SOLAR MAGNETIC POLARITY EFFECT ON NEUTRON MONITOR COUNT RATES: COMPARING LATITUDE SURVEYS AND ANTARCTIC STATIONS

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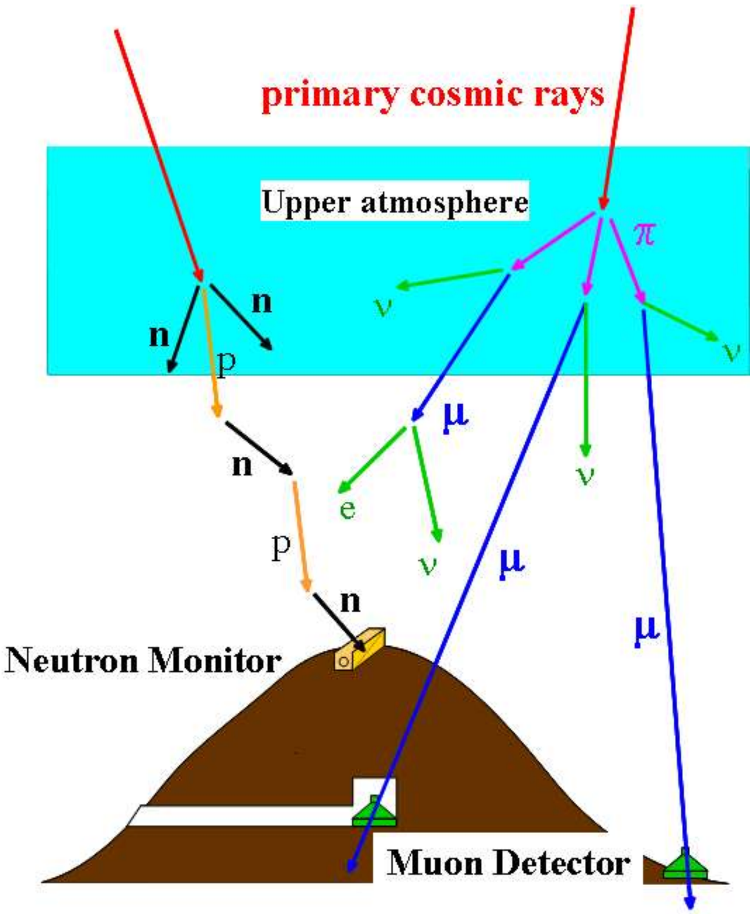
OUTLINE

- Introduction
  - Cosmic rays
  - Solar modulation
  - Crossover spectrum
- Observation
  - Ship-borne NM
  - Mawson Neutron Monitor
- Results

OBSERVATION OF COSMIC RAYS WITH GROUND-BASED DETECTORS



- Ground-based detectors measure byproducts of the interaction of primary cosmic rays with Earth's atmosphere
- Two common types:

  Neutron Monitor

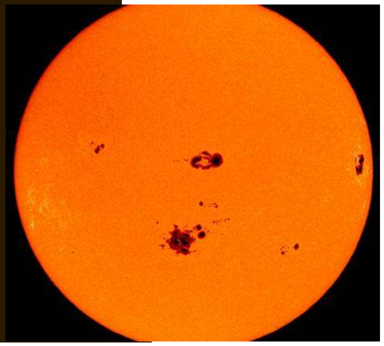
  Typical energy of primary: ~1 GeV for solar cosmic rays, ~10 GeV for Galactic cosmic rays

  Muon Detector

  Typical energy of primary: ~50 GeV for Galactic cosmic rays (surface muon detector) and greater for underground muon detector

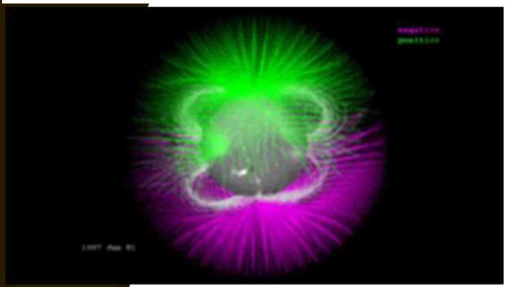
(Adapted from Ground-Based Cosmic Ray Detectors for Space Weather Applications slide, Bieber, 2011)

SOLAR MODULATION



Credit: NASA

Credit: NASA/GSFC/PFSS



(Poopakun et al., 2021)

