

# Real time MSTIDs modelling and application to improve the precise GPS and GALILEO navigation

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## BIOGRAPHIES

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## ABSTRACT

The present study will be concentrated on the kind of ionospheric activity so called Medium Scale Travelling Disturbances (MSTIDs). It will be shown that a significant increase of precise navigation service area (in this case Wide Area RTK service area) can be achieved by means of a simple “blind” modelling of the MSTIDs, which can be applied in real-time. This model incorporates its spatial and temporal characteristics, in terms of occurrence and propagation parameters, obtained by the authors in previous works. Neglecting the MSTIDs (as it has been typically done so far), can introduce errors greater than several tenths of TECU, exceeding the exigent limit of 0.25 TECU, and impeding the right carrier phase ambiguity fixing under any technique, and the corresponding accurate navigation. This can easily happen with differences, for instance, of MSTID phases greater than 0.1 cycles, which can appear under distances of ~15 km or greater, considering a typical MSTID wavelength of 150 km. This can occur in any part of the Solar cycle, without geomagnetic activity and at mid latitude, for instance.

## INTRODUCTION

The feasibility of real time GNSS navigation, at distances greater than few tens of kilometers from a reference site, is strongly related to the capability of providing accurate

differential ionospheric refraction values to the user, in real-time. If such provided differential STEC values are very accurate (more than 0.25 TECU, about 4.5 cm in L1 GPS frequency, see Hernández-Pajares et al. 2000), then the user has the chance of fast carrier phase ambiguity fixing (near instantaneous with Galileo and modernized GPS systems) thanks to this additional datum. In this way the corresponding positioning capability with errors below 10 cm can be attained, as it was demonstrated, for instance, in Hernandez-Pajares et al. (2004), in a difficult scenario including baselines greater than 100 km (Wide Area Real Time Kinematics technique, WARTK).

Two of the main typical sources which make such task difficult are: (1) The differences between the user and reference site ionospheric states and paths. This larger-scale effect is especially important for long baselines, at low latitudes, or during Solar Max. or geomagnetic activity conditions. It has been studied and modelled by the authors in previous works (see for example Hernandez-Pajares et al. 2000, 2002). And another effect, (2), at shorter scales and which is the main goal of this work: the ionospheric perturbations so called Medium Scale Traveling Ionospheric Disturbances (MSTIDs).

As we will see in next section, the MSTIDs are wave-like signatures appearing in the STEC with typical amplitudes of several TECUs and wavelengths of 100-300 km. The MSTIDs show a strong seasonal behavior (which seems related to Solar Terminator and associated Atmospheric Gravity Waves, in such a way that they happen mostly in the day-time in winter season, moving towards the equator with typical horizontal velocity of ~100-250 m/s, and happen mostly in the night-time in summer season moving westward with velocities of ~50-150 m/s (see Hernández-Pajares, Juan and Sanz, 2006, hereinafter HJS06), making feasible a simple MSTID modelling for practical applications such as precise GNSS navigation, which is the main goal of this work.

The paper is organized as follows: the next section is devoted to a summary of MSTID occurrence and parameters. As a consequence, the real-time MSTID model and the performance results will be summarized in the two following sections, respectively, right before the conclusions.

## MEDIUM SCALE TRAVELLING IONOSPHERIC DISTURBANCES

Travelling ionospheric disturbances (TIDs) are plasma

density fluctuations that propagate through the ionosphere at an open range of velocities and frequencies. TIDs have been observed in most of the ionospheric measurements (Faraday rotation, ISR, VLBI, GPS). Many authors distinguish between Large scale TIDs (LSTIDs) and Medium Scale TIDs (MSTIDs). LSTIDs present a period greater than 1 hour and moving faster than 300 m/s. They seem to be related to geomagnetic activity and Joule effect at high latitudes, which produce thermospheric waves towards lower latitudes. MSTIDs have shorter periods (from 10 min to 1 hour) and move slower (50-300 m/s). The origin of MSTIDs seems to be more related with meteorological phenomena like neutral winds or solar terminator that produce atmospheric gravity waves manifesting as TIDs at ionospheric heights.

Despite the small amplitude of the MSTIDs, typically of tenths of a TECU in STEC GPS observations, several authors (Chen et al. 2003, Wanninger 2004, Hernández-Pajares et al. 2001) have shown that the presence of such ionospheric disturbances can cause a significant performance decrease on precise GPS navigation. This is because, for precise navigation, it is required that the differential ionospheric delays should be predicted with a very high precision, better than 0.25 TECU (such as in the case of the above mentioned WARTK technique).

An example of high correlation between poor simple ionospheric interpolation performance and the occurrence of MSTIDs can be seen in **Figure 1**, suggesting as well a Seasonal MSTID occurrence pattern. As it can be seen in this figure, the poorest results in ionospheric prediction occurs at the same time as the MSTID detection. This is the reason why we decided to focus on the improvement of MSTIDs detection and characterization in HJS06, in order to confirm the seasonal occurrence as far as the seasonal dependence of propagation parameters such as velocity, azimuth and periods. This has been a previous step (summarized in next section) to the real-time modelling, the main target of this paper.

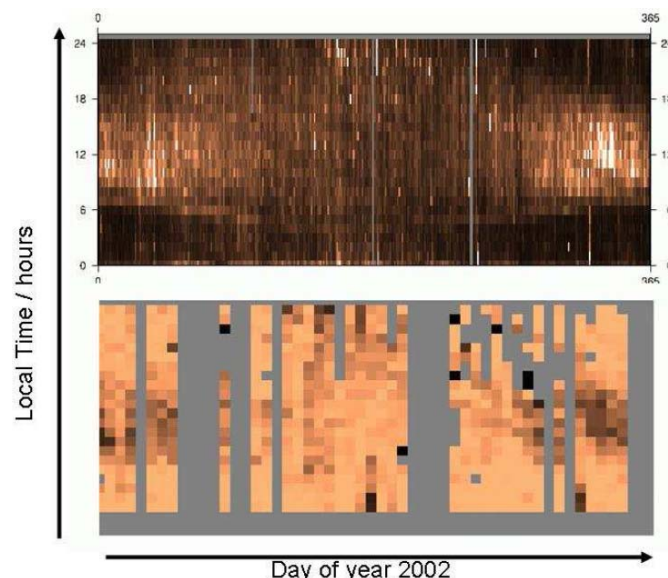
### MAIN CHARACTERISTICS OF MSTIDS

As it has been mentioned above, simple methods of detecting and characterizing the MSTIDs with data coming from ground based GNSS receivers (see MSTID example in **Figure 2**) have been developed recently by the authors in HJS06. Let us summarize its main results in order to build a simple real-time MSTID modelling, useful for precise GNSS navigation applications.

