LORAN-C PREDICTION PROBLEMS

Carl F. Lukac
U. S. Naval Observatory
Washington, D. C.

ABSTRACT

Control of time and frequency at remote stations and the
maintenance of a constant time scale for Loran-C chains
are problems of practical importance. The stability of
stations monitoring a Loran-C chain is analyzed - in par-
ticular, those stations monitoring the Northwest Pacific
chain (LC/9970). Part of the analysis consists of com-
paring individual determinations of the quantity, U. S.
Naval Observatory Master Clock (USNO MC) - LC/9970, with
an averaged value and in making intercomparisons of
monitored data.

The values for the relationship

USNO MC - LC/9970

are published weekly in the Time Service Series 4 announcements to en-
able users to establish and maintain traceability to the USNO MC.
These values also are available on a daily basis by telephonic communi-
cation with an HP 1000 computer located in the Time Service building.
Details of some of the work done and problems encountered in the deter-
mination of USNO MC - LC/9970 are illustrated here.

How does one keep a chain on time? Some chains are monitored at the
Naval Observatory and the differences, USNO MC minus the chains, are
published in Series 4 as direct measures. However, the Observatory
cannot receive the Loran-C signals of most chains, especially the North-
west Pacific chain. Nonetheless, even at a distance of some 8,000 miles
from Washington, it is possible to determine and publish the result of
emission time of LC/9970 to a high degree of accuracy.

Figure 1 compares the values of USNO MC - LC/9970 for both the pub-
lished data in Series 4 and the computed average values. The computed
values are represented by the curve which has been labelled periodically
with large symbols for easier recognition. The difference between the
two curves, which has been plotted against an offset zero line, appears
near the bottom of the plot. The x axis units are in terms of Modified
Julian Day and the y axis units are microseconds. These axis designa-
tions are the same for all plots used in this paper. It is obvious
that the two curves do not always agree and can be more than 0.5µs
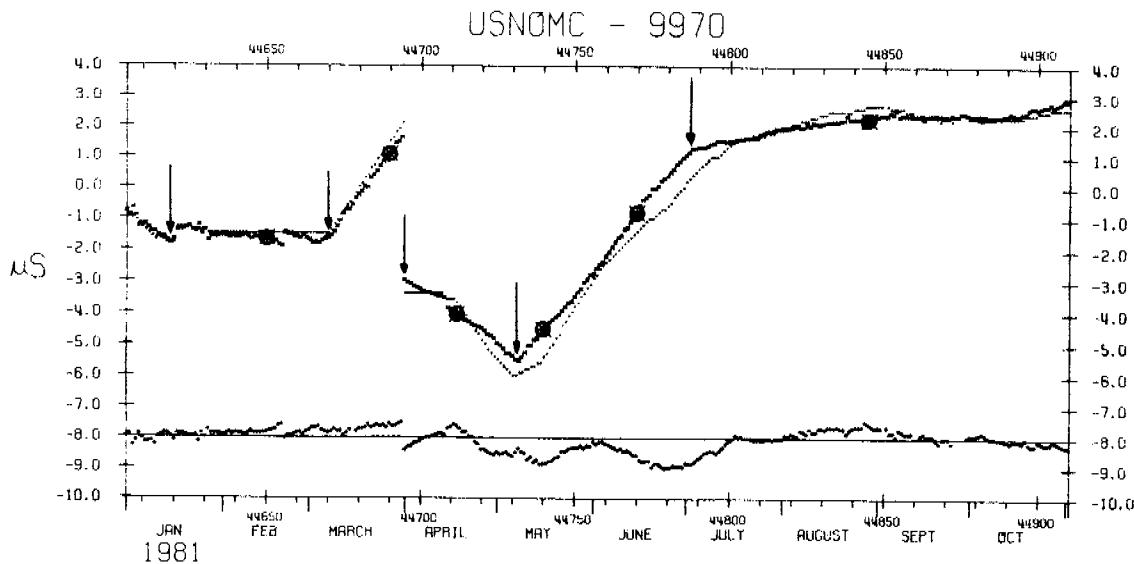apart, but generally the residual is less than 0.5µs.

Figure 1.

The upper curves are values as published in Series 4 and as determined from the computed average (traced with large symbols). The lower plot is the difference between the two curves. Announced frequency changes are indicated by arrows.

