DETECTION AND CHARACTERIZATION OF MEDIUM SCALE TIDS USING GROUND GPS RECEIVERS

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ABSTRACT

In this work we summarize the main characteristics of Medium Scale Travelling Ionospheric Disturbances occurring at mid latitudes during several years of GPS data, corresponding to representative permanent stations and networks at both hemispheres. Several parameters are estimated, including temporal dependencies (diurnal, seasonal..), typical frequencies and propagation parameters such as phase velocity and direction. The methods developed and used for detecting and measuring those TID's parameters will be described, as far its application to a set of isolated and networked receivers at several locations.

INTRODUCTION

Traveling ionospheric disturbances (TID) are understood as plasma density fluctuations that propagate through the ionosphere at an open range of velocities and frequencies. The trend of such fluctuations can be seen in most of the ionosphere measurements techniques such as Faraday rotation [1], incoherent scatter radar [2], radio interferometry [3] and, in the last years, in GPS total electron content (TEC) observations ([4], [5], [6]). The TIDs have been explained as a consequence of the interaction between Atmospheric Gravity Waves (AGW) on the thermosphere with the ionosphere. Some authors distinguish between large scale TIDs (LSTIDs) with a period greater than 1 hour and moving faster than 300 m/s, and medium scale TID (MSTIDs) with shorter periods (from 10 min to 1 hour) and moving slower (50-300 m/s). While the origin of LSTIDs seems to be related with geomagnetic disturbances (i.e. particle precipitation, ionospheric storms, etc.), some authors has pointed out that the origin of MSTIDs is more related with meteorological phenomena like neutral winds or solar terminator (ST) that produces AGWs manifesting as TIDs at ionospheric heights.

In this context, not only from the point of view of the physical phenomena but from the applications as well, a comprehensive characterization of the MSTIDs is still required. In particular in order to go towards a system being able to detect and model them accurately enough to mitigate its effects for different GNSS users, such as those needing real-time precise positioning.

In this work we present a study about the presence of Medium Scale TIDs at medium latitudes by using GPS derived Total Electron Content. The results confirm and extend those obtained with other techniques such as VLBI, Incoherent Scatter Radar or GPS Local Networks (see above mentioned references). The wide coverage of the GPS receivers allows in this work to extend the study both temporally (the major part of one Solar cycle) and spatially (4 networks at different latitudes) regarding to the previous techniques.

DETECTING AND MEASURING MSTIDS

The basic observable that we use to detect TIDs is the geometric-free combination of GPS carrier phases, that, as it is well known, is proportional to the Total Electron Content (TEC) plus an unknown bias that includes the carrier phase ambiguity and the instrumental delays, in such a way that for every satellite-receiver pair we have:

$$L_i = L_1 - L_2 = \alpha \cdot TEC + b \quad (1)$$

where L_i is the geometric-free combination, L_1 and L_2 are the two GPS carrier phases (in meters), α is a proportionality factor ($\alpha = 0.105 \frac{m}{TECU}; \quad 1\,TECU = 10^{16} \frac{electrons}{m^2}$), and b is the unknown bias different for each satellite-receiver pair, but constant when the satellite is locked.

Temporal dependencies

The first step is to detrend the data from low frequency dependencies such as diurnal variation and elevation angle dependences. This detrending can be done by a polinomical adjustment that results in a smoothed series of L_i. However, the measurement noise is low enough (typically few milliliters) when is compared with the natural variation of L_i (i.e. L_i is smooth, also when TIDs occurs). So the detrending can be done simply by subtracting to each value an average value of a previous and a posterior measurements.

$$\delta L_i(t) = L_i(t) - 0.5 \cdot (L_i(t+\tau) + L_i(t-\tau)) \tag{2}$$

Where τ must be chosen in order to have a significative variation on L_i (300 secs in this work). We have compared this detection technique with a polinomical adjust (taking a wider data window) obtaining similar results with both methods.

Once the data are detrended, the following step is to identify TEC perturbations. This is done through the Fast Fourier Transform (FFT) over the detrended data. As the data has a temporal resolution of 30 secs we have chosen arc windows of 3840 secs (2^7 samples) with steps of 900 secs.

Propagation parameters

The propagation parameters (i.e. velocity, wavelength, etc.) can be obtained by using small networks of receivers with distances between receivers lower than the expected wavelength (horizontally projected), i.e. tens of kilometers. These propagation parameters can be determined cross-correlating the TEC measurements between receivers.

