EXPLORING LONG-TERM VARIATIONS OF IONOSPHERIC TOTAL ELECTRON CONTENT OVER SOUTH AFRICA

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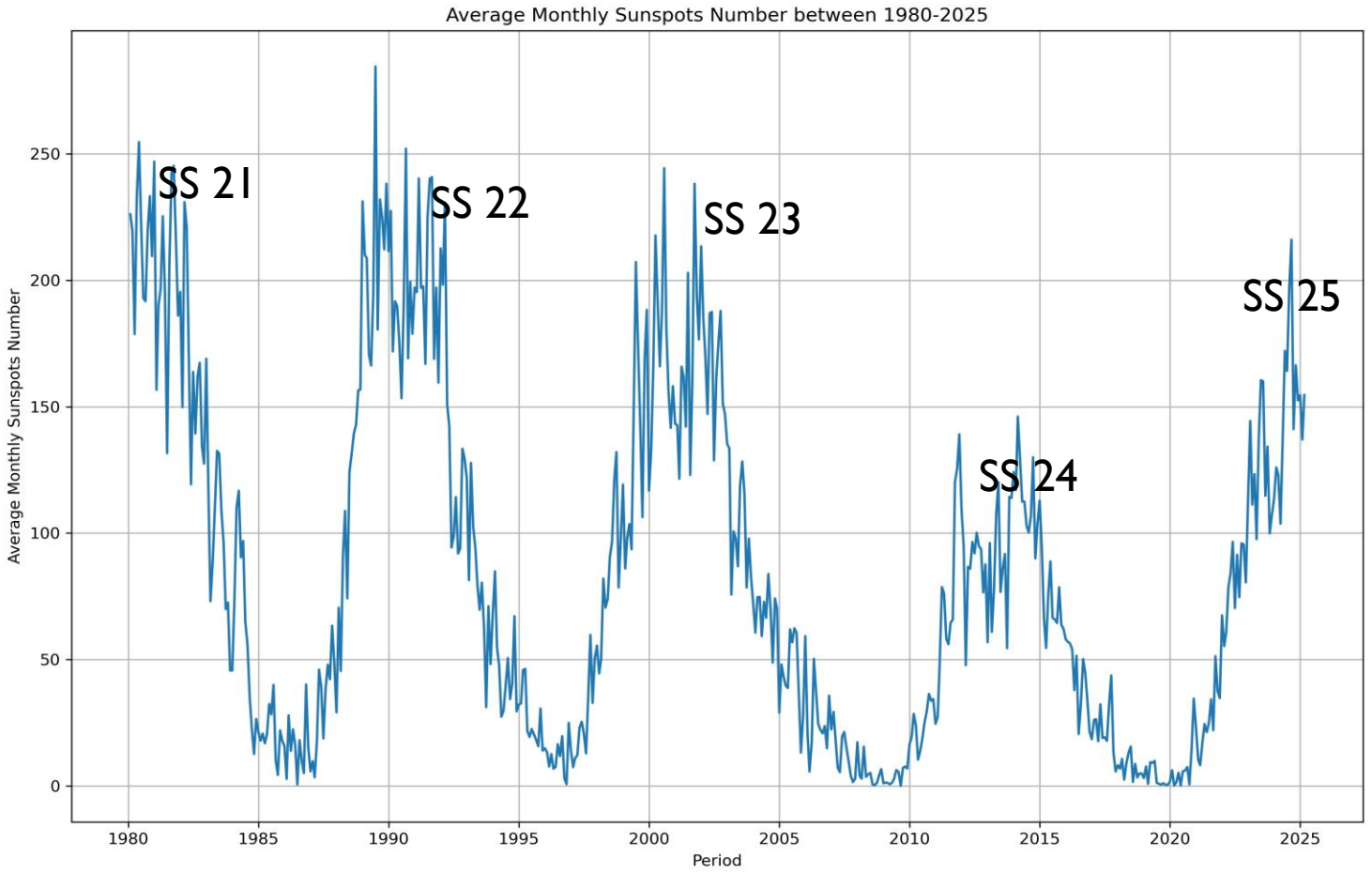
OUTLINE

- The Sun, and Solar Cycle
- Global Navigation Satellite System
- Total Electron Content
- Ionosphere
- Software Technique
- Results
- Summary and Future work

