Curtin University

Analysis of Differential ISBs (DISBs) for New GNSS Signals/Satellites

Dennis Odijk, **Nandakumaran Nadarajah, Safoora Zaminpardaz**

and Peter J.G. Teunissen

GNSS Research Centre, Department of Spatial Sciences

Curtin University, Perth, Australia

IGS Workshop,
8-12 February 2016, Sydney, NSW, Australia

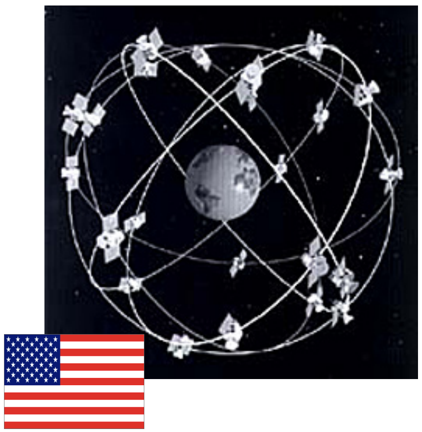
Outline

- Multi-GNSS Constellations and Their Frequency Bands
- Review of Differential Inter-System Bias (DISB) Estimation and Application
- Results of DISB Estimation for New Signals/Satellites: IRNSS with Respect to GPS, Galileo and QZSS
- Example: DISB-corrected GPS+Galileo+QZSS+IRNSS Ambiguity Resolution and Positioning
- Conclusions

Multi-GNSS Constellations and Their Frequency Bands

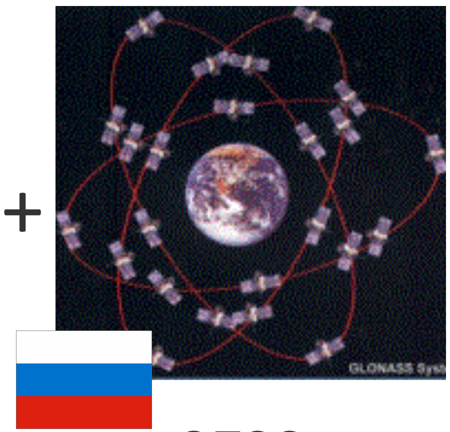
Global and Regional Navigation Satellite Systems in Progress…

