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Real time generation of Australian Regional Ionospheric Corrections for single-frequency GNSS positioning

Charles Wang, Wenjiao Liu and Yanming Feng
Queensland University of Technology, Australia (y.feng@qut.edu.au)

Fu Zheng and Shenfeng Gu
Wuhan University, China

Motivation

- The needs of mass-market and high precision GNSS applications have been supported with the standard positioning services (SPS) and network RTK services, respectively in Australia.
- Space-based augmentation systems (SBAS), such as WAAS, EGNOS and MSAS, can provide down to the sub-meter positioning accuracy for low-cost single-frequency users. However, as with most of the southern hemisphere, Australia is not covered by any SBAS services, including both wide area differential GNSS and integrity services via geostationary satellites.
- There is an increasing need for low cost single-frequency decimetre positioning services for emerging applications, such as Intelligent Transport System (ITS), Unmanned Airborne Vehicle (UAV) and many others. In the instance of ITS, for safety applications and lane-level traffic management, vehicles must reliably determine which lanes they are travelling and predict where the surrounding vehicles are in the lanes. The horizontal accuracy requirement for this ITS application is 1.0 metre at 95% of time.
- This works aims to explore use of the GNSS networks of about 150 stations in Australia and New Zealand to generate more accurate regional ionospheric corrections in real time. Along with the IGS orbits and real time clocks, we offer a substitute of SBAS type of services to single-frequency (SF) GNSS users for decimetre-to submetre positioning accuracy. The experiments will show the achievable positioning accuracy and demonstrate the potential of the system to support the emerging ITS road safety applications.

Generation of Regional Ionospheric Corrections over Australia and New Zealand

Using the station-based computing approach [1], raw data streams from each station are processed individually. It aims to determine all the biases in the right-hand side of the two equations, to generate station-based solutions. Being different from the geometry-free models for global ionosphere modelling, we apply the geometry-based model to estimate ionospheric delays station by stations. The ionospheric vertical total electric contents (VTEC) at the ionosphere-piece point (IPP) is modelled to reflect the spatial-temporal variation in ionosphere by a set of parameters [1,2,3]:

$$dP_i \equiv P_i - (\rho - c \cdot t^s + tropm_d ZTD_d - b_i^s)$$
$$= c \cdot t^r + tropm_w ZTD_w + \frac{f_1^2}{f_i^2} I_i + b_i^r + e_{P_i}$$
$$dL_i \equiv L_i - (\rho - c \cdot t^s + \Delta\emptyset_{windup} + tropm_d ZTD_d)$$
$$= c \cdot t^r + tropm_w ZTD_w - \frac{f_1^2}{f_i^2} I_i - \lambda_i \cdot k_i + e_{L_i}$$
$$I_i = ionom \cdot (a_0 + a_1 dL + a_2 dL^2 + a_3 dB + a_4 dB^2)$$

Precise IGS products for orbits, clocks, PCO/PCV and DCB inputs must be used in the computations. Based on station-based slant TEC results, the regional ionospheric map (RIM) for VTEC are represented by the grid of 1x2 degrees ranging from 0N to 70S, and 90E to 170W, updated every 30 to 300 seconds.

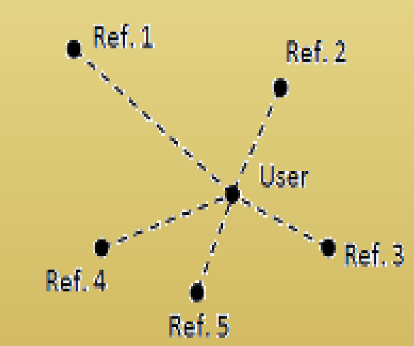
User-end computing

User-terminals must complete a number of computations in order to achieve better positioning accuracy, on top of standard navigation processing[4]:

1) Use the real time precise orbits and clock products instead of broadcast ephemerides
2) Apply the corrections of PCOs and PCVs
3) Apply the corrections for Differential Code Biases
4) Apply the corrections for solid earth tide
5) Apply the phase windup corrections for phase measurements

