Global Navigation Satellite Systems (GNSS)

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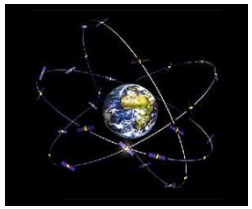
Overview of Presentation

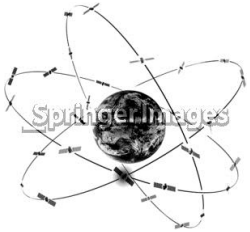
1. Overview of current GNSS/RNSS status

2. Opportunities with multi-GNSS

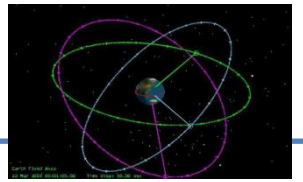
Multi-GNSS/RNSS – System Overview

- Global systems
  - USA Global Positioning System (GPS)
  - Russia Global'naya Navigatsionnaya Sputnikovaya Sistema (GLONASS)
  - EU Galileo
  - China BeiDou





- Regional and augmentation systems
  - Japan Quasi-Zenith Satellite System (QZSS)
  - India Indian Regional Navigation Satellite System (IRNSS)
  - WAAS, EGNOS, MSAS, GAGAN, SDCM



GNSS in a Nutshell: Operational Status

	Healthy SV	Orbiting SV	As of	Source
GPS	31	31	30/04/2016	NAVCEN*1
GLONASS	23	28	30/04/2016	Information Analysis Centre *2
Galileo	10	12	29/03/2016	European GNSS Service Centre*3
BeiDou-2 BeiDou-3	14 6	16 6	29/03/2016	China Satellite Navigation System Office
QZSS	-	1	30/04/2016	QZ-vision*4
IRNSS	7	7	30/04/2016	Indian Space Research Organisation*5
	91	101		

*1: http://navcen.uscg.gov/?Do=constellationStatus
*2: http://www.glonass-ianc.rsa.ru/en/index.php
*3: http://www.gsc-europa.eu/system-status/Constellation-Information
*4: http://qz-vision.jaxa.jp/USE/en/naqu
*5: http://www.isro.gov.in/irnss-programme/towards-self-reliance-navigation-irnss

GPS

GPS Constellation Status
(30.04.2016)

31 Healthy Satellites
Baseline Constellation: 24

- 12 Block IIR satellites
- 7 Block IIR-M satellites
- 12 Block IIF satellites
  - Broadcasting L5 “safety of life” signals
  - Better resistance to jamming
  - The final GPS IIF satellite was launched on 5 February 2016 and became available to users on March 9.
- Future Block III satellites (FY17)
  - Signals 3 times more accurate than current GPS
  - Provide military users up to 8 times improved anti-jamming
  - Increase SV operational life (25% longer than Block IIF)
  - New L1C signal – interoperable with other GNSSs

GPS Modernisation Program

Increasing System Capabilities ◆ Increasing User Benefit

Block IIA/IIR

Basic GPS

- Standard Service
  - Single frequency (L1)
  - Coarse acquisition (C/A) code navigation
- Precise Service
  - Y-Code (L1Y & L2Y)
  - Y-Code navigation

Block IIR-M, IIF

IIR-M: IIA/IIR capabilities plus

- 2nd civil signal (L2C)
- M-Code (L1M & L2M)

