IERS Rigorous Inter-Technique Combination
Implications to IGS

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Content

- IERS Combination Pilot Project (CPP) and IERS2005
- Reduction of Systematic Effects
- Reprocessing Capabilities
- Consistency of the IGS Products
- Conclusions
## IERS Combination Pilot Project

Parameter space for a rigorous combination:

<table>
<thead>
<tr>
<th>Parameter Type</th>
<th>VLBI</th>
<th>GPS/GLON.</th>
<th>DORIS/PRARE</th>
<th>SLR</th>
<th>LLR</th>
<th>Altimetry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quasar Coord. (ICRF)</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nutation</td>
<td>X</td>
<td>(X)</td>
<td></td>
<td>(X)</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Polar Motion</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>UT1</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length of Day (LOD)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Coord.+Veloc.(ITRF)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>(X)</td>
</tr>
<tr>
<td>Geocenter</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Gravity Field</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>(X)</td>
<td>X</td>
</tr>
<tr>
<td>Orbits</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>LEO Orbits</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Ionosphere</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
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<tr>
<td>Troposphere</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Time/Freq.; Clocks</td>
<td>(X)</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>(X)</td>
</tr>
</tbody>
</table>

IERS Combination Pilot Project: sub-space (red rectangle)
IERS Combination Pilot Project

**Step 1**
- **VLBI**  
  - IVS AC 1  
  - IVS AC 2  
  - IVS AC n  
  - Site Coords., EOPs, Quasar Coords.
- **GPS**  
  - IGS AC 1  
  - IGS AC 2  
  - IGS AC n  
  - Site Coordinates, EOPs
- **SLR/LLR**  
  - ILRS AC 1  
  - ILRS AC 2  
  - ILRS AC n  
  - Site Coordinates, EOPs
- **DORIS**  
  - IDS AC 1  
  - IDS AC 2  
  - IDS AC n  
  - Site Coords., EOPs

**Step 2**
- **IVS Combination**  
  - Site Coords., EOPs, Quasar Coords.
- **IGS Combination**  
  - Site Coordinates, EOPs
- **ILRS Combination**  
  - Site Coordinates, EOPs
- **IDS Combination**  
  - Site Coords., EOPs

**IERS Combination Centers**

**Step 3**
- Combined "weekly" Inter-technique Solutions  
  - Site Coordinates, EOPs, Quasar Coordinates
- **Local Tie Information**
- **Remove Biases Between Techniques**
- **External Information**  
  - (Geophysical Fluids, Models, ...)

**Validation of Combined "Weekly" Inter-Technique Solutions**  
- Site Coordinates, EOPs, Quasar Coordinates
**IERS CPP: Submission Schedule**

- **Intra-technique combinations** (weekly SINEX files) due 8 weeks after the observations → no problem for the IGS
- **Inter-technique combinations** (weekly SINEX files) due 12 weeks after the observations
- **Validation of inter-technique combinations** (report) due 16 weeks after the observations
- **Special combined products** due 8 weeks after the observations
## IERS CPP: Proposals

<table>
<thead>
<tr>
<th>Institution</th>
<th>Intra-Techn. (Step 1)</th>
<th>Inter-Techn. Comb. (Step 2)</th>
<th>Validation (Step 3)</th>
<th>Misc. Comb.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILRS</td>
<td>SLR</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>IDS</td>
<td>DORIS</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>IVS</td>
<td>VLBI</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>IGS</td>
<td>GPS</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>IGN/OP/BIPM</td>
<td>—</td>
<td>GPS,SLR,VLBI,DORIS</td>
<td>S,E,R</td>
<td>—</td>
</tr>
<tr>
<td>JPL</td>
<td>—</td>
<td>—</td>
<td>E</td>
<td>—</td>
</tr>
<tr>
<td>DGFI</td>
<td>SLR</td>
<td>GPS,SLR,VLBI,DORIS</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>FESG</td>
<td>—</td>
<td>(07/04)</td>
<td>—</td>
<td>E</td>
</tr>
<tr>
<td>USNO</td>
<td>—</td>
<td>—</td>
<td>E</td>
<td>E</td>
</tr>
<tr>
<td>JCET/GSFC</td>
<td>SLR</td>
<td>SLR, LEO GPS (07/04)</td>
<td>S,E (07/04)</td>
<td>S,E,O (12/04)</td>
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<tr>
<td>NCL</td>
<td>GPS,SLR</td>
<td>GPS,SLR</td>
<td>S,E</td>
<td>—</td>
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<tr>
<td>GRGS/CNES.</td>
<td>—</td>
<td>GPS,SLR/LLR,VLBI, DORIS: Obs.Level</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>CAS</td>
<td>—</td>
<td>GPS,SLR,VLBI,DORIS</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

