The IGS in a Multi-GNSS World

Never Stand Still

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Member of the IGS Governing Board (2004-15)

President International Association of Geodesy (2011-15)

IGS Today... http://igs.org

- The IGS is a *voluntary federation* – more than 200 worldwide agencies in more than 90 countries – *that pool resources and permanent GNSS station data to generate precise IGS products*
- The IGS operates on a "best efforts" basis – *though with considerable redundancy*
- IGS products are *combinations* of independent results from several ACs – *reliability through redundancy*
- Geospatial applications & earth science missions rely upon *IGS products* – *IGS is the "gold standard"*
- All IGS data and products are available *free of charge*
- IGS products are critical to ITRF definition, maintenance & accessibility
- Improvements in signals, receivers and computations have led *to progressive improvements in product quality*
- IGS launched in 2011 a Multi-GNSS Experiment
- IGS launched in 2013 a Real-Time Service

IGS Products

- Primary products
  - global tracking data
  - GPS and GLONASS orbits
  - station coords, contribution to global terrestrial reference frame ITRF
- Related products
  - clock corrections for satellites and selected stations
  - daily Earth rotation parameters
  - global ionosphere maps
  - station troposphere parameters
  - Standards (site guidelines, RINEX, ANTEX, IONEX, ...)
  - GNSS systems monitoring (constellation status, DCB, …)

http://igs.org/components/prods.html

IGS Products and Users

	Q1 2014	2013	2012
www.igs.org (incl. RTS and MGEX web)			
# visits	252,697	740,048	692,315
# users/month	22,817	21.824	16,200
# countries	142	146	134
ftp.igs.org			
# visits	14,829	57,170	49,064
# users/month	6,265	5,743	4,800
# files	3,763,668	12,713,995	11,100,187
# countries	118	113	108
cddis.gsfc.nasa.gov			
# data files *per day*	1,700,000 (150 GB)		
# product files *per day*	375,000 (42 GB)		


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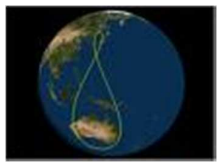
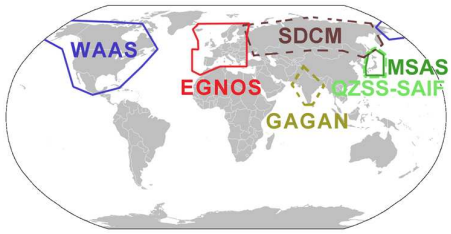



- GNSS:
  - GPS (30) *(32)*
  - GLONASS (24) *(30)*
  - Galileo (4) *(30)*
  - BeiDou (14) *(35)*
- RNSS:
  - QZSS (1) *(5-7)*
  - IRNSS (2) *(7)*
- SBAS:
  - WAAS
  - MSAS
  - EGNOS
  - GAGAN
  - SDCM



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

Motivation for M-GNSS

IGS

- IGS is the **International GNSS Service**
  - Well established infrastructure, data & service for GPS + GLONASS
  - IGS Strategic Plan foresees extension to multi-GNSS
  - IGS Strategic Plan includes (multi-GNSS) Real-Time Service
  - IGS transition plan to full multi-GNSS capability
- Ongoing deployment of new GNSSs with new signals and satellites
  - BeiDou, Galileo, QZSS, IRNSS, SBASs
- *Continued evolution of products supporting multi-constellation GNSS for PP users drives IGS innovation*
- **Multi-GNSS Experiment**
- **Real-Time Service Pilot Project**

Multi-GNSS Experiment (MGEX)

- Multi-GNSS Experiment (MGEX)
  - Multi-GNSS Working Group, chaired by Oliver Montenbruck
  - Build-up of new multi-GNSS tracking network started 2012 (ongoing)
  - First MGEX results
- Currently about 27 contributing agencies from 16 countries
- 90+ stations worldwide, plus numerous real-time stations
- Tracking of Galileo, BeiDou, QZSS, SBAS signals
- Free data/product access:

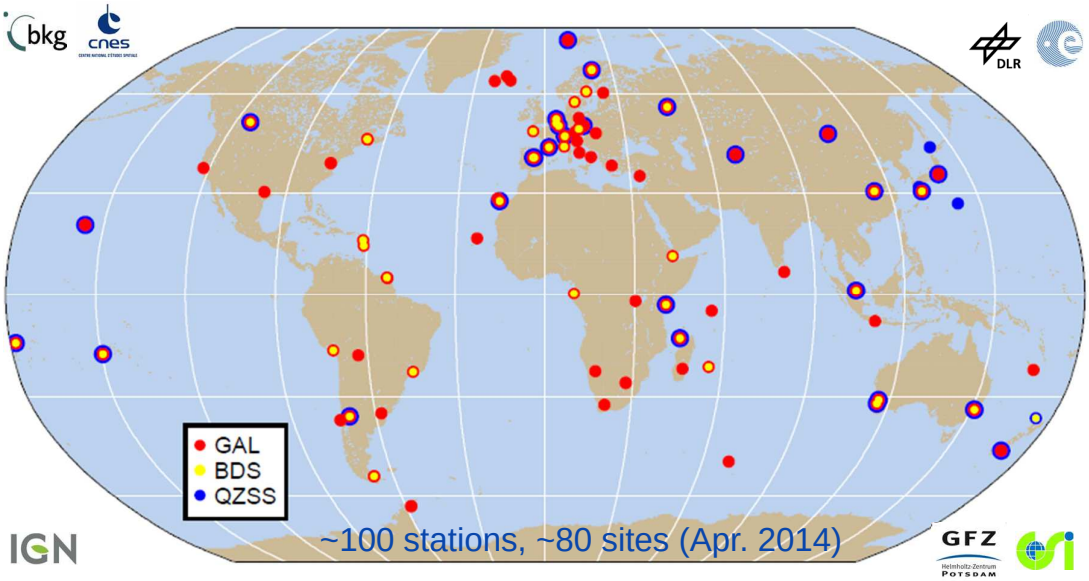
  ftp://cddis.gsfc.nasa.gov/pub/gps/data/campaign/mgex/

