Comparative analysis of EUV solar radiation proxies during minimum activity levels

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Outline:

• Correlation between solar EUV proxies during different solar activity phases

• Some characteristics during minimum: time of occurrence, minimum proxy value, duration?

• Solar EUV proxies adequacy to determine foF2 long-term trends considering the role of minimum periods

• Discussion
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EUV solar proxies analyzed

Timescale

Example: monthly means

Example: 12-month running means

Rz, Mg II, Lyman α, and F10.7
(monthly mean data, January 1979 – December 2020)

Monthly means – 12-month running means
Many ways to do a “comparison” and to approach this analysis.
Here: Statistical !! (but ... many ways from the statistical point of view, as well !!)

Let's notice first that:

**Source region in the Sun:**

\[
\begin{align*}
Rz & \rightarrow \text{photosphere} \\
\text{Mg II} & \rightarrow \text{chromosphere} \\
\text{Lym } \alpha & \rightarrow \text{transition region} \\
\text{F}10.7 & \rightarrow \text{corona}
\end{align*}
\]

**Sensitivity along solar activity cycle:**

\[
100 \times \frac{\text{X}(\text{max}) - \text{X}(\text{min})}{\text{mean}(\text{X})}
\]

\[
\begin{align*}
Rz & \rightarrow \sim 250 \% \\
\text{Mg II} & \rightarrow \sim 10 \% \\
\text{Lym } \alpha & \rightarrow \sim 45 \% \\
\text{F}10.7 & \rightarrow \sim 120 \%
\end{align*}
\]

**12-month running means:**

\[
\begin{align*}
r(Rz, \text{Mg II}) &= 0.99 \\
r(Rz, \text{Lyman } \alpha) &= 0.98 \\
r(Rz, \text{F}10.7) &= 0.99 \\
r(\text{Mg II, Lyman } \alpha) &= 0.98
\end{align*}
\]

...
Correlation between:
- \( R_z \) & Mg II
- \( R_z \) & Lyman \( \alpha \)
- \( R_z \) & F10.7
- F10.7 & Mg II
- F10.7 & Lyman \( \alpha \)
- Lyman \( \alpha \) & Mg II

Vertical dashed lines: solar minima – Vertical dotted lines: solar maxima

12-month running means

Monthly means


Rz & Lyman \( \alpha \) ??
F10.7 & Lyman \( \alpha \) ??
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Superposition:
0: minimum considering 12-month running means

\[ \text{Rz} < 50 \quad \text{Mg II} < 0.155 \]
\[ \text{Lyman } \alpha < 0.0069 \quad \text{F10.7} < 97 \]

1. min 21-22: solid
2. min 22-23: dashed
3. min 23-24: dotted
4. min 24-25: dot-dashed

- Minimum values order: (1) & (2) clearly higher than (4)&(3), in Rz, F10.7 and Lyman \( \alpha \)
- Less pronounced in Mg II. Due to the lowest sensitivity?
- Lowest minima [(4) & (3)] → longer duration
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Ionosphere parameters forced by EUV solar radiation: foF2 [MHz] (at noon) !!
Kokubunji station (35.7°N, 139.5°E), Wakkanai station (45.4°N, 141.7°E), Syowa station (69.0°S, 39.6°E)

Trend estimation considering foF2 “experimental” data:

1st step: Filtering of solar activity effect (solar EUV effect):

\[ \text{foF2}_{\text{residual}} = \text{foF2} - (a \text{ Rz} + b) \]

foF2: “experimental” foF2 value
a & b coefficients of foF2 vs. Rz linear regression (least square)

2nd step: Linear trend “\( \alpha \)” estimation:

\[ \text{foF2}_{\text{residual}} = \alpha \ t + \beta \]

t: time in year
\( \alpha \ t \) & \( \beta \) coefficients of foF2_{residual} vs. t linear regression (least square)

In general:
\[ r^2 (\text{foF2, Rz}) \text{ and } r^2 (\text{foF2, F10.7}) > 0.95 \]
⇒ more than 95% of foF2 variance explained by Rz or F10.7
What we expect regarding foF2 trends:

- residuals to decrease steadily due to increasing CO2
- If EUV is higher than the level indicated by solar proxies during the last two minima ⇒ (+) trend
- If EUV is lower than the level indicated by solar proxies during the last two minima ⇒ (-) trend
- If EUV behaves like solar proxies, then everything fine !!! No trend !! or same trend as before !!

Mg II: trend values more stable for different periods
Rz: least stable trend values
What does this mean about their EUV “proxy” role ??
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About correlations:

• Correlation coefficients between any pair of solar EUV proxies (Rz, Mg II, Lyman $\alpha$, F10.7), for the entire period 1979-2020 is greater than 0.96 and, when we focus on shorter periods, it decreases specifically during maximum and minimum periods.

• A reason for this could be purely statistical:
About foF2 trend analysis:
- Mg II → “produce” the most stable foF2 trend values.
- Rz → trend values are the most unstable.
- Does this indicate that Mg II plays the best role as EUV solar measure and Rz the worst?
- Analysis of more stations data and other parameters affected by EUV !!!
- Another possibility: the association between foF2 and solar EUV, through its dependence with proxies, should be revised during minima.

About comparison with superposed epoch analysis:
- The first two minima were clearly higher and shorter than the last two, particularly for Rz and F10.7.
- In terms of percentage difference (relative to the solar cycle amplitude) they are all similar, being greater for Rz.
- In contradiction to what we just deduced from foF2 trend analysis?
Thank you !!