



Precise Point Positioning from Combined GPS, GLONASS & BeiDou

Never Stand Still

Faculty of Engineering

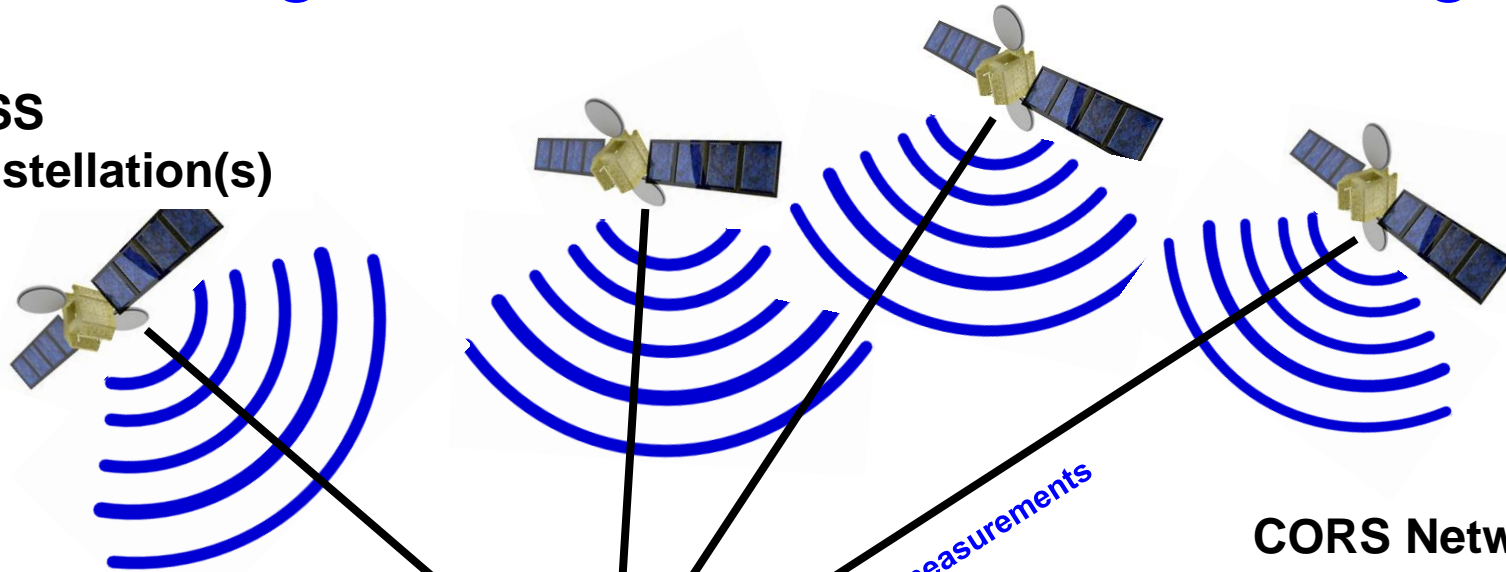
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Mazher Choudhury

Chris Rizos

Challenges of Precise Point Positioning (PPP)

