# DORIS as a potential part of a Global Geodetic Observing System

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**Abstract**

We have processed all available DORIS data from all available satellites, except JASON over the past 10 years (from January 1993 to April 2003). Weekly solutions have been produced for stations positions coordinates, geocenter motion and scale factor stability. We present here the current accuracy presently achievable for all types of potential geodetic products. Typically weekly stations positions can be derived with a repeatability of 1 cm using data from 5 satellites simultaneously, showing the improvement in precision that has been gained recently using the additional new DORIS satellites. As an example, we show how such new results can detect displacement from large magnitude earthquake, such as the 2003 Denali fault earthquake in Alaska. Displacements of –5 cm in latitude and +2 cm in longitude were easily detected using the DORIS data (confirmed by recent GPS determination). The terrestrial reference frame was also well be monitored with DORIS as well as tropospheric corrections for atmospheric studies. Finally, we discuss here the possible advantages and weaknesses of the DORIS system as additional geodetic tool, in conjunction with the already existing GPS, VLBI and SLR services, to participate in a Global Geodetic Observing System.

**Keywords** Geodesy, DORIS, reference frame, Denali fault, Alaska Earthquake troposphere.

## Introduction

For more than 10 years, DORIS has been used successfully for precise orbit determination (Jayles, 2002) but also for geodetic and geophysical applications, such as stations velocities determinations (Cazenave, 1994, Cretaux, 1998, Soudarin, 1999) or monitoring of the geocenter motion (Bouille, 2000). More recently, 3 new DORIS satellites have launched: JASON on December 7, 2001; ENVISAT on March 1, 2002 and SPOT-5 on May 4, 2002. This doubled the number of available DORIS satellites, as SPOT-2, SPOT-4 and TOPEX/POSEIDON still continue to operate. Further more, JASON and SPOT-5 are equipped with a new type of DORIS allowing a better signal-to-noise-ratio and allowing them to observe 2 ground stations simultaneously using its newly developed dual-channel receiver. The goal of this paper is to investigate how these additional number of more precise DORIS data improve the current geodetic results. We have then investigated how useful could DORIS be as a possible part of more general Global Geodetic Observing System that is currently being established using the already existing geodetic services, such as the IGS for GPS, the IVS for VLBI and the ILRS for laser ranging.

**DORIS weekly solutions**

We have processed all available DORIS data at CDDIS, from January 1993 to April 2003 using the Gipsy/Oasis II (GOA) software developed at the Jet Propulsion Laboratory. We have processed these 10 years of data on a day-by-day basis using a multi-satellite approach (Willis, 2003) in a free-network adjustment (Blewitt, 1992; Heflin, 1992). Such an approach makes full use of all parameters in common to all satellites data, such as Earth orientation parameters, as well as tropospheric delays. It makes it also easy to provide the coordinates using a mathematically rigorous procedure in a refined terrestrial reference frame (eg from ITRF-96 to ITRF2000) without having to reprocess the original DORIS data themselves. For a reason that would be too long to explain in this paper, we have chosen not to use the DORIS/JASON data, due to presently mismodeled satellite clock acceleration effect due to the crossing of the South Atlantic Anomaly (Willis, 2003).

As the total number of available DORIS data per day is rather small (a few thousands data per satellite depending on its altitude), we have combined these individual daily results into weekly solutions using their respective full variance-covariance matrices. By projecting and transforming (Sillard 2001) these weekly solutions into a specific reference frame, we can then deduct products of geodetic interest such as stations coordinates, Earth rotation parameters, geocenter offsets. Instead of transforming directly our results into ITRF2000, we have transformed into our internal solution that has been previously aligned on ITRF2000 (transformation parameters and their time derivatives). By doing this, we ensure that the reference system is still the International Terrestrial Reference System (ITRS) but we can avoid some of the (small) inaccuracies that were inherent to the latest ITRF2000 DORIS coordinates. For example, several errors were found in the last ITRF2000 coordinates, such as a slow antenna fall in Sainte-Helene, or previously undetected stations displacements as recently presented by Willis (2003a).

