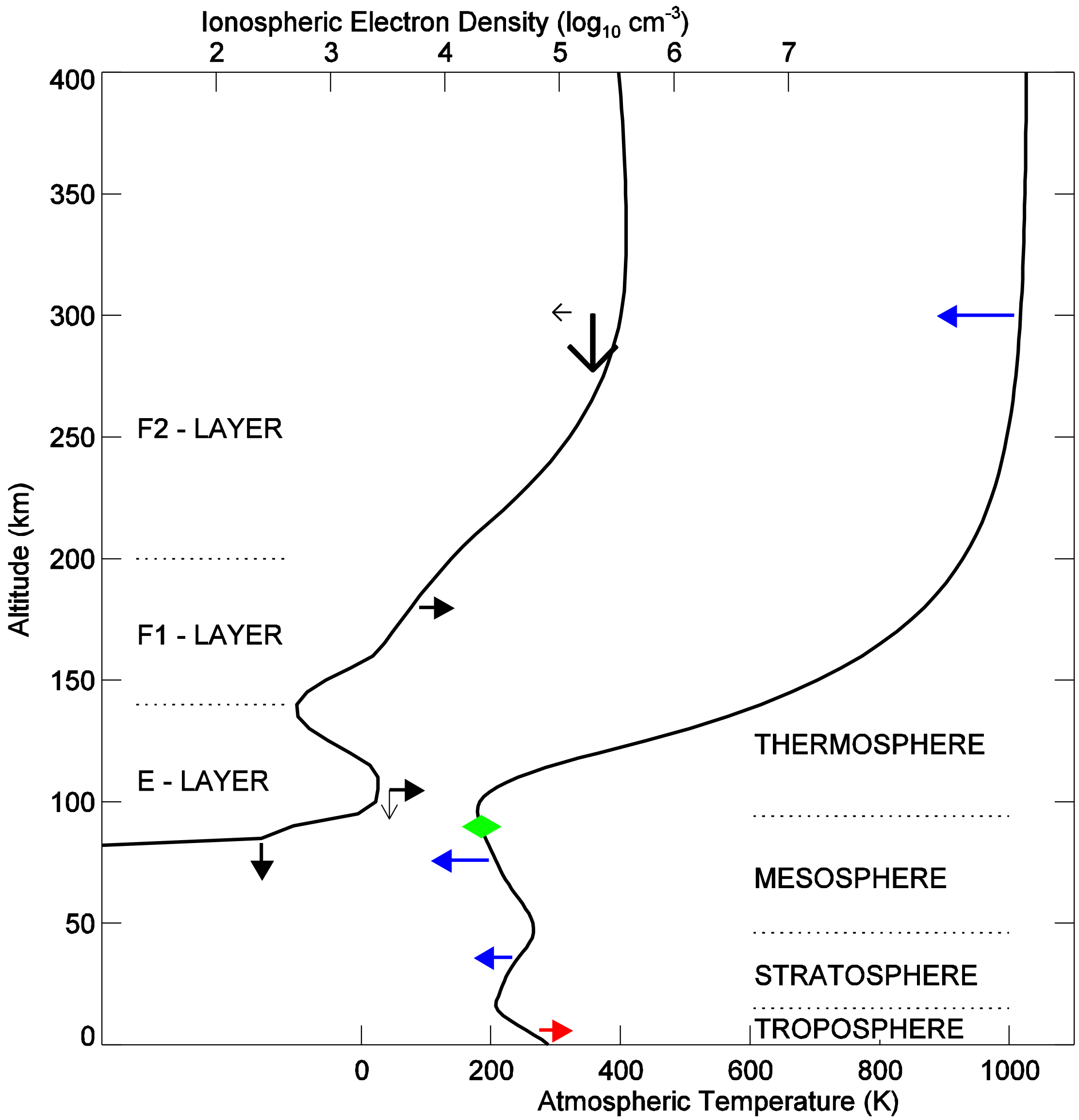
Long-term trends in the Ionosphere and Thermosphere

Jan Laštovička

Institute of Atmospheric Physics CAS, Prague, Czech Republic, jla@ufa.cas.cz

The anthropogenic emissions of greenhouse gases affect not only the weather and climate in the troposphere; they affect also the upper atmosphere (thermosphere and ionosphere) together with some other trend drivers. The state-of-the-art of knowledge and understanding of long term trends in the upper atmosphere (ionosphere and thermosphere) will briefly be presented.

