ICE DRIFT AND DRAFT MEASUREMENTS FROM MOORINGS AT THE CONFEDERATION BRIDGE

Donald J. Belliveau , Helen Hayden, Simon Prinsenberg

Department of Fisheries and Oceans
Bedford Institute of Oceanography
1 Challenger Drive
Dartmouth, Nova Scotia
Canada B2Y 4A2

ABSTRACT

Instruments capable of measuring ice thickness and drift velocity were deployed near the Confederation Bridge during the winter months of 1999 and 2000. The instruments were moored inline with the main navigation channel, close to one of the bridge piers. The data were gathered, in part, to complement measurements of bridge pier tilt, being conducted by the National Research Council for studies of ice forces on structures. Data are presented on ice draft and speed as the ice approaches the bridge from both sides in a strong tidally driven environment with a mean flow to the southeast. Data are compared to ice thickness data collected by helicopter-borne sensors. Also presented are some of the challenges in processing data contaminated by flow around the piers.

INTRODUCTION

From January until April of 1999 and 2000, field programs were conducted to study pack ice properties in the southern Gulf of St. Lawrence and Northumberland Strait. Ice drift, ice draft and ocean current data were collected using moored Acoustic Doppler Current Profilers (ADCP) and Ice Profiling Sonars (IPS). The instruments were deployed south of P.E.I., in Northumberland Strait, where the 13km-long Confederation Bridge links the Island with Canada’s mainland (Fig.1). The data were gathered, in part, to support a study of ice forces on bridge piers being conducted by the National Research Council (Kubat et al., 2000).

During the experiment, helicopter-borne sensors monitored the ice properties on several occasions (Prinsenberg and Peterson, 2001).

The bridge is located at the narrowest portion of the Northumberland Strait, where currents are highest. The primary axis of flow is along 310/130 degrees true. There is very little cross channel flow.

This paper describes ice draft and velocity data collected by the moored sensors to determine what effect the bridge has on pack ice conditions and to compare them with helicopter borne sensor data.

MEASUREMENT TECHNIQUES / INSTRUMENTS

ADCP’s, manufactured by RD Instruments of San Diego, California, have been used since the late 1980’s to measure ice velocity from moorings below the ice (Belliveau et al, 1990). These instruments use four acoustic beams to measure the water velocity and the ice drift as they pass above the mooring. By measuring the Doppler shift of the acoustic signal returned from scatterers in the water column and from the ice/water interface the instrument can determine the velocity of the water and ice. The ADCP uses a minimum of three valid beams to measure the two horizontal components of velocity. The vertical velocity can be measured using only two opposing beams. The vertical velocity is assumed to be zero on average and can be used as a data quality check. A more sensitive quality check is the difference between the vertical velocity as measured by the two pairs of opposing beams. This “error velocity” is very sensitive to surface waves and can be used to determine periods of open water. The ADCP provides a profile of the water velocity with bins of 1 to 8 meter depth averages.

The Ice Profiling Sonar, manufactured by ASL Environmental of Sydney, British Columbia, was developed at the Institute of Ocean Science during the late 80’s and early 90’s (Melling et al, 1995). The IPS is a 420 kHz sonar with a 2 degree beamwidth, capable of pinging once a second to range off the bottom of the ice. The unit also has a very accurate pressure sensor so the range data can be corrected for tidal and atmospheric variations to produce accurate measurements of ice draft.

Weather data was collected at the bridge by IFN Engineering Ltd., under contract for Public Works Government Services Canada, the government department responsible for the bridge project. The data included wind speed and direction, atmospheric pressure and temperature.

INSTRUMENT SET UP AND DEPLOYMENT

In 1999 one ADCP and one IPS unit were deployed to the north-west of bridge pier 23 in 20 metres water depth. The IPS was approximately 200 metres from the pier and the ADCP 400 metres. The two degree IPS beamwidth corresponds to a 1 meter spot size on the surface at 20 metres range. The ice velocities were anticipated to reach 1 m/s. To ensure that no ice features were missed, the IPS was set up to collect ranges every second, its fastest sampling rate. The ADCP was set up to collect profiles, with 2 meter resolution, every 30 minutes. Unfortunately, the IPS unit did not range properly for the first 30 days of deployment. After it started working the data shows that the mooring motion during the high current periods made most of the data unusable. Therefore, this paper will deal with data collected in 2000.

