SIGNATURE OF EL NINO IN LENGTH OF DAY AS MEASURED BY VLBI

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INTRODUCTION

Very Long Baseline Interferometry (VLBI) is one of the most accurate techniques for measuring Earth orientation parameters (EOP), and is unique in its ability to make high accuracy measurements of UT1, and its time derivative, which is related to changes in the length of day, conventionally called LOD. The accuracy of the best VLBI measurements using 24 hours of data is 2 μs for UT1, 4 μs/day for LOD. Changes in EOP are due to either external torques from gravitational forces, or to the redistribution of angular momentum between the solid-Earth, atmosphere, oceans and inner core. Discrepancies between predicted and measured EOP values point to areas where either the measurements or the models need improving.

The theoretical models that predict the response of the Earth to external forces are conceptually simple. To a good first approximation, the planets can be represented as point masses. Highly accurate predictions for nutation have been around for some time, and continue to be refined. Furthermore, EOP changes due to external forces are for the most part strictly harmonic in nature, and the analysis of the nutation measurements is amenable to the techniques of harmonic analysis. Measurements taken at different times can be combined to estimate the harmonic amplitudes of the nutation series. Since both the theoretical predications and VLBI measurements are very precise and of comparable precision, the status of comparisons between observation and theory is fairly mature. For example, a comparison of the predicted nutation series with the VLBI measured series led to the conclusion that the nutation model was incorrect. The VLBI measurements led to a change in the ellipticity of the inner-core. VLBI measurements continue to be used to check and improve the nutation models.

In contrast, the changes in the orientation of the Earth due to exchange of angular momentum between the Earth, core, oceans and atmosphere are by their very nature much more complicated. Instead of dealing with simple gravitational forces, you are dealing with a complicated distributed system specified by many more parameters. After compensating for external torques, the total angular momentum of the Earth-atmosphere-oceans-core is constant:

$$J_{Earth} + J_{Atm} + J_{Ocean} + J_{Core} = J_{Total}$$

The only quantity that is directly measurably is the first. The remaining contributions must be indirectly inferred. For the atmosphere and the oceans this is done by calculating the angular momentum predicted by some global circulation model [Salstein, 1997]. Comparisons of the

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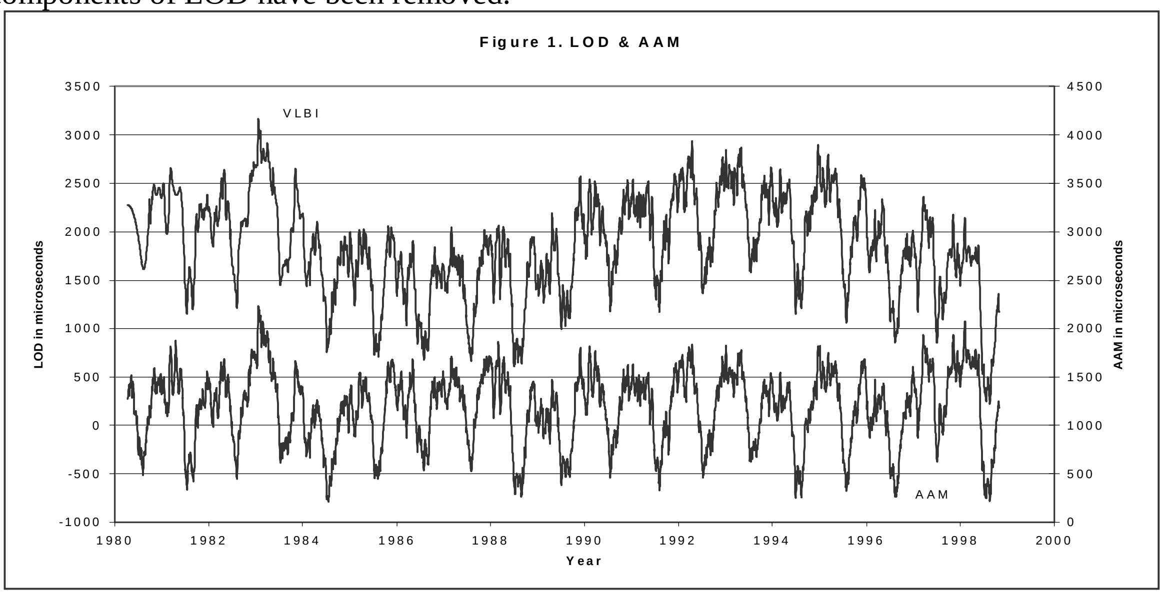
predictions of these models with measured LOD indicate generally good agreement, although currently the discrepancies between different models is much larger then the uncertainties in the VLBI measurements.

