Assessment

Before a Spill

Before a spill it is important to identify what the particular sensitivities are for the area covered by any particular oil spill contingency plan, and to put the information on a sensitivity map which will be available to response teams. An example is shown in **Figure 6**. Maps should include information on the following.

- Shoreline sensitivity. Shorelines may be ranked using the basic principles that sensitivity to oil increases with increasing shelter of the shore from wave action, penetration of oil into the substratum, natural oil retention times on the shore, and biological productivity of shore organisms. Typically, the least sensitive shorelines are exposed rocky headlands, and the most sensitive are marshes and mangrove forests.
- Other ecological resources such as coral reefs, seagrass and kelp beds, and wildlife such as turtles, birds and mammals.
- Socioeconomic resources, for example fishing areas, shellfish beds, fish and crustacean nursery areas, fish traps and aquaculture facilities. Other features include boat facilities such as harbors and slipways, industrial water intakes, recreational resources such as amenity beaches, and sites of cultural or historical significance. Sensitivities are influenced by many factors including ease of protection and clean-up, recovery times, importance for subsistence, economic value and seasonal changes in use.

After a Spill

The response options need to be reviewed and fine-tuned throughout the response period, in the light of information being received about distribution and degree of oiling and resources affected. In extreme cases this process can be lengthy, for example over three years for the shoreline response to the *Exxon Valdez* spill in Prince William Sound, Alaska. In this case information was provided by shoreline clean-up assessment teams who carried out postspill surveys with the following objectives: assessment of the presence, distribution, and amount of surface and subsurface oil, and collection of information needed to make environmentally sound decisions on clean-up techniques. The standardized methods developed have subsequently been used as a model for other spills.

Acknowledgment

The International Petroleum Industry Environmental Conservation Association is gratefully acknowledged for permission to use material from its Report series.

See also

Coral Reefs. Mangroves. Seabirds as Indicators of Ocean Pollution. Seabird Overview. Seamounts and Off-ridge Volcanism.

Further Reading

American Petroleum Institute, Washington, DC. *Oil Spill Conference Proceedings*, published biennially from 1969 onwards. The primary source of detailed papers on all aspects of oil pollution.

IPIECA Report Series. Vol. 1 (1991) *Guidelines on Biological Impacts of Oil Pollution*; vol. 2 (1991) *A Guide to Contingency Planning for Oil Spills on Water*; vol. 3 (1992) *Biological Impacts of Oil Pollution: Coral Reefs*; vol. 4 (1993) *Biological Impacts of Oil Pollution: Mangroves*; vol. 5 (1993) *Dispersants and their Role in Oil Spill Response*; vol. 6 (1994) *Biological Impacts of Oil Pollution: Saltmarshes*; vol. 7 (1995) *Biological Impacts of Oil Pollution: Rocky Shores*; vol. 8 (1997) *Biological Impacts of Oil Pollution: Fisheries*; vol. 9 (1999) *Biological Impacts of Oil Pollution: Sedimentary Shores*; vol. 10 (2000) *Choosing Spill Response Options to Minimize Damage*. London: International Petroleum Industry Environmental Conservation Association.

ITOPF (1987) *Response to Marine Oil Spills*. International Tanker Owners Pollution Federation Ltd, London. London: Witherby.

OKHOTSK SEA CIRCULATION

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Introduction

The Okhotsk Sea (**Figure 1**) is one of the marginal seas of the north-western North Pacific. The circulation in the Okhotsk Sea is mainly counterclockwise. The Okhotsk Sea is the formation region for the intermediate water layer of the North Pacific. Water entering the Okhotsk Sea from the North Pacific is transformed in temperature, salinity, oxygen, and other properties through ice processes, convection, and vigorous mixing before returning to the North Pacific. Relatively saline water from the Japan Sea assists in making Okhotsk Sea waters denser than those of the Bering Sea, which otherwise has similar

Figure 1 Okhotsk Sea geography.

processes but which does not produce intermediate water. Tides are exceptionally large within the Okhotsk which has broad, shallow continental shelves, providing a significant location for dissipation of tidal energy.

Geography

The Okhotsk Sea is enclosed by the Russian coastline to the north, Sakhalin and Hokkaido Islands to the west, the Kamchatka peninsula to the east and the Kuril Islands to the south east. Two other marginal seas are nearby: the Bering Sea east of Kamchatka, and the Japan (East) Sea west of Sakhalin and Hokkaido. These three marginal seas are characterized by limited connections to the North Pacific, relatively deep basins, and the presence of sea ice in winter. The Okhotsk Sea has a highly productive fishery, and is the site of explorative oil lease sites. The Okhotsk also occupies a unique role as the highest density surface source of waters for the North Pacific, feeding into the intermediate depth layer down to about 2000 m. All deeper water (and indeed, much of the water even in this intermediate layer) comes from the Southern Hemisphere.

