The IGS: A Multi-GNSS Service

Chris Rizos, Urs Hugentobler, Ruth Neilan
International Union of Geodesy and Geophysics (IUGG)
65 Member Countries (Adhering Bodies), 8 Associations

International Association of Geodesy (IAG)

Council
Exec Committee
Bureau
Office
COB

Commission 1
Reference Frames

Commission 2
Gravity Field

Commission 3
Earth Rotation & Geodynamics

Commission 4
Positioning & Applications

Inter-Commission Committee on Theory (ICCT)

Services:
IERS
IGS
IGFS
BGI
ICET
BIPM
IAS
ILRS
IVS
IDS
ICGEM
IGeS
IDEMS
PSMSL
IBS

Global Geodetic Observing System (GGOS)
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.

IGS products are critical to ITRF definition, maintenance & its accessibility.

Reliability through *redundancy*.

Improvements in signals, receivers and computations have led to *progressive improvements in product quality*.

All IGS data and products are available *free of charge*.

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http://igs.org
Evolution of a Multi-GNSS Service

• Mission, structure & governance
IGS Mission

“The International GNSS Service provides the highest-quality GNSS data, products, and services in support of the Earth observations and research, positioning, navigation and timing, the terrestrial reference frame, Earth rotation, and other applications that benefit society.”*

*From IGS Strategic Plan 2008-2012
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*From IGS Strategic Plan 2008-2012
Evolution of a Multi-GNSS Service

- Mission, structure & governance
- Innovation, experimentation & expertise
## IGS Working Groups & M-GNSS

<table>
<thead>
<tr>
<th>Working Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Centre WG</td>
</tr>
<tr>
<td>Reference Frame WG</td>
</tr>
<tr>
<td>Tide Gauges WG</td>
</tr>
<tr>
<td>Space Vehicle Orbit Dynamics WG</td>
</tr>
<tr>
<td>Clock Product WG</td>
</tr>
<tr>
<td>Troposphere WG</td>
</tr>
<tr>
<td>Ionosphere WG</td>
</tr>
<tr>
<td>Antenna WG</td>
</tr>
<tr>
<td>Bias and Calibration WG</td>
</tr>
<tr>
<td>GNSS WG</td>
</tr>
<tr>
<td>RINEX WG</td>
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<tr>
<td>Real Time PP</td>
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</tbody>
</table>

- **how to convert IGS network to multi-GNSS?**
- **radiation pressure modelling for new satellites?**
- **clock products for new signals?**
- **remote sensing**
- **new systems and signals**
- **patterns for new frequencies**
- **biases of new signals**
- **new systems, M-GEX observation format (RINEX 3.0)**
- **real-time service/products**

ICG-7, Beijing, China, 4-9 November 2012
Evolution of a Multi-GNSS Service

• Mission, structure & governance
• Innovation, experimentation & expertise
• Network infrastructure
IGS Real-Time Network

~180 Stations streaming data to ACs
Evolution of a Multi-GNSS Service

- Mission, structure & governance
- Innovation, experimentation & expertise
- Network infrastructure
- Improved product suite
• Precise GNSS orbits (post-processed & predicted):
  – GPS (2-5 cm, 3Dwrms), predictions (<5-10 cm)
  – GLONASS (~5-10 cm, 3Dwrms)
• GNSS clock corrections (satellite & stn: sub-ns)
• Earth rotation parameters (polar motion, PM rate, LOD)
• Ground positioning (sub-cm), definition, maintenance & access to ITRF
• Ionospheric delay mapping (VTEC)
• Tropospheric parameters (integrated water vapour)
• Tracking data from IGS stations (RINEX files, or real-time data streams)
## GPS Broadcast Values Included for Comparison

