The Decadal Variability of Cosmic Ray Flux Outside of a Grand Solar Maximum

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EGU General Assembly 2016

Overview

Introduction:
- What are galactic cosmic rays (GCRs)?
- Cosmic ray detection by neutron monitors.
- The modulation of GCRs by the Sun's magnetic field.
- The 22-year cycle in cosmic ray flux.

Results:
- Splitting neutron monitor data by solar magnetic polarity.
- Comparison of data between consecutive solar cycles.
- Particle drifts versus direct heliospheric modulation.
- Implications of our results on future solar activity.

Summary

What are Galactic Cosmic Rays (GCRs)?

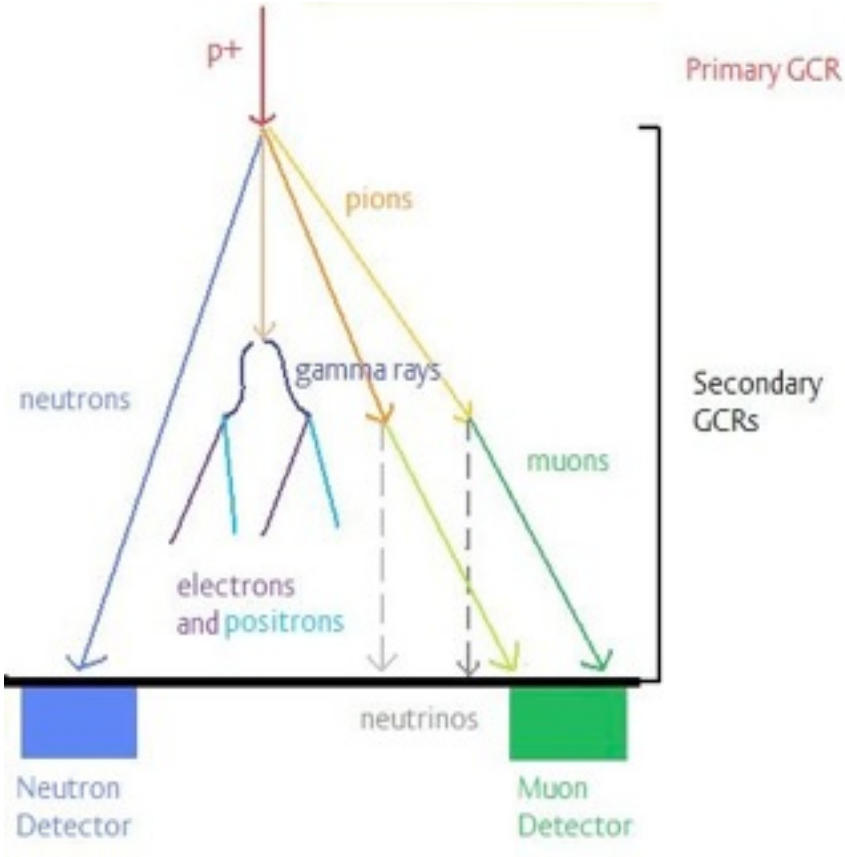
Highly energetic charged particles that are accelerated outside of our solar system at sources such as supernovae and neutron stars.

Their energy is large enough so that they can be detected at Earth's surface ~ 100 MeV – 100 GeV.

~ 90% of GCRs are protons but they can also be electrons or heavy nuclei.

They are almost always isotropic in their direction of arrival at Earth.

GCR Detection in the Atmosphere



- GCRs interact with atmospheric particles and produce a “cascade” of secondaries.
- Neutrons are one such secondary that reaches the surface.
- These are detected by a global network of neutron monitors and muon telescopes.
- For this work, a variety of latitudes and longitudes of neutron monitors are used.

GCRs are Modulated by the Heliospheric Magnetic Field

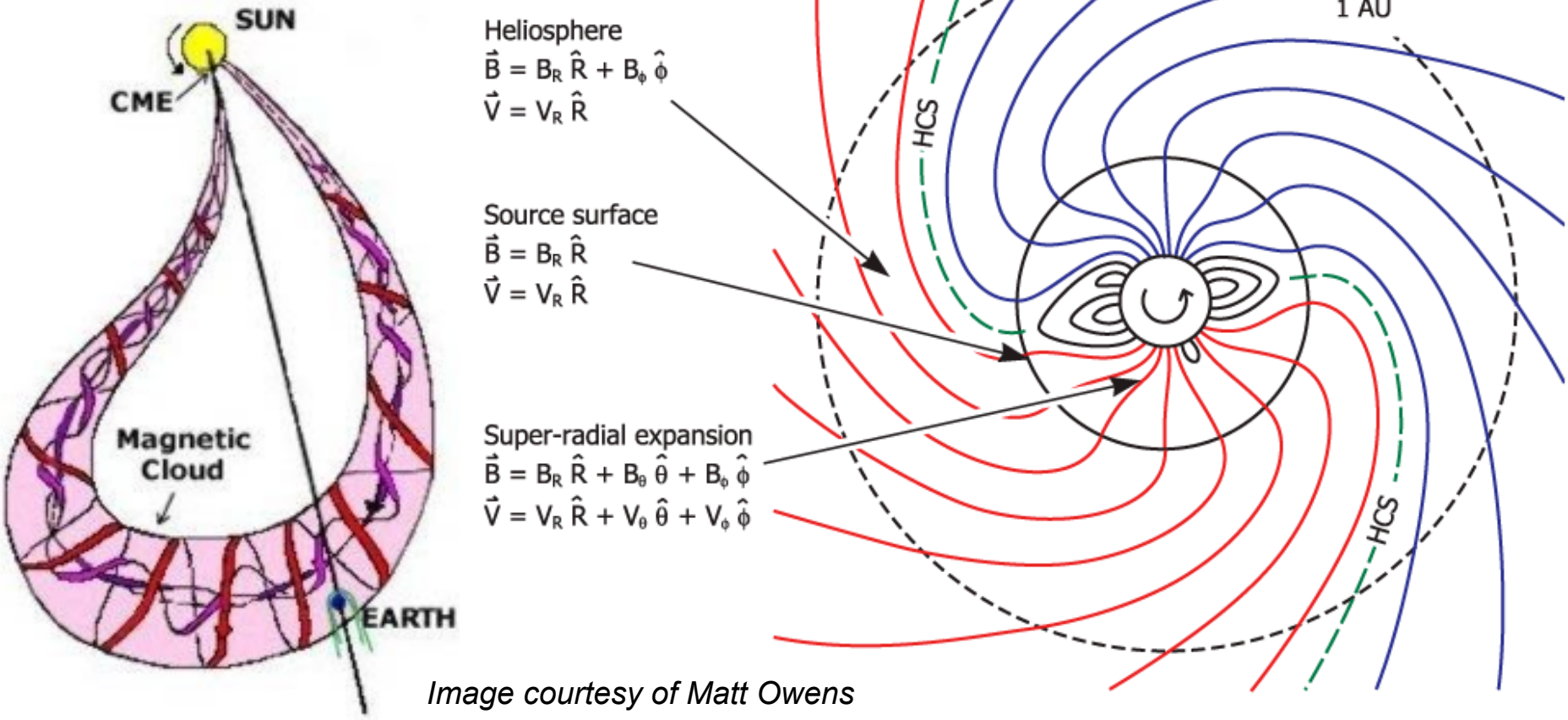
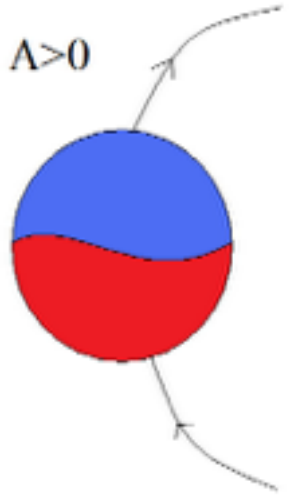


