14 Internationale EIKE Klima- und nergiekonferenz, IKEK-14

12-13 November 2021, Gera

Solar influence on long-term changes in the lower and upper atmosphere

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INFINOA (CONICET – UNT)

Outline:

- Introduction and a little of history about some results on anthropogenic and natural forcing effects
- On atmospheric long term trend detection and on some solar variability features
- Some results on solar influences as a natural forcing and as a proxy
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Definition of climate change:

"Climate change in IPCC usage refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity."

(IPCC, 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, page 30, 2008)

Trends in the atmosphere

- ✓ Increase in greenhouse gases concentration, like CO_2
- ✓ Deforestation
- ✓ ...

- ✓ **Long-term trends in solar activity**
- ✓ **Long-term trends in geomagnetic activity**
- ✓ Secular variation of the Earth's magnetic field
- ✓ Internal factors, like Volcanic eruptions
- ✓ ...

Lower atmosphere: troposphere, tropopause

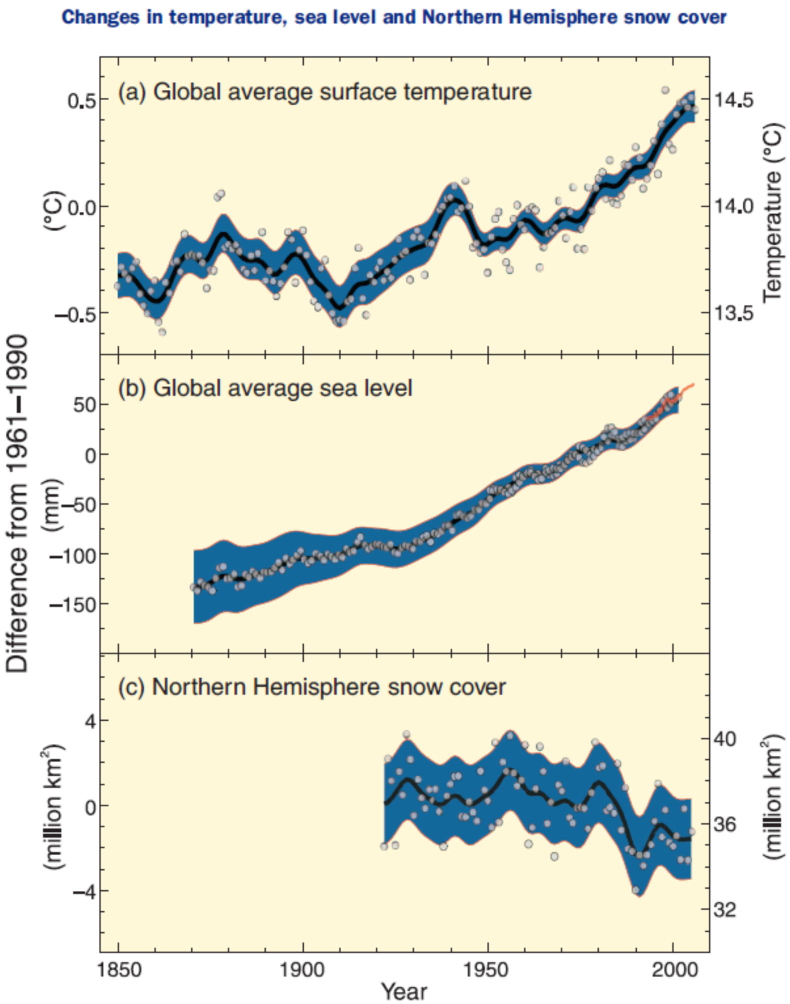

Figure 1.1. Observed changes in (a) global average surface temperature; (b) global average sea level from tide gauge (blue) and satellite (red) data; and (c) Northern Hemisphere snow cover for March-April. All differences are relative to corresponding averages for the period 1961-1990. Smoothed curves represent decadal averaged values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c).

(IPCC, 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, page 31, 2008.

Friis-Chirstensen and Lassen (1991), Length of the solar cycle: An indicator of solar activity closely associated with climate, Science, 254, 698-700.

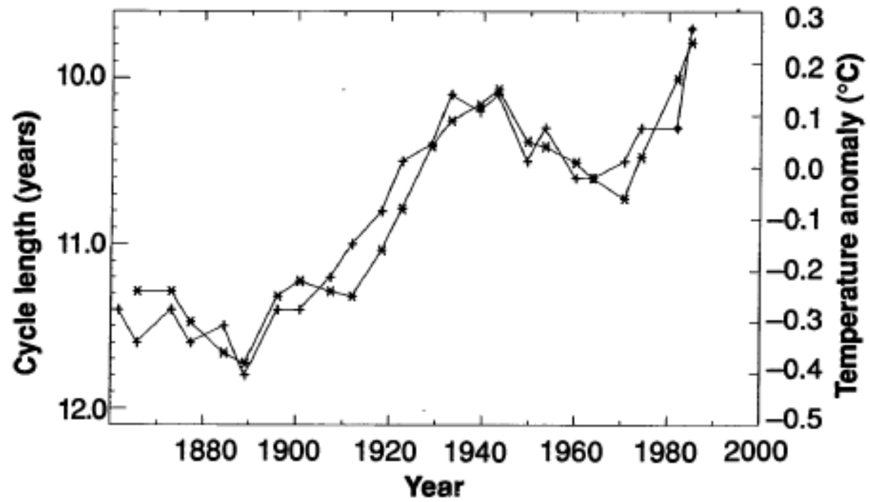

Fig. 2. Variation of the sunspot cycle length (left-hand scale) determined as the difference between the actual smoothed sunspot extremum and the previous one. The cycle length is plotted at the central time of the actual cycle (+). The unsmoothed last values of the time series have been indicated with a different symbol (*) which represents, as in Fig. 1, the Northern Hemisphere temperature anomalies.

