# IMPROVED EPHEMERIDES OF PLUTO

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Abstract

The history of the Pluto ephemerides created at JPL is given. The uncertainties of present and possible future ephemerides are illustrated, and it is shown how rapidly the error grows for any present-day ephemeris of Pluto which is extrapolated into the future - tens of thousands of kilometers after only a decade. Continuing the observations into the future will not only reduce the extrapolation time but will provide a substantial improvement to the ephemeris itself.

## 1. Introduction

This paper describes the short history of the Pluto ephemerides created at JPL, illustrates the present-day uncertainties, and shows different improvements that might be expected in the future. Section II describes the existing JPL ephemerides of Pluto and the observational data to which they have been adjusted. Section 111 describes what types of observations and accuracies might be expected in the future. Section IV presents a covariance study - estimations of the expected uncertainties in the Pluto ephemeris at present and in future possible ephemerides which would benefit from future observational data. Section V contains the conclusions, and the Appendix lists the published references to the observational data.

## 2. The JPL Ephemerides of Pluto

The quality of modern-day ephemerides depends most importantly upon the observational data to which the ephemerides are adjusted. The usefulness of the observations, in turn, depends upon the data type, the coverage in time, and the accuracy of the measurements. In the collection of positional observations of Pluto at JPL, there are 14 pre-discovery photographic observations beginning in 1914 and about 900 observations since the discovery in 1930. The standard deviation for a single observation is about 0"5, corresponding to about 10,000 km at Pluto. However, since many of these observations have been reduced to secondary stellar catalogues, they are subject to additional systematic (zone) errors which can also amount to 0"5. Since 1989, photoelectric transit observations have been taken of Pluto with the Carlsberg Automatic Meridian Circle on La Palma. These observations show a scatter of about 0"25; more importantly, comparisons of the La Palma stellar observations with similar ones taken at Bordeaux indicate that the photoelectric observations seem to show no significant systematic zone errors at the 005 level (see, e.g., Carlsberg Meridian Catalogue 1989). References to all of the Pluto observations are listed in the Appendix.

The following are the significant milestones for the JPL ephemerides of Pluto:

DE200, created in 1980 (see Standish 1990a), was not fit to any of the observational data of Pluto. Instead, members of the US Naval Observatory, using their own set of Pluto observations, analysed a previous JPL ephemeris, DE1 14, and then transmitted corrections which were applied to the creation of DE200 at JPL.

DE202, created in 1987, was the first JPL ephemeris for Pluto that was actually adjusted directly to observational data, being fit to the photographic observations through 1985.

DE211, the current experimental ephemeris at JPL, has been fit not on] y to all of the photographic observations of Pluto, but also to the photoelectric transit observations from La Palma.

Figures 1 a-3b show the right ascension and declination residuals of the observational data of Pluto, as fit by the three JPL ephemerides, DE200, DE202 and DE211. One can best see the improvements in the most recent years, shown especially by the La Palma data- These plots agree with Morrison et al, 1992 who indicate that though DE202 removed about 80% of the ephemeris error from DE200 during the present decade, a further correction of about 0"5 is necessary. This seems to be accommodated by DE211. However, as will be seen below, future run-off, even in the DE211 ephemeris of Pluto, is expected to be uncomfortably large.

Figs 1a-3

## 3. Possible Future Improvements to the Pluto Ephemerides

Figures 4a and b show the residuals of DE211 after a constant bias has been removed in right ascension and declination for each of the different sources of photographic data. These biases simulate equinox offsets, unmodeled instrumental corrections, etc. in right ascension and altitude circle offsets,

Figs 4a-

etc. in declination, respectively. Since these biases are purely empirical, however. they do not increase the knowledge of the Pluto ephemeris. On the other hand, possible re-weighting of the observations and/or applying actual catalogue corrections would certainly give marked improvements, In fact, it is apparent that the handling of the Pluto data has not been complete. In particular, each observational source should be corrected according to the known zone errors, equinox offset, etc. which exist in the particular catalogue used in the data reduction. Thus, Figs. 4a and 4b tend to indicate what is possible using only data from existing published observations.

