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The informational and methodical support of the aerospace monitoring of a sea shelf for the detection of anomalies over hydrocarbon deposits

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The article describes the informational and methodological support of the aerospace monitoring of a sea shelf for revealing the temperature and optical anomalies over the deposits of hydrocarbons. The geology-geophysical and hydrophysical factors, as the most important ones, affecting the efficiency of the searching for hydrocarbon deposits are considered. It is established that, between the hydrophysical and hydrodynamic processes in near-surface water layers on the boundary between water and atmosphere, dynamical processes in a fluid, geological structure of the lithosphere, and underwater landscapes, there is an interconnection that should be taken into account, when detecting the hydrocarbon deposit, by using the remote sensing.

Keywords: *informational and methodological support, aerospace monitoring, hydrocarbon deposits, sea shelf.*

The water surface for the aerospace monitoring is a natural information integrator that enables one to detect processes occurring not only on the sea surface, but also in the water column and near the bottom. Information about the temperature of the surface layer of the ocean is given by infrared thermal radiation, the intensity of which is associated with the usual (thermodynamic) temperature of the well-known Stefan–Boltzmann law. At shallow depths under conditions of low pollution, the relief of the bottom can be observed visually. On aerospace images in the visible range, it is reflected as optical anomalies.

According to the generally accepted definition, the anomaly is a deviation of the value of a specific sea surface parameter in a certain period (for example, for a day, a week, a month, a season) from its average value for the same period. Anomalies can be calculated by comparing the values of the parameters of the sea surface images at the same points measured at the given time with the calculated mean values of the parameter, for example, for the same period of the year through several years. The following anomalies are distinguished among the natural ones: anomalies due to the local rise of cold deep water, heat exchange and mixing, and anomalies caused by currents, meanders along the currents and vortices.

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The purpose of the work is to show the peculiarities of the formation of temperature and optical anomalies over the deposits of hydrocarbons in the sea shelf and to determine their informative features and methods of decoding of the aerospace images.

The analysis of the process of creation of the anomalies of various origin over the deposits of hydrocarbons has shown that the most important factors in this case are: geological and geophysical, hydro-hydrophysical, hydrometeorological, hydrobiological, and others [1]. Due to the limited volume of the article, only two first factors will be considered.

As was noted, many factors influence the informative signs of the presence of oil and gas on the sea shelf. The most important geological and geophysical features are neotectonics and geofluid dynamics, under the influence of which anomalies are formed over the deposits of hydrocarbons with the corresponding parameters.

Geofluid dynamic structures of the lithosphere are subdivided by the morphogenetic features and the nature of the manifestation of geodynamic processes into the following types: linear, isometric or ring-like, dissipation zones (newest fractures), discontinuous disturbances, and geodynamic nodes.

The problem of the physical nature of fluid-conducting structures at the present time is rather complex and ambiguous. Under the latter, the linear roughening zones of rocks, which are detected by remote sensing methods in the form of linear domains and nodes of their intersection, are considered. The movement of reservoir and deep fluids, which have a discrete or porous mode, in the zone of a geodynamic node is associated with a change in the pressure both in the fluid-conducting structure and in adjacent zones. Many different structures are preserved in a pristine form on underwater landscapes, which contributes to the more complete expression of geodynamic nodes in the modern underwater landscapes and their in-depth study using aerospace methods [2].

Gas sources on the sea bottom are caused by a considerable dissipation and a high fluid conductivity of rocks, vertical migration processes of reservoir and deep, both gaseous and liquid fluids, and cause temperature anomalies on the sea surface. The parameters of gas “torches” depend on the geofluid dynamic structure, pressure, volume, and composition of migrating gases. The high density of gas sources is typical of most of the Black Sea, which can be considered as a result of the active degassing of the subsoil of the region due to the expansion of the lithosphere as a result of the mantle diapirism and the processes of expansion of the planet at the present stage [3].

The analysis of the location of gas torches on the seabed with the snapping of the latter to the corresponding remotely sensed images gives possibility to determine that they are confined to the cells with high density of lineaments and cause thermal anomalies on the sea surface, which indicate the presence of geofluid dynamic processes in the lithosphere within fractured zones, their nodes, and hydrocarbon deposits.

