High frequencies wave propagation in Earth ionosphere

Foucault E., Blelly P.-L., Marchaudon A.
IRAP, CNRS, Toulouse, France

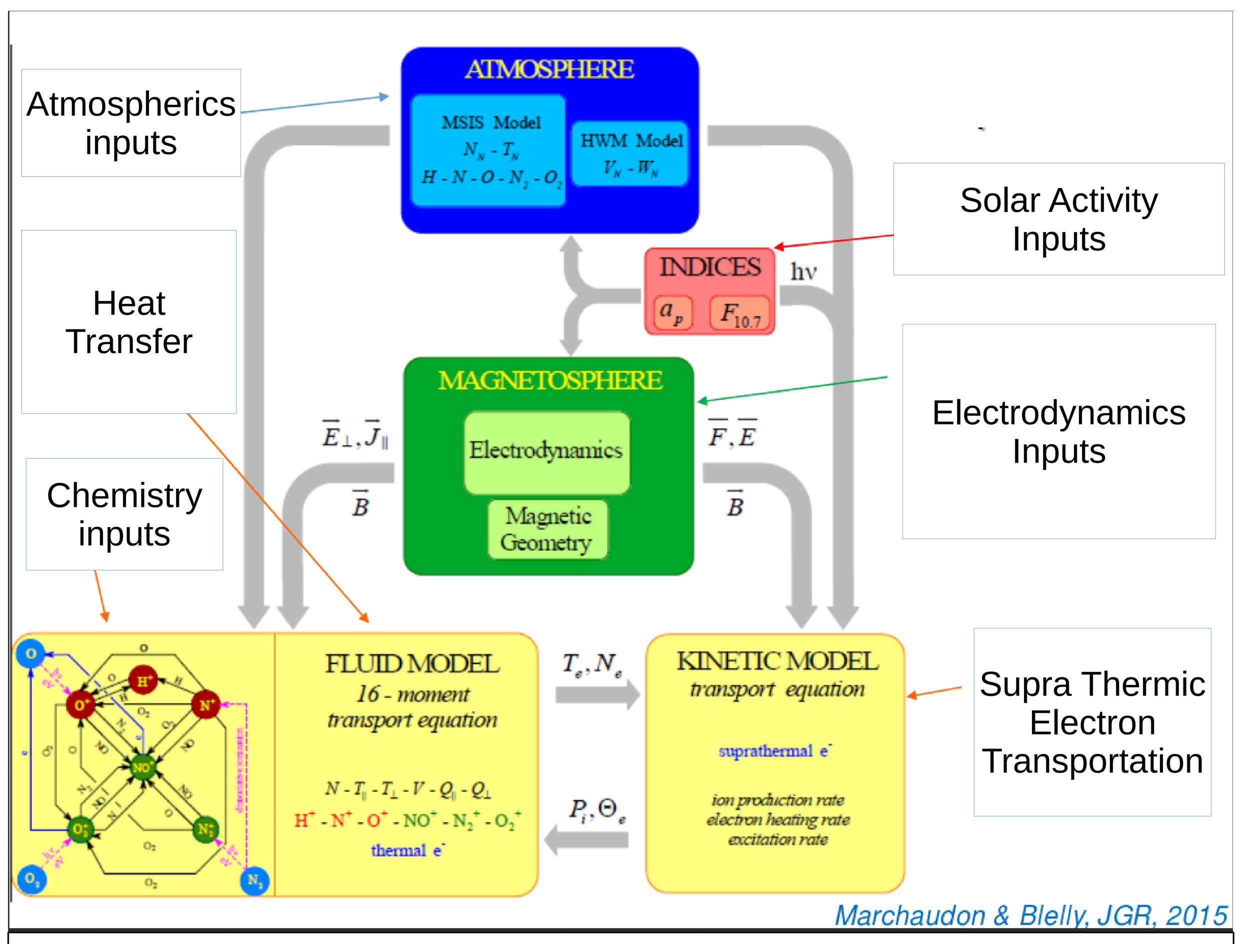
Motivation

The ionosphere (altitude 60-200km) (3) is defined as the atmosphere region that affects the propagation of radio waves. It is composed of plasma content (ions and electrons) created by the ionization of the atmospheric neutral compounds. It can be used as a mirror for ground-ground over-the-horizon communication in HF range. To do so the electronic content must be well known along the propagation path. Most ionosphere models are often empirical models which are not able to reproduce rapid spatio-temporal variations generally encountered in the high-latitude ionosphere.

We present a new approach of the propagation of HF radio waves in a realistic medium generated by the ionosphere model developed at IRAP (TRANSCAR/IPIM family model) (1). Once developed this ray tracing tool will be coupled with IPIM to reproduce the ionosphere observed by ground based instrumentation. By comparing the simulated results of