Determining atmospheric aerosol content with an infra-red radiometer

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Motivation: the recovery of compromised observing runs, eg taken as part of a multiwavelength campaign

Trigger rates as a function of zenith angle **θ**

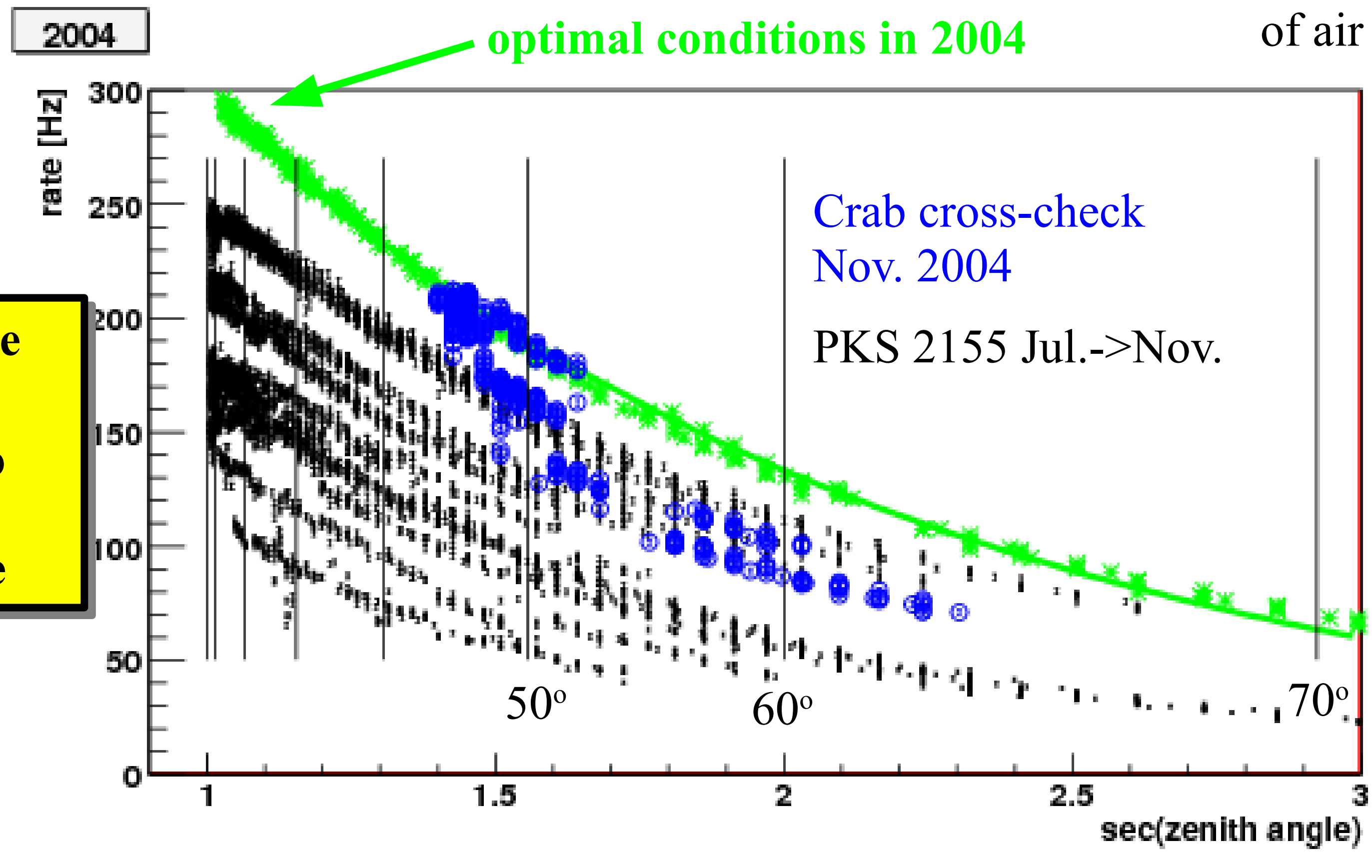
$$R(\theta) = R_{(\theta=90)}\exp[-(t_0/\Lambda)\sec(\theta-1)]$$

$\mathbf{R_0}$ rate at zenith

$\mathbf{t_0}$ depth of experiment

Λ is attenuation length of air shower

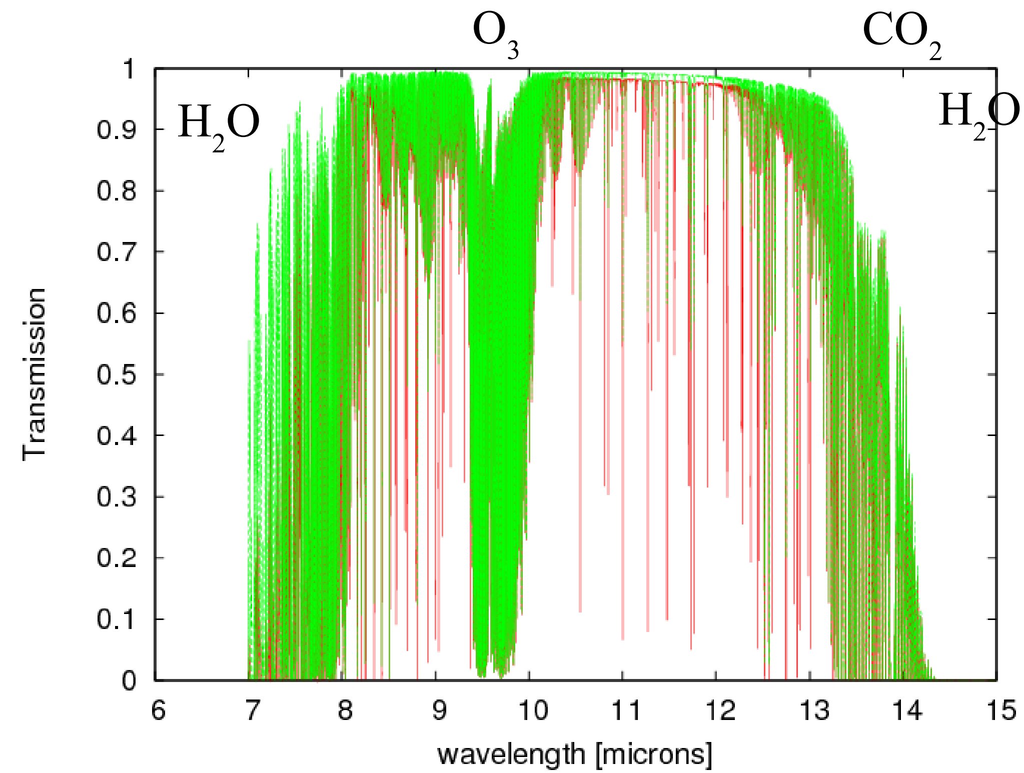
Want to relate T_{sky}/lidar conditions to telescope performance



All 2004 observations of PKS 2155 are compromised

Heitronics KT19.82 IR radiometer

Atmospheric window 8-14µm



Gemini North, Lock (1992).

Scanning Radiometer

Remember, the radiometer is not measuring *temperature*, it is measuring **radiance**

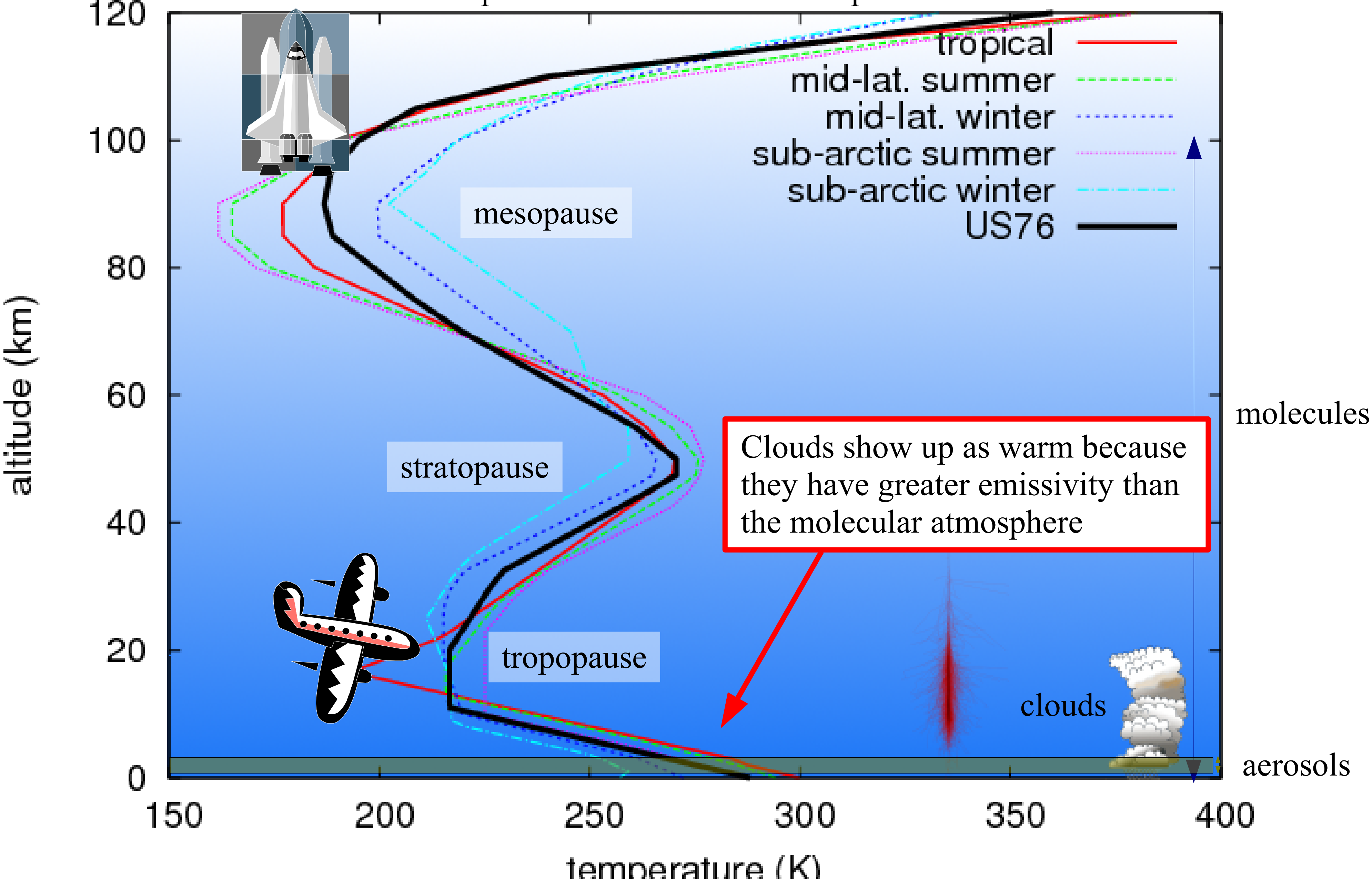
$$L_{sky} = \sigma T^4_{sky}$$
$$= L_{window} + L_{H_2O} + L_{aerosol} + L_{molecular} + \ldots$$
$$= \epsilon_w \sigma T^4_{window} + \epsilon_{wv} \sigma T^4_{H_20} + \epsilon_a \sigma T^4_{aerosol} + \epsilon_m \sigma T^4_{molecular} + \ldots$$

this is not a linear function of temperature

The efficient emitters and the warmest components are going to dominate the effective sky brightness temperature

We just need to work out how best to make use of the sensitivity

A quick reminder on the atmosphere



Large aerosols (e.g. pollen, sand grains) can add 30W/m^2 to the 8-13μm atmospheric window
Dalrymple & Unsworth, Quart. J. R. Met. Soc. **104**, 989 (1978)
this can be the difference between the sky having a brightness temperature of -56C or -70C...

Effect of aerosol contribution on sky brightness temperature

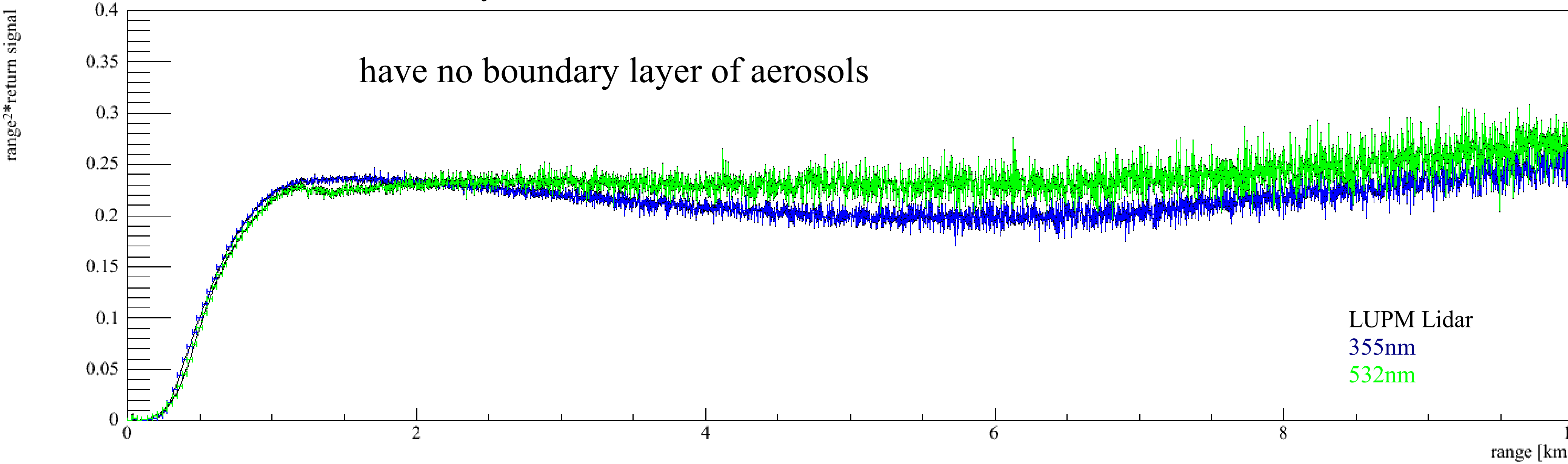
Large aerosols (e.g. pollen, sand grains) can add 30W/m^2 to the 8-13μm atmospheric window

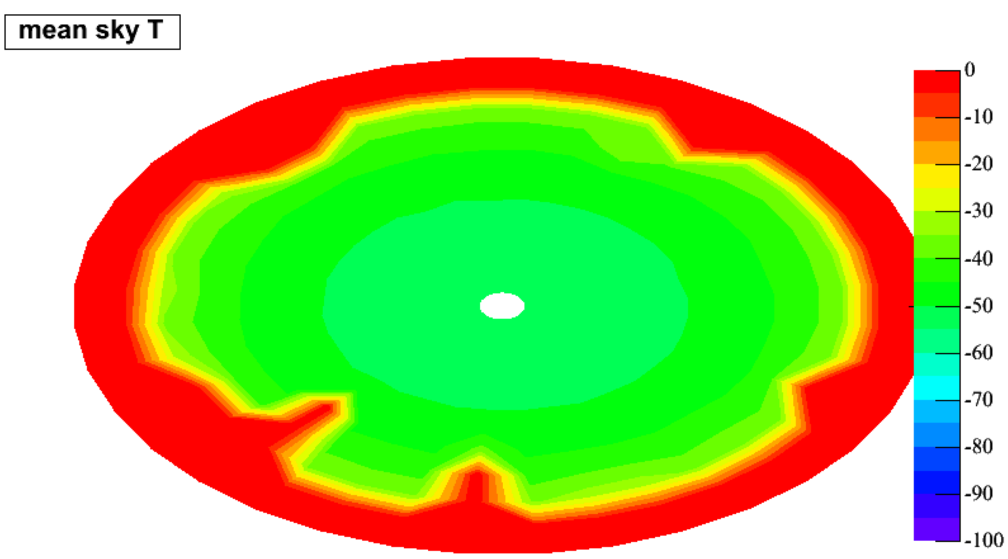
Dalrymple & Unsworth, Quart. J. R. Met. Soc. **104**, 989 (1978)

