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An approach for parameter decorrelation in precise dynamic orbit determination

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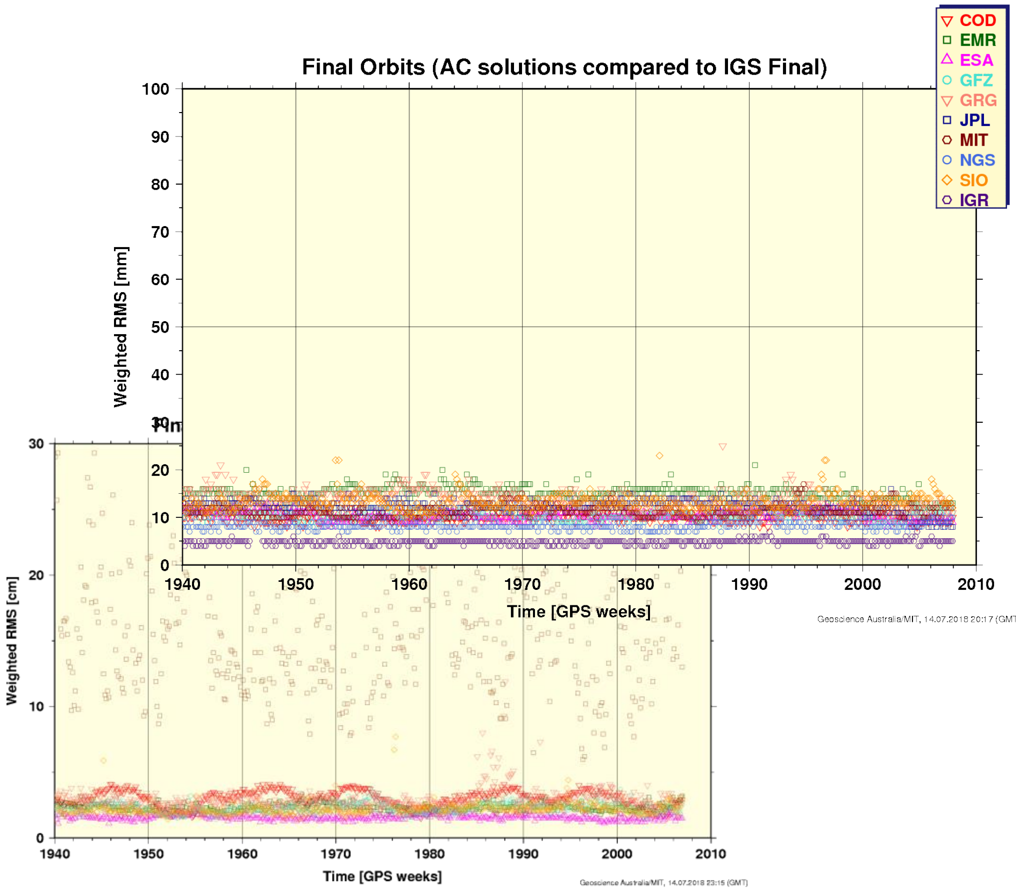
Precise GNSS Products

- **Final satellite orbits: a combination of orbits from different analysis centers**
- **Accuracy [1]:**
  - ✓ **2.5 cm for GPS**
  - ✓ **3 cm for GLONASS**

