Aerosol Characteristics at VERITAS

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VERITAS

Fred Lawrence Whipple Observatory (FLWO) in southern Arizona, USA

Spec's pre upgrade

- **energy range:** 100 GeV to >30 TeV (spectral reconstruction starts at 150 GeV)
- **energy resolution:** 15% at 1 TeV
- **peak effective area:** 100,000 m2 (compare to Fermi-LAT)
- **angular resolution:** 0.1 deg at 1 TeV, 0.14 deg at 200 GeV (68% containment radius)
- **source location accuracy:** 50 arcseconds
- **point source sensitivity (with new array configuration as of summer 2009):** 1% Crab in < 30h, 10% in 30 min
- **observation time per year:** ~750 hours non-moonlight, ~200 hours moonlight. Typically 70-100 hours total per month over 10 months

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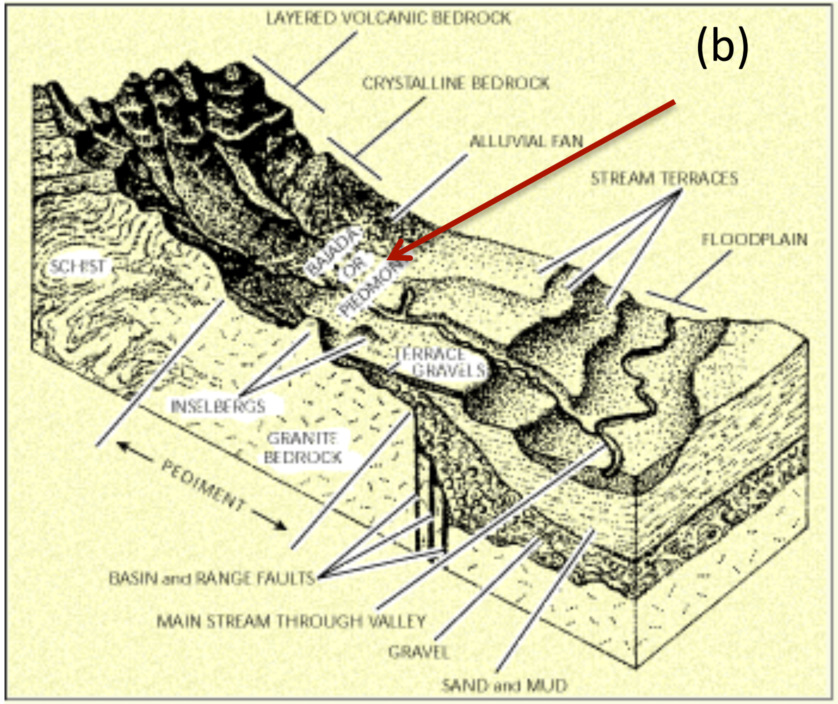
VERITAS site – F.L. Whipple administrative complex
1268m a.s.l., 31 40' 30.21 N, 110 57' 07.77" W

Where desert dust originates

(a)

(a) = MMT ; (b) = example of telescope location



Typical Sonoran Desert landforms

The Sonoran desert is interspersed with large alluvial planes, formed by rain water carrying debris from higher altitude locations and depositing downstream, forming large valleys areas. In short, fine grain particulate material abounds in the valleys.

Courtesy of DesertMuseum.

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Vaisala CL51 ceilometer

What's good about our CL51

- 24hr operation
- 905nm-sensitive to H_2O droplets & outside of Cherenkov range
- Cloud algorithm h_{max} = 13km; Boundary Layer software displays up to 4km
- No overlap
- 10m height binning (corrected)
- Narrow beam divergence; 0.15 x 0.25 mRad (0.017^o x 0.029^o)

What need to be considered

- Low signal to noise ratio (SNR)
- Low maximum reliable range (MRR). Range at which backscatter (a.u.) first dips below 0.
- InGaAs relatively broad line width laser; complicates background suppression, though good.
- Laser power 1.6μJ (+/- 20%) $pulse^{-1}$, 65kHz
  Power (avg) = 104mW at 905nm.

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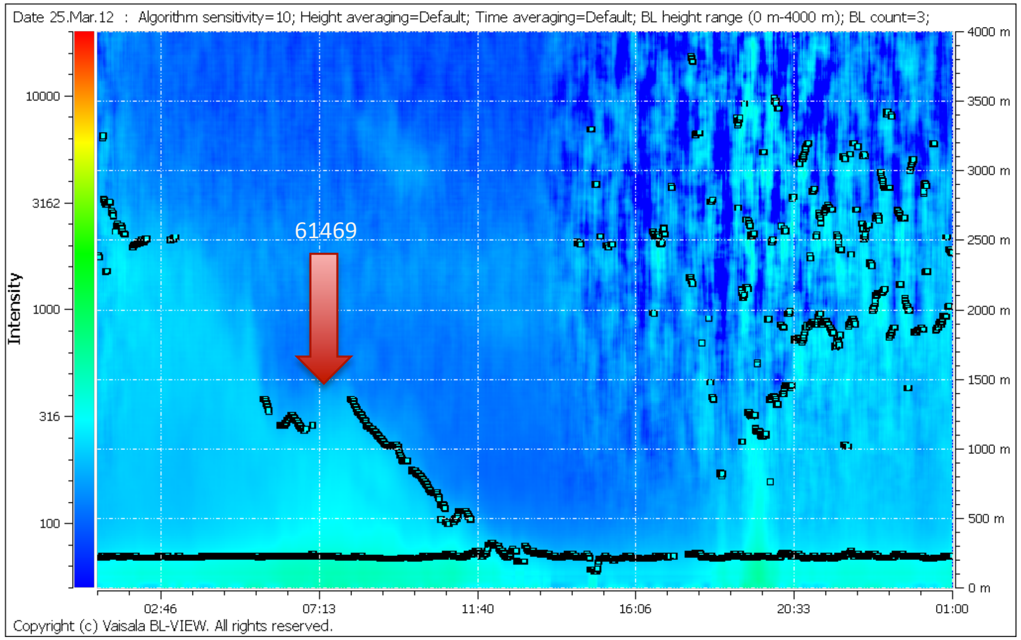
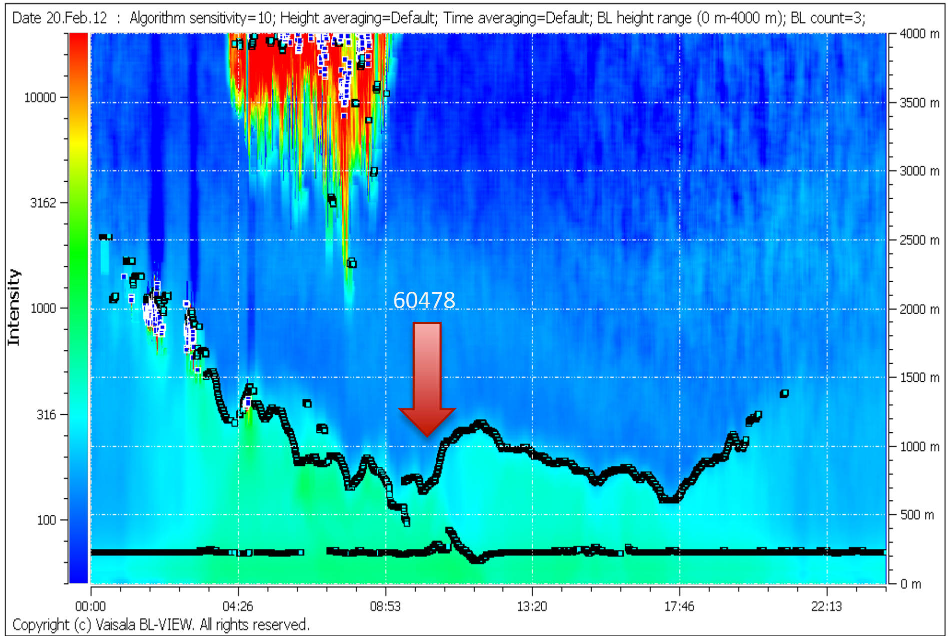
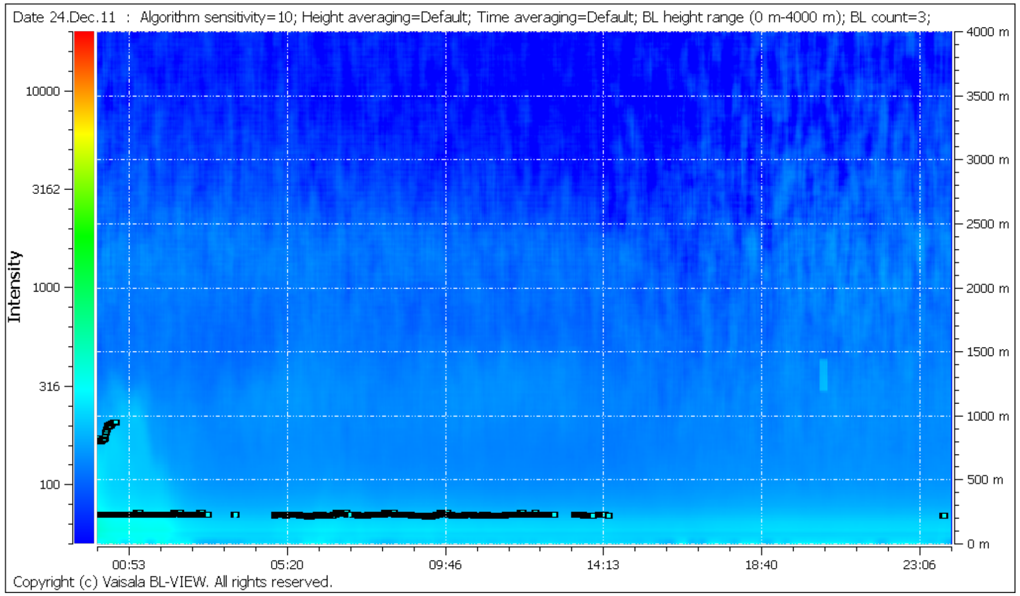
BL view plots - height bin = 320m, time bin = 30min, sensitivity = nom.

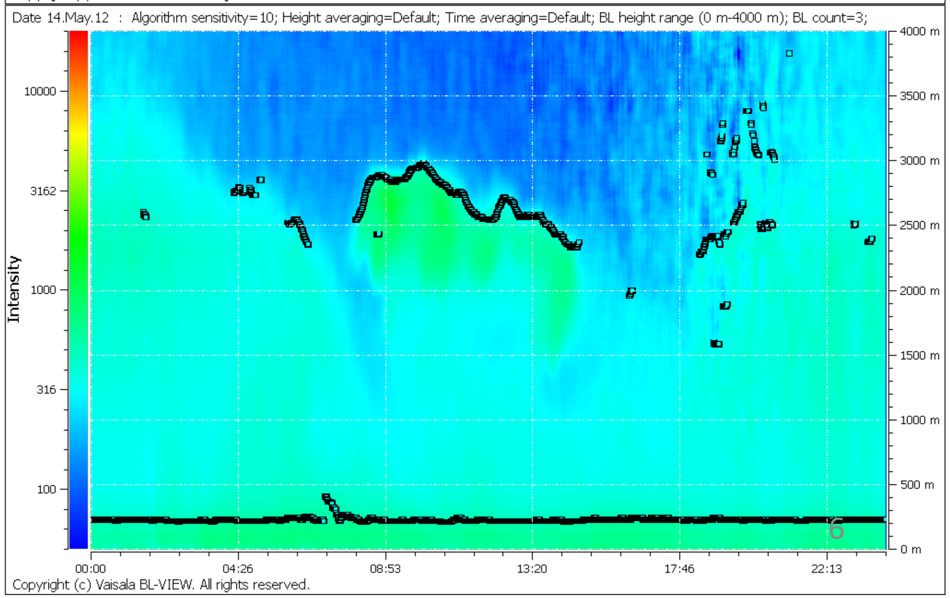
24th Dec 2011, 14th May 2012, 25th March 2012, 20th Feb 2012

Temporal Development of Aerosol Layer – 24hr duration









***MODTRAN 5** – preliminaries to fitting a model atmosphere – Raisôn d'Étre of research*

- For the purpose of assigning aerosol models, the atmosphere was first divided into vertical regions (a.s.l.):
- the boundary layer (1.5 – 3 km),
- the free troposphere (background troposphere) (3 - 8 km),
- the lower stratosphere (8 - 17 km)

(This, however, will have to be changed) →

Normally the surface dust layer extends 2km above sea level. At VERITAS site this extended ~ 4-5km a.s.l.

