Review of SHEBA Ice Pack/Ship Stability from ARM GPS Data

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Introduction

From October 1997 through October 1998, Atmospheric Radiation Measurement (ARM) Program instrumentation was deployed on and around the Canadian icebreaker Des Groseilliers as part of the experiment portion of SHEBA (Surface Heat Budget of the Arctic). Early on we realized that we would be vulnerable to the movement and rotation of the ship and ice pack as it moved throughout the year-long deployment. A method of determining absolute heading was required. After querying the appropriate instrument mentors, it was determined that heading accuracies of ±0.5° would be required.

Because the ship would be operating in high latitudes, we decided that magnetic compass headings would not give us the accuracy needed. Checking with the ship's captain, René Grenier, we found that the ship's gyrocompass would be accurate to only ±3.0°. Various other searches led us to the prospect of using a GPS (global positioning system) attitude determination system that would provide us with latitude, longitude, heading, roll, pitch, and time. After a competitive procurement process, the Ashtech Attitude Determination Unit 2 (ADU-2) was selected.

Instruments Requiring Heading Data

- Solar tracker—needs to be precisely aligned with true north. The solar tracker has a diffuse PSP (precision solar pyranometer), diffuse PIR (precision infrared radiometer), NIP (normal incidence pyranometer), and NIMFR (normal incidence multifilter radiometer). The solar tracker was connected to a laptop computer in the ARM instrument shelter and changes in heading were entered by the ARM on-site operator. The solar tracker is mounted on the SKYRAD stand and was originally installed on the flight deck of the Des Groseilliers. In March 1998, the flight deck was needed for flight operations and the SKYRAD stand was moved to the ice aft of the ship. A data link to the solar tracker was achieved with a radio frequency (RF) modem.

- Whole sky imager (WSI)—the WSI has an occultor that obscures the sun to prevent the charge-coupled device (CCD) array from being saturated. The WSI was connected to the ARM data system and heading information was sent to the WSI via a fiber optic RS232 link. The ARM on-site operator also entered the heading information manually. The WSI stayed on the ship throughout the SHEBA experiment.

- Multifilter rotating shadowband radiometer (MFRSR)—needs to be precisely aligned to true north so that the shadowband occults the sensor as part of its measurement. The MFRSR was mounted on a machinist turntable for alignment to true north. The MFRSR moved with the tracker to the ice in March 1998.

Figure 1 shows a picture of the above instruments when they were located on the Des Groseilliers flight deck from October 1997 through March 1998. In March, it was necessary to move the instruments located on the flight deck. The SKYRAD stand was moved to the ice aft of the ship. Its location is shown in Figure 2, a picture taken from the tethered sonde.

