IGS Preparations for the Next Reprocessing and ITRF

- what is IG2?
- who will contribute?
- expected performance
- remaining issues

Jake Griffiths, NOAA/National Geodetic Survey
Paul Rebischung, Institut Géographique National
Bruno Garayt, Institut Géographique National
Jim Ray, NOAA/National Geodetic Survey
How will IG2 Differ from IG1?

- more details at http://acc.igs.org/reprocess2.html

• Longer data span (~1994 thru mid-2012)
  – IG2 + operational prods thru 2013 -> IGS contribution to next ITRF

• Updated models, frames & methodologies
  – IERS 2010 Conventions
  – IGS08.SNX/igs08.atx framework (possibly updated version – IGb08)
  – AC SINEX files based on 1d TRF integrations (w/ consistent non-TRF products)
    • improve sampling of non-tidal loading displacements
    • reduces distortions in non-TRF prods (slightly noisier)
    • but no non-tidal atmospheric loading at obs eqn
  – some ACs to apply 2nd order iono corrections
  – Earth-reflected radiation pressure (albedo) modelling
    • reduce ~2.5 cm radial bias w.r.t. SLR [e.g. Urschl et al., 2007; Zeibart et al., 2007]
  – satellite-attitude modelling by all clock ACs
  – satellite antenna PCOs included in long-term TRF stacking

• Sub-daily alias and draconitic errors will remain
  – [e.g. Griffiths & Ray, in prep]
  – new diurnal & semi-diurnal EOP tide model needed

• Final preps and initial processing by mid-2012
• Expect to deliver SINEX files for next ITRF by late 2013
Expected AC and IG2 Products
- more details at http://acc.igs.org/reprocess2.html -

• Daily GPS orbits & satellite clocks
  – 15-minute intervals (SP3c format)
  – clocks in IGS timescale

• Daily satellite & tracking station clocks
  – 5-minute intervals (clock RINEX format)
  – in IGS timescale

• Daily Earth rotation parameters (ERPs)
  – from SINEX & classic orbit combinations (IGS erp format)
  – x & y coordinates of pole
  – rate-of-change of x & y pole coordinates (should not be used due to sensitivity to subdaily tidal errors)
  – excess length-of-day (LOD)

• Weekly (IG2 only) & daily terrestrial coordinate frames with ERPs
  – with full variance-covariance matrix (SINEX format)

• May also provide (TBD)
  – daily GLONASS orbits & satellite clocks
  – 30-second GPS clocks in IGS timescale
  – ionosphere maps, tropospheric zenith delay estimates
  – new bias products
Who will Contribute to IG2?
- more details at http://acc.igs.org/reprocess2.html -

• All IGS Final-product Analysis Centers:
  – CODE/AIUB – Switzerland
  – EMR/NRCan – Canada
  – ESA/ESOC – Germany
  – CNES/GRGS – Toulouse, France
  – GFZ – Potsdam, Germany
  – JPL – USA
  – MIT – USA
  – NGS/NOAA – USA
  – SIO – USA

• Plus 1 reprocessing Center
  – ULR – University of La Rochelle TIGA (tide gauges), France

