Precise Point Positioning from Combined GPS, GLONASS & BeiDou

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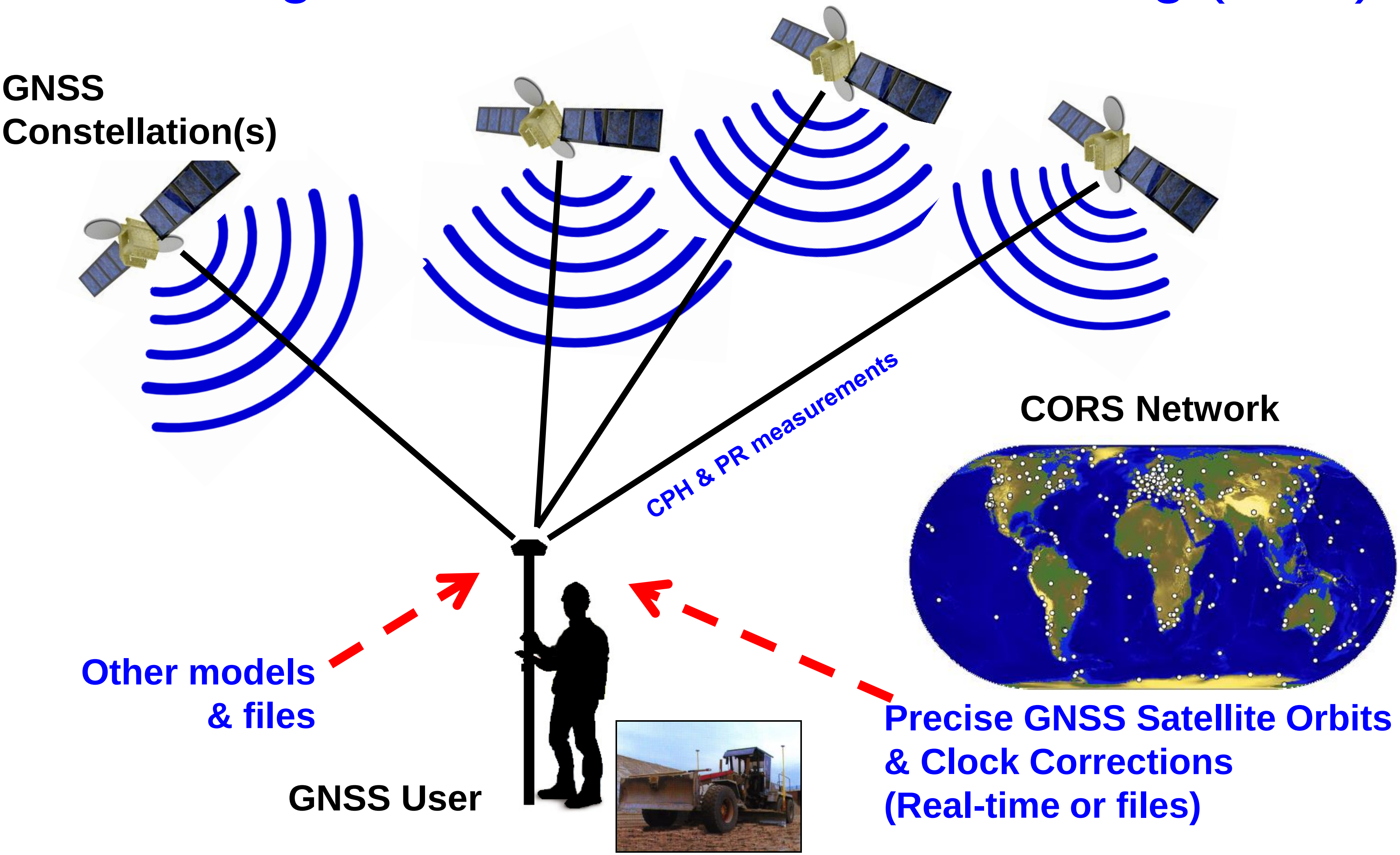
Challenges of Precise Point Positioning (PPP)



