Estimating the Fluid Core Resonance Based on Strain Observation

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[Abstract] Esashi Earth Tides Station has been operated for tidal observations from 1979. Among the observations, a long term extensometer data set for 3 components of both free end and middle point transducers are calibrated and corrected to solve the tidal drift and tidal admittances. Based on the estimated admittances of diurnal tidal constituents, the fluid core resonance parameters are obtained as 419.9+/-1.3 sidereal days for the eigenperiod, and 5,900-7,440 for the quality factor. This result is precise enough to compare with the results obtained from other independent methods.

1. Introduction

Since 1979, the Earth tides and the secular crustal motion are observed at the Esashi Earth Tides Station of the Mizusawa Astrogeodynamics Observatory of National Astronomical Observatory by collocating three kind instruments of the gravimeter, the quartz tube extensometers and the water tube tiltmeters. Here after this site is referred to the Esashi station. The data obtained from these instruments clearly indicate that the Esashi station is very stable. For example, the average strain rate in the EW direction is to be about -3×10^{-8} per year in the sense of the contraction as a mean rate over the past 17 years.

The data obtained at the Esashi station have an high potential to study not only the detailed features of the Earth tides but also to study the tectonic phenomena around this area that should be related to the plate motion. We have compiled the strain data obtained from 1980. Based on this data set, we started the researches related to the Earth tide and the secular crustal motion. As a report using the newly compiled data, we will introduce here the analysis results for the fluid core resonance (FCR) due to the resonant motion of the Earth's core introduced by the diurnal tidal forces of the Sun and the Moon. The tidal factors of the strain tides are represented with a pure combination of the Love and Shida number *h* and *l*. There is a possibility that the strain tides reflect the time variations inside the Earth's elastic structural parameters.

The Esashi station (141°20'7"E, 39°8'53"N, +393m) is located on the north side of the Mt. Abara, about 16 km east of the Mizusawa Astrogeodynamical Observatory of NAOJ. The station consists of three observation tunnels and a gravity measurement room. (See Figure 1) The 150 m long tunnel is dug into granite bedrock and offers very stable environment for reliable measurements of the Earth tides and crustal deformation. Three quartz tube extensometers along north-south (NS), east-west (EW) and north-east (NE) directions, respectively and two water tube tiltmeters have regularly been used for observation since June 1979. The observation with a borehole strainmeter started in January 1985. In addition, atmospheric pressure, rainfall and air temperature are also measured. Log-file of the entrances into the observational tunnel, offset of the signals, and occurrences of earthquakes, etc., is also recorded and available in machine-readable forms. A new type of absolute gravimeter (AG) is under construction. A cryogenic superconducting gravimeter (SG) was installed in 1988 for detecting tiny signals from the core of the Earth. Since 2001, the observation of comparing the AG and the SG is carried out once a year. The data observed from the extensometers, the tiltmeters and the borehole strain meter are sampled at every 1-minute interval, then, the data are sent to the Mizusawa campus by the telemeter system.

2. Strain data obtained by the extensometers and data preprocessing

The extensometer consists of a quartz-glass tube as the standard for measurement, supporting frames and a transducer. One end of each tube is fixed on bedrock and the other is kept free. The displacements of the pedestals at the free end (indexed by F) and the middle point (indexed by M) relative to the fixed-end are measured with differential transformers with primary exciting signal of 5 kHz and 2.5 Vp-p. (Tsubokawa & Asari, 1979). The resolution is better than 10^{-10} strain units for each component of the extensometers. To calibrate the transducer and to adjust the zero point of the output signal, each transducer is mounted on sliding stage with a differential micrometer. The routine strain observation at the free ends was started from June 1979. The observation at the middle points began in the beginning of 1980 to check the reliability of the observed strain steps caused by earthquakes (Sato et al., 1980)

