



Including ephemeral regions in surface flux transport simulations and solar irradiance reconstructions

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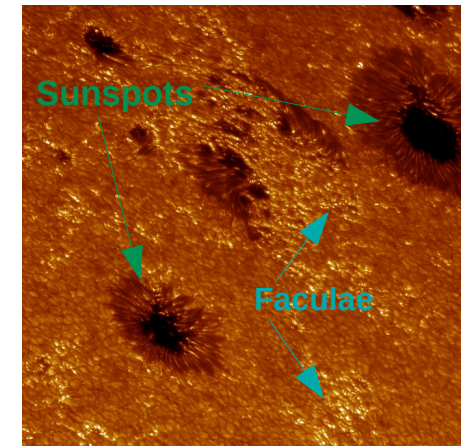
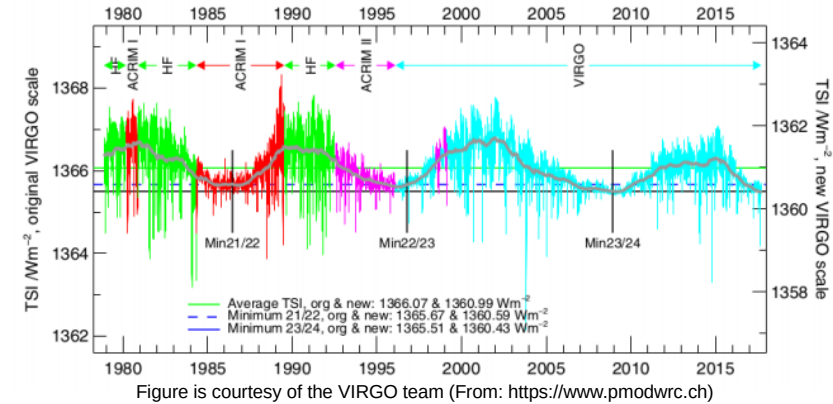
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Total solar irradiance and magnetic activity



- Total solar irradiance (**TSI**) is an important input to climate models.
- Before 1978, TSI can only be retrieved through **reconstructions** from proxies.
- **Magnetic features** drive the solar variability.
- ➔ The longest direct proxies of the surface magnetism are **sunspot number records**.



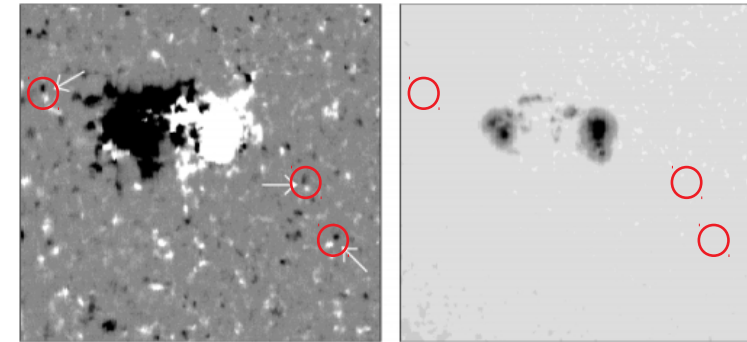
Credit to: Dan Kieselmann & Mats Löfdahl (Royal Swedish Academy of Science)
(From: <https://ttt.astro.su.se/news/20060913en.html>)



Ephemeral regions & SATIRE model



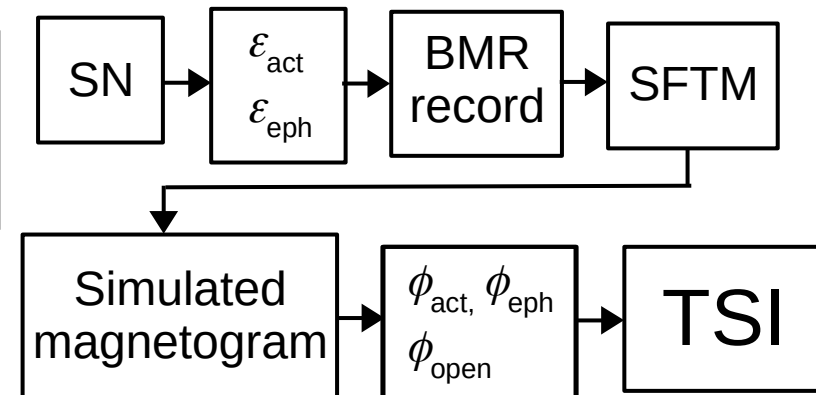
- **ERs** are short lived bipolar magnetic regions (**BMRs**) too small to feature sunspots.
 - They are important for secular TSI variation, but are *missed by SN records!*
- **Goal:** Reconstruct magnetic flux and TSI from a Surface Flux Transport Model (**SFTM**)
- TSI is reconstructed by the SATIRE model.



