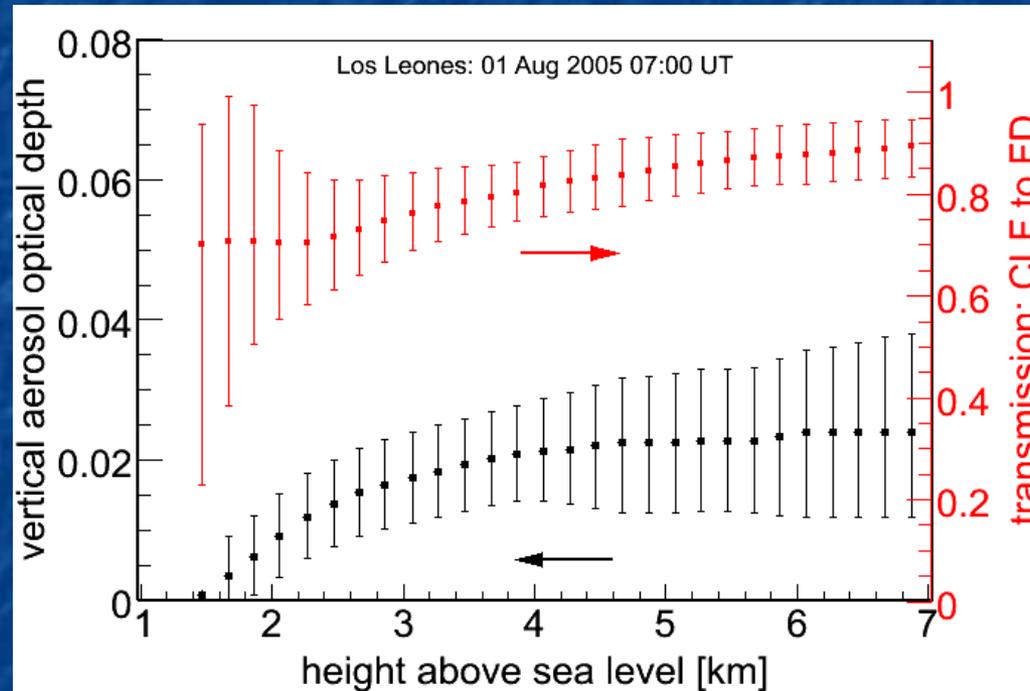
Calculation of VAODs

- Transmission is dependent on molecular & aerosol optical depths
- Vertical Aerosol Optical Depth – a measure of the transparency of the atmosphere above
- $\tau_M > \tau_A$, but aerosols are not uniform and cannot be modeled easily

$$T = \exp(-\tau_M - \tau_A)$$

$$\tau_A = -\frac{\ln(N_{meas} / N_{clear})}{1 + \csc \theta}$$

Transmission of Light through Atmosphere & VAOD



- Black is typical VAOD curve
- Red is transmission

Calculation of VAOD

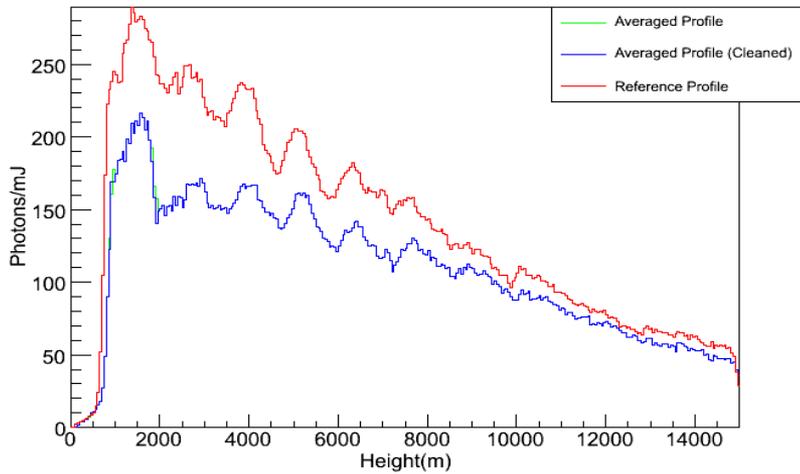
- Molecular Reference \approx Measured indicates a clear night with very few aerosols
 - Implies VAOD is zero
- Thus, the program applies cuts to instances in which the measured profile is significantly greater than the reference.

