Atmospheric monitoring with an infra-red radiometer

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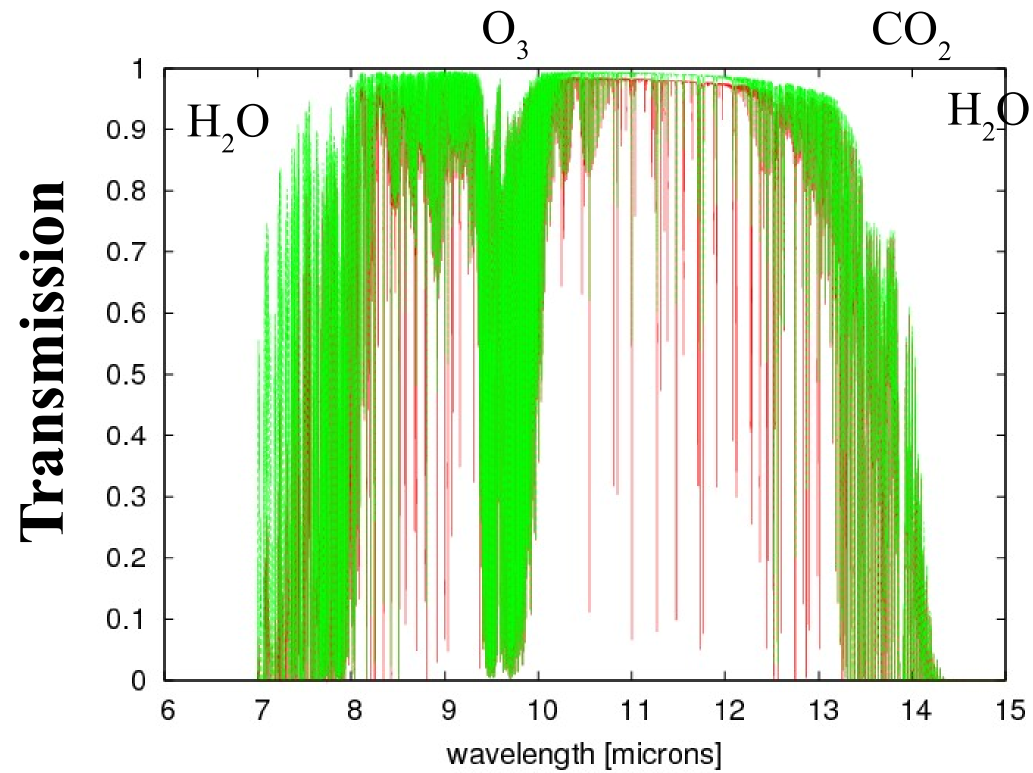
Order of play

- Introduction
- Monitoring of
  - Clouds
  - Aerosols
  - Molecules

Heitronics KT19.82 IR radiometer

Atmospheric window 8-14µm



Gemini North, Lock (1992).

Infrared Radiometer

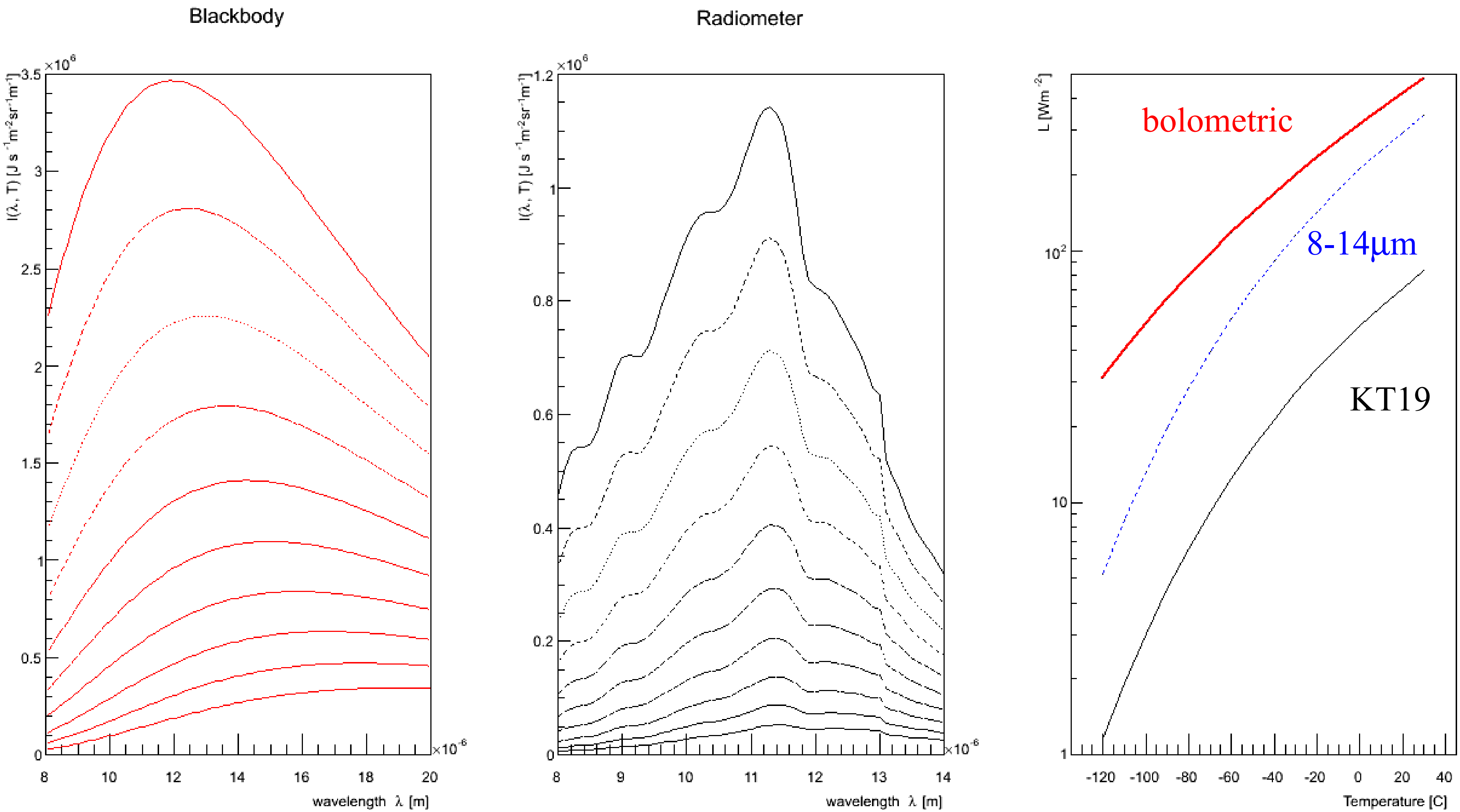
Whilst we usually talk about looking at the sky temperature as if it were a blackbody...
Remember, the radiometer is not actually measuring *temperature*, it is measuring **radiance**

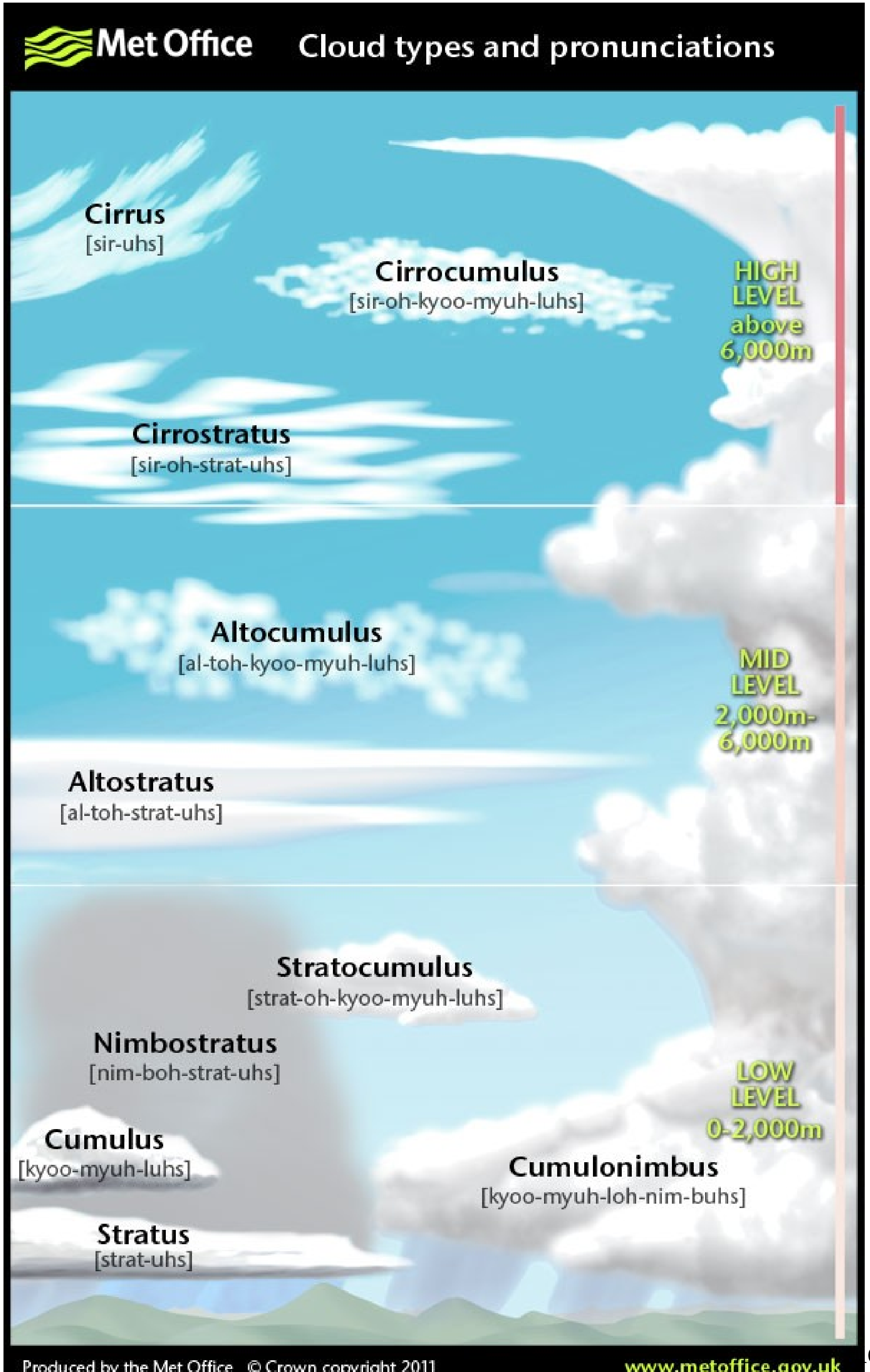
$$L_{sky} = \sigma T_{sky}^4$$
$$= L_{window} + L_{H_2O} + L_{aerosol} + L_{molecular} + \ldots$$
$$= \epsilon_w \sigma T_{window}^4 + \epsilon_{wv} \sigma T_{H_20}^4 + \epsilon_a \sigma T_{aerosol}^4 + \epsilon_m \sigma T_{molecular}^4 + \ldots$$

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 to characterise/estimate the constituent components of the observed atmosphere.

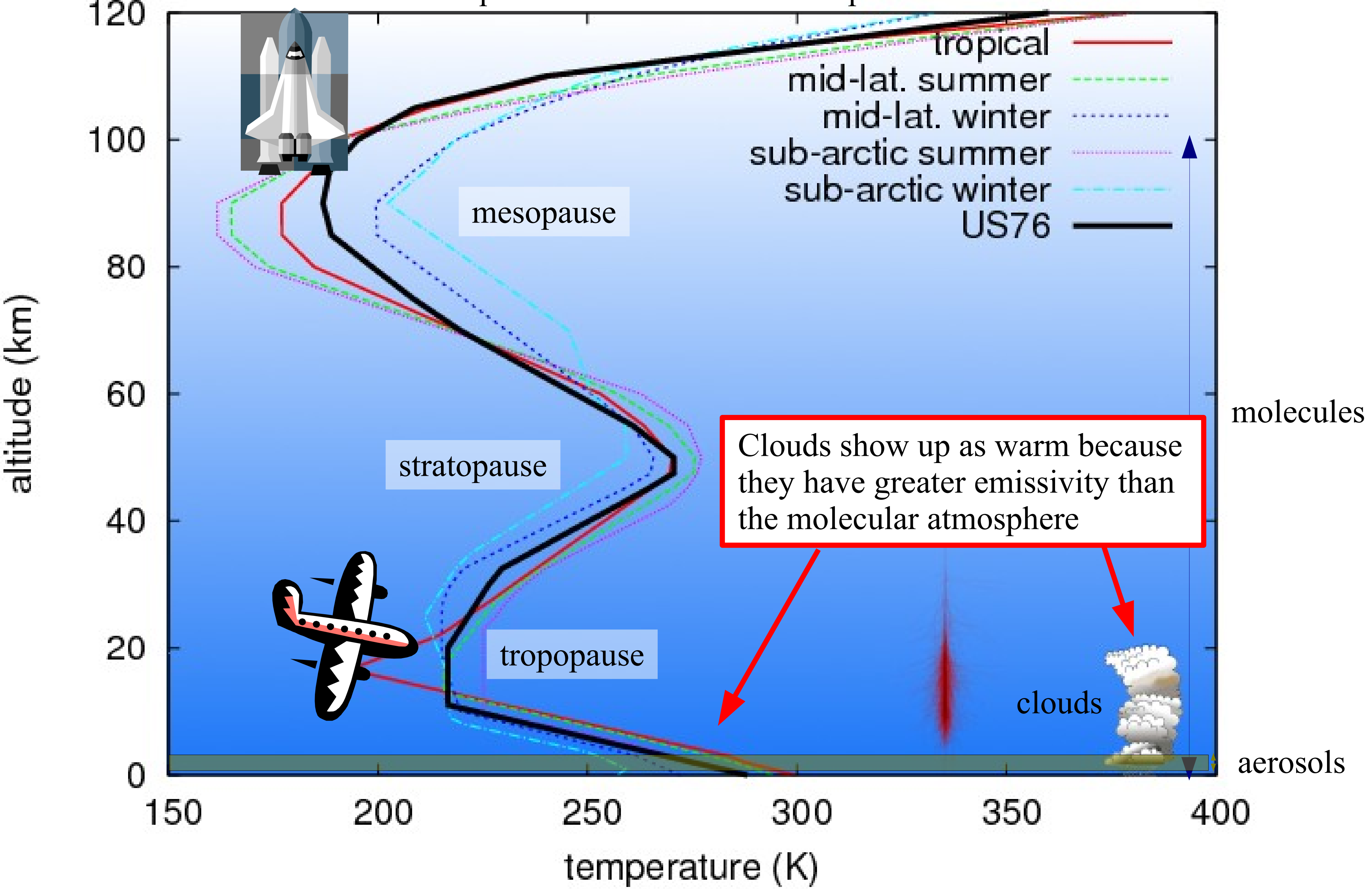

Blackbody
Radiometer
I(λ, T) [J s⁻¹m⁻²sr⁻¹m⁻¹]
×10⁶
wavelength λ [m]
×10⁻⁶
L [Wm⁻²]
bolometric
8-14μm
KT19
Temperature [C]



Clouds

$$\epsilon_{wv} \sigma T^4$$

A quick reminder on the atmosphere



Radiometers as cloud detectors

long history of using paraxially mounted radiometer to determine rate changes due to presence of clouds, but only works well if radiometer fov is well matched to IACT fov.

KT17 on Durham Mark 6 IACT

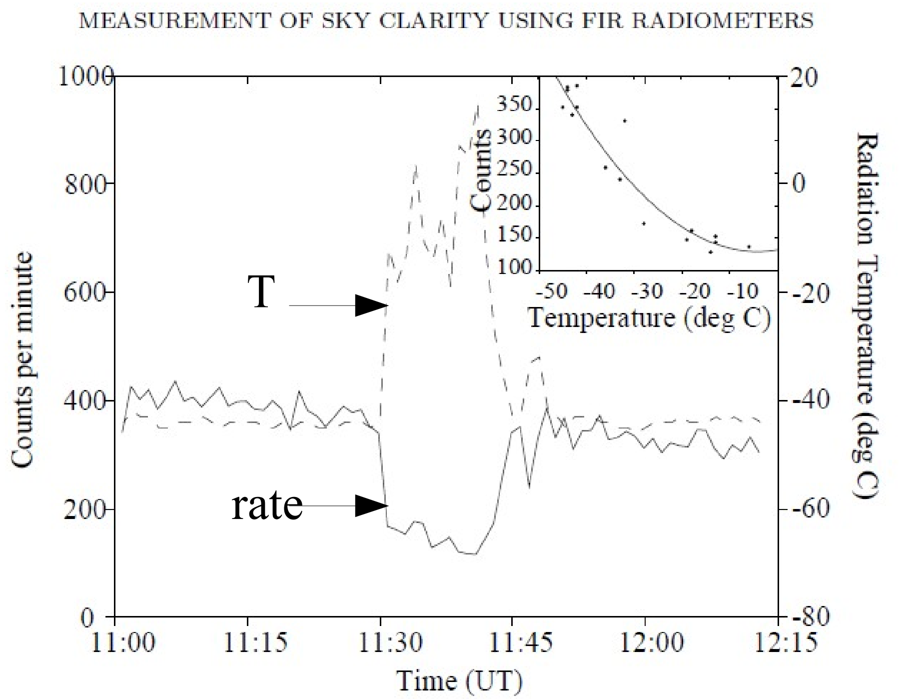
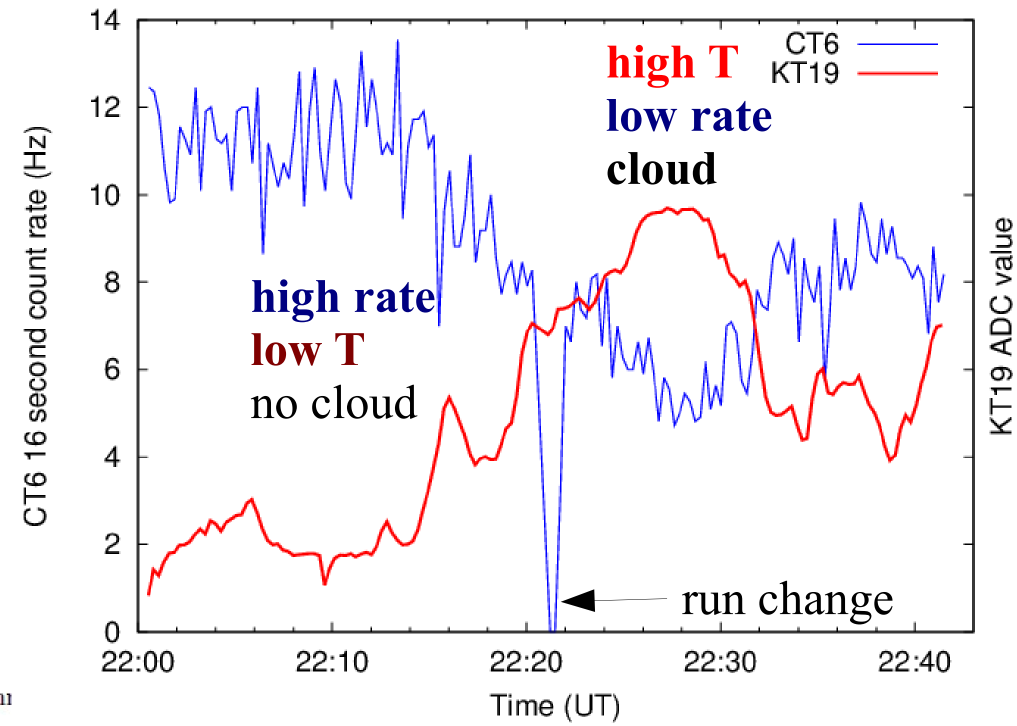


