Local Augmentation to Wide Area PPP Systems

A Case Study in Victoria, Australia

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Outline

1. PPP as a wide area positioning technique
2. PPP-RTK: augmented PPP with local corrections
3. Case study in Victoria: slant ionosphere generation
4. Case study in Victoria: PPP-RTK positioning
5. Summary

Precise Positioning: PPP and RTK

PPP

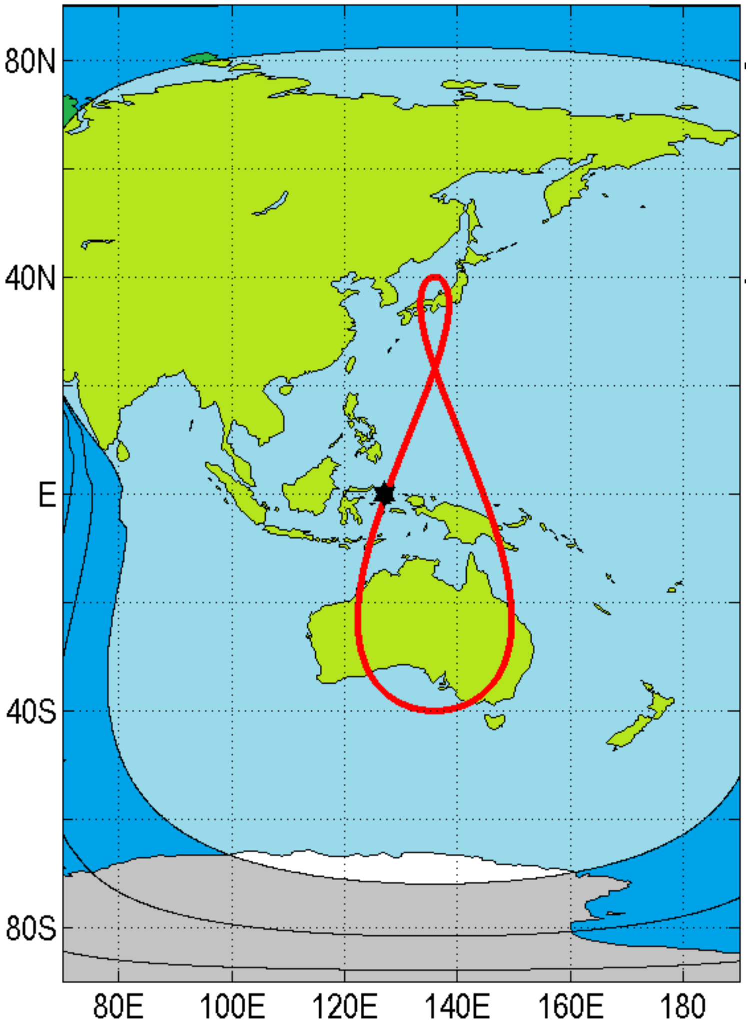
- Light infrastructure requirements
- Relative low data rate requirements
- Sub-decimetre steady state accuracy
- Tens of minutes of convergence time
- **Suitable for wide area infrastructure**

RTK

- Relatively dense CORS network required
- Interactive or high data rate communication system required
- Centimetre level accuracy
- Rapid to instantaneous convergence
- **Optimal for regions with dense CORS and communication networks**

PPP: MADOCA and CLK91 Corrections

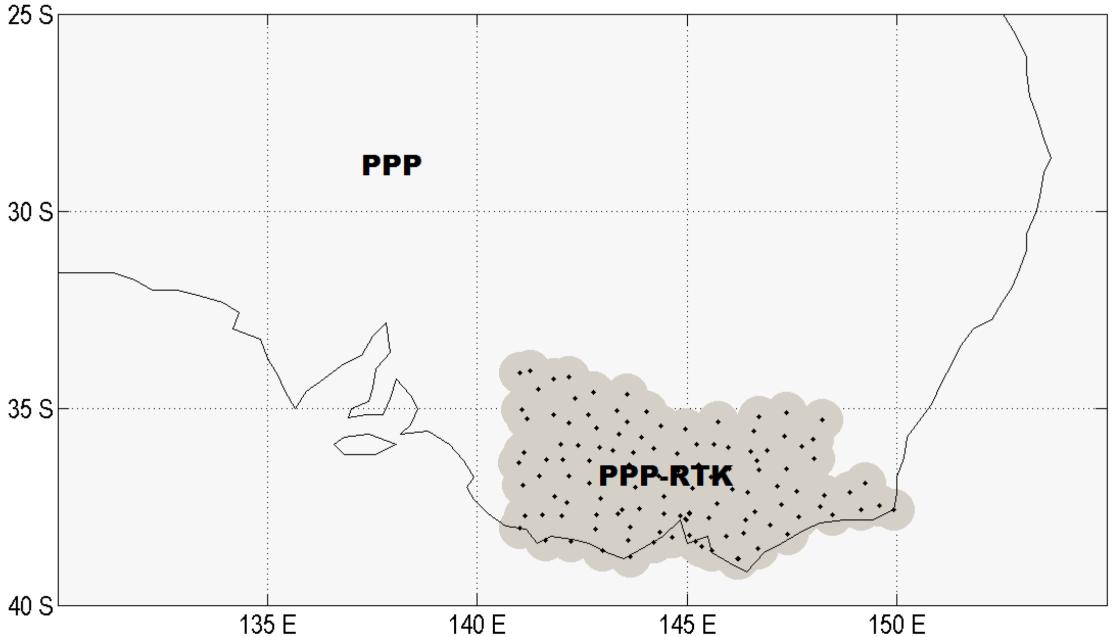
- Global real-time PPP streams are available from multiple sources
- CLK91
  - GPS & GLO
  - Satellite orbits, clocks and signal biases
  - Available through IGS NTRIP caster
- MADOCA:
  - GPS, GLO & QZSS
  - Satellite orbits, clocks and estimated URA
  - Signal bias in development
  - Undergoing broadcast tests by QZSS LEX signal



