INVESTIGATION OF FAR EAST SEAS WITH THE AID OF REGIONAL SATELLITE MONITORING: EXPERIENCE AND PROBLEMS

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Introduction

Regional satellite monitoring of environment (RSM) on regular acquisition and real-time processing of digital multi-channel satellite information occupies a significant position among various tools of ocean and atmosphere investigations. In the worldwide practice RSM includes both stand-along methods and combination with routine tools of oceanographic researches. Particularly, interesting results may be obtained by satellite support of research cruises when in-situ observation program is corrected during the cruise depending on the results of operational satellite data processing. Retrospective researches that use archive satellite and in-situ data are widely practiced as well.

Since 1993 the multi-computer system for acquisition, processing and archiving of the NOAA/HRPT data operates in the Institute of Automation and Control Processes (Vladivostok). From the beginning of 1999 the Inter Institute Center is established and operates on the basis of the system. Among other things, the center includes the operational service of satellite observations and historical archives of satellite data for the Far East Region.

The paper describes the main possibilities of the monitoring and some problems we solved.

The RSM We Are Carrying Out: General Description

We began our activity in the field of RSM at 1984. At the time we had developed the shipboard NOAA/HRPT Data Acquisition and Processing System that was installed and operated on board of R/V "Academic Korolev" (since 1984 on the base of digital APT data, and since 1988 as HRPT). The main purpose of the system was to determine sea surface temperature fields and identification of oceanographic objects (such as mesoscale eddies, currents, fronts, *etc.*) and to correct ship tracks and in-situ measurements program according to the object locations. The system was operated until the R/V remain to be a scientific one.

After that the System was installed on the Institute building and since autumn of 1993 began support both various research cruises and stand-alone investigations of the Far East Seas and adjacent areas of the Pacific (Herbeck *et al.*, 1996). As before our studies were focused on ocean variability mentioned above. Tropical cyclones studies were added to our list of interest since 1997 and forest fires since 1999. In total we have carried out an information support for more than 10 marine cruises related with physical oceanography and fisheries research.

Being started from compact mobile station, our system evolved into a complex of 12 computers and appropriate electronic supplementation. Now the system includes some workstations for data processing, new RSM methods development and software creation. All the computers are consolidated in Fast Ethernet local network and have access into the institute network and Internet. We support FTP server that is accessible via city telephone lines and Internet. To pass satellite data to the users and demonstrate our possibilities the Inter-Institute RSM Center was established on the basis of our system in the beginning 1999. The Center realizes NOAA/HRPT data acquisition and processing as well as collection of satellite archives for supports both marine cruises and stand-alone researches.

It should be pointed out that the historic archive contains every day records from the beginning of 1999 only. Before this year monitoring sessions were carried out sporadically (as a rule, 4...7 months per year in correspondence with marine cruises spending).

Although we can cover a wide area (from Taiwan to Kamchatka and up to 170°E) the usual areas of our monitoring are:

- Sea of Japan;
- Sea of Okhotsk including Pacific area along Kuril Islands;
- areas to the south-east from Japan including Kuroshio Extension.

The main negative factor of satellite marine observations in the areas listed above is cloudiness; the second factor is warm fog in the Okhotsk Sea. We developed special methods and technology that make it possible to filter out cloudiness by constructing so called "composite maps" using several multichannel images of all available NOAA satellite passes collected over 2-10 days period.

Very important RSM application is identification of various natural objects on sea surface and evaluation of their dynamic parameters. In most cases a visual analysis is difficult to sea detail of its structure. Partial cloudiness makes it still more difficult. The same is also true for sea surface current velocities (SSCV) determinations based on manual feature tracing procedure because it is quite complicated to monitor features by consequence of satellite images at such conditions. To overcome this obstacle we developed special method of sea surface thermal structures (SSTS) analysis. Thermal structure constructing is based on the fact that thermal contrasts are oriented along local currents and the higher local current velocity value corresponds to higher correlation between contrast orientations and velocity directions. Thus to construct SSTS map one should determine the most statistically reliable orientations of thermal contrasts at every pixel. (Note that SSTS map may be based both on a single image and composite one.) It is easy to see that SSTS less depends on cloudy condition than SSCV because the first does not need image pair selection. Therefore in many cases SSTS may be used instead of SSCV.

