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By Rick Birch
David Fissel
ASL Environmental Sciences Inc.
Sidney, British Columbia, Canada
Humfrey Melling
Institute of Ocean Sciences
Sidney, British Columbia, Canada
Ken Vaudrey
Vaudrey & Assoc.
San Luis Obispo, California
Ken Schaudt
Marathon Oil/Sakhalin Energy
Houston, Texas
John Heideman,
Exxon Production Research
Houston, Texas
and
Wilson Lamb
Infometric Assoc.
Hillsborough, North Carolina

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

By Rick Birch
David Fissel
ASL Environmental Sciences Inc.
Sidney, British Columbia, Canada
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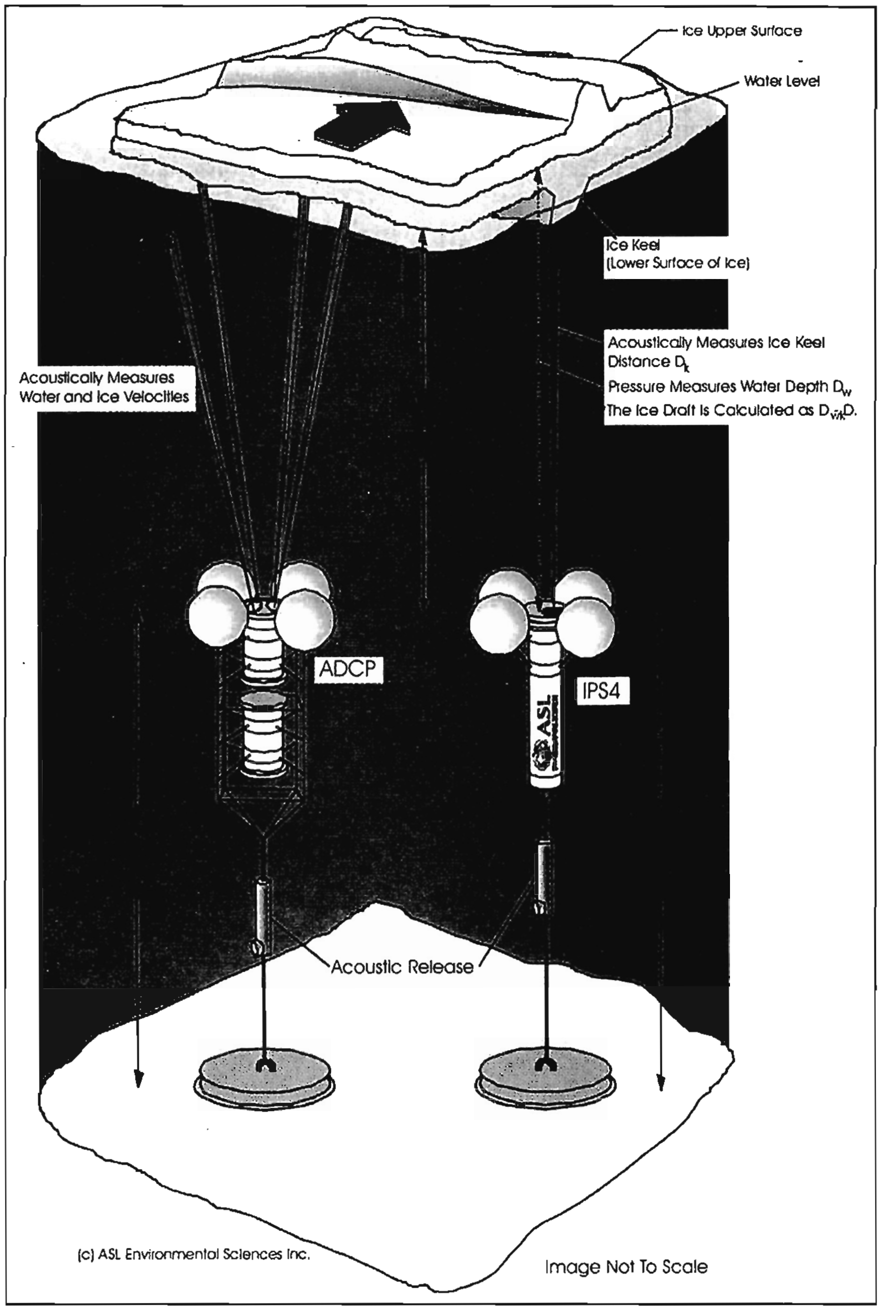
A two-year program of ice keel-depth and ice-velocity measurements was conducted offshore of Sakhalin Island during the winters of 1996-1997 and 1997-1998. The project was part of a joint industry project for Sakhalin Energy Investment Company Ltd. (SEI) on behalf of the Sakhalin II Consortium and Exxon Neftegaz 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
- Document the openings of the recurrent flaw lead, or coastal polynya
- Use acoustic-doppler current pro-