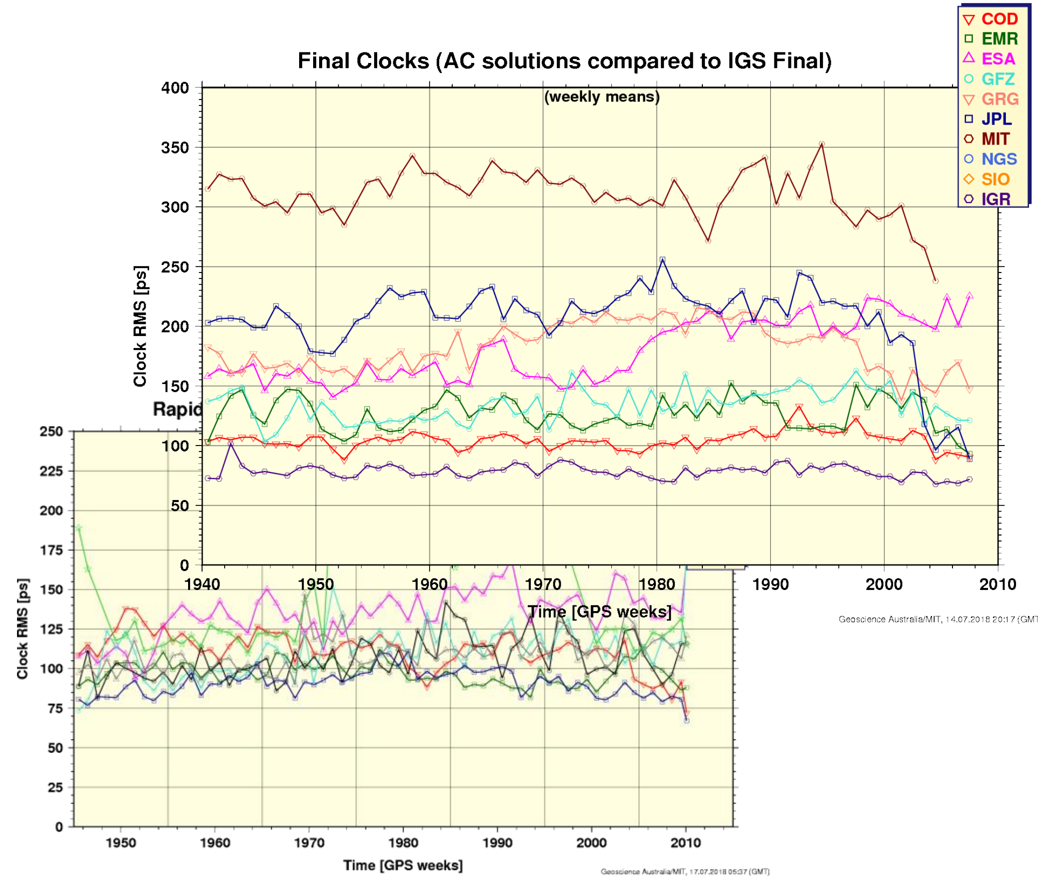


1: http://www.igs.org/products

Precise GNSS Products

- **Final satellite clocks: a combination of orbits from different analysis centers**
- **Accuracy [1]:**

✓ **75 ps (2.25 cm) for GPS**



1: http://www.igs.org/products

Precise GNSS Products

☐ Orbit combination strategy[2]:

✓ **L1-norm with different weighting**

☐ Clock combination strategy[3]:

✓ **Radial orbit difference corrected**

Bulletin Géodésique (1995) 69: 200–222

Bulletin Géodésique

Combining the orbits of the IGS Analysis Centers

Gerhard Beutler [1], Jan Kouba [2], and Tim Springer [3]

[1] Astronomical Institute, University of Bern, Bern, Switzerland
[2] Geodetic Survey of Canada, SMRRS, NRCan, Ottawa, Canada
[3] Delft University of Technology, Delft, The Netherlands

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Abstract. Currently seven Analysis Centers of the International GPS Service for Geodynamics (IGS) are producing daily precise orbits and the corresponding Earth Orientation Parameters (EOP). These individual products are available at several IGS Data Centers (e.g. CDDIS, IGN, SIO, etc.). During 1993 no official IGS orbits were produced, but the routine orbit comparisons by IGS indicated that, after small orientation and scale alignments, the orbit consistency was approaching the 20 cm level (a coordinate RMS), and that some orbit combination should be possible and feasible. An IGS combined orbit could provide a precise and efficient extension of the IERS Terrestrial Reference Frame (ITRF). Another advantage of such a combined orbit would be reliability and precision.

different and independent techniques, into a single EOP series and the corresponding station coordinate sets in the IERS Terrestrial Reference Frame (ITRF). During 1993 no 'official' product was issued by the IGS. The IGS could, however, provide a logical and efficient extension of the ITRF through the definition of IGS orbits plus the timely approximation and resolution enhancements of the IERS EOP series (e.g. the IERS Rapid Service). It is clear that orbits, station positions and EOP must be made as compatible as possible. This is the main reason why there is such close cooperation with IERS both at the operational and management levels (observation and processing standards, governing boards, terms of references, etc.).

