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Satellite Hydrophysics

Observations of the sea surface temperature variability using daily and nightly IR measurements from the NOAA satellite*

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Abstract — We considered the procedure of digital processing of IR data on the Black Sea and Mediterranean Sea obtained at the automated data reception station (ADRS) operated by the Marine Hydrophysical Institute, UkSSR Academy of Sciences during the daily and nightly communication session with the NOAA satellite in the APT regime. Two methods were used: a histogram method (for the daily one-channel measurements) and a spectral-angular one (for the nightly dual-channel measurements). As a result, 117 and 99 digital charts of the sea surface radiation temperatures, respectively, were obtained for these basins, as well as 10-day and monthly combinations of the nightly and partially daily digital images. The compositions derived by these two techniques have been compared with the data set for July, which was statistically most complete.

INTRODUCTION

A variety of methods for reconstructing the sea surface temperature (SST) using satellite IR measurements can be found in the literature. However, only some of them are used for plotting, on regular basis, SST maps which are further used in economy [1–6].

A program-technical complex (PTC) DIZON which permits the digitization and processing of video and IR data received regularly from the NOAA satellite in the APT regime [1] has been working in the Marine Hydrophysical Institute of the UkSSR Academy of Sciences since 1987. Two sequentially taken pictures provide a panoramic view of the whole of Europe, including the Black Sea and Mediterranean Sea.

A block diagram of the PTC DIZON and its basic functions are described in ref. 2. During the last 3 years, a large number of video and IR images has been received, treated, and analysed using this complex [3–5]. Most of the data were obtained during the daily communication sessions with the satellite, i.e. within the ranges of $\lambda_2 = 0.9\,\mu$m and $\lambda_4 = 10.8\,\mu$m. In 1989, approximately 100 nightly images of the Black Sea and Mediterranean Sea in the 'transparency windows' of λ_4, $\lambda_3 = 3.7\,\mu$m were received and processed simultaneously with the daily pictures. In view of this, it is interesting to compare the results of IR measurements of the SST in the above ranges, which is done in this paper.

PROCESSING METHODS

First, we describe the digital methods of obtaining the radiation (brightness) SST maps for the Black Sea and Mediterranean Sea (RSST) allowing for the features of the IR data recorded from the daily and nightly communication sessions with the satellite.

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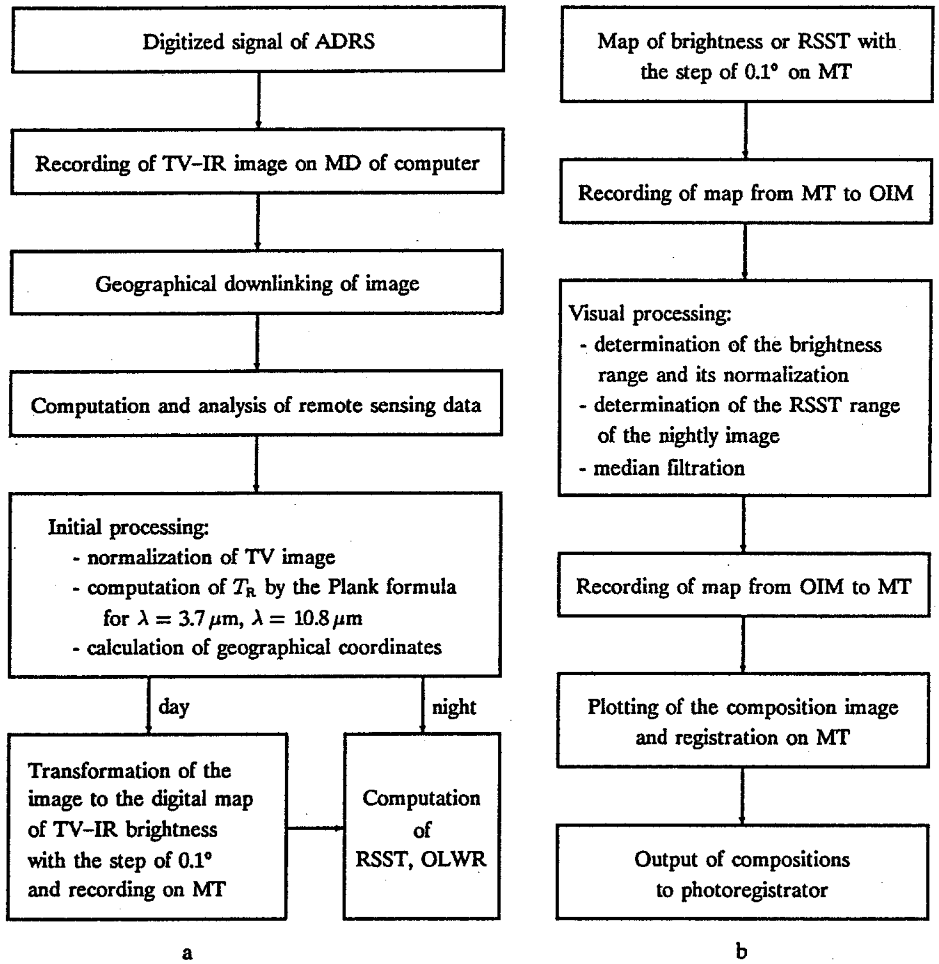

Figure 1. Block diagram of the processing of TV and IR data on the PTC DIZON. (a) Current processing; (b) plotting of composition maps.