Going further, if the original plate measurements still exist, new reductions might be performed using more accurate modern stellar catalogues. Better still, if the plates themselves exist, it might also be possible to re-measure these with modern measuring machines and then to reduce the new measurements using modem catalogues. Such a project is being considered by Gemmo 1993, using some plates taken at the Asiago Observatory in 1946. This is especiall y attractive since these plates have never been reduced before. HopefuLly, the ensuing accuracy could approach that of the astrometric observations reported by Gemmo et al. 1993, which seem to be in close agreement with the La Plama observations.

The greatest contribution to the Pluto ephemerides, however, lies in the future data; for, as will be seen in the next section, extrapolation of the Pluto ephemeris is virtually impossible for more than a few years into the future,

## 4. Covariance Studies

The uncertainties of present and possible future Pluto ephemerides are estimated in this covariance study. The uncertainties of a planetary ephemeris depend mainly upon the observational data to which the ephemeris is adjusted. In this study, different sets of data are assumed, and the resulting covariance matrices are mapped throughout the present centuries. As such, the relative strengths of the

existing data types are shown, and the capabilities of the ephemerides for extrapolating into the future are seen. The following six cases are considered:

Case #1: Present photographic data only, 1914-1988 (modeled with catalogue offset uncertainties of 0"5).

Case #2: Present photoelectric data only, 1989-1992 (modeled with a catalogue offset uncertainty of 0"05).

Case #3: Full present data set (Cases #l and #2 combined).

This case may be considered to represent the present capability of the Pluto ephemeris.

Case #4: Present data, with some of the plates re-measured and re-reduced with respect to the Hipparcos Catalogue. Thus, the catalogue offset uncertainties are assumed to be 0"002 during the mid-1990's, but growing backward in time at a rate of 0"2/cty, in accordance with the uncertainties expected for the Hipparcos Cataolgue mean motions. This case is what could be done with present-day data only, using modern measuring equipment and the Hipparcos catalogue.

Case #5: Present data plus a few photographic plates of Pluto taken until the year 2007, measured and reduced with respect to the Hipparcos Catalogue, with the offset uncertainties growing forward in time from the mid- 1990's.

Case #6: Present data plus photoelectric La Palma observations taken from now until the year 2007 with the same frequency as the existing data.

The formal matrices from the least-squares fits have been multiplied by a factor of 2-squared in order to partially account for the unmodeled (and unknown) systematic errors which most certainly exist in the observations. Certainly, it would be preferable to perform a "consider covariance" study, directly modeling the contributing error sources. Such is not possible here, however, where most of the error sources are unknown.

Figures 5-7 show plots of longitude, latitude and radial distance, respectively, for the first three cases. One can see how the photoelectric data (Case #2) provide an instant position fix on the plane of the sky (longitude and latitude). On the other hand, the radial distance is so uncertain, due to the short time-span of the data, that it doesn't even appear in the plot. Thus, the longer span of the photographic data (Case #1) is important in determining the radial distance, whose uncertainty depends upon the mean motion and centers around the weighted mean of the total data set. Nevertheless, it , is startling to note in all three components how quickly the uncertainty grows outside of the data time-Span.

Continued data will certainly improve the situation. The three components of Case #3 are plotted again in Figs. 8-10 along with those from Cases #4 through #6. Re-measuring and re-reducing of the existing data (Case #4) provide an improvement, but not as great as either of the two future data types - photoelectric or photographic astrometry. This is especially apparent for extrapolations into the future.

## 5. Conclusions

Present ephemerides of Pluto deteriorate rapidly when extrapolated into the future - tens of thousands of kilometers within less than a decade. The rapidly accumulating error of Pluto wrt JPL's DE200 is, therefore, not surprising. Moreover, this is not atypical; such rapid run-off is expected for even today's ephemerides. This has a direct bearing upon the predictions of stellar occultations by Pluto and also upon the Pluto Fast Flyby Mission, envisioned by JPL for the next decade.

Re-measuring and re-reducing of existing plates would improve the situation somewhat, if modem catalogues are used with substantial y better accuracies. However, the most effective improvements to the ephemerides of Pluto come from continuing the observational data into the future: photographic astrometry using modern stellar catalogues and the photoelectric transit observations from La Palma.