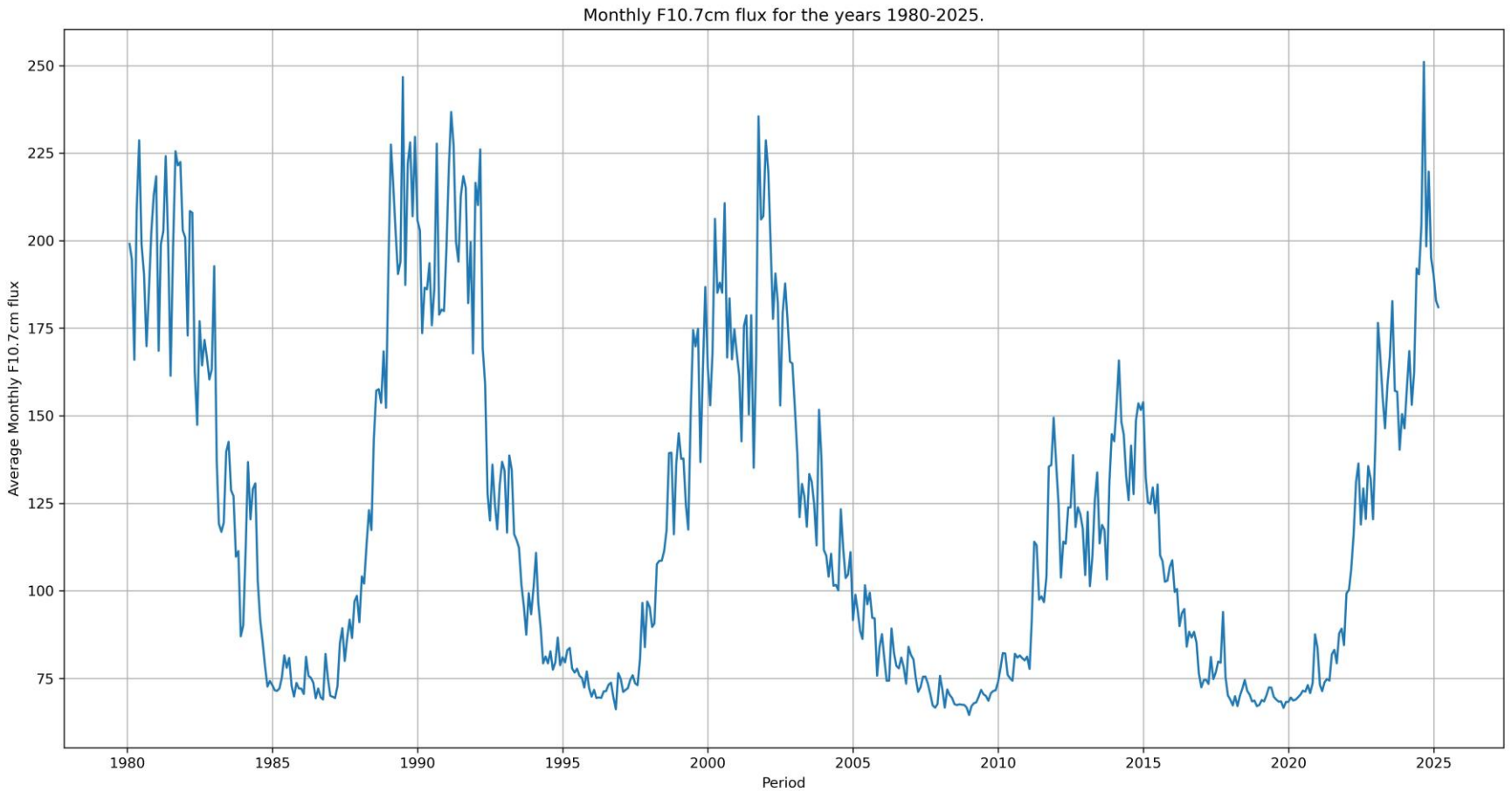
THE SUN AND SOLAR CYCLE

- Primary driver of atmospheric and geo-magnetic variability of the Earth
- Spatial, temporal nature of Earth atmosphere depend on solar activity, solar cycle (SS) progression, geomagnetic activity, seasons, local time
- Solar activity can be characterized by different solar proxies:
  - 11-year cycle using sunspot numbers (R),