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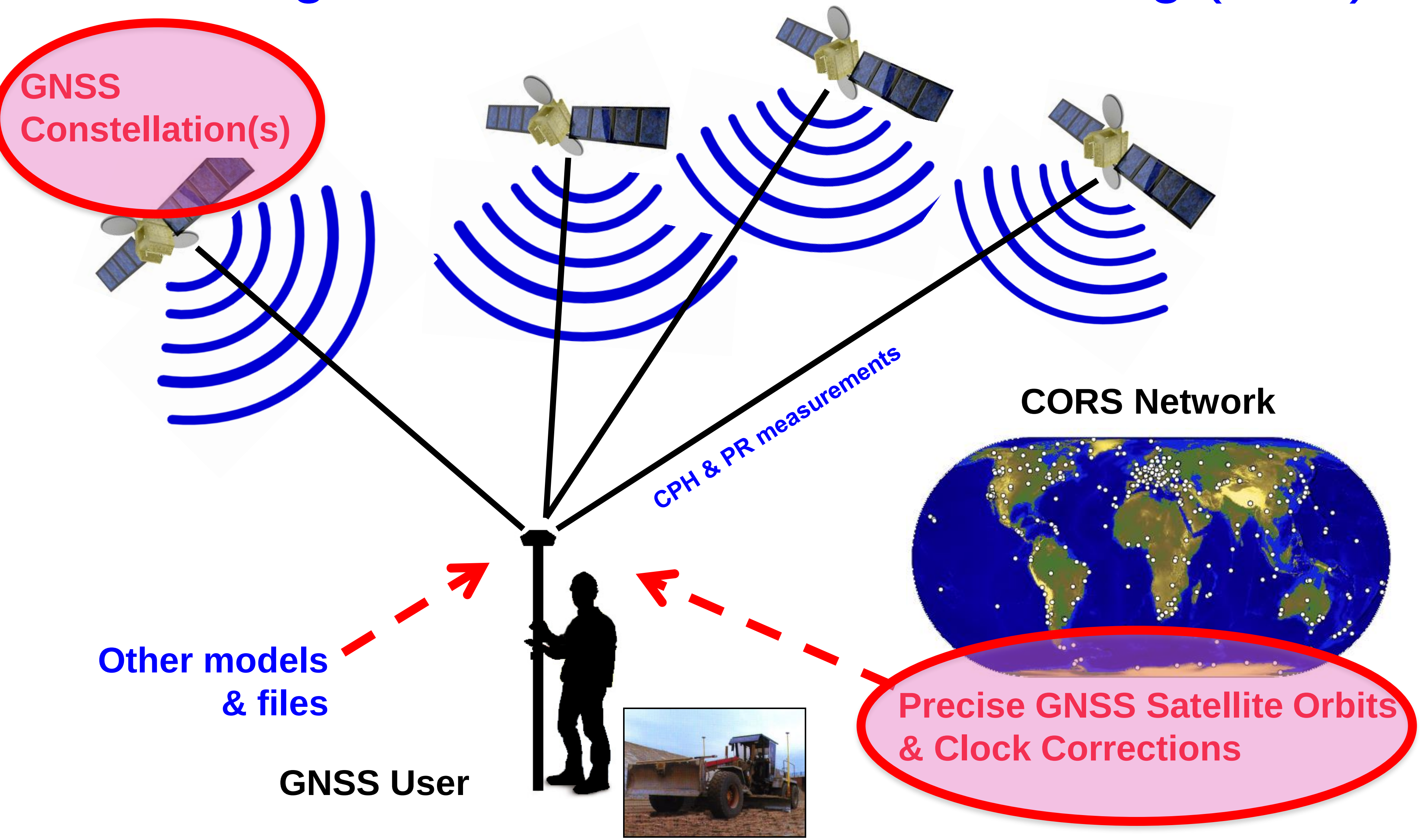
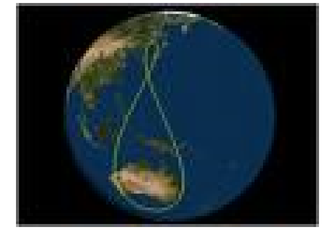
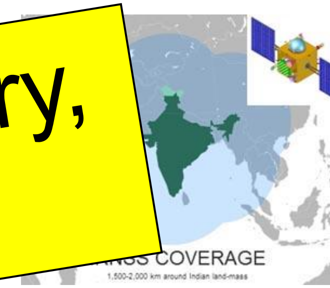


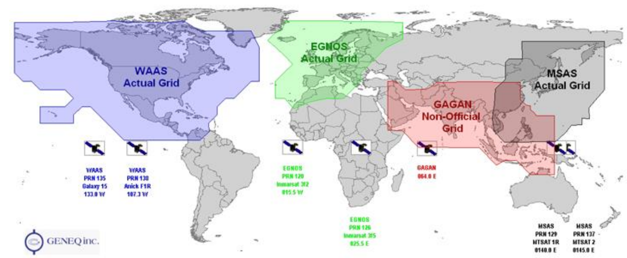
From GPS to Multi-GNSS...

\+ 



More satellites improves geometry, redundancy, precision...

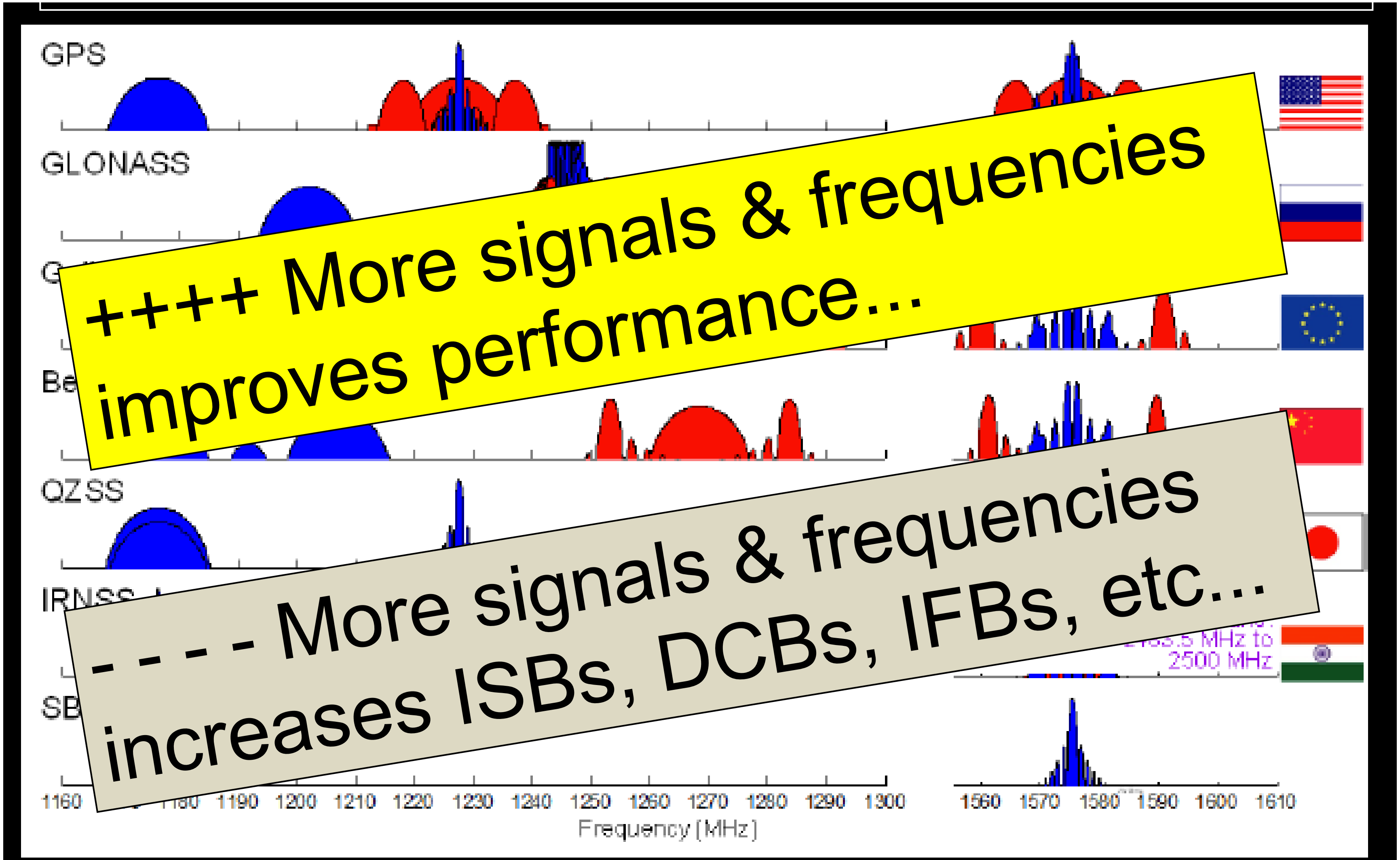
- GNSS:
  - GPS (
  - BeiDou (13-14) *(35)*
- SBAS:
  - EGNOS
  - GAGAN
  - SDCM



