SURFACE THERMAL FRONTS OF THE OKHOTSK SEA

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The Pathfinder AVHRR sea surface temperature (SST) data from 1985–1996 were processed with the Cayula-Cornillon edge detection and declouding algorithms. The following 11 fronts were distinguished: West Kamchatka, TINRO Basin, North and South Shelikhov Bay, North, West, Shantar, East Sakhalin, Central, Kashevarov Bank and Soya fronts. The large-scale pattern of these fronts is consistent with the dominant cyclonic circulation of the Okhotsk Sea. The West Front, TINRO Basin Front, Central Front and Shelikhov Bay Fronts have not been identified before. The West Kamchatka and TINRO Basin fronts form a double front observed in winter only. The North Front continues farther west than it was known, up to 146°E, where it likely connects to the West Front, which often joins the Shantar Front. The latter extends from Shantar Islands to Sakhalin Bay where the Amur River Plume interrupts a nearly continuous line of fronts around the northern and western Okhotsk Sea. The Amur discharge feeds the East Sakhalin Front that follows the shelf break, branches eastward at 48°N and 46°N, and eventually merges with Soya Front, which exits the sea via Vries Strait. The 48°N branch of the East Sakhalin Front seems to join the Central Front, which in turn merges with the TINRO Basin Front, thus forming the southern limb of the sea-wide frontal pattern. The Kashevarov Bank Front likely consists of three separate fronts around the namesake bank, St. Iona Island and Iona Bank. Fronts are seasonally persistent: they emerge and disappear in certain seasons in the same locations. Dominant frontogenetic mechanisms in the Okhotsk Sea are tidal mixing, water mass formation and advection, river discharge, and wind upwelling. Most fronts are generated owing to tidal mixing. Front genesis in the marginal ice zone and around polynyas is likely important; although these processes have not yet been investigated by in situ measurements.

INTRODUCTION

Ocean fronts are sharp boundaries between different water masses and different types of vertical structure (stratification) that are usually accompanied by enhanced horizontal gradients of temperature, salinity, density, nutrients and other properties (Belkin, 2003). Fronts and the associated currents play important roles in heat and salt transport, ocean-atmosphere interaction and ecosystem functioning. Four principal mechanisms have been suggested in the literature that can generate fronts in the Okhotsk Sea (Figure 1): (1) tidal mixing along the sea’s coasts, on top of banks, in the Kuril Straits and along the Kuril Islands (Zhabin, 1991; Zhabin et al., 1990; Staritsin and Foux, 1996b; Gladyshev, 1994; Kowalik and Polyakov, 1998, 1999; also http://www.ims.uaf.edu:8000/okhotsk/; Rogachev et al., 2000; Bobkov et al., 2001; Rostov et al., 2002; Nakamura and Awaji, 2004); (2) water mass advection from the Pacific Ocean and Japan Sea that is accountable for the West Kamchatka front (Figurkin, 1997; Pavlychev, 1997), Soya Warm Current front (Aota, 1975; Aota et al., 1988) and some fronts off the Kuril Islands (Bogdanov and Moroz, 1998, 2001; Moroz and Bogdanov, 1999; Rostov et al., 2002); (3) Amur River runoff that contributes to the formation of the Amur River plume front (Rostov and Zhabin, 1991; Zhabin, 1992) and eventually the East Sakhalin front; and (4) wind-induced upwelling, mainly off eastern Sakhalin (Krasavtsev et al., 2000). Fronts are also known to form near the ice edge (Paquette and Bourke, 1981; Muench, 1983); it is unclear, however, if this mechanism plays a significant role in the Okhotsk Sea. Coastal polynyas and Kashevarov Bank Polynya are important in water mass formation (Martin et al., 1998; Martin et al., 2003) and hence could contribute to front genesis.

DATA AND METHOD

Fronts are high-gradient zones; therefore most objective computer-based approaches to front identification are based on gradient computations. The approach used in this study is based on histogram analysis. Since a front is a boundary between two relatively uniform water masses, histograms of any oceanographic characteristic (e.g. SST) in the vicinity of the front should have two well-defined modes that correspond to the water masses divided by the front, while the latter corresponds to the frequency minimum between the modes. The front detection and tracking is conducted at three levels: window, image and a sequence of overlapping images. The optimum window size found by Cayula and Cornillon (1992) is 32 by 32 pixels. The front detection algorithm uses all pixel-based SST values within each window to compute a SST histogram for the given window. For each window that contains a front (a relatively narrow zone of enhanced SST gradient), the corresponding SST histogram would have a frequency minimum identified with the front.

