Combined processing of IR and MW radiometric data in the ice reconnaissance during the survey for the harp seal puppy grounds in the White sea

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Abstract - Studied is the question on correlation of the IR and MW radiometer data, as well as on the expediency of using MW radiometry to solve the specific problems of ice aerial reconnaissance.

Keywords: White Sea, multispectral aerial surveys, harp seal population.

1. INTRODUCTION

During a number of years, the Laboratory of Remote Sensing (PINRO) has been conducting multispectral aerial surveys for puppy areas of the White Sea harp seal population with the aid of IR scanner, photo and video equipment. To have proper quality of the investigations the ice aerial reconnaissance is required since the ice conditions are highly affecting the distribution and boundaries of animal grounds. Combined using passive IR and MW radiometers allows us to derive data on ice closeness, the borders of ice packs et cetera. The methods of MW and IR radiometry, mainly, differed in dielectric properties and, hence, in the radiation coefficients of such natural environment as the sea surface and the ice cover. This difference is the basis of all the developed methods for the aerial and satellite MW remote sensing (Anon, 1968; 1979).

1.1 Physical fundamentals of the heat field remote registration

The sensing of the Earth surface by methods of passive radiolocation is based on the registration of the intensity of radio heat fields (fields emitted in radio range) created by the earth's thermal radiation.

Radiation of any body, the thermodynamic temperature of which is different than 0, is caused by chaotic thermal movement of the charged parcels inside it. This chaotic movement is the source of thermal radiation within a wide range of electromagnetic spectrum.

The principal law of thermal radiation is described by Planck formula and expressing the relationship of the spectral density of the absolute black body (ABB) radiant exitance, the wavelength and the temperature. Within the MW range with a high rate of accuracy the law is described by the long-wave approximation of the Planck's formula and that one of Rayleigh and Jeans. The spectral brightness of ABB is taken as a standard, with which radiation of heated bodies is compared. The ratio of spectral brightness $g_1(\lambda,T)$ under the given temperature and spectral brightness $g(\lambda,T)$ of ABB under the same temperature is called radiation ability (the rate of blackness) ε. Radiation ability $\varepsilon_{\lambda,T}$ shows the difference of the real body radiation power and the maximum possible one, i.e. the power of ABB radiation with the given temperature and wave length. In the common case, real artificial and natural objects are the selective radiators, for which radiation coefficient is the function of the wavelength and the absolute temperature. However, the energy distribution of many real solids by spectrum is of the same character that in ABB, i.e. the radiation coefficient does not depend on the wavelength ($\varepsilon_{\lambda,T} = \varepsilon_T$). The Stefan-Boltzmann distribution law determines the summary power of radiation emitted by the body from the surface unit and, hence, the radiant exitance of ABB is proportional to the fourth rate of its thermodynamic temperature (Anon, 1968; 1979).

In accordance with the law by Golitsyn-Wien, the wavelength λ_m, to which the maximum spectral density of radiation corresponds, is inversely with the absolute temperature of radiator, i.e. when the radiator temperature increases the maximal spectral density of radiation shifts to more short-wave zone. According to L.Z.Kriksunov and D.Lloid, about 71% of all the energy emitted by body were concentrated within the range of 0.5 μm$<\lambda_m<$2 μm. From this it follows that practically all the real bodies with the absolute temperature of to several thousands degrees are, mainly, emitting in spectrum infrared field. The possibility to detect objects is determined by the temperature contrast meaning the temperature difference of the objects. With a temperature contrast the objects are different in emitted radiation intensity.

The thermodynamic temperature of the objects observed is, approximately, the same, usually (about 300˚K) and the intensity of the radio thermal signals is determined, to a considerable extent, by radiation ability of the bodies. In compliance with the Wien law, the maximum of spectral density of radiation, which is typical for the earth surface bodies, falls within the infrared field of spectrum, radiofrequency range accounts for not less than 1% of the total power of radiation .

