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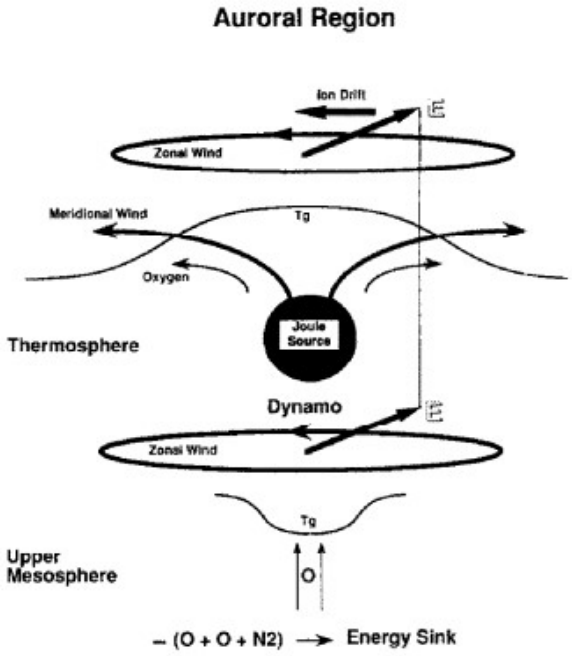
Variations of total electron content with solar wind parameters at high-latitude ionosphere

P. Iochem[1], C. Borries [1], F. Davis[1,2], S. Tasnim[1], J. Vogt[3]

[1]German Aerospace Center (DLR), Institute for Solar-Terrestrial Physics, Neustrelitz, Germany
[2]University of Applied Sciences Neubrandenburg, Neubrandenburg, Germany
[3]Constructor University, Bremen, Germany

Solar wind impact on high-latitude ionosphere

- Interaction between solar wind and magnetosphere drives the upper atmosphere.
- Changes in solar radiation, geomagnetic disturbances, and lower atmosphere forcing can all contribute to variability of maximum electron density of the F2 layer and the **total electron content** (TEC). (Cai et. al., 2021)
- Intense **Joule heating** in thermosphere results in upwelling of nitrogen-rich or oxygen-depleted air. Depleted **O/N_2** air causing a decrease in electron density in **polar regions** due to a higher recombination process through ion-molecule exchange reaction with **N_2** molecules (Ranjan et. al., 2023).
- There exist positive storm effects (electron density enhancements) and negative effects (electron density depletion) in the ionosphere (Borries et. al., 2015)



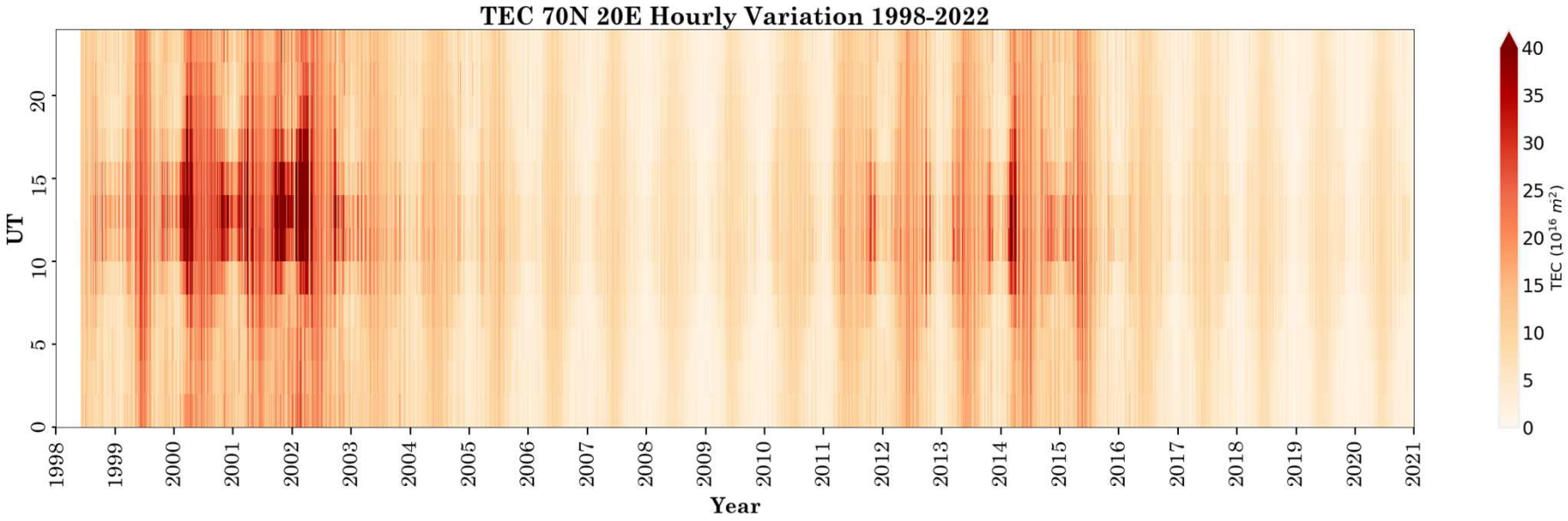
Mayr et. al. (1990)

- **How does the thermosphere-ionosphere system respond to solar wind variation and how it changes with season and local time?**

