Direct access to the ITRF anywhere on Earth

Henno.Boomkamp@itrf.cloud
Introduction

**A**
- User PPP analysis
  - Open loop analysis
  - Unknown processing errors
- Consistency with ITRF

**B**
- Global GPS analysis
  - Parallel processing in the cloud
  - Any number of sites can join
  - 200+ ITRF core sites included
  - Identical treatment of all sites in network

- Compare
- Absolute accuracy
  - Consistency with ITRF monitored for the 200+ ITRF core sites
  - Consistency with ITRF implied via
    * Internal consistency with core sites
    * Core site consistency with ITRF
Basics of GPSdancer (GPSdancer.org)

1. A GPSdancer instance accumulates the normal equations from the most recent 24 hours of data from a single receiver.
   - Pre-elimination of local parameters leaves a singular normal equation for the global parameters (orbits, sat clocks, pole).

2. Distributed P2P accumulation of N contributions:
   - All N computers end up with total network sum
   - Bandwidth per computer only grows by \( \log(N) \)

\[
\begin{align*}
(A - BC^{-1}B^t)x_g &= y_g - BC^{-1}y_l \\
x_l &= C^{-1}(y_l - B^tx_g)
\end{align*}
\]

**square dance algorithm**

- All global normal matrix contributions are accumulated among N GPSdancer processes that can run anywhere in the world.
- All N computers then solve the same non-singular global normal equation.
- All N computer find their own local solution after back-substitution.
- Data and local products remain private to each GPSdancer instance.
GPSdancer and GCCS timeline

(1) development of GPSdancer software
(2) creation GCCS
(3) start-up phase
(4) ops

Prototype
V 1.0

T0 10/2015
T1 10/2017
T2 10/2018

IGS Sydney
Deploymen
Calibration
Validation

IGS Paris

IGS Workshop 2017
Paris
Objectives of Calibration / Validation campaign:

1. **Evolve towards stable, routine analysis @ 30 minutes**
2. **Test and tune the process to reach IGS quality**

- 24 hour data arcs
- 60 min
- Time sharing of server capacity
- Duration of each process < 30 minutes
Nominal process

Station inputs
- observations
- site logs

Global inputs
- Broadcast msg
  - a priori parameters
  - For testing only
    - IGS products

Model data
- ITRF 2014
- IERS 2010 conv
- IGS repro 2

Global network batch LSQ

Station outputs
- position
- recv clocks
- troposphere estimation products

Global outputs
- orbits
- sat clocks
- polar motion

Process metadata
- obs residuals
- log messages
- performance
Precise Point Positioning

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Null test

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RMS sets upper limit to combined errors in data, IGS products & software
# Stations processed in routine analysis

Number of stations in solution @ 0:00h (...out of 24 hourly solutions per day)

Jan 2016

June 2017

RMS of ionosphere-free phase L1, L2 (mm)

- 15 minute RINEX files preferred as input (30 hr buffers)
- 1 CPU reserved for BNC client to handle RTCM streams
Observations residuals for ionosphere-free phase (L1, L2)
RMS per station for GPS week 1947

- Null test (all parameters fixed) @ 3 weeks
- Precise Point Positioning w.r.t IGS final @ 2 weeks
- GCCS global network solution @ 30 minutes

<table>
<thead>
<tr>
<th></th>
<th>mm</th>
<th># sta</th>
<th>obs used(*)</th>
<th>RMS wgt</th>
<th>RMS nrm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Null-test</td>
<td>134</td>
<td>2,987,240</td>
<td>5.7</td>
<td>14.7</td>
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<tr>
<td>PPP</td>
<td>575</td>
<td>12,686,354</td>
<td>4.3</td>
<td>11.6</td>
<td></td>
</tr>
<tr>
<td>Nominal</td>
<td>575</td>
<td>12,692,358</td>
<td>3.8</td>
<td>10.2</td>
<td></td>
</tr>
</tbody>
</table>

(*) anomalous sites excluded

BAKE
NYA1
YELL
Observations residuals for ionosphere-free phase (L1, L2)
Details for 3 stations in GPS week 1947

-20 mm  2017/04/30  2017/05/01  2017/05/02  2017/05/03  2017/05/04  2017/05/05  2017/05/06
+20 mm

BAKE

-20 mm  2017/04/30  2017/05/01  2017/05/02  2017/05/03  2017/05/04  2017/05/05  2017/05/06
+20 mm

NYA1

-20 mm  2017/04/30  2017/05/01  2017/05/02  2017/05/03  2017/05/04  2017/05/05  2017/05/06
+20 mm

YELL
Observations residuals for ionosphere-free phase (L1, L2)

Example stations BAKE, NYA1, YELL

<table>
<thead>
<tr>
<th>GPS week 1947</th>
<th>Null test</th>
<th>PPP</th>
<th>Global solution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td># obs</td>
<td>Used</td>
<td>Rejected</td>
</tr>
<tr>
<td>BAKE</td>
<td>22213</td>
<td>21797</td>
<td>416</td>
</tr>
<tr>
<td>NYA1</td>
<td>22362</td>
<td>21956</td>
<td>406</td>
</tr>
<tr>
<td>YELL</td>
<td>21601</td>
<td>21213</td>
<td>388</td>
</tr>
<tr>
<td>RMS (mm)</td>
<td>wghtd</td>
<td>nrmlzd</td>
<td>wghtd</td>
</tr>
<tr>
<td>BAKE</td>
<td>3.51</td>
<td>11.98</td>
<td>3.22</td>
</tr>
<tr>
<td>NYA1</td>
<td>3.65</td>
<td>13.53</td>
<td>3.33</td>
</tr>
<tr>
<td>YELL</td>
<td>3.53</td>
<td>11.73</td>
<td>3.32</td>
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</tbody>
</table>