For joint processing of image series it is necessary to improve image navigation methods and software. It is true that standard navigation makes spatial errors up to 10 km, even if GPS UTC time is used as a scan line time mark. To decrease the errors due to satellite platform deviation we developed special method that emulates current platform state (yawing, pitching, and rolling angles) using several ground controls points (GCP) for realizing pixel-by-pixel image navigation. As a result, we have reached subpixel accuracy at every pixel.

RSM technology consists of day-to-day acquisition, preprocessing (including accurate navigation described above), and collection of NOAA/HRPT data at the first step. Then thematic processing of satellite data is carried out. In general RSM output products include:

1) raw data files with appropriate records in archive catalogue;
2) sea surface temperature fields (calibrated single-channel Mercator projected images);
3) momentary (single-session) SST, SSCV, and SSTS maps (Fig. 1, 2, 3);

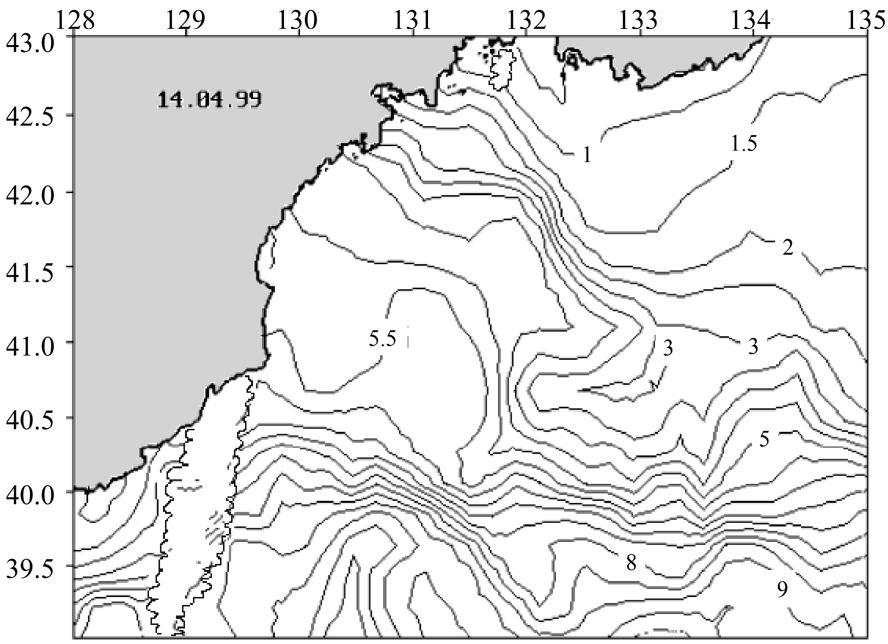

Fig. 1. Sea surface temperature in isotherms on 14.04.99, created by IR-data of AVHRR/NOAA