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



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

filers to measure the ice speed as a function of time throughout the winters.

Instrumentation

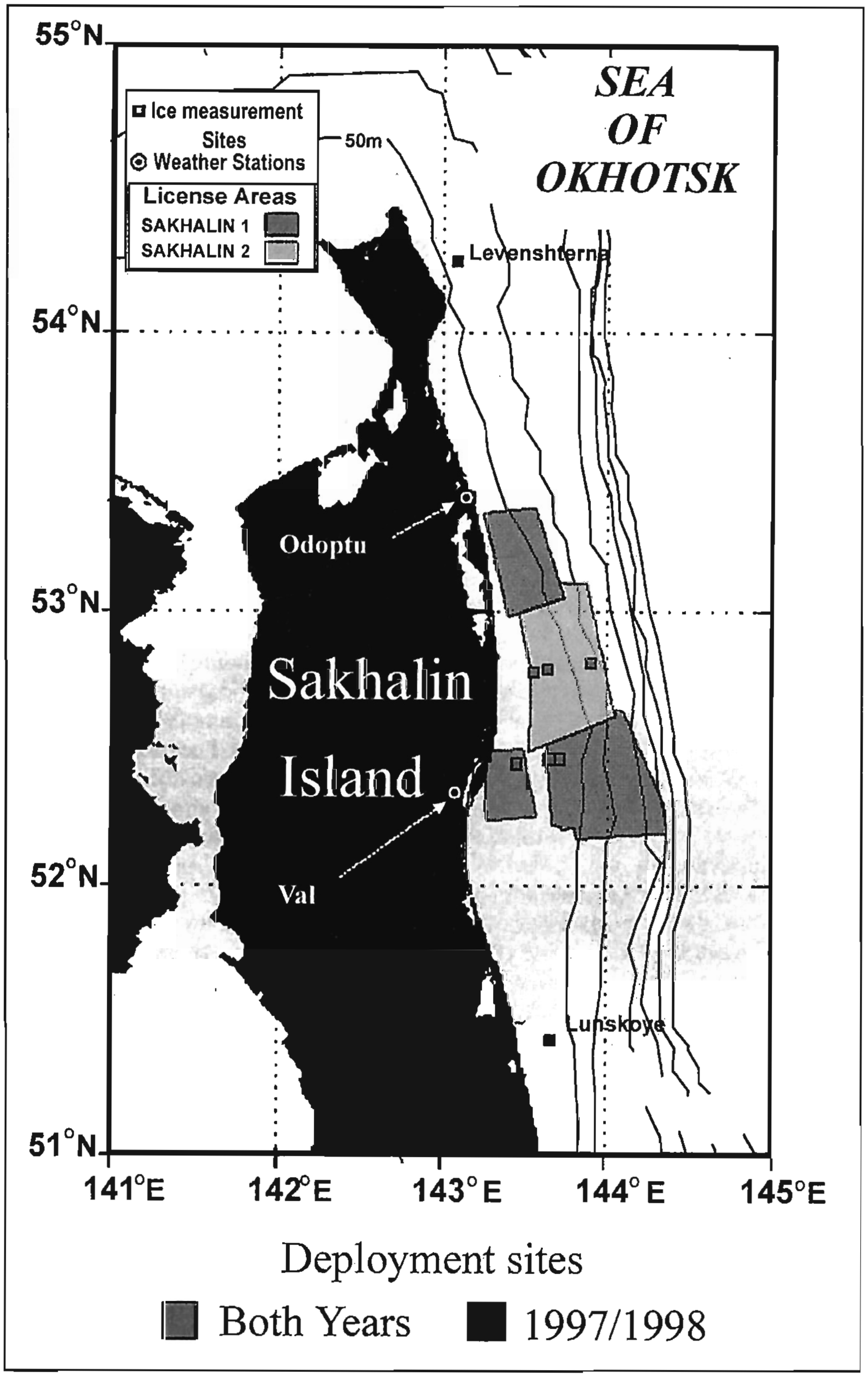
Upward-looking Ice Profiling Sonar (IPS4). The ASL upward-looking ice-profiling sonar model 4 (IPS4) is an instrument that provides high-quality ice thickness data. It was originally designed by the Institute of Ocean Sciences and with further development is now being manufactured by ASL Environmental Sciences. Exxon Production Research provided support in the development of IPS4.