Orbit combination by itself and as such would not be

$$\ddot{x}_i(t) = \frac{\partial}{\partial x} V(x)\,\Big|_{x_i},$$

and that the weighted average orbit is:

$$x_0(t) = \sum_{i=1}^{n} k_i x_i(t),$$

where k_i denotes the weight coefficients of the average and t is time. Differentiating $x_0(t)$ twice with respect to time, while assuming that the coefficients k_i are constant during the considered period, gives:

$$\ddot{x}_0(t) = \sum_{i=1}^{n} k_i \ddot{x}_i(t) = \sum_{i=1}^{n} k_i \frac{\partial}{\partial x} V(x)\,\Big|_{x_i}.$$

$$\frac{\partial}{\partial x} V(x)\,\Big|_{x_i} = \frac{\partial}{\partial x} V(x)\,\Big|_{x_0} + (x_i - x_0)\,\frac{\partial^2}{\partial x^2}\big(V(x)\big)\Big|_{x_0} + \ldots$$

and

$$\sum_{i=1}^{n} k_i = 1.$$

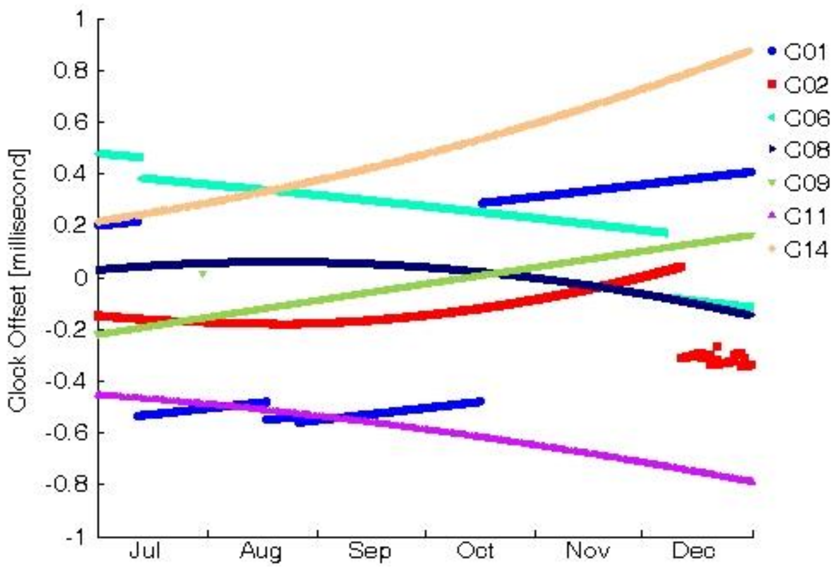
2: Beutler, G.et al. (1995), *Bulletin Geodesique*, *69*(4), 200--222.
3:T.A. Springer et al. presentation at the IGS Analysis Center Workshop, 1998

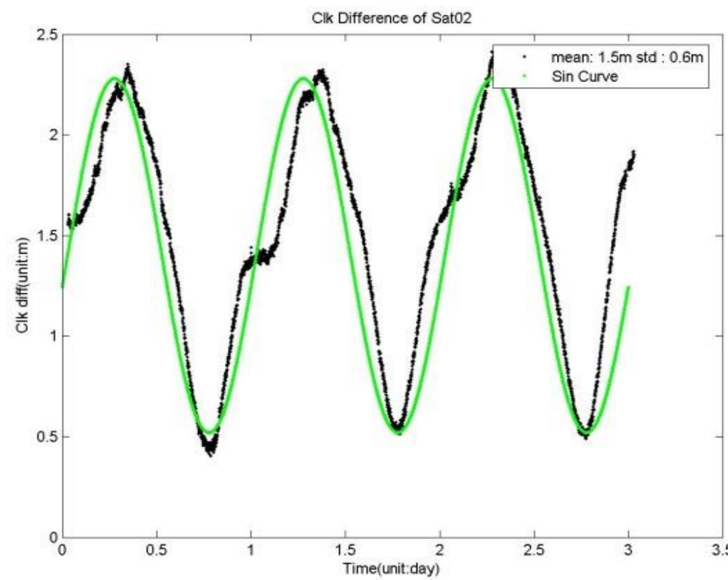
Contents

Orbit/clock Correlations

□ Satellite clock characteristics[4]