Measuring the integral power of radiation within a wide spectral range permits us to determine radiation temperature of objects, i.e. that one of ABB, having the same radiation intensity, as the given body has. The properties of real radiator, which radiation is different from that one of ABB may be characterized by the brightness temperature T_B representing the product of thermodynamic temperature T multiplied by the radiation ability ε:

$$T_B = \varepsilon \cdot T \qquad (1)$$

Thus, the brightness temperature of a real radiator is a temperature of ABB giving the same power of radiation that a real body does. For this, in the formula expressing the law of Rayleigh-Jeans, the brightness temperature should be substituted instead of thermodynamic temperature.

When studying seas and oceans the radiometric facilities allow us to determine the state of water surface and the extent of its contamination, to measure water temperature and salinity, to carry out ice reconnaissance and to map the areas, to estimate parameters of atmosphere and wind above the water (Kondratjev et al., 1992; Rabinovich et al., 1970).

2. THE USE OF MW RADIOMETERS WHEN INVESTIGATING THE ICE COVER

The most prevailing methods to determine characteristics of the ice cover are visual, aerial photographic surveying and radiolocation. The first two ones have a significant disadvantage: it is impossible to conduct ice reconnaissance under the cloudiness. Besides, the first method is a highly dependant on the personality of an observer and the second one permits us only to have the relative measurements, since even in the low-loss transmision windows of the infrared range the atmospheric radiation must be taken into consideration. The radiolocation survey for the ice cover with the aid of the side view locators provides obtaining ice images. But it gives a way to radio thermal location survey in the terms of increase in the energy consumption and the weight of equipment though the data obtained are more informative. Thanks to a great difference in dielectric contacts of water and ice, a passive radiolocation is an efficient method of the ice reconnaissance, most of all, aimed at obtaining the data on the boundaries of the ice fields and their closeness. Methods of radio thermal location enable the ice reconnaissance to be carried out through the cloudiness, which is quite transparent in the centimeter range of the wavelength. Thus, applying radiometry facilities is of the great interest from the viewpoint of diminishing size and weight of equipment and, mainly, the economical power consumption due to the lack of the powerful generators of sounding oscillations.

Using of radiometry facilities to study the ice cover and carry out the ice reconnaissance, that based on the difference in ice radiation ability and the dependence of the ice radio brightness temperature on its age, electrical and physical properties is given in details in (Anon, 1968 and 1979).

The problem of the ice cover closeness distance indication is solved the most simply for the salt-water ice, since the differences between radiation coefficients of water and ice are quite significant (the contrasts of radio brightness temperature reach 50-120ºK). The radiation ability of the area partly covered with ice depends on the ratio of the ice cover areas and the open water surface in the field of radiometer transducer vision. The linear dependence of radio brightness temperatures on the closeness of ice S is determined as follows:

$$S = \frac{T_b - T_{bc}}{T_{ba} - T_{bc}} \qquad (2)$$

where T_b – measured radio brightness temperature of the ice field;
T_{bc} – radio brightness temperature calculated for water temperature T_0=273ºK;
T_{ba}- radio brightness temperature calculated for average climatic temperature and given coefficient of the ice radiation (for instance, 0.96). (Anon, 1980; Basharinov et al., 1974)

A great difference in radiation ability of the ice-free water and ice permits us to imagine the closeness of the ice fields estimated using a 10-point scale, as the function of brightness temperature measured with the aid of IR and MW radiometers. Fig.1 shows that the brightness temperature ~250ºK corresponds to the solid ice cover, that one of ~100ºK – to the ice-free water surface.