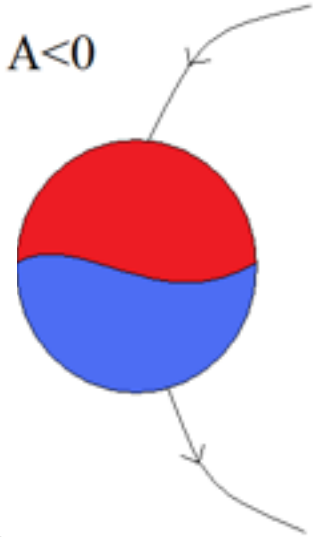
Image courtesy of Matt Owens

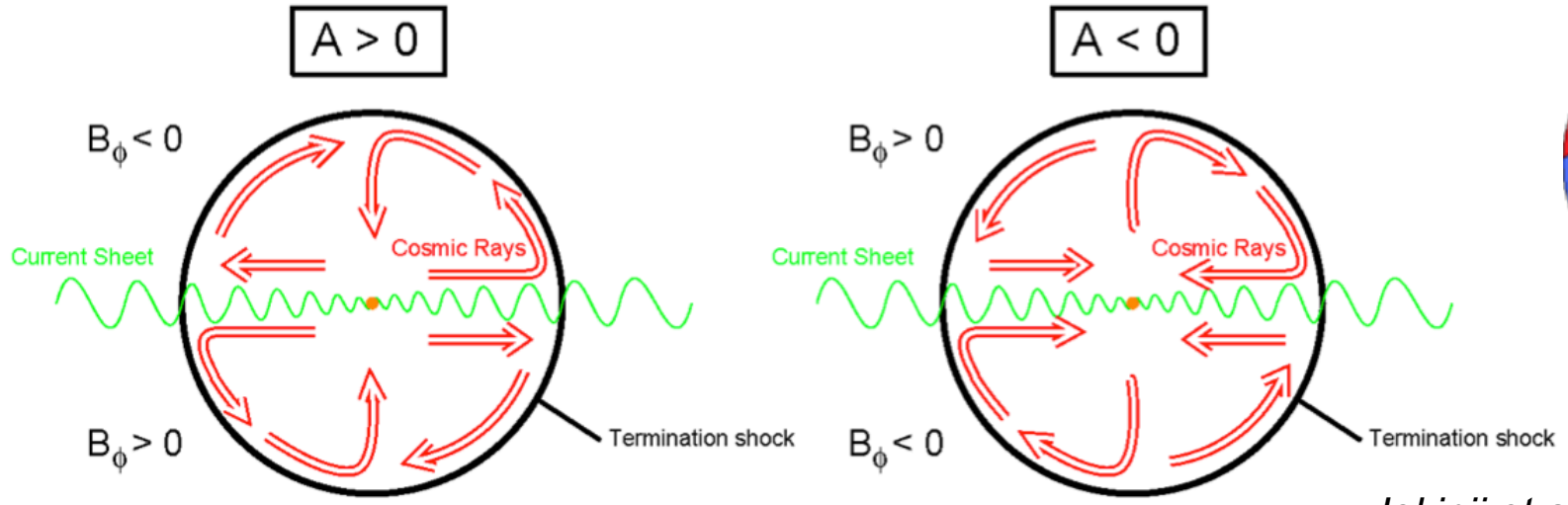
Research Question: What effect does the change in heliospheric magnetic polarity have on cosmic ray flux on decadal time-scales?

Particle Drifts Cause a 22-year Cycle?

- Due to the change in polarity, cosmic rays drift through the heliosphere differently between cycles.
- During A > 0 cycles, they arrive at Earth after travelling over solar poles.
- During A < 0 cycles, they arrive at Earth up the equatorial plane from outer heliosphere.
- More inhomogenities in the field from this trajectory.