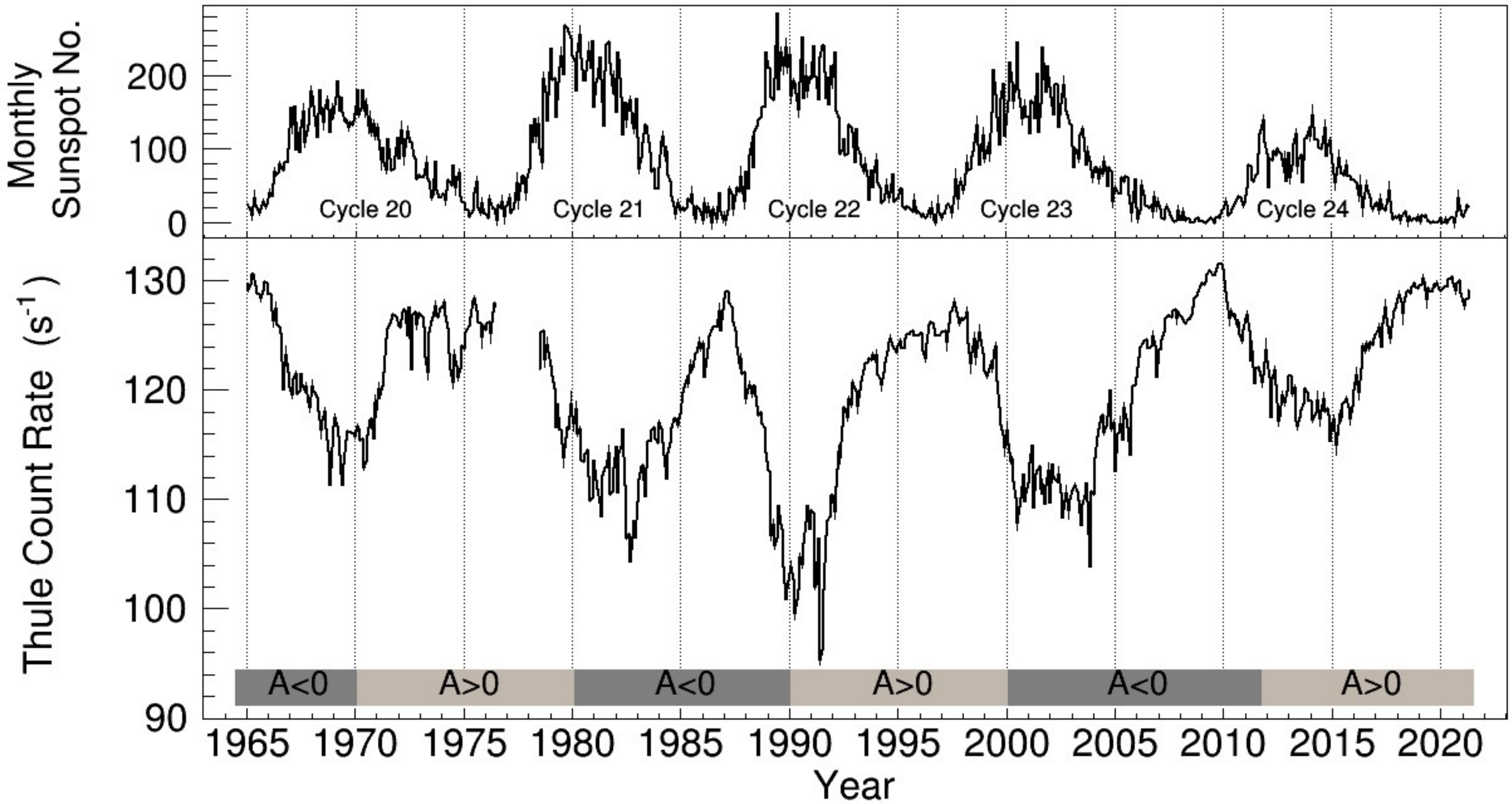


Fig. Solar modulation : As solar activity rises (top panel, Source: WDC-SILSO Royal Observatory of Belgium, Brussels), the pressure-corrected count rate recorded by the neutron monitor in Thule decreases (bottom panel, Source: Bartol Research Institute, University of Delaware, USA). The solar magnetic polarity reversal can be seen between positive (denoted by A > 0) and negative (denoted by A < 0)

CROSSOVER

(Moraal et al.,1989)

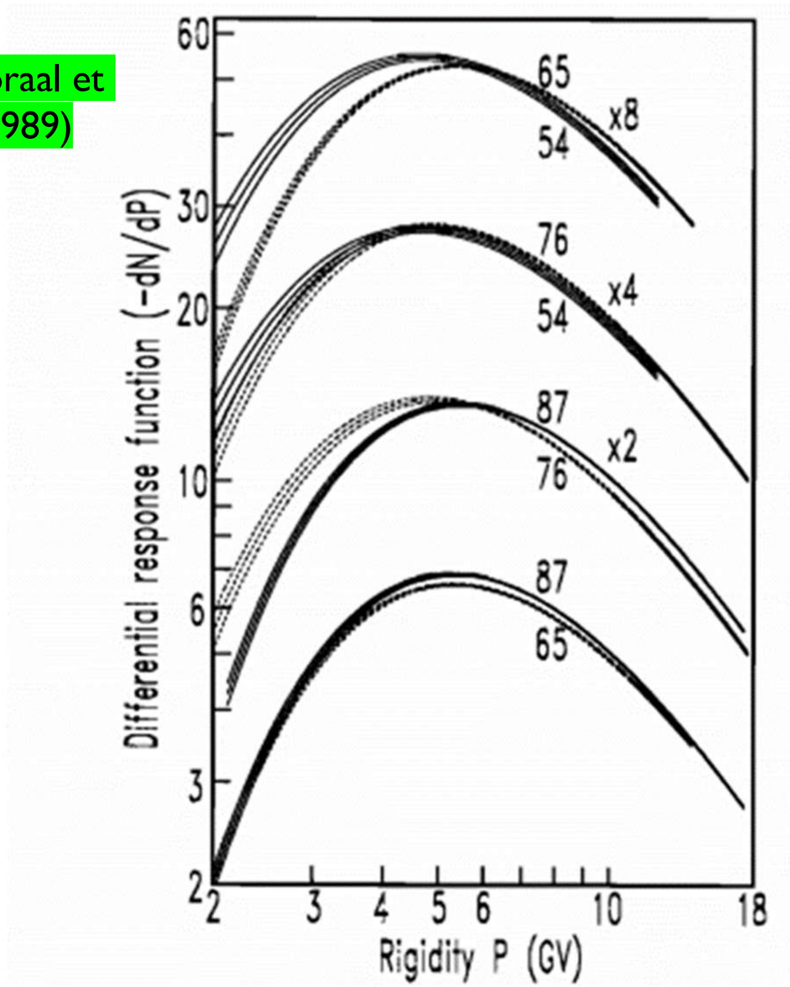


Fig. Differential response functions (Moraal et al.,1989)

(Nuntiyakul et al., 2014)

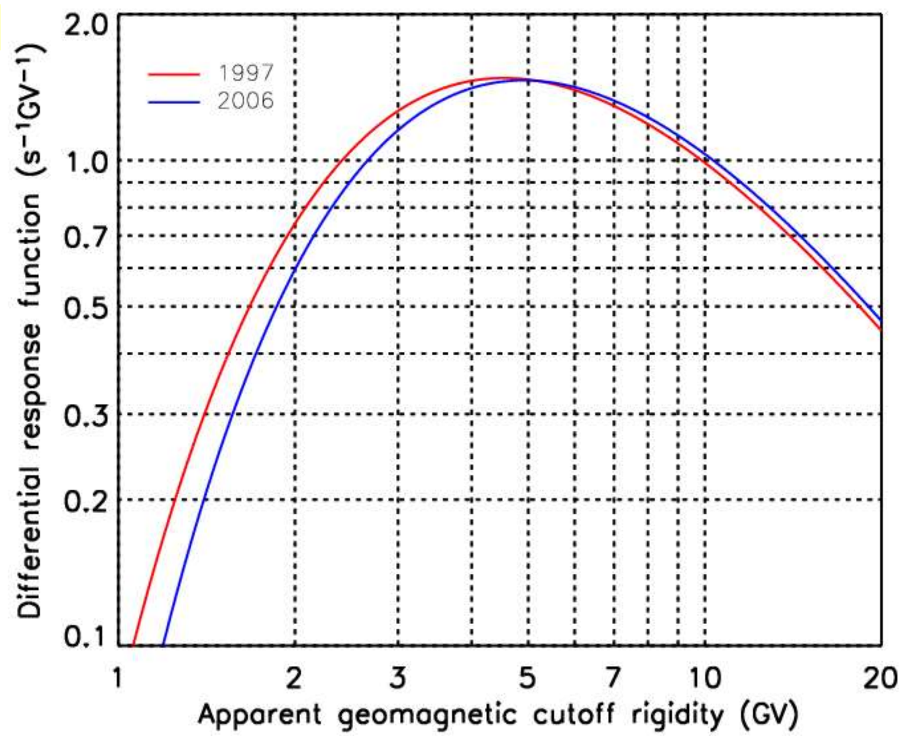


Fig. Differential response functions for two survey years, near solar minimum, of opposite polarity and similar modulation level. A crossover is apparent at 4.9 GV. (Nuntiyakul et al., 2014)