Objectives

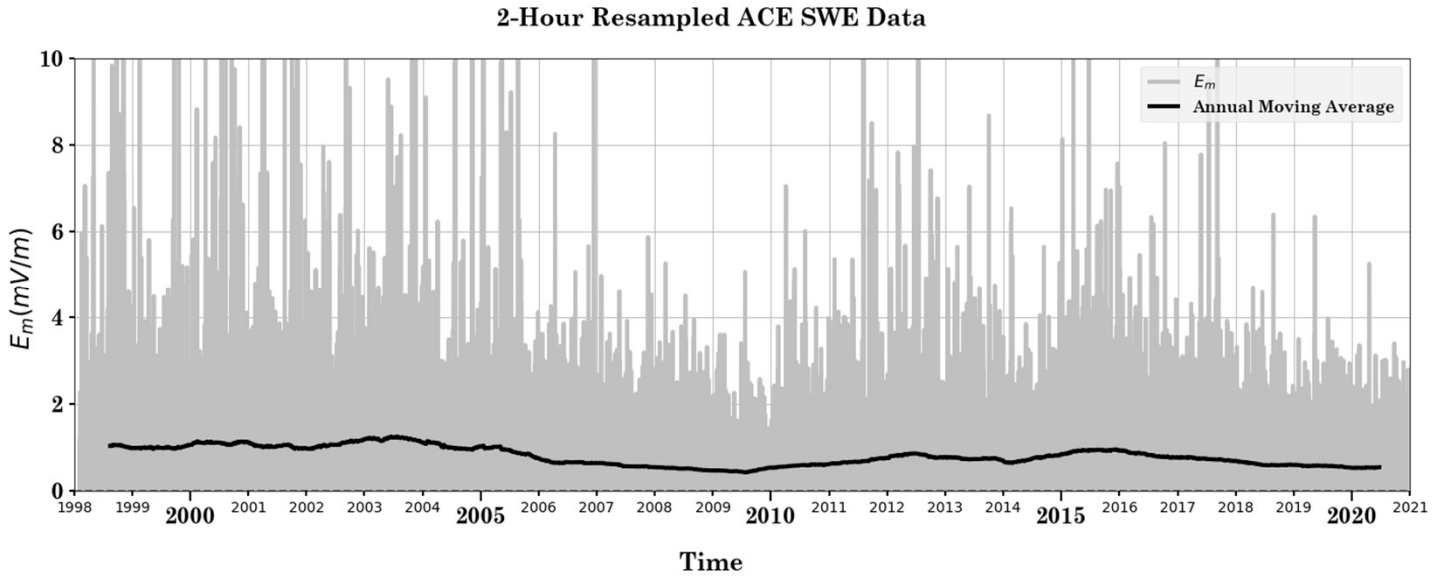
- Study the impact of solar wind on high-latitude ionospheric total electron content (TEC) on time scales of hours, seasons, years, and solar cycles.
- Reveal the differences in TEC and solar wind correlations.
- Study the response time of the ionosphere to solar wind variations.
- Explain the possible reasons and mechanisms behind the correlations.

Total Electron Content (TEC) and Daily Sunspot Number (SSN) Data



Data: 2 hours resolution IGS TEC Map
Location: Near Tromsø/Norway, 70N 20E
Time span: 23 years (1998-2021)
Local time: UTC+1 (+2 daylight savings)

Merging Electric Field as Solar Wind Coupling Function



$$E_{\mathrm{m}} = v_{\mathrm{sw}} B_{\mathrm{t}} \sin^2\left(\frac{\theta}{2}\right)$$

Kan & Lee (1979)

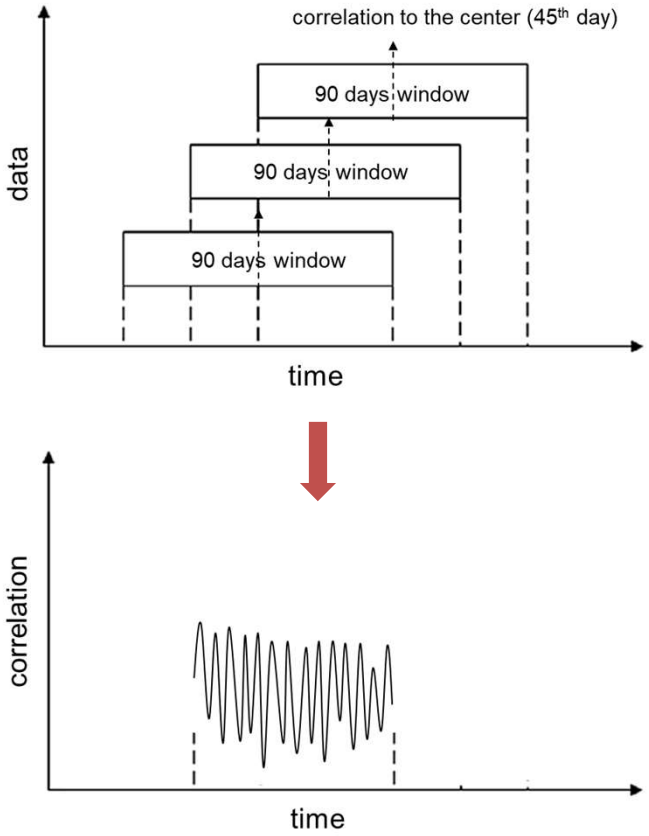
$\boldsymbol{B_T} = \sqrt{B_y^2 + B_z^2}$ Magnitude of IMF in yz plane

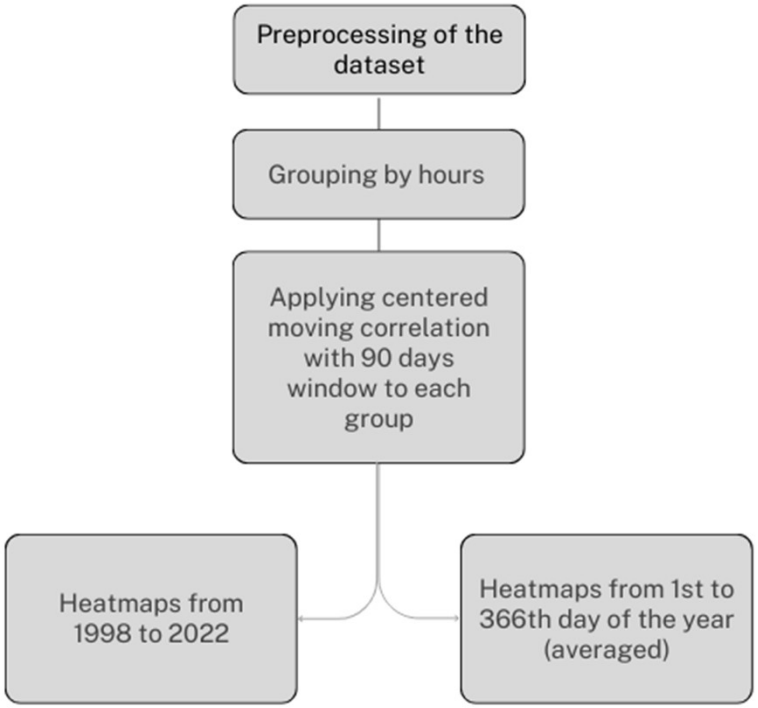
$\boldsymbol{V_{SW}}$ = solar wind speed

