Comprehensive Ionospheric Delay Modelling for Single-Frequency GNSS Precise Positioning: First Steps

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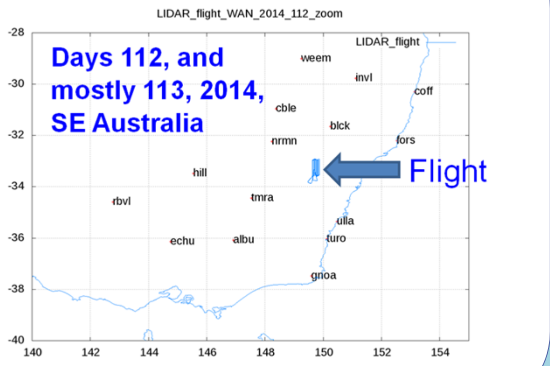
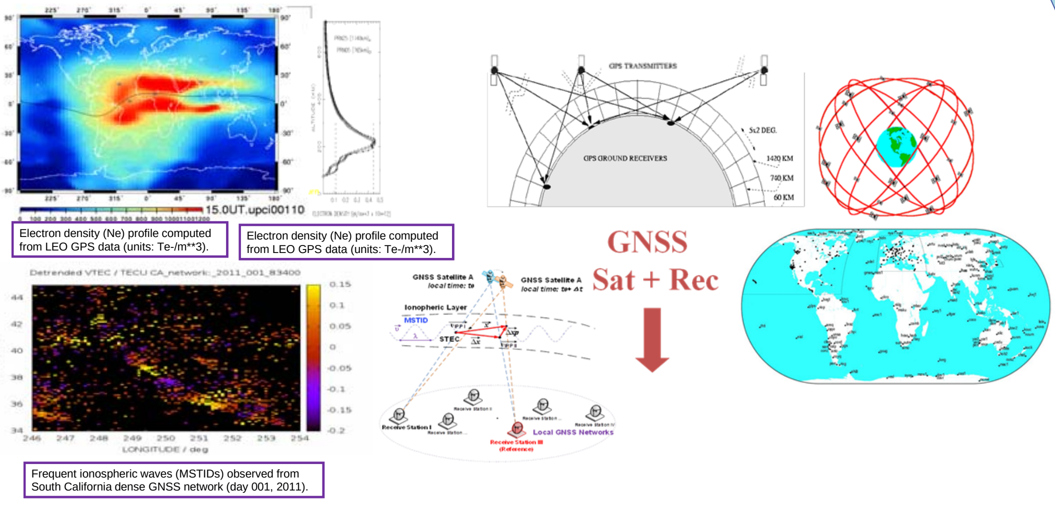
Summary: The goal of this poster is to summarise the main ionospheric delay components and accurate modelling approaches for precise positioning of single-frequency GNSS users moving up to distances of several hundred kilometres from the permanent GNSS sites, updating the work presented by Colombo et al. (2015).

1. The Problem

- Accurate single-frequency (dm error-level) GNSS aircraft positioning at hundreds of km from reference receivers.
- Ionospheric delay becomes a main source of error.
- Dual-frequency measurements → ground truth.
- Previous works of the authors with dual-freq data for speeding up the convergence and improving accuracy *(Colombo et al. 2002)*.

