# Assessment of NRCan Rapid and Predicted GPS Satellite Orbits

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## BIOGRAPHY

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## ABSTRACT

Natural Resources Canada (NRCan) is one of the seven International GPS Service for Geodynamics (IGS) Analysis Centers providing independent computation of GPS satellite orbits, clocks and Earth Orientation Parameters (EOP). Precise satellite orbits and clocks have been generated at NRCan using the Jet Propulsion Laboratory (JPL) GIPSY-OASIS II software since August 1992. Currently, NRCan generates satellite ephemerides and clocks at 15 minute intervals on a daily basis. NRCan final orbits and clocks are usually produced 3 days after the end of each UT day. Since January 1996, NRCan has been generating rapid orbits and clocks with a delay of less than 24 hours after the last observation. Also, predicted orbits have been generated since March 1997 and are available a few hours prior to the day to which they apply.

The NRCan rapid and predicted orbits are compared to the final IGS orbits which are produced as a combination of the final orbital solutions provided by the 7 IGS Analysis Centers [Kouba *et al.*, 1995]. Current NRCan final orbits are produced with a precision of about 10cm RMS when compared to the IGS final orbits. Results indicate that this precision decreases to approximately 15cm RMS for the rapid orbits and to 92cm RMS for the predicted orbits.

## I INTRODUCTION

Since 1992, Natural Resources Canada (NRCan) has been producing precise GPS satellite ephemerides, clock corrections and Earth Orientation Parameters (EOP) in support of the Canadian Active Control System (CACS) and as one of the seven Analysis Centers for the International GPS Service for Geodynamics (IGS). Daily solutions for all GPS satellites are computed using the observations from up to 10 CACS continuously tracking stations and the observations from other globally distributed IGS stations [Kouba and Popelar, 1994]. Presently, NRCan produces final, rapid and predicted orbits for all GPS satellites on a daily basis.

The strategy used at NRCan for computation of the rapid and predicted orbits will be reviewed and the performance of the rapid and predicted orbits will be presented.

## II NRCAN ORBIT COMPUTATION STRATEGY

NRCan production of final, rapid and predicted orbits is highly automated and requires minimal user intervention. The final and rapid orbits are produced three days and one day after the end of the last observation, respectively. The predicted orbits are produced a few hours prior the beginning of the day to which they apply. The final and the rapid orbits are computed using the GIPSY-OASIS II developed at the Jet Propulsion Laboratory (JPL). The basic strategy consists in computing a one day (24 hours) arc solution with no data overlap and with most of the apriori information obtained from the previous day solution [Tétreault *et al.*, 1995]. Undifferenced pseudo-range and carrier-phase measurements decimated at 7.5 minutes are used and assumed independent. Table 1 summarizes the list of the estimated parameters along with their apriori values.

Table 1: Estimated Parameters in NRCan final and rapid orbit solutions

| Parameter | Apriori Value |
|---|---|
| Stations (X,Y,Z) | IGS/ITRF94 (of date) |
| Pole (x,y) | previous day extrapolation |
| DUT1 | previous day extrapolation |
| LOD | previous day extrapolation |
| Trop. Zenith Delay | previous day extrapolation |
| Satellite States (X,Y,Z,dX,dY,dZ) | previous day estimate |
| Sol. Rad. Press. (GX,GZ) | previous day estimate |
| Sol. Rad. Press. (GY) | previous day estimate |
| Phase Ambiguity | pseudorange estimate |
| Tropospheric Bias | about 2.0m station dependent |
| Station Clock | point positioning |
| Satellite Clock | previous day estimate |

Satellite and station clocks are estimated at a sampling of 7.5 minutes using a white noise stochastic model. The tropospheric bias is estimated every 7.5 minutes using a random-walk process. The other parameters are estimated once per day at noon time. A selected number of station's coordinates, all satellite states and solar radiation pressure parameters are subject to significant apriori weighting.

The number of stations available 12 hours after the last observation is considerably smaller than after 72 hours. The selection of stations and the number of constrained stations used are two important differences in the processing of the rapid and the precise orbits. In order to improve the robustness of the rapid orbit, 17 stations are constrained to their ITRF values. Only 13 stations are constrained in the final orbit as recommended by IGS. A maximum of 26 globally distributed IGS and CACS stations are used in the rapid orbit solutions. The status of all the IGS stations is illustrated in the Appendix.

