Università degli studi di Torino

Corso di laurea in fisica

Study on expected sky conditions during Super Pressure Balloon flights and observation of cosmic rays

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PIEMONTE
Arpa
Agenzia Regionale
per la Protezione Ambientale

Outlook

- JEM-EUSO and EUSO-SPB;
- My work;
- Clouds climatological datasets*;
- Expected sky conditions during balloon flights*;
- Cosmic rays detection by EUSO-SPB;

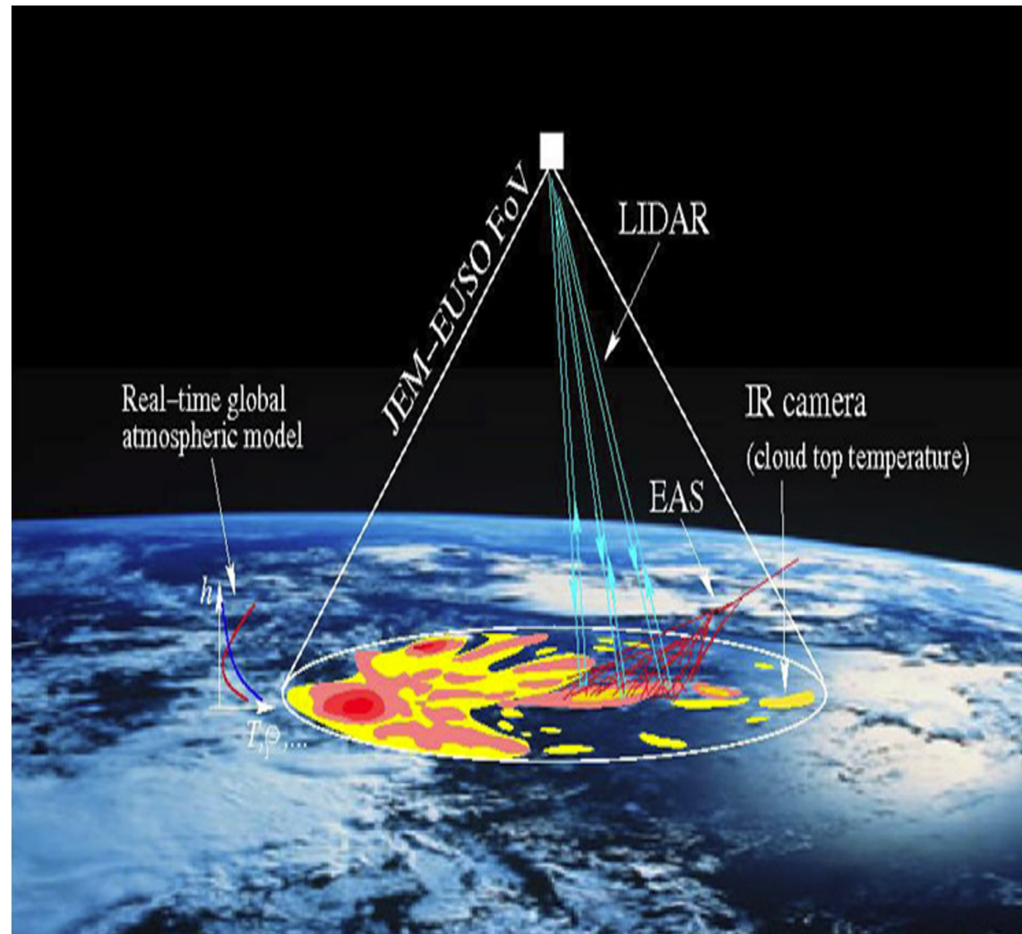
* stage presso Arpa Piemonte

JEM-EUSO Program

Extreme Universe Space Observatory

- JEM-EUSO is a new type of high-energy astronomical observatory that uses the atmosphere as a `detector';

- Fluorescence and Cherenkov light produced by air showers;

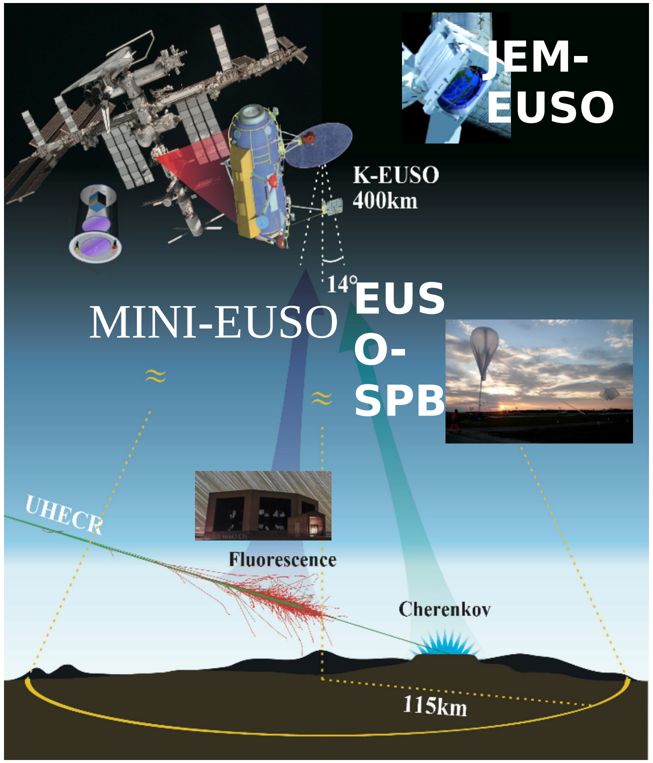


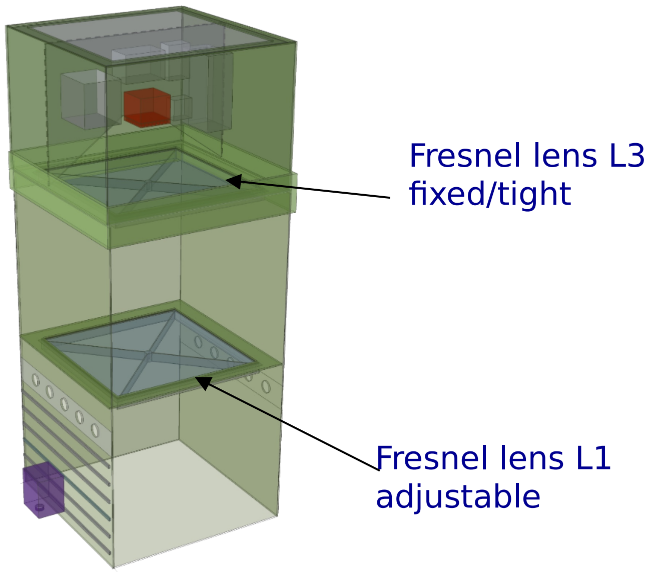
- Detection of Extreme Energy cosmic rays (E > $5 \cdot 10^{19}$ eV);

- It will be housed on ISS.

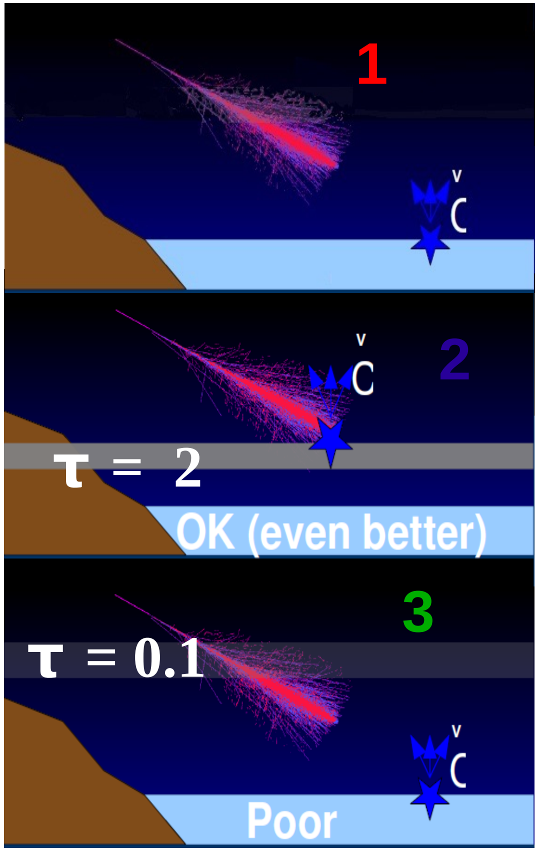
EUSO-SPB

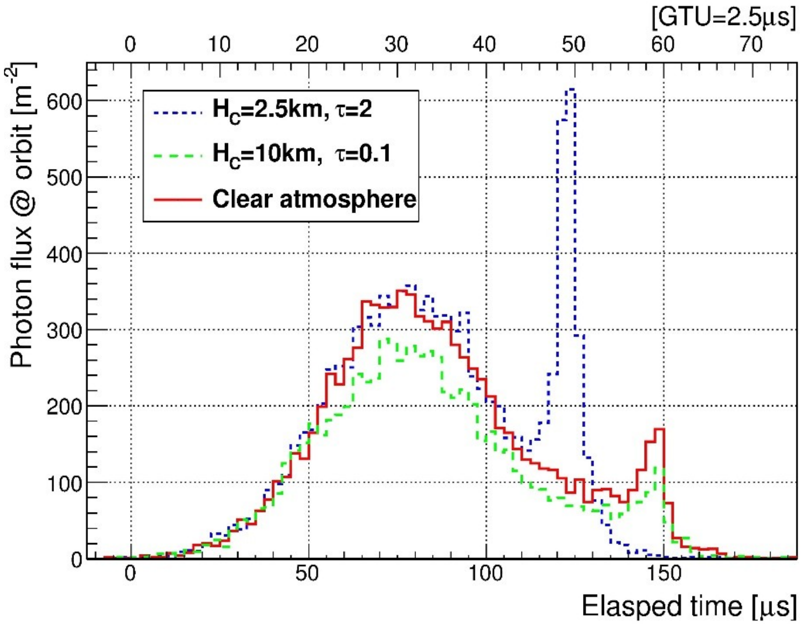
- JEM-EUSO prototypes: to test JEM-EUSO instruments (16 countries engaged);
- EUSO-SPB is a scaling prototype of the JEM-EUSO experiment. It will measure showers using the fluorescence technique from the stratosphere. It will be placed on a super pressure balloon (Wanaka, March 2017).