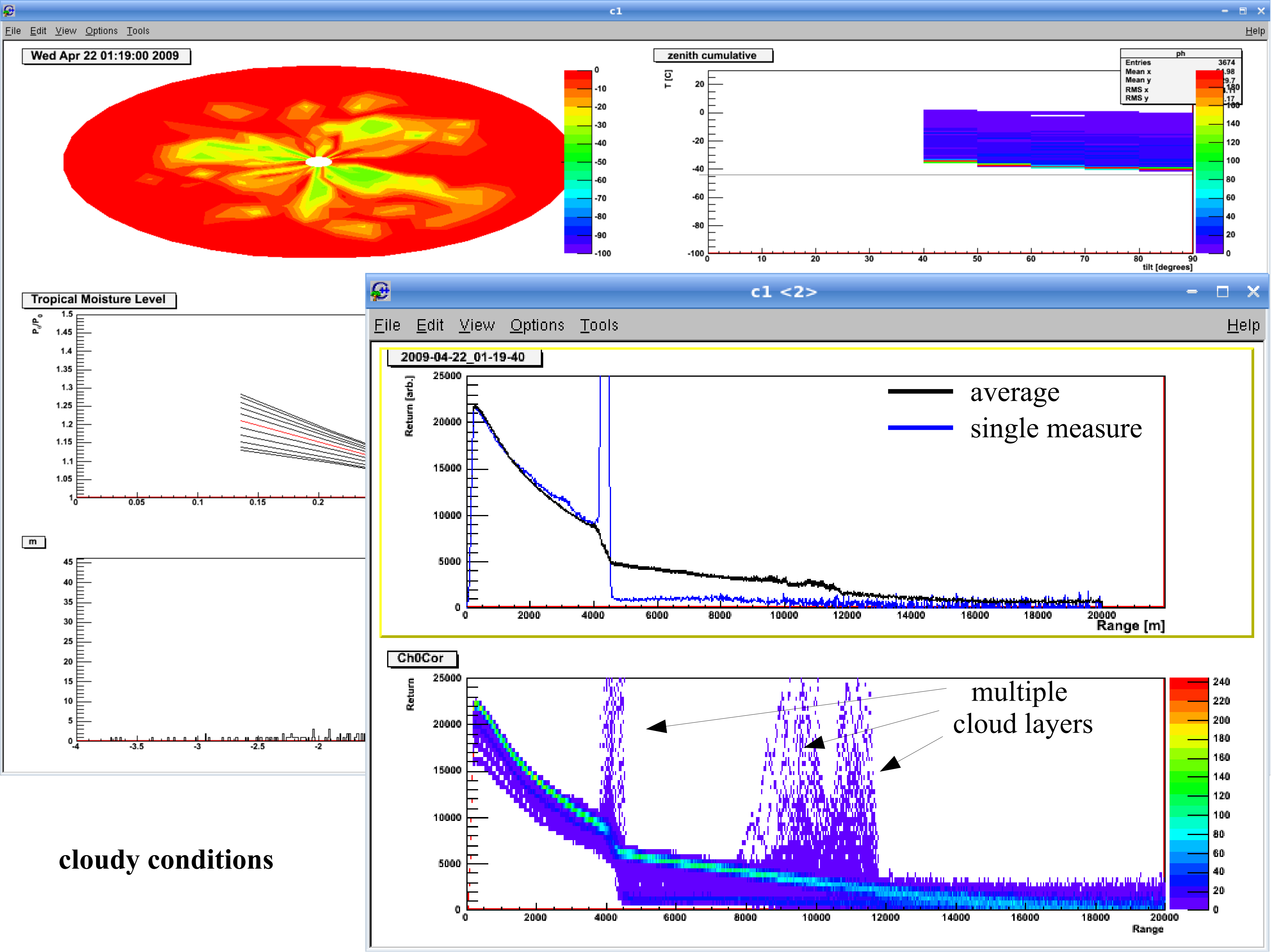
Figure 1. The correlation between the background counting rate of the Mark 6 gamma ray telescope (solid line) and the radiative temperature of the sky (broken line).

Buckley et al. *ExA* **9**, 237 (1999).

KT19 on Hegra CT6 IACT



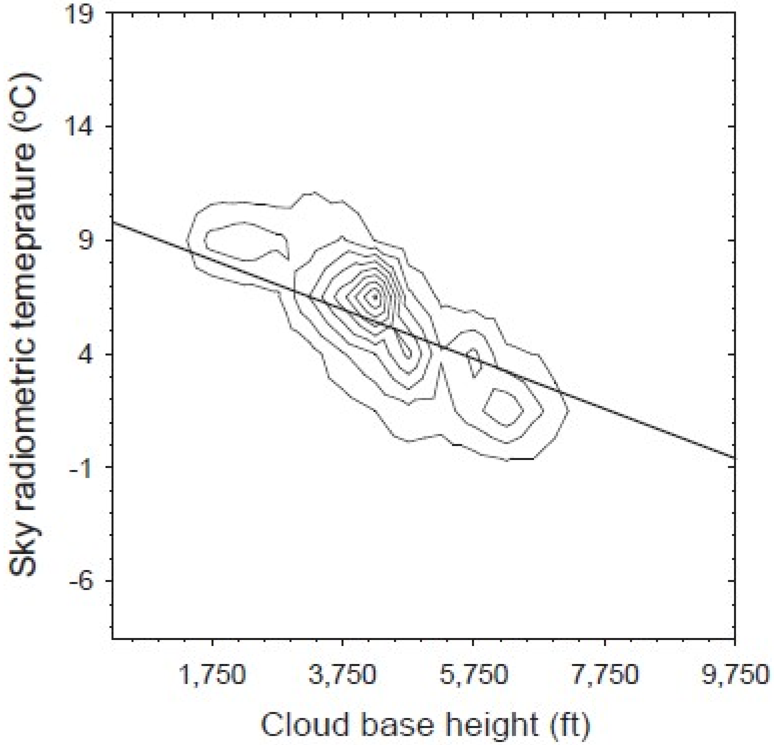
Daniel PhD thesis (Durham, 2002).



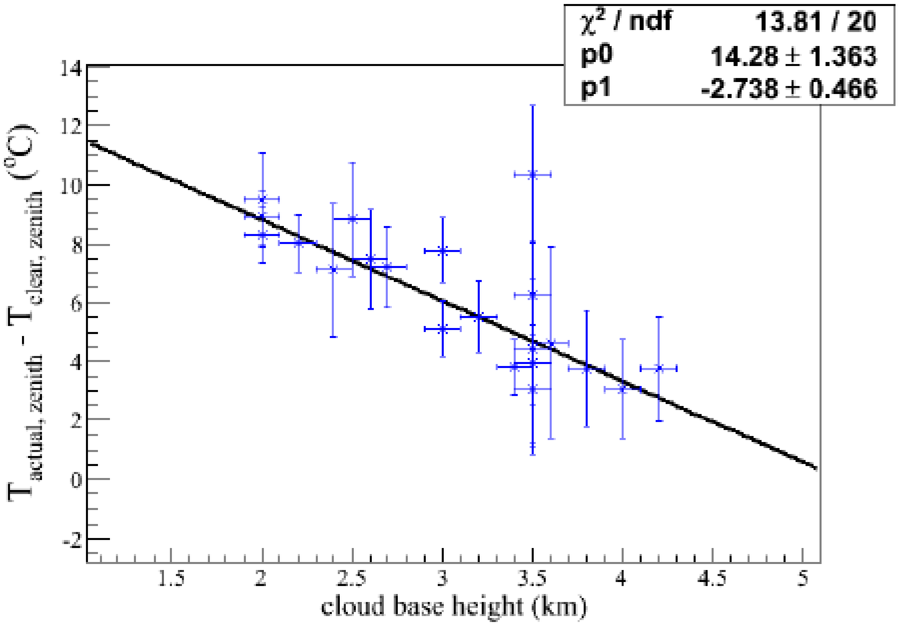
c1
File Edit View Options Tools Help
Wed Apr 22 01:19:00 2009
zenith cumulative
T [C]
tilt [degrees]
ph
Entries 3674
Tropical Moisture Level
m
c1 <2>
2009-04-22_01-19-40
Return [arb.]
average
single measure
Range [m]
Ch0Cor
Return
multiple cloud layers
Range
cloudy conditions

Radiometers as cloud height detectors

There is clearly a correlation between sky brightness temperature and cloud height



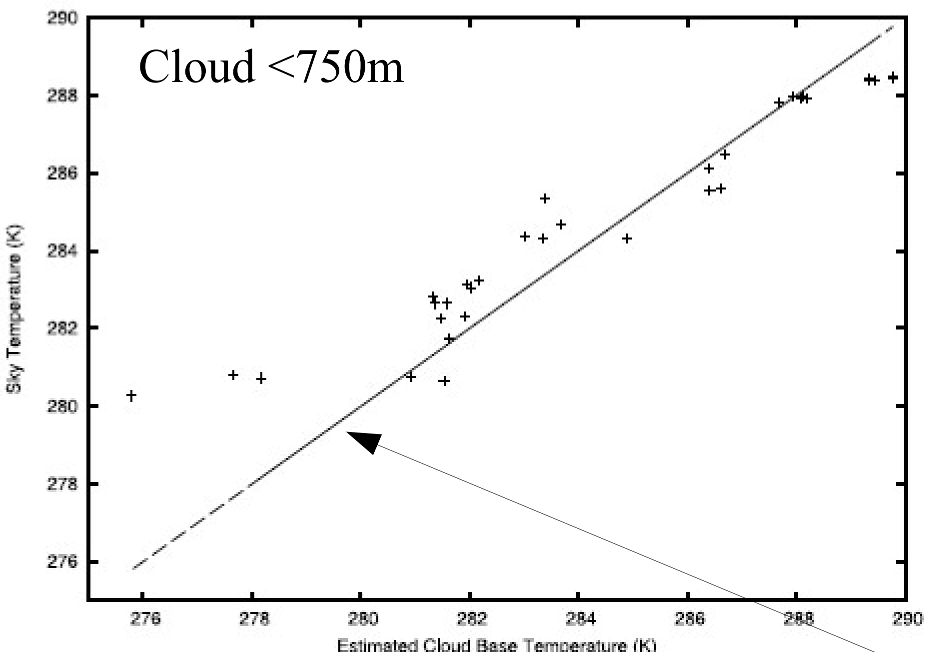
Buckley et al. *ExA* **9**, 237 (1999).

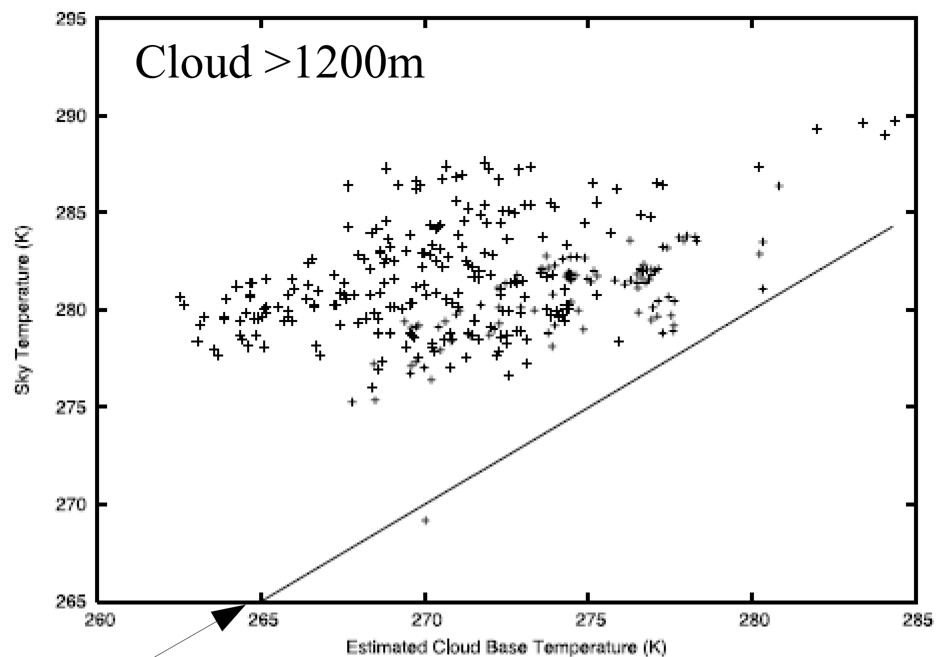


YTE Lo 'Determining Atmospheric Clarity for the Calibration of Ground-based Gamma-ray Telescopes' L4 project report, Durham (2013).

Radiometers as cloud height detectors?

There are subtleties that skew the estimate of cloud base height from its temperature. Close to the ground the cloud may be acting more like a mirror than a blackbody, higher altitude cloud likely has the temperature mediated by effects of intervening water vapour, very high cloud will have different emissivity dependent on whether it is composed of water drops or ice crystals





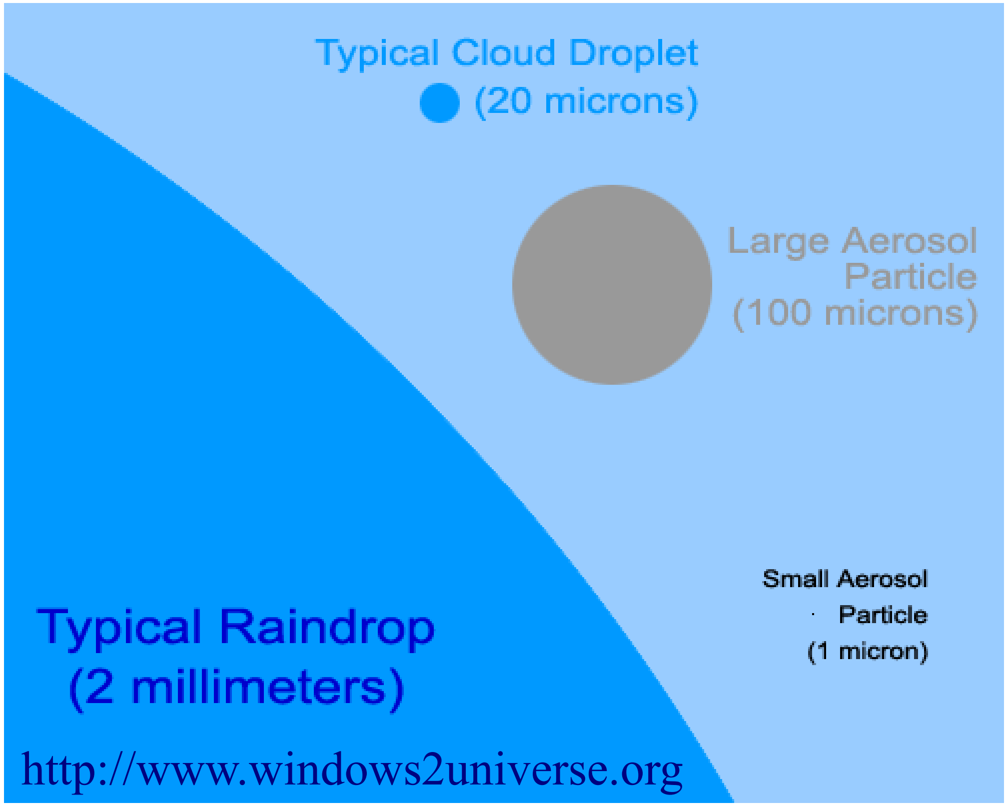
Heimann TPS354 thermopile
5.5->14μm
fov 3^{o} FHWM
sited Southern Australia

equality of sky & cloud base temperatures

cloud base temperature estimated from a model with 2.2K/300m lapse rate and assumed cloud base emissivity.

Riordan et al. Journal of Geophysical Research **110**, *3207* (2005).

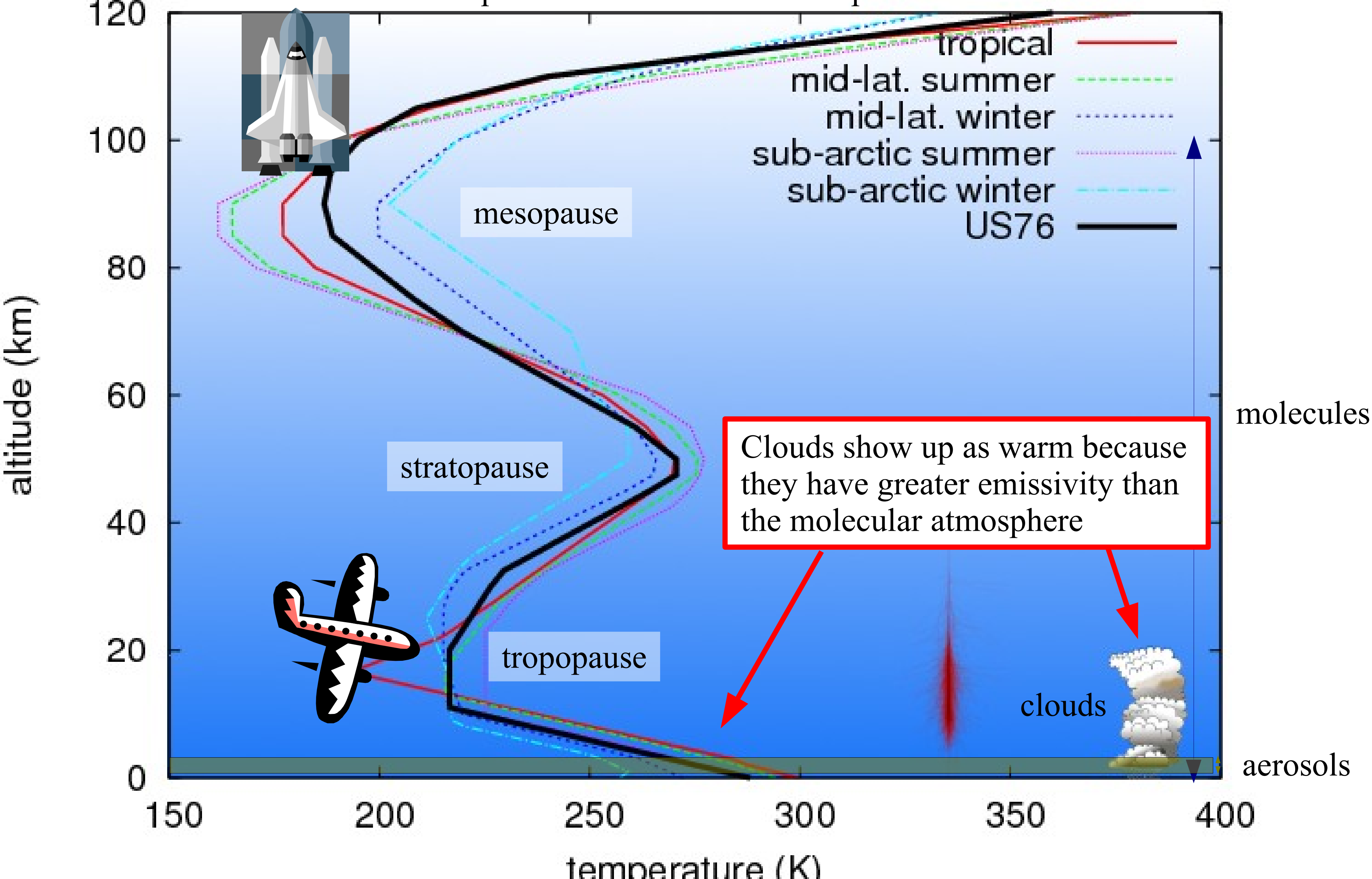
Aerosols



Sources of the key climate-affecting aerosol types

Source	Region	Dominant Species
Industrial pollution	Eastern North America, Europe, Eastern Asia	water-soluble inorganic (e.g., sulfate, nitrate, ammonium), organic carbon, elemental carbon
Biomass combustion	tropical/subtropical South America and Africa	organic carbon, elemental carbon
Wind-blown dust	disturbed arid soils	mineral dust
Natural	remote continental, remote marine, free troposphere	

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

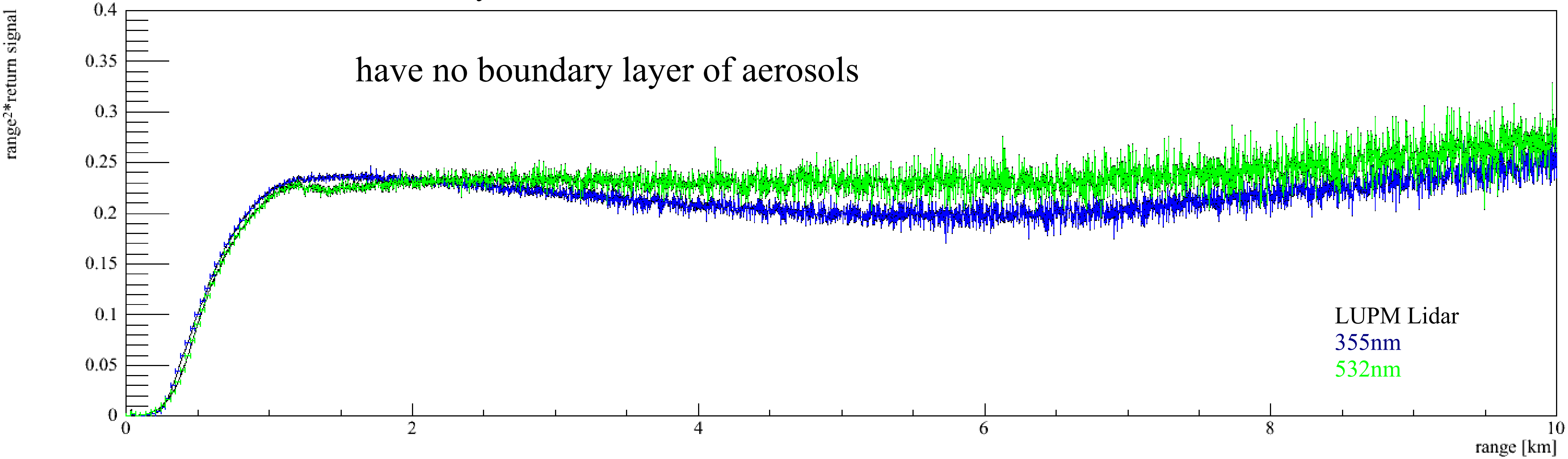
Large aerosols (e.g. pollen, sand grains) can add 30W/m^2 to the 8-13μm atmospheric window