The published values of USNO MC - LC/9970 are based on extrapolation of the time scales for several monitoring sites. Run-offs occur when additional data is received from other monitoring stations which do not send their Loran readings to the Observatory on a daily basis. If, after new data is received, the computed average curve takes a new direction, then the published values will be steered to the correct value over a period of a week or two rather than have a jump of a fraction of a microsecond.

Figure 1 also shows announced frequency changes (indicated by arrows) in the Loran as well as some discontinuities which will be discussed later. In what follows, attention will be given to the data sources used in generating the computed average and to some of the factors which affect the relative displacement of the two curves.

The Northwest Pacific chain is tied to the Naval Observatory by

1. Portable clocks,
2. Defense Satellite Communication System (DSCS) time transfers, and
3. The rate correlation method.

Each of these methods has advantages and drawbacks, the ideal situation employing all three simultaneously. Using LC/9970 transmissions,

218

differences of USNO MC - station are seen in Figure 2. In this case, the data is for a cesium at the DSCS terminal in Finegayan, Guam. As with all Loran data, the readings taken by the station are forwarded to the Observatory and calculations made to reduce all the data to USNO MC - station.
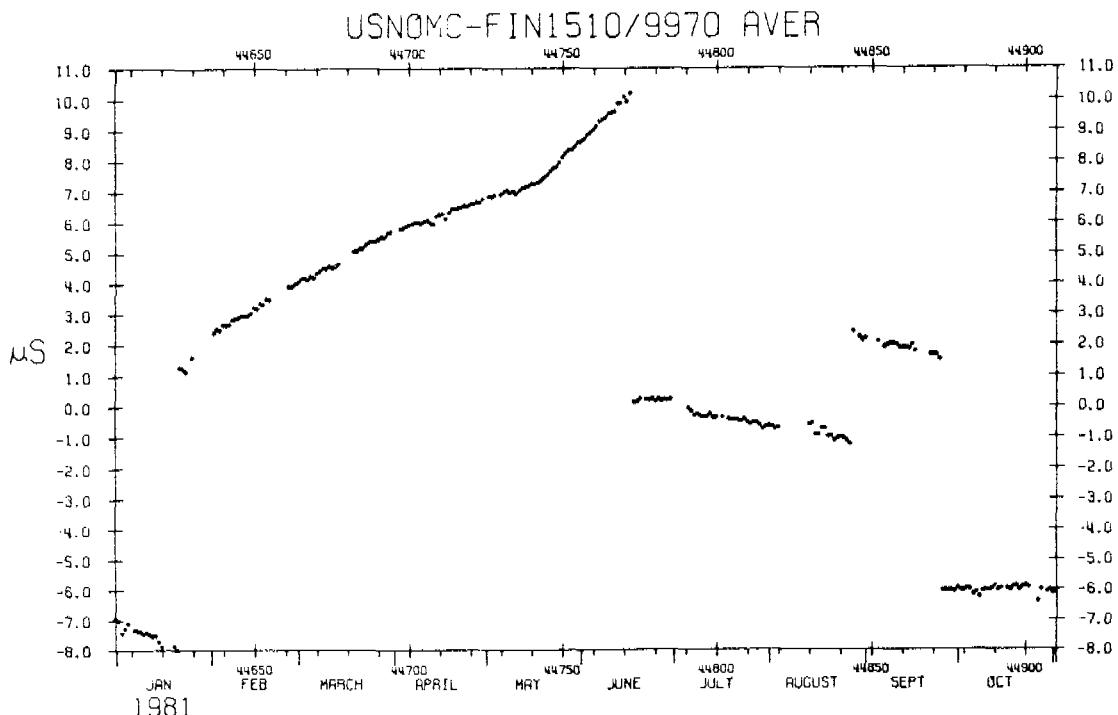

Figure 2.

Performance of Cesium 1510

In January, this particular clock was stepped per instruction from the Observatory; later, there were several spontaneous rate changes. Another step was programmed in June as well as a frequency change. In August, the clock jumped and changed rate. In September, it jumped again with another corresponding rate change. There are frequent power outages which contribute to missing data. This plot shows that a clock trip once or twice a year (a typical average for this chain) is far from adequate to tie the LC/9970 chain to the USNO time scale when a clock performs in the manner of cesium 1510.