By comparing each individual weekly solution to our nominal reference for positions velocities expressed at the epoch of the measurement, we can provide for all stations a global RMS that represents the precision of our weekly solutions (weekly repeatability, taken into account the stations velocity effect). Figure 1 to 3 displays the results obtained in latitude, longitude and altitude. It can first be observed that the results in latitude and longitude are better than the results in longitude. This is due to the helio-synchronicity of the SPOT satellites (tracks are almost North-South for equatorial stations). The satellites tracks being almost polar, the longitude of the station is more much weaker observed. It can also be seen that the precision for all components clearly depends on the number of available DORIS satellites. While weekly positioning could previously be obtained at 3 cm for 2 satellites and 2 cm with 3 satellites, the most recent results show typically 1 to 1.5 cm precision with 5 satellites. We have also verified that the spikes on those curves can be linked with weeks for which a large number of data were lost (typically several days from one or more satellites).

**An example of an Earthquake displacement detected with DORIS**

In order to show the potential geodetic and geophysical interests of these weekly DORIS solutions, we have taken the example of the DORIS Fairbanks station for which a large displacement has happened on November 3, 2002 as a large magnitude earthquake (M=7.9) had happened related to the Denali Fault in Alaska (Ebehart, 2003; Jones, 2003). Figure 4 to 6 display the DORIS positioning results for Fairbanks after removing trend (position and velocity of the reference). While no displacement can be seen on the vertical component, a clear –5 cm (resp +2 cm) discontinuity can be seen on the latitude (resp longitude) component. It can also be seen that the latest DORIS results (using 5 satellites) show a smaller dispersion.

As Fairbanks is a GPS, DORIS (and VLBI) collocation, we were able to compare our DORIS estimation of the coseismic displacement with some GPS results. Table 1 shows that our results are very compatible with the GPS results available on Web,

| | latitude offset (in mm) | longitude offset (in mm) | altitude offset (in mm) |
|---|---|---|---|
| GPS (Bock, 2003) | -53.5 ± 4 | +15.1 ± 4 | 0 |
| DORIS | -50 | +20 | 0 |

Table 1: DORIS and GPS detected post-seismic displacement at Fairbanks after the November 3, 2002 Denali Fault Earthquake.

**Geocenter and scale factor stability**

These weekly comparisons with the reference solution also provide valuable information on the Terrestrial Reference Frame realized by DORIS. Figure 7 to 9 shows the results obtained for the transformation parameters in translation. It can be seen that a clear trend is visible in TX translation (2 mm/year). Table 2 presents the estimated secular drifts towards ITRF2000 and compares them with recently derived similar results using GPS data on almost the same period of time (Dong, 2003).

| | X rate (in mm/yr) | Y rate (in mm/yr) | Z rate (in mm/yr) |
|---|---|---|---|
| GPS (Dong, 2003) | -2.9 ± 0.3 | 0.1 ± 0.1 | 6.1 ± 0.2 |
| DORIS | -1.85 ± 0.03 | -0.58 ± 0.03 | 1.98 ± 0.04 |

Table 2: Geocenter secular drifts vs ITRF2000 reference estimated from GPS and DORIS data.

In our estimation of the drift, we have disregarded the period mid 1998.34 to 1999.02 for reasons explained above. It can be seen that the standard deviation are much better for DORIS compared to GPS. In our opinion, this is due to the difference in geocenter accuracy between the early GPS results from 1993 to 1997 to the more recent solutions (especially for the Z-component). The GPS and DORIS results are compatible and could show a systematic effect in the ITRF2000 that is mainly based on SLR results and for which continuity conditions were imposed (Altamimi, 2003).

Figure 10 show the weekly scale factor obtained over the past 10 years. It can be seen that there is a very clear bias of –2.68 ppb (equivalent to –17.1 mm for all stations heights). Such a bias is currently being investigated in the software and in the preprocessing adopted by CNES (ionospheric, electronic bias or time scale definition). However, the discrepancy towards this mean value is quite small (typically 1.3 ppb for a weekly solution with 2 satellites and 0.6 ppb for recent solutions with 5 satellites). Furthermore, if we look at the long-term stability, the securlar scale drift estimated towards ITRF2000 is 0.06 ppb/year ± 0.004 ppb/year. It can be noted that the DORIS scale is extremely stable in time, especially there is no long-term drift. In our opinion, this could come from an appropriate selectionof the DORIS frequencies (2 GHz and 400 MHz, well apart from each other) and from the fact that there is only 2 types of DORIS antennas (Starec and Alcatel), which create a more stable environment than GPS.