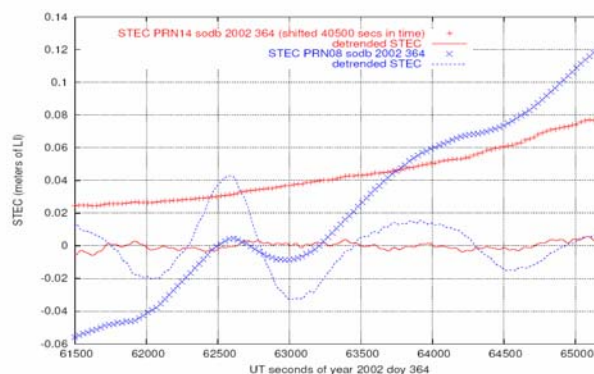
#### *TIDs occurrence for more than half Solar Cycle*

The TIDs occurrence since end of 1996 at EBRE GPS permanent receiver (NE Spain, 0°E 40°N, **Figure 3**) repeats the seasonal dependence (midday winter, midnight

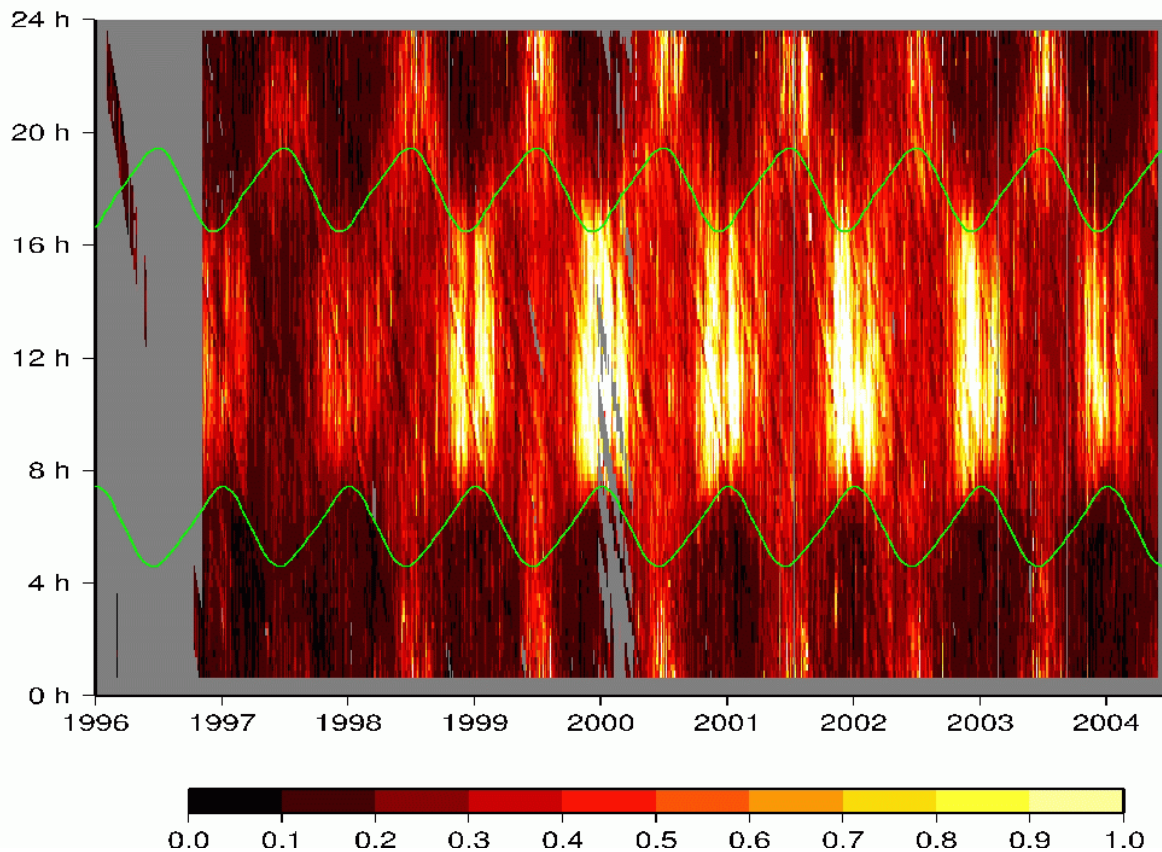
summer), apparently confined by the terminator, and modulated by the Solar Cycle. Similar results are obtained for south hemisphere in terms of the local season and local time (HART, South-Africa, 28°E 26°S). On the other hand it can be seen that the corresponding TIDs affecting WARTK are Medium Scale TIDs with Power Spectral Density quite concentrated (wave packets) at around 1mHz (periods of about 15-20 minutes).



**Figure 1:** This figure shows the relationship between the distribution of the detected TID (top-side plot in terms of day of year 2002 and local time, rescaled at arbitrary units –more brilliant colour represents higher MSTID activity–), and the error in the ionospheric correction for a roving receiver at 70km far from the nearest receiver (in terms of day of year 2002 and local time, and rescaled as well –being greater errors indicated by darker colour–), in the ICC GPS network in Catalonia, at the NE of Spain.



**Figure 2:** Two examples of the detrending method acting over one STEC series without apparent TIDs (blue lines, PRN14) and other where a TID is present (red lines, PRN08). In both cases the STEC has been divided by an obliquity factor in order to diminish the variation in the time window.



**Figure 3:** Rescaled amplitude of MSTIDs detected over the EBRE GPS receiver (40.6N,0.5E). Horizontal axis represents the day in years, and the vertical axis represents the local time in hours. The green line represents the Solar Terminator.

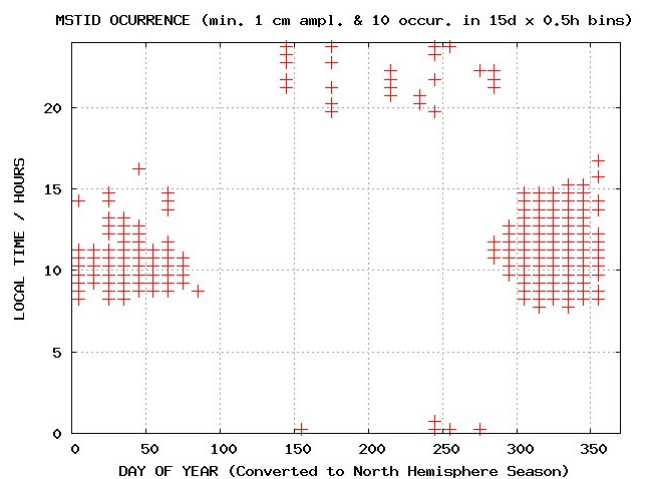
### Summary of the MSTID parameters

In HJS06 optimal procedures to estimate MSTID parameters and the corresponding results from four local networks worldwide distributed (the above mentioned EU, NA, ME, and NZ local networks respectively), during 2002-2003 with low geomagnetic activity ( $K_p < 4$ ), were depicted, fulfilling the MSTIDs the simple assumption of a planar wave. We refer the reader again to this reference for additional details on the procedure, results and discussion. In this section, we are going to summarize such results, taking into account, as it was mentioned above, that our main goal goes beyond the above mentioned paper scope: towards the generation of a simple real-time MSTID model and its application to GNSS navigation. And hence the overall results (corresponding to results obtained in 2002-2003 from the above mentioned local networks) are summarized in the following figures, in terms of the main Local Time (LT) and seasonal (day of year) dependences for the MSTID occurrence, horizontal velocity and period.