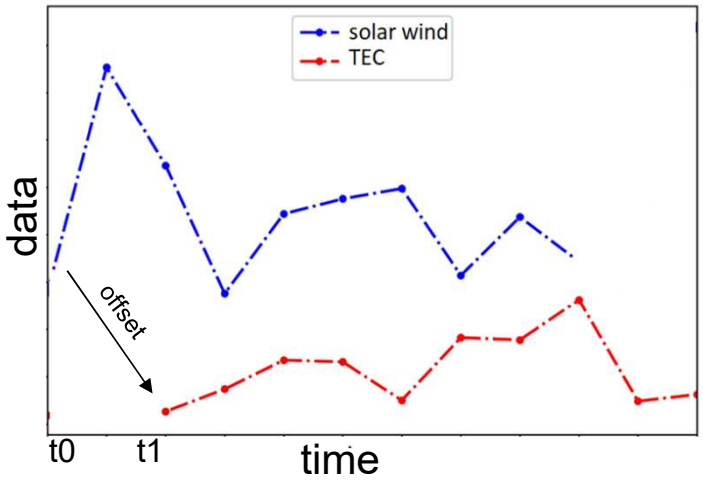
Θ = Angle between z direction and projection of IMF in yz-plane

Data: 2 hours resampled ACE SWE data
Time span: 23 years (1998-2021)

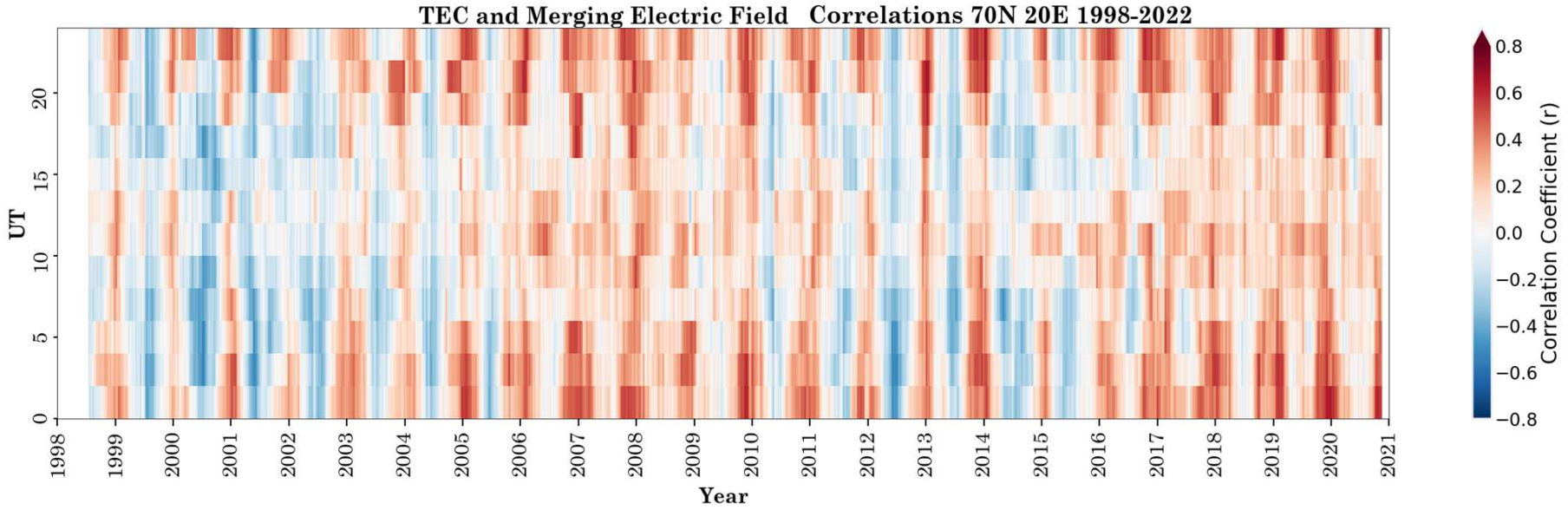
Method: Centered Moving Correlation with 90 Days Window and Delay





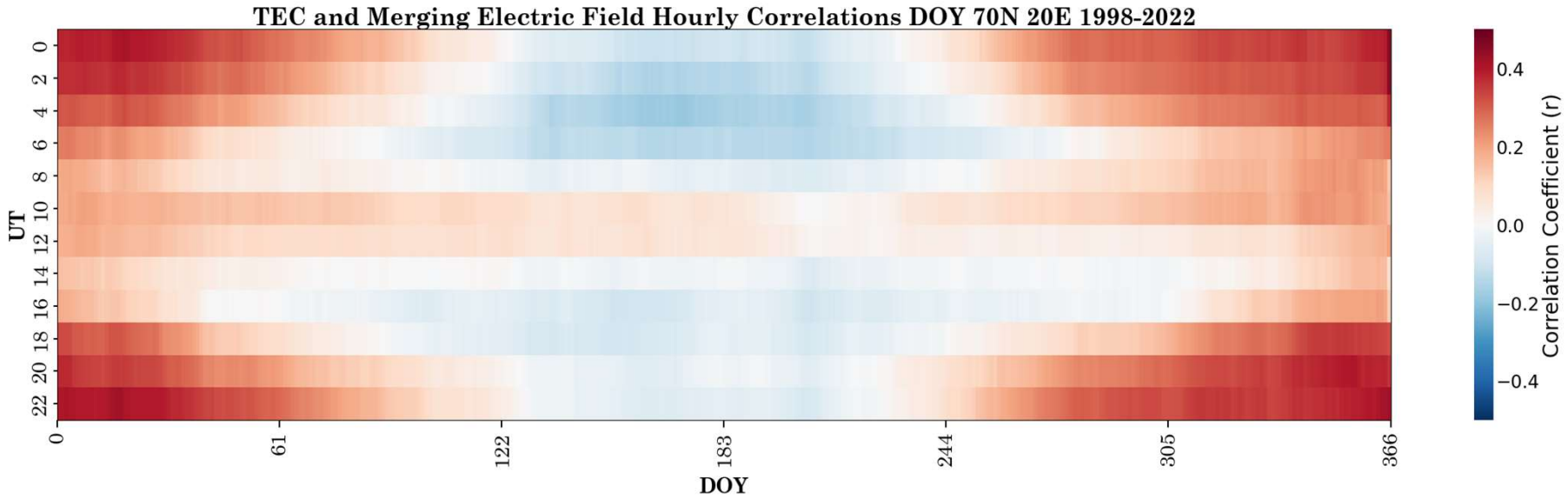


Temporal Evolution of the TEC and E_m Correlations



- Positive correlations during winter nighttime
- Negative correlations during summer daytime solar max