GPS



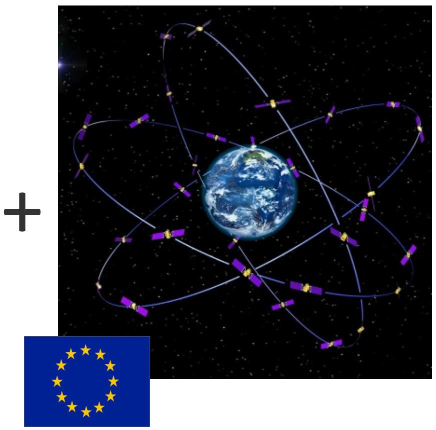
\+

GLONASS



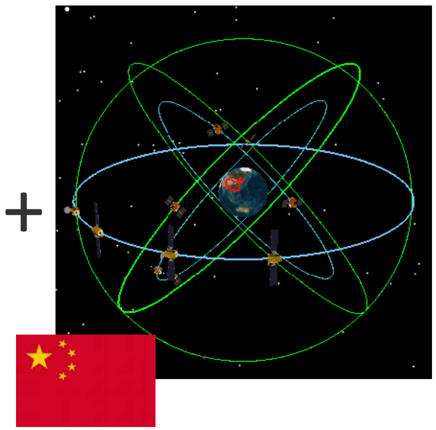
\+

GALILEO



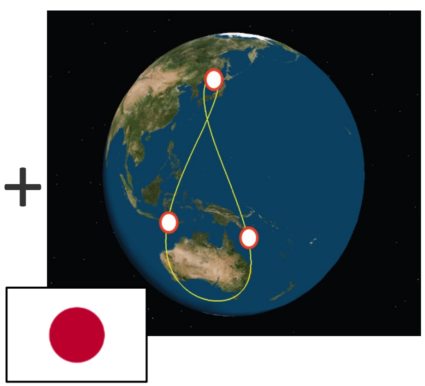
\+

BDS



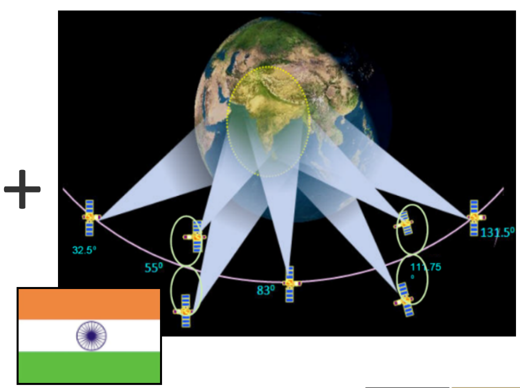
\+

QZSS



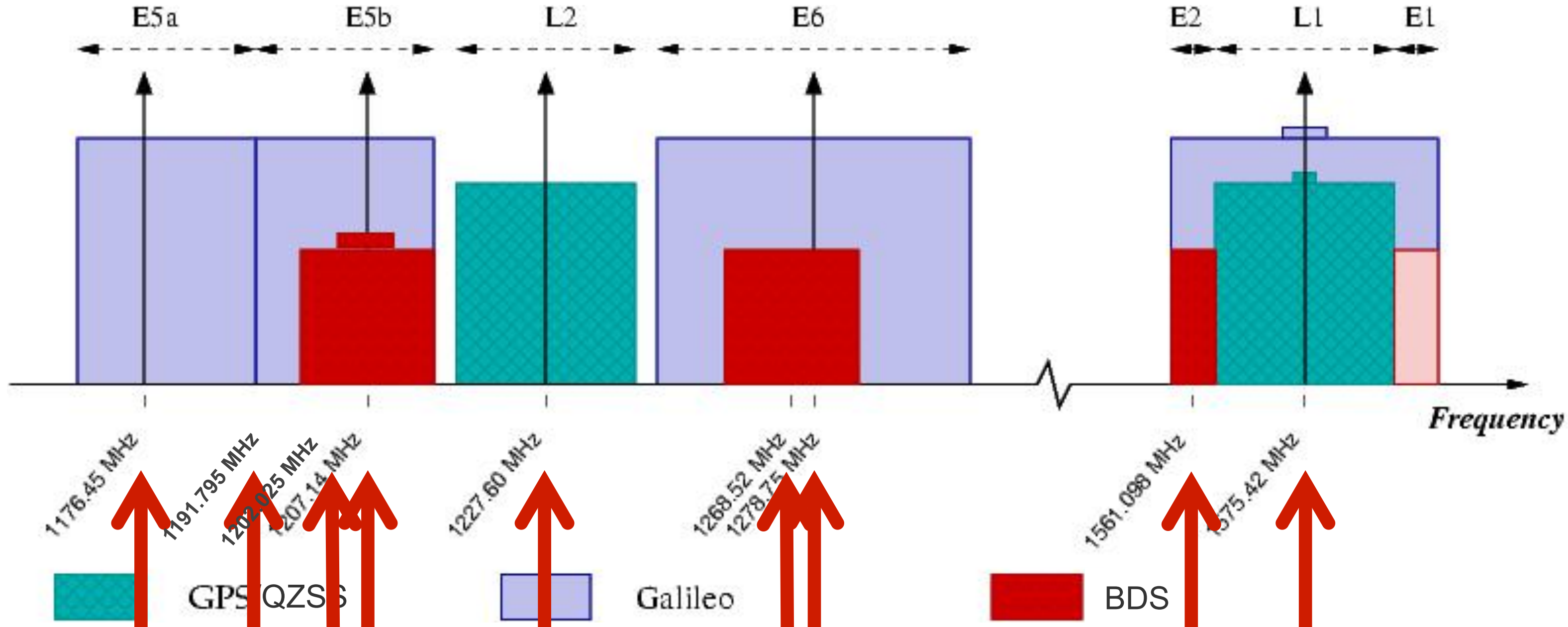
\+

IRNSS



Curtin University

GNSS Frequency Bands (CDMA Signals)



GPS L5
Galileo E5a
QZSS L5
IRNSS L5

Galileo E5

Galileo E5b
BDS B2

GPS L2
QZSS L2

GLONASS L3

Ga o E6
QZS LEX

BDS B3

E

GPS L1
Galileo E1
QZSS L1
(BDS B1 – new satellites)

Review of Differential Inter-System Bias (DISB) Estimation and Application

Definition of Inter-System Bias (ISB)

- **ISB** = difference between **receiver hardware biases** of signals of **different constellations**, since

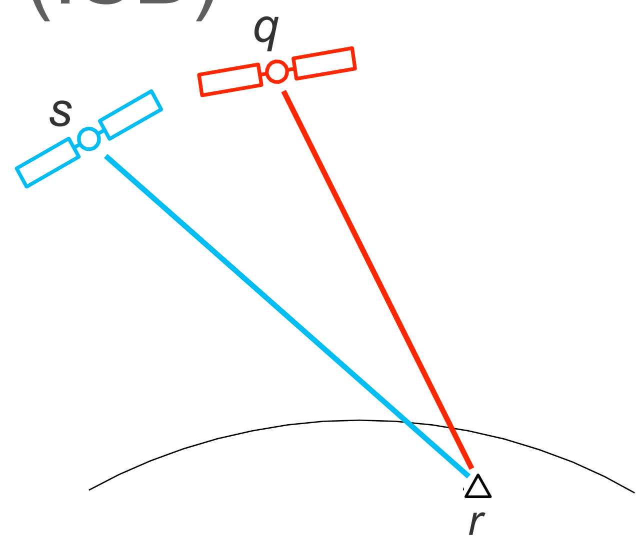
$$d_{r,j}^{A} \neq d_{r,j}^{B}$$

- **Absolute ISBs** (CDMA signals):

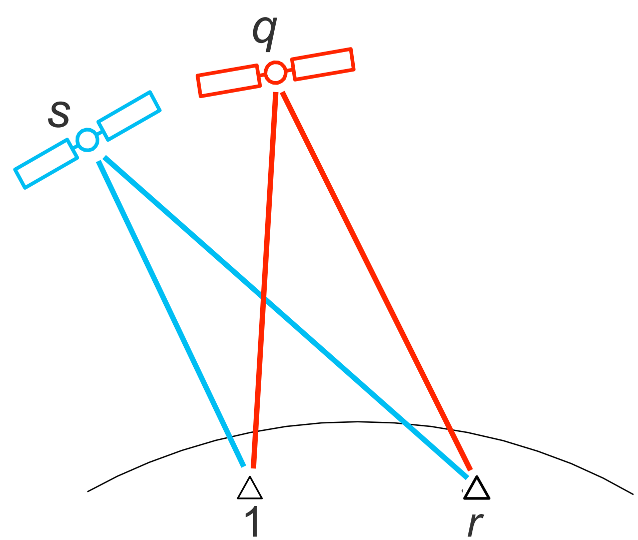
$$d_{r,j}^{AB} = d_{r,j}^{B} - d_{r,j}^{A} - c\,t^{AB}$$

↑ system time offset

- **Differential ISBs (DISBs)** are relevant for multi-GNSS differential (RTK) positioning:
  - for code: $d_{1r,j}^{AB} = (d_{r,j}^{B} - d_{r,j}^{A}) - (d_{1,j}^{B} - d_{1,j}^{A})$
  - for phase: $\delta_{1r,j}^{AB} = (\delta_{r,j}^{B} - \delta_{r,j}^{A}) - (\delta_{1,j}^{B} - \delta_{1,j}^{A})$

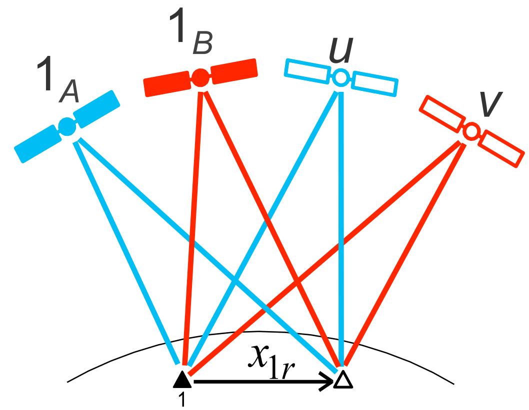


Constellation A & B



Curtin University

Review of DISB Estimation: Classical Differencing



Constellation A & B

- **Identical frequencies** between constellations
- **Classical double differencing** (pivot satellite per constellation):