**GNSS
Constellation(s)**



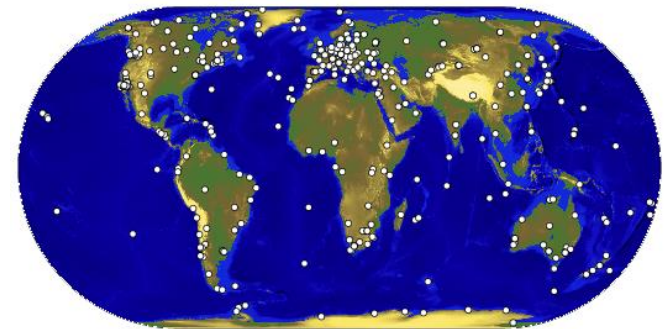
**Other models
& files**

GNSS User



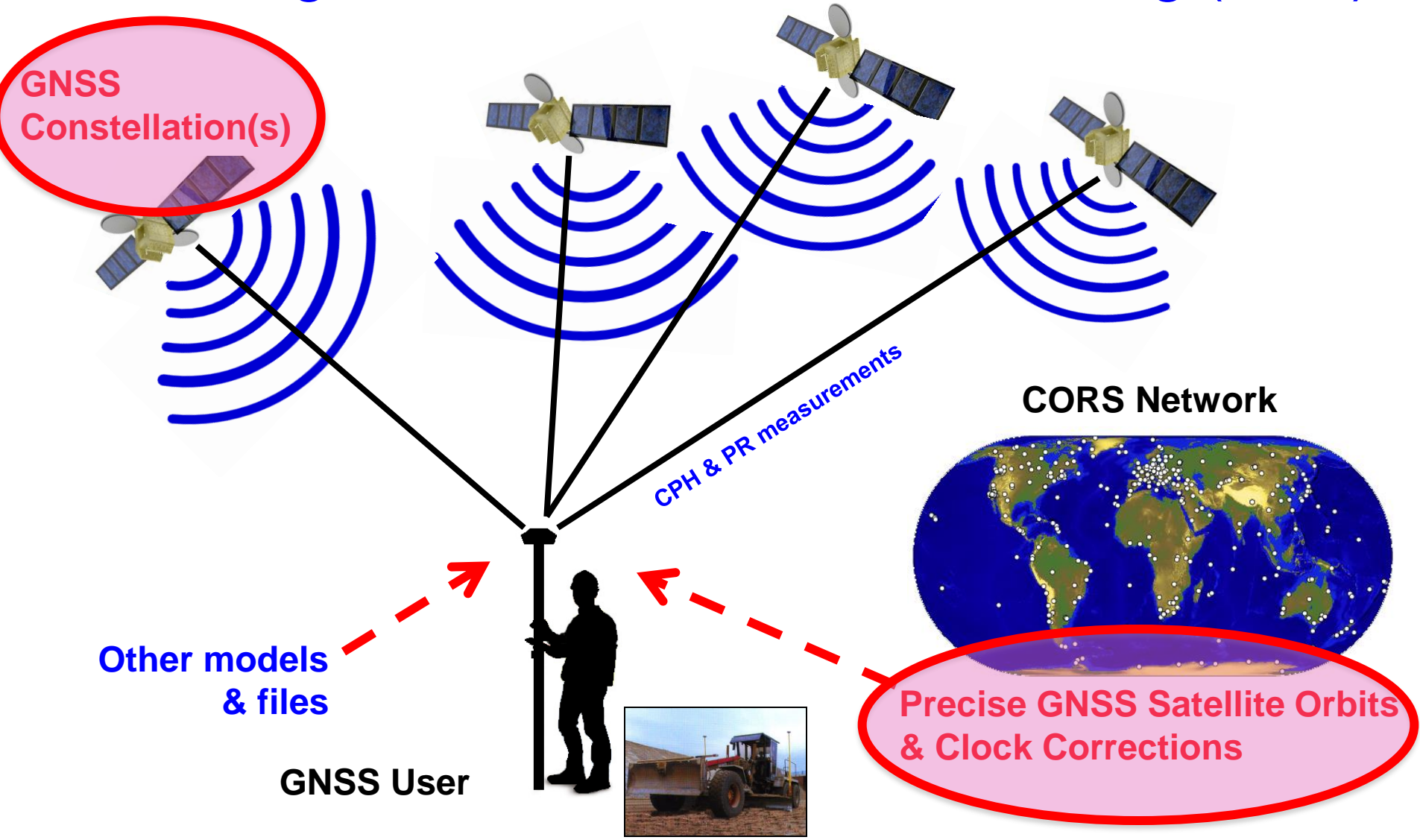
CPH & PR measurements

CORS Network



**Precise GNSS Satellite Orbits
& Clock Corrections
(Real-time or files)**

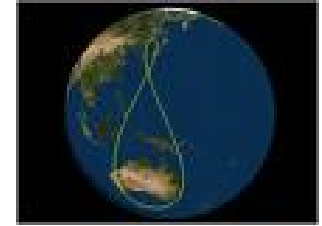
Challenges of Precise Point Positioning (PPP)



From GPS to Multi-GNSS...



+



- GNSS:

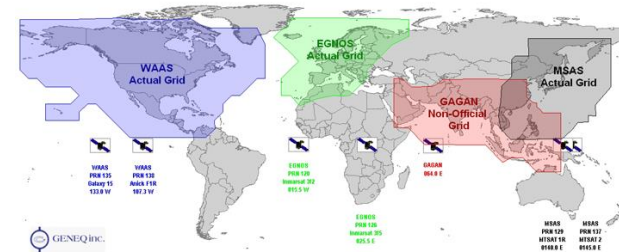
More satellites improves geometry, redundancy, precision...

- BeiDou (13-14) (35)

- EGNOS
- GAGAN
- SDCM

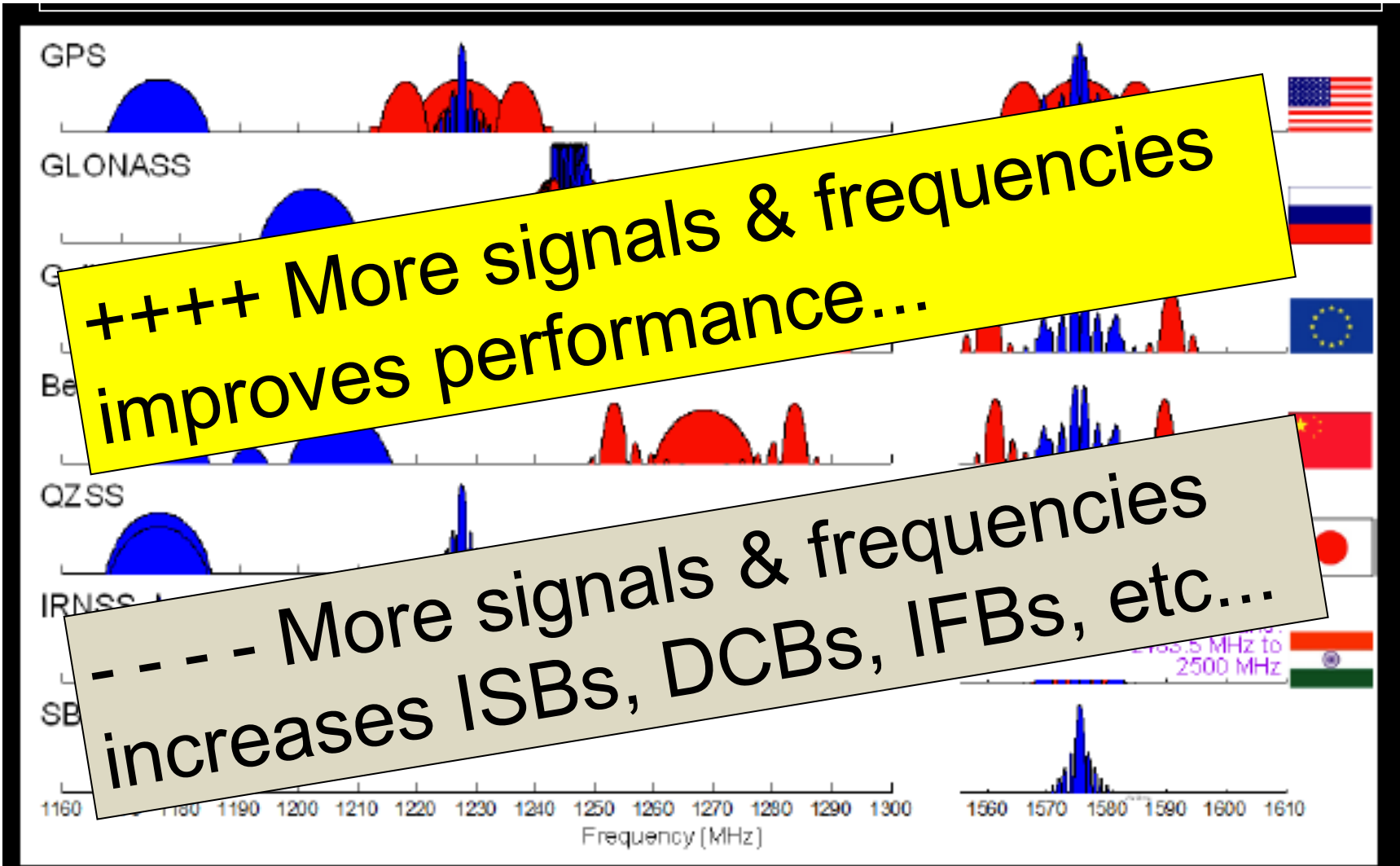
- RNSS:

- QZSS (1) (5-7)
- IRNSS (4) (7)



Number of satellites: (Current) (Planned)

More Signals, More Frequencies...



