High & low latitude ionosphere

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Role of the ionosphere and space weather in military communications

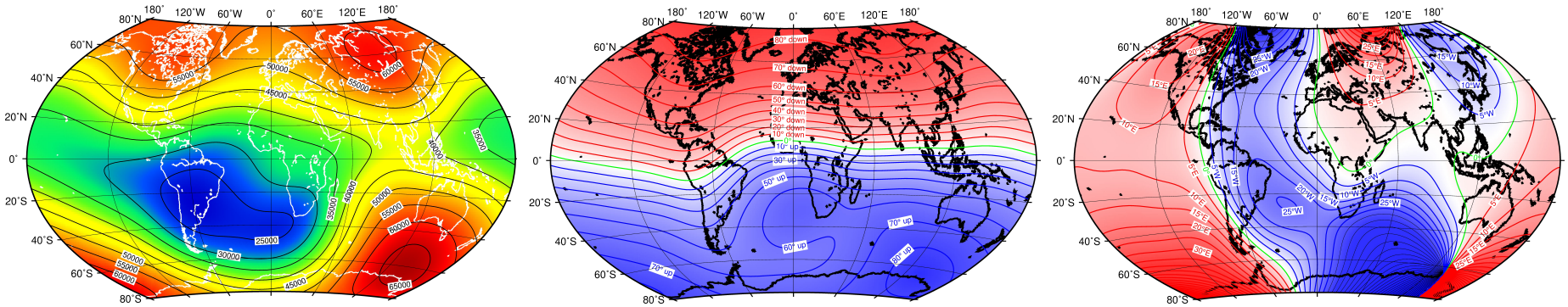
Solar-Terrestrial
Centre of
Excellence

Outline

The geomagnetic field

The global geomagnetic field

Besides solar irradiation, the ionosphere is strongly influenced by the geomagnetic field.



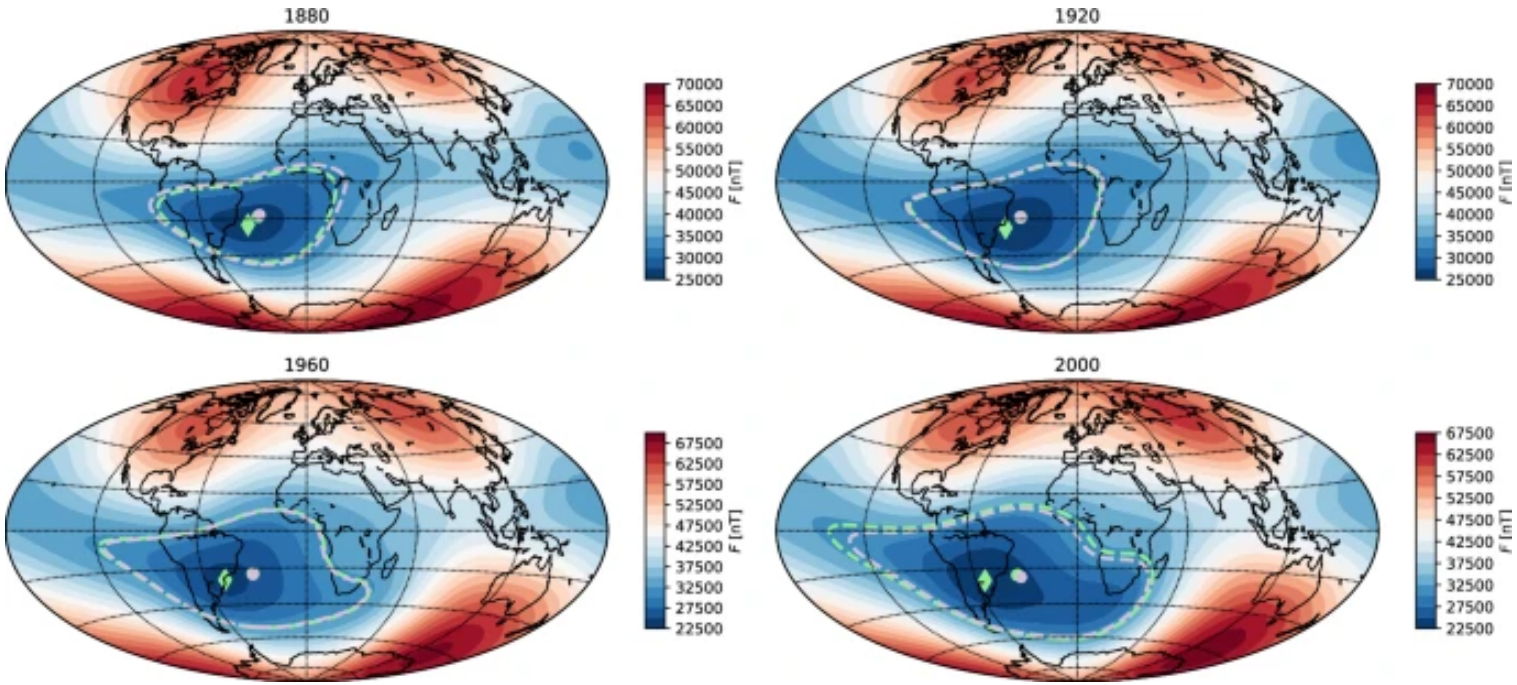
The best fitting dipole for the geomagnetic field is tilted from the rotational axis, but it is also laterally displaced by about 700 km.

1. Latitudinal variation in strength and inclination.
2. Orientation of neutral winds to the magnetic field varies a lot.
3. Regions of weaker/stronger magnetic field at the same latitude.

