# Improved MSTID modelling and impact on precise GNSS processing

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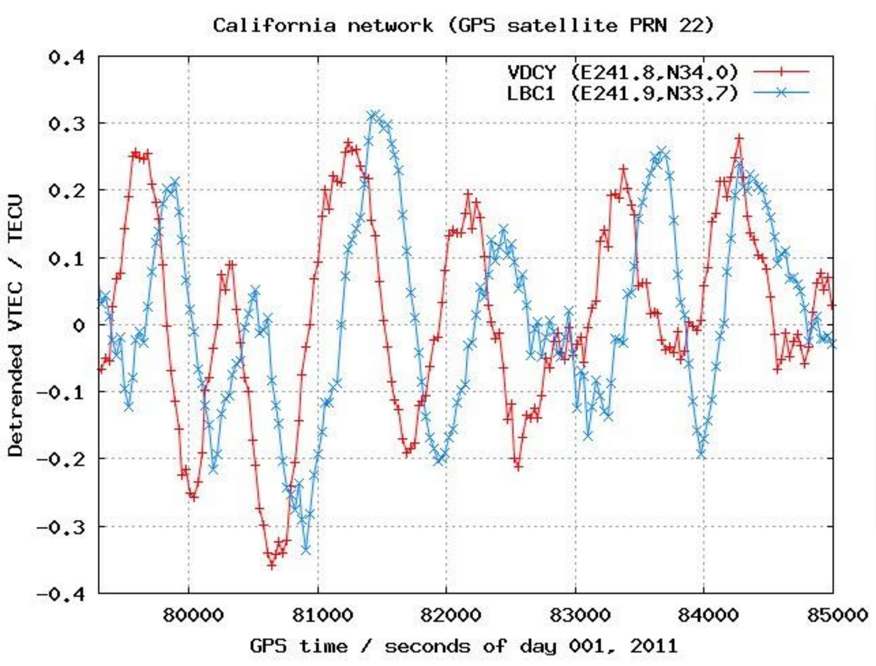
## Abstract

The ESA PIOM-FIPP research study of MSTID determination and application to precise GNSS positioning over Poland faced an unexpected and main issue in the first stage of the project development: the lack of enough populated local GNSS networks over most part of Europe, in order to apply the foreseen state of the art MSTID propagation techniques. In this work, the authors introduce un update of the GII method, the direct GNSS Ionospheric Interferometry (dGII) which provides a simple MSTID mitigation in real time. It is based on the direct correlation in time-domain of the user detrended ionospheric delay, with the corresponding value of the reference receiver, affected previously by the TID. dGII is performed independently for each continuous arch transmitter-receiver in sparse RTK and regional GNSS networks.

## Introduction

The Medium Scale Travelling Ionospheric Disturbances (MSTIDs) are ionospheric signatures of waves, up to few TECUs of amplitude (1 TECU = 1016 m-2), which propagate with typical periods ranging from several minutes to less than one hour, and velocities from 50 to 300 m/s (**Hernández-Pajares et al. 2012**).

**Fig. 1:** Example of MSTID signature in the detrended VTEC, directly obtained from the ionospheric combination of GPS carrier phases corresponding to an MSTID affecting GPS satellite PRN 22, advancing from receiver VDCY (E241.8,N34.0) toward LBC1 (E241.9,N33.7) in California network, January 1st, 2011 (reproduced from **Hernández-Pajares et al. 2012**).




- **The practical disadvantage of GNSS Ionospheric Interferometric techniques** is the lack of local GNSS networks with enough receivers (> 5 ) within a diameter of less than half wavelength (~50km) which prompted an update for **GII: the direct GII method (dGII)**.