- RNSS:
  - QZSS (1) *(5-7)*
  - IRNSS (4) *(7)*

Number of satellites: (Current) *(Planned)*

More Signals, More Frequencies...



++++ More signals & frequencies improves performance...

- - - - More signals & frequencies increases ISBs, DCBs, IFBs, etc...

Courtesy: John Betz, MITRE

IGS Multi-GNSS Experiment

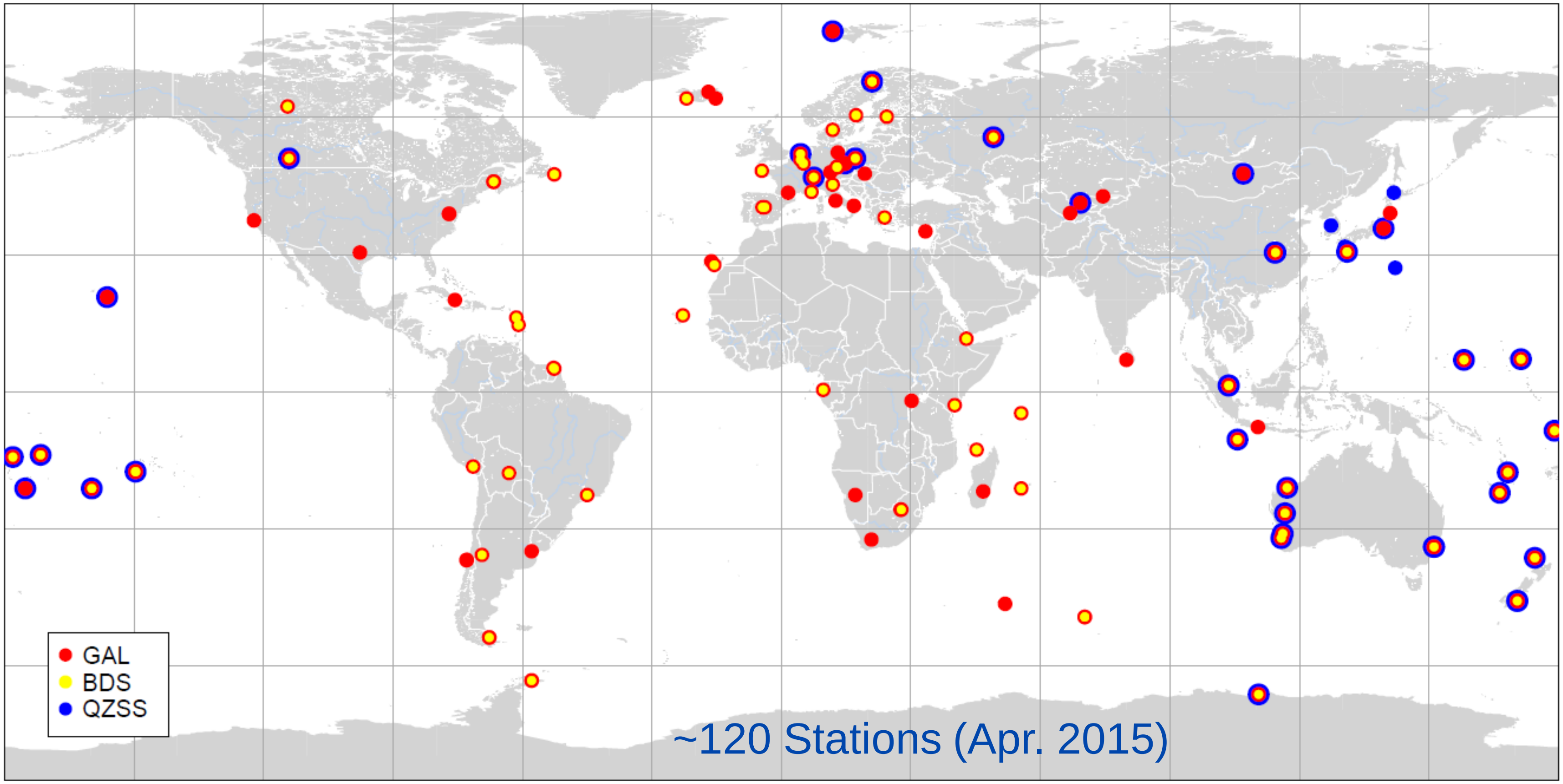
IGS

- 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

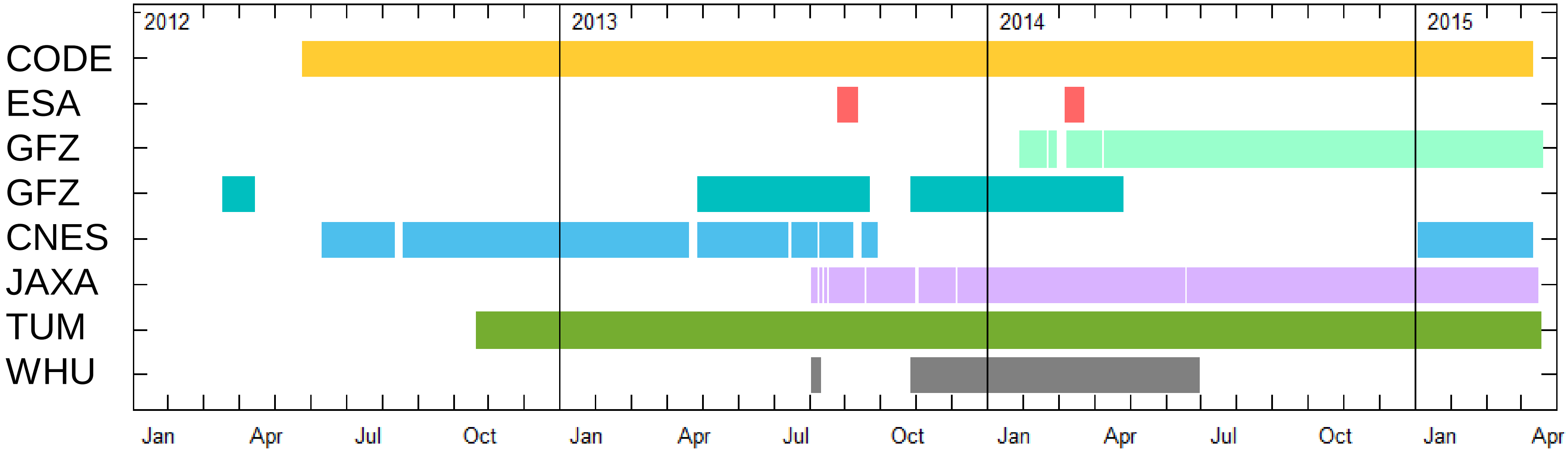


Offline : ftp://cddis.gsfc.nasa.gov/pub/gps/data/campaign/mgex/
Real-time: http://mgex.igs-ip.net/

