Spatial distribution of thermal fronts in the Japan Sea and some elements of their variability by satellite data

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Abstract – The generalized scheme of surface thermal fronts of the Japan Sea is made on the basis of the analysis of references and satellite IR- and TV-images from satellite NOAA series for 1976-2003. Their basic elements, their features are considered, some elements of their variability are analyzed in given paper. The intensive subtropical water advection to the northwest part of the sea, marked last years will be kept on rather high level in 2005-2006.

Keywords: satellite and ship data, IK- and TV- images, Japan Sea, Subarctic front, thermal front, warm, cold, eddies, structure.

1. INTRODUCTION

Earlier many authors investigated the position of Subarctic front and of its frontal branches and their variability in Japan Sea (Uda, 1934; Suda, 1938; Istoshin, 1960; Nikitin, Kharchenko, 1989; Isoda et al., 1991; Isoda, 1994; Ostrovskii, Hiroe, 1994; Danchenkov et al., 1997; Nikitin, Dyakov, 1998; Zuenko, 1996, 1999, 2000). The generalized scheme of surface fronts of Japan sea is offered with the indication of their position (including Subarctic front) and research of their interannual and seasonal variability will be carried out in this work.

2. DATA AND ANALYSIS METHOD.

The satellite IR- and TV- images of the Japan Sea for 1975-2003 were analyzed in the present work. The technique of processing of satellite snapshots is described earlier (Recommendations…., 1984). About 1000 cards of the frontology analysis on the data of the satellite observations were analyzed. There were used the satellite temperature cards obtained in the Institute of Automatics and Control Procedures of Far East Branch of the Russian Academy of Sciences (IAP FES RAS). Ship hydrological data (temperature and salinity) on sections on 132° E and 132°20' E and the Japanese week facsimile cards of temperatures (the Japanese Meteorological Agency) were used in addition. The supply by the satellite data on all surface of the Japan Sea was non-uniform: from the several maps per day up to full absence within 1-2 months. The greatest quantity of cards was built in March - May and October - November, least - in summer of July - August. The greatest supply came on 1980-1982, 1985-1986, 1987 and from 1992 to 1996.

The hydrological (thermal) fronts as zones of increased gradients of temperature are mapped on IK-images as zones of sharp change of image tone. Next terms such as frontal section, branch of front, front in the given work will be used as boundary between warm and cold waters (Fedorov, 1977).

The monthly average line of the Subarctic Front in the Japan sea was drawn on condensation of the frontal lines for the certain month during all years of observations.

The hydrological seasons in the Japan Sea were adopted on classification of G. I. Yurasov (1977). January – March are concerned to winter, April – June - to spring, July – September - to summer and October - December - to autumn.

3. RESULTS AND DISCUSSION

The generalized scheme of the surface thermal fronts of the Japan Sea on the satellite and ship data for 1975 - 1997 is shown in the figure 1. The main of these fronts, Subarctic front,