This basic idea has been implemented by Cayula et al. (1991), Cayula and Cornillon (1992, 1995, 1996) and Ullman and Cornillon (1999, 2000, 2001); the reader is referred to these works for pertinent details. The fronts used for this study were derived from the NOAA/NASA Pathfinder SST fields (Vazquez et al., 1998) for the period 1985–1996. Version 4.0 Pathfinder data were used for 1985–1994 and Version 4.1. Pathfinder data were used for 1995–1996.
These fields were obtained from the AVHRR Global Area Coverage data stream (two 9.28 km resolution fields per day) and are available from the Jet Propulsion Laboratory. SST fronts were obtained from the cloud-masked SST fields with the multi-image edge detection algorithm (Cayula and Cornillon, 1996; Ullman and Cornillon, 1999, 2000, 2001). The cloud masking and front detection algorithms were applied to each of the 8,364 SST images in the 12 year sequence. The frontal data were aggregated over months (e.g. 12 Januaries taken together), and seasons (e.g. the winter climatology is obtained from all Januaries, Februaries, and Marches taken together). Two basic types of frontal maps are used in the analysis: long-term frequency maps and quasi-synoptic composite maps. The long-term frequency maps show the pixel-based frequency $F$ of fronts normalized on cloudiness: For each pixel, $F = N/C$, where $N$ is the number of times the given pixel contained a front, and $C$ is the number of times the pixel was cloud-free. Thus, the frequency maps are best suited for displaying most stable fronts. At the same time, frontal frequency maps understate some fronts associated with widely meandering currents. In such cases quasi-synoptic composite maps are most helpful because they present all of the synoptic snapshots of the “instant” fronts detected in individual SST images within a given time period (e.g. week, month, or season), without any averaging or smoothing. The frontal composite maps thus allow one to detect the most unstable fronts that are not conspicuous in the frontal frequency maps.

**RESULTS**

The Pathfinder SST dataset was used to objectively derive thermal fronts in the Okhotsk Sea as part of the Pacific/global frontal survey (Belkin and Cornillon, 2003; Belkin et al., 2003; Hickox et al., 2000). Frontal maps for each month from January 1985 through December 1996 and long-term monthly frontal frequency maps have revealed the Okhotsk Sea frontal pattern and its seasonal and interannual variability (Belkin, 2001). The Okhotsk Sea regime is known to be strongly seasonally dependent (Preller and Hogan, 1998). In this study we found the regional frontal pattern to be seasonally variable but inter-annually persistent. The following 11 fronts have been distinguished: West Kamchatka, TINRO Basin, North and South Shelikhov Bay, North, West, Shantar, East Sakhalin, Central, Kashevarov Bank and Soya fronts. Each front is described below, with emphasis on new findings.

Figure 1 is a new schematic of the Okhotsk Sea frontal pattern that improves and supersedes a provisional frontal schematics by Belkin (2001, Figure 1). Most of the portrayed fronts are strongly seasonal: they wax and wane in different months, so at any given moment just a few fronts have been seen. Figure 2 (pp. 10–12) presents monthly frontal frequency maps that reveal the seasonal evolution of this pattern, whereas Figures 3–6 (pp. 13–14) demonstrate examples of quasi-synoptic frontal pattern observed within an individual month. As could be gleaned from Figure 2 (pp. 10–12), surface thermal fronts rapidly form and then degenerate, during the ice-free period (May–November). Most fronts are best defined in late summer.

The West Kamchatka Front (#1 in Figure 1) is best visible in March and April (respectively, 6 and 8 years out of 12) (Figure 3, p. 13). Sometimes this front appears as a double front, but only in winter (December–April) as noted earlier (Belkin, 2001). In this study we prefer, however, to consider the western part of this double front as an independent frontal feature, tentatively termed the TINRO Basin Front (#2 in Figure 1) since this feature extends along the western slope of the TINRO Basin. This double-front structure was repeatedly observed in the same location and is therefore apparent even in the long-term frequency maps (Figures 1 and 2, pp. 9–12). The interannual variability is noticeable in summer: the front was usually visible in summer from 1985 through 1989 (e.g. Figures 4 and 5, pp. 13–14), but from 1990 on its summertime appearance was very rare. This change might have been a manifestation of the sea’s regime shift in 1989–1990, alongside with the early emergence of the Central Front, discussed below.