For the presented data, the following criteria applied…

1. 4 telescope only,
2. multiplicity = 2,
3. zenith angle < 50^{o},
4. CFD threshold of PMT's nominal,
5. no moonlight.

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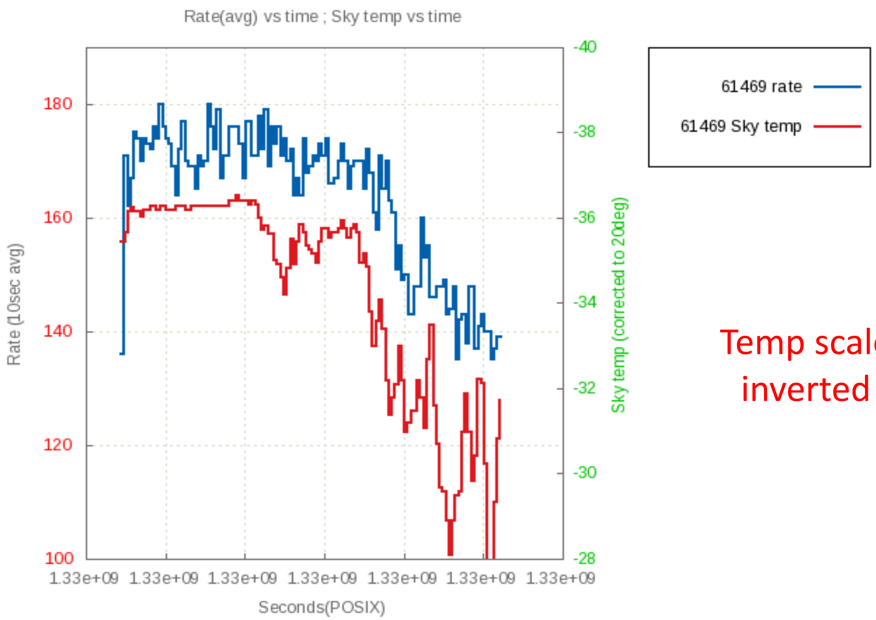
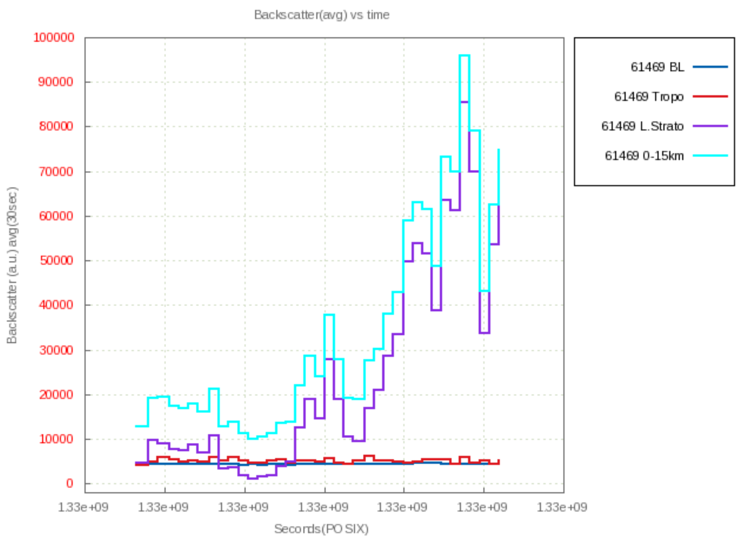
High Elevation runs 1ES1218 – 61469 (2012-03-25 07:06UTC)

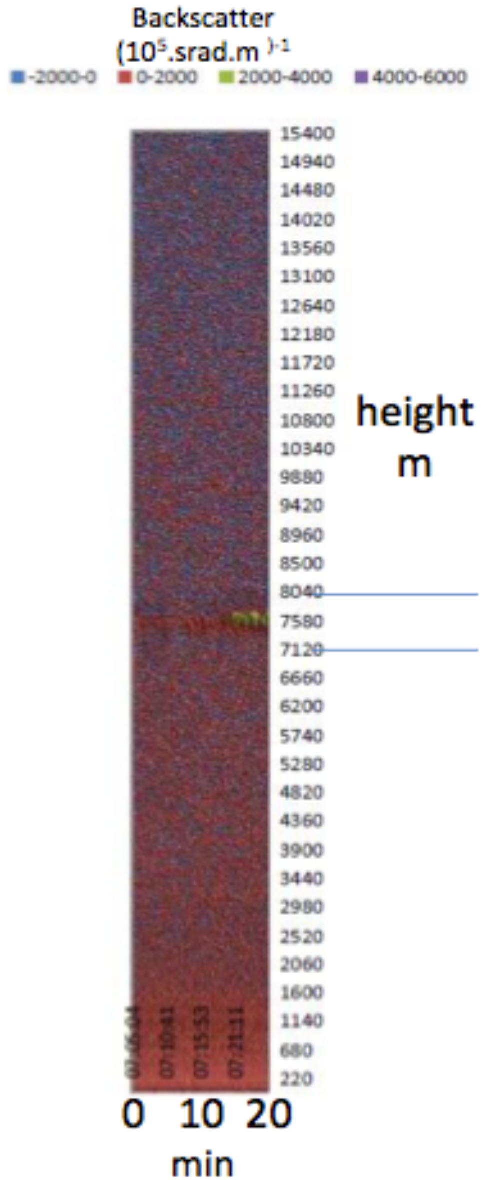
Elev = 86°, wob = 0.58°W, Tel's = T1-4, live = 93%, events = 197k

Temporal Development of Aerosol Layer – 20min duration



Temp scale inverted





FIR ambient temp corrected (20°C)
No zenith correction to data

FIR2 camera:
Heitronics KT15.82D
8-14 µm
100 to 100 °C

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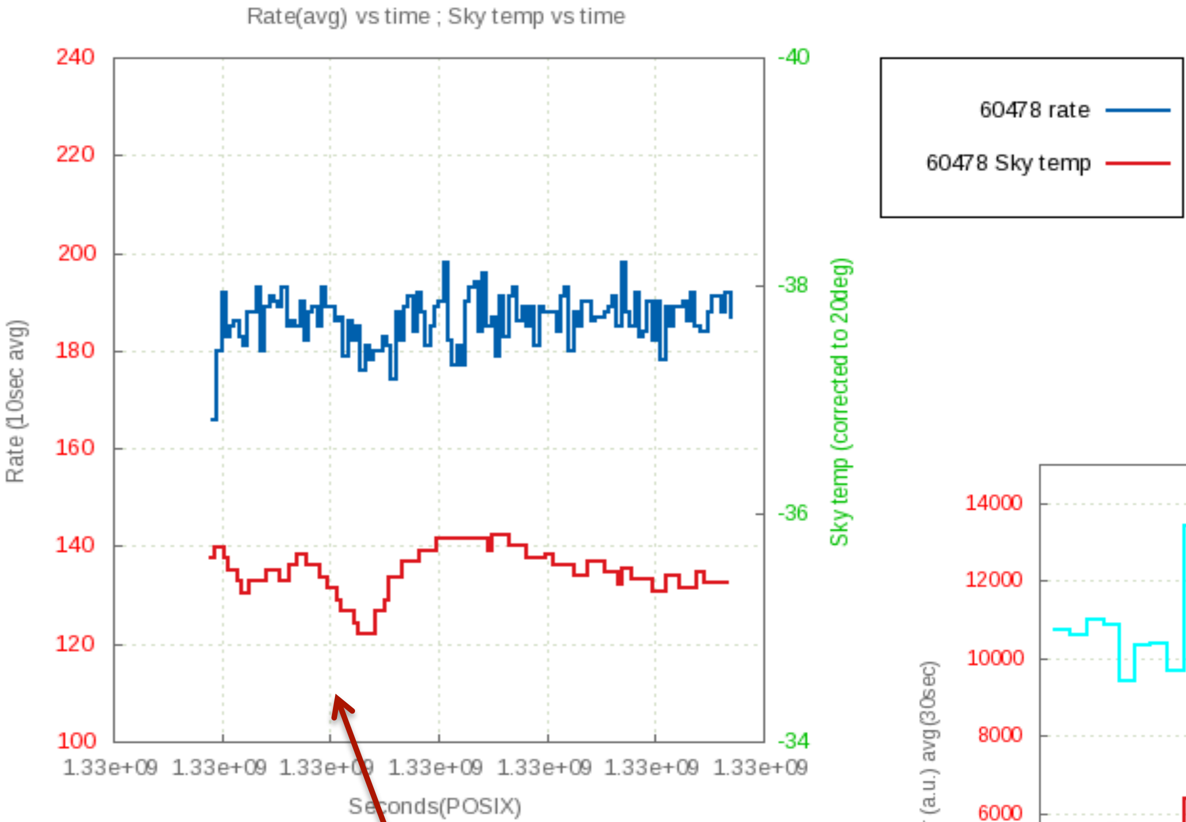
High Elevation runs 1ES1218 – 60478 (2012-02-20 09:18UTC)