The Okhotsk Sea is connected to the North Pacific through 13 straits between the numerous Kuril Islands. Because of the political history of this region, most straits and islands bear both Russian and Japanese names. The two deepest straits are Bussol' and Kruzenshtern, with sill depths of 2318 m and 1920 m, respectively, through which there is significant exchange of water with the North Pacific. Other straits of importance for exchange are Friza and Chetvertyy Straits, both with sill depths of about 600 m. The Okhotsk Sea is connected to the

Japan Sea through two straits on either end of Sakhalin: Soya (La Perouse) Strait to the south and Tatar Strait to the north. Soya Strait, while shallow (55 m), is an important source of warm, saline water for the Okhotsk Sea. Tatar Strait is extremely shallow (5 m) and there is little exchange through it. The Okhotsk Sea is not connected directly to the Bering Sea, but much of the water flowing into the Okhotsk Sea originates in a current from the western Bering Sea.

Within the Okhotsk Sea there are three deep basins, with the greatest depth being 3390 m in the Kuril Basin. An important characteristic of the Okhotsk Sea is its very broad continental shelves in the north; these impact tidal energy dissipation and formation of dense waters in winter. The fairly shallow, isolated Kashevarov Bank is found in the north west. A major river, the Amur, drains into the Okhotsk Sea north-west of Sakhalin.

Tides

The Okhotsk Sea is one of the major tidal dissipation areas of the world ocean as a result of its very broad continental shelves. Tides in the North Pacific rotate counterclockwise. The tidal energy passing by the Kuril Islands enters the Okhotsk Sea. Tides around the Kuril Islands can have associated currents of 4–8 knots (20–40 cm s^{-1}). The currents through each of the Kuril Straits associated with the tides are northward at the eastern side of each strait and southward at the western side, leading to a net clockwise circulation of water around each of the Kuril Islands. Within the Okhotsk Sea, the maximum tidal currents and sea surface height displacements are in the northern bays and on Kashevarov Bank (**Figure 2**). Sea surface displacements can reach several meters in Penzhinskaya Bay in the north east. Maximum energy dissipation occurs in Shelikov Bay, with a somewhat less important site on Kashevarov Bank.

Circulation and Eddy Field

The mean circulation of the Okhotsk Sea is counterclockwise (**Figure 3**). Because ocean currents are in geostrophic balance, this means that there is low pressure in the center of the Okhotsk Sea. The flow in the Okhotsk Sea is driven by the same wind field that drives the cyclonic circulation of the adjacent subpolar North Pacific. The prevailing winds are the western side of the Aleutian Low. These winds create upwelling in the subpolar region and Okhotsk Sea. Upwelling over a broad region causes counterclockwise (cyclonic) flow in the Northern Hemisphere.

North Pacific water enters the Okhotsk Sea through the northernmost passages through the Kurils, primarily Kruzenshtern and Chetvertyy Straits. The North Pacific water comes from the East Kamchatka Current, which is a narrow south-

