F10.7 and Picard

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The Relevance of Ground-Based Monitoring to Picard

- The duration of the Picard mission is limited. What happens after the mission is problematic. Will there be another satellite, or will we be basing data extrapolation on proxies?
- Understanding what we have depends upon data extending back into the past, before the mission. We need to extrapolate the data set backwards in time as far as possible.
- Only ground-based observations have long data records, high internal consistency in the data sets, statistical homogeneity and good continuity.
- The only long-duration data sets meeting these criteria are sunspot number and the 10.7cm Solar Radio Flux.
- Sunspot number dates back at least 300 years, but is totally empirical. Getting back further in time than that is problematical, being dependent upon terrestrial proxies for solar activity.
- Canada has been producing the 10.7cm solar radio flux data for more than 60 years. This index can be interpreted physically, and because of its very high correlation with sunspot number, can be used to pull sunspot number into the scientific discussion.
What’s to be Covered Here

• The 10.7cm solar radio flux, the data, instrumentation and nature of the measurements.
• Its relationship with sunspot number (useful because of the length of the sunspot number record).
• Something about the physics.
• The Next Generation Solar Flux Monitor
F10.7 Monthly Means

Monthly Means

Flux Density in sfu

Year

Located at DRAO, the instruments run in parallel, with one acting as a hot backup for the other.
Dominion Radio Astrophysical Observatory
DRAO Viewed from North-West

- 26m Radio Telescope
- Solar Radio Telescopes
- 7-element Synthesis Radio

North
F10.7 and the S-Component
Where Does the S-Component Come From?

Images of the Sun at 21 cm wavelength made using the DRAO Synthesis Radio Telescope
Simple Model

• The S-component originates largely in active regions.
• Assume the emission originates in the coronal plasma slabs overlying active regions.
• If we average over entire years, over many active regions, we can assume simple models ($i$ is the emitting structure class).

\[
F_{10.7} = \frac{2k}{\lambda^2} \left( \sum_i \Omega_i T_i + \left( \Omega_0 - \sum_i \Omega_i \right) T_0 \right)
\]

\[
F_{10.7} = \frac{2k}{\lambda^2} \left( \sum_i \Omega_i (T_i - T_0) + \Omega_0 T_0 \right)
\]

\[
F_{10.7} = \frac{2k}{\lambda^2} \left( \sum_i \Omega_i (T_i - T_0) \right) + F_{10.7,0}
\]

Quiet sun flux density at 10.7 cm wavelength
Karen Harvey

• Used the magnetograph at the Kitt Peak Observatory to map the distribution of photospheric magnetic flux.

• Found there are only two classes of magnetic pixel: strong-field pixels \((B>B_0)\), and weak-field pixels \((B<B_0)\), where varying \(20<B_0<45\) Gauss makes little difference in the proportional breakdown between strong and weak-field elements. The strong-field elements occur mainly in active regions.

• She measured the total strong and weak-field magnetic fluxes over the solar sphere, as a function of time.
Rough Model for F10.7: 1

- The emission comes from active regions.
- There are two emission mechanisms, thermal free-free emission from density enhancements over active region plage and thermal gyroresonance from plasma trapped in the strong fields overlying sunspots.
- Assume on average, over all active regions, over years, we can assume the brightness temperatures to be the same over all free-free emission sources and over all thermal gyroresonant sources.

\[ F_{10.7} = \alpha A_p T_{ff} + \beta A_s T_{gr} + \gamma (A_0 - A_p - A_s)T_0 \]

Where \( A_p \) is the total plage area and \( T_{ff} \) the average free-free emission brightness temperature, \( A_s \) is the total spot area and \( T_{gr} \) the average brightness temperature of thermal gyroresonance emission. \( A_0 \) is the total disc area and \( T_0 \) the quiet sun temperature.
Rough Model for F10.7: 2

\[
F_{10.7} = \alpha A_p T_{ff} + \beta A_s T_{gr} + \gamma (A_0 - A_p - A_s)T_0
\]