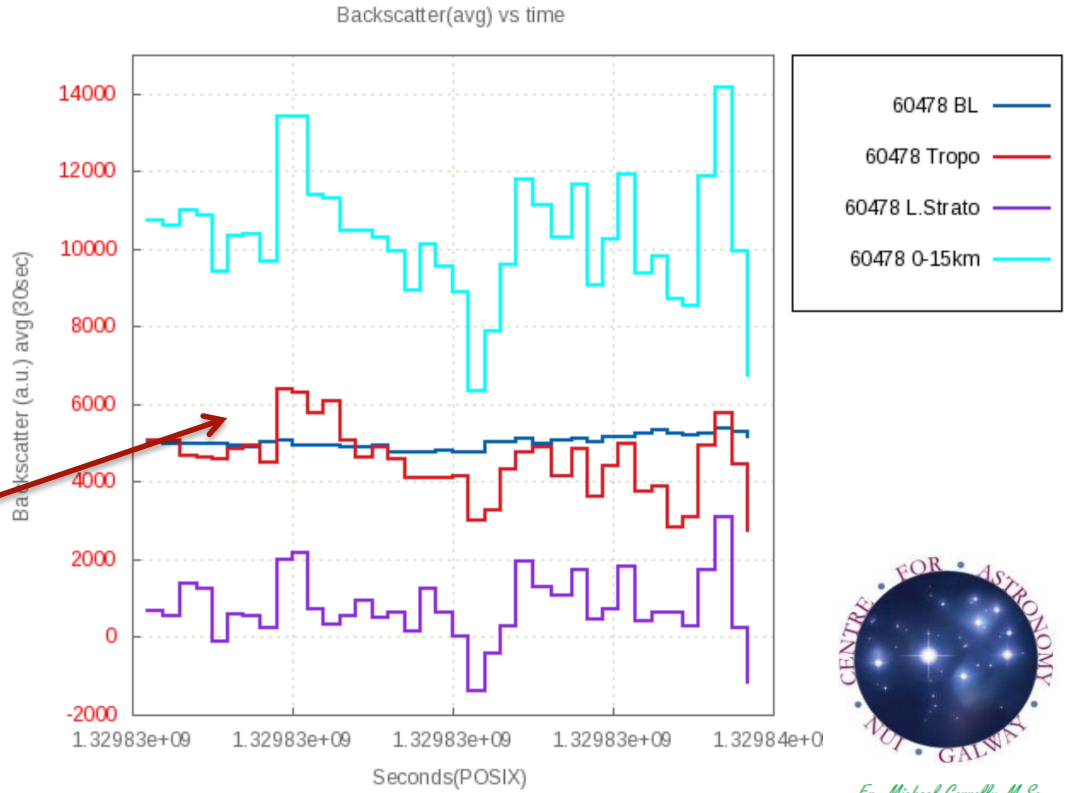
Elev = 85º, wob = 0.50ºS, Tel's = T1-4, live = 92%, events = 224k

Temporal Development of Aerosol Layer – 20min duration



Run included to show example of resolution in aerosol detection.

Temporal development of Lower Strato backscatter follows from Troposphere



Small passing cloud at 4km height

FIR ambient temp corrected (20ºC)
No zenith correction to data

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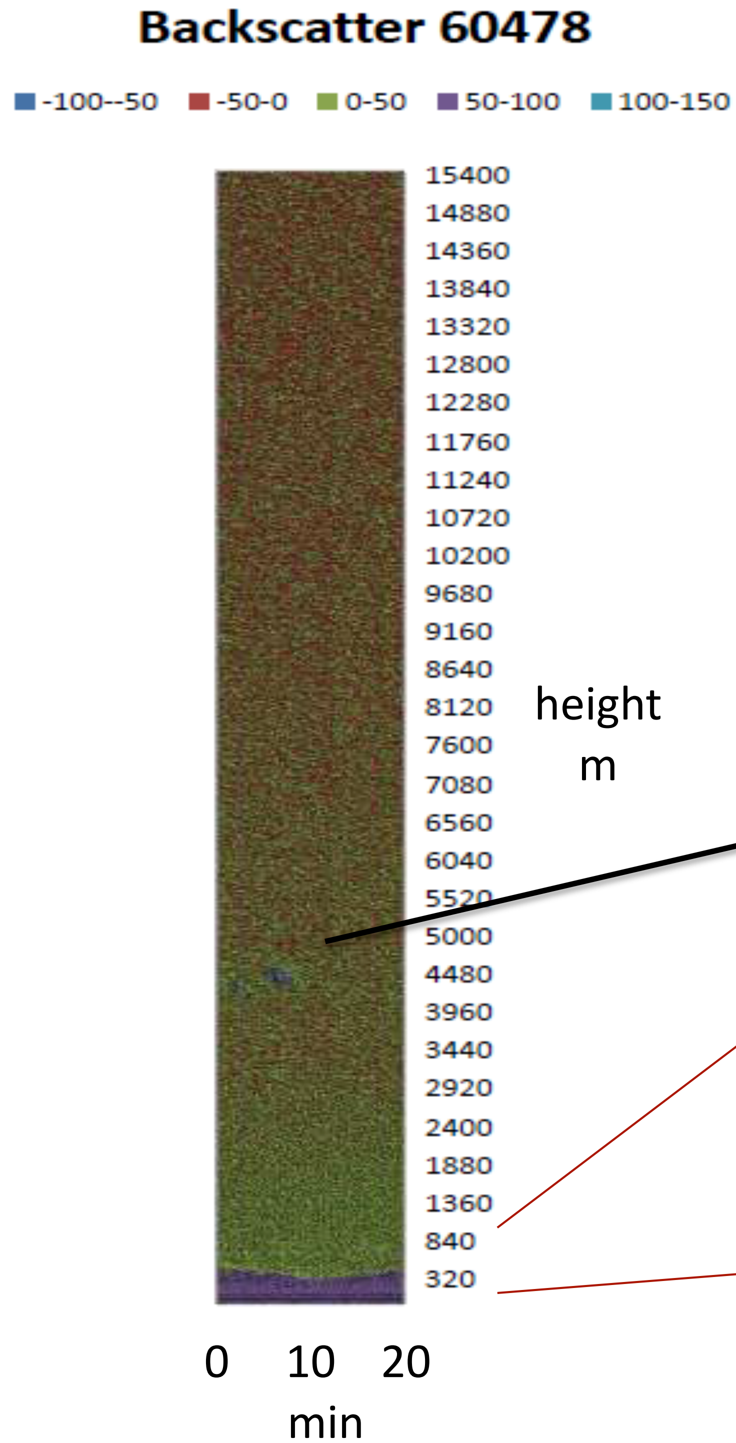
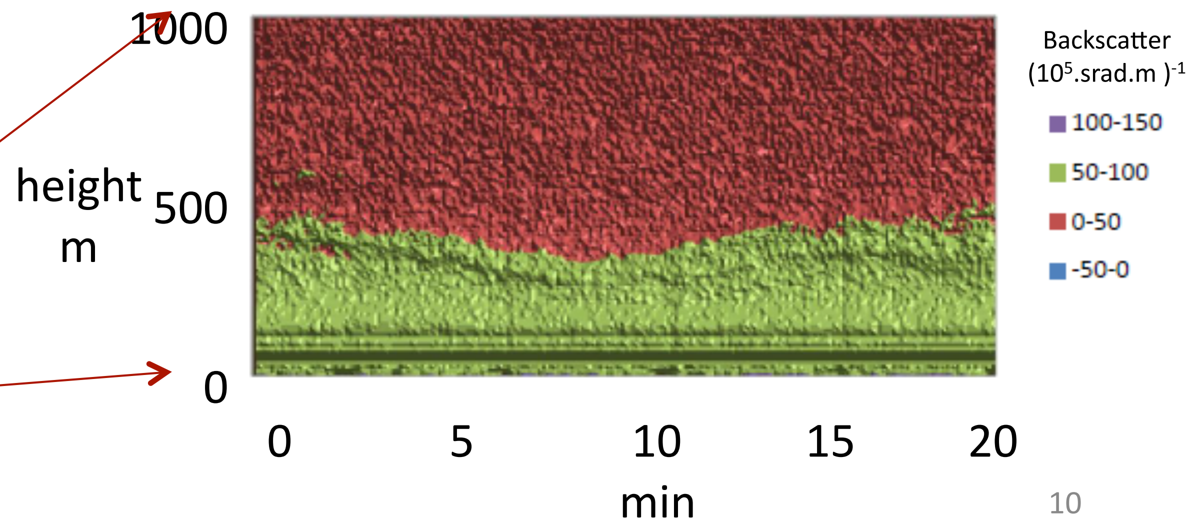


Plots from Tucson presentation (June 2012)

Horizontal plot resolution→ ceilometer 'shot' every 6 sec. Verticle plot resolution → 10m.
Matrix contains ((1200/6) * 1540) elements = 3.1e5.
Backscatter plot for 60478 reveals a clear aerosol layer from 300-400m above basecamp; expanded plot below shows first 1000m.
Passing aerosol at 4km recorded.
Parallel lines close to ground - possibly due to the inability of the ceilometer to resolve h<100m?

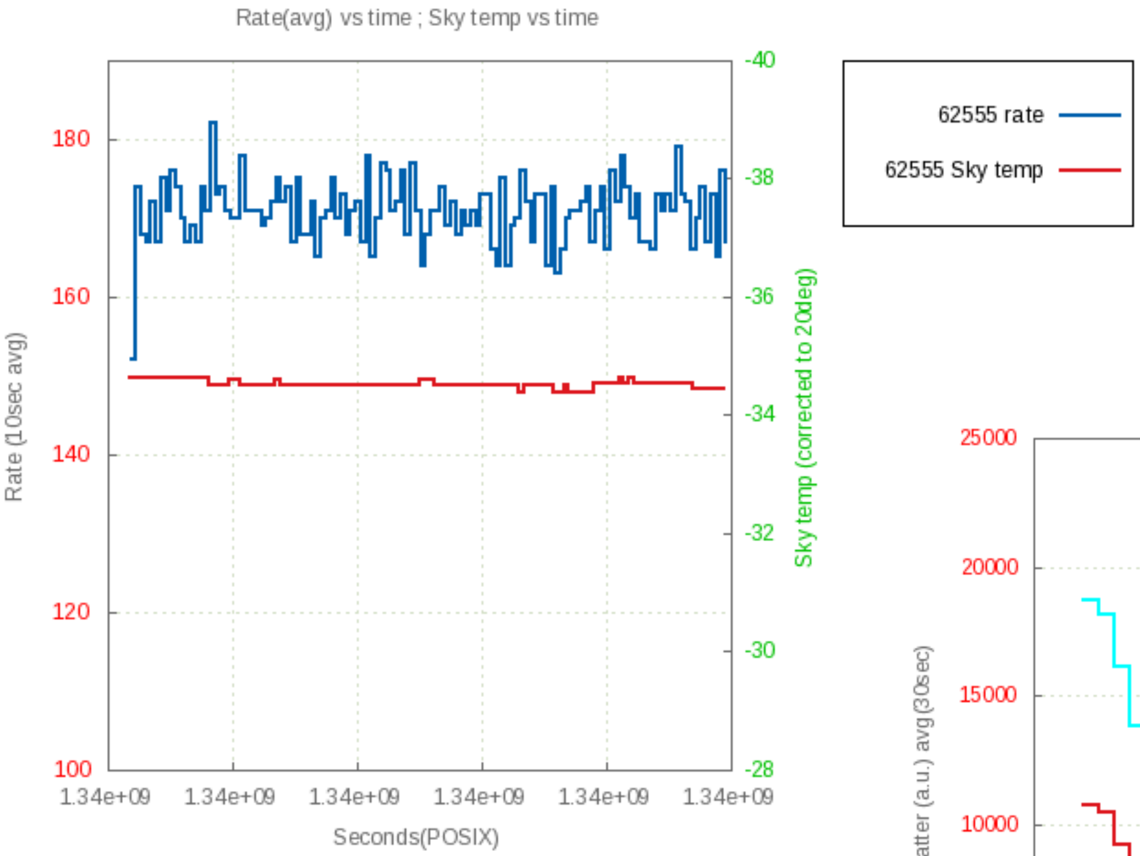
Faint shadow in high-res plot reveals diffuse aerosol concentration that caused L3 dip, recorded by the FIR's.

