17th SYMPOSIUM ON HYDROACOUSTICS

Jurata May 23-26, 2000

PHASE-DIFFERENCE METHODS OF STUDY TRAVEL TIME FLUCTUATIONS OF THE BROADBAND SIGNAL

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Phase-difference methods for a measurement of small time intervals by use of pseudo-random signals are suggested and its applications for processing of experimental data. The significant influence of tidal oscillations on travel time at Hawaii - Kamchatka path is shown. The possibility of an evaluation of the form of a flexible antenna without use of special basic sources is demonstrated.

INTRODUCTION

Now in acoustic researches of ocean it is accepted to use pseudo-random signals such as m-sequences with a carrier frequency. Using of these signals allows to measure a small intervals of time. One of the approaches to solution of this problem is the using of phase-difference algorithms. In this work such algorithm and its applications for the travel times measurements on a stationary path and restoration of the form of a flexible array in ship experiment is considered.

1. PHASE-DIFFERENCE METHOD

The acoustic source emits the M-sequence with a carrier frequency f_0 repeating through an interval, equaled to the length of sequence. Then the accepted signal is divided on the parts, equals to duration of one M-sequence. Then the signal of k part $y_k(t)$ is correlated with a replica of the transmitted signal in the traditional algorithm.

$$b_k(\tau) = \int_t^{t+T} y_k(t) M^*(\tau - t)dt, \qquad (1)$$

where $M(t)$ is a replica of the transmitted signal, T is the length of the M-sequence, $b_k(\tau)$ is the output of a matched filter (or an evaluation of the impulse response of a researched stationary path).

The phase-difference algorithm assumes using values of the cross-covariance function in the points n=1,2... of time or space:

$$R(k,n) = \int_T b_k(\tau) \cdot b^*{}_{k+n}(\tau) d\tau = \rho(k,n) e^{i\varphi(k,n)}, \qquad (2)$$

where *k is the* number of signal parts, which corresponds to current time $t = kT$, n is the shift between the signal parts, $\rho(k)$ is the enveloping a cross-covariance function $R(k,n)$, and $\varphi(k,n)$ is its phase.

It is possible to write difference of travel time $\Delta T = T_p(k) - T_p(k+n)$ approximately

$$\Delta T(k) = \frac{\varphi(n)}{2\pi f_0} \tag{3}$$

A nonzero value $\varphi(k,n)$ is possible only at presence on a researched acoustic path of dynamic processes changing travel time of a signal. The increasing of the value n leads to the increasing of the measurement accuracy. But the same time, the increasing n decreases accuracy of measurement owing to a diminution of cross-correlation value. The optimal value n depends on a level of noise and interval of correlation. It's obviously, that a residual of travel times should not exceed half's period of carrier frequency, so that a phase ambiguity not appears. This condition is possible to satisfy by a diminution n in the most cases. This method is suitable for a research of small time fluctuations.

Derivative of travel time is defined by

$$T_r' = \frac{dT_r}{dt} \approx \frac{\varphi(n)}{2\pi n f_0}$$

Actually the given algorithm allows estimating this parameter.

The possibilities of use of phase-difference algorithms in underwater acoustic were considered in work [1]. The similar phase-difference algorithm for an evaluation of fluctuations of signal travel time is offered in [2].

2. RESEARCH OF INFLUENCE OF TIDES ON TRAVEL TIME.

As known, a basic ATOC task is the definition the global temperature trend of the Earth by using an evaluation of ocean average temperature. This approach offered by Munk and Wunsch [3] assumes presence of connection between water temperature and distribution of sound speed along path. Unfortunately, the magnitude of travel time fluctuations owing to the various reasons (seasonal variations, tides, internal waves and currents) is comparable to year climatic modifications of travel time. Therefore it is necessary to study the properties of these hindering factors.

We investigated fluctuations of travel time on a Hawaii - Kamchatka path. The signals of the American source permanently established near the Hawaiian Islands were registered by the Russian stationary reception system near peninsula Kamchatka. The radiation was carried out with a four-day interval. During a day a package with 44 M-sequences were transmitted six times with an interval at 4 hours. The carrier frequency of an M-sequence was 75 Hz with duration of a series of the order 20-m (1200.32 c). Path length was 4800 km.

The derivative of travel time per few days of 1998 is shown on a fig. 1. The lack of seasonal variations is well visible. The values by derivative of travel time sorted by daytime are shown on a fig. 2. Significant scatters of data were not masking systematic half-day association. It's obviously, that the presence of fast fluctuations of travel time masks the seasonal trend. It is to assume that half-day association was caused by tides, having the same phase approximately.

