

SOLAR IRRADIANCE VARIABILITY: KNOWN AND UNKNOWN

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With thanks to: K.L. Yeo, C.J. Wu, A. Shapiro, S.K. Solanki



SUN - CLIMATE



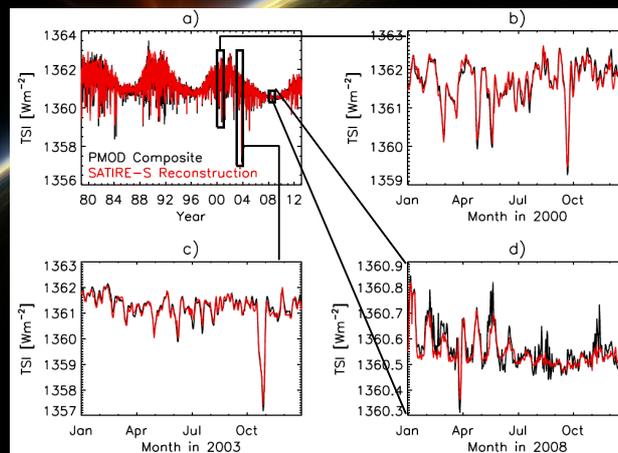
<http://www.mps.mpg.de/projects/sun-climate/>

DRIVER OF THE VARIABILITY

😊 Over 96% of the measured variability is reproduced by models assuming surface magnetism is the driver

- Input: direct measurements of the surface magnetic field - NO proxy - over 1974-2015
- Single value of the free parameter, fixed independently of any TSI composite
- Consistent with spectral irradiance measurements where they are reliable

😞 No evidence for alternative sources on time scales longer than observed



Yeo et al. 2014

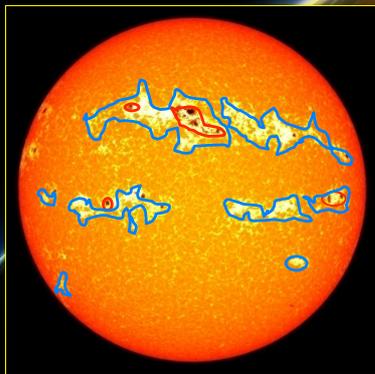
PROXY MODELS

Combine

- sunspot darkening, e.g. **PSI**,
- with facular/plage/network brightening, **Facular Proxy** (e.g. Mg index, Ca II, F10.7)
- via linear or multiple regressions

$$\Delta S(t) = k_1 \Delta PSI(t) + k_2 \Delta FP(t)$$

☹️ ≥ 2 free param. at *each* wavel.



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SEMI-EMPIRICAL MODELS

Combine

- surface area coverage and ideally positions – **change with time, t**
- brightness of each component (depend on wavelength and disc position)
- calculated from semi-empirical model atmospheres (e.g., Kurucz models, Fontenla et al. 1999, 2009, 2011; Unruh et al. 1999; Shapiro et al. 2010) using spectral synthesis codes (e.g., SRPM, ATLAS9 or NESSY 🇨🇦)

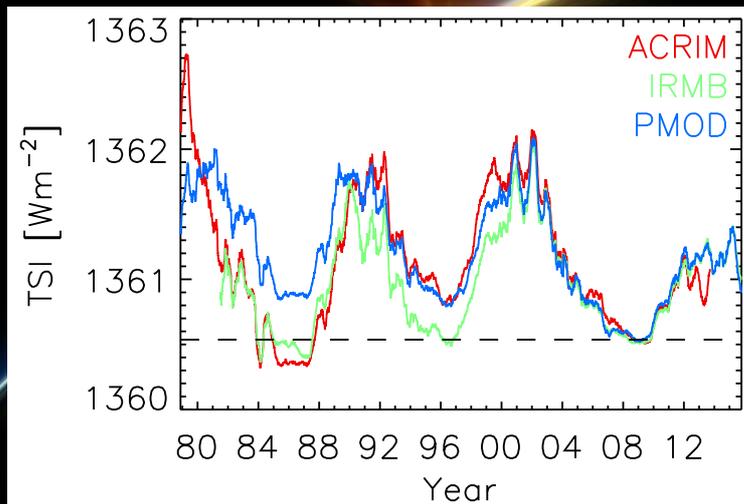
$$\Delta S(t) = \Delta \alpha_s(t) I_s(\lambda) + \Delta \alpha_f(t) I_f(\lambda)$$

