Ice Profiling Sonar:

Upward Looking Sonar Provides Over-Winter Records of Ice Thickness and Ice Keel Depths off Sakhalin Island, Russia.

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Background

A two-year program of ice keel depth and ice velocity measurements was conducted offshore of Sakhalin Island during the winters of 1996-97 and 1997-98. The project was part of a Joint Industry Project for Sakhalin Energy Investment Company Ltd. (SE on behalf of the Sakhalin II Consortium) and Exxon Neftegas Ltd (ENL on behalf of the Sakhalin I Consortium).

To support the design and operational planning for offshore oil and gas activities off the northeastern coast of Sakhalin Island in the Russian Federation, accurate and reliable information were required on ice thickness and velocity, and on winter physical oceanographic conditions in the Sakhalin I and II license areas. The primary objectives of the data acquisition program were:

- to use ice profiling sonar to measure ice keel depths (including thick rafted ice), and to document the openings of the recurrent flaw lead, or coastal polynya, and
- to use acoustic Doppler current profilers to measure the ice speed as a function of time throughout the winters.

Figure 1. IPS4 and ADCP moorings laid out on the stern of the vessel "Neftegaz '70" in preparation for deployment.

Instrumentation

Upward-looking Ice Profiling Sonar (IPS4)

The ASL-IPS4 instrument is an upward-looking ice profiling sonar which provides high quality ice thickness data. It was originally designed by the Institute of Ocean Sciences, Sidney, BC, and with further development is now being manufactured by ASL Environmental Sciences. EXXON Production Research provided support in the development of the IPS, Model 4.

The ice thickness or keel depth is determined from the return travel time of an acoustic pulse (420 kHz; 1.8° beam at -3 dB) reflected off the underside of the sea ice. The ping rate is usually once per second (1 Hz). The narrow beam results in a "footprint" of less than 0.5 m, at typical operating depths of 30 m. The instrument eliminates spurious echoes based on amplitude and persistence settings. A pressure sensor (Paroscientific Digiquartz), incorporated within each IPS4, is used to measure water level changes caused by tidal and wind forcing, as well as apparent water level changes associated with depression of the mooring in response to current drag. Correction for these effects are necessary in the computation of ice keel depths. The IPS4 also contains tilt-x and -y sensors, to permit compensation for instrument tilt, and collects near-bottom ocean temperature data.

The measurements are stored internally on 64 MB of flash EPROM memory. At the 1 Hz sampling rate, memory and battery will last about 9 months. Up to 122 Alkaline D-cell batteries provide the necessary power.

Acoustic Doppler Current Profiler (ADCP)

ADCP technology uses the Doppler effect to measure the velocity of the water relative to the instrument. Acoustic energy is transmitted along four beams spaced 90° in azimuth and oriented 20° from the vertical. From scatterers in the water column, some of the acoustic energy reflects back to the instrument. The frequency of the back-scattered signal differs from that transmitted by an amount proportional to the velocity of the scatterers along the direction of each ADCP beam. Assuming the scatterers move at the same velocity as the water and that the field of motion is spatially uniform, then the frequency shifts from three of the beams are sufficient to calculate the three components of the water velocity. By time-gating the returns, the water velocity can be determined in bins at varying ranges from the instrument.

