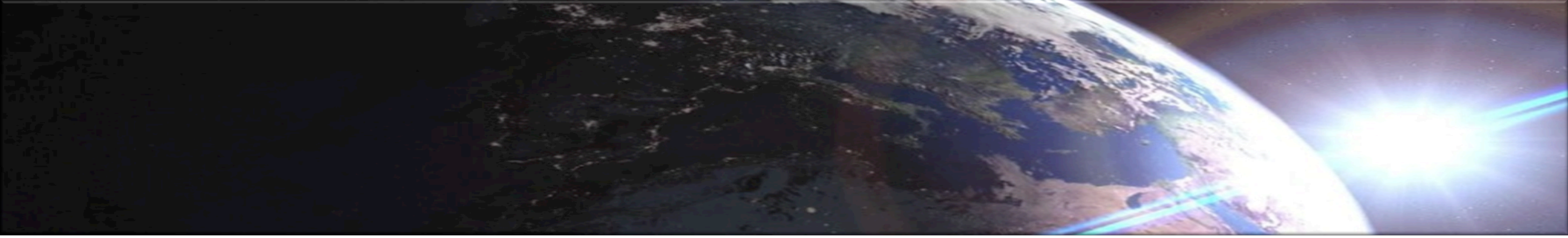

How Multi-GNSS Brings Benefits to SEA

A Technical Point of View

The Abdus Salam
International Centre
for Theoretical Physics
50th Anniversary 1964-2014

ICTP Workshop on the use of Global Navigation Satellite Systems for the Scientific Applications

LA THE VINH, TA HAI TUNG

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NAVIS Centre, HUST, Vietnam

navis International Collaboration Centre for R&D on Satellite Navigation Technology in South East Asia

"The mission of Navis is to boost the R&D of satellite navigation technology, especially the European Galileo System, in South-East Asia."

http://navis.hust.edu.vn

ĐẠI HỌC BÁCH KHOA

UPC

POLITECNICO DI TORINO 1859 1906

ISMB Istituto Superiore Mario Boella

Work Motivation

- South East Asia (SEA) region is covered by:
  - All 4 GNSSes (GPS, Galileo, GLONASS, Beidou); and
  - 1 RNSS (QZSS).
- Now: GPS-standalone solution still dominates, but
- Future is multi-GNSS + RNSS;

Verification of the advantages of Multi-GNSS over stand-alone solutions in SEA by <u>real data collected from all system constellations.</u>

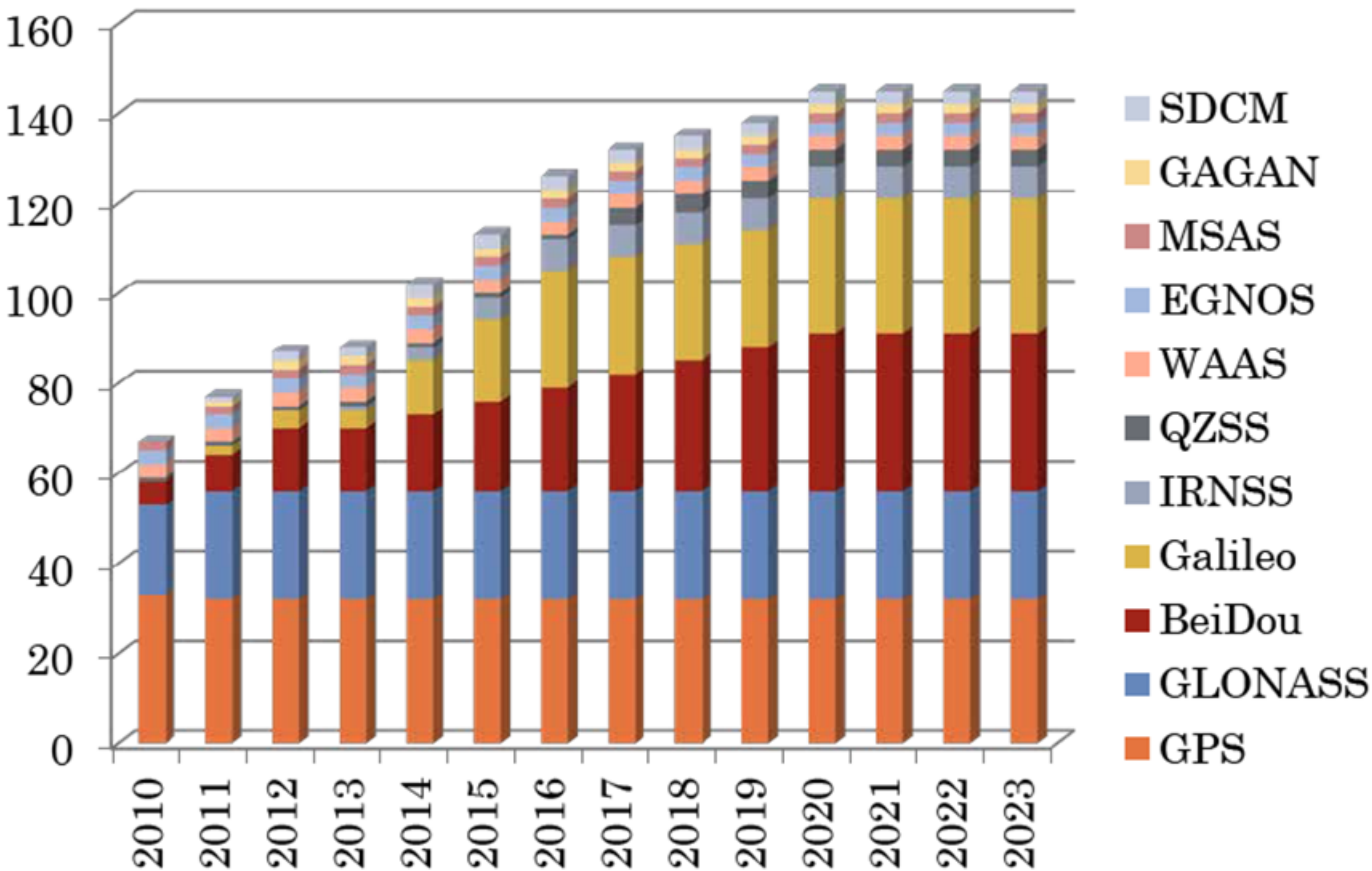
Content

1. **Multi-GNSS Environment**
   – Challenges of Multi-GNSS Environment
   – Advantages of Multi-GNSS Environment
2. **Multi-GNSS Signal Processing Chain**
   – Experiment Result
3. **QZSS augmentation services:**
   – Centimeter class: L6-LEX.
4. **Conclusions**

Content

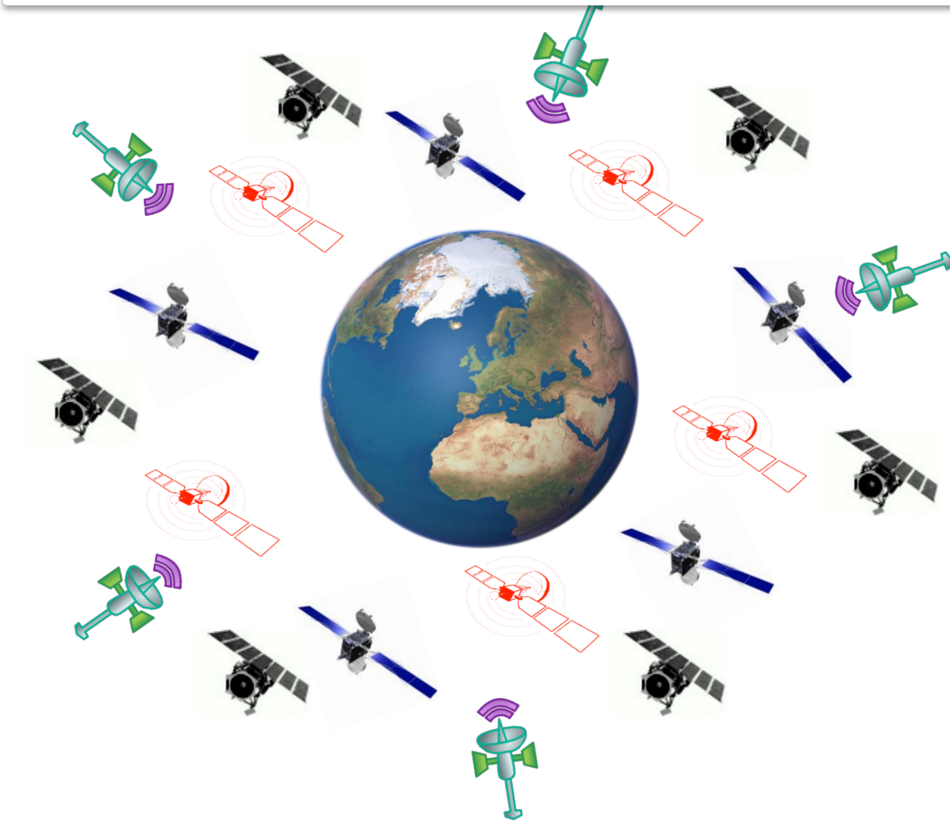
- **Multi-GNSS Environment**
  - Challenges of Multi-GNSS Environment
  - Advantages of Multi-GNSS Environment
- **Multi-GNSS Signal Processing Chain**
  - Experiment Result
- **QZSS augmentation services:**
  - Sub-meter class: L1-SAIF;
  - Centimeter class: L6-LEX.
- **Conclusions**

Multi-GNSS Environment



Multi-GNSS Environment

Global Navigation Satellite Systems (GNSS)



GPS: 1995 (32)

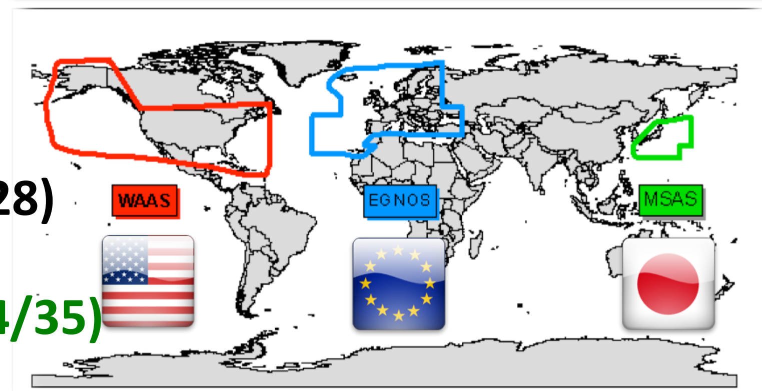
GLONASS: 2011 (28)

Galileo: 2019 (6/30)

Beidou: 2020 (14/35)