In this note we study the influence of the El Nino – La Nina on LOD, as measured by VLBI. We find that these have obvious signatures in LOD. During an El Nino, the atmospheric angular momentum increases, and hence the angular momentum of the Earth decreases. The Earth slows down, and the length of day increases. In a La Nina exactly the opposite happens.

LOD AND AAM

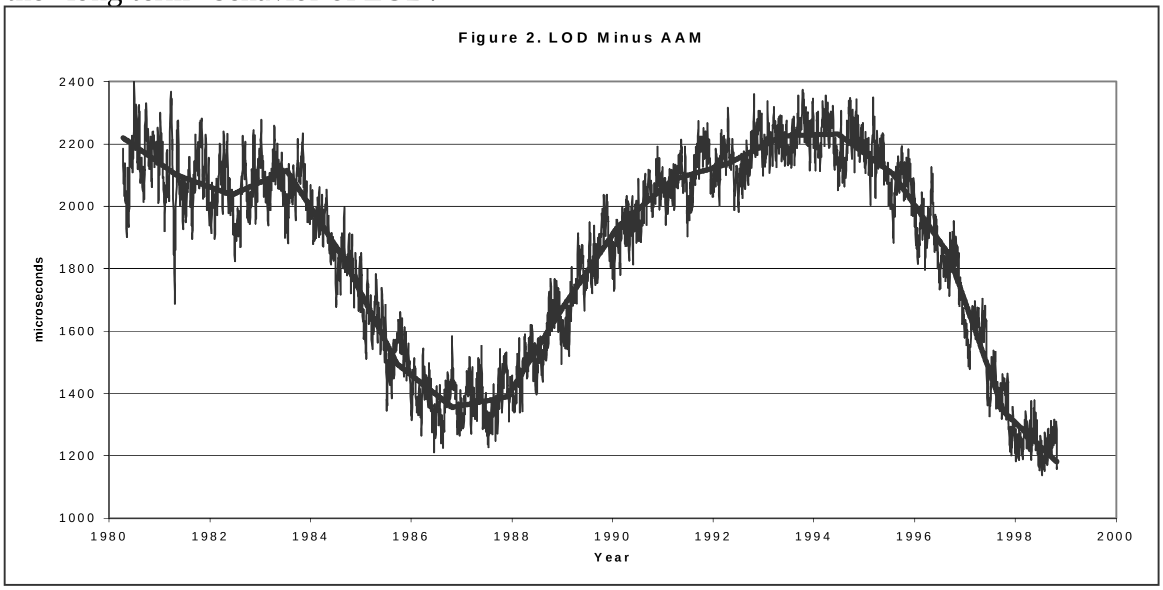
Beginning in 1979 and continuing to the present time the international VLBI community has conducted over 2700 VLBI experiments. The spacing of the VLBI data is far from uniform. However, from 1984 onwards there was at least one VLBI experiment per week specifically designed to measure EOP. The VLBI measurements of LOD are displayed in Figure 1. The VLBI data has been Kalman filtered to obtain daily estimates of EOP. The tidal components of LOD have been removed.



