DTRF2013: Results of the analysis and impact of the contribution of the International DORIS Service

Manuela Seitz, Detlef Angermann, Mathis Bloßfeld
Deutsches Geodätisches Forschungsinstitut (DGFI), Munich, Germany

e-mail: seitz@dgfi.badw.de
Motivation

Many model improvements for DORIS

Infrastructure
- Development of space and ground infrastructure
- More data collected from DGXX receiver (on Jason-2 first) – seven stations observed in parallel

Modelling: satellites
- Physical models of satellites
- Improved solar radiation pressure modelling
- Improved air drag parameterization
- Gravity field: EIGEN-6S2 which includes annual variations

Modelling: station antennae
- Frequency offset considered (difference between actual admitted frequency and the nominal value)
- Antenna phase center corrections

Willis, P.; Lemoine, F.G.; Moreaux, G.; Soudarin, L.; Ferrage, P.; Ries, J.; Otten, M.; Saunier, J.; Noll, C.; Biancale, R.; Luzum, B., in press. The International DORIS Service (IDS) - Recent developments in preparation for ITRF2013, IAG SYMPOSIA SERIES, 143
Input data and parameterization (I)

- Input data
  - SINEX files between 1993.0 and 2014.0
  - Weekly solutions (minimum constraints, not booked in SINEX → cannot be removed; need to introduce 7 similarity transformation parameters)
Input data and parameterization (I)

- Input data
  - SINEX files between 1993.0 and 2014.0
  - Weekly solutions (minimum constraints, not booked in SINEX → cannot be removed; need to introduce 7 similarity transformation parameters)

- Satellite constellations (changes might have an effect on many time series)
Input data and parameterization (I)

- **Input data**
  - SINEX files between 1993.0 and 2014.0
  - Weekly solutions (minimum constraints, not booked in SINEX → cannot be removed; need to introduce 7 similarity transformation parameters)

- **Satellite constellations** (changes might have an effect on many time series)
Input data and parameterization (II)

- 6 different Analysis Centers (ACs) using 5 different software packages

\[
\sigma^2 (AC)
\]

- Variance factors

6 different Analysis Centers (ACs) using 5 different software packages mostly caused by lack of INA & IGN.

\[
\sigma^2 (AC)
\]

- Variance factors

mostly caused by lack of INA & IGN.
Input data and parameterization (II)

- Input data
  - 6 different Analysis Centers (ACs) using 5 different software packages

- Weekly SINEX files contain
  - 3D station coordinates at mid-week epoch
  - Terrestrial pole coordinates as offsets at 12h epochs (7 per week)

- Up to now, four iterations with IDS Combination Center, last iteration is expected for mid of November

![Graph showing variance factors for different analysis centers (ES, GOP, GSC, IGN, INA, LCA) over time.](image)
Combination strategy at DGFI

- Combination at DGFI is performed on normal equation (NEQ) level

Input SINEX time series

- Reconstruction of constraint free NEQ from SINEX
  - VLBI session NEQ
  - SLR weekly NEQ
  - GPS weekly NEQ
  - DORIS weekly NEQ

Analysis of time series and accumulation of NEQs to one NEQ per technique
- Set up station velocities
- Epoch transformation of the VLBI EOP

- VLBI TRF+EOP
- SLR TRF+EOP
- GPS TRF+EOP
- DORIS TRF+EOP

Combination of the technique NEQ
- Selection of local ties
- Combination of station velocities
- Realisation of the geodetic datum
- Estimation of variance factors

Global Terrestrial Reference Frame + EOP
DTRF2013

Changes w.r.t. DTRF2008 processing:
- Correction for non-tidal atmospheric loading (NT-ATML) at NEQ level using an unique model provided by GGFC
- A posteriori estimation of annual/-semi-annual signal of station position time series

Picture taken from
Solution of combined system

\[ \hat{x} = N^{-1}y \]

\[ \sigma^2 = \frac{(\hat{v}^T P \hat{v})}{(n - u)} \text{ with } v^T P v = b^T P b - \hat{x}^T b \]

\[ C_{\hat{x}\hat{x}} = \sigma^2 N^{-1} \]

with \( C_{\hat{x}\hat{x}} \) is the variance-covariance matrix of the estimated variables.