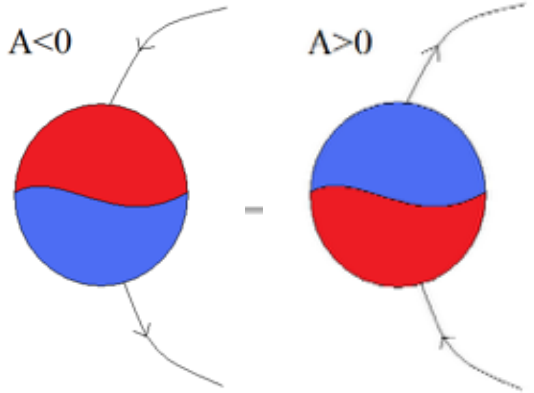


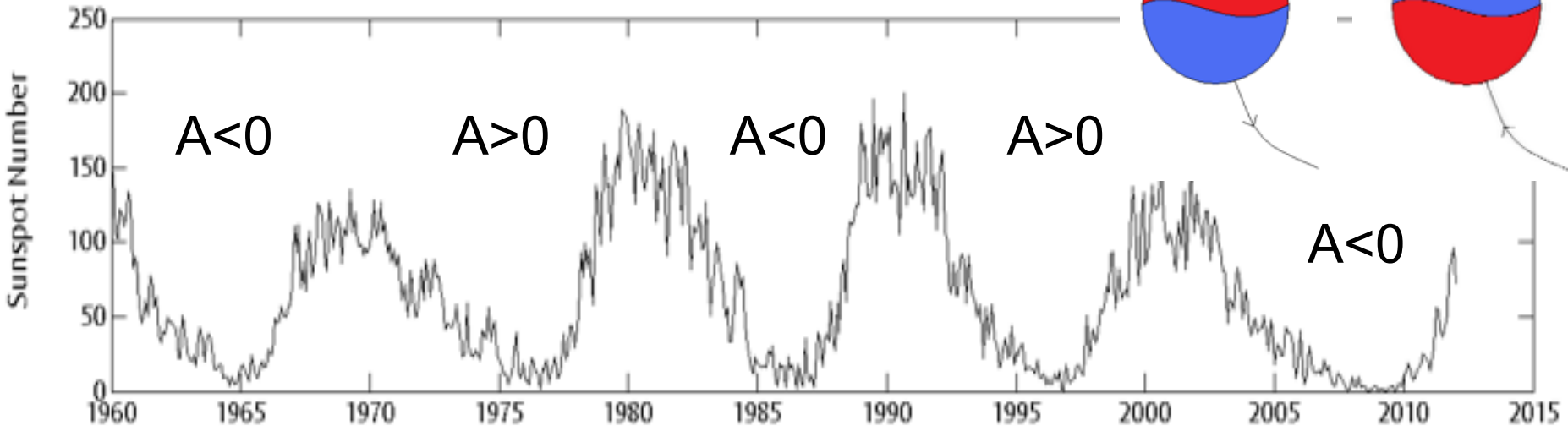




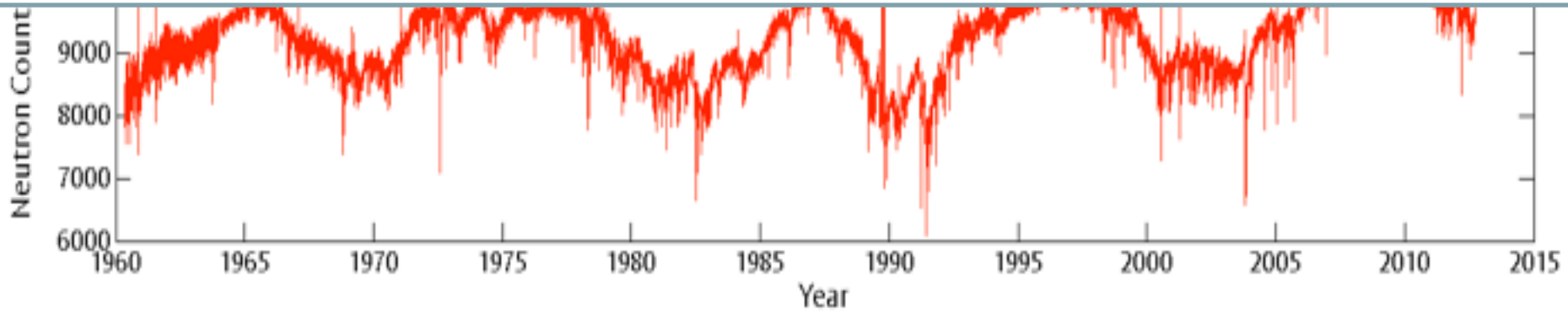
Jokipii et al. (1977)