radio waves propagation with observed data from HF ionospheric radars of the SuperDARN chain, the main ionospheric parameters (e.g. density and temperature of electrons/ions) will be adjusted in the model through a recursive loop in order to fit as best as possible the observations.

First a new ray tracing tool has been developed and the first tests of our code using realistic IPIM simulation of the ionosphere are presented in this poster.

IPIM



Irap Plasmasphere-Ionosphere Model (IPIM) Working Scheme (1)

Ray Tracing Tool

Aim:

- Integrating HF wave propagation path in a refractive medium
- Ray bending estimation

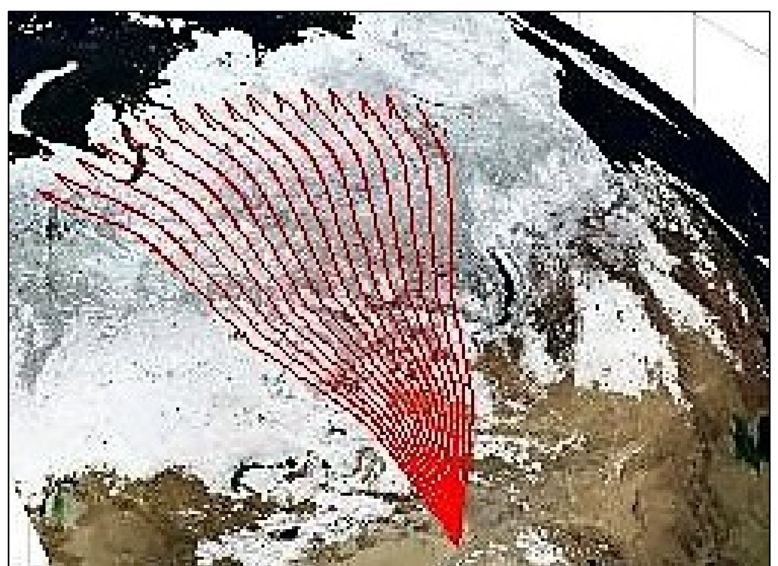
Algorithm:

- Based on Fermat Principle
- Geocentric problem – 3D Problem
- Entries: **(R, Lon, Lat, Az, El)** Where : **R** is the distance to Earth center, **Lon** the geocentric longitude, **Lat** the geocentric latitude, **Az** the azimuth angle and **El** the elevation angle
- Outputs: **(S, R, Lon, Lat, Az, El)** Where **S** is the curvilinear abscissa
- Runge-Kutta scheme (Order 1 to 5), using variable integrating step