Stochastic model

\[ N = \frac{1}{\sigma_1^2} N_1 + \ldots + \frac{1}{\sigma_m^2} N_m \]

\[ y = \frac{1}{\sigma_1^2} y_1 + \ldots + \frac{1}{\sigma_m^2} y_m \]

\[ b^T P b = \frac{1}{\sigma_1^2} b_1^T P b_1 + \ldots + \frac{1}{\sigma_m^2} b_m^T P b_m \]

Solution of NEQ pseudo-observations are necessary

Solution TRF+EOP

Reduced by the number of common parameters
Stochastic model

\[ N = \frac{1}{\sigma_1^2} N_1 + \ldots + \frac{1}{\sigma_m^2} N_m \]

\[ y = \frac{1}{\sigma_1^2} y_1 + \ldots + \frac{1}{\sigma_m^2} y_m \]

\[ b^T P b = \frac{1}{\sigma_1^2} b_1^T P b_1 + \ldots + \frac{1}{\sigma_m^2} b_m^T P b_m \]

\[ n = n_1 + \ldots + n_m \]
\[ u = u_1 + \ldots + u_m \]

Reduced by the number of common parameters

Solution of combined system

\[ \hat{x} = N^{-1} y \]

\[ \sigma^2 = \frac{(\hat{v}^T P \hat{v})}{(n - u)} \text{ with } v^T P v = b^T P b - \hat{x}^T b \]

\[ C_{\hat{x}\hat{x}} = \sigma^2 N^{-1} \]

with \( C_{\hat{x}\hat{x}} \) is the variance-covariance matrix of the estimated variables.

Solution of NEQ pseudo-observations are necessary

Errorneous or missing \( b^T P b \), \( n \) and \( u \) lead to incorrect standard deviations and affect the relative weighting of the techniques!

Correct SOLUTION/STATISTICS are required!

→ Now, IDS SINEX contain \( n \), \( u \) and dof values.
Analysis of DORIS input data

- Accumulation
- Set up of velocities
- (ATM loading)
- Discontinuities

NEQ reconstructed from SINEX

combined NEQ

• Alignment to DTRF2008

DORIS multi-year solution

Similarity transformations w.r.t. DTRF2008
- datum differences
- RMS

Weekly solution

• (ATM loading)
• Discontinuities
• Alignment to DTRF2008

Time series of
- station positions
- datum parameters
- RMS
Analysis results

- Histogram of length of station time series (many short-terms?)
  - 149 stations in total (DTRF2008: 136)
  - 182 solution numbers → 33 jumps (DTRF2008: 48)
  - 35% of stations contain less than 3.5 years of data (25% less than 2.5)
  → Estimation in DTRF2013? Final decision after a detailed analysis of the remaining signals in station position time series (correcting for NT-ATML may allow shorter length of time series (<2.5 years?).

![Graph showing length of time series distribution](image_url)
Analysis results

Number of stations vs. DTRF2008

- Three new stations
- Replacement of all Alcatel antennae with Starec generation (Willis et al., 2014)

- Cold Bay, since 2010.8
- Betio Island, since 2006.9
- Rikitea, since 2006.8
Number of discontinuities; Which of DTRF2008 can be removed?