IGS MGEX Test Products

IGS

- 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



Status: April 2015

Background to M-GNSS PPP

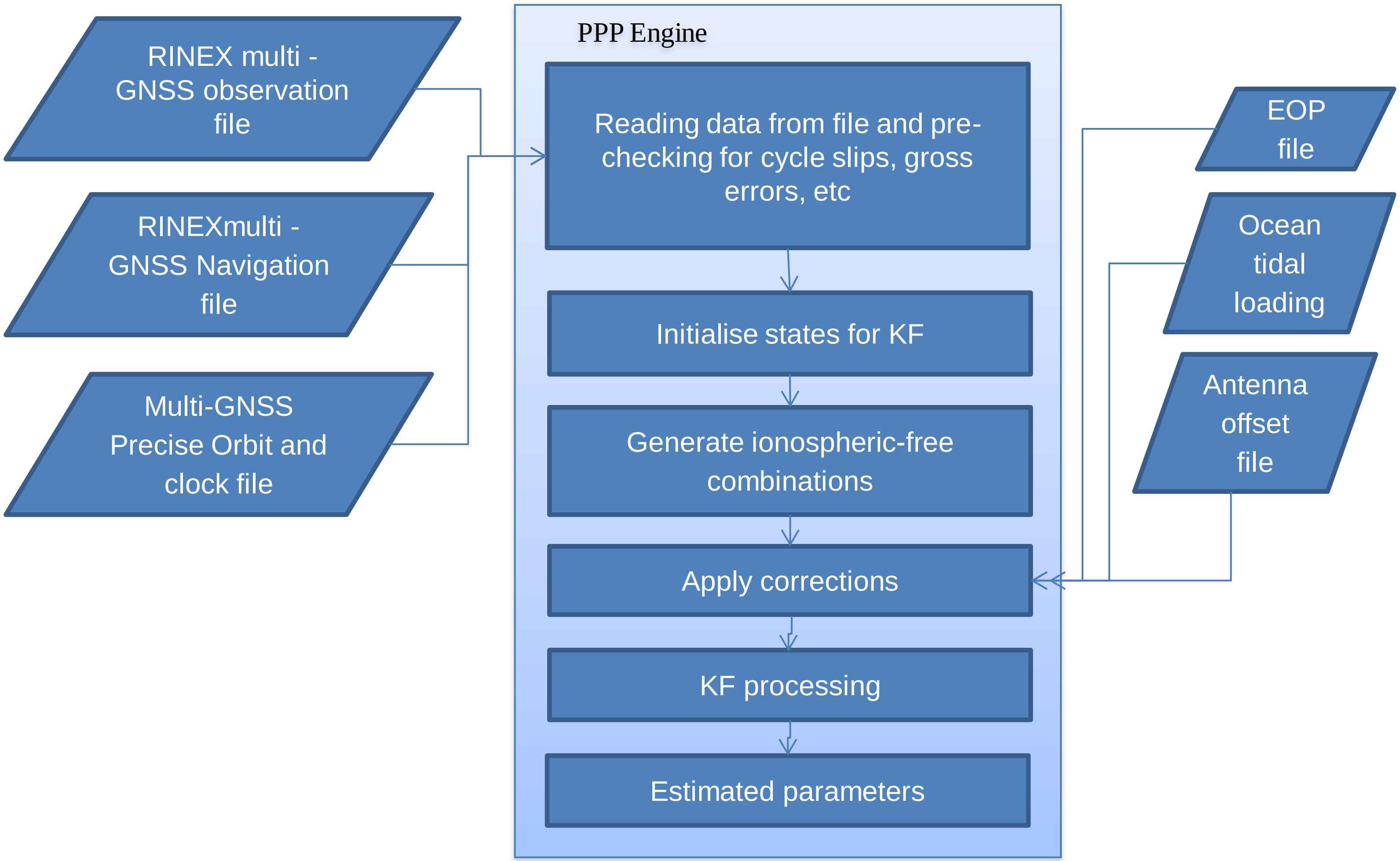
Previous work

- 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...