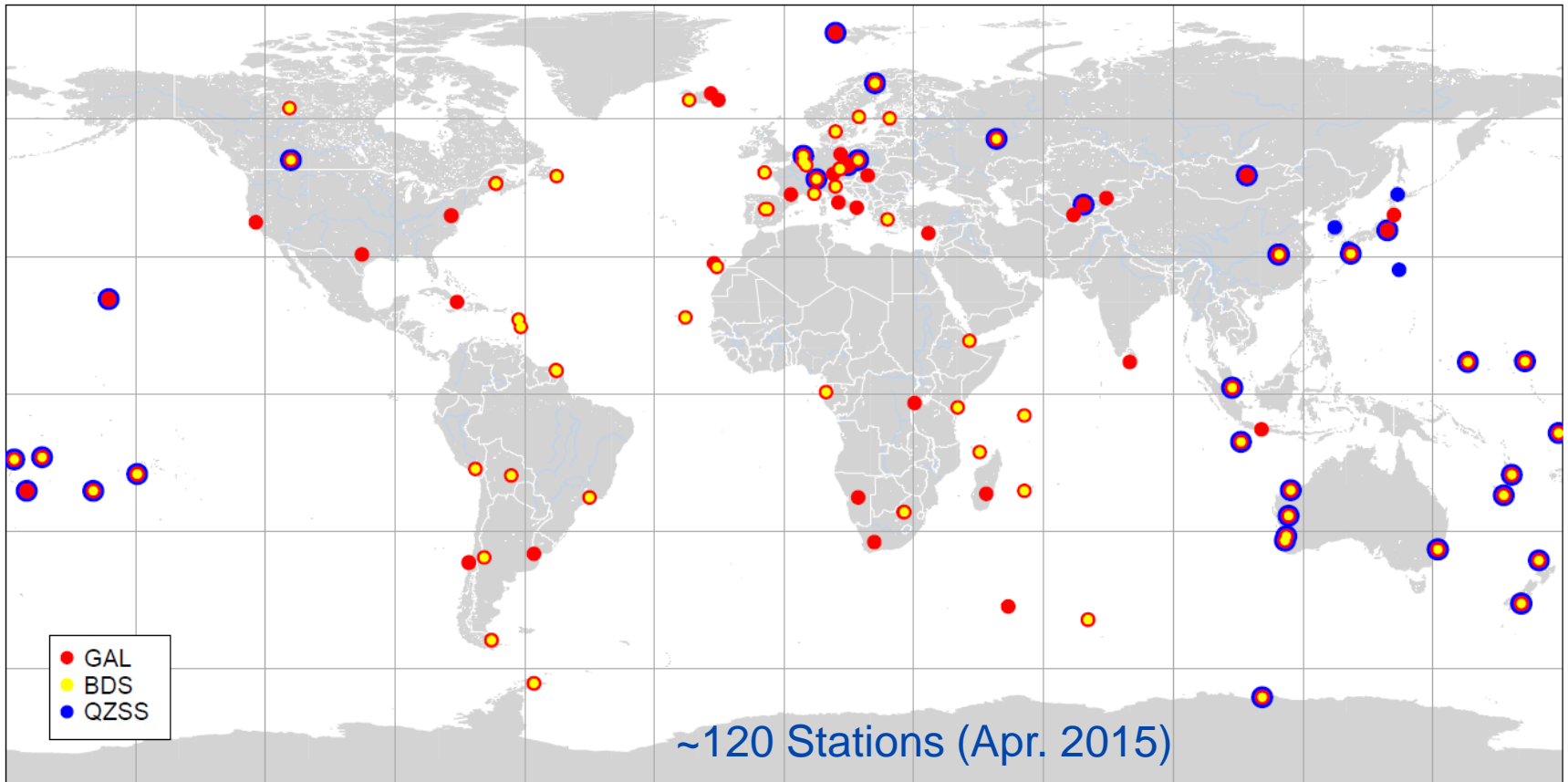
Courtesy: John Betz, MITRE

IGS Multi-GNSS Experiment



- Multi-GNSS Experiment (MGEX)
 - Multi-GNSS Working Group, *chaired by Oliver Montenbruck*
 - Build-up of new multi-GNSS tracking network started 2012 (ongoing)
 - Preliminary MGEX results from variety of ACs
 - <http://igs.org/mgex/>
- About 30 contributing agencies from >16 countries
- More than 120 stations worldwide, *plus 75 real-time stations*
- Tracking of Galileo, BeiDou, QZSS, SBAS signals
- Free data/product access:
 - <ftp://cddis.gsfc.nasa.gov/pub/gps/data/campaign/mgex/>
 - <ftp://cddis.gsfc.nasa.gov/pub/gps/products/mgex/>

