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RECONSTRUCTION OF IONOSPHERIC ELECTRON DENSITY PROFILES WITH THE LANNEMEZAN IONOSONDE

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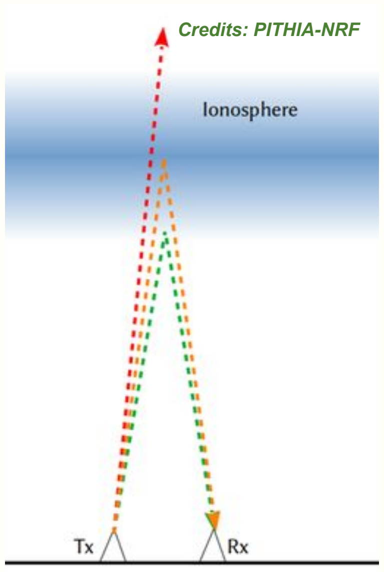


Location: Lannemezan (Centre de Recherche Atmosphérique / Observatoire Midi-Pyrénées)

Operational since: September 2025

Measurement cadence: Quasi-continuous ionograms every 15 minutes

Instrument type: HF ionosonde (ground-based ionospheric sounder)

Frequency range: 1–20 MHz frequency sweep

Operating principle:

- Transmits HF radio waves vertically into the ionosphere
- Waves are reflected when the transmitted frequency matches the local plasma frequency
- Signal travel time is used to estimate the virtual reflection height assuming propagation at the speed of light
- Sweeping the sounding frequency allows reconstructing of the electron density profile

Primary measurements:

- Ionograms (frequency vs. virtual height) for ordinary (O) and extraordinary (X) modes induced by the Earth's magnetic field
- Electron density derived from the plasma frequency relation:

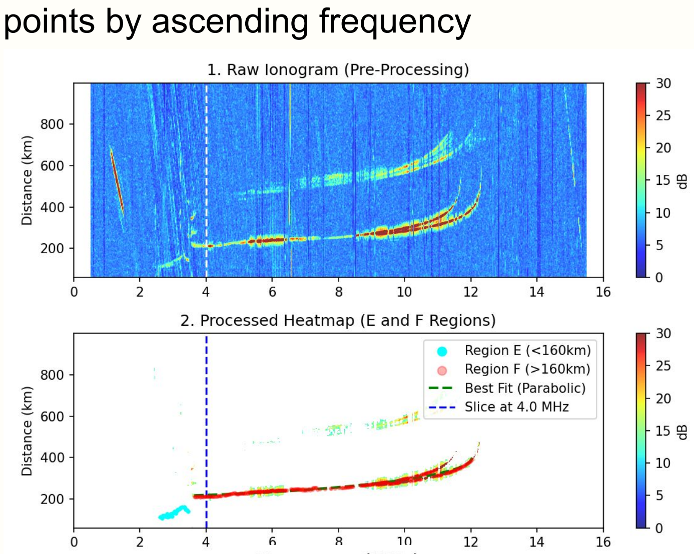
$$f_p = 8.98\sqrt{n_e}$$

OBJECTIVE

Reconstruct realistic real-time electron density profiles of the ionosphere at mid-latitudes and make them available to the scientific community for scientific and space weather purposes.

Step 1: Automatic Detection of True Ionogram Points

- Remove noise and non-physical signals
- Discard points occurring after large frequency gaps (> 2MHz)
- Remove second and higher-order echoes
- For F-region analysis, retain only points after the end of E-region traces and keep the lowest signal corresponding to the X-mode
- Sort the points by ascending frequency



Result: ***Clean set of ionogram points*** (f_{pi}, z_i)

