Correcting the Ice Draft Data from the SCICEX '98 Cruise

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Technical Memorandum

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ABSTRACT

A solution is presented for correcting the data collected by the digital ice profiling system (DIPS) from the first half of the SCICEX '98 cruise. The ice draft measurements are intrinsically related to the depth of the submarine and were corrupted by faulty measurements of depth. The ship's digital depth detector measured the gross movements of the submarine, but was unresponsive to small changes in depth associated with the natural porpoising of the boat. This porpoising, which is a periodic vertical movement of the submarine of several feet, was transferred to the ice draft data. An independent sensor package, the Icecat2, collected pressure data, which were converted to depth. The DIPS and Icecat2 systems had different clocks. To align them the depth signatures from each system were compared during large, rapid descents of the submarine. A time-dependent time offset between the two clocks was computed. By removing the DIPS depths from the ice draft measurements and replacing them with the depths measured by the Icecat2 system, the ice draft data were corrected.

1. INTRODUCTION

The SCICEX '98 cruise was conducted on the USS *Hawkbill* from August 2 through September 2, 1998. Data recorded during the cruise include ice draft as well as submarine depth, speed, and heading. A chronology of instrumentation shows that the Digital Ice Profiling System 3 (DIPS3) was online during the first half of the cruise (Table 1). A spare DIPS2 was put online when the DIPS3 failed on August 17. The primary difference between DIPS2 and DIPS3 is the recording medium. Two other sensor packages located on the sail of the submarine, the Icecat1 and Icecat2, recorded pressure (and other variables) and were operational during the entire cruise. The days when the submarine was in the Surface Heat Budget of the Arctic Ocean (SHEBA) project area are also shown in Table 1.

Table 1: SCICEX '98 Instrumentation Chronology

	August and September 1998																															
Date	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	1	2
DIPS 3																																
DIPS 2																																
Depth																																
Icecat1																																
Icecat2																																
SHEBA																																

The cruise naturally divides into two parts, the first when the DIPS3 was online (depths will be referred to as DIPS3 depths) and the second when the DIPS2 was online (depths will be referred to as DIPS2 depths). Overviews of the DIPS depth data and the Icecat2 pressure data converted to depth are shown in Figure 1. The DIPS3 depths in (a) followed the large scale movements of the submarine, as they look similar to the Icecat2 depths in (c), except for a short time from late on August 3 to late on August 4. The DIPS2 depths in (b), however, do not resemble the Icecat2 depths in (d) at all. The ship's depth detector (same for both DIPS systems) may have been improperly connected to the DIPS2 system. The DIPS2 depths, and hence the ice draft data from that time, are beyond repair. Therefore, we treat only the data from the first part of the cruise when the DIPS3 was active.