  ftp://cddis.gsfc.nasa.gov/pub/gps/products/mgex/

IGS MGEX web site... http://igs.org/mgex/

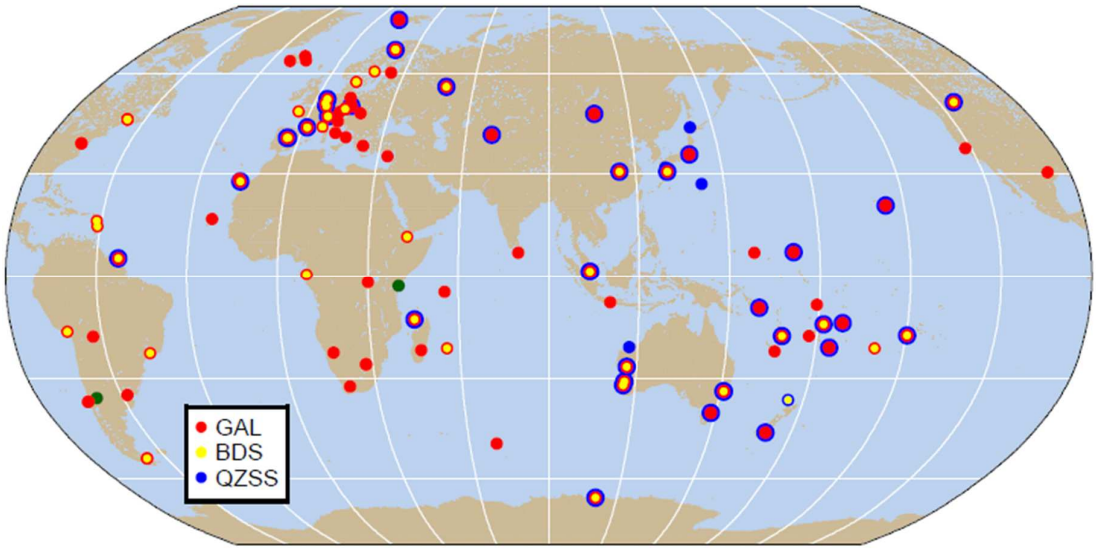
Clone for international access at UNAVCO (http://igsws.unavco.org/mgex/)

The IGS MGEX Network



Archive: ftp://cddis.gsfc.nasa.gov/pub/gps/data/campaign/mgex/
Streams: http://mgex.igs-ip.net

IGS MGEX Network Progress



Planned contribution of 13 GA stations in Asia Pacific Region

IGS MGEX Equipment...

- One to four systems in addition to GPS+GLONASS:
  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
- 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

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

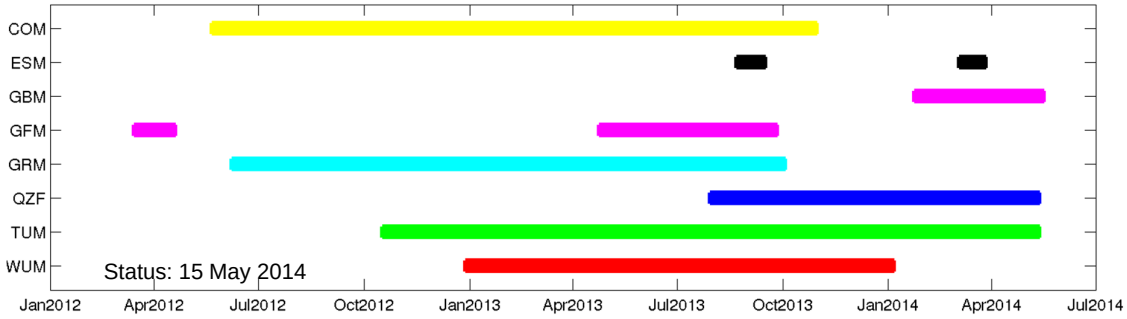
- Antennas
  AOAD/M_T
  JAV_RINGANT_DM
  JAV_RINGANT_G3T
  LEIAR10
  LEIAR25
  LEIAR25.R3
  LEIAR25.R4
  TPSCR.G3
  TRM55971.00
  TRM57971.00
  TRM59800.00

MGEX Data Repository

- RINEX 3.x observation & navigation files
- Three archives:
  - Crustal Dynamics Data Information System (CDDIS) (ftp://cddis.gsfc.nasa.gov/pub/gps/data/campaign/mgex)
  - Institut Géographique National (IGN) (ftp://igs.ign.fr/pub/igs/data/campaign/mgex)
  - Bundesamt für Kartographie und Geodäsie (BKG) (ftp://igs.bkg.bund.de/MGEX)
- Approximately 2.5 years of data
- Real-time streams in RTCM3-MSM format
- One NTRIP caster at BKG:
  (http://mgex.igs-ip.net/)

IGS MGEX Test Products...