The variability always comes from the change in the surface distribution, i.e. from **proxies** of surface magnetism with a **single exception** - SATIRE-S based on direct MF measurements

☺️ ≥ 1 free param.
(TSI & SSI in a single run)

SECULAR CHANGE IN MEASUREMENTS:

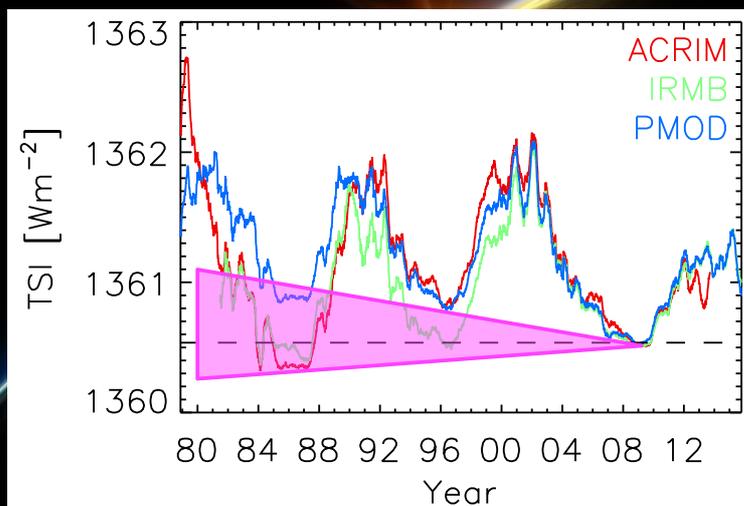
☹️ Decadal and longer-term changes – uncertain

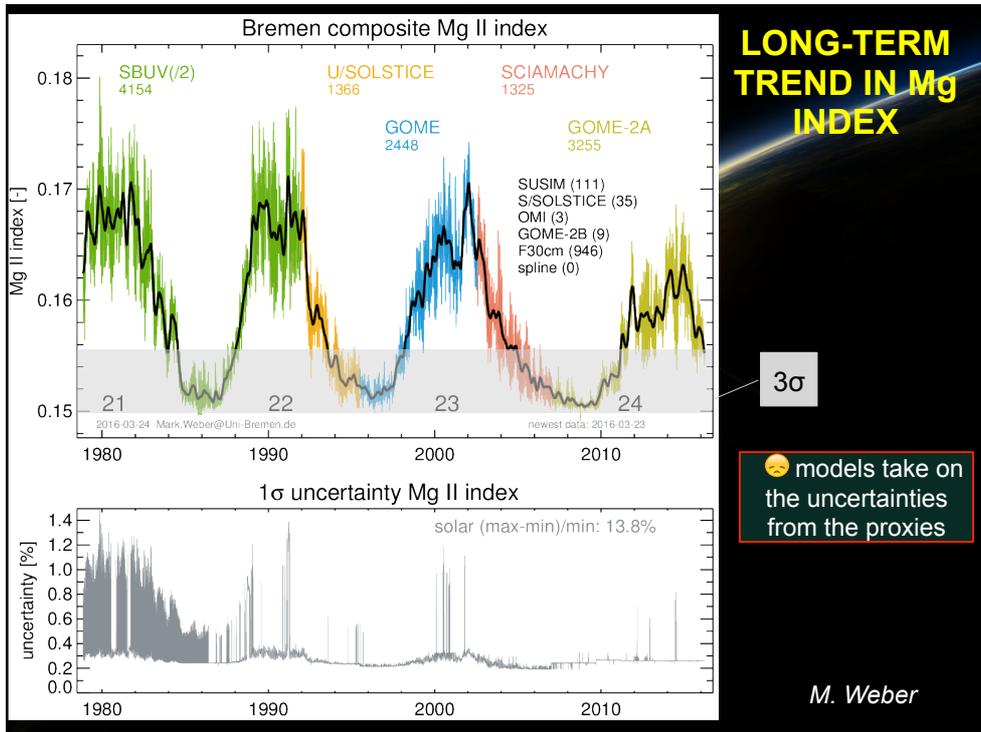


SECULAR CHANGE IN MEASUREMENTS:

☹️ Decadal and longer-term changes – uncertain

☹️ Linear extrapolations into the past – yet more uncertain



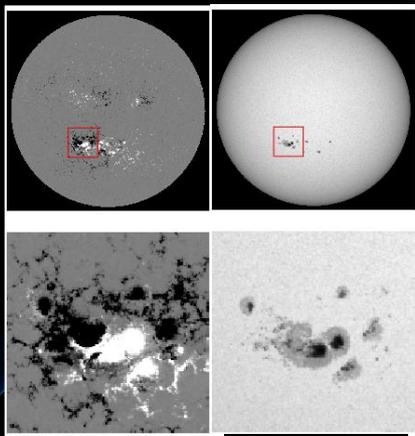




Spectral And Total Irradiance Reconstructions for the Satellite era (SATIRE-S)

Magnetograms and continuum images
KP/512, KP/SPM, SoHO/MDI, SDO/HMI

Intensity spectra, $I_s(\lambda)$ - from semi-empirical model atmospheres;
time-independent



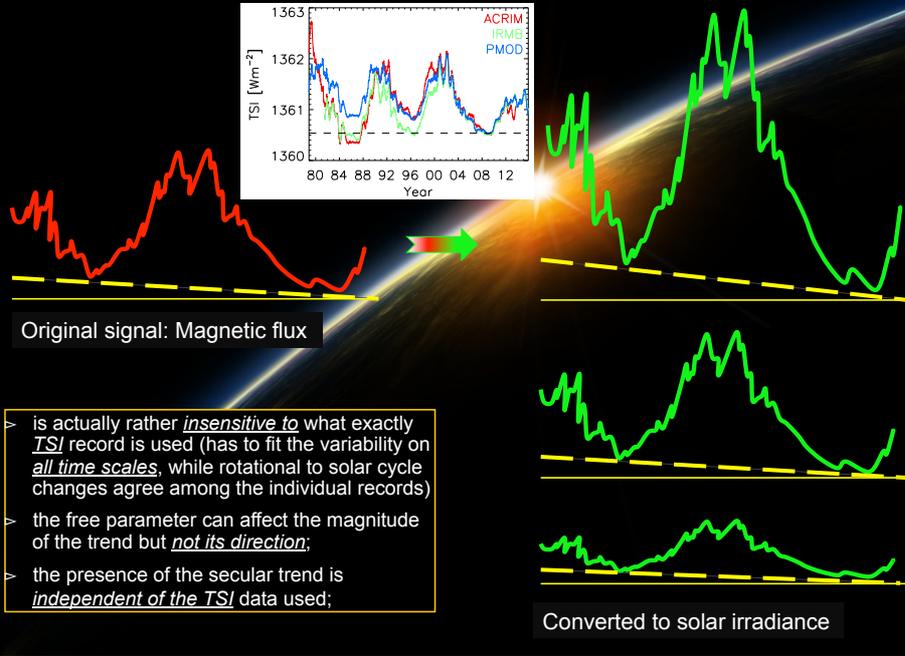
$$\Delta S(t) = \Delta \alpha_s(t) I_s(\lambda) + \Delta \alpha_f(t) I_f(\lambda)$$

The fractional disc coverage is directly related to the magnetic field

- The conversion factor MF \Rightarrow area coverage is the only free parameter;
- It only scales the amplitude of the variations (by roughly the same factor on all times scales – days, weeks, solar cycle, decades!)

