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Regularization of Nutation Time Series at GSFC

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Abstract

VLBI is unique in its ability to measure all five Earth orientation parameters. In this paper we focus on the two nutation parameters which characterize the orientation of the Earth's rotation axis in space. We look at the periodicities and the spectral characteristics of these parameters for both R1 and R4 sessions independently. The study of the most significant periodic signals for periods shorter than 600 days is common for these four time series (period of 450 days), and the type of noise determined by the Allan variance is a white noise for the four series. To investigate methods of regularizing the series, we look at a Singular Spectrum Analysis-derived method and at the Kalman filter. The two methods adequately reproduce the tendency of the nutation time series, but the resulting series are noisier using the Singular Spectrum Analysis-derived method.

1. Introduction

We consider the nutation longitude and obliquity time series ($d\psi$,$d\varepsilon$) obtained from the GSFC solution 2011a. These series cover the period 1979 to 2011. In this paper we only use data after 1993 which is of better quality than the earlier data. In Section 2, we discuss periodicities and spectral characteristics of the time series considered. In Section 3, we apply two methods to regularize these series: the Kalman filter and a Singular Spectrum Analysis (SSA)-derived method.

2. Periodicities and Spectral Characteristics of the GSFC 2011a Nutation Time Series

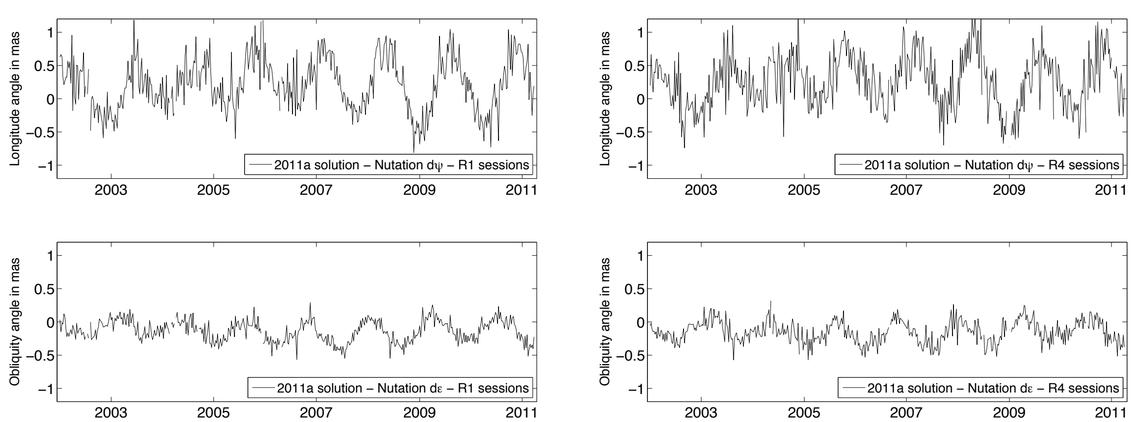

Figure 1. Nutation time series obtained from the solution GSFC 2011a. The points corresponding to the R1 sessions are plotted on the left, R4 sessions on the right.

To study the spectral characteristics of these time series, we decided to focus on two subsets: one obtained from R1 sessions and the other from R4 sessions (see Figure 1). These time series have a regular data span of one week between observations, making them easier to analyze with common statistical tools such as the Allan variance.

2.1. Periodicities

To analyze our time series of nutation parameters, we first determined the periodic signals for periods shorter than 600 days. Figure 2 shows two sets of periodograms for each time series. The left plot shows that the four time series have a common periodicity of 450 days. The four plots on the right show the periodograms for the same four time series but with the major periodic signal 450 days previously determined removed. Different periods are visible for each time series independently: 510 days, 180 days, and 385 days are examples of the most significant of them.

