GNSS Precise Point Positioning (PPP)

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2. Theory of Precise Point Positioning (PPP)
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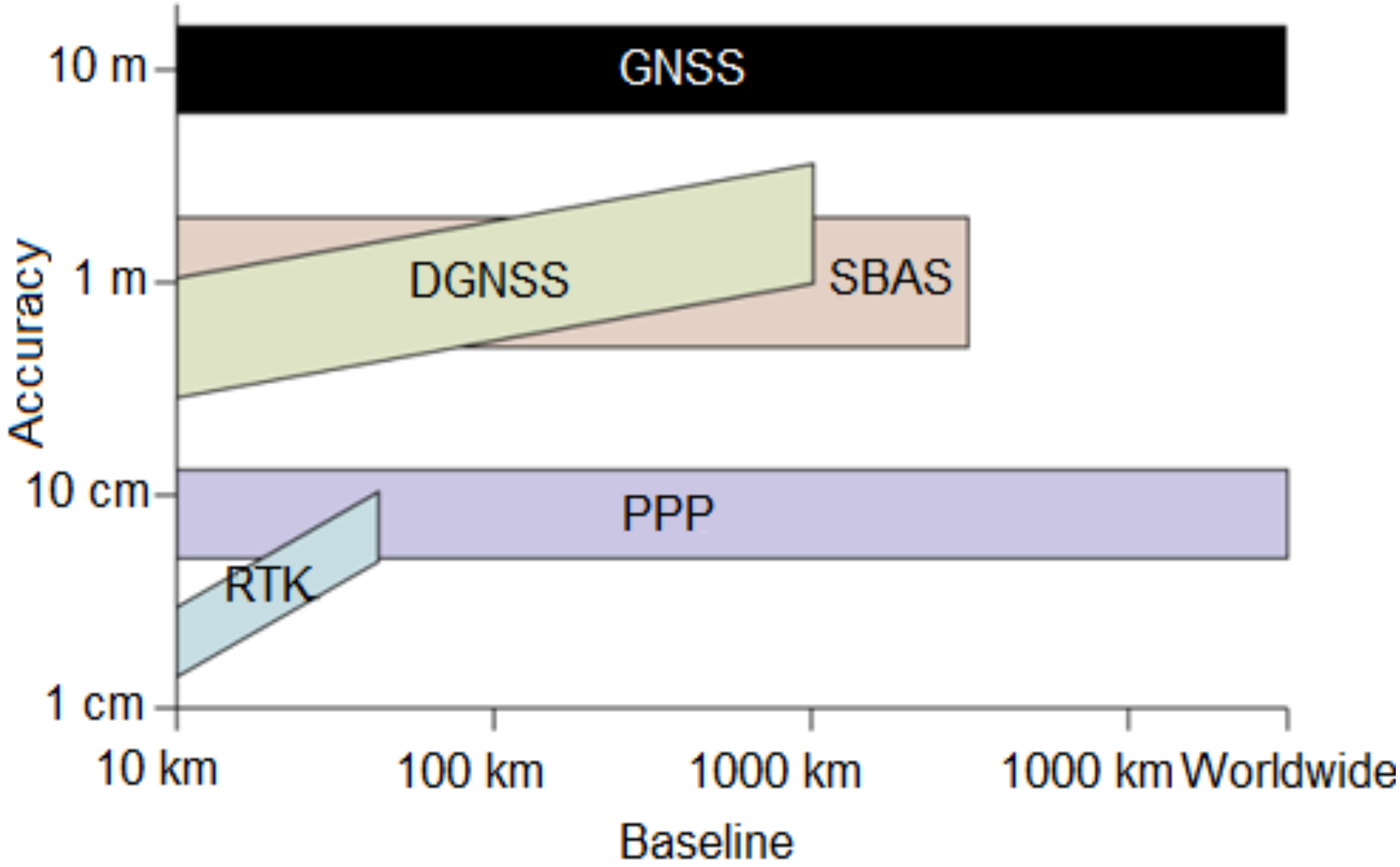
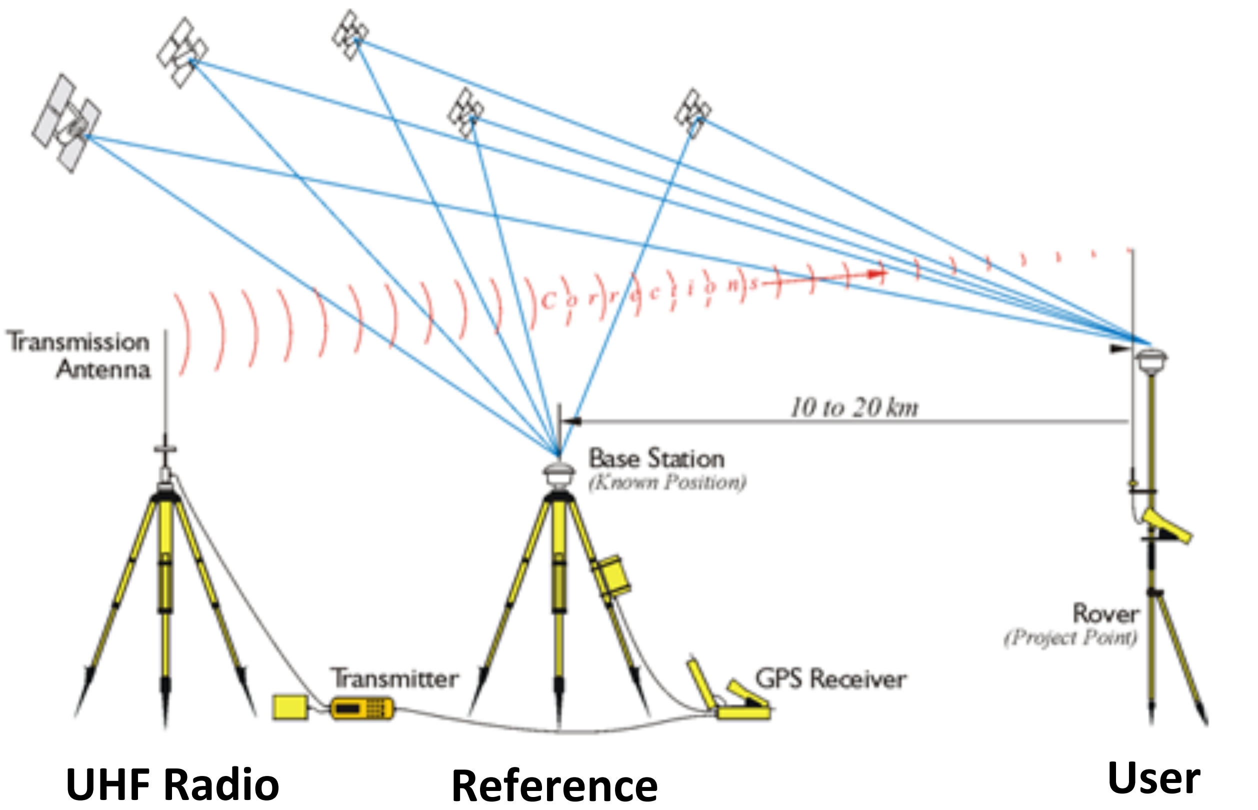
GNSS Positioning Techniques



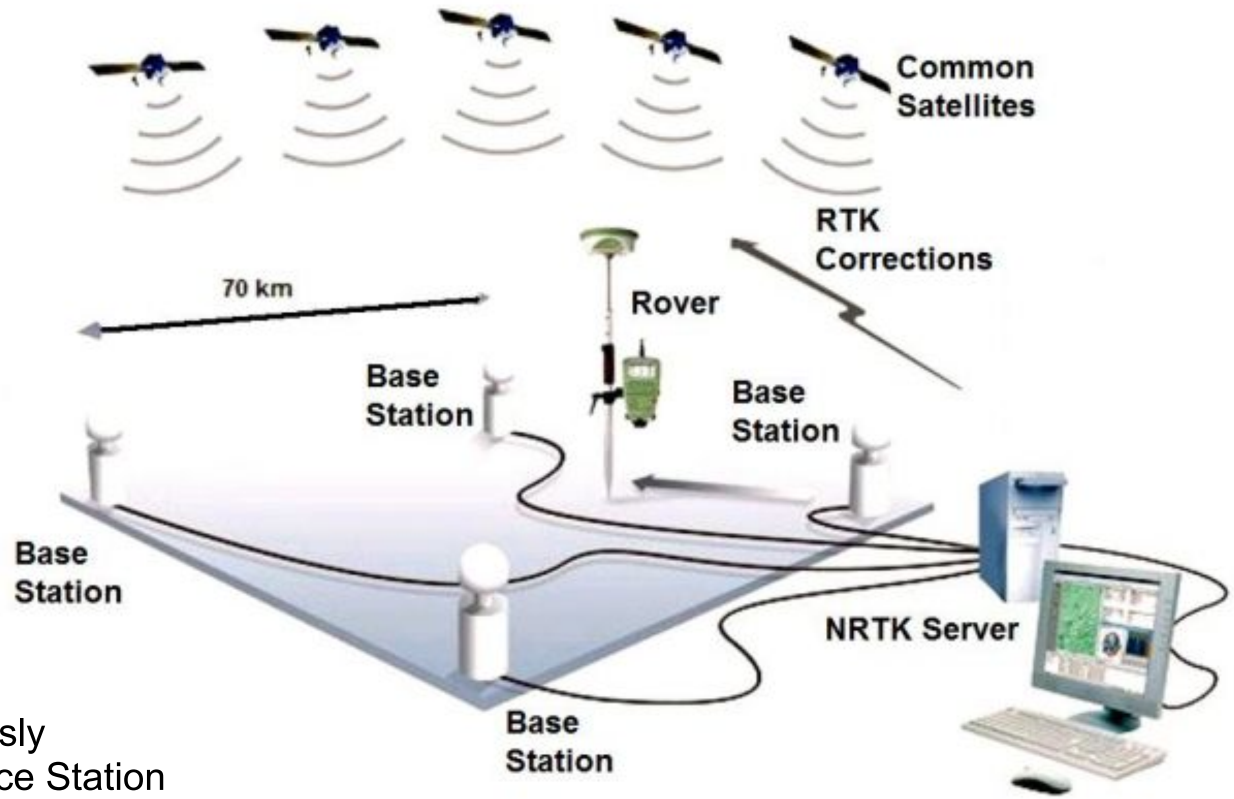
Real-Time Kinematic (RTK)

