MINISTRY OF SCIENCE AND HIGHER EDUCATION OF THE RUSSIAN FEDERATION

federal state budgetary education institution

of higher education

«RUSSIAN STATE HYDROMETEOROLOGICAL UNIVERSITY»

Department of experimental atmospheric physics

FINAL QUALIFICATION THESIS

(bachelor thesis)

Theme «Oil pollution analysis in Caspian Sea with multispectral imagery»

Done by Sergeev Roman Anatolievich

Supervisor Doctor of physics and mathematics, professor

Kuznetsov Anatoliy Dmitrievich

«admitted to defend»

Head of the department

(signature)

doctor of physics and mathematics, professor

Kuznetsov Anatoliy Dmitrievich

« 1st » June , 2020

Saint Petersburg

2020

Content

Introduction

There are numerous households, transport and agricultural facilities in the Caspian Sea and its shores, where there may be repeated emergency situations when contaminants are released into the sea substances. Since exploration and development of oil and gas-bearing fields began, the number of cases of marine pollution has increased dramatically. For this reason, it is relevant and important to identify oil pollution sites in the offshore zone, as their timely detection makes it possible to take the following measures and minimize the damage caused[4].

Oil reserves have a tendency to deplete, so more and more new fields are being discovered. The places of oil deposits are located all over the earth. On continents, deserts, seas and oceans shelves.

Oil production in the seas is one of the most dangerous for nature and people, as man-made disasters in oil production can cause the death of many people and the surrounding animal world. Oil spills on the water surface occur due to pipeline ruptures or damage to the shelf during exploration of the subsoil leads to a cataclysm as a spill of oil products.

In the event of a catastrophe, it is necessary to localize and prevent the spread of oil as soon as possible, the sooner it occurs, the less environmental damage it will cause.

Oil spills are also unfavorable in economic terms, because of its lack, the economy can collapse. And purification works are not the cheapest and easiest task, so companies suffer losses when oil spills occur.

The Caspian Sea is not a leader in oil production and sales, but there are oil production stations on its territory, so a spill may occur there too. On average, this happens 2-3 times a year.

Spills can be detected by means of radar systems, either by aerial photography or by eyewitness reports. This work will present a way to detect oil spills using satellite multispectral imagery.

Multispectral (or spectrozonal) images are space images presented as separate spectral channels (RGB and infrared channels) or as synthesis of separate channels to obtain a color image.

By locating an oil slick, it is possible to track its movement and development in order to transmit information to the rescue services to start the spill response.

Chapter 1. Physical and geographical characteristics of the Caspian Sea

The Caspian Sea is one of the most amazing water areas in the world. It is the largest drainless water body on the planet, whose level is below the level of the World Ocean, equal to -27 meters. The area of the catchment basin is 3.5 million km2. It lies between 36º33' and 47º07' N and 45º43' and 54º03' E. The meridional length is 1200 km, the maximum width is 435 km and the average width is 310 km. The sea area is 392.6 thousand km2 and the volume of water is 78.7 thousand km3. The maximum depth is 1025 meters, with an average depth of 208 meters[3].

Morphologically speaking, the Caspian Sea is divided into three parts:

1) Northern Caspian Sea

2) Middle Caspian Sea

3) South Caspian Sea

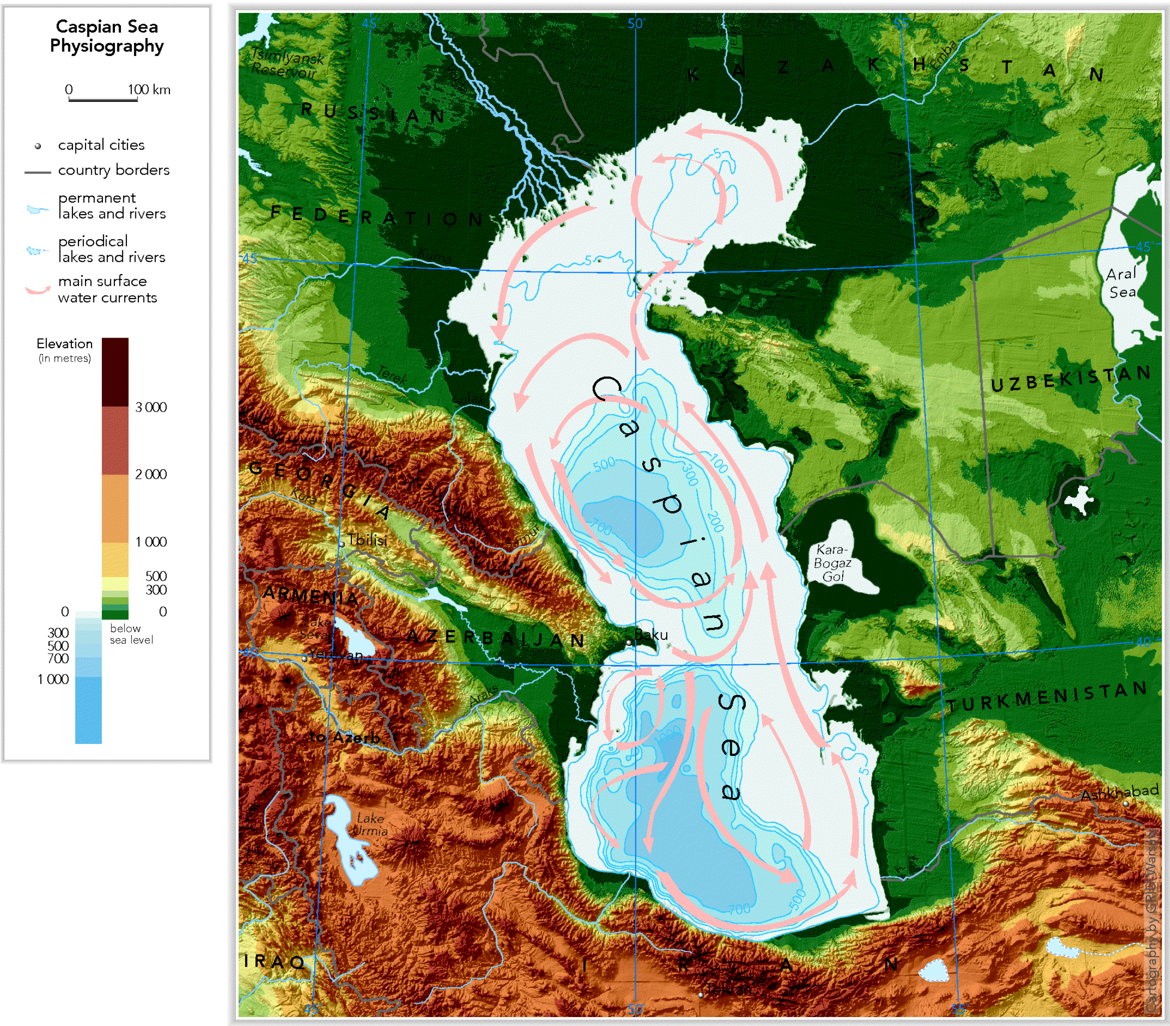

Figure 1. Caspian Sea Physiography.

The North and Middle Caspian Sea is divided by the Mangyshlak Threshold; the conditional boundary of the division runs from Chechnya (Russia) to the Tyub-Karagan Cape (Kazakhstan). The border of the Middle and South Caspian is on the Absheron-Pribalhan Threshold, while the conditional boundary is on the island of Zhiloy (Azerbaijan) - Cape Kuuli (Turkmenistan).

The average depth of the Caspian Sea shelf is about 100 m. The continental slope ends in the middle part at depths of 500-600 m. In the southern part it is very steep and the continental slope ends at 700-750 m, its width is about 5-10 km. The west coast has a narrow shelving and a width of about 40 km. The average width of the east coast shelf is 130 km.

The shallow northern part of the sea has an average depth of 5-6 m, with maximum depths of 15-20 m. The bottom relief is complicated by the presence of islands, cans and furrows.

In the middle part of the sea there is the Derbent Depression. Its average depth is 190 m and its maximum depth is 788 m. It has a steep and narrow western slope and a heavily stretched eastern one. The bottom of the depression is a slightly sloping plain, whose depth range is from 400 to 600 meters[3].

The Absheron Threshold is an extension of the Main Caucasian Range. Above its underwater ridge, the depth is no more than 180 m. The deepest part is in the South Caspian Basin, which is 1025 m deep. At the bottom of the basin there are 500 m high underwater ridges.