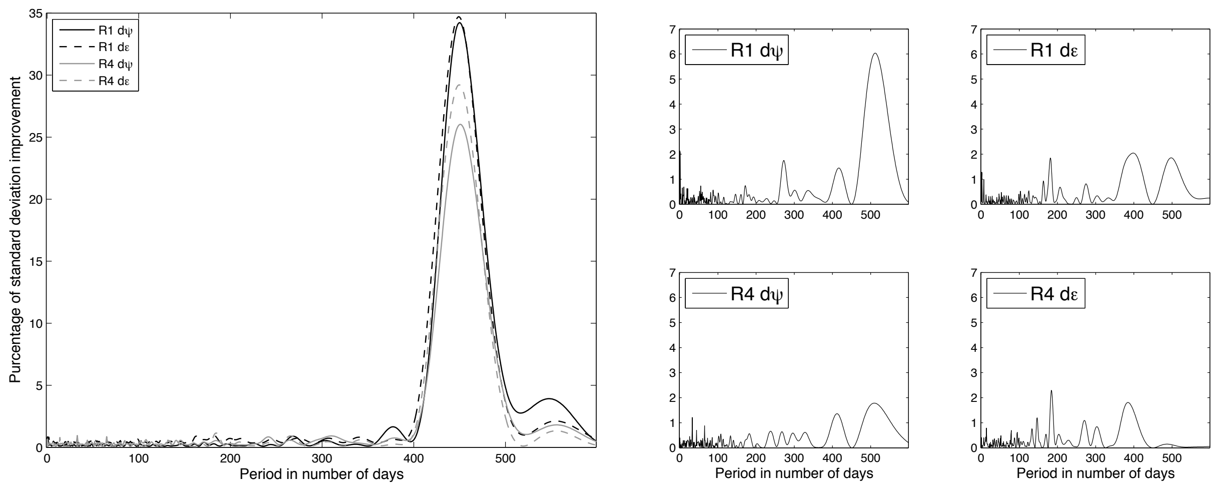

Figure 2. Periodograms. Left: initial time series. Right: time series with the major periodic signal removed.

2.2. Type and Level of Noise

The Allan variance is used here to determine the type and level of noise. In Figure 3, the plots show the Allan curves and their slopes. These slopes indicate the type of noise of the time series: -1 for white noise, between -0.5 and $+0.5$ for flicker noise, and $+1$ for random walk. On the left plot of Figure 3, the Allan variances are given for the initial time series. The peaks of the curves are indicators of periodic signals which need to be removed before giving conclusive results on noise. Once we remove six of the major periodic signals, the dominant noise in the time series is determined as white noise (slope of the curve equal to -1).

When comparing R1 and R4 determinations of the nutation parameters, we notice that the R4 sessions series have a higher level of noise than the R1 sessions. When looking at the Allan standard deviations at $\tau = 7$ days, the differences between the R4 series and the R1 series are 0.06 milliarcseconds for $d\psi$ and 0.02 milliarcseconds for $d\varepsilon$.

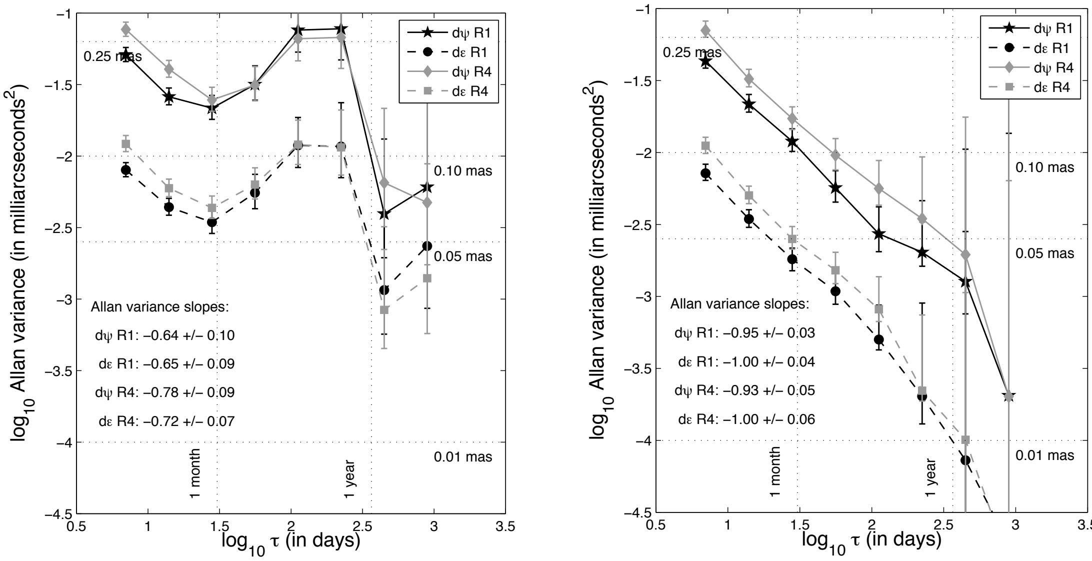

Figure 3. Allan variance plots. Left: initial time series. Right: time series with six major periodic signals removed.

