What is happening with solar activity indices - and ionospheric implications?

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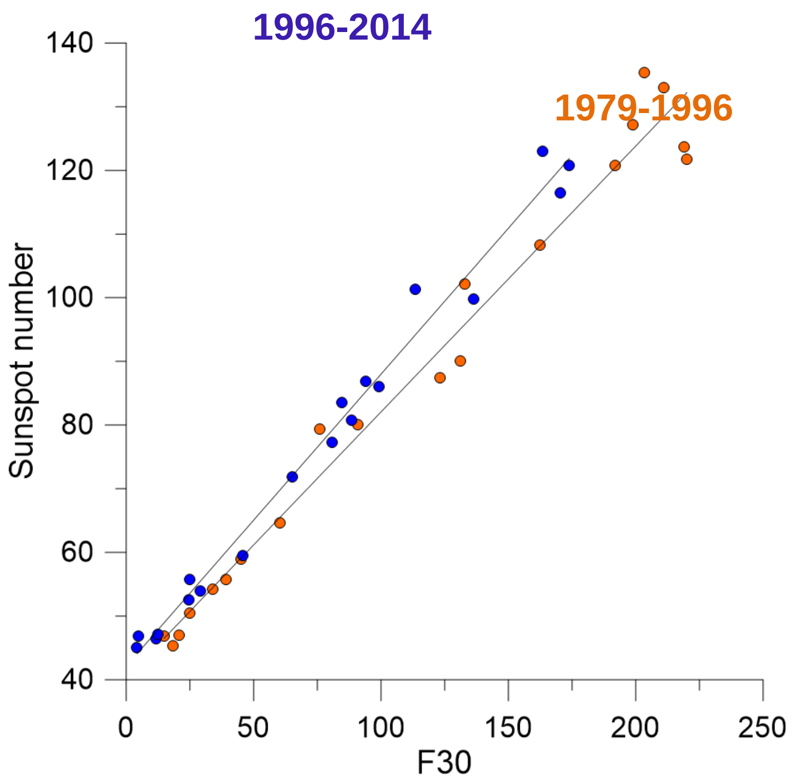
Introduction

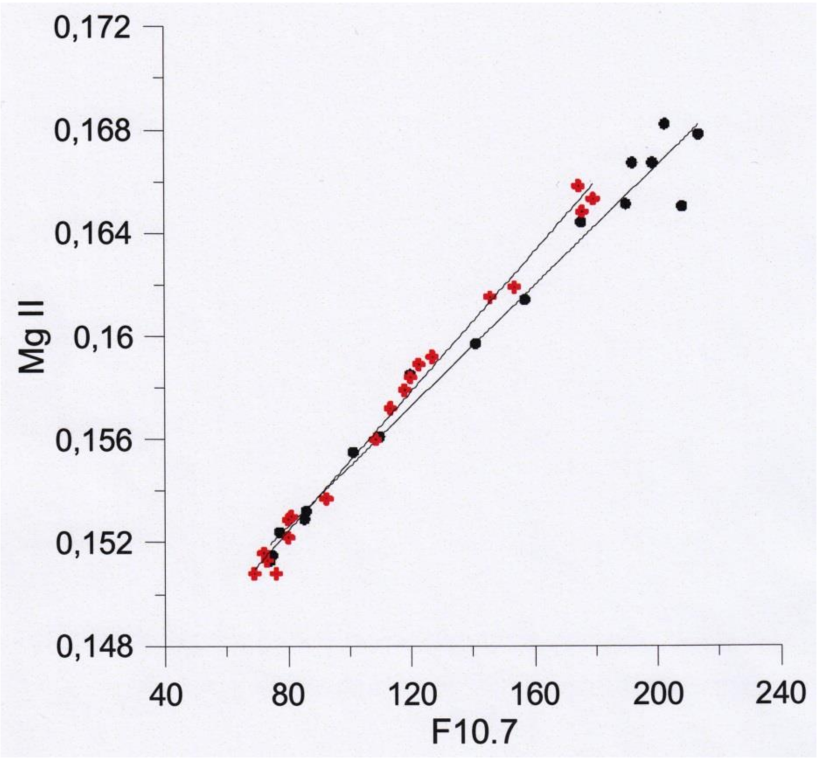
There are some indications of **changes of relationships between solar activity indices** during the last two solar cycles compared to previous solar cycles (Lukianova and Mursula, 2011; Tapping and Valdes, 2011; Clette and Lefevre, 2012; Balogh et al., 2014; Lastovicka, 2019). Therefore we analyze behavior of six solar activity indices, F10.7, F30, Mg II, He II, sunspot number R and the solar Lyman-α flux Lα in two consecutive periods, 1976-1995 and 1996-2014.