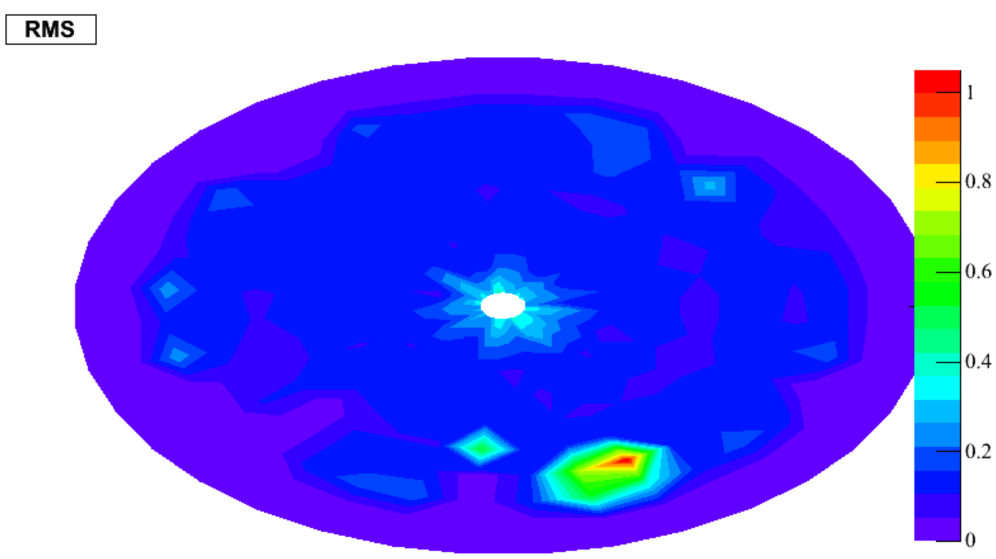
molecular luminosity [W/m^2]	brightness temperature [C]		T with additional 30 W/m^2 [C]
140	-50		-39
117	-60		-47
97	-70		-56
79	-80		-64

nb, all these nights listed as clear in shift logs & web summary.

really clear skies 2011/08/25

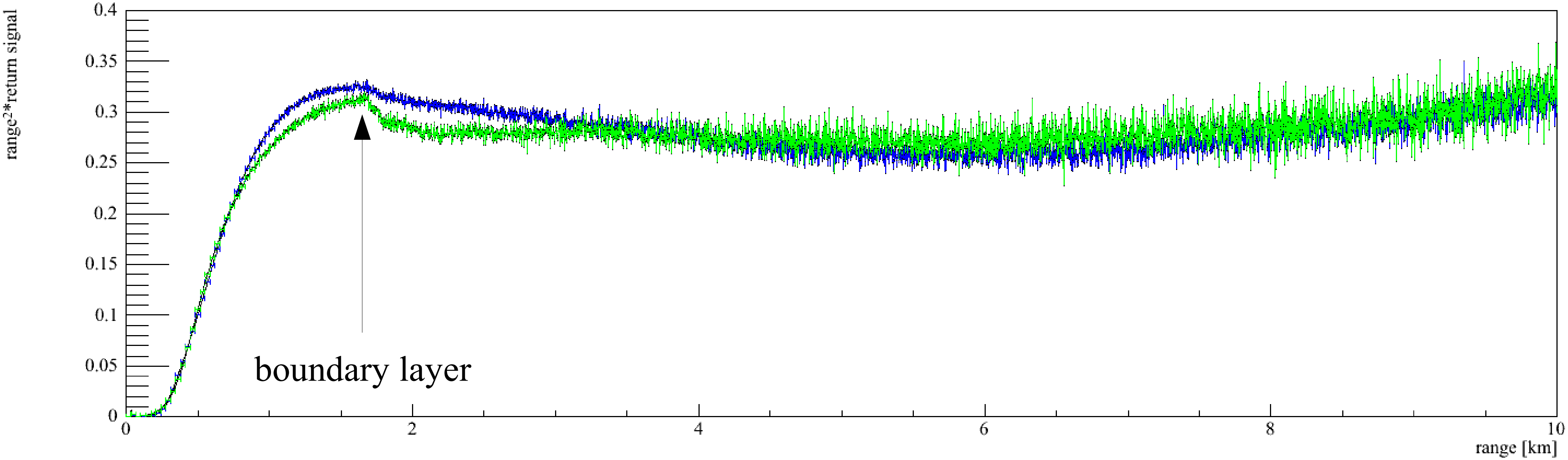


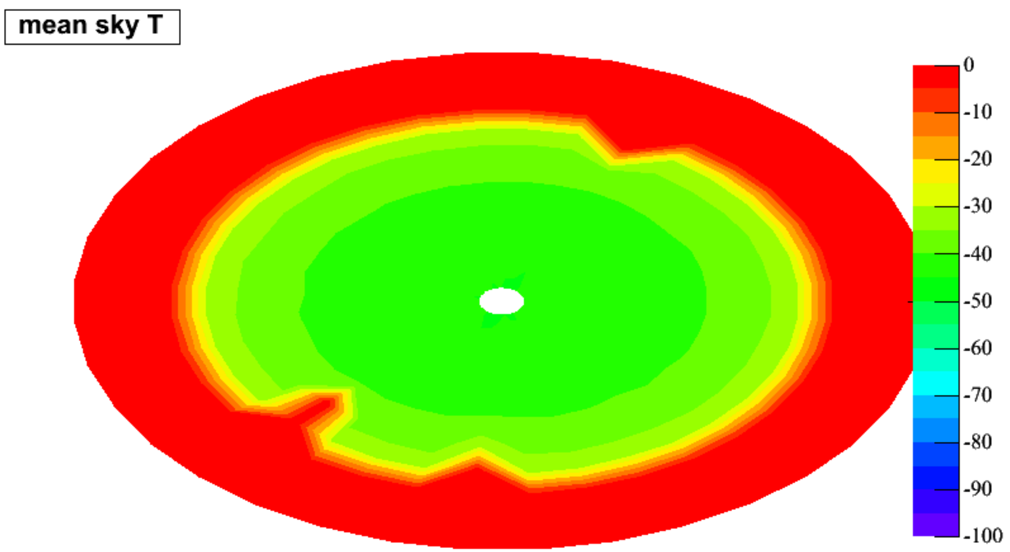


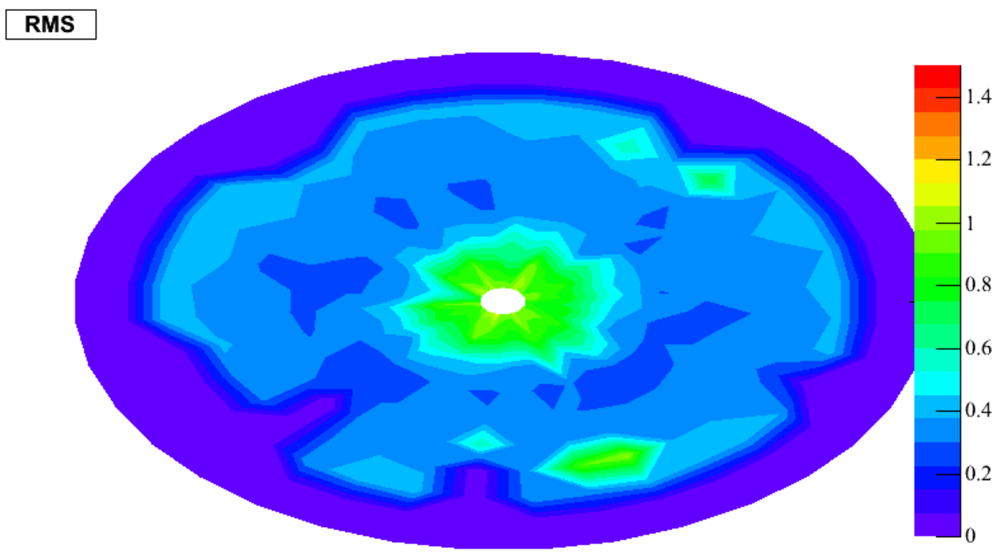


nb, all these nights listed as clear in shift logs & web summary.

2011/08/26

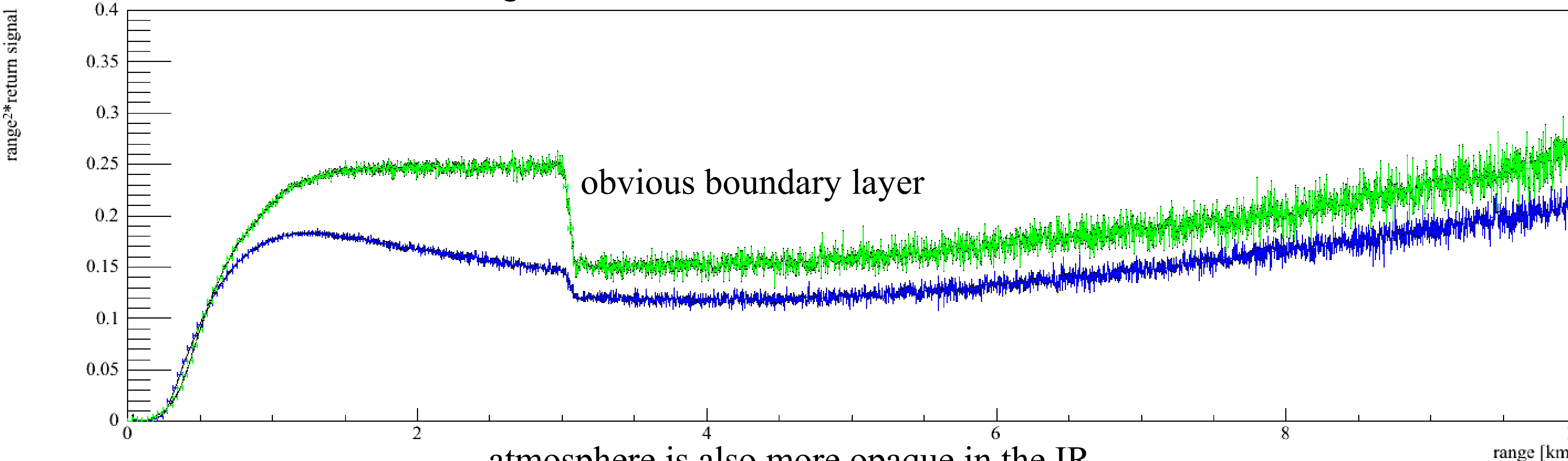




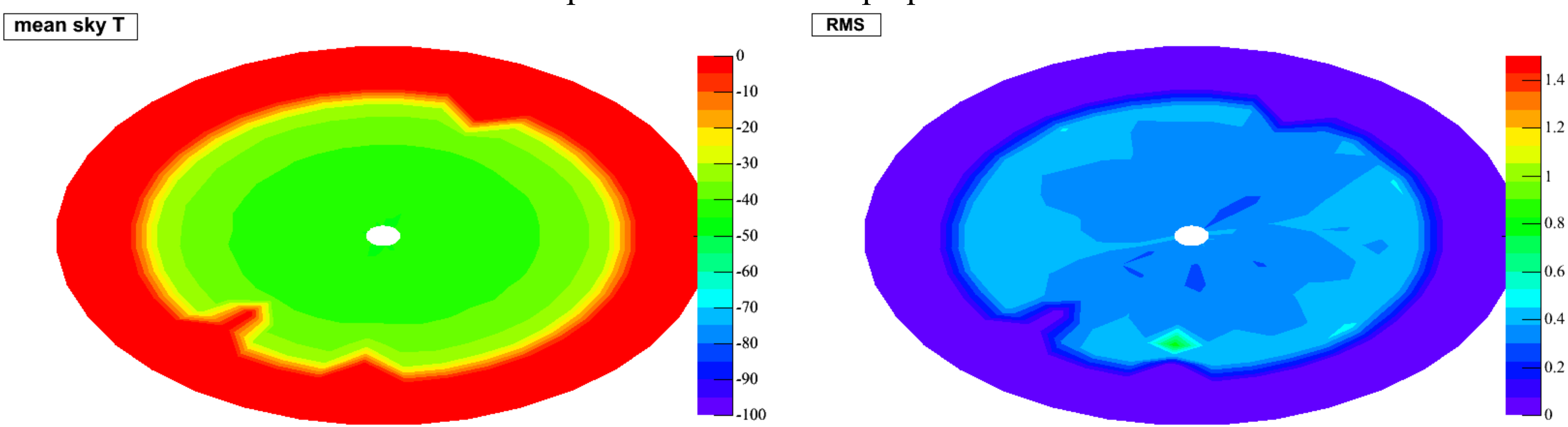


nb, all these nights listed as clear in shift logs & web summary.

“normal” observing conditions 2011/08/29

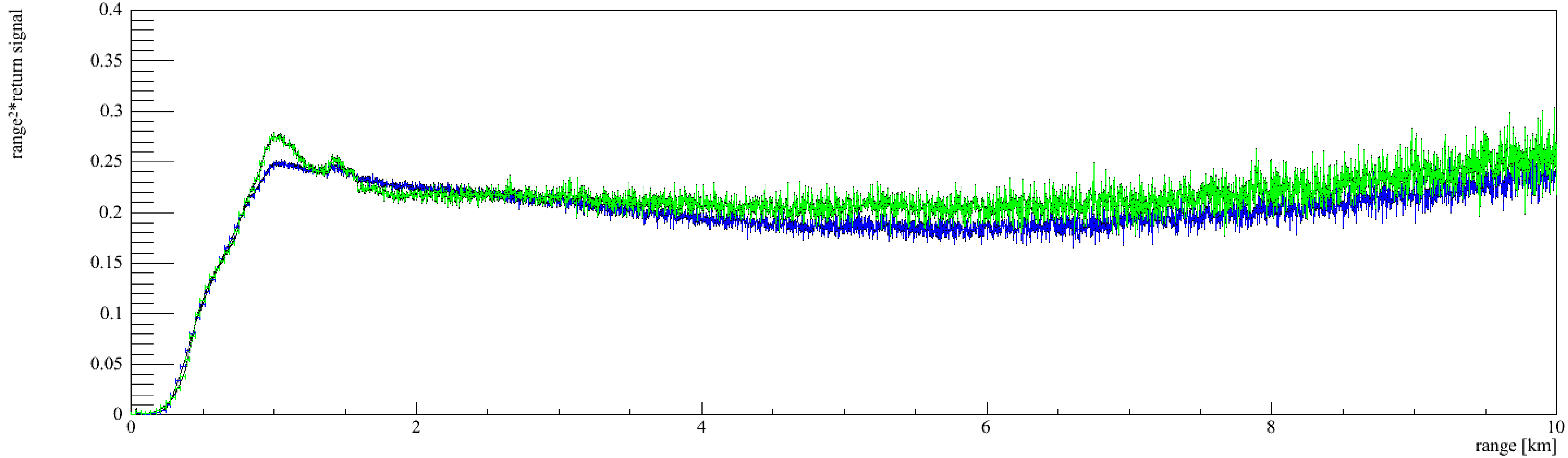


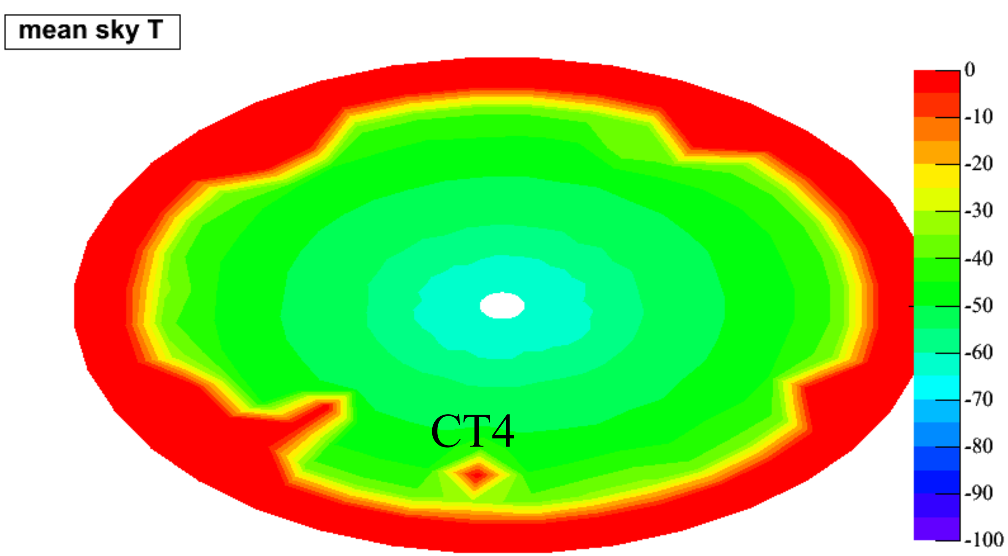
atmosphere is also more opaque in the IR

