Monitoring the ionosphere

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Role of the ionosphere and space weather in military communications

Solar-Terrestrial
Centre of
Excellence

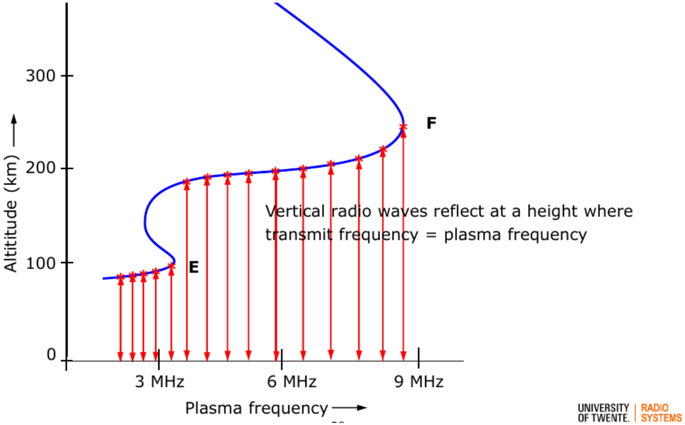
Outline

Introduction

How to observe the ionosphere?

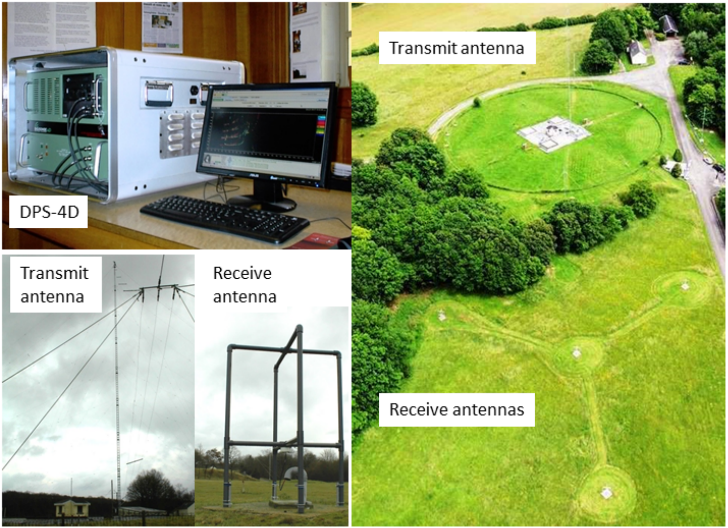
1. *in situ* (sounding rockets, satellites): very good, but limited in coverage and expensive
2. Using radio waves:
    1. Trans-ionospheric signals (GNSS, radio telescopes,...)
    2. Reflection from the ionosphere (ionosonde, Doppler sounder,...)
    3. Incoherent scatter radar

The principle of the ionosonde

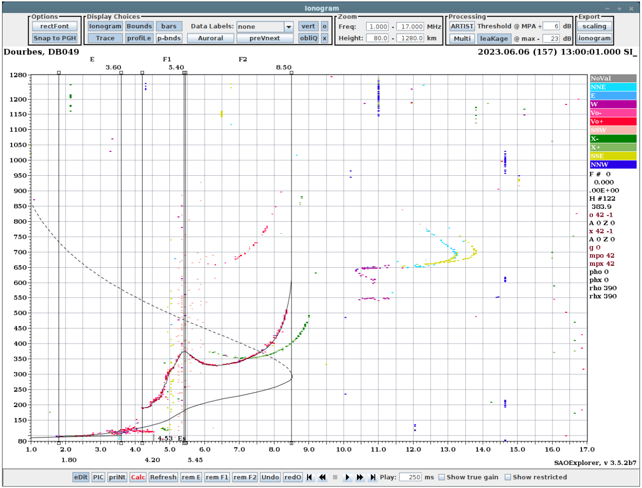


1. Transmit various frequencies, one after the other.
2. For each frequency, register the time of arrival for the echoes (if any).
3. From the arrival times, reconstruct electron density profile up to hmF_2.
4. Monitoring of VLF beacons (for the *D* layer).

