Enhancing global PPP with Local Ionospheric Corrections

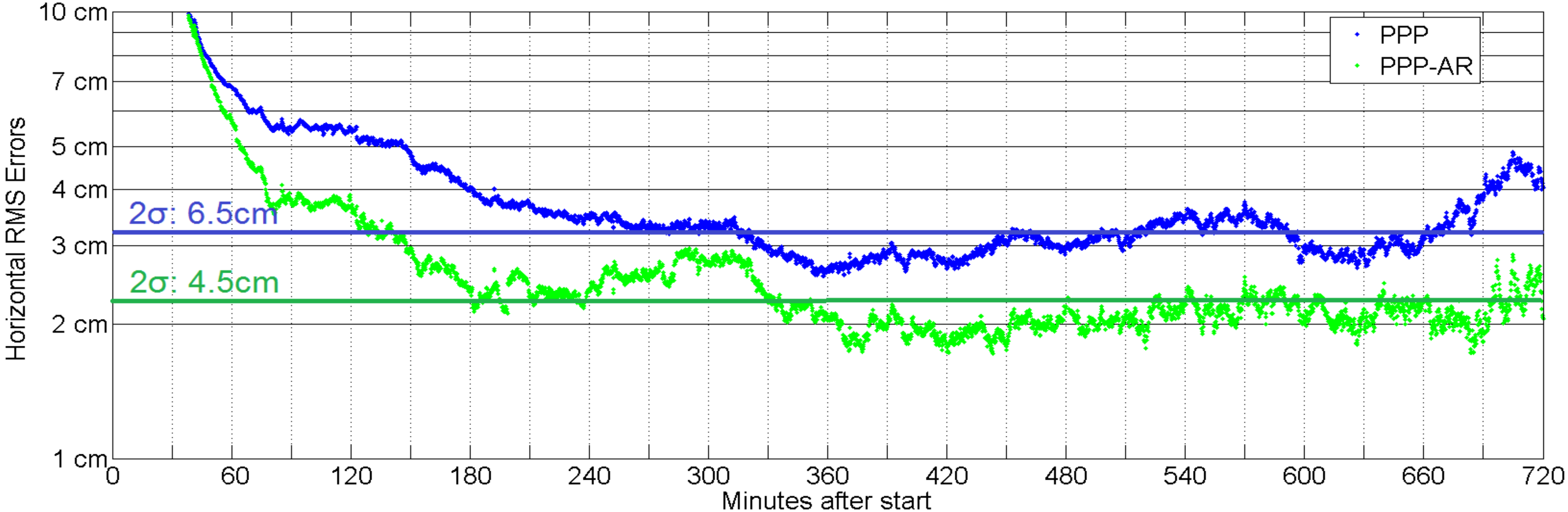
Suelynn Choy[1], Ken Harima[1], Satoshi Kogure[2]

[1] School of Mathematical and Geospatial Sciences, RMIT University, Australia
[2]Satellite Navigation Office, Space Applications Mission Directorate I, Japan Aerospace Exploration Agency, Japan

RMIT UNIVERSITY

Real-time Precise Point Positioning (PPP)