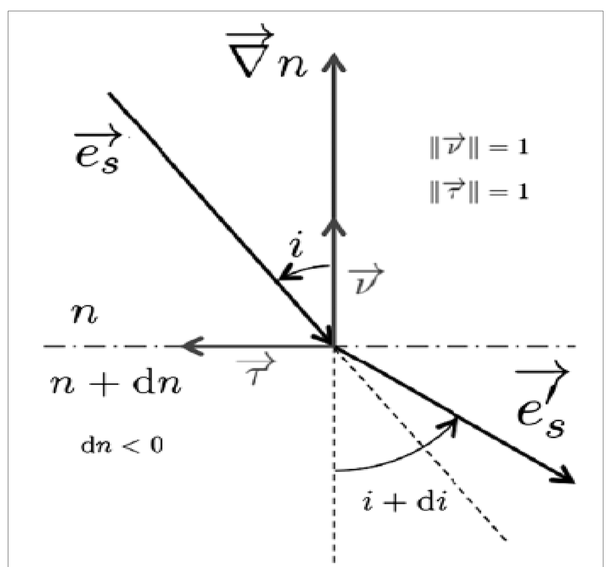
Equations :

- At each step, the tool estimate the propagation vector's rotation due to the refractive index gradient along the ray path :

$$\frac{\delta i}{\delta s} = -\frac{\left\|\vec{\nabla} n\right\|}{n}\vec{\tau}.\vec{e_s}$$



Propagation SuperDARN-like, 16 Beam at 12MHz, in an analytical ionosphere with a n_e peak at 2.10^{11} m^{-3}



Local wave path variation along the trajectory frame (2)

Validation

First Step :

- Propagation Equation Validation

Medium :

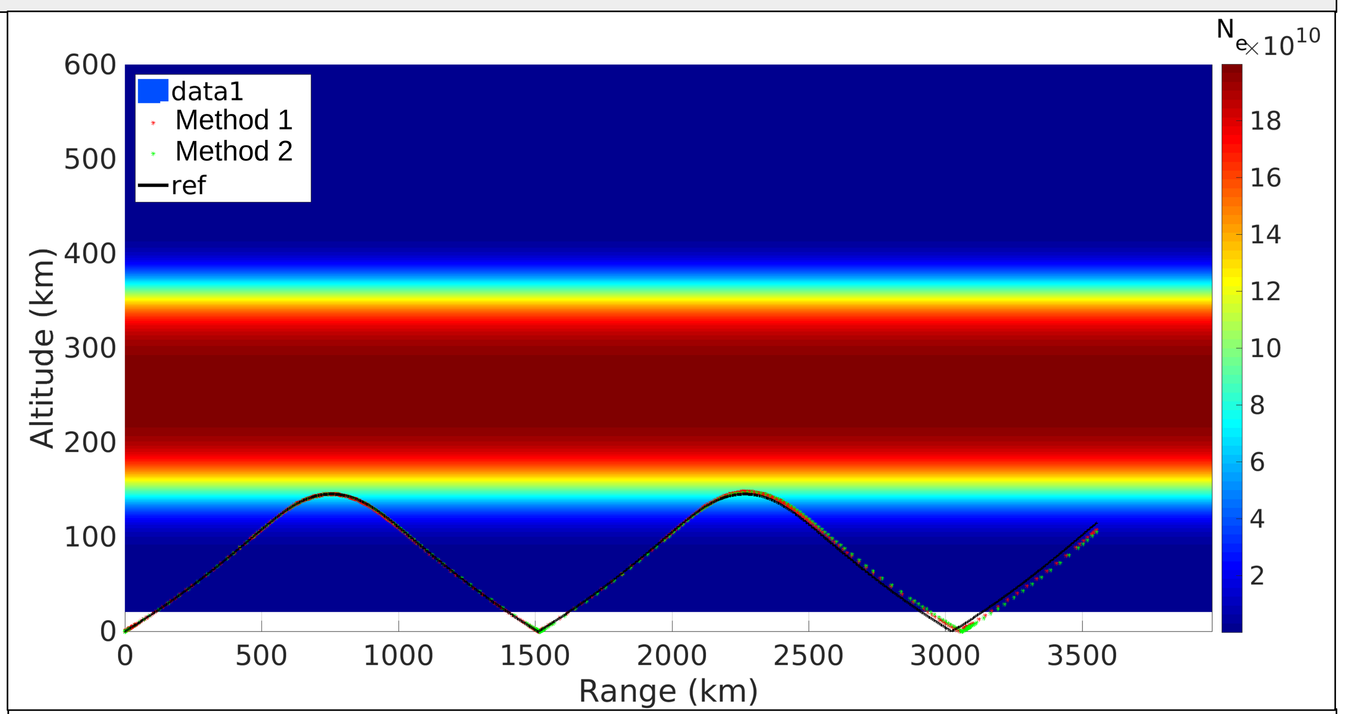
- Perfectly known medium → Analytical Ionosphere