- ✓ For the lower atmosphere ⇒ TSI
- ✓ TSI variation in an 11-year solar cycle ~ 0.1% ⇒ Not enough according to models
- ✓ Gleissberg periodicity (~80-90 years) would be more important
- ✓ ⇒ SCL appears to be a possible indicator of long-term changes in the total energy output of the sun

  (short cycles → higher activity & long cycles → lower activity)
- ✓ ⇒ Real physical mechanism?

Explanation?

Svensmark & Friis-Christensen (1997), Variations of cosmic ray flux and global cloud coverage – a missing link in solar-climate relationships, J. Atmos. Solar-Terr. Phys. 59,1225-1232.

Indirect effect of solar variability $\Rightarrow$ Galactic cosmic rays, GCR, inducing clouds

Higher solar activity $\Rightarrow$ less GCE $\Rightarrow$ less clouds $\Rightarrow$ temperature increase

Two different mechanisms proposed to link the GCR flux with clouds

- The ionization from GCRs influences the production of new aerosol particles in the atmosphere, which then grow and may eventually increase the number of cloud condensation nuclei (CCN), upon which cloud droplets form.
- GCR ionization modulates the entire ionosphere-Earth electric circuit which, in turn, influences cloud properties through charge effects on droplet freezing and other microphysical processes.

Kirby (2007), Cosmic Rays and Climate, Surv. Geophys. 28, 333–375, 2007.

But is the GCR flux directly affecting the climate or merely acting as a proxy for variations of the solar irradiance or a spectral component such as UV?

Upper atmosphere: thermosphere, ionosphere

Roble and Dickinson (1989), How will changes in carbon dioxide and methane modify the mean structure of the mesosphere and lower thermosphere?, *Geophys. Res. Lett.* **16**, 1441–1444

Roble and Dickinson: Trace Gases and the Upper Atmosphere

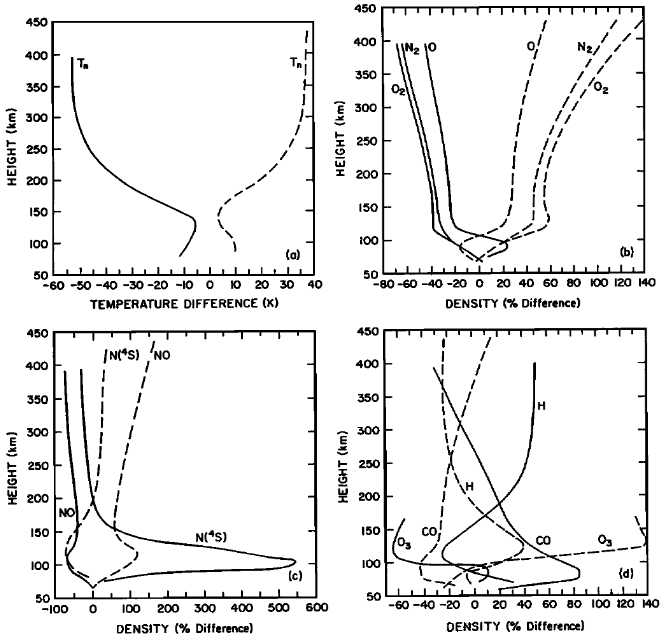

Fig. 2. Calculated (a) neutral gas temperature difference profile from the base case for the case where trace gases are doubled (solid lines) and halved (dashed lines), (b) density difference profiles (%) for O, O_2 and N_2 for the case where trace gases are doubled (solid lines) and halved (dashed lines), and (c) same as (b) except for NO and $N(^4S)$ and (c) same as (b) except for O_3, H and CO.

Effects of greenhouse gases increase in the thermosphere:

- ✓ cooling
- ✓ density decrease
- ✓ shrink

Effects of greenhouse gases increase in the ionosphere:

- ✓ layers going lower (descending !!)
- ✓ E-layer electron density increase
- ✓ F2-layer electron density decrease

Solomon, S. C., Liu, H.-L., Marsh, D. R., McInerney, J. M., Qian, L., & Vitt, F. M. (2018). Whole atmosphere simulation of anthropogenic climate change. Geophysical Research Letters, 45, 1567–1576.

Table 1. Model Inputs and Key Results

Inputs	**1972–1976**	**2001–2005**	**Change per decade**
<CO_2 > at surface	330 ppmv	375 ppmv	+16 ppmv
<CH_4 > at surface	1.44 ppmv	1.74 ppmv	+0.1 ppmv
<CFC11 + CFC12 > at surface	0.29 ppbv	0.79 ppbv	+0.2 ppbv
$F_{10.7}$ index	70	70	0
Kp index	0.3	0.3	0

Results	**1972–1976**	**2001–2005**	**Change per decade**
<T > at surface	287.8 K	288.4 K	+0.2 K
<T > at 10 km (266 hPa)	225.8 K	226.9 K	+0.4 K
<T > at tropopause	204.2 K	204.5 K	+0.1 K
<T > at stratopause	262.9 K	259.6 K	−1.1 K
<T > at mesopause	193.1 K	191.0 K	−0.7 K
<T > at 400 km	697.9 K	689.9 K	−2.8 K
<ρ > at 400 km (mass density)	0.584 ng m^{-3}	0.518 ng m^{-3}	−3.9%
<NmF_2 > (peak ion density)	1.78 × 10^5 cm^{-3}	1.71 × 10^5 cm^{-3}	−1.2%
<h_mF_2 > (height of peak)	261.5 km	257.8 km	−1.3 km
<T_i > at h_mF_2 (ion temperature)	712.8 K	704.9 K	−2.7 K

Experimental counterpart:

- trends from ionospheric measurements, after filtering the strong solar effect, was not globally uniform
- values were not completely consistent

Possible additional trend sources in the ionosphere:

- solar long term variation (of time-scales longer than decadal) which can be not filtered through traditional methods
- Bad solar filtering
- Earth’s magnetic field secular variations