Global trend scenario



Summary of consistent mesospheric, thermospheric and ionospheric trends, which form the global pattern/scenario – in terms of temperature and electron density.

foE and solar correction

Is solar correction for trend studies stable? No.

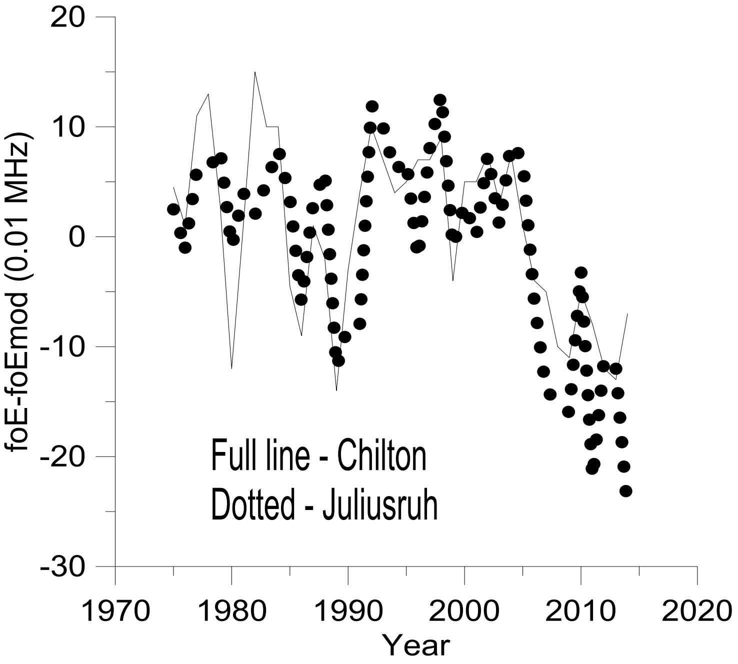
	F10.7	Fα
1975-2014	0.88/0.91	0.89/0.92
1975-1990	0.96/0.91	0.93/0.92
1990-2005	0.94/0.98	0.93/0.95
2006-2014	0.79/0.96	0.86/0.96

foE = A + B * solar

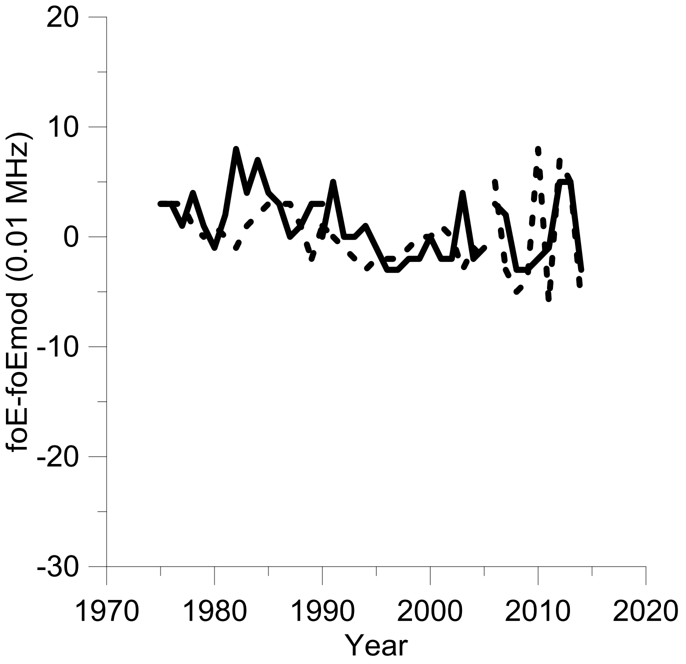
Percentage of total variance of **foE** explained by eq. foE = A + B*solar for **Juliusruh/Chilton**, yearly values, and solar proxies F10.7 and Fα. **Clearly better for three separate corrections.**