The 22-Year Cycle

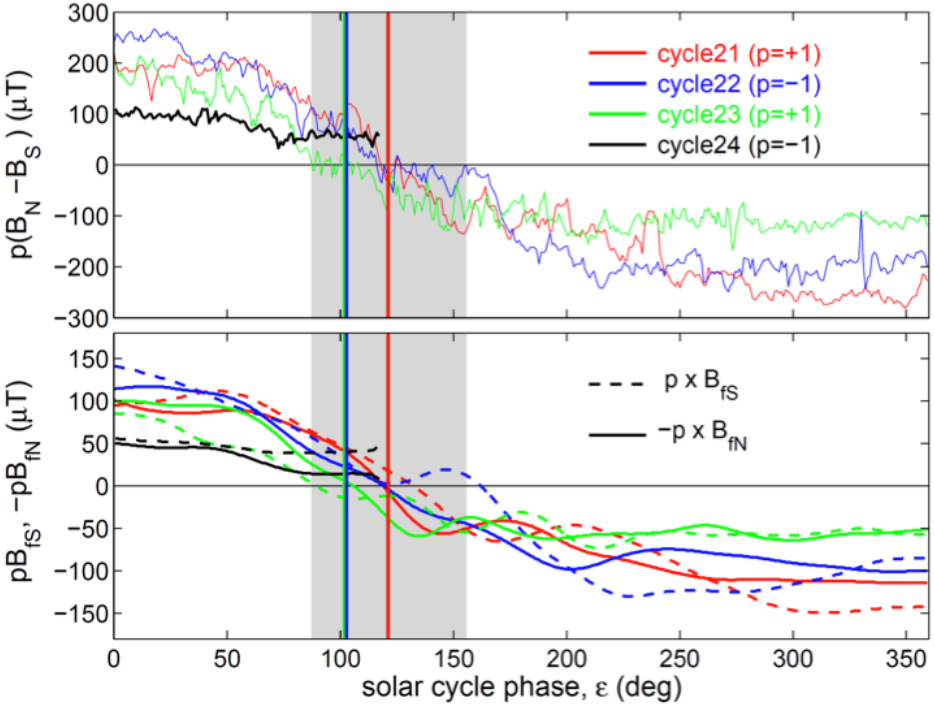




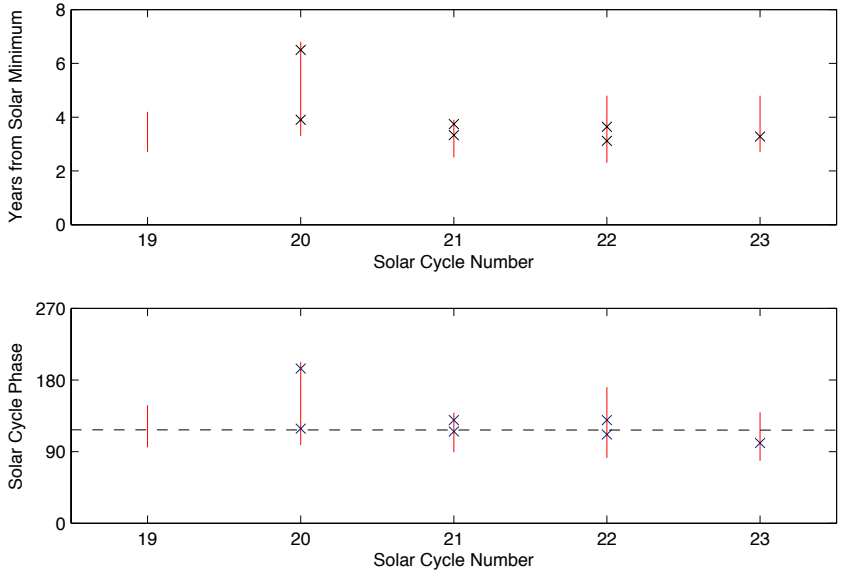
Problem: When do these changes in solar magnetic polarity happen?



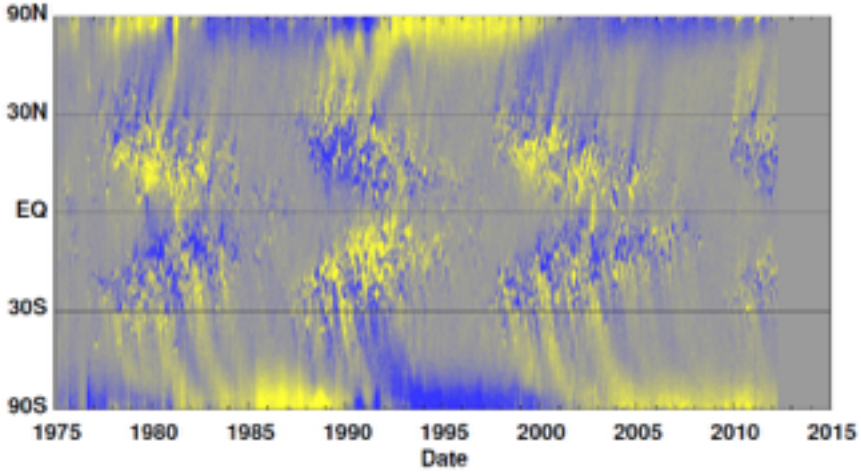
Estimating Polarity Reversal Times



Lockwood et al. (2012)

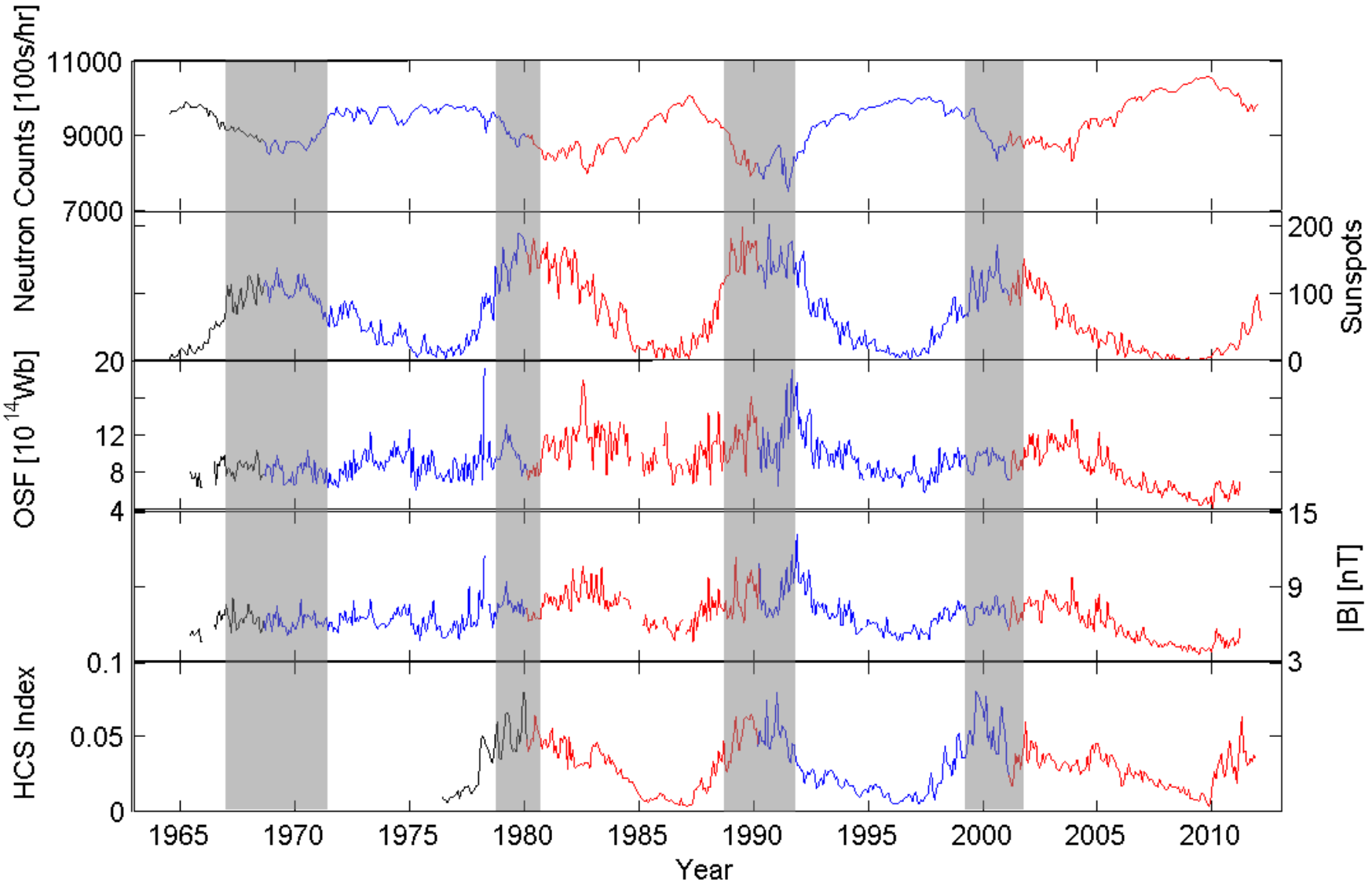


Thomas et al. (2014)