The Dourbes Ionosonde



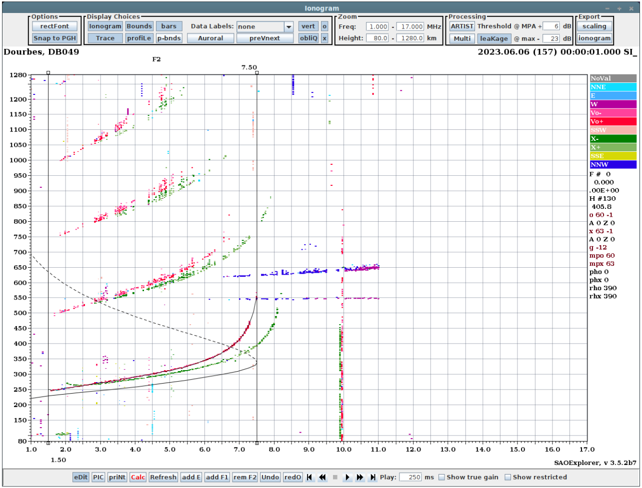
A quiet, day-time example



All the main layers visible.

Minor sporadic-*E*, up to 4.5 MHz.

Oblique trace from Spanish ionosonde.

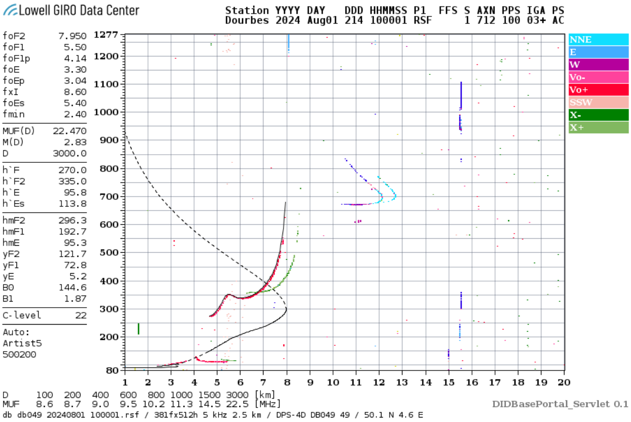


Only a single F-layer exists.

foF_2 is (somewhat) lower.

In this case, hmF_2 close to day-time value.

Ionogram derived characteristics



- Min. & max. frequencies from each layer (f_oF_2, $foEs$, f_min,...).

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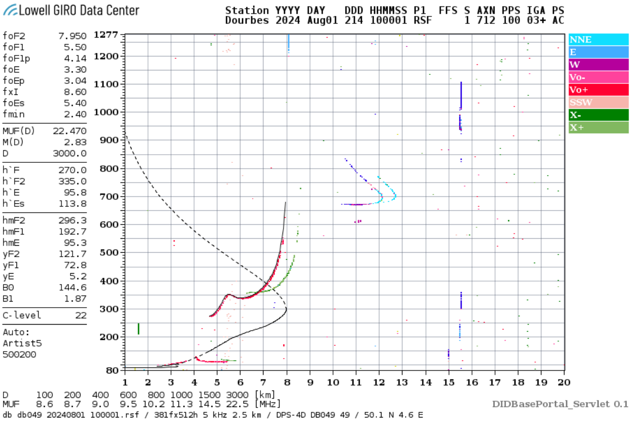

