Ionospheric Disturbances

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Space Weather Impacts Course, 2023-12-04

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Outline

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Response to geomagnetic storms

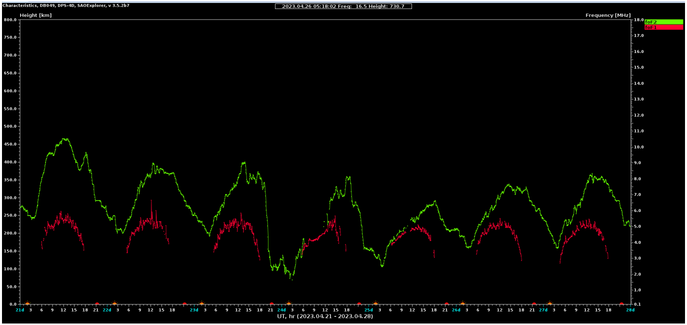
Geomagnetic/ionospheric storms

The most significant disturbances to the ionosphere result from solar events (CMEs, CIRs), propagating through the solar wind and interacting with the magnetosphere.

1. Energy injected into the ionosphere, mainly at high latitude.
2. As a result, the auroral oval expands.
3. This causes large scale movement of plasma towards the equator.
4. Drift along the magnetic field lines cause the ionosphere to move up, which can increase electron density ("positive storm phase").
5. Finally, upwelling of N_2 causes increased recombination, leading to a depletion of ionisation ("negative storm phase").

Geomagnetic storm effect at mid-latitude

The negative phase of a storm is always seen, and lasts for a few days. The positive phase is not always present (this depends among others things on the local time at storm onset).

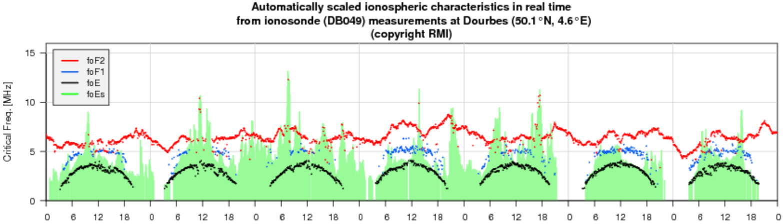


These ionospheric storms mostly affect the F_2 layer, as it is the one produced through plasma transport processes.

The negative phase of a storm has a major impact on HF radio communication frequencies (and other HF-based technologies).

Other radio reflection anomalies

Sporadic E layers



Sporadic E layers are thin (in altitude) reflecting layers around the altitude of the E layer, but with densities that can far exceed those of the F layer.

Formation of *Es* layers

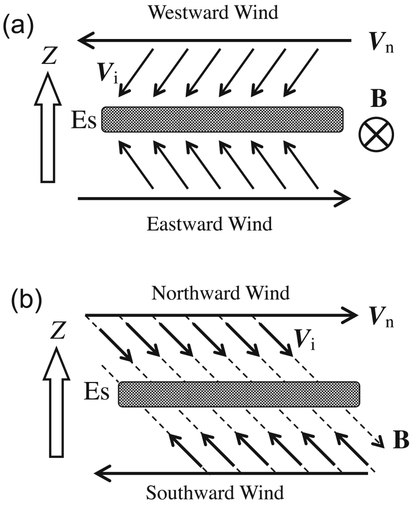
Es layers are (usually) formed by long-lived, metallic ions getting trapped at wind shear boundaries.

They can for very quickly, and persist for periods of minutes to hours.

There are strong seasonal patterns to *Es* occurrence; in Europe mostly around June solstice.

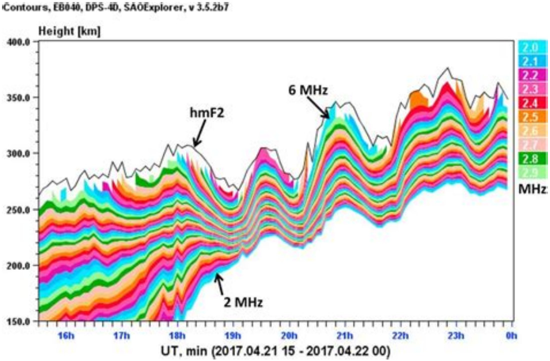
There are also regional variations, which are not really understood yet.