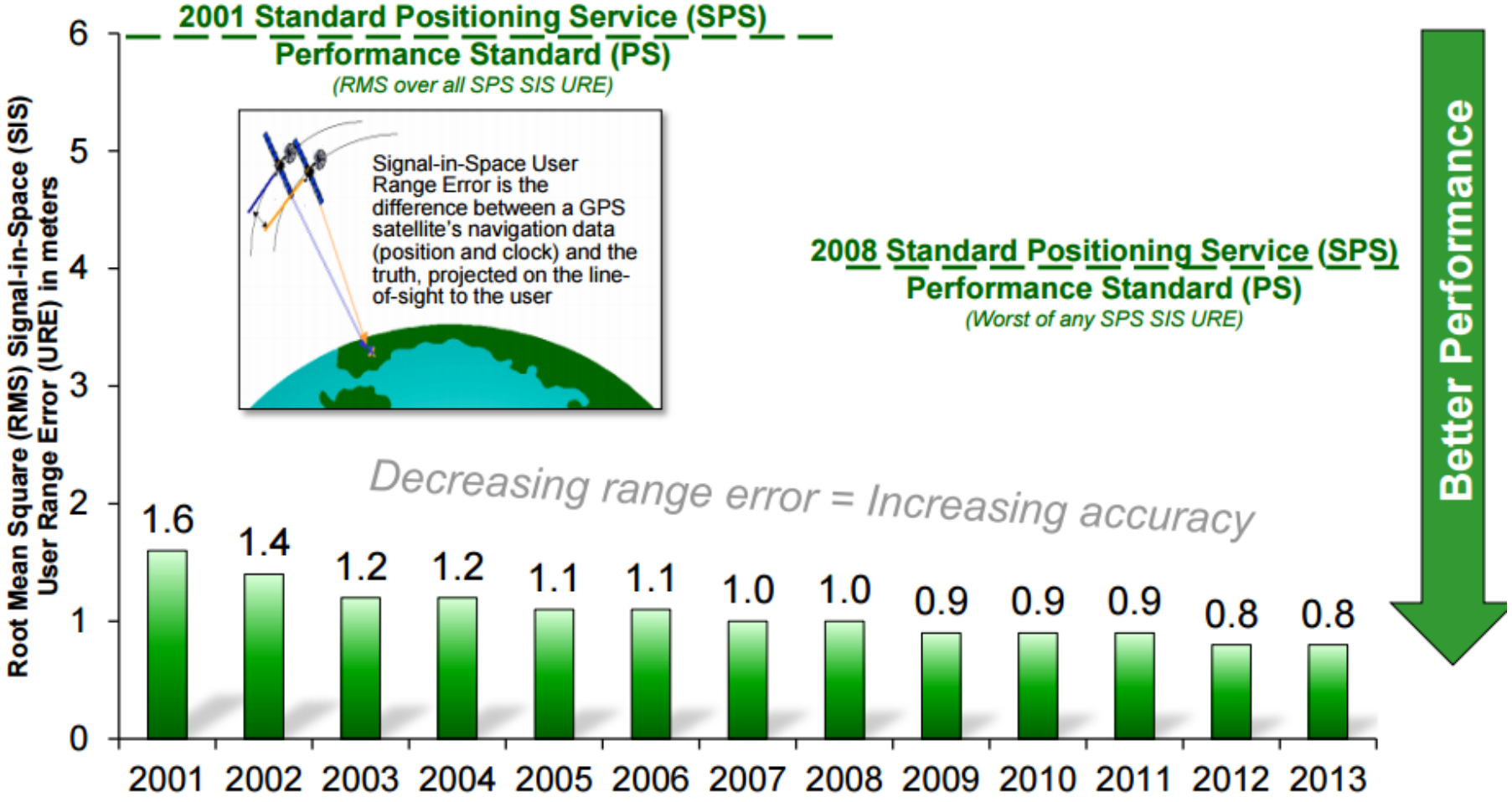
IIF: IIR-M capability plus

- 3rd civil signal (L5)
- 2 Rb + 1 Cs Clocks
- 12 year design life

Block III

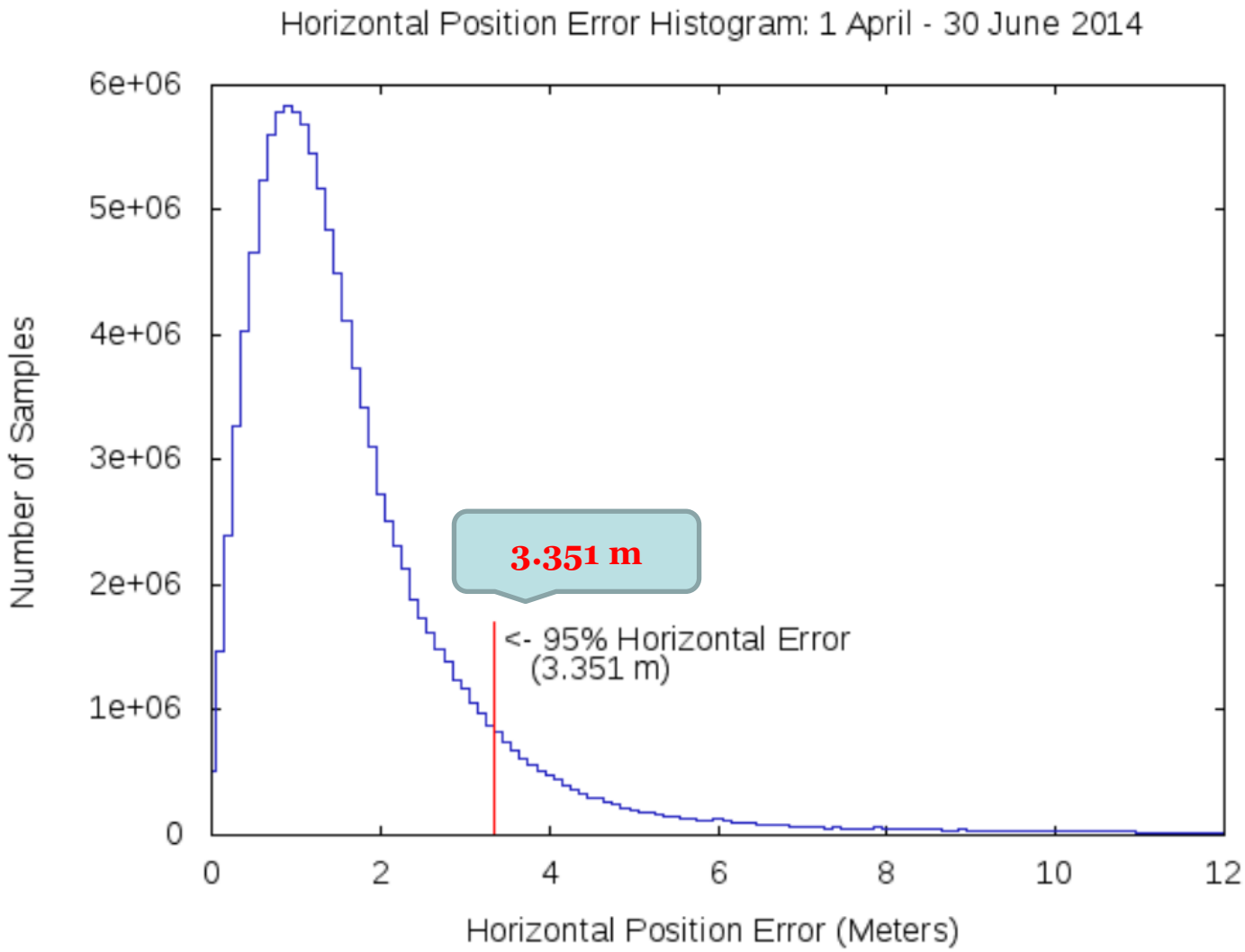
- Backward compatibility
- 4th civil signal (L1C)
- 4x better User Range Error than IIF
- Increased availability
- Increased integrity
- 15 year design life

Standard Positioning Service (SPS) Signal-in-Space Performance



System accuracy better than published standard

GPS Horizontal Position Accuracy



Source: http://www.gps.gov/systems/gps/performance/accuracy/

GLONASS

Summary

- GLONASS Program is high priority of the Russian Government

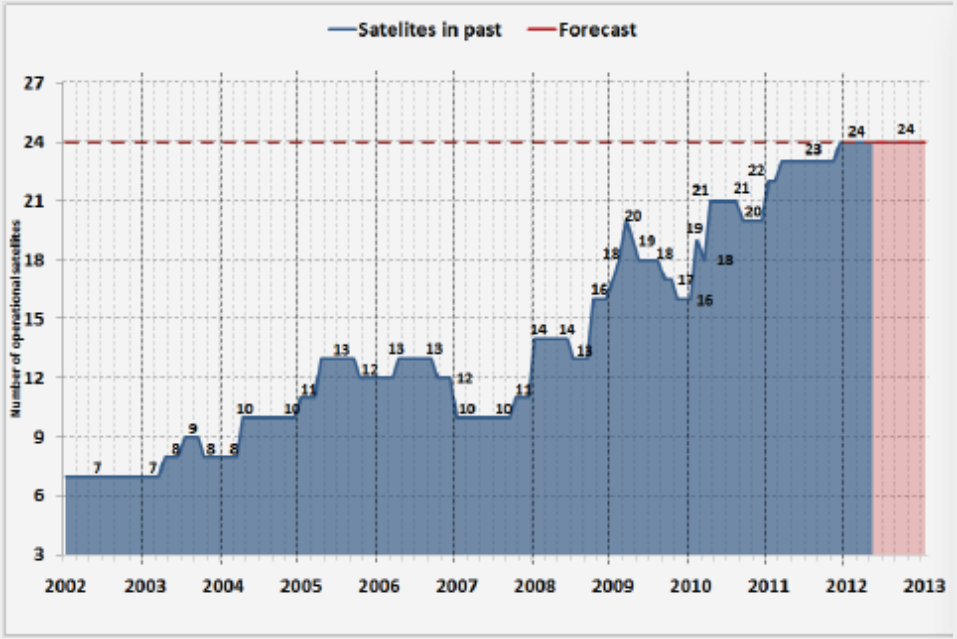
  The Presidential Decree № 638 dated May 17, 2007: “On Use of GLONASS (Global Navigation Satellite System) for the Benefit of Social and Economic Development of the Russian Federation”

- GLONASS open service is free for all users
- GLONASS achieved FOC 19 December 2011
- GLONASS performance to be comparable with GPS
- GLONASS will continue
  - Keep the GLONASS traditional frequency bands
  - Transmit existing FDMA signals
  - Introduce new CDMA signals
- New GLONASS Program (2012 – 2020)
  - Adopted 3 March 2012
  - GLONASS sustainment, development, use
- International cooperation – make GLONASS as one of key elements of the international GNSS for worldwide use

Constellation Status
(30/04/2016)

Total in orbit	28 SV
Operational (healthy)	23 SV
In maintenance	1 SV
Under check by the Satellite Prime Contractor	2 SV
Spares	1 SV
Flight Test	1 SV