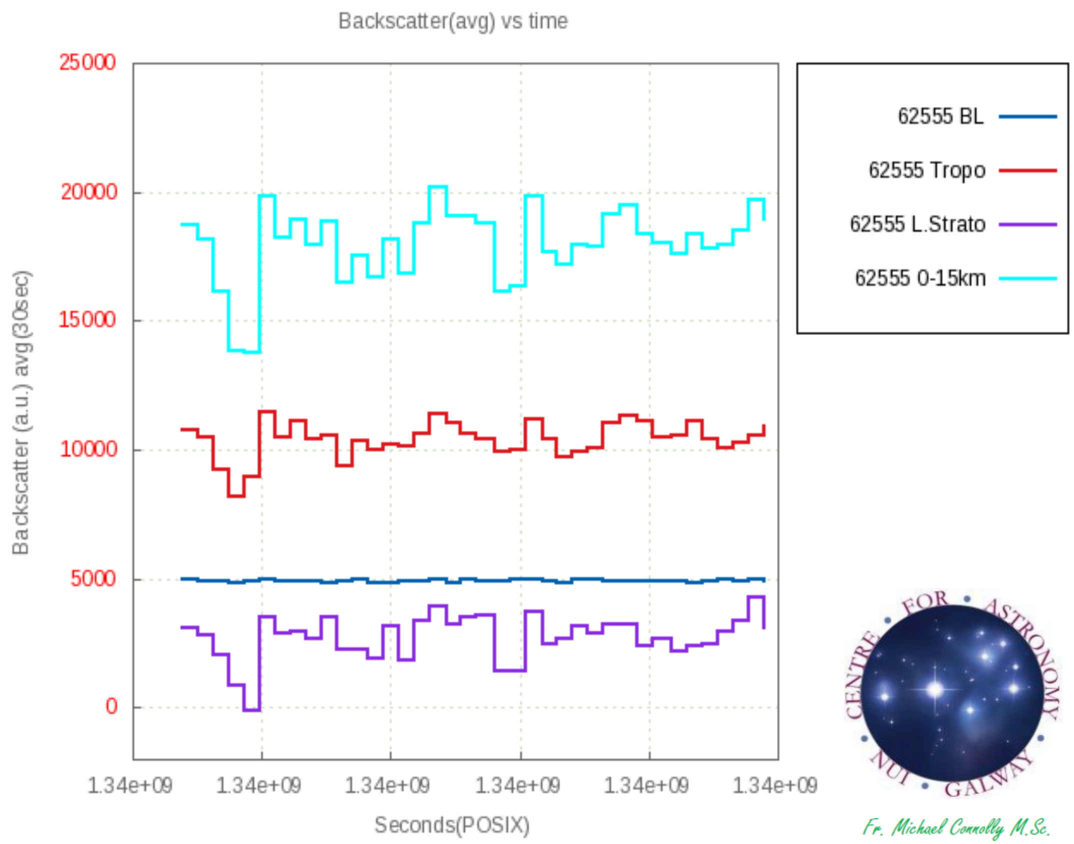


High Elevation runs 1ES1218 – 62555 (2012-05-16 04:13UTC)

Elev = 87°, wob = 0.50°N, Tel's = T1-4, live = 93%, events = 206k

Temporal Development of Aerosol Layer – 20min duration





FIR ambient temp corrected (20°C)
No zenith correction to data

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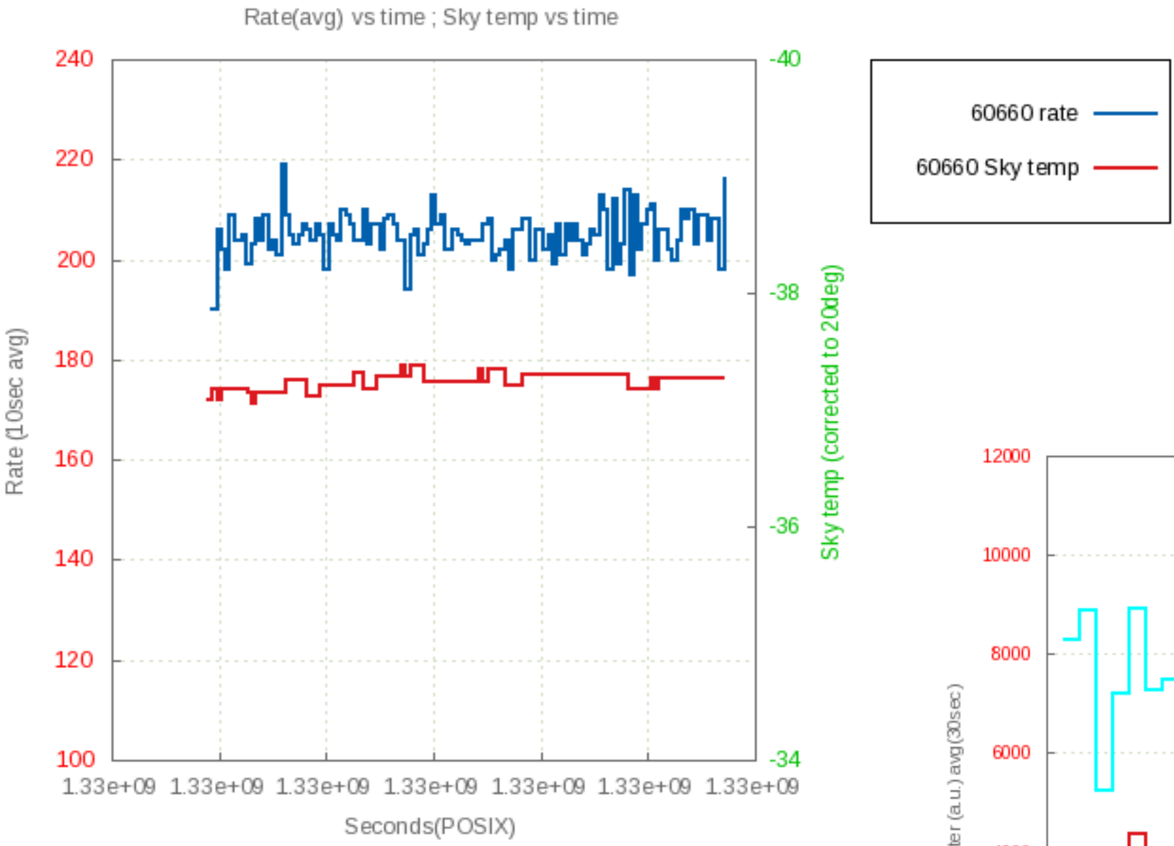
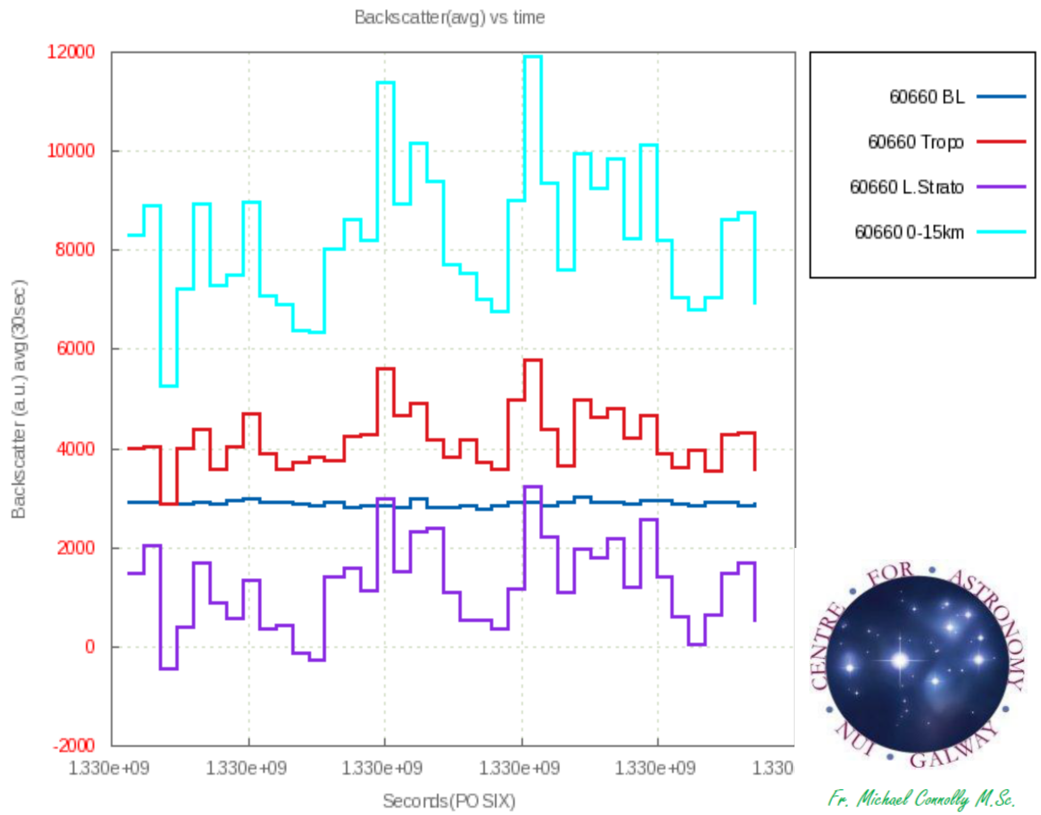
High Elevation runs 1ES1218 – 60660 (2012-02-26 09:24UTC)
Elev = 87°, wob = 0.50°N, Tel's = T1-4, live = 93%, events = 206k
Temporal Development of Aerosol Layer – 20min duration





FIR ambient temp corrected (20°C)
No zenith correction to data

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Preliminary findings from high elevation runs

Run #	BL	Tropo	L Straro	FIR °C	L3 rate	Cloud	Δ T °C	Δ L3
61469	5k	5k	5(+/-2)k	- 36	170	Yes	6.0 (17%)	30 (18%)
60478	5k	4(+/-2)k	1(+/-)2k	-35.5	190	Yes	0.7 (2%)	10(5%)
62555	5k	10k	3(+/-1)k	-34.5	170	No	---	---
60660	3k	4(+/-1)k	1(+/-1)k	-37.5	205	No	---	---

First Observations:

•FIR2 camera more sensitive to changes in water at altitude than desert dust.

•L3 rate good indicator of dust.