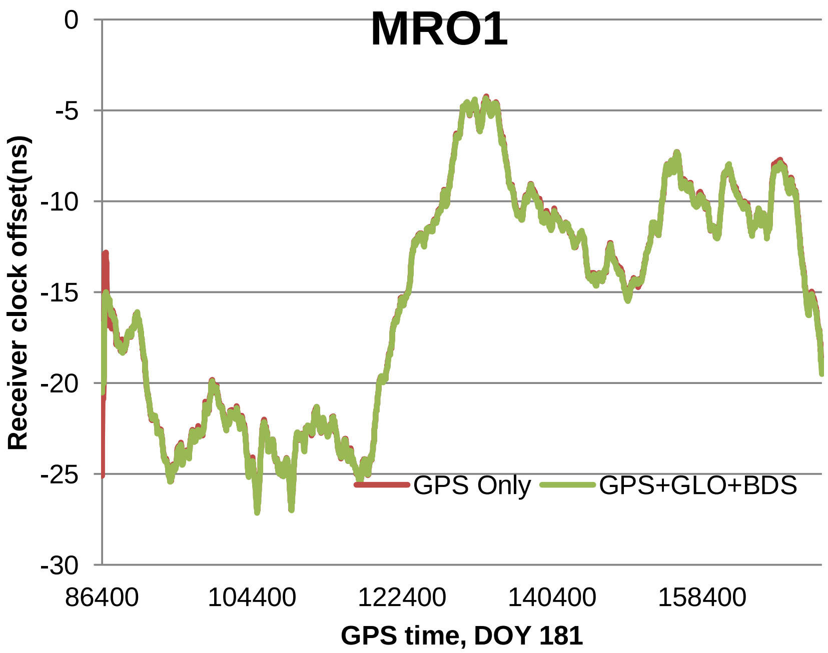


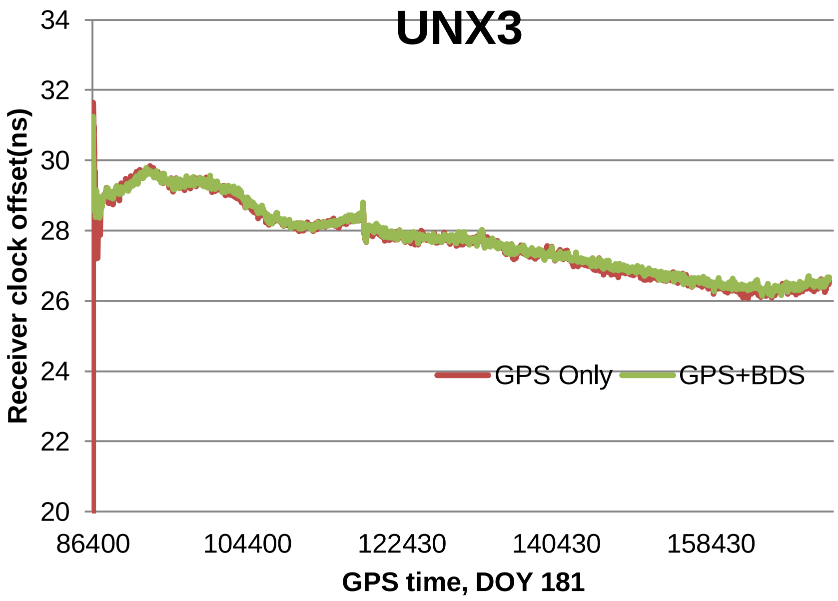
Data Source

- 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