QZSS LEX coverage area

PPP-RTK: Concept

- **Challenge:** precise ionospheric corrections are required for rapid convergence
- Global precise ionospheric delay estimations for PPP-RTK are not yet available
- They are impractical for satellite transmission for nationwide coverage
- **PPP-RTK:** Using CORS networks to generate a local augmentation to global PPP products:
  - RTK-like performance inside or near network
  - PPP performance over wide area coverage
  - Seamless transition between PPP and RTK mode



PPP-RTK concept

PPP-RTK: GNSS Corrections and PPP Modes

- **PPP:** Precise satellite orbits and clocks allows to calculate float ambiguities

$$\Delta L_{if} + c\Delta \boldsymbol{dt^S} = \Delta\rho + \lambda_{NL}\Delta N_1 - C_2\lambda_2(\Delta N_1 - \Delta N_2) - \Delta b_{if}$$

- **PPP-AR:** Signal biases allows for isolation and resolution of ambiguities

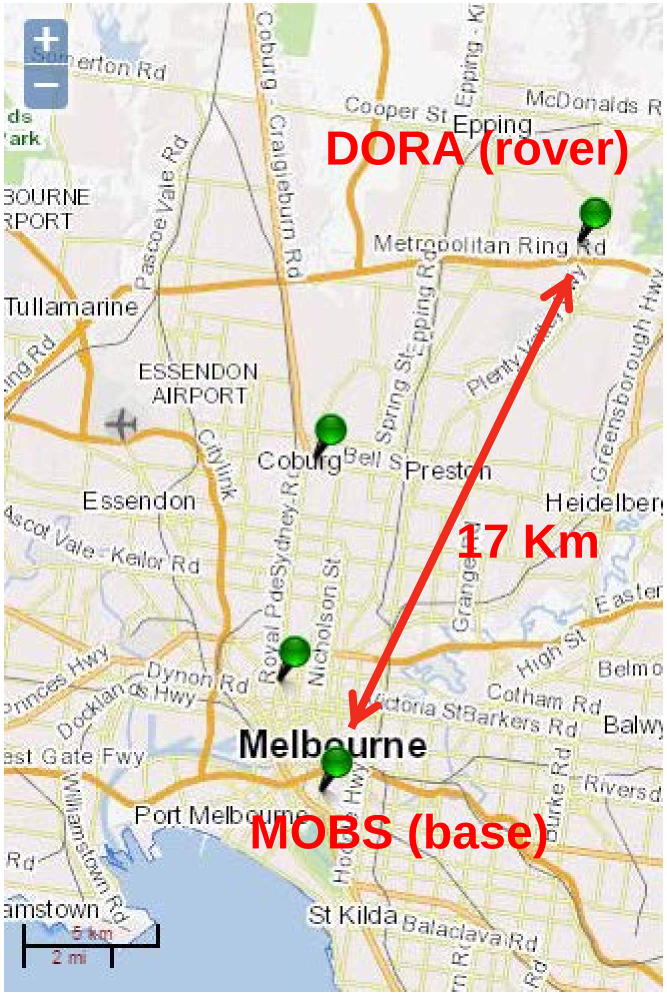
$$\Delta L_{if} + c\Delta \boldsymbol{dt^S} + \Delta \boldsymbol{b_{if}} = \Delta\rho + \lambda_{NL}\Delta N_1 - C_2\lambda_2(\Delta N_1 - \Delta N_2)$$