What I did

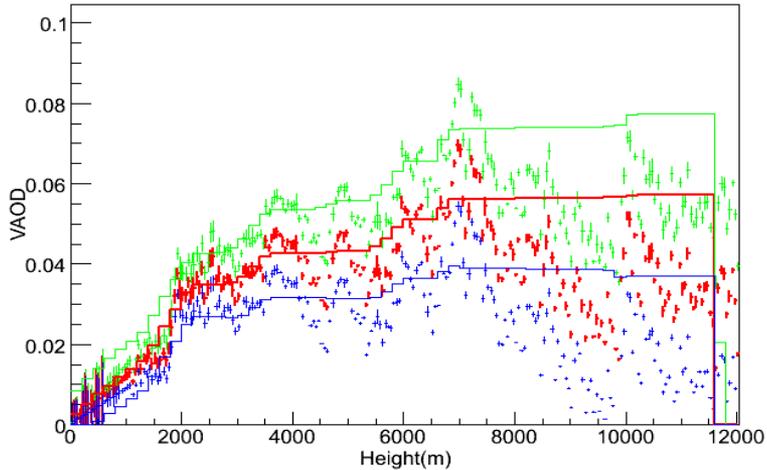
- Ran old code (CLFatmos.cc) on Los Leones data from July – December 2006
- Classified the plots to determine where the errors were
- Realized that many of the fits to the VAOD plots were not physical
 - Fits sometimes failed on very clear days

