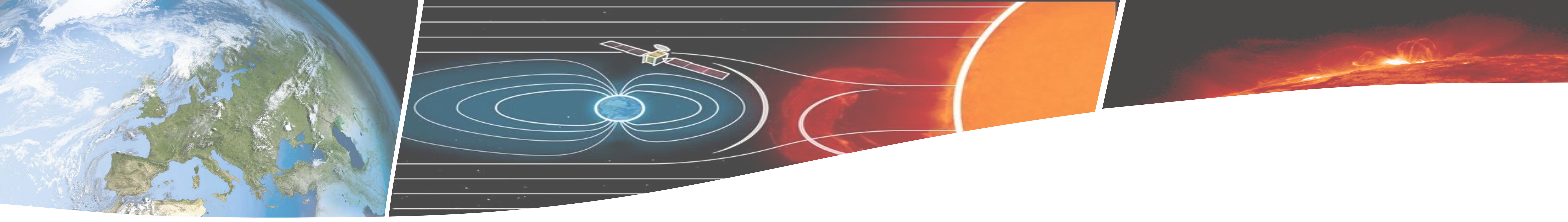

Ionospheric response to the variations of the solar wind

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Introduction

Solar wind-magnetosphere interaction causes persistent energy deposition at the high latitudes Earth system continuously modifying the ionospheric and thermospheric structures. The modifications are reflected in variations of the electric field, thermosphere heating, plasma transport, thermospheric composition, circulation and other effects. These significant variations do not only affect the high latitude region but also have an impact on a global scale. This work aims to explain the mechanisms that could be responsible for the response of the ionosphere-thermosphere system to the solar wind and interplanetary magnetic field variations.

Data and Methods

Since the variations in the ionosphere are easily monitored by the Total Electron Content (TEC), with a data coverage of more than twenty years and with 2.5°x5° degree spatial and 2-hour temporal resolution is used. The ionosphere conditions are studied at Tromsø, Norway (69.58°N, 19.23°E), where the most continuous dataset of IGS TEC can be combined with EISCAT UHF incoherent scatter radar observations on electron density altitude profiles. For the solar wind data, 2-hour resampled Advanced Composition Explorer (ACE) and derived geoeffective interplanetary electric field, is used for the estimations of the solar wind energy input into the magnetosphere.

$$E_m = v_{sw} B_t \sin^2\left(\frac{\theta}{2}\right)$$

Kan & Lee (1979)

$B_T = \sqrt{B_y^2 + B_z^2}$ Magnitude of IMF in yz plane

V_{SW} = solar wind speed

Θ = Angle between z direction and projection of IMF in yz-plane

In the analyses, a cross-correlation method with a moving 90-day window, which generates a dataset of the correlation values corresponding to the variation of TEC with merging electric field, is used. The method also delivers the time lag between ionosphere and solar wind variations. Later for selected 5 EISCAT campaigns, the same method is applied.

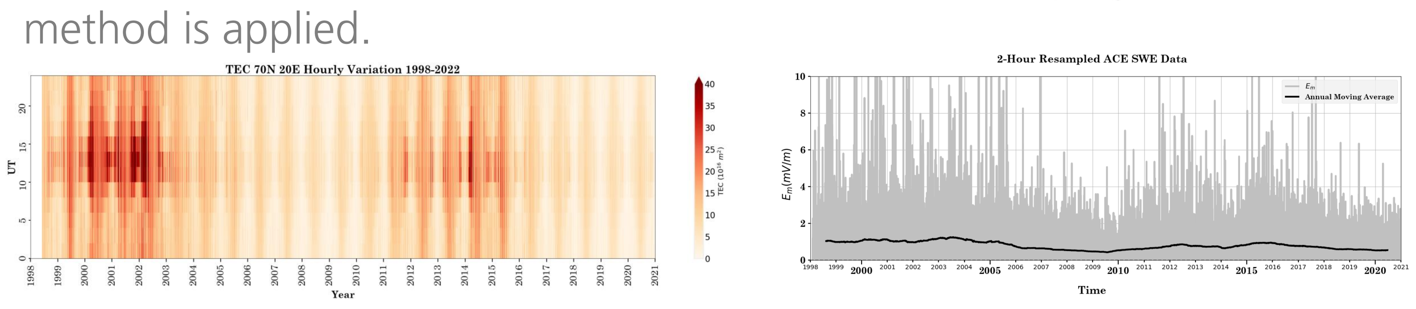

Figure 1. TEC **variations from 1998 to 2021 for high latitudes, near Tromsø/Norway (left) and variation of merging electric field,** E_m**, (right). The black solid line represents the annual moving average of** E_m**.**

