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Analysis of Star Pair Latitudes

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Goddard Space Flight Center
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ABSTRACT

Star pair latitude observations form the basis for the pole positions reported by the International Polar Motion Service (IPMS). The IPMS processes these observations to produce a mean pole position. However, the time series of raw observations contains high frequency information which is lost in the calculation of the mean pole. In this study, 2931 star pair observations are analyzed. A possible large excitation at one cycle per solar day is observed. The average power level in the frequency band of the tesseral tides is seen to be high, although the peaks do not occur at the expected tidal frequencies.

ANALYSIS OF STAR PAIR LATITUDES

Polar motion and the variation of latitude have usually been analyzed in the long period domain, primarily for the study of the Chandler wobble. However, a great volume of data exists at the high frequencies. The measurement technique utilized by the International Polar Motion Service (IPMS) is based on the viewing of eighteen star pairs every night by each of five observatories [see Melchior, 1957]. These raw star pair observations are usually neglected in favor of the reported pole positions, although the actual observations are published in the annual reports of the IPMS.

In this analysis, 61 days of data from 7 May 1964 to 6 July 1964 were utilized. These dates were chosen because all five observatories had a large number of successful observing sessions. During this period, 2931 star pairs were observed by the five stations: Gaithersburg, 691; Ukiah, 724; Mizusawa, 347; Carloforte, 505; and Kitab, 664. The data are reasonably distributed among the five.

Prior to studying the power distribution, the data was preprocessed. The first step was to remove the average station latitudes. The second step was to remove the latitude biases introduced by such errors as star catalogue declination errors. This second step was done by removing the average star pair latitudes, with the average being taken over all five stations. The biases ranged from -0″.45 to +0″.78 and are listed in Table 1, where the group and pair numbers are taken from the IPMS system. These biases are analogous to the declination corrections, $\Delta\delta$, published by the IPMS [Yumi, 1966, Table 12], and their values

Table 1

Star pair biases determined from 61 days of data.

Group	Pair	Number Observed	Bias	IPMS $-\Delta\delta_{64}$	Difference
VIII	43	80	0.″18	0.″03	0.″15
	44	81	0.″09	-0.″03	0.″12
	45	83	-0.″23	-0.″35	0.″12
	46	84	-0.″37	-0.″50	0.″13
	47	85	0.″04	-0.″09	0.″13
	48	86	0.″19	0.″04	0.″15
IX	49	174	0.″03	-0.″13	0.″16
	50	173	-0.″16	-0.″29	0.″13
	51	171	0.″14	0.″01	0.″13
	52	168	-0.″23	-0.″37	0.″14
	53	169	0.″05	-0.″04	0.″09
	54	165	0.″78	0.″64	0.″14
X	55	164	0.″11	-0.″05	0.″16
	56	159	-0.″18	-0.″33	0.″15
	57	156	-0.″17	-0.″31	0.″14
	58	160	0.″32	0.″19	0.″13
	59	156	-0.″25	-0.″39	0.″14
	60	156	-0.″11	-0.″26	0.″15
XI	61	76	-0.″37	-0.″45	0.″08
	62	80	-0.″11	-0.″28	0.″17
	63	76	-0.″21	-0.″37	0.″16
	64	76	-0.″45	-0.″60	0.″15
	65	76	0.″30	0.″19	0.″11
	66	77	0.″24	0.″11	0.″13

for 1964 are also presented in Table 1. The last column in the table gives the difference between the calculated bias and the IPMS declination correction. This difference is quite stable at approximately 0.″14 for all the star pairs. It was expected that this difference column would be distributed around 0.″00, and the reason for the variation is not known.

Following the preprocessing, the residual latitudes were studied to determine whether the sample had any abnormal error distributions which might have invalidated the analysis. The residual latitudes were found to follow a normal distribution with a standard deviation of 0.″21, which means that each star pair observation has a standard error of this value. It was concluded that the data sample is a reasonable one for statistical analysis.

The data was now analysed for the power distribution. The time series was very irregular, with the spacing from one point to the next varying from 11 minutes to 15 hours. Therefore, a least squares technique was used. At each frequency, an amplitude and phase were determined for a circularly polarized sinusoid. With the frequency steps made small compared to the inverse of the data length, the result was a smoothly varying amplitude and phase as a function of frequency. This type of analysis neglects the correlations which might exist between the various physical processes in the variation of latitude. The amplitude was then squared to generate the power spectrum in Figure 1.