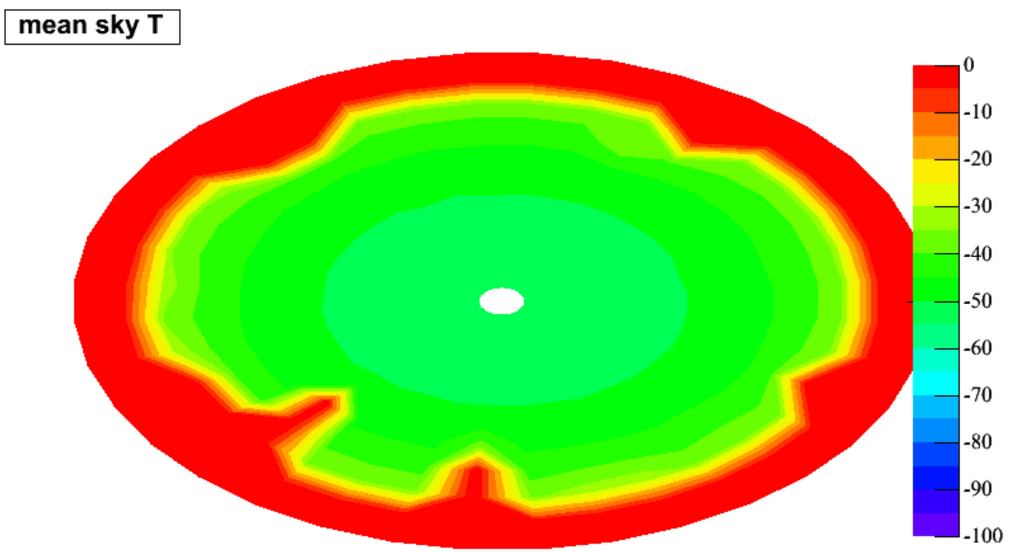
Dalrymple & Unsworth, Quart. J. R. Met. Soc. **104**, 989 (1978)

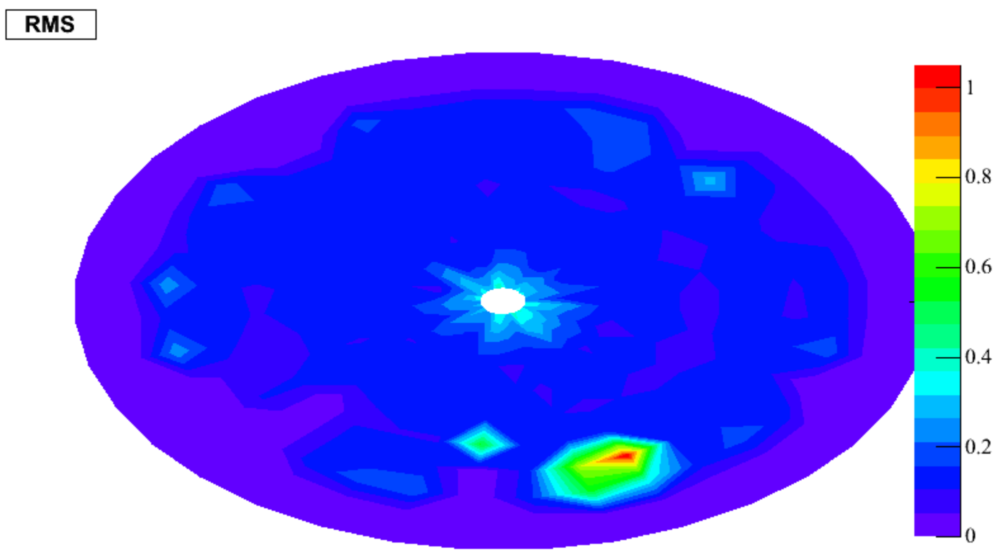
molecular luminosity [W/m^2]	brightness temperature [C]		T with additional 30 W/m^2 [C]
140	-50		-39
117	-60		-47
97	-70		-56
79	-80		-64

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

really clear skies 2011/08/25

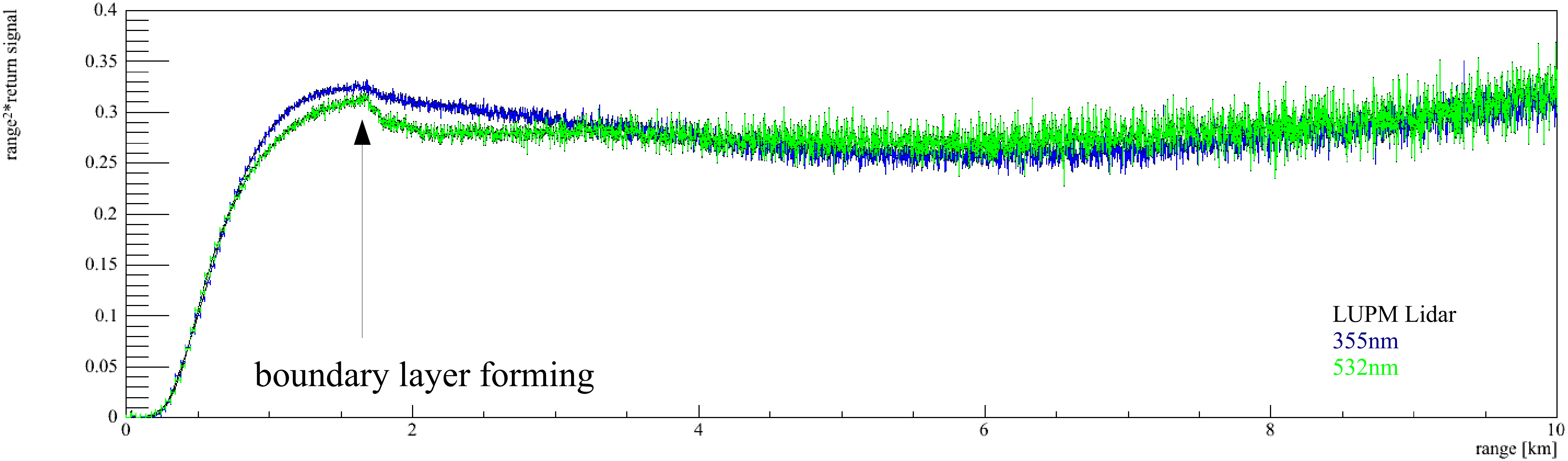


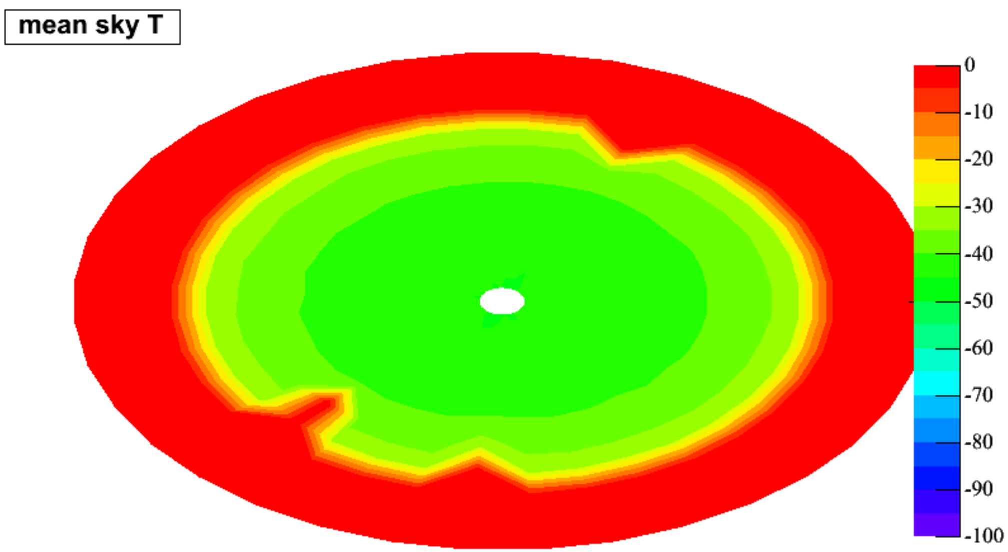


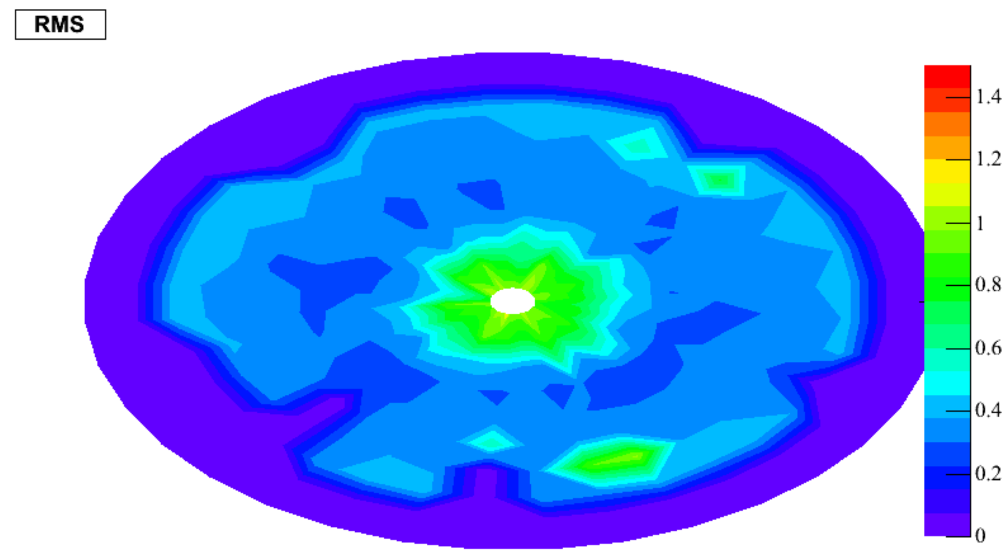


nb, all these nights listed as clear in shift logs & web summary.

2011/08/26

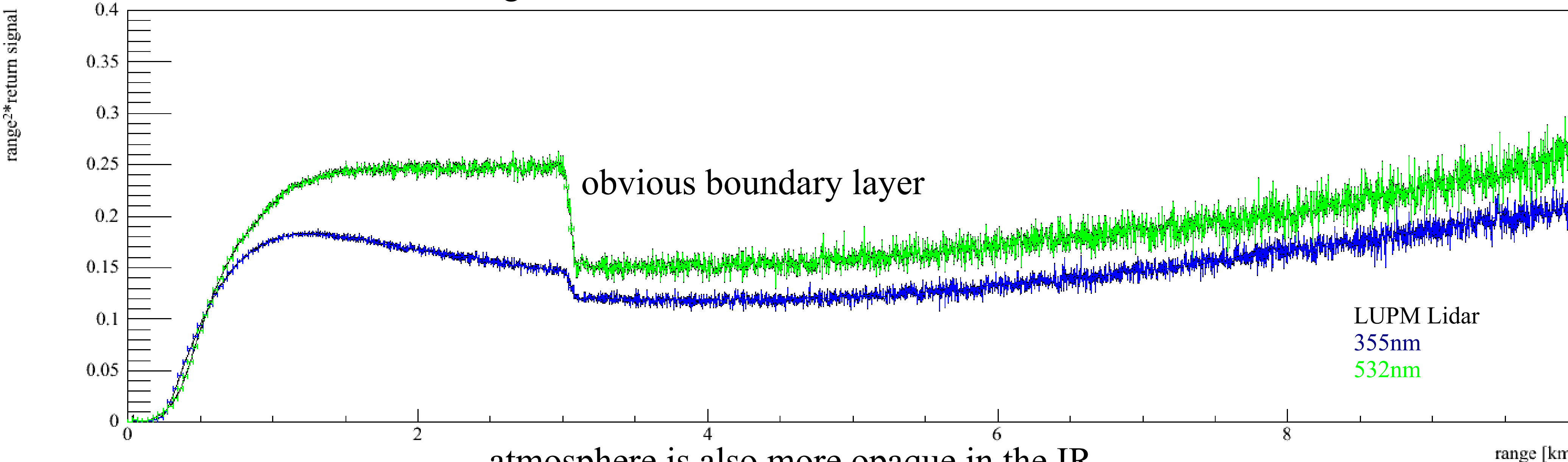




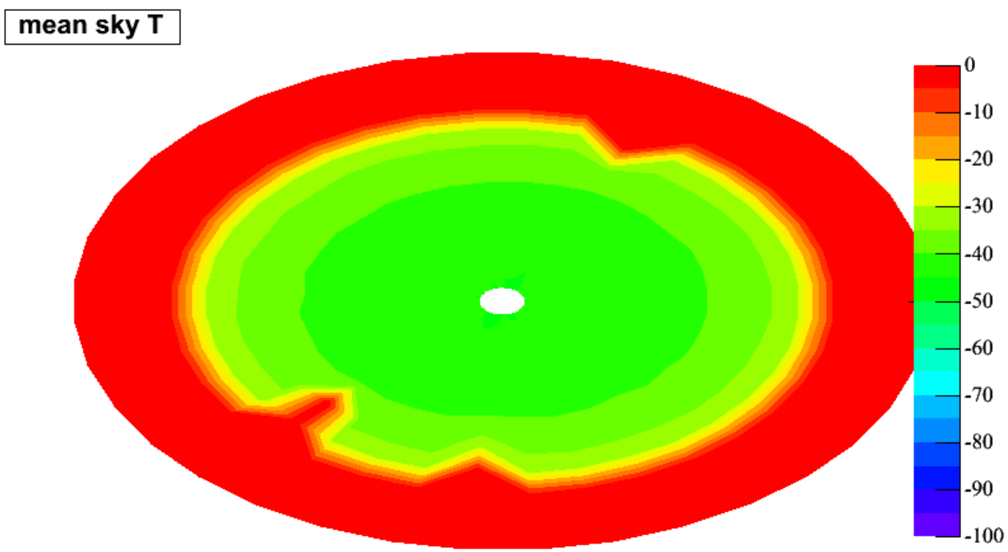


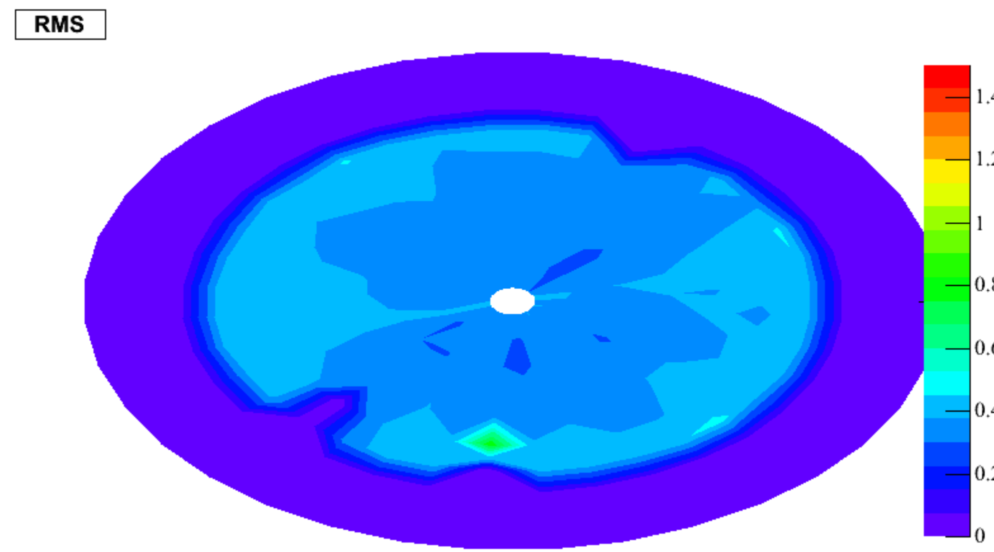
nb, all these nights listed as clear in shift logs & web summary.

“normal” observing conditions 2011/08/29



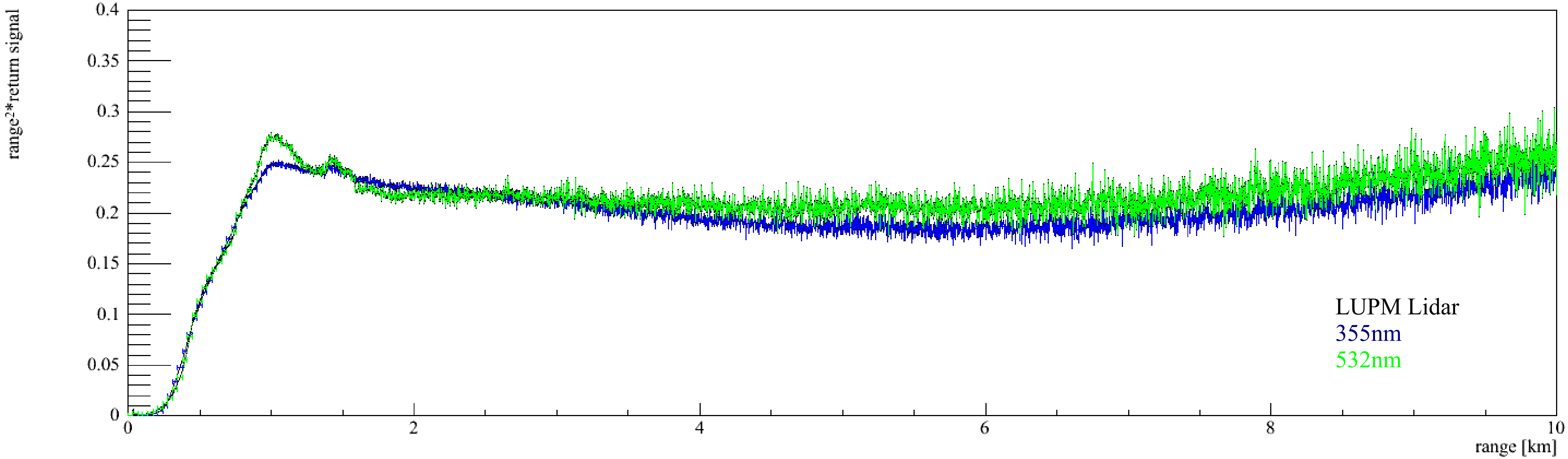
atmosphere is also more opaque in the IR

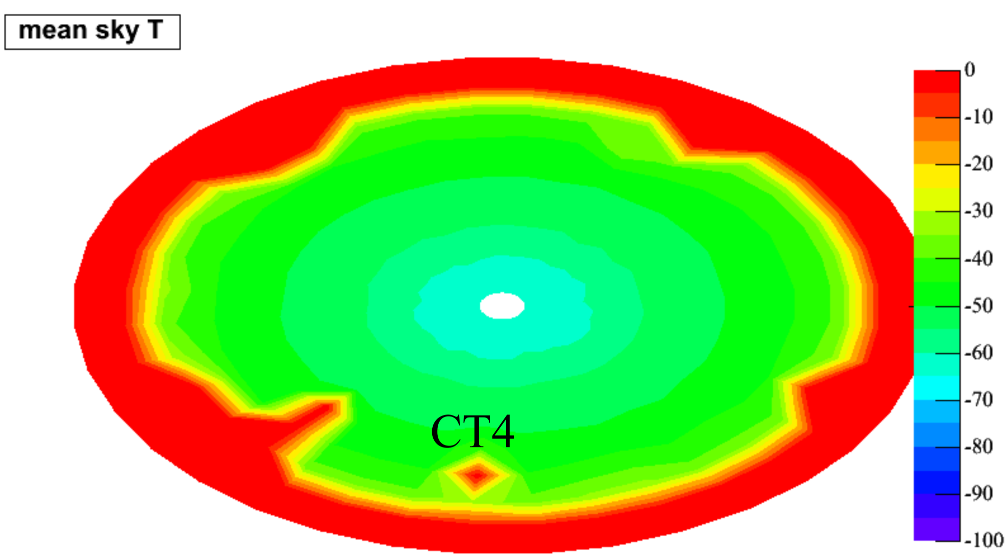


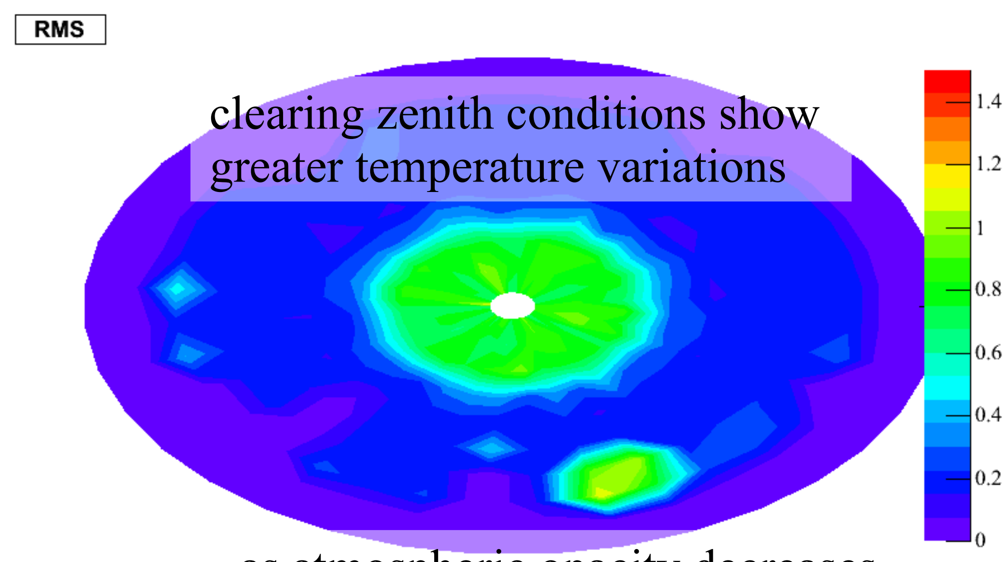


nb, all these nights listed as clear in shift logs & web summary.