**Tropospheric delay estimated with DORIS**

It must be noted that DORIS also allow precise estimation of the tropospheric correction. Fig. 11 displays results obtained at the DORIS Greenbelt station, comparing our DORIS results (obtained per pass) and the GPS results (kindly provided by the IGS). It can be seen that both estimation are in very good agreement. Additional studies on a significant number of GPS/DORIS collocations have shown that 3 mm precision can easily be achieved for tropospheric zenith delays from DORIS data using 5 satellites (Willis, 2000 and 2003). On the other hand, the DORIS data delivery (typically 1 month or more delay) makes it less attractive for meteorological studies, which are more real-time oriented.

However, for climatic-related studies (long-term variations of global temperature and humidity), DORIS could play some role, at least for external calibration with GPS.

**Potential interests of DORIS as a part of a Global Observing System**

We have seen that some of the geodetic products derived from the DORIS data presently possess an excellent accuracy and time stability when using the 5 available DORIS satellites simultaneously. It must be noted that the DORIS network is also a key point for an observing techniques. Fig 12 shows the DORIS network from 1993-2003. Out of the total 68 stations, 39 stations have observed 10 years or more, 11 stations have observed between 5 and 10 years and only 18 stations have observed less than 5 years usually in campaigns. The equipment itself is very stable: there are only 2 types of antennas and the instruments changes are very rare (Tavernier, 2003).

**Conclusions**

We have shown that the recent 5-satellites solutions, using a multi-satellite analysis, provide better geodetic results. Weekly stations positioning at 1 cm level are now obtainable from the DORIS data and allow easy detection of large Earthquake displacement, such as the Alaska 2002, November 3 Denali fault Earthquake near the DORIS Fairbanks station. The DORIS technique can also provide valuable information for Terrestrial Reference Frame maintenance and especially long-term monitoring. In particular, the DORIS-derived scale has been particularly stable over the past 10 years showing an 0.6 ppb stability for most recent solutions. There is no secular scale drift towards ITRF2000 (less than 0.06 ppb/year). DORIS, as an individual technique has several advantages (simplicity and robustness of the technique, long-term observations on a large number of tracking stations). The international community has made several important step in the last 2 years in order to create a truly International DORIS Service, that could in the future act, as IGS, IVS and ILRS as part of a Global Geodetic Observing System.