## II.1 NRCAN PREDICTED ORBIT COMPUTATION

Predicted orbits are generated using the BERNESE software developed at the Astronomical Institute of the University of Bern (AIUB). The predicted orbit is computed from the most recent NRCan rapid orbit. A 4-day fit is performed using this NRCan rapid orbit and the three previous days of IGS rapid orbits (IGR). The IGR orbits are daily combinations of the rapid orbital solutions of the 8 IGS Analysis Center (see Table 2) as produced by the IGS Analysis Coordinator. The three IGR and the NRCan rapid ephemerides are used in an orbit improvement program as pseudo-observations and are improved by estimating six Keplerian elements and nine radiation pressure parameters for each satellite [Beutler *et al.*, 1994]. The solution is then extrapolated over 4 days to generate the predicted orbit informations a few hours prior the beginning of the day to which they apply making the satellite ephemerides available for real time application [Kouba and Mireault, 1997].

Table 2: IGS Analysis Centers

| Center | Description |
|---|---|
| cod | Center for Orbit Determination in Europe (CODE) |
| emr | Natural Resources Canada (NRCan) |
| esa | European Space Agency (ESA) European Space Operations Center (ESOC) |
| gfz | GeoforschungsZentrum (GFZ) |
| jpl | Jet Propulsion Laboratory |
| ngs | National Oceanic and Atmospheric Administration (NOAA) |
| sio | Scripps Institution of Oceanography |
| usn[1] | United States Naval Observatory (USNO) |

(1) Contribution to the IGS rapid solutions only.

## III PERFORMANCE EVALUATION OF NRCAN RAPID AND PREDICTED ORBITS

The IGS final orbits were used as a reference in the evaluation of the precision of the NRCan rapid and predicted orbits. The seven Analysis Centers contributing to the IGS solutions are listed in Table 2 [Kouba *et al.*, 1995]. Currently, the IGS final orbits and clocks are approaching the 5cm and 0.5nsec precision level [Kouba *et al*., 1996]. Results spanning from GPS week 882, December 1, 1996 for the rapid and from GPS week 894, February 23, 1997 for the predicted were analyzed. The second day predictions (24-48 hours) were chosen for the analysis. Figure 1 shows daily RMS average of the differences between the NRCan rapid and IGS final ephemerides after a 7-parameter Helmert transformations. The horizontal line shows an overall median RMS value of 13 cm. The three peaks appearing in weeks 886, 887 and 897 are mainly due to modeling problems on PRN14, 16 and 19, also observed in the IGS rapid combinations.

Figure 1: Differences between NRCan rapid and IGS final orbits for weeks 882 to 903