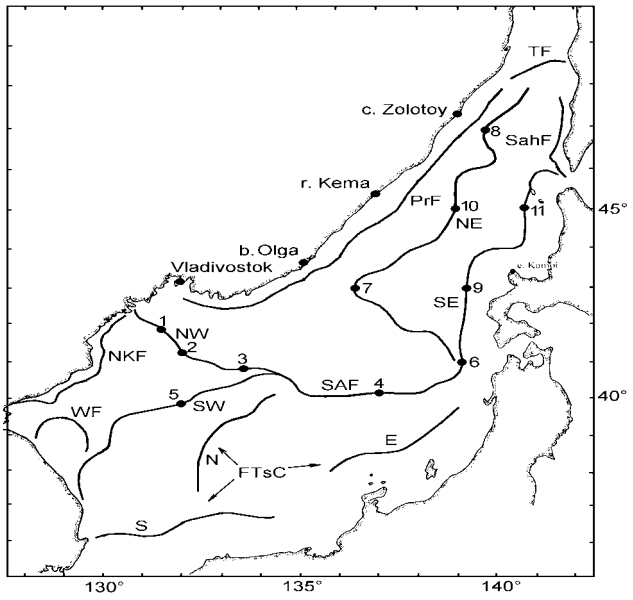

Fig. 1. The generalized schema of superficial thermal fronts in the Japan Sea.
Designations: SAF - Subarctic front; NW - northwest branch SAF; SW - southwest branch SAF; WF - western front; NE – northeast branch SAF; SE - southeast branch SAF; FTsC - fronts Tsushima Current (S –south branch, N north branch, E – eastern); PrC - Primorye front; SF - Sakhalin front; TF - front of the Tatar Strait; NKF - North-Korean front; - 1-11 points indicating where were carried out measurements; ——— - Line of front.

dividing the subtropical water masses from subarctic, extends from Korea coast up to the Japan islands. Between 134°30' and 139° E the Subarctic Front (SAF) is oriented in the latitude direction and is sharply defined on 40° N, where it is the most stable in space and time (Isoda et al., 1991). To the west from 134°30' SAF is divided into 2 branches: northwest (NW) and southwest (SW). The northwest SAF branch passes from the boundary between Russia and Northern Korea (43° E) up to 40°30' N, 134°30' E; and the southwest - from this point up to coast of Republic of Korea on 38° N and then it is directed on the south along the coast. In the east from 138°30' E SAF sharply turned up to the north. Here in the region of 41°N it is divided into Southeast branch (SE), tracked on 139°E up to a La Perousa strait, and one more, less noticeable, North-east branch (NE). Thus, in western and northern parts of the sea the Subarctic Front is divided into two branches. The North-Korean front (NKF) passes between 40°-42° E along Korea coast as the

narrow zone. The western front (WF) passes from the Korean bay to the east between 39-40° N. In the southern part of the sea the system of fronts of Tsushima Current (FTC) is selected, which one can be divided into the southern branch (S), approximately on 36°20' N, on northern (N), located between 36°30'-40° N, 132°-134° E and on the eastern branch (E), located to the north-east of Note peninsula. The Tatar front (TF) is tracked in the north of Japan Sea in the Tatar Strait, it separates the more cold waters in the north from warmer, but salty in the south in winter, and in summer - on the contrary. The front of Primorye current (PF) passes to the south from this front along the continent, and the Sakhalin front (SF) - along the Sakhalin coast.

It is possible to mark on the configuration of the SAF position (fig. 1), that the main feature of SAF contour in the central part of the Japan Sea is the presence of three meanders, where the warm waters are spread most far to the north. The first meander is located between 130°-132° E, the second - between 133°-135° E and the third – between 136°-138° E. The advection of subtropical waters to the north from 40° N is connected as with East - Korean current, as with rows of eddies to the east from 130° E (Danchenkov et al., 1997; Nikitin et al., 2002). The branches of the East - Korean current in warm years can reach 42° N, but in some years they are spread only up to 37°-38° N. In the southeast part of the sea on 137° E one more eddies path is observed which action is traced up to 41°N. These features (more it concerned to the distribution of subtropical waters on 131° E and partially on 134° E) were used for creation of typisation of the thermal structure of the Japan Sea waters (Nikitin, Kharchenko, 1990, 2002). It was supposed, that the warm type of the year was watched at northern SAF position, and cold - at southern one (Nikitin, Dyakov, 1998; Dyakov, 2002). Thus the absolute value of the sea surface temperatures can be higher or be low of average annual data. For example, at northern SAF position the temperature anomaly can be negative, and on the contrary, at southern - positive. Thus the boundaries of cold flow (between warm meanders) vary in rather narrow limits and are watched basically as the narrow zone at the Korean coast, and also between 132°-133° E and 135°-136° E.