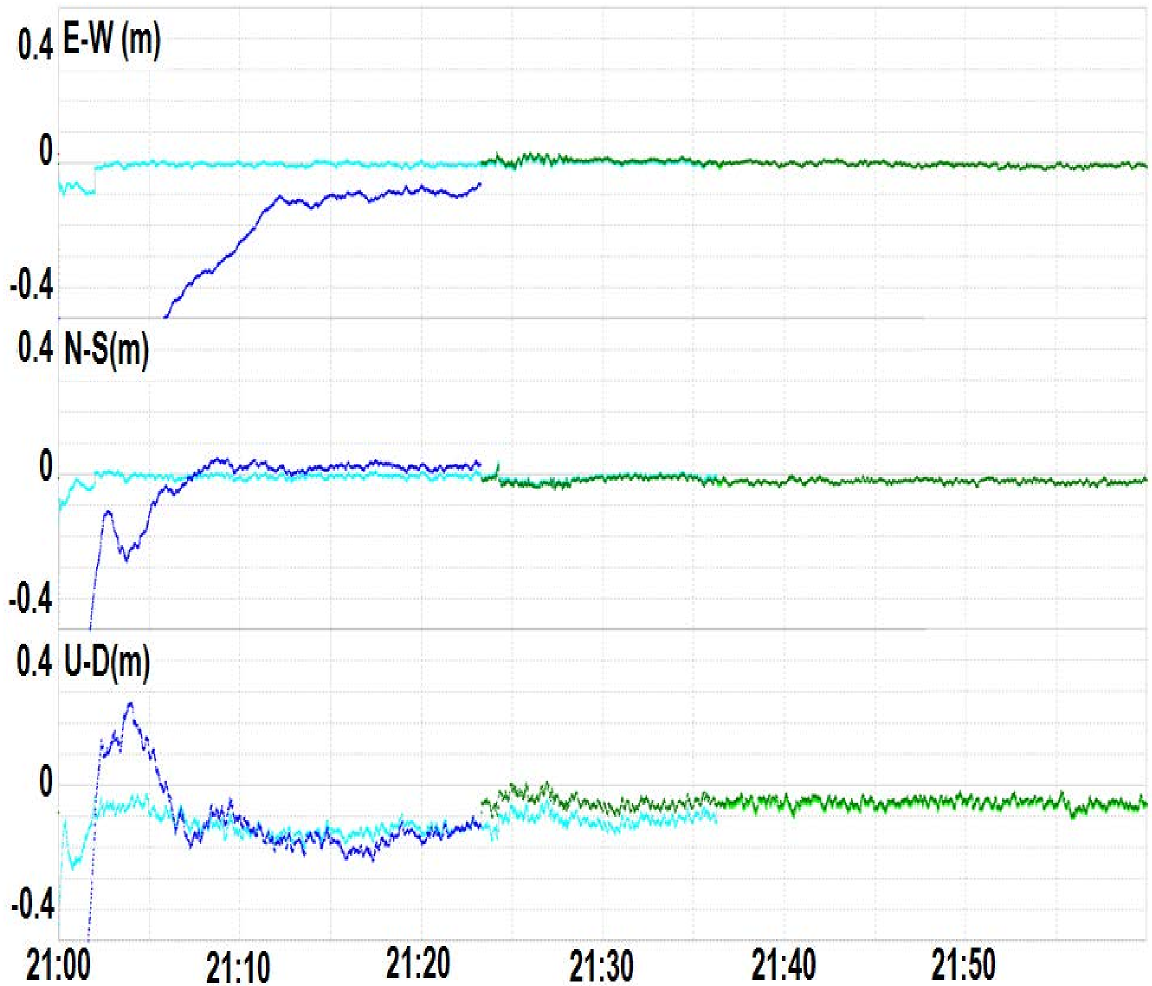
$$\Delta P_{mw} + \Delta \boldsymbol{B_{mw}} = \lambda_{WL}(\Delta N_1 - \Delta N_2)$$

- **PPP-RTK:** Ambiguity convergence can be assisted by ionospheric corrections

$$\Delta L_{gf} + \Delta \boldsymbol{b_{gf}} - \frac{1}{C_2}\boldsymbol{I} = (\lambda_1 - \lambda_2)\Delta N_1 + \lambda_2(\Delta N_1 - \Delta N_2)$$