The South-Atlantic Anomaly

The most important longitudinal anomaly is over equatorial South-America and the Atlantic Ocean: both low field intensity and declination anomaly.

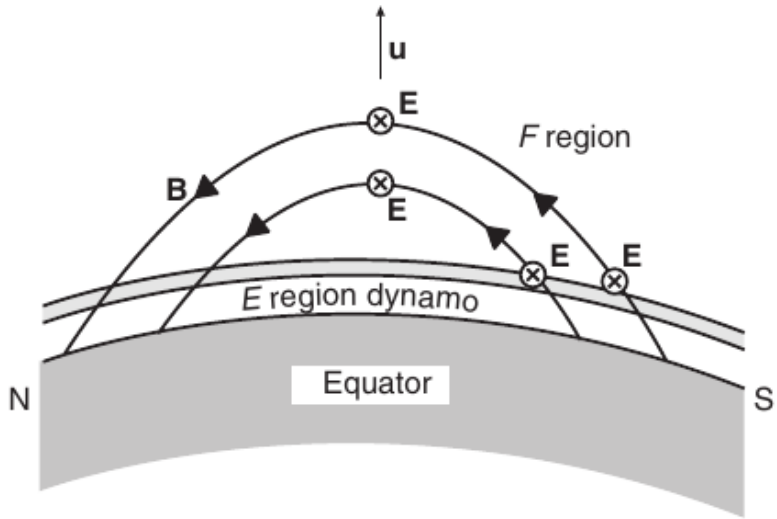
- Particle precipitation from the radiation belts increases ionisation, especially in the lower ionosphere.
- Thermospheric winds not aligned with magnetic field.
- Often peculiar behaviour during geomagnetic storms.



Low-latitude ionosphere

The equatorial ionisation anomaly

1. Thermospheric wind creates dynamo **E**, eastward during day-time.



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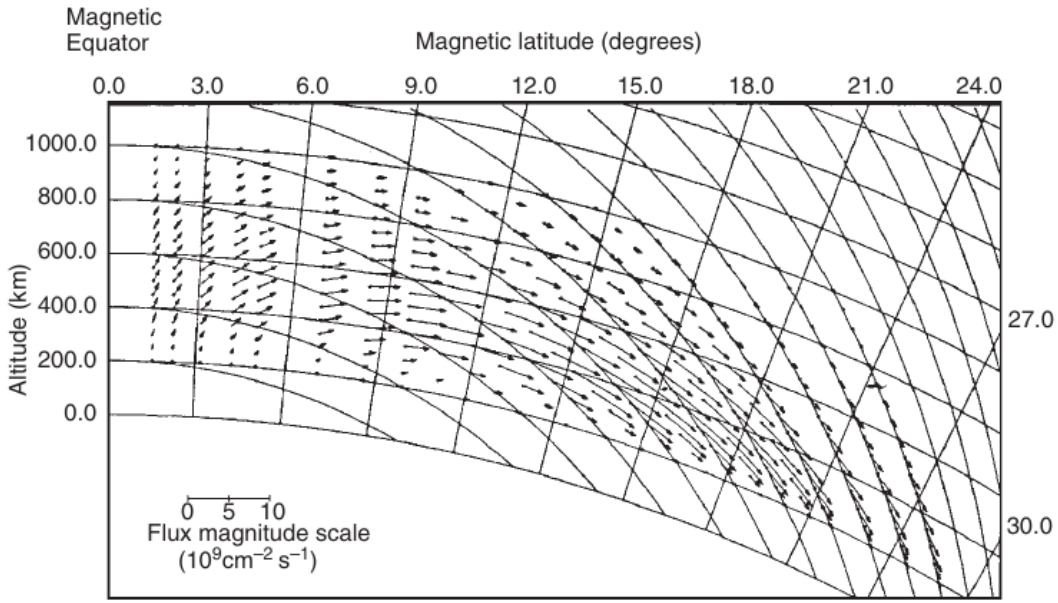

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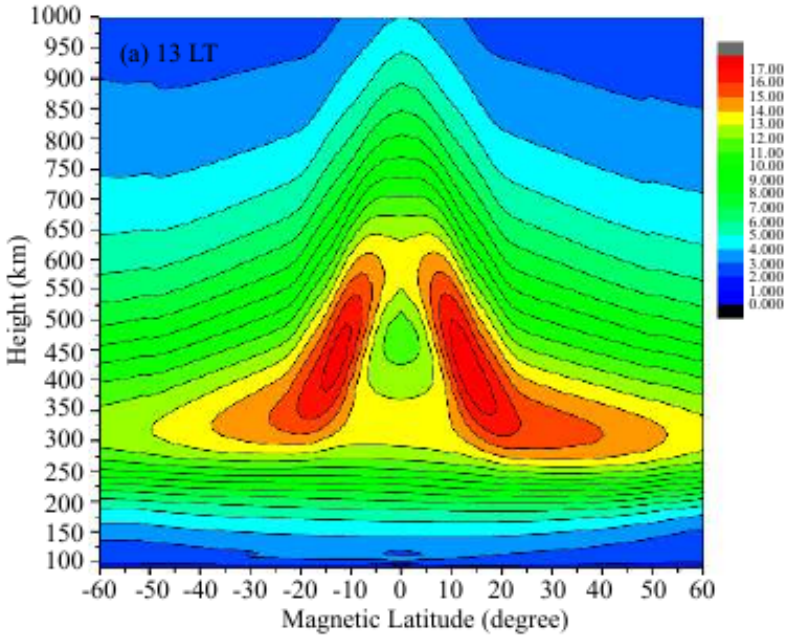