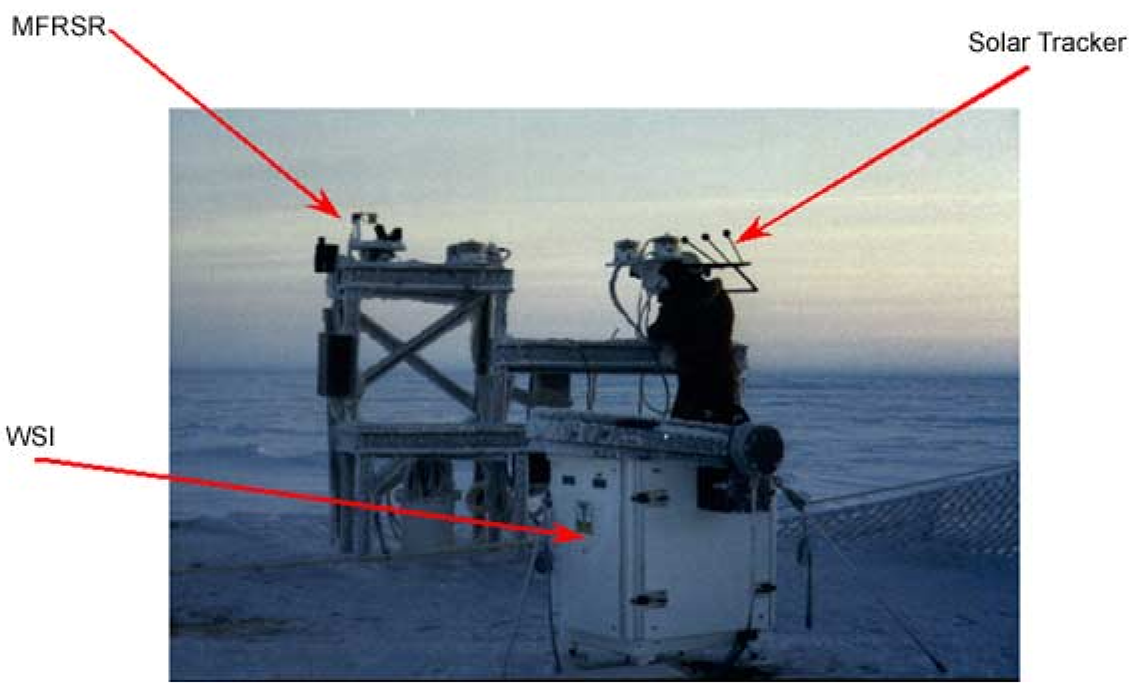

Figure 1. Heading sensitive instruments.

Figure 2. SKYRAD from tethered sonde.

Description of GPS System

The ADU-2 utilizes four 12-channel GPS receivers to make carrier phase measurements that provide attitude (heading, pitch, roll), position (latitude and longitude), and time (see Figure 3). The antennas were mounted at the highest point on the ship possible on the deck above the bridge spaced approximately 2 meters apart (Figure 4). According to Ashtech information, this should provide attitude accuracy better than 0.1°. The GPS receiver was located in the Special Navigation Chart Room next to the ARM data acquisition system (ADaM).

ADaM queried the ADU-2 approximately once every ten minutes via its RS-232 port. ADaM kept track of the ship's heading and when the heading changed by more than a degree, an alarm was sent to the monitor advising the operator to take appropriate action. ADaM also used the time from the ADU-2 to keep accurate time synchronization of all ARM measurements.

Reception Problems

We were plagued with multipath reception problems that resulted in significant dropouts of data throughout the experiment. This affected the attitude measurements (heading, roll, and pitch) but not location and time measurements. Several attempts were made to relocate the antennas, but we were limited to a location within 30 meters of the Special Navigation Chart Room due to the length restrictions on the antenna cables (Figure 5).

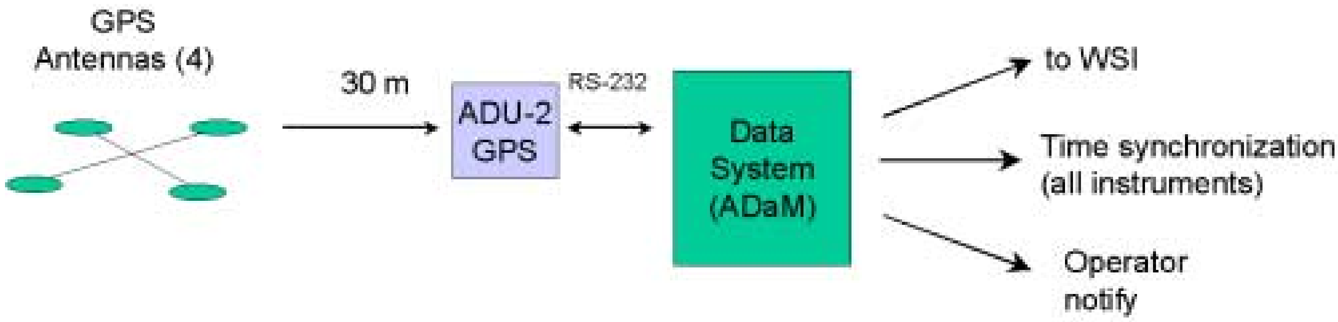

Figure 3. GPS block diagram.

Figure 4. GPS antenna array.