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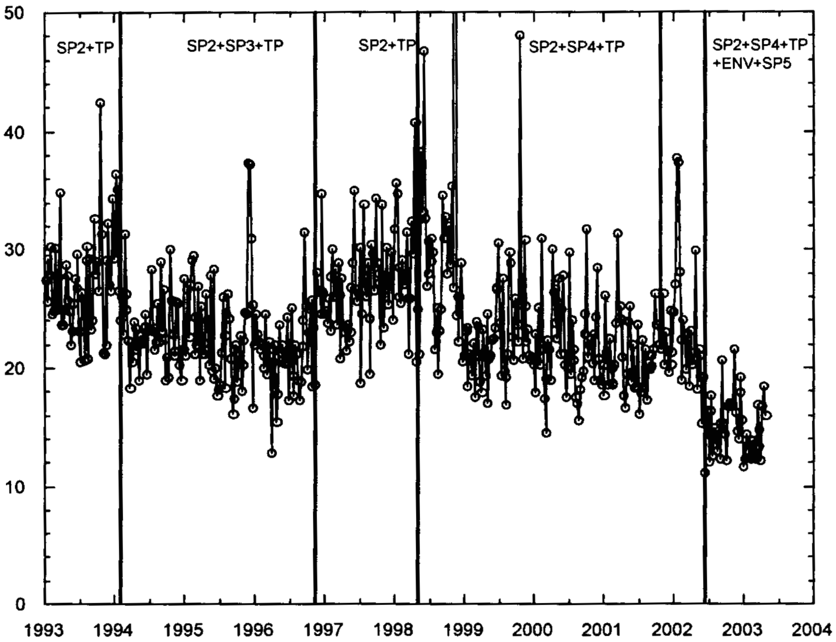
# List of figures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SP2+TP
SP2+SP4+TP
SP2+SP4+TP
+ENV+SP5
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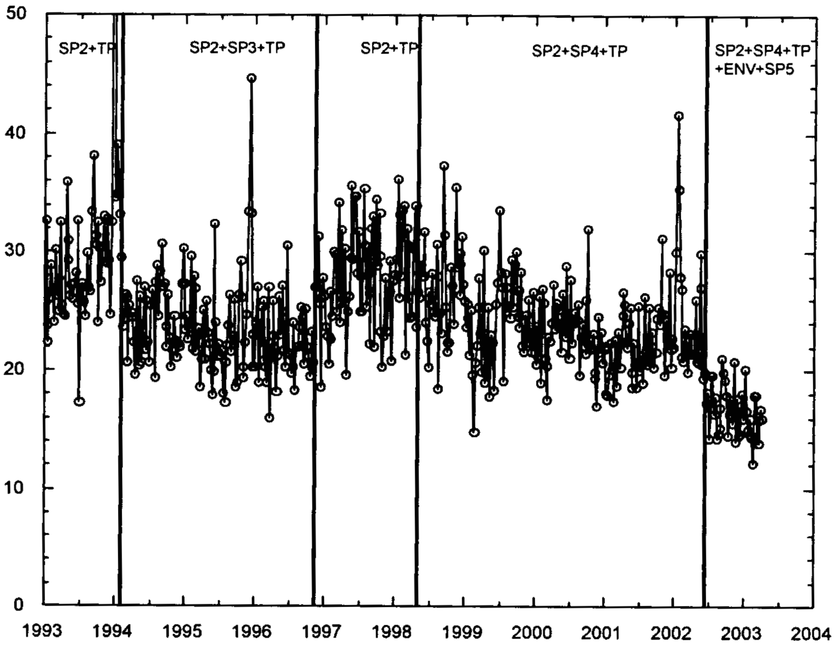
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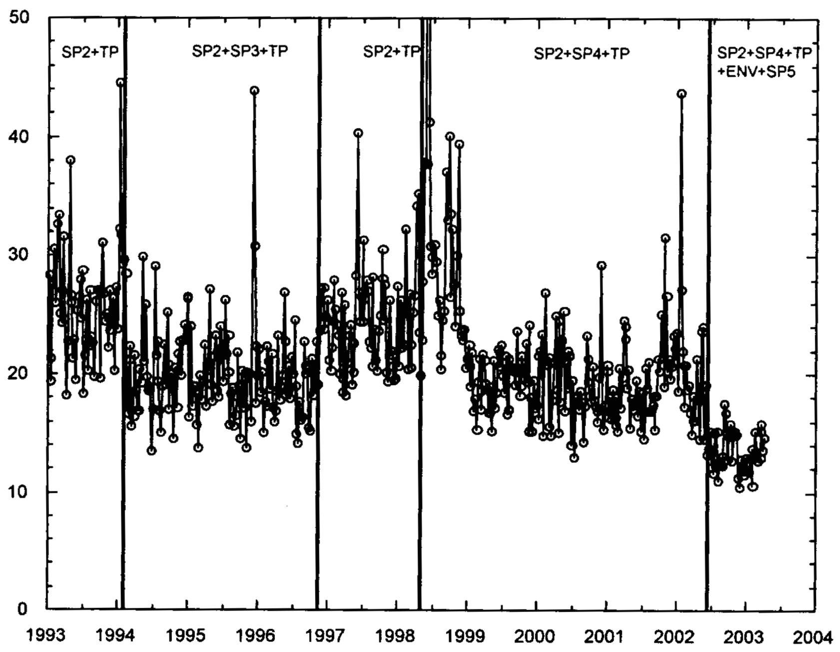
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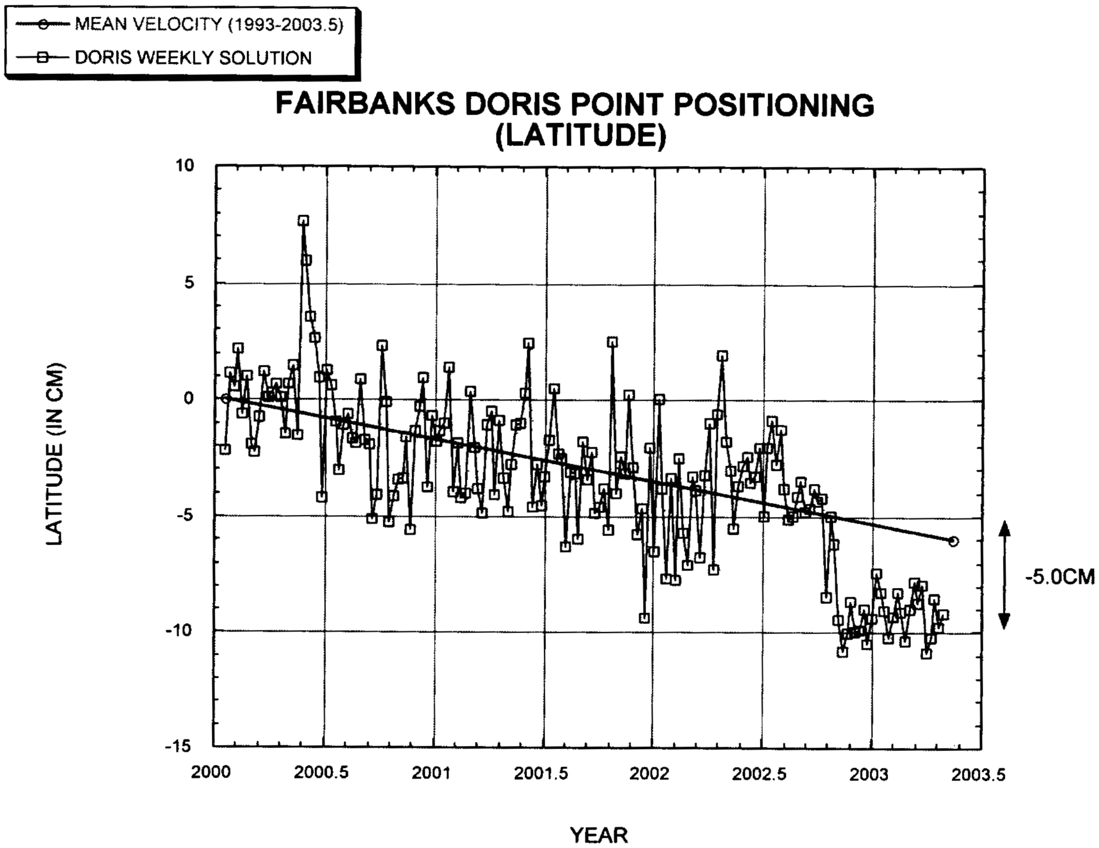

