Identifying Clouds over the Pierre Auger Observatory using Satellite Data

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ATMON10

Identifying Clouds over the Pierre Auger Observatory

Atmospheric studies for Pierre Auger Observatory:

Identifying clouds in the field of view of the **Fluorescence Detectors**(FD) is important for getting correct **shower profiles**.

- With our own equipment:

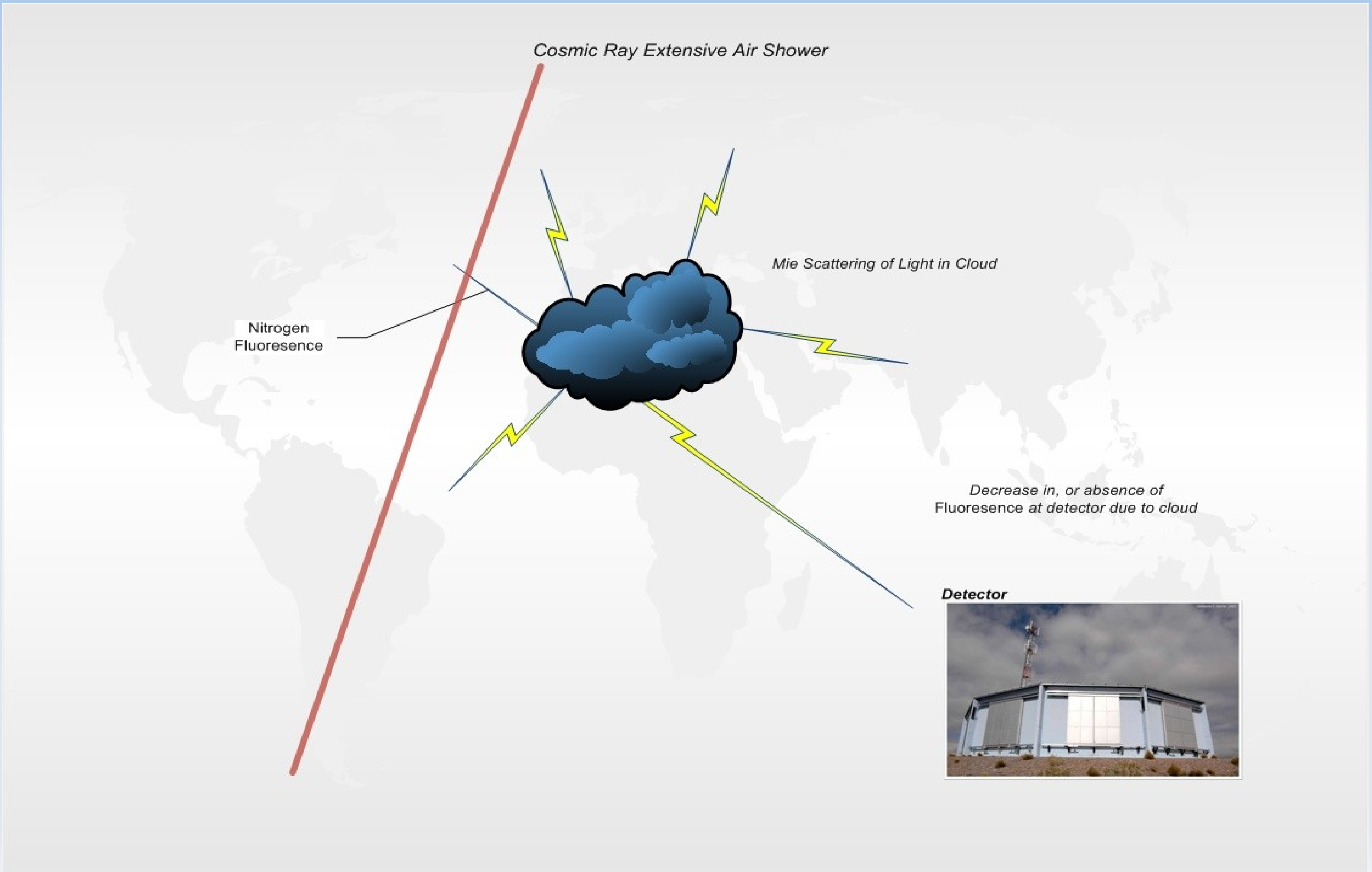
  - Infrared **Cloud Cameras** and **LIDAR**s

  - **XLF** and **CLF** laser shots seen by FDs

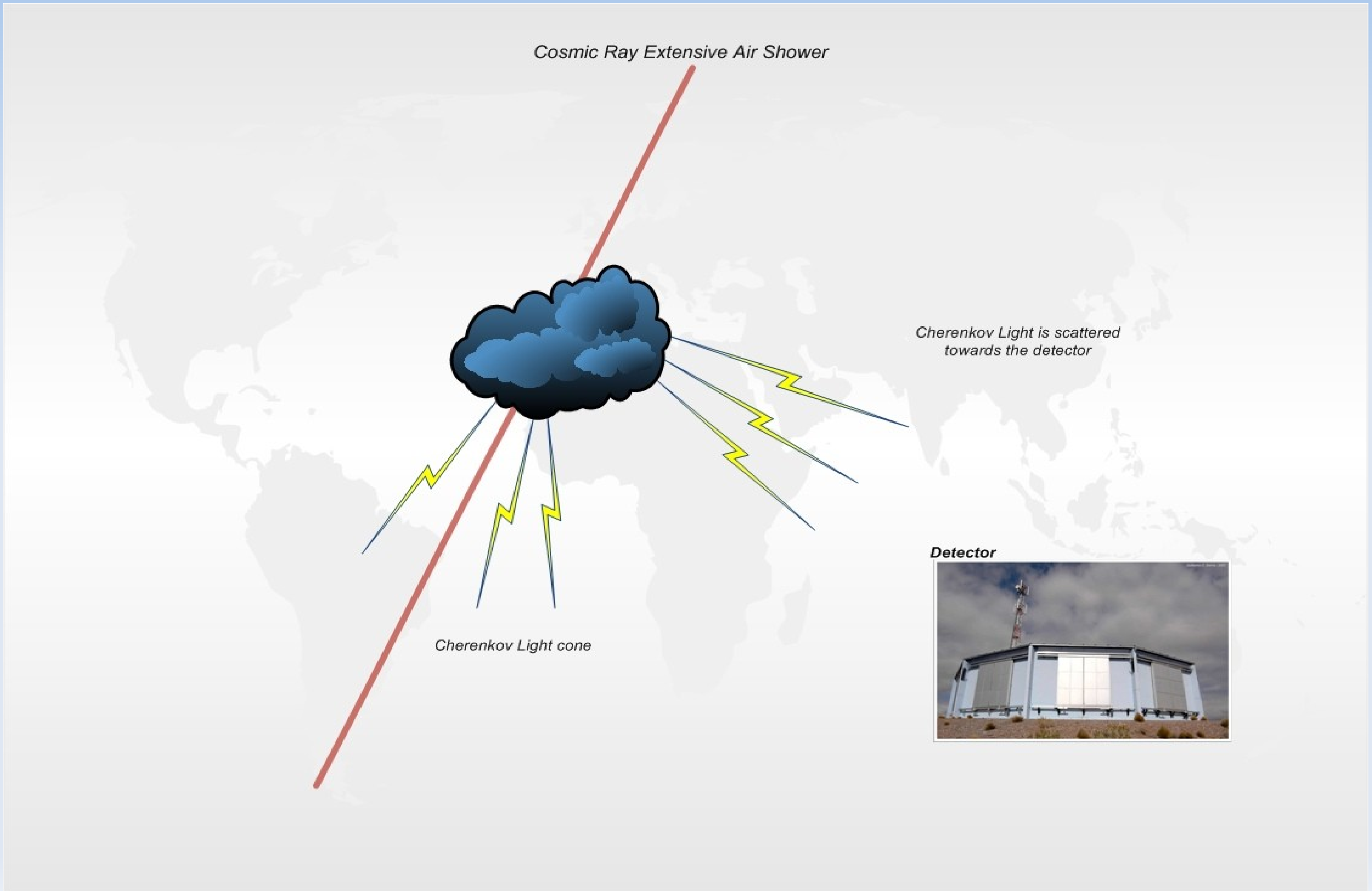
- With satellite images:

  - **GOES12 satellite** images over Southern Hemisphere

Identifying Clouds over the Pierre Auger Observatory

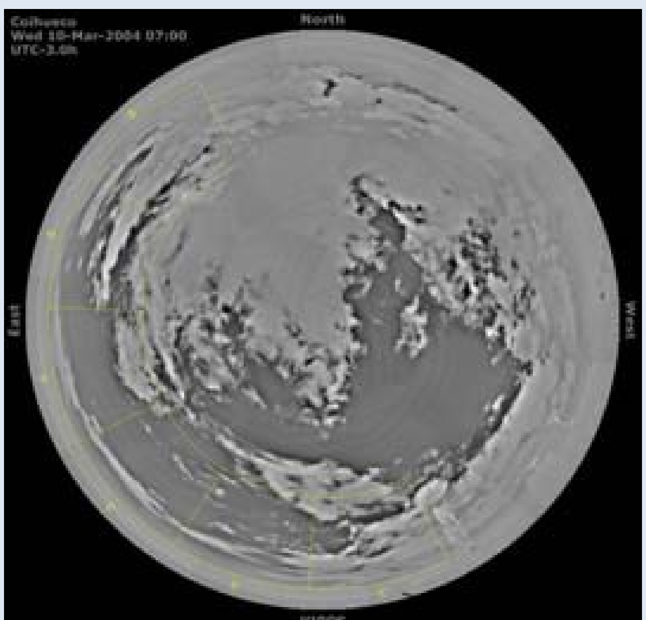


Identifying Clouds over the Pierre Auger Observatory

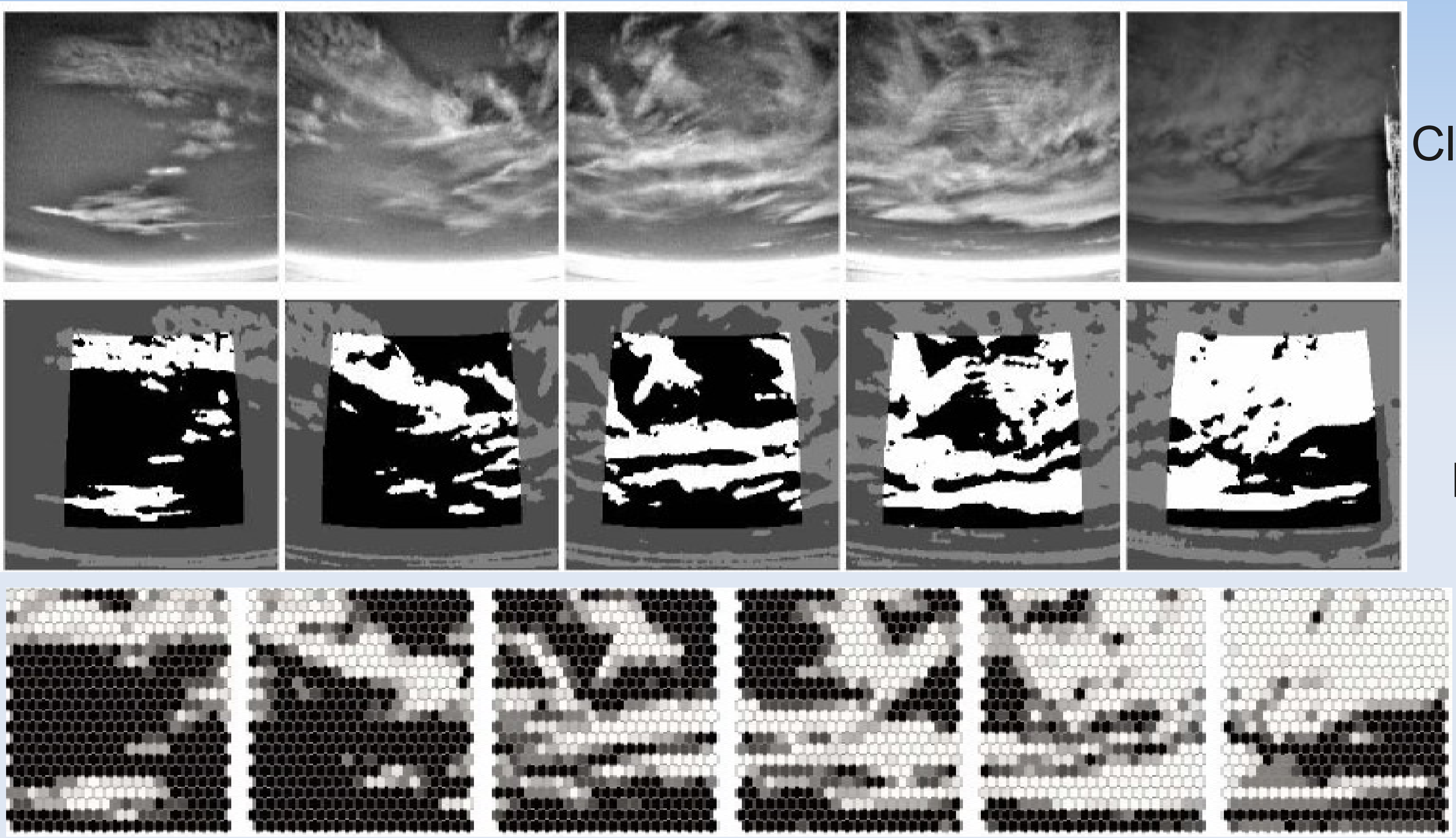


IR Clouds Cameras

- 4 cameras installed, one at each **FD site**. Raytheon 2000B IR Camera (320x240pixels).
- During FD operation:
  -**5** images across **FDs field-of-view** every **5'**
  -Full sky **mosaic** (27 images) every **15'**



IR Clouds Cameras



Cloud Camera Images

Image Processing

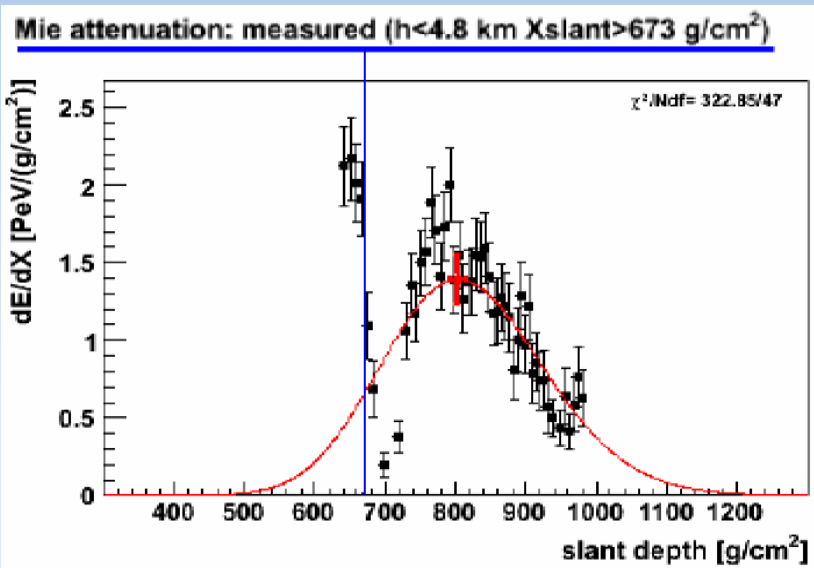
FD Pixels Index

Cloud index value between **0-5** for each pixel every 5'.

With cloud height from CLF or LIDAR: **position of cloud**.