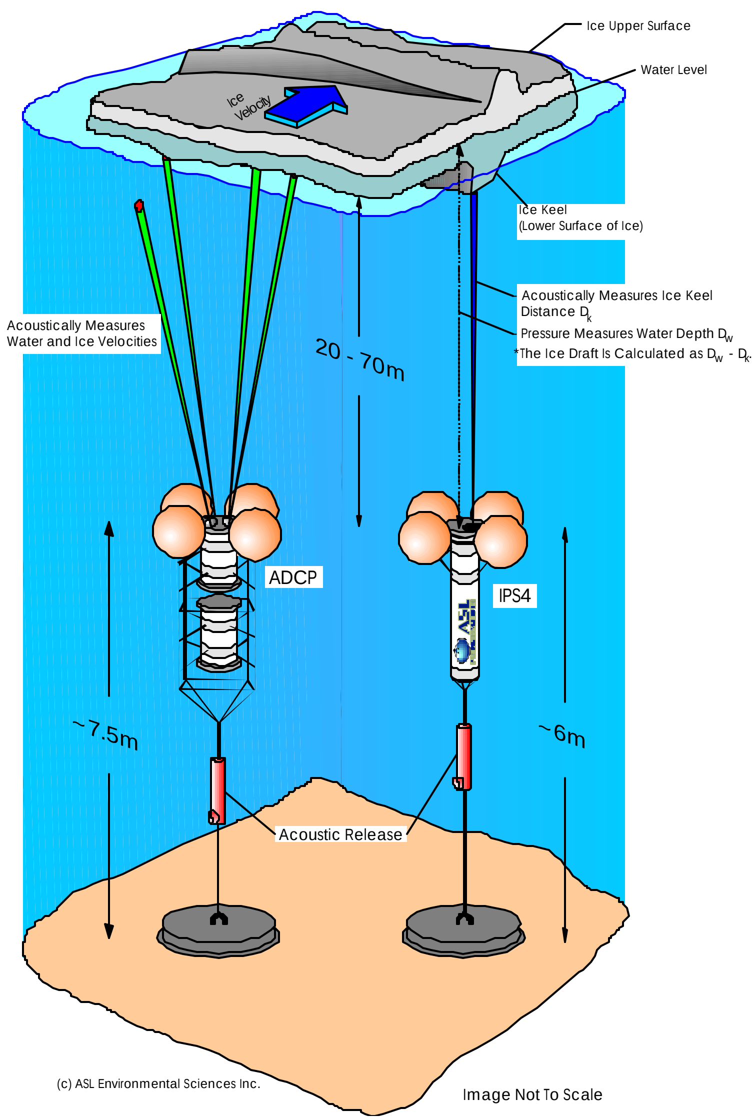

Figure 2. Mock-up presentation of the moored instrumentation used to measure ice keel depths (IPS4) and ice velocity (ADCP).

The reflected signal from the underside of the ice can be similarly used to determine the ice velocity. Comparative measurements using this technique under various ice conditions have been reported by Belliveau et al (1989), Melrose et al (1989), Melling et al (1995) and Galloway and Melling (1997). RDInstruments, the manufacturer of the 300 kHz Sentinel ADCP's, modified the instruments for this study to include "Bottom-Tracking" functions. This is now an option of the Sentinel Workhorse. The sampling scheme (50-60 water-track pings per ensemble, interspersed with 10-12 bottom-track pings, over a period of 3-3.6 minutes) achieves an estimated accuracy of ±0.2 cm s^{-1} for ice velocity. In real data, accuracy is degraded because of the relatively weak scattering from sea ice (Garrison et al, 1991; Melling, 1998). Lower accuracy is also expected for ice velocities in conditions of open pack, because of "noise" associated with spatially non-uniform wave orbital velocities. Overall, accuracy of the ice velocities is estimated as better than ±1 cm s^{-1}, except for low ice concentrations.

Measurement Program

The study area is located along the northeast coast of Sakhalin Island, where water depths range from 10 to 100 m. The continental shelf is about 60 km wide here, deepening eastward into the Sea of Okhotsk. Sea ice usually begins to form in December, and can persist until June. Most ice forms further north and is transported south under the influence of the winds and the Sakhalin Current. Equipment was shipped to Yuzhno-Sakhalinsk for mobilization, then by truck to the ship docked at Korsakov. Steaming time from Korsakov to the study area is 1-2 days.

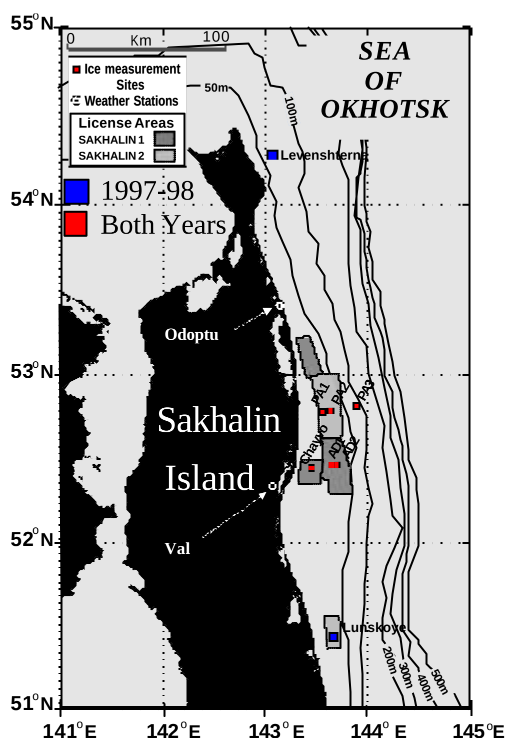

Figure 3. Study area – northeastern Sakhalin Island (just north of Japan).

The IPS and ADCPs were moored near-bottom using relatively short taut-line moorings. Flotation was provided by plastic “Viny” floats, attached to the cage as high as possible in order to maximize the righting torque (thereby minimizing instrument tilt). This was particularly important for the IPS. The ADCPs automatically compensate for tilts up to 20°. A swivel, an acoustic release, a drop line and an anchor comprised the remainder of each mooring.