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>Earthquake 8.1 Mw</td>
<td>98.084 2</td>
</tr>
<tr>
<td>25</td>
<td>Antenna offset</td>
<td>95.927 1</td>
</tr>
<tr>
<td>26</td>
<td>Unknown</td>
<td>94.599 1</td>
</tr>
<tr>
<td>16</td>
<td>Earthquake</td>
<td>91.162 2</td>
</tr>
<tr>
<td>17</td>
<td>Unknown</td>
<td>95.052 2</td>
</tr>
<tr>
<td>24</td>
<td>Data gap</td>
<td>95.203 2</td>
</tr>
<tr>
<td>25</td>
<td>Unknown</td>
<td>92.075 2</td>
</tr>
<tr>
<td>20</td>
<td>Unknown</td>
<td>95.001 3</td>
</tr>
<tr>
<td>12</td>
<td>Earthquake</td>
<td>92.097 2</td>
</tr>
<tr>
<td>13</td>
<td>Postseismic</td>
<td>93.033 2</td>
</tr>
<tr>
<td>14</td>
<td>Postseismic</td>
<td>92.013 2</td>
</tr>
<tr>
<td>9</td>
<td>Postseismic</td>
<td>96.001 2</td>
</tr>
<tr>
<td>8</td>
<td>Unknown</td>
<td>96.005 2</td>
</tr>
<tr>
<td>11</td>
<td>Hettner Mine Earthquake</td>
<td>99.299 2</td>
</tr>
<tr>
<td>16</td>
<td>Antenna tilt</td>
<td>95.051 2</td>
</tr>
<tr>
<td>22</td>
<td>After gas</td>
<td>95.213 2</td>
</tr>
<tr>
<td>5</td>
<td>Earthquake</td>
<td>95.056 2</td>
</tr>
<tr>
<td>6</td>
<td>Unknown</td>
<td>98.206 2</td>
</tr>
<tr>
<td>7</td>
<td>Earthquake</td>
<td>95.244 2</td>
</tr>
<tr>
<td>8</td>
<td>Unknown</td>
<td>95.162 2</td>
</tr>
<tr>
<td>9</td>
<td>Unknown</td>
<td>95.184 2</td>
</tr>
<tr>
<td>10</td>
<td>Unknown</td>
<td>95.169 2</td>
</tr>
<tr>
<td>11</td>
<td>Antenna offset</td>
<td>95.956 2</td>
</tr>
<tr>
<td>15</td>
<td>Antenna offset</td>
<td>97.313 2</td>
</tr>
<tr>
<td>16</td>
<td>Antenna offset</td>
<td>97.313 2</td>
</tr>
<tr>
<td>17</td>
<td>Earthquake</td>
<td>97.314 2</td>
</tr>
<tr>
<td>18</td>
<td>Equipment problem</td>
<td>95.152 2</td>
</tr>
<tr>
<td>19</td>
<td>Equipment problem</td>
<td>94.284 1</td>
</tr>
<tr>
<td>20</td>
<td>Beacon event</td>
<td>98.210 2</td>
</tr>
<tr>
<td>21</td>
<td>Earthquake</td>
<td>95.169 2</td>
</tr>
<tr>
<td>22</td>
<td>Unknown</td>
<td>97.072 1</td>
</tr>
<tr>
<td>23</td>
<td>Earthquake</td>
<td>95.167 2</td>
</tr>
<tr>
<td>24</td>
<td>Unknown</td>
<td>95.154 2</td>
</tr>
<tr>
<td>25</td>
<td>Unknown</td>
<td>95.483 2</td>
</tr>
<tr>
<td>26</td>
<td>Unknown</td>
<td>95.950 1</td>
</tr>
<tr>
<td>27</td>
<td>Unknown</td>
<td>95.952 2</td>
</tr>
<tr>
<td>28</td>
<td>Unknown</td>
<td>97.349 1</td>
</tr>
<tr>
<td>29</td>
<td>Unknown</td>
<td>96.122 1</td>
</tr>
<tr>
<td>30</td>
<td>Earthquake</td>
<td>97.285 2</td>
</tr>
<tr>
<td>31</td>
<td>Unknown</td>
<td>95.198 2</td>
</tr>
<tr>
<td>32</td>
<td>Unknown</td>
<td>93.213 2</td>
</tr>
<tr>
<td>33</td>
<td>Unknown</td>
<td>95.071 2</td>
</tr>
<tr>
<td>34</td>
<td>Unknown</td>
<td>97.244 2</td>
</tr>
<tr>
<td>35</td>
<td>Earthquake</td>
<td>95.234 2</td>
</tr>
<tr>
<td>36</td>
<td>Earthquake</td>
<td>95.234 2</td>
</tr>
</tbody>
</table>