Examples of Good Plots

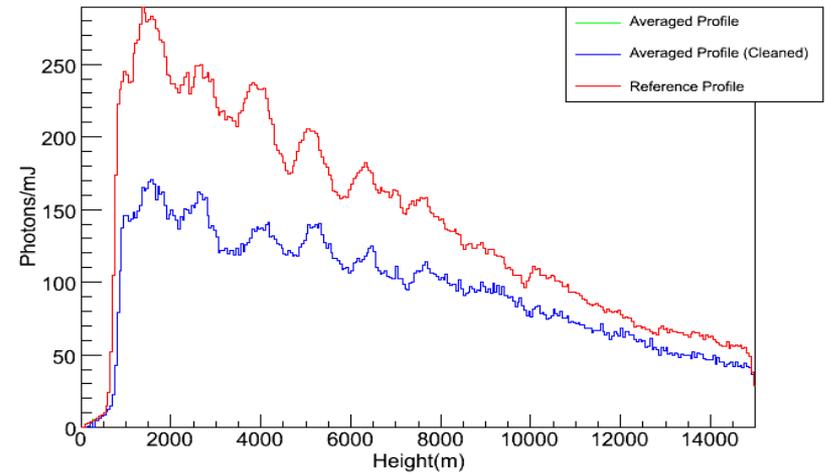
20AUG200604 Hourly summed data



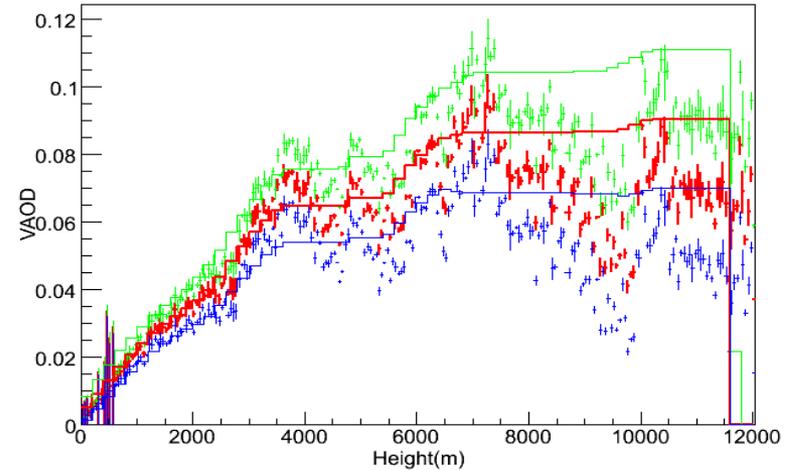
VAOD measured



20SEP200602 Hourly summed data

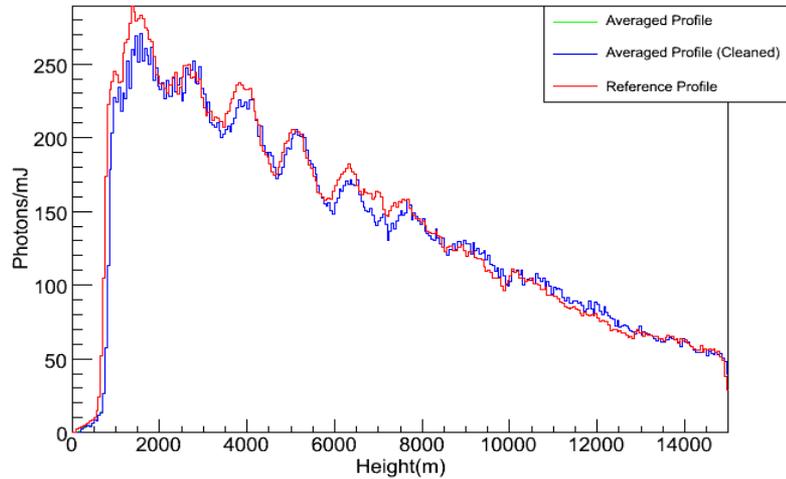


VAOD measured

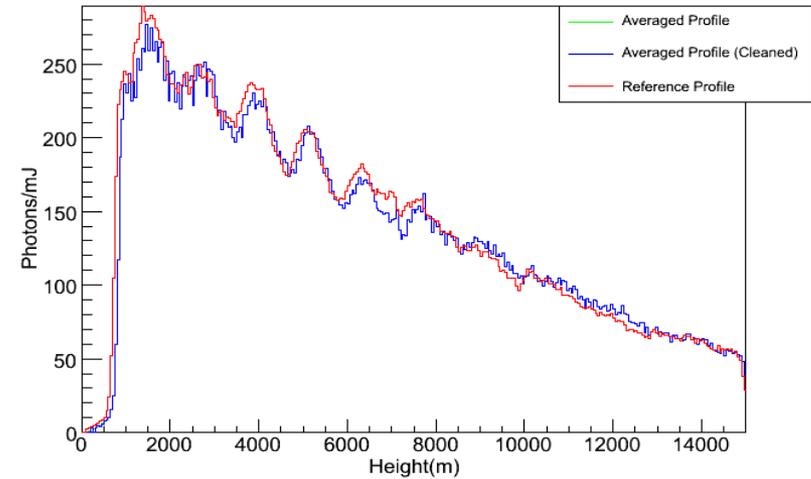


Examples of Bad Plots

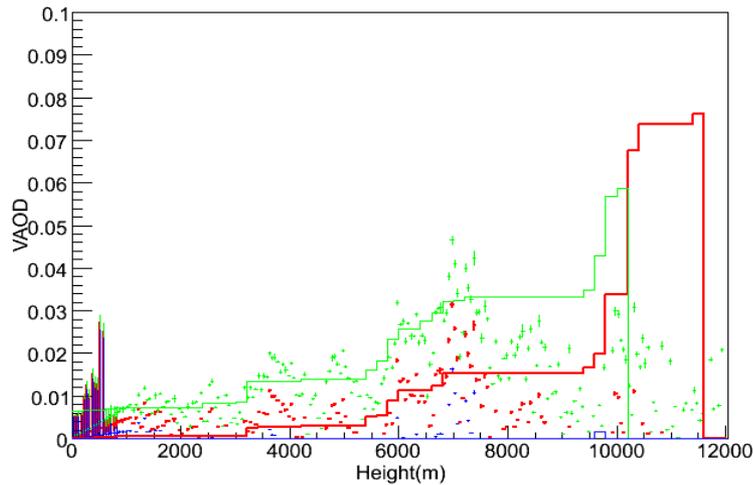
22AUG200600 Hourly summed data