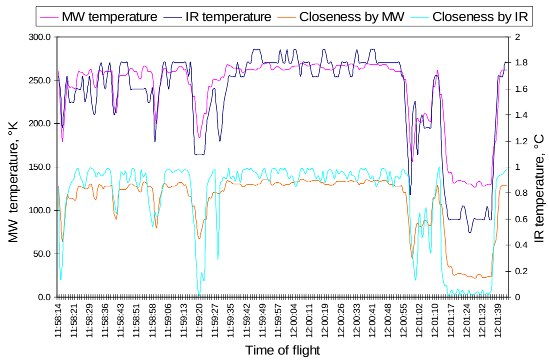

Figure 1. Registogram from MW and IR radiometers and calculated values of ice closeness

But, the scattering on the heterogeneities of the ice density may be the noticeable obstacle when estimating ice closeness using the abovementioned formula. A layer of water or wet snow on the ice surface noticeably reducing the radio brightness temperature may become an additional source of obstacles when determining ice closeness. Such layers are highly decreasing radiation that leads to the seeming reduction in closeness. With low temperature, the data on closeness obtained within a wide spectrum of radiation are quite reliable.

2.1 Experimental works

Experimental data were derived aboard the airborne laboratory AN-26 "Arktika" during the annual surveys for puppy areas of the harp seal in the White Sea in 2001 and 2002. IR radiometer "AIR-2" and the MW one "Fish" with the following characteristics were applied for monitoring of the sea surface and ice cover.

To have the images of the ice cover the IR-scanner "Malakhit" and a digital camera "Nikon D1X" were used. Applying IR-scanner obtained were continuous underlying surface images overlapping the coverage zone by all the aerial survey equipment due to a great angle of vision.

Table 1. Technical parameters IR and MW radiometers

Technical parameters	IR radiometer	MW radiometer
Spectral range	10-12 μm	5 cm
Measured temperature range	-10-+40ºC	0-400ºK
Accuracy of temperature measurement, δT	0.1ºC	0.1ºK
Constant of integration time	1s	1.4 s

Using digital camera the series of pictures of the most important, in our opinion, areas, where the closeness and type of ice varied, to a great extent, were made. IR-scanner "Malakhit" and digital camera "Nikon D1X" have the following specifications:

Table 2. Technical parameters IR-scaner and digital camera

Equipment	Specifications	Value
IR-scanner	Spectral range	8-14 μm
	Instantaneous visual field angle	1.55 mlrad.
	Visual field angle	120º
	Min.registered temperature difference	0.1ºC
Digital camera	Image size, pixels	3008x1960
	Sensitivity, ISO	125-800
	Focus distance	24-120 mm
	Exposure	30-1/16000 s

All the experimental flights were carried out at the low altitude H=150-350 m so that the effect of atmosphere on IR radiation from the sea surface might be not taken into account. It allowed the brightness temperature received by IR radiometer to be considered as equaled to that one of the surface.

Profiles of synchronous registration of radio brightness and radiation temperature from the MW and IR radiometer records, as well as IR record, photo and video images of the ice cover parts with different closeness were registered for experimental check of the possibility to determine the closeness by the results of radiometric measurements.

At the initial stage all the data on radio brightness temperature of water surface were processed to calculate its average value. Then, the pictures with the same ice structure and data from MW radiometer related to the filmed surface were selected. It allowed us to derive the data to calculate ice closeness by the above-mentioned formula (2). Figure 1 showed that readings of both radiometers varied synchronously. For this, it should be considered that higher variability of IR radiometer is explained by better spatial resolution as compared to MW radiometer. It should be noticed that taken equality of IR radiometer readings to the temperature of the surveyed surface permits us, in accordance with (1), to come from the radio brightness temperature to radiation ability ε. Figure 1 also presents the plots of calculated values of ice closeness according to formula (2) and calculated by the programme using the IR scanner "Malakhit". In some cases, when it was necessary to check the reliability of the programme calculation of closeness, the digital pictures were used.