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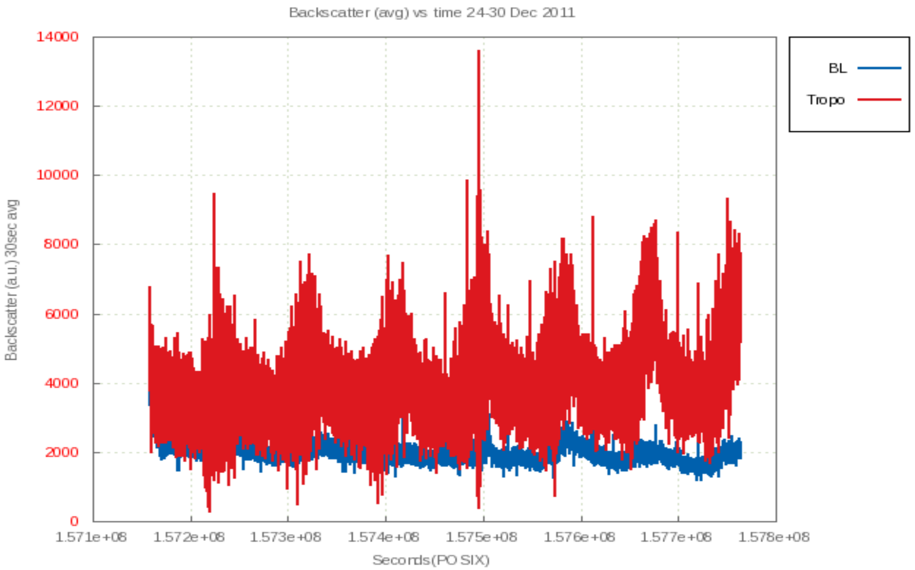
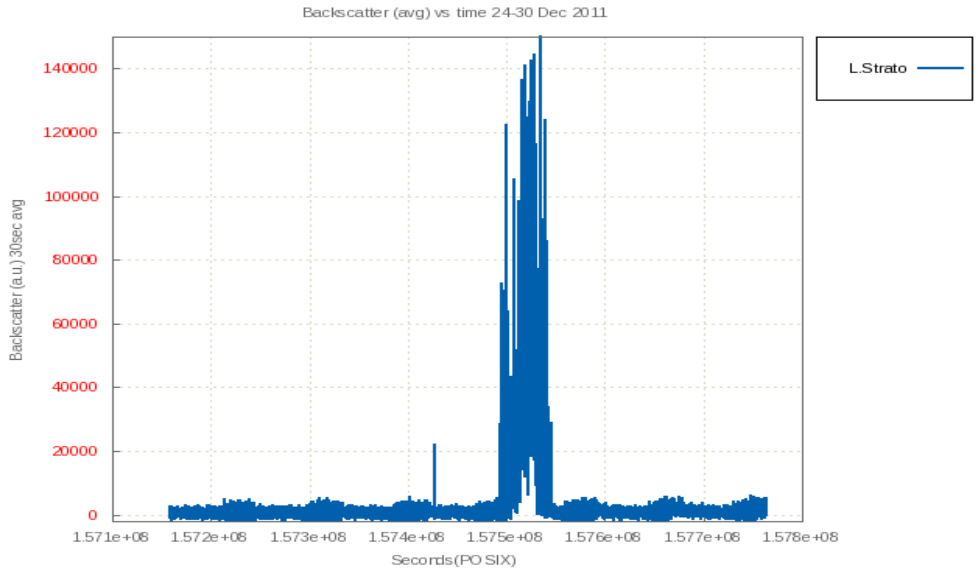
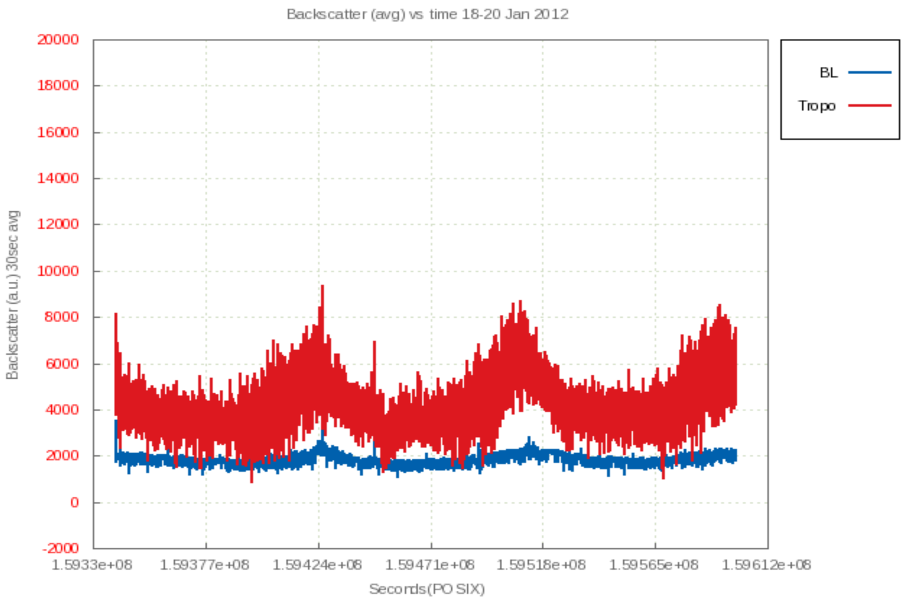
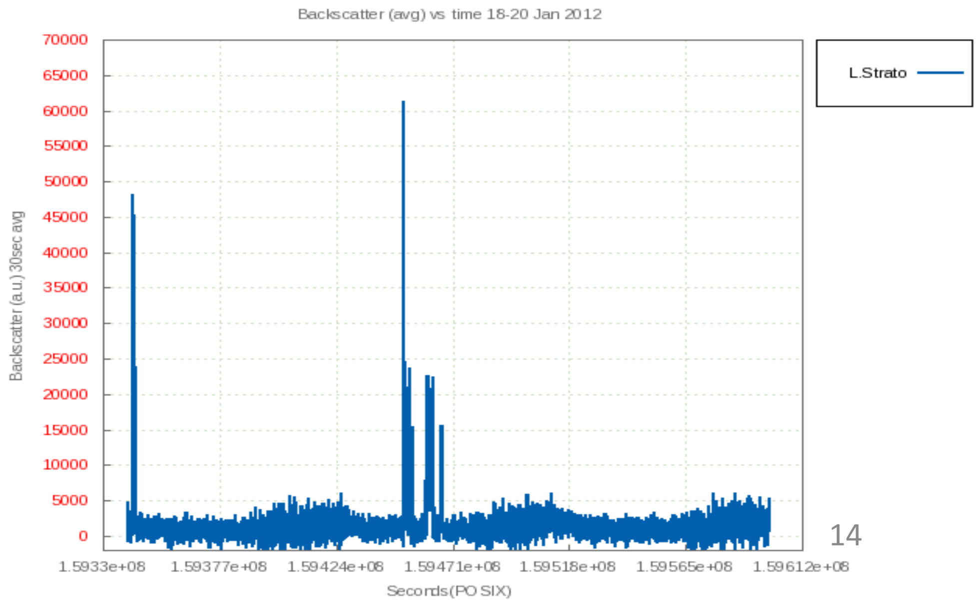
Ceilometer Backscatter continuous (0-1.5km, 1.5-6.5km, 6.5-15km) 24-30 Dec 2011, 18-20 Jan 2012. Temporal resolution /6sec.

Temporal Development of Aerosol Layer – 7 day and 3 day duration

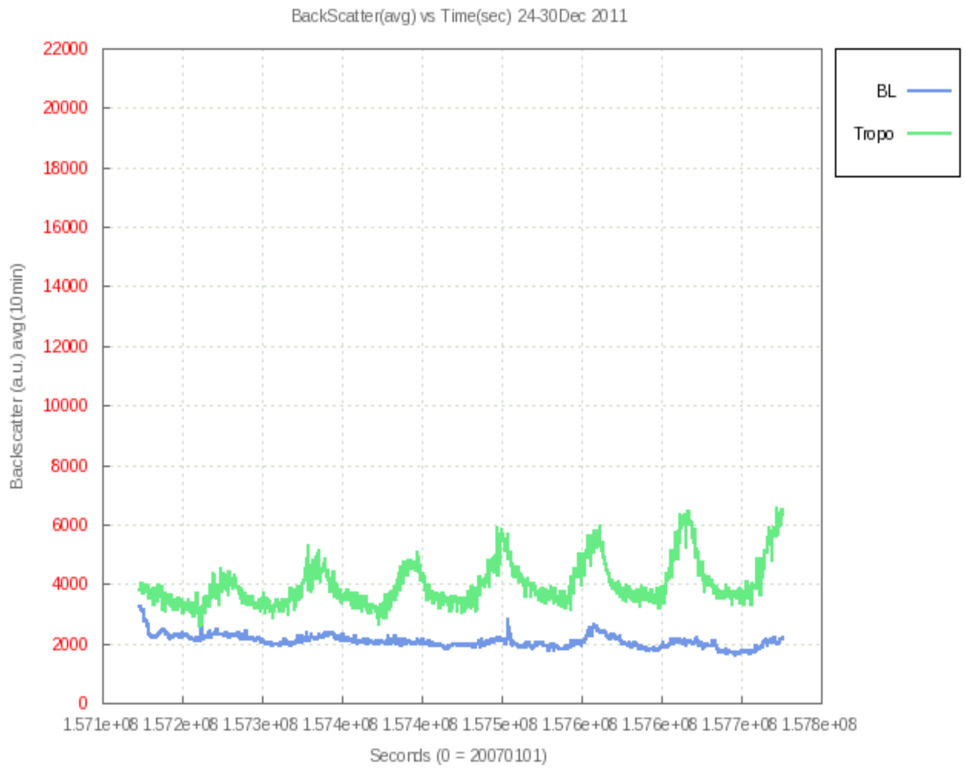


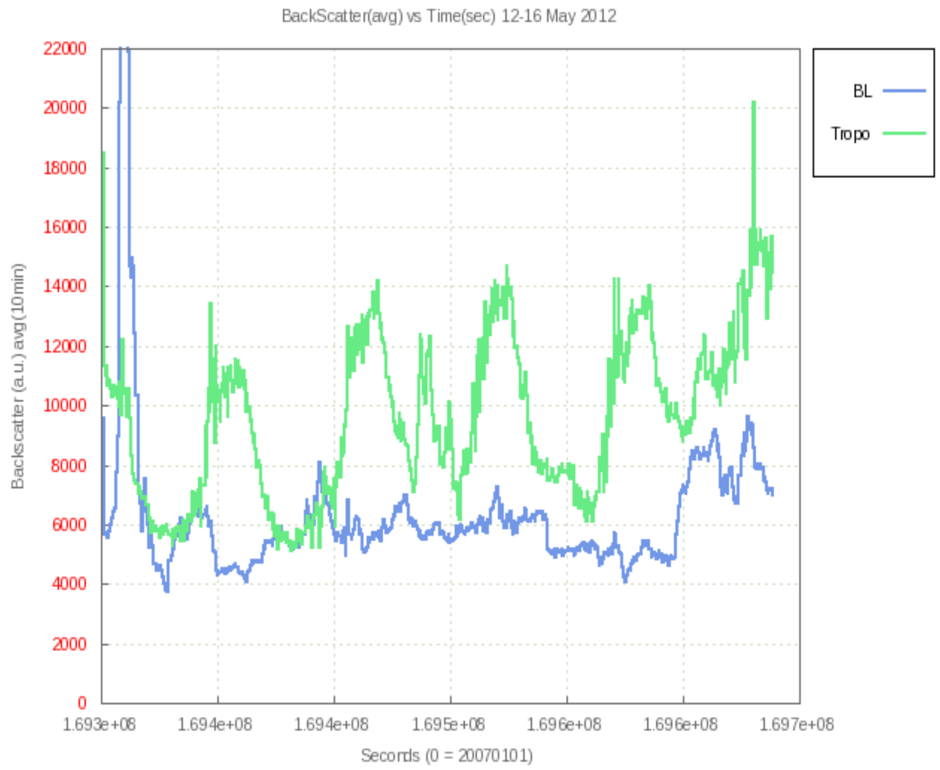






Time averaged Backscatter 24-30 Dec 2011 and 12-16 May 2012
0-1.5km, 1.5-6.5km





10 min averaging makes diurnal effect evident in higher elevations,. Very stable lower atmosphere.

Quite amount of dust turbulence.
Note spike in BL dust beginning 12 May,
Possibly due to smoke.
Diurnal effect erratic.