LATITUDE SURVEY

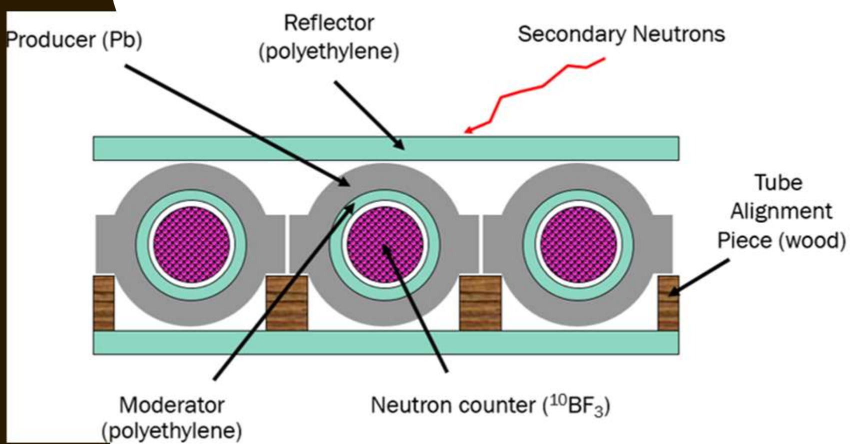


Fig. Standard Neutron Monitor (NM64)

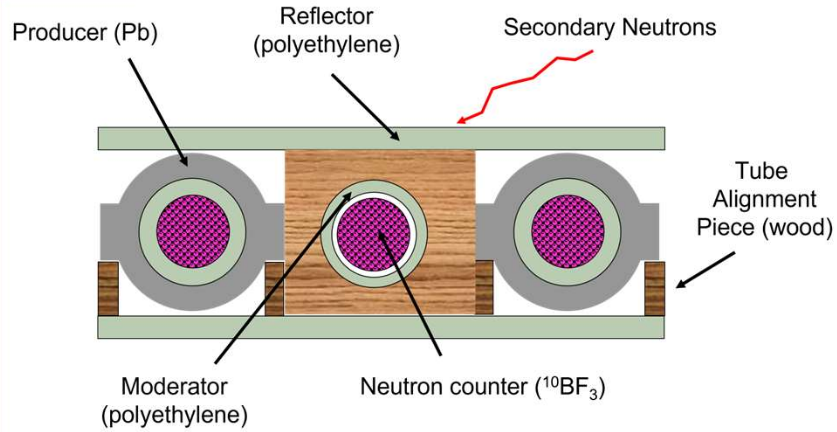


Fig. Semi-leaded Neutron Monitor

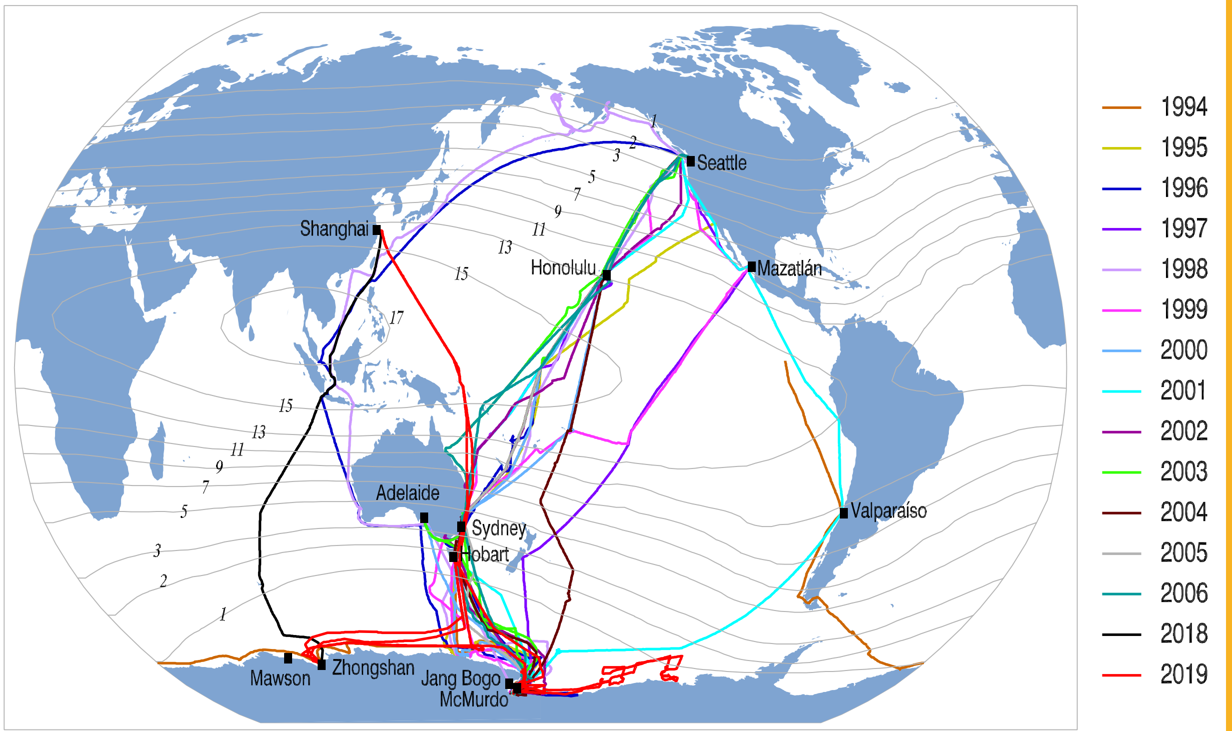


Fig. The track of the ship-borne neutron monitor latitude surveys for 1994-2007, and 2018-2019

GEOMAGNETIC CUTOFF RIGIDITY

- Rigidity is defined as momentum per unit charge

magnetic field → momentum

$$P = Br = pc/q$$

rigidity — gyroradius — charge

- The magnetic field of the Earth excludes particle below a well-defined rigidity at any given location known as cutoff rigidity