- Positional accuracy +/- 2cm (horiz)
- Single base solution
- Range < 10-20 km (accuracy decreases with distance)
- Data transfer via UHF radio



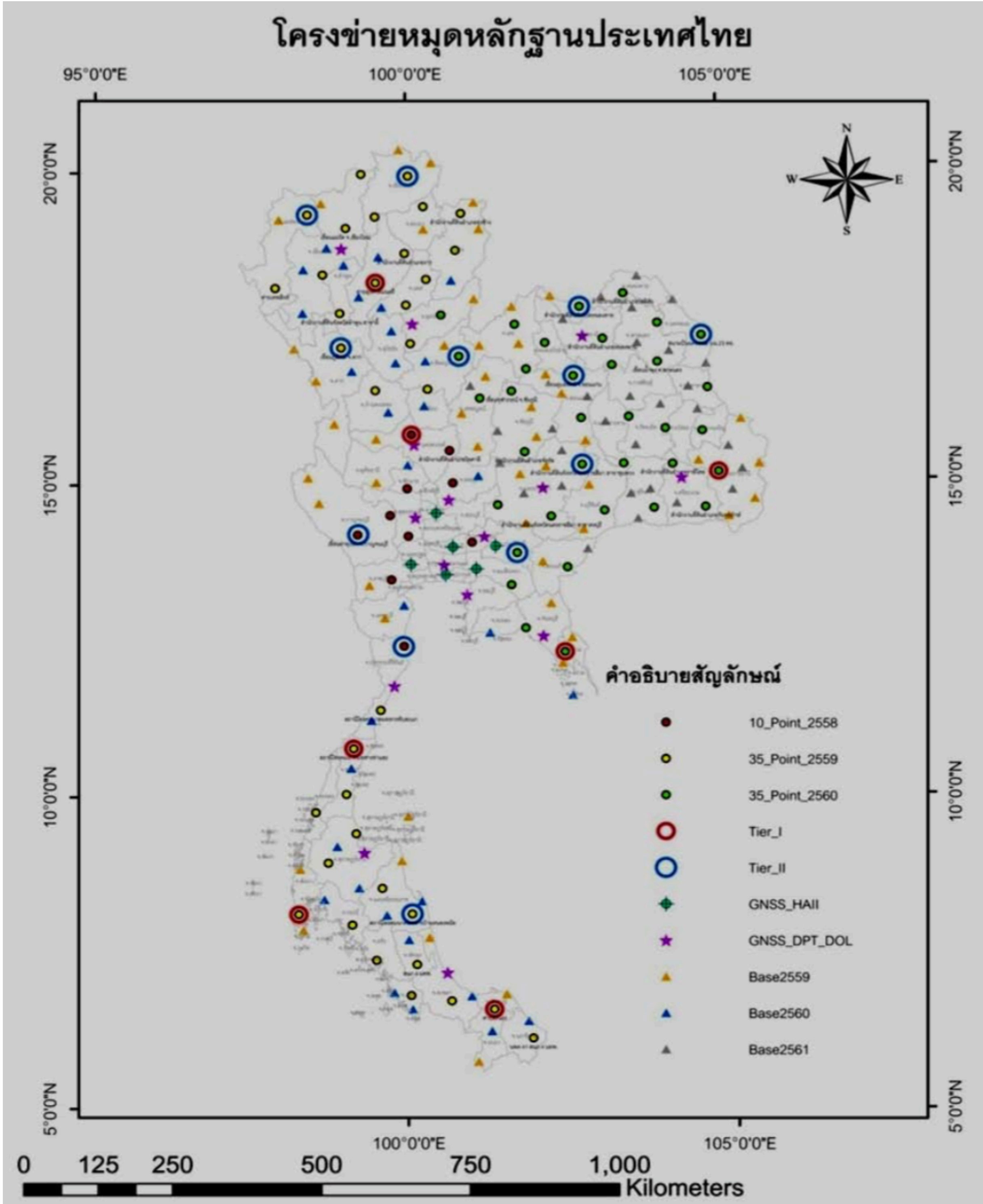
Network RTK

- Positional accuracy +/- 2cm (horiz)
- Based on CORS network
- Range increased up to 70 km between CORS sites
- Data transfer via mobile internet

