INTERNATIONAL TIME AND FREQUENCY COMPARISON FOR LONG TERM VIA VLF AND LORAN-C

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ABSTRACT

The results are given of the time and frequency comparison for about eight years between Radio Research Laboratories(RRL), Tokyo and the U. S. Naval Observatory(USNO), Washington, D. C. via the VLF transmission, NLK, on 18.6 kHz from Jim Creek, Washington and Loran-C transmission from Iwo-Jima.
The phase of the received signal from Jim Creek for daytime path showed a seasonal variation, and was the most stable in summer. The values of stability of frequency comparison, $\sigma_y(\tau)$, between RRL and USNO in summer were $\simeq 1 \times 10^{-11}$ and $\simeq 6 \times 10^{-13}$ for the averaging times of one day and one month, respectively. The long-term stability of the time comparison in summer was about 2 μs (1σ) for recent six years.
On the other hand, long-term stability of time comparison via Loran-C was as good as 0.3 μs for recent four years because of the improvement in the Loran-C monitoring system of the U. S. Coast Guard and USNO including the time transfer by satellites.

Reception of VLF transmission from NPG/NLK[1] commenced in 1964 at RRL and that of Loran-C from IWO-Jima in around 1965. The locations of transmitters of NLK and Loran-C and receving sites are shown in Fig. 1.

In the case of NLK, daily values of phase of the received signals at RRL[2] and USNO[3] for the daytime paths ($\sim$ 7700 km and $\sim$ 3700 km, respectively) are used, and they are shown by (a) UTC (RRL)-NLK and (b) UTC (USNO)-NLK in Fig. 2. Seasonal variations are found in (b) as well as (a), the amplitude of the former is much larger than the latter. After removing the long-term drifts in (a) and (b), $\sigma_y(\tau)$ for UTC (RRL)-NLK and UTC (USNO)-NLK were calculated for winter as well as summer and plotted in Fig. 3 (a) and Fig. 3 (b). The difference of the phase values between (b) and (a) in Fig. 2 gives the relative time difference between USNO and RRL, and corresponding values of $\sigma_y(\tau)$ are plotted in Fig. 3 (c). The values for summer are as follows:

$$\sigma_y(1\ \text{day}) \simeq 1 \times 10^{-11}, \quad \sigma_y(10\text{days}) \simeq 1 \times 10^{-12},$$

and $$\sigma_y(1\ \text{month}) \simeq 6 \times 10^{-13}$$

The values of the time difference between USNO and RRL, via Loran-C, are plotted at intervals of ten days associated with the values via portable clock of USNO. Relative variations are very small. Fig. 4 shows the variations of mean values for 90 days, centered on the summer solstice, of UTC (USNO)-UTC (RRL) via NLK (Fig. 2) relative to the corresponding mean values of that via Loran-C. Scatter of the values as a whole is as large as 10 μs in one sigma, but it is only 2 μs for the period 1972 to 1977 because an old homemade receiver was replaced in 1972 by a new commercial one (TRACOR 599-J). No significant correlation is found from Figs. 2 and 4 between the phase and the sunspot number in the long term.

Fig. 5 shows the relation between the amplitude of yearly variation of time difference and the sunspot number, but it is not evident whether the correlation exists or not, because the number of data is too small.

As to the Loran-C, the data analysis was made of the published values of time of emission from Iwo-Jima by RRL(2) and USNO (3) after 1969. Since the greater part of the propagation path from Iwo-Jima to Tokyo consists of sea water, day-to-day phase variations of the received signal at RRL have been 0.1 μs or so. Stability of the time difference between RRL and USNO via Loran-C, with respect to the time difference via the portable clock is shown in Fig. 6. The stability has been very good — about 0.3 μs (1σ) — because of the improvement in the Loran-C monitoring system of the U.S. Coast Guard and USNO including the time transfer by satellites.

Besides, the phase stability of several types of Loran-C receivers has been investigated in Japan by the Radio Research Laboratories and the Tokyo Astronomical Observatory. The analysis of four years of signal reception data from these two laboratories produced a standard deviation of less than 0.3 μs and indicated that the yearly mean could vary by as much as ± 0.3 μs, corresponding to a rate of about 1×10^{-14} for a year. The magnitude of the receiver delay instability is therefore not of great significance even in frequency comparisons among recent primary atomic standards (4).

References:

(1) Yoshio Azuma, Results of the phase measurement of VLF radio waves received from NPG/NLK, Journal of the Radio Research Laboratories, Vol. 13, No. 65, pp. 13-23, January 1966.

