7th Workshop
Solar Influences on the Magnetosphere, Ionosphere and Atmosphere
Sunny Beach, Bulgaria, 1-5 June 2015

Effects of filtering solar activity from noon and midnight hmF2 to assess long-term variability

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Ionospheric trends

- increase in CO_2 concentration
  (Rishbeth, 1990, 1992; Roble and Dickinson, 1989)
- long-term changes in geomagnetic activity and F2-layer storm mechanisms
  (Danilov and Mikhailov, 1999; Mikhailov and Marin, 2000)
- secular variation of the Earth's magnetic field
  (Foppiano et al., 1999)
- solar influence (long-term changes in solar activity)

- **Usually first step ⇒ FILTERING of solar activity effects (~90%)**
- **Or using statistical method which includes a solar activity proxy, such as multiple regression**

Incorrect filtering

The ionosphere varies greatly because of:

- changes in the sources of ionization (solar EUV radiation)
- changes in the neutral part of the upper atmosphere in which it is embedded (the thermosphere) which also depends on solar radiation

Solar EUV ⇒ dominant influence on ionosphere

foE

foF2

} $q_m \propto I_\infty$

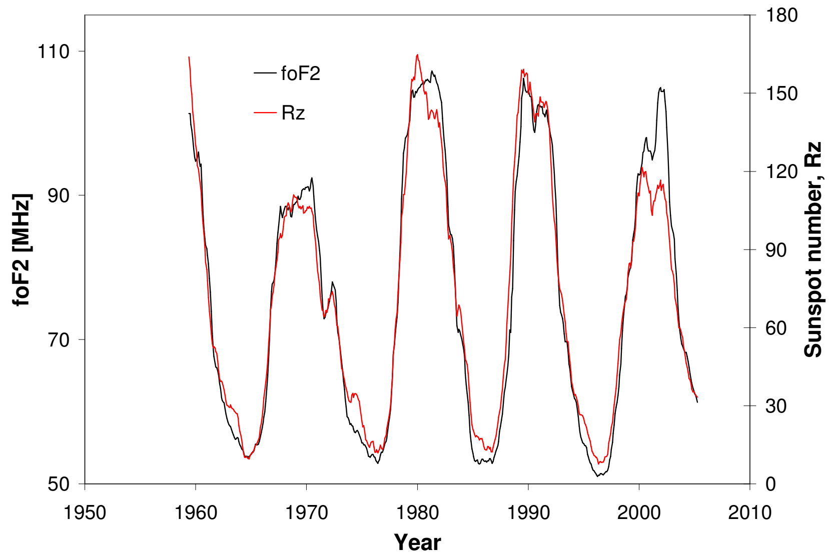
hmE

hmF2

conductivities

...

Example: Juliusruh: 54.6°N, 13.4°E



r^2 (foF2, Rz) = 0.963 ⇒ 96% of foF2 variance explained by Rz

r^2 (foF2, F10.7) = 0.969 ⇒ 97% of foF2 variance explained by F10.7

An important point in the ionospheric trend analyses is the elimination of the solar and geomagnetic activity-induced parts.

Filtering problems:

- Filtering process (method, etc.)
- Inappropriate selection of data
- Proxy used
- ...

All affect trend determination

Trend estimation:

Solar activity filtering:

$$foF2A = foF2_{exp} - foF2_{mod}$$

$foF2_{exp}$: experimental foF2 value
$foF2_{mod}$: modeled foF2 value = a Rz + b

$$\mathbf{foF2A = foF2_{exp} - (a\,Rz + b)}$$

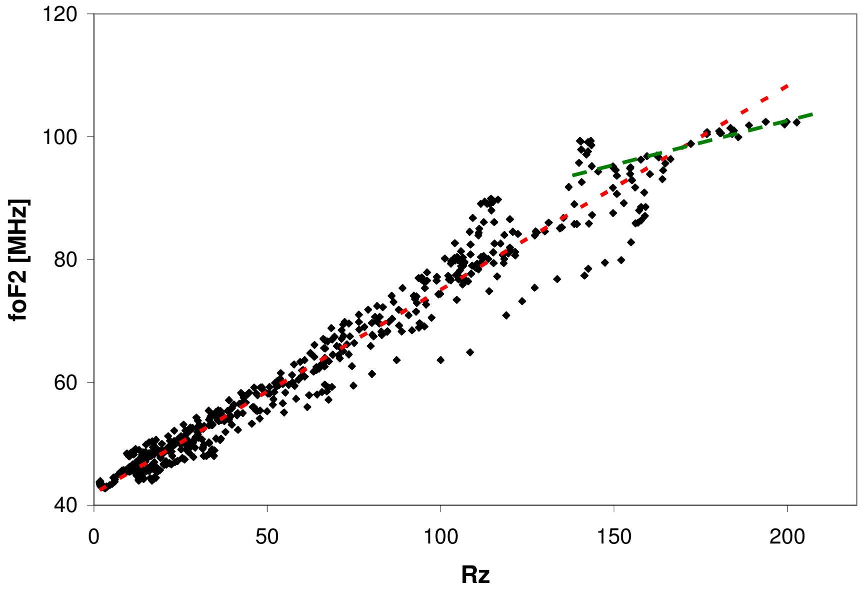
Linear trend, α, estimated using least squares