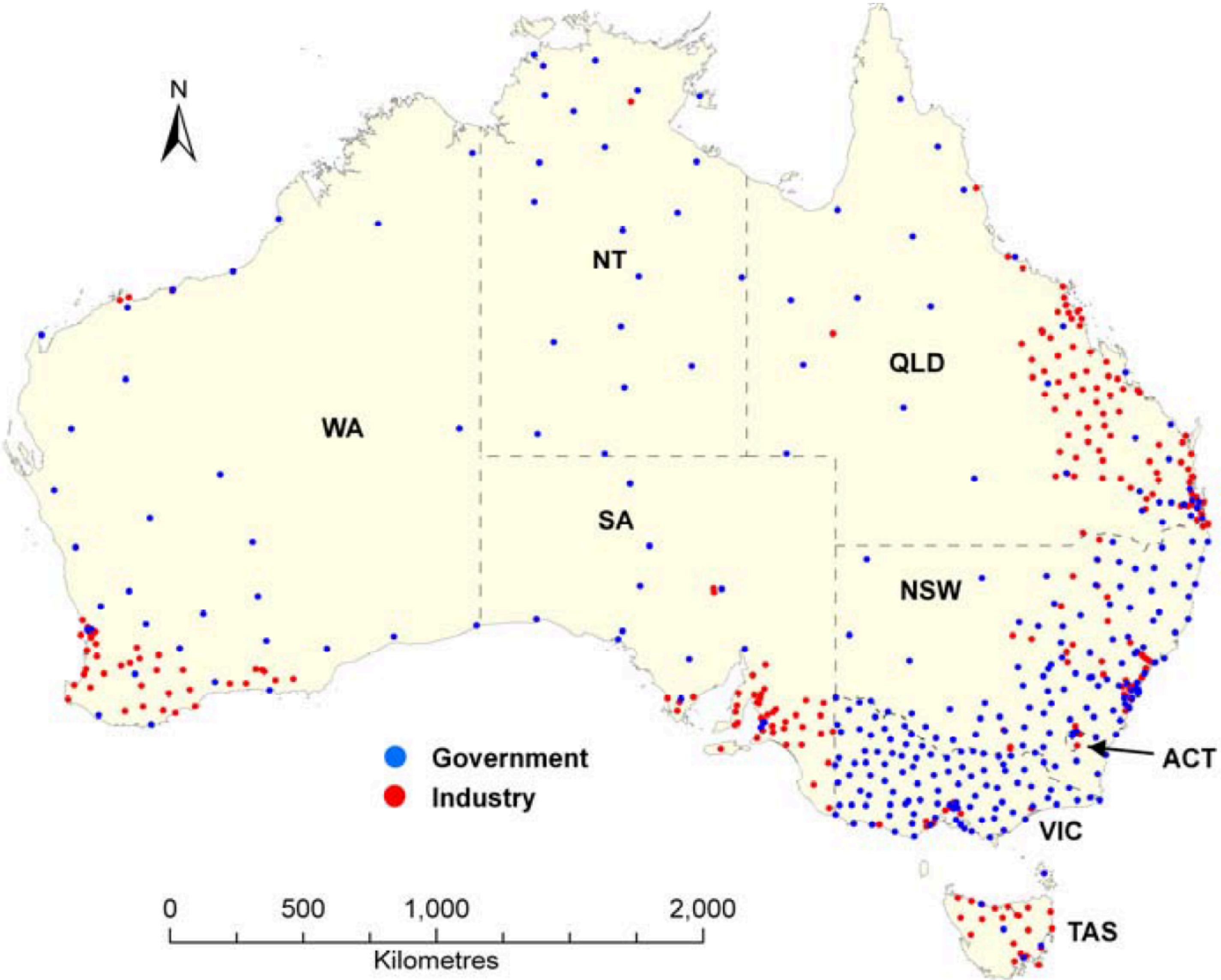


CORS - Continuously
Operating Reference Station

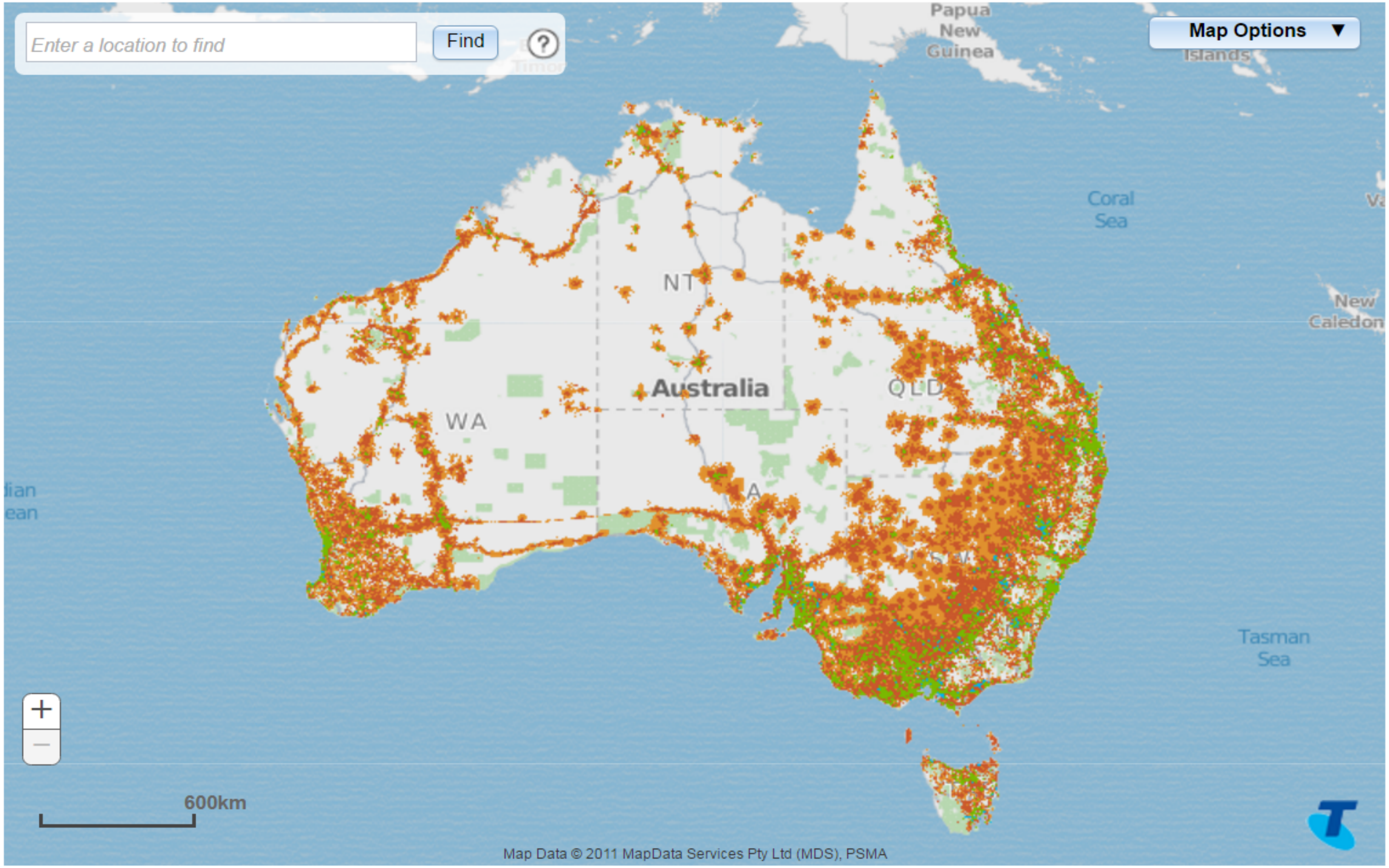
Thailand's CORS network providing NRTK Services

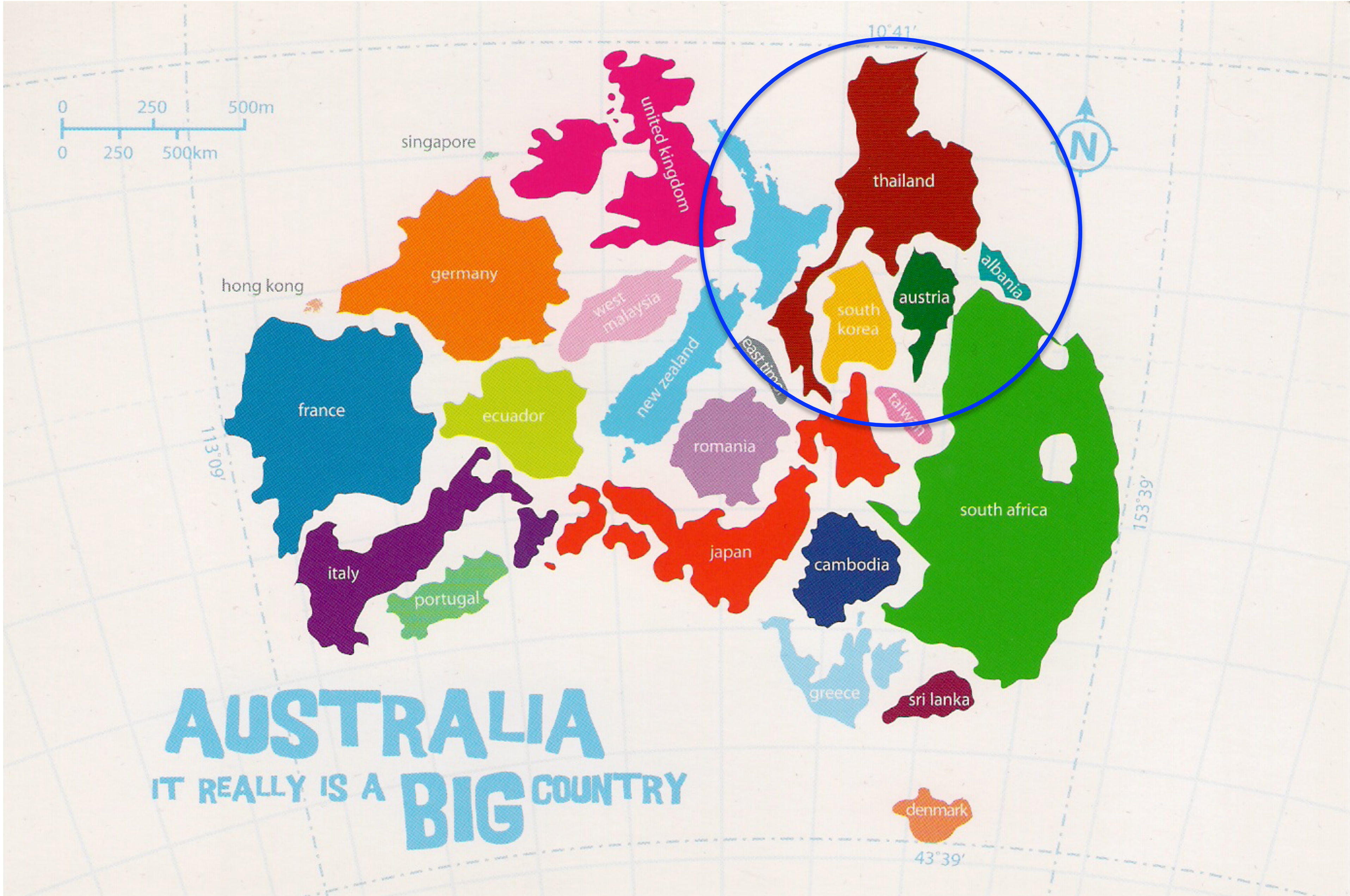


Australia's CORS Network



Australia's Mobile Connectivity





0 250 500m
0 250 500km
singapore
hong kong
united kingdom
germany
west malaysia
france
ecuador
new zealand
thailand
albania
austria
south korea
east timor
taiwan
romania
italy
portugal
japan
cambodia
south africa
greece
sri lanka
denmark
10°41′
113°09′
153°39′
43°39′
N
AUSTRALIA
IT REALLY IS A BIG COUNTRY

Precise Point Positioning (PPP)

- **Precise Point Positioning (PPP)** allows a single GNSS receiver user to determine position at the decimetre / centimetre error level in kinematic / static mode using precise satellite orbits and clocks.

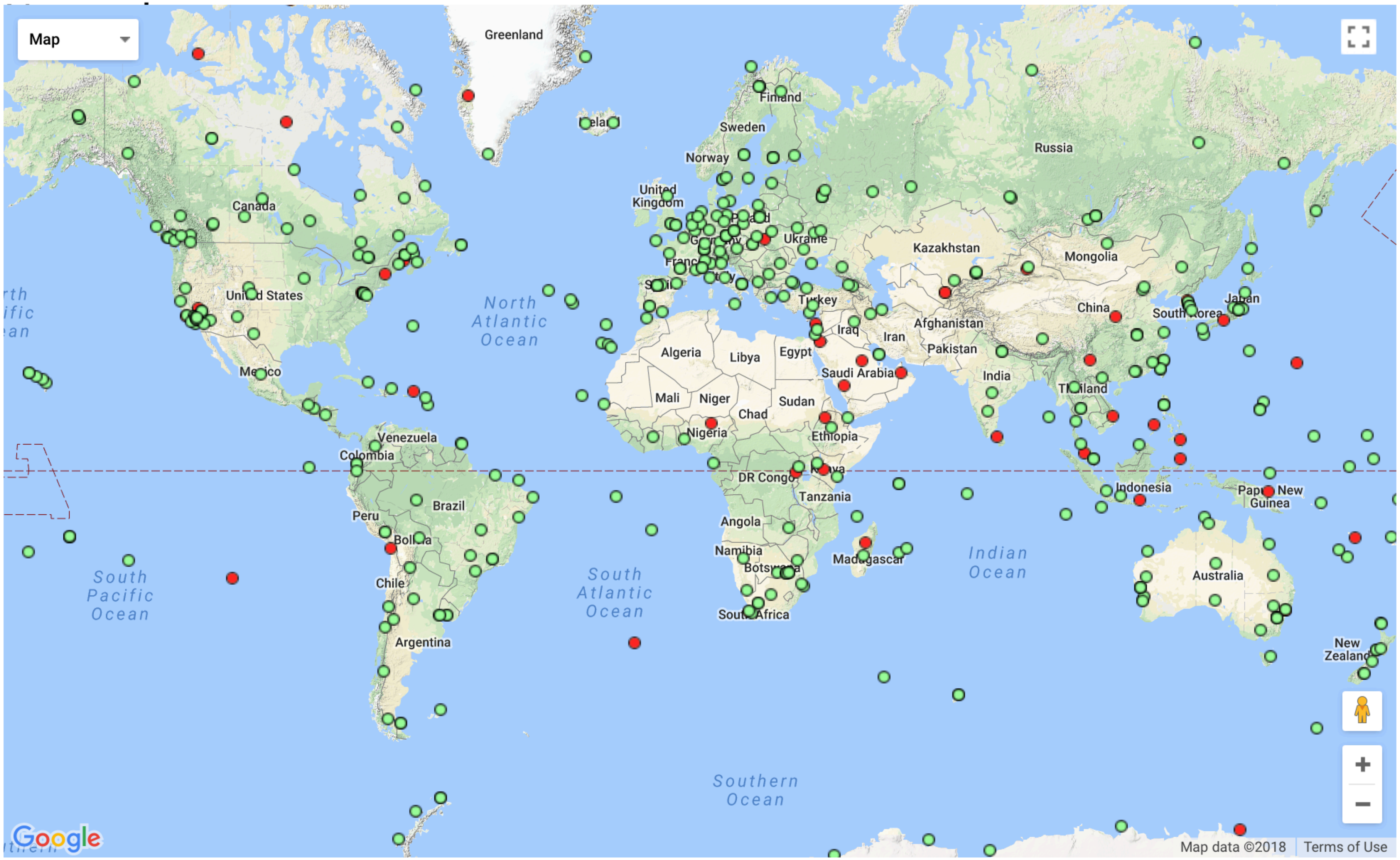
Standard Positioning Service

- Broadcast orbit and clock information
- **+**
- User satellite tracking information
- **=**
- m-level user position estimates

