

# MEASUREMENTS OF THE PROPAGATION TIME OF LORAN-C SIGNALS

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## Abstract

LORAN-C signals of Iwo Jima (9970-M) and Hokkaido (9970-X) of the Northwest Pacific chain were received at 21 locations in northern Japan to estimate the accuracy of time comparison by the LORAN-C method. The distance between transmitting sites and receiving sites ranges from 24 km (9970-X to Onbetsu, Hokkaido) to 1777 km (9970-M to Ajigasawa, Aomori). The Navy Navigation Satellite System was used to determine the antenna location to an accuracy of  $\pm 10$  m, which is necessary to estimate the propagation time. The secondary phase is calculated by the Millington-Pressey method using Brunav's approximate formula for secondary phase computation and an effective conductivity map. The phase delay shows a general tendency of +0.65 microseconds per 100 km with respect to a wave moving at vacuum velocity. The range of deviation is  $\pm 0.5$  microseconds. The observed phase shows the additional delay of about 0.35 microseconds per 100 km. With this correction applied, the observed phase deviates usually in the range of  $\pm 0.5$  microseconds. However, sometimes the observed phase shows deviations as much as  $\pm 1.5$  microseconds, which seem to be due to the terrain effect.

## INTRODUCTION

The LORAN-C signals reveal a very high precision potential in time comparison as stable as  $\pm 0.1$  microseconds or better in the region where the ground wave is utilized. The LORAN-C method, however, sometimes shows pretty large offsets in time epoch comparison compared with other, for example portable clock, methods. The main purpose of this paper is to estimate the accuracy of time comparison via the LORAN-C method. Discussions are confined to the ground wave. There are some problems which are concerned with time comparison, such as the identification of the reference tracking point, system delay calibration, and propagation delay estimation. The accuracy of the system delay calibration is around  $\pm 0.2$  microseconds, which includes the effect of delay variations according to the setting of the center frequency of the notch filters for the Decca signals (Horiai, et al. 1983). The propagation delay over sea water can be estimated pretty accurately. The one over land is pretty erroneous and limits the time comparison accuracy. So, the discussion will be made mainly on the accuracy of estimation of the propagation time of the ground wave over land. We would like also to estimate the effect of terrain on ground wave propagation by experiments, because the effect seems to

be strongly associated with the accuracy of time comparison. The terrain effect is considered to be dependent on the topography of the site and experimental examination is indispensable.

## OUTLINE OF THE HARDWARE

The received signals are Iwo Jima (9970-M) and Hokkaido (9970-X) of the Northwest Pacific chain. The receiving sites are 21 points in northwest Japan as shown in Fig. 1. Distances of the propagation paths over sea, land and mixed range from 24 to 1777 km. Two sets of LORAN receivers, Austron model 2000C and Aerospace Research Inc. model LFT-504 were used at the mobile sites and fixed site, Mizusawa, respectively, to compare the phase of the received signals. The time differences between 9970-M/X and UTC(ILOM) were monitored regularly at the fixed site. Loop antennas were used with both receivers and were set to point to the transmitting sites.

A Hewlett-Packard cesium beam clock model 5061A was used as a portable clock (PC) with the aid of a portable power supply.

The Navy Navigation Satellite System receiver, Magnavox model MX-1502, was used to determine the location of the mobile sites. The formal error of the estimated three dimensional coordinates are about  $\pm 10$  m after a data accumulation of twenty four hours. Measurements were conducted automatically with the aid of a laptop computer system, Epson model HC-88. Ambient temperature was also recorded, to monitor the rate change of the portable clock due to temperature change. The temperature coefficient of our portable clock was determined in our laboratory as  $+1.0 \times 10^{-13}$  per degree before the experiments. We tried to maintain the ambient temperature as stable as  $\pm 5$  degrees so that the clock error remains within  $\pm 0.1$  microseconds during the experiments. The effects of magnetic field and humidity seemed to be less than  $\pm 0.1$  microseconds and they were not monitored throughout our experiments.