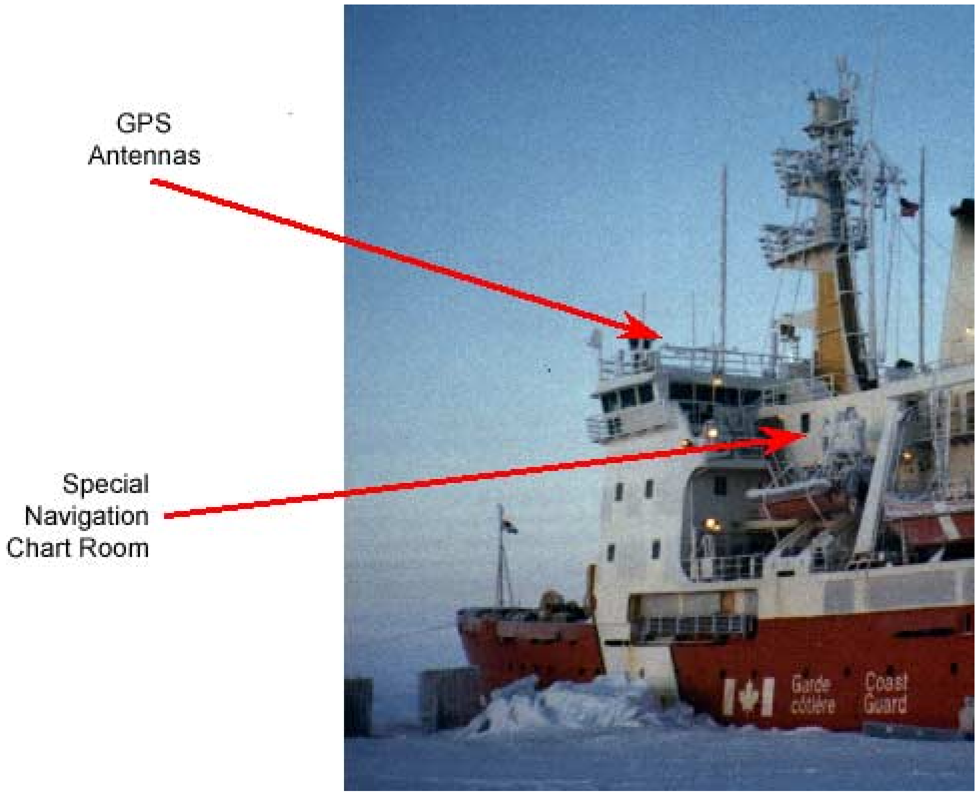

Figure 5. GPS ship location.

Latitude/Longitude Data Summary

The Des Groseilliers' movement during the SHEBA experiment is shown in Figure 6. Included in the plot are GPS daily data recorded by the ship's GPS as provided by the SHEBA Program Office. The data that are shown in blue are daily readings from the ARM GPS when we had good attitude determination (hence the gaps when compared to the SHEBA Program Office data in red). ARM GPS data were recorded at a 15-minute interval and longitude/latitude data are available for the times when the attitude (roll, pitch, heading) were not good. During the experiment, the ship moved a total of 2363 km. Interestingly, when one looks at the cumulative distance traveled as a function of time scales of a year, it is extremely linear with an $R^2 = 0.99$ (Figure 7)!

Heading Data

Figure 8 shows the heading data throughout the experiment year from the ARM GPS plotted in blue with the daily reading of the ship's gyro compass reported to the SHEBA Program Office in red. The ship rotated through a maximum of 150° though the year. There was a significant jump of 55° in early February when a lead opened around the ship. Figures 9 and 10 show the open water around the ship.