The typical magnitude for the standard deviation of the amplitude was 0.″006. As was expected, this number is approximately equal to 0.″21 (the standard deviation of the residual analysis above) divided by the square root of the number of star pair observations in the data set. However, this 0.″006 is not a measure of the noise level in the data. It is a measure of how well the amplitude is determined in the least squares calculation. Since the data time series is not equally spaced, statistical tests which might have identified the noise level could not be applied.

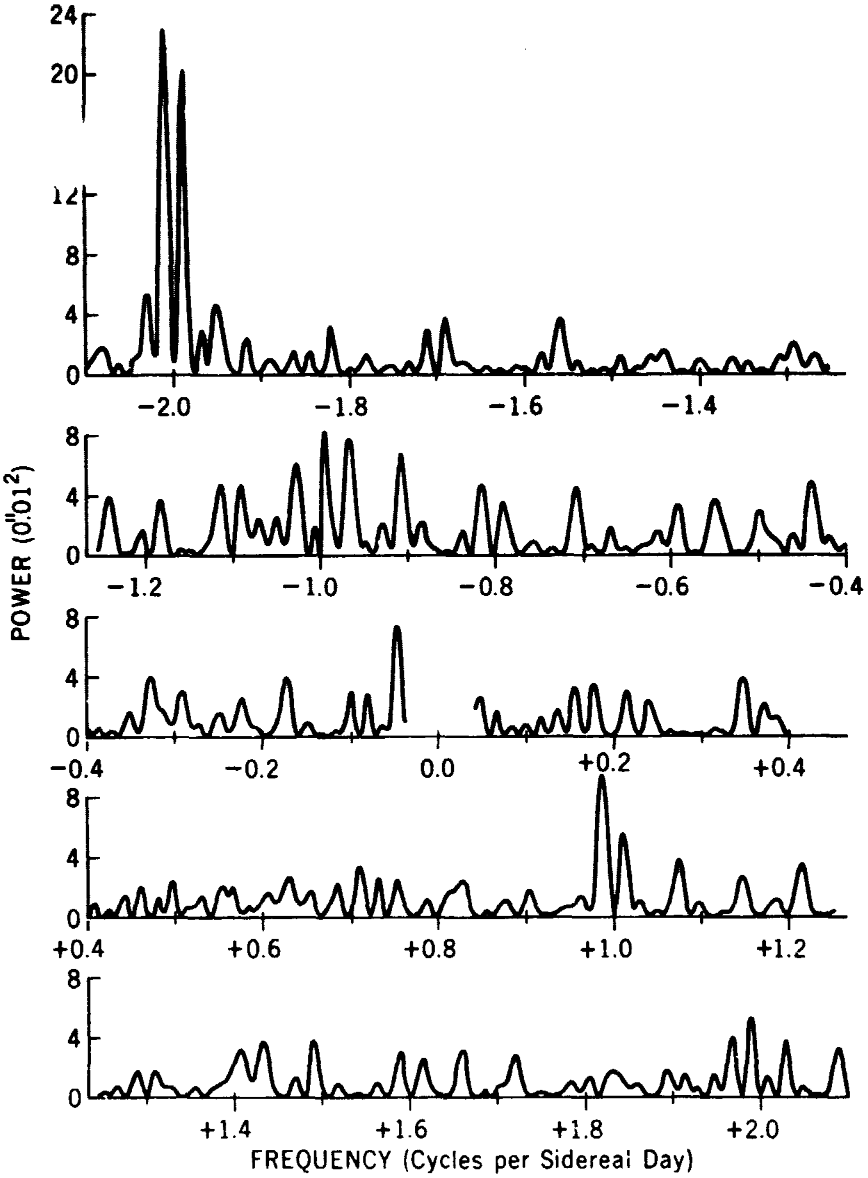

Figure 1. Power spectrum generated with 61 days of star pair latitude data.

