

RECONSTRUCTING THE GLOBAL HELIOSPHERE BACK TO 1610

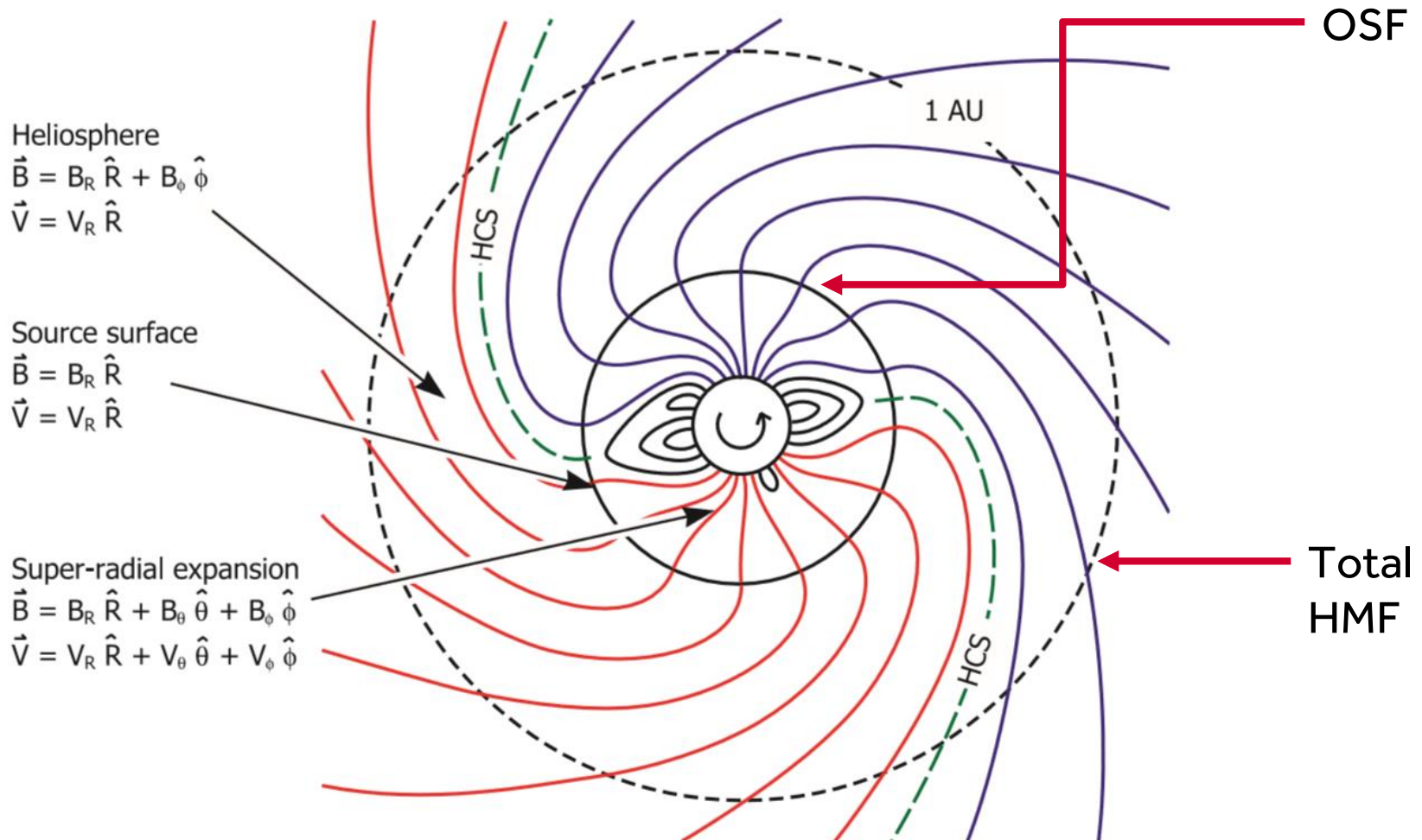


Mathew Owens, Mike Lockwood, Pete Riley

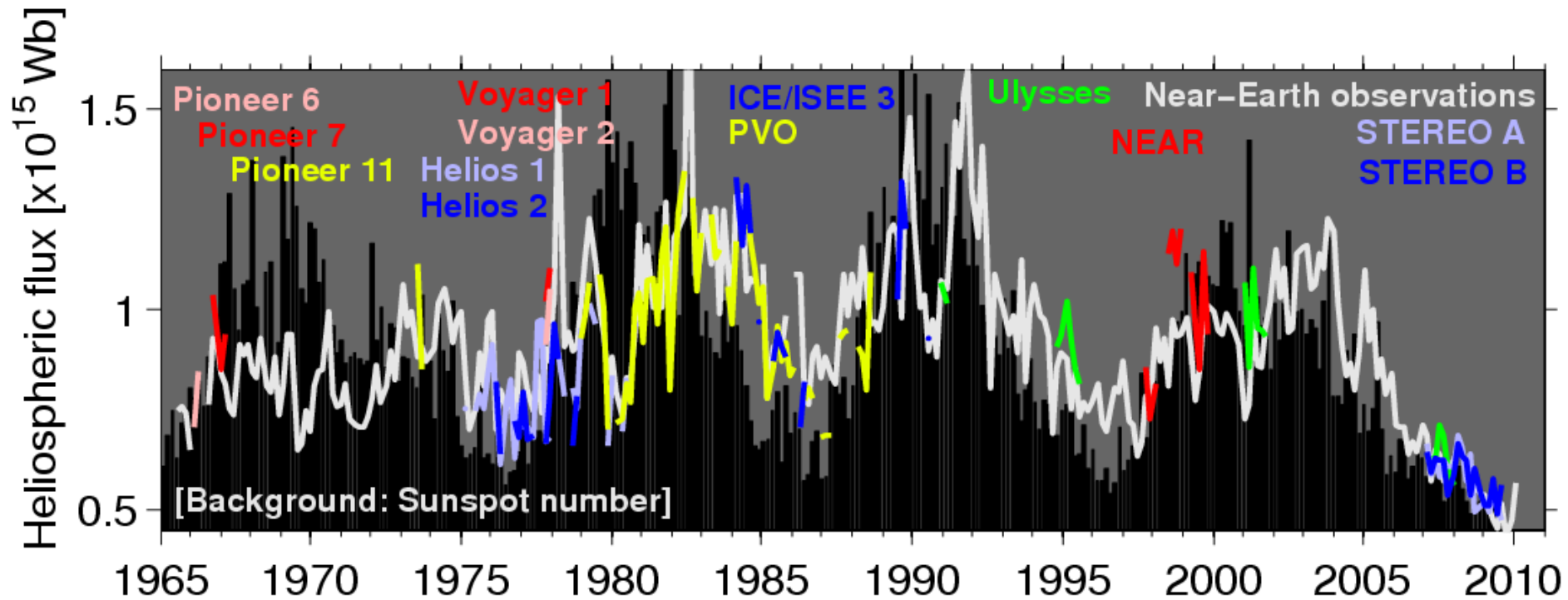
OVERVIEW

- Background
 - In situ observations of the heliosphere
 - Geomagnetic reconstructions of B, V and OSF
 - Sunspot-based reconstructions of OSF
 - Cosmogenic isotopes of OSF
- Reconstructing streamer belt width, comparisons with eclipses
- Reconstructing V, n and B from sunspots
- Implications to heliosphere size and shape
 - Cosmic ray propagation
 - Geomagnetic activity

OPEN SOLAR FLUX

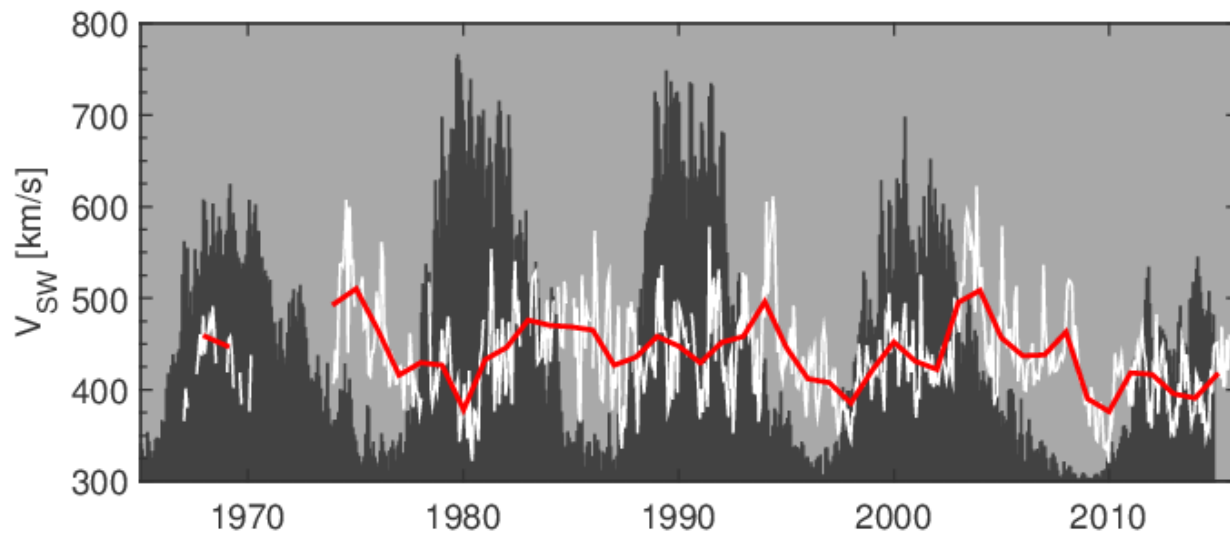
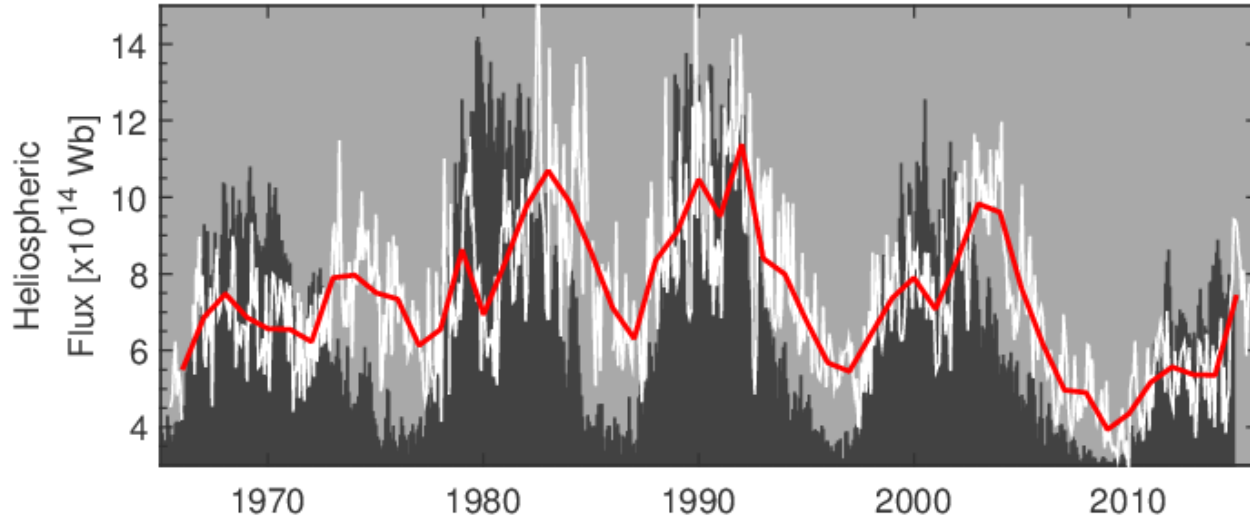