IGS MGEX Network

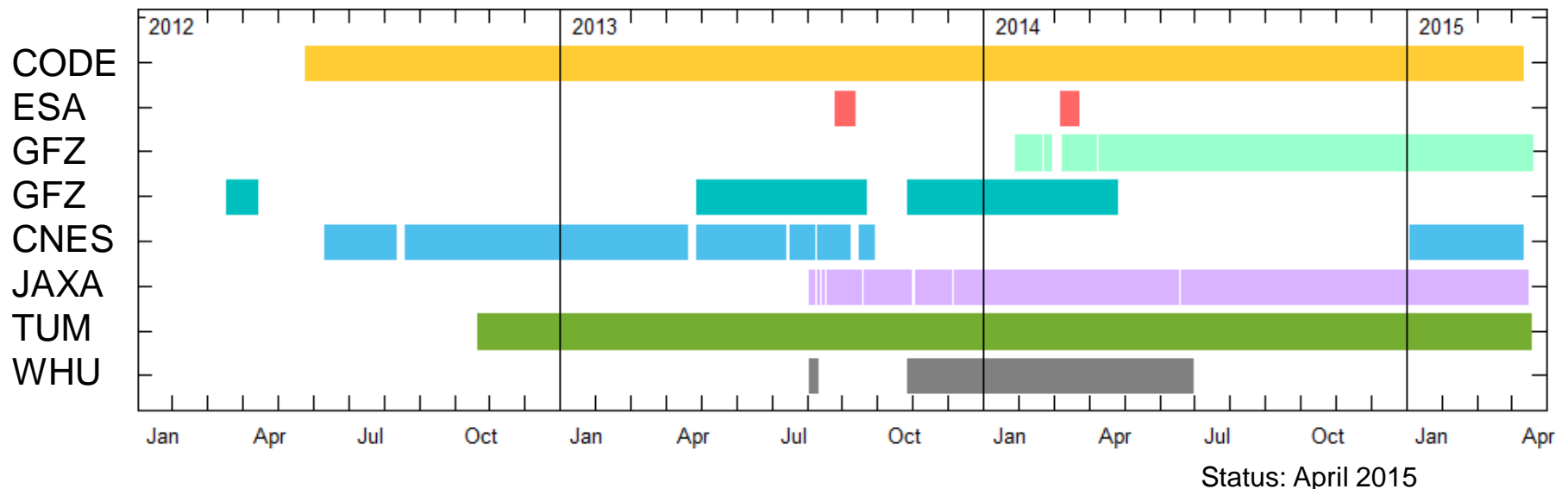


Offline : <ftp://cddis.gsfc.nasa.gov/pub/gps/data/campaign/mgex/>
Real-time: <http://mgex.igs-ip.net/>

IGS MGEX Test Products



- Currently Galileo, BeiDou, QZSS orbits and clocks
- 7 contributing ACs: CNES, ESA, CODE, GFZ, JAXA, TUM, WUM
- Orbits & clocks at decimetre-level accuracy
- “all-in-one” constellation broadcast ephemeris file (“brdm”)
- ISB, DCBs results
- SLR residuals for several GNSS satellites



Background to M-GNSS PPP

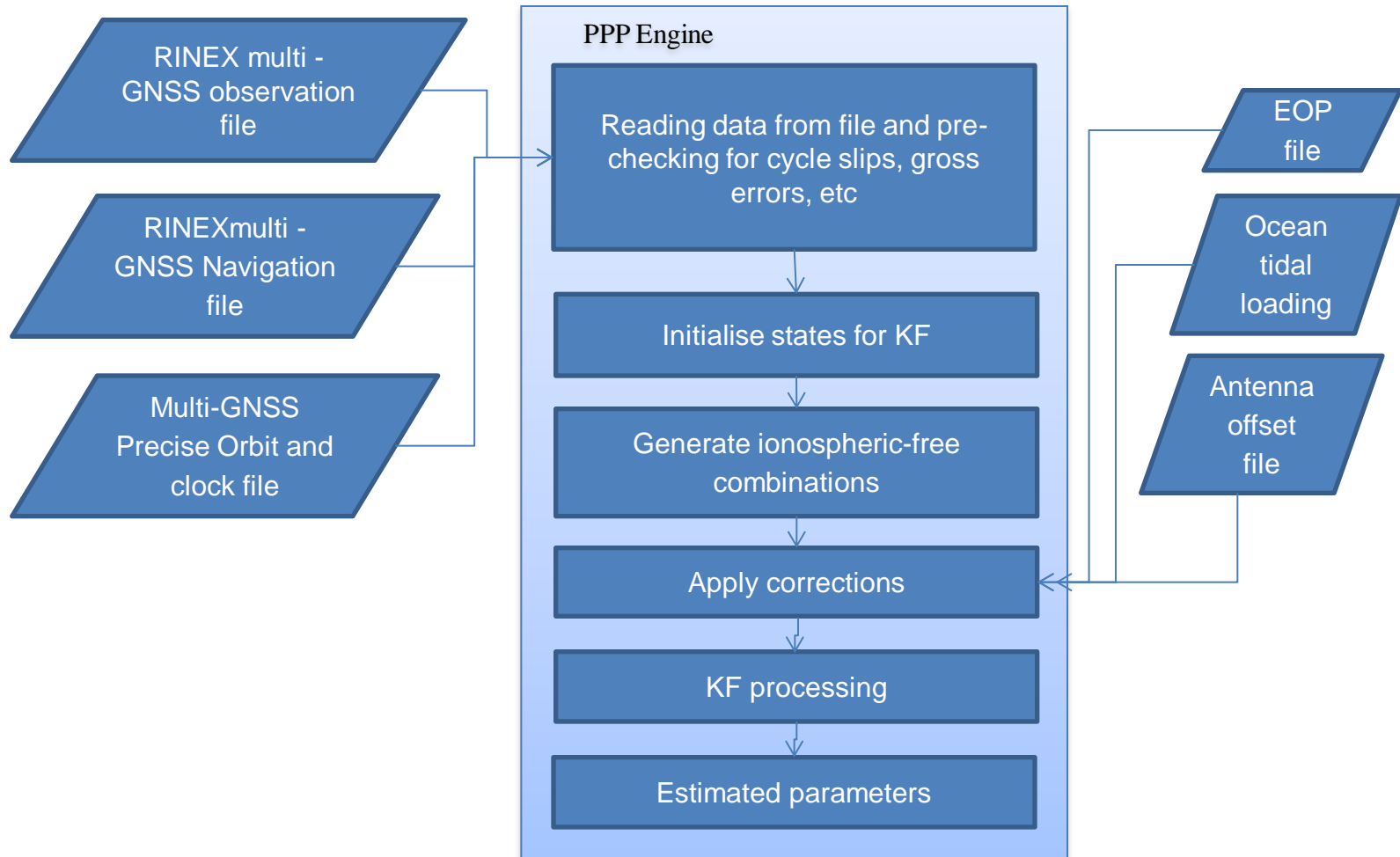
Previous work

- Cai & Gao (2007): GPS + GLONASS
- Afifi & El-Rabbany (2014): GPS + Galileo
- Tegedor et al. (2014): GPS + GLONASS + Galileo + BeiDou
(This is implemented using sequential least squares approach within ESA proprietary software NAPEOS)

In this work

- Implemented in SNAPP GNSS data processing software (based on Open Source RTKLIB)
- Kalman filter is used
- Extended for real-time PPP & RTK-PPP
- Galileo measurements are not included

Data Flow Through Software...