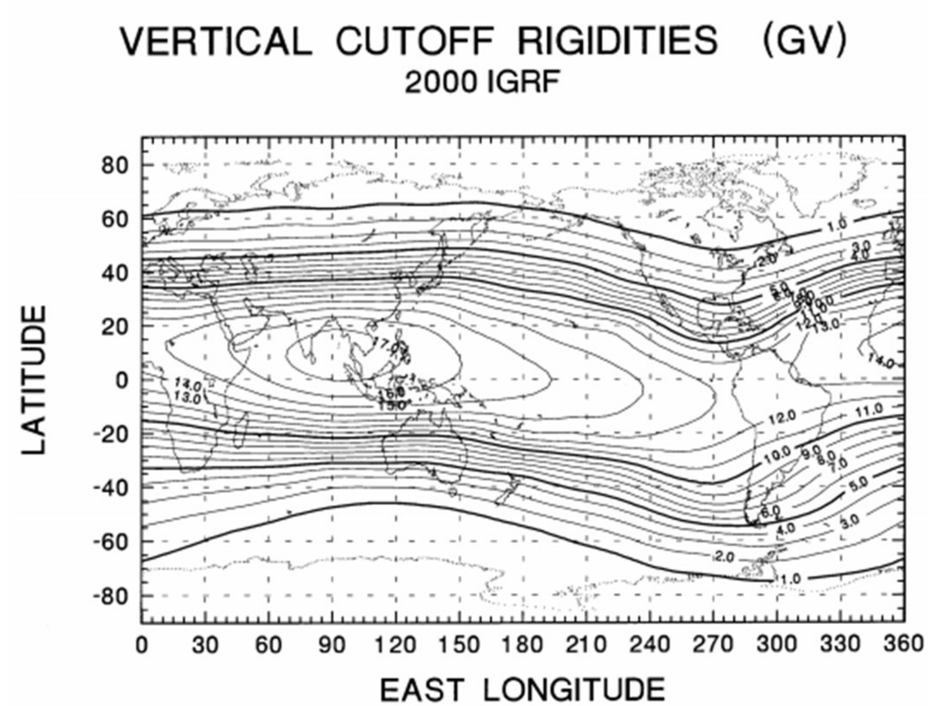


Fig 7. Rigidity contours for vertical geomagnetic cutoff rigidities for epoch 2000. (Smart & Shea, 2006)

Vertical cutoff rigidity
→ the minimum rigidity for a vertical incident particle

Apparent cutoff rigidity
→ an estimate rigidity for each possible direction of incident particle

CUTOFF-RIGIDITY

- $R_c = [M \cos \lambda^4]/\{r^2\ [\ 1 + (1 - \sin \epsilon \sin \xi \cos \lambda^3\ )^{1/2}]^2\}$

Where

- R_c is the geomagnetic cutoff rigidity
- λ is the latitude
- M is the magnitude of the dipole moment
- r is the distance from the dipole center in centimeters
- E is the angle from zenith
- ξ is the azimuthal angle measured clockwise from magnetic north

(Smart and Shea, 2003)

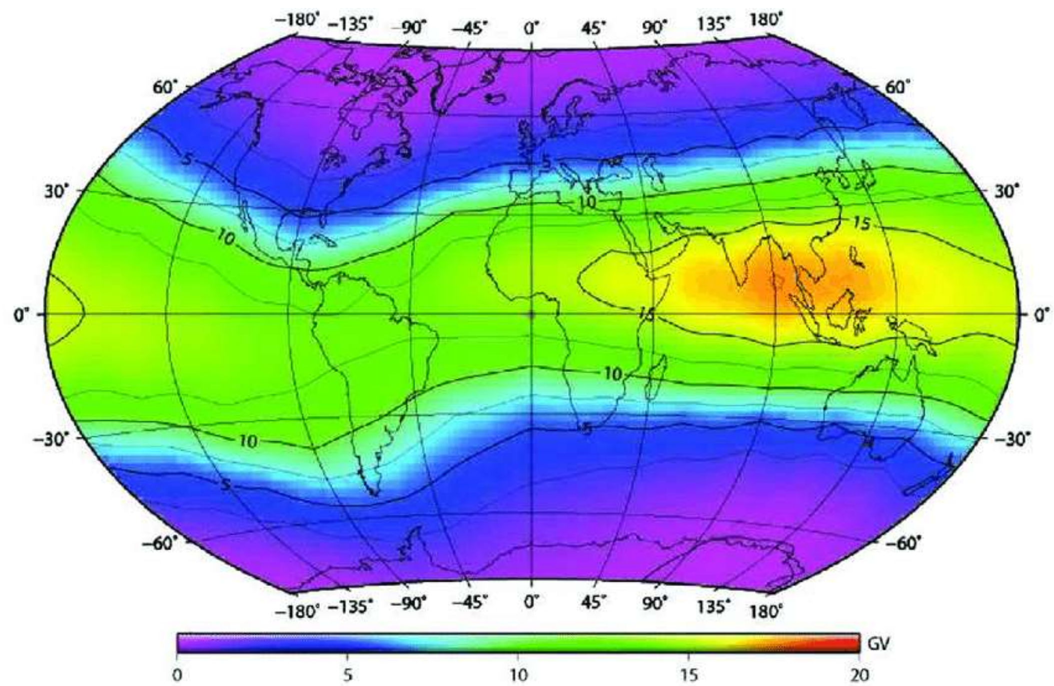
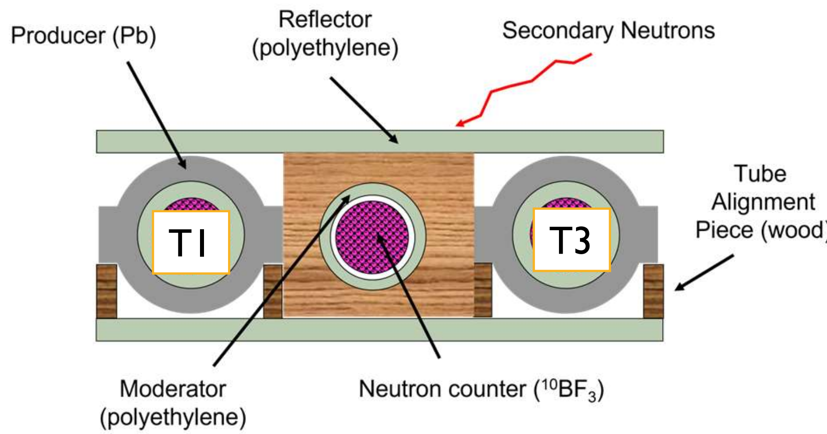


Fig 11. The effective vertical geomagnetic cutoff-rigidity (Nevalainen, Usoskin & Mishev, 2013)