Results

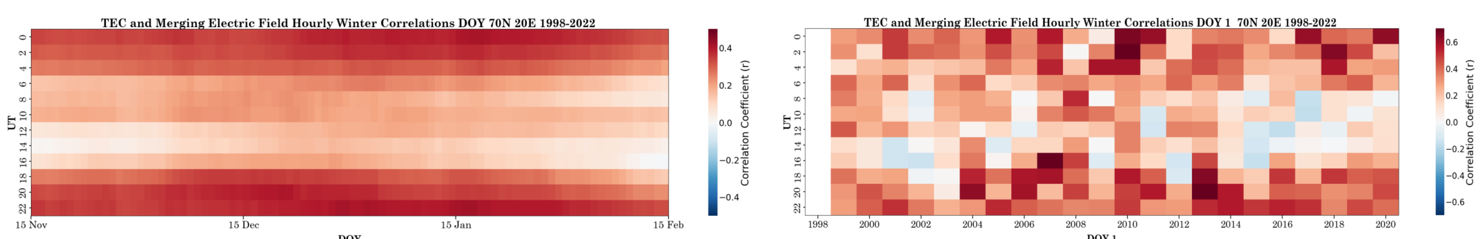

Figure 2. Averaged winter variation (left) and temporal evolution of DOY 1 between 1998 and 2021 (right) of the TEC **and** E_m**, correlations (SLT ≈ UT + 1.33).**

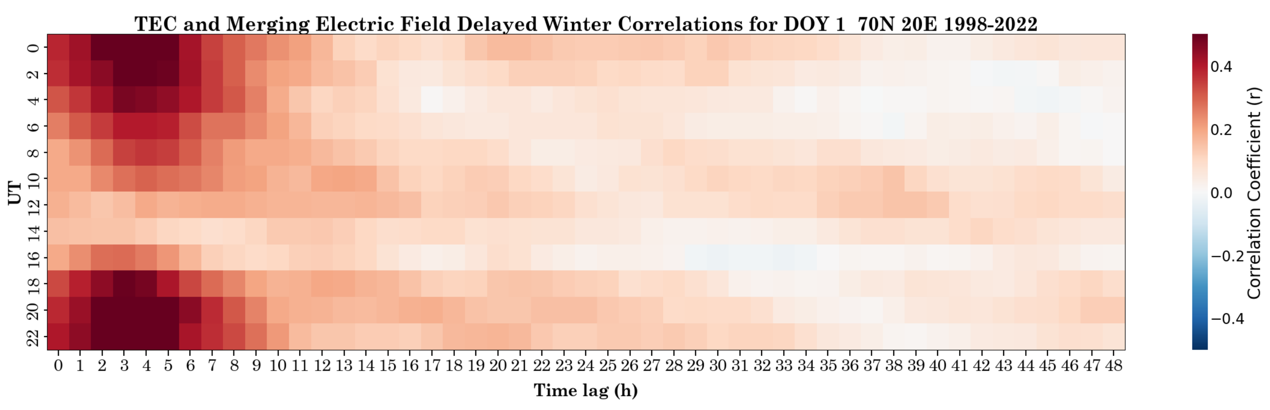

Figure 3. Response of TEC **to** E_m **for DOY 1 with a time lag from 0 to 48 hours in x-axis, and UT hour in y-axis.**

- The TEC at high latitudes show strong seasonal variability, with pronounced effects during winter nighttime (Borries et al., 2024).
- The ionospheric response during winter nighttime represented by positive correlation, increased E_m with increased TEC, is intensifying with ≈ 4 h time lag (contribution from convection and precipitation processes).