Appendix: Data References


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Figure Captions

Figure 1. Residuals of Pluto in right ascension (1-a) and declination (1-b) wrt the JPL ephemeris DE200.

Figure 2. Residuals of Pluto in right ascension (2-a) and declination (2-b) wrt the JPL ephemeris DE202.

Figure 3. Residuals of Pluto in right ascension (3-a) and declination (3-b) wrt the JPL ephemeris DE211.

Figure 4. Residuals of Pluto in right ascension (4-a) and declination (4-b) wrt the JPL ephemeris DE211, after applying an empirical bias correction for each of the different data sources.

Figure 5. Uncertainties in Pluto's longitude for ephemerides fit to three different sets of observational data: #1) existing photographic astrometry only, #2) existing photoelectric transit timings only, and #3) both photographic and photoelectric observations together. This third case represents the capabilities of present-day ephemerides for Pluto.

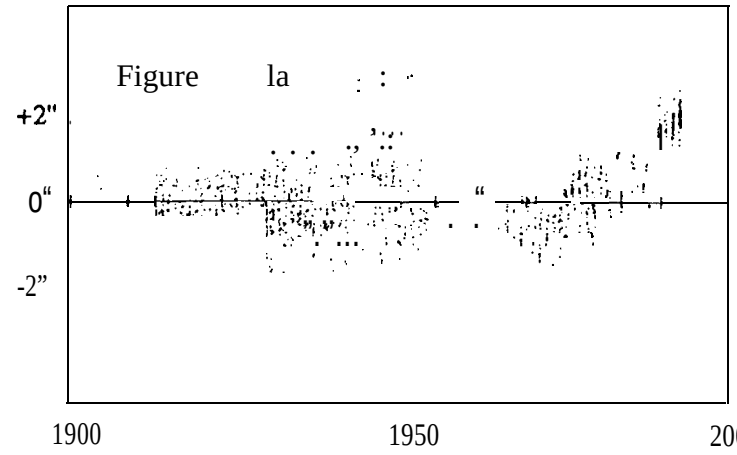
Figure 6. The latitude uncertainties corresponding to the three observational data sets considered in Figure 5.

Figure 7. The radial distance uncertainties corresponding to the three observational data sets considered in Figure 5.

Figure 8. Uncertainties in Pluto's longitude for ephemerides fit to four different sets of observational data: #3) same as above, #4) present set with some of the observations re-measured and re-reduced wrt modern-day catalogues, #5) present set plus future photographic observations extending until the year 2007, and #6) present set plus future photoelectric transit observations extending until the year 2007.

Figure 9. The latitude uncertainties corresponding to the four observational data sets considered in Figure 8.