IR Clouds Cameras

Cloud-affected event



Cloud Camera Image

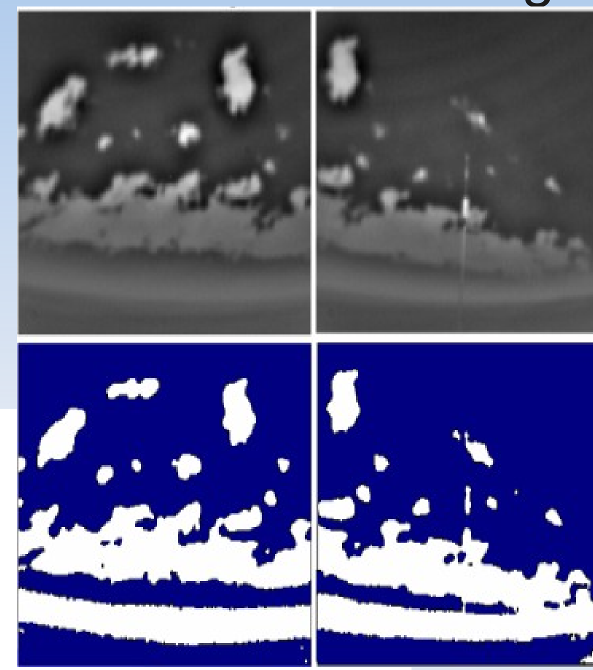
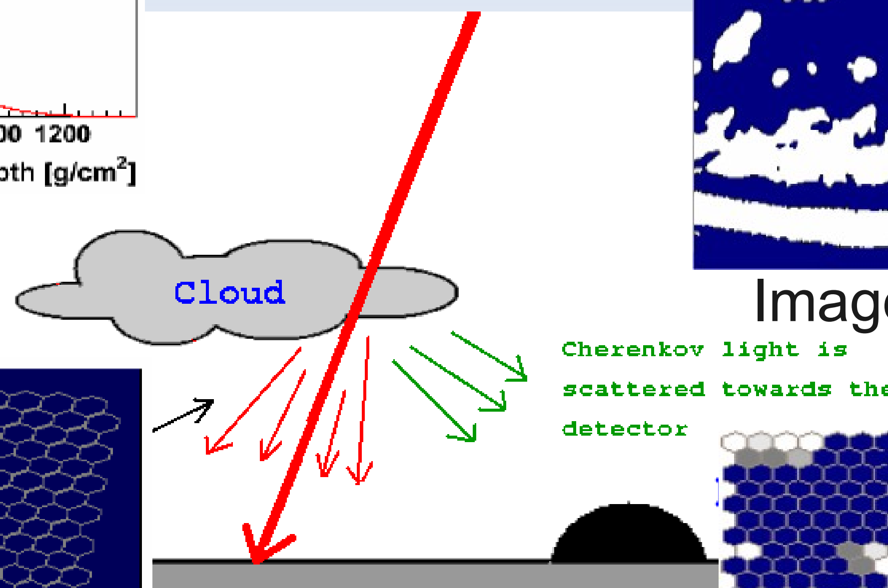
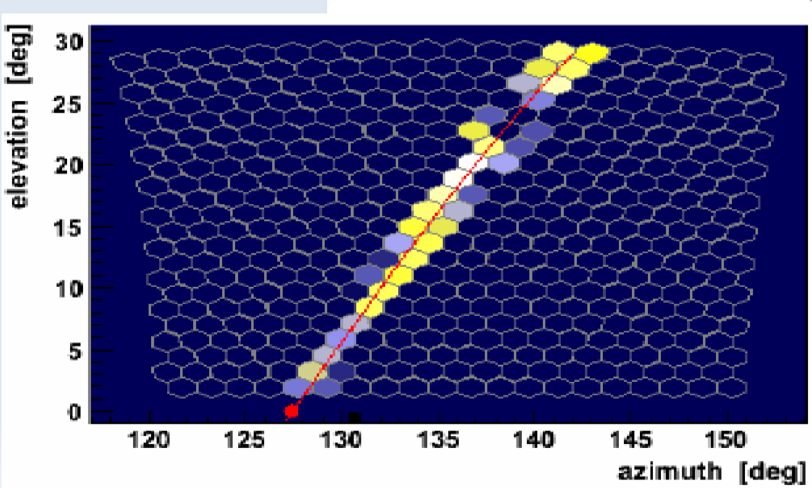
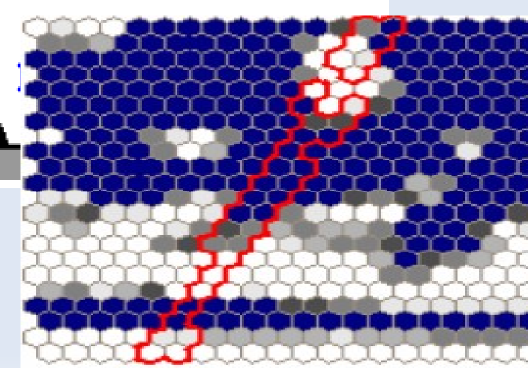


Image Processed





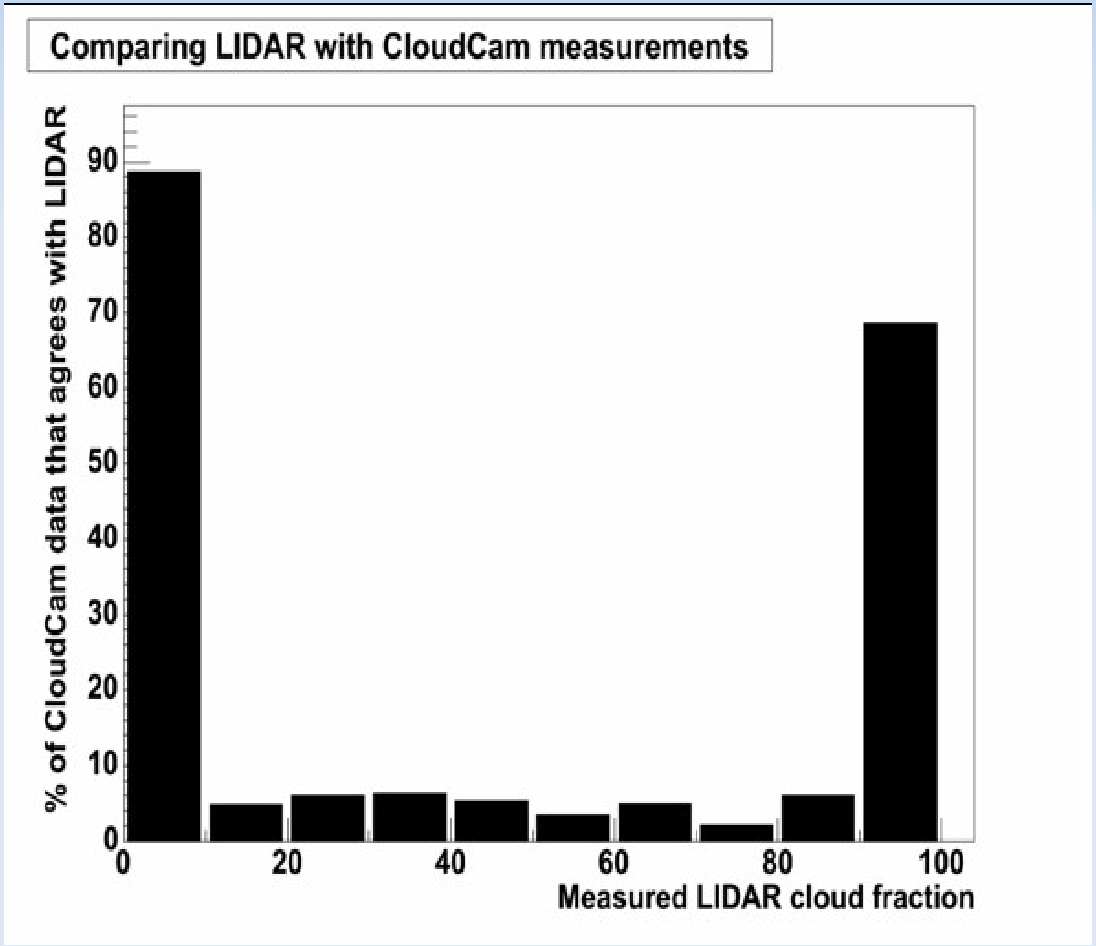


Los Morados

IR Clouds Cameras

Comparing LIDAR with associated cloud camera:

- Not same field of view.
- **Agreement** on both
  clear and **overcast** days.



IR Clouds Cameras

- Normal Hybrid Reconstruction:

  if > 20% cloud coverage by LIDAR: all hour of data cut.

  ~1/3 of time cut.

  Improvement in time cut:

- Offline function

  CloudCam: cloud direction and Lidars: min. cloudbase height.

  Is cloud affecting event?

- CloudCam DB currently 3.8 Gb.

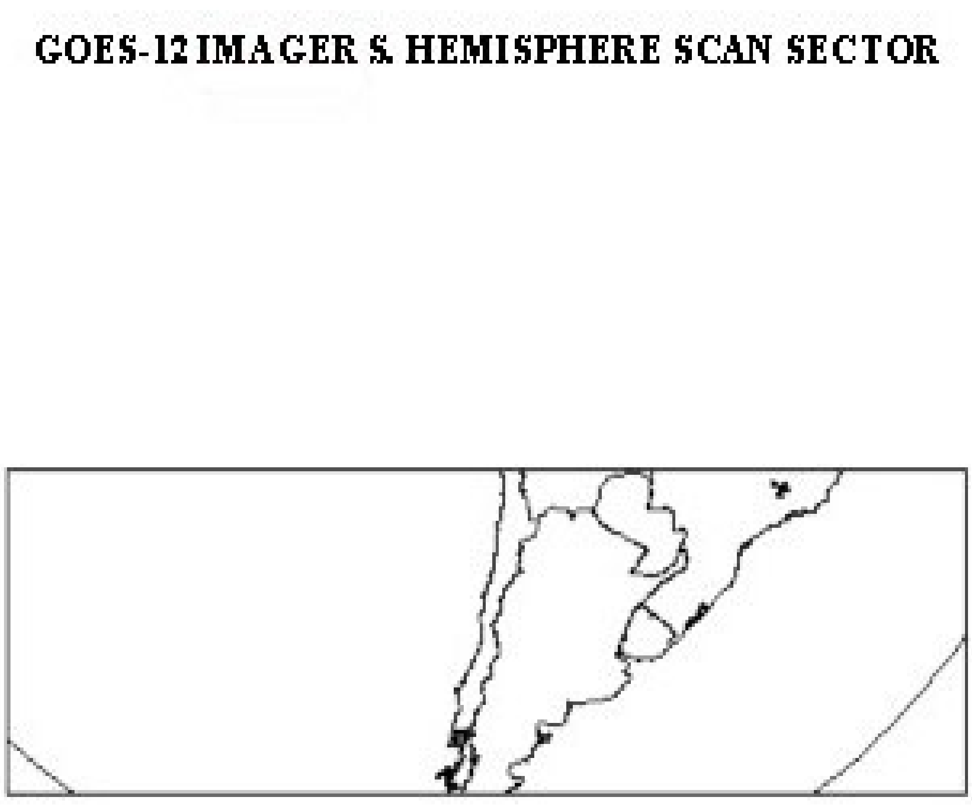
  Every 5', pixels for FD have value 0-5.

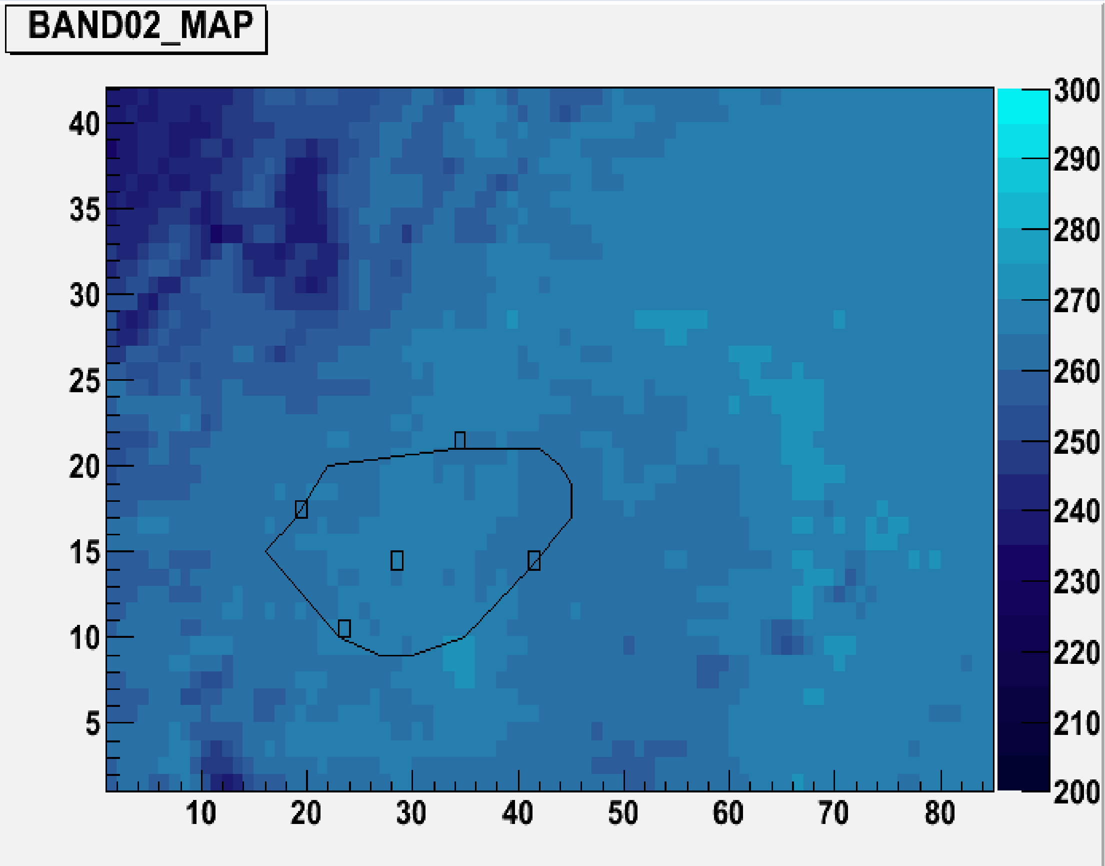
Satellite GOES12

- Pierre Auger Observatory: very big area of **3000km²**.
- Big atmospheric monitoring task for many topics.
  - Handling equipment needs **big effort**:
    local/remote human power for maintenance,
    for running them,
    for software/hardware, etc.
    Equipment was done by us or customized to our needs.
  - Equipment is far away (30'-2h) from our local staff.
    Gaps with no data.
  - 1 device for each topic not enough always (4 LIDARs).
- Satellite data will eliminate these worries.
  Better resolution in **space and time**, specially to identify exotic events.

