ISSN 1028-334X, Doklady Earth Sciences, 2007, Vol. 415, No. 5, pp. 769–772. © Pleiades Publishing, Ltd., 2007.
Original Russian Text © A.G. Grankov, A.A. Mil'shin, S.K. Gulev, 2007, published in Doklady Akademii Nauk, 2007, Vol. 414, No. 6, pp. 824–827.

OCEANOLOGY

Analysis of the Role of the Ocean and the Atmosphere in Their Thermal Interaction Based on Satellite and Research Vessel Data in the Newfoundland Zone, North Atlantic

A. G. Grankov[a], A. A. Mil'shin[a], and S. K. Gulev[b]

Presented by Academician Yu.V. Gulyaev June 28, 2006

Received June 28, 2006

DOI: 10.1134/S1028334X07050248

Results of the analysis of the processes in the ocean–atmosphere system (OAS) are presented. In our opinion, these processes trigger perturbations in the thermal balance of the system and simultaneously influence directly the intensity of natural microwave (MCW) radiation (brightness temperature) measured from satellites.

This work is based on the data of onboard measurements during the ATLANTEX-90 experiment carried out at the final stage of the RAZREZY Program in the Newfoundland energetically active zone (EAZ) of the North Atlantic. This ocean region has a notable influence on the weather conditions and climatic trends in Europe and the European territory of Russia.

We consider the value of leading (in time) of a certain parameter (relative to variations in other parameters) as the quantitative criterion of primarity (priority) of this parameter in the OAS; i.e., we consider this parameter as the source of thermal perturbations in the system and the behavior of other parameters as the response to the influence of various sources.

Idea about time shift between thermal processes in the ocean and atmosphere was the starting point for us, specialists in remote sensing and oceanology. This indicator is most reliable for satellite MCW radiometric means as compared to measurements of the intensity of natural radiothermal radiation of the OAS (radiobrightness temperature) because the results of the remote measurements and their interpretation are very sensitive to the accuracy of satellite measurements.

We apply this approach here in a narrow sense when the scopes of influence of the thermal perturbation sources in the OAS are considered in local regions of the ocean confined, for example, to the coordinates of the location of research vessels. The data of measurements at these points can be compared either with the results of modeling the brightness temperature of the system based on results of onboard (oceanographic, meteorological, and aerological) observations or with the data of satellite measurements.

The problem of primarity of the role of the ocean (or atmosphere) in their interaction at spatiotemporal scales has been an important object of research for a long time for specialists working in the field of oceanic and atmospheric physics [1–4]. This problem is difficult in itself. However, it is even more difficult to apply the satellite data for the analysis of the contribution of different components of thermal and dynamical interaction in the OAS because the intensity of the natural radiothermal (infrared) radiation of the Earth's surface measured by satellite radiometers in the UHF and IR ranges, respectively, is only an indirect characteristic of thermal processes at the OAS interface. The data of satellite measurements can be used most effectively for the solution of this problem if they are related to oceanic EAZs, which have been studied well from research vessels during recent decades. For example, well-known North Atlantic regions, such as the Newfoundland, Norwegian–Greenland, and Gulf Stream zones located on the pathway of the Gulf Stream and North Atlantic currents, can be used as test sites for investigation of thermal process using MCW radiometric methods because they show significant contrasts of natural thermal and radiothermal characteristics of the OAS.

[a] *Institute of Radio Engineering and Electronics, Russian Academy of Sciences, pl. Vvedenskogo 1, Fryazino, Moscow oblast, 141120 Russia; e-mail: agrankov@inbox.ru*

[b] *Shirshov Institute of Oceanology, Russian Academy of Sciences, Nakhimovskii pr. 36, Moscow, 117897 Russia*

Table 1. Discrepancy of approximation of total heat fluxes as a function of the brightness temperature of the OAS in the 5.6 mm–3.2 cm wavelength range for different radiation models

Wave-length, cm	Discrepancy, $W \cdot m^{-2}$				
	d	$d\,T_s$	$d\,V$	$d\,T_A$	$d\,Q$
0.59	27.8	27.8	28.2	48.5	27.8
0.8	26.6	26.8	27.3	27.0	37.8
1.35	27.0	27.2	28.4	27.5	35.9
1.6	26.1	26.3	27.8	26.5	35.9
3.2	34.2	34.2	30.2	34.3	39.4

Intense horizontal motions in the atmospheric boundary layer (ABL) in these zones during the cyclonic activity sharply and, which is more important, simultaneously (at almost all horizons) change the thermal properties and change the heat balance between the ocean surface and the atmosphere. Thus, they serve as the sources of perturbation (generation) of vertical turbulent thermal fluxes at the OAS interface [5]. At the same time, this leads to the variations in the temperature and humidity characteristics of the ABL (1000–1500 m), because the field of the natural OAS radiation is formed precisely in this layer. This is the explanation for the direct correlation frequently observed in different experiments between characteristics of the MCW radiation of the OAS (brightness temperature) and thermal fluxes at the OAS interface.

