

Implications of the SSN for Solar Dynamo Studies & Climate Change

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Disclaimer

 For the sake of explanation I have made many simplifications and left out a fair amount of details on the work of others.

 This talk is not a critique of said works, but an attempt to assess the impact that changes in the SSN has on some of the results.

THE MAGNETIC NATURE OF SUNSPOTS

Created by large concentrations of magnetic flux which change the properties of convective heat transport



Rempel 2012

Cooler and darker than the surrounding area

Typically appear in groups of mixed magnetic polarity



Image from Hinode

Typically appear in groups of mixed magnetic polarity



Image from Hinode

Sunspot groups have systematic tilt, which increases with latitude.
Their associated magnetic signature is typically called Active region.

They are believed to be a consequence of the buoyant emergence of twisted flux-tubes See review by Fan (2009)

- Originating from toroidal bands of magnetic field located at the bottom of the convection zone.
- Tilted by the Coriolis force and helical convective turbulence.
- With starting magnetic field strengths of the order of 10⁴⁻⁵ G. (Weber et al. 2011).

They are believed to be a consequence of the buoyant emergence of twisted flux-tubes

See review by Fan (2009)



Image by A. van Ballegooijen

SUNSPOTS, THE SOLAR CYCLE AND THE HELIOSPHERE

Crucial link in for the solar dynamo



Since we can only observe surface magnetism, sunspots are a window into the dynamo both in terms of the interior and the future.

Highly energetic events are modulated by the solar cycle

Both Flares...



Highly energetic events are modulated by the solar cycle

... and CMEs



Owens & Lockwood 2012

In terms of climate models the cycle also modulates two particularly important quantities:

The radiative output of the Sun

• Particularly evident in UV and X-rays



The radiative output of the Sun

• Can also be observed in total solar irradiance



Image taken from PMOD-WRC

Cosmic ray flux



The link to Climate and the Dynamo

- Solar irradiance represents the main source of energy input into the climate system.
 - UV variability greatly affects the upper atmosphere.
- Cosmic rays have been proposed as seeds for the formation of clouds.
 - They can be used as a proxy for solar magnetism that goes back farther than the 1600s

ESTIMATIONS OF TOTAL SOLAR IRRADIANCE AND THE SUNSPOT NUMBER

Cycle modulation of solar irradiance is a close fight between brightening (faculae) and darkening (sunspots) features



Credit: NASA/Goddard/SORCE

In order to calculate irradiance we need to estimate the fractions of the disk covered by sunspots and faculae and their contribution

$$I = \alpha_{qs}(t)I_{qs}(\lambda) + \alpha_{sp}(t)I_{sp}(\lambda) + \alpha_{fc}(t)I_{fc}(\lambda)$$
Quiet Sun Sunspots Faculae

Surface Flux Transport Simulations

Wang et al. 2005

- Based on the induction equation and limited to the surface of the Sun (not self excited).
- Driven by synthetic AR data in order to generate the weak fields associated with faculae consistently.



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Surface Flux Transport Simulations

Wang et al. 2005



- Number of ARs (or AR flux) for each cycle has been adjusted to sunspot number.
- Meridional flow is used as a free parameter to ensure agreement with open flux.

Surface Flux Transport Simulations

Wang et al. 2005

• The working hypothesis is that the average unsigned magnetic field is a proxy for facular brightness.



Vieira et al. 2011 (MPS)

- Simplified model for the evolution of different types of magnetic flux (Φ): (AR, open flux)
- AR fluxes and rate of emergence are taken from magnetic data (or from sunspot number).
- Open flux is taken from in-situ measurements
- The decay timescales are free parameters that obtained through an optimization process.

Vieira et al. 2011 (MPS)

 Simplified model for the evolution of different types of magnetic flux (Φ): (AR, open flux)



Vieira et al. 2011 (MPS)

 Simplified model for the evolution of different types of magnetic flux (Φ): (AR, ephemeral, open flux)C



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Vieira et al. 2011 (MPS)

- Simplified model for the evolution of different types of magnetic flux (Φ): (AR, ephemeral, open flux)
- Once you have an idea of the evolution of AR flux, you can use the Sunspot number to estimate which percentage of this flux belongs to spots and which to faculae.

They have looked at the differences introduced by using SSN vs. SSI!!!

Krivova et al. J of A&STP (2011)



MODULATION OF COSMIC RAYS (CR) AND THE USE OF THE SUNSPOT NUMBER TO INTERPRET COSMOGENIC PROXIES

Solar wind drags magnetic field lines past the source surface generating a spiral which gives structure to the heliosphere



The path of low energy CRs is affected by the solar wind and the heliospheric magnetic field

















Solanki et al. 2004

IMPLICATIONS FOR DYNAMO, SOLAR CYCLE, AND CLIMATE STUDIES

- Theoretical models are not yet on a point where they can be used to make detailed and meaningful reconstruction of past solar activity.
- However, SSN and the CR proxies can and are used to make conclusions about dynamo operating regimes so is very important to have them right.
- Looking at solar irradiance and cosmic ray as the principal products of interest for the climate community I find data products to have variations of the same order as changes to the reference SSN

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