In the second part of this talk, impact of such changes on the relationships between the ionospheric parameter foF2 and various solar activity indices is briefly analyzed.

All analyses are carried out with yearly average values, which are for ionospheric parameters based on noon time monthly medians.

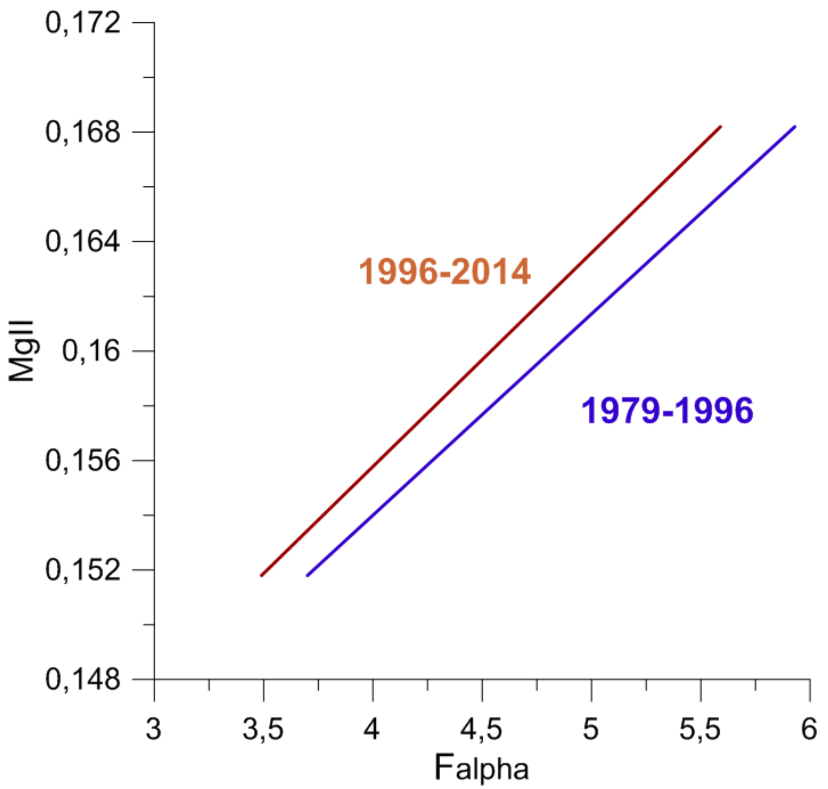
Relationships between solar activity indices