Figure 1 is a block diagram of the processing of the satellite images on a CM-4 class computer (NAIRI-41) and video processor SILUET [1]. The data from 2–4 channels of the advanced, very high resolution radiometer (AVHRR) digitized in the complex GAMMA-KH is recorded on a magnetic disc (MD) of the computer. Then geographical referencing of the images is implemented in a dialogue regime. Some orbital parameters satisfying the requirements of the referencing accuracy (2 pixels) are selected automatically using reference points on the land.

Using the following programme, we carry out the procedure of searching the marks of time and the beginning of the telemetric frame, as well as the computation and analysis of telemetric data. Then the image is normalized for the second channel, and the radiation temperatures T_{Ri} ($i = 3, 4$) are computed for the third and fourth channels using Plank's formula. The first line of the image contains initial data for the subsequent data processing, and the following line the preliminarily treated data of the image and the geographical coordinates for 10 points of every line. At any stage of the primary processing, the image recorder on the MD or magnetic tape (MT) can be brought to the SILUET's screen for examination, having been recorded previously in the operative image memory (OIM). The subsequent methods of processing the daily and nightly IR images differ essentially.

The daily TV and IR images are transformed into digital maps with latitudinal and longitudinal steps of 0.1°. Data from the fourth channel in the OIM are subjected to median filtration to remove the failure pixels. Afterwards, the sea radiation brightness range is determined and the image is normalized by the histogram method. Normalization consists in the following. A histogram of the T_{R4} distribution is plotted for the rectangular region of the cloudless sea surface in every image and its mode is determined. Then the corrections (differences between the average value of the mode for the composition and the modes of separate images) are determined for the images which make up a composition. They are used for the reduction of modes of all histograms to a single value. This is completed by the procedure of plotting the composition maps of the radiation temperature T_R with cloudiness filtered for any number of daily communication sessions.

During the nightly observations, we employed a method based on the recording of radiation in the third and fourth channels of the AVHRR, which permits simultaneous correction of clouds and water vapour — the basic atmospheric characteristics stipulating the accuracy of SST reconstruction.

The expression $T_s = f(T_{R_i}, \theta)$ from ref. 6, where θ is the angle of scanning, is the initial formula for calculating the radiation temperature T_s. When the water areas are observed from the main satellite track, the value θ is limited by the values $\theta_{max} \simeq \pm 20°$. Obviously, owing to such a small amplitude of the angle θ, the SST determination error conditioned by the T_s–θ relationship is low enough. Unfortunately, this is not true for the measurements made from the following or previous (edge) satellite tracks, since in the general case this error reaches 3–4 K at the scanning band edges (i.e. when $\theta \simeq 45$–$55°$). The algorithm described in ref. 6 permits its rejection.

In the case under consideration, cloudiness and aerosol haze affect the accuracy of the retrieval of the SST digital maps, especially when they are plotted as compositions with the averaging from 5 days to 1 month. Their incomplete filtration results in the appearance of 'false' SST fronts [7, 8]. To reject them in the course of processing the nightly IR images, we employed five criteria of data rejection [6]. The pixel is rejected if:

(1) $T_{R_i}(\theta) < T_{i,\text{threshold}}$, where $T_{i,\text{threshold}} = \max\{T_{i,\text{cl}}, T_{i,\max}\text{–}10°\text{C}\}$, $i = 3, 4$. Here $T_{i,\text{cl}}$ is the SST climatic threshold value typical of the given latitudinal belt and $T_{i,\max}$ is the maximum value of T_{R_i} for the current line in the i-th channel.

(2) $T_{R_i} > 305\,\text{K}$, $i = 3, 4$.

(3) $|T_{R3} - T_{R4}| > 5\,\text{K}$ or $T_{R3} - T_{R4} < -\ 0.25\,\text{K}$.

(4) $|T_{R3} - T'_{R3}| > 3\,\text{K}$, where $T'_{R3} = 1.0916T_{R4} - 25.09$.

(5) $|\Delta T_{R_i}| > 2\,\text{K}$, where ΔT_{R_i} is the difference between the radiation temperatures of the given pixel and those ambient in the i-th channel.