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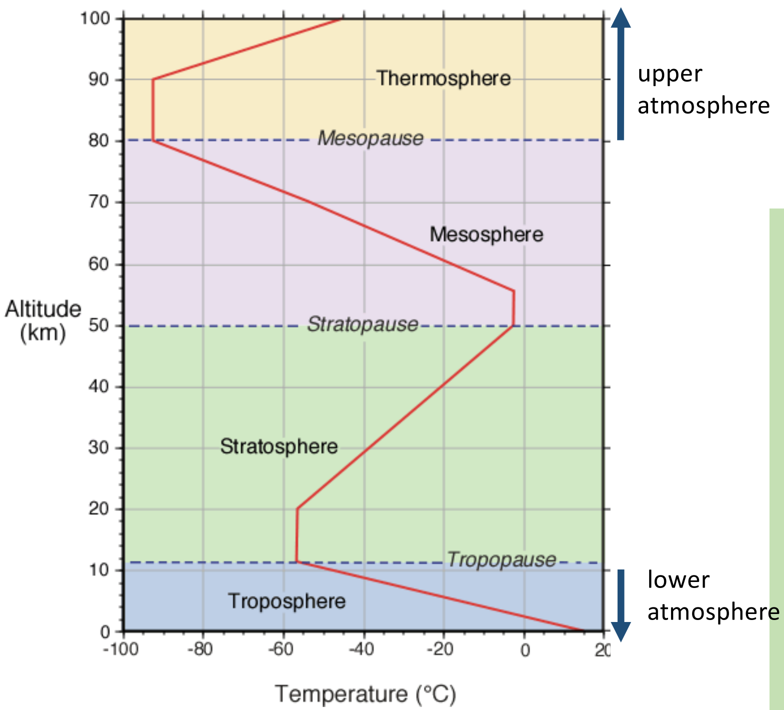
What do we certainly know?

Climate changes (**lower,** middle & **upper atmosphere**)

- ✓ anthropogenic sources (i.e. increasing greenhouse gases concentration, deforestation)
- ✓ natural sources (i.e. **solar variation**, volcanic activity, astronomical factors, geomagnetic field)



http://www.eoearth.org/article/Atmosphere_layers

Response to a source of variation

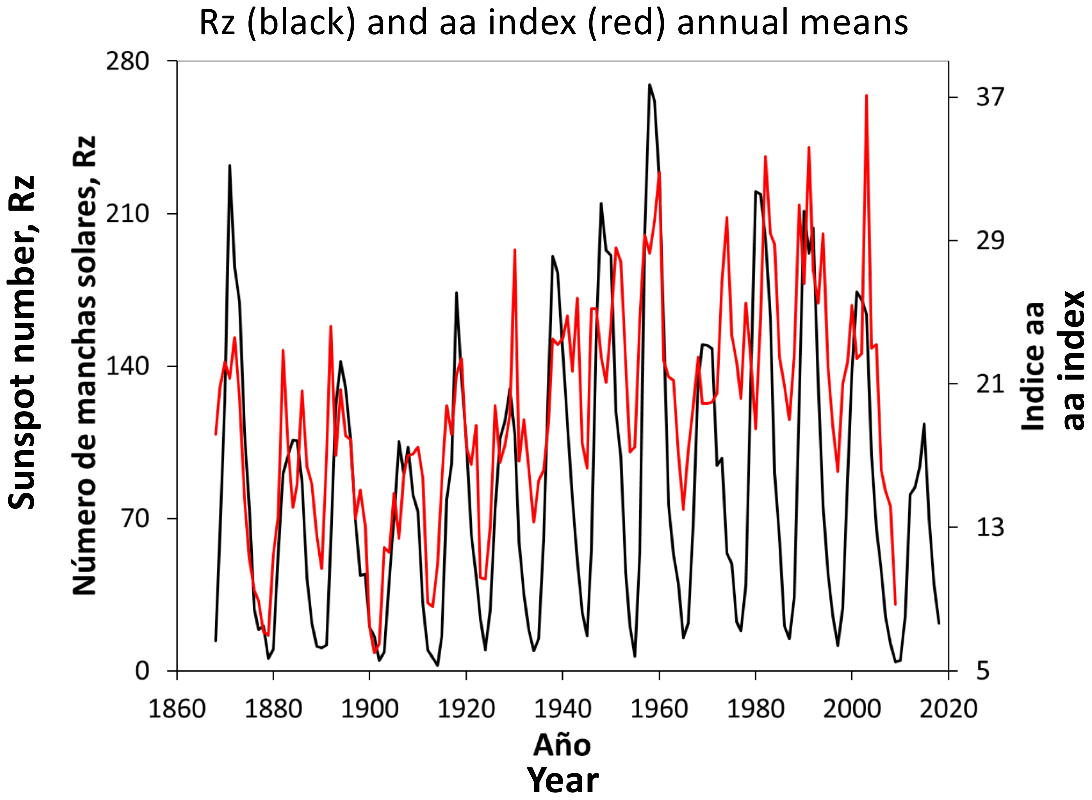
- ✓ Theory
- ✓ Experiment

Detection and analysis of atmospheric responses

- ✓ **physics, models** (i.e. GCMs which numerically solve fundamental equations describing the conservation of mass, energy, momentum, etc.) followed by **experimental proofs**
- ✓ **statistics** (analysis of experimental data using statistical tools such as FFT, wavelet analysis, correlations, SSA) followed by **physical explanation** of results (special care with forcing proxies or indices, and statistical methods)

Solar variation

- Solar activity: changes in the output of the sun in all forms (light, solar wind and energetic particles)
- Geomagnetic activity: geomagnetic storms, substorms, and aurora



Solar "periodicities"