A better behaved clock in terms of long time spans is cesium 211 at NASA, Guam, whose performance is shown in Figure 3. Here is a clock with reasonably small scatter, no discontinuities and relatively few rate changes. This clock is heavily relied upon for the determination of USNO MC - LC/9970 not only because of performance but also because

219
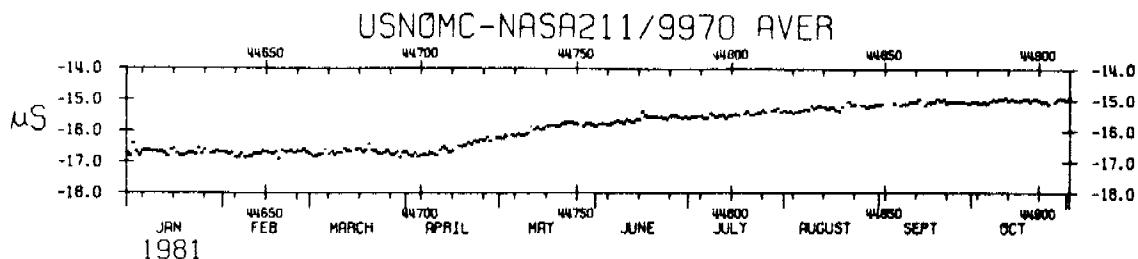
its Loran values are reported daily.

USNOMC-NASA211/9970 AVER

Figure 3.

Performance of Cesium 211. A constant of 19μs has been sub-
tracted from values of USNO MC-Cs 211.

From a practical point of view, satellite time transfers are more use-
ful in establishing the relationship between a Loran chain and the
Naval Observatory Master Clock than are portable clock trips, by virtue
of the greater frequency of the satellite time transfers. There are
three DSCS terminals which can monitor the LC/9970 chain. These termi-
nals are located at:

1. Futema, Okinawa,
2. Finegayan, Guam, and
3. Kwajalein, Marshall Islands.

Time transfers from Futema were resumed in late 1980 after a long ab-
sence. The transfers are done on a weekly basis and would normally be
quite useful were it not for the fact that no Loran receiver was opera-
ting at the site. Recently, Loran-C monitoring has resumed but the
data is erratic and equipment problems may still exist. Thus, it is
presently impossible to use the Futema time transfers directly.

The DSCS terminal at Finegayan, data from which are presented in Figure
4, is the present 'workhorse' for satellite time transfers in the
Pacific. Here, using LC/9970 transmissions, differences of USNO MC -
Cs 1061 are plotted along with the intermittent time transfers shown
by the large symbols. The satellite points have relatively low scatter
and are extremely useful for predicting the direction in which the
system should be moving. Cesium 1061 also serves as the primary
through which two other clocks at Finegayan are monitored. The draw-
back is that time transfers are not regular enough due to higher
priority requirements at Finegayan. Also, equipment problems tend to
produce frequent gaps in the Loran data resulting in cesiums being
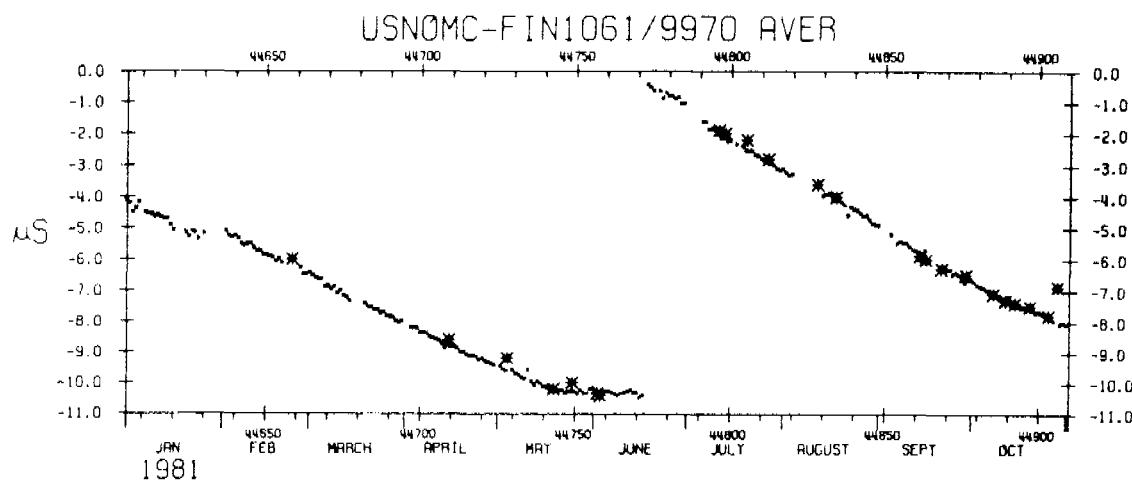reset--usually, one to another.