Thus, under shallow conditions, the neotectonic active structure associated with the Schmidt field (Fig. 1) is clearly manifested in the relief of the seabed, in which a lighter photo tone corresponds to a section in the relief located above the Schmidt deposit. This is the neotectonic factor of the formation of an optical anomaly on the aerospace image of the sea surface through the thickness of water shining light bridges of the relief.

Neotectonic movements are the factor of the formation of deposits at the latest stage and determine the degree of disclosure of bursting violations. The general role of neotectonic move-

ments in the formation and placement of hydrocarbon deposits will be formulated as follows [4]:

the formation of an abnormal structure of the modern relief over the neotectonic active deep structure, which became the stage of possible intensive penetration of hydrocarbons from the subsoil depths and their propagating up to the cut;

the formation of hydrocarbons is assumed during periods of abrupt changes in the compression under conditions of stretching (general uplift);

recognition of the promise of all tectonic structures, regardless of the time of their formation;

hydrocarbon reservoirs are determined not only by the size of the traps and the collector properties of the enclosing rocks, but also by the quality of the tires and the difference between the receipt and release of hydrocarbons from the deposit;

the most favorable for the vertical migration are the areas of the crust that rise in the neotectonic stage.

The physical basis for the formation of geo-indications of underwater landscapes is the transfer of information about the intensity of the stress-strain state of the lithosphere and fluid-geodynamic processes passing from the depths to the Earth's surface.

Direct and indirect geoindication signs of underwater landscapes are distinguished. Direct signs are related to the physiognomic features of the underwater landscapes, which shine through the water layer everywhere. These signs of sufficient transparency of water make it possible to identify underwater shafts, sand spits, terraces, buried rivers, as well as the shape, color, and size of underwater objects.

Indirect geoindication signs associated with hydrodynamic processes occurring in the water column and on the surface of the sea, where the hydro-hydrophysical factor plays a major role.

The passage of a migratory flow of hydrocarbon fluids through the water layer and their interaction with the water surface is due to hydrological and hydro physical processes, which depend on many factors. Releasing through the fracture structures of the lithosphere of the shelf zone into the water column, hydrocarbon gases form, depending on the hydrology, bubbles, and internal waves. Figure 2 schematically presents the thermal structure of the upper layer of the sea surface, which includes: the skin layer, upper semihomogeneous layer, and daytime thermocline (according to E.A. Akimov, etc.). The existence or absence of one or another component of the upper layer of the ocean depends largely on the conditions on the surface [5].

The interest in studying the hydrodynamics of the temperature of the sea surface and its distribution in the surface layer of water is due to two factors. First, in the mechanism of energy-mass transfer between atmosphere and ocean, the spatial temperature distribution is important. Its study is necessary in the simulation of large-scale processes in climate models, which is essential for forecasting a weather and assessing a long-term climate change. In the other case, the interest in the hydrodynamics of the surface layer of water can be used as one of the informative features in the search for deposits of hydrocarbons in the shelf zone.

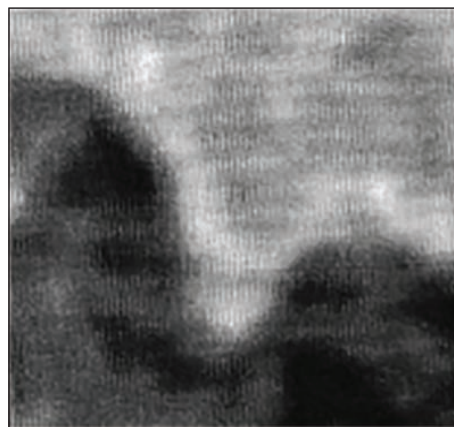


Fig. 1. Fragment of the satellite image of the optical anomaly over the "Schmidt" field