In 1996-97 six IPS, four ADCP and two single-point electromagnetic current meters were deployed at six central sites (one IPS and one CM per site). All but one of the IPS was recovered and all instruments contained 100% good data. The next year, 1997-98, the program was expanded to include the Lunskoye and Levenshterna sites; all instruments were recovered with 100% data. In November 1998, the same suite of instruments was again deployed, with recovery scheduled for June 1999.

Each of the IPS provided continuous over-winter records of ice thickness. Tilts were generally less than 5°, but reached 10° when current speed increased occasionally to 100 cm s^{-1}. All but one ADCP provided complete water column and ice velocity data.

Processing of the IPS4 ice draft data

The IPS4 data provide the information needed to compute a time series of the draft of the sea ice. Ice draft, ***d***, is defined as the difference between the instantaneous depth of the IPS4 and the acoustically-derived distance from the IPS4 to the underside of the sea ice. Depth, ***?,*** is determined from the hydrostatic equation, using the measured bottom pressure (at one minute intervals), adjusted for the time-varying atmospheric pressure (three-hourly measurements) measured at nearby coastal site. The IPS4 acoustic range measurement, ***r***, is obtained at 1 second intervals, and is corrected for instrument tilt, ***?***.

Ice Draft - Definition

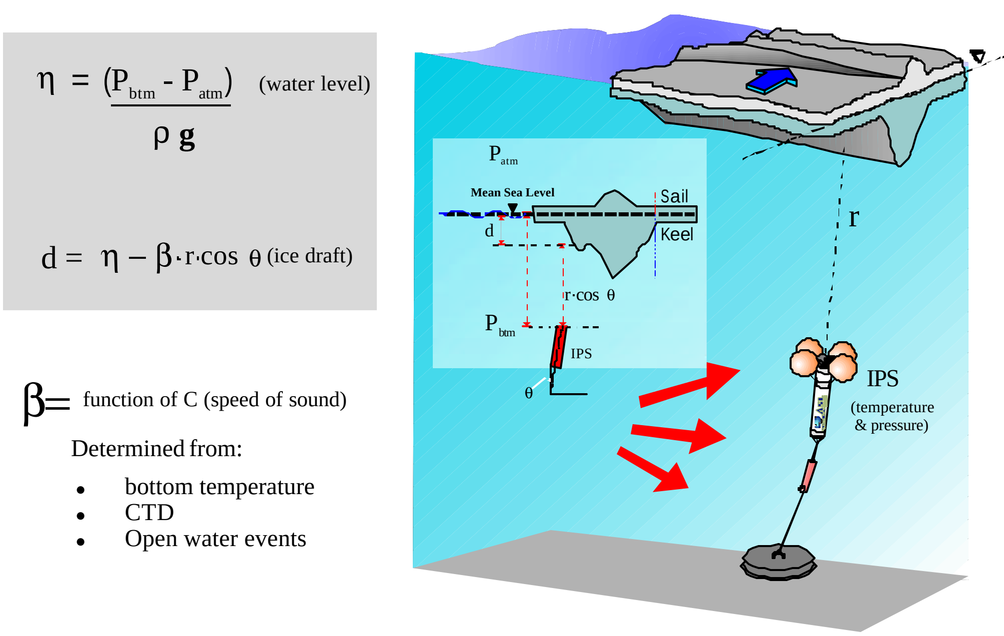

Figure 4. Representation of method used to convert IPS range data, into ice draft data.

To achieve optimal accuracy in ice draft measurements, the measured acoustic range must also be corrected for the effect of the time-varying changes in the speed of sound, ***c***, within the water column. This procedure requires considerable effort, because measurements of the sound speed profile were available only from the deployment and recovery cruises, seven months apart. During the intervening period, the variations in ***c***, are represented by a correction factor, ***ß***, applied to the measured range; ***ß*** represents the ratio of the actual sound speed to the nominal value of 1438 m s^{-1}. To determine *b*, open water segments in the range data set were selected (i.e. ***d*** = 0) and *b* was empirically computed. These sporadic values of *b* followed reasonably well the variation in the local speed of sound computed assuming that the measured near-bottom temperatures were representative of the overlying water column. When the coastal polynya opened for long periods at some sites in March and at all sites starting in mid-April, the upper water column apparently warmed through absorption of solar radiation, increasing the average sound speed. This warming was not detectable by the instruments near the sea-floor. However, the common occurrence of open water periods, at these times, allowed empirical computation of *b* values frequently enough to track the effects of upper layer warming. Further information on processing and analysis methods for derivation of ice drafts from acoustic ranges is given by Melling et al. (1995).