Influence of the clouds on cosmic rays showers





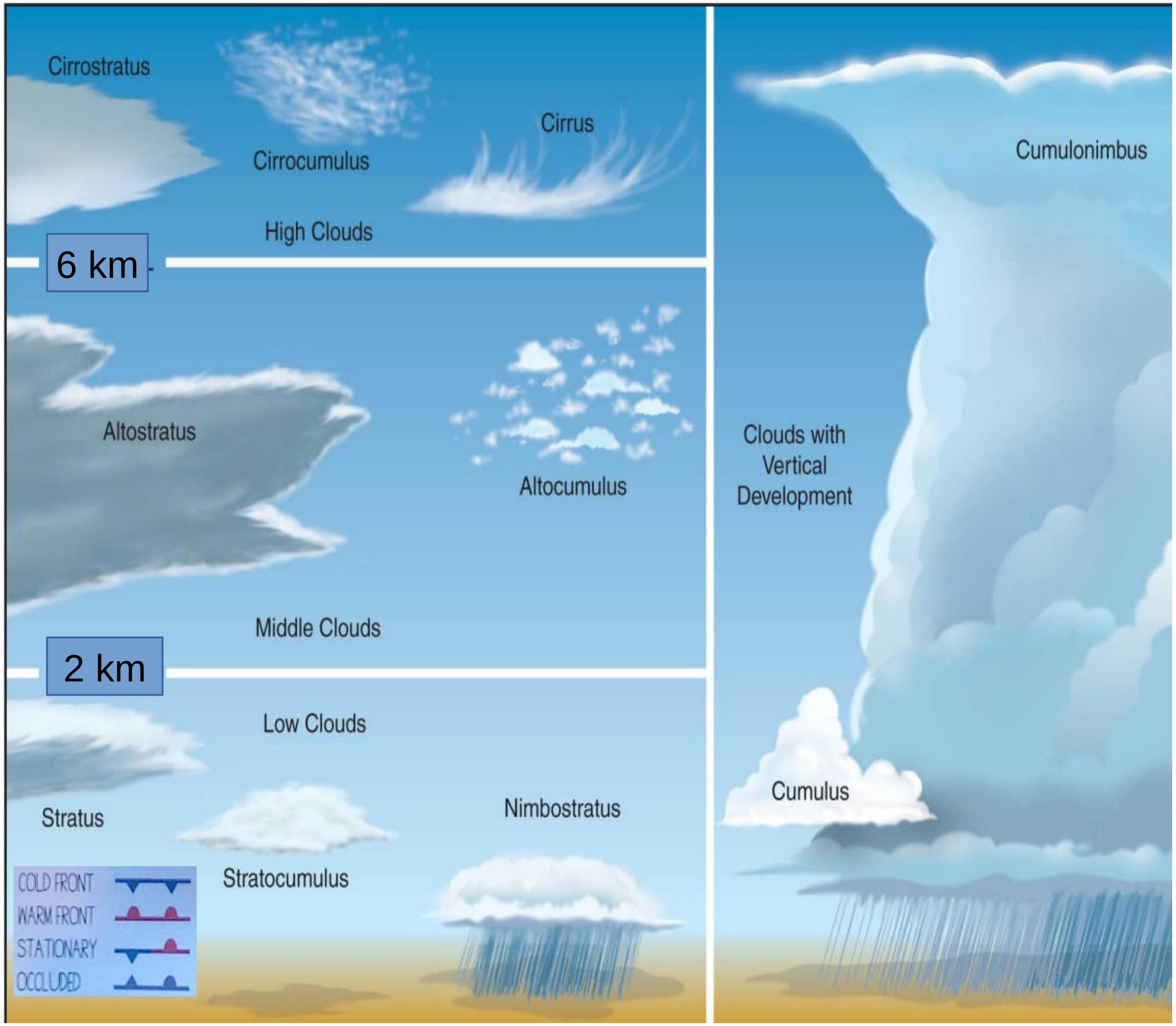
- Fluorescence and Cherenkov light:

- Clear sky;
- Low thick cloud;
- High thin cloud;

My work

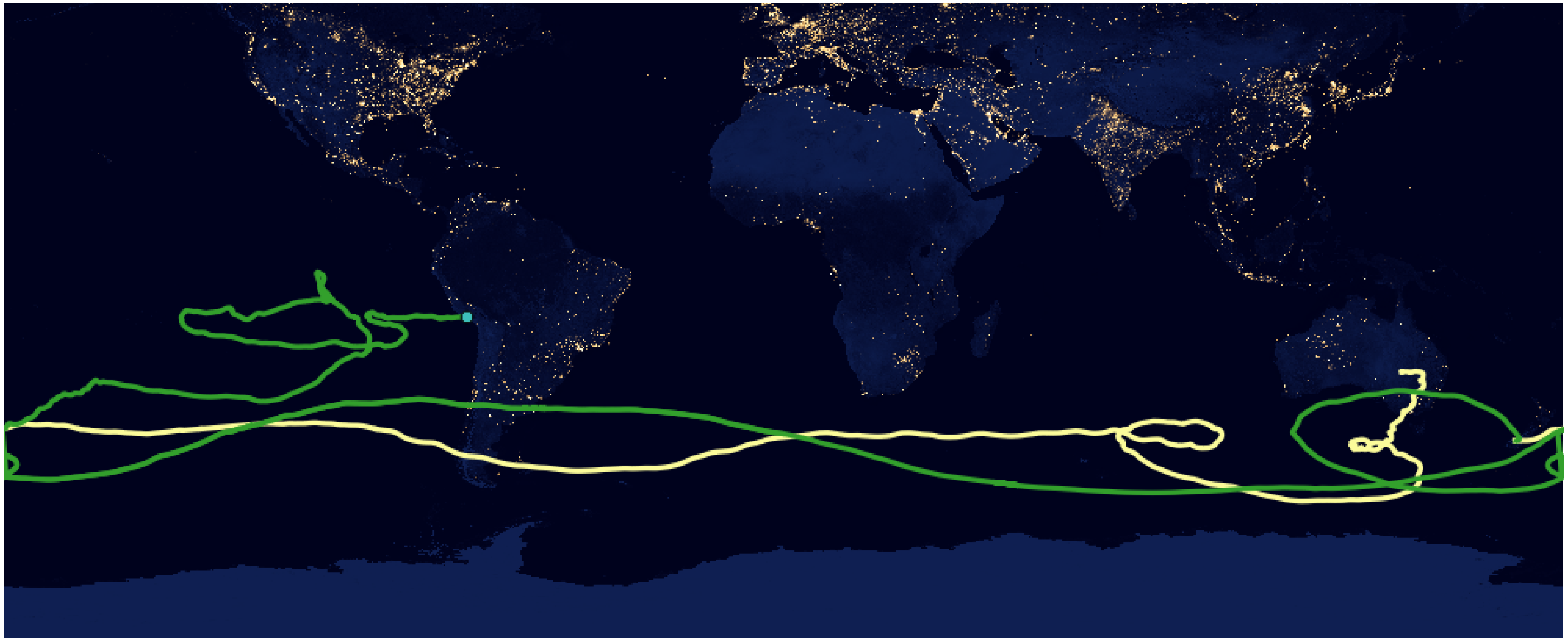
- Cloud fraction along the super pressure balloon flights;
- Cosmic rays simulations under different sky conditions;
- Realistic estimate of dark sky conditions;
- Estimation of EUSO-SPB performance;

Cloud classification



- **Low clouds**: H < 2km ;
- **Middle clouds**: 2 km < H < 6 km ;
- **High clouds**: H > 6 km ;