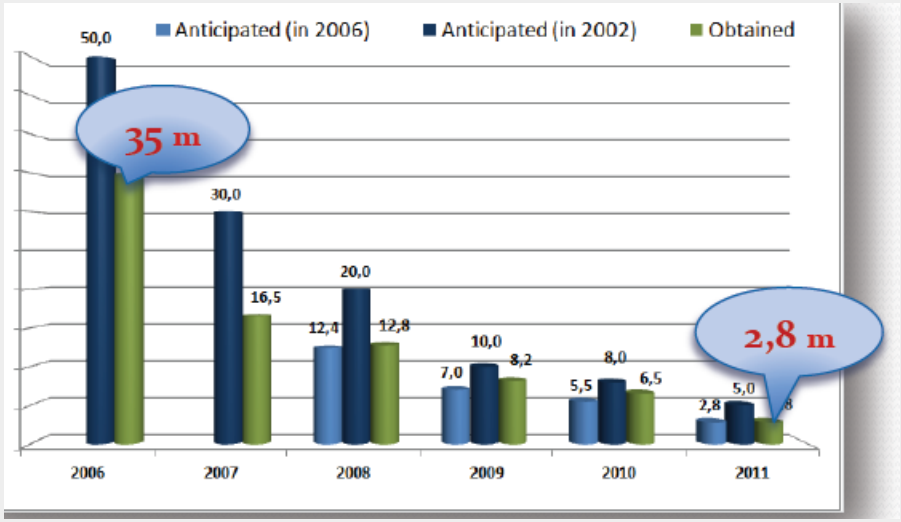
Number of operational satellites

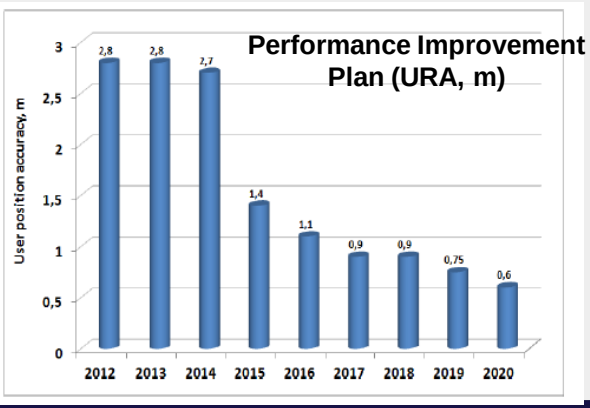


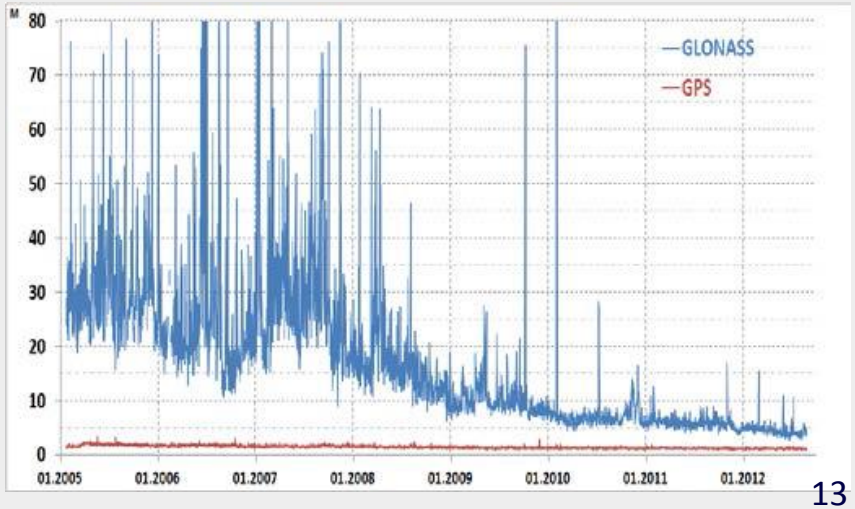
The current configuration of GLONASS constellation enables continuous navigation worldwide.

Results of the Federal GLONASS Program (2002 – 2012)

- GLONASS constellation is 100% deployed
  - 2002 6-7 satellites
  - 2012 24 satellites
- Availability
  - 2002 18%
  - 2012 100%
- Accuracy
  - 2006 35 m (1 sigma)
  - 2012 2.8 m (1 sigma)







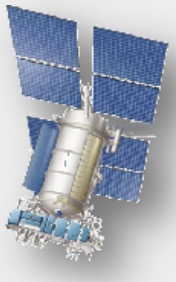
GLONASS Modernisation Plan

1982 — **2003** — **2011** — **2013-2014**

“Glonass”

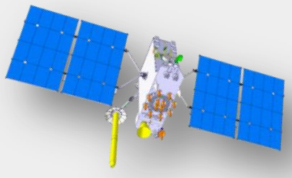
- 3 year design life
- Clock stability - $5*10^{-13}$
- Signals: L1SF, L2SF, L1OF, (FDMA)
- Totally launched 81 satellites
- Real operational life time 4.5 years

“Glonass-M”



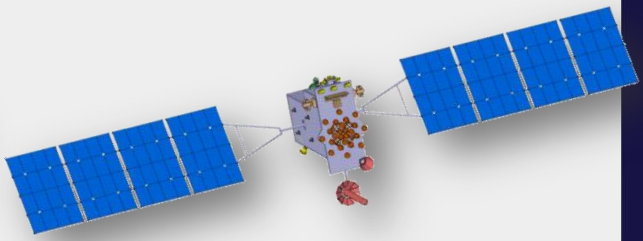
- 7 year design life
- Clock stability $1*10^{-13}$
- Signals: Glonass + L2OF (FDMA)
- Totally launched 28 satellites and going to launch 8 satellite by the end 2012

“Glonass-K1”



- 10 year design life
- Unpressurized
- Expected clock stability ~10…$5*10^{-14}$
- Signals: Glonass-M + L3OC (CDMA) – test
- SAR

“Glonass-K2”



- 10 year design life
- Unpressurized
- Expected clock stability ~5…$1*10^{-14}$
- Signals: Glonass-M + L1OC, L3OC, L1SC, L2SC (CDMA)
- SAR

CDMA signals general structure already designed

Galileo

Galileo Implementation Plan

Navigation solutions powered by Europe

Galileo is implemented in a step-wise approach

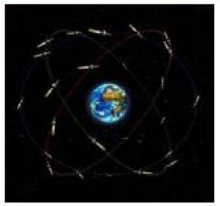
By 2020 Galileo will be:

- ★ fully deployed and recognised
- ★ adopted by the widest user communities
- ★ a civilian infrastructure delivering robust positioning and timing services with high degree of performances

Full Operational Capability
Full services, 30 satellites

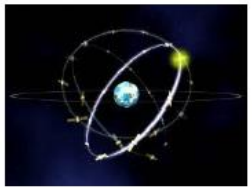
Initial Operational Capability
Initial services for OS, SAR, PRS, and demonstrator for CS

2016



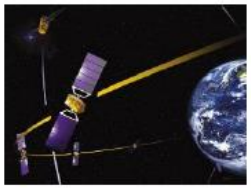
In-Orbit Validation
4 fully operational satellites and ground segment

2013



GIOVE A/B
2 test satellites

2005/2008



Galileo System Testbed v1
Validation of critical algorithms

2003

GALILEO GIOVE

GALILEO GSTB-V1

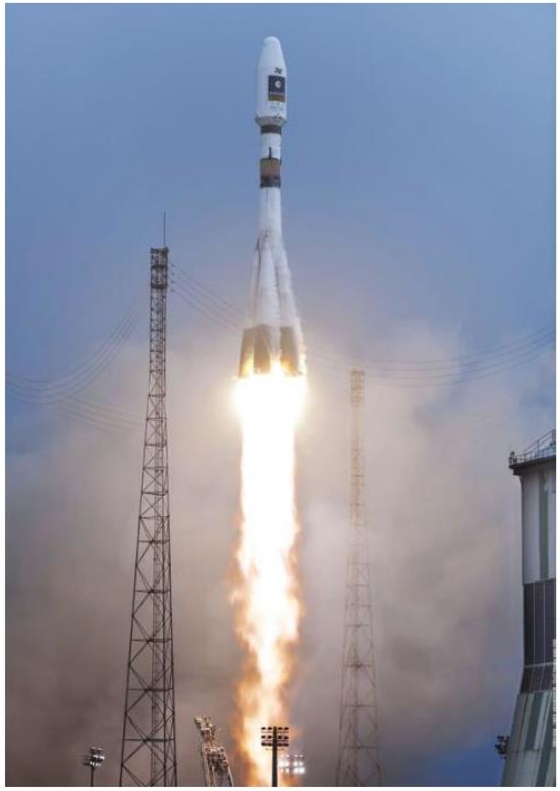
The Galileo Service

Navigation solutions powered by Europe

Open Service (OS)	Freely accessible service for positioning, navigation and timing	
Public Regulated Service (PRS)	Encrypted service designed for greater robustness in challenging environments	
Search and Rescue Service (SAR)	Locates distress beacons and confirms that message is received	
Commercial Service (CS)	Delivers authentication and high accuracy services for commercial applications	

Integrity Monitoring Service	Provides vital integrity information for life-critical applications	