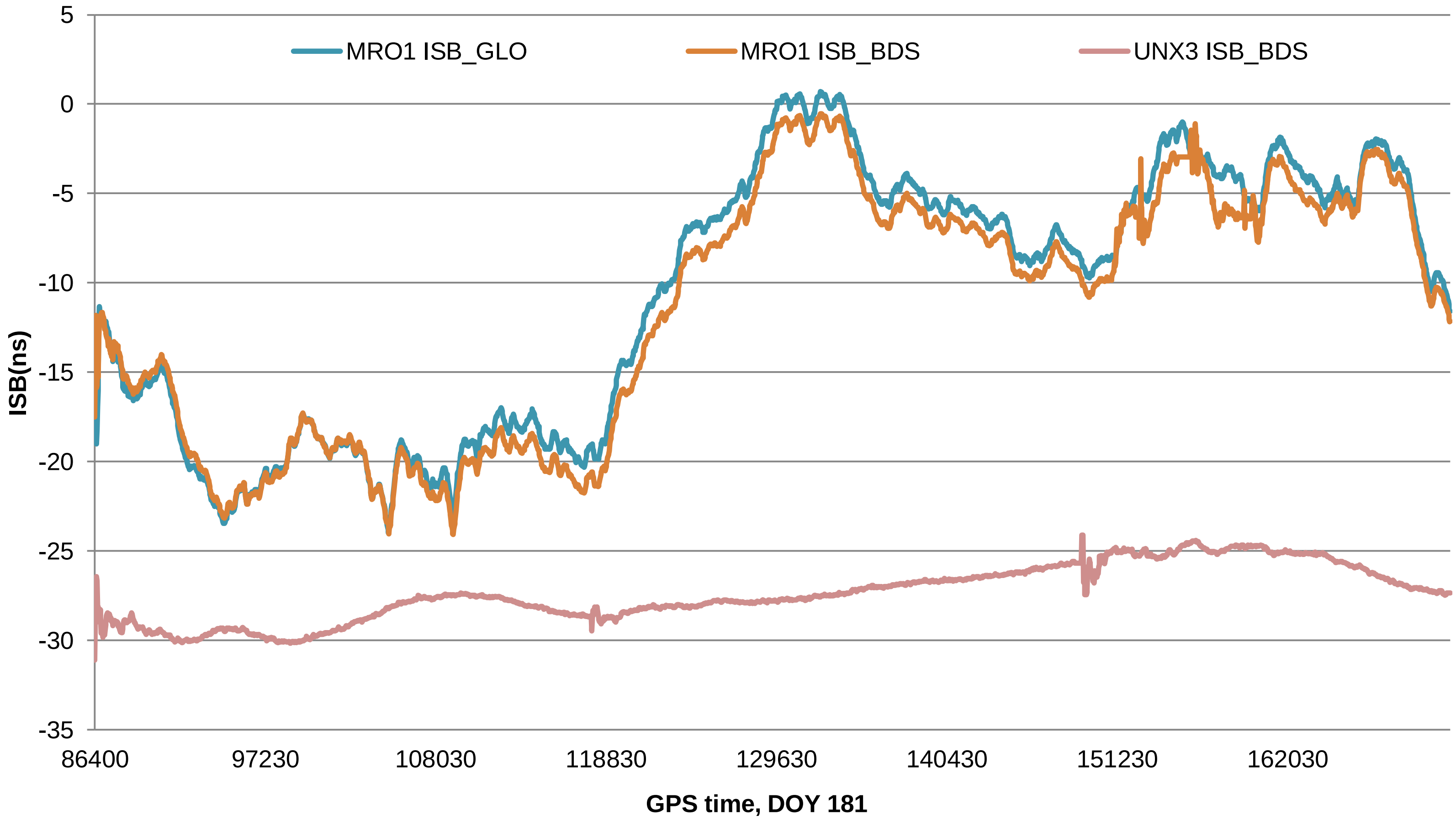




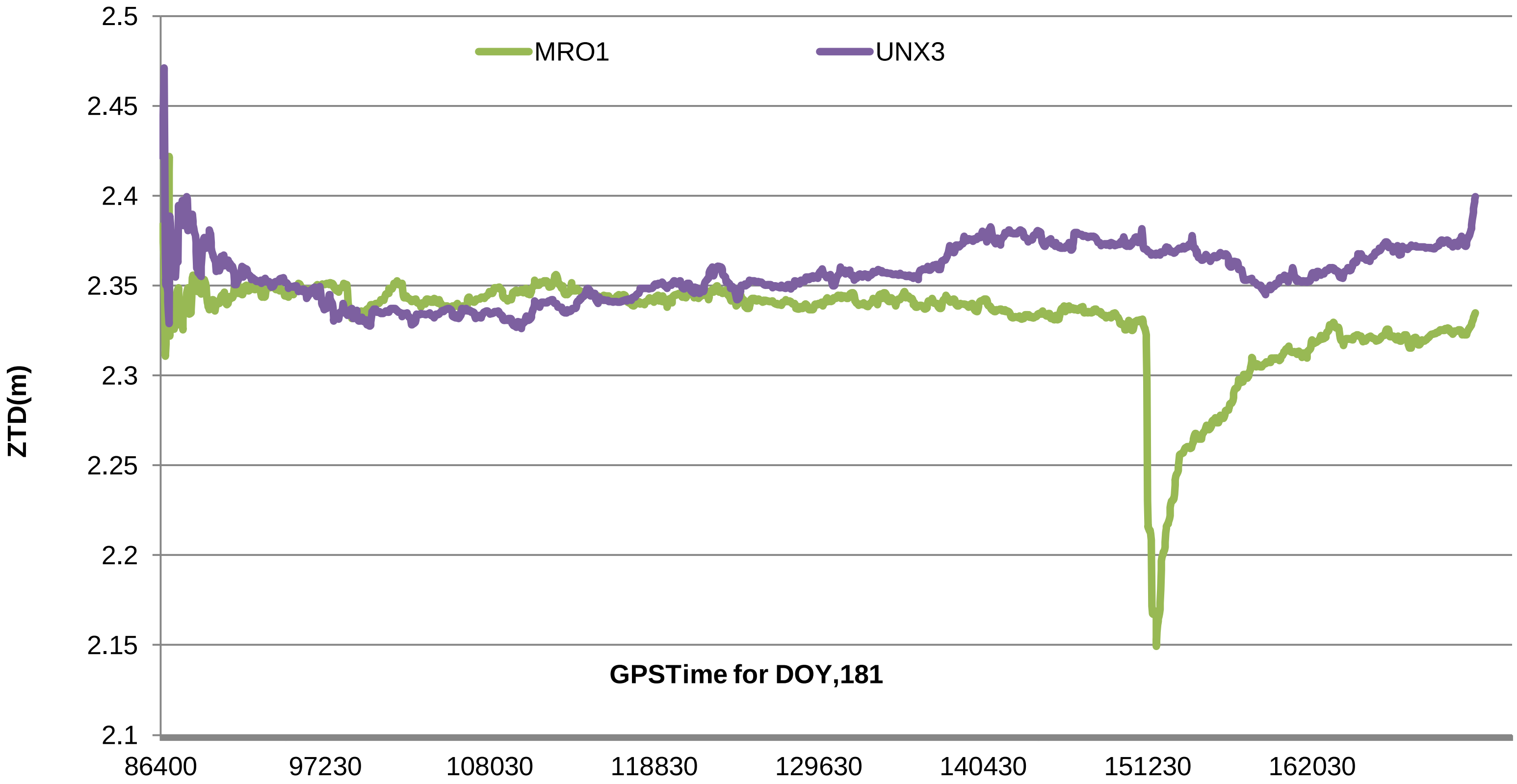
Multi-GNSS processing has no significant impact on (GPS) Receiver Clock Offset solutions

