Long term reduction of F2 layer peak electron density at mid-latitudes

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Outline

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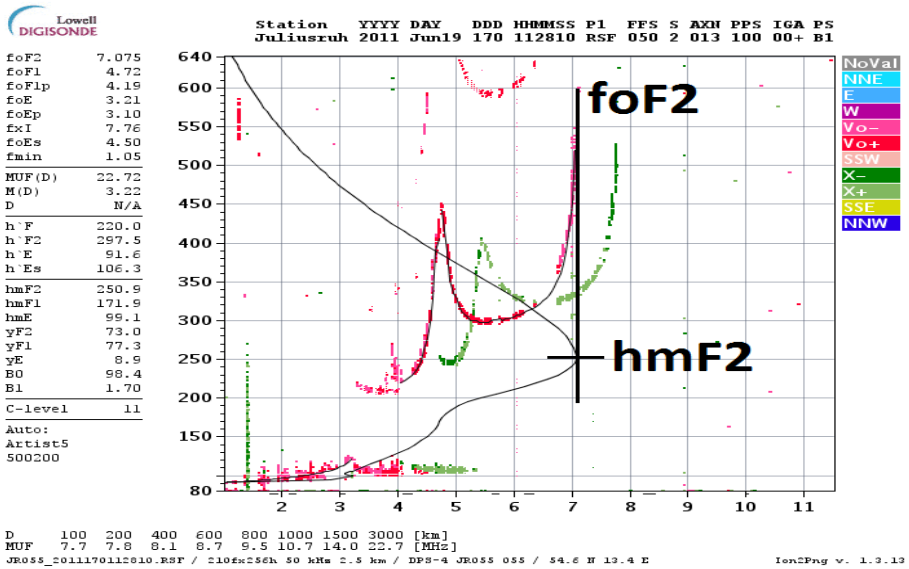
- Data base
- Long term electron density decrease in the ionosphere
- Correlation study with the Temperature Anomaly (TA) in the Troposphere
- Summary & conclusions

Introduction

- Mitigation of various impact factors on the electron density in the ionosphere is a challenging task in long term trend studies.
- To mitigate diurnal, seasonal and solar cycle dependencies of the peak electron density NmF2 noon-time values of NmF2 are averaged over noon-time, months, years and 11 years solar cycle.
- In a former long term study of NmF2 data averaged in such a way, we have shown a strong decrease of the averaged peak electron density after about 1980.
- Many studies have shown that greenhouse gases like CO_2 cause cooling of the thermosphere, reduce thermospheric density, change composition and consequentially, also change the ionospheric plasma.
- At Earth surface an increase of CO_2 emissions causes a long-term increase of atmospheric and oceanographic temperatures.
- Considering the common origin of both effects, a correlation of the temperature increase at the ground with long term trends of thermospheric temperature and ionospheric density is expected.

Data base

F2 layer peak electron density NmF2
derived from vertical sounding data



Vertical sounding data:
https://www.sws.bom.gov.au/World_Data_Centre/1/3
https://downloads.sws.bom.gov.au/wdc/iondata/medians/Damboldt/
https://wdc.nict.go.jp/IONO/HP2009/ISDJ/index-E.html

Ionosonde stations used

Ionosonde station	URSI ID	Geographic Latitude /°N	Geographic Longitude /°E	foF2/NmF2 data coverage years
Slough	SL051	51.5	359.4	1952 - 1993
Chilton	RL052	51.1	359.4	1994 – 2021
Juliusruh	JR055	54.6	13.4	1958 – 2023
Kokubunji	TO536	35.7	139.5	1958 – 2022
Wakkanai	WK545	45.0	141.0	1952 - 1987 2001 – 2022
Canberra	CB53N	-35.3	149.0	1952 - 2023
Brisbane	BR52P	-27.5	152.9	1953 - 1986
Hobart	HO54K	-43.0	147.3	1952 – 2023**
Boulder	BC840	41.6	254.7	1958 – 2022*
Port Stanley	PS5J5	-51.6	302.1	1957 - 1990

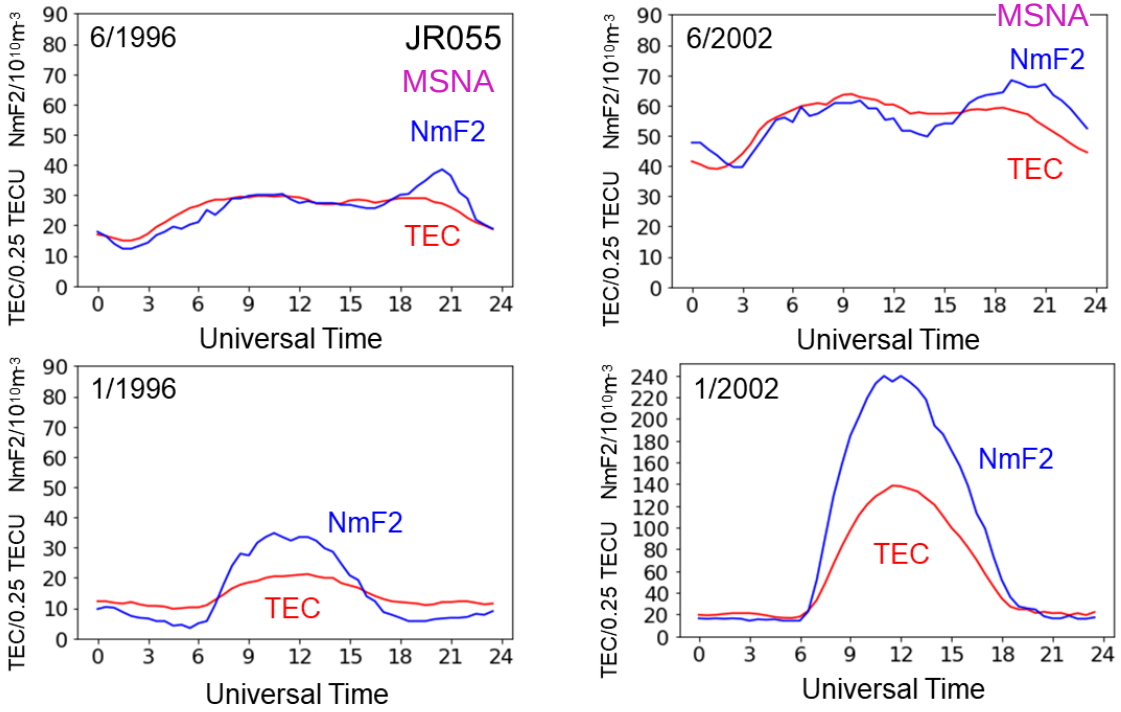
*2003 missing, **1960 missing

Use of noon time (12-14 LT) foF2 data
Transformation to NmF2 according to:

$$NmF2 = 1.24 \cdot 10^{-2} (foF2)^2 \quad (SI\ units)$$

Temperature anomaly data: https://ds.data.jma.go.jp/tcc/tcc/products/gwp/temp/list/year_wld.html.

Why focusing on noon-time values?