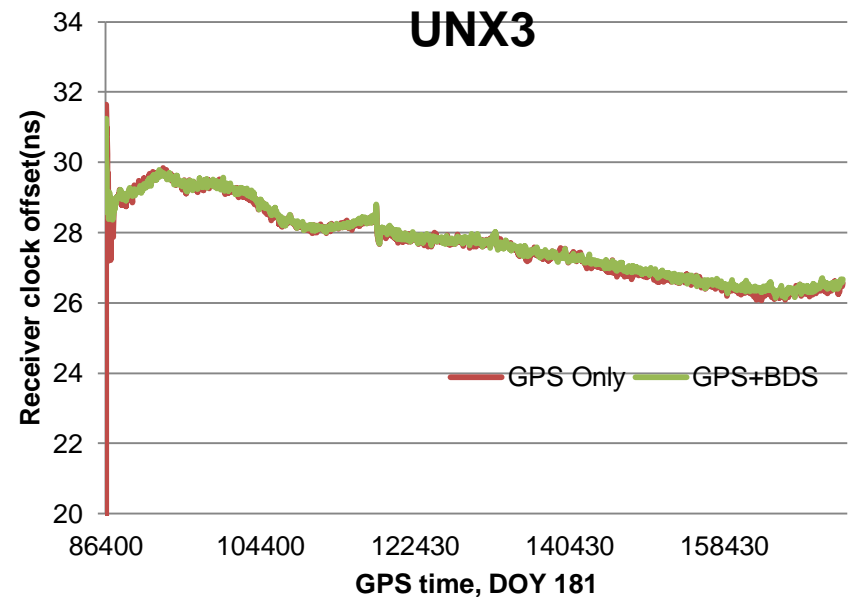
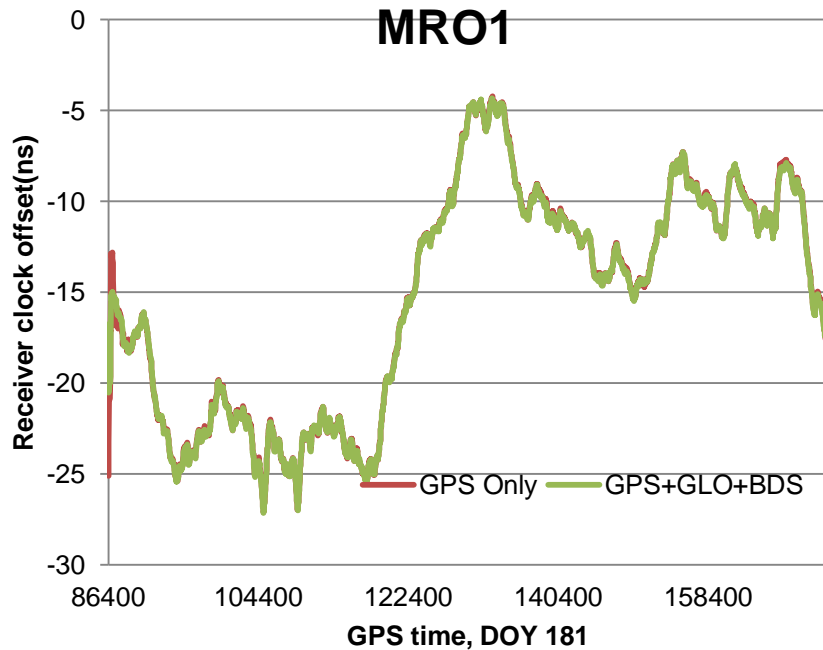


Data Source

- IGS MGEX provides satellite orbit/clock files for BDS from 28 January 2014
- Dual-frequency measurements for GPS Week 1799, DOY 181 (30 June 2014) for two GNSS stations in Australia: GPS, GLO & BDS from MRO1, GPS+BDS from UNX3

Station	Receiver	Firmware	Antenna		Tracking GNSS
MRO1	TRIMBLE NETR9	4.81	TRM59800.00	NONE	GPS+GLO+BDS
UNX3	SEPT ASTERX3	2.3.4	LEIAR25.R3	LEIT	GPS+GLO