220

USNOMC-FIN1061/9970 AVER

Figure 4.

Performance of Cesium 1061. The large symbols indicate
satellite time transfers. A constant of 1µs has been sub-
tracted from the values of USNO MC - Cs 1061.

The third DSCS terminal is located at Kwajalein. Even though there is
considerable scatter in the Loran data (Figure 5), the large symboled
time transfers were very useful until approximately June 1981. At that
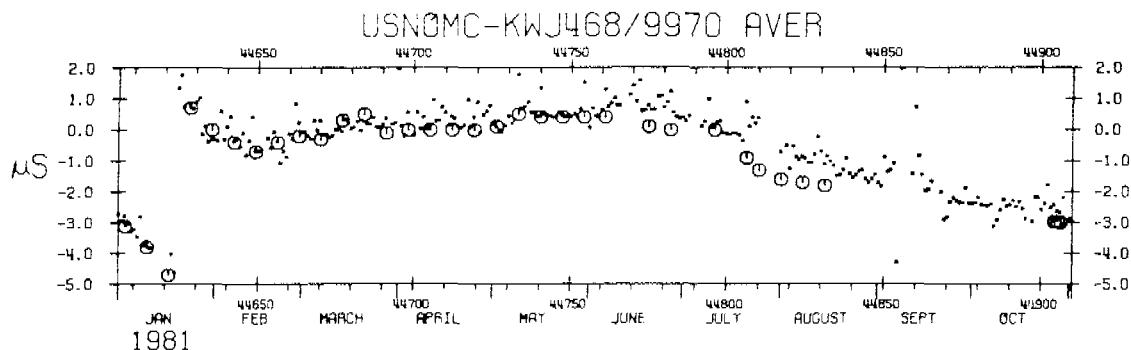
USNOMC-KWJ468/9970 AVER

Figure 5.

Performance of Cesium 468 at Kwajalein. Large symbols
indicate satellite time transfers.

time the satellite points departed from the Loran system (defined by
the many other clocks which make up the MEAN). In fact, there seems to
be an offset of about 1µs. No transfers were performed after August
due to problems with a time transfer modem at the DSCS terminal at Camp
Roberts, California. Hence, Kwajalein is temporarily unavailable in
helping to determine USNO MC - LC/9970 from a time transfer point of
view. This is an example of why one cannot rely exclusively upon any
one source of data!

221

Scatter problems of Loran monitored data in Kwajalein are illustrated
in Figure 6 which is obtained by subtracting USNO MC - LC/9970 via each
station from USNO MC - LC/9970 as determined by the average of all
clocks in the MEAN. Here, NASA (with relatively low scatter) and
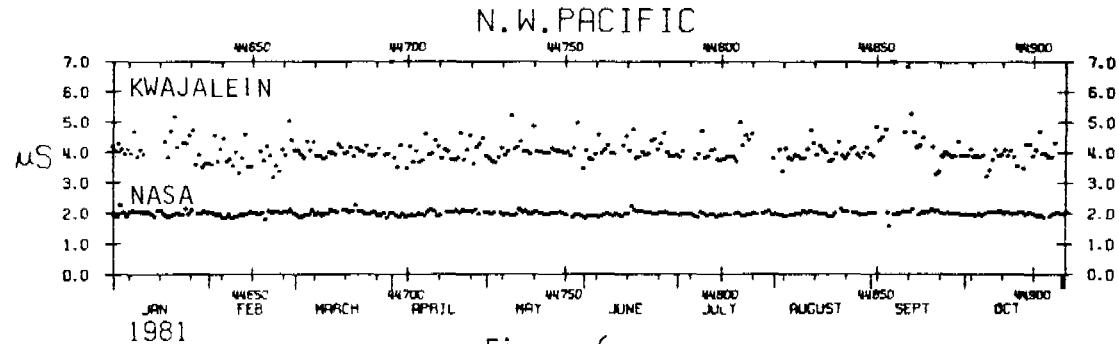
N.W.PACIFIC

Figure 6.