Method :

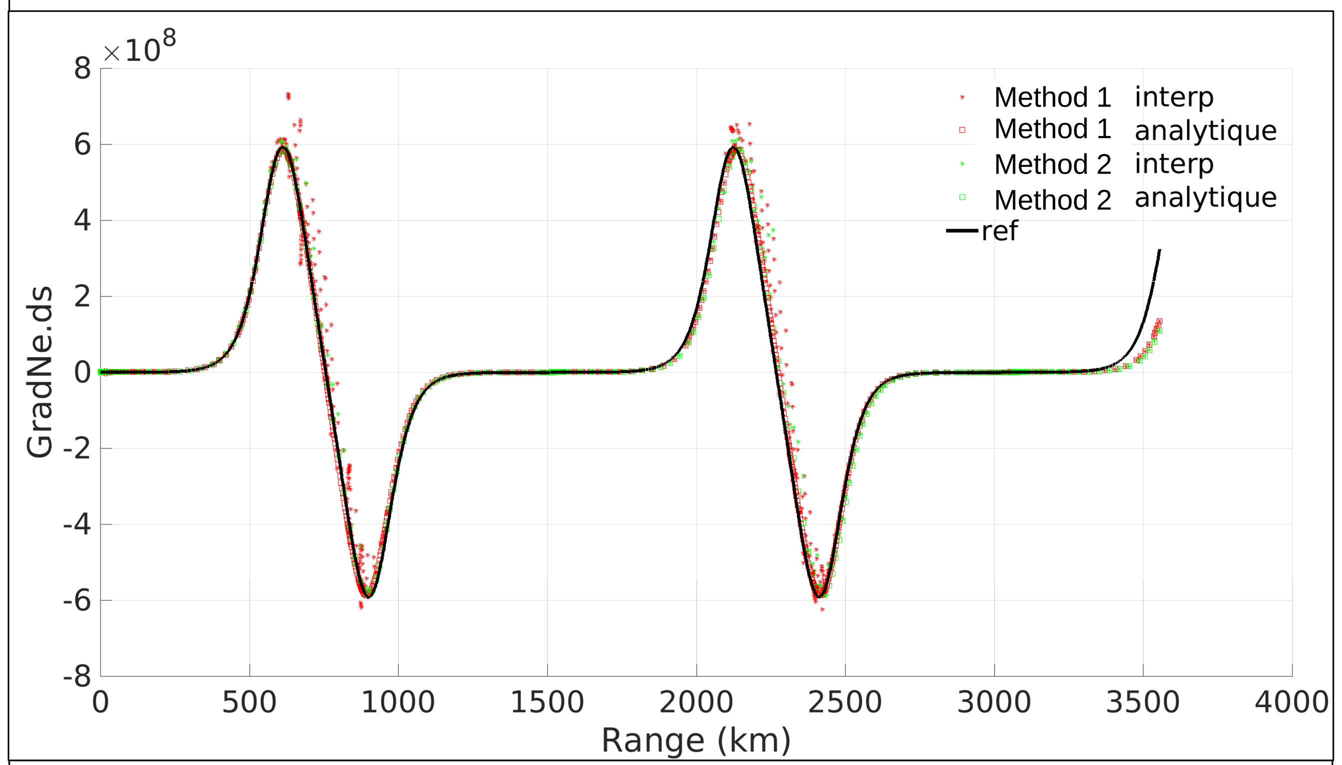
- Reference : Wave path estimating using Snell-Descartes law
- Method 2 : Fully analytical propagation (both Electron density and Electron Density gradient are analytically known)
- Method 1 : Wave path estimating using 3D interpolation of the Electron Density and Electron Density Gradient

Results :

- Good agreement at close range
- Small error due to our initial hypothesis, leads to differences between trajectories with the same initial inputs at mid and long range.