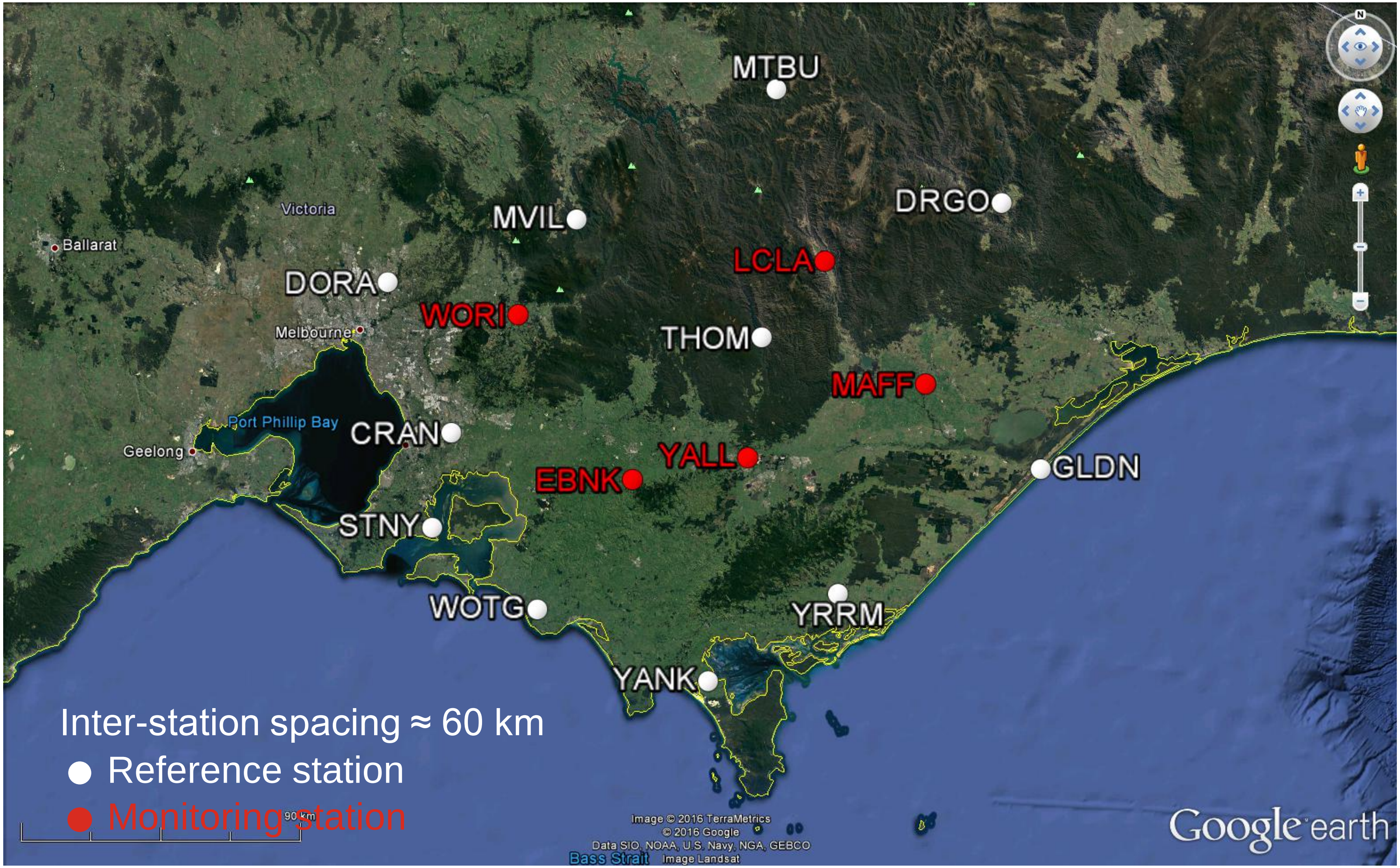
PPP-RTK: Single Base Station Example





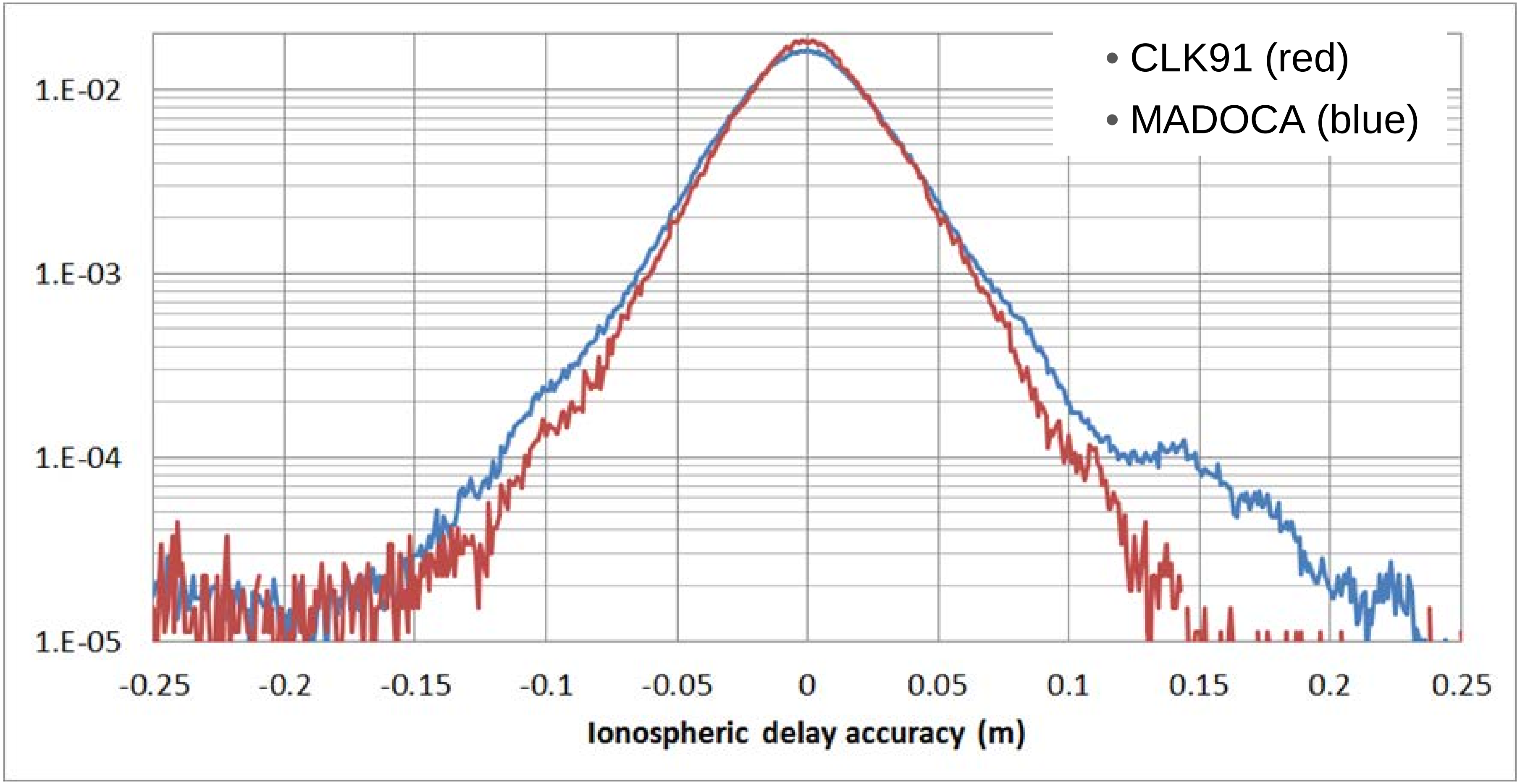
Single base PPP-RTK test on 7th July 2016

