ON THE CORRELATION BETWEEN EARTHQUAKE OCCURRENCE AND DISTURBANCES IN THE PATH OF THE ROTATION POLE

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Abstract. The hypothesis that earthquakes may be the principal excitation of the Chandler motion of the rotation pole is examined in the light of recent theoretical and observational developments. There is some doubt about the amount of excitation by a large earthquake necessary to maintain the Chandler Wobble, but it appears to be about 10 ft. Theoretical calculations for the Alaskan Earthquake ($M = 8\frac{1}{2}$) give available excitations in the range 1–5 ft, but there are considerable uncertainties in these calculations. Earthquakes may be able to provide all of the required excitation, or only a small portion (10% or less). The problem is confused by observational studies, which show differences between various sets of data on polar motion which seem to be larger than the expected error in each set. The earthquake hypothesis, though reasonable, is still very much open to debate.

1. Introduction

The hypothesis that earthquakes may be the principal excitation of the Chandler motion of the pole has been presented and rejected by numerous authors. It was recently reproposed by Smylie and Mansinha (1967, 1968), and since then it appears to have gained a wide acceptance, at least among the seismological community. The purpose of this paper is to review the current status of this hypothesis, in the light of work carried out in the last few years.

Smylie and Mansinha presented a two-fold argument. First, using a simple model of a fault in a uniform half-space, they showed that appreciable displacements may occur at large distances from a large earthquake. They estimated that a magnitude $8\frac{1}{2}$ earthquake may move the pole of moment of inertia by several inches. This estimate was approximately two orders of magnitude larger than previous calculations had suggested (e.g., Munk and MacDonald, 1960), and opened the way to a more detailed study of the problem.

Second, using the published polar motion data (particularly the BIH data), they presented evidence that abrupt changes in the pole of inertia occurred at about the times of major earthquakes, during the period 1957–1965. The magnitude of these changes was estimated to be of the order of 10 ft (0.1 sc of arc). Their procedure of fitting circular arcs to the polar data has been criticized, but their correlation between earthquakes and 'breaks' in the pole path was good enough to make a reasonably convincing case.

Unfortunately, more recent developments both in the theoretical calculations and in the analysis of the polar observations have not clarified the validity of the hypothesis to the extent that was originally hoped.

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2. Theoretical Development

The model of a fault in a uniform half-space, as originally used by Smylie and Mansinha, was clearly inadequate. Subsequent extensions of the theory to the layered half-space (McGinley, 1969; Chinnery and Jovanovich, 1971) showed an increase in far field displacement over the simple model of about 30%. Other investigations (Ben-Menahem and Israel, 1970) studied the effect of faulting in a homogeneous sphere, and again an appreciable increase in teleseismic displacements over those predicted for the simple model was found.

These studies have set the stage for the final calculation, the displacements caused by faulting within a layered selfgravitaing sphere. This very difficult problem is the subject of two recent papers (Smylie and Mansinha, 1971; Dahlen, 1971). The net result of this work has been to increase the theoretical estimate of the excitation of the pole of inertia by a large earthquake ($M=8\frac{1}{2}$) to several feet.

At first sight, the problem appears to be nearing a consistent solution, but on closer examination some problems arise. There is a disturbing difference between the results of Dahlen (1971) and those of Smylie and Mansinha (1971). Dahlen's estimate (about 5 ft) of the effect of the Alaskan earthquake on the inertia pole is larger, by a factor of 3 to 5, than that of Smylie and Mansinha. Furthermore, potential difficulties in calculations of this kind have been pointed out by Chinnery and Jovanovich (1971). They showed that thin soft layers in the upper mantle may effectively decouple earthquake displacements from the Earth's interior. This is likely to reduce the excitation of the pole that will be caused by an earthquake. A further difficulty, of course, is that the amount of excitation needed to explain polar motion data is not clear, except in a long-term statistical sense. Even the overall power injected into the polar motion by earthquakes is questionable. Dahlen's estimates for the power available from earthquakes are roughly an order of magnitude smaller than that necessary to maintain the wobble, though he argues that this may be due to our poor understanding of earthquake statistics.