## OUTLINE OF THE EXPERIMENTS

The experiments were conducted as follows:

Year	Received Signals	Visited Sites
1984	9970-M	Miyatojima, Hanaizumi, Wakuya
1985	9970-M	Katsuura, Tsukuba
	9970-X	Erimo, Kosode, Taro, Tsukuba
1986	9970-M	Kizukuri, Ajigasawa, Odate
		Takanosu, Maebashi, Noshiro, Inubo
	9970-X	Maebashi, Sano, Shibetsu, Hinata
		Onbetsu, Makubetsu, Inubo

Time synchronization between UTC(ILOM) and 9970-X was made using the received value at Onbetsu, Hokkaido where the distance from the transmitting station was 24 km and is considered to be the best to obtain time synchronization accurately, because the error of the time delay estimation seemed to be the smallest.

Time synchronization between 9970-M and 9970-X was confirmed by receiving both signals at Cape Inubo in the Chiba prefecture, where both propagation paths were over sea water.

Phase deviations were derived as follows; 9970-M/X - UTC(ILOM) are regularly monitored at Mizusawa and labeled  $\alpha$ ; time difference data 9970-M/X - UTC(ILOM) is labeled  $\beta$ ; phase deviations

are obtained by subtracting  $\mathcal{A}$  from  $\mathcal{B}$ . The data were reduced to the same epoch by interpolation. corrections were made for propagation delay, system delay and emission delay (Horiai, et. al., 1983)

The secondary phase was calculated by the Millington-Plessey method using Brunav's approximate formula for phase delay computation (Samaddar, 1979; Brunav, 1977) with the aid of the effective conductivity map (CCIR, 1986), where the terrain effect is included. The formula C of Brunav's paper which has eight variable coefficients was used. Permittivity was set at 81 and 15 for sea and land, respectively. The parameter (alpha) which is connected with the lapse rate of the Earth's atmosphere is taken as 0.75. The method explained here to calculate the secondary phase will be called "our method" hereafter.

## RESULTS

Time synchronization was attained between LORAN-C(9970-M/X) and UTC(ILOM) to an accuracy of about  $\pm 0.2$  microseconds.

Time synchronization was confirmed between 9970-M and X to an accuracy of about  $\pm 0.1$  microseconds.

The estimated secondary phase delay by our method has a general tendency of +0.65 microseconds per 100 km in northern Japan with a range of deviation of  $\pm 0.5$  microseconds as shown in Fig. 2. The observed phase deviation becomes larger by this amount if we use the above linear relation instead of the delay calculated by our method.

The observed phase variation shows that additional phase delay of +0.35 microseconds per 100 km is necessary in addition to the secondary phase delay calculated by our method.

The observed phase usually shows a discrepancy in the range of  $\pm 0.5$  microseconds with exceptions of +1.5 microseconds observed at Erimo, Hokkaido and -1.5 microseconds observed at Noshiro, in the Akita prefecture if the correction of +0.35 microseconds per 100 km is made in addition to the secondary phase delay calculated by our method.

Phase deviations of  $\pm 0.2$  microseconds and offset of -0.2 microseconds were observed for the propagation path in the distance range from 1200 to 1500 km over sea water. The negative offset Shows that the conductivity of the sea water is smaller than 5 S/m, if the ground conductivity of 0.01 S/m is correct for the propagation path from Hokkaido station to Onbetsu.

## DISCUSSION

The additional phase delay of +0.3 microseconds per 100 km seems to be due to the terrain effect and partly due to the low conductivity layer which is just under the Earth's surface.

The large phase delay observed at Erimo is probably due to steep mountains which are just in front of the site.

The large phase advance observed at Noshiro is probably explained by a smaller effect of terrain than expected, because this site is 100 km away from the mountains.

The conductivity map which was used here is for the frequency of 100 MHz. The map for 100 kHz would improve the accuracy of the estimation of the propagation time of the ground wave. The effect of the terrain would, however, be larger than the one which would be improved by using the more precise value for the conductivity. The phase integration method would pursue the terrain effect more effectively.