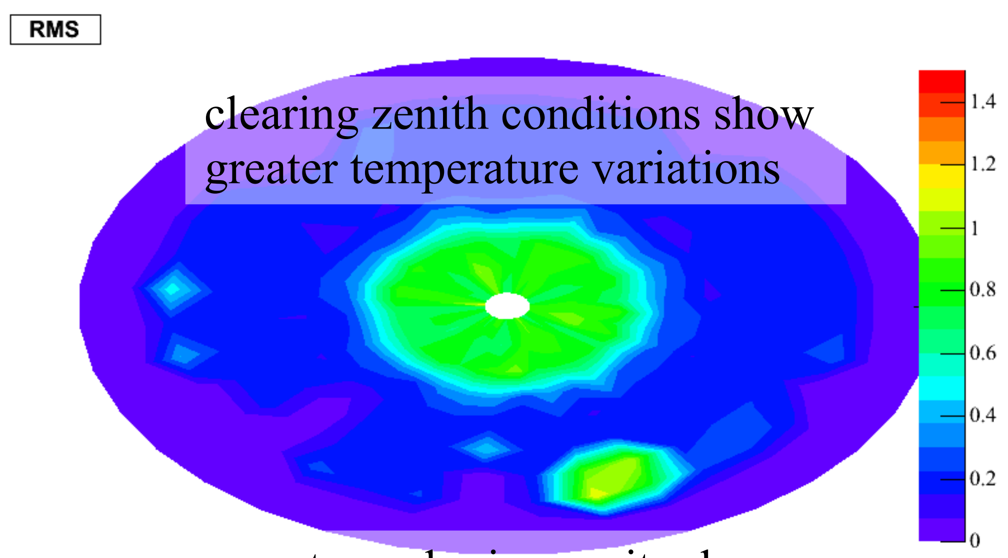


nb, all these nights listed as clear in shift logs & web summary.

2011/09/01



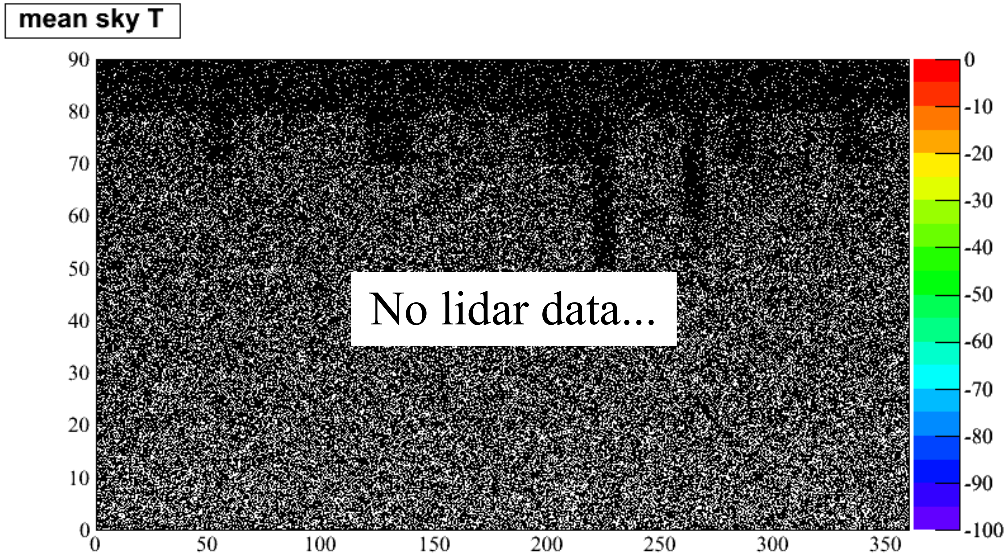


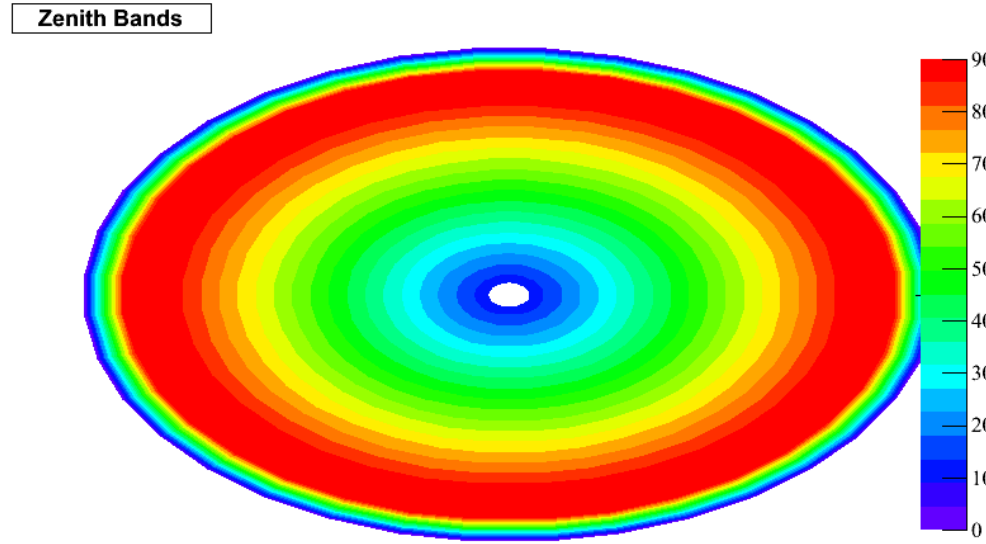


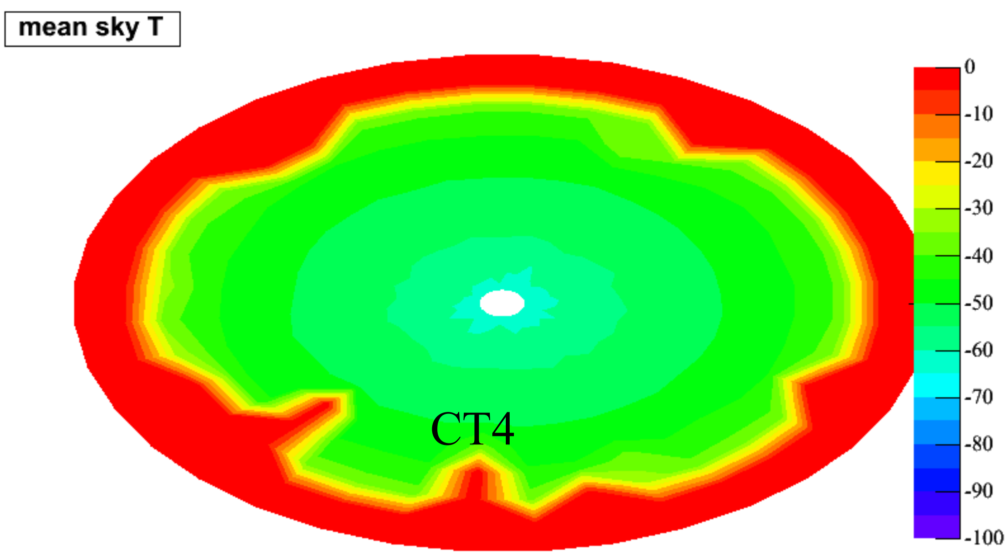
as atmospheric opacity decreases new features become apparent

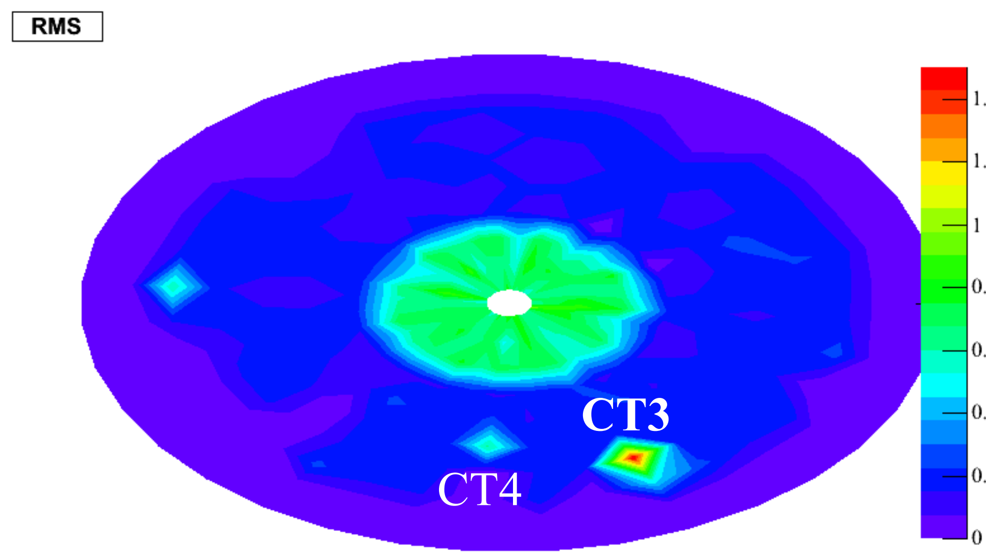
nb, all these nights listed as clear in shift logs & web summary.

2011/09/04





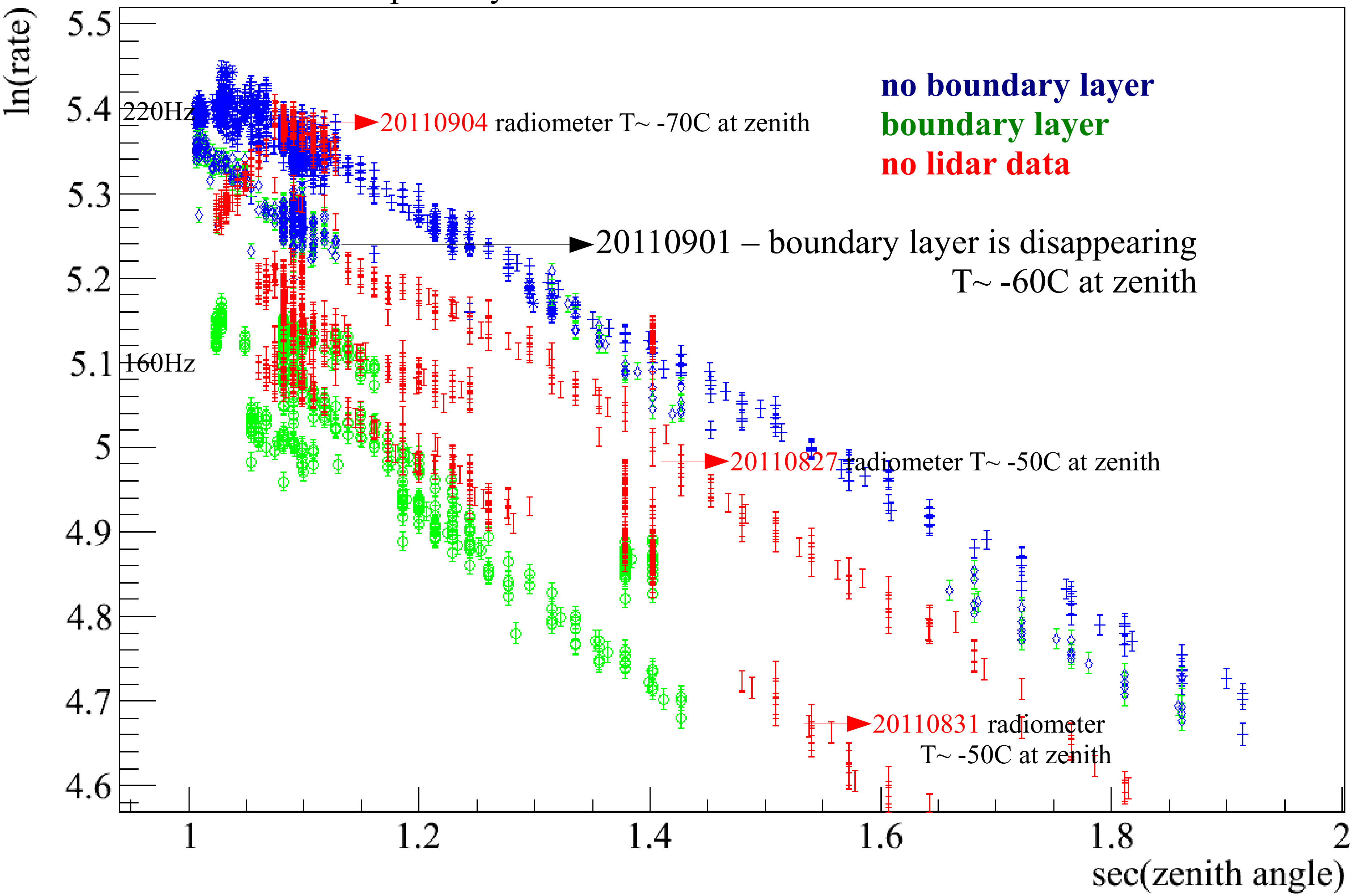




IR optical depth has dropped to ~200m as boundary layer moves down and aerosols have sedimented out of atmosphere comparing those nights telescope trigger rates

nb, all these nights listed as clear in shift logs & web summary.

runs with 4 telescopes only



Extending the study

H.E.S.S. July 2011 – July 2012

To provide a comparison with telescope trigger rates & lidar observations

Clear sky:

- no obvious clouds, haze or aerosols
- at least 7 runs with >35^o spread in zenith angles
- full 28 minute observing run (no hardware, or sun/moon rise contamination)
- lidar run before/after shows no developed aerosol boundary layer

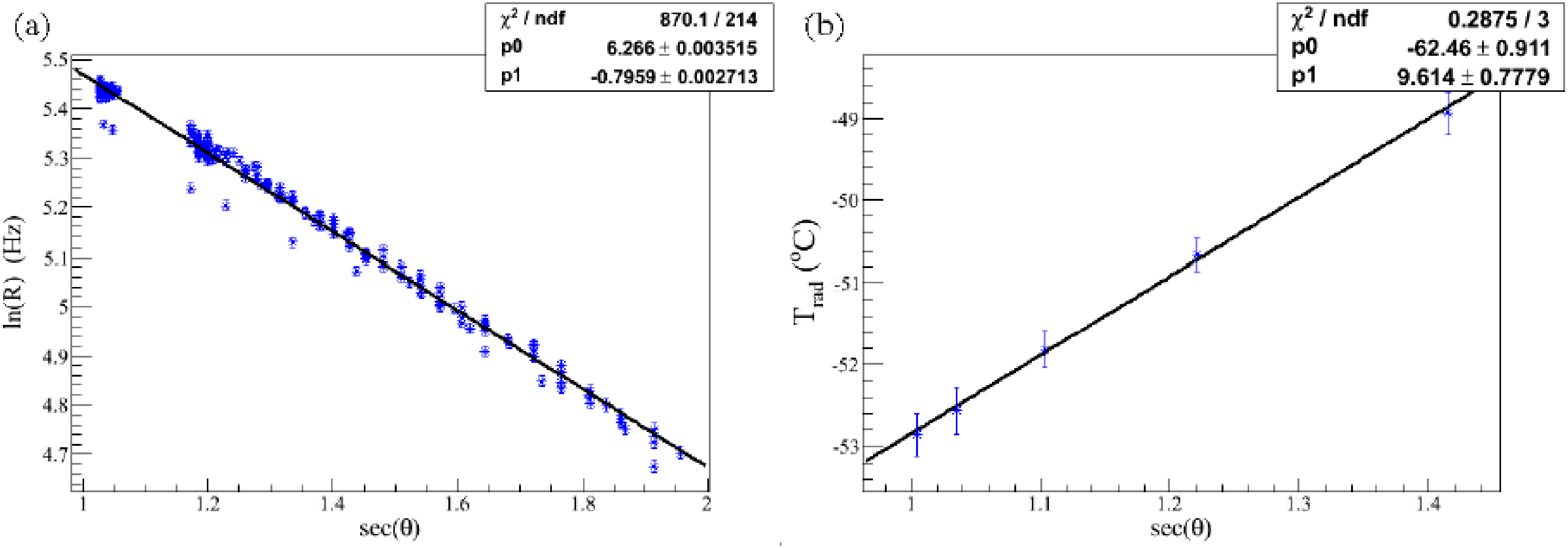
Leads to 19 'good' nights (~100 runs with lidar data) concentrated July->December