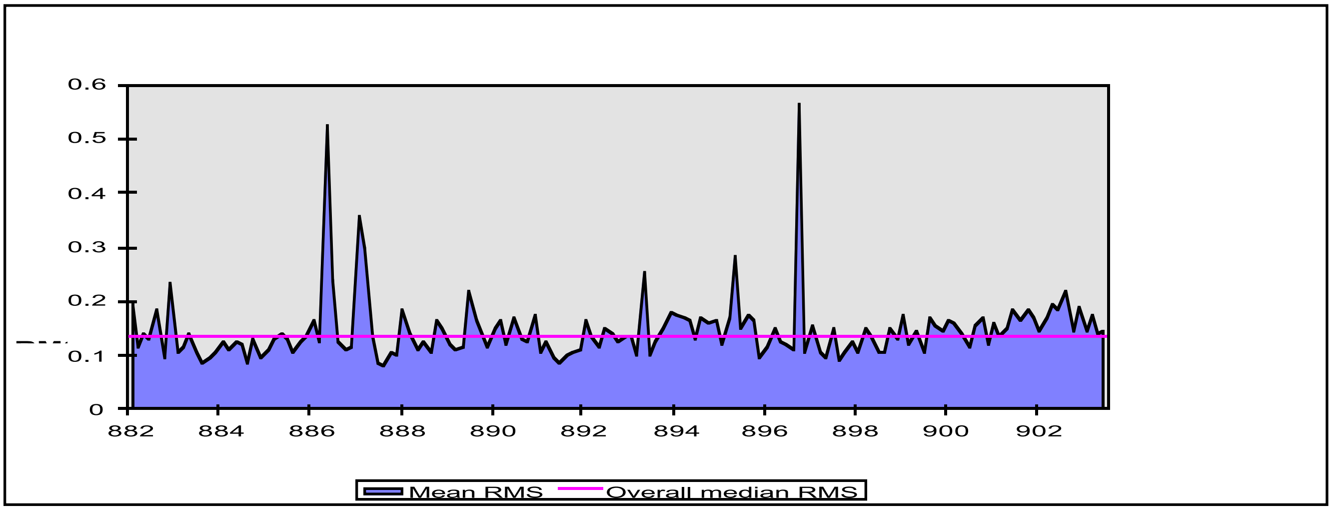
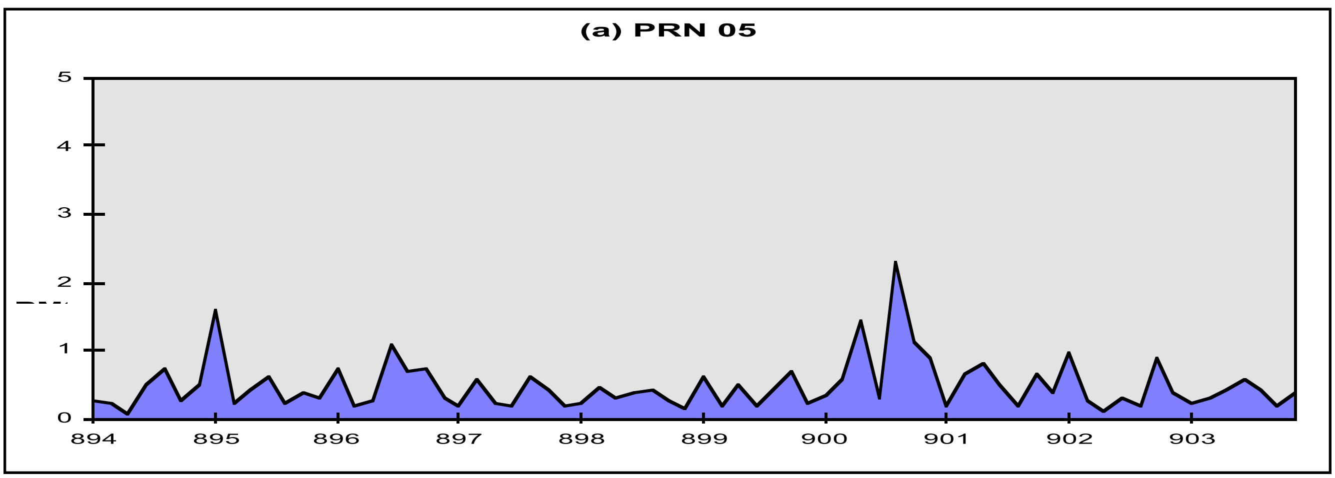



Figure 2: Differences between NRCan predicted and IGS final orbits for PRN05 and PRN06 (weeks 894-903)