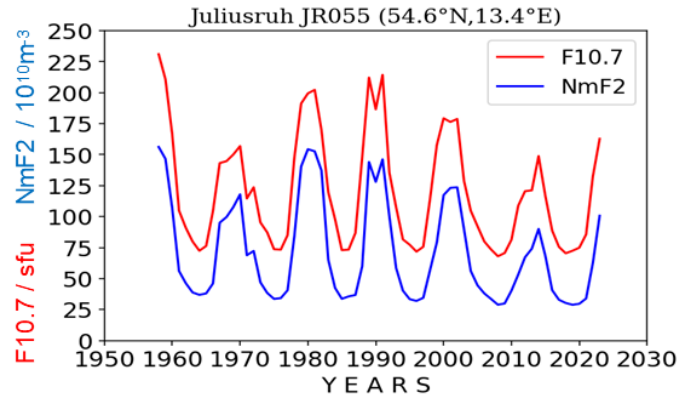
- Noon time is characterized by equilibrium conditions between gain and loss of plasma.
- Transport processes are low under regular conditions.
- Sunrise/sunset hours are characterized by a strong increase/decrease of electron density that creates unstable conditions for LTT studies.
- Furthermore, evening and nighttime ionosphere is feeded by plasmaspheric fluxes which maintain the ionospheric ionisation (MSNA*, NWA**)

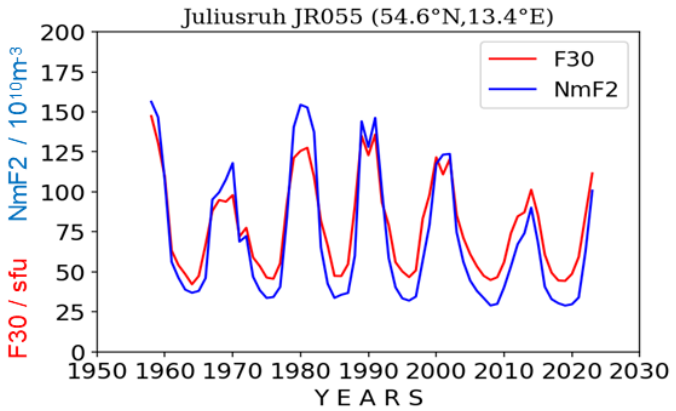
***Mid-latitude Summer Nighttime Anomaly (MSNA)**
Thampi, SV, Balan, N, Lin, C, Liu, H, Yamamoto, M. 2011, Ann. Geophys., 29, 157–165, doi:10.5194/angeo-29-157-2011.

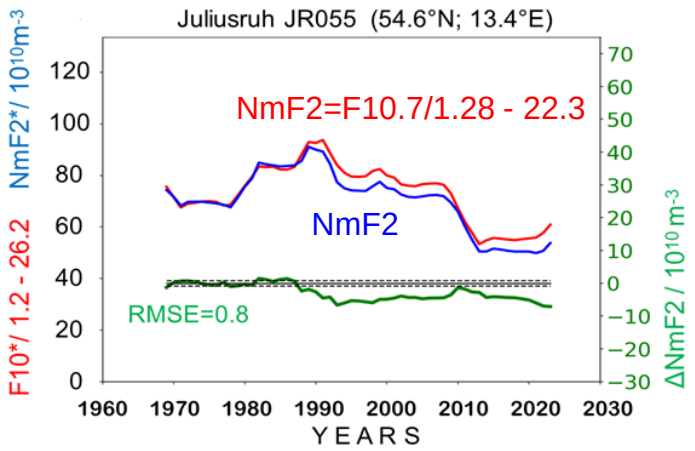
****Nighttime Winter Anomaly (NWA)**
Jakowski, N, Hoque, MM, Kriegel, M, Patidar, V. 2015, J. Geophys. Res. Space Physics, 120, doi:10.1002/ 2015JA021600.

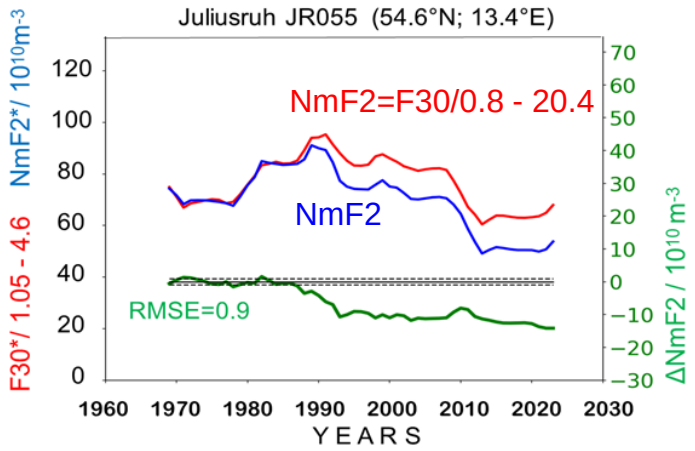
- Data preparation of NmF2(12-14 LT) to mitigate
  - monthly medians — ionospheric storms
  - yearly arithmetic means — seasonal variation
  - previous 11 years averaged — solar cycle variation

LTT modelling using solar radio flux indices (F10.7, F30)









Following Jakowski et al. 2024*, left panel:

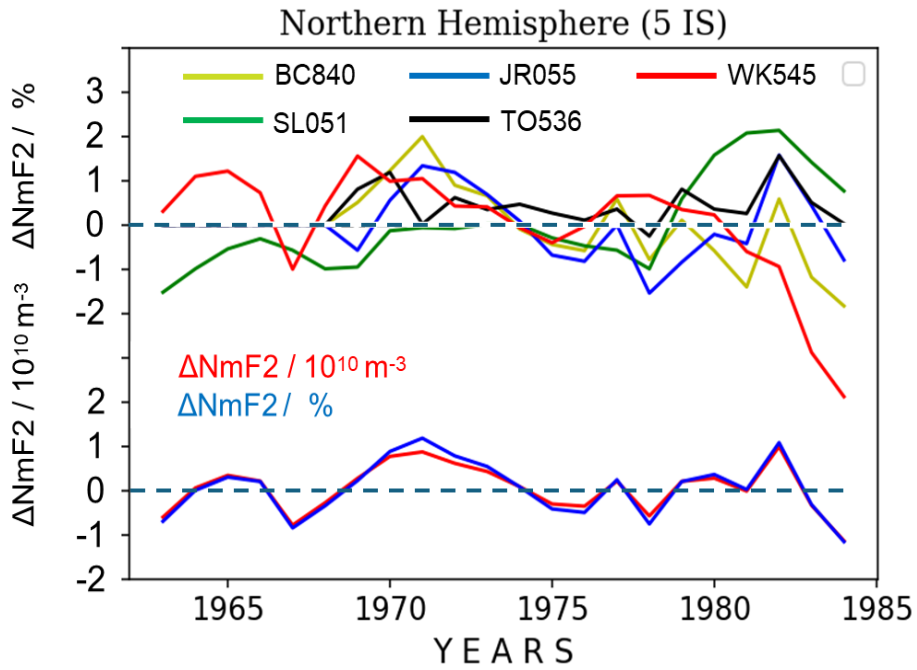
- Model approach for period 1970-1985
- RMS error < $1 \cdot 10^{10}$ m^{-3}
- Observations start to deviate strongly from the NmF2 model during the decade 1980-1990.
- Similar behaviour at 3 ionosonde stations at mid-latitudes and different longitude sectors indicate a **global effect.**

