Multi-GNSS Environment

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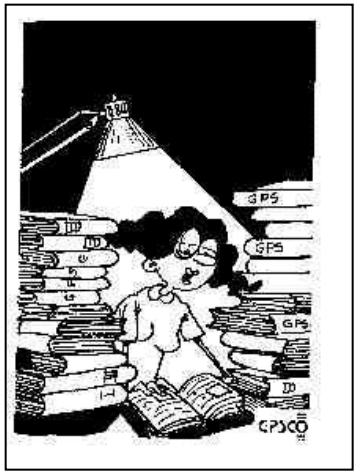
UNSW, Australia
President IAG

Visit official GNSS web sites:

- *GPS* - www.navcen.uscg.gov & www.gps.gov
- *GLONASS* - glonass-ianc.rsa.ru/en/
- *Galileo* - www.esa.int/Our_Activities/Navigation
- *BeiDou* – en.beidou.gov.cn
- *QZSS* - http://qzss.jaxa.jp/index_e.html
- *ICG* - http://www.unoosa.org/oosa/en/SAP/gnss/icg.html



Outline …

- Status of Multi-GNSS
- Multi-GNSS & the ICG
- Multi-GNSS & PPP/DGNSS
- The International GNSS Service

Status of Multi-GNSS

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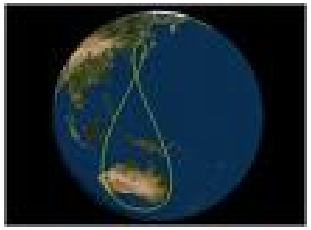
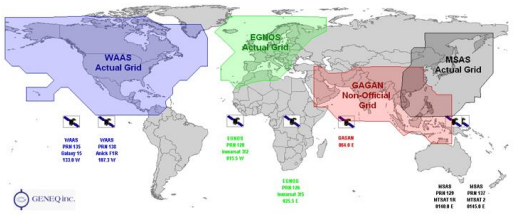
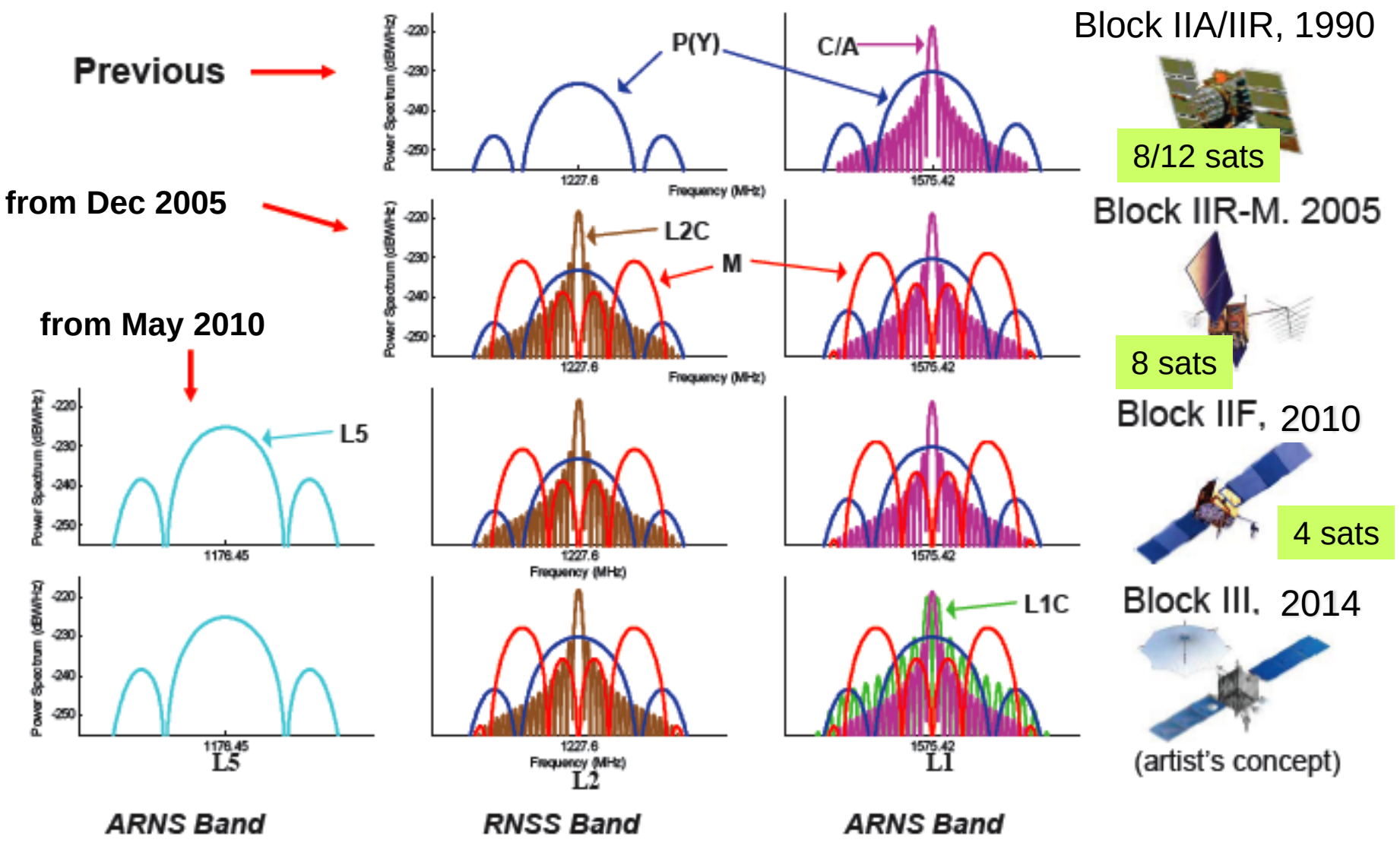


Multi-Constellation GNSS

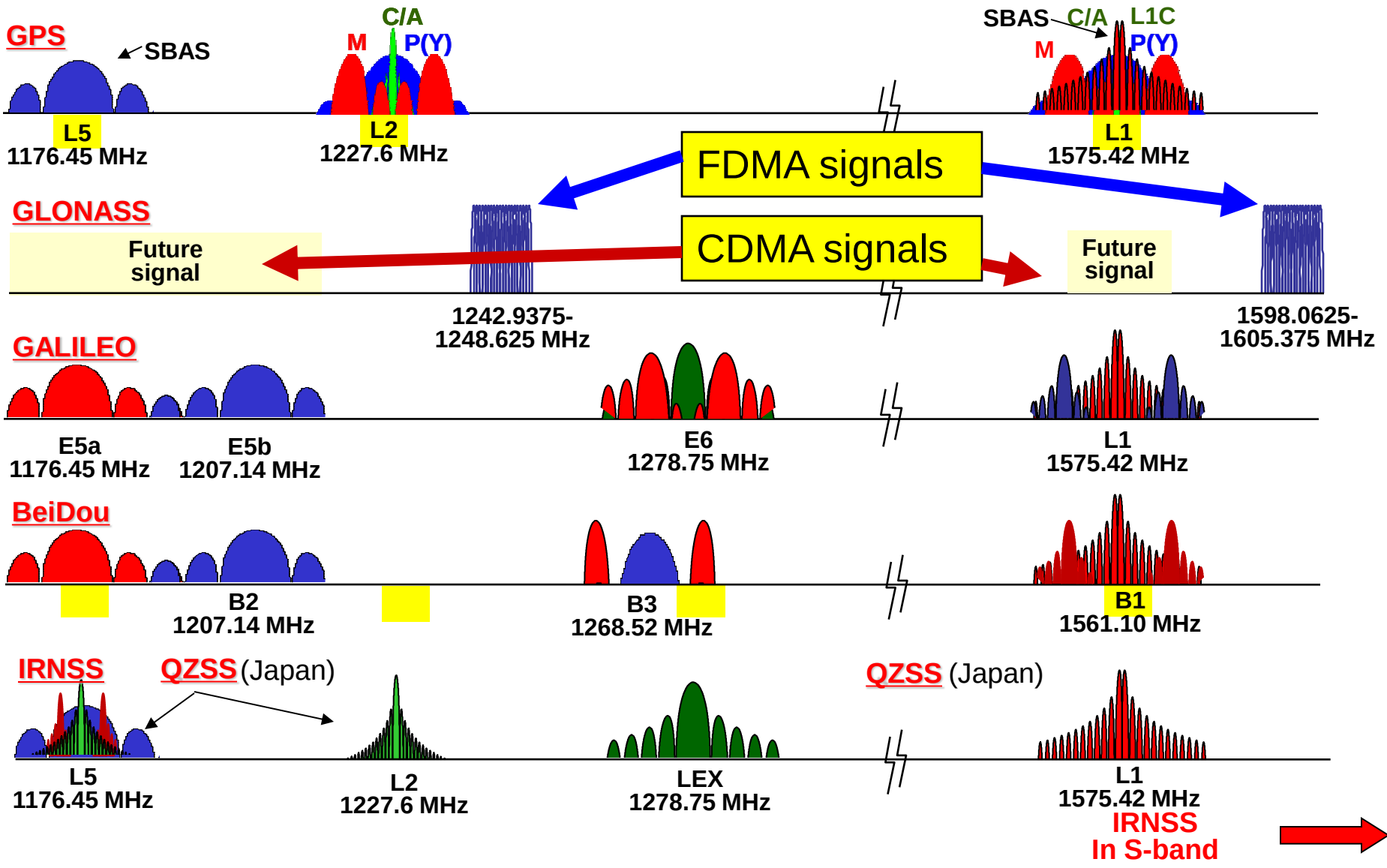
- Global Constellations:
  - GPS (32)(32)
  - GLONASS (30?)(24)
  - Galileo (30)(4)
  - BeiDou (35)(14)
- Regional Constellations:
  - QZSS (3-5+)(1)
  - IRNSS (7)(?)
- SBAS:
  - WAAS (3)
  - MSAS (2)
  - EGNOS (3)
  - GAGAN (2)
  - SDCM (2)