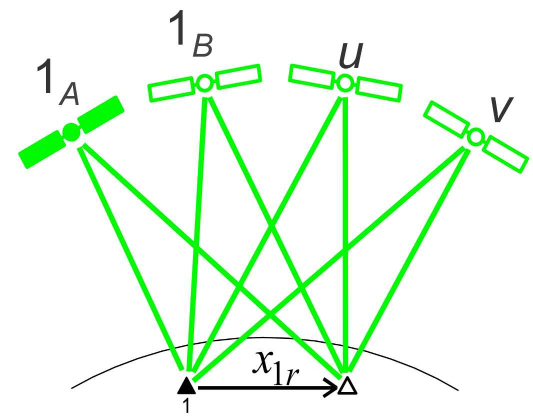
■E(ϕ↓j↑1↓A u)&=&ρ↓↑1↓A u &+λ↓j a↓j↑1↓A u &&@E(ϕ↓j↑1↓B v)&=&ρ↓↑1

$u=2_A,\cdots,m_A$

$v=2_B,\cdots,m_B$

- **Short baselines:** no differential atmospheric biases

Review of DISB Estimation: DISB-Float Model



- **Identical frequencies** between constellations
- **Inter-system double differencing** (common pivot satellite for all constellations):

$$E(\phi_j^{1_A u}) = \rho^{1_A u} + \lambda_j a_j^{1_A u}, \quad E(\phi_j^{1_A v}) = \rho^{1_A v} \ldots$$

"As if one constellation"

$u = 2_A, \cdots, m_A$

$v = 1_B, \cdots, m_B$

- **Estimable short-baseline DISB parameters:**

phase DISB: $\delta_j^{AB} = \delta_j^{AB} + a_j^{1_A 1_B}$ ⇦ biased by integer ambiguity

code DISB:

Application of DISBs: DISB-Fixed Model

- DISBs are **insignificant** for baselines of receivers of **same manufacturer** but **significant (though stable)** for receiver pairs of **different manufacturers**.

- **A priori knowledge of DISBs** → data of constellation B can be corrected

- **Inter-system double differencing** calibrated for DISBs:

■E(ϕ↓j↑1↓A u)&=&ρ↓1↓A u &+λ↓j a↓j↑1↓A u &[−μ↓j I↓1↓A u]@E(ϕ↓j↑1↓A v −λ

fractional phase DISB:

Δδ↓j↑AB =δ ↓j↑AB −a ↓j↑1

estimable ambiguity of B:

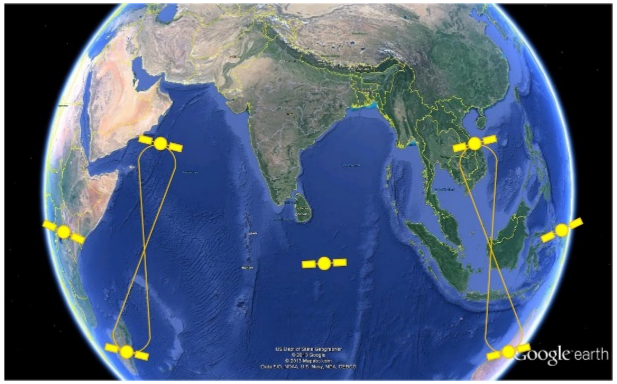
a ↓j↑1↓A v =a↓j↑1↓B v +a

→ *Model is valid for both **short** baselines and **long** baselines*

Results of DISB Estimation for New Signals/ Satellites: IRNSS with Respect to GPS, Galileo and QZSS

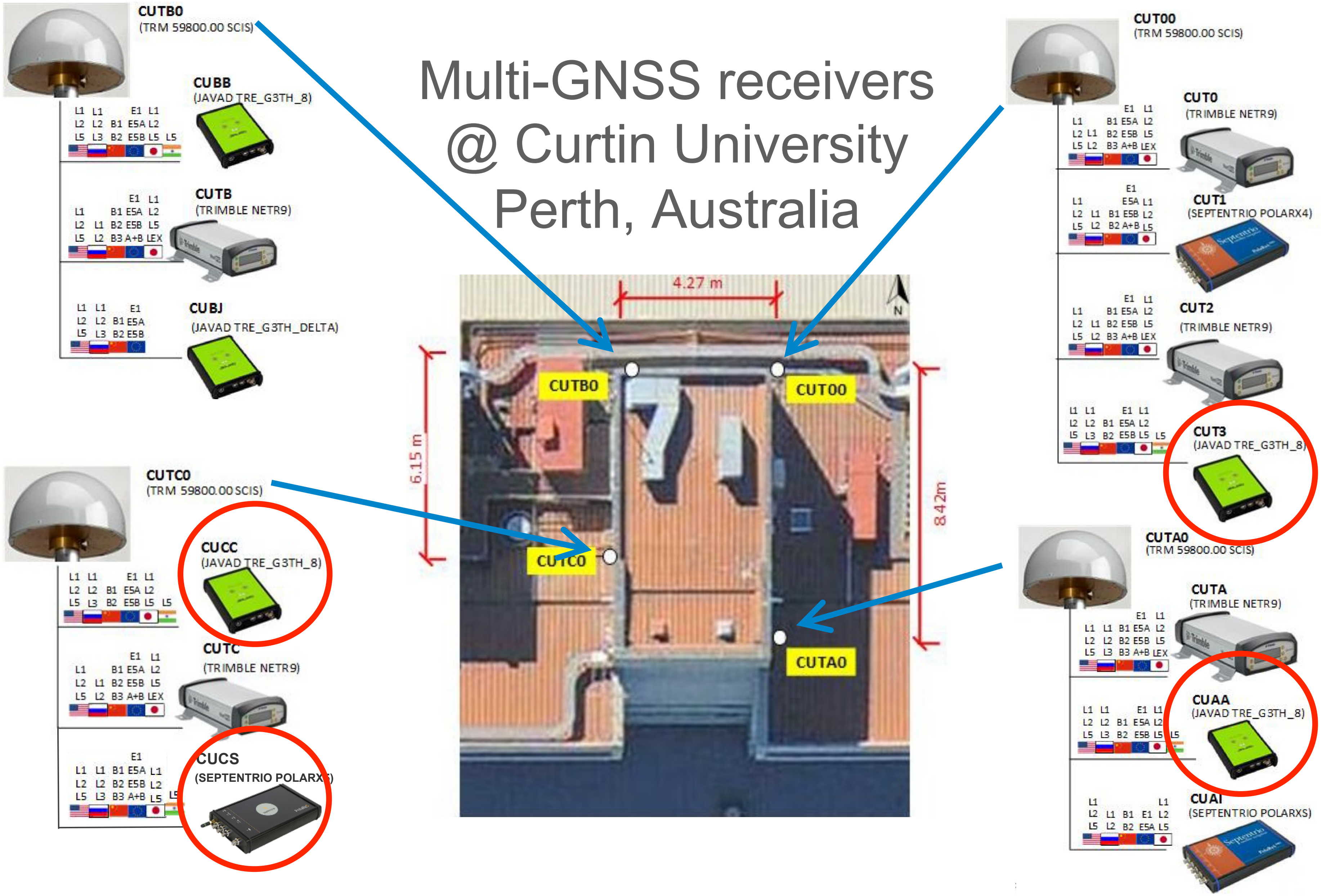
Indian Regional Navigation Satellite System (IRNSS)