Yeo et al. 2014

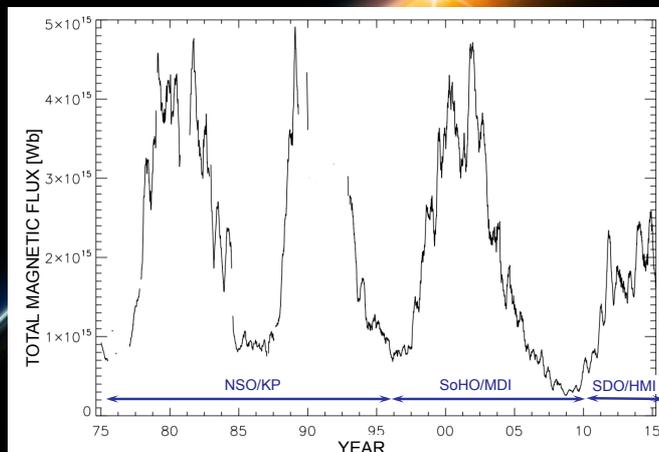
LONG-TERM TREND IN SATIRE-S



LONG-TERM TREND IN SATIRE-S

☹️ TSI has been declining from minimum to minimum

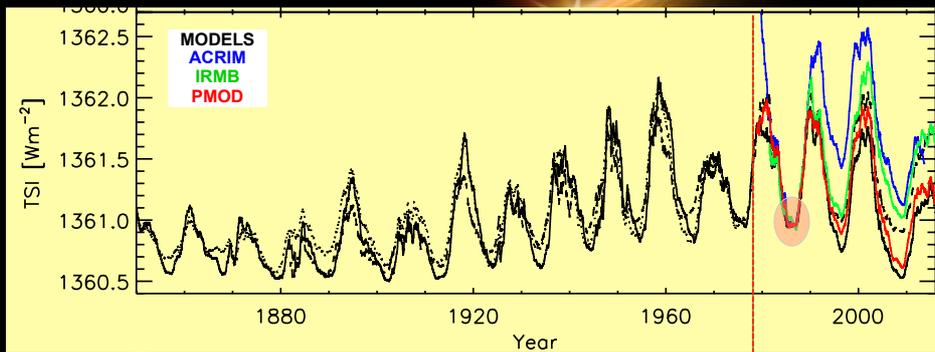
☹️ The exact magnitude of the secular change even over the last decades is uncertain



LONG-TERM TREND

😊 Over space era - the two models agree well within the observational uncertainty

😊 Before space era - the two models agree even better !

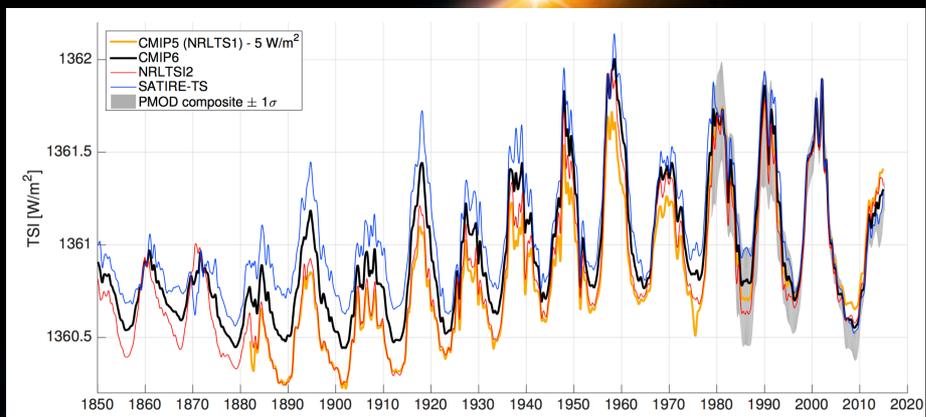


Sunspot Areas

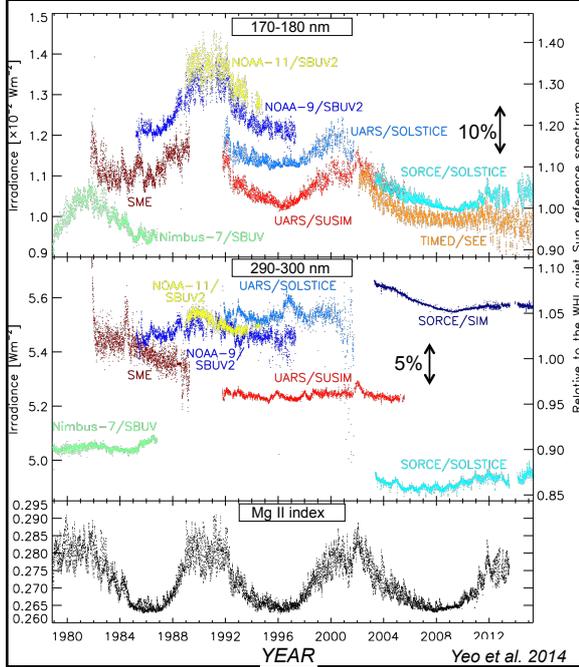
Spot Areas + Mg II, NRLTSI [dashed]
Magnetic field, SATIRE-S [solid]