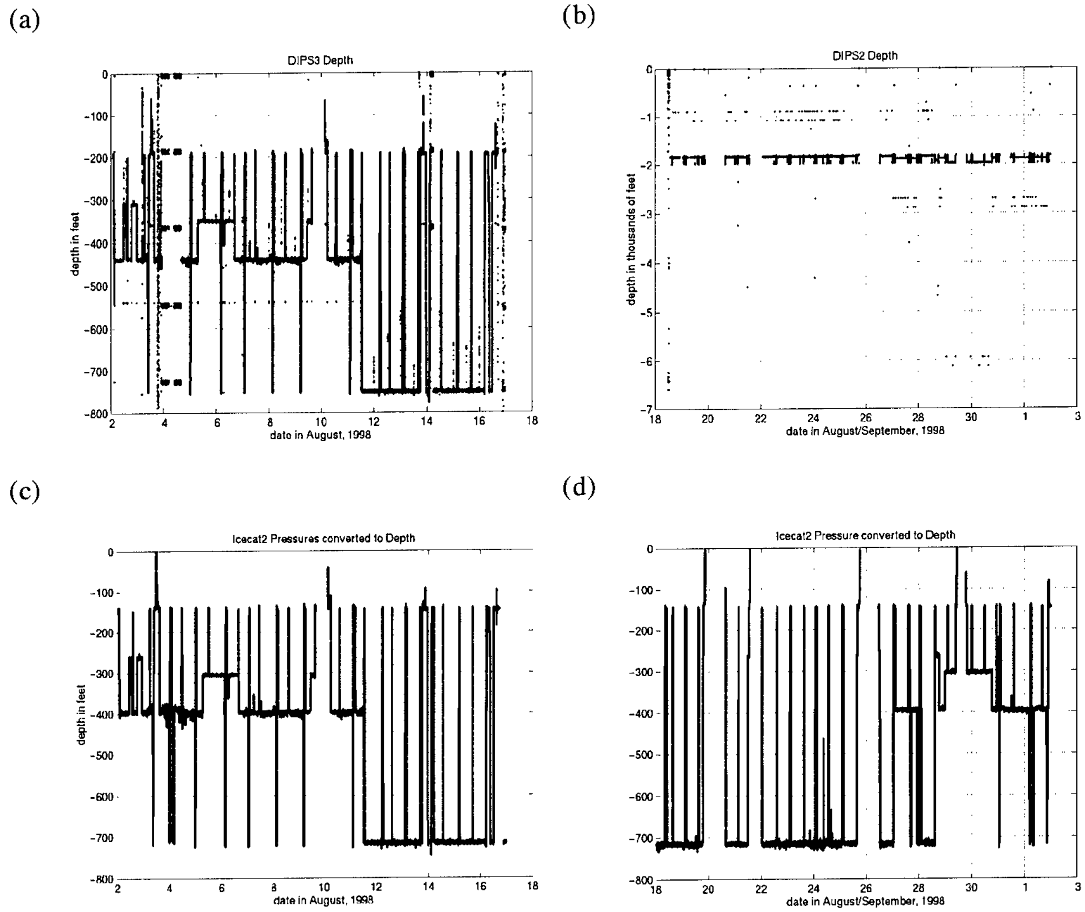


Figure 1. *Overview of depth data from SCICEX '98. DIPS depths while (a) DIPS3 is online and (b) DIPS2 is online. Icecat2 pressure data converted to depth (c) and (d). The submarine's depth detector was (a) not working from late August 3rd through most of August 4th and (b) thought to be improperly connected to the DIPS2 system. Note scale of depth in thousands of feet in (b).*

2. THE PROBLEM

The DIPS3 depths, although they follow the gross movements of the submarine, did not respond well to small changes in depth. The ship's depth detector was sticking, as can be seen by the trace of red dots in Figure 2. The actual movement of the submarine is shown by the Icecat2 depths (Figure 2, blue dots).

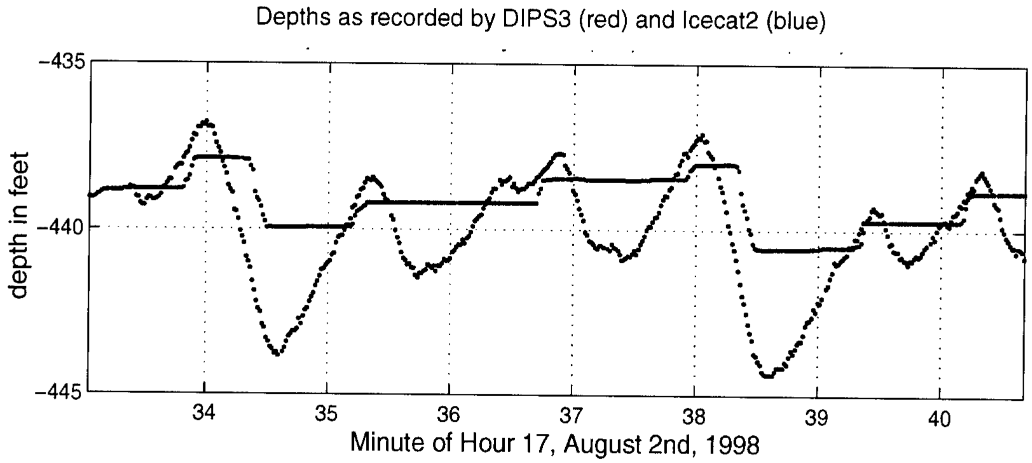


Figure 2. *Sample depth data from DIPS3 (red) and the Icecat2 pressure data converted to depth (blue). The depth detector is sticking, not responding to small changes in depth. The Icecat2 data were shifted down by 45 ft and to the right by 20 sec to overlay the DIPS data.*

The measure of depth is used to compute the draft:

$$Draft = Depth - \frac{t_{travel} \cdot C}{2} \qquad (1)$$

where t_{travel} is the time it takes the sonar ping to reach the ice or water surface, and C is the speed of sound in water. When the submarine is sailing on a level run, it is nearly impossible to maintain a constant depth. In order to stay at approximately the same depth, the pilot has to continually compensate for the overshooting of the submarine. This is called porpoising. Normally, this porpoising would be +/- 1 ft, but the sticking depth detector in this instance caused much larger variations (Figure 2, blue dots). When the depth input into the draft measurement is not properly reported, i.e., when the depth detector reports a constant value for a time because the valve is sticking, the porpoising is transferred to the draft data. Figure 3a shows the drafts for the same time period as in Figure 2. It is not obvious at a glance that these data have been corrupted by porpoising. In the trace from the submarine's strip chart recorder (top sounder roll; Figure 3b), the porpoising is clearly evident. The poor depth data have indeed corrupted the ice draft data.