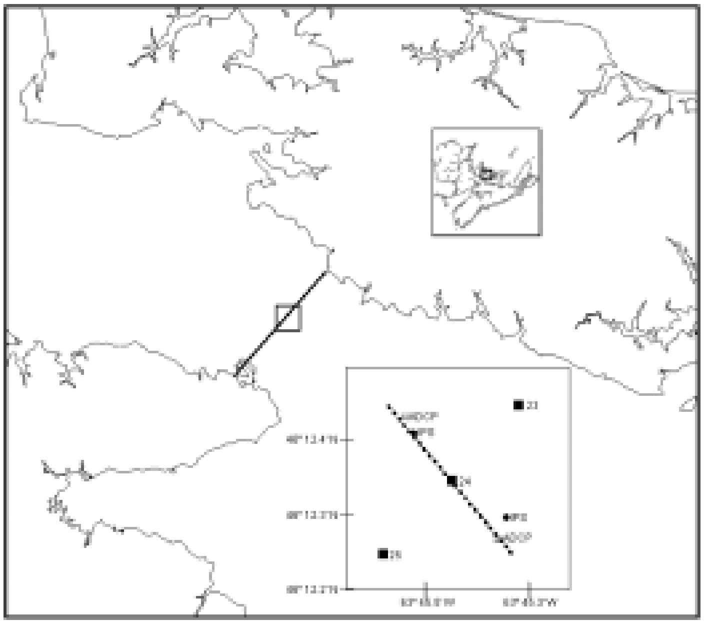


Figure 1. Location map showing the Confederation bridge relative to the Maritime Provinces, and the location of the instruments in 2000 relative to Bridge Pier 24. The dotted line shows the primary axis of flow.

In 2000, two pairs of instruments were deployed on either side of pier 24 (Fig. 1). Pier 24 was selected because the researchers from NRC found that its response to forcing by wind and ice was larger than pier 23. The IPS units were approximately 150 metres from the pier along the main channel axis, with the ADCP slightly further out. The IPS units were located closer to the pier at the request of the NRC researchers to try to provide better correlation between the ice thickness and speed, and the bridge tilt measurements. Note that the IPS to the northwest is almost directly in line with the flow past pier 24 to the northwest. The IPS's were set up to range every second. The ADCP was set up to collect profiles every 15 minutes. The IPS's were mounted in a bottom moored frame to avoid the high tilt problems that occurred the previous year.

DATA PROCESSING

To produce spatial data from the time series of IPS ranges involves a large effort. The one second sampling rate of the IPS creates large data volumes The range data must be corrected for variations in sound velocity as determined by CTD (Conductivity, Temperature, Depth) profiles taken at deployment, recovery and through the ice during the deployment period. The corrected ranges are combined with the pressure data and the atmospheric data to produce ice draft time series. The draft data are edited to ensure periods of open water are set to zero ice draft. The ADCP ice velocity measurement will show large vertical and error velocities during periods when there is significant amounts of open water. Open water periods can also be determined by examining the IPS draft data and looking for periods of zero draft or obvious surface waves. The ice velocity records are also edited to remove periods with open water. As we do not have a valid measurement of ice velocity during these periods, an estimate of the expected ice velocity must be provided so the ice draft data can be converted to a draft vs. distance data set. A regression is run between the remaining ice velocity data, the water velocity below the ice, and the wind speed and direction. The regression is then used to fill in the open water data points. During the main part of the ice season, most of the ice velocity record is from direct measurements. The final ice draft data set is a continuous spatial series with a 0.5 meter resolution in the horizontal and 1 cm resolution in the vertical.