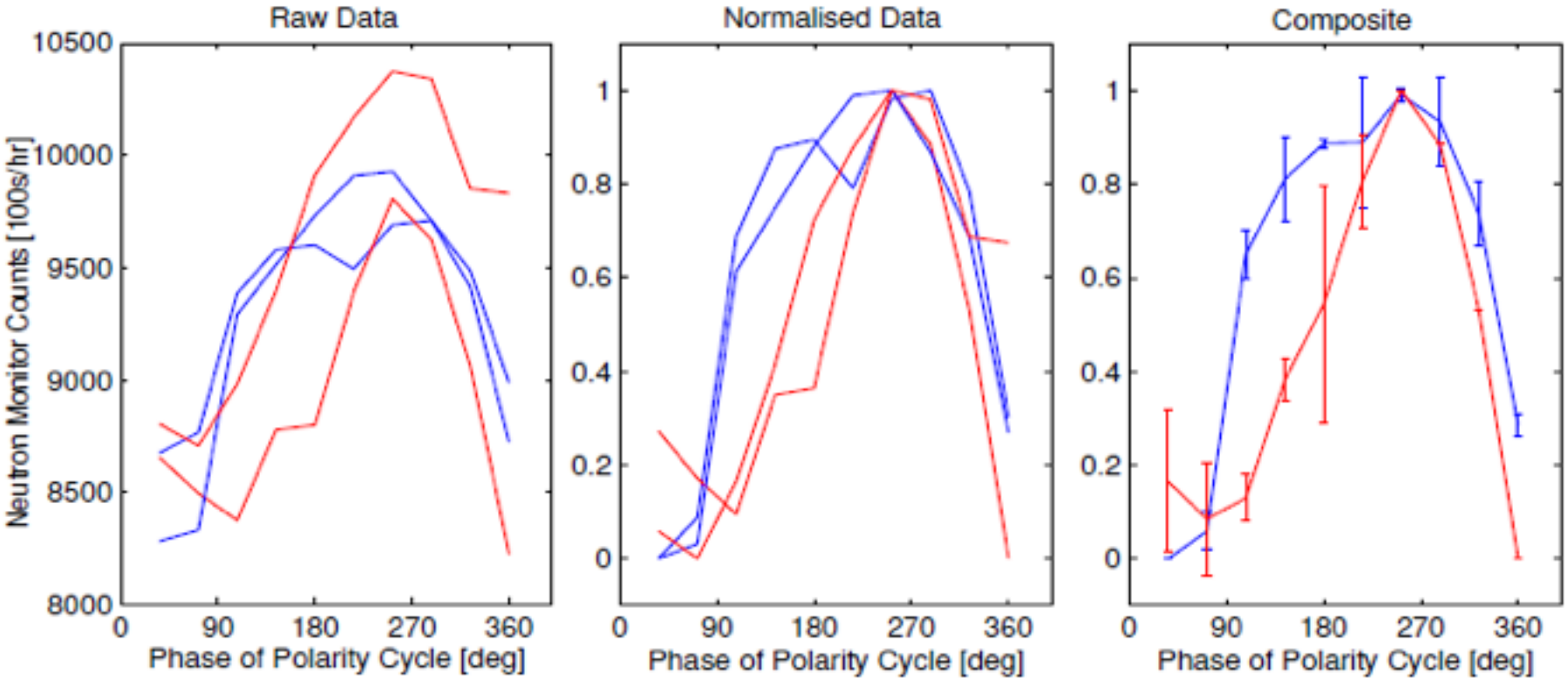
D. Hathaway, NASA

Uncertainty on Space-Age Reversals

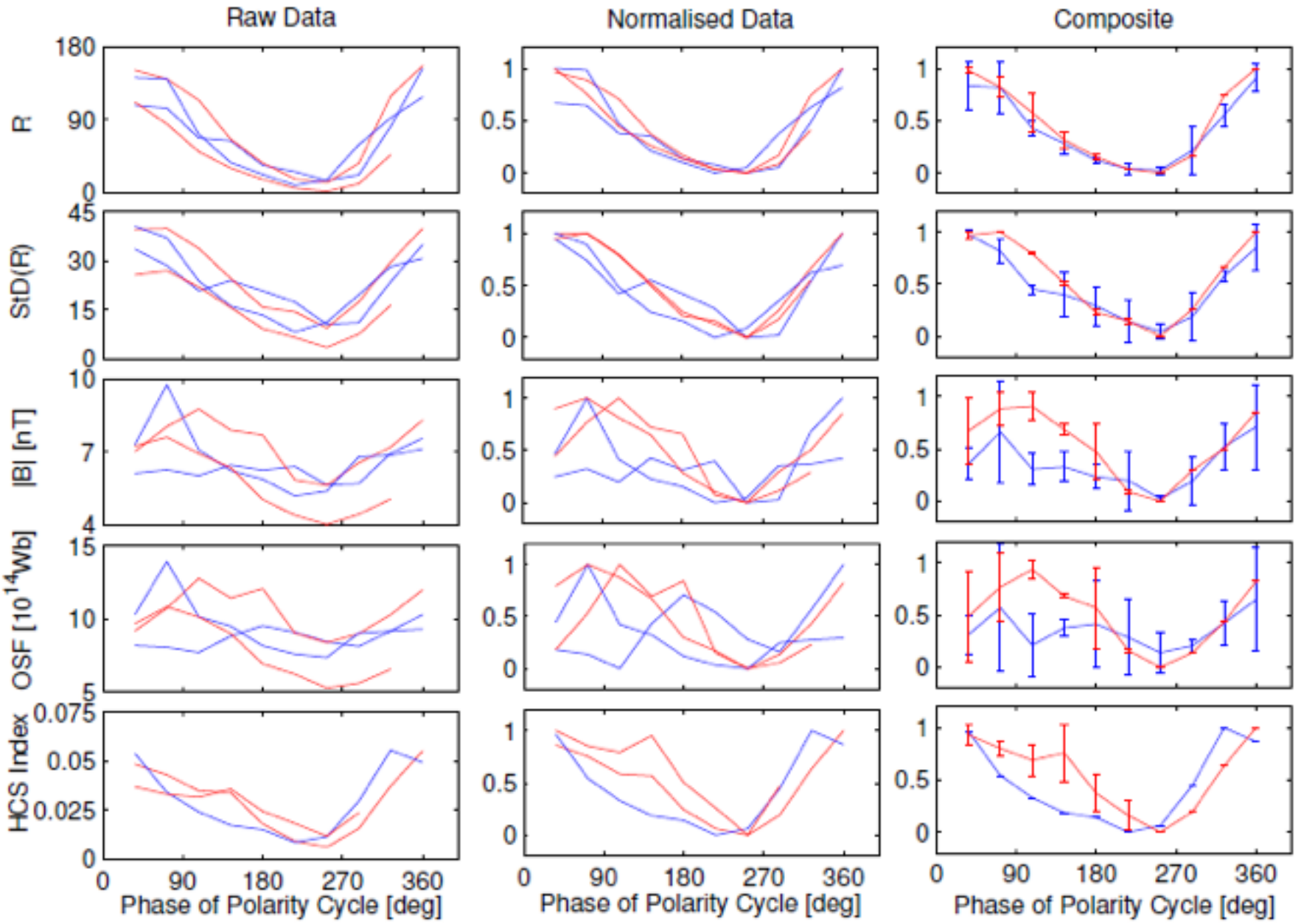


Superposed Epoch Study of GCR Data

Blue - qA > 0 cycles
Red - qA < 0 cycles