- Offering positioning service **in/around India**



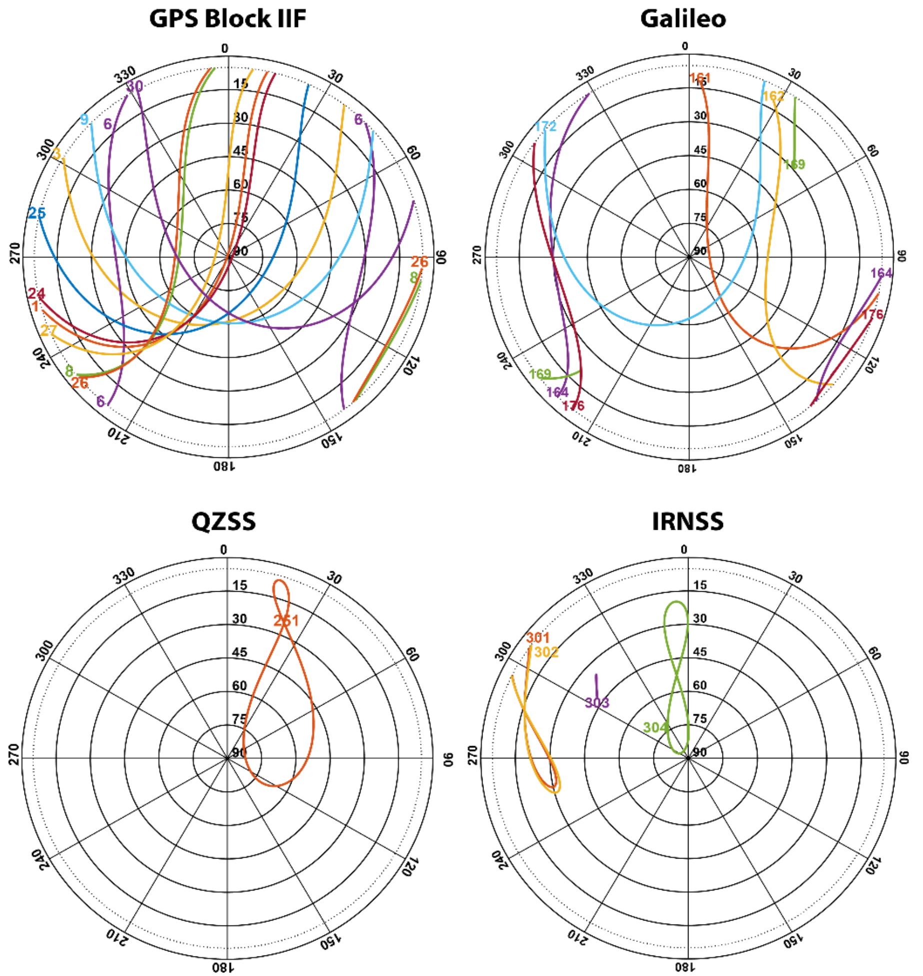
- IRNSS constellation will consist of:
  - **3 GEO satellites**
  - **4 IGSO satellites**
- Satellites **launched 2013 – 2016** (last two satellites to be launched in March 2016)
- IRNSS signals (Open Service):
  - **L5 band** (1176.45 MHz)
  - **S band** (2492.028) MHz

Multi-GNSS receivers @ Curtin University Perth, Australia

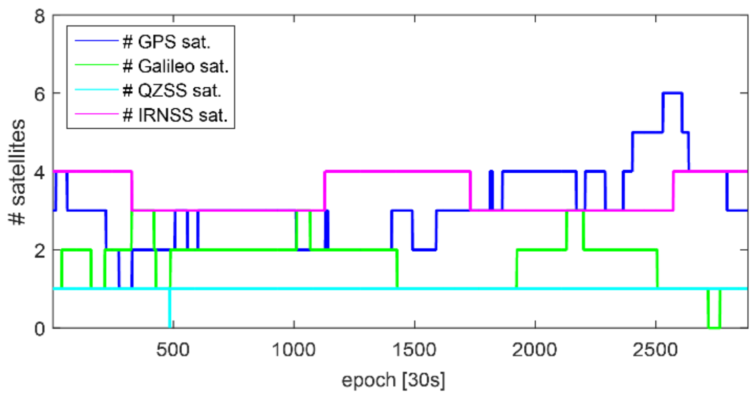


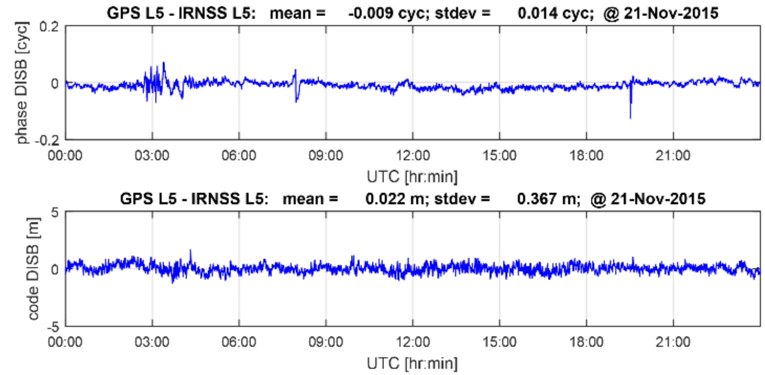
DISB estimation for IRNSS (L5) relative to GPS (L5), Galileo (E5a) and QZSS (L5)

