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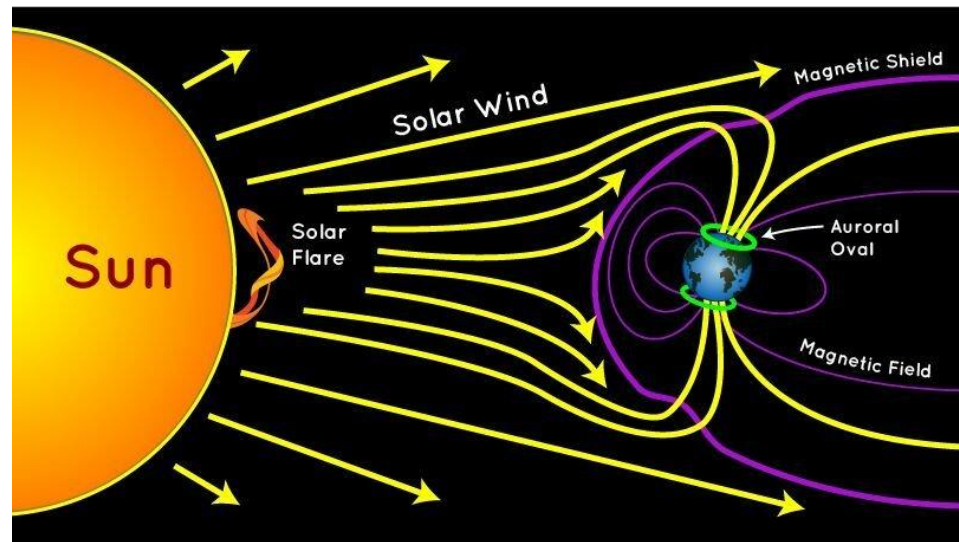
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1

- Introduction, motivation

- Connection between solar activity and free electron content
- This phenomenon can cause problems in communication and navigation fields
- Could the increased activity of the ionosphere be predicted?