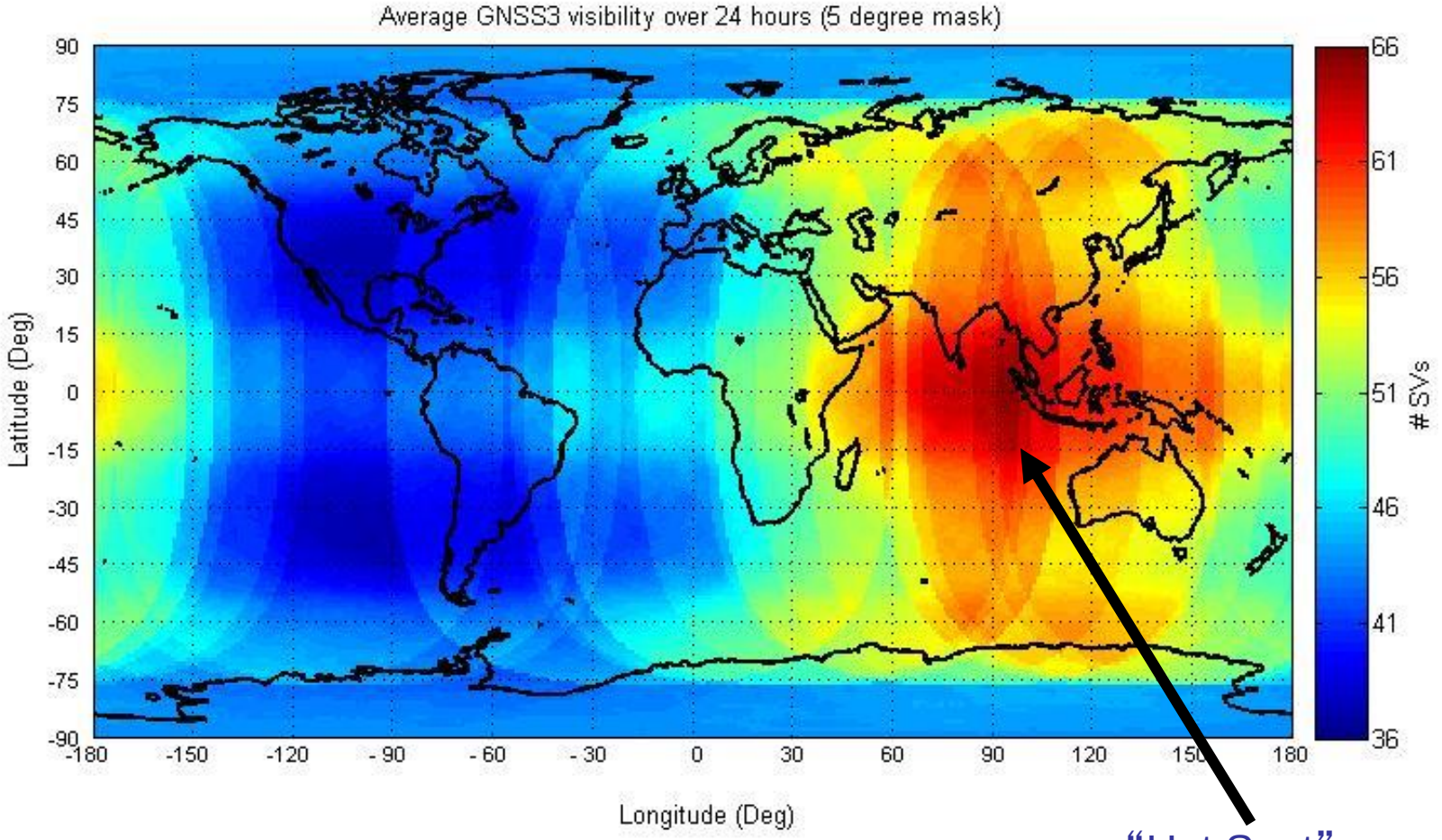
GPS Modernization



GNSS Frequency Bands & Interoperability

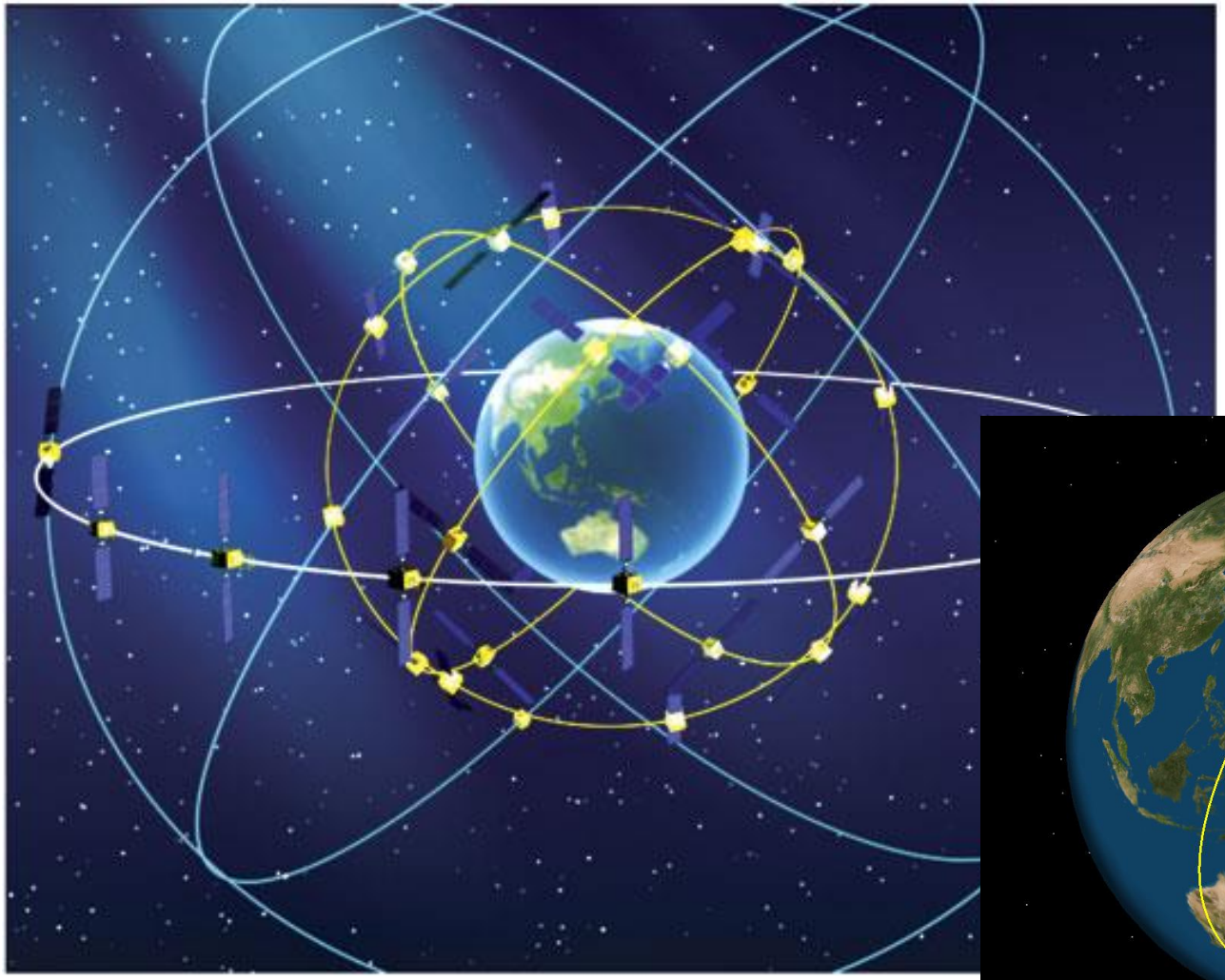


Future GNSS Visibility…

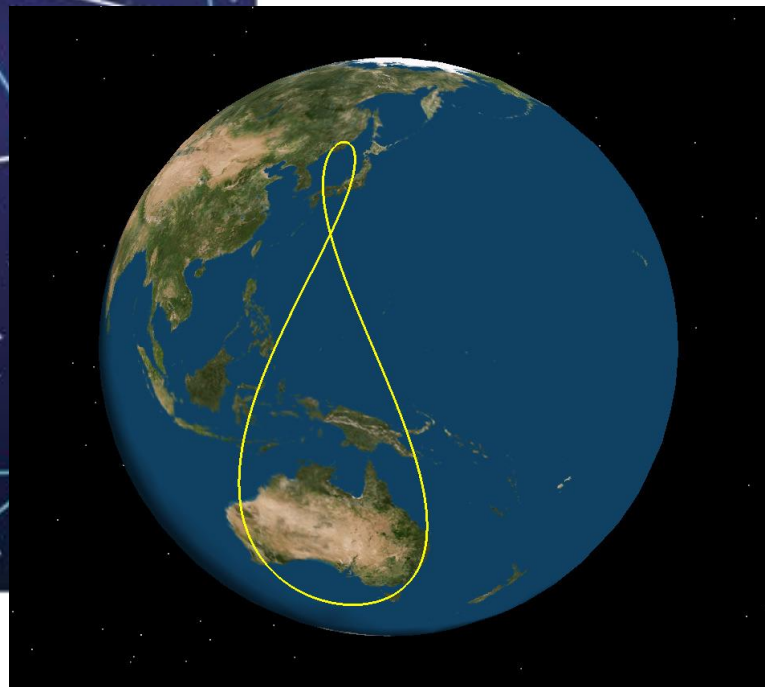


148 sat constellation

BeiDou Mixed Constellation:
MEO, IGSO, GEO



QZSS
IGSO



The constellation

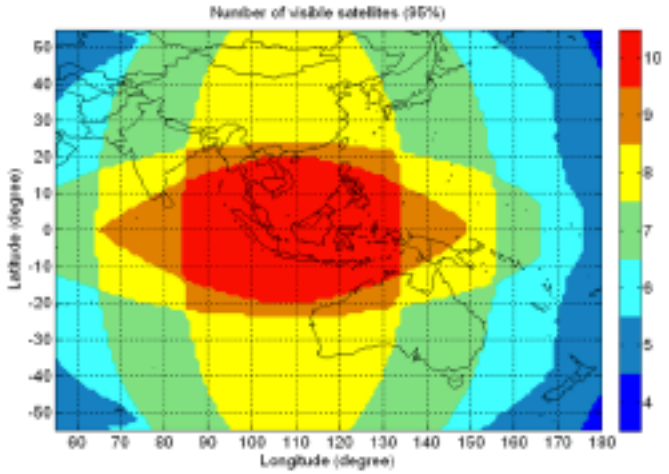
- The last GEO satellite of the regional BDS was launched on 25, Oct. 2012
- Service started on 27, Dec. 2012
- 14 working satellites: 5 GEO, 5 IGSO and 4 MEO.
- Three frequencies have been provided:

  B1: 1561.098 MHz

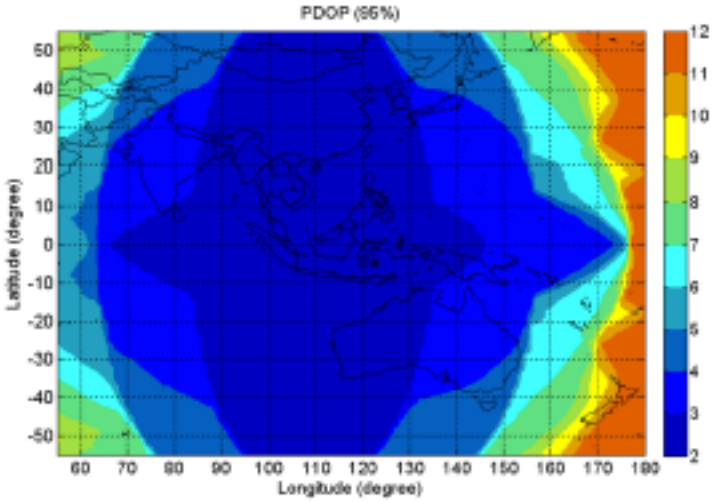
  B2: 1207.14 MHz

  B3: 1268.52 MHz
- PNT performance achieved the design target

■ Service area



Number of visible BDS sat in service area

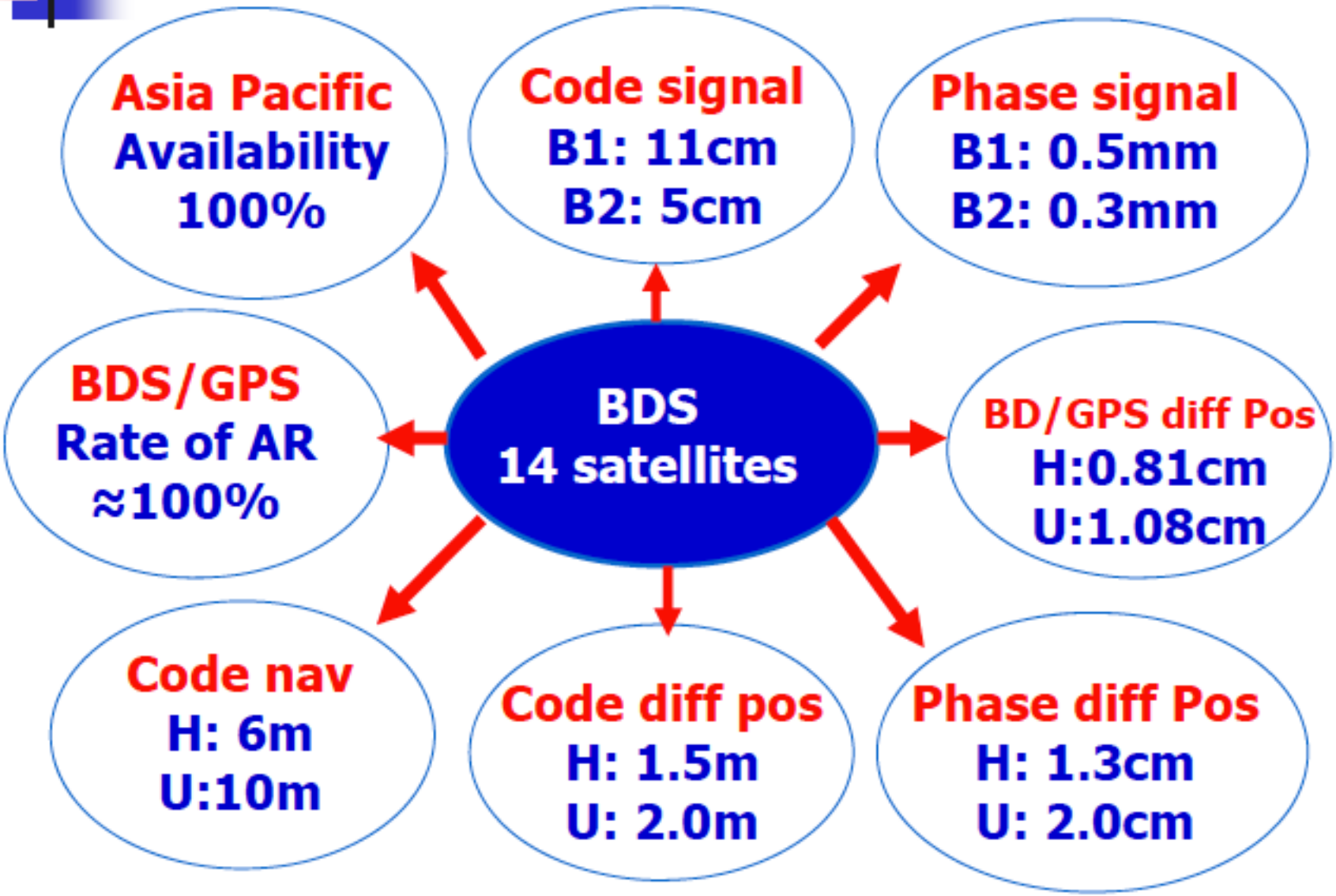


PDOP of BDS

- Area -50° ~50° B & 85° ~135° L

  visible sats >8

  PDOP~(2-3)