The main results were obtained on the basis of oceanographic, meteorological, and aerological measurements from research vessels *Victor Bugaev*, *Musson*, and *Volna* in April 1990 in the region of the Newfoundland EAZ within the framework of the ATLANTEX-90 experiment. From among the entire set of archival data accumulated during the period of onboard observations, we used the data of the stationary phase of the experiment (April 1990), which differed from other stages by the highest regularity in measurements and the possibility to study the temporal dynamics of the oceanic and atmospheric parameters owing to the stable location of the research vessels in the specific regions of the ocean.

During this period, the research vessels carried out observations in the Gulf Stream delta and in the eastern branch of the Labrador Current characterized by strong synoptic variability of the oceanic and atmospheric parameters [3, 4]. Data of onboard measurements served as the basis for the calculation of the brightness temperature of the natural OAS radiation in the centimeter and millimeter MCW ranges commonly used in the satellite measurements. We also investigated correlation of the brightness temperature with synoptic variations of the vertical turbulent fluxes of the total (sensible and latent) heat and impulse (momentum) at the ocean–atmosphere boundary. We can definitely rely on the results of calculations because they are based not only on measurements of the boundary values of OAS parameters but also on detailed information about the vertical distribution of the atmospheric parameters in the layers characterized by the formation of the natural MCW radiation of the OAS system.

Let us determine the role of different OAS parameters in the formation of the correlation between the characteristics of the natural MCW radiation of the system and intensity of heat and moisture exchange between the ocean and atmosphere in the synoptic time-scale range characterized by the maximal interaction energy. Therefore, let us approximate the daily mean fluxes of the total heat q_{he} during the stationary phase of the ATLANTEX-90 experiment with their estimates as linear combinations of the OAS brightness temperature T^b in different spectral intervals calculated on the basis of onboard measurements of the ocean surface temperature T_s, wind velocity V, temperature of near-water air T_a, and total humidity of the atmosphere Q. We shall apply the method of sequential omission (neutralization) of one OAS parameter or another for elucidation of its contribution to processes of both heat exchange and radiation. The discrepancy d between the research vessel and satellite estimates of the thermal fluxes (Table 1) will serve as the quantitative criteria of each contribution. Detailed information about the onboard measurements during this period is given in [4]. Let us only note that parameters determining the intensity of heat and moisture exchange in the ocean surface–atmosphere system were measured with a time interval of 1 h, while aerological soundings of the atmosphere (important for correct calculations of the OAS brightness temperature) were accomplished with a frequency of 6 h. The results obtained (Table 1) demonstrate the important role of the atmospheric parameters (first of all, parameters T_a and Q) in the formation of the correlation between the intensity of heat and moisture exchange and natural MCW radiation of the OAS system in the synoptic time-scale range. This is most prominent in the resonance absorption range of molecular oxygen (~5 mm) and the water vapor line of the atmosphere (1.35 cm). This conclusion is also confirmed by the results of investigation of the correlation between the OAS brightness temperature (T^b) at wavelengths of 5.9 mm and 1.35 cm with the heat content (enthalpy) of the ABL equal to J_1000 in the 1000-m layer and by the fluxes of the total heat q_{he} at the location of research vessels *Victor Bugaev*, *Musson*, and *Volna* in April 8–13 in the Newfoundland EAZ. Figure 1 presents an example for the vessels *Victor Bugaev* (1a) and *Musson* (1b).

One can see a time lag of a few hours (part of the day) in the response of the total heat flux at the ABL boundary (and brightness temperature of the OAS) to variations in the ABL enthalpy. This is exactly the inertia of the thermal process in the atmospheric layer due to the horizontal motion of heat fluxes in the atmosphere, which form the vertical heat and electromag-