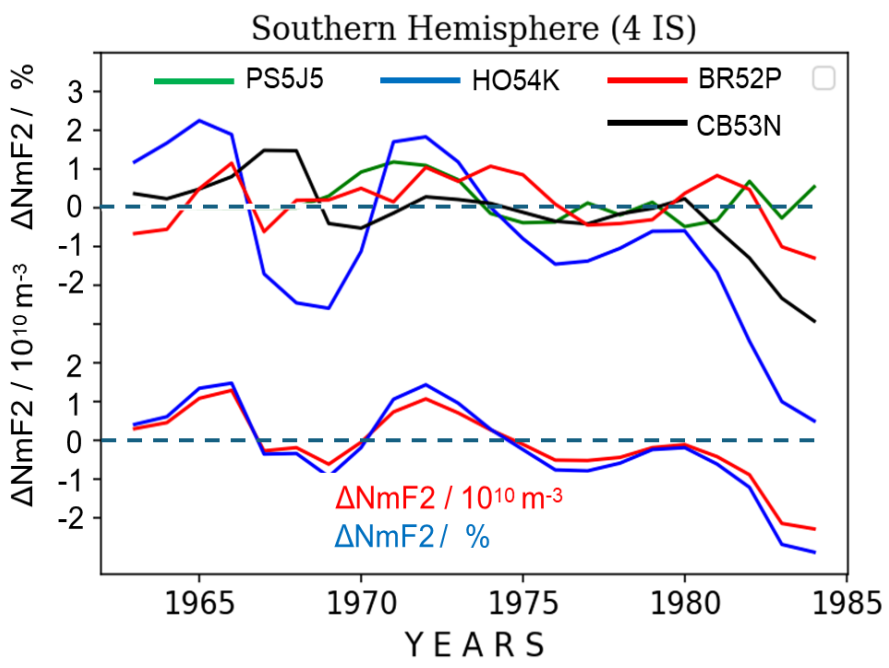
Motivation to include more ionosonde stations in an extended study
Replacement of F10.7 radio flux index by F30 as recommended by several authors**

- Jakowski, N, Hoque, MM, Mielich J. 2024, Long-term relationships of ionospheric electron density with solar activity. J. Space Weather Space Clim. 14, 24. J. Space Weather Space Clim..14, 24

* * Laštovička, J, 2024, ASR, 685-689,https://doi.org/10.1016/j.asr.2023.09.047
Dudok De Wit, T, & Bruinsma, S, 2017. J. Space Weather Space Clim. 7, A9
. https://doi.org/10.1051/SWSC/2017008.

Linear model of NmF2 in the early phase of observations until 1984



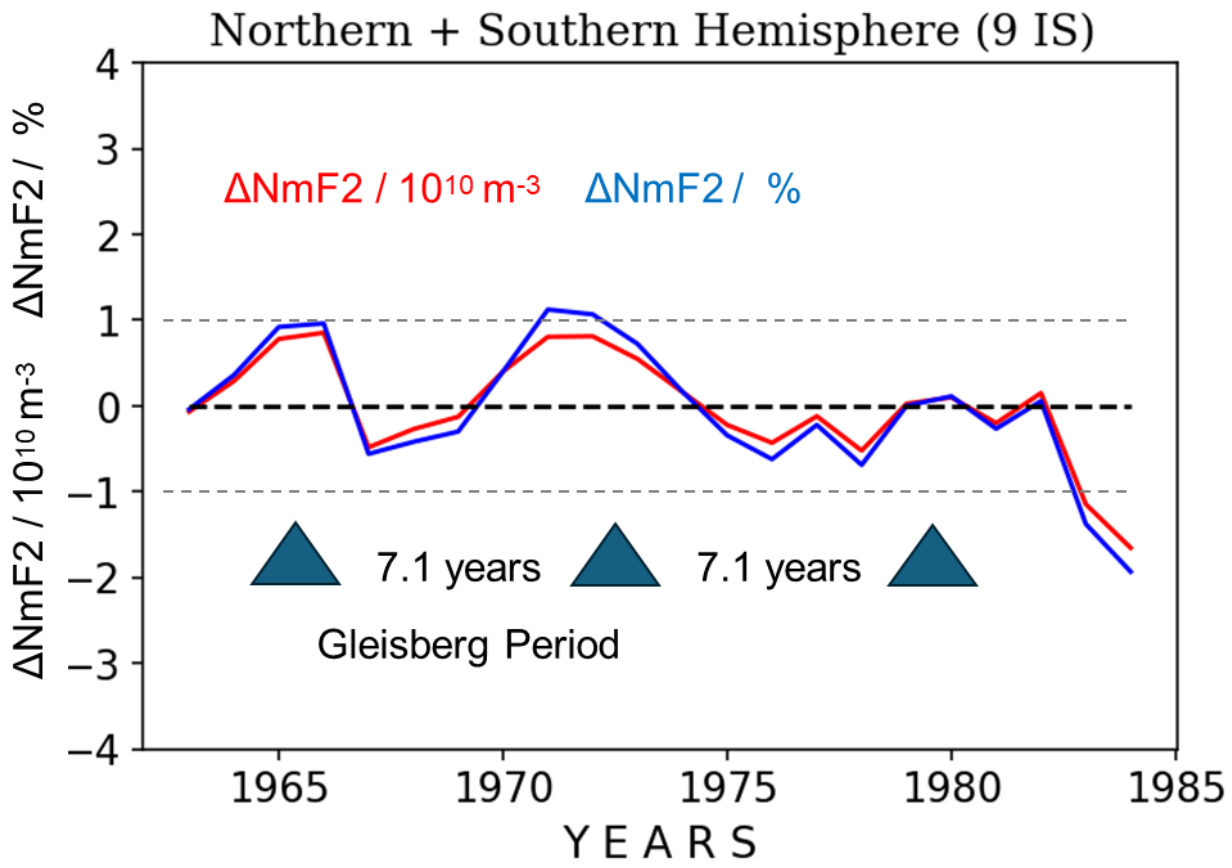


Linear models of NmF2 by the F30 solar radio flux indicate only small errors at all ionosonde stations in the order of about 1-2 %.

Separate averages of remaining errors show similar pattern for Northern and Southern hemispheres, thus confirming a reliable data analysis and from the physical point of view, indicating a common origin.

Possible cause: Assumed solar cycle period of 11 years in the computations is only a proxy, i.e. other periodicities might interfere.

Check of periodicities caused by the Gleisberg cycle



The duration of the cycle varies in accordance with the level of SA in such a way that during high activity short cycles are observed, while longer cycles are characteristic of low activity.*

Here, the averaged model residuals show a period of about 7- 8 years in the early phase of NmF2 measurements until 1984.

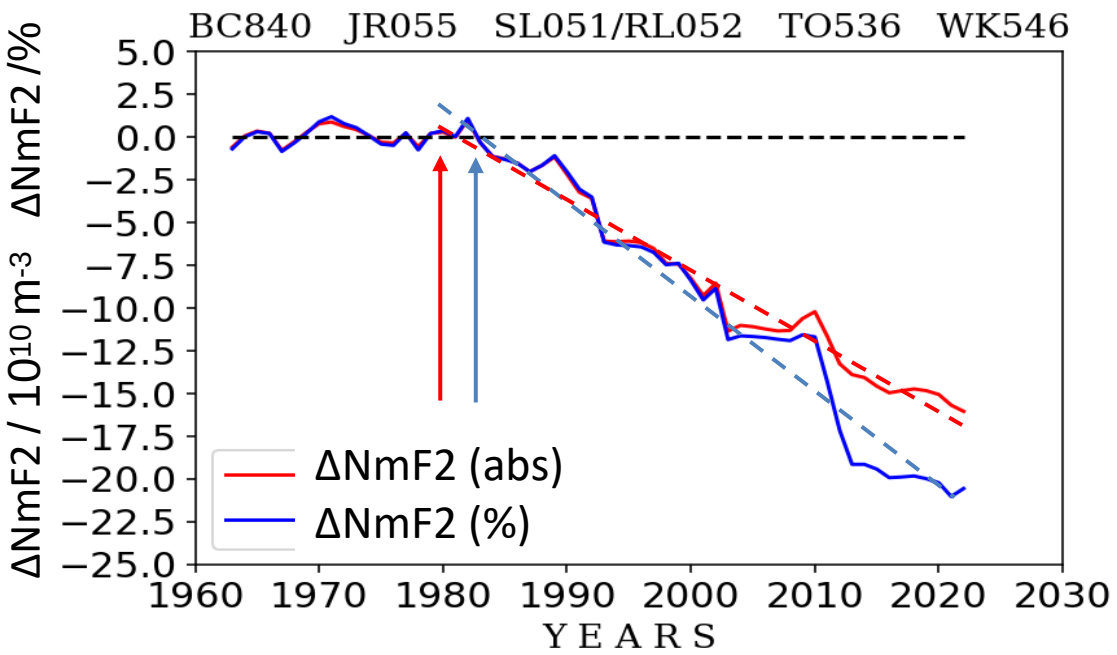
Considering frequency modulation by the Gleisberg cycle of 60 years, additional periods of 7.1, 8,0 and 9.3 years can be created*.