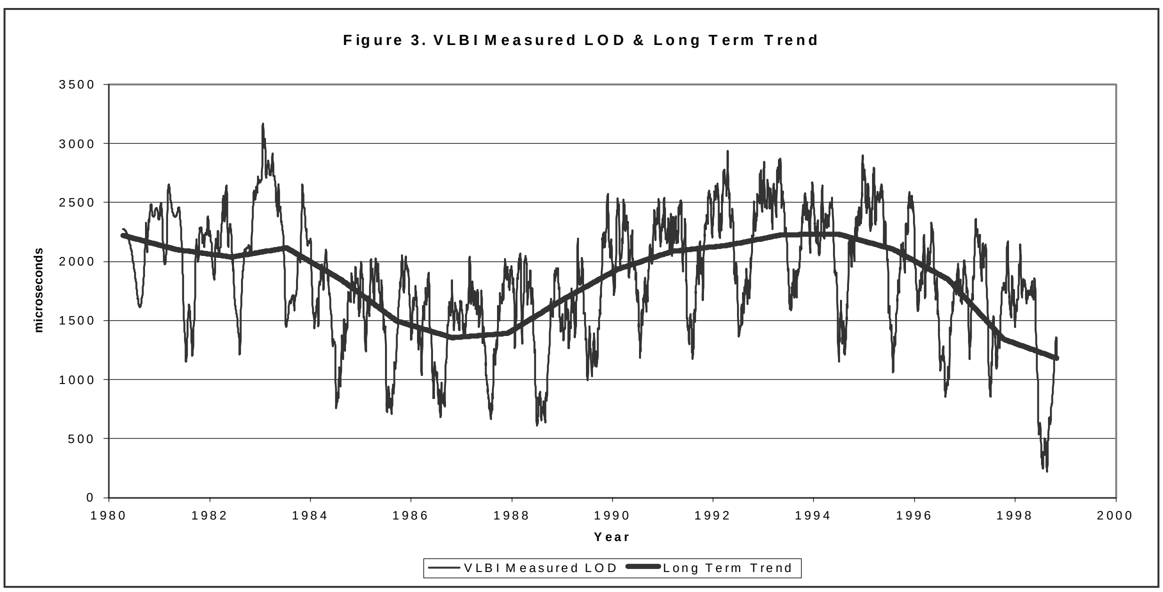
Also plotted on Figure 1 is the total atmosphere angular momentum (AAM). This data is derived from the NCEP global circulation model, and was provided by AER [Salstein and Rosen, 1998]. It includes wind and pressure terms to the top of the model (10 mbar) and uses the inverted barometer approximation for the oceans. The AAM data has been converted to LOD to make comparison between the VLBI measurements and AAM easier. The AAM vertical axis, which is on the left of the plot, has been displaced from the LOD to make comparison easier.

It is also apparent that there is excellent short-term agreement between LOD and AAM. Both LOD and AAM have seasonal variations of order 1000 μs/year. The AAM values oscillate about some mean. In contrast, the LOD measurements have a long term drift, which is thought to be due to exchange of angular momentum between the mantle and the core. This introduces a time varying offset between LOD and AAM.

This drift is emphasized in Figure 2, which plots the difference between LOD and AAM. Note that the vertical scale is different from Figure 1. The sub-annual variation is reduced by almost an order of magnitude, indicating that most of the short-term variation in LOD is due to AAM. The variation in the residual curve is due either to other EOP contributions, e.g., the oceans or the core, or to errors in either the LOD measurements or AAM predictions. In any case, after removal of the residual sub-annual variation, this difference curve should be a good proxy for the “long term” behavior of LOD.



We tried various means of fitting the long-term variation in LOD while leaving the short-term variation alone. This included Fourier filtering, singular spectrum analysis, temporal empirical



functions, and fitting the difference curve to a piecewise linear function. All of these techniques gave similar results except at the end of the data. We finally settled on using the piecewise linear function. This approximation is displayed in Figures 3 and 4 as a solid curve, with rate breaks every 400 days. We tried using intervals between 100 and 700 days, and settled on 400 as a compromise between capturing yearly and longer variations without being unduly influenced by the short variation.

To study the short-term behavior of LOD we need to remove the long-term drift. The result is shown in Figure 4. This figure emphasizes the seasonal dependence of LOD. It is worth noting that the day is longer by about 1 ms in the Northern Hemisphere winter than in the summer.

The physical reason for this is that the atmosphere carries more angular momentum in the winter. The asymmetry between summer and winter is because the landmass of the Earth is not symmetrically distributed between Northern and Southern hemispheres.