- ✓ **Linear and quadratic trend in general**
- ✓ **Remaining periodical residuals coming from satellite orbit errors**





4:Kenneth L. Senior et al. GPS Solut 2008, (12):211–225

Orbit/clock differences

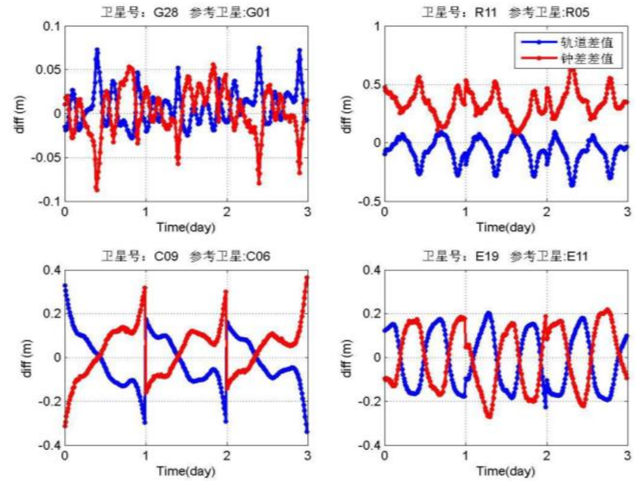
- Satellite orbits and clock differences among different ACs [5]

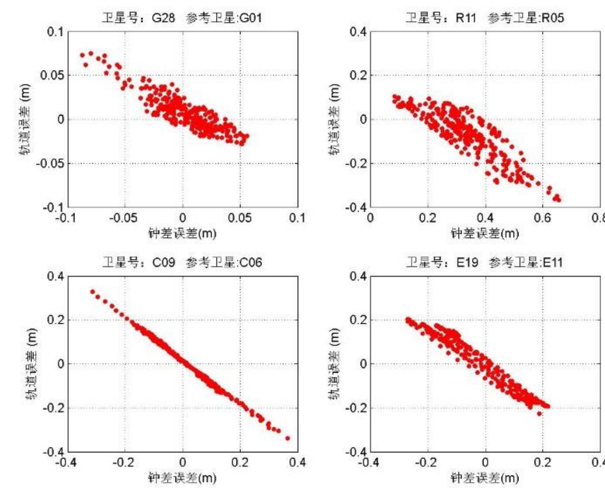
✓ 1 reference satellite

✓ 2 steps difference (between satellites and ACs)

- Orbit differences(blue) vs. Clock differences(red):Negative linear correlation

- Correlation issue limits accuracy!!





5:Junping Chen et al. GEOMATICS AND INFORMATION SCIENCE OF WUHAN UNIVERS),2017,42(11):1649-1657

Parameter Correlation problems

☐ Scaled Sensitivity Matrix approach[6,7]

✓ **quantitative assessing the influences of unresolved parameters**

Table 4. Mean Annual Vertical Amplitude and Power Explained[a]

	SOPAC, mm	JPL
Mean amplitude without pole tide correction	5.47 (5.49) mm	–
Mean amplitude after pole tide correction	4.19 (4.19) mm	3.49 (3.44) mm
Mean amplitude after mass loading correction	3.19 (3.08) mm	2.89 (2.74) mm
Ratio of site numbers[b]	90/128 (90/123)	81/121 (79/116)
Power explained (pole tide and mass loading together)[c]	66% (67%)	–
Power explained (mass loading only)[c]	42% (46%)	31% (37%)

$$y = A_1 \cdot X_1 + A_2 \cdot X_2 \quad (12)$$

where X_2 is defined as the ISB parameter and could be removed from (12), X_1 includes the other parameters; A_1, A_2 are design matrices for corresponding parameters. The corresponding normal equation is,