- 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 results
- SLR residuals for several GNSS satellites



IGS MGEX Test Products...

http://igs.org/mgex/#products

Institution	Products		Constellations	Availability (week/day)
CNES/CLS	grm*yyyyd*.sp3	GNSS orbits and clocks (15 min)	GAL	since 1692/1
CODE	com*yyyyd*.sp3	GNSS orbits and clocks (15 min)	GPS+GLO+GAL/GIO	since 1689/5
	com*yyyyd*.clk	GNSS and station clocks (5 min)		
	com*yyyyd*.bia/dcb	Biases	GPS (DCBs) GAL (ISBs)	
	com*yyyyd*.erp	Earth rotation parameters		
GFZ	gfm*yyyyd*.sp3	GNSS orbits and clocks (15 min)	GPS+GAL	1680/0-1683/0
	gfm*yyyyd*.clk	GNSS and station clocks (5 min)		
	gfm*yyyyd*.bia	Inter-system biases		
	gfb*yyyyd*.sp3	GNSS orbits and clocks (15 min)	GPS+BDS	since 1777/2-1781/5
	gfb*yyyyd*.clk	GNSS and station clocks (5 min)		
	gfb*yyyy7*.erp	Earth rotation parameters		
JAXA	qzf*yyyyd*.sp3	GNSS orbits and clocks (5 min)	GPS+QZS	since 1751/6
TUM	tum*yyyyd*.sp3	GNSS orbits and clocks (5 min)	GAL+QZS	since 1711/1
Wuhan Univ.	wum*yyyyd*.sp3	GNSS orbits and clocks (15 min)	BDS	since 1721/2
	wum*yyyyd*.clk	GNSS clocks (15 min)		

Orbit Validation: SLR Residuals

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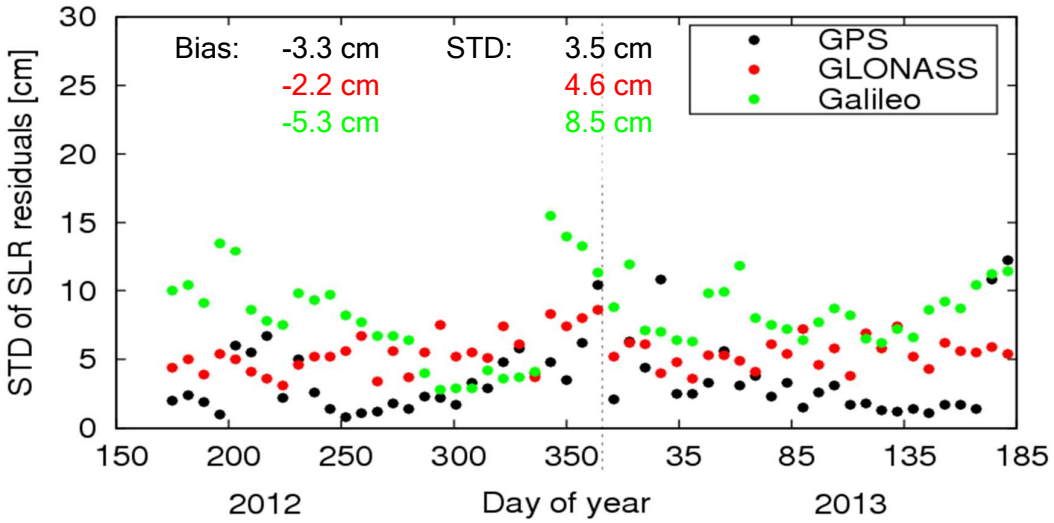
STD of SLR residuals per week



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Broadcast Performance Assessment

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- Broadcast orbits and clocks from combined „brdm“ product
- MGEX precise orbit and clock products
- Signal in Space Range Error (SISRE)

System		SISRE (orb) [m]	SISRE [m]
GPS	all	0.24	0.71
	IIA	0.31	1.09
	IIR	0.21	0.53
	IIF(Rb)	0.18	0.34
GLO		0.54	1.97
GAL		0.76	1.64
BDS	all	1.02	1.46
	MEO+IGSO	0.57	1.02
QZS		0.50	0.57

(Montenbruck et al. 2014, GPS Solutions, submitted)

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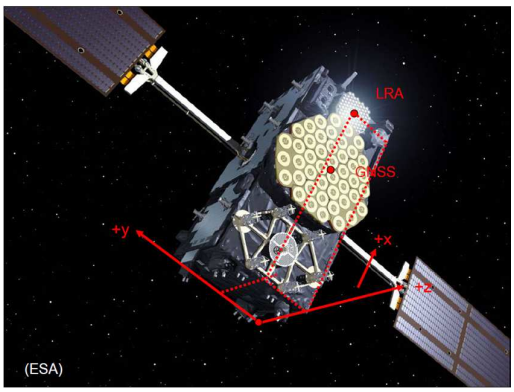
MGEX DCB Product