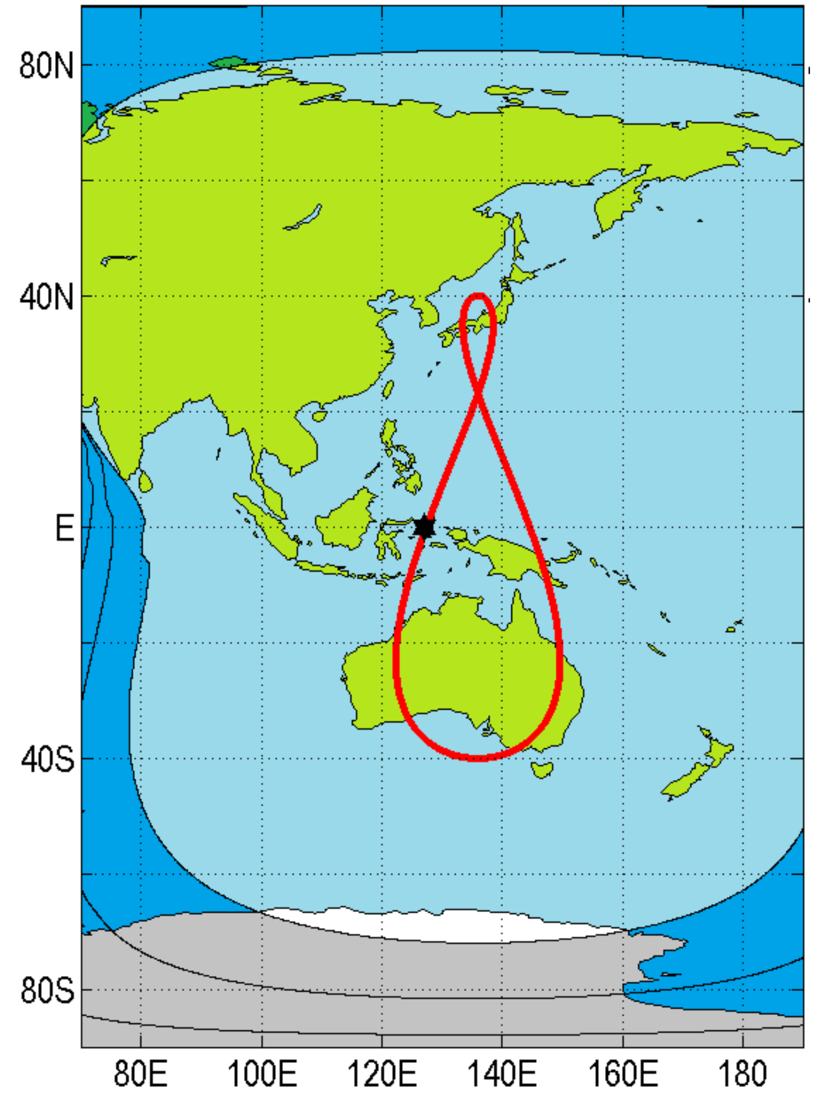
- Autonomous positioning with centimetre-level accuracy
- Relies on products with global validity: satellite orbit and clock corrections and signal biases.
- IGS post-process and real-time products have demonstrated PPP capability
- With ambiguity resolution, can achieve accuracies comparable with RTK
- Long convergence times still an issue



Horizontal accuracy of PPP with floating (blue) and integer (green) ambiguities.

Satellite delivered real-time PPP

- Satellite delivery is a natural fit for PPP
- Example using QZSS in Australia
  - Real-time products: Multi-GNSS Advanced Demonstration tool for Orbit and Clock Analysis (MADOCA)
  - RTCM messages for orbit, clock, code bias and accuracy estimates broadcasted using QZSS LEX signal
  - Centimetre level accuracy was verified in both fixed point and kinematic tests
- QZSS coverage includes most of East-Asia and Oceania
- MADOCA products delivered through QZSS L6 has great potential as an infrastructure for the region
- Similar systems can be expected to be developed in the future