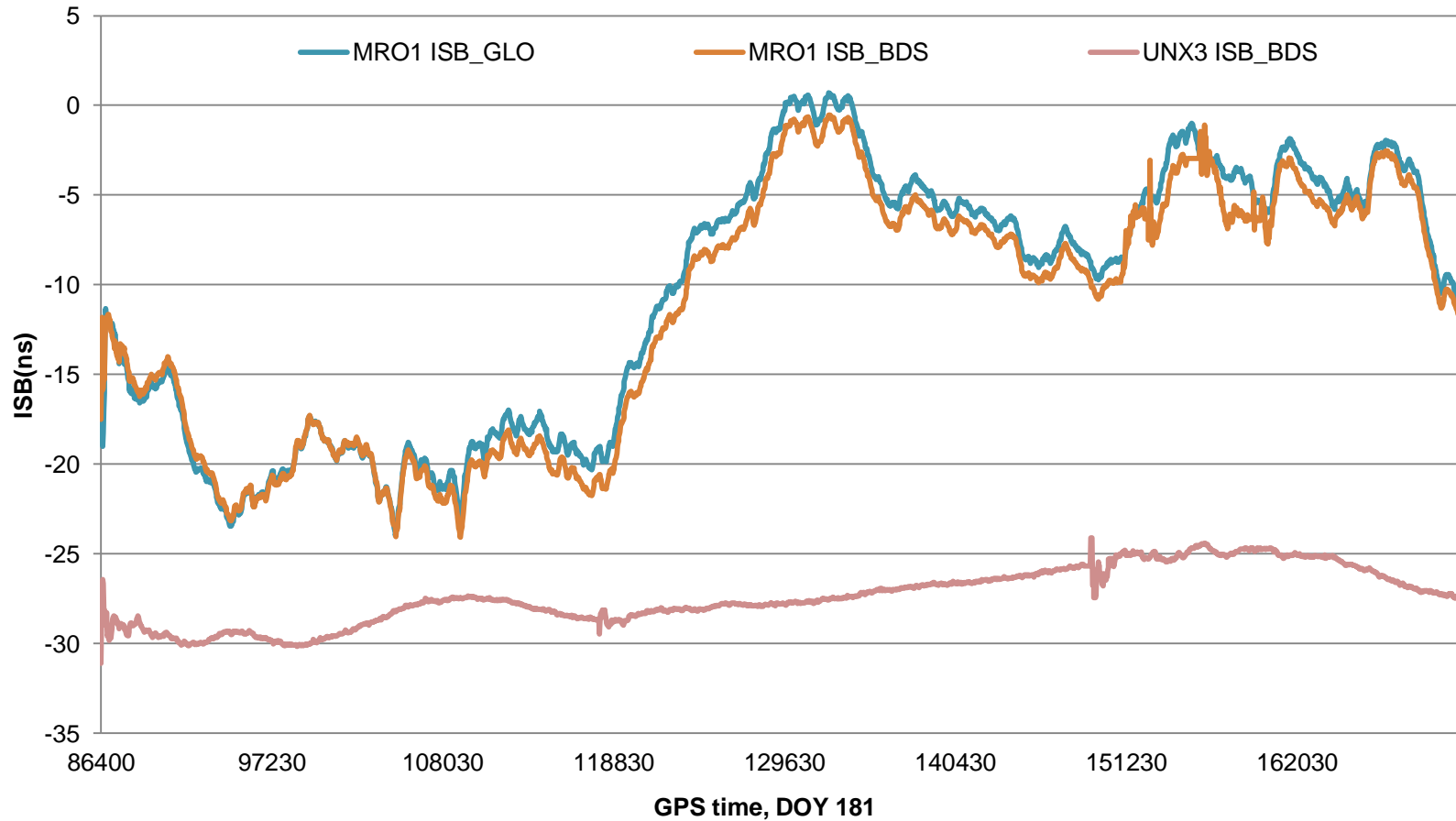
Receiver (GPS) Clock Error Solutions



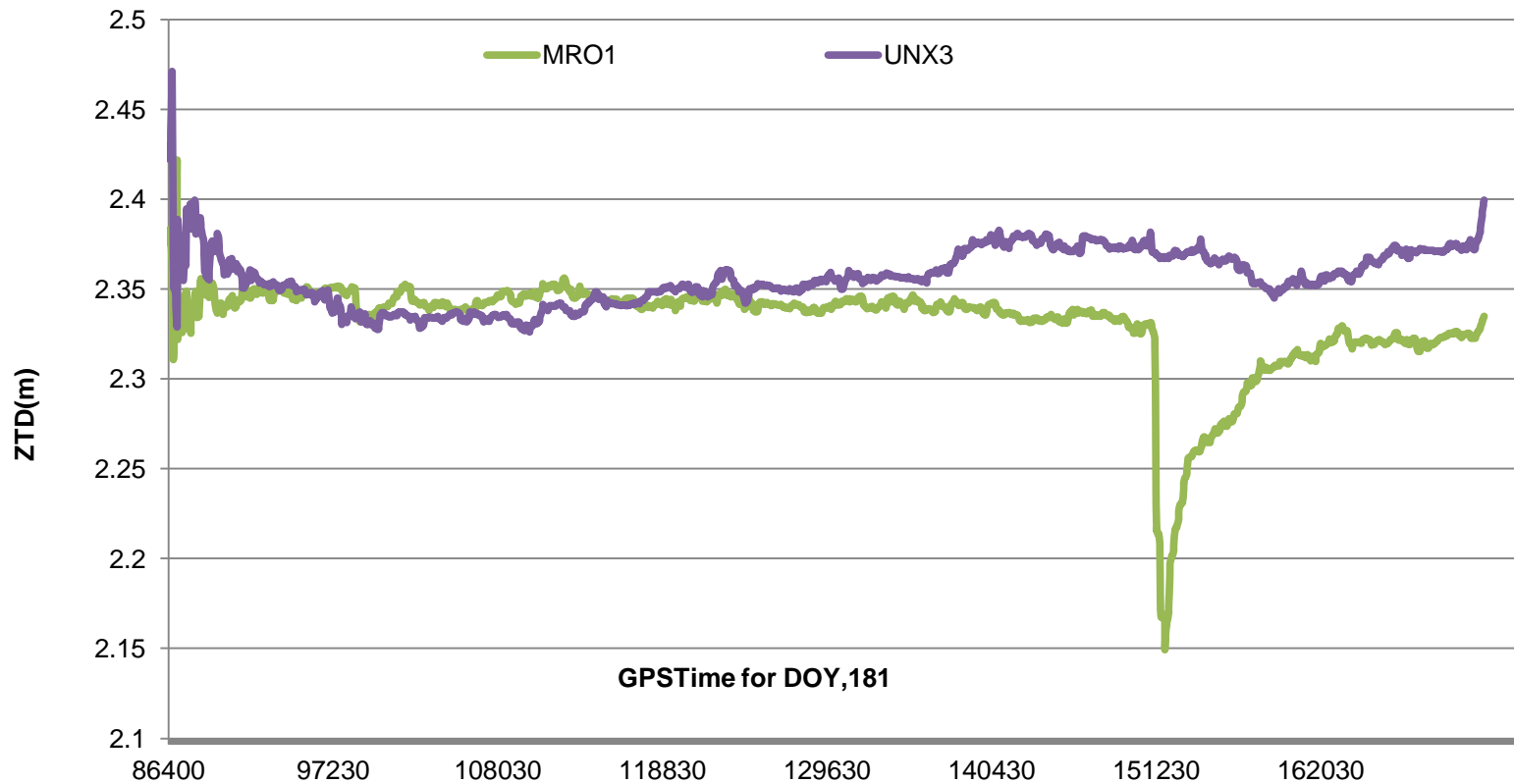
Multi-GNSS processing has no significant impact on (GPS) Receiver Clock Offset solutions