Galileo Space Segment



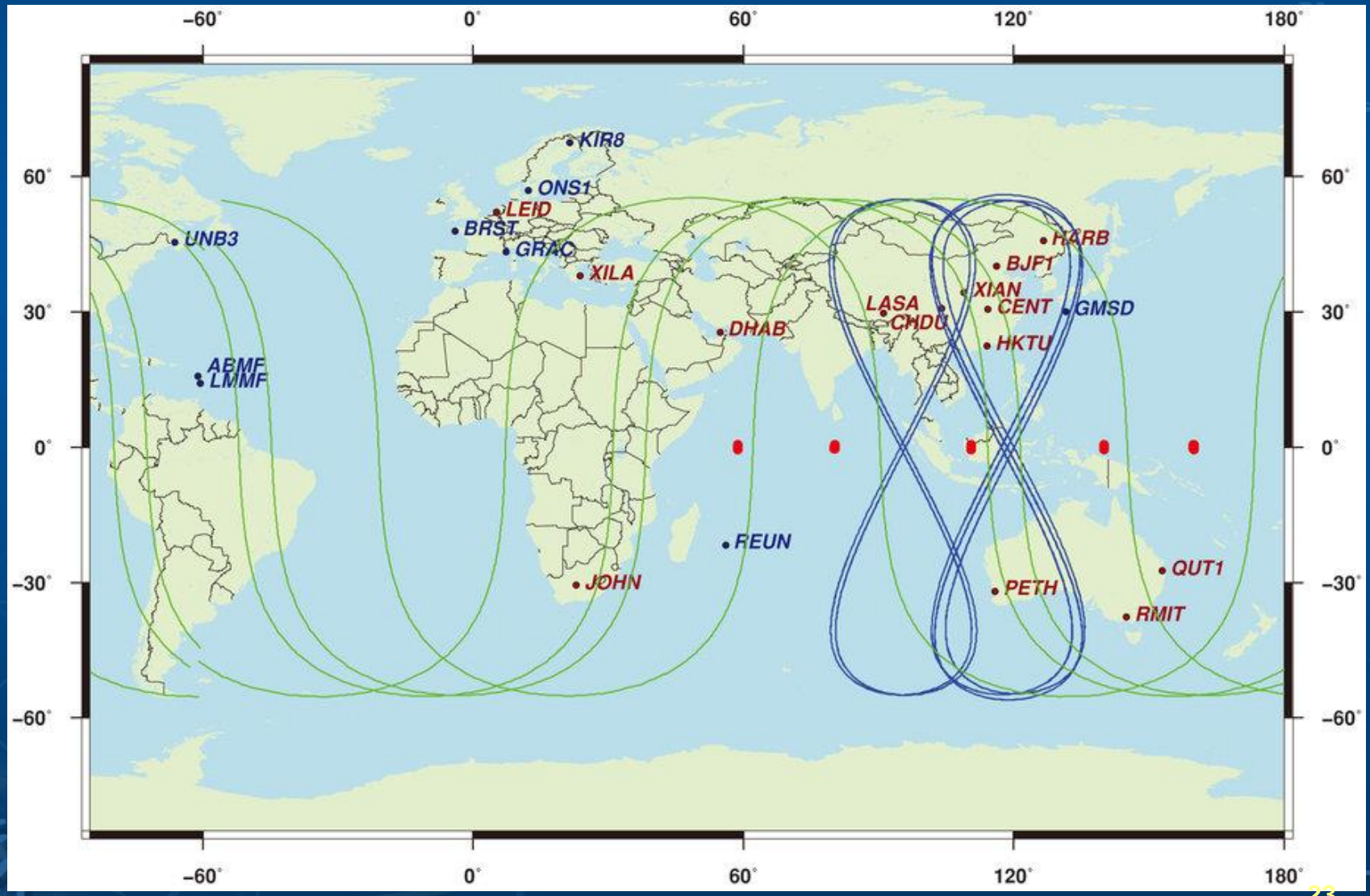
- First four satellites (IOV) launched in 2011 and 2012
- Satellite 5 & 6 are recovered and safe on improved orbits
- Satellite 7 & 8 launched on 27 March 2015
- 26 satellites to be launched by 2018

BeiDou

History and Innovation

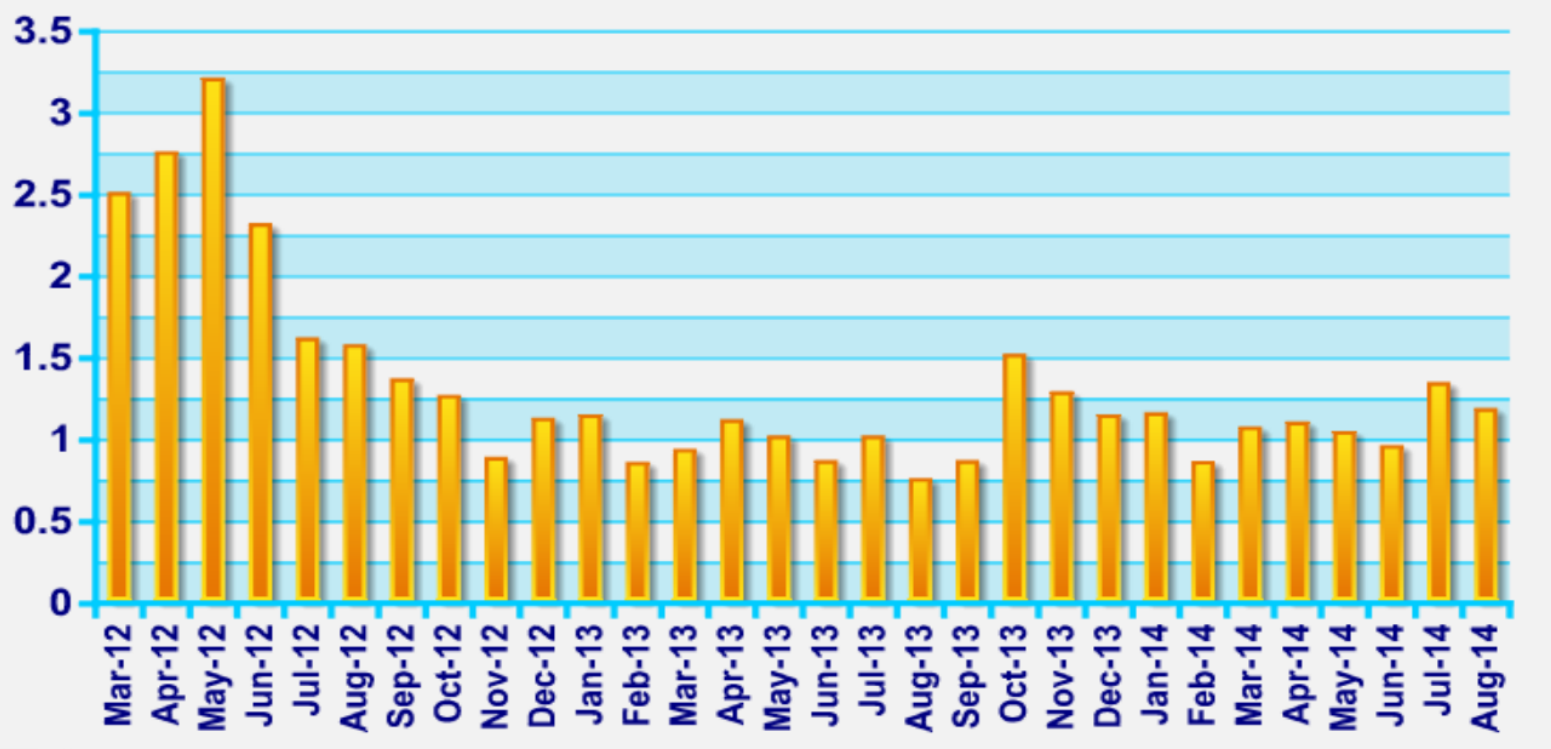
- BeiDou-1 (2000s)
  - 2 GEO satellites, active positioning system
- BeiDou-2 (formerly Compass, 2007-2015)
  - Regional service with a total of 15 satellites
    - 6 GEO, 6 IGSO, 4 MEO (Feb 2016)
- BeiDou-3 (2015 - 2020)
  - Global service with a total of 35 satellites
    - 5 GEO, 27 MEO, 3 IGSO
    - 1 February 2016: 21st BDS (MEO) satellite
    - 5 April 2016: 22nd BDS (IGSO) satellite
    - Another 18 satellites by the end of 2018