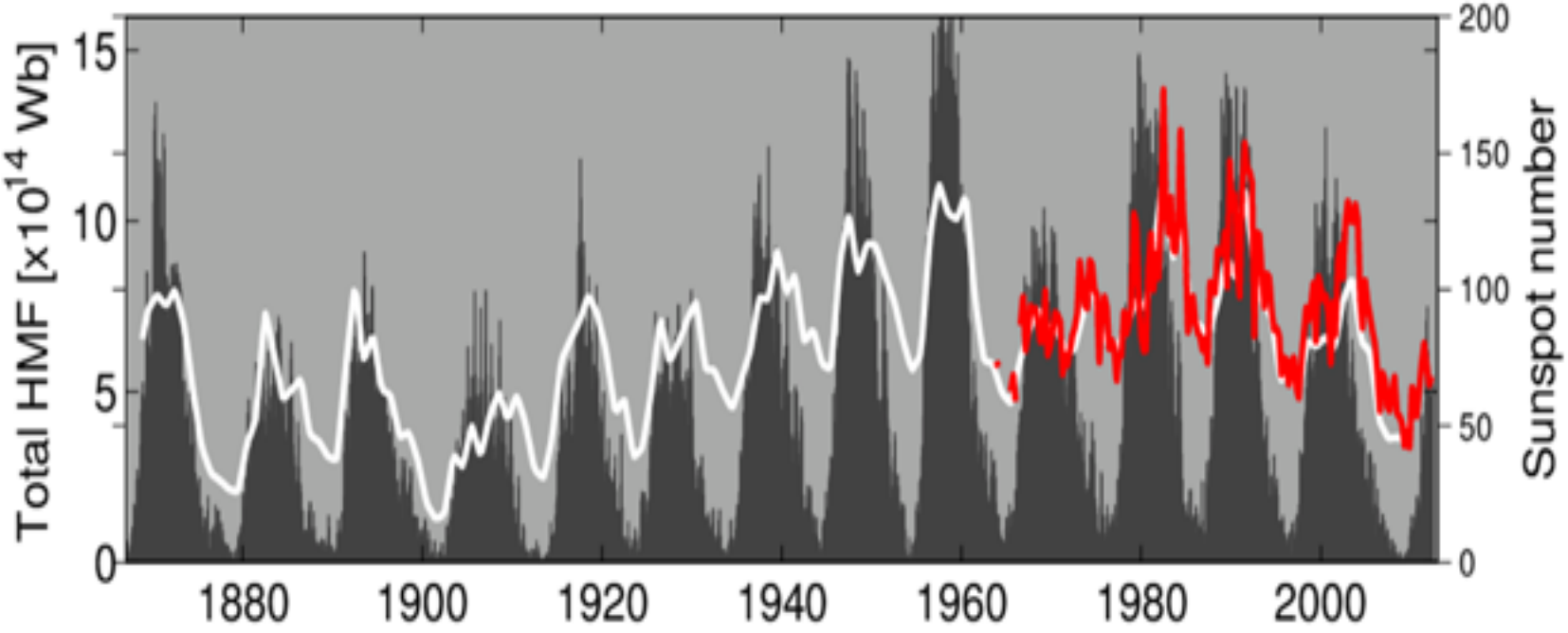
Thomas et al. (2014)


Raw Data
Normalised Data
Composite
R
StD(R)
|B| [nT]
OSF [10^14 Wb]
HCS Index
Phase of Polarity Cycle [deg]
Phase of Polarity Cycle [deg]
Phase of Polarity Cycle [deg]