<table>
<thead>
<tr>
<th>GPS Satellite Ephemerides/ Satellite &amp; Station Clocks</th>
<th>Accuracy</th>
<th>Latency</th>
<th>Updates</th>
<th>Sample Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broadcast</td>
<td>Orbits: -100 cm</td>
<td>real time</td>
<td>daily</td>
<td></td>
</tr>
<tr>
<td>Sat. clocks</td>
<td>-5 ns</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ultra-Rapid (predicted half)</td>
<td>Orbits: -5 cm</td>
<td>real time</td>
<td>4x daily</td>
<td>15 min</td>
</tr>
<tr>
<td>Sat. clocks</td>
<td>-3 ns</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ultra-Rapid (observed half)</td>
<td>Orbits: +3 cm</td>
<td>3 hours</td>
<td>4x daily</td>
<td>15 min</td>
</tr>
<tr>
<td>Sat. clocks</td>
<td>-0.15 ns</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rapid</td>
<td>Orbits: +2.5 cm</td>
<td>17 hours</td>
<td>daily</td>
<td>15 min</td>
</tr>
<tr>
<td>Sat. &amp; Stn. clocks</td>
<td>75 ps</td>
<td></td>
<td></td>
<td>5 min</td>
</tr>
<tr>
<td>Final</td>
<td>Orbits: +2.5 cm</td>
<td>-12 days</td>
<td>weekly</td>
<td>15 min</td>
</tr>
<tr>
<td>Sat. &amp; Stn. clocks</td>
<td>75 ps</td>
<td></td>
<td></td>
<td>5 min</td>
</tr>
<tr>
<td>Real Time Combination</td>
<td>Orbits: -10 cm</td>
<td>25 sec</td>
<td>10 sec</td>
<td>10 sec</td>
</tr>
<tr>
<td>Sat. clocks</td>
<td>+0.3 ns</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real Time AC Streams</td>
<td>Orbits: -10 cm</td>
<td>8-20 sec</td>
<td>5-10 sec</td>
<td>5-10 sec</td>
</tr>
<tr>
<td>Sat. clocks</td>
<td>-0.3-2 ns</td>
<td></td>
<td></td>
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Note: 1. IGS accuracy limits, except for predicted orbits, based on comparisons with independent laser ranging results. The precision is better.

Note 2: The accuracy of all clocks is expressed relative to the IGS timescale, which is linearly aligned to GPS time in one-day segments.

Note 3: Real Time products are provided on an experimental basis. See http://www.igs.org/index.php and http://igs.bkg.bund.de/igsc/igsc/iges.

Note 4: The methods used by some RT Analysis Centers result in high clock biases for individual satellites. Clock standard deviation, which is the more important metric for Precise Point Positioning, is typically of the order of 0.1 ns.

### GLONASS Satellite Ephemerides

<table>
<thead>
<tr>
<th>Final</th>
<th>5 cm</th>
<th>12-18 days</th>
<th>weekly</th>
<th>15 min</th>
</tr>
</thead>
</table>

### Geocentric Coordinates of IGS Tracking Stations (>100 Sites)

<table>
<thead>
<tr>
<th>Final Positions</th>
<th>Horizontal</th>
<th>3 mm</th>
<th>12 days</th>
<th>weekly</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vertical</td>
<td>6 mm</td>
<td></td>
<td>weekly</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Final Velocities</th>
<th>Horizontal</th>
<th>2 mm/yr</th>
<th>12 days</th>
<th>weekly</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vertical</td>
<td>3 mm/yr</td>
<td></td>
<td>weekly</td>
</tr>
</tbody>
</table>

### Earth Rotation Parameters

<table>
<thead>
<tr>
<th>Ultra-Rapid (predicted half)</th>
<th>Polar Motion</th>
<th>0.2 mas</th>
<th>real time</th>
<th>4x daily</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Polar Motion Rate</td>
<td>0.3 mas/day</td>
<td></td>
<td>4x daily</td>
</tr>
<tr>
<td></td>
<td>Length-of-day</td>
<td>0.05 ms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ultra-Rapid (observed half)</td>
<td>Polar Motion</td>
<td>0.05 mas</td>
<td>3 hours</td>
<td>twice daily</td>
</tr>
<tr>
<td></td>
<td>Polar Motion Rate</td>
<td>0.15 mas/day</td>
<td></td>
<td>twice daily</td>
</tr>
<tr>
<td></td>
<td>Length-of-day</td>
<td>0.01 ms</td>
<td></td>
<td>(00 &amp; 12 UTC)</td>
</tr>
<tr>
<td>Rapid</td>
<td>Polar Motion</td>
<td>-0.04 mas</td>
<td>17 hours</td>
<td>daily</td>
</tr>
<tr>
<td></td>
<td>Polar Motion Rate</td>
<td>-0.2 mas/day</td>
<td></td>
<td>(12 UTC)</td>
</tr>
<tr>
<td></td>
<td>Length-of-day</td>
<td>0.01 ms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final</td>
<td>Polar Motion</td>
<td>0.03 mas</td>
<td>-13 days</td>
<td>weekly</td>
</tr>
<tr>
<td></td>
<td>Polar Motion Rate</td>
<td>0.15 mas/day</td>
<td></td>
<td>daily</td>
</tr>
<tr>
<td></td>
<td>Length-of-day</td>
<td>0.01 ms</td>
<td></td>
<td>(12 UTC)</td>
</tr>
</tbody>
</table>

Note: The IGS uses VLBI results from IERS Bulletin A to calibrate for long-term LOD biases.