Case Study in Victoria: Generation of Ionosphere



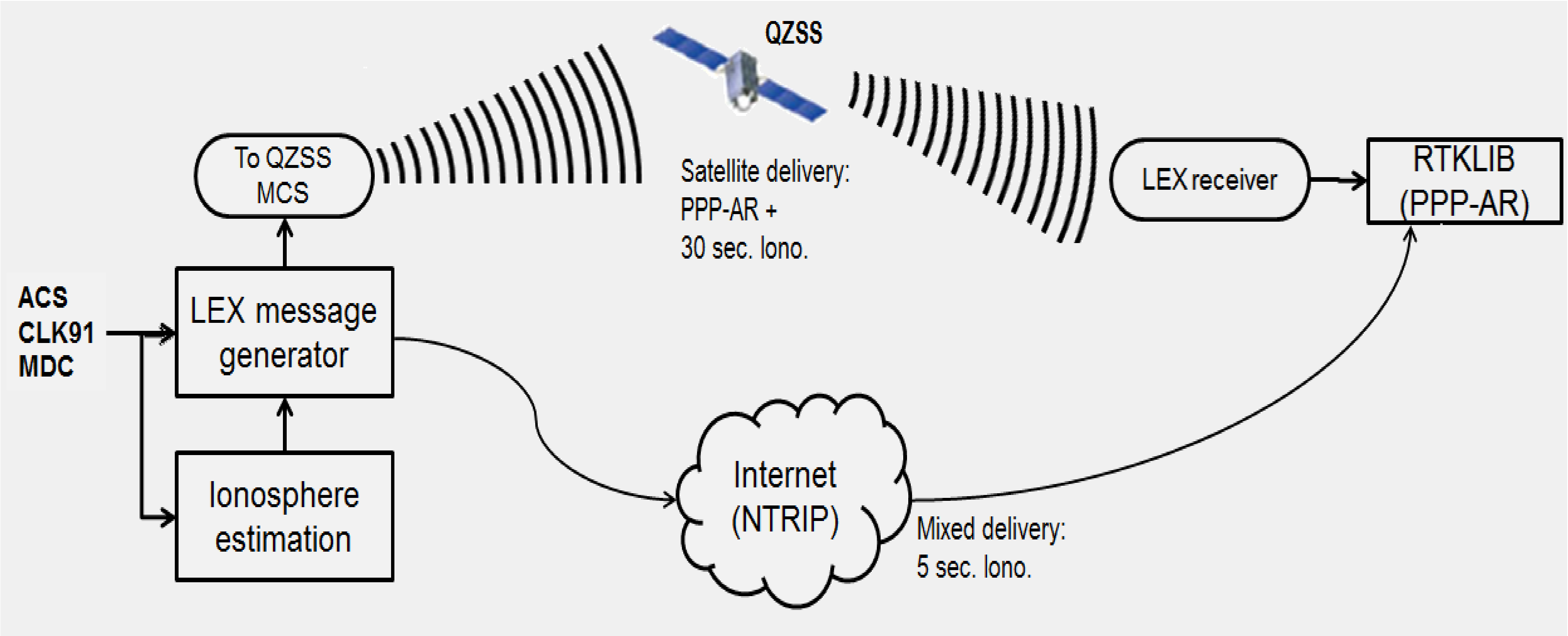
Small network PPP-RTK test in August-September 2016

Case Study in Victoria: Accuracy of Ionosphere



- Interpolated vs measured Ionosphere, 31st August to 5th September 2016
- RMS: 2.6 cm (CLK91); 3.2 cm (MADOCA)