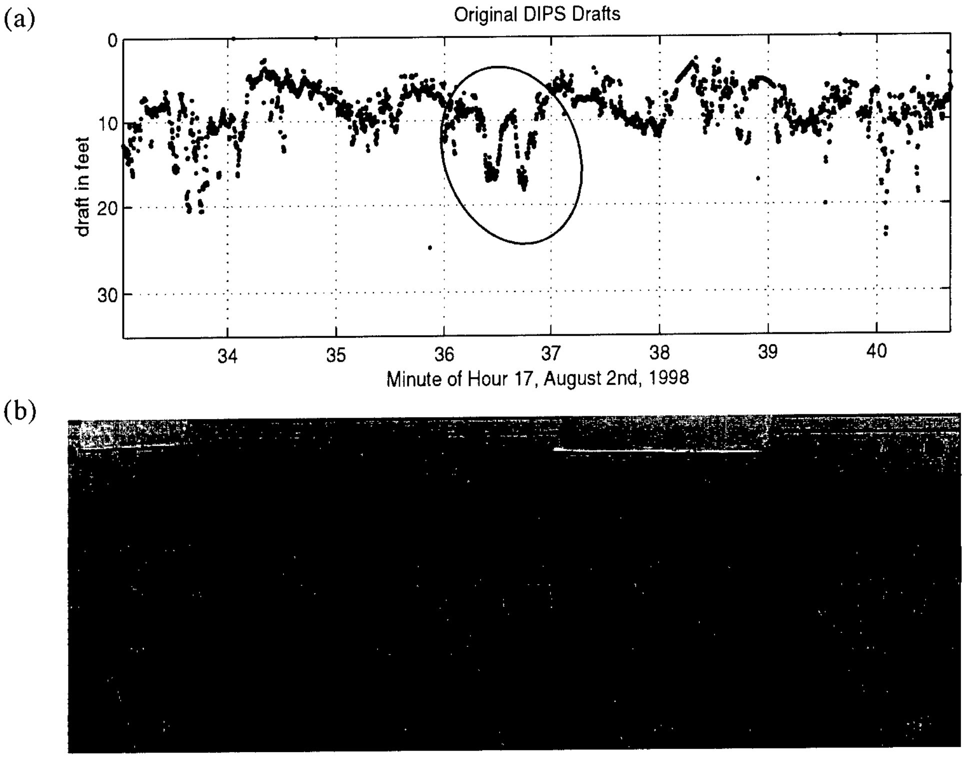


Figure 3. *(a) Draft data recorded by DIPS. (b) Draft data recorded on the top sounder roll on the OD-161. The red circle encloses the same feature in both panels to help orient the reader. Note that in (b) time marches from right to left.*

3. THE SOLUTION

We use the Icecat2 pressure data converted to depth to replace the poor DIPS depth data. The pressure data, recorded in decibars, are converted to depth as follows:

$$Depth = pressure \cdot (1/0.29890729) \cdot (-1) \ , \tag{2}$$

where 1 ft of water = 29.89072898 mbar (from *Handbook of Oceanographic Tables*; U.S. Naval Oceanographic Center, Washington, D.C.).

Each Icecat and DIPS had its own clock. These clocks were not synchronous and as further analyses show, they did not march at exactly the same rate. The Icecat1 clock differed from the Icecat2 clock by roughly six minutes (personal communication, Miles McPhee, McPhee Research Company, Naches, WA). The Icecat2 clock was less than one minute ahead of the DIPS3 clock. We chose to replace the DIPS3 depths with the Icecat2 depths because the time adjustment would be smaller.

3.1 Aligning the clocks

To find the actual time difference between the two data sets, we compared the depth signatures from the DIPS3 and the Icecat2. We know the ship's depth detector was sticking during small changes in depth (Figure 2) but it read large changes in depth (Figure 1). The goal was to choose and compare the parts of the depth signature where we were the most confident of the accuracy of the depth measurements recorded by the DIPS3. After much discussion, it was decided that the sticking depth detector would most accurately record the depths during rapid, large descents and it would probably take several feet of descending motion to get the detector in the proper position. During these descents the depth gauge is forced into the proper position by the associated increased pressure. Once the gauge begins moving with the increased pressure, the assumption was made that it keeps going smoothly as the submarine continues to descend. As the submarine ascends, on the other hand, the detector could stick in the open position with a decrease in pressure and therefore report an incorrect depth.