(2) Standard Frequency and time Service Bulletin, Radio Research Laboratories, Koganei, Tokyo, JAPAN.

(3) Daily Phase Values and Time Differences Series 4, U. S. Naval Observatory, Washington, D. C.

(4) CCIR Report 363-3 (Rev. 76).

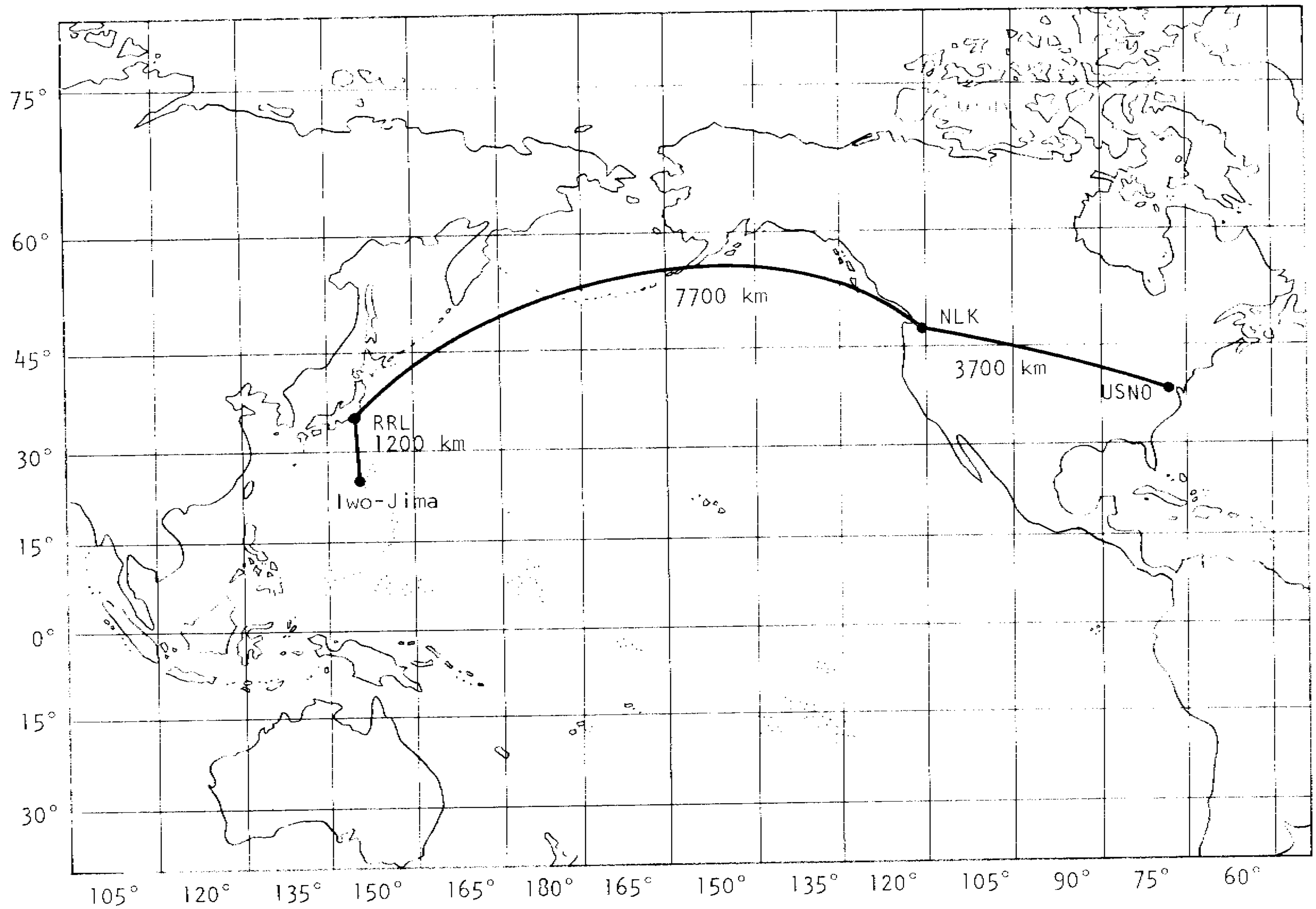

Fig. 1 Locations of transmitters of NLK and Lorna-C and receiving sites.