**S**: Site Coordinates; **E**: EOP; **R**: Radio sources; **O**: Orbits
### IERS CPP: Timetable

<table>
<thead>
<tr>
<th>Date</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 26, 2004</td>
<td>Dissemination of the Call for Participation</td>
</tr>
<tr>
<td>February 22, 2004</td>
<td>Due date for proposals</td>
</tr>
<tr>
<td>February 27, 2004</td>
<td>Information of participants about proposal acceptance</td>
</tr>
<tr>
<td>February 29, 2004</td>
<td>Start of IERS Combination Pilot Project with GPS Week 1260 (first intra-technique combinations due 8 weeks later, i.e. end of April 2004; first inter-technique solutions due 12 weeks later, i.e., end of May).</td>
</tr>
<tr>
<td>April 25, 2004</td>
<td>Meeting of IERS WG on Combination (before the EGU Meeting in Nice)</td>
</tr>
<tr>
<td>October 2004</td>
<td>Progress Meeting of the IERS CPP at the IERS Workshop 2004</td>
</tr>
<tr>
<td>October 2005</td>
<td>Evaluation of the CPP and discussions concerning the transitions to new IERS products</td>
</tr>
</tbody>
</table>
IERS2005: Plan

- “Integrated Earth orientation parameters, Radio sources, and Site coordinates 2005”
- IERS2005 will be based on “weekly” SINEX files from all techniques (site coordinates, EOP, and quasar coordinates) over the entire history of their data acquisition
- This step will complement the IERS CPP for years already past
- The Technique Services (TS) should deliver time series as homogeneous as possible over a time span as long as possible (following IERS conventions)
- Individual AC solutions might be accepted if the corresponding TS agrees
IERS2005: Timetable

Draft Schedule:

April, 2004: Call for submission of homogeneous weekly SINEX files

July, 2004: Due date for submissions of weekly SINEX files

March 2005: Submission of IERS2005 solutions by the Combination Centers (e.g, the ITRF CCs)

August, 2005: IERS2005 solutions evaluated and compared; Presentation at the IAG Scientific Assembly 2005 (Cairns, Australia)

October 2005: After final refinements and documentation, official IERS2005 ready for IERS DB decision at IERS Workshop 2005 (Evaluation of IERS CPP)
Systematic Effects

General Modeling Consistency (IERS Conventions 2003):
- Solid Earth and pole tides
- Subdaily ERP ocean tide model; IAU2000 precession/nutation
- Ocean loading, atmospheric loading
- Subdaily geocenter variations
- Troposphere mapping functions

Antennas and Environment (easily reaching 1cm or more):
- Antenna phase center variations (PCV) of receiver antennas
- Antenna phase center variations of satellite antennas
- Multipath effects, environment (e.g. snow), equipment changes

Orbit modeling and parameterization:
- Systematic effects in geocenter variations; SLR-GPS orbit bias of 5cm
- Systematic effects in LOD and nutation rates
Comparison of GPS & VLBI Troposphere