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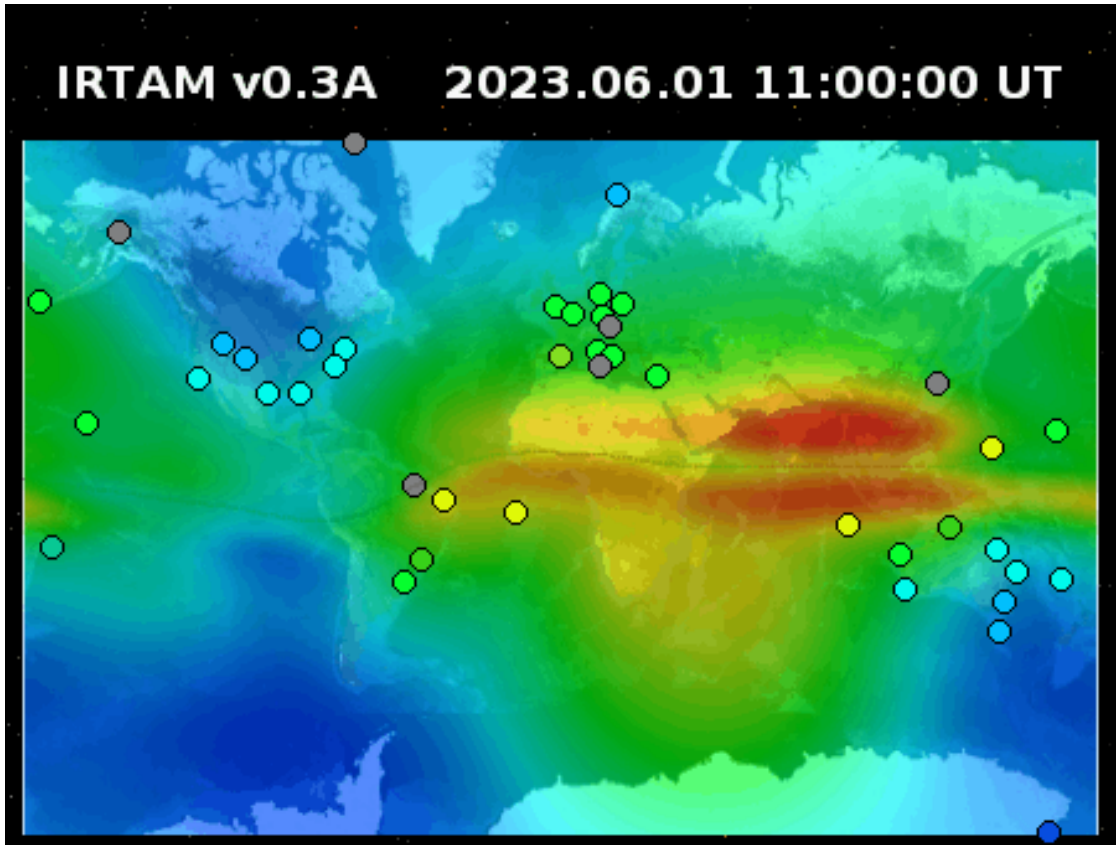
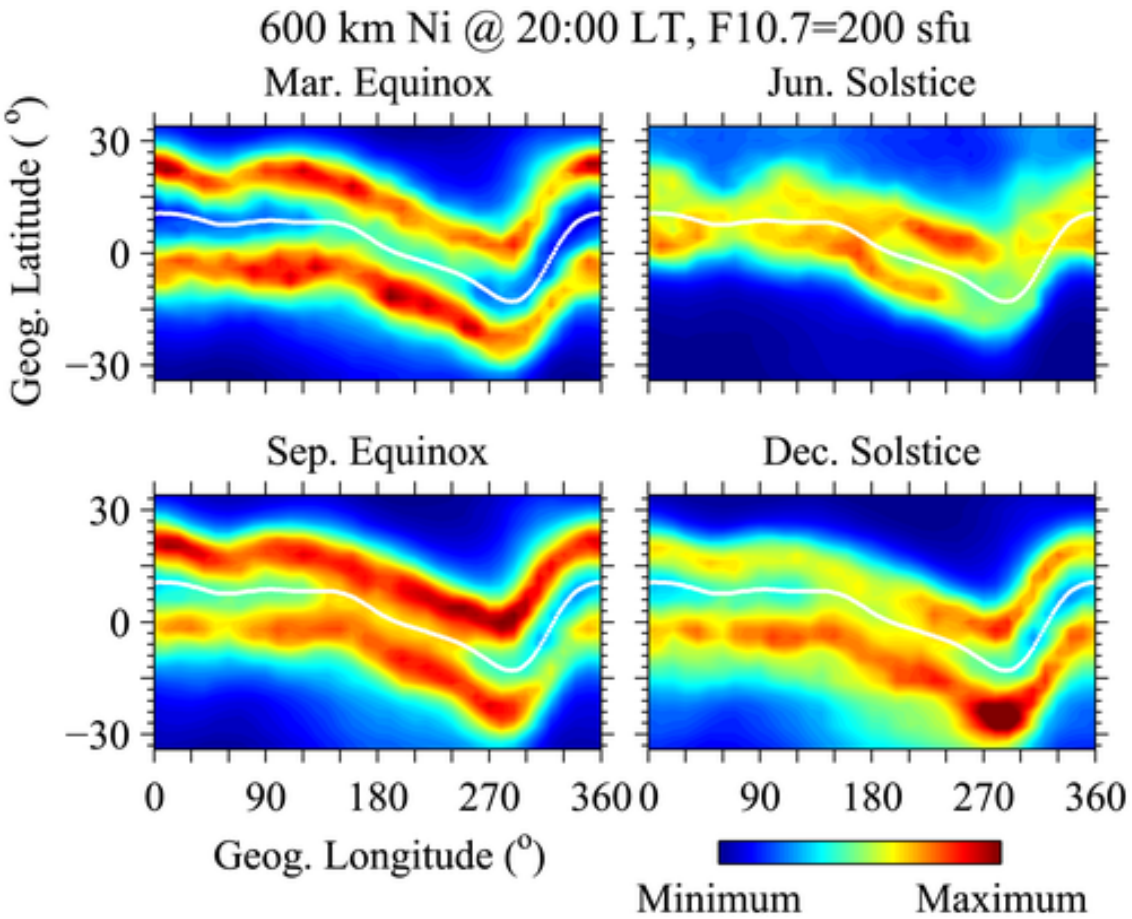
4. This causes the "equatorial anomaly" or "Appleton anomaly."