Laštovička et al. (2016)

One solar correction

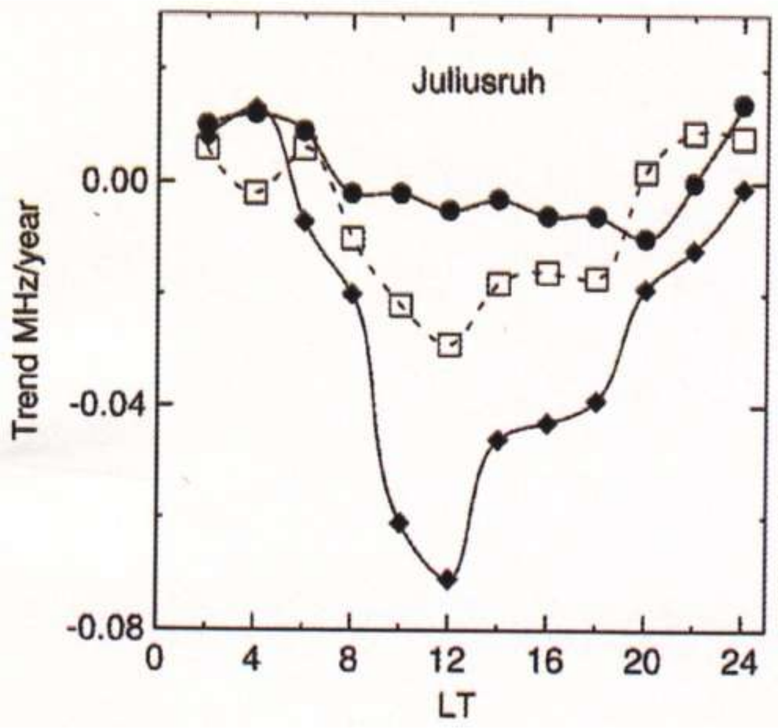


Three solar corrections



foF2 and hmF2

Trends in foF2 critically depend on local time and season. They are close to no trend at night and in summer daytime and they are negative and not quite small in winter daytime, because hmF2 is close to the boundary where a positive anthropogenic trend in electron density below changes to a negative trend above according to model calculations (Qian et al., 2008). **Therefore foF2 is not a good parameter for studying trends of anthropogenic origin.**



Dependence of trends in foF2 on local time and season for Juliusruh, northernmost Germany. Circles – June; rectangles – September; diamonds – February. Danilov (2015).

X. Yue et al. (2018) digitized and homogenized very long dataset foF2 and hmF2 from the **Wuhan** (30.5^{o}N, 114.5^{o}E) ionosonde observations over **1947-2017**. Table shows mean trends from observations and simulations. Trends fairly well agree each other. For foF2 the main trend driver is the secular change of the Earth’s magnetic field, for hmF2 slightly dominates the effect of CO_2.

Trend	**CO_2**	**Magn. field**	**CO_2 + Magn. field**	**Observations**
foF2 (MHz/year)	-0.0005	**-0.0016**	**-0.0022**	**-0.0021**
hmF2 (km/year	**-0.0379**	-0.0362	-0.0763	-0.106