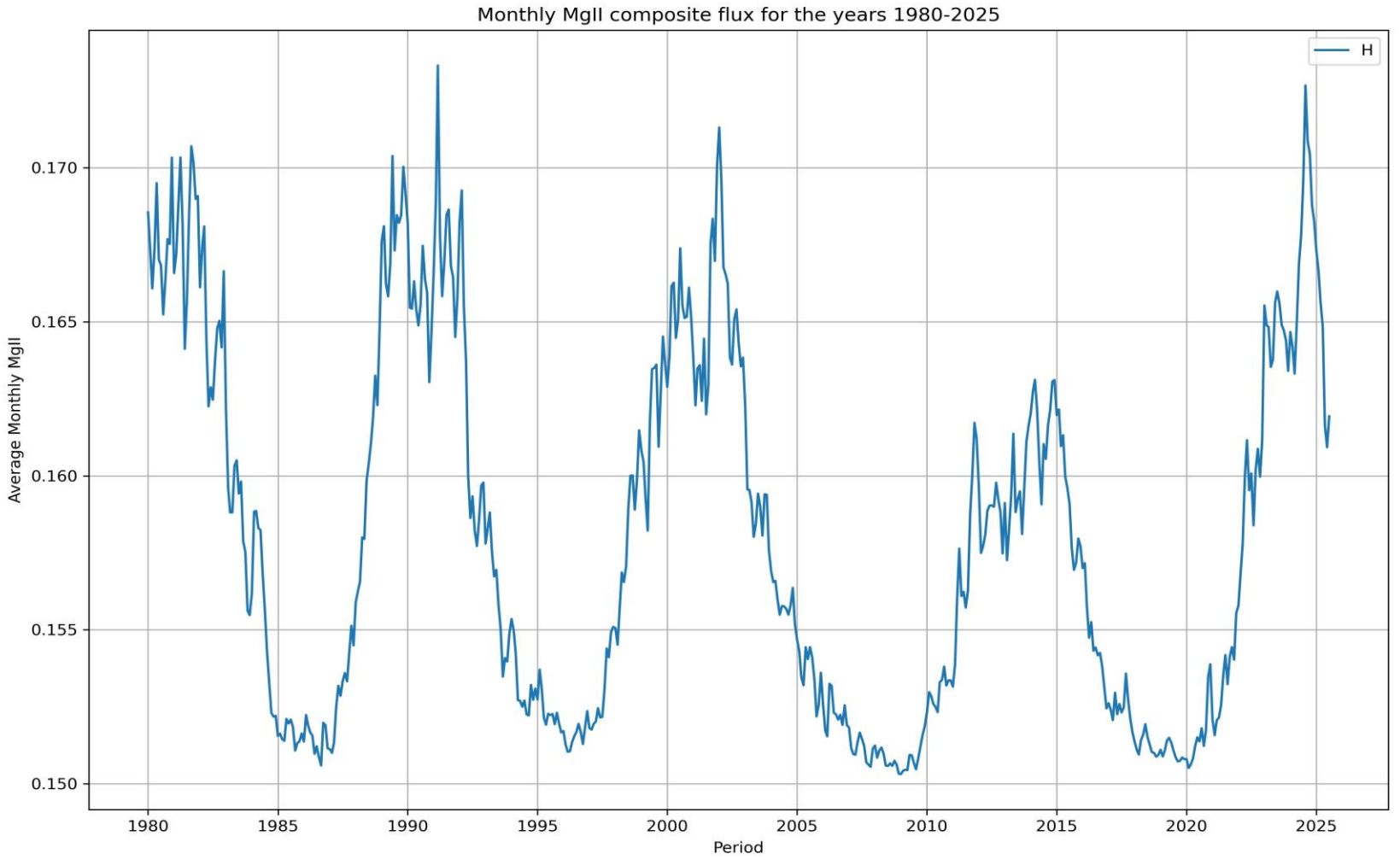
THE SUN AND SOLAR CYCLE*(CONT…)*

- Can be characterized by different solar proxies:
  - A 10.7 cm solar radio flux (F10.7),