The relative movement of the GPS satellite and the receiver makes that observations, for a same satellite-receiver pair, occurs in different ionospheric pierce points. This introduce a Doppler effect that must be corrected in the observational equations. In our case this is corrected assuming a thin layer model for the ionosphere (with an altitude of 300km) and that the TID propagates as a planar wave, i.e. for an instant t and a pierce point $\mathbf{r}_{pp}$:

$$\delta L_i(t, \mathbf{r}_{pp}) = F(\omega t - \mathbf{k} \cdot \mathbf{r}_{pp}) \tag{3}$$

where F is an arbitrary function, ω is the frequency and $\mathbf{k}$ is the propagation vector. Thus defining, as [7], the slowness vector $\mathbf{s} = \frac{\mathbf{k}}{\omega}$, δL_i can be expressed as:

$$\delta L_i(t, \mathbf{r}_{pp}) = F(t - \mathbf{s} \cdot \mathbf{r}_{pp}) \tag{4}$$

Then, after some algebra, it is easy to see that the temporal delay dt between two receivers, with a relative position vector between its pierce points $\Delta \mathbf{r}_{pp}$, must verify:

$$dt = (\Delta \mathbf{r}_{pp} + dt \cdot \mathbf{v}_{pp}) \cdot \mathbf{s} \tag{5}$$

Applying this equation in a network of receivers one can obtain the components of $\mathbf{s}$ and, as a consequence, the horizontal velocity.

The importance of this Doppler effect is proportional to the ratio between the velocity of the pierce point in this layer model and the propagation velocity of the TID. This pierce point velocity will depend on the assumed altitude for the ionospheric layer: it can be of 50m/s for an altitude of 300km, or 20m/s for an altitude of 100km Then the model for the ionosphere (i.e. the height of the thin layer) will have some influence in the velocity estimation and other parameters like frequencies, mainly if the propagation velocity is comparable with the pierce point velocity. This Doppler effect can account up to a 20% of the parameter estimation (velocity or frequency). Because GPS satellites have a net movement eastward, Doppler effect will affect mainly to the estimation of the east-west velocity components.

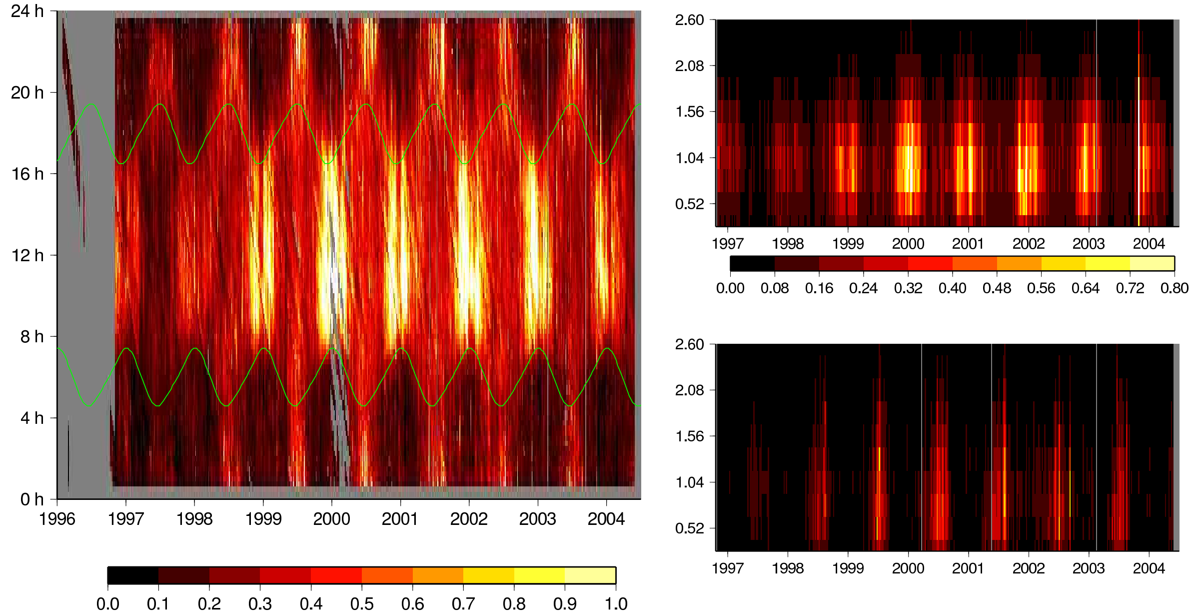

Figure 1: **Left hand plot:** Amplitude of the TIDs as a function of the local time (vertical axis) during 7 consecutive years (horizontal axis) for the IGS receiver Ebre (40N,0E) (the Solar Terminator lines are also plotted). **Right hand plot:** Example of two corresponding power spectral densities (vertical axis) of the TIDs at 1100UT (top) and 2300UT (bottom), along the whole period 1997-2004 (horizontal axis).

RESULTS AND CONCLUSIONS

We have applied the procedure described in last subsection in order to characterize the amplitude and spectral behavior of the MSTIDs at several latitudes and during several years. For example, in figure 1 the measured amplitudes for an IGS receiver EBRE (40.6N,0.5E) are represented as a function of the year from 1997 to 2004 and the UT (that in this case is mostly coincident with the local time) in the vertical axis.