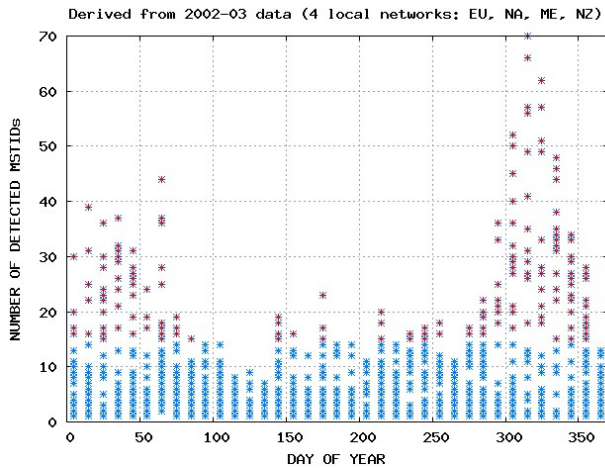
### MSTID occurrence

Indeed, as it could be expected from the above mentioned results (Figure 3), it can be seen in Figure 4 that the MSTID occurrence is mostly concentrated in local winter and day time, by noon. The maximum intensity happens around November at 1000LT (Figure 5 and Figure 6).

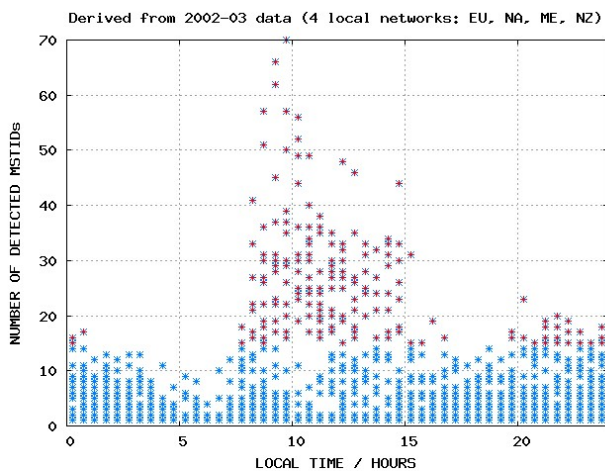
There is also significant MSTID activity in local summer nighttime. It must be emphasized that this pattern repeats in both North and South hemispheres (in Europe -EU-, North America -NA-, Middle East -ME- and New Zealand -NZ-), after correcting to local season and local time, and considering the poleward propagation.



**Figure 4:** MSTID occurrence in terms of day of year (X-axis) and Local Time (Y-axis), corresponding to bins of 10 days x 0.5 hours, with a minimum number of 10 MSTID events detected (with an amplitude greater than 1 cm). The data comes from four local networks -EU, NA, ME and NZ- during years 2002, 2003 (see more details in HJS06). The day of year is corrected from local season effects (day+183 for Southern Hemisphere data).



**Figure 5:** Number of MSTID occurrences in terms of the day of year (selected bins in red -with a number above the threshold of 15 occurrences-, unselected in blue).



**Figure 6:** Number of MSTID occurrences in terms of the Local Time (selected bins in red, unselected in blue).

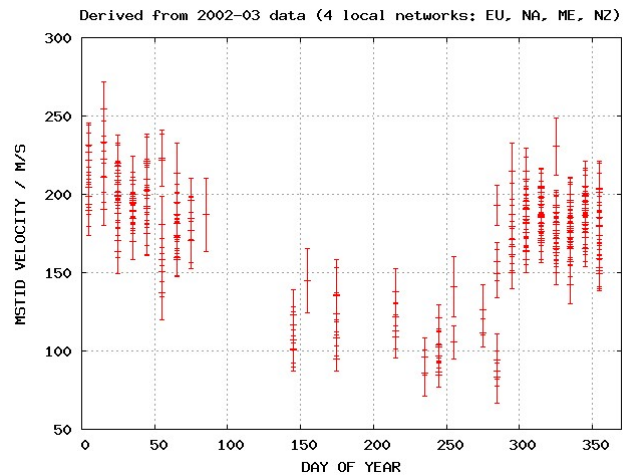
### MSTID velocity distribution

The corresponding MSTID horizontal velocity estimation distributes around 150-250 m/s in local winter / daytime and 80-140 m/s in local summer / night time (see **Figure 7** and **Figure 8**). The corresponding horizontal MSTID displacements are equatorward, equatorward-East (southward in North Hemisphere and northward in South Hemisphere, with azimuths of 130-200 deg.), in local winter and daytime, and westward (azimuths around 200-300 deg.) in local summer / night time (see **Figure 9** and **Figure 10**).

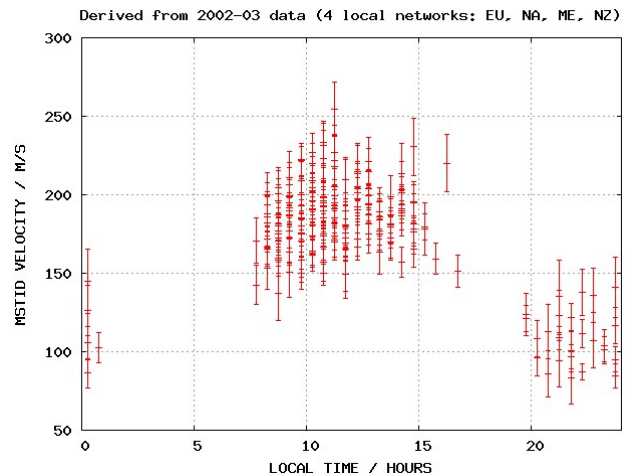
### MSTID periods

In spite that the period will not be strictly needed in the real-time MSTID model to be developed in next section, we show its distribution here to complement the MSTID description: You can see in **Figure 11** and **Figure 12** that the MSTID periods are typically distributed around 1000 sec. (~900-1100 sec. in local winter/daytime and ~800-1200 sec. in local summer/night time).

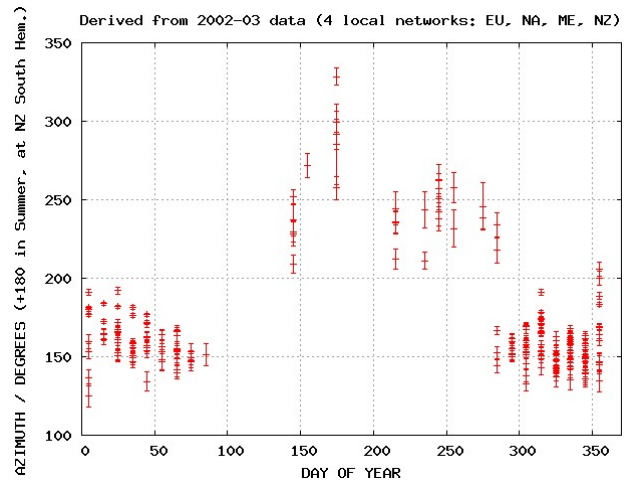
Finally you can see in **Table 1** a summary with the MSTID parameters which can be considered the base of the real-time MSTID model (DMTID, see next section). The specific parameters corresponding to the experiment to be described below are also included.



**Figure 7:** MSTID velocity in terms of the day of year.



**Figure 8:** MSTID velocity in terms of Local Time.



**Figure 9:** MSTID displacement azimuth (origin from North, clockwise) in terms of the day of year.

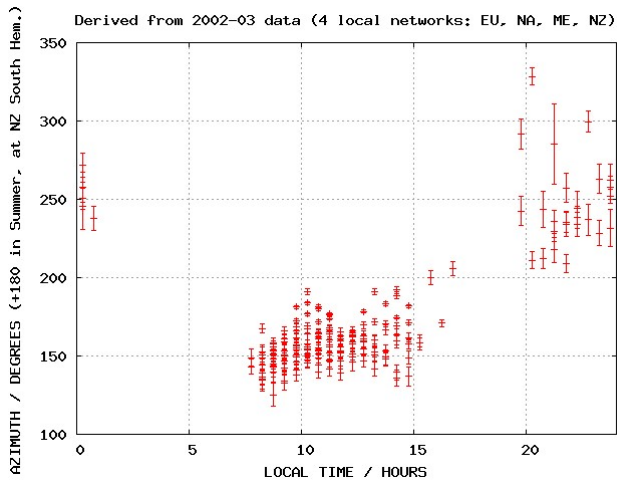


Figure 10: MSTID displacement azimuth vs. Local Time.

