Atmospheric Monitoring Systems for the AUGER Observatory

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2) Cloud Detection

III School on Cosmic Rays and Astrophysics
Arequipa - 9/2008

Cloud Detection in FD data

- The principle:
  - The variance of FD pedestals can be used to measure the photon flux in each pixel
- The goal:
  - Derive cloud coverage information from variance data
- The advantages:
  - no transformation needed from another pixel space.
  - Background data and FD data almost completely overlap in time coverage.
- The disadvantages:
  - Understanding background data is not at all trivial

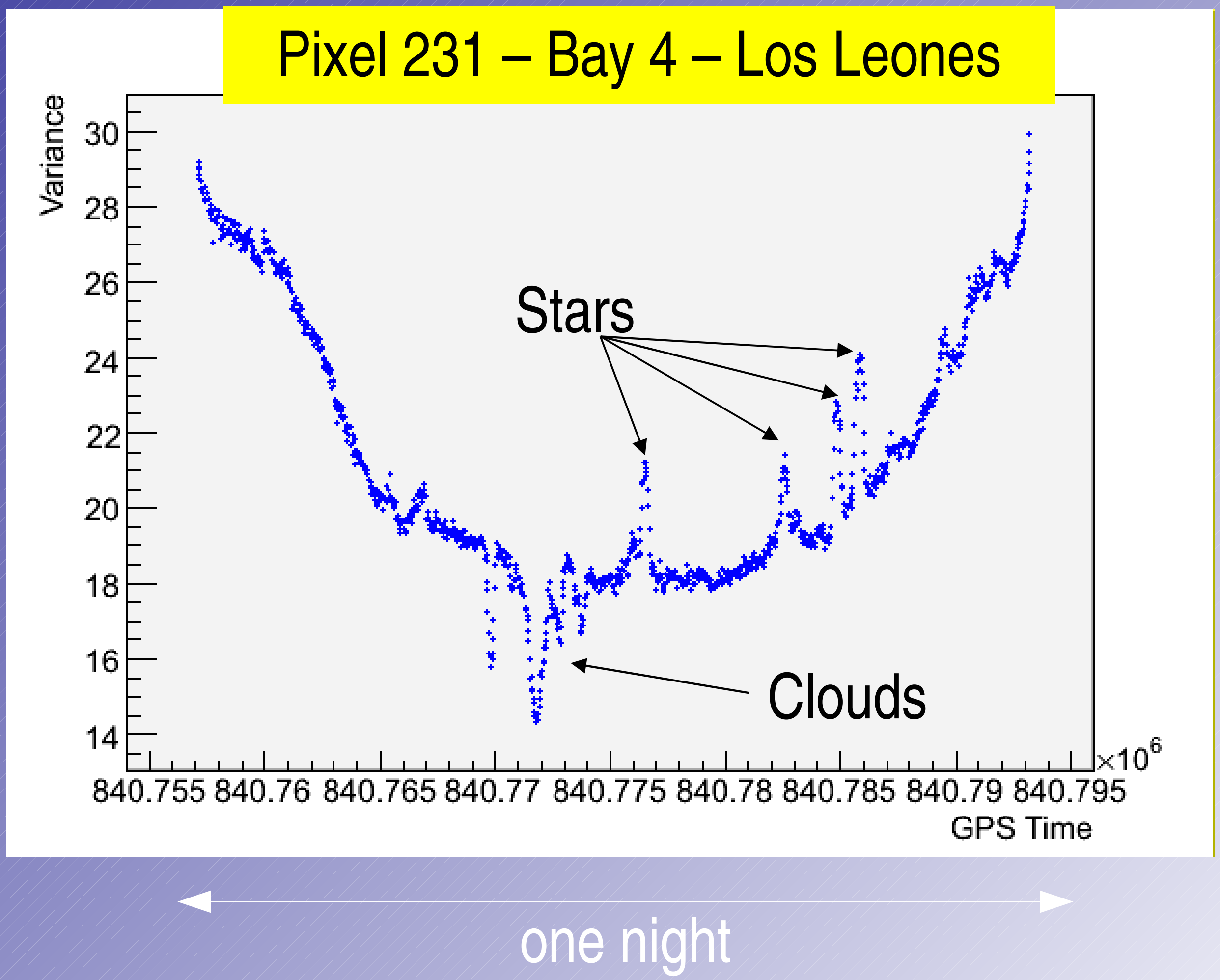
Sky background from 1 FD pixel

Stars are easily visible as peaks

Smooth background due to many sources:

- Milky Way
- Moonlight (Rayleigh)
- AirGlow (hard to model)

Clouds are identified as dips in sky background, but can have smooth edges and can even reflect light from the moon.

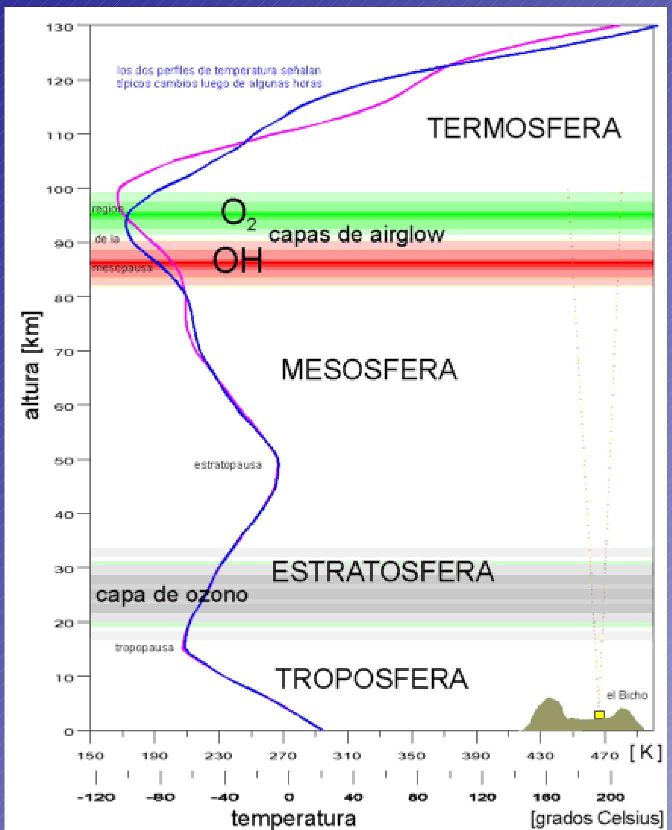


Air Glow

Solar radiation dissociates N_2, N_2, O_2, O_3, H_2O, N_2, in atoms N, O, OH, H or ions $O^{2+}, N^{2+}, O^{+}, N^{+}$

About 100 km in altitude the following reactions occur:

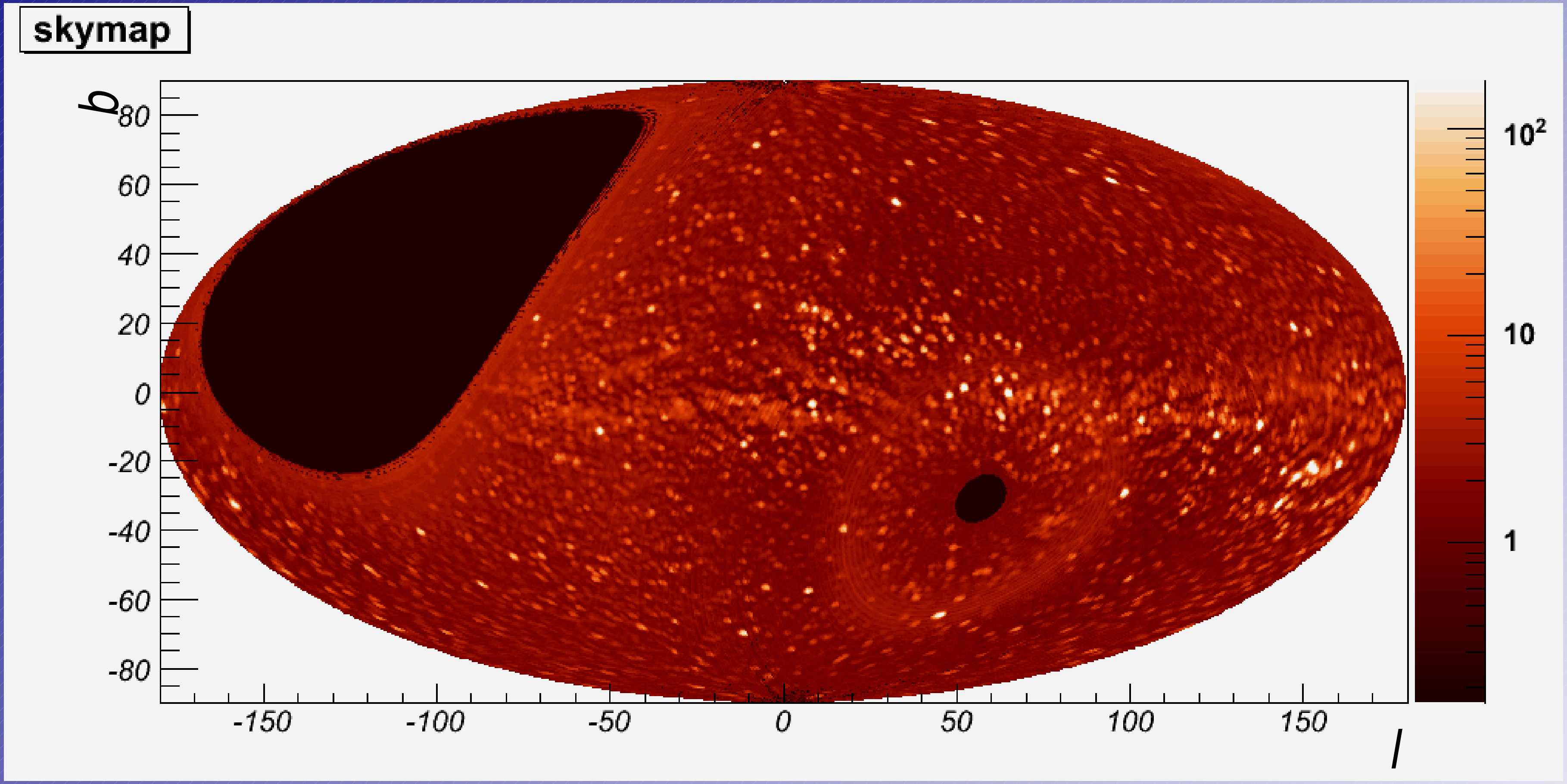
- $H + O_3 \rightarrow OH + O_2 + \gamma$
- $O + O + X \rightarrow X + O_2 + \gamma$ (in presence of a third body X)



Esquema de la estructura térmica de la atmósfera, y de como se observa la luminiscencia nocturna desde el suelo.

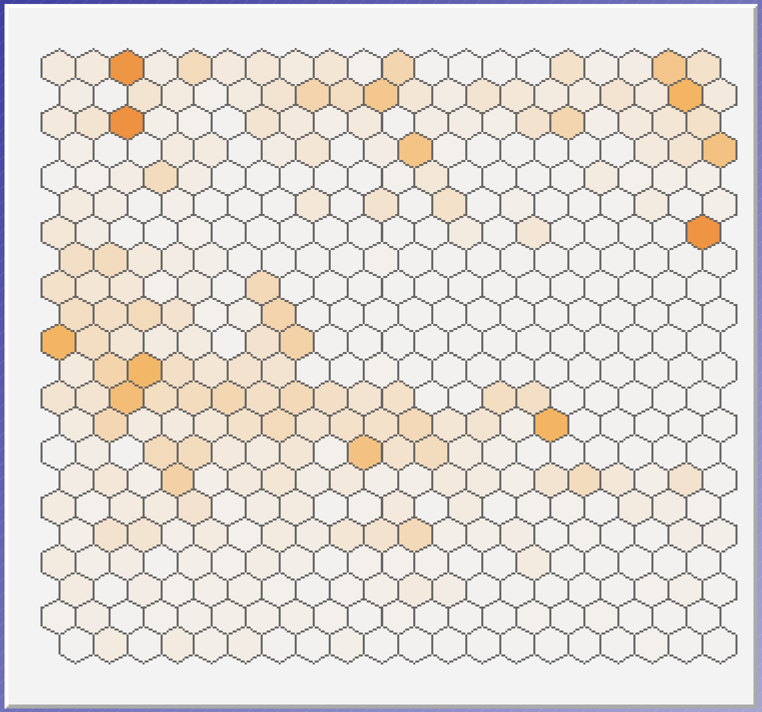
Full sky map from FD pedestals

Transform each pixel from local to galactic coordinates
Integrate over long period of time
Correct for different exposures of each pixel