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 about 1-meter, at typical operating depths of 30 meters. 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. Corrections 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 megabyte (MB) of flash erasable programmable read-only memory (EPROM). At the 1-Hz sampling rate, memory and (alkaline) battery will last about nine months.

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.

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[1,2,3,4]. RD Instruments, the manufacturer of the 300-kHz Sentinel ADCP, modified the instruments for this study to include "bottom-tracking" functions. This is now a standard feature in 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) resulted in an estimated accuracy of 1 centimeter/second for ice velocity. Accuracy is degraded, compared to seafloor bottom-tracking, because of the relatively weak scattering from sea ice. Lower accuracy is also expected for ice velocities in conditions of open pack, because of "noise" associated with spatially non-uniform wave orbital velocities.



Study area-Northeastern Sakhalin Island (bottom, just north of Japan).

Measurement Program

The study area is located along the northeast coast of Sakhalin Island, in water depths of 10-100 meters. The continental shelf is about 60 kilometers 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 winds and the Sakhalin Current.

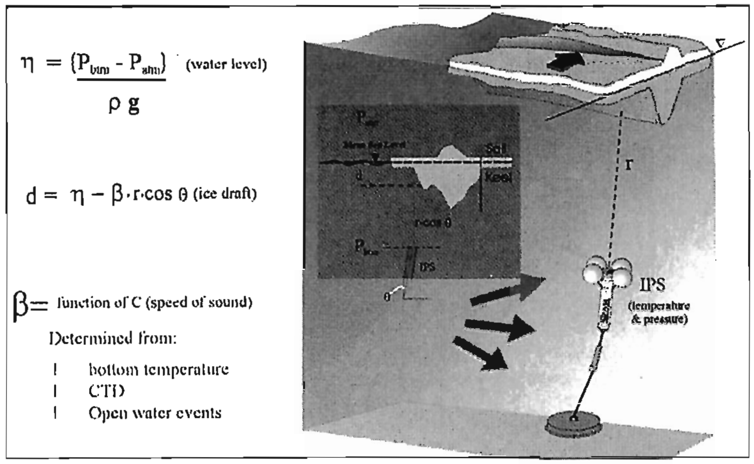
The IPS and ADCPs were moored near-bottom using relatively short taut-line moorings. Flotation was provided by plastic "Viny" floats, attached to the cage as high as possible in order to maximize the righting torque (thereby minimizing instrument tilt). This was particularly important for the IPS, whereas the ADCPs automatically compensate for tilts up to 20°.

In 1996-1997, 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, except for one ADCP, contained 100 percent good data. The next year, 1997-1998, the program was expanded to include the Lunskoye and Levenshterna sites; all instruments were recovered with 100 percent data. In November 1998, the same suite of instruments was again deployed, with recovery in June 1999.

Processing 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 (η) 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 a nearby coastal site. The IPS4 acoustic range measurement (r) is obtained at 1-second intervals, and is corrected for instrument tilt (θ).

