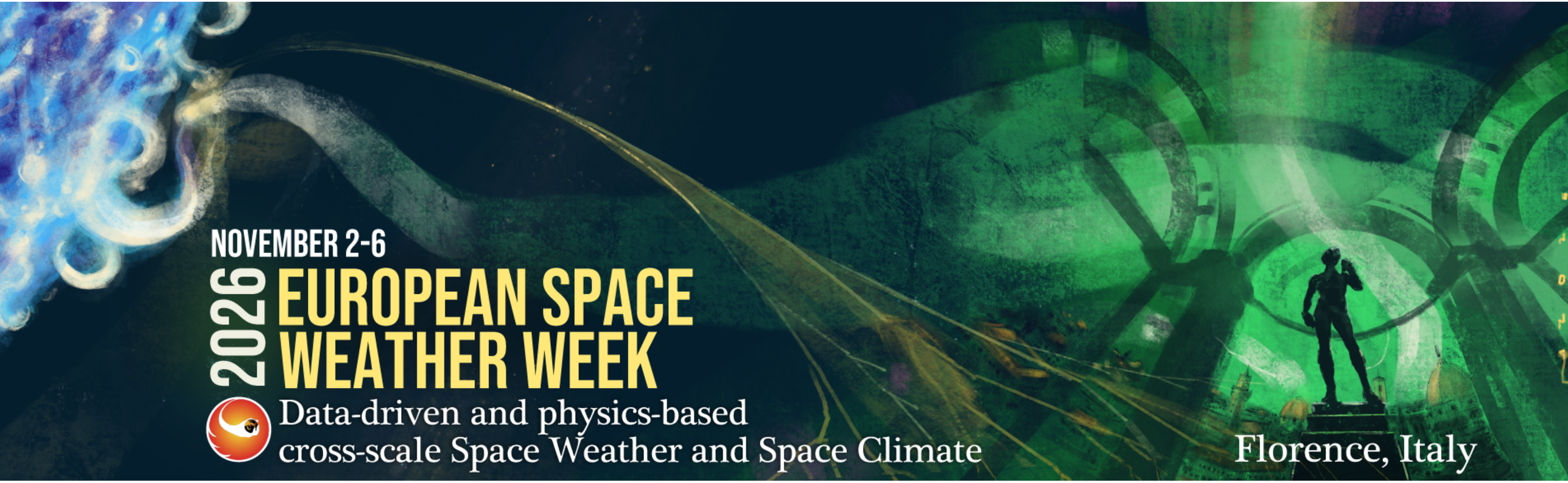
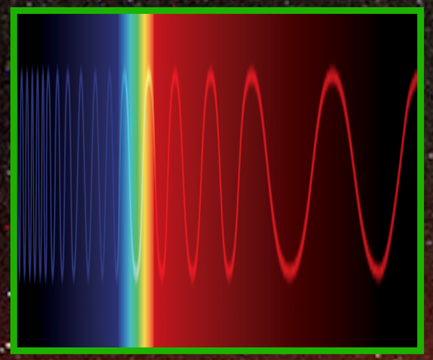
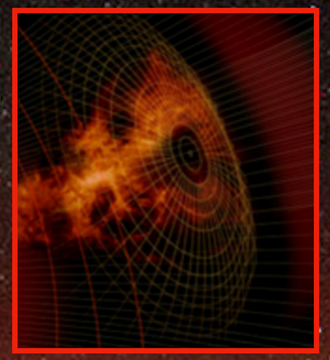
Space Weather Training Course



e-swan

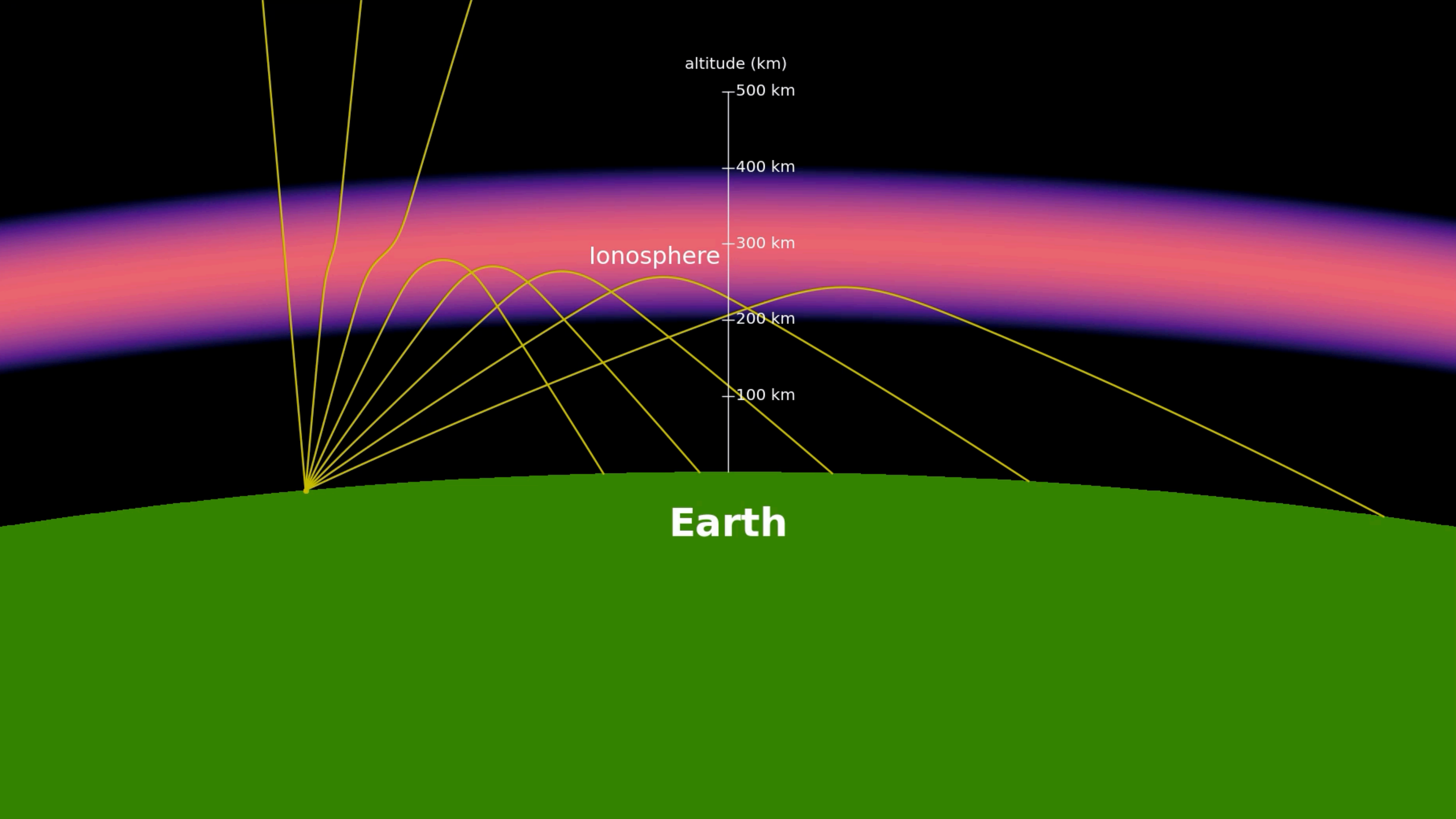
SWEC
Space Weather Education Centre

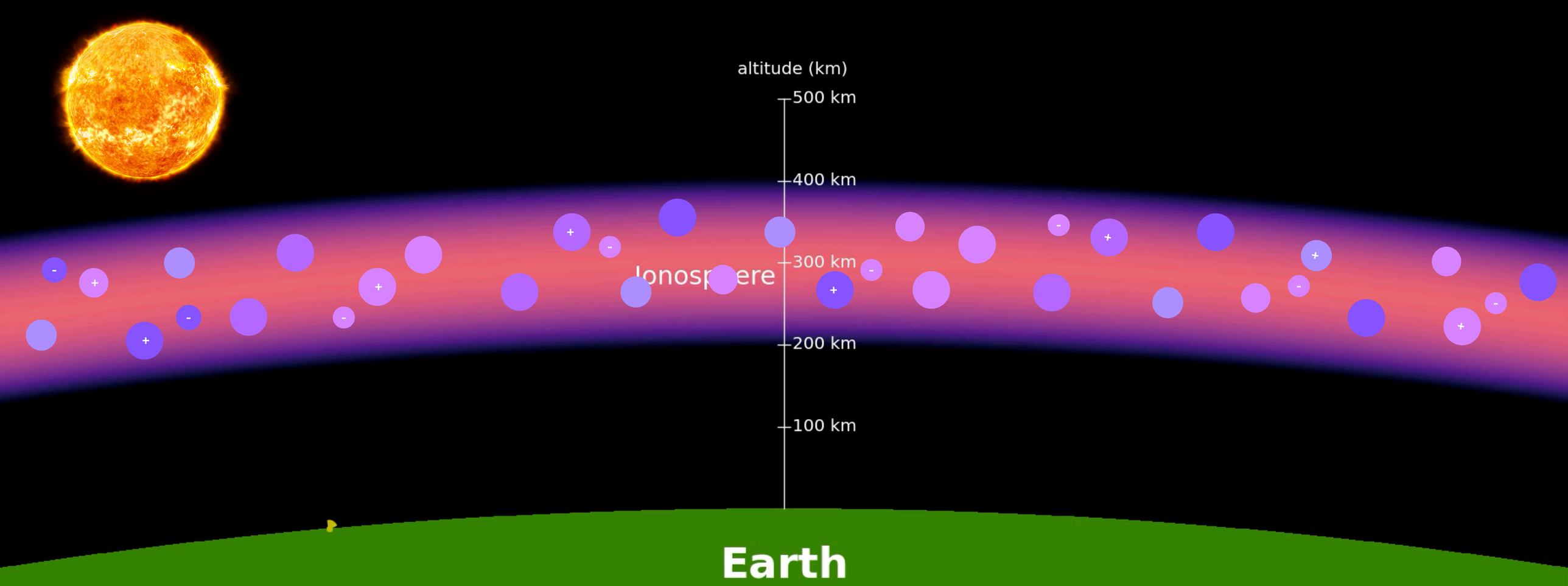
COMMUNITY COORDINATED MODELING CENTER


IONOSPHERE

Petra Vanlommel, Tobias Verhulst, Ben Witvliet

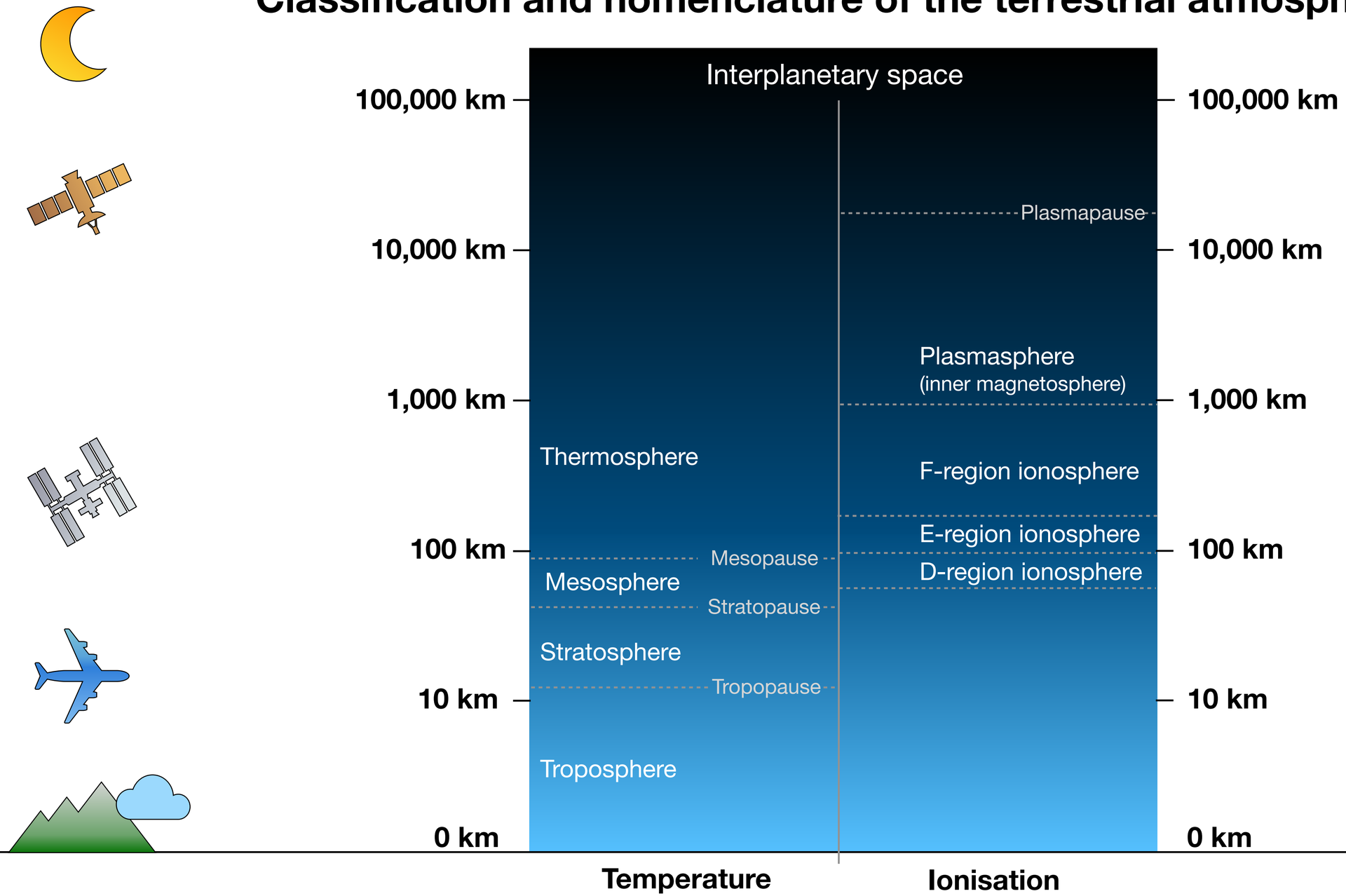

altitude (km)
500 km
400 km
300 km
200 km
100 km
Ionosphere
Earth



How is the ionosphere built?

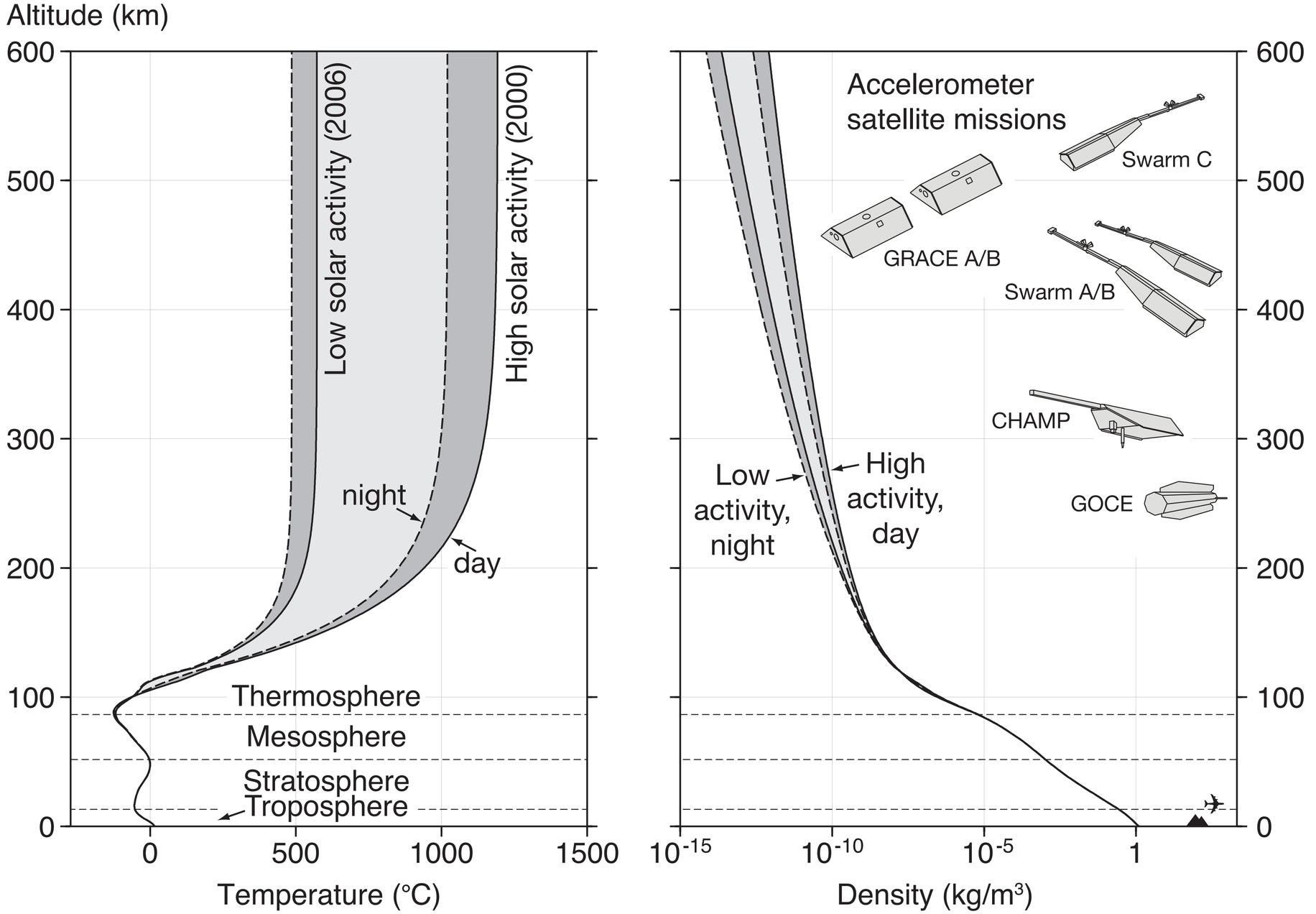
What can change it?

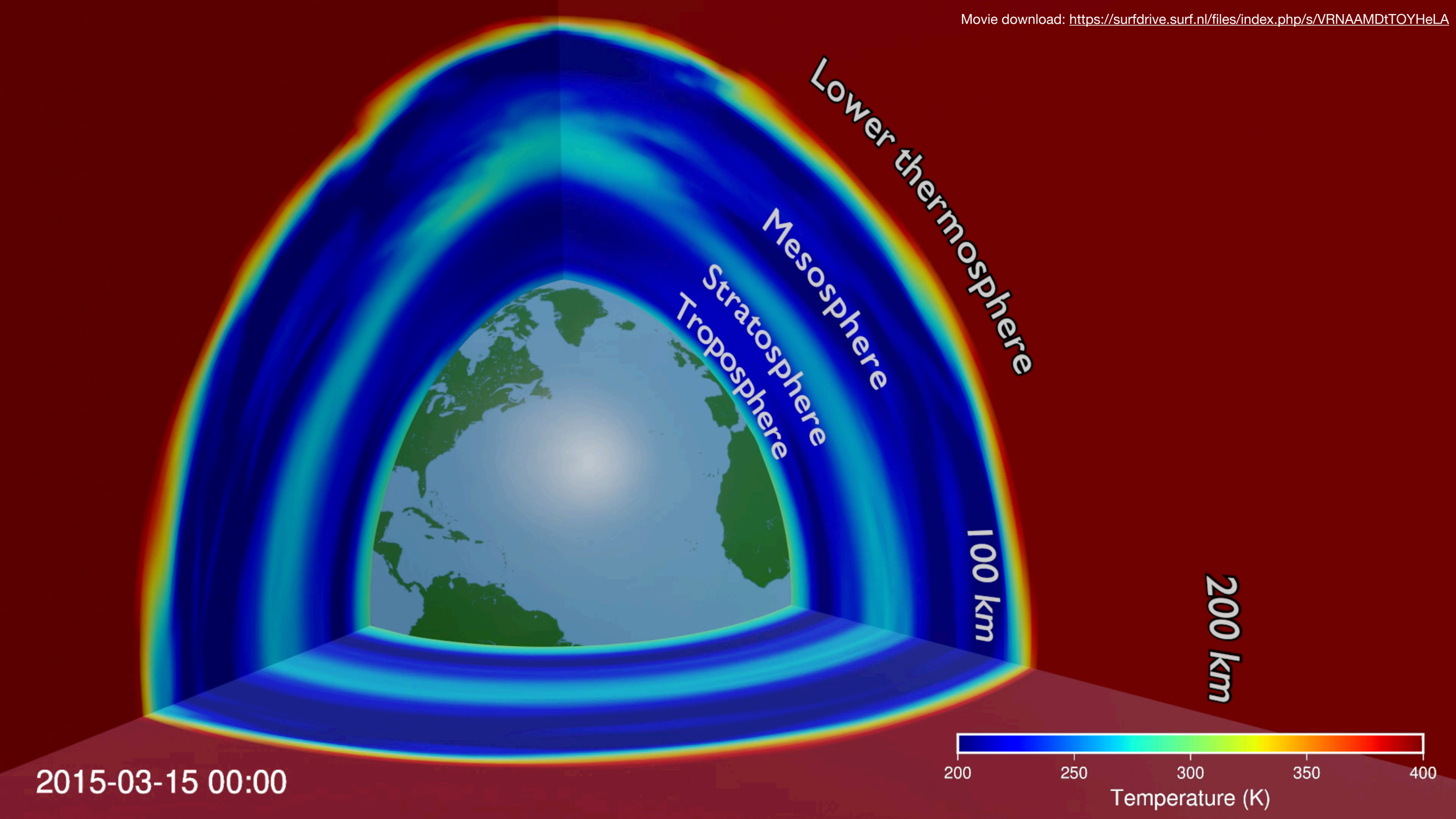
Classification and nomenclature of the terrestrial atmosphere