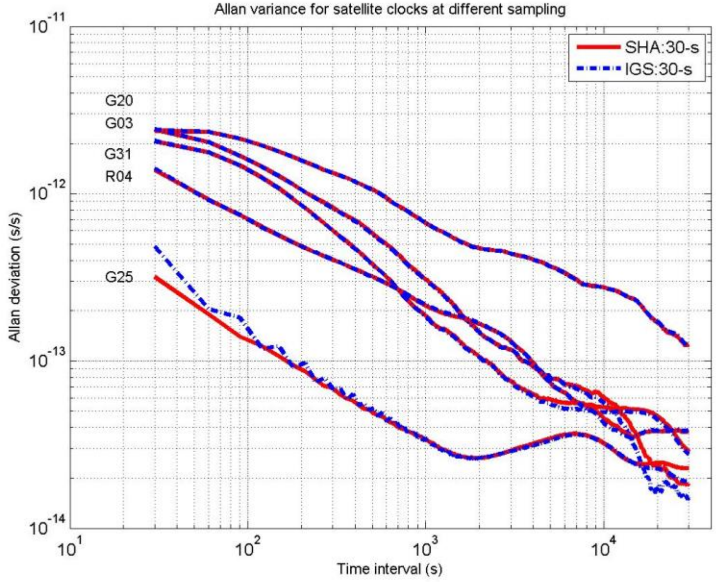
$$\begin{bmatrix} N_{11} & N_{12} \\ N_{21} & N_{22} \end{bmatrix} \cdot \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} = \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} \quad (13)$$

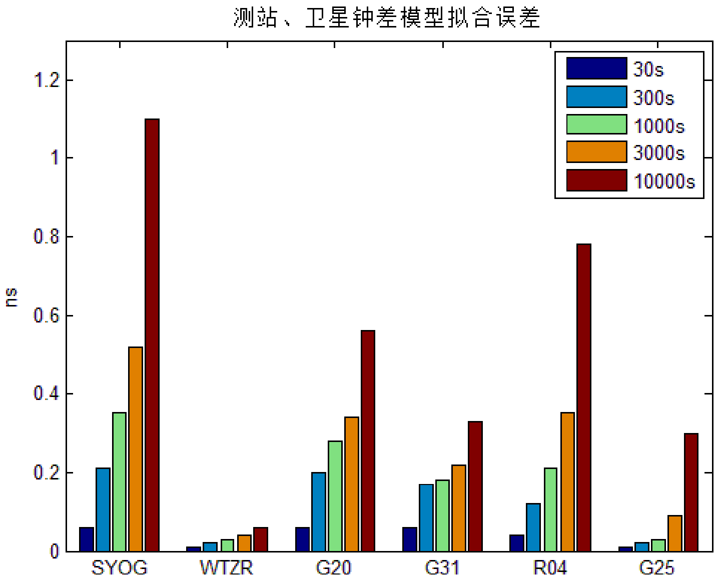
6: Dong, D. et al., 2002. J. Geophys. Res.107 (B4), 2075.
7: Junping Chen et al. (2015): Advances in Space Research, 55 (2015) 125–134

Contents

Satellite clock modelling

- Modelling satellite clock as quadratic terms for **satellite-dependent periods**





- Modelling period from minutes to hours!

