Cosmic ray variations and time lag during high solar activity days with geomagnetic storms

A. Mubashir*, A. Ashok**, A.G. Bourgeois**, A.G.U. Perera,* A. Mikler**, C. Tiwari***, E. H. Mudiyanselage*, E. Potdevin*, M. Connors*, M. Sarsour*, P. Martens*, T. Hettiarachchi*, V. M. Sadykov*, X. He*, Y.T. Chien*
* Department of Physics and Astronomy, ** Department of Computer Science, ***Department of Geosciences, Georgia State University

Abstract

In May 2024, a powerful geomagnetic storm occurred, causing a significant drop in cosmic ray activity, known as a "Forbush decrease." This storm, along with another in March 2024, gave researchers an opportunity to study how these disturbances affect cosmic rays—tiny particles that come from space and hit the Earth's atmosphere. In our study, we used four detectors: two muon detectors and two neutron monitors, placed in different locations to measure cosmic rays. After correcting for factors like atmospheric pressure and temperature, we found clear patterns in how cosmic rays changed during these storms. Interestingly, there was a time delay, or "time lag," between when muon and neutron detectors recorded changes, showing a delay of about two hours. We also looked at how much cosmic rays dropped before and during the storms, with the biggest decrease happening around six hours before the storms peaked. By comparing cosmic ray data with changes in the Earth's magnetic field (measured by Disturbance storm tine (Dst index)) and solar wind, we found a time lag of 2-3 hours between cosmic ray changes and the Dst index, and 2-4 hours between cosmic rays and solar wind speed. This time lag is important because it suggests that cosmic rays might be able to give us an early warning before geomagnetic storms occur. If we can predict these changes in the Earth's magnetic field in advance, it could help protect satellites, power grids, and other technology affected by solar storms. In simple terms: We're trying to see if cosmic rays can help us predict geomagnetic storms a few hours before they hit, which could be really valuable for preparing in advance.

Introduction and Motivation

- High Solar activity can produce geomagnetic storms which can cause radio and GPS blackouts and damage spacecraft electronics.
- Interplanetary space is highly affected by solar magnetic activity resulting in cosmic rays flux modulations in space and on earth
- Deploy many efficient and affordable cosmic ray detectors across the world to monitor changes in Space and Earth weather
- Demonstrating the sensitivity of our high elevation detectors and building more detectors to be distributed in other countries.
- The study of correlation between muon counts and space parameters is essential for better understanding and mitigating the impacts of space weather on spacecraft, astronauts, and terrestrial infrastructure.