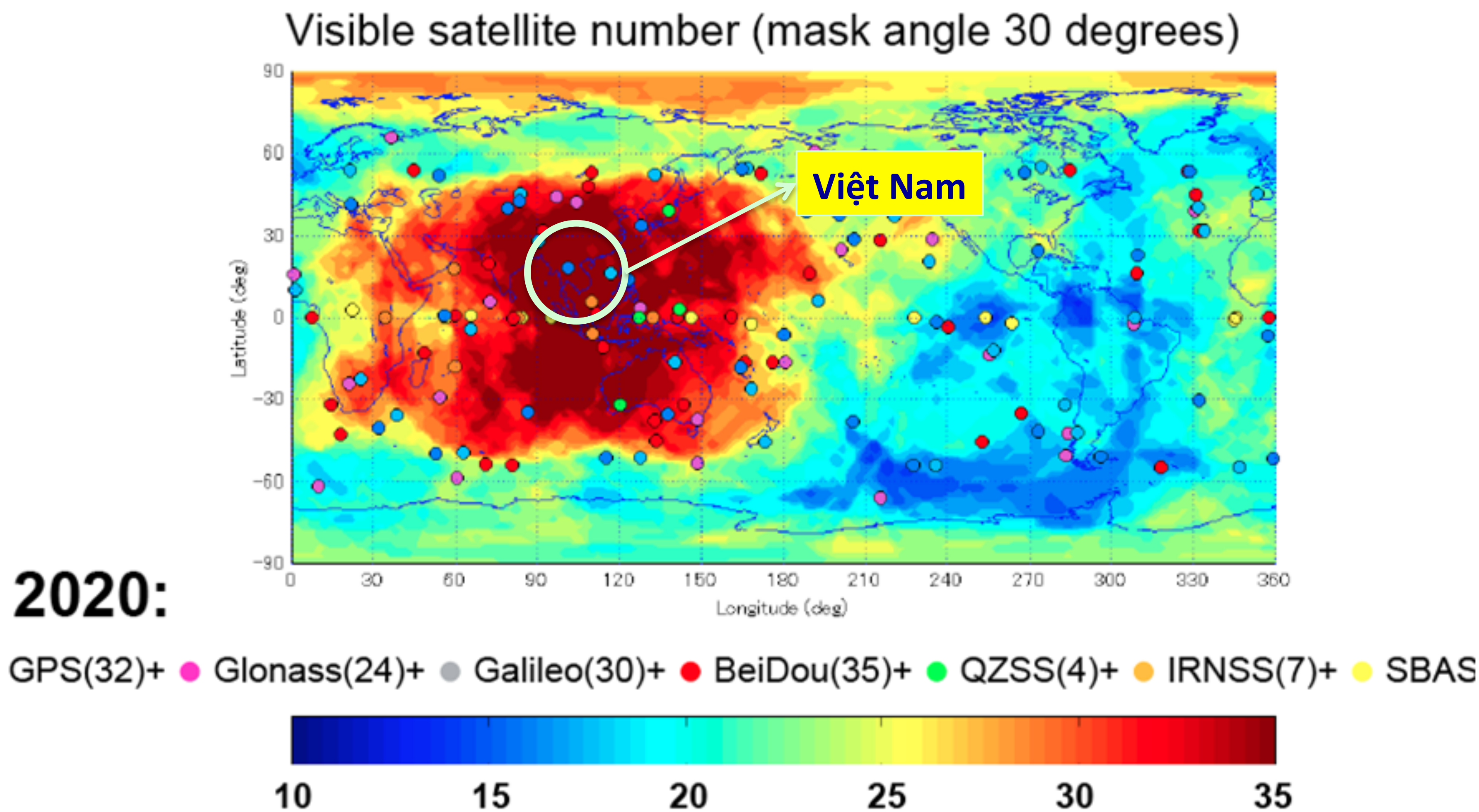
RegionalNSS

Augmentation Systems



2020:~ 140 satellites for navigation purposes

Multi-GNSS Environment



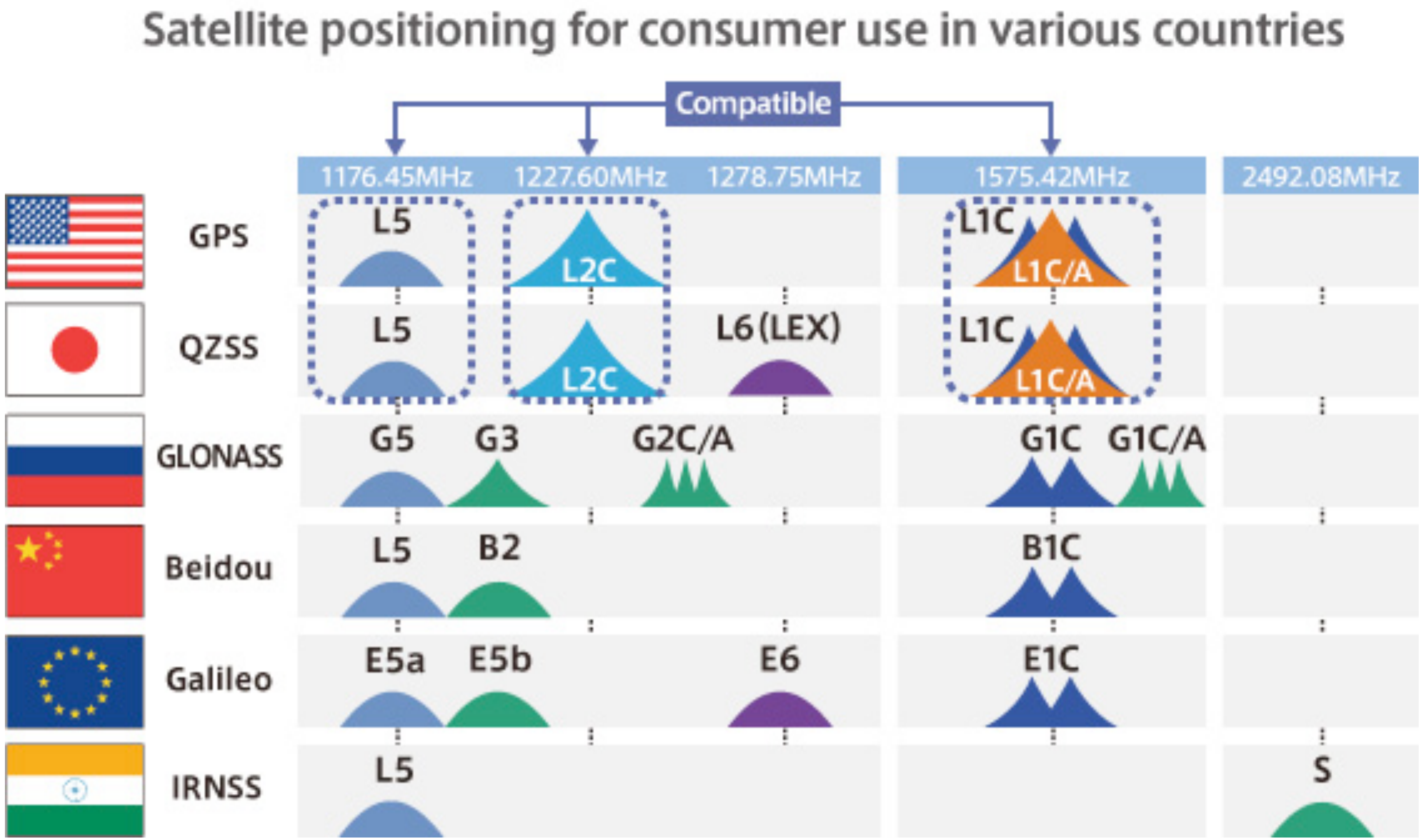
Challenges of Multi-GNSS Environment

- Inter-system interference: GNSSes broadcast navigation signals in overlapped frequency bands → Inter-system interference.
- Complexity increase:
  - Analog part: operate with multiple systems, multiple frequency bands at larger signal bandwidths → Increase complexity and receiver cost.
  - Digital part: More advanced and complex algorithms, more channels for more satellites → Increase the computational complexity, the resource capability requirements and receiver cost.
- Different Coordinate Reference System: each GNSS uses its own coordinate reference systems

System	GPS	GLONASS	Galileo	Beidou
Satellite position	Kepler param.	ECEF	Kepler param.	Kepler param.
Coordinate reference system	WGS-84	PZ-90.02	GTRF	CGCS2000

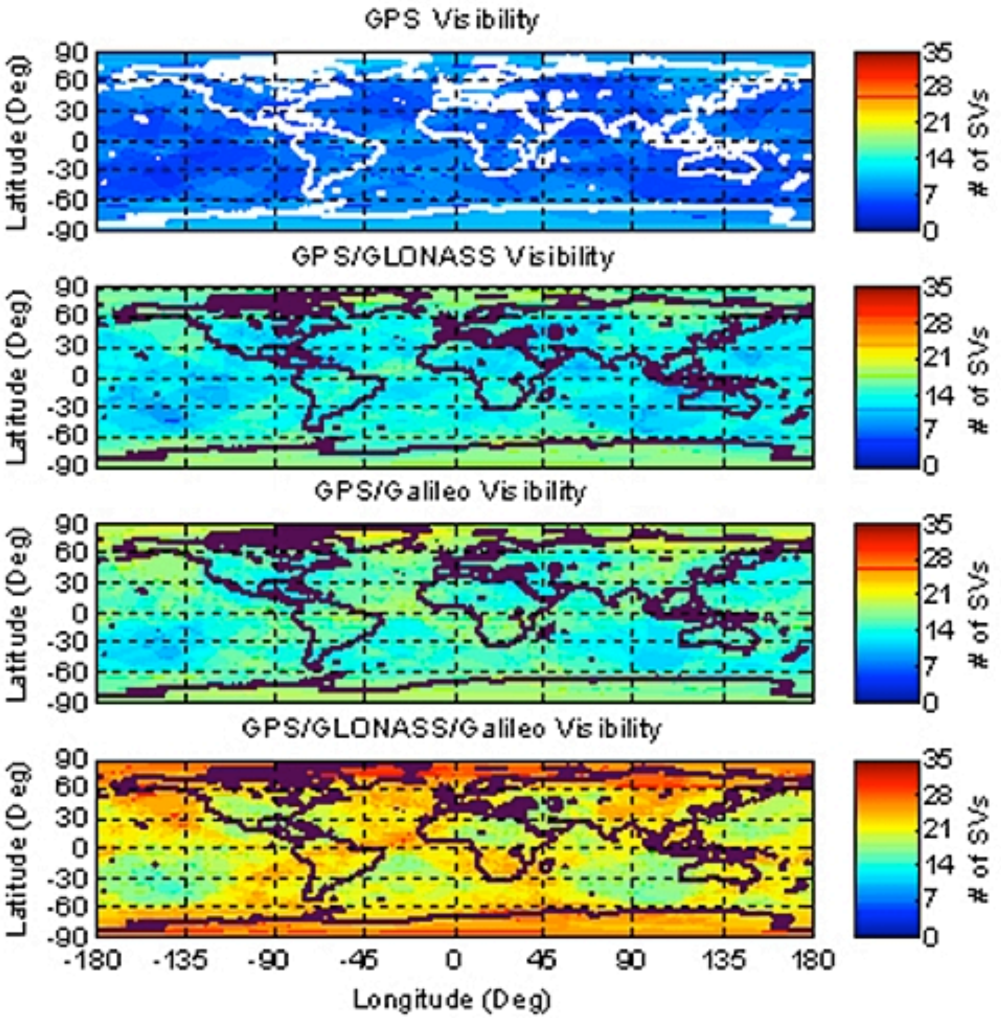
Advantages of Multi-GNSS environment

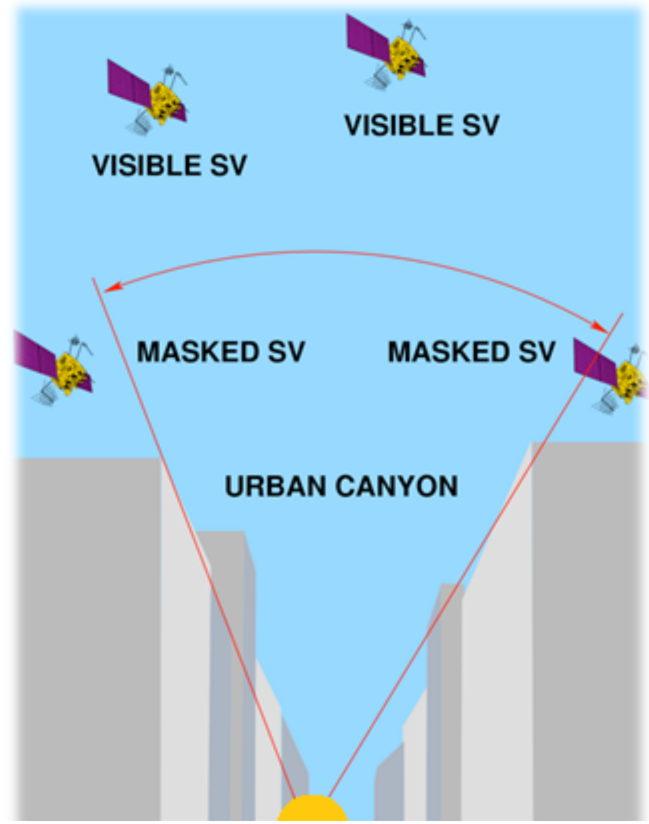
- More signals, more services => more options