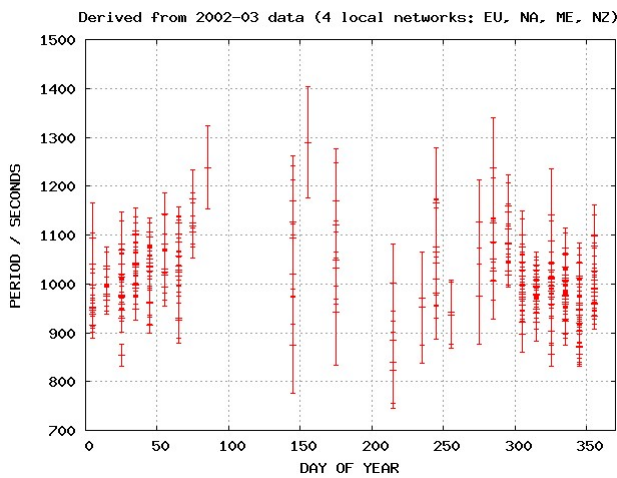


Figure 11: MSTID period in terms of the day of year.

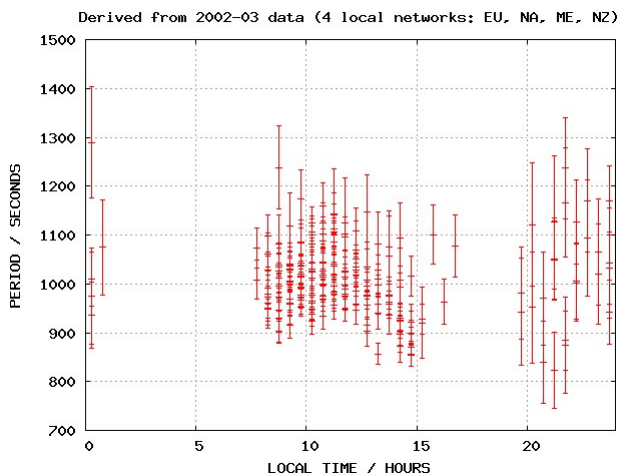


Figure 12: MSTID period in terms of Local Time.

### REAL-TIME MSTID MODEL (DMTID)

It has been demonstrated in previous works with both actual and simulated data, that the “linear” (or “larger scale”) dependence of the differential ionospheric

correction can be well addressed also in difficult scenarios (low latitude, Solar cycle maximum and distances of many hundreds of kilometres), by means of the two-layer ionospheric model (see Hernández-Pajares et al. 1999, 2000, 2002, 2003, 2004). And the typical main remaining source of errors was the “non-linear” (or “shorter scale”) contribution given by Medium Scale Travelling Ionospheric Disturbances, MSTIDs.

Local season	In Winter	In Summer	Adopted value in the experiment
Days* of year	270-366 001-110	130-290	048
Local Time / hours	0700-1800	1800-2400 0000-0400	0700-1800
Velocity / m/s	150-250	80-140	200
Azimuth** / degrees	130-200	200-300	180
Period*** / seconds	900-1100	800-1200	1000

**Table 1:** Summary of MSTID parameters estimated from different local networks during 2002-2003. They can be considered the definition of the “Differential Delay Mitigation Model for MSTIDs” (DMTID) through a simple planar wave model. The particular parameters corresponding to the analyzed experiment are also included. (Remarks: \* Day of year in North Hemisphere, day of year + 183 days (modulus 366) in South Hemisphere; \*\* Azimuth referred to the north, clockwise in North Hemisphere, and referred to the south, anticlockwise in South Hemisphere; \*\*\* The period is indicated just for information purposes -not strictly needed in DMTID-). The last column corresponds to the adopted values for the analyzed experiment (February 17<sup>th</sup>, 2005).

Hence the real-time modelling of the MSTID effect on precise GNSS navigation (using RTK, VRS, TCAR or WARTK techniques among others) has the potential of increasing the corresponding Service Areas, because of in this way the differential ionospheric correction computed by the user can be still more accurate, helping on fixing carrier phase ambiguities at still larger baselines, with the corresponding precise navigation with errors below 10 centimeters.

In this context, a new simple model is proposed in this paper to improve the precise GNSS navigation performance significantly: it is the so called “real-time differential delay model for mitigating MSTIDs” (hereinafter DMTID, under patent approval). It consists of applying a planar wave MSTID horizontal propagation model, taking into account the propagation parameters given by the seasonal behaviour shown in HJS06, and summarized in the last section. From this simple model, a MSTID differential delay ( $\Delta t$ ) is computed for each given satellite between the roving user and reference receiver ionospheric pierce points (red and yellow dots in Figure 13, respectively). In this case, the reference receiver should be the closer one experiencing the MSTID before the user

(poleward in local winter/day time and eastward in local summer/night time, taking into account the typical azimuth distribution shown in **Figure 9** and **Figure 10**). We will call such receiver the “precursor reference site” (PRS).