Inter-System Biases

Clearly receiver HW dependent... for this dataset



Zenith Tropospheric Delay Estimates



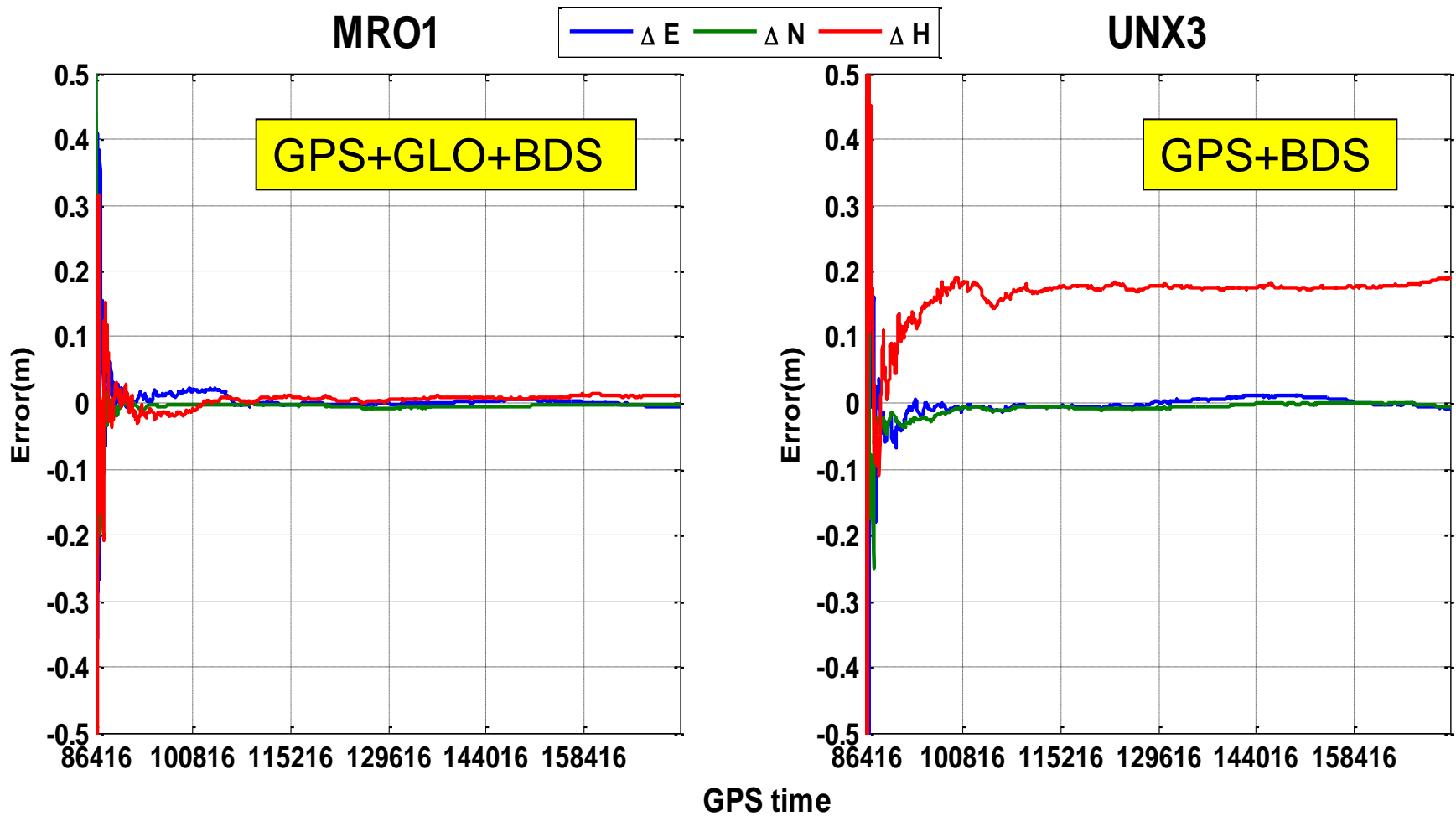
M-GNSS PPP Results...

Accuracy compared to AusPos solution

		GPS	GLO	BDS	GPS+GLO	GPS+BDS	GPS+GLO+BDS
MRO1	E	0.005 (0.009) (0.002)	-0.007 (0.014) (0.001)	0.018 (0.047) (0.002)	0.002 (0.007) (0.002)	0.004 (0.018) (0.002)	0.004 (0.008) (0.002)
	N	-0.002 (0.004) (0.001)	0.000 (0.007) (0.001)	-0.087 (0.093) (0.002)	-0.001 (0.003) (0.001)	-0.010 (0.010) (0.001)	-0.005 (0.006) (0.001)
	H	-0.004 (0.011) (0.118)	-0.003 (0.013) (0.044)	-0.300 (0.444) (0.351)	-0.003 (0.010) (0.112)	-0.013 (0.019) (0.073)	-0.003 (0.014) (0.070)
	2D	0.006 (0.010) (0.003)	0.011 (0.015) (0.002)	0.097 (0.105) (0.002)	0.006 (0.008) (0.002)	0.018 (0.021) (0.002)	0.009 (0.010) (0.002)
UNX3	E	-0.007 (0.016) (0.002)		-0.038 (0.085) (0.001)		-0.003 (0.011) (0.001)	
	N	-0.005 (0.008) (0.001)		-0.010 (0.035) (0.003)		-0.007 (0.011) (0.001)	
	H	0.161 (0.163) (0.113)		0.366 (0.421) (0.342)		0.169 (0.170) (0.094)	
	2D	0.012 (0.017) (0.002)		0.071 (0.092) (0.004)		0.011 (0.015) (0.002)	