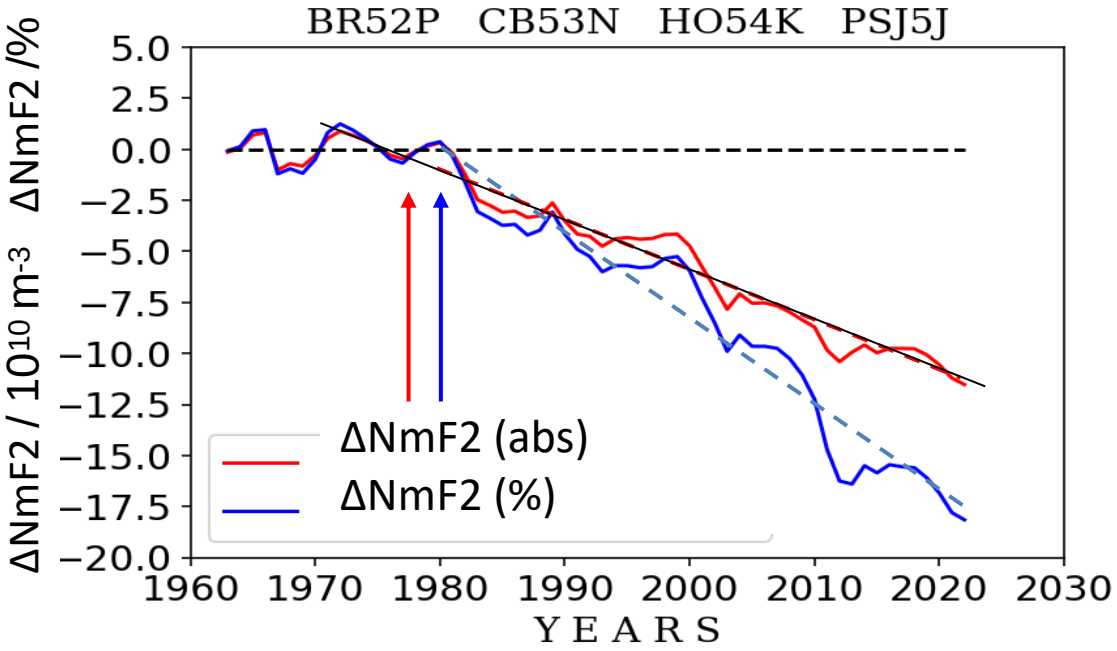
The computations agree with the 7.1 years period quite well.

If approved in a refined study, this knowledge could help to improve NmF2 modelling results.

* Ptitsyna, NG, Demina, IM. 2023. Influence of the Gleissberg Cycle on Variations of the 11-Year Cycle of Solar Activity in 1700–2021. Geomagnetism and Aeronomy. 63, 3, 248 - 260. ISSN 0016-7932.

Electron density anomaly (EDA) at Northern and Southern hemisphere



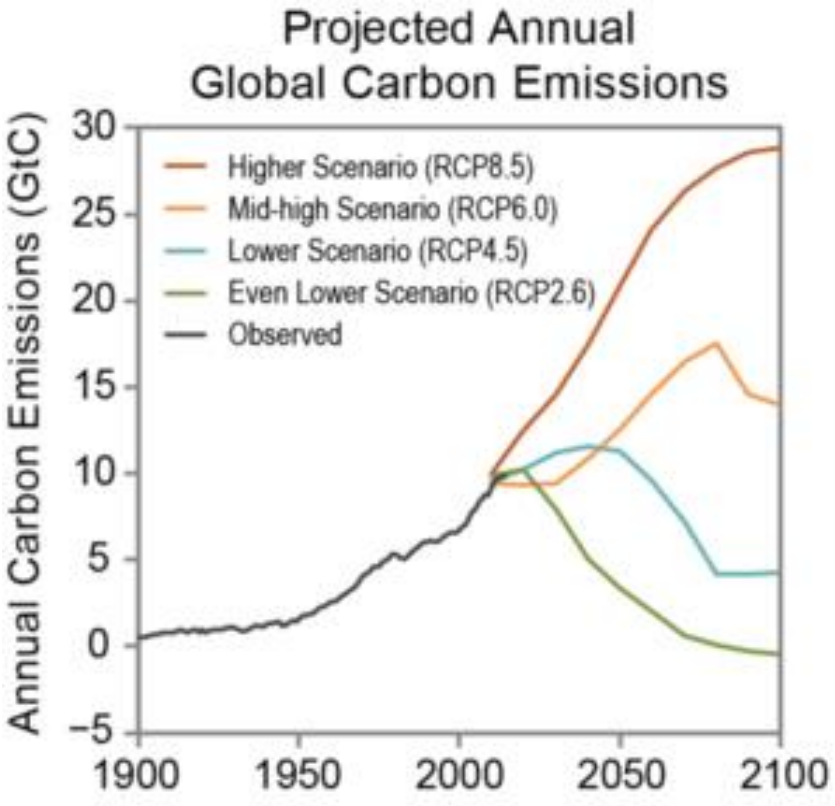


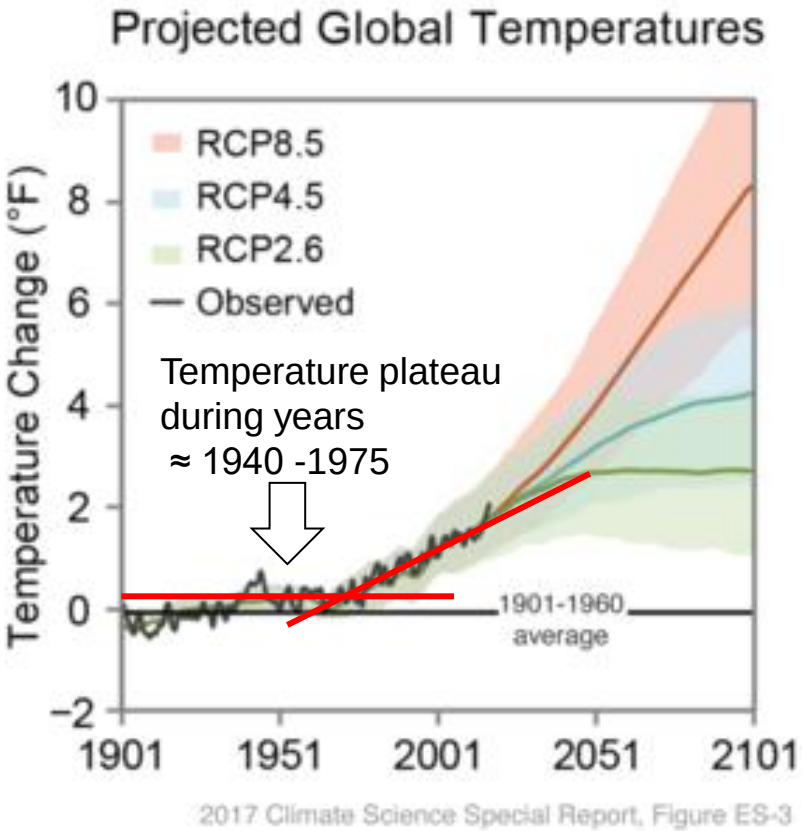
- Taking the linear NmF2 (F30) model derived from early ionosonde measurements until 1984 as reference, a strong decrease of the electron density starts at around 1980 at both hemispheres.