Figure 10. The radial distance uncertainties corresponding to the four observational data sets considered in Figure 8.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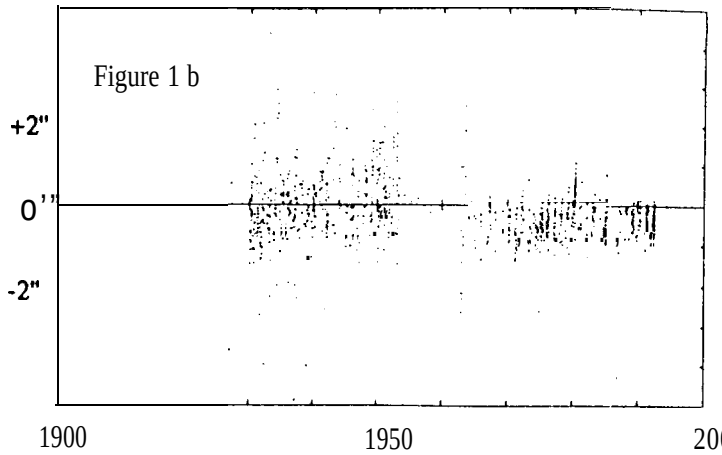
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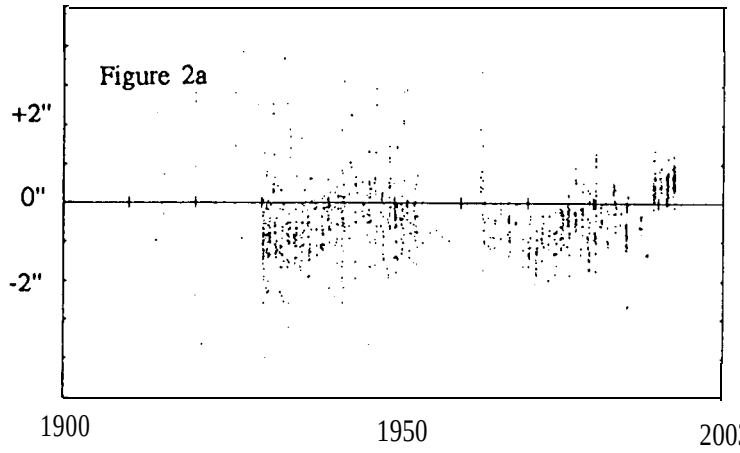
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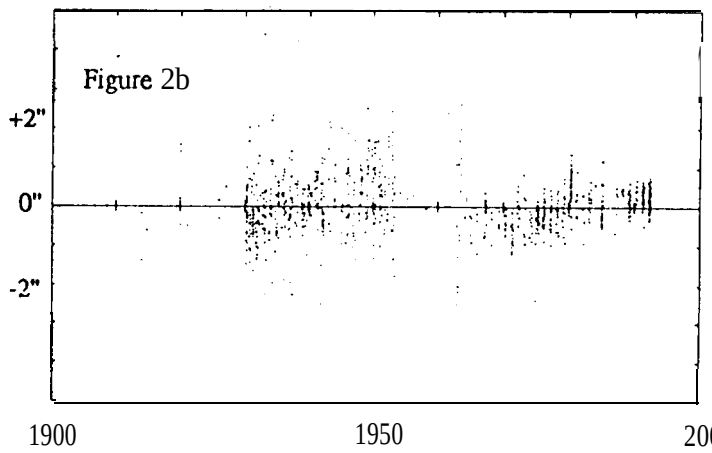