In view of these problems, it is not clear what has been accomplished by the theoretical developments. It appears that the calculated excitation of the inertia pole by large earthquakes may lie anywhere from 100% to less than 10% of the amount required to explain the polar motion data. In this case we are forced to turn to the polar data themselves. If a clear cut correlation between breaks in the pole path and the occurrence of earthquakes can be established, the theoretical calculations can be used to explain the correlation. By itself, however, the theory is inconclusive.

3. Analysis of Observations of Polar Motion

The difficulty in trying to establish a correlation between the occurrence of an earthquake and a corresponding disturbance in the path of the pole is illustrated by Figure 1. This figure is taken from Dahlen (1971), and shows the BIH pole positions for parts of 1963 and 1964, after removal of the 12 month term. The solid lines are the circles fitted by Smylie and Mansinha (1968), and there is an apparent break near the time of the Alaskan earthquake of March 28, 1964. If the construction of Smylie and Mansinha is valid, the centers of the two circular arcs should represent the positions of the inertia pole before and after the earthquake. The vector motion of the inertia pole so obtained is marked 'observed' on Figure 1.

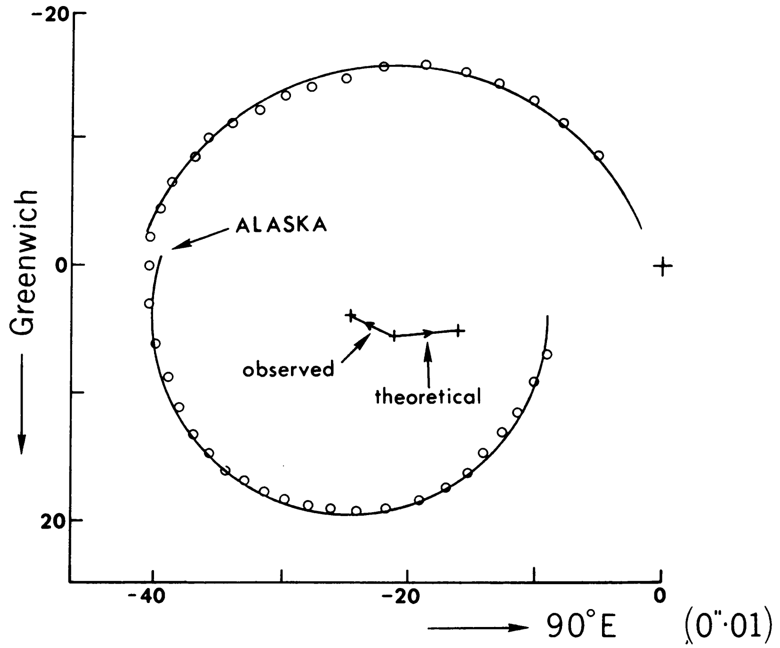

Fig. 1. A comparison of the 'observed' motion of the inertia pole at the time of the Alaskan earthquake, determined by the method of Smylie and Mansinha (1968), with the 'theoretical' excitation calculated by Dahlen (1971). After Dahlen (1971).

It is possible to compare this result with the theoretical calculations. The Alaskan earthquake (magnitude 8.5) was one of the largest of recent years, and it is logical to look at this particular event in detail. Furthermore, most calculations of earthquake excitation (including those by Smylie and Mansinha, and Dahlen) have studied this earthquake. Unfortunately, though there is some disagreement about the amount of the motion of the pole of inertia, the direction of motion appears to be largely independent of the Earth model used, and is shown by the vector labelled 'theoretical' on Figure 1. Clearly the agreement between theory and observation is poor.

One possible reason for this has been given by Haubrich (1970), who argues that the noise level in the data is so high that correlations obtained by the method of Smylie and Mansinha are as likely to be with noise as with real events. Another possibility is that the assumption that the inertia pole remained at fixed locations for long time intervals before and after the earthquake (which is implied by the circular arcs in Figure 1) is invalid. There are likely to be many movements of crustal material that are not associated with earthquakes (Chinnery, 1970), and it may be more reasonable to expect continuous movements of the inertia pole, as well as sudden changes in position at the time of earthquakes. This suggests that shorter segments of the pole path should be fitted with circular arcs. This has been attempted, but the irregularities in the data, and the estimated standard error (which may be of the order of 1 m), make it impossible to draw any consistent conclusions.