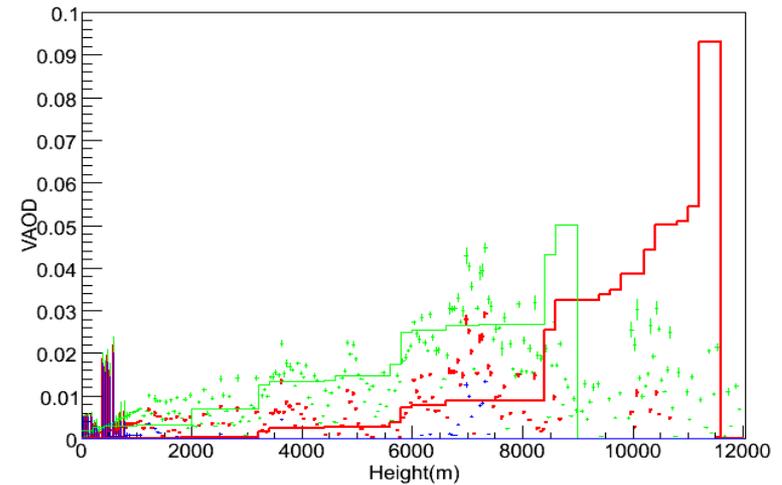
22AUG200603 Hourly summed data



VAOD measured



VAOD measured



Problem Points in Program

- Sliding window
 - Tool to calculate VAODs over an interval
 - Helps to smooth the result
 - Previous code ran window over altitudes to 14 km
 - Introduces problems when clear and measured profiles are similar on clear days
 - Thus, run until about 8 km if there are problems