- In analogy to the global temperature increase in the troposphere that is called **Temperature Anomaly (TA)** Hereafter**,** we call the strong peak electron density decrease in the order of $2 - 4 \cdot 10^{10}\ m^{-3}$/decade as **Electron Density Anomaly (EDA).**

Considering the impact of greenhouse gases in the atmosphere and thermosphere, the question arise: **Is EDA related to TA?**

Global Temperature Anomaly (TA)



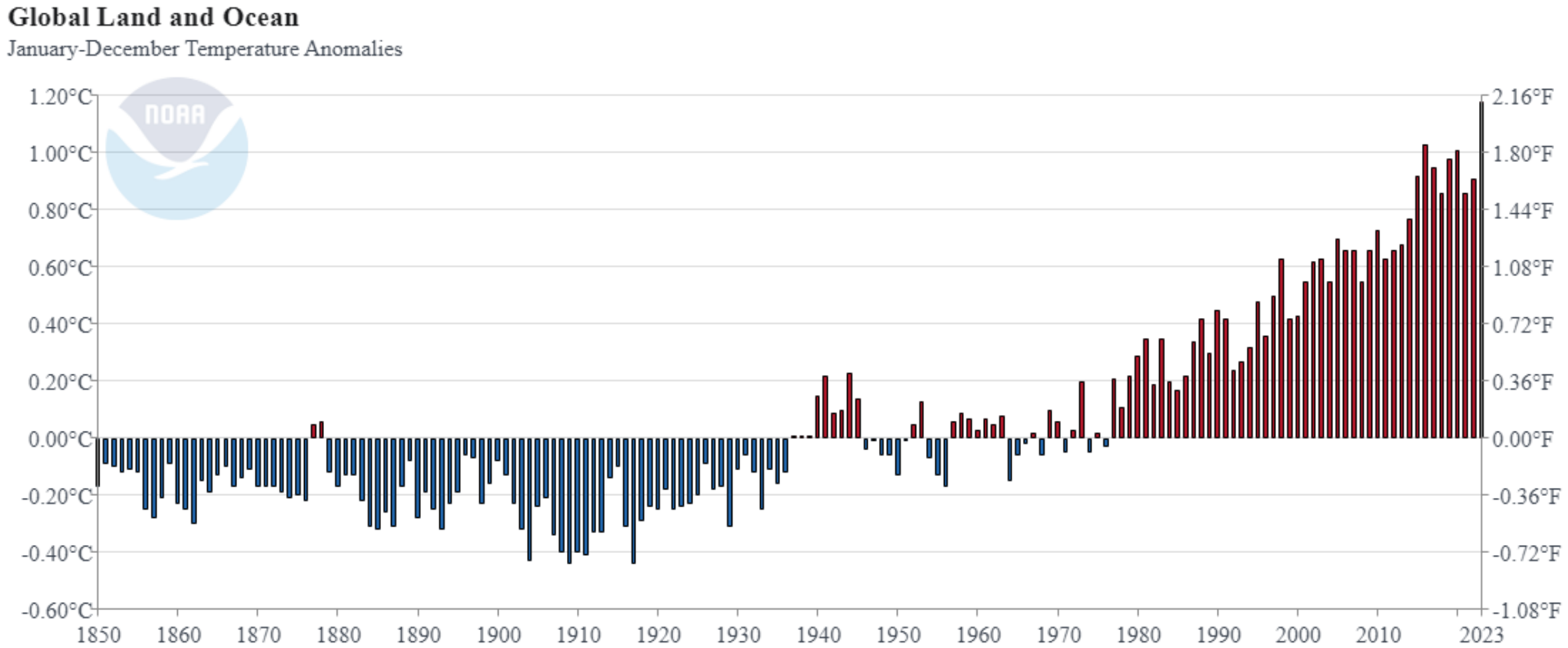


Temperature Anomaly (TA)
departure from a reference value or long-term average.

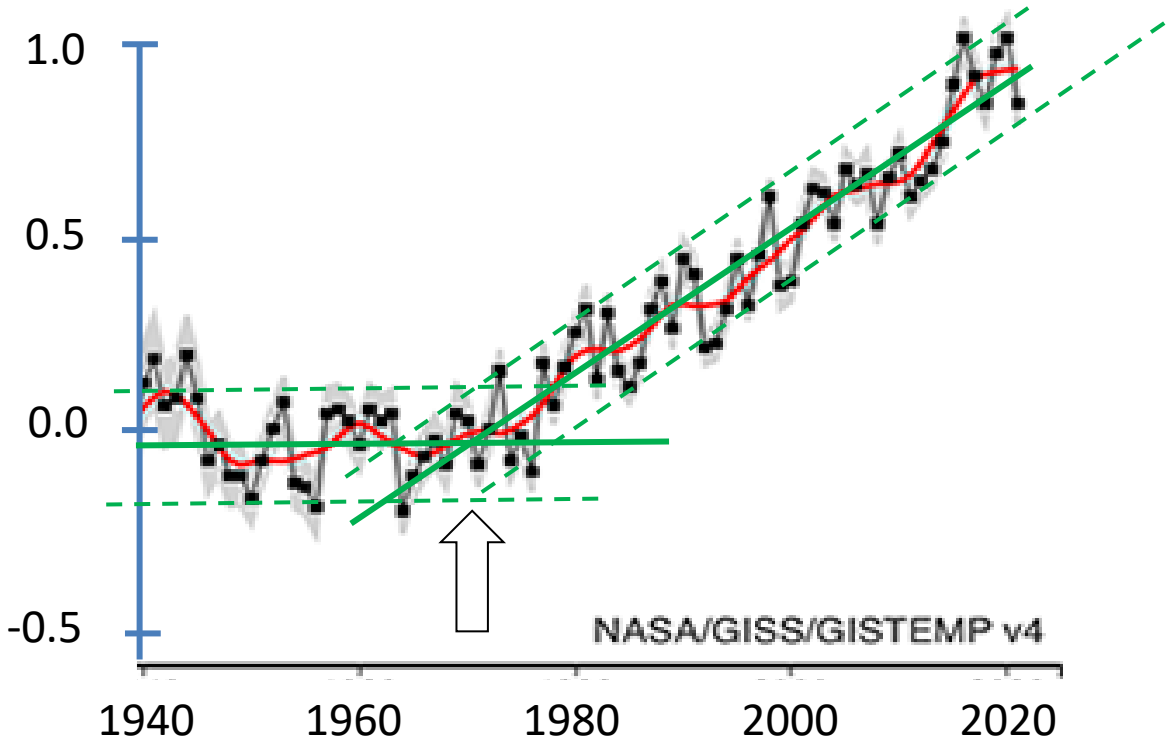
TA caused by growing greenhouse gas emissions:
Carbon dioxide
Methane
Nitrous oxide

Global warming will continue to increase in the near term (2021–2040) mainly due to increased cumulative CO_2 emissions in nearly all considered scenarios and modelled pathways
(IPCC report 2023)

Global Temperature Anomaly (TA)



Global Temperature Anomaly (TA)



Linear temperature increase observed at Earth surface since about 1965 -1975.

