Updates of CGCS 2000

Yuanxi YANG

China National Administration of GNSS and Applications (CNAGA)
The same geocentric coordinate system has to be used (benefits for providers and users), because the satellites run around the geocenter.

The same coordinate reference is needed (not the frame, it is impossible and unnecessary).

Orbit parameters reflect reference frame.

The dynamic effects should be considered in the coordinate system, otherwise the coordinates of tracking stations may be in error, result in orbit error—agreement to update coordinates by xx years?
1. Background of CGCS 2000

Definition of CGCS 2000

- Global, three-dimensional;
- Right-handed, orthogonal;
- Geo-centered;
- Frame: ITRF97;
- Epoch: 2000.0;

- CTRF (Chinese Terrestrial Reference Frame)
  - Aligned to ITRF
  - Consistent with international standards
Main Parameters of Reference Ellipsoid

Semi major axis:
\[ a = 6\,378\,137\,m \]

Gravitational constant:
\[ GM = 3.986\,004\,418 \times 10^{-14} \, m^3s^{-2} \]

2nd degree harmonic coefficient:
\[ J_2 = 0.001082629832258 \]

Mean angular velocity of the earth:
\[ \omega = 7292115.0 \times 10^{-11} \, rad \, s^{-1} \]
1. Background of CGCS 2000

Deduced Parameters of Reference Ellipsoid

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semi minor axis:</td>
<td>b = 6 356 752.31414</td>
</tr>
<tr>
<td>1\textsuperscript{st} eccentricity:</td>
<td>e = 0.0818191910428</td>
</tr>
<tr>
<td>2\textsuperscript{nd} eccentricity:</td>
<td>e’ = 0.0820944381519</td>
</tr>
<tr>
<td>Flattening:</td>
<td>f = 1/298.257222101 dif. 1/298.257223563</td>
</tr>
<tr>
<td>Ratio of the axes:</td>
<td>a/b = 1/0.996647189335</td>
</tr>
<tr>
<td>Mean radius of the ellipsoid:</td>
<td>R_1 = 6371008.77138m</td>
</tr>
</tbody>
</table>
Deduced Gravitational Parameters

Normal potential: $U_0 = 62636851.7149 \text{m}^2\text{s}^{-2}$

Polar normal gravity: $\gamma_p = 9.8321849402 \text{ms}^{-2}$

Equator normal gravity: $\gamma_e = 9.7803253361 \text{ms}^{-2}$

Total mass of the earth: $M = 5.9733328 \times 10^{24} \text{kg}$

Consistency in definition and diversity in realization!----Benefit for compensate the systematic errors
1. Background of CGCS 2000

- IGS Stations used in CTRF computation

47 IGS stations were included in establishing CTRF 2000
1. Background of CGCS 2000

IGS stations in China

BJFS
CHAN
KUNM
LHAS
SHAO
URUM
WUHN
XIAN
1. Background of CGCS 2000

- China Terrestrial Reference Frame (CTRF 2000)

- The first order: 28 CORS, which is the key frame of CGCS 2000 with mm accuracy.

- The second order: “2000’ national GPS network”, with about 2500 stations with cm accuracy.

- Realized using some IGS even distributed over the world.
1. Background of CGCS 2000

Problems of CTRF 2000

- The accuracy of the CTRF 2000 is not so homogeneous, compared to the ITRF, because some old and low order GPS networks were integrated.

- Only 28 CORS and about 1000 monitoring stations with high accuracy were used in the CGCS2000.

- The geometry structure of 2000’ GPS network is quite weak for vast territory in China.

- The positional velocities were not provided.

- The tracking stations of Beidou have not been integrated in the CTRF 2000.
2. Extended national CTRF stations

- CORS stations will be increased from 28 to 260

- 28 existing stations
- 3 co-located stations with VLBI, 6 co-located stations with fixed SLR
- 232 new stations will be established.
2. Extended national CTRF stations

Regional stations from 1000 to 2000

- 1000 existing regional stations
- 1000 stations will be established.
3. Coordinate Updating by Collocation

- Velocities from Cartesian coordinates to local coordinates (Based on Euler vector)

\[
\begin{bmatrix}
\dot{v}_x \\
\dot{v}_y \\
\dot{v}_z
\end{bmatrix} =
\begin{bmatrix}
0 & z & -y \\
-z & 0 & x \\
y & -x & 0
\end{bmatrix}
\begin{bmatrix}
\omega_x \\
\omega_y \\
\omega_z
\end{bmatrix}
\]

- Neglecting the vertical component, we have the error equation

\[
\begin{bmatrix}
v_n \\
v_e
\end{bmatrix} =
\begin{bmatrix}
R\sin\lambda & -R\cos\lambda & 0 \\
-R\sin\phi\sin\phi & -R\sin\phi\sin\phi & R\cos\phi
\end{bmatrix}
\begin{bmatrix}
\omega_x \\
\omega_y \\
\omega_z
\end{bmatrix}
\]

\[V = A\hat{\omega} - L\]
3. Coordinate Updating with Collocation

Considering the local variations of the velocities, we add a new term $S$ (Signal) in the error equation, and get a collocation model based on Euler vector

$$V = A\hat{\omega} + \hat{S} - L$$

$$A\hat{\omega} = \begin{bmatrix}
R\sin\lambda & -R\cos\lambda & 0 \\
-R\sin\phi\sin\phi & -R\sin\phi\sin\phi & R\cos\phi \\
-R\sin\phi\sin\phi & -R\sin\phi\sin\phi & R\cos\phi
\end{bmatrix}
\begin{bmatrix}
\hat{\omega}_x \\
\hat{\omega}_y \\
\hat{\omega}_z
\end{bmatrix}$$

$$C_N(d) = \frac{38.33170}{1 + 0.651987 \cdot d^2}$$

$$C_E(d) = \frac{21.47733}{1 + 1.063019 \cdot d^2}$$

$$\hat{\omega} = (A^T P_L A)^{-1} A^T P_L L$$
$$\hat{S} = \Sigma S B^T P_L (L - A\hat{\omega})$$
$$\hat{S}' = \Sigma S S \Sigma S^{-1} \hat{S}$$
3. Coordinate Updating with Collocation