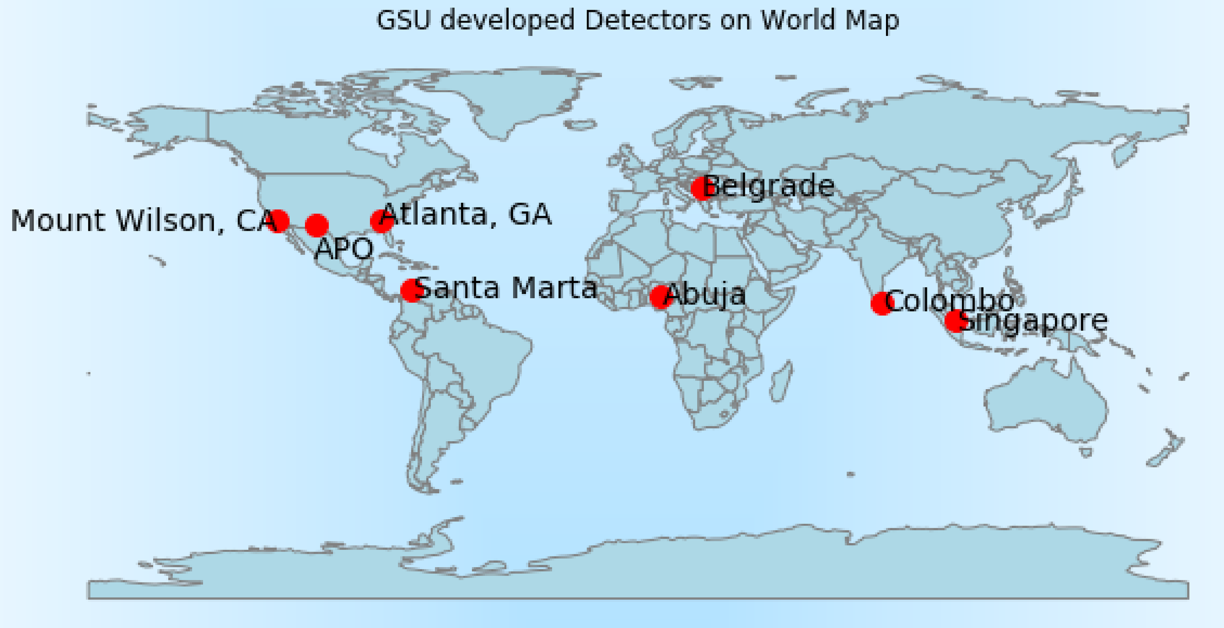


Fig1. Global Network of Cosmic Ray Detectors for Space and Terrestrial Weather Observation (gLOWCOST) developed by GSU cosmic ray team

Detector Setup and Data Sources

Cosmic ray data sources

- Portable, low cost GSU developed muon detectors: CHARA, Mount Wilson Observatory, CA ; Apache Point Observatory, NM
- Neutron detectors: Newark, DE* and Oulu, Finland*

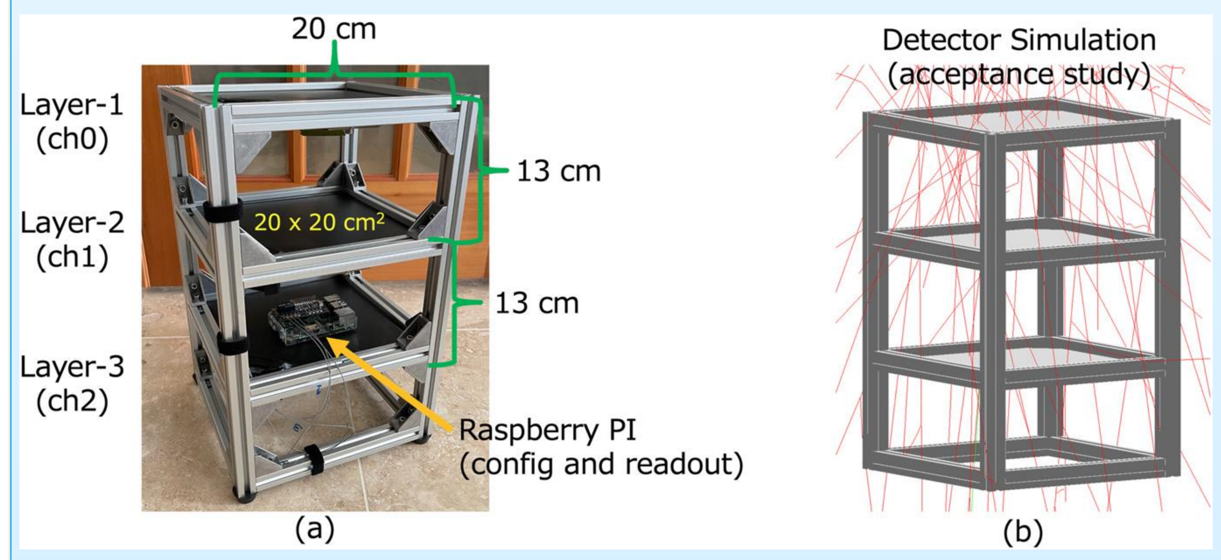


Fig2. (a) The baseline muon detector setup with adjacent scintillator layers (b) Detector acceptance study using GEANT4 simulation

http://www01.nmdb.eu/nest/

Detectors Cross Correlation and Time lag

Cross-correlation and time lag analysis between muon and neutron detectors help identify relationships, synchronize events and to quantify which type of particle detection tends to precede the other.