Satellite GOES12

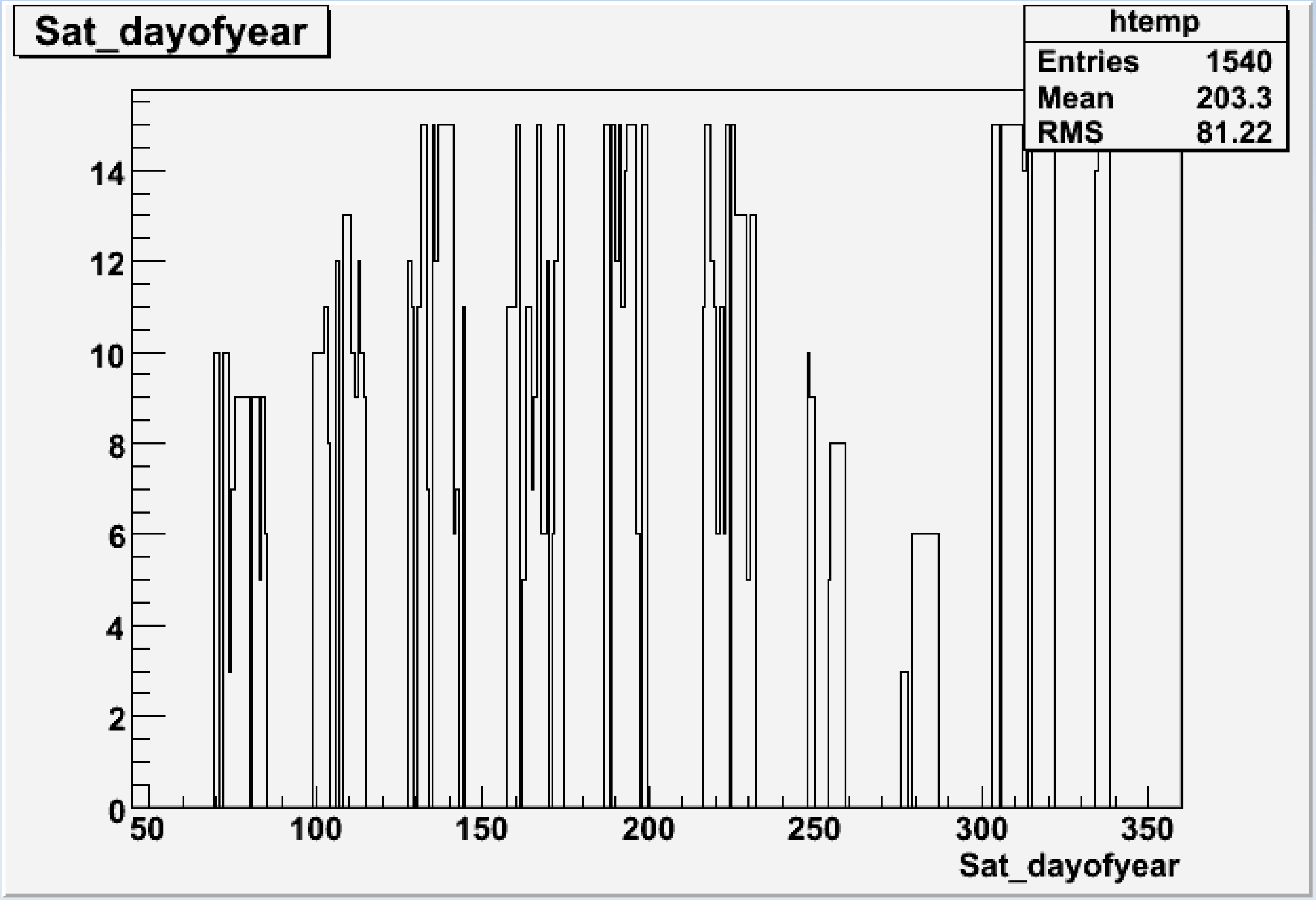
- GOES (**Geostationary** Operational Environmental Satellite) at 35,800 km.
- Full-disc view of Earth: **1 visible** band: 1km by 1km.
  4 IR bands: 4km by 4km.
- GOES-12 Imager at 75º W:
  68-70º W longitude and 34-36º S latitude each 30' (**hh09ss, hh39ss**)





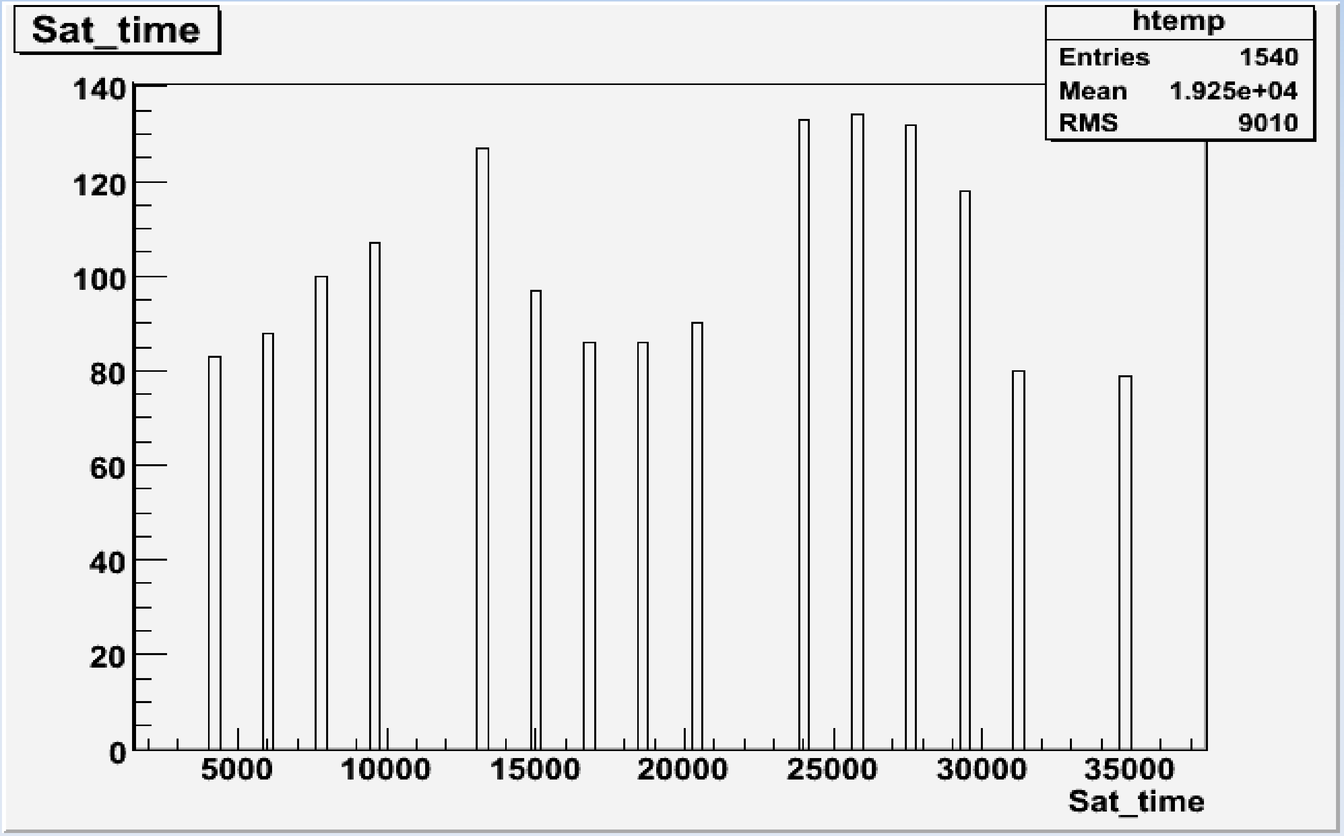
Satellite GOES12

- 2007 satellite images



Satellite GOES12

Time in seconds of the day(UT): **night period**



Satellite dark time: 00:09am / 03:09am / 06:09am / 09:09am
Cloud identification during **FD shifts**.

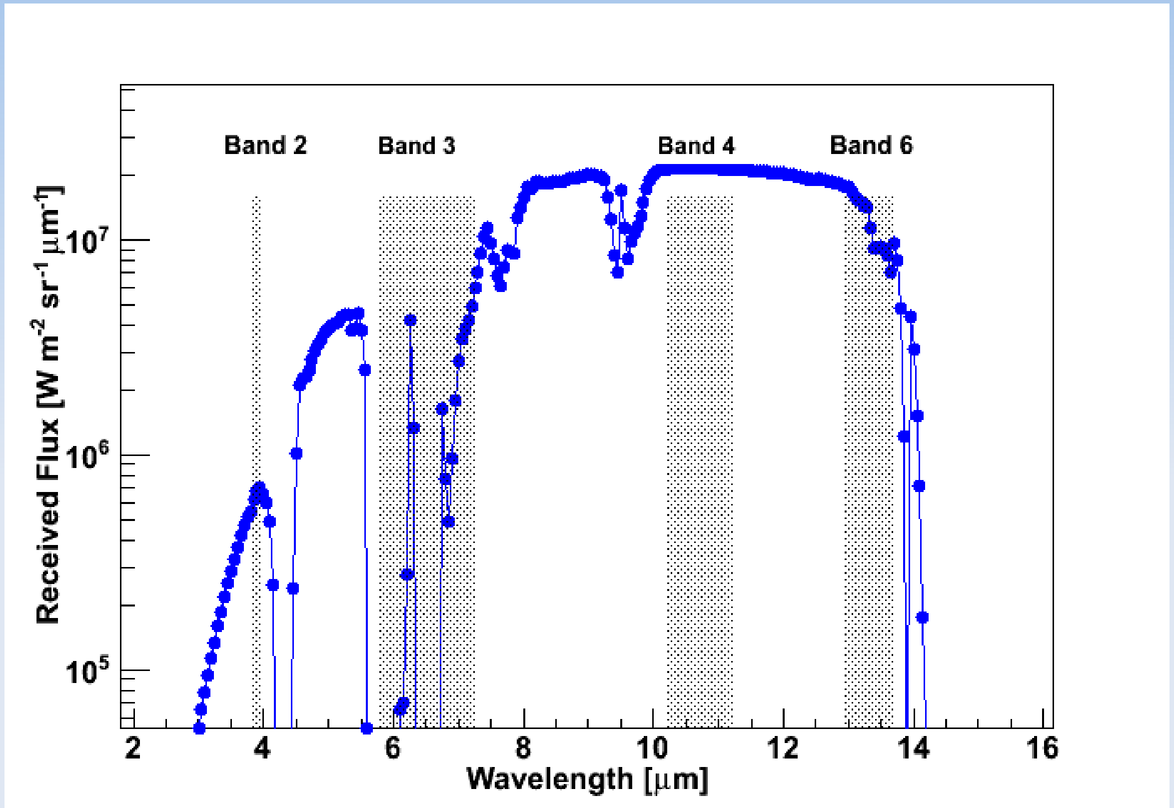
4 Satellite IR Bands

Band 2: 3.9μm.

Band 3: 6.5μm.

Band 4: 10.7μm.

Band 6: 12.3μm.



Emission spectrum for a 280 K black-body at Earth's surface.

Absorption effects of atmospheric **water vapor**:

Bigger effect in band 3.

Less effect in band6.

Band **2 & 4: unaffected**.

4 Satellite IR Bands

- We download IR images during FD duty cycle from **NOAA** site.

- We transform the files of the images to an ASCII file.

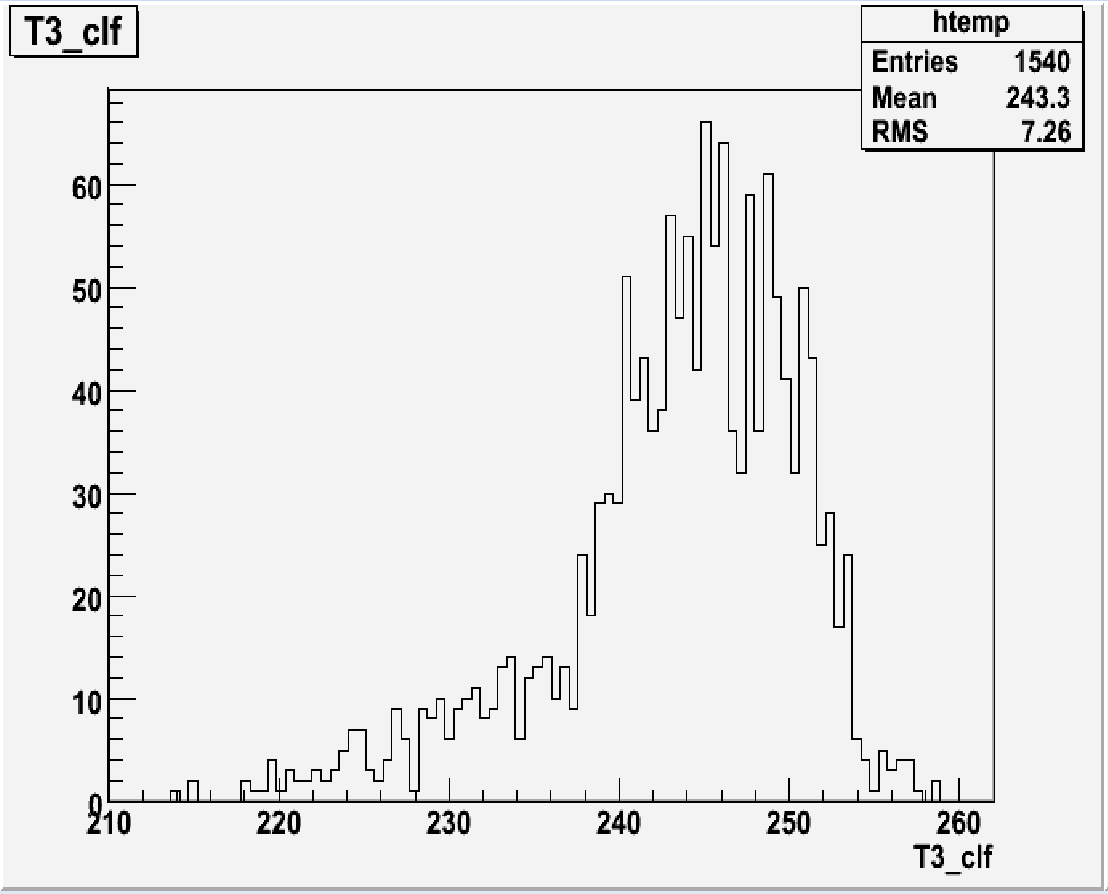
- Each pixel have **counts**.

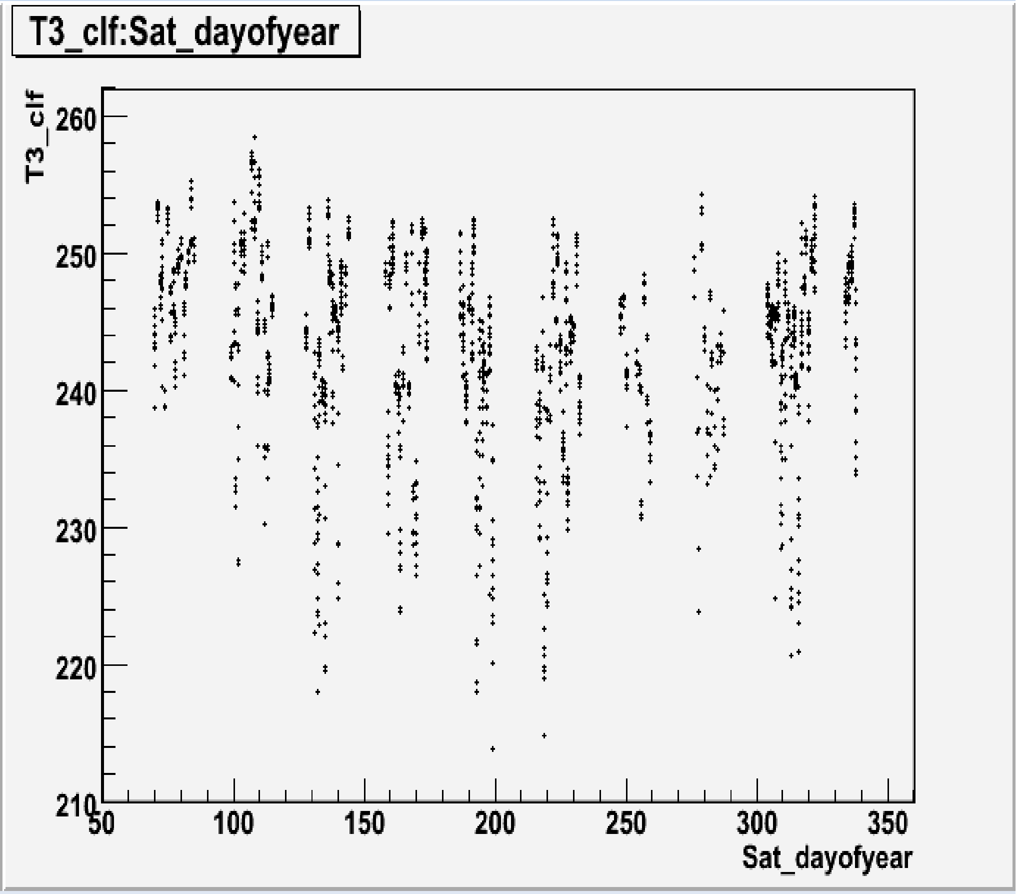
- For each band we have **calibration coefficients** given by NOAA:
We transform counts to **radiance** and radiance to **brightness temperature** using the inverse Planck function.

- We get **brightness temperature** for each pixel at each band.