LONG-TERM TREND

😞 PLEASE, do not be misled by the plot in CMIP6 GMDD paper



Solar Spectral Irradiance



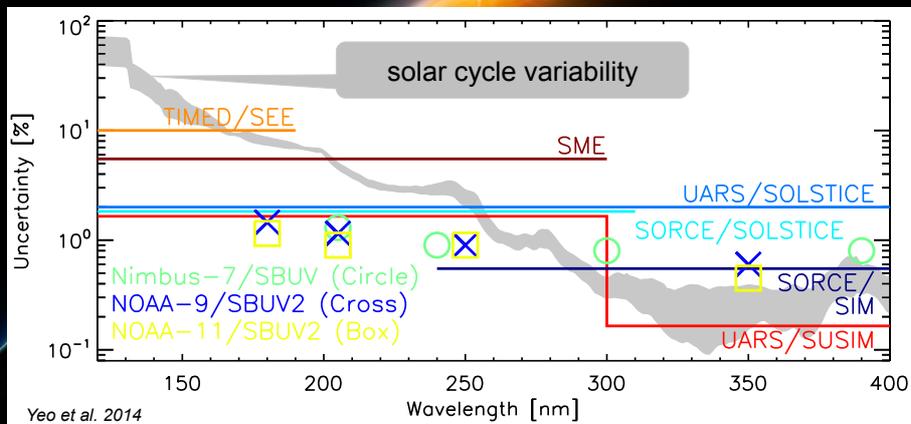
😊 Variability below 250 nm well known

What about near-UV ?

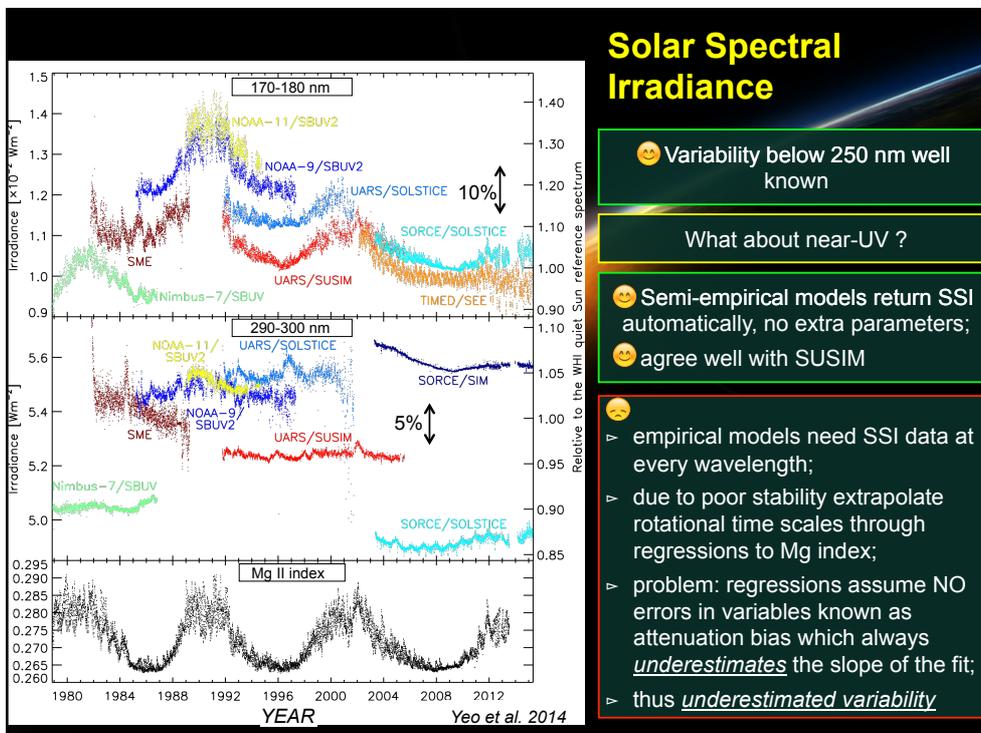
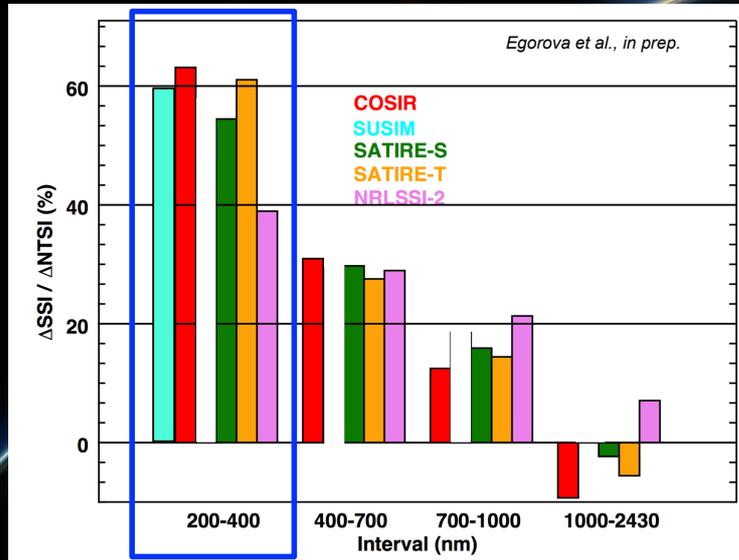
MEASUREMENTS OF UV IRRADIANCE