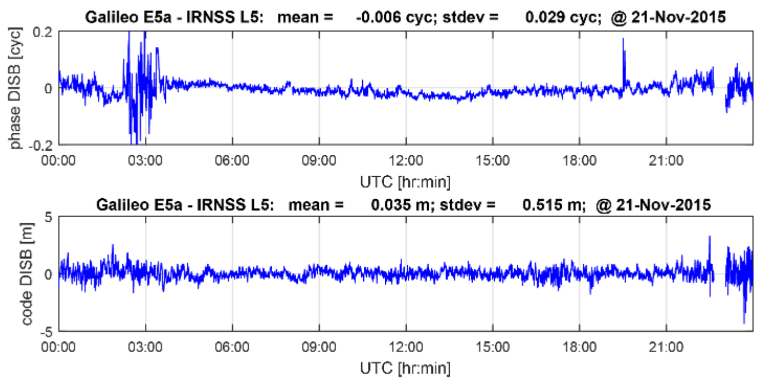
- **Ultrashort (~8 m) baseline** CUT3 (Javad) – CUAA (Javad), measured 21/11/2015
- **Zero baseline** CUCC (Javad) – CUCS (Septentrio), measured 17/01/2016
- Sky plots for 21/11/2015 and cut-off elevation of 5 degrees
- Galileo E20 not used as E5a is not transmitted

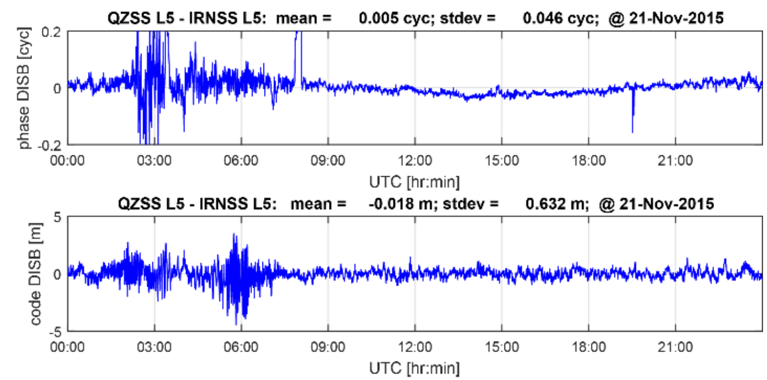


Estimated DISBs for 8-m baseline CUT3-CUAA (Javad – Javad; 21/11/2015)





