Università degli Studi di Torino - dipartimento di Fisica

Characterisation of the atmospheric conditions and sky luminosity in measurements of cosmic rays from space

Francesco Imberti

Prof. Bertaina Mario

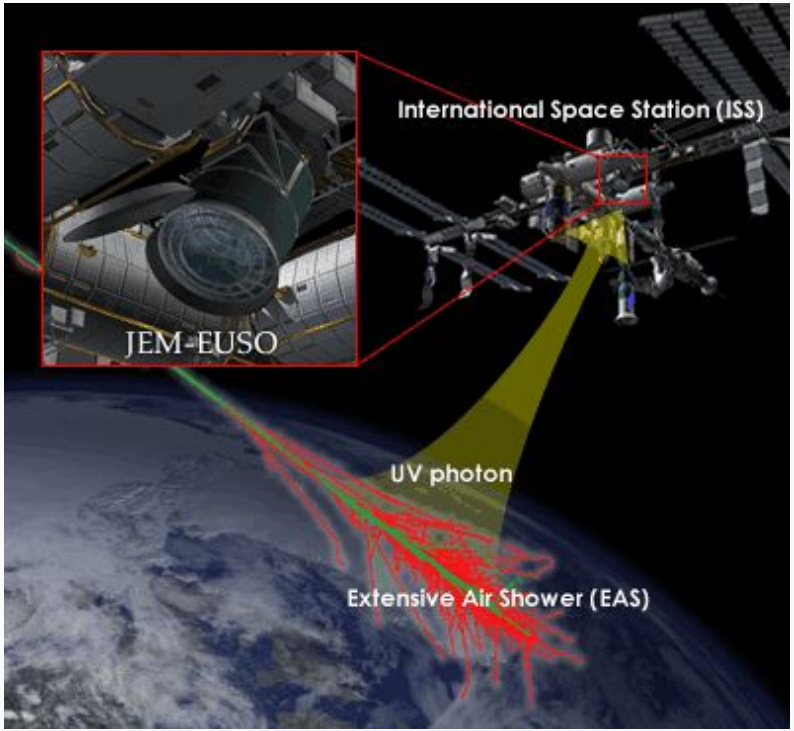
Prof. Manfrin Massimiliano

Cosmic Rays and JEM - EUSO

- Cosmic rays: nuclei of various chemical elements, produced in astrophysical elements such as supernovae

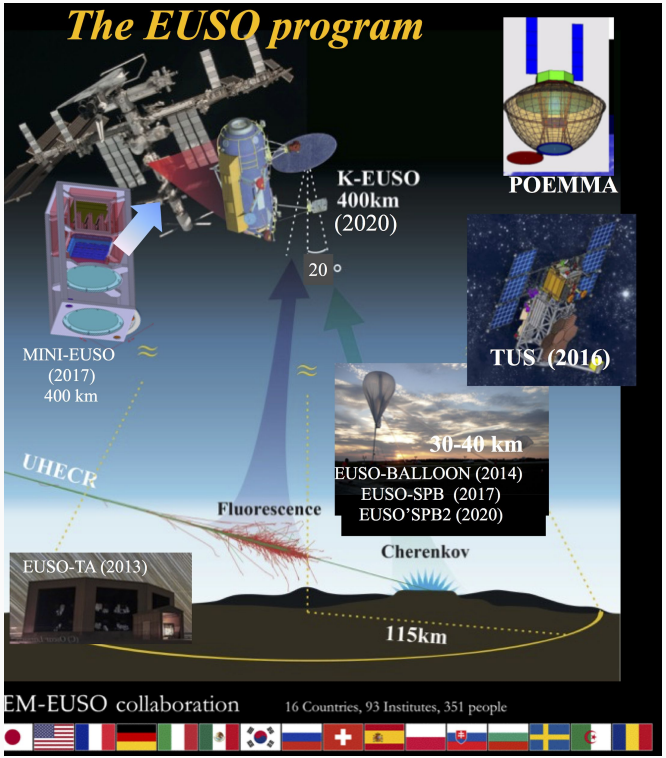
- JEM - EUSO: Joint Experiment Missions for Extreme Universe Space Observatory

- Very large exposure space based detector looking at the fluorescence light produced by EECR ($E > 5x10^{19}$ eV) interacting in the atmosphere



JEM - EUSO Program

- EUSO - TA (2013): ground detector installed at Telescope Array site: currently operational
- EUSO Balloons: first balloon flight from Timmins (Canada), 2014; **NASA SPB1, 2017**; NASA SPB2, 2021
- TUS (2016): free-flyer (Roscosmos)
- Mini-EUSO (2018): Inside the ISS (ASI and Roscosmos)
- K-EUSO (2022): Outside ISS
- POEMMA (2023+): NASA twin free-flyer