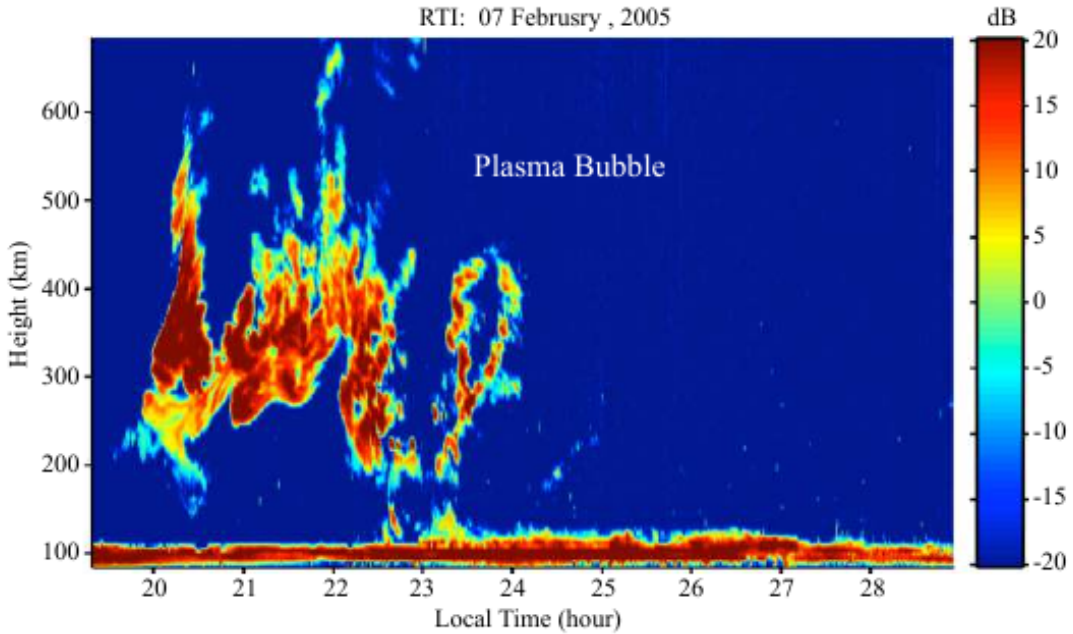
Longitudinal structure of the EIA

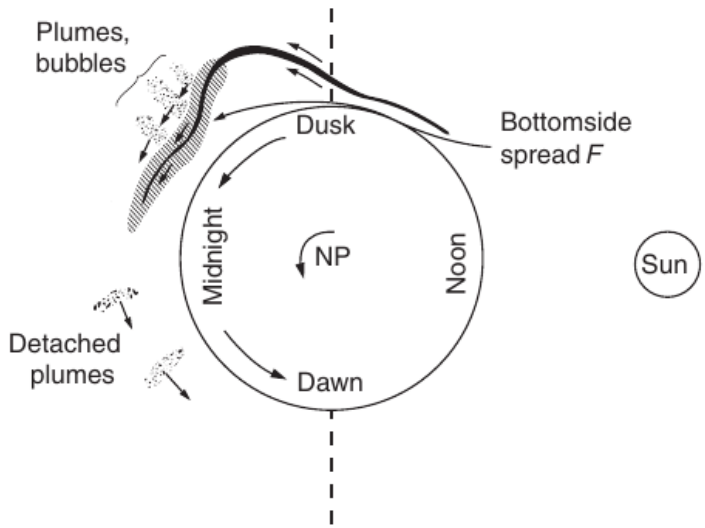


- There is longitudinal structure in the Equatorial Ionisation Anomaly, most importantly related to the South-Atlantic Anomaly.
- There is seasonal variation, due to orientation between neutral winds & magntic field.

Plasma bubbles

A common feature of the equatorial region is the formation of plasma bubbles after sunset.