The largest feature in Figure 1 is the doublet at -2.00 cycles per sidereal day (cpd). This feature is not really a doublet. The optical observing technique based on meridian passage of a star allows the star catalogue biases to create a "blind spot" in the spectrum at integral multiples of 1.00 cpd. This large feature at -2.00 cpd is most likely a single broad peak split by the blind spot. In fact, the structure at -1.00 and +1.00 cpd can be generated by assuming a broad peak centered at one cycle per solar day and split by a blind spot at one cycle per sidereal day. This is shown in Figure 2 where the line represents the actual power spectrum and the crosses represent the theoretical model.

The theoretical model takes a damped harmonic oscillator line shape

$$F(\omega) = \frac{P \times \left(\frac{\omega_0}{2Q}\right)^2}{(\omega - \omega_0)^2 + \left(\frac{\omega_0}{2Q}\right)^2}$$

centered on the solar frequency 0.997 or -0.997 cycles per sidereal day and multiplies it by a simple V-shaped filter envelope centered on 1.000 cycles per sidereal day

$$H(\omega) = \left|\frac{1. - \omega}{0.012}\right| \qquad 0.988 < \omega < 1.012$$

$$= 1. \qquad \text{otherwise}$$

The best fit indicated by the crosses in Figure 2 is achieved by the following parameter values