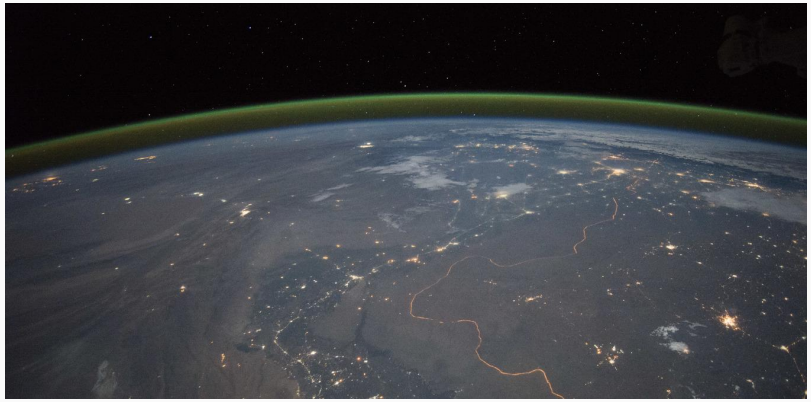
Objective

JEM - EUSO from space will detect every photon produced by any source (stars, planets, zodiacal light, airglow, man made light), not only cosmic rays: necessity to study and cut every other source of light off the data. I concentrated on two different parts of the project:

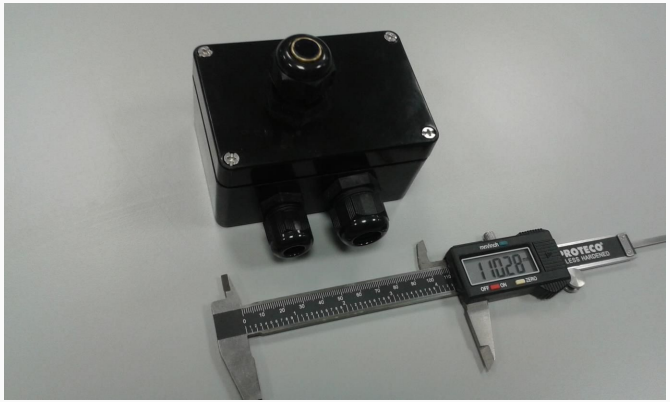
- Study of the background light produced by the airglow: calibration of the detector
- Clouds distribution

Airglow and AMON

- Airglow: faint light emission produced by a oxygen layer positioned at about 80 - 100 km above the Earth surface



- AMON: Detector used in the study of Airglow, mainly composed by a photomultiplier, flanked by some smaller climate detectors (pressure, temperature, light). QE linked to photon wavelength: 300 - 500 nm



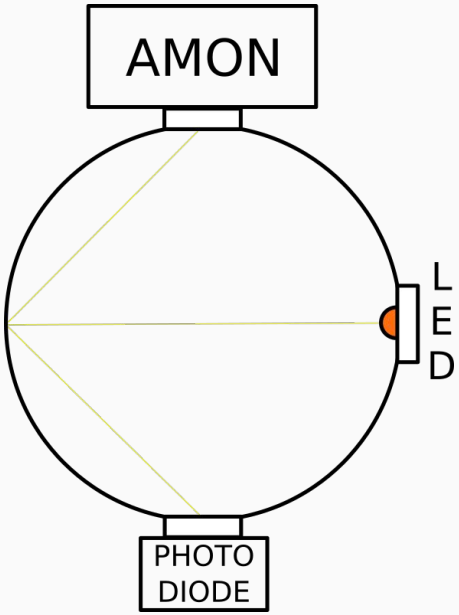
AMON

- Very sensitive photomultiplier (PMT): Hamamatsu μPMT HI24-00-01
- Thorlabs BG3 bandpass filter
- Narrow collimator with geometrical factor $3{,}45 \cdot 10^{-6}$ cm^2sr
- 70% of observed airglow light is in the 300 - 400 wavelength range
- Photons aquired in 1s period and converted in ADC counts
- Waterproof - 575 grams - 110 x 75 x 57 mm
- Thermometer, balometer, luxmeter, GPS sensor
- Standard internet connection