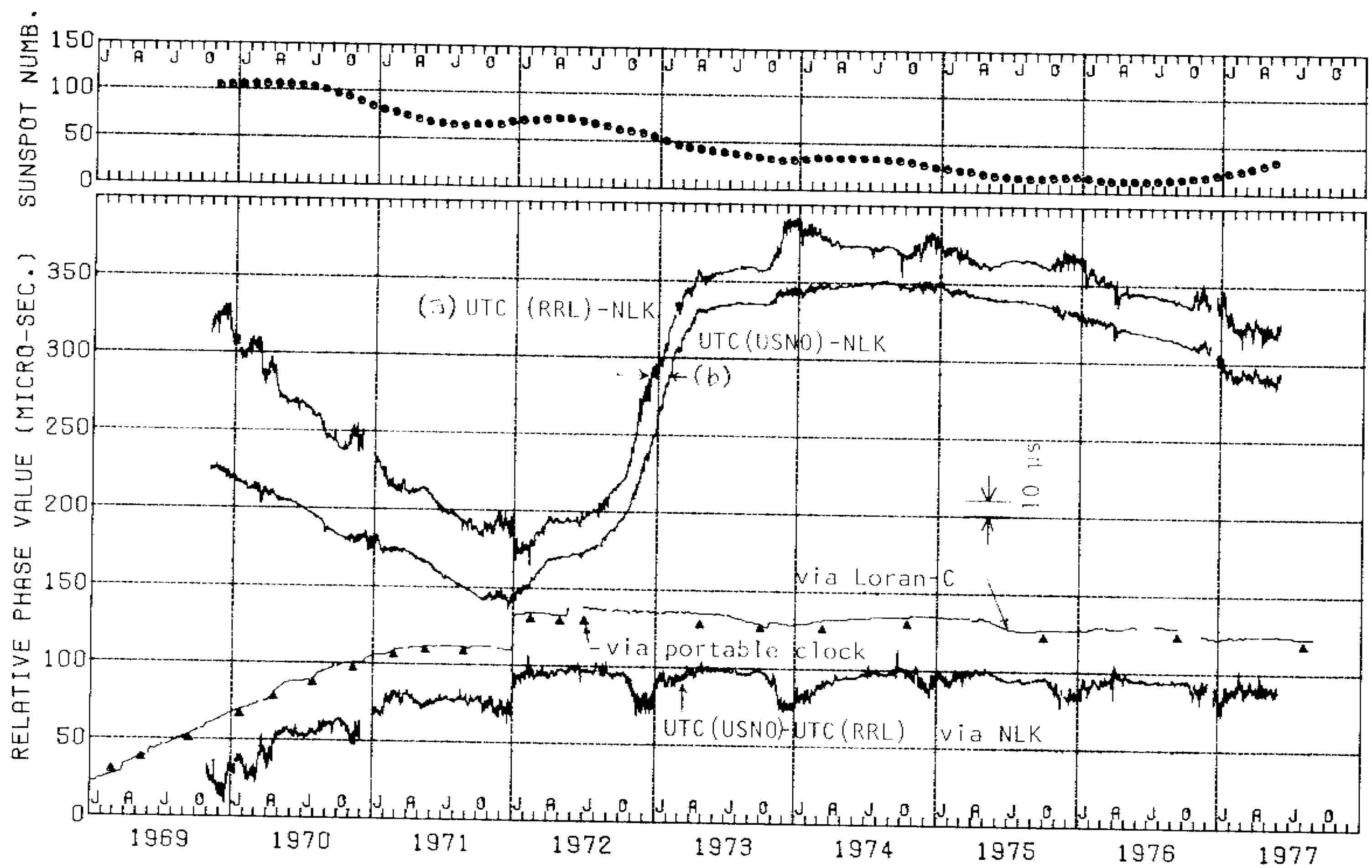

Fig. 2 Time comparisons between RRL and USNO via NLK, Loran-C and Portable clock.