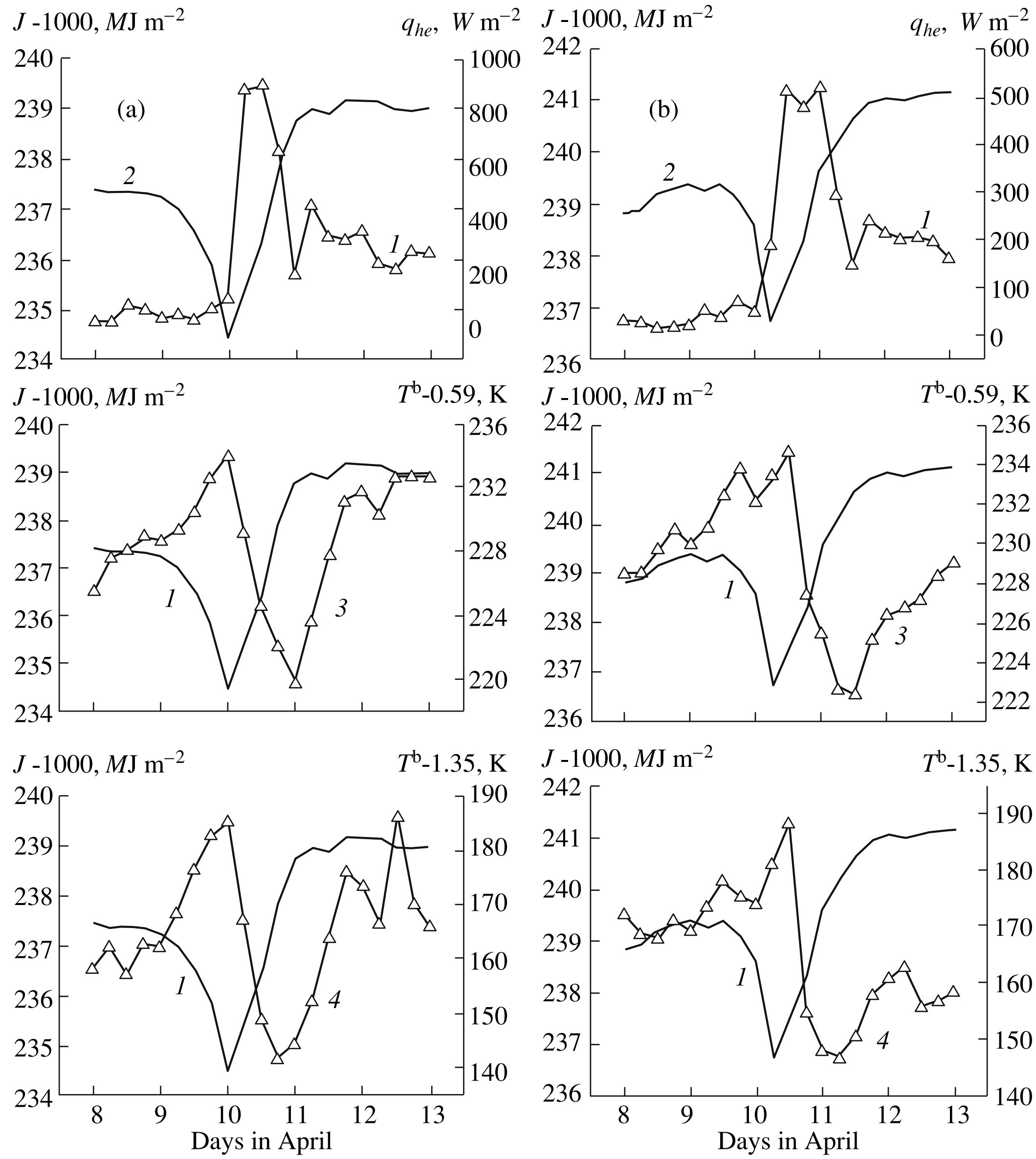

Fig. 1. Analysis of (*2*) responses of the total heat flux q_{he} at the OAS boundary to (*1*) variations in enthalpy of the atmospheric boundary layer J_1000 and brightness temperature at wavelengths (3) 5.9 mm T^b_5.9 and (4) 1.35 cm T^b_1.35. (a) R/V *Victor Bugaev*; (b) R/V *Musson*.

netic fluxes of energy observed at mid-latitudes of the North Atlantic.

Let us estimate more strictly the time shift between estimates of the brightness temperature T^b in the spectral ranges of 5.9 mm and 1.35 cm based on oceanographic, meteorological, and aerological measurements and estimates of heat fluxes q_{he} obtained on research vessels *Victor Bugaev* and *Musson* in the ATLANTEX-90 experiment during the propagation of a powerful mid-latitude cyclone on April 8–13, 1990. Theoretically, this dependence is described by the Duhamel equation (variation of the classic Volterra equation of the first kind of convolution type):

$$T^{Я}(t) = \int_0^t q(\tau)r(t-\tau)d\tau.$$

Here, we shall present some estimates [6] of the degree of the conservative property of the ABL, i.e., the time lag in the response of the OAS brightness temperature to the perturbations of its thermal properties in the synoptic time-scale range at the location of research vessels *Victor Bugaev* and *Musson*, that is, the response function $r(t)$ from this equation (Fig. 2).