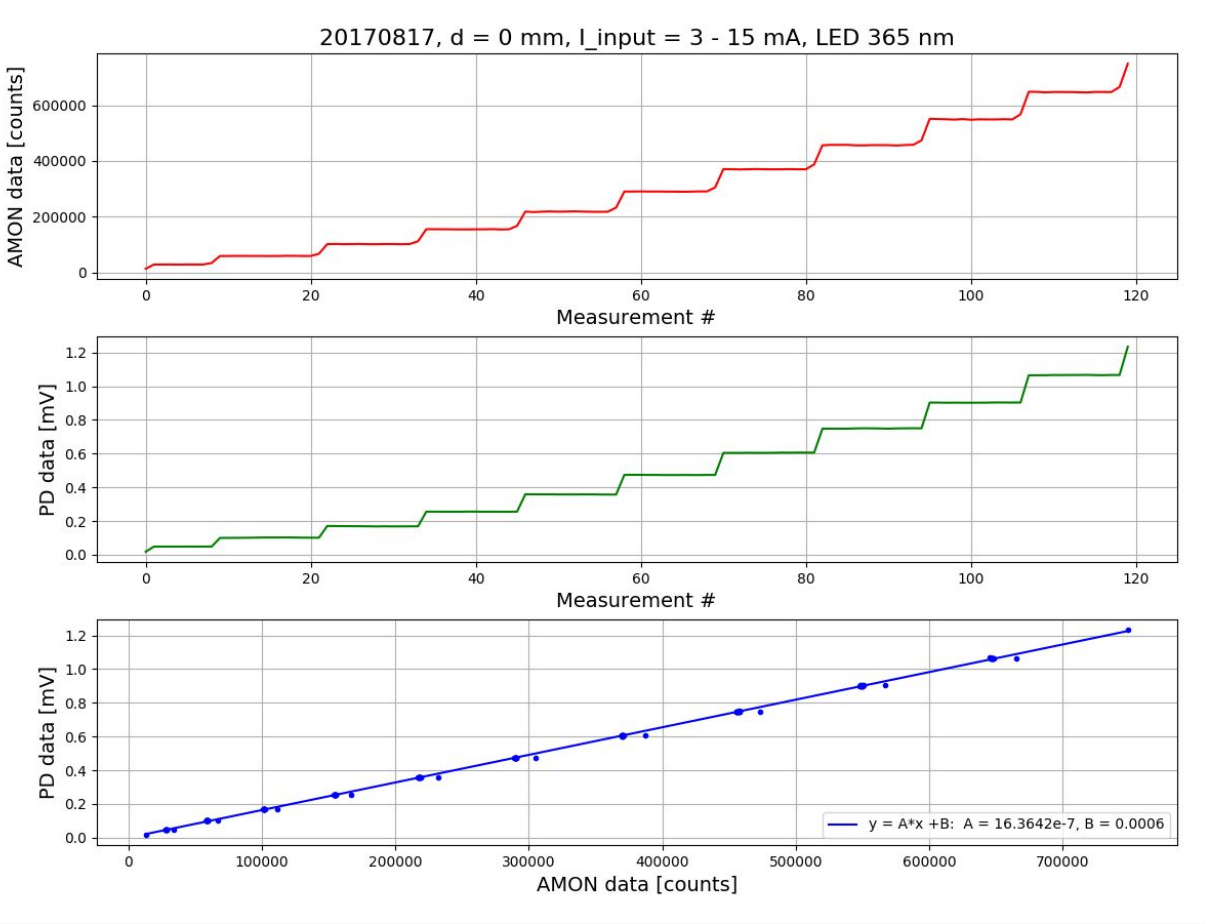
AMON Calibration

Two steps:

- comparing output of photodiode and AMON using an LED and a integrating sphere
- comparing output of PD and AMON using different LEDs and a integrating sphere



Experiment scheme



A_1	$16.36 \cdot 10^{-7}$
A_2	$16.26 \cdot 10^{-7}$
A_3	$16.38 \cdot 10^{-7}$
A_4	$15.84 \cdot 10^{-7}$
A_5	$16.18 \cdot 10^{-7}$

AMON Calibration results - LED: 365 nm

Cloud movements

Cloud distribution and movements important for two reasons:

- shield function for the cosmic ray light: showers generate in the atmosphere, high and medium clouds cover the interactions

- shield function for background lights studies from the ground

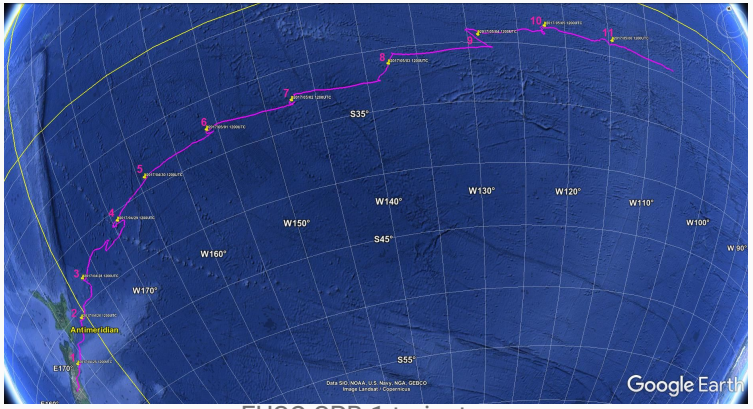
Cloud movements study - Objective

Objective of the study:

- qualitative study of satellite images from the IR/Water Vapour/Visible channels, taken from Himawari 8 and GOES West Satellites (Credit: Dundee Satellite Receiving Station archive), following the path of EUSO SPB-1

- comparison of the pictures obtained with WRF models

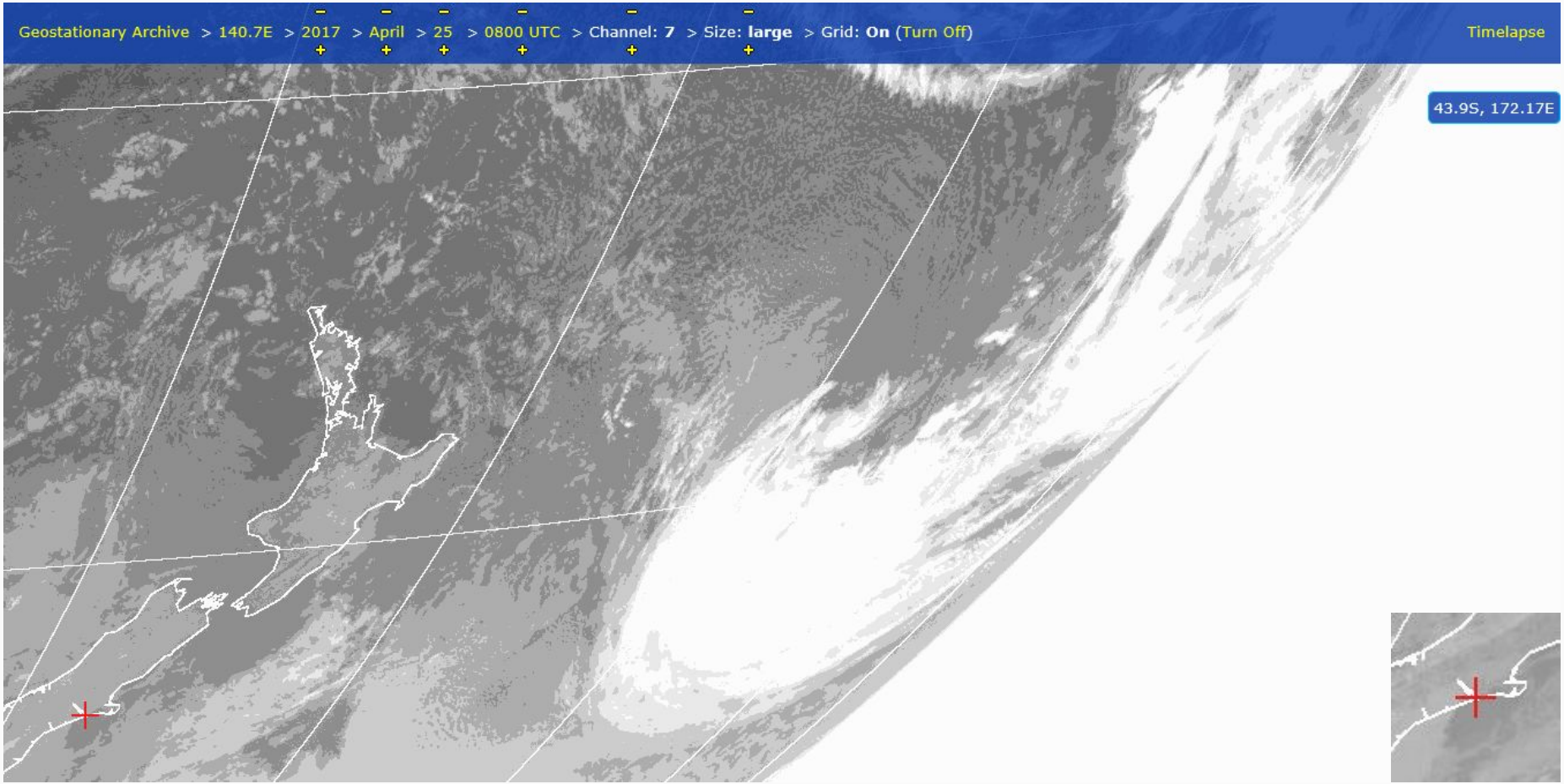
EUSO SPB-1 before the launch



EUSO SPB-1 trajectory

Cloud movements - Procedure

- download from Dundee Satellite Receiving Station archive of the pictures
- Image editing and zoom on Photoshop
- Qualitative study and description of the pictures
- Comparison of the study with the ARW model images



EUSO SPB-1 trajectory with related zoom, from 04/25/2017 to 05/01/2017 - Himawari 8 Satellite, Mid - IR Channel