Hazy sky:

- no obvious clouds
- at least 7 runs with >35^o spread in zenith angles
- full 28 minute observing run (no hardware, or sun/moon rise contamination)
- lidar observes aerosol layer up to 3.5km

Leads to 28 observing runs from July->March

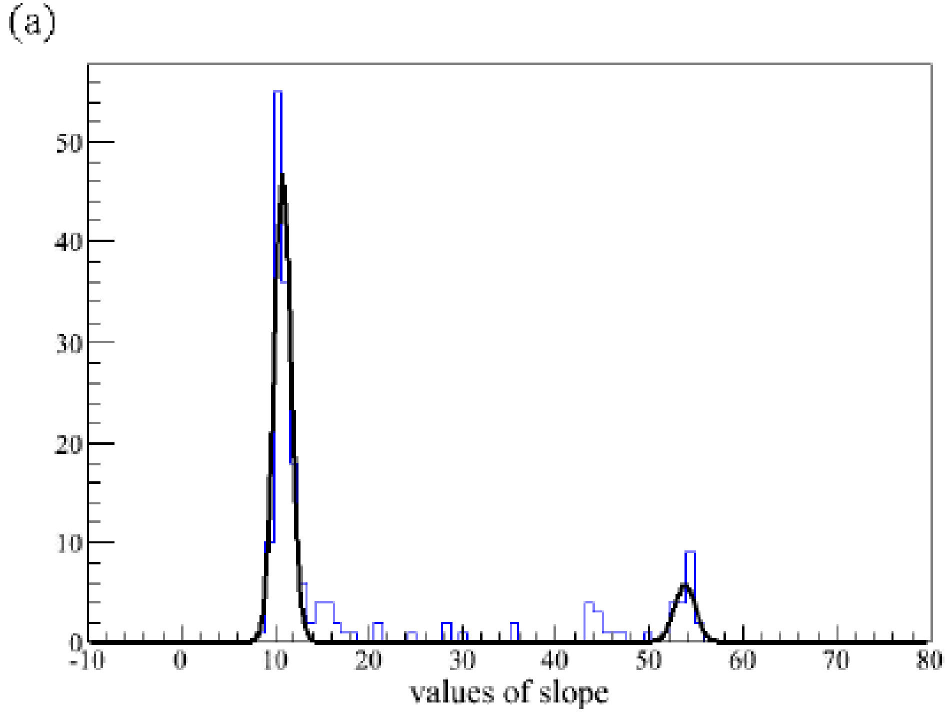
20110824

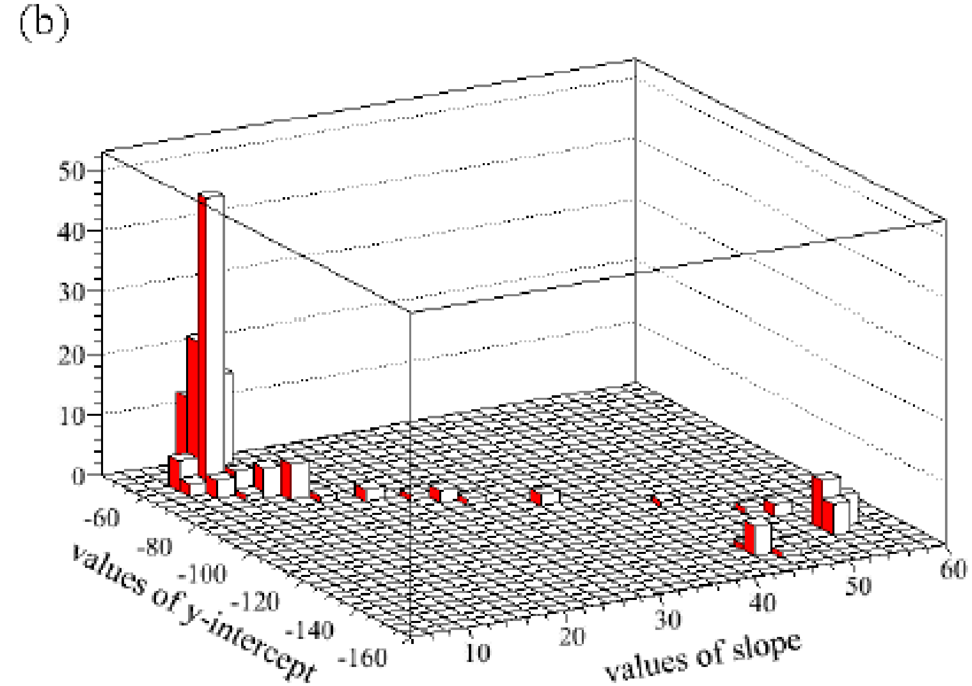


Use clear sky runs to calculate an empirical estimate of clear sky conditions

$T_{clear,zenith}$

$R_{clear,zenith}$



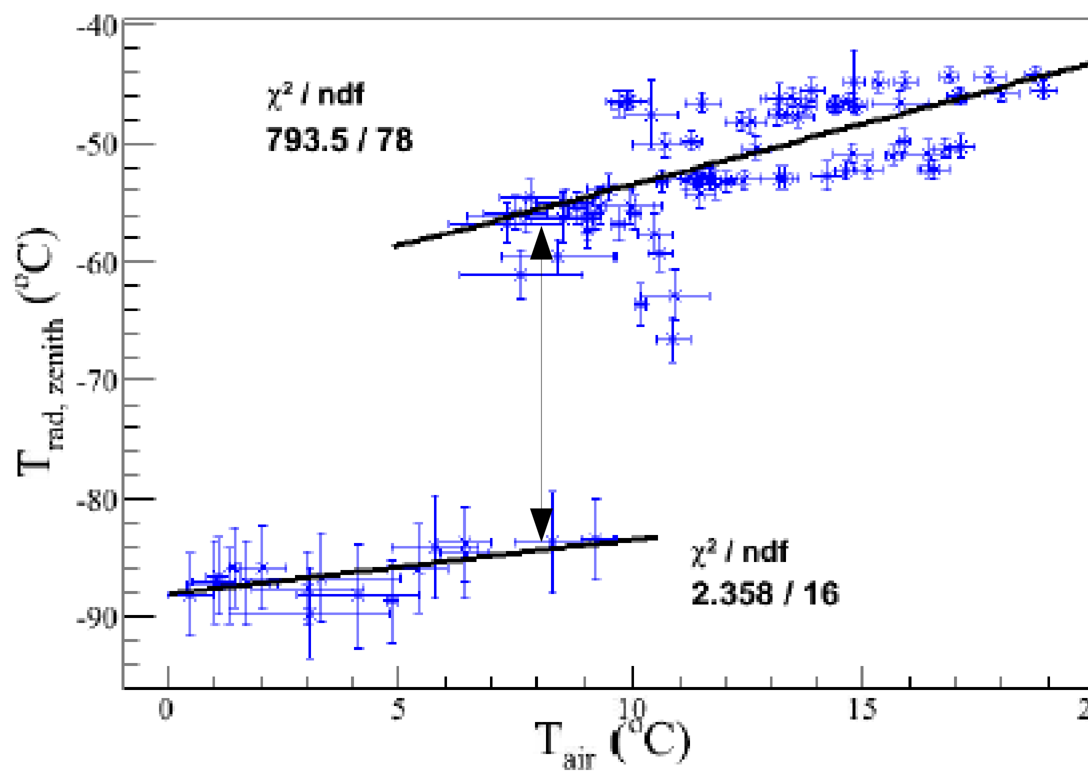


Need to take note of possible systematics

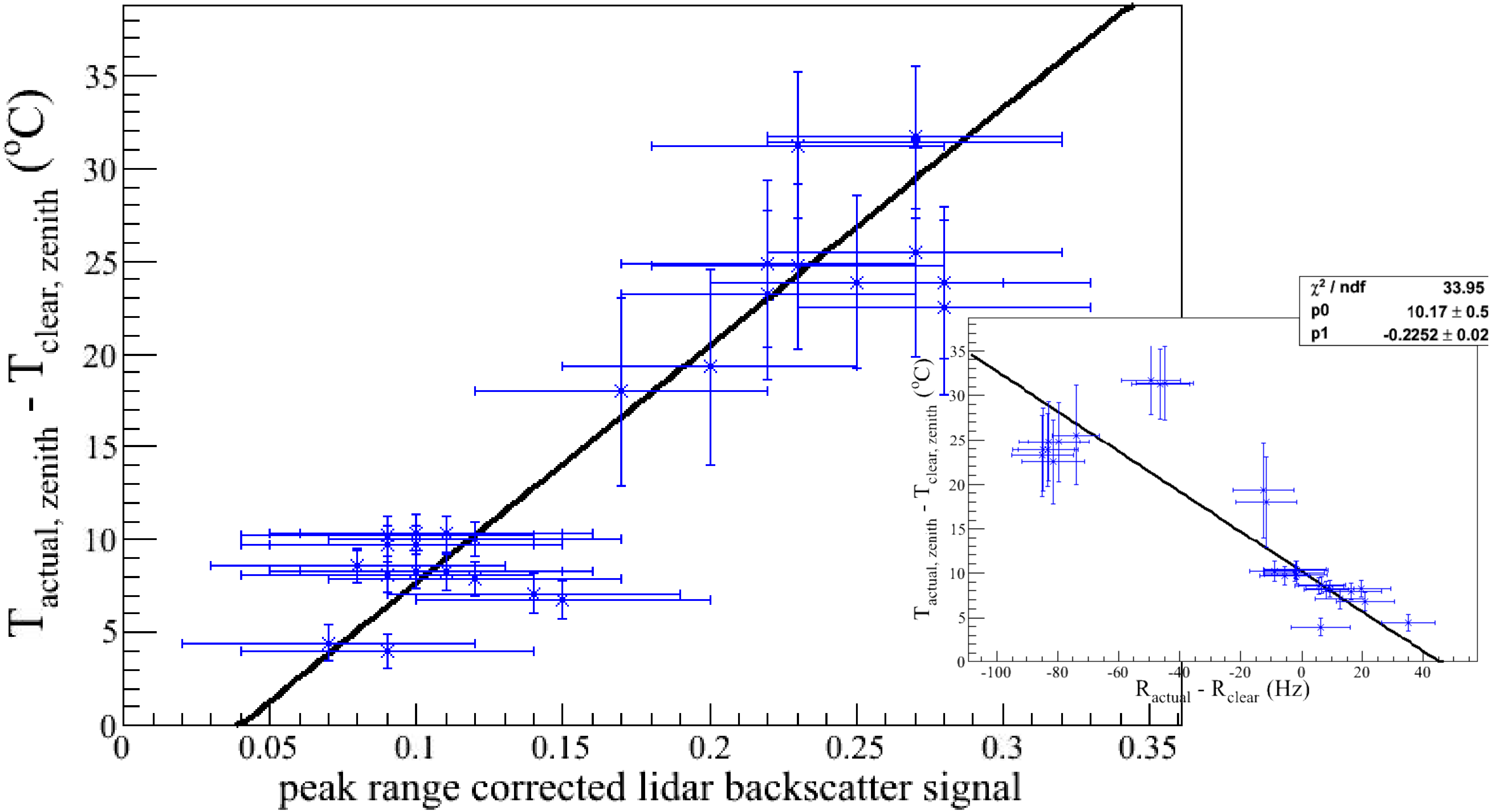
-50C is temperature limit of unmodified KT19

The opacity of a germanium lens varies as a function of temperature

etc, etc...



Observe a strong correlation between sky brightness temperature and aerosols

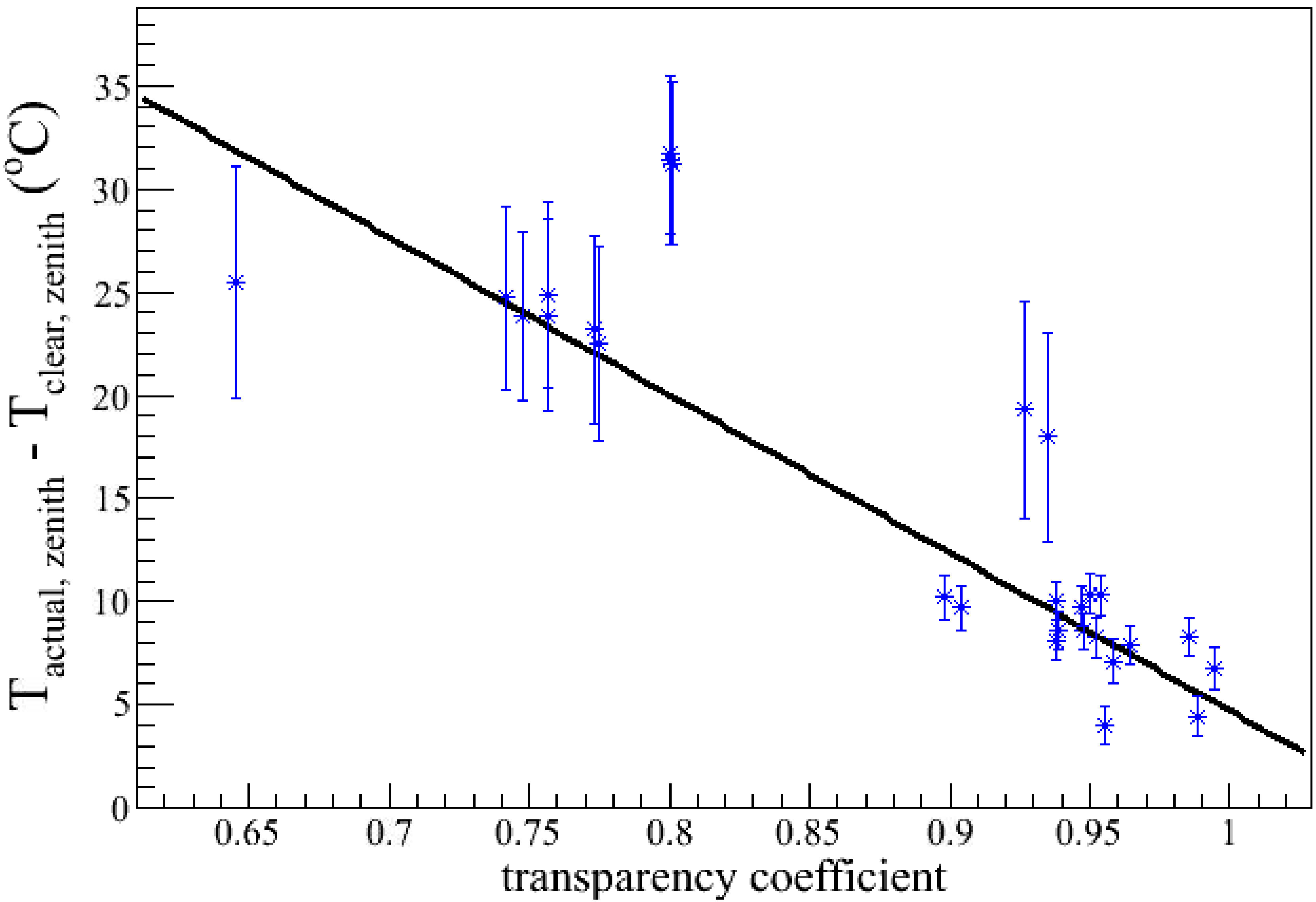


Summary

- Aerosols can contribute a measurable amount to the equivalent sky brightness temperature between 8-14μm.
- An IR radiometer is a useful addition to the suite of atmospheric monitoring tools
- Measuring the IR can give an estimate of sky clarity independent of telescope systematics; and as it is a passive measurement it will not interfere with an observation
- Whilst not sensitive to the aerosol distribution the IR is sensitive to low altitude aerosols in the crossover region a lidar is not
- Measurements can be made during daytime to give a forecast of the night's observing conditions

extra slides:

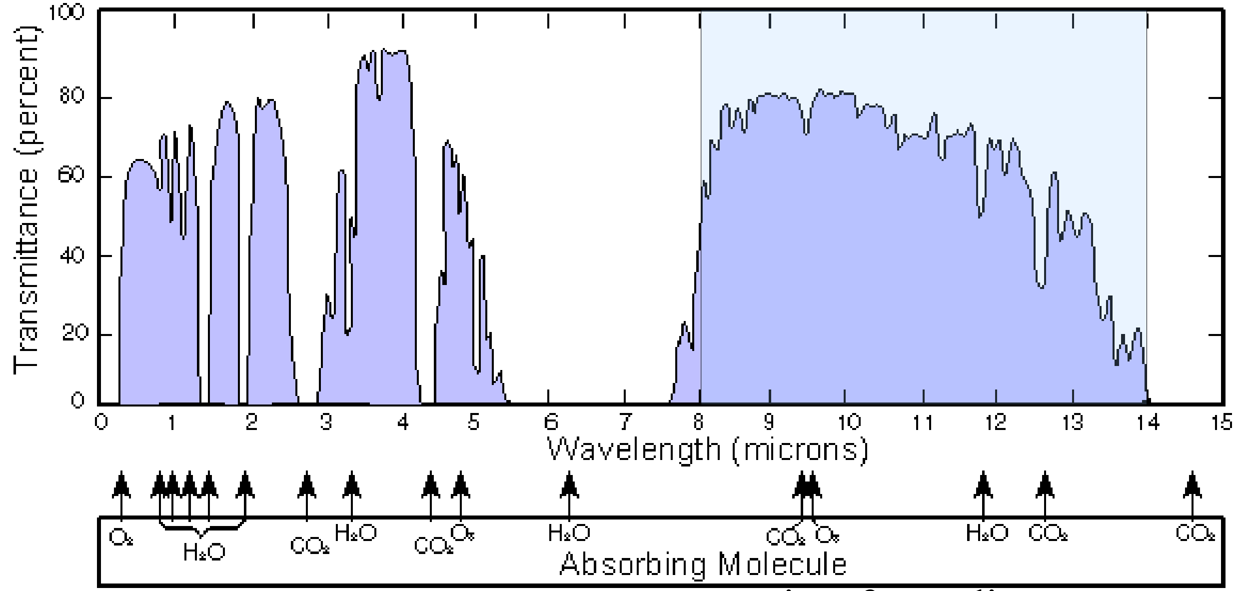
* IR brightness temperature versus transparency co-efficient
* Radiometer window contribution to IR flux & brightness temperature
* Temperature lapse rate
* extra nights for 2011
* initial study in 2009 with Leosphere lidar
* Luminosity versus temperature curve for KT19 with Germanium lens
* Lidar overlap factor



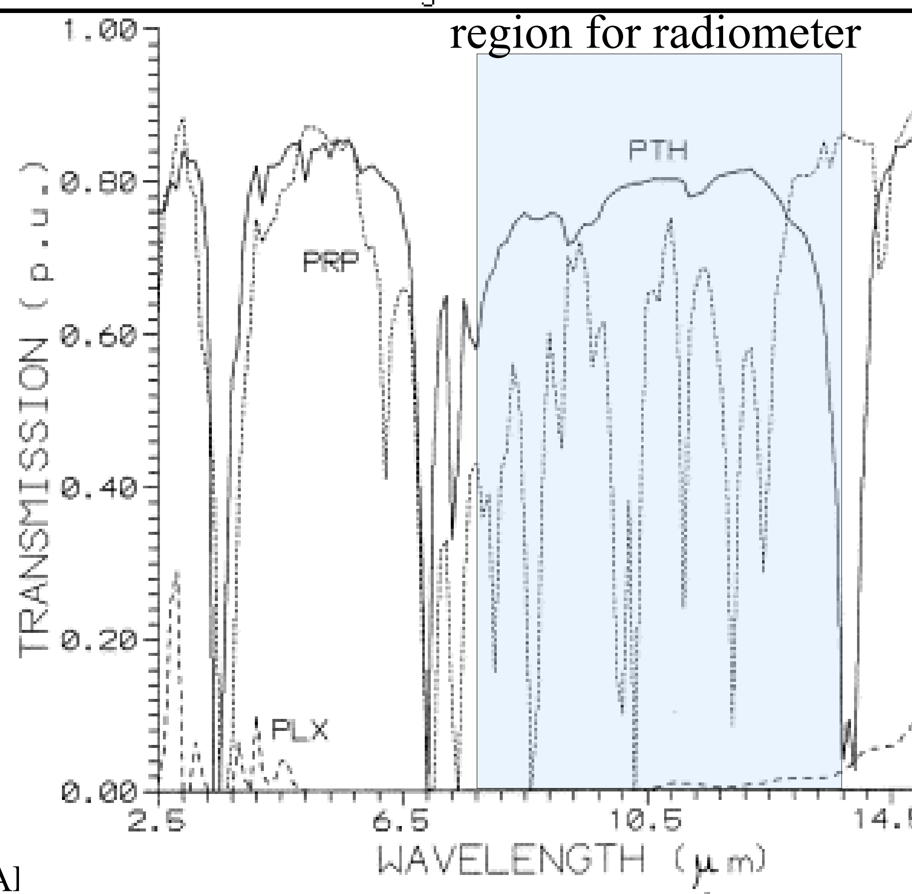
$T_{actual, zenith} - T_{clear, zenith}$ (°C)
35
30
25
20
15
10
5
0
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1
transparency coefficient

Reason for removing the radiometer window material

IR transmission of atmosphere



IR transmission of polyethylene (PTH)



Whilst polythene has the best window in the 8 to <14µm range it will contribute greatly to the IR flux, biasing it toward ambient ground temperature values.

Temperature Lapse Rate Γ_a

Taking the atmosphere to be in hydrostatic equilibrium, transparent to all radiation and containing no liquid particles, the first law of thermodynamics gives

$$C_V\,dT + P\,dV = dq = 0$$

Differentiate the equation of state, taking $\rho = 1/V$

$$P\,dV + V\,dP = \frac{k}{MM_0}\,dT$$

For an ideal gas

$$\frac{k}{MM_0} = C_P - C_V$$

Combining and replacing for $dP/dz = -g\rho$ gives

$$\frac{dT}{dz} = \frac{-g}{C_P} = -\Gamma_a$$

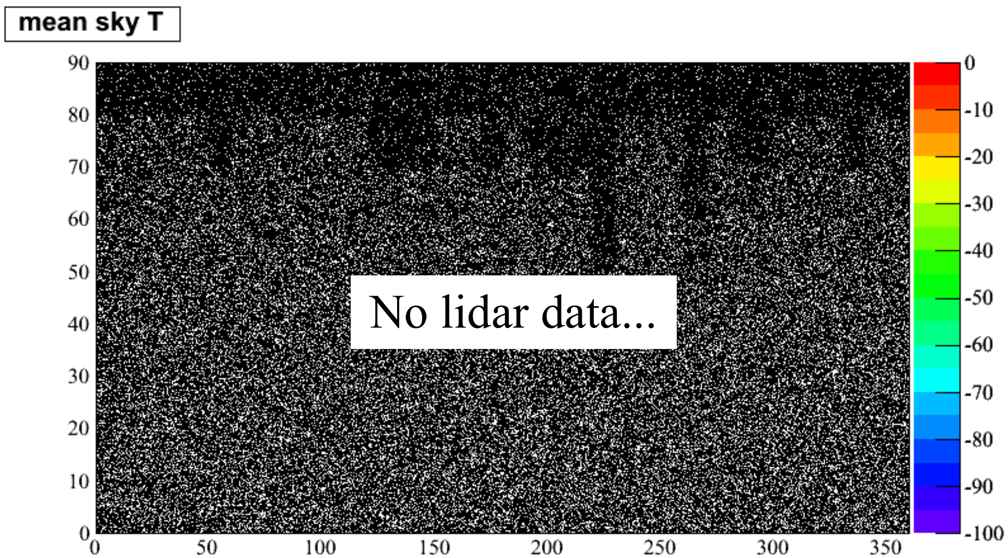
$$\therefore T(z) = T_0 - \Gamma_a z$$

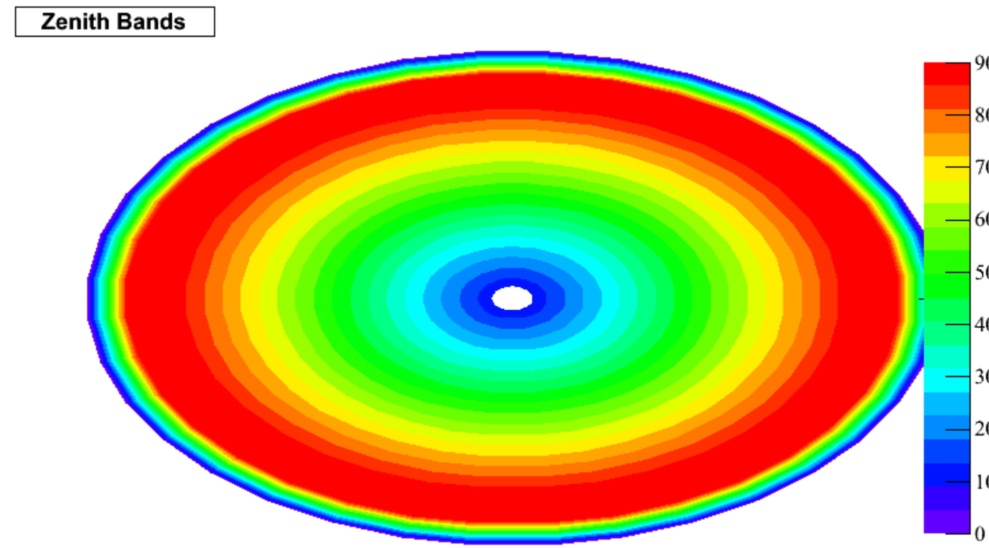
For a dry atmosphere Γ_a~9K/km

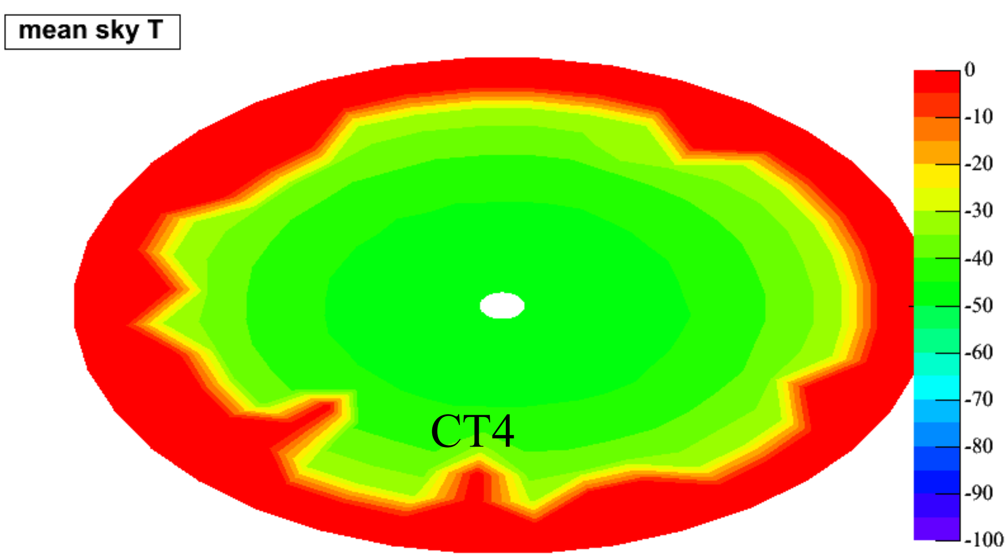
The latent heat released by water vapour condensing out of the air (RH>60%) serves to raise this to ~6.5K/km

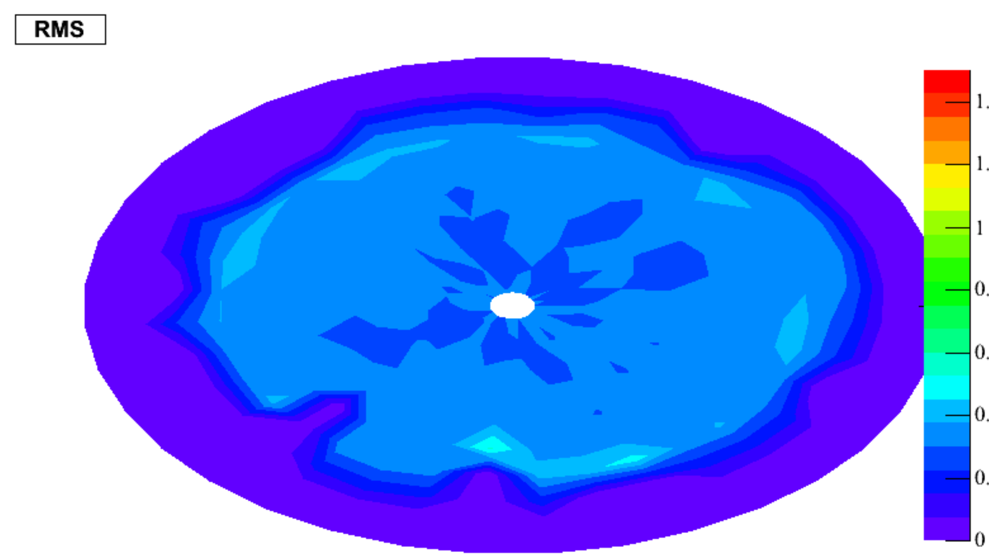
nb, all these nights listed as clear in shift logs & web summary.