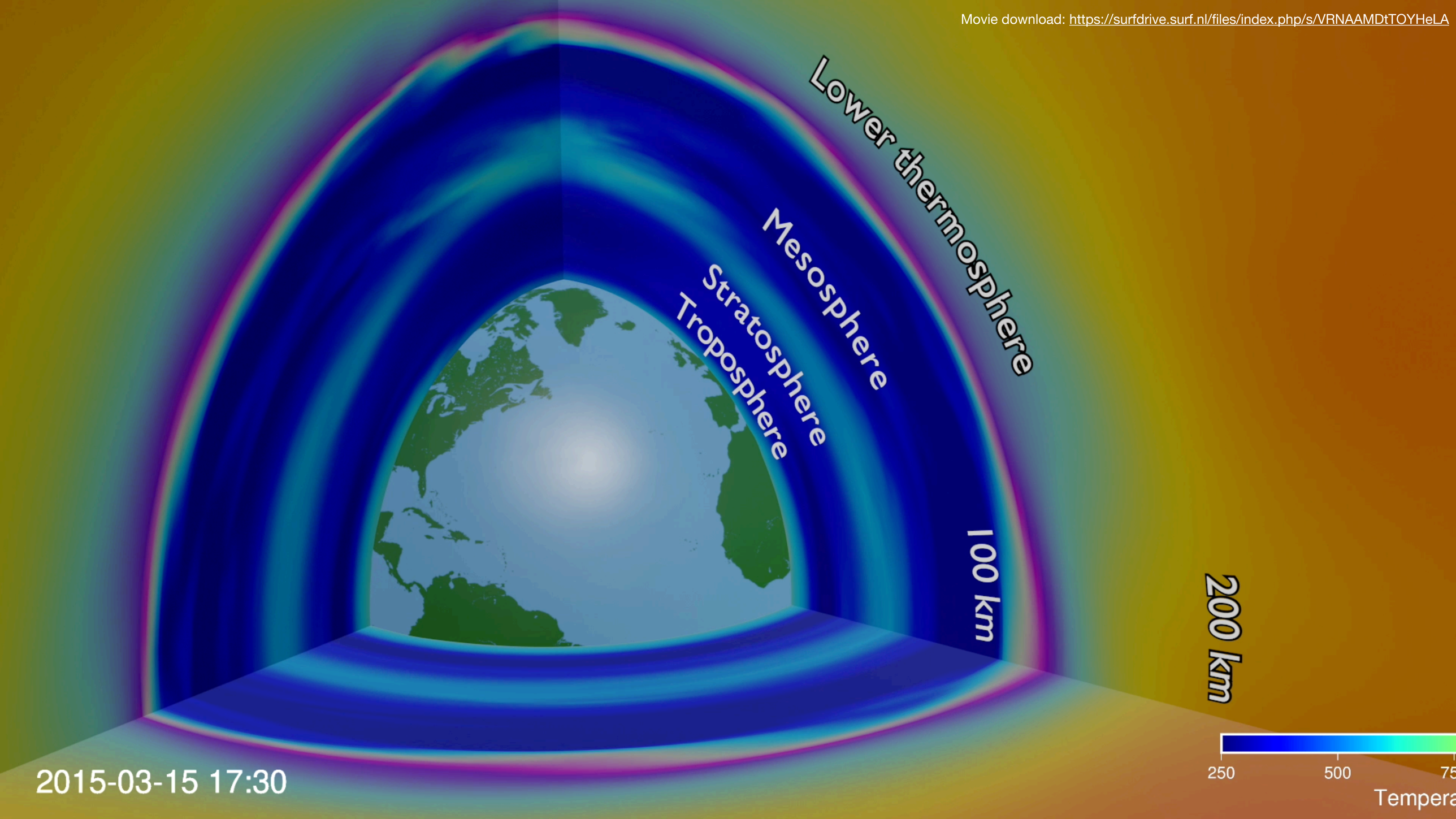


Based on G.W. Prölss, Physics of the Earth's Space Environment, Figure 2.13

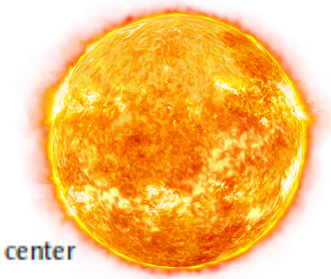
THERMOSPHERE IS THE ATMOSPHERE ABOVE 90 KM



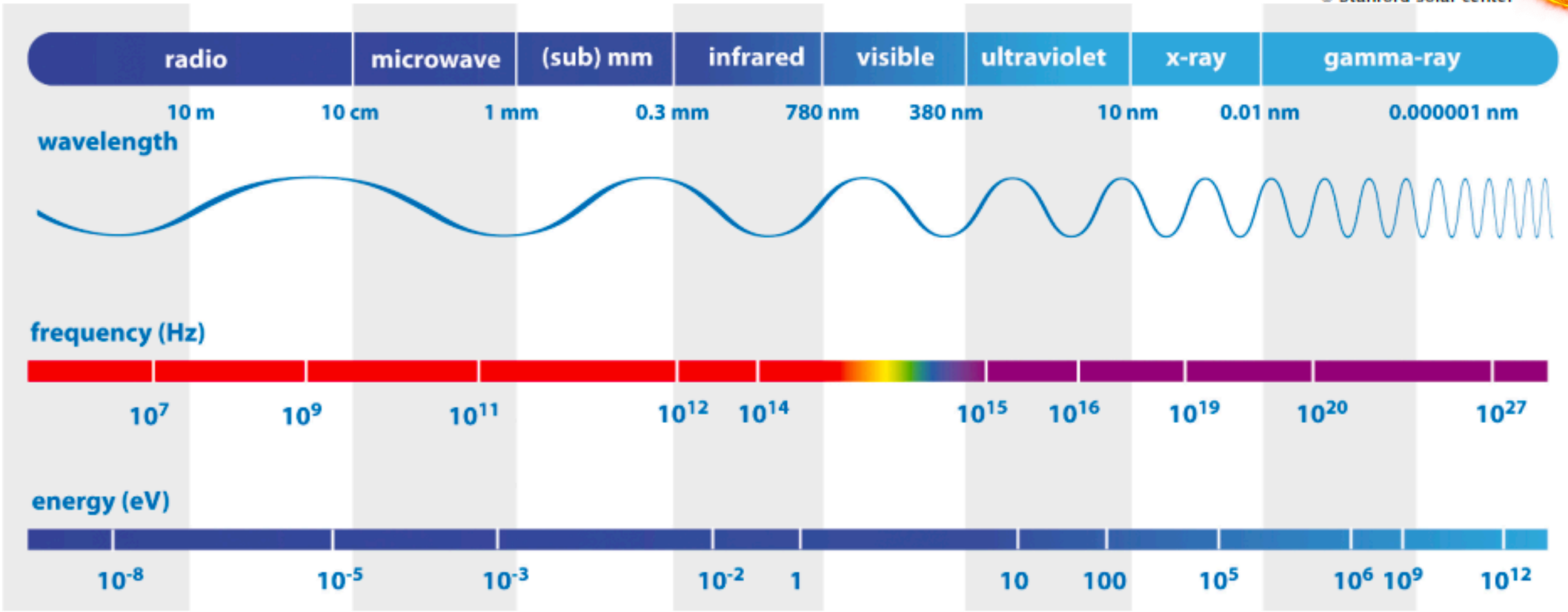

Movie download: https://surfdrive.surf.nl/files/index.php/s/VRNAAMDtTOYHeLA
Lower thermosphere
Mesosphere
Stratosphere
Troposphere
100 km
200 km
2015-03-15 00:00
200
250
300
350
400
Temperature (K)


Movie download: https://surfdrive.surf.nl/files/index.php/s/VRNAAMDtTOYHeLA
Lower thermosphere
Mesosphere
Stratosphere
Troposphere
100 km
200 km
2015-03-15 17:30
250
500
Tempera

THE SOLAR ELECTROMAGNETIC SPECTRUM



© Stanford solar center



does not affect the thermosphere (much), but affected by the ionosphere

causes heating of the thermosphere

photo-dissociating radiation

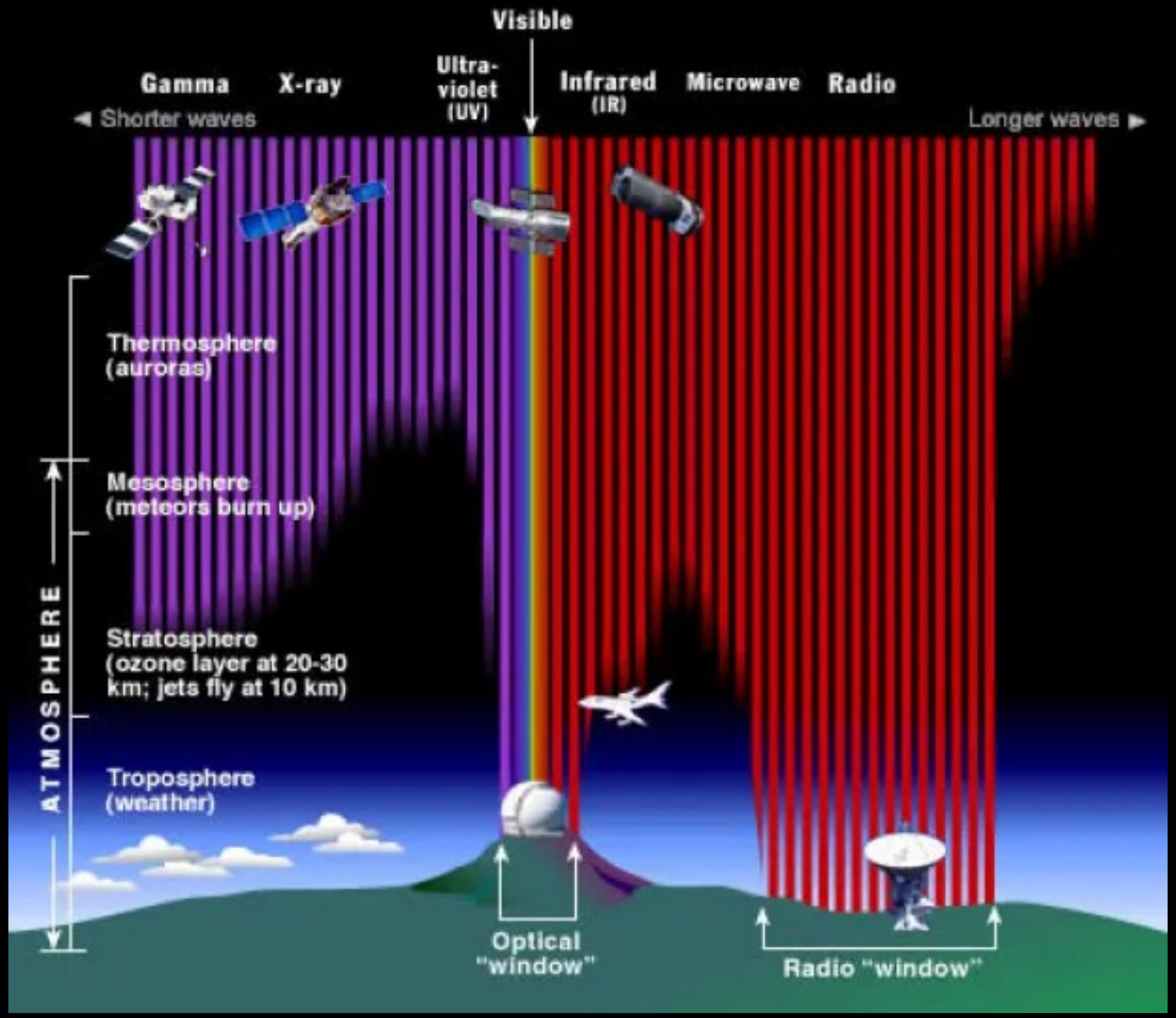
ionising radiation

ionising radiation (lower altitude)

also ionising radiation, but low flux

SWEC
Space Weather Education Center

Electromagnetic radiation penetration depth



Ionisation and recombination in the thermosphere

Very fast

$$O + \hbar\nu \longrightarrow O^+ + e^-$$

$$O + \hbar\nu \longleftarrow O^+ + e^-$$

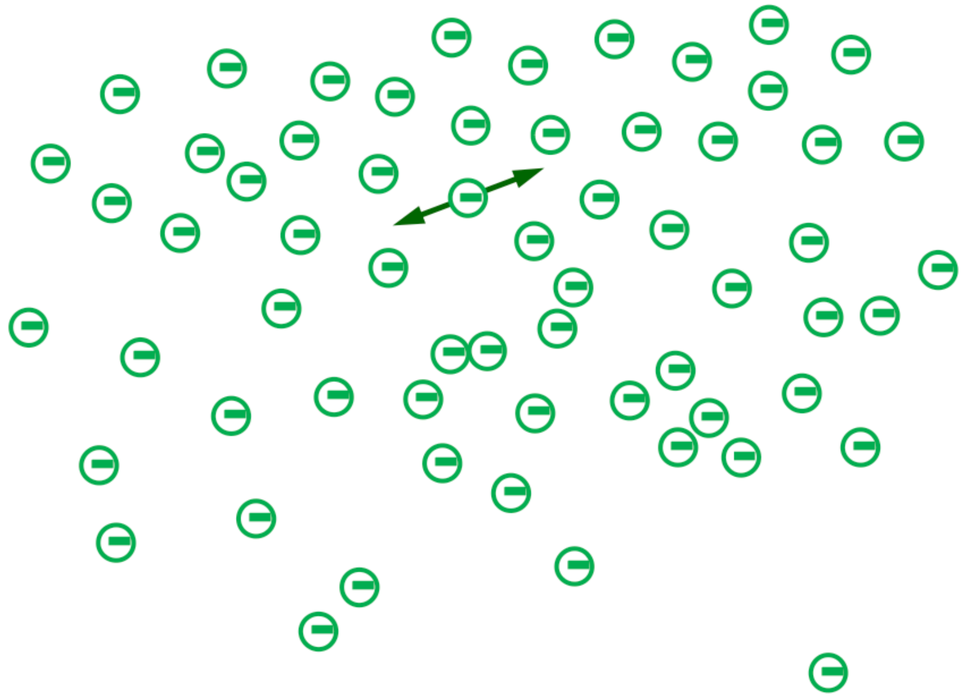
Very slow

Instead, recombination goes like this (for example)

$$O^+ + N_2 + e^- \longrightarrow NO^+ + N + e^- \longrightarrow NO + N + \text{dissipated energy}$$

Regions in the mid-latitude ionosphere

The electron density and the plasma frequency are related



Oscillation of free electrons in the plasma depends on the electron density

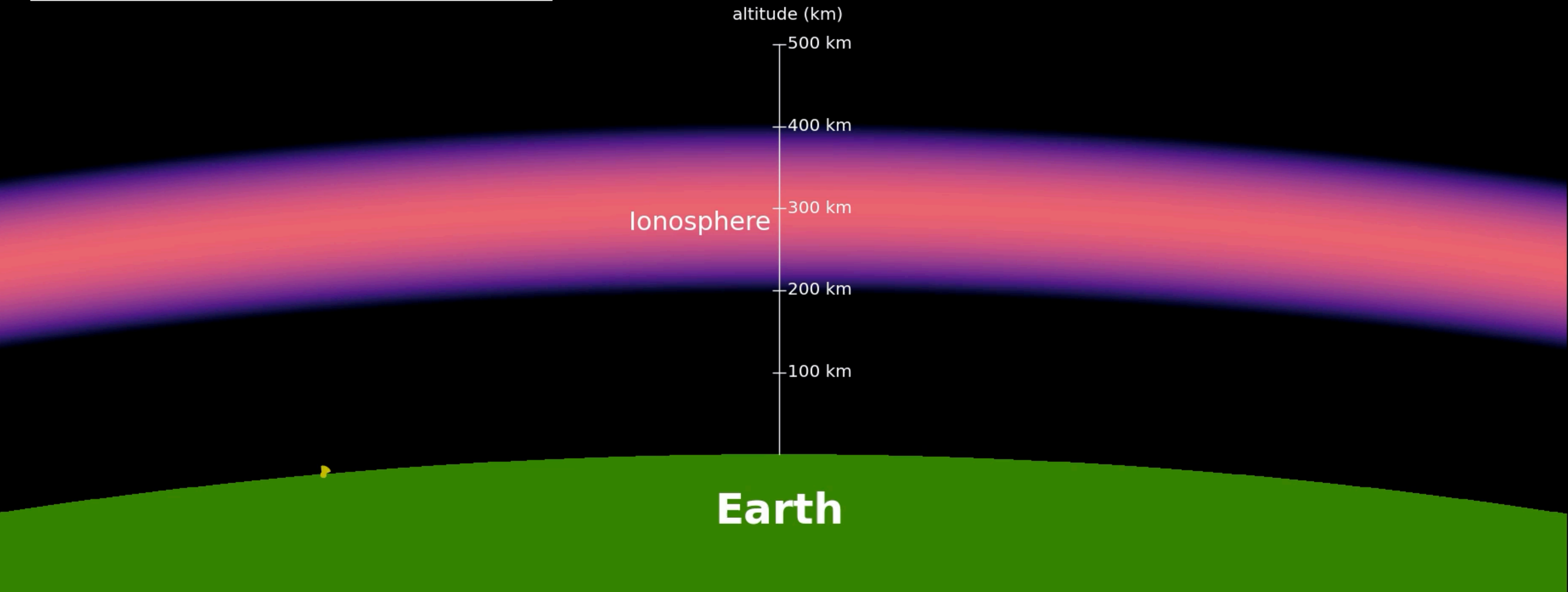
Plasma frequency

$$f_p \propto \sqrt{n_o}$$

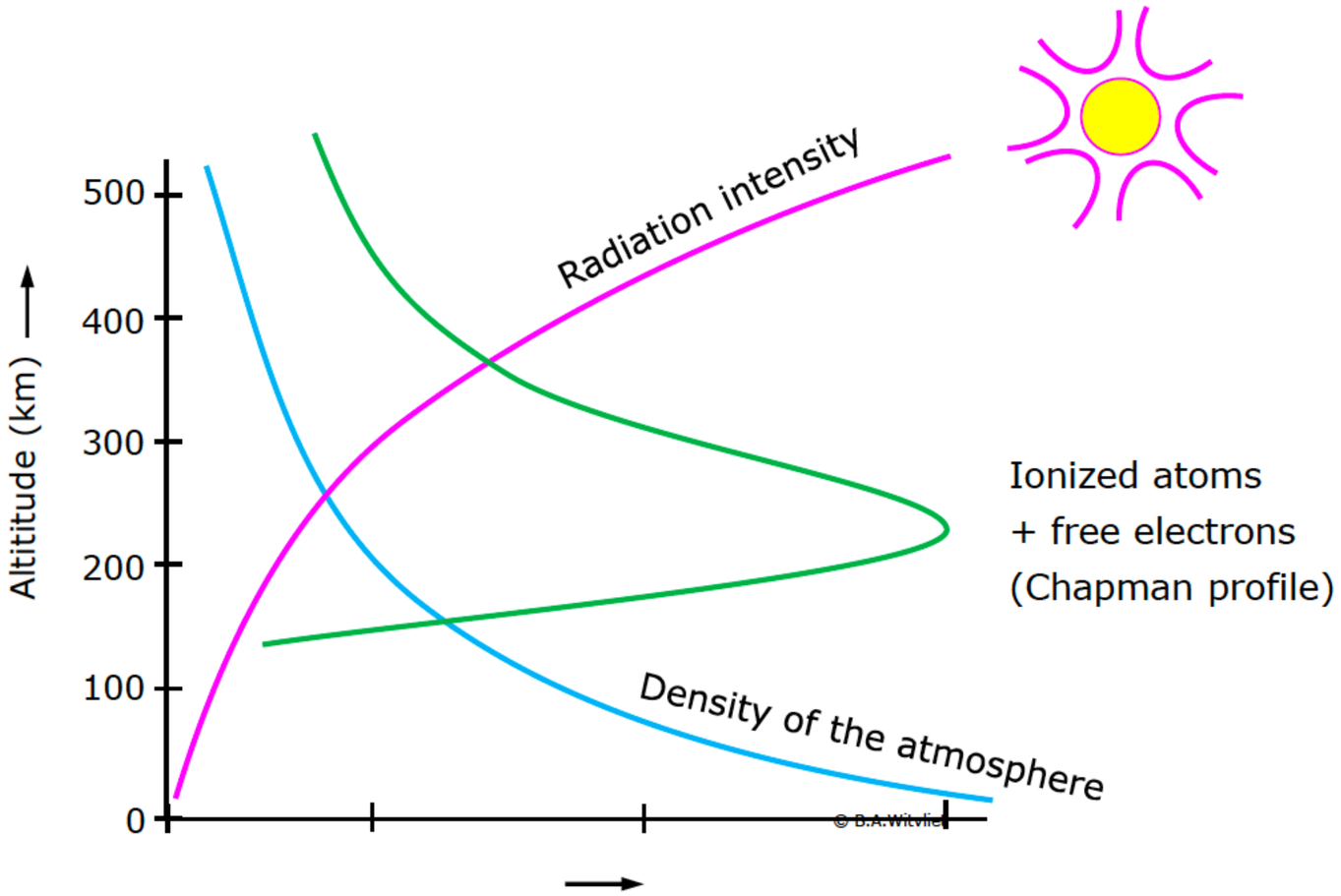
The plasma frequency affects the refractive index of the medium

$$f_p \propto \sqrt{n_o} \qquad n = \sqrt{1 - \frac{f_p^2}{f^2}}$$

Each layer will reflect or absorb or let pass radio waves depending on their frequencies and on the characteristic frequency.