New Zealand Operations: trajectories of Super Pressure Balloon Flights 2015-2016

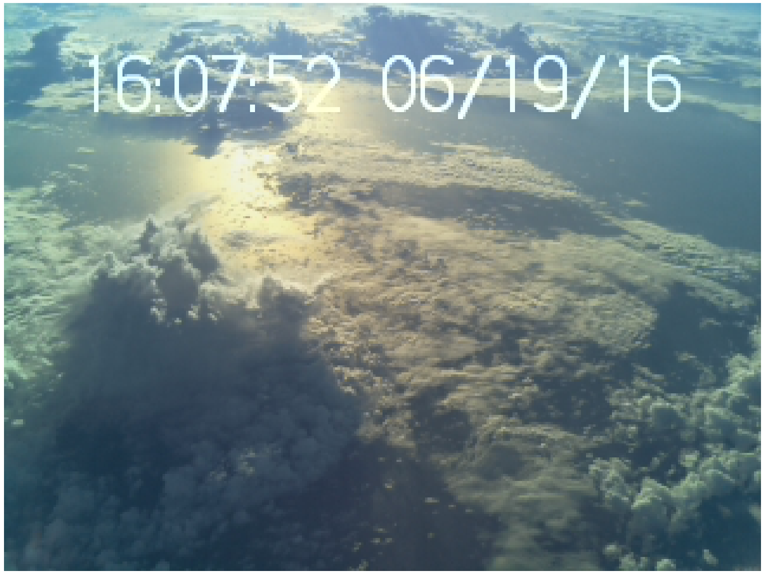


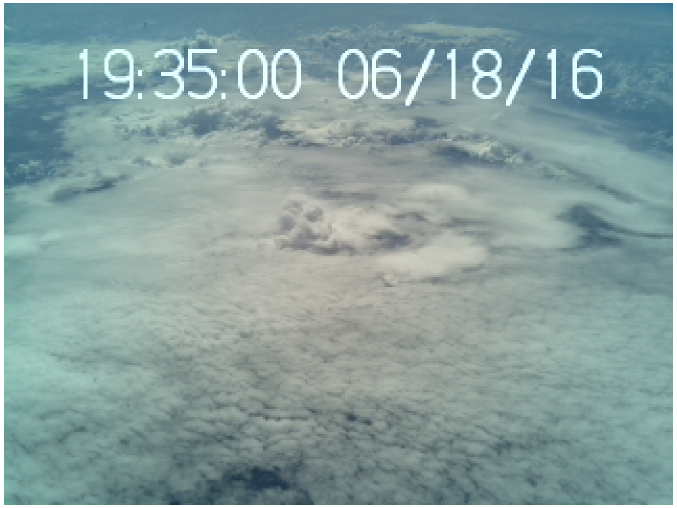
- **I flight** (March-April 2015) : 32d 5h 51m;
- **II flight** (May-July 2016) : 46d 20h 19m;

New Zealand Operations: Super Pressure Balloon Flights 2015-2016

- The first balloon flight was a Nasa test flight;

- The second balloon flight was a NASA balloon which carried a science payload, the Compton Spectrometer and Imager (COSI).



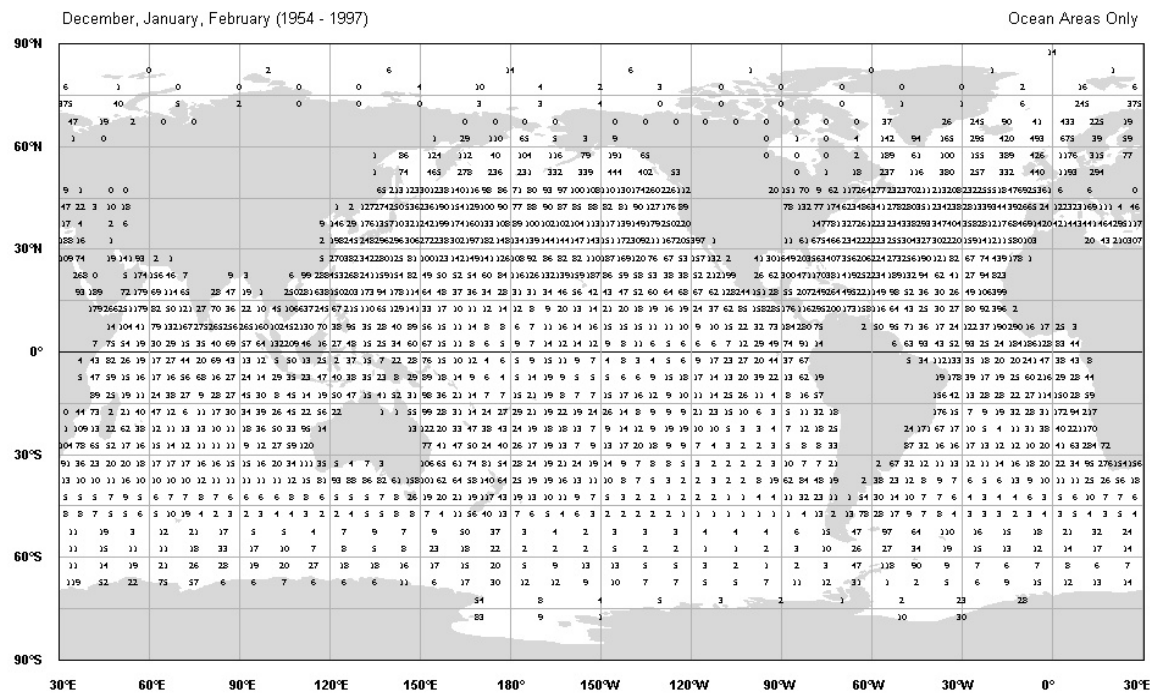


(from SPB 2016)

Cloud Atlas 1/2

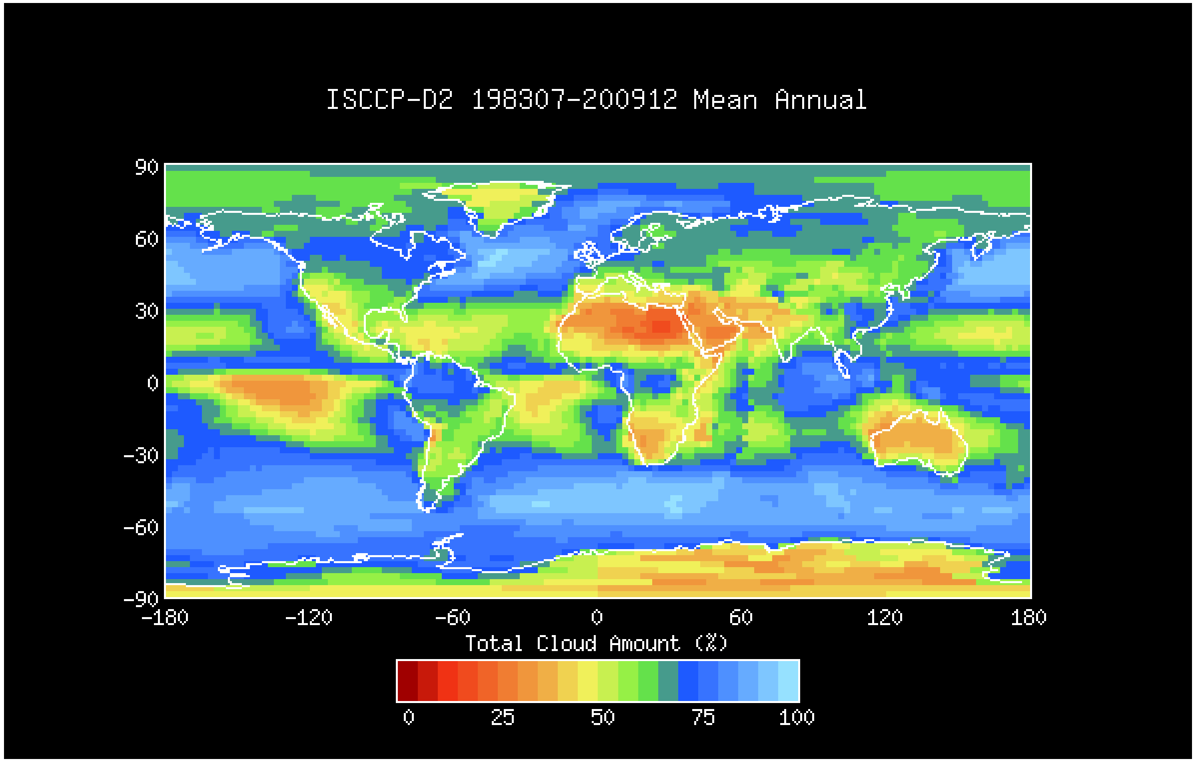
- CACOLO (Climatic Atlas of Clouds Over Land and Ocean);
- Ground data from 1954 to 1997;
- Land (SYNOP) and Ocean (SHIPS) observations;
- ~ World coverage;
- 5 degree equal area grid;
- Monthly averages;

Number of Cloud Observations (hundreds)