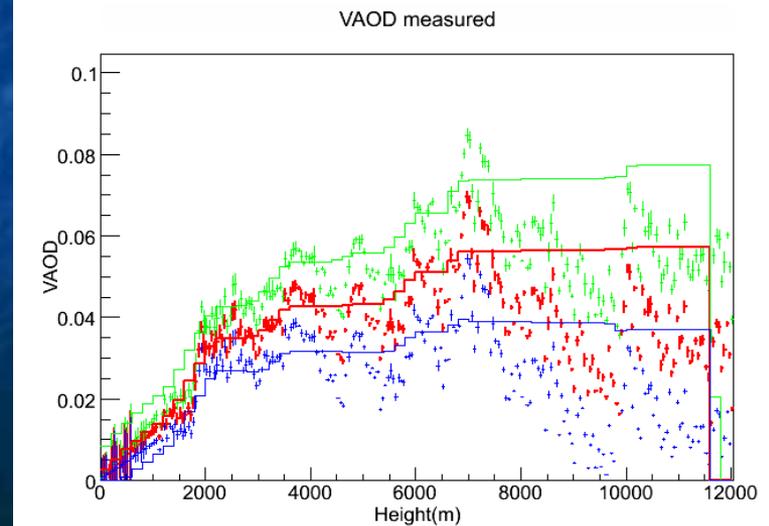
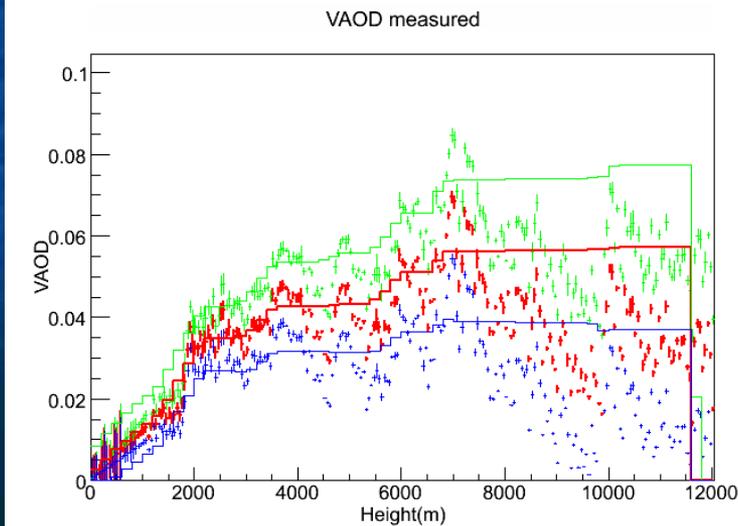
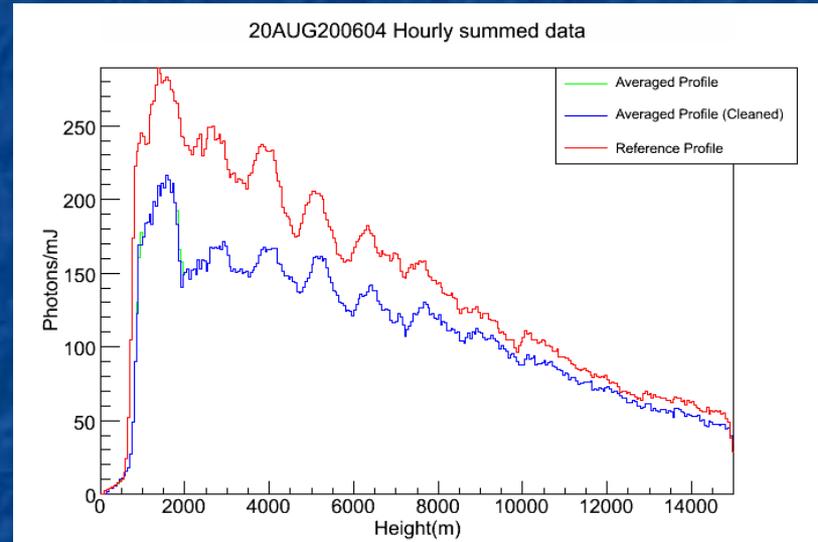
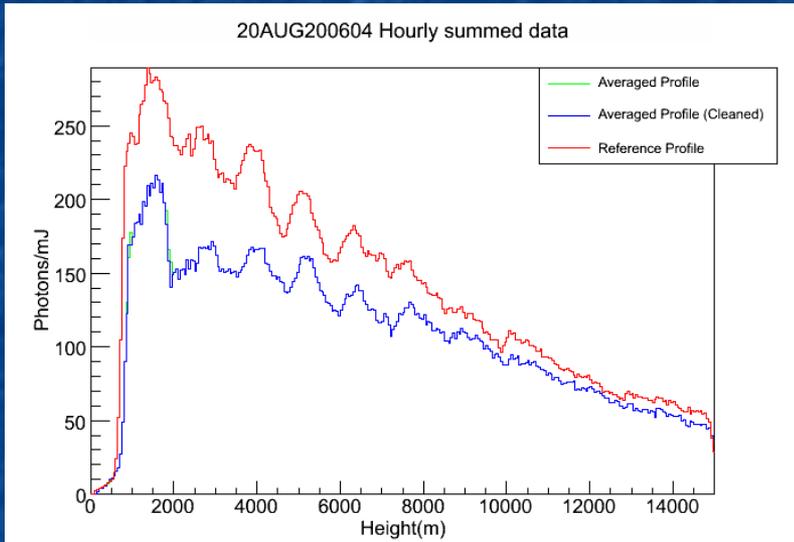
Problem Points in Program