Satellite clock modelling in POD

- **Using precise TWTT Satellite clocks as constrains [8]**

$$\mathrm{L}_{\mathrm{i}}^{\mathrm{j}} = \rho(\mathrm{r}_i, \mathrm{r}^j) + \mathrm{c} \cdot dt_i - c \cdot (\mathrm{a}_0 + \mathrm{a}_j \cdot \Delta\tau + b_j \cdot \Delta\tau^2) + N_i^j + T_i^j + \varepsilon_i^j$$

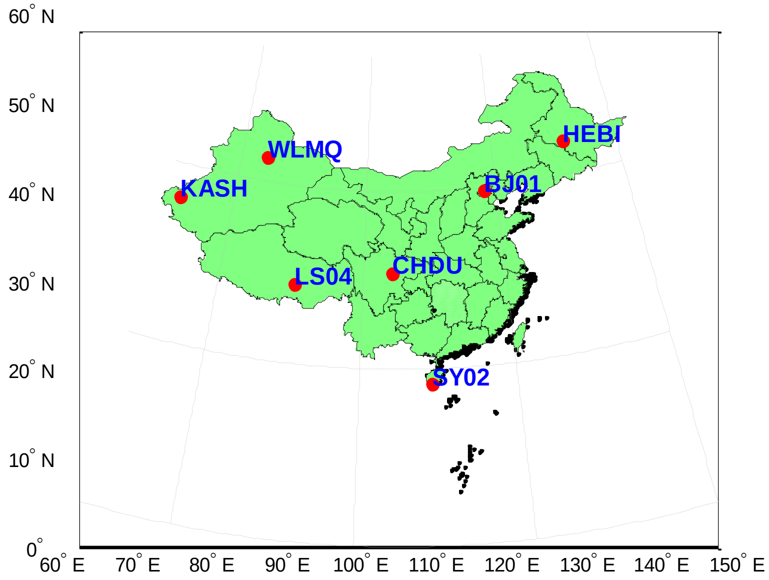
$$\frac{\partial \mathrm{L}}{\partial par} = \left(\frac{\partial \mathrm{L}}{\partial a_0}, \frac{\partial \mathrm{L}}{\partial a_j}, \frac{\partial \mathrm{L}}{\partial b_j} \right)^T = \left(-c, -c \cdot \Delta\tau, -c \cdot \Delta\tau^2 \right)^T$$

- **Advantages:**
  - ✓ **None effects from orbit errors**
  - ✓ **Better modelling and more stable solutions**

8:Qian Chen et al. China Satellite Navigation Conference (CSNC) 2018 Proceedings, Lecture Notes in Electrical Engineering 498,2018,399-407

Experiments

- Data of 7 tracking stations in Mainland China are used. Three periods where BDS GEO satellites experienced maneuver in October 2017 are selected



Satellite maneuver information

SatID	Start time	End time	Available time
C01	2017-10-31 8:55	2017-10-31 10:15	4h after maneuver
C02	2017-10-19 8:59	2017-10-19 11:15	4h after maneuver
C03	2017-10-23 8:46	2017-10-23 11:15	4h after maneuver

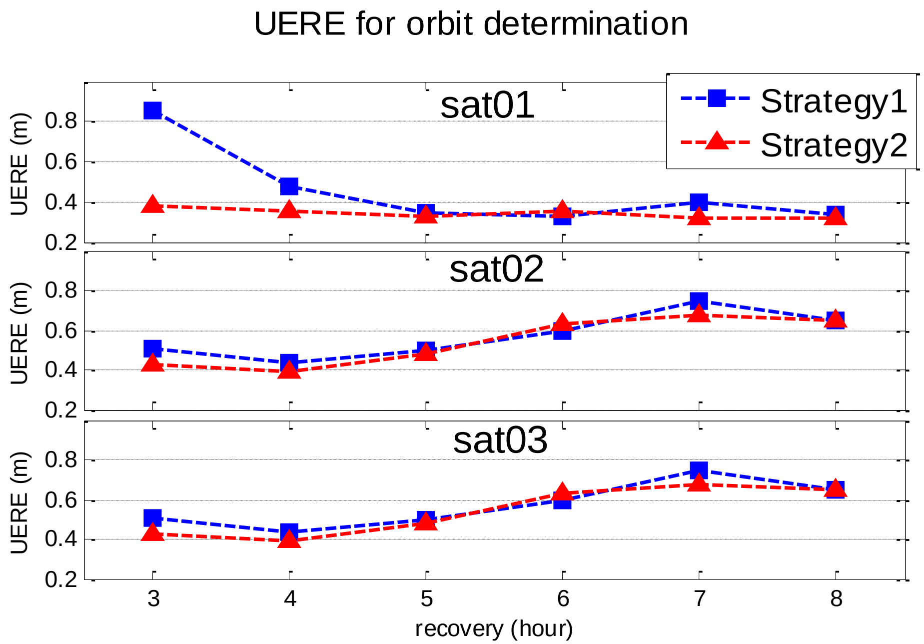
Results

- ☐ Satellite clock modelling accuracy secured
- ☐ Orbit accuracy with new and traditional approach
  - ✓ Much more stable and higher accuracy for the NEW

