Detection of TID activity from ionogram virtual height variations

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Abstract

Travelling Ionospheric Disturbances (TIDs) constitute a specific phenomenon that can be excited by space weather or driven by other processes acting below the ionosphere. Independent of their source, the effects imposed by TIDs in the ionosphere are very detrimental to an array of user technologies. TechTIDE (http://techtide.space.noa.gr/) is a project funded by the European Commission Horizon 2020 research and innovation program that aspires to establish a pre-operational system to demonstrate reliability of a set of TID (Travelling Ionospheric Disturbances) detection methodologies to issue warnings of the occurrence of TIDs over the region extending from Europe to South Africa. One of these detection methodologies is based on the height-time-reflection intensity (HTI) methodology applied on Digisonde ionograms to infer TID activity over Digisonde stations. In this paper we describe the steps for the implementation of this technique in the frames of TechTIDE.

1. Introduction

Travelling Ionospheric Disturbances (TIDs) are plasma density fluctuations that propagate as waves through the ionosphere at a wide range of velocities and frequencies and play an important role in the exchange of momentum and energy between various regions of the upper atmosphere. TIDs constitute a specific phenomenon that can be excited by space weather or driven by other processes acting below the ionosphere. Independent of their source, the effects imposed by TIDs in the ionosphere are very detrimental to an array of user technologies and in particular for Real Time Kinematic (RTK) and Wide Area Real Time Kinematic (WARTK) as the enhanced TID disturbance of the ionosphere is directly translated to user positioning error. Large-scale TIDs (LSTIDs) associated with auroral and geomagnetic activity propagating with wavelengths of 1000 to 3000 km and velocities of 300 – 1000 m/s have the most dramatic effect on such systems.

The height-time-reflection intensity (HTI) methodology is similar to the technique producing range-time intensity (RTI) radar displays within a given time interval. The application of this method in TechTIDE enables the identification and tracking of the TID activity over each Digisonde station by using the actual ionograms produced over each station. This technique considers an ionogram as a ‘‘snapshot’’ of reflected intensity as a function of virtual height and Digisonde signal frequency, and it uses a sequence of ionograms to compute an average HTI plot, (for a given frequency bin) that is essentially a 3-D plot of reflected signal-to-noise ratio in dB as a function of height within a given time interval. This display reveals dynamic changes in the ionosphere.

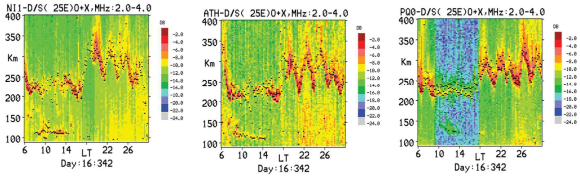

Figure 1: HTI plots over Nicosia (left), Athens (middle) and Pruhonice (right) for December 7, 2016.

Figure 1 depicts TID-like variations on typical HTI plots corresponding to a Digisonde frequency band, of 2.0-4.0 MHz for three stations over Europe. The periodicity of the dominant wave activity is estimated by applying spectral analysis to points of maximum intensity reflected at certain F-region virtual heights indicated by black dots on these HTI plots. In the present paper, using ionograms obtained by the DPS-4D Digital ionosonde (Digisonde) at the lower mid-latitude European station near Nicosia, Cyprus (35^{o}N, 33^{o}E geographic; magnetic dip. 29.38°N). we demonstrate the main concepts behind this technique as implementated in the frames of TechTIDE project and we apply it during two geomagnetic storm events that triggered TID activity.

2. Methodology

The HTI method uses raw ionograms (Figure 2a) in order to estimate the optimal frequency bin within which the F-region trace of the ionograms will be processed at each instant during a 24 hour interval. For each ionogram at the appropriate frequency bin a virtual height profile of signal strength is obtained (indicated by different colour in Figure 2b).

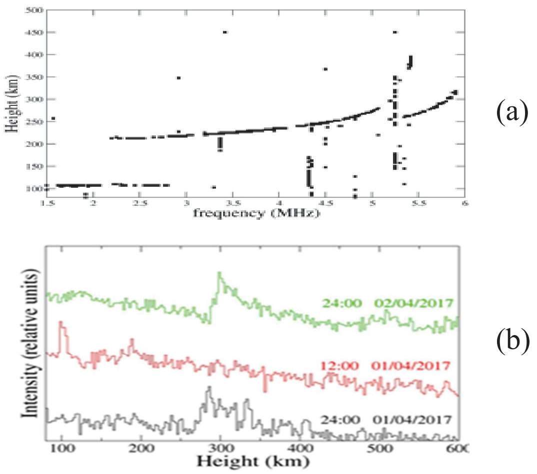

Figure 2: (a) Ionogram ready to be processed by HTI (b) Output virtual height intensity profile for three different ionograms.