Regarding the ionosphere corrections, users can either select several surrounding grids or stations within a radius threshold to interpolate the VTECs or slant TECs for reliable positioning:

$$sTEC_{user} = \frac{\sum_{ref=1}^{n} \frac{sTEC^{ref}}{D_{user}^{ref}}}{\sum_{ref=1}^{n} \frac{1}{D_{user}^{ref}}}$$
$$for \quad (D < threshold)$$



The ionospheric corrections can support the following types of positioning solutions, depending on user positioning algorithms:

1) Single-frequency single point positioning (SF-SPP)
2) Single-frequency precise point positioning (SF-PPP)
3) Dual-frequency precise point positioning (DF-PPP)
4) Dual-frequency precise point positioning-Ambiguity Resolution (PPP-AR)

Numerical Results

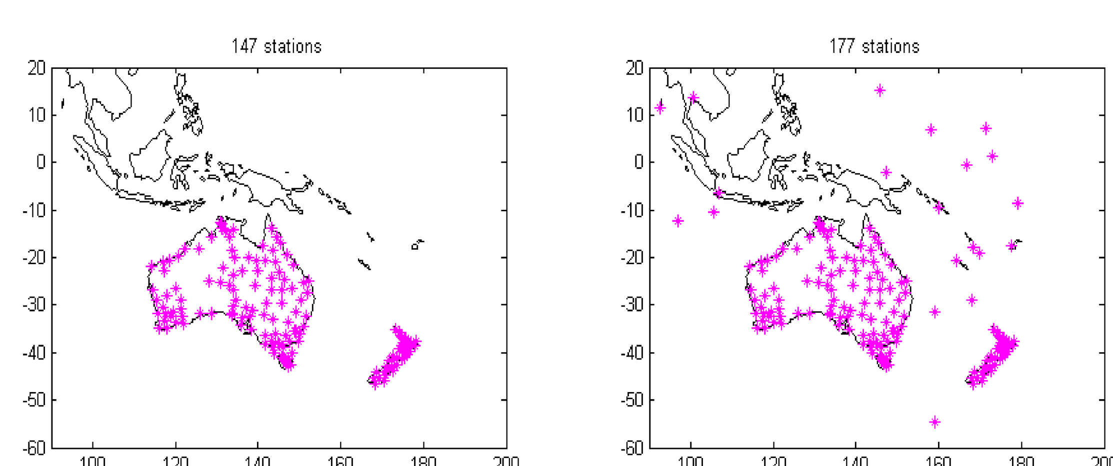


Fig. 1 Illustration of two network schemes of different densities: (1) 147 stations in Australia and New Zealand; (2) 177 stations including the previous 147 and 30 in the Oceania region. This is to study the impact of the outside stations on the positioning performance.

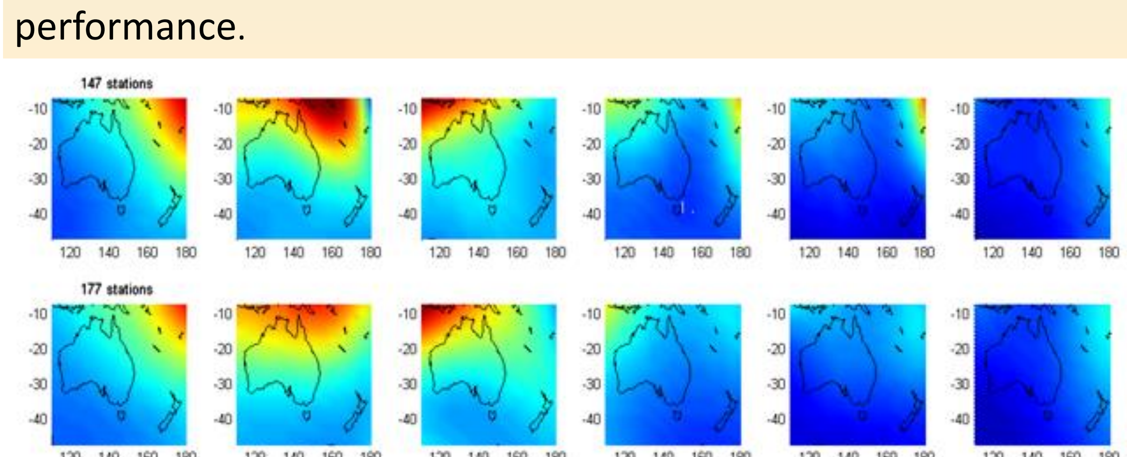


Fig. 2 Illustration of Australian regional ionospheric Vertical TECs generated by four network schemes for the time instants 00:00, 04:00, 08:00, 12;00, 16:00, 20:00 UTC, DOY 30, 2016.