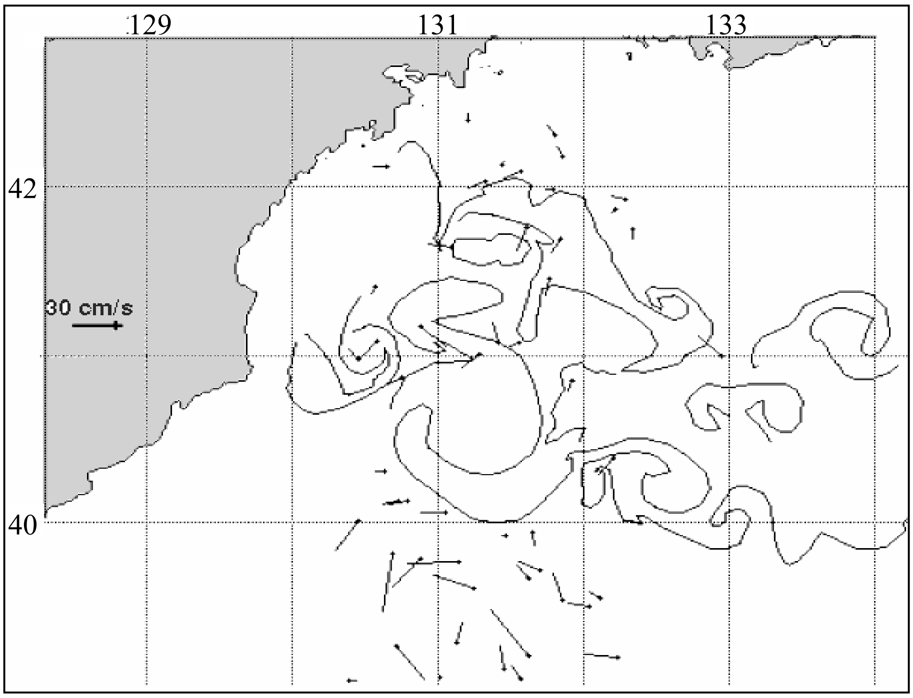

Fig. 2. Vectors of sea surface currents and contours of thermal fronts on 14.04.99 created by IR-data of AVHRR/NOAA

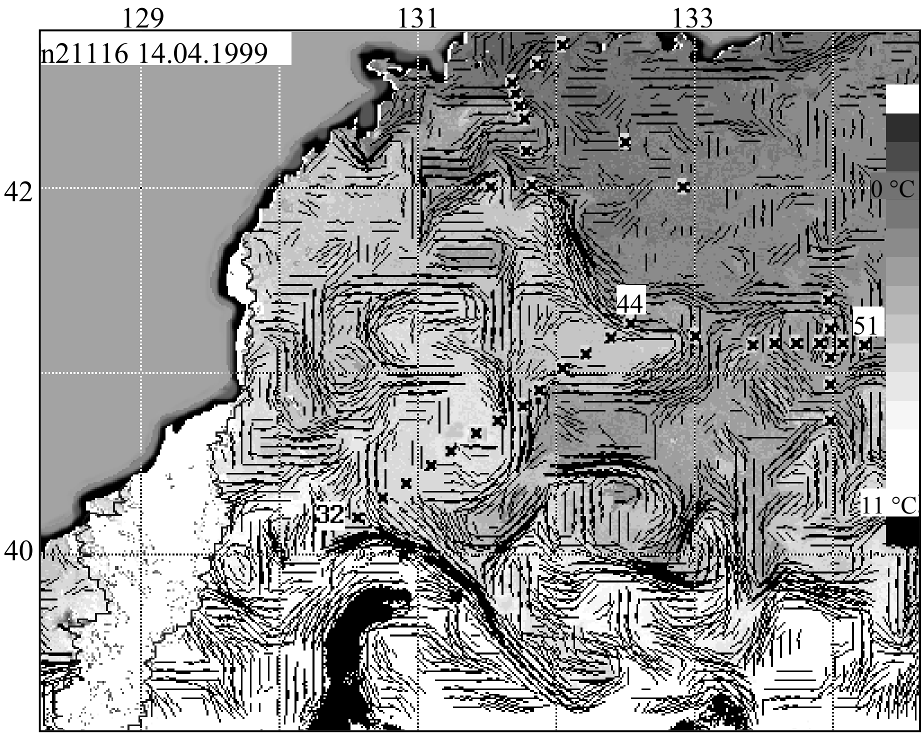

Fig. 3. AVHRR/NOAA IR-image and dominant orientations of brightness contrasts. It is seen that dominant orientation of contrasts corresponds well with thermal structures at the sea surface. Location of hydrographic stations of the 32-th cruise of R/V "Pavel Gordienko" in April 1999 is shown by crosses

4) composite SST and SSTS maps for various time intervals;
5) summary of oceanographic object location and characteristics
6) for research cruise control (Table 1).