- Edge Effects
 - Inserted check such that for its last interval, sliding window would choose the minimum between 8 km and the maximum valid bin calculated.
- Fits cannot be negative

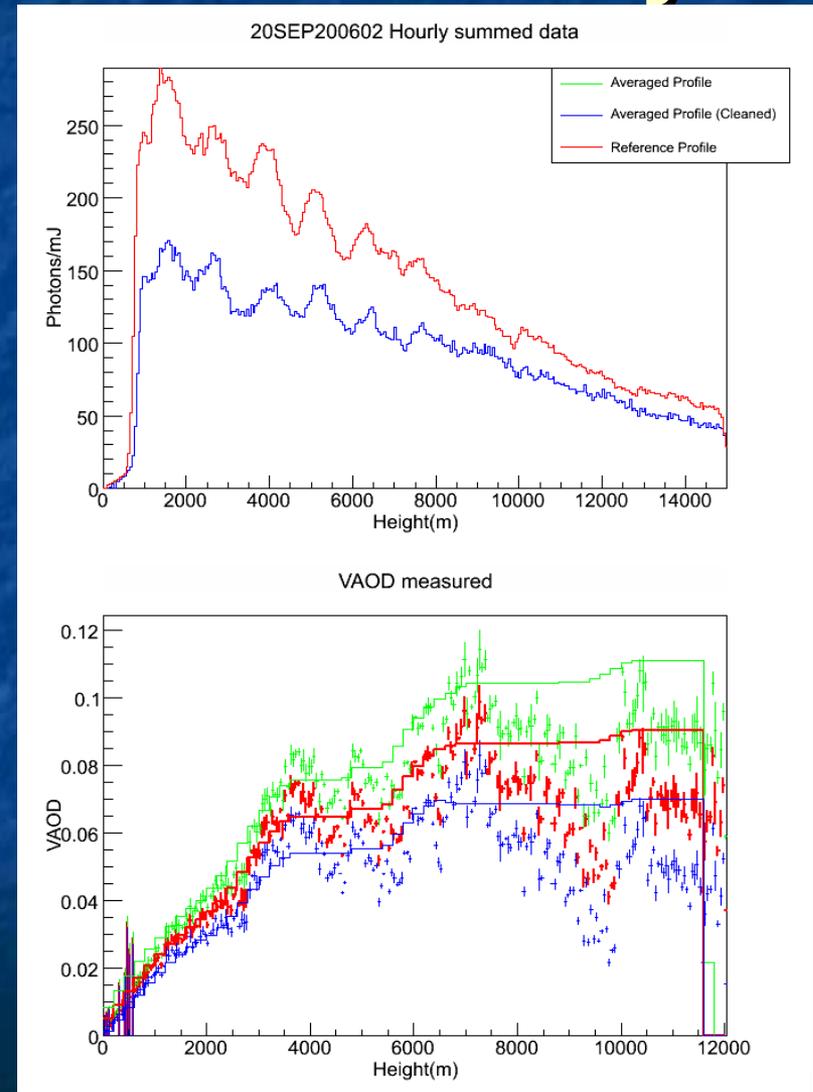
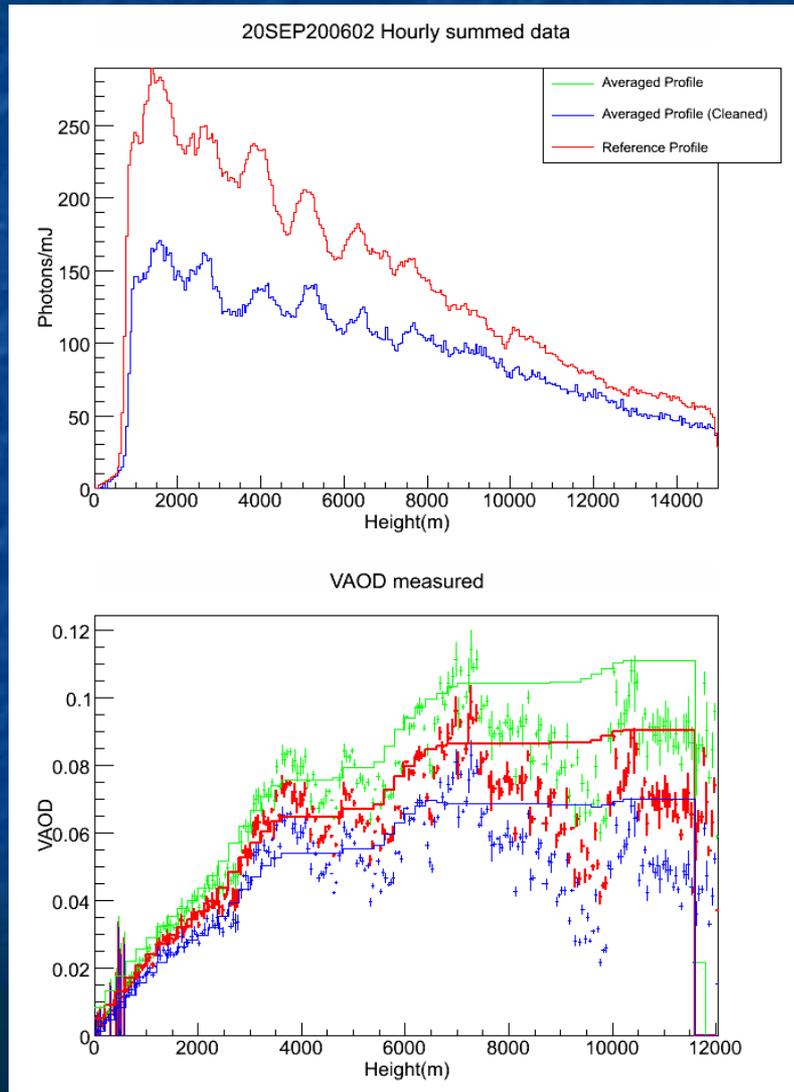
Result