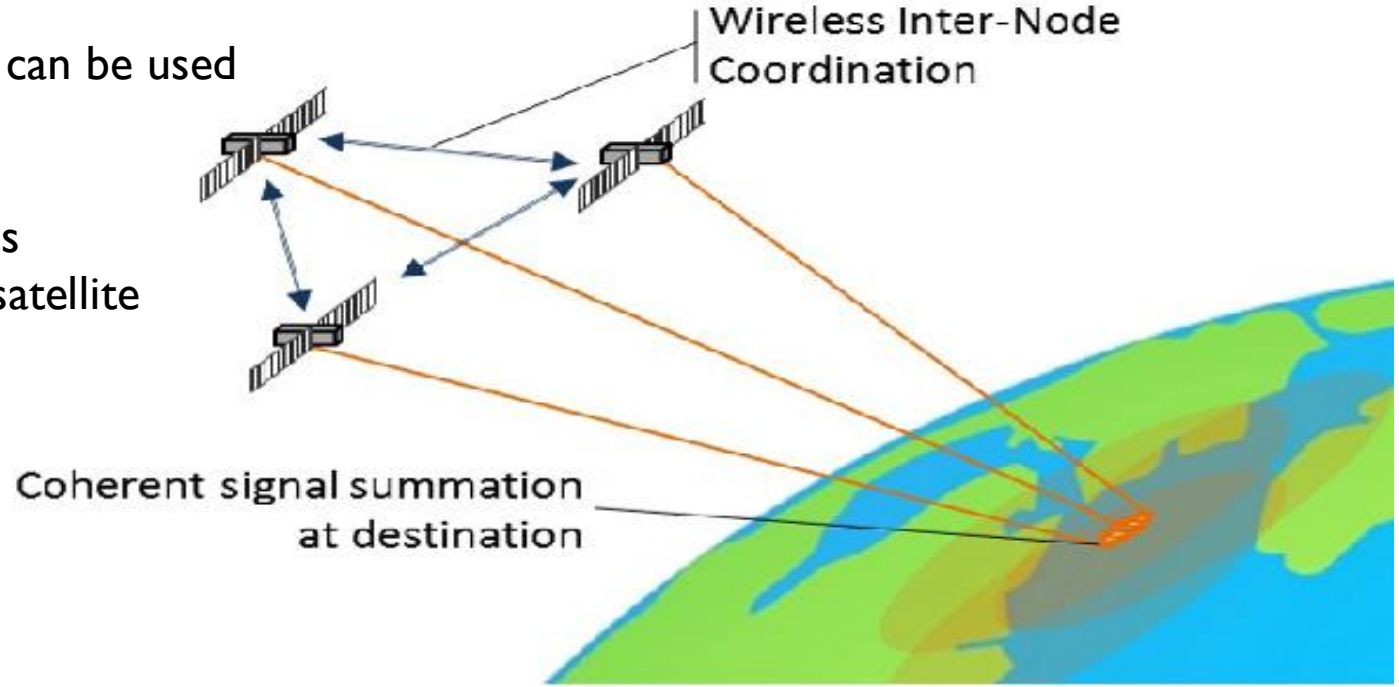
THE SUN AND SOLAR CYCLE*(CONT…)*

- Can be characterized by different solar proxies:
  - the ratio of the h (279.9nm) & k (280.3nm) lines of the magnesium II emission (MgII)



GLOBAL NAVIGATION SATELLITE SYSTEM (GNSS) AND TEC

- GNSS with a global coverage comprising of the GPS, GLONASS, BDS, Galileo.
- The GPS system uses a dual-frequency signals to transmit data between the satellite and ground-based receiver, which is transmitted through the atmosphere
- These signals undergo reflection, refraction, delay and can be used to study its dynamic nature, specifically
- Total Electron Content (TEC); the number of electrons in a cylinder of $1m^2$ area between receiver and GPS satellite



GNSS AND TEC *(CONT…)*

- TEC is defined mathematically as $\int_L^0 N_e dl$ where L: ray path length between a satellite and a receiver, N_e: electron number density
- It is derived from the delay of dual-frequency GPS signals either by phase-delay measurements (L1, L2) as relative TEC or pseudo-ranges (P2, P2) as absolute TEC
- Calculated as vertical TEC (vTEC) and/or slant ray TEC (sTEC),

Figure 5: GPS ground receiver. Source:https://www.sonel.org/spip.php?page=gps&idStation=699

IONOSPHERE

- Ionized layer between ~60km – 1000km (stratosphere, mesosphere, thermosphere), EUV , X-rays
- Effect on radio waves propagation (dispersive plasma), HF communications, navigation, remote sensing
- Understanding the dynamics allows proper calibration of astronomic equipment for better observation
- Better understanding of the influence of the sun on earth systems and technology, space weather monitoring, by studying long-term changes in the ionosphere

SOFTWARE

- Novel regularized Estimation technique of VTEC/STEC from GPS data (https://www.ionolab.org/index.php?page=tec&language=en) Arikan et. al. 2004, 2005 and Nayir et. al 2007
- This technique combines multiple GPS signals at a given receiver for 24hrs at 30s resolution and assumes the ionosphere to be a single layer at 428.8 km
- Provides short-term and long-term variations in GPS-TEC

