Recent Contribution to the ITRF and its Realization in Canada

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Abstract

Natural Resources Canada (NRCan) is processing data daily from a subset of at least eight Canadian automated GPS tracking stations, the Active Control Points (ACP), and from at least twenty five of the International GPS Service (IGS) stations using a modified version of JPL GIPSY-OASIS II software. NRCan contributes to IGS solutions for satellite orbit, clock corrections, earth orientation parameters (EOPs), station coordinates and more recently tropospheric delays and ionospheric grids.
In the daily estimation process, station coordinates are constrained by a subset of station positions of the current epoch in of the International Terrestrial Reference Frame (ITRF). Removing apriori constraints is required for the rigorous station coordinate and velocity estimation.
In the most recent NRCan contribution to IERS, four years of daily station coordinates and EOPs were combined. A consistent set of station coordinates, velocities and EOPs were obtained by back substituting the final station coordinates in the daily solutions. The NRCan and ITRF station coordinate and velocity solutions were compared, as well as the NRCan station velocity estimates were compared to the NUVEL1A plate motion model. Analysis and comparison between the time series of residuals are also presented.
This approach, through the Canadian Active Control System, provides a convenient globally consistent realization of ITRF in Canada.

1. Introduction

NRCan yearly contribution to IERS includes a consistent set of station coordinates, velocities and EOP estimates for the maintenance of the ITRF and EOP time series. The NRCan contribution is obtained by combining daily station coordinates and EOP estimates. The estimates are extracted from the daily NRCan GPS orbit processing performed in support of the Canadian Active Control System (CACS) and the International GPS Service (IGS). A brief description of the processing and combination strategies are given in section 2 and 3 respectively. Combination residual statistics, comparisons with the ITRF96 solution and the NUVEL1A plate motion model are given in section 4.

2. Processing Strategy

The daily processing of the GPS tracking data at NRCan requires the estimation of several parameters, which can be divided in 3 groups: station related, satellite related and EOPs. Ionospheric-free (L3) combinations of code and phase measurements every 7.5 minutes are used in the processing. Station coordinates, initial phase ambiguities, clock offsets and wet tropospheric delays are estimated at each station; state vectors, radiation pressure and clock offsets are estimated for each satellite. The estimated EOP parameters include the polar motion and UT1-UTC as well as their rates (Tétreault et al. 1996). Apriori information for a number of parameters is used to constrain the estimation process. Station coordinates and their uncertainties are provided in the current ITRF. The tropospheric delay at each station is initialized using the previous day solution. Initial state vector for each satellite is also taken from the previous day solution and is given a nominal uncertainty. Radiation pressure is initialized with a moving average of the previous 4 days. Apriori clock parameters are unconstrained subject only to the reference clock.

3. Daily Stations and EOPs Processing

The station coordinates and EOPs, along with their appropriate variance-covariance information, are extracted from the complete daily solutions and stored using the Software INdependent EXchange format (SINEX). A number of software modules developed at NRCan are used to combine the station coordinates and EOPs. The combination process can be divided into daily, weekly, annually or multi-year solutions. Unconstrained solutions are used in the combination process. This removes the small discontinuities introduced when changing ITRF realization as well as the small inconsistencies present in ITRF station positions. To avoid singularity in orientation of the unconstrained daily solutions, small orientation constraints at 1 to 10 arc-seconds are left in the "unconstrained" solutions. They prevent numerical problems while having no adverse consequence on the processing. The implicit geocenter can also affect the daily and combined solutions. In this analysis, the effect of the implicit geocenter is removed from the unconstrained daily solutions. This introduces a singularity in position. A small 1m constraint is left on the geocenter in the "unconstrained" daily solutions for the same reason as for the orientation. The unconstrained daily solutions are aligned in rotation and translation to ITRF96 of the epoch using the common stations. This removes small rotations and translations that occur when removing the apriori constraints and the geocenter effect. The daily unconstrained solutions are tested for abnormal behavior of the parameters and appropriate corrections are applied whenever required. Variations between each station solution are caused by the measurements noise, the changes in the network geometry, the processing strategy and also by the local conditions at a site.