• Plus 1 Center contributing to TRF only:
  – GFZ TIGA – Potsdam, Germany
<table>
<thead>
<tr>
<th>ANALYSIS CENTER</th>
<th>SYSTEM</th>
<th>OBS TYPE</th>
<th>ORBIT DATA ARC LENGTH</th>
<th>DATA RATE</th>
<th>ELEVATION CUTOFF</th>
<th>ELEVATION INVERSE WGTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>CODE</td>
<td>GPS + GLO</td>
<td>DbDiff (weak redundant)</td>
<td>24 + 24 + 24 h</td>
<td>3 min</td>
<td>3 deg</td>
<td>1/cos²(z)</td>
</tr>
<tr>
<td>EMR</td>
<td>GPS</td>
<td>UnDiff</td>
<td>24 h</td>
<td>5 min</td>
<td>10 deg</td>
<td>none</td>
</tr>
<tr>
<td>ESA</td>
<td>GPS + GLO</td>
<td>UnDiff</td>
<td>24 h</td>
<td>5 min</td>
<td>10 deg</td>
<td>1/sin²(e)</td>
</tr>
<tr>
<td>GFZ (&amp; GTZ)</td>
<td>GPS + ?GLO?</td>
<td>UnDiff</td>
<td>24 + 24 + 24 h</td>
<td>5 min</td>
<td>7 deg</td>
<td>1/2sin(e) for e &lt; 30 deg</td>
</tr>
<tr>
<td>GRG</td>
<td>GPS</td>
<td>UnDiff</td>
<td>24 h</td>
<td>5 min</td>
<td>10 deg</td>
<td>none</td>
</tr>
<tr>
<td>JPL</td>
<td>GPS</td>
<td>UnDiff</td>
<td>3 + 24 + 3 h</td>
<td>5 min</td>
<td>7 deg</td>
<td>none</td>
</tr>
<tr>
<td>MIT</td>
<td>GPS</td>
<td>DbDiff (weak redundant)</td>
<td>(SRPs over 9d)</td>
<td>2 min</td>
<td>10 deg</td>
<td>a² + (b²/sin²(e)) a,b from site residuals</td>
</tr>
<tr>
<td>NGS</td>
<td>GPS</td>
<td>DbDiff (redundant)</td>
<td>24 h</td>
<td>30 s</td>
<td>10 deg</td>
<td>[5 + (2/sin(e)) cm]²</td>
</tr>
<tr>
<td>SIO</td>
<td>GPS</td>
<td>DbDiff (weak redundant)</td>
<td>24 h</td>
<td>2 min</td>
<td>10 deg</td>
<td>a² + (b²/sin²(e)) a,b from site residuals</td>
</tr>
<tr>
<td>ULR</td>
<td>GPS</td>
<td>DbDiff (weak redundant)</td>
<td>24 h</td>
<td>3 min</td>
<td>10 deg</td>
<td>a² + (b²/sin²(e)) a,b from site residuals</td>
</tr>
<tr>
<td>ANALYSIS CENTER</td>
<td>NUTATION &amp; EOPs</td>
<td>SRP PARAMS</td>
<td>VELOCITY BRKs</td>
<td>ATTITUDE</td>
<td>SHADOW ZONES</td>
<td>EARTH ALBEDO</td>
</tr>
<tr>
<td>-----------------</td>
<td>----------------</td>
<td>------------</td>
<td>---------------</td>
<td>----------</td>
<td>--------------</td>
<td>--------------</td>
</tr>
<tr>
<td>CODE</td>
<td>IAU 2000A&lt;sub&gt;r06&lt;/sub&gt;; BuA ERPs</td>
<td>D,Y,B scales; B 1/rev</td>
<td>every 12 hr + constraints</td>
<td>nominal yaw rates used</td>
<td>E+M: umbra &amp; penumbra</td>
<td>? applied ?</td>
</tr>
<tr>
<td>EMR</td>
<td>IAU 2000A&lt;sub&gt;r06&lt;/sub&gt;; BuA ERPs</td>
<td>X,Y,Z scales stochastic</td>
<td>none</td>
<td>yaw rates estimated</td>
<td>E: umbra &amp; penumbra</td>
<td>applied</td>
</tr>
<tr>
<td>ESA</td>
<td>IAU 2000; BuA ERPs</td>
<td>D,Y,B scales; B 1/rev</td>
<td>none; Along, Along 1/rev accelerations</td>
<td>nominal yaw rates used</td>
<td>E+M: umbra &amp; penumbra</td>
