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IMPROVING SATELLITE-TRACKED DRIFTER BUOY RESOLUTION BY USING LORAN-C

Ronald W. Muzzi and Gerald S. Miller

Great Lakes Environmental Research Laboratory, NOAA
2205 Commonwealth Blvd.
Ann Arbor, MI 48105

ABSTRACT

Free-drifting satellite-tracked drifter buoys have provided a wealth of in situ data to examine global scale spatial variations in surface circulation over vast ocean areas. But in the Great Lakes, their position inaccuracies and limited number of positions makes them unsuitable for measuring the lake's smaller scale processes. To overcome this problem, a low-cost system was designed by adding a LORAN-C receiver to a satellite-tracked buoy. LORAN gives improved spatial and temporal resolution. A modified Si-Tex EZ97 LORAN-C receiver, Campbell Scientific SM192 solid-state storage module, and an 80C31 CMOS microprocessor control interface were added to a Polar Research Lab mini-TOD drifter. The LORAN antenna was positioned next to the ARGOS antenna on the top of the buoy. The micro-processor controlled cycling of the LORAN receiver and recording of the data. The ARGOS platform was not modified, and provided position comparison and near real-time positions for aid in retrieval. LORAN position data was recovered from the buoy after retrieval. Two prototype tests were fully successful, revealing evidence of smaller scale processes that could not be determined by satellite position tracking.

INTRODUCTION

Free-drifting satellite-tracked drifter buoys have provided a wealth of in situ data from remote ocean regions and from the Great Lakes. For example, during the First GARP (Global Atmospheric Research Program) Global Experiment (FGGE) more than 300 drifters were deployed in the southern hemisphere [1] [2]. Other large scale ocean programs followed. These drifting buoy datasets have afforded the opportunity to examine global scale spatial variations in surface circulation over vast ocean areas. In the Great Lakes, satellite-tracked drifters have also proven valuable for measuring near-surface currents [3] [4] [5] [6] [7] and ice movements [8].

The horizontal scales of motion in the Great Lakes are much smaller than in the deep ocean. ARGOS positioned drifter buoys, suitable for examining lake-wide near-surface circulation, are not as well adapted for measuring smaller scale processes because of the position inaccuracy and limited number of positions. Buoy positions are determined from TIROS and NOAA satellite tracking of the Doppler-shifted radio signals generated by the onboard ARGOS system. Position accuracy is about ±0.3 km [4]. At the latitude of the Great Lakes, an average of 11 positions per day are obtained from ARGOS [11]. There are often two periods each day for intervals of 3 to 8 hours when positions are not available.

LORAN-C coverage is continuously available over the entire Great Lakes region. The geodetic accuracy is ±0.46 km. Repeatable accuracy varies from ±25 to ±200 m, depending on geographic location [9]. In a local region of study, the small scale accuracy would be better than ±200 m. A LORAN-C tracked drifter buoy would provide the necessary resolution for smaller scale lake processes.

Buoys designed specifically for a LORAN-C system that transmits data via FM radio have been used successfully in the ocean [10]. However, the FM receiver must be within range of the buoy (typically 100 km over seawater, less over fresh water). This is a serious constraint for examining lake-wide circulations.

The cost of the LORAN drifter buoy was reduced by modifying our existing inventory of mini-TOD drifters. An advantage of using drifters in the Great Lakes is that they are generally recoverable and reusable. Adding LORAN-C to our drifters gives the added advantage of obtaining both ARGOS and LORAN-C position data for comparison. In addition, ARGOS position data is directly available through satellite downlink in near-real time to aid in the recovery of the buoy.

DESIGN

A Si-Tex EZ-97 LORAN-C receiver, modified by Si-Tex for NOAA use, was selected. The modifications provided default power up operation, disabling of display, and serial output of time delay values. The default power up operation also allowed the LORAN-C chain to be selected by the EPROM instead of by the keyboard control. Disabling the display reduced the power consumption to about 200 mA. The LORAN-C receiver tracked a master and two secondary stations providing the time delays, signal lock status, and error flags indicating signal-to-noise ratio errors and cycle select errors for the master and both secondaries.