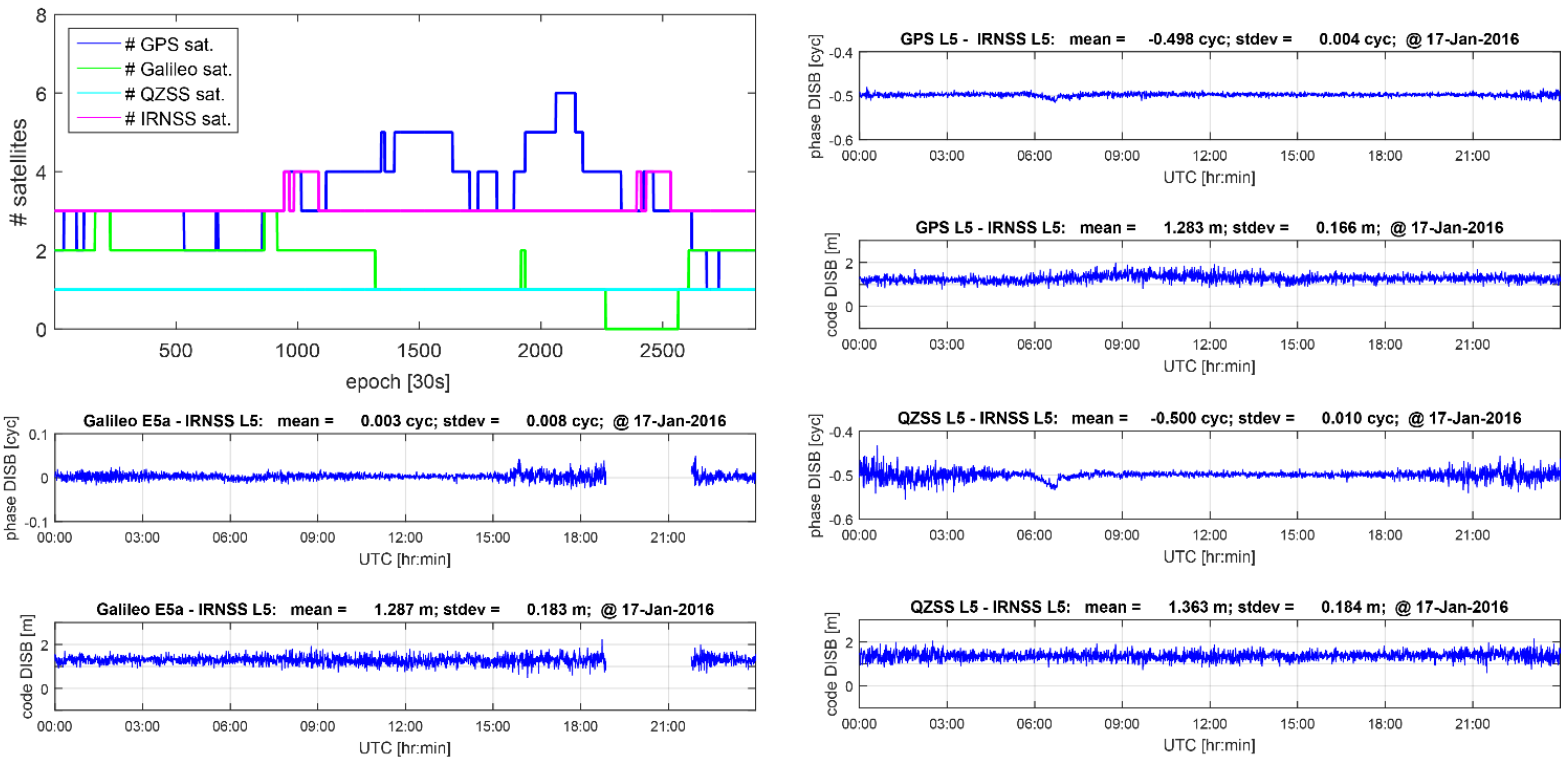




Identical receiver types (Javad-Javad):

$$\delta_j^{GI}=0,\ d_j^{GI}=0; \quad \delta_j^{EI}=0,\ d_j^{EI}=0; \quad \delta_j^{JI}=0,\ d_j^{JI}=0$$

Estimated DISBs for zero baseline CUCC-CUCS (Javad – Septentrio; 17/01/2016)



Mixed receiver types (Javad-Septentrio):

$\delta_j^{GI}=0.5$ cyc, $d_j^{GI}=1.3$ m; $\delta_j^{EI}=0$ cyc, $d_j^{EI}=1.3$ m; $\delta_j^{JI}=0.5$ cyc, $d_j^{JI}=1.3$ m

Example:
DISB-Corrected GPS+Galileo+QZSS +IRNSS Ambiguity Resolution and Positioning

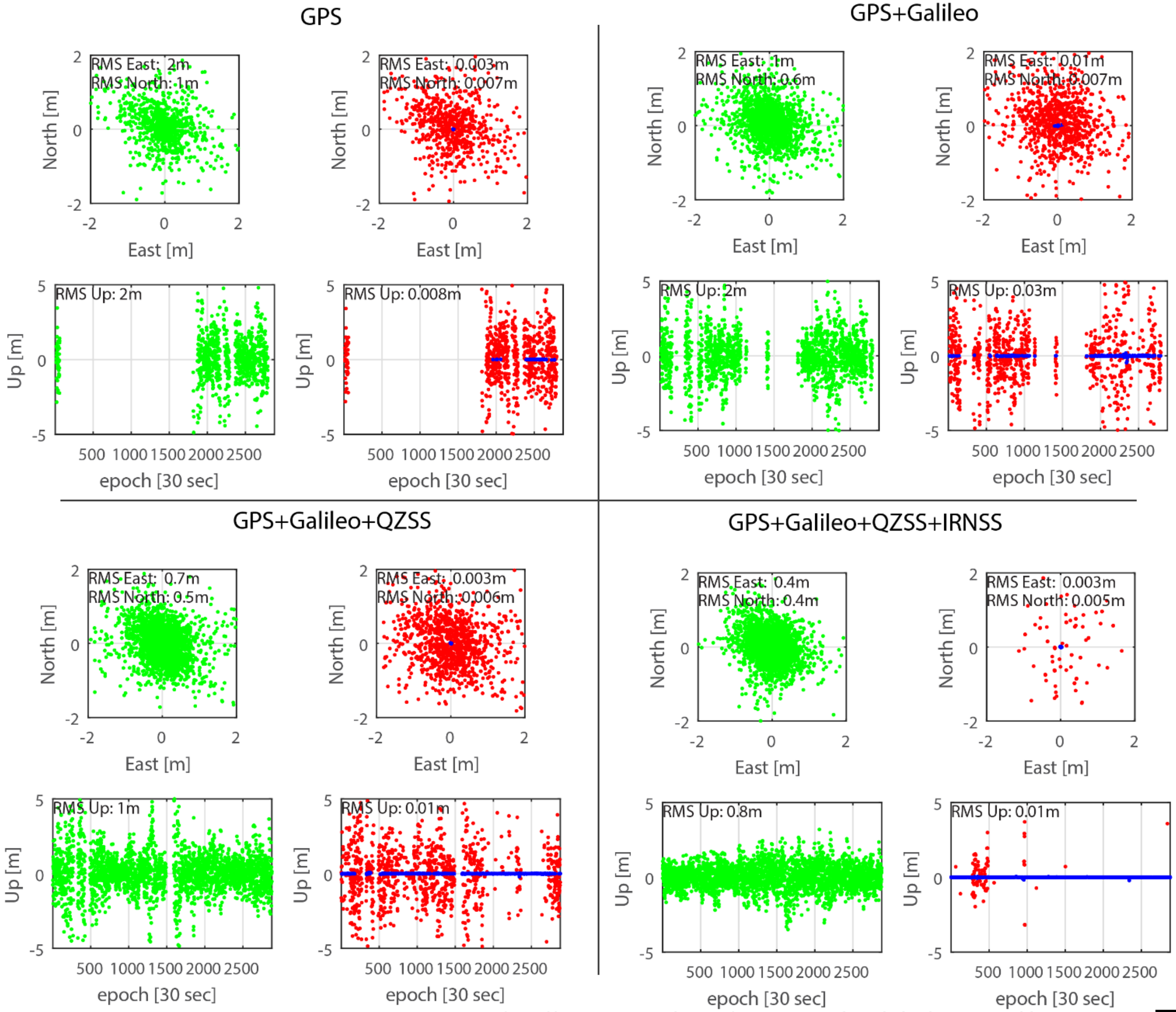
Classical vs. Inter-System Differencing: Performance of IAR

- Short (~350 m) baseline between CUAA (Javad) – SPA7 (Javad) @ Curtin; full day of 21/11/2015
- Single-frequency L5/E5a epoch-by-epoch integer ambiguity resolution:

	Classical differencing
G	82/2880 = 2.8%
GE	171/2880 = 5.9%
GEJ	171/2880 = 5.9%
GEJI	1284/2880 = 44.6%