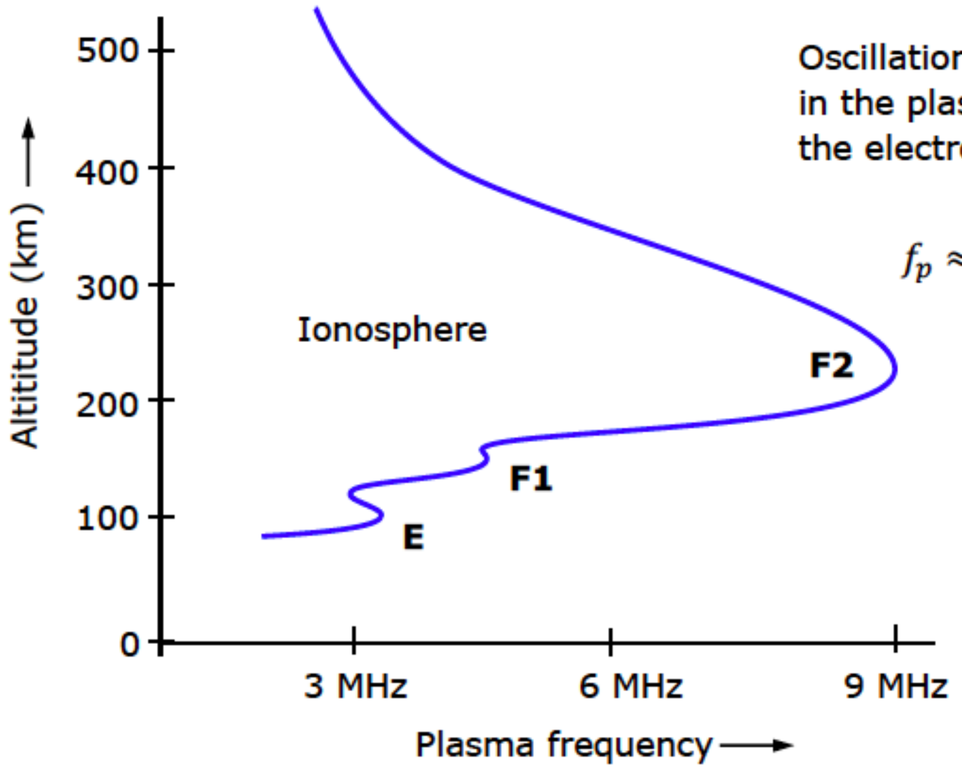


Balance between ionisation and recombination



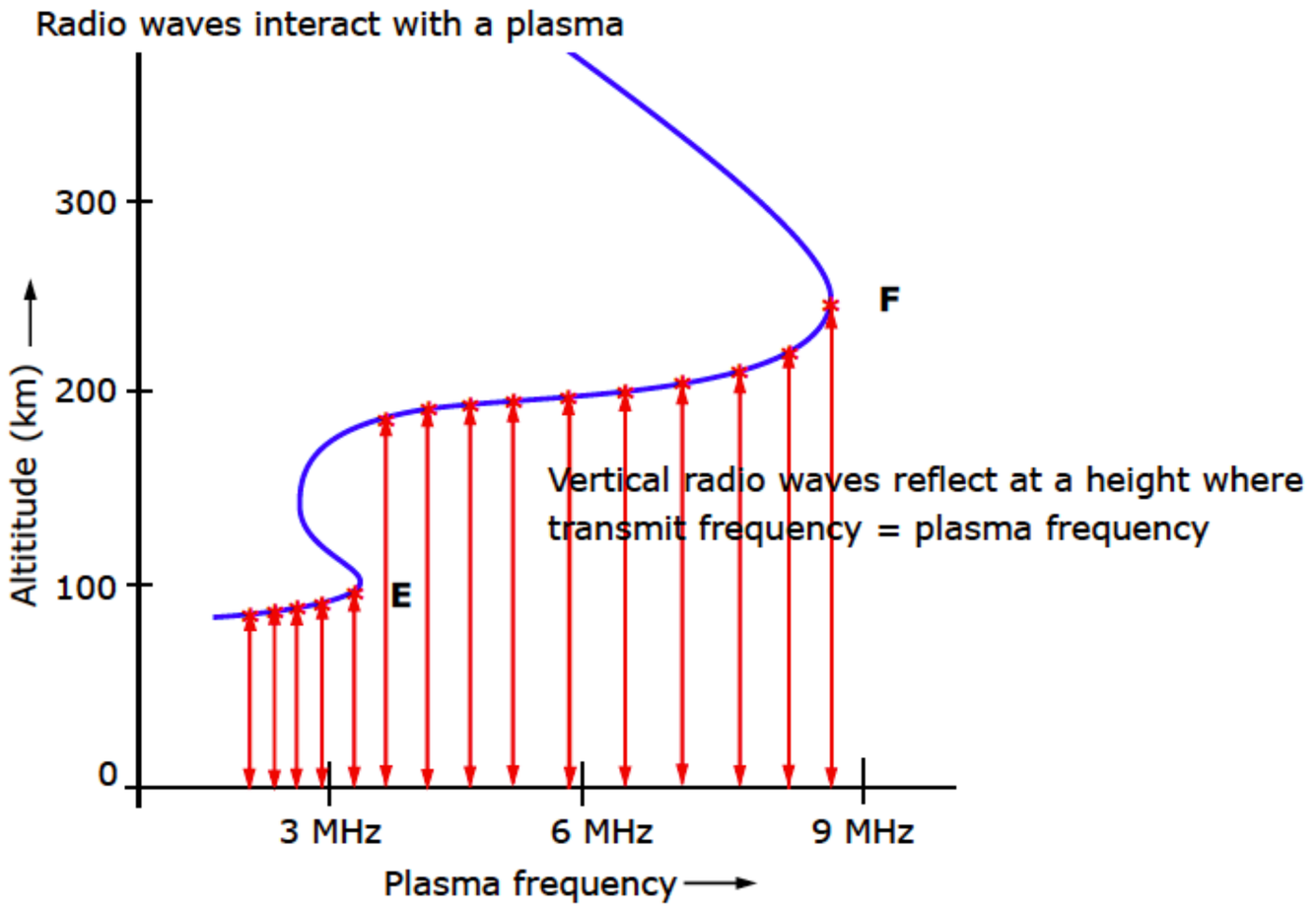
Distribution of free electrons

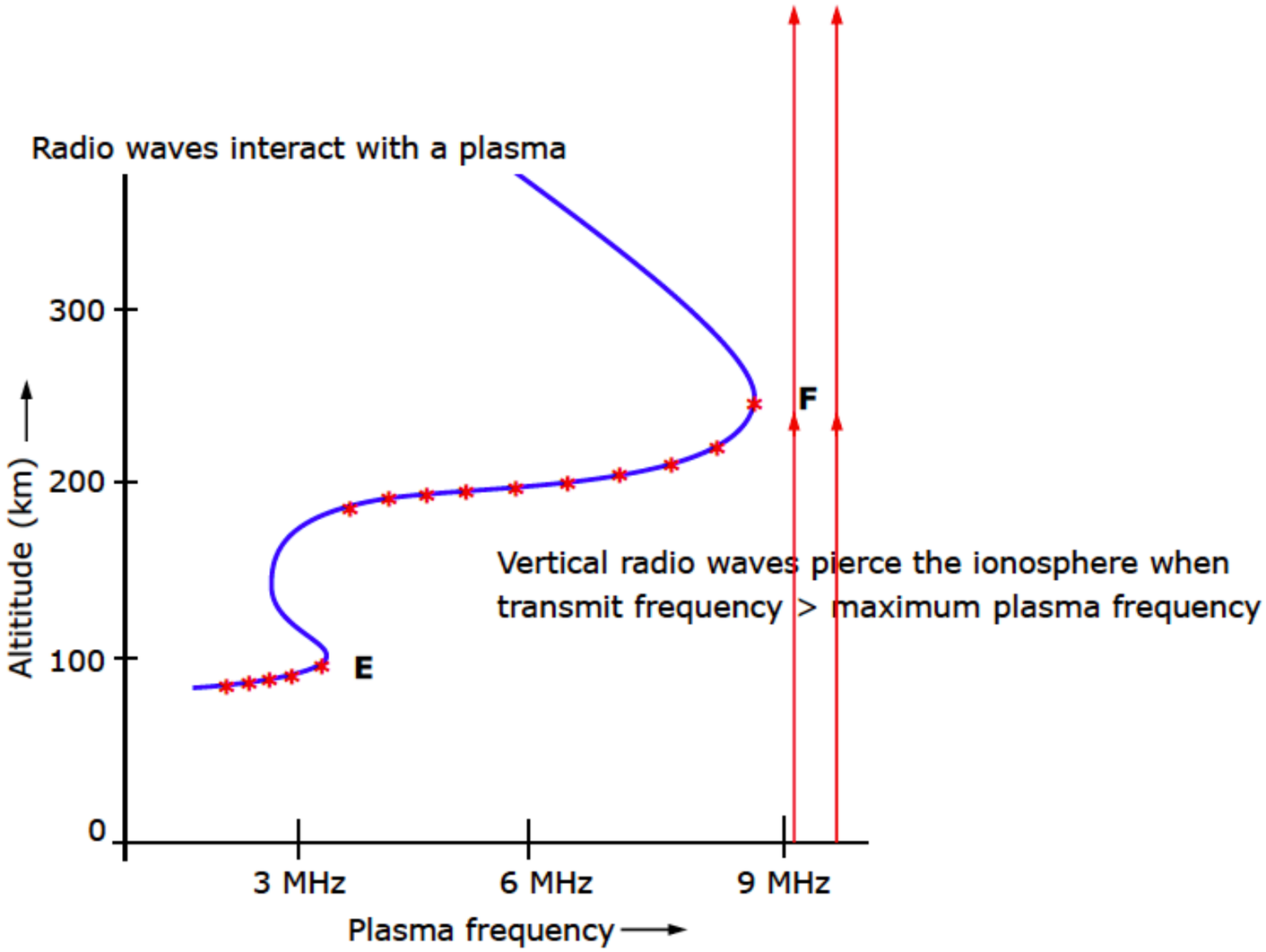
We can calculate the plasma frequency if we know the electron density

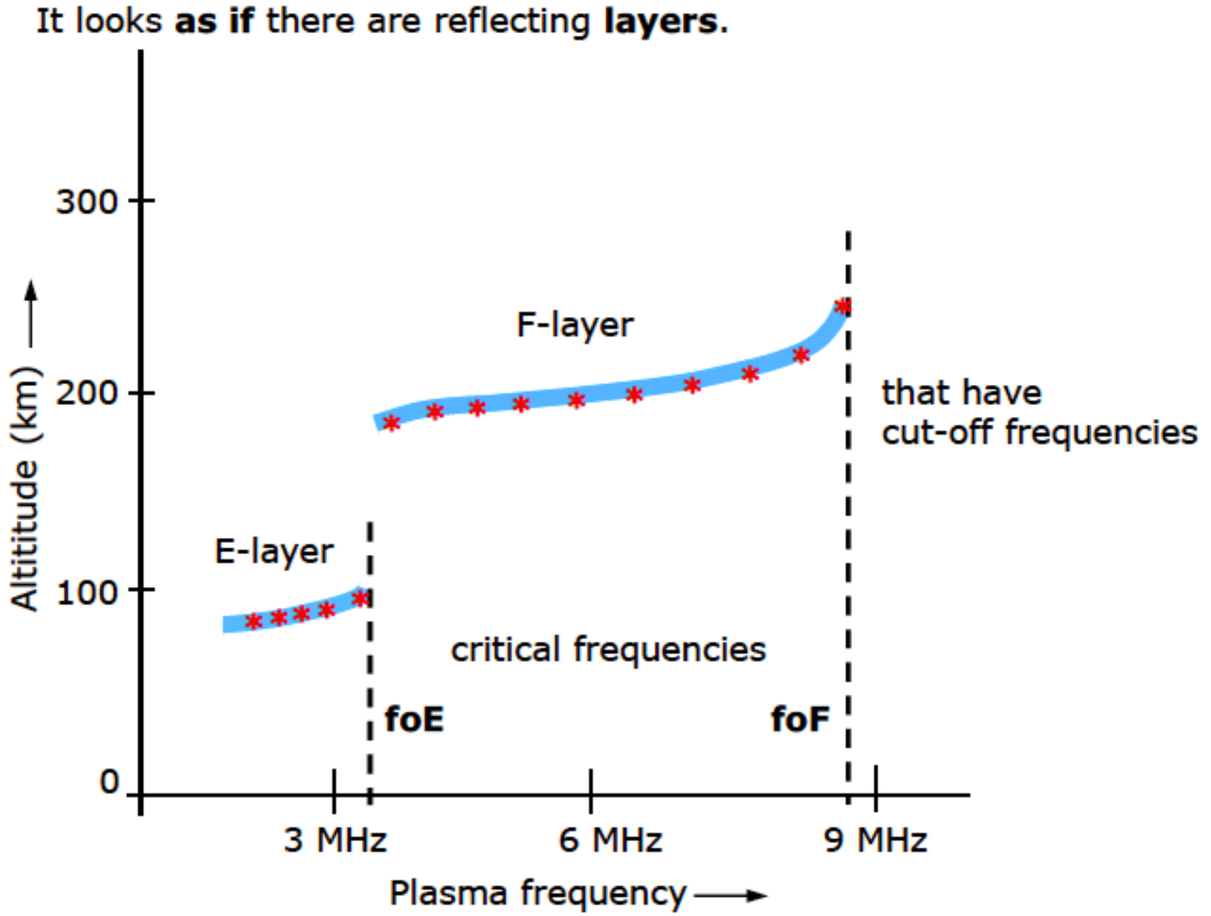


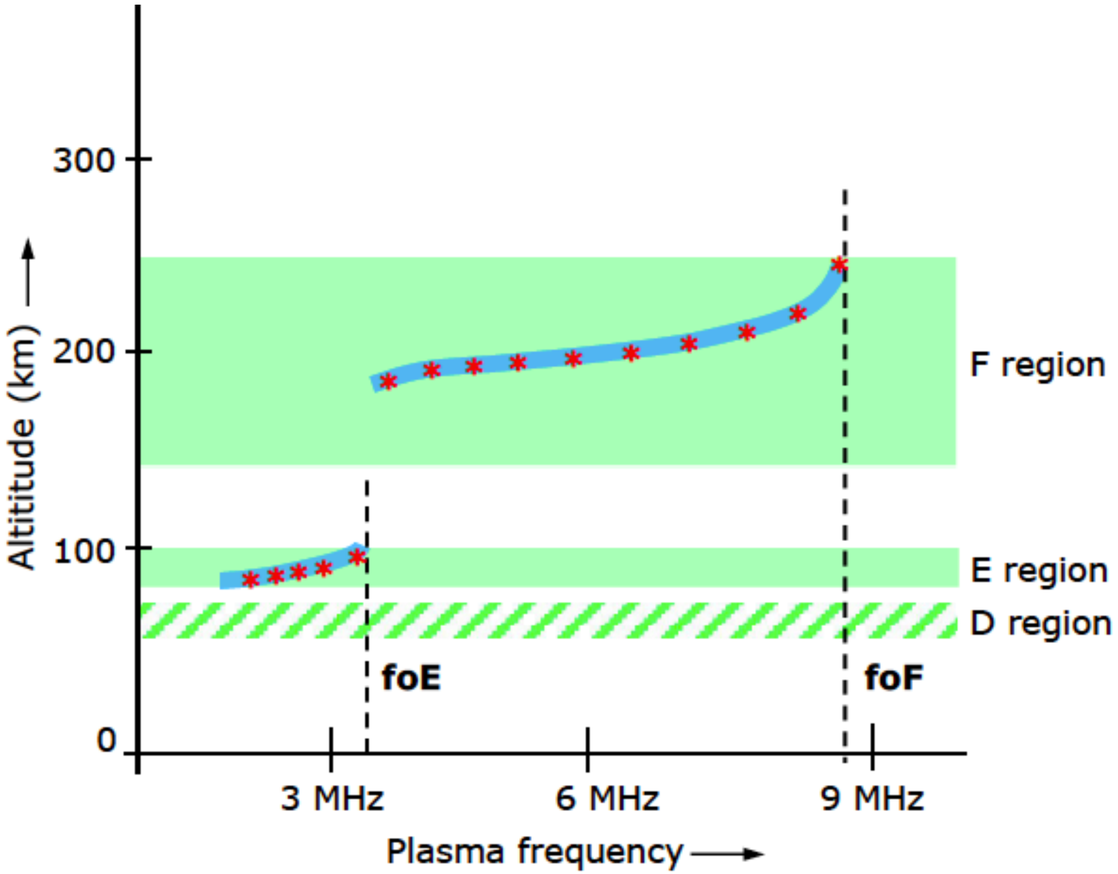
Oscillation of free electrons in the plasma depends on the electron density

$$f_p \approx 8.9\sqrt{N_e}$$


Radio waves interact with a plasma
300
200
100
0
Altitude (km)
F
E
Vertical radio waves reflect at a height where
transmit frequency = plasma frequency
3 MHz
6 MHz
9 MHz
Plasma frequency

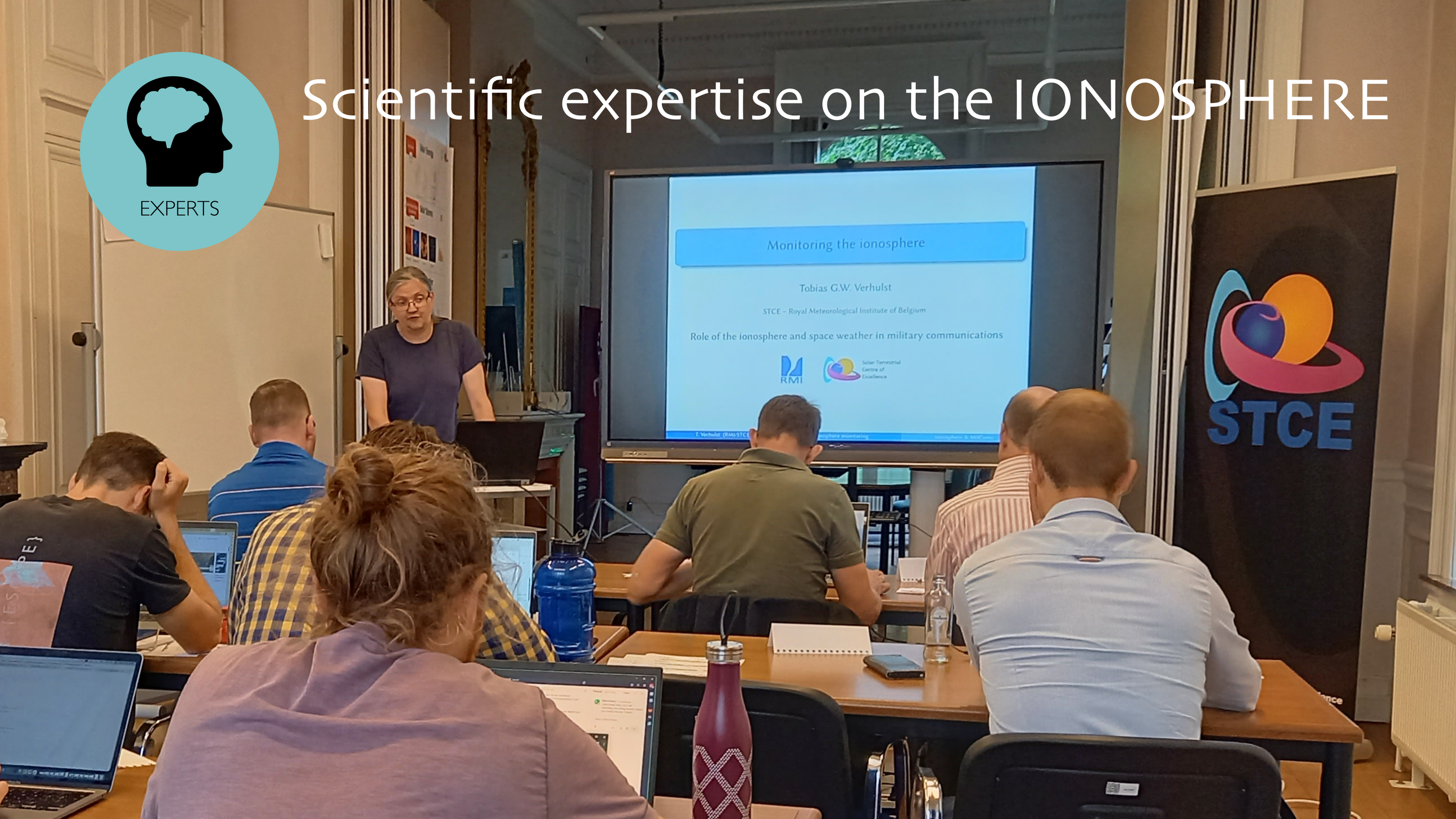

Radio waves interact with a plasma
300
200
100
0
Altitude (km)
F
E
Vertical radio waves pierce the ionosphere when
transmit frequency > maximum plasma frequency
3 MHz
6 MHz
9 MHz
Plasma frequency


It looks as if there are reflecting layers.
300
200
100
0
Altitude (km)
F-layer
that have
cut-off frequencies
E-layer
critical frequencies
foE
foF
3 MHz
6 MHz
9 MHz
Plasma frequency

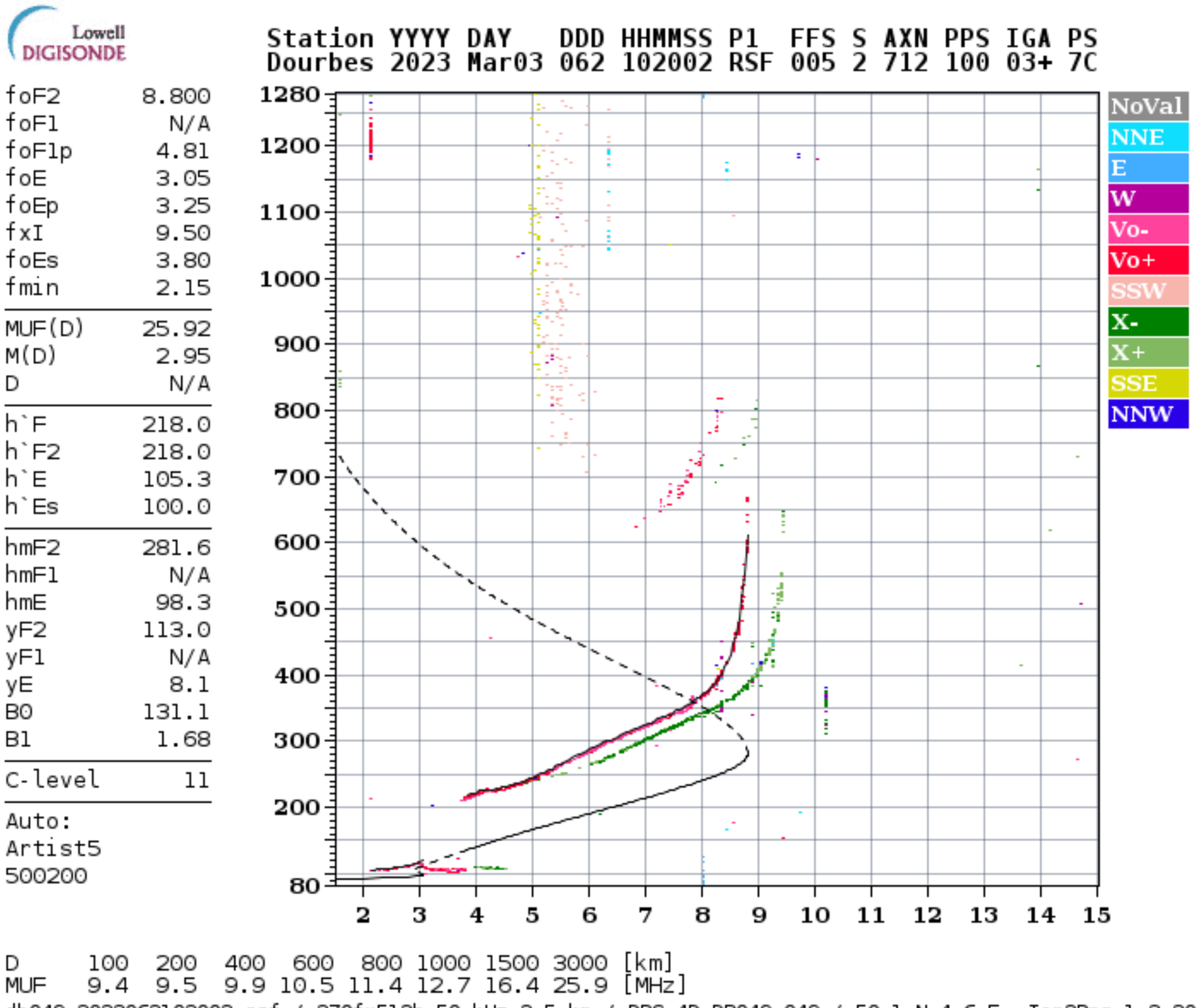

300
200
100
0
Altitude (km)
F region
E region
D region
foE
foF
3 MHz
6 MHz
9 MHz
Plasma frequency