- Differential Code Biases from ionosphere-corrected pseudorange differences(1)
- Prototype Bias SINEX format
- Daily satellite and station DCBs; weekly satellite DCBs
- Supported constellations: GPS, GLONASS, BeiDou, Galileo
- Available at:
  ftp://cddis.gsfc.nasa.gov/pub/gps/products/mgex/dcb

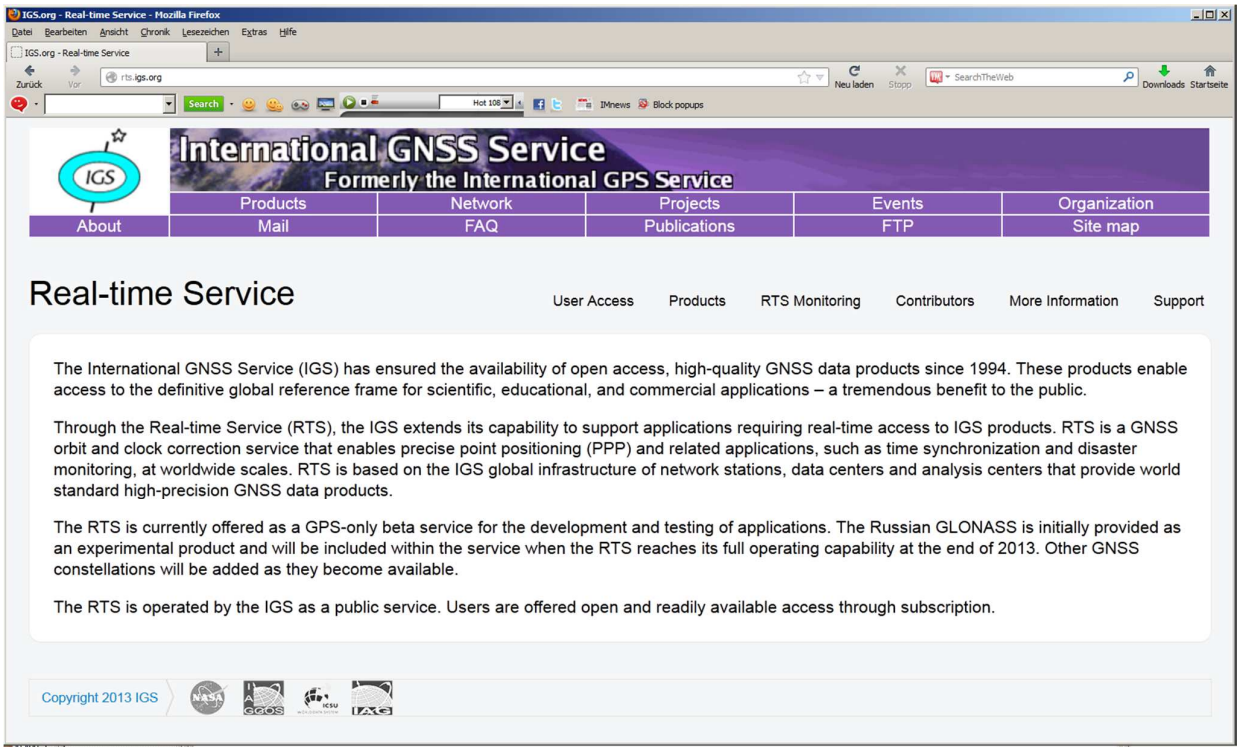
(1) Montenbruck et al., ION-ITM 2014

Standardisation Efforts...

- Continued interactions with:
  - GNSS system providers
  - GNSS equipment manufacturers
  - Other IGS Working Groups
- Recommendations, conventions & processing standards:
  - Attitude models
  - Antenna offsets & patterns
  - SRP models
- Data formats:
  - Observations & navigation data (RINEX v3.x, RTCM v3.2)
  - Biases (DCBs, ISB - SINEX?)
  - Orbits & attitude (SPx – ORBEX?)



IGS RTS web site... http://rts.igs.org/



IGS Real-Time Service (RTS)

- International effort of many contributions
- Maintain & extend real-time infrastructure (data transfer, broadcasting, product generation, combination, quality control)
- Develop necessary data formats & transmission protocols together with RTCM SC104
- Launched on April 1, 2013
- Currently GPS + experimental GLONASS real-time orbit & clock products
- Support scientific & other PP applications
- Open data & open standards policy
- Working towards FOC

IGS Real-Time Tracking Network

150+ stations

RTS Products... http://rts.igs.org/products

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 (via web site)
- 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.

RTS Analysis Centres...