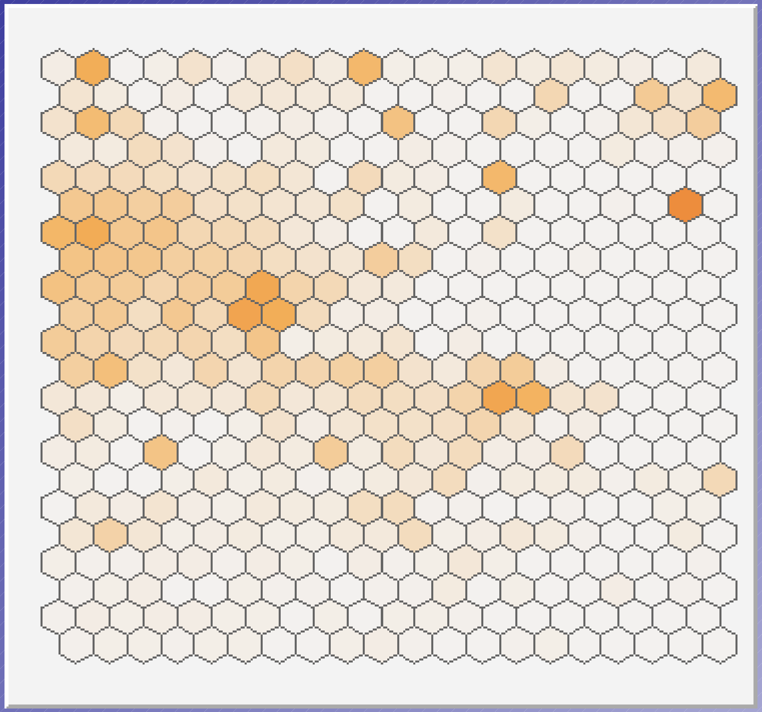


Galactic coordinates

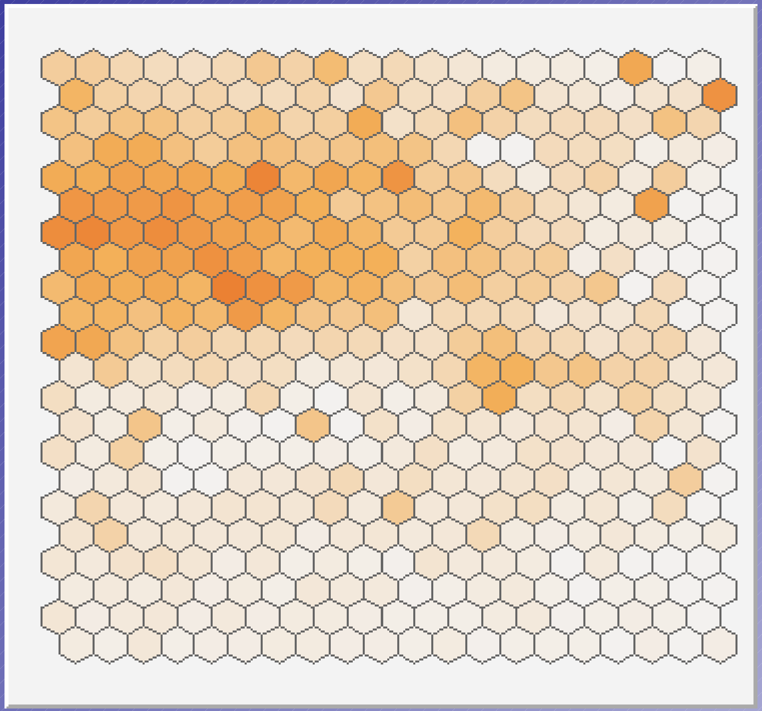
Background Sky variance: frame 1/7



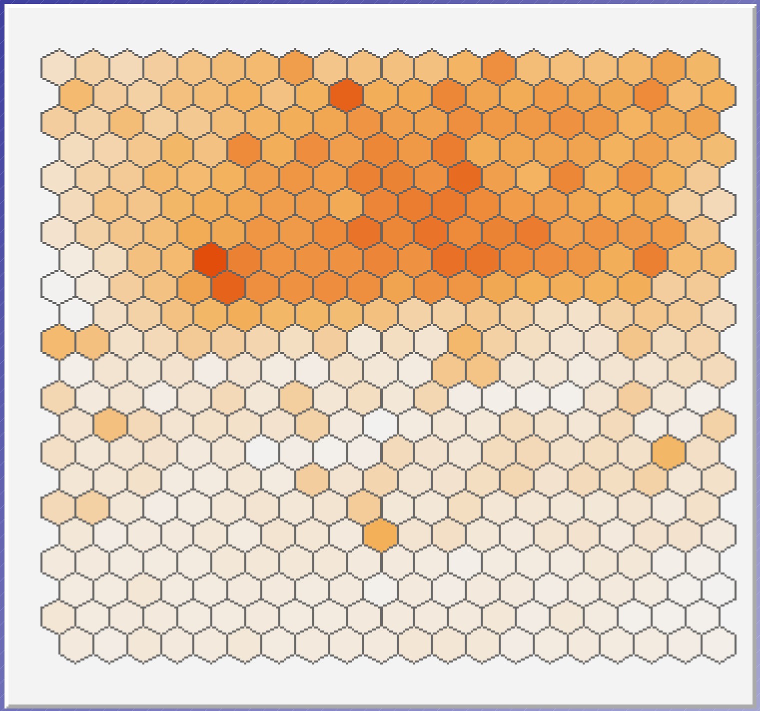
Background Sky variance: frame 2/7



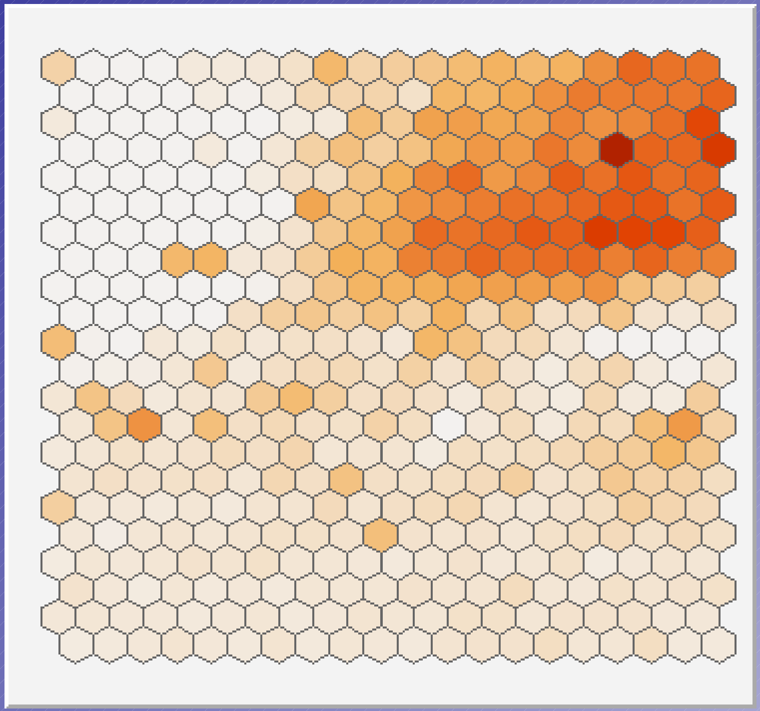
Background Sky variance: frame 3/7



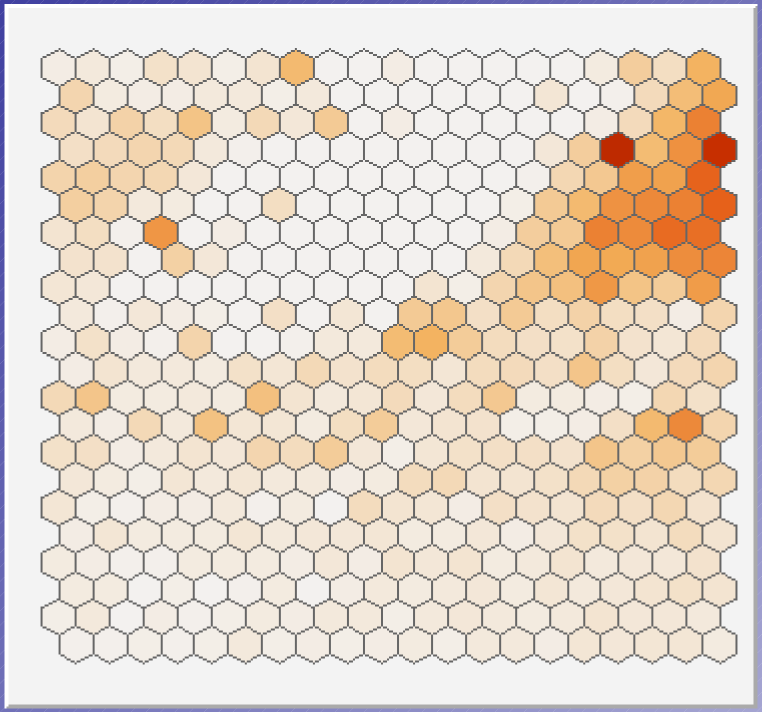
Background Sky variance: frame 4/7



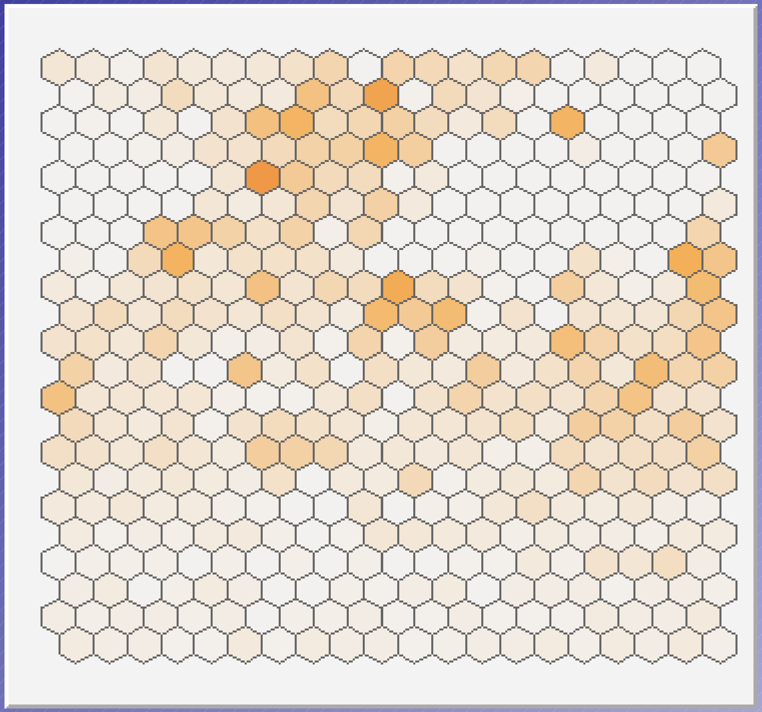
Background Sky variance: frame 5/7



Background Sky variance: frame 6/7



Background Sky variance: frame 7/7



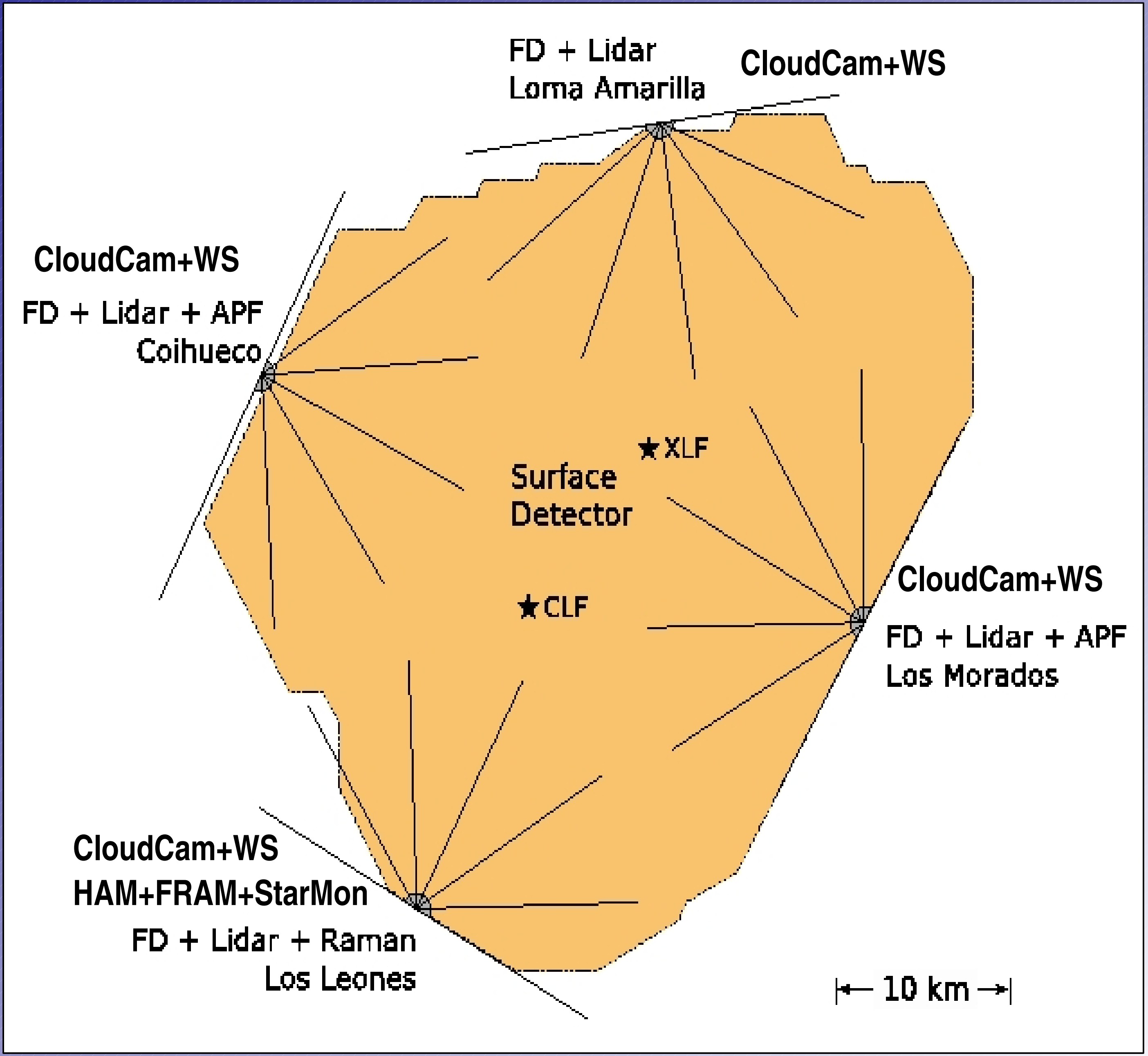
AUGER atmospheric monitoring

Non invasive devices:

- Weather Stations
- Radiosondes
- Cloud Cameras
- StarMonitor
- FRAM

Light Sources:

- LIDARs
- CLF,XLF
- APF
- HAM



Cloud Cameras

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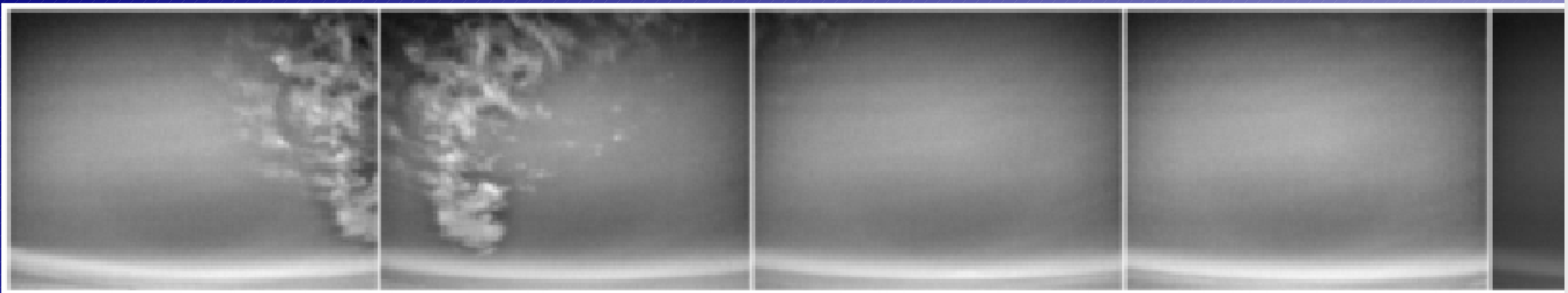
Raytheon 2000B IR camera