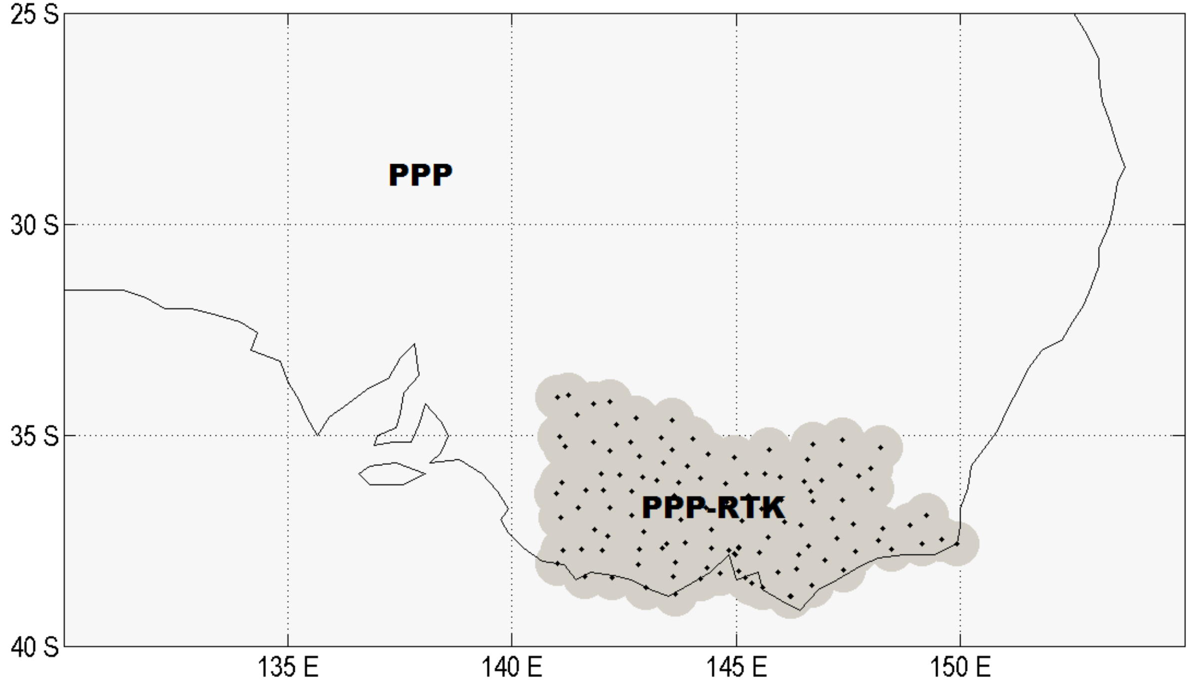
Satellite PPP in Precision Agriculture

- IGS real-time orbits
- Clock corrections adjusted using local network
- Signal biases generated using local network
- No Ionospheric corrections was transmitted (up to a few hour of convergence time)
- Integrated GNSS PNT and INS was used to guide an autonomous tractor
- Performance similar to short baseline RTK (2 cm horizontal RMS)
- Operated at about 291Km from the network

QZSS LEX PPP for Precise Agriculture: Jerilderie 11/14 & 01/15
PPP: Hitachi Zosen
Automation & control: Yammar, Univ. of Hokkaido

Local enhancements to PPP

- Challenge: precise Ionospheric delay estimation required for rapid convergence
- Global precise Ionospheric delay estimations are yet unavailable
- They are impractical for satellite transmission
- Using CORS networks to generate a local supplement to global PPP products:
  - RTK-like convergence times inside or near network
  - PPP performance over the wider coverage area
  - Improved accuracy and reliability using adjusted clock corrections and signal bias
- Joint CRCSI (Aus.) and JAXA (Jap.) project is studying Australian enhancement of MADOCA products



Local enhancements to PPP: product calculation

- Ionospheric corrections only (≥1 ref. station)

$$P_{i,st}^S - \rho - dt^S - B_i^S = m_{st}^S T_{st} + \mu_i I_{1,st}^S + \epsilon_i$$

$$L_{i,st}^S - \rho - dt^S - b_i^S = m_{st}^S T_{st} - \mu_i I_{1,st}^S + \lambda_i N_{i,st}^S + \varepsilon_i$$

- Phase bias adjustment (≥ 3 ref. stations)

$$P_{i,st}^S - \rho - dt^S - B_i^S = m_{st}^S T_{st} + \mu_i I_{1,st}^S + \epsilon_i$$

$$L_{i,st}^S - \rho - dt^S = m_{st}^S T_{st} - \mu_i I_{1,st}^S + b_i^S + \lambda_i N_{i,st}^S + \varepsilon_i$$