MEAN VELOCITY (1993-2003.5)
DORIS WEEKLY SOLUTION
FAIRBANKS DORIS POINT POSITIONING
(LATITUDE)
LATITUDE (IN CM)
10
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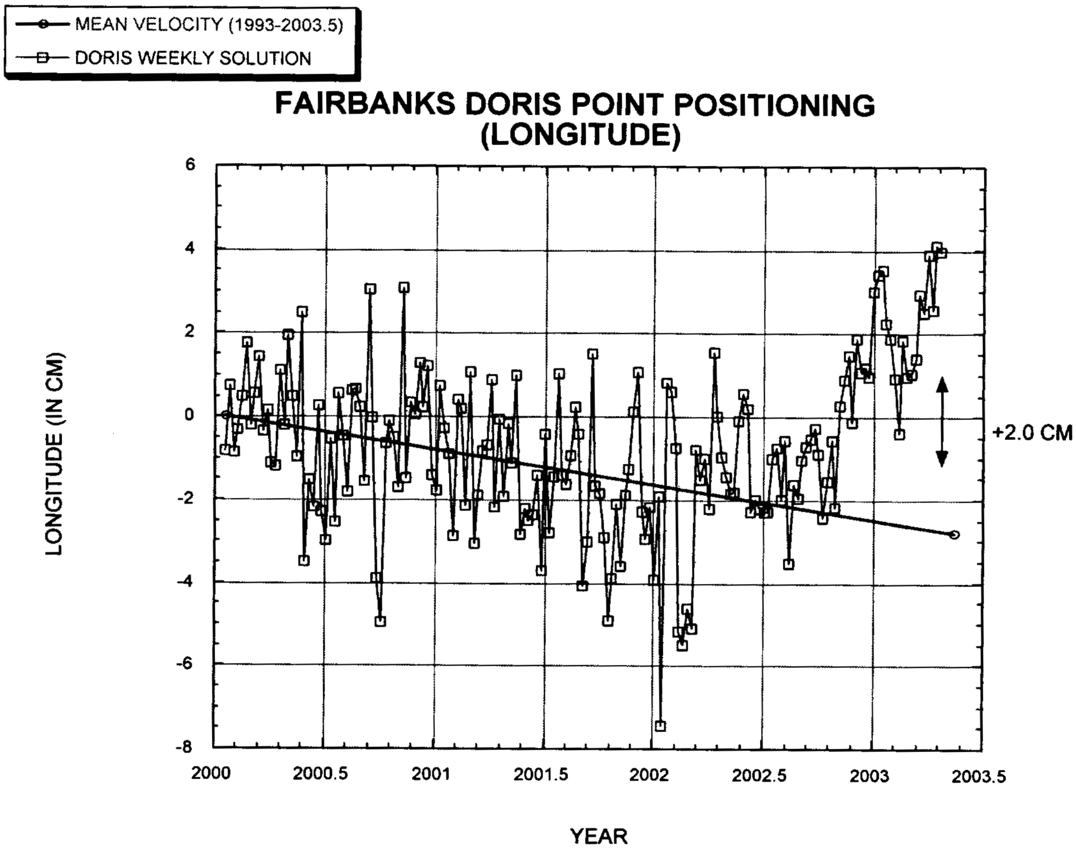
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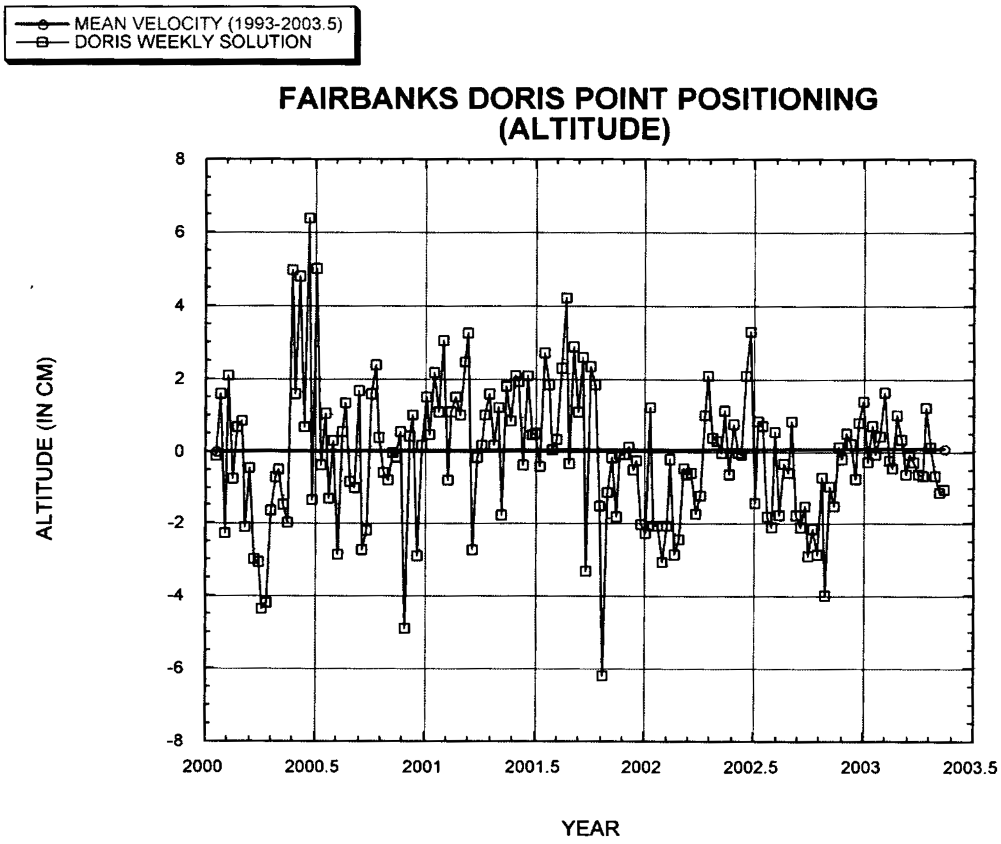
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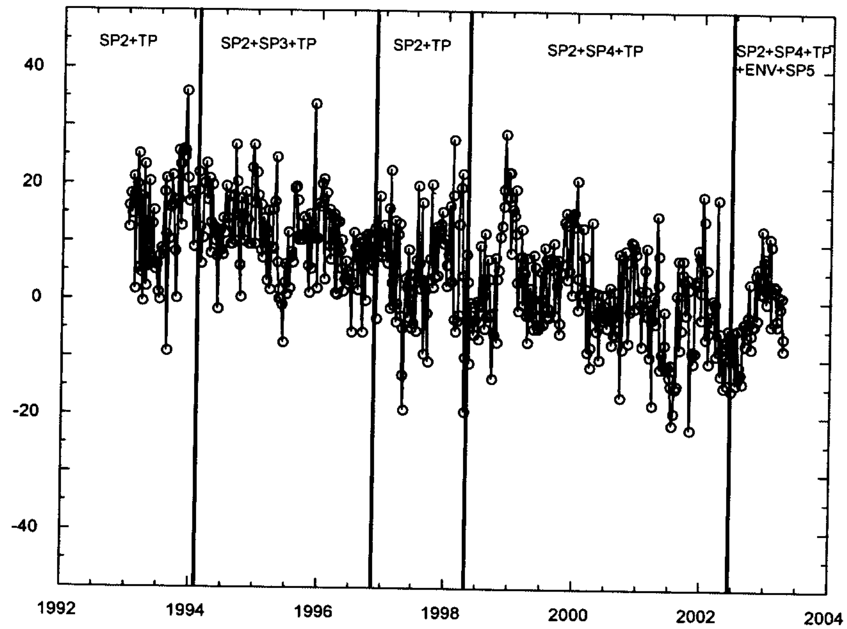