- MSTID velocity no needed,
- Smooth,
- Potentially applicable to scales of ~100 km.
- It improves **Precise GNSS positioning** (RTK)

1. The VTEC detrended (**δV**) to show up MSTID signatures for each given GNSS satellite s, is directly based on single difference in time of $L_I=L_1-L_2$ (similarly to Deng et al. 2013), and with **dt=60 sec**: **$\delta V = \delta L_I / M$** where **M** is the ionosphere mapping function,.
2. The MSTID time delay **Δt** is estimated by cross-correlating $\delta L_{I,ref}$ with $\delta L_{I,user}$ with an sliding window of ~< T/2 = 600 sec.
3. The precise slant ionospheric delay $S_{ref}$ provided by the permanent reference receiver for each given GNSS transmitter in view is taken as approximation of the user value, in the following simple way:

$$S_{user}(t)= V_{ref}(t-\Delta t)\, M_{user}(t)$$

which has been shown most accurate than other simple aproximates of $S_{ref}(t)$ like $S_{user}(t-\Delta t)$

## Results

- **Implementation of dGII**

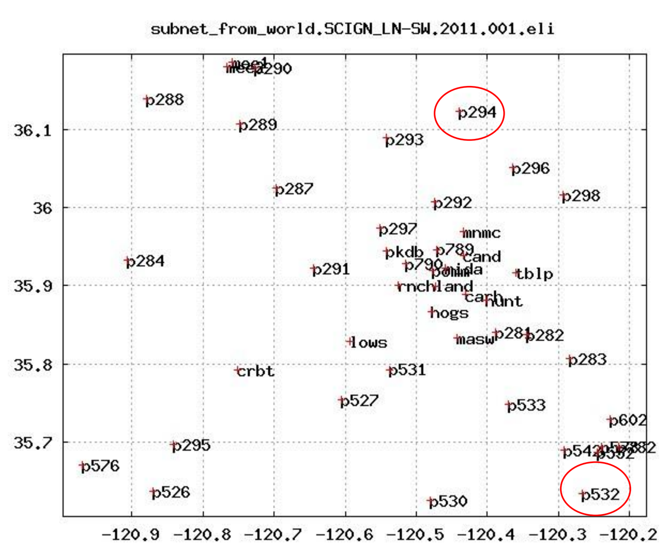



**Fig. 3:** Location of two GNSS SCIGN receivers, initially selected due to its southward-oriented baseline, for the GII test case studies, as case study.

- **Double–differenced Ionospheric delay domain 60-80 km baselines**

| | | DD iono del. res. <0.05m [%] | | DD iono del. res. <0.10m [%] | | DD iono del. res. <0.20m [%] | | DD iono del. std [mm] | |
|---|---|---|---|---|---|---|---|---|---|
| DOY | Baseline | Red RNX | Mod.RNX+ Prop.STEC | Red RNX | Mod.RNX+ Prop.STEC | Red RNX | Mod.RNX+ Prop.STEC | Red RNX | Mod.RNX+ Prop.STEC |
| 168 | BOR1-KONI | 34 | 56 | 63 | 81 | 92 | 97 | 115 | 85 |
| | GNIE-KONI | 52 | 68 | 83 | 91 | 99 | 99 | 76 | 60 |
| 353 | BOR1-WRKI | 67 | 64 | 83 | 84 | 93 | 96 | 96 | 84 |
| | GNIE-WRKI | 64 | 59 | 81 | 80 | 93 | 94 | 105 | 97 |

**Table1**: Example of statistics of the double-differenced ionospheric residuals obtained CWP network for original and corrected observations

- **Positioning – ambiguity and coordinate domain 60-80 km baselines, summer day (168/2013)**