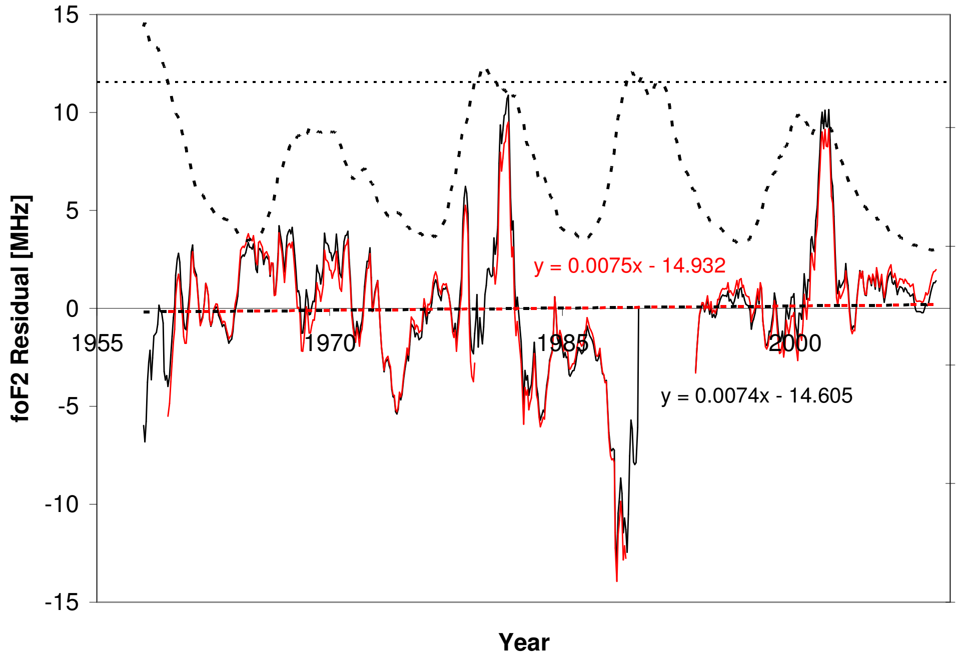
$$\mathbf{foF2A = \alpha\, t + \beta}$$

Or you can use: $\mathbf{foF2A = a\,Rz + \alpha\, t + c}$

Saturation effect

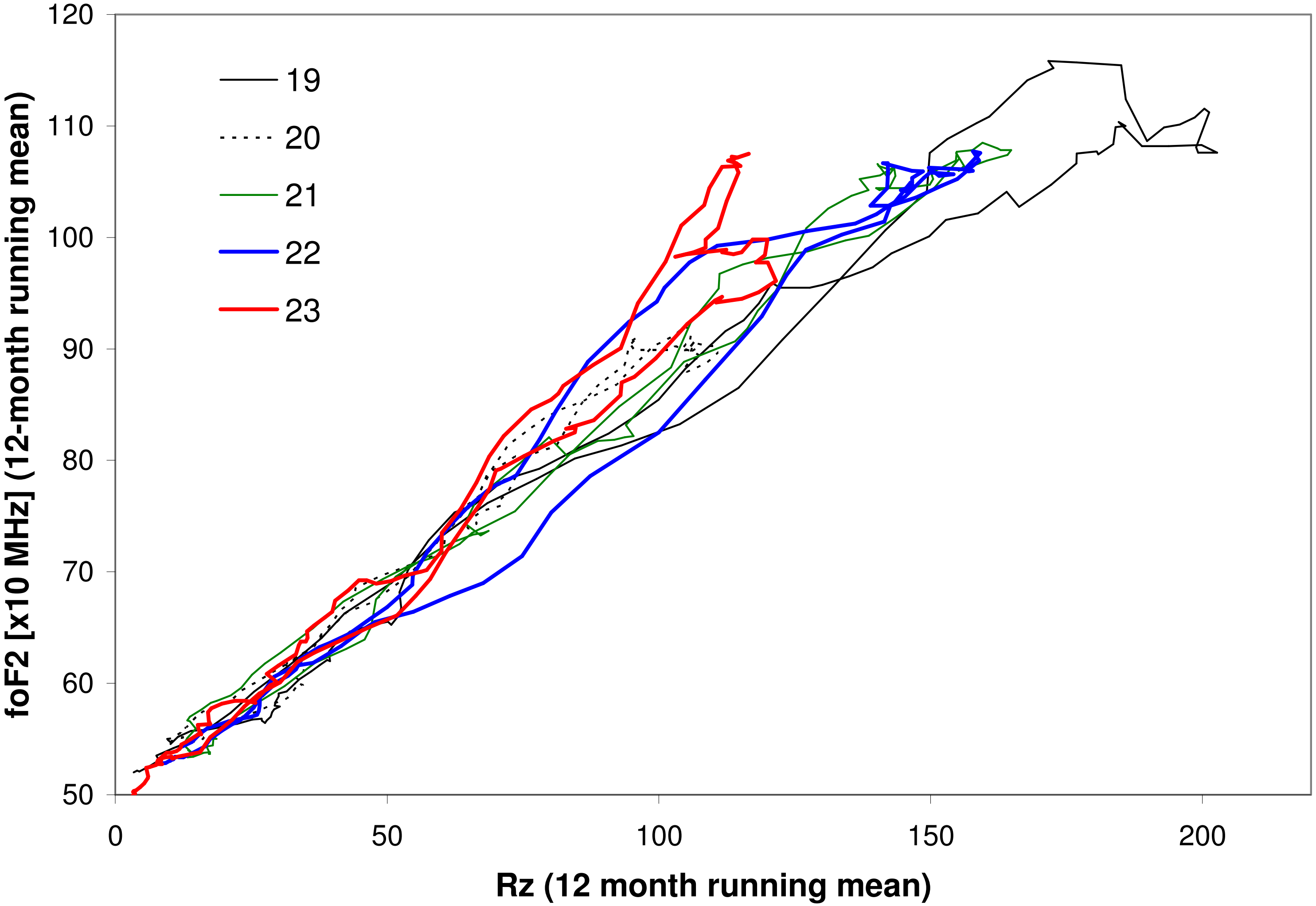
Sodankyla: 67.3°N, 26.3°E





Hysteresis effect

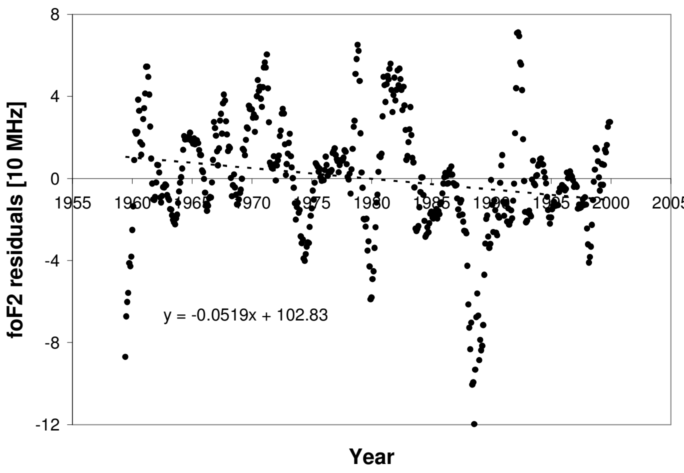
Slough: 51.5°N, 359.4°E



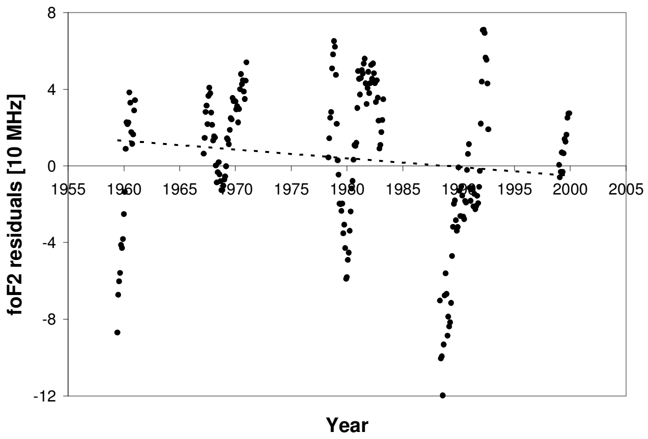
Non-linearity:

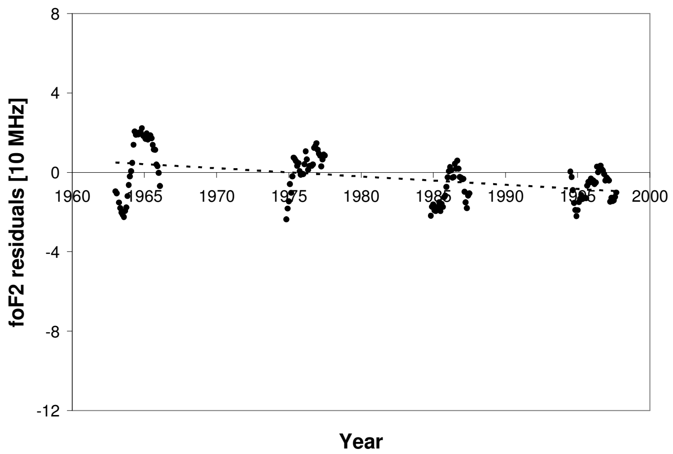
Different trends if we consider only minimum or only maximum

Juliusruh: 54.6°N, 13.4°E



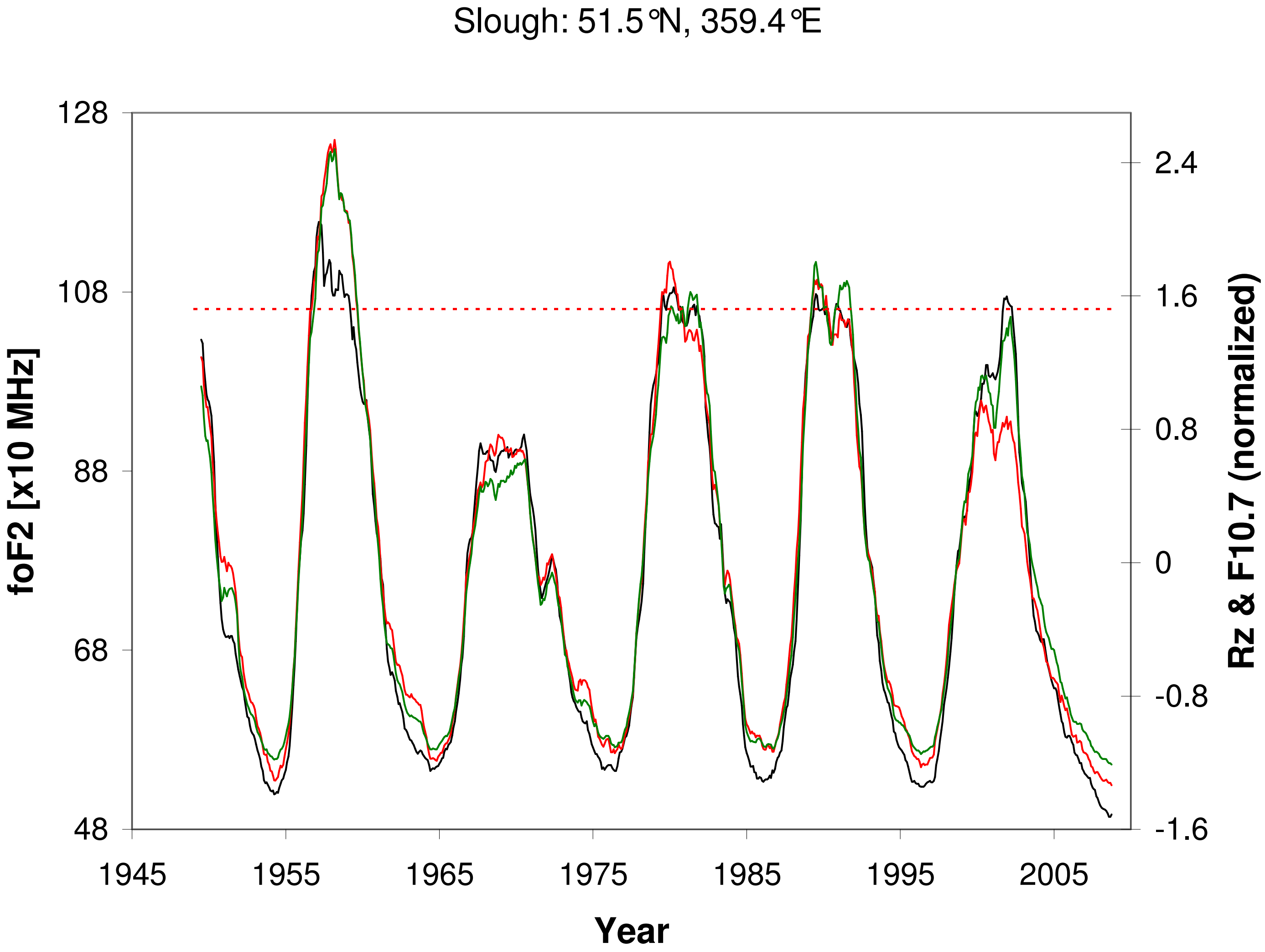
For Cawses II Working Group, Project 2: "The enhancement of the anthropogenic effect on the ionosphere/thermosphere during a quiet sun period"





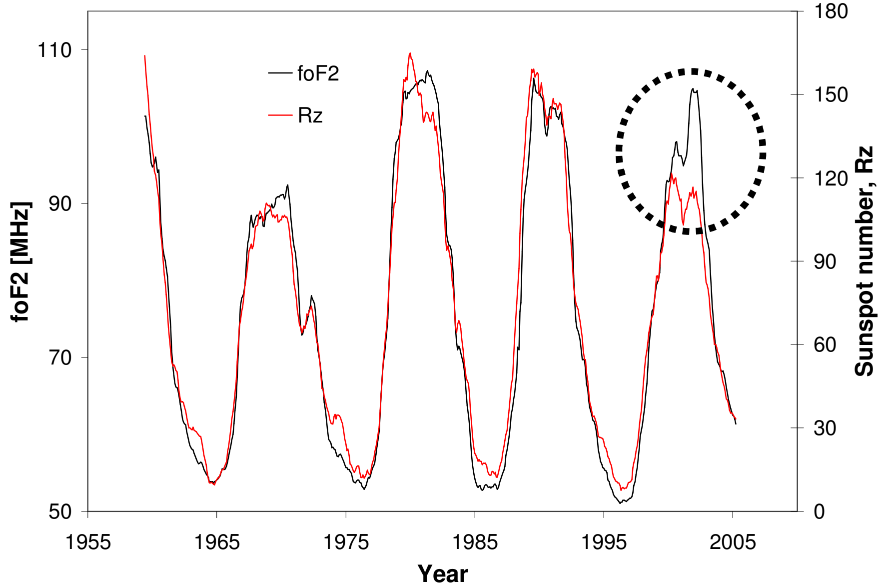
Thermospheric density trend is different during maximum and minimum solar activity levels (Emmert et al., 2008 - Mlynczak et al. 2010)

Rz, F10.7, or ...?

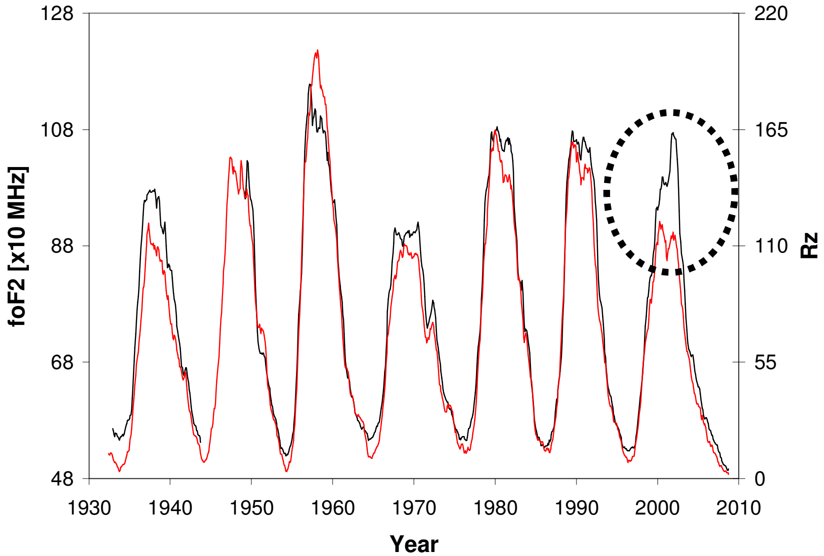


foF2 (black line), Rz (red line), F10.7 (green line)