Satellite Band 3

- **Water vapor** channel at 6.7 um,
  responds to water vapor at **middle and upper** layers of **atmosphere**.
- Using CLF pixel:

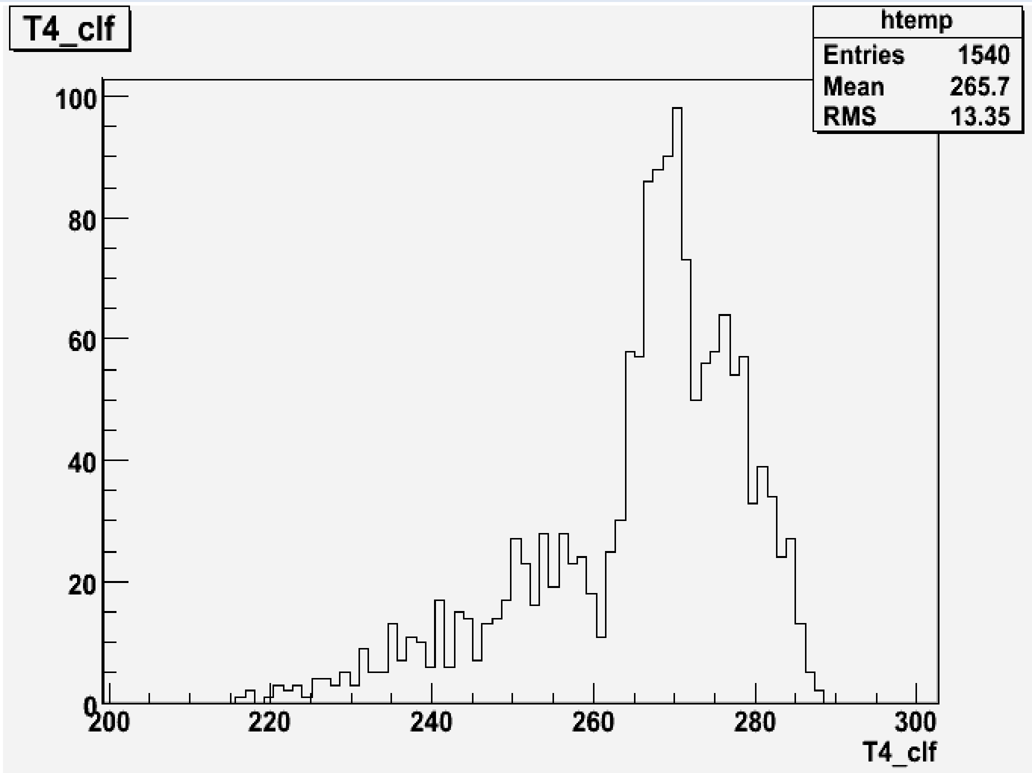


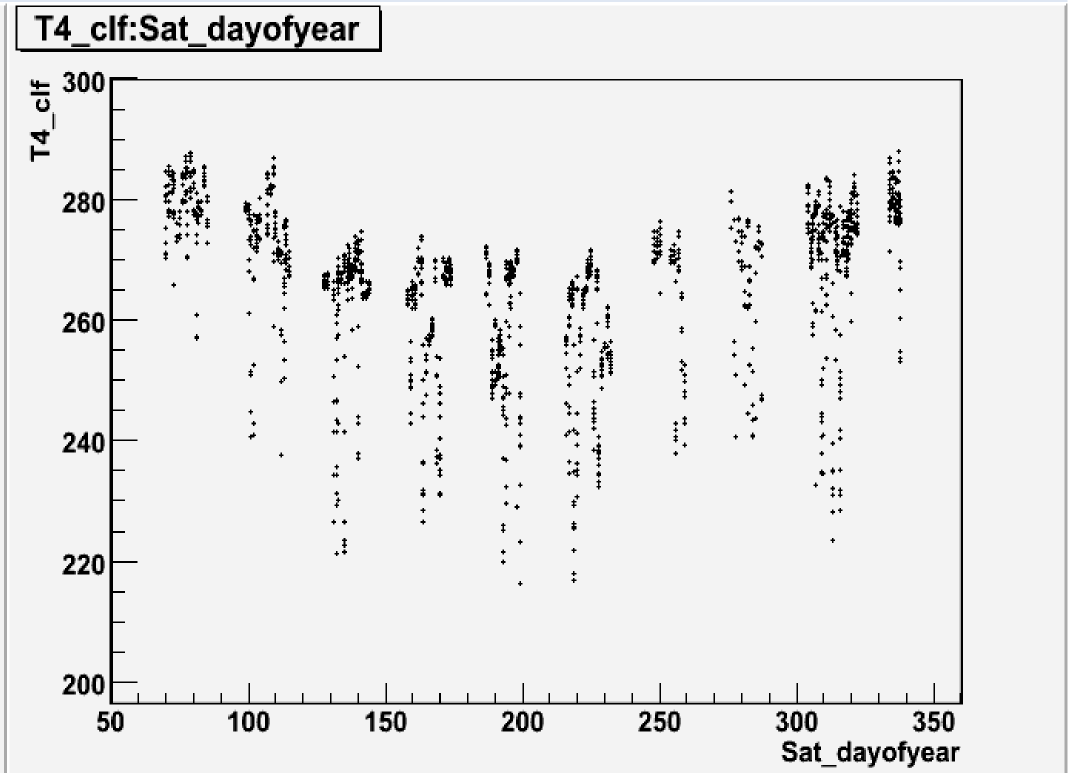


- **Not obvious seasonal effect**, since only restricted to middle and upper layers.

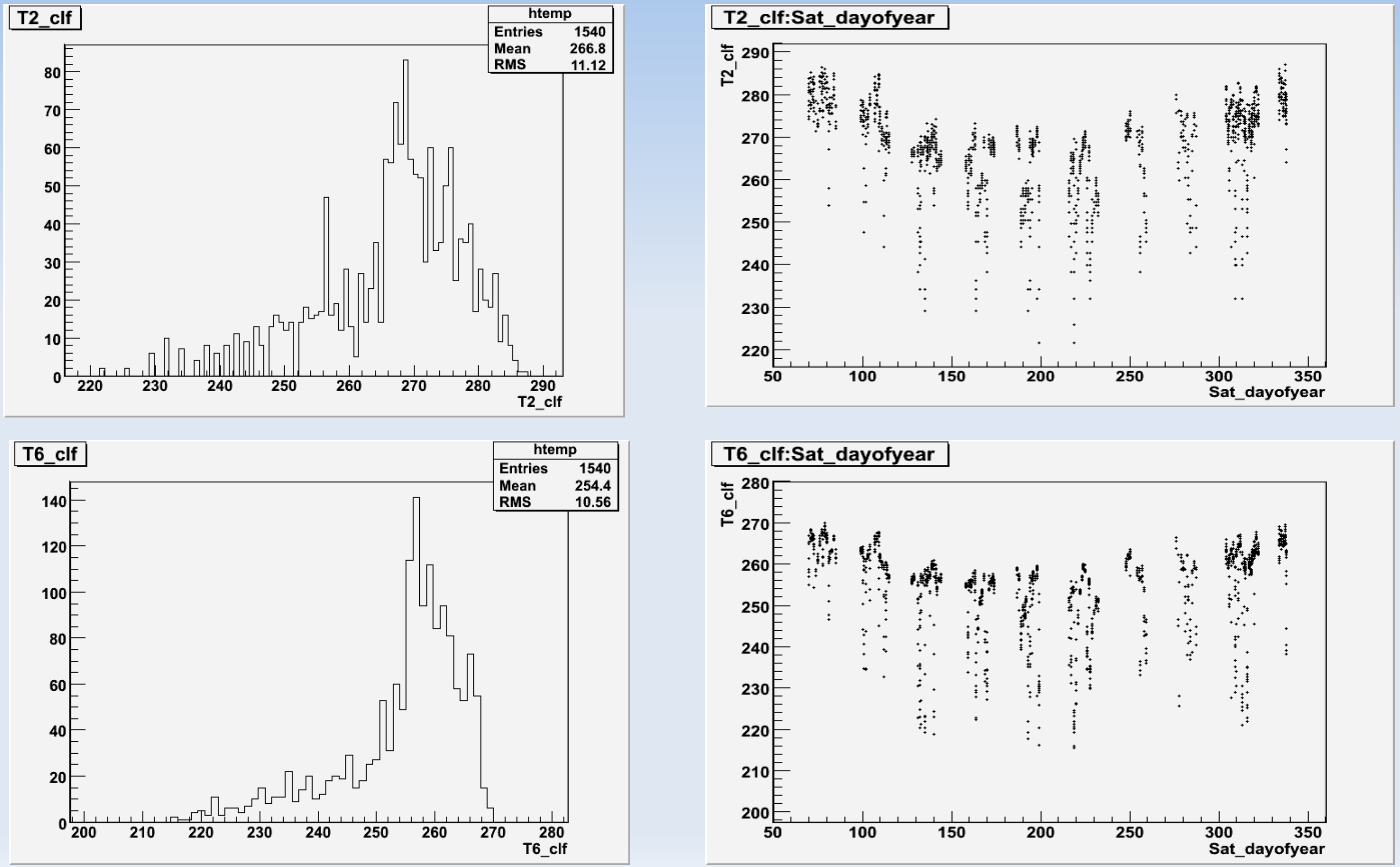
Satellite Band 4

- **Longwave IR** at 10.7um: none of earth's atmospheric gases absorb very well. Able to sense **earth's surface and clouds.**
- Best for thick clouds. For thin clouds: signal is combination of radiance from below cloud as well as from cloud, resulting in T warmer than T of cloud.
- **Seasonal effect.**
- Using CLF pixel:





Sat. Band 2(3.9um) & Band 6(13.3um)



Cloud Identification Principles

What properties of clouds could distinguish between clear and cloudy?

- **Clouds** are typically **colder** than **Earth's** surface:

  T2 & T4 (non-absorbing IR bands): ↓ for **cloudy** pixel.

  Measure unattenuated radiation from **emitting surface**.

  ↓ T2 or T4: marker for clouds.

- Clouds are not pure black-body emitters at IR:

  Very low emissivities (~0.1)

  as compared with the nearly black-body emitting Earth.

  This further **lowers T2 & T4 for cloudy pixels.**

Cloud Identification Principles

- **Wavelength dependence** in **emissivity** of **clouds**, but not for Earth.
  Depends on relationship between **cloud droplet size and wavelength**.
  T2-T4: sensitive to emissivity differences between the two bands.
  T2-T4: ↑ for **clouds**. T2 ~T4: for clear air.

- Clouds: mixture of **water vapor** and liquid water droplets,
  modulate **absorption** at band **3**.
  T3 varies with fraction of **cloud** in a pixel.

- Cloud identification algorithms with
  T2, T4, T2-T4, and T3 appear promising.

Cloud Verification

To test efficacy of whatever algorithm,

comparison with instruments at Auger Observatory:

- Cloud Camera and LIDAR

  Different field of view/timing: not easy and perfect comparison.

- **CLF**:

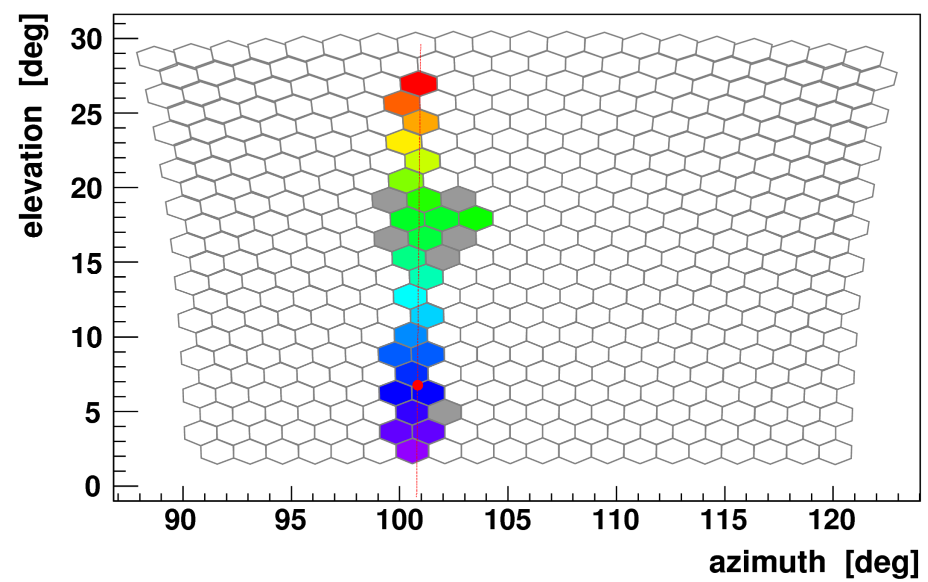
  Cloud/clear state of CLF pixel is regularly monitored by CLF.

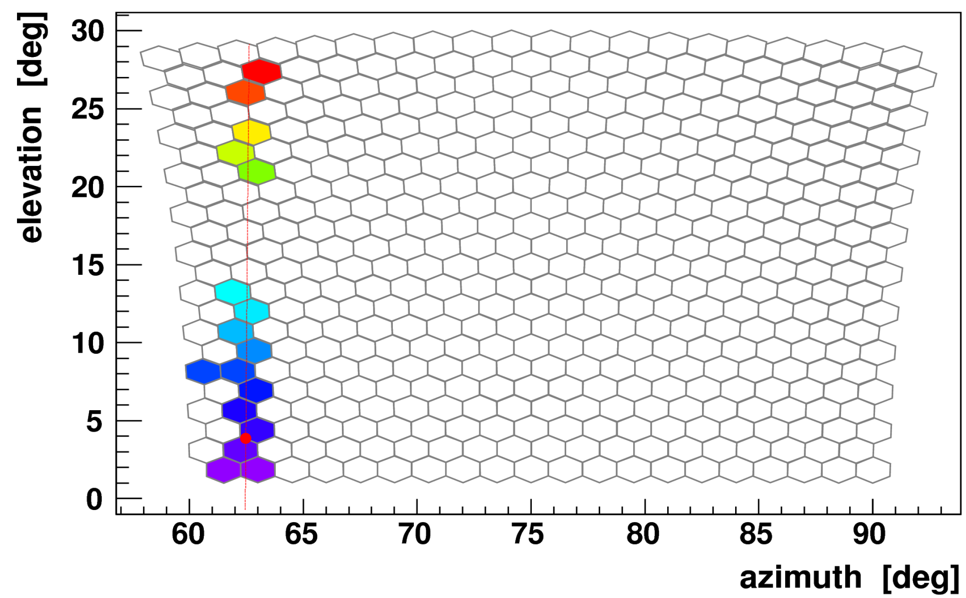
  Every 15' during FD shifts,

  CLF produces 50 vertical laser shots seen by FD stations.

  We reconstructed all 2007 data(shot by shot) and plot all of them every 15'.