Own features SAF are tracked in the northern part of the Japan Sea. As well as in the central part of the sea in the northern part it is possible to mark three meanders (fourth, fifth and sixth meanders), which one are tracked on NE of a branch SAF. The fourth meander is arranged between 42°-44° N, fifth - between 45°-46° N and sixth - between 46°30'-47°30' N. In the region of the fourth meander the bending of the north-east branch SAF towards the continent is well seen, where the warm meander is formed. At the latitude of this meander one of branches Tsushima Current (the region of cape Camoi) separates from the main flow towards the middle Primorye. Considerably meandering, the branch in separate years can reach the coast (42°30'-43°30' N) also is the idiosyncrasy of structure and dynamics of waters of this part of the sea. Many small-sized eddies of the different sign are connected to this branch, which one also are an idiosyncrasy of this branch. Other part of warm waters (at a latitude 45°-46° N) deviates to the west, the southwest also to Primorye coast and forms the warm fifth meander. In this region the small bend of front toward to the continent also is seen. In the waters of this branch many mesoscale eddies of 15-50 kms in the diameter also takes place, the majority of which one have anticyclonic character. The following branch is oriented in the northwest direction in the region of the cape Zolotoy, where the sixth warm meander is formed and also the deviation NE of a branch SAF toward to the continent is visible.

The interannual features of front can be quantitatively expressed in deviations of its position from the average annual position. Let's consider the diagrams of the average annual positions of the branches of the Subarctic Front in points 1-5 during 1976-2003 (fig. 2). In the point 1 extremely northern position NW branch of SAF was in 1979-1980, and the southern - in 1978. The same branch in the point 2 extremely northern position was in other years (1978, 1979, 1999 and 2001), and southern - in 1977, 1980, 1981, 1983, 1984, 1985 and 1989 (almost all 80-th years). It is possible to mark, that the character of oscillations in these points differs from each other, despite of small distance between these points.

Analyzing the dynamics of SW branch in the point 5, it is possible to mark, that the extremely northern position it took in 1978, 1979, 1988, 1992, 1995 and 2000, and southern - in 1977, 1980, 1984, 1987, 1989, 1990, 1991, 1993 and 1996. In the region of Yamato Rise (point 3) extremely northern position SAF took in 1985, and southern – in 1979 and 1995. The periods of the most weak development of the central meander are marked in the begining of 80-th and in the middle of 90-th years, and from middle of 80-th up to the middle of 90-th it was strongly advanced. Exception made 1988, 1989 and 1995. But as a whole the space-time variability was least (fig. 1) on this site of the front.

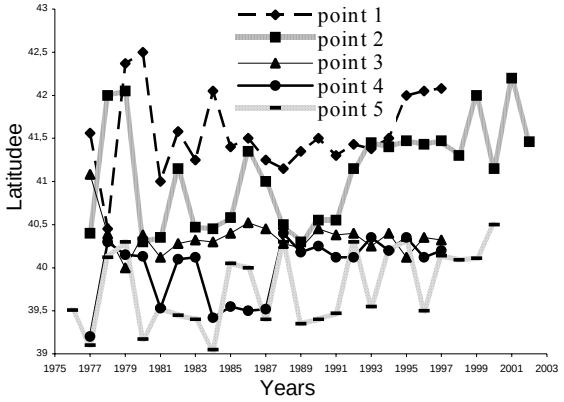

Fig. 2 Interannual variability of position of NW and SW branches of the Subarctic front in points 1, 2, 3, 4, 5 in the period 1976 - 2003.

On eastern site (point 4) SAF took extremely northern position in 1978, 1988 and 1993, southern - 1977, 1984. For this site of front it is typical of two periods: one in the period 1976 - 1987 with a southern position (cold type), and another - with northern (warm type) - 1988 - 1997. Exception made 1978-1980 and 1982-1983. 2-3 and 5 years cycles are tracked in changing of front position.

Let's return to the analysis of the western meander. The most weak meander was watched from 1980 to 1991, and the strong meander, at simultaneous increase of intensity of heat receipt by means of eddies derivations (Danchenkov et al., 1997; Nikitin et al., 2002) to the north from 40° N, was in 1978 and 1979, and also since 1992 till the present time. It is necessary to underline, that at northern SAF position (warm years), specially in winter and spring, the well developed eddies structure is watched. As a whole it is possible to mark, that the changes of the advection of subtropical waters in western and central meanders in the northwest part of the sea happen synchronously, however in separate years of deviation of NW branch from average annual position on sites of two meanders can be opposite.