Reduction of necessary discontinuities
Analysis results

- Number of discontinuities; Which of DTRF2008 can be removed? → unify with IGN, JPL!
- e.g., Station AMTB (Amsterdam Islands)
Analysis results

Datum parameter series vs. DTRF2008

- $t_x$ [cm]
- $t_y$ [cm]
- $t_z$ [cm]

Weekly IDS (DTRF2013) w.r.t. DTRF2008
Weekly IDS (DTRF2008) w.r.t. DTRF2008
Analysis results

- Datum parameter series vs. DTRF2008 – z translation

- Datum time series of IDS weekly (DTRF2008) vs. IDS multiyear (DTRF2008)

→ Correlation with solar cycle is still visible.

Analysis results

- Datum parameter series vs. DTRF2008 - scale and RMS of transformation

- Inclusion of Saral
- Inclusion of HY-2A
- Drift in DTRF2008 IDS input: ~1.8 mm/yr

- Extrapolation of DTRF2008

Weekly IDS (DTRF2013) w.r.t. DTRF2008
Weekly IDS (DTRF2008) w.r.t. DTRF2008
### Analysis results

**Terrestrial pole coordinates**

<table>
<thead>
<tr>
<th>x-pole w.r.t. IERS 08 C04</th>
<th>y-pole w.r.t. IERS 08 C04</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Graph" /></td>
<td><img src="image2.png" alt="Graph" /></td>
</tr>
</tbody>
</table>

| ![Graph](image3.png)      | ![Graph](image4.png)      |

- Why is scatter of DTRF2013 IDS input higher than DTRF2008 IDS input?
- What cause higher STDs in DTRF2013 IDS input? Can the effect be just related to the more realistic stochastic model?
Analysis results

- Terrestrial pole coordinates - Frequency analysis

- GPS draconitics in x-pole; good agreement in y-pole
- Why are the GPS draconitics for the IDS DTRF2013 input higher than for the IDS DTRF2008 input?
Analysis results

- DORIS multi-year solution
  
  RMS of transformation \rightarrow Agreement of network geometries
  
  - IDS multiyear (DTRF2013) w.r.t. DTRF2008: 7.9 mm (coord), 1.6 mm (vel)
  
  - IDS multiyear (DTRF2008) w.r.t. IDS multiyear (DTRF2008): 7.0 mm (coord), 1.5 mm (vel)

- Histogram of transformation residuals
Summary & Outlook

- Many model improvements for DORIS since DTRF2008
- Realistic stochastic model due to the availability of stochastic values
- Annual signal in translation time series is reduced vs. DTRF2008
- Correlation of Tz with solar cycle still visible but with a slightly smaller amplitude
- Scale drift seen in DTRF2008 input data is removed but scale jump in 2012 needs to be further investigated. Correlation with HY-2A and Saral?
- Pole coordinates of DTRF2013 input show higher scatter and STDs than DTRF2008 input. Can the increased STD be explained by the more realistic stochastic model only?

Outlook

- Unification of discontinuity list with IGN and JPL
- Application of a posteriori NT-ATML correction at normal equation level
- Please keep in mind that another iteration will be provided by the IDS CC. Therefore, results may slightly change!
DTRF2013: Results of the analysis and impact of the contribution of the International DORIS Service

Manuela Seitz, Detlef Angermann, Mathis Bloßfeld
Deutsches Geodätisches Forschungsinstitut (DGFI), Munich, Germany

e-mail: seitz@dgfi.badw.de

For more details on DTRF2013, please visit http://dgfi.badw.de/en/products/dtrf2013

Thank you very much for your attention!
Many thanks to the IDS for providing the data!
Analysis results

- Datum parameter series vs. IDS multiyear

Weekly IDS w.r.t. IDS multiyear
Analysis results

- Datum parameter series vs. IDS multiyear
  - No increase of RMS as for transformation of DTRF2008