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[3]. This procedure requires considerable effort, as measurements of c were available only from the deployment cruise and then, seven months later, the recovery cruise. For 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 1,438 meters/second. To determine ß, open water segments in the range data set were selected (i.e. d = 0) and ß was empirically computed. These sporadic values of ß 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. During extended polynya occurrences at some sites in March and at all sites starting in mid-April, heating of the upper water column apparently resulted in a warmer upper layer. Unlike the isothermal conditions of the water column from late autumn through early spring, this could not be detected by the instruments near the sea-floor. However, the common occurrence of open water periods, at these times, allowed empirical computation of ß values frequently enough to track the effects of upper layer warming. For further information see reference 3.



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

Overview: Data/Results

Sea-ice generally first appears in December. Seasonal ice conditions within the study area were largely determined by the width of the polynya zone which separated 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 can persist through much of the winter, interrupted by a few, short-lived closures. The summertime melt and dispersal of the pack ice largely took place in situ. By late April these changes confined East Sakhalin ice to a tongue of heavy pack ice extending southward from Levenshterna and scattered fields of rapidly dissipating ice near and south of Lunskoye.

Mean ice draft at the northern site is typically 1.5 to 2.0 meters through the winter, and considerably larger at times in the early spring. Large ice keels (drafts greater than 10 meters) 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 ADCPs, averaged 20-50 centimeters/second. The vector average ice velocities were in all cases directed to the south.

Ocean currents (ADCP) and water levels (IPS4 depth minus pressure sensor) were measured continuously. The data were analyzed and separated into tidal and residual components. Typical tidal current amplitudes were 30-40 centimeters/second. 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 residual current is to the south from late fall through early spring (the East Sakhalin current). The magnitude increases through the late fall reaching a maximum monthly value in January of 10-30 centimeters/second. The magnitude decreases from February through to April; in May and early June, the vector mean flow has reversed to a weak northerly flow of a few centimeters/second. The monthly residual ice velocities follow a similar seasonal pattern, but with larger magnitudes (30-50 centimeters/second). By April, the vector mean velocities are still directed south, but at greatly reduced magnitudes (5-10 centimeters/second). These winter ice data have provided a wide-variety of detailed information essential to the oil industry design and operations planning specialists. This information has included not only basic data on ice concentrations and mean and maximum ice drafts but, as well, offered quantitative descriptions of:

- Draft and size statistics for the various types of deformed ice present in the area
- The roles of local residual and tidal currents in controlling major shifts in ice pack position and approach speeds
- Anomalous large wave events a few hundred kilometers inside the outer edge of the regional pack
- 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 meters; after conversion to ice thickness, the accuracy is typically 0.3 meters. Under typical ice velocities, the horizontal resolution is approximately 1 meter.

Acknowledgements

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Rick Birch is a physical oceanographer whose interests and responsibilities within ASL include programs in support of marine facility construction and studies related to hydroelectric dams.

David Fissel is President/CEO of ASL. He has over 25 years of experience as a physical oceanographer, mostly with ASL since joining the company in 1977 as a founding partner.

Humfrey Melling is a physical oceanographer whose main focus is on the physical coupling between pack ice and the ocean in polar regions. He pioneered techniques for aircraft-based oceanography in ice-covered seas, and developed the ice-profiling sonar and other specialized instruments for polar ocean research.

Ken Vaudrey is a sea-ice consultant with 28 years of Arctic and Antarctic experience.

Ken Schaudt joined Marathon Oil Companies as an oceanographer, meteorologist, ocean engineer supporting worldwide design and operations. Schaudt is a certified consulting meteorologist and a member of the American Meteorological Society.

John Heideman has over 30-years experience in the petroleum industry, primarily with oceanographic criteria and wave forcing on offshore structures. Recently he has been responsible for sea-ice criteria for structures offshore Sakhalin Island.

Wilson Lamb, while with Exxon Production Research, was a driving force in the initial development of the IPS. Wilson and Dee Lamb now operate Infometric Associates.