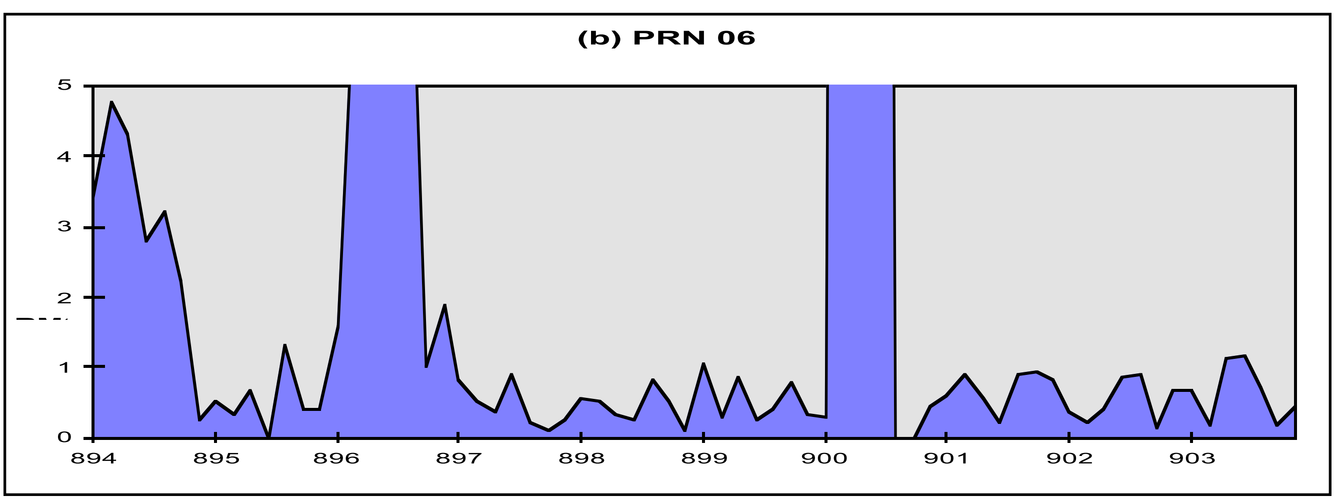



Figure 2 shows the daily RMS for two satellites (PRN05-06) representing typical results encountered in the prediction process. Figure 2a shows that the daily RMS for PRN05 are below the meter most of the time. Figure 2b shows the mean RMS obtained at a problematic satellite (PRN06). The high RMS shown on GPS week 900 is due to a manoeuver which occurred on GPS week 900 day 1 (NANU 041-97097). The two other peaks in week 894 and week 896 are due to modeling problems. NRCan has been experiencing similar problems with satellites PRN14, 16, 18, 19, 29 and 30. A mean RMS of about 92cm was computed over the studied period using daily satellites RMS after excluding completely problematic satellites (PRN14, 16, 18, 19 and 30). With better control over the problematic satellites and maneouvered satellites, the NRCan predicted orbits should be closer to an overall median value of 53cm.

Table 3 lists the means and standard deviations of the daily 7-Helmert parameter transformations with respect to the IGS final combination for the period covering GPS week 894 to GPS week 903. These differences are due to small errors and biases in the orbit solutions and the chosen ITRF coordinates/velocities [Kouba and Mireault, 1997].

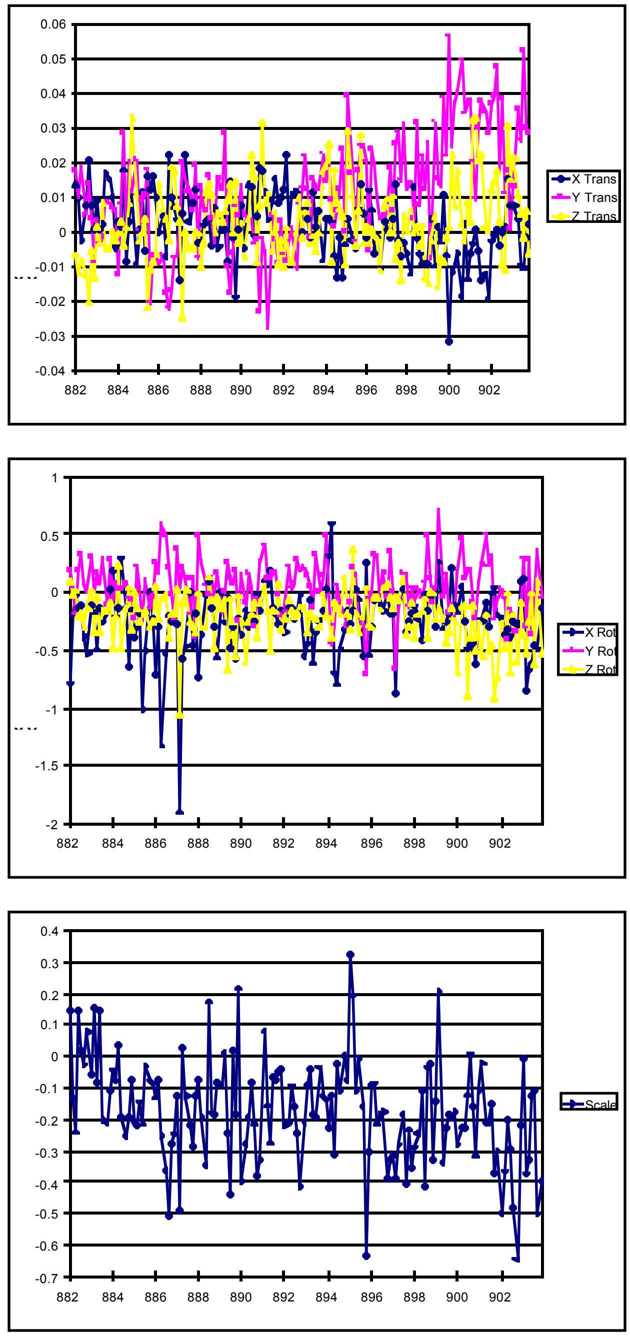
Table 3: 7-Parameter Helmert transformations with respect to IGS Final Orbit.

| | DX | DY | DZ | RX | RY | RZ | SCL |
|---|---|---|---|---|---|---|---|
| **Rapid** | | | | | | | |
| mean | -.00 | .02 | .01 | -.22 | -.00 | -.24 | -.21 |
| std | .01 | .01 | .01 | .27 | .26 | .25 | .17 |
| **Prediction** | | | | | | | |
| mean | .01 | -.01 | .01 | -.16 | .60 | -.23 | -.22 |
| std | .02 | .01 | .04 | .98 | 1.66 | 4.73 | .45 |