- Spectral range: 7-14 microns
- Resolution: 320x240 pixels

Total of four cameras now installed, one at each FD site

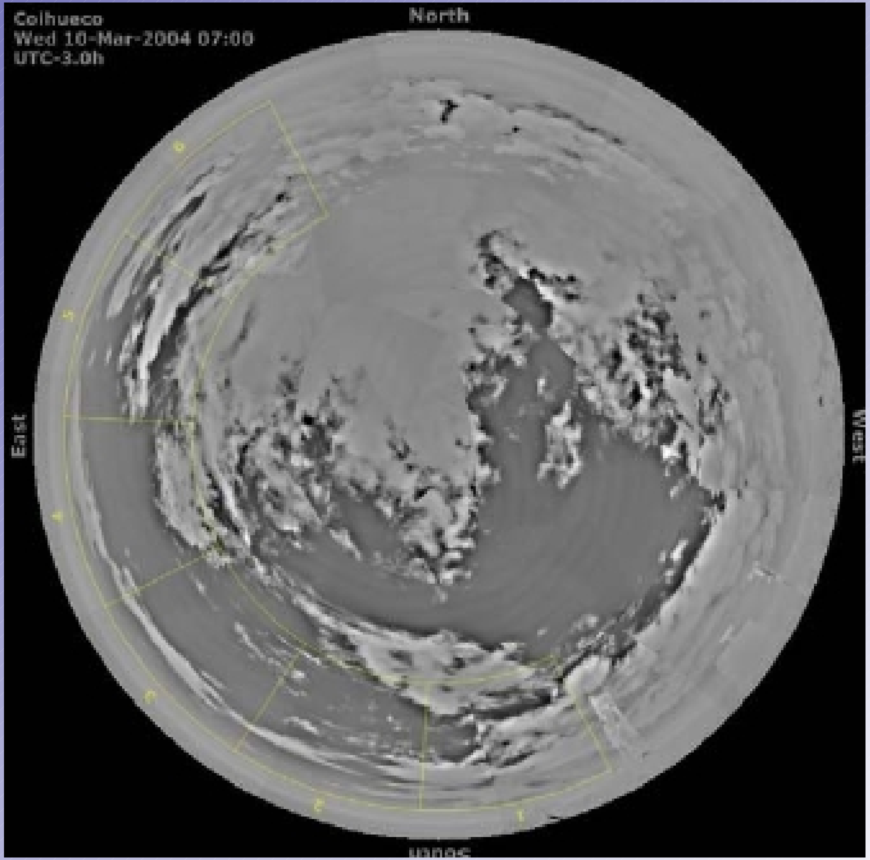
Housed within a weather protective box and mounted on a pan-and-tilt device

IR Cloud Cameras: Modes of Operation



Every 5 min: 5 images across FD FoV

Every 15 min: Full Sky Mosaic

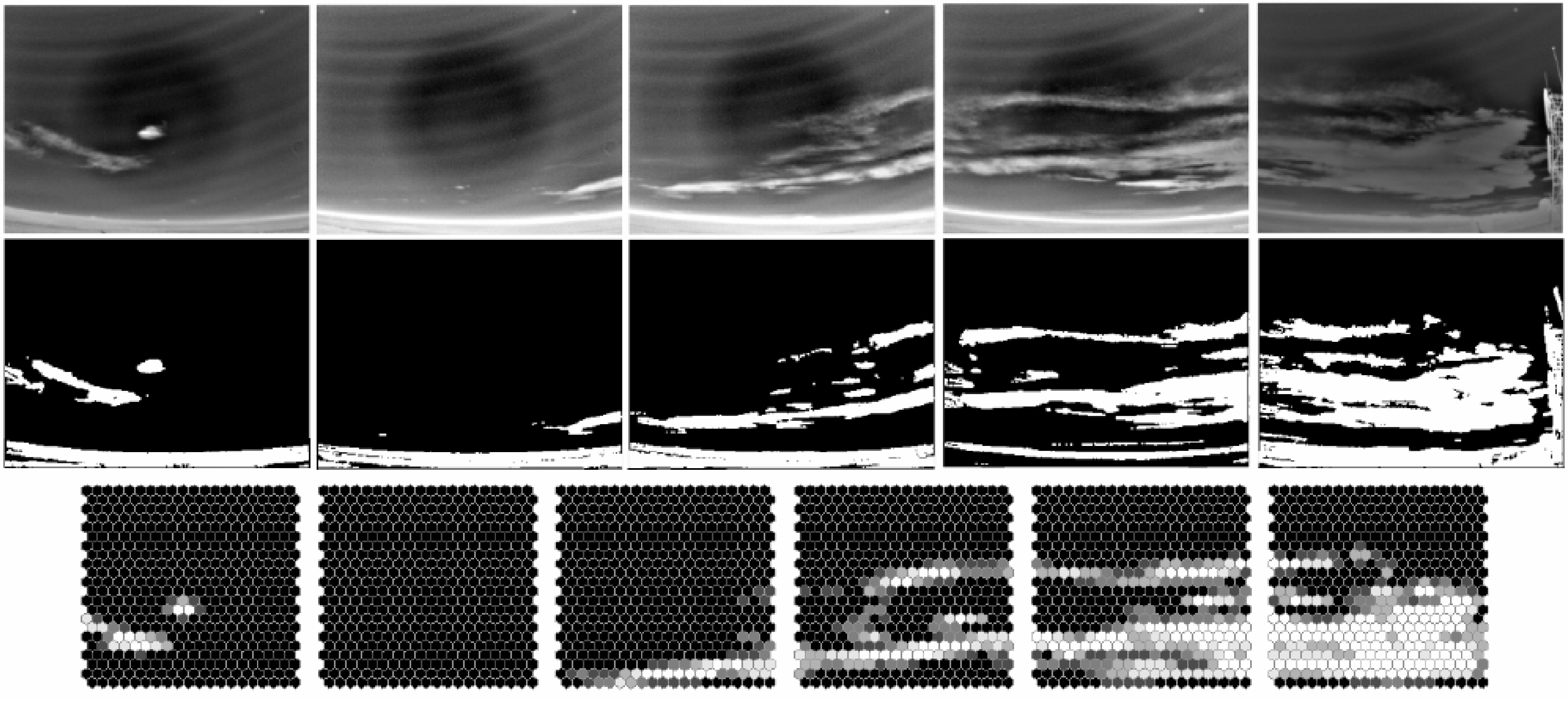


Principle of Operation:

Werner J,Appl.Meteorology 12,1394 (1973)

- Clouds are warmer than clear sky
- Clouds emit infrared light
- IR emission depends on T
- Temperature depends on height

IR CloudCam: Digital Image Processing



Record images → Find cloud → Cloud in each FD pixel

Want cloud index value between 0-5 for all times,
for each pixel, in each mirror, for each fluorescence detector.

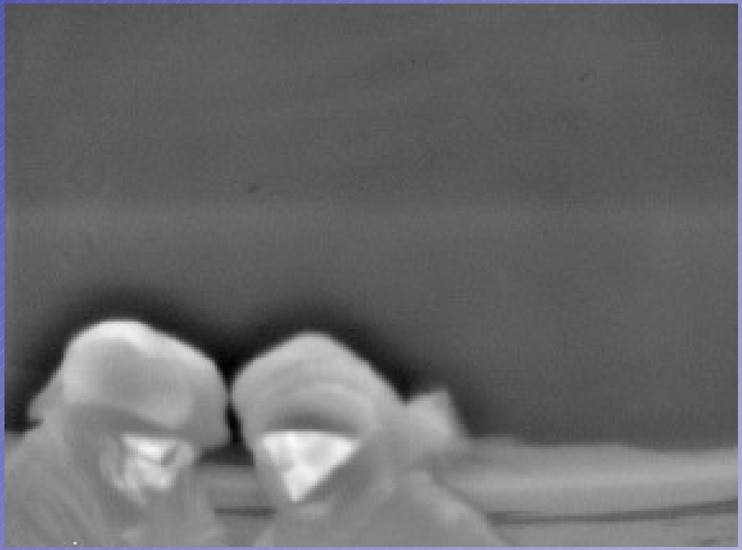
IR CloudCam: Digital Image Processing

Huge Picture Database:
> 300k images, ~7k eye hours
3.7 Gigabyte database

Digital Processing is required

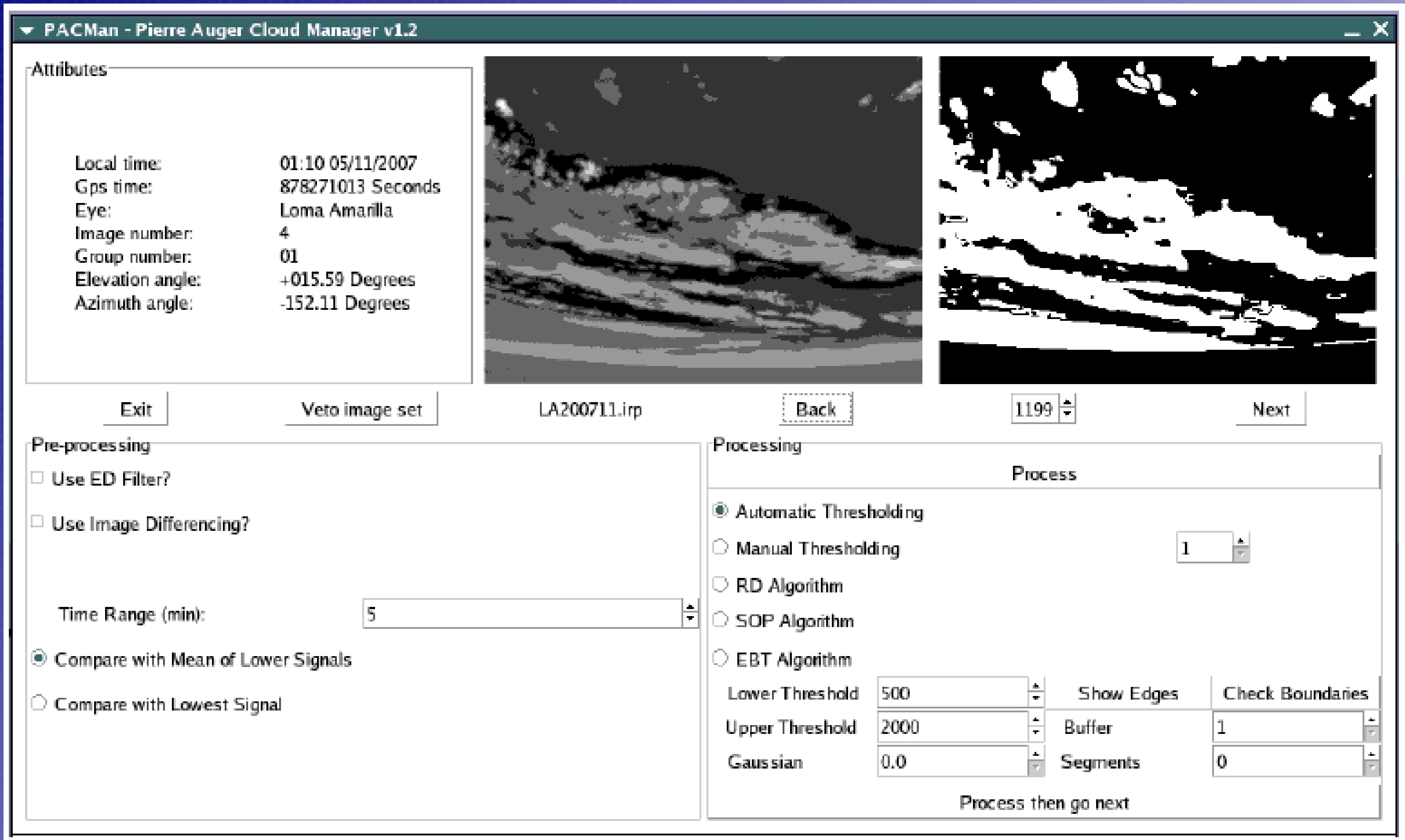
Many cloud detection algorithms are needed to cover all the range of cloud conditions:

- Thresholding
- Differentiation
- Edge Detection



CloudCam is NOT a radiometer (no absolute T scale) :
Pixel signal is proportional to the sky temperature in a given direction and the average temperature of the entire scene.

IR CloudCam: PACMan



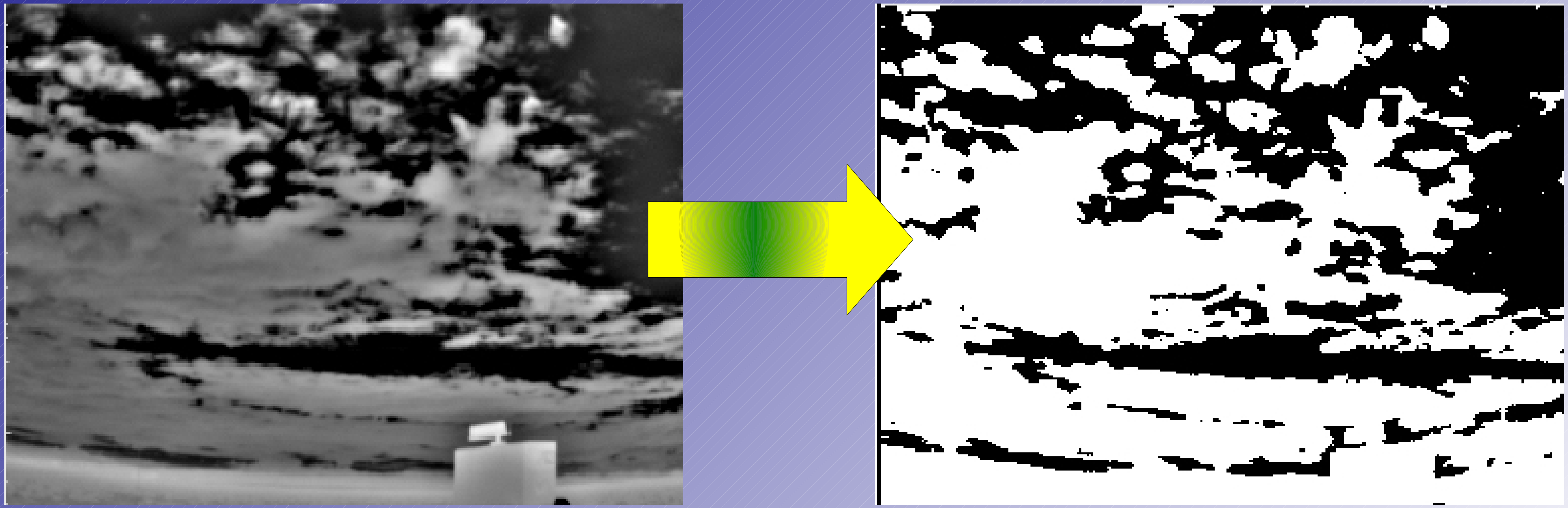
Approx 5hrs needed to process 1 FD shift per 1 eye

IR CloudCam: Thresholding

Simplest approach: all pixels above a given threshold are labeled as cloudy

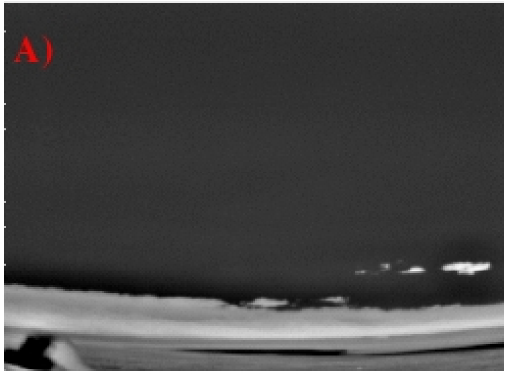
Pro: fast and simple

Contra: Impossible to define the threshold uniquely. It depends on overall contents of the scene, on humidity, on pixel elevation (i.e. on cloud height) .