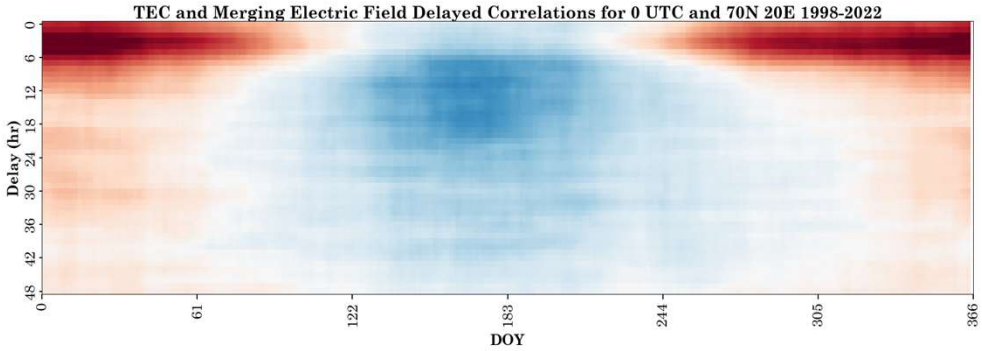
Average Annual Variation of TEC and E_m Correlations

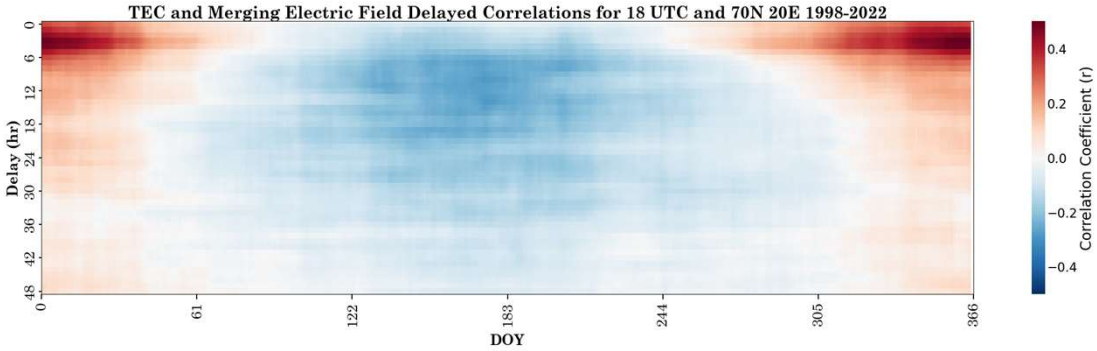


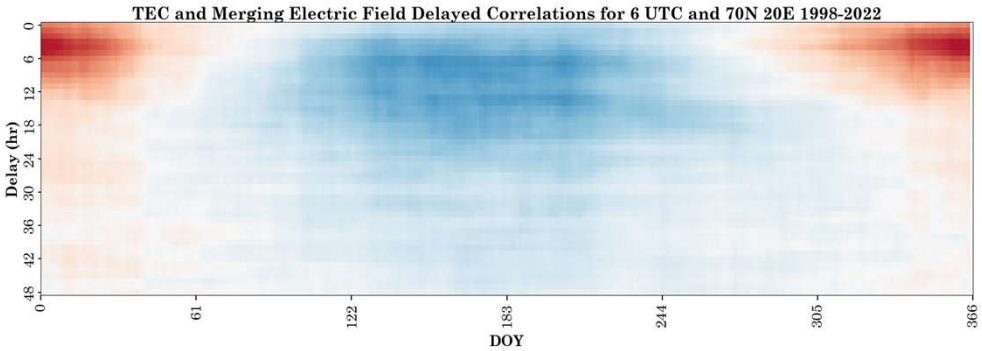
Positive-negative correlation effect

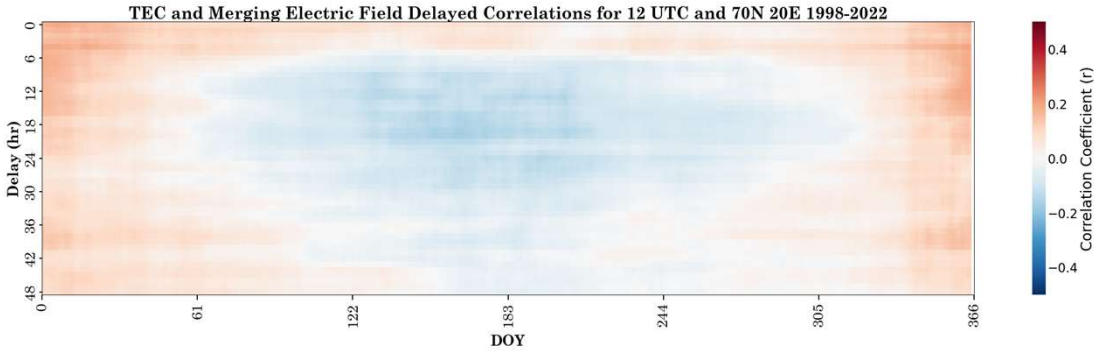
- Convection (winter-transport of plasma)
- Recombination (summer-reduction of plasma)

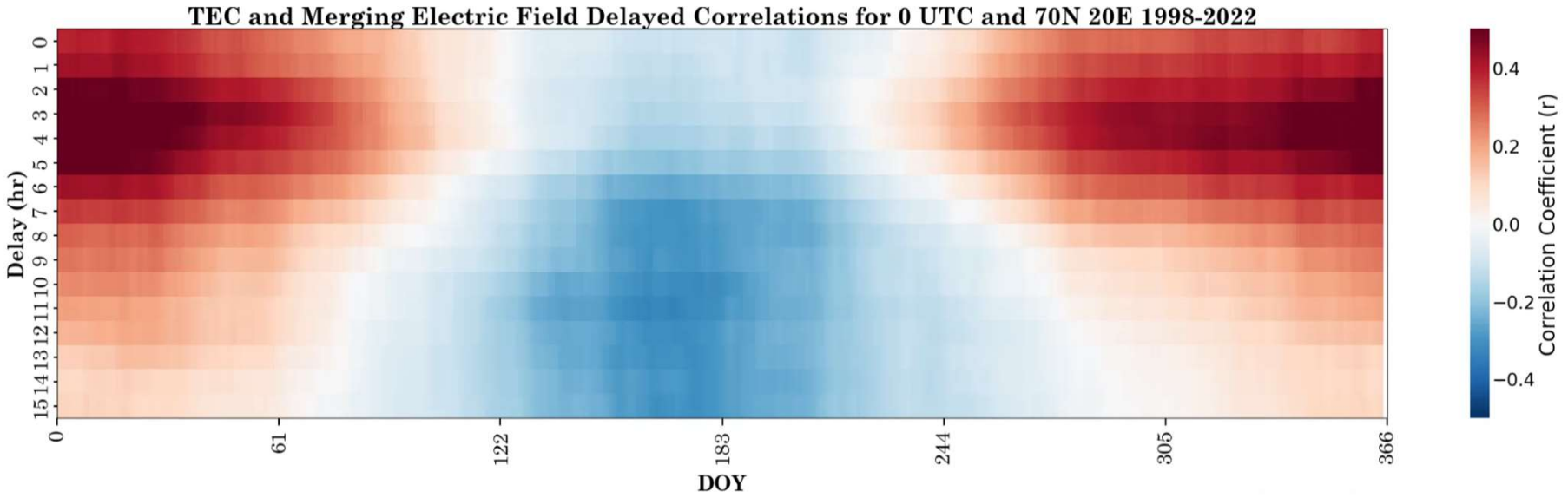
Response Time of TEC to Solar Wind (E_m)