	Inter-system differencing
G	82/2880 = 2.8%
GE	630/2880 = 21.9%
GEJ	1396/2880 = 48.5%
GEJI	2770/2880 = 96.2%

Inter-System Differencing: Positioning Results



Horizontal position scatter and Vertical position time series of **SPA7**

Green = **float** positions

Red = **fixed** positions based on **wrong** integers

Blue = **fixed** positions based on **correct** integers

Curtin University

Conclusions

Conclusions

- Recent launches of **new GNSS satellites** (GPS Block IIF, Galileo FOC, IRNSS) necessitates the **continuation of DISBs analyses**, benefitting **multi-GNSS RTK ambiguity resolution** and **positioning**

- **DISBs** have been estimated **for the first time** for **IRNSS**, for its L5 frequency identical to **GPS L5 (Block IIF), Galileo E5a** and **QZSS L5**:
  - DISBs are **zero** for baseline of **identical** receiver types
  - DISBs are **nonzero**, but **constant** for baseline of **mixed** receiver types

- Short-baseline **single-frequency, multi-GNSS RTK** results demonstrate:
  - That the performance of IAR improves tremendously when **DISB-based inter-system differencing** is applied instead of **classical differencing**
  - That the **fixed position** solutions are very precise, showing **no biases**

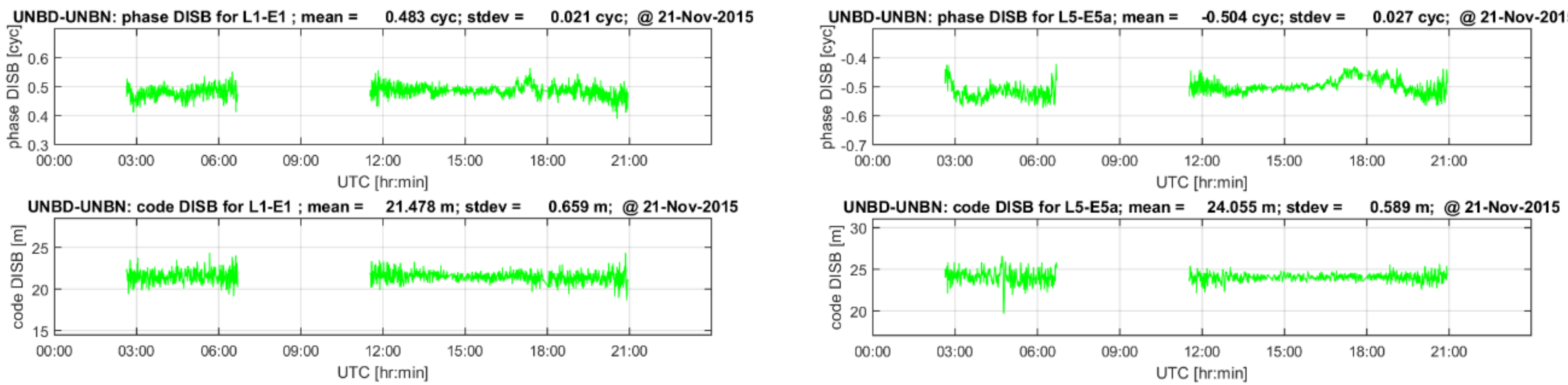
Thank you! Questions?

Acknowledgments:

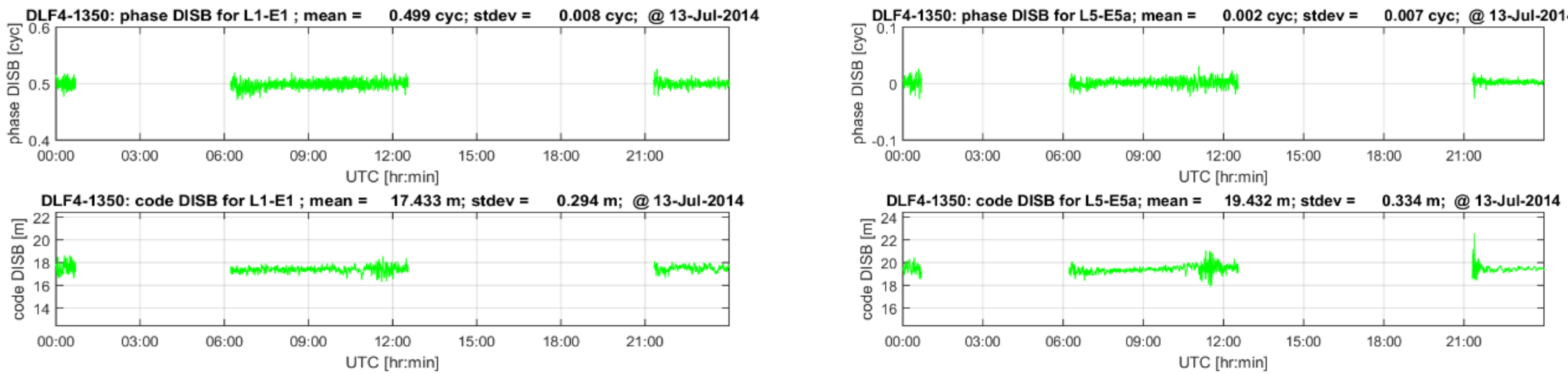
- The Cooperative Research Centre for Spatial Information (CRC-SI) in Australia for supporting the research

- The International GNSS Service for providing the MGEX data

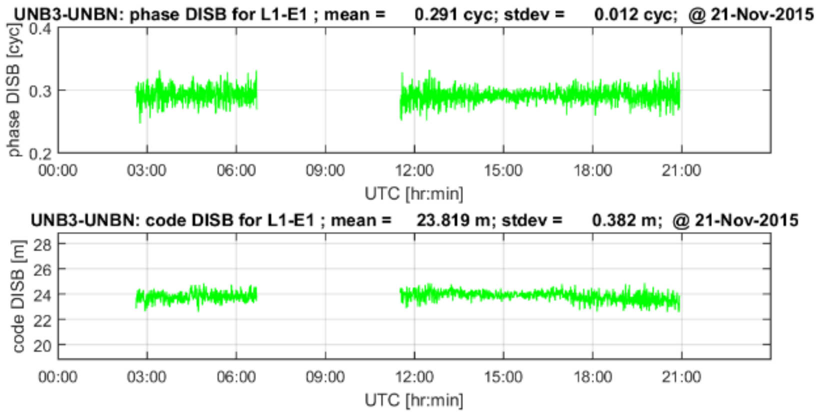
19-m baseline UNBD (Javad TRE_G2T Delta) – UNBN (Novatel OEM6) in Canada