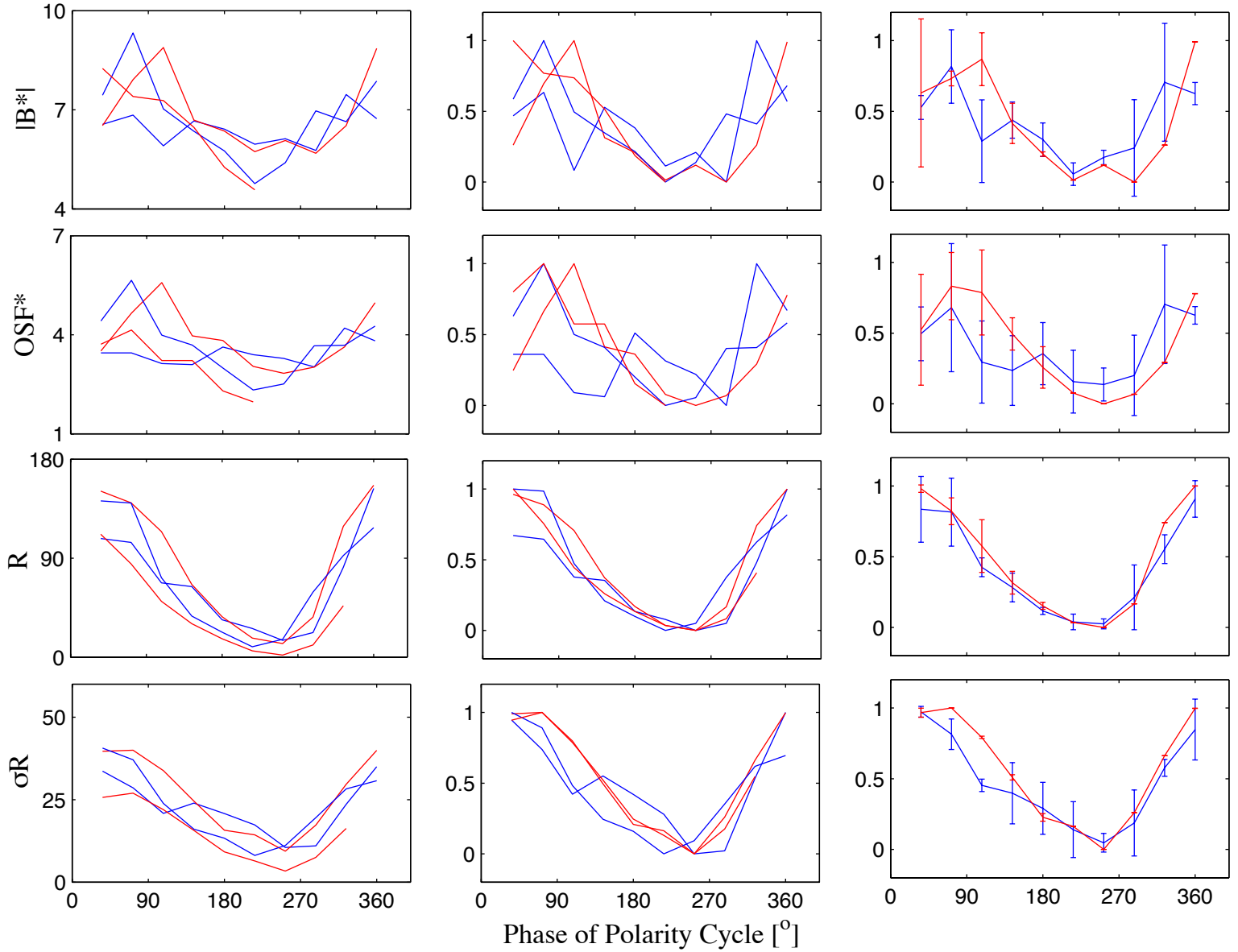
Geomagnetic Reconstructions (for more solar cycles of solar wind data)

- Reconstructions of the Earth's magnetic field deduced from geomagnetic activity.
- Data set back to 1860, at the time of analysis this was only certainly reliable back to 1905.