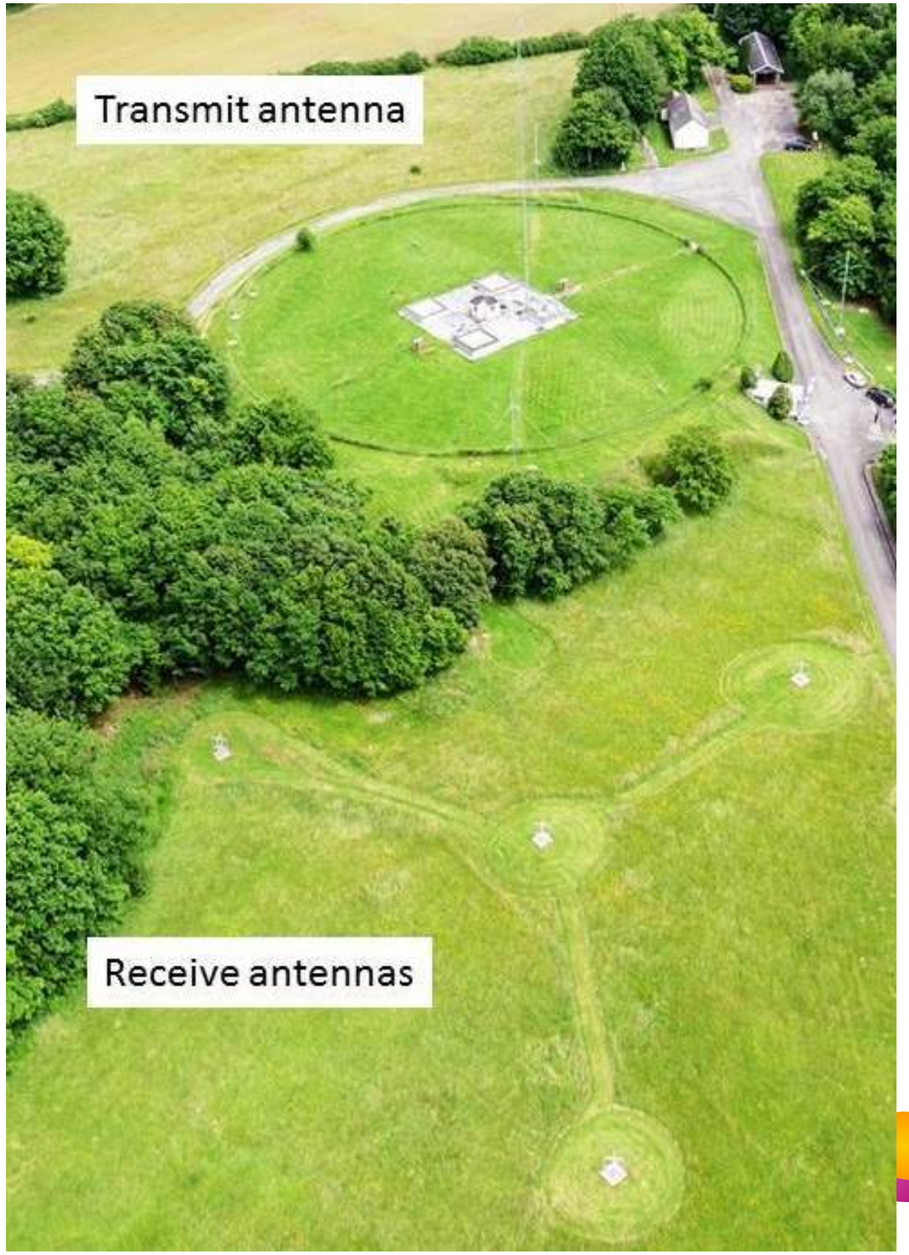
EXPERTS

Scientific expertise on the IONOSPHERE

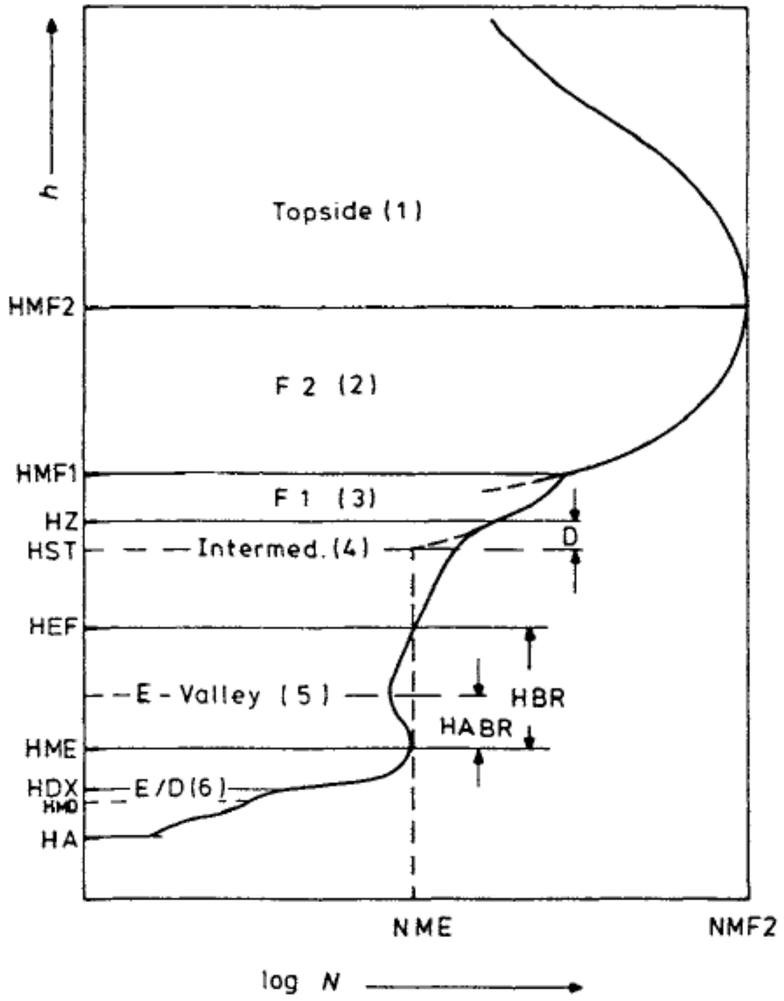


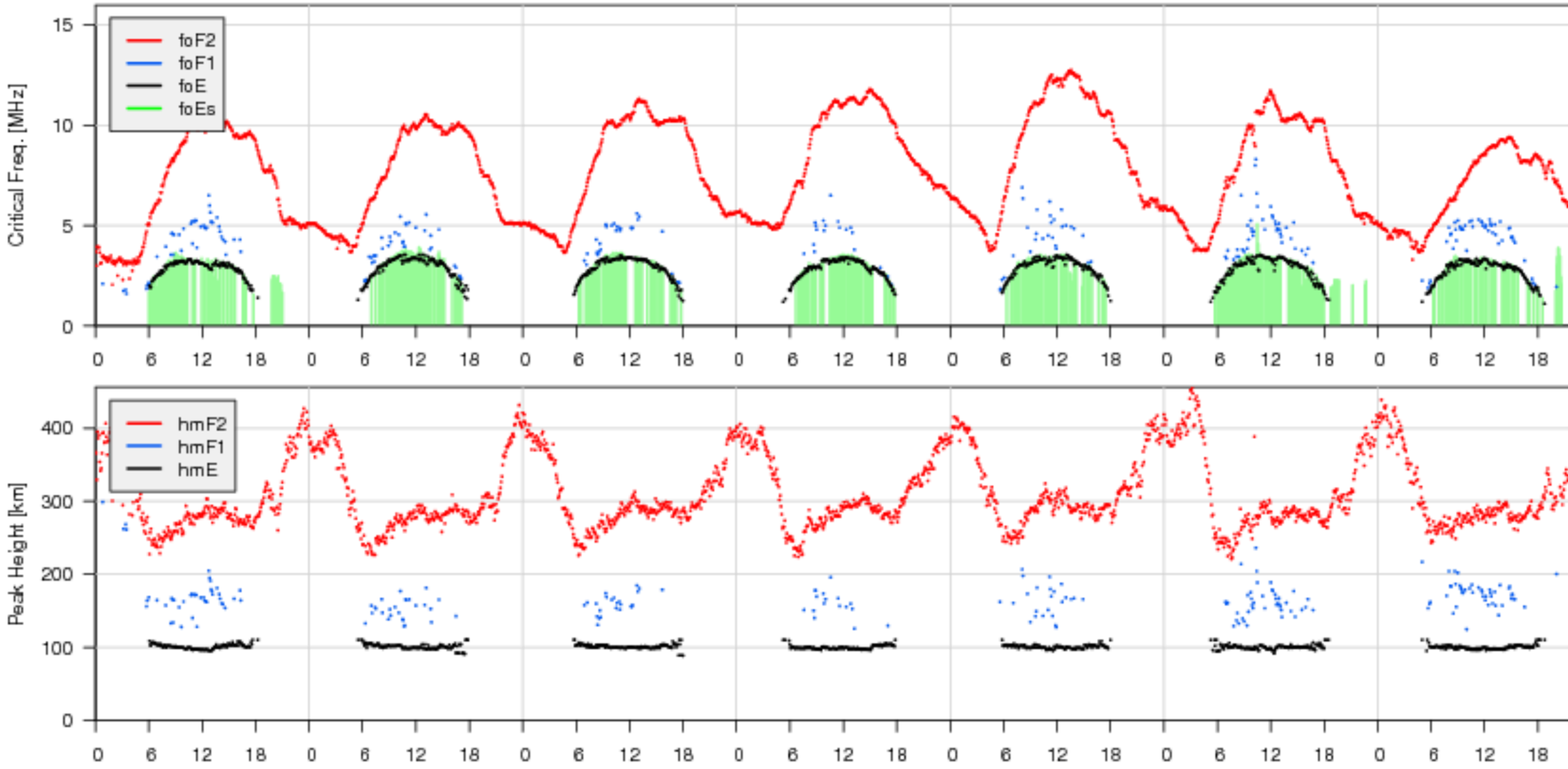
MONITORING THE IONOSPHERE FROM BELOW - IONOSONDE