“normal” observing conditions 2011/08/31



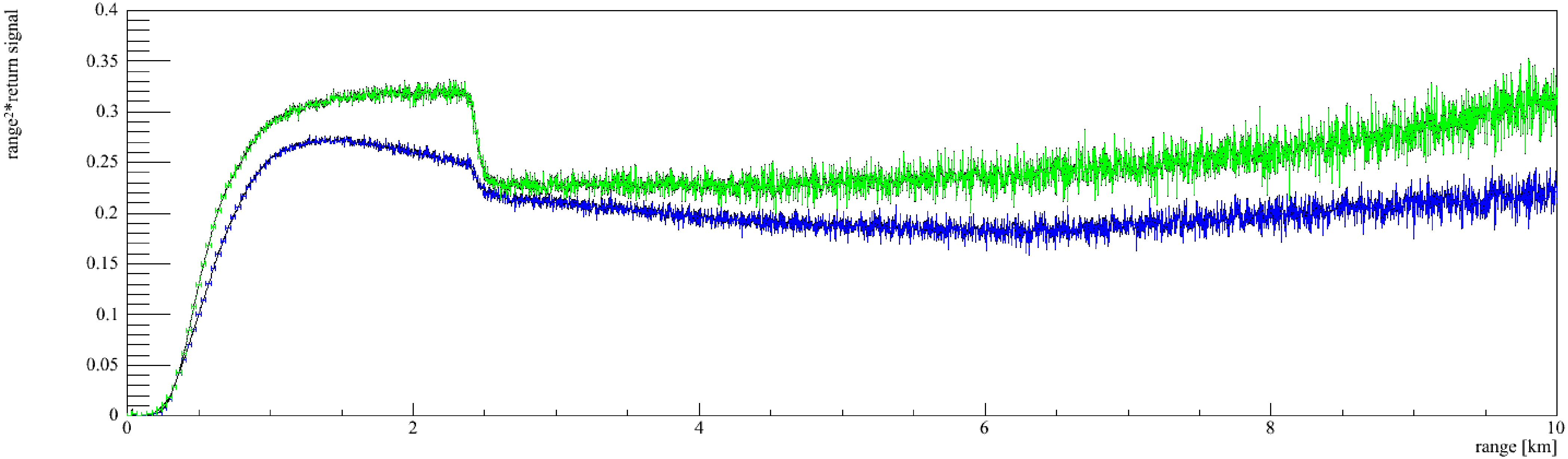


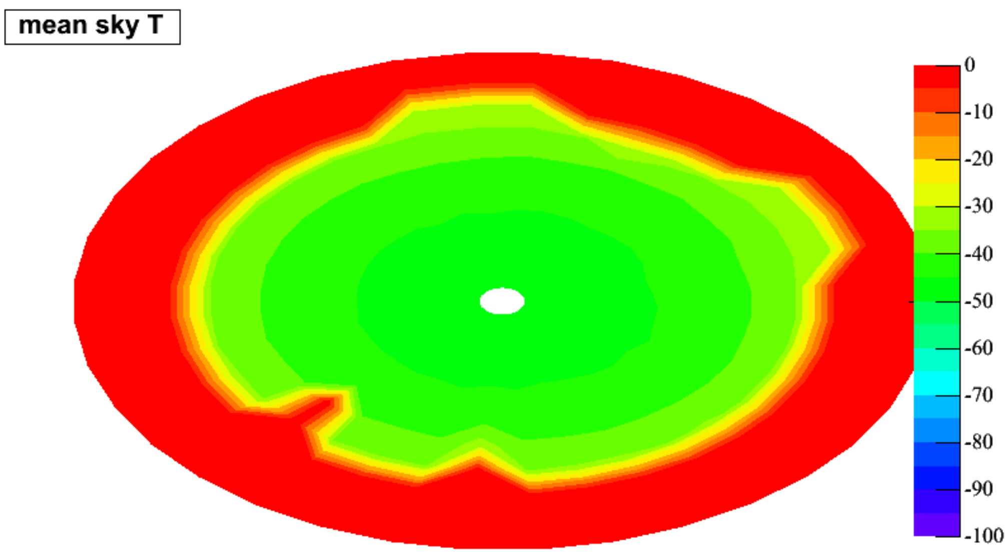


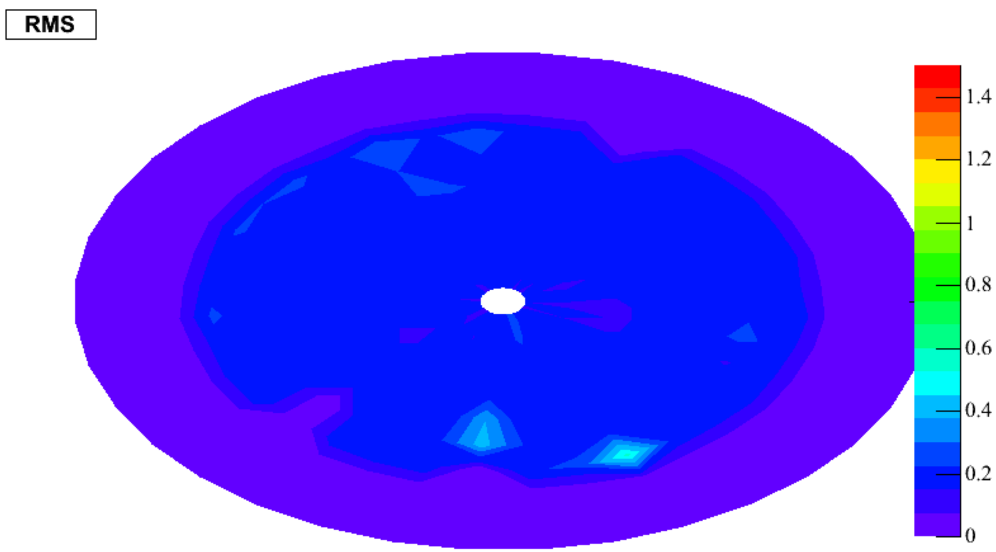


nb, all these nights listed as clear in shift logs & web summary.

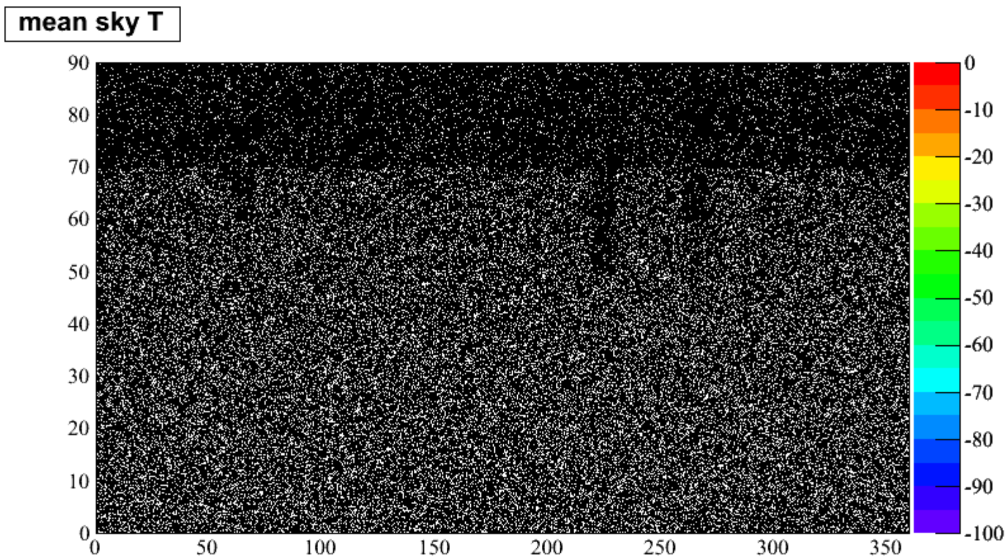
"normal" observing conditions 2011/08/30

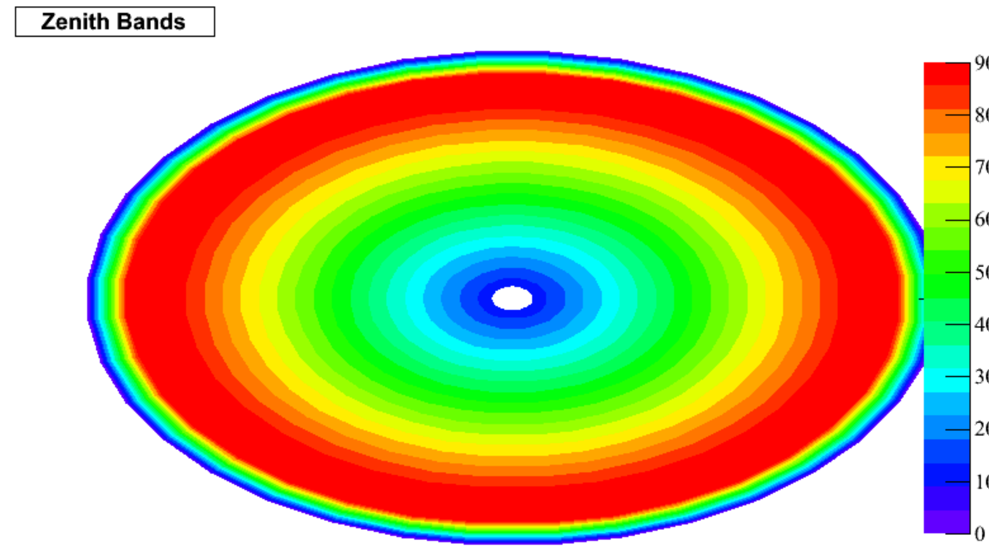


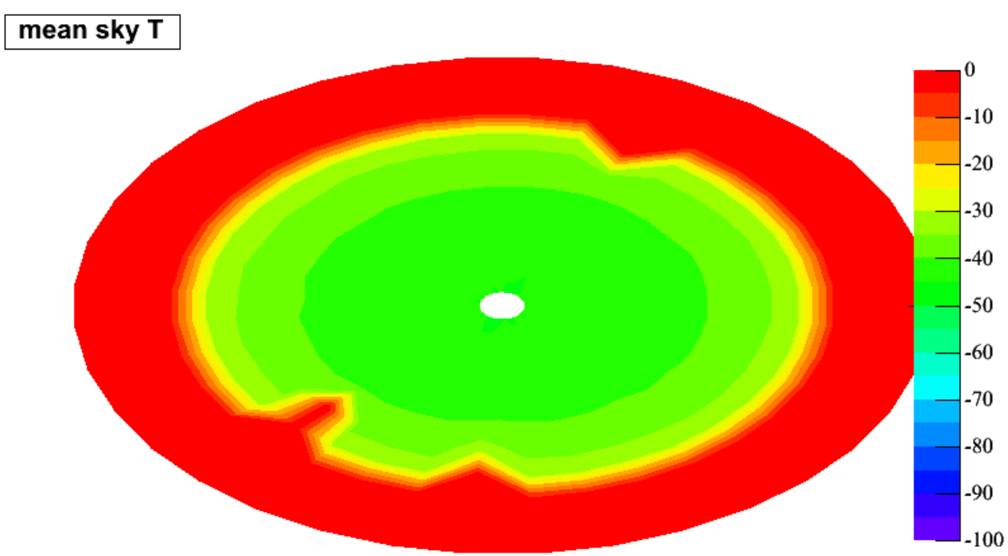


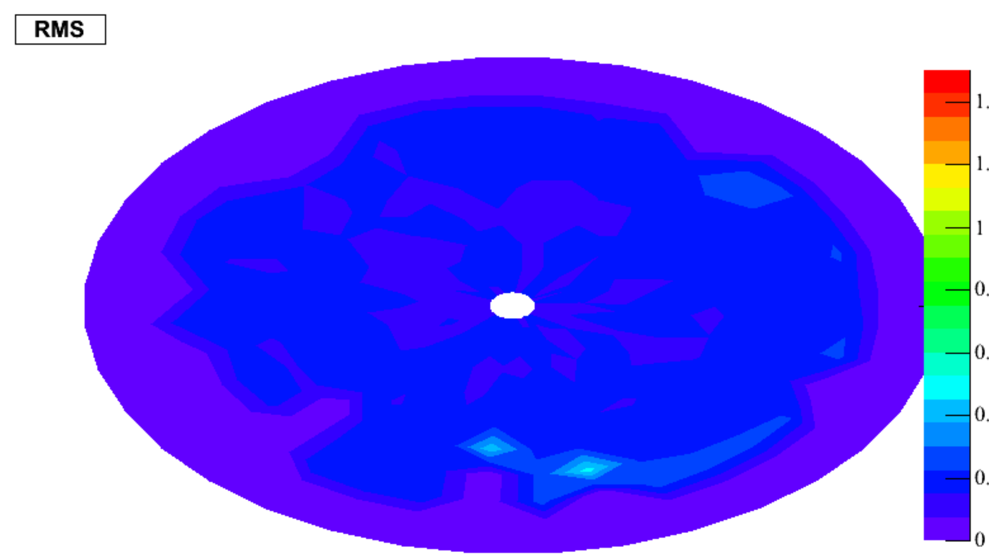


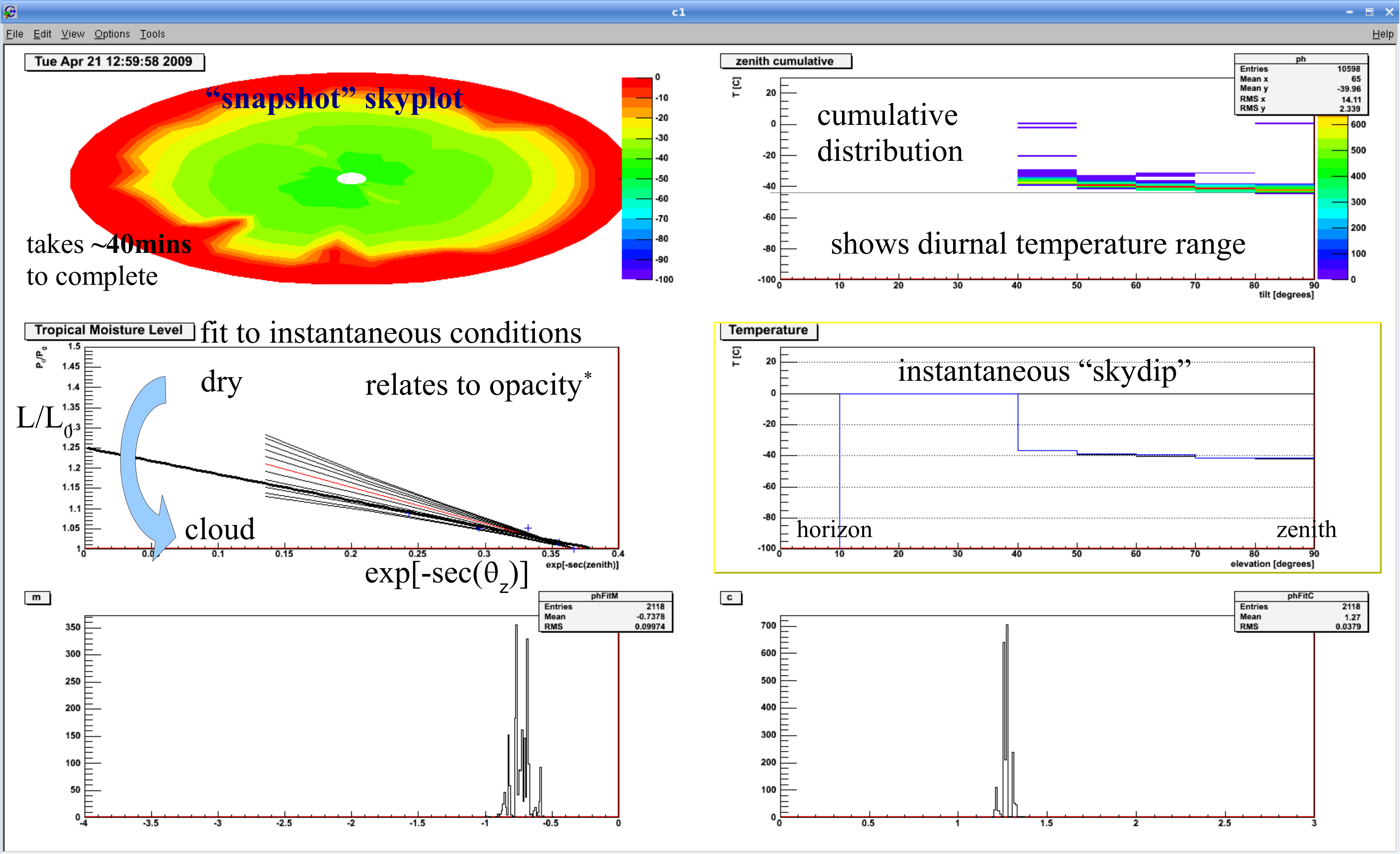
3 tel runs, can't compare rates.


mean sky T
90
80
70
60
50
40
30
20
10
0
0
50
100
150
200
250
300
350
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100