IN-SITU MEASUREMENTS

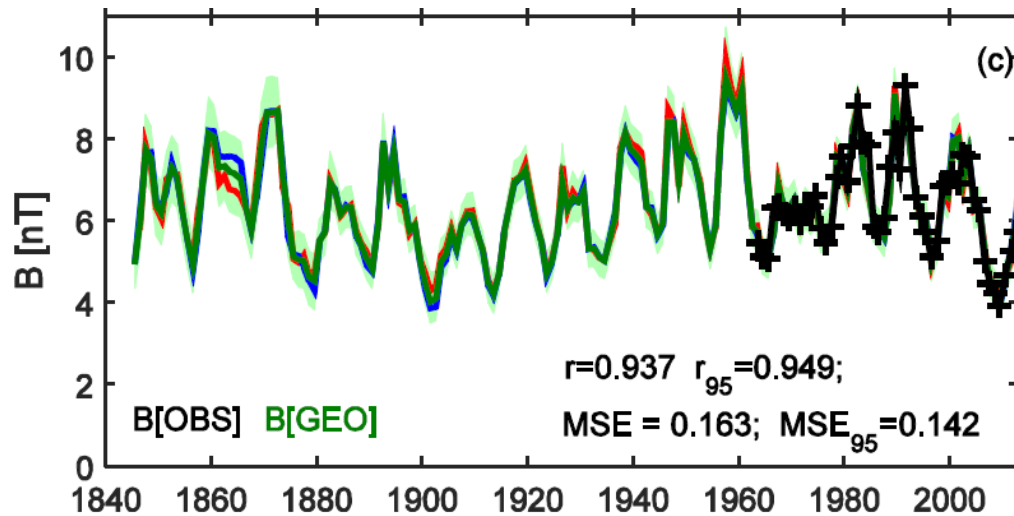


Owens et al., JGR, 2008

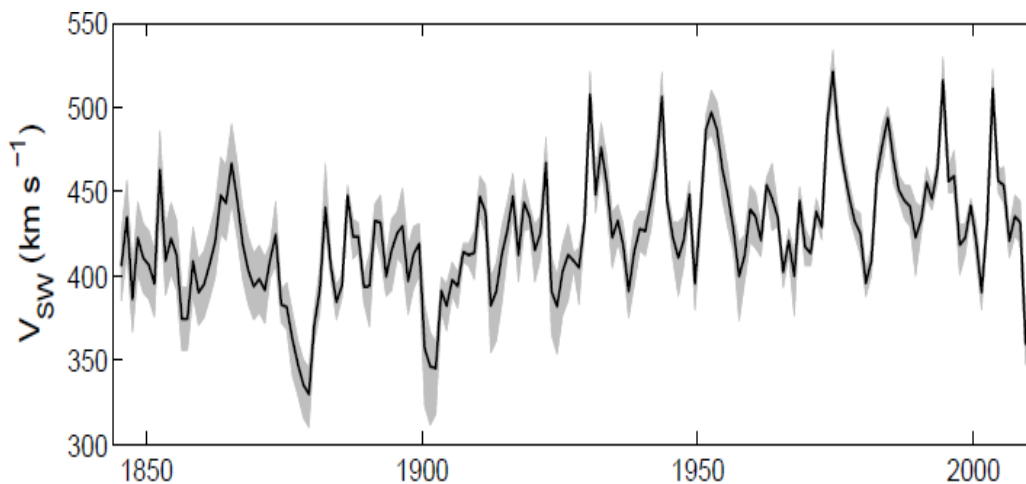
SPACE-AGE VARIATIONS



GEOMAGNETIC RECONSTRUCTIONS



Owens et al.,
ISSI workshop.
JGR under review.



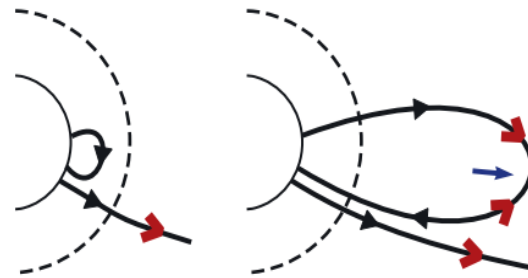
Lockwood et al.,
Ann. Geophys, 2014

HELIOSPHERIC FLUX FROM SUNSPOTS

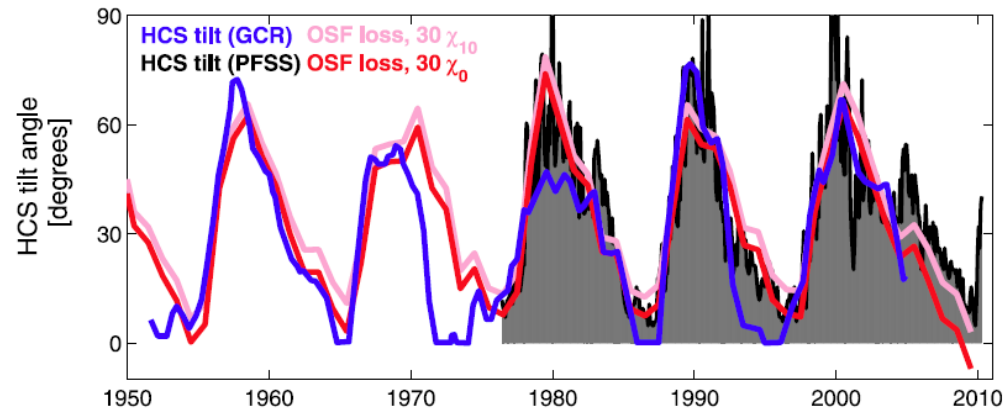
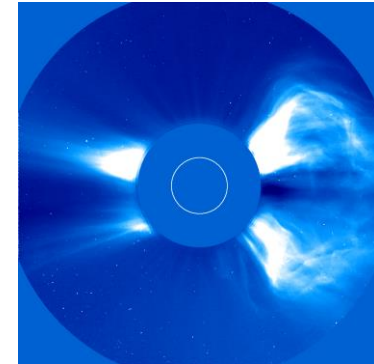
- HMF can be modelled as a continuity equation (Solanki et al., Nature, 2000)

$$\frac{d(\text{OSF})}{dt} = S - L$$

- Source: New closed loops. (Sunspots or CMEs)
- Loss: Disconnection of magnetic flux.
 - Computed loss matches HCS variation (Owens et al., JGR, 2011; 2012)