Inter-System Biases

Clearly receiver HW dependent... for this dataset



Zenith Tropospheric Delay Estimates



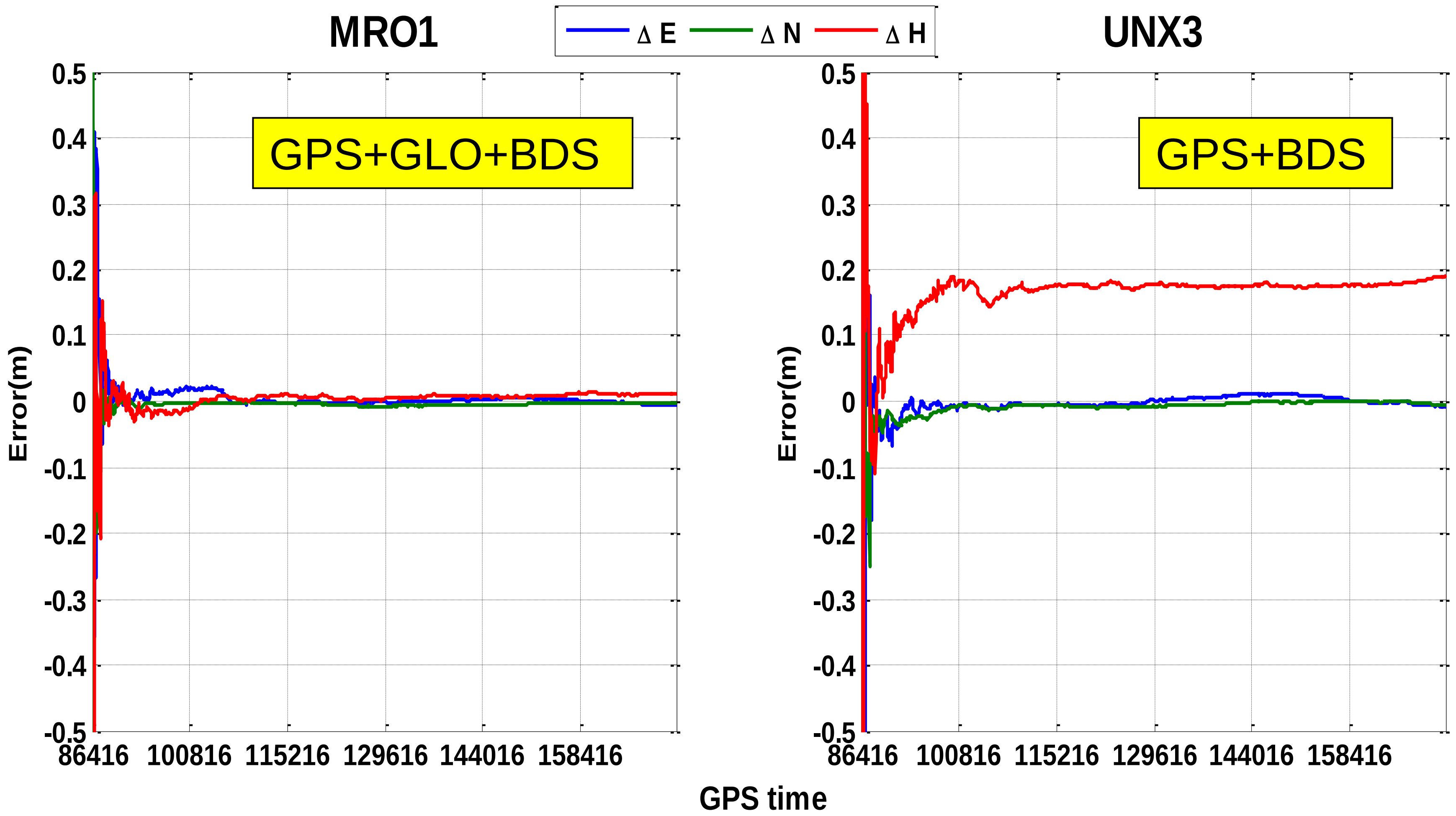
M-GNSS PPP Results...