The West Kamchatka-TINRO Basin fronts’ early emergence in February 1994 is consistent with the analysis of meteorological and sea ice data by Pavlychev (1997) who noted that the ice conditions in January–April 1994 were very light compared with the average conditions (e.g. the Kamchatka's west coast south of ~55°–57°N was ice-free through the winter), apparently owing to the northward movement of atmospheric cyclones from the Japan Sea and Kurosio regions. Pavlychev (1997) has also estimated the West Kamchatka Front's gradients (his Table 3); the cross-frontal SST range was about 1°C, with colder waters inshore.

The West Kamchatka Front is mainly a water mass front although tidal mixing is also important, especially in the near-shelf zone (Staritsin and Foux, 1996a).

The South and North Shelikhov Bay fronts (#3 and 4, respectively, in Figure 1) are almost always present from May–June through October, sometimes through November (e.g. Figures 4 and 5, pp. 13–14); from December through April, the Gulf is covered by ice. The North Shelikhov Bay front is much better developed compared with its southern counterpart (Figure 4, p. 13). Both fronts are likely to be of the tidal origin. Maximum tidal amplitudes exceed 10 m in Gizhiga Bay and 13 m in Penzhina Bay (Supranovich, 1998, Figure 5.7) and tidal currents are very strong (Kowalik and Polyakov, 1998).

The North Front (#5 in Figure 1) is defined as a front along the northern coast of the Okhotsk Sea, from
143°E up to 155°E. The front becomes established usually in August (Figures 2 and 4, pp. 10–13); and is always distinct, sometimes even prominent, in September–October (Figures 5 and 6, p. 14); it remains visible as late as November and is sporadically noticed in December. From January through March–April, the sea ice cover prevents remote sensing of the front.

This front was considered as a water mass front by Chernyavskiy (1970; cited after Pinchuk and Paul, 2000, p. 8) who wrote: “South of the Koni Peninsula and Zaviyalov Island, roughly between 57°50′N and 58°30′N and between 150°20′E and 151°20′E, the convergence of the cold Yamsk Current and the warmer Northern Branch Current produces a strong seasonal oceanographic front…” We believe that the North Front is a tidal mixing front, which is evident from the characteristic vertical structure that can be seen, e.g., on cross-frontal summer sections (Kotlyar and Chernyavskiy, 1970; cited after Pinchuk and Paul, 2000, Figures 9–10; Sapozhnikov et al., 2001, Figures L1–L2). The North Shelf has an extremely high rate of the tidal energy dissipation (Egbert and Ray, 2003). Sharp thermal fronts were noted by Zhabin et al. (1990) off Yamsky Islands and farther WSW, up to 152°E, interpreted as tidal mixing fronts. Zhabin (1992) has identified a front south of Koni Peninsula and P'yagin Peninsula (151–155°E) as a tidal mixing front that exists from June through October. Our data extended the spatial range of this front westward to 146°E, as well as expanded its temporal range through November.

The West Front (#6 in Figure 1) is located over the narrow North West Shelf. The front is best defined in August–October (Figure 4, p. 13) when it appears as an extension of the North Front, which is consistent with the large-scale cyclonic circulation pattern of the Okhotsk Sea (Moroshkin, 1964, 1966). Considering a strong tidal mixing on the western shelf (Kowalik and Polyakov, 1998; Egbert and Ray, 2003), we suggest that the West Front is a tidal mixing front. Inter-annual variability of the West Front is strong: sometimes the front is robust, e.g. in 1988 (Figure 4, p. 13), whereas in other years it is poorly organized, e.g. in 1993 during the occupation of the WOCE P11W section (Freeland et al., 1998). Formation of a tidal mixing front in this area might be facilitated by a series of narrow, steep terraces found in the central part of the North Shelf (Fedorov, 1997). An apparent empirical association between shelf terraces and fronts in the Bering Sea was noticed by Coachman (1986) who suggested the terraces were important in front formation and maintenance.