<td>applied + IR</td>
</tr>
<tr>
<td>GFZ (&amp; GTZ)</td>
<td>IAU 2000; GFZ ERPs</td>
<td>D,Y scales</td>
<td>@ 12:00 + constraints</td>
<td>yaw rates estimated</td>
<td>E+M: umbra &amp; penumbra</td>
<td>applied + AT</td>
</tr>
<tr>
<td>GRG</td>
<td>IAU 2000; IERS C04 &amp; BuA ERPs</td>
<td>D,Y scales; X &amp; D 1/rev</td>
<td>stoch. impulse during ecl.</td>
<td>yaw rates estimated</td>
<td>E+M: umbra &amp; penumbra</td>
<td>applied + IR</td>
</tr>
<tr>
<td>JPL</td>
<td>IAU 2000A&lt;sub&gt;r06&lt;/sub&gt;; IERS C04</td>
<td>X,Y,Z scales stochastic</td>
<td>none</td>
<td>yaw rates estimated</td>
<td>E+M: umbra &amp; penumbra</td>
<td>applied</td>
</tr>
<tr>
<td>MIT</td>
<td>IAU 2000; BuA ERPs</td>
<td>D,Y,B scales; B(D,Y) 1/rev</td>
<td>none; 1/rev constraints</td>
<td>nominal yaw rates used</td>
<td>E+M: umbra &amp; penumbra</td>
<td>applied</td>
</tr>
<tr>
<td>NGS</td>
<td>IAU 2000; IGS PM; BuA UT1</td>
<td>D,Y,B scales; B 1/rev</td>
<td>@ 12:00 + constraints</td>
<td>none; del eclipse data</td>
<td>E+M: umbra &amp; penumbra</td>
<td>applied + AT</td>
</tr>
<tr>
<td>SIO</td>
<td>IAU 2000; BuA ERPs</td>
<td>D,Y,B scales; D,Y,B 1/rev</td>
<td>none; 1/rev constraints</td>
<td>nominal yaw rates used</td>
<td>E+M: umbra &amp; penumbra</td>
<td>applied</td>
</tr>
<tr>
<td>ULR</td>
<td>IAU 2000; BuA ERPs</td>
<td>D,Y,B scales; D,Y,B 1/rev</td>
<td>none</td>
<td>nominal yaw rates used</td>
<td>E+M: umbra &amp; penumbra</td>
<td>applied</td>
</tr>
<tr>
<td>ANALYSIS CENTER</td>
<td>SOLID EARTH POLE</td>
<td>EARTH POLE</td>
<td>OCEAN LOAD</td>
<td>OCEAN POLE</td>
<td>OCEAN CMC</td>
<td>SUBDAILY EOPs</td>
</tr>
<tr>
<td>-----------------</td>
<td>------------------------</td>
<td>---------------------</td>
<td>-----------------</td>
<td>-----------------</td>
<td>----------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>CODE</td>
<td>IERS 2010; dehanttideinel.f</td>
<td>eqn 23a/b mean pole</td>
<td>FES2004; hardisp.f</td>
<td>none</td>
<td>sites &amp; SP3</td>
<td>IERS 2010; subd nutation</td>
</tr>
<tr>
<td>EMR</td>
<td>IERS 2010</td>
<td>eqn 23a/b mean pole</td>
<td>FES2004; hardisp.f</td>
<td>none</td>
<td>sites &amp; SP3</td>
<td>IERS 2010</td>
</tr>
<tr>
<td>ESA</td>
<td>IERS 2010; dehanttideinel.f</td>
<td>eqn 23a/b mean pole</td>
<td>FES2004; hardisp.f</td>
<td>none</td>
<td>sites &amp; SP3</td>
<td>IERS 2010 &amp; PMsdnut.for</td>
</tr>
<tr>
<td>GFZ (&amp; GTZ)</td>
<td>IERS 2010</td>
<td>eqn 23a/b mean pole</td>
<td>FES2004</td>
<td>none</td>
<td>sites &amp; SP3</td>
<td>IERS 2010; PMsdnut.for</td>
</tr>
<tr>
<td>GRG</td>
<td>IERS 2010</td>
<td>eqn 23a/b mean pole</td>
<td>FES2004</td>
<td>none</td>
<td>sites &amp; SP3</td>
<td>IERS 2010</td>
