BeiDou Coordinate System And Its First Realization

13th Meeting of the International Committee on Global Navigation Satellite Systems

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Outline

- Introduction
- Definition of BDCS
- First Realization of BDCS
- Summary
1 Introduction


Why?
1 Introduction

- Main Consideration

BDS monitor stations

<table>
<thead>
<tr>
<th>Beijing</th>
<th>Haerbin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sanya</td>
<td>Wulumuqi</td>
</tr>
<tr>
<td>Chengdu</td>
<td>Kashi</td>
</tr>
<tr>
<td>Shantou</td>
<td>Lasa</td>
</tr>
</tbody>
</table>

CGCS2000 reference stations
1 Introduction

- Principles
  - Advanced and Scientific
  - BDCS should be aligned to the latest ITRF.
2 Definition of BDCS

- **Name**

To differentiate the updated realizations, BDCS (W*** ) is presented, where W*** indicates BeiDou week, for example BDCS (W465), which means the new frame is adopted from BeiDou week 465.
2 Definition of BDCS

- **Definition**
  - **Origin**: the center of mass for the whole earth, including oceans and atmosphere.
  - **Scale**: the unit of length is meter (SI). The scale is consistent with the TCG time coordinate.
  - **Orientation**: conform to the recommendation of BIH.
  - **Time evolution**: no-net-rotation with regards to horizontal tectonic motions over the whole earth.
2 Definition of BDCS

- Definition

IERS Reference Pole
IERS Reference Meridian
BDCS Reference Ellipsoid
Earth’s center of mass
2 Definition of BDCS

- **Ellipsoid**

<table>
<thead>
<tr>
<th>Defining parameters of BDCS Ellipsoid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semi-major axis</td>
</tr>
<tr>
<td>Flattening</td>
</tr>
<tr>
<td>Geocentric gravitational constant</td>
</tr>
<tr>
<td>Earth's angular velocity</td>
</tr>
</tbody>
</table>
## 2 Definition of BDCS

### Derived parameters of BDCS Ellipsoid

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semi-minor axis</td>
<td>$b = 6356752.3141\text{m}$</td>
</tr>
<tr>
<td>Linear eccentricity</td>
<td>$E = 521854.00970025\text{m}$</td>
</tr>
<tr>
<td>First eccentricity squared</td>
<td>$e^2 = 0.00669438002290$</td>
</tr>
<tr>
<td>Second eccentricity squared</td>
<td>$e'^2 = 0.00669438002290$</td>
</tr>
<tr>
<td>Radius of sphere of equal volume</td>
<td>$R = 6371000.7900\text{m}$</td>
</tr>
<tr>
<td>Normal gravity potential of the ellipsoid</td>
<td>$U_0 = 62636851.7149\text{m}^2\text{s}^{-2}$</td>
</tr>
<tr>
<td>Second degree zonal harmonic coefficient</td>
<td>$J_2 = 0.1082629832258 \times 10^{-2}$</td>
</tr>
<tr>
<td>Normal gravity at the equator on the ellipsoid</td>
<td>$\gamma_e = 9.7803253361\text{ms}^{-2}$</td>
</tr>
<tr>
<td>Normal gravity at the pole on the ellipsoid</td>
<td>$\gamma_p = 9.8321849379\text{ms}^{-2}$</td>
</tr>
<tr>
<td>Normal gravity formula constant</td>
<td>$k = 0.00193185261931$</td>
</tr>
</tbody>
</table>
3 First Realization of BDCS

✓ the collection of geophysical models and parameters
✓ positions and velocities for the monitoring stations
✓ satellite ephemerides
✓ corresponding EOPs
## 3 First Realization of BDCS

### BDCS monitor stations

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</table>
3 First Realization of BDCS

- Time span of data
  - The initial observation: in 2007 ~2009, one station after another.
  - The second observation: in December 2011, the joint campaign, totaled 15 whole days.
  - The third observation: in April 2014, the joint campaign, totaled 15 whole days.
  - The fourth observation: in 2016, regional joint survey.
3 First Realization of BDCS

- Data processing

  - First step: loosely constrained solutions
  
  - 8 reference stations (not monitor stations)
  - 27 CMONOC stations
  - 64 IGS stations.