☹️ Solar cycle variability above 250-300 nm \leq uncertainty, for all instruments

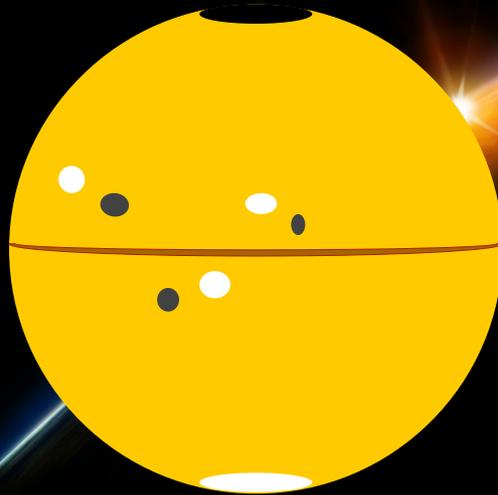
😊 UARS/SUSIM is just around the limit



SSI VARIABILITY 2003-2009

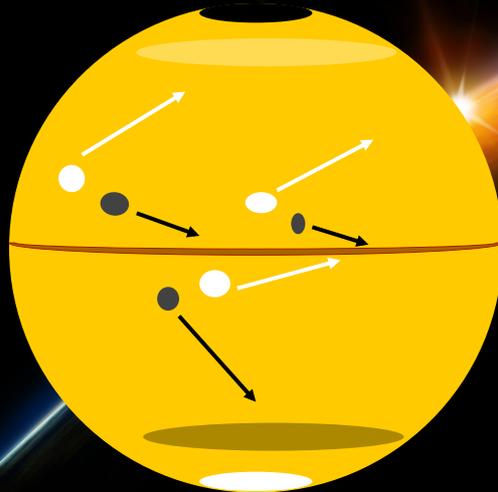


CAN WE PREDICT SOLAR ACTIVITY?



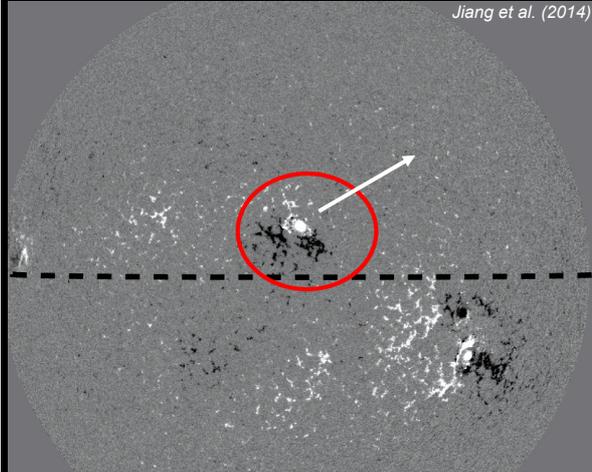
- Active regions emerge in pairs with opposite polarities;
- The leading polarity is reversed in the two hemispheres;