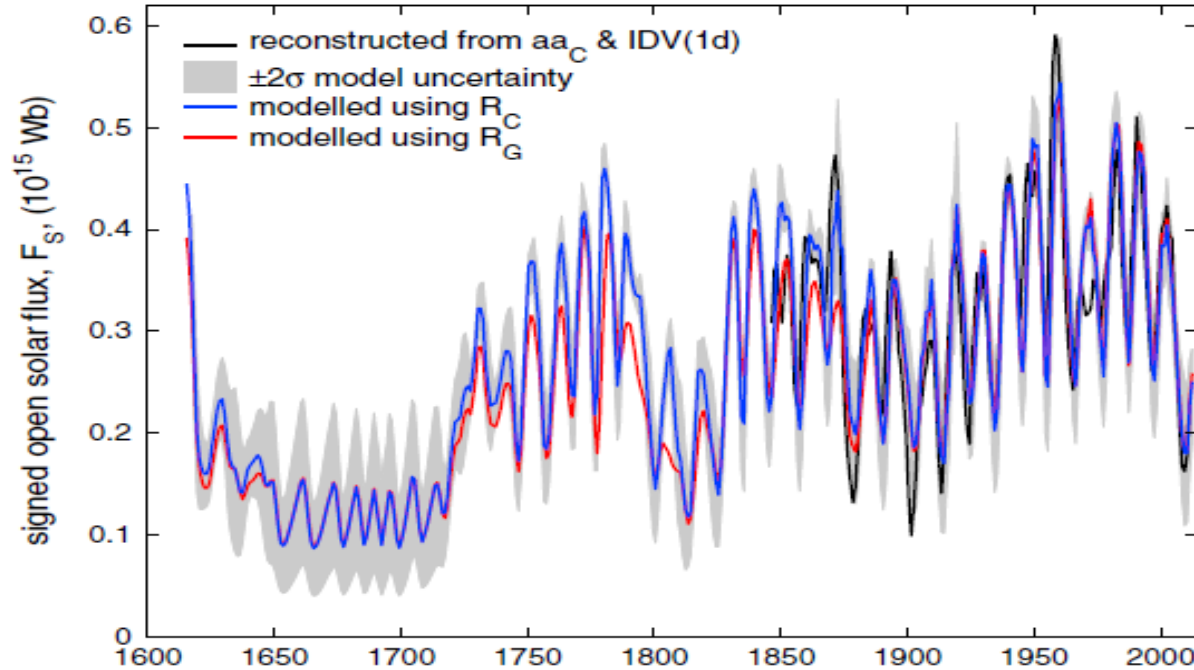


Owens and Crooker, JGR, 2006

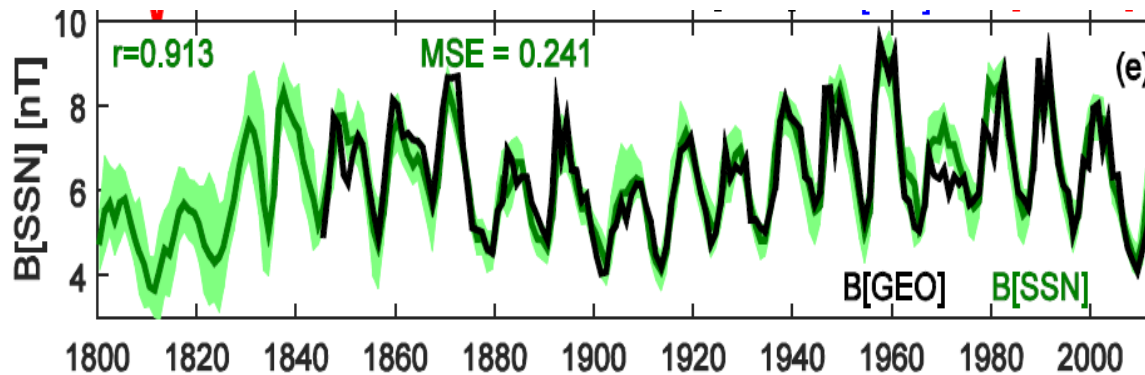


Owens and Lockwood, JGR, 2012

HMF/OSF FROM SUNSPOTS



Lockwood and Owens,
ApJ, 2014



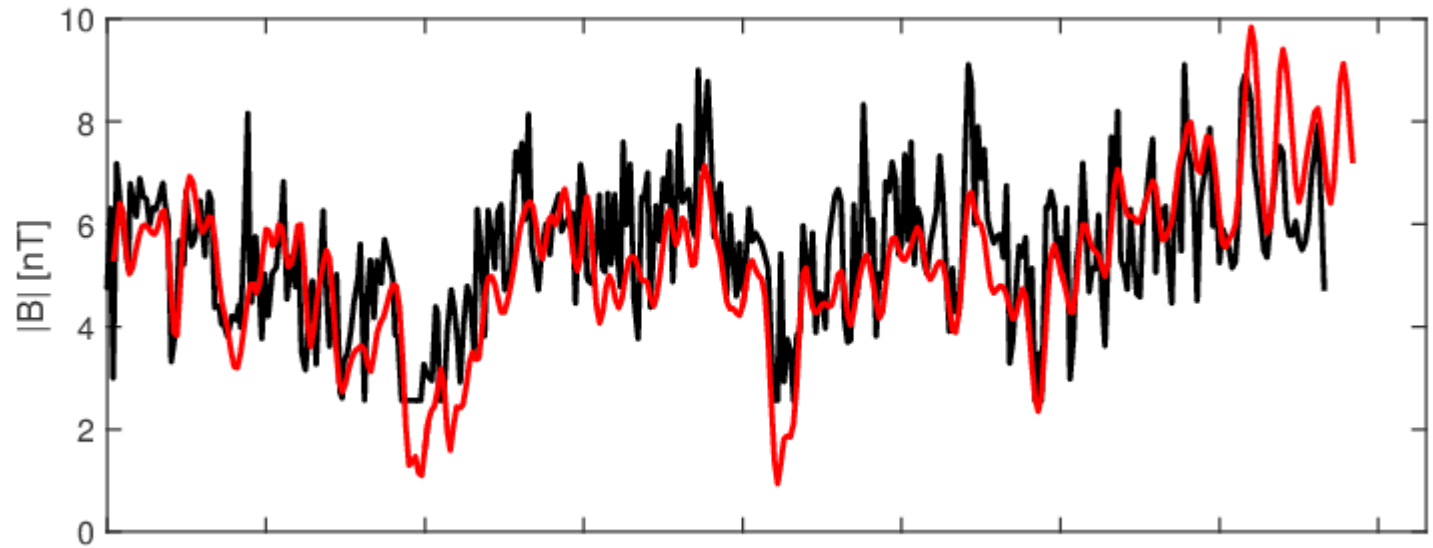
Owens et al.,
ISSI workshop.
JGR, under review.

GALACTIC COSMIC RAYS

^{10}Be :