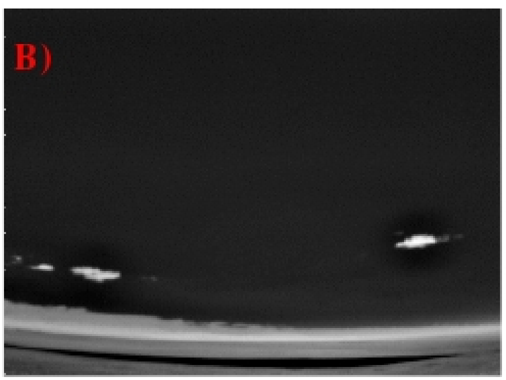


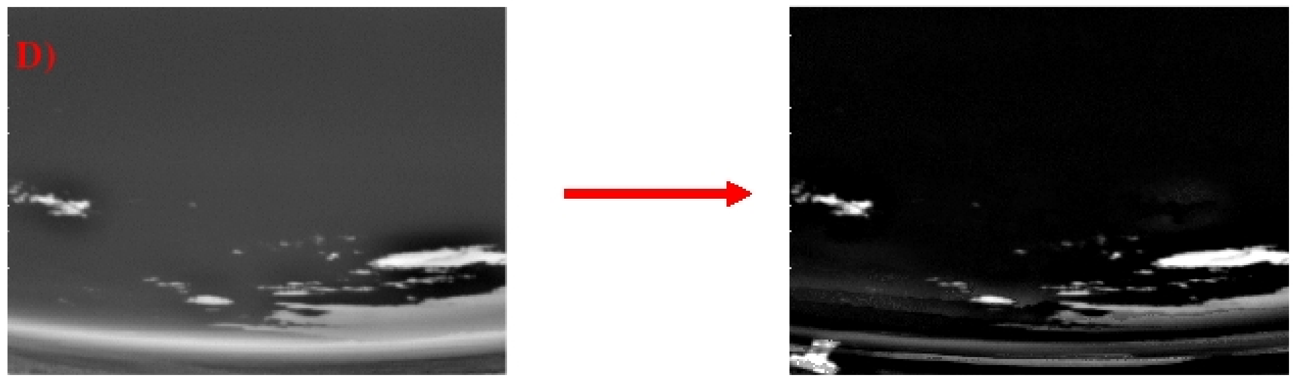
IR CloudCam: Image Difference

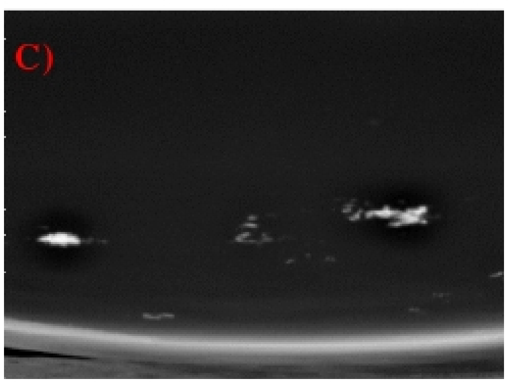
Determine a clear-sky template from recent images, and subtract from the image in question.



For each pixel in image D, check the corresponding pixel in A,B and C (images close in time). Take the mean of any pixels with lower intensity than that in D as the clear sky background for that pixel. Subtract the 'clear sky background' from the original image







Can either apply edge detection to the new image or threshold it

Does not work well when confronted by static situations or very bright cloud - due to auras causing us to underestimate the background clear sky signal

IR CloudCam: Edge Detection

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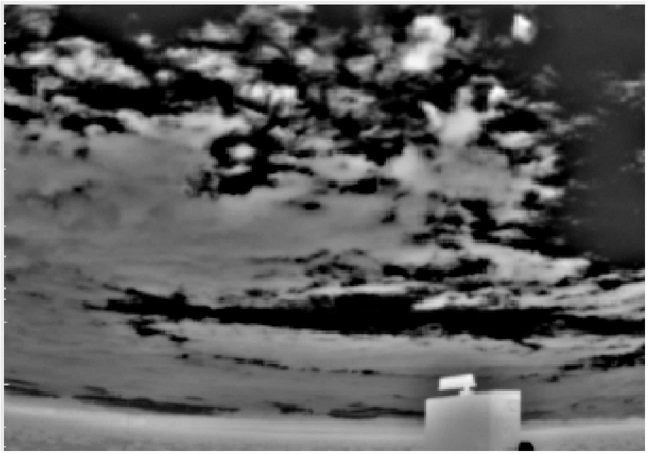
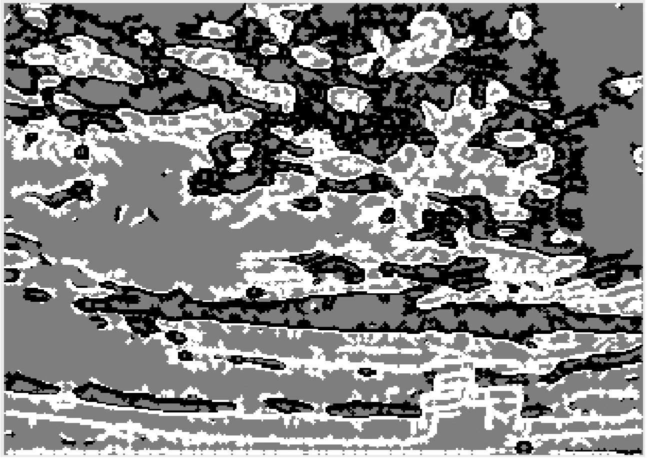


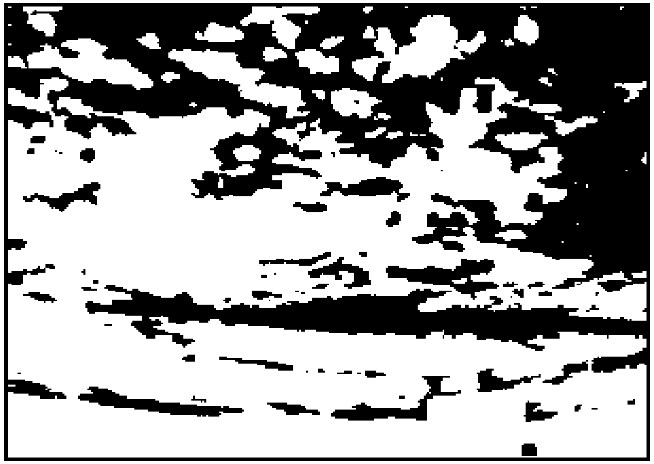
Canny edge detection algorithm

- Noise reduction with Gaussian filter
- Dual threshold on edge intensity gradient

Localized thresholding in image of pixels identified as edges to identify cloud

Cannot distinguish between clear/overcast situations due to lack of strong edge gradients





Overlapping cloud layers are also problematic, as the algorithm will sometimes decide that the less bright layer of cloud is clear sky

Canny, J., A Computational Approach To Edge Detection,
IEEE Trans. Pattern Analysis and Machine Intelligence, 8:679-714, 1986

see also : http://matlabserver.cs.rug.nl for online examples

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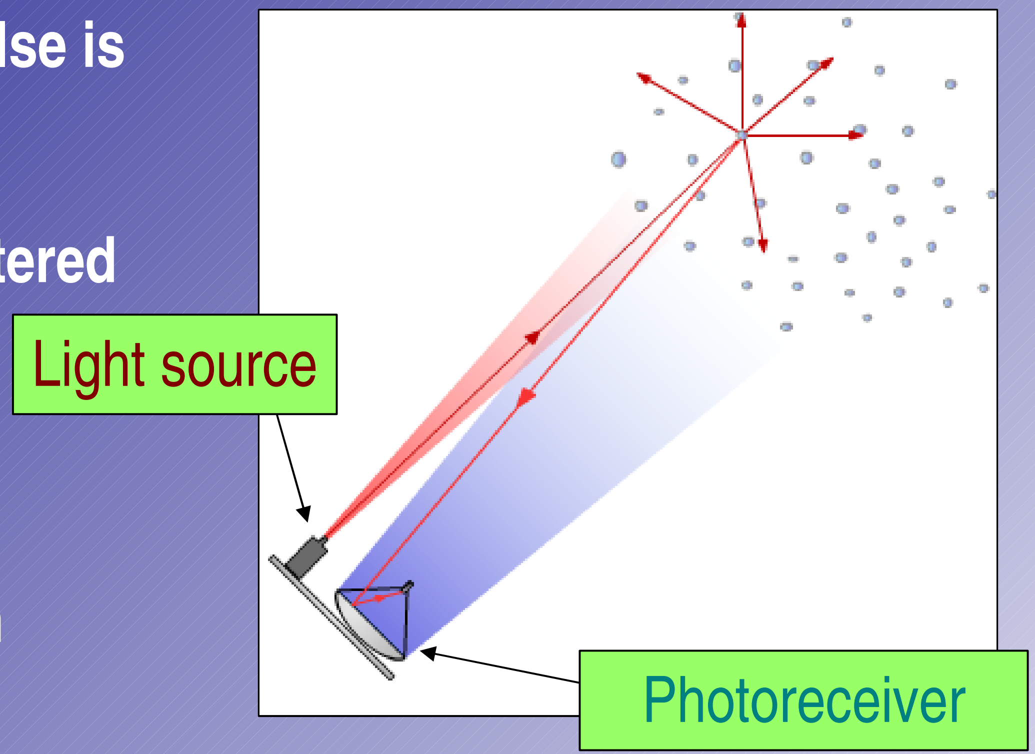
LIDARs

LIDAR : working principles

LIDAR = LIght Detection And Ranging

- A short ($t_0 \sim 10^{-8}$ sec) **light pulse is emitted** in the atmosphere
- A fraction of the light is **scattered back** toward the lidar system



- This light is **collected by a telescope** and focused upon a photodetector

***We measure the amount of backscattered light** as a function of time → distance.*

$$P(r) = P_0 \frac{ct_0}{2} \left(\frac{A}{r^2}\right) \beta(r) e^{-2\tau(r)}$$

LIDAR equations

Raw Signal : Power Return (r = ct/2)

$$P(r) = P_0 \frac{ct_0}{2} \left(\frac{A}{r^2}\right) \beta(r) e^{-2\tau(r)}$$

Optical Depth

$$\tau(r) = \int_0^r dr' \alpha(r')$$

Range corrected Power Return:

$$S(r; r_n) = ln \frac{P(r) r^2}{P(r_n) r_n^2} = ln \frac{\beta(r)}{\beta(r_n)} - 2\tau(r_n, r)$$

- normalized at fixed distance

$$S(h; h_n) = ln \frac{P(h) h^2}{P(h_n) h_n^2} = ln \frac{\beta(h)}{\beta(h_n)} - 2\tau(h_n, h) sec\theta$$

- normalized at fixed height

Extinction coefficient

$$\alpha(r) = \alpha_{mol}(r) + \alpha_{aer}(r)$$

==

$$\sigma_{mol} N_m(r) + \Sigma_k \sigma_k N_k(r)$$

Backscattering Coefficient :

$$\beta(r) = \beta_{mol}(r) + \beta_{aer}(r)$$

==

$$\left[\frac{d\sigma_{mol}}{d\Omega}\right]_{\theta=\pi} N_m(r) + \Sigma_k \left[\frac{d\sigma_k}{d\Omega}\right]_{\theta=\pi} N_k(r)$$

==

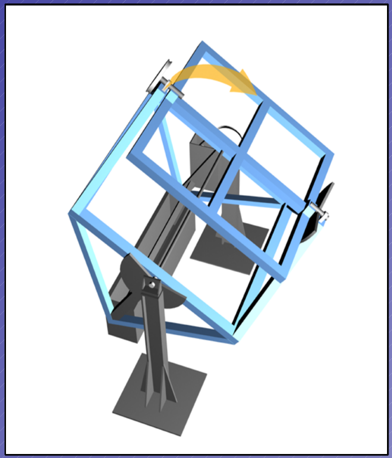
$$\mathcal{P}_{mol}(\theta = \pi) \alpha_{mol}(r) + \Sigma_k \mathcal{P}_k(\theta = \pi) \alpha_k(r)$$

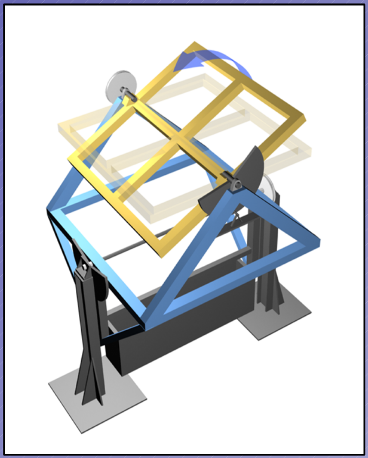
where

$$\mathcal{P}(\Omega) = \frac{1}{\sigma} \left(\frac{d\sigma}{d\Omega}\right)$$

LIDAR : mechanics

Alt-altazimuthal motorized mount
Encoder controlled steering
Aligned to the axis of each FD
Fully retractable cover





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Lidar : scanning patterns

Every hour, each Lidar performs a set of scans :