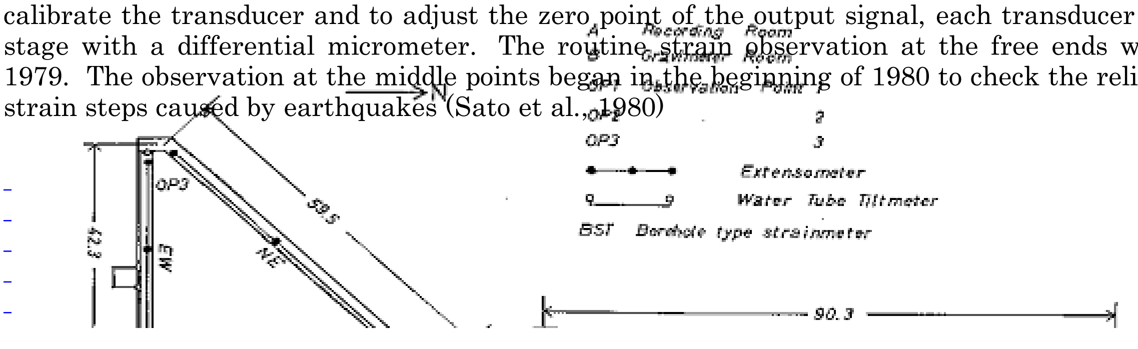


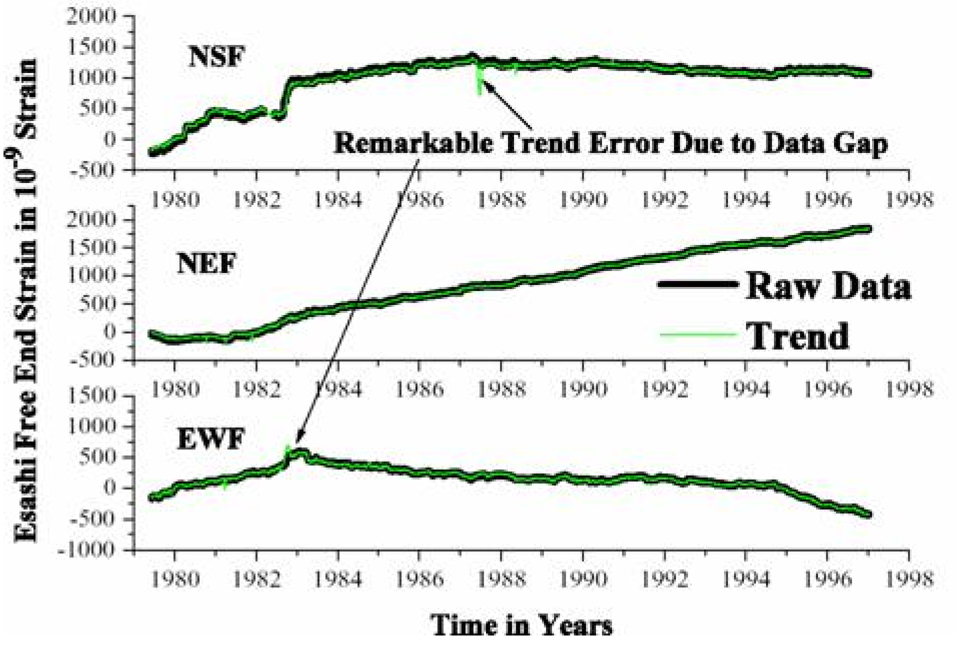
Figure 1. Plan figure of the observation tunnel

Seventeen years (i.e. the period from January 25, 1980 to January 25, 1997) strain data obtained from the 3 extensometers at both the free ends and the middle points are used in this study. Due to the limitation of computer memory, but in order to get high time resolution for estimating the admittance of diurnal and semi-diurnal tidal constituents, the raw 1-minute data were decimated at the rate of every 30 minutes by using moving average method to make a standard database for tidal analysis, although usually 1-hour data are used for the tidal analysis. The original data include irregular parts due to the malfunction of the instrument, the works in the observation tunnel, the power failure and so on. Commonly, the magnitude of step like changes due to these irregular origins are carefully estimated and corrected using the data based on the trend component that was estimated by using the tidal analysis program ‘BAYTAP-G’ (Tamura et al., 1991) without estimating the response to the atmospheric pressure changes, in the empirical way.