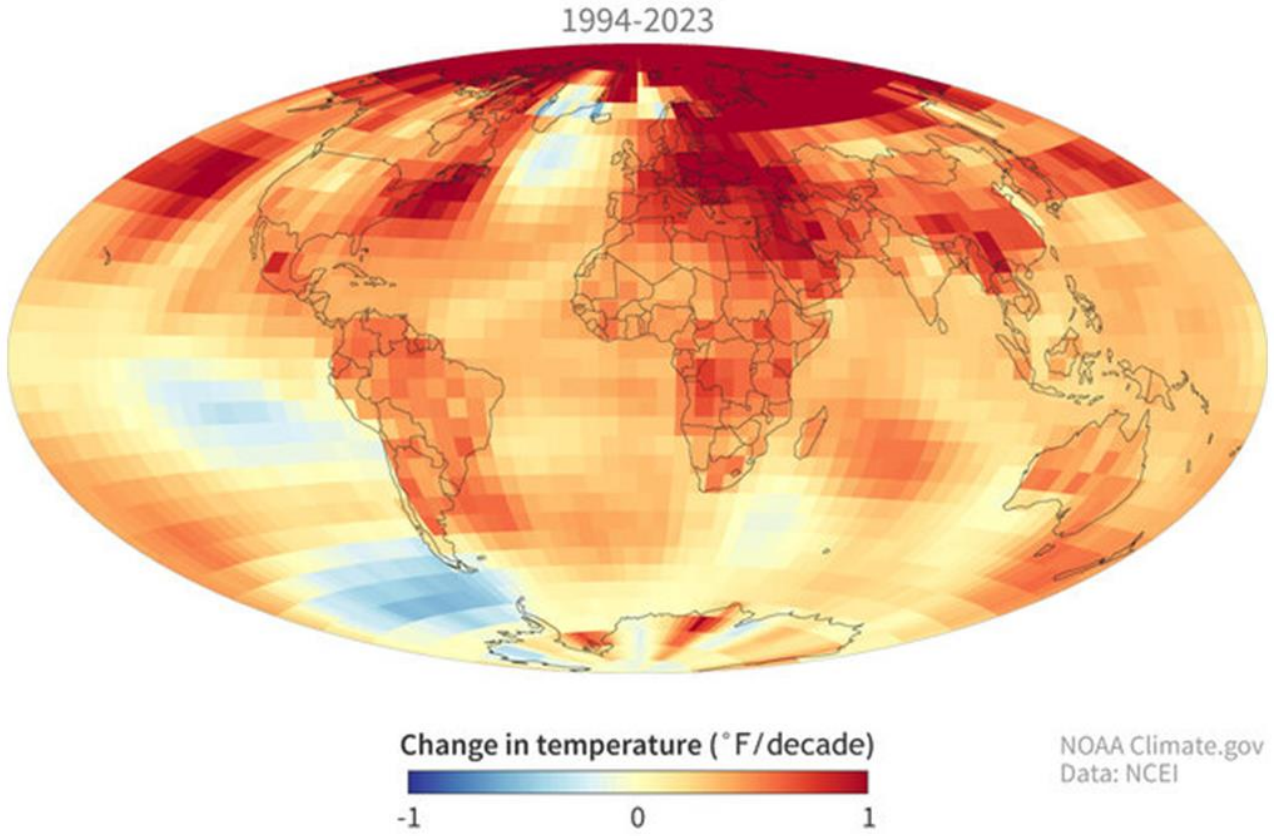
At thermosphere/ionosphere heights cooling of thermosphere.

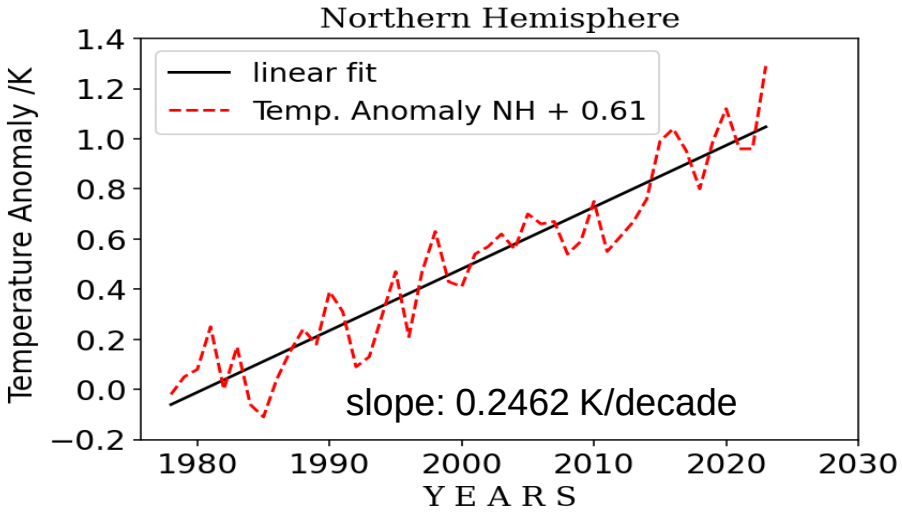
How neutral gas density in the thermosphere and electron density in the ionosphere react on this cooling?

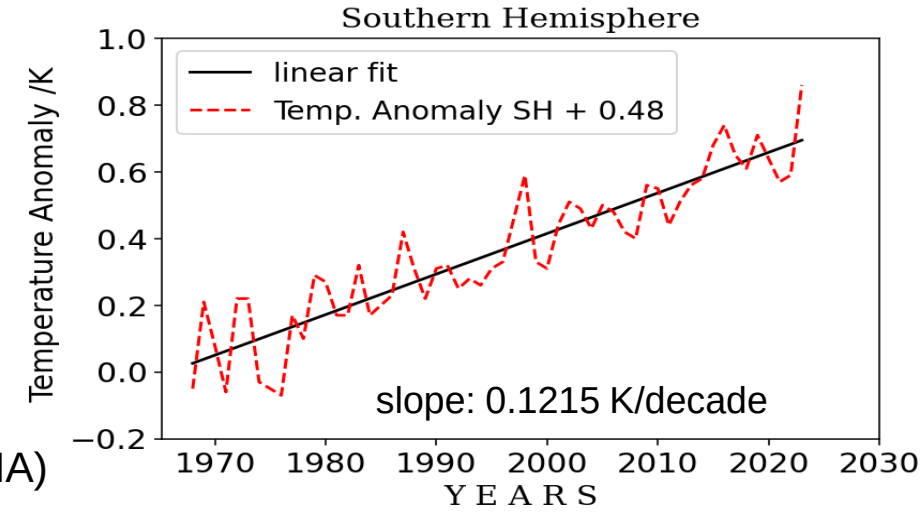
Analysis of noon-time NmF2 data from ionosonde stations distributed globally over Northern and Southern hemispheres.