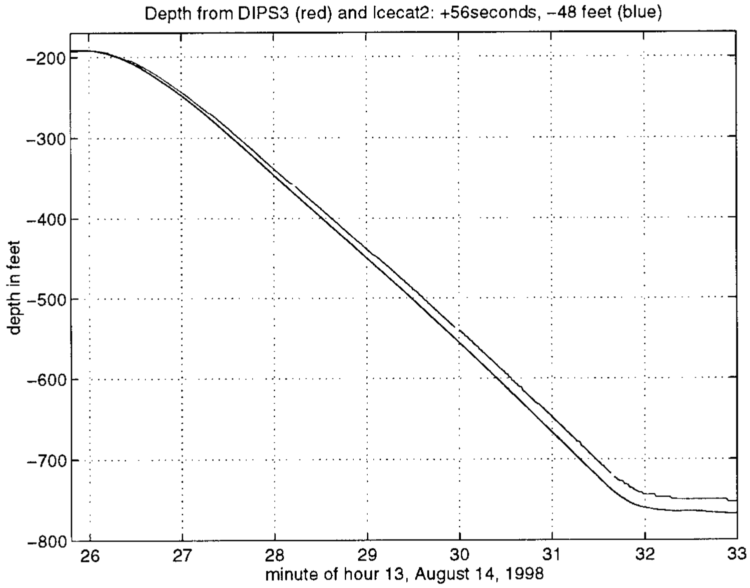


Figure 4. *Depths recorded by the DIPS3 (red) and the Icecat2 (blue) during a large, rapid descent. The Icecat2 data were shifted in time and space to match it to the DIPS3 depths. Fifty-six seconds were added to the time and 48 ft were subtracted from the depths measured by the Icecat2. Although the depth records start at the same value, the DIPS3 has a shallower value than the Icecat2 at the end of the descent.*

In a typical plot of both depth datasets during a descent (Figure 4), the DIPS3 depth detector (red) reads too shallow and increasingly so as the submarine goes to depth, compared to the Icecat2 depths (blue). (To match these two particular curves at the top, 48 ft was subtracted from the Icecat2 depths and 56 sec added to the time). The actual physical distance between the two sensors is approximately 50 ft. If the Icecat2 depths only have to be moved 48 ft down, the DIPS3 depth is too shallow at around 200 ft by a couple of feet. At the bottom of the descent near 770 ft, the DIPS3 depths are about 15 ft shallower still than the Icecat2 depths, meaning the difference between the two data sets is about 33 ft at the deepest depths. Therefore only the top portion of the descents were analyzed, where perhaps the two curves had the most similar slopes.

Here, we defined a descent as period when the Icecat2 data showed a dive >100 ft. To determine which portion(s) of the descents to compare, we analyzed several cases of varying range near the top of the descent. The ranges extended from 5–30 ft to 70–140 ft from the top of a descent (Figure 5a). Figure 5b shows how the slopes of these portions of the descents compare between the two data sets. For case 10, (10–70 ft below the top of the descent) the slopes of the descents match the best; they have the lowest mean difference (blue stars) and lowest mean standard deviation (green stars). We assumed that the ship's depth detector was working best in this range. We fur-