DIURNAL VARIATION

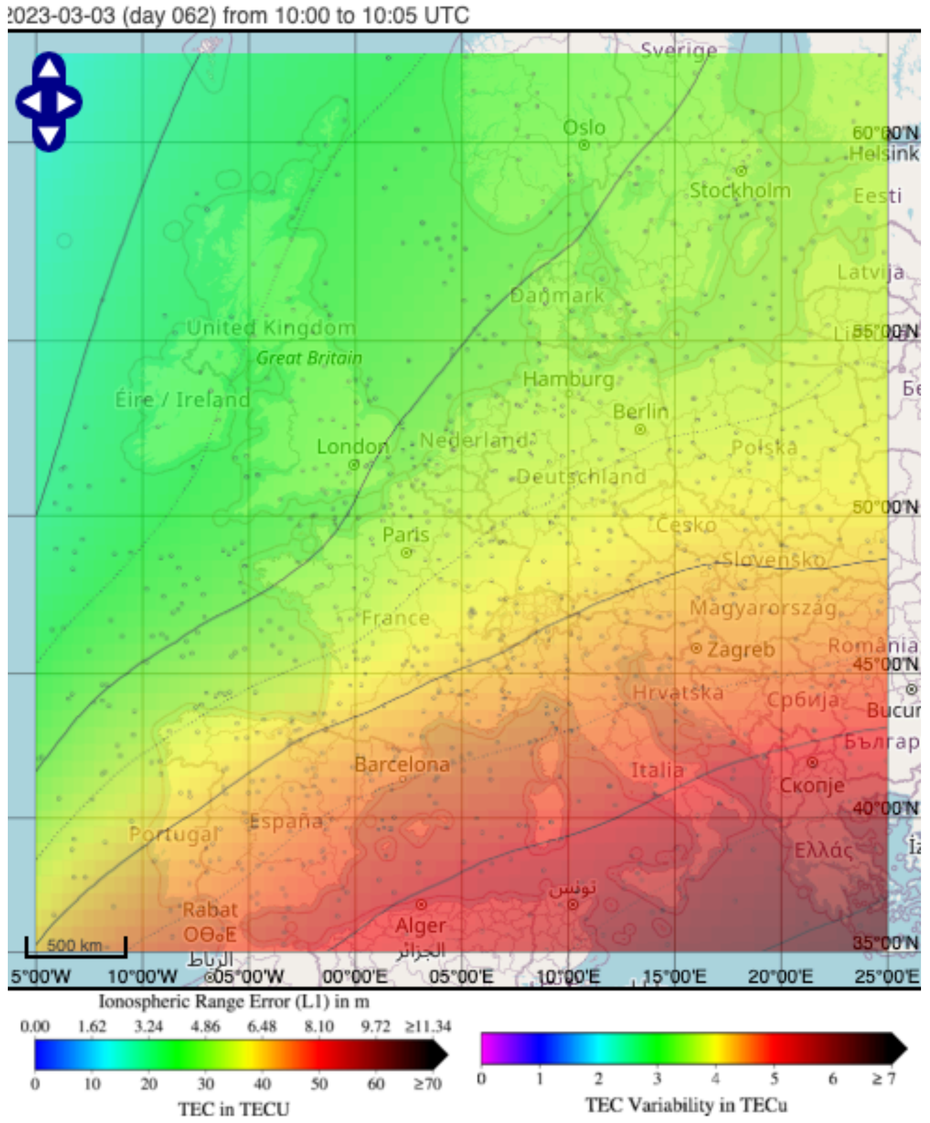




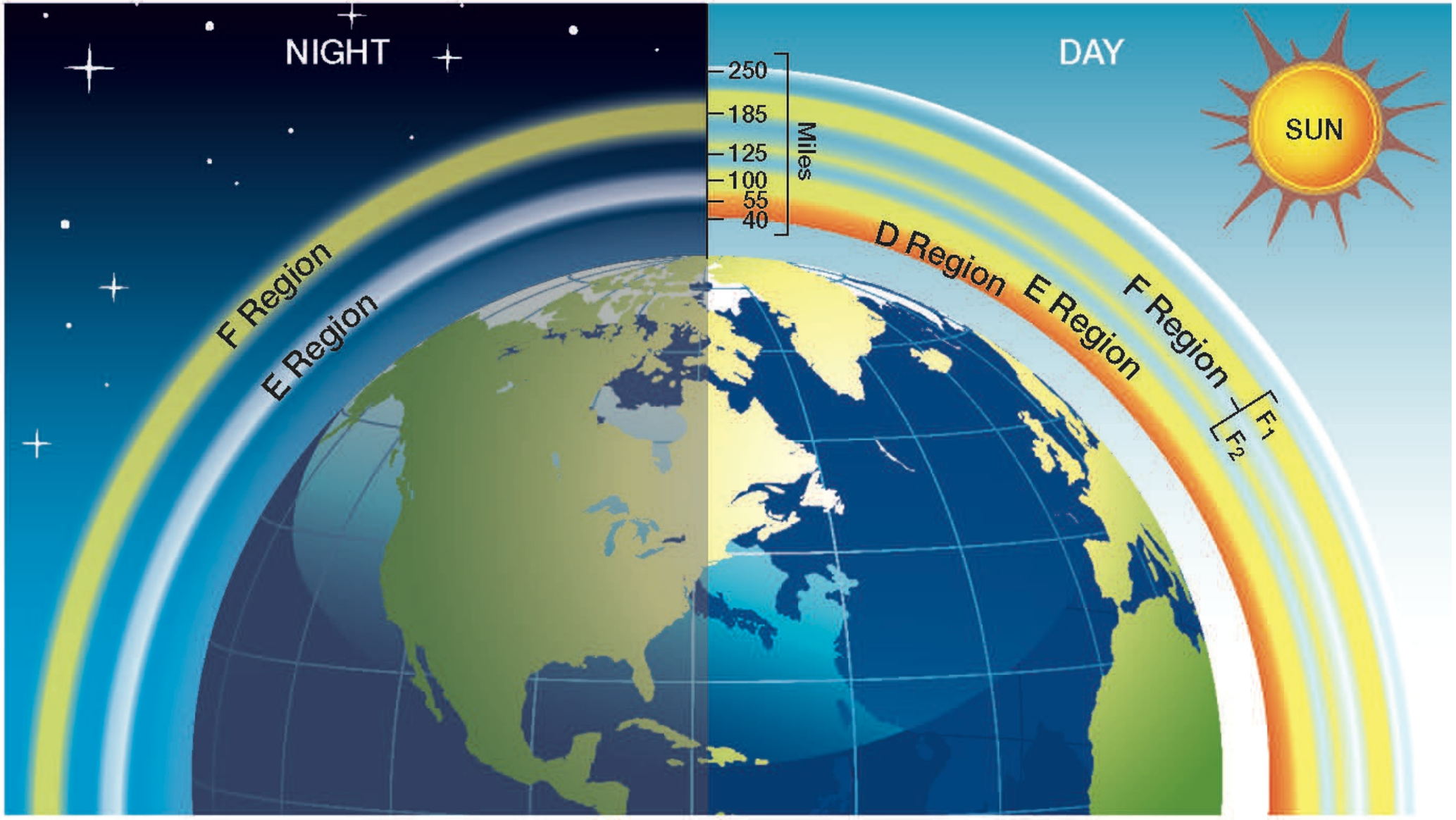
VTEC = surface

Monitoring the Ionosphere from ABOVE - GNSS

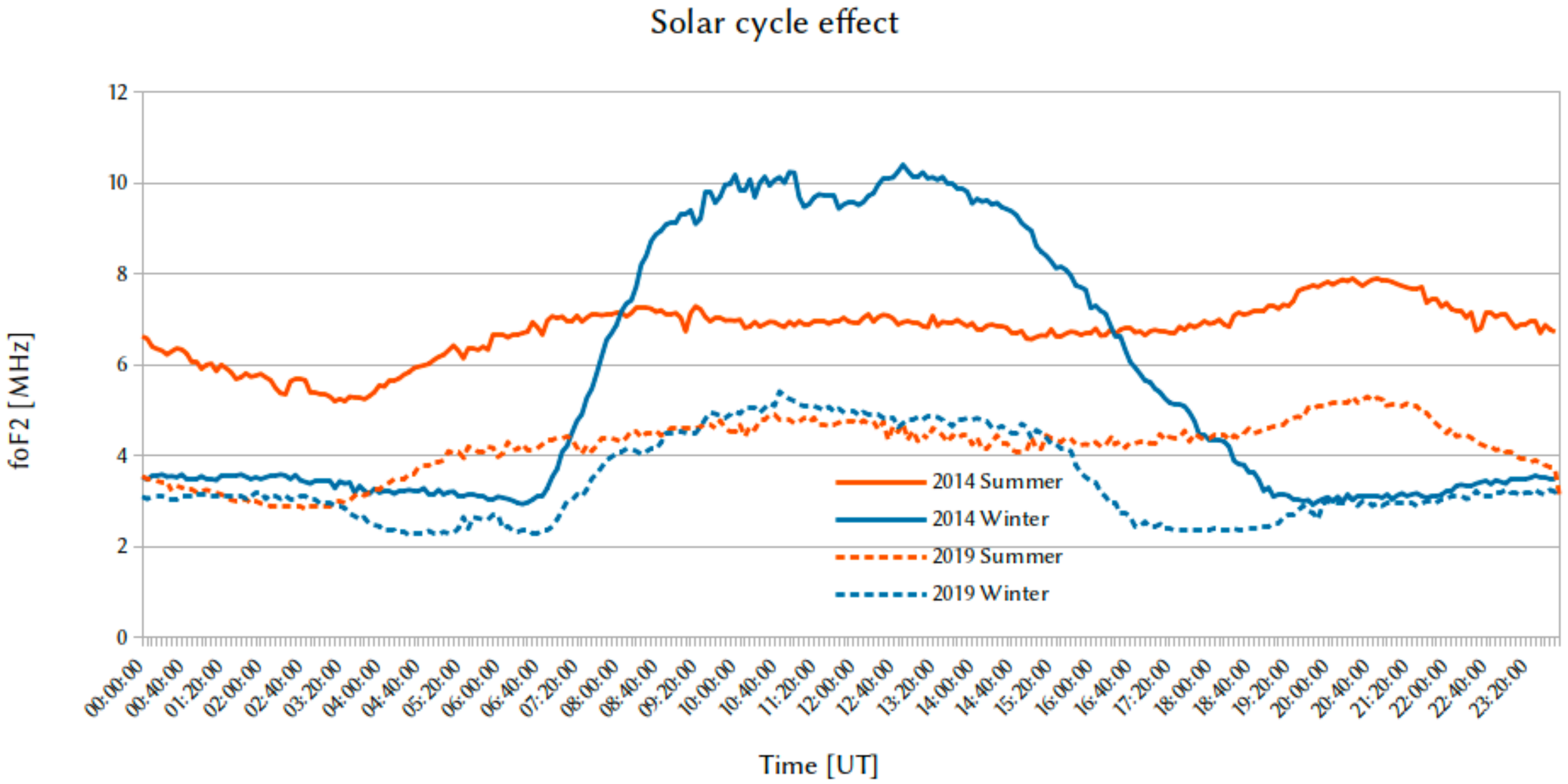




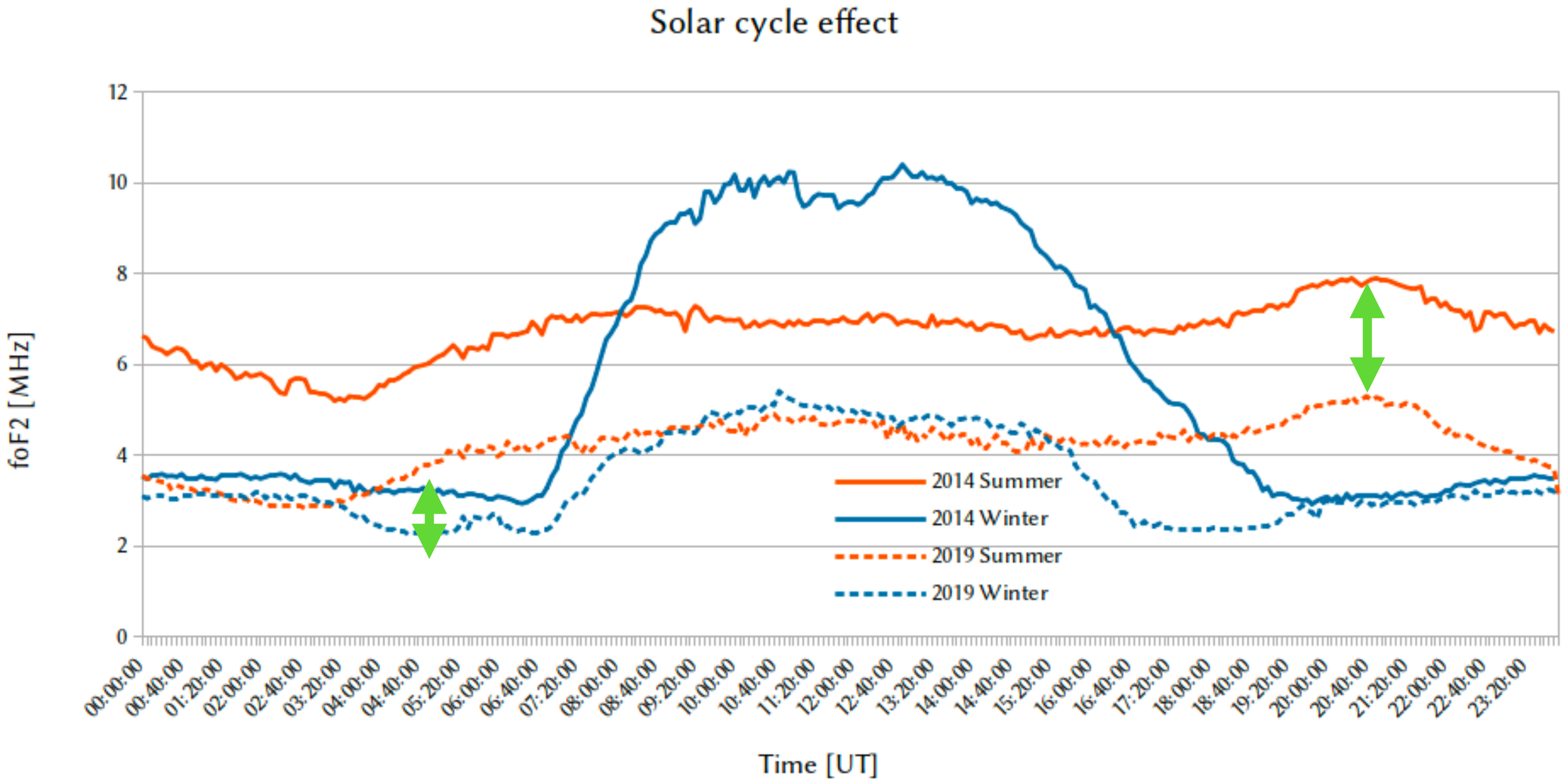
DIURNAL VARIATION



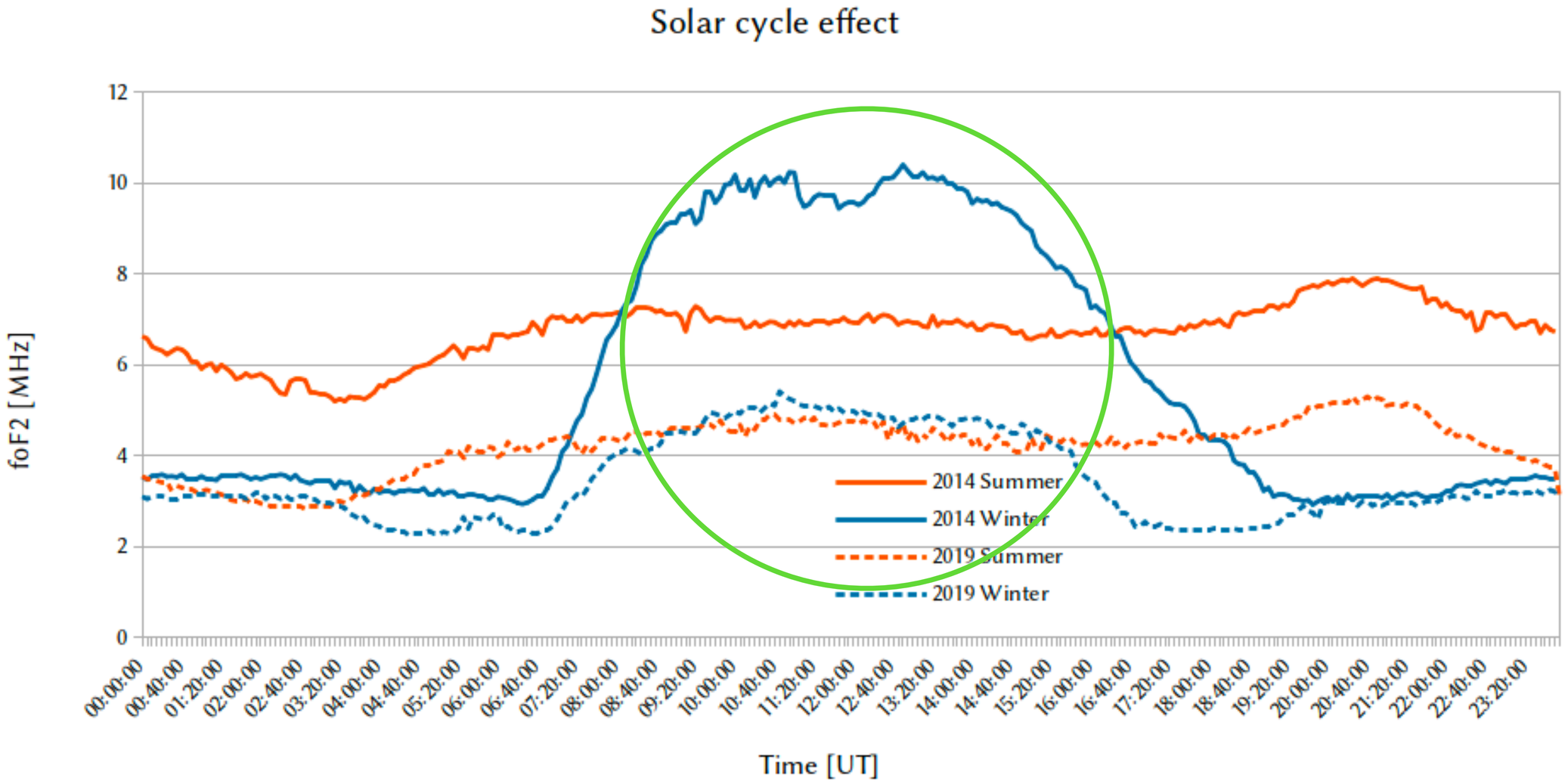
SEASONAL AND SOLAR CYCLE VARIATION



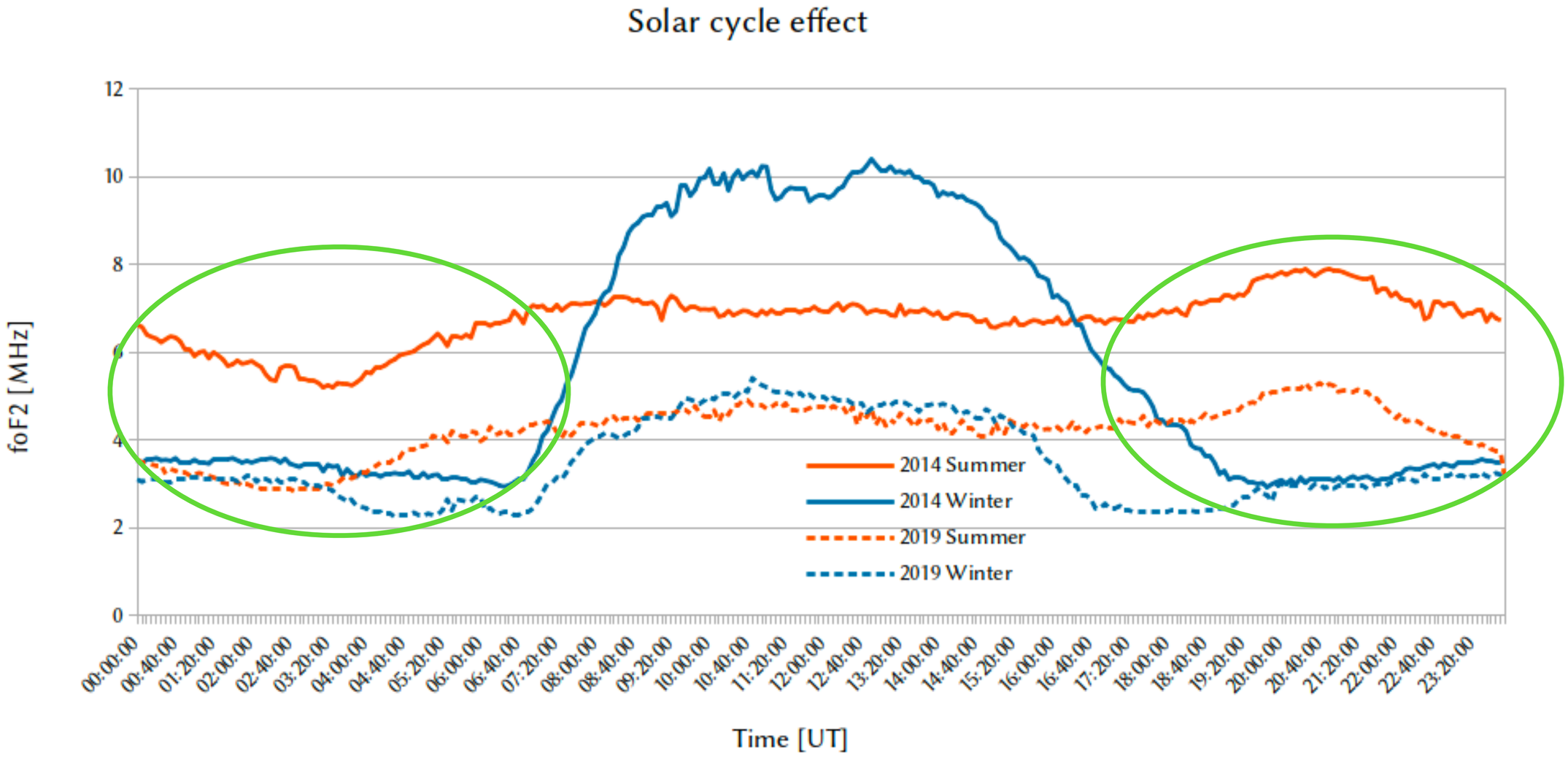
SEASONAL AND SOLAR CYCLE VARIATION



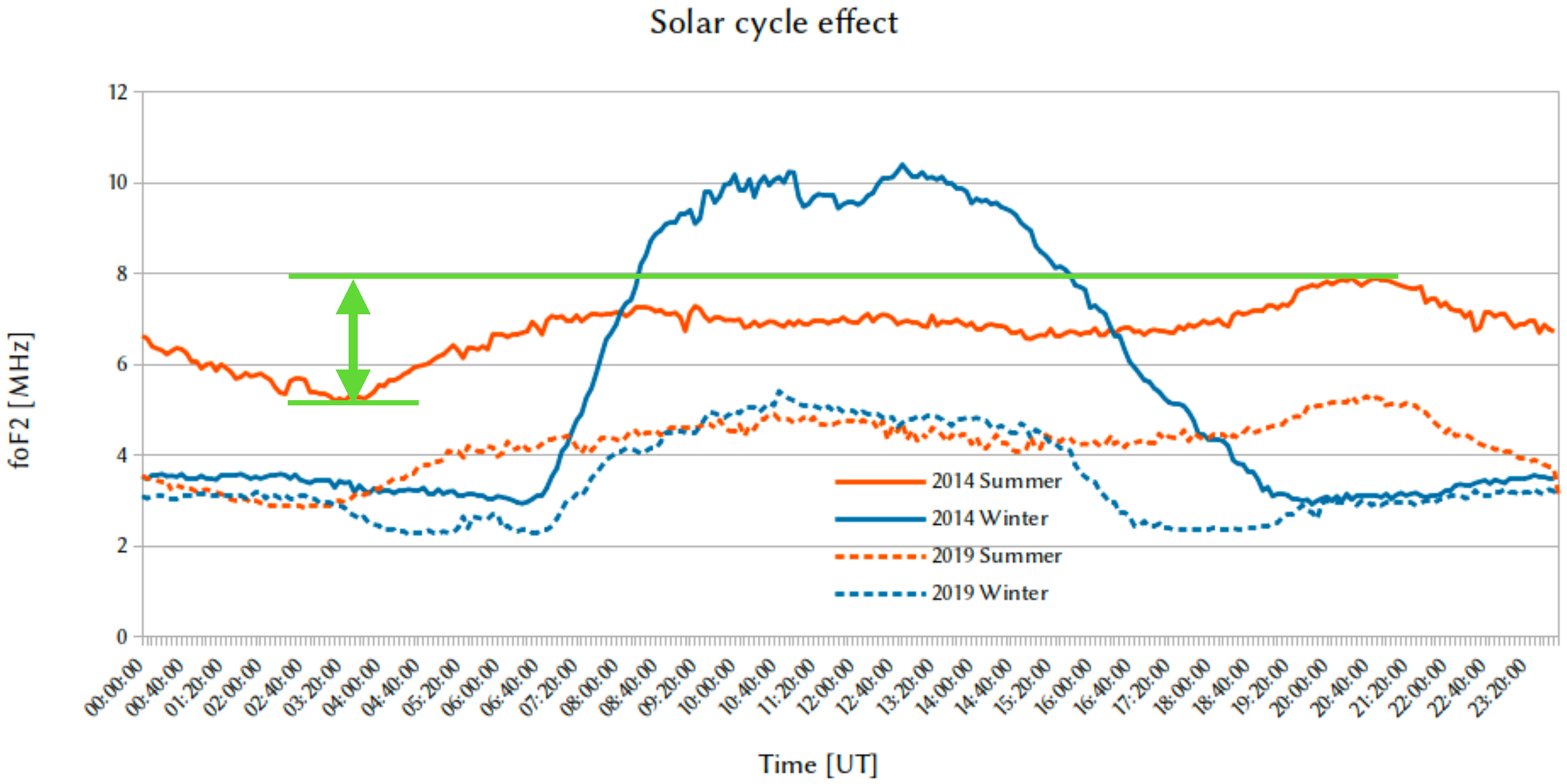
SEASONAL AND SOLAR CYCLE VARIATION



SEASONAL AND SOLAR CYCLE VARIATION



SEASONAL AND SOLAR CYCLE VARIATION

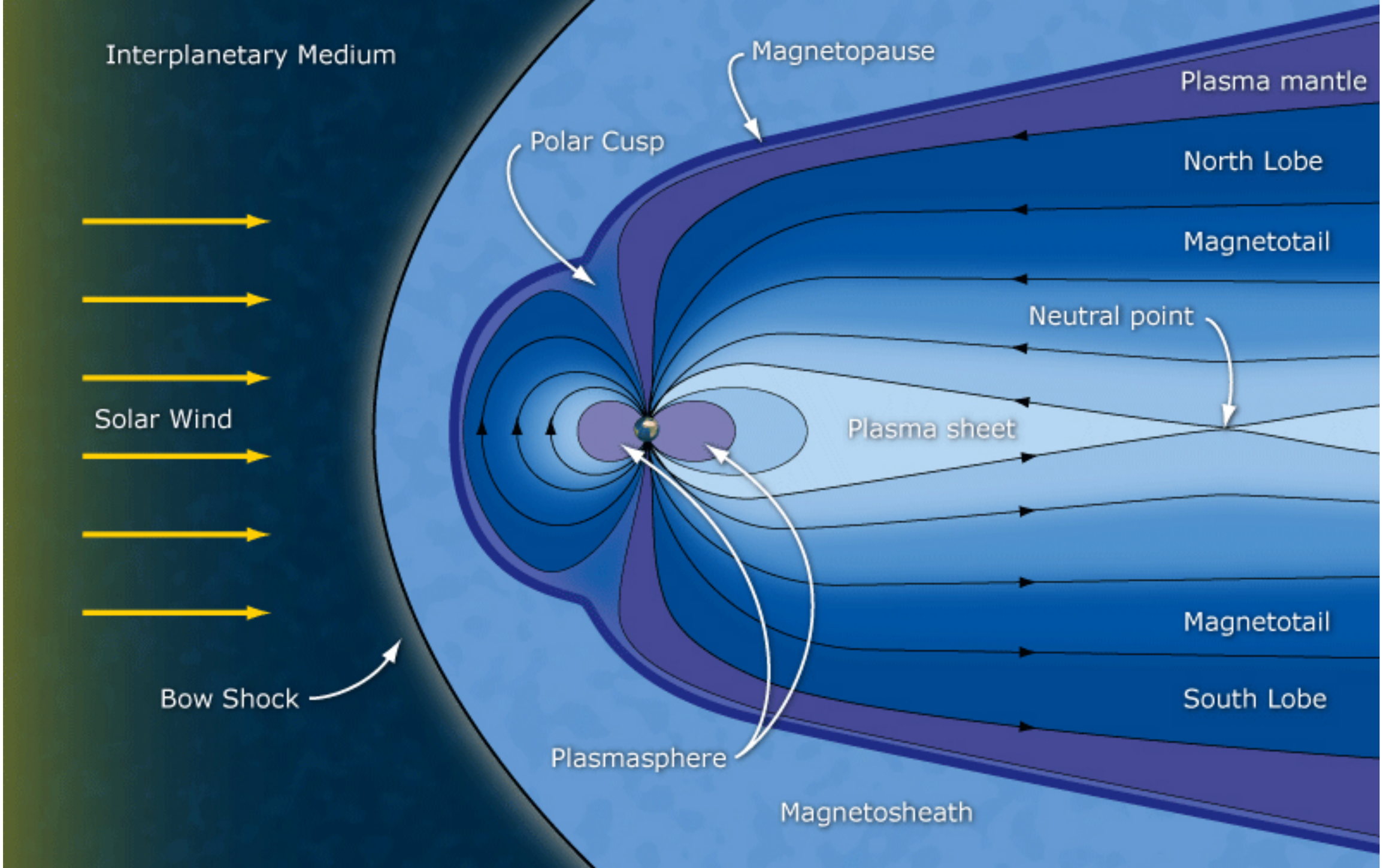


- (Mid latitude) ionosphere has typical variations with time of day, season, and solar cycle.
- Seasonal anomaly: higher ionisation in winter than in summer.
- Lower layers only depend on solar irradiation, F2 layer is more complicated.

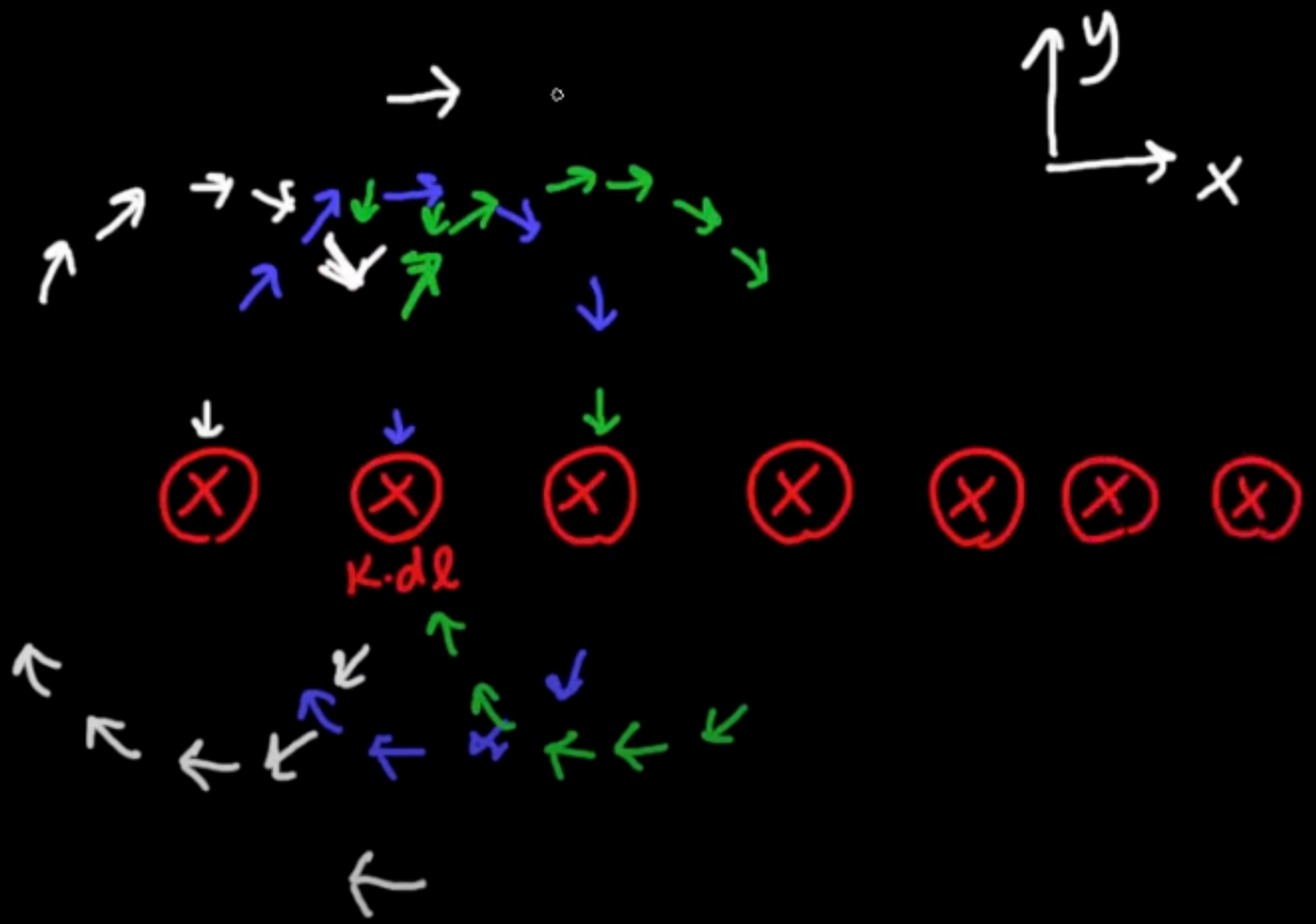
Low and high latitude ionosphere

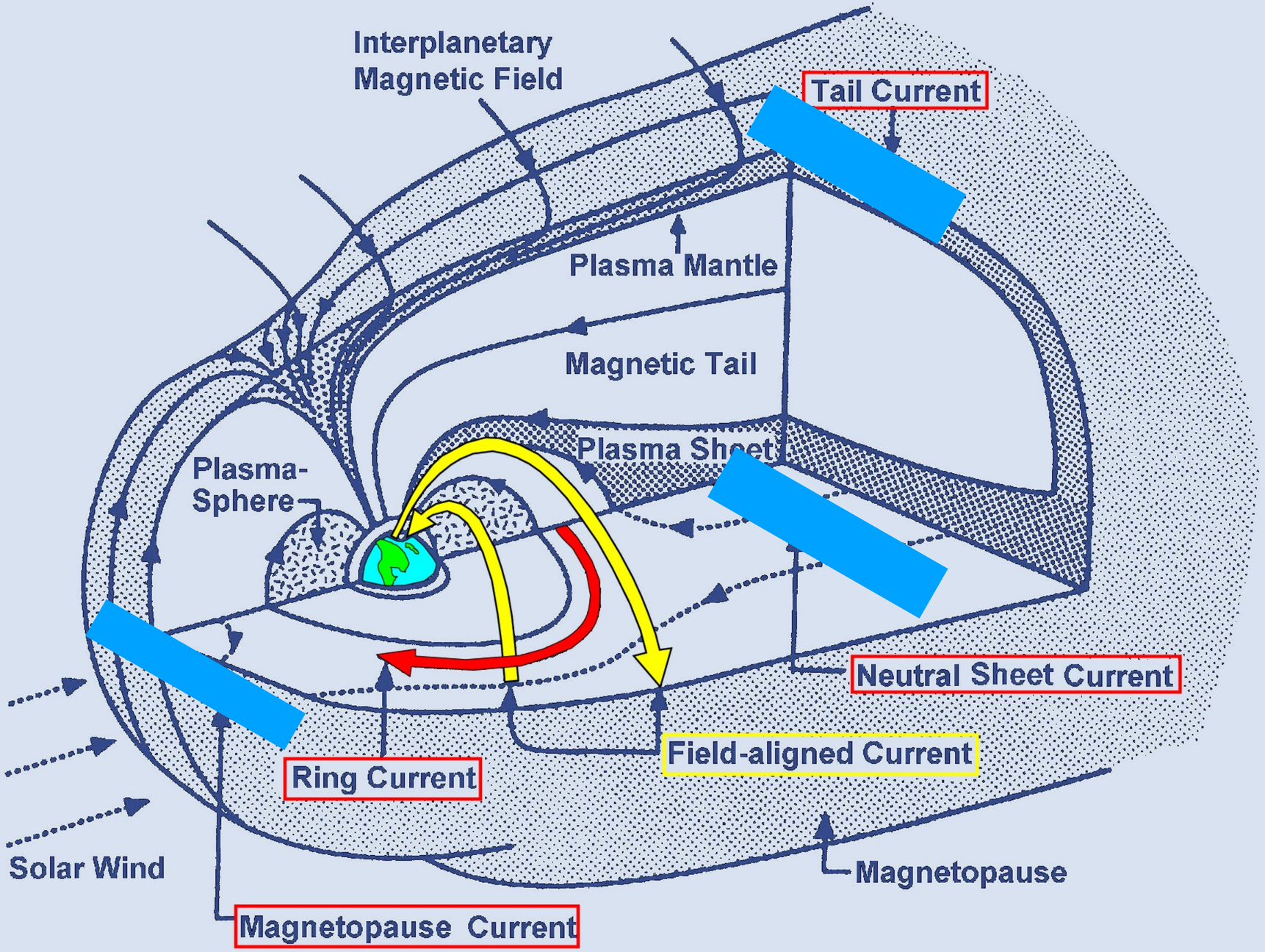
magnetosphere

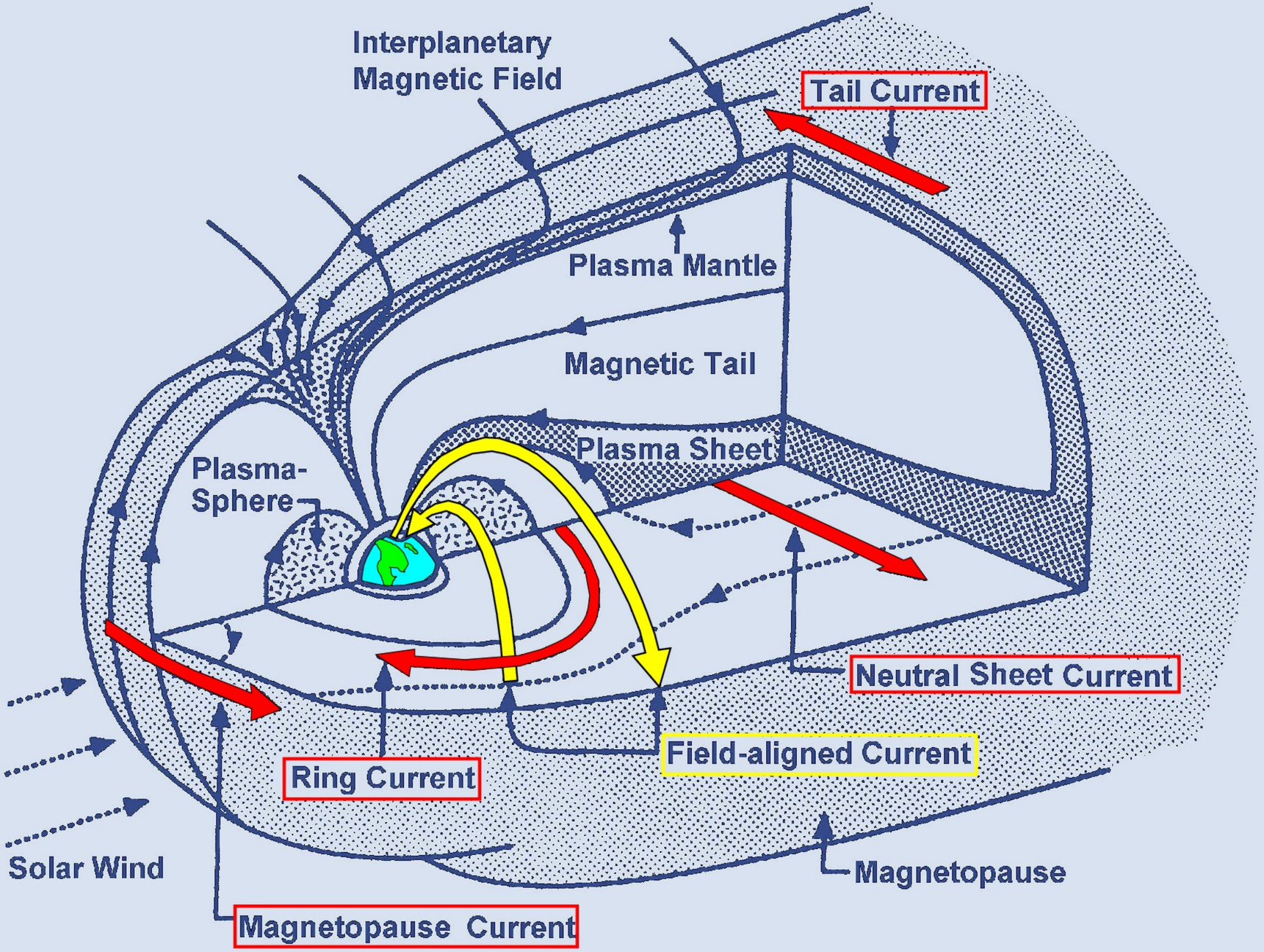
magnetosphere-ionosphere coupling


Interplanetary Medium
Magnetopause
Plasma mantle
Polar Cusp
North Lobe
Magnetotail
Neutral point
Solar Wind
Plasma sheet
Magnetotail
Bow Shock
South Lobe
Plasmasphere
Magnetosheath