In our data analysis, the input data for BAYTAP-G are 30 minutes sampling standard database with its corresponding scale factors, the barometer data obtained at the same period with the same sampling rate as strain data and its scale factors. The barometer data is applied to estimate the strain response to the variation of atmospheric pressure in the tunnel. When running BAYTAP-G, relatively short span and time lag are set at first step. The strain steps, the strain drift and the atmospheric response are estimated together with the amplitudes and phase lags for various tidal constituents in this procedure.

Using the data with the sampling period of 30 minutes can improve the time resolution and precision of the final analysis results for the tidal admittances. By adjusting the step like changes together with solving atmospheric response, it can reduce the systematical biases between the estimated trend and original data to less than 1.5x10^{-8} strain units. If not introducing atmospheric response here, the biases will be 1 order larger or more for the data of last several years. The results from data pre-processing are given in Figure 2.

At east-west direction, the interseismic shortening rate has been investigated by many researchers based on continuous GPS observation in northeast Japan. Two groups of Sheng-Tu & Holts (1995) and Mazzotti (et al., 2000) obtained an average strain rate of about -3x10^{-8} per year in the EW direction. Heki (2004) pointed out that even in the same area, the shortening rate is not exactly the same by different place, and it is about 1x10^{-7} per year around Esashi station in recent years. By linear fitting the drifts of EW free end strain component in Figure 2, its has been obtained as +1.8x10^{-7}, -4x10^{-8} and -2.0x10^{-7} for the year periods of 1979.4-1983.1, 1983.1-1994.6, and 1994.6-1997.0, respectively. The average over the whole observation period is estimated to be at -3x10^{-8} per year, which agrees with the mean strain rate from GPS data analysis (Sheng-Tu & Holts, 1995; Mazzotti, et al., 2000).



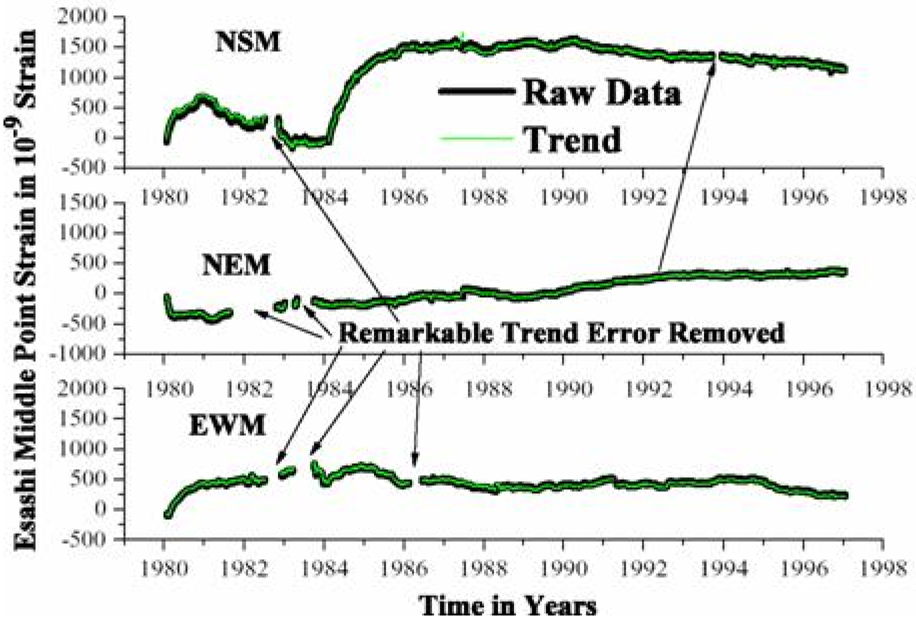


Figure 2, 17 years strain data obtained by Esashi extensometers, which were calibrated by introducing scale factor time series, and were corrected for the irregular steps. 3 free end and 3 middle point components. Thick line and thin line show the observed strain and the strain trend estimated by BAYTAP-G, respectively. Due to the large data gaps in strain observable, BAYTAP-G cannot handle the database perfectly, and introduces remarkable error into trend estimation. However, these errors can be simply removed or be replaced by more reasonable interpolating data.