2011/09/01



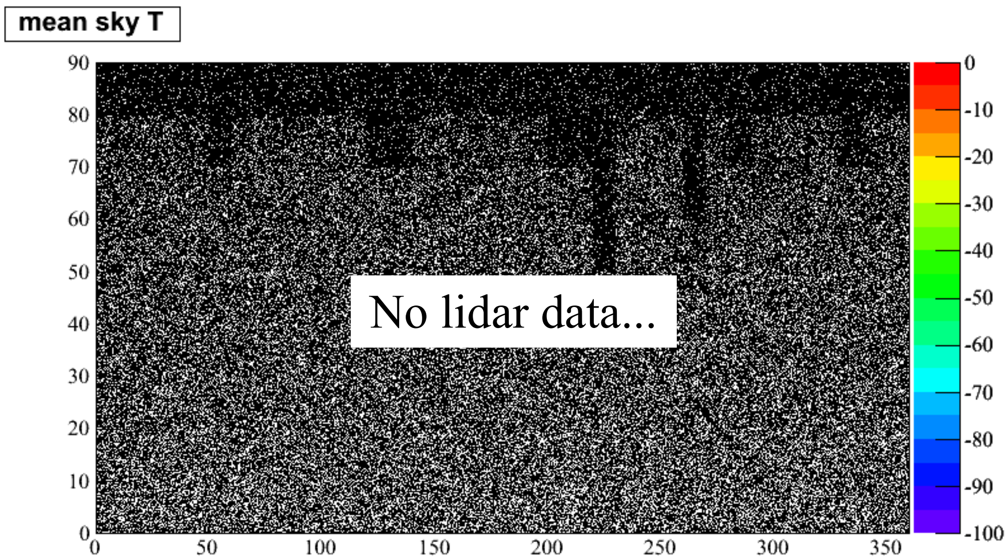


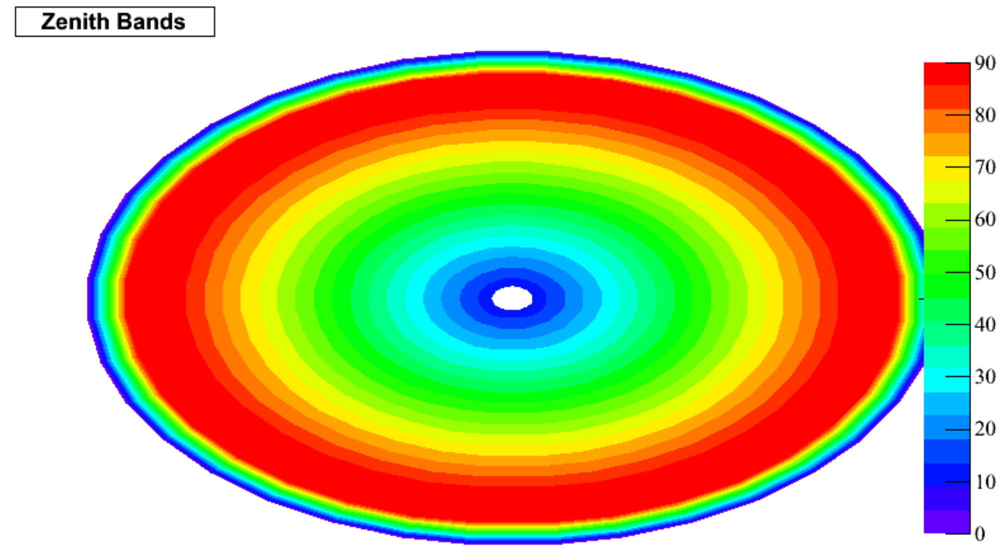


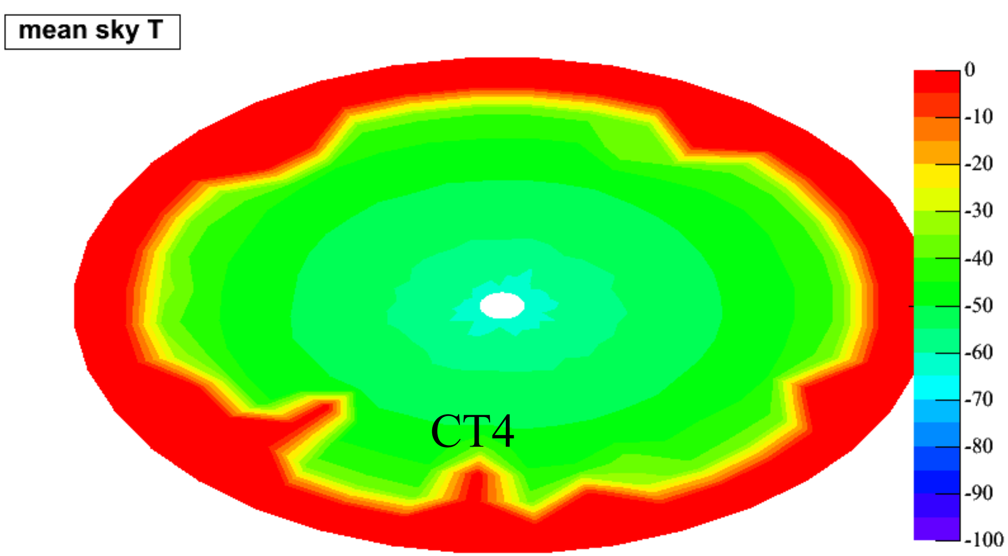
as atmospheric opacity decreases new features become apparent

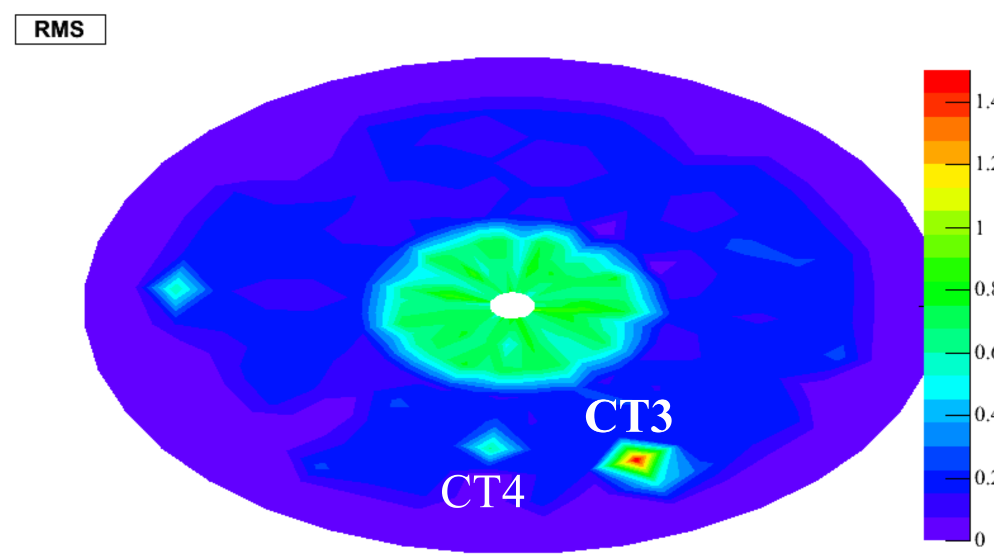
nb, all these nights listed as clear in shift logs & web summary.

2011/09/04





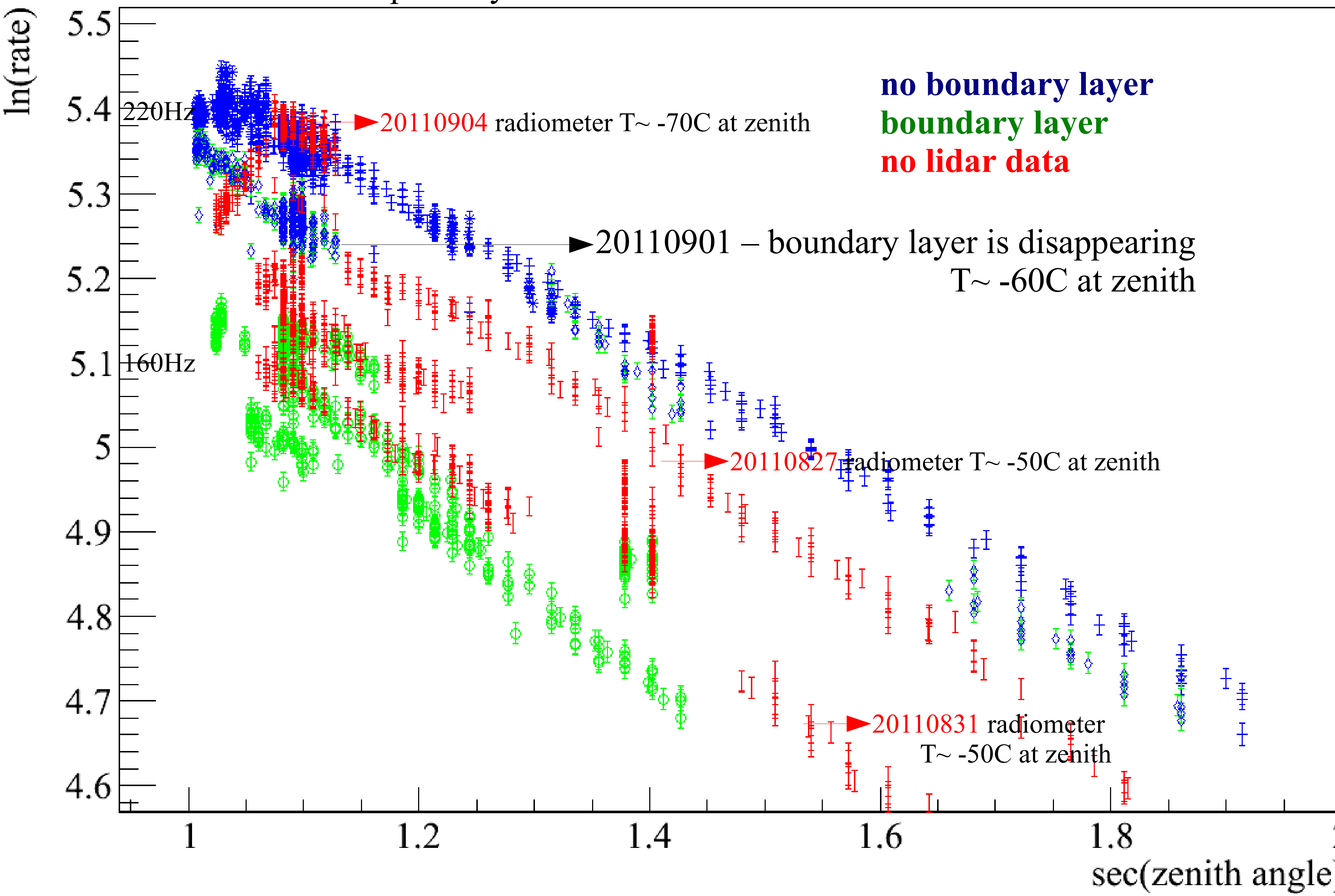




IR optical depth has dropped to ~200m as boundary layer moves down and aerosols have sedimented out of atmosphere comparing those nights telescope trigger rates

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

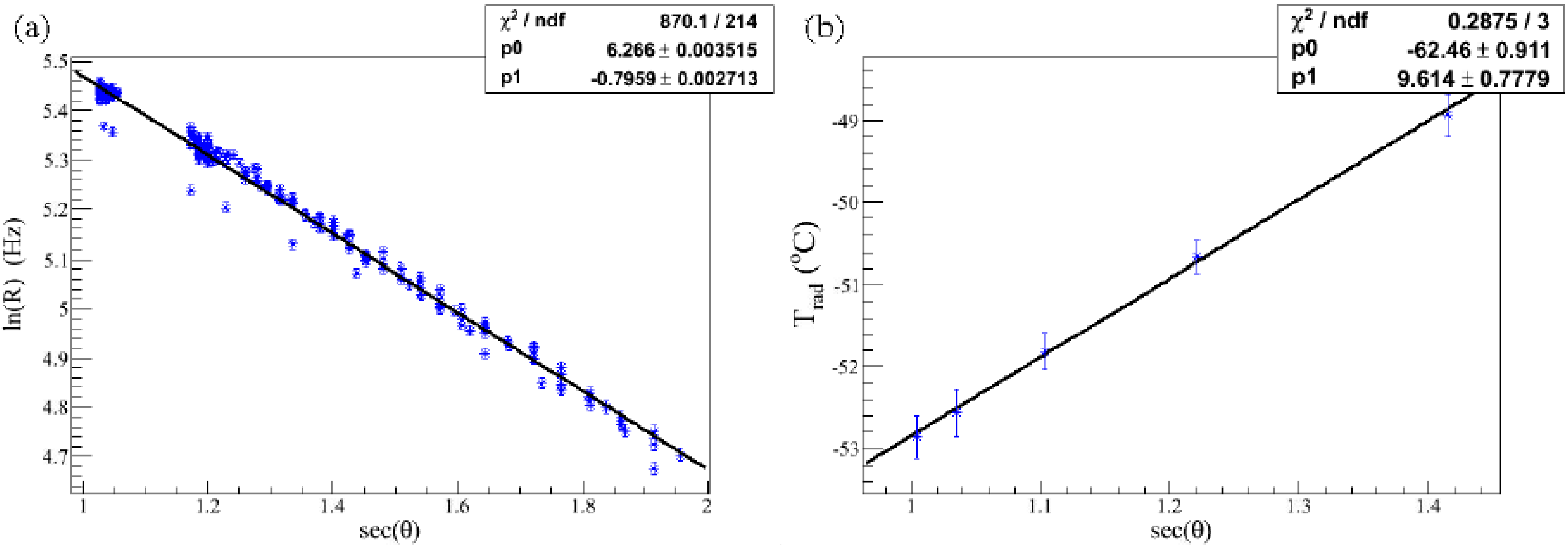
Leads to 19 'good' nights (~100 runs with lidar data) concentrated July->December