- **Horizontal Shots**

  Horizontal omogeneity

  Aerosol extinction at ground

- **Continuous Scans**

  Cloud coverage

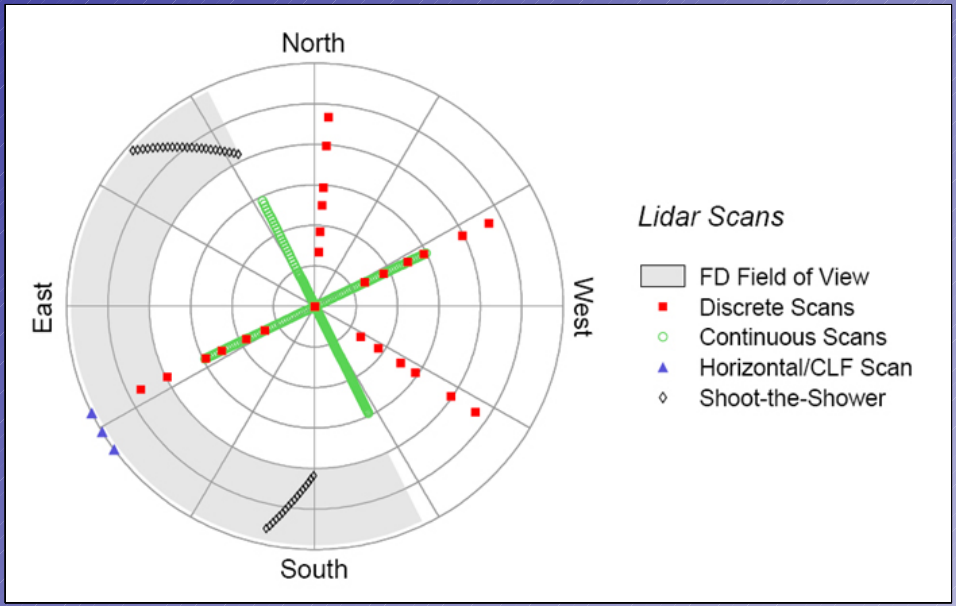
  Cloud characterization

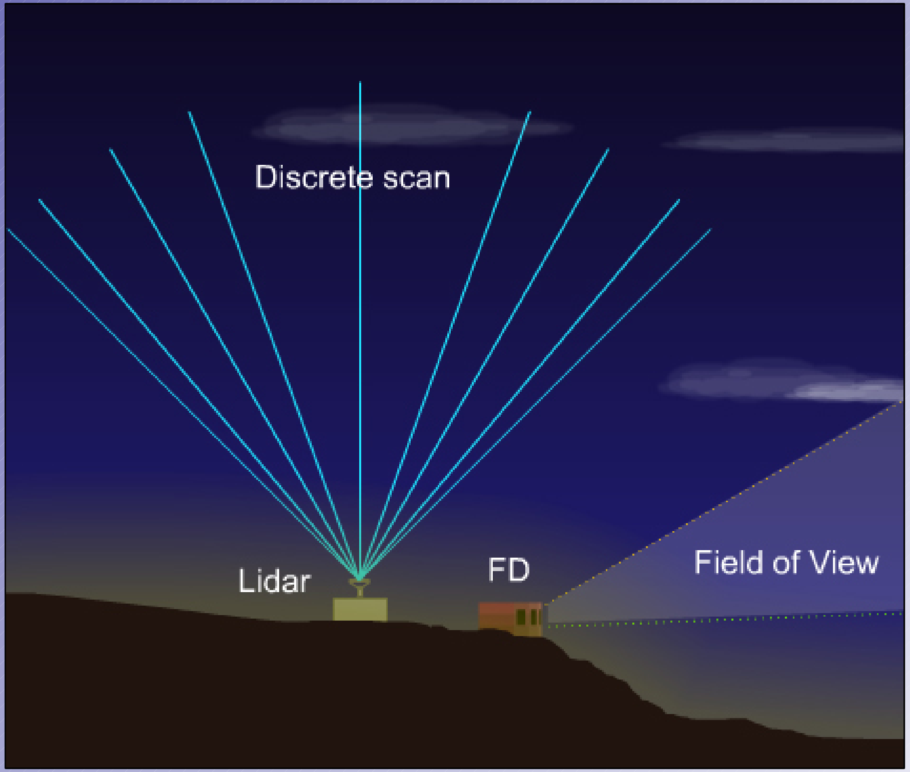
- **Discrete Scans**

  Vertical Aerosol optical depth (VAOD) with multiangle inversion technique

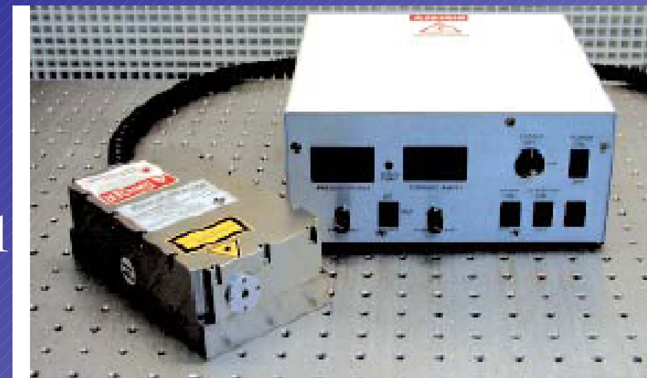
- **Vertical Shots**

  VAOD with Fernald inversion technique





Lidar: photonics



LASER Photonics DC30-351

Laser Type:	Nd:YLF
Main wave length:	351 nm
Pulse Energy:	0.1 m J
Pulse width:	15 ns
Repetition rate:	0.333 kHz

PMT 3xHamamatsu R7400 U-03

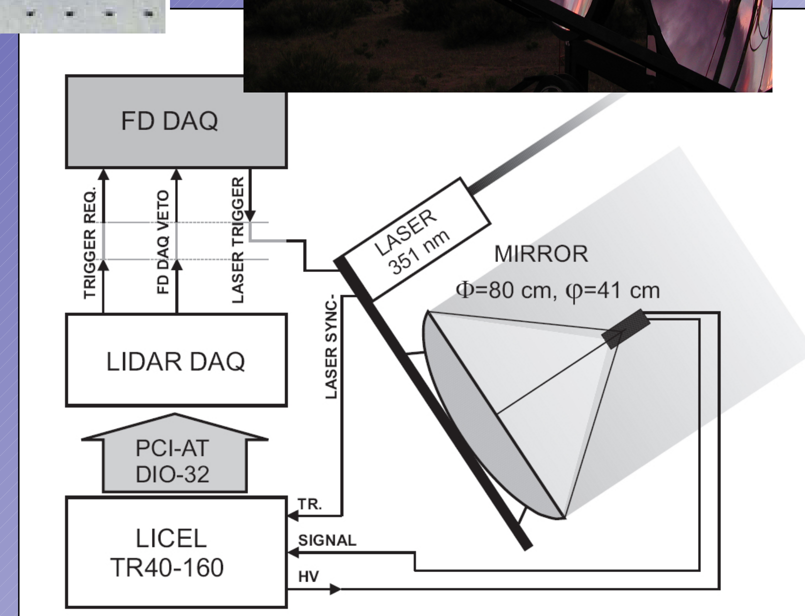
HV: 770, 850 V

FWHM single photon: 2 ns

photocathode diameter: 8 *mm*,

peak wavelength: 420 *nm* (at 25*ºC*),

UG1 filter (PMT entrance window)



DATA ACQUISITION Licel TR40-160 (3 channels)

A/D converter

Resolution:**12 bit**

Sampling frequency: **40 MHz**

$\rightarrow$ Spatial resolution: **3.75 m**

Trace length: **16k (60 km)**

High speed discriminator

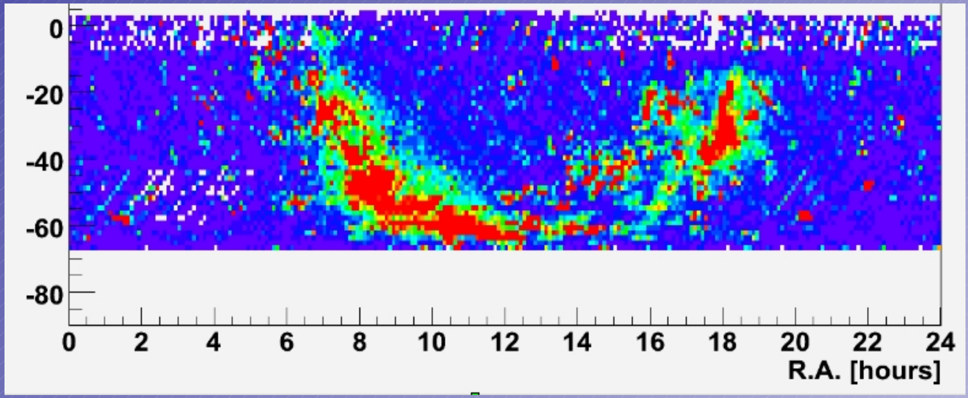
Frequency: **250 MHz**

Configurable threshold level

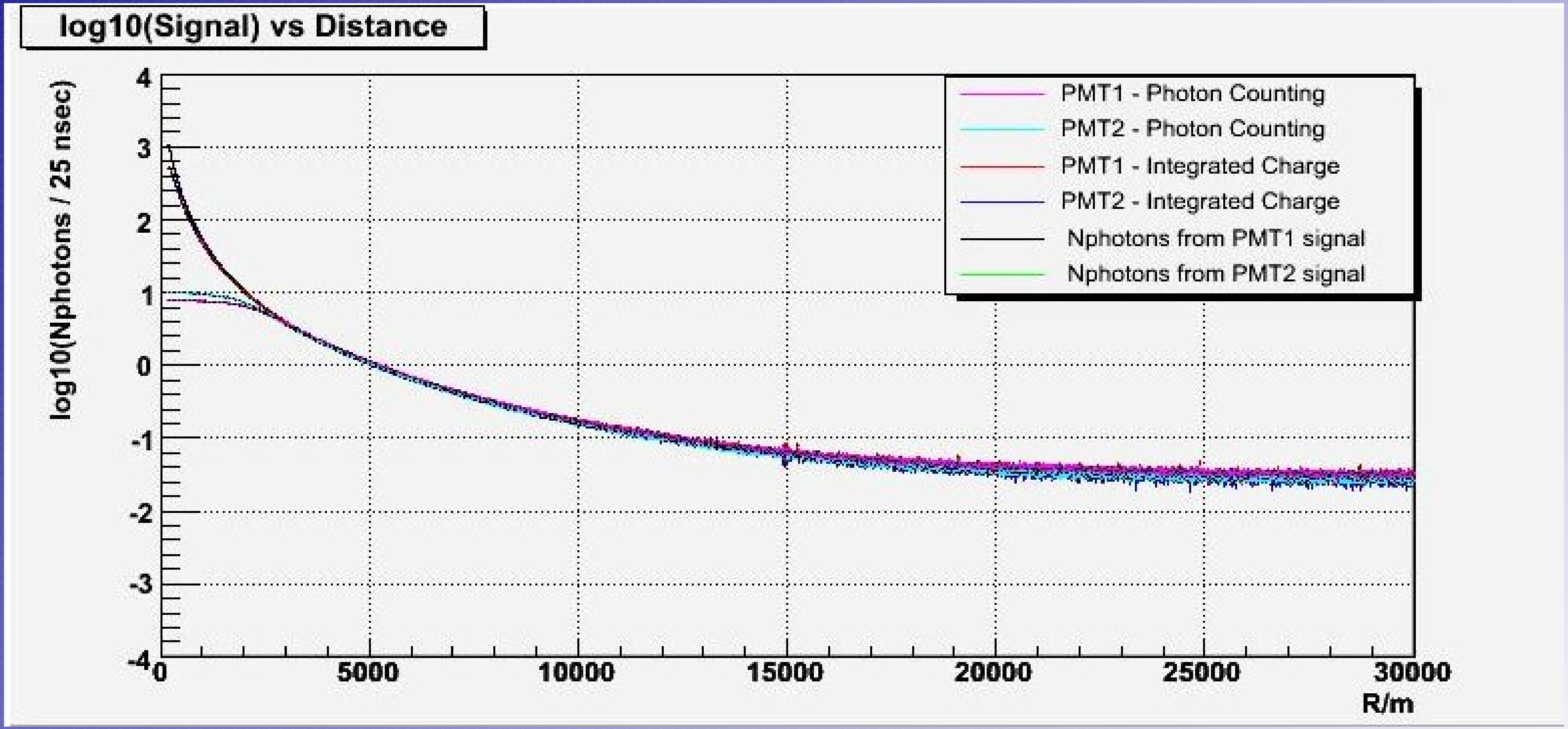
(64 levels between 0 and –100 mV)

Lidar: typical signals

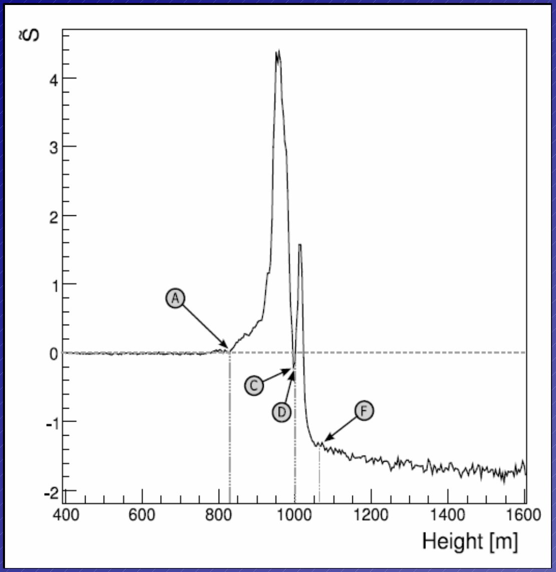
Signal is the sum of 1000 shots in 3 seconds
Dynamic range : almost 5 orders of magnitude
Lower limit: sky background (stars, airglow)
Range: almost 30 km