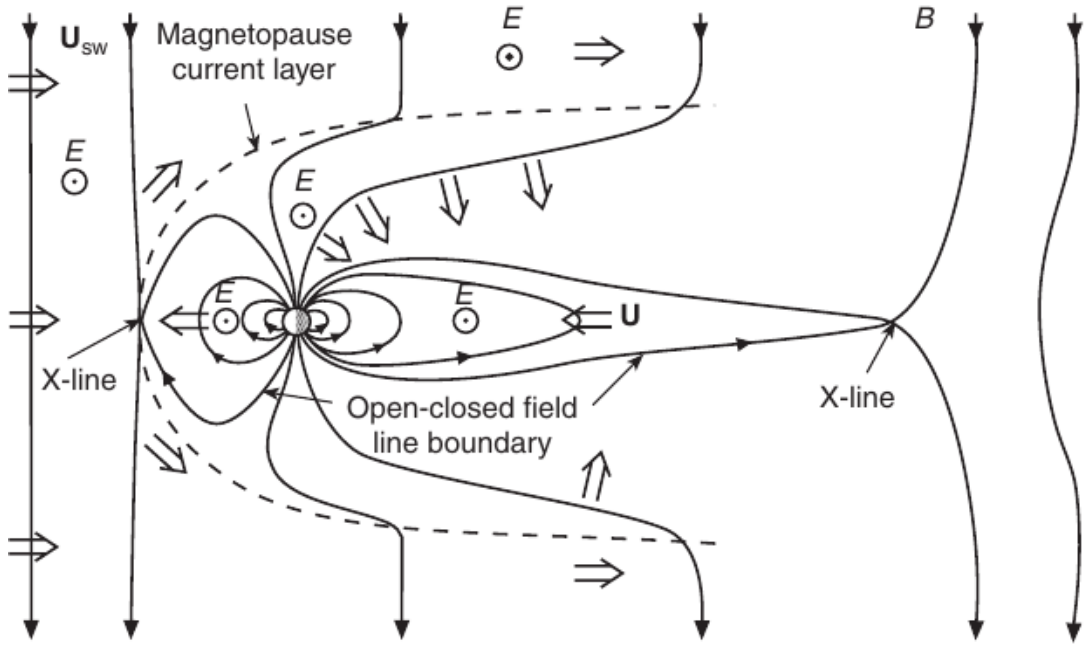
Plasma bubbles are formed at *Rayleigh–Taylor instabilities* when the lower ionosphere rapidly recombines after dusk, creating very strong electron density gradients. They form below hmF_2 and rise to over 700 km, while drifting eastward.

Consequences for radio systems

1. Plasma bubble cause (sometimes severe) scintillation in trans-ionospheric signals (VHF, UHF, L-band), as well as irregular reflections in HF.
2. Plasma bubbles can occur at any time, even when there is no geomagnetic storm, but the occurrence rate varies with season and solar cycle.
3. The Equatorial Ionisation Anomaly causes some strong gradients, complicating the finding of useful HF frequencies: *MUF* at the same distance in east-west direction may be very different from that in north-south direction!

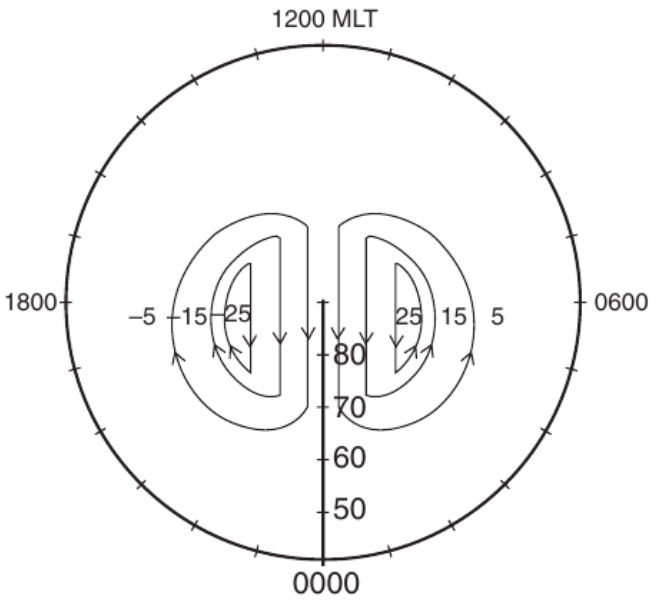
High-latitude ionosphere

High latitude ionosphere



In the *polar cap*, magnetic field lines are open, connected to the interplanetary field. The *auroral oval* is the transition region to closed field lines.

The polar cap

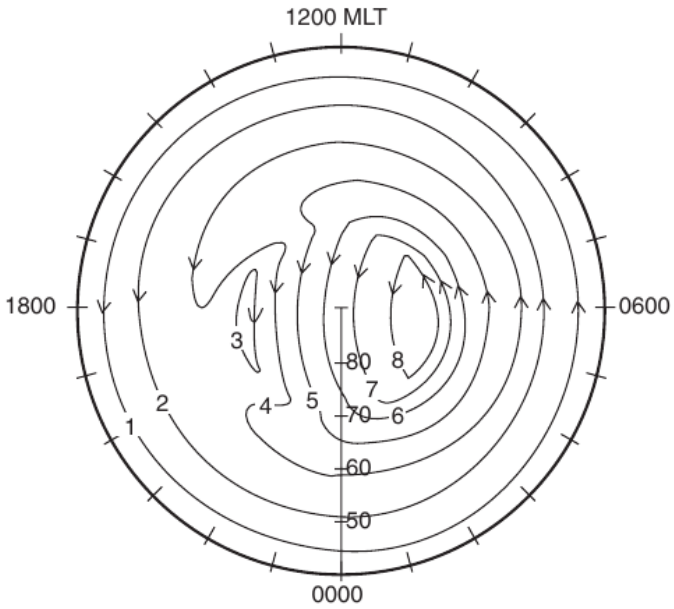


- Solar wind blowing over the polar cap, across the nearly vertical magnetic field, induces an electric field $\mathbf{E} = -\mathbf{v} \times \mathbf{B}$, pointing from dawn to dusk.
- This **E** field in turn causes plasma to drift around the polar cap towards day side.
- More complicated because co-rotation drag and magnetic pole offset.

When the interplanetary magnetic field is northward, these convection cells break up into more complex, multi-cell configurations.

Particle impact is an important source of ionisation, especially in winter.