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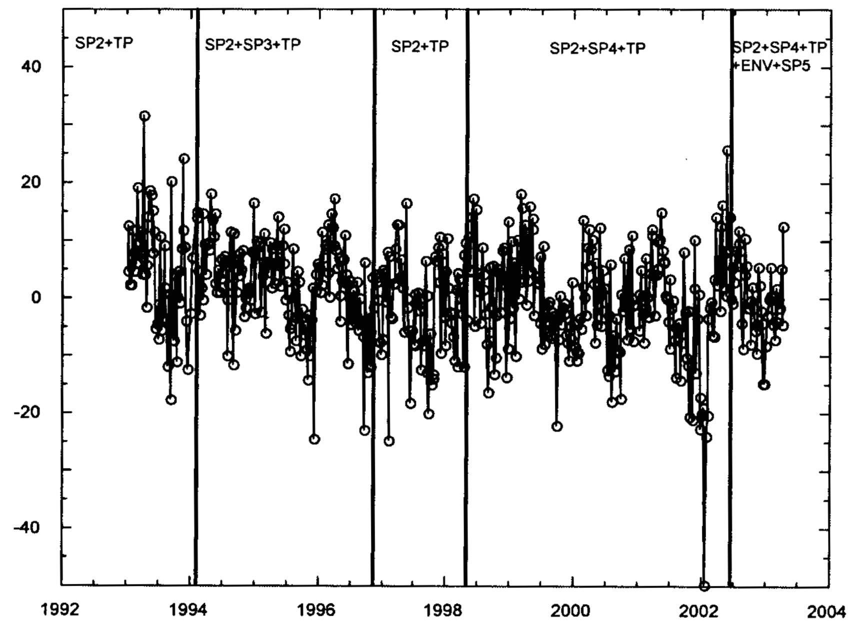