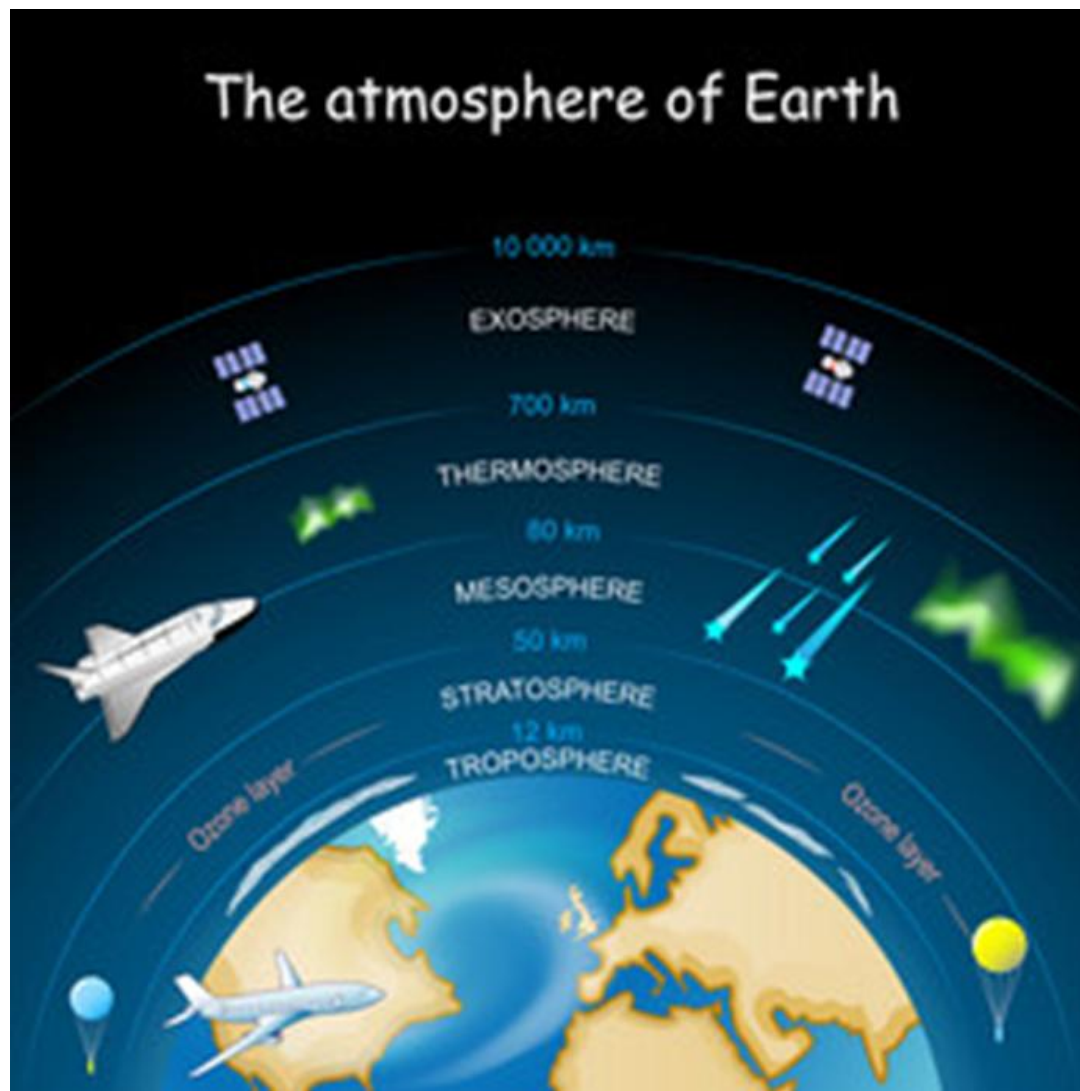
- Theoretical overview

- Structure of the Earth's Atmosphere:

- Troposphere
- Stratosphere
- Mesosphere
- Thermosphere
- Exosphere
- +Ionosphere



Polar mesospheric clouds



2

• Theoretical overview

➤ The colors of Aurora → which atom or molecule is charged in the atmosphere



Oxygen atoms are ionized



Oxygen atoms are ionized above 200 km



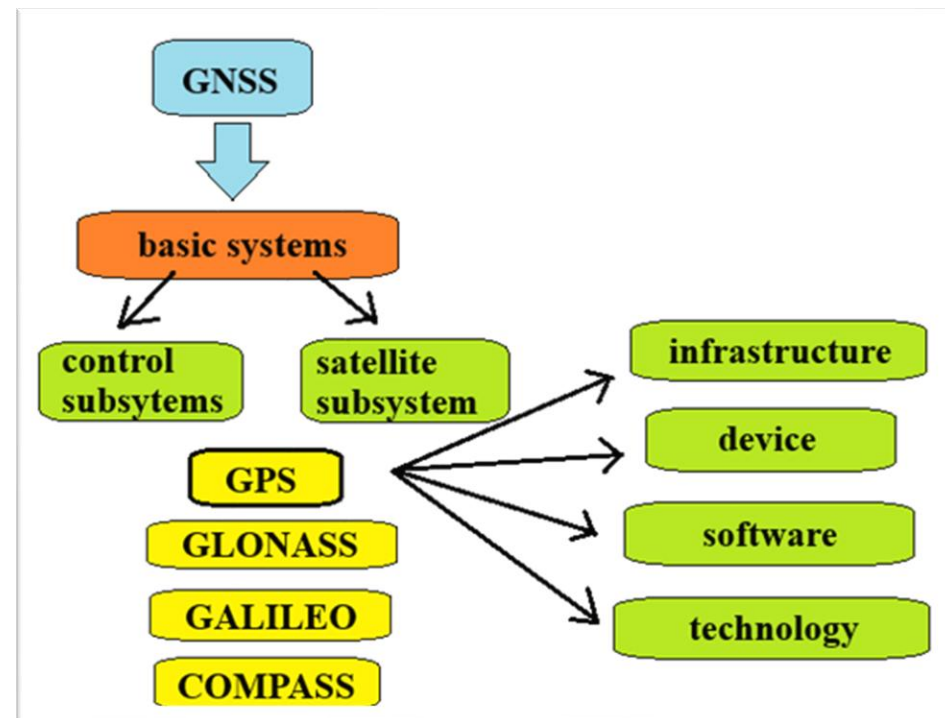
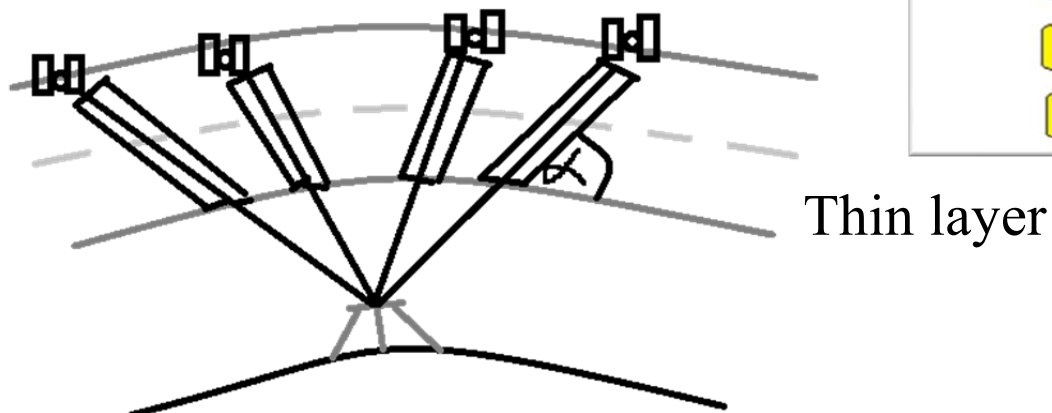
Nitrogen molecules are ionized below 100 km