Adaptive collocation

\[
\Omega = V^T P_e V + \alpha \hat{S}^T P_s \hat{S} = \min
\]

\[
\begin{bmatrix}
\hat{\omega} \\
\hat{S}
\end{bmatrix} = \left[
\begin{bmatrix}
A^T P_e A \\
B^T P_e A
\end{bmatrix}
\begin{bmatrix}
A^T P_e B \\
B^T P_e B + \alpha P_s
\end{bmatrix}
\right]^{-1} \cdot \begin{bmatrix}
A^T P_e \dot{X}
\\
B^T P_e \dot{X}
\end{bmatrix}
\]

\[
\hat{\omega} = (A^T \overline{P}_L A)^{-1} A^T \overline{P}_L L
\]

\[
\hat{S} = \Sigma_s B^T \overline{P}_L (\dot{X} - A \hat{\omega})
\]

\[
\overline{P}_L = (B \Sigma_s B^T / \alpha + \Sigma_s)^{-1} = \alpha (B \Sigma_s B^T + \alpha \Sigma_s)^{-1}
\]

\[
\hat{S}' = \Sigma_{s's} \Sigma_{s'}^{-1} \hat{S} = \frac{1}{\alpha} \Sigma_{s's} \left( \frac{1}{\alpha} \Sigma_s \right)^{-1} \hat{S} = \Sigma_{s's} \Sigma_{s'}^{-1} \hat{S}
\]
### 3. Coordinate Updating with Collocation

#### Euler vector from different calculation model

<table>
<thead>
<tr>
<th>Model</th>
<th>$\omega_x$ (Rad/Ma)</th>
<th>$\omega_y$ (Rad/Ma)</th>
<th>$\omega_z$ (Rad/Ma)</th>
<th>$\lambda$ (°)</th>
<th>$\phi$ (°)</th>
<th>$\omega$ (°/Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LS Euler Vector</td>
<td>-0.0004415</td>
<td>-0.0037950</td>
<td>0.0035848</td>
<td>-96.6</td>
<td>43.2</td>
<td>0.300</td>
</tr>
<tr>
<td>Collocation Model</td>
<td>0.0001159</td>
<td>-0.0042049</td>
<td>0.0031925</td>
<td>-88.4</td>
<td>37.2</td>
<td>0.302</td>
</tr>
<tr>
<td>Adaptive Collocation</td>
<td>0.0001367</td>
<td>-0.0041396</td>
<td>0.0032090</td>
<td>-88.1</td>
<td>37.7</td>
<td>0.300</td>
</tr>
</tbody>
</table>
4. Coordinate velocities from Euler Vector

- 1041 stations with velocity accuracy better than 3mm/y are employed in Euler vector estimation.
- 29 CORS are acted as checking stations which are not included in the velocity estimation.

The CRTF station movements are generally in eastern direction. The velocities of the western part are much larger than those of eastern part.
5. Comparison of Various Models

The residuals have significant regional trend marked by 104° of longitude. The residuals in western part are much larger than those of eastern part.

In the Northwest, the residuals are in the northeastern direction; The Northeast are in west-north direction; and in the South, the residuals are in northwestern direction but not significant.
5. Comparison of Various Models

- Residuals transformed by collocation model

The local trends of the residuals transformed by collocation model nearly disappear.
Outside Checking

Discrepancy in N direction
In Checking stations

Discrepancy in E direction
In Checking stations
5. Comparison of Various Models

RMS calculated by the 29 CORS (mm)

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Component</th>
<th>Max</th>
<th>Min</th>
<th>Mean</th>
<th>RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Euler vector model</td>
<td>E (mm)</td>
<td>13.72</td>
<td>-7.99</td>
<td>-0.49</td>
<td>3.92</td>
</tr>
<tr>
<td></td>
<td>N (mm)</td>
<td>17.78</td>
<td>-12.94</td>
<td>1.73</td>
<td>6.59</td>
</tr>
<tr>
<td>Collocation model</td>
<td>E (mm)</td>
<td>4.10</td>
<td>-4.66</td>
<td>0.07</td>
<td>1.81</td>
</tr>
<tr>
<td></td>
<td>N (mm)</td>
<td>5.35</td>
<td>-3.13</td>
<td>0.19</td>
<td>1.78</td>
</tr>
<tr>
<td>Adaptive Collocation</td>
<td>E (mm)</td>
<td>5.10</td>
<td>-4.83</td>
<td>0.28</td>
<td>1.76</td>
</tr>
<tr>
<td></td>
<td>N (mm)</td>
<td>2.68</td>
<td>-2.50</td>
<td>-0.06</td>
<td>1.35</td>
</tr>
</tbody>
</table>
6. Future development of CTRF

- Much more National CORS station will be established (CORS belong to various provinces will be integrated).
- Multi GNSS (inc. Beidou) with their multi frequencies will be applied in the frame maintenance.
- The coordinate frame will be updated.
- Non of the geodynamic model can be used in updating the Chinese coordinate reference frame.
- Local and regional geodynamic effects should be taken into account in the updating of the coordinate reference frame.
- Collocation method can be a choice for updating the reference frame.
Thank you!