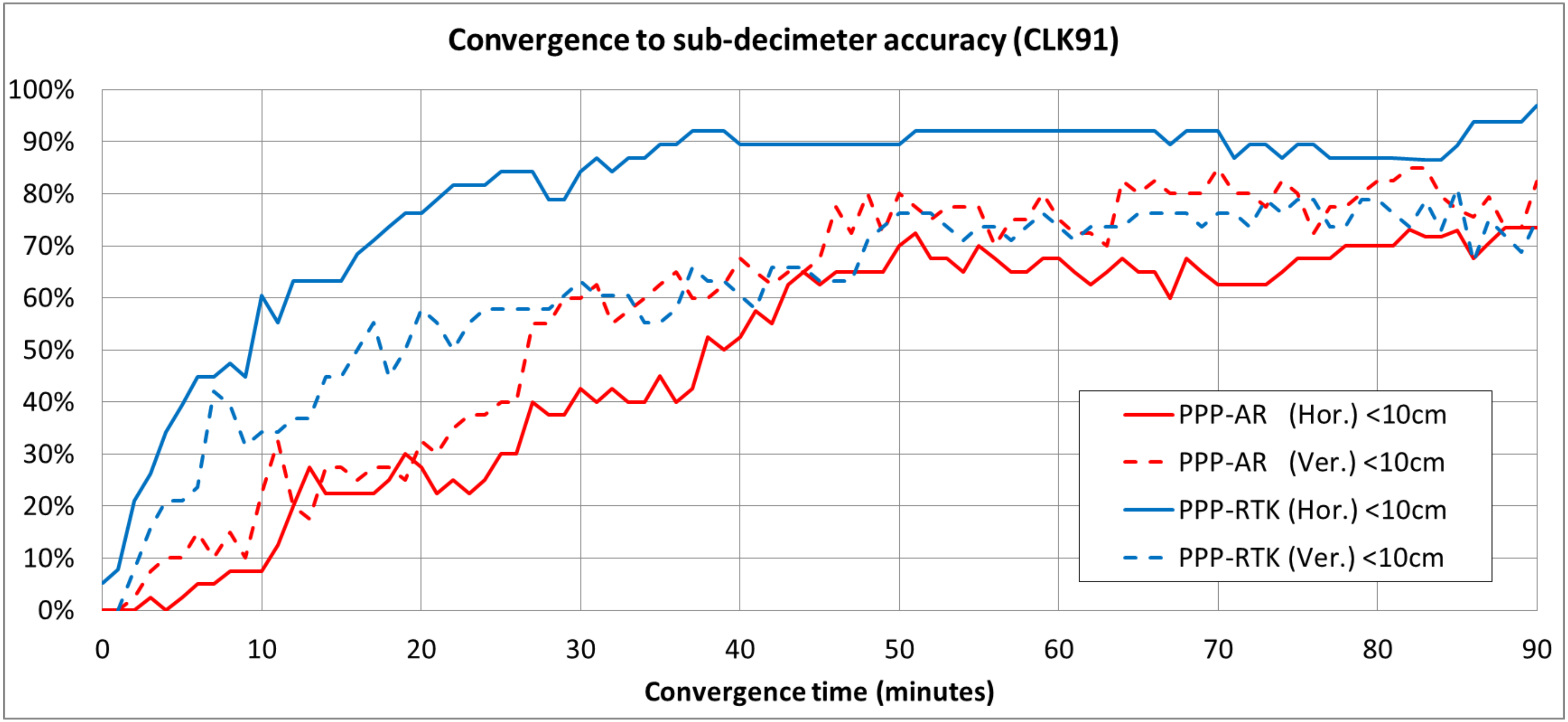
Case Study in Victoria: Transmission of Corrections



Local enhancement delivery modes: satellite delivery and mixed delivery

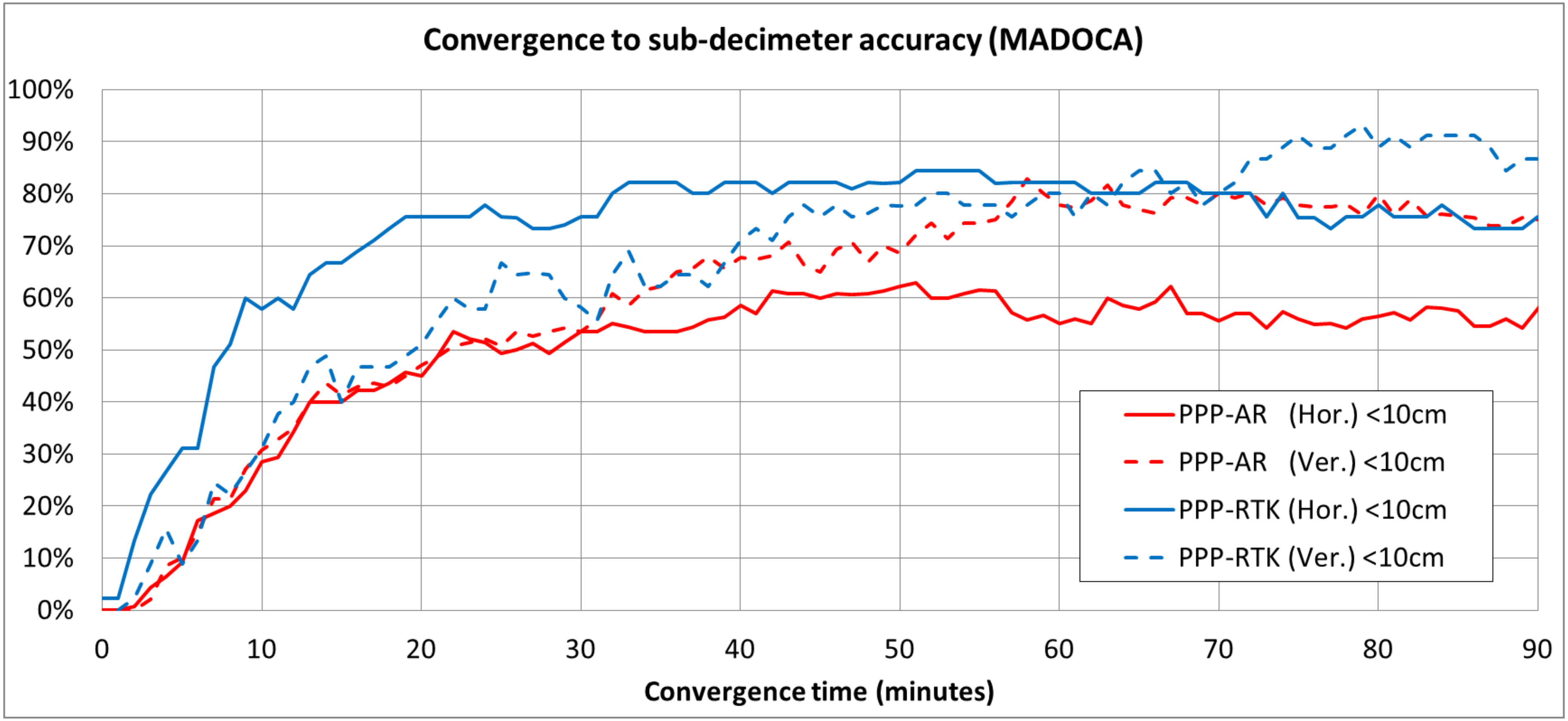
Constellation	Orbit (s)	Clock (s)	Code Bias (s)	Phase Bias (s)	Ionosphere (s)
GPS	30	5	30	30	30 or 5
GLONASS	30	5.	30	30	-