3. Regularization of Nutation Time Series

The histograms in Figure 4 give the number of days between observations for two intervals of observation: the long period 1979–2011 containing the earliest VLBI observations with a mean of 2.45 days and a maximum value of 251 days between two observations, and the period 1991–2011 with a mean of 2.25 days and a maximum value of 11 days between two observations.

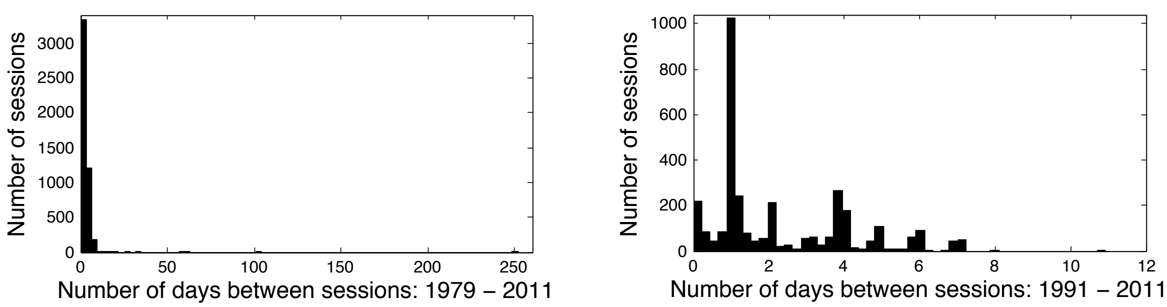

Figure 4. Histograms giving the number of days between two consecutive observations, considering the interval 1979–2011 (left) and considering the interval 1991–2011 (right).

As the goal of this study is to develop a tool which can regularize non-regular nutation time series into daily time series, we investigated two methods: the Kalman filter, which is used at Goddard, and a method using the SSA which interpolates where data is missing.

3.1. Kalman Filter

At GSFC, John Gipson [1] developed a FORTRAN routine, *nutkal.f*. This routine uses the Kalman filter to regularize nutation time series from the output of a *Solve* run. We applied this filter routine to our 2011a solution and obtained a daily determination of the nutation time series, plotted in Figure 5.

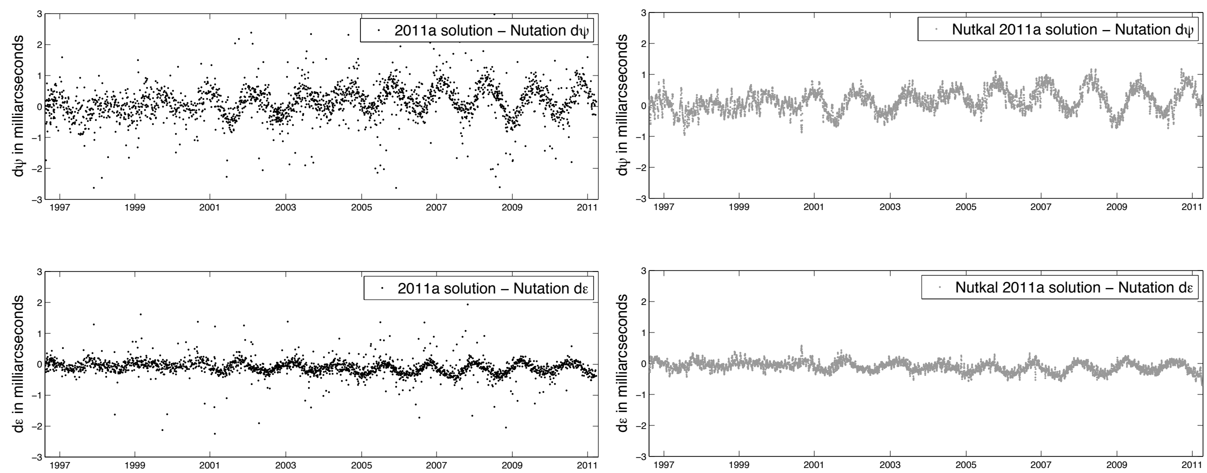

Figure 5. Nutation parameters from the GSFC 2011a solution (left) and regularized in a daily time series (right) using a Kalman filter.