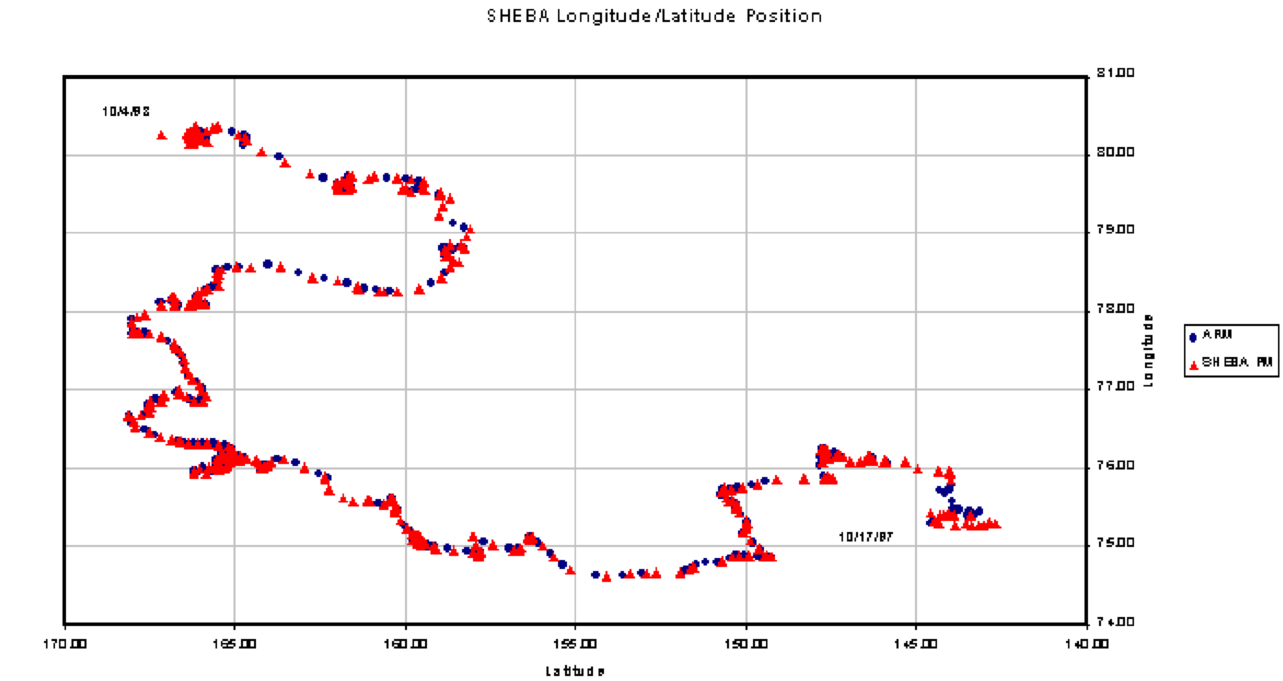

Figure 6. SHEBA path.

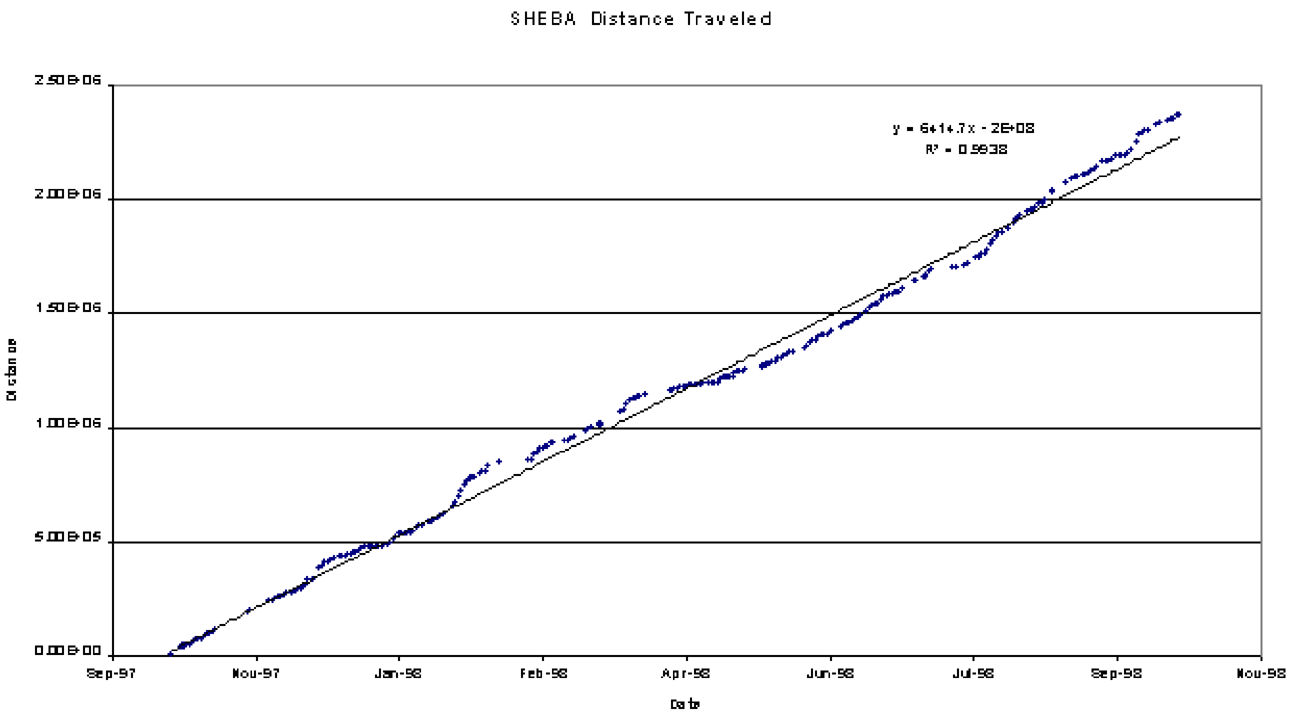

Figure 7. Cumulative distance traveled.