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

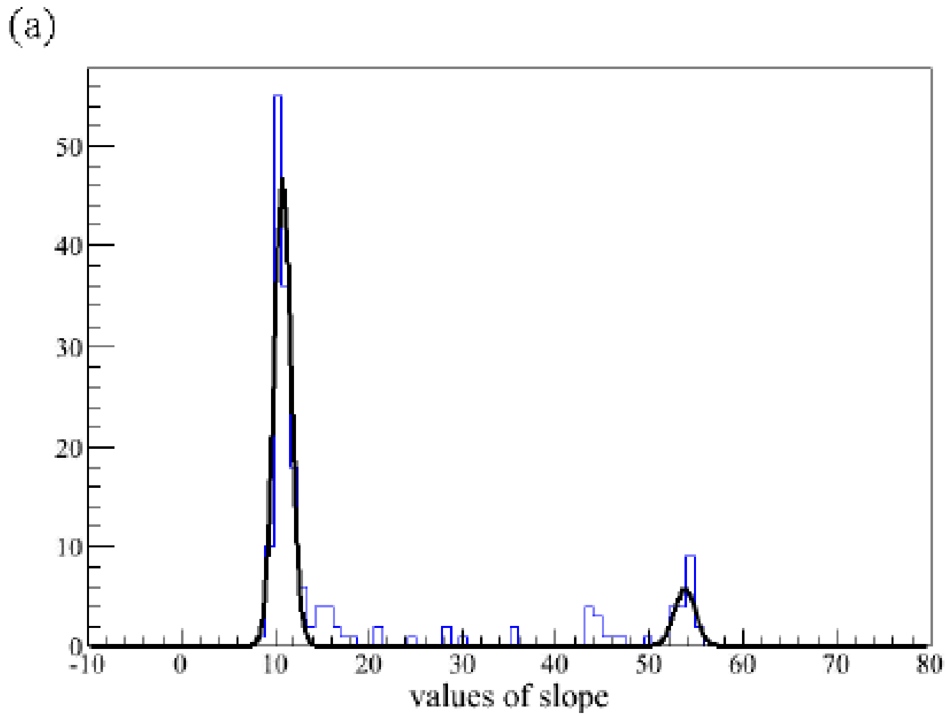
20110824

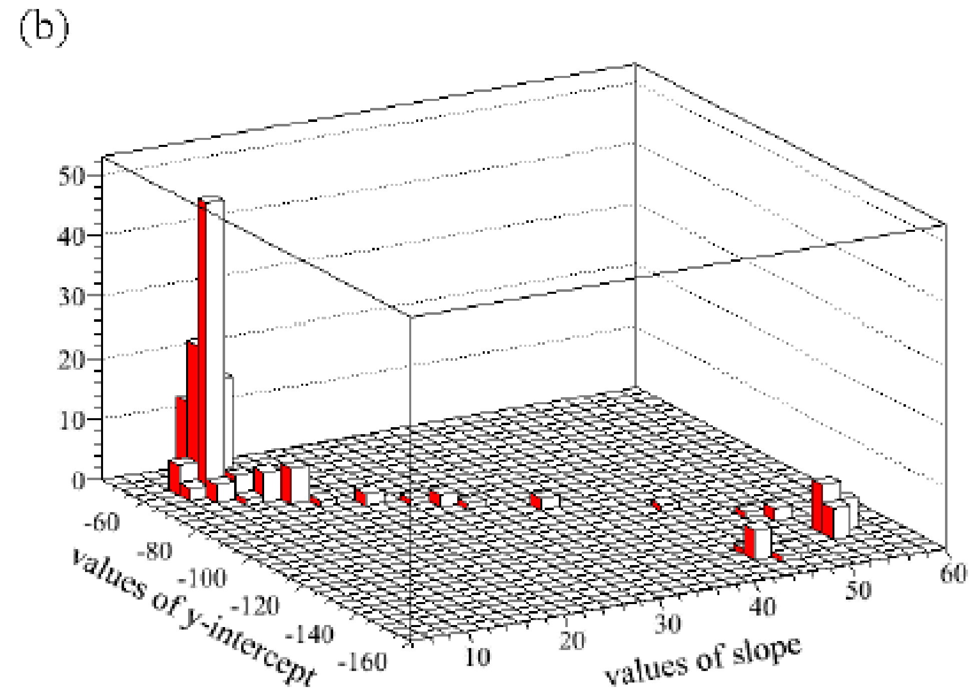


Use clear sky runs to calculate an empirical estimate of clear sky conditions

$T_{clear,zenith}$

$R_{clear,zenith}$



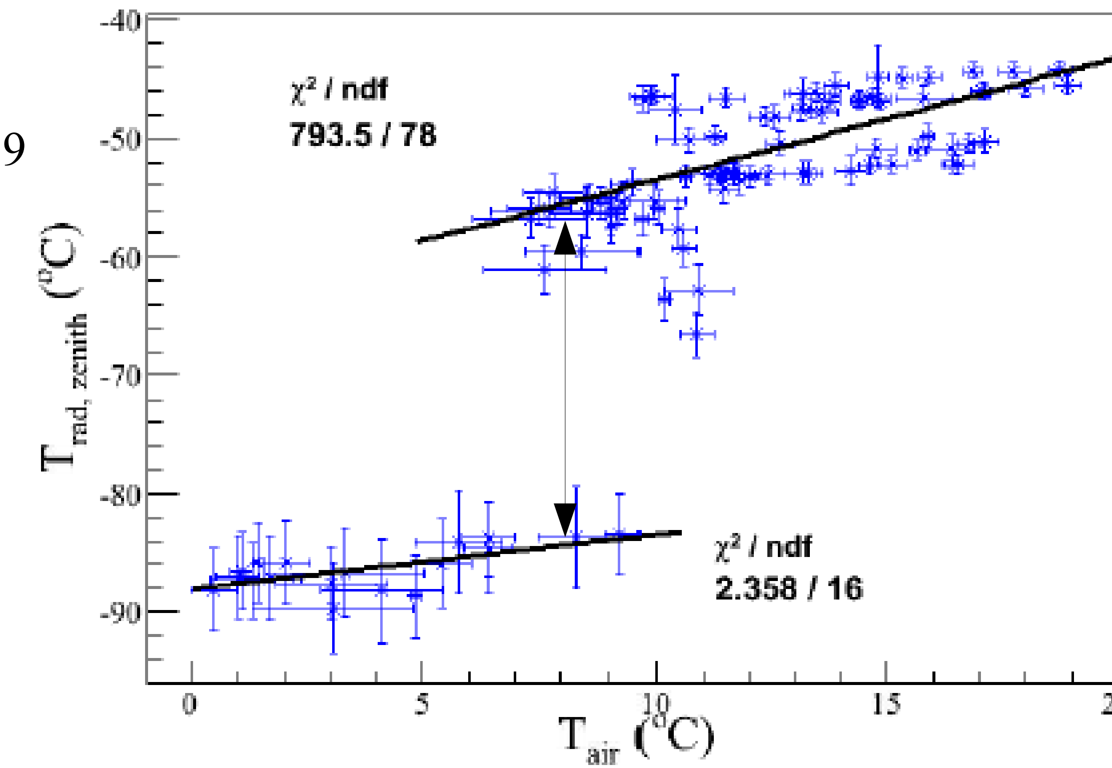


Need to take note of possible systematics

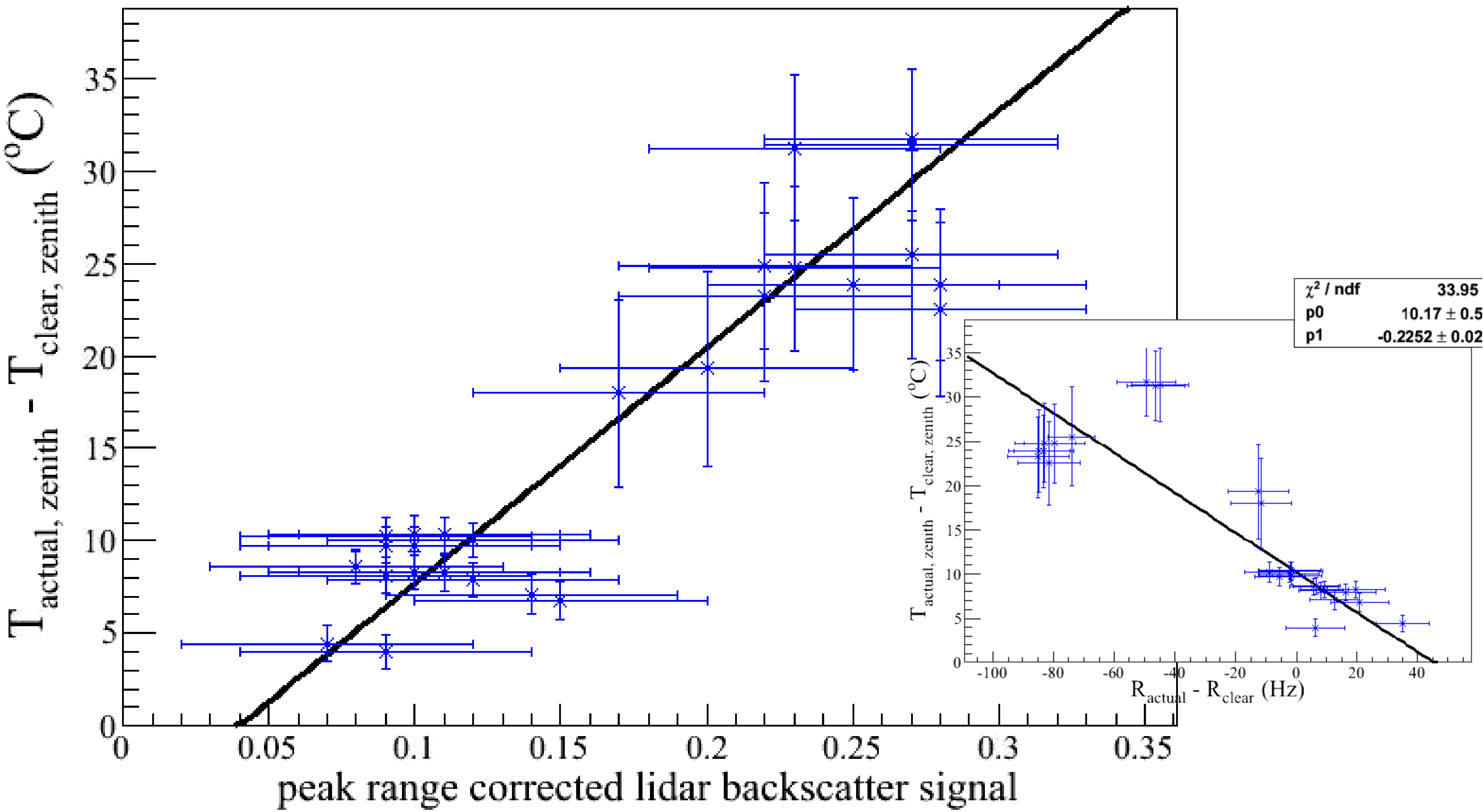
-50C is temperature limit of unmodified KT19

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

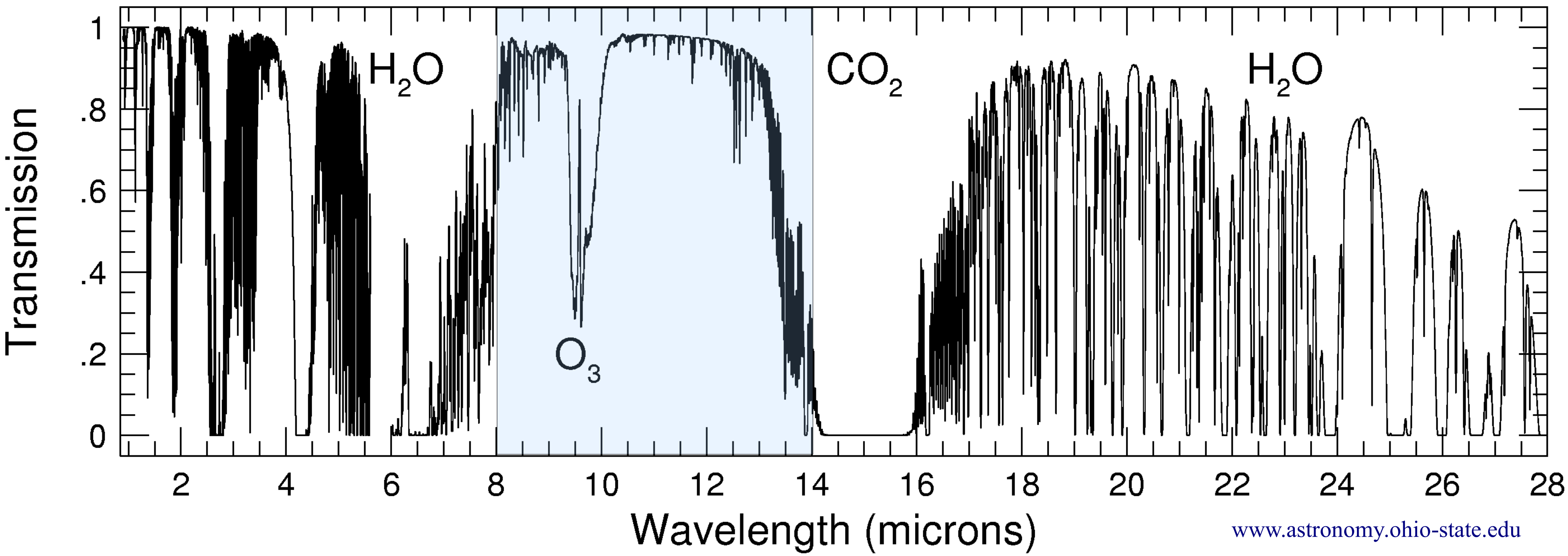
etc, etc...



Observe a strong correlation between sky brightness temperature and aerosols



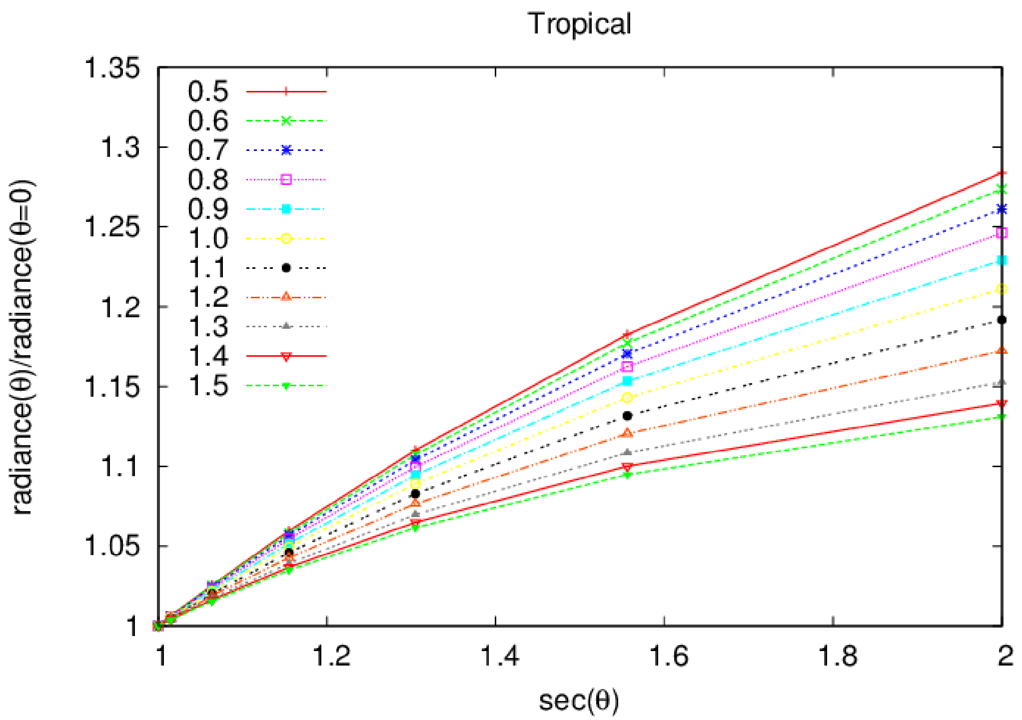
Molecules?



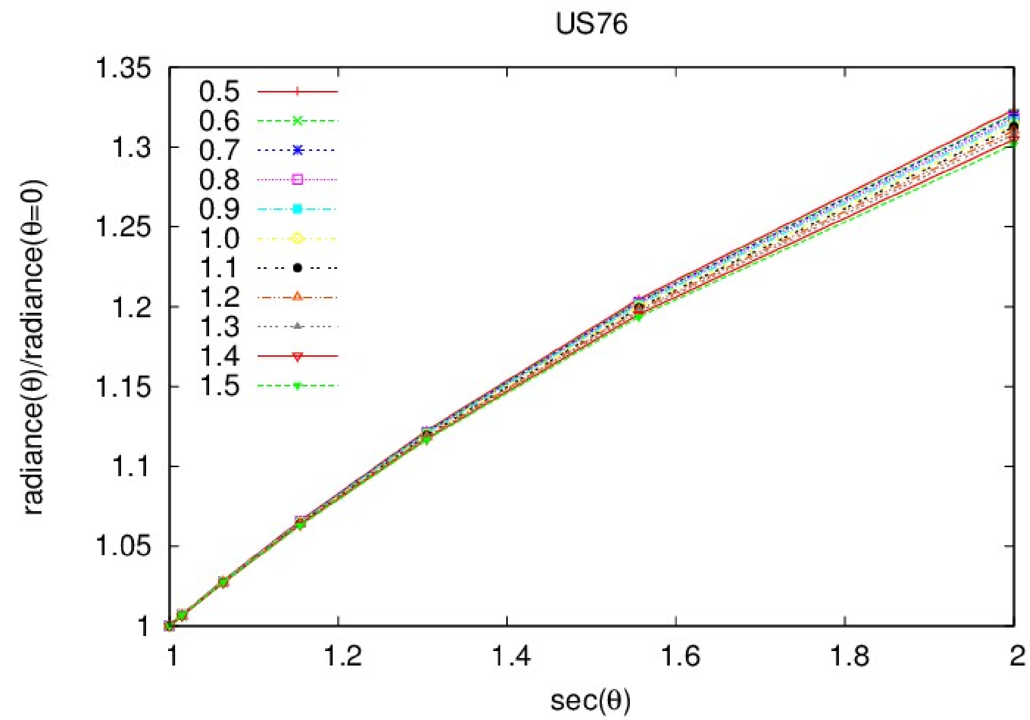
www.astronomy.ohio-state.edu

Detecting changes in the molecular content of the atmosphere?

Scale the water vapour content of a model atmosphere from 50% to 150% of nominal value and see how the brightness changes as a function of zenith angle...



A warm atmosphere can contain a lot of water vapour before it condenses and this can potentially show up as quite a range in the temperature behaviour

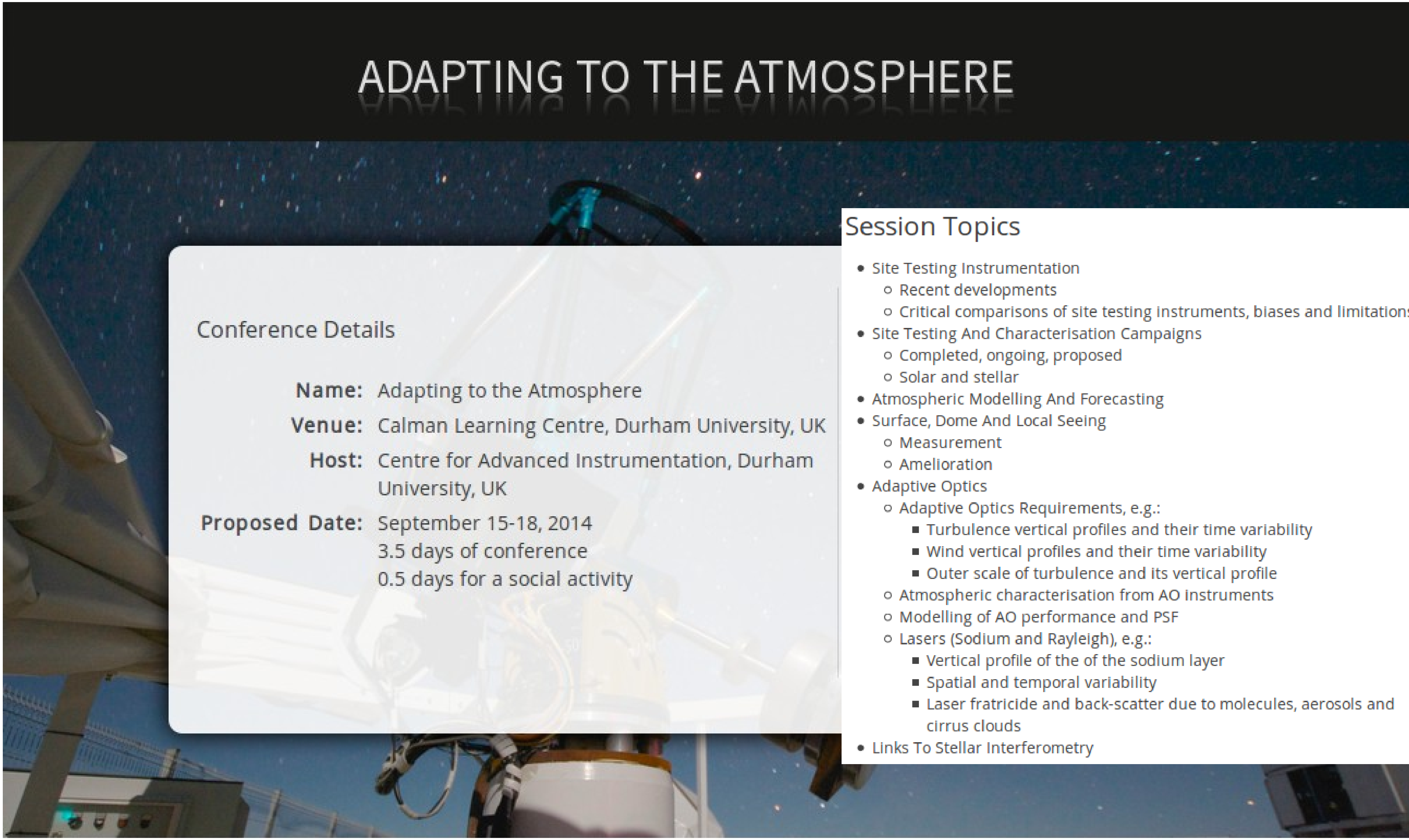


But a cooler atmosphere, not so much change..

Daniel PhD thesis (Durham, 2002).

