

## Abstract

The first cut-off frequency (1.6-1.8 kHz) of the Earth-ionosphere waveguide has been monitored during more than three years by means of DEMETER satellite electric field measurements. At this resonant frequency, most of the energy radiated by lightning remains trapped inside the cavity, and DEMETER (orbit at 700 km altitude) registers a minimum of energy at the cut-off frequency. Due to its polar orbit with 98° of inclination, DEMETER covers practically the whole Earth. Therefore it has been possible to draw maps of the cut-off with spatial dependence. These maps have shown a seasonal variation of the cut-off frequency in South Pacific, Indian and Atlantic Oceans. We have no clear proof for the connection between the Earth-ionosphere waveguide properties and the troposphere surface. That being said, we suggest sea-salt aerosol or changing conductivity of sea water as the responsible for these shifts. The cut-off frequency,  $f_1$ , value is directly related to effective height of the ionosphere, h, by the relation  $f_1 = c/2h$ , where c is the speed of light. Monitoring the first cut-off frequency from space can give additional information of the ionosphere D-region, since the effective height of the waveguide is directly related to the electron density in this region.

#### Contact

Sergio Toledo Redondo University of Granada, Spain Email: sergiotr@ugr.es http://electrodinamica.ugr.es

#### References

[1] Berthelier, J. et al. (2006), ICE, the electric field experiment on DEMETER, Planetary and Space Science, 54(5), 456-71.

[2] Cummer, S.A., U.S. Inan, and T.F. Bell (1998), Ionospheric D region remote sensing using VLF radio atmospherics, Radio Science, 33(6), 1781-92.

[3]Cheng, D.K. (1983), Field and wave electromagnetics, Addison-Wesley, Massachussets, USA.



# Remote sensing of the Earth-ionosphere waveguide properties based on cut-off frequency detection from DEMETER satellite measurements

## Introduction

A novel technique to obtain global maps of the ionospheric effective height of the Earth-ionosphere waveguide is presented. The aim is to characterize the dimensions and properties of the waveguide, with the purpose of better understanding the electrodynamics which occur inside it and the couplings between its layers. The technique is based on electric field measurements (ICE instrument) taken from the satellite DEMETER [1]. Lightning in the atmosphere generates signals in the VLF band known as **atmospherics**, which propagate in the waveguide several thousand of km before vanishing [2]. Part of their energy leaks up to the satellite orbit (~700 km), and therefore the first **cut-off frequency** of the waveguide can be tracked from the space (see Fig. 1). This frequency, f, is directly related to the height of the waveguide, h, by the relation **f=cl2h**, where c stands for the speed of light [3].



Fig. 1 Electric field spectrogram recorded by DEMETER. The cut-off frequency of the Earth-ionosphere waveguide can be observed

# Cut-off detection from VLF DEMETER data

- first cut-off frequency (see Fig 2). -The effective height is inferred:  $h=c/2f_c$



Fig. 2 Steps involved in the cut-off frequency detection.

S. Toledo-Redondo<sup>(1,2)</sup>, M. Parrot<sup>(2)</sup>, A. Salinas<sup>(1)</sup>, J. Portí<sup>(3)</sup>, J. Fornieles<sup>(1)</sup>, and J. A. Morente<sup>(3)</sup> <sup>(1)</sup>Department of Electromagnetism (UGR), <sup>(2)</sup>Laboratoire de Physique et Chimie de l'Environnement (CNRS), <sup>(3)</sup>Department of Applied Physics (UGR)

- Nighttime spectra from DEMETER electric field measurements, VLF band. - A spatial and temporal grid is defined (e.g., 5° and one month). - All available spectra belonging to each cell are averaged and smoothed. - An algorithm finds the spectra minima and selects the corresponding to the

## Effective height shifts and global evolution

- see Fig 4.

- 2. Thunderstorm activity.
- order to confirm the correlation.



Seasonal effect over the Pacific Ocean. It has annual period, and occurs for latitudes between -60° to 0° and longitudes from 180° to 280°. The effective height shifts from 100 km during local cold season to 90 km during local warm season (see Fig. 3).

Seasonal effect over equatorial Atlantic and Indian Oceans. This shift occurs twice a year. A low effective height area (under 88 km) appears during March-April and again during September-October. Their central locations are (0°N, 20°W), and (0°N, 80°E),

We point at three possible explanations for the shifts: **1.** Aerosols produce changes in the atmosphere. **3.** Ionization by Transient Luminous events (TLE).

Global decrease of the cut-off frequency. The global cut-off frequency decreases among the four years of the study. It may be related to the decrease of solar activity during this period, as Fig. 5 suggests. However, a longer time span is needed in





Fig. 4 Monthly evolution of the effective height (2006-2009).

1 There is a **seasonal pattern** on the ionospheric **effective height**. 2 There exists a coupling between the lithosphere and the ionosphere, since effective height variations are related to the kind of Earth's surface.

3 The effective height of the ionosphere increases when the solar activity diminishes.



Fig. 5 Comparison between effective height and F10.7 solar index.

#### Conclusions