Relative scatter about an offset zero line of Loran-C signals
as observed at two separate monitoring sites in the Pacific.

Kwajalein (with relatively high scatter) are being compared. The
scatter in Kwajalein may be a combination of skywave contamination,
oscillator or receiver problems, or personnel. Previously, Kwajalein's
scatter was much less.

Figure 7 illustrates Loran data for NASA again but this time the x axis
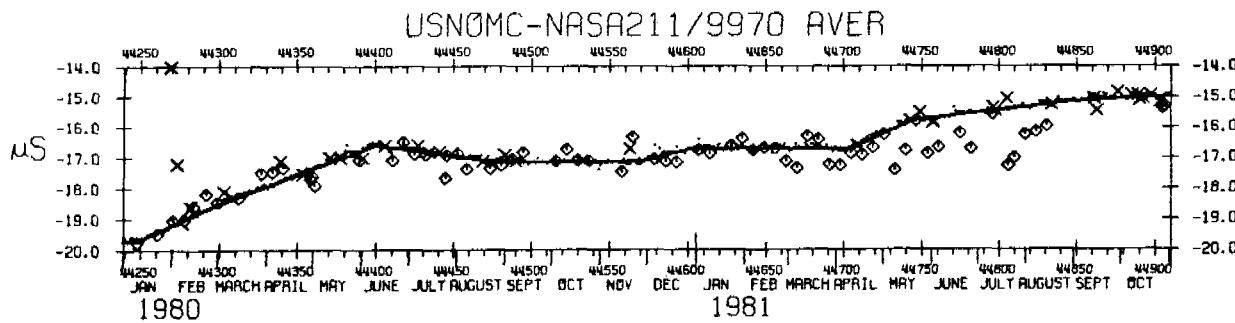has been compressed to go back two years. Also, the time transfers at

USNØMC-NASA211/9970 AVER

Figure 7.

Values obtained through the computed average of LC/9970, using the
satellite time transfers at Finegayan (X) and Kwajalein (◈). A
constant of 19μs has been subtracted from these data.

Finegayan and Kwajalein (large symbols) have been reduced to obtain
values of USNO MC - NASA through the commonly monitored Loran data. In
addition to the usual scatter of Loran-C, a solid line is plotted which

222

is the adopted frequency offset for USNO MC - station. These are
straight lines, changing slope only when indicated by the raw data. It
is evident that Kwajalein was definitely better before May of 1981, even
though it shows somewhat more scatter than Finegayan. This plot demon-
strates that a good clock with several sources of time transfers is a
powerful tool for remote time scale determination.

A similar situation (Figure 8) is that in which satellite time trans-
fers from the Finegayan and Kwajalein terminals have been reduced to
obtain USNO MC minus Tokyo Astronomical Observatory (TAO) and USNO MC
minus Radio Research Laboratory (RRL) via the Loran. These time systems
(both located in Tokyo, Japan) are very good members of the clock en-
semble which is used in determining the average, but their Loran data
are usually two or three weeks behind. Notice the discontinuity in RRL
during April. This type of break is easily identified with the actual
problem clock if that clock is constantly intercompared with a tightly
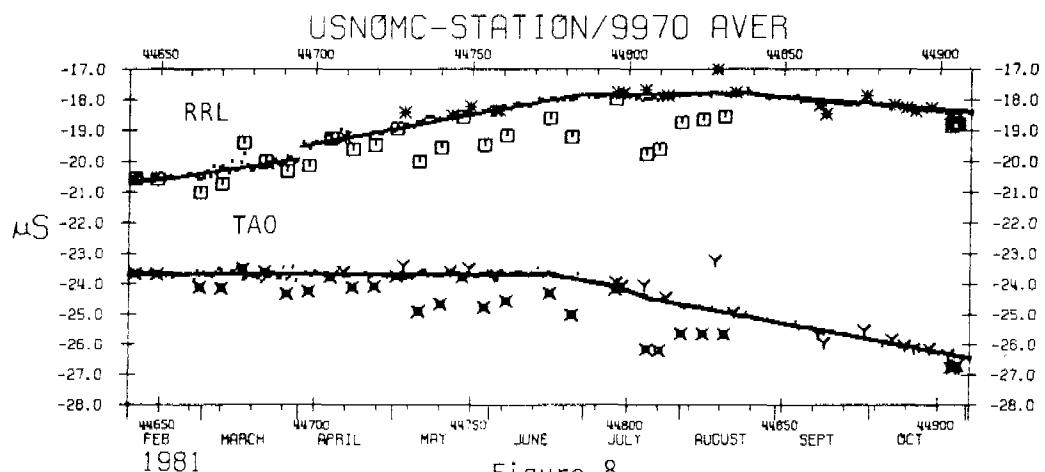bound system of clocks, as is maintained for the Northwest Pacific chain.