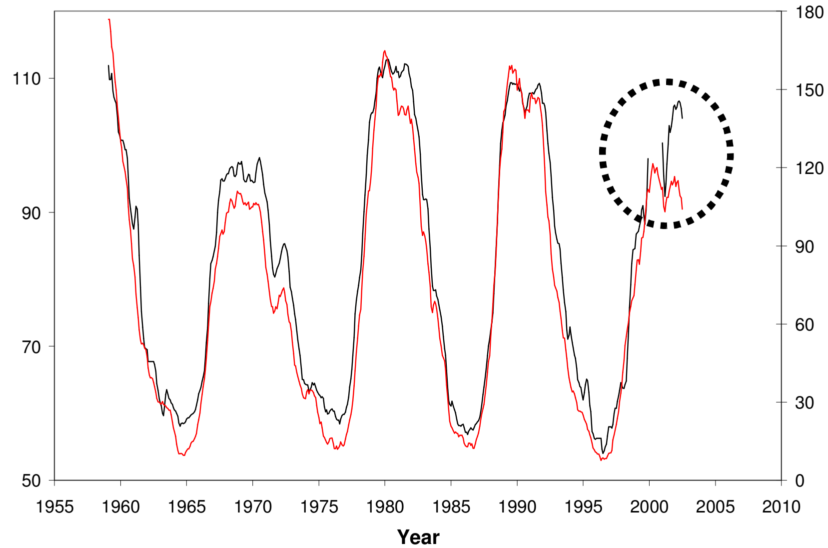
Juliusruh: 54.6°N, 13.4°E

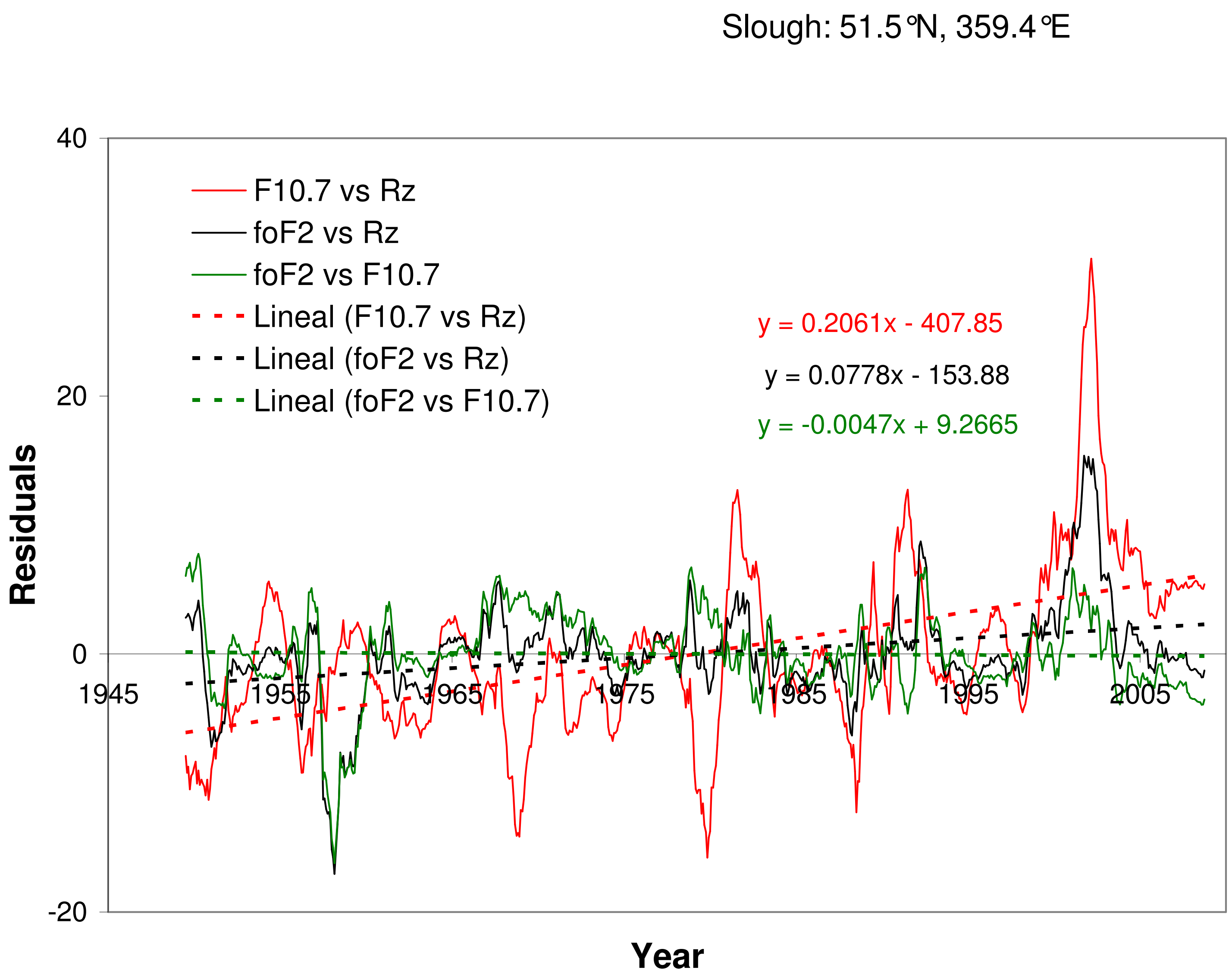


Slough: 51.5°N, 359.4°E



Boulder: 40°N, 254.7°E

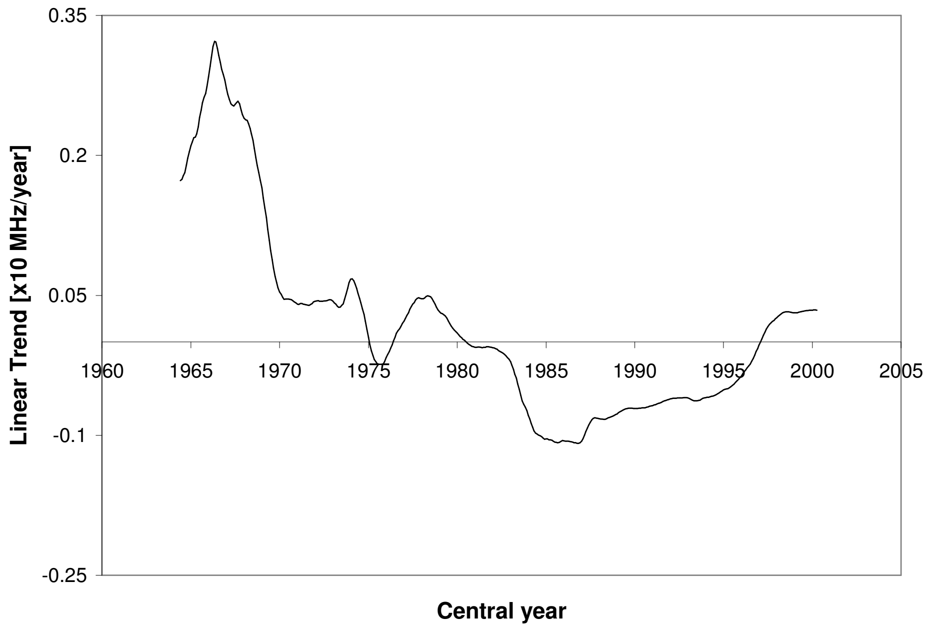




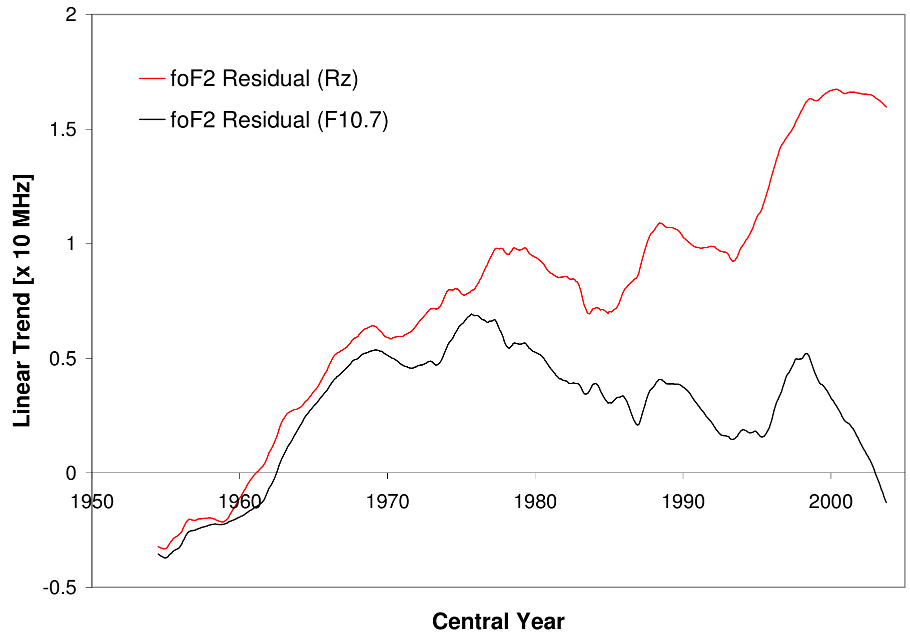
Slough: 51.5°N, 359.4°E
40
20
0
-20
Residuals
1945
1955
1965
1975
1985
1995
2005
Year
F10.7 vs Rz
foF2 vs Rz
foF2 vs F10.7
Lineal (F10.7 vs Rz)
Lineal (foF2 vs Rz)
Lineal (foF2 vs F10.7)
y = 0.2061x - 407.85
y = 0.0778x - 153.88
y = -0.0047x + 9.2665