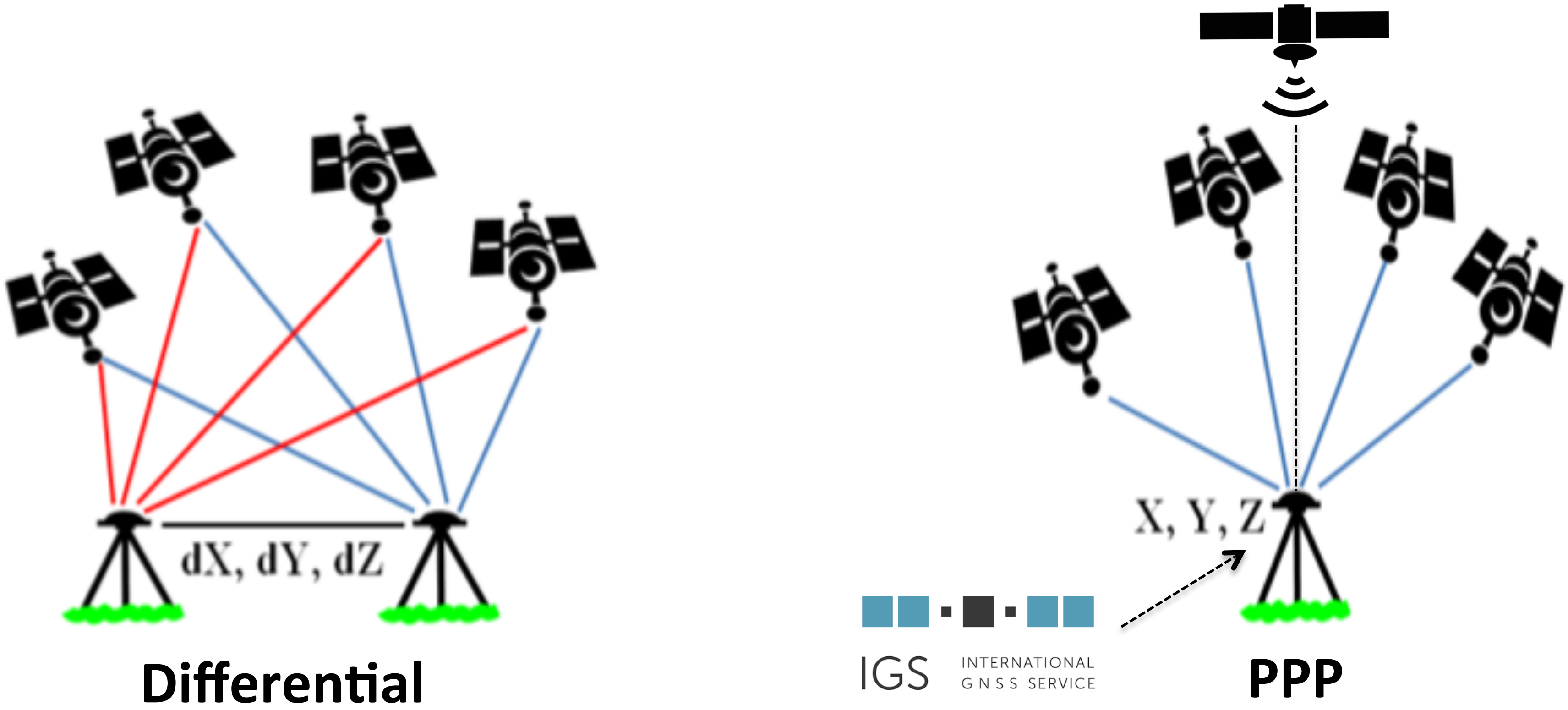
Precise Point Positioning

- Precise orbit and clock information
- **+**
- User satellite tracking information
- **+**
- Additional error modelling
- **=**
- dm- to cm-level user position estimates

International GNSS Services (IGS)



How Does PPP Work?



PPP uses state space representation (SSR) correction products such as **precise satellite orbits**, **clocks** and **signal biases** from either commercial or/and public (e.g., IGS) that are delivered to the user via satellite and/or internet.

Mathematical Model

$$L_i^k - \rho_i^k - c(\Delta t_i - \Delta t^k) - \alpha_i^k T_i + I_i^k - \lambda B_i^k - \varepsilon = 0$$

$$P_i^k - \rho_i^k - c(\Delta t_i - \Delta t^k) - \alpha_i^k T_i - I_i^k - c(b^k + b_i) - \varepsilon = 0$$

L_i^k, P_i^k - undifferenced carrier phase and code observations (meters)

ρ_i^k - geometric distance (satellite-receiver)

B_i^k - carrier phase bias, where $\lambda B_i^k = \lambda(N_i^k + \delta N_i^k) + c(d^k + d_i)$

$N_i^k, \delta N_i^k$ - integer carrier phase ambiguity and non-zero initial fractional phase

$\Delta t_i, \Delta t^k$ - receiver and satellite clock offsets

T_i - tropospheric total zenith delay

α_i^k - troposphere mapping function

I_i^k - slant ionospheric delay

$b_i, b^k;\ d_i, d^k$ - receiver and satellite code and phase hardware delays

λ - corresponding carrier wavelength

c - speed of light

ε - random error or residual

PPP Error Budget

Effect	Magnitude	Domain	Mitigation method	Residual error
Ionosphere	10s m	range	linear combination	mm
Troposphere	few m	range	modelling; estimation	dm - mm
Relativistic	10 m	range	modelling	mm
Sat phase centre; variation	m - cm	pos; range	modelling	mm
Code multipath; noise	1 m	range	filtering	dm - mm
Solid Earth tide	20 cm	position	modelling	mm
Phase wind-up (iono-free)	10 cm	range	modelling	mm
Ocean loading	5 cm	position	modelling	mm
Satellite orbits; clocks	few cm	pos; range	filtering	cm - mm
Phase multipath; noise	1 cm	range	filtering	cm - mm
Rcv phase centre; variation	cm - mm	pos; range	modelling	mm

IGS Orbit and Clock Products

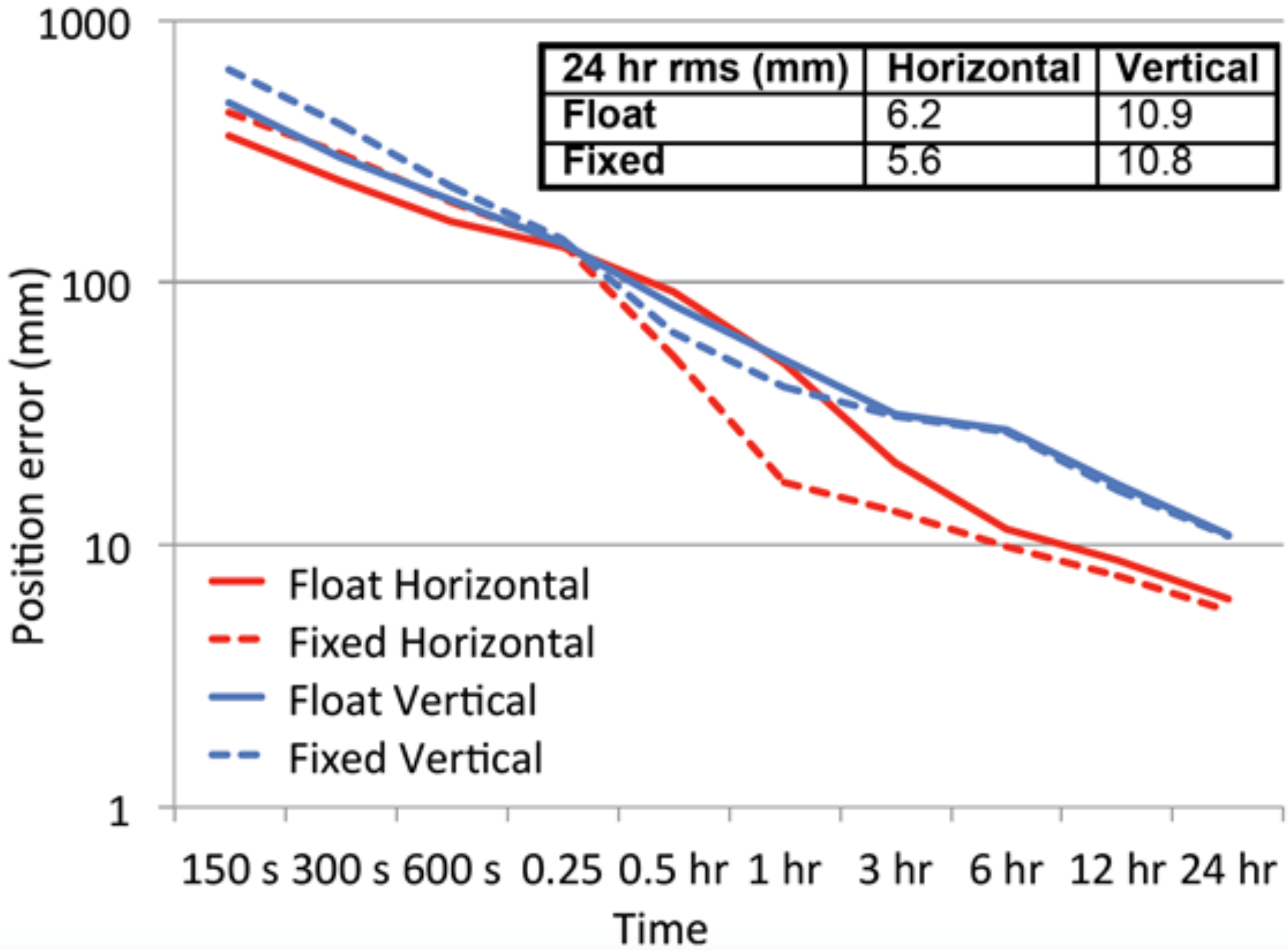
Type		Accuracy	Latency	Updates	Sample Interval
Broadcast	orbits	~100 cm	real time	--	daily
	Sat. clocks	~5 ns RMS ~2.5 ns SDev			
Ultra-Rapid (predicted half)	orbits	~5 cm	real time	at 03, 09, 15, 21 UTC	15 min
	Sat. clocks	~3 ns RMS ~1.5 ns SDev			
Ultra-Rapid (observed half)	orbits	~3 cm	3 – 9 hours	at 03, 09, 15, 21 UTC	15 min
	Sat. clocks	~150 ps RMS ~50 ps SDev			
Rapid	orbits	~2.5 cm	17 – 41 hours	at 17 UTC daily	15 min
	Sat. & Stn. clocks	~75 ps RMS ~25 ps SDev			5 min
Final	orbits	~2.5 cm	12 – 18 days	every Thursday	15 min
	Sat. & Stn. clocks	~75 ps RMS ~20 ps SDev			Sat.: 30s Stn.: 5 min
Real-time IGS	Orbit Clock	< 10 cm 0.15 ns	10-20 secs		