Asia Pacific
Availability
100%
Code signal
B1: 11cm
B2: 5cm
Phase signal
B1: 0.5mm
B2: 0.3mm
BDS/GPS
Rate of AR
≈100%
BDS
14 satellites
BD/GPS diff Pos
H:0.81cm
U:1.08cm
Code nav
H: 6m
U:10m
Code diff pos
H: 1.5m
U: 2.0m
Phase diff Pos
H: 1.3cm
U: 2.0cm

Multi-GNSS and the ICG

- What's new
- Office for Outer Space Affairs
- Meetings Calendar
- Committee on the Peaceful Uses of Outer Space
- Programme on Space Applications
- UN-SPIDER
- International Committee on GNSS
  - Providers Forum
  - ICG Meetings
  - **Working Group A**
  - Other Meetings and Events
  - ICG Activities
  - Regional Reference Systems
  - International Space Weather Initiative
  - Relevant Links
  - Education Resources
  - Publications
  - Videos
- Regional Centres for Space Science and Technology Education
- Space Law
- Register of Space Objects

ICG International Committee on Global Navigation Satellite Systems

A forum to discuss Global Navigation Satellite Systems (GNSS) to benefit people around the world

Following the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III), held in 1999, in its resolution 54/68, the United Nations General Assembly endorsed the "Vienna Declaration: Space Millennium for Human Development". The Vienna Declaration called for action, among other matters, to improve the efficiency and security of transport, search and rescue, geodesy and other activities by promoting the enhancement of, universal access to and compatibility of, space-based navigation and positioning systems. In response to that call, in 2001 the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) established the Action Team on Global Navigation Satellite Systems (GNSS) to carry out those actions under the chairmanship of Italy and the United States of America. The Action Team on GNSS, consisting of 38 member States and 15 inter-governmental and non-governmental organizations, recommended, among other things, that an International Committee on GNSS (ICG) should be established to promote the use of GNSS infrastructure on a global basis and to facilitate exchange of information. The Committee included this recommendation in the Plan of Action proposed in its report to the General Assembly on the review of the implementation of the recommendations of UNISPACE III. In 2004, in its resolution 59/2, the General

VIDEO PRESENTATIONS

- Global Positioning System (GPS)
- BeiDou Navigation Satellite System
- Global Navigation Satellite System (GLONASS)

PUBLICATIONS

International Committee on GNSS (ICG)

A forum to discuss Global Navigation Satellite Systems to benefit people around the world.

- **2005: Establishment of ICG**
  - **ICG Membership: Members, Associate Members and Observers**
    - **9 nations & the European Union**
    - **20 organisations (UN system entities, IGOs, NGOs) – IAG & FIG: founding members**

ICG participation is open to all countries and entities that are either GNSS providers or users of GNSS services, and are interested and willing to actively engage in ICG activities.

IAG
150 years

International Committee on GNSS (ICG)

2006 – 2012: ICG Annual Meetings

- **UNOOSA (2006), India (2007), USA (2008), Russia (2009), Italy & EU (2010), Japan (2011)**

2007: Establishment of Providers' Forum

- **China (BeiDou), India (GAGAN/IRNSS), Japan (QZSS/MSAS), Russia (GLONASS), US (GPS), EU (Galileo/EGNOS)**

2012: ICG-7, Beijing, China, 5 – 9 November

2013: ICG-8, Dubai, United Arab Emirates

IAG 150 years

International Committee on GNSS (ICG)

ICG Working Groups:

- ***Compatibility and Interoperability (USA and Russia)***
- ***Enhancement of performance of GNSS services (India and ESA)***
- ***Information dissemination and capacity building (UNOOSA)***
- ***Reference Frame, Timing and Applications (IAG, IGS, FIG)***

ICG Executive Secretariat: UNOOSA

ICG website: www.icgsecretariat.org

Achievements of providers and users of positioning, navigation, and timing services, under the umbrella of the United Nations, in promoting GNSS over the past 10 years.

http://www.unoosa.org/oosa/en/SAP/gnss/icg.html

IAG 150 years

International Committee on GNSS (ICG)

WG-A: Compatibility & Interoperability

- **Definitions of “Compatibility” & “Interoperability”**
- **GNSS Spectrum Protection and Interference Detection and Mitigation**
- **Consensus on Open Service GNSS performance parameters, including definitions and calculation methods**
- **International GNSS Monitoring and Assessment (IGMA), what parameters to monitor?**

IAG 150 years

Compatibility & Interoperability

- Ensure **compatibility** – ability of U.S. and non-U.S. space based PNT services to be used separately or together without interfering with each individual service or signal
  - Radio frequency compatibility
  - Spectral separation between M code and other signals
- Achieve **interoperability** – ability of civil U.S. and non-U.S. space-based PNT services to be used together to provide the user better capabilities than would be achieved by relying solely on one service or signal
  - Primary focus on the common L1C and L5 signals

IAG
150 years

Benefits of Interoperability

- Ideal interoperability allows navigation with one signal each from four different systems with no additional receiver cost or complexity

Interoperable = Better Together than Separate

IAG
150 years

GPS Constellation Performance

Specification values from the Standard Positioning Service (SPS) Performance Standard (L1-only), September 2008

PDOP (Geometry) Availability

- **Specification - PDOP of 6 or Less, 98% of the time**
- **Actual - 99.98798%**

Horizontal Service Availability

- **Specification - 95% Threshold of 17(36*)m, >99% of the Time**
- **Actual – 2.74m**

Vertical Service Availability

- **Specification - 95% Threshold of 37(77*)m, >99% of the Time**
- **Actual – 3.89m**

User Range Error (SIS)

- **Specification - 4(6*)m or Less, Constellation Average**
- **Actual – < 1m**

System accuracy and availability far exceed 2008 specifications (* 2001 specs)

International Committee on GNSS (ICG)

WG-B: Enhancement of the Performance on GNSS Services

- **Integrity via ARAIM**
- **Satellite Navigation in Natural Disasters**
- **Workshop on New Message Broadcasts in New Signals**
- **Establishment of a subgroup on “GNSS Applications”**
- **Interoperable GNSS Space Service Volume**
- **Standardisation for Maritime Applications**

IAG 150 years

International Committee on GNSS (ICG)

WG-C: Information Dissemination and Capacity Building

- **Education and Training programmes on GNSS**
- **Promoting the use of GNSS technologies as tools for scientific applications**
- **Observation of space weather phenomena through the deployment of ground-based instrument arrays such as GPS receivers, magnetometers, solar telescopes, very low frequency (VLF) monitors, solar particle detectors, and data analysis and the sharing of recorded data**
- **Regional workshops on applications of GNSS**

IAG
150 years

International Committee on GNSS (ICG)

WG-D: Reference Frames, Timing and Applications

- **Finalization and publication of Templates on Geodetic and Timing References**
- **Interoperability of geodetic references among the different GNSS systems**
- **IGS M-GEX, as follow up to JAXA's Multi-GNSS Demonstration Campaign in Asia and Oceania**

IAG 150 years

Templates on Geodetic and Timing References

Global Navigation Satellite Systems Timescale Descriptions:

- Global Positioning System (GPS): GPS Time
- GALILEO (satellite navigation): Galileo System Time (GST)
- International GNSS Service (IGS): IGS Time V1.0

Global Navigation Satellite Systems Reference Frames Descriptions

- National Geospatial-Intelligence Agency: World Geodetic System 1984 (WGS84)
- Global Geocentric Coordinate System of the Russian Federation (presentation made at the Seventh Meeting of the ICG, 5 - 9 November 2012, Beijing, China): Earth Parameters (PZ-90)
- National Bureau of Surveying and Geo-information : China Terrestrial Reference Frame 2000 (CTRF2000)
- European Space Agency (ESA): Galileo Terrestrial Reference Frame (GTRF)
- Reference System Description of QZSS: Japan satellite navigation Geodetic System (JGS)
- International Earth Rotation and Reference Systems Service (IERS): International Terrestrial Reference System (ITRS)
- International Earth Rotation and Reference Systems Service (IERS) : International Terrestrial Reference Frame (ITRF)

http://www.unoosa.org/oosa/en/SAP/gnss/icg/regrefsys.html

The WGS84 Reference Frame

The general GPS user want coords "in the WGS84 datum" ... accessed by SPP solutions using the Navigation Message.

- In mid-1994 WGS84 was re(de)fined to align it with ITRF91 (at decimetre level) -- *WGS84(G730)*, at the beginning of 1997 WGS84 was again re(de)fined to align it with ITRF94 (sub-decimetre level) -- *WGS84(G873)*, at the beginning of 2002 realigned to ITRF2000 (cm level) -- *WGS84(G1150)*, and in Feb 2012 realigned to ITRF2008 (cm level) – *WGS(G1674)*.
- WGS84 therefore uses ITRF to give it stability.
- Ref Epoch is 2005.0 (same as ITRF2008).
- Changes in GPS Ground Segment coords (& therefore users' SPP) occur each year, referred to the mid-year epoch – not clear what other GNSSs will do.

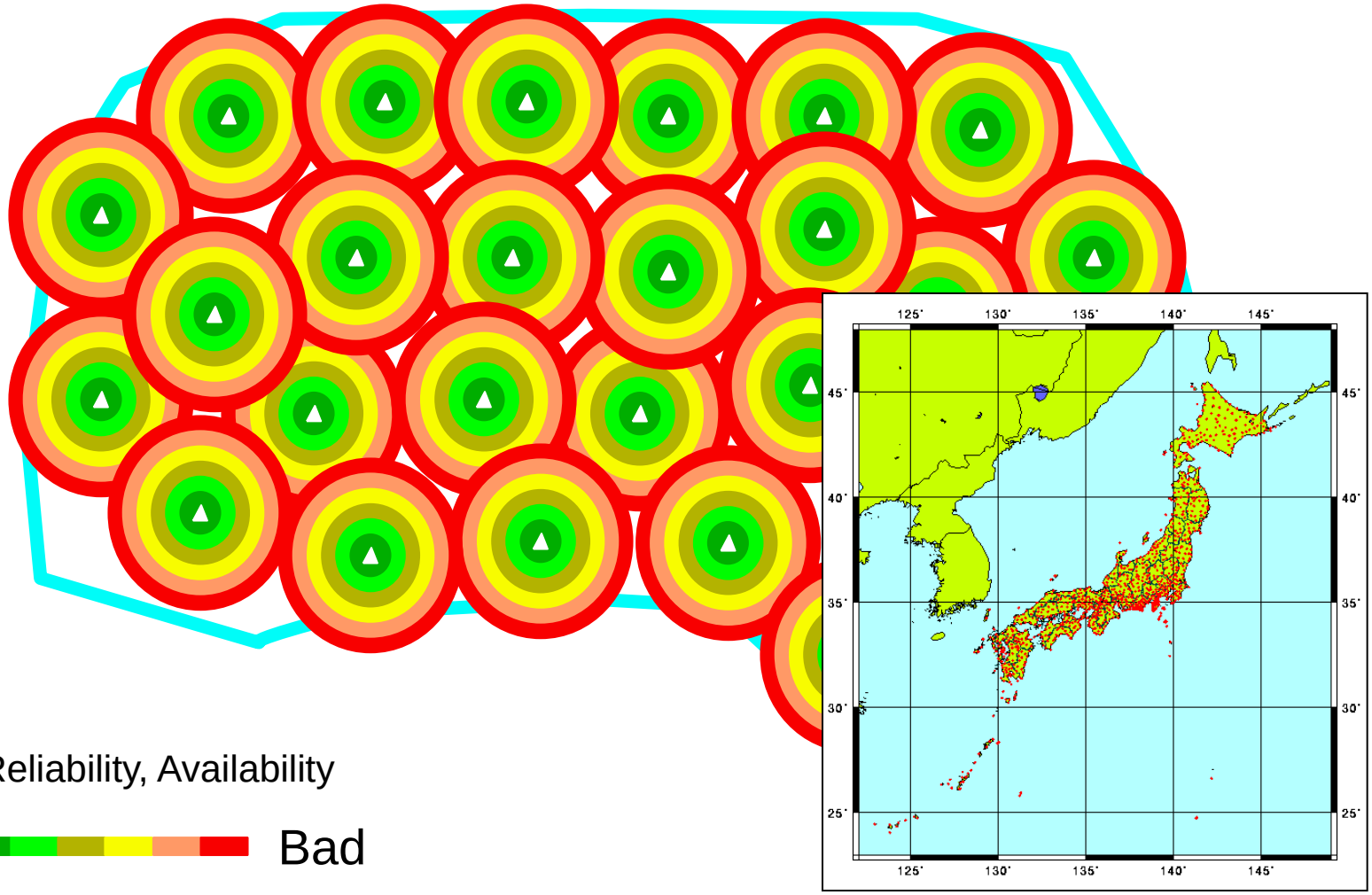
Multi-GNSS and PPP/DGNSS

DGNSS techniques have evolved over many years... *balancing constraints of accuracy, complexity, timeliness, cost & performance*... specialised HW, SW & operations, supported by considerable CORS investment...