- Fits no longer shoot up at higher altitudes
- Fits stop where the data is cut off
- Fits have a zero slope when VAOD looks negative.

Before & After: Good Days

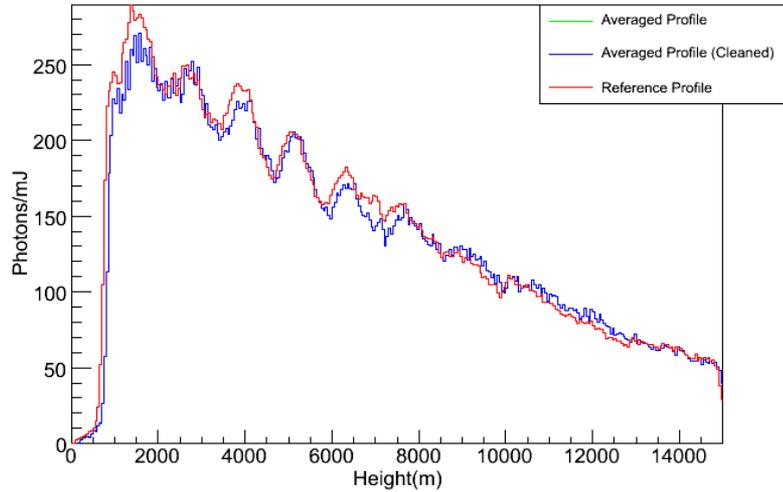


Before & After: Good Days

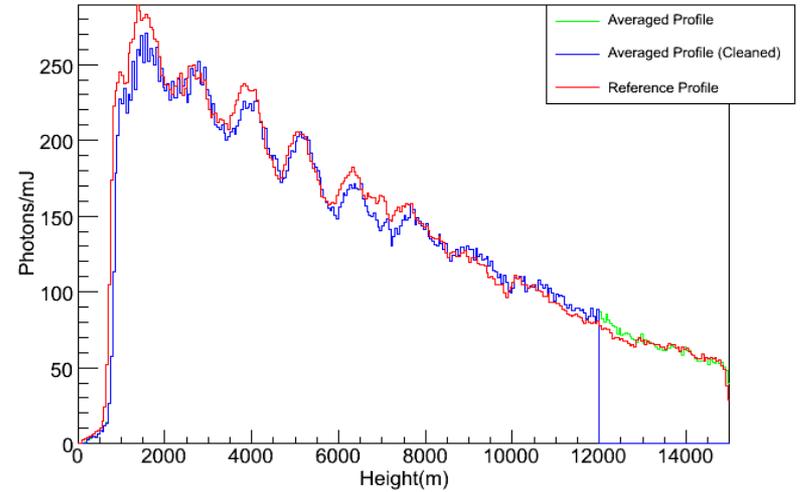


Before & After: Bad Days

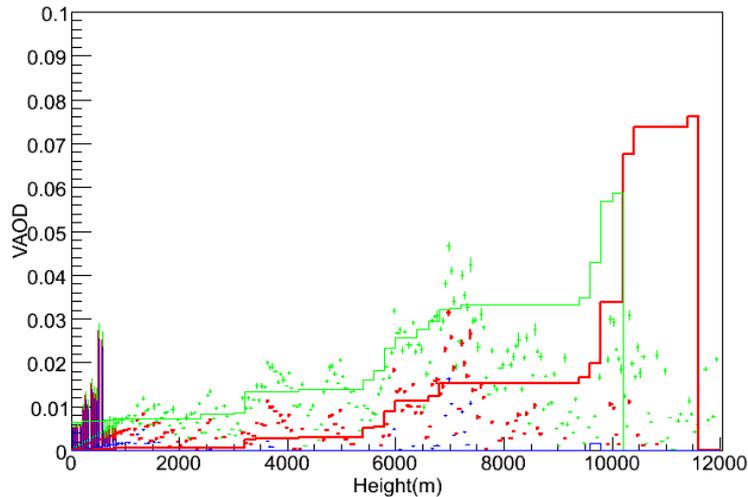
22AUG200600 Hourly summed data



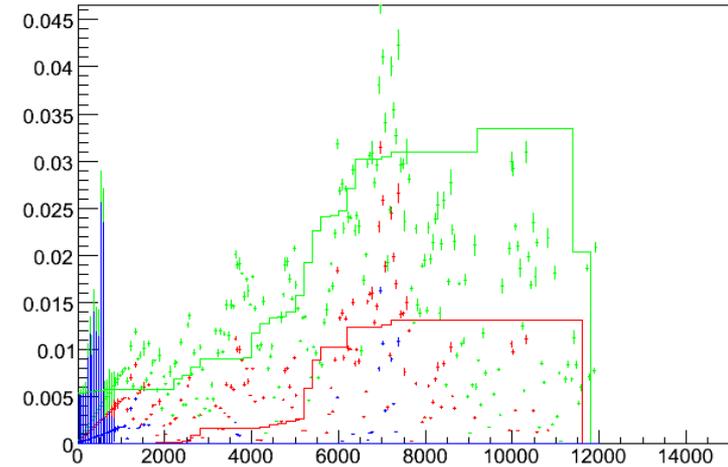
22AUG200600 Hourly summed data



VAOD measured

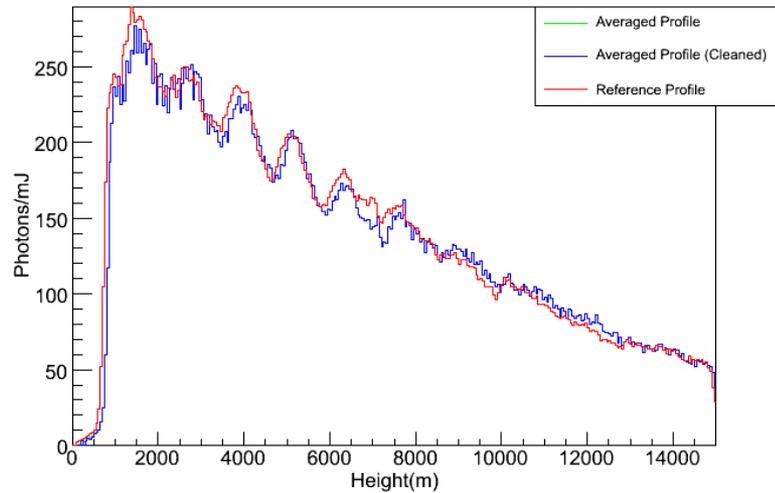


VAOD measured

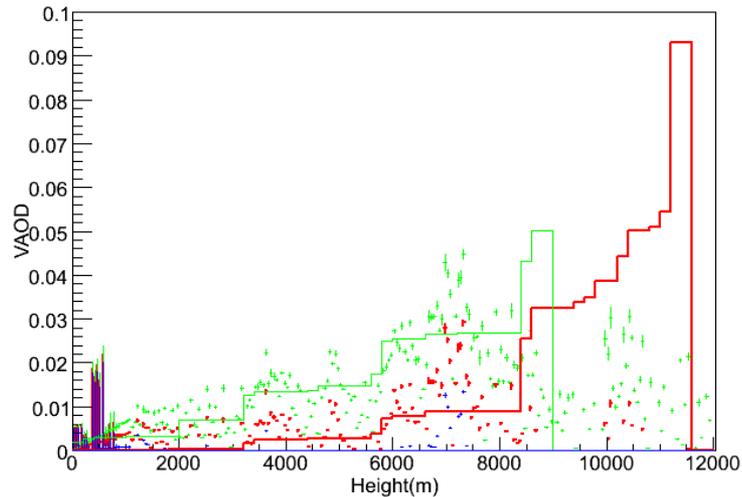


Before & After: Bad Days

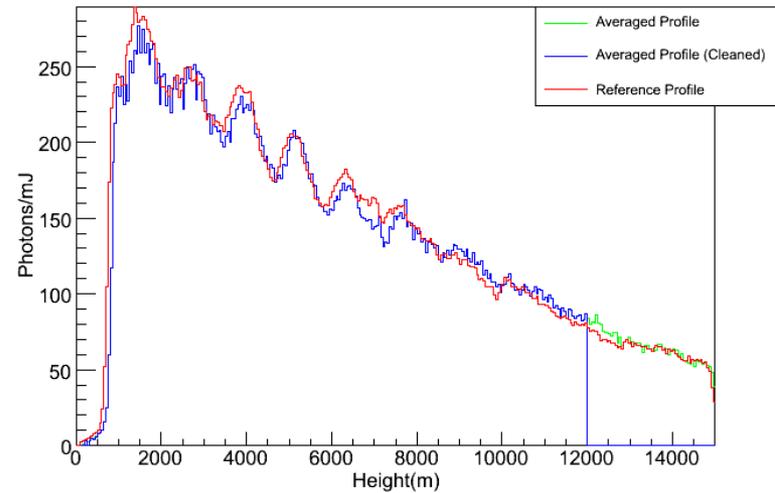