RESULTS

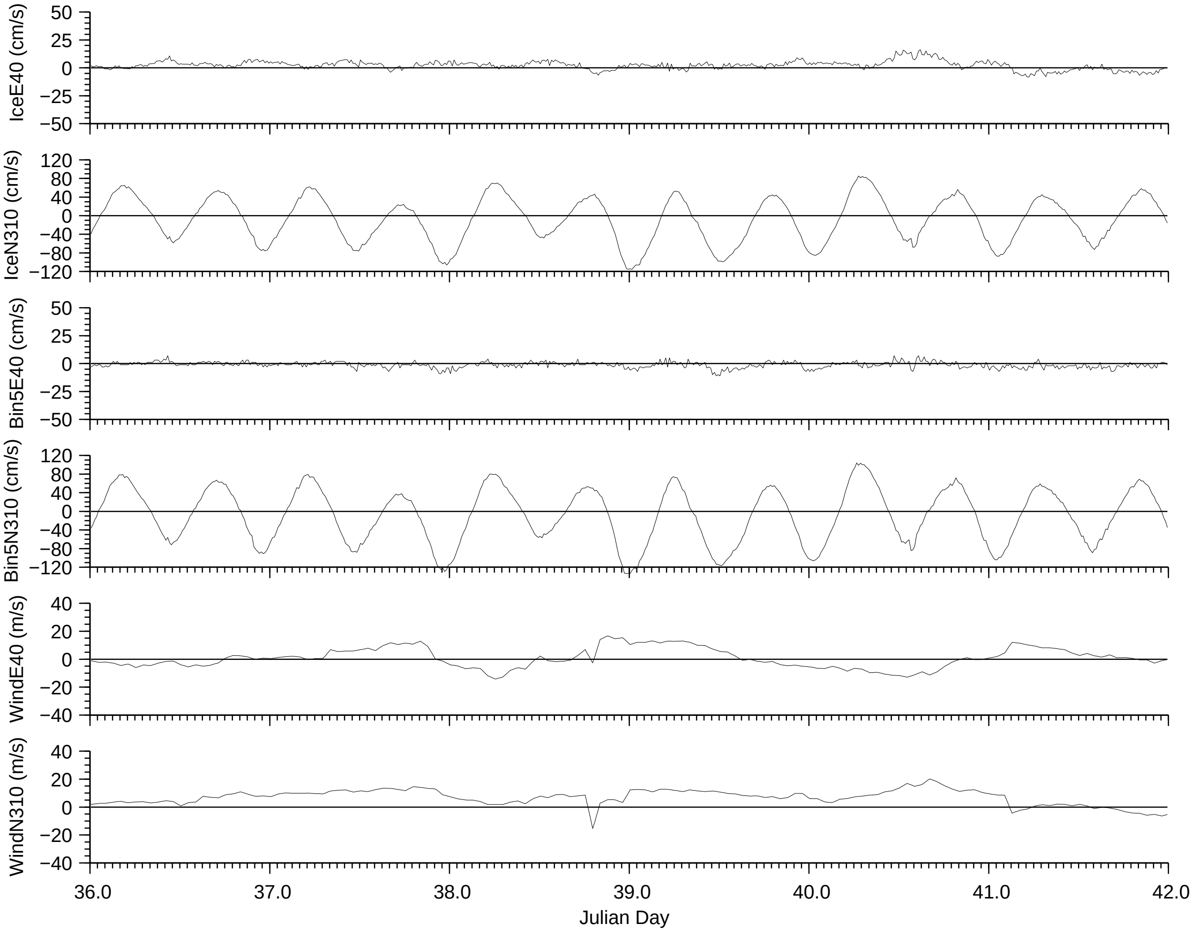


Figure 2 Time series of ice, water (Bin5, approximately 8m below surface), and wind velocities in along (310°) and cross (40°) channel components , February 5-10.

Effects of Water and Wind Velocities on Ice Velocities

The velocity components for ice, water and wind were transformed to provide along channel (310 degree) and cross channel (40 degree) components. The ice velocity is 80 to 85% of the water velocity, at a depth of 8m, and less than 1% of the wind velocity at the bridge site. This is lower than the 3% of the surface wind speed in the along-strait direction, and 1% in the cross-strait direction found in Peterson and Prinsenberg (1998), probably due to the fact that the wind data used in 2000 was from a sensor mounted on top of the bridge, (no attempt was made to correct for the height difference for this analysis). The accuracy of the regression is subject to the fact that the ice velocity is not truly linearly related to the water or wind velocities. At times of high ice concentration, and low velocity, the ice may stop moving as it compresses against the bridge and shoreline.