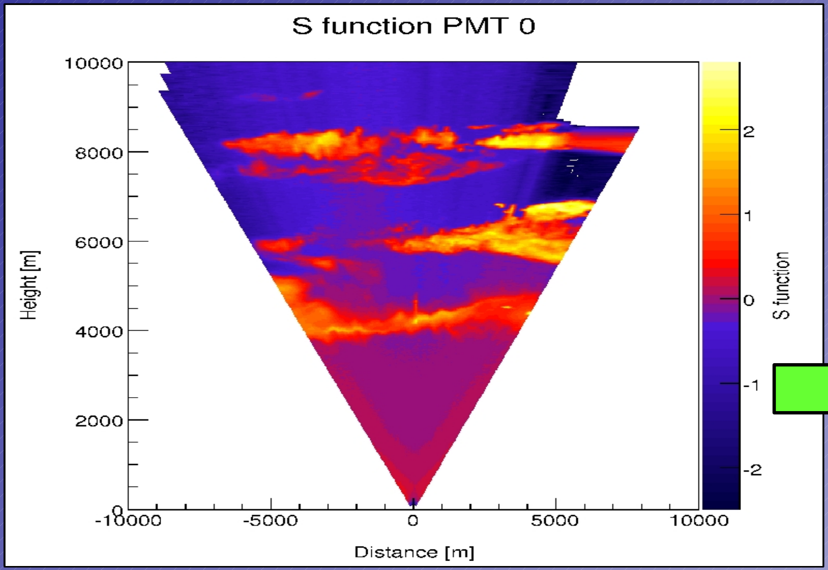


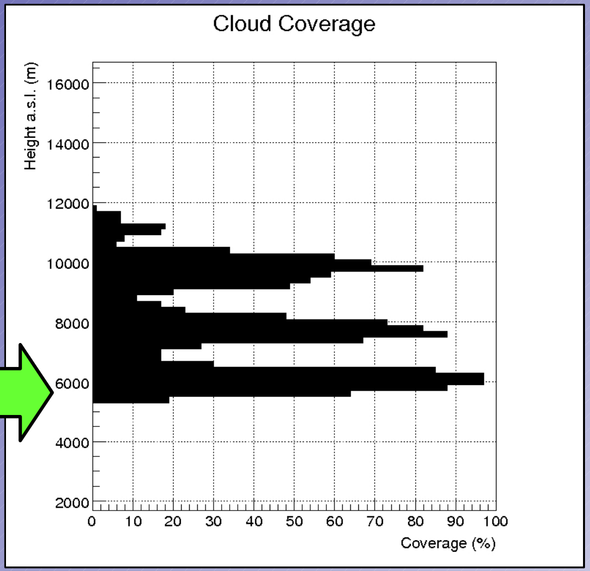
Southern Sky with Lidar Pedestals

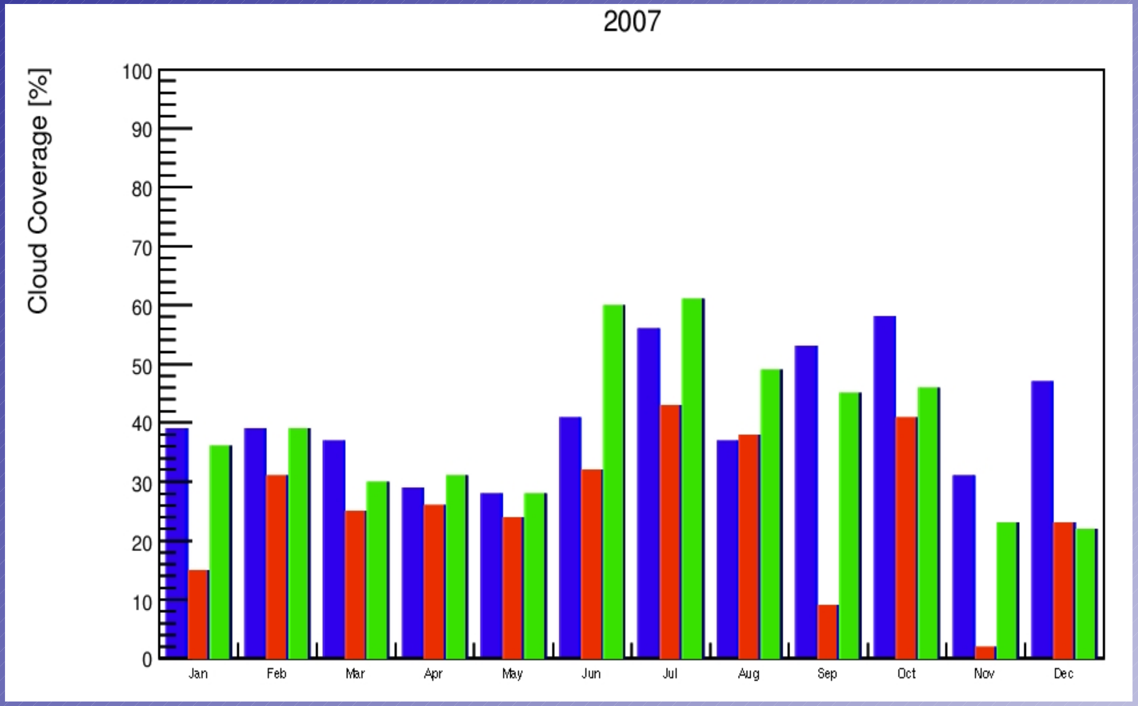


Lidar: Cloud Detection and Cloud Coverage







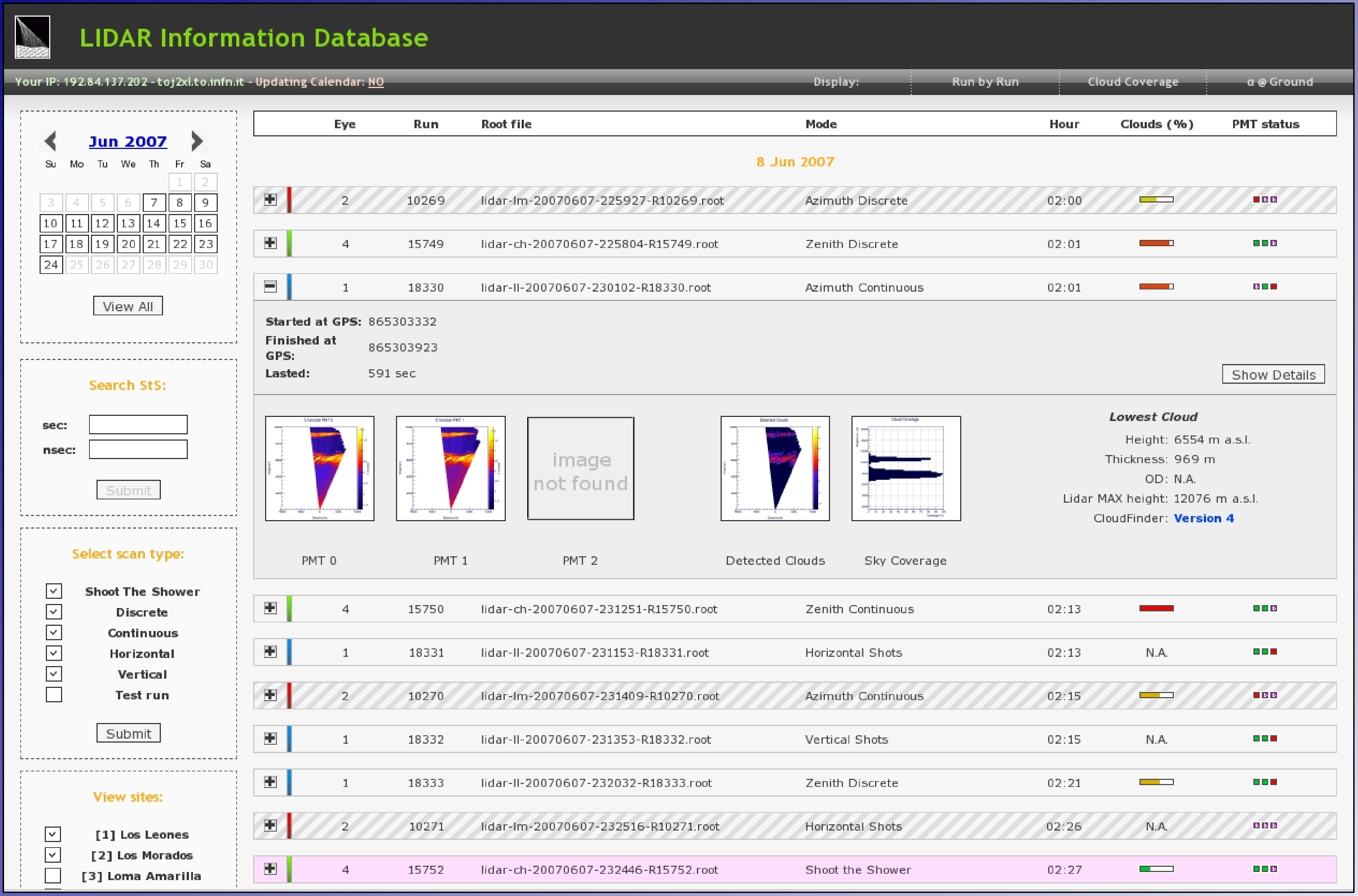


Hourly average of cloud conditions above each FD site:

- Cloud base height
- Cloud layer count
- OD of each cloud layer

is sent to Cloud Database

LIDAR information on the web



Web interface (AJAX) for displaying all the information, comparing results, and creating summary plots.

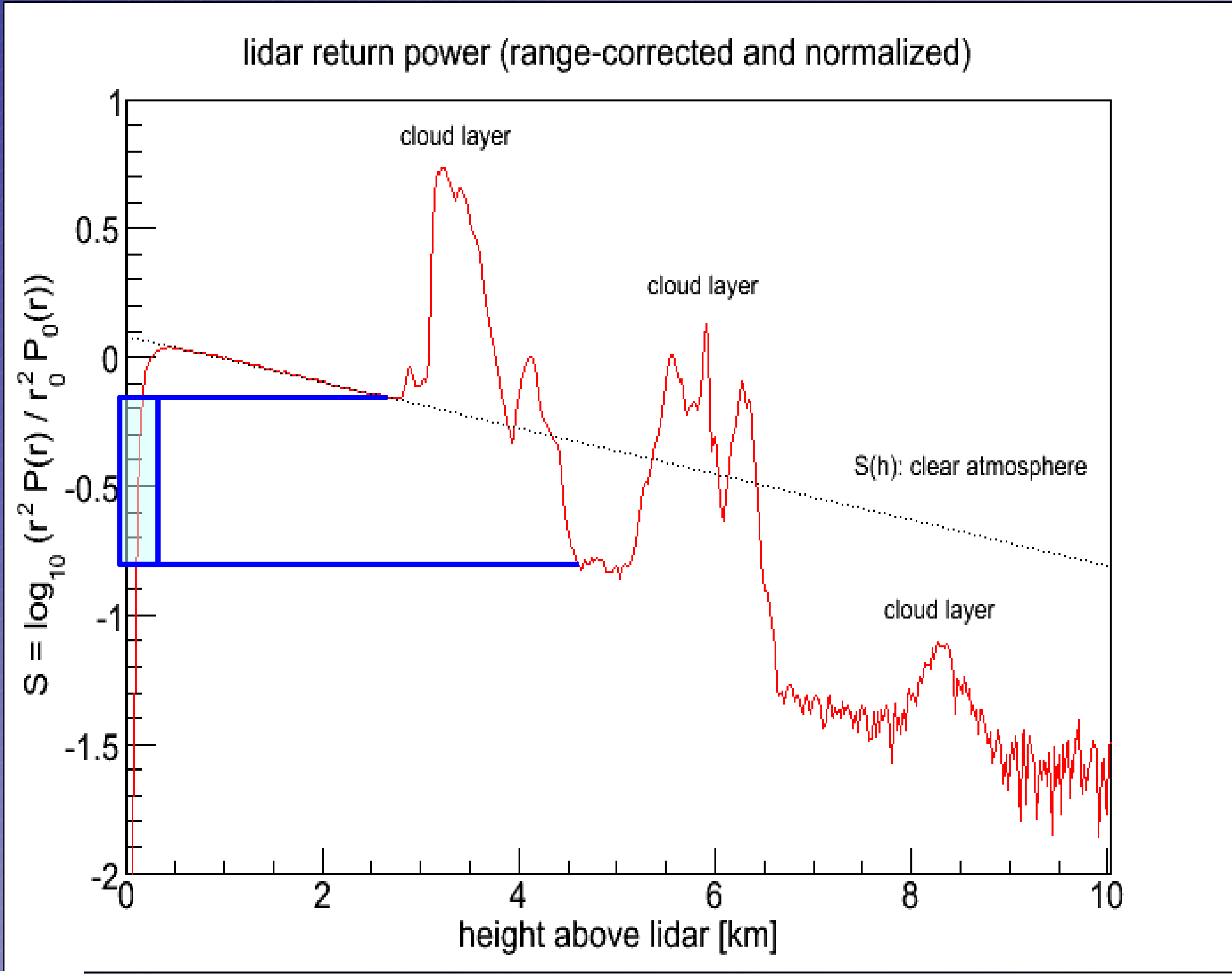
Lidar: Cloud Optical Depth measurement

Return power is corrected for the molecular contribution (from monthly profiles)

$$S_a(h, h_n) = S(h, h_n) - S_{mol}(h, h_n)$$

The drop in S_a, corrected for the polar angle, gives the VOD of the cloud:

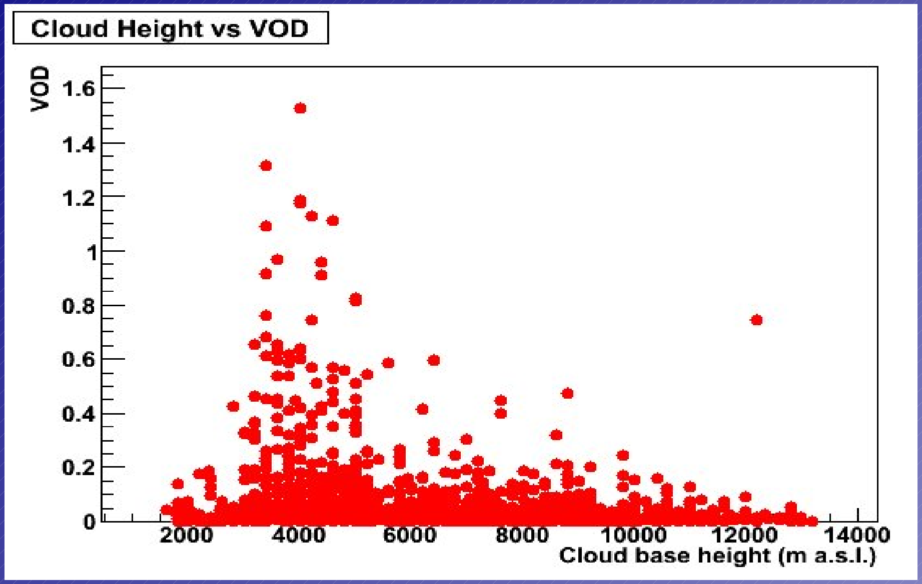
$$\tau(h_1, h_2) = \cos\theta \, [S_a(h_1) - S_a(h_2)]$$

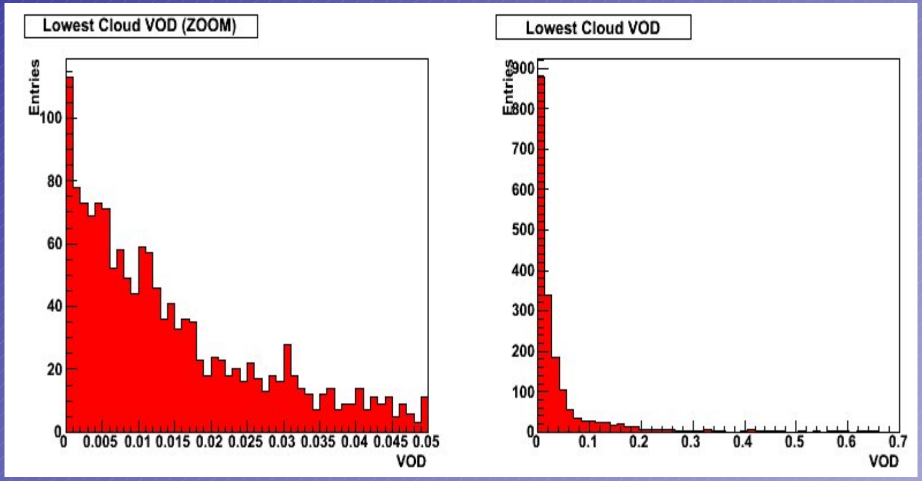


Reminder:

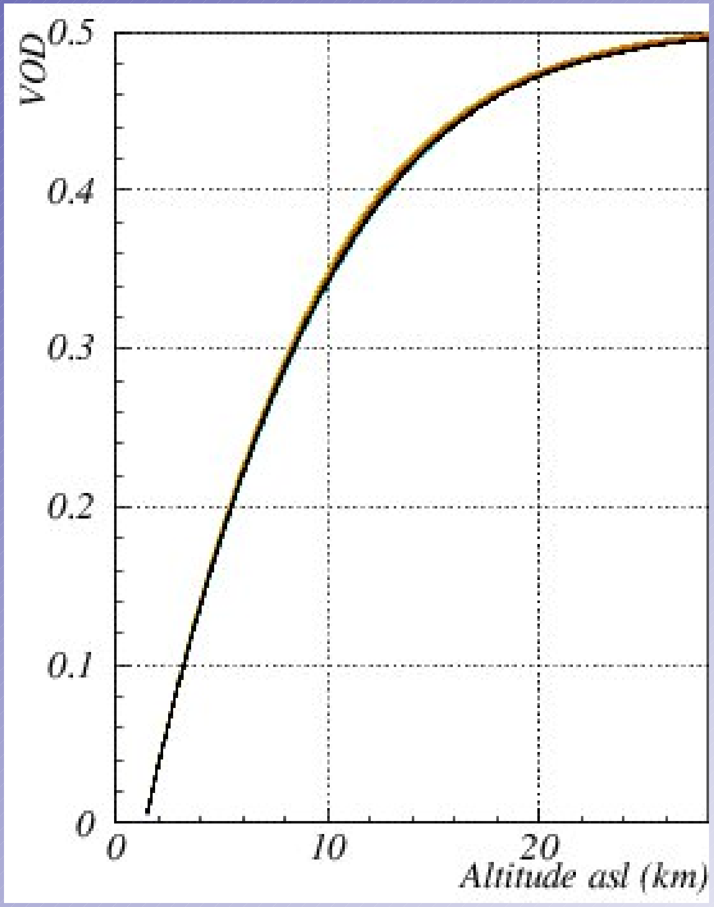
$$S(h; h_n) = ln\frac{P(h)h^2}{P(h_n)h_n^2} = ln\frac{\beta(h)}{\beta(h_n)} - 2\tau(h_n, h)sec\theta$$