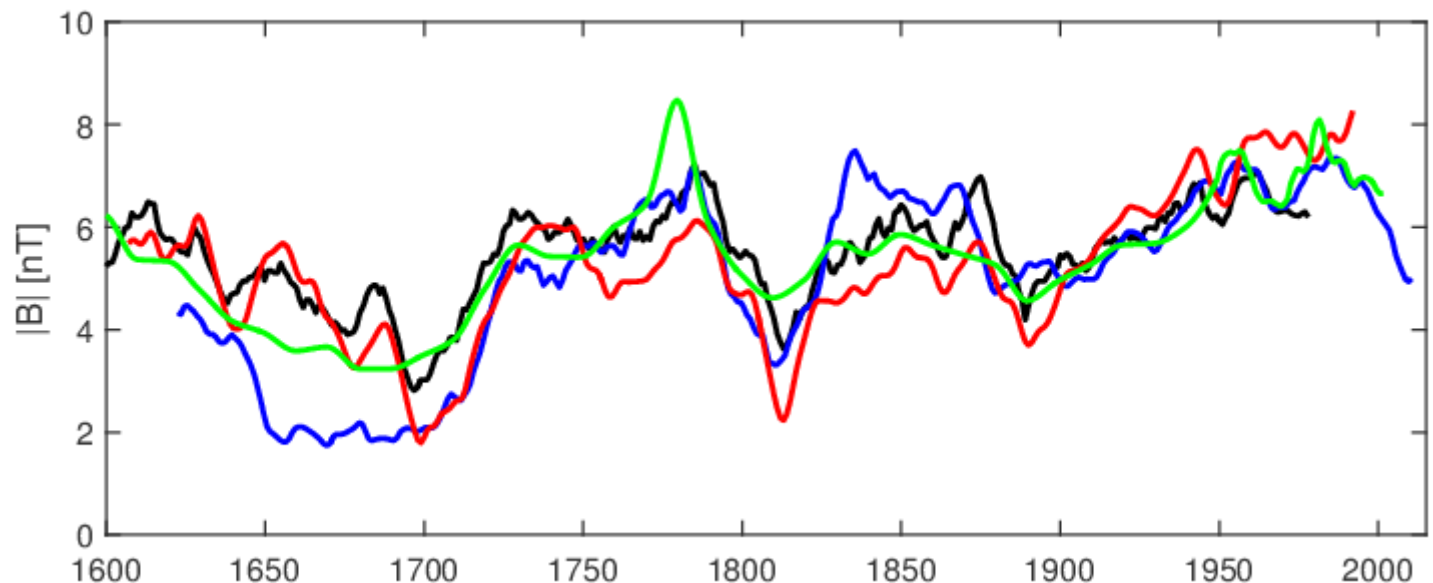
McCracken &
Beer, *Sol. Phys.*,
2015

Usoskin,
Liv. Rev., 2013



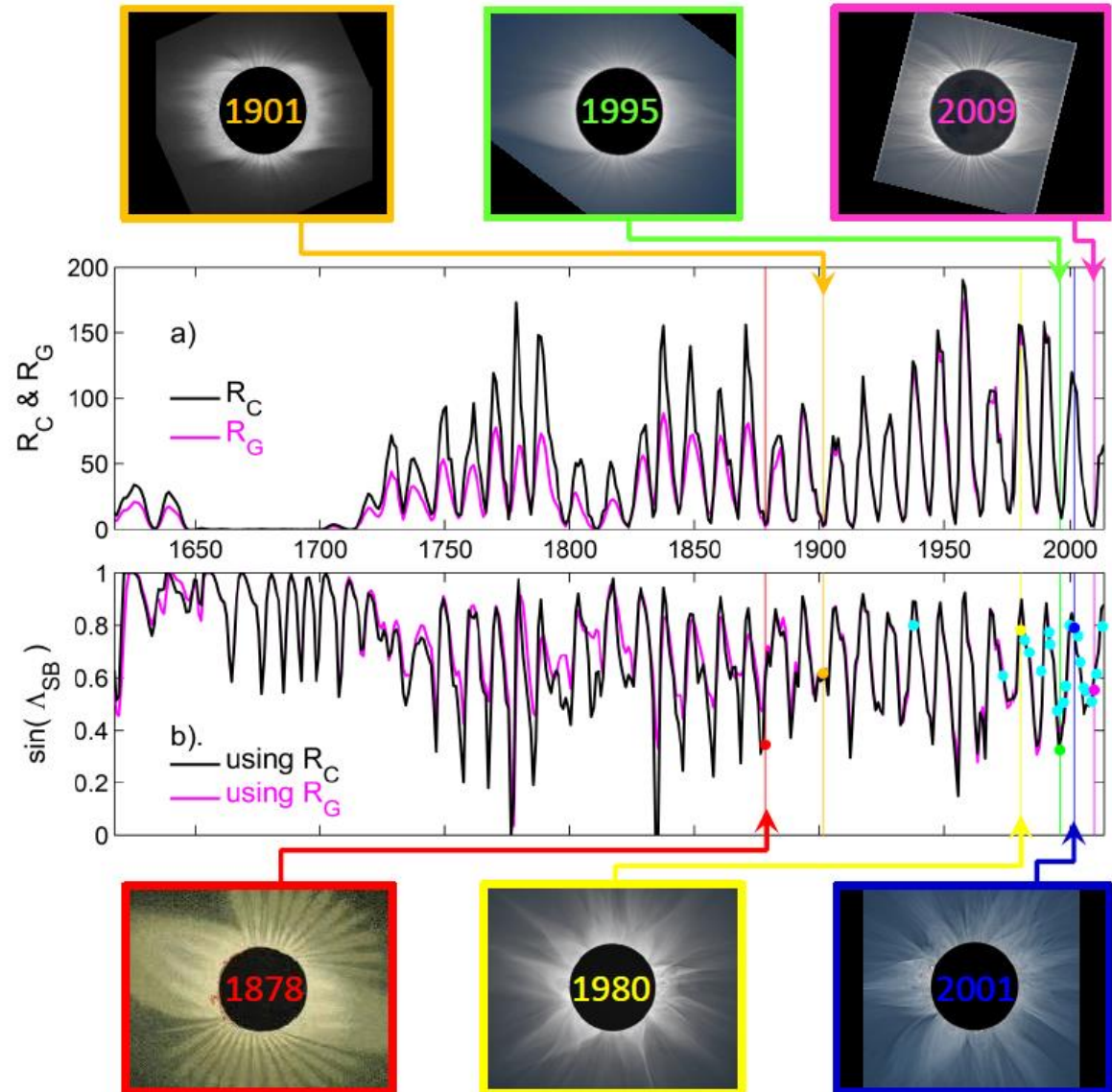
SSN: Owens &
Lockwood,
JGR, 2012

^{14}C : Lockwood
& Frohlich, *Proc.*
Roy. Soc., 2008

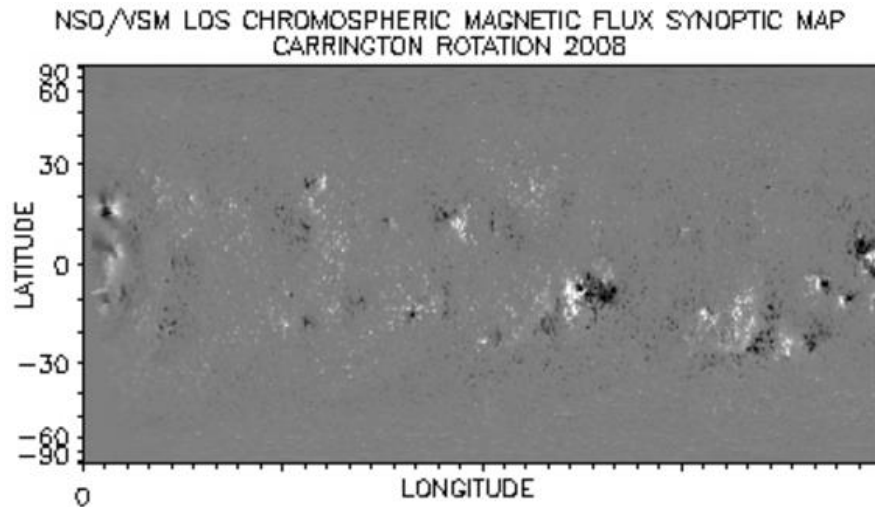


STREAMER BELT WIDTH

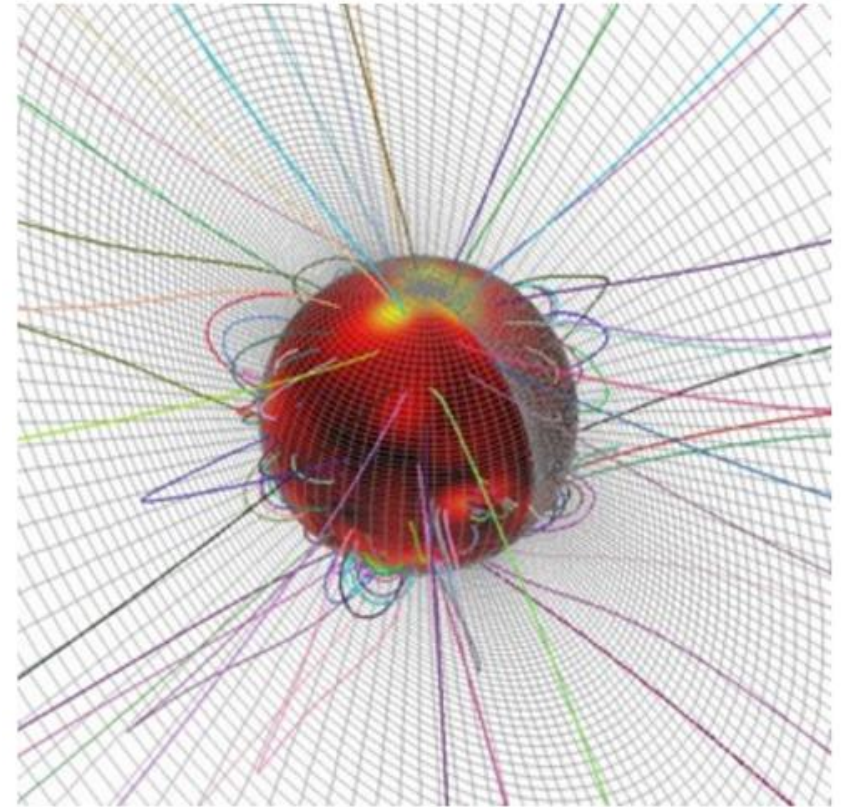
- Assume new flux enters the streamer belt
 - Time constant for conversion to coronal hole field
 - E.g., Schwadron et al, ApJ, 2010
- Allows estimate of streamer belt width
 - Lockwood and Owens, ApJ, 2014
 - Matches eclipse observations



GLOBAL SOLAR WIND

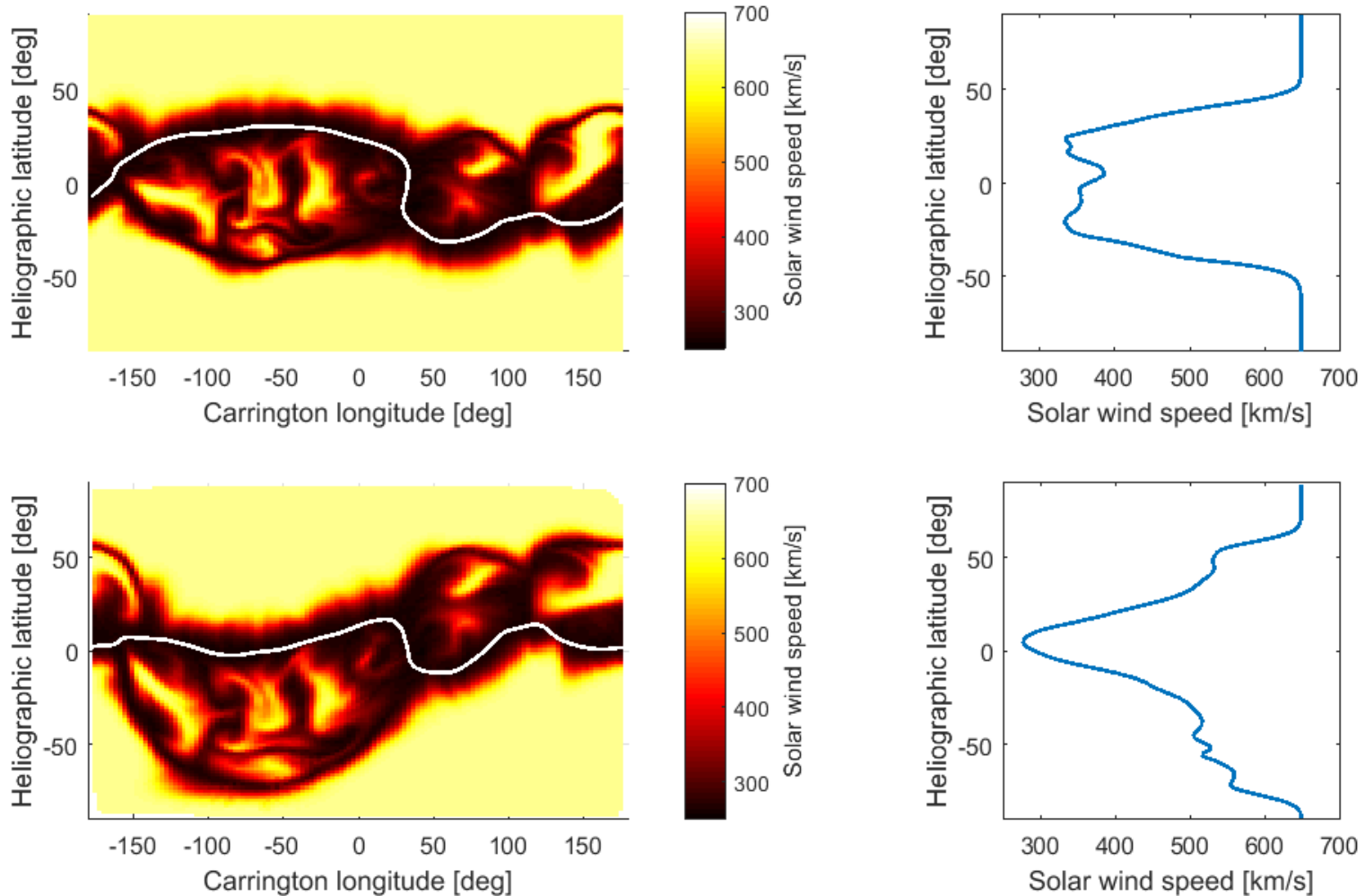


SOLIS magnetogram (CR2008)

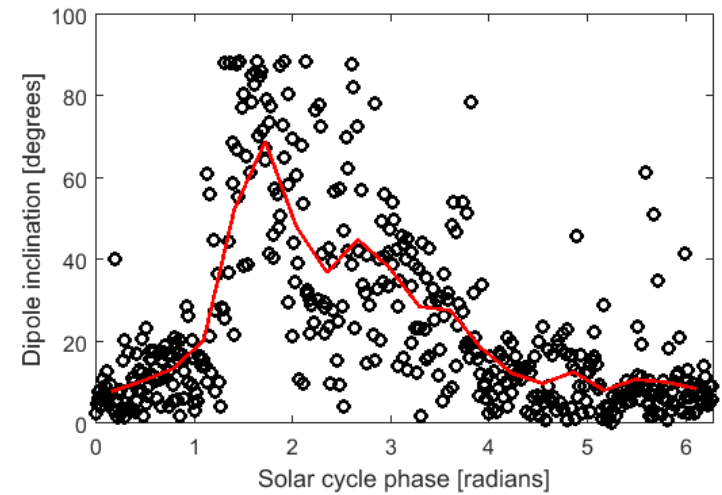
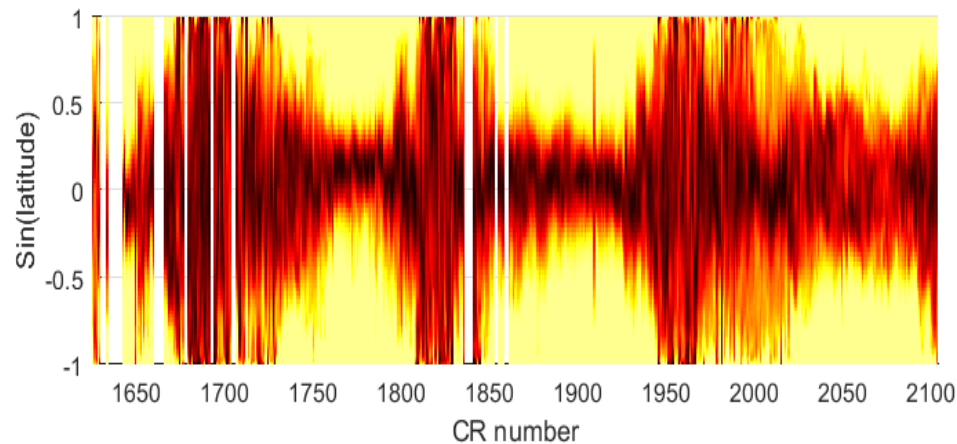
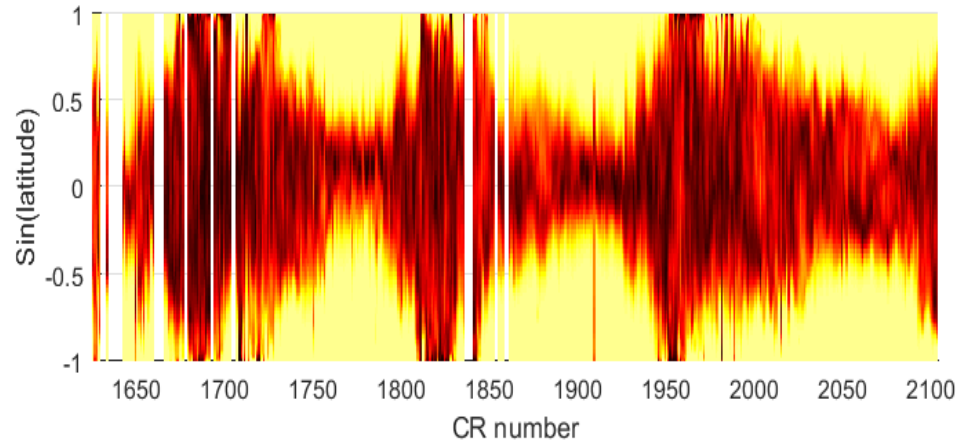