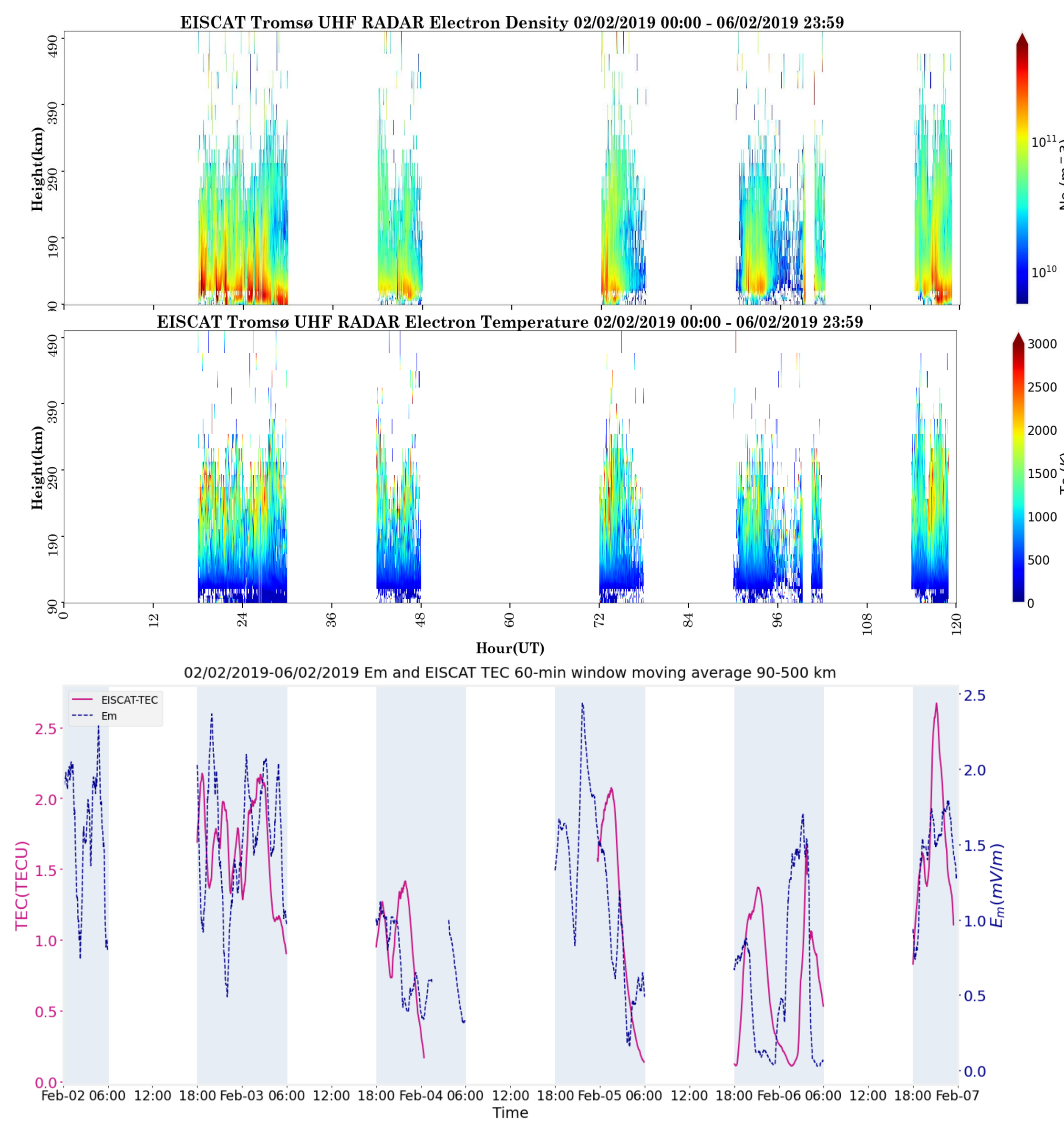

Figure 4. EISCAT Tromsø UHF radar 1-min electron density N_e **(top),** T_e **(middle), and 60-min moving averaged** TEC **(violet red) estimated between 90-500 km with OMNI merging electric field (dark blue) on 2-6 February 2019 between 18 and 6 UT.**

- For the E-region ionosphere, the lag time ranges between 45 to 90 minutes, while it ranges from 75 to 135 minutes for the F-region.