Satellite Channels

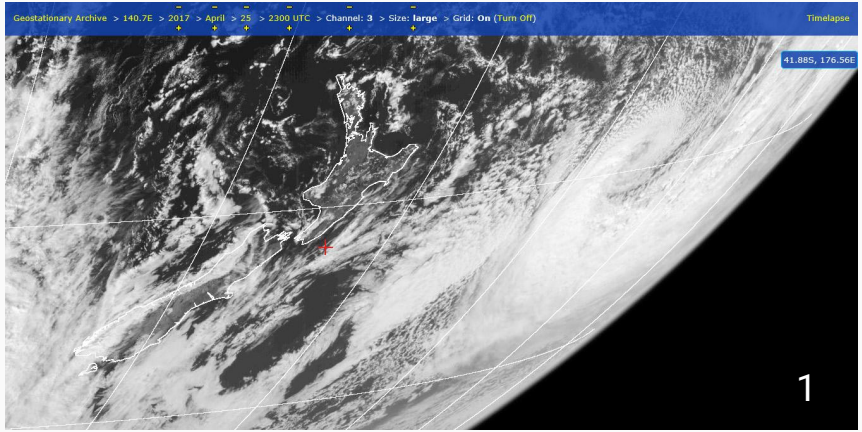
To have a better understanding of the cloud displacement and movement, the state of the atmosphere is studied using different acquisition channels of both satellites.

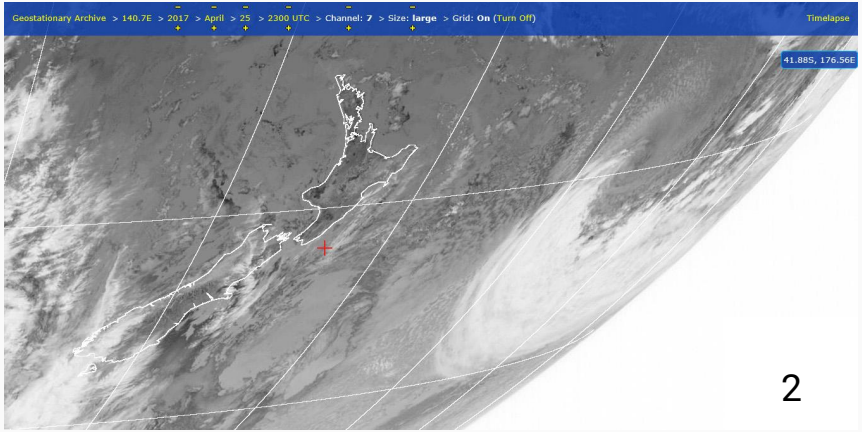
GOES West:

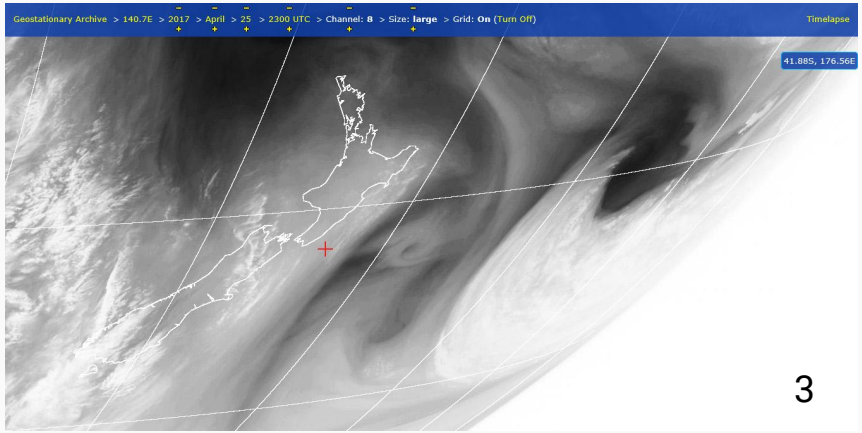
- Mid Infrared (3.8 - 4.0 µm)
- Mid IR/Water Vapour (5.8 - 7.3 µm)
- Thermal Infrared (10.2 - 11.2 µm)

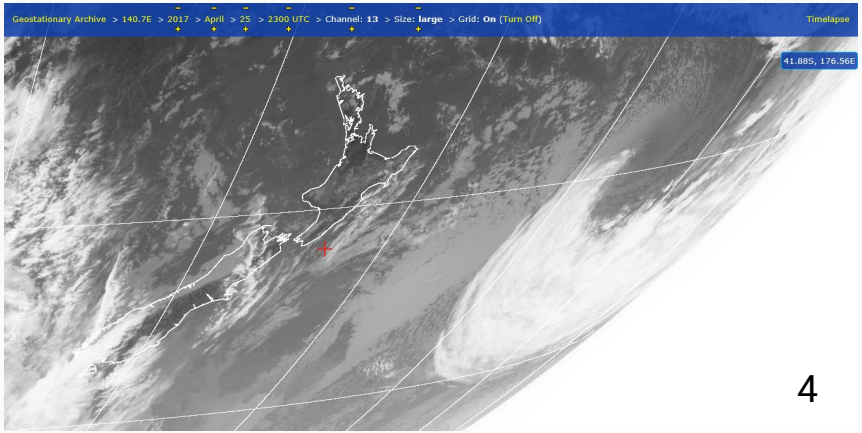
Himawari 8:

- Mid Infrared (3.74 - 3.96 µm)
- Mid IR/Water Vapour (6.06 - 6.43 µm)
- Mid IR/Water Vapour (6.89 - 7.01 µm)
- Mid IR/Water Vapour (7.23 - 7.49 µm)
- Thermal Infrared (10.3 - 10.6 µm)
- Red Visible (0.63 - 0.66 µm)









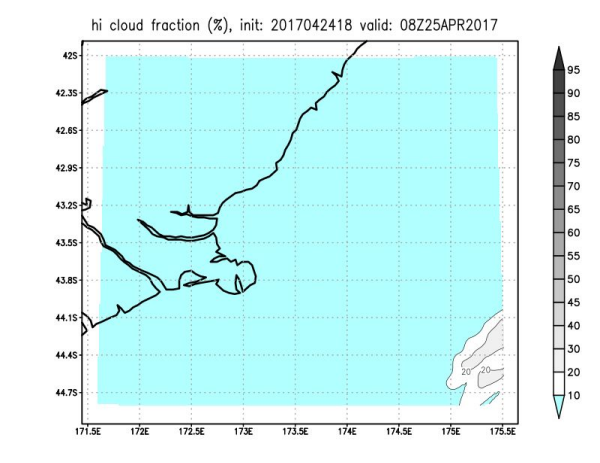
04/25/2017, 23.00 - Himawari 8 Satellite pictures - 1) Red Visible 2) Mid IR 3) Water Vapour 4) Thermal IR

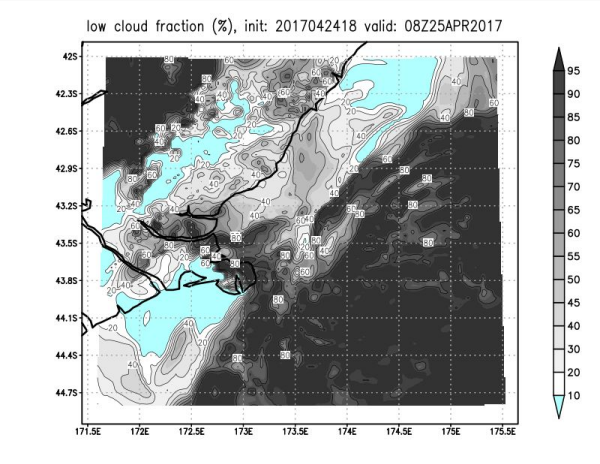
Satellite Images study - Mid IR channel

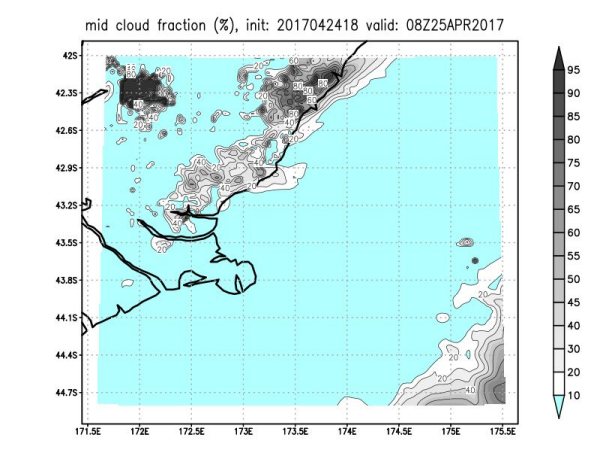
25/04 08.00 – 12.00	Predominance of low clouds, presence of medium clouds in the last hour.
25/04 13.00 – 18.00	Medium clouds dissolving in the first hours, predominance of scattered low clouds with wide openings throughout the period.
26/04 10.00 – 13.00	Predominance of low clouds to the S and medium - high clouds to the N, gradually dissolving. Wide openings, mostly in the balloon area.
26/04 14.00 – 17.00	Low scattered clouds mostly to the E. Wide openings.
27/04 07.00 – 12.00	Scattered high clouds to the NW moving towards E and dissolving.
27/04 13.00 – 17.00	Predominance of low - medium clouds moving towards NW.
28/04 06.00 – 12.00	Predominance of low - medium clouds, more openings to the NW as time goes on.
28/04 13.00 – 18.00	Scattered low clouds to the W dissolving throughout the period, scattered medium clouds to the NW at the end of the day, already dissolving.
29/04 05.00 – 11.00	High clouds to the NW moving towards the balloon and dissolving, leaving space to medium clouds. medium clouds to the SE throughout the period.
29/04 12.00 – 17.00	Medium clouds with wide openings in the central zone, dissolving at the beginning of the period and then covering the N and W zones.
30/04 06.00 – 11.00	Thick high clouds with few openings.
30/04 12.00 – 17.00	Like the previous period, more openings.
01/05 04.00 – 10.00	High clouds to the N and W, medium clouds to the SE, with more openings until 10, when high clouds seem to intensify.
01/05 11.00 – 17.00	Like the previous period, high clouds with few openings at the end of the day.

