Status Report of the IGS Clock Products

2015 September 17 – 18

Michael J. Coleman
Clock Products Coordinator
International GNSS Service
U.S. Naval Research Laboratory
Washington, DC, USA

Consultative Committee on Time and Frequency
Bureau International des Poids et Mesures
Sèvres, Cedex, France
### Existing IGS Core Products

<table>
<thead>
<tr>
<th>SERIES</th>
<th>Product</th>
<th>Interval</th>
<th>Accuracy</th>
<th>Issue Time</th>
<th>Latency</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ultra Rapid (igu)</strong></td>
<td>GPS ORBITS</td>
<td>15 MIN</td>
<td>~ 3.0 cm</td>
<td>Daily at 03:00 – 09:00</td>
<td>3 – 9 Hours</td>
</tr>
<tr>
<td></td>
<td>GPS CLOCKS *</td>
<td>15 MIN</td>
<td>~ 150 ps</td>
<td>15:00 – 21:00 UTC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>POLAR MOTION</td>
<td>6 HRS</td>
<td>~ 40 µas</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>LENGTH OF DAY</td>
<td>6 HRS</td>
<td>~ 10 µs</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Rapid (igr)</strong></td>
<td>GPS ORBITS</td>
<td>15 MIN</td>
<td>~ 2.5 cm</td>
<td>Daily at 17:00 UTC</td>
<td>17 – 41 Hours</td>
</tr>
<tr>
<td></td>
<td>GPS CLOCKS †</td>
<td>5 MIN</td>
<td>~ 75 ps (RMS)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>POLAR MOTION</td>
<td>1 DAY</td>
<td>~ 40 µas</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>LENGTH OF DAY</td>
<td>1 DAY</td>
<td>~ 10 µs</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Final (igs)</strong></td>
<td>GPS ORBITS</td>
<td>15 MIN</td>
<td>~ 2.5 cm</td>
<td>Weekly on Wednesday or Thursday</td>
<td>11 – 17 Days</td>
</tr>
<tr>
<td></td>
<td>GLONASS ORBITS</td>
<td>15 MIN</td>
<td>~ 5.0 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>GPS CLOCKS †</td>
<td>5 MIN</td>
<td>~ 75 ps (RMS)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>POLAR MOTION</td>
<td>1 DAY</td>
<td>~ 30 µas</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>LENGTH OF DAY</td>
<td>1 DAY</td>
<td>~ 10 µs</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Only satellite clocks are reduced in the Ultra Rapid products.

† Both satellite and station clocks are reduced but **not** all IGS network station clocks.
IGS Time

The current IGS timescale is formed for both the IGS rapid and final products and is derived using a standard Kalman Filter approach.

Kalman Filter was introduced in IGS2.0 version. This second version was implemented in 2011 with reprocessing computed from 2010.

Specifications for IGST

- Consists of an average of 50 – 60 positively weighted member clocks.
- Timescale is generated and exchanged with the IGS data clock reference for the Rapid and Final products.
- Stability performance as low as $E^{-16}$ for longer averaging intervals.
- Steers to UTC via AMC2 or USNO. Goal is towards UTC(USNO).

Timescale Features

- Institutes a harmonic component into model for all satellite clocks.
- Automated break detection responds to phase and frequency breaks in clock data as well as day–by–day boundaries.
- Steering achieved using Linear Quadratic Gaussian Steering Algorithm.
Filter uses a four state clock model for all station clocks. The total phase state incorporates additional white noise process.

For satellite clocks, two fixed period harmonics are estimated and added to the total phase state. Hence, some clocks have 8 states.

\[
\begin{align*}
\int dt \quad \text{White Noise} & \quad u_f \\
\int dt \quad \text{Drift} & \quad r \\
\int dt \quad \text{White Noise} & \quad u_p \\
\int dt \quad \text{Frequency} & \quad f \\
\int dt \quad \text{White Noise} & \quad u_\theta \\
\int dt \quad \text{Phase} & \quad p \\
\end{align*}
\]

Periodic #1 \( (a_1 + u_{a_1}) \cos(2\pi \omega_1 t) + (b_1 + u_{b_1}) \sin(2\pi \omega_1 t) \)

Periodic #2 \( (a_2 + u_{a_2}) \cos(2\pi \omega_2 t) + (b_2 + u_{b_2}) \sin(2\pi \omega_2 t) \)
IGS(R)T Offset from UTC

Assumes that GPS Time via Circular T is equivalent to GPST
GPS Clock Frequency Weight Contribution

GPS Clock Contribution to IGS(R)T

Size of IGS(R)T Clock Membership

M. Coleman (IGS // US NRL)

IGS Clock Products

2015 September 17 – 18
These tables show some common stations that are weighted in the timescale over the first 257 days of year 2015.