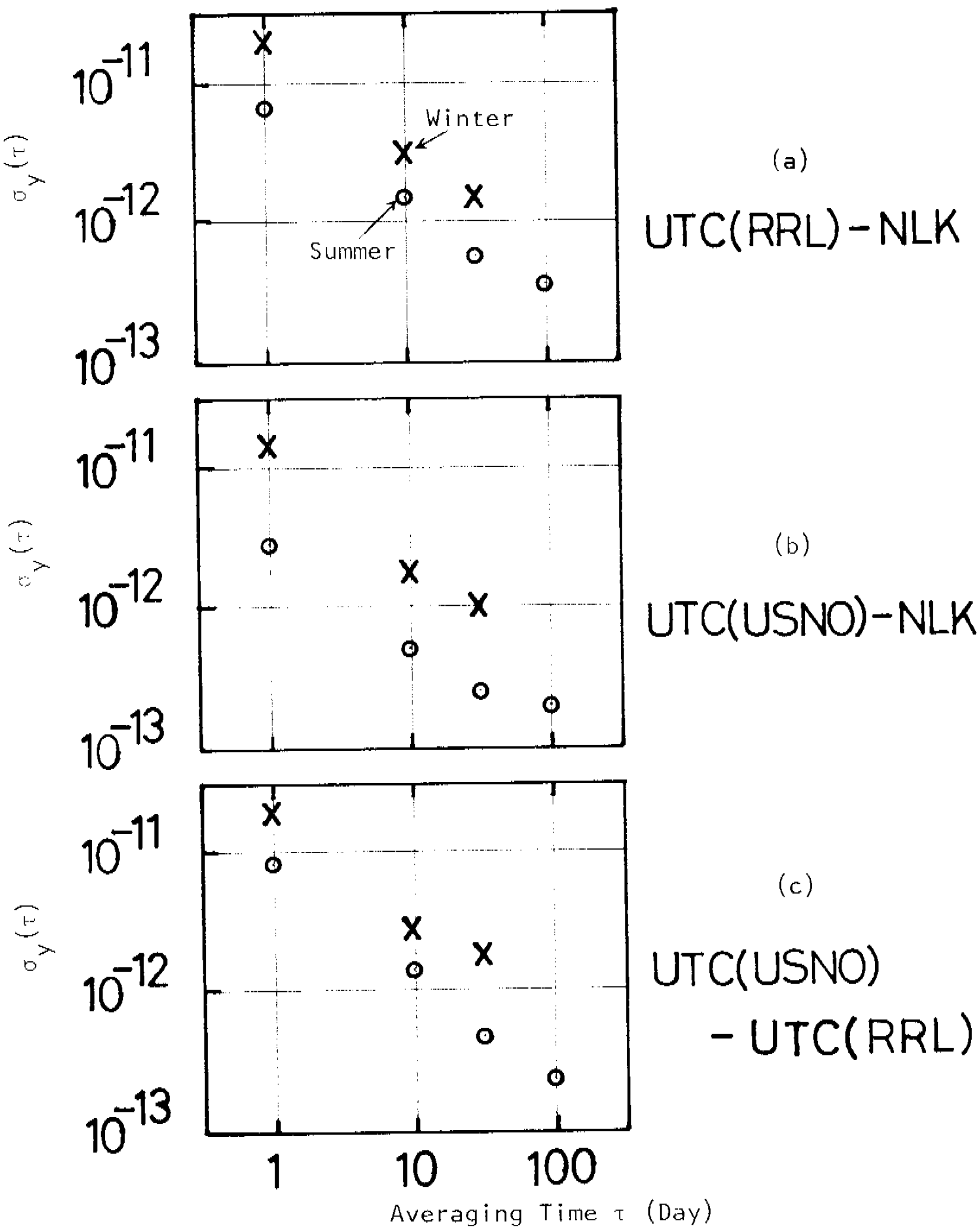

Fig. 3 Stabilities of received signals from NLK at RRL (a) and USNO (b), and of the time difference between RRL and USNO via NLK (c).

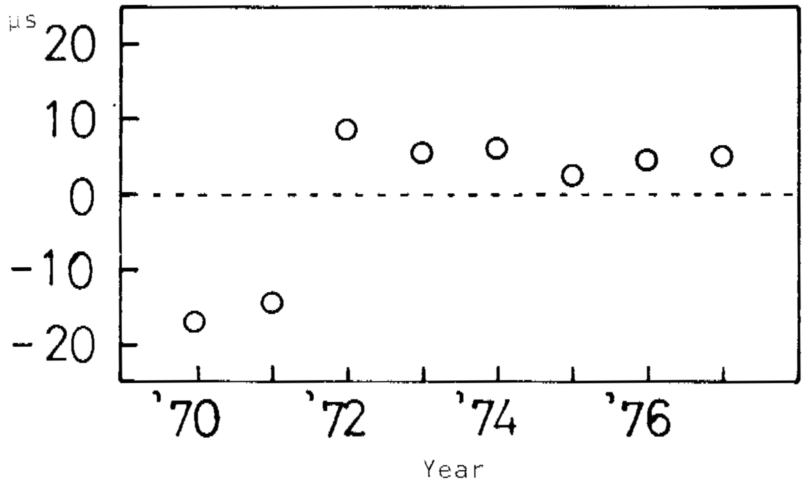

Fig. 4 Long-term stability of the time comparison via NLK relative to that via Loran-C.