Hence user GNSS coords expressed in datum defined by fixed coords of CORS

CORS Spacing…*full coverage single-base RTK*

L1+L2 GPS Rxs

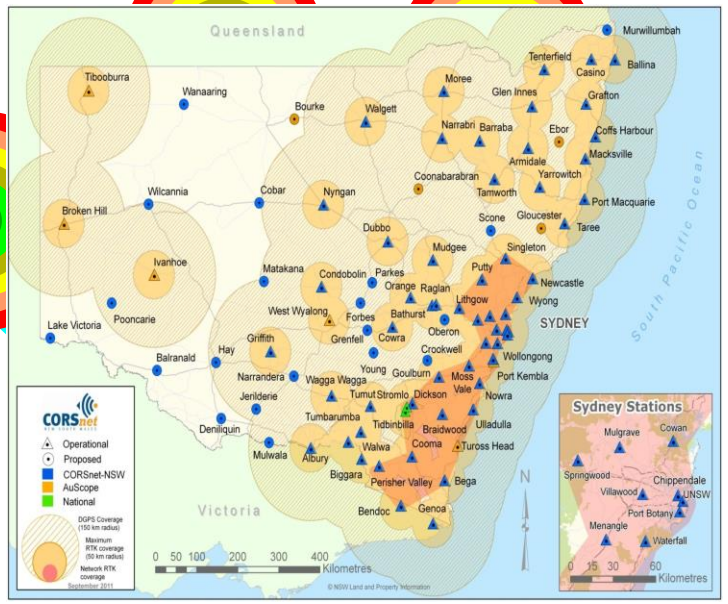


Accuracy, Reliability, Availability

Good — Bad

CORS Spacing…*gaps in coverage single-base RTK*

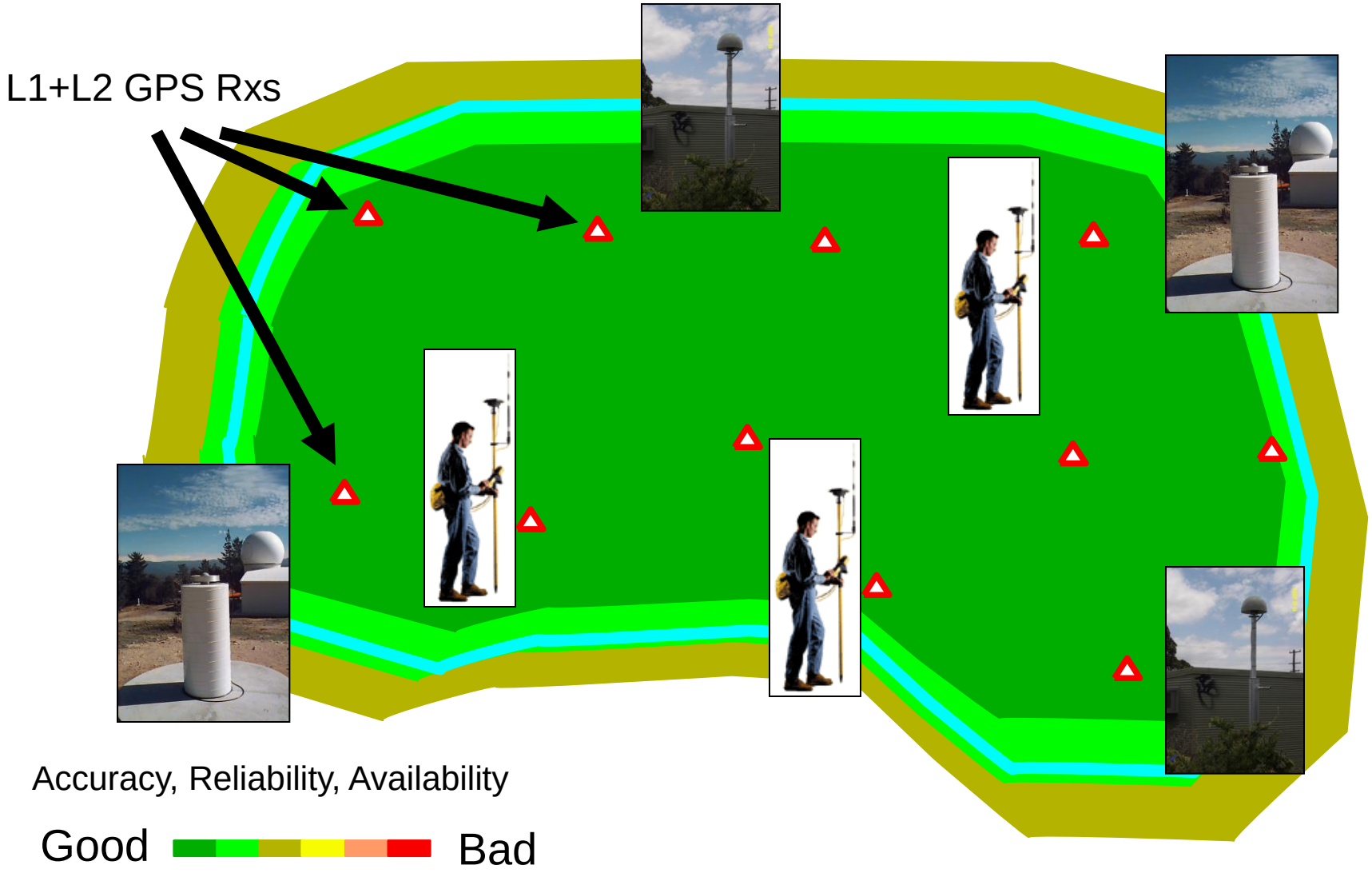
L1+L2 GPS Rxs



Accuracy, Reliability, Availability

Good — Bad

CORS Spacing…*full coverage Network-RTK*



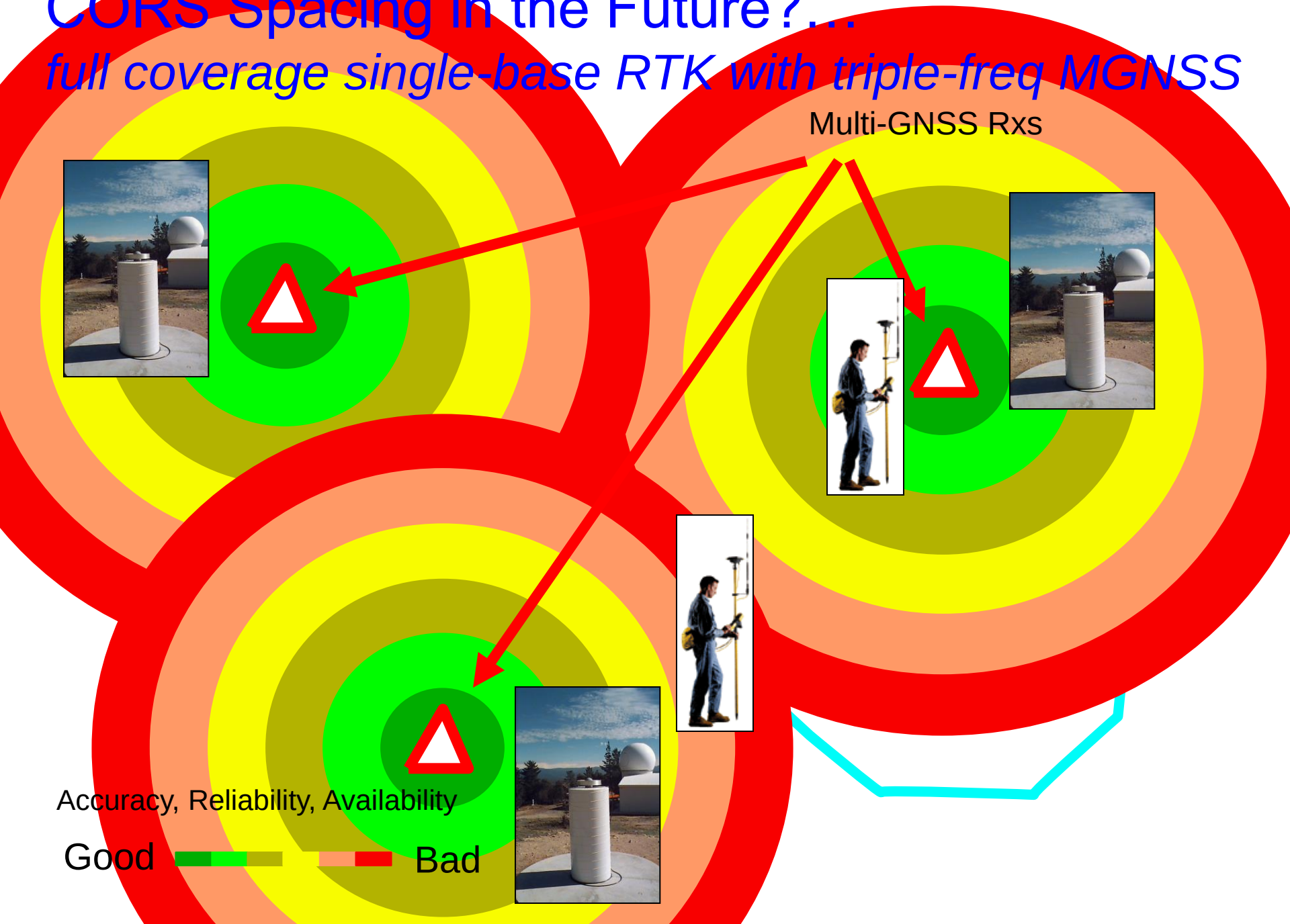
CORS Spacing in the future?…

full coverage N-RTK with dual-freq MGNSS

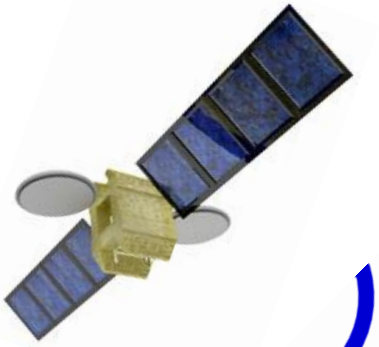
Same spacing, but faster AR & better reliability

CORS Spacing in the Future?…

full coverage single-base RTK with triple-freq MGNSS

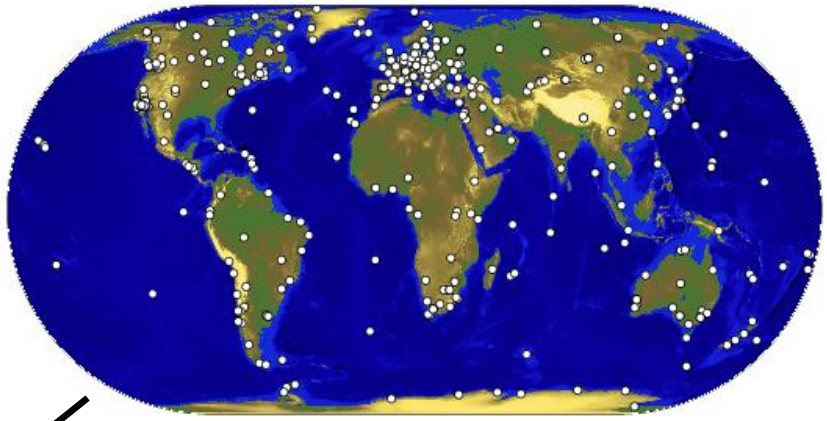


PPP: How It Works



GNSS Constellation(s)

CORS Network



GNSS Satellite Orbit and Clock Corrections
(Real-time or post-processed)

GNSS User

Reduction in CORS infrastructure! But currently less efficient & less accurate than DGNSS