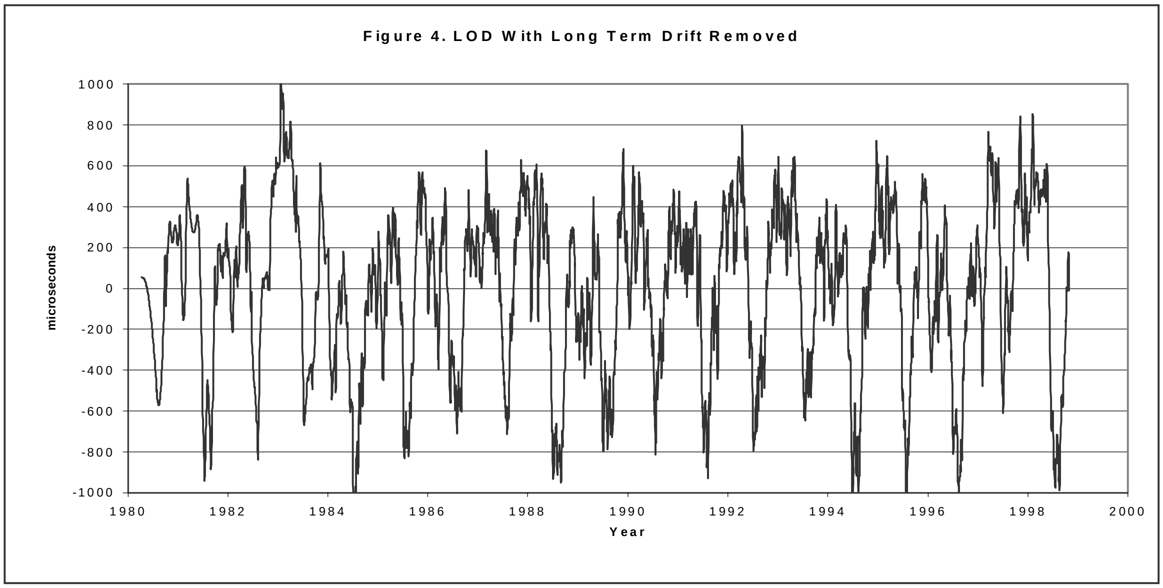
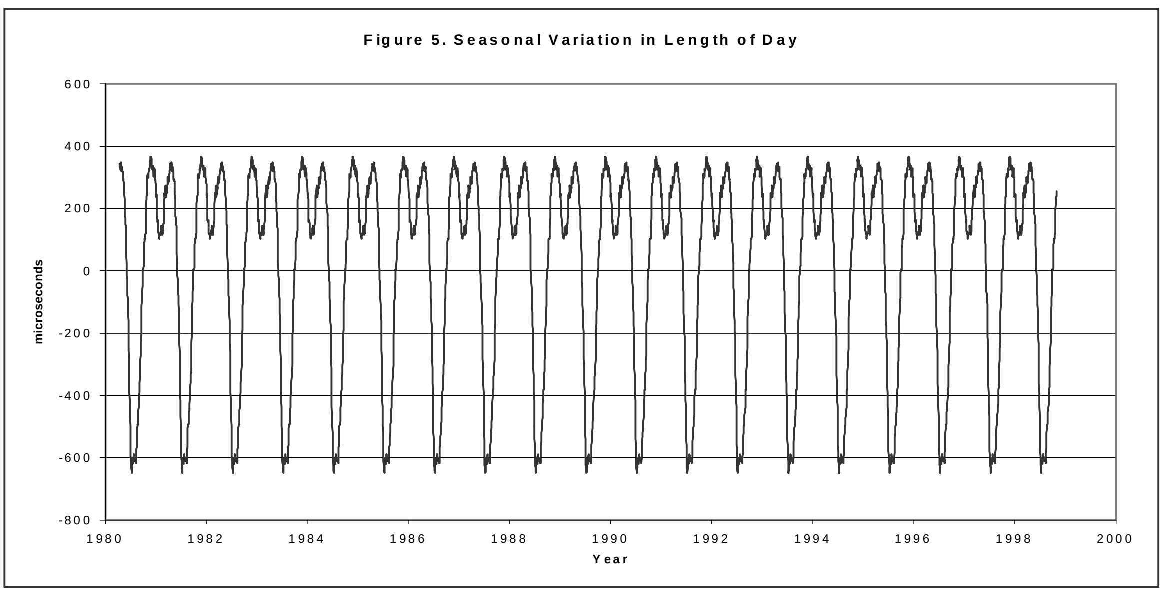