Summary

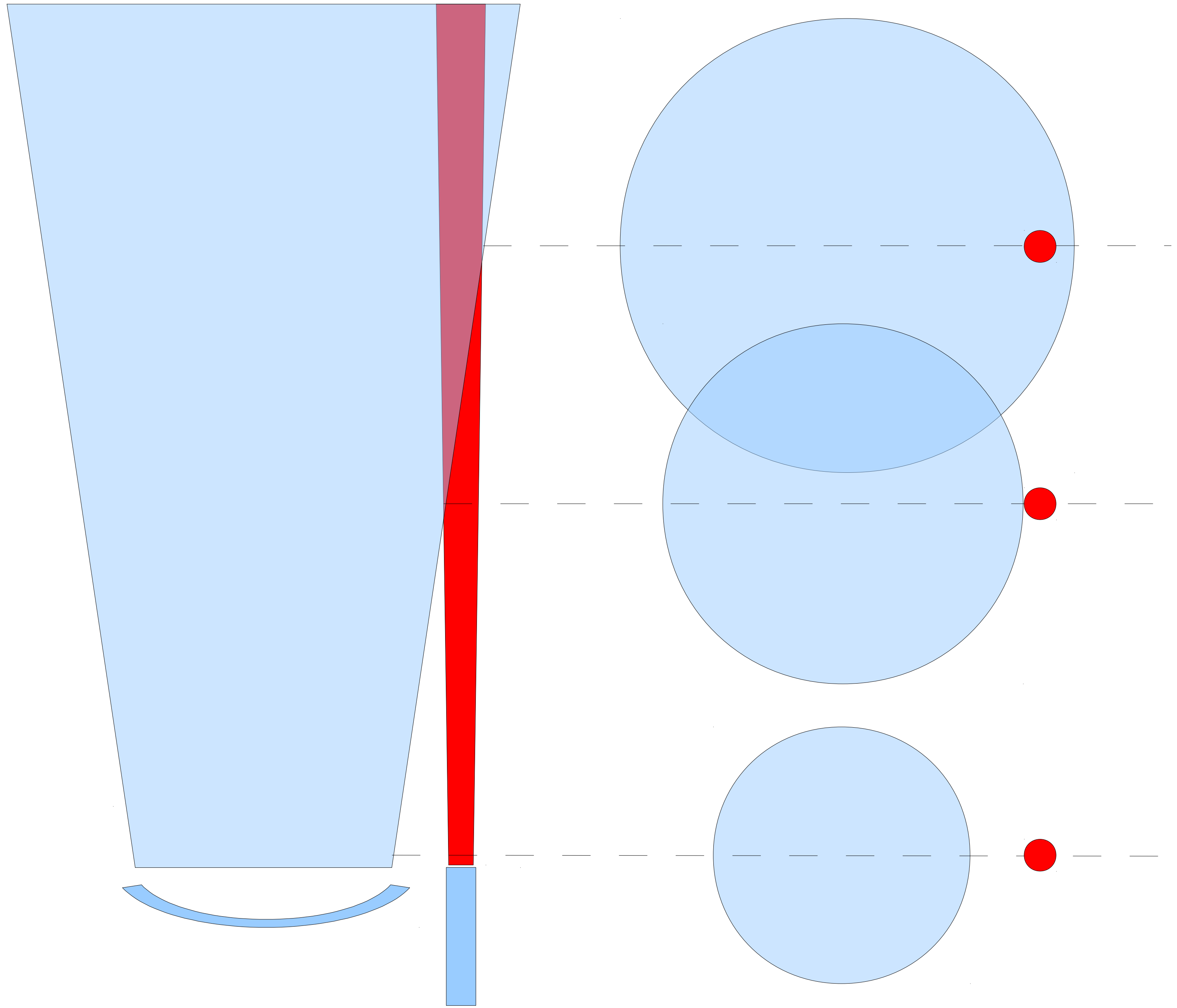
- An IR radiometer is a useful addition to the suite of atmospheric monitoring tools
- Measuring the IR can give an estimate of sky clarity independent of telescope systematics; and as it is a passive measurement it will not interfere with an observation
- Aerosols can contribute a measurable amount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



visit https://www.dur.ac.uk/cfai/sitecharacterisation/profconf/ for details 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

Lidar overlap factor



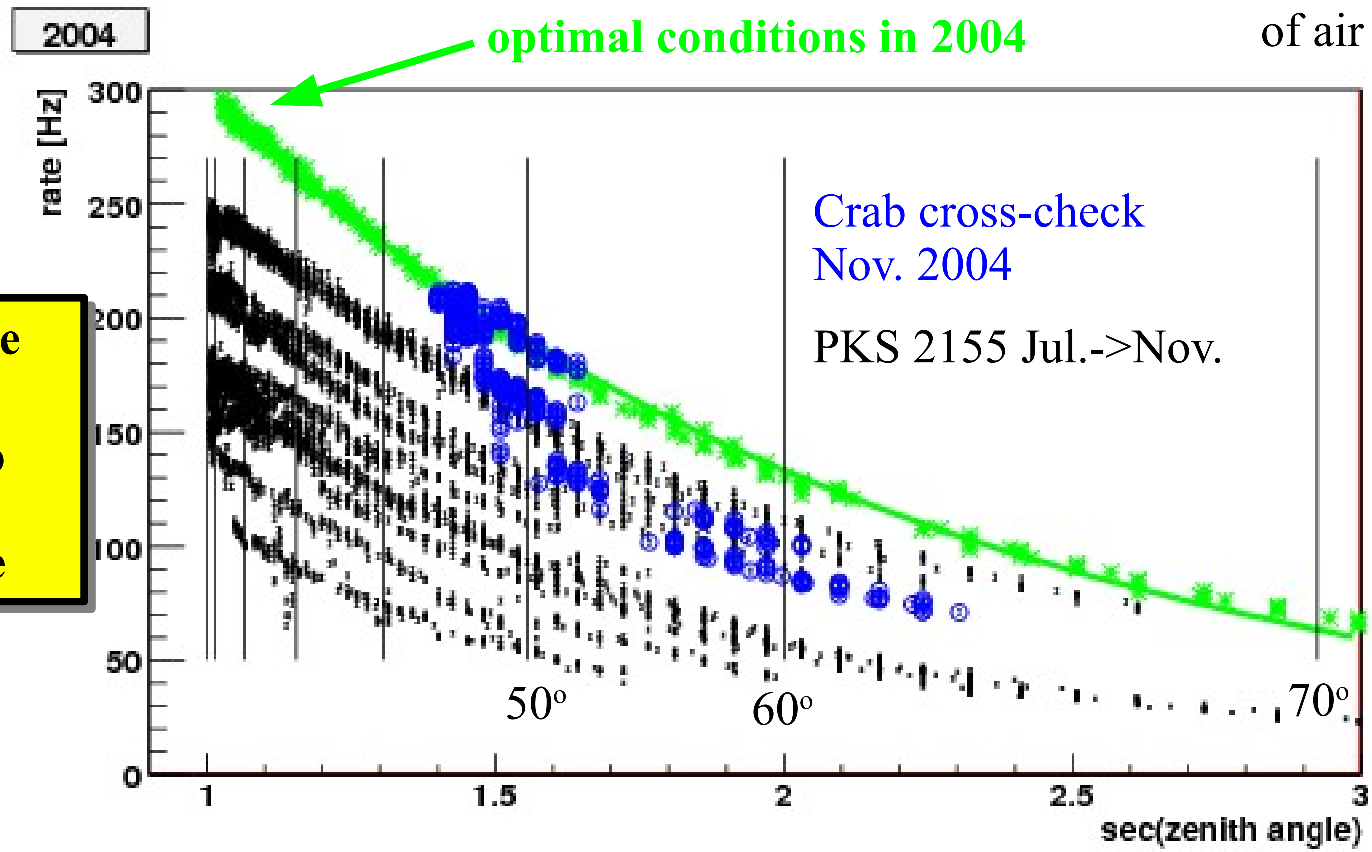
Motivation: the recovery of compromised observing runs, eg taken as part of a multiwavelength campaign

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

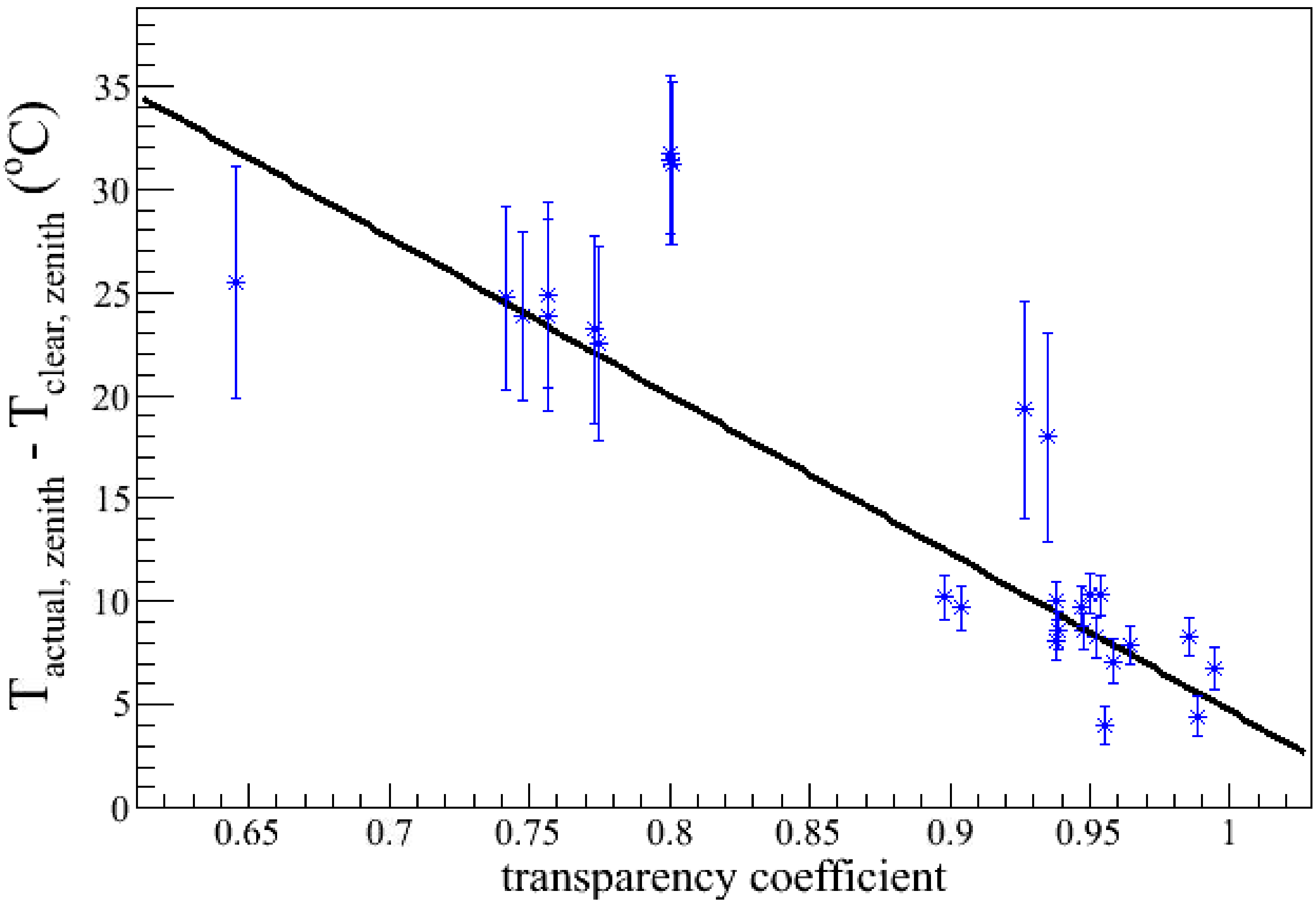
$$R(\theta) = R_{(\theta=90)}\exp[-(t_0/\Lambda)\sec(\theta-1)]$$

R_0 rate at zenith
t_0 depth of experiment
Λ is attenuation length of air shower

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



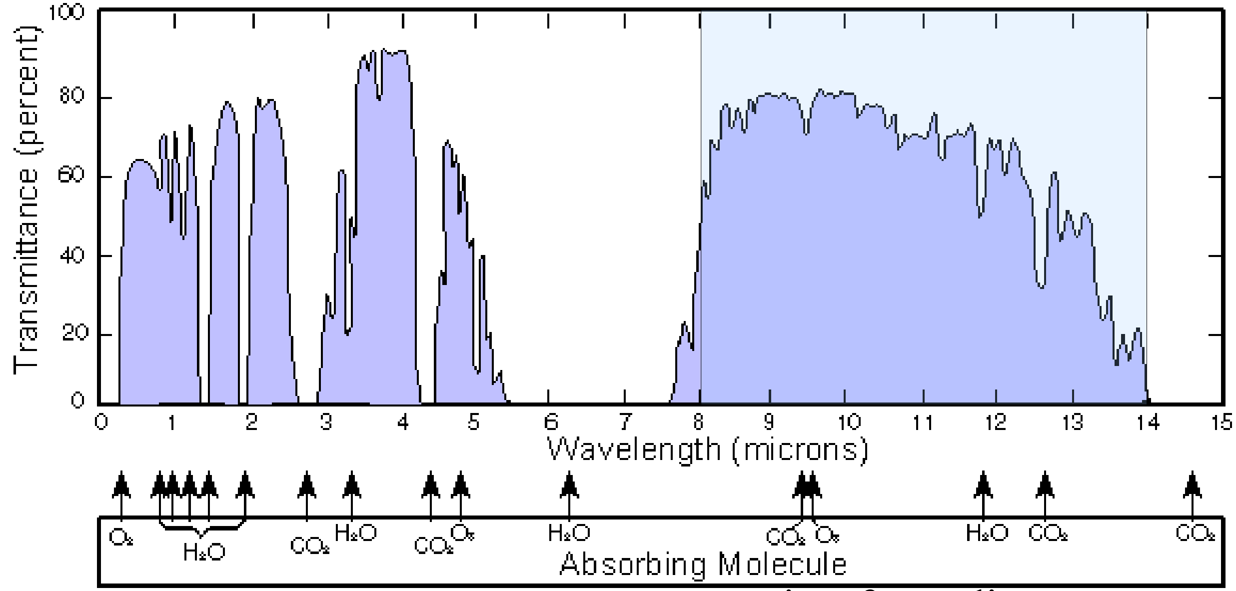
All 2004 observations of PKS 2155 are compromised



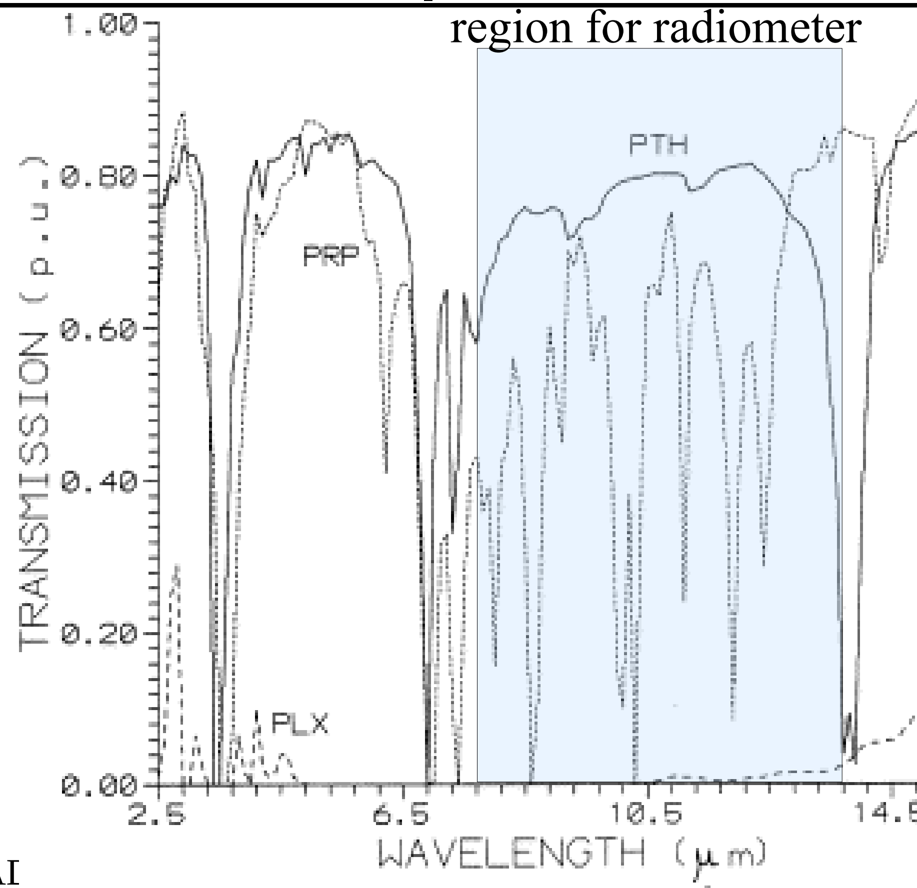
$T_{actual, zenith} - T_{clear, zenith}$ (^oC)
0
5
10
15
20
25
30
35
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1
transparency coefficient

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 $\rho = 1/V$

$$P dV + V dP = \frac{k}{M M_0} dT$$

For an ideal gas

$$\frac{k}{M M_0} = C_P - C_V$$

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

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

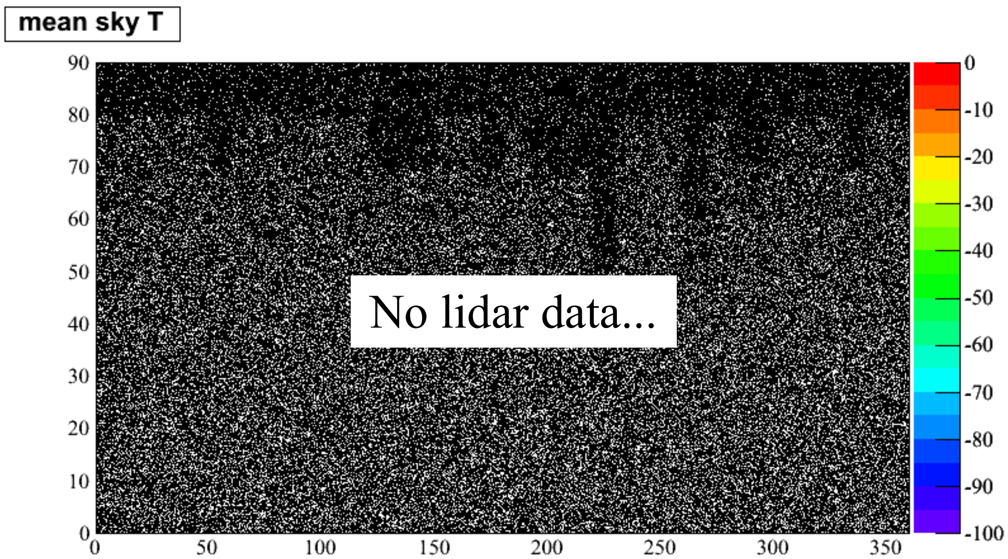
$$\therefore T(z) = T_0 - \Gamma_a z$$

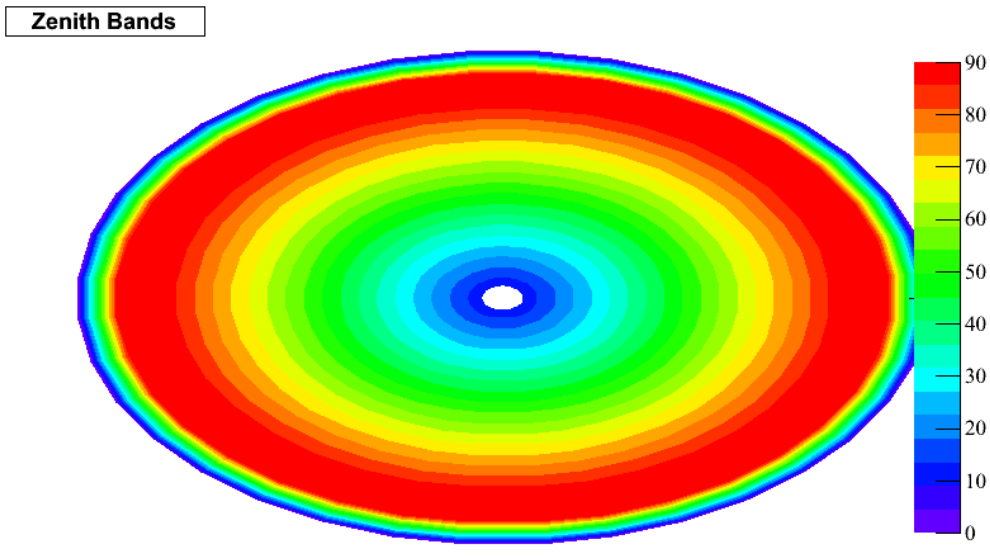
For a dry atmosphere Γ_a~9K/km

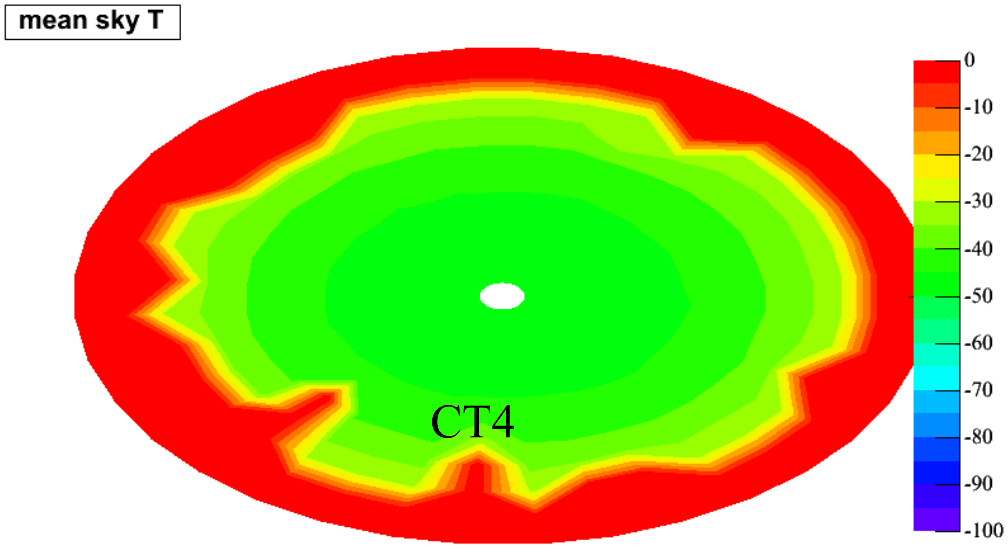
The latent heat released by water vapour condensing out of the air (RH>60%) serves to raise this to ~6.5K/km

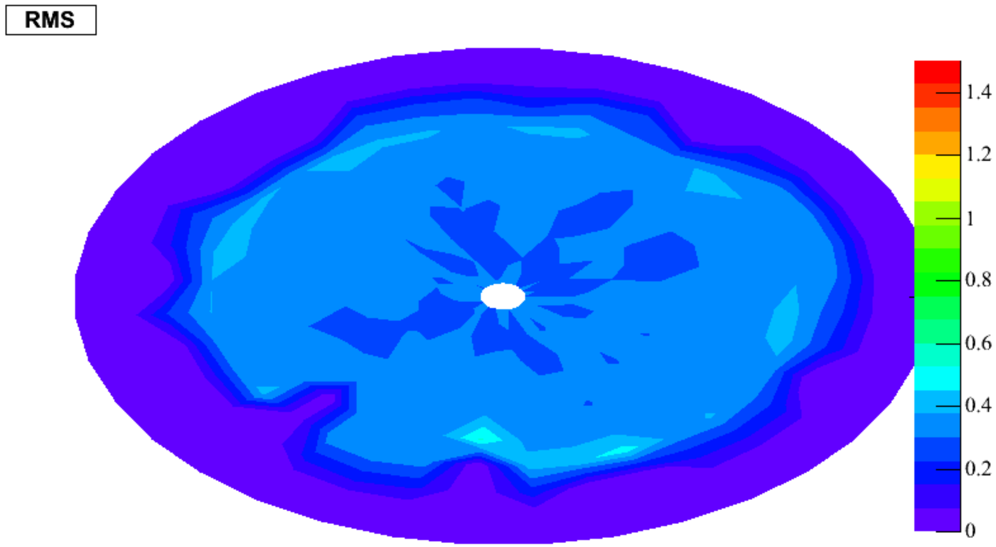
nb, all these nights listed as clear in shift logs & web summary.