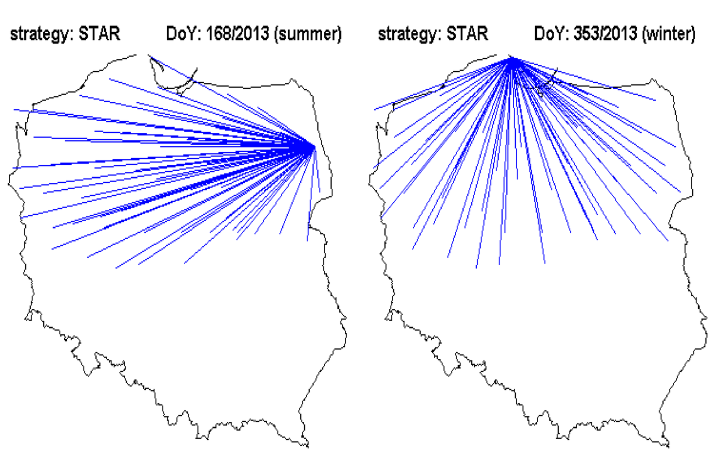
| 168 DOY CWP net | | | | | | |
|---|---|---|---|---|---|---|
| Baseline | strategy | ASR [%] | TTFF [epochs] | N std [m] | E std [m] | U std [m] |
| BOR1-KONI | Original obs. | 53 | 29.9 | 0.011 | 0.006 | 0.029 |
| | MSTID-corrected | 78 | 12.8 | 0.012 | 0.007 | 0.035 |
| GNIE-KONI | Original obs | 74 | 18.3 | 0.013 | 0.008 | 0.025 |
| | MSTID-corrected | 83 | 15.7 | 0.013 | 0.009 | 0.036 |

**Table 2:** RTK positioning performance statistics. **Improvement in the ambiguity resolution domain.**

- **Improvement in the troposphere modeling**

**Experimental campaign:**

- Sub-network of Polish ASG-EUPOS network was selected (61 stations).
- DoY 168/2013 (summer campaign) and DoY 352/2013 (winter campaign).
- STAR baseline definition strategy.




a) Summer b) Winter

| No. | Solution name | RINEX files | Ionosphere model |
|---|---|---|---|
| 1. | Org.RNX+CodeION | Original (full) | CODE (ION format) |
| 2. | Red.RNX(noSTEC) | Reduced number of observations | None |
| 3. | Red.RNX+CodeION | Reduced number of observations | CODE (ION format) |
| 4. | Mod.RNX(Sim.STEC) | MSTID corrections included | “Simultaneous” MSTID model |
| 5. | Mod.RNX(Truth.STEC) | MSTID corrections included | “Truth” MSTID model |
| 6. | Mod.RNX(Prop.STEC) | MSTID corrections included | “Propagated” MSTID model |

**Table 3:** MSTID modeling (dGII) solutions.

Original RINEX files:
- smaller AR%, ZTD estimates close to EPN final solution

Reduced/modified RINEX files with MSTID dGII models:
- **small differences** in WL and NL AR%, improvement in QIF AR% up to 14%
- **different ZTD estimates** than using CODE iono model (but equal formal errors)

## Conclusions

- Our research resulted in advancement in MSTID modeling that overcome shortcomings of the existing methods (more suitable for application in sparse GNSS networks).
- The direct GNSS Ionospheric Interferometry (dGII) was developed to be applied in real-time conditions, and just based on ionospheric data from a single permanent receiver.
- Subsequent application of MSTID corrections to relative kinematic positioning resulted in reduction of size and variability of DD ionospheric residuals during MSTID occurrence.
  - In particular, ambiguity success rate ASR was improved (up to 40%), at the same time the number of epochs required to obtain precise position decreased (to less than 50%)
- The MSTID models did not degrade the tropospheric solutions, but also did not improved it significantly: there were negligible differences in a posteriori error of unit weight and RMS of coordinates
  - The improvements were observed in the percent of resolved ambiguities when using QIF method (long baselines, up to 14%).

## References

Hernández-Pajares, M., Juan, J. M., Sanz, J., & Aragón-Àngel, A. (2012). Propagation of medium scale traveling ionospheric disturbances at different latitudes and solar cycle conditions. Radio Science, 47(6).