Zenith Bands
90
80
70
60
50
40
30
20
10
0

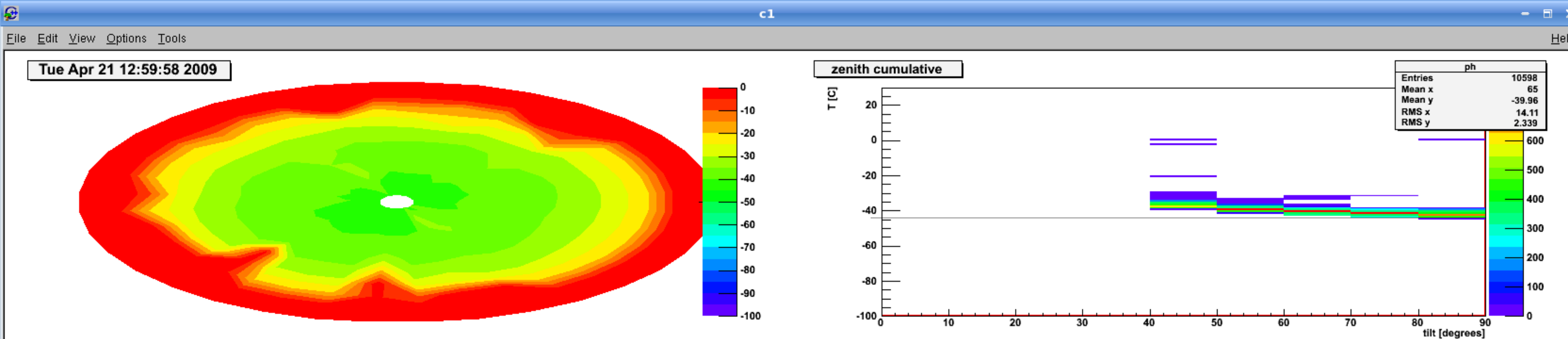

mean sky T
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100

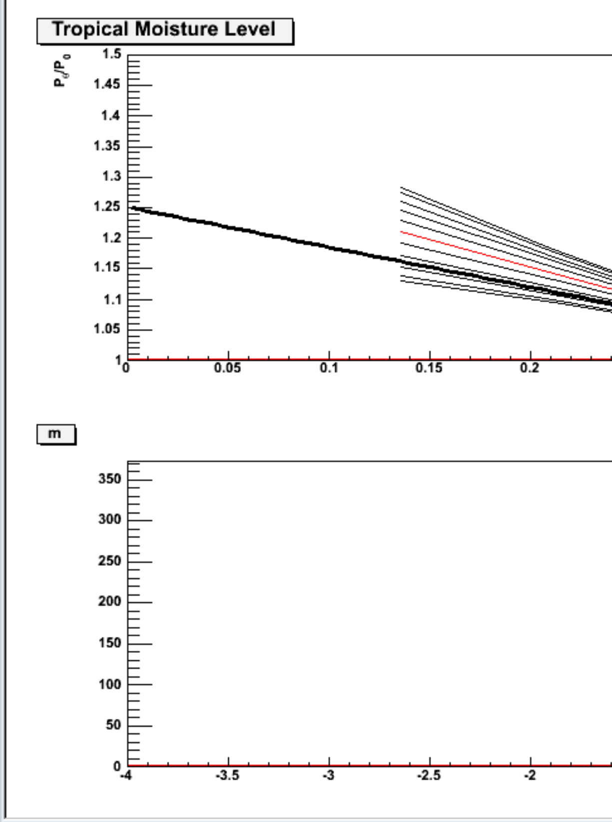

RMS
1.4
1.2
1
0.8
0.6
0.4
0.2
0

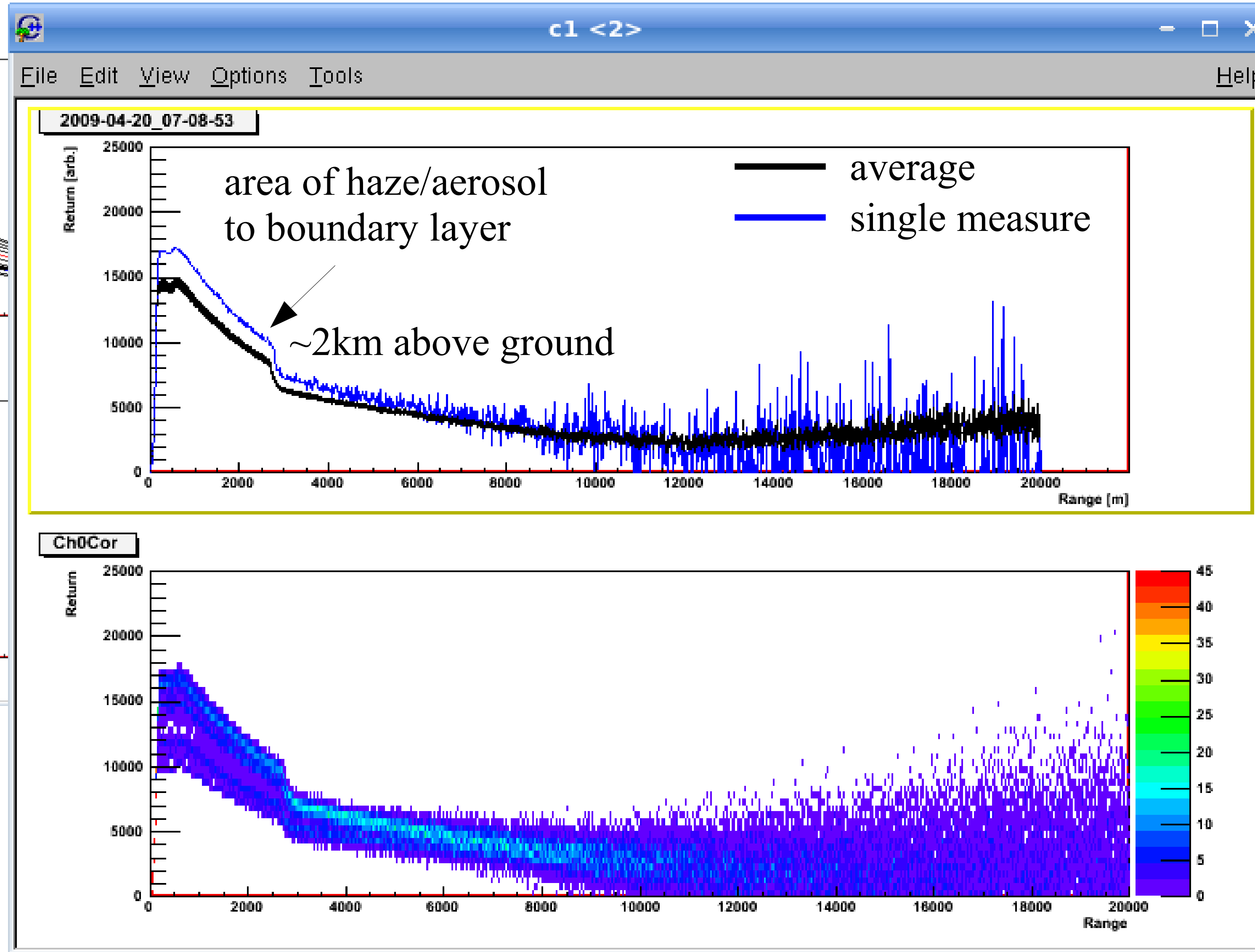


* Daniel, PhD Thesis, University of Durham (2002).
Unsworth & Dalrymple Q J Roy Met Soc (1976).