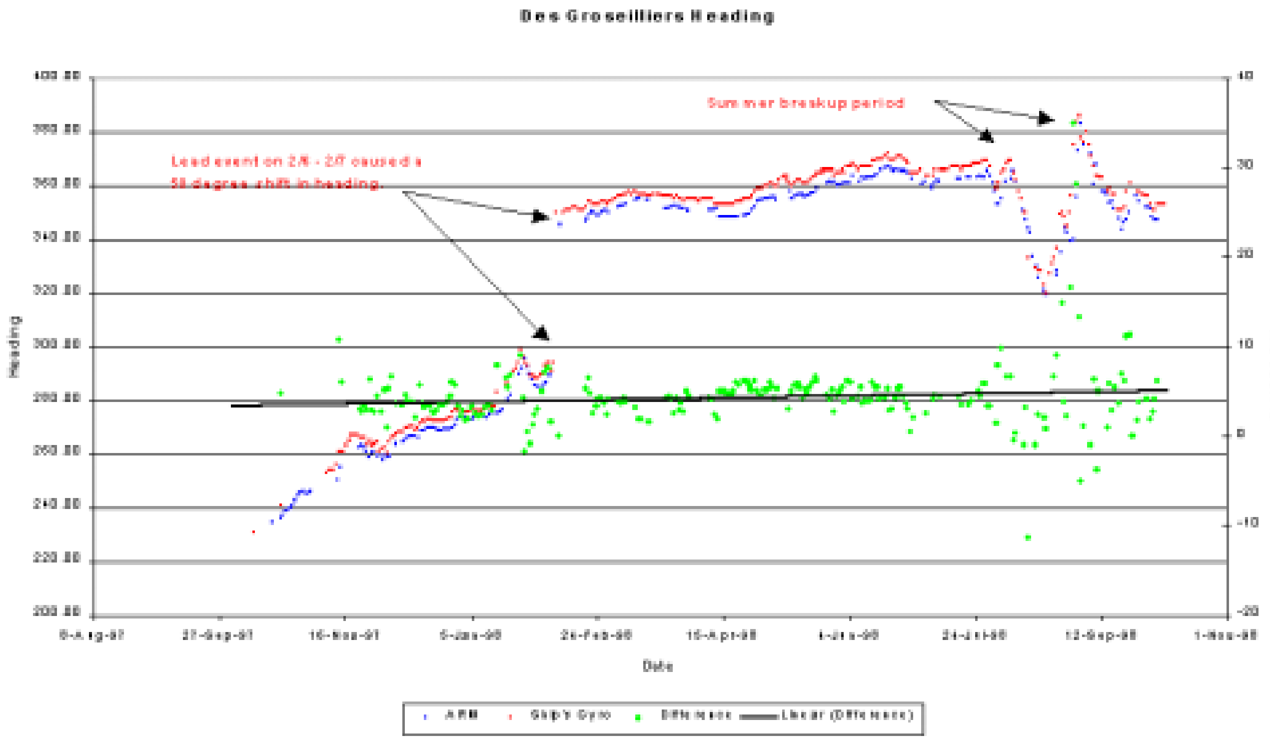

Figure 8. Des Groseilliers heading.

Figure 9. February's lead.

Figure 10. Lead from the bow.

After the movement in February, the ship's bow stayed pointing near to true north for approximately five months until the summer melt season began in late July. This stable period saw a rotation of only 20°. Toward the end of July, leads and melt ponds began forming in earnest. This apparently caused the more frequent movement and heading swings of up to 64°. One can see the beginning of freeze-up in mid-September as the movement slackens.

Figure 8 also shows the difference (in green) between the ship's gyro compass and the ARM GPS. There is an approximate 5° offset between the two. This can be due to several factors. First, the GPS antenna array installation was visually aligned with the ship's centerline. For our purposes, a very accurate alignment to true north was not required. We aligned our instruments manually and used the GPS heading data to make relative changes. We then checked the individual alignment manually when the sun cooperated.

Roll/Pitch Data

In addition to heading data, it is important to know if the ship has changed in either roll or pitch. The instruments were checked daily with a bubble level but we also obtained roll/pitch measurements from the GPS ADU. Figure 11 shows a plot of roll (in green) and pitch (in red) taken near 0000 Greenwich mean time (GMT) each day. As can be seen by the plot, the ship was relatively stable throughout the experiment. There were concerns prior to deployment that ice pressure might cause excessive roll (it did with the Fram). Fortunately, we did not experience this at SHEBA.

Figure 11. Daily roll/pitch.

Summary/Conclusions

Despite problems with multipath dropouts of the attitude data, the GPS ADU proved valuable in keeping ARM operators apprised of the ship's heading and were able to keep the solar tracker, MFRSR, and WSI properly aligned throughout the experiment. On a future deployment, it would be nice to get a better location for the antennas and receiver to eliminate the multipath problems.

Despite traversing over 2300 km, the ship's heading did not vary much, only 150° over the course of a year. This made it relatively easy keeping instruments aligned with the sun.

Roll and pitch of the ship trapped in the ice was not a problem. The Des Groseilliers (and the surrounding ice floe) provided us with a stable platform for making atmospheric measurements during SHEBA.