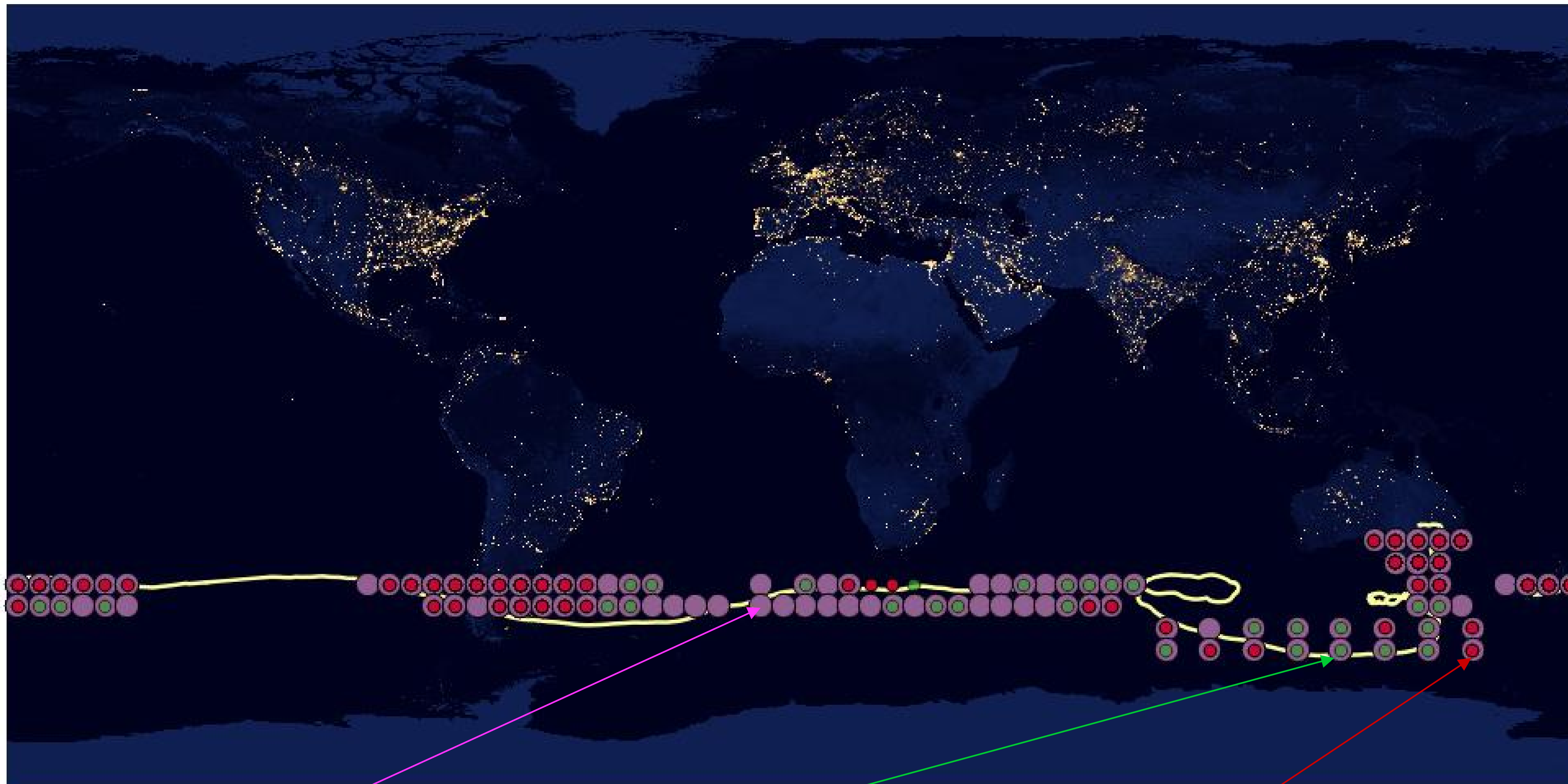


Cloud Atlas 2/2

- ISCCP (International Satellite Cloud Climatology Project) ;
- Geostationary satellites;
- Data from 1983 to 2009;
- ~ World coverage;
- 2.5 degree equal area grid;
- Monthly averages;



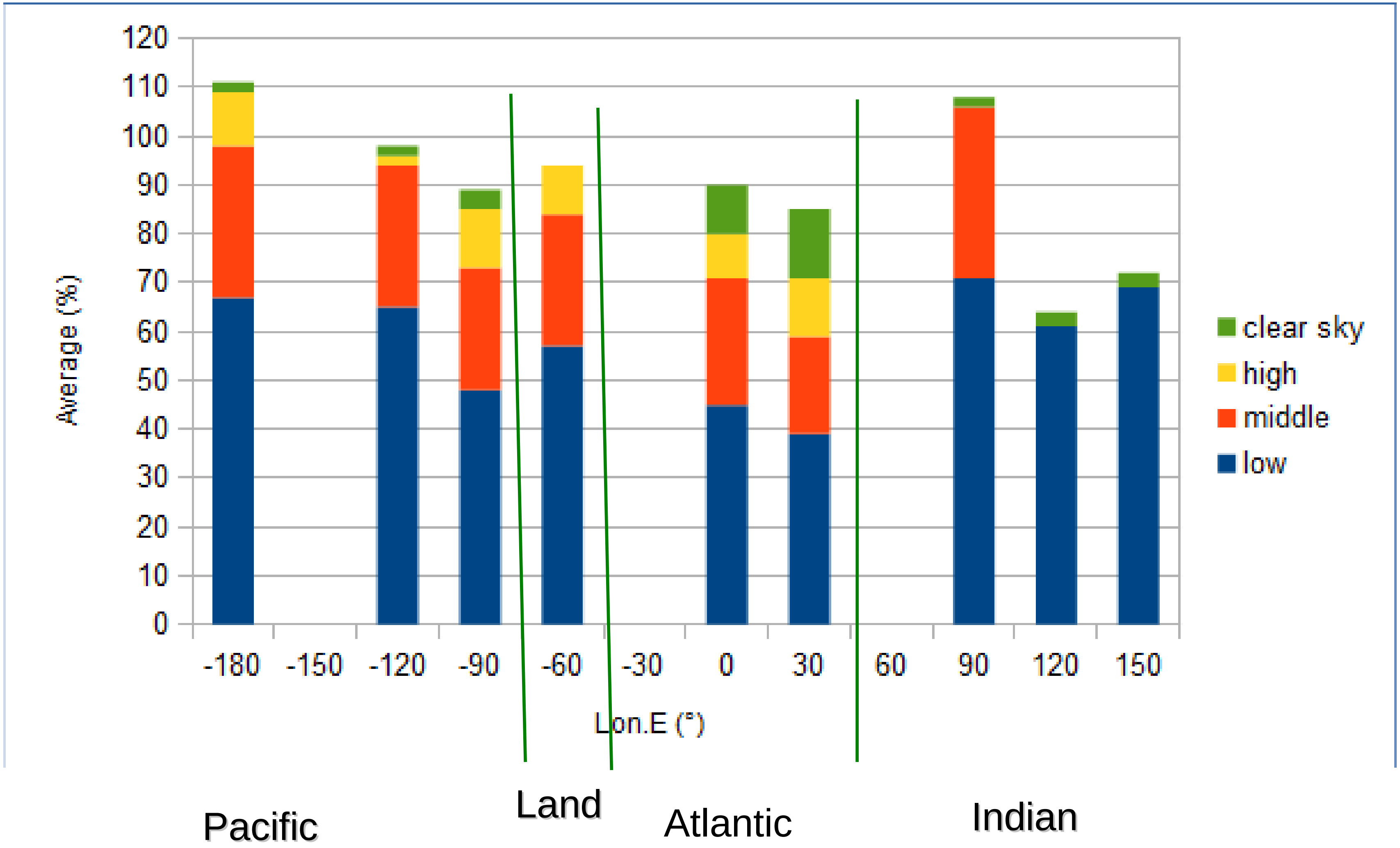
Super Pressure Balloon Flight 2015



purple: high clouds green: middle clouds red: high clouds

Sky conditions along the first balloon path:

CACOLO



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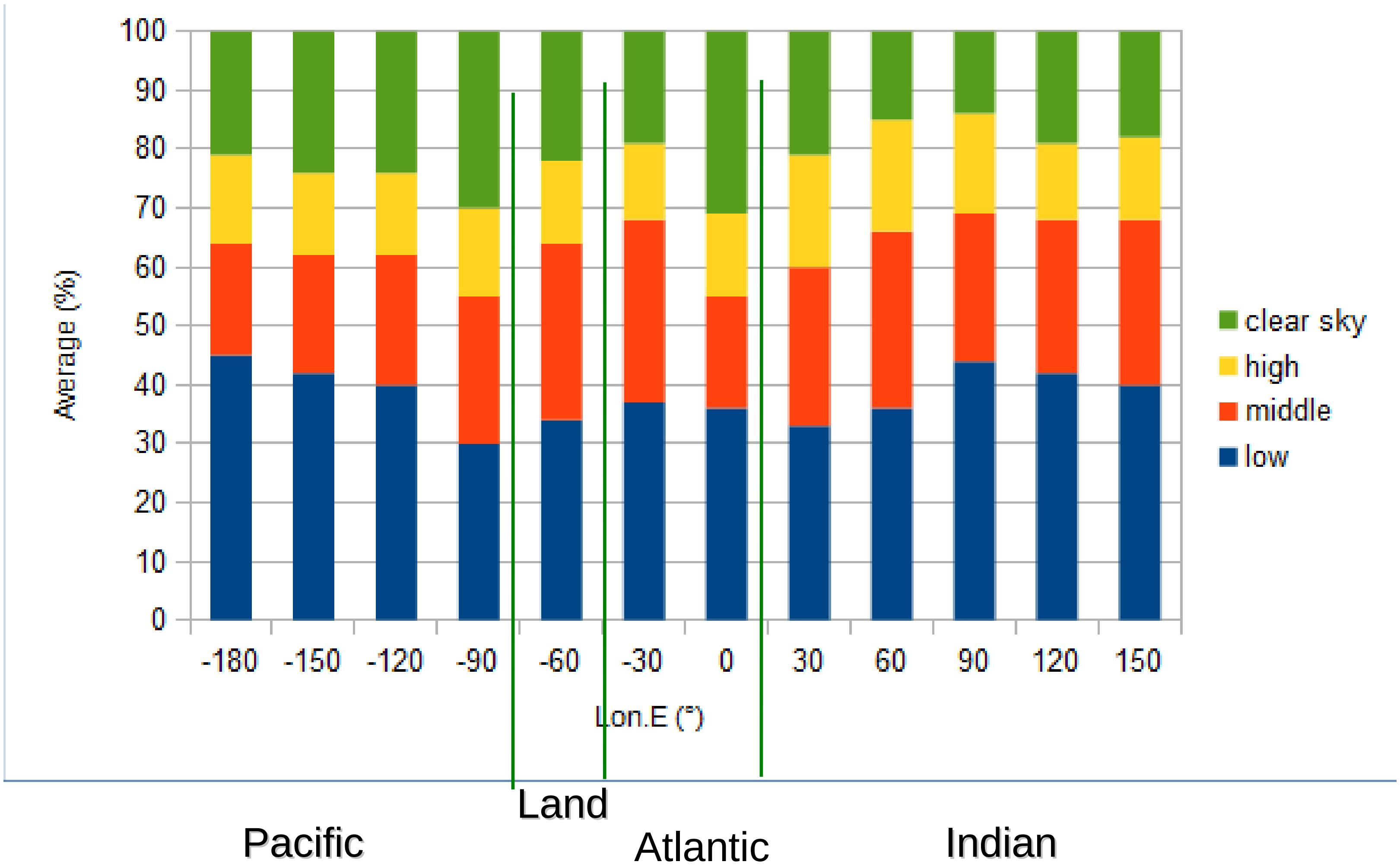
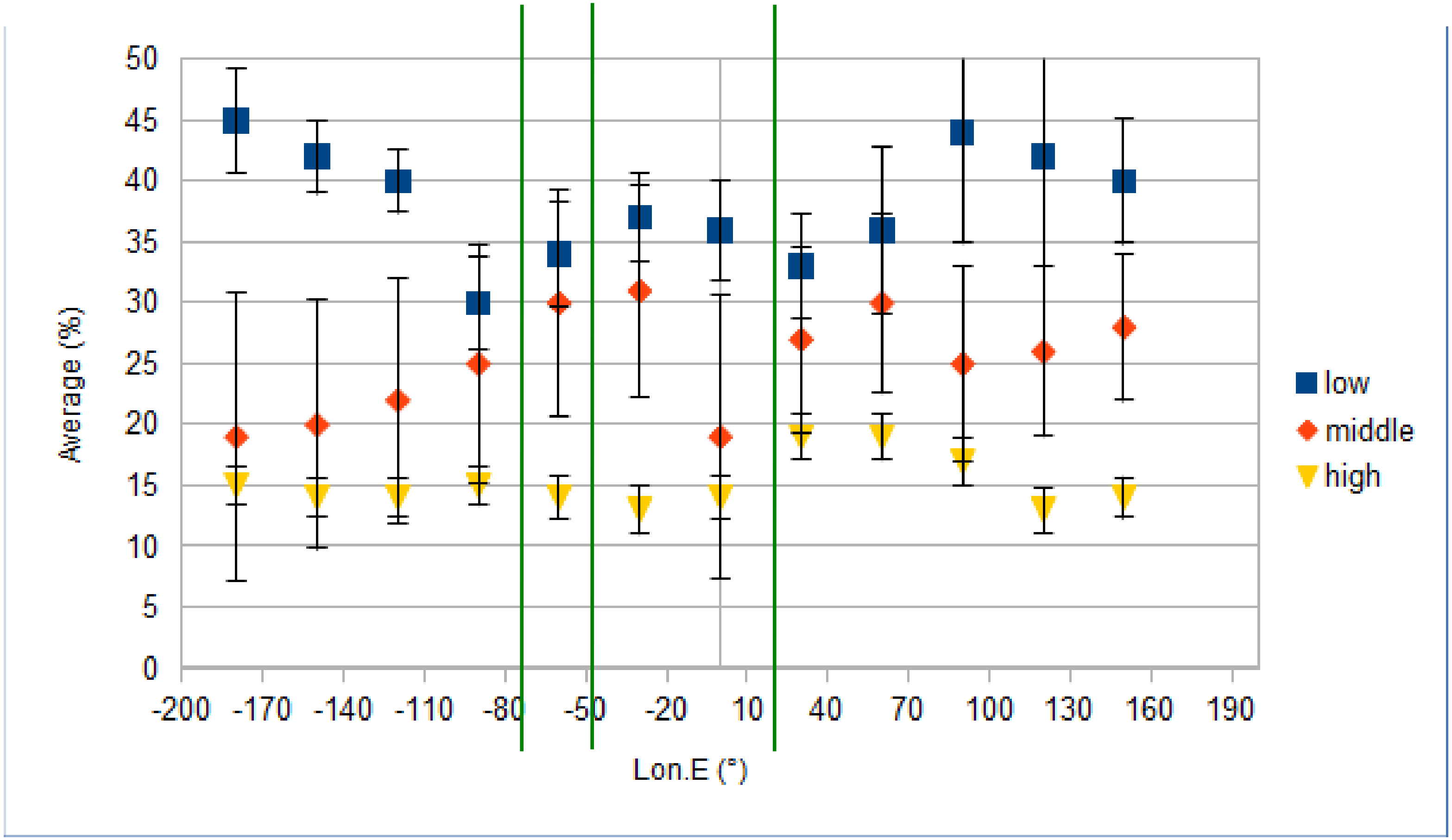
Sky conditions along the first balloon path:

ISCCP



Sky conditions along the first balloon path:

ISCCP



Land

Pacific Atlantic Indian

Sky conditions along the first balloon path:

ISCCP

- Highest occurrence for low clouds;

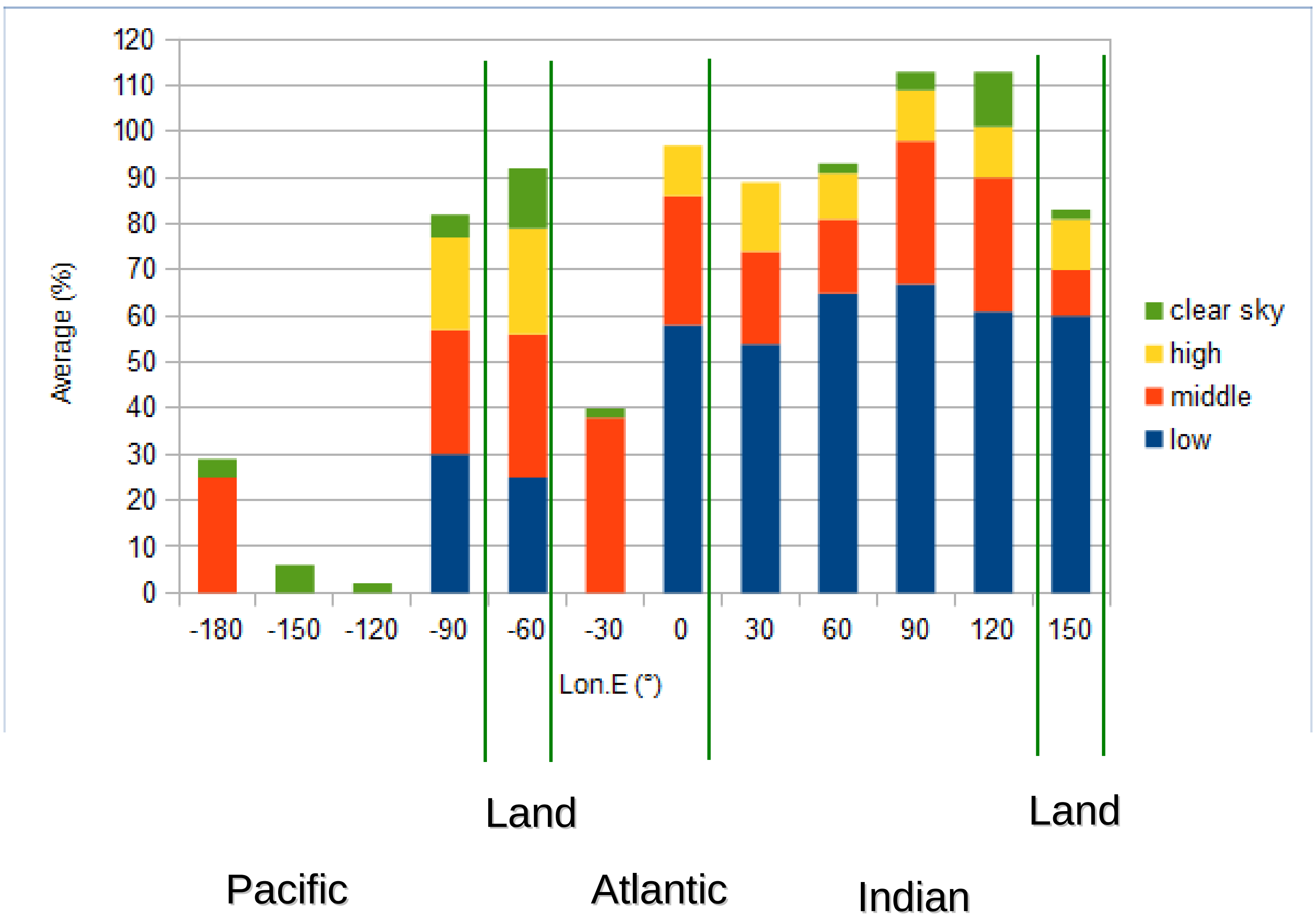
- Higher occurrence of clear sky than high clouds;

Cloud type	Average (%)	Variability (%)
low	37	± 5
middle	25	± 4
high	15	± 2
clear sky	23	± 7

- α_{Cs} clear sky fraction ;
- α_{low} low clouds fraction ;
- α_{middl} middle clouds fraction ;