SEMI LEADED TO 3NM64



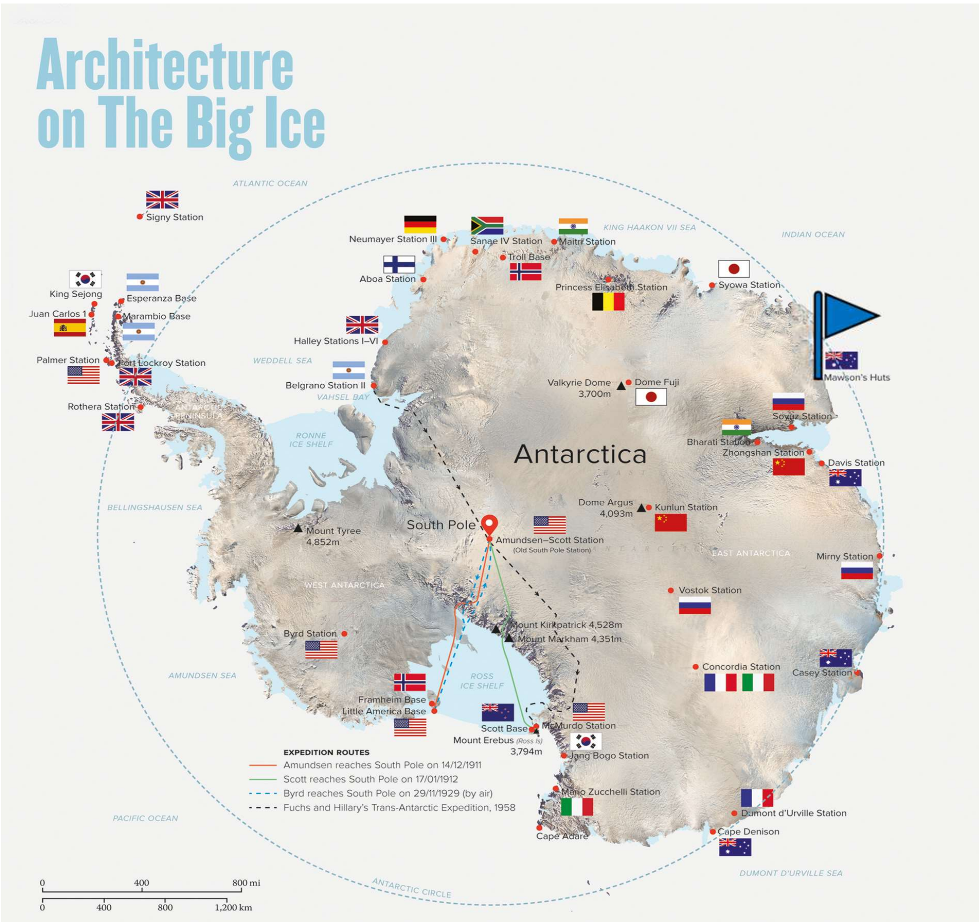
ship-borne count rate which cutoff rigidity < 1 of previous studies each year average in positive magnetic polarity period

count rate which cutoff rigidity < 1 of recent studies(T1&T3) average in each year

$$Factor = \frac{CR_{3nm64(R<1)}}{CR_{Mawson}} \div \frac{CR_{(T1+T3)(R<1)}}{CR_{Mawson}}$$

Mawson neutron monitor count rate average in each year

NEUTRON DETECTORS AT ANTARCTICA

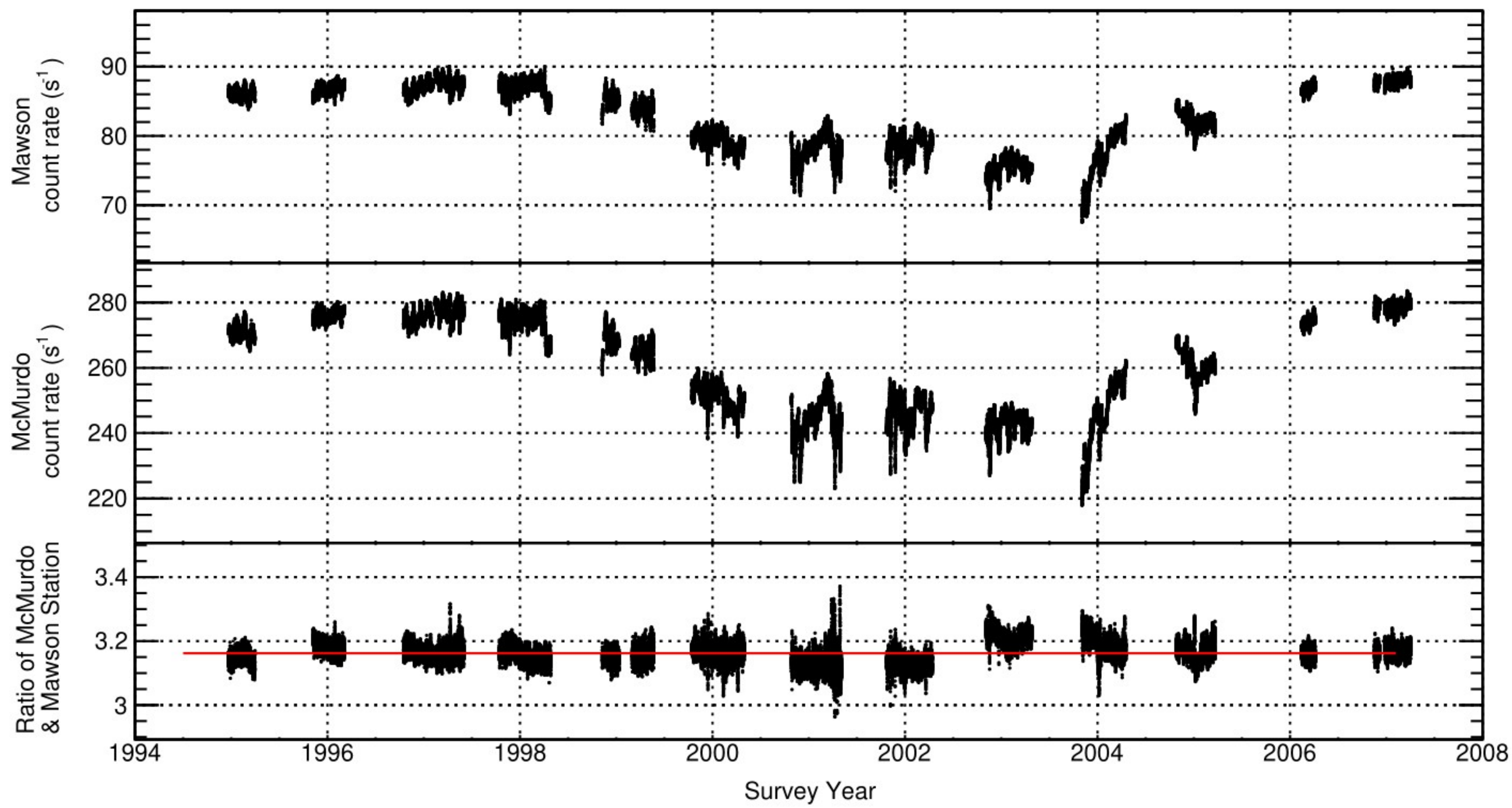


Mawson Station

- Detector Type : Feb 1986 - Oct 2002 - 6NM64
  Oct 2002 - 18NM64.
- Latitude : 67.60S
- Longitude : 62.88E
- Altitude : abount 30 m
- Rigidity (1965) : 0.22 GV

- Mawson is located at the edge of the Eastern Antarctic plateau. It is the first continental station and the longest continuously operating station south of the Antarctic Circle.