By estimating the virtual height of the points of maximum intensity within each profile and by superimposing these resulting from each ionogram an HTI plot may be determined (Figure 3a). At times strong reflections from sporadic E (Es) are received (indicated by the circles in Figure 3b) that are strong enough to mask F-region reflections so appropriate procedures have been applied to treat these points as outliers and not consider them in the subsequent spectral analysis.

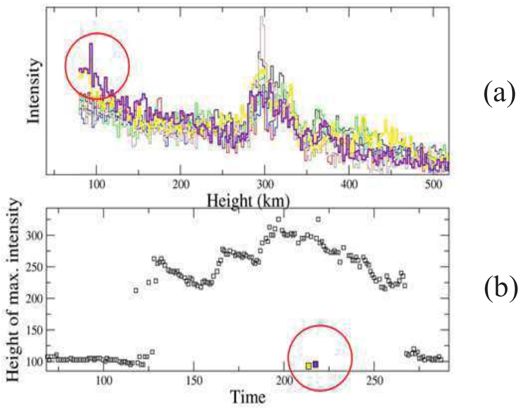

Figure 3: (a) Estimation of reflection intensities at various F region virtual heights including E region outliers (b) Resultant HTI plot indicating strongest signal reflection points for a full day.

The points of maximum intensity are extracted from the HTI density with an appropriate statistical error. We aim in fitting the data with a superposition of a low period signal (in the range of 1-3 hours) with an arbitrary number of higher period signals, which essentially correspond to established background ionospheric activity. The low period signal aims in capturing possible persistent TID activity during a chosen time interval.

We employ a statistical model fitting technique, Athens Model Independent Analysis Scheme (AMIAS) which is appropriate for analyzing data with large error. The starting point of AMIAS is a set of measurements with the associated statistical errors, in this case the points of maximum intensity. The model we use for this analysis is given in Equation 1 where the first period, T_1, is in the range between 1 and 3 hours. AMIAS determines a probability distribution function (PDF) Π(Ar) for each fit parameter Ar. The estimates for the values of the fit parameters and their uncertainties are the expectation values and the standard deviations of the corresponding PDFs given in Equations 2-3. The PDF for the complete set of fit parameters is defined by Equation 4.

$$f(t) = a_0 + \sum_{n}^{\square} a_n \sin\left(\frac{2\pi}{T_n} + \varphi_n\right) \qquad (1).$$

$$\bar{A}_r = \int dA_r A_r \Pi(A_r) \qquad (2).$$

$$\sigma(A_r) = \left(\int dA_r (A_r - \bar{A}_r)^2 \Pi(A_r)\right)^{1/2} \qquad (3).$$

$$P(A_1, A_2, \ldots) = \frac{1}{N} e^{-\chi^2/2} \qquad (4).$$

AMIAS is able to handle a rather large number of parameters using Monte Carlo techniques, i.e., it is suited to study several superimposed periodicities. The key property of our methodology is that model parameters that contribute to the solution have well defined distributions which are not biased when ‘insensitive’ parameters are inserted in the model i.e. we can selectively search in a number of ranges for the possible periodicities.

At present the HTI method along with the AMIAS extension for spectral analysis are applied off-line for test cases characterized by TID activity. The test cases and the required data are obtained from the TechTIDE open access repository and on time intervals when persistent TID activity of significant amplitude is observed by the Net-TIDE experiment (http://tid.space.noa.gr). The final code will provide near-real-time information of detected LSTID activity above given Digisonde sites within European and South African regions as shown in blue dots in Figure 4. The final products provided through TechTIDE system portal relevant to the HTI technique will be the prevailing TID periodicity (if any) over each Digisonde station (corresponding to a sufficient number the most recent ionograms) and a F-region HTI plot. These are expected to be updated every 5 min as soon as a new ionogram is made available.

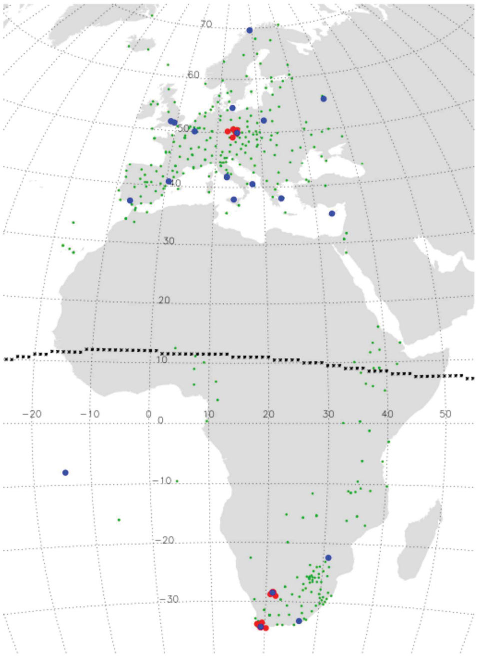

Figure 4: TechTIDE network of observing stations. The Digisonde stations are marked with blue dots,