The polar cap



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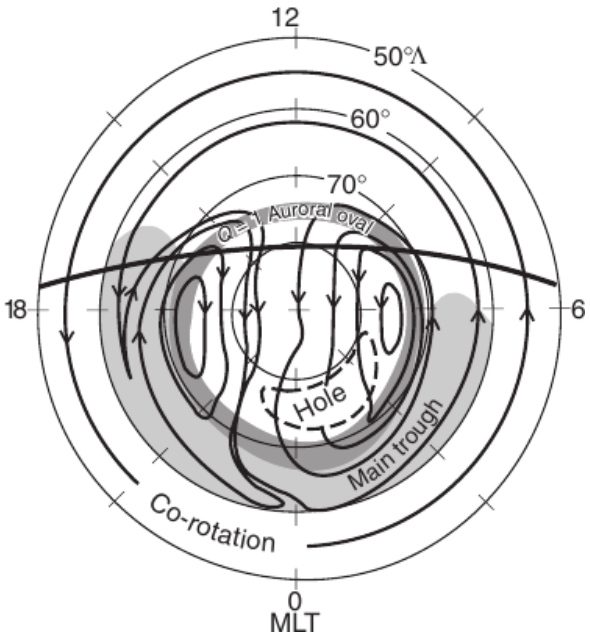

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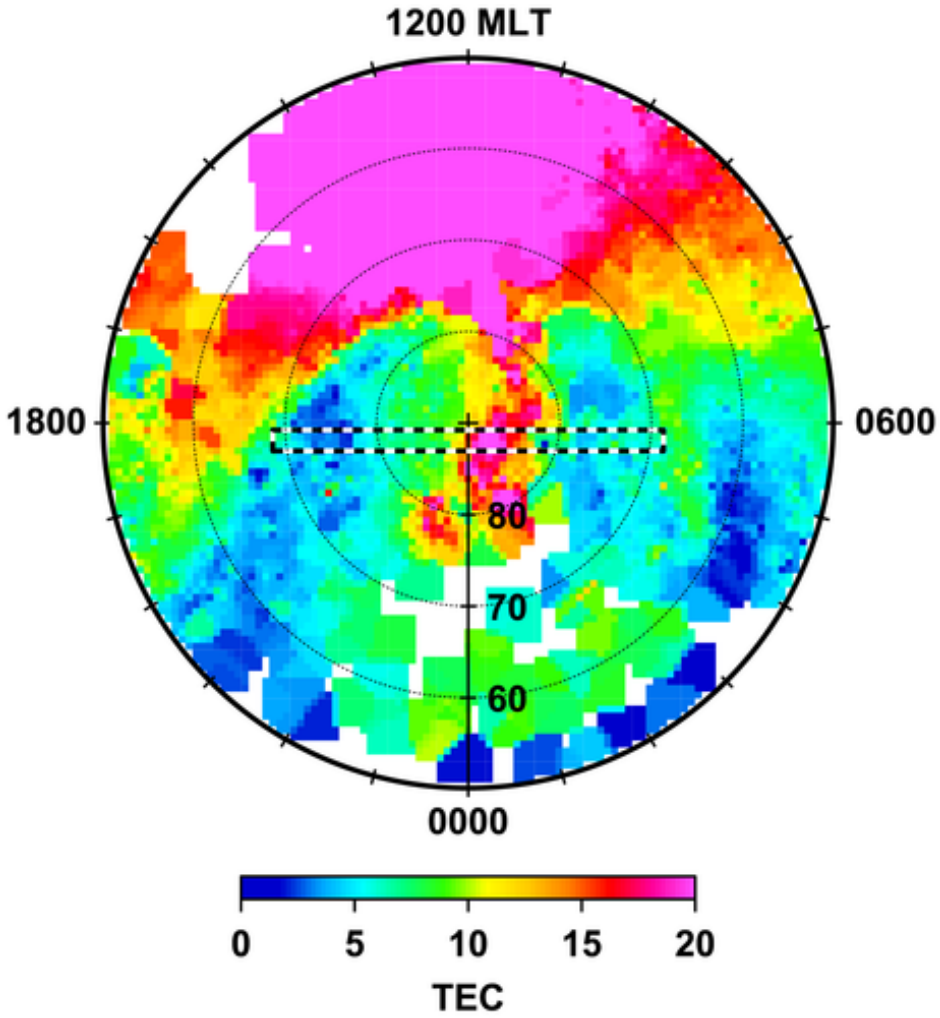
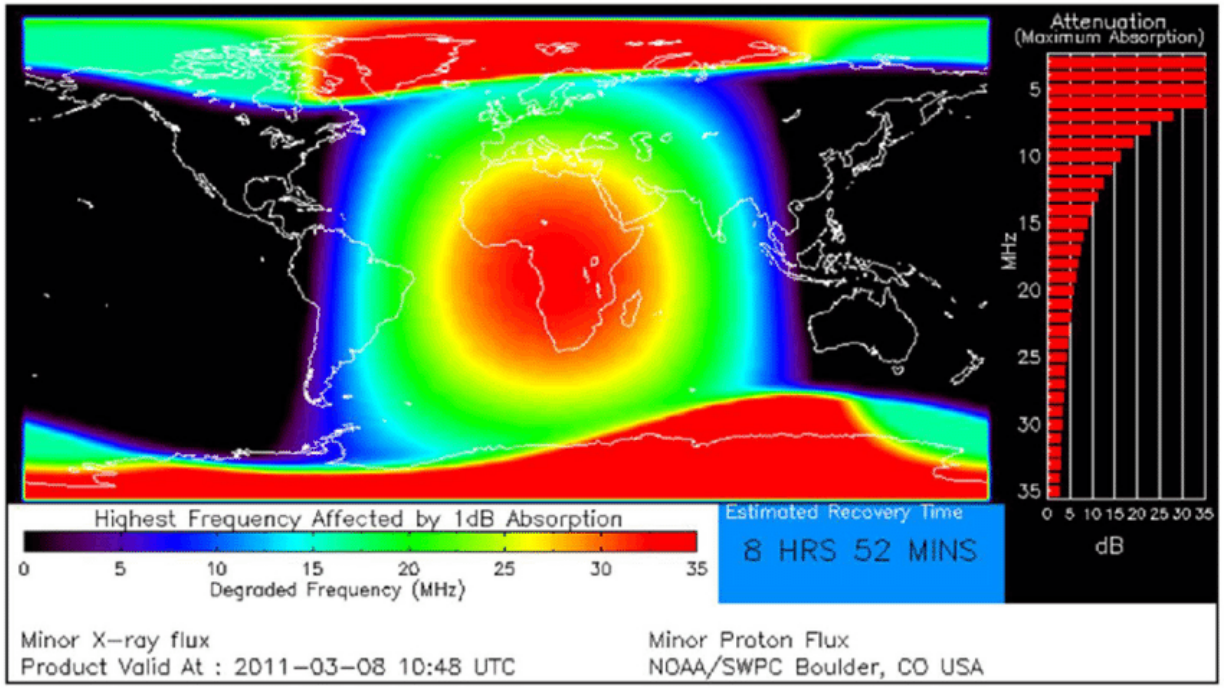
Polar cap patches & ionisation tongues