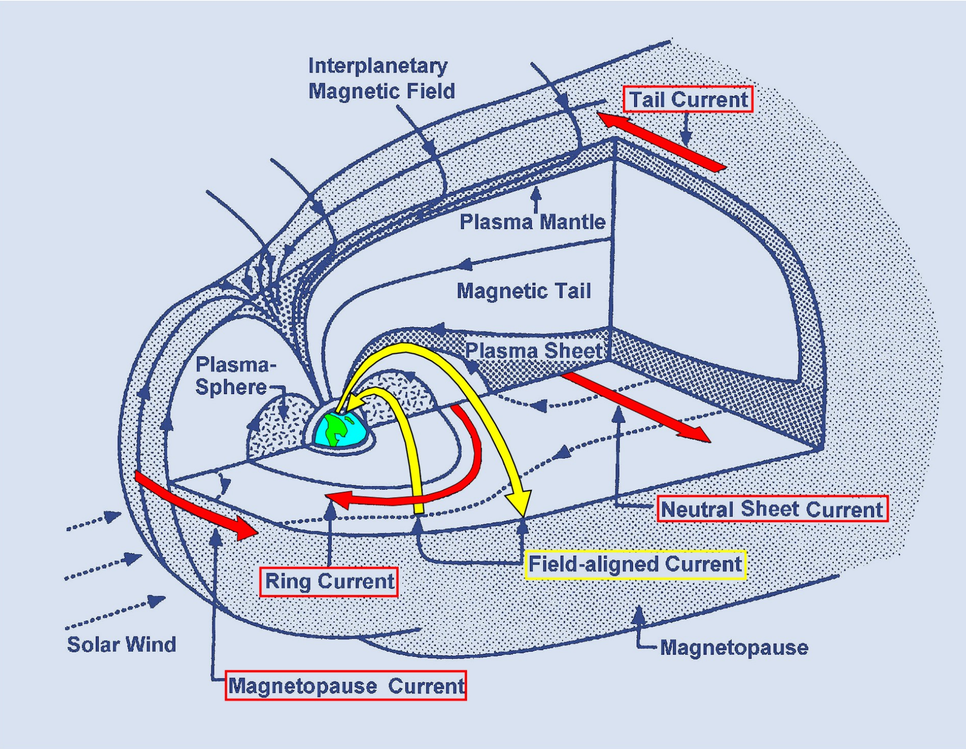
AMPERES LAW

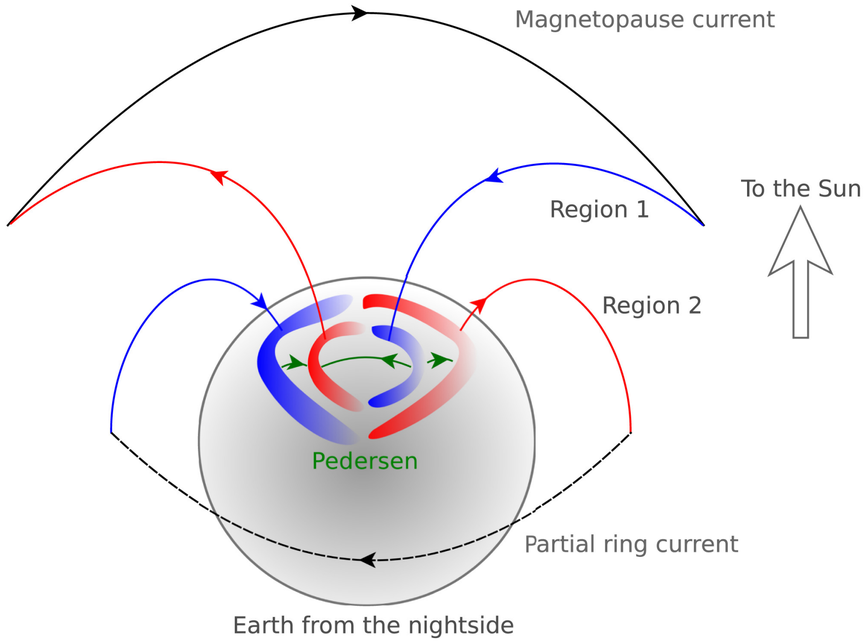



Interplanetary
Magnetic Field
Tail Current
Plasma Mantle
Magnetic Tail
Plasma Sheet
Plasma-
Sphere
Neutral Sheet Current
Field-aligned Current
Ring Current
Solar Wind
Magnetopause
Magnetopause Current


Interplanetary
Magnetic Field
Tail Current
Plasma Mantle
Magnetic Tail
Plasma Sheet
Plasma-
Sphere
Neutral Sheet Current
Field-aligned Current
Ring Current
Solar Wind
Magnetopause
Magnetopause Current

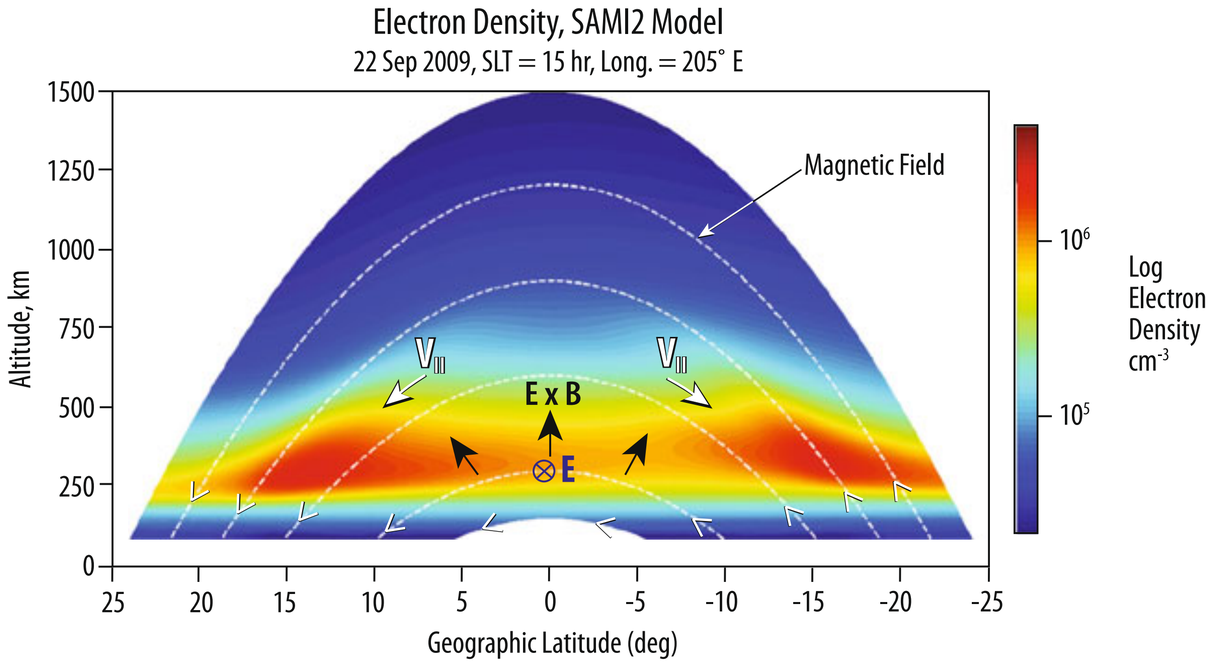
MAGNETOSPHERE - IONOSPHERE COUPLING





Low-latitude ionosphere

THE EQUATORIAL IONISATION ANOMALY



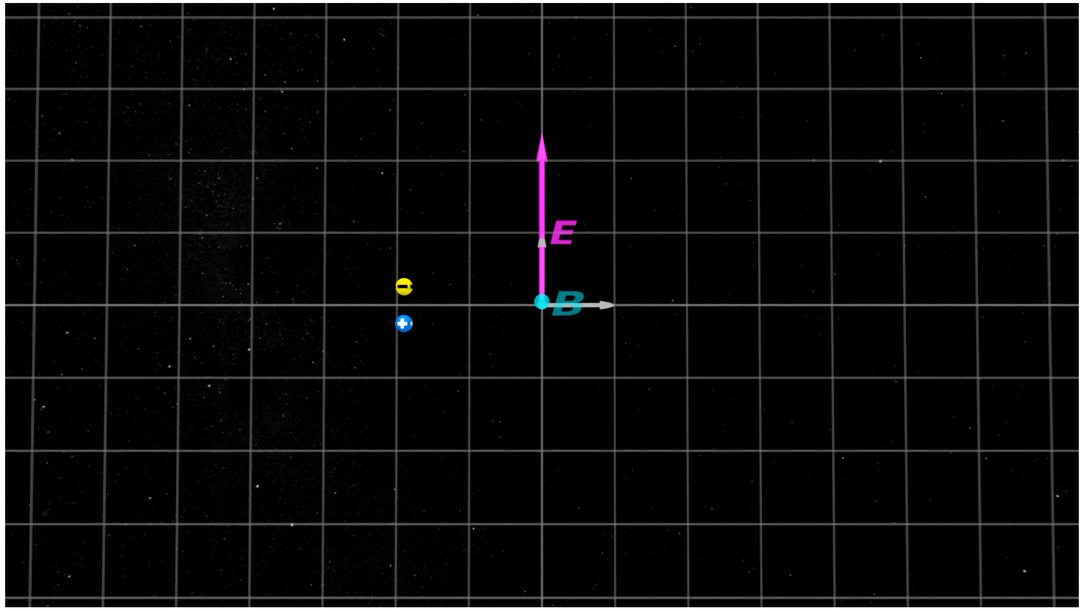
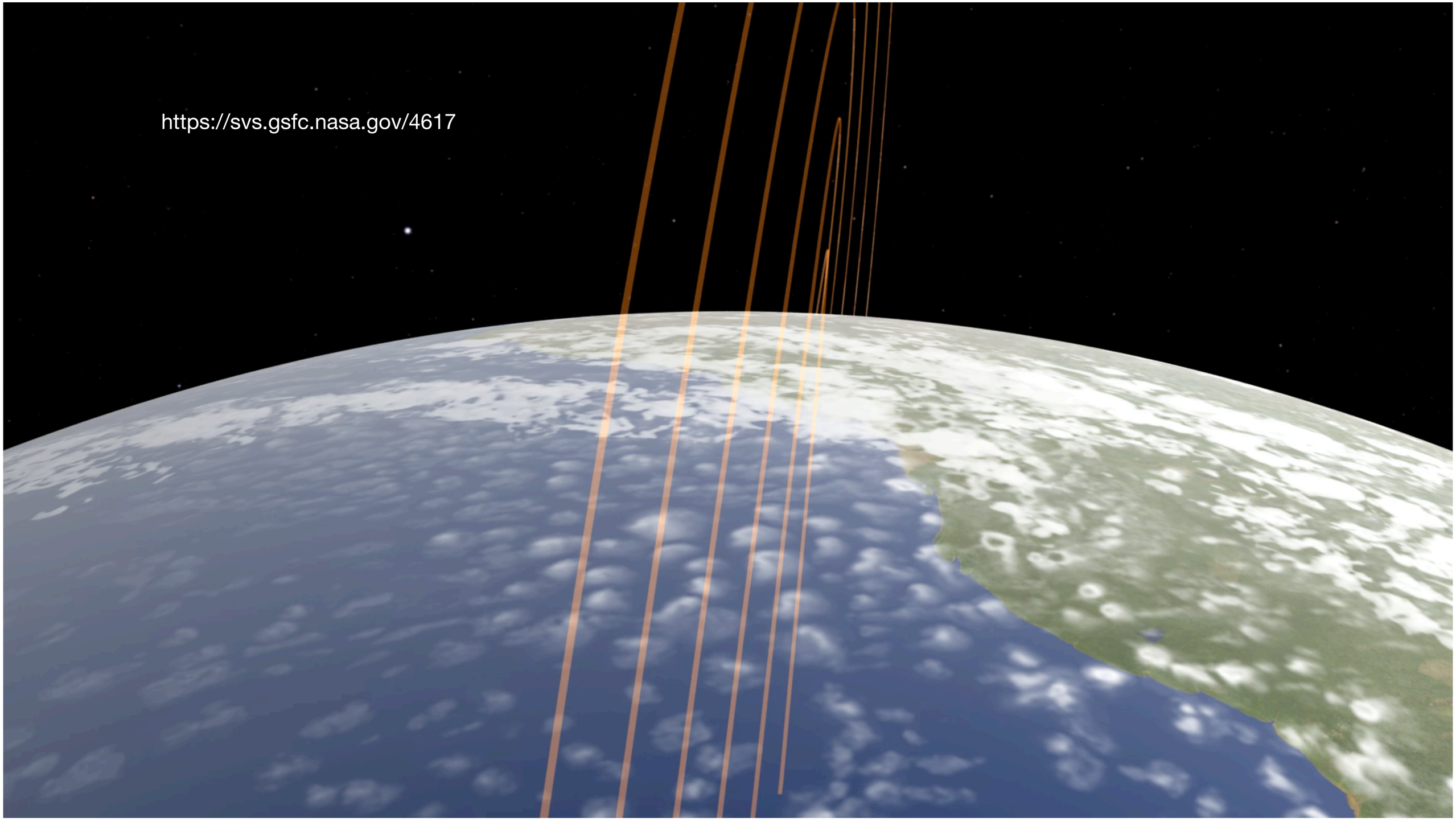
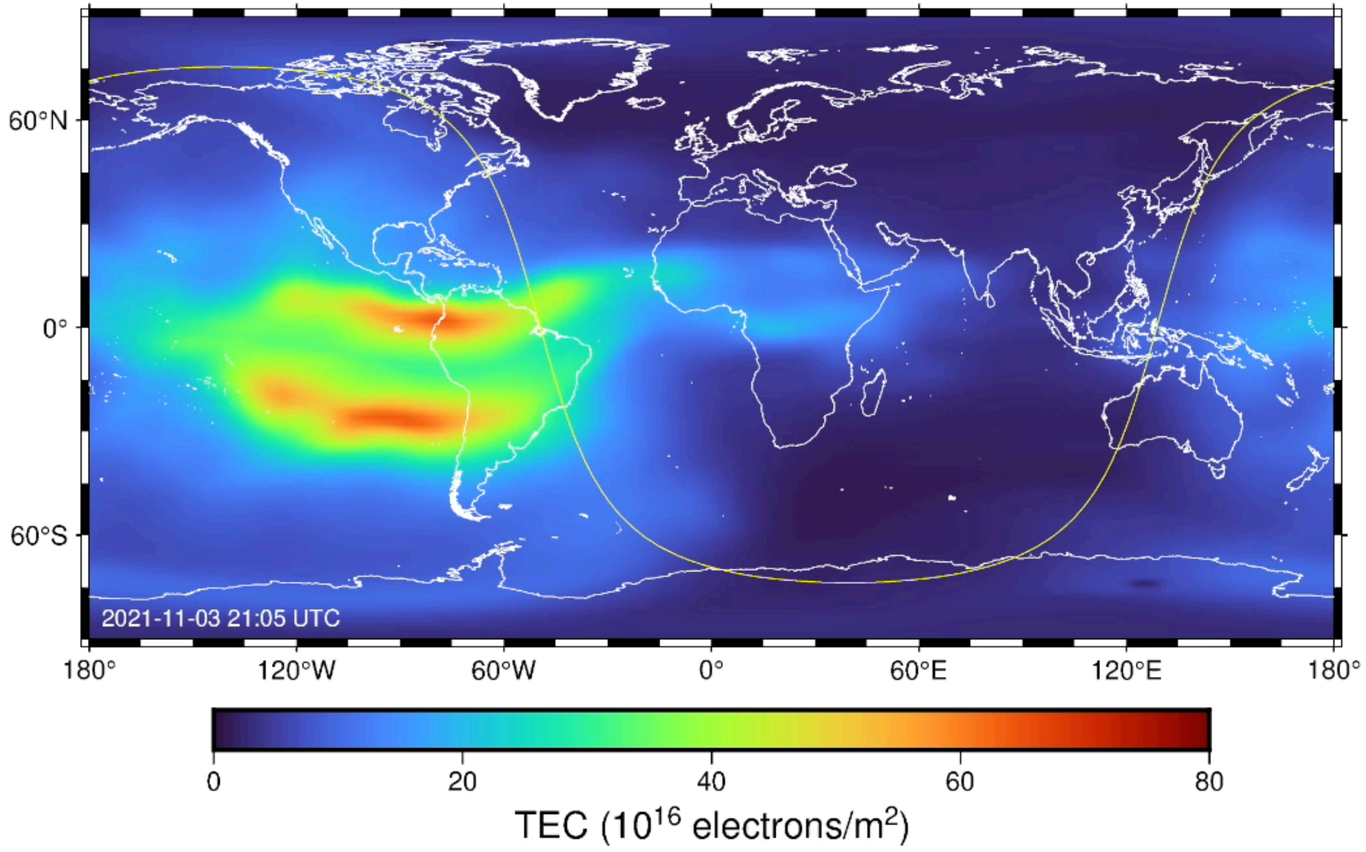


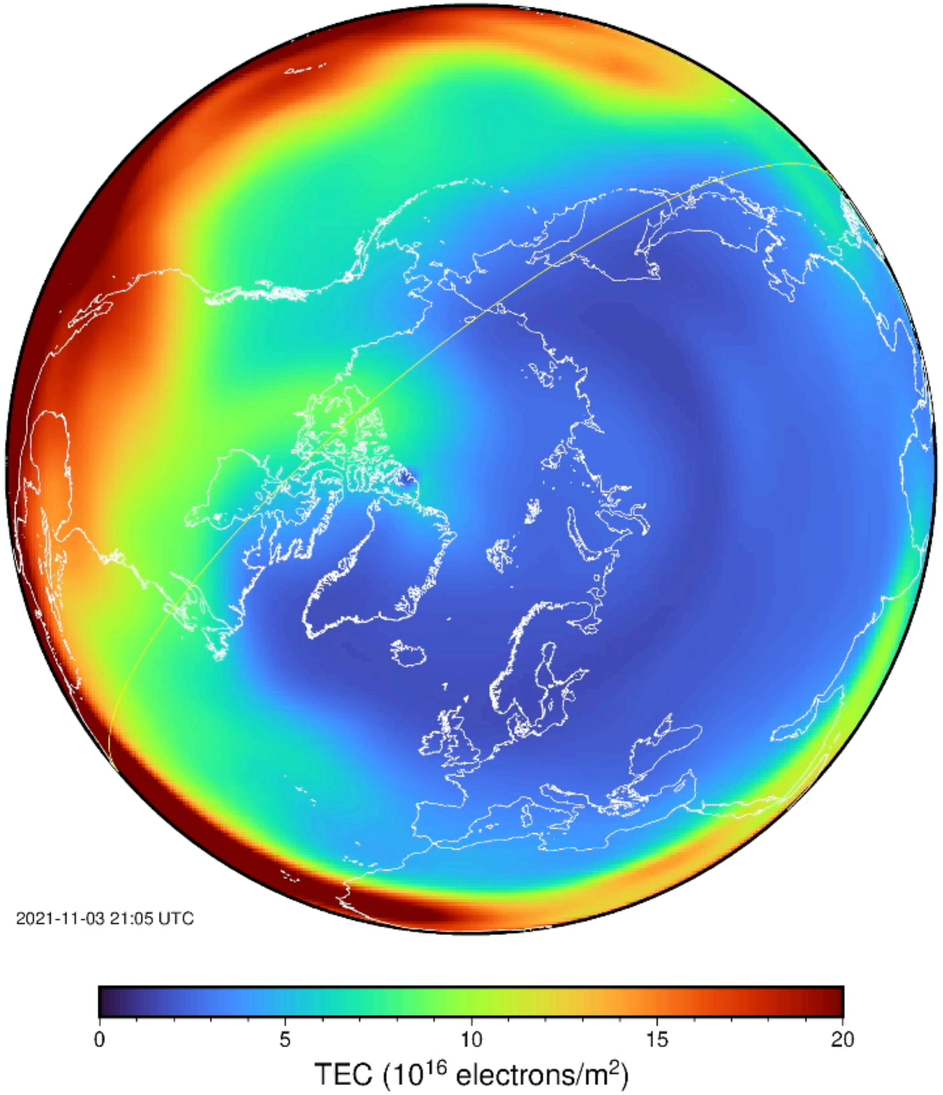
Fig. 19 SAMI2 model calculations versus latitude and altitude of the plasma density for 1500 SLT at 205° East. The upward $\mathbf{E} \times \mathbf{B}$ drift at the magnetic equator is driven by the eastward electric field, and there is subsequent flow downward along the magnetic field lines

