Modeling of the ionosphere for HF & L bands propagation: impact of Space Weather

Aurélie Marchaudon, IRAP, Pierre-Louis Blelly,IRAP

Space weather is the set of conditions in the space environment that can have an impact on human activities on Earth and in space. It mainly characterises the Sun-Earth relationship, which affects the dynamics of the magnetospheric system and more particularly the behaviour of the ionosphere. Ionospheric physics is the subject of renewed interest for a key reason related to the dispersive properties of this medium as it plays a critical role in affecting ground-to-space (GNSS) or ground-to-ground (HF) communications. This medium, characterised by a high ionisation rate, is very sensitive to physico-chemical couplings with the atmosphere and electrodynamic couplings with the magnetosphere, with extremely variable response times ranging from a few seconds to a few days, and the characterisation of the dynamics of its state is therefore a difficult task. Figure 1 gives an illustration of these ionospheric dynamics through the couplings with the atmosphere (gravity waves, photoproduction) and the magnetosphere (electric fields, aligned currents). This figure shows the time evolution (over 42 hours) of the vertical profiles of electron density and temperature, temperature and vertical ion velocity, measured by the incoherent scattering radar EISCAT, located in Tromsø, before and during a magnetic substorm. A regular diurnal variability can be seen superimposed by intense dynamics controlled by electrodynamics: temperatures increase by several thousand degrees in a few minutes, leading to a concomitant variation of the electron density by a factor of more than 2.

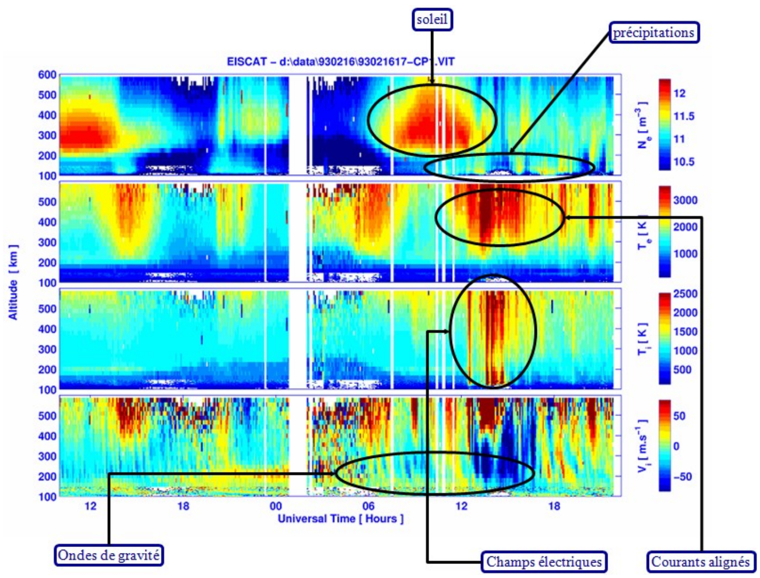

Figure 1 Colour panels showing from top to bottom the time evolution of the vertical profiles of electron concentration (in logarithmic scale), electron temperature, ion temperature and vertical ion velocity, measured by the EISCAT UHF radar during a measurement campaign from 16 February to 17 February 1993. The local noon corresponds to 1040 UT.

However, the most widespread representations of the ionosphere are based on statistical approaches, which result in empirical models that are able to reproduce calm coupling conditions, but fail to monitor the dynamics of the medium during intense activity (such as solar flares or magnetic storms), which correspond to the most critical situations for HF propagation. The reason for this lies in the mathematical approach used to develop these models, which does not consider the physics of the couplings, nor their complexity.

The ionosphere is a key element of space weather in that it actively participates in the couplings in the magnetosphere-ionosphere-thermosphere (MIT) system, with a fluid/electrodynamic duality, which is critical for the system (Figure 1). The characterisation of the space environment therefore requires the most precise knowledge possible of both the state of the ionosphere and its dynamics, and in order to be able to provide a nowcast at half-hourly (or even hourly) intervals, or a forecast at more than six hours, it is necessary to be able to correctly model the couplings that constrain these dynamics. Only physical models integrating data assimilation capabilities can achieve such objectives. Major efforts have been made in the United States for over 20 years and Europe is trying to catch up.

We will present the expertise in ionospheric physics existing in France and we will show the efforts made to develop research models (figure 2) which are world reference models, as well as more operational models which are able to meet the needs of public and private organisations. Finally, we will conclude with some examples of HF propagation work associated with a ray tracing module.

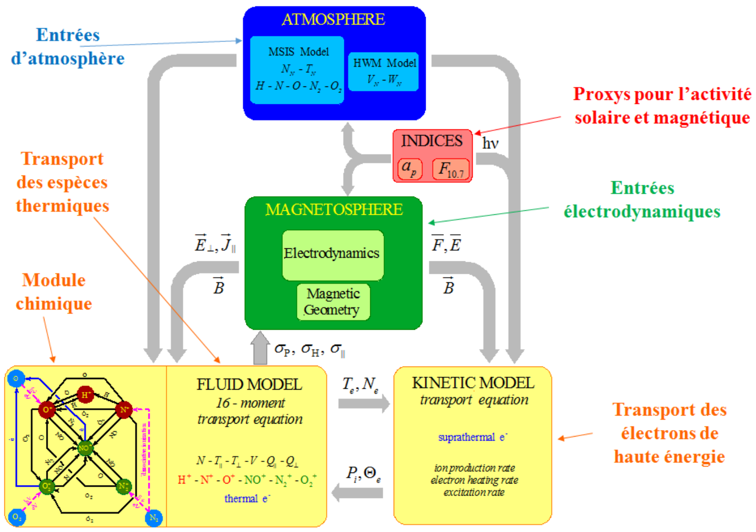

Figure 2 synopsis of the IPIM ionospheric model developed at IRAP, describing the couplings in the MIT system and the underlying processes considered