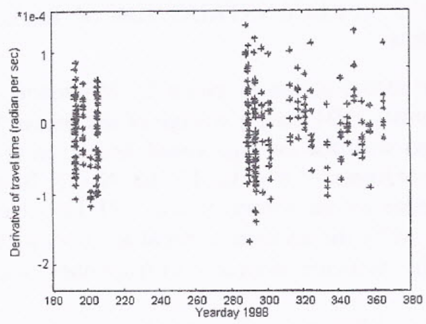

Fig. 1. The derivative of travel time per Yeardays 1998

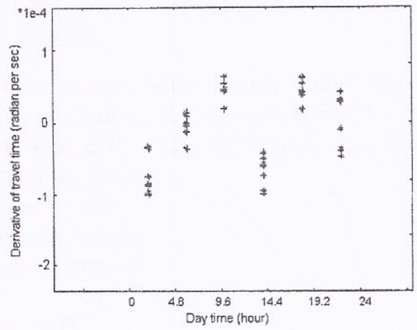

Fig. 2. Derivative of travel time sorted by daytime

To examine this hypothesis the comparison of temporal associations of a vertical speed of ocean surface and derivative of travel time is carried out. On a fig. 3 a vertical speed of a ocean level at the Hawaiian Islands [4] and derivative of travel time of a signal for few measurements in 1998 are shown. The solid line shows a vertical velocity of a modification of a level of ocean in mm/h. The dotted line and asterisks shows derivative of travel time of an acoustic signal accepted on Kamchatka. It is easy to find presence of connection between these two performances.

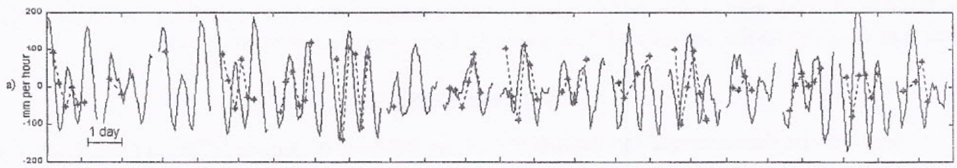

Fig. 3. Vertical speed of a ocean level at the Hawaiian (solid) and derivative of travel time of a signal near Kamchatka (dotted line and asterisks)

To suppose of a linear regression with delay between travel time and level of ocean surface the evaluation of a time delay is obtained by using a method of least squares. The temporal shift between tide magnitude at Hawaii Islands and fluctuations of time of distribution of a signal up to Kamchatka was 2.49-2.51 hours. The path length at latitude is 41 degrees approximately and the delay of geographical time from Hawaii to Kamchatka is 2.73 hours. The large magnitude of residual factors shows the presence of the other reasons (except tide) causing fluctuation and the regression was chosen not enough correctly. It's obviously, that the tide doesn't act at one point of a path, and act distributed at whole path. So it is necessary to take advantage of one of tide models, for example, as in [5], where the tidal model TPXO.2 was used and to calculate how tides influence on travel time along a path.

So the value of phase difference on the M-sequence length has maximum equals 0.02 radian. It means, maximal tide fluctuations of time will be 0.1 sec that corresponds to changing because of climate influence per year.

3.USING PHASE-DIFFERENCE METHOD FOR RECONSTRUCTION OF REAL ARRAY FORM.

The registration pseudo-noise signals with the manipulation of phase by M-sequence code from THETIS-II sources was carried out in summer 1994 during voyage of the research vessel "Akademik Sergey Vavilov". The ship drifted with the average speed 1m/sec in the position with coordinates 5.834 E, 40.763 N (15 June 1994). The distance to the source S was 171 km. The signal was received by the acoustic vertical array with 16 hydrophones. The distance between hydrophones was 7.5 m.

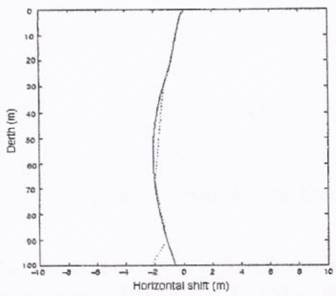

Fig. 4. The reconstruction of real arrav form

The phase difference of complex conjugate multiplication of correlation responses is essential determined by two angles: the arriving angle of corresponding ray and the angle of inclination of array relative to vertical. The angle of arrived ray can be estimated a priori from the hydrological data and used for reconstruction of real array form. The result of such reconstruction is shown on Fig. 4. The calculation of an array form by measuring of difference of phases between the hydrophones and taking into account a priori ray angles is represented by the dot curve. The cubic spline approximation is shown by solid line. The estimation of array form exactly corresponds with the real conditions. The array was not strong enough for the heavy cargo. The bottom of array was connected to a heavy cargo hanged on steel rope. The cargo drew the lower part of array to the vessel and down and its form becomes convex.

4. CONCLUSION

These results demonstrate the possibility of application of phase-difference methods for measuring the small time intervals by use of pseudo-random signals. The significant influence of tidal oscillations on travel time at Hawaii - Kamchatka path is discussed. The possibility of an evaluation of the form of a flexible antenna without use of special basic sources is shown.

This work was supported by Russian Foundation for Fundamental Research, project no. 97-05-65657.

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