Magnetogram

Continuum Intensity

Adapted from: Harvey, K. L., 2001





Emergence model



- The emergence of **all BMRs** is described by a single **powerlaw size distribution**. (Krivova et al. 2021)
- Flux emergence (**exponent** m_{SN}) varies with the sunspot number (**SN**).
- Mean emergence **latitude** and **tilt angles** of **ARs** from the empirical relationships by Jiang et al. 2011.

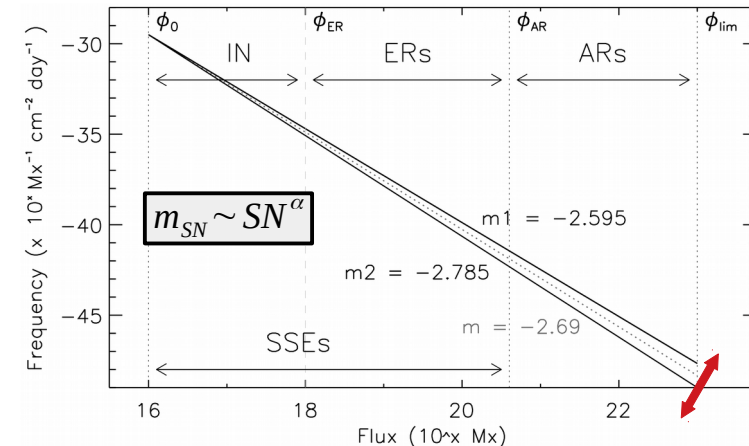


Figure adapted from Krivova et al. 2021

Average latitude

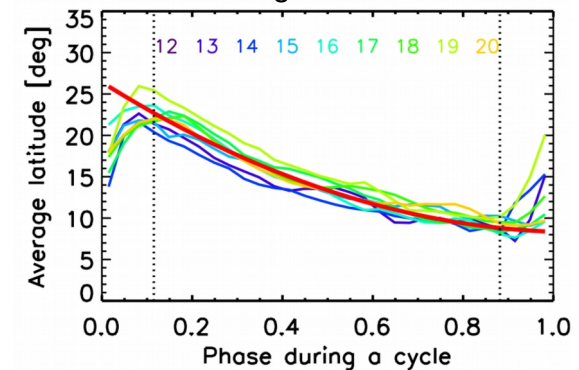


Figure from Jiang et al. 2011

Average tilt angle

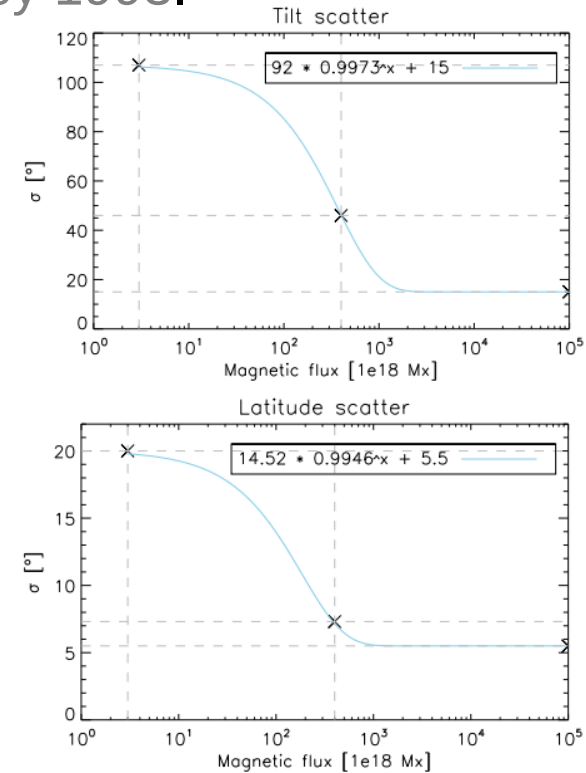
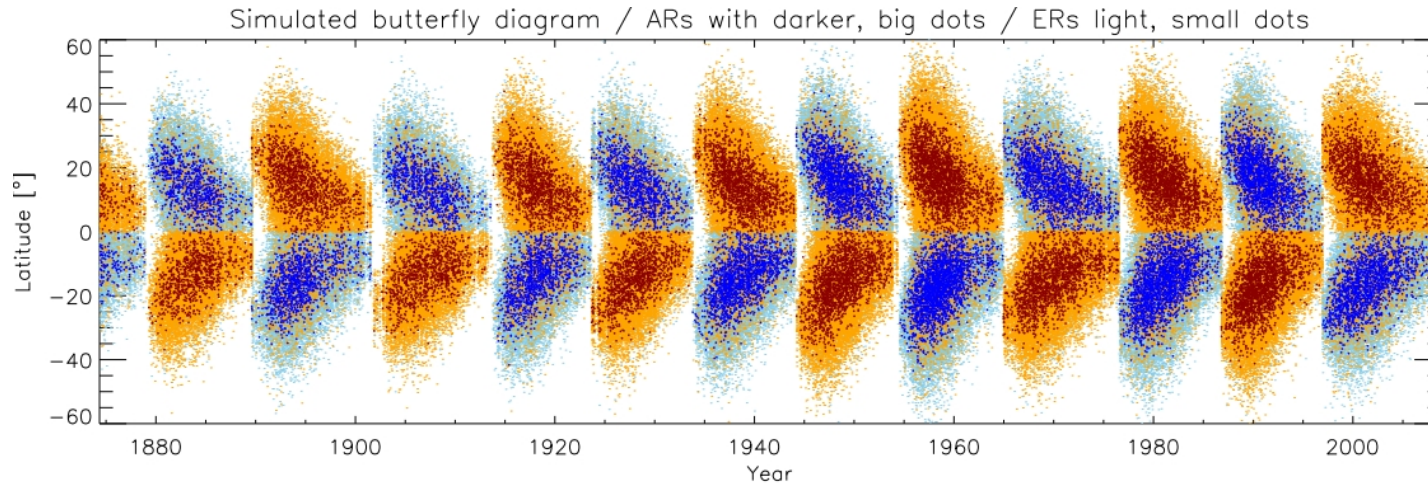
$$a_n = T_n \sqrt{(|(\lambda)|)}$$