The mounting of a LORAN-C antenna on a buoy bouncing in the waves may make reception of LORAN-C poor. LORAN-C receivers, however, use filters on the order of minutes to "lock on" to the signal. Waves causing signal drop-outs on the order of seconds should be filtered out. Field tests were conducted to determine how well LORAN-C can be captured in rough sea conditions.

The addition of a LORAN-C antenna poses the potential problem of interference between the ARGOS and LORAN-C antennas. The mounting of the LORAN-C antenna is shown in Figure 1. The base of the 2.6 m fiberglass whip antenna is mounted 0.2 m off the side and 0.7 m from the top of the buoy. The ARGOS antenna is only 0.37 m high. Tests showed no significant interference between the two antennas. LORAN-C is not affected by ARGOS transmissions because ARGOS transmission power is low, 0.5 watts, and the frequency difference is 400 MHz/100 KHz or 400,000 to 1, which is easily filtered by the LORAN-C preamplifier. ARGOS transmissions are not significantly affected by LORAN-C because the

LORAN C antenna is narrow. A light was mounted across from the antenna to balance the antenna weight and provide a beacon to mariners.

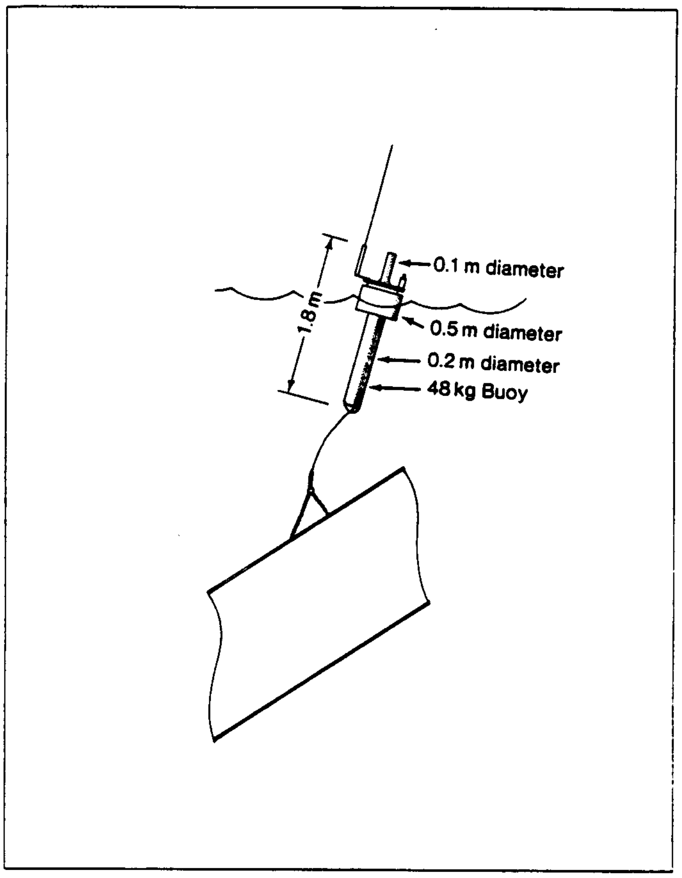

Figure 1: Schematic drawing of the long mini-TOD drifter.

There are two ways to collect position data from the LORAN-C receiver: 1) transmit it on the ARGOS signal, or 2) record it internally inside the buoy. The latter was chosen. ARGOS does not provide enough data transmission capability to transmit a past history of LORAN-C positions. Transmitting only the most recent position severely limits the temporal resolution. A GOES transmitter could be substituted, but the cost would be excessive (> $2K per transmitter). A Campbell Scientific SM192 solid-state storage module was chosen to record the data internally. The module has a capacity of 192896 bytes or 7144 data records. This is more than adequate for our purposes.

The control of the system is provided by an 80C31 microprocessor interface board, specifically designed for this project. The microprocessor turned on the LORAN-C receiver at a selected interval (10 to 60 minutes) using a quartz crystal as a time reference. A record counter was used as a time mark for the data. The microprocessor examined the LORAN-C data until the receiver acquired signal lock or timed out (7 minutes). The LORAN-C data, record counter, battery voltage, and time to capture were recorded in a data record that was sent to the storage module.

The entire electronics package, including the LORAN-C receiver, storage module, and control electronics, was mounted inside the hull of the drifter. The 1.8 m long hull of the mini-TOD drifter has enough space to include the package.