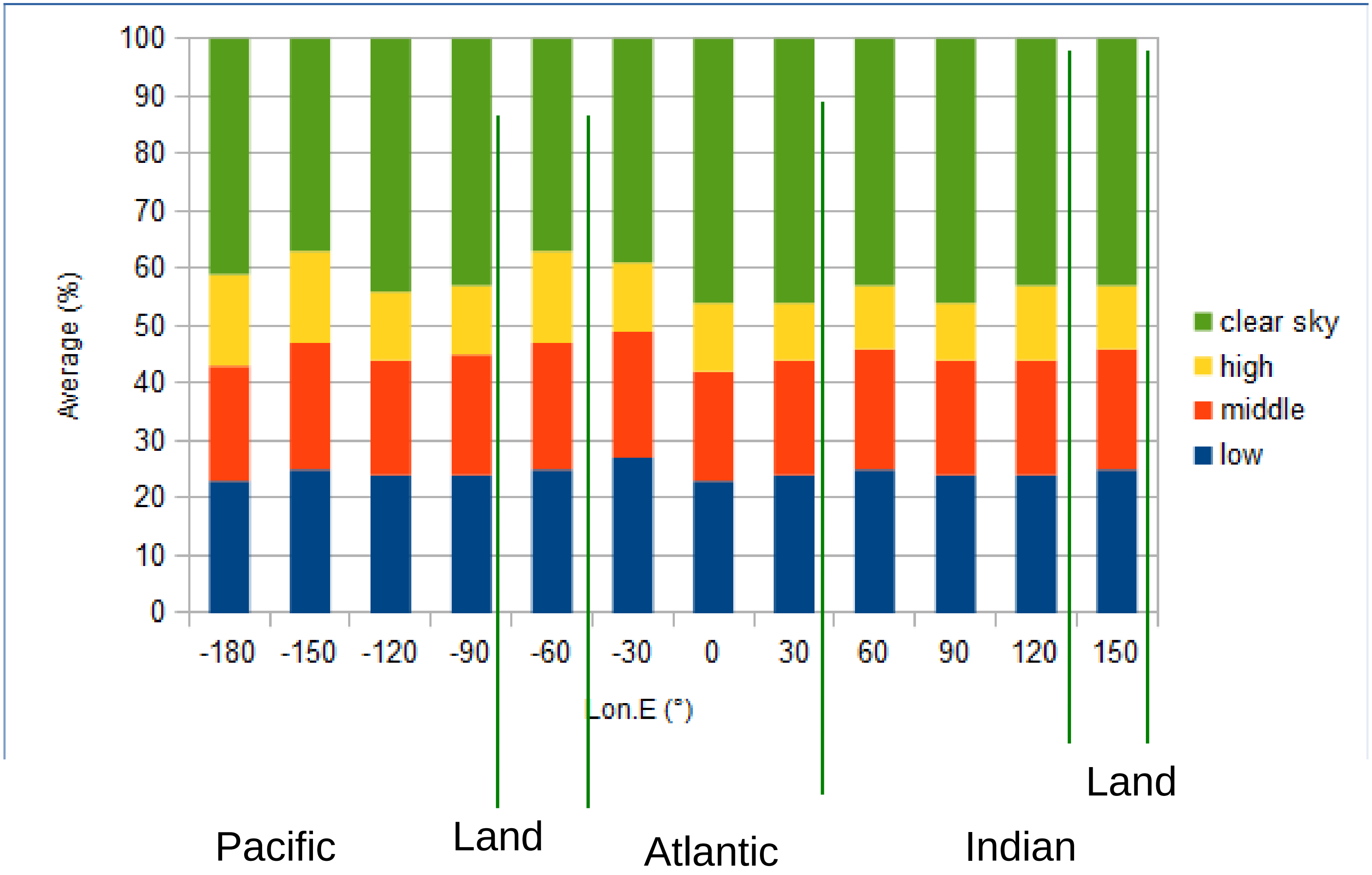
Sky conditions along the second balloon path:

CACOLO

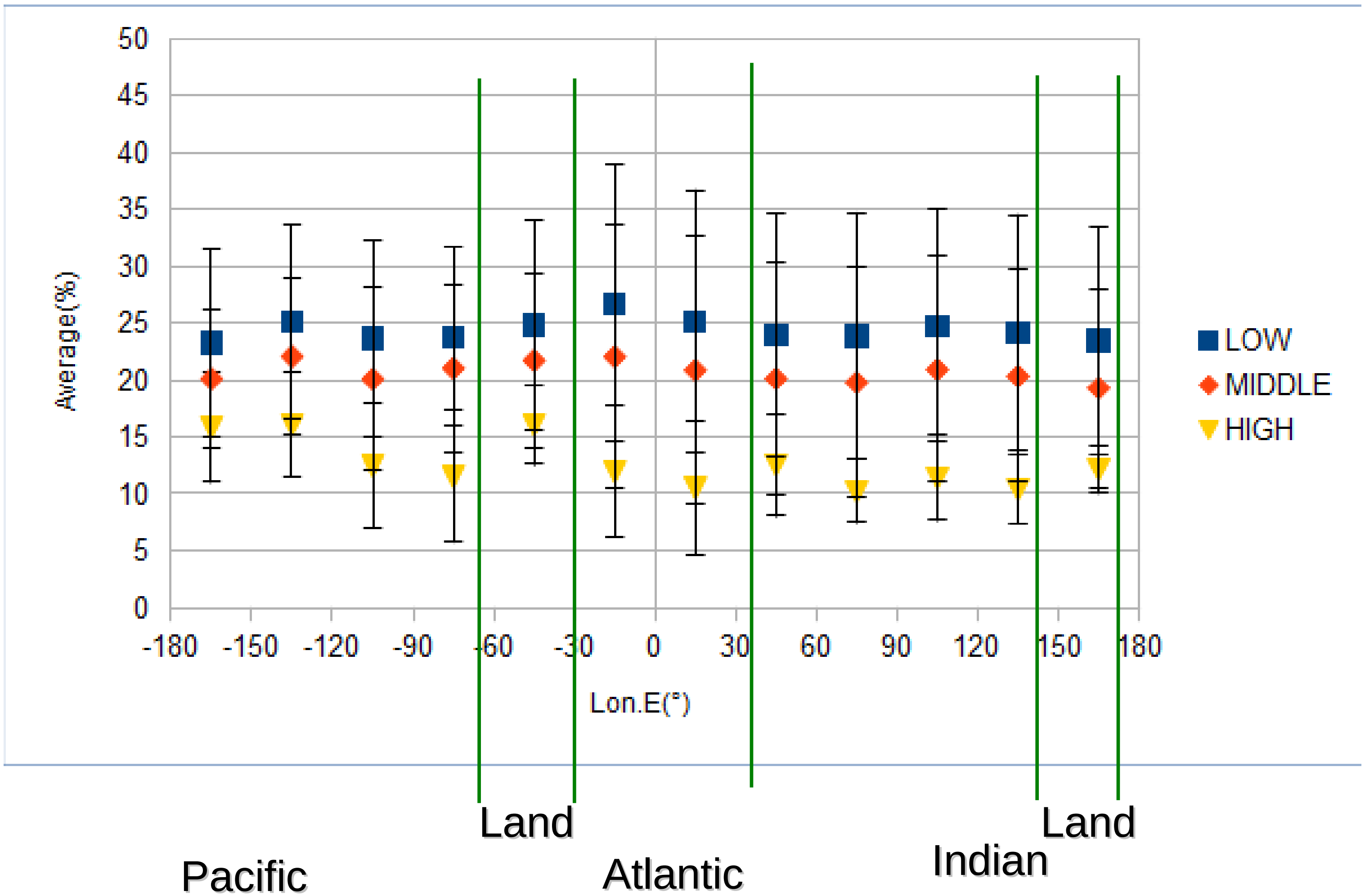


Sky conditions along the second balloon path:

ISCCP



Sky conditions along the second balloon path: ISCCP



Sky conditions along the second balloon path: ISCCP

- Highest occurrence for clear sky conditions;
- Almost the same occurrence of low and middle clouds;

Cloud type	Average (%)	Variability (%)
low	25	± 1
middle	22	± 1
high	13	± 2
clear sky	40	± 2

- α_{Cs} (Average of clear sky) ;
- α_{low} (Average of low clouds) ;
- α_{middle} (Average of middle clouds) ;

Optical Depth

A cloud with optical thickness lesser than 3 is a thin cloud: as this value increases, the cloud is thicker.

OD	variability
4,6	± 1,0

Results

- As expected low clouds have highest occurrence (typical for sea weather);
- High clouds occurrence runs from 15% of the time;
- Probable underestimated percentage of low clouds from satellite observations;
- Probable underestimated percentage of high clouds from ground observations;
- There are missing data along the balloon trajectory from ground observations.

Cosmic Rays:

Esaf (EUSO SIMULATION AND ANALYSIS FRAMEWORK)

The ESAF package is a simulation software specifically designed for the performance assessment of space based cosmic ray observatories.