3. Free core resonance from calibrated strain data

The long term tidal observation will give an independent way to estimate the parameters of fluid core resonance (FCR). Due to the slight misalignment between the rotation axes of mantle and outer core and due to the ellipticity of the core-mantle boundary (CMB) of the Earth, the Free Core Nutation (FCN) will be excited by the pressure torque acting through the CMB, due to the core-mantle coupling. When we observe the FCN on the Earth's surface, it shows a period close to a sidereal day, therefore, the FCN is also called the nearly diurnal free wobble (NDFW). It is responsible of the resonant behavior of the Earth tides in the diurnal band. Precise observation of the FCR parameters gives an opportunity to retrieve the information on CMB related to the core-mantle coupling.

After the drifts and steps of strain components were being estimated, the steps were corrected to the original data. Finally the tidal admittances were estimated from the corrected strain data in one step using BAYTAP-G software. The precision of the result is improved by a factor of 5 or better, compared with the formal errors obtained by Sato(1989) only using 3 years data. The diurnal tidal constituents of O1, P1, K1, Psi1 and Phi1 are used to estimate the FCR parameters in this study. As an example, the observed tidal strain admittance for the NS middle point is given in Table 1.

Table 1. Tidal Admittance of NS Middle-Point Strain. Period: 1980.01.25.0 – 1997.01.21.0

SYMBOL	FACTOR (RMS)	PHASE (RMS)
O1	.27010(.00029)	.581°(.062°)
P1	.25669(.00060)	3.432°(.134°)
K1	.18496(.00019)	6.967°(.060°)
Psi1	.89915(.02479)	13.830°(1.579°)
Phi1	.40144(.01398)	3.286°(1.995°)

Table2.1 FCR parameters estimated from observed and corrected tidal admittances

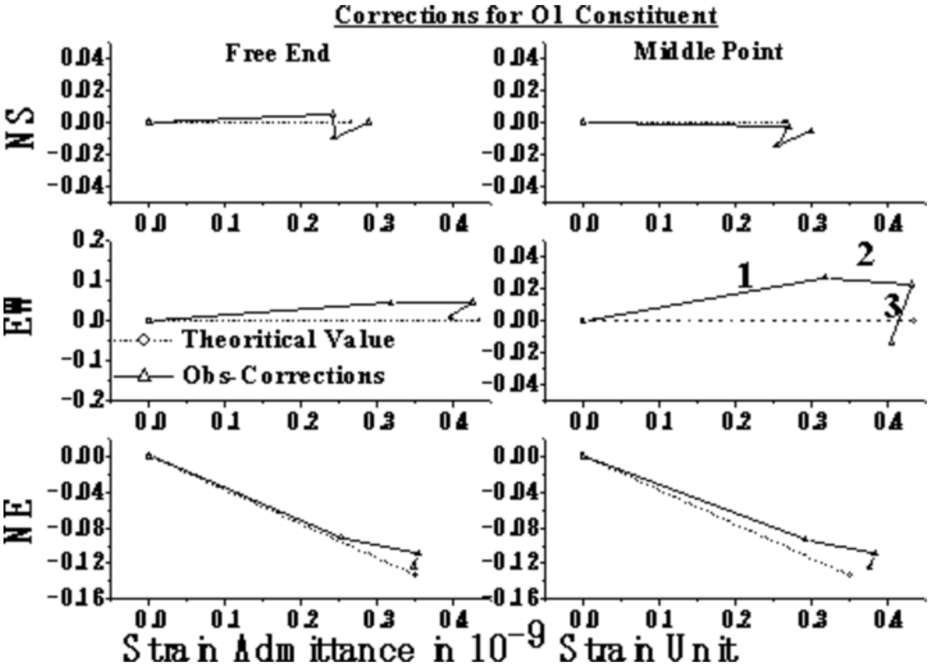
Input Data	Correction	PFCR(s.d.)	PFCR_err	1/Q	1/Q_err
Free_end	none	429.387	4.66	3.139×10^{-4}	6.22×10^{-5}