An important result of this analysis is confirmation of the fact found in [5] that the response of the bright-

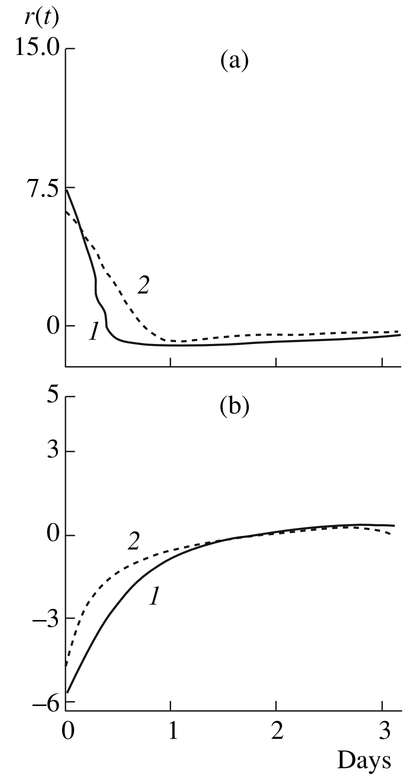

Fig. 2. Function of the response of brightness temperature of the OSA $r(t)$ to total heat fluxes q_{he} measured from research vessels (a) *Victor Bugaev* and (b) *Musson*. The dimension of r is K (W m^{-2} day)$^{-1}$. Wavelength (cm): (*1*) 1.35, (*2*) 0.59.

ness temperature has a lag of 12–18 h with respect to the variations in the thermal fluxes in the regions of mid-latitude cyclone propagation.

The role of the lag in the response of the OAS brightness temperature to the variations in the thermal fluxes is also illustrated by the results of regression analysis between the time series of parameters T^b at wavelengths 0.59 and 1.35 cm and parameter q_{he} for R/V *Musson*, i.e., the correlation coefficients between these parameters and the discrepancy (root-mean-square difference) d between them (Table 2).

Table 2. Influence of time shift Δt between time series of brightness temperature of the OAS at the wavelengths 0.59 cm and 1.35 cm and thermal fluxes on correlation R and discrepancy d (R/V *Musson*)

Wave-length, cm	$\Delta t = 0$		$\Delta t = 6$ h		$\Delta t = 12$ h		$\Delta t = 18$ h	
	R	d, W · m^{-2}	R	d, W · m^{-2}	R	d, W · m^{-2}	R	d, W · m^{-2}
0.59	0.25	160	0.67	124	0.86	85	0.84	98.7
1.35	0.34	157	0.74	113	0.85	93	0.71	127.3

Thus, we can make the following conclusions.

(1) Lags in the response of the OAS brightness temperature to the variations in the thermal fluxes in the system caused by the horizontal atmospheric motions in the Newfoundland EAZ of the North Atlantic testify to the important role of the atmosphere in the interaction with the oceanic surface (as a physical substance) and of the atmospheric brightness temperature (as a quantitative indicator of this interaction).

(2) Even an insignificant (by 1–2 h) shift in the comparison of time series of parameters T^b and q_{he} can distort the results of the analysis of their correlation at synoptic scales. Therefore, this factor must be taken into account for the validation of satellite MCW radiometric estimates of heat fluxes based on the research vessel data.

REFERENCES

1. T. P. Barnett, Role of Oceans in the Global Climatic System, in *Climatic Change*, Ed. by J. Gribbin (Cambridge Univ. Press, Cambridge, 1978; Gidrometeoizdat, Leningrad, 1980), pp. 209–237.
2. G. I. Marchuk, V. P. Dymnikov, G. P. Kurbatkin, and A. S. Sarkisyan, The Role of Ocean in Short-Period Climate Fluctuations and the Razrezy Program, in *Progress in Science and Technology. Atmosphere, Ocean, and Space: The RAZREZY Program* (VINITI, Moscow, 1986), Vol. 6, pp. 6–29 [in Russian].
3. S. S. Lappo, S. K. Gulev, and A. E. Rozhdestvenskii, *Large-Scale Thermal Interaction in the Ocean–Atmosphere System and Energetically Active Zones of the World Ocean* (Gidrometeoizdat, Leningrad, 1990) [in Russian].
4. S. K. Gulev, A. V. Kolinko, and S. S. Lappo, *Synoptic Interaction between the Ocean and Atmosphere at Mid-Latitudes* (Gidrometeoizdat, St. Petersburg, 1994) [in Russian].
5. A. G. Grankov, and A. A. Mil'shin, *Interaction between Radio Radiation of the Ocean–Atmosphere System and Dynamic Processes at their Boundary* (Fizmatlit, Moscow, 2004) [in Russian].
6. A. G. Grankov, A. A. Mil'shin, and V. Yu. Soldatov, *Analysis of Radio Brightness Response of the Ocean–Atmosphere System to Variations in the Surface Thermal Fluxes*, *Proc. Int. Symposium on Engineering Ecology, Moscow, 2005* (Moscow, 2005), pp. 27–31 [in Russian].