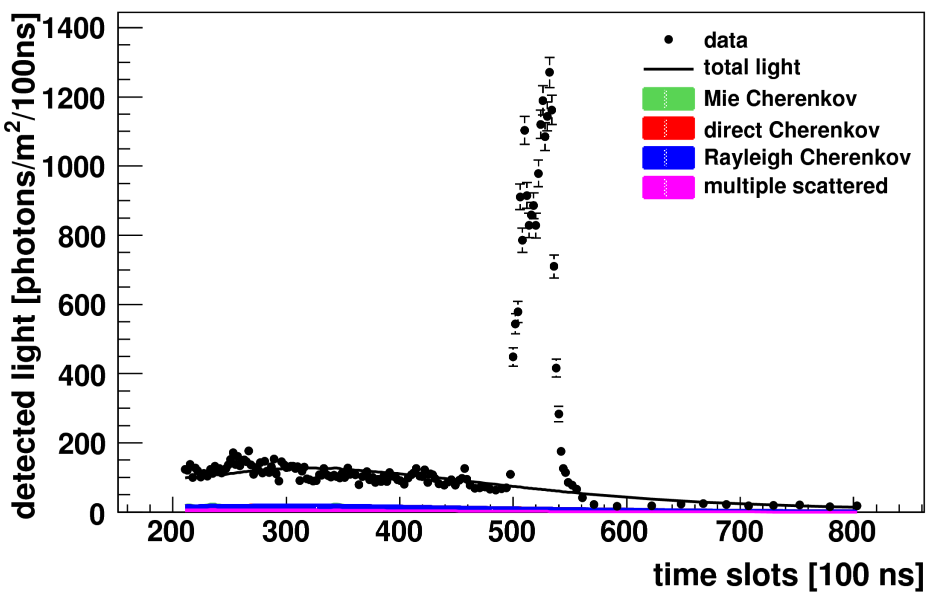
CLF

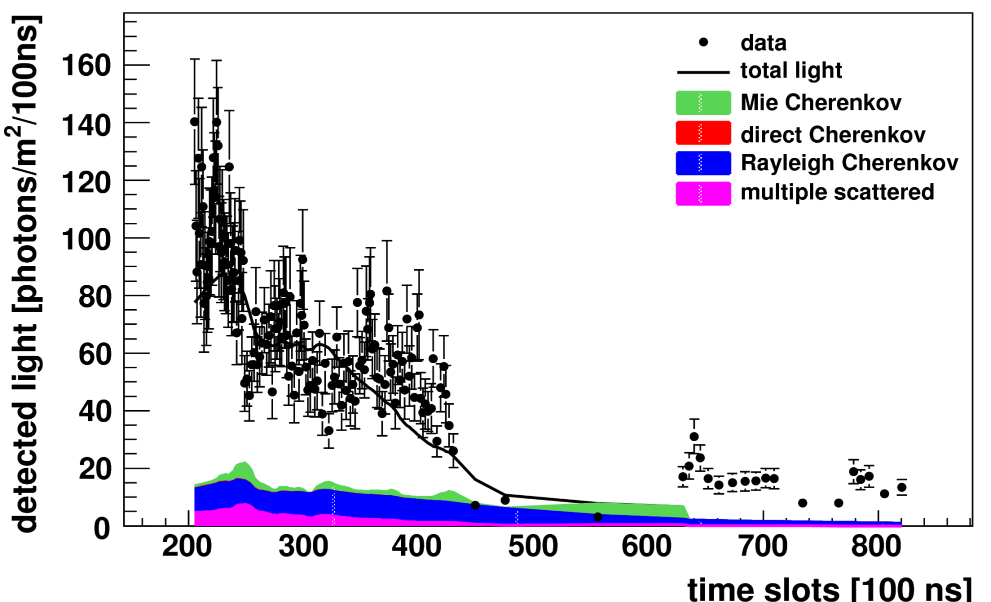




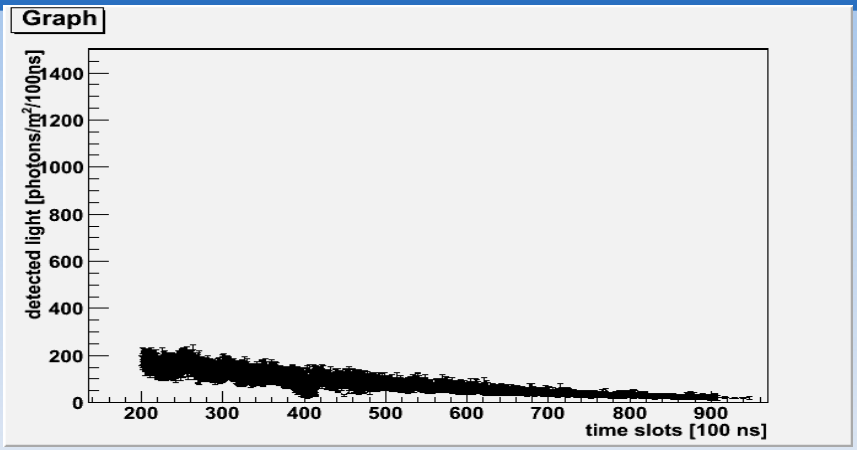
Cloud over CLF

Cloud between CLF & Eye





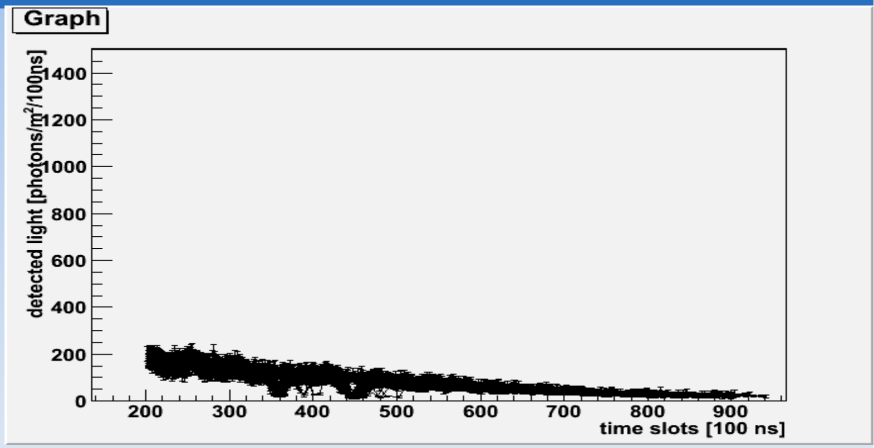
CLF(1 hour data)



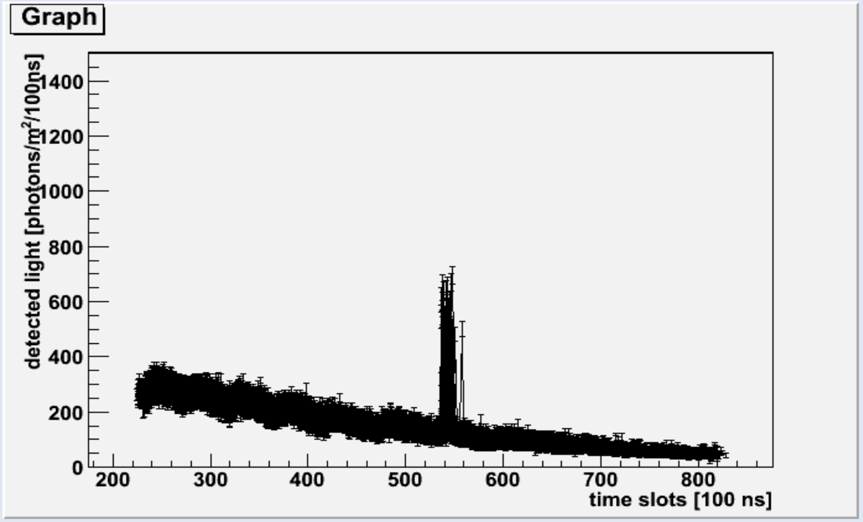
07:00 Clear

Sat

07:09



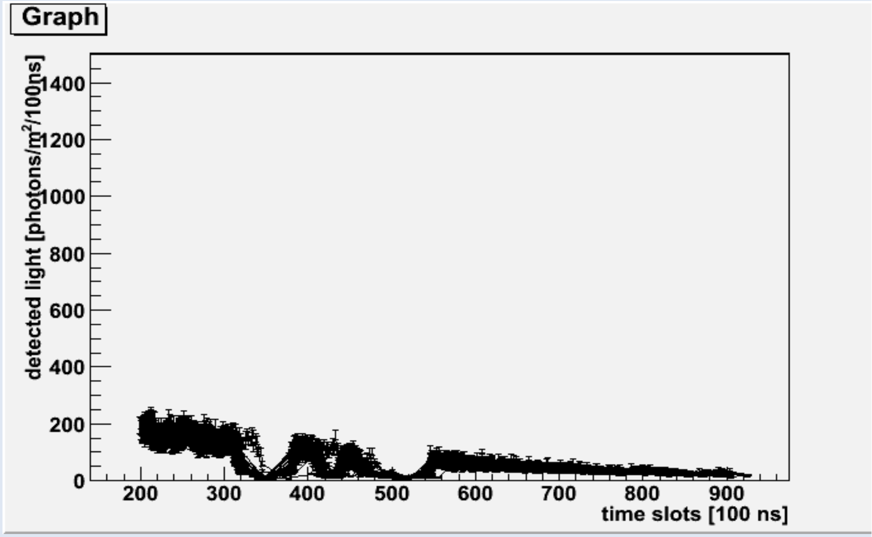
07:15 Clear



07:30 Cloudy over CLF

Sat

07:39



07:45 Cloudy between CLF & Eye

Clear/Cloud tag of CLF pixel:

If CLF vertical shots 9' before & 6' after are **both** clear/cloudy.

Ground Temperature Correlation

- T2 & T4: sensitive to temperature of emitting surface.

  For **clear** pixels: **T2 & T4** should be **correlated** with **ground T**.

  T2 & T4 from ground ~equal to ground T (**emissivity of ground ~1**).

- T4 for CLF pixel vs. T of ground from weather station at CLF(Tclf).

  Correlation for clear nights:

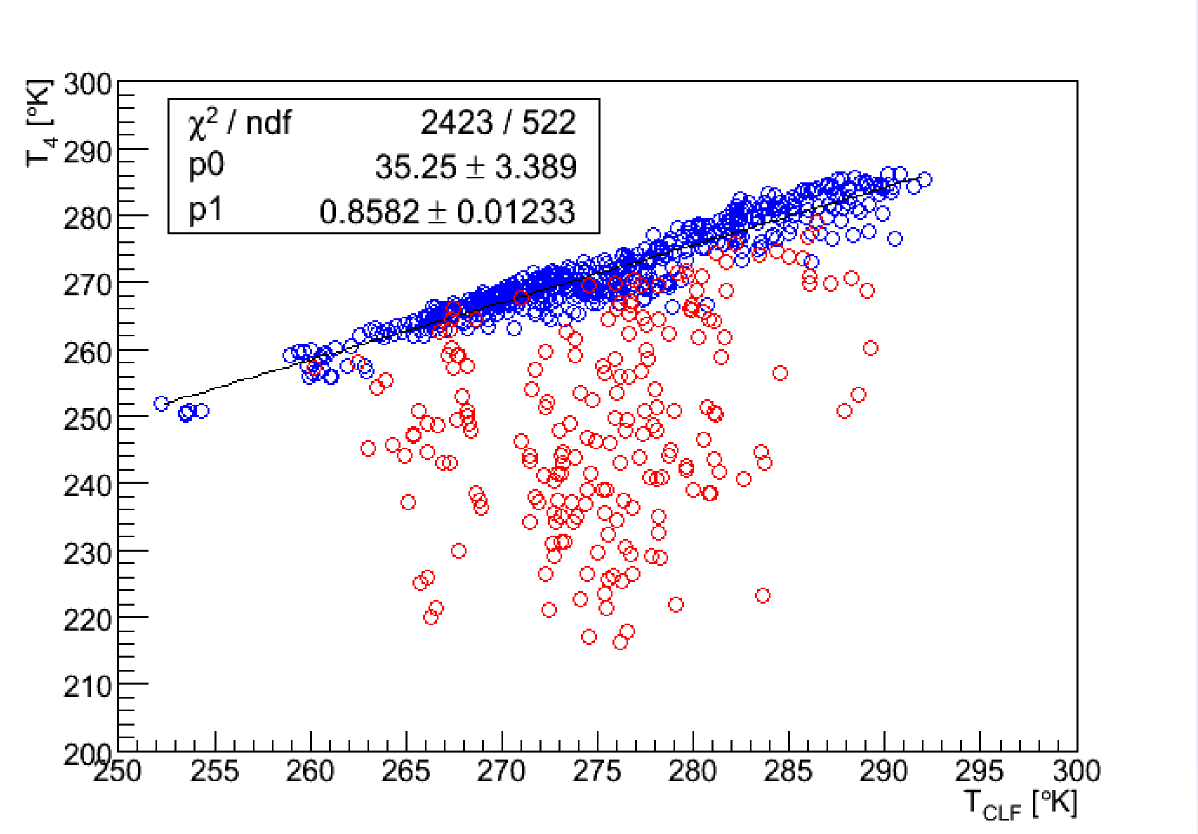
  T4 ~ Tclf

  T4 < Tclf when cloudy.

- Linear fit for clear nights:

  Small residual: clf clear.

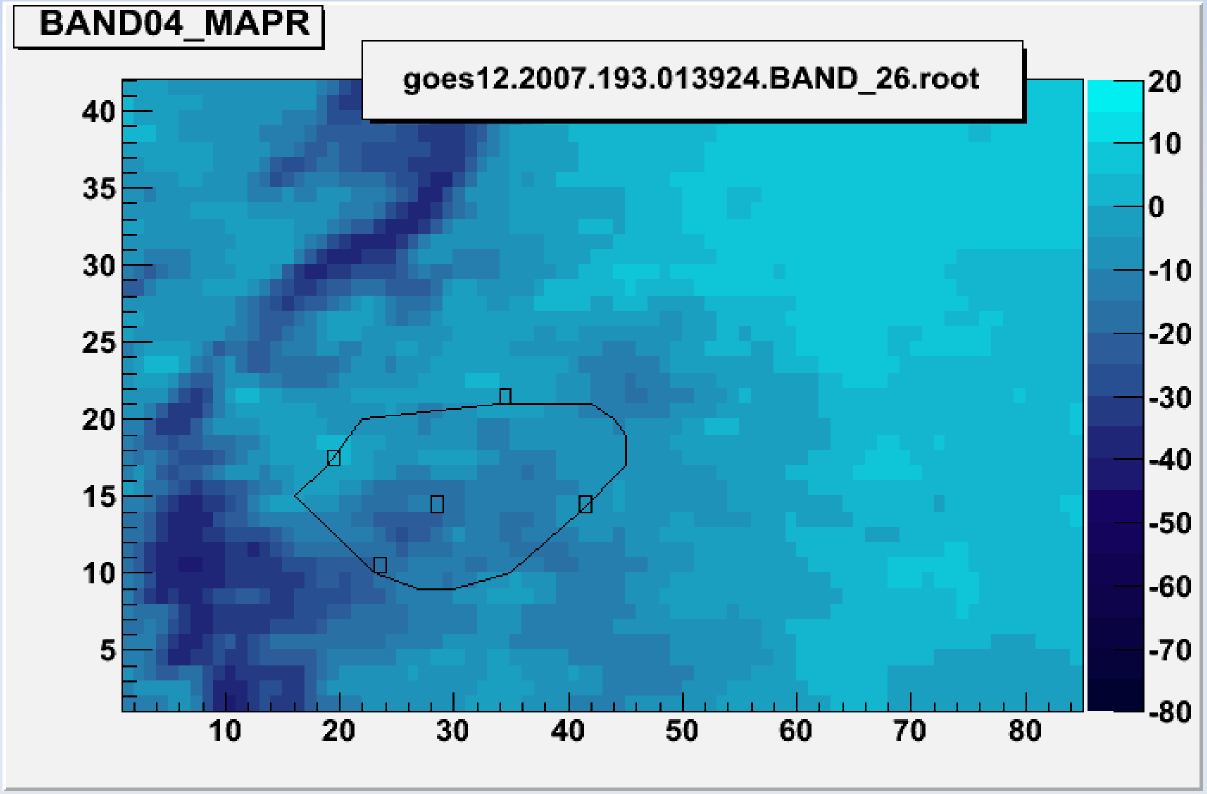
  Big residuals: clf cloudy.