Occasionally, sporadic layers can be formed by other drivers, e.g. particle precipitation or large meteors.



Wave-like ionospheric disturbances

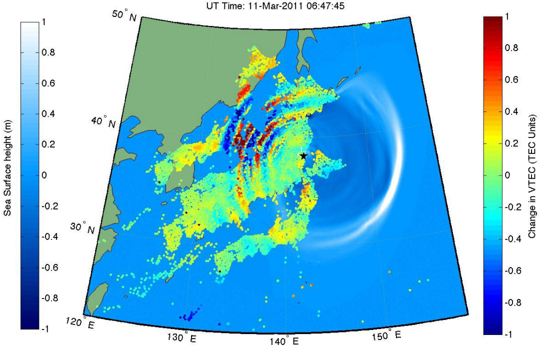
Waves of various scales (hundreds to thousands of km) and periods (several minutes to hours) can change the altitude and direction of radio reflections by the ionosphere.



This can lead to major disturbances in reflected signals, but also to disruption in high-precision GNSS positioning.

Sources of travelling disturbances

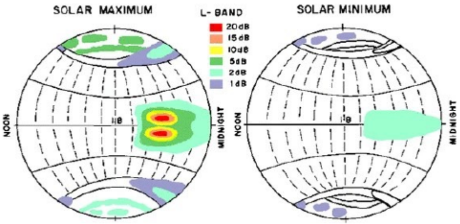
Such disturbances can be produced by a wide range of drivers, including geomagnetic storms, but also disturbances propagating from the lower atmosphere (e.g. due to typhoons, earthquakes, etc.), or even artificial sources (major explosions, rocket launches,...).



Scintillation producing disturbances

Scintillation

Scintillation is an important issue for transionospheric UHF signals.

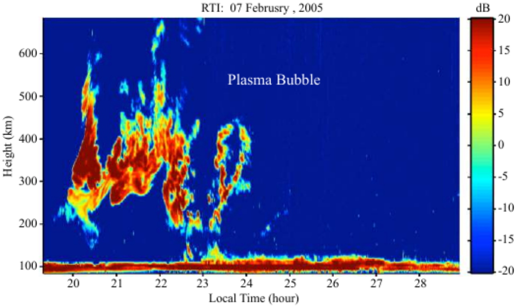


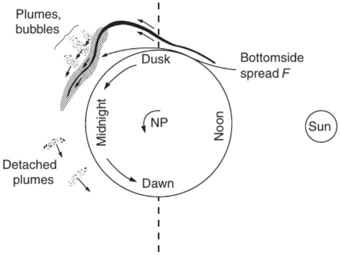
Global variation of amplitude scintillation fades at L band (after Basu et al. 1988a, b, colored by A.W. Wernik)

Although the effect on radio waves is similar, the equatorial, auroral, and polar-cap scintillation have different physical origins.

Plasma bubbles

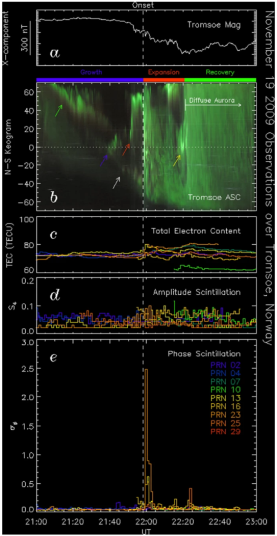
The equatorial scintillation is due to plasma bubbles (discussed before).





This is a rather common feature of the night-time equatorial ionosphere, but there are significant variations with solar activity and longitude.

Auroral oval structures



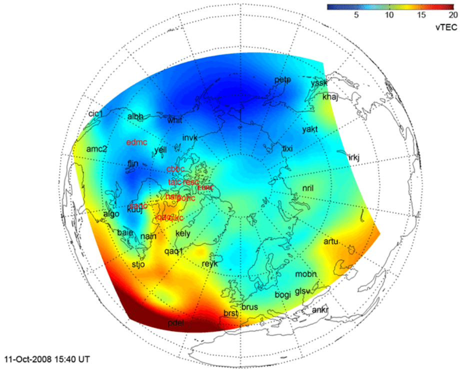
Scintillation in the auroral oval is due to small scale structures in the currents patterns associated with inflowing particles.