Some explanations to the detected thermodynamic features in the Japanese sea were retrieved in researches of atmospheric processes above the Far East seas (Shatilina et al., 1998). The course of anomalies of the geopotential H500 is clear testifies, that the new period in change of atmospheric circulation above Far East has begun from 1989, which one promoted western, southwest transport of air masses, as near the ground, as in the middle troposphere. These changes have begun from pressure increase in the begining of 90-th.

Analyzing SAF oscillations in the listed above points it is possible to select the periods with frequency 3-4, 5-6 years. But the considerable oscillations of NW branch concerned with 2-3 years.

Changes with the period, close by 10 years (Zuenko, 2000) are marked in oscillations of NW branch of the arctic front (fig. 2). It is visible, that during 90-th the tendency of displacement of NW and SW branches of SAF to the north is marked. During all number of observations the Subarctic Front took extremely northern position in 1979, 1995 and 1997, and extremely southern in 1977, 1981-1991. Such SAF position guesses the gradual increase of the advection of subtropical waters to the northwest part and its preservation on the rather high level in next years.

Variability of Subarctic front in meridian direction in northern part of the Japan Sea is characterized by his rejections in 6, 7, 8, 9 and 10 points (fig. 3).

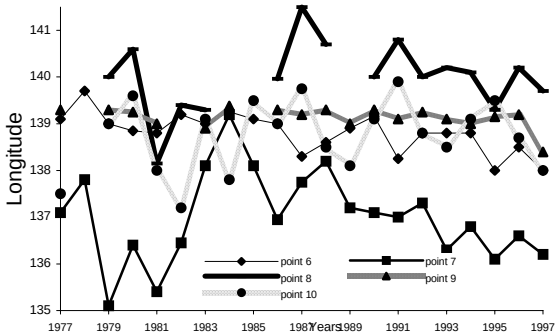

Fig. 3 Interannual variability of position of the Subarctic front in points 6, 7, 8, 9, 10 in the period 1977 - 1997.

In a point 6 the Subarctic Front is extremely close to coast of Japan in 1978, and was removed from it - in 1995 and 1997. In a point 7 the extremely western position the north-east SAF branch took in 1979 and 1981, and eastern - in 1984. The weak meander was observed in 1984 - 1988, and strong - in 1979-1982 and in 1989-1997. On this site of the front the interesting tendency is observed, which one appears in SAF motion to the continent. Such tendency in SAF motion appears in other points of northern part of basin. This process is prolonged and now. The motion of Subarctic front towards continent was marked in 1984-85. In the result the greatest in-leak of warm subtropical waters was directed to the northwest part of the Japan Sea (fig. 3). In the following point (point 8) extremely western position NE branch took in 1981, and eastern - in 1987. In 1981 Tsushima current penetrated far to the north, in contrast to 1987. In point 9 SAF oscillations are negligible, except for 1997, when the front strongly deviated to the west. In a point 10 extremely eastern position NE branch took in 1980, 1987, 1991 and 1995, and extremely western - in 1982.

Thus, for all northern part of the Japan Sea in SAF dynamics the general tendency takes place, which one appears in motion of NE and SE branches towards the continent since 1984-85. Strong deviation of NE and SE branches towards the continent, the intensive advection of subtropical waters accompanying with formation of eddies of different signs as it is observed in 1981 and 1995. Accordingly, the negligible SAF deviation towards the continent can indicate the weak advection of waters observed, for example, in 1987 and 1988.

It is known, that the Subarctic front represents a vast zone, restricted by two high gradient frontal sections, between which one there is an area with decreased horizontal gradients of the hydrological characteristics. Let's consider and compare the dynamics of the interfrontal zone on 132 meridian, 43 and 45 parallels, in the first case on distance between 2 - 5 points, in second between 7 - 9 and in the third case between 10 and 11 points (fig. 4). In the period from the beginning of 80-th up to beginning of 90-th the negative anomalies are characteristic for all three regions.