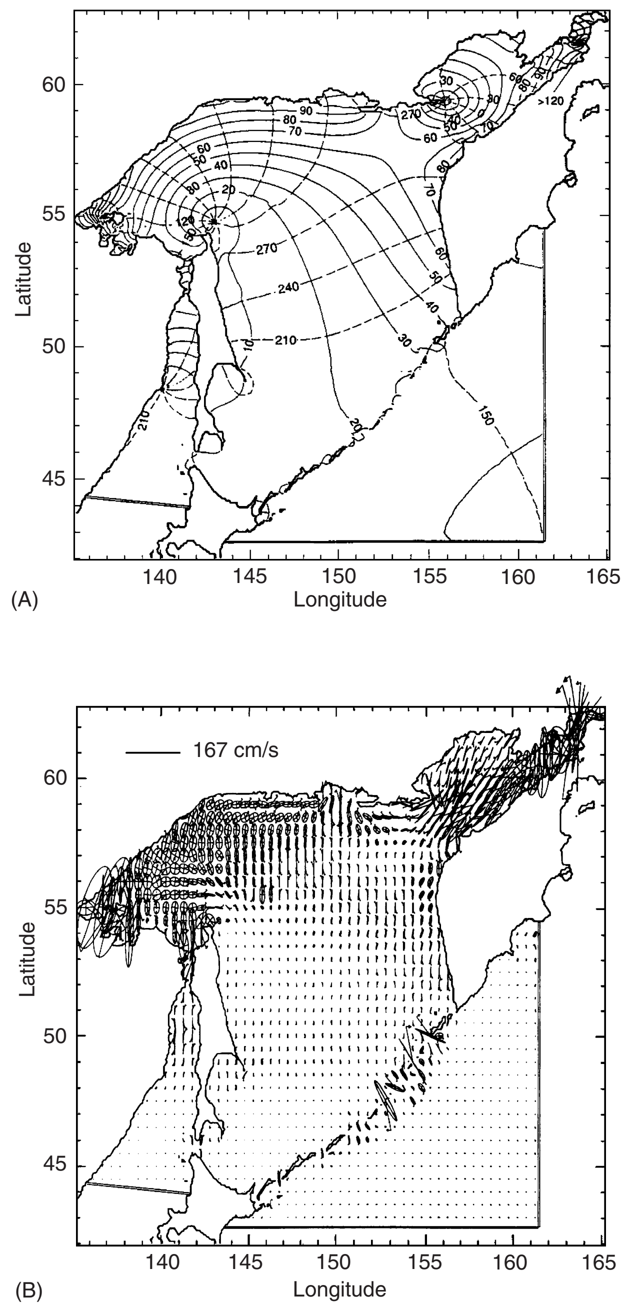

Figure 2 (A) The amplitude (cm) and phase and (B) current ellipses of the dominant semi-diurnal tide (M_2) in the Okhotsk Sea, from Kowalik and Polyakov (1998).

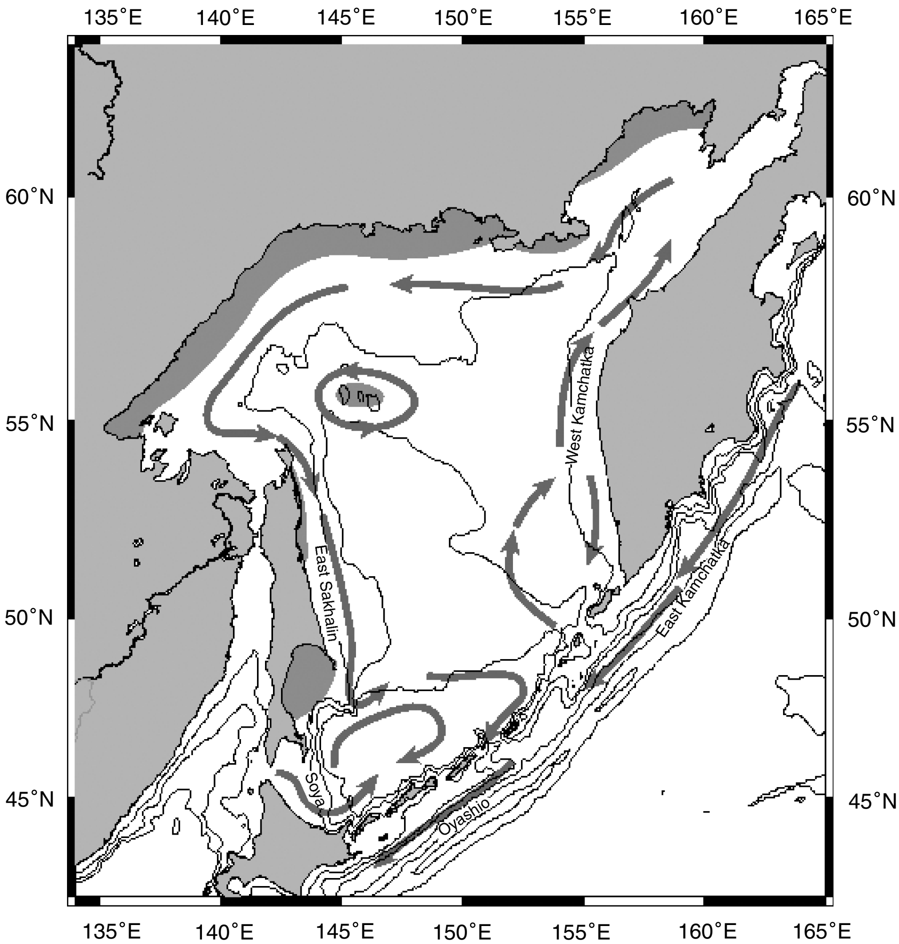

Figure 3 Mean circulation of the Okhotsk Sea, after numerous sources. (See Talley and Nagata, 1995, for collection of the many cartoons of the flow.)

ward boundary current along the eastern coast of Kamchatka, from the Bering Sea. The water that leaves the Okhotsk Sea through the southern Kuril Islands turns southward along the Kurils and joins the narrow, strong Oyashio. The Oyashio flows to the southern coast of Hokkaido, where it turns eastward and enters the North Pacific gyres. The net exchange between the Okhotsk Sea and the North Pacific is superimposed on clockwise flow around each of the Kuril Islands, driven by the strong tidal currents.

Within the Okhotsk Sea, the inflow from the Pacific feeds a broad northward flow in the east called the West Kamchatka Current. The West Kamchatka Current is fragmented and broad and often contains an inshore countercurrent. The warmth of the West Kamchatka Current region keeps this region ice-free throughout the year.