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)	

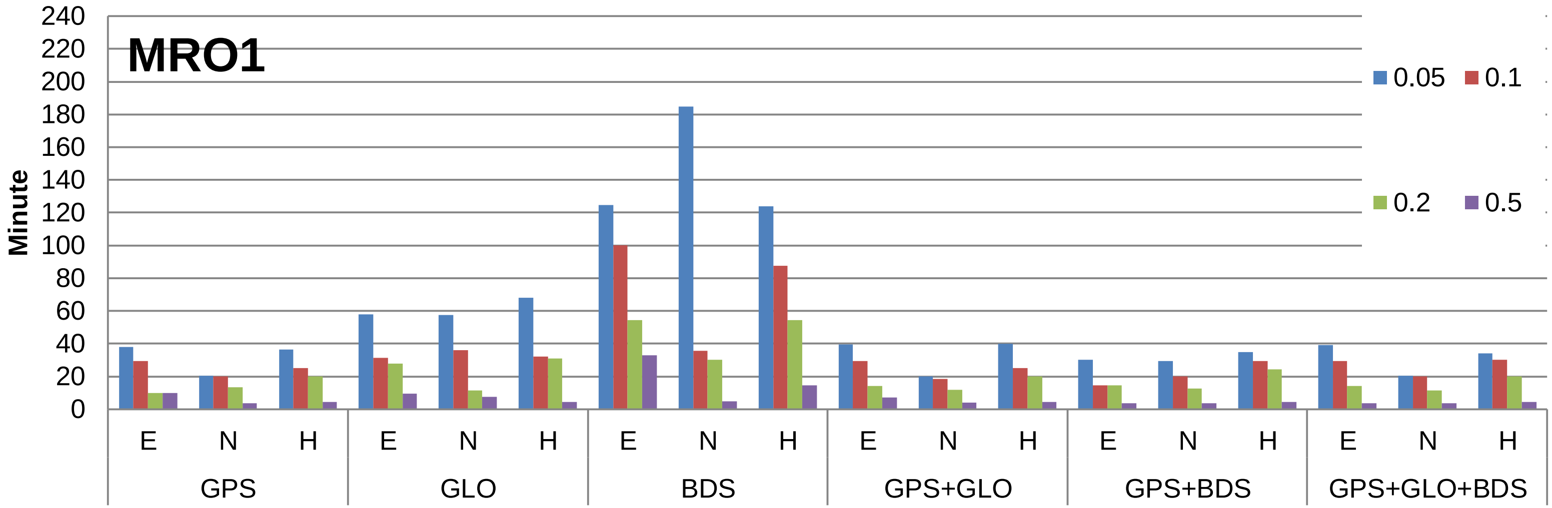
Row 1: mean
Row 2: RMS
Row 3: Std Dev

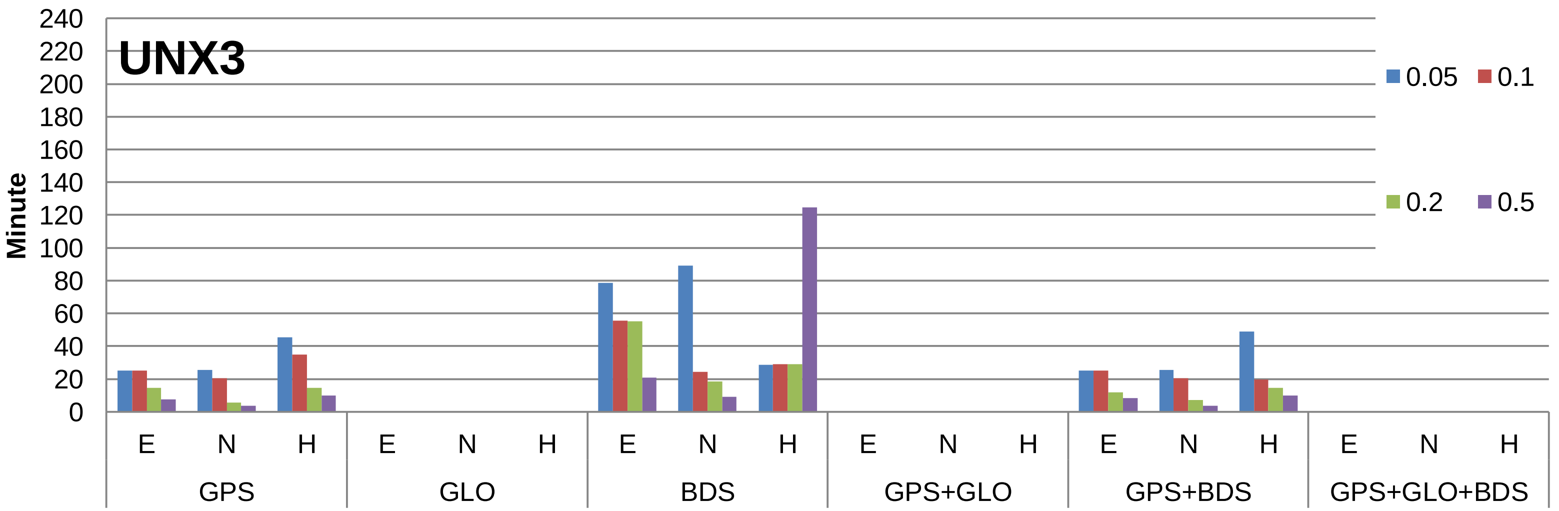
PPP Results... *issue of convergence*



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