Source: qzs.jp

- Increase in availability and coverage:

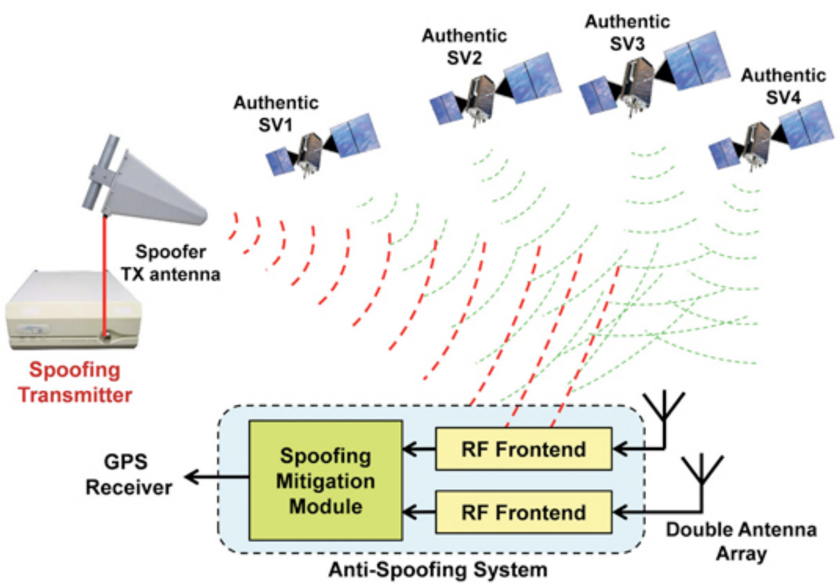




Urban canyon problem

- More robust and reliable services:
  - Reliable services: Integrity information is provided by SBAS or GNSSes;
  - Robustness positioning:
    - New advanced signals
    - The redundancy of multi-systems and multi-bands;

    => more difficult to be jammed and spoofed;



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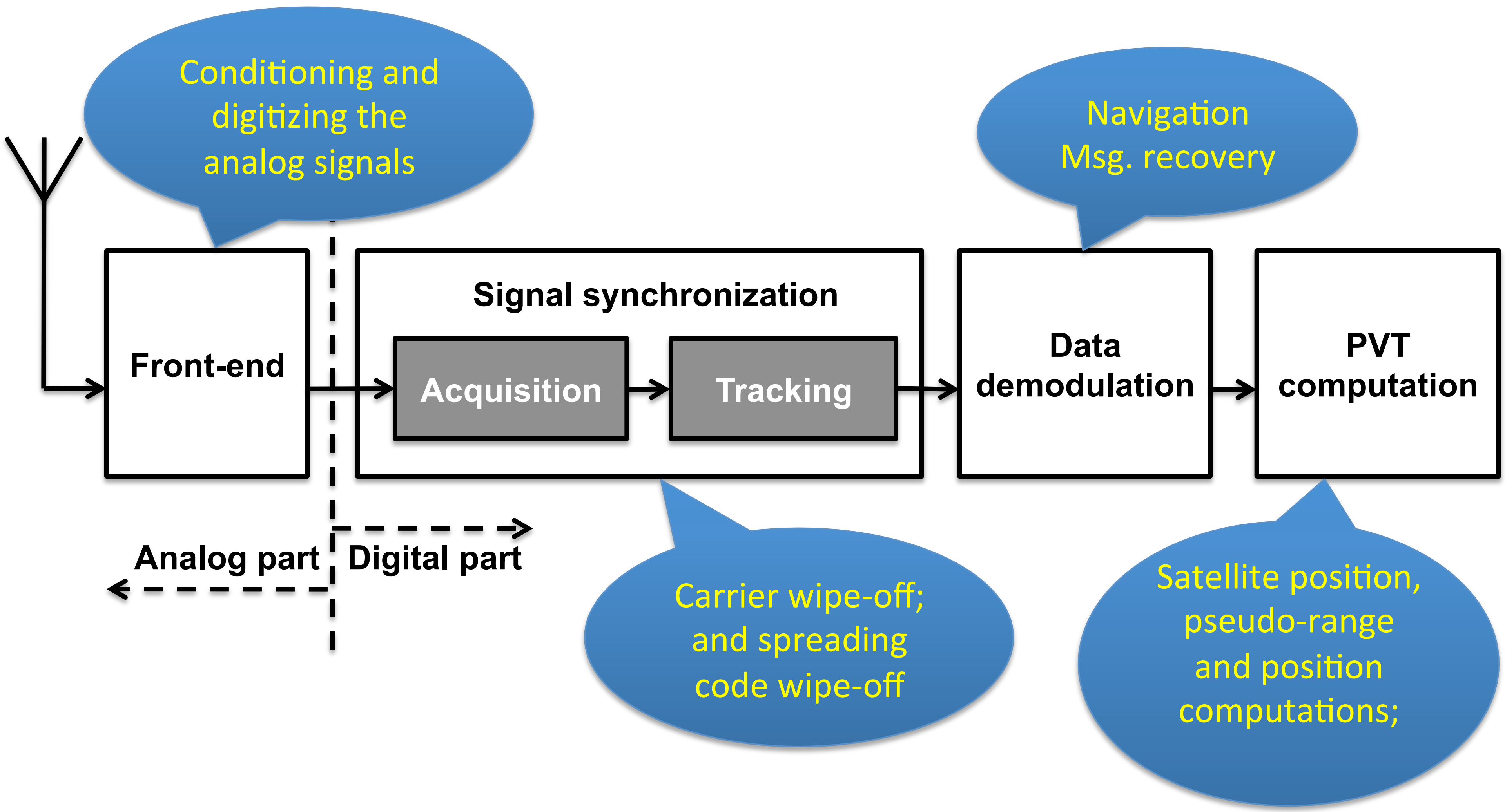
GNSS Signal Processing Chain



- Signals in concerns: open and free signals of the 5 systems, namely:

Signals	**Carrier (MHz)**	**PRN code**	**Code Length**	**Code rate**	**Data rate**
GPS L1-C/A	1575.42	Gold	1023	1.023	50
Galileo E1	1575.42	Memory	4092	1.023	250
Beidou B1	1561.098	Gold	2046	2.046	
Glonass L1-OF	1602+ k×0.5625	Maximal length	511	0.511	50

Note: GLONASS L1-OF is the only FDMA signal; the others are CDMA ones

Adaptations to Multi-GNSS:

Analog parts (1/2): (Antenna & Front-end)

- Antenna requirements:
  - Capable of receiving all 4 signals;
  - Aero Antenna Choke Ring AT1675-120: [1525 ÷1615] MHz

Analog parts (2/2): (Antenna & Front-end)

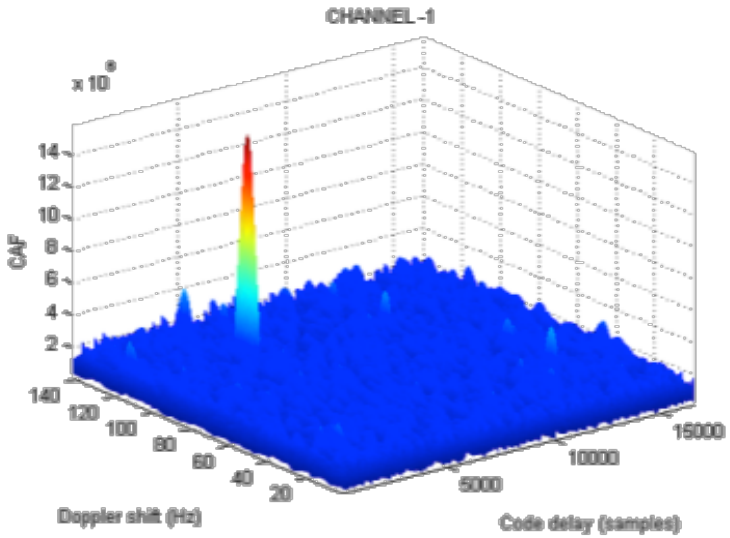
- Front-end:
  - Functionalities: conditioning and digitizing analog signals
  - Chosen front-end: MAX2769

Table 1: MAX 2769 front-end configuration

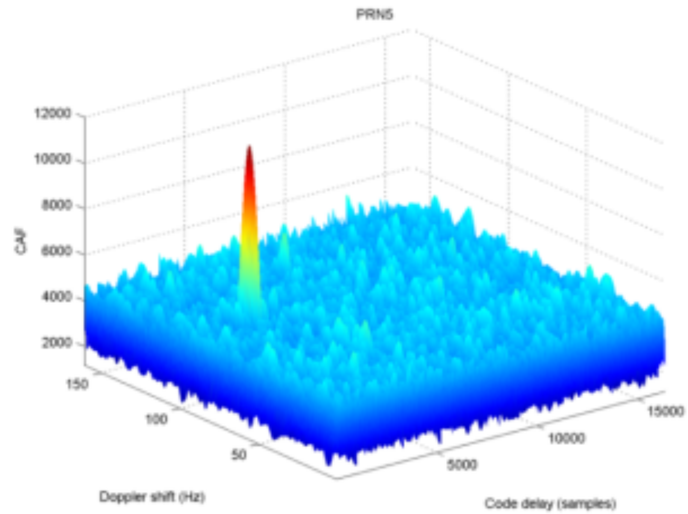
Sampling frequency	F_S = 16.368 MHz
Intermediate frequency	F_{IF1} = 4.092 MHz (for L1-C/A, E1 and B1) F_{IF2} = -16 kHz (for L1-OF)
Bandwidth	B_{w1} = 4.2 MHz (for L1-C/A, E1 and B1) B_{w2} = 8 MHz (for L1-OF)
Number of quantization bits	2 bits