Coordinate datum now ephemeris datum (not CORES), i.e. IGS08/ITRF2008

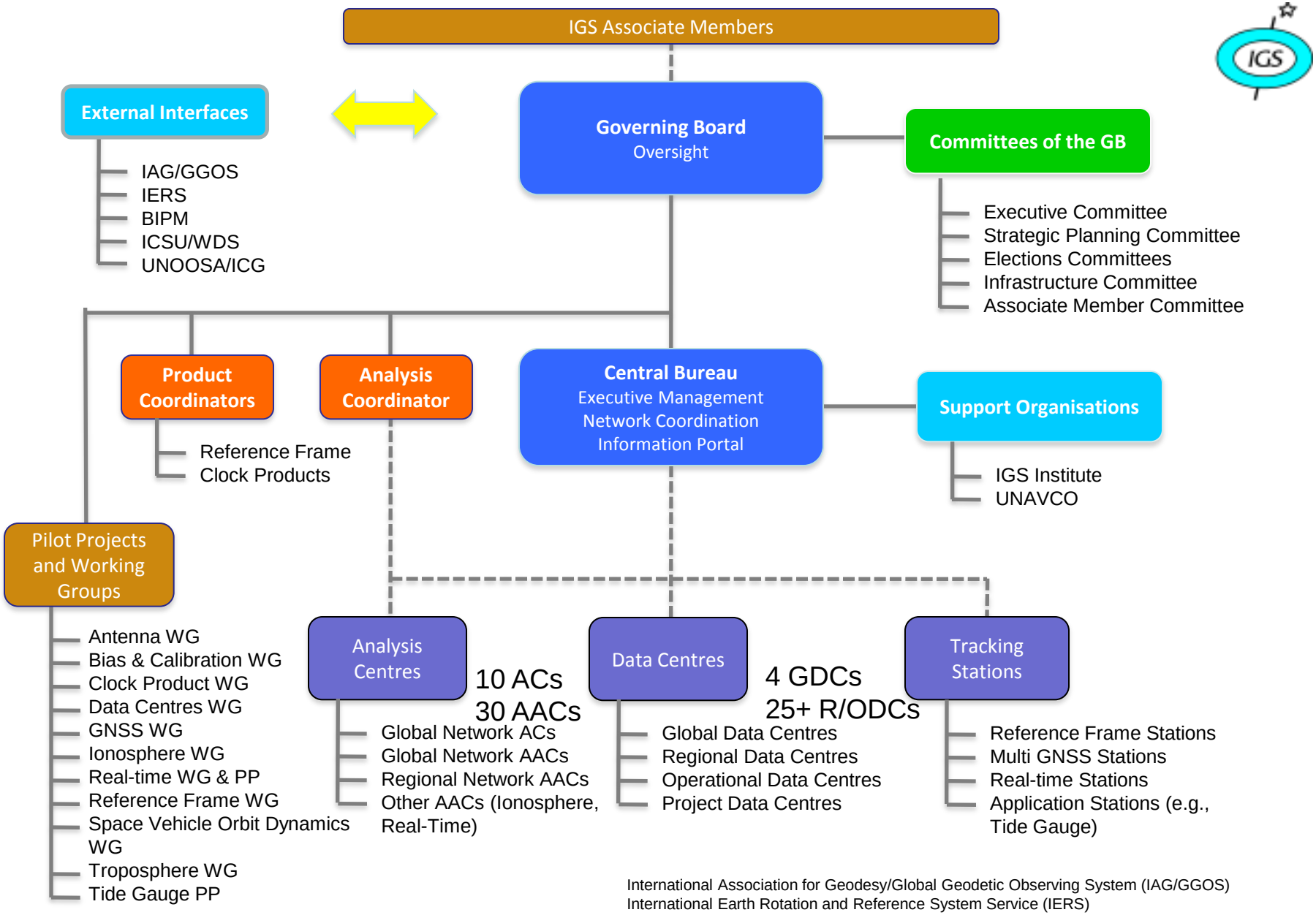
How will PPP be used?

Using DGNSS for T3 surveys to densify or connect to ITRF (e.g. via IGS T1 or national T2 CORS)...

But if PPP technique used for T3 surveys, then CORS can be used to monitor stability of national datum... i.e. 4-D coords...

.

The International GNSS Service

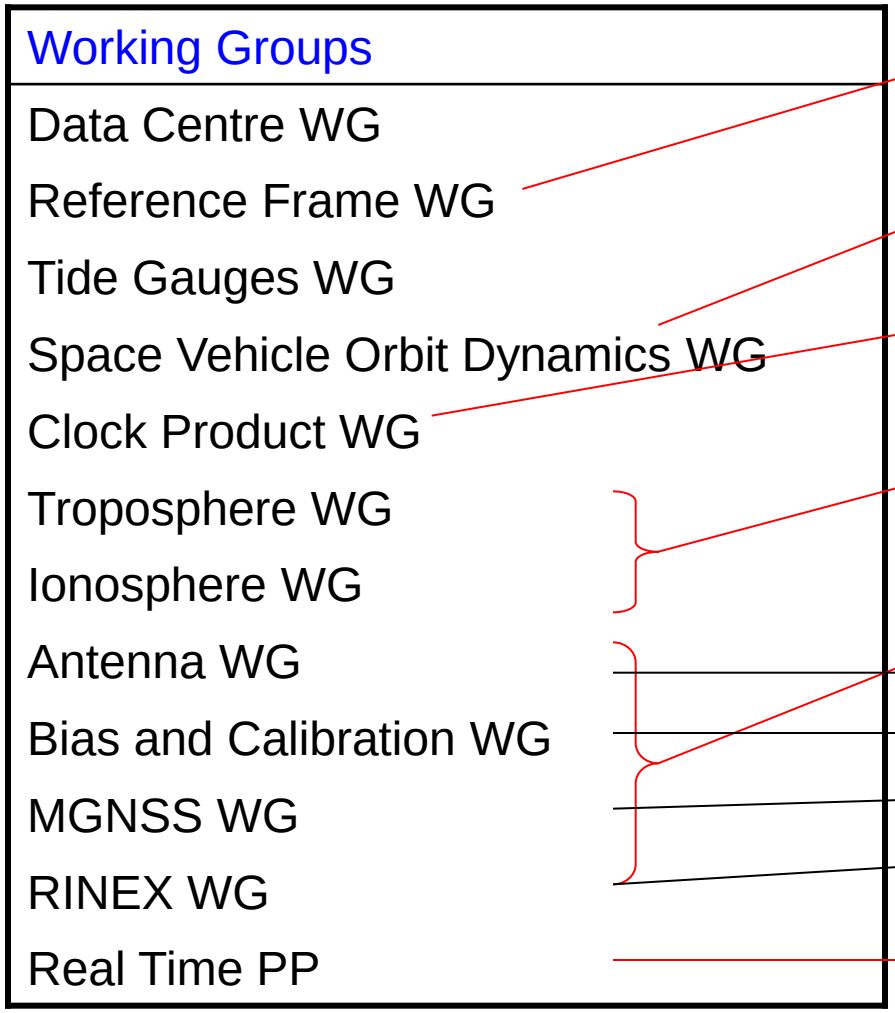


International Association for Geodesy/Global Geodetic Observing System (IAG/GGOS)
International Earth Rotation and Reference System Service (IERS)
Bureau International des Poids et Mesures (BIPM)
International Council for Science/Word Data Systems (ICS/WDS)
United Nations Office for Outer Space Affairs/International Committee on GNSS (UNOOSA/ICG)
Analysis Centre (AC)
Associate Analysis Centre (AAC)

Motivation for M-GNSS

- IGS is the International GNSS Service
  - Well established infrastructure, data and service for GPS (+ GLONASS)
  - IGS Strategic Plan foresees extension to all new GNSSs
  - IGS Strategic Plan includes (multi-GNSS) Real-Time Service (RTS)
- Ongoing deployment of new GNSSs with new signals and satellites
  - BeiDou, Galileo, QZSS, SBAS
- Continued evolution of products supporting multi-constellation, multi-frequency GNSS
- **Multi-GNSS Experiment (MGEX)**
  - Steered by Multi-GNSS Working Group (MGWG)
  - MGEX call-for-participation released in mid-2011 (ongoing)
  - Build-up of new multi-GNSS tracking network during 2012 (ongoing)
  - First MGEX results in 2013
- **Launch of RTS 1 April 2013**

IGS Working Groups & M-GNSS



how to convert IGS network to multi-GNSS?

radiation pressure modelling for new satellites?

clock products for new signals?

atmospheric remote sensing

new systems and signals

patterns for new frequencies

biases of new signals

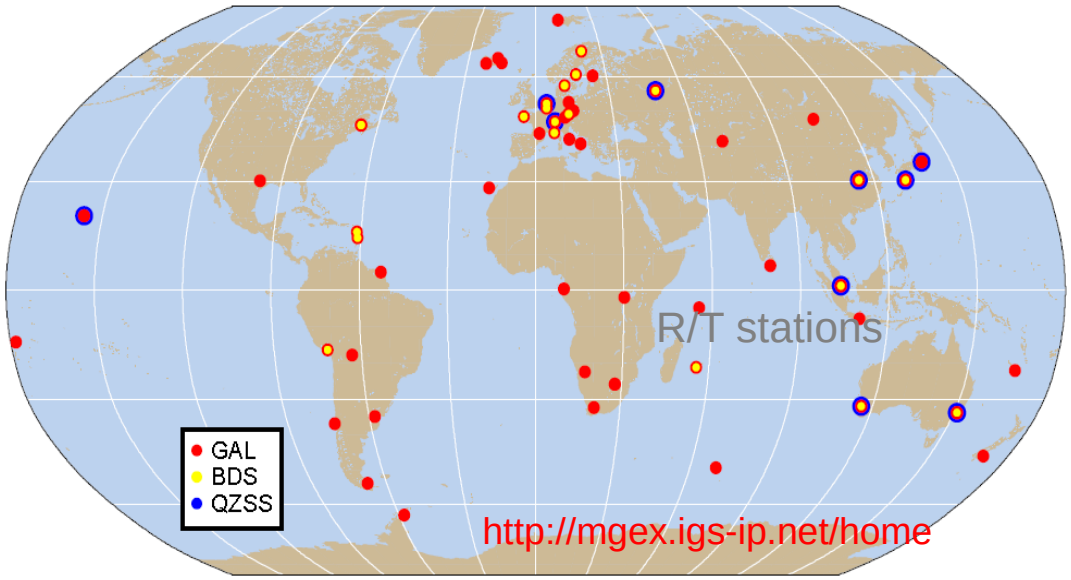
MGEX

observation format (RINEX 3.0)

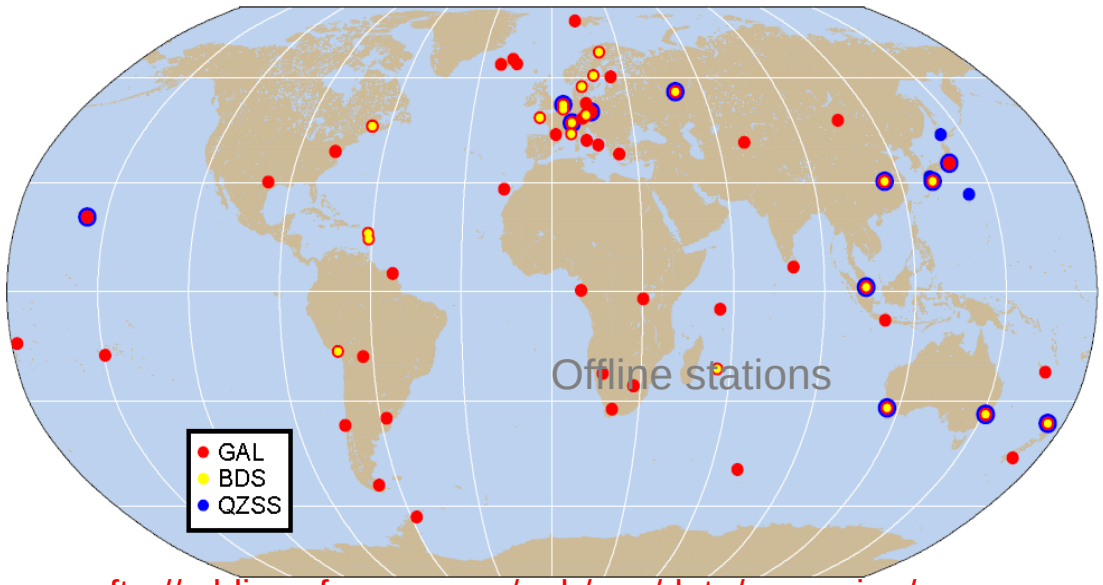
real-time service/ pilot project

MGEX Network (April 2013)

- ~10 contributing agencies
- >70 stations worldwide
- Numerous R-T stations (NTRIP, RTCM3-MSM)
- 6 major receiver types, 7 major antenna types
- Tracking of Galileo, BeiDou, QZSS
- Data archives at CDDIS, IGN, BKG
- RINEX 3.x
- R-T caster at BKG
- Free data/product access