Constellation



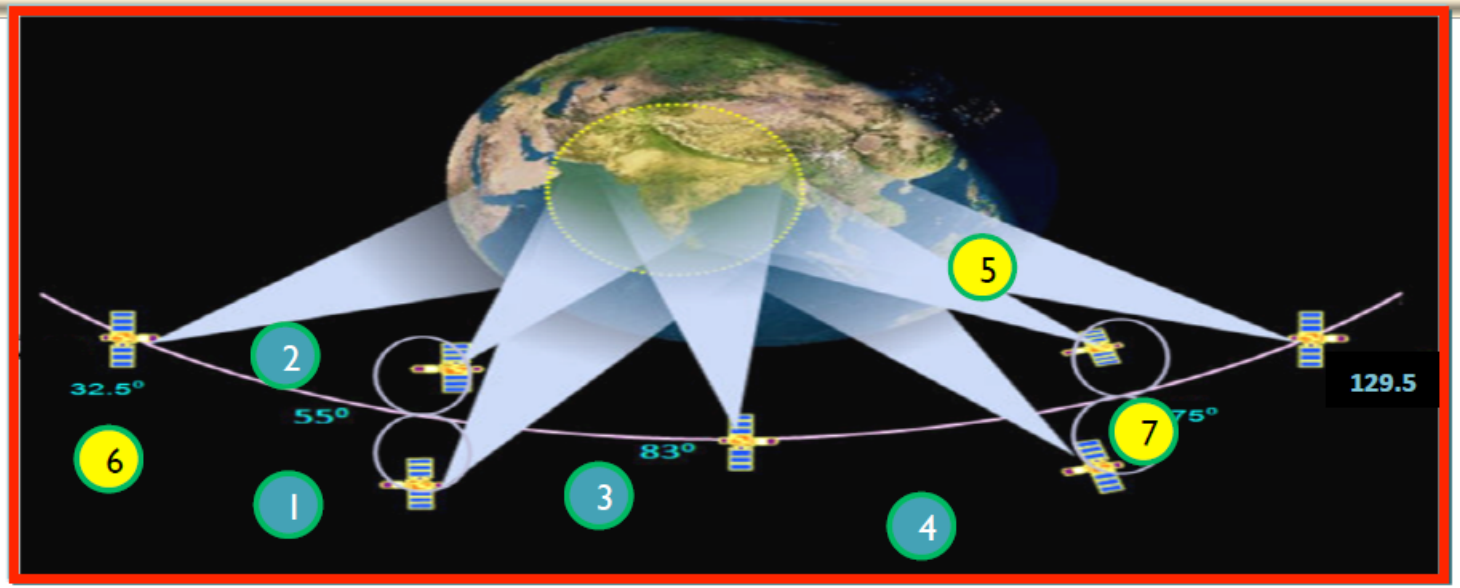
Operational Performance

- ★ Continuous and stable operation.
- ★ Constantly-improving performance



IRNSS

Indian Regional Navigation Satellite System (IRNSS)

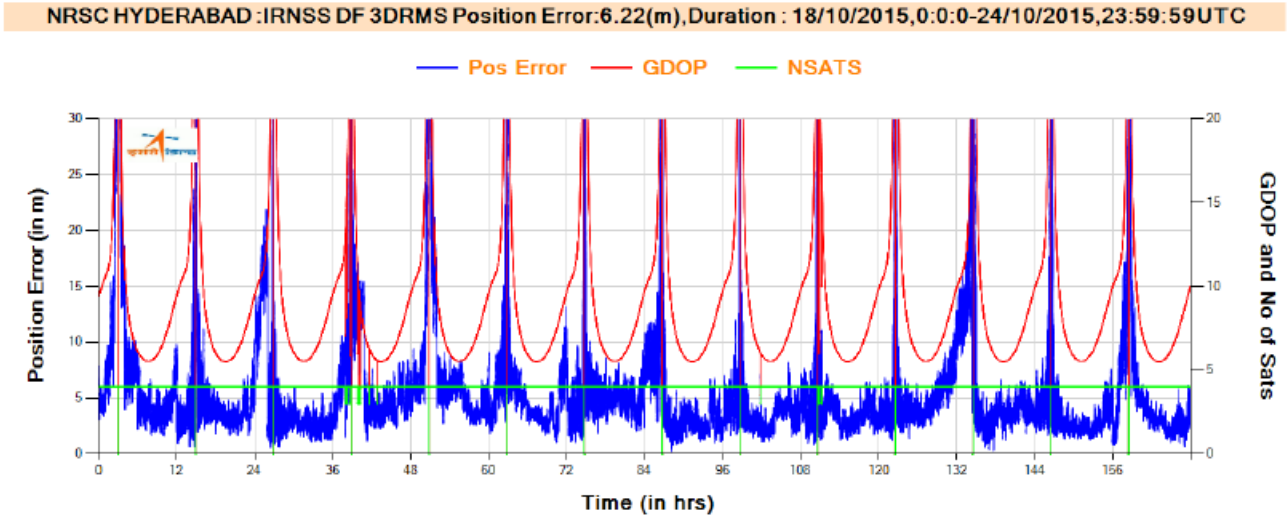


- IRNSS – Regional Navigation Satellite System
- IRNSS consists of 7 Satellites
  - 4 Geo Synchronous Orbit (GSO) satellites at 55° E and 111.75° E at an inclination of 29°
  - 3 Geo Stationary Satellites (GEO) at 32.5° E, 83° E and 129.5° E
- IRNSS transmits signals in L5 band (1176.45 MHz) and S band (2492.048 MHz)

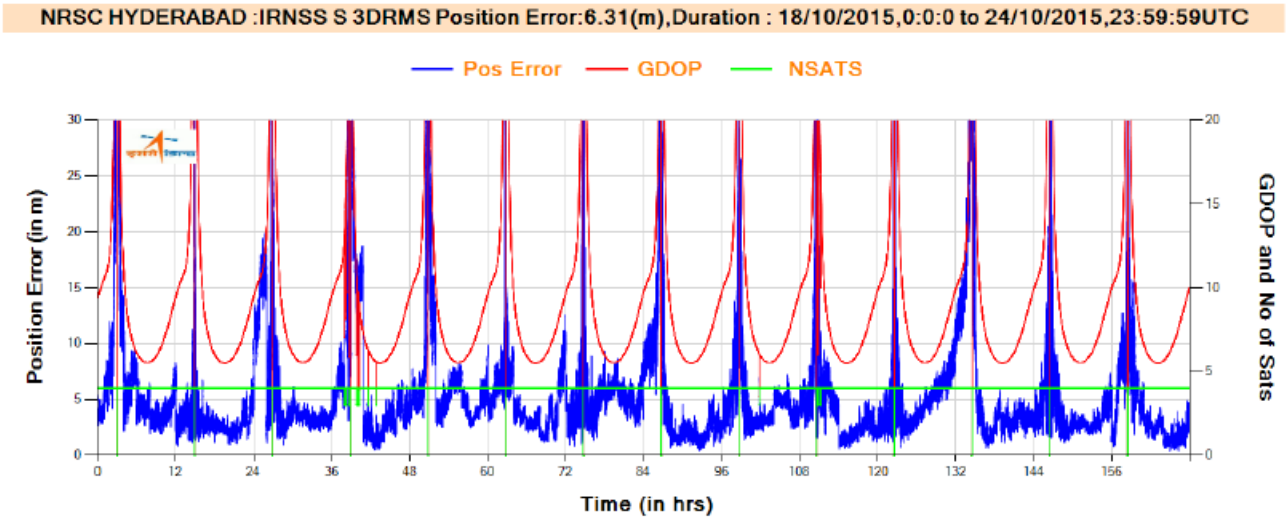
Indian Regional Navigation Satellite System (IRNSS)

- IRNSS shall provide two types of services – Standard Positioning services (SPS) and Restricted Services (RS)
- 7 IRNSS satellites are successful realized in orbit:
  - 5th: IRNSS-1E, GSO (20 January 2016)
  - 6th: IRNSS-1F, GEO (10 March 2016)
  - 7th: IRNSS-1G, GEO (28 April 2016)
- Current constellation satellites are functional with navigation signals in L5 and S-band.
- Efforts to bring in L1-band in future satellites are under progress.
- Renamed - Navigation with Indian Constellation or NavIC (नाविक = sailor/navigator)

Indian Regional Navigation Satellite System (IRNSS)



Position Error with Dual Frequency Receiver (L5 and S band)