Negative Peak $P = 26. \times 0''01^2$
$Q = 130.$

Positive Peak $P = 15. \times 0''01^2$
$Q = 40.$

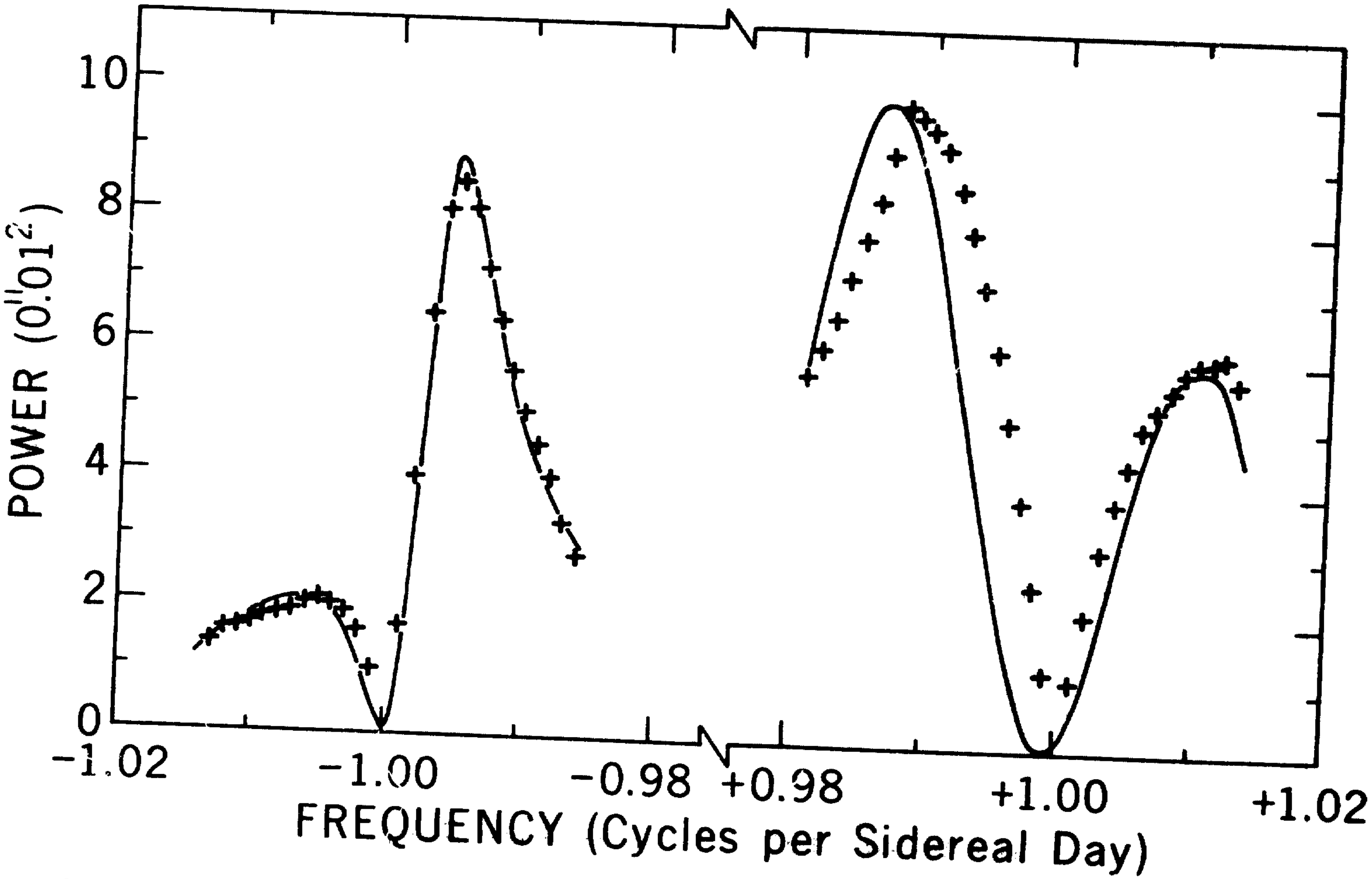

Figure 2. Power spectrum in region of -1.00 and +1.00 cpd. The line is the calculated power and the crosses represent a model calculation based on a filtered damped harmonic oscillator line shape centered on the solar frequency.

The positive peak in Figure 2 appears to be shifted to the left according to the frequency scale. However, a better local frequency marker is the minimum which is known to occur at precisely +1.000 cpd. This minimum is also shifted. Using the minimum to calibrate the frequency scale causes much of the apparent frequency shift to disappear.

The general envelope of the spectrum in Figure 1 indicates an interesting feature. In the region from -1.2 to -0.8 cpd the spectrum envelope is higher than it is in most of the other regions. This frequency band is the location of the tesseral constituents of the solid earth and ocean tides. These tesseral constituents are the only ones in which the perturbing tidal potential has the geometry necessary to cause motion in the pole position. Thus, if any tidally generated polar motion were present, it would be in this frequency band. However, the peaks in this band are not located at the tidal frequencies.

The primary value of Figure 1 is that it highlights the deficiencies of previous high frequency analyses of the latitude variation. These previous analyses (for example, Spencer-Jones [1939], Markowitz and Bestul [1941]) sought to determine certain elastic parameters of the earth by determining the amplitude and phase of the latitude variation at precisely the tidal frequencies. Implicit in this type of study is the assumption that a local maximum occurs at the tidal frequency and that this peak is associated with the tidal potential rather than another physical phenomenon.

In Figure 1, the peaks at the tidal frequencies are conspicuous by their absence. If this analysis had proceeded in the previous manner, the results for the O_1 and M_2 tides would have been 0.″014 ± 0.″006 and 0.″001 ± 0.″006, in the retrograde sense respectively, and 0″.003 ± 0″.006 and 0″.008 ± 0″.006, in the positive sense respectively. Noting that the observing stations are all at the same latitude, these values could then have been associated with tidal deflections of the vertical and tidally induced shifts in the principal axes of the earth.

When these frequencies are seen in Figure 1 it becomes apparent that this simplistic view is not adequate. The major peaks are not at the tidal frequencies. There are a number of peaks in this region with amplitudes larger than $3. \times 0''.01^2$. The periodic phenomena which generate these peaks are not understood. The only possible tidal peak is the small one at the O_1 frequency. When viewed with the nearby peaks it becomes impossible to assert that this peak is due to the tidal potential rather than some phenomenon associated with the larger peaks. Until the major features of the spectrum of the latitude variation are understood, conclusions based on the minor features should be viewed with suspicion.

High frequency analysis of the variarion of latitude opens up for study a new region of the dynamical processes of the earth. The relatively new techniques of satellite laser ranging and long baseline radio interferometry offer the opportunity for an independent data source and subsequent comparison with Figure 1. Present observing schedules are not geared toward providing the high frequency data and would have to be altered to at least three latitude measurements per day. These techniques are not based on the meridian passage of a star and therefore do not have the blind spot at one cycle per sidereal day. And if the data can be acquired as an unbroken series of equally spaced data points, then more sophisticated statistical tests would be able to be applied.

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