<table>
<thead>
<tr>
<th>Station</th>
<th>( \Delta \text{Height} ) (local tie) [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALGO</td>
<td>23.11</td>
</tr>
<tr>
<td>FAIR</td>
<td>13.08</td>
</tr>
<tr>
<td>HRAO</td>
<td>1.54</td>
</tr>
<tr>
<td>KOKB</td>
<td>9.24</td>
</tr>
<tr>
<td>NYAL</td>
<td>3.07</td>
</tr>
<tr>
<td>ONSA</td>
<td>13.71</td>
</tr>
<tr>
<td>WEST</td>
<td>1.75</td>
</tr>
<tr>
<td>WTZR</td>
<td>3.10</td>
</tr>
</tbody>
</table>

Theory: \( \Delta \text{Height} = 10\text{m} \)
\[ \Delta \text{ZD} \approx 3\text{mm} \]
Systematic Effects: LOD

Comparison to Bulletin A
Systematic Effects: Nutation

GPS nutation rates in longitude:
- systematic effects due to orbit modeling and parameterization
- visible in the values and the formal errors
Reduction of Systematic Effects

Statement 1: All systematic effects in the IGS results have to be eliminated or reduced to the extent possible for an IERS inter-technique combination to be successful.

- Not only internal consistency is important, but also absolute accuracy
- We should try to come as close as possible to the point, where ITRF coordinates are as consistent as the IGS GPS-only realization of the ITRF
- Each technique has its own systematic biases to care about
Reprocessing Capability

Importance of reprocessing:

• **Inhomogeneous** old time series with inconsistent modeling $\rightarrow$ quality, consistency and long-term stability cannot be guaranteed

• Upgrades of solution series to **new standards** in modeling and parameterization are necessary (e.g. orbit parameterization)

• Improvements in **processing strategies** (e.g. ambiguity resolution) should be exploited for the entire GPS series

• Effects of **reference frame changes** cannot be fully removed (GPS week 1143: ITRF97 $\rightarrow$ ITRF2000)

• Examples: introduction of **absolute antenna PCV** or switch to **IERS Conventions 2003** $\rightarrow$ reprocessing necessary

• IERS requires most up-to-date and consistent time series of products from all techniques (e.g., for IERS2005 products)
Reprocessing: Coordinate Repeatability

- North [mm]
- East [mm]
- Up [mm]

Reprocessed and CODE results with refined ambiguity resolution.
Reprocessing: Geocenter

RMS(IGS) = 6.6mm    RMS(Reproc.) = 4.2mm
RMS(IGS) = 5.8mm    RMS(Reproc.) = 4.8mm
Reprocessing: Geocenter
3- and 7-Day Solutions
Reprocessing Capability

Statement 2: Development of reprocessing capabilities must be an important goal for the IGS in the near future

- Most other techniques already have such capabilities (VLBI, SLR, DORIS, LLR)
- Some or most of the IGS Analysis Centers should reach a status, where they can periodically (e.g., once a year) reprocess the entire global IGS dataset
- Associate Analysis Centers might join the effort (?)
- IGS strategy required on how to improve products of the past (new submissions, new combinations, …)
Consistency of AC and IGS Products

Troposphere Zenith Delays:
- Systematic and quite large differences between individual ACs
- Indicates inconsistencies in modeling
- Effects heavily correlated with the station height and the global scale
- Try to understand these effects, not just remove them
- Troposphere zenith delay product not consistent with core products

Geocenter, Scale and LOD:
- Quite large systematic offsets and variations exist in these quantities
- They make a rigorous combination difficult

Statement 3: Despite the consistency already reached, the IGS should to strive for further consistency between AC solutions and between IGS products
Conclusions

• IERS is on the way to a rigorous combination of its products (IERS CPP, IERS2005).

• Systematic effects have to be understood and removed to the extent possible before a successful combination can be done.

• Reprocessing capabilities are important for the IGS to contribute official consistent long-term series to the IERS.

• The consistency between ACs as well as the consistency between IGS products should further be improved.

• Work together with the IERS to obtain a set of rigorously combined IERS products, which will be beneficial to the IGS and all other space geodetic techniques.