*CMONOC=Crustal Movement Observation Network of China*
3 First Realization of BDCS

- Data processing

27 CMONOC stations
3 First Realization of BDCS

- Data processing

[Map showing 64 IGS Stations]
3 First Realization of BDCS

- Data processing

  Second step: minimum constrains solutions

  Coordinates of monitor stations are aligned to ITRF2014 over a set of 64 IGS core stations.

  \[
  \hat{X} = X_{apr} + \left( N + B^T \Sigma^{-1} B \right)^{-1} \left[ K + B^T \Sigma^{-1} B \left( X_R - X_{apr} \right) \right]
  \]
3 First Realization of BDCS

- Data processing

Third step: positions time series

Local tie data were added to the coordinates of reference stations.

CDJC01 X, Y, Z coordinate series
3 First Realization of BDCS

- **Data processing**

  - Last Step: the coordinates at any epoch can be obtained by linear regression.

\[
\begin{align*}
X(t) &= X_0 + v_X \times (t - 2010.0) \\
Y(t) &= Y_0 + \nu_Y \times (t - 2010.0) \\
Z(t) &= Z_0 + v_Z \times (t - 2010.0)
\end{align*}
\]
## 3 First Realization of BDCS

### Accuracy

Comparison of the coordinates and velocities

<table>
<thead>
<tr>
<th>stations</th>
<th>dx(m)</th>
<th>dy(m)</th>
<th>dz(m)</th>
<th>dvx(m/a)</th>
<th>dvy(m/a)</th>
<th>dvz(m/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDJC01</td>
<td>-0.0004</td>
<td>0.0018</td>
<td>-0.0005</td>
<td>0.0001</td>
<td>0.0005</td>
<td>-0.0003</td>
</tr>
<tr>
<td>CDJC02</td>
<td>-0.0004</td>
<td>0.0016</td>
<td>-0.0009</td>
<td>0.0001</td>
<td>0.0010</td>
<td>0.0002</td>
</tr>
<tr>
<td>CDJC03</td>
<td>-0.0005</td>
<td>0.0015</td>
<td>-0.0019</td>
<td>0.0002</td>
<td>0.0010</td>
<td>0.0021</td>
</tr>
<tr>
<td>HEBJC01</td>
<td>-0.0020</td>
<td>0.0042</td>
<td>0.0024</td>
<td>-0.0010</td>
<td>0.0022</td>
<td>0.0018</td>
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<tr>
<td>HEBJC02</td>
<td>-0.0021</td>
<td>0.0041</td>
<td>0.0020</td>
<td>-0.0008</td>
<td>0.0024</td>
<td>0.0024</td>
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<tr>
<td>HEBJC03</td>
<td>-0.0024</td>
<td>0.0047</td>
<td>0.0024</td>
<td>-0.0004</td>
<td>0.0016</td>
<td>0.0020</td>
</tr>
<tr>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
<td>…</td>
</tr>
<tr>
<td>RMS</td>
<td>0.002</td>
<td>0.002</td>
<td>0.004</td>
<td>0.003</td>
<td>0.002</td>
<td>0.002</td>
</tr>
</tbody>
</table>
3 First Realization of BDCS

- **Accuracy**

RMS of differences between calculated coordinates and ITRF2014 coordinates of 64 IGS stations

The accuracy of monitor station coordinates is better than 1 cm.
4 Summary

- BDCS will replace CGCS2000 as BDS’s geodetic reference system.
- The definition of BDCS is the same as that of CGCS2000, but the realization is separate.
- The first realization of BDCS is aligned to ITRF2014, and the accuracy of the coordinates is superior to 1 cm.
- BDCS will pave the way for the interoperation between BDS and other GNSS.
THANK YOU!

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