MAWSON DATA SCALING



RESULTS

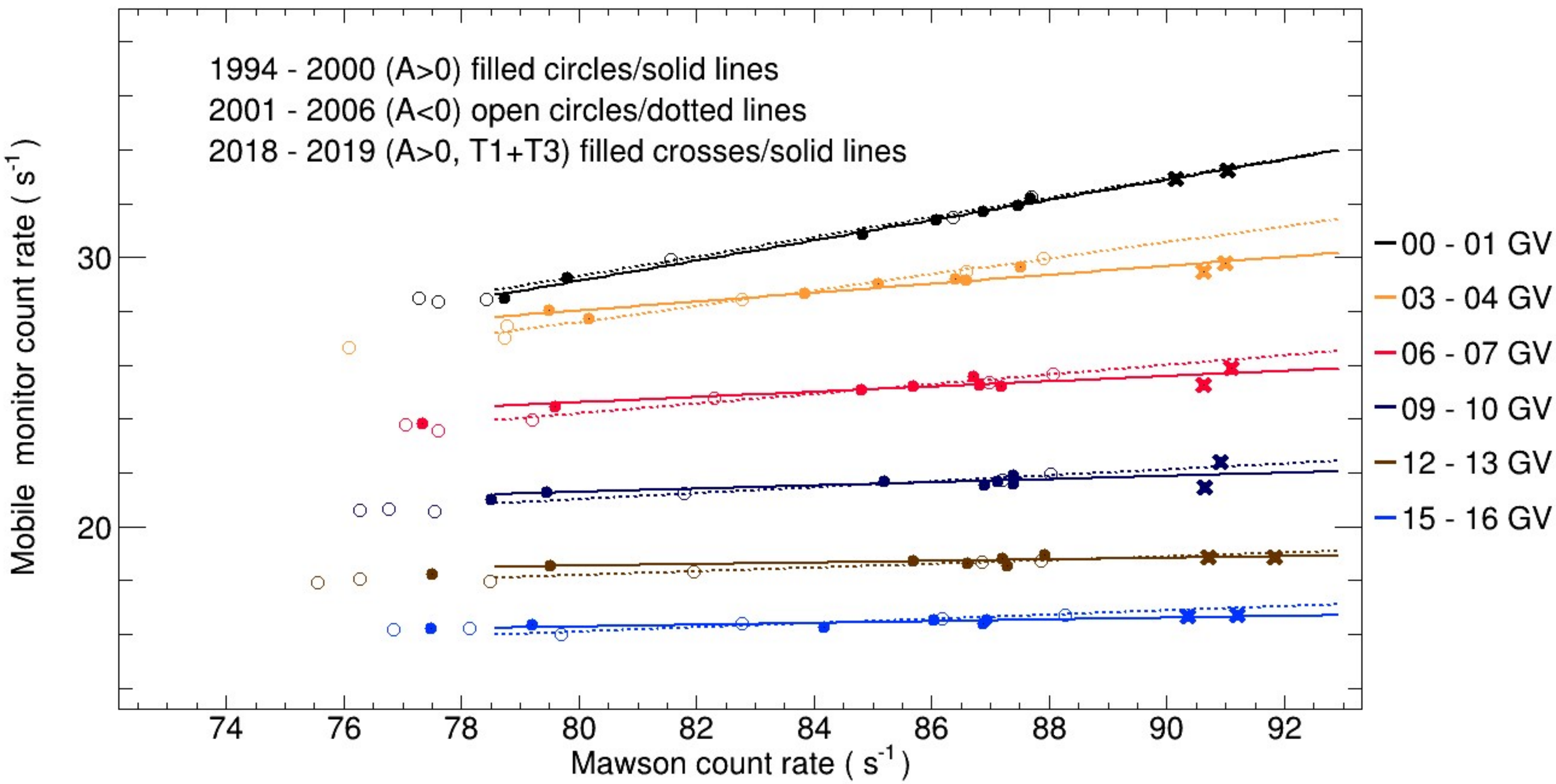
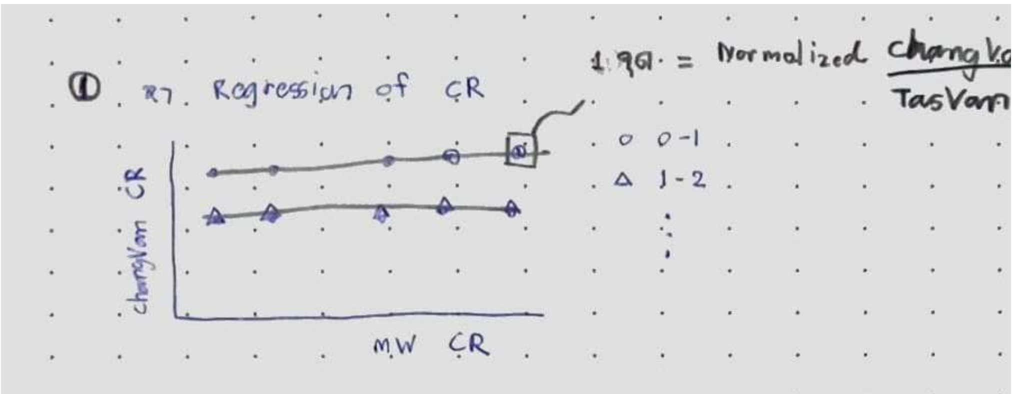
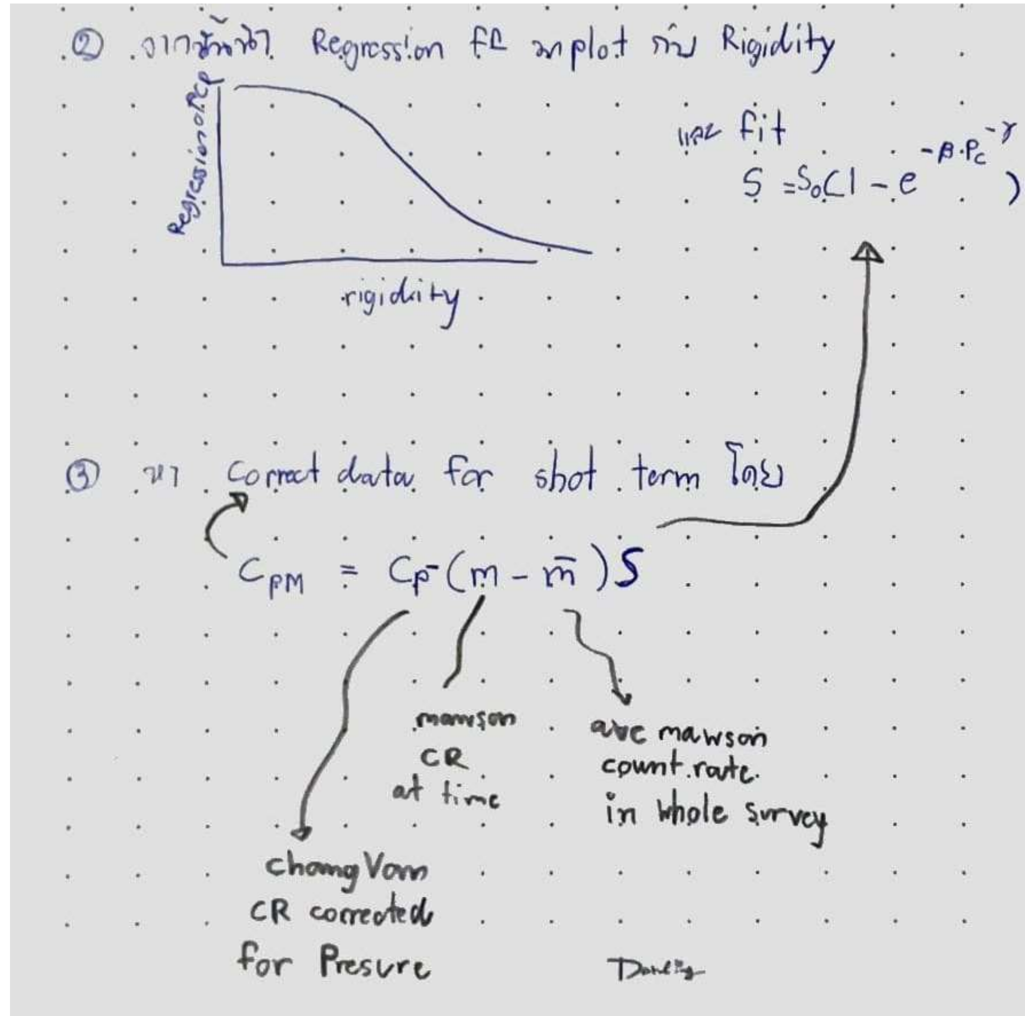