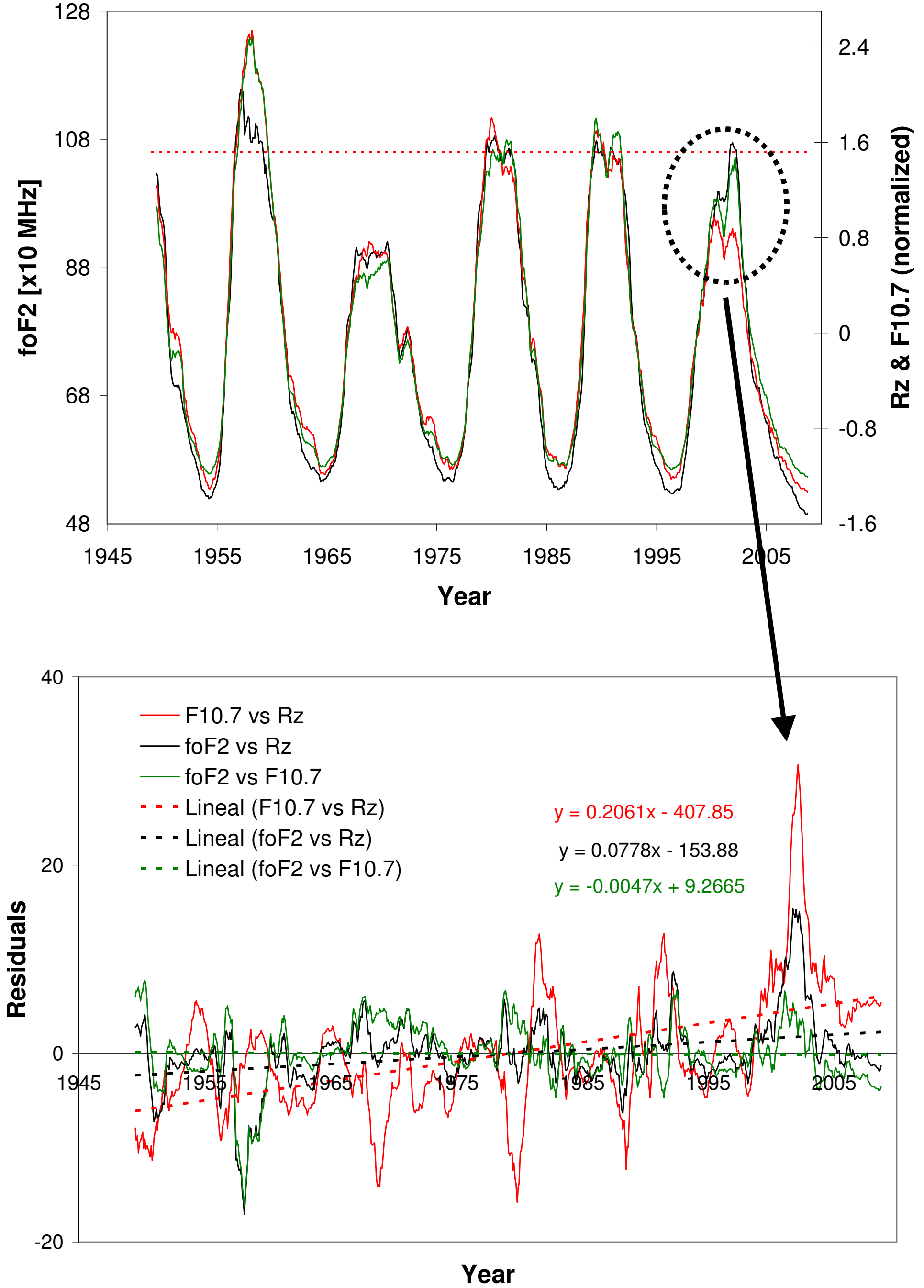
Period analyzed?

Juliusruh: 54.6°N, 13.4°E



Slough: 51.5°N, 359.4°E





Livingston et al. 2012 , Decreasing Sunspot Magnetic Fields Explain Unique 10.7 cm Radio Flux, The Astrophysical Journal Letters, 757.

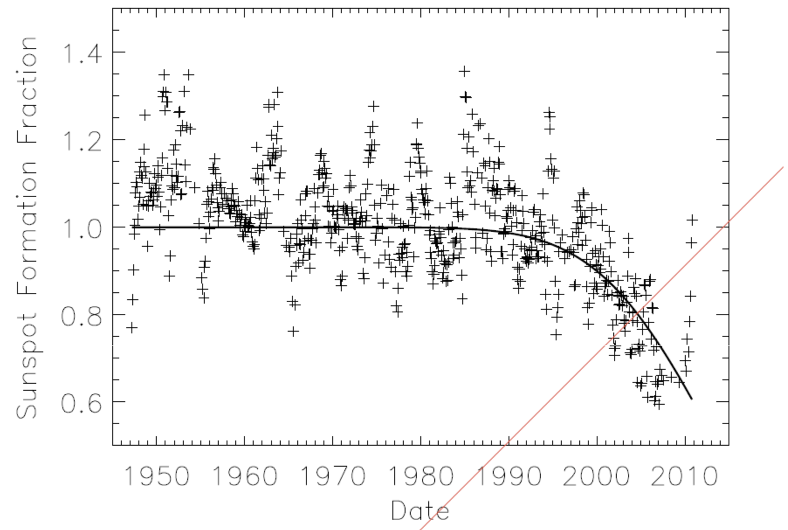


Fig. 4.— The sunspot formation fraction is defined as the number of sunspots seen on the solar surface divided by the number of sunspots predicted by the solar radio emission at 10.7 cm. The value is 1.0±0.11 from 1947 through about 1995, and then it shows a statistically significant decline. It is least-squares fit with an erf(x) function, and it independently confirms the rate of change of the sunspot magnetic field strengths and the 1500 Gauss threshold. Extrapolating this function into the future would predict about 50% fewer spots in Cycle 24 than seen in Cycle 23, and almost no spots in Cycle 25.

Mielich and Bremer, Long-term trends in the ionospheric F2 region with different solar activity indices, Ann. Geophys., 31, 291–303, 2013

Main results:

"The elimination of the solar-induced variations can preferably be made with the solar 10.7 cm radio flux. Especially during the years from 2001 until 2009, the relative solar sunspot number R markedly underestimated the solar EUV flux."

1) F10.7 is a better index for the description of the solar activity than the relative solar sunspot number R as well as the solar EUV proxy E10.7

2) The global mean *fo*F2 and *hm*F2 trends derived for the interval between 1948 and 2006 are in good agreement with model calculations of an increasing atmospheric greenhouse effect (Rishbeth and Roble, 1992).

3) During the years 2007 until 2009, the *hm*F2 values and to a smaller amount the *fo*F2 values strongly decrease. The reason for this effect is a reduction of the thermospheric density and ionization due to a markedly reduced solar EUV irradiation and extremely small geomagnetic activity during the solar cycle 23/24 minimum.

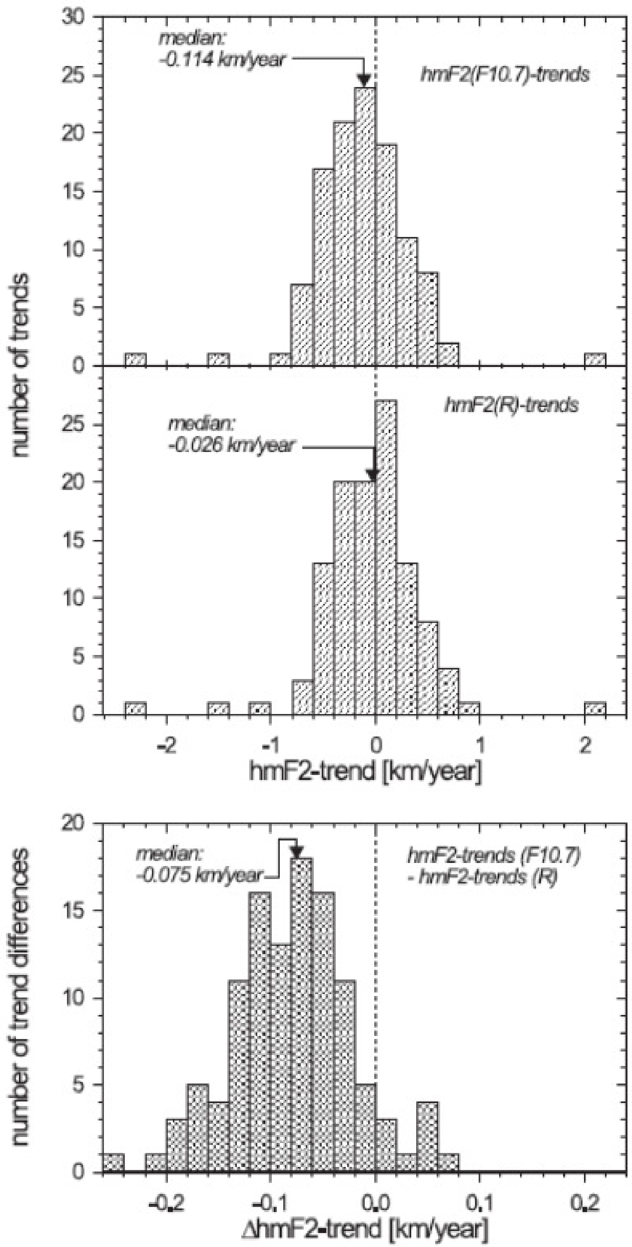
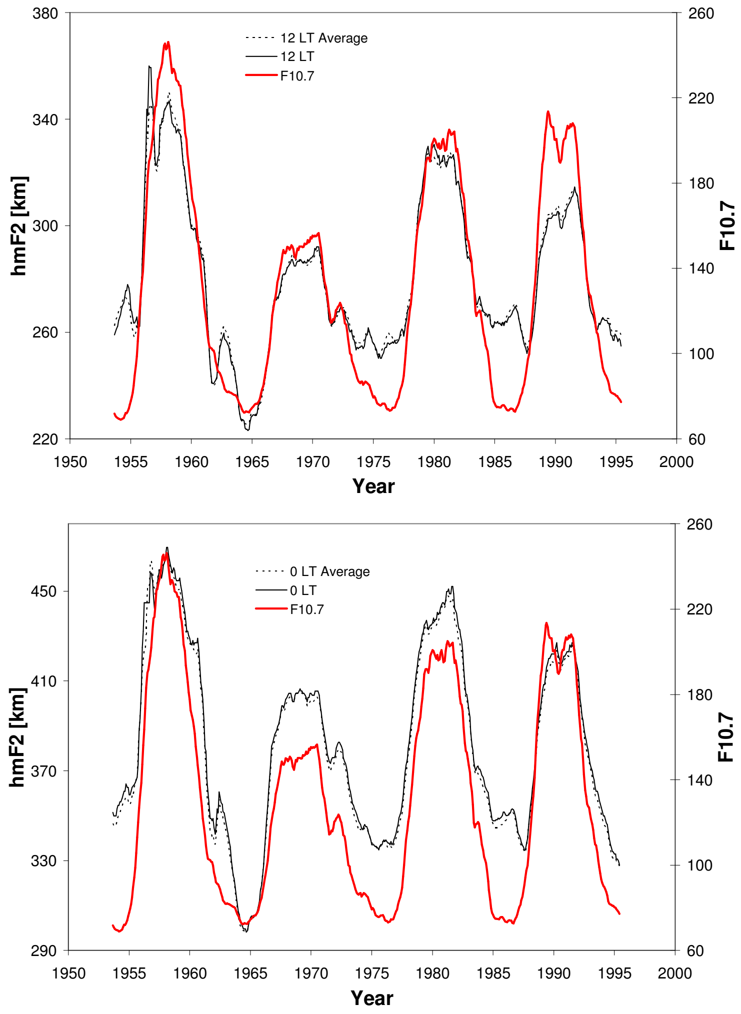