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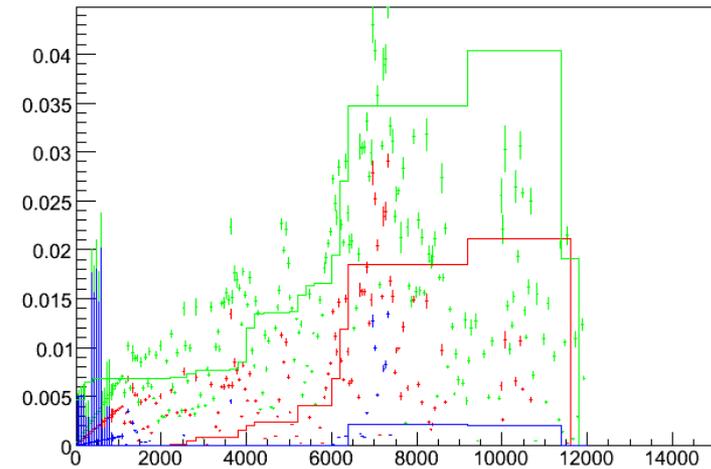
VAOD measured



22AUG200603 Hourly summed data



VAOD measured



Acknowledgements

- Thank you to:
- Dr. Stefan Westerhoff
- Segev BenZvi
- Michael Prouza



Works Cited

- www.auger.org (pictures and science background)
- <http://hea.cwru.edu/auger/index.html> (pictures)
- M.D.Roberts: “Atmospheric aerosol determination using vertical laser tracks from the central laser facility,” GAP Note 2006-067.
- <http://www.physics.rutgers.edu/hex/HIRES.html> (GZK cutoff information)
- R. Abbasi, et.al.: “Techniques for measuring atmospheric aerosols at the high resolution fly’s eye experiment,” Astroparticle Physics 25 (2006) 74-83