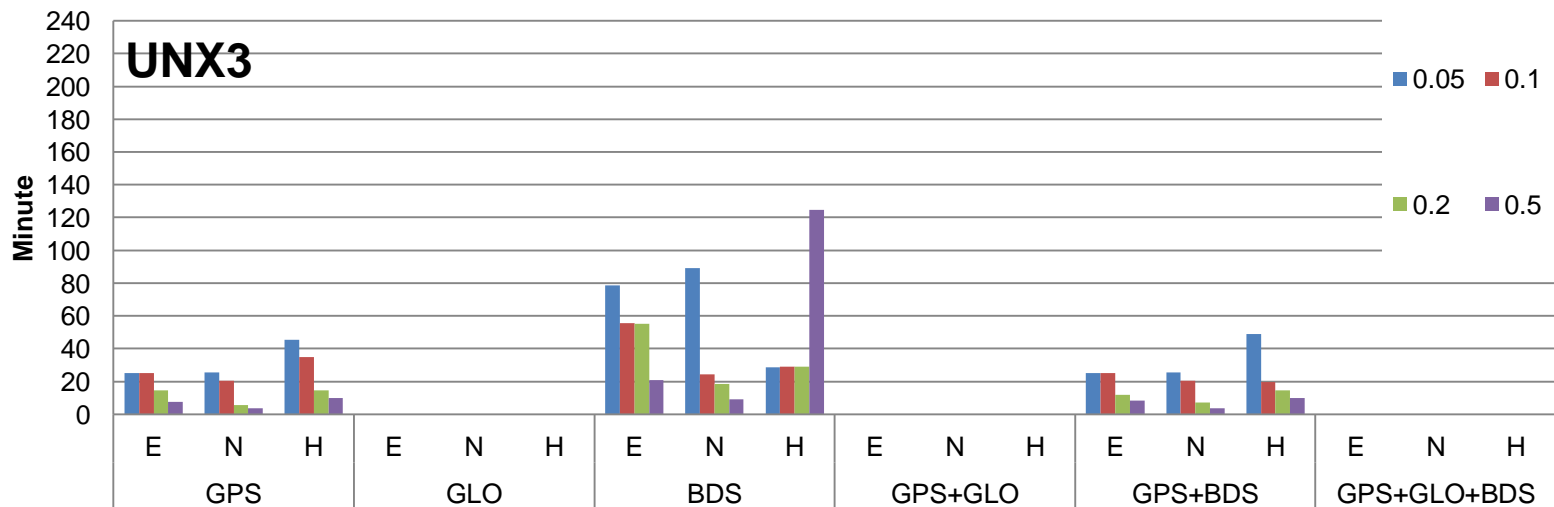
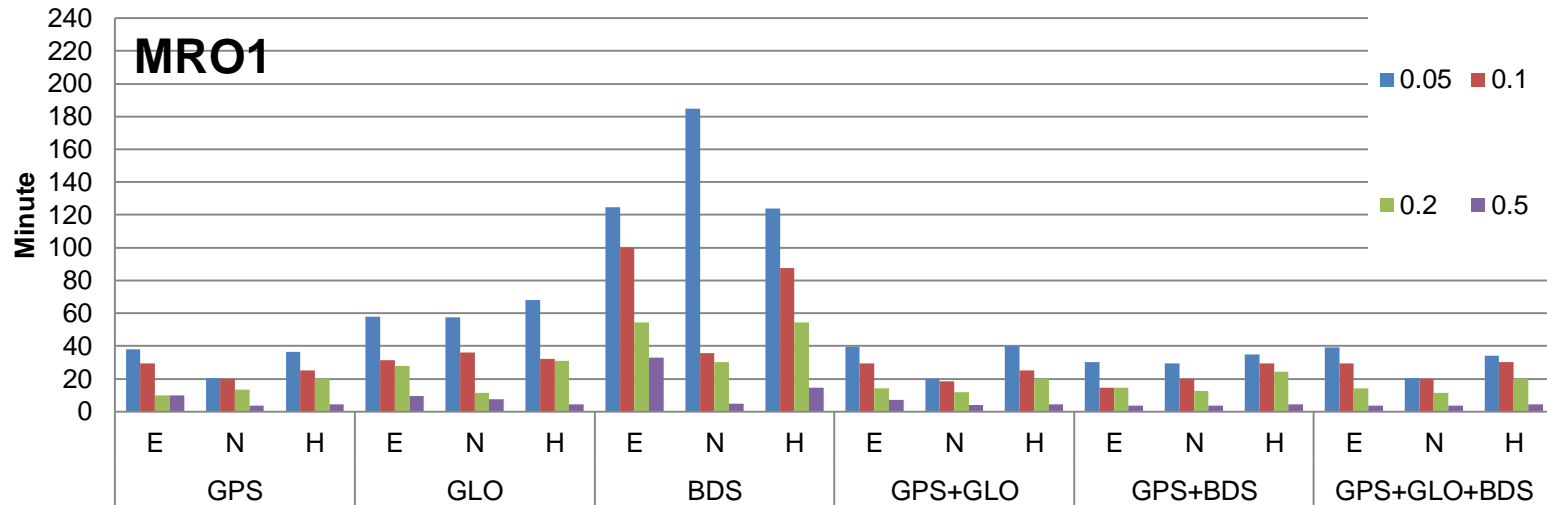
Row 1: mean
Row 2: RMS
Row 3: Std Dev

PPP Results... *issue of convergence*



PPP Filter/Ambiguity Convergence...

Time taken to reach 5cm, 10cm, 20cm, 50cm accuracy



Concluding Remarks

- Kalman filter was implemented for multi-GNSS PPP solutions (GPS, BDS and GLO), in which ZTD and ISB were also estimated.
- Mathematical model & software was tested using 24 hours static data from two IGS stations
- Sub-decimetre-level accuracy can be achieved within a convergence time of about 40 minutes
- Future work includes implementation of an adaptive robust Kalman filter, which is expected to improve accuracy and reduce convergence time using knowledge of measurement residuals