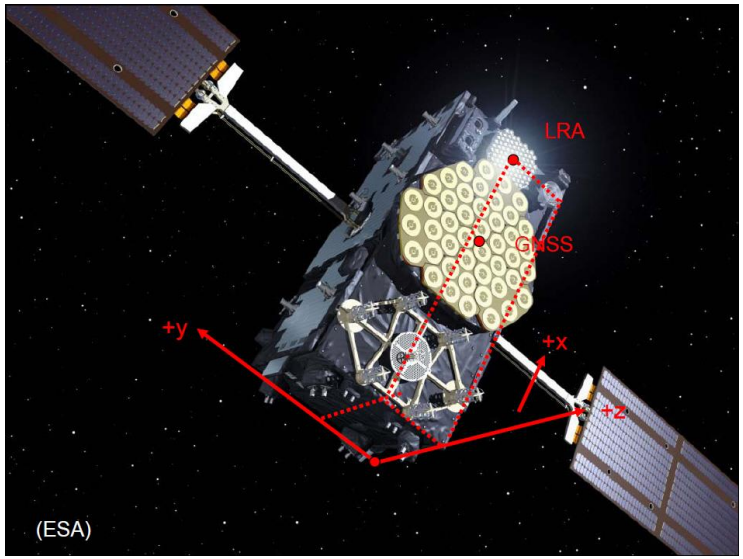
http://mgex.igs-ip.net/home



ftp://cddis.gsfc.nasa.gov/pub/gps/data/campaign/mgex

Standardisation Efforts

- Continued interactions of MGWG with:
  - GNSS system providers
  - Equipment manufacturers
  - Other IGS Working Groups (esp. R-T WG)
- Recommendations, conventions and processing standards:
  - Attitude models
  - Antenna offsets and patterns
- Data formats:
  - Observations and navigation data (RINEX, RTCM3-MSM)
  - Biases (DCBs, intersystem - SINEX?)
  - Orbits



IGS MGEX Equipment

- One to four systems in addition to GPS+GLO

  GPS+GAL+SBAS
  GPS+GLO+GAL
  GPS+GLO+QZSS
  GPS+GLO+GAL+SBAS
  GPS+GLO+GAL+BDS
  GPS+GLO+GAL+BDS+SBAS
  GPS+GLO+GAL+BDS+QZSS
  GPS+GLO+GAL+QZSS+SBAS
  GPS+GLO+GAL+BDS+QZSS+SBAS

- heterogeneous equipment environment
- many combinations
- cross-validation of equipment performance
- high robustness
- open to new equipment
- similar to future user environment

- Receivers

  IfEN SX_NSR_RT_800
  Javad TRE_G3TH Delta
  Javad TRE_G3T Delta
  Leica GR10
  Leica GR25
  Leica GRX1200+GNSS
  Novatel OEM6
  Septentrio PolarX4TR
  Septentrio PolarXS
  Trimble NETR8
  Trimble NETR9

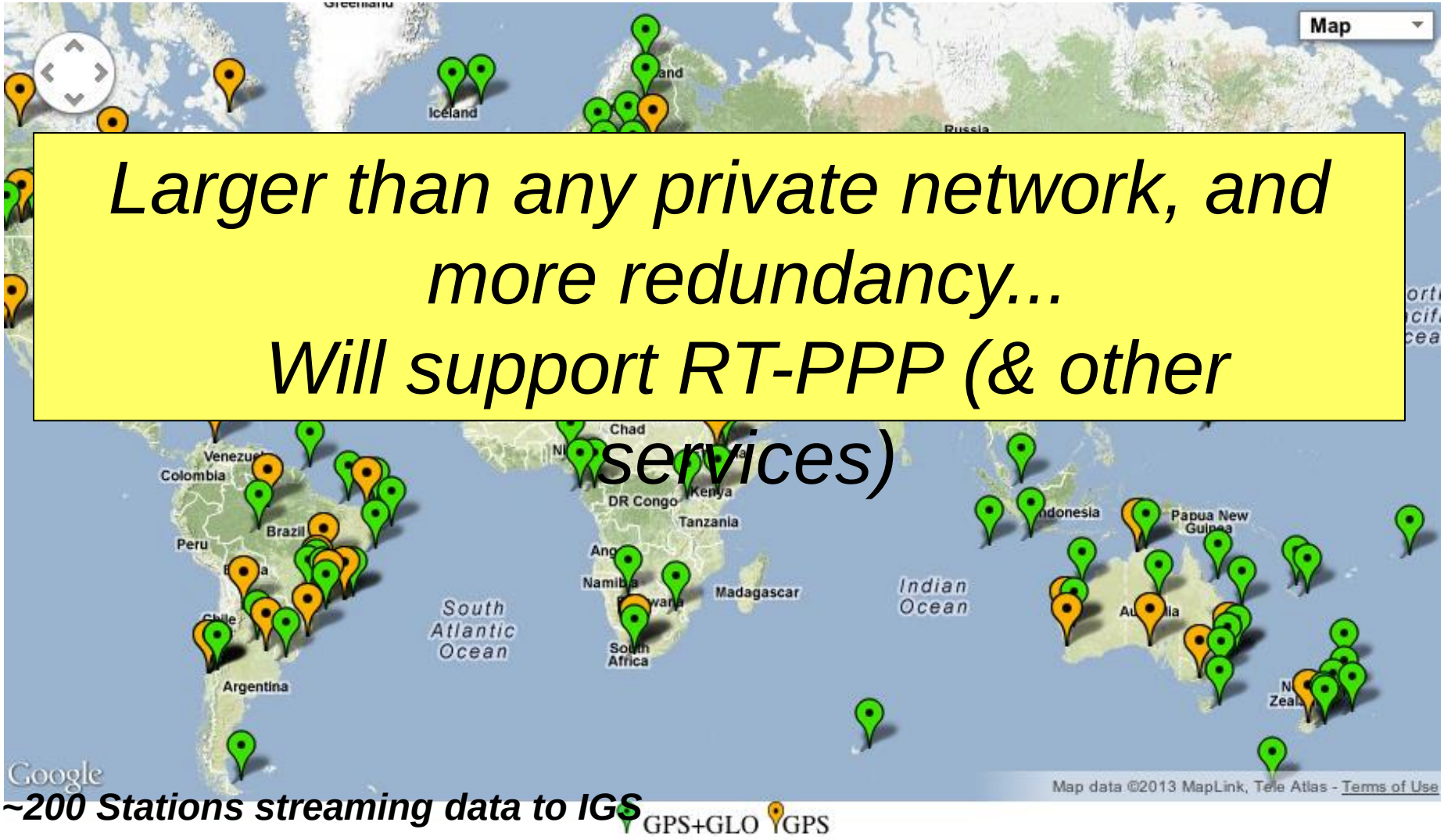
- Antennas

  AOAD/M_T
  JAV_RINGANT_DM
  JAV_RINGANT_G3T
  LEIAR10
  LEIAR25
  LEIAR25.R3
  LEIAR25.R4
  TPSCR.G3
  TRM55971.00
  TRM57971.00
  TRM59800.00

MGEX Website – http://igs.org/mgex/

- IGS multi-GNSS portal
- Links to data and products
- Network status
- Constellation status
- Conventions

IGS Real-Time Network



Larger than any private network, and more redundancy...
Will support RT-PPP (& other services)

~200 Stations streaming data to IGS

GPS+GLO GPS

Real-Time Service – http://rts.igs.org/

- **RTS launched 1 April 2013**

Note:

- IGS01/IGC01 (GPS-only) and IGS02 (GPS-only) streams now fully configured and running on 2 or more servers
- IGS03 (GPS+GLONASS) “experimental” stream
- RTCM3EPH streams
- Reference is ITRF2008
- Stream access via BKG NTRIP Client (BNC) or RTKLIB
- Register for user access (next slide)
- Products:

Stream Name	Description	Ref Point	RTCM Messages	Provider / Solution ID	Bandwidth kbits	Software
IGS01	Orbit/Clock Correction, Singe-Epoch Combination	APC	1059 (5),1060 (5)	258 / 1	1.8/sec	ESA/ESOC
IGC01	Orbit/Clock Correction, Singe-Epoch Combination	CoM	1059 (5),1060 (5)	258 / 9	1.8/sec	ESA/ESOC
IGS02	Orbit/Clock Correction, Kalman Filter Combination	APC	1057 (60), 1058 (10), 1059 (10)	258 / 2	0.6/sec	BKG
IGS03	Orbit/Clock Correction, Kalman Filter Combination	APC	1057(60), 1058(10), 1059(10), 1063(60), 1064(10), 1065(10)	258 / 3	0.8/sec	BKG

APC: Antenna Phase Center CoM: Center of Mass, (not compliant with current RTCM-SSR standard). The figures in brackets next to each RTCM message ID denote the message sample interval in seconds.

Real-Time Service – http://rts.igs.org/

- 10 Analysis Centres:

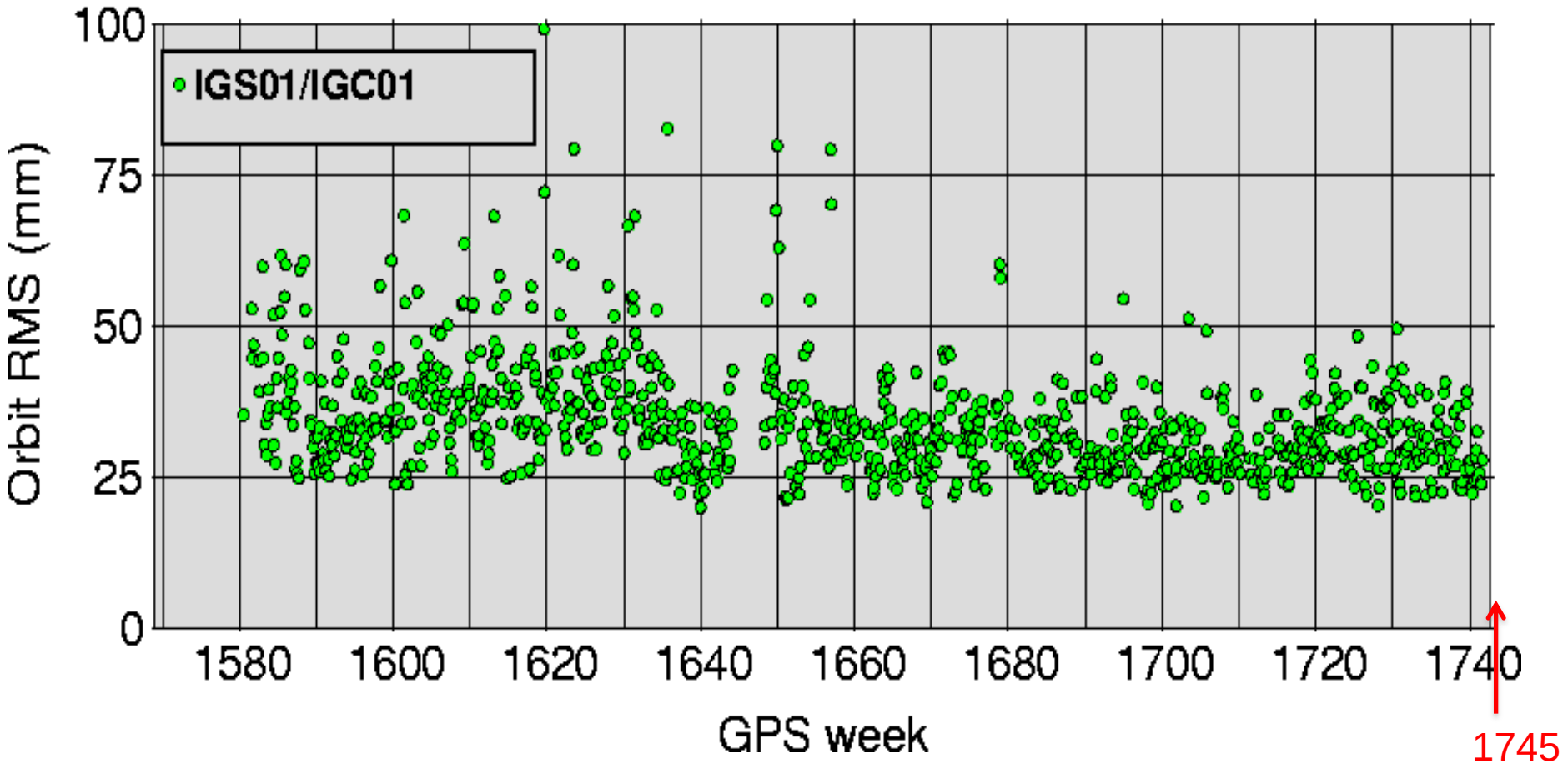
Center	Description
BKG	GPS RT orbits and clocks using IGU orbits GPS + GLONASS RT orbits and clocks using IGV orbits
CNES	GPS RT orbits and clocks based on IGU orbits GPS+GLONASS orbits and clocks
DLR	GPS RT orbits and clocks based on IGU orbits GPS+GLONASS orbits and clocks
ESA/ESOC	GPS RT orbits and clocks using NRT batch orbits from ESOC s/w running every 2 hours GPS RT orbits and clocks using IGU orbits
GFZ	GPS RT orbits and clocks and IGU orbits
GMV	GPS RT orbits and clocks based on NRT orbit solution GPS+GLONASS orbits and clocks
Geo++	Not contributing at present. Working on RTCM SSR Standard.
NRCan	GPS RT orbits and clocks using NRT batch orbits every hour
TUW	Not contributing at present
WUHAN	GPS RT clocks based on IGU orbits

The following agencies have additional functions in the RTS:

- NRCan – RT Working Group Chair
- ESOC – Real Time Analysis Center Coordinator
- BKG – Data Flow Coordination