4. Stations and EOPs Combination

The combination of station coordinates and EOPs are treated differently. The station coordinates have in general a smooth linear time evolution and, therefore, both position and velocity are estimated for each station. All the available stations are included in the combination. But, in this analysis, only the stations (Figure 1) with daily solutions spanning at least six months are used. Several of the excluded stations have only a few days of observations. With very short observation time span, velocity estimates are unreliable. The EOPs have a more complicated time evolution and therefore, their velocity is not modeled. The daily estimates are kept independent from day to day. To prevent the number of parameters from becoming unreasonably large due to the daily addition of new EOP parameters, a solution without the EOP is first estimated.

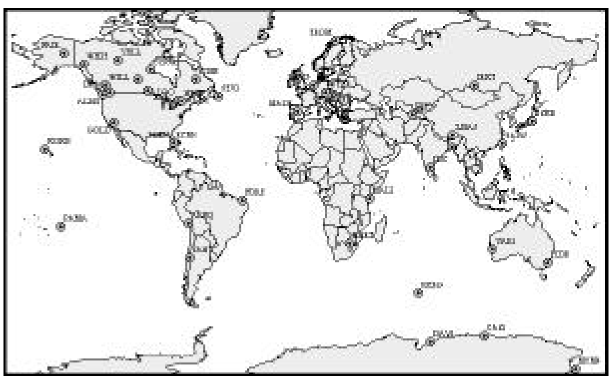

Figure 1

Stations in the NRCan contribution to ITRF.

The unconstrained daily solutions are combined into weekly solutions without velocity estimation. The weekly solutions are then combined into annual solutions with station velocity estimation. All annual solutions have been estimated at the reference epoch 1998.0. The annual solutions are then combined to form the unconstrained 1994-1997 cumulative solution. The 4-years cumulative solution is then aligned in position and velocity to ITRF96 using a 14-parameter transformation (3 rotations, 3 translations, 1 scale and their first derivative). The transformation is determined using all stations common to the solution and ITRF96 at the reference epoch. Outliers are either corrected if the problems are known (e.g.: incorrect antenna height) or rejected.