Lidar: Cloud Optical Depth



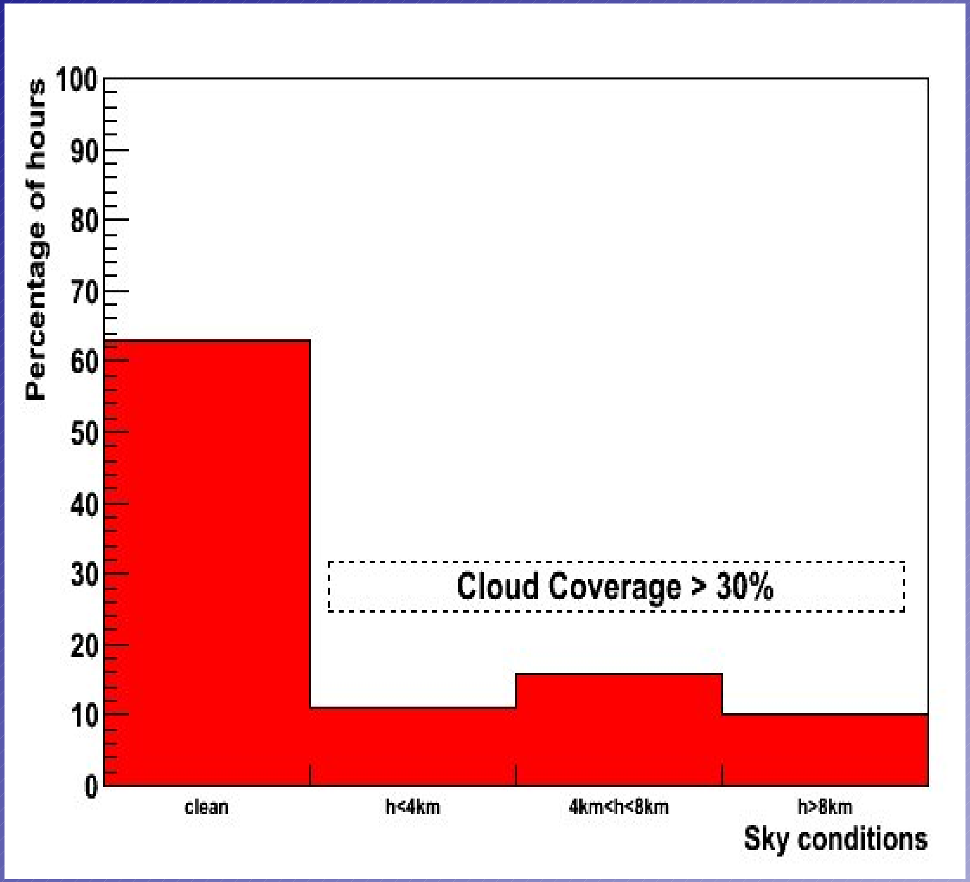


Molecular Optical Depth vs H

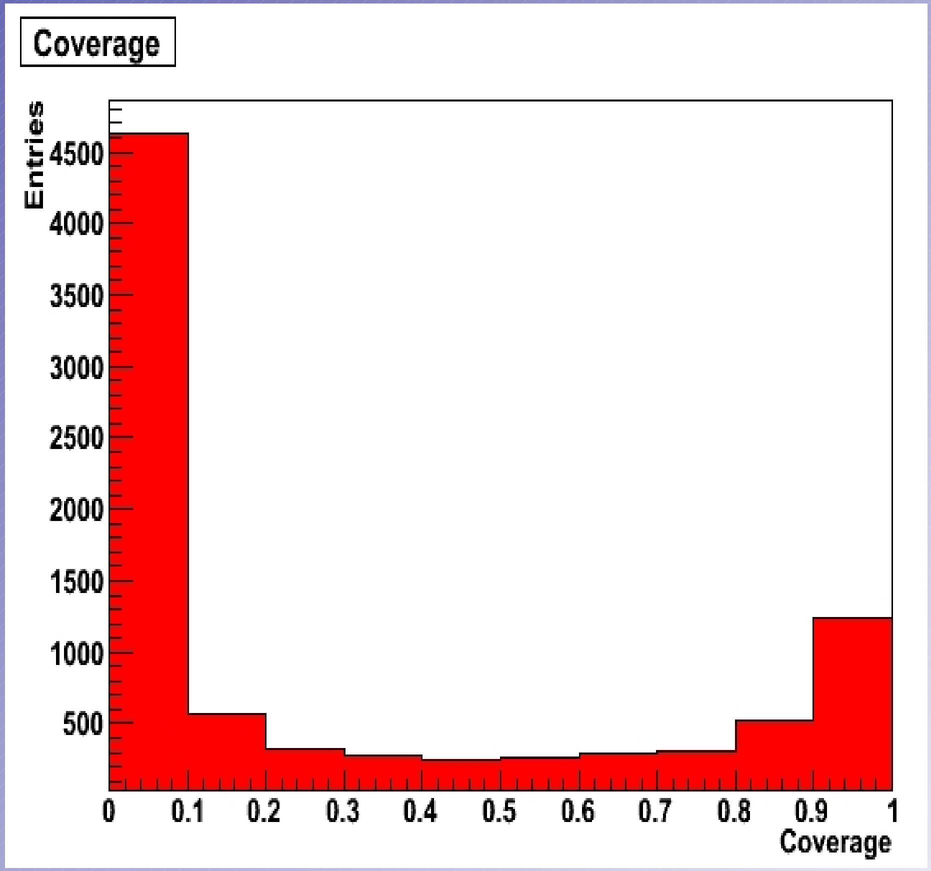


Lidar: Cloud Coverage

Cloud coverage vs Height of lowest cloud



Hours of data taking vs cloud coverage

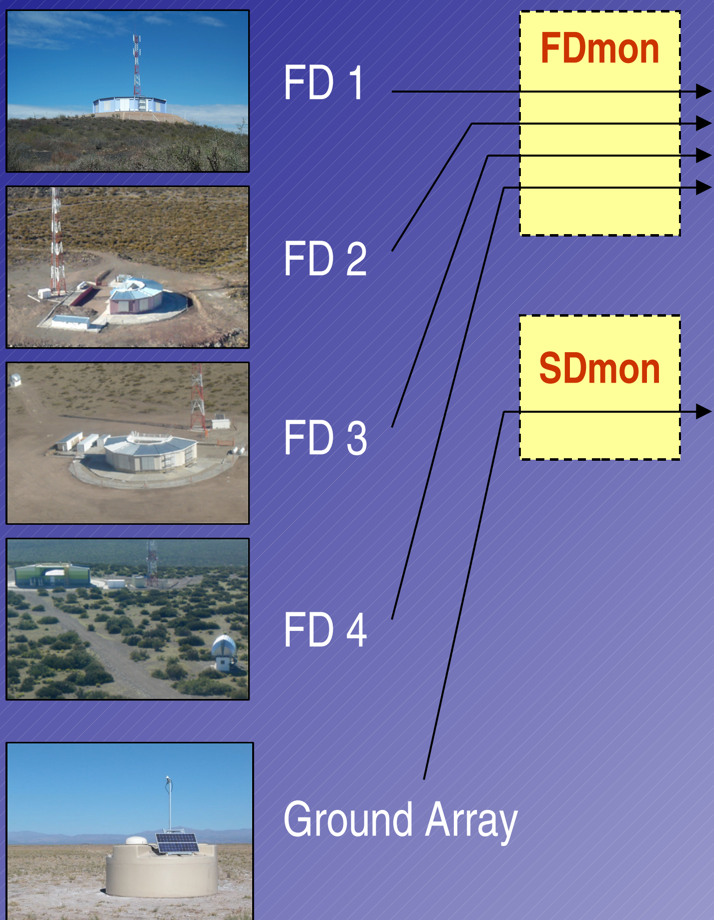


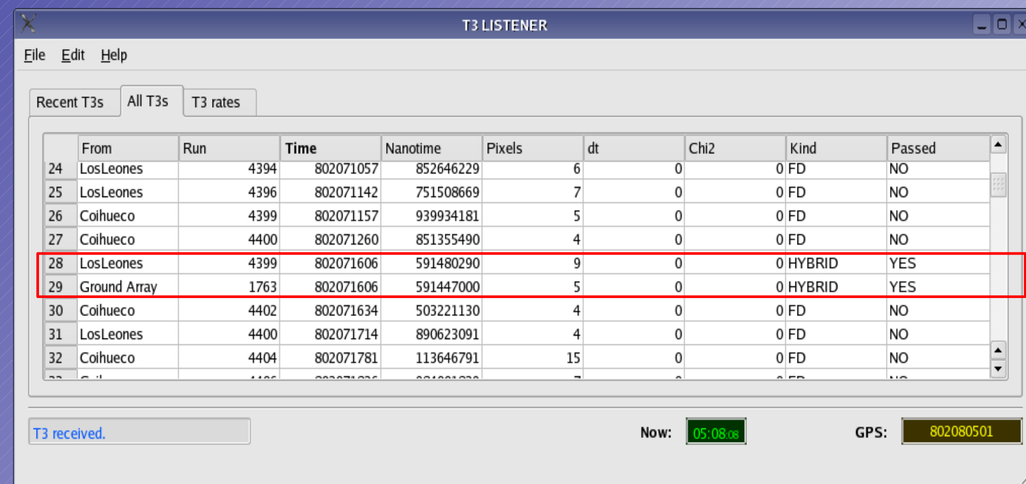
About 30% of the cloudy hours have more than 1 layer of clouds

LIDAR network: Shoot-the-Shower mode

When a very interesting event is observed by FD and SD a precise characterization of the atmosphere is quite important.

In 5 minutes, LIDARs can perform a scan along the angular shower track detected by the Fluorescence Detectors:





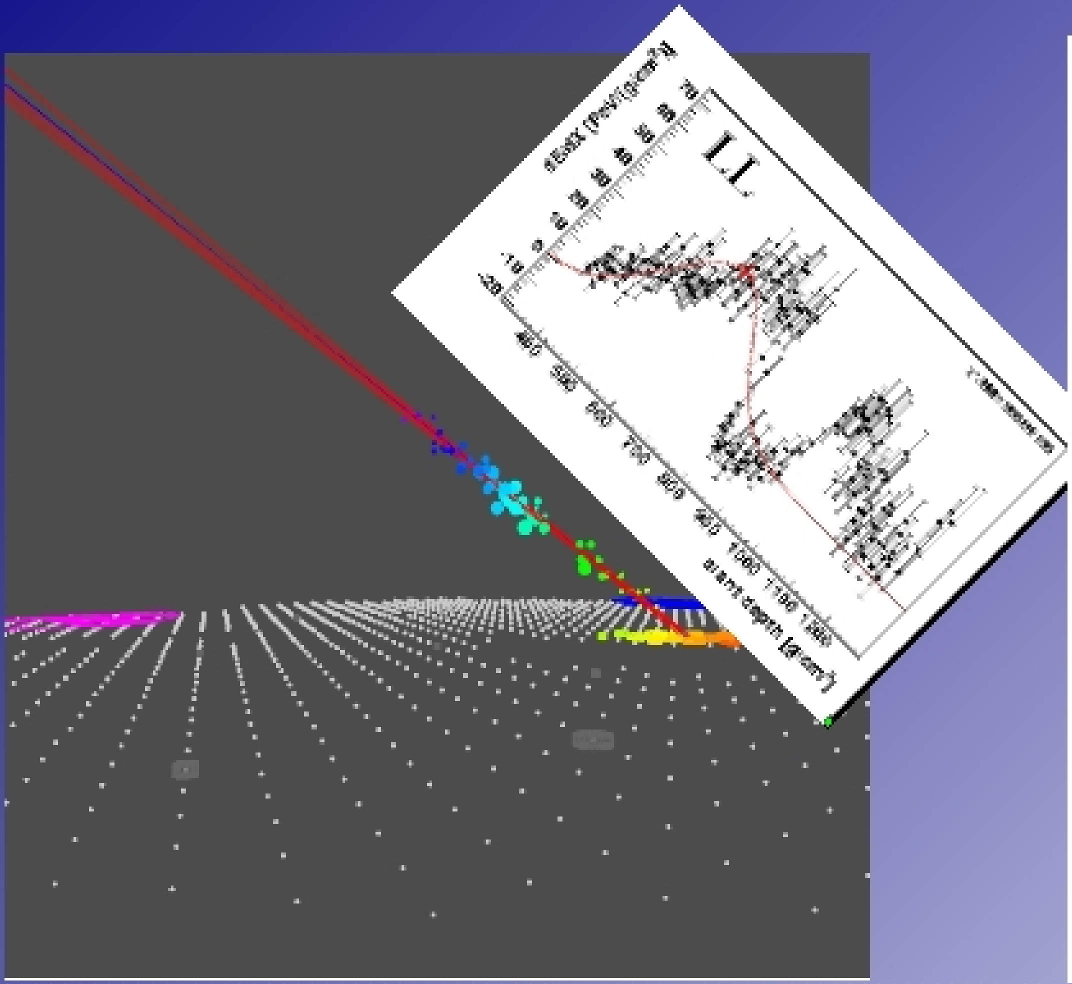
If a **hybrid** or **stereo** event occurs, the *local* client **T3 Listener** orders the LIDAR to shoot the shower

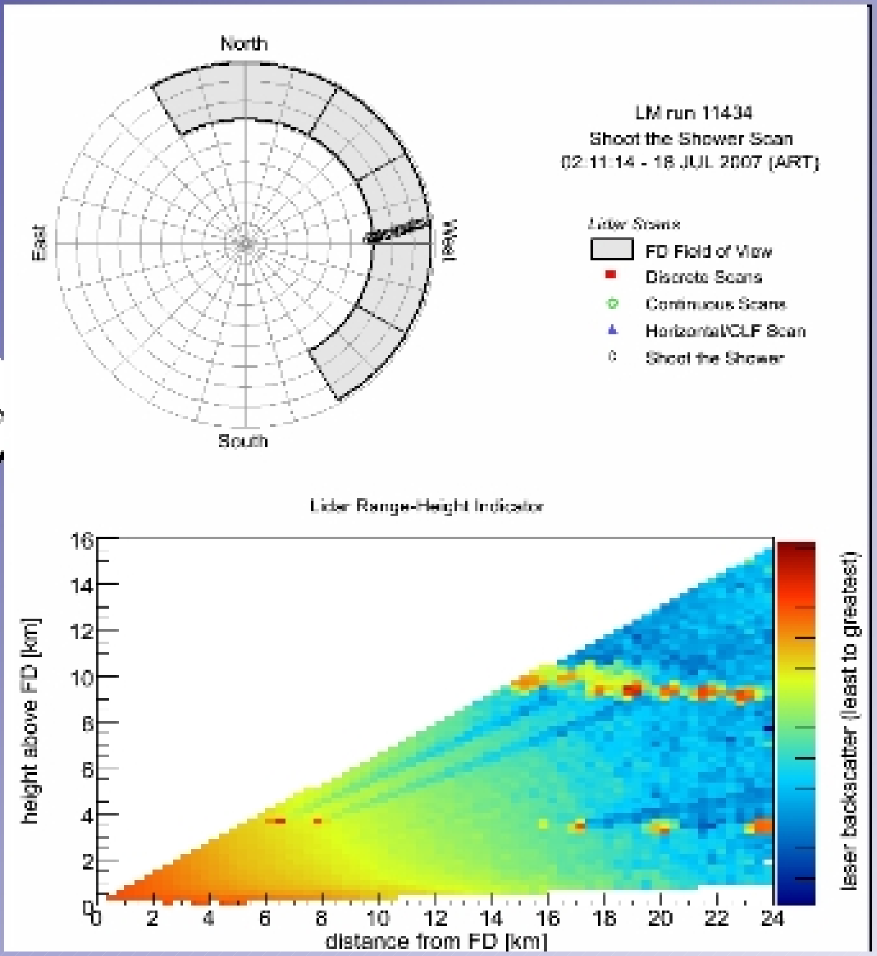
Coincidence time window:

0.2 ms for stereo events

0.4 ms for hybrid events

LIDAR network: Shoot-the-Shower mode





15 minutes after the event occured, a StS scan is written on Lidar PC and can be used to precisely determine the cloud coverage in the shower-detector plane.