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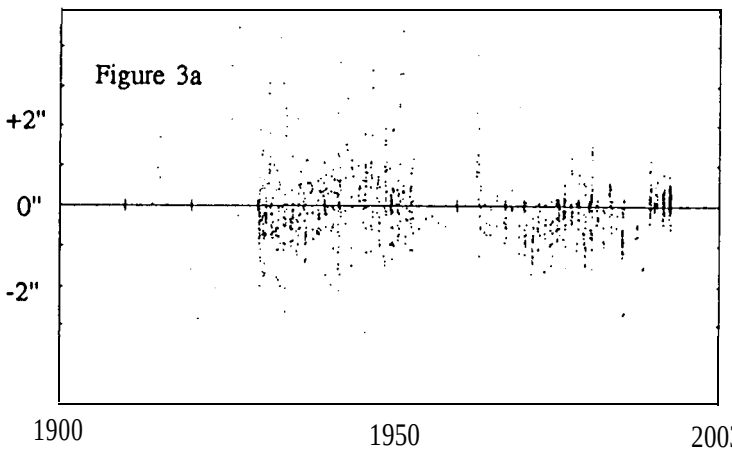
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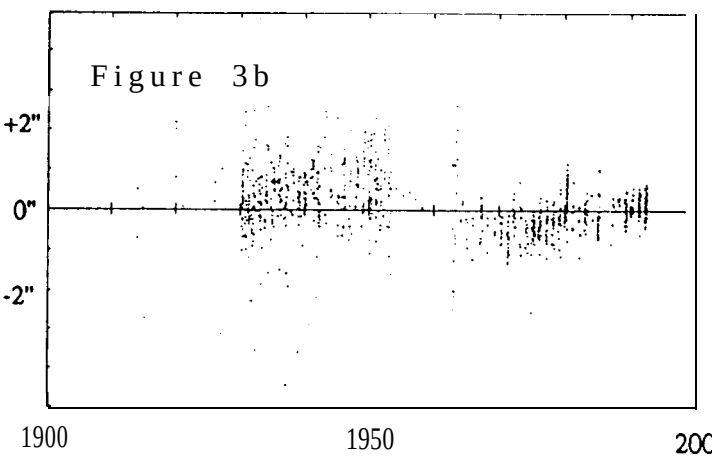
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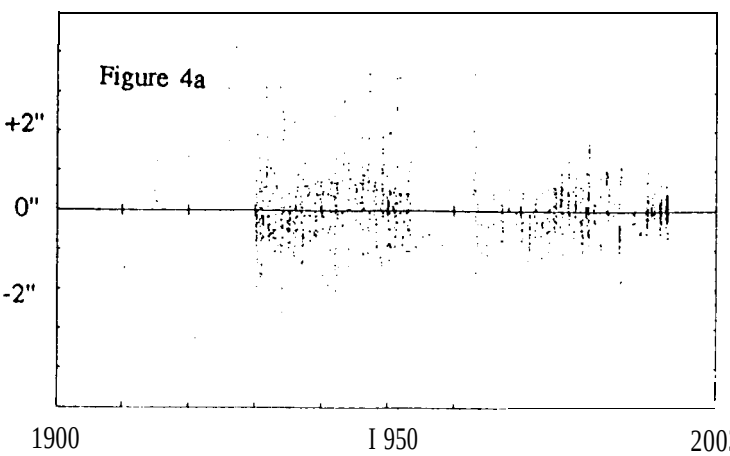
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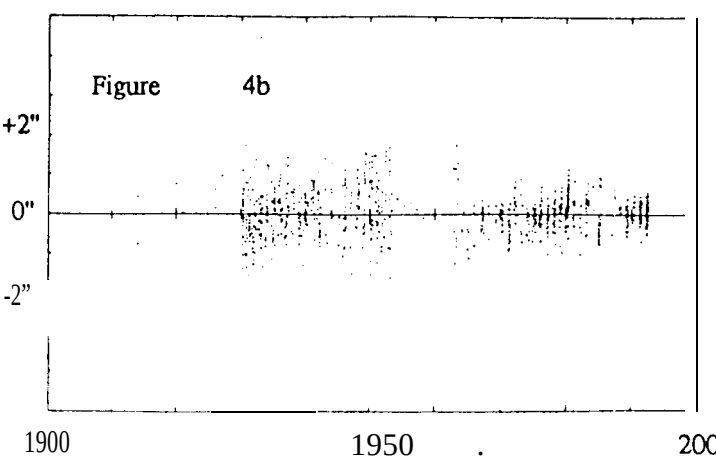
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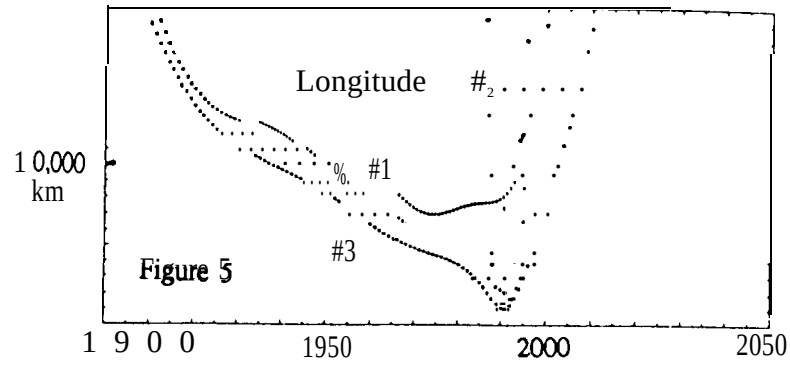