Along the northern shelves there is westward flow. The shelf flow rounds the northern tip of Sakhalin (Cape Elizabeth) and collects into a swift, narrow boundary current flowing southward along the east side of Sakhalin, called the East Sakhalin Current. Where the East Sakhalin Current ends at Cape Terpeniya at the southern end of Sakhalin, it feeds into an eddy field with net transport toward Bussol' Strait, in the center of the Kuril Islands. Southward motion of the winter ice pack from Cape Terpeniya to Hokkaido suggests that some of the East Sakhalin Current also continues southward.

Water also enters the Okhotsk Sea from the Japan Sea, through Soya Strait. The narrow Soya Current carries this water along the northern coast of Hokkaido, moving towards the Kuril Islands. The typical speed of the Soya Current is 25–50 cm s^{-1}, with greater speeds in Soya Strait. The Soya Current peaks in summer and is submerged or very weak in winter, which allows ice to form along Hokkaido in the absence of this relatively warm water. The Soya

Current water joins the other waters exiting the Okhotsk Sea through the southern Kuril Islands, including through Bussol' Strait.

The Okhotsk Sea has a vigorous eddy field, meaning that often it is difficult to discern the mean flow because of the presence of moving, transient eddies of about 100–150 km scale. The eddy field is especially pronounced in the Kuril Basin as tracked by satellite imagery of the sea surface temperature. The two to four Kuril Basin eddies that are formed each year are clockwise (anticyclonic). A mean clockwise flow, perhaps divided into smaller subgyres, has been discerned in this eddy-rich basin. This anticyclonic permanent flow or eddy field conveys the East Sakhalin Current waters towards the central Kuril Islands and hence to the exit through Bussol' Strait.

The Soya Current often has dramatic eddies that form as the current becomes unstable and rolls up horizontally into backward-breaking waves. Eddies of the Soya Current also form mushroom-shaped vortices. Soya Current eddies have been photographed and tracked using loose sea ice in winter (**Figure 4**).

Sea Ice in the Okhotsk Sea

Ice forms every winter in the Okhotsk Sea and melts away completely every summer. Thus all ice in the Okhotsk is first-year ice. A small amount of ice is usually present by the end of October in the coastal areas of Shelikof and Penzhinskaya Bays, with formation by mid-November in Shantarsky Bay and off the west coast of Kamchatka. Ice expansion is rapid and by December ice is found throughout much of the northern Okhotsk Sea and around Sakhalin. Ice forms off Hokkaido by early January. Maximum ice extent in the Okhotsk occurs in late March when ice can cover almost the entire Okhotsk Sea in a heavy-ice winter. The south-eastern Okhotsk Sea, where relatively warm North Pacific waters enter, remains ice-free in even the most extreme winters. Fast ice (attached to land) is found in late winter in Shantarsky, Shelikov, and Penzhinskaya Bays and around Sakhalin. Maximum ice thickness in the Okhotsk is about 1.5 m in the north and 1 m in the central Okhotsk Sea.

Figure 4 Loose sea ice in the Soya Current, showing a counterclockwise eddy off the Hokkaido coast from an aircraft at altitude 1000 ft. The eddy was about 20 km in diameter. From Wakatsuchi and Ohshima (1990).

Circulation along the coast of Hokkaido is dominated by the warm, saline Soya Current entering from the Japan Sea. The Soya Current inhibits ice formation. It also exhibits large seasonality, being nearly completely submerged under fresh, cold water in winter and so ice can form along the Hokkaido coast. Pack ice from the Sakhalin area also reaches Hokkaido in early February.

Ice melt begins in late March and usually finishes by the end of June or early July, with the last vestiges of ice usually found in Shantarsky Bay. In heavy-ice winters, this last ice melts in late July.

In winter, pack ice often flows out of the Okhotsk Sea into the Pacific through the southern Kuril Islands. This and the fresh water generated by ice melt form the fresh coastal part of the Oyashio along the southern coast of Hokkaido.

Within the ice-covered zones, there are usually several areas that are either free of ice or contain only thin frazil ice. Such openings are called polynyas. A polynya often forms over Kashevarov Bank in the north, where strong tidal currents continually upwell warm waters to the sea surface and keep the region ice-free. The heat flux maintaining this polynya is provided by an upwelling of 0.3–0.6 m d^{-1} of water at 2°C.

Polynyas are also usually found in a narrow band along the north-western and northern coast between Shantarsky and Tauskaya Bays. The coastal polynyas are kept open by northerly or north-westerly winds that force the coastal ice offshore. Therefore ice forms continuously within these polynyas. Similar wind-forced polynyas are found in several spots along Sakhalin and in Terpeniya Bay at the southern end of Sakhalin.

