論文 / 著書情報
Article / Book Information

論題(和文)	
Title	Differential travel time series of the reciprocal transmission in 1999 ocean acoustic tomography data
著者(和文)	王 勇, 蜂屋 弘之
Author	Yong Wang, Hiroyuki Hachiya
出典(和文)	, Vol. 26, No. 1, pp. 76-78
Journal/Book name	Acoust. Sci. Technol., Vol. 26, No. 1, pp. 76-78
発行日 / Issue date	2005, 1

ACOUSTICAL LETTER

Differential travel time series of the reciprocal transmission in 1999 ocean acoustic tomography data

Yong Wang[1] and Hiroyuki Hachiya[2,*]

[1]*Graduate School of Science and Technology, Chiba University, 1–33 Yayoi-cho, Inage-ku, Chiba, 263–8522 Japan*
[2]*Faculty of Engineering, Chiba University, 1–33 Yayoi-cho, Inage-ku, Chiba, 263–8522 Japan*

(*Received 6 September 2004, Accepted for publication 14 October 2004*)

Keywords: ocean acoustic tomography, underwater sound, reciprocal transmission, differential travel time
PACS number: 43.30.Qd, 43.30.Re [DOI: 10.1250/ast.26.76]

1. Introduction

Ocean acoustic tomography (OAT) [1] is widely recognized as a powerful technique for studying the thermal and current structure of the ocean. A number of sea trials have been conducted since the late 1970's to determine the feasibility of OAT (see [2] for summary).

Sound travels faster in warm water than in cold water. By measuring the travel time of sound over a known path, the sound speed and thus temperature can be determined. Sound also travels faster with a current than against. By measuring the reciprocal travel times in each direction along a path, the absolute water velocity can be determined.

Travel time perturbations due to ocean currents are correspondingly one to two orders of magnitude smaller than travel time signals due to sound speed perturbations. The chief difficulty encountered in performing long-range reciprocal transmissions is the small size of the expected differential travel times, typically only a few milliseconds at 300-km range.

In the conventional method, the differential travel time by the ocean current is measured using amplitude information of the received signal. We presented the phase information of the signal is effective for realizing the high-precision measurement of travel time [3,4]. To measure the small order and short time current fluctuations, we proposed a new measurement technique, referred to complex vector method (CV method), using both the amplitude information and the phase information. In pervious paper we demonstrated preliminary results for several differential travel times using CV method. The preliminary result was promising [5]. In this paper, we present estimation results of the differential travel time series in about 1 month with the distance of 500 km, using the CV method.

2. Experiment

The Central Equatorial Pacific OAT experiment was conducted by the Japan Marine Science and Technology Center (JAMSTEC:the present Japan Agency for Marine-Earth Science and Technology) in December 1998 for two years to study El Niño and the Southern Oscillation (ENSO). Five acoustic transceivers were deployed over the flat beds (T1 to T5; Fig. 1). The transceivers were moored at near the depth of the sound channel axis (1,000 m) of the total depth of about 5,000 m. The motion of each transceiver was tracked using bottom-mounted acoustic transponders, allowing the pulse travel times to be corrected. The 200 Hz (f_0) tomography source with 62.5 Hz bandwidth produced a 1,023 digit, phase-modulated M-sequence signal with a digit length of 2 cycles, giving a total of 10.22 s per sequence. The sequence was repeated 14 times during each transmission, for a total transmission time of 143.22 s. The received signals were sampled at 800 Hz ($4f_0$). Conductivity, temperature, depth (CTD) measurements were carried out during the deployment of the transceivers.

In this paper, we use the acoustic data during April–May 1999. The digitized signal was cross-correlated with a replica of the transmitted sequence to achieve an adequate signal-to noise ratio and a high signal resolution. Clock drift and time delays in the system were corrected. Figure 2 shows a typical reciprocal transmission data of correlated signals along the T3–T4 path obtained in the 1999 OAT experiment. The reciprocal arrival patterns are different in each direction of transmissions, which is mainly due to the presence of ocean current.

The ray paths between T3 and T4 are predicted using the sound speed fields that were determined from CTD measurements. There are arrival signals at about 330.1 s, 330.4 s, 330.7 s and 331.2 s, which correspond to -15, ± 16, $+17$ and -17 ray path, respectively. Each ray path can be labeled with an identifier $\pm n$, where $+$ ($-$) indicates a ray that initially travels upward (downward) at the source and has a total of n upper and lower turning points between the source and receiver. The stable and strong -15 path is used to measure the time series of travel time differences in this paper.