⇨ separate view possible

Temperature Anomaly (TA) – different at Northern and Southern hemispheres

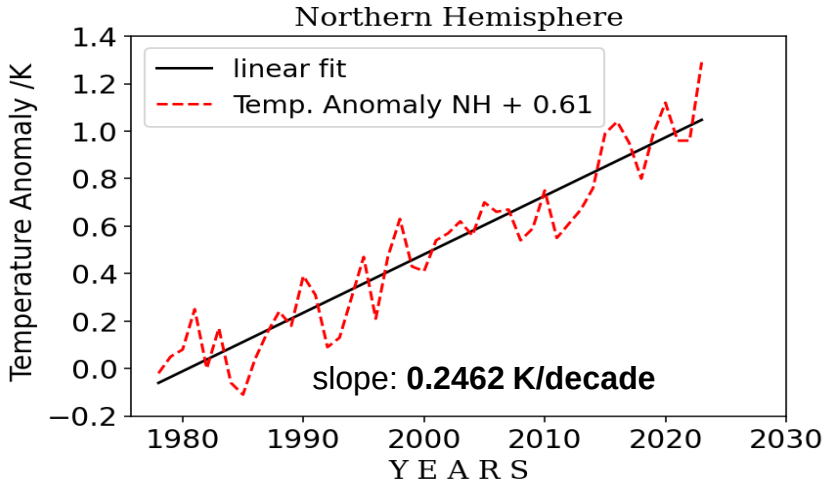


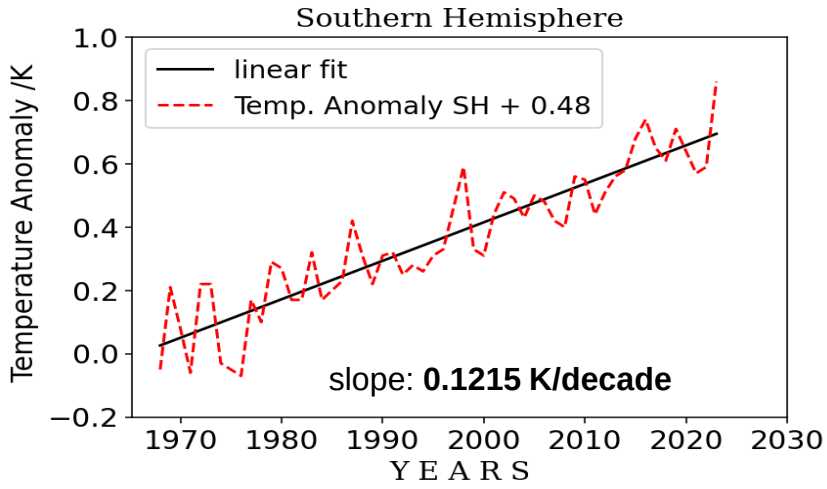


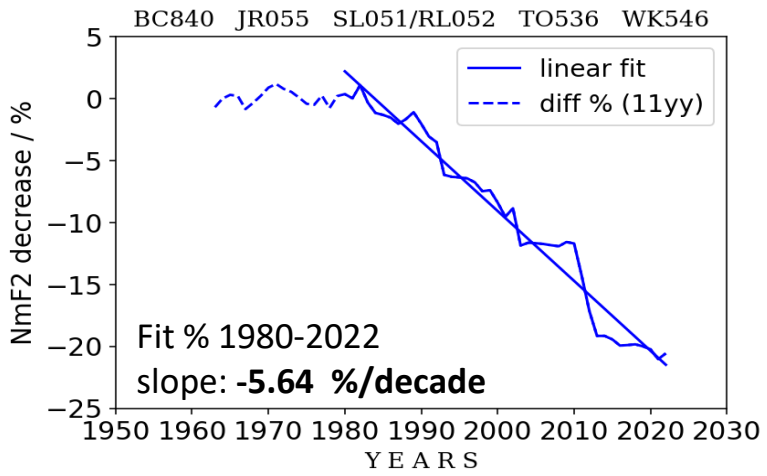


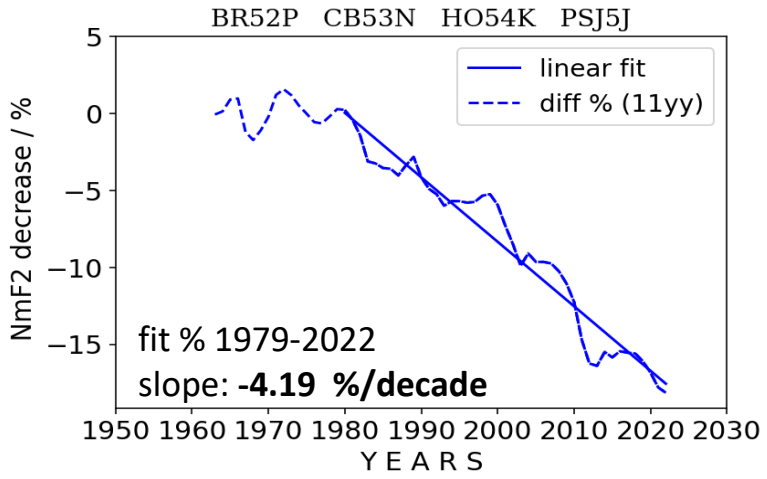
Temperature data from Japan Meteorology Agency (JMA)
Ref: long term average over 1991-2020 baseline

Hemispherical TA and EDA – different at Northern and Southern hemispheres







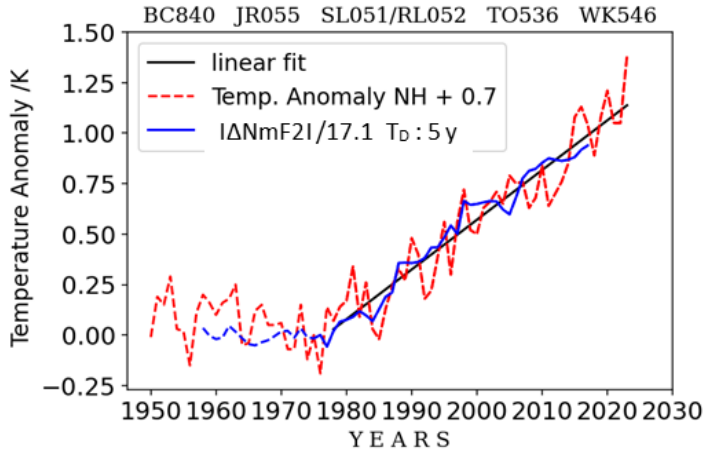


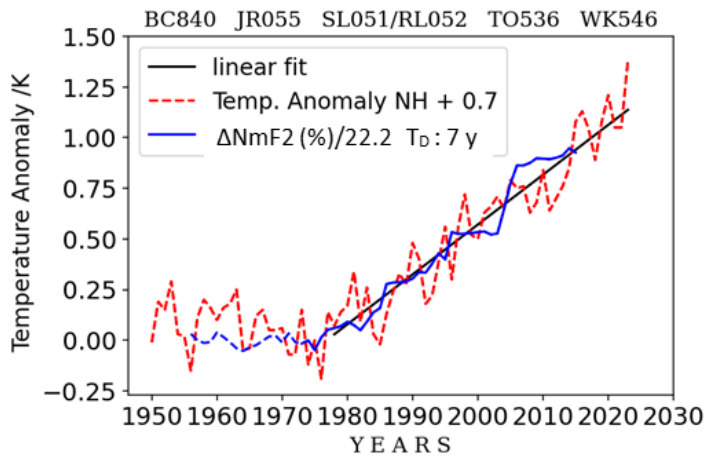
Different TA behaviour at both hemispheres with stronger (factor 2) temperature increase at the Northern than at the Southern hemisphere.