Sea ice is always fresher than the sea water from which it forms since salt is rejected from the developing ice lattice. The rejected salt collects in pockets of brine within the ice and drips out at the bottom of the ice. This brine rejection process increases the salinity of the waters underneath the sea ice, which thus increases the density of these waters. This densification process is most effective in areas of active ice formation, such as the wind-created coastal polynyas, and where the water depth is not too great, so that the brine is less diluted as it mixes into the underlying water. In the Okhotsk Sea, the broad northern shelf with its coastal polynya is a site of active dense water formation.

Water Properties of the Okhotsk Sea

The main water source for the Okhotsk Sea is the North Pacific just east of the Kuril Islands and upstream of the Okhotsk Sea in the East Kamchatka Current. These North Pacific waters are characterized by a shallow temperature minimum below the sea surface, which is often called the 'dichothermal' layer (**Figure 5A**). Below this is a temperature maximum (the 'mesothermal' layer). The temperature minimum is supported by the existence of a low salinity surface layer (**Figure 5B**) since both temperature and salinity contribute to seawater density. The temperature minimum is a remnant of winter cooling, although it may reflect cooling farther upstream in the flow. The Okhotsk Sea waters also have this structure, although modified from the North Pacific's, as described below.

The second major source of water for the Okhotsk Sea is the Japan Sea, through Soya Strait. Japan Sea water is relatively saline, since it all originates as a branch of the Kuroshio at much lower latitude. Even though net precipitation in the Japan Sea reduces the salinity of the Kuroshio waters that enter it, the Soya Current waters feeding into the Okhotsk Sea are relatively saline. There is no similar source of relatively high salinity water for the Bering Sea. The resulting difference in overall salinity between the Okhotsk and Bering Seas is likely the main reason that the intermediate waters of the North Pacific are ventilated (originate at the sea surface) in the Okhotsk Sea rather than in the higher latitude Bering Sea.

Salinity within the Okhotsk Sea is reduced by flow from the Amur River and local precipitation. Sea ice production each winter creates higher density waters through brine rejection from the ice, and sea ice melt in spring and summer produces a freshened surface layer.

Within the Okhotsk Sea the dichothermal layer is colder than outside in the Pacific. Ice formation throughout most of the Okhotsk Sea depresses the temperature of the minimum. In the north-west Okhotsk Sea, the temperature minimum is close to the freezing point due to ice production in this shallow region in winter, causing the waters to the shelf bottom to be near freezing. Fresh, cold,

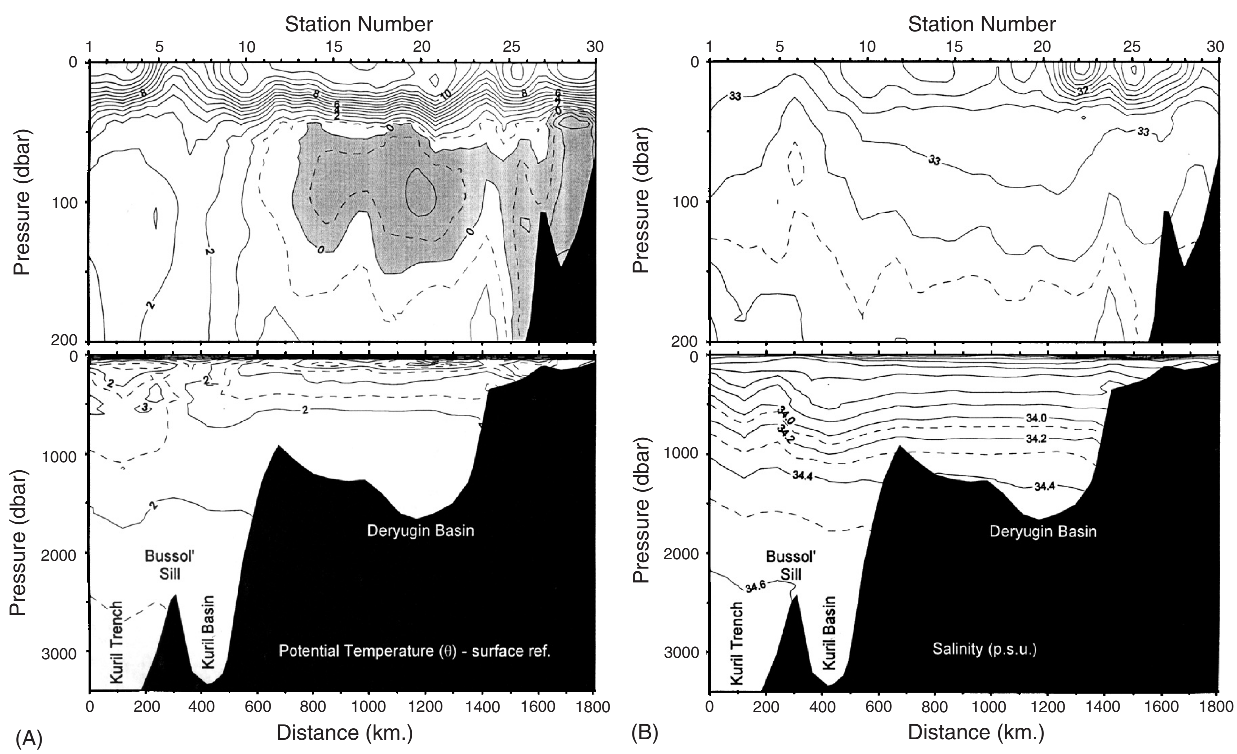

Figure 5 Cross-sections of (A) potential temperature and (B) salinity extending from the North Pacific through Bussol' Strait and to the northwest Okhotsk Sea, from Freeland *et al.* (1998).