↓

27-day rotational period

semiannual variation

11-year or Schwabe cycle

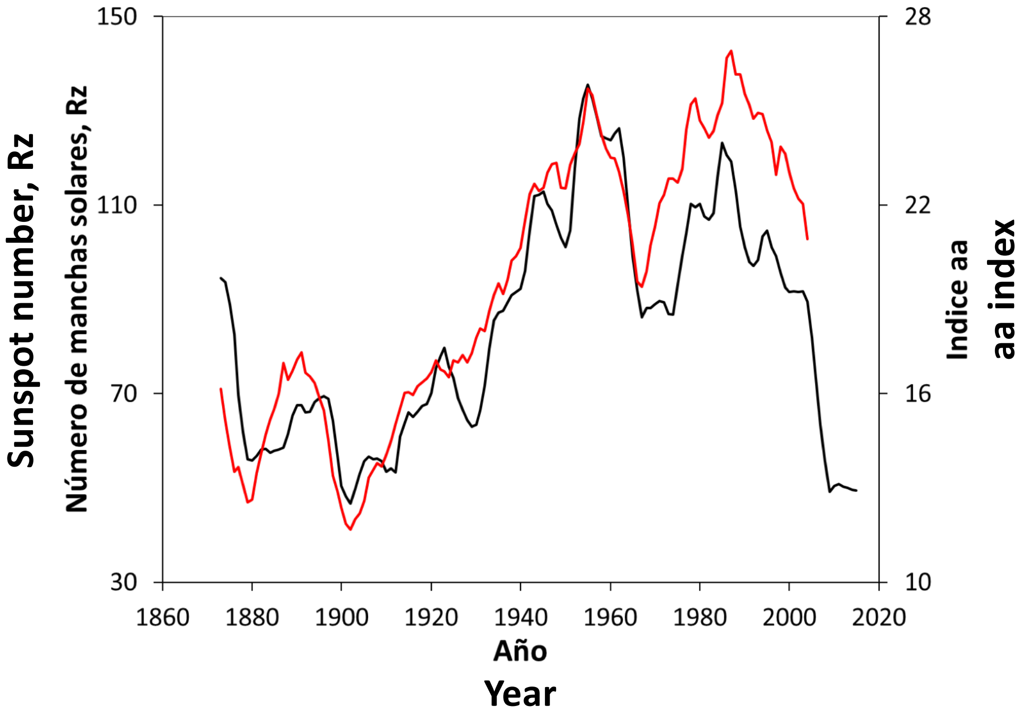
22-year Hale magnetic polarity cycle

Gleissberg cycle (~80-90 years)

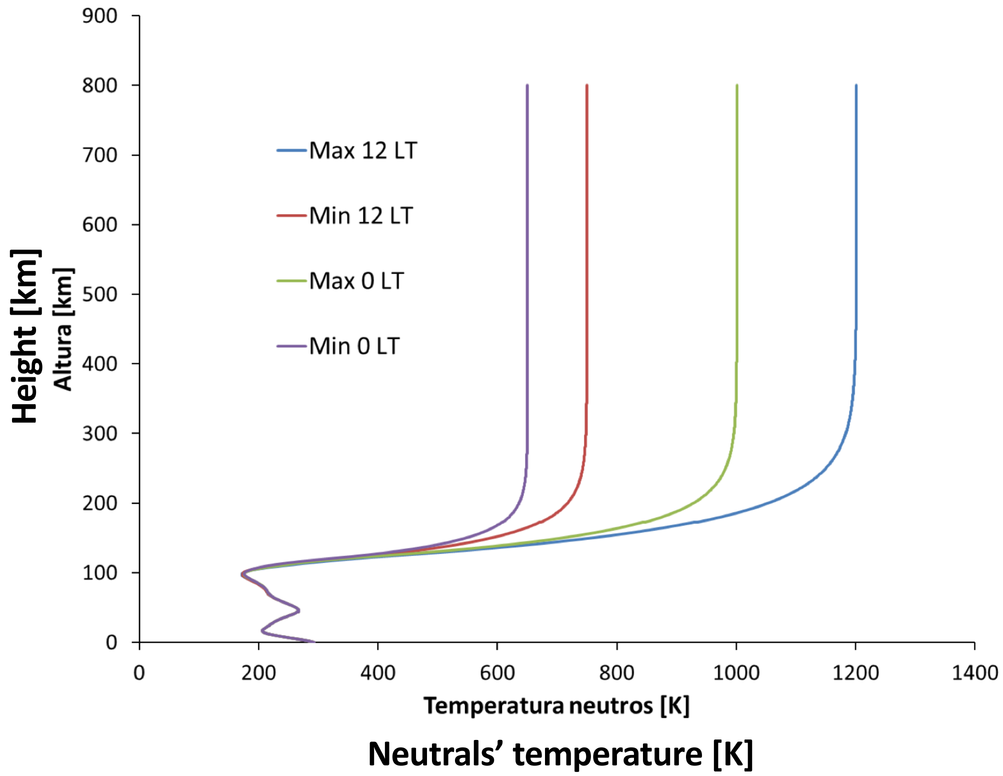
de Vries or Suess cycle (~200-210 years)

...

11-year running mean of annual Rz (black) and aa index (red)



Neutral atmosphere temperature sensitivity to solar activity decadal variation



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Heredia, Bazzano, Cionco, Soon, Medina & Elias (2019), Searching for solar-like interannual to bidecadal effects on temperature and precipitation over a Southern Hemisphere location, J. Atmos. Solar-Terr. Phys., 193, 105094.