Tilt and latitude scatter



- We estimate **tilt** and **latitude scatter** of **ERs** from Harvey 1993.
- The tilt scatter of **large ARs** is taken from Schunker et al. 2020: $\sigma_{\text{tilt}, \text{limit}} = 15^\circ$.





SFTM source function

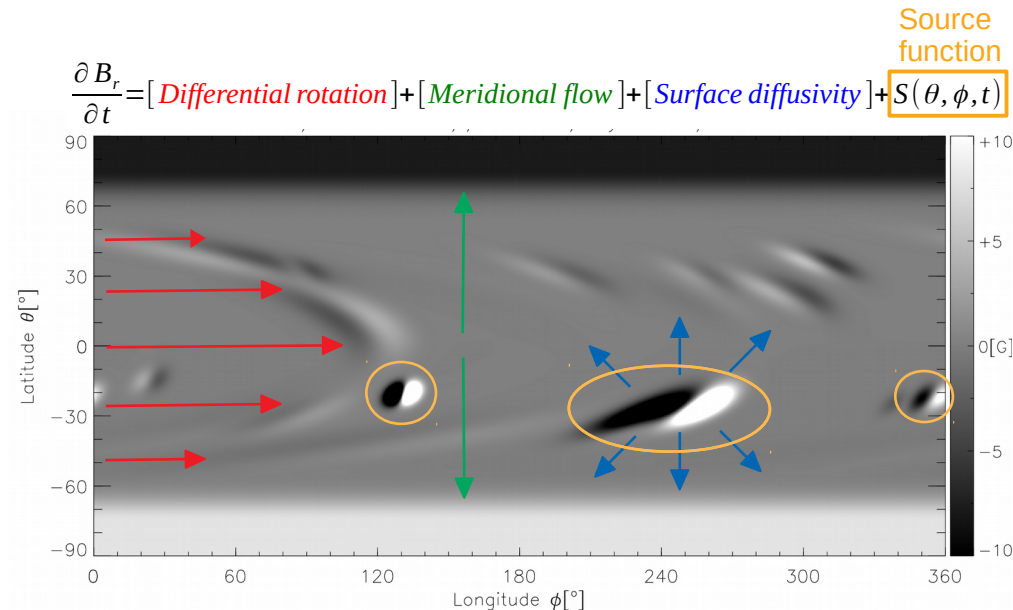


- The shape of BMRs in the SFTM depends on the **angular separation** ($\Delta\beta$)
- $\Delta\beta$ determines the **lifetime** of a BMR.
We estimate the expected lifetimes from Thornthorn&Parnell 2011 and Parnell 2009.
- We derive a relationship between $\Delta\beta$ and the **initial magnetic flux** ϕ_{BMR} :

$$\Delta\beta = 5.4 \times 10^{-11} \sqrt{\phi_{BMR} \times \frac{250 [G]}{B_{amp}}}$$

$$B_r^{\pm}(R_{\odot}, \theta, \phi) = B_{amp} \exp \left\{ \frac{-2[1 - \cos(\beta_{\pm}(\theta, \phi))]}{\delta_{init}^2} \right\}$$