TEC and Merging Electric Field Delayed Correlations for 0 UTC and 70N 20E 1998-2022
Delay (hr)
0
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2
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10
11
12
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14
15
0
61
122
183
244
305
366
DOY
0.4
0.2
0.0
−0.2
−0.4
Correlation Coefficient (r)

Summary

- Seasonal and local time dependency of solar wind in high latitude ionosphere

- Merging electric field correlation analysis with Total Electron Content

    1. During winter (summer) it is strongly positive (mostly negative during daytime)
    2. Positive winter effect – plasma transport (convection)
    3. Negative summer effect – recombination (upwelling of molecules and more intense heating)

- Response of ionospheric TEC to solar wind:

    1. Shorter– positive winter effect
    2. Longer– negative summer effect

References

Borries, C., J. Berdermann, N. Jakowski, and V. Wilken (2015), Ionospheric storms—A challenge for empirical forecast of the total electron content, *J. Geophys. Res. Space Physics*, *120*, 3175–3186, doi:10.1002/2015JA020988

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Mayr, H. G., Harris, I., & Dube, M. (1990). Polar thermospheric Joule heating, and redistribution of recombination energy in the upper mesosphere. Journal of Atmospheric and Terrestrial Physics, 52(2), 103–112. https://doi.org/10.1016/0021-9169(90)90072-u

Ranjan, A. K., Sunil Krishna, M. V., Kumar, A., Sarkhel, S., Bharti, G., Bender, S., & Sinnhuber, M. (2023). Aspects related to variability of radiative cooling by NO in lower thermosphere, TEC and O/N2 correlation, and diffusion of NO into mesosphere during the Halloween storms. *Advances in Space Research: The Official Journal of the Committee on Space Research (COSPAR)*, *71*(1), 29–45. https://doi.org/10.1016/j.asr.2022.07.035


Thanks!

Sources for negative/positive effect on ionosphere

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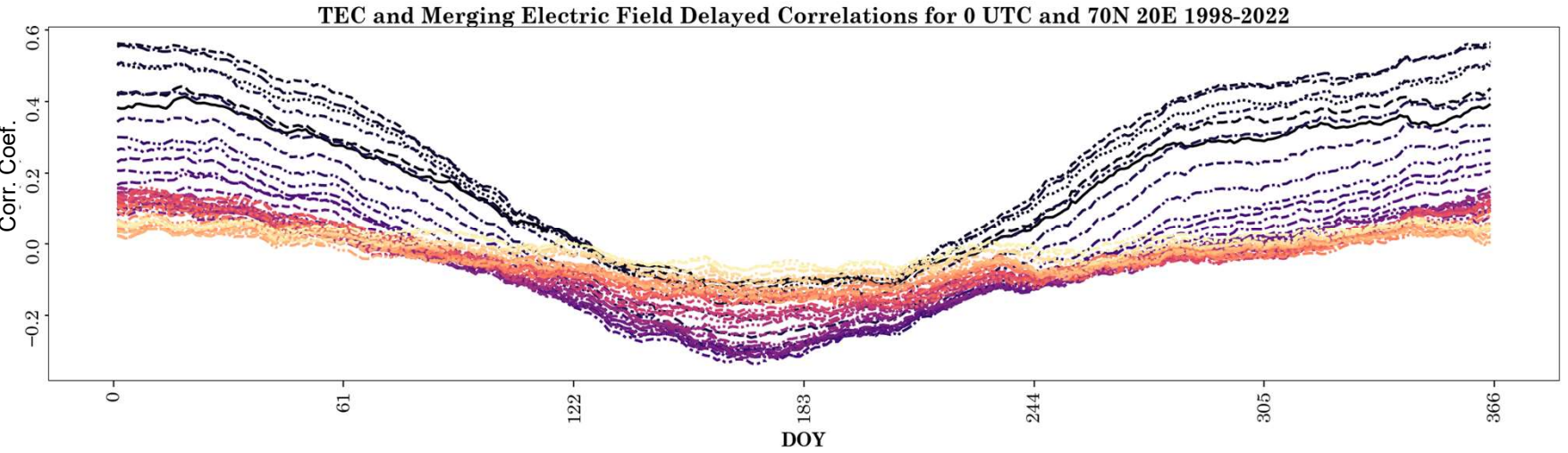
- Mayr, H. G., Harris, I., & Dube, M. (1990). Polar thermospheric Joule heating, and redistribution of recombination energy in the upper mesosphere. *Journal of Atmospheric and Terrestrial Physics*, *52*(2), 103–112. https://doi.org/10.1016/0021-9169(90)90072-u

- Richmond, A. D. (n.d.). Joule Heating in the Thermosphere Space Physics and Aeronomy. *Space Physics and Aeronomy, Volume 4: Upper Atmosphere Dynamics and Energetics*, *4*. https://cedarscience.org/sites/default/files/workshops/2022/Richmond2020preprint.pdf