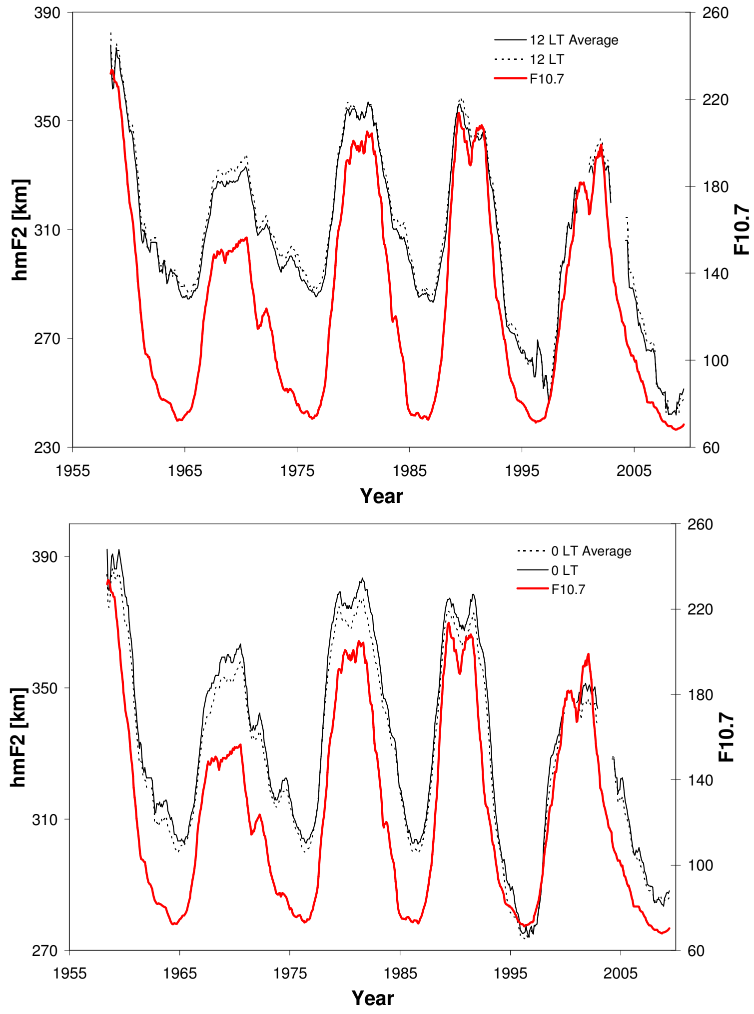
Fig. 4. Histograms of *hm*F2 trends by use of F10.7 or *R* data in the trend analyses (upper part) as well as a histogram of the differences of both *hm*F2 trends (lower part). The corresponding median values are marked by arrows.

Argentine Island (-65.2, 295.7)



	0 LT	12 LT
r	0.95	0.92
a	0.79	0.53
b	279.4	209.9

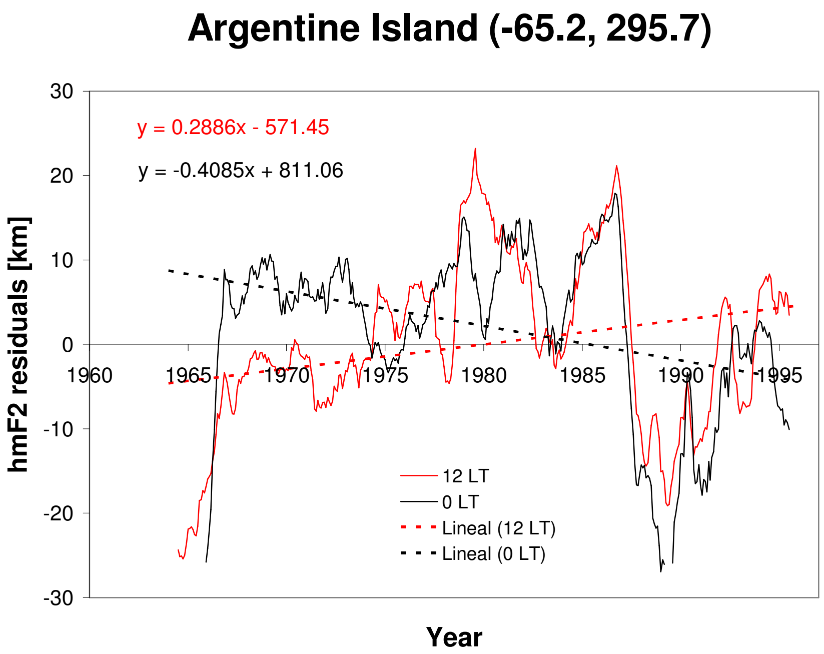
Boulder (40.0, 254.7)

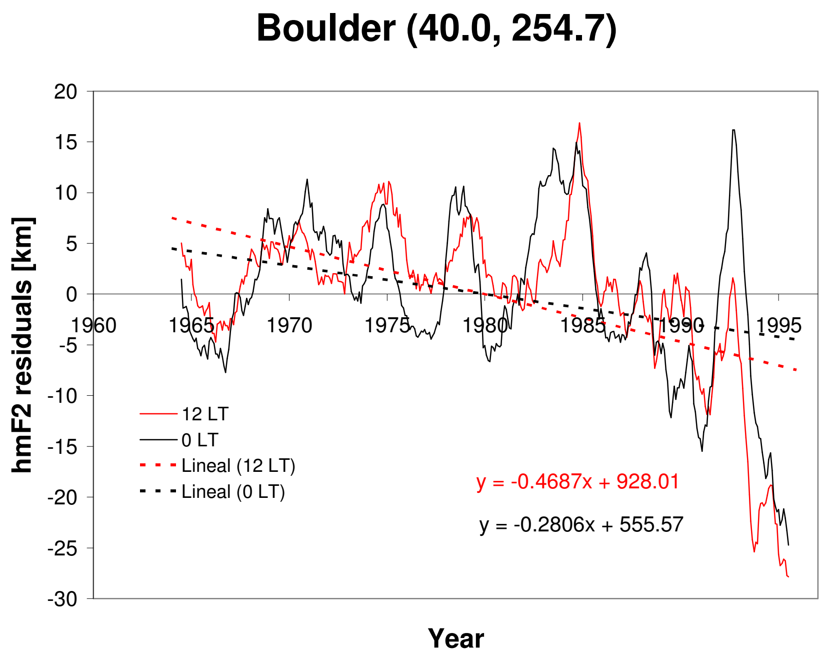


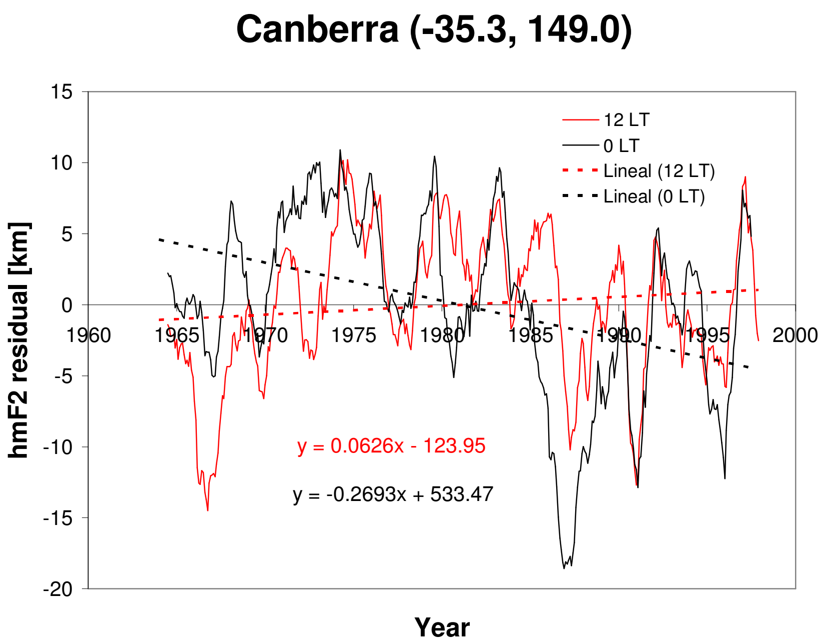
	0 LT	12 LT
r	0.94	0.92
a	0.61	0.57
b	258.3	241.3

$hmF2 = a\ F10.7 + b$

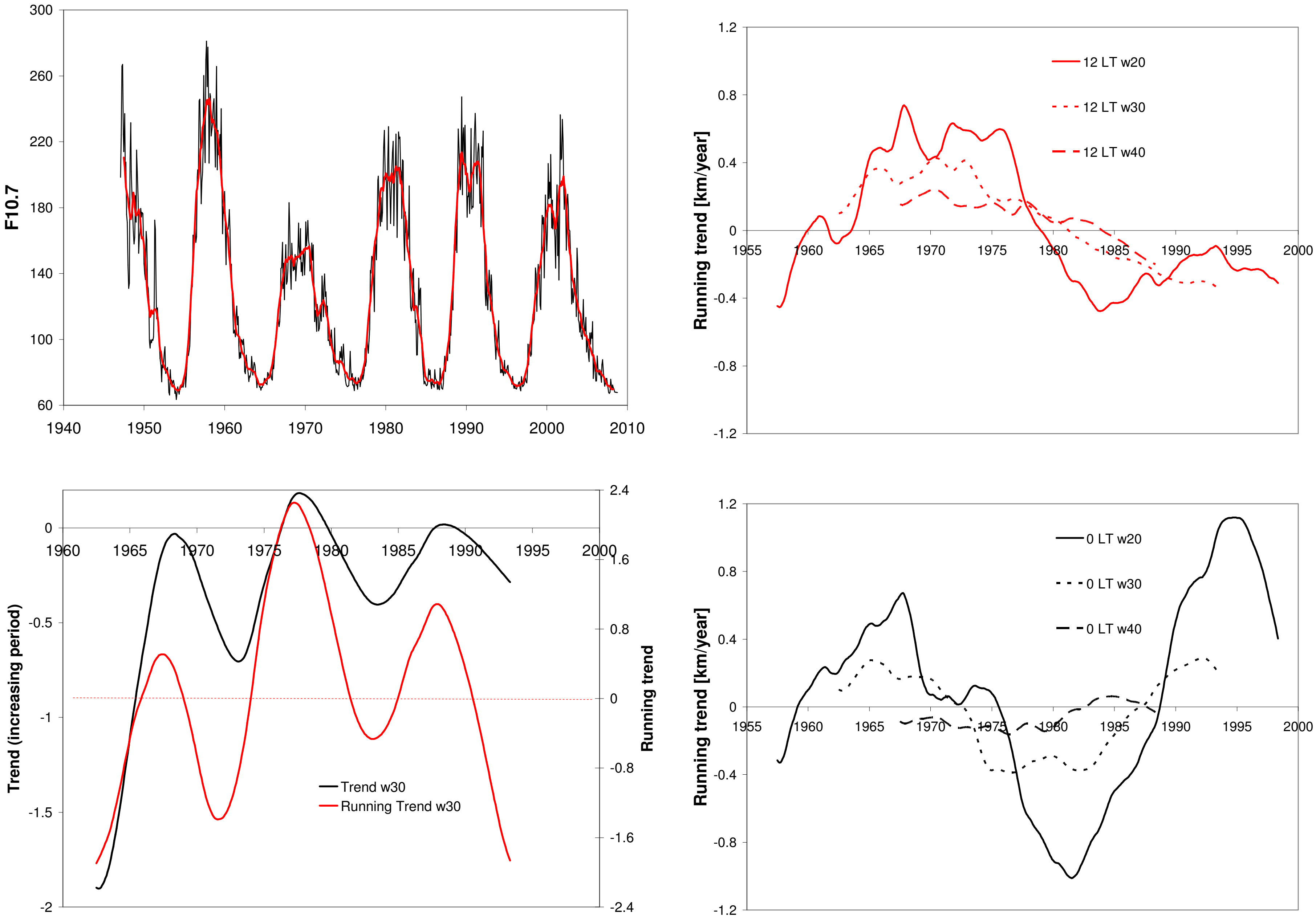
a [km / sfu: $\times 10^{-22} W\ m^{-2}\ Hz^{-1}$]