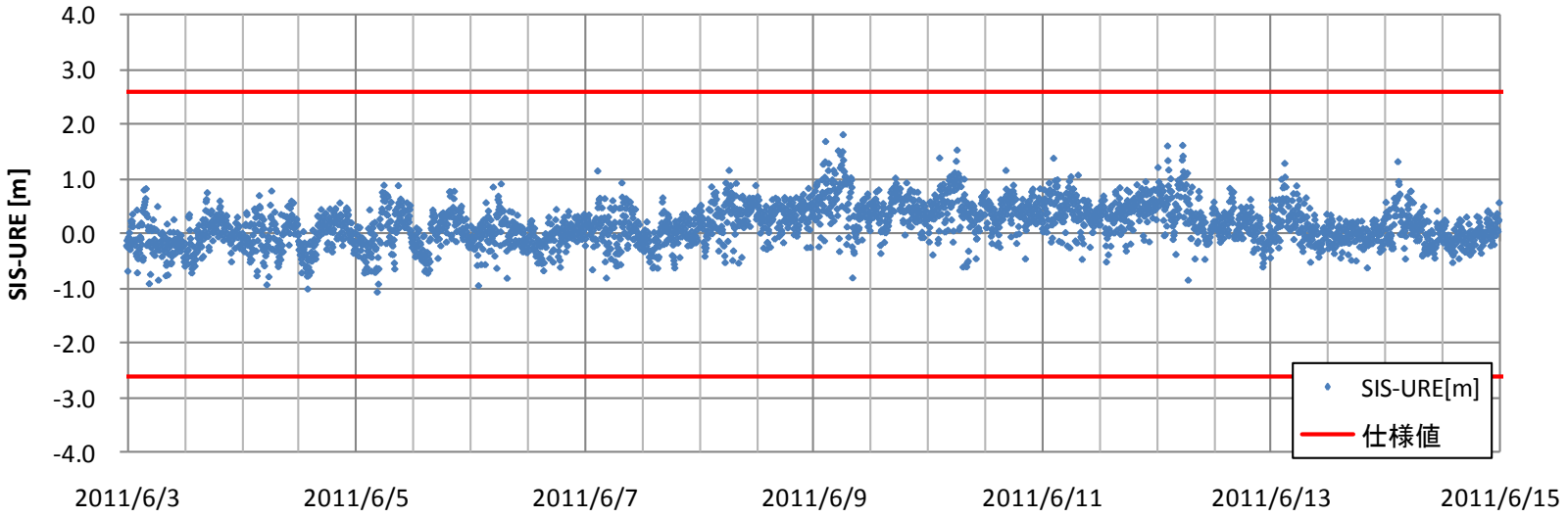
Position Error with Single Frequency Receiver (S-band with Grid Model for Iono Correction)

QZSS

Current Status

- The first satellite “MICHIBIKI” was launched on 11 September 2010.

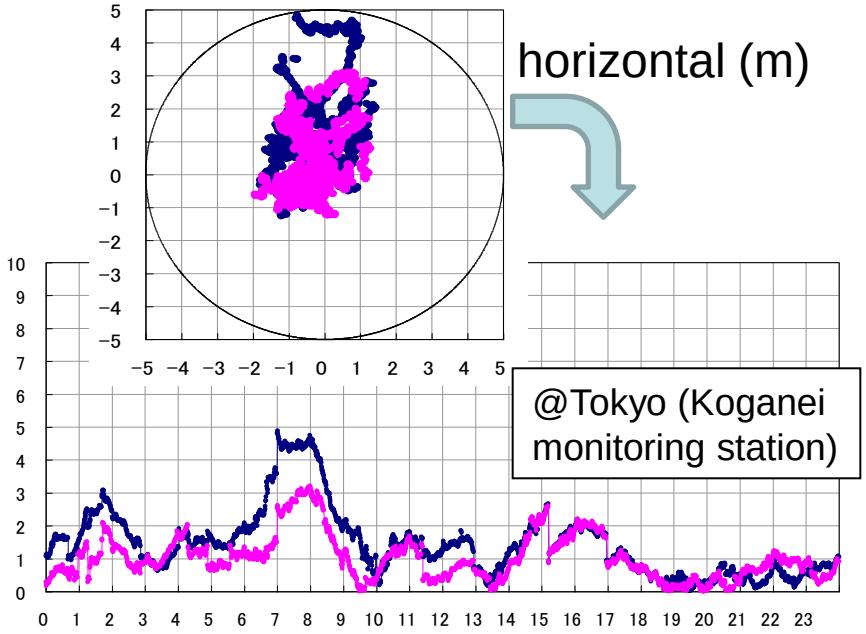
SIS-URE in the IS-QZSS (Interface Specification of QZSS) is +/- 2.6m (95%). JAXA confirmed that the stability of MICHIBIKI SIS-URE using 12 days duration, and the time percentage in spec is 100%.

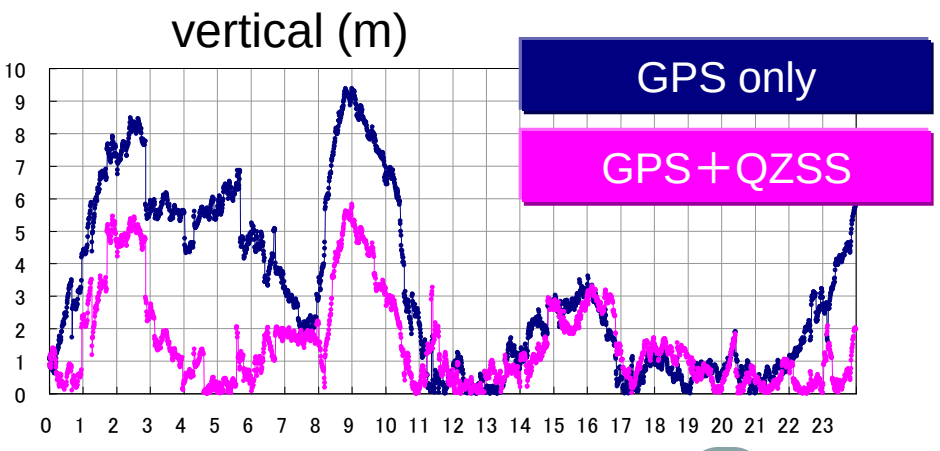


MICHIBIKI SIS-URE (12 days duration)

Accuracy (Combination of GPS + QZSS)

We confirmed the accuracy of the combination of GPS+QZSS improves because of DOP and good ionospheric correction parameters from MICHIBIKI.





Improvement

Positioning accuracy (m)		GPS only	GPS+QZSS
Horizontal	Average	1.451	1.027
	RMS	1.773	1.232
	Max	4.885	3.209
Vertical	Average	3.204	1.540
	RMS	4.122	2.080
	Max	9.388	5.828

Evaluation conditions

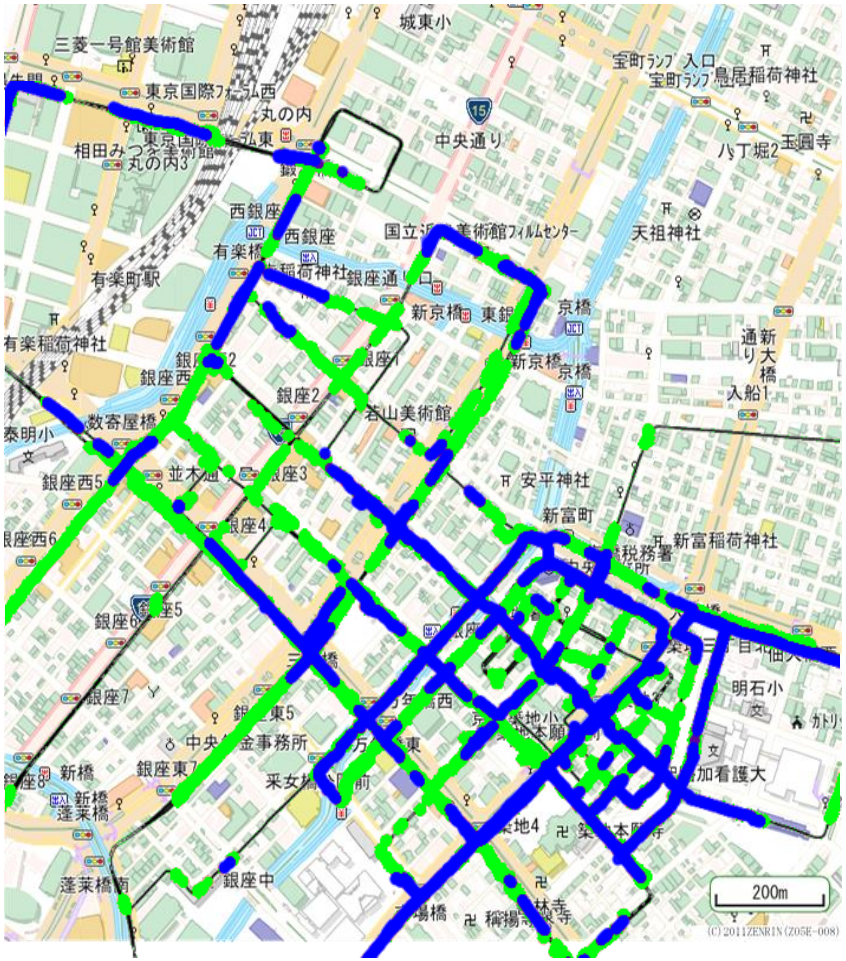
- point: Tokyo (Koganei Monitoring Station)
- date: 2011/06/03 00:00:00 23:59:30(GPST)
- mask elevation angle: 10 degrees
- ionospheric correction