Case Study in Victoria: PPP-RTK Results (CLK91)



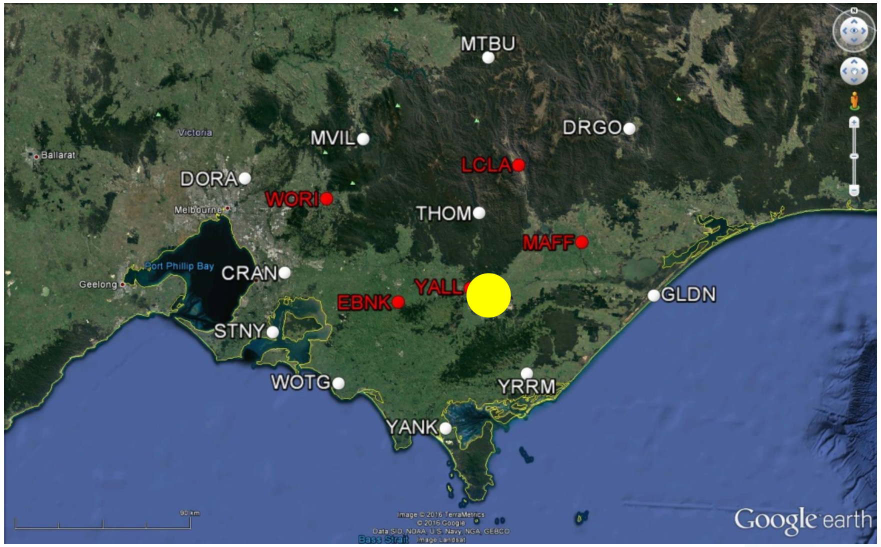
PPP-AR (red) and PPP-RTK (blue) solutions convergence times to within < 10 cm using CLK91 corrections.

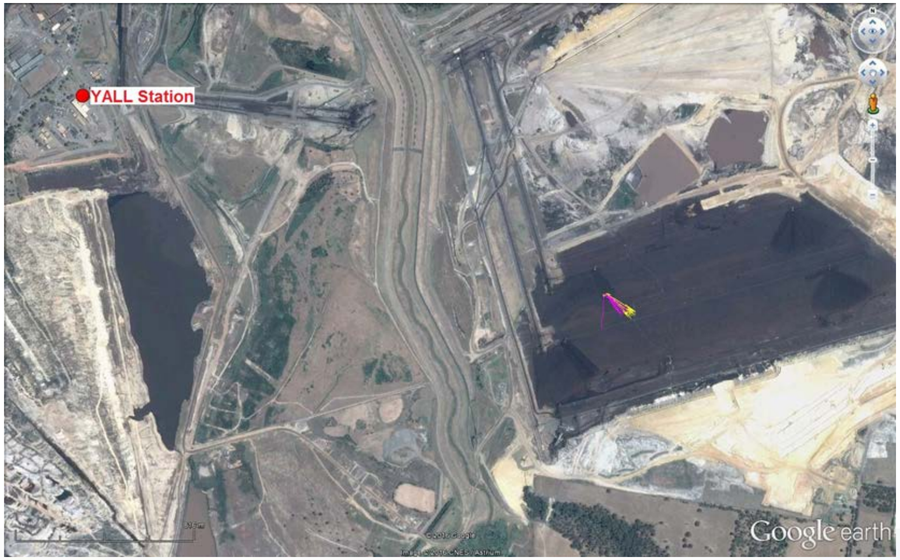
Case Study in Victoria: PPP-RTK Results (MADOCA)