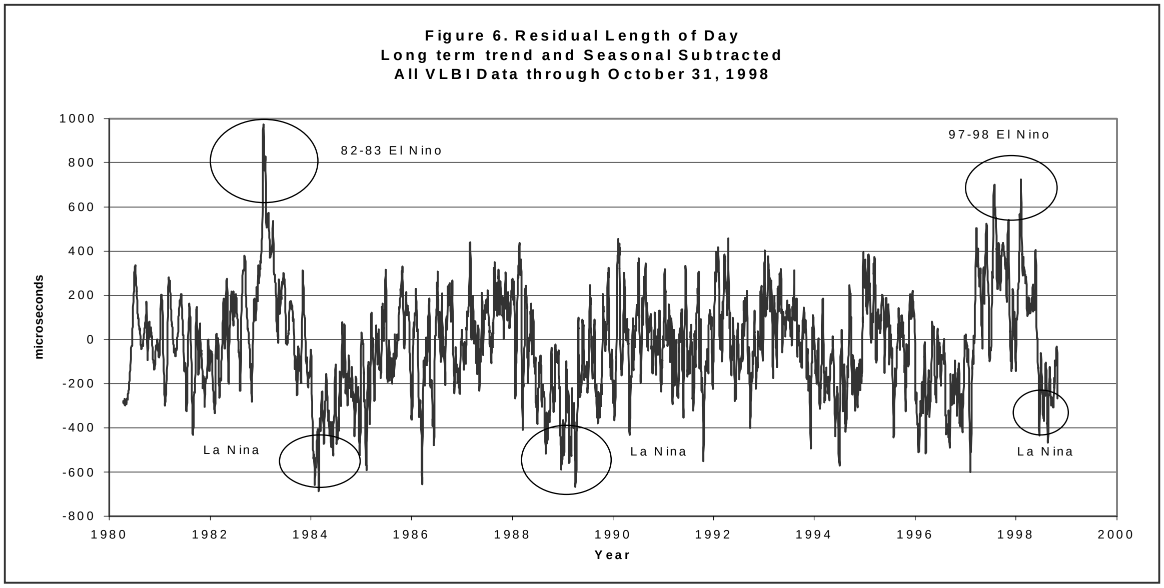