Free_end	**local**	**417.318**	**1.31**	**$1.053x10^{-4}$**	**$1.35x10^{-5}$**
Free_end	**local&ocean**	**421.732**	**1.6**	**$9.499x10^{-5}$**	**$2.12x10^{-5}$**
Mid_Point	**none**	**418.273**	**14.4**	**$1.725x10^{-4}$**	**$2.86x10^{-4}$**
Mid_Point	**local**	**404.544**	**17.5**	**$2.835x10^{-4}$**	**$1.43x10^{-4}$**
Mid_Point	**local&ocean**	**410.628**	**1.13**	**$1.456x10^{-4}$**	**$1.77x10^{-5}$**

Table2.2 FCR parameters estimated from different combinations of global tidal strain with local and ocean corrections.

Combination Case	**PFCR(s.d.)**	**PFCR_err**	**Q**	**Q_err**
1.Free_end_only	**421.732**	**1.6**	**10500**	**2350**
2.Mid_Point_only	**410.628**	**1.13**	**6870**	**830**
3.Free_end+Mid_Point	**419.867**	**1.31**	**6670**	**770**

Two corrections were applied to the observed strain admittances. One is the local correction, which include the following four effects: namely, the topography, the cavity, the regional and local geologies. Another is the ocean loading correction. The transform matrices estimated by Sato (1989) were adopted to get homogeneous strain from the observed strain, however, the possible error of the matrices was not taken into account in this work. The ocean loading effects were estimated based on NAO'99b ocean tide model, which had been obtained from



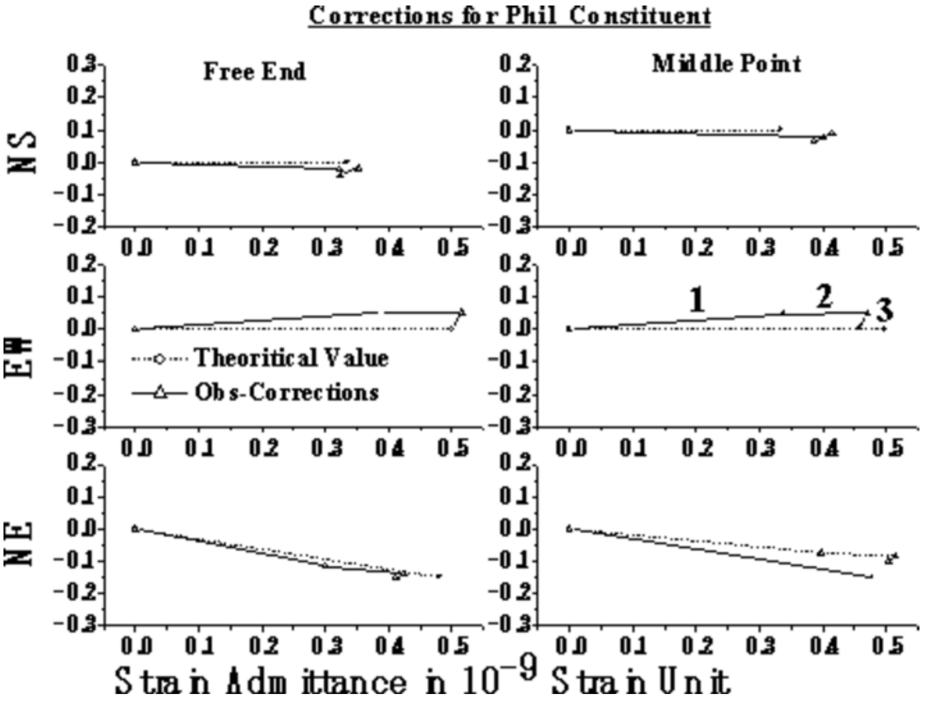


Figure 3. Phasor plots of the observation and theoretical body tides of O1 and Phi1 constituents. The dash line is the theoretical body tide. The solid lines 1,2,3 indicate the observed strains, local effects and ocean loadings respectively.