Satellite clock modelling and prediction

SatID	Accuracy	1 h Prediction
C01	0.11	0.81
C02	0.09	0.80
C03	0.06	0.78
C04	0.11	1.14
C05	0.07	0.93
C06	0.24	1.23
C07	0.23	1.30
C08	0.17	1.33
C09	0.21	1.41
C10	0.26	1.44

Orbit accuracy with old and new approach



Results

SatID	DATA SPAN	OBSERV. UERE			1 h Prediction		
		OLD	NEW	Improvement (%)	OLD	NEW	Improvement (%)
C01	3h	0.856	0.378	55.848	3.982	0.717	81.996
	4h	0.476	0.354	25.672	1.997	0.341	82.919
	5h	0.341	0.326	4.368	0.367	0.435	-18.484
	6h	0.331	0.352	-6.377	0.400	0.486	-21.600
	7h	0.402	0.323	19.497	0.697	0.376	46.114
	8h	0.336	0.320	4.911	0.744	0.819	-10.052
C02	3h	0.505	0.423	16.261	2.308	0.338	85.369
	4h	0.436	0.394	9.529	0.889	0.632	28.941
	5h	0.502	0.483	3.845	1.733	1.130	34.785
	6h	0.600	0.628	-4.600	1.251	1.163	7.049
	7h	0.750	0.679	9.433	1.415	0.564	60.158
	8h	0.647	0.650	-0.526	0.502	0.501	0.179
C03	3h	0.801	0.673	15.980	1.929	0.568	70.561
	4h	0.670	0.680	-1.462	0.503	0.502	0.219
	5h	0.683	0.643	5.801	0.842	0.546	35.139
	6h	0.645	0.672	-4.169	0.506	0.476	5.873
	7h	0.638	0.638	-0.063	0.494	0.513	-3.742
	8h	0.611	0.614	-0.541	0.461	0.463	-0.456
mean		0.568	0.513	8.523	1.168	0.587	26.943

Results

SatID	DATA SPAN	OBSERV. UERE OLD	OBSERV. UERE NEW	Improvement (%)	1 h Prediction OLD	1 h Prediction NEW	Improvement (%)
C01	3h	0.856	0.378	55.848	3.982	0.717	81.996
	4h	0.476	0.354	25.672	1.997	0.341	82.919
	5h	0.341	0.326	[illegible]	0.367	0.435	-18.484
	6h	[illegible]	[illegible]	[illegible]	[illegible]	0.486	-21.600
	7h	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	46.114
	8h	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-10.052
C02	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	85.369
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	34.785
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.049
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	60.158
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
C03	3h	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	70.561
	4h	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.219
	5h	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	35.139
	6h	[illegible]	[illegible]	[illegible]	[illegible]	0.476	5.873
	7h	0.638	0.638	[illegible]	0.494	0.513	-3.742
	8h	0.611	0.614	-0.541	0.461	0.463	-0.456
mean		0.568	0.513	8.523	1.168	0.587	26.943

Satellite clock modelling contributes the most for the first few hours of satellite maneuver, where very few data are available. It improves orbit determination accuracy by more than 15% and over 70% on orbit prediction accuracy

Conclusions

- **IGS orbit and clock accuracy is limited by parameter correlations**

- **New strategy with satellite clock modelling is proposed and validated for the precise orbit determination process, especially for satellite in maneuver period**

- **With the new approach, orbit determination accuracy improved by more than 15% and orbit prediction accuracy improved by over 70%**

谢谢！

Thank you！

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