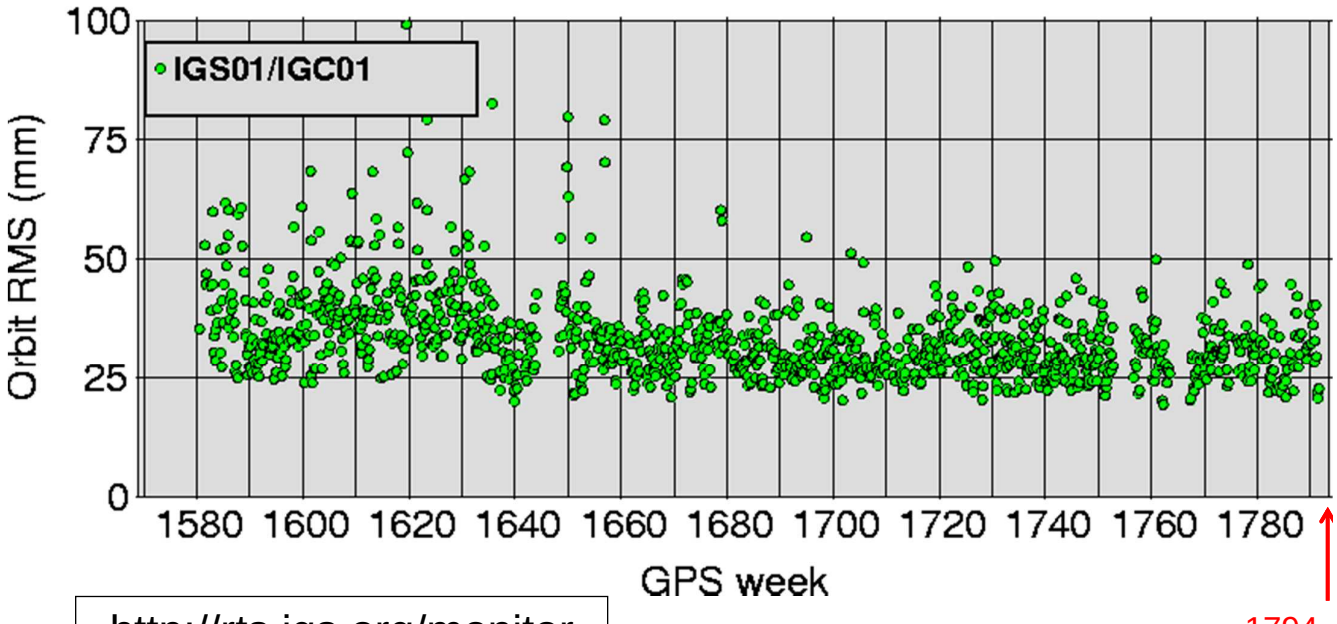
10 Analysis Centres:

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:

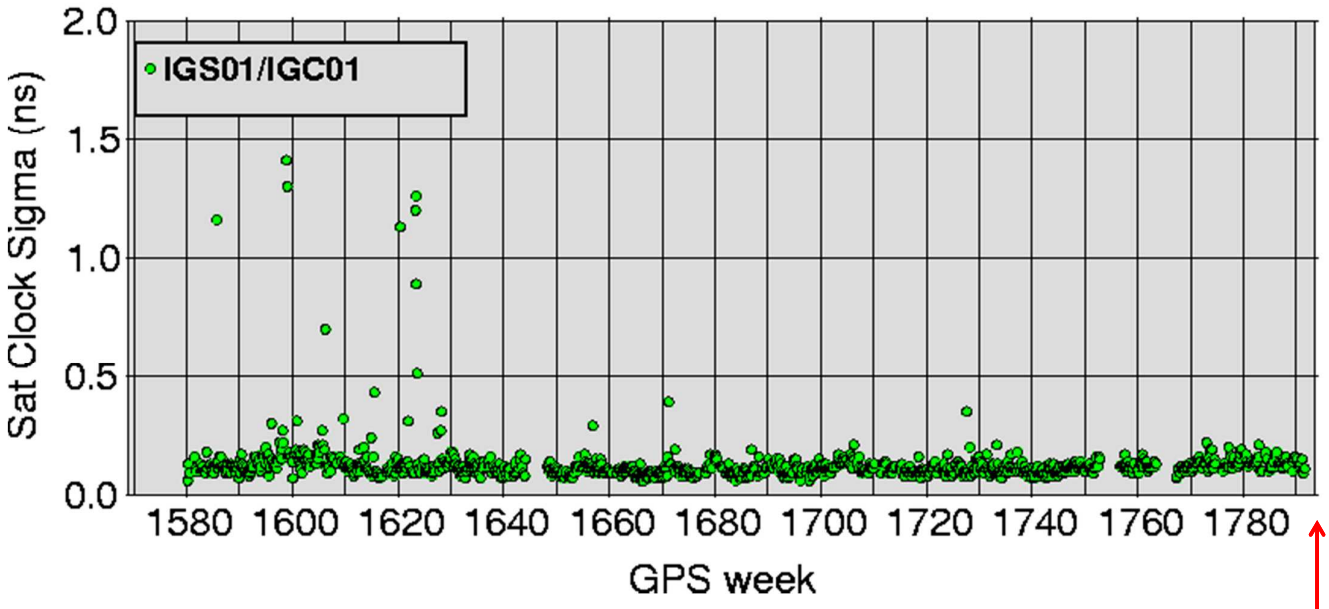
- NRCan – RT Working Group Chair
- ESOC – Real Time Analysis Center Coordinator
- BKG – Data Flow Coordination