Step 2: First estimation of electron density profile

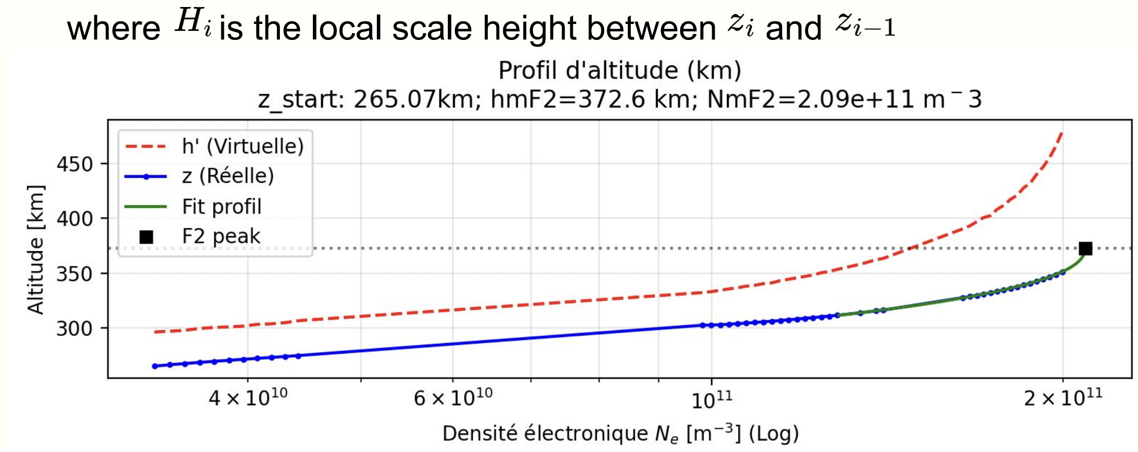
Lamination approach

- Ionosphere horizontally stratified
- f_p is a monotonic function of altitude
- **Assumption**

In each layer, ionospheric concentration varies exponentially:

$$f_{pi-1}^2 = f_{pi}^2\, e^{\frac{z_{i-1}-z_i}{H_i}}$$

where H_i is the local scale height between z_i and z_{i-1}



Main challenge: ***Identify the ionospheric entry point***

Step 3: Direct Signal Modelling (Ongoing)

Modeling Ordinary and Extraordinary Modes from Ionogram Signal

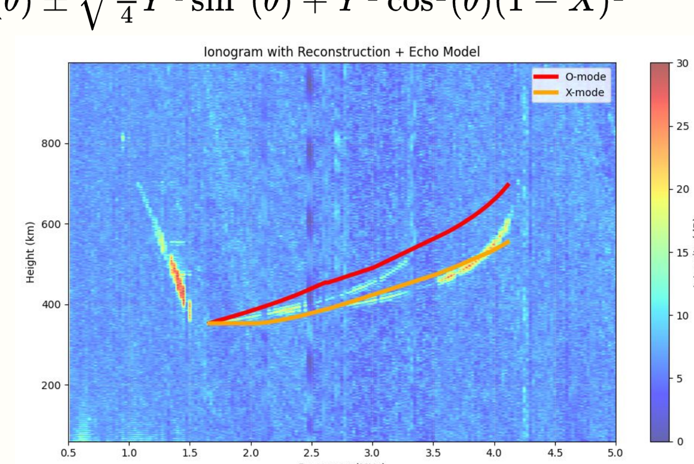
Refraction index:

$$\mu^2 = 1 - \frac{X(1-X)}{(1-X) - \frac{1}{2}Y^2\sin^2(\theta) \pm \sqrt{\frac{1}{4}Y^4\sin^4(\theta) + Y^2\cos^2(\theta)(1-X)^2}}$$

$$X = \frac{\omega_p^2}{\omega^2} \qquad Y = \frac{\Omega_e}{\omega}$$

Traveling Time:

$$\delta t(f) = \frac{2}{c}\int_0^{z(f)} \frac{dz}{\mu(f)}$$



This signal is used to refine the electron density profile by retaining only points consistent with the model and adding missing ones from the reconstruction

DERIVED PRODUCTS

Continuous and in near real-time estimation of:

- F2 layer peak height (hmF2)
- F2 layer critical frequency (foF2)
- F2 layer density (NmF2)

NEXT STEPS

- **Validate the method through comparison with existing inversion techniques (e.g. POLAN)**
- **Test the method on more complex ionograms and during disturbed ionospheric conditions**

- *Real-time ionograms are available on the OFRAME dashboard (see link below)*
- *Derived ionospheric parameters will be made available on the dashboard upon completion of processing*
- *Future integrations in a new AA-ANO6 SNO "Ionosphere Monitoring" and into the international GIRO ionosondes network are envisaged*

https://meteo-espace.irap.omp.eu/dashboard

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