Exception made 1981, 1982, 1984, 1986, 1987 and 1989. The positive anomalies were observed in 1993-1999. Exceptions made 1994, 1995 and 1998. At the same time on 132° E and on 43° N is uniquely observed single-phase oscillations of the interfrontal zone, at the same time, in northern regions (45° N) there is a disturbance of these processes. Exception made 1981, 1986, 1987, 1988, 1990, 1991 and 1992.

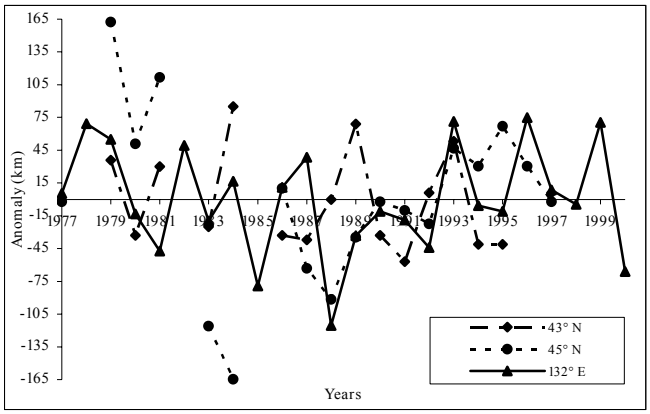

Fig. 4 Anomalies of the interfrontal zone (in km) on 43° E and 45° E and on 132°E during 1977-2000

This fact indicates that in all northwest part of the sea (along 132° E and on 43° N) the same factors act, which one are formed under effect of Tsushima or Primorye Current and depending on their development the heat or cold advection will predominate. At the same time to the north of 45° E the advection factor yields to other, for example to radiation and wind factors.

Now let's consider the changing of thermal fronts in the Japan Sea from the season to season on average annual data (fig. 5). Distribution of the surface fronts in Japan Sea essentially change within one year. In the difficult and changeable picture in the spring period it is possible to note forward promotion of northwest SAF branch to the north. And during summer and autumn periods the NW branch is situated to the north of gulf Posiet. In winter and spring in northern part of the sea homogeneous distribution TSS is observed, the thermal contrasts are observed only in area of Tsushima Current.

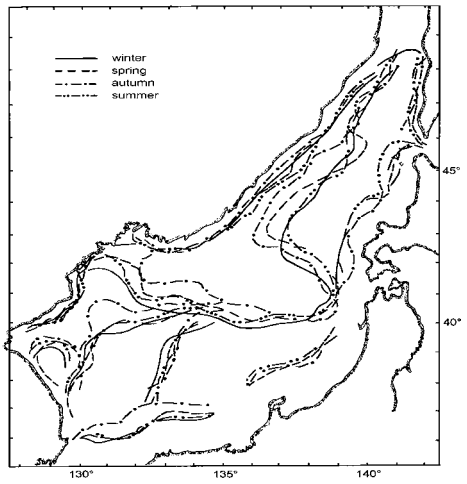

Fig. 5 Scheme of fronts in various seasons: in the winter, spring, summer and autumn.

In summer period on the background of the total increase of the sea-surface temperature the fronts are formed, concerned with the local destruction of a thermocline and output of cold waters on the surface (Jabin, 1992). In the autumn fronts observes both summer and winter type. The amplitude of oscillation of front in the climatic plan from a season to a season can reach 110-148 kms. The greatest deviations of NW branch of front from average annual position of a western meander have basically for winter and summer and make 56-110 kms. For the central meander the greatest deviations have for spring and winter and make approximately 46 kms, and for eastern - are watched in the summer and makes 28 kms. The considerable SAF displacement is marked and in northern part and specially between 43° and 45° E (fig. 5). Here the front oscillation from season to season can reach 74-92 kms.

In annual aspect the most northern position of the Subarctic front takes in July - September (fig. 6).