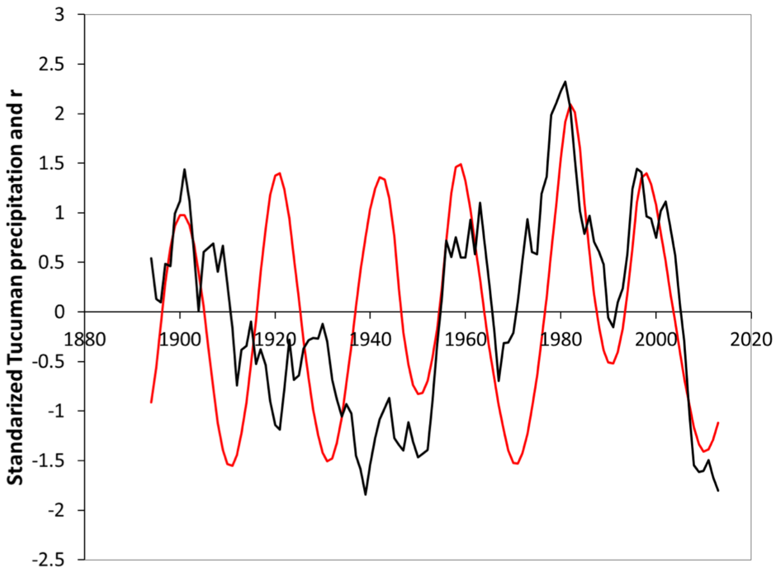
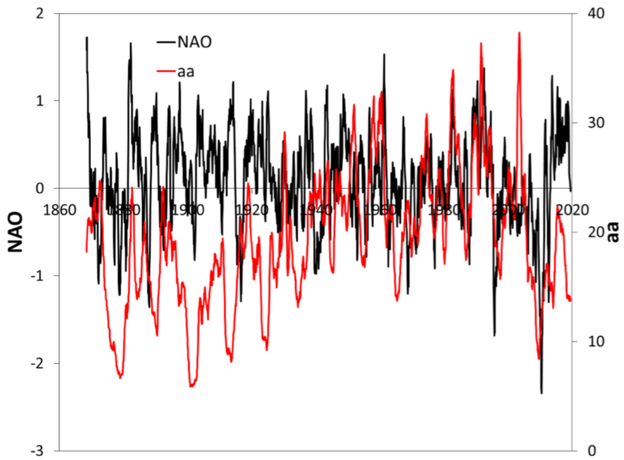


Figure 11. Tucuman total annual precipitation (black) and between the solar barycentric distance *r* (red) after an 11-year running mean. Both series are standardized.

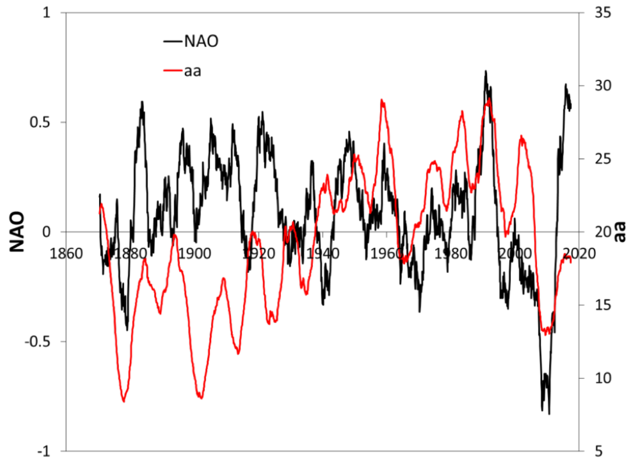
- ✓ An overall warming and augmented precipitation tendencies are detected at Tucuman climatic series, possibly linked to the increasing greenhouse gases concentration.
- ✓ A relatively strong ~20-year oscillation after the 1950s is detected, linked to "the planetary hypothesis of the solar cycles".
- ✓ A significant coherence at the ~20-year cycle is found, which is clearly present in the Sun's barycentric dynamic that could in turn be linked to some features of the quasi-decadal solar activity variations.

Asociación entre las tormentas geomagnéticas y la Oscilación del Atlántico Norte (Association between geomagnetic storms and the North Atlantic Oscillation), Flores Ivaldi, Physics Undergraduate Thesis, Director: Ana G. Elias, FACET, UNT, Argentina, 2020.

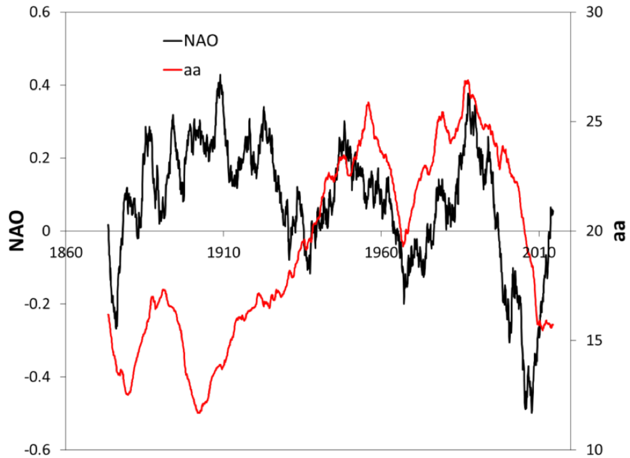
12-month running mean (1 year)



60-month running mean (5 years)



132-month running mean (11years)