</tr>
<tr>
<td>JPL</td>
<td>IERS 2010</td>
<td>eqn 23a/b mean pole</td>
<td>FES2004; hardisp.f</td>
<td>none</td>
<td>sites &amp; SP3</td>
<td>IERS 2010</td>
</tr>
<tr>
<td>MIT</td>
<td>IERS 2010</td>
<td>eqn 23a/b mean pole</td>
<td>FES2004</td>
<td>none</td>
<td>sites &amp; SP3</td>
<td>IERS 2010</td>
</tr>
<tr>
<td>NGS</td>
<td>IERS 2010; dehanttideinel.f</td>
<td>eqn 23a/b mean pole</td>
<td>FES2004; hardisp.f</td>
<td>none</td>
<td>sites &amp; SP3</td>
<td>IERS 2010 &amp; PMsdnut.for</td>
</tr>
<tr>
<td>SIO</td>
<td>IERS 2010</td>
<td>eqn 23a/b mean pole</td>
<td>FES2004</td>
<td>none</td>
<td>sites &amp; SP3</td>
<td>IERS 2010</td>
</tr>
<tr>
<td>ULR</td>
<td>IERS 2010</td>
<td>eqn 23a/b mean pole</td>
<td>FES2004</td>
<td>none</td>
<td>sites &amp; SP3</td>
<td>IERS 2010</td>
</tr>
<tr>
<td>ANALYSIS CENTER</td>
<td>GRAVITY FIELD</td>
<td>EARTH TIDES</td>
<td>EARTH POLE</td>
<td>OCEAN TIDES</td>
<td>OCEAN POLE</td>
<td>RELATIVITY EFFECTS</td>
</tr>
<tr>
<td>-----------------</td>
<td>---------------</td>
<td>-------------</td>
<td>------------</td>
<td>-------------</td>
<td>------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>CODE</td>
<td>EGM2008; C21/S21 due to PM</td>
<td>IERS 2010</td>
<td>IERS 2010</td>
<td>IERS 2010 – FES2004</td>
<td>none</td>
<td>dynamic corr &amp; bending applied</td>
</tr>
<tr>
<td>EMR</td>
<td>EGM2008</td>
<td>IERS 2010</td>
<td>IERS 2010</td>
<td>IERS 2010 – FES2004</td>
<td>none</td>
<td>no dynamic corr; bending applied</td>
</tr>
<tr>
<td>GFZ (&amp; GTZ)</td>
<td>JGM3; C21/S21 due to PM</td>
<td>IERS 2010</td>
<td>IERS 2010</td>
<td>IERS 2010 – FES2004</td>
<td>none</td>
<td>no dynamic corr &amp; bending applied</td>
</tr>
<tr>
<td>GRG</td>
<td>EIGEN GL04S; C21/S21 due to PM</td>
<td>IERS 2010</td>
<td>IERS 2010</td>
<td>IERS 2010 – FES2004</td>
<td>none</td>
<td>dynamic corr; bending applied</td>
</tr>
<tr>
<td>JPL</td>
<td>EGM2008; C21/S21 due to PM; C20, C30, C40</td>
<td>IERS 2010</td>
<td>IERS 2010</td>
<td>IERS 2010 – FES2004</td>
<td>none</td>
<td>dynamic corr &amp; eqn 6.23a, bending applied</td>
</tr>
<tr>
<td>MIT</td>
<td>EGM2008; C21/S21 due to PM</td>
<td>IERS 1992; Eanes Love #</td>
<td>none</td>
<td>none</td>
<td>none</td>
<td>no dynamic corr; bending applied</td>
</tr>
<tr>
<td>SIO</td>
<td>EGM2008; C21/S21 due to PM</td>
<td>IERS 1992; Eanes Love #</td>
<td>none</td>
<td>none</td>
<td>none</td>
<td>no dynamic corr; bending applied</td>
</tr>
<tr>
<td>ULR</td>
<td>EGM2008; C21/S21 due to PM</td>
<td>IERS 1992; Eanes Love #</td>
<td>none</td>
<td>none</td>
<td>none</td>
<td>no dynamic corr; bending applied</td>
</tr>
</tbody>
</table>
Expected Performance of IG2?
- WRMS of AC repro1 orbits wrt IG1 -