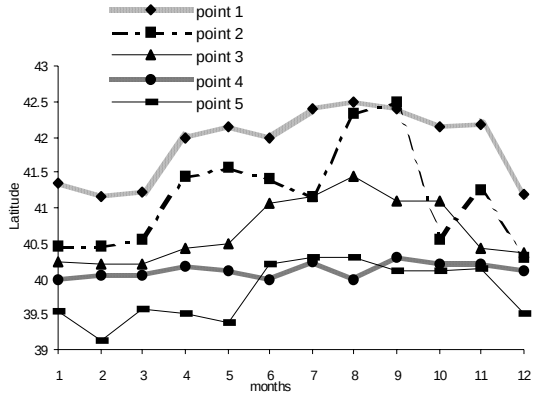

Fig. 6 Inneryear variability of position of the Subarctic front in 1, 2, 3, 4, 5 points in the period 1976-2002.

But between 134°30'-139° E SAF is most stable and saves the position in all seasons. In region of Yamato Rise (the point 3), SAF takes the most northern position in August, and southern - in December - March. It is interesting to mark, that in connection with change of monsoon, the Northwest branch SAF in April move forward sharply to north and to November saves northern position and only in December the front starts to lower to the south. Against of NW branch, SW branch starts to be transferred to the north only in June and prolongs to save northern position till November. It is possible to suspect, that the northwest SAF branch reacts to intensive in-leaks of subtropical waters to the north through the eddies pattern earlier, than southwest. From here follows, that the delay in motion of SW branch to the north, against NW, can reach 1-1,5 months.

The extreme breadth of the interfrontal zone on distance between 2 and 5 points was observed in April - May and August - September and can reach 222 kms. Least width of an interfrontal zone was observed in December and March and can make 110-148 kms. The most western position in the northern part of the Japan Sea SAF (point 6, 7, 8, 9 and 10) took in July - August (fig. 7).

One more peak marked in April, is tracked practically on all points. Probably, the SAF deviations to the continent marked in April and July - August are connected to strengthening of effect of western spur of a pacific maximum. In the same periods (April and July) the extreme breadth of the interfrontal zone on distance between 7 and 9 points was marked, which one can reach 240-278 kms. Least width of interfrontal area was observed in December and made only 56 kms.

The analysis of SAF oscillations in northwest and northern parts of the Japan sea has allowed in annual aspect to select cycles with the period close by 2-3 months. Certainly, here it is possible to select periods with 7-9 monthly cycles, but cycles with the period of 2-3 months appears here, which one are to dominating.

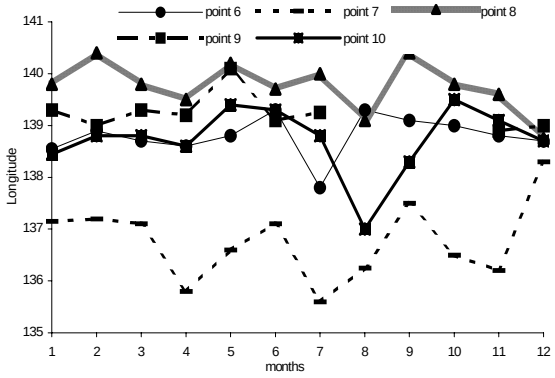

Fig. 7 Within-year variability of a rule of the Subarctic front in 6, 7, 8, 9, 24 in the period with 1977 on 1997.

From the table it is visible, that the greatest gradients of temperature of water on an arctic Front are marked in the winter and autumn between 134°30'-139° E. On the northwest SAF branch the increase of gradients of temperature of water is observed only in autumn, and on southwest – in winter and spring. The greatest values are connected to the Southwest branch. The peaking of the north - east branch can be marked in the spring, summer and autumn. It is interesting, that the peaking of Primorye front is marked only in summer and autumn. The north-Korean front most brightly appears in the spring and during the maximum warming of the sea surface.

Thus, the greatest variability is observed in southern part of NE branch of SAF. The big variability is observed in the western part on northwest branch of SAF. But variability of other fronts of Japan Sea is insignificant. Interannual SAF changes are actually comparable to seasonal changes, but rejections in separate months can be even more. However the seasonal and short-term variability considerably prevails above the interannual and seasonal variability.