### Stations with IGS & UTC (Partial List)

<table>
<thead>
<tr>
<th>Station</th>
<th>IGS</th>
<th>UTC</th>
<th>Location</th>
<th>Days</th>
<th>$w_p$</th>
<th>$w_f$</th>
<th>Days</th>
<th>$w_p$</th>
<th>$w_f$</th>
</tr>
</thead>
<tbody>
<tr>
<td>BJNM</td>
<td>NIM</td>
<td>Beijing, CHINA</td>
<td>59</td>
<td>4.31</td>
<td>4.30</td>
<td>0</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>IENG</td>
<td>IT</td>
<td>Torino, ITALY</td>
<td>38</td>
<td>2.31</td>
<td>0.89</td>
<td>239</td>
<td>3.77</td>
<td>3.85</td>
<td></td>
</tr>
<tr>
<td>NIST</td>
<td>NIST</td>
<td>Boulder, CO, USA</td>
<td>0</td>
<td>--</td>
<td>--</td>
<td>212</td>
<td>4.80</td>
<td>4.80</td>
<td></td>
</tr>
<tr>
<td>OPMT</td>
<td>OP</td>
<td>Paris, FRANCE</td>
<td>223</td>
<td>4.37</td>
<td>4.38</td>
<td>1</td>
<td>4.86</td>
<td>4.96</td>
<td></td>
</tr>
<tr>
<td>PTBB</td>
<td>PTB</td>
<td>Braunschweig, GERMANY</td>
<td>233</td>
<td>4.44</td>
<td>4.44</td>
<td>249</td>
<td>4.85</td>
<td>4.84</td>
<td></td>
</tr>
<tr>
<td>SFER</td>
<td>ROA</td>
<td>San Fernando, SPAIN</td>
<td>225</td>
<td>4.36</td>
<td>2.21</td>
<td>6</td>
<td>5.16</td>
<td>3.53</td>
<td></td>
</tr>
<tr>
<td>SPT0</td>
<td>SP</td>
<td>Boras, SWEDEN</td>
<td>130</td>
<td>3.69</td>
<td>3.68</td>
<td>194</td>
<td>4.66</td>
<td>4.66</td>
<td></td>
</tr>
<tr>
<td>TWTF</td>
<td>TL</td>
<td>Chung-Li, TAIWAN</td>
<td>119</td>
<td>4.32</td>
<td>4.31</td>
<td>113</td>
<td>5.07</td>
<td>5.07</td>
<td></td>
</tr>
<tr>
<td>USNO</td>
<td>USNO</td>
<td>Washington, DC, USA</td>
<td>73</td>
<td>3.58</td>
<td>1.09</td>
<td>58</td>
<td>4.37</td>
<td>4.36</td>
<td></td>
</tr>
<tr>
<td>WAB2</td>
<td>CH</td>
<td>Bern, SWITZERLAND</td>
<td>231</td>
<td>1.64</td>
<td>1.97</td>
<td>238</td>
<td>2.13</td>
<td>0.11</td>
<td></td>
</tr>
</tbody>
</table>
Data is mostly present for the rapid product.
Data is largely absent for the final product.

Filter States & Sigmas
IENG

Sigmas
Proposed Improvements

UTC\(^{(k)}\) Laboratory Inclusion

- UTC labs occasionally fall from IGS(R)T due to Analysis Center computation changes and/or drop outs. This is especially more prominent in IGR.
- Request that Analysis Centers utilize some collection of UTC\(^{(k)}\) labs to allow improved IGS(R)T stability and UTC steering (as best possible / if possible).
- Request at next Governing Board Meeting in [December 2015 @ AGU]
- Goal via steering to these references is to maintain

\[|\text{UTC} - \text{IGS(R)T}| < 10 \text{ ns}\]

Satellite Clock Models

- Improvements to the initialization of clock states and covariances are being timescale filter. This will assist with false starts for GPS clocks and/or resets.
- Increase the contribution of GNSS clocks in IGS(R)T; in particular, include from Galileo, Glonass and Beidou as data becomes available after MGEX project complete. [Longer term timeline]
- GPS (in future, GNSS) clocks are nearly always part of the IGS combinations.
For more information on the IGS core products, experiments and working groups:

www.igs.org

For suggestions or requests for the Clock Products:

michael.coleman@nrl.navy.mil