Argentine Island (-65.2, 295.7)
y = 0.2886x - 571.45
y = -0.4085x + 811.06
hmF2 residuals [km]
Year
12 LT
0 LT
Lineal (12 LT)
Lineal (0 LT)

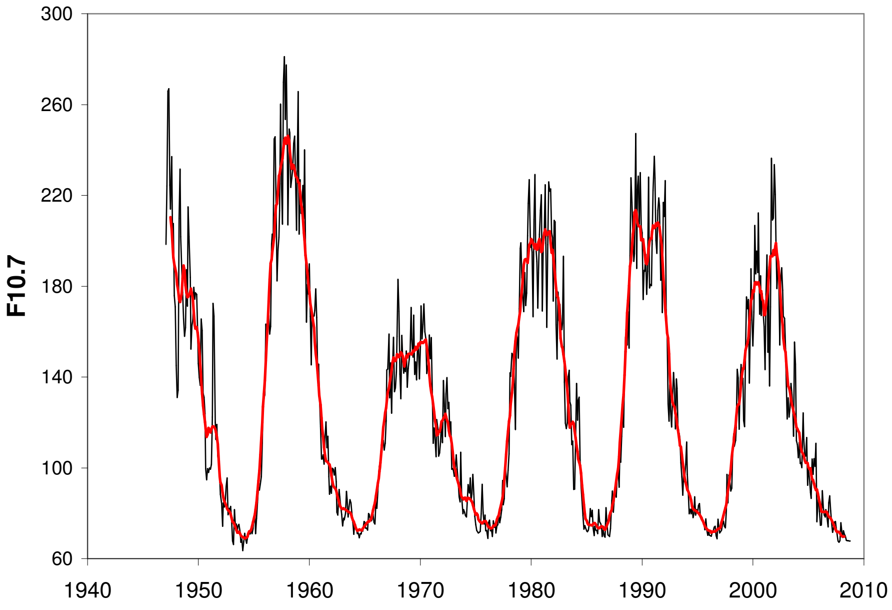

Boulder (40.0, 254.7)
hmF2 residuals [km]
Year
12 LT
0 LT
Lineal (12 LT)
Lineal (0 LT)
y = -0.4687x + 928.01
y = -0.2806x + 555.57

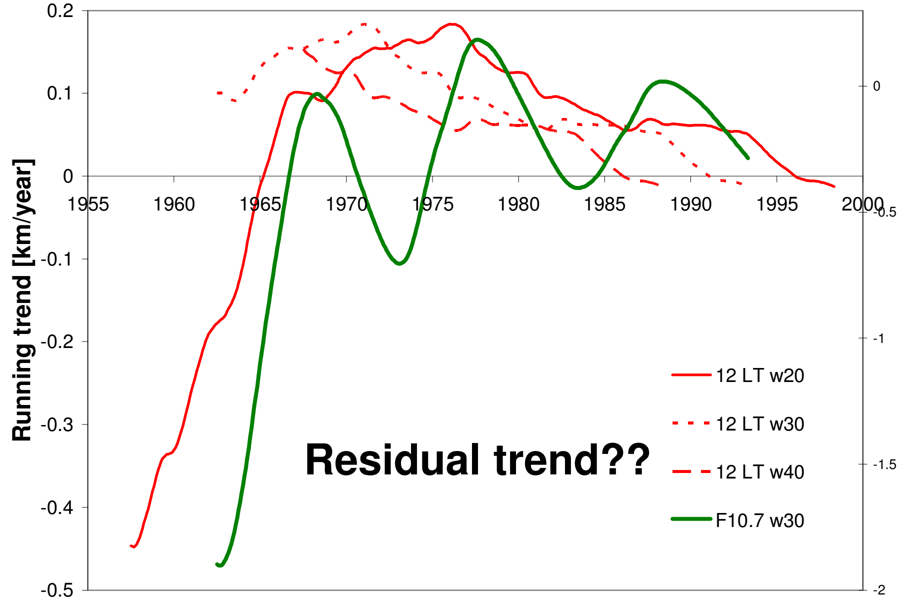

Canberra (-35.3, 149.0)
hmF2 residual [km]
Year
12 LT
0 LT
Lineal (12 LT)
Lineal (0 LT)
y = 0.0626x - 123.95
y = -0.2693x + 533.47

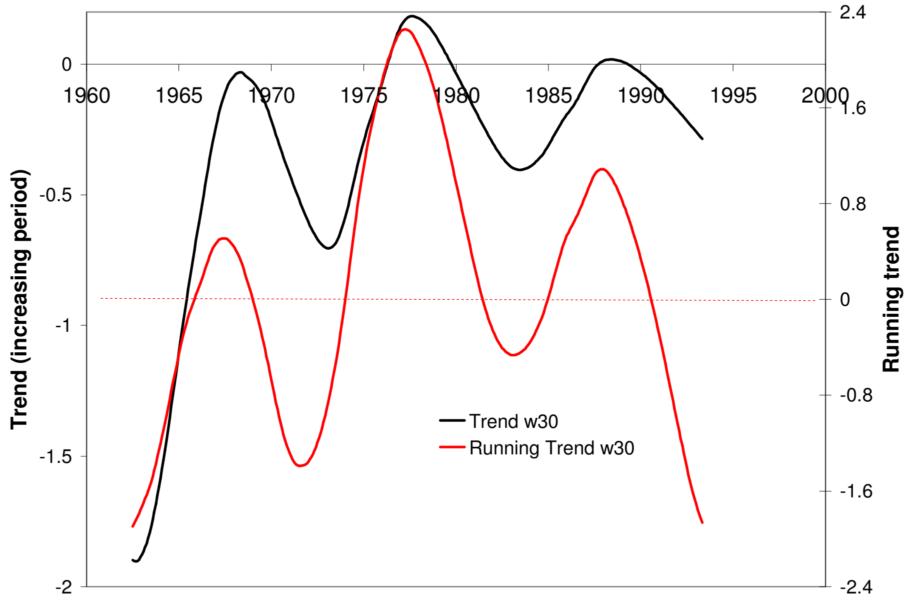
Canberra (-35.3, 149.0)

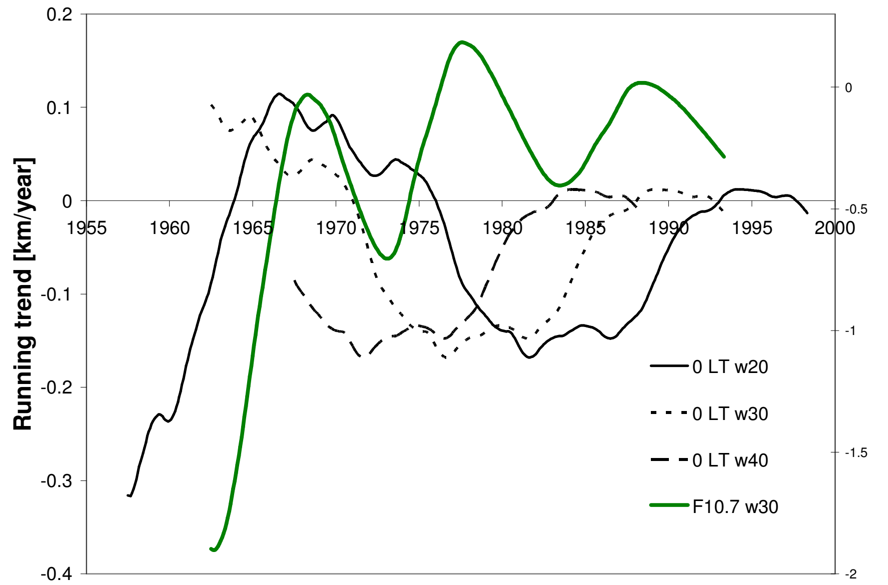


Canberra (-35.3, 149.0)

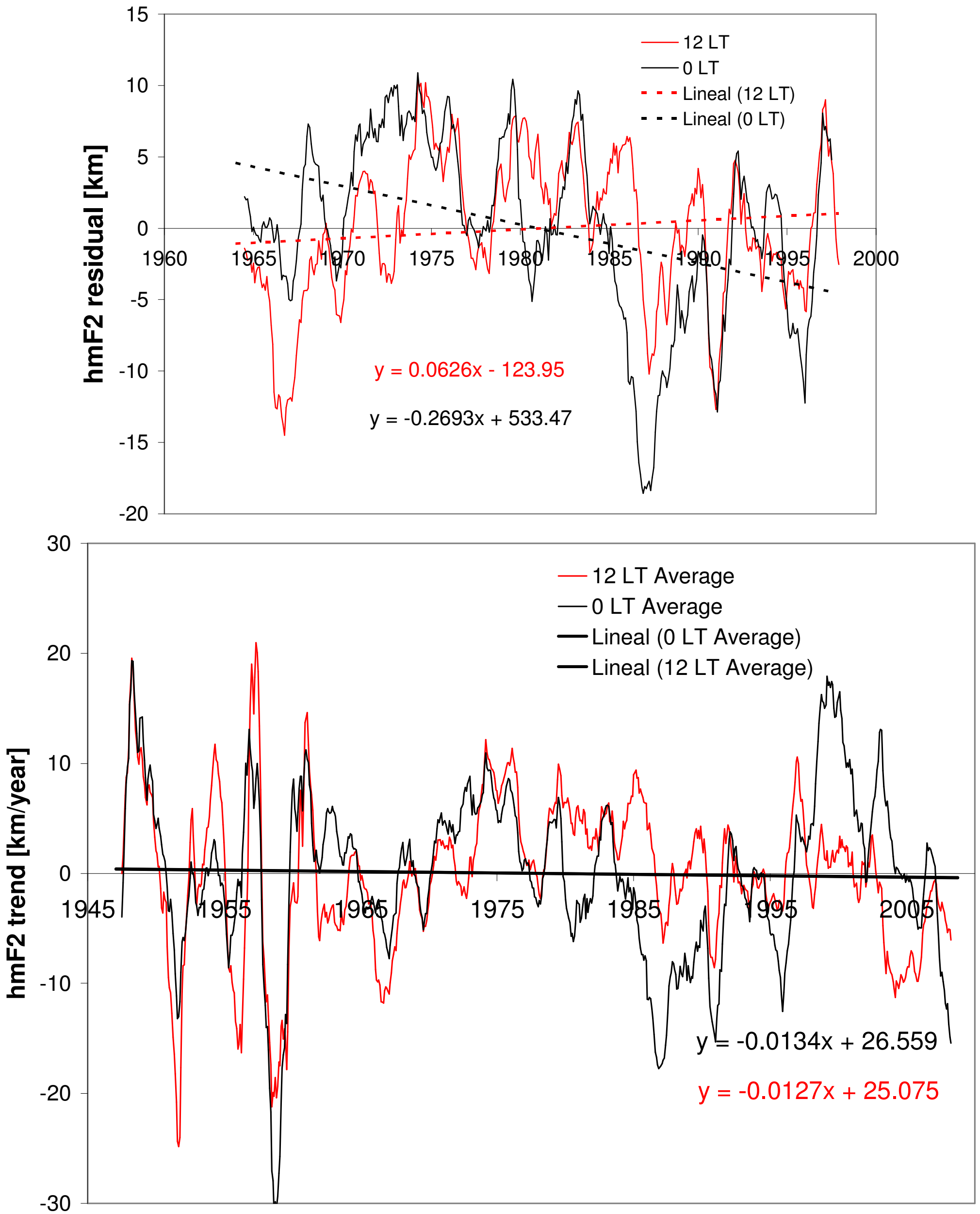








Canberra (-35.3, 149.0)



Facts:

*** NmF2, TEC, increase linearly with integrated EUV flux ??**

*** Nonlinear variations of solar EUV flux with F107**

*** + ionospheric dynamics and neutral atmosphere variations**

Photoionization processes can be neglected in the F-region during nighttime.