(van Ballegooijen et al. 1998) $\delta_{init} = 0.4 \Delta\beta$... initial width
 $\Delta\beta$... angular separation



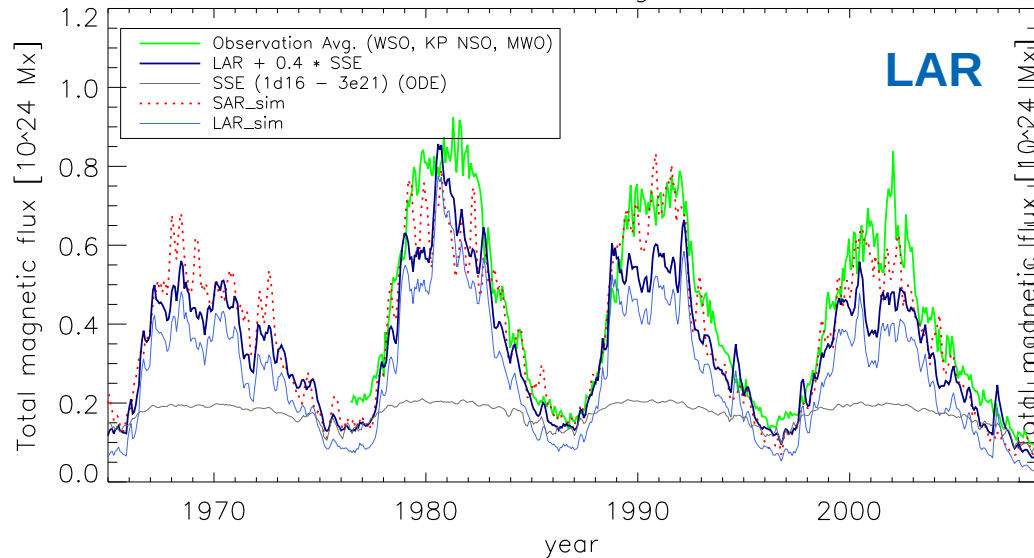


Total magnetic flux

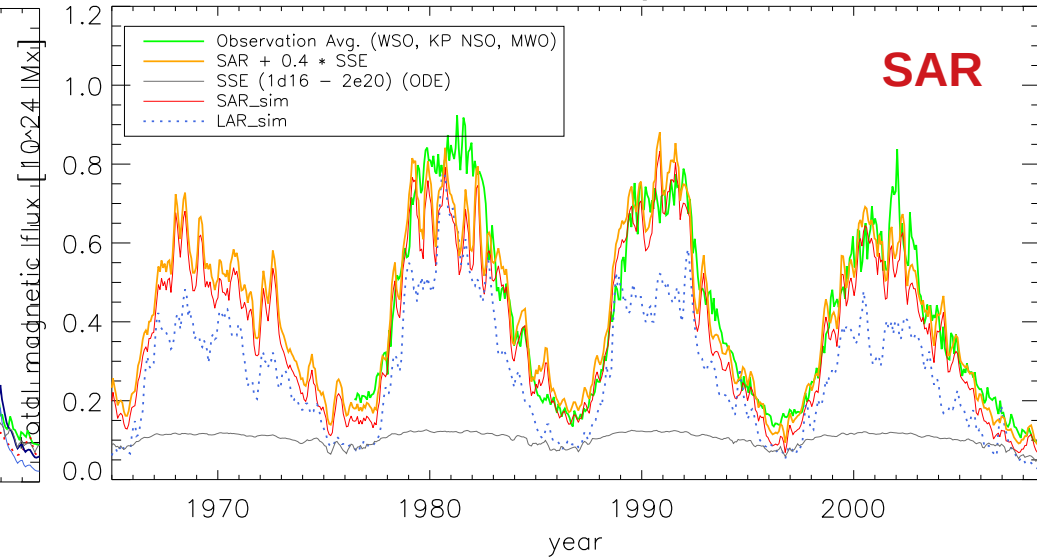


- Two populations of BMRs are tested in the SFTM.
 - LAR**: Large active regions forming sunspots ($>3 \times 10^{21} M_x$).
 - SAR**: Includes small active regions ($>2 \times 10^{20} M_x$) with lifetimes > 1 day.

Absolute total magnetic flux



Absolute total magnetic flux





Summary & Conclusion



- The emergence of all BMRs regions is described by a single powerlaw distribution following Krivova et al. 2021.
 - We model the tilt and latitude **emergence patterns** for BMR of all sizes.
 - A relationship between **angular separation** of magnetic polarities and the region size is derived in agreement **diffusion lifetimes**.
 - The observed **total magnetic flux** is well reproduced by the simulations.
- We aim to improve magnetic flux reconstructions and reconstruct the TSI.



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