3. Estimation of differential travel time series

We proposed a new measurement technique of travel time termed as the complex vector (CV) method and demonstrated the ability of this method by computer simulation and the actual measurement of received signals [5]. In this method, we first discriminate an approximate signal position using the maximum value of the quotients of the amplitude correlation coefficient and the complex vector distance between the received and reference signals on the demodulated signal

*e-mail: office@hachiya.net

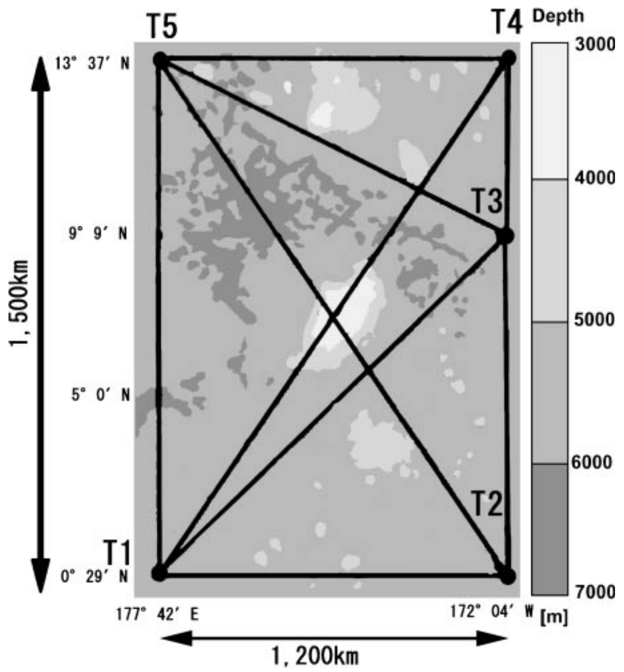

Fig. 1 Transceiver position (black solid circles T1–T5) in the Central Equatorial Pacific OAT experiment. Gray scale bar and solid line show water depth and eigenray paths between transceivers, respectively.

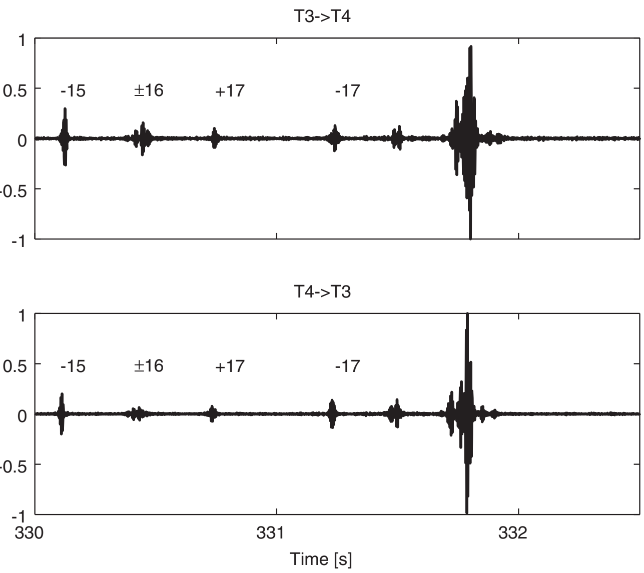

Fig. 2 Reciprocal arrival patterns at 500 km along the T3–T4 path, 18:00 12 May 1999.

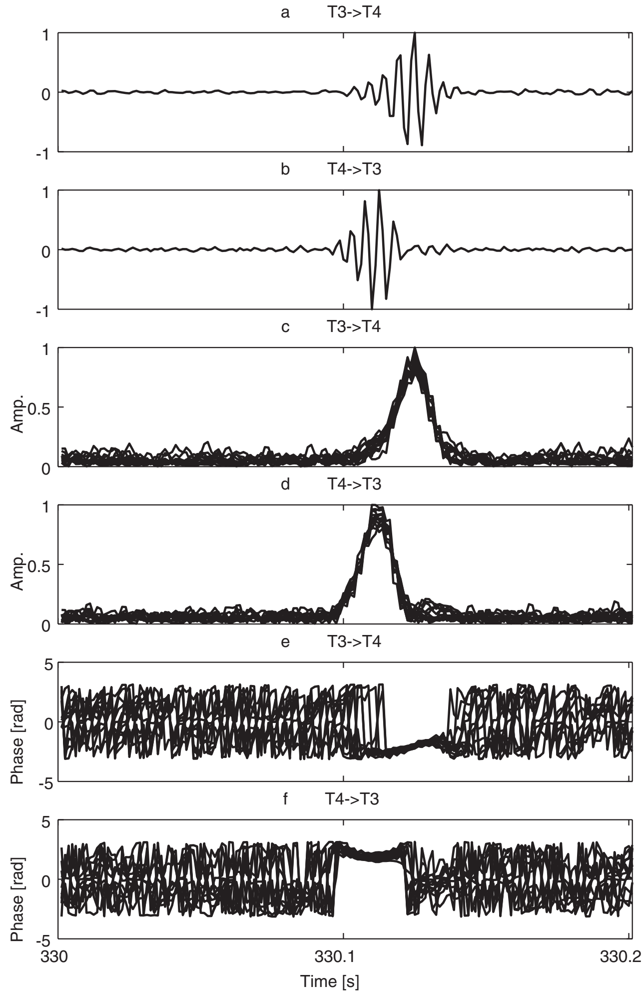

Fig. 3 Reciprocal arrival patterns (a, b), amplitudes (c, d) and phases (e, f) of 13 shots in ray path −15.

complex plane. And secondly, the travel time of the received signal is obtained by introducing the phase analyses of the complex received signals. From the theoretical analysis, we can estimate the travel time with error of 0.1 ms in SNR = 13 dB of the correlated signal.