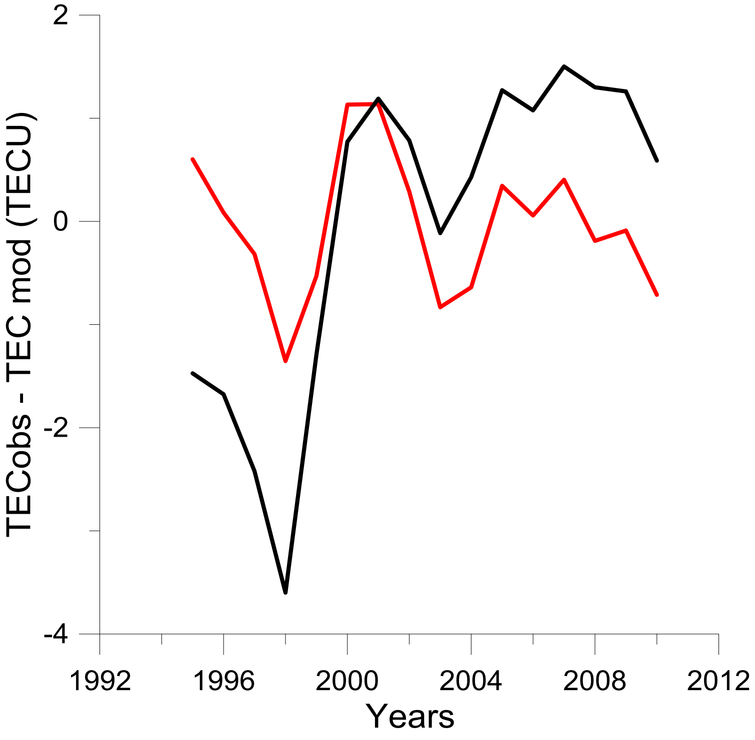
Summary of the linear trends from simulations (first three columns) and observations

Locally substantial effect of secular change of geomagnetic field on hmF2 calculation and trend has been found by Elias et al. (2017).

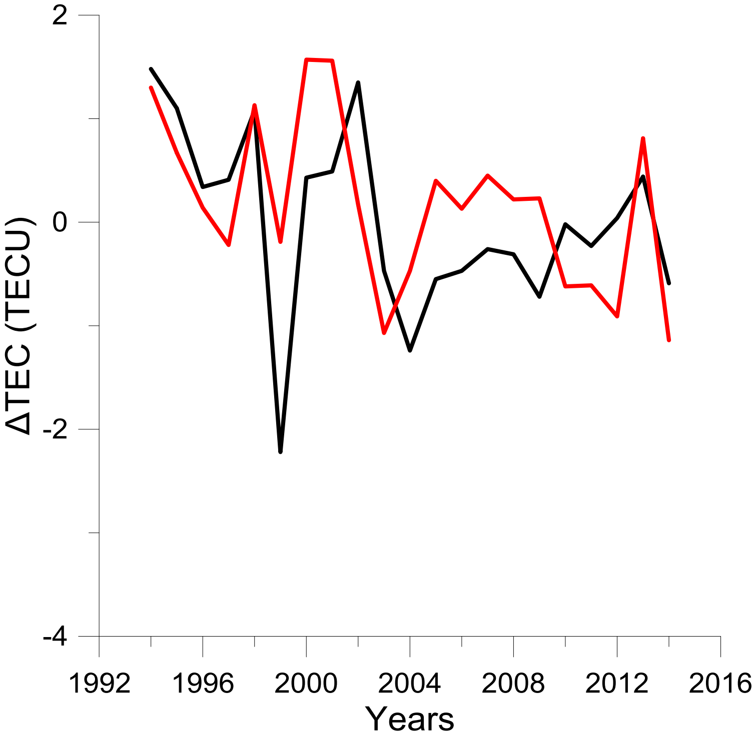
Total electron content (TEC)

Trend in total electron content (TEC)

Lean et al. (2011, 2016) used IGS TEC data for 1998-2010 and CODE TEC data for 1995-1997 - trend too positive. Lean et al. (2016) - for 1998-2015 trend insignificantly different from zero. Emmert et al. (2017) constructed homogeneous TEC data series JPL35 for 1994-2014. Yearly global TEC. **JPL trend – negative, then none.**