USNØMC-STATIØN/9970 AVER

Figure 8.

Values obtained through the computed average of LC/9970
using the satellite time transfers at Finegayan (*, Y)
and Kwajalein (□, ✗). A constant of 13µs was subtracted
from the values of RRL. A constant of 20µs was sub-
tracted from TAO.

When all else fails and there are no portable clock or satellite time
transfer values available, the course a system should be taking can be
deduced by an intercomparison scheme called rate correlation. This is
simply a method which says that if one clock changes in frequency, that
change should appear in any differences measured with respect to that
clock. For instance, if one has the differences A-B and A-C and A
changes by five parts in 10^{13}, both differences should also change by
five parts in 10^{13} whereas B-C should not exhibit any changes. This
technique requires at least three oscillators but usually is employed

223

with as many as possible. The method works very well in the Pacific and is easily capable of 1/2μs accuracy.

In Figure 9, Loran data for the National Research Laboratory of Metrology (NRLM) located in Tokyo, Japan, has been subtracted from that obtained at NASA, TAO, and RRL. A change in frequency is clearly evident during July which is attributed to NRLM--the station common to all three differences.
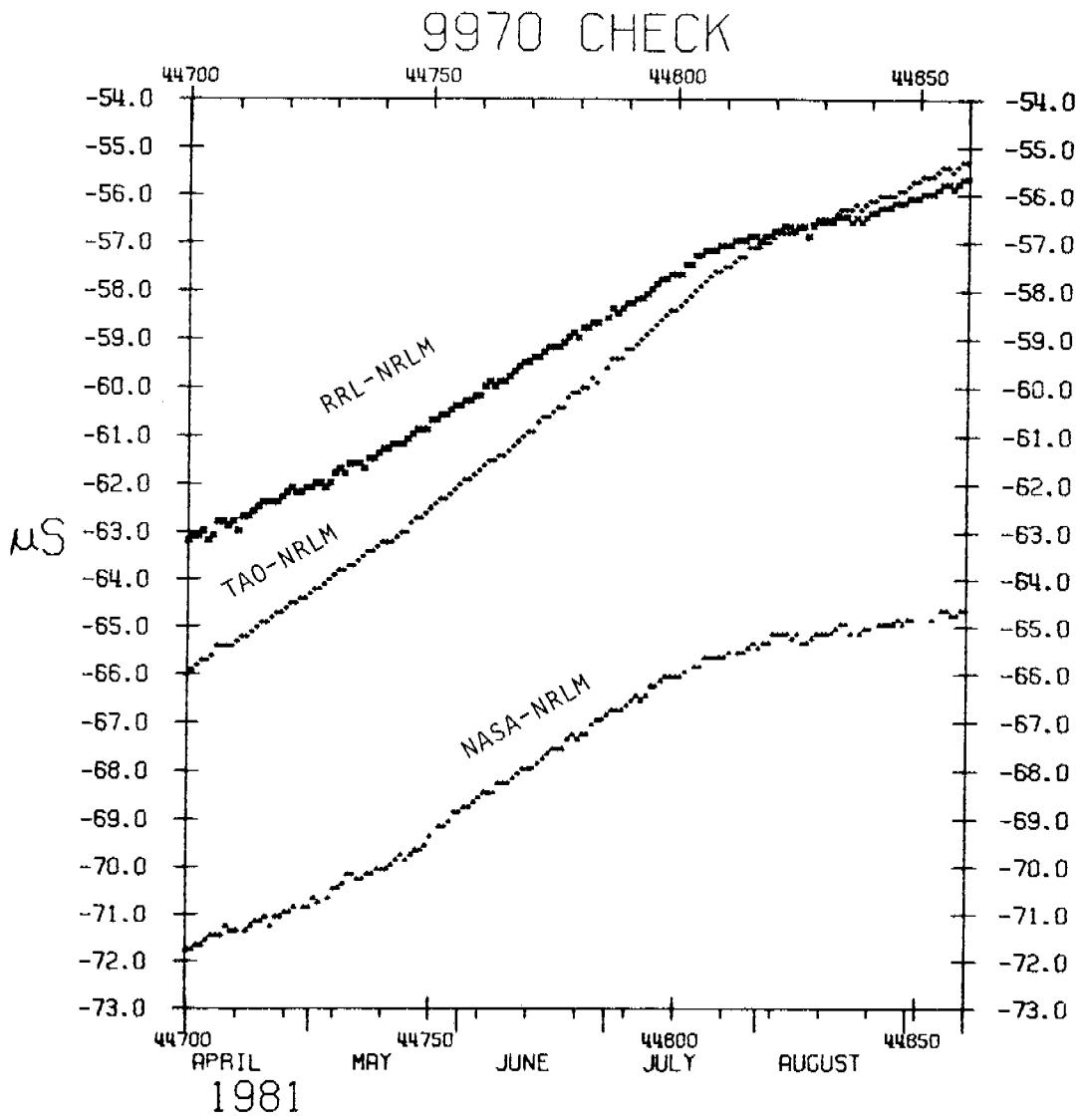