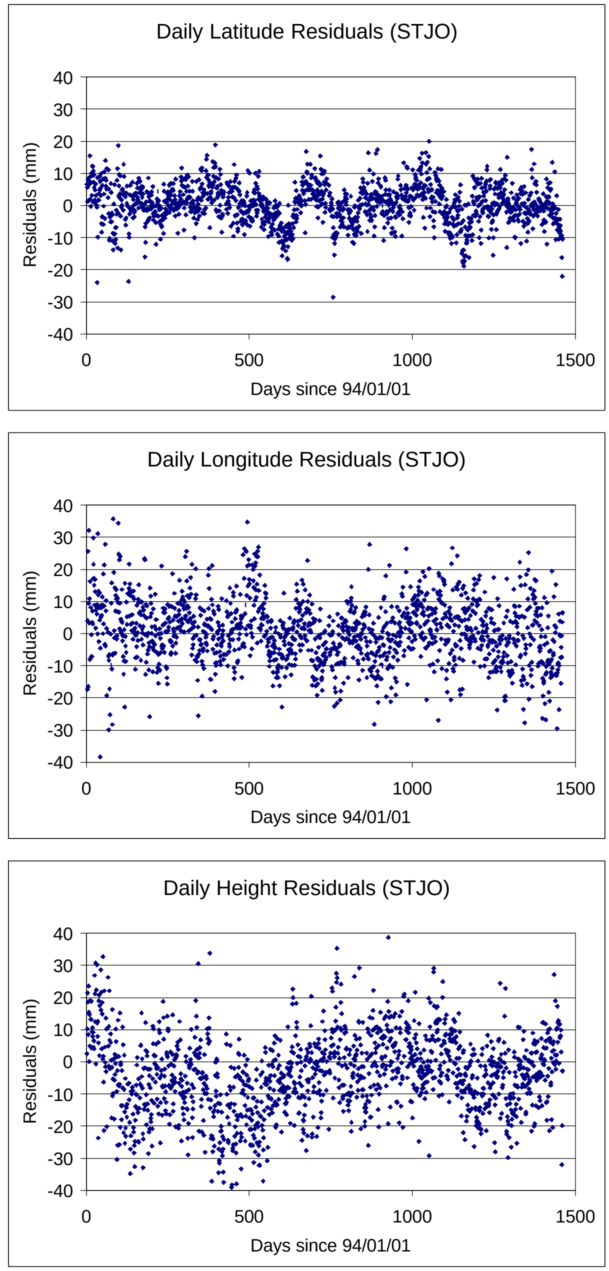

Figure 2

Daily Residuals in Latitude, Longitude and Height at station STJO.

Year	ϕ (mm)	λ (mm)	h (mm)	n
94	11.6	17.0	23.8	6956
95	8.9	12.8	20.3	8997
96	7.6	12.0	18.3	10093
97	8.7	14.4	18.7	9926
94-97	9.1	14.0	20.1	35972

Table 1

Yearly and 4-year daily station residuals R.M.S.

Stns	NRCan			NRCan-NUVEL1A		
	Residual R.M.S.			Velocity Differences		
	N mm	E mm	U mm	dVN mm/y	dVE mm/y	dVU mm/y
ALBH	5.9	8.8	11.4	4.7	7	-0.6
ALGO	5.6	8.0	13.6	-2.1	1.1	0.1
AREQ	9.8	18.3	20.8	3.2	13.9	-0.6
CAS1	7.4	10.6	15.8	-6.9	-5.9	3.6
CHUR	5.1	6.7	10.2	-1.4	2.1	12
DAV1	10.4	15.6	22.5	-9.3	-4.4	2.9
DRAO	5.7	8.5	11.3	1.6	3.3	3.3
DUBO	3.9	5.6	11.7	-1.2	-5.5	-15.6
FAIR	7.2	10.2	18.3	-2.3	2.5	0.1
FLIN	4.5	6.3	6.5	-5.9	4.5	2.1
FORT	12.0	19.2	33.0	0.3	4.2	3.4
GOLD	6.6	10.0	15.0	6.8	-2.7	0.2
HART	12.7	20.6	33.4	-0.6	-4.3	2.3
IRKT	8.1	12.4	13.6	3.7	4.1	0.4
KERG	8.2	15.0	21.9	-5.6	-4.9	6.4
KIT3	11.0	16.1	17.9	5.9	5.8	3.3
KOKB	9.4	19.3	28.1	0.8	-2.8	-1.5
KOSG	8.8	11.4	13.5	4.6	-2.6	4.3
LHAS	7.8	14.4	17.5	23.5	18.7	2.1
MADR	11.4	14.1	17.4	-1.8	1.5	3.8
MALI	9.0	23.5	25.4	-2.7	22.4	-17.6
MCM4	10.8	12.0	22.4	-1.4	8	11.3
NRC1	5.7	7.8	11.4	-0.6	2.7	8.8
PAMA	14.7	25.6	35.6	2.2	19.5	-0.2
RCM5	6.8	13.8	20.9	-1.6	-3.3	-4.7
SANT	13.5	20.2	24.9	2.6	18.8	6.9
SCHE	5.2	6.6	11.4	0	-0.3	20.5
STJO	6.2	10.2	13.2	-4.2	-1.6	4.5
TAIW	13.4	16.8	23.2	1.4	18.9	-1.4
TIDB	11.1	15.9	23.8	1.6	6	-4
TROM	9.9	10.8	19.8	3.5	-4.3	-0.6
TSKB	9.6	13.3	18.0	6.5	-19.1	-2.8
WETT	9.9	10.9	15.1	2.8	1.5	5.6
WHIT	5.5	8.4	10.8	3	0.9	-4.5
WILL	5.5	7.5	10.6	0.9	1.8	3.7
WTZR	8.7	13.4	14.8	-0.1	0.2	-2.3
YAR1	10.6	17.1	24.2	-4	3.5	-0.3
YELL	5.6	9.1	13.9	-0.7	2	0.2

Table 2

The NRCan station daily residuals R.M.S. and the velocity solution differences with respect to NUVEL1A.