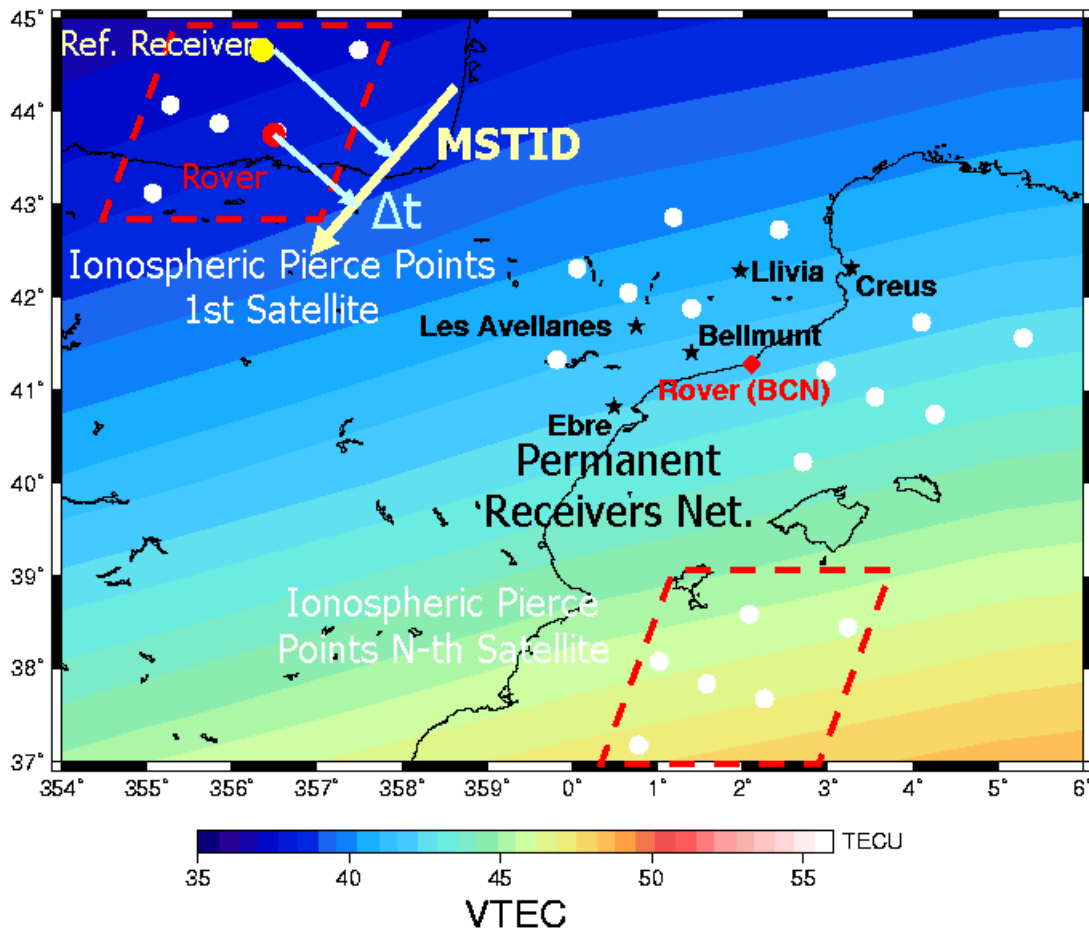
Indeed, in this way, the buffered values of MSTID state for the chosen reference receiver, conveniently stored by the user, can be used as predictor of its pierce point state, applying the temporal delay  $\Delta t$  (see **Figure 13**). In which way such MSTID states can be estimated in real-time? Firstly we will consider the broadcasted ionospheric corrections, corresponding to the cluster of pierce points associated with the observation of each given satellite from the local, regional or wide area network of permanent GNSS receivers, used to compute them. Secondly, such values are adjusted at each given updating epoch under a linear or quadratic model –depending on the baselines lengths-. Such adjustment performs a sort of spatial detrending of the TEC variation in the corresponding ionospheric region (see **Figure 13**). Hence the corresponding residuals, which can be broadcasted to the users as well, can be interpreted as the MSTID state estimations affecting the satellite measurements observed from each permanent receiver. But in fact, as it has been mentioned above, the user should store, in real-time, such

residuals corresponding to the “precursor” reference site only, PRS, during a typical time, for instance, up to  $\Delta t \sim 100 \text{ km} / 200 \text{ m/s} = 500$  seconds or more, for a baseline user-precursor reference site of 100 km under local winter / daytime MSTIDs.

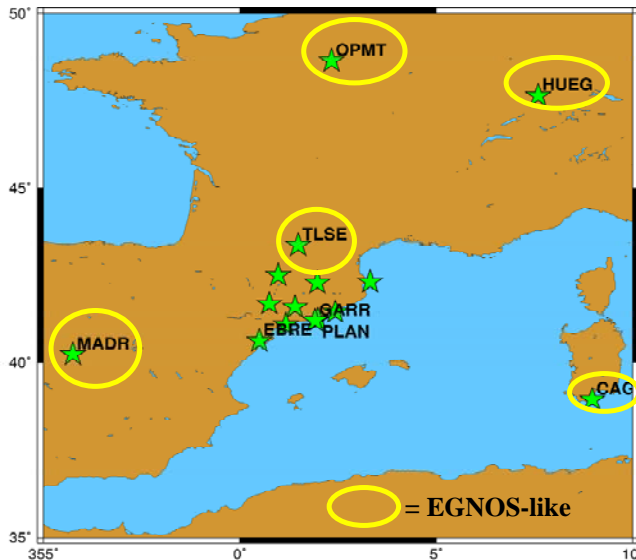
It is important to say that the above mentioned delay  $\Delta t$  to be applied to the PRS MSTID states (per-satellite adjustment series), before subtracting it from the ionospheric correction provided to the rover, should take into account the pierce point Doppler effect, due to the relative movement of the piercepoints, as it is done in HJS06. In particular, and from equation (6) of such paper, the following expression can be derived:

$$\Delta t = \frac{\vec{s} \cdot \Delta \vec{r}_{pp}}{1 - \vec{s} \cdot \vec{v}_{pp}}$$

Being  $s$  the slowness vector (following the MSTID propagation direction, with modulus equal to the inverse of the velocity),  $\Delta r_{pp}$  the baseline vector between the ionospheric pierce points of the given satellite viewed from the rover referred to the PRS and  $v_{pp}$  the rover pierce point velocity (Doppler term).



**Figure 13:** Layout supporting the MSTID real-time model description.



**Figure 14:** Map indicating the reference receivers: encircled in yellow for large network, and the remaining labelled ones for small network; the remaining receivers (non-labeled) are treated as roving users.

One last comment in this point is that applying such delay to a satellite not affected by any MSTID should not be a problem because usually the PRS would know that (for instance using the SRTI index). Otherwise this would not be an issue too, because the residual (MSTID state) should be a small random factor in such a case.

### APPLICATION TO WIDE AREA RTK

In order to test the performance of the real-time MSTID model, DMTID, we have selected 5 IGS permanent receivers in West Europe (circled points in **Figure 14**), with typical distances between them of 500 km or more, acting as reference sites. In this way, it is possible to emulate a real-time Wide Area RTK Central Processing Facility (WARTK-CPF, see Hernández-Pajares et al. 2004 for details). Nine additional permanent receivers, belonging to real-time CATNET network in Catalonia, at NE Spain (Talaya & Bosch, 1999), were treated as rovers, emulating the real-time positioning with WARTK corrections broadcasted from the CPF. Additionally, the CATNET receivers EBRE, GARR and PLAN were used as well as references in a second independent configuration. In this way, we are able to test the DMTID performance for 14 different baselines ranging from 10 to more than 300 kilometers to the nearest reference site.

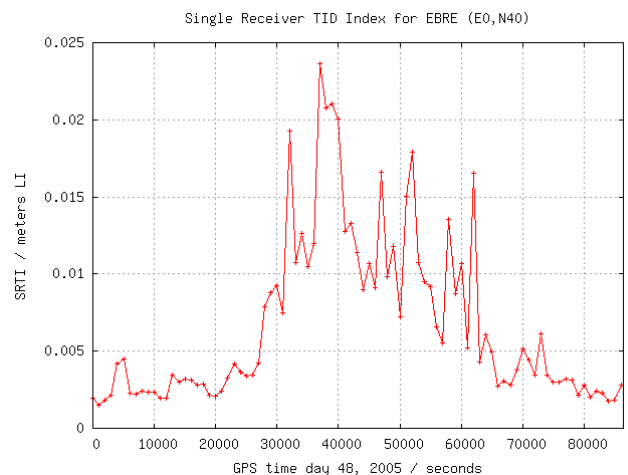
This test has been performed with data gathered during day 048 of 2005 (February 17th), coinciding with the SIS-2 EGNOS campaign. Hence, this corresponds to a winter day, and according to the previous study (see **Table 1**), it constitutes the worst case scenario, from the point of view of MSTID activity, expected at noon time.