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## **REFERENCES**

- 1) Brunavs, P., 1977, Phase lags of 100 kHz radio frequency ground wave and approximate formulas for computation
- 2) CCIR, 1986, World atlas of ground conductivities, Document 5/1015-E, XVIth Plenary Assembly, Dubrovnik, p.75
- 3) Horiai, K., M. Fujishita, T. Hara, M. Aihara, 1938 Clock comparison system at the International Latitude Observatory of Mizusawa, Proc. Int. Latit. Obs. Mizusawa, No. 22, pp 1-9
- 4) Samaddar, S. N., 1979, The theory of LORAN-C ground wave propagation—A review, Navigation, Vol. 26, No. 3, pp. 173-187

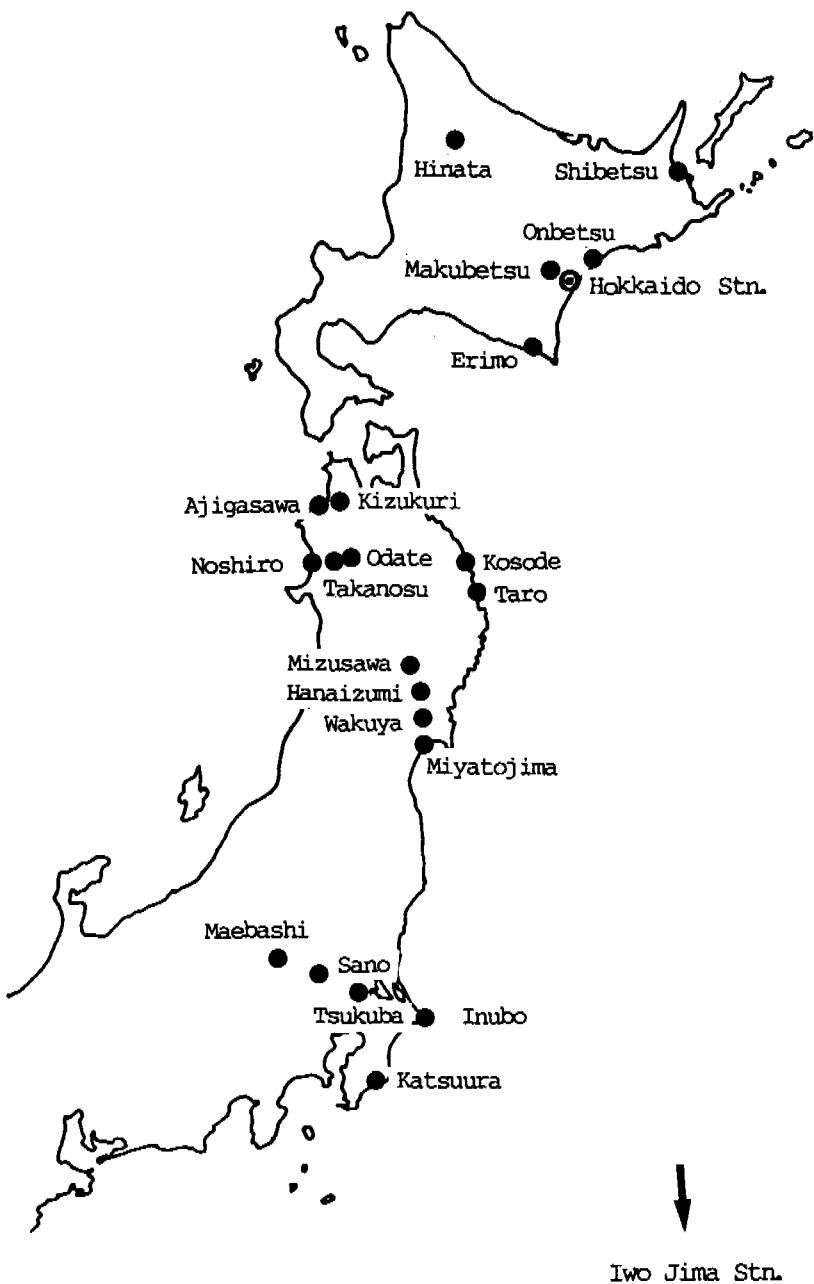


Figure 1. Sites of experiments of Loran-C receptions. The signal from Hokkaido is received through mountainous region at Hinata, Erimo, Mizusawa, Tsukuba, Sano, and Maebashi. Odate, Takanosu, Noshiro, Kizukuri, and Ajigasawa are in the similar situation as above for the signal from Iwo Jima.