Figure 5 plots the purely seasonal variation in LOD. We generated this figure by calculating the average LOD as a function of the day of the year, and plotting the results.

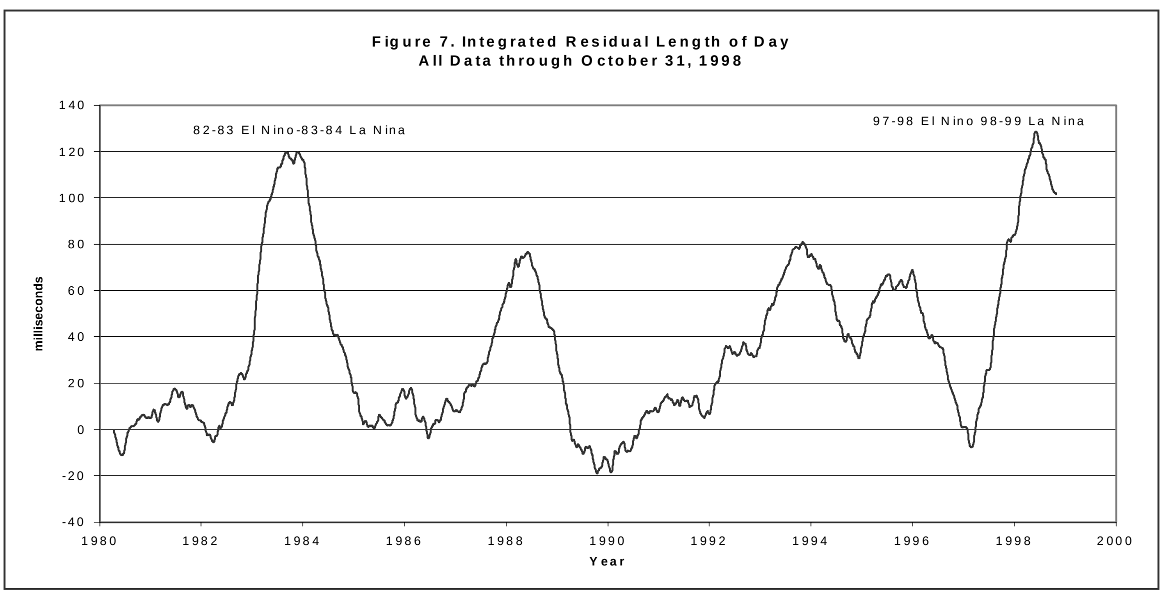


To isolate the anomalous behavior in LOD we need to remove both the long-term drift and the expected seasonal variation. The residual LOD is shown in Figure 6. All of the excursions are associated with El Nino – La Nina events. The most prominent of these is the 1982-83 El Nino, which was followed by a La-Nina. As the angular momentum of the atmosphere increased, the Earth slowed down. As the Earth slowed down, the length of day increased. The maximum change in LOD was about 1 ms/Day. This increase was followed by a decrease, as El Nino begat La Nina. The 1997-98 El Nino exhibits both similarities and differences from the 1982-83 El Nino. At its peak the 1997-98 El Nino resulted in a 0.8 ms increase in LOD.

Although the size of this event was not as large as the earlier one, it lasted much longer. Like the earlier event, it has been followed by a La Nina.



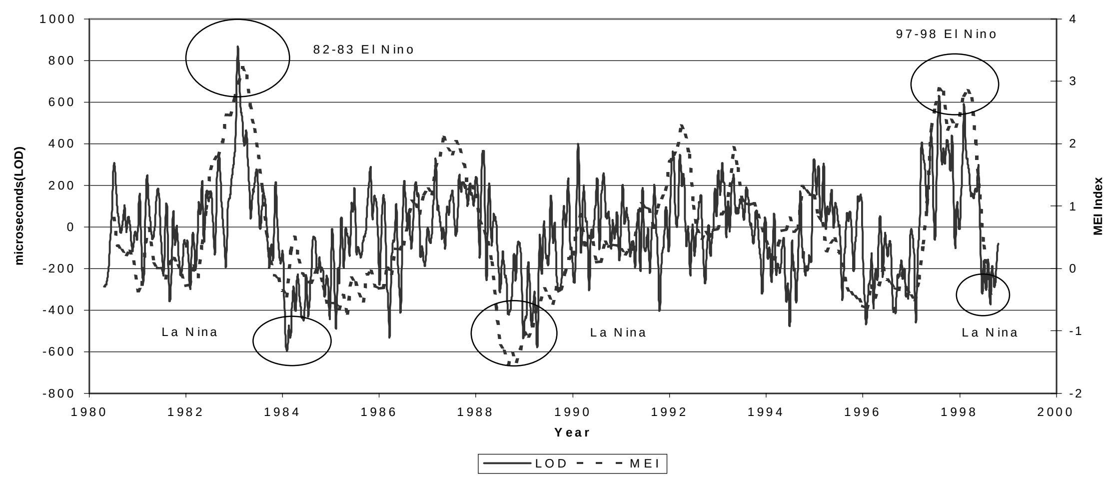
We have focused our discussion on LOD, that is the rate of rotation of the Earth. It is also interesting to look at the integrated effect of the LOD. If we view the Earth as clock, LOD corresponds to how fast or slow the clock is, that is how much time the clock gains or loses in a day. When we integrate this we find how far off the clock is in keeping perfect time. Figure 7 plots the integrated effect of variations in LOD. The 1982-83 El Nino led to a total integrated effect of 0.12 s, while the latest El Nino was slightly higher, at 0.125 s. As we transition from El Nino to La Nina the Earth slows down, and we lose the time we have gained.



In the discussion above we identified various excursions in the residual LOD with El Nino and La Nina events. However, we gave no evidence for these excursions actually being caused by the El Nino or the La Nina. One way of demonstrating that this is the case is to show that an index associated with the El Nino/La Nino is correlated with LOD. We show this in Figure 8 below, which plots the Multivariate ENSO Index. [Wolter, 1998]. This index uses two months of data, so it is smoothed compared to the LOD measurements. Also plotted on this figure are

15-day averages of the residual LOD. The correlation between the two series is high and obvious.

Figure 8.
Residual LOD Long term trend and Seasonal Subtracted 15 Day Box Car Average
Modified Enso Index



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