MAS (Predictive Science)
e.g., Linker et al., 1999; Riley et al, 2001

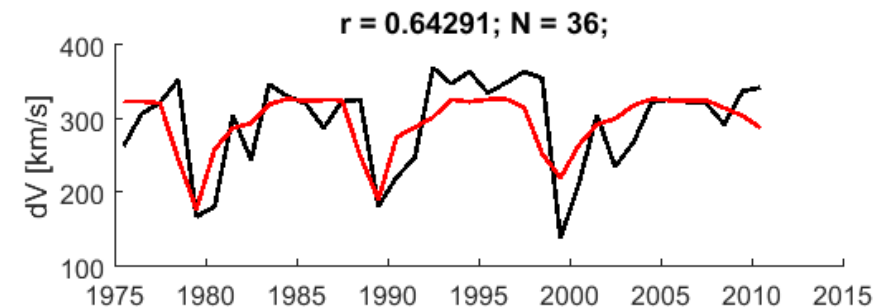
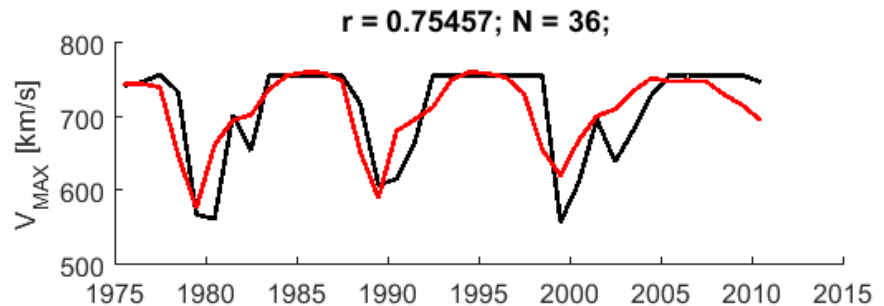
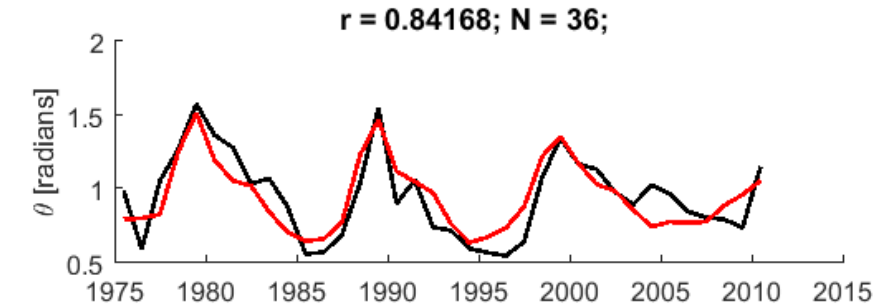
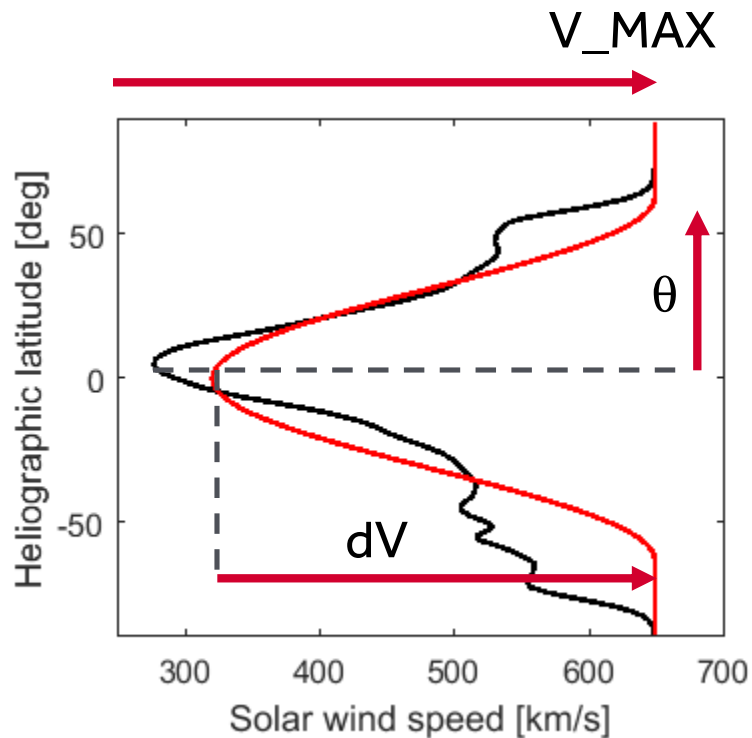
CALIBRATION: MAS (MAGNETOGRAMS)