"normal" observing conditions 2011/08/31



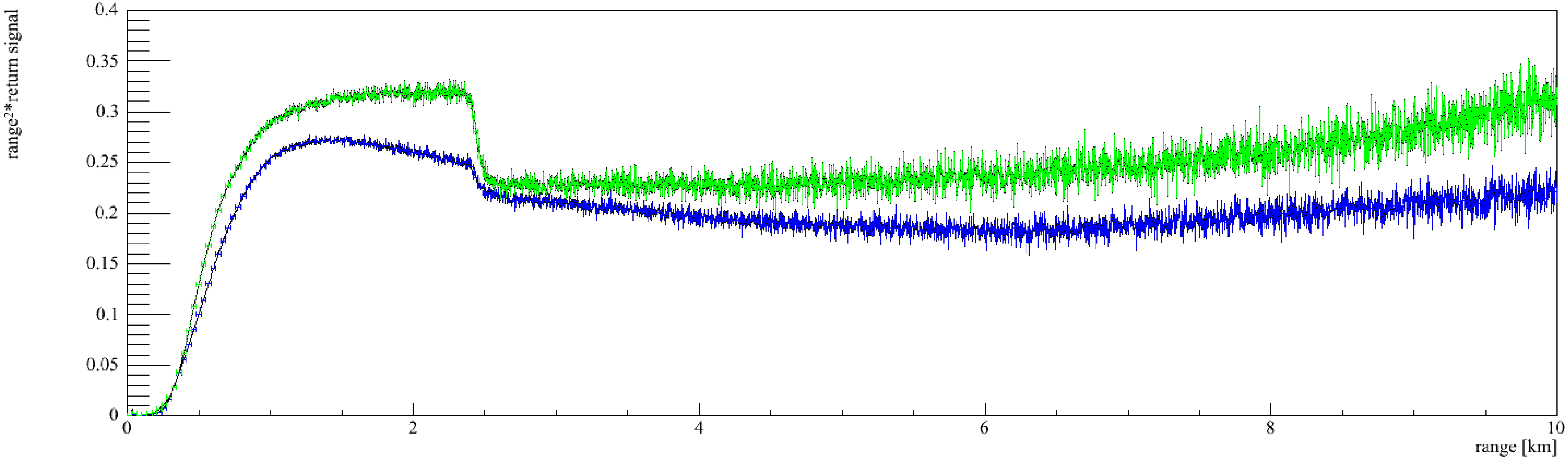


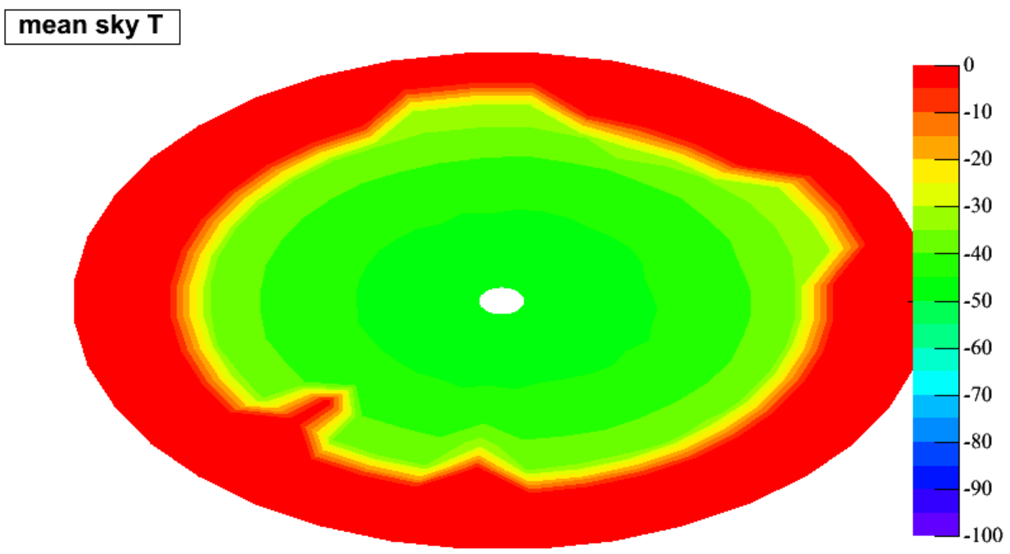


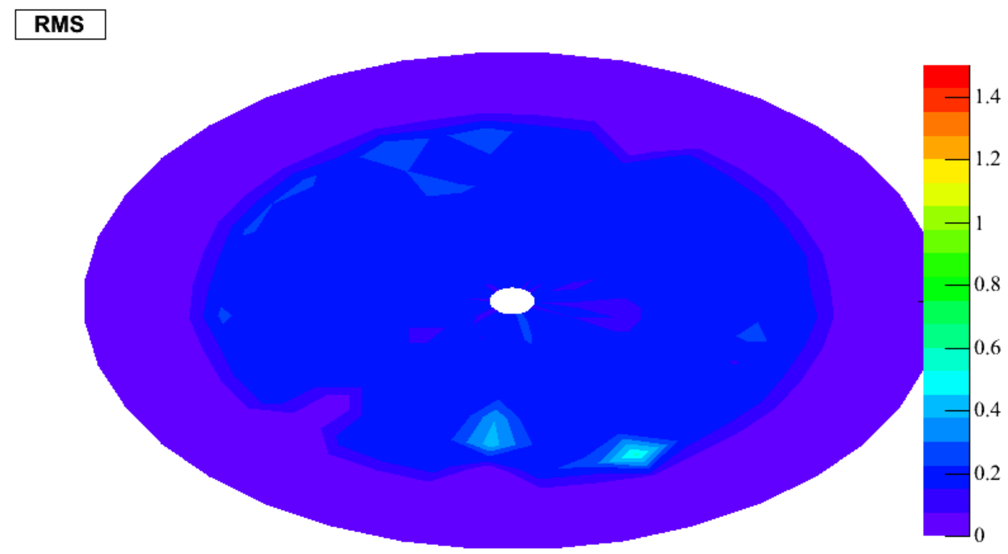


“normal” observing conditions 2011/08/30

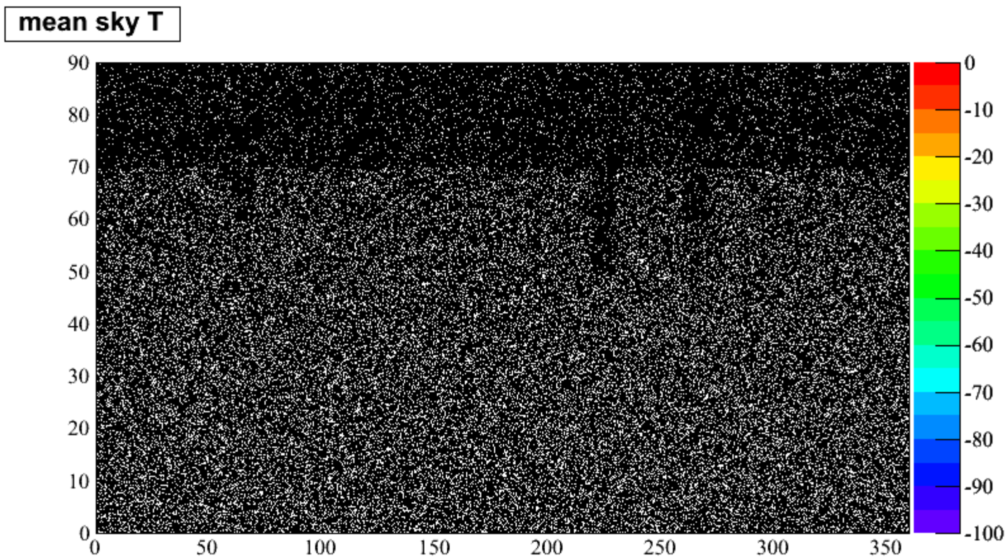
nb, all these nights listed as clear in shift logs & web summary.

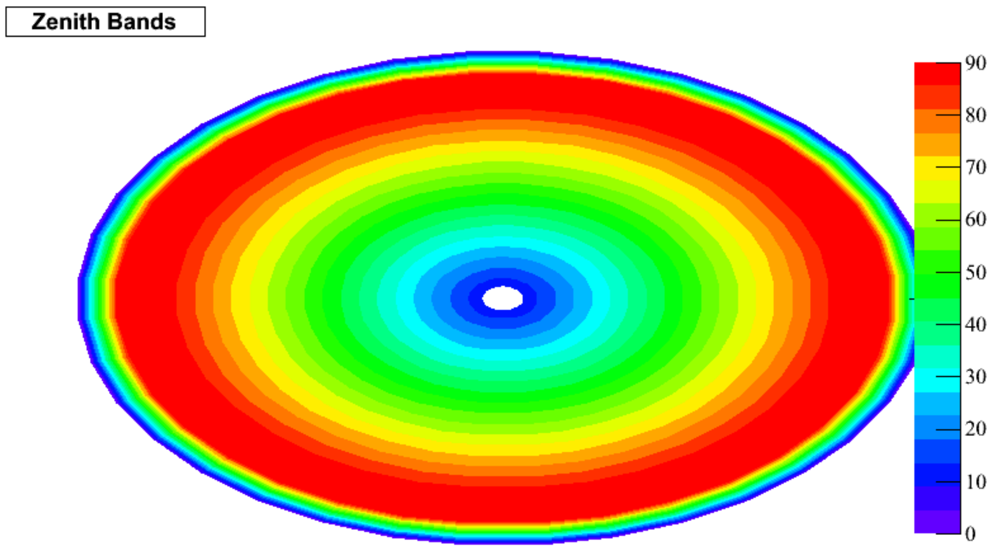


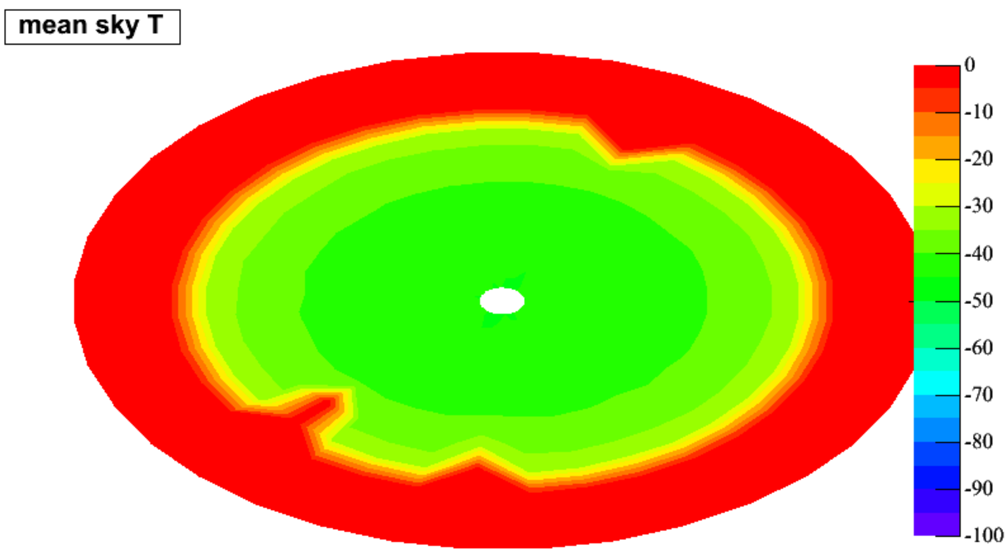


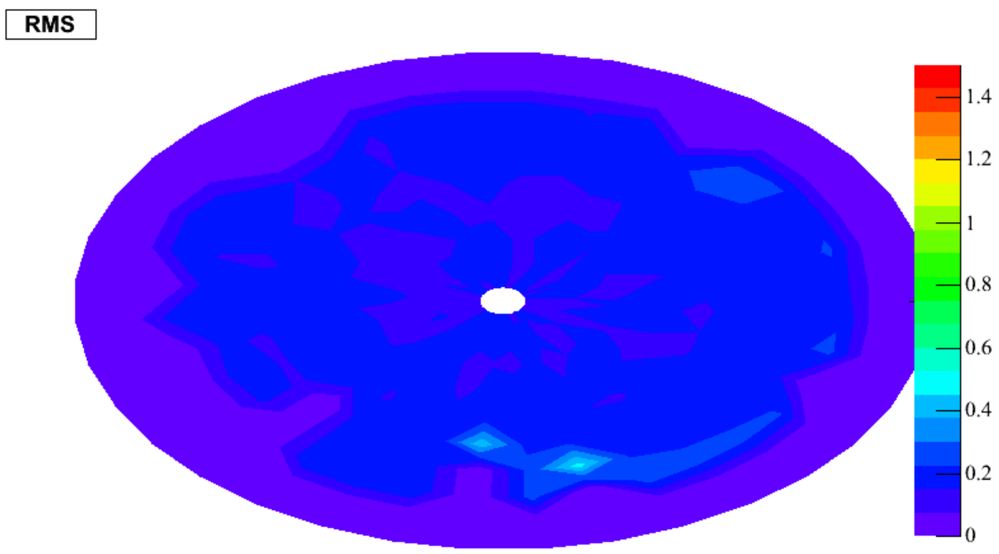


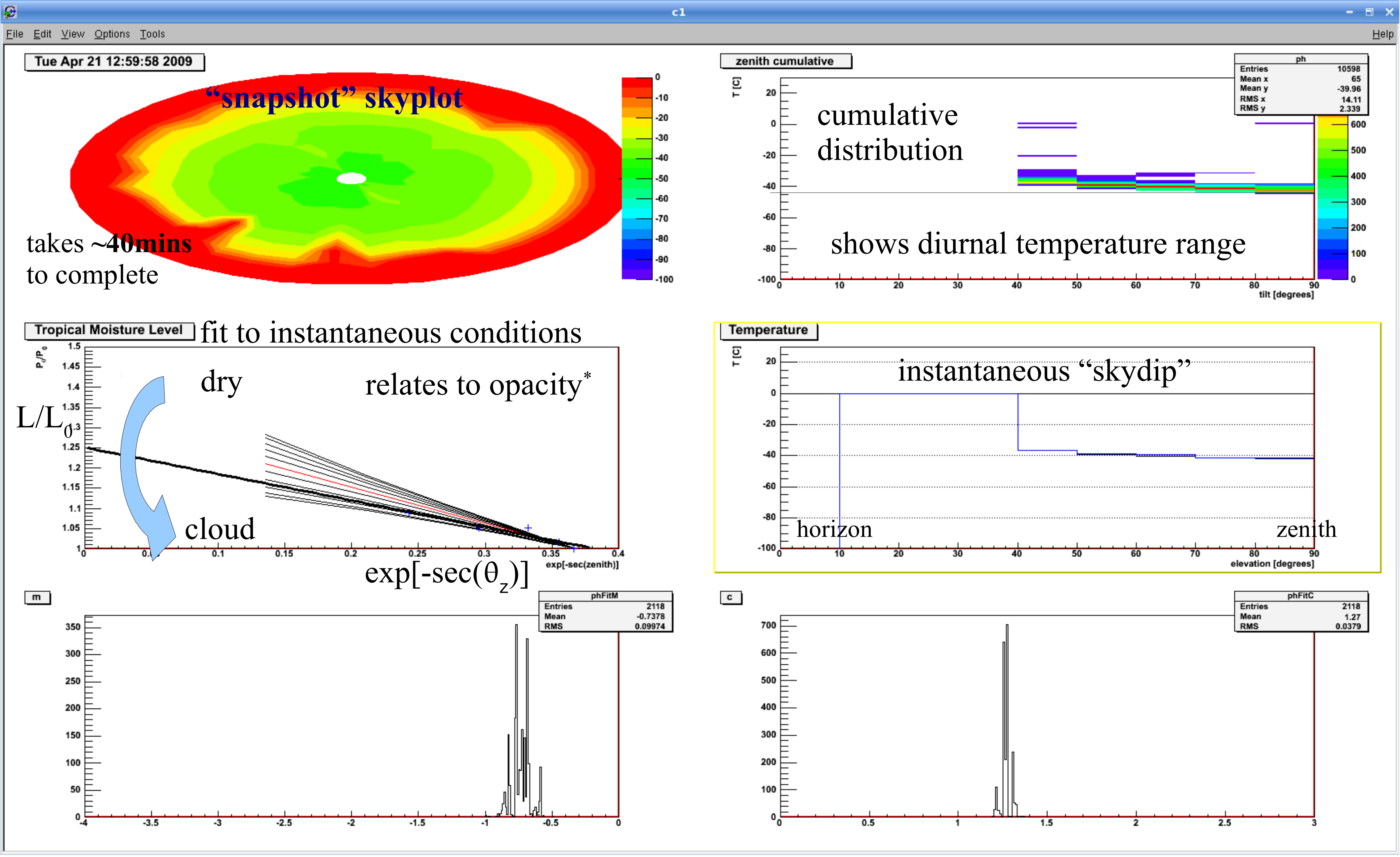
3 tel runs, can't compare rates.