The Shantar Front (#7 in Figure 1) is sometimes connected to the West Front, although most of the time there is a clear break between the two fronts. Strong tidal mixing and front formation around the islands was noted by Zhabin et al. (1990). From our data the Shantar Front is most robust in September–October, whereas Zhabin (1992) determined that the front exists from July through October. We concur with Zhabin et al. (1990) and Zhabin (1992) in that the Shantar Front is a tidal mixing front. An extremely high rate of tidal energy dissipation around the Shantar Islands is noticeable in maps published by Egbert and Ray (2003).

The East Sakhalin Front (#8 in Figure 1) is observed east and southeast of Sakhalin and is associated with the southward East Sakhalin Current (Ohshima et al., 2002; Mizuta et al., 2003). The front is best developed in September–October (Figures 5 and 6, p. 14), although the front could be sporadically observed any time from April through December. Based on a 7-month surface drifter data set, Ohshima et al. (2002) reported two current cores in the current, near-shore (over 50–150 m depth) and shelf slope (300–900 m depth). These cores are especially pronounced in the north (apparently thanks to a much wider shelf) and in September–October. The near-shore core appeared to originate from the northwest, whereas the slope core from the east (ibid., Figure 18). The East Sakhalin Front follows the continental slope off Terpeniya Bay and Cape Aniva (e.g. Bulatov et al., 1999, Figure 4) and eventually reaches the Soya Front described below. Our observations are basically consistent with this general pattern, although any instantaneous view is more complex mostly due to the East Sakhalin Current’s intermittent branching at 48°N and 46°N and vigorous eddy field in the Kuril Basin (Wakatsuchi and Martin, 1991; Darnitsky and Bulatov, 1997; Bulatov et al., 1999; Ohshima et al., 2002).

The Central Front (#9 in Figure 1), from 1985 through 1989, could only be seen in April (Figure 2, pp. 10–12). From 1990 on, the front emerges approximately a month earlier, in March; this might be related to the favorable sea ice conditions, discussed below. The Central Front is collocated with the maximum extent of sea ice cover and is apparently related to the marginal ice zone processes. On the other hand, the front location and configuration are similar to these of the northward Kamchatka Current as shown by Moroshkin (1964, 1966) and the so-called “northern branch of the Western Kamchatka Current” (Markina and Chernyavsky, 1984; Kuznetsov et al., 1993, Figure 1; Sapozhnikov et al., 2001, Figure 3, left plate). The anticyclonic meander of the Central Front at 53°–54°N is reminiscent of the eastward branch of the Kamchatka Current at 53°–53.5°N in the circulation schematic by Luchin (1998, p. 244, Figure 7.4). The front’s position is very close to that of a structural front that can be seen in distributions of characteristics of the subsurface layer of minimum temperature, the so-called “dichothermal water,” e.g. in Kitani (1972, Figures 1–2). This structural similarity suggests that the Central Front might be analogous to the North Pacific Polar Front (Belkin et al., 2002).
Figure 1. Surface thermal fronts of the Okhotsk Sea from Pathfinder data, 1985–1996.
Figure 2. Long-term (1985–1996) monthly frontal frequency $F$ (%) of SST fronts normalized on cloudiness. For each pixel, $F = N/C \times 100$, where $N$ is the number of times the given pixel contained a front, and $C$ is the number of times the pixel was cloud-free (to be continued).
Figure 2 (continued).
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Figure 3. Frontal composite map from March 1992

Figure 4. Frontal composite map from August 1988
Figure 5. Frontal composite map from September 1987

Figure 6. Frontal composite map from October 1992
The Kashevarov Bank Front (#10 in Figure 1, p. 9) encompasses the namesake bank, St. Iona Island, and Iona Bank. This front is caused by tidal mixing, although local topographic upwelling is also important (Zhabin et al., 1990; Kowalik and Polyakov, 1998, 1999; Rogachev et al., 2000, 2001). Our June frequency map (Figure 2, pp. 10–12) strongly suggests that the front likely consists of three separate fronts that surround Kashevarov Bank, St. Iona Island, and Iona Bank. From a single SST image in August 1988 Zhabin et al. (1990) observed three cold spots surrounded by thermal fronts, over these bathymetric features. Fortnightly modulation of tidal mixing near Kashevarov Bank is accountable for the observed changes in water stratification in summer (Rogachev et al., 2001); the same mechanism is likely responsible for temporal changes in the front’s structure and cross-frontal gradients.