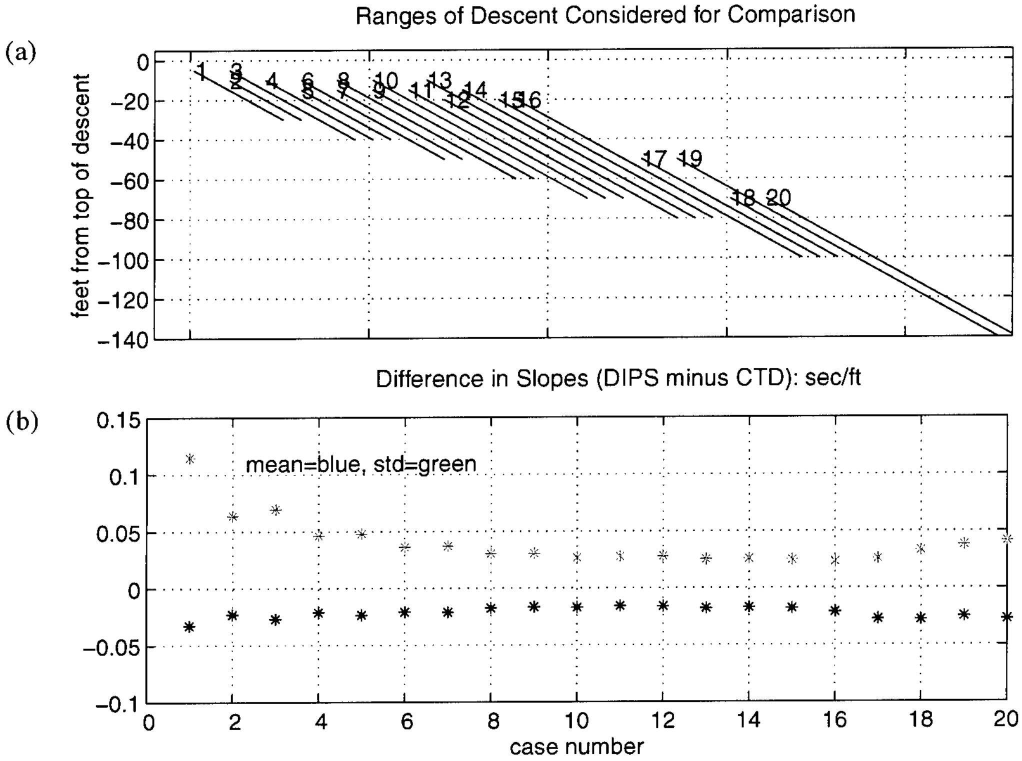


Figure 5. *(a) Cases of varing range considered for slope comparison in feet from top of descent. (b) Mean difference of slopes (green stars) and standard deviation of slopes (blue stars) for descents starting near 200 ft. Case 10, red line in (a), shows the closest comparison of slopes between the DIPS3 and Icecat2 depths.*

ther restricted the descents to start near 200 ft, because the depth detector may have worked better nearer the surface. We computed the mean time difference between the two data sets over the range of 10–70 ft below the start of the descent. The time difference in seconds is plotted against the time and day of the descent (Figure 6a, red stars). The best linear fit of the red stars is the red line, which finds the Icecat2 ahead of the DIPS3 by roughly 15 sec on August 2 and by about 70 sec on the August 17.

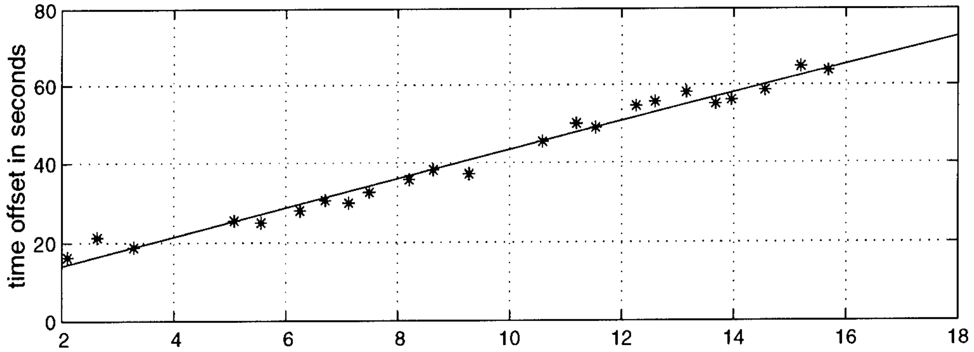
In an attempt to automate this analysis, we studied the individual 10-min files. If the time derivative of the depths was continually negative, and the DIPS3 data were well behaved (follow the Icecat2 data), we assumed a good record of a descent for that 10-min file. We then calculated the time lag with the maximum correlation and plotted it against time and day of the descent (Figure 6b, green diamonds). The best fit is represented by the green line. The best fit from Figure 6a is also plotted for easy comparison. The mean difference between the two is 0.03 sec. We concluded that the restriction to have the descents start near 200 ft was unnecessary.

There were more 10-min files containing level runs than descents. In an effort to get more points to make up a more robust best fit line of time-dependent time offsets, we also analyzed the depth signatures during these level runs, matching the periodic porpoising signature between the two data sets. Although the ship's depth detector was sticking, it did show a periodic characteristic that may be matched to the Icecat2 data.