⇒ Controlling processes: recombination + ionospheric dynamics

Ionospheric dynamics strongly affects recombination processes by changing the altitude of the ionosphere:
* the F2-layer is uplifted to higher altitudes during nighttime by the upward plasma drift caused by equatorward neutral winds.
* recombination processes in the F-region are strongly affected.

⇒ nighttime ionosphere may be more sensitive to ionospheric dynamics.

Downward field-aligned plasma influx also maintain the nighttime F2-layer.

F2 peak ⇒ interplay of **photochemical processes** with **transport processes**

hmF2 ⇒ controlled by **plasma diffusion** ⇒ $\beta \sim \dfrac{D}{H^2}$

β: recombination coefficient at the height of maximum ($\sim e^{-hmF2/H}$)

D: diffusion coefficient

hmF2 can be affected by **vertical drift**

- **winds in the thermosphere** caused by daily processes of heating and cooling
- **electric fields**

W = vertical drift due to wind = U cos(I) sin(I)

vertical drift due to diffusion

Total vertical drift ⇒ $\approx \dfrac{D}{H} + W$

Field aligned ion drift: V = U cos(I)

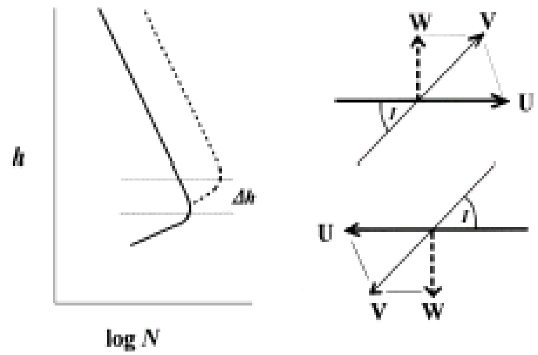


Figure from "How the thermospheric circulation affects the ionospheric F2-layer", **H. Rishbeth**, JASTP 60, 1385-1402, 1998.

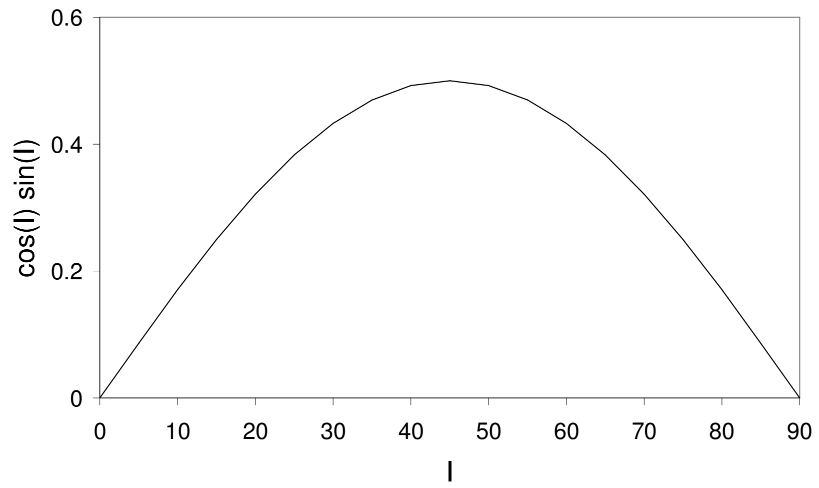
Height of maximum where $\beta \sim \frac{D}{H^2}$ ➡ $\beta \sim \frac{D}{H^2} + \frac{W}{H}$

β: recombination coefficient at the height of maximum ➡ $e^{\frac{-h_m}{H}}$

Effect of the neutral wind: $$\frac{\beta(\text{with wind})}{\beta(\text{without wind})} \approx \frac{\frac{D}{H} + W}{\frac{D}{H}} \sim \exp\left(\frac{\Delta h_m}{H}\right) \sim 1 + \frac{\Delta h_m}{H}$$

For small increment: $$\Delta h_m \sim \frac{W H^2}{D} \sim \frac{W}{\beta}$$

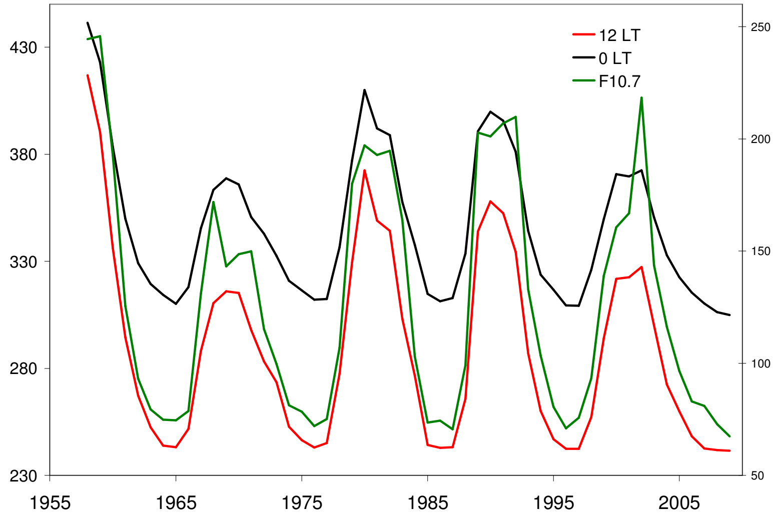
➡ $$\Delta h_m \sim \frac{U \cos(I) \sin(I) H^2}{D}$$



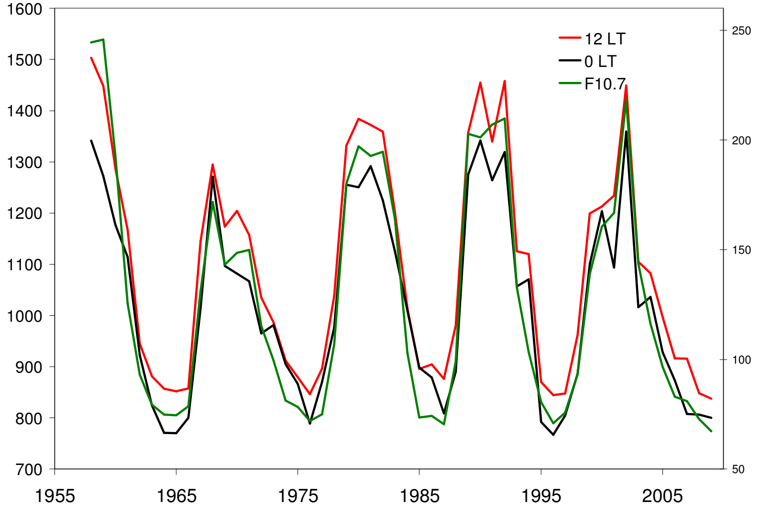
According to a simple kinetic theory → $D_m = \frac{4.4\times10^{18}\sqrt{T}}{n(O)}$

→ $f(\sqrt{T}, n(O), U_x, I)$

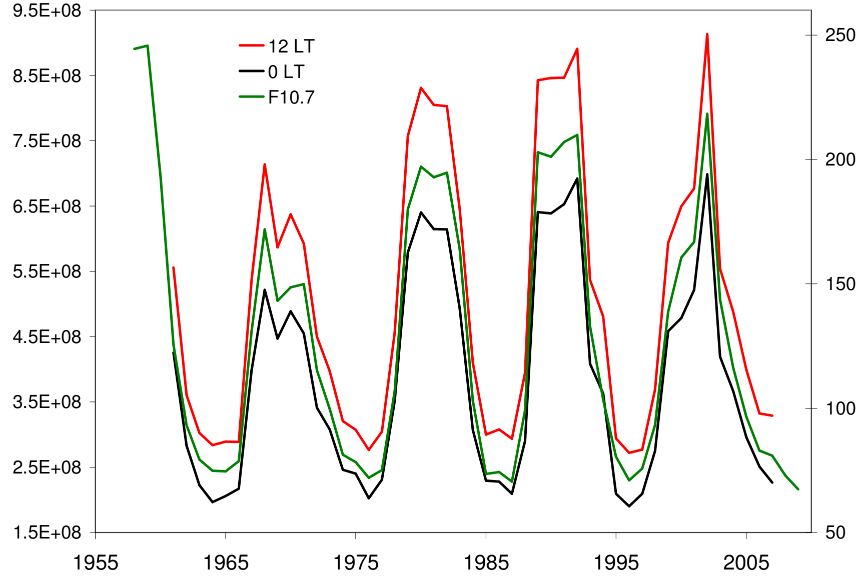
hmF2 (Argentine Island) - IRI2012



TN (Argentine Island) - IRI2012



n(O) (Argentine Island) - NRLMSISE-00



Drifts + thermal contraction + variations of background atmosphere

$\Downarrow$

affect the recombination loss around the F2-peak

β_m: recombination rate at the peak height of the F2-layer, due to N2
H: N2 scale height

$$\beta_m = \beta_{ref} \exp\left(- \frac{hmF2 - h_{ref}}{H} \right)$$

hmF2 increases with F107 $\Rightarrow$ β_m should decrease if the background atmosphere does not change

β_m increases with F107 at any fixed height due to change of the background atmosphere