TOPEX/POSEIDON altimeter data (Matsumoto *et al.*, 2000) and Green's function for 1066A Earth model by using a modified GOTIC2 software (Matsumoto 2001). The strain corrected for these effects is consistent with that corresponding to the strain due to the theoretical body tidal strain. The corrections for O1 and Phi1 constituent of all 6 components are shown in Figure 3 in the form of the phasor plot. The discrepancy is remarkably reduced between the observed tide and the theoretical body tide by correcting for the local effects and the oceanic loading effect. The theoretical admittances of the body tide are calculated by using the Love numbers for the 1066A Earth mode (Wahr, 1981) with a FCR period obtained from VLBI method (Defraigne, *et al.,* 1994&1995).

Based on the Eqs. 6 & 7 in Sato (*et al.*,1994), the admittance of **O1** is used to normalize tidal admittances for other waves. From these normalized body tidal admittances, the SALS (Nakawaga, 1984) code with so called "Marquardt method" for nonlinear least-squares fitting is used to estimate the complex resonance strength parameters **B**s, FCR period (**PFCR**) and quality factor **Q**. Here PFCR and Q are assumed as the common or global parameters for all strain components adopted in the fitting. After finding a set of closest initial value for the parameters to be solved by using a relatively complicated procedure with artificial constrains, all of the parameters were estimated without any constraint conditions for all parameters. The results for FCR parameters estimated from the observed tidal admittances and from corrected tidal admittances are listed in Table 2.1.

Because the observation is obtained at the same station, local effects may introduce large biases into the data analysis. This can be noticed by the large estimation errors for both of **PFCR** and **1/Q** in the table in the case of using observed admittances without any correction. Also, due to the ocean loading effects, **PFCR** will be shortened, and **Q** will be reduced for the global FCR parameters. These phenomena can also be seen in Table 2.1. For the final results, corrected for local effects and ocean loading, FCR parameters are estimated from 3 kinds of combinations of input data sets, calibrated free end data only, calibrated middle point data only, and the combination of them. For the first two cases, the global FCR parameters are set independently and separately. For the third case, the FCR parameters are set the same for both free end and middle point data. The results are given in Table2.2. A shorter FCR period and a relatively larger quality factor are obtained. Among them, result in case 3 is more reasonable than in cases 1 & 2, because the complex resonance strength parameters **B**s are usually different for each strain component, where the global parameter FCR period **PFCR** and quality factor **Q** are homogeneous ones, and will be the same for all strain components.

4. Discussions

Long period tidal data, i.e. strain, tilt and gravity, obtained by Esashi Earth Tide Station may contribute to geophysical research in many directions. In this paper, we calibrated 17 years strain data of the three horizontal components for both free end and middle point transducers of the extensometers, estimated the strain rate at EW direction for Esashi station, and then estimated the FCR parameters as a first report of the research work on long period tidal measurements at Esashi station.

FCR parameters have been obtained from different kinds of observations. Using super conducting gravity data of GGP, Sato (2004) got a new result of 429.66+/-1.43s.d. & 9,350-10,835; from VLBI observation, Defraigne, (*et al.,* 1994&1995) got a result of 433.9 +/-0.5 & 40,000 for PFCR and Q, respectively. Till now, all of the estimated eigenperiods are significantly shorter than the theoretical value, i.e. 460s.d. given by Wahr (1981). It can be explained by a departure from the hydrostatic flattening at the core-mantle boundary. Our result is the shortest among them. This may be partly explained by the possible error in the local transform matrices, and leave this problem as an open topic for the future work. And/or there is a possibility that the small number of the tidal waves used in the fitting is responsible to the obtained short FCR period. This will be checked, and the data analysis will be renewed by introduce more diurnal tidal constituents in number into the fitting procedure. However, as an independent average result from 17 years stable and sensitive strain data, it is precise enough to compare with others. The shorter period of FCR may indicate a larger bias or a departure of the figure of CMB that is expected from hydrostatic theory.

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