Residuals animated gif

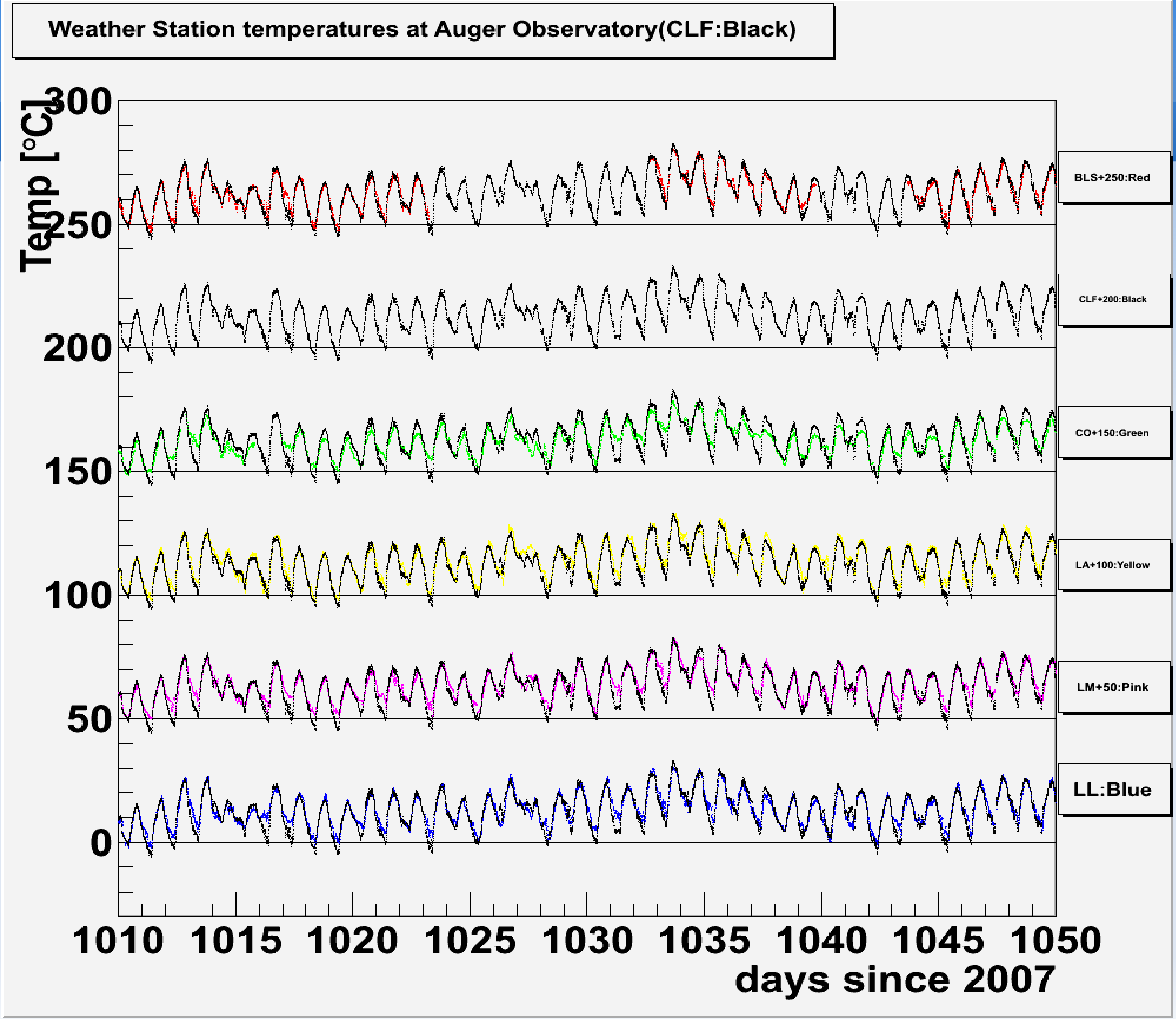
- Assuming a relative uniform T of region: T of all pixels from region ~ Tclf

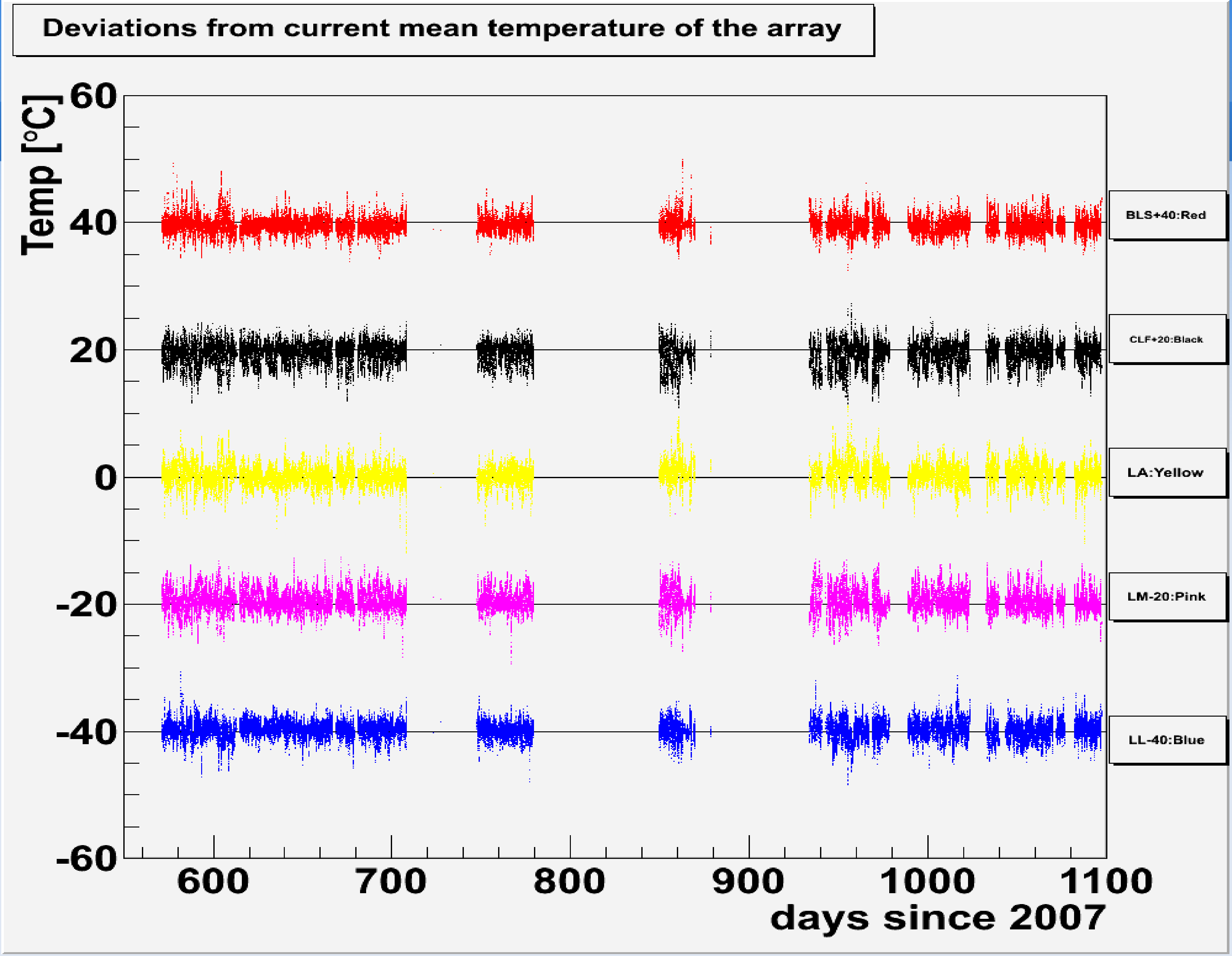
  For every pixel: When residuals small, pixel is clear(clear blue) .
  When residuals is big, pixel is cloudy(dark blue).



http://befnet.auger.mtu.edu/satellite/output/gif/All/Anim_gif_nightly/Residuals/

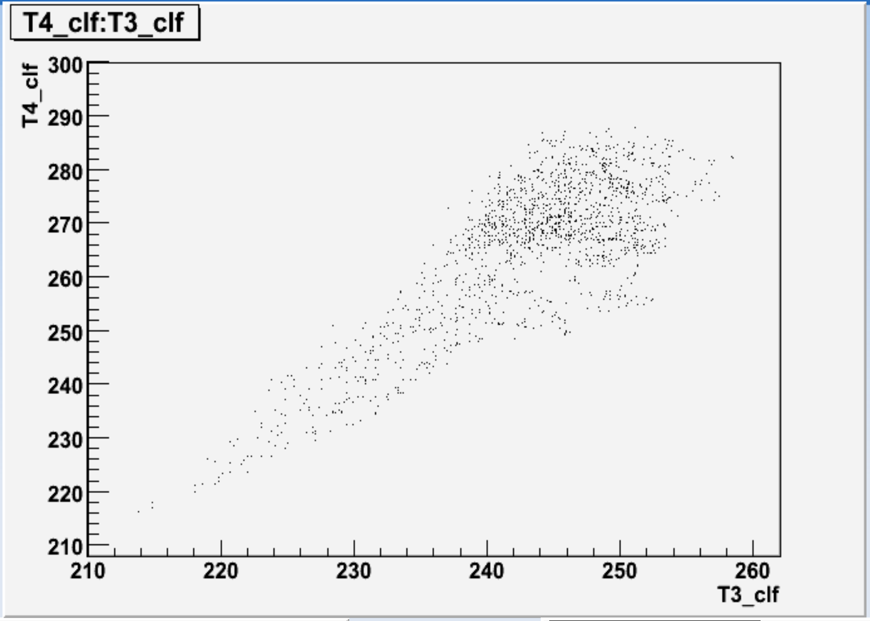
- Better model of T over array: WS at CLF, at 4 FD, at BS and nearby towns.

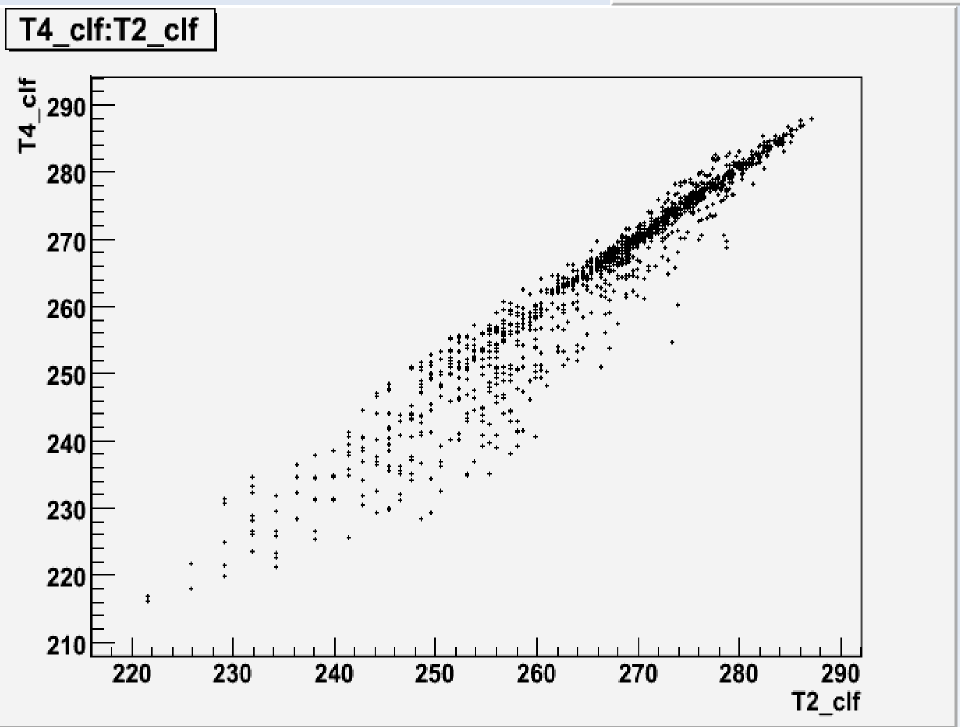

Weather Station temperatures at Auger Observatory(CLF:Black)
Temp [°C]
300
250
200
150
100
50
0
BLS+250:Red
CLF+200:Black
CO+150:Green
LA+100:Yellow
LM+50:Pink
LL:Blue
1010
1015
1020
1025
1030
1035
1040
1045
1050
days since 2007

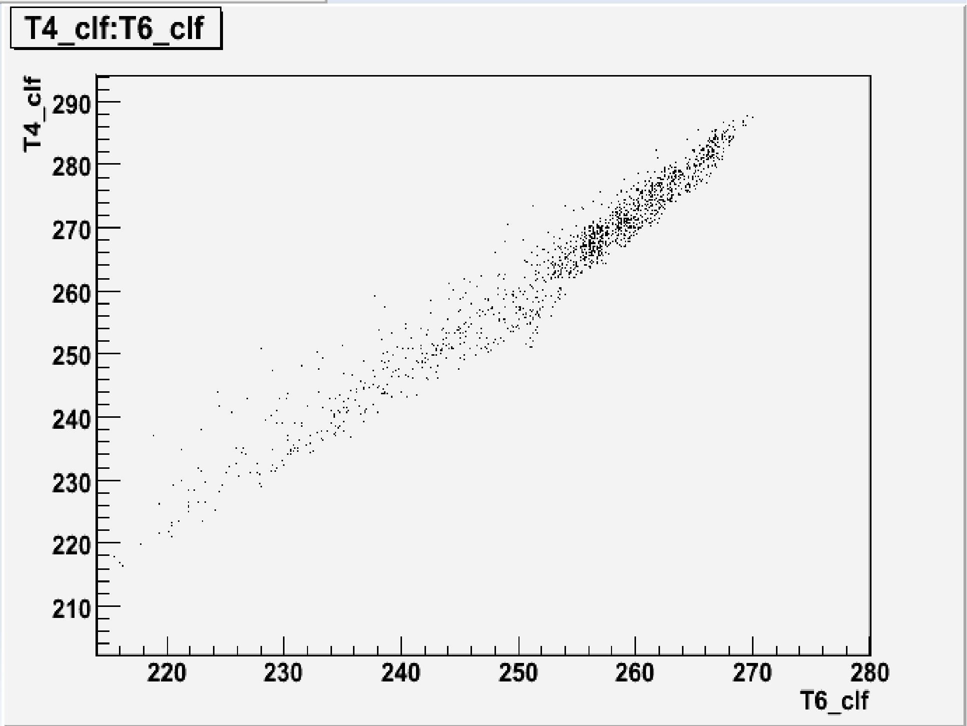


3000km², extrapolations might be insufficient sometimes.

Satellite info only?







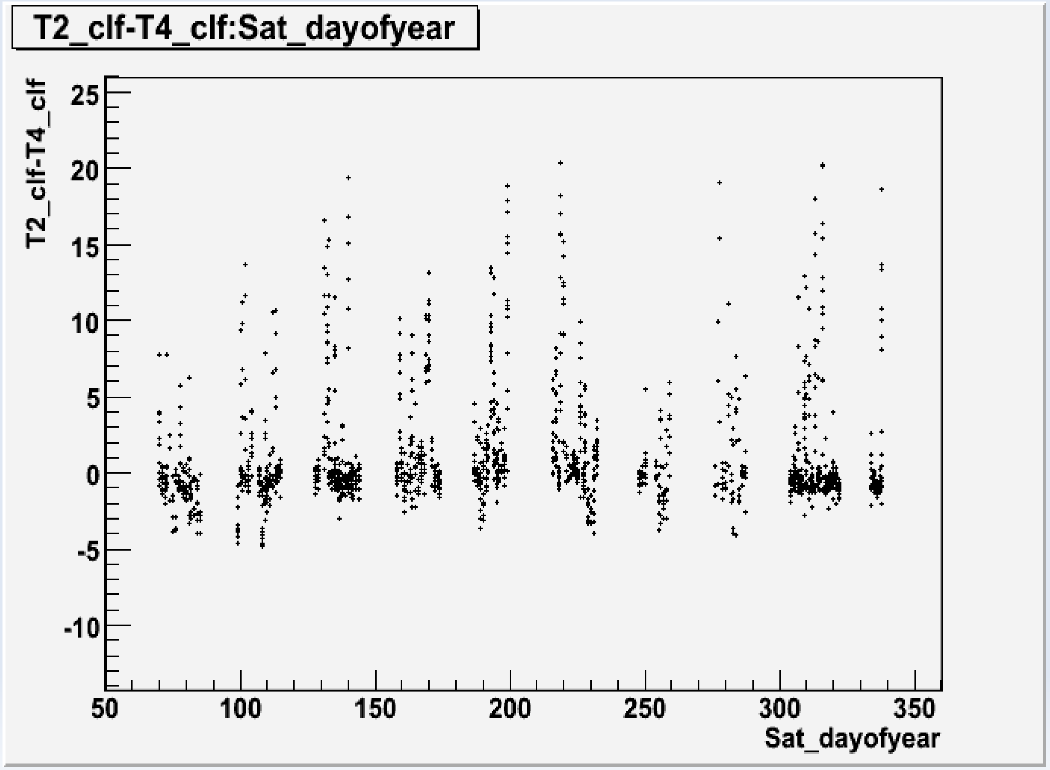
Satellite info only

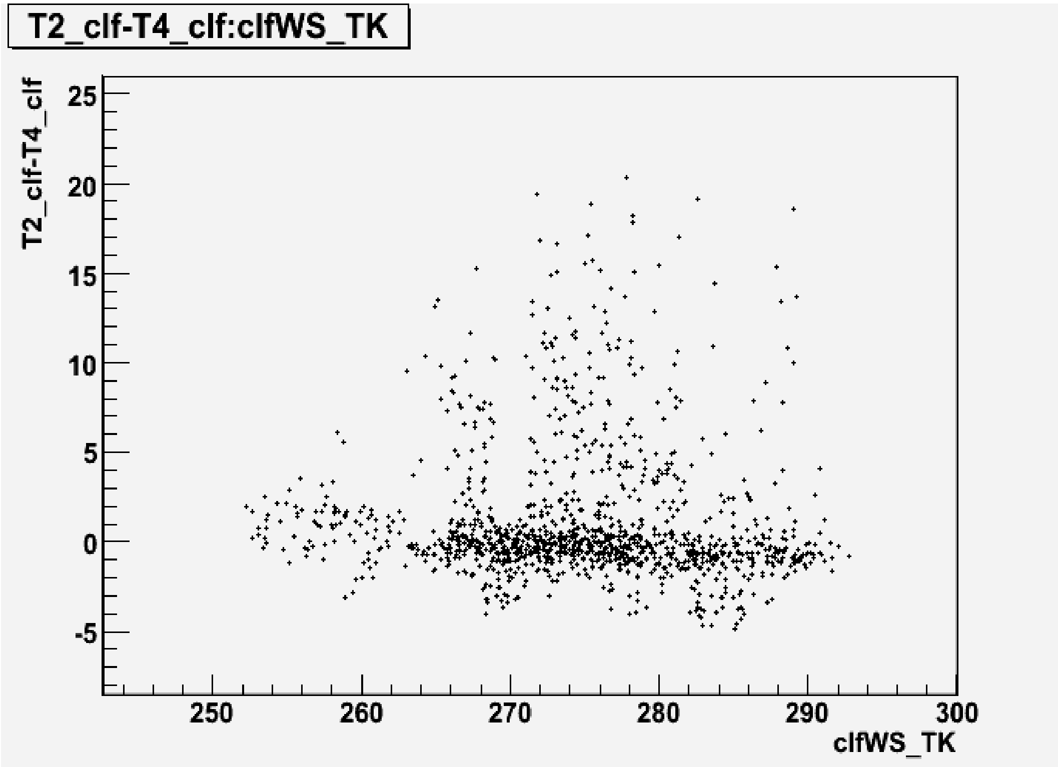
We need variables **not** dependent on **ground T**.