Model - Satellite comparison

25/04 08.00 – 12.00	Good prediction of the model on low clouds, differences in the first hour on the medium clouds channel.
25/04 13.00 – 18.00	Good prediction of the model on the low clouds, overestimation of the high clouds in the last hours.
26/04 10.00 – 13.00	Overestimation of the model on the low clouds. Presence of medium clouds in the model not seen in the satellite images.
26/04 14.00 – 17.00	Like the previous period.
27/04 07.00 – 12.00	Overestimation of the model on the low clouds, underestimation of low and high clouds in the first hours.
27/04 13.00 – 17.00	Overestimation of the model on the low clouds, presence of medium clouds to the SE not seen from the model.
28/04 06.00 – 12.00	Sky covered by thick low clouds dissolving throughout the period, overestimation of the model which anyway shows the fade-out.
28/04 13.00 – 18.00	Like the previous period, overestimation of the model on the low channel, still showing the fade-out.
29/04 05.00 – 11.00	Model overestimates low clouds and underestimate, in the first hours, the high clouds. Possible medium clouds not seen from the model.
29/04 12.00 – 17.00	Like the previous period, overestimation of the model on the low clouds. Medium clouds not shown by the model, which anyway well predicts the movements and fade-out of the high clouds.
30/04 06.00 – 11.00	Good prediction by the model showing the sky completely covered by low and high clouds, slightly overestimated in the last hours.
30/04 12.00 – 17.00	Like the previous period, model still overestimating high clouds.
01/05 04.00 – 10.00	Good prediction of the model, showing the sky completely covered by low and high clouds.
01/05 11.00 – 17.00	Like the previous period.


hi cloud fraction (%), init: 2017042418 valid: 08Z25APR2017


low cloud fraction (%), init: 2017042418 valid: 08Z25APR2017


mid cloud fraction (%), init: 2017042418 valid: 08Z25APR2017

Conclusion and future work

AMON

- First calibration of the detector obtained
- Necessity to have more balanced equipment
- Creation of a worldwide AMON network, with similar detectors positioned in strategic areas of the Earth