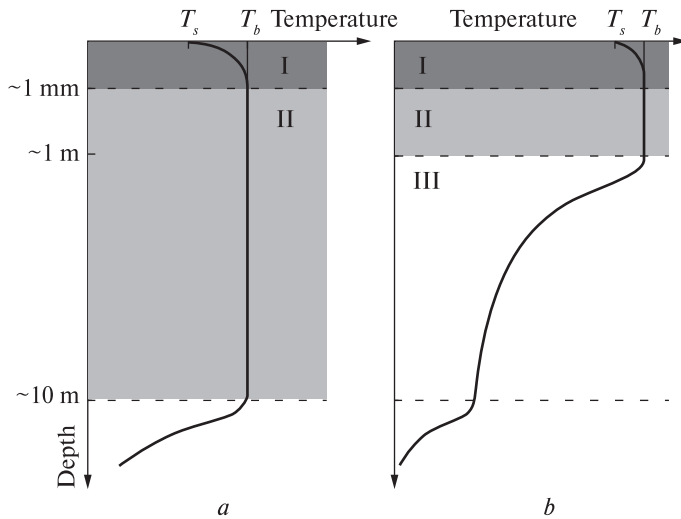


Fig. 2. Idealized temperature profile for night time in winter during strong wind (a) and for daytime in summer during a weak wind (b): I – skin-layer, II – upper bound of the semi homogeneous layer, III – daytime thermocline; T_s – temperature of the skin-layer, T_b – temperature of the upper bound of the semihomogeneous layer

lished that the specific boundary layer is formed in the surface layer in a few millimeters and a temperature gradient of several degrees. This hydrophysical formation was called the skin layer. The thickness of this boundary layer and the temperature difference between its boundaries mainly depend on the local conditions that determine the flow of heat through the water-atmosphere boundary and the characteristics of turbulence in the upper layer of the sea.

With the advent of clouds, the initial stationary state of the cold laminar layer, which was balanced by a heat flux, is violated. Effective radiation is reduced, which causes an increase in the temperature of the skin layer and an increase in the evaporation, which is accompanied by the return of heat to the atmosphere. The latter is compensated by the flow of heat from a homogeneous layer into the cold sublayer until a new semistationary state occurs due to the absence of direct solar radiation. After passing the cloud, the temperature of the skin-layer remains somewhat higher than its initial state till the complete disappearance of clouds, when the thermal parameters of the skin-layer begin to asymptotically approach their initial values. Thus, with the advent of clouds, an increase in the temperature of the water surface was detected and substantiated.

The cold film is stored at wind speeds of up to 10 m / s, and the time of recovery of the skin layer depends on many external factors. After its destruction as a result of the decay of waves and other factors, the recovery time of the film can be tens of seconds. Therefore, one can assume that the existence of a cold skin layer phenomenon is fairly stable.

In most cases, the surface temperature is less than the temperature below the lying water layers, which initially increases with depth, and then begins to fall monotonically to the temperature of the deep horizons. The reason for this phenomenon, with the rare exception, is that the water surface gives heat to the atmosphere by radiation and turbulent heat transfer. To fulfill the condition of heat balance, it is necessary to compensate for these losses of the flow to the surface from the lower layers of water. In addition, the surface layer is influenced by the convective flows occurring therein, turbulence, internal and surface waves, hydrology, wind pressure, evaporation, precipitation, cloudiness, flow, and surface-active substances. As a result, the unstable stratification occurs in the surface layer, which can lead to convective movements, and the upper layers of water fail to penetrate deep into the liquid, forming cold flames. The process of formation of such cold flames is periodic.

The first experiments on remote studies of the processes occurring in a layer between the sea and the atmosphere were carried out by Mac Alister using a radiometer developed by himself [6]. Experimentally, it was estab-