Table 1

A sample of summary on mesoscale eddies and front location and structure provided for research cruises of R/V "Pavel Gordienko" on 14.04.1999

Eddies	Lat. /long. in degrees	V cm/s	Radius small half axis in km	Orientation of big axis	Rate of axes	Core
1(A)	41.15 133.90	–	35	circle	1.0	mixing
2(A)	40.25 132.50	–	20	north-west	1.4	mixing
3(A)	41.10 132.20	15-20	20	north-west	1.7	warm
4(A)	40.50 131.2	30-35	55	circle	1.0	warm
5(A)	41.30 131.15	20	15	circle	1.5	
6(C)	41.10 130.90	30	very small	west-east		
7(C)	41.60 131.35	–	20	west-east	1.5	cold

Note: front of 131.20°E located at 39.50°N and has shifted by 3 km over 12 Hours.

Information support of marine research cruises is our common work. Since 1994 we provide current information to control oceanographic cruise in real time. This includes monitoring of the cruise working area, determination of position and other characteristics of oceanographic objects investigated and transfer information to ship for correction of in-situ measurements according to nearly real-time data received. The information being sent a few times per week for the 32-th cruise of R/V "Pavel Gordienko" in April 1999 is presented on Fig. 1, 2, 3 and in the Table 1. The ship track was corrected by satellite information passed exactly through the centers of mesoscale eddies (Fig. 3).

Satellite Information and Its Accuracy

Sea Surface Temperature (SST)

Within the framework of our SST field retrieval technology the main output products are SST charts in isotherms in Mercator projection. It is cloud cover that is major problem of ocean flow imaging by using satellite measurements. During an expedition only a few images can yield useful data *i.e.* cloud-free images. That is why the charts may be classified according to time-averaging as follows:

- *type A*: averaged SST charts over a period of 5-10 days and 50-100 km resolution;
- *type B*: composite charts of 2-3 days period and 10-20 km averaging;
- *type C*: high-resolution charts of 5 km averaging from a single image.

It should be mentioned that SST fields of *type A* are used for hierarchical control while product *(B)* and *(C)* are processed. Type *(A)* is successfully applied to fine cloud filtering of an every individual image from the sequence and to normalize images for (*B)* composition. The last procedure required avoiding artificial defects associated with errors in an atmospheric correction and false thermal front appearances. The data may be presented both as a picture and a digital grid field information.

We apply the operative linear atmospheric correction MCSST for NOAA-11/12/14 satellites recommended by NOAA/NESDIS to make a preliminary SST retrieval. The technique provides an accuracy of SST determination about 0.5 °C. Both filtration and correction procedures use only satellite data from AVHRR channels 2 (0.725-1.1 μm), 4 (10.3-11.3 μm) and 5 (11.5-12.5 μm) without in-situ measurements.

Quite accordance between satellite data and ship observations is demonstrated in Fig. 4. In spite of time discrepancy from 3 to 5 days a good suitability of temperature trends obtained by different instruments is observed. The three anticyclonic eddies on the upper profile (stations 32-38, 40-44, 46-53 on Fig. 4a) correspond linear segments A, B, C on Fig. 4b. Some variance of boundaries and fine details can be explained by non-simultaneous data.