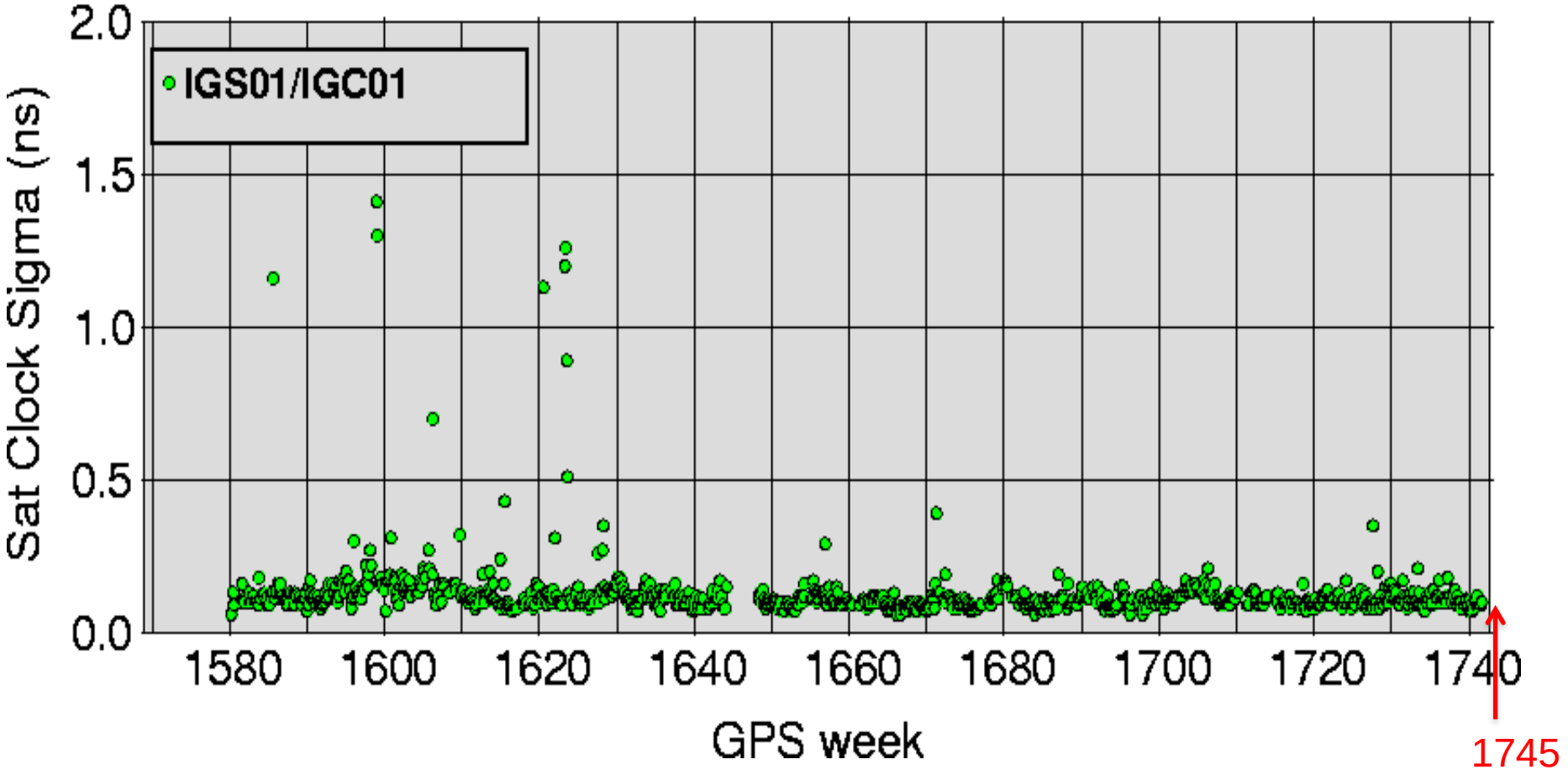
RTS Product Performance

Satellite orbit RMS (compared to IGS Rapid)



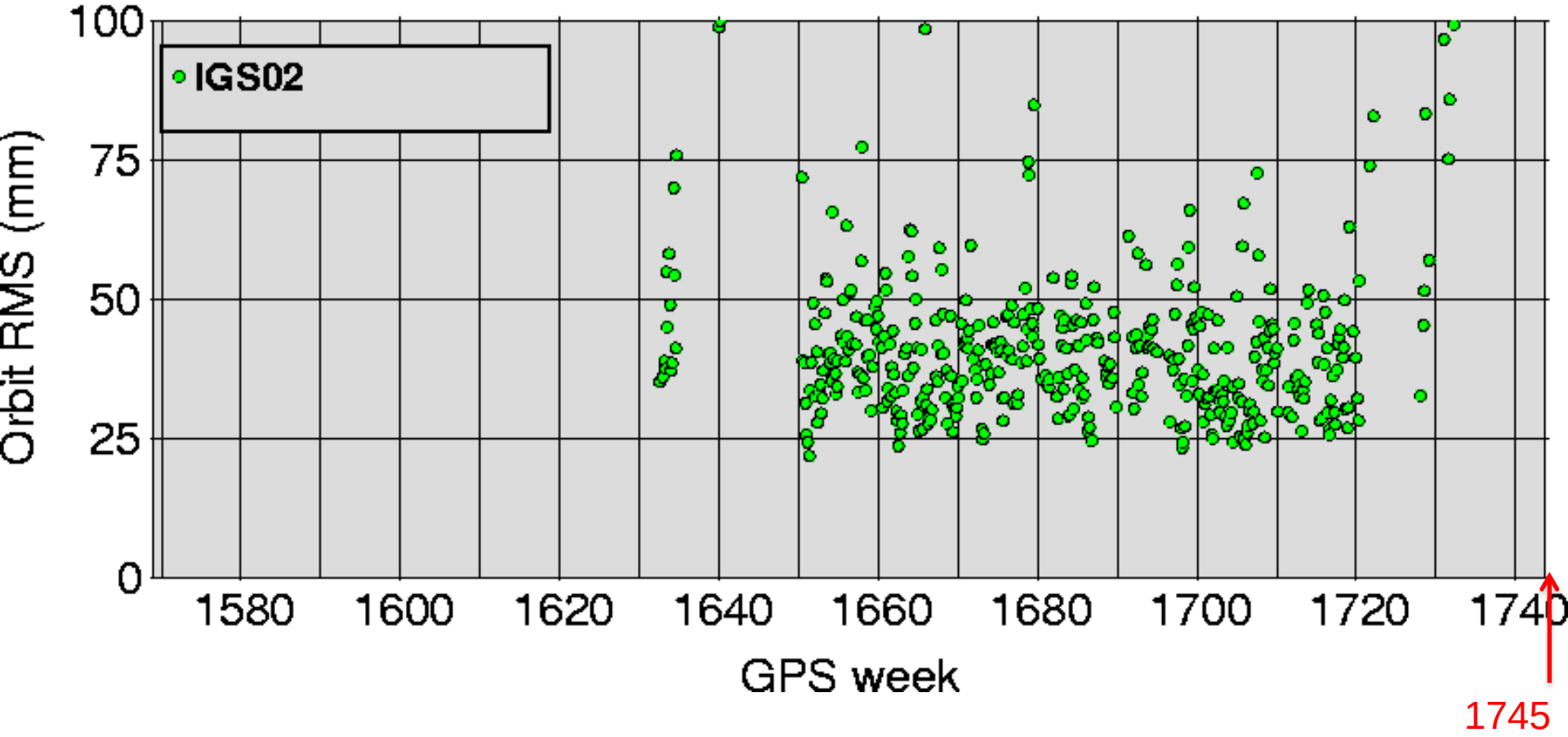
RTS Product Performance

Satellite clock std.dev. (compared to IGS Rapid)



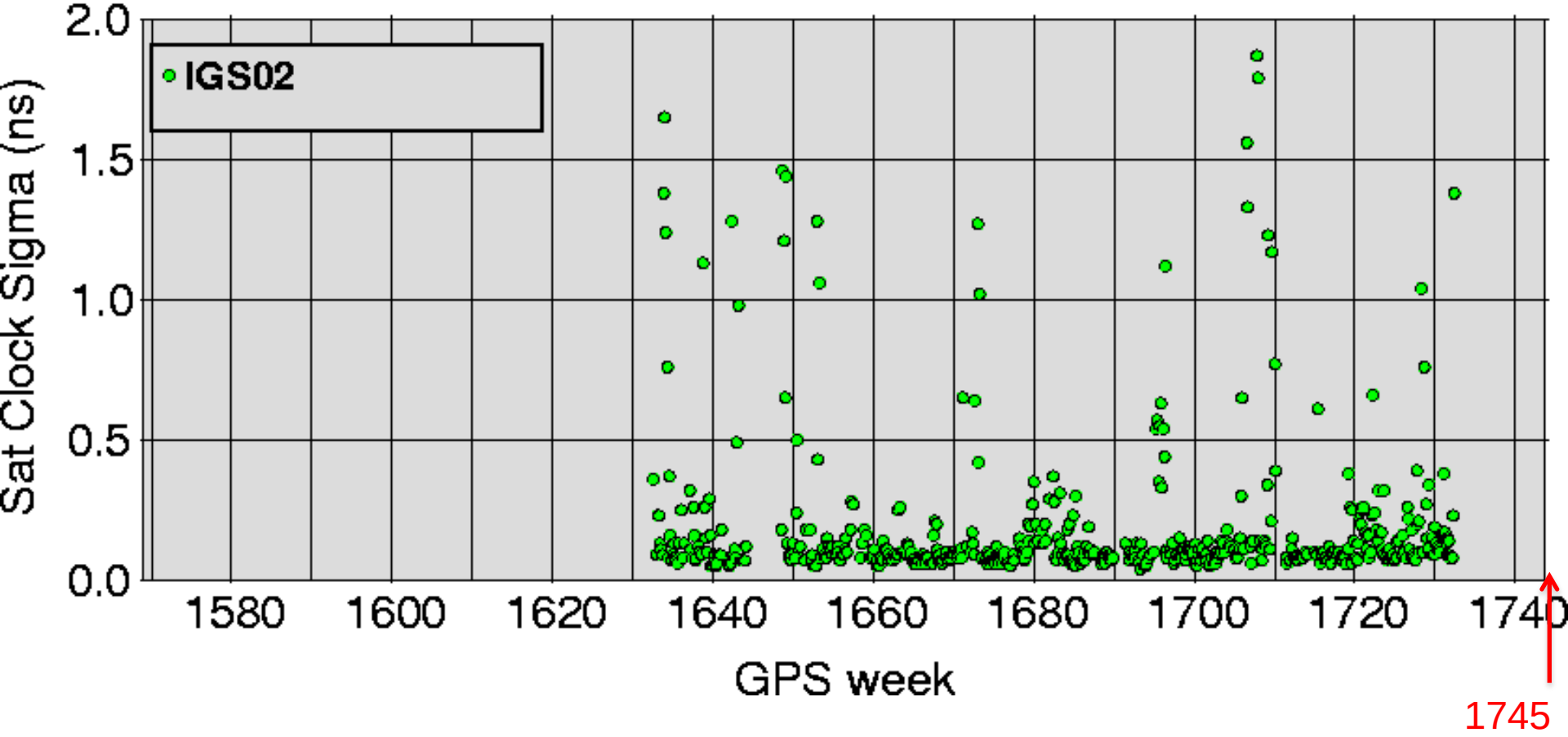
RTS – IGS02 Products

(compared to IGS Rapid)