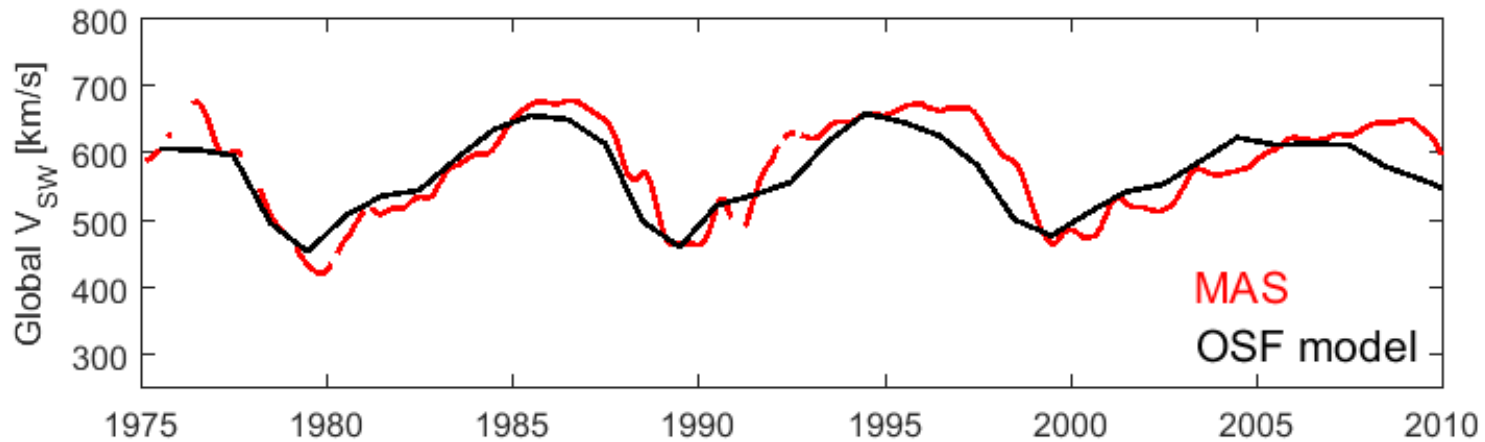
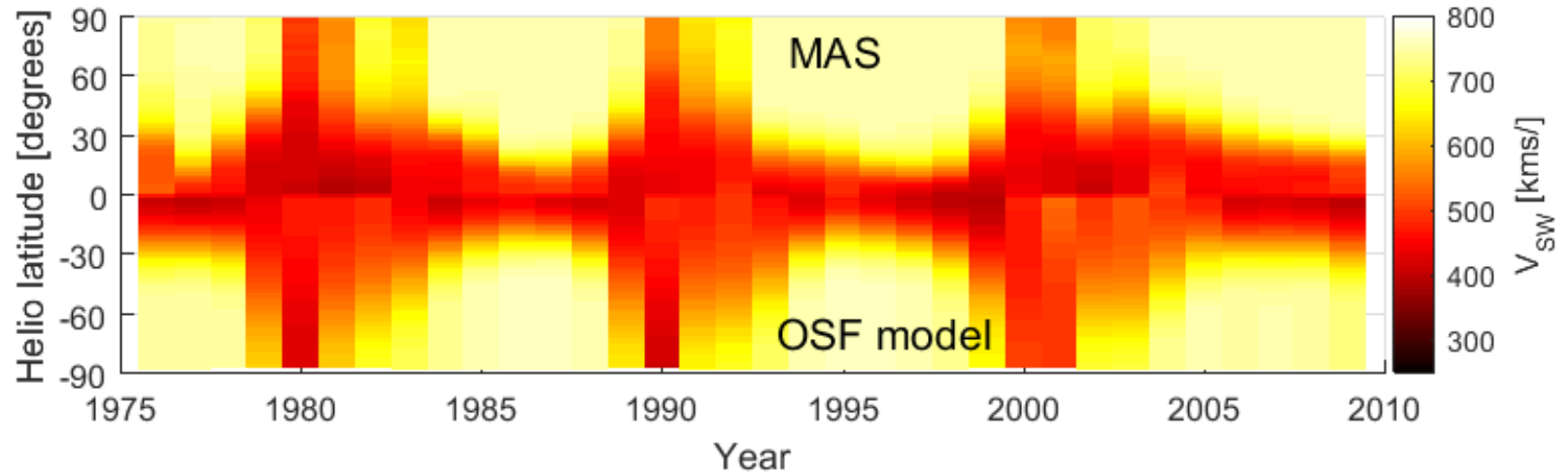
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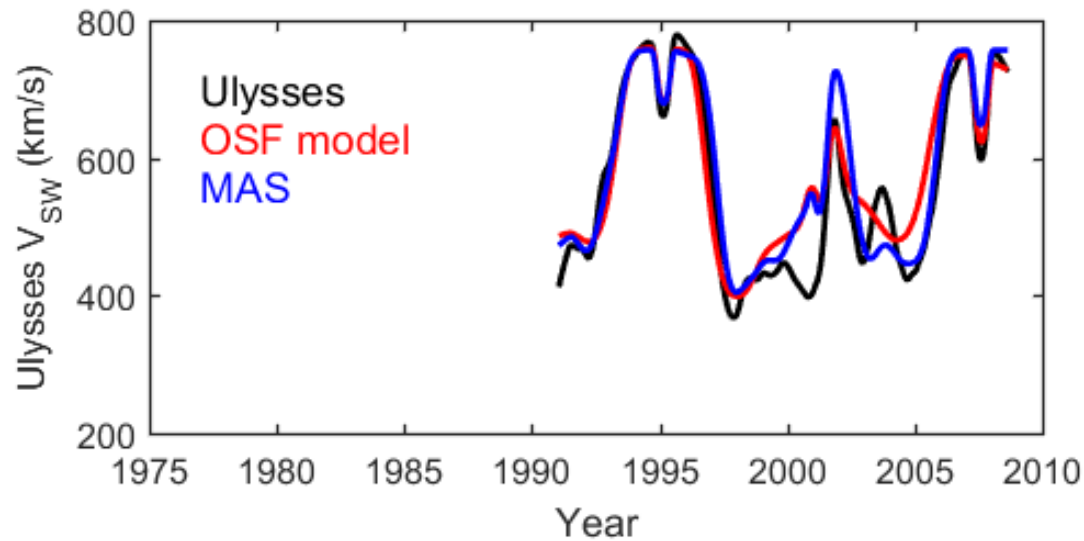
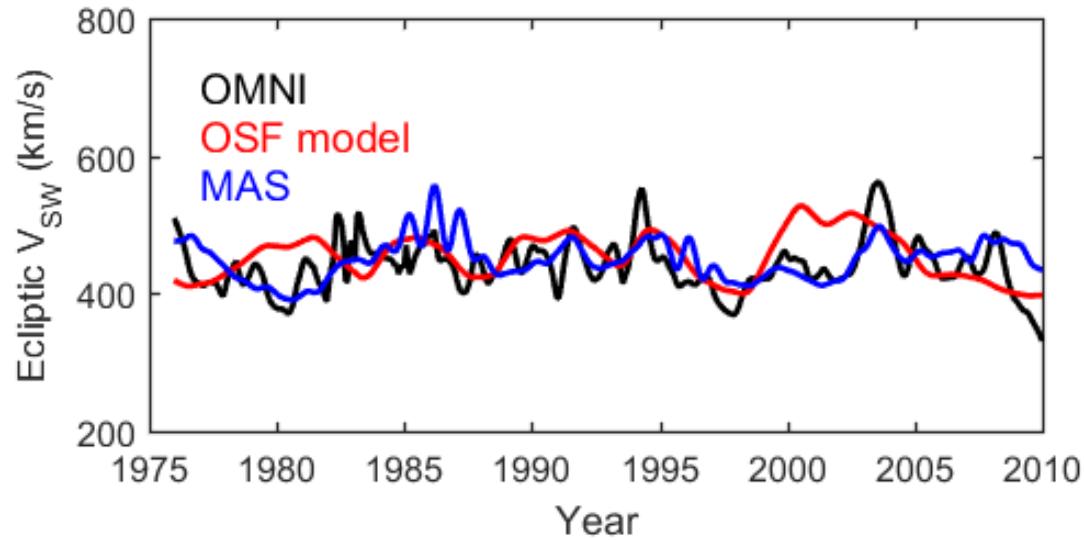
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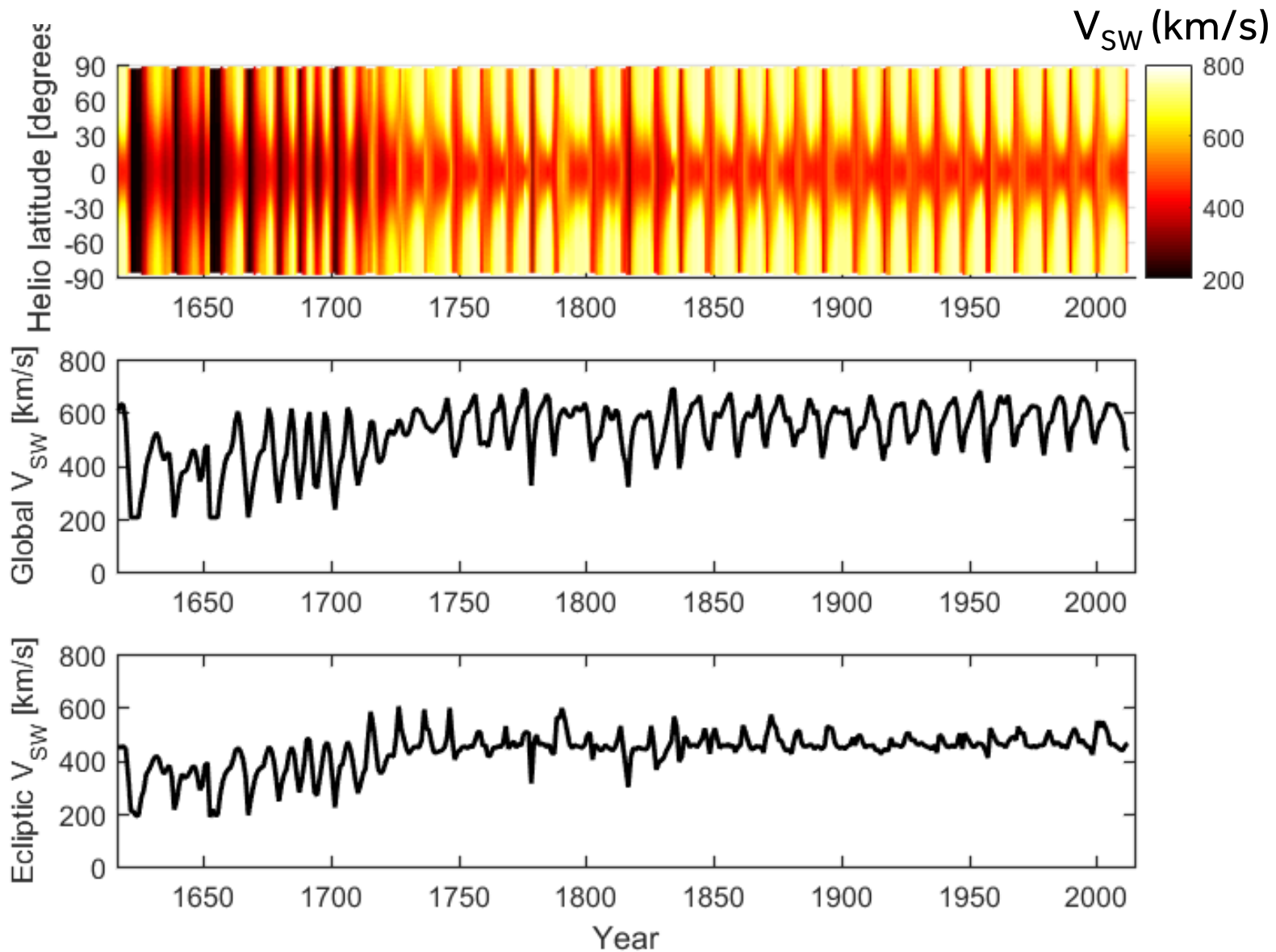
CALIBRATION: MAS (MAGNETOGRAMS)



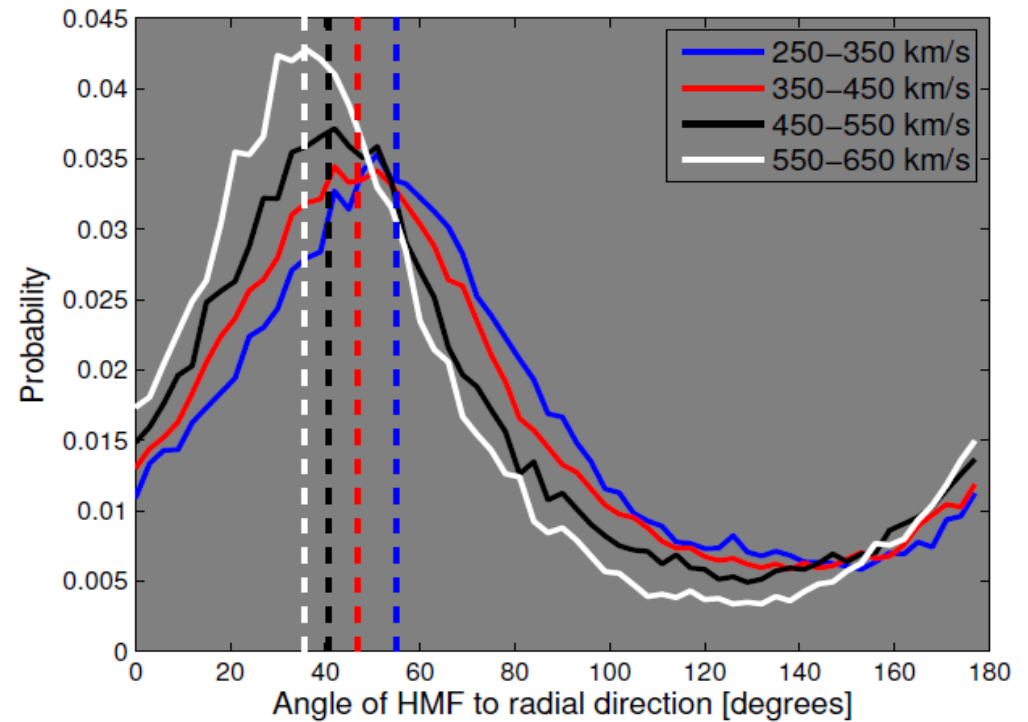
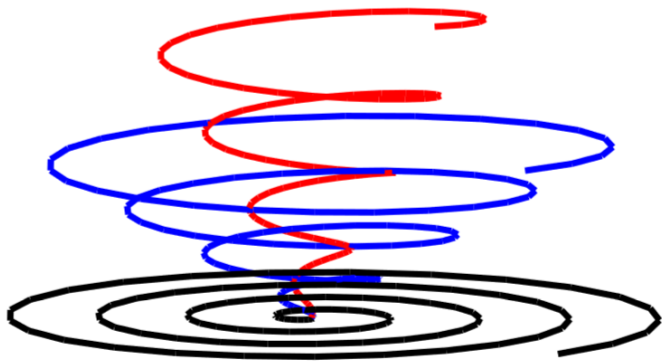
SPACECRAFT DATA