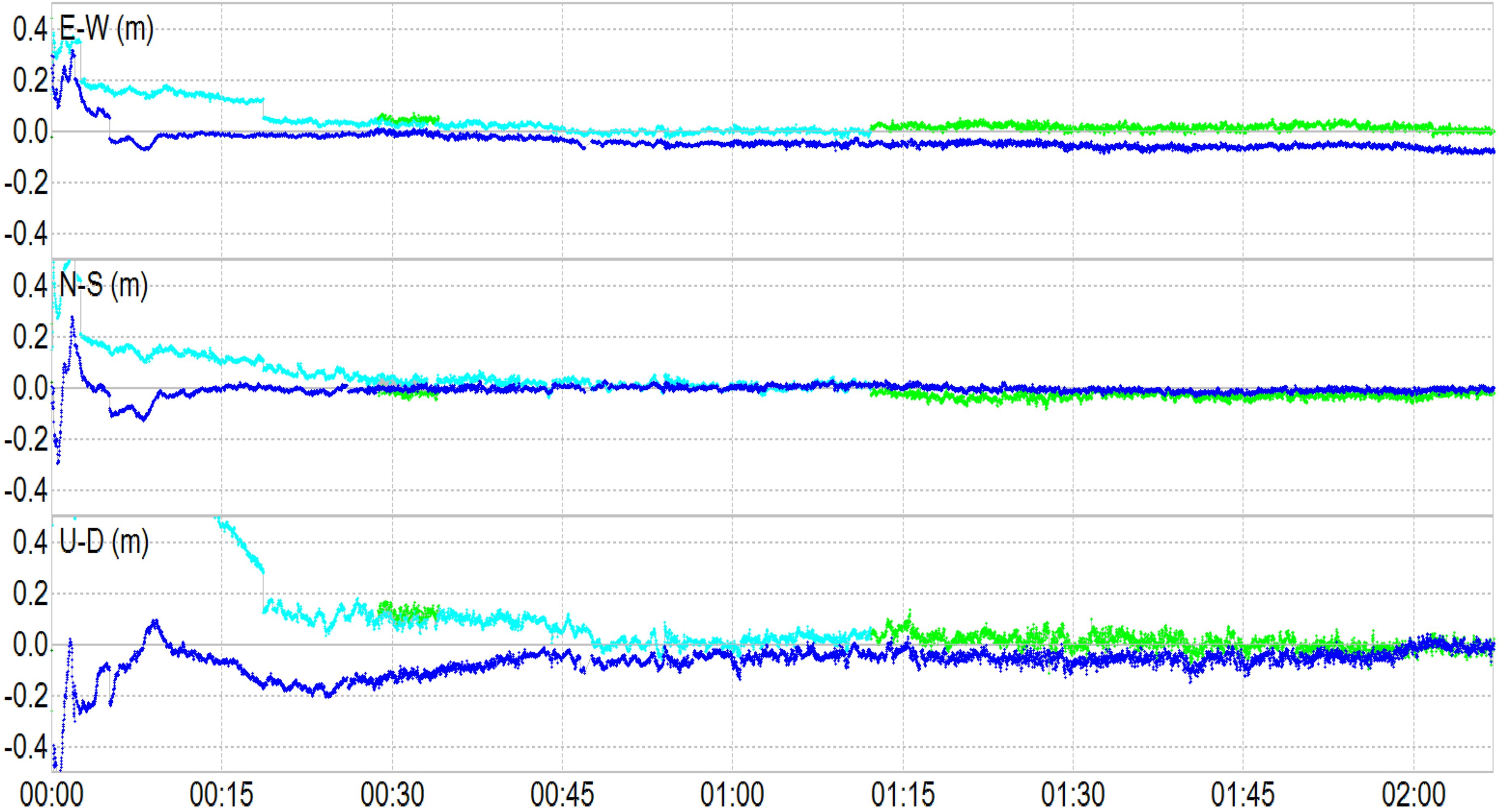
PPP-AR (red) and PPP-RTK (blue) solutions convergence times to within < 10 cm using MADOCA corrections.

Case Study in Victoria: La Trobe Valley Coal Mine





Case Study in Victoria: Dynamic Tractor Results



Accuracy of MADOCA (blue) and CLK91 (cyan/green) based PPP-RTK solutions. Yallourn 1st September 2016

Summary

- PPP provides wide area coverage with sparse CORS network.
- RTK provides fast convergence to centimetre level positioning accuracy, but has high dependency on the density of CORS network.
- PPP-RTK is a synthesis of the positive characteristics of PPP and network-RTK
- The computed ionopheric corrections have an estimated accuracy of 3 cm or better.
- PPP-RTK kinematic processing on fixed stations:
  - 40% reduction in horizontal RMS
  - 40% reduction in vertical RMS in the first 30 minutes
  - 67% of solutions converge to 10 cm horizontal accuracy in 16 minutes (compared to 75 minutes without ionospheric corrections)
- Future work: ionosphere mapping for wider areas, tropospheric corrections.

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Thank you