- **Cosmic ray event simulation;**
- **Light propagation;**
- **Detector simulation;**
- **Trigger logic;**

Simulation Set-up

Cosmic rays energy

$6.3 \cdot 10^{17} <= E <= 1.6 \cdot 10^{19}$ eV

Simulations with ESAF:
-detector parameters;
-atmospheric conditions;
-cosmic rays parameters;

Atmospheric conditions:
-clear sky;
-low clouds(2km);
-middle clouds (5km);

Cloud optical depth = 5

Height of detector:
-30 km;
-38 km;

Triggered events:
-clear sky (low background);
-low and middle-high clouds (high background);
-uniform and non-uniform detector;

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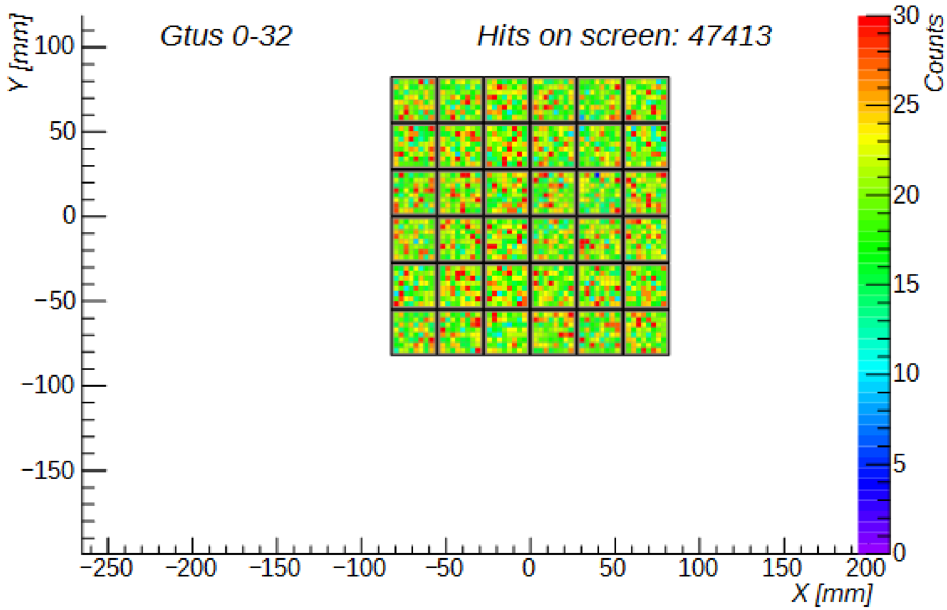
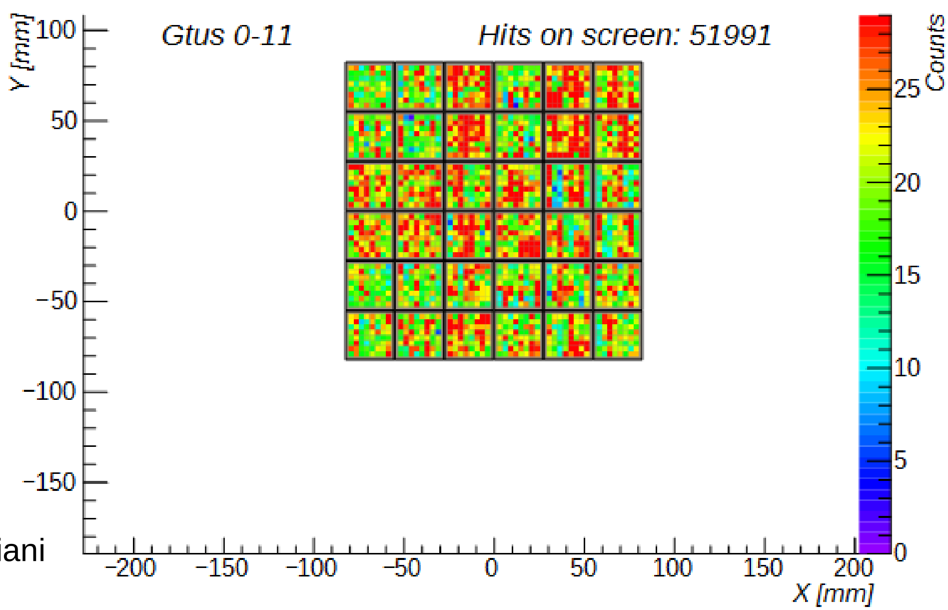
Uniform and Non-Uniform detector

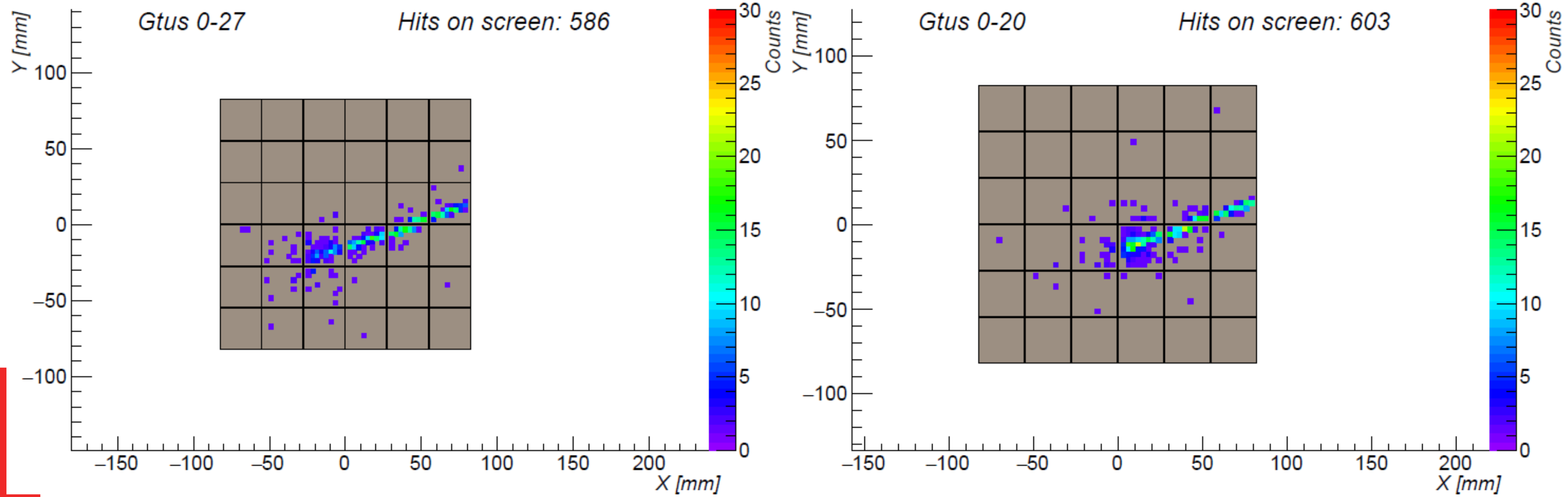


- **Uniform detector**: same pixel efficiency;



- **Non-uniform detector**: different pixel efficiency;
- **Measured map**;

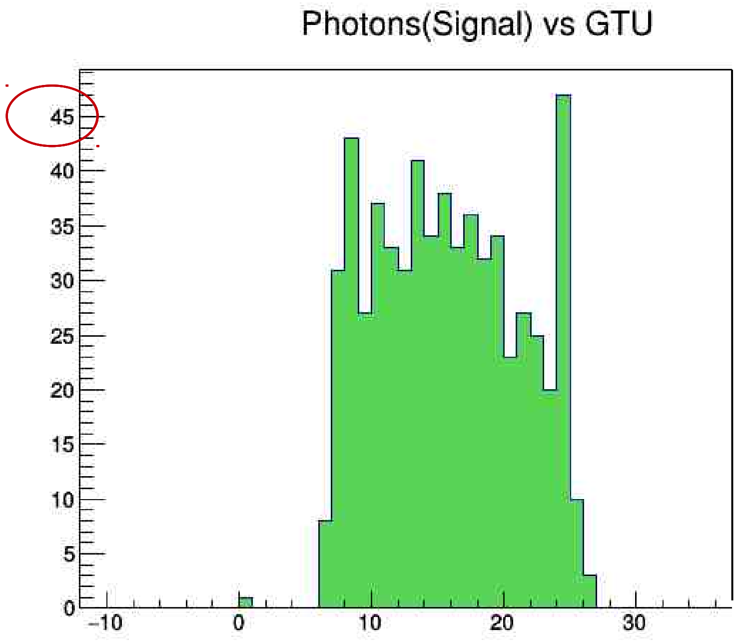
Cosmic signals:
Clear sky-low thick cloud(*)

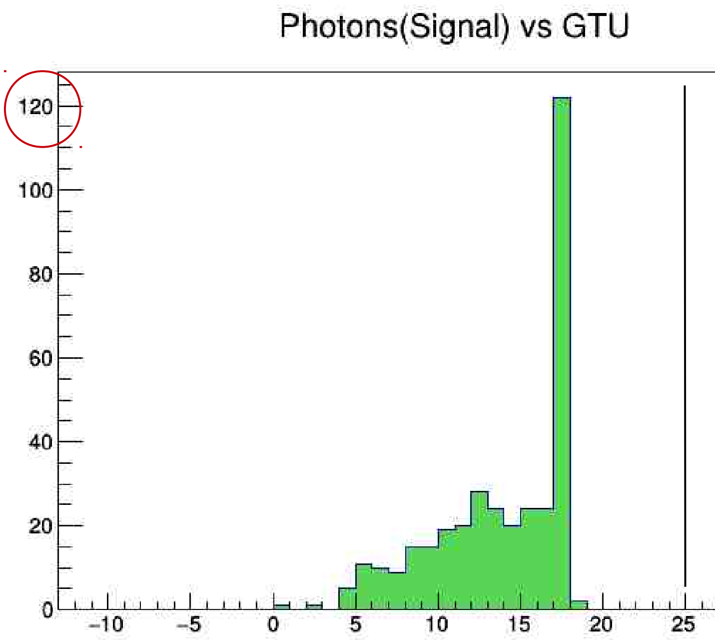


- Signals without background;
- **Clear sky:** longer event;
- **Low thick cloud:** detector sees the event's end on the top of the cloud;

(*)detector height = 38km

Light curves: Clear sky-low thick cloud(*)





- Fluorescence light and Cherenkov for clear sky;
- Many Cherenkov events with low cloud;

Triggered spectra calculation

Trigger performances evaluated in term of events collected in a spectrum

Number of events per energy bin → $\Delta N(E) = \frac{d\Phi(E)}{dE} \cdot \Delta(E) \cdot \Psi(E)$

Differential flux → $\frac{d\Phi(E)}{dE}$ **(Auger flux – ICRC 2013)**

Detector exposure → $\Psi(E) = \epsilon(E) \cdot A_{fov} \cdot \pi \cdot t \cdot DC$