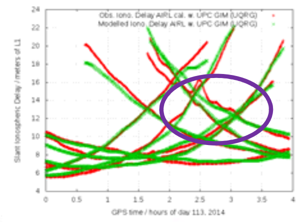


2. Ionosphere, GNSS & Comprehensive Models



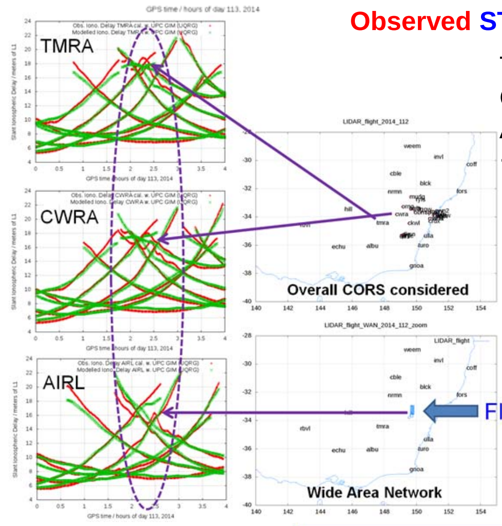
- GNSS 1st order ionospheric delay is proportional to Slant Total Electron Content (STEC) and inversely proportional to squared frequency.
- Dual-freq users can cancel out 99.9% of iono delay.
- Dual-freq CORS can feed:
  - # accurate iono models for single-freq GNSS users
  - # speed up convergence for precise dual-freq users
- The main 3D distribution of electron content (top-left), and its temporal evolution, can be well captured *(Hernández-Pajares et al. 2002)* by means of a tomographic model (with low vertical resolution for ground users), estimated in synergy with the precise geodetic modelling from a permanent network of GNSS receivers separated hundreds of kilometres (top-right).
- The very frequent ionospheric waves (Medium Scale Travelling Ionospheric Disturbances, MSTIDs, top left) *(Hernández-Pajares et al. 2012)* constitute a second source of error typically neglected in precise GNSS positioning (either for increasing accuracy in single-frequency users or for reducing the convergence time for dual-frequency users).
- They propagate equatorward in daytime (autumn & winter) and westward in night-time (spring & summer), with typical periods of 500-2000 sec and velocities of 50-400 m/s.
- In spite of its small amplitude (<~ tens of cm in L1), MSTIDs are relevant for their non-linear nature, unless you are only a few kilometres from the nearest reference site. MSTIDs can be modelled as planar waves using interferometric techniques from local GNSS networks *(Hernández-Pajares et al. 2016)*.

3. Ionospheric Waves & the Experiment

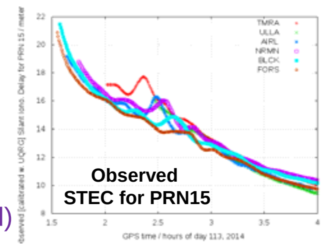


Observed STEC vs. UPC-GIM Modelled STEC: Aircraft (AIRL) (from *Colombo et al. 2015*): Wave-like signature affects several satellites (e.g. PRN15) with amplitudes up to ~1 m & periods ~20 min (like MSTIDs).

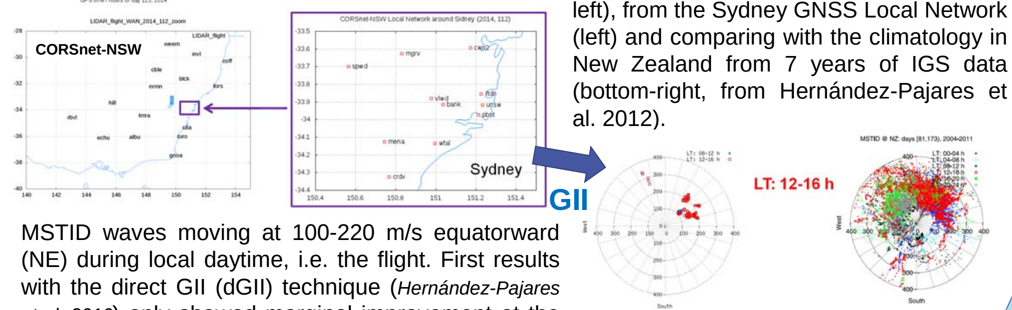
Observed STEC vs. UPC-GIM Modelled STEC:



TMRA
CWRA
AIRL (aircraft)
→ Wave propagates towards NE (equatorward)

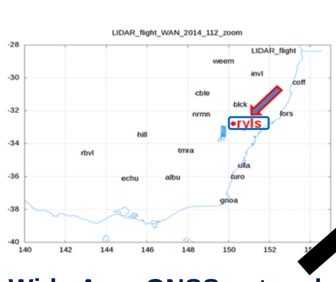


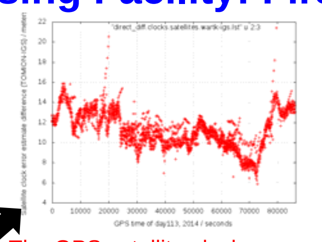
From STEC signatures at the SW-to-NE chain of receivers: TMRA, ULLA, AIRL, NRMN, BLCK & FORS. The signature in PRN15 (as in other satellites) is clearly a wave, with an amplitude of ~0.5 m propagating from SW to NE. This is confirmed by performing GNSS Ionospheric Interferometry, GII (bottom-left), from the Sydney GNSS Local Network (left) and comparing with the climatology in New Zealand from 7 years of IGS data (bottom-right, from Hernández-Pajares et al. 2012).