Distribution and gradients surface thermal fronts (Gradient °C/mile) in Japan Sea

Table

N	Name of fronts		Start of front фронта (Latitude, Longitude)	Finish front фронта (Latitude, Longitude)	Winter (Gradient °C/mile)	Spring (Gradient °C/mile)	Summer (Gradient °C/mile)*	Automn (Gradient °C/mile)
1	Subarctic front (SAF)		40.6 N, 134.5 E	41.0 N, 139.0 E	0.16-0.23	0.1-0.16	0.13	0.1-0.23
1.1	Northeast branch SAF (NE)		41.0 N, 139.0 E	48.0 N,. 141.0 E	0.02-0.03	0.03-0.15	0.06-0.1	0.06-0.1
1.2	Southeast branch SAF (SE)		41.0 N, 139.0 E	46.0 N, 141.30 E	0.05	0.05	0.05	0.06
1.3	Northwest branch SAF (NW)		42.0 N, 130 E	40.6 N, 134.5 E	0.05-0.06	0.06-0.11	0.1	0.11-0.2
1.4	Western front (WF)		39.0 N, 128.0 E	38.5 N, 129.5 E	0.1-0.13	0.06-0.16	0.05	0.13
1.5	Southwest branch SAF (SW)		37.0 N, 129.5 E	40.6 N, 134.5 E	0.1-0.16	0.1-0.13	0.1	0.06-0.13
2.1	- Fronts Tsushima Current (FTsC)	South branch (S)	36.0 N, 130.0 E	37.0 N, 135.0 E	0.06	0.04	0.03	0.04
2.2		north branch (N)	37.5 N, 132.5 E	40.0 N, 134.5 E	0.03-0.06	0.06-0.1	0.1	0.03-0.06
2.3		Eastern (E)	38.0 N, 136.0 E	39.8 N, 139.0 E	0.05	0.04	0.03	0.05
3.1	Tatar front (TF)		48.0 N, 140.0 E	48.4 N, 141.8 E			0.06	
3.2	Sakhalin front (SF)		46.0 N, 141.7 E	48.0 N, 141.7 E		0.13	0.1-0.11	0.1
3.3	Primorye front (PrF)		42.7 N, 132.0 E	48.0 N, 140.0 E	0.06	0.03-0.06	0.06-0.1	0.03-0.1
4	North-Korean front (NKF)		40.0 N, 128.0 E	42.3 N, 130.7 E	0.03-0.06	0.06-0.1	0.08	0.01-0.03

4. CONCLUTIONS

The analysis of the satellite images available in our disposal, proves, that the allocated basic elements of hydrological structure are steadily enough shown in all seasons. Some exception makes the summer period. Here it is necessary to tell, that the satellite information adequately displays basic elements of hydrological structure, and allows to receive the valuable qualitative and quantitative information on parameters, existential variability and small-scale structure of frontal zones.

As a result of researches with use of a plenty of the satellite data the generalized scheme of position of surface thermal fronts of Japan sea was made and their interannual and seasonal variability is considered.

The western meander in the western part of Japan sea was weakened in the period 1980 - 1991, and advanced - in 1978, 1979 and since 1992 up to the present time. Thus the advanced vortical structure was observed during northern SAF position (warm type of the year), especially marked in winter-spring time and, on the contrary - at southern position (cold type of years).

Marked, last years, intensive advection of waters of subtropical structure in a northwest part of the sea will be kept on rather high level and in 2005-2006.

In northern part of Japan sea in SAF dynamics the general tendency – SAF movements aside continent since 1984-85 till now takes place.

The allocated cycles with the period to relatives by 2-3 months are essentially reflected in a seasonal course of position of Subarctic front in a northwest part of sea of Japan. Distribution of surface fronts in Japan sea essentially changes within one year. In the winter and in the spring in northern part of the sea homogeneous SST distribution is observed, thermal contrasts are kept only in a zone of influence of Eastern-Korean and Tsushima currents. In the summer on the background of the general increase of temperature of the sea surface the fronts connected to local destruction of thermocline and exit of cold waters on a surface are formed. In autumn fronts both of summer and winter type exist.

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