To calculate ice closeness by the data from the IR scanner "Malakhit" the software to select the area filmed by MW radiometer from the continuous IR image and to convert it to the bit one based on the data on brightness values corresponding to the ice-free water and ice was designed. Besides, the data array given in Figure 1 was obtained. In the course of experimental works the following results were obtained:

1. When calculating values of closeness by IR-images, the average value of brightness, on the basis of which the image is presented as a binary one, changes, to a great extent. This is, for the first time, caused by the fact that the IR scanner "Malakhit" does not give absolute temperature values and, hence, the brightness of image varies depending on the temperature of surveyed surface and environment.
2. The value of closeness by IR images differs from those ones by the data from MW radiometer due to the fact that when converting to the binary type lost is the part of information on the type of ice, since the average value of the brightness of initial and new ices (frazil, ice fat, ice crust and others) is close to that one of the water brightness. This problem appears with grated or hummock ice in the image, since in the sites of brakes the value of brightness sharply decreases though the open water is not observed here. It leads to the underestimation of ice closeness value calculated using the IR image.

Thus, it may be concluded that the data on ice closeness are expedient to be derived using MW radiometer, the readings of which are significantly less influenced by the temperature of surrounding air and underlying sub-subsurface, which, to a greater extent, depends on radiation activity of the surveyed surface.

In the course of the experiment, the dependencies of difference in IR and MW radiometer readings were obtained, as well as the errors of surface temperature recovery were revealed with the aid of the MW radiometer readings. It permits us not to take the weather conditions into consideration when conducting the ice reconnaissance, as the MW radiometer with this range is suitable for the weather of all types. For this, the errors in the recovery of underlying surface temperature may reach ~2.5ºK under the different values of ice closeness. It is caused by the fact that in the IR range the radiation ability of surveyed surface varies significantly less, than radiation ability in MW range.

Figure 2 presents the dependence of radio brightness registered by MW radiometer on the ice closeness. There (in Figure 2 the similar dependences were derived while investigating sea surface and ice cover. The plot indicated that the relationship of these two parameters is a linear regression that follows from the ratio (2).

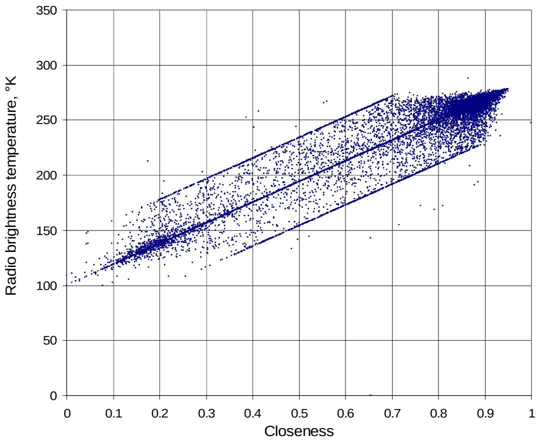

Figure 2. The dependence of ice closeness from the radio brightness temperature.

After receiving the data array on ice closeness by the results of the joint analysis of the readings of IR and MW radiometers, in the GIS package “ArcView” the spatial processing of the results from calculation of the seal abundance by computer and visual method and of the values of ice closeness along the flight track was executed. The data from the aerial survey for the harp seal obtained on 20 March 2002 were used as an example. In the course of analysis the data array on the relationship of animal abundance on the ice with different closeness were derived.

As it is known, the areas of abundant seal concentrations in the period of puppying and moulting are in the relationship with the certain concentration of sea ice. The seals avoid the areas of very close ice, since it is a serious obstacle for feeding of adults, which makes them to spend their energy for arranging air holes. Seals also avoid the areas of highly scattered drifting ice, since in these areas the contacts of pups with water, super-cooling and death of pups are the most probable.

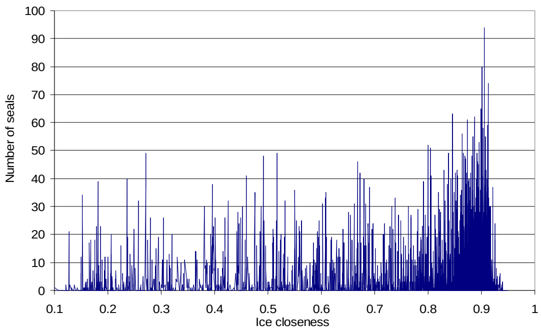

Figure 3. Histogram of the number distribution of assessed animals on ice with different closeness.