Result Analyses: Acquisition

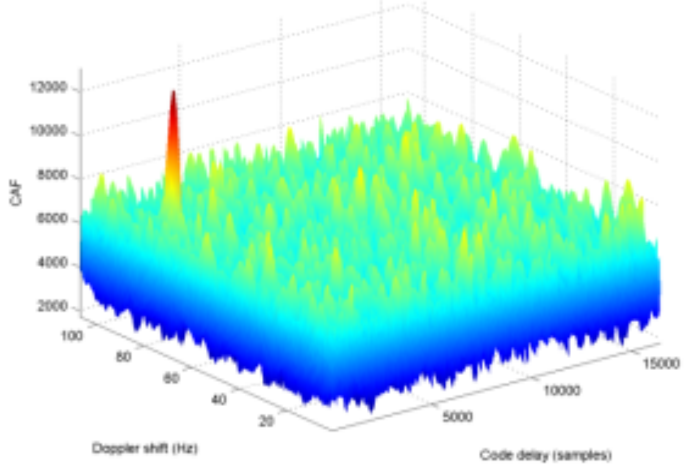
GLONASS PRN 1



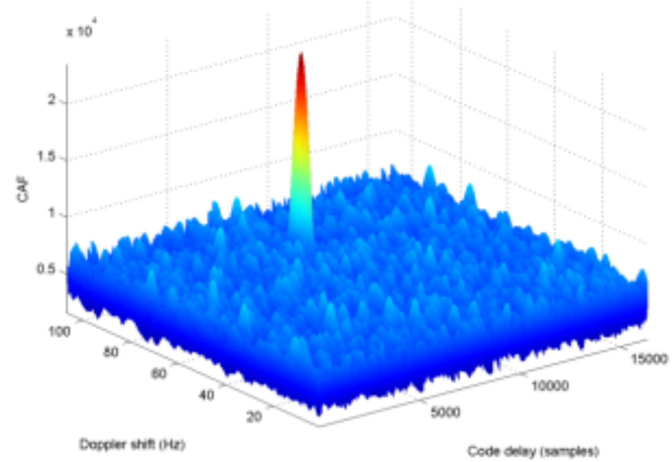
Beidou PRN 5



Galileo PRN 20

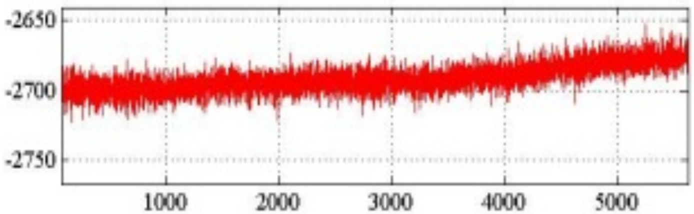


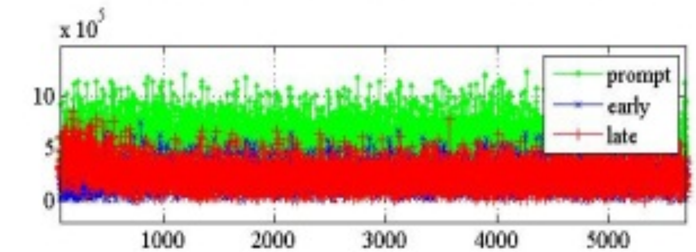
GPS PRN 22



Result Analyses: Tracking

GLONASS PRN 1

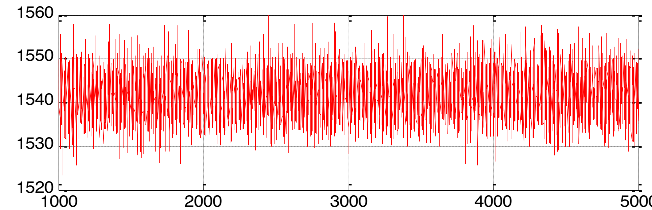


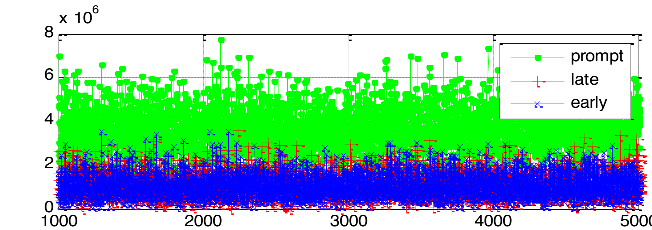


PLL output

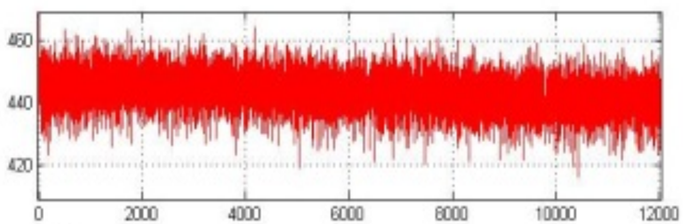
DLL output

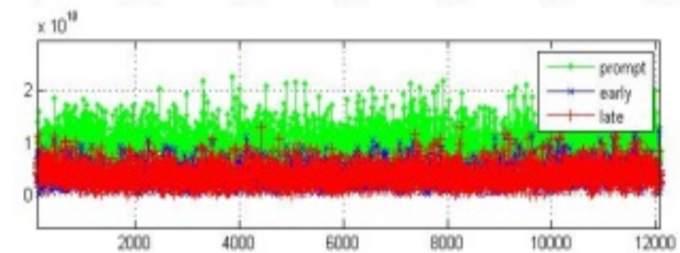
Beidou PRN 5





Galileo PRN 20

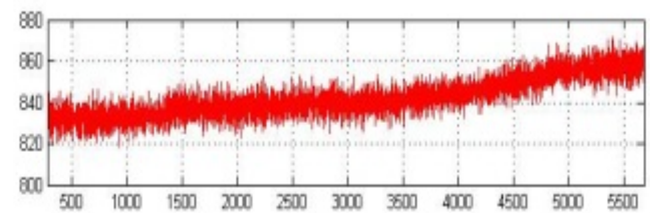


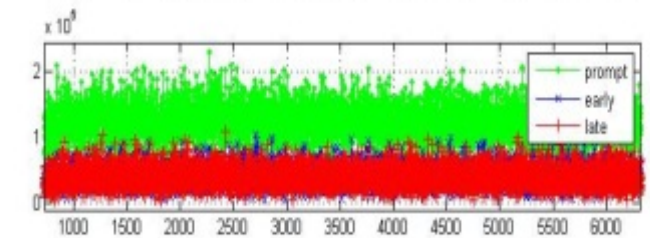


PLL output

DLL output

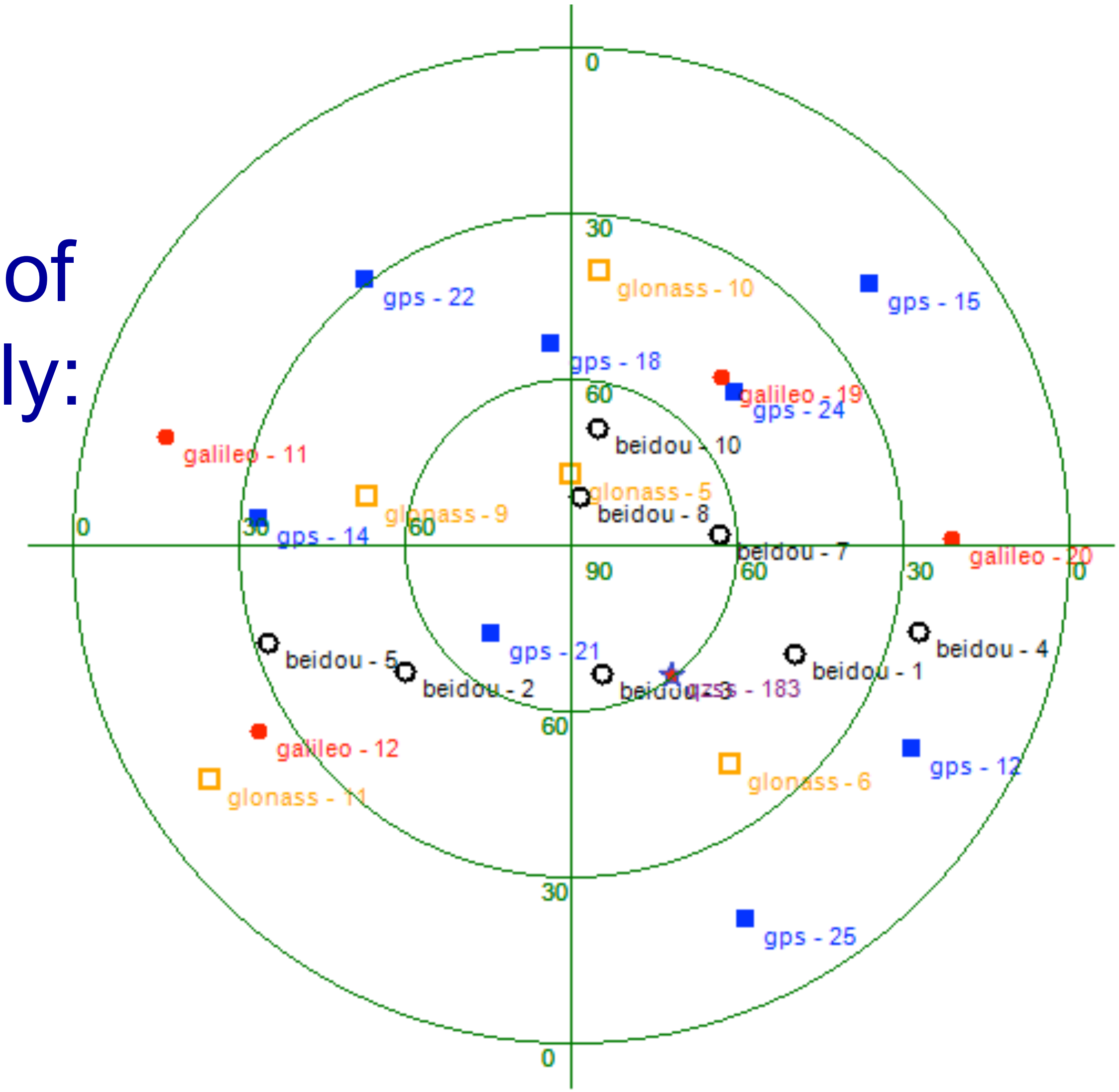
GPS PRN 22





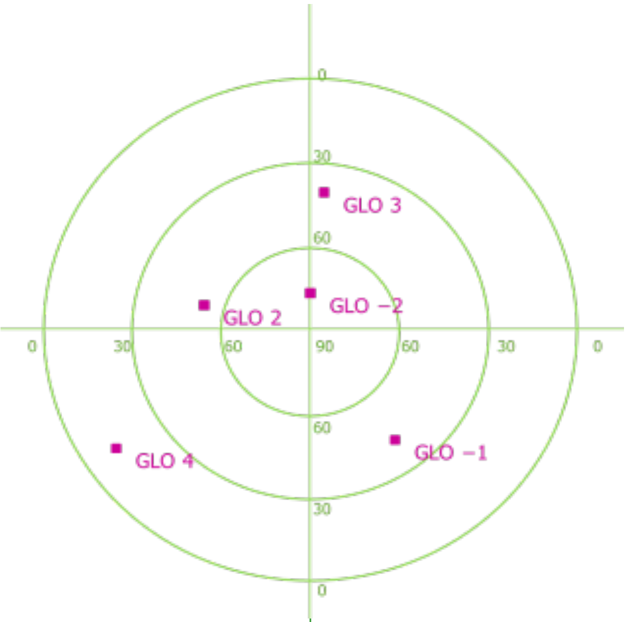
Result Analyses: Data demodulation

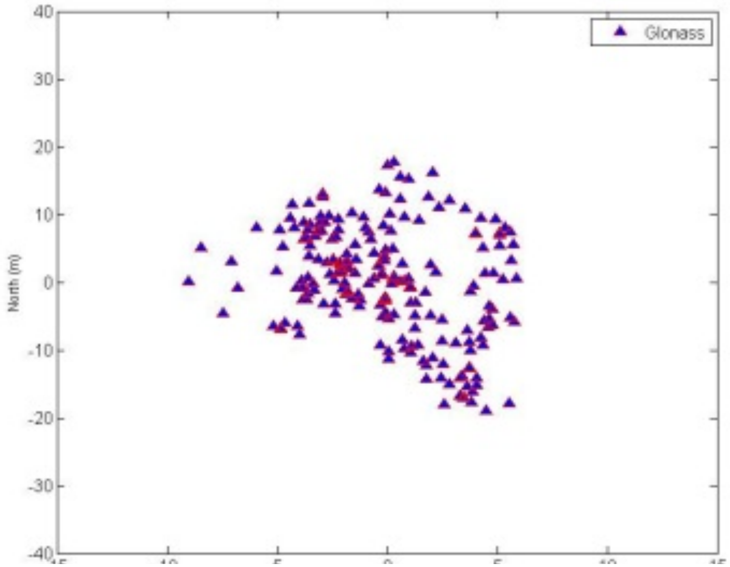
- Sky-plot (satellite positions): 26 satellites-in-view of 5 systems, namely:
  - 8 GPS;
  - 4 Galileo;
  - 5 GLONASS;
  - 8 Beidou;
  - 1 QZSS.