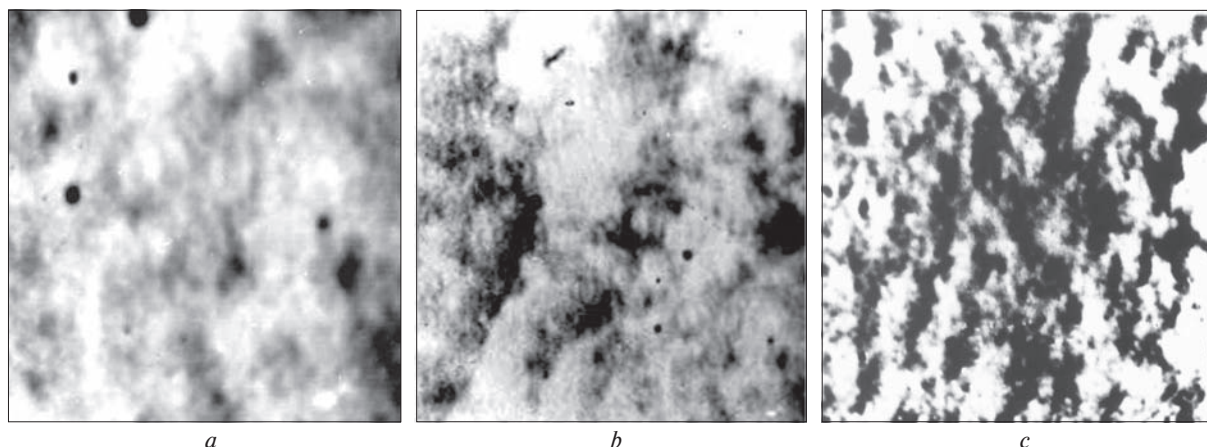


Fig. 3. Examples of different states of the marine environment on the deep horizons: isotherm or weakly stratified (a), stratified (b), thermocline (c)

The microconvection process in the near-surface layer several minutes in duration can be seen on the images of shaded pictures of a vertical section. Wherein, water cooled by evaporation and radiation, which is more severe, collapses (in the form of dark bands) downward, forming a thin, superficial film. The reason for this phenomenon, with the rare exception, is that the water surface gives heat to the atmosphere through the radiant and turbulent heat transfer. A flow that compensates these losses must be present on the surface of the lower water layers to fulfill the condition of the heat balance [7].

Shadowing photographs of the marine environment located in different hydrological conditions are in Fig. 3. Photographing was carried out with the help of the Tepler camera on the 100-m depth.

Lifting bubbles to the free water surface can be accompanied by the airlift process (lifting cold deep water to the sea surface), when hydrology is close to isotherm (see Fig. 3, a). In the second case, the flux of hydrocarbon fluids causes fluctuations in the density, forms internal waves distributed from the perturbation region to the free water surface in the case of the presence of density gradients in a stratified water column (see Fig. 3, b) and hydrology with a pronounced thermocline (Fig. 3, c). The frequency of these waves is known as the Brunt–Väisälä frequency, and the magnitude inversed to it (wave period) is a fundamental time scale that causes oscillatory motions in a stratified aquatic environment. As a result, internal waves interacting with the water surface cause changes in the hydrophysical characteristics of the near-surface water layer.

The Black Sea thermocline is at 10–15 m depth in the summer-autumn period. The thermocline water volume shifted upward or downward will be affected by forces acting in the direction inversed to a displacement. Therefore, the perturbation arisen in thermocline generates density and temperature fluctuations that spread from the region of perturbation. The convergence and divergence processes caused by internal waves influence the distribution of surface-active substances, oils, and organic liquid films, which are always present on the ocean surface, and result in the formation of specific “bands” that can be seen from air or from outer space [8].

Figures 2 and 3 show the different structures of the water environment at different depths, including the surface and the thermocline. They depend on hydrological conditions, tempera-



Fig. 4. Temperature anomaly over the “Golitsyn” field

is water vapor above the water surface usually, which, under the influence of external factors, is not in a state of thermodynamic equilibrium with water. As a result, phase transitions occur on the boundary of the water-vapor section. The mathematical model of the non-equilibrium thermal structure of the boundary of the water-atmosphere separation is based on the assumption that the surface of the water-vapor partition is: for $z > 0$, vapor, for $z < 0$, water (Z is the depth). There is external radiation from the vapor side — I_0 . Water and vapor are assumed to be absorbing media, while scattering is not considered. The transfer of radiant energy in a vapor and a liquid with some refinement is described by means of the Bouguer law.