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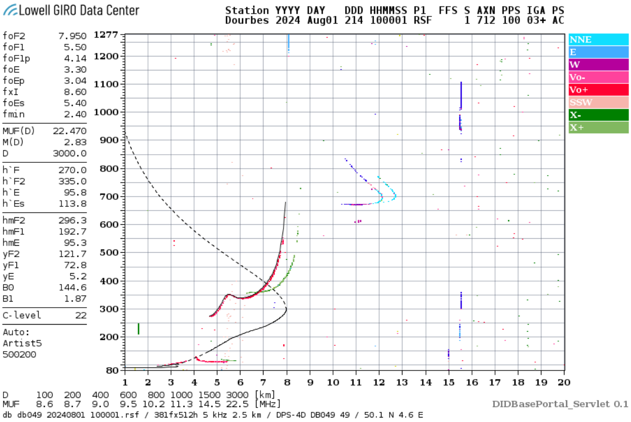
- *MUF* for some distances.



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- *MUF* for some distances.
- Measured heights of layers ($h'F_2$, $h'E$,...).

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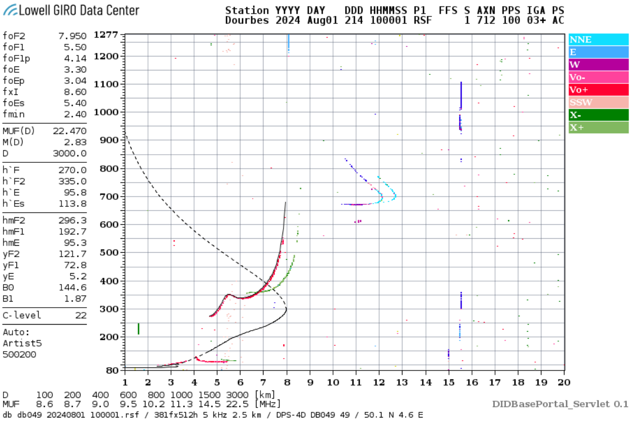
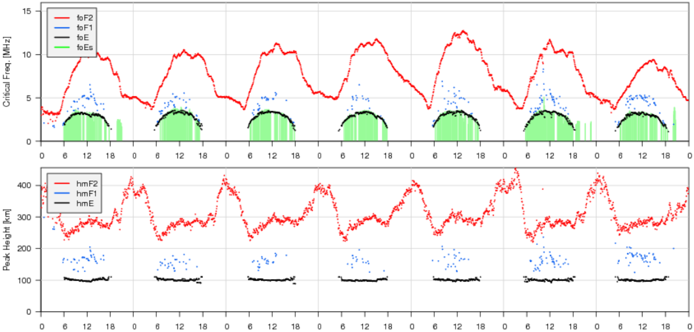


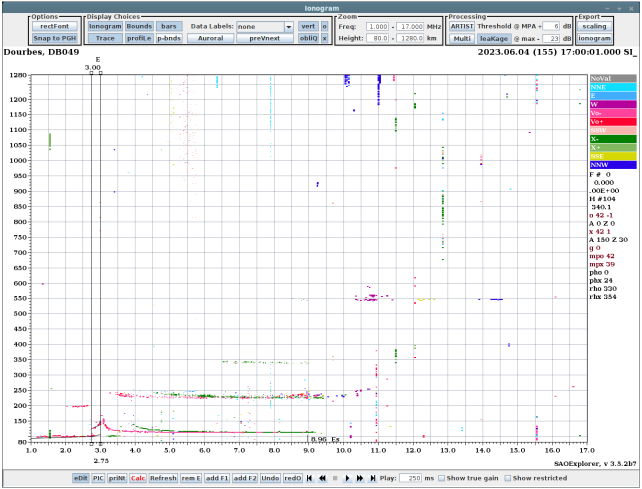
- Min. & max. frequencies from each layer (f_oF_2, $foEs$, f_min,...).
- *MUF* for some distances.
- Measured heights of layers ($h'F_2$, $h'E$,...).
- Real heights, compensated for retardation, and other shape parameters.

Automated ionogram interpretation



From the ionosonde, we can obtain (automatically, in real-time) most ionospheric weather parameters. The main exception is *TEC*.