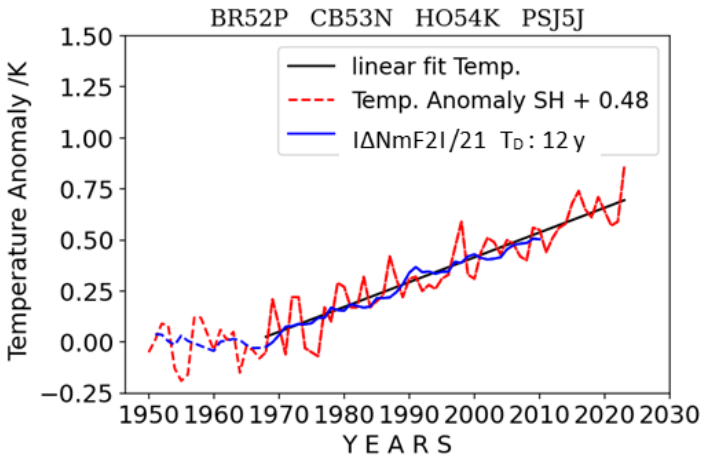
Similar behaviour is observed for the electron density decrease with stronger decrease (factor 1.35) of electron density at the Northern than at the Southern hemisphere.

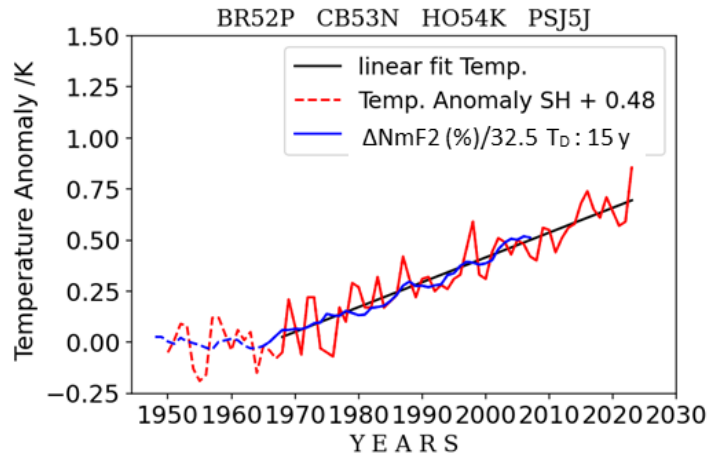
Linear LTT behaviour of TA and EDA promotes simple fitting of both trends to quantify TA and EDA relationship.

TA and EDA (IΔNmF2I,%) fits - Northern and Southern hemispheres









- Absolute ΔNmF2 and related percentage decrease values are fitted to temperature increase at Northern and Southern hemisphere separately.
- The fit requires a shift of the time axis of EDA values against TA
  - about 5-7 years at the Northern hemisphere
  - about 12-15 years at the Southern hemisphere.
- Since EDA values represent previous 11 years averages, the underlying physical processes act 4-6 years earlier as the time axis indicates.

Summary and conclusions

Long term datasets of noontime foF2 /NmF2 data have been analyzed for **9 ionosonde stations globally distributed over Northern and Sothern hemispheres.**

The early phase of measurements until 1984 has been used to develop **models of solar cycle averaged NmF2** as a linear function of corresponding radio flux index F30.

The **modelling approaches of NmF2 agree quite well** with measurements (errors < $2 \cdot 10^{10}\ m^{-3}$ / %).

To quantify deviations from model values after1984, the **model approaches are taken as a reference**.

Deviations from the reference are termed as **Electron Density Anomaly (EDA)** in analogy to the **Temperature Anomaly (TA)** characterizing the temperature increase at the Earth surface.

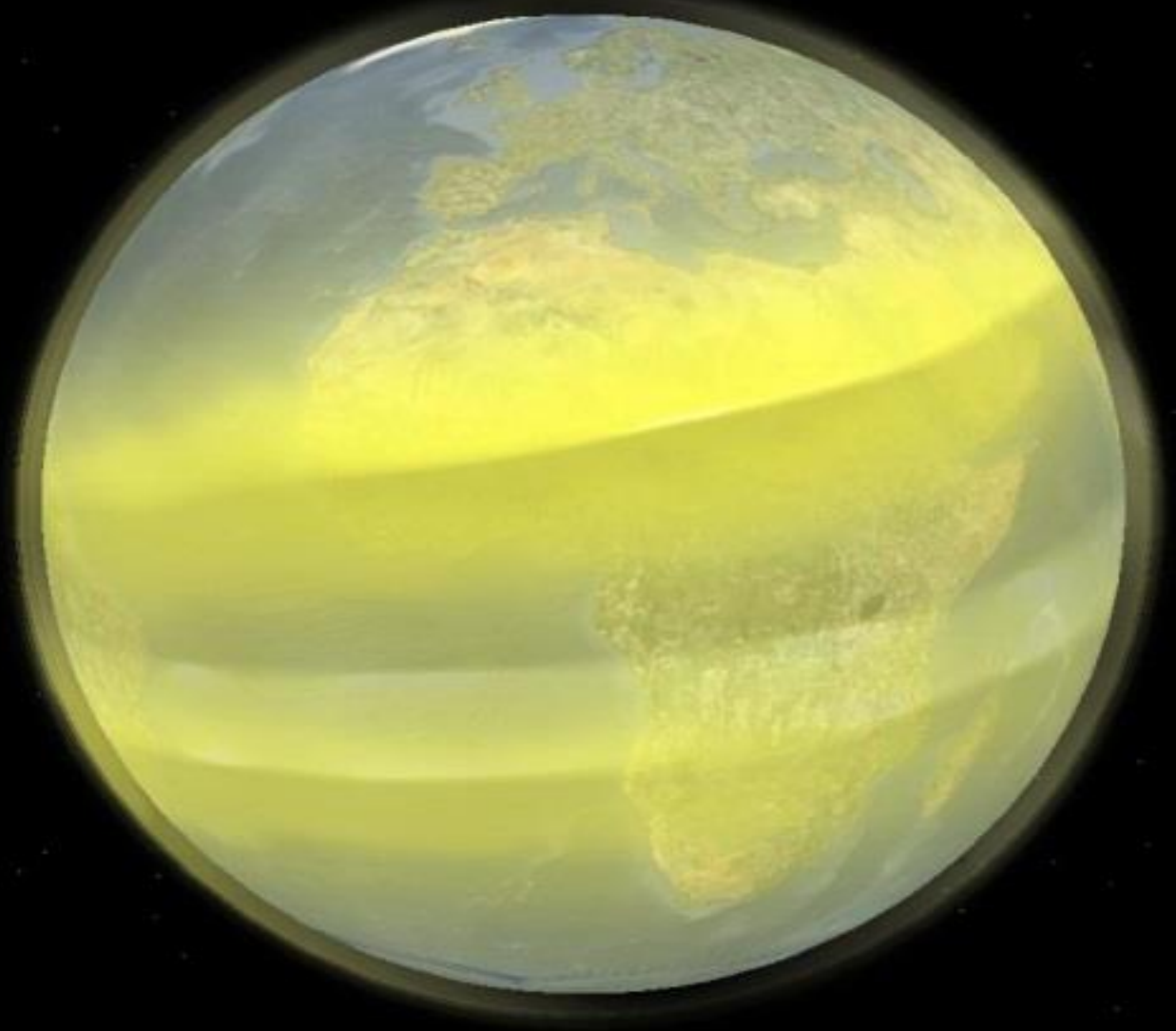
The **decrease of NmF2 is in the order of about 5%/decade.**

EDA and TA fit quite well if a time delay of EDA data against TA is assumed.

The delay (several years) could indicate the transport time of CO_2 needed to reach thermosphere heights.

Ionosphere from space

Electron density
July 23, 2011
14:00 UT



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Thank you for your attention!