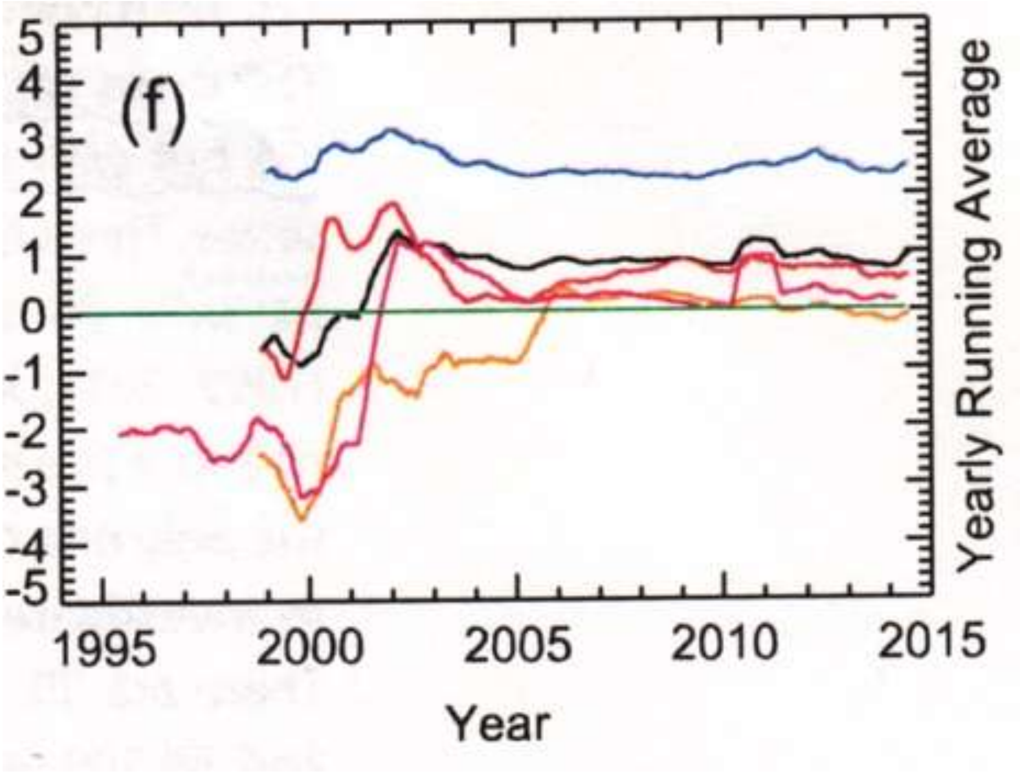


Black line Lean et al. (2011), red line JPL35, 1995-2010



JPL35 – red line with Mg II, black line with F10.7, 1994-2014

Lastovicka et al. (2017, GRL)



Differences of yearly running global TEC between JPL35 (green) versus CODE (purple), standard JPL (blue), ESA (orange), UPC (red), and IGS (black). Emmert et al. (2017).