- The neutral wind can drag ionisation into the dark side of the polar cap, producing ionisation patches and tongues.
- Such structures can cause unexpected reflection patterns in HF as well as scintillation of trans-ionospheric signals.
- The relevant physical processes are still poorly understood, and currently hard to forecast in detail.



Radio absorption in the *D* layer

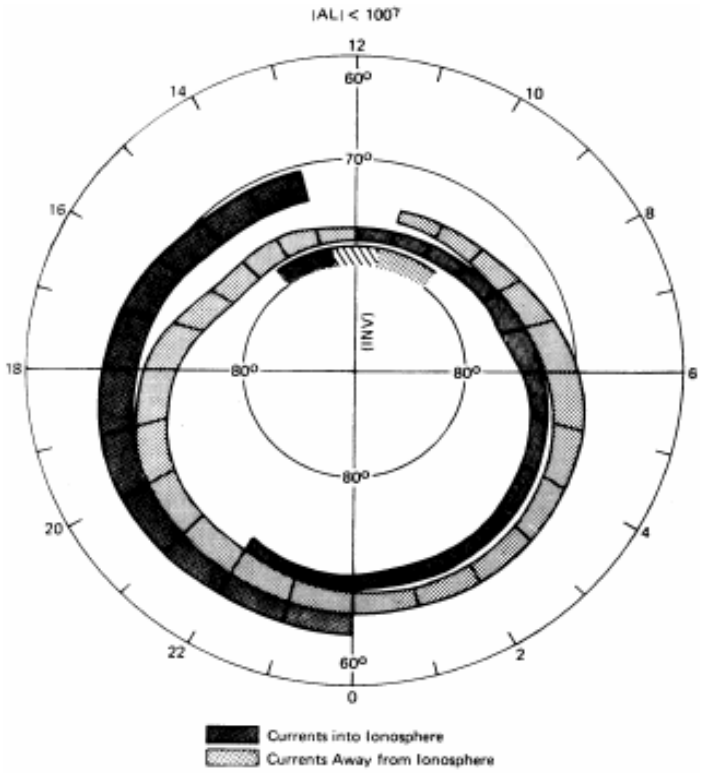
Enhancement to *D*-region ionisation leads to absorption of HF radio waves.

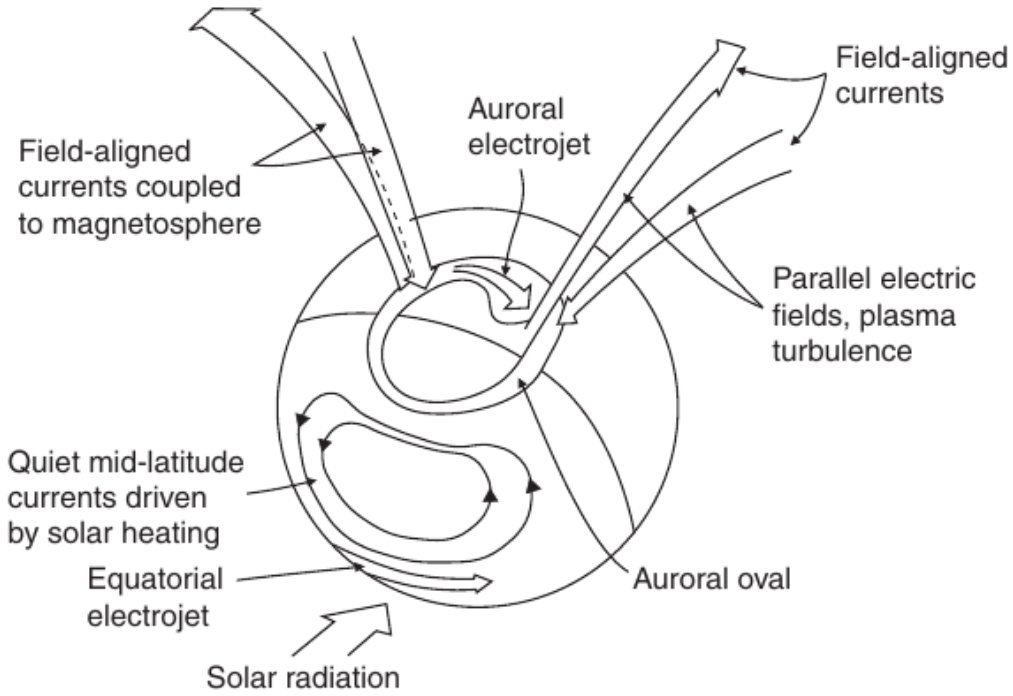


In the polar cap, X-ray impact is not so important. But: open magnetic field lines allow high energy particles to enter the ionosphere, producing similar effects.