3.2. Singular Spectrum Analysis

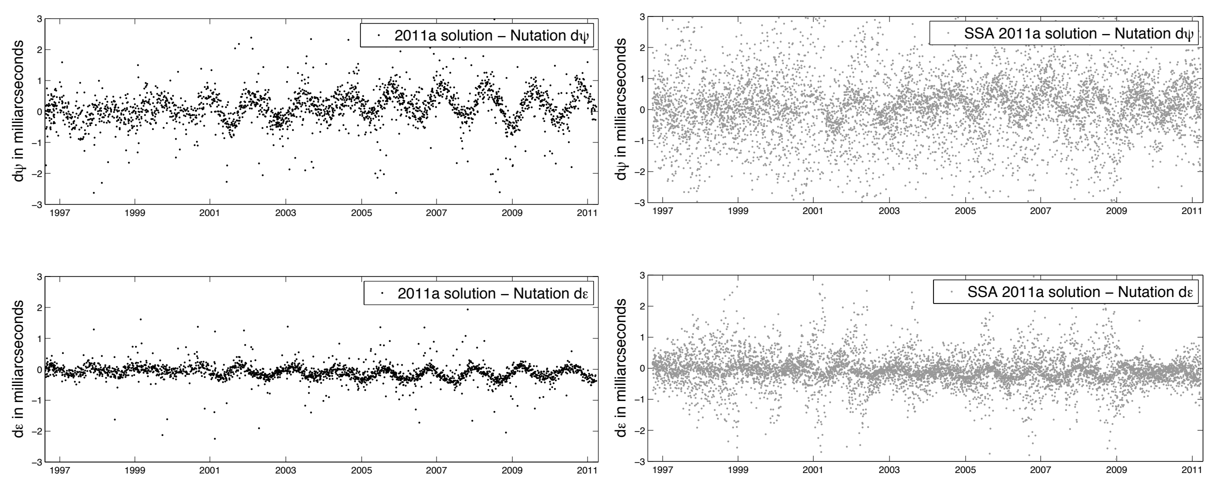

Figure 6. Nutation parameters from the GSFC 2011a solution (left) and regularized in a daily time series (right) using an SSA-derived method.

Another method of regularizing the time series is to consider the time series as daily and to fill in missing data. To do so, we use an iterative method derived from the SSA developed by Zhang from Elsner/Tsonis [2]. As covariance-lag, we used the most significant period determined in Section 2 (450 days). As seen in Figure 6, the SSA captures the tendency of the time series. The resulting time series using the SSA are noisier than the ones using the Kalman filter.

4. Conclusions

Regularizing time series properly means keeping the same characteristics of the initial time series: same signals and same type and level of noise. That is the reason why a simple interpolation does not work sufficiently for the nutation time series and why we investigated the Kalman filter as well as Singular Spectrum Analysis.

In this study, we show that both the Kalman filter and the SSA adequately reproduce the tendency of the two time series. The SSA induces a high level of noise in contrast to the Kalman filter. We need to determine the kind of noise in the regularized time series to see if it is consistent with the conclusion of white noise given by the Allan variance on the R1 and R4 sessions time series.

Furthermore, we did not take into account phenomena seen in these time series, such as the Free Core Nutation. The next step in this study is to develop the Kalman filter modeling and to modify the noise component.

References

[1] Gipson, J., Implementation of the Goddard EOP Kalman Filter/Smoother, In: Internal NASA/GSFC report, 1997.

[2] Elsner, J.B., Tsonis, A.A., Singular Spectrum Analysis: A New Tool in Time Series Analysis (Language of Science), In: Plenum Press, 1996.