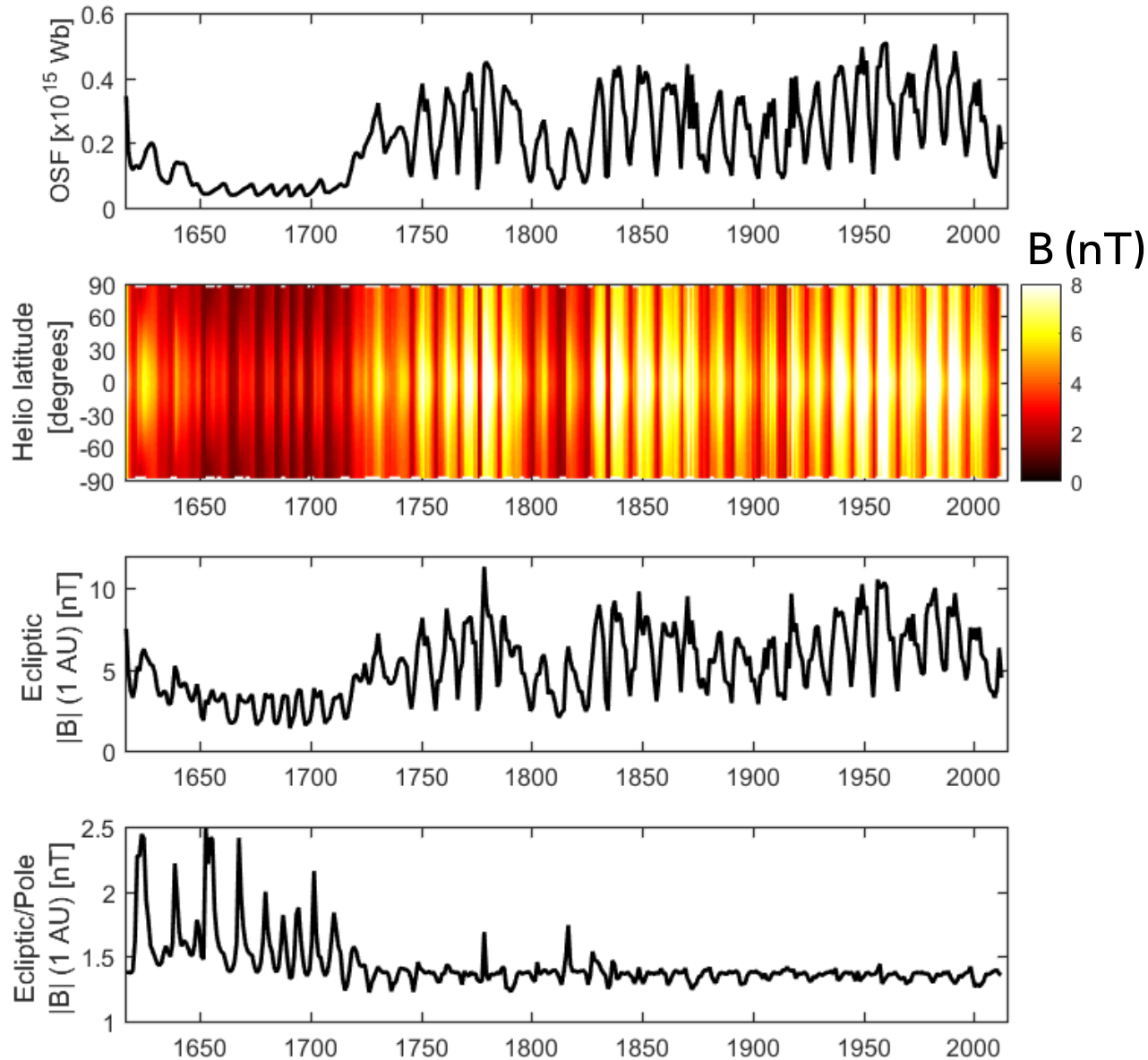
SOLAR WIND SPEED



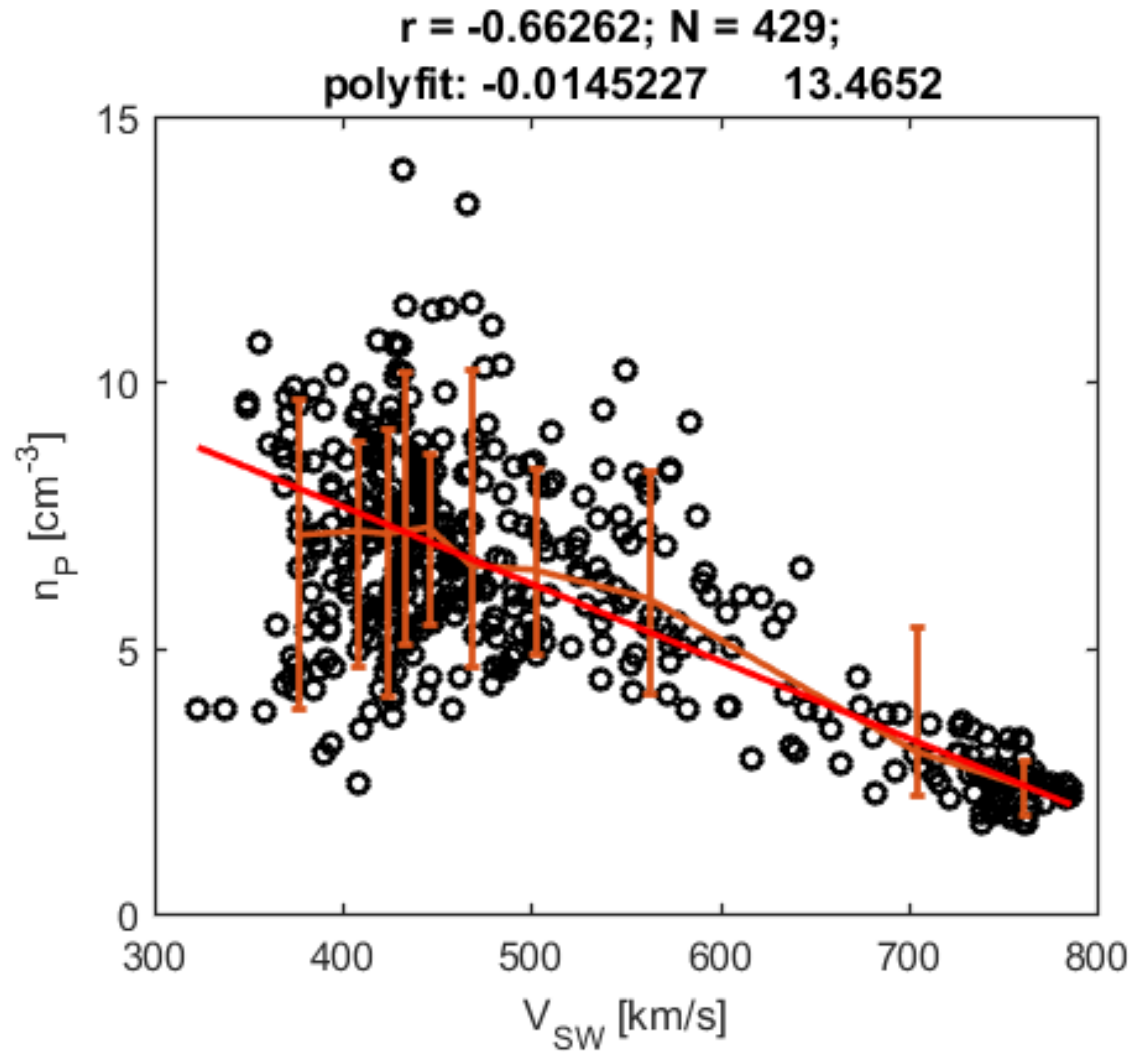
PARKER SPIRAL



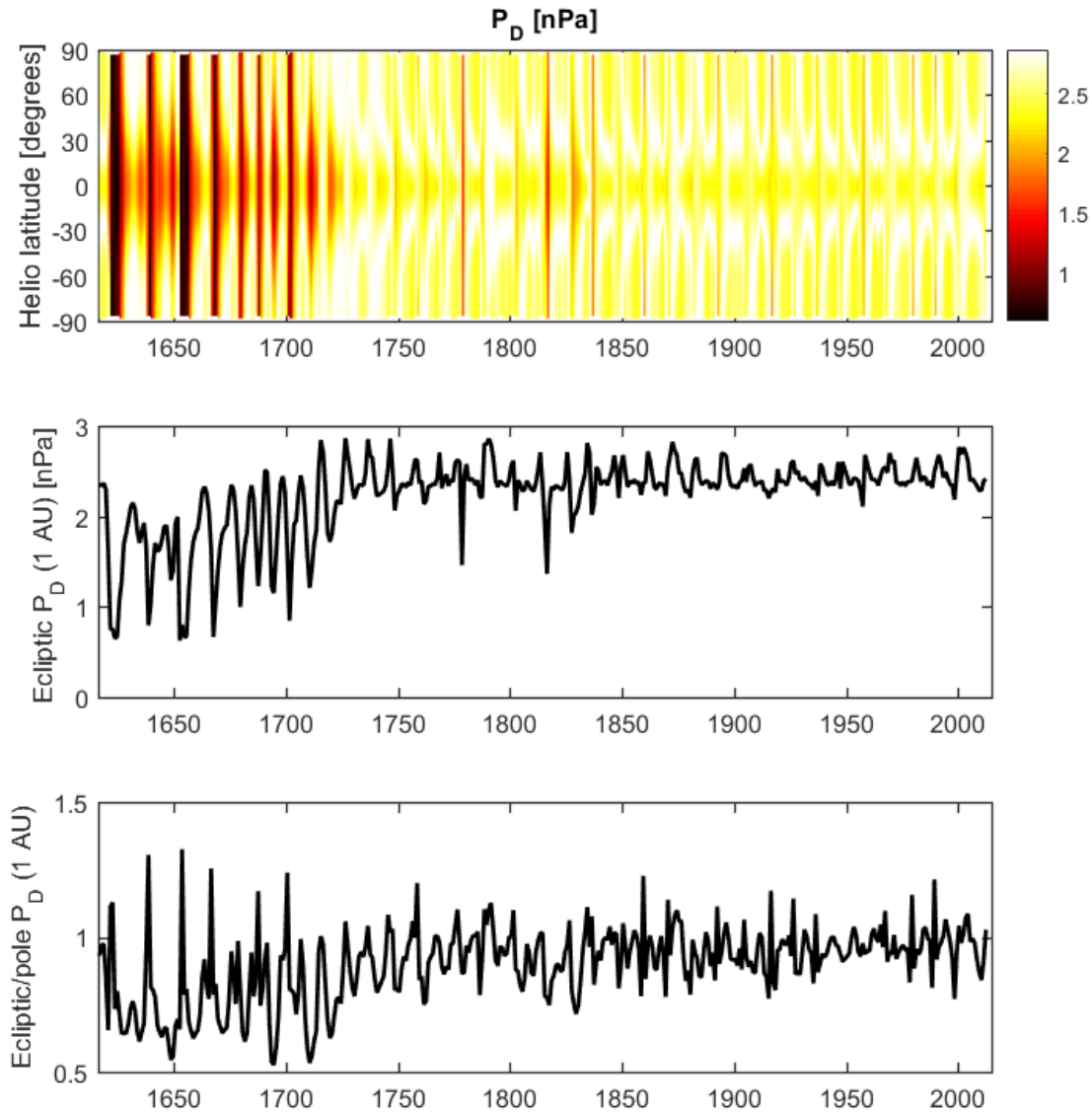
MAGNETIC FIELD (1 AU)



