Combination of ground and satellite observations associated to the August 5, 2018 Bayan Earthquake

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on behalf of the CSES-Limadou Collaboration

Lithosphere-atmosphere-ionosphere coupling: the MILC Model*

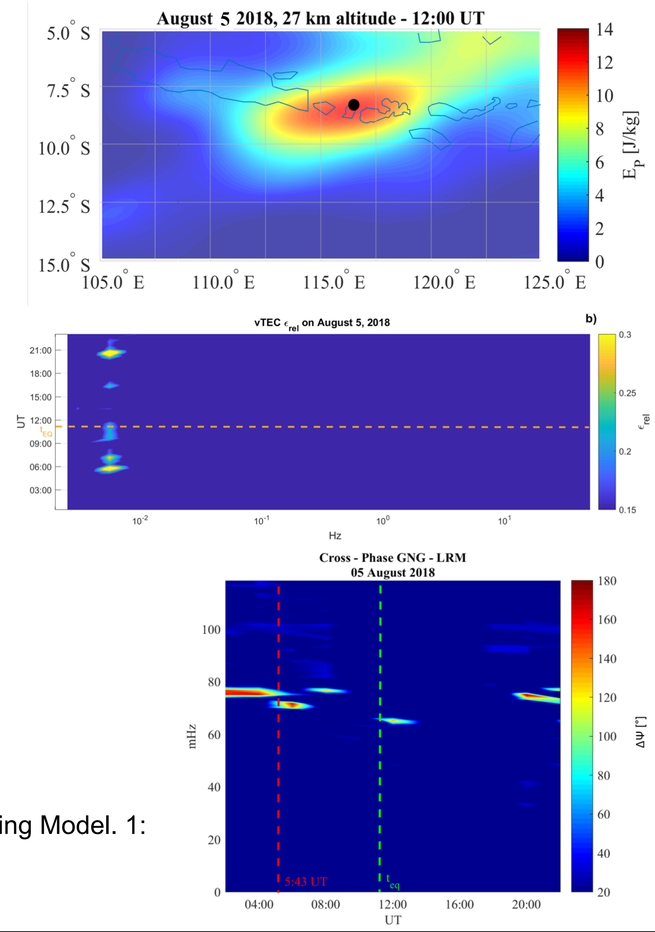
The MILC model provides a quantitative description of how a seismic events can impact the ionosphere

- Atmospheric acoustic gravity waves (AWG), triggered by temperature/pressure gradient and ground motion propagates upwards towards the ionosphere
- Observables are: vertical atmosphere temperature profiles, vertical-Total Electron Content (vTEC) , geomagnetic Field Line Resonances (FLR) variations

Combination of ground based and satellite data:

1. Temperature profiles from ERA-5 (European Centre for Medium-Range Weather Forecasts)
2. vTEC from International GNSS Service and UNAVCO consortium
3. FLR from ground magnetometer; observations from a pair of magnetometers slightly separated in latitude and suitably aligned along the same magnetic meridian

*[M.Piersanti et. al., Magnetospheric–Ionospheric–Lithospheric Coupling Model. 1: Observations during the 5 August 2018 Bayan Earthquake, Remote Sens. 2020, 12, 3299]



August 5 2018 Bayan Earthquake

Mw 6.9 earthquake Lombok, Indonesia at 11:46 UT
Epi-center: North Lombok Regency at 8.28ºS 116.4ºE

Observation at the time of the EQ:

- AGW with ~7km vertical wavelength
- vTEC perturbation with ~97s periodicity
- Step increase in FLR seconds after EQ

Observation ~6h before the EQ:

- AGW with ~3km vertical wavelength
- vTEC perturbation with 112.3±5s periodicity
- ULF EM wave, at ~180 Hz, propagating upwards between ~5:40 UT and ~5:46 UT

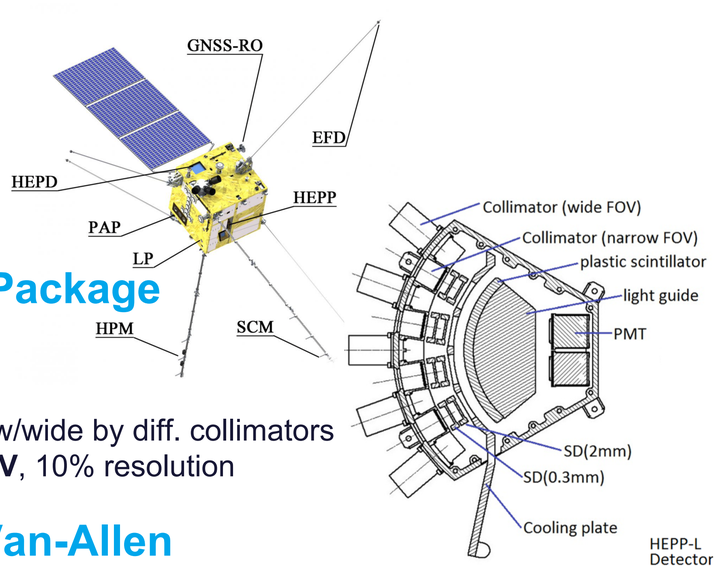
Magnetospheric–Ionospheric–Lithospheric Coupling (M.I.L.C.) model:

1. AGW generated around EE, propagates through the atmosphere
2. AGW in ionosphere created disturbance in plasma, results in EM wave
3. EM wave interacts with magnetospheric field changing the FLR eigenfrequency.

*[Carbone et al., A mathematical model of lithosphere – atmosphere coupling for seismic events. Sci Rep **11,** 8682 (2021)]*

CSES01 Satellite

- Launch February 2nd, 2018
- 9 payloads on board
- Sun-synchronous
- ~507km altitude

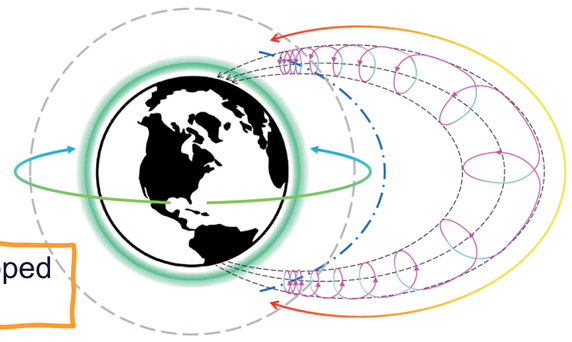


High Energy Particle Package (HEPP-L)

- Silicon telescope array
- 9 channels, grouped into narrow/wide by diff. collimators
- Electron energy range **0.1-3MeV**, 10% resolution

Trapped particles in Van-Allen Belts

- Gyromotion of charged particles along magnetic field lines
- Bouncing between conjugate points
- Longitudinal drift Est wards for negatively charged particles



Goal: Detect correlations between trapped particles flux variation and EQ

Electron Flux Analysis

in invariant parameter space

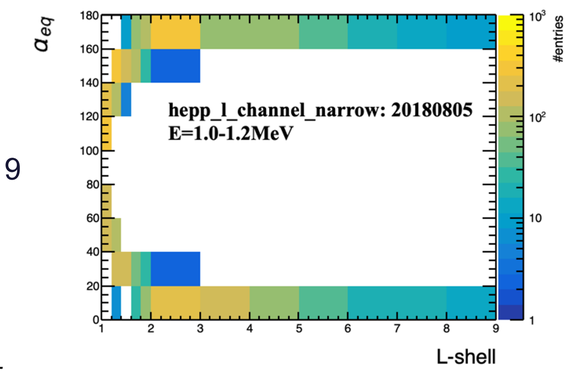
1. Electron flux measured in 16 energy ranges, associated to 12 L shell and 9 equatorial pitch angle α intervals

$$\alpha_{eq}=\begin{cases} \operatorname{asin}\left(\sin(\alpha_{loc})\sqrt{\frac{B_{eq}}{B}}\right), \alpha_{loc} \le \frac{\pi}{2} \\ \pi - \operatorname{asin}\left(\sin(\alpha_{loc})\sqrt{\frac{B_{eq}}{B}}\right), \alpha_{loc} > \frac{\pi}{2} \end{cases}$$

1. Determination of background, threshold by selecting the highest 1% fluxes (RMS99), per energy/L/α bin
2. Time clustering of highest 1% electron flux measurements in L/α.

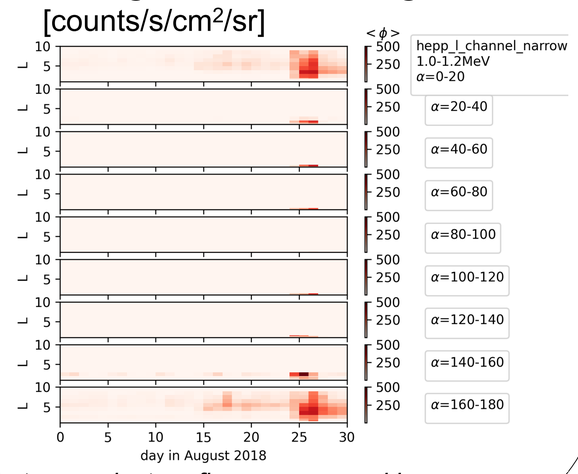
Observation of geomagnetic storm August 25:

- Sensitive down to the lowest L-shells
- Sensitive overall energy range



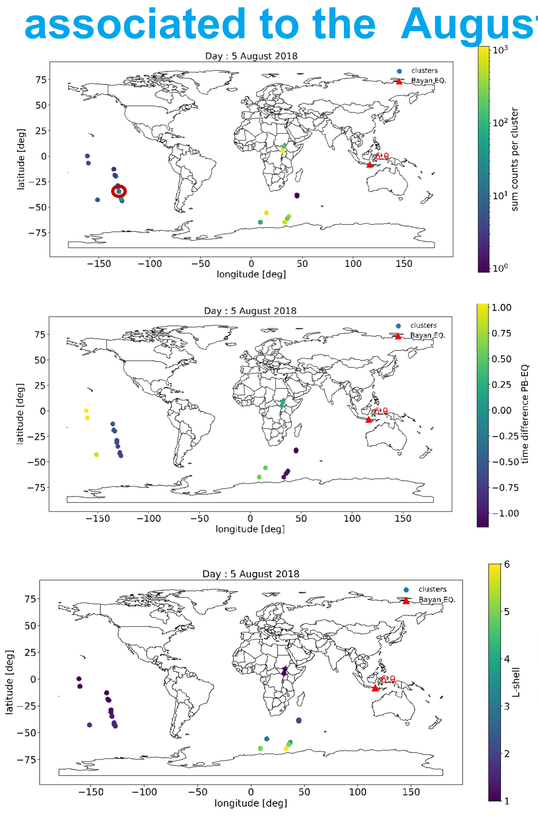
Average electron flux August 25 2018

[counts/s/cm²/sr]



[R. Battiston et. al., First evidence for correlations between electron fluxes measured by NOAA-POES satellites and large seismic events, Nucl.Phys.B 243–244 (2013) 249–257]

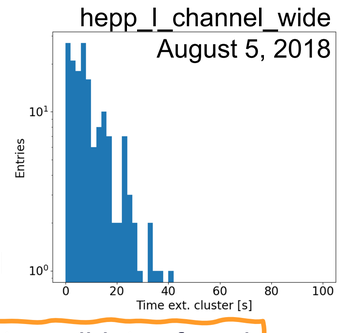
First look at Particle Burst (PB) candidates associated to the August 5, 2018 Bayan EQ



Clusters/Particle Burst (PB) candidates are build on:

- 1% highest fluxes
- using density-based spatial clustering algorithm
- Minimum of 2 fluxes above threshold
- 10s time window

Time extension of clusters not limited by window size, but depends on found fluxes above threshold



~35 Particle Burst candidates found within ±1.5h

- search for correlation will take drift time and mirror bouncing into account..

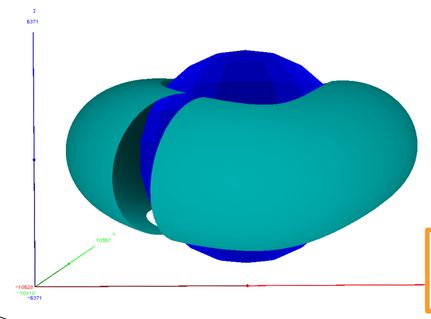
[R. Battiston et. al., First evidence for correlations between electron fluxes measured by NOAA-POES satellites and large seismic events, Nucl.Phys.B 243–244 (2013) 249–257]

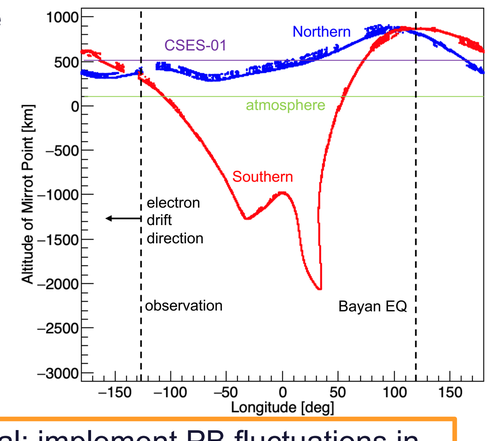
Summary

- The MILC model provide a coherent, quantitative description of the sequence of physical phenomena, starting from AGWs and reaching the magnetosphere, which can be observed by ground and satellite instrument
- The HEPP payload of the CSES01 satellite detects low energy electrons that belong to the trapped electron population of the Van-Allen belts
  We developed an analysis chain to build PBs in order to search for correlations with seismic events; fine-tuning and testing of the clustering algorithm is ongoing

Example – Search for PB/EQ spatial correlation

- Back-tracing of electrons sampled from the PBs along L-shell to search for spatial correlation with seismic events
- Select drft time correllated PB/EQ pairs





Final goal: implement PB fluctuations in the analysis chain and in the MILC model