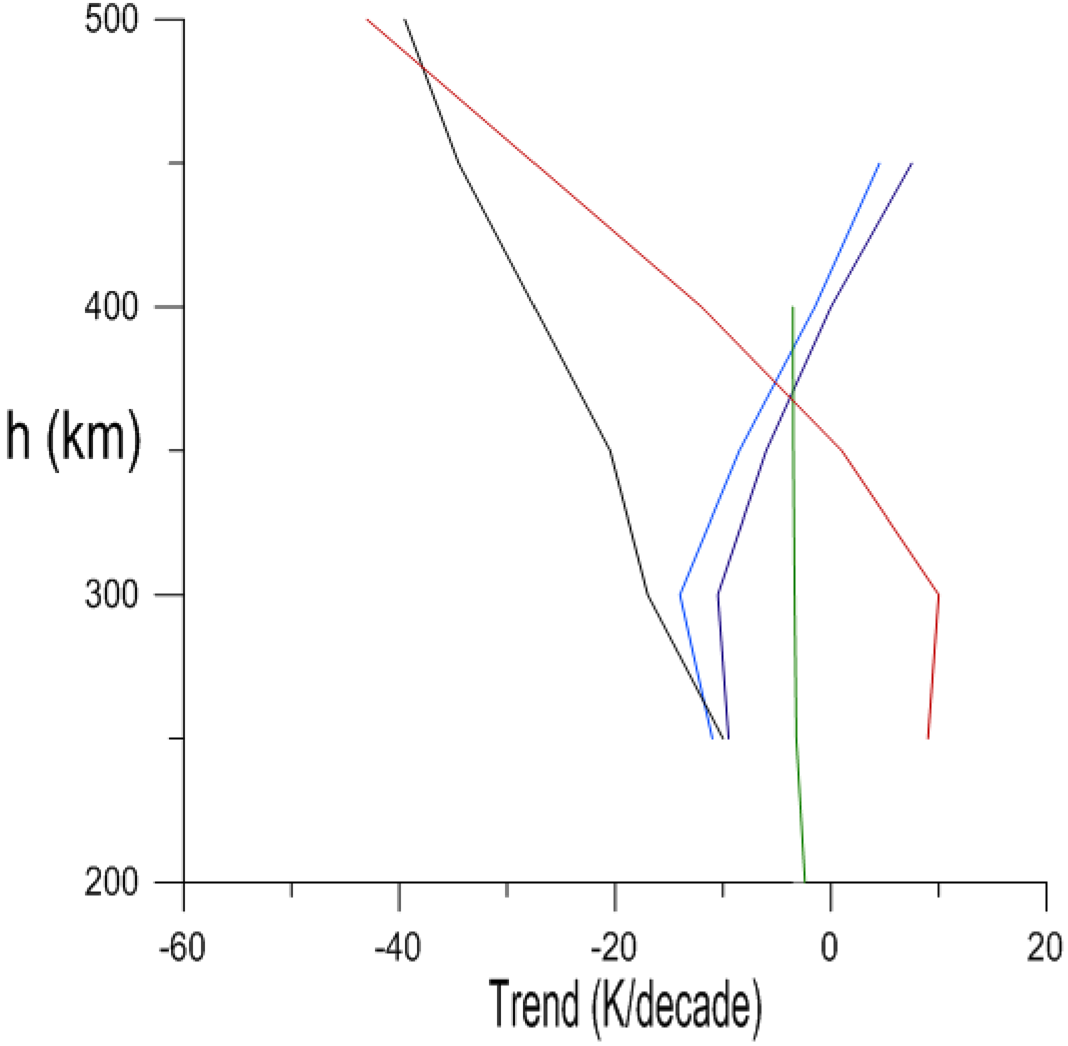
IGS data 1999-2000 are by 2 TECU lower than the level of IGS, and CODE data before are by 3 TECU lower.

1. The surprisingly positive trend of TEC obtained by Lean et al. (2011) for 1995-2010 was caused by data problem in 1995-2001.
2. A slight negative trend of global TEC was found over 1994-2014, which is at the edge of reliability; trend with break in 2003-2004 is also possible – but not a positive trend.

Lean et al. (2016) provided better results than Lean et al. (2011) due to less data affected by data problem – 1998-2015 versus 1995-2010.

Ion T_i and neutral T_n temperatures

Height profiles of temperature trends (T_i and T_n).



Height profiles of trends of T_i at Millstone Hill (black – noon; red – midnight), of noontime T_i at EISCAT (light blue with MgII, black-blue with F10.7), and of Tn at noon (green).

T_i trends in Millstone Hill and EISCAT are remarkably different above 300 km.