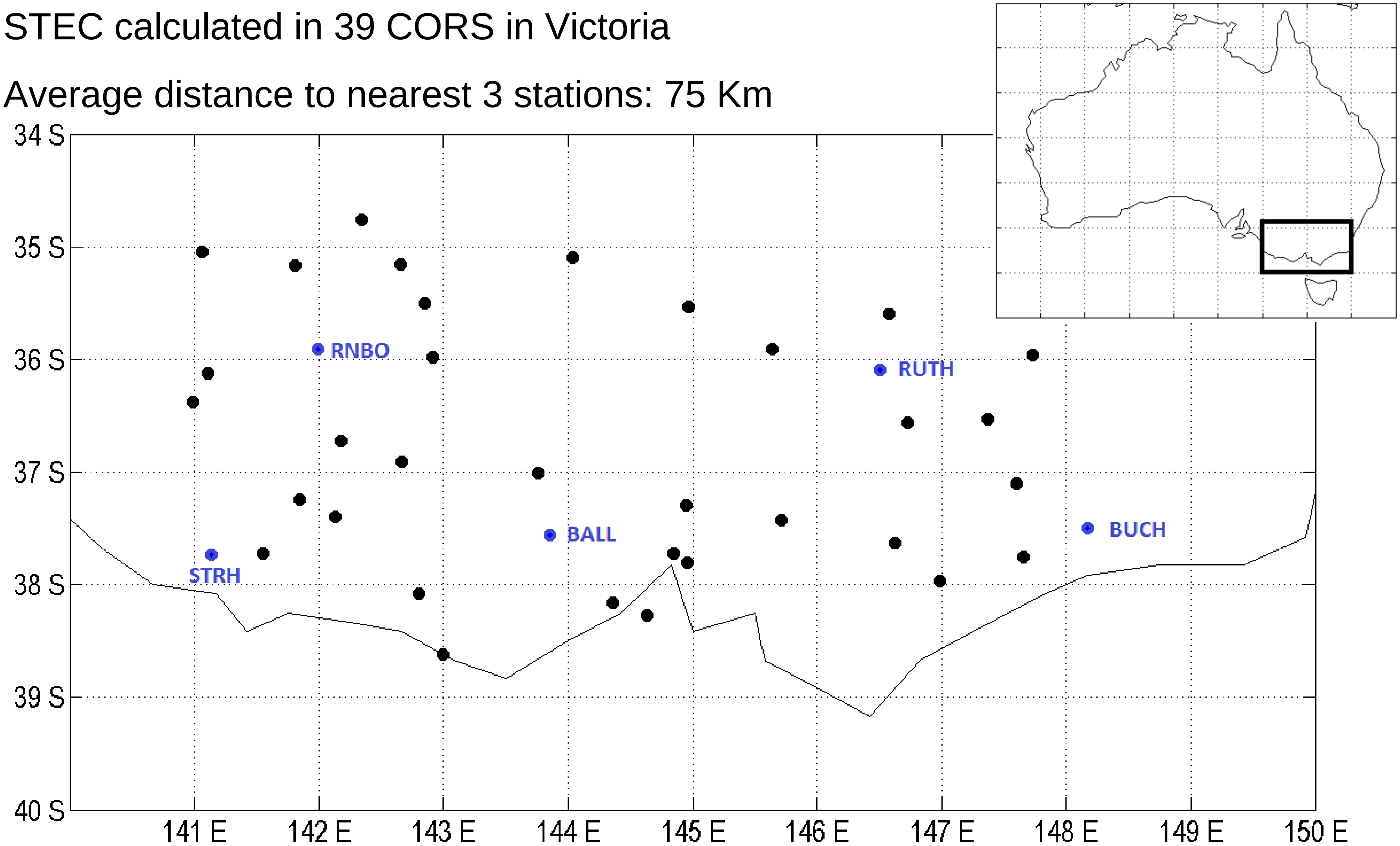
- Phase bias and clock adjustment (≥ 4 ref. stations)

$$P_{i,st}^S - \rho - B_i^S = dt^S + m_{st}^S T_{st} + \mu_i I_{1,st}^S + \epsilon_i$$

$$L_{i,st}^S - \rho = dt^S + m_{st}^S T_{st} - \mu_i I_{1,st}^S + b_i^S + \lambda_i N_{i,st}^S + \varepsilon_i$$