Along channel ice and water (Bin 5) velocities as high as 120 cm/s are obvious on days 38 and 39 (Fig 2). The dominant wind for most of the period is from the north causing both the water and ice velocities to be offset to the south. The water (Bin 5) cross channel velocity shows no effect from the wind. There is very little cross channel ice velocity with the exception of late on day 40 as the wind blowing from the New Brunswick shore pushes the ice towards PEI.

Effects of the Bridge Piers on Ice Draft Measurements

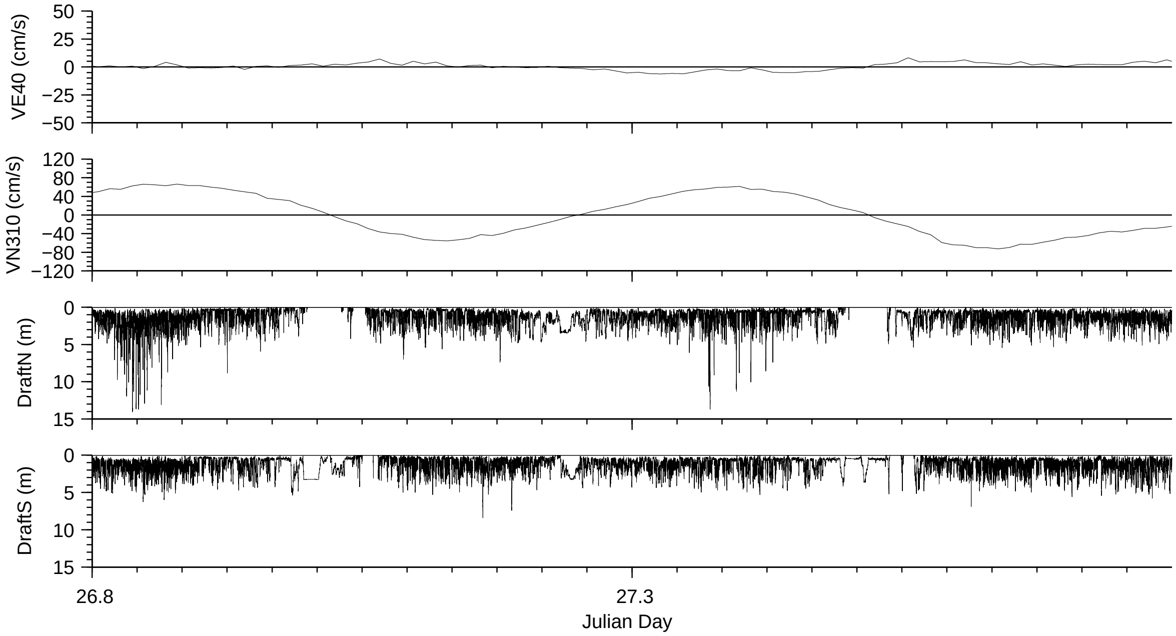


Figure 3 Ice velocity (northwest ADCP) and ice draft (IPS to the northwest and southeast of bridge) for the first 24 hours of the deployment.

The first day of deployment provides an example of the effects of the bridge pier on the ice draft measurements (Fig 3). When the tidal flow moves the ice and water to the northwest, the draft measurement of the IPS moored to the northwest shows drafts as deep as 13 metres. Drafts of these magnitudes are not apparent in the IPS to the southeast during these periods. Drafts of this depth are not apparent during periods of flow to the southeast. As the ice impacts on the bridge pier, the ice is pushed up over the conical ice shield on the pier at the air/water boundary. As it moves around and over the pier it slides back into the water. We hypothesize that ice crystals are scraped off the larger blocks and mixed with the water. These ice crystals are carried along with the turbulent water behind the pier, slowly floating back to the surface. It is these submerged ice crystals that the IPS is detecting as deep ice keels. This effect is more noticeable in the IPS moored to the northwest as it is directly in line with the direction of water flow from the pier. The IPS moored to the southeast is off slightly to the east of the direction of flow from the pier. The effect is not purely a measure of the turbulence in the water, as the effect is not noticeable during periods with no ice. The effect is not always as severe, in Fig 4 there is only one obvious spike eight hours into the day. The velocities on day 56 were stronger to the south and weaker to the north allowing most of the submerged ice crystals to float to the surface before they reached the IPS.