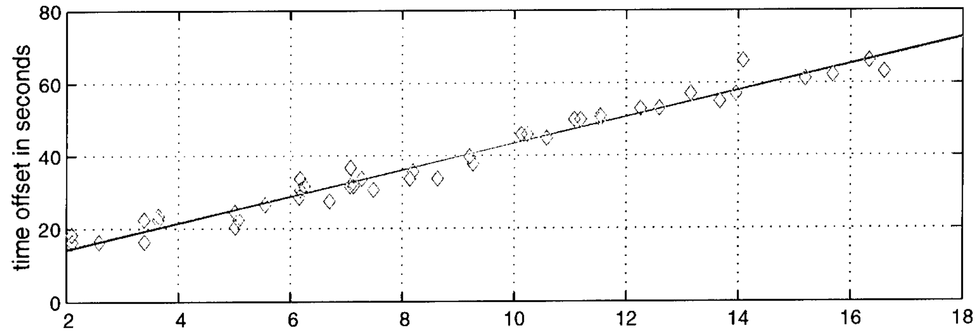
As with the descents from the 10-min files, we computed the lag correlation for the porpoising signatures in the depth data. After several attempts to find good criteria for well-behaved DIPS3 data during level runs, we obtained the results plotted in Figure 6c, with the best fit represented by the blue line (best fit lines from Figures 6a and b are also shown). The time shift found by comparing level runs is substantially higher than for the descents (and the points seem to jump after the surfacing on August 9–10). We concluded this was probably due again to the faulty sensor, which may have responded more slowly to a small depth change than the pressure sensor on the Icecat2. A slow response would result in a longer lag time. This is not the time offset needed. We used the best fit line from comparing the top of the descents (Figure 6a).

The difference in seconds between the best fit line and the time offset found for the descents in Figures 6a and b are shown in Figure 7a (symbols consistent between figures). Most differences are within 5 sec. To estimate the depth error in inches associated with an incorrect offset in time, we compared two sine waves with varying periods and amplitudes (representing the porpoising in the two data sets, DIPS3 and Icecat2). These sine waves were shifted in time and their amplitudes subtracted. Figure 7b shows the error in inches as a function of error in time offset for periods of 2 to 4 min with amplitudes of 2 to 4 ft. Considering the example in Figure 2, if the offset were 3 sec in error, for porpoising with a period of 2 min and an average amplitude of 3 ft, our error in depth (and therefore ice draft) would be under 5 in. The amplitude and period of porpoising is very driver-dependent.

(a) Time offset determined by comparing first 10–70 ft in descents that start near 200ft



(b) Time offset determined by lag correlations in descents



(c) Time offset determined by lag correlations in level runs

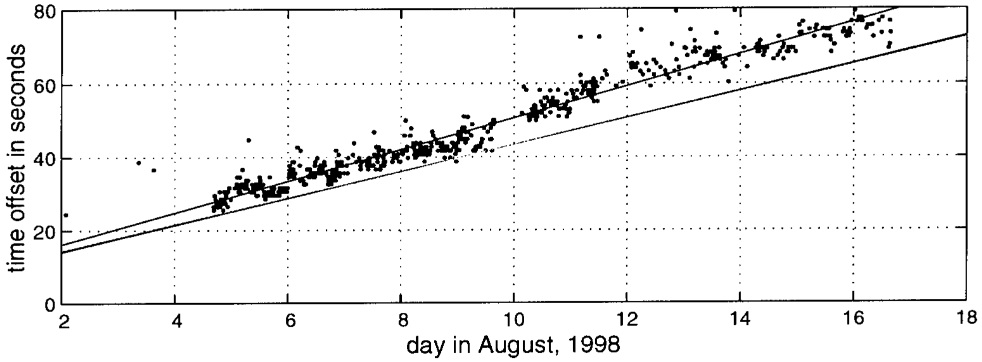


Figure 6. *Time difference between Icecat2 and DIPS3 for (a) top 10–70 ft of the descents that start near 200 ft and (b) for 10-min files containing descents. (c) Time difference between Icecat2 and DIPS3 for level runs.*