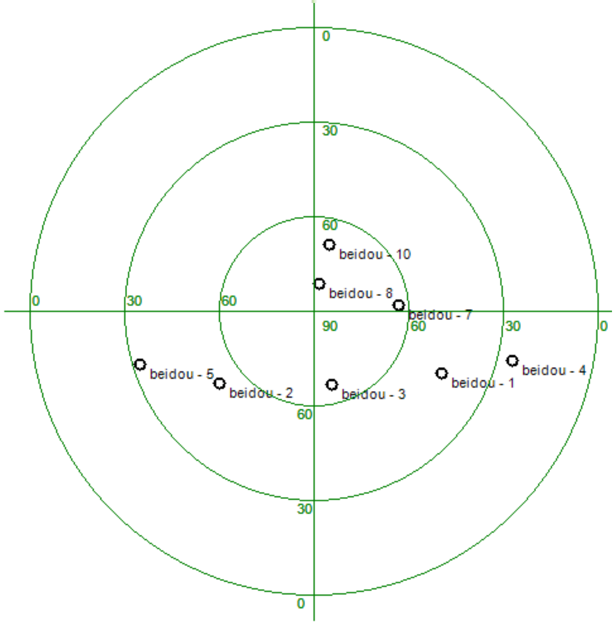
Result Analyses: Stand-alone Positioning (1/3)

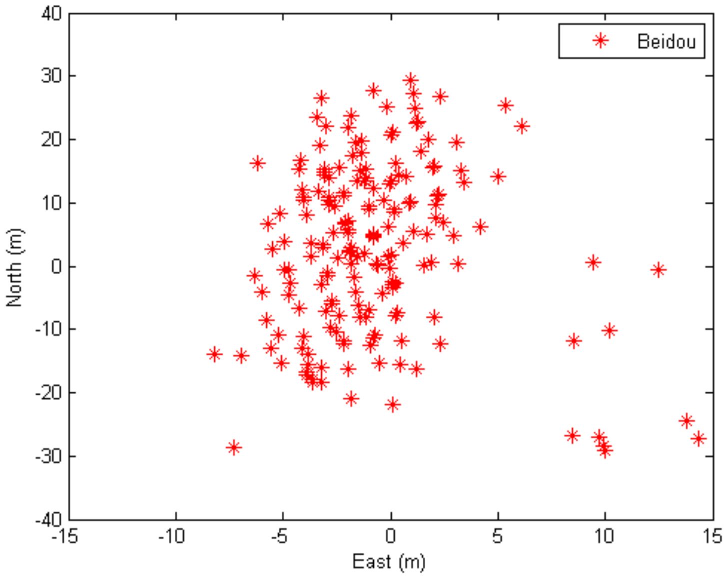
GLONASS





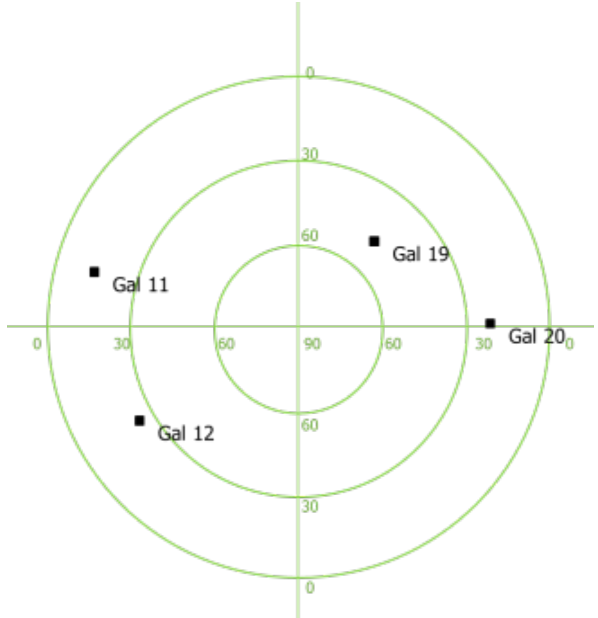
Beidou

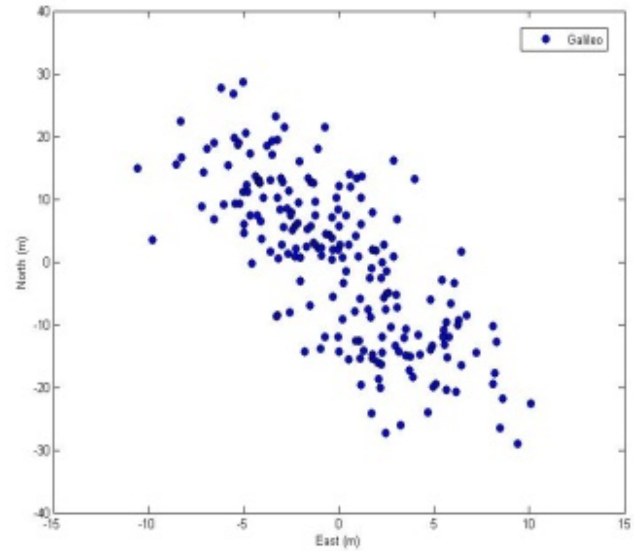




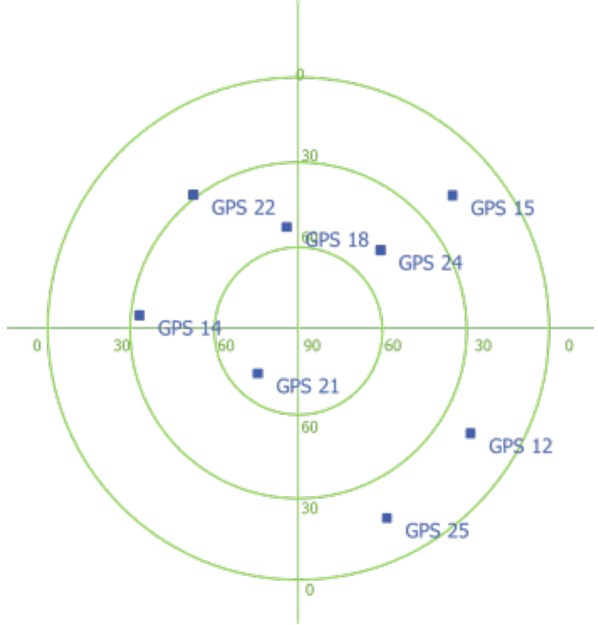
Result Analyses: Stand-alone Positioning (2/3)

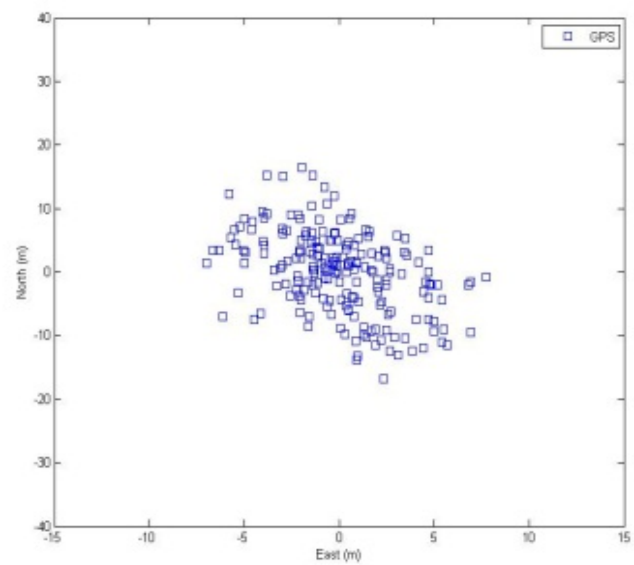
Galileo





GPS



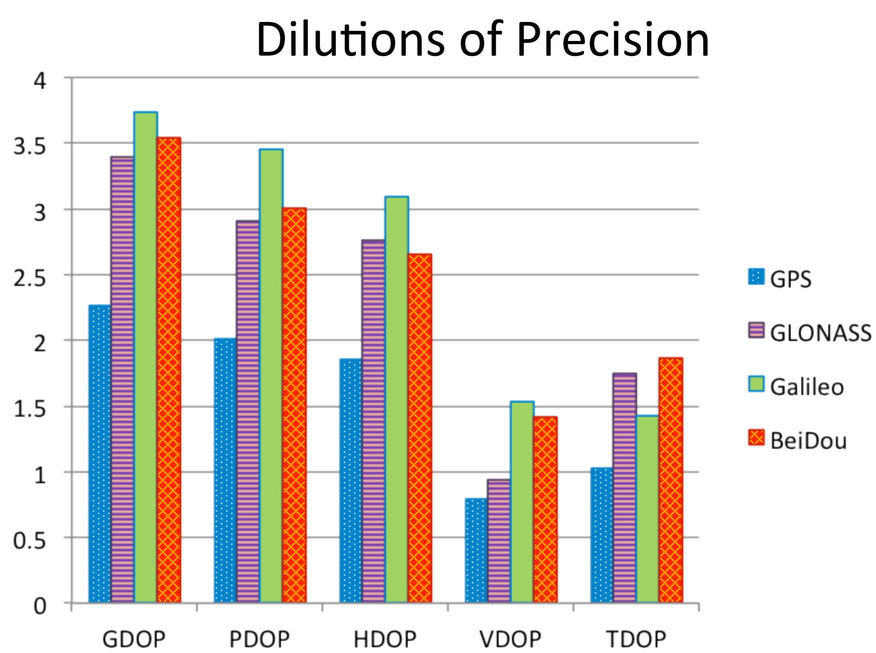


Result Analyses: Stand-alone Positioning (2/3)