*wghtd = elevation weighted residuals
nrmlzd = unweighted residuals*
### Estimated parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Frequency</th>
<th>per run</th>
<th>initial value</th>
<th>initial sigma</th>
<th>constraint</th>
<th>est sigma</th>
<th>units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Global</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polar motion</td>
<td>Xp, Yp</td>
<td>2 pair per arc</td>
<td>4</td>
<td>mean pole</td>
<td>1.00E-02</td>
<td>no</td>
<td>1.00E-05</td>
</tr>
<tr>
<td></td>
<td>dUT1</td>
<td>1 per arc</td>
<td>1</td>
<td>0</td>
<td>1.00E+00</td>
<td>no</td>
<td>1.00E-06</td>
</tr>
<tr>
<td>Orbit</td>
<td>X, Y, Z</td>
<td>per sat per arc</td>
<td>96</td>
<td>broadcast</td>
<td>1.00E+02</td>
<td>no</td>
<td>1.00E-02</td>
</tr>
<tr>
<td></td>
<td>vx, vy, vz</td>
<td>per sat per arc</td>
<td>96</td>
<td>broadcast</td>
<td>1.00E-02</td>
<td>no</td>
<td>1.00E-06</td>
</tr>
<tr>
<td>SRP</td>
<td>5-param Bernese</td>
<td>per sat per arc</td>
<td>160</td>
<td>0</td>
<td>1.00E-08</td>
<td>no</td>
<td>1.00E-10</td>
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<tr>
<td>Clocks</td>
<td>transmitter</td>
<td>per sat per epoch</td>
<td>9216</td>
<td>broadcast</td>
<td>1.00E-06</td>
<td>no</td>
<td>1.00E-11</td>
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<tr>
<td><strong>Local</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clocks</td>
<td>receiver</td>
<td>per sta per epoch</td>
<td>288</td>
<td>0</td>
<td>1.00E-06</td>
<td>no</td>
<td>1.00E-11</td>
</tr>
<tr>
<td>Displacement</td>
<td>dX, dY, dZ</td>
<td>per sta per arc</td>
<td>3</td>
<td>0</td>
<td>1.00E-03</td>
<td>yes</td>
<td>1.00E-03</td>
</tr>
<tr>
<td>Troposphere</td>
<td>zenith delay</td>
<td>per sta per 2 hour</td>
<td>12</td>
<td>0</td>
<td>1.00E-01</td>
<td>no</td>
<td>1.00E-03</td>
</tr>
<tr>
<td></td>
<td>gradients N, E</td>
<td>2 pair per sta per a</td>
<td>4</td>
<td>0</td>
<td>1.00E-03</td>
<td>no</td>
<td>1.00E-04</td>
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<tr>
<td>Other</td>
<td>ambiguity</td>
<td>per pass</td>
<td>60</td>
<td>L - P</td>
<td>1.00E+00</td>
<td>no</td>
<td>1.00E-02</td>
</tr>
</tbody>
</table>

- Parameter initialization independent from previous run
  - Goal is to maximize decorrelation, in spite of large overlaps
- Unconstrained LSQ except for station displacements
  - No-net rotation condition w.r.t. ITRF core network
  - Absolute constraints → see next slide
Constraints on station displacements

- **no constraints**
- **5mm constraints**

- "up" noise caused by weak VDOP
- "up" noise no longer dominates but data still has more influence than a priori
Introduction of new sites in solution

(A) Estimated displacement U (, N, E)

(B) "Datum": mean value of time series

(C) Change in datum w.r.t previous process

(D) Mean of (C) over most recent 100 points (50 hours)

Any site anomaly restarts time series

0.5 mm threshold

Site contributes to global solution

Process nr since start of series

Process nr since start of series

IGS Workshop 2017
Paris
Example: recovery after shift

With 5 mm constraints on site displacements:
- Solution time series relatively noisy (RMS > 5mm)
- Quick response to real events: impact invisible after 24 hours
  - Data arc no longer contains “old” position data
- Long-term site datum recovered after several days
Comparison with IGS orbits

End-of-arc effects

Week 1942 to 1947
Remaining steps

• Before 10/2017:
  – GCCS website on-line at “itrf.cloud”
    • Detailed Cal-Val report also on this site
  – Routine analysis at 30 minute latency
    • No more time sharing with test runs
  – Server capacity will be extended
    • Currently 3 x 200 stations (@Frankfurt, D)
    • Extended with 4 x 100 stations (@Strassbourg, F)
      – Capacity will be 1000 stations but arbitrarily scalable

Subsidized servers will only remain available until 11/2018

• Gradual incorporation of real users is needed
  – Regional RTK operators, receiver manufacturers, etc.
  – Target: 10,000 stations using GPSdancer in the cloud by 2020
Summary and conclusions

• Distributed global analysis based on GPSdancer is approaching its mature operational status
  – Station products are comparable with IGS
    • Combined noise in data, IGS finals and GPSdancer does not exceed 5 mm RMS
  – Processing capacity now 600, soon 1000 sites
    • ...twice the size of the IGS network

• ITRF datum can be transferred reliably to any non-ITRF CORS site
  – ITRF sites and non-ITRF sites are processed in exactly the same solution
  – 200+ ITRF sites in network demonstrate the absolute solution accuracy
  – Non-ITRF sites show identical output characteristics (noise, sigmas)
    • Stable mean of the output position time series accurately represent the ITRF
    • Risk of unobservable systematic errors in regional PPP has been mitigated

• ...we still need the IGS!
  – IGS defines ITRF as conventional reference frame
  – GCCS can densify the ITRF to include all CORS stations on Earth