Pfaff, 2012, The Near-Earth Plasma Environment

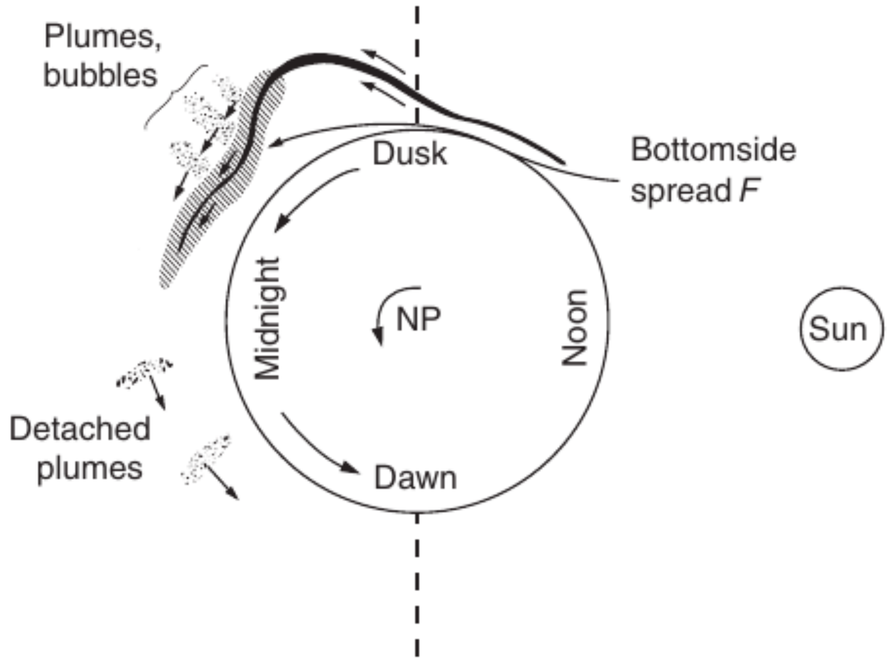

https://svs.gsfc.nasa.gov/4617

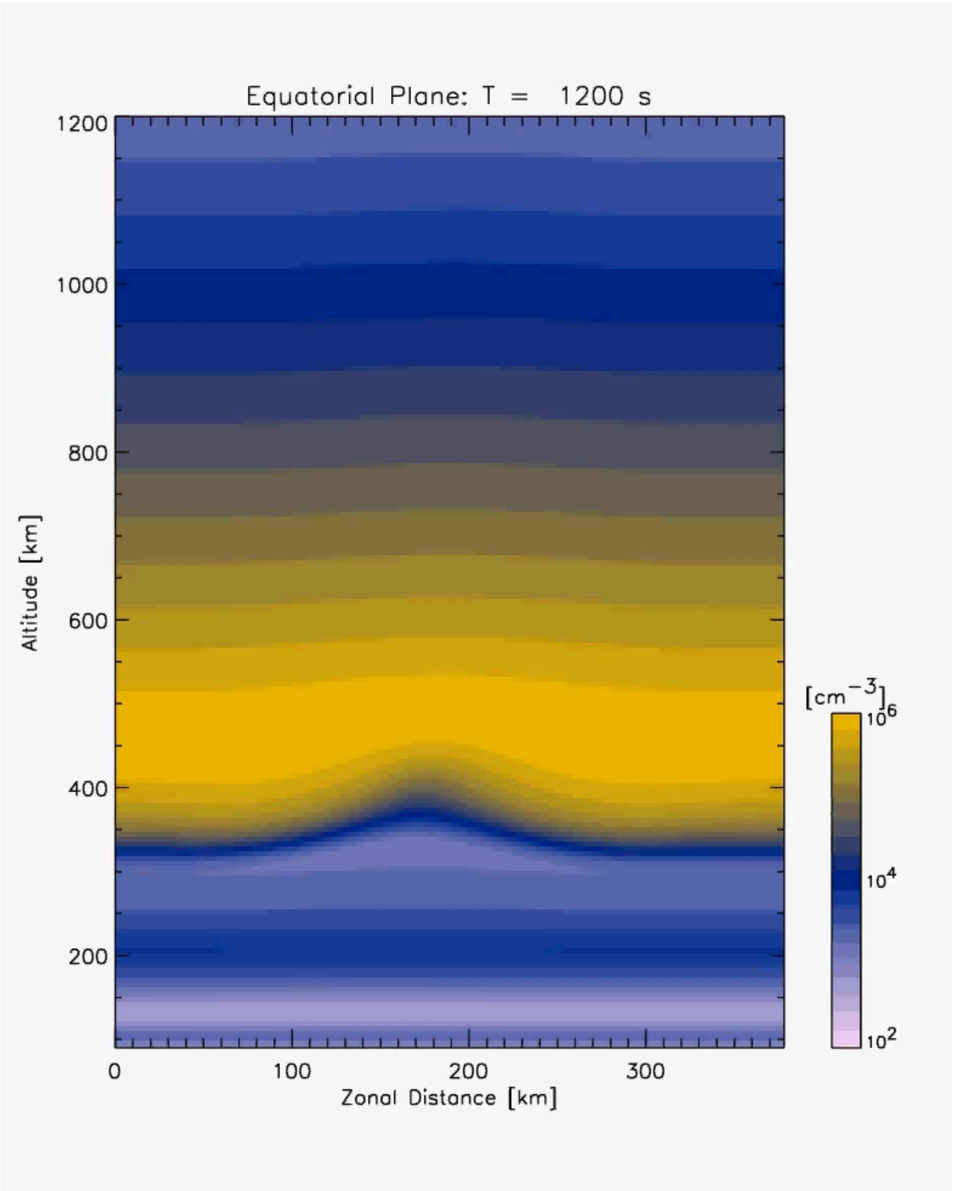
THE EQUATORIAL IONISATION ANOMALY





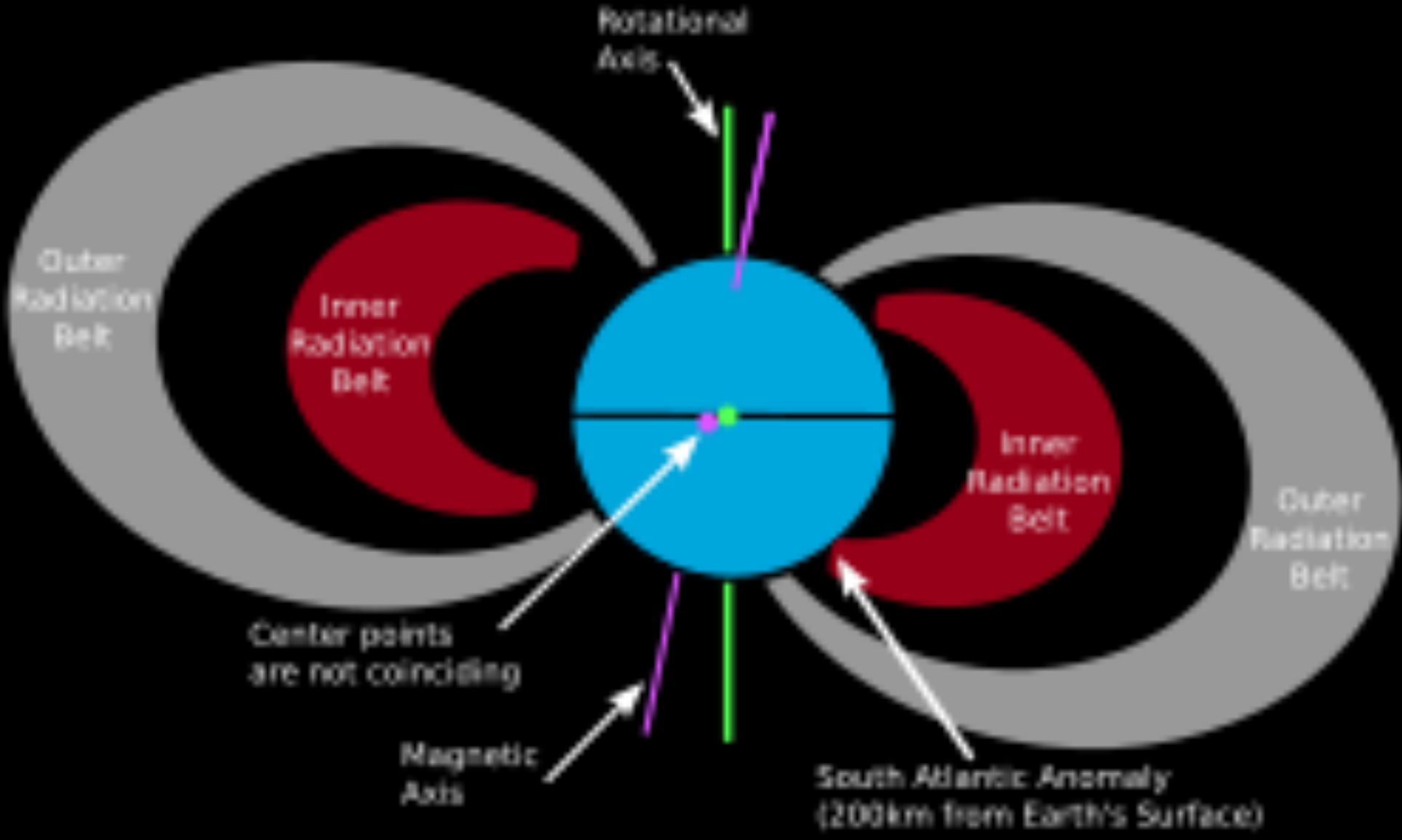
EQUATORIAL PLASMA BUBBLES





https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2014JA020708

South Atlantic Anomaly

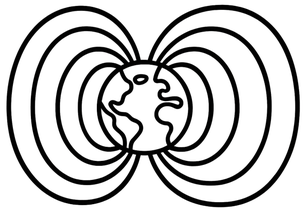


High-latitude ionosphere

Impact of Solar Storms









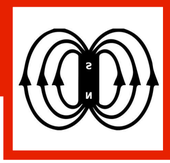


Ionisation

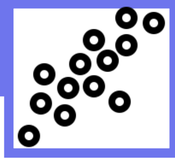


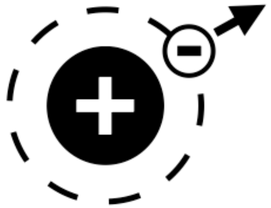
Particle content

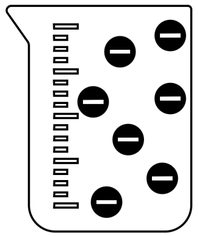


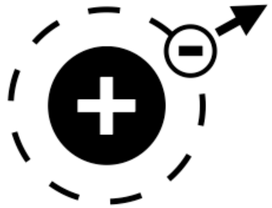


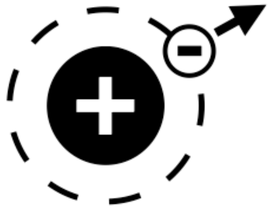
Ionisation
Particle Radiation









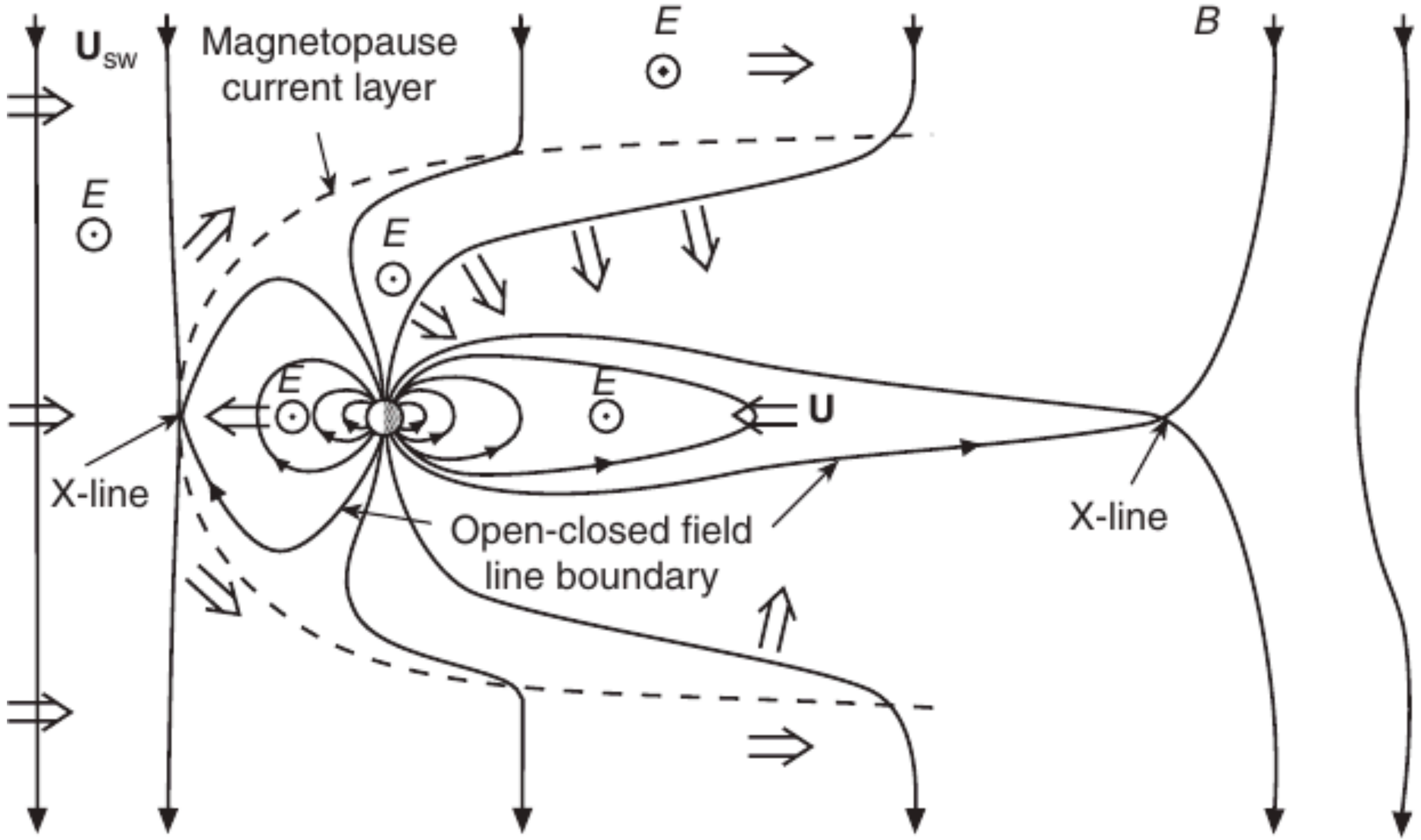




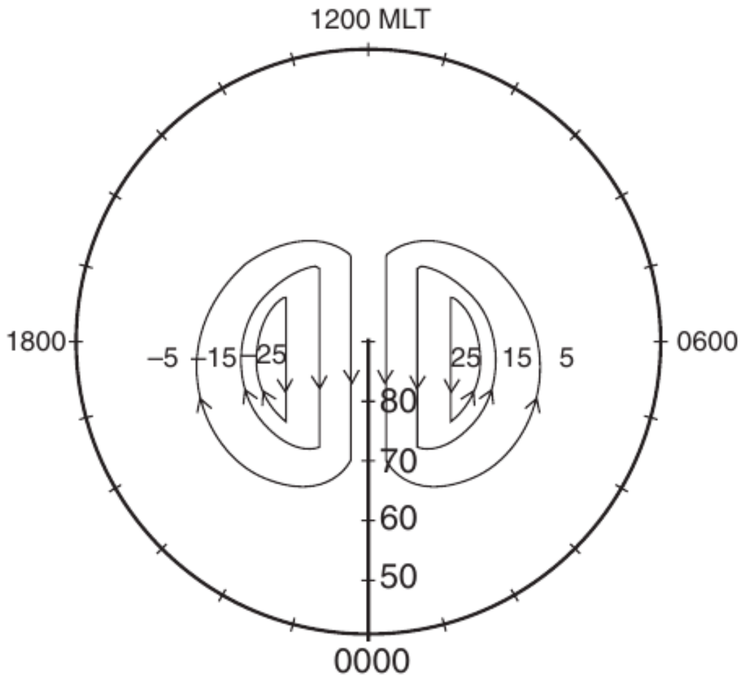


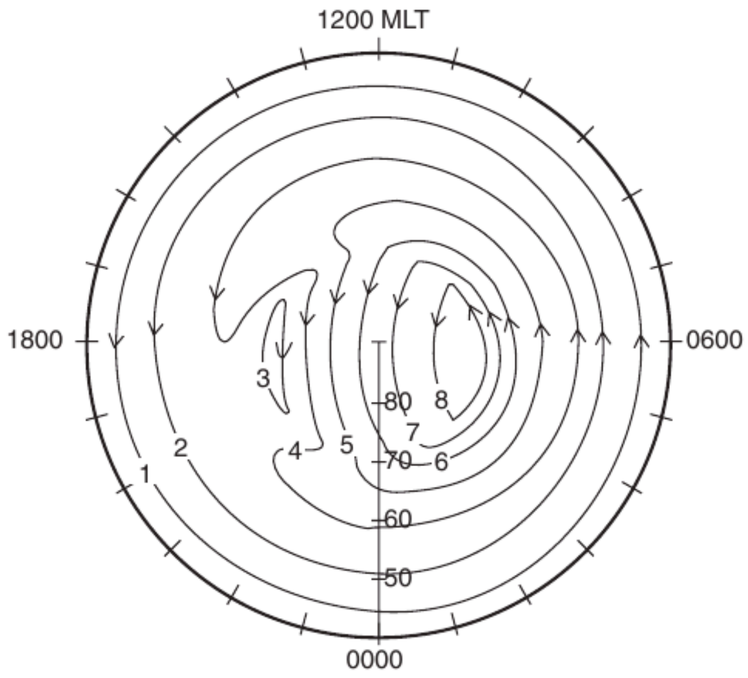
SWEC
Space Weather Education Center

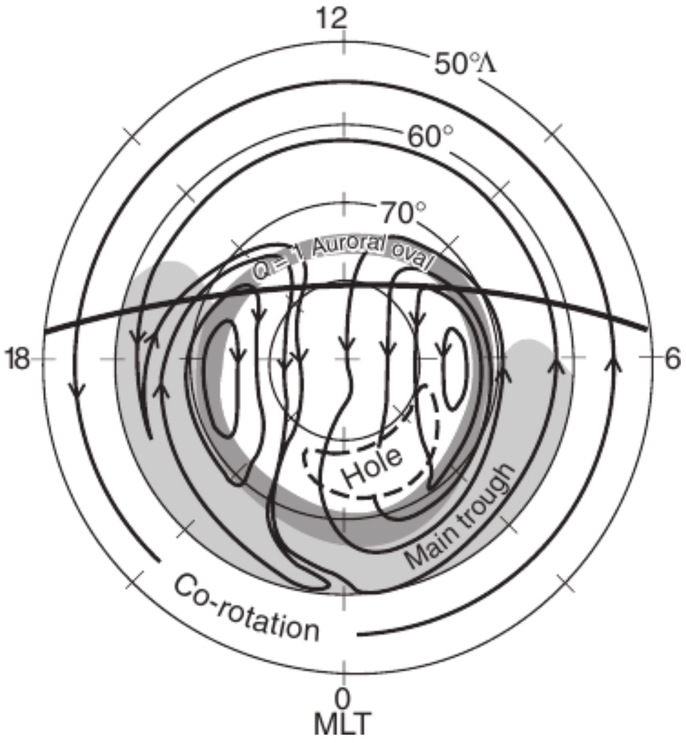
Polar Cap and Auroral Oval



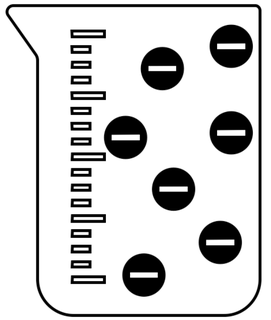
Polar Cap

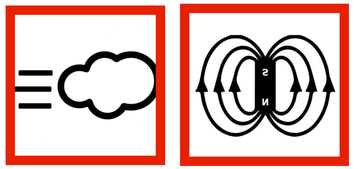

1200 MLT
1800
0600
0000
–5
15
25
25
15
5
80
70
60
50