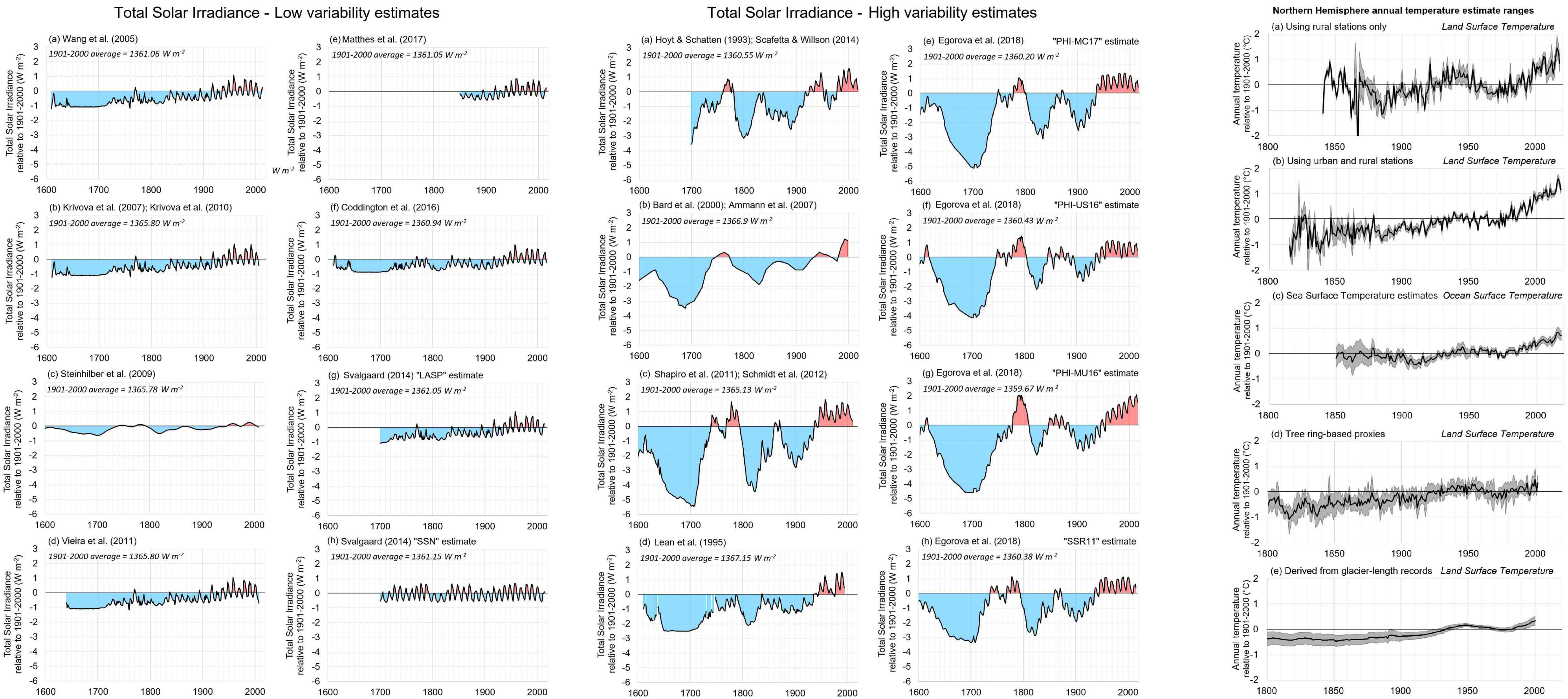


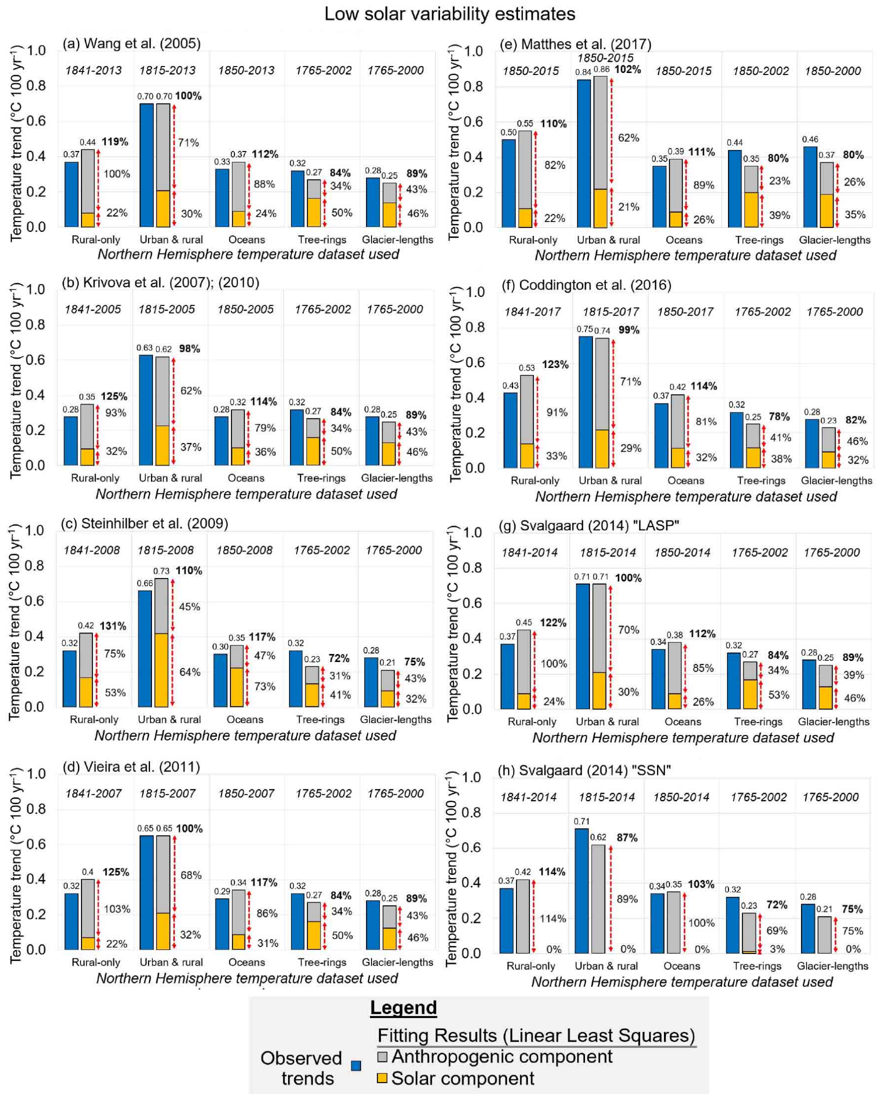
Chain of effects:

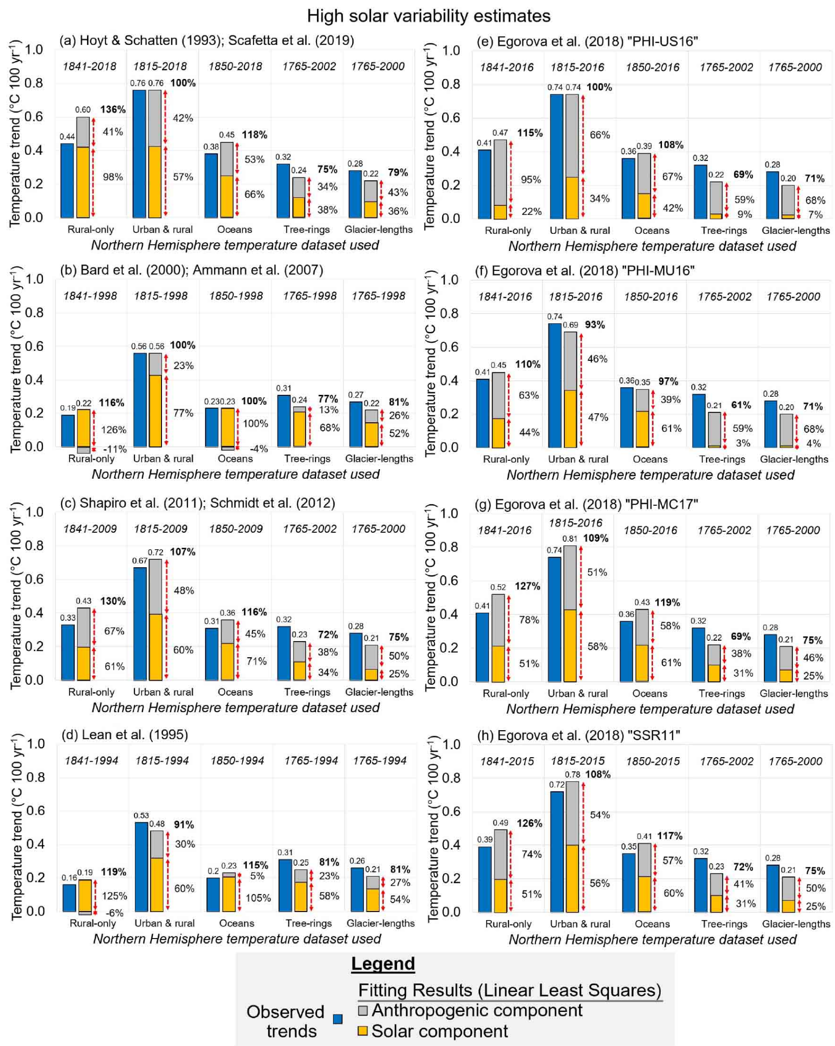
Geomagnetic activity
⇓
Polar vortex
⇓
NAO

Stronger geomagnetic activity
⇓
Increase in NOx component which help ozone destruction
⇓
Less ozone
⇓
Cooler polar stratosphere
⇓
Stronger polar jet
⇓
Stronger positive NAO phase

Connolly et al. (2021), How much has the Sun influenced Northern Hemisphere temperature trends? An ongoing debate. Research in Astronomy and Astrophysics, 21, 131.




Low solar variability estimates
(a) Wang et al. (2005)
(b) Krivova et al. (2007); (2010)
(c) Steinhilber et al. (2009)
(d) Vieira et al. (2011)
(e) Matthes et al. (2017)
(f) Coddington et al. (2016)
(g) Svalgaard (2014) "LASP"
(h) Svalgaard (2014) "SSN"
Temperature trend (°C 100 yr⁻¹)
Rural-only
Urban & rural
Oceans
Tree-rings
Glacier-lengths
Northern Hemisphere temperature dataset used
Legend
Observed trends
Fitting Results (Linear Least Squares)
Anthropogenic component
Solar component


High solar variability estimates
(a) Hoyt & Schatten (1993); Scafetta et al. (2019)
(b) Bard et al. (2000); Ammann et al. (2007)
(c) Shapiro et al. (2011); Schmidt et al. (2012)
(d) Lean et al. (1995)
(e) Egorova et al. (2018) "PHI-US16"
(f) Egorova et al. (2018) "PHI-MU16"
(g) Egorova et al. (2018) "PHI-MC17"
(h) Egorova et al. (2018) "SSR11"
Temperature trend (°C 100 yr⁻¹)
Rural-only
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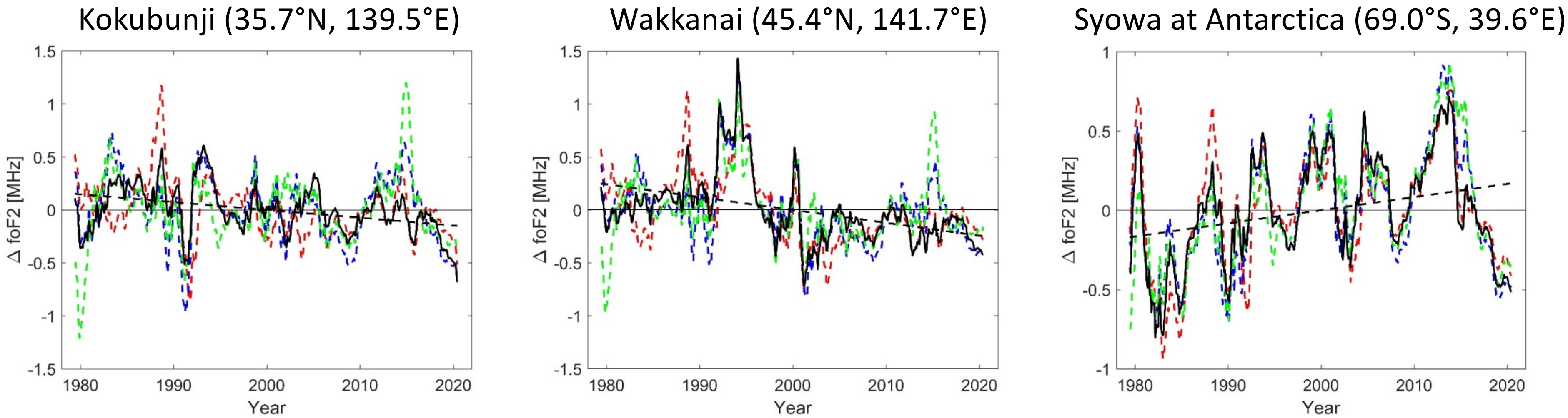
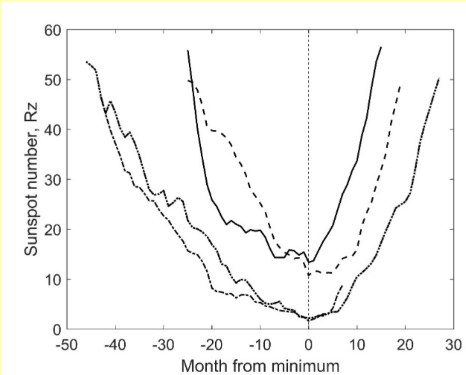
Oceans
Tree-rings
Glacier-lengths
Northern Hemisphere temperature dataset used
Legend
Observed trends
Fitting Results (Linear Least Squares)
Anthropogenic component
Solar component