2

• Theoretical overview

Principles of GNSS positioning

- Consists of 3 segments: satellites, ground stations, and receivers
- 3 main tasks: positioning, navigation, time measurement
- Code and phase measurement



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• Theoretical overview

➤ The GNSS infrastructure is the same as GNSS Augmentation Systems

BUTE
BUTE is BME's
permanent
GNSS station

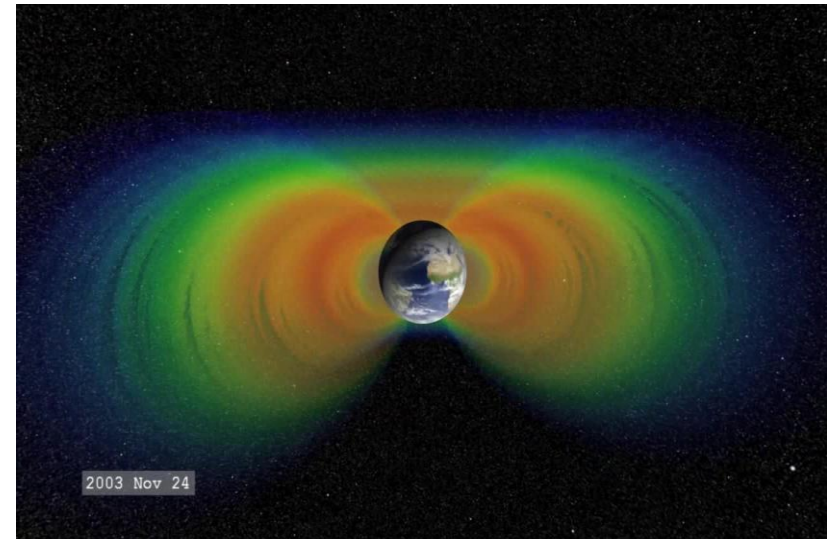
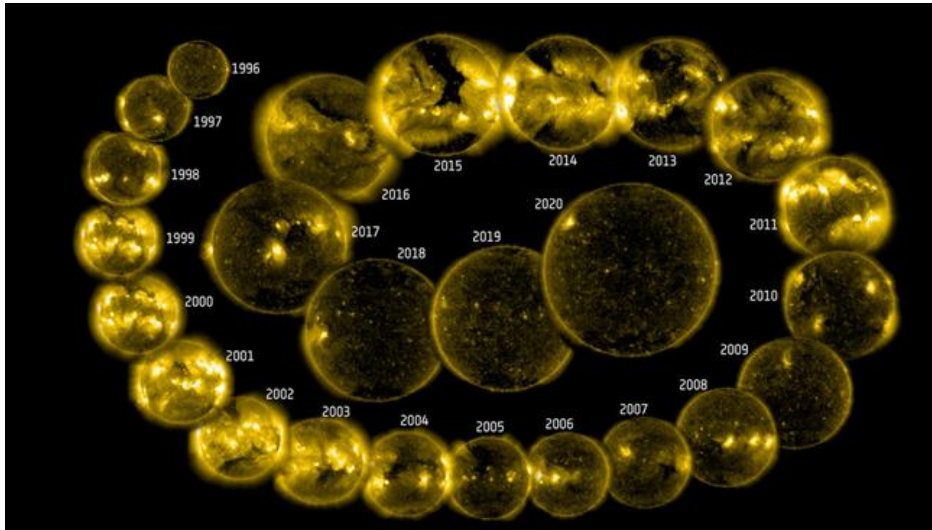


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• Theoretical overview

Solar cycles

- 11-year cycles
- Coronal mass ejection → magnetic field deformation
- Van Allen belts (inner and outer) are radiation belts



• Case study

- Winter: shorter days → activity increases
- NOAA (National Oceanic and Atmospheric Administration) → five-point scale

Prédikálószerék 30. 09. 2025.