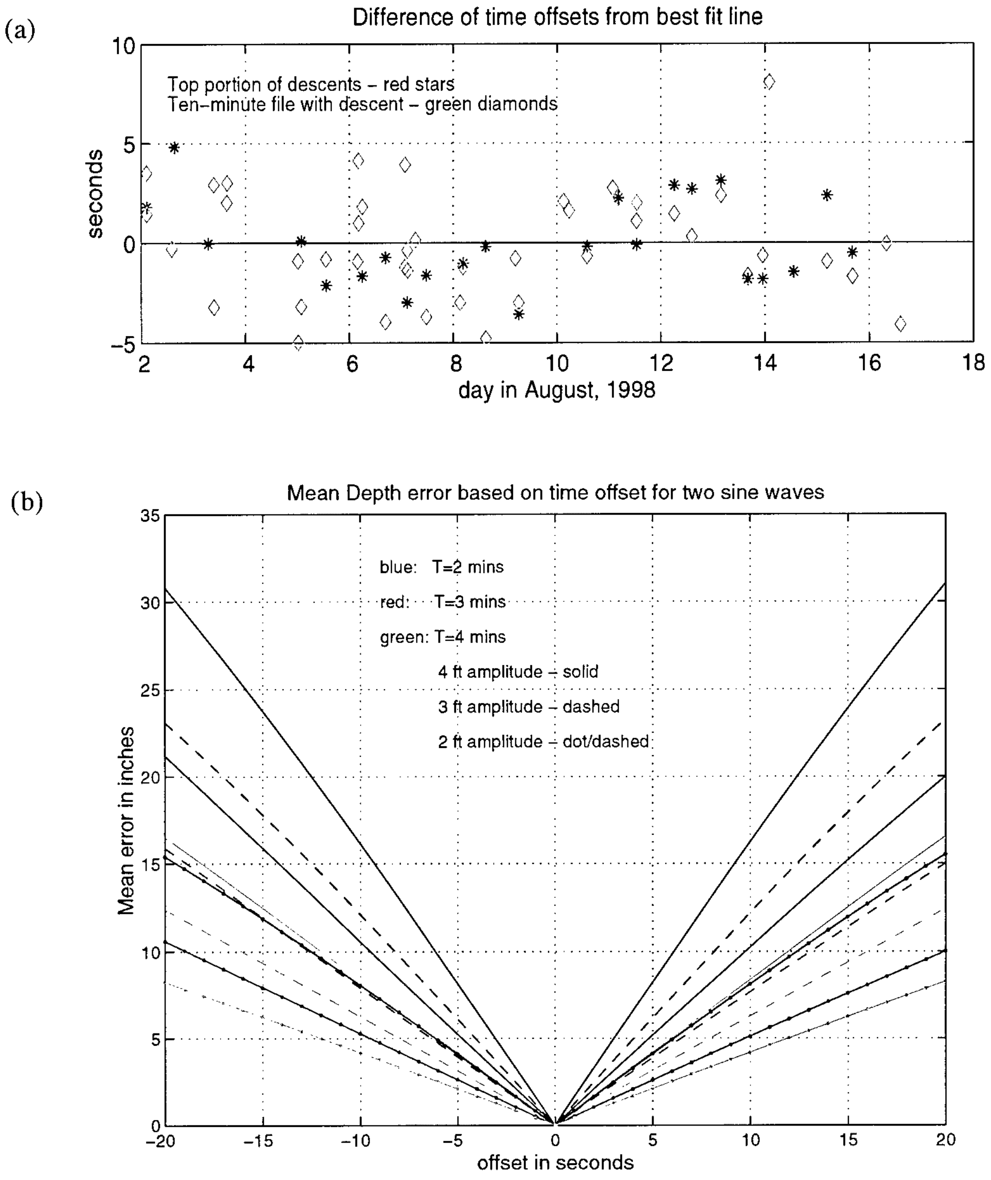


Figure 7. *(a) Time difference in seconds between best fit line and time offset of desents, top 10–70 ft of the descents starting near 200 ft (red stars), descents from 10-min files (green diamonds). (b) Mean depth error determined by offsetting two sine waves in time. Blue lines show a 2-min period, red lines show a 3-min period and green lines show a 4-min period. The solid lines correcspond to a sine wave with a 4-ft amplitude, the dashed lines a 3-ft amplitude and the dot-dashed lines a 2-ft amplitude.*

3.2 Replacing the depths

The Icecat2 pressure sensor is located in the submarine sail (Figure 8, black dot). The ship's depth gauge is located in the ship's control room (red star), yet is referenced to the keel (red dot). Nominally, the depths should differ by 50 ft, 8 and 9/16 in.