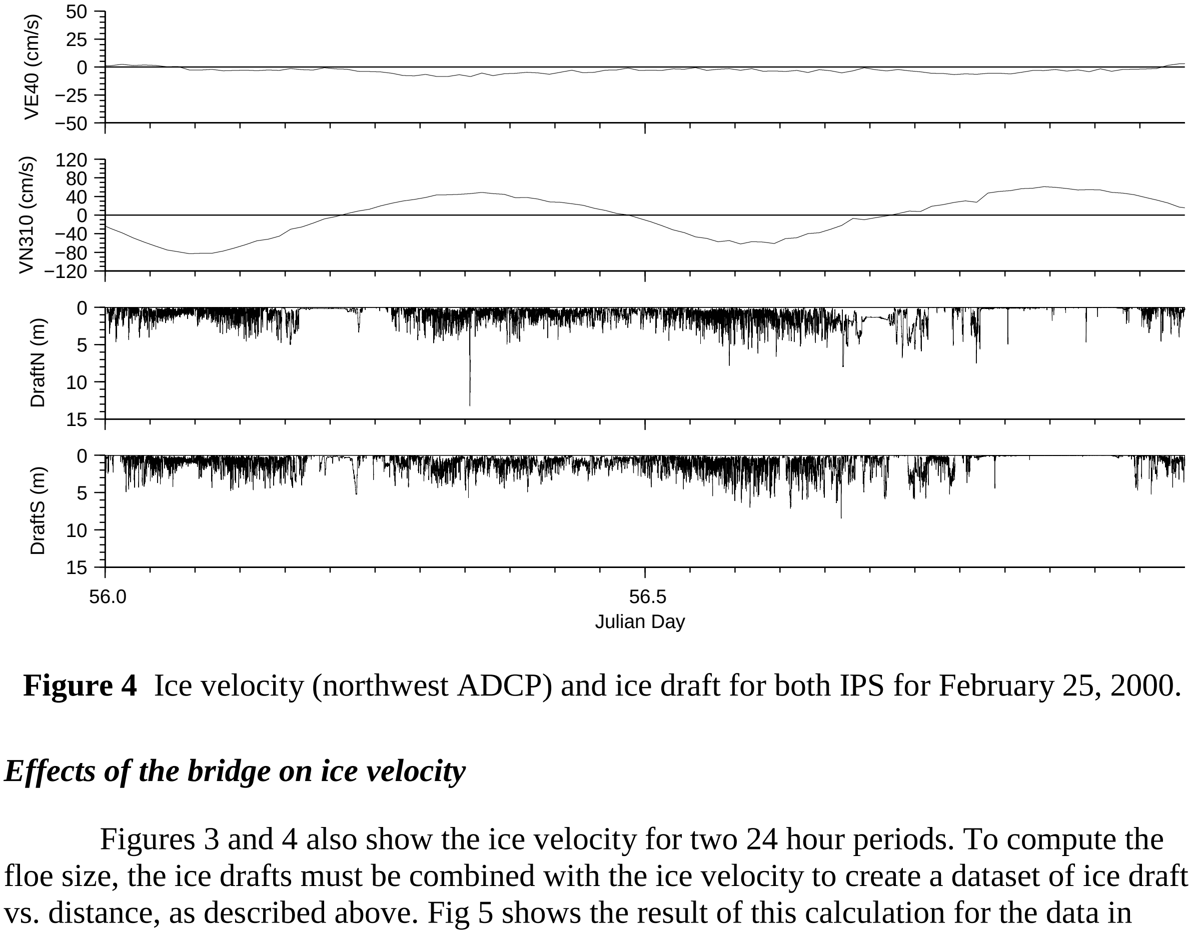


Figure 4 Ice velocity (northwest ADCP) and ice draft for both IPS for February 25, 2000.