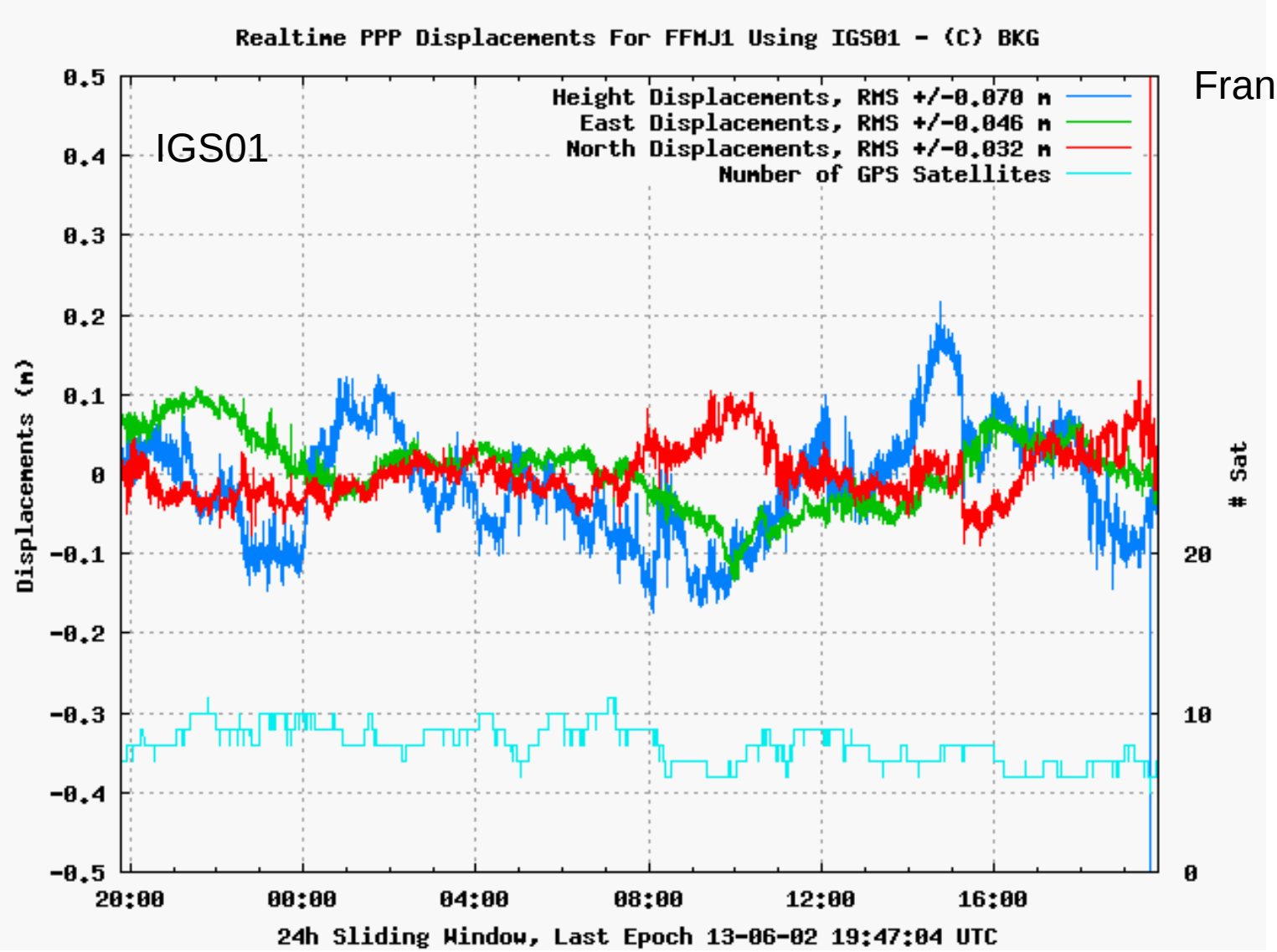


RTS – IGS02 Products

(compared to IGS Rapid)

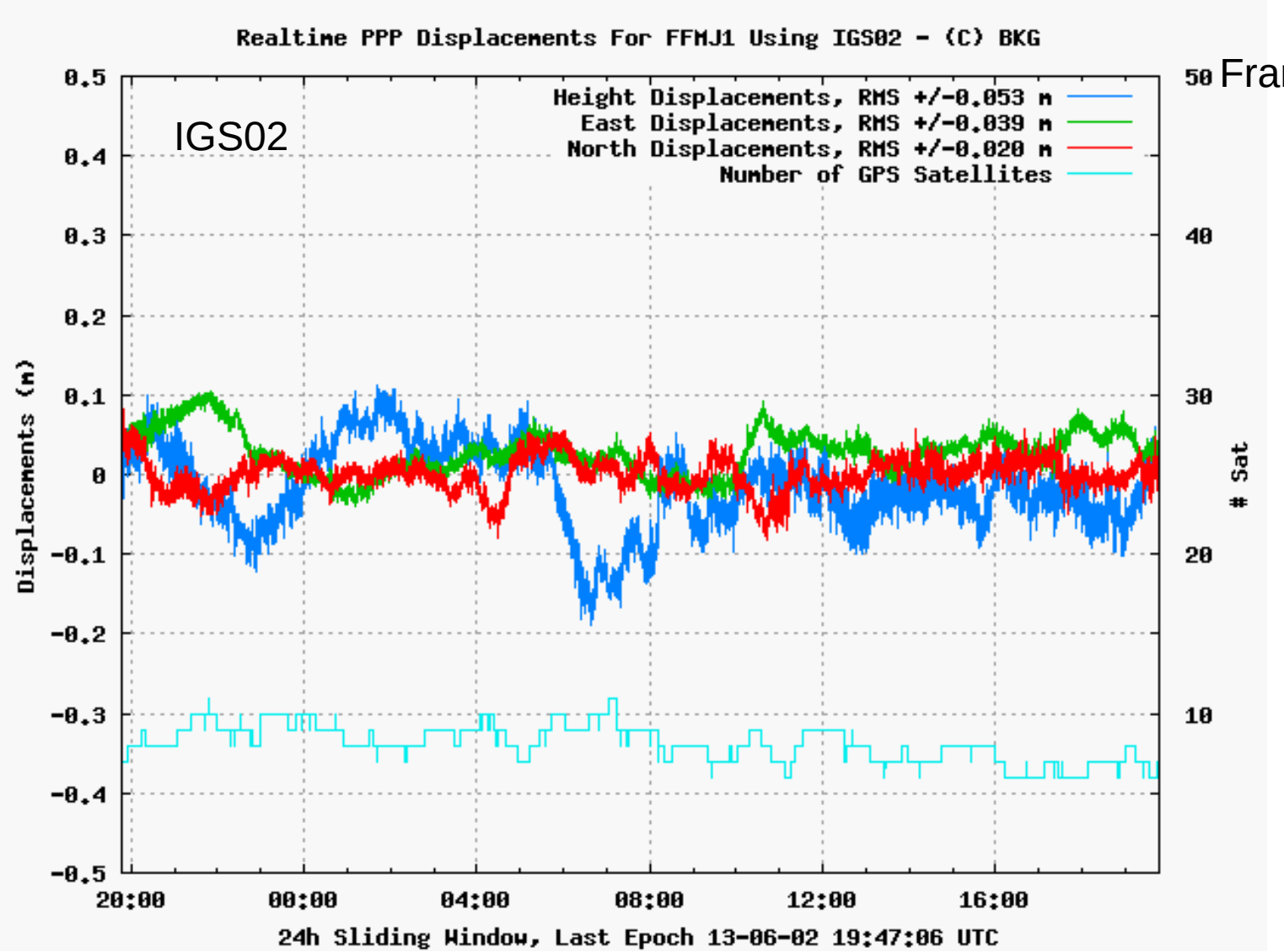


RTS – PPP Results (1)



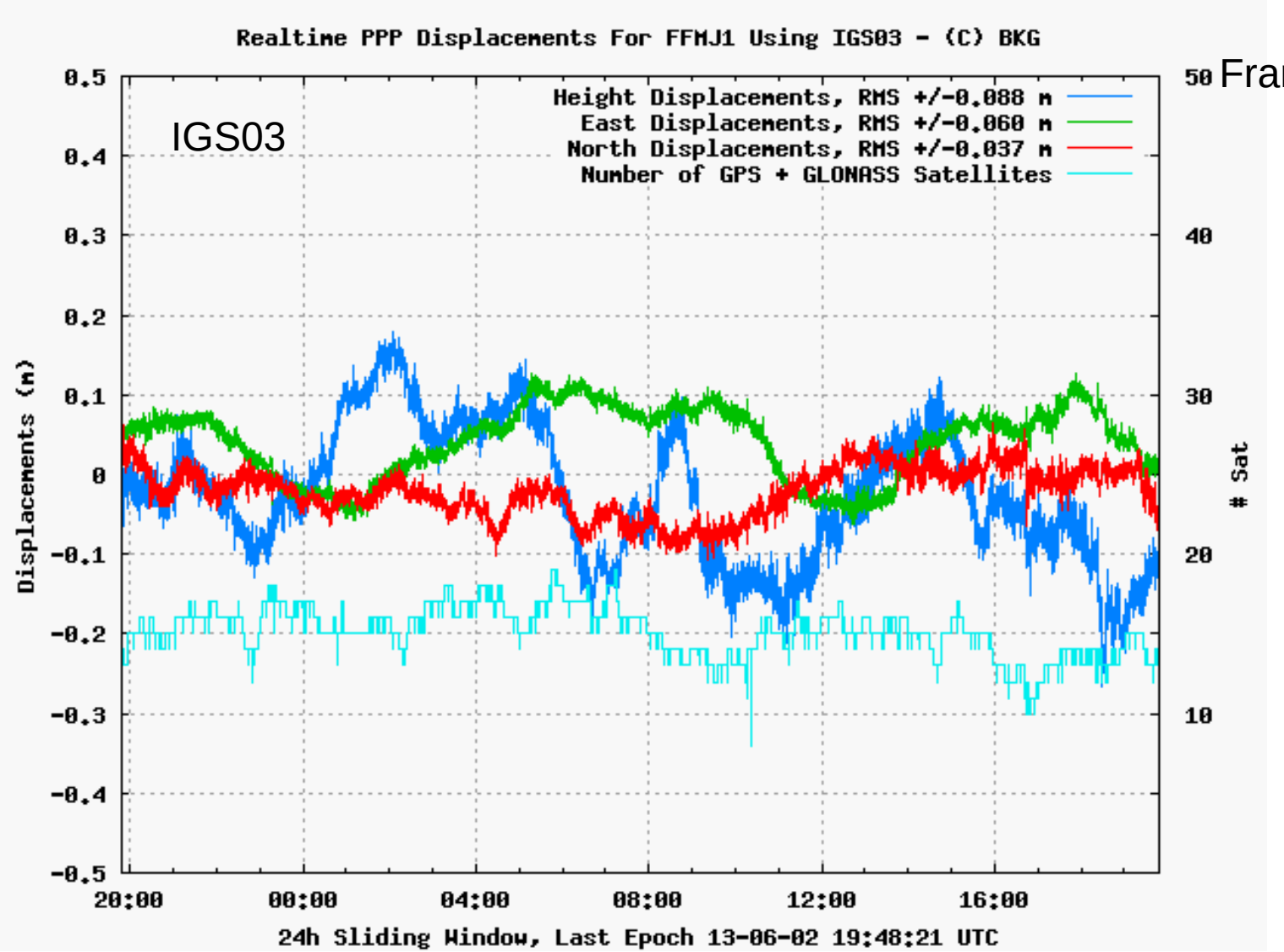
Frankfurt a.M.

RTS – PPP Results (2)



Frankfurt a.M.

RTS – PPP Results (3)



Frankfurt a.M.

RTS – Who Appears Interested?

- 80 user registrations within days of launch
- 142 user registrations by 22 April, from 38 countries

By Organization Type	
Engineering Services/Consulting	25
Academic	23
GNSS Equipment/Software	15
Aerospace	4
Government Geological/Geophysical	3
Government Geodetic/Mapping	2
Positioning Services	2
Telecommunications	2
Other	2
Civil Aviation Authority	1
Government Meterology	1
Military	0

By Country	
USA	14
Canada	7
Australia	6
Brazil	5
Japan	5
Russia	5
Italy	3
Malaysia	3
UK	3
Bosnia Herzegovina	2
Bulgaria	2
China	2
France	2
Germany	2
Iran	2
Republic of Korea	2
Romania	2
Saudi Arabia	2
Spain	2
Austria	1
Egypt	1
Finland	1
Greece	1
Indonesia	1
Kenya	1
Philippines	1
Ukraine	1
Uruguay	1

IGS Multi-GNSS Plan (tentative)

High quality GPS/GLONASS network and products → High quality multi-GNSS network and products

2012 | 2013 | 2014 | 2015 | 2016 | 2017

MGEX

- Build-up and share multi-GNSS know-how
- Build-up network and provide access to multi-GNSS data
- Develop prototype multi-GNSS products
- Develop recommendations and standards
- Engage with receiver manufacturers and system providers
- RTS GPS PP

Transition

- Merge legacy and multi-GNSS networks
- Achieve interoperability of legacy and multi-GNSS products and services
- RTS GPS+ GLONASS

Multi-GNSS Pilot Service

- Incorporate BeiDou, Galileo, and QZSS into standard IGS processing
- Issue combined and quality controlled multi-GNSS IGS orbit, clock and iono products
- Regular multi-GNSS intersystem, interfrequency and intersignal bias estimation
- Link GNSS system times with IGS system time
- Embed new GNSSs into IGS/IAG reference frames
- RTS for multi-GNSS

Summary Remarks

- IGS has made important steps towards a multi-GNSS service:
  - New global multi-GNSS network is being built up
  - First experimental multi-GNSS products released
  - Real-Time Service (GPS, GPS+GLONASS) launched
- Next steps:
  - Engagement with industry, system providers, service providers, manufacturers
  - Network extension for greater Galileo, BeiDou and QZSS coverage
  - Bias and ionosphere products
  - System characterisation (ground and space segment)
  - Recruitment of additional analysis centres
- Challenges:
  - Resources (three new constellations, new products, improved performance)
  - Lack of tools (in particular: automated quality control)
  - Lack of information from system providers (exception: QZSS)

Reference Frame in Practice

Manila, Philippines 21-22 June 2013

Thank You

150th Anniversary

1862-2012