IGS INTERNATIONAL GNSS SERVICE

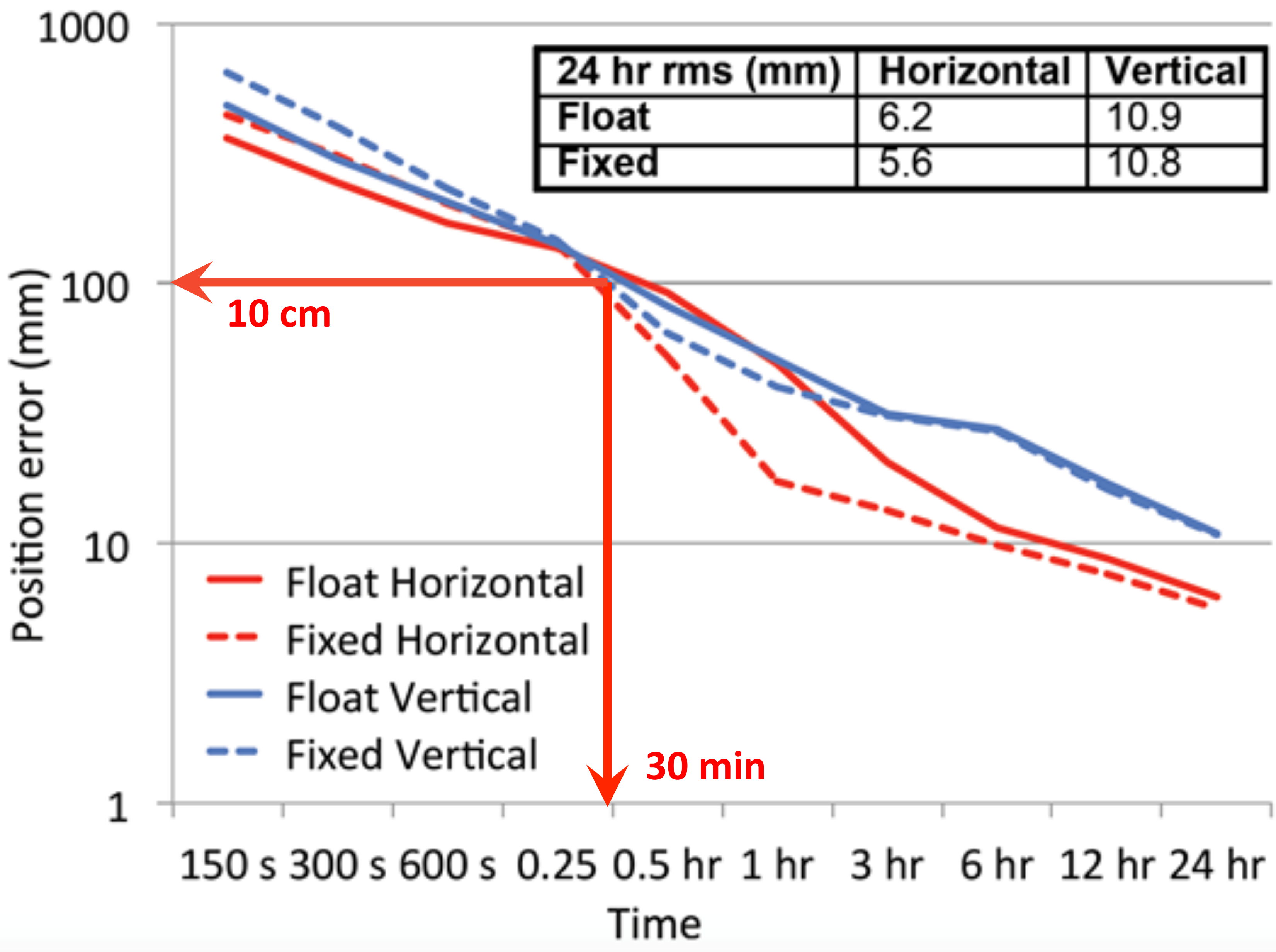
PPP Accuracy

Processing Mode	RMS (cm)		
	East	**North**	**Up**
Daily static	<0.5	<0.5	<1
Hourly static	~4	~2	~3
Post-processed kinematic	~5	~4	~10
Real-time kinematic	<10	<10	<20