Within the auroral oval, there are various sub-regions more or less featuring such structures, and therefore scintillation. This is still a topic of ongoing research.

When the auroral oval expands in response to a geomagnetic storm, these features can be seen also at mid-latitude.

Structures in the polar cap

Arcs and patches of plasma can be driven from the day-side region over the polar cap, by the large scale convection patterns related to the IMF.

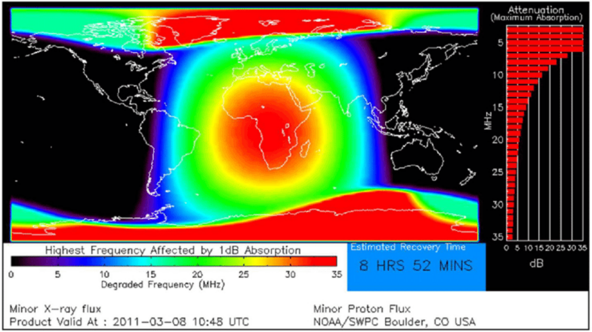


Note that the scintillation here is caused by patches of enhanced plasma density, while in the equatorial region the same effect is due to bubbles of decreased density.

Radio absorption events

Radio absorption in the *D* layer

Enhancement to *D*-region ionisation leads to absorption of HF radio waves.



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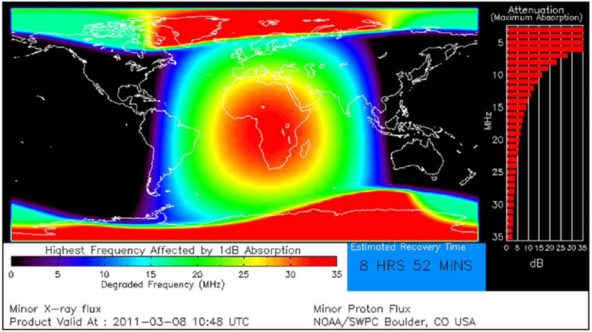
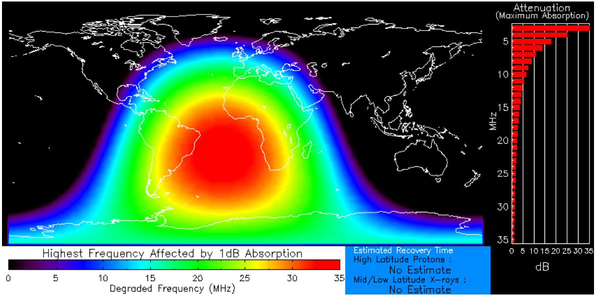


Question:

Why does ionisation in *D*-region cause absorption instead of reflection?

Solar flare effect

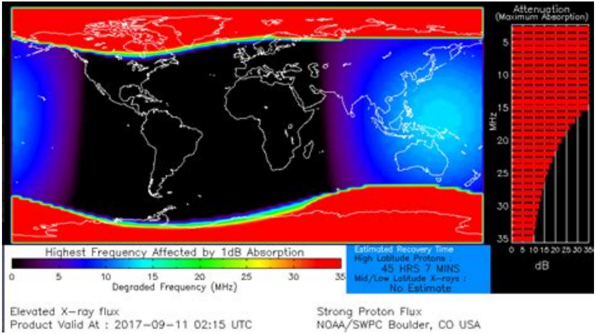
Hard X-rays can penetrate the thermosphere to altitudes below the *E*-region. The sun only emits significant intensity at these wavelengths during major flares.



The absorption in this case is most severe around the sub-solar point.

Effect of solar energetic particles

Low-altitude ionisation can also be produced by solar energetic particles (mostly high-energy protons), coming in from the solar wind along open field-lines.



These events cause severe absorption in the polar region, but strictly limited to the area of open field lines.

Summary

1. Three main effects of disturbances:
    1. unexpected radio reflections (or non-reflections),
    2. scintillation of transionospheric signals,
    3. excess absorption of radio waves.
2. Each of these effects can however be produced through multiple physical processes.
3. In general, the high latitudes suffer most disturbances, the mid-latitudes the least.
4. Most types of disturbances are more common and more severe at high solar activity.

The end!

Questions?