TEC and Merging Electric Field Delayed Correlations for 0 UTC and 70N 20E 1998-2022
Corr. Coef.
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0.4
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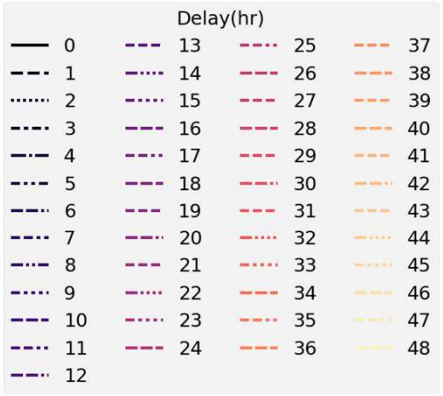
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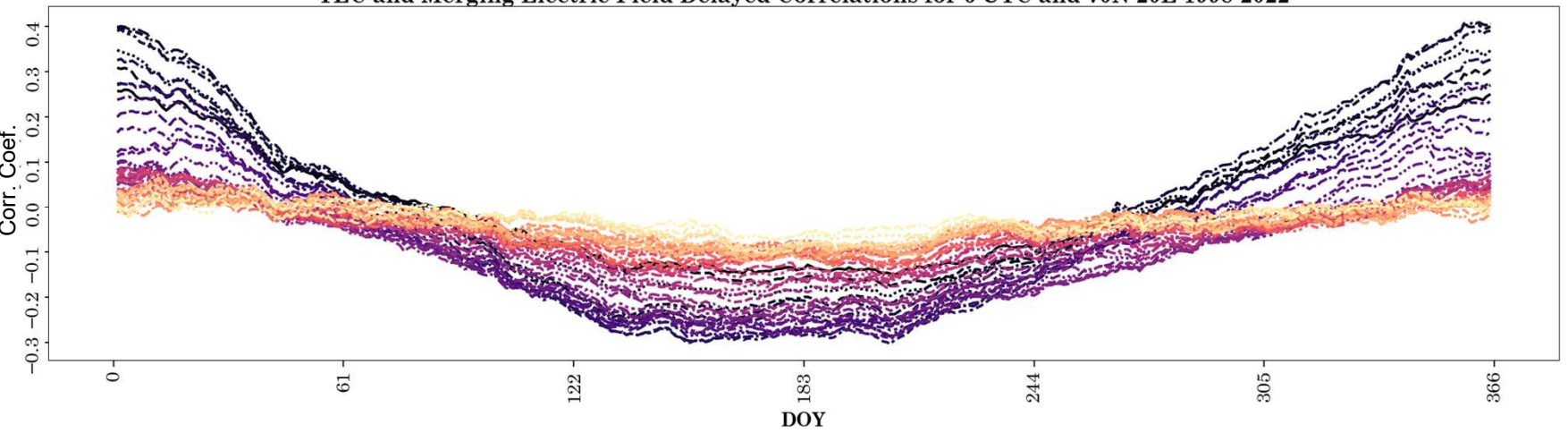
TEC and Merging Electric Field Delayed Correlations for 6 UTC and 70N 20E 1998-2022
Corr. Coef.
0.4
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
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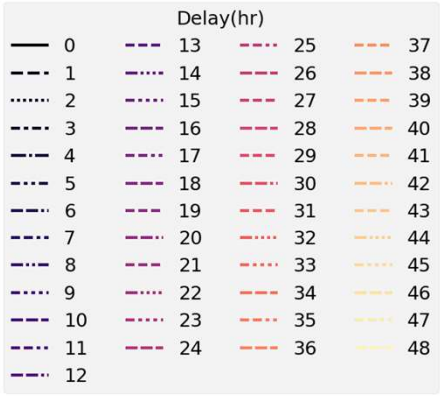
183
244
305
366
DOY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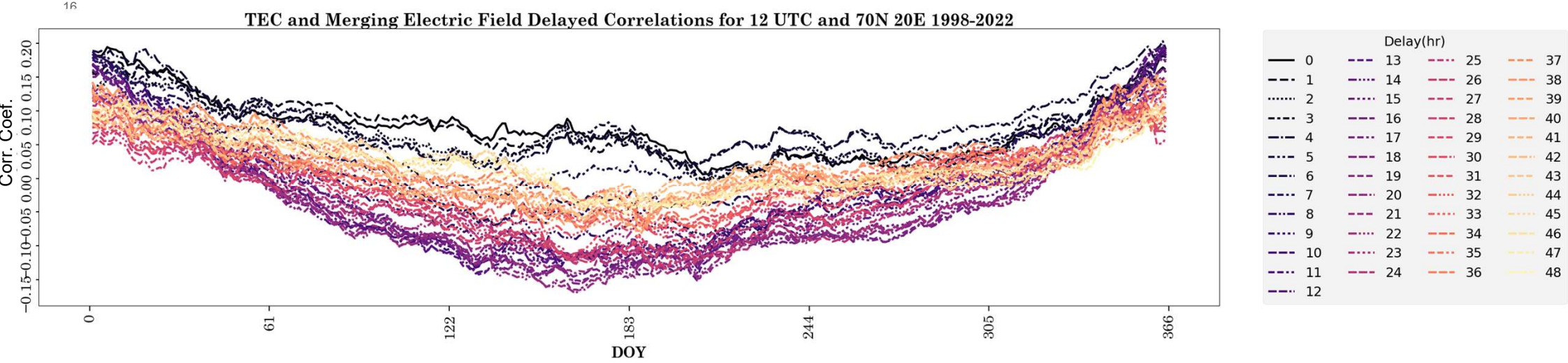
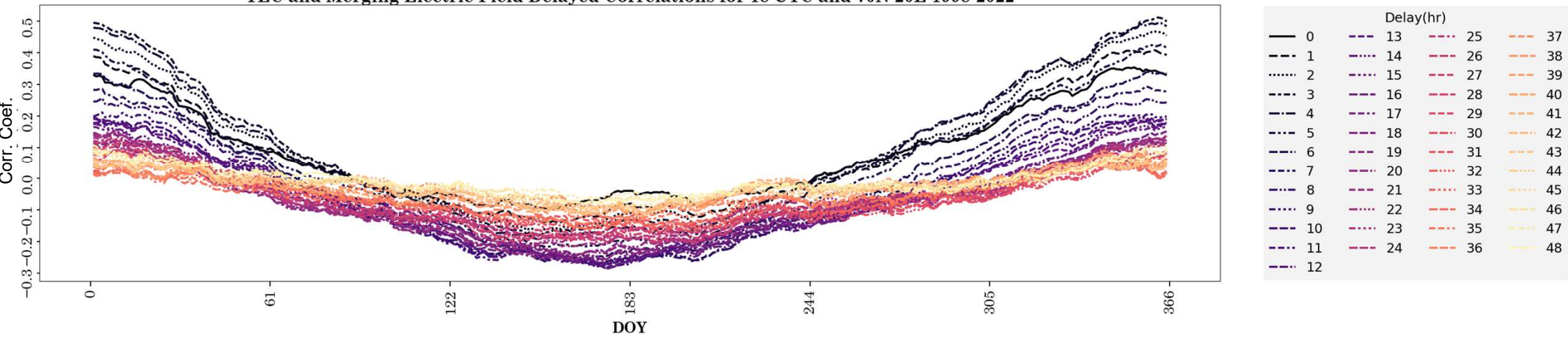
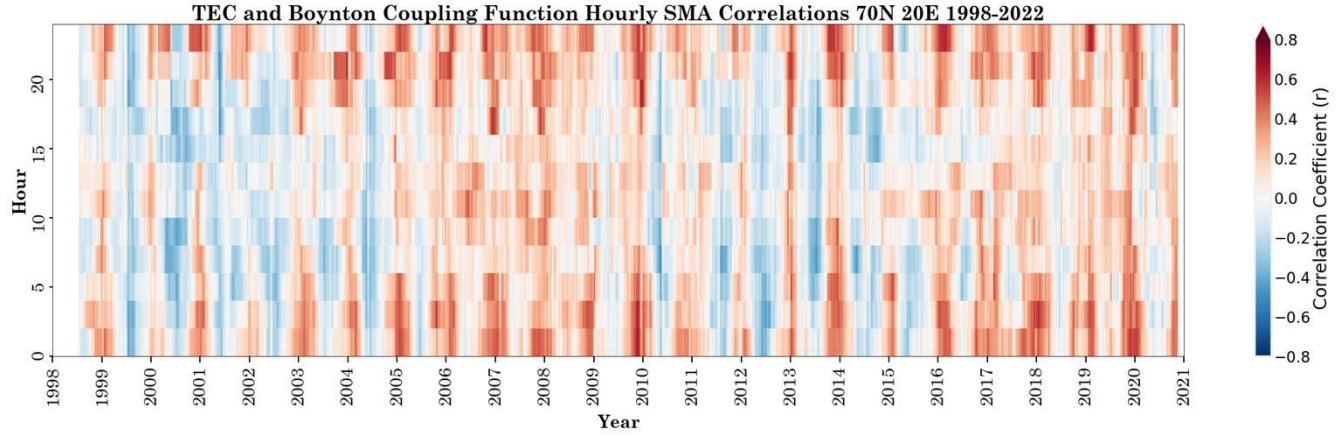
DLR