The cumulative solution is then back-substituted in the daily solutions to estimate the EOPs and optionally the explicit daily geocenter. After the back-substitution, the station coordinates/velocities, EOPs and optionally the geocenter are available in a consistent reference frame. The final residuals are the differences between the unconstrained daily solutions and the cumulative solution where a 6-parameter (3 rotations and 3 translations) transformation has been applied to align each daily solution to the cumulative solution of the epoch.

Stns	NRCan – ITRF96 (1998.0)					
	Position Differences			Velocity Differences		
	dN mm	dE mm	dU mm	dVN mm/y	dVE mm/y	dVU mm/y
ALBH	2.6	-3.7	-7.6	-0.3	-1.5	-3.5
ALGO	4.1	-1.3	3.3	0.1	0.0	0.6
AREQ	2.0	3.3	0.2	0.1	-0.7	0.6
CAS1	12.7	-18.9	-5.9	0.4	-8.2	-10.3
CHUR	2.1	0.8	22.0	-0.9	1.1	13.0
DAV1	14.0	7.3	2.8	-1.3	-0.3	1.6
DRAO	3.1	0.3	0.5	0.2	0.6	2.1
DUBO	1.9	5.7	11.4	-3.4	4.4	6.3
FAIR	2.3	-5.1	-6.6	0.2	0.2	0.2
FLIN	8.4	-0.4	4.4	4.4	0.2	3.3
FORT	5.8	-7.7	-7.2	0.4	0.9	1.2
GOLD	3.1	0.6	-5.8	-0.1	-0.1	0.0
HART	7.8	5.5	-5.3	0.6	-0.2	0.8
IRKT	-0.8	-1.6	-4.8	0.5	1.8	0.5
KERG	10.9	14.9	2.7	0.1	1.7	-0.5
KIT3	3.2	-4.1	-2.8	2.1	2.0	1.4
KOKB	0.1	6.5	-1.6	0.0	-0.3	0.1
KOSG	5.2	-6.4	3.0	3.9	-1.7	3.5
LHAS	-2.6	2.2	-2.3	-0.4	-0.8	0.2
MADR	-6.4	-2.8	-4.6	-1.2	0.5	-0.1
MALI	7.6	25.0	-26.9	2.9	26.6	-20.3
MCM4	-5.2	-19.5	-23.3	-1.8	-1.5	-16.1
NRC1	1.5	0.8	17.9	-1.5	0.9	11.8
PAMA	-1.5	35.5	-27.7	1.7	15.4	-5.5
RCM5	2.2	-18.8	-15.8	-1.2	-5.2	-10.5
SANT	-1.5	7.0	3.2	-1.6	-0.3	-1.2
SCHE	4.0	1.6	10.7	-0.1	0.4	5.3
STJO	1.1	-1.4	17.0	-1.8	-1.3	5.7
TAIW	-5.5	4.2	-0.9	-0.6	4.8	4.0
TIDB	-4.7	2.0	3.8	-0.7	0.9	-0.2
TROM	-0.8	-1.0	-4.6	0.3	0.0	0.1
TSKB	-0.3	-2.8	-4.9	1.5	1.7	2.5
WETT	2.6	-2.9	5.6	2.9	1.3	7.9
WHIT	6.5	-3.6	-4.3	4.4	-2.8	-3.1
WILL	3.4	-1.8	-2.4	0.2	-0.3	-0.8
WTZR	2.8	-4.4	-0.6	0.0	0.0	0.0
YAR1	-0.2	-0.4	-2.9	-0.6	-0.1	0.3
YELL	3.4	-1.0	1.5	0.2	0.3	-0.5

Table 3

Station position and velocity differences between the NRCan solution and ITRF96 at epoch 1998.0.

Daily residual time series for station STJO, shown in Figure 2, are fairly typical. The annual and total R.M.S. of the daily residuals for all stations is summarized in Table 1. A 10% annual R.M.S. improvement can be seen between 1994 and 1996, while there is a slight degradation for 1997. The number of stations/days processed has also increased significantly between 1994 and 1996. The number of daily solutions available at each station as well as the time span of the series is summarized in Table 4.