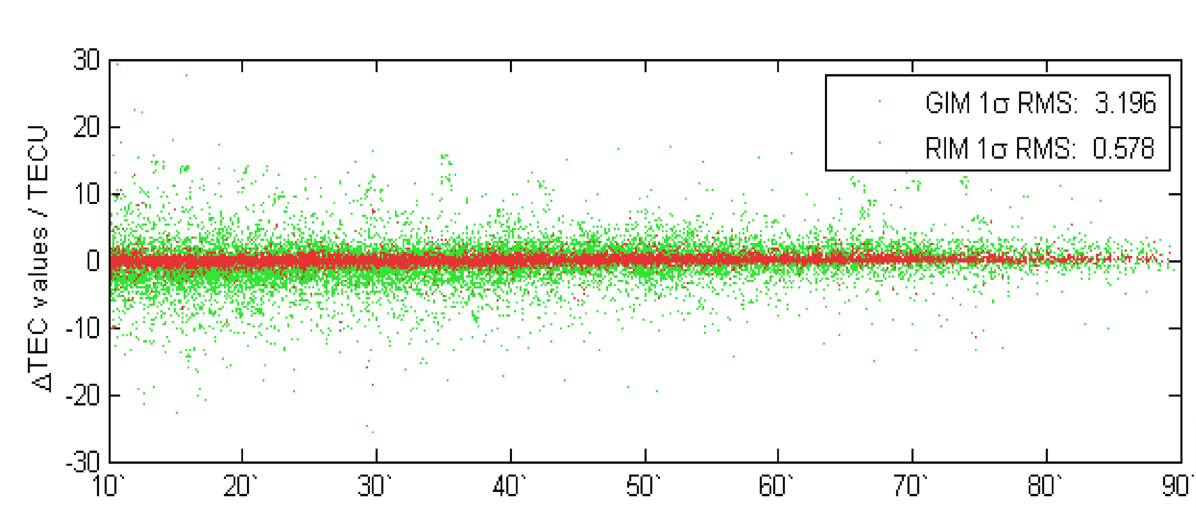


Fig. 3 Illustration of difference between the station-based VTEC values and RIM/GIM VTEC values, plotted against the elevation angle.