- Ɛ (E) : detector efficiency;
- A_{FOV} : detector field of view area;
- t : triggering time;
- π : solid angle;
- N(E) : number of triggered events;
- ΔE : range of energy;
- DC : (duty cycle);

Triggered spectra calculation

Number of triggered events in different sky conditions → $N^{(CS,low,middle)} = \sum_{i=1}^{k} N_i(E)$

- K : number of bins;

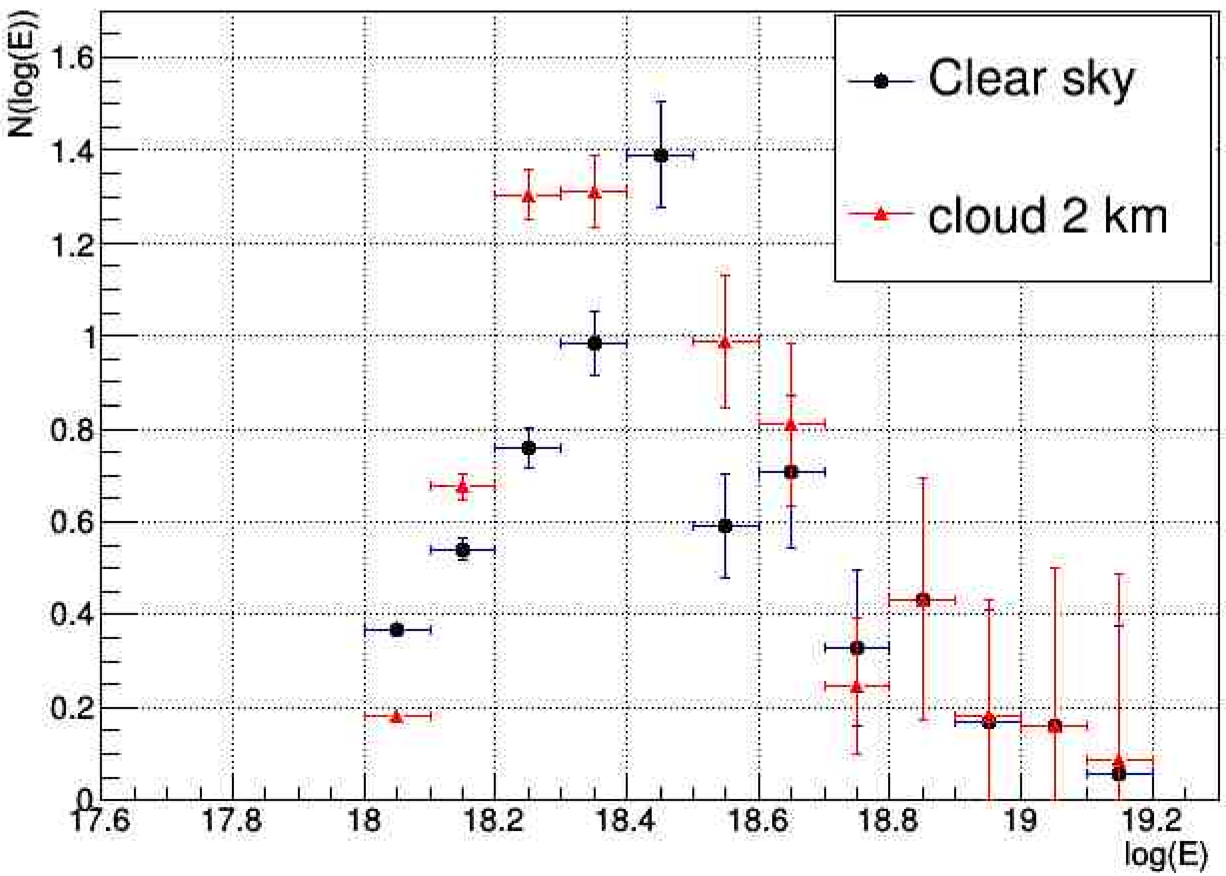
Uncertainty on triggered events → $\sigma N(E) = \left(\sqrt{(1-p)\cdot p\cdot N_{tot}} / N_{tot}\right)\cdot \phi(E)\cdot \Delta E\cdot A_{FOV}\cdot t\cdot \pi$

- N_{tot} : number of simulated events;
- $P = N(E) / N_{tot}$;

Weighted sum → $N_{ws} = \alpha_{cs}\cdot N^{cs} + \alpha_{low}\cdot N^{low} + \alpha_{middle}\cdot N^{middle}$

- $\alpha_{(Cs,low,middle)}$: ISCCP average fraction;

Spectrum of triggered events



- Spectrum of triggered events in different sky conditions;
- Highest peaks:
  - Clear sky: $2.82 \cdot 10^{18}$ eV
  - Cloud (2 km): $2.24 \cdot 10^{18}$ eV;

Triggered Events:
Uniform detector

- **Detector height:** 38 km;
- 10000 simulated events;
- Number of triggered events;
- **118 hours:** trial period for a moon phase (March-April 2017);

detector height			
38 km	Low background	High background	High background
uniform detector	clear sky	low (2km)	Middle (5km)
118 h	5,2 ± 0,5	10,0 ± 0,6	7,3 ± 0,5

- **Weighted sum;**

detector height	uniform detector
38 km	
118 h	weighted sum
I flight (2015)	6,7 ± 0,8
II flight (2016)	6,2 ± 1,3

Triggered Events:
Non-Uniform detector

- **Detector height:** 38 km;
- 10000 simulated events;
- Number of triggered events;
- **118 hours:** trial period for a moon phase (March-April 2017);

Non-uniform detector			
118 h	Low background	High background	High background
detector height	clear sky	low (2km)	Middle (5km)
38 km	3,8 ± 0,5	4,2 ± 0,5	3,2 ± 0,4

- **Weighted sum**

Non-uniform detector	weighted sum	weighted sum
118 h	I flight (2015)	II flight (2016)
detector height		
38 km	3,2 ± 0,7	3,3 ± 0,7

Triggered Events:
Non-Uniform detector

- **Detector height:** 38 km-30km;
- 10000 simulated events;
- Number of triggered events;
- **118 hours:** trial period for a moon phase (March-April 2017);

Non-uniform detector			
118 h	Low background	High background	High background
detector height	clear sky	low (2km)	Middle (5km)
38 km	3,8 ± 0,5	4,2 ± 0,5	3,2 ± 0,4
30 km	8,0 ± 0,6	6,4 ± 0,6	4,9 ± 0,5

- **Weighted sum**

Non-uniform detector	weighted sum	weighted sum
118 h	I flight (2015)	II flight (2016)
detector height		
38 km	3,2 ± 0,7	3,3 ± 0,7
30 km	5,4 ± 0,8	5,9 ± 1,3

February moon phase

detector height	Non-uniform detector
38 km	
90 h (february 2017)	weighted sum
I flight (2015)	2,4 ± 0,5
II flight (2016)	2,5 ± 0,5

detector height	Non-uniform detector
30 km	
90 h (february 2017)	weighted sum
I flight (2015)	4,1 ± 0,6
II flight (2016)	4,5 ± 1,0

- EUSO-SPB will be on the starting position in Wanaka in February 2017;
- 90 hours: it’s the time of a moon phase in February 2017;
- comparison between the number of triggered events with the detector at two different heights;
- when the detector is at 30 km there are more lower energy events;

June moon phase

detector height	Non-uniform detector
38 km	
154 h (june 2017)	weighted sum
I flight (2015)	4,2 ± 0,9
II flight (2016)	4,3 ± 0,9

detector height	Non-uniform detector
30 km	
154 h (june 2017)	weighted sum
I flight (2015)	7,0 ± 1,0
II flight (2016)	7,7 ± 1,7

- **154 hours:** it's the time of a moon phase in June 2017;

- comparison between the number of triggered events with the detector at two different heights;

- when the detector is at 30 km there are more lower energy events;

Triggered events: dark hours during the super pressure balloons 2015-2016

I flight (2015)		detector height	detector height
Non-uniform detector		38 km	30 km
138 h (March-April 2015)	weighted sum	3,7 ± 0,8	6,3 ± 0,9

- **138 hours:** time without sunlight and moonlight during the balloon flight 2015;
- comparison between the triggered events with the detector at two different heights;

II flight (2016)		detector height	detector height
Non-uniform detector		38 km	30 km
211 h (May-July 2016)	weighted sum	5,9 ± 1,3	10,6 ± 2,3

- **211 hours:** time without sunlight and moonlight during the balloon flight 2016;
- comparison between the triggered events with the detector at two different heights;

- the second balloon flought during the winter: more dark hours than the first balloon;

Conclusions

- Study of atmospheric conditions along two super pressure balloon flights;
- Average of cloud amount during the paths;
- Thick clouds (from the study of optical depth);
- Simulations of cosmic rays with ESAF, changing detector and atmospheric parameters;
- Estimate of triggered events, changing detector and atmospheric parameters;
- N (30km) > N (38km);
- N (June) > N (February);
- N (I flight) ~ 6 ;
- N (II flight) ~ 10;

Grazie per l’attenzione!

References

- CACOLO: http://www.atmos.washington.edu/CloudMap/WebO/index.html ;
- ISCCP: http://isccp.giss.nasa.gov/ ;
- http://jemeuso.riken.jp/en/ ;
- http://jem-euso.roma2.infn.it/?page_id=1055 ;
- Simone Cambursano’s thesis;
- http://www.free-online-private-pilot-ground-school.com/;