Overview of Data/Results

Sea-ice generally first appears in December off northeast Sakhalin Island. Ice conditions within the study area were largely determined by the longitude of the ice pack and, hence, by the width of the polynya zone which separates the pack from landfast ice on the east coast of Sakhalin Island. Changes in polynya width were closely related to contemporary wind and surface current conditions. The polynya persisted through much of the winter, interrupted by a few, short-lived closures. The summertime melt and dispersal of the pack ice occurred locally, with advection having little importance. East Sakhalin ice was reduced to a tongue of close pack extending southward from Levenshterna and scattered fields of rapidly dissipating ice near and south of Lunskoye.

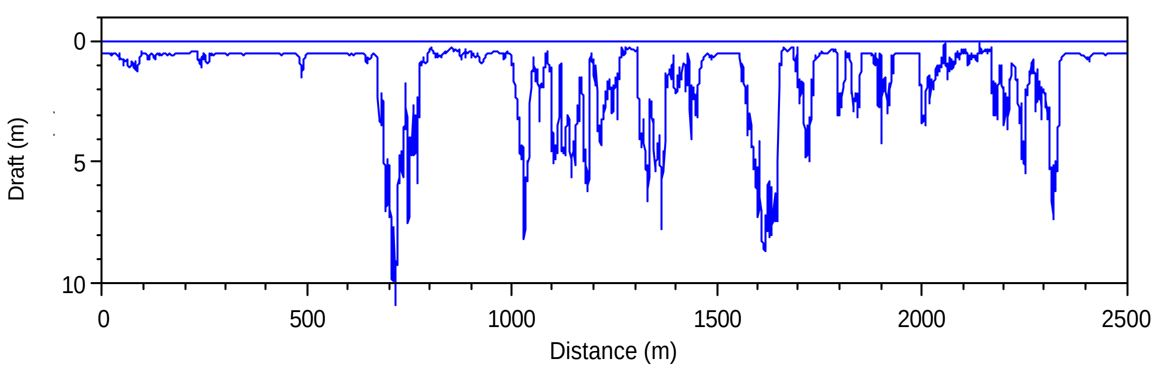

Figure 5. Ice draft data, northeastern Sakhalin Island shelf, March 20, 1998. The IPS upward looking sonar time series data (1 Hz) has been converted to distance using the ice velocity data from the ADCP.

Mean ice draft at the northern site is typically 1.5 and 2.0 m through the winter, and considerably larger at times in the early spring.

Large ice keels (drafts greater than 10m) generally appear by late December at the northern site (Levenshterna) and by January at the rest of the sites. Large keels persisted at the central and southern sites through late April, and into June at the most northern site.

ASL Environmental Sciences developed automated software techniques to analyse the ice draft time series data. These included:

- detection of ice keels, for subsequent statistical analyses,
- ice classification system (keel, thick ice, thin ice, etc).

Ice velocities, measured using the BT feature of the ADCP's, averaged 20-50 cm s^{-1}. The vector average ice velocities were in all cases directed to the south.

Ocean currents (ADCP) and water levels (IPS4 – pressure sensor) were measured continuously. The data were analyzed and separated into tidal and residual components. Typical tidal current amplitudes were 30-40 cm s^{-1}. There was a strong seasonal variation in the amplitude and phase of the dominant diurnal tidal currents. The spatial variation in the phase of the tidal currents is caused by the presence of diurnal continental shelf waves.

The vector mean current is to the south from late fall through early spring (the East Sakhalin Current). The speed increases through the late fall reaching a maximum monthly value in January (10-30 cm s^{-1}) among the various measurement sites. The speed decreases from February through to April; in May and early June, the vector mean flow reverses to a weak northerly flow of a few cm s^{-1}. The monthly residual ice velocities follow a similar seasonal pattern, but with larger magnitudes (30-50 cm s^{-1}). By April, the vector mean velocities are still southward, but at greatly reduced magnitudes (5-10 cm s^{-1}).

These winter ice data have provided a variety of detailed information essential to the design and operations specialists who are planning offshore Sakhalin oilfield development. This information has included basic data on ice concentrations and mean and maximum ice drafts, and has also provided quantitative descriptions of:

- draft and extent statistics for the various types of deformed ice in the area,
- the roles of local residual and tidal currents in controlling shifts in ice edge position and speed of approach,
- moderate waves (up to a couple of meters H_s) appearing several hundred km inside the outer edge of the regional pack, and
- the large masses of ridged ice which pose particular threats to platforms and vessels.

Summary

The high sampling rate (1 Hz) and narrow beam of the ASL-IPS4 instrument enables resolution of the underside of sea ice to unprecedented levels. IPS4 range accuracy is ±0.05 m; after conversion to ice thickness, the accuracy is typically ±0.3 m. Under typical ice velocities, the horizontal resolution is approximately 1 m.

Acknowledgements

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