The Soya Warm Current Front (#11 in Figure 1, p. 9) extends along the northern coast of Hokkaido and is visible in frontal frequency maps as well as in frontal composite maps (Figures 2 and 5, pp. 10–12, 14). This current was a subject of numerous, mostly Japanese, studies (Talley and Nagata, 1995, part 2, chapter 4; Itoh and Ohshima, 2000; Ohshima et al., 2001). The front is distinct during the entire ice-free season (Aota, 1975), generally from March through November (Takizawa, 1982; Zhabin, 1992); the cross-frontal SST/SSS ranges in summer exceed, respectively, 11°C (from 8°C to 19°C) and 0.4 ppt (from 33.2 to 33.6) (Aota et al., 1988). As suggested by earlier researchers (e.g. Aota, 1975), the front exists in winter also, masked by seasonal ice cover (Ohshima et al., 2001). The Soya Warm Current is known to extend ENE along the southern Kuril Islands, where it only exists from August through November (Zhabin, 1992). The current exits the Okhotsk Sea via Vries Strait (Proliv Friza) (Zhabin, 1992; Bobkov, 1993), where it forms a strong TS-front at the contact with colder and fresher Pacific waters, with the summertime cross-frontal ranges of SST = 4–14°C and SSS = 33.2–33.7 (Bogdanov and Moroz, 1998, Figures 2–3 and table; Moroz and Bogdanov, 1999). Our data corroborate this pattern (e.g. Figure 5, p. 14). The Near-Kuril Front that extends northeastward along the Okhotsk Sea side of the Kuril Islands chain (Moroz and Bogdanov, 1999) is not resolved by our data.

The seasonal variability of the Okhotsk Sea fronts is conspicuous. The sea is covered by ice largely from December through April (Gloersen et al., 1992; NASA, 1998), when the surface fronts are absent. There are two exceptions only, (a) the West Kamchatka Front which could be seen, albeit rarely, any time in winter and (b) the Central Front which was seen almost each March from 1990. Notably, this front was never seen in March before 1990. This obvious, abrupt change might have been a manifestation of the sea’s regime shift in 1989–1990 (another sign was the summertime disappearance of the West Kamchatka Front, noted above). The sharply improved visibility of the Central Front from 1990 on might have been related to the favorable sea ice conditions in the southern Okhotsk Sea where Tachibana et al. (1996) have found an abrupt decrease of sea ice cover in 1989 (continued since then), coincident with (and apparently caused by) an abrupt weakening in 1989 of the wintertime Aleutian Low.

In late spring and early summer, the frontal pattern is quite chaotic. Unlike many other seas, the Okhotsk Sea frontal pattern is more distinct by the summer’s end and is best defined from August through October, especially in September. This very peculiar seasonal variability of frontal visibility could be accounted for by the local atmospheric conditions: persistent fog in spring and late fall that obscures surface fronts, and the summertime Siberian anticyclone accompanied by clear skies and good visibility.

Several fronts exhibited a strong long-term variability. Based on our 12-year data set, only year-to-year variability could be rigorously analyzed, even though some changes in fronts’ appearance, briefly described above, might have been associated with longer time scales and larger spatial scales such as the ocean-scale “regime shifts” of 1977 and 1989 in the North Pacific (Hare and Mantua, 2000).