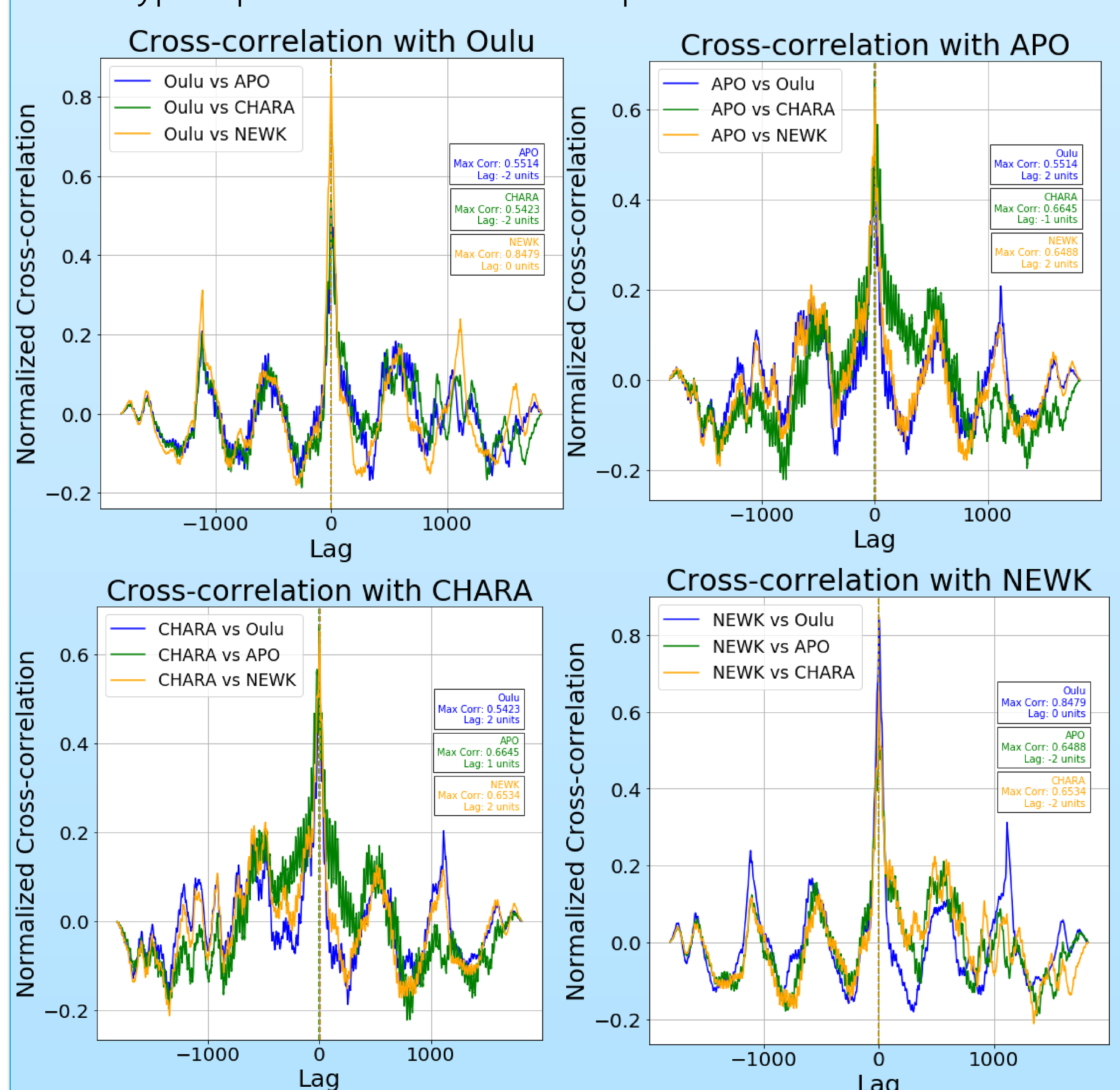


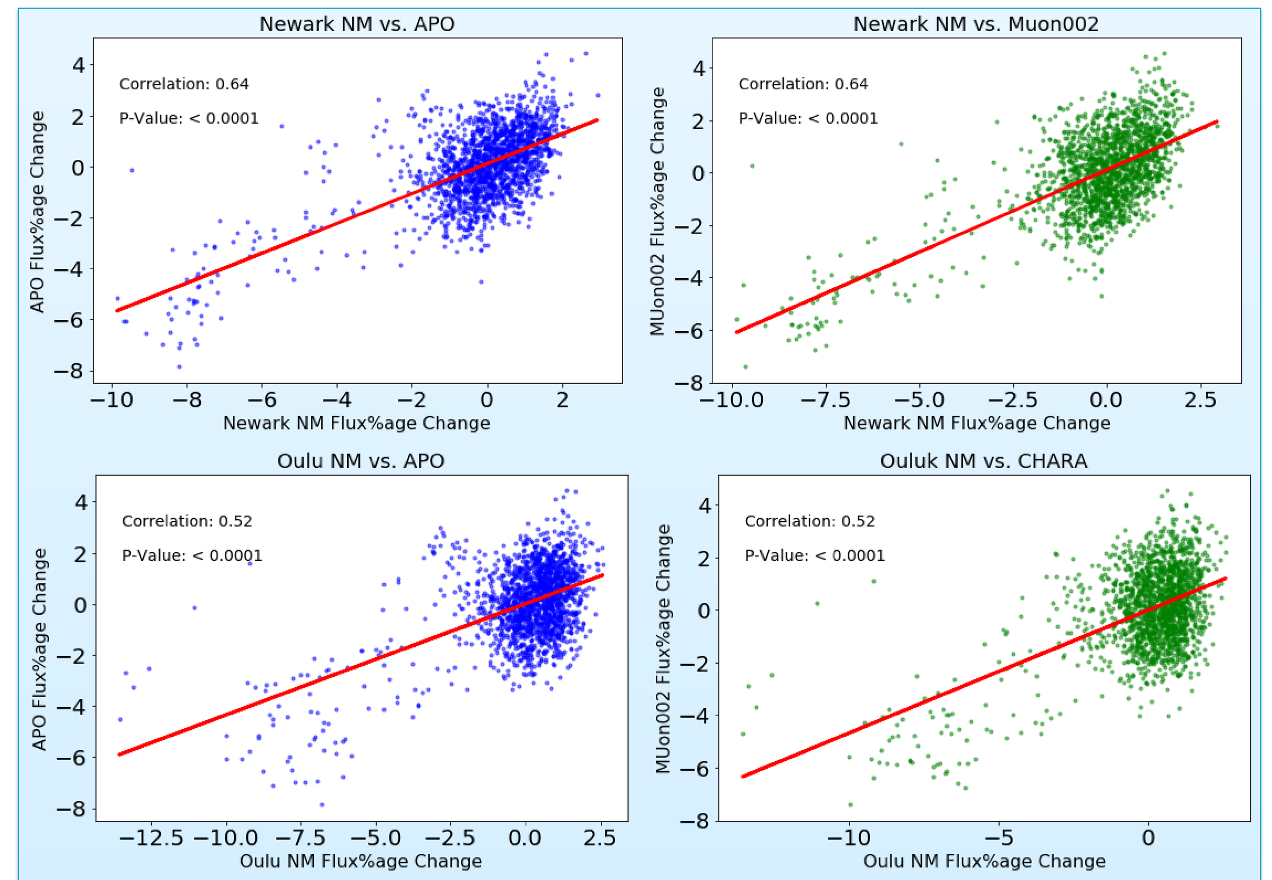
Fig3. . Cross correlation for Oulu, NEWK, CHARA and APO detectors using time lag Analysis

$$(F \star G)[i] := \sum_{j=-\infty}^{\infty} F^*[j]G[i+j].$$

$$\tau_{\text{delay}} = \arg\max \left[(F \star G)[i] \right] \Big|_i .$$

$$cc(k) = \frac{\sum_{i=1}^{n-k}(Y_i - \bar{Y})(X_{i+k} - \bar{X})}{\sqrt{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2}} .$$