Figure 3 presents the histogram of the abundance distribution of animals to have been assessed, occurring on the ice with different closeness. As it may be noticed, the bulk of the harp seals when choosing the areas for puppying prefer the ice with the closeness of 7-9. The tendency is traced well on the histogram of the summary number of animals assessed during the flight and presented in the upper left corner of Figure 4.

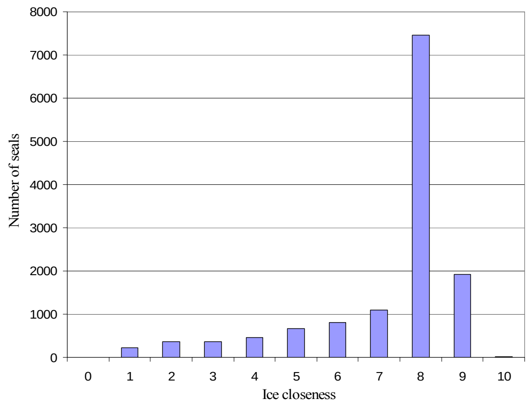

Figure 4. Histogram of the summary number of animals assessed during the flight.

The final stage of work included making the chart of closeness by the data from MW radiometer and the comparison of obtained results with available data from the satellite. Figure 5 showed the ice closeness charts made using the data from experimental flight on 20 March 2002 and those ones from SSM/I sensor of DMSP satellite. It is pronounced well that with a larger spatial resolution the airborne MW radiometer allows the ice reconnaissance to be executed at a higher level, especially, near the coast. Also it may be noticed, that in the Gorlo of the White Sea, where the distance between Zimny and Tersky coasts is about 50 km, the data of the satellite sounding significantly differ from those ones obtained from the aircraft. It is, first of all, connected with methods of SSM/I sensor data processing, as well as with a minor spatial resolution of the latter.

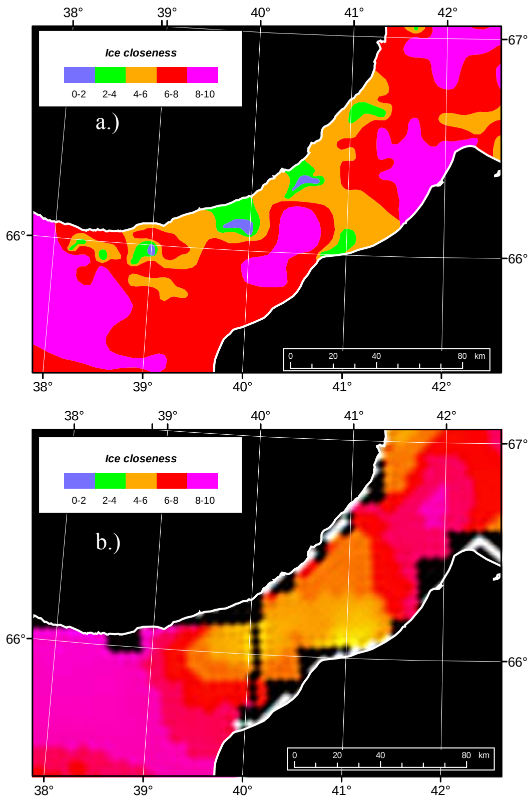

Figure 4. Ice closeness charts made using the data from experimental flight on 20 March 2002 (a) and those ones from SSM/I sensor of DMSP satellite (b).

3. CONCLUSION

In conclusion, it may be noticed that the use of passive MW radiometry permits the weather conditions not to be taken into consideration, the qualitative data on the most probable site of the harp seal puppying to be derived, and also the analysis of the data on calculation of surveyed surface radiation ability to be continued.

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