Table 1.
Volume of the received and processed IR data for 1989

Month	Images received			RSST maps obtained		
	Daily	Nightly	Total	Daily	Nightly	Total
May	26	24	50	12	5	17
June	44	42	86	25	8	33
July	44	48	92	34	38	72
August	28	29	57	14	17	31
September	45	50	95	32	31	63
Total	187	193	380	117	99	216

As compared with ref. 6, where the threshold values in criteria (2)–(5) were assigned on the basis of measurements made in the Atlantic Ocean, they were selected by us in (1) and (5) in view of the SST variability range in the Black Sea and Mediterranean Sea. In this case, the determination accuracy was estimated using separate ship's measurements and appeared to be equal to 0.7–1.0 K. The amount of output data was about 50% of the total number of nightly IR measurements. In view of this, we note that the RMS error of the T_s reconstruction may reach 0.2–0.3 K owing to the more rigid conditions of the data rejection; however, the amount of data obtained by this method will not be more than 20–25% of the total data received [6].

After the rejection of cloudiness and the geographical referencing, the nightly and daily IR images are transformed into digital T_s maps, with spacing of 0.1°, and filtered. After plotting the $\overline{T}_s$ compositions using any amount of initial data and their recording on MT, they were fed into a photorecorder (PR) to obtain quality negatives and positives.

ANALYSIS OF MEASUREMENTS

In total, 380 images of the Black Sea and Mediterranean Sea (from them 187 daily and 193 nightly, respectively) were received in the APT regime at the ADRS of MHI UkSSR AS from May to September 1989. And 117 and 99 images, respectively, were processed to digital maps (Table 1). As a result, 11 and 12 composition (10-day) digital T_s maps for the Black Sea and Mediterranean Sea, respectively, were obtained during these communication sessions. Also, six 10-day compositions of T_R for both seas were obtained in July (the data set for this month was the most supported statistically).

Figures 2 and 3 show typical compositions of the T_R and T_s spatial distributions. Comparison of these figures indicates a significant difference between the radiation temperatures as to their values and spatial structure. The difference $\Delta\overline{T}_{SR} = \overline{T}_S - \overline{T}_R$ amounts to approximately 3–4 K for the entire temperature range of the sea. For example, the regression equation calculated from the 10-day digital maps for the Mediterranean Sea has the following form for July: $T_s = 1.01T_R + 3.56$.

A detailed analysis of the considerable shift of T_s with respect to T_R is beyond the scope of this paper. However, we can give three or four reasons which stipulate it.

The evolution of the daily thermocline influences significantly the difference between the fields of T_R and T_s. Indeed, the results of theoretical and field research indicate (see, for example, ref. 9 and refs cited therein) that under the conditions of intense insolation and lacking wind mixing, the average value of the daily heating of the upper levels of the sea is 2–3°C, and sometimes it can reach 5–10°C [10]. In view of the fact that the daily thermocline is the most developed by 16.00–17.00 LT (local time) and completely vanishes in the early morning, the SST measurements made in various communication sessions with the satellite must have a considerable data scattering. The latter is supported practically especially in summer.

In addition to the diurnal thermocline, a skin layer with a day temperature lower than that of the deeper layers by approximately 0.3–0.5 K produces a diverse effect on the behaviour of the T_R, T_s fields [11]. As is known, the skin layer almost vanishes at night; therefore, the day single-channel measurements of T_R must also be corrected properly if the processing is aimed at SST reconstruction.

In the end, if T_s is calculated by the above procedure, we take into consideration the radiation temperature value $T_{3.7}$ associated with the water vapour concentration in the atmosphere. According to our estimates, the difference $T_{3.7} - T_{10.8}$ is approximately 0.5–0.8 K for observations close to the nadir angles θ, and it increases when moving off the image centre. This is supported by the results of independent measurements [12].