RTS – IGS01/IGC01 products



http://rts.igs.org/monitor

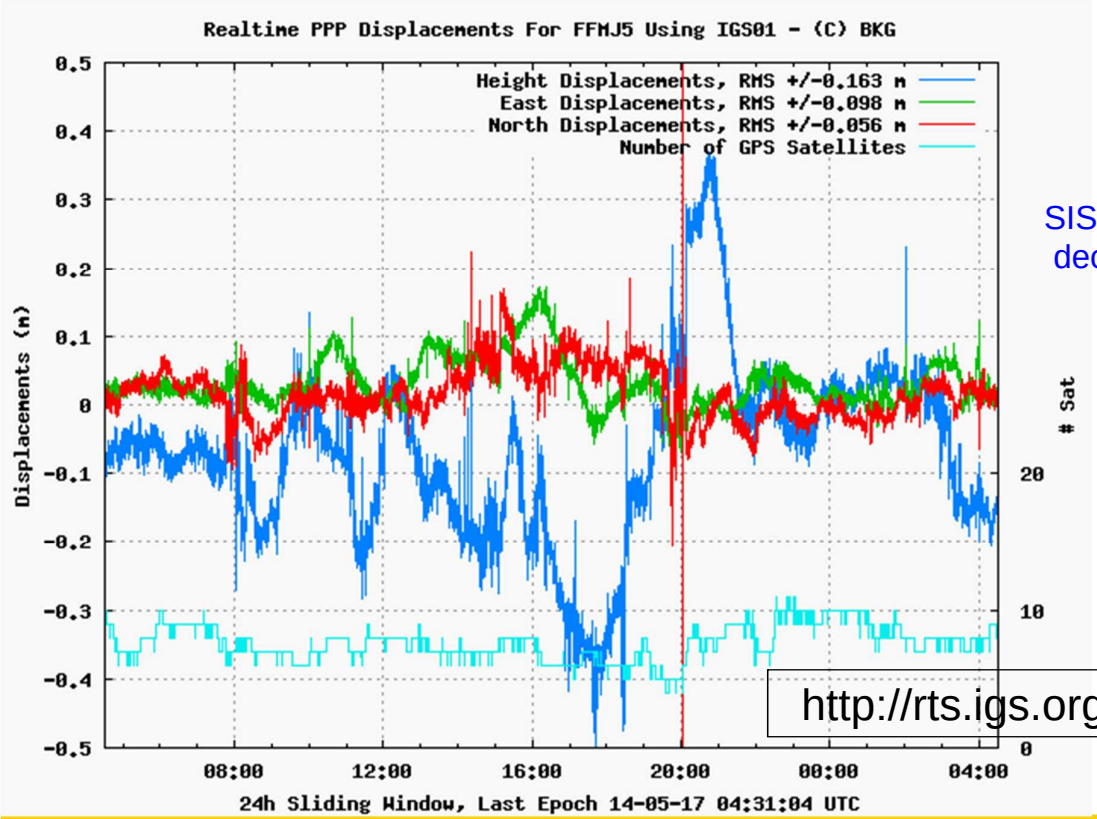
RTS – IGS01/IGC01 products



http://rts.igs.org/monitor

1794

RTS IGS01... PPP Results



Frankfurt a.M.

SIS-UERE at decimetre-level

http://rts.igs.org/monitor

RTS IGS03... PPP results

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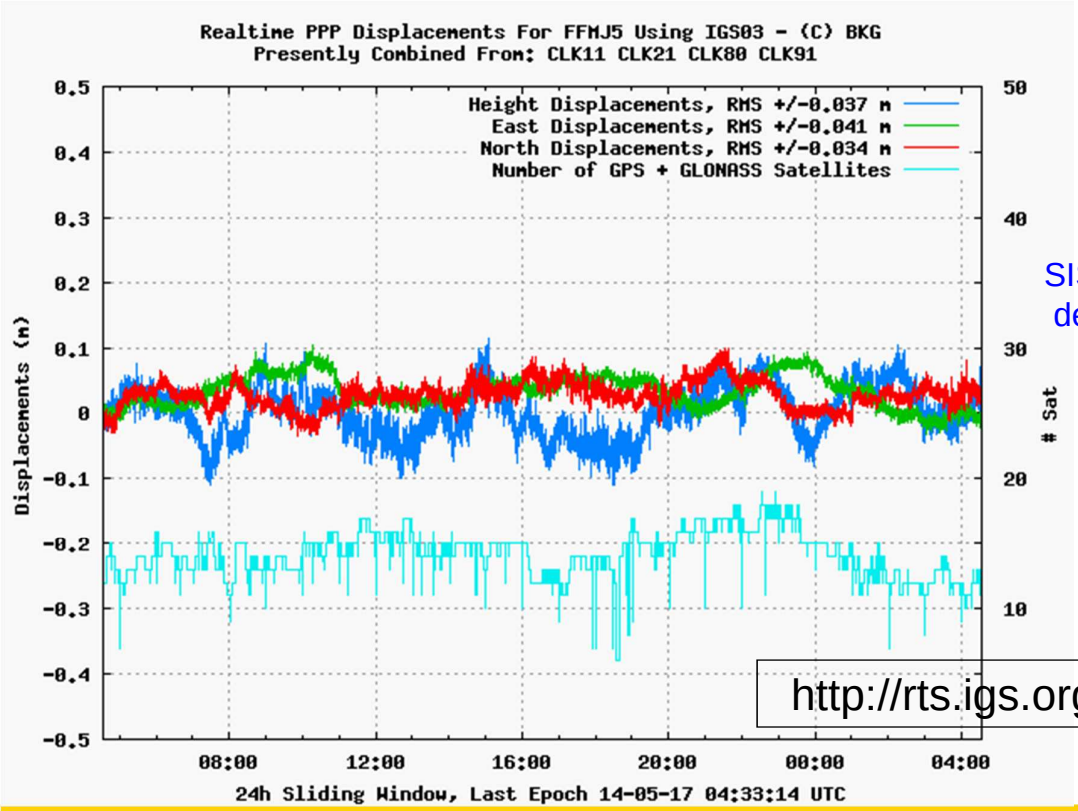

SIS-UERE at decimetre-level

http://rts.igs.org/monitor

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RTS... who is using it?