Slant TEC from loose network: a test in Victoria

- CNES real-time stream CLK91 used to solve phase ambiguities
- STEC calculated in 39 CORS in Victoria
- Average distance to nearest 3 stations: 75 Km



STEC estimation at monitor station

- Tests performed between 25th and 26th of November 2015
- Slant TEC was calculated on each station using ambiguity resolved PPP technique
- Slant TEC on 5 monitoring stations were compared with values interpolated/extrapolated from nearby stations
  - Stations within 200Km were selected
  - Slant TEC was estimated as a linear regression from values on selected stations

$$\boldsymbol{I}_{rc} = \boldsymbol{I}_{st} + dI_{lat}(lat_{st} - lat_{rc}) + dI_{lon}(lon_{st} - lon_{rc})$$

  - Using weighted least squares

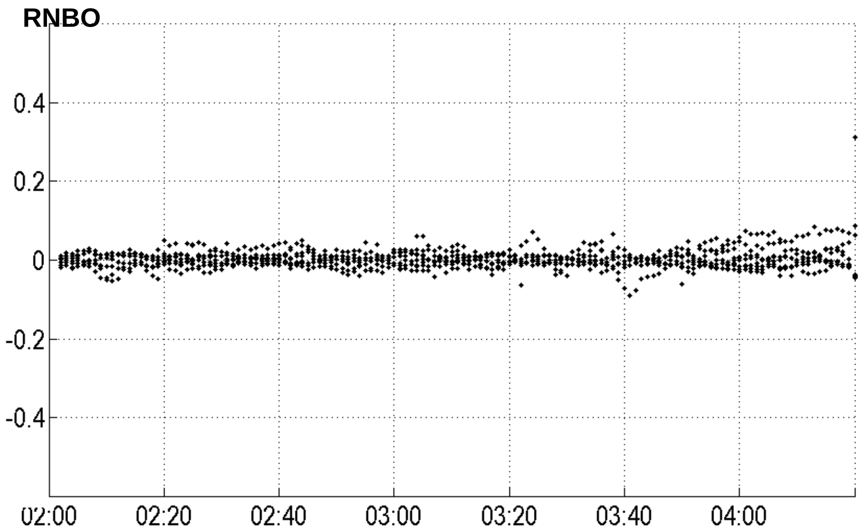
$$H^T W H \boldsymbol{I}_{rc} = H^T W \boldsymbol{I}_{st} \qquad W_{st,st} = (1/dist_{st-rc})^2$$

Estimated STEC accuracy

- RMS of Ionospheric correction errors was 30.5 cm
- Ionosphere errors were dominated by a handful of satellite/station combinations with very large errors.
- 80% of Slant TEC values had less than 10 cm of RMS errors
- RMS discarding the satellite with large errors was 13.0 cm

RNBO

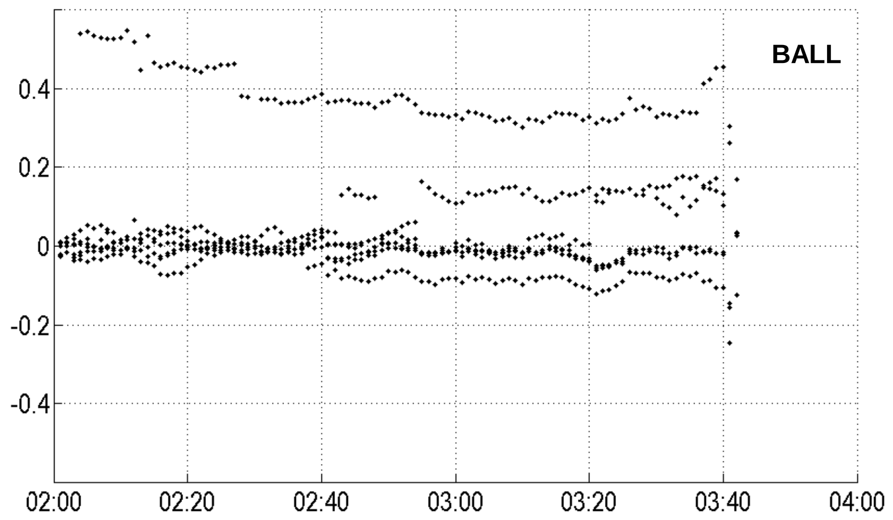
– #stations used: 9
– Dist. to stations(Km): 82.1, 82.3, 83.5
– Ion. Error(cm RMS): 2.32
– <5cm error: 11/12