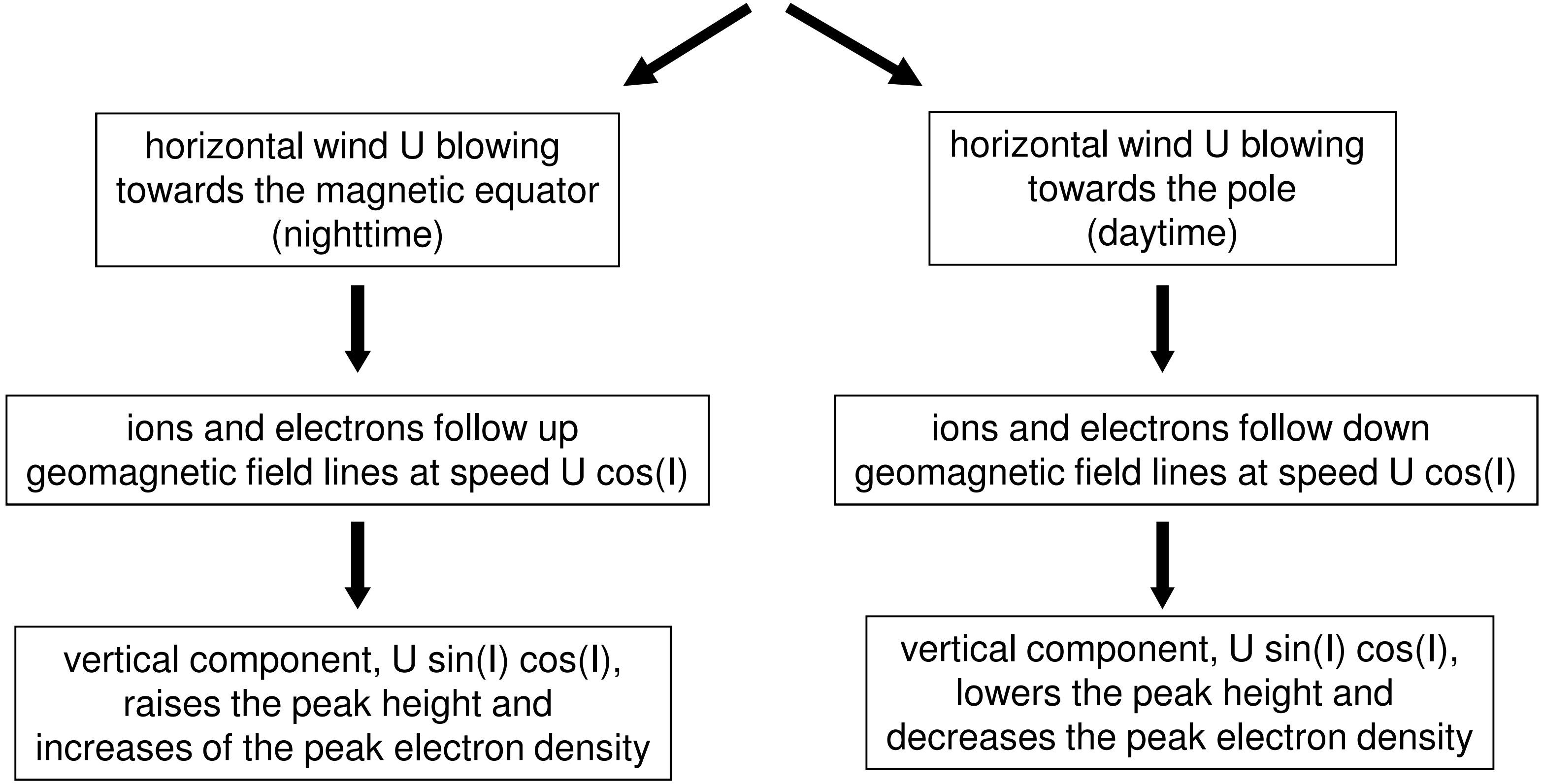
Counteracting effects!

$\Rightarrow$ these two factors produce contrary effects on $\beta_m = \beta_m(F10.7)$
$\Rightarrow$ $\beta_m = \beta_m(F10.7)$ depends on the relative intensity of two factors

The variation rates of neutral parameters and hmF2 with F107 differ in different seasons.

The peak height of the F2-layer is strongly controlled by neutral winds

Long-term changes in the dip angle (I) and declination (δ)

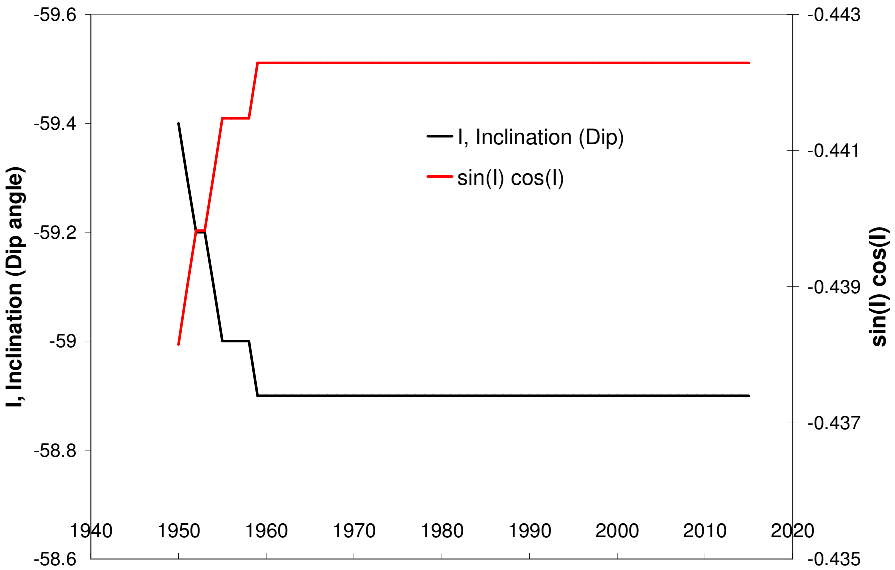


For small increment:
(Rishbeth, 1998)

$$\Delta hmF2 \sim \frac{W\,H^2}{D} \sim \frac{W}{\beta} \sim \frac{U\cos(I)\sin(I)\,H^2}{D}$$

W = vertical drift due to wind = U sin(I) cos(I)
$U = U_\theta \cos\delta \pm U_\phi \sin\delta$
D = diffusion coefficient

Argentine Island (-65.2, 295.7)



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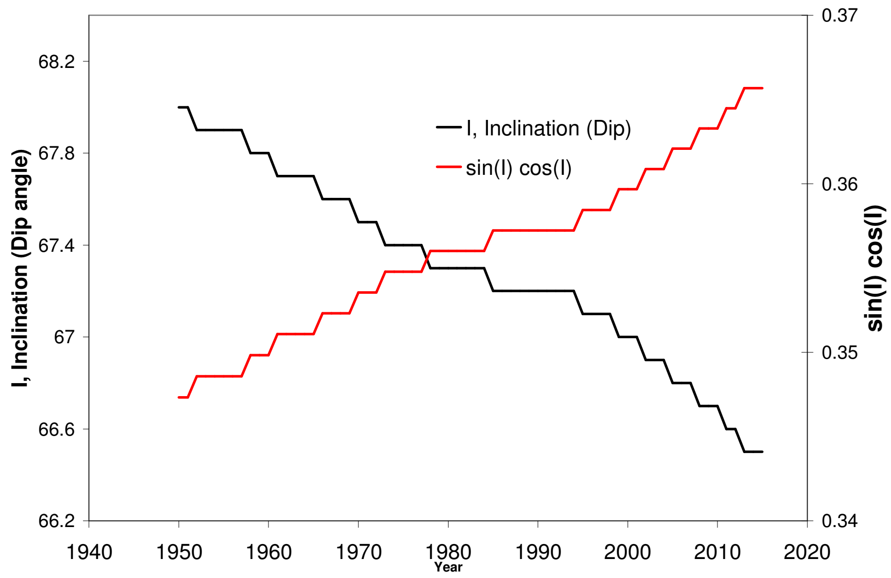

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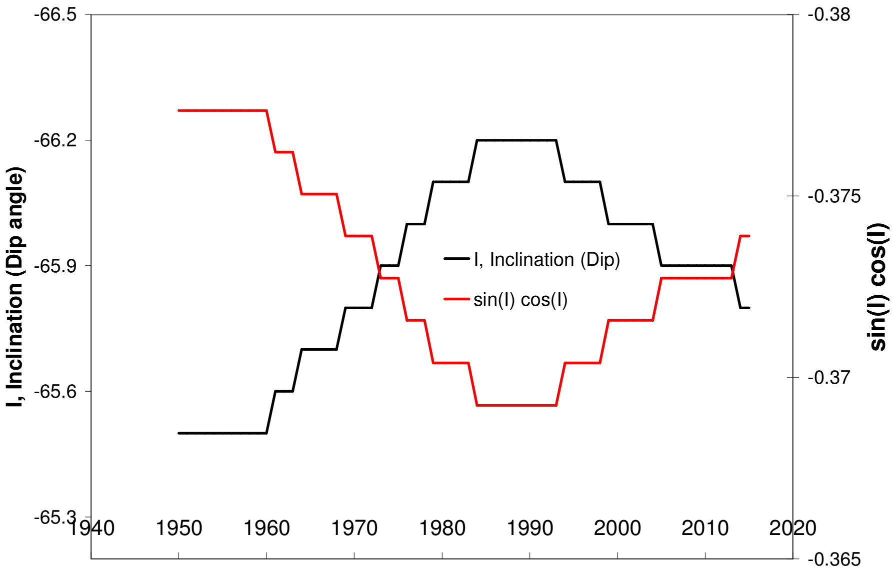

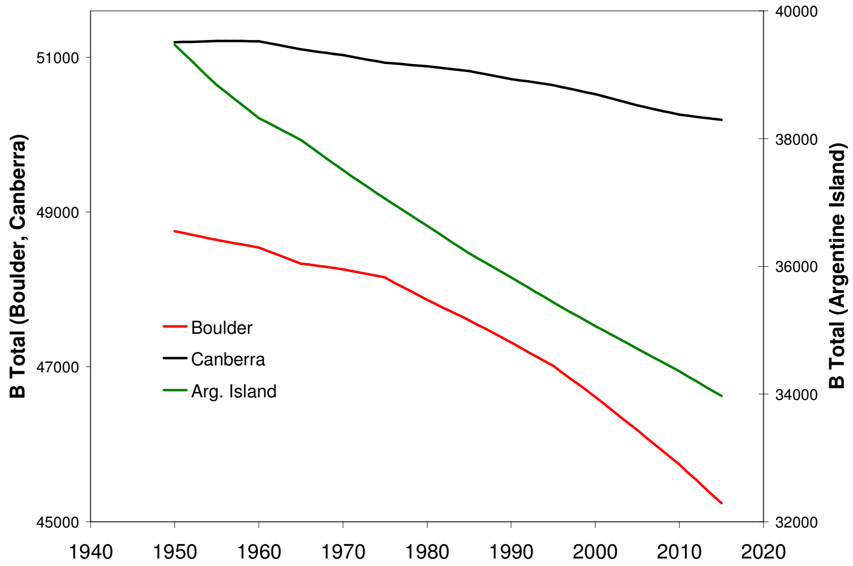

Discussion and Conclusion

Some facts to consider:

- The effect of trend sources (increasing greenhouse gases, Earth's magnetic field secular variation, ...) may not be constant along the solar activity cycle → filtering problems??

- Filtering procedures normally applied to ionospheric parameters (foF2, hmF2, ...) may not be 100% correct or effective.

- Index used do not show "all variation" in solar EUV radiation → incomplete filtering??

Advantage??
Recombination processes and the ionospheric dynamics simultaneously control the variations of the nighttime ionosphere.

Why is important to do a correct filtering of ionospheric (or atmospheric in general) parameters?

- We live in the Earth and we want to understand and predict the atmosphere behavior which is essential for human life.
- One of climate science main focus is to determine the extent to which human activities are altering the planetary energy balance through the emission of greenhouse gases and pollutants.
- This anthropogenic effect is so small that all other variability must be filtered out first.
- This happens in every layer of the atmosphere.
- Bad filtering $\rightarrow$ Bad results.

Thank you very much for your attention