Cloud identification independent on

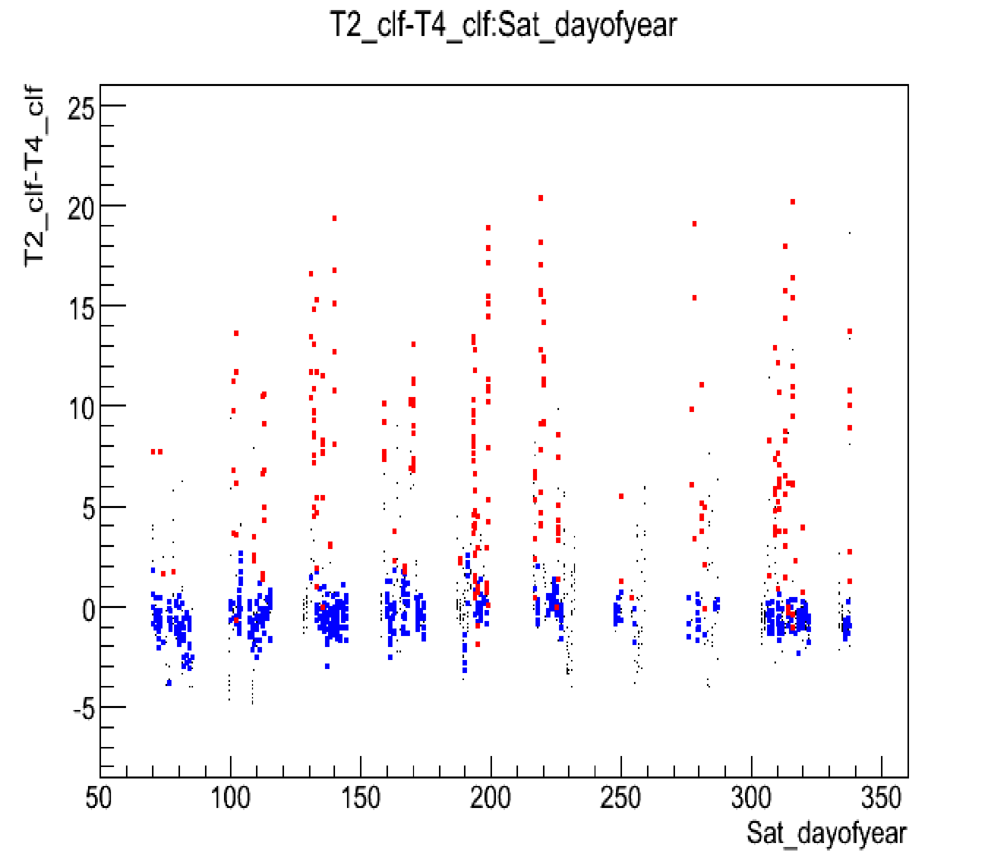
time of year or current weather conditions.

Seasonal effect almost out, when clear?



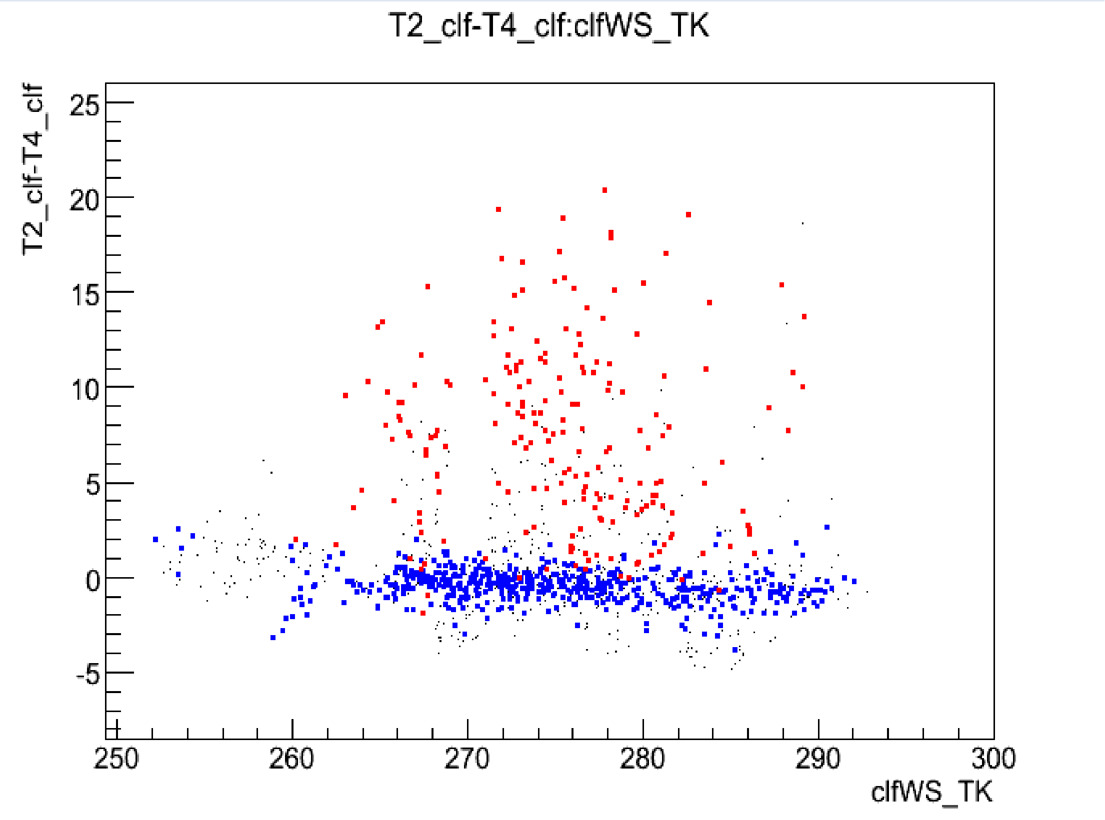


Satellite info only

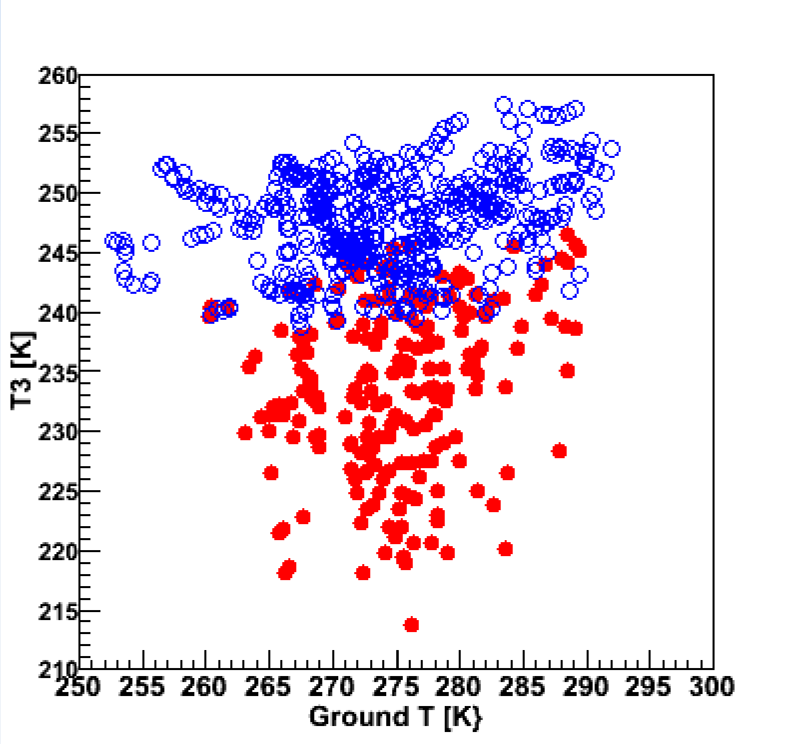


With tagging: T2-T4

Seasonal effect almost out, when clear.



Satellite info only



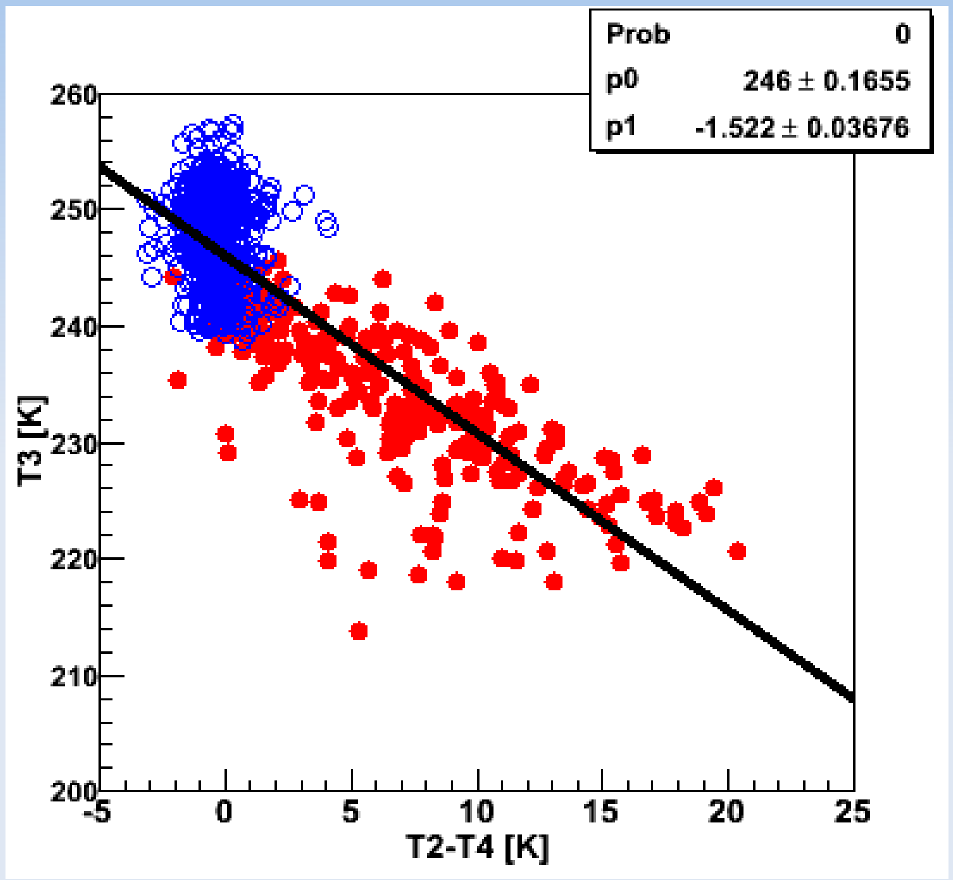
With tagging: T3

Seasonal effect almost out, when clear.

T2-T4 & T3 are good variables(**independent of current weather**)

also show **good separation** between clear and cloudy events.

Satellite info only: T3 vs T2-T4



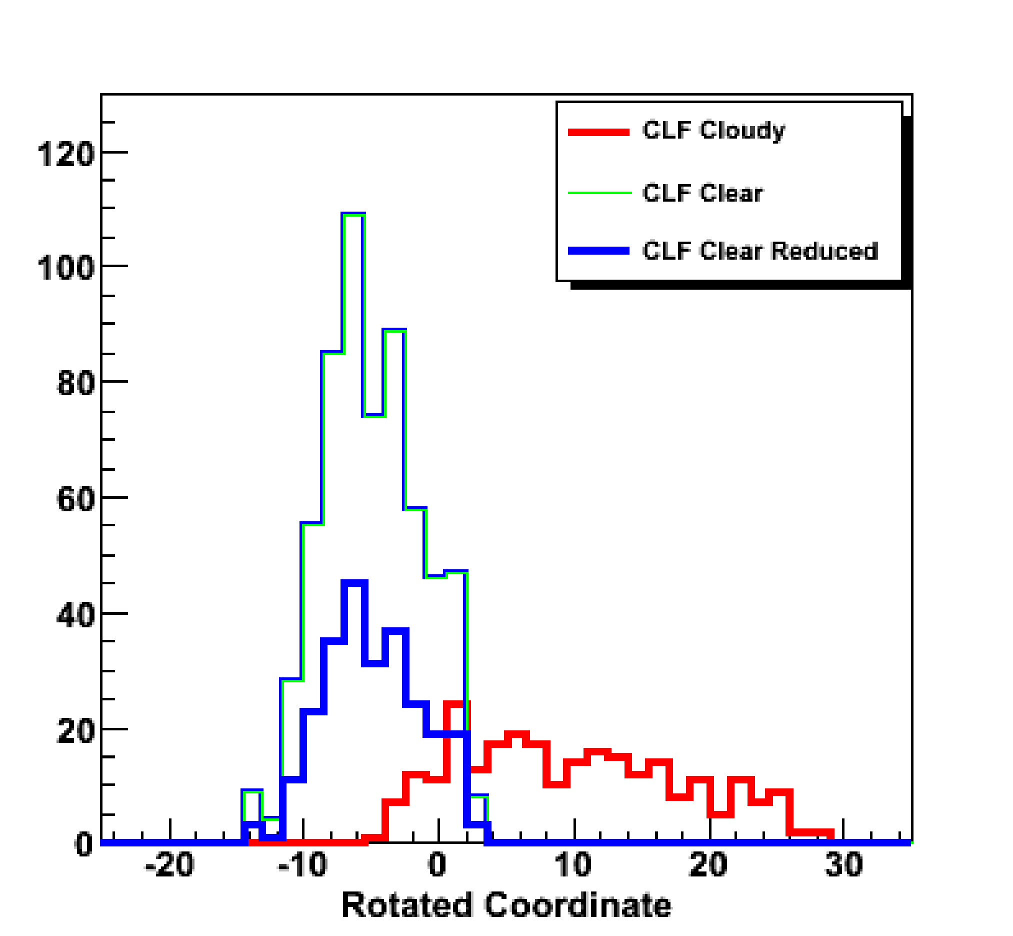
Clear: condensed blob

Cloudy: anti-correlated line

Greatest separation between clear and cloudy tagged pixels along line fit.