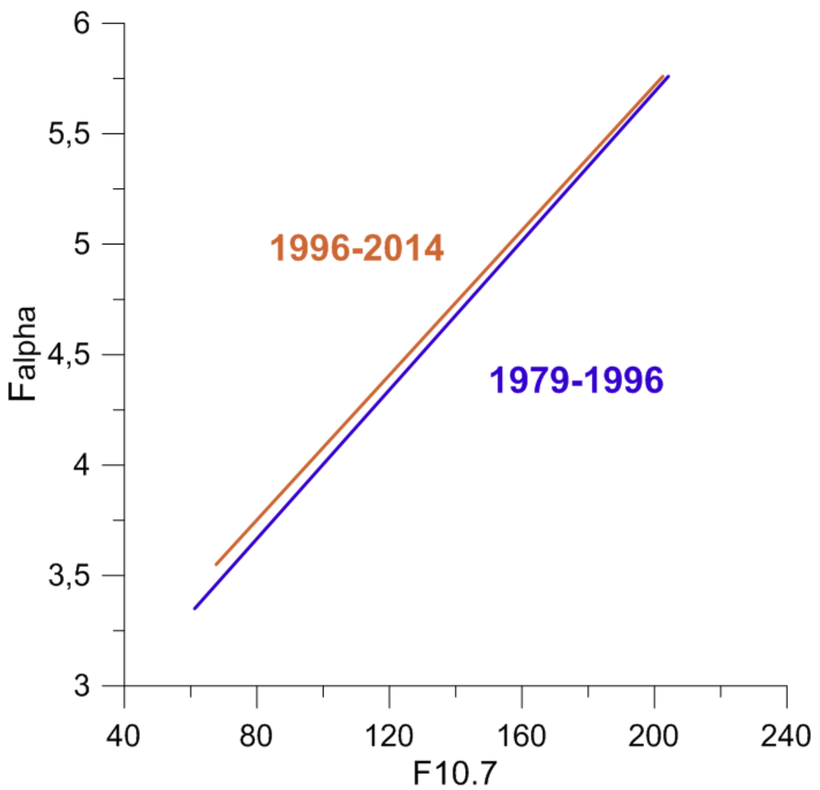




The relationship between the yearly average values of **sunspot numbers and F30** is **steeper in 1996-2014 than in 1979- 1995.**

The relationship between the yearly average values of **Mg II index and F10.7** is **steeper in 1996-2014 than in 1979- 1995**.

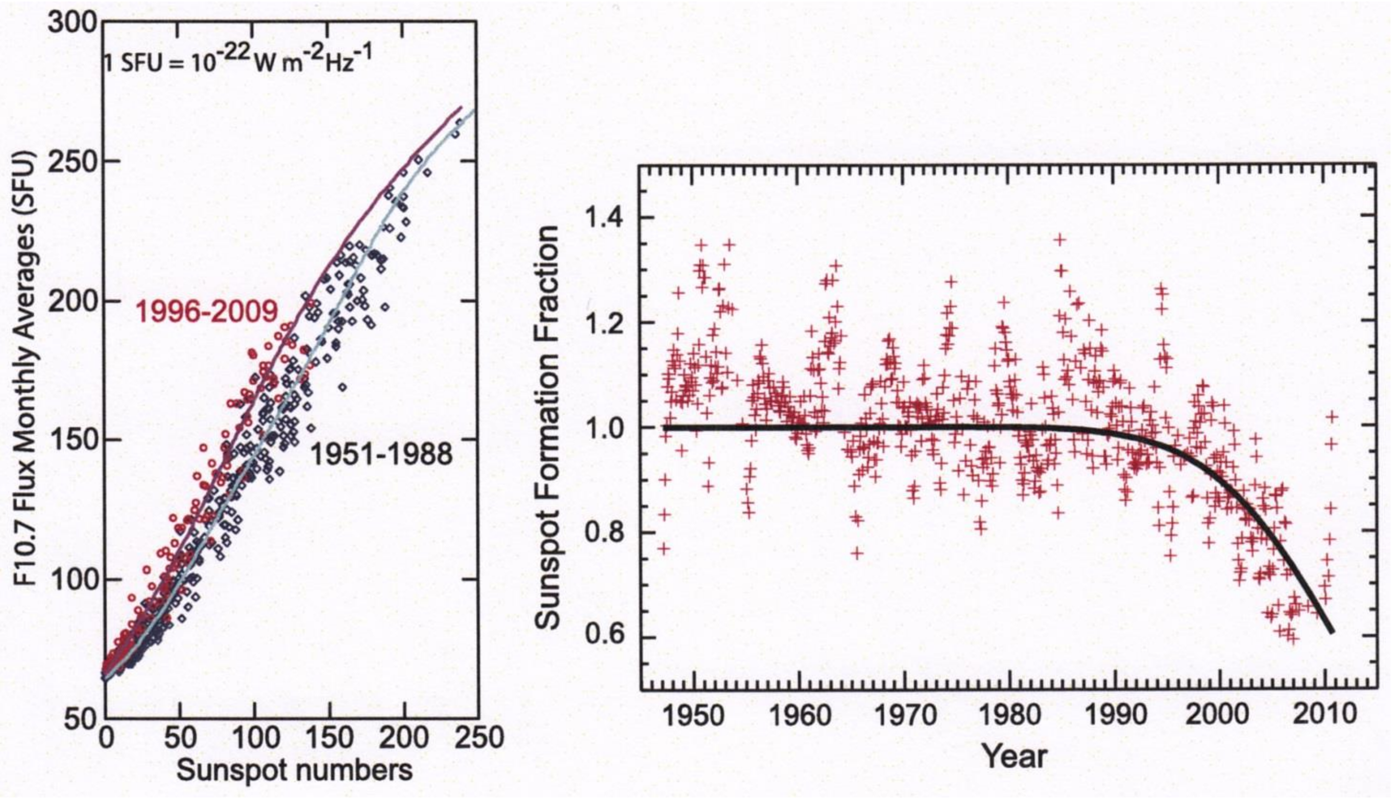




The relation between the yearly average values of **Mg II index and Falpha. This relation is evidently different in 1996-2014 compared with 1979-1995**.