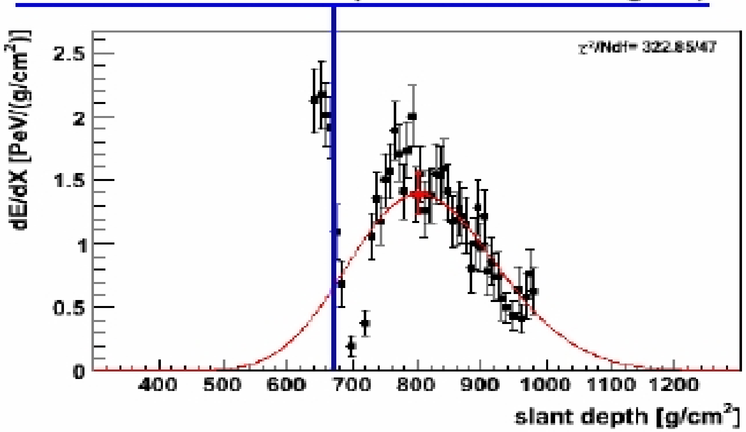
Cloud effects on shower profiles / 1

SDEvent 3027983
Los Morados - Mirror 2

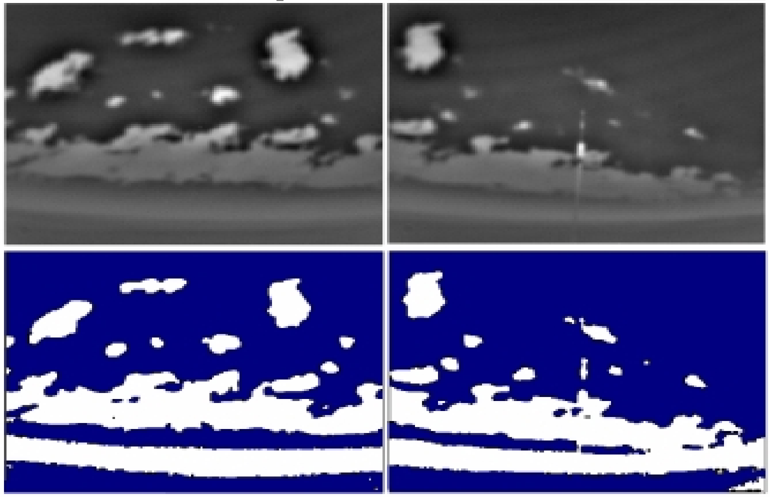
Run 1284 Event 1751
time stamp: 852606254 s 113501109 ns
UTC date: 2007/1/12   03:04:00

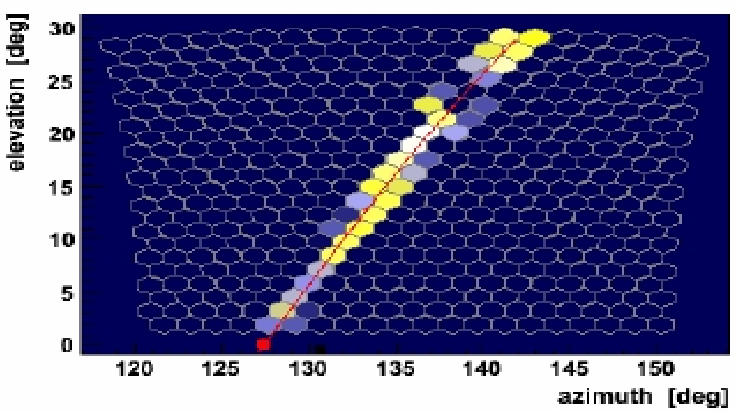
$E = (4.53 \pm 0.41 \pm 4.47) \times 10^{17}$ eV
Xmax = 803 ± 11 g/cm^2
dEdXmax = 1.39 ± 0.16 PeV/(g/cm^2)
(λ,X0) = (14±8,-150±426) g/cm^2
Cherenkov-fraction = 14%
(θ,ϕ)=(29.9±0.4, 60.7±1.0) deg
(x,y)=(57.08±0.02, 39.32±0.04) km
dca to Eye=5.26 ± 0.03 km

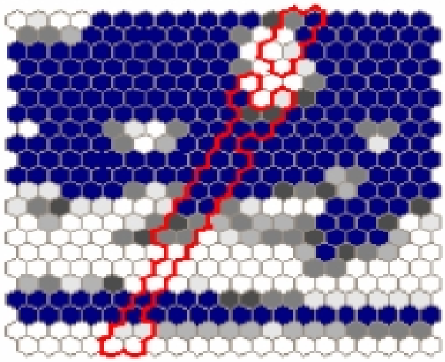
Mie attenuation: measured (h<4.8 km Xslant>673 g/cm^2)



Cloud camera images recorded at UTC 2007/1/12 03:05

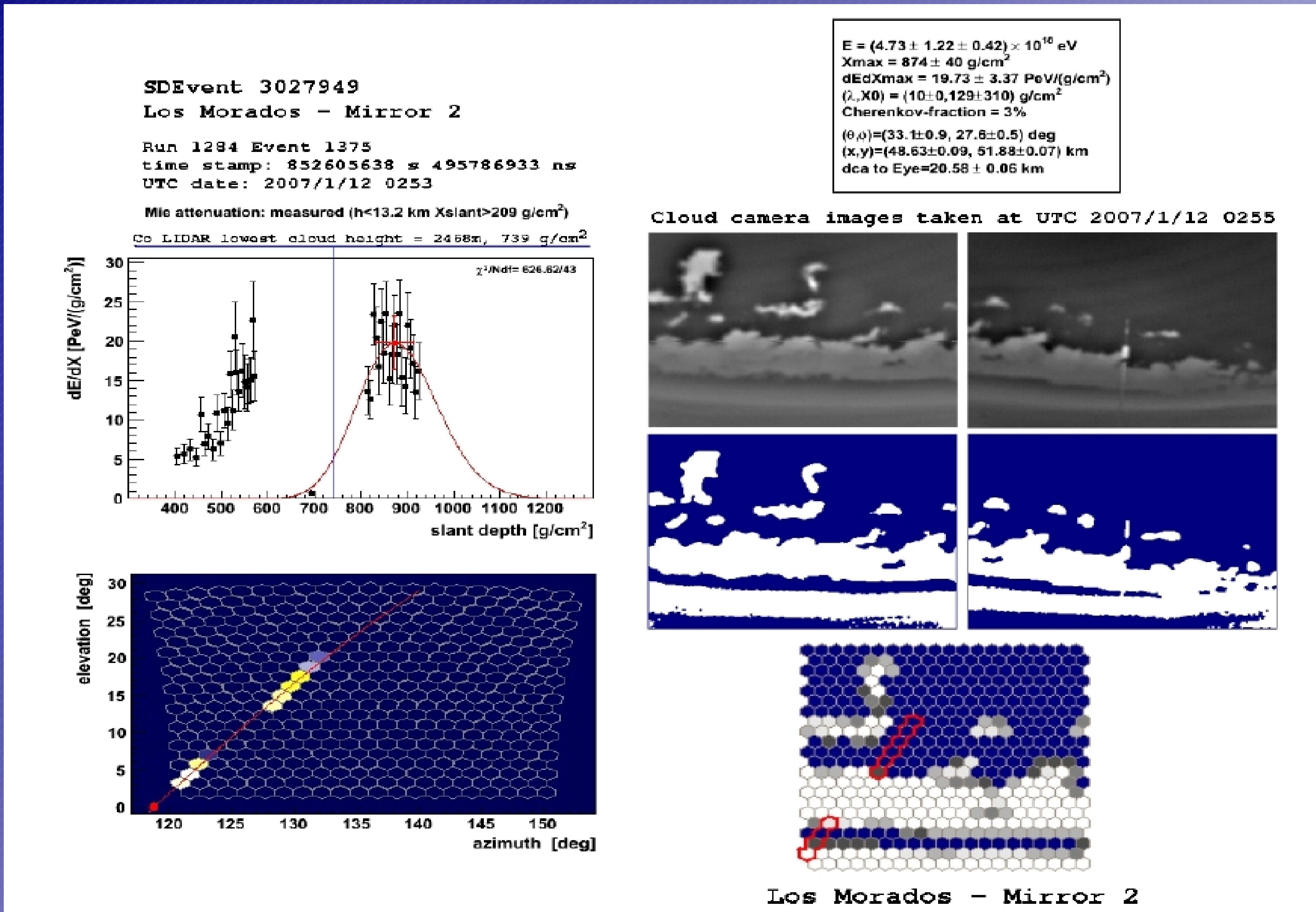




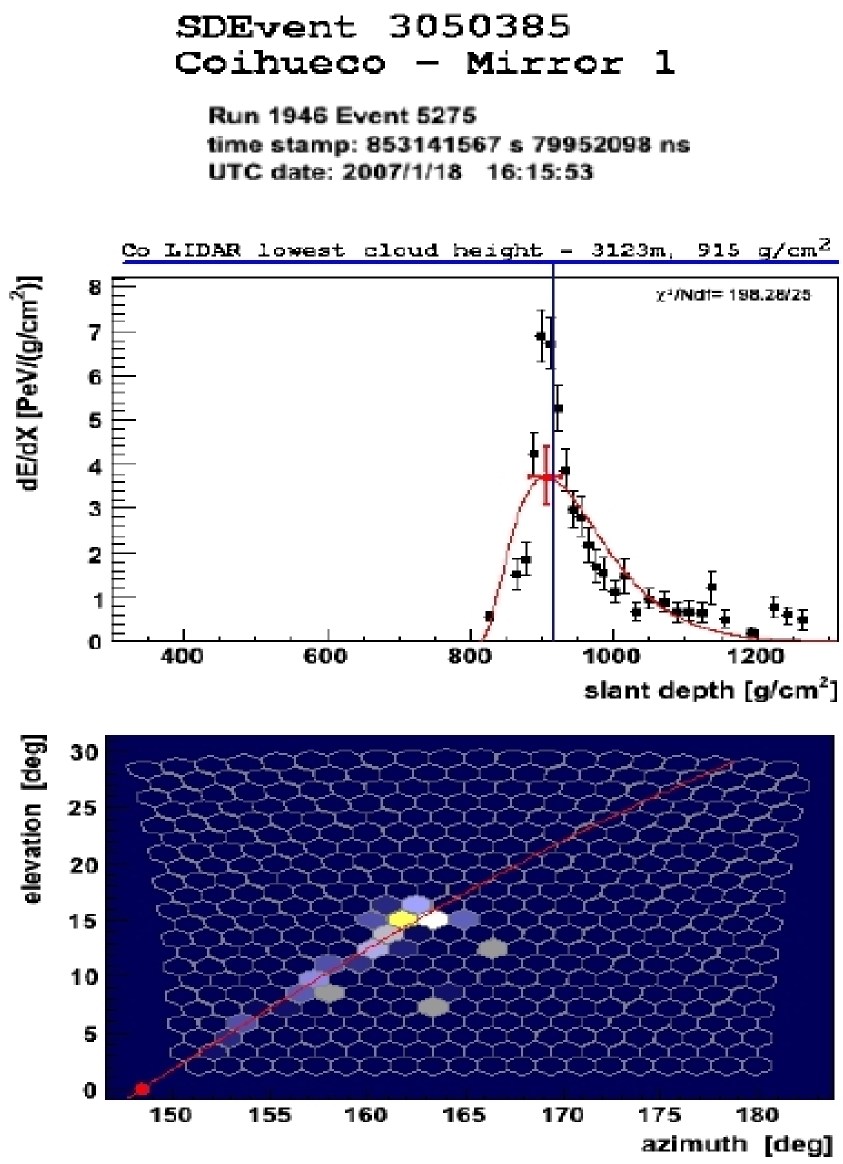


Los Morados - Mirror 2

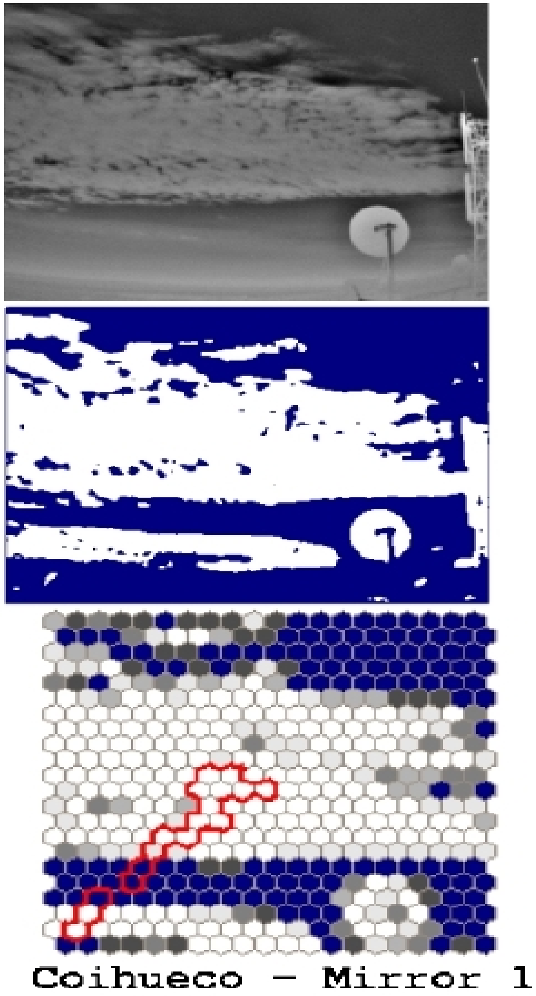
Cloud effects on shower profiles / 2



Cloud effects on shower profiles / 3



$E = (6.97 \pm 0.72) \times 10^{17}$ eV
Xmax = 906 ± 23 g/cm^2
dEdXmax = 3.72 ± 0.65 PeV/(g/cm^2)
$(\lambda, X0) = (43 \pm 23, 813 \pm 28)$ g/cm^2
Cherenkov-fraction = 18%
$(\theta,\phi) = (51.7 \pm 0.7,\ 228.8 \pm 0.5)$ deg
$(x,y) = (6.43 \pm 0.07,\ 45.19 \pm 0.07)$ km
dca to Eye=7.51 ± 0.05 km



Cloud effects on showers: conclusions

Clouds can impact significantly the quantities measured by Fluorescence detectors:

- can bias the hybrid flux (reducing the effective aperture)
- can bias Energy measurements
- can bias Xmax measurements

Standalone determination of cloud coverage with FD is not feasible
IR Cloud Cameras can provide a 2D coverage map for each pixel every 5 min
IR Cloud Cameras cannot measure cloud height and multiple layers
LIDARs can complement Cloud Cameras with height and layer information
but outside the field of view of the FD's
Shoot-the-shower: a full LIDAR scan on shower-detector plane is done when very interesting events are observed