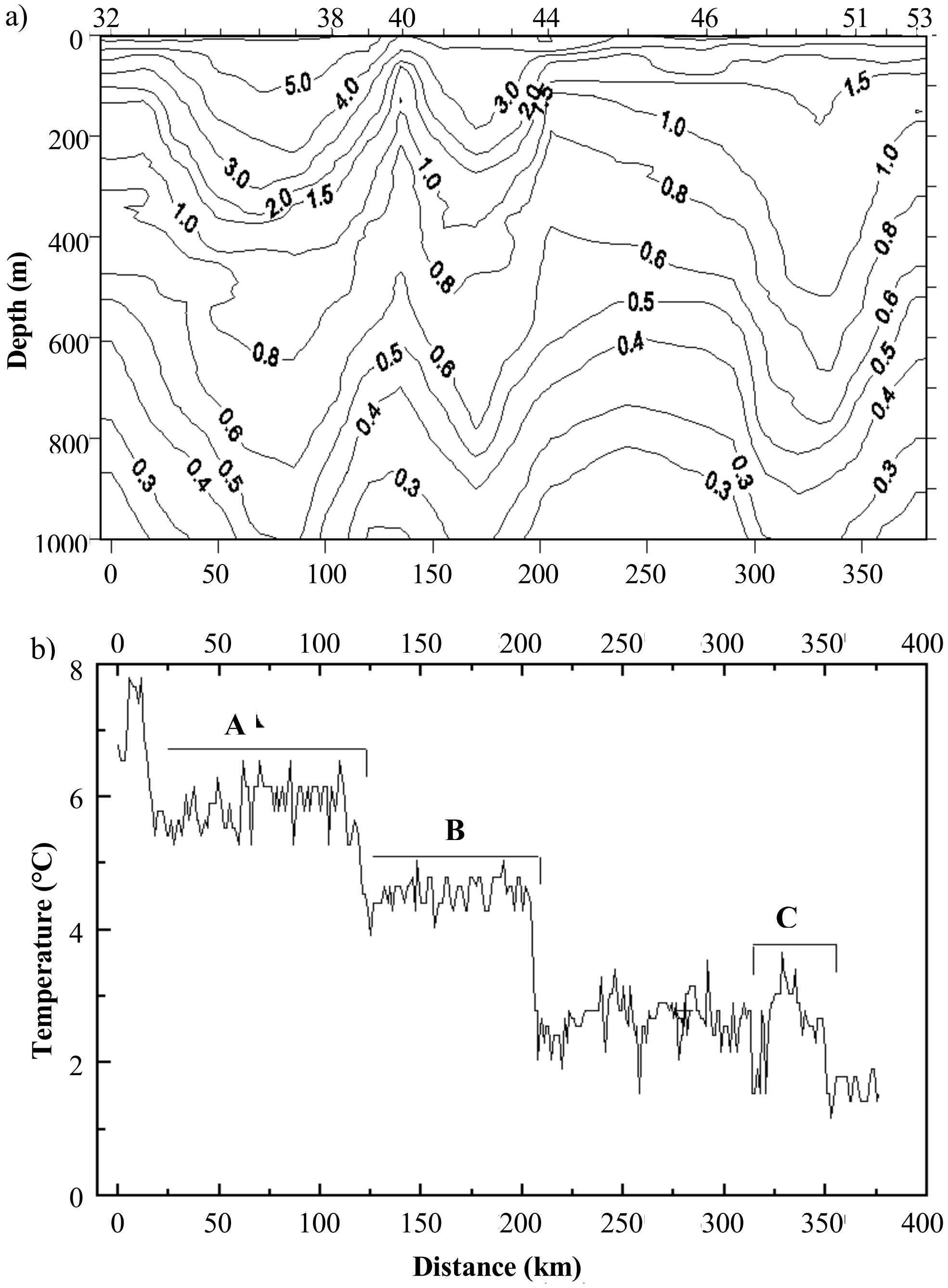

Fig. 4. (a) Temperature vertical section through three anticyclones eddies in the Japan Sea on 18-20 April obtained by the 32-th cruise of R/V "Pavel Gordienko" and (b) appropriate sea surface temperature profile obtained from NOAA AVHRR data by our system on April 14, 1999

<u>*Sea Surface Currents Velocity (SSCV)*</u>

There are two methods based on sequential satellite images analysis we use for creation of a sea surface velocity charts:

- manual feature tracing (FT);
- maximum cross-correlation technique (MCC).

We use FT technique usually. This method gives more information about circulation, than demand to measurement accuracy is severe. MCC method is used only for ice velocity calculations.