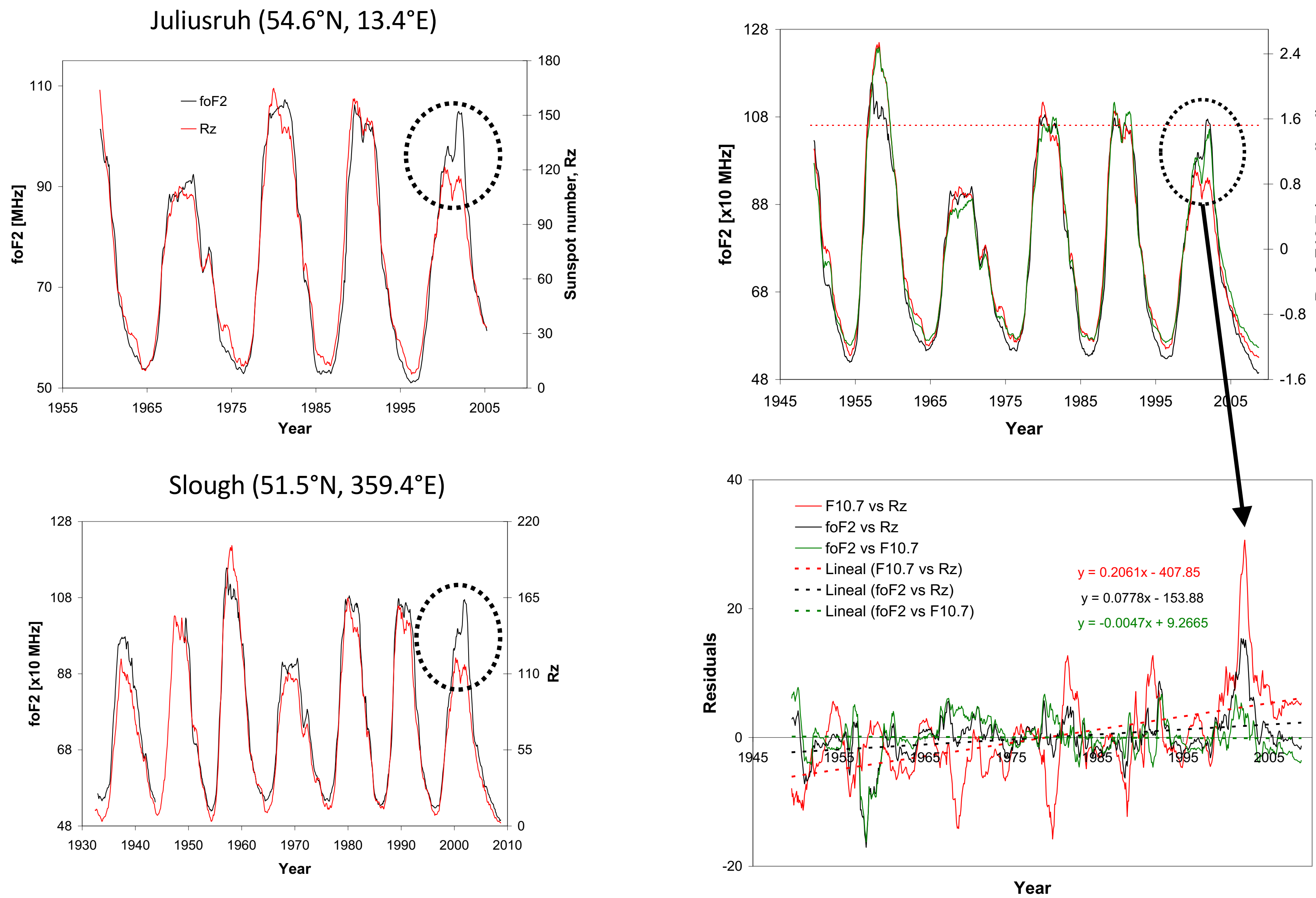
de Haro Barbas, Elias, et al. (2021), Mg II as a solar proxy to filter F2-region ionospheric parameters, Pure and Applied Geophysics, in press.



foF2 residuals, ΔfoF2 [MHz], for the period 1979-2020, obtained from the linear regression between foF2 and Mg II (black solid), Lyman α (red dashed), F10.7 (blue dashed) and Rz (green dashed) together with the linear trend in the case of Mg II filtering (black dashed).

Superposition: 0: minimum considering 12-month running means (Rz < 50)
(1) min 21-22: solid
(2) min 22-23: dashed
(3) min 23-24: dotted
(4) min 24-25: dot-dashed





Juliusruh (54.6°N, 13.4°E)
foF2
Rz
foF2 [MHz]
Sunspot number, Rz
Year
Slough (51.5°N, 359.4°E)
foF2 [x10 MHz]
Rz
Year
foF2 [x10 MHz]
Rz & F10.7 (normalized)
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
Residuals
Year

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Important facts and conclusions

- ✓ Model and statistics: the lower and upper atmosphere respond to long-term solar variation
- ✓ The lower atmosphere is a complex system, and so the solar-climate "associated variability", which could be more noticeable in long-term time-scales, is harder to detect and still controversial.
- ✓ The upper atmosphere is highly affected by solar variability in short and long-term time-scales.
- ✓ In addition to the "true" solar influence in the atmosphere, its experimental detection can be hindered by statistical procedures and/or bad choice of the solar proxy used to measure it.

Why is important to understand and measure the atmosphere response to solar variation?

We live in the Earth and we want to understand and predict the atmosphere behavior which is essential for human life.

Understanding and interpreting the causes of atmospheric trends requires a fundamental understanding of the atmosphere response to solar variations. This is an essential focus of climate science, which is seeking to determine the extent to which human activities are altering the planetary energy balance through the emission of greenhouse gases and pollutants.

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Thank you