Figure 4 shows a fragment of the space image (NOAA, Channel 4 (10.3–11.3 μm) of the temperature anomaly above the Golitsyn hydrocarbon deposit (according to O. Y. Kotlyar). As we can see, cold (black spots) and warm (bright spots) anomalies are present on the water surface. Therefore, we can assume that there are two surface temperature anomaly formation processes: bubbles and internal waves.

Analysis of changes in the structure and texture of the surface layer of water under the influence of hydrocarbon deposits, which is one of the important methods in the analysis and classification of images of anomalies over hydrocarbon deposits now, is an important step in understanding

ture changes, salinity, underwater currents, internal waves, etc.

Hydrophysical processes occurring in the near-surface layer of water and forming its hydrothermodynamic regime are quite complicated. First, this is due to the receipts of solar radiation and the proper radiation of the atmosphere and the water into the aquatic environment across the boundary of the atmosphere-water. In turn, hydrodynamic deep processes (HDPs) risen by hydrocarbon fluids create internal waves and change the hydrophysical characteristics of the surface layer of water, which are reflected on the surface of the sea as temperature changes, temperature anomalies, and in the near-surface layer as a change in the gradient temperature.

There is no sharp boundary between the water surface and the atmosphere under real conditions. There

Haralick’s parameters values over the “Schmidt” and “Golitsyn” field

Haralick’s parameters	“Schmidt” field		“Golitsyn” field	
	Anomaly	Background	Anomaly	Background
Contrast	11.33	1.55	4.88	0.01
Sum Variance	8.1	0.8	2.88	0.37
Sum Entropy	0.12	0.08	4.24	0.41
Entropy	13.9	5.0	5.18	0.42
Difference Entropy	0.7	0.5	1.93	0.08

and describing the space images of water objects. They significantly outperform morphological features by simplicity and compactness of descriptions, and they can be compared with moment invariants or stochastic invariants. These features are based on the notion of texture — the most important characteristic of visual models of images. The texture is represented by the estimates of the statistics of energy and space-energy distributions (so-called amplitude and amplitude-phase characteristics), the estimates of autocorrelation and interrelationship functions (correlation signs), spectra of spatial frequencies (spectral signs), or local geometric and energy Rhone parameters. The most commonly used methods of space research are the following texture methods: linear orthogonal transformations (Fourier, Hadamar, Haar et al.), autocorrelation transformations, histogram transformations, and transformations into adjacency matrices.

This paper describes the texture characteristics of anomalies images over hydrocarbon deposits and the background of a free sea surface using the set of Haralick's parameters [9]. The Tables show values of Haralick's parameters for the optical anomaly over the hydrocarbon deposit "Schmidt" and the temperature anomaly and background over the "Golitsyn" hydrocarbon deposit [10]. The following assumptions can be made based on these data: both for the optical anomaly of the "Schmidt" hydrocarbon deposit and for the temperature anomaly over the "Golitsyn" hydrocarbon deposit, Haralick's parameters have the maximum values in relation to the optical and temperature background of the sea surface.

In this regard, it is proposed to use changes in the texture of temperature and optical anomalies of the near-surface water layer under the influence of hydrocarbon deposits in relation to the surrounding background as an additional informative feature in order to increase the effectiveness of the aerospace monitoring of the sea shelf to detect anomalies over the deposits of hydrocarbons. The proposed method is implemented by the following sequence of actions:

1. Create the database of aerospace images in the infrared range of the sea area with sites, which have the confirmed presence of hydrocarbons deposits.
2. Calculate Haralick's parameters for the reference sites at the sea surface.
3. Calculate Haralick's parameter values for the background temperature distributions at the sea surface.
4. Calculate the Haralick's parameters for the studied areas — K_i .
5. Calculate the averaged values of Haralick's parameters for the reference sites.
6. Calculate the averaged values of Haralick's parameters for the background temperature distribution.
7. Calculate the relation of Haralick's parameters for each studied area to the averaged values of Haralick's parameters of background distributions of the sea temperature.
8. Calculate the ratios of the averaged values of Haralick's parameters of the reference areas to the averaged values of Haralick's parameters of background distributions of the sea surface temperature K_e .
9. Determine threshold value — K_{en} .
10. Perform the comparison of the relations between K_i and K_{en} .