  GPS only : using the parameters from GPS

  GPS+QZS : using the parameters from QZSS

One Example of Availability Improvement at Ginza in Tokyo (Feb. 19, 2011)

∞∞∞∞∞∞∞∞∞Quasi-Zenith Satellite System∞∞∞∞∞∞∞∞∞Quasi-Zenith Satellite System∞∞∞∞∞∞∞∞∞Quasi-Zenith Satellite System∞∞∞∞∞∞∞∞∞



© 2011ZENRIN (Z05E-008)

Date of Observation: 19/02/2011
250 minutes driving observation data during 6:00-12:30 obtained under JAXA-Melco joint research experiment

Single Frequency DGPS positioning Availability

GPS: 39.5%

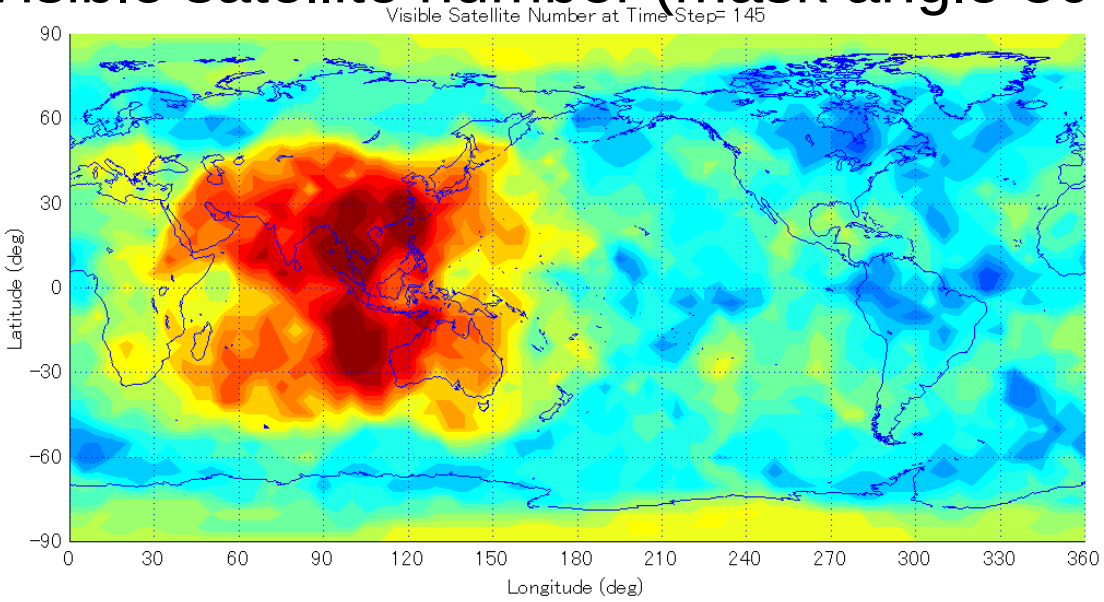
→ **GPS+QZSS: 69.1%**

- Reference trajectry (measured by MMS)
- Positioning result for GPS standalone use
- Positioning result for GPS+QZSS combining use

What does multi-GNSS mean for users?

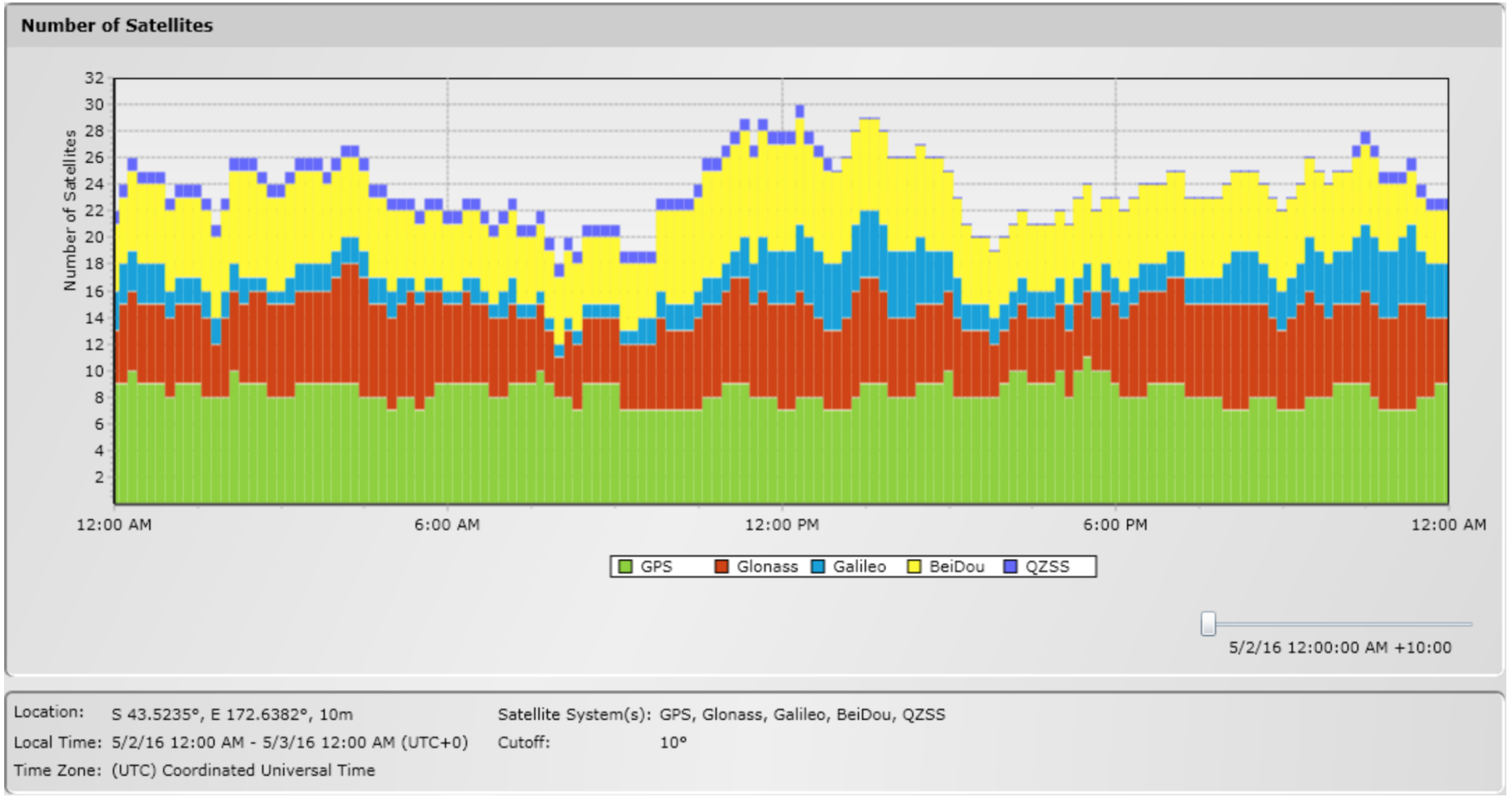
More Satellites

Visible satellite number (mask angle 30º)



GPS(27)+Glonass(24)+Galileo(30)+BeiDou(35)+QZSS(3)+IRNSS(7)+SBAS(7)

10 15 20 25 30 35


Number of Satellites
Number of Satellites
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
12:00 AM
6:00 AM
12:00 PM
6:00 PM
12:00 AM
GPS
Glonass
Galileo
BeiDou
QZSS
5/2/16 12:00:00 AM +10:00
Location: S 43.5235°, E 172.6382°, 10m
Local Time: 5/2/16 12:00 AM - 5/3/16 12:00 AM (UTC+0)
Time Zone: (UTC) Coordinated Universal Time
Satellite System(s): GPS, Glonass, Galileo, BeiDou, QZSS
Cutoff: 10°