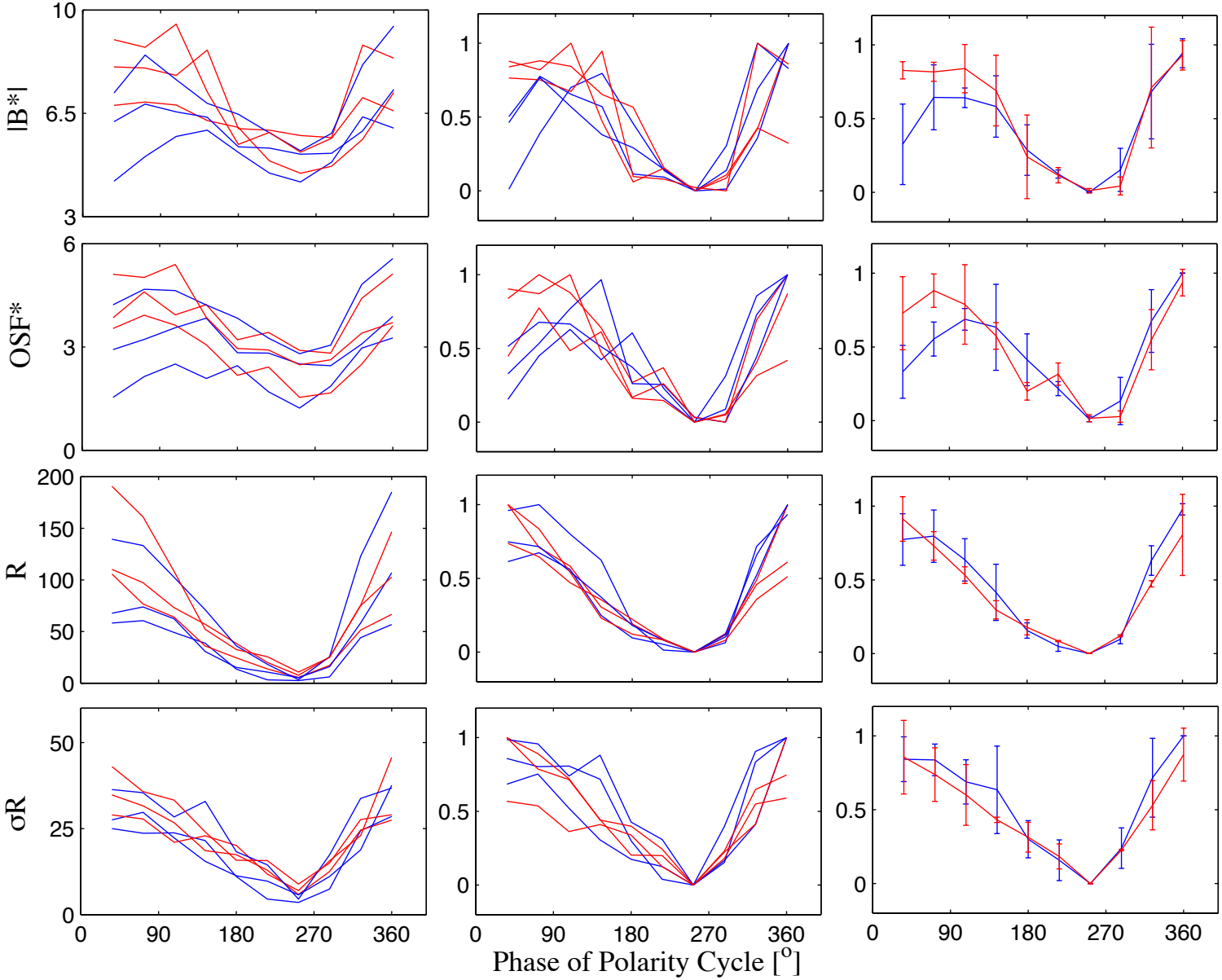
Image courtesy of Mike Lockwood



Geomagnetic Data - *Same 4 Cycles*

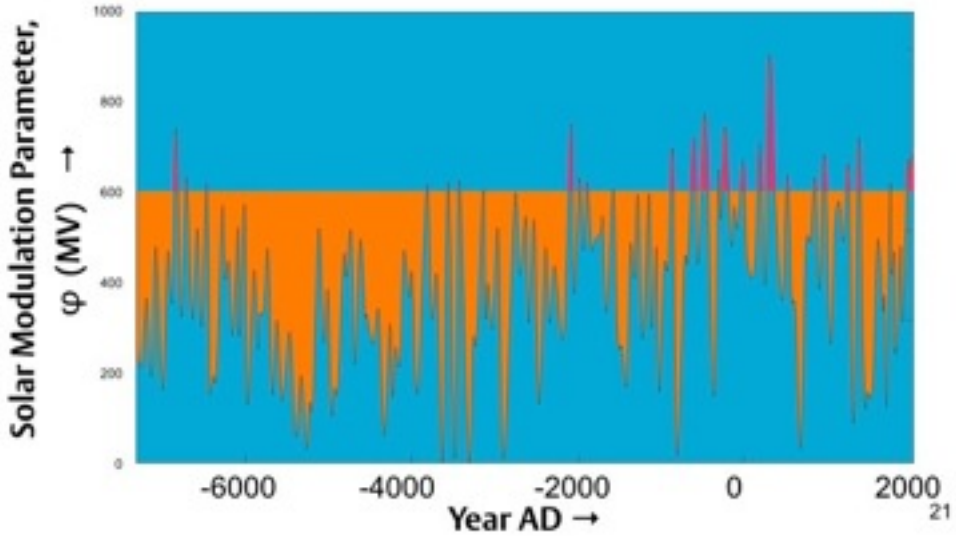


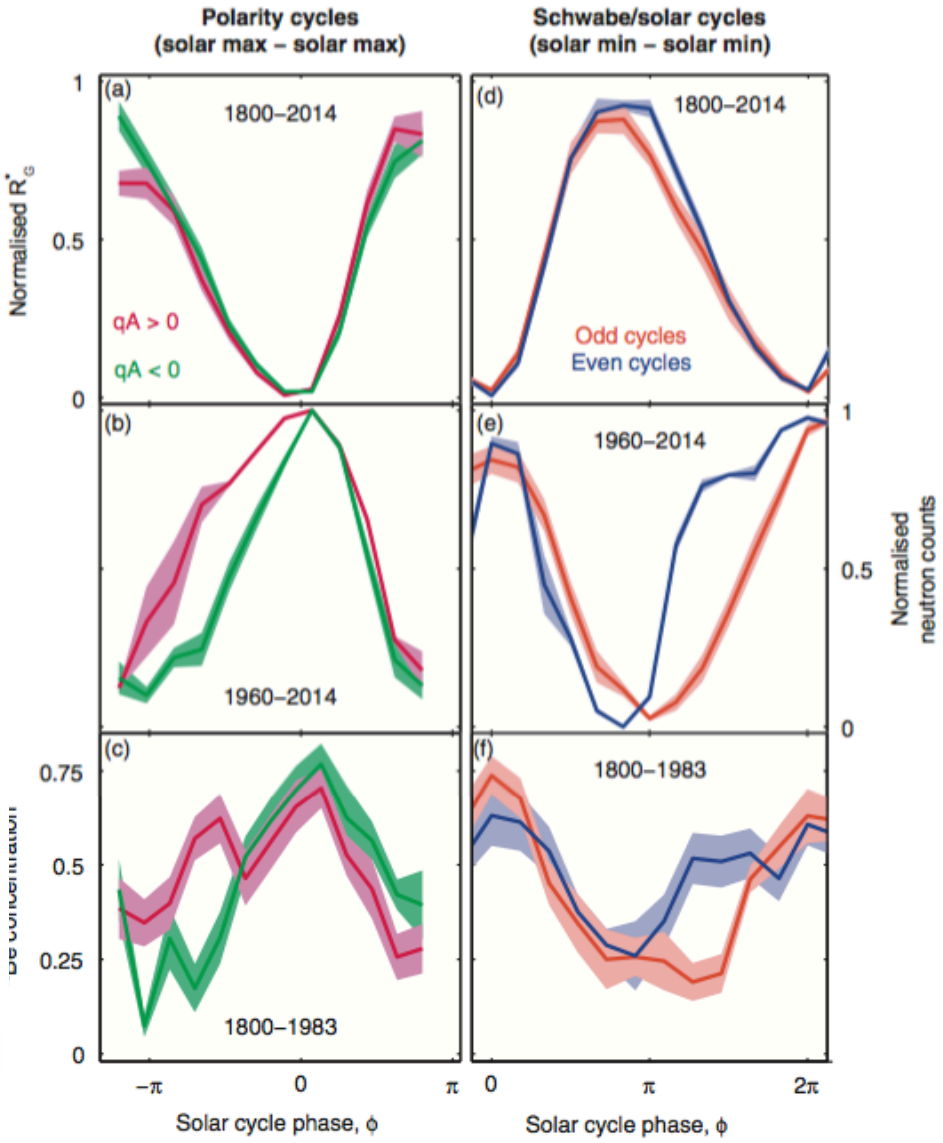
Geomagnetic Data - *1905 to 1965*



Grand Solar Maxima

- Reconstructions produced from Be-10 found in ice-cores.
- Been in a GSM for past ~50-60yrs.
- Previously, solar activity much lower.
- Owens et al. (2015) showed that 22-year variation seen in ice-core data.
- Further work is required to deduce why 22-year cycle suppressed before space-age.





Steinhilber et al. (2006)

Summary

- We have investigate the effect of heliospheric magnetic field polarity on GCR flux.
- The 22-Year Cycle has been shown not to just be because of different cosmic ray drifts but due to direct heliospheric modulation of GCRs.
- This change is no longer present in cycles prior to the space age.
- We have seen a “Grand Solar Maximum” in solar activity persisting throughout the space age that was not present before ~1960.
- The enhancement in the 22-year cycle is thought to be a grand solar maximum phenomenon.
- Traces of Beryllium-10 in ice-core reveal more data and a new opportunity to study cause of this variation.