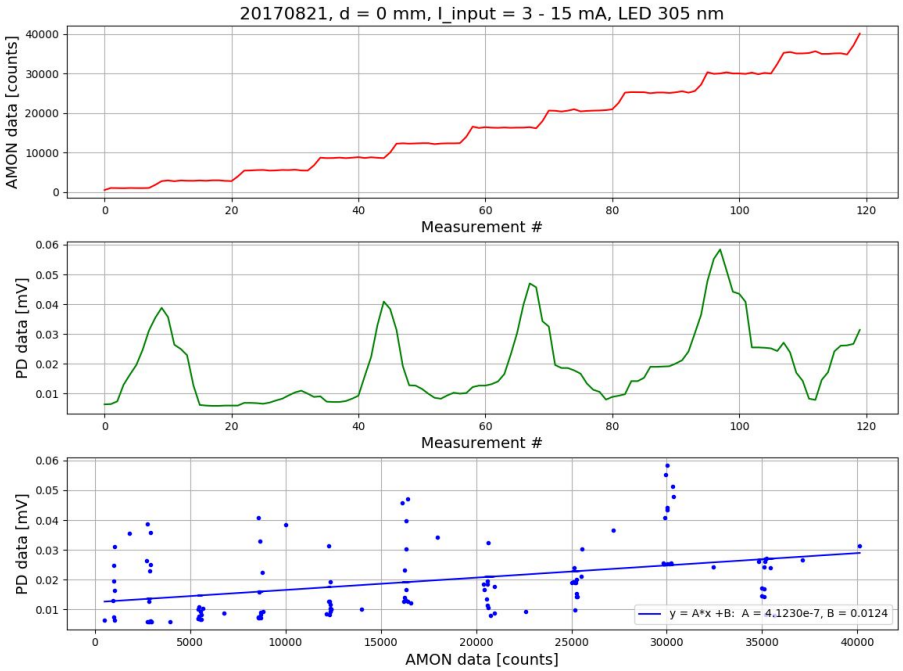
CLOUD DISTRIBUTION and MOVEMENTS

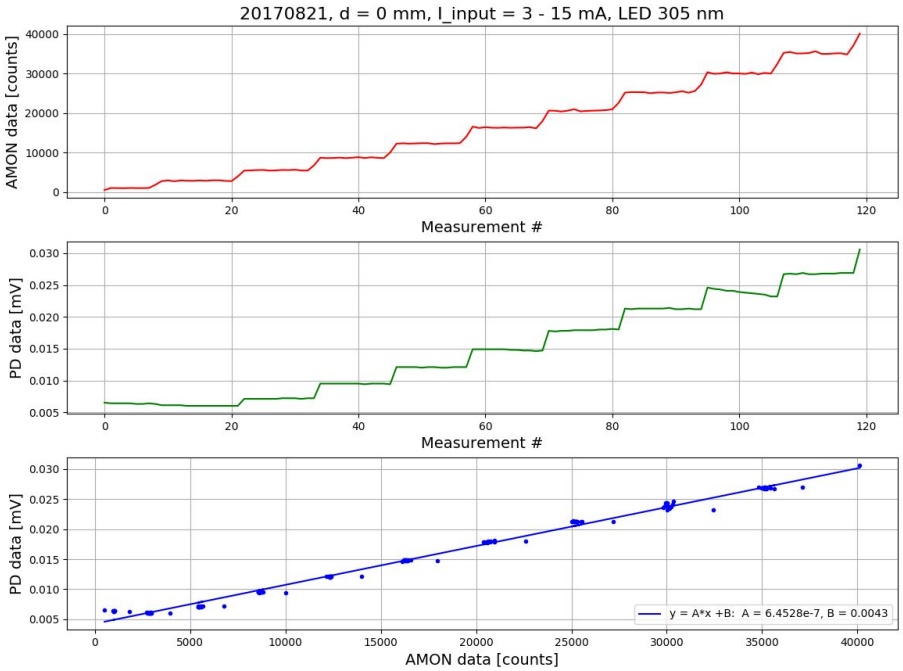
- ARW model fairly describes cloud presence and movements
- Necessity to enlarge photo database
- Possibility to use numerical satellite raw images
- Comparison with other WRFs
- Comparison with EUSO SPB1 data

I’d like to thank everyone here today for the attention and, in particular, my mentors Prof. Manfrin and Prof. Bertaina, Prof. Pavol Bobik and Doc. Simon Mackovjak for their assistance during all the process of my bachelor.

AMON switched on

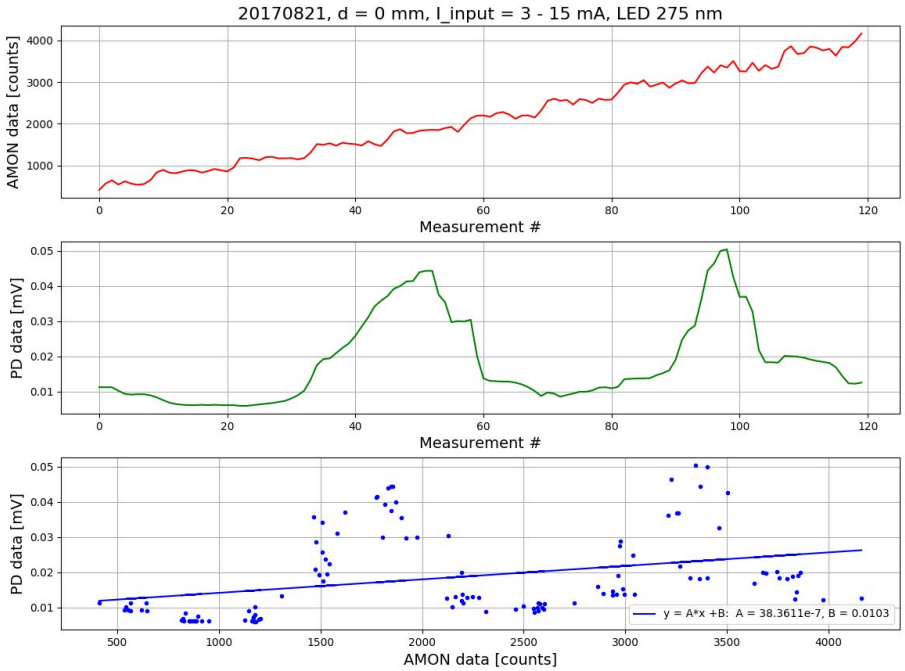
AMON switched off





AMON Calibration - Wavelength efficency: 305 nm

AMON switched on



AMON switched off