3. Results

3.1. Case studies of January 20, 2016 and April 21, 2017

The validation of the HTI method has been implemented in case studies in which the algorithm was validated against LSTIDs detected by other methods implemented in the TechTIDE project. We show here two examples of the detection of LSTIDs with the HTI method for 20 January 2016 and 21 April 2017. In Figure 5 we can see the dominant LSTID periods for the two cases as extracted by AMIAS and in Figures 6,7 and 8 the extracted periods over each station and the corresponding HTI plots for the two events.

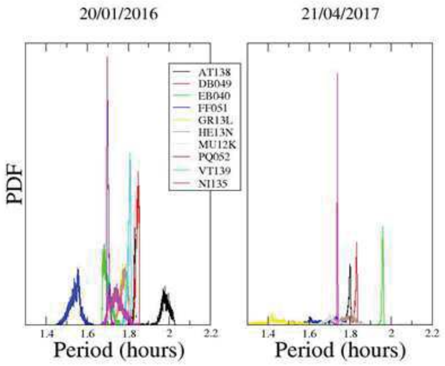

Figure 5: Dominant LSTID periods as extracted by HTI method and AMIAS over each station.

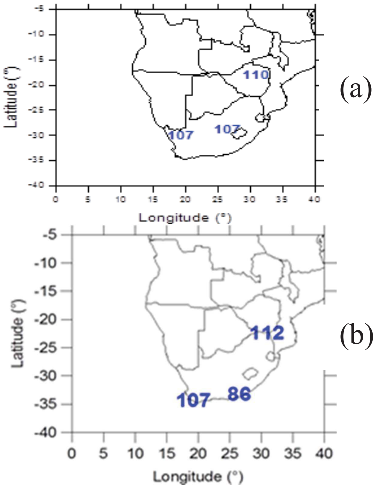

Figure 6: Extracted periodicities (in minutes) by HTI and AMIAS over South African stations for (a) January 20, 2016 (b) April 21, 2017.

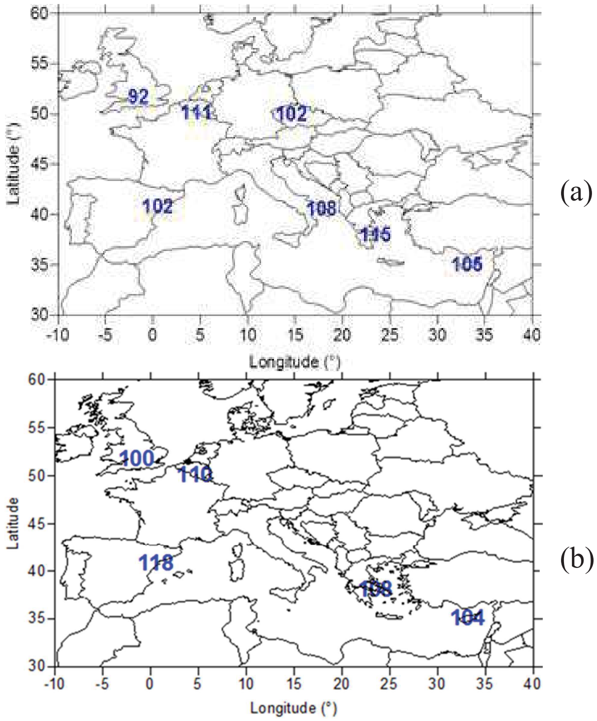

Figure 7: Extracted periodicities (in minutes) by HTI and AMIAS over European stations for (a) January 20, 2016 (b) April 21, 2017.

As we clearly see in Figures 6 and 7 the periodicities extracted are comparable and correspond to LSTID events that were associated with auroral heating effects.