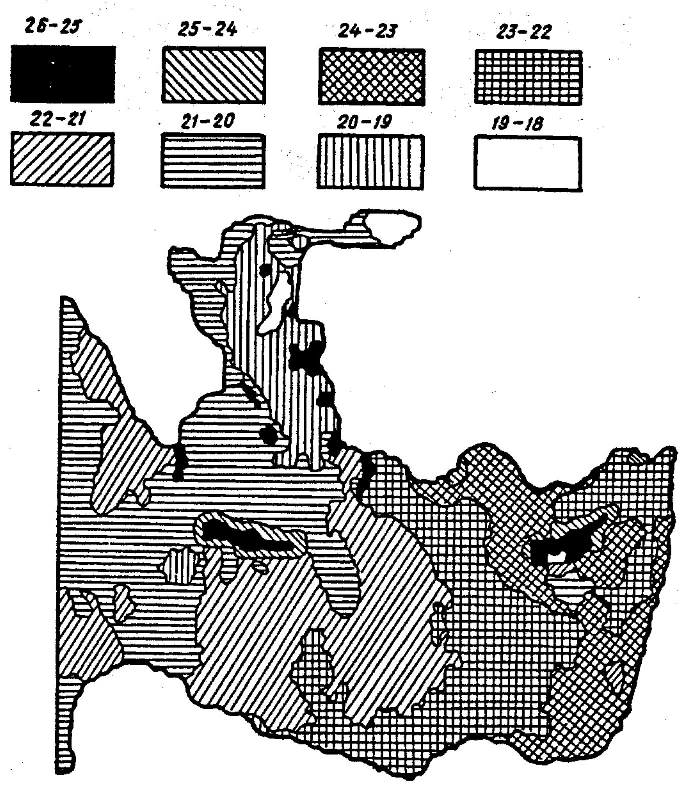

Figure 2. Radiation temperature in the eastern Mediterranean Sea $\overline{T}_R$ (derived from measurements in the range of 10.8 μm) with the data averaged for July.

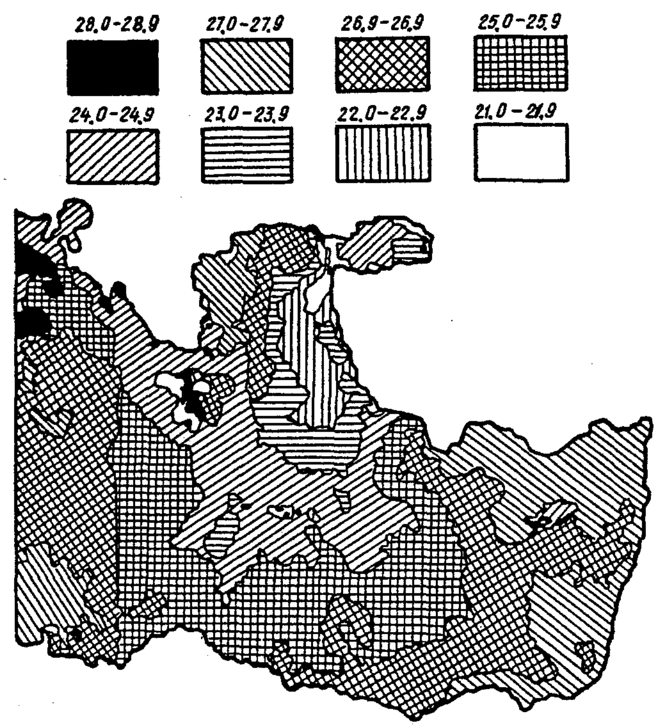

Figure 3. Radiation temperature in the eastern Mediterranean Sea $\overline{T}_S$ (derived from measurements in the range of 3.7 and 10.8 μm) with the data averaged for July.

Unfortunately, it is practically impossible to allow for all the components of ΔT_{SR} with different signs. However, in the general case ΔT_{SR} is equal to at least 3–4 K. Thus, SST reconstruction by the histogram method from daily single-channel IR measurements from the NOAA satellite entails considerable errors. However, it should be recognized that this very method is the most widespread in practice [13]. The procedure of mass treating IR data using a spectral-angular method allows us to obtain not only qualitative, but also quantitative data on the surface temperature field variability in vast oceanic basins with acceptable accuracy.

Table 2 shows the extreme values of the radiation temperatures of the Black Sea and Mediterranean Sea estimated for different regions of the basins using the results of processing 99 nightly IR images averaged over separate 10-day periods (columns 1–3). Column 4 indicates the averaged values for the entire month. As one can see, the differences of the RSSTs are rather significant. They are associated with significant features in the dynamic and thermal state of the areas under investigation. An analysis of these features represents an independent problem and is not treated in this paper.

Table 2.
Minimum and maximum radiation temperatures (K) of the sea basins (1989)

Sea	May				June				July				August				September			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Black Sea	—	—	15.3/20.1	—	—	15.9/23.1	19.8/25.3	17.2/24.8	21.5/26.8	22.0/26.5	20.3/25.5	21.7/26.0	21.8/25.9	—	22.5/28.2	22.4/27.6	22.3/27.1	17.8/24.4	18.3/24.4	18.4/25.4
Levantine Sea	—	—	19.8/26.4	—	20.8/26.6	20.8/26.2	22.7/28.1	21.7/27.6	23.7/28.6	23.9/29.2	23.3/29.4	23.8/29.0	24.0/29.5	—	25.5/30.0	24.6/29.8	23.5/29.6	22.8/29.0	23.5/28.5	23.4/29.3
Aegean Sea	—	—	17.5/21.2	—	18.8/22.2	19.2/22.4	21.1/25.3	20.0/23.9	22.1/26.3	21.8/26.5	20.8/26.4	21.6/26.6	21.5/26.4	—	21.3/27.6	21.4/37.1	23.0/26.6	22.3/25.9	20.3/26.5	21.0/25.8

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