Northern lights on 03. 10. 2025.



- Stronger solar activity → Aurora at mid-latitudes

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- 3 • Case study

- 3 • Case study

Background of GNSS measurements processing

- **Goal**: detection of total electron content during Aurora Borealis phenomena
- **Data**: satellite-receiver distances performed with code measurements at BUTE permanent GNSS station on two frequencies

BUTE permanent station



Satellite-receiver distances on RINEX format

```

24 R01 -1 R02 -2 R03 5 R04 6 R05 1 R06 -4 R07 5 R08 6 GLONASS SLOT / FRQ #
R09 -2 R10 -7 R11 0 R12 -1 R13 -2 R14 -7 R15 0 R16 -1 GLONASS SLOT / FRQ #
R17 4 R18 -3 R19 3 R20 2 R21 4 R22 -3 R23 3 R24 2 GLONASS SLOT / FRQ #
C1C -71.940 C1P -71.940 C2C -71.940 C2P -71.940 GLONASS COD/PHS/PTS
18 R1 1929 7 LEAP SECONDS R21
END OF HEADER
> 2023 11 01 00 00 0.0000000 0 46
G05 24886412.545 130779013.75307 -3356.761 47.900 24886410.301
101905724.77107 -2615.658 47.800
G07 26014506.802 136707148.99607 1830.059 42.550 26014505.697
106525046.12906 1426.023 37.100
G10 23499078.687 123488510.02908 3488.905 49.350 23499080.562
96224825.49708 2718.627 49.200 23499078.653 92215458.58908
G15 24390968.573 128175418.81207 2220.149 44.950 24390968.149
99876954.08307 1729.994 45.050
G16 20791227.018 109258647.51108 432.001 50.400
85136600.68307 336.625 47.750

```

3

• Case study

Pre-processing

- The slant total electron content can be calculated using the geometry-free linear combination
- Delay effect caused by the ionosphere

$$I = -\frac{40,3}{f^2} \cdot STEC$$

- Geometry-free linear combination of code measurements performed at two frequencies:

$$GF = R_1 - R_2$$

- Slant electron content:

$$STEC = 10^{-16} \frac{(GF + C \cdot T_{GD}(1 - \gamma))}{\frac{40,3}{f_1^2} - \frac{40,3}{f_2^2}}$$

Differential
Group Delay
(from orbital
data)

$$\gamma = \frac{f_1^2}{f_2^2}$$

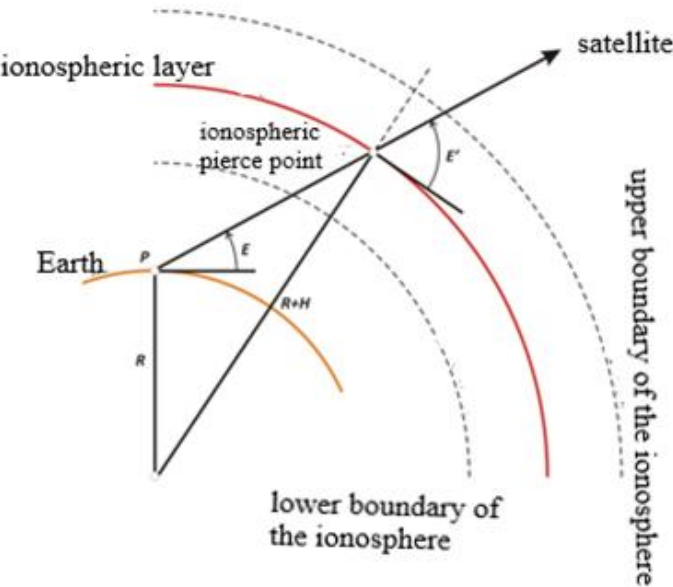
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• Case study

Calculation of vertical electron contents and their variance

- The slant electron content (in the direction of the satellite) depends on the elevation angle of the satellites (this can be calculated based on orbital data and station coordinates)

Task: Calculate the Total Vertical Electron Content (TVEEC) for every satellite!