The auroral oval

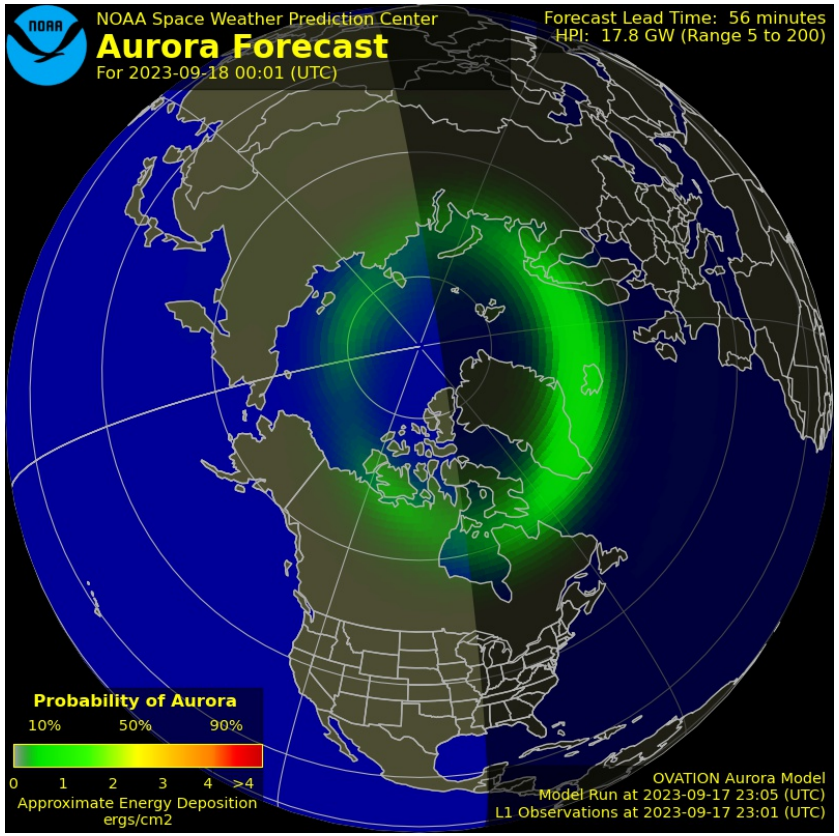
Defining feature: magnetic field lines connecting to the plasma sheet. This allows for particles to precipitate, producing a complicated current system in the auroral ionosphere.





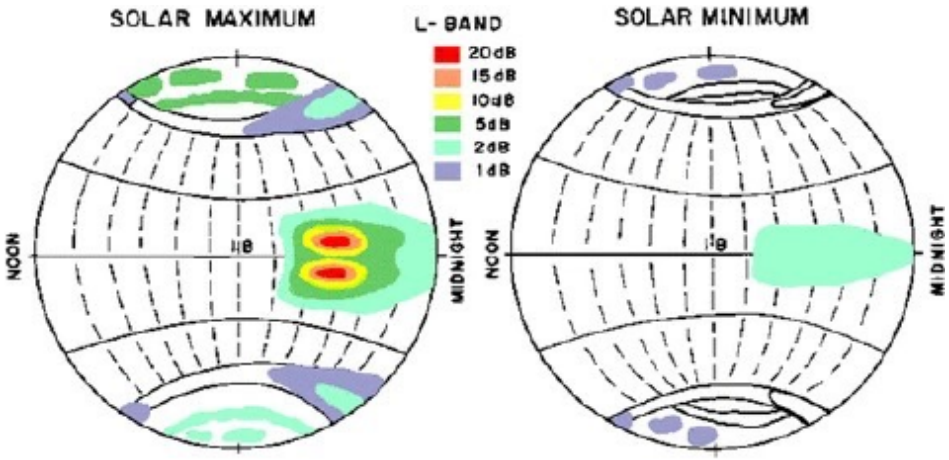
Radio in the auroral oval

- The auroral oval has many structures and instabilities, due to the various currents and particle streams interacting.
- This is in particular the case for the night-side of the oval, and especially during geomagnetic storms.
- As a result: many (often unpredictable) perturbations in all radio bands.



Global occurrence of scintillation

Scintillation is an important issue for transionospheric radio signals.



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

There are different sources, affecting different latitudes:

1. Plasma bubbles, mostly in the post-sunset equatorial ionosphere.
2. Polar cap patches etc. and auroral oval structures in the high latitudes.

At mid-latitudes, scintillation only occurs when the auroral oval expands during major geomagnetic storms.

Summary

The high and low latitude ionosphere is very different from that of mid-latitudes, due to the structure of the geomagnetic field.

1. Low latitude:
   - Dominated by the Equatorial Ionisation Anomaly (which has some longitudinal structuring).
   - EIA leads to instabilities and plasma bubble formation after sunset.
2. High latitude:
   - Polar cap: thermospheric winds blow patches of ionisation into the PC, which can cause perturbations in all radio signals.
   - Auroral oval: the most complex region of the ionosphere; often unpredictable radio conditions.

Scintillation and absorption occur in different regions through different physical processes, so one has to pay attention to many drivers.

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The end!

Questions?