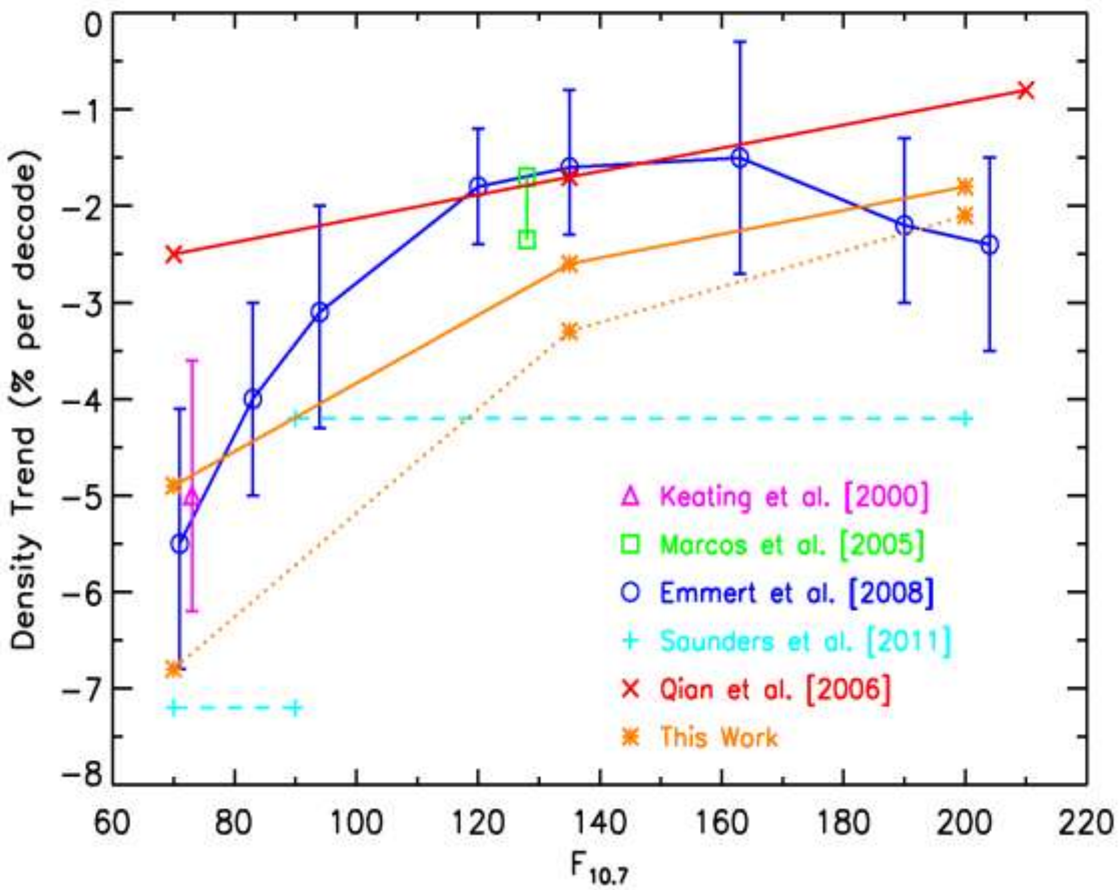
Model calculations by Qian et al. (2011) reveal **positive** trends in T_i above ~350 km, midlatitudes. Donaldson et al. (2010) found **negative** trends in T_i from historical data of Saint Santin ISR radar.

S.-R. Zhang (2018): The Ti – Tn difference in trends at midlatitudes is mainly due to effects of geomagnetic activity and of secular change of Earth’s magnetic field.

Trends in neutral density

Neutral density

Model calculations with improved CO_2 trends fit observations evidently better than old calculations.