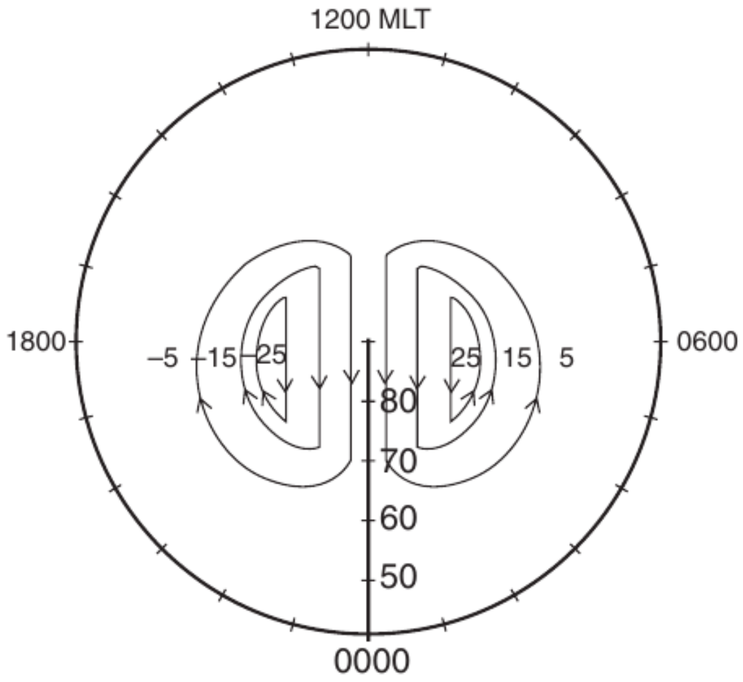

1200 MLT
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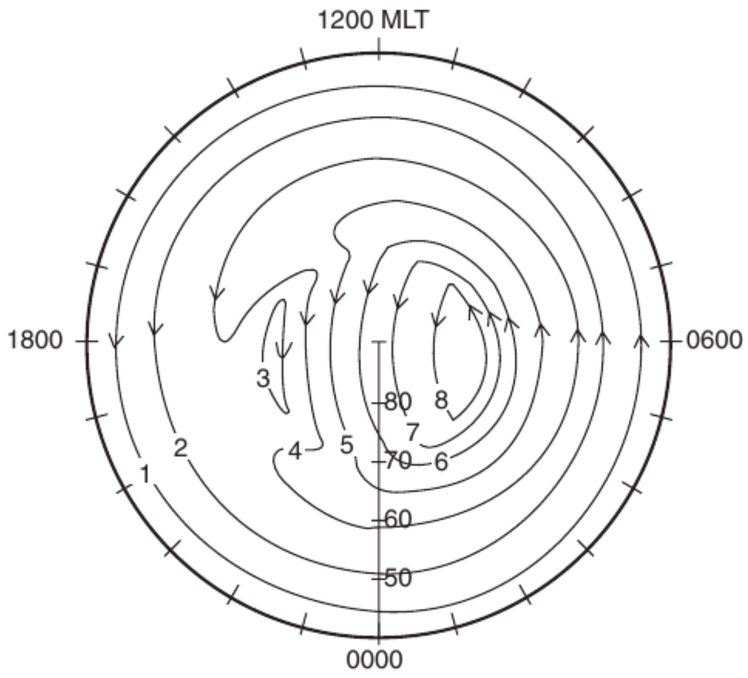

12
50°Λ
60°
70°
Auroral oval
18
6
Hole
Main trough
Co-rotation
0
MLT

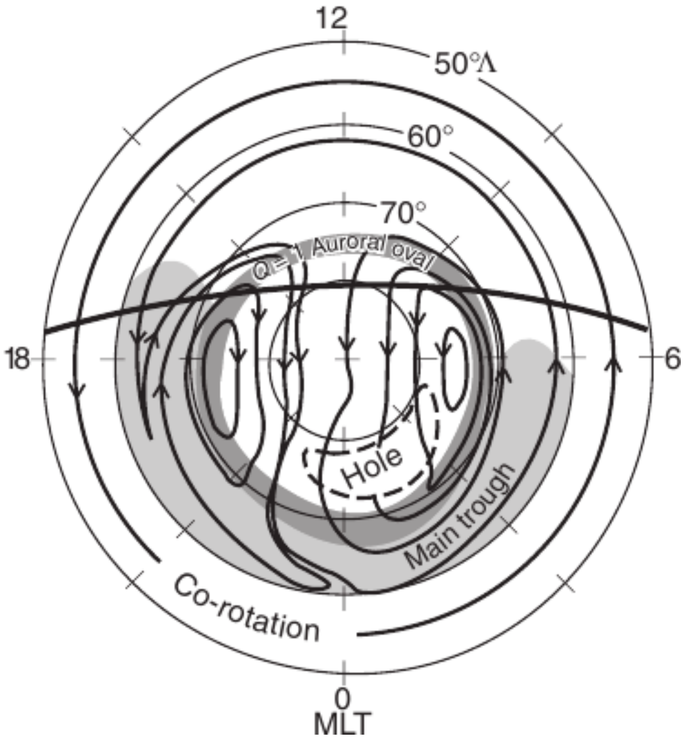
POLAR CAP - COMPLICATED



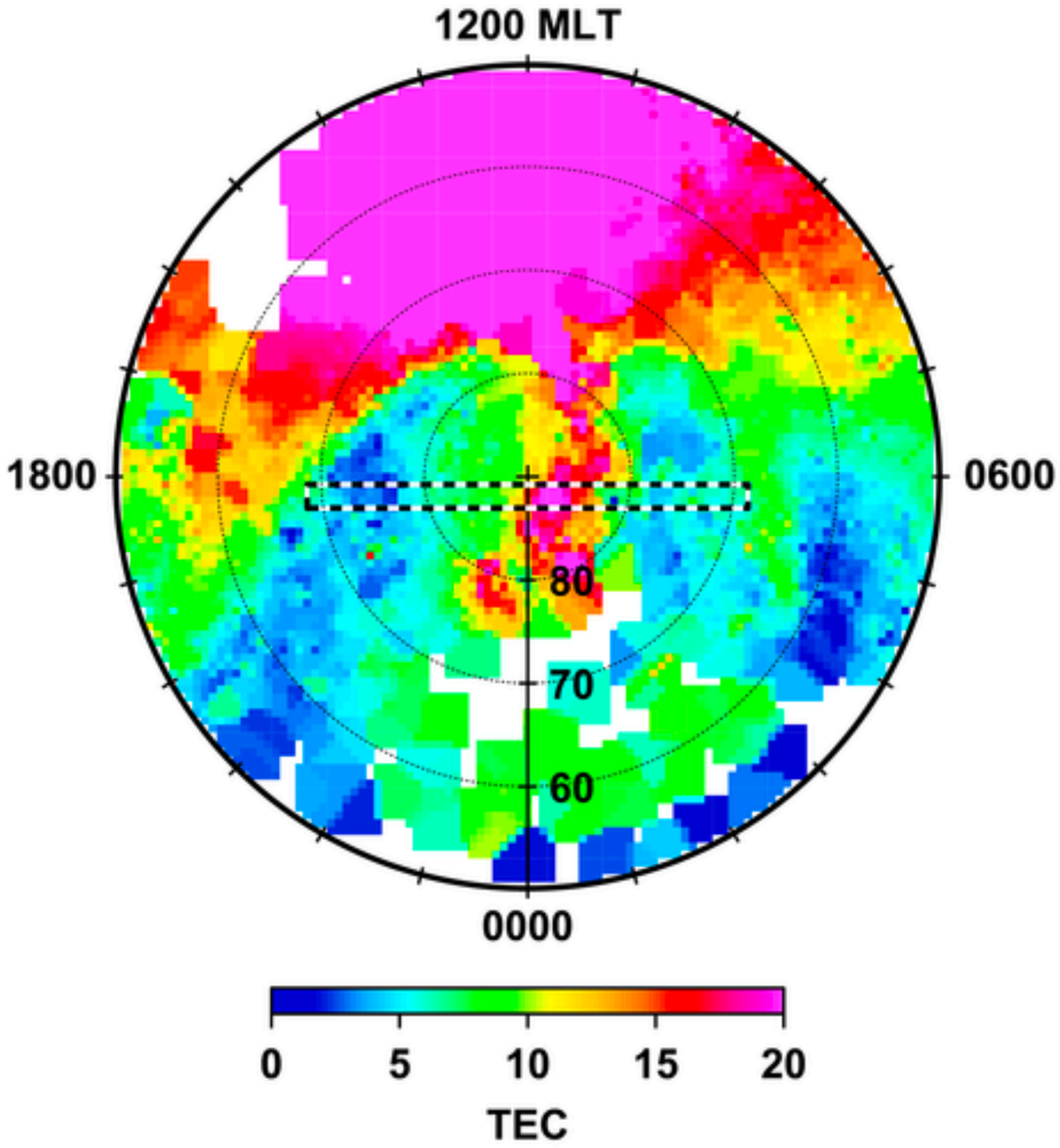


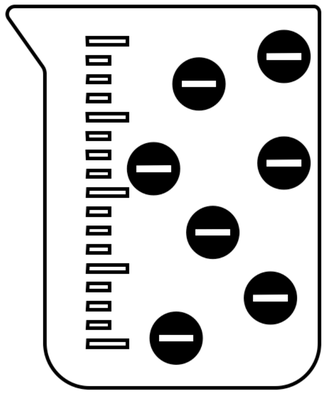






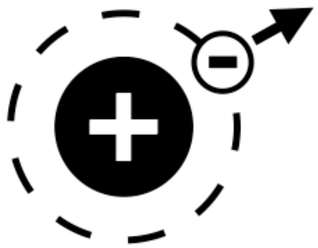
Polar Cap Patches & Ionisation Tongues

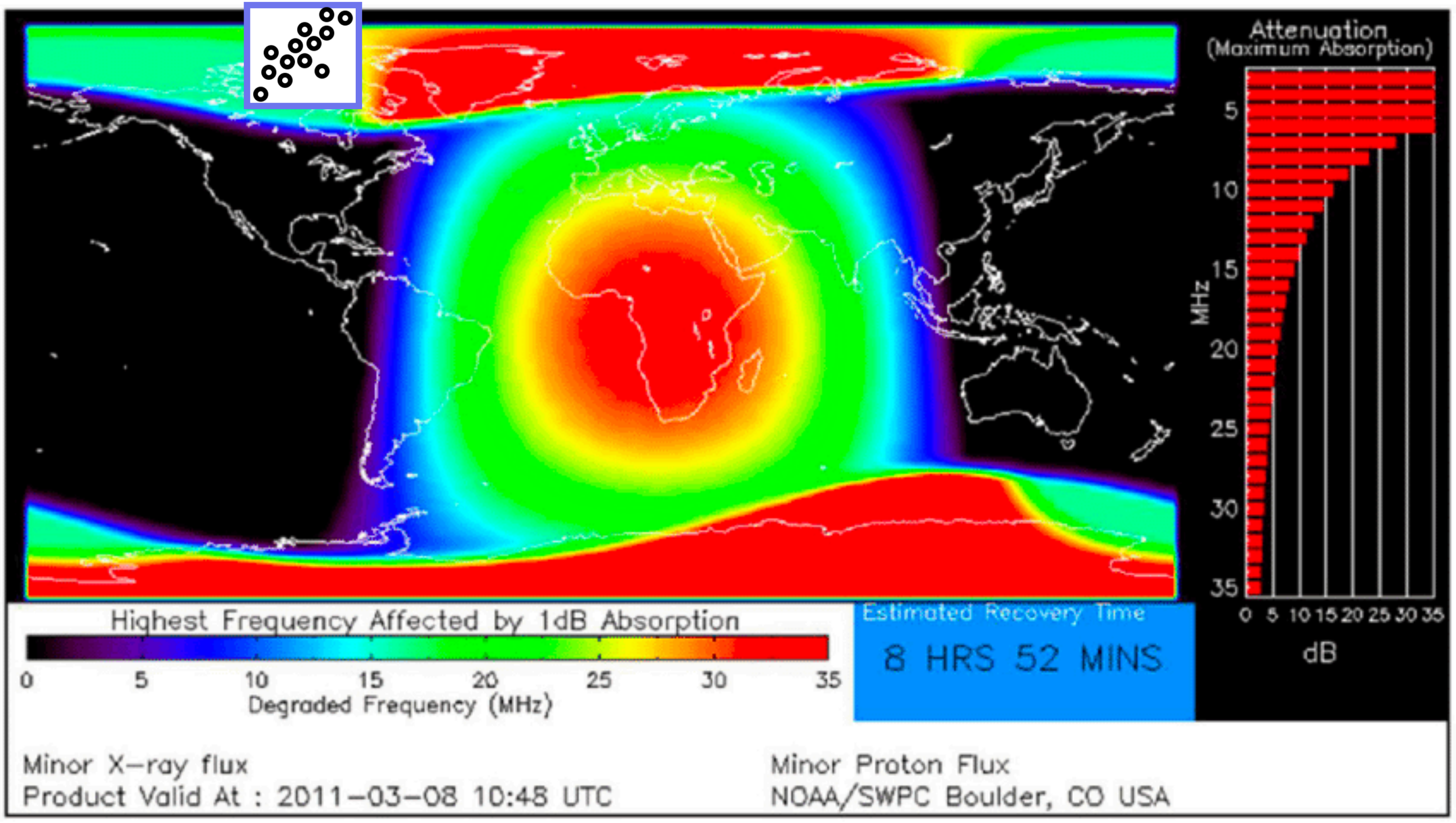




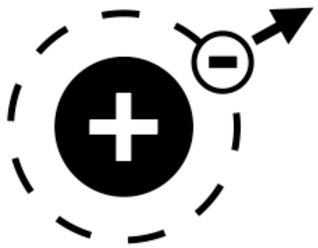
Irregularities

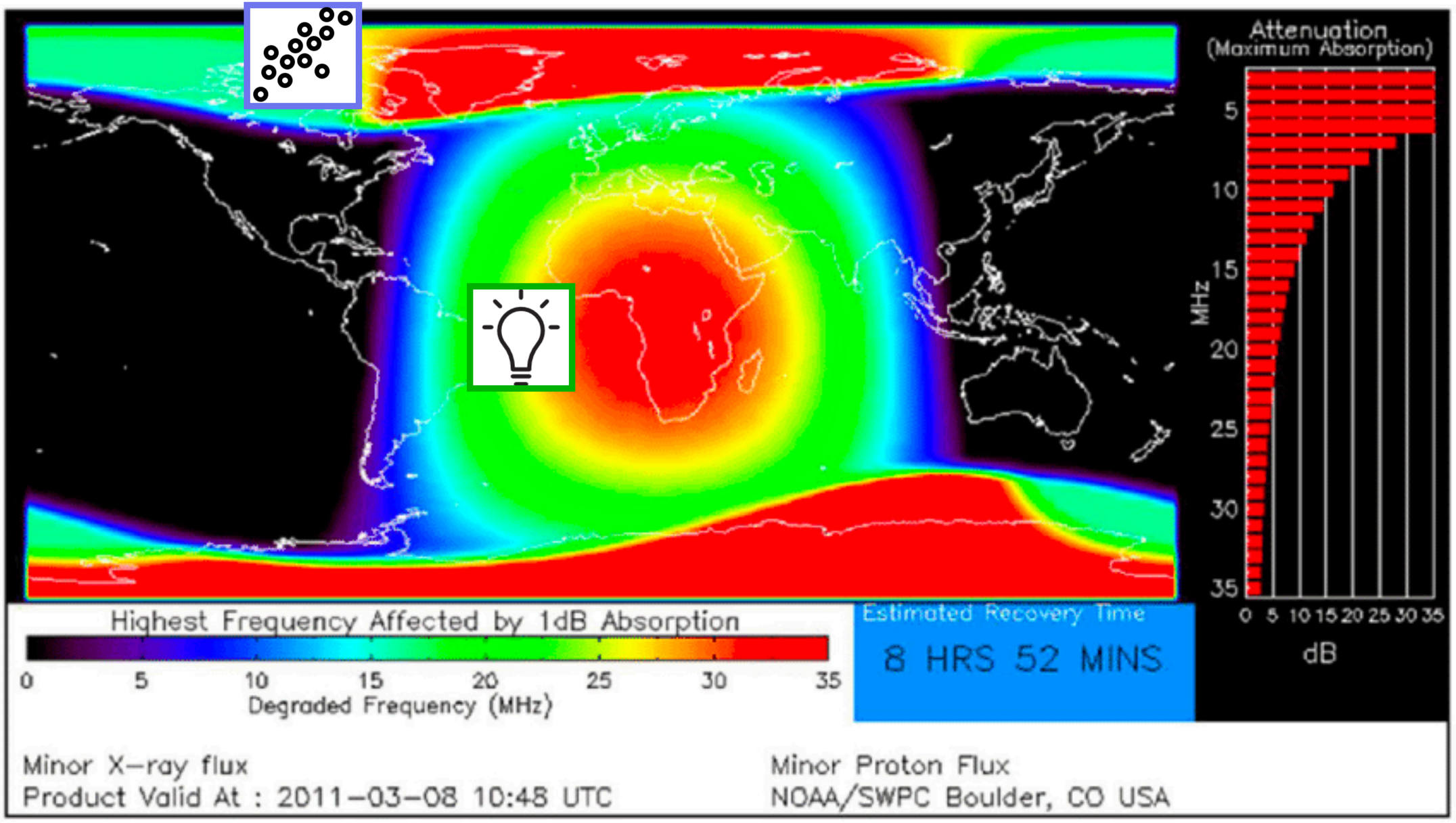
Polar Cap - Open Magnetic Field Lines



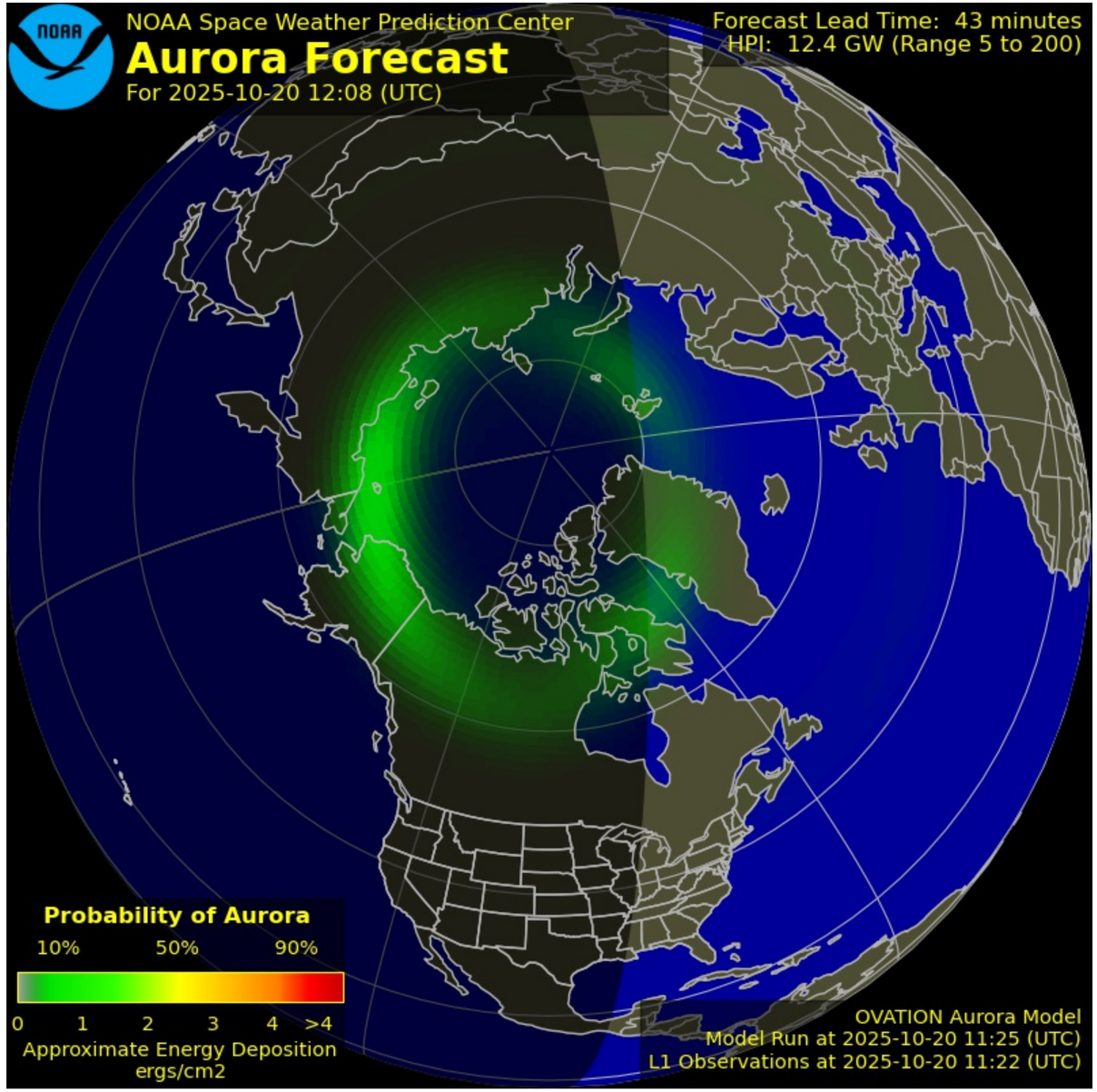


Polar Cap - Open Magnetic Field Lines

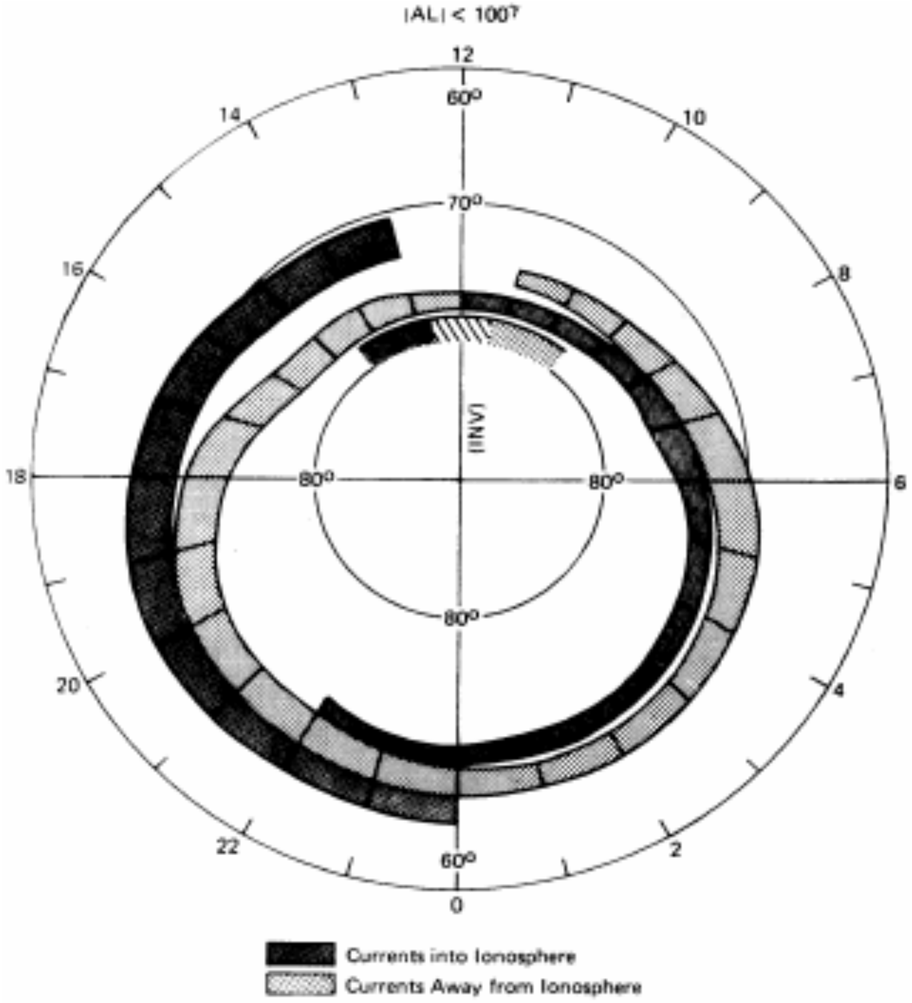


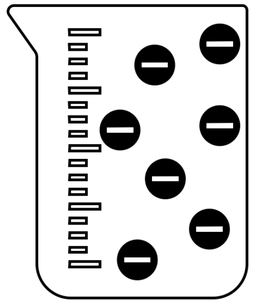


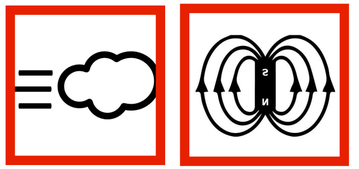
Auroral Oval

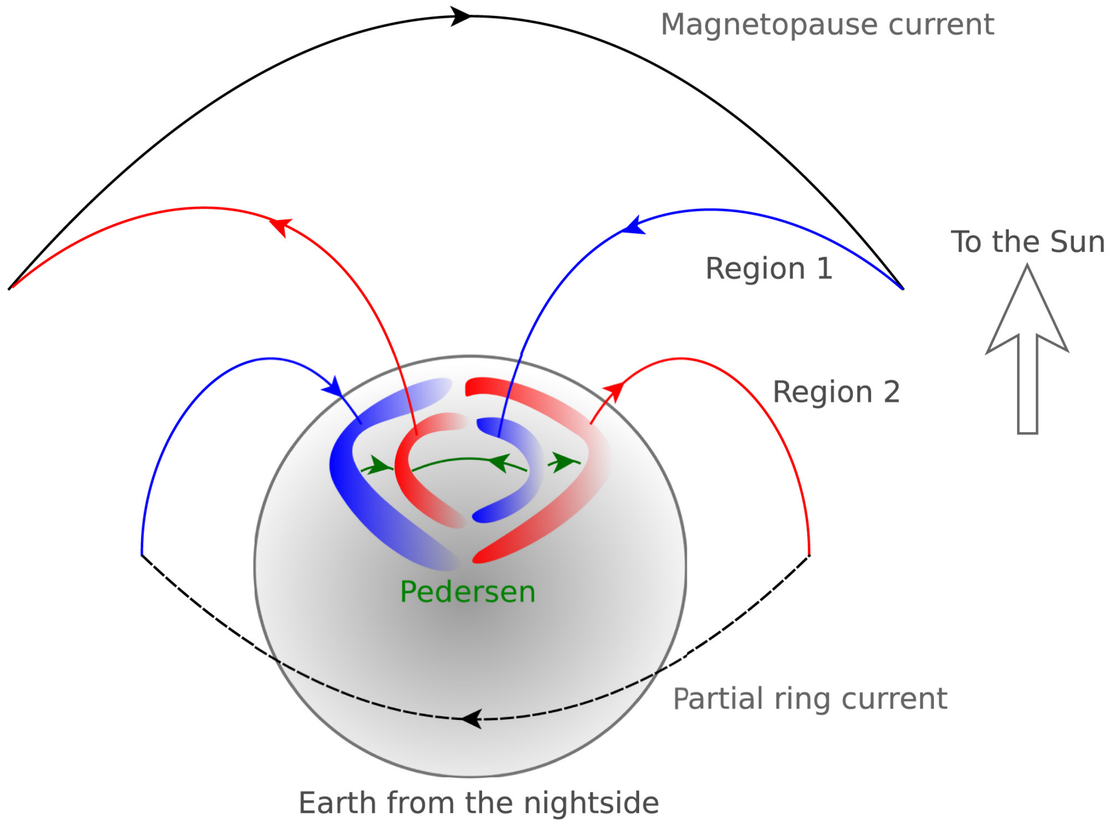


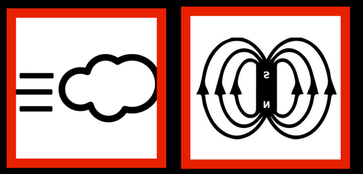
Auroral Oval

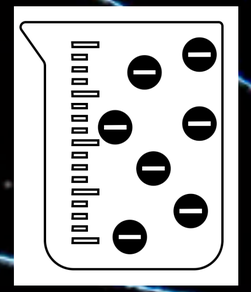


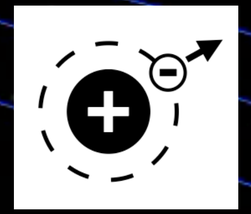












Increase and depletion of electrons
in the F-layer / auroral oval - Mid Lat

Increase of electrons due to Precipitating electrons
in the D-layer in the Auroral oval