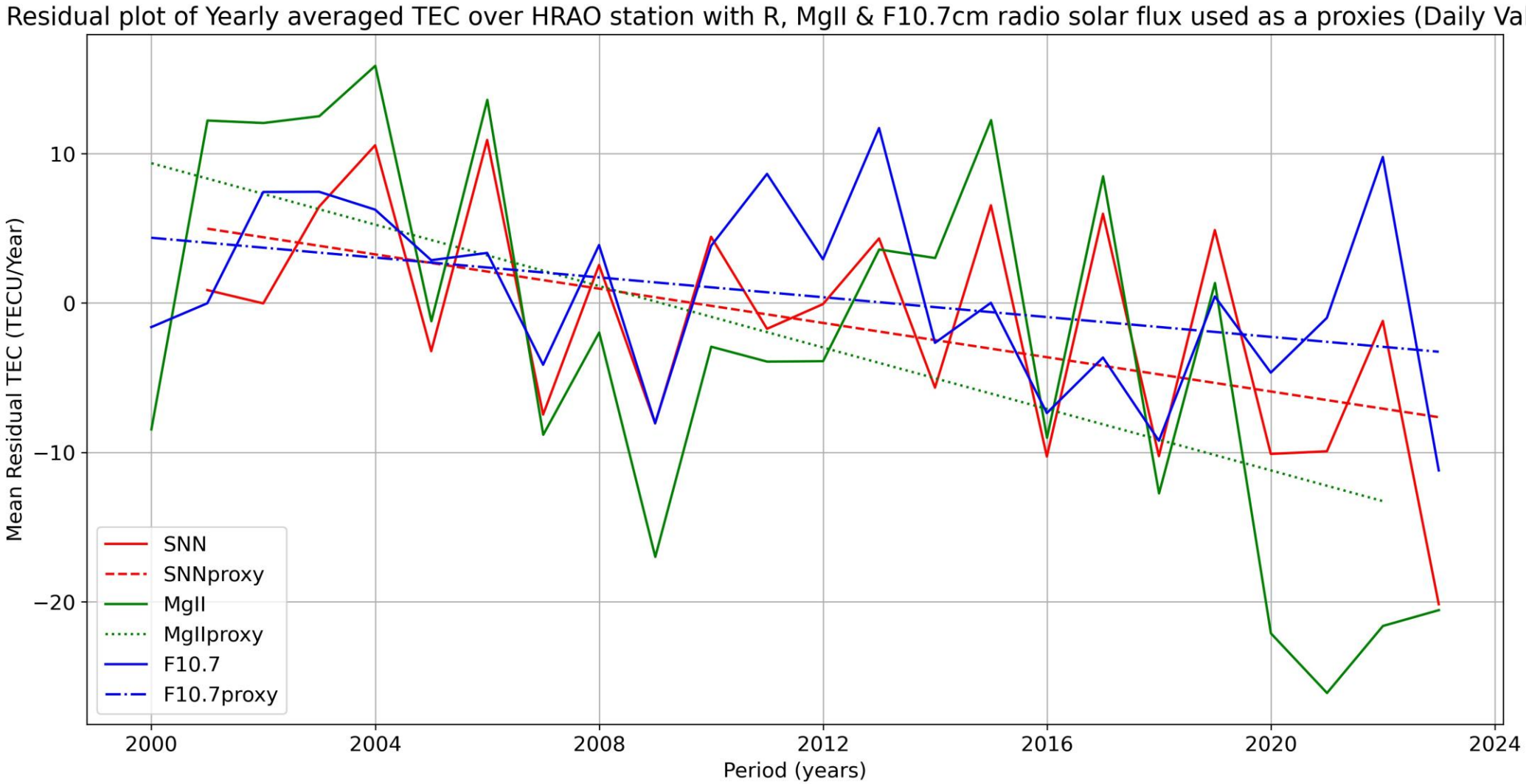
IONOLAB
IONOSPHERIC RESEARCH LABORATORY
Hacettepe University Dep. of Electrical & Electronic Engineering
Harita Genel Komutanlığı
Bilkent University Dep. of Electrical & Electronic Engineering