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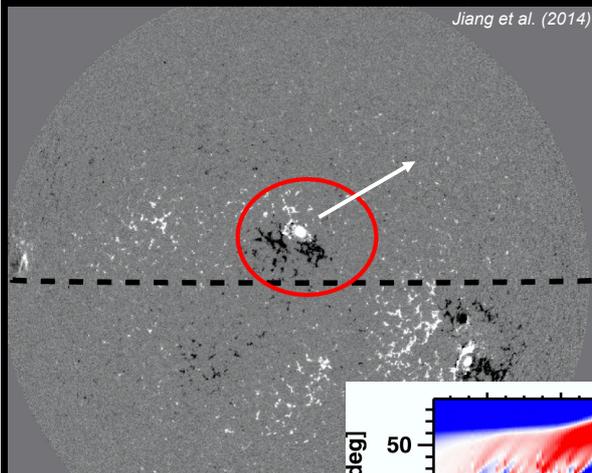
- Active regions emerge in pairs with opposite polarities;
- The leading polarity is reversed in the two hemispheres;
- The leading polarities cancel out when crossing the equator;
- The following polarities form the polar field, which determines the strength of the next cycle

CAN WE PREDICT SOLAR ACTIVITY?



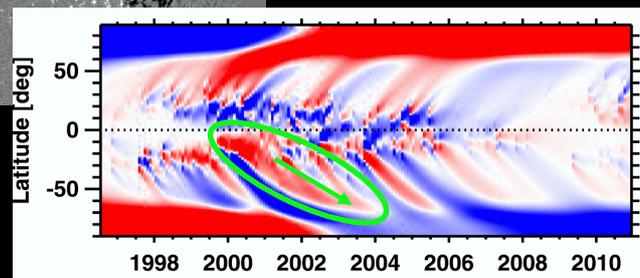
- In cycle 23, a few large active regions with wrong polarities emerged close to the equator;
- The leading wrong polarity went to the pole and cancelled the flux there;

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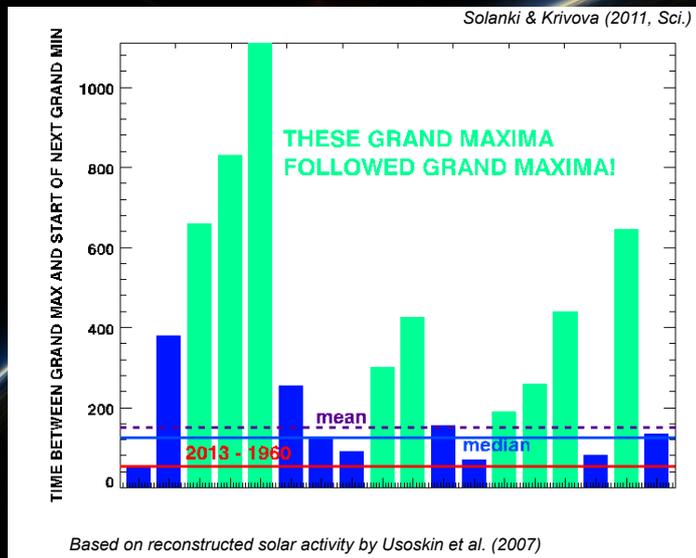
- In cycle 23, a few large active regions with wrong polarities emerged close to the equator;
- The leading wrong polarity went to the pole and cancelled the flux there;
- The MF accumulated at poles was low;
- Next solar cycle - C24 - turned to be low

☹️ Randomness makes predictions impossible



CAN WE PREDICT SOLAR ACTIVITY?

☹️ ... also statistically



Summary

- ☹️ TSI has been declining from minimum to minimum
- ☹️ The exact magnitude of the secular change even over the last decades is uncertain
- ☹️ Variability below 250 nm well known
- ☹️ Above 250 nm: semi-empirical models agree well with SUSIM, the only instrument with the stability sufficient to detect the solar cycle variability
- ☹️ Attenuation bias is responsible for weaker variability in empirical models; when taken into account – the variability is similar to that in semi-empirical models and SUSIM
- ☹️ Randomness makes predictions impossible