### Atmospheric Parameters

<table>
<thead>
<tr>
<th>Final tropospheric zenith path delay</th>
<th>4 mm</th>
<th>&lt;4 weeks</th>
<th>daily</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ionospheric TEC grid</td>
<td>2-8 TECU</td>
<td>-11 days</td>
<td>weekly</td>
</tr>
<tr>
<td></td>
<td>2 hours; 3 deg (lon) x 2.5 deg (lat)</td>
<td></td>
<td></td>
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</tbody>
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## Evolution of IGS

| From experimental to operational products... a **titanic** journey |
| Self-improvement & competitive culture... *leads* to increases in accuracy, reduced latency |
| Address new user requirements... *new data & products supporting science & societal needs* |
| GPS to GPS+GLONASS to multi-GNSS... |
Evolution of a Multi-GNSS Service

- Mission, structure & governance
- Innovation, experimentation & expertise
- Network infrastructure
- Improved product suite
- From service focused on post-processing applications, to real-time products
IGS Real-Time Products

• Real-time product generation is part of IGS Strategic Plan, started 2002

• Infrastructure:
  – More than 180 active real-time stations, streaming data using NTRIP
  – Close link to RTCM...*joint WG established to develop standards*

• Analysis:
  – 8 real-time Analysis Centres
  – Real-time orbit & sat clock combination...*can support RT-PPP*

• Users tap into product streams from NTRIPcaster via internet link

• Future:
  – Real-time Beta service (late 2012)...*initially GPS-only*
  – Satellite clock corrections, orbits, ionosphere corrections (later)
  – *Progressively include new systems and signals*
  – *New derived products, e.g. integrity monitoring & assessment*
Larger than any private network, and more redundancy...
Will support readily available RT-PPP (& other services)

~180 Stations streaming data to ACs
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IGS Multi-GNSS Experiment (M-GEX)

- Call for Participation to realise M-GNSS *global* network (Feb 2012).
- Include RT tracking and signal utilisation, coordinated by the IGS Real-Time WG.
- M-GEX will not disrupt daily IGS operations, and delivery of its current data and products.
- Analysis of data from multi-GNSS by IGS ACs to extend standard IGS product suite.
- Data and engineering analysis by *any* interested groups.
- Coordinated by IGS GNSS WG.
- *Initial phase of M-GEX to continue until end of 2013.*
M-GEX sites

Geoscience Australia’s GNSS Stations

igs.org/mgex

ICG-7, Beijing, China, 4-9 November 2012
IGS Multi-GNSS Challenges

- Improve tracking network distribution.
- BeiDou, Galileo, IRNSS tracking data; global receiver stations; & signal/engineering specifications.
- Information on satellite antenna offsets & patterns, attitude modes, etc.
- Detailed modelling of observations on new GNSS signals, e.g. DCBs.
- Across-the-board upgrade of IGS AC processing capability.
- Upgrade of file formats, e.g. RINEX 3.0, ANTEX, etc.
- Ensure benefits of multi-GNSS propagate into variety of standard (e.g. ITRF, site time series, etc.) and new (e.g. RTS, integrity, etc.) IGS/GGOS products.
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- Mission, structure & governance
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- Improved product suite
- From service focused on post-processing applications, to real-time products
- From GPS-only to multi-GNSS
- Concluding remarks...the future IGS
The IGS is working towards...

- An expanded IGS M-GEX tracking network...the future M-GNSS network.
- Recruitment of more Analysis Centres & participants...wider spread of GNSS expertise.
- Cooperation with other M-GNSS initiatives...minimise wasteful duplication, develop open standards, etc.
- Generation of experimental M-GNSS products...be ready to support users in a M-GNSS world.
- Accelerate transition to RT+M-GNSS service to support expanded IGS role.
- Liaison with Signal Providers to ensure high product quality.
- Supporting ICG mission & objectives...with growth in IGS expertise & reputation, by harnessing strong IGS culture.

The IGS is transitioning to a full multi-GNSS service...

Several initiatives have been launched to address (current & new) user requirements

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