Sporadic-*E*

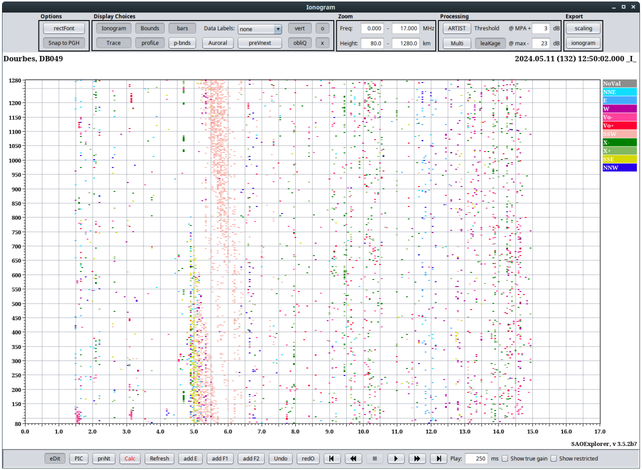


Sporadic *E*-layers: very thin but very high electron density layers below the *F* layer.

Little effect on the *TEC*, but makes Ionosonde soundings impossible.

Also lower ionosphere absorption can prevent ionogram soundings.

D-layer absorption

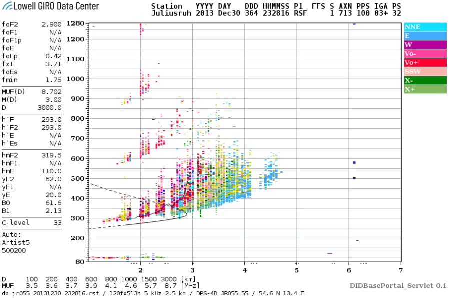


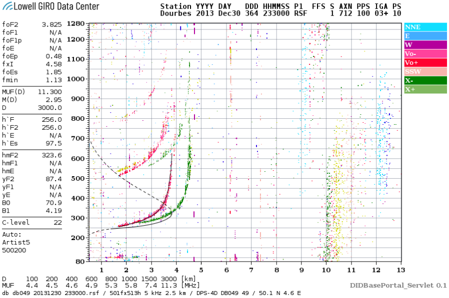
The ionosodne does not record reflections from *D*-layer, but from the layers above.

In case of severe HF absorption events, no signals are recordedd at all.

Scintillation ↔ spread-*F*

Example of expanding auroral oval during geomagnetic disturbances.

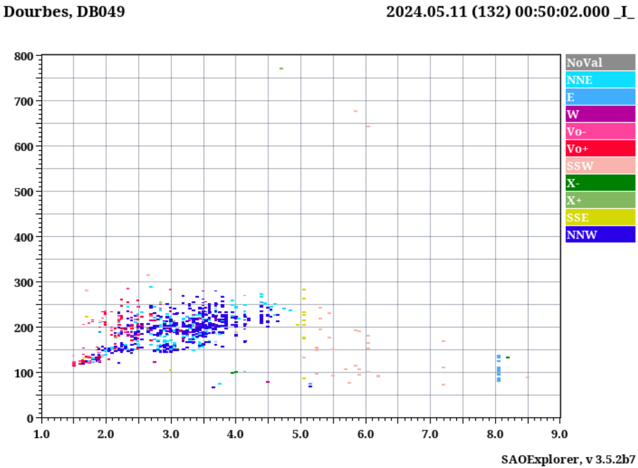




The auroral oval extends here to between Juliusruh (55°N, left) and Dourbes (50°N, right). Spread-*F* in ionograms is associated with scintillation in GNSS signals.