Estimated STEC accuracy (cont.)

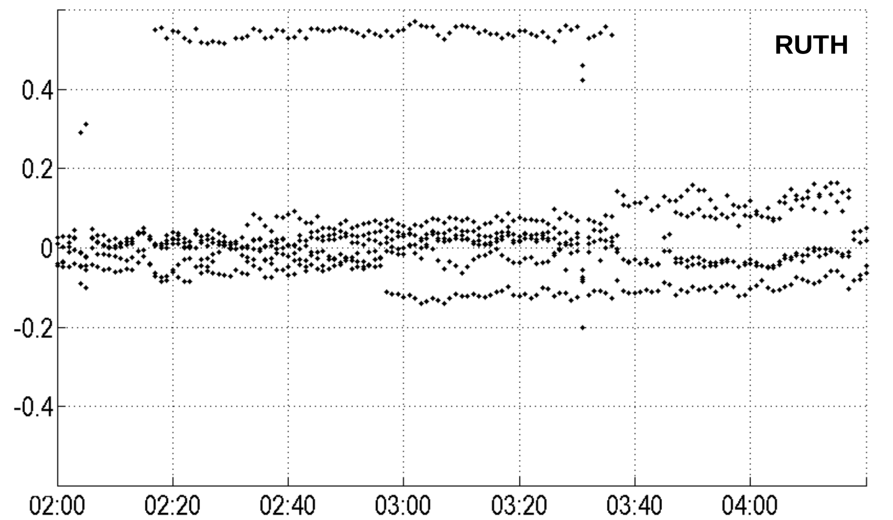
BALL

- #stations used: 14
- Dist. to stations(Km): 62.0, 80.5, 90.2
- Ion. Error(cm RMS): 6.10*
- <5cm error: 6/9



RUTH

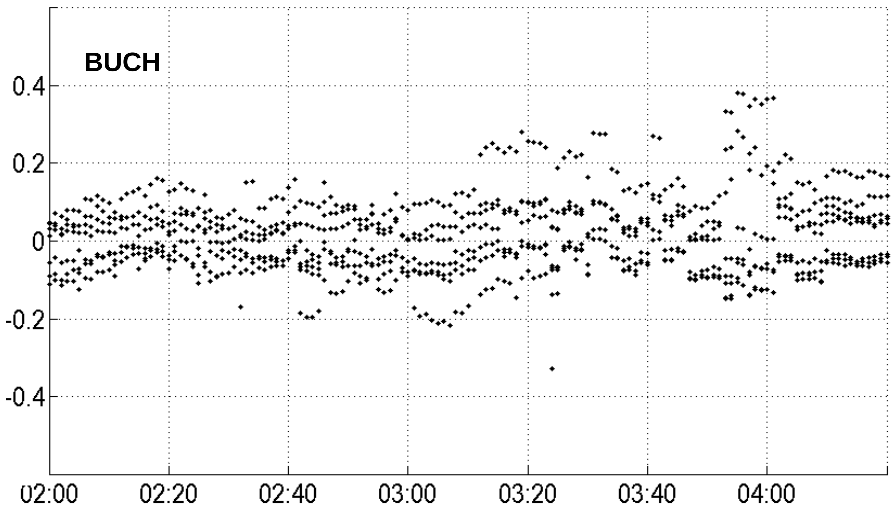
- #stations used: 7
- Dist. to stations(Km): 54.4, 56.4, 79.7
- Ion. Error(cm RMS): 6.50*
- <5cm error: 6/10



Estimated STEC accuracy (cont.)