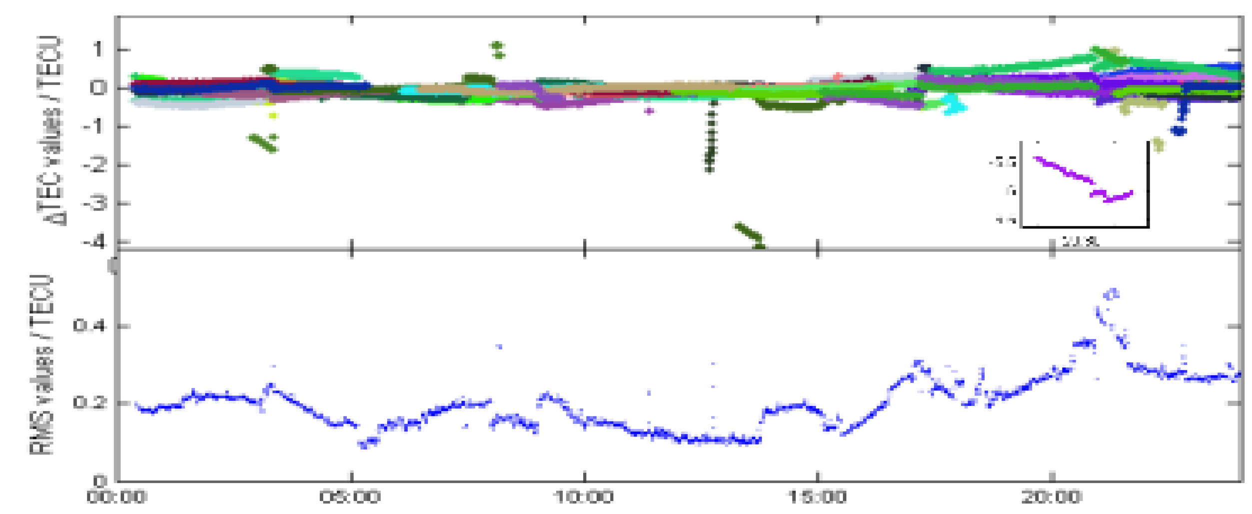


Fig. 4 (Upper) Illustration of difference between the station-based slant TEC values and interpolated slant TEC values for PRN14 and PRN04, showing good consistence in general and outliers for some periods. The lower panel shows the RMS values ranging from 0.20 to 1.0 TECU.

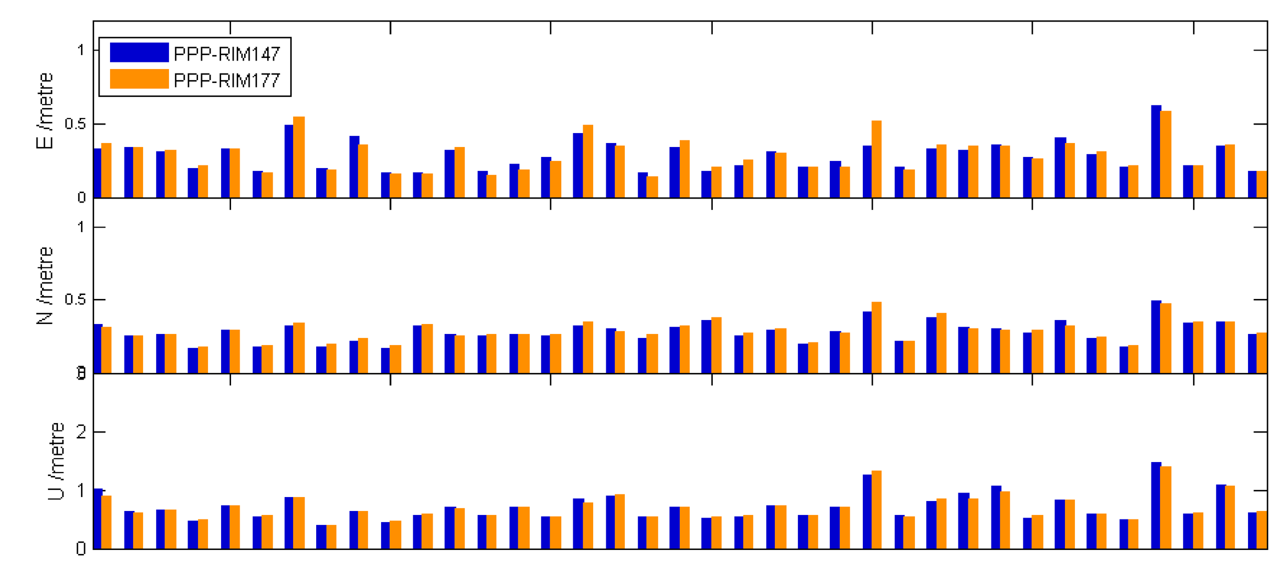


Fig. 5 Comparison of SF-PPP solutions at 37 stations inside Australia with ionosphere corrections from four different densities. The networks of 147 and 177 stations offer the decimeter RMS accuracy in North and East components and submetre in the Up component. Stations outside the area of interests do not offer evident performance improvement

Summary

1. We have developed the capability for generating regional ionosphere correction to support single-frequency SPP and PPP in Australia, by processing real time data streams from hundreds of stations.
2. The quality of the regional ionospheric map depends on the density of the network. For the network of 147 stations, the RMS accuracy is proved to range from 0.2 to 1 TECU at the users, depending on the user's locations.
3. The SF-PPP solutions from 37 reference receivers have shown the decimetre RMS accuracy better than 30 cm for the East/North directions and 60 cm for the Up-component.
4. Overall, this work demonstrates the promising potential for the Australia GNSS network to offer decimetre to submeter positioning services with single-frequency GNSS receivers, supporting many new emerging applications over Australia and New Zealand.

References

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Queensland University of Technology

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