E' can be calculated using the law of sines:

$$\frac{R + H}{\sin(90 + E)} = \frac{R}{\sin(90 - E')}$$

Rearranged:

$$\frac{R + H}{\cos E} = \frac{R}{\cos E'}$$

Solved for E' :

$$E' = \arccos \left(\frac{R}{R + H} \cos E \right)$$

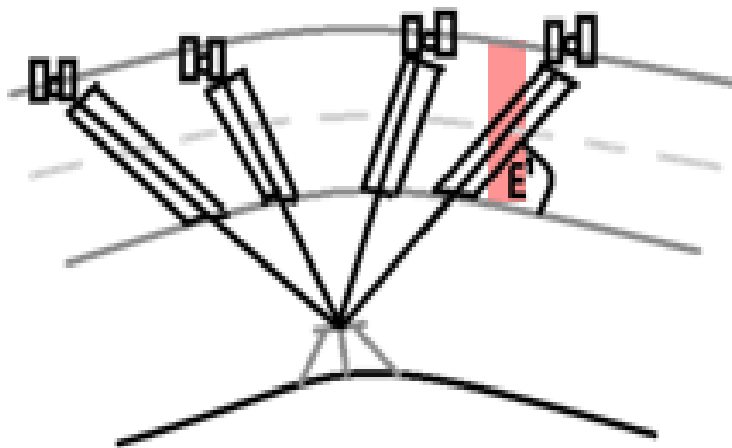
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• Case study

Calculation of vertical electron contents and their variance - 2

➤ The vertical electron content can be easily calculated from the value in the direction of the satellite as follows:

$VTEC = STEC \cdot \sin E'$



Date	Satellite	Elevation Angle		GF (R2-R1)	STEC	TVEC
2023. 11. 1. 0:00:00	10	24,051		1,875	13,55052	6,783345
2023. 11. 1. 0:00:00	18	66,999		-0,817000002	7,698176	7,150569
2023. 11. 1. 0:00:00	23	48,578		-0,474999998	10,95389	8,531691
2023. 11. 1. 0:00:00	26	57,320		1,811000001	4,343636	3,731493
2023. 11. 1. 0:00:00	27	37,307		0,412	1,342806	0,882024
2023. 11. 1. 0:00:00	29	20,457		-0,193999998	16,2082	7,447158
2023. 11. 1. 0:00:30	10	24,278		1,710000001	11,97978	6,02878
2023. 11. 1. 0:00:30	15	10,106		-0,48	15,20511	5,461229
2023. 11. 1. 0:00:30	18	66,767		-0,848000001	7,403068	6,865986
2023. 11. 1. 0:00:30	23	48,775		-0,566	10,08761	7,876734
2023. 11. 1. 0:00:30	26	57,137		1,805	4,286519	3,675879
2023. 11. 1. 0:00:30	27	37,515		0,224	1,342806	0,882024

3

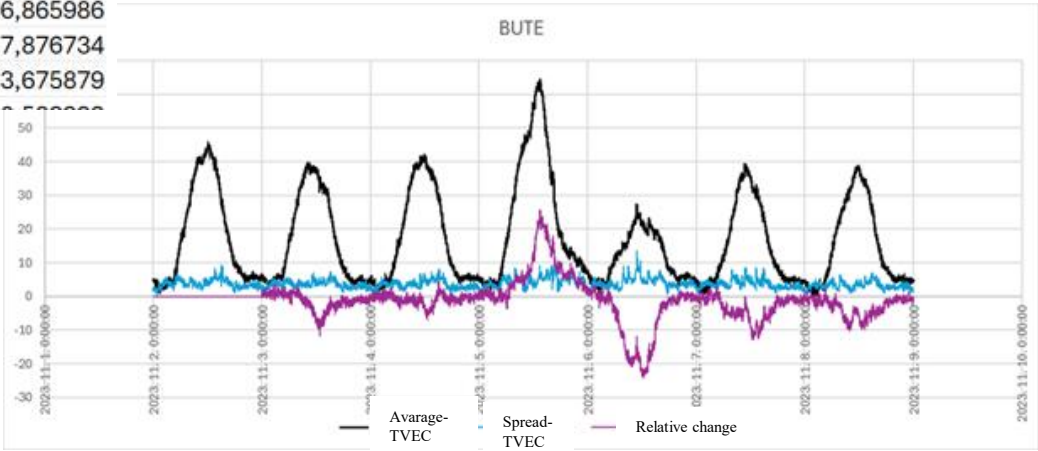
• Case study

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Calculation of
avarage and
standard
deviation,
visualization of
results