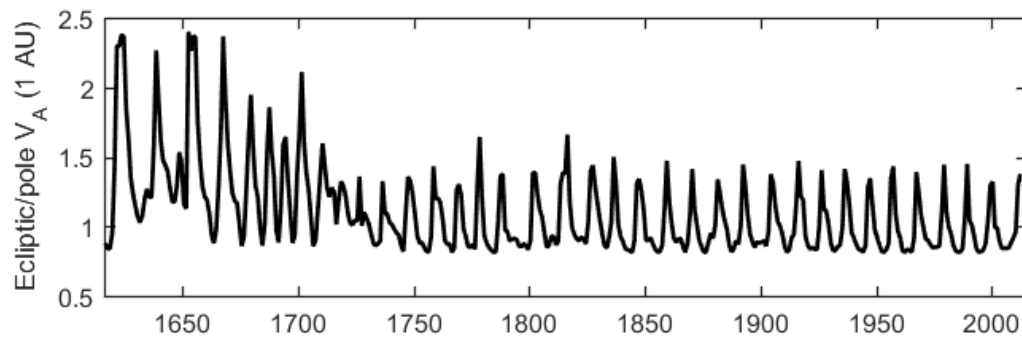
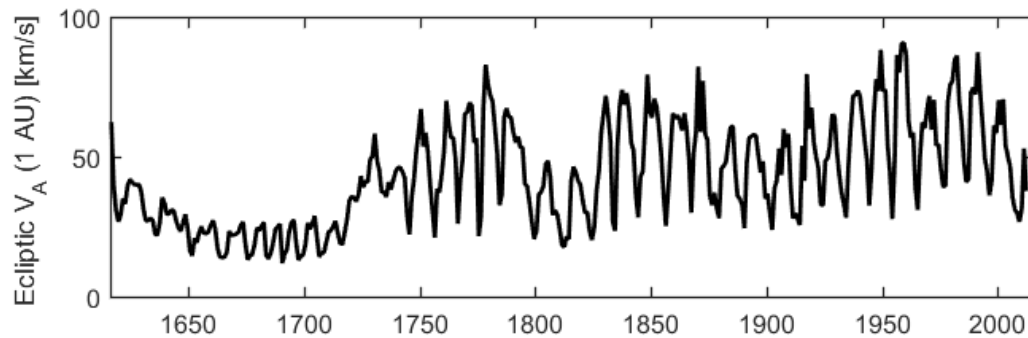
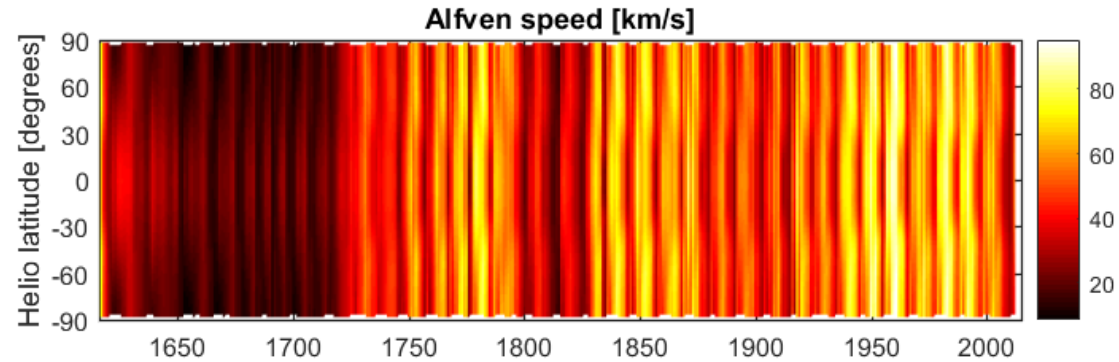
MASS FLUX



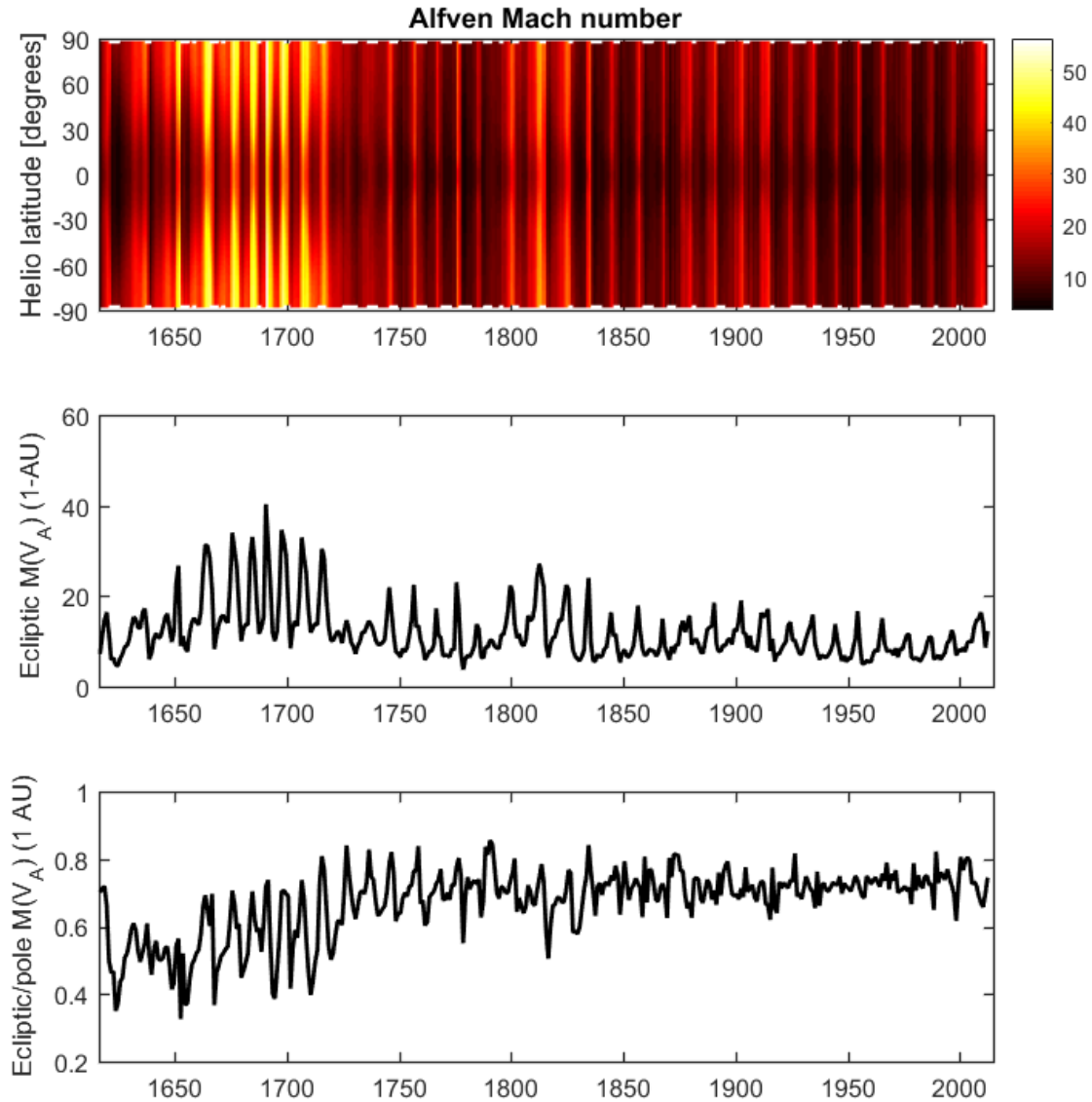
DYNAMIC PRESSURE (1 AU)



ALFVEN SPEED (1 AU)



ALFVEN MACH NUM. (1 AU)



SUMMARY

- Annual open solar flux (OSF) can be reconstructed from sunspot records
 - Streamer belt width can also be reconstructed
- Reconstruct zonal mean V_{SW} at annual resolution back to 1610(ish)
 - Assuming Parker spiral, can estimate B
 - Assuming constant mass flux, estimate n_p
- Ecliptic V_{SW} shows little variability after ~1720. Global V_{SW} shows strong solar cycle variation
 - During Maunder min (MM), approx 30% lower
- B varies less than OSF (from ~6 nT to ~2 nT during Maunder min).
 - B has stronger solar cycle variation in MM than OSF
 - Ratio of ecliptic-to-pole B is ~constant (~1.5) after ~1720
 - Much larger during MM (up to ~ 2.5)
- Dynamic pressure approx symmetric after ~1720
 - ~40% lower over poles during MM

IMPLICATIONS

- Coming cycles similar to MM? If so, what can we expect?
 - Lower dynamic pressure, magnetopause standoff $> 15 R_E$
 - Displacement of the auroral oval?
 - Different propagation and interaction of CMEs with m'sphere?
 - Reduced Alfvén speed – increased Mach number (up to factor 4)
- Cosmogenic radionuclide reconstructions of grand minima
 - Reduced solar wind speeds also affect heliospheric modulation
 - Heliosphere size and asymmetry: GCR drift patterns
 - More effective SEP acceleration?