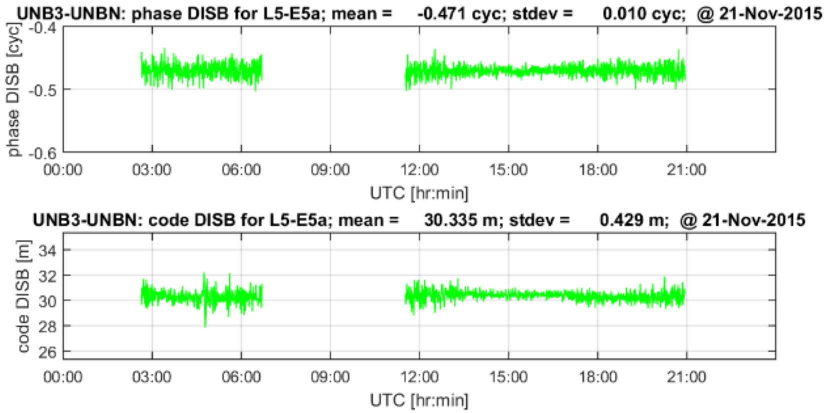


Zero baseline DLF4 (Septentrio PolaRx4) – DLF6 (Leica Gr25) in the Netherlands



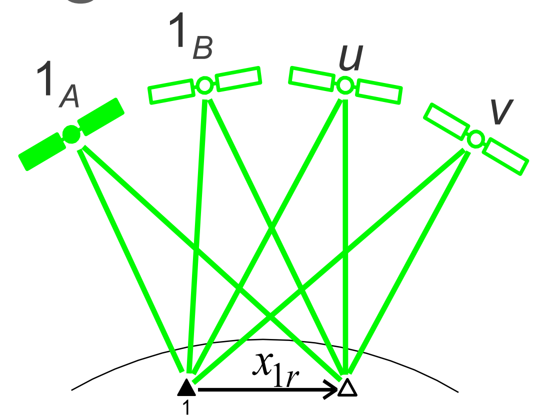
Zero baseline UNB3 (Trimble NetR9) – UNBN (Novatel OEM6) in Canada





Review of DISB Estimation – Long Baselines

- **Multi-GNSS RTK positioning** based on multi-frequency carrier-phase and code data
- **Identical frequencies** between constellations
- **Inter-system double differencing** (common pivot satellite for all constellations):



"As if one constellation"

$$E(\phi_{j}^{1_A u}) = \rho^{1_A u} + \lambda_j a_{j}^{1_A u} - \mu_j I^{1_A u} \quad E(\phi_{j}^{1_A v}) \ldots$$

$u = 2_A, \cdots, m_A$

$v = 1_B, \cdots, m_B$

$\mu_j = \lambda_j^2 / \lambda_{\ldots}$

- **Estimable DD ionosphere parameters of B**:

$I^{1_A v} = I^{1_A v} + d_{GF}^{AB}$ ← biased by **geometry-free code DISB** (difference of scaled receiver DCB of B and scaled receiver DCB of A)

Review of DISB Estimation – Long Baselines

- **Estimable long-baseline DISB parameters:**

phase DISB: $\delta_{j}^{AB} = \delta_{j}^{AB} + \frac{\mu_j}{\lambda_j} d_{GF}^{AB} + a_{j}^{1_A 1_B}$,

ionosphere-free code DISB:

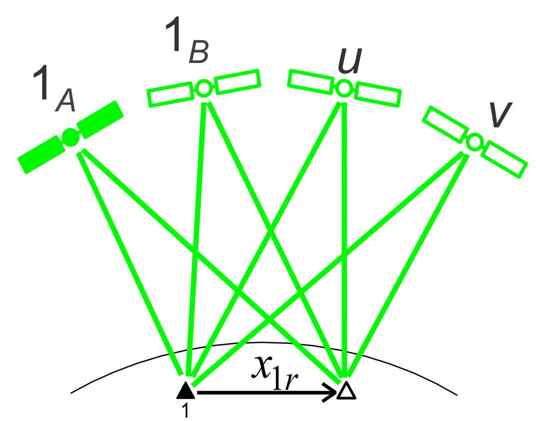
code DISB (>3 frequencies):

- Ionosphere-free code DISB (estimable):

$$d_{IF}^{AB} = \frac{\mu_2}{\mu_2 - \mu_1} d_1^{AB} - \frac{\mu_1}{\mu_2 - \mu_1} d_2^{AB}$$

- Geometry-free code DISB (inestimable):

$$d_{GF}^{AB} = -\frac{1}{\mu_2 - \mu_1} (d_1^{AB} - d_2^{AB})$$



"As if one constellation"

Application of DISBs: Short vs. Long Baselines

- DISBs have **different estimability** and **interpretation** when estimated from either a short or long baseline. They are related as follows:

■δ ↓j≥1↑AB &=&δ ↓j≥1↑AB −μ↓j /λ↓j d↓GF↑AB @d↓j≥1↑AB &=

short-baseline DISBs

long-baseline DISBs

- Short-baseline DISBs **can** be used to calibrate long baselines, but long-baseline DISBs **cannot** be used to calibrate short baselines!
- **Inter-system double differencing** calibrated for short-baseline DISBs:

■E(ϕ↓j↑1↓A u)&=&ρ↓↑1↓A u &+λ↓j a↓j↑1↓A u &[−μ↓j I↓↑1↓A u]@E(ϕ↓j↑1↓A v −λ

fractional phase DISB:

Δδ↓j↑AB =δ ↓j↑AB −a ↓j↑1

estimable ambiguity of B:

a ↓j↑1↓A v =a↓j↑1↓B v +a

Curtin University