Effects of the bridge on ice velocity

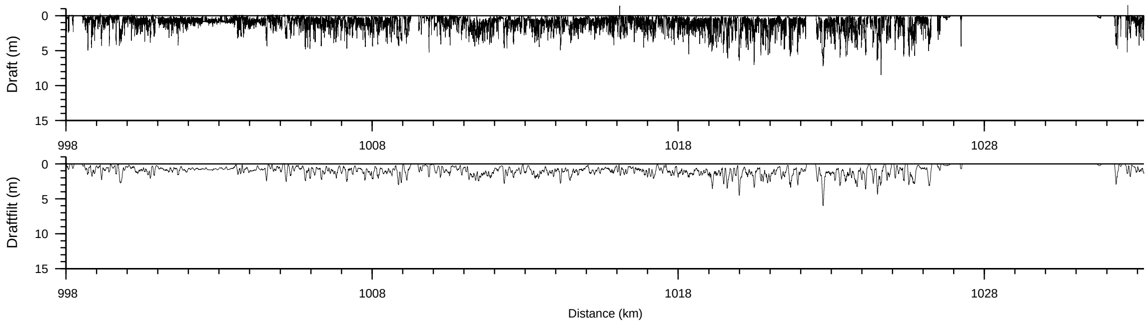
Figures 3 and 4 also show the ice velocity for two 24 hour periods. To compute the floe size, the ice drafts must be combined with the ice velocity to create a dataset of ice draft vs. distance, as described above. Fig 5 shows the result of this calculation for the data in Fig 4. Ice velocities are measured on both sides of the bridge and combined with the appropriate IPS. Table 1 summarizes the distance the ice travels, the mean draft and the direction of flow for the two days in figures 3 and 4. The data are divided into sections of tidal flow direction. Day 56 is only broken into three sections as the last section of the day was primarily open water.

The table shows that in all cases the distance traveled by the ice is always greater on the downstream side of the bridge. As the ice approaches the bridge from the upstream side it is decelerated as it comes in contact with the piers. As the ice moves over and around the piers it accelerates again in the looser pack ice on the down stream side. Although not presented here, there are periods in the dataset during which the ice motion is completely arrested, on the upstream side, by the bridge. These periods typically occur during the change in tidal direction when there is little forcing by the water. After the current flow is high enough the ice is once again forced past the piers.

Table 1 Section lengths, mean ice draft and direction of flow for two 24 hour periods.

Day	Section Number	Northwest distance (m)	Mean draft (m)	Southeast distance (m)	Mean draft (m)	Direction of flow
26/27	1	9845	1.60	8956	1.45	To NW
	2	6412	1.31	7713	1.14	To SE
	3	9188	1.27	8540	1.23	To NW
	4	11456	1.39	12987	1.32	To SE
56	1	10976	0.70	11789	0.84	To SE
	2	7332	0.93	5795	1.08	To NW
	3	8725	1.27	9840	1.28	To SE