oxygenated water penetrates much deeper with the Okhotsk Sea than in the East Kamchatka Current which is its primary source. The temperature maximum in the Okhotsk Sea is near 1000 m, considerably deeper than the mesothermal layer in the East Kamchatka Current which lies at about 300 m.

In summer, the surface salinity is very low, < 32.8 PSU, and considerably lower near the Amur River outflow. The generally low salinity is due to ice melt and river discharge. Salinity at the temperature minimum is about 33.0 PSU and then increases gradually to the bottom, consonant with the North Pacific source of the deep waters.

Several important water transformation processes occur in the Okhotsk: densification resulting from ice formation, convection resulting from cooling, input of low salinity at the surface from rivers, precipitation and ice melt, and mixing which is greatly accentuated in the Okhotsk because of its large tidal amplitudes. Ice formation over the northern shelves, particularly in the coastal polynyas, creates a dense shelf water that moves cyclonically around to Shantarsky Bay and then out past the northern end of Sakhalin and down along the

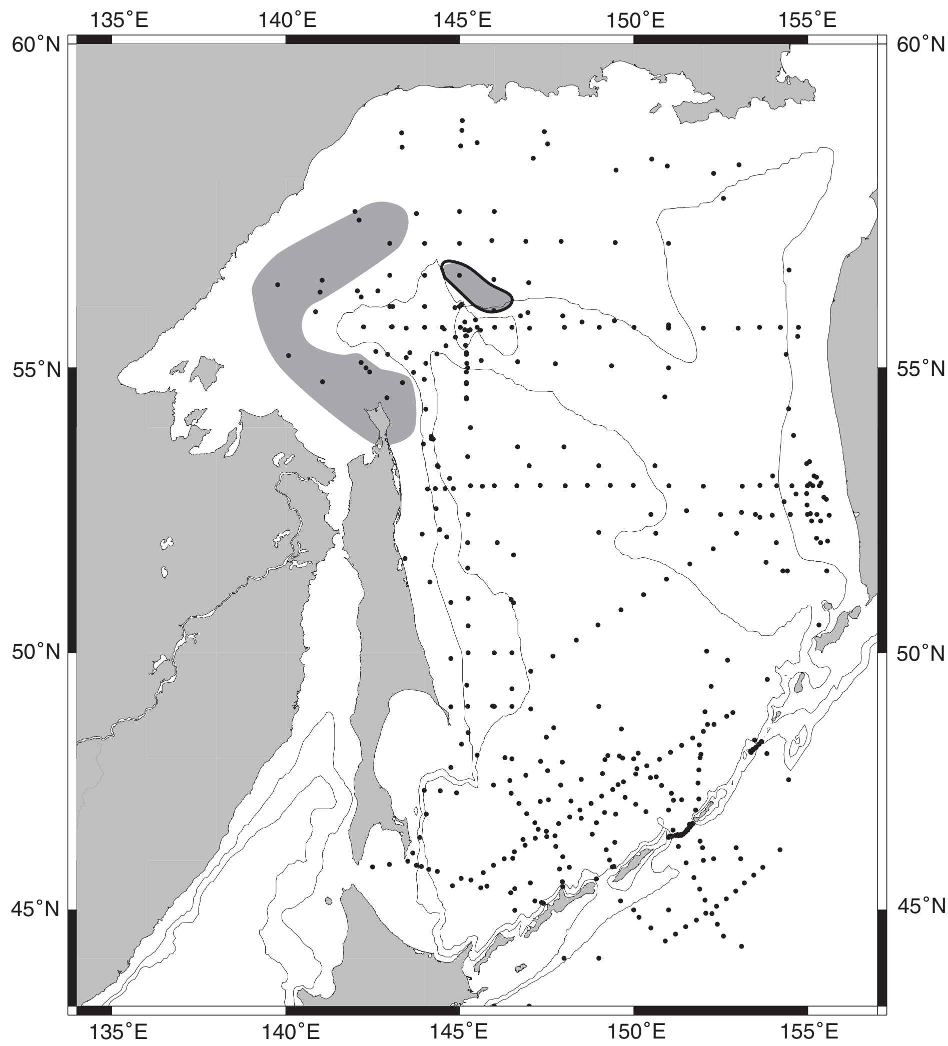

Figure 6 Bottom density (in units of kg m^{-3} – 1000) for depths less than 300 m is shown with the heavy contours. Bottom density is shaded where especially dense shelf water is found, with density greater than 1026.9 kg m^{-3}. The light contours show bottom depths of 300 and 1000 m. The dots indicate where observations were made. Large diamonds show observation positions where the water depth is less than 300 m. Large stars indicate that the temperature at the bottom is colder than $-1.0\,^{\circ}$C. The data are from Kitani (1973) and from surveys of the Okhotsk Sea in 1994 and 1995, with the latter data provided by Rogachev (Pacific Oceanological Institute, Vladivostok, Russia) and Riser (University of Washington).

sloping side to feed the dichothermal layer. The density of the new shelf water (**Figure 6**) can be surmised from nonwinter observations. Based on data collected over many years, it appears that the maximum density of the shelf waters and their offshore mixture is 1027.2 kg m^{-3}.

Convection due to heat loss occurs in the Okhotsk Sea, notably in the Kuril Basin to a depth of about 500 m. The maximum density affected by convection is about 1026.85 kg m^{-3}, and so ice formation on the shelves creates denser water than does convection. This limit on the density created by convection is set by the salinity of surface waters in the Kuril Basin and the maximum density they can reach when cooled to freezing. (Densification through ice formation has negligible effect in deep water since the rejected salt mixes into a thick water column.) However, the convective mixing is important as a signature of Okhotsk Sea water transformation as the waters enter the Oyashio and move southward into the North Pacific, since the thickness of the newly convected layer is retained to some extent.