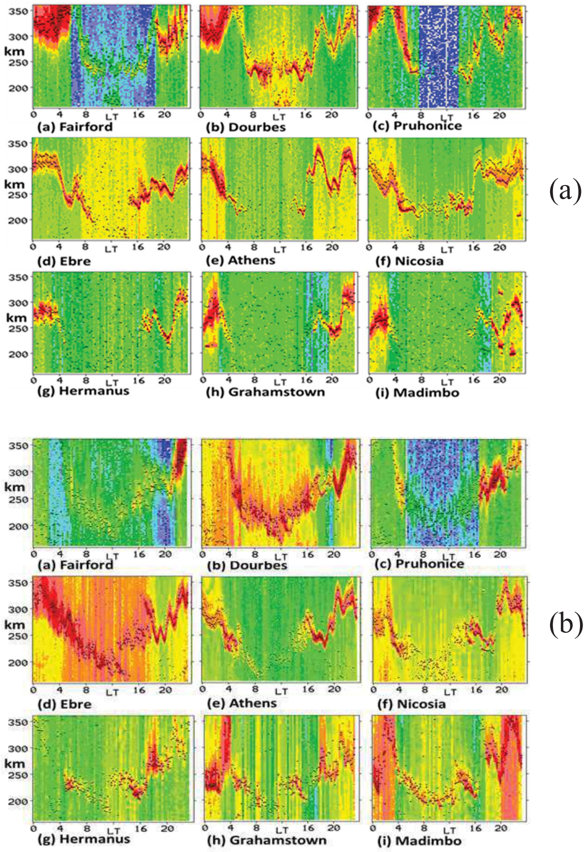

Figure 8: HTI plots over each station at a frequency bin of 2-4 MHz (a) January 20, 2016 (b) April 21, 2017.

3.2. Some identified problems

During summer months the occurrence of strong sporadic E (Es) increases significantly over European stations (especially low latitude stations). As a result a lot of ionograms become unusable for processing using HTI because of the fact that the F region can not be illuminated by Digisonde signals that are completely blocked by strong (blanketing) Es layers. This can last for extended periods of time as shown by a series of ionograms over Nicosia in 30 June 2014 in Figure 9. Figure 10 shows the corresponding HTI plot which exhibits absence of F layer information within the time interval indicated by the red oval. For this time period, the HTI plot for the corresponding station will not contain any F region reflection points necessary for the spectral analysis to operate correctly as this will appear as an extended gap in the HTI plot. Therefore at times when strong Es appears, increased foEs from the auto-scaled real-time characteristics in conjunction with lack of foF2 autoscaled values indicating absence of F layer information must be utilized to detect these circumstances and issue a warning.

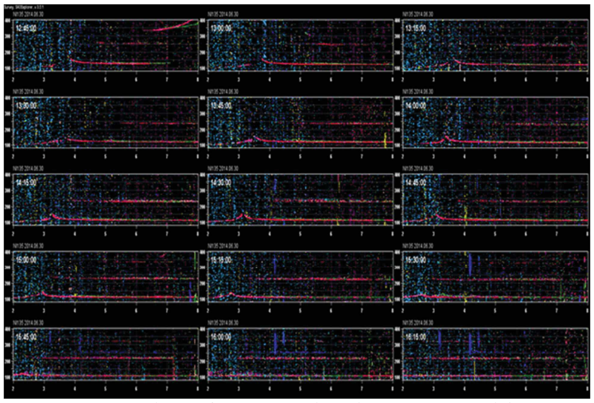

Figure 9: Series of consecutive ionograms with strong (blanketing) Es for 30 June 2014 over Nicosia station.

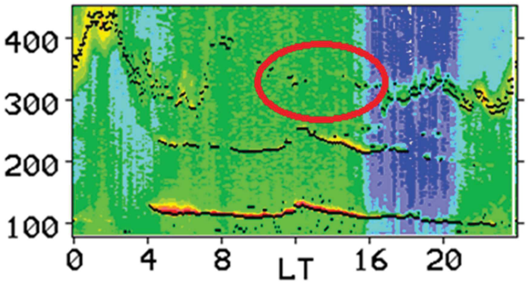

Figure 10: Example of HTI plot for 30 June 2014 at Nicosia with F layer data gap during strong Es.

4. Acknowledgements

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5. References

1.Haldoupis,C.,Meek,C.,Christakis,N.,Pancheva,D.,Bourdillon,A.,.Ionogram height–time–intensity observations of descending sporadic E layers at mid- latitude. *Journal of Atmospheric and Solar Terrestrial Physics 68*, 539–557 2006.

2. Oikonomou, C., Haralambous, H, Haldoupis, C., Meek, C., Sporadic E tidal variabilities and characteristics observed with the Cyprus Digisonde. *Journal of Atmospheric and Solar-Terrestrial Physics, 119*, 173–183. 2014.

3. Lynn KJW, Otsuka Y, Shiokawa K Simultaneous observations at Darwin of equatorial bubbles by ionosonde-based range/time displays and airglow imaging. *Geophys Res Lett 38*:L230101 2011.

4. Lynn KJW, Otsuka Y, Shiokawa K Ionogram-based rangetime displays for observing relationships between ionosonde satellite traces, spread F and drifting optical plasma depletions *Journal of Atmospheric and Solar Terrestrial Physics 98*:105–112 2013.