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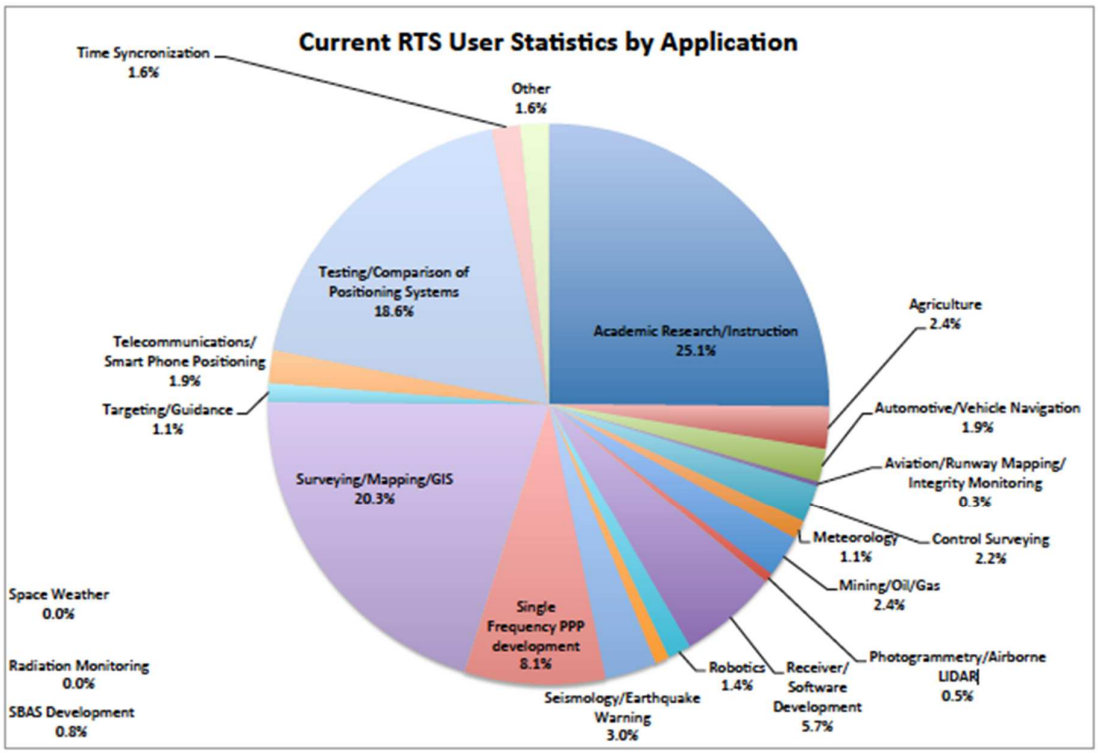
- 80 user registrations within days of launch
- 372 user registrations by 21 May 2014, from 51 countries



IGS-RTS... Some Comments

- SIS-UERE at sub-decimetre-level...
- Important activity for developing & promoting new data formats & transmission protocols...
  driving innovation in, and beyond the IGS
- Crucial for new RT scientific applications... *pre-, co-, post-seismic displacement; deformation monitoring; tsunami modelling; atmospheric sounding; etc*.
- IGS-RTS promotes open, interoperable GNSS PPP services
- Some criticism for "competing" with *commercial RT services*
- *IGS-RTS can also be used to satisfy new demands for a "GNSS monitoring & assessment" service*
- *IGS-RTS can support new geohazard services (e.g. GGOS)*

IGS M-GNSS Policies

Open Data

- Observations & derived products freely available
- Streaming data over IP networks in real-time
- Best effort operations, distributed governance
- Funded by national agencies, institutions, science
- Playing a global coordination role

Open Source

- Supporting real-time GNSS tools for Linux, Solaris, Window, Mac
- Multi-stream decoder, feeding GNSS engines, etc.
- Combining, encoding and uploading orbit/clock corrections
- Precise Point Positioning (PPP) options
- Support of all GNSS through RINEXv3

Open Standards

- Standardisation in RTCM is a key issue
- Concepts and messages for all types of corrections
- Make PPP an viable alternative to Network-RTK

IGMA... IGS Monitored Quantities

- Satellite orbits (4x per day for GPS, GLONASS; adjusted & predicted)
- Satellite clocks (daily & RT for GPS, GLONASS; 30sec)
- Satellite differential code biases (daily for GPS, GLONASS)
- Earth rotation parameters (daily; daily resolution)
- Station coordinates (daily; daily resolution; & RT-PPP)
- Receiver differential code biases (daily)
- Receiver clock corrections for selected sites
- Global ionosphere TEC maps (daily & predicted; 2hr resolution)
- Station troposphere parameters (daily ZTD & gradients; 5min resolution with relative constraints)