This raises the fundamental question of how smooth is the pole path. Geophysical considerations suggest at least the possibility that the pole path may be quite complex. Figure 2 shows a comparison of three pole paths for the year 1964, each with the annual term removed. For simplicity these curves have each been referred to an arbitrary origin, so that their shapes may be compared. The difference between the BIH

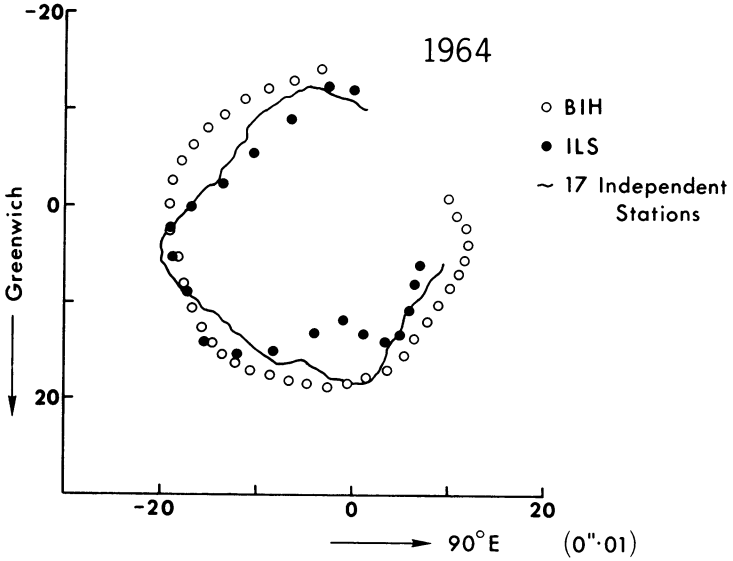

Fig. 2. A comparison of the shapes of the BIH and ILS pole paths for 1964. Also included is a path obtained from 17 independent stations (unweighted and unsmoothed). An arbitrary origin is used. In each case the 12-month term has been removed.

and the ILS-IPMS paths is well known, and is somewhat larger than the expected error in either set of data. The difference is usually attributed to the small number of stations used in the determination of the ILS-IPMS path. It is worth noting, however, that the data used in the BIH determination has been heavily smoothed and weighted. It seems likely that the weights assigned to the various stations were chosen in such a way as to lead to a smooth pole path, and it is therefore not clear that the smoothness of the BIH path is necessarily real.

Also shown on Figure 2 is a pole path determined by us from the 17 'best' independent stations listed in the *IPMS Bulletin*. The stations chosen were those that departed least, in the amplitude and phase of their latitude variation, from the mean of all the independent stations. The path shown is unweighted and unsmoothed, and (not surprisingly) shows considerable irregularity. It is interesting to note that this path agrees rather better with the ILS-IPMS path than it does with the BIH data, though this may be fortuitous.

In view of the differences between these three sets of data, it seems that attempts to trace the motion of the inertia pole must depend heavily on the data set selected. The interpretation of the 'breaks' in pole path by Smylie and Mansinha requires a greater faith in the accuracy of the BIH pole path than is, perhaps, justified by our present understanding of the noise level of latitude variation data. In particular, their suggestion that these 'breaks' may precede earthquakes seems based on very weak evidence, and may be a result of their method of analysis.

4. Conclusions

In our view, therefore, it is not possible at the present time, with presently available data, to establish a convincing correlation between the occurrence of earthquakes and disturbances in the path of the rotation pole. This leaves the hypothesis that earthquakes may excite the Chandler motion of the pole in an unsatisfactory position. Though to us the hypothesis is an eminently reasonable one, very much more accurate pole paths are necessary before the validity of the hypothesis can be established.

The suggestion that more accurate pole paths may be obtained in the near future from satellite data is encouraging. It is likely that this new information may provide some new insights into the crustal adjustments that precede and follow earthquakes.

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DISCUSSION

E. P. Fedorov: The larger the number of stations used in computing the polar motion the smoother the path of the pole looks. So the jumps of the pole are supposed to be due mostly to some errors of observation.

M. A. Chinnery: I agree. It is very difficult to justify belief in the fine details of any pole path. On the other hand, there is a limit to the validity of your argument. No pole path is completely smooth unless the data themselves are smoothed. Within the limits of error for any pole path there is considerable opportunity for movements of the inertia pole. It is very difficult to prove or disprove the reality of these jumps, given presently available data.