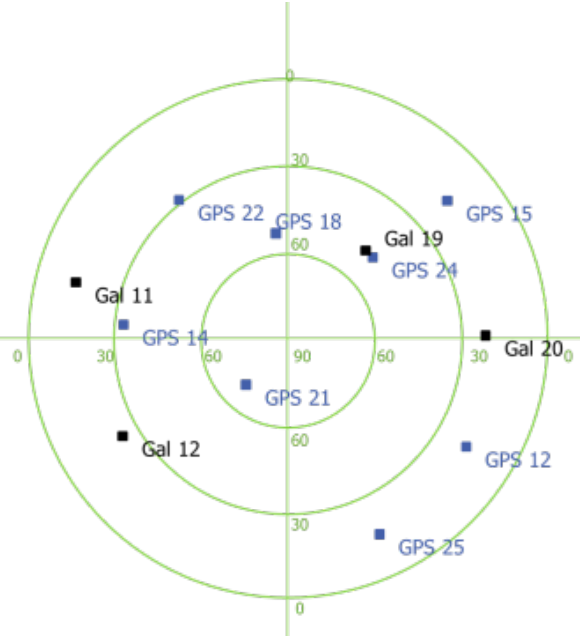
- Accuracy of GNSSes at the campaign

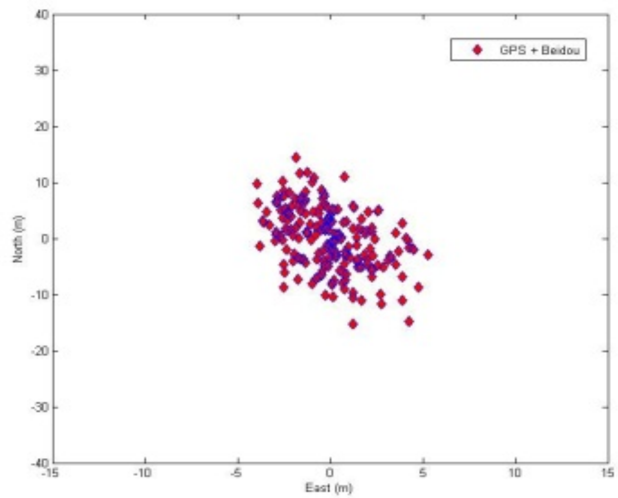
Horizontal Errors

System	δ_{East} (m)	δ_{North} (m)
Glonass	3.2584	8.1746
Beidou	3.7629	13.4952
Galileo	4.0887	12.8882
GPS	2.9859	6.3924

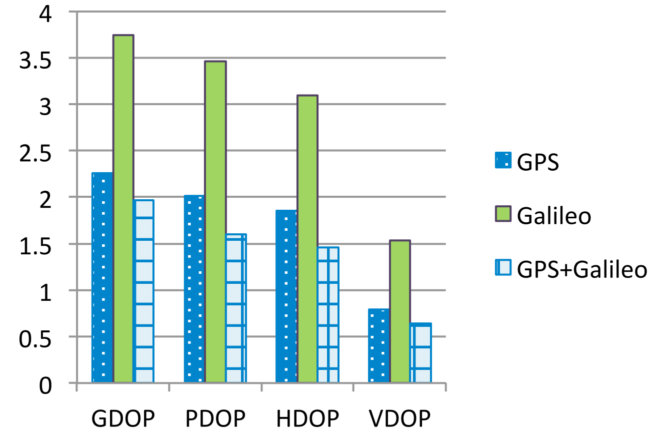


Result Analyses: Multi-GNSS Positioning GPS+Galileo





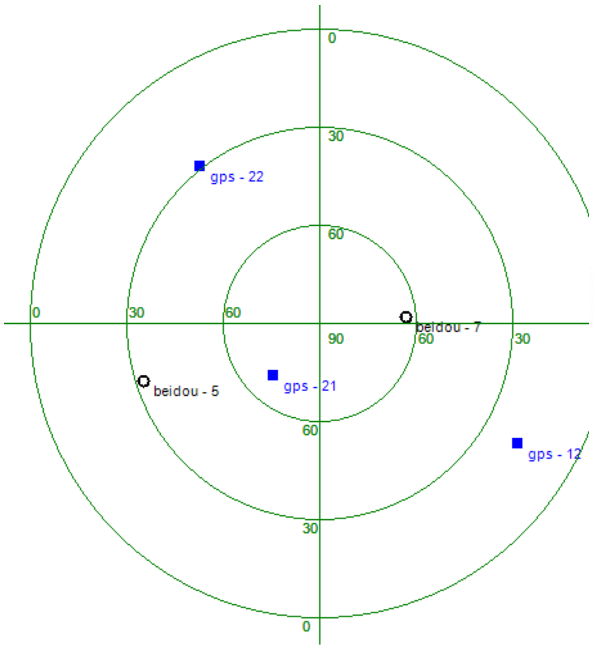
δ_{East} = 2.4029 m δ_{North} = 5.8056 m

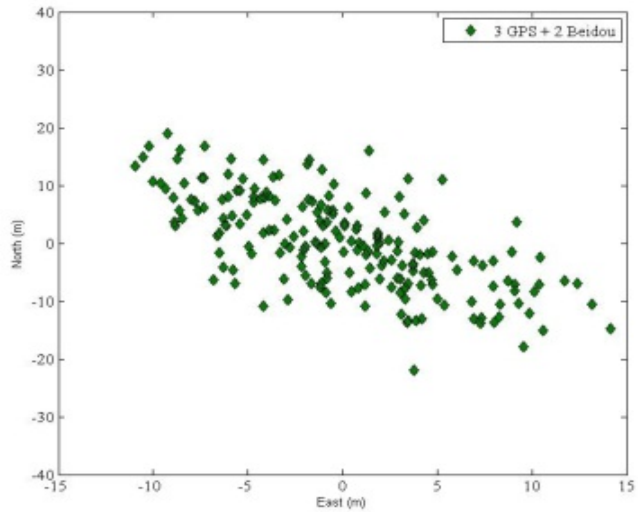


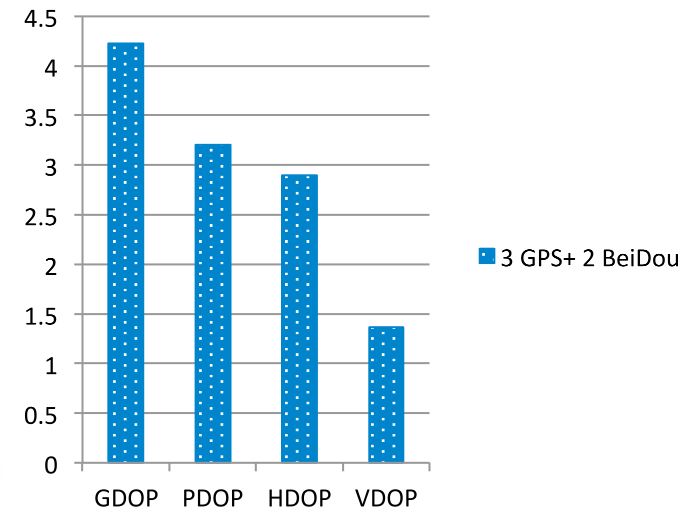
- GPS L1 C/A and Galileo BOC(1,1) are two interoperability signals with a common carrier frequency

Result Analyses: Multi-GNSS Positioning

3 GPS + 2 Beidou





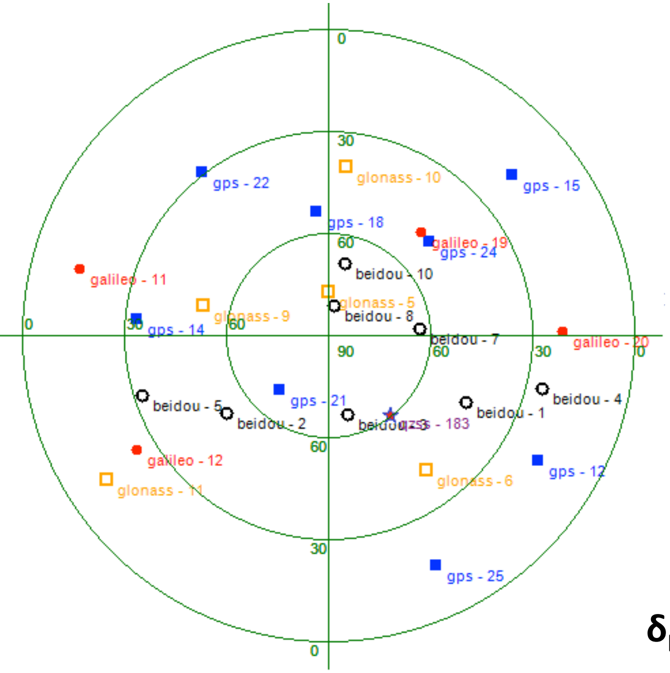


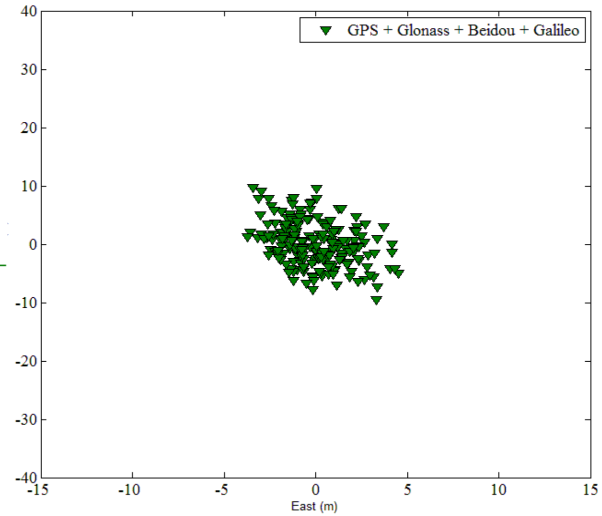
δ_{East} = 5.4983 m δ_{North} = 8.0544 m

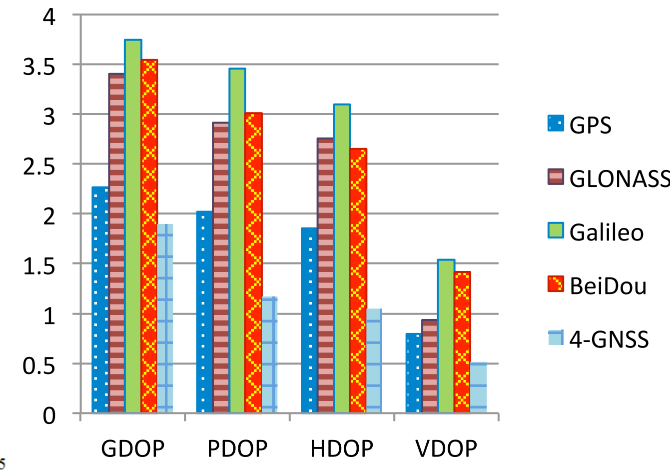
- Geostationary SVs of Beidou always visible at high elevation in SEA

Result Analyses: Multi-GNSS Positioning

All GNSSes + QZSS

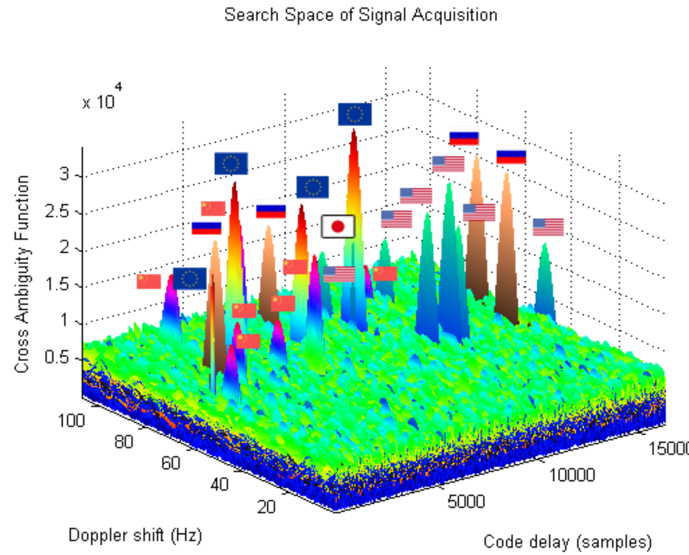






δ_{East} = 1.7582 m δ_{North} = 3.7840 m

- GPS/GLONASS/Galileo/Beidou/QZSS: 26 satellites are involved
- Better accuracy in comparison with any stand-alone
- But complexity increase