Fig. Regression of the mobile neutron monitor count rate in different apparent cutoff rigidity bins against the count rate of Mawson monitor superimposing the data for different solar magnetic polarities.





SHOT TERM NORMALIZATION

DIFFERENTIAL RESPONSE FUNCTION

$$N(P_c) = N_0\left(1 - e^{-\alpha P_c^{-\kappa}}\right),$$

$$N(P_c) = \int_{P_c}^{\infty} DRF(P)dP,$$

$$DRF(P) = N_0 \alpha P^{-\kappa-1} \kappa e^{-\alpha P^{-\kappa}}.$$

$$DRF(P) = -\left[\frac{dN}{dP_c}\right]_p$$

$$= \sum G(P)M(P,t)Y(P,h)$$

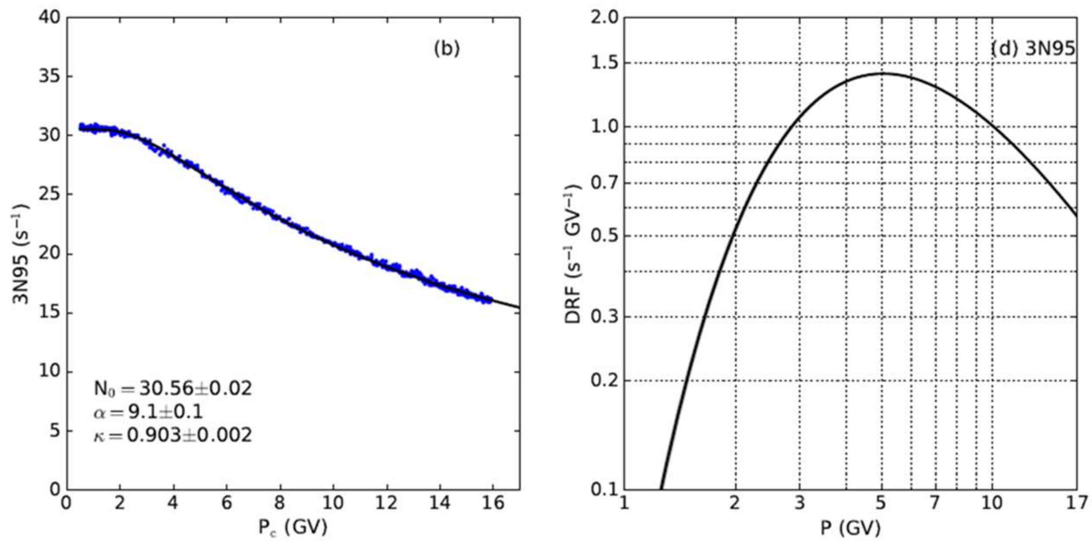


Fig. Dorman function fits to neutron monitor data (b) and show the resulting differential response functions (DRFs) (d) (Nuntiyakul et al., 2018)