We use the time offset in seconds of the red best fit line in Figure 6a to add time to the Icecat2 time vector. The data frequency from Icecat2 was about two per second. The data frequency from DIPS3 was a bit less than one per second. The depths from the Icecat2, shifted in time, were linearly interpolated to the DIPS3 time vector. Then the ice drafts were corrected by replacing the poor DIPS3 depths with the good Icecat2 depths as follows:

$$Draft_{corrected} = Draft_{original} - Depth_{DIPS3} + Depth_{Icecat2} + 50 + \frac{8}{12} + \frac{9/16}{12} , (3)$$

where the depths are positive numbers. Figure 9a shows the original drafts from Figure 3a. The pressure-corrected draft data are plotted in Figure 9b. Much of the porpoising has been removed. The pressure-corrected ice draft data may now be edited by the staff at the Arctic Submarine Laboratory, San Diego, where they can be treated as raw DIPS data returned from a typical cruise.

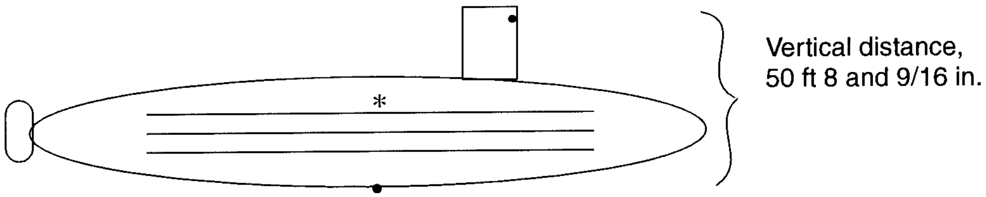


Figure 8. *Schematic showing relationship between the Icecat2 pressure sensor (black dot) and the ship's depth detector (red start). The depth detector, although in the control room, is referenced to the ship's keel (red dot).*

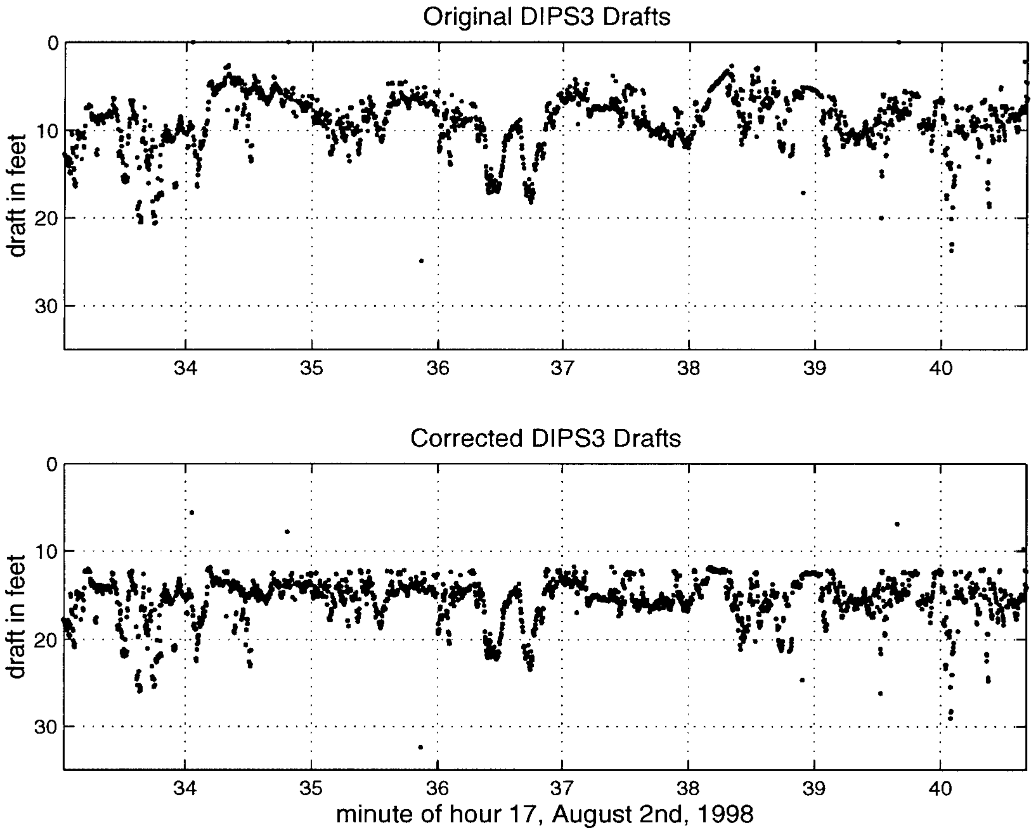


Figure 9. *(a) Original DIPS3 drafts (same as in Figure 3a) and (b) pressure-corrected drafts.*

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13. ABSTRACT *(Maximum 200 words)*

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