The following parameters have been selected for DMTID,

taking into account the study summarized in the previous section: southward planar waves moving at 200 m/s with a period of 1000 seconds, acting from 0700 to 1800LT (see again **Table 1**). Such parameters, obtained from analyzing data coming from 2002-2003 datasets of different local networks worldwide distributed, are quite compatible with the actual ones, computed only for checking purposes from a subset of the data used in the experiment (see **Figure 14**), as it can be seen in **Figure 15** and **Figure 16**. In the first figure, the Single Receiver TID Index (SRTI) computed from EBRE data can be seen. SRTI is basically the second order derivative of the ionospheric carrier phase combination for a given satellite-receiver temporal series (see details in HJS06). Such plot confirms the prediction of MSTIDs occurrence in the day time, as it corresponds to a winter day. And the propagation parameters derived from the network are well represented by the selected parameters as well (see **Figure 16** and **Table 1**).

In order to show the DMTID performance, we will mostly concentrate on the representative case of receiver LLIV treated as rover at more than 100 km from the nearest reference site, TLSE (see **Figure 14**).

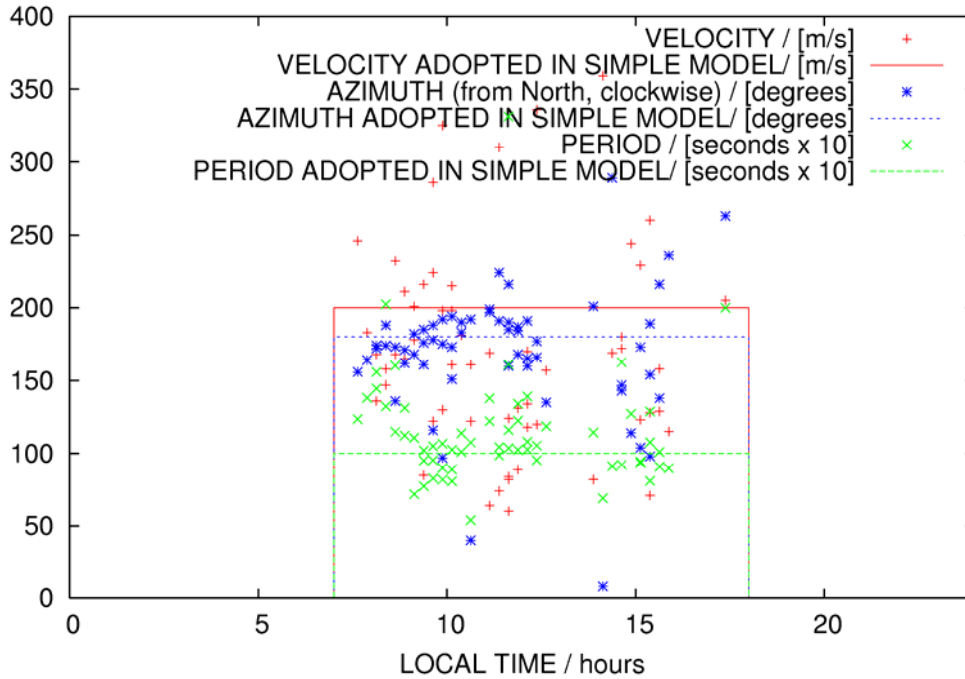
The typical results obtained at the ionospheric corrections level are well represented in **Figure 17** for three different satellites. It can be seen that the MSTID model correction (DMTID, dark blue points) tracks the actual ionospheric perturbations (red points) better, compared with a simple local or more broad lineal adjustment (light blue and green points respectively).



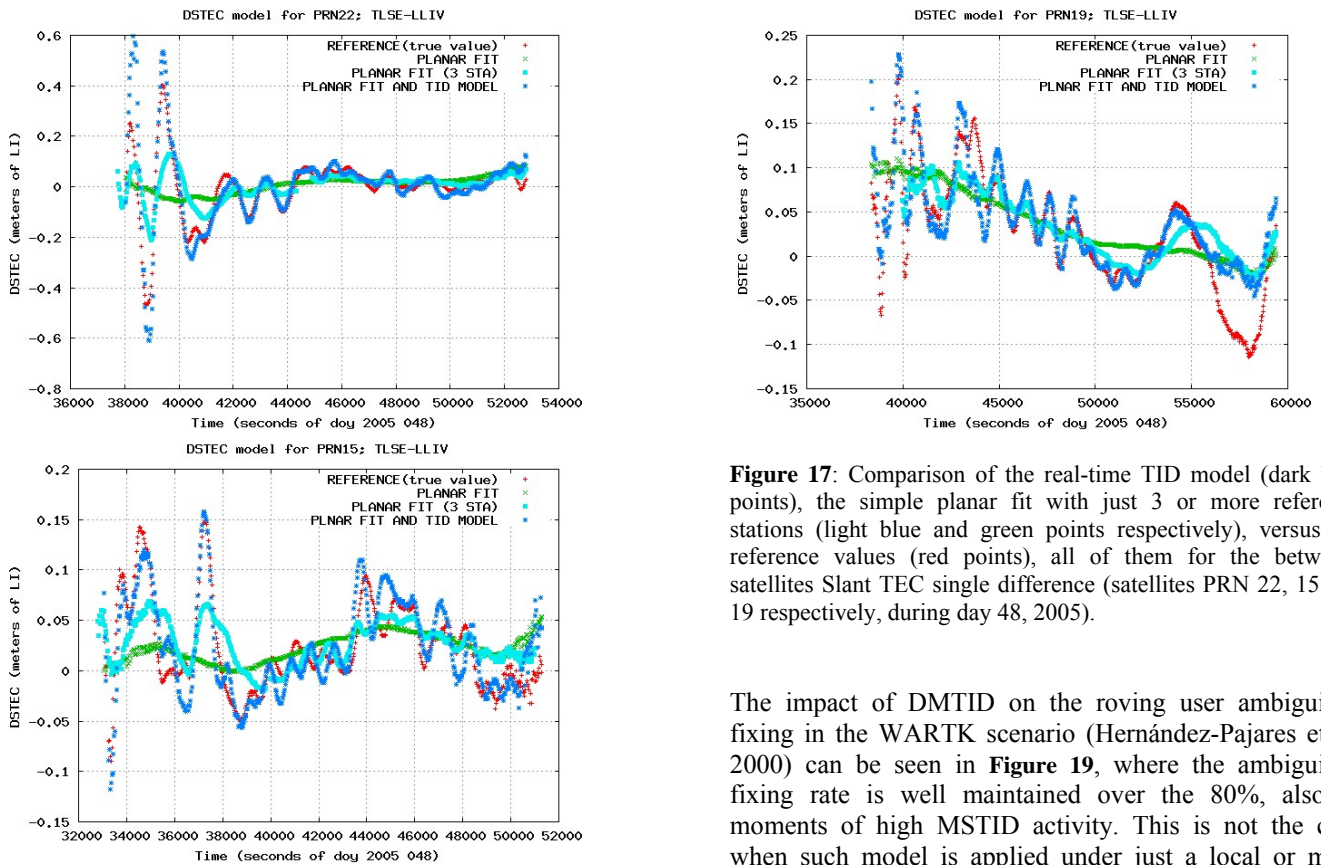
**Figure 15:** Single Receiver TID Index computed for receiver EBRE, in terms of GPS time, for day 48 of 2005.