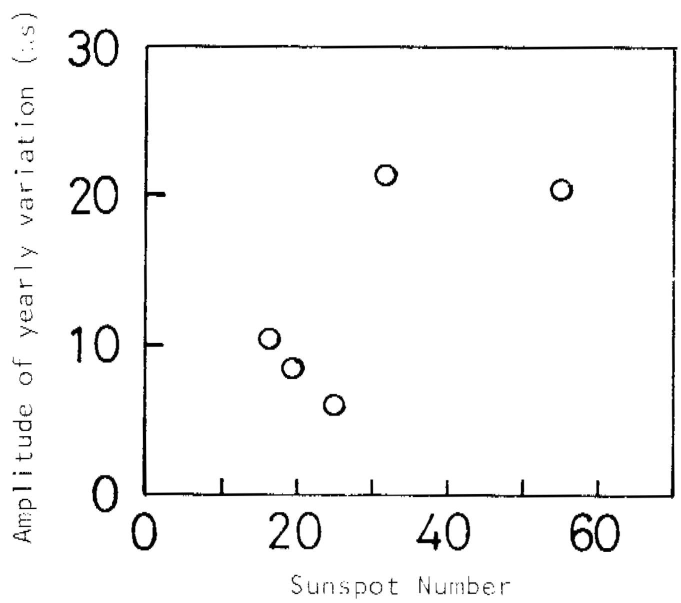

Fig. 5 Correlation between the amplitude of yearly variation of time difference and sunspot number.

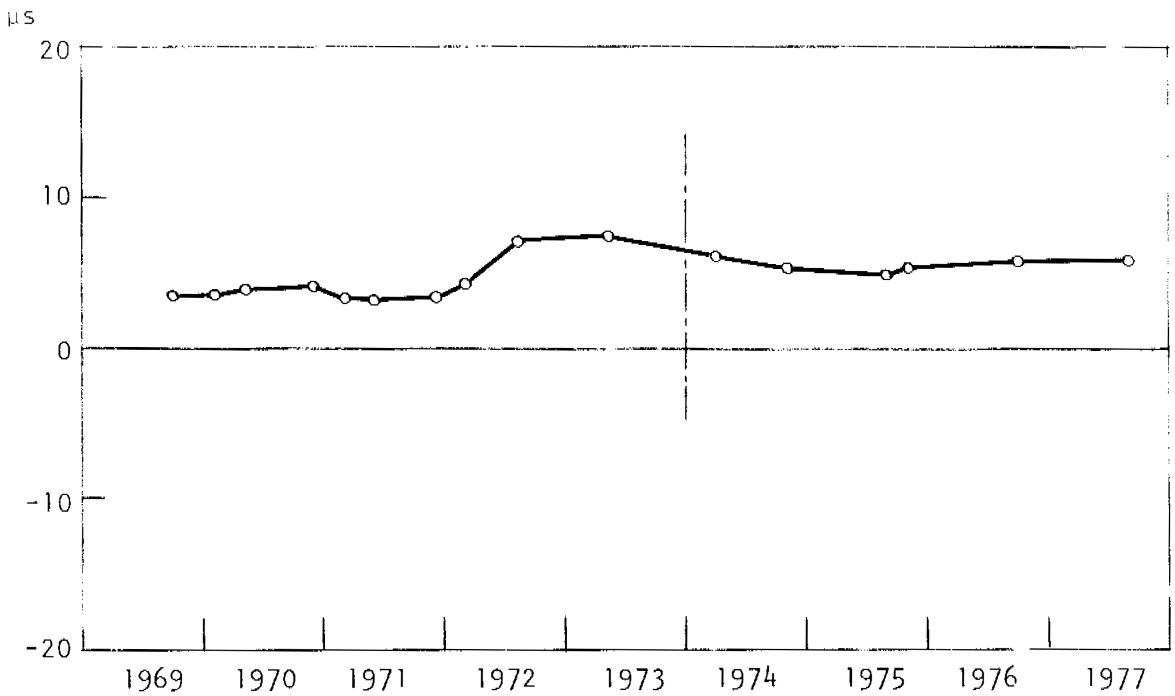

Fig. 6 Long-term stability of the time comparison via Loran-C relative to that via the portable clock.