Comparison with helicopter-borne sensor data at the Bridge



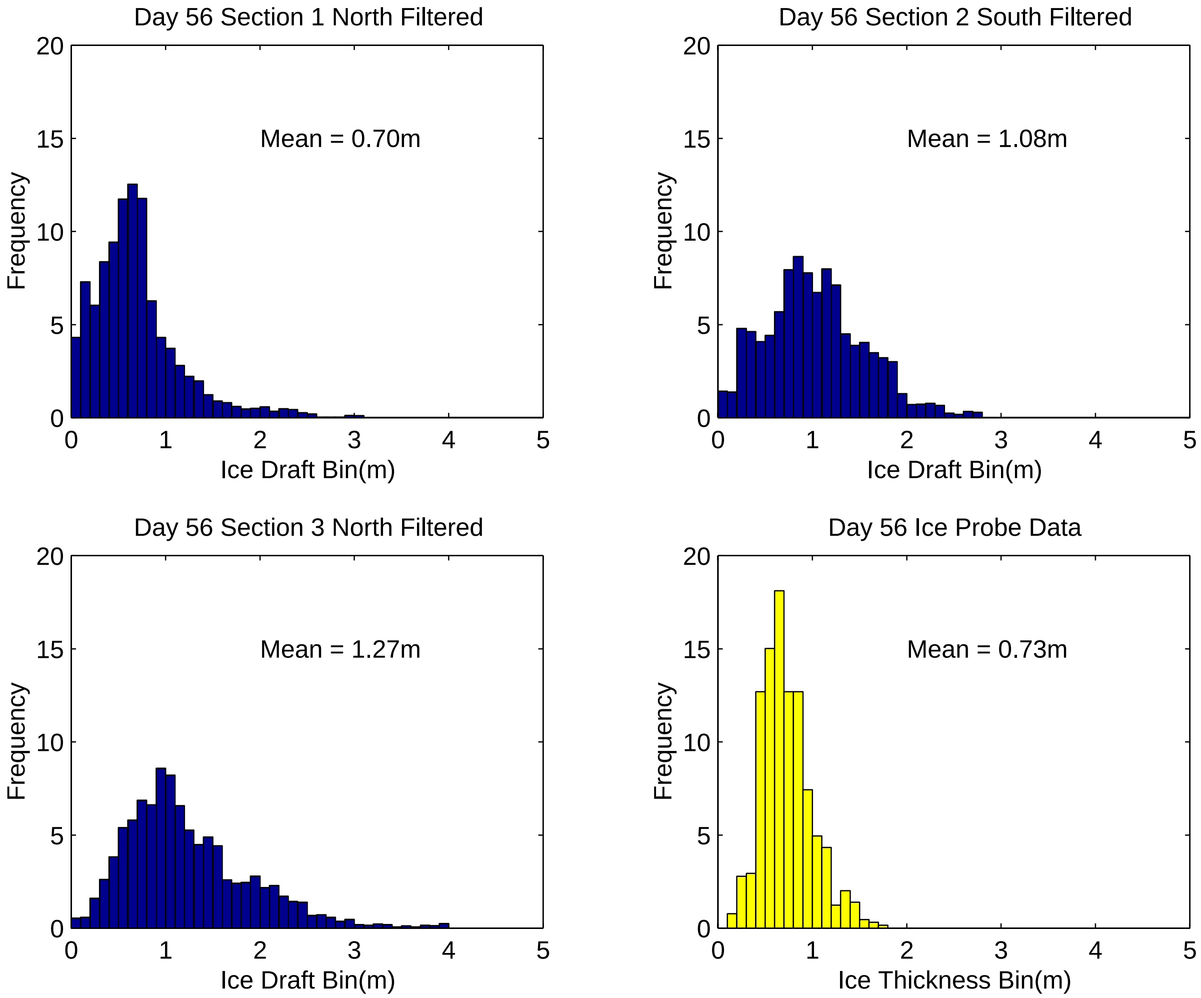


Figure 6 Histograms of ice draft, 50m boxcar filtered, on February 25, 2000 for ice being compressed against the bridge for: 1) northwest side of bridge during ice movement to the southeast, approx. first five hours of day; 2) southeast side of bridge with flow to the northwest, hours five to twelve; 3) northwest side of bridge with flow to the southeast, hours twelve to seventeen; 4) ice thickness measured by helicopter towed ice probe , southeast of bridge , snapshot during section 3.

Prinsenberg and Peterson (2001) presented pack ice property data collected with helicopter-borne sensors from the Confederation Bridge area. Two types of sensors were used: an electromagnetic induction system called the "Ice Probe" and a Video/laser system.