Figure 9.

Differences in rates between pairs of cesiums can detect a rate change in a single clock.

224

There are approximately 21 cesium clocks monitoring Loran-C in the
Northwest Pacific. Eleven of these cesiums are currently in the MEAN.
The relationship USNO MC - LC/9970 via each station contributing to the
MEAN is plotted in Figure 10. The scatter produced by these different
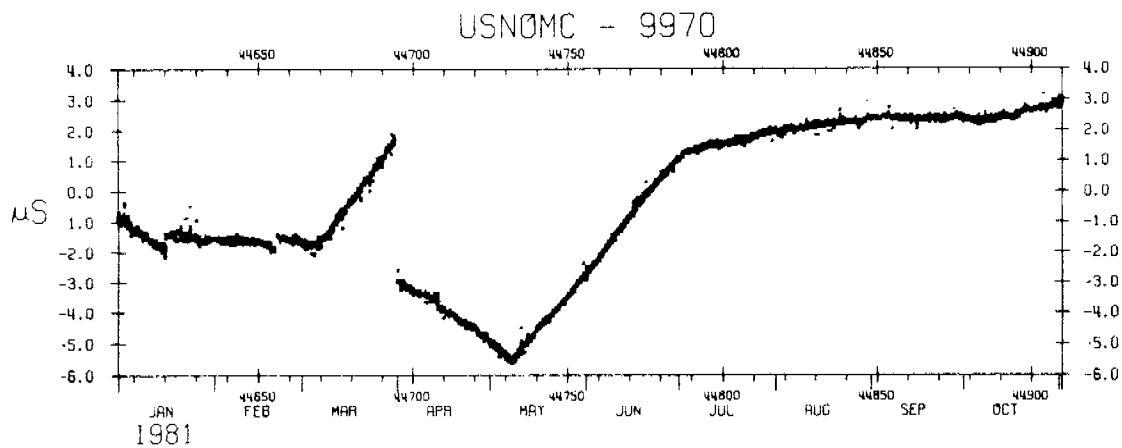sites is about 0.2 to 0.3μs.

Figure 10.

Scatter of clocks used in the ensemble determining the time
scale for LC/9970.

It is the average of the better stations which are used to compute the
values published in Series 4. Since not all stations report their data
on a daily basis, evaluation of the adopted time scale is continuously
being made as additional data are received. Final values may differ
from those published. Sometimes revision of Series 4 values becomes
necessary and is done automatically if differences between computed and
published values approach 0.7μs. An example of just such a revision is
given in Figure 11.