We estimate differential travel time series of the ray −15 reciprocal transmission along T3–T4 path in 1999 data. Figure 3 shows the correlated signals (a, b), amplitudes (c, d) and phases (e, f) of the −15 ray path obtained by the reciprocal transmissions. The consecutive 13 amplitudes and phases are superposed in one figure. The overall structures of signal are almost identical to each other. The stability of time series of travel time differences is remarkable.

Figure 4 shows two-dimensional plot of the correlated signal amplitude between T3 and T4 from 10 April 1999 to 20 May 1999 (Fig. 4 a and b), and differential travel times Δt of −15 path (Fig. 4 c). The differential travel time between T3 and T4, Δt is given by

$$\Delta t = t_{43} - t_{34},$$

where t_{43} is the time in the direction from T4 to T3, t_{34} is the time in the reverse direction. The fluctuation in travel times of −15 path in the reciprocal transmission is very similar (Fig. 4 a and b), which was caused by transceivers position drift and temperature perturbation. The time series of travel time differences (Fig. 4 c) of −15 path is computed using the CV method. The high-frequency variation as shown Fig. 4 c is probably due to tides and internal-wave-related fluctuations. The long-term variation with a low-frequency trend is also evident in Fig. 4 c, which is most likely a result of the passage of a mesoscale feature. The passage of a mesoscale feature seems to be reversed after April 30.

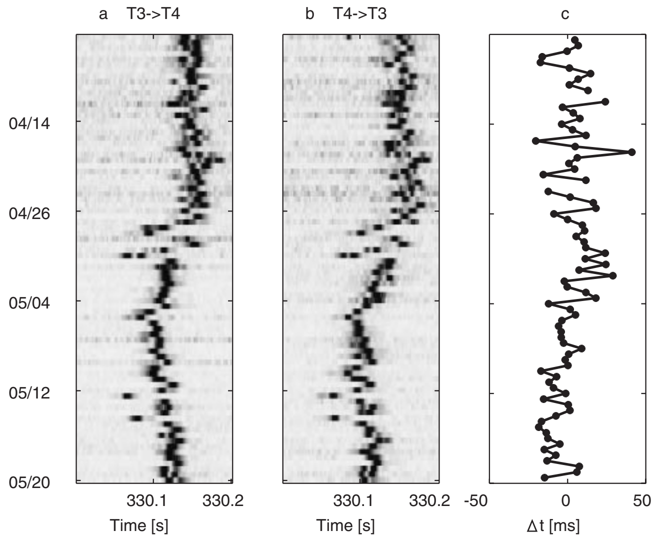

Fig. 4 Two-dimensional plot of the amplitude of the correlated signals between T3 and T4 (a, b) and differential travel time series (c) from 10 April 1999 to 20 May 1999.

4. Conclusion

We presented the estimation results of the differential travel time series in reciprocal transmission data collected during the tomography experiment performed by JAMSTEC in 1999 at the Central Equatorial Pacific. The CV method was used for the estimation of differential travel times using reciprocal transmissions. The differential travel time series of -15 path have reasonable magnitudes, and we concluded presumably that the overall trend of low-frequency is caused by mesoscale fluctuations in this ocean region.

Acknowledgments

This research is partly supported by the Grant-in-Aid for the Creation of Innovations through Business-Academic-Public Sector Cooperation of the Japan Ministry of Education, Culture, Sports, Science and Technology.

References

[1] W. Munk and C. Wunsh, "Ocean acoustic tomography: A scheme for large scale monitoring," *Deep Sea Res.*, **26**, 123–161 (1979).

[2] W. Munk, P. Worcester and C. Wunsch, *Ocean Acoustic* Tomography (Cambridge University Press, Cambridge, 1995).

[3] Y. Wang, H. Hachiya, T. Nakamura and I. Nakano, "Estimation of the stability of acoustic reciprocal transmission in long-range propagation at the central equatorial pacific," *Jpn. J. Appl. Phys.*, **41**, 3525–3529 (2002).

[4] Y. Wang, H. Hachiya, T. Nakamura and I. Nakano, "Estimation of the travel time using the new measurement technique for the long-range transmission," *Jpn. J. Appl. Phys.*, **42**, 3206–3211 (2003).

[5] Y. Wang, H. Hachiya, T. Nakamura and H. Fujimori, "Precise measurement of travel time difference for acoustic reciprocal transmission," *Jpn. J. Appl. Phys.*, **43**, 3169–3175 (2004).