Power was provided by the same battery pack used by the ARGOS transmitter. The alkaline battery stack has a rated capacity of 60 AH. Battery life is a function of capture time and the sampling interval. The system consumed about 0.023 AH of power for each position capture (at the 7 minute maximum capture time) and 0.6 AH of power per day for the ARGOS transmitter and microprocessor operation. Assuming we obtain only 80% of the battery capacity because of temperature derating, the drifter should operate for 17 days at a 15 minute sample rate and 42 days for a 60 minute sample rate.

TEST RESULTS

Two field tests were conducted for a short period of time in Lake Michigan. LORAN positions were captured every 15 minutes. The LORAN time-out was extended from 7 minutes to 10 minutes for the second test.

The first test covered a period of 5 hours on November 22, 1988 during 10 m/s winds with 1.5 m wave height and 5 s period wave. During this test only 3 ARGOS positions were captured while 22 LORAN positions were captured. The positions by both ARGOS and LORAN are shown in Figure 2. LORAN capture times ranged from 4.4 to 7 minutes (the maximum allowed) and averaged 5.7 minutes. Five LORAN-C positions did not attain a lock condition within the seven minutes allowed, however, with the exception of two lane jumps, the positions did not appear degraded. One lane jump occurred when lock had been achieved. The 10 μs lane jumps, caused by the LORAN receiver locking on the wrong cycle, are obvious (about 2 km) and correctable during data editing.

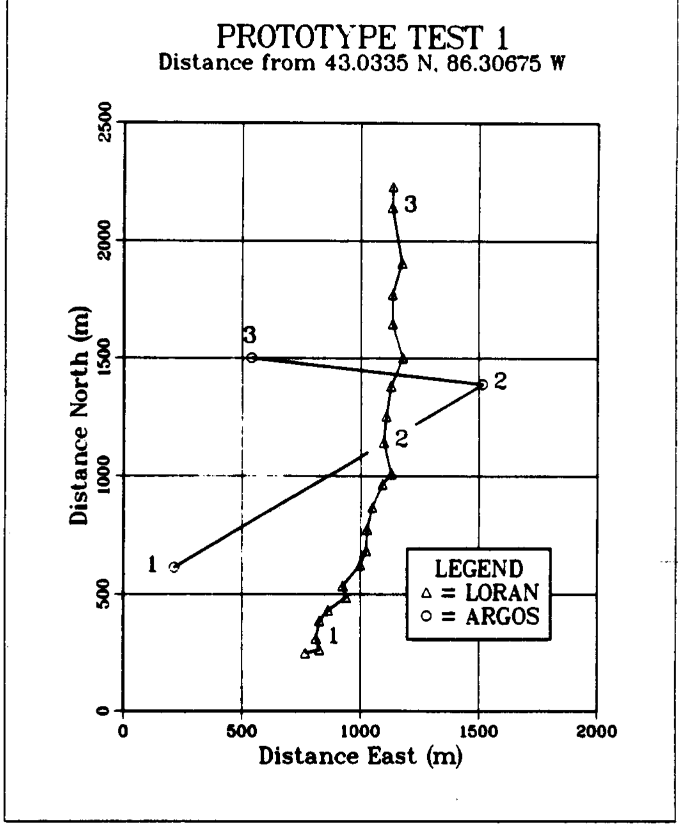

Figure 2: LORAN-C and ARGOS positions during the first test in Lake Michigan, November 22, 1988. Concurrent ARGOS and LORAN-C positions are numbered.

The second test covered a period of 28 hours on March 29-30, 1989 during winds ranging from 3-10 m/s and wave heights and periods ranging from 0.5-2.0 m and 3-7 s, respectively. The positions from this test are shown in Figure 3. During this test 11 ARGOS positions were captured and 112 LORAN positions were captured. LORAN capture times ranged from 2.8 to 9 minutes and averaged 4.9 minutes. There were no lane jumps. The LORAN reception was significantly better during the second test than it was in the first test, most likely due to better weather conditions.