It can be seen as well the correlation between the ionospheric error (**Figure 18**) and the corresponding SRTI index (**Figure 15**), as it could be expected from the above commented previous studies (**Figure 1**). And more important: it can be seen that the DMTID impact on the ionospheric error reduction can reach up to 50% or more in some epochs.

MSTIDs, day 048 2005 @ (~E0,N40): MATA, BELL, GARR, SBAR, PLAN (ref.)

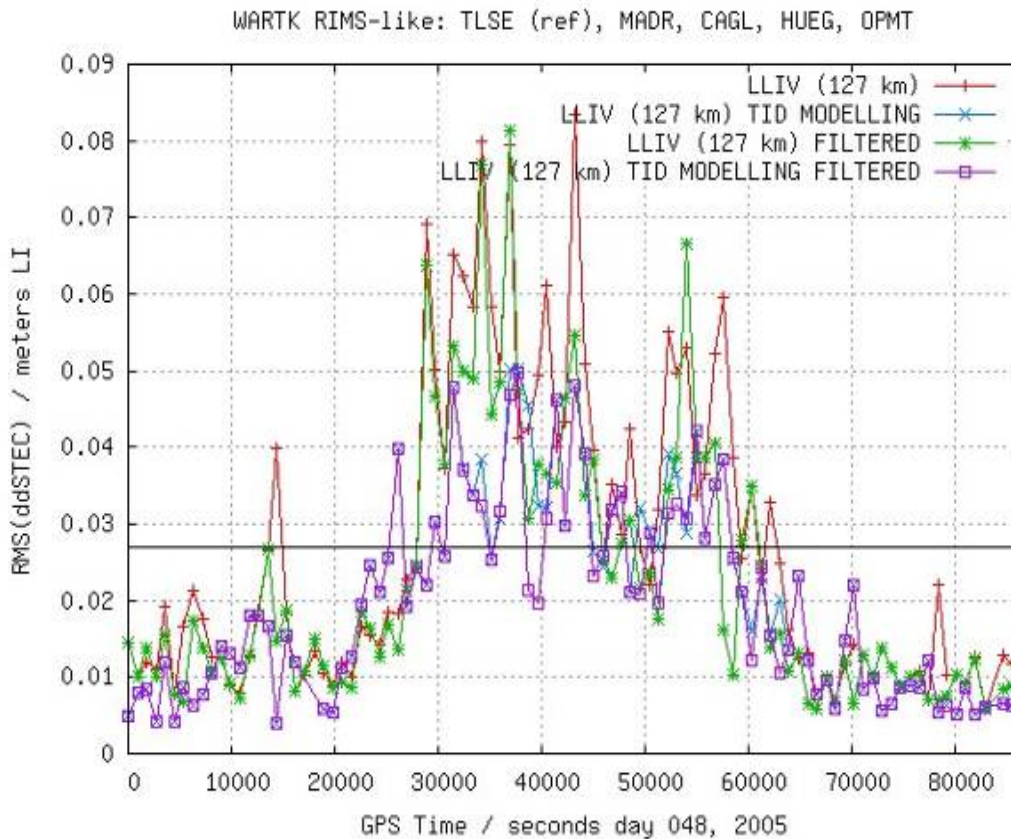


**Figure 16:** Plot showing the compatibility of the actual and modelled MSTID characteristics (DMTID) during the experiment analyzed in this paper (day 048, 2005).

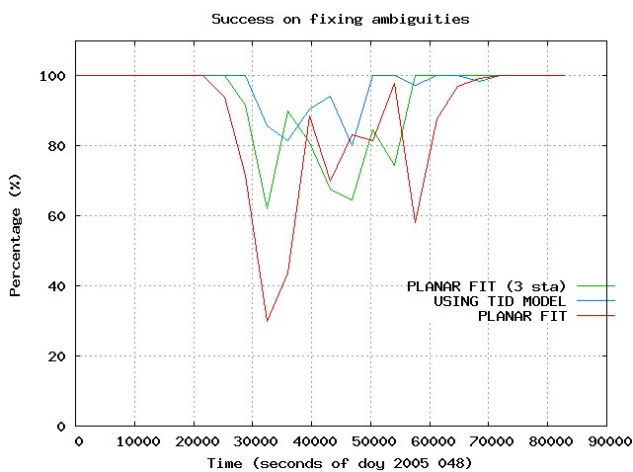


**Figure 17:** Comparison of the real-time TID model (dark blue points), the simple planar fit with just 3 or more reference stations (light blue and green points respectively), versus the reference values (red points), all of them for the between-satellites Slant TEC single difference (satellites PRN 22, 15 and 19 respectively, during day 48, 2005).

The impact of DMTID on the roving user ambiguities fixing in the WARTK scenario (Hernández-Pajares et al. 2000) can be seen in **Figure 19**, where the ambiguities fixing rate is well maintained over the 80%, also in moments of high MSTID activity. This is not the case when such model is applied under just a local or more general linear fitting.



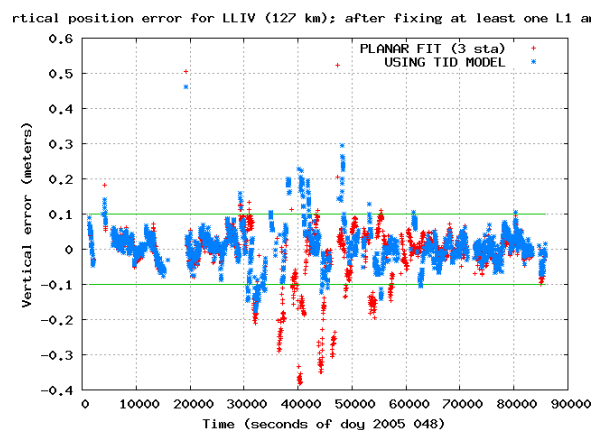
**Figure 18:** Performance of ionospheric WARTK user corrections, vs the reference values provided by WARTK in post-processing: planar-fit –red-, planar-fit with satellite downweighting –green-, versus using, as well, real-time MSTID modelling (DMTID) –blue- and adding satellite downweighting as well –magenta- (“large network”, with baseline of 127 km between LLIV -rover- and TLSE -ref. site-). The black line represents an RMS equal to 2.7cm, the maximum allowable ionospheric error to be able to fix the carrier phase ambiguities in single epoch ideally (day 048, 2005).



**Figure 19:** Comparison of the ambiguity fixing rate for receiver LLIV treated as rover (127 km baseline) between using linear (planar) fit (green and red with 3 and more reference receivers) compared to additional use of the MSTID model –DMTID- (blue line, day 048, 2005).

Moving towards the final target, the real-time positioning, the corresponding navigation improvement can be seen in **Figure 20** (blue points), with respect to not using DMTID (red points). In such difficult scenario the vertical coordinate error (the more affected one by the ionospheric

errors) is significantly reduced. Additional improvements in the epochs with higher MSTID rates are foreseen with the use of dedicated local network (in the east-poleward part of the reference receiver network) to provide more accurate user MSTID precursors.



**Figure 20:** Navigation accuracy comparison between using or not the new real-time MSTID model (blue and red points) for LLIV treated as rover (127 km baseline).