Example of trajectories obtained with the ray tracing tool. Initial Elevation is set at 10°.



Details of the Electron Density Gradient estimated along the path. In black is set the GradNe seen by the reference, in Green the Gradne of the Method 1 and in Red the GradNe of the Method 2.

On-Going

Next Step :

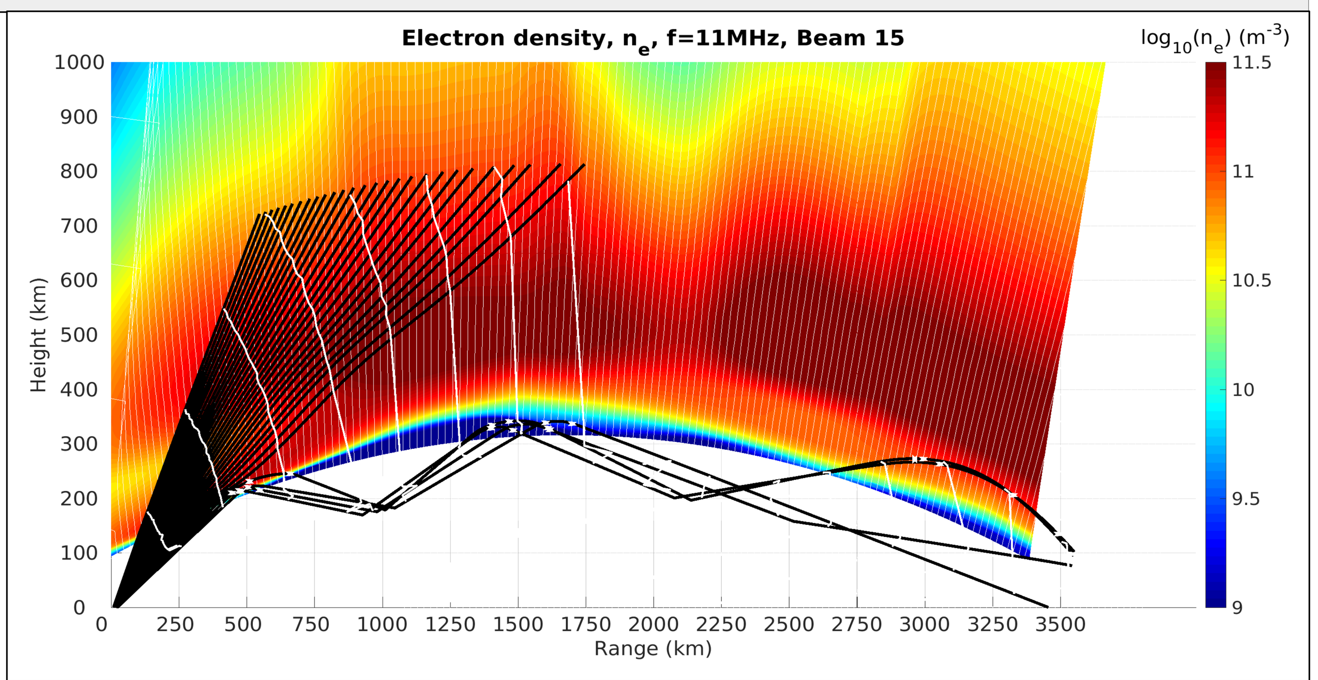
- Re-writing the propagation equations to take into account the rotation of the trajectory respect to the curve radius