Mixing is a much more significant process in the Okhotsk than in the open North Pacific because of the large tidal amplitudes and topography within the sea. Two locations especially deserve mention – in the straits between the Kuril Islands and over Kashevarov Bank in the north west. Mixing over the latter moves relatively warm water to the sea surface, melting out the sea ice there. Mixing over the nearby shelves may also be an important factor in setting the maximum density of the winter shelf waters, since the mixing could bring higher salinity waters from offshore onto the shelves. In the Kuril Straits, tidal currents are large, and oppose each other on opposite sides of each strait. In particular, water properties in Bussol' Strait have long been observed to be strongly mixed, to the bottom of the strait. This mixing brings the high oxygen of the upper waters down to the sill depth and is the major source for the North Pacific down to this depth of oxygen and other atmospheric gases such as chlorofluorocarbons.

Connection of the Okhotsk Sea with North Pacific Processes

The Okhotsk Sea is an important factor in air–sea exchange and overturn in the North Pacific. The 'ventilation' processes of the Okhotsk directly affect densities higher than elsewhere in the North Pacific. Deep and bottom waters are not formed at the sea surface in the North Pacific – globally they are formed only in the North Atlantic and around Antarctica. However, the intermediate layer of the North Pacific, between about 500 and 2000 m, is ventilated through Okhotsk Sea processes, similar to the impact of intermediate water formation in the Labrador Sea of the North Atlantic and Southern Hemisphere intermediate water formation around southern South America.

The intermediate layer of the North Pacific lies between the salinity minimum found in the subtropical region, at a density of 1026.8 kg m^{-3}, and the deep waters found below 2000 m, or a density of about 1027.6 kg m^{-3}. The most recently ventilated water in the North Pacific, as marked by laterally high oxygen (**Figure 7**) and chlorofluorocarbons and other gases of atmospheric origin, is found in the north west, in the neighborhood of the Okhotsk Sea. The intermediate layer is also freshest in this area. The evidence described above indicates that the Okhotsk Sea is the source of the ventilation. The bottom of the North Pacific's ventilated intermediate water layer is set by the sill depth of Bussol' Strait, that is, by the maximum depth and density of the vertical mixing that moves ventilated waters downward in the Okhotsk Sea, with outflow into the North Pacific.

The water that leaves the Okhotsk Sea through Bussol' Strait turns southward and becomes the Oyashio. Its properties are significantly different from those of the East Kamchatka Current, that feeds water into the Okhotsk Sea farther north. The Oyashio continues southward to the southern end of Hokkaido and then turns offshore and to the east. The Oyashio waters, including the

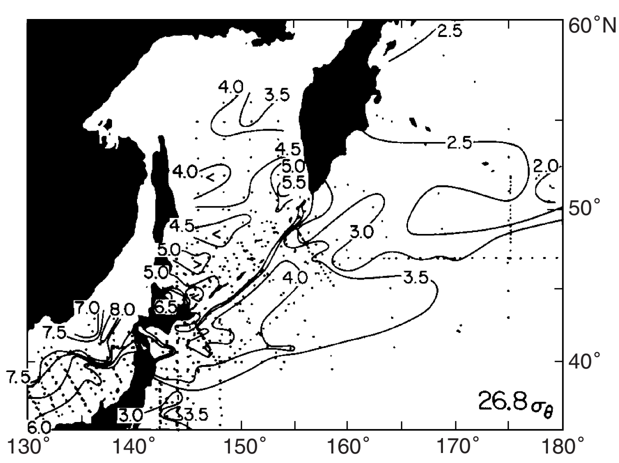

Figure 7 Oxygen on a constant density surface in the North Pacific Intermediate Water layer, from Talley (1991). This surface lies at about 300–400 m depth within the Okhotsk Sea.