The interval from roughly January through April that appears in Figure 1
is examined more closely in Figure 11. On the left are the original
Series 4 values (represented by the curve marked with large symbols)
plotted with the final (not original) average. On the right are the
revised Series 4 values (again labelled with large symbols) plotted with
the same final average. The drastic change in Series 4 values has two
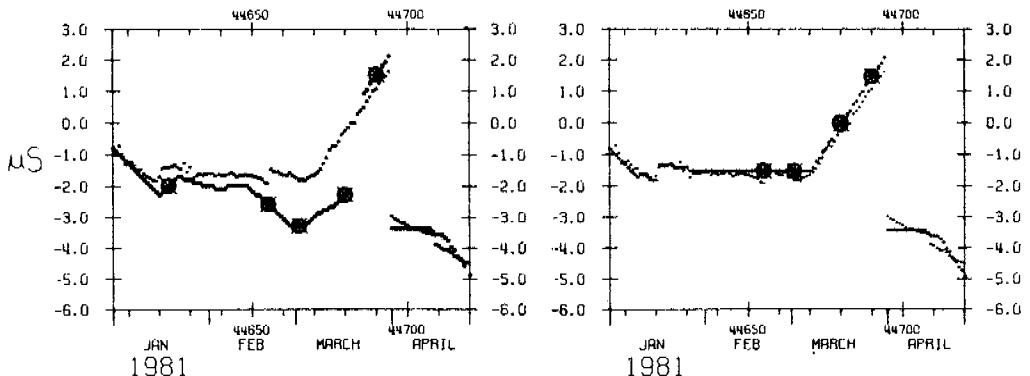primary causes: Chain reconfiguration and insufficient data.

Figure II.

Original values of USNO MC - LC/9970 published in
Series 4 are in the left figure (curve marked with
large symbols). The revised values (again marked
with large symbols) are in the right figure. The
second curve in each figure is the final computed
average.

In mid-January an oscillator change occurred. It apparently caused a
discontinuity and a frequency change in the Loran data. On 21 February,
a chain reconfiguration began--at which something happened, producing
a second discontinuity. Another frequency change occurred in early
March. Then, a step adjustment and an additional frequency change took
place on 1 April. During the reconfiguration, there were no time trans-
fers from Finegayan. Kwajalein was noisy and data was not coming in on
a current basis. In addition to the delay change at the beginning of
the reconfiguration, Finegayan Loran-C data jumped and changed delay
within the reconfiguration. Some monitoring sites stopped sending in
data altogether for a while! Hence, Series 4 had to be revised during
this period with the final result appearing as in the right-hand figure.
It is planned that final revised Series 4 values for the entire year
will be available as part of the annual Time Service report (Series 11).
Information also will include any revisions for chains other than LC/
9970.

It is apparent that a remote Loran-C chain can be kept on time if there
is an abundance of data. Control points such as those furnished by
satellite time transfers and portable clocks are most useful in helping
to remove prediction and system errors. However, care must be exercised
in using the control points as they themselves are subject to error.
For instance, weekly time transfers can show scattering of $\pm0.3\mu s$.

Portable clock measurements also are affected by various types of
errors--many of which could have gone unnoticed if the data were not

226

correlated to the Loran-C chain reduction procedures that are described herein. A major problem with reducing portable clock measurements to USNO MC is how to characterize the portable clock's performance during a trip. From the time it leaves the Observatory, or any other controlled environment, little is known about a clock's operation until it returns and monitoring resumes again.

The major difficulty in this work is insufficiently trained personnel. Some specific problems affecting remote time scales are:

1. Insufficient clock trips,
2. Insufficient satellite time transfers,
3. Long-term interruptions of satellite time transfers due to high priority missions,
4. Lack of operational Loran-C receivers at DSCS terminals.
5. Insufficient knowledge of propogation delays,
6. Skywave contamination of signals,
7. Reconfigurations,
8. Constant steering of cesiums, and
9. Delay in receiving monitored data.

Despite these and other problems, the Northwest Pacific chain is kept within 0.5μs of the USNO MC on a routine basis.

ACKNOWLEDGEMENT