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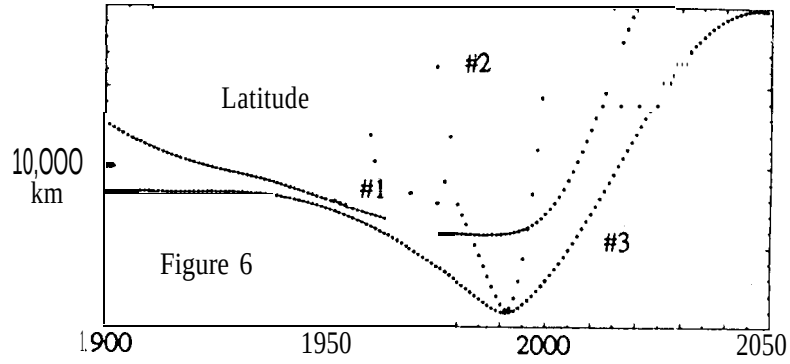

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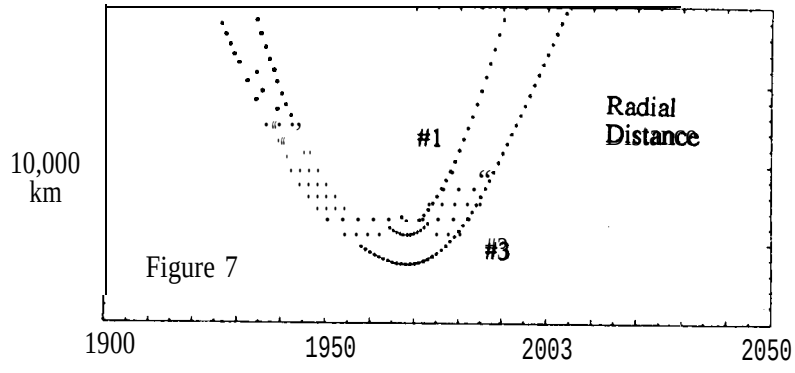

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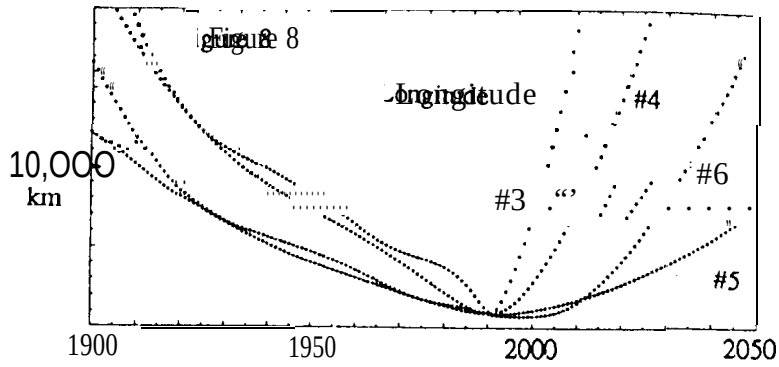
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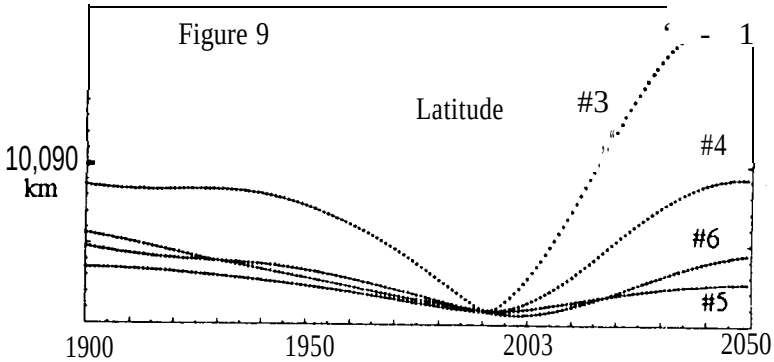
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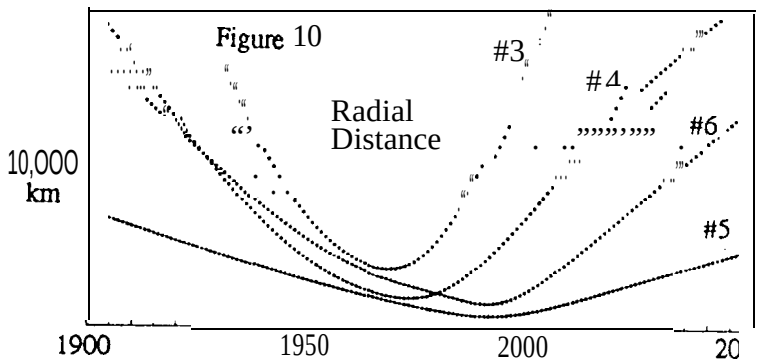
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