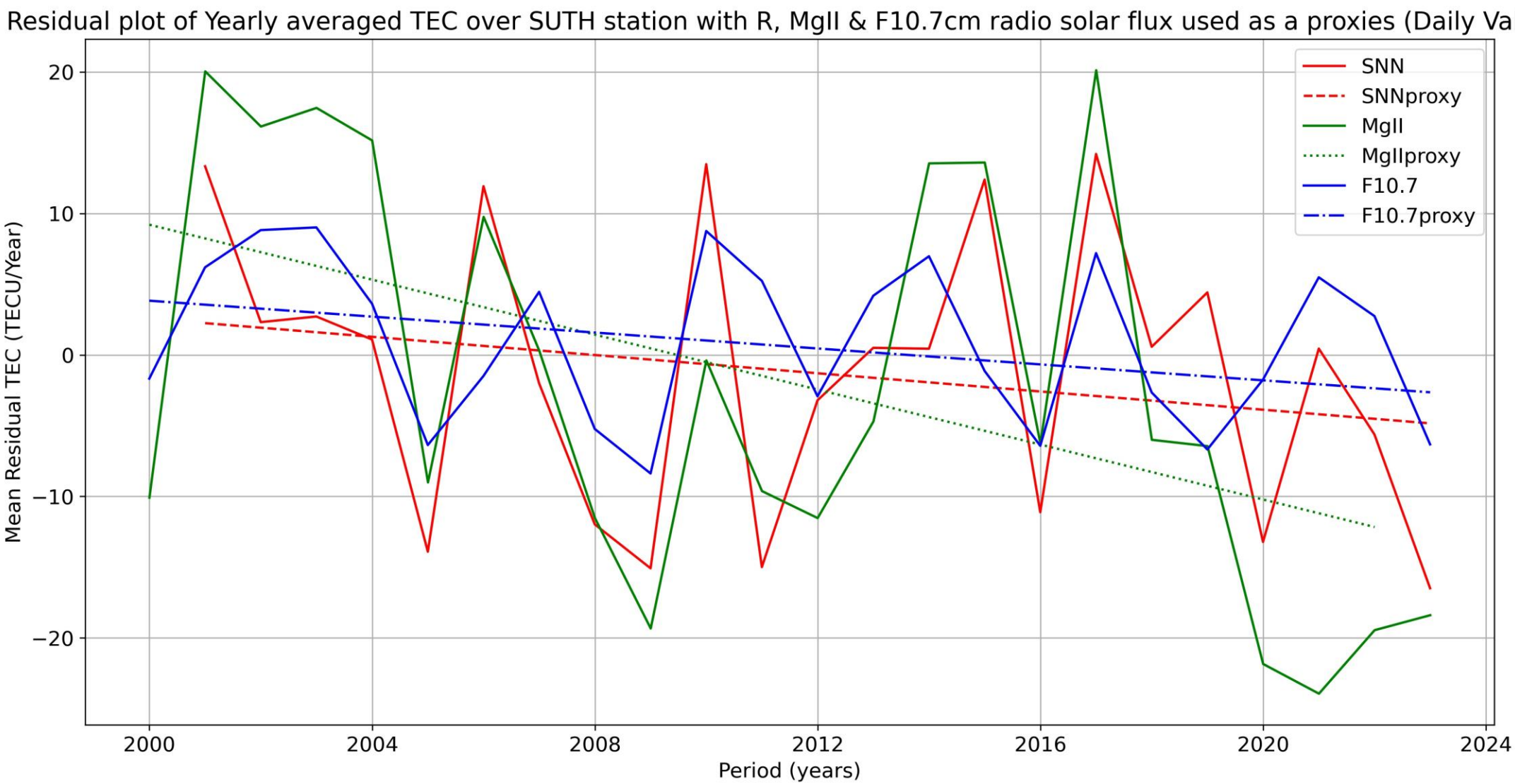
MODELLING

- Sutherland (SUTH) and Hartebeeshoek (HRAO) GPS station data is used, at a 25 years period
- To calculate trends in TEC, model data by linear regression
- TEC_mod = A + B*solarproxy
- Solar proxy: R, MgII, F10.7 as they eliminates solar cycle effects
- To calculate trends, we use residuals:

residuals = TEC_obs – TEC_mod, perform another regression

with residuals = C + ß*time (monthly & yearly averages)