DISCUSSION

The Okhotsk Sea belongs to the most productive areas of the World Ocean, rivaling the Bering Sea, and supports fisheries with the total annual catch exceeding 2 million tons, mainly walleye pollock and also flounder, herring, and salmon (Kuznetsov et al., 1993; Shuntov and Dulepova, 1997; Shuntov, 1999b; TINRO, 2003). The frontal schematic that emerged from this study (Figure 1, p. 9) correlates strongly with numerous biological patterns such as biomass distributions of phytoplankton, zooplankton, and benthos (Markina and Chernyavsky, 1984, cited after Kuznetsov et al., 1993, Figures 2–4), and zooplankton faunistic zonation (Lubny-Gertsik, 1959, cited after Pinchuk and Paul, 2000, Figure 2). Pelagic fish and squid tend to concentrate in frontal areas, especially the most commercially important fish, walleye pollock (Shuntov et al., 1993). Apex predators such as sea birds and marine mammals also congregate at fronts (Shuntov, 1999–2001). The most important breeding ground of northern fur seals in the Okhotsk Sea is located on Robben Island (Ostrov Tyuleniy) off southern Sakhalin (Gentry, 1998), just a few miles from the East Sakhalin Front that the seals could use as a feeding ground. Steller sea lion rookeries at Yamsky Islands and on St. Iona Island (NMFS, 1992) are also located in a close proximity to SST fronts, namely, the North Shelikhov Front and the St. Iona’s branch of Kashevarov Bank front, respectively.
Field studies of the Okhotsk Sea fronts were focused mainly on the Kuril Basin and Kuril Straits (Zhabin, 1992; Gladyshev, 1994; Foux and Karlin, 1998; Moroz and Bogdanov, 1999) and on the Kashevarov Bank (Rogachev et al., 2000, 2001). The Northern Shelves, especially the North West Shelf, are nearly void of cross-shelf sections save for a single synoptic section across the North Shelf (Verkhunov, 1997, Figure 4) and a WOCE section P1W across the North West Shelf (Freeland et al., 1998). The scarcity of suitable data explains why even the latest frontal schematic of Sapozhnikov et al. (1999, Figure 2) contains just three fronts, east of Sakhalin, west of Kamchatka, and south of Magadan. The inaccessibility of most Soviet/Russian data exacerbates the data coverage problem. Even the historic R/V “Vityaz” data collected in 1949–1952 has only recently become available in the West (Hill et al., 2003).

Due to the paucity of in situ data, any ideas about the fronts’ origin are bound to be speculative and contradictory as can be seen from the above-cited literature. The West Kamchatka Front seems to be a traditional water mass front that separates the warmer water of the northward West Kamchatka Current from the colder inshore waters of the southward Compensatory Current. A tidal mixing front likely exists between the West Kamchatka Front and the west coast of Kamchatka. The Shelikhov Bay, North and West fronts are caused by the enormous tidal mixing in the Bay and over the North and North West shelves. The East Sakhalin Front appears to form mainly owing to the Amur River outflow of warm, fresh water that passes anticyclonically around Sakhalin Island and comes in contact with cold, salty waters of the Okhotsk Sea proper; hence this is a water mass front. The Central Front is collocated with the maximum extent of the sea ice cover; thus, the front might represent a TS-signature of the receding marginal ice zone (MIZ), a fossil MIZ front. The Soya Warm Current Front is a typical water mass boundary between warm and salty waters of the Soya Warm Current and cold, less saline waters of the Okhotsk Sea. Elucidation of the fronts’ vertical structure and its seasonal evolution will be the main subjects of our future research, as well as a study of long-term variability of fronts and of adjacent water masses separated by the fronts.

SUMMARY

The Pathfinder SST data from 1985–1996 were processed with the Cayula-Cornillon edge detection and declouding algorithms. The following 11 fronts were distinguished: West Kamchatka, TINRO Basin, North and South Shelikhov Bay, North, West, Shantar, East Sakhalin, Central, Kashevarov Bank and Soya fronts. The large-scale pattern of these fronts is consistent with the dominant cyclonic circulation of the Okhotsk Sea. The West Front, TINRO Basin Front, Central Front and Shelikhov Bay Fronts have not been identified before, as well as a double front formed in winter by the West Kamchatka and TINRO Basin fronts. The North Front was traced farther west than it was known, up to 146°E, where it connects to the West Front, which often joins the Shantar Front, which extends from Shantar Islands to Sakhalin Bay, where the Amur River Plume interrupts a semi-continuous line of fronts around the northern and western Okhotsk Sea. The Amur discharge feeds the East Sakhalin Front that follows the shelf break, branches eastward at 48°N and 46°N, and eventually merges with Soya Front that leaves the sea via Vries Strait. The 48°N branch seems to join the Central Front, which in turn merges with the TINRO Basin Front, thus forming the southern limb of the sea-wide frontal pattern. The Kashevarov Bank Front likely consists of three separate fronts around the namesake bank, St. Iona Island and Iona Bank. Fronts are seasonally persistent: they emerge and disappear in certain seasons in the same locations. Four dominant physical mechanisms of frontogenesis are tidal mixing, water mass formation and advection, river discharge, and wind upwelling. Most fronts are generated owing to tidal mixing. Front genesis near the sea ice edge, including polynyas, deems of importance; however these processes have not been investigated in situ yet.

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