Figure 1, right hand plots, also shows the evolution along the studied period of the spectral components for a daytime hour (1100LT) and for a nighttime hour (2300LT). From this figure it can be seen the seasonal dependencies mentioned above (for the amplitudes) and that the strongest spectral component occurs at a frequency of about 1mHz in both the winter and summer TIDs. Notice the effect of the 2003 October 30th super-storm that can be clearly seen saturating in all the frequency modes.

We have also studied the propagation parameters for 4 small networks placed on North of Italy, California, Middle East and New Zealand. As an example, in figure 2 it is plotted along the year 2002 the horizontal components (right hand plot) for the Californian network (left hand plot).

From these studies one can extract the following conclusions:

- MSTIDs occur at mid latitudes mostly in winter during day time and in summer during nighttime and in both cases seem to have relation with the Solar Terminator. As it is expected, the amplitude of the ionospheric perturbation is modulated by the Solar cycle (figure 1).
- Winter MSTIDs (i.e. daytime) seem to be faster than summer/nighttime TIDs: around 150 m/s in winter and 100 m/s during summer. The propagation direction of winter TIDs is mostly equator-ward , while summer TIDs propagates mainly westward in all four networks (figure 2).

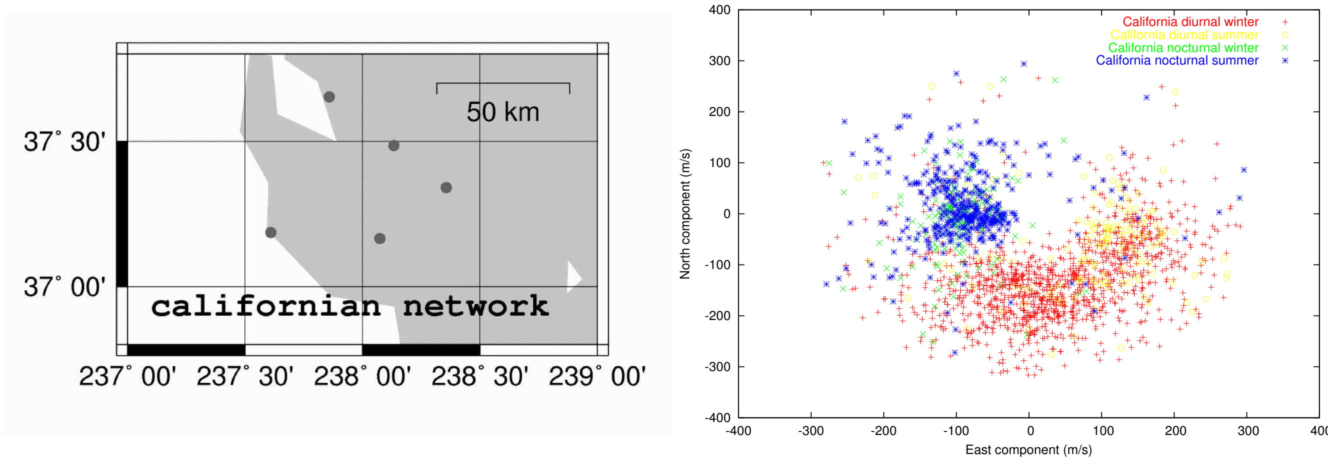

Figure 2: **Left hand plot:** Map of the Californian network used as example in this paper. **Righthand plot:** Horizontal components of the propagation velocity for the Californian network

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REFERENCES

[1] Bertin, F., J. Testud, L. Kersley and P. R. Ress The meteorological jet streem as a source of medium scale gravity waves in the termosphere: an experimental study *J. Atmos. Terr. Phys.*, *40*,1161-1183, 1978.

[2] Galushko V.G., V.V. Paznukhov, Y.M. Yampolski and J.C. Foster, Incoherent scatter radar observations of AGW/TID events generated by the moving solar terminator, *Ann. Geophysicae*, *16*, 821–827, 1998.

[3] Jacobson A. R., R.C. Carlos, R. S. Massey and G. Wu, Observations of traveling ionospheric disturbances with a satellite-beacon radio interferometer: Seasonal and local time behavior, *Journal of Geophysical Research*, *100*(A2), 1653–1665, 1995.

[4] Saito A., S. Fukao and S. Miyazaki., High resolution mapping of TEC perturbations with the GSI GPS network over Japan, *Geophysical Research Letters*, *28*, 689–692, 2001.

[5] Afraimovich E.L., K.S. Palamartchouk and N.P. Perevalova, GPS radio interfereometry of travelling ionospheric disturbances, *Journal of Atmospheric and Solar-Terrestrial Physics* ,*60*,1205–1223,1998.

[6] Calais E. and J.S. Haase, Detection of ionospheric perturbations using a dense GPS array in Southern California. *Geophysical Research Letters*, *30(12)*, 1628, doi:10.1029/2003GL017708, 2003.

[7] Jacobson A. R., R.C. Carlos, R. S. Massey and G. Wu, Observations of traveling ionospheric disturbances with a satellite-beacon radio interferometer: Seasonal and local time behavior, *Journal of Geophysical Research*, *100*(A2), 1653–1665, 1995.