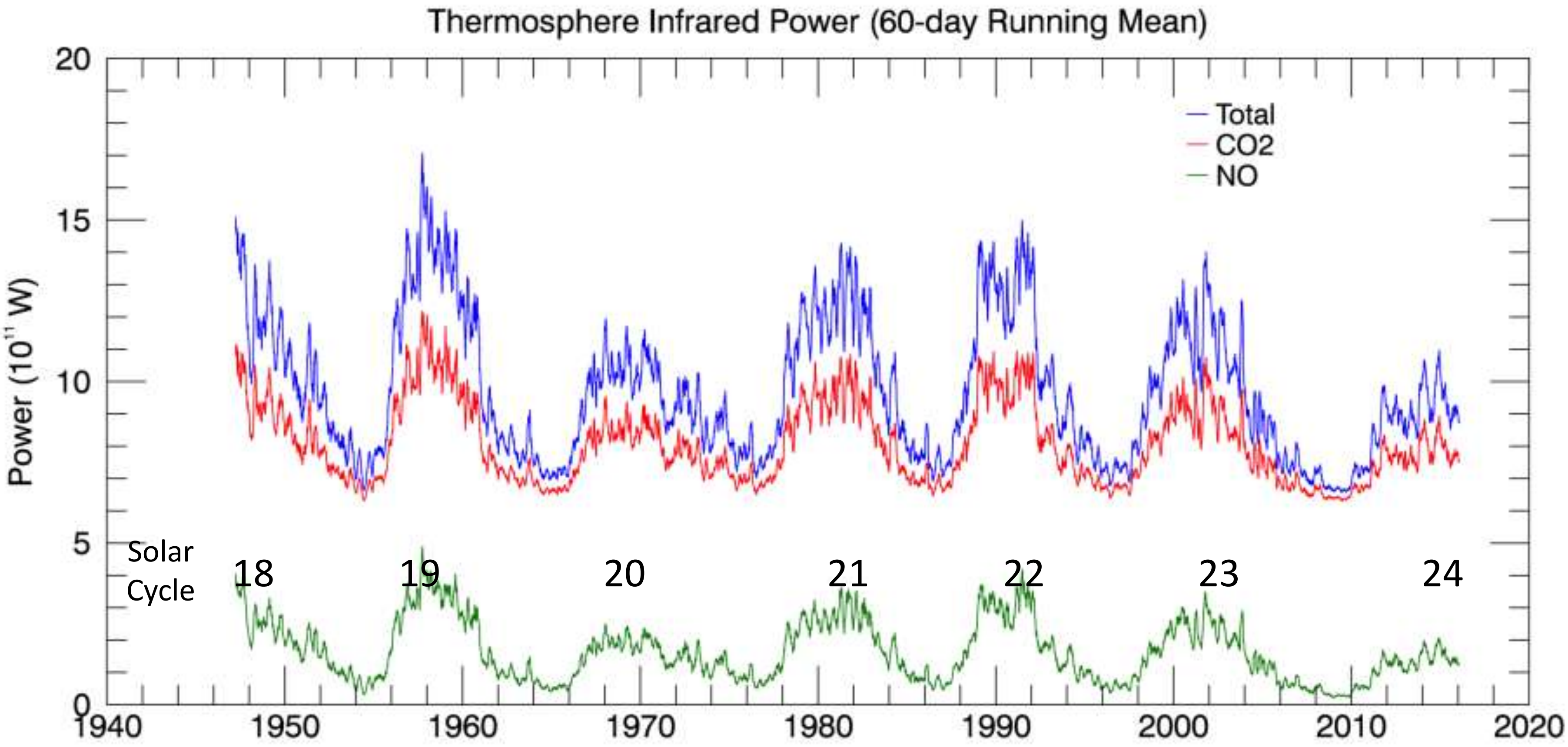
Neutral density trends at 400 km. Crosses – model calculations, middle curve are new calculations with model WACCM and new more realistic profile of CO_2 concentration. Other symbols – observational trends from satellite drag measurements. Adopted from Solomon et al. (2015).

Questioned by Emmert et al. (2015)

Indirect effect of solar cycle – higher trends at solar cycle minimum.

Infrared cooling of the thermosphere

Reconstruction of Thermosphere Infrared Power



Reconstructed cooling time series back to 1947 using extant F10.7, Ap, Dst

CO_2 is the dominant cooler above 100 km – depends less on solar activity

Solar cycle is stronger in NO than CO_2 IR cooling.

Integrated IR power over solar cycle is rather stable

M. Mlynczak et al.

Conclusions

1. In recent years information about long-term trends in various parameters appeared, some controversies (e.g. in TEC trends) were solved and some gaps in scenario filled in but sometimes new information makes situation more difficult/controversial, e.g. for thermospheric density trends.

2. Agreement between observational and model simulated long-term trends was improved.

3. Not only CO_2 but also other trend drivers, particularly secular changes of Earth magnetic field play a role in (ionospheric) trends.

4. Various problems still remain open.