Note: Based on dual-frequency measurements

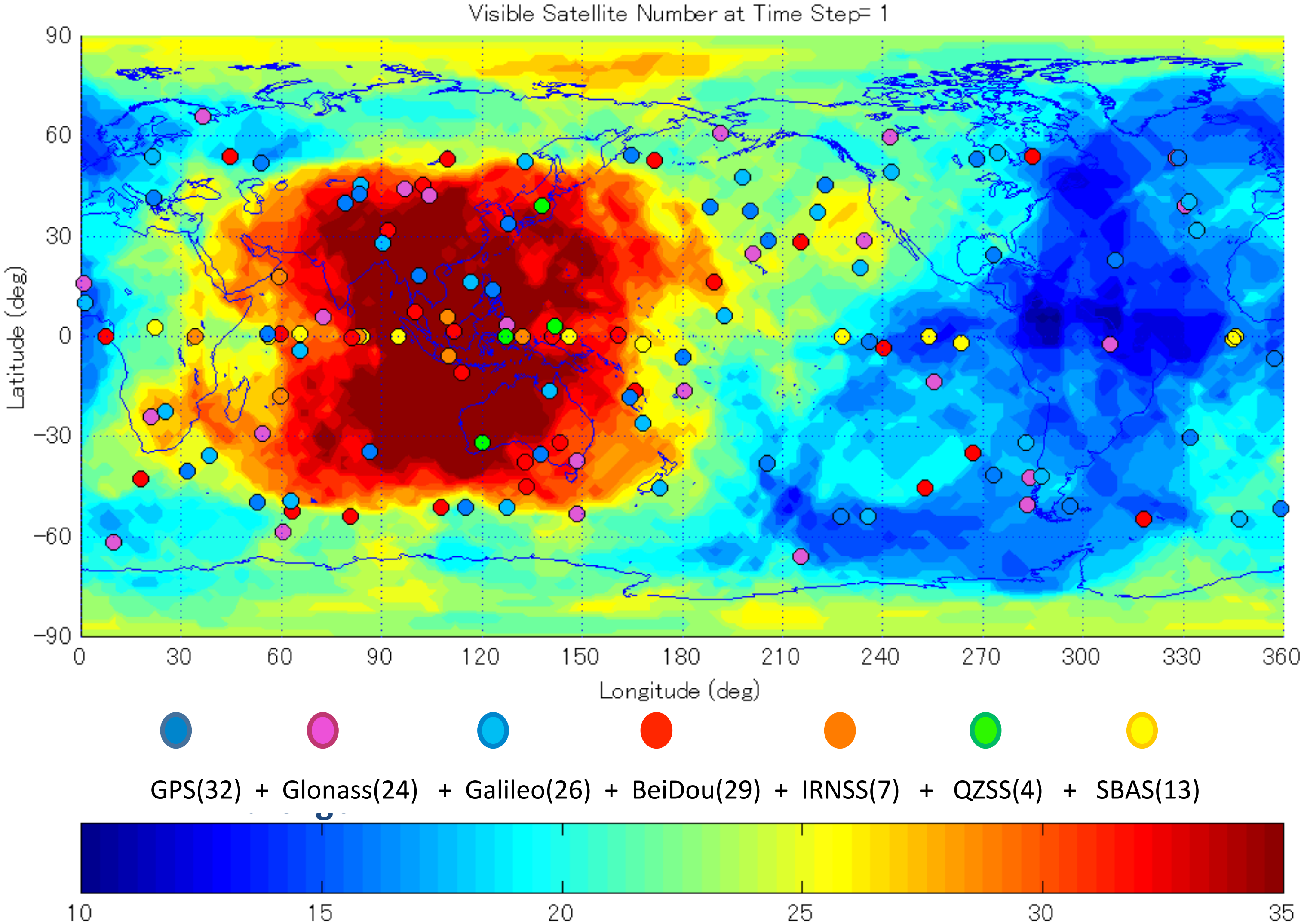


24 hr rms (mm)	Horizontal	Vertical
Float	6.2	10.9
Fixed	5.6	10.8

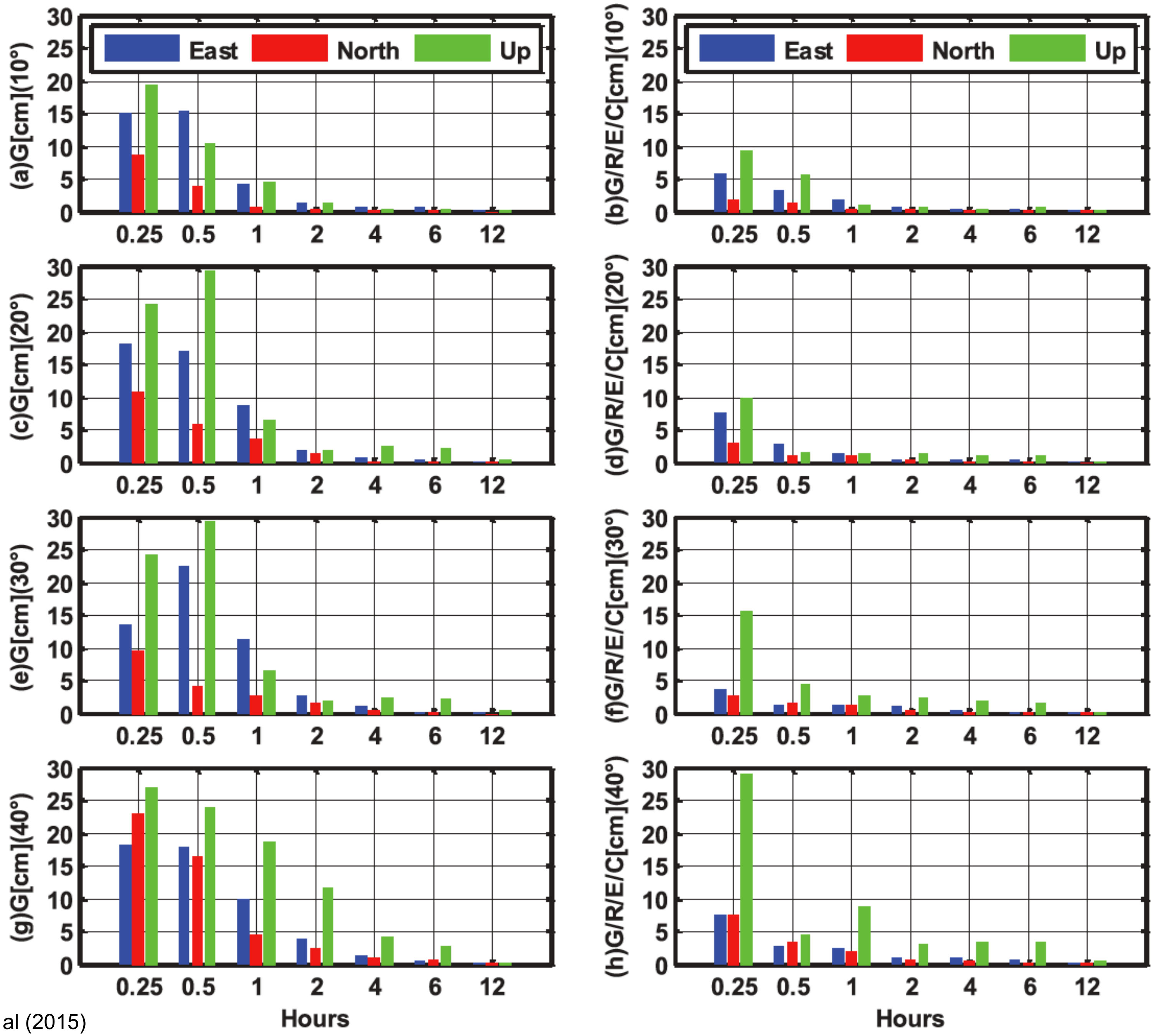


1000
100
10
1
Position error (mm)
24 hr rms (mm) | Horizontal | Vertical
Float | 6.2 | 10.9
Fixed | 5.6 | 10.8
10 cm
30 min
Float Horizontal
Fixed Horizontal
Float Vertical
Fixed Vertical
150 s 300 s 600 s 0.25 0.5 hr 1 hr 3 hr 6 hr 12 hr 24 hr
Time

Multi-GNSS



Source: UNSW



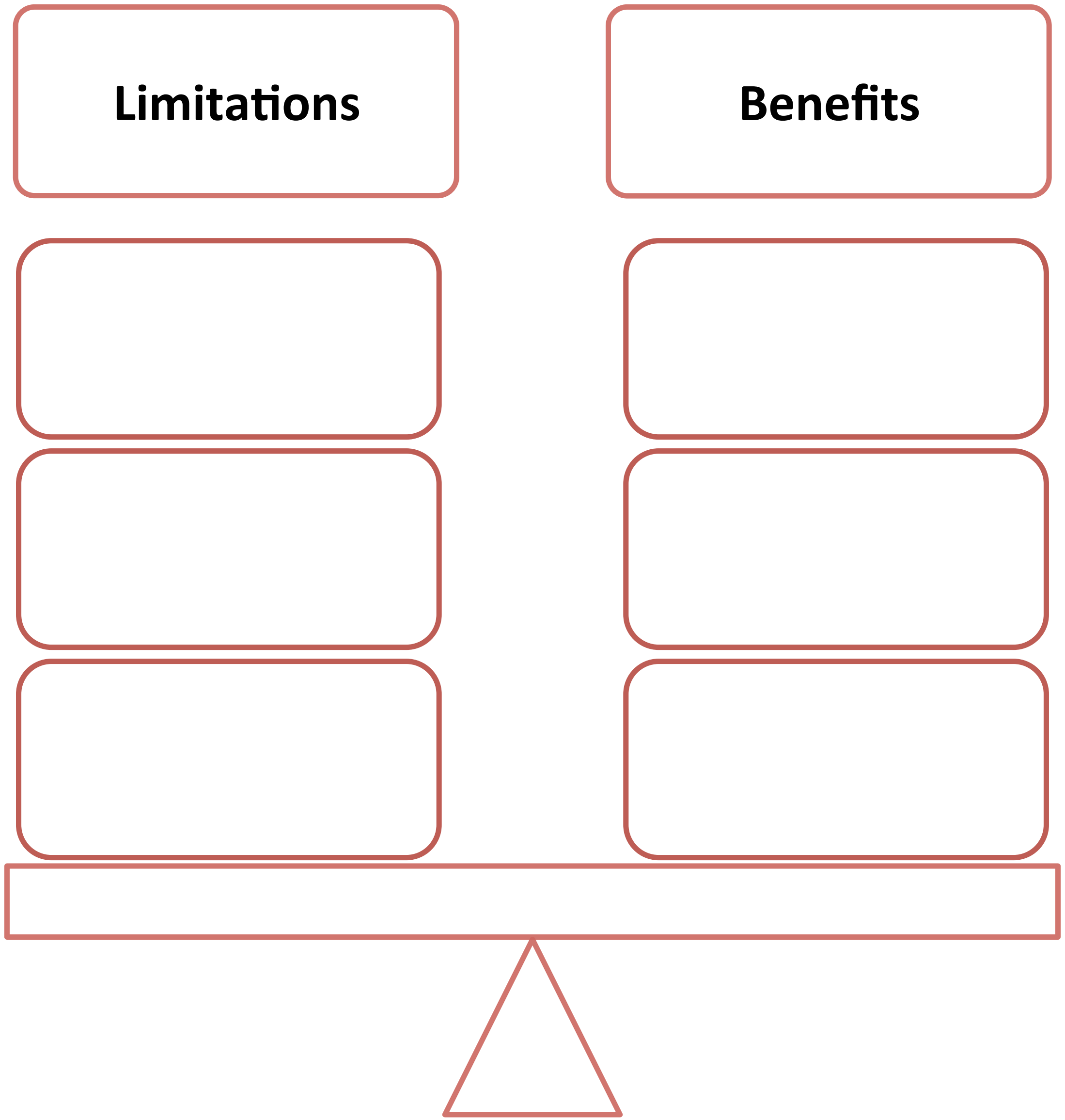
Source: Li et al (2015)

Key Points to Remember

PPP

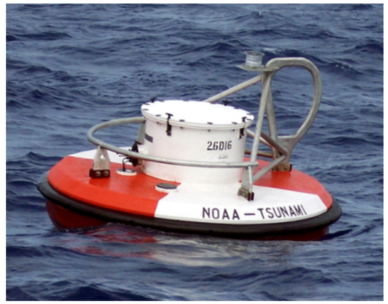
- Absolute position
- Global coverage
- Precise orbits and clocks are indispensable
- Iono error is canceled by using iono-free combination (DF) or estimated by models (SF)
- Cm-dm accuracy but with long convergence time

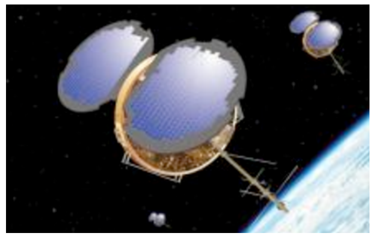
Benefits and Limitations of PPP



Primary Applications of PPP

Engineering (commercial) and scientific applications





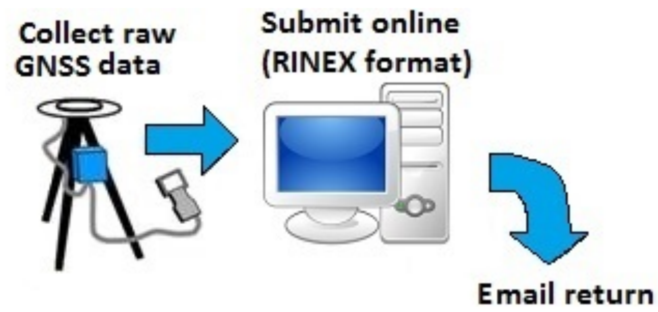
PPP is **feasible** for positioning and navigation in **remote areas** or regions of **low GNSS reference stations**