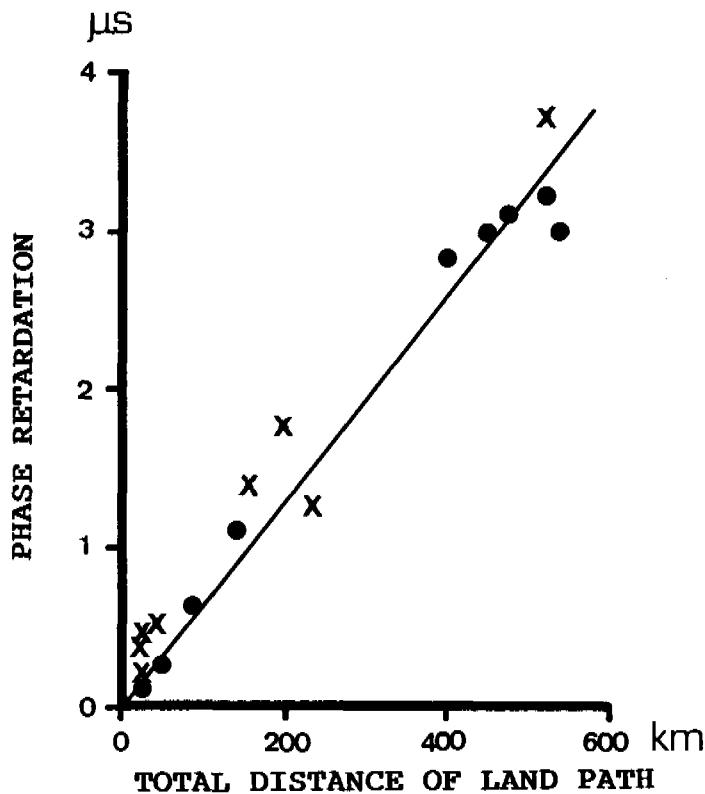


Figure 2. Calculated secondary phase delay shown in units of micro-seconds. The integrated distance of the land path of the propagation of the ground wave is taken for abscissa. The dots are for the received data from Iwo Jima and crosses are Hokkaido. The thin line shows the phase delay of +0.65 micro-seconds per 100km in respect to a wave moving at the vacuum velocity.

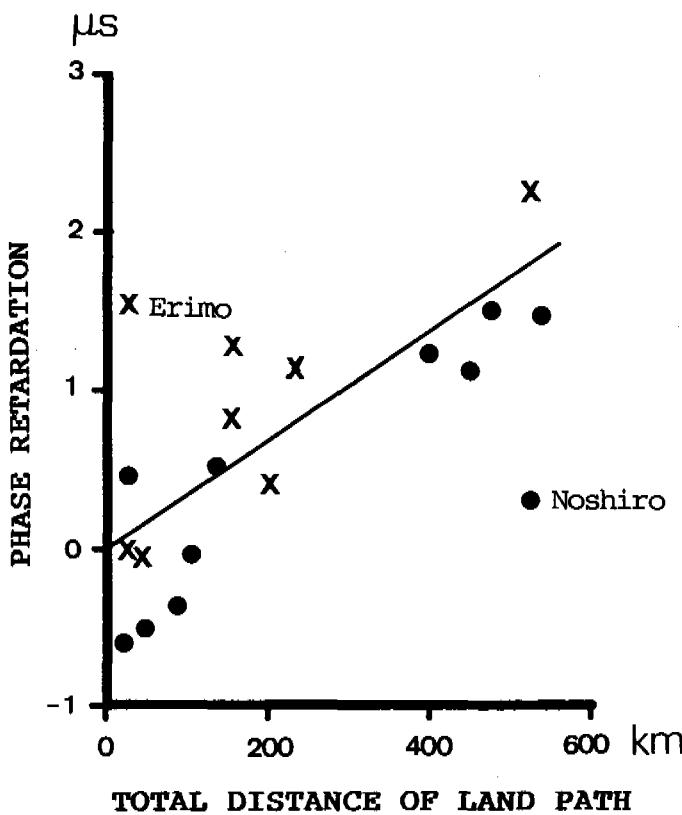


Figure 3. Phase deviations of received signals. The symbols and abscissa have the same meaning as Figure 2. The thin line shows the phase delay of +0.35 micro-seconds per 100km. The received sites are shown only for Erimo and Noshiro because these show very large deviations.