Among 50 first users of the Galileo system

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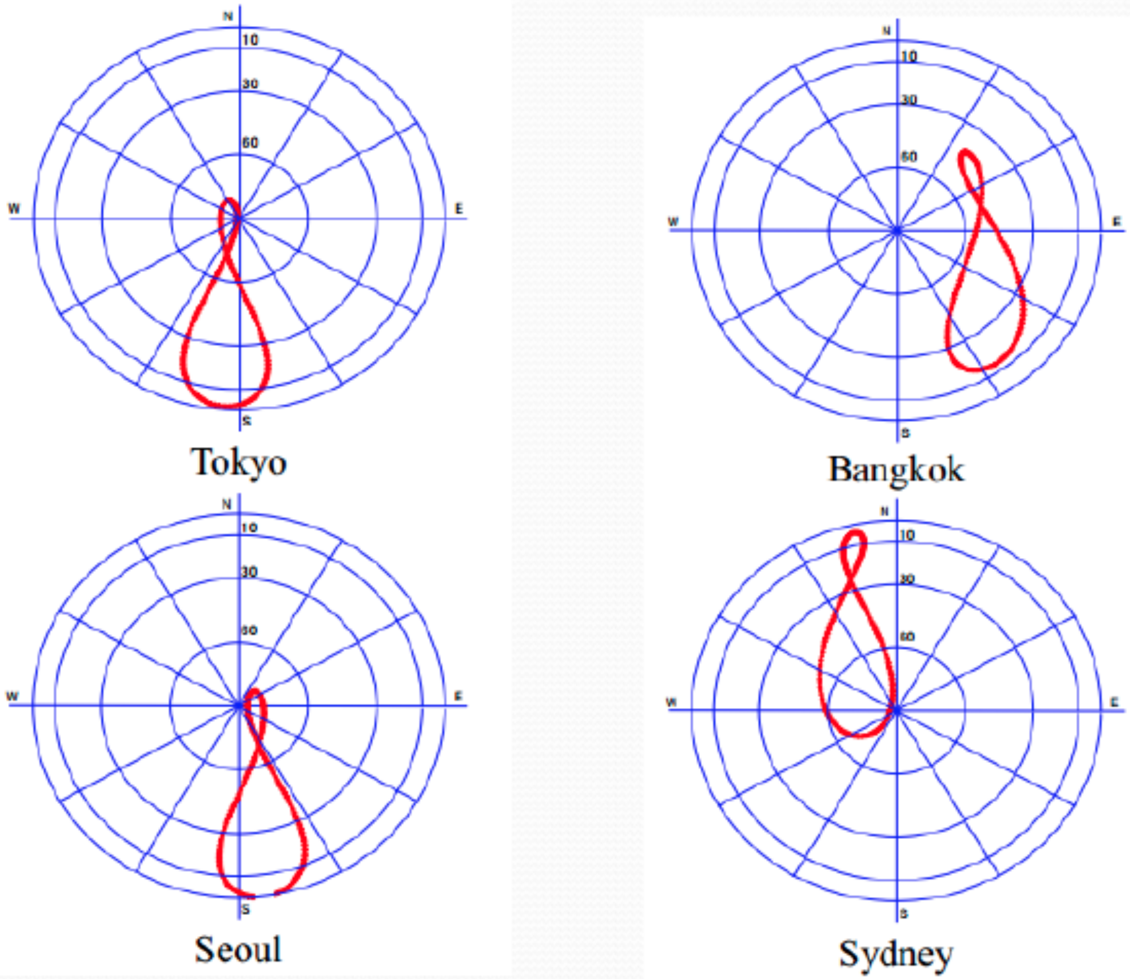
Overview of QZSS

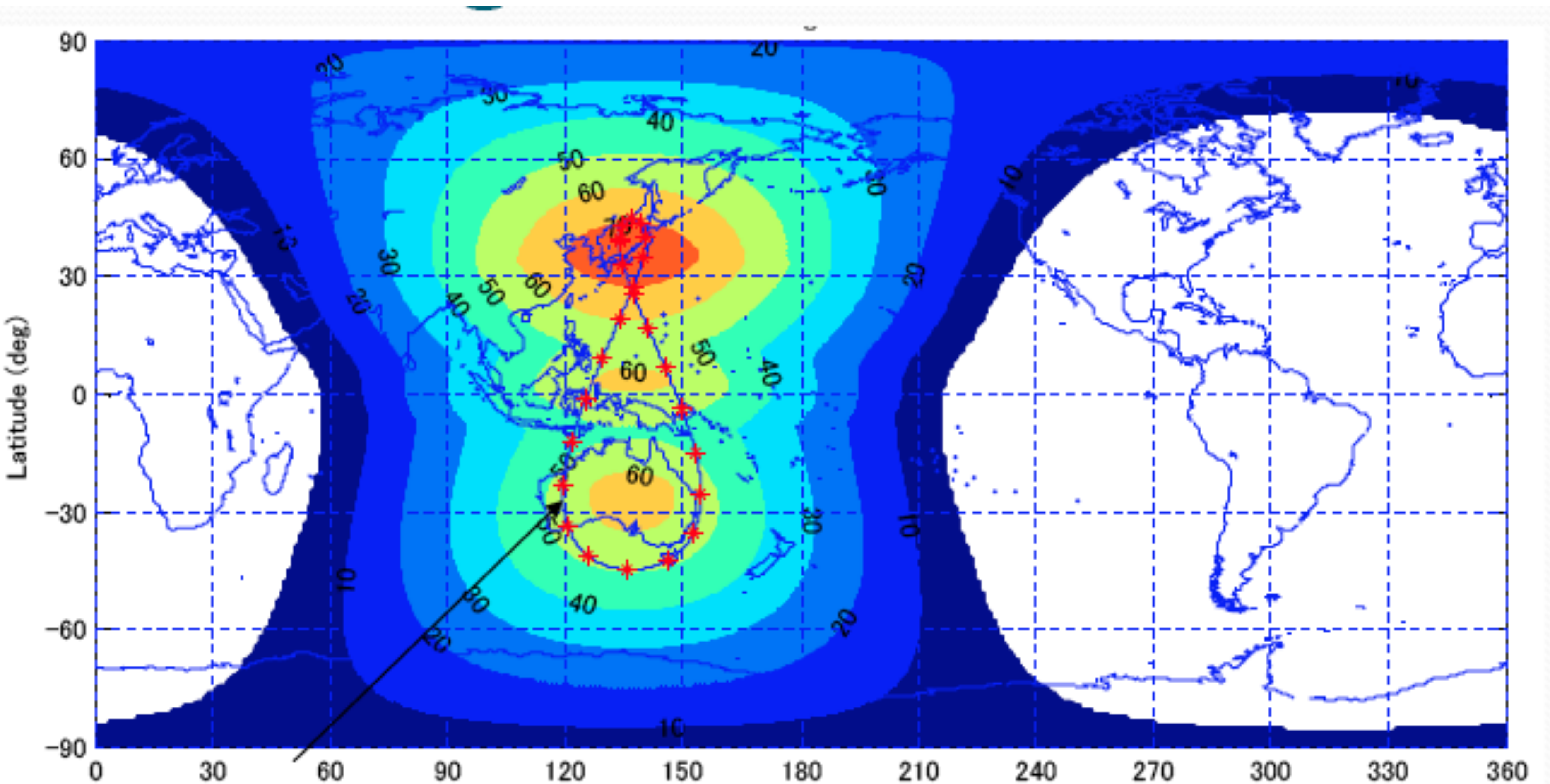
- The Quasi-Zenith Satellite System (QZSS) is a RNSS of Japan.
- Functional Capability:
  - GNSS Complementary
  - GNSS Augmentation:
    - Sub-metter class
    - Centimeter class
  - Messaging Service
- Signals:
  - L1C/A, L1C, L2C and L5
  - L1S (L1-SAIF)
  - L6 (LEX)
- 2018: provide services by 4 SVs

- Elevation and Azimuth of the 1st SV: Michibiki



Elevation and Azimuthal angles for each city (Observation EPOCH = 2009/Dec/26/12:00 UTC)