GNSS Online Processing Services

PPP

1. CSRS-PPP: Canadian Spatial Reference System, Natural Resources Canada
2. MagicGNSS: GMV
3. CenterPoint RTX: Trimble Navigation
4. GAPS: University of New Brunswick
5. APPS: Jet Propulsion Laboratory
6. SCOUT: Scripps Orbit and Permanent Array Center (SOPAC), University of California, San Diego
7. AUSPOS: Geoscience Australia
8. OPUS: U.S. National Geodetic Survey's Online Positioning User Service

Baselines



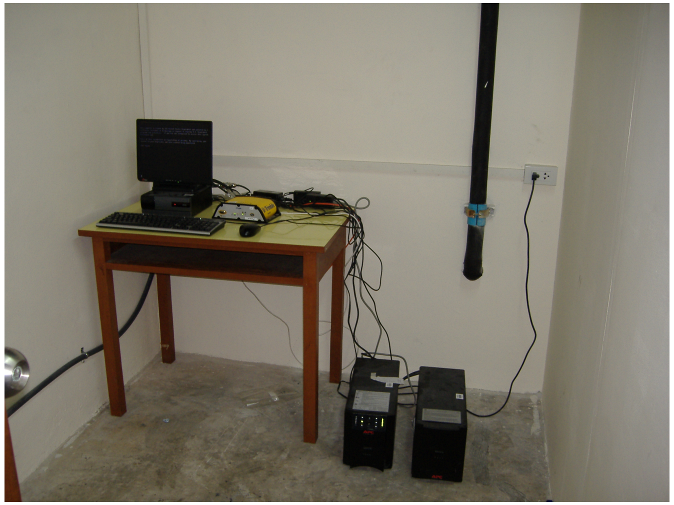
Work Example

Station Information

- CUSV, Bangkok, Thailand
- 1 December 2017 (1 day, 24 hours)
- Dual-frequency, static processing

Online GNSS Processing Service(s)

- CSRS-PPP
- MagicGNSS
- CenterPoint RTX
- AUSPOS
- GAPS



Compute and compare X, Y, Z coordinates of CUSV

Work Example: Notes

1. Check RINEX file(s)
   - antenna
   - sampling rate

2. Upload and submit RINEX file(s)
   - CSRS-PPP (https://webapp.geod.nrcan.gc.ca/geod/tools-outils/ppp.php)
   - MagicGNSS (https://magicgnss.gmv.com)
   - CenterPoint RTX (http://trimblertx.com)
   - AUSPOS (http://www.ga.gov.au/bin/gps.pl)
   - GAPS (http://gaps.gge.unb.ca/submitbasic.php)

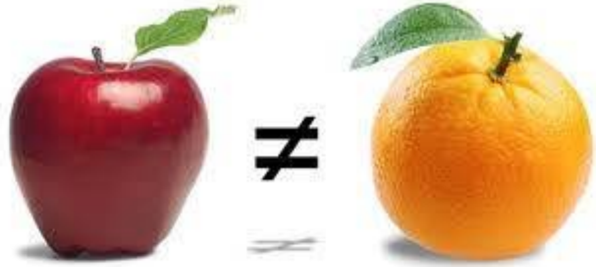
Work Example: Notes

3. Assess the reports provided by the processing services and note any warnings/errors

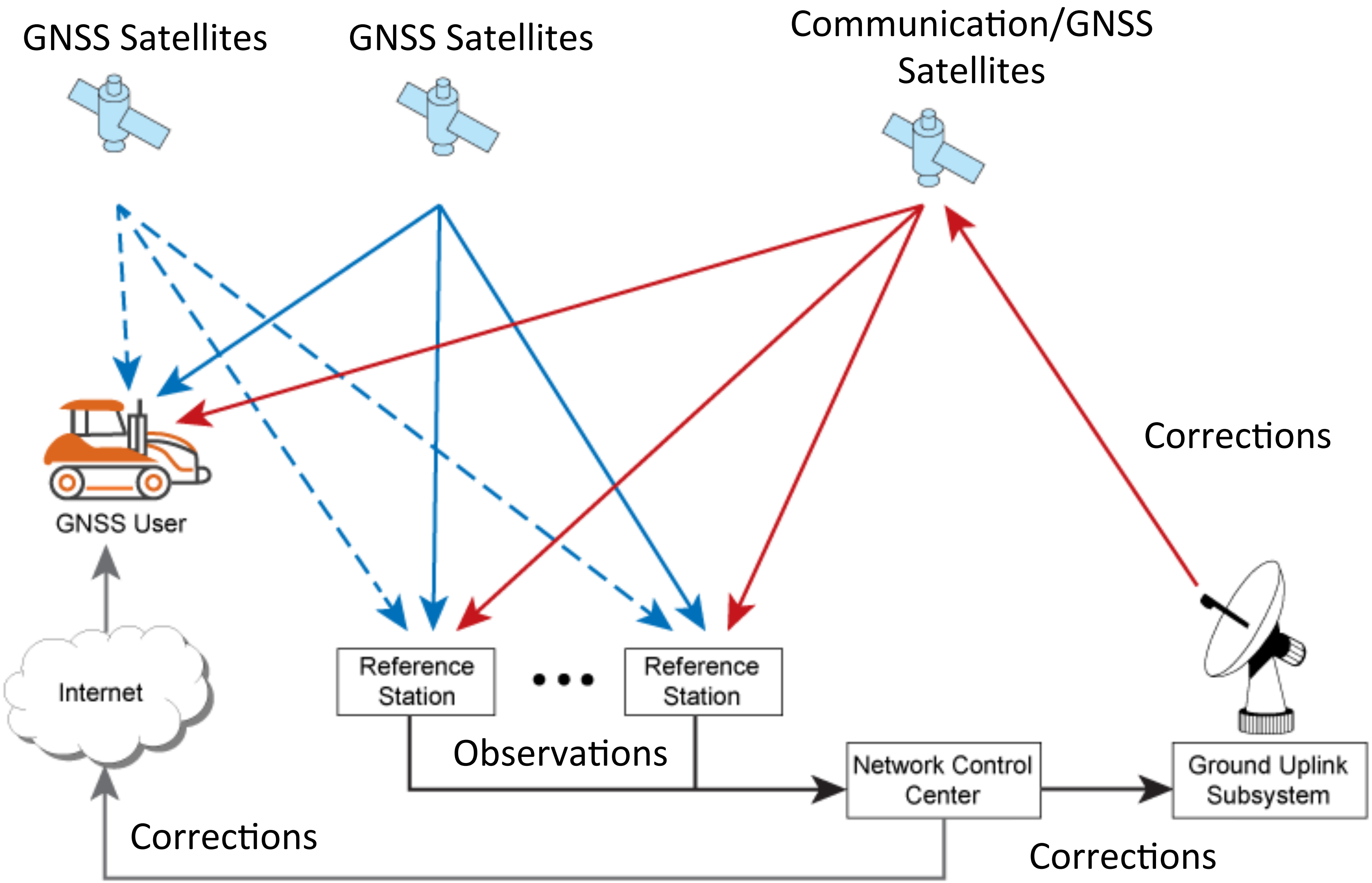
4. Collate and compare the coordinates
   - reference frame, e.g., ITRF (year and epoch)
   - cartesian, geodetic or local, etc

5. Plot ΔX, ΔY, ΔZ

Make sure the coordinates are in the same reference frame !!



Real-time PPP System



Commercial PPP Services

Company	Services	Company	Services
OmniSTAR	OmniSTAR HP	NavCom	StarFire
	OmniSTAR G2	C-Nav	C-NavC2
	OmniSTAR XP		C-NavC1
Trimble	CenterPoint RTX	Veripos	Apex 2
	RangePoint RTX		Apex
	ViewPoint RTX		Ultra 2
Fugro	Starfix.G2+		Ultra
	Starfix.G4	TerraStar	TerraStar-C
	Starfix.G2		TerraStar-D
	Starfix.XP2	Novatel	CORRECT (PPP)
	Starfix.HP	Hemisphere	Atlas

Next Generation GNSS/RNSS

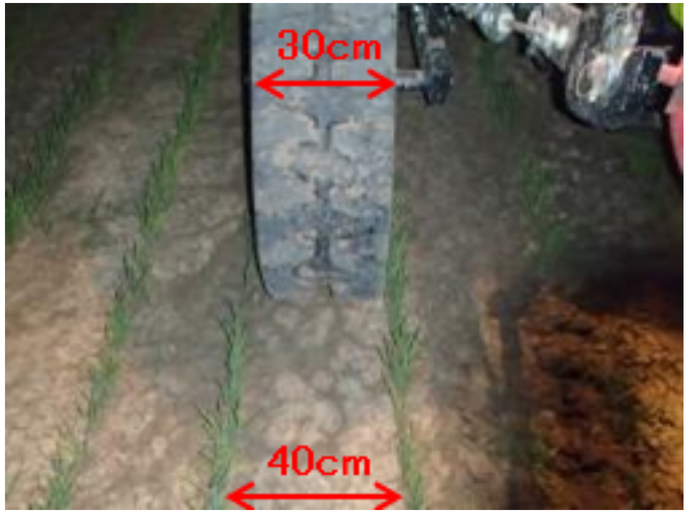
Regional/Global Precise Positioning Service(s)

Next generation GNSS/RNSS satellites augmentation signals, which could be used for real-time PPP services

Constellation	Augmentation Signal	Frequency (MHz)	Data Rate (bps)
EGNOS	E5b	1207.14	250
Galileo	E6	1278.75	500
BeiDou	B2b	1207.14	1000
QZSS	L6	1278.75	2000
GLONASS	L3	1207.14	?