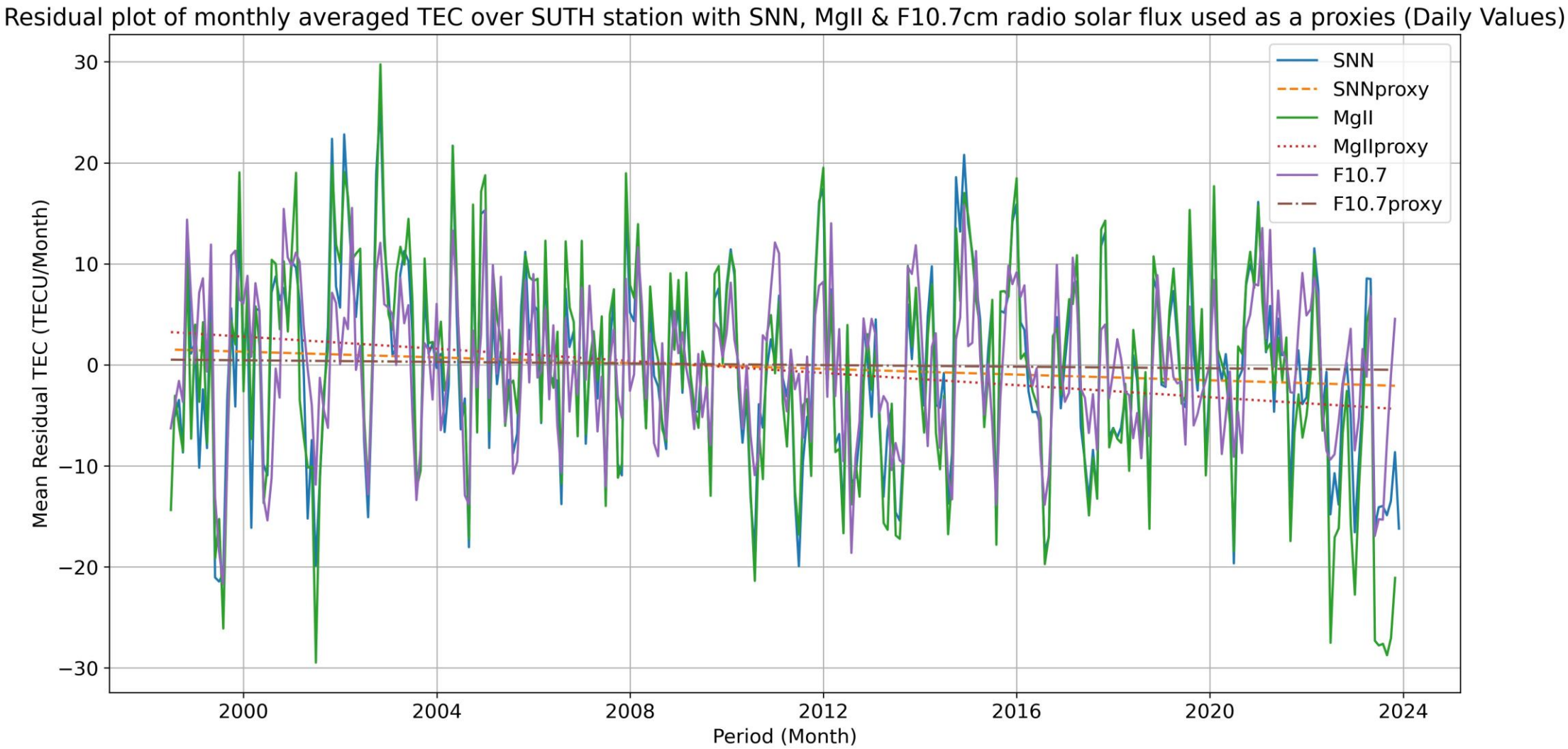

Residual plot of Yearly averaged TEC over HRAO station with R, MgII & F10.7cm radio solar flux used as a proxies (Daily Values)
Mean Residual TEC (TECU/Year)
10
0
−10
−20
2000
2004
2008
2012
2016
2020
2024
Period (years)
SNN
SNNproxy
MgII
MgIIproxy
F10.7
F10.7proxy