The weekly combination residuals R.M.S. is reduced by a factor of about 2 when compared to the daily residuals which is less than the expected 2.6 (√7). This indicates potential non-random behavior of the residuals. The first 3 columns of Table 2 show the R.M.S. for 38 stations. The R.M.S varies significantly from station to station.

Stns	Time span dT y	# of daily Soln's -	Stns	Time span dT y	# of daily Soln's -
ALBH	4.0	1239	**MADR**	4.0	1376
ALGO	4.0	1444	**MALI**	1.6	346
AREQ	3.6	1049	**MCM4**	2.9	1034
CAS1	0.6	100	**NRC1**	3.7	1278
CHUR	2.7	411	**PAMA**	3.2	410
DAV1	3.1	638	**RCM5**	2.7	908
DRAO	4.0	1445	**SANT**	4.0	1209
DUBO	1.0	101	**SCHE**	1.4	191
FAIR	4.0	1399	**STJO**	4.0	1428
FLIN	1.1	128	**TAIW**	2.9	1077
FORT	4.0	1121	**TIDB**	4.0	1379
GOLD	4.0	1374	**TROM**	3.4	1016
HART	4.0	1101	**TSKB**	3.0	1076
IRKT	2.0	562	**WETT**	2.1	743
KERG	3.0	965	**WHIT**	1.4	492
KIT3	3.2	848	**WILL**	2.7	870
KOKB	4.0	1327	**WTZR**	1.9	674
KOSG	3.9	1346	**YAR1**	4.0	1259
LHAS	1.2	315	**YELL**	4.0	1451

Table 4

Daily solution time span and the number of daily solutions at each station

A spectral analysis of the residuals reveals a significant annual period at a number of stations. Height amplitude of the annual period approaching the cm level can be found at some stations; horizontal amplitude is significantly smaller. Seasonal variations at some stations could explain part of this annual signal. However, seasonal variations cannot explain the significant differences in R.M.S. between the stations. They range in height (Table 2) from 11mm to over 35mm. The R.M.S. variations are influenced by local environment and receiver performance variations between stations and to a lesser degree the processing strategy. Large station residual R.M.S. is probably not a reliable indication of a poor station coordinate and velocity estimate. Several stations with large RMS have an excellent agreement with ITRF96.

The NRCan aligned and unconstrained 4-year solution is compared to ITRF96 (1998.0). Table 3 lists the position differences (dN, dE and dU) and the velocity differences (dVN, dVE, dVU) for each station. Position and velocity differences R.M.S. are 6.8mm, 12.1mm, 15.0mm and 2.8mm/y, 6.4 mm/y, 8.3 mm/y in the north, east and vertical components, respectively. The agreement with ITRF96 in the north position and velocity component is significantly better than in the east and vertical by factors of about 2 and 3, respectively. Stations with longer historical information tend to have better agreement with ITRF96.

The NRCan 4-year solution velocity was also compared to the NUVEL1A plate motion model. The difference with NUVEL1A is contained in the last 3 columns of Table 2. Velocity differences R.M.S. for the north, east and vertical are 5.2 mm/y, 8.7 mm/y and 6.7 mm/y respectively. NUVEL1A models the horizontal rigid plates motion only; whereas, the vertical R.M.S. is with respect to an assumed zero vertical motion.

5. Conclusion

The NRCan solution covering a period from 1994 to 1997 includes 38 stations with a minimum of 6 months of data. Daily residuals R.M.S. are 9.1mm, 14.0mm and 20.1mm for the north, east and height components respectively. The R.M.S. decreases at an annual rate of about 10% between 1994 and 1996. The station coordinate and velocity solution was compared to ITRF96. Position and velocity differences R.M.S. are 6.8mm, 12.1mm, 15.0 mm; and 2.8mm/y, 6.4mm/y and 8.3 mm/y for the north, east and height components, respectively. The stations velocity solution was compared to the plate motion model NUVEL1A and the velocity differences R.M.S. are 5.2mm/y, 8.7mm/y and 6.7 mm/y for the north, east and height components, respectively.

References

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