(smoothed)

Weighted RMS [mm]

Time [GPS weeks]

IGS05

Courtesy of G. Gendt (GFZ Potsdam)
Expected Performance of IG2?
- WRMS of AC repro1 orbits wrt IG1 -

Large scatter for some ACs in early IG1—expected to be improved in IG2 contributions

Courtesy of G. Gendt (GFZ Potsdam)
Expected Performance of IG2?

- WRMS of AC repro1 orbits wrt IG1 -

inter-AC agreement approaches ~2.5 cm by late 2007

Courtesy of G. Gendt (GFZ Potsdam)
Expected Performance of IG2?
- WRMS of current AC orbits wrt IGS -

![Graph showing expected performance of IG2 with WRMS values for different periods](Image)
Expected Performance of IG2?

- WRMS of current AC orbits wrt IGS -

inter-AC agreement reaches 1.5 cm

Weighted RMS [mm]

Time [GPS weeks]
Expected Performance of IG2?

- WRMS of current AC orbits wrt IGS -

Scatter of individual ACs decreases for short time after IGS08, but grows again as “core” network degrades—IG2 should have full RF network.
Expected Performance of IG2?
- Rotational scatter of AC orbits wrt IGS -

- First ~15 weeks of IGS08, scatter in most AC rotations quite small
  - increase in scatter correlated w/decrease in # of “core” stations
- Rotational errors for single AC distort the combined orbit (see RY for ESA @ ~1660)
  - long-term orientation of IG2 orbit frame maybe improved over IG1, but rotational scatter still dominates
• Lack of an independent “truth” for IGS orbits
  – can compute discontinuities between daily orbit sets
  – doing so aliases sub-daily differences into longer-period signals
  – approach can reveal systematic errors

• Orbit jumps
  – fit orbits for each day with BERNE (6+9) orbit model
  – parameterize fit as $X, Y, Z, \dot{X}, \dot{Y}, \dot{Z}$ plus 3 SRPs per SV component
  – fit 96 SP3 orbit positions for each SV as pseudo-observations for Day A
  – propagate fit forward to 23:52:30 for Day A
  – repeat for Day B & propagate backwards to 23:52:30 of day before
  – compute IGS orbit jumps at 23:52:30

• Compute IGS orbit jumps over recent ~5.6 yr span

Expected Performance of IG2?
- IGS orbit jumps as measure of orbit inaccuracy -
Expected Performance of IG2?
- *IGS orbit jumps as measure of orbit inaccuracy (cont.)* -

- IGS orbit jumps computed from Berne model fit to adjacent days
  - compute spectra for each SV orbit jump set, stack & smooth
  - “calibrated” for errors due to (fit + extrapolation) method
Expected Performance of IG2?
- IGS orbit jumps as measure of orbit inaccuracy (cont.) -

- IGS orbit jumps computed from Berne model fit to adjacent days
  - compute spectra for each SV orbit jump set, stack & smooth
  - “calibrated” for errors due to (fit + extrapolation) method

peaks at mostly odd harmonics of GPS draconitic

peaks in ~29, ~14, ~9 and ~7 d at alias frequencies of beating sub-daily EOP tide errors

[Griffiths & Ray, in prep]
Expected Performance of IG2 TRFs?
- RMS of Current AC TRFs wrt IGS -

• Improvement in precision expected from:
  – horizontal tropo gradients estimated by all ACs
  – 2\textsuperscript{nd} order iono corrections
  – Earth-reflected radiation pressure (albedo) modelling

• Improvement in accuracy expected from:
  – igs08.atx (depending on antenna type)

• Switch to daily AC TRFs:
  – should not impact quality of weekly combined TRFs (input to ITRF)
IG2 contribution to the next ITRF

• Contribution to the ITRF scale rate?
  – satellite PCOs will be included in combination & stacking of IG2 TRFs.
  – assumption that PCOs are constant → “intrinsic GNSS scale rate”

• No contribution to the ITRF origin yet
  – remaining unmodeled orbital forces
  – origins of IG2 TRFs likely not reliable enough

• Systematic errors will remain!
  – main source: antenna calibrations
    • > 1 cm errors revealed at stations with uncalibrated radomes
    • few mm errors likely at stations with “converted” antenna calibrations
  – will cause trouble in use of local ties for ITRF colocation sites
    • consider to exclude in next ITRF
Summary (1/2)

- Latest models, frames & methods to have largest impact since IG1
  - IERS 2010 Conventions
  - IGS08/igs08.atx framework
  - Earth-reflected radiation pressure (albedo) modelling
    - sub-daily & draconitic signatures will remain

- To result in full history of IG2 products (1994 to present)
  - truly daily products (assuming all ACs remove overconstraints & smoothing):
    - GPS orbits & SV clocks (SP3c) @ 15 min intervals
    - GPS SV and station clocks (clock RINEX) @ 5 min intervals
    - Earth Rotation Parameters (IGS ERP)
    - terrestrial coordinate frames (IERS SINEX)
  - expected delivery for next ITRF -> late 2013

- And possibly some ancillary products
  - GLONASS orbits & clocks
  - 30-second SV & station clocks
  - bias products
Summary (2/2)

• Generally, IGS aims for ~1 cm orbit & ~1 mm terrestrial accuracies
  – to meet needs of most demanding user applications

• Performance of current IGS products quite good
  – GPS orbits
    • overall <2.5 cm (1D)
    • errors dominated primarily by rotational scatter in AC orbital frames
    • random noise ~1.6 cm
    • sub-daily alias and draconitic errors from IERS diurnal/semi-diurnal tides
  – EOPs [Ray & Griffiths; G5.1 Monday AM]
    • PM-x & PM-y: <30 μas
    • dLOD: ~10 μs
  – terrestrial frames (weekly)
    • ~2 mm N&E
    • ~5 mm U

• IG2 quality should approach current IGS prods, maybe better
  – quality for later (~2000 -> present) IG2 products will be best
  – early IG2 probably better than IG1 equivalents, but not as good as later IG2
Extra Slides