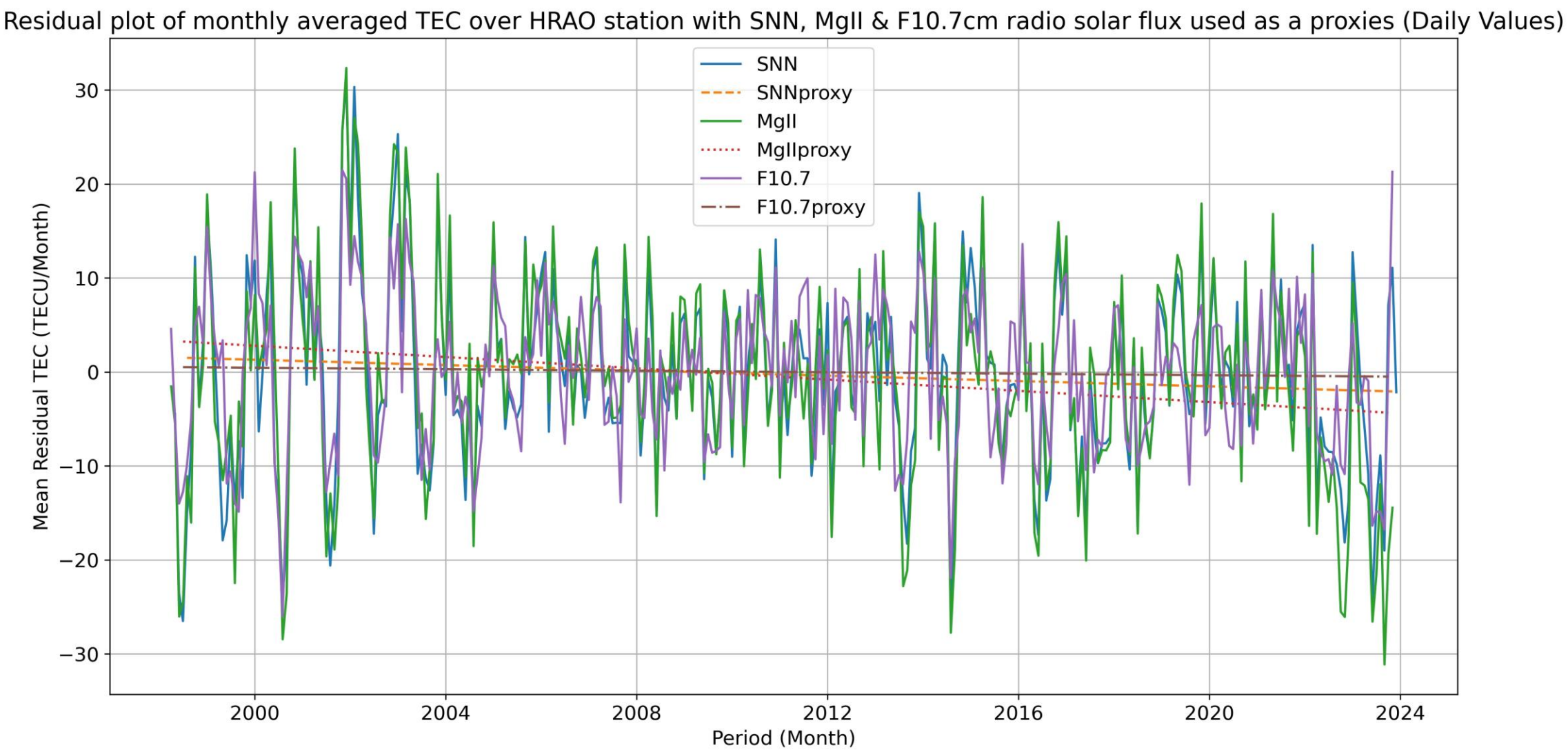

Residual plot of Yearly averaged TEC over SUTH station with R, MgII & F10.7cm radio solar flux used as a proxies (Daily Values)
SNN
SNNproxy
MgII
MgIIproxy
F10.7
F10.7proxy
Mean Residual TEC (TECU/Year)
Period (years)
20
10
0
−10
−20
2000
2004
2008
2012
2016
2020
2024

RESULTS

- These values show the coefficient ß against 3 literature articles

Results			Urbar, Lastovika 2024	Lastovicka, Urbar, 2017	Natali et. al. 2024
STATION	SUTH	HRAO	JPL35 (Global)	JPL35, Lean et al. 2011 (Global)	Global TEC
Proxy					
R	-0.0001±0.030	-0.043±0.057	0.012±0.032	-	0.01±0.01
MgII	-0.0073±0.12	-0.20±0.13	-0.067±0.028	-0.06±0.03	-0.39±0.05
F10.7	-0.21±0.11	-	-0.048±0.025	-0.05±0.03	-0.12±0.03


Residual plot of monthly averaged TEC over SUTH station with SNN, MgII & F10.7cm radio solar flux used as a proxies (Daily Values)
SNN
SNNproxy
MgII
MgIIproxy
F10.7
F10.7proxy
Mean Residual TEC (TECU/Month)
Period (Month)
30
20
10
0
−10
−20
−30
2000
2004
2008
2012
2016
2020
2024


Residual plot of monthly averaged TEC over HRAO station with SNN, MgII & F10.7cm radio solar flux used as a proxies (Daily Values)
SNN
SNNproxy
MgII
MgIIproxy
F10.7
F10.7proxy
Mean Residual TEC (TECU/Month)
Period (Month)
30
20
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−30
2000
2004
2008
2012
2016
2020
2024

Results			Urbar, Lastovika 2024	Lastovicka, Urbar, 2017	Natali et. al. 2024
STATION Proxy	SUTH	HRAO	JPL35 (Global)	JPL35, Lean et al. 2011 (Global)	Global TEC
R	-0.15±0.064	0.0029±0.056	0.012±0.032	-	0.01±0.01
MgII	-0.3478±0.091	-0.1814±0.054	-0.067±0.028	-0.06±0.03	-0.39±0.05
F10.7	-0.2638±0.074	-0.0906±0.052	-0.048±0.025	-0.05±0.03	-0.12±0.03

SUMMARY AND FUTURE WORK

- Study used 2 stations to investigate long-term changes in the ionosphere over the South African midlatitude
- Linear regression provides a close approximation of the model of observed data
- R, MgII & F10.7 verifies a negative trend similar to literature
- The ionosphere is slowly decreasing over this region
- Ingest South African TrigNET from HNUS and GRHM stations data into the IONOLAB algorithm

END

THANK YOU