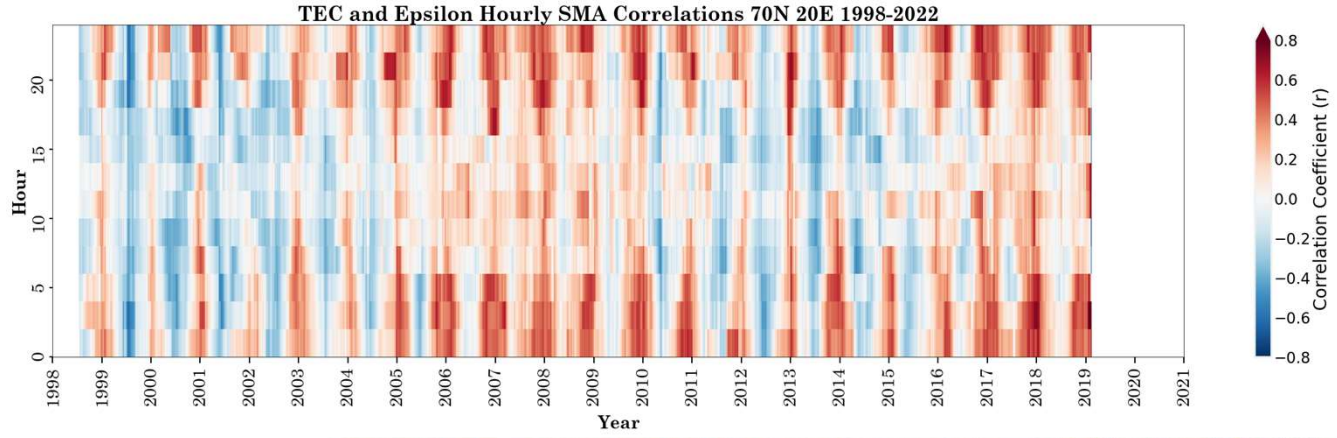

TEC and Merging Electric Field Delayed Correlations for 12 UTC and 70N 20E 1998-2022
Corr. Coef.
−0.15 −0.10 −0.05 0.00 0.05 0.10 0.15 0.20
0
61
122
183
244
305
366
DOY
Delay(hr)
0 1 2 3 4 5 6 7 8 9 10 11 12
13 14 15 16 17 18 19 20 21 22 23 24
25 26 27 28 29 30 31 32 33 34 35 36
37 38 39 40 41 42 43 44 45 46 47 48


TEC and Merging Electric Field Delayed Correlations for 18 UTC and 70N 20E 1998-2022
Corr. Coef.
−0.3 −0.2 −0.1 0.0 0.1 0.2 0.3 0.4 0.5
0
61
122
183
244
305
366
DOY
Delay(hr)
0 1 2 3 4 5 6 7 8 9 10 11 12
13 14 15 16 17 18 19 20 21 22 23 24
25 26 27 28 29 30 31 32 33 34 35 36
37 38 39 40 41 42 43 44 45 46 47 48