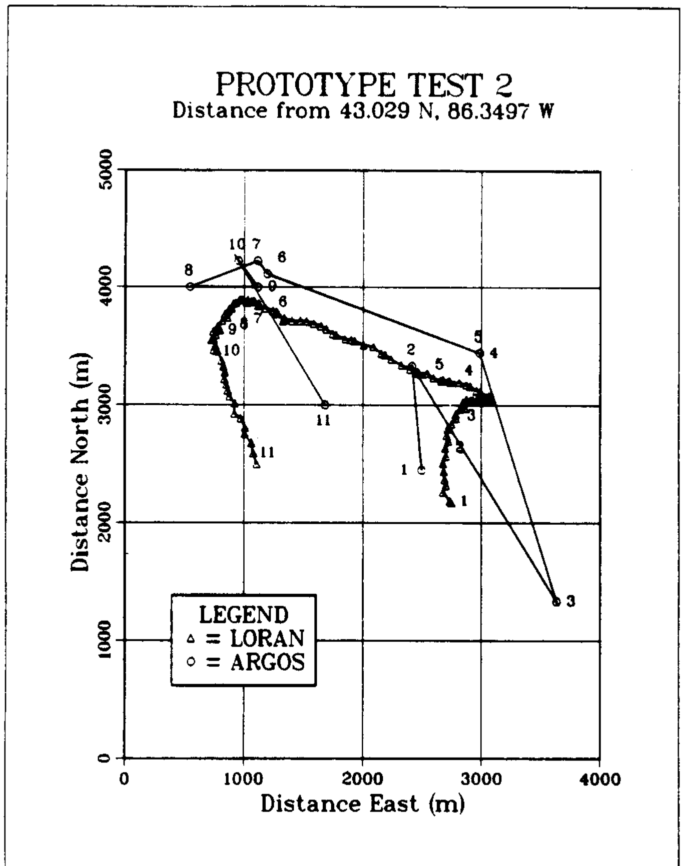

Figure 3: LORAN-C and ARGOS positions during the second test in Lake Michigan, March 29-30, 1989. Concurrent ARGOS and LORAN-C positions are numbered.

The tests show differences between the ARGOS position and the LORAN position ranging from 0.29 to 0.88 km. The standard deviation of the difference for the second test was 0.39 km. The data points are shown in Table 1. This is comparable to ±0.3 km reported in the Great Lakes [4] and 96% within 0.72 km during FGGE [12].

The LORAN positions were converted from time delays to geodetic position according to theoretical propagation delays without including secondary corrections from observed data. Adding the secondary corrections should improve the geodetic accuracy of the LORAN positions and most likely remove the offsets seen in the data. Geodetic accuracy is not important for Lagrangian current measurements, but relative accuracy between measurements is important. LORAN is considerably better than ARGOS in relative accuracy between measurements.

TEST 1 - LAKE MICHIGAN - NOV 22, 1988
Difference between ARGOS and LORAN positions

	Latitude (m)	Longitude (m)	Magnitude (m)
1.	290.6	599.9	666.6
2.	251.7	-417.4	487.4
3.	-652.4	593.2	881.8
Average:	-36.7	258.6	678.6

TEST 2 - LAKE MICHIGAN - MAR 29-30, 1989
Difference between ARGOS and LORAN positions

	Latitude (m)	Longitude (m)	Magnitude (m)
1.	257.8	238.1	350.9
2.	694.2	283.0	733.9
3.	-1699.8	-712.7	1843.2
4.	281.8	-78.1	292.4
5.	239.7	-325.0	403.8
6.	373.4	143.4	400.0
7.	362.8	12.5	363.0
8.	180.2	331.4	377.2
9.	371.7	-333.4	499.3
10.	767.8	-175.9	787.7
11.	414.9	-601.9	731.0
Average:	394.4	-50.6	493.9

(Not including point 3)

Standard Deviation of Difference = 393.2 m

Table 1: Comparison of ARGOS and LORAN positions.

SUMMARY

A free-drifting satellite tracked buoy with a LORAN-C onboard recording system operated successfully during two field tests in Lake Michigan. The advantage of LORAN over ARGOS position is the increased relative position accuracy and frequency of data. Near uniform time series of Lagrangian current measurements do not require the extensive averaging and filtering necessary with ARGOS positions. The LORAN drifter allows measurements of dynamic processes on smaller spatial and temporal scales. The disadvantages are the increased battery drain limiting deployments from 17 to 42 days for cycle times of 10 to 60 minutes. The success of the system also depends upon the successful recovery of the buoy.

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