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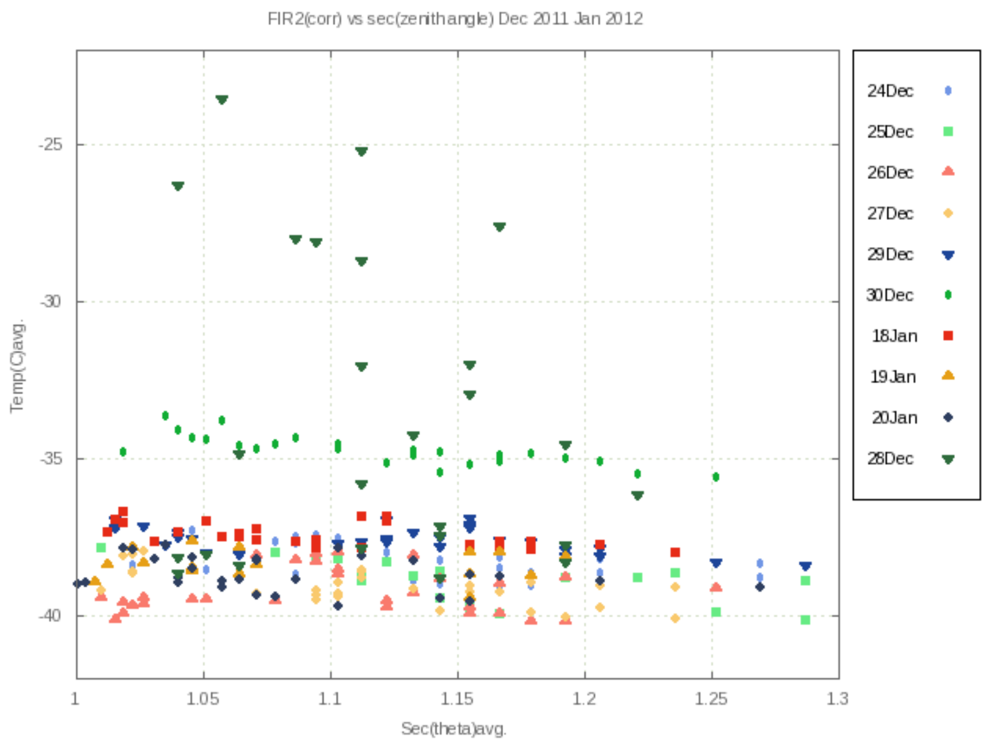
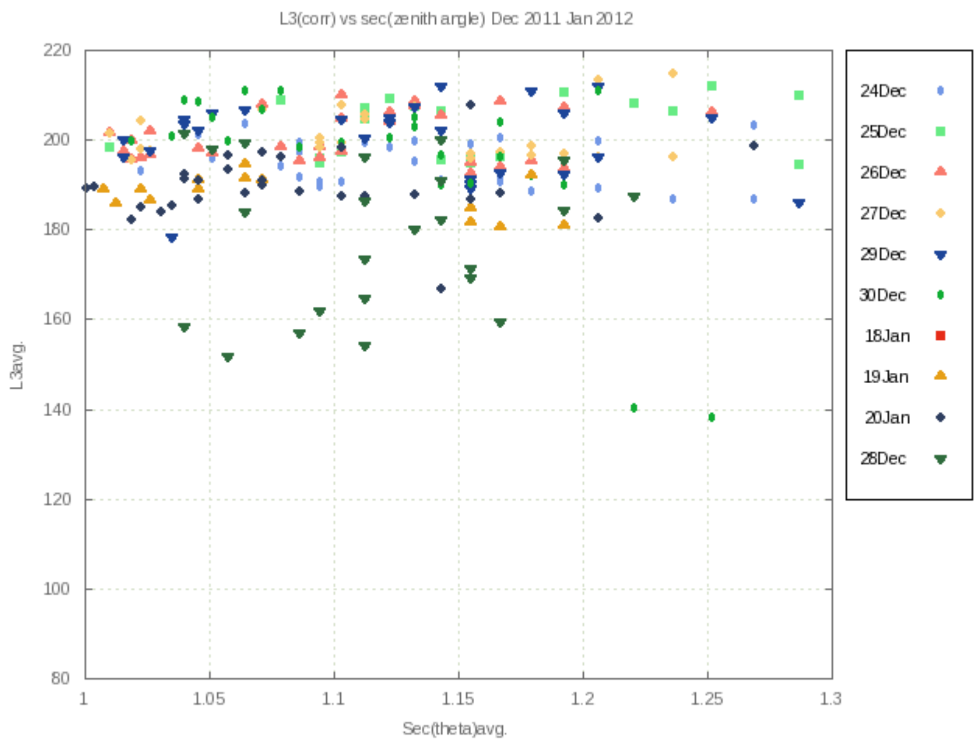
FIR2(corr) and L3(corr) for ~320 runs (~95Hrs)
24-30 Dec 2011, 18-20 Jan 2012 – Low Desert Dust





All data elevation averaged, temperature averaged, rate averaged for duration of run (1200 sec).
L3 rate zenith angle corrected
FIR temps zenith angle corrected and ambient temp corrected (20°C).

Mean L3
185 to 210 Hz
Mean Sky temp
-40 to -37 °C

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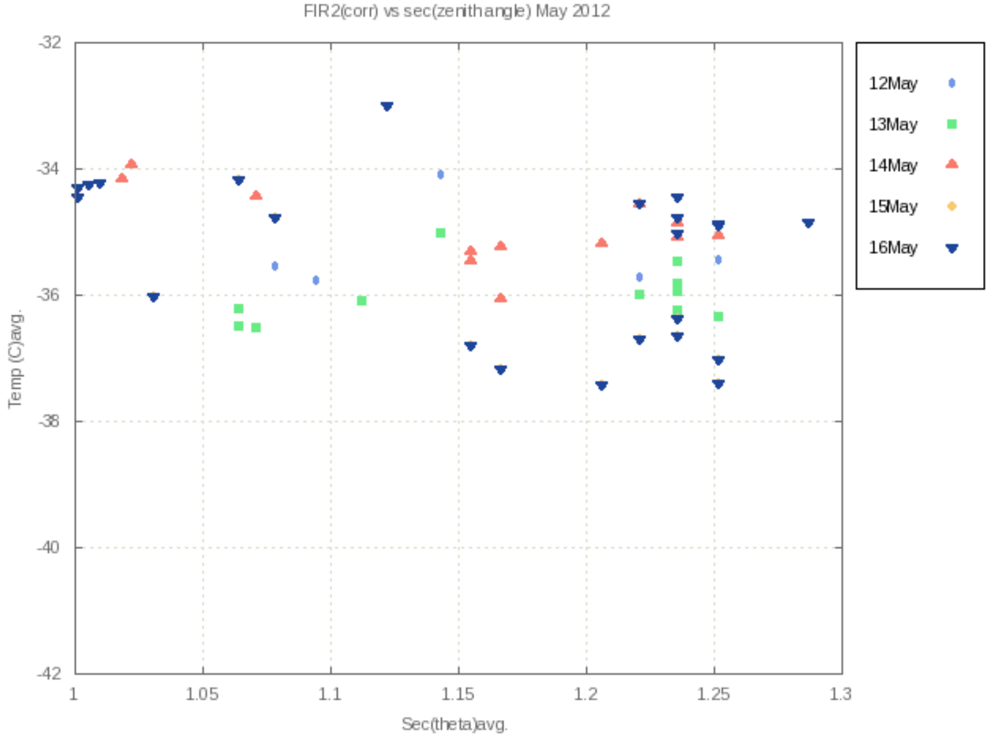
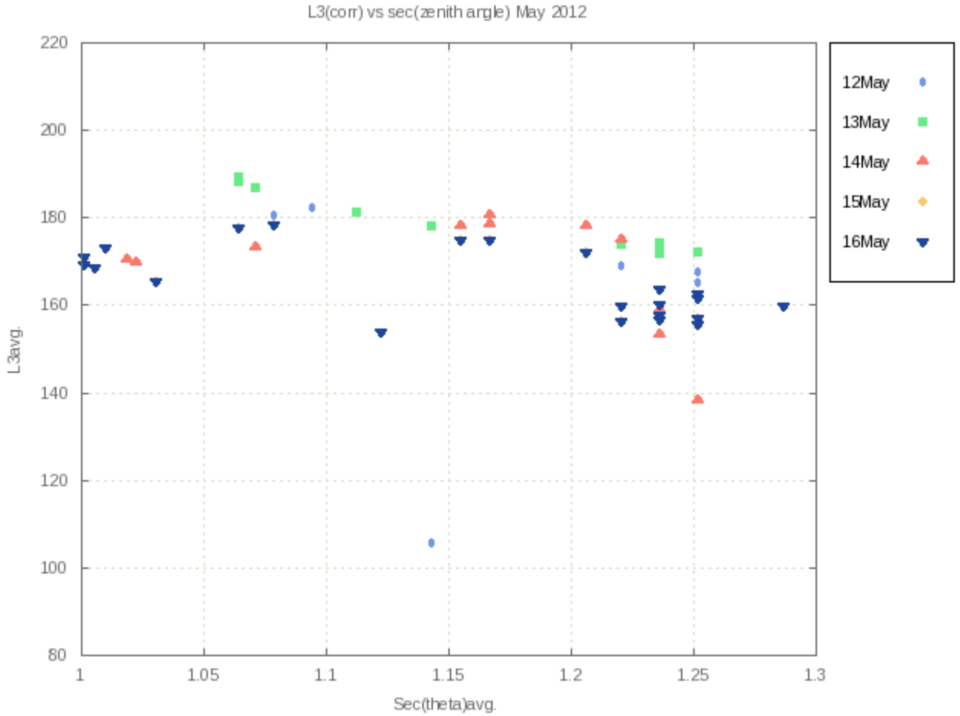
FIR2(corr) and L3(corr) for ~69 runs (~23Hrs)
12-16 May 2012 – High Desert Dust





All data elevation averaged, temperature averaged, rate averaged for duration of run (1200 sec).
L3 rate zenith angle corrected
FIR temps zenith angle corrected and ambient temp corrected (20^{o}C).

Note: Fewer runs due to presence of moon during aerosol episode.

Mean L3
160 to 185 Hz
Mean Sky temp
-37 to -34 ^{o}C

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Preliminary findings –high/low dust aerosol runs

FIR cameras are sensitive to boundary layer (0-3km) and Tropospheric (3-10km) desert dust. There is possible sensitivity to NSB.

Hence the FIR cameras will require

1. zenith angle correction,
2. ambient temperature correction,
3. Possible NSB correction (noted temp change at moon rising/setting)
4. Desert dust level correction (zenith angle dependant)
5. Humidity profile correction (from radiosonde)
6. Absolute temp calibration of FIR2 and FIR3

to maximise sensitivity to water vapour for cloud modeling. The ceilometer can determine cloud height and possibly cloud thickness. Radiosonde data matched.