- Coverage: East Asia and Pacific Region



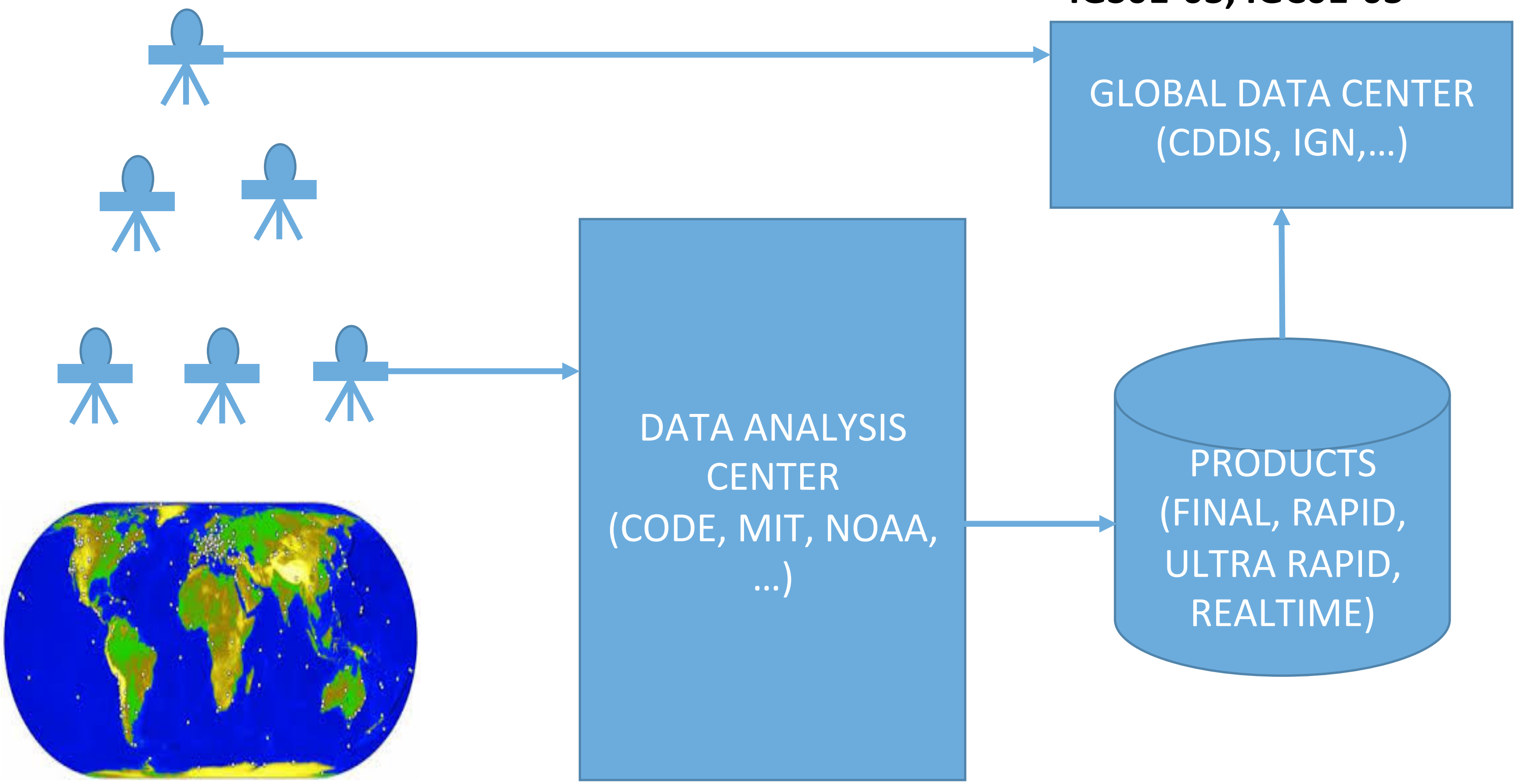
Ground Track of a QZSS satellite

QZSS – LEX: Centimeter Service

- Based on Precise Point Positioning (PPP) Technology:
- With single receiver (no reference station)
- Conventionally post-processing
- With recent services such as: IGS Realtime, QZSS LEX it is possible to have realtime PPP
- Need satellite orbit and clock
  - Post-processing (IGS final) or real-time (IGS RT, QZSS LEX)
  - Require observation data of tracking stations world-wide
  - Vietnam does not have any IGS station, NAVIS is the first one in MGA
  - Data format:
    - SP3 for orbit (ECEF positions of satellite mass center)
    - CLK for clock biases

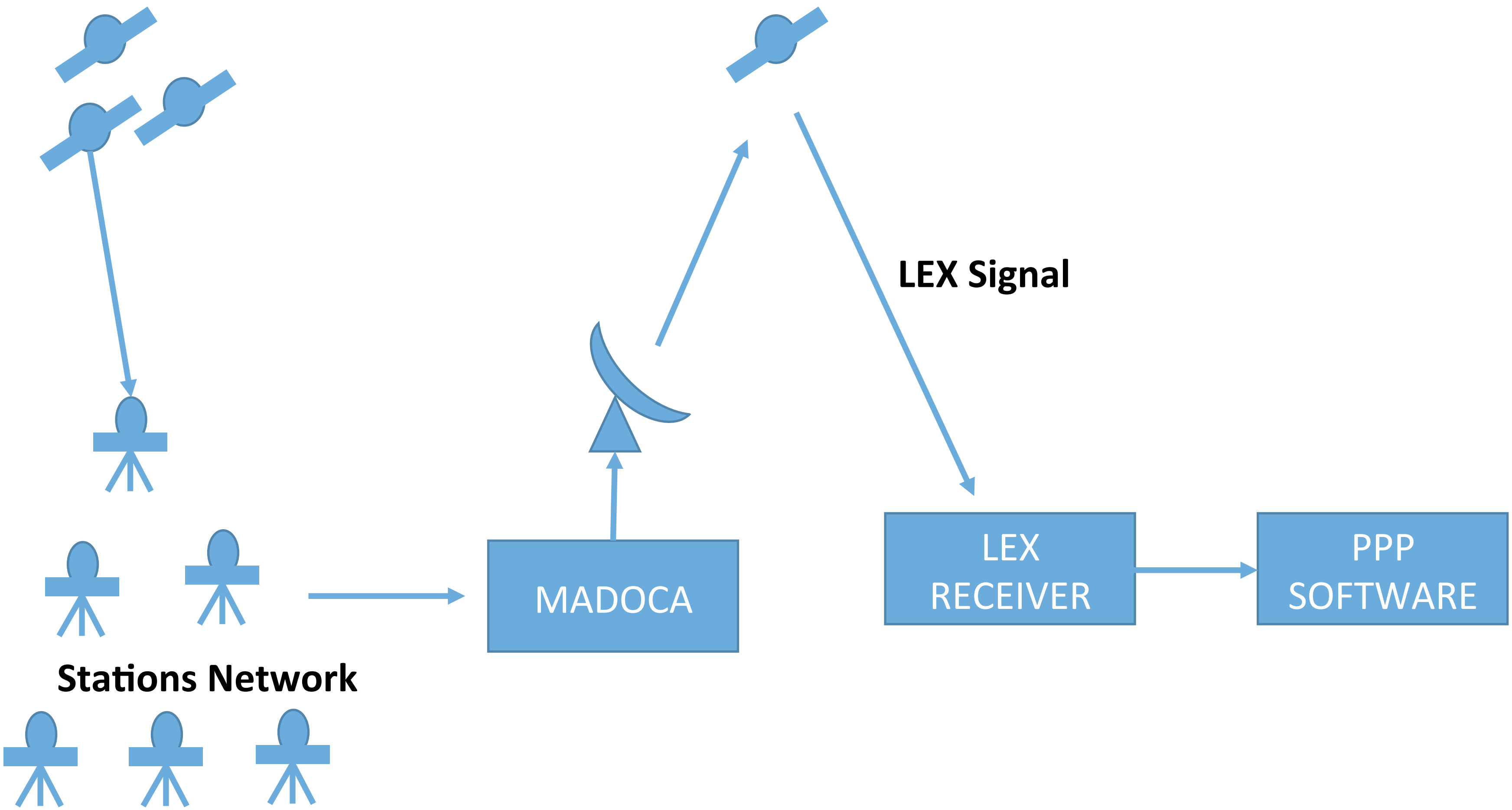
Precise Point Positioning – IGS Products

Sample IGS Realtime services:
products.igs-ip.net, mountpoint
IGS01-03, IGC01-03

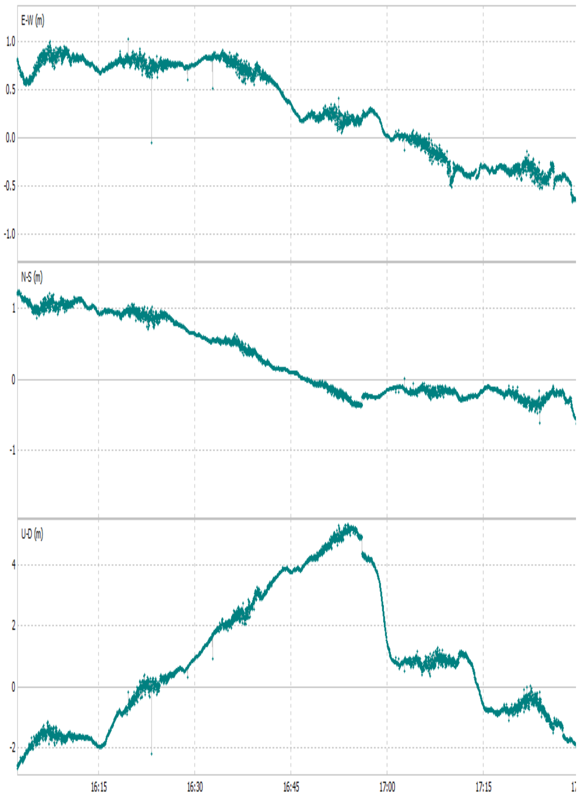


IGS Station Network

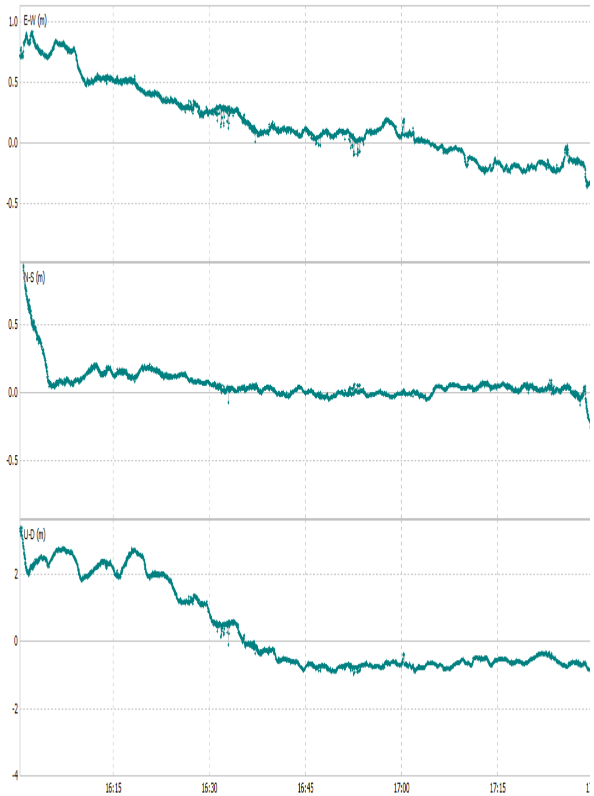
Precise Point Positioning – QZSS LEX



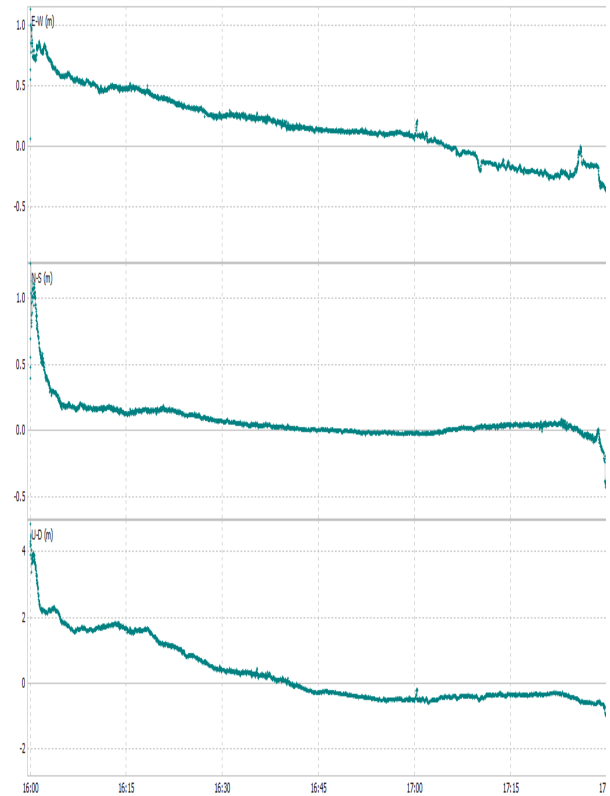
Precise Point Positioning – Some Results



Kinematic – IGS Ultra Rapid



Kinematic – IGS Rapid



Kinematic – QZSS LEX

- LEX Realtime positioning is possible (almost as good as IGS Rapid product)
- Convergence time is still a problem (30-60 minutes to reach decimeter level in kinematic mode)

Conclusions

- Multi-GNSS environment increases: availability, reliability and accuracy of the navigation services
- South-East Asia is covered by the largest number of systems (GNSSes + RNSSes) => interesting region for GNSS research
- Multi-GNSS positioning solutions are validated in South-East Asia, with results showing the advantages of multi-GNSS solutions
- QZSS-LEX is a good solution for precise positioning (no local infrastructure required, good performance…)
- … but just the beginning, exhaustive research on “smart” combinations of G(R)NSSes (with complexity & cost concerns) must be done.

Thank you very much for your attention!

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