Real Case Study :

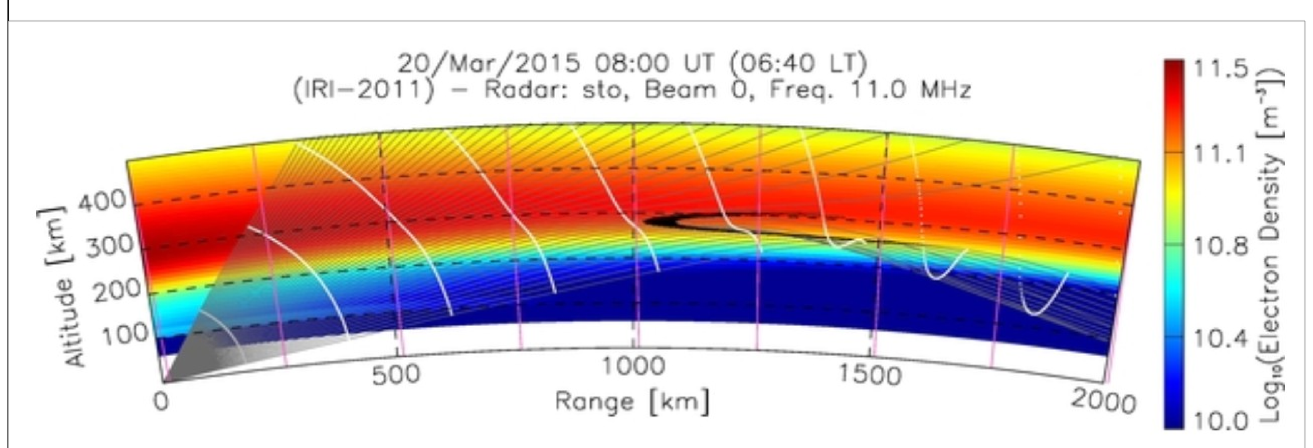
- Using the ray tracing tool in an ionosphere generated by IPIM and compare the results with existing ground monitored experimentation (e.g., EISCAT, SuperDARN…)

First results of real case study show that for the same time and location, ionosphere derived from IPIM and IRI are different. It leads to different path estimation.

Comparison with ground based instruments are mandatory to validate our ray tracing model.



Examples of trajectories calculated with the ray tracing on the Stokkseyri SuperDarn radar Field-Of-View, at 08h00 UT the March 20th 2015.. The ionosphere used is an IPIM product.



Examples of trajectories calculated with the ray tracing developped by de Larquier S. (4) (for the SuperDARN community) on the Stokkseyri SuperDarn radar Field-Of-View, at 08h00 UT the March 20th 2015.. The ionosphere used is derived from IRI profiles.

Bibliography

(1) Marchaudon, A., and P.-L. Blelly (2015), A new interhemispheric 16-moment model of the plasmasphere-ionosphere system: IPIM, *J. Geophys. Res. Space Physics*, 120, 5728–5745, doi:10.1002/2015JA021193.
(2) Grandin, M., P.-L. Blelly, O. Witasse, and A. Marchaudon, (2014), Mars Express radio-occultation data: A novel analysis approach, *J. Geophys. Res. Space Physics*, 119, doi:10.1002/2014JA020698
(3) P.-L. Blelly and D. Alcaydé, Ionosphere. In: Y. Kamide/A. Chian, Handbook of the Solar-Terrestrial Environment, pp.189-220 (2007). DOI: 10,1007/11367758_8
(4) de Larquier, S., J. M. Ruohoniemi, J. B. H. Baker, N. Ravindran Varrier, and M. Lester (2011), First observations of the midlatitude evening anomaly using Super Dual Auroral Radar Network (SuperDARN) radars, *J. Geophys. Res.*, 116, A10321, doi:10.1029/2011JA016787.