Detectors Correlation and Scatter plots



Geomagnetic Storms and Cosmic Ray Flux

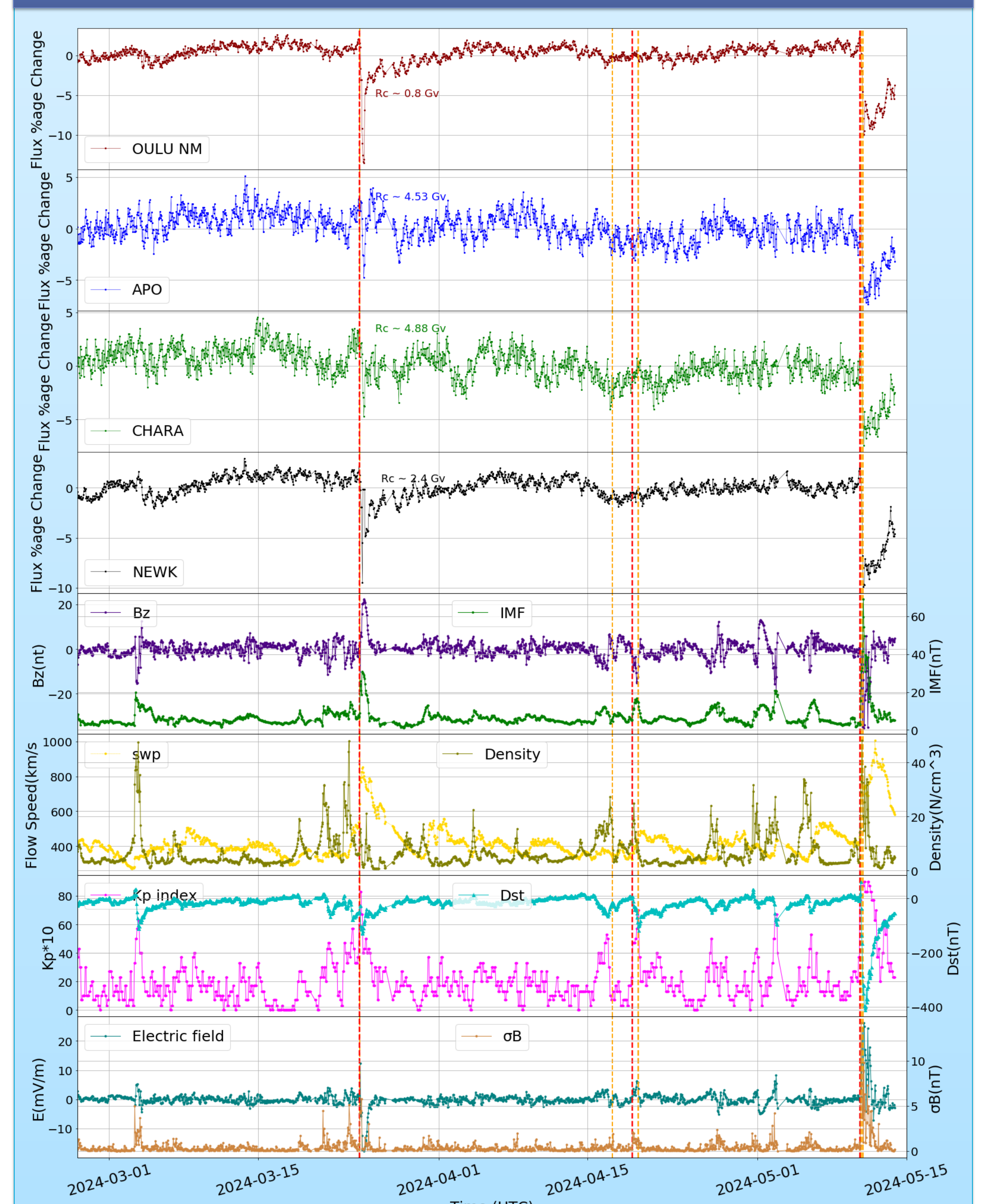


Fig4. Time series of cosmic ray flux and the space parameters . The vertical red dashed line marks the times of the geomagnetic storm at 2024-03-24T12:00:, 2024-04-19T18:00 and 2024-05-10T15:00, while vertical orange lines mark the Interplanetary shocks.