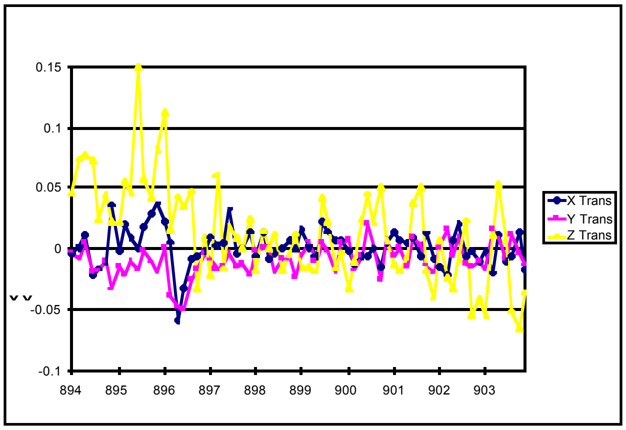
DX, DY, DZ : X,Y,Z translations in metres (m)
RX RY RZ : X, Y,Z rotations in milliarc-seconds (mas)
SCL : scale in parts-per-billion (ppb)

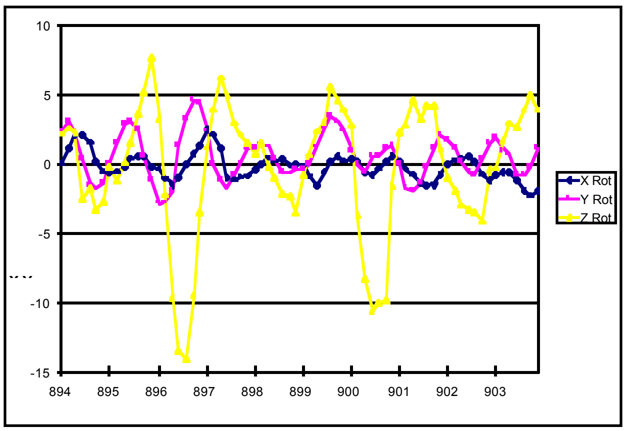
Figure 3 shows the daily variations in the 7-parameter Helmert transformations between the rapid orbits and the IGS final orbits. The X-rotation component was noisier on week 886 day 2 and week 887 day 1. Only 18 stations were used on these two days and modeling problems at PRN10, 14 and 16 were experienced. The three translation components are noisier since week 900 and are currently under investigations. Figure 4 shows the daily variations in the 7-parameter Helmert transformations between the predicted orbit and the IGS final orbits. The translation parameters are more consistent since week 897. The Z rotation series have the largest amplitude of all rotation parameters. This is probably related to UT1-UTC extrapolation.

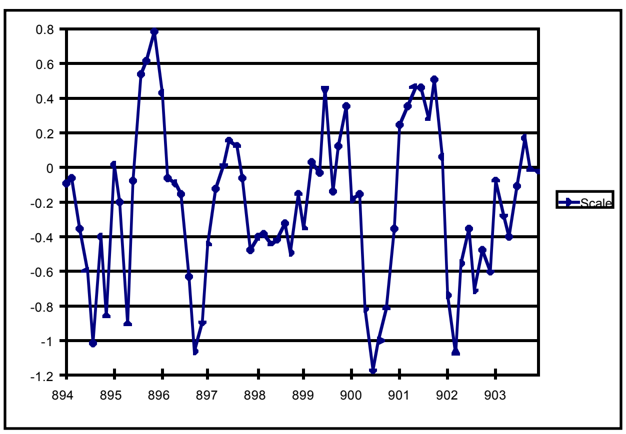
Figures 3: Daily 7-parameter Helmert transformations of NRCan rapid orbit with respect to IGS final orbit



Figures 4 : Daily 7-parameter Helmert transformations for NRCan predicted orbit with respect to IGS final orbit




## IV CONCLUSION

Since January 1992, NRCan has been producing final GPS satellite orbits. A growing demand for faster delivery time of orbital informations for real-time applications made NRCan implement two new orbit products. Rapid orbits have been produced since January 1, 1996 and predicted orbits have been generated since early March, 1997. Results indicate that a mean RMS of 15cm with a median of 13cm is achievable when rapid orbits are used. A mean RMS of 92cm with a median of 53cm is obtained with the predicted orbits after excluding completely problematic satellites. Future work will be directed towards improving satellite modeling problems in both rapid and predicted orbits and efficiently dealing with maneouvered satellites in the predicted orbits.

## ACKNOWLEDGMENTS

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