FT is based on determination of water submesoscale non-homogeneity displacement and on appropriate calculation of velocity vector. Accuracy of velocity appreciation depends on space resolution of satellite images and time interval between sequential images. The final accuracy estimated by comparison with in-situ measurements is in the range of 2-6 cm/s.

There are significant contradictions in this question in scientific literature (Svejkovsky, 1988; Kelly & Strub, 1992; Tokmakian *et al*., 1990). The underestimation of surface velocities derived by MCC technique is the result of peculiarity of this method, coarse scheme of comparison and different nature of a measurements for a point and for a square in some kilometers, from our point of view.

If we want to consider the accuracy of satellite technique of large-scale water mass velocity determination, then we ought to make comparison between satellite and ship measurements under the follow conditions:

- at first, the flow has negligible small-scale (1-2 km) and short-term (24 hours) velocity variability;
- at second, the space and time discrepancies between compared measurements are less then a typical spatial and temporal variability of the flow.

Some estimations of FT technique accuracy on such kind of flow are presented by Svejkovsky (1988); Alexanin (1991); Alexanin & Kazansky (1994); Ro *et al.* (1997). According to these results the satellite velocity determination does not differ from another one in the limits of scheme accuracy (not worse than 20% of value). We have not received any obvious contradiction between satellite velocity vector estimation and *in situ* direct current measurements during ten years practice.

An example of SSCV chart is presented in Fig. 2. Unfortunately the SSCV charts can be obtained not always. Time interval for SSCV charts creating must be from 7 to 15 hours and the region under consideration must be without clouds. Cloudless conditions are not often over Far East region. Because of this reason in addition to SSCV charts and as alternative to them the SSTS technique was created.

Sea Surface Thermal Structures (SSTS)

A new method for deriving thermal structures on the sea surface by satellite IR-images has been developed (Alexanina, 1997). An example of SSTS chart is presented on Fig. 3. The procedure is based on an approach for extraction of oriented texture from images. An infrared sea surface image may be considered as a set of oriented textures on the temperature field. The oriented texture is a two dimensional image of dominant local orientation of the IR radiation contrasts in every point. Calculation of the oriented textures is based on estimation of the dominant contrast orientations and their statistical significance from field of brightness gradients. In brief, thermal contrast orientations are statistically significant tangents to isotherms in the vicinity of any point.

Due to dynamical properties of sea surface currents (shear nature), the thermal contrasts are stretched along flow currents. To validate the method, a quantitative comparison of the current velocities and structure maps was done by Alexanin *et al.* (1998, 1999, 2000). The directions of sea surface velocities and thermal contrast directions were compared. A correlation coefficient of the fields, mean mismatch of the angles and mean value of statistical significance of thermal contrast orientation were calculated. The comparison showed that:

- the correlation coefficient is near 0.8;
- the coincidence of the flow currents and the contrast orientations is better when the velocity values are higher;
- the correlation coefficient reaches the correlation value 0.9 (angle mismatch is 20°-25°) for velocities higher than 30 cm/s.

Generally, the comparison study demonstrates that the method gives suitable quantitative estimations for the flow direction especially for strong current systems. It was verified that statistically significant orientations of the thermal contrasts have good agreement with location and orientation of surface currents.

Conclusion

Since 1993 we are conducting the environmental regional satellite monitoring of the Far East marginal seas and adjacent areas of Pacific and maintaining our Satellite Data Archive. On the base of the monitoring the operational information is provided to support various oceanographic research cruises, fisheries, ice analysis, and other kinds of operative works. Using archive data we are conducting a wide range of investigations of marine processes and phenomena both its characteristics and variability.

For these goals we developed some original methods and software that were testing thoroughly and are using during several years. It seems the methods are to be quite suitable both for us and for our users. It should be pointed that our methods are working very reliable under partly cloud conditions, that is very important for the Far East region.

More information you can obtain by visiting our *ftp://ftp.satellite.dvo.ru* (with e-mail address as password).

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