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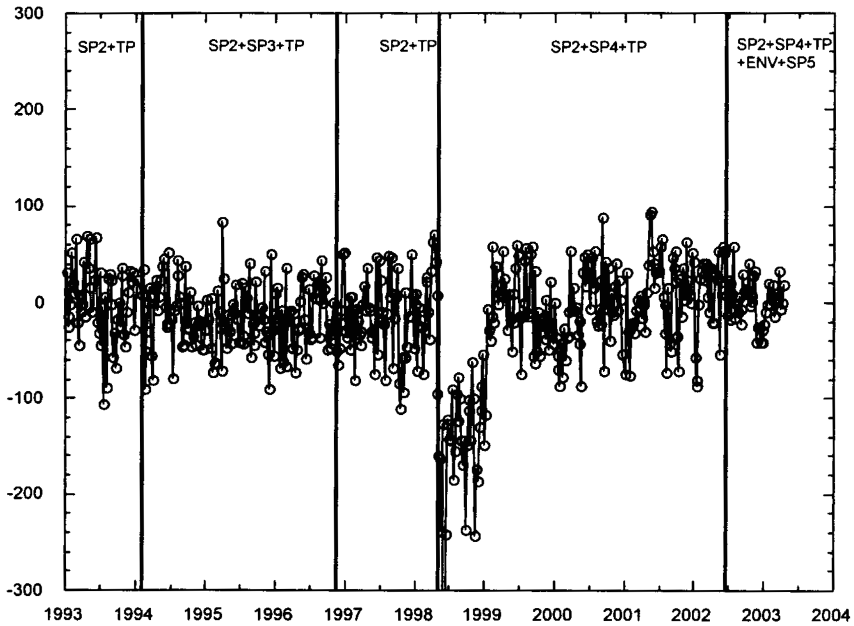