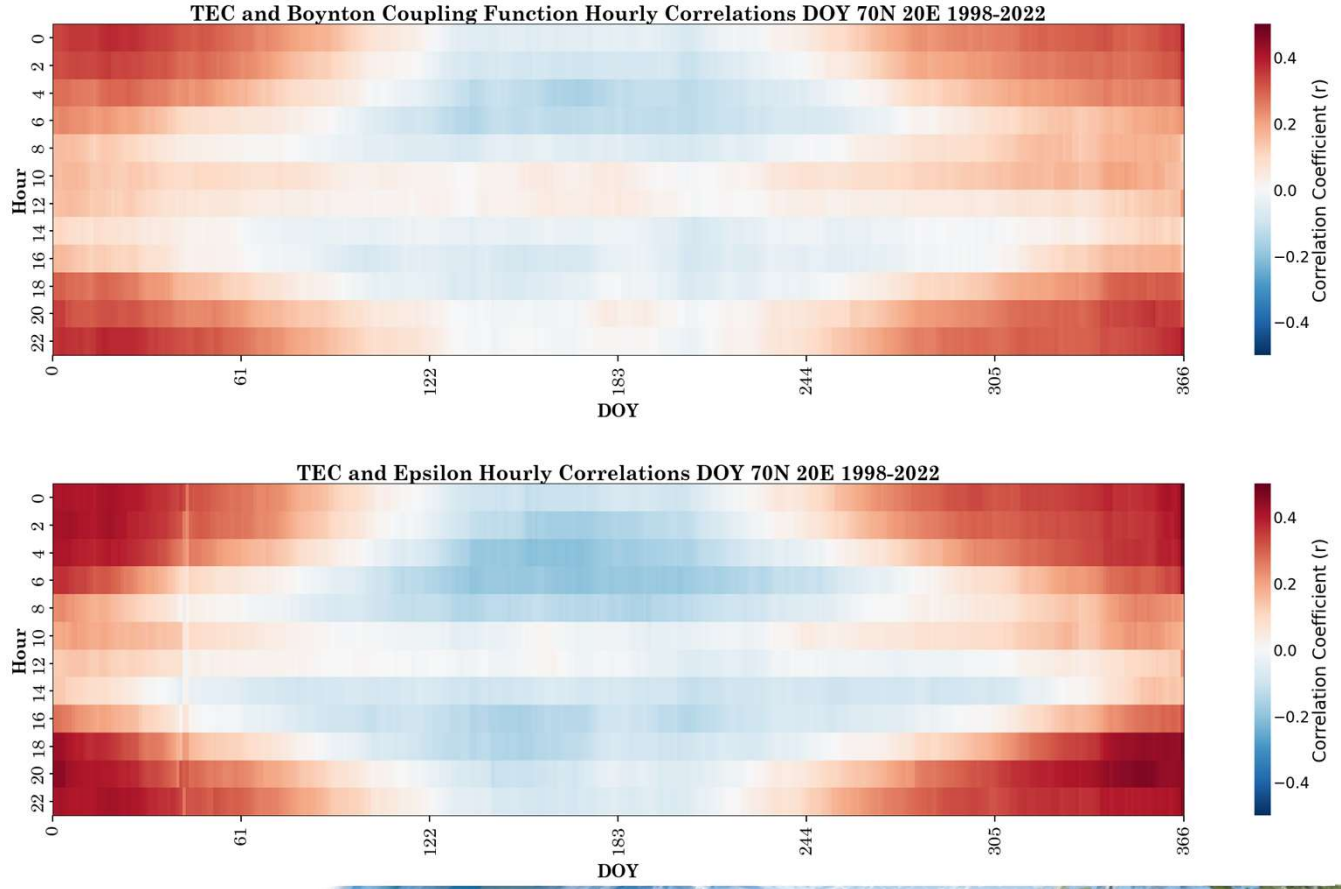

DLR

Temporal Evolution of the TEC and Other Coupling Parameters Correlations

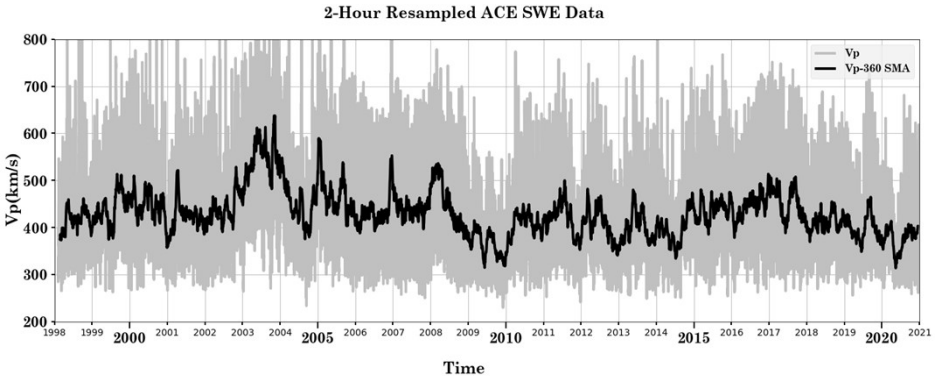


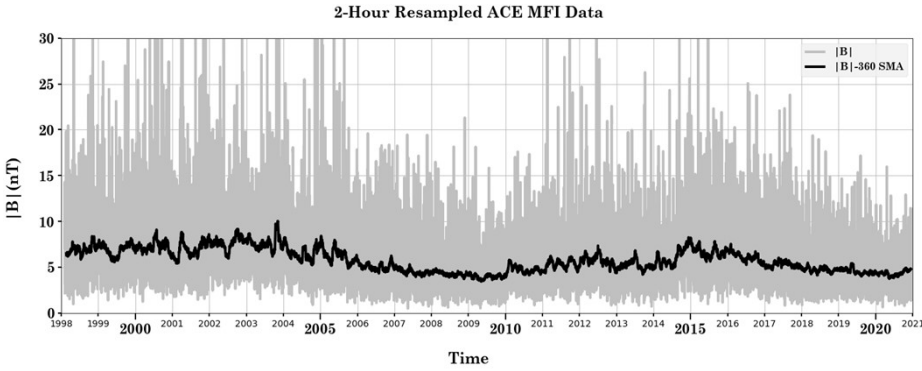


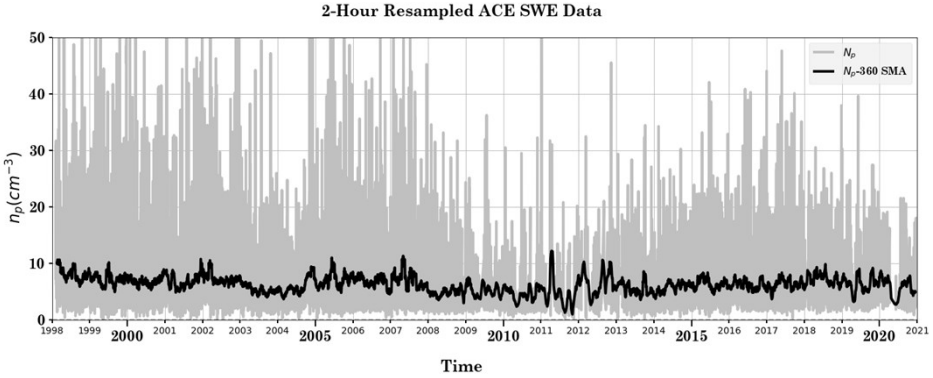
Average Annual Variation of TEC and Other Coupling Parameters Correlations



Solar Wind Parameters







Geomagnetic Activity Parameters