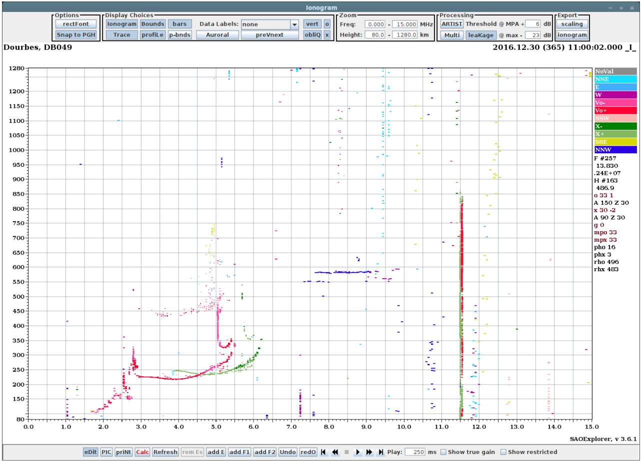
Auroral particle precipitation

During major disturbances, precipitating particles can strong cause (night-time) sporadic layers; the is usualy associated with visible auroras.



Small scale disturbances

Electron density gradients and small scale travelling disturbances can be seen as distortions to the “normal” ionogram traces.



Strengths & limitations of ionosondes

Strengths:

- Detailed observations of the bottomside ionosphere.
- Fairly good time resolutions (five minutes).
- For high-end instruments: oblique measurements, Doppler data,...

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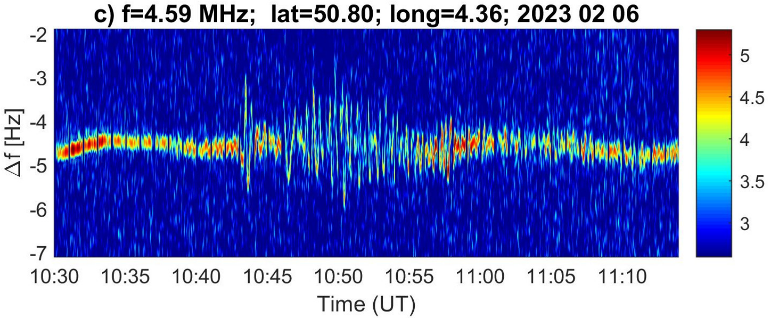
Limitations:

- No information above hmF_2 (so no TEC).
- Measurements affected by absorption, sporadic-E, etc.
- No information at very short scales (both in time and space).
- Big and expensive equipments, so a sparse network of observatories.

Continuous wave Doppler sounding

The time resolution of the ionosonde is limited by the duration of a single ionogram sounding.

Continuous-wave sounding allows detection of smaller disturbances.

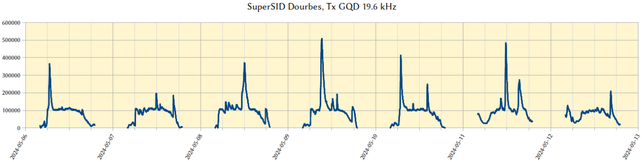


However: only a single frequency is sounded, so no complete electron density profile can be obtained.

D layer measurements

Various techniques can be used to measure absorption in the lower ionosphere:

- **Method A1: pulse reflection.** A fixed pulse at a single frequency (usually around 2 MHz) is transmitted, and the amplitude (or SNR) of the echo is measured. This can be done either vertically or oblique.
- **Method A2: cosmic radio noise detection.** A riometer (Relative Ionospheric Opacity Meter for Extra-Terrestrial Emissions of Radio noise) is used to monitor the amount of cosmic radio noise that passes through the ionosphere.
- **Method A3: oblique signal strength.** The strenght of VLF beacons is monitored for enhancements.



Summary

1. The most detailed information about the (bottom-side) ionosphere is obtained trough HF soundings by ionosondes.
2. Compelmentary techniques can be used for example continous wave sounding for high time resolution.
3. *D* layer can be measured either by HF absorption or by VLF SNR.
4. For research purpose, satellites, ISR, sounding rockets, etc. are very useful, but often not that suitable for operational use.

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The end!

Questions?