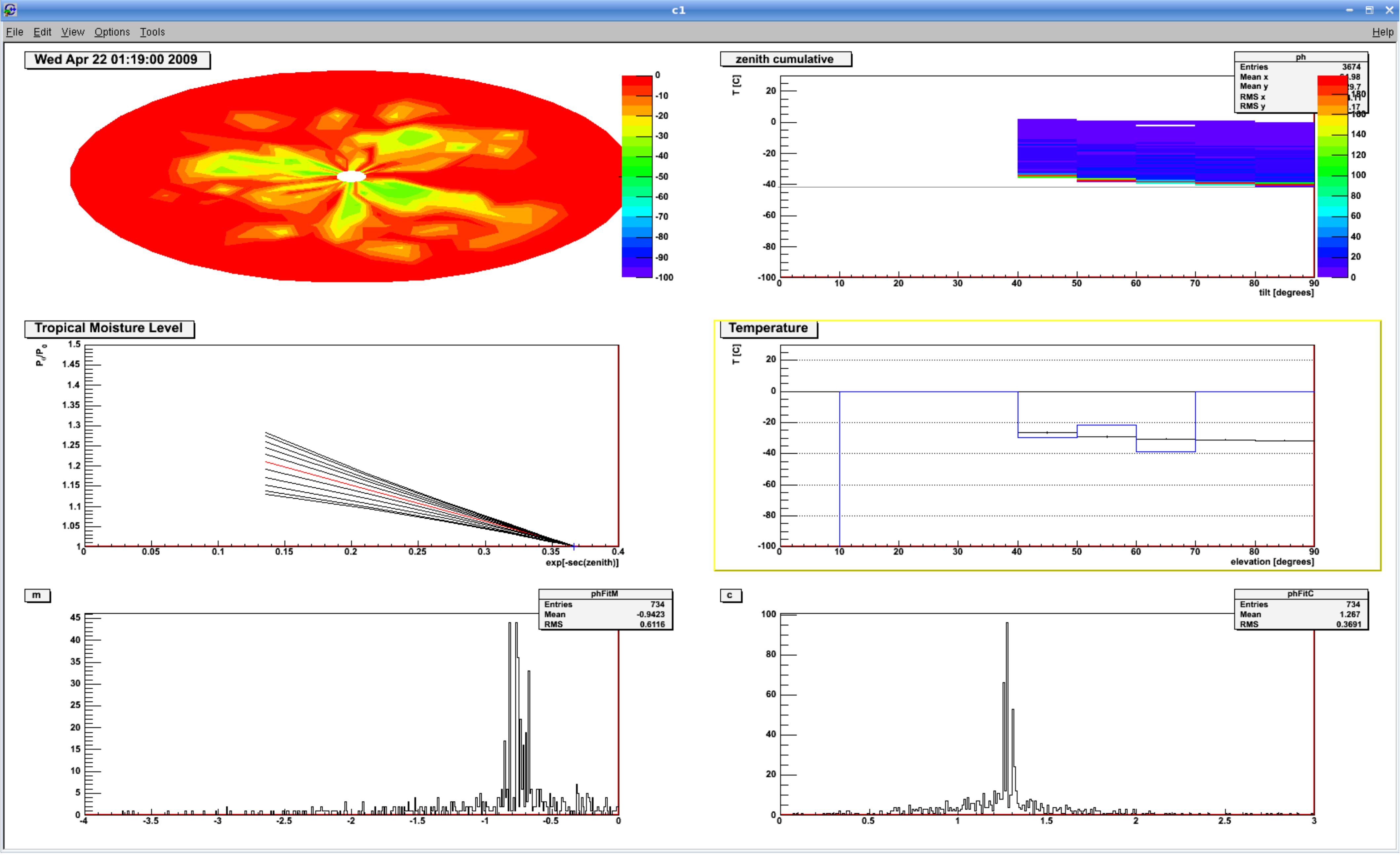
"clear" sky



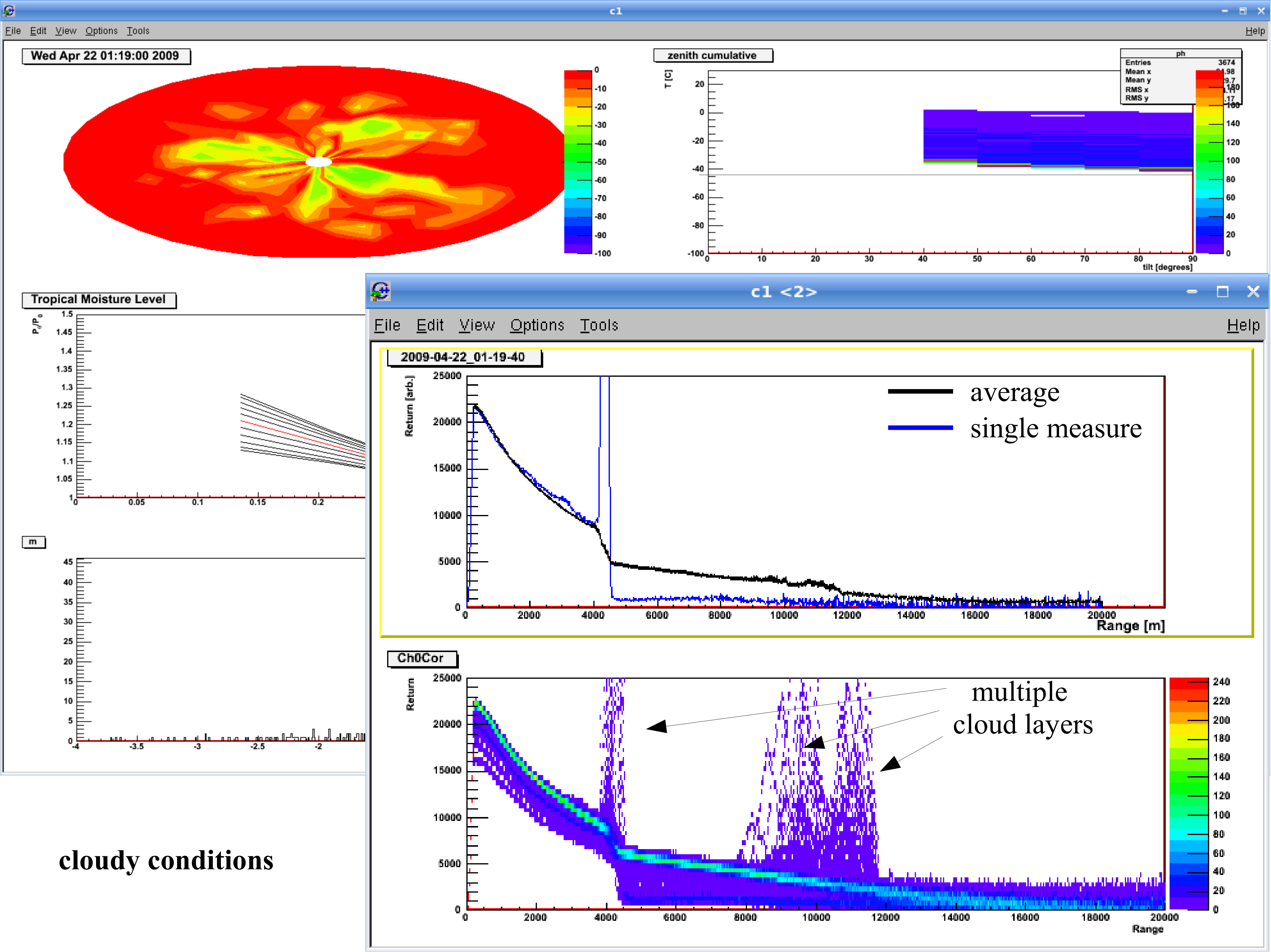




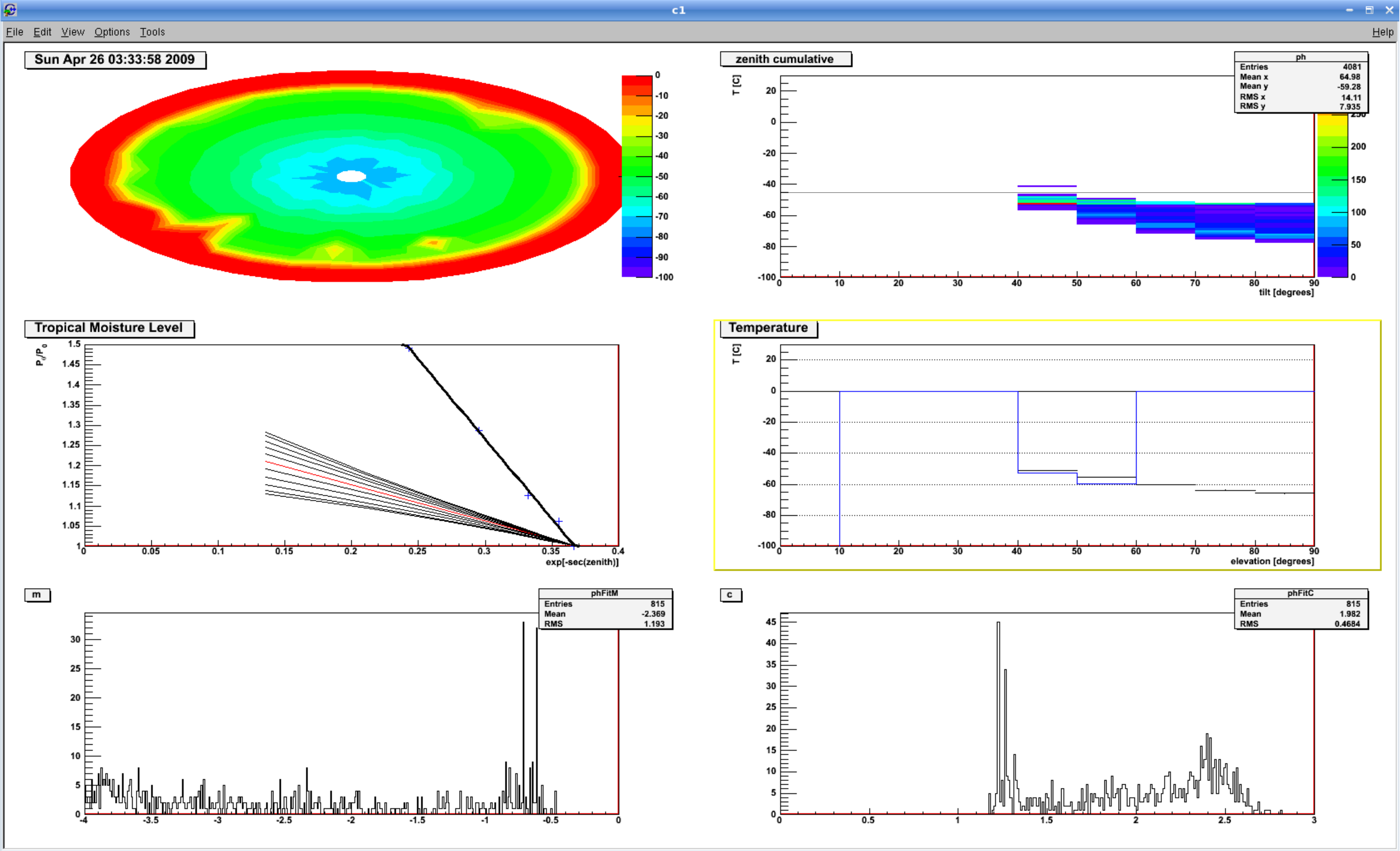
“clear” sky actually hazy



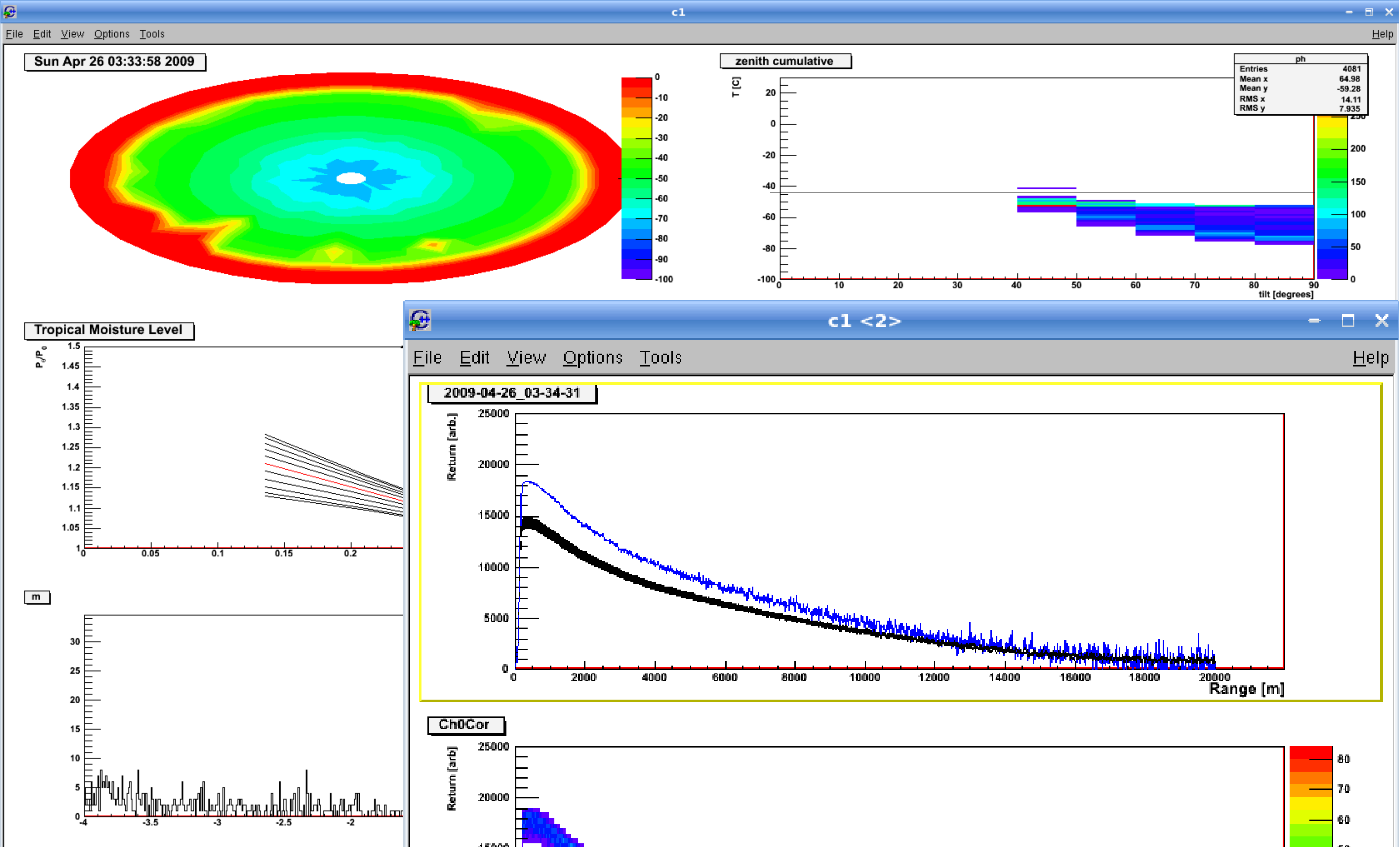
cloudy conditions

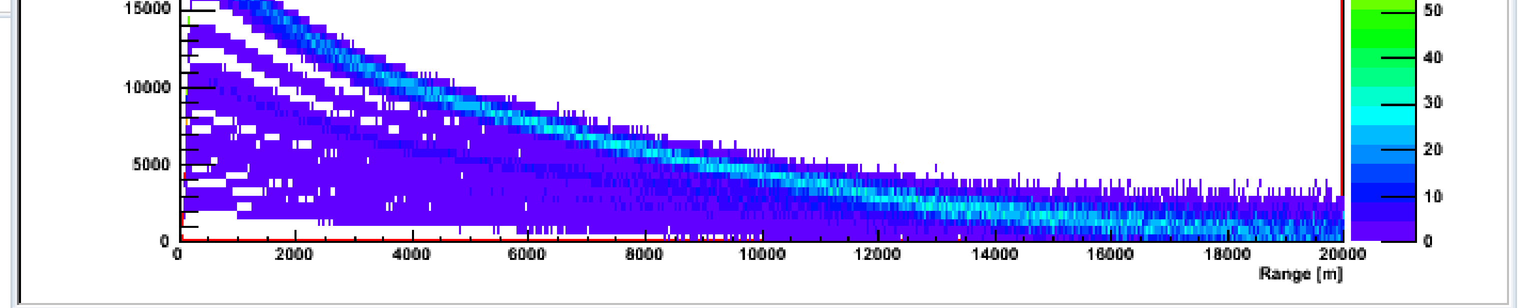


c1
File Edit View Options Tools Help
Wed Apr 22 01:19:00 2009
zenith cumulative
T [C]
tilt [degrees]
Tropical Moisture Level
m
c1 <2>
File Edit View Options Tools Help
2009-04-22_01-19-40
Return [arb.]
average
single measure
Range [m]
Ch0Cor
Return
multiple
cloud layers
Range
cloudy conditions



really clear sky

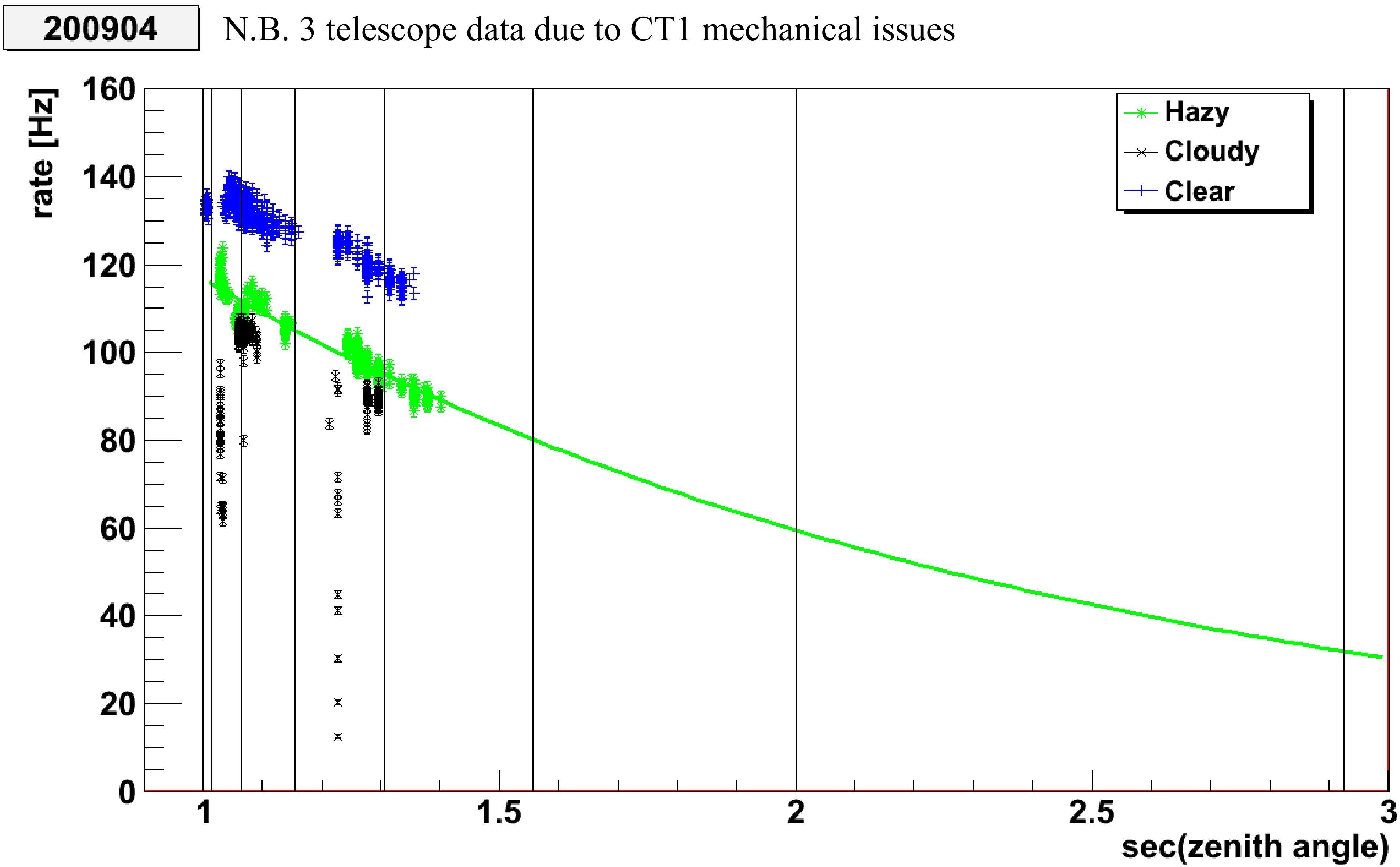




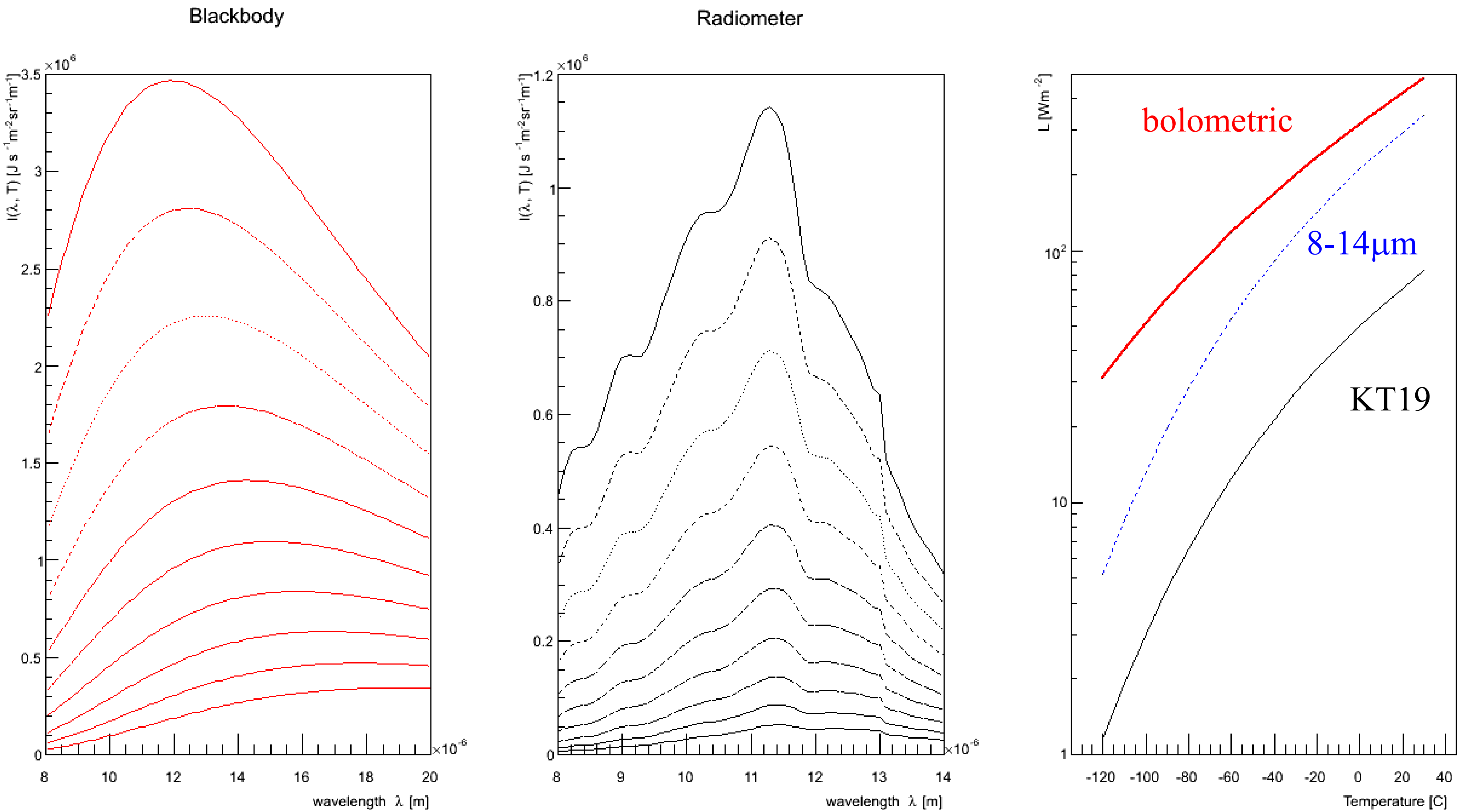
really clear sky

Trigger rates as a function of zenith angle θ for those nights in April 2009...

N.B. 3 telescope data due to CT1 mechanical issues



All 3 nights have similar temperatures & relative humidities



Blackbody
Radiometer
I(λ, T) [J s⁻¹m⁻²sr⁻¹m⁻¹]
×10⁶
wavelength λ [m]
×10⁻⁶
L [Wm⁻²]
bolometric
8-14μm
KT19
Temperature [C]

Lidar overlap factor