Regions of a given area have more spot area when activity is high. In addition, assuming the area of the active region can be defined in terms of the total magnetic flux divided by the mean magnetic flux, and then lumping all the constants together:

\[
F'_{10.7} = a\Phi_{Str} + b\Phi_{Str}^2 + F_{10.7,0}
\]

Where we assume the total plage and spot area is small compared with the area of the solar disc.
F10.7 and Active Region Magnetic Flux

The relationship between F10.7 and Active Region Magnetic Flux is described by the equation:

\[ y = 0.0003x^2 + 2.0317x + 65.243 \]

with a correlation coefficient \( R^2 = 0.9626 \).

F10.7 in absence of active region magnetic flux is 65 sfu.
Active Region Magnetic Flux $\Phi = -0.0007 F_{10.7}^2 + 0.6553 F_{10.7} - 40.674$

$R^2 = 0.9662$
A Relevant Application: Modelling Total Irradiance: 1

\[ I = \sum_i A_i \varepsilon_i + \zeta(t) I_0 \]

\[ I = \sum_i \frac{\Phi_i}{B_i} \varepsilon_i + \zeta(t) I_0 \]

\[ I = \eta_s \Phi_s + \mu_w \Phi_w + \zeta(t) I_0 \]

Assuming the disc temperature varies only slowly and is due to a magnetic flux reservoir from which the photospheric magnetic fluxes come. Since the variation is small (~1K), we can get away with a simple linear model

\[ I = \eta_s \Phi_s + \mu_w \Phi_w + \left( 1 + \mu \int_{t-T}^{t+T} \Phi_d dt \right) I_0 \]
A Relevant Application: Modelling Total Irradiance: 2

\[ \Phi_{Str} = F_{10.7,0} + \alpha F_{10.7} + bF_{10.7}^2 \]

\[ \frac{\partial \Phi_W}{\partial t} = E_W(t) + \gamma \Phi_{Str}^{1/2} - \frac{1}{\tau_W} \Phi_W \]

Where active region strong-field elements fragment round the edges of the region into weak-field elements.
Modelled Weak-Field Magnetic Flux

Rotationally-totalled values measured by Karen Harvey

Model
F10.7 and Sunspot Number

Total Irradiance in Watts per Square Metre

Observed
Modelled

rms

Year

F10.7 v. Sunspot Number (Annual Averages)

\[ F_{10.7} = 4\times10^{-8}N^4 - 3\times10^{-5}N^3 + 0.0061N^2 + 0.5178N + 67.016 \]

\[ R^2 = 0.9801 \]
Modelled Irradiance back to 1600
Modelled Irradiance back to 850 AD

Using measurements of Be10 from Ice Cores, compiled by Solanki

Modelled from Solanki Be10

The Model

Medieval

Wolf

Sporer

Maunder

Dalton
• $F_{10.7}$ is an effective basis for the development of proxies for quantities such as total irradiance.
• This value comes from the dependence of $F_{10.7}$ and irradiance components upon magnetic flux (mainly that in strong-field elements).
• Using this commonality we can use it extrapolate irradiance measurements back or forward in time beyond the time window covered by the measurements.
• However, the single observing wavelength hides a problem that could show up over shorter integration intervals and possibly at other times.
• Thermal free-free emission comes from trapped plasma over active region plage or faculae. This is where the trapped plasmas also enhance $u.v.$ and other irradiance components.
• Thermal gyroresonance comes from trapped plasmas in intense magnetic fields over sunspots. This enhances $F_{10.7}$, however, sunspot blocking causes irradiance decreases.
• To get a better handle on radio proxies for irradiance components we need to separate out the emission mechanisms. This requires consistent, well-calibrated multi-wavelength flux measurements.
Next Generation Solar Flux Monitor

- Accurate, consistent measurements made at several wavelengths in the range 3-30 cm, so that the spectral profile can be estimated.
- Since we know the form of the free-free emission spectrum and to some extent that of the gyroresonance spectrum, we can separate the components, producing indices that are more related to the phenomena modulating that particular irradiance component.