The observed time lags reveal that the soft electron precipitation (<keV) in the F-region and convection is slowing the response down, whereas the response of E-region to the energetic electron precipitation (>keV) and variations in the convection electric field is faster.

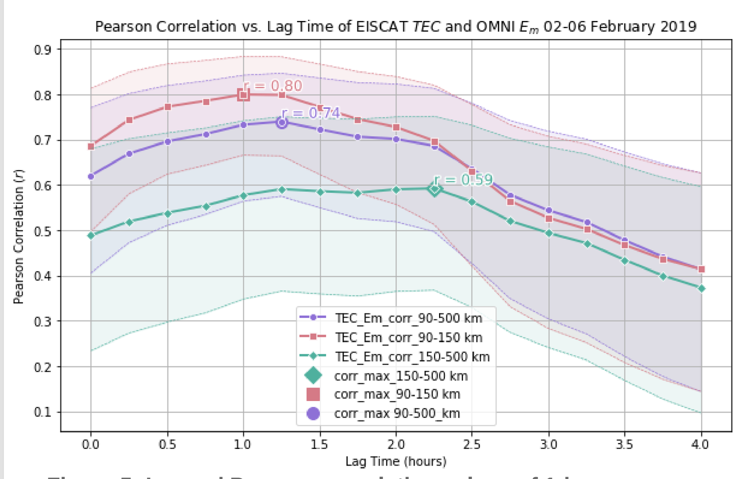

Figure 5: Lagged Pearson correlation values of 1-hour resampled EISCAT TEC **and OMNI** E_m **between the time range of 18 and 6 UT on 2-6 February 2019. Pink color represents the E-region of the ionosphere (90-150 km), while green color is used to represent the F-region in the ionosphere (150-500 km) and lilac color for the combined region (90-500 km). Shaded area corresponds to the 0.95 confidence level.**

	90-500 km		90-150 km		150-500 km	
	Offset time (min)	Max correlation (r_{max})	Offset time (min)	Max correlation (r_{max})	Offset time (min)	Max correlation (r_{max})
9-12 January 2013	90	0.81	90	0.80	90	0.77
6-9 December 2004	75	0.71	75	0.52	90	0.66
2-6 February 2019	75	0.74	60	0.80	135	0.59
19-29 January 2010	135	0.74	75	0.60	135	0.75
6-9 February 2007	90	0.63	45	0.69	90	0.58

Table 1: The maximum Pearson correlation values of 1- hour resampled height-integrated EISCAT TEC **in three regions of the ionosphere and OMNI** E_m **with the corresponding lag time during 5 selected EISCAT Tromsø UHF campaigns.**

Summary and Conclusions

The presented results show a moderate positive correlation between TEC and merging electric field during winter nighttime. It is also shown that the ionospheric response is with a delay of ≈4 hours during winter nighttime conditions. Particle precipitation and plasma convection are the suggested driving mechanisms behind the observed delayed ionospheric response to persistent solar wind forcing. It is known that polar cap plasma convection (PCPC) processes take about ≈1-2 hours. EISCAT UHF radar CP1 and CP2 measurements at the Tromsø location are analyzed for five corresponding events to identify the contribution of the particle precipitation to the response. EISCAT TEC and OMNI merging electric field delayed correlations demonstrate that the lag time is shorter in the E-region ionosphere (90-150 km) between 45 to 90 minutes and response is stronger with higher correlation values, while it ranges from 75 to 135 minutes in the F-region (150-500 km). The delayed response in the ionosphere is suggested to be originated from the contribution of slower moving of plasma and the soft electron precipitation (<keV) in the F-region, whereas the response of E-region to the energetic electron precipitation (>keV) variations is faster. These results are consistent among multiple selected EISCAT campaigns.

References:

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DLR Deutsches Zentrum für Luft- und Raumfahrt

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