L3 rates are more sensitive to desert dust than FIR cameras. Hence one recommends

1. zenith angle correction ,
2. NSB correction (uv and optical(?))
3. Desert dust level correction (only if wish to profile cloud layer)

With these FoV instruments, and zenith pointing ceilometer, modeling
of BL, Troposphere and Lower Stratosphere may begin by matching
Data with MODTRAN models…

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Need to measure NSB_{uv}

As shown previously,

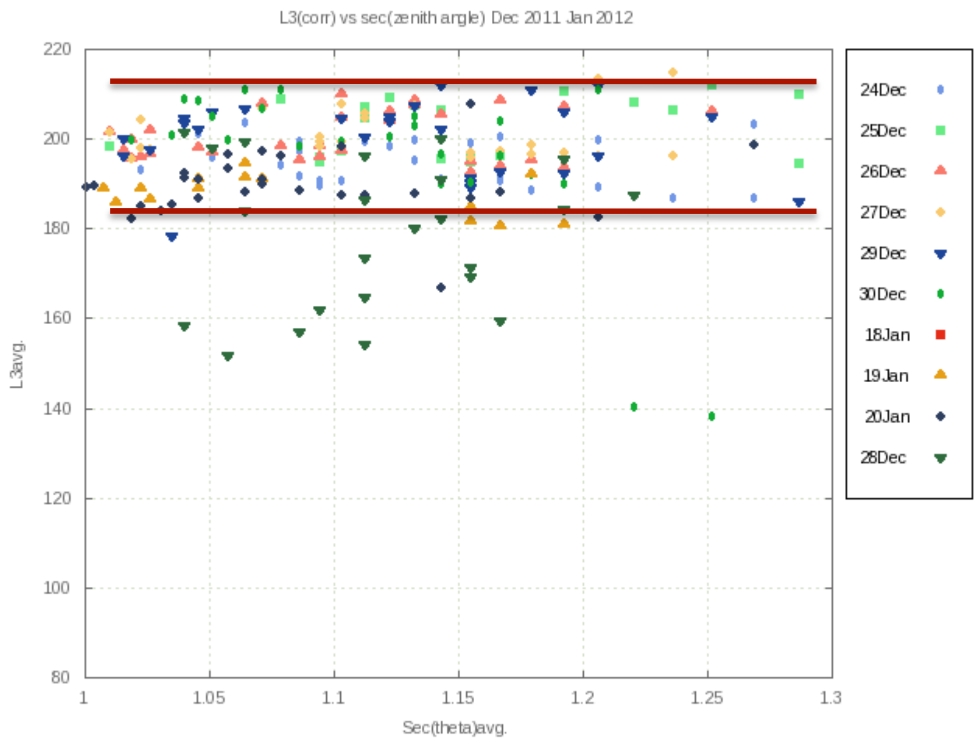
L3 correction for zenith angle 0-50°. A broad band of L3 counts hints at another parameter to correct for.

$L3_{min}$ - $L3_{max}$ ≈ 185 – 215 Hz

How to calculate NSB_{uv} for 300, 450 and 600 nm? Possibly using the PMT I_{avg}? Possibly building photo detector at these freq's?

Could the pointing monitors be used, necessitating integration of CCD charge in FoV?

300nm important frequency to measure, Ozone absorption.



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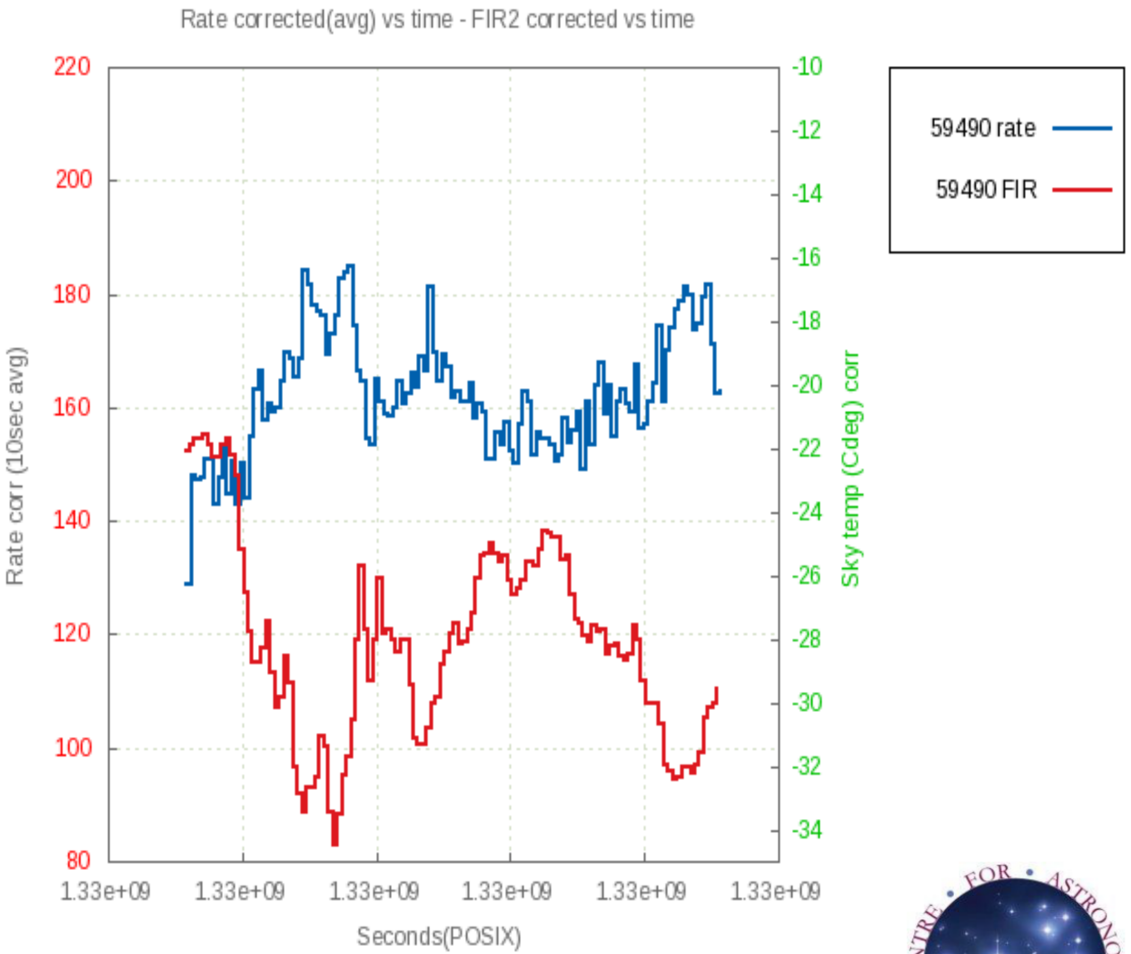
Passing cloud on 28th December 2011
run 59490, 06:26UTC, elev.(avg) = 66°, wob = 0.5°S, L3(avg) = 152
Temporal Development of Aerosol Layer – 20min duration

Run chosen due to low aerosol content below passing cloud

Cloud height at (8.8 -9) km

Time	Δ T	Δ L3
0-340	- 13°C	+ 45
340-440	+8°C	- 30
440-540	-5°C	+ 25
540-840	+6°C	- 25
840-1100	-8°C	+ 30



FIR2 corrected for ambient 20°C, and zenith angle
L3 rate corrected for zenith angle alone

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Passing cloud on 28th December 2011

run 59491, 06:47UTC, elev.(avg) = 70°, wob = 0.5°E, L3(avg) = 174

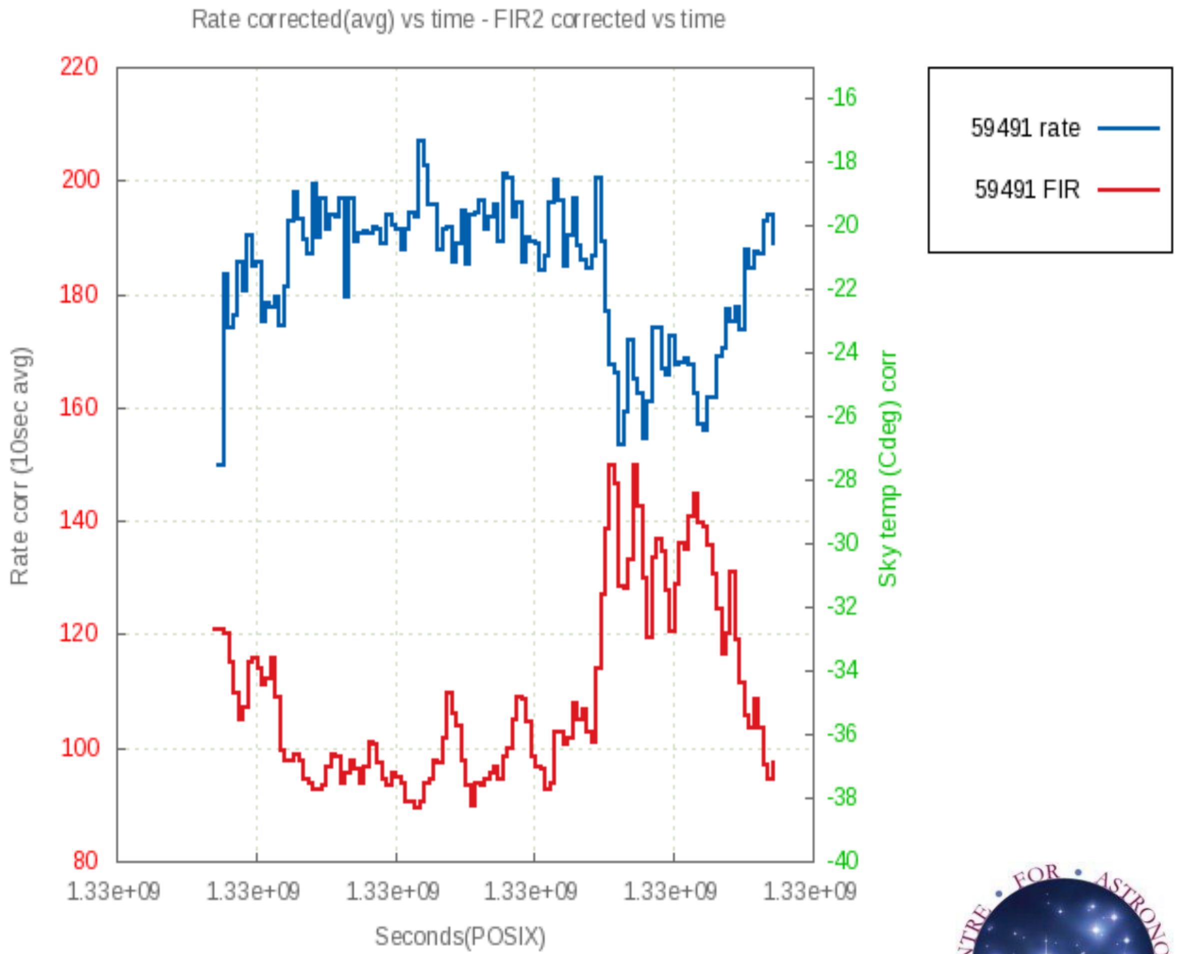
Temporal Development of Aerosol Layer – 20min duration

Cloud height at (8.8 -9) km

Time	Δ T	Δ L3
0-560	- 6°C	+ 25
560-820	0(+/-1) °C	0(+/-10)
820-910	+ 9°C	- 45
910-1010	0(+/-)4°C	-?
1010-1200	-8°C	+ 30

This plot raises questions of
- Time binning - 10 sec or 30 sec
- Curve fitting – can straight line approximations suffice Δ T, Δ L3.