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

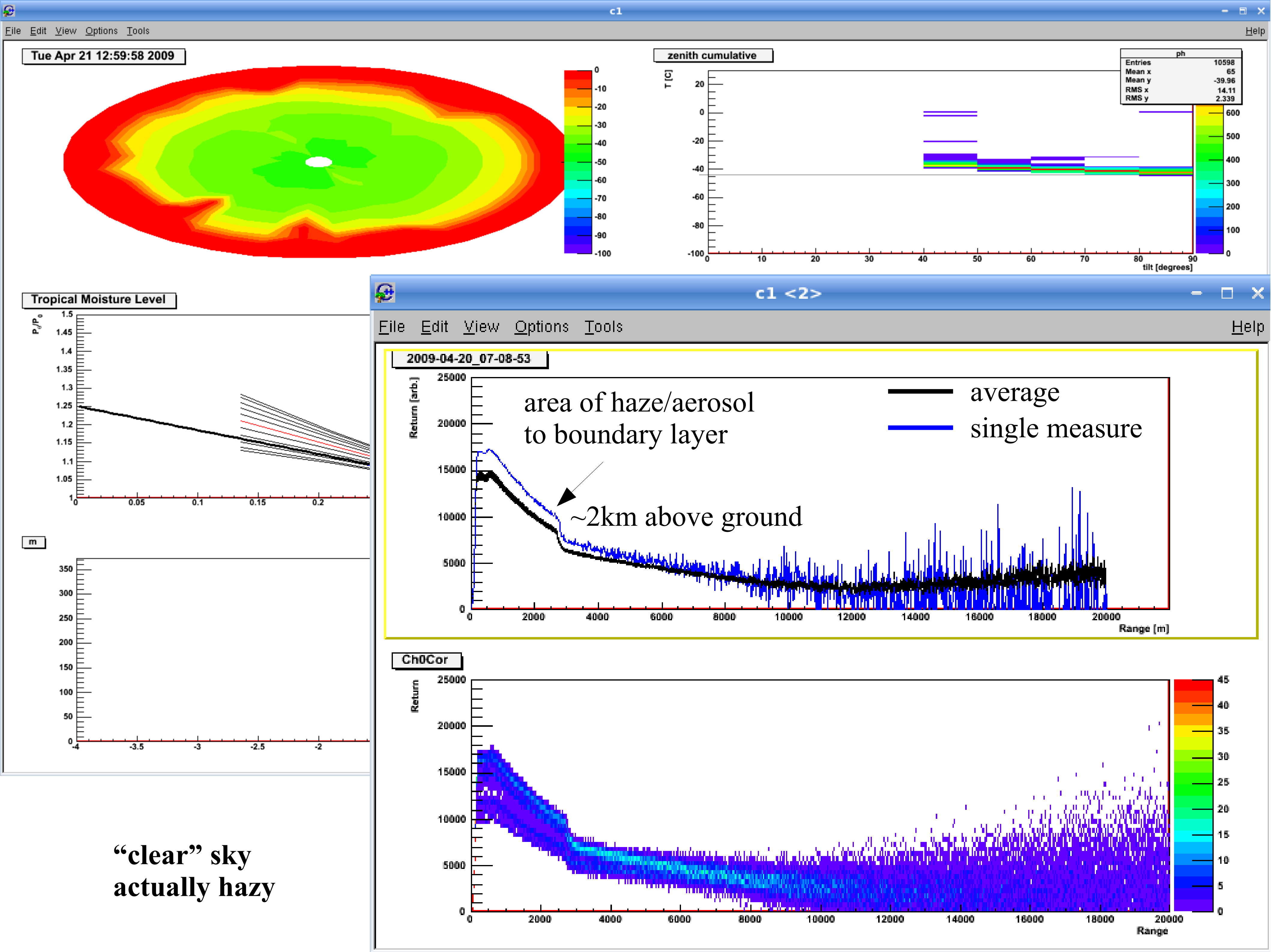

mean sky T
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100


RMS
1.4
1.2
1
0.8
0.6
0.4
0.2
0

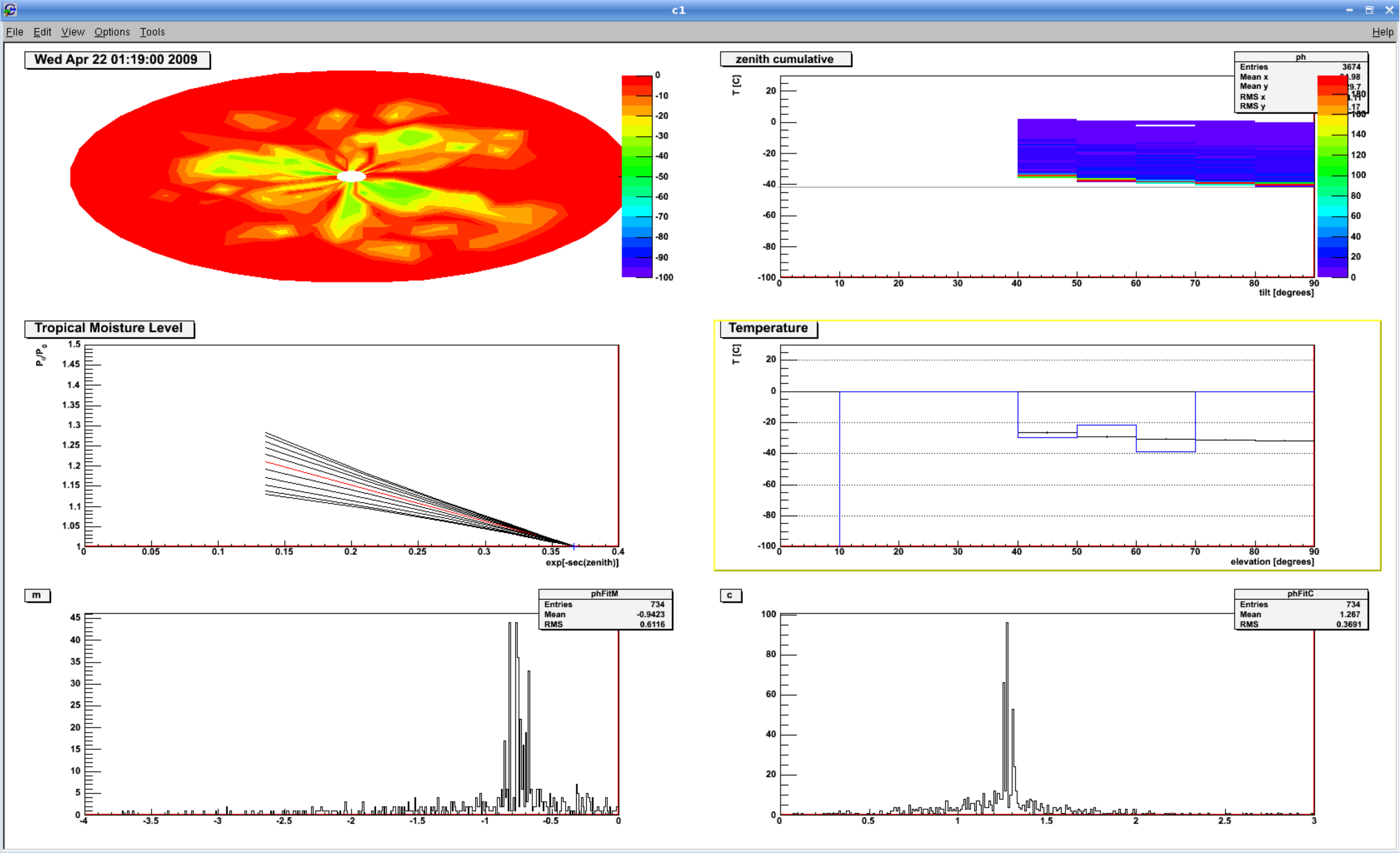


* Daniel, PhD Thesis, University of Durham (2002).
Unsworth & Dalrymple Q J Roy Met Soc (1976).

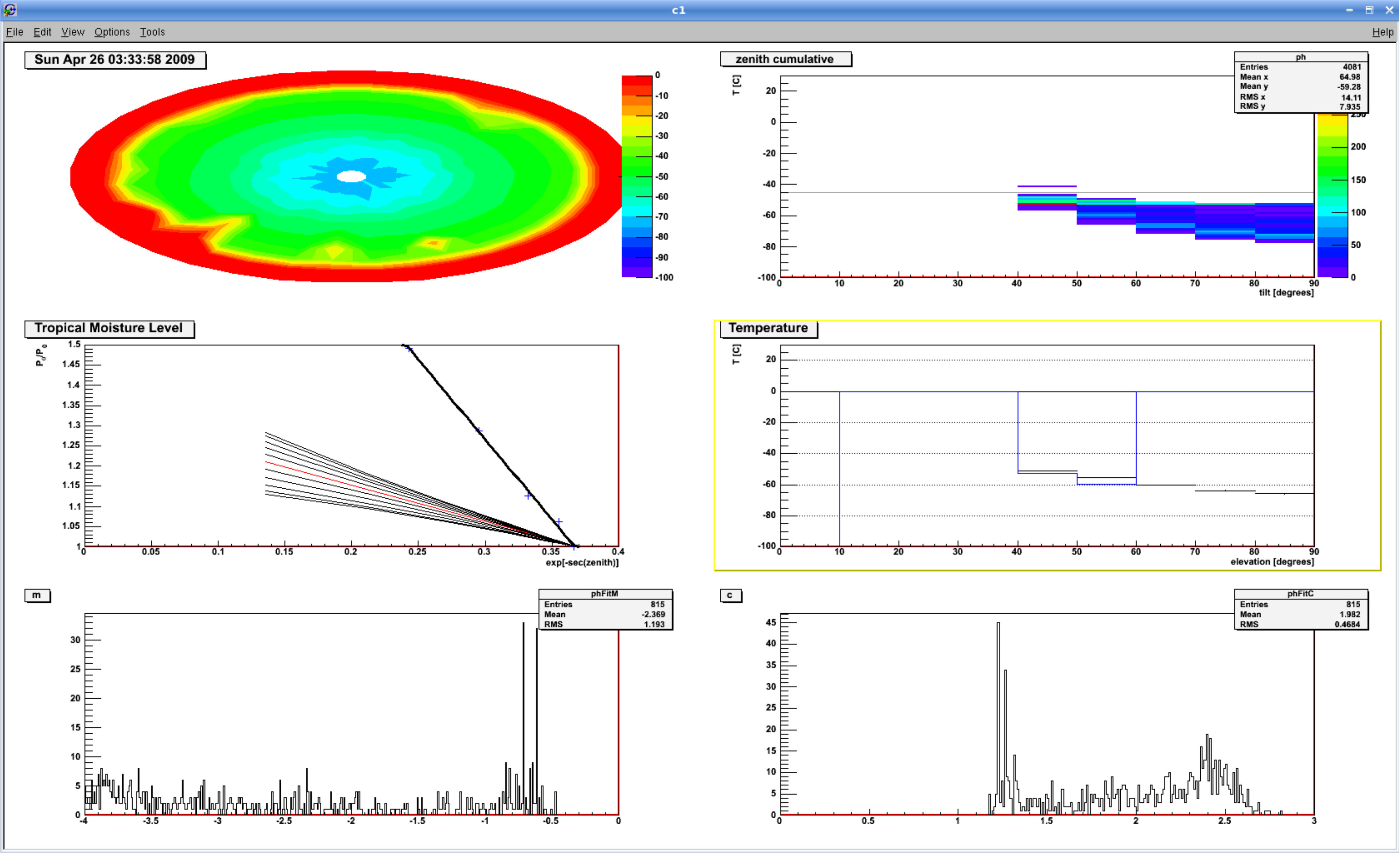
"clear" sky



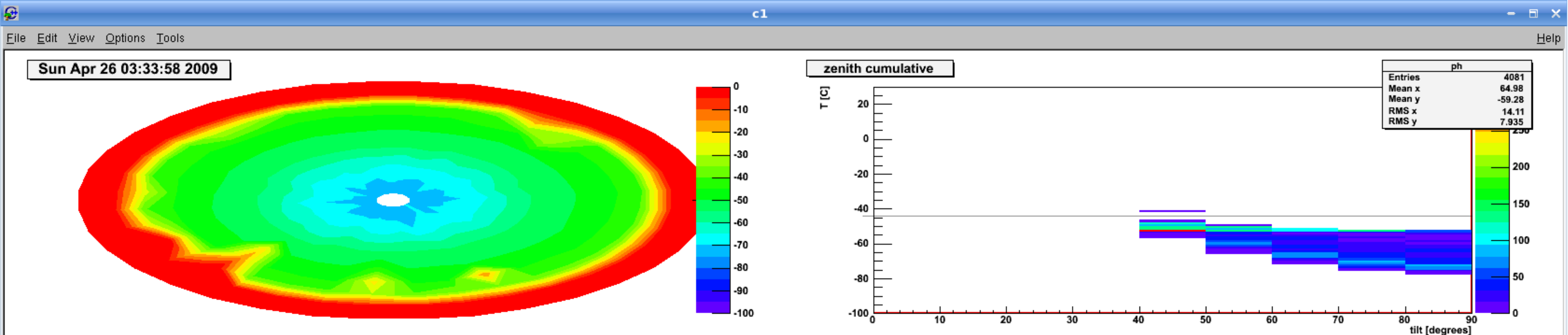
“clear” sky
actually hazy

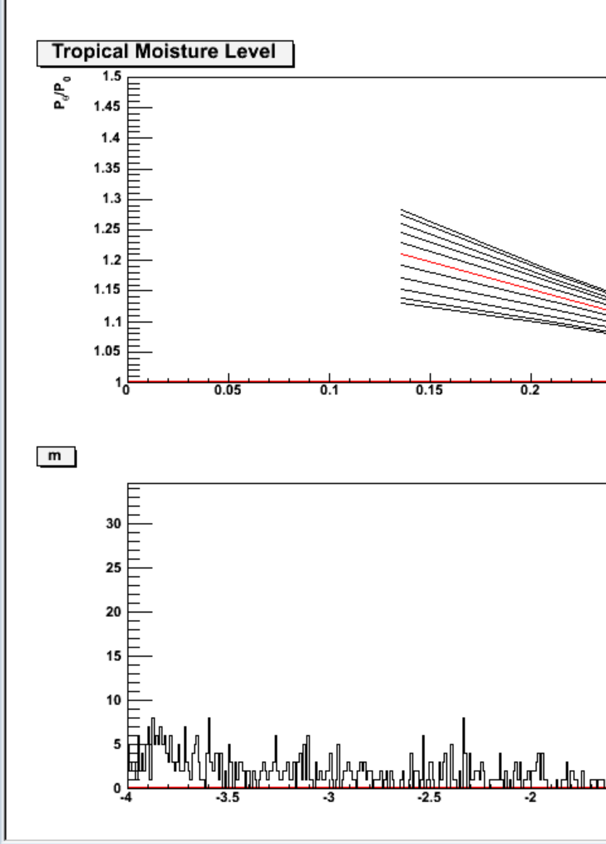


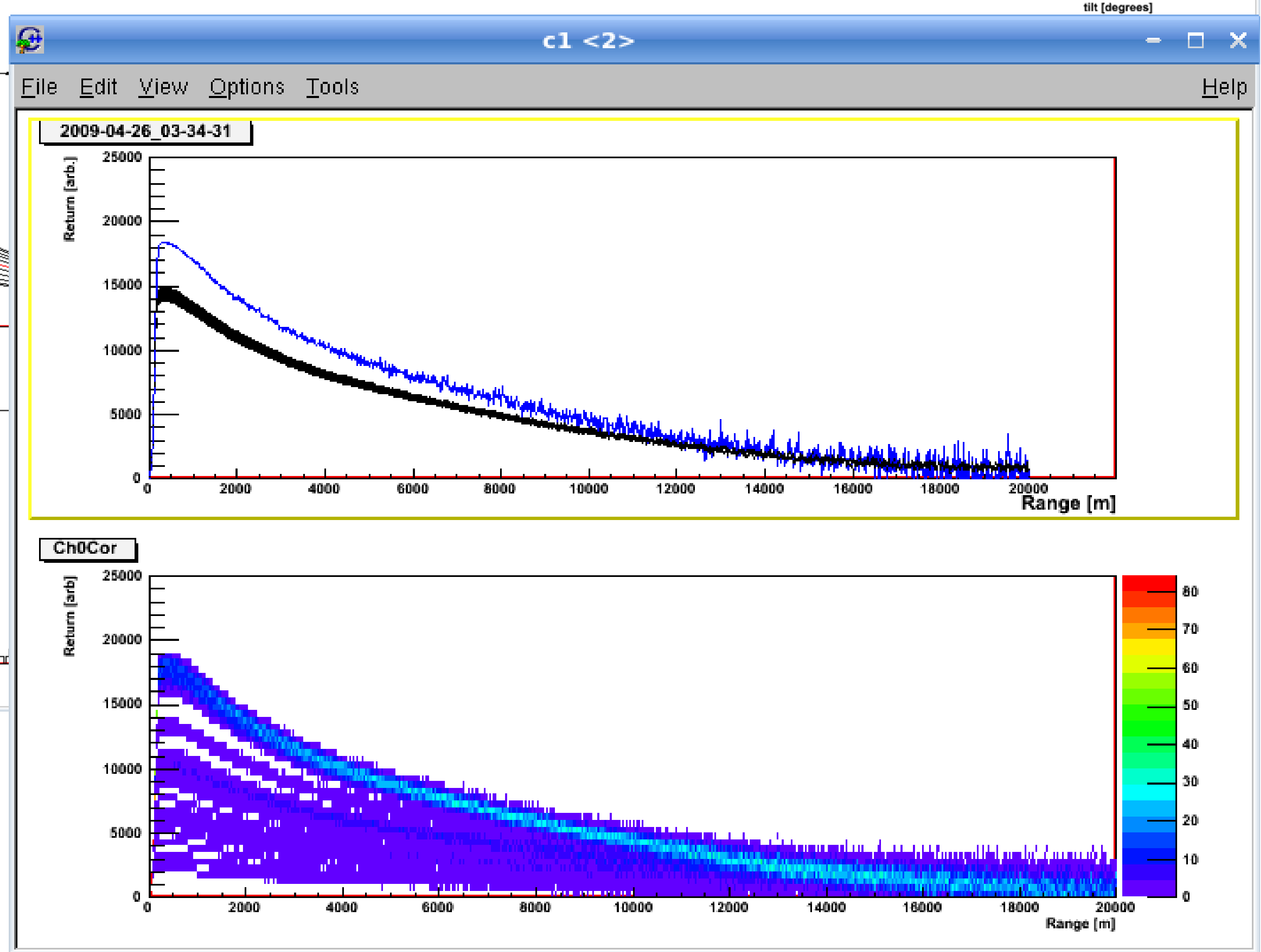
cloudy conditions



really clear sky

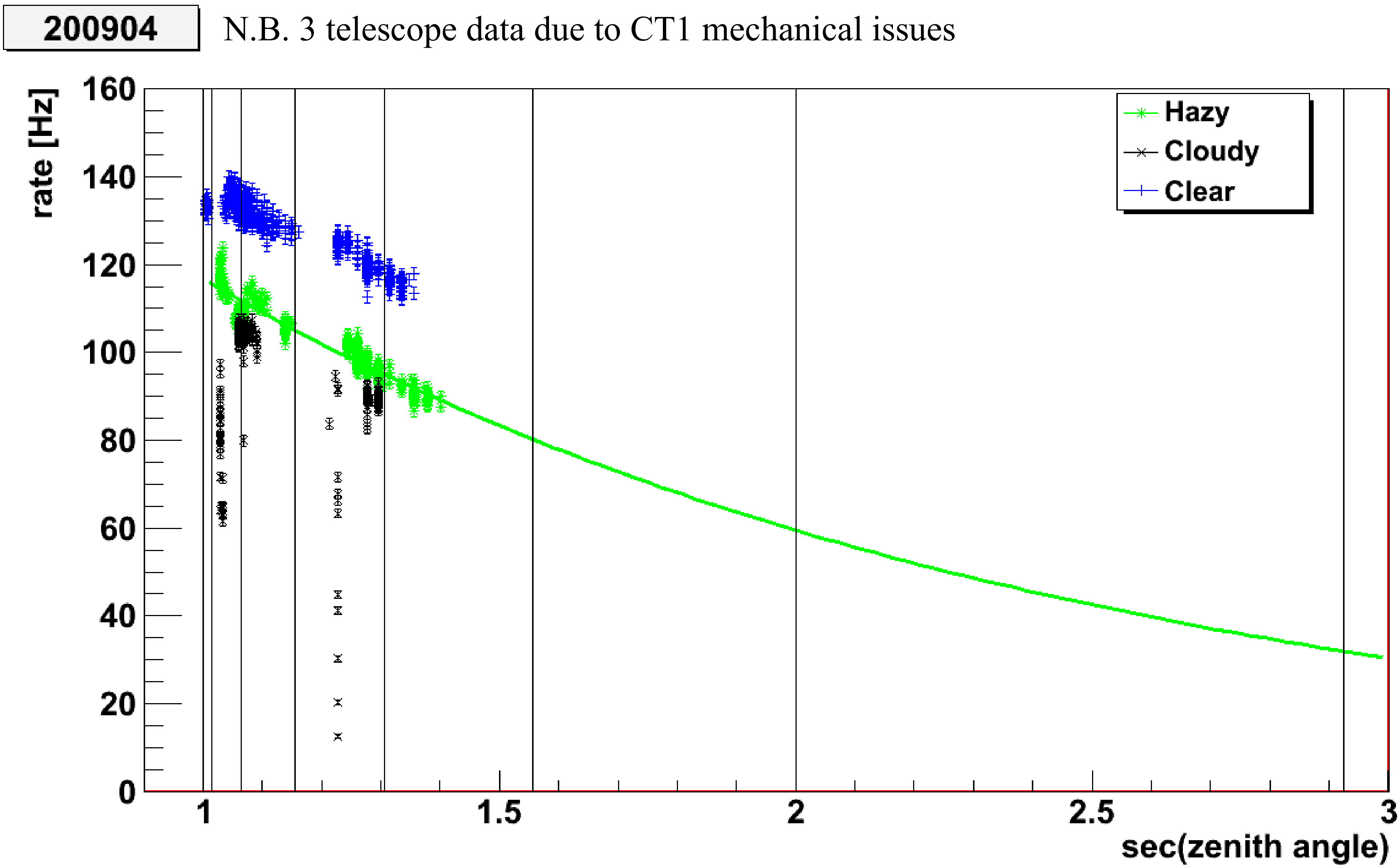






really clear sky

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



All 3 nights have similar temperatures & relative humidities