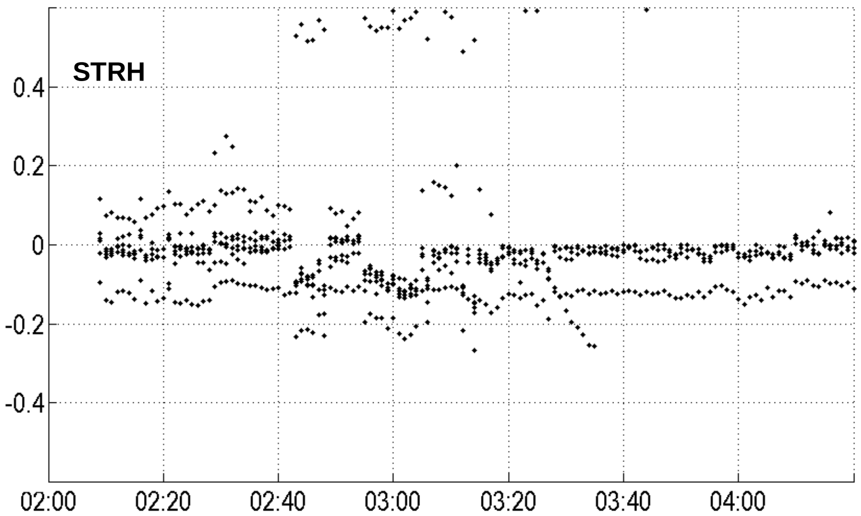
BUCH

- #stations used: 7
- Dist. to stations(Km): 54.0, 66.9, 117.7
- Ion. Error(cm RMS): 15.76
- <5cm error: 0/12