FIR2 corrected for ambient 20°C, and zenith angle
L3 rate corrected for zenith angle alone



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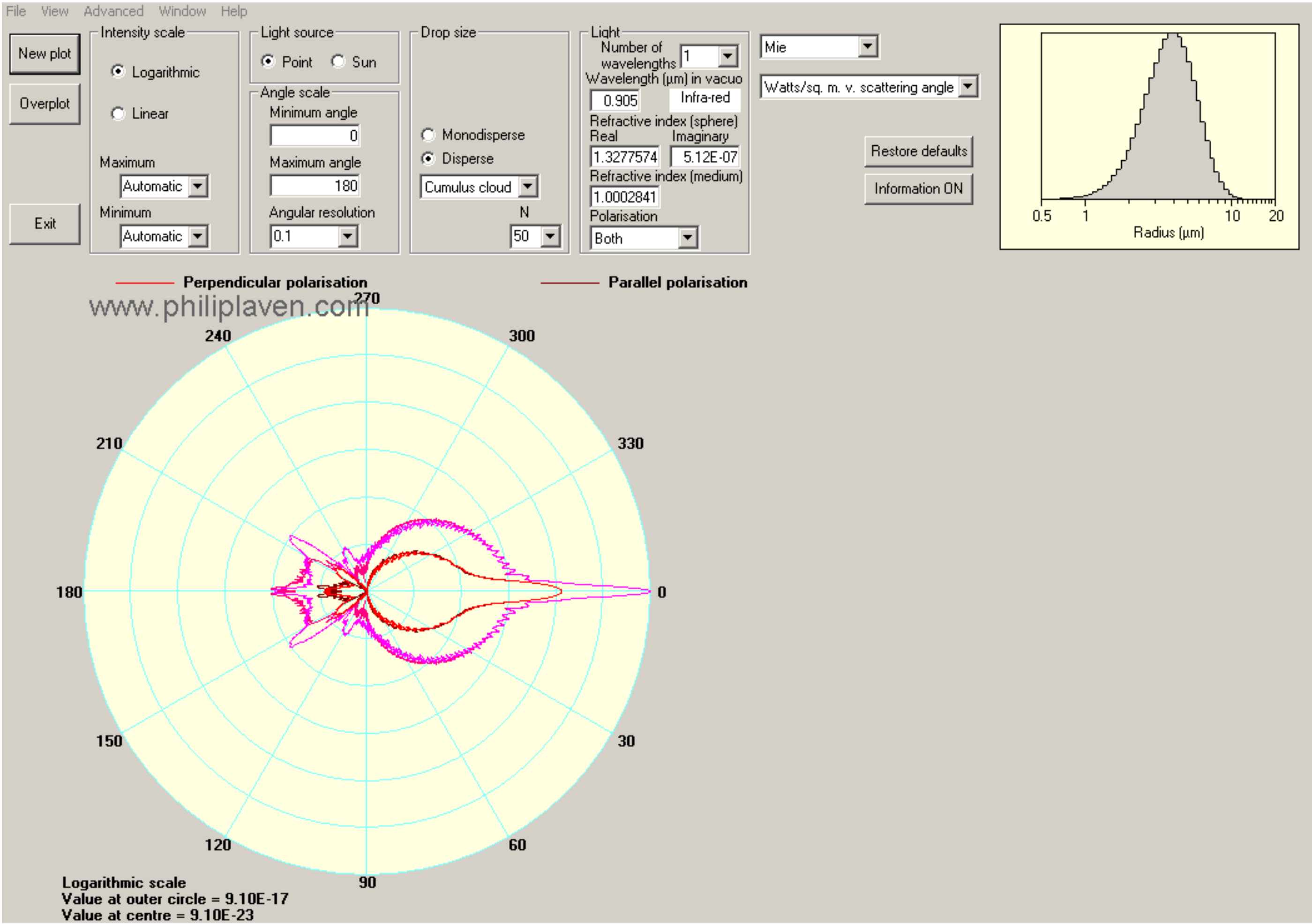
Mie scattering due to water vapour at 10km
(Cumulus cloud size distribution)

Pink = 300 nm
Red = 905nm

Water droplets
5µm
Normal distribution

Ceilometers intensity at 10km

0.0277 Wm^{-2}



Code source:
Bohren and Huffman, *Absorption and Scattering of Light by small particles* (2007).
BHMIE code

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Refractive index studies of desert dust

- To date, have not found definitive study of optical properties of dust in Southern Arizona; they should exist.
- Many have used the refractive index of Saharan dust (1.53 + 0.003i)
- The dust refractive indices (mainly the imaginary part) are highly dependent on the mineral components of dust, which will affect the dust absorptivity..
- There are large variations in the dust refractive index. The imaginary part of this index, ni, recommended by the WMO (World Meteorological Organisation) in 1983 for Sahara was 0.008. For the Saharan dust, ni, is now estimated to be in the range of 0.0054–0.0066 at 360 nm and about 0.0025 at 440 nm (Dubovik et al., 2002).

- See Balkanski et al., 2007; McConnell et al., 2010; Zhao et al., 2011

for imaginary part of refractive index

Mie Scattering due to desert dust

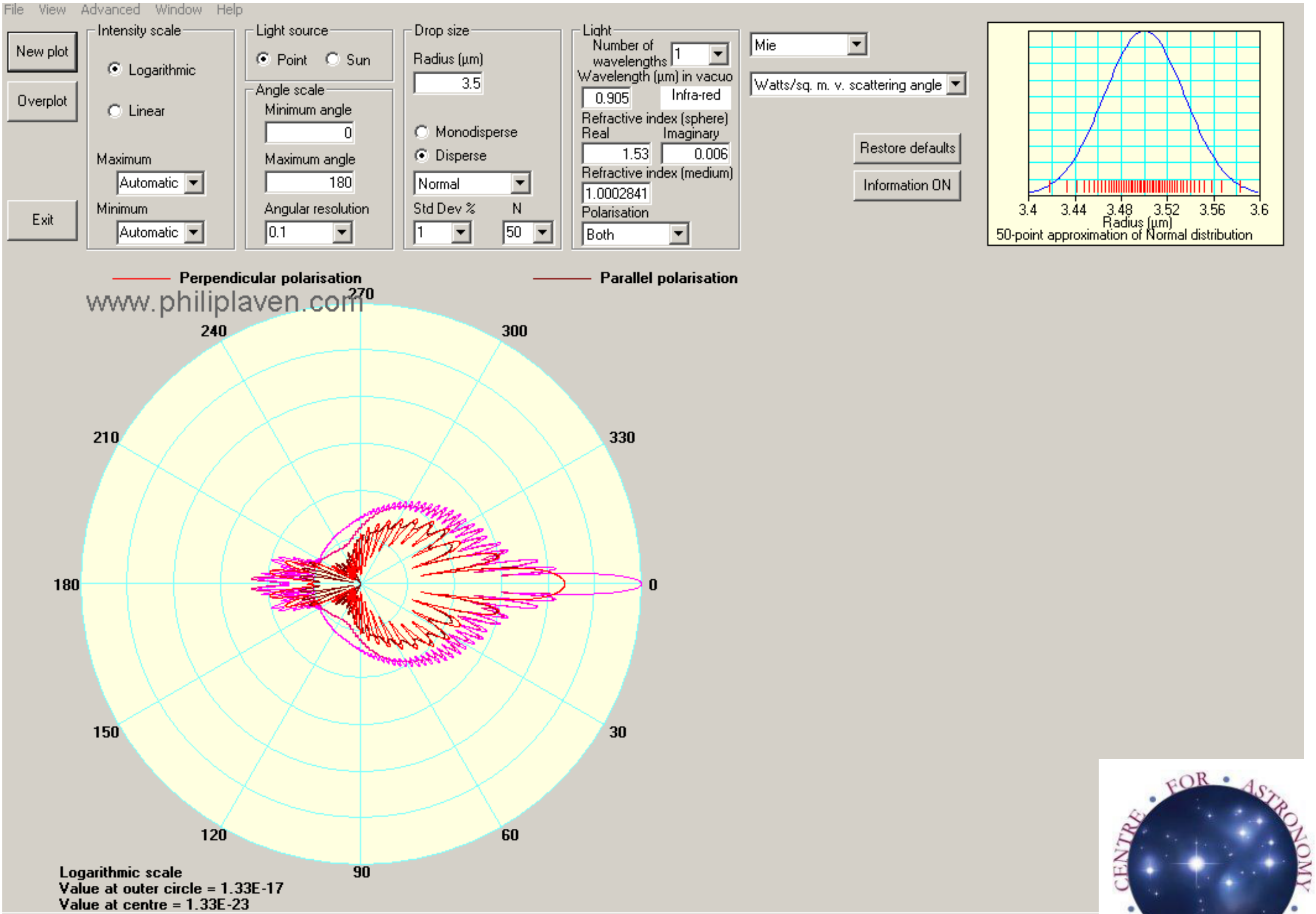
refractive index = $1.58_{(real)}$ $0.006_{(imag)}$

imaginary component chosen for Cherenkov peak ≈ 350nm

Aerosol size distribution
3.5μm
(Normal distribution)

Remember:
We scale from 905nm
To 550nm.
This is input frequency
for MODTRAN.

Scaling to 350nm for
estimating aerosol
concentration seen in
L3 data.



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Future direction – Fitting models to MODTRAN 5

This work will succeed or fail depending on possibility to accurately match data profiles to MODTRAN model profiles.

Need:

Large sample of post-upgrade data - relationships between ΔT and ΔL3.

Accurate corrections (as per mentioned).

ceilometers ability to penetrate high cloud; thickness and height needed.

Accurate Mie theory scaling.

Kind weather alignment with moon phases

Some knowledgeable colleagues of course…

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Corsika sims – how to simplify

0-50^o zenith angle

4 telescope only

No moonlight

3 x BL models (clear, Light, moderate dust concentrations)

2 x Troposphere models (clear-light dust ; clear-light H_2O vapour)

3 x Lower Stratosphere models (clear, Light, moderate H_2O vapour concentrations)

Incorporate radiosonde data

Why undertake this study?

Its plausible to consider data retrieval as a viable option for some atmospheric conditions.

Modeling for 3 example atmospheres enables more data to make it into analysis.

How will this method work?

Will have to solve lidar equation for ceilometer, α coeff. & β coeff.
Or
Will have to borrow a raman scattering inelastic multiwavelength lidar
Or
Monte carlo sims may guide choice of best model fit to data

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In Summary

- Correcting for FIR2 and L3 necessary 1st step
- Large population of data runs → relationships between FIR2 and L3 for 3 atmospheric layers, using post upgrade data
- Determine appropriate BL aerosol binning; i.e. what cut off of L3 rate could we use to categorise BL dust…

1. $L3(1) \approx$ 100-75% $L3_{mol}$, $L3(2) \approx$ 75-50% $L3_{mol}$?
2. $L3(1) \approx$ 100-85% $L3_{mol}$, $L3(2) \approx$ 85-70% $L3_{mol}$?
3. $L3(1) \approx$ 100-90% $L3_{mol}$, $L3(2) \approx$ 90-80% $L3_{mol}$, $L3(3) \approx$ 80-70% $L3_{mol}$?

- Determine appropriate Lower Troposphere aerosol binning

1. $FIR2(1) \approx$ 100-75% $FIR2_{mol}$, $FIR2(2) \approx$ 75-50% $L3_{mol}$? Etc…

- What to do with 'no mans land', the Troposphere?
- $L3.FIR2(1) \approx$ 100-90% $L3.FIR2_{mol}$ etc; where L3.FIR2 is some coeff.

of 2 readings

- Make sims and test…

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