Finally, the increase of WARTK service area under such difficult scenario can be seen in **Figure 21**, taking as reference a daily averaged error given by the threshold of 0.25 TECU (green line). It can be seen that the

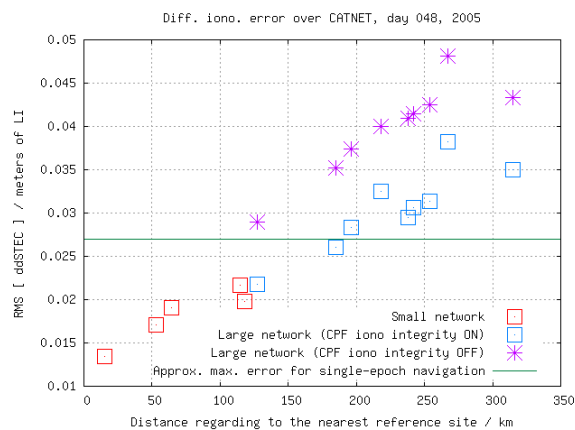
corresponding baseline distance increase, given by DMTID, goes from 110 or 180 km under plain or MSTID downweighted WARTK respectively, up to about 250 km with the new approach, from the nearest reference site. This means an increase of about 40% in distance, and about doubling the service area. This improvement is also significant for shorter baselines (typical of RTK for instance) with an improvement of more than 20% for baselines below 50 km (see same figure).

## RESULTS AND CONCLUSIONS

From the above summarized results, we can say that the repeatability of MSTIDs characteristics opens the door to simple ways of mitigation, by simple real-time modelling from the reference receiver observables themselves. We have shown the performance of this approach, in one of the worst scenarios, in winter daytime and in wide-area networks, with typical distances between reference sites of hundreds of km. Our starting point is the last version WARTK technique, as was defined and tested in Hernandez-Pajares al, 2004.

To do that, just a small network of receivers separated up to few tens of kilometers, well located (poleward-east oriented), are necessary to estimate the specific MSTID parameters (velocity, propagation azimuth, period) for the whole Wide Area Network. But in this first work, we have chosen a more simple but less accurate approach: without any local GNSS network, just climatological MSTIDs parameters are used to define a simple “blind” model (DMTID), able to mitigate in real-time the MSTIDs effect in precise user navigation.

In order to test the effect of real-time MSTID modelling in precise GNSS navigation, we have used a dataset composed of several IGS receivers in Europe, selected with baselines up to several hundred of kilometers, similar to the EGNOS reference station –RIMS- distribution. Moreover, the GPS receivers of the ICC Catalonia's network have been treated as rovers, emulating the real-time computation during all the processing. The data studied were gathered during day 048 of 2005.

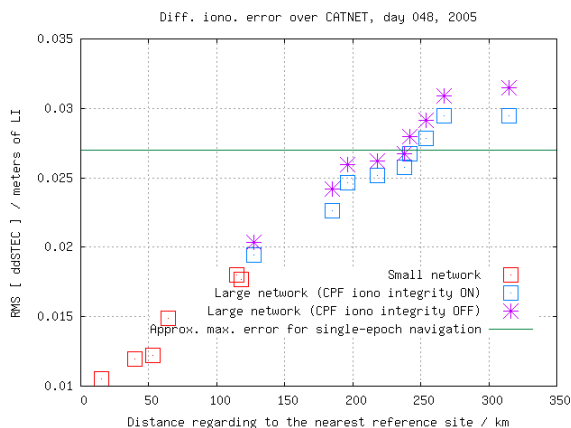


**Figure 21:** Real-time WARTK correction error –in meters- in terms of baseline length –in kilometers- averaged during 24 hours: it can be seen in topside plot using the new real-time MSTID modelling (DMTID) with and without downweighting (similar results), and just using the linear interpolation in the bottom side plot, (with and without satellite downweighting in function of its MSTID affection as well). The reference ionospheric error threshold of 2.7 cm (0.25 TECU) is also indicated as a green line, coinciding approximately with the ability of real-time ambiguity fixing for about 2/3 of the observed satellites (1-sigma in an assumed Gaussian distribution).

Different results have been shown, being the main one that the STEC interpolation error can be reduced up to more than 50%, coinciding with the periods of higher MSTID activity (noon time in the case of the analyzed dataset in winter), in such a way that the sub-decimeter error-level navigation service area with WARTK is approximately twice compared to not using such real-time MSTID modelling technique (more than 40% of daily increase in maximum baselines, from about 170 to ~250 km of maximum distance to the nearest GNSS reference site).

Finally to say that we have shown, as the main conclusion, that the use of a simple “climatological” or blind MSTID model can significantly mitigate the errors introduced in the STEC prediction for a roving user in both Wide Area and Local networks of reference GNSS sites.

Further additional improvements can be studied by using a dedicated poleward local network providing support to a whole Wide Area GNSS network (such as EGNOS or WAAS reference stations or future Galileo and GPS III reference receivers) in order to reduce the error of the used MSTID model, with regards to the “climatological” approach presented here, the DMTID blind model.



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## REFERENCES

Chen, X., H. Landau, and U. Vollath, New tools for network RTK integrity monitoring, Institute of Navigation ION-GPS'2003 Proceedings, Portland, OR, September 2003.

Hernández-Pajares, M., J.M. Juan, J. Sanz and O.L. Colombo, Precise Ionospheric Determination and its Application to Real-Time GPS Ambiguity Resolution, Institute of Navigation ION-GPS'2001, Proceedings, Nashville, TN, USA, September 1999.

Hernández-Pajares, M., J.M. Juan, J. Sanz and O.L. Colombo, Application of ionospheric tomography to real-time GPS carrier-phase ambiguities resolution, at scales of 400-1000 km, and with high geomagnetic activity, Geophysical Res. Letters, 27, 2009-2012, 2000.

Hernandez-Pajares M., J.M. Juan, J.Sanz, O.L. Colombo, Tomographic modeling of GNSS ionospheric corrections: Assessment and real-time applications, Institute of Navigation ION-GPS'2001, Proceedings, Salt-Lake, UT, USA, September 2001.

Hernández-Pajares M., J.M. Juan, J. Sanz and O. Colombo, Improving the real-time ionospheric determination from GPS sites at Very Long Distances over the Equator, Journal of Geophysical Research - Space Physics, (A) Vol. 107, pp.1296-1305, 2002.

Hernandez-Pajares M., J.M. Juan, J.Sanz, O.L. Colombo, Feasibility of Wide-Area Subdecimeter Navigation With GALILEO and Modernized GPS, IEEE Transactions on Geoscience and Remote Sensing, Vol. 41, No. 9, September 2003.

Hernandez-Pajares M., J.M. Juan, J.Sanz, A.García-Rodríguez, O.L. Colombo, Wide Area Real Time Kinematics with Galileo and GPS Signals, awarded Oral presentation, Institute of Navigation ION-GNSS'2004, Proceedings, Long Beach, CA, USA, September 2004.

Hernandez-Pajares M., J.M. Juan, J. Sanz, "Medium scale Traveling Ionospheric Disturbances affecting GPS measurements: Spatial and Temporal analysis", JGR-Space Physics, VOL. 111, A07S11, doi:10.1029/2005JA011474, 2006.

Talaya, J., E. Bosch, CATNET, a permanent GPS network, Institute of Navigation ION-GPS'2001, Proceedings, Nashville, TN, USA, September 1999.

Wanninger, L., Ionospheric disturbance indices for RTK and network RTK positioning, Institute of Navigation ION-GNSS'2004, Proceedings, Long Beach, CA, USA, September 2004.