If the value of the parameter of the investigated area — K_i is more or equal to the threshold value K_{en} , the optical anomaly is present. In the other cases, it is absent.

The calculations of Haralick's parameters (see Tables) were performed according to the Coelho program, LP 2013 <http://dx.doi.org/10.5334/jors.ac>.

Conclusions

1. On underwater landscapes, many different structures are preserved in a pristine form, which contributes to a more complete expression of geodynamic nodes in the modern seabed relief and to the in-depth study of them using aerospace methods.

2. Between the hydrophysical and hydrodynamic processes in the near-surface water layers on the water-atmosphere boundary, on the one hand, and the fluid dynamical processes, the geological structure of the lithosphere, and underwater landscapes, on the other hand, there is a relationship that needs to be taken into account when detecting hydrocarbon deposits on the basis of remotely sensed data.

3. Hydrophysical processes occurring in the near-surface layer of water are due to the flow of solar radiation into the water through the atmosphere-water boundary and the action of hydrocarbon fluids, which create internal moments that are reflected on the sea surface with the appearance of temperature anomalies.

4. The use of Haralick's informational features in the aerospace monitoring of the sea surface will expand the search capabilities in identifying anomalies over the hydrocarbon deposits.

5. Important factors and conditions for obtaining the qualitative remotely sensed images of the sea for the effective search for hydrocarbons are the time and season, cloudiness, sea temperature, the presence of wind and fog, the density of phytoplankton, and the salinity of sea water.

6. Along with the continuation of the study of the hydrophysical nature of temperature and optical anomalies, it is advisable to use the aerospace geomonitoring in combination with other measuring instruments.

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ІНФОРМАЦІЙНО-МЕТОДИЧНЕ ЗАБЕЗПЕЧЕННЯ АЕРОКОСМІЧНОГО МОНІТОРИНГУ МОРСЬКОГО ШЕЛЬФУ ДЛЯ ВИЯВЛЕННЯ АНОМАЛІЙ НАД ПОКЛАДАМИ ВУГЛЕВОДНІВ

Виконано аналіз інформаційно-методичного забезпечення аерокосмічного моніторингу морського шельфу для виявлення температурних і оптичних аномалій над покладами вуглеводнів. Розглянуто геолого-геофізичний і гідролого-гідрофізичний фактори, як найважливіші, що впливають на ефективність пошуку покладів вуглеводнів. Встановлено, що між гідрофізичними, гідродинамічними процесами в приповерхневих шарах води на межі розділу вода—атмосфера, флюїдодинамічними процесами і геологічною будовою літосфери та підводних ландшафтів існує взаємозв'язок, який необхідно враховувати при виявленні покладів вуглеводнів на основі дистанційної космічної зйомки.

Ключові слова: *інформаційно-методичне забезпечення, аерокосмічний моніторинг, поклади вуглеводнів, морський шельф.*

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ІНФОРМАЦІЙНО-МЕТОДИЧЕСЬКЕ ОБЕСПЕЧЕННЯ АЕРОКОСМІЧЕСЬКОГО МОНІТОРИНГУ МОРСЬКОГО ШЕЛЬФА ДЛЯ ВИЯВЛЕННЯ АНОМАЛІЙ НАД ЗАЛЕЖАМИ УГЛЕВОДОРОДІВ

Выполнен анализ информационно-методического обеспечения аэрокосмического мониторинга морского шельфа для выявления температурных и оптических аномалий над залежами углеводородов. Рассмотрены геолого-геофизический и гидролого-гидрофизический факторы, как важнейшие, влияющие на эффективность поиска залежей углеводородов. Установлено, что между гидрофизическими, гидродинамическими процессами в приповерхностных слоях воды на границе раздела вода—атмосфера, флюидодинамическими процессами, геологическим строением литосферы и подводных ландшафтов существует взаимосвязь, которую необходимо учитывать при выявлении залежей углеводородов на основе дистанционной космической съемки.

Ключевые слова: *информационно-методическое обеспечение, аэрокосмический мониторинг, залежи углеводородов, морской шельф.*