Real-time PPP Application: Precision Agriculture

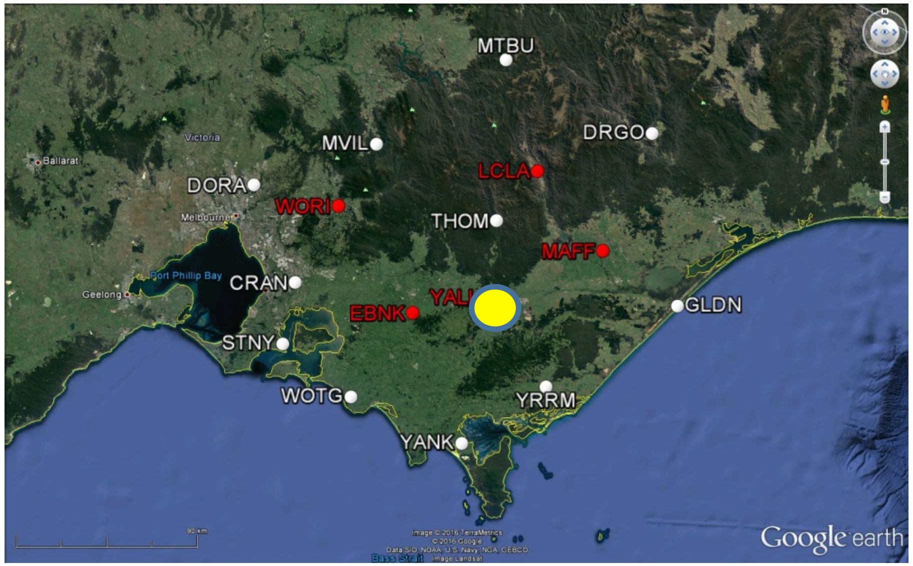
- Rice farming: Nov 2014 – Feb 2015
- Location: Jerilderie, NSW
- Funded by Japan Ministry of Internal Affairs and Communications
- Japanese Partners:
  - Hitachi, Hitachi Zosen, Hitachi Solutions, JAXA, Hokkaido University, Yanmar
- Australian Partners:
  - CRCSI, Hitachi Australia, Rice Research Australia, SmartNet, CRK, PACA, UNSW, UNE, RMIT
- Aim: Evaluate the performance of QZSS-PPP



Real-time PPP Application: Mining and Construction

- Mining: Aug 2016 – Sep 2016
- Location: Morewell, Victoria
- Funded and supported by the CRCSI and JAXA
- Australian Partners:
  - Position Partners, Energy Australia, Victoria government (DELWP)
- Aim: Evaluate QZSS-PPP in mining applications

Dozer used on mining operations



Location of Morwell coal mine site

Dozer operation path

Real-time PPP Application: Auto-Driving Vehicle

- Autonomous vehicle: Dec 2017 (on-going)
- Location: Melbourne
- Funded by the Australian and New Zealand Governments
- International Partners:
    - Lockheed Martin, Inmarsat and GMV
- Local Partners:
    - Geoscience Australia, CRCSI, Bosch, VicRoads and RMIT
- Aim: Evaluate the performance of PPP and its suitability for autonomous driving

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The Future?
RTK, NRTK, PPP, PPP-RTK

Commonly used term	Technically better term	What does it mean?	What is the difference?
RTK	Differential GNSS *or* Observation Space Representation (OSR)	Elimination of most errors *and* Estimation of some errors	Only common errors are eliminated
NRTK			Combination of elimination and estimation
PPP	State Space Representation (SSR)	Estimation of errors	Only some errors estimated
PPP-RTK			Almost all errors estimated

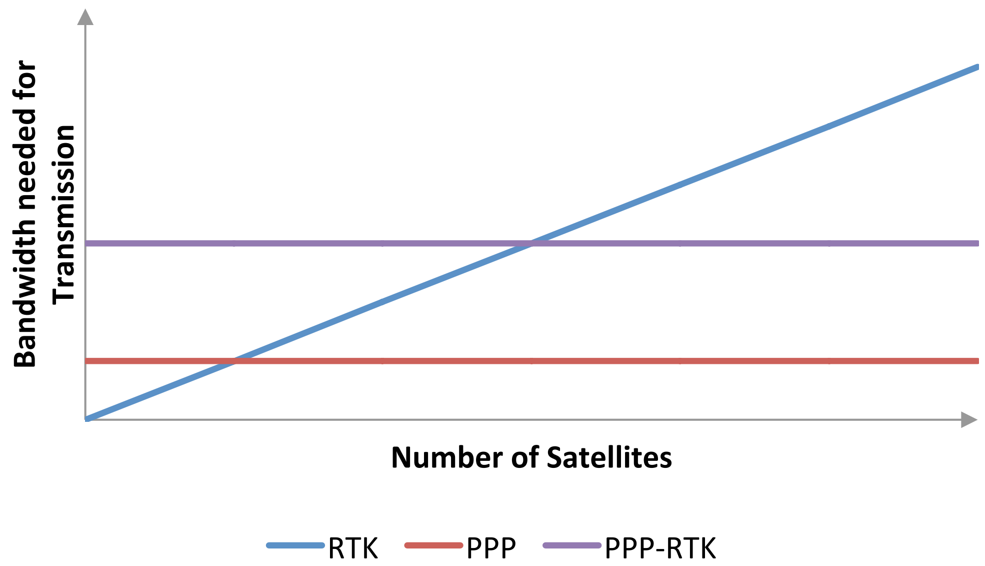
The Future?
RTK, NRTK, PPP, PPP-RTK

Method	What is transmitted?	Initialisation time	Accuracy (horiz)
RTK/NRTK	Corrections per satellite and per (virtual) reference station	< 20 s	~ 2 cm
PPP	▪ Orbits ▪ Clocks	> 40 min for float	a few cm
PPP-AR	▪ Orbits ▪ Clocks ▪ Phase biases	~ 30 min	a few cm
PPP-RTK	▪ Clocks ▪ Orbits ▪ Phase biases ▪ **Troposphere** ▪ **Ionosphere**	< 1 min	a few cm

PPP-RTK

Advantages

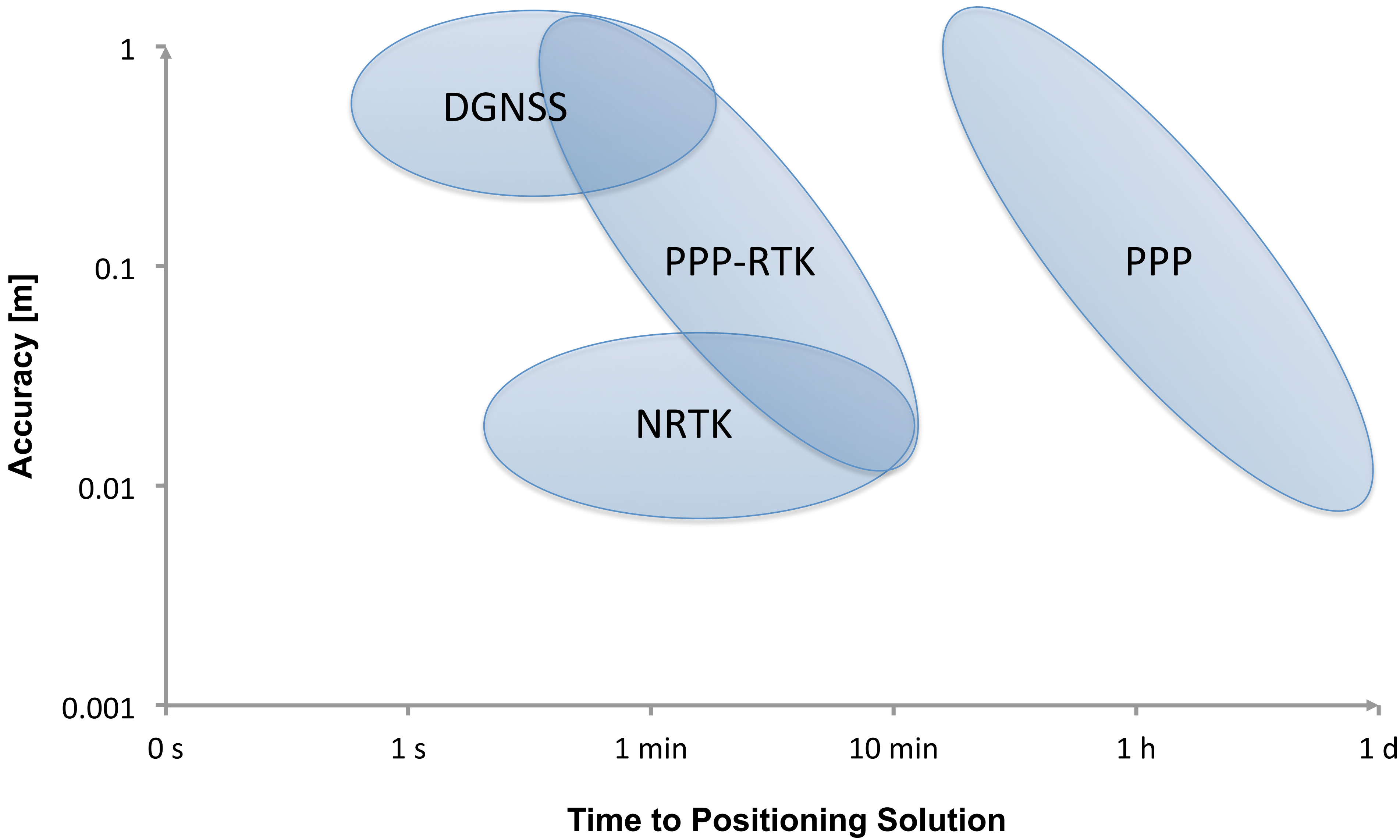
- Rapid cm level accuracy like NRTK
- Transmission bandwidth less dependent on the number of satellites (important when 4 global systems are available)
- Independent from individual reference station and satellites
- Reduced influence of local errors, e.g. multipath
- Scalable accuracy, i.e. different accuracy levels can be realized by using only parts of the models, e.g., PPP, PPP-AR, PPP-RTK



Disadvantages

- Needs local ground infrastructure as NRTK
- Can not be applied globally
- Method not yet widely accepted in practice
- No standardised data formats available yet (still in development)

Comparison NRTK, PPP and PPP-RTK



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