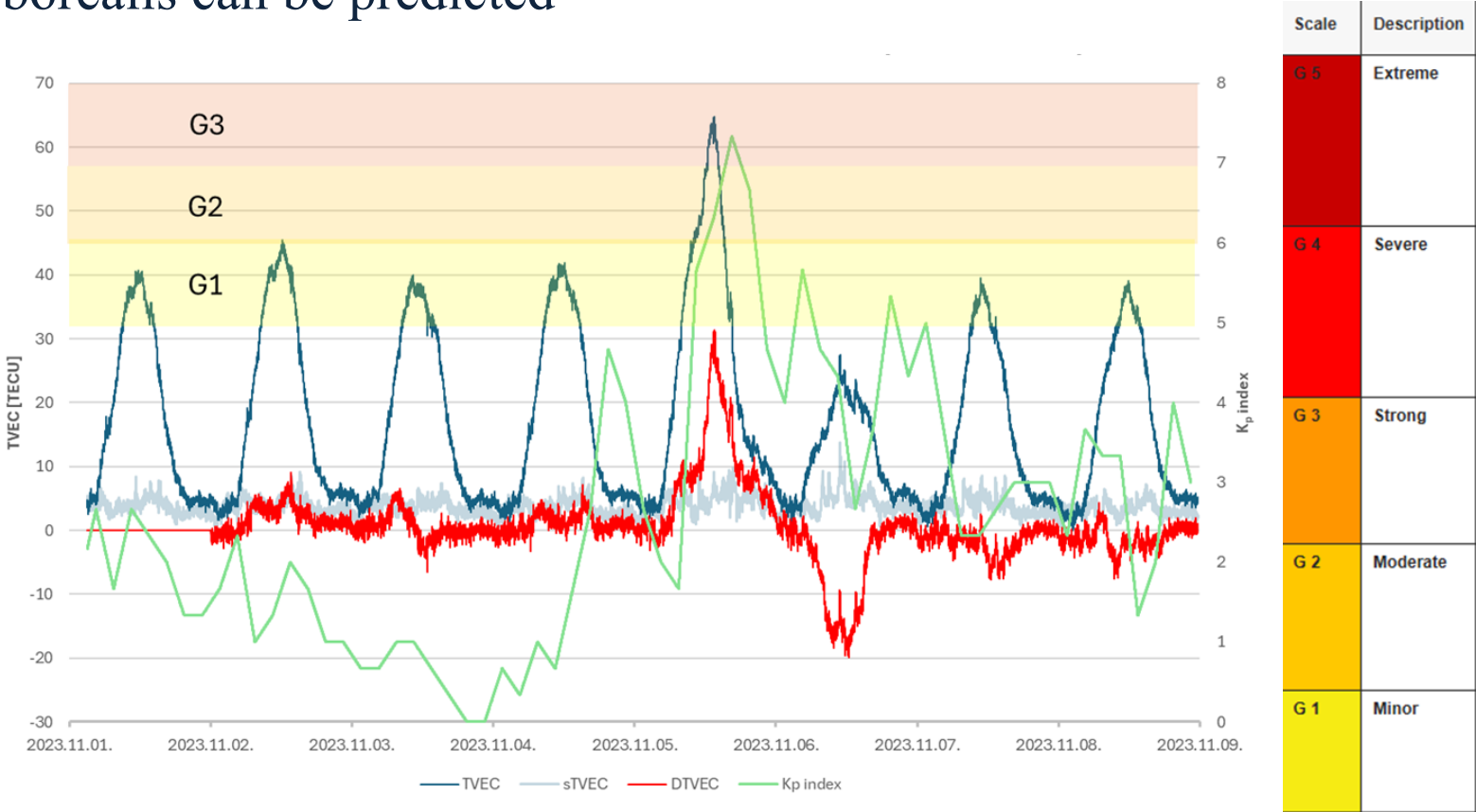
Date	Spread - TVEC
2023.11.02	1,584680069
2023.11.02 0:00	1,473667033
2023.11.02 0:01	1,764601807
2023.11.02 0:01	2,046220713
2023.11.02 0:02	2,202319526
2023.11.02 0:02	2,46808889
2023.11.02 0:03	2,201234647
2023.11.02 0:03	2,046856588
2023.11.02 0:04	1,855622938
2023.11.02 0:04	1,845090253



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• Results

➤ By observing changes in the number of free electrons, the aurora borealis can be predicted



• Conclusion



Thank you for your attention!



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