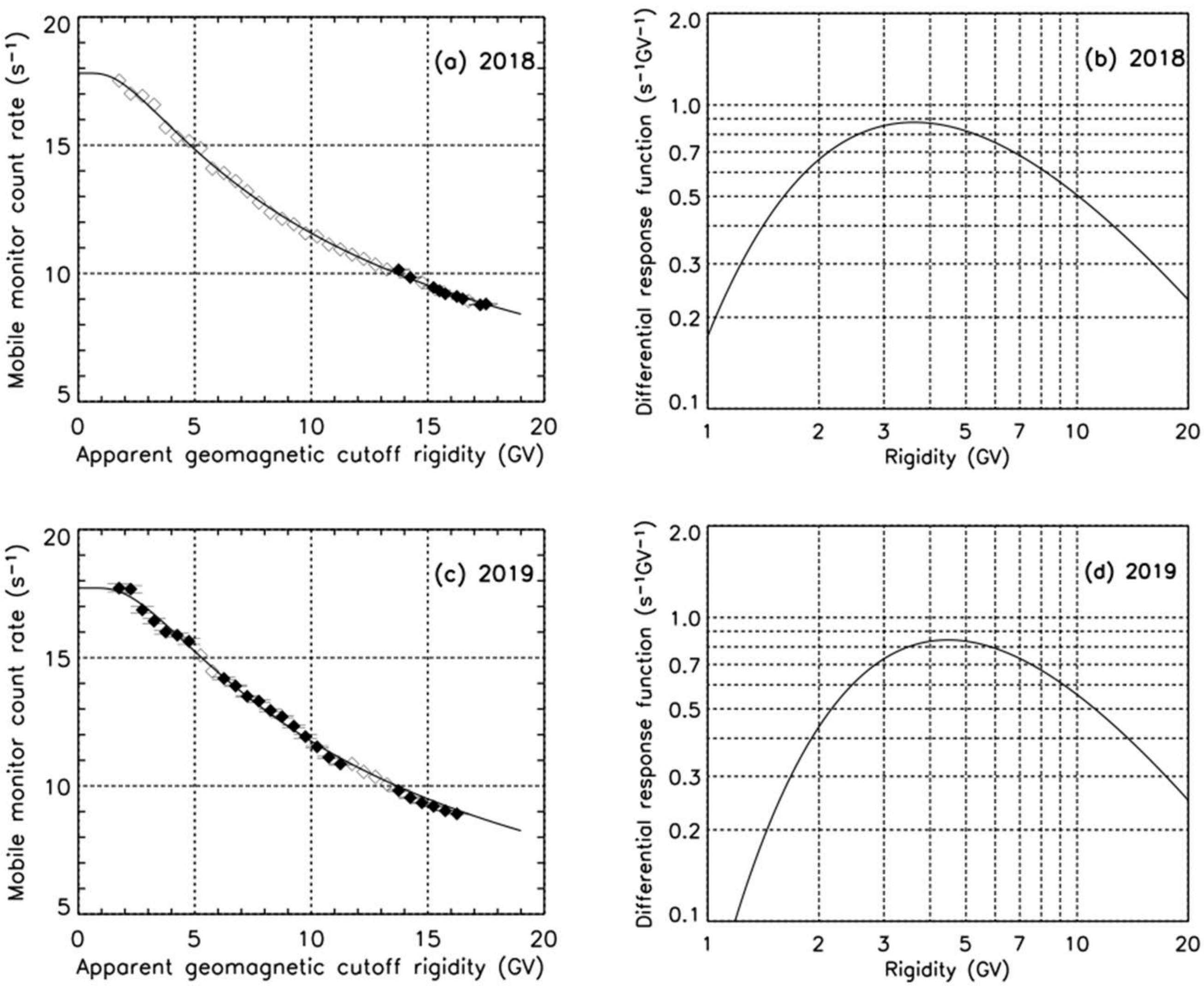


Fig. Dorman function fits to neutron monitor data of survey year 2018 (a) and 2019 (c) and show the resulting differential response functions (DRFs) of survey year 2018 (b) and 2019 (d)

CROSSOVER ANALYSIS

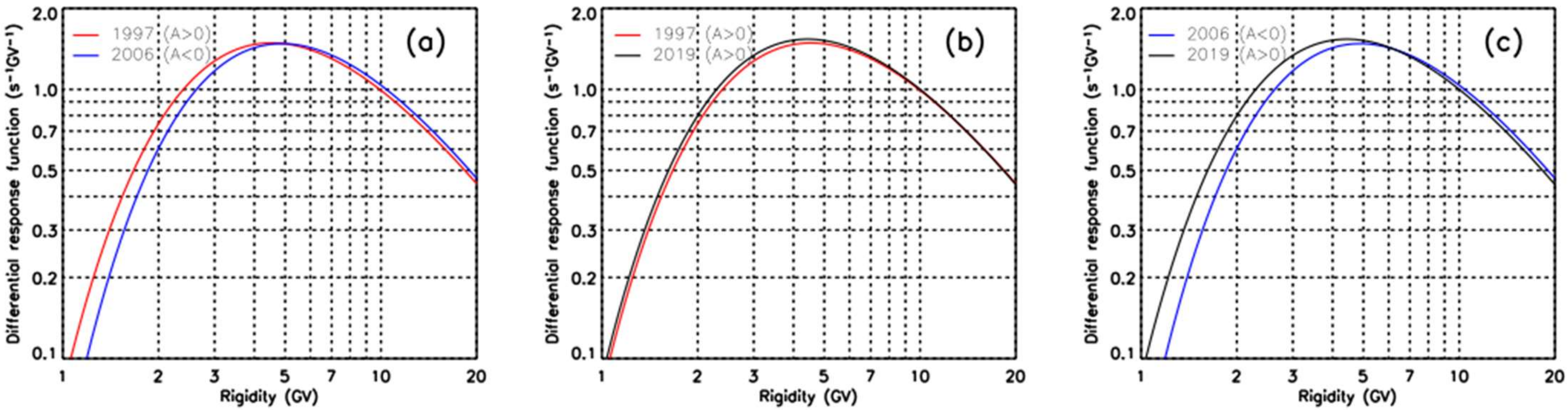


Fig. (a) indicate differential response functions from (Nuntiyakul et al. (2014). (b) indicate differential response functions from survey year 1997 and 2019 which are both positive magnetic polarity and solar minimum. (c) indicate differential response functions from survey year 2006 and 2019 which are difference magnetic polarity and solar minimum. The crossover spectrum appear clearly in (a) and (c) which are the differential response functions of difference magnetic polarity

CONCLUSION

- In this work, we have analyse two recent latitude surveys in survey year 2018 and 2019 with a monitor similar to the 3NM64 but without the lead producer surrounded the central tube. We also repeat the analysis follow Nuntiyakul et. al, 2014. but using neutron monitor data from Mawson, instead of McMurdo station.
- To compare the two tubes in the recent survey years to the 3NM64 in a 13-year survey, we apply a normalization factor of 1.824 for the survey year 2018 and that of 1.797 for the survey year 2019 to T1+T3.
- Our results confirm linear trends between count rates at different geomagnetic cutoff rigidity and changes in slope before and after the polarity reversal in 2000 as an effect of solar magnetic polarity similar to the results shown in Nuntiyakul et. al, 2014.
- Results from two recent latitude surveys are consistent with the previous conclusions. We also confirm the "crossover" in spectra measured near solar minima during epochs of opposite solar magnetic polarity using recent latitude surveys and verify the absence of crossover for the same solar magnetic polarity. Thus we confirm both the change in the linear relationship and the crossover as effects of solar magnetic polarity on the cosmic ray spectrum resulting from solar modulation.

THANK YOU

ANY QUESTIONS ?