GLONASS April 1st Incident in the IGS

Time (UTC)	Chronicle of Events
April 1, 21:00	GLONASS starts transmitting "infected" Broadcast messages simultaneously from all satellites.
April 2, 7:00	All GLONASS satellites transmit again correct broadcast messages (satellite 21 last satellite).
April 3, 9:23	E-Mail by Chris Rizos (IAG President and IGS GB member) to IGS GB et al: "What do you guys know about this? Have you been fielding any questions from media? users?" (wake-up call for IGS)
April 3, 10:36	E-Mail by Tim Springer (ESA Analysis Center) stating in essence that the "normal" IGS processing (final, rapid, ultra-rapid) was not affected ("nobody noticed")
April 4, 14:29	E-mail by Urs Hugentobler, Chair IGS Governing Board : First IGS-internal analysis of the event. Osculating elements derived from GLONASS Broadcast analyzed. He "sees" rotations of orbital planes, specific to three GLONASS planes
Since	Various attempts to explain the signature of the event (from cyber war to more technical and resonable)

XXV FIG Congress, Kuala Lumpur, Malaysia, 16-21 June 2014

GLONASS April 1st Incident in the IGS

Understood:

- The GLONASS April 1st event was *not* a joke
- The failure was caused by wrong Broadcast Ephemerides
- … probably caused by a software update, activated on April 1st at 9h pm UTC (24h/0h "Moscow Time")
- The error was
  - identified by the GLONASS provider almost immediately after the activation of the new BE …
  - but not communicated to the users of GLONASS.
- The correction (switch back to "old" software release?) took place satellite-by-satellite (starting on April 1, 10h45m pm UT)
- The effect on receivers was dependent on the receiver type & firmware release

GLONASS April 1st Incident in the IGS

Aspects to be considered by the IGS:

- The Broadcast Ephemerides (BE) are not needed for the IGS post-processing activities (ultra-rapid, rapid, final):
  - →No actions needed concerning BE for these applications
  - →Report about malfunctioning receivers might be collected routinely and made available in a report
- The BE are, however, of vital importance for the IGS Real-Time Service (corrections w.r.t. BE are sent out); the BE are a "single point of failure" for the IGS RTS
- Therefore the IGS should:
  - →implement an IGS real-time validation of all BE of all GNSS and make it available to the user community
  - →reconsider the use of the BE for the IGS RTS, as well

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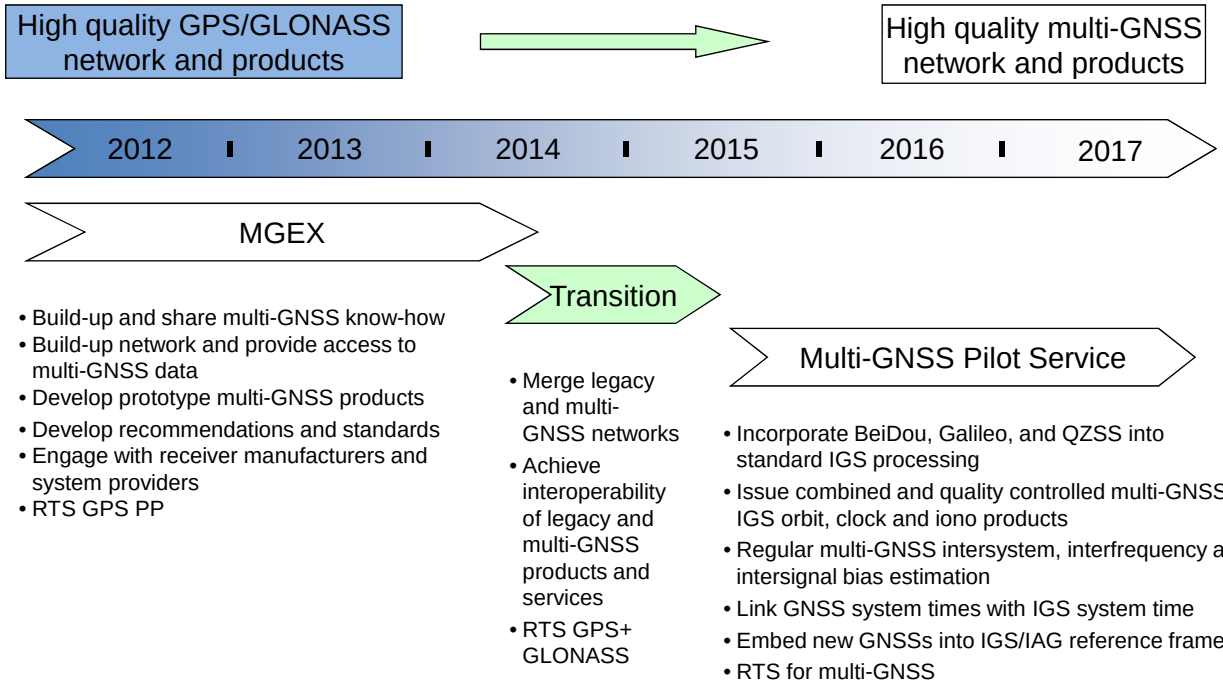
IGS Multi-GNSS Plan (tentative)



Final Remarks...

The IGS ...

... is in its 20th year of service

... is at the forefront of high quality GNSS product generation

... continues to develop new, & improve existing products

... has a large & diverse user community

... is well-connected (& respected) beyond scientific community

... is a robust service

... has a well-developed governance structure

... is evolving into a trusted (& independent) multi-GNSS real-time positioning & system monitoring service

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Terima Kasih!