More Signals

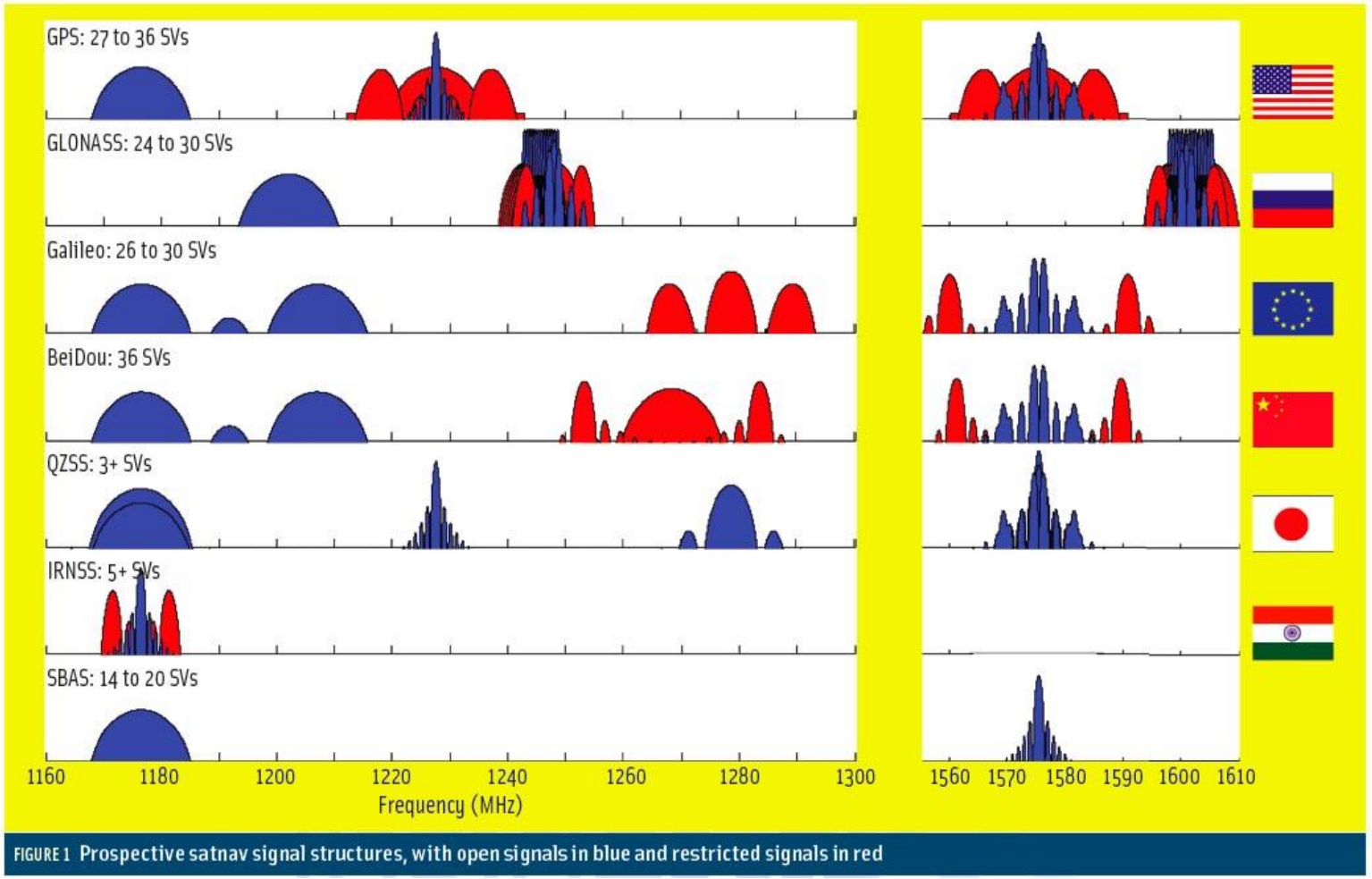
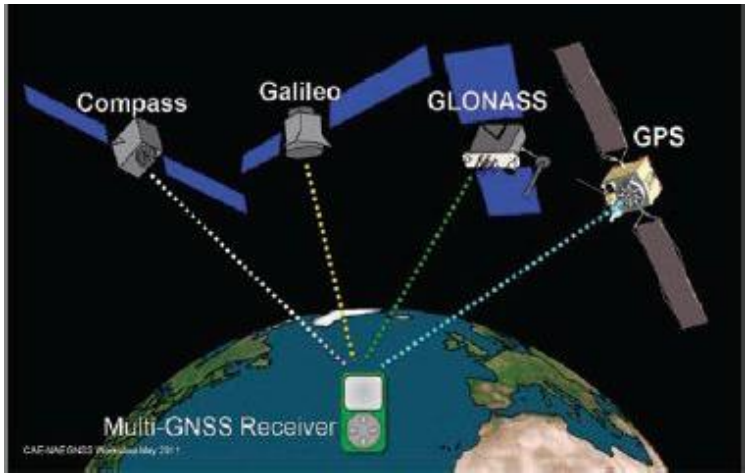


FIGURE 1 Prospective satnav signal structures, with open signals in blue and restricted signals in red

Different Coordinate Systems

GNSS	Coordinate System	Time System
GPS	WGS84	GPS Time
GLONASS	PZ90	GLONASS Time
Galileo	GTRF	Galileo System Time
BeiDou	CGCS2000	BeiDou Time
QZSS	JGS	QZSS Time
IRNSS	WGS84	IRNSS System Time



Transparent multi-GNSS interoperability is achievable through improved system and receiver design

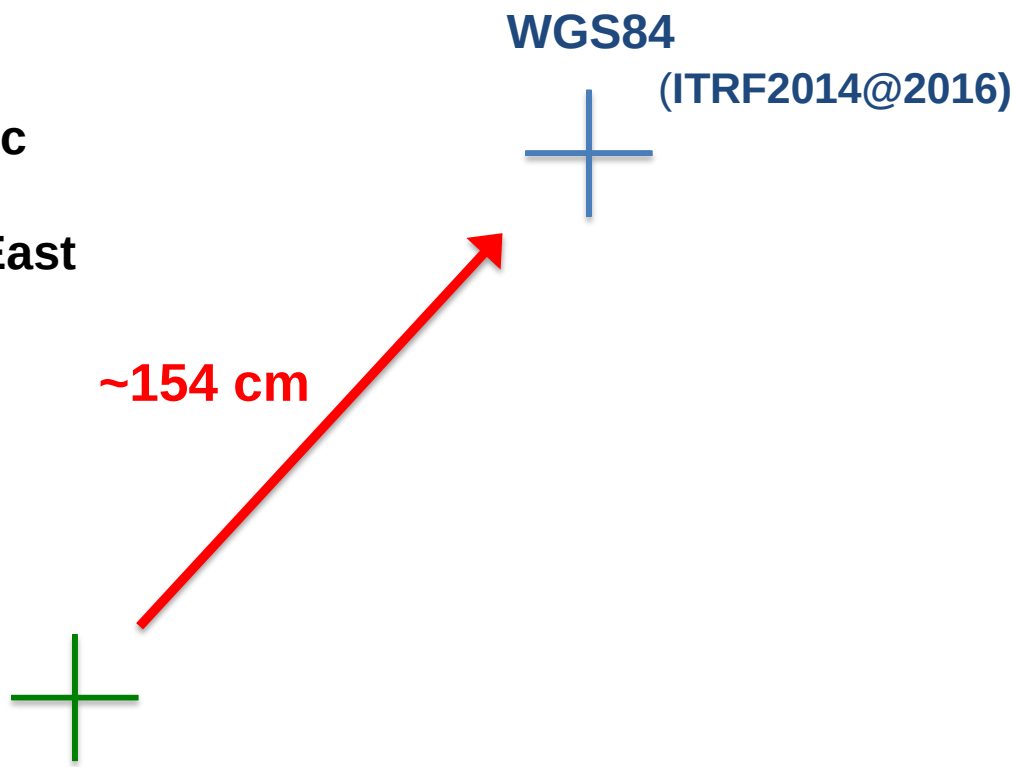
To my knowledge, most (if not all) GNSS coordinate systems are already ''aligned'' to ITRF:

- WGS84(G1762)≈ITRF at cm level
- PZ90.11≈ITRF at cm level
- GTRF≈ITRF at the mm level
- CGCS2000≈ITRF at the mm level
- JGS≈coordinate system defined to follow ITRS

Using the ITRF as a common reference frame will facilitate the interoperability!

Need to better handle Tectonic Motion

Australian Tectonic Plate's Velocity is ~7cm/year North East



Thanks for your attention!

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