Determination of Tsukuba VLBI station post-Tohoku earthquake coordinates using VieVS

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Overview

• Goals and strategy
• Analysis with VieVS
• Results and conclusions
• Further development
Goals

• Determination of initial and post-seismic displacement of Tsukuba VLBI station using VieVS
  – Displacement and coordinates for TSUKUB32
• Create an efficient tool to inspect coordinate time series to be used with VieVS result files
  – Possibility for future VieVS GUI implementation
• Find out possible ways improve VieVS in the process
Strategy

• Select an adequate number of 24-hour R1 sessions before and after the 11 March 2011 earthquake
  – Tsukuba included in R1 sessions
• Identify and deal with problematic sessions
• Try out different parametrizations
Analysis conditions and procedure

- Done with VieVS 1d
- A total of 32 R1 sessions from 2011-01-03 to 2011-09-12
- Modeling options

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>TRF</td>
<td>VTRF2008</td>
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<tr>
<td>CRF</td>
<td>ICRF2</td>
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<tr>
<td>Ephemerides</td>
<td>JPL421</td>
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<tr>
<td>EOP</td>
<td>C04 08</td>
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<tr>
<td>Precession/Nutation</td>
<td>IAU2006/IAU2000</td>
</tr>
<tr>
<td>Tidal ocean loading</td>
<td>FES2004</td>
</tr>
<tr>
<td>Mapping function</td>
<td>VM1</td>
</tr>
</tbody>
</table>
Analysis conditions and procedure

• TSUKUB32 and TIGO removed from VTRF2008.mat
  – exclude TSUKUB32 and TIGO from NNR/NNT conditions for all epochs
  – excluded also before the earthquake for consistency
  – TIGO had noisy data -> removing TIGO in OPT-files decreased the std error of mean unit weight
  – Estimated parameters
    • Station position
    • clock parameter 60 min, relative constraint 0.5 ps²
    • ZWD, 20 min interval, relative constraint 0.7 ps²
    • Atmosphere gradient, 6h interval, relative constraints, 2mm/day
Analysis conditions and procedure

• Each session was first analyzed stationwise without main solution to remove clock breaks, bad baselines and other sources of error e.g. problems with a station

• OPT-files were created for each session. Example (11JAN18XA.OPT):
  
  CLOCK REFERENCE:
  WETTZELL
  STATIONS TO BE EXCLUDED: 1
  TIGOCONC
  CLOCK BREAKS: 2
  HOBART12 55580.265
  BADARY 55580.386

• One removed due to a crashing issue
  – 11SEP06XA_N004 -> index out of bounds error in Lagrange interpolation

• Main solution applied twice to every session to remove outliers

• - simple outlier test (5*mo)
• - 229 outliers removed
Visualization

• To visualize the resulting time series a Matlab tool was written
• Data initialization and collection (stationwise)
• Generates coordinate time series from the input of VieVS result directory and 8-letter IVS station name
  – e.g. timeseries('resultsdir','TSUKUB32')
  – Time series in ECEF and ENU coordinates
  – Corresponding series of standard error of mean unit weight for session
  – Possibility to divide data/timeseries to inspect a select interval(s)
TSUKUB32 ECEF

![Graph of TSUKUB32 ECEF data with X, Y, and Z axes labeled and DOY (Day of Year) on the x-axis. The graph shows variations in XYZ coordinates over time.]

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TSUKUB32 ENU

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Results and conclusions

• Five of the biggest aftershocks between 2011-04-07 and 2011-06-30 were pictured in the graphs

• From 6.1 to 7.1 Mb (body wave magnitude)

• They do not seem to correspond to any major changes in the solution
Aftershocks

TSUKUB32 and aftershocks

DOY

\[ \Delta ENU \text{ (cm)} \]

- East
- North
- Up
- Aftershocks

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Standard error of unit weight

A posteriori standard error of unit weight

DOY

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Results and conclusions

Based on the analysis of 31 sessions, the initial displacement of Tsukuba VLBI station was

<table>
<thead>
<tr>
<th>$\Delta X$ (cm)</th>
<th>$\Delta Y$ (cm)</th>
<th>$\Delta Z$ (cm)</th>
<th>$\Delta E$ (cm)</th>
<th>$\Delta N$ (cm)</th>
<th>$\Delta U$ (cm)</th>
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</thead>
<tbody>
<tr>
<td>-36.9</td>
<td>-54.7</td>
<td>-2.4</td>
<td>65.6</td>
<td>2.0</td>
<td>-6.9</td>
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</tbody>
</table>

A priori coordinates + initial change

<table>
<thead>
<tr>
<th>X (m)</th>
<th>Y (m)</th>
<th>Z (m)</th>
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<tbody>
<tr>
<td>-3957409.121</td>
<td>3310228.820</td>
<td>3737494.765</td>
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</table>
Postseismic movement

Postseismic movement: VLBI and GPS

\[ \Delta ENU \, (\text{cm}) \]

\[ \text{DOY} \]

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Results and conclusions

- Results agreed relatively well with analyses of displacement of Tsukuba in other publications.
- East and north components seem to have more stable movement.
- There was a clear postseismic movement in the coordinates:
  - Motion was most prominent in the East, to the direction of coseismic slip, in the region of 10-15cm over a period of 161 days.
  - Some postseismic movement to the South, under 5cm.
  - Relatively large variation of Up-component makes interpretation more difficult.

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Further development

• Further study to improve the estimates, especially the Up-component and some of the more problematic sessions
• Incorporate the time series tool created in the process to VieVS
• Create a more general visualization tool for plotting time series of all the geodetic parameters estimated by VieVS
• Develop the visualization tool to a standalone version with a more versatile language to get more flexibility and functionality
• Python + matplotlib + NumPy + SciPy
Thank you!