The Ice Probe collects snow-plus-ice thickness profiles while the Video system collects information on ice type, ice concentration and surface roughness profiles. For comparison, the ice thickness histogram of a line section flown by the helicopter southeast of, and parallel to, the bridge on February 25, 2000 will be compared to the ice draft histograms generated from the moorings. As the Probe data was collected 1.4 hours before the maximum northwestward tidal current, the pack ice was compressed southeast of the bridge against the bridge piers. The mooring data draft histograms from February 25 also represent pack ice conditions when the pack was compressed against the piers due to tidal currents. The ice draft data was spatial averaged to 50m (Fig 5), to correspond to the footprint area of the Probe. Both data sets represent pack ice conditions near the bridge area. They differ in the fact that ice draft data from the moorings cover line sections perpendicular to the bridge taken over half a tidal cycle, while the Probe data is a snap shot covering a line parallel to the bridge.

Fig. 6 shows the results from the two data sets. The mean ice drafts varied from 0.70m to 1.27m compared to the mean ice thickness of 0.73m measured by the Ice Probe. The peak value in the EM histogram is between 70-80cm. The distribution of the histogram in the IPS ice draft broadens and the peak increases to thicker ice as the day progresses. On February 24, a Radarsat image shows that the ice had been pushed to the PEI side of the Strait by the wind (Prinsenberg and Peterson, 2001). On February 25 the wind reversed and pushed the ice against the New Brunswick coast as is shown in the negative VE40 velocity component in Fig 4. As the day progressed more of the ridges formed by the ice being forced against the PEI shoreline pass over the IPS until late in the day the ice has been pushed past the IPS and there is primarily open water.

The IPS and Ice Probe sensors also vary in their capability in sensing porous brash ice, found both between and below the ice floes. The Ice Profiling Sonar (IPS) will sense the bottom of brash ice trapped or floating beneath the pack ice while the Ice Probe will not detect the submerged brash ice due to its high salinity content. Larger drafts will thus always be seen from below by an IPS in comparison to the ice thickness seen from above by the Ice Probe. The IPS draft data and Probe thickness data do compare well, even though they measured different parts of the pack ice using different, but closely related, properties of the pack ice. Further analysis with other data sets are required to see if these histograms and peak values will approach each other when uniform level ice conditions are encountered.

CONCLUSION

The combined IPS and ADCP sensors provide a working system for measuring ice motion through the narrows of the Northumberland Strait. The data set shows that the bridge piers slow the ice velocity on the upstream side and cause pieces of ice to be displaced deep beneath the surface.

Although they monitored different ice properties, in different areas of the pack ice near the Bridge, the IPS ice draft data and helicopter sensor ice thickness data from the Bridge area are similar. Further analysis is required to determine how these observations can be best compared and related.

ACKNOWLEDGEMENTS

The sea ice program is funded through the Program of Energy Research and Development of Natural Resources Canada and logistically supported by the Canadian Coast Guard. The authors wish to thank the officers and crew of the CCG ships Earl Grey and Sir William

Alexander for their assistance during the deployments and recoveries, and Jim Bruce of IFN Engineering Ltd. for supplying the meteorological data. The authors also wish to thank John Francis, General Manager, Confederation Bridge Authority, Borden, Prince Edward Island, for his ongoing support.

REFERENCES

Belliveau, D.J., G.L. Bugden, B.M. Eid, C.J. Calnan, 1990. Sea ice velocity measurements by upward-looking Doppler current profilers. *J. Atmos. Oceanic Technol*. 5:602-613.

Kubat, I., R. Frederking and T. Hayakawa, 2000. Response of the Confederation Bridge to ice action. CSCE 2000 Conference, London, Ontario, June 7-10. 8pp.

Melling, H., P.H. Johnston, D.A. Riedel, 1995. Measurements of the underside topography of sea ice by moored subsea sonar , *J. Atmos. Oceanic Technol*, 3: 589-602.

Peterson, I.K. and S. Prinsenberg, 1998. 1997 pack ice properties in Northumberland Strait. *Proceedings of the 8th (1998) Int. Offshore and Polar Conf.*, Montreal, Canada, May 24-29, 1998.

Prinsenberg,S.J. and I.K. Peterson, 2001. Pack ice thickness and concentration measurements from the area around the Confederation Bridge (Canada) using helicopter-borne sensors . *Proceedings of the 16th Int. Conf. on Port and Ocean Engineering under Arctic Conditions,* Ottawa, Canada, August 12-17, 2001.