The relation between the yearly average values of **Falpha and F10.7 - it changed little between 1979- 1995 and 1996-2014** (gaps in the Falpha data series were interpolated based on observed F10.7.

Left panel: F10.7 plotted vs. sunspot numbers. Relationship between them has changed significantly during solar cycle 23. Right panel: The sunspot formation fraction parameter changed remarkably during solar cycle 23. Balogh et al. (2014).



Compared to previous solar cycles, the Sun has changed its behavior in cycles 23 and early 24 (present).

	F30	F10.7	Mg II	R	He II
Lα	0.92	1.07	0.95	1.10	0.98 (0.98)
He II	0.88 (0.96)	1.00 (1.06)	0.95 (1.02)	1.05 (1.10)	
R	0.88	1.03	0.91		
Mg II	0.97	1.08			
F10.7	0.89				

1996-2014 to 1976-1995 ratio of parameter B from equation Y = A + B*X for yearly average values of solar activity proxies; Y are solar indices on vertical axis, X on horizontal axis; He II (i.ii) – 1996-2010.

Ratio smaller than 1 means that B is larger in the first period. It is clear that **the dependence among various solar activity proxies is rather different in the first and second period**.

The origin of the change of relationships among solar activity proxies is not clear. It is likely related to the fact that different solar proxies are related to partly different parts of the solar irradiance spectrum and to different parts of the solar atmosphere. Mursula (2022) found that the solar spectral irradiance in the range from the near ultraviolet through visible to infrared radiation changes its spectrum with time; **some parts display positive, some parts negative and some parts no long-term trend** over the period 2003-2019. If similar spectral changes occur in the EUV range between periods 1976-1995 and 1996-2014, they could change the relationships between solar activity proxies. However, more investigations of this problem are necessary.

Ionospheric impact for middle latitudes

We use **yearly average values of ionospheric parameter foF2** based on noontime monthly medians, 1976-1995 and 1996-2014, from midlatitude ionospheric stations Juliusruh, Pruhonice, Roma (Europe), Boulder (USA), Canberra (Australia), Kokubunji (Japan).

Linear regression

foF2 = A + B * solar proxy

This simple linear regression can be used, it is not oversimplification, because this regression describes for yearly values and optimum solar activity proxies ~99% of the total variance of foF2 as shown for European stations by Laštovička (2021).

Proxy	Mg II	F30	F10.7	R	Lα	He II
Juliusruh	1.00	**0.96**	1.15	1.07	1.07	1.00
Pruhonice	1.10	**1.08**	1.28	1.25	1.19	1.13
Roma	1.07	**1.01**	1.22	1.18	1.15	1.06
Boulder	0.98	**0.93**	1.05	1.07	1.02	0.96
Kokobunji	1.05	**1.01**	1.13	1.13	1.09	1.06
Canberra	1.02	**0.98**	1.10	1.12	1.05	1.02

1996-2014 to 1976-1995 ratio of **parameter B** from Eq. **foF2 = A + B * solar proxy** for all six midlatitude stations and for all six solar activity proxies.

Middle latitudes: The dependence of foF2 on solar proxies is **clearly steeper in the period 1996-2014 for F10.7 and R**, less steep for Lα, even less steep for Mg II and He II, and there is in average **no difference between 1996-2014 and 1976-1995 for F30.**

Conclusions

1. **The relationships among different solar activity proxies very predominantly change from solar cycles 21 and 22 to solar cycles 23 and 24**. The origin of this change is not well understood.

2. **The dependence of foF2 on F10.7 and R is clearly steeper for 1996-2014 than for 1976-1995**. For Mg II and He II the dependence of foF2 on solar proxies in both periods differs only slightly. **There is no difference for F30.** This is valid for middle latitudes. Origin is likely solar.

3. Since at **middle latitudes**, the **optimum solar proxies** for yearly values of foF2 are **Mg II and F30** as shown by Laštovička (2021) for European stations, the **most stable dependence of foF2** on solar proxy is for **F30**, and F30 is available for longer period than Mg II, I recommend **F30 as the best solar proxy** for analyzing **yearly average values of foF2,** not traditionally used F10.7 or sunspot numbers.