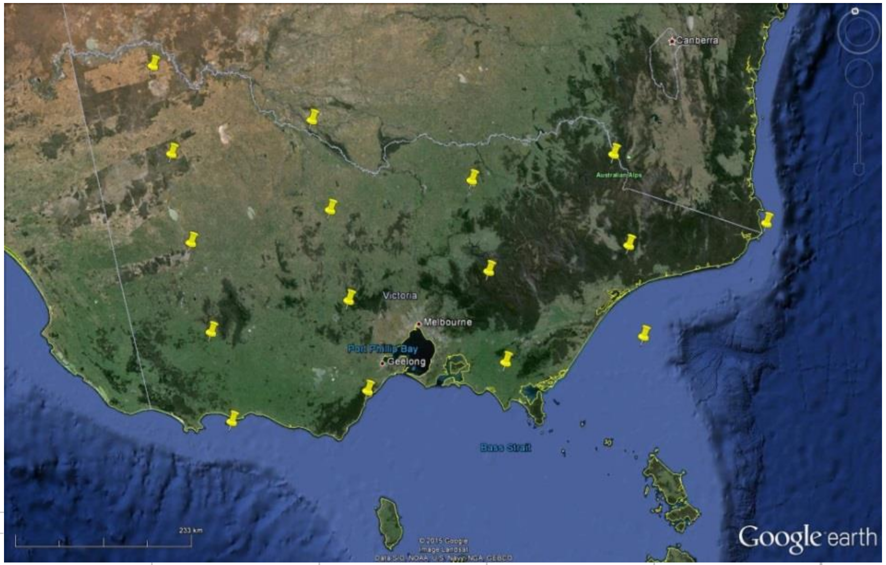
STRH

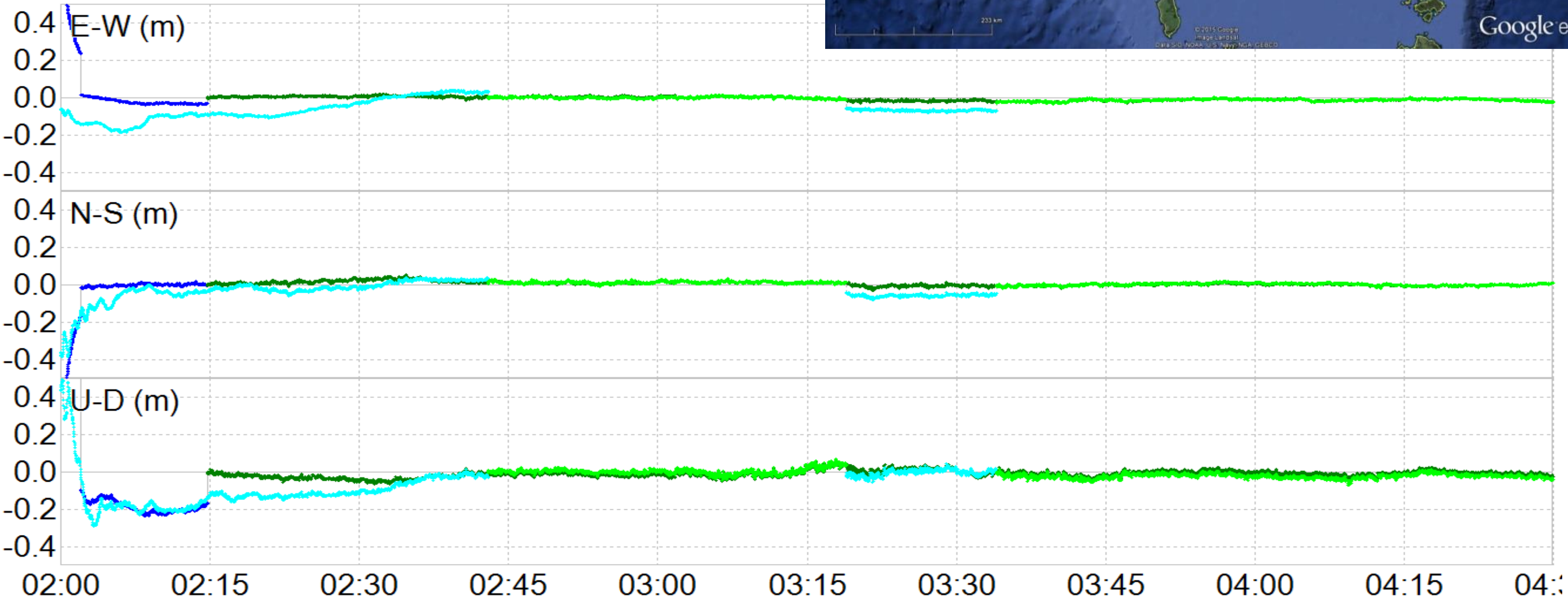
- #stations used: 6
- Dist. to stations(Km): 36.7, 82.9, 95.7
- Ion. Error(cm RMS): 25.20*
- <5cm error: 2/9



Slant TEC maps for PPP

- PPP using STEC maps
  - Ionospheric corrections calculated in 117 stations from GPSnet in Victoria
  - Mapped into a 1° lat. × 2° lat. Slant TEC maps
  - 10cm accuracy in a few minutes
  - Significantly reduced ambiguity resolution





Summary and future work

- PPP, specially satellite delivered PPP has potential as positioning infrastructure
- Precise estimate of Ionospheric delays is required for instantaneous convergence
- Ionospheric corrections from local networks could be used to enhance global PPP products where infrastructure is available
- Preliminary studies conducted are being conducted using CORS stations in Australia
  - Products from CNES CLK91 were used to calculate PPP solutions for reference stations in Victoria
  - Resulting Ionospheric delay estimates were used to calculate Slant TEC in monitoring stations (average distance to three stations 75Km)
  - 80% of satellites showed less than 10 cm RMS errors
  - Few satellites show large errors
- Short term objective is the enhancement of real-time MADOCA streams
- Real-time testing to be conducted by September this year

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