Okhotsk Sea products, then enter the interior of the North Pacific.

See also

Bottom Water Formation. Kuroshio and Oyashio Currents. Polynyas. Sea Ice: Overview; Variations in Extent and Thickness. Thermohaline Circulation. Tides. Tidal Energy. Upper Ocean Mixing Processes. Water Types and Water Masses. Wind Driven Circulation.

Further Reading

Alfultis MA and Martin S (1987) Satellite passive microwave studies of the Sea of Okhotsk ice cover and its relation to oceanic processes, 1978–1982. *Journal of Geophysical Research* 92: 13 013–13 028.

Favorite F, Dodimead AJ and Nasu K (1976) *Oceanography of the Subarctic Pacific region, 1960–71*. Vancouver: International North Pacific Fisheries Commission 33: 1–187.

Freeland HJ, Bychkov AS, Whitney F *et al*. (1998) WOCE section P1W in the Sea of Okhotsk – 1. Oceanographic data description. *Journal of Geophysical Research* 103: 15 613–15 623.

Kitani K (1973) An oceanographic study of the Okhotsk Sea – particularly in regard to cold waters. *Bulletin of Far Seas Fisheries Research Laboratory* 9: 45–76.

Kowalik Z and Polyakov I (1998) Tides in the Sea of Okhotsk. *Journal of Physical Oceanography* 28: 1389–1409.

Moroshkin KV (1966) *Water Masses of the Okhotsk Sea*. Moscow: Nauka. (Translated from the Russian by National Technical Information Services, 1968.)

Preller RH and Hogan PJ (1998) Oceanography of the Sea of Okhotsk and the Japan/East Sea. In: Robinson AR and Brink KH (eds) *The Sea*, vol. 11, New York: John Wiley and Sons.

Reid JL (1973) Northwest Pacific ocean waters in winter. *Johns Hopkins Oceanographic Studies*. Baltimore, MD: The Johns Hopkins Press 5: 1–96.

Talley LD (1991). An Okhotsk Sea water anomaly: implications for ventilation in the North Pacific. *Deep-Sea Research* 38 (Suppl): S171–S190.

Talley LD and Nagata Y (1995) *The Okhotsk Sea and Oyashio Region*. PICES Scientific Report No. 2. Sidney BC, Canada: North Pacific Marine Science Organization (PICES), Institute of Ocean Sciences.

Wakatsuchi M and Martin S (1990) Satellite observations of the ice cover of the Kuril Basin Region of the Okhotsk Sea and its relation to the regional oceanography. *Journal of Geophysical Research* 95: 13 393–13 410.

Wakatsuchi M and Ohshima K (1990) Observations of ice-ocean eddy streets in the Sea of Okhotsk off the Hokkaido coast using radar images. *Journal of Physical Oceanography* 20: 585–594.

Warner MJ, Bullister JL, Wisegarver DP *et al*. (1996) Basin-wide distributions of chlorofluorocarbons CFC-11 and CFC-12 in the North Pacific – 1985–1989. *Journal of Geophysical Research* 101: 20 525–20 542.

OPEN OCEAN CONVECTION

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Introduction

Free convection is fluid motion due to buoyancy forces. Free convection, also referred to as simply convection, is driven by the static instability that results when relatively dense fluid lies above relatively light fluid. In the ocean, greater density is associated with colder or saltier water, and it is possible to have thermal convection due to the vertical temperature gradient, haline convection due to the vertical salinity gradient, or thermohaline convection due to the combination.

Since sea water is about 1000 times denser than air, the air–sea interface from the waterside can be considered a free surface. So-called thermocapillary convection can develop near this surface owing to the dependence of the surface tension coefficient on temperature. There are experimental indications that in the upper ocean layer more than 2 cm deep, buoyant convection dominates. Surfactants, however, may affect in the surface renewal process. This article will mainly consider convection without these capillary effects.

Over most of the ocean, the near-surface region is considered to be a mixed layer in which turbulent mixing is stronger than at greater depth. The strong mixing causes the mixed layer to have very small vertical variations in density, temperature, and other properties compared to the pycnocline region below. Convection is one of the key processes driving mixed layer turbulence, though mechanical stirring driven by wind stress and other processes is also