Transient Rates

Table1. Transient Rates of Muon and Neutron Flux Percentage Change at the Times of Geomagnetic Storms

Detectors	At time of storm (2024-03-24 14:00:00+00:00)			At time of storm (2024-05-10 15:00:00+00:00)		
	+/- 3 hrs	**+/-6 hrs**	**+/-12 hrs**	**+/- 3 hrs**	**+/-6 hrs**	**+/-12 hrs**
Newark	-0.58	-0.86	-0.25	-0.06	-0.59	-0.29
Oulu	-0.85	-1.04	-0.23	-0.22	-0.42	-0.26
APO	-0.23	-0.28	-0.1	0.20	-0.25	-0.20
CHARA	-0.24	-0.32	-0.18	0.5	-0.31	-0.21

Transient Rates: how quickly the flux changes before and immediately after geomagnetic storms.

$$\text{Slope} = \frac{y_2 - y_1}{x_2 - x_1}$$

Time lag with Space Parameters

Fig5. Cross correlation time lag for Oulu, NEWK, CHARA and APO detectors vs space parameters from Feb2024-May2024

Variability of Cosmic Rays and Dst

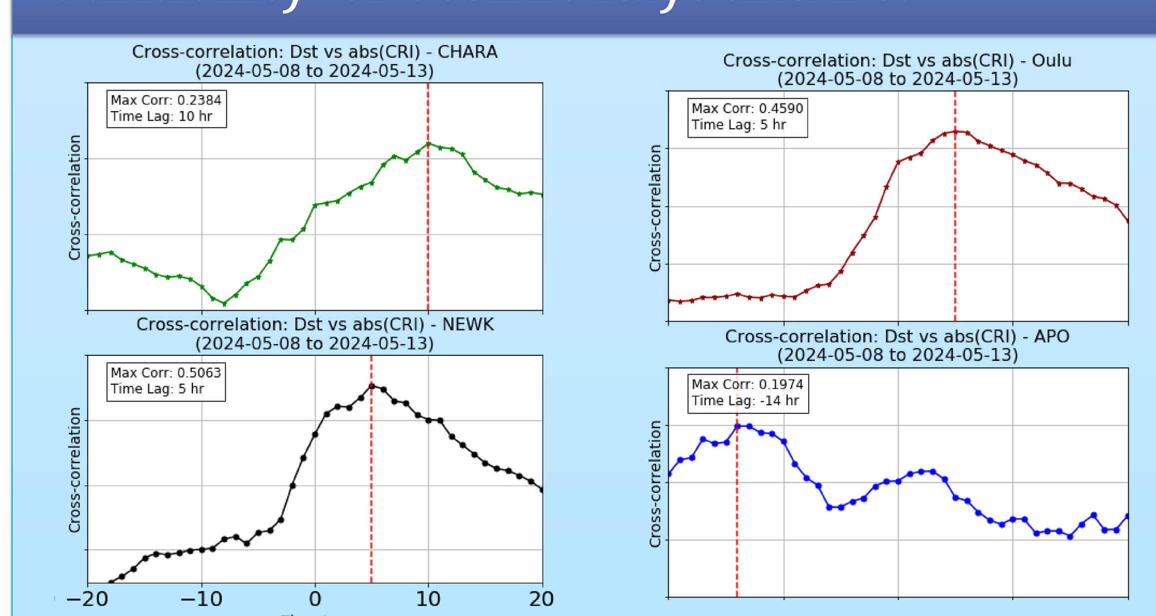


Fig.6. Cross correlation for absolute differences in CRI values = abs (CRI (i)- CRI (i-1)) at the time of geomagnetic storm.

Summary and Outlook

- Srong correlation between muon and neutron detectors, confirms the accuracy of the muon network. (gLOWCOST).
- Significant decreases in flux during geomagnetic storms helping us understand how solar activity affects Earth's magnetic field and contributes to our goal of developing better predictive models for geomagnetic storms, which could help protect technology and infrastructure
- Future plans include expanding detector coverage from the equator to the poles to monitor cosmic ray variations globally, providing a more complete picture of how solar storms impact different regions.