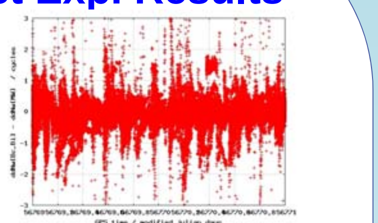
MSTID waves moving at 100-220 m/s equatorward (NE) during local daytime, i.e. the flight. First results with the direct GII (dGII) technique (*Hernández-Pajares et al. 2016*) only showed marginal improvement at the aircraft (as opposed to large improvement at CORS).

4. Ionospheric & Geodetic Wide Area RTK Central Processing Facility: First Exp. Results



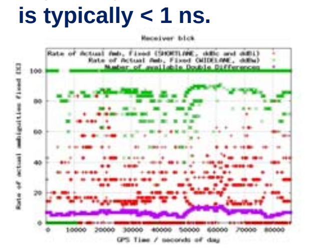


The GPS satellite clocks precision (tmra is the reference) regarding to IGS final values is typically < 1 ns.

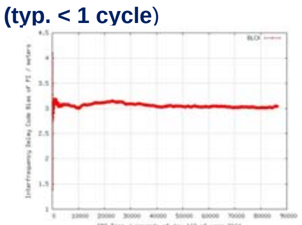


The inst. double diff. widelane ambiguity computed from the iono. & geom. models fits well with the inst. Melbourne-Wübbena value (typ. < 1 cycle)

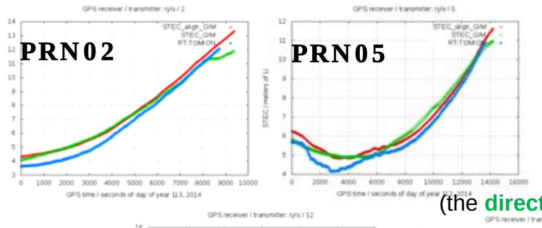
Wide Area GNSS network used to run RT-TOMION (iono-tomo. + geodetic model) and **GNSS receiver RYLS, close to AIRL, treated as user** during second day, 113, 2014 (after CPF convergence), combining undifferenced processing with fixing of double diff. ambiguities



The ambiguity fixing rate is typ. above 80% for the widelane and < 50% for the narrowlane (rec. blck).

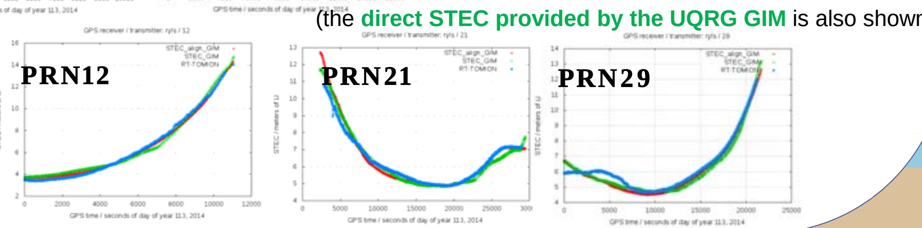


The intefrequency delay code bias estimate is typ. quite stable for the receivers, at the few decimetre level (ex.: rec. blck).



First RT-STEC results computed for **'user' RYLS** during flight match in general well (e.g. PRN21, 12) with the external reference (**STEC from L1-L2 calibrated with UQRG GIM**) with discrepancies below a few decimetres.

(the **direct STEC provided by the UQRG GIM** is also shown)



References

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Conclusions and Future Work

- The first steps on the comprehensive ionospheric delay modelling for single-frequency GNSS precise positioning, exemplified in a flight experiment, have been presented.
- The first validations are consistent for: (1) the MSTID ionospheric wave occurrence and propagation properties, affecting the aircraft and surrounding Wide Area network; (2) the performance of the WA-RTK Central Processing Facility (RT-TOMION software) during the experiment, e.g. in terms of satellite clock precision, widelane ambiguity consistency, differential code bias stability and widelane & narrowlane ambiguity fixing rates; (3) the RT-STEC correction given to a static receiver treated as rover.
- These first results are encouraging in order to pursue real-time ionospheric corrections good enough to allow precise single-frequency GNSS navigation of roving users, such as aircraft, hundreds kilometres away from a GNSS network site.
- Next steps: overall assessment and tuning of WA-RTK CPF performance for the given experiment (vs. GIPSY-OASIS software as external software for comparison – ongoing) and improvement of RT-MSTID correction procedure for the aircraft, a high dynamics user.

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