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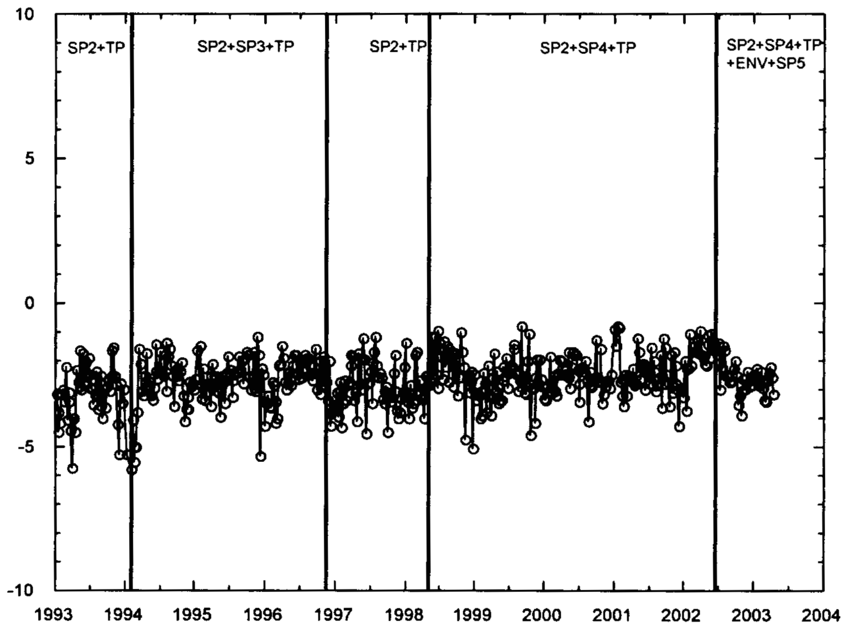

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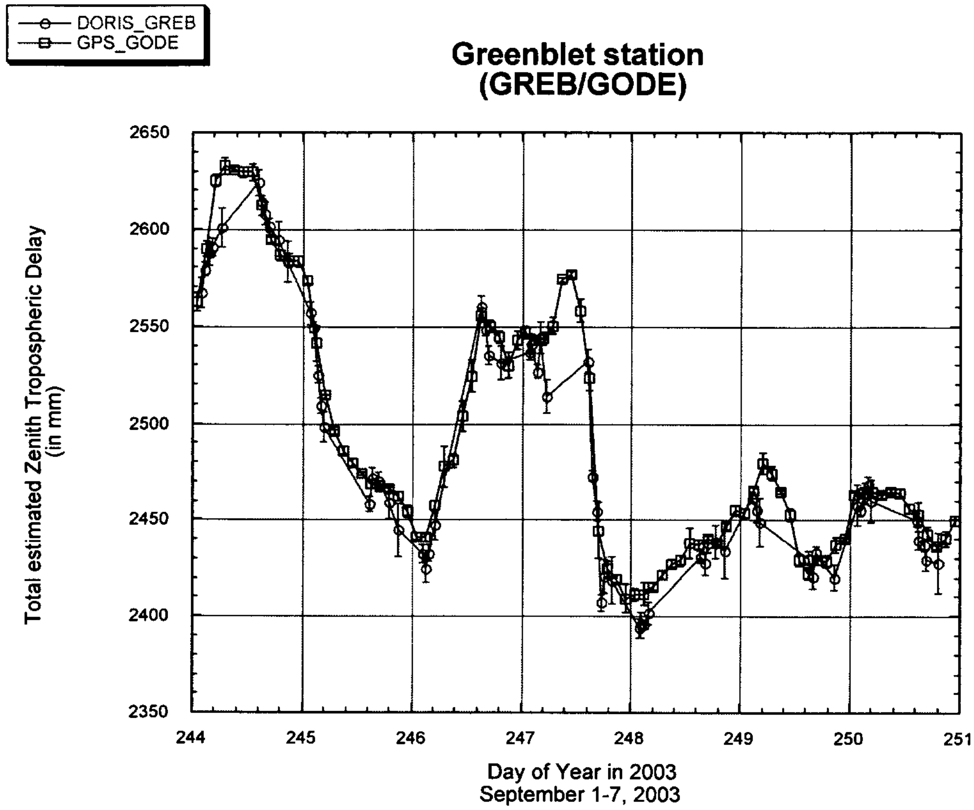
+ENV+SP5



DORIS_GREB
GPS_GODE
Greenblet station
(GREB/GODE)
Total estimated Zenith Tropospheric Delay
(in mm)
2650
2600
2550
2500
2450
2400
2350
244
245
246
247
248
249
250
251
Day of Year in 2003
September 1-7, 2003