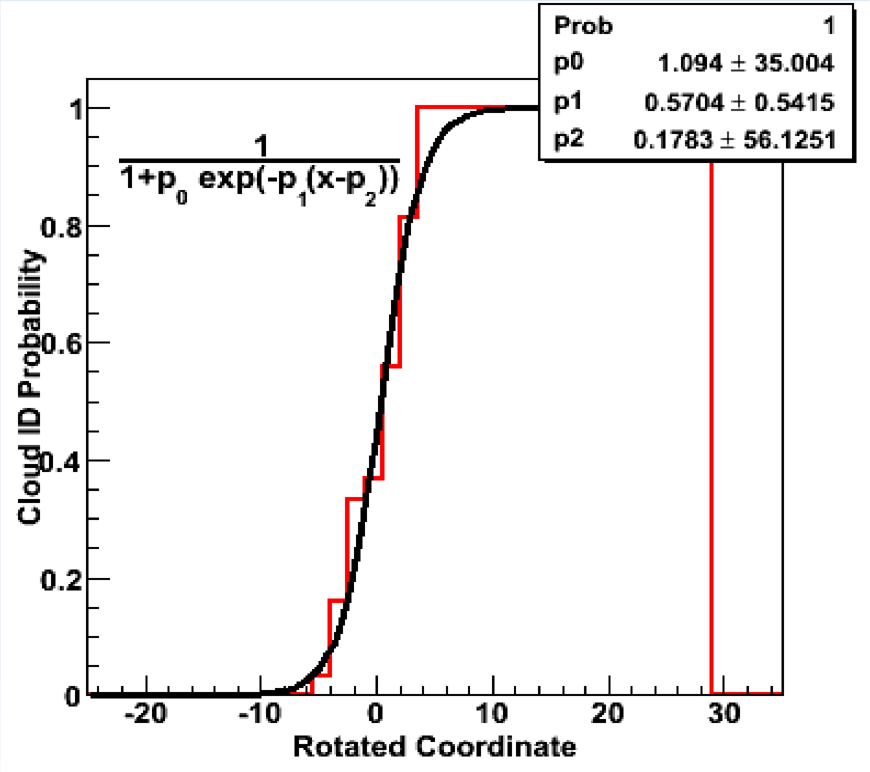
We project the data on to this line.

Satellite info only: T3 vs T2-T4



Probability distribution functions

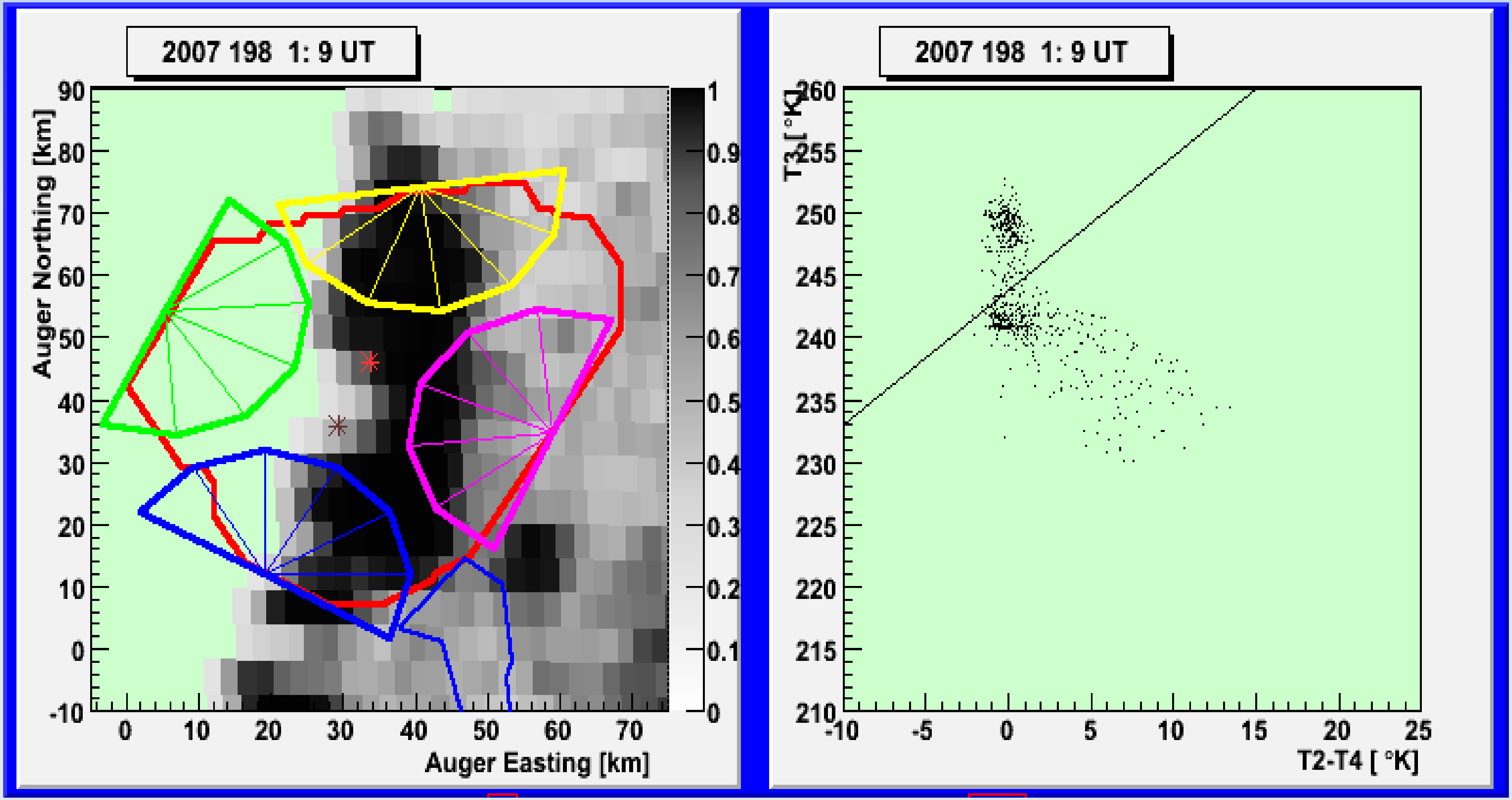
fit to empirical function:



Satellite info only: maps

Pixels with cloud probability < 20%: light green, clear .

Pixels with higher cloud probabilities in grey scale.



http://befnet.auger.mtu.edu/satellite/giffiles/2007/AnimatedCloudMaps/

Satellite images & CLF comparison

- Pixel Resolution: ~4km by ~4km.

  If cloud smaller may or may not change T of pixel depending on its size, height and thickness.

  If small cloud is over CLF, CLF would report it.
  If it is in the same pixel but not over CLF, CLF wont report it.

  We are comparing an **area of 4kmx4km with a spot**.

- Comparison with **~6' delay** between CLF and satellite images.

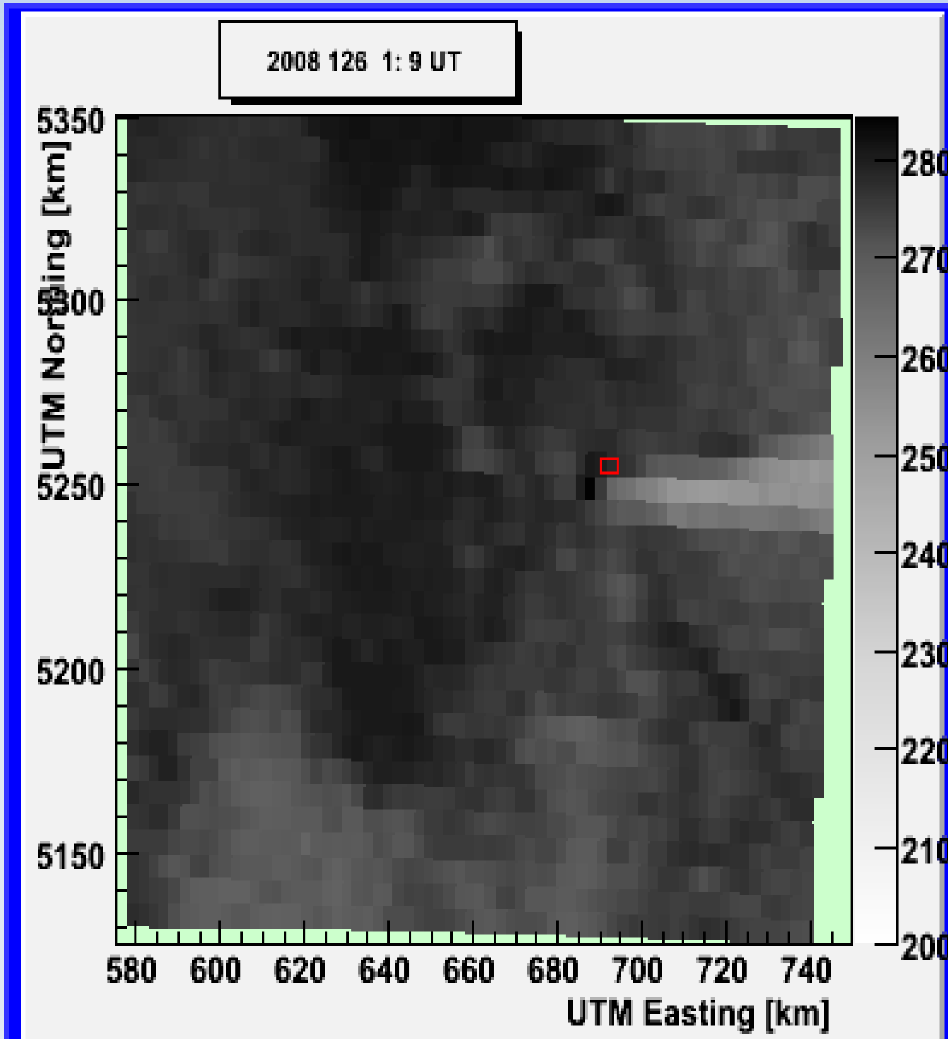
- **Thin clouds** difficult to be identified by satellites/CLF could report them.

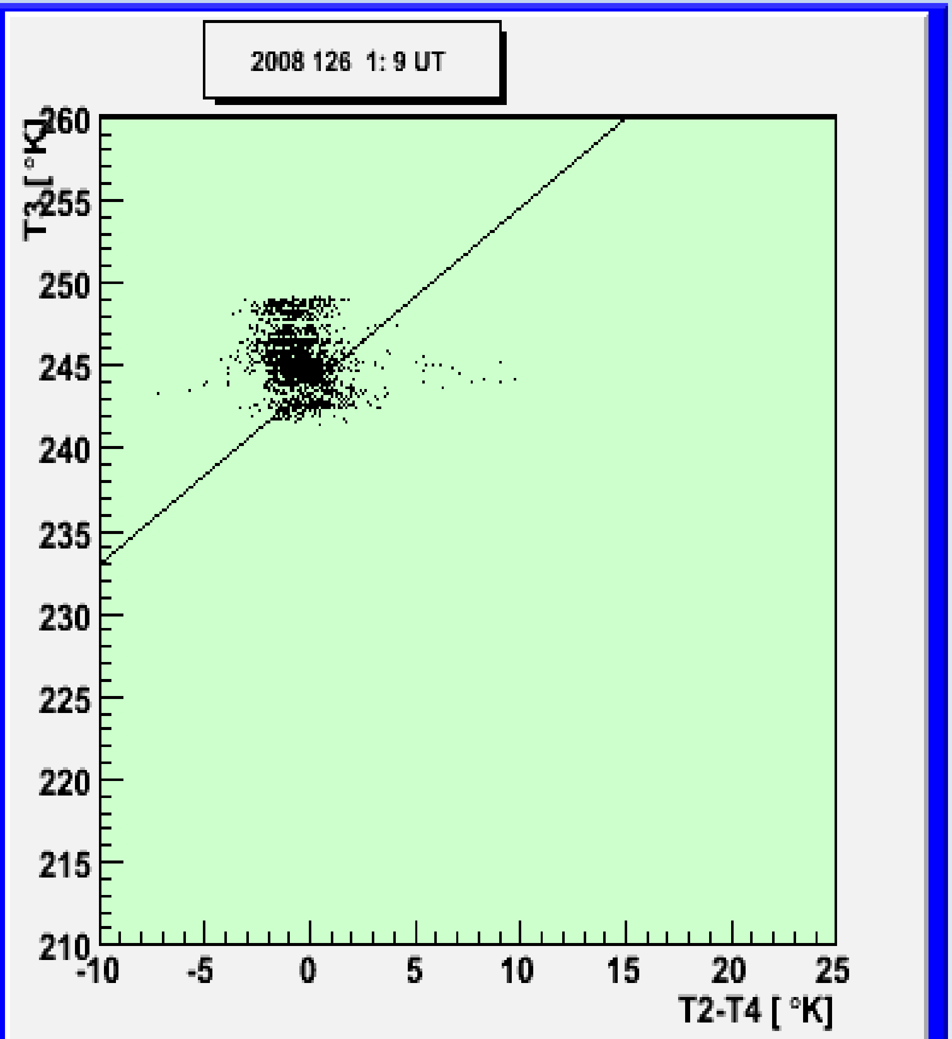
- CLF detects clouds only up to ~13km height (FD field of view).

  Higher clouds are detected by satellite images.

Satellite images & CLF comparison

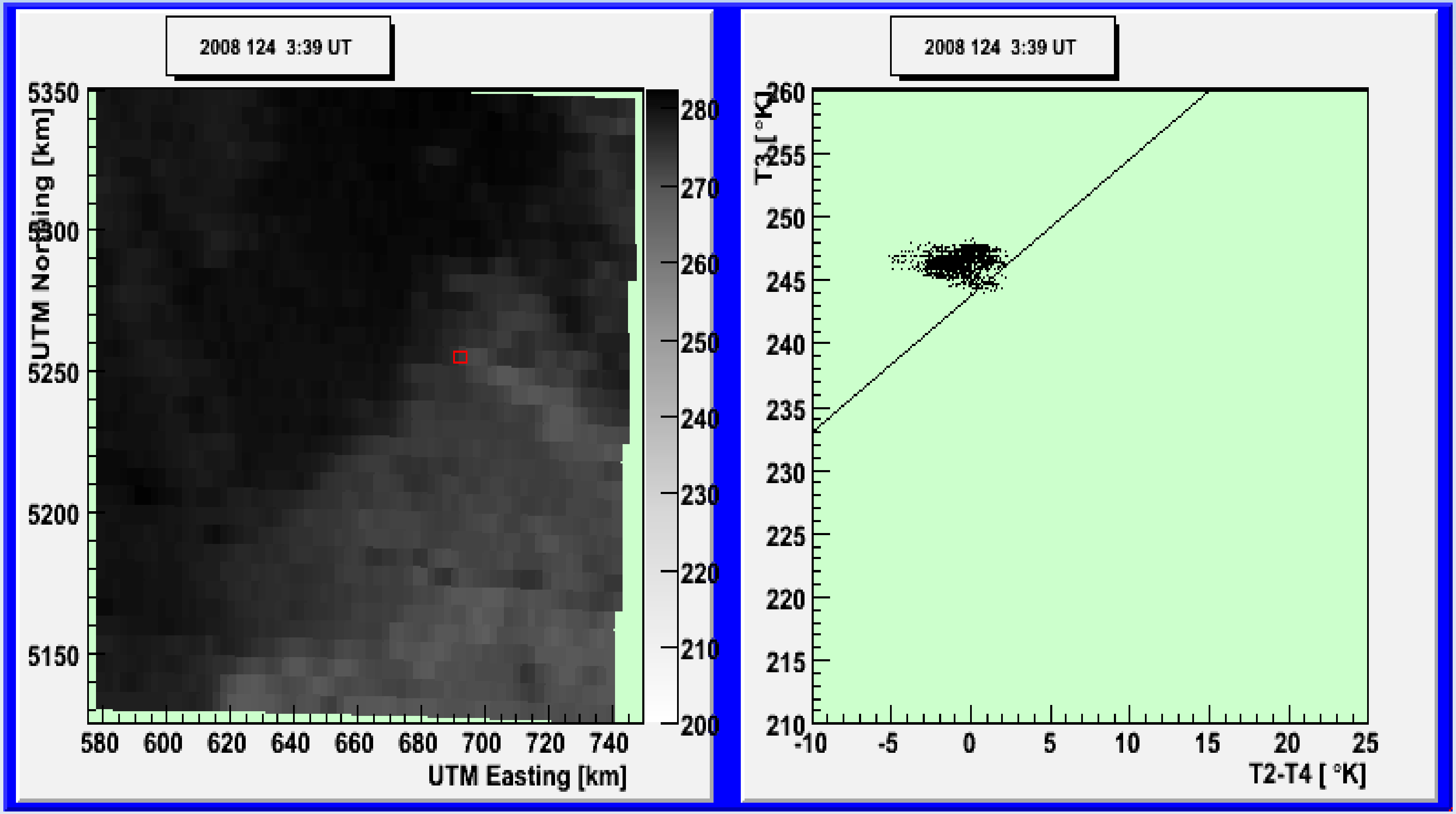
- Satellites are having some errors of ± ~1 pixel for location.
- Chaiten Volcano in Chile, near the Observatory erupted in 2008.





Satellite images & CLF comparison

- But



Next

Auger Star

Monitor