The northern coast of the Caspian Sea is full of bays, peninsulas and shallow bays. Of the large islands, one can distinguish the island. The Tyuleniy Island and the Tyuleniy Island. Kulaly Island. A large number of small islands and ducts, which are the influence of the Volga River activity, make this part of the sea rugged. A more even coastline runs in the Middle Caspian Sea. The Absheron Peninsula stands out on the west coast and extends far into the sea. To the west of the peninsula stands out the islands of the Absheron archipelago, among which stands out the island of Absheron. The inhabited island of the Absheron archipelago stands out. On the east coast there is the Kara-Bogaz-Gol Bay and the Kazakh Gulf, and a number of capes. To the south of the peninsula there are islands of the Baku archipelago. On the east coast there are two bays: Krasnovodsky and Turkmensky.

The Caspian Sea hydro-meteorological regime is determined by its geographical position at the intersection of Europe and Asia.

Air masses affecting the climatic conditions of the Caspian Sea:

1) Cold Arctic, which comes from the north;

2) Wet sea, which comes from the eastern Atlantic;

3) Dry continental, moving from Kazakhstan;

4) Warm tropical, influenced by the Mediterranean Sea and Iran.

Synoptic conditions over the Caspian Sea are determined by frequent changes in air masses in all seasons of the year. The field of atmospheric pressure in some areas of the Caspian Sea depends on seasonal changes in circulation over Eurasia and local atmospheric processes over the entire region.

In winter above Asia the Central Asian maximum is located, whose center has a pressure of 1040 hPa. One of its ridges is oriented towards the Caspian Sea. The reason for the formation of low-pressure areas over the Caspian Sea in winter is caused by cyclones and hollows, which move from west to south of the European part of North Caucasus Russia, caused by the Icelandic minimum. According to monthly average long-term values of January, the atmospheric pressure over the North and Middle Caspian Sea is 1022-1023 hPa and 2021 hPa over the southern Caspian Sea.

In spring, the intensity of the Central Asian maximum and the Icelandic minimum decreases. The Caspian Sea continues to be affected by the southwestern periphery of the Siberian maximum and the moving areas of the Azores maximum pressure. The average annual atmospheric pressure values for April are 1015-1017 hPa.

In summer, there is a vast area of low pressure over Asia, with the main centers over northwest India (998 hPa) and the Persian Gulf (995 hPa). The intensity and area of the Azores maximum increases, the influence of multi-center Asian depression appears, and air mass circulation over the Caspian Sea is determined. The atmospheric pressure for July is usually 1009-1010 hPa.

In autumn, the Central Asian maximum and Icelandic minimum develop again, the intensity of the Azores maximum decreases, and the southwestern periphery begins to influence the Caspian Sea more. In the south the atmospheric pressure values for October will be 1017-1020 hPa, and in the rest of the region 1021-1023 hPa.

For the year the average atmospheric pressure values are 1014-1018 hPa, with the increase to the north. During the winter period the pressure increases, and in summer it decreases. The amplitude of atmospheric pressure variability throughout the year is in the range of 10-12 hPa. In winter daily pressure fluctuations are better expressed than in summer and average values for the year are 0.5-1.0 hPa. During the cold period the daily atmospheric pressure variation is 23 hPa, and during the warm period it is 10 hPa. Sharp changes in pressure are observed when a deep cyclone or a powerful anticyclone passes over the water area. The largest pressure changes are observed on the Absheronsky Peninsula. Large changes in atmospheric processes take place on its territory.

Due to the large meridional length of the Caspian Sea, different physical and geographical conditions of the coasts and different types of circulation (depending on areas), a variety of wind conditions are observed. Based on data on wind characteristics, strong and hard storms, the Caspian Sea is zoned by the prevailing wind. The basis of zoning is the criterion of wind speed 15 m/s. Based on atmospheric and terrain circulation, strong and storm winds are generated in a particular area.

On the territories of the Middle and Southern Caspian Sea in the Absheron Peninsula, Makhachkala and Fort Shevchenko areas the strongest storm winds are observed. Storm activity is less frequent in the North Caspian Sea, as well as in the south-eastern and south-western areas of the sea. Heavy storms (wind speed >25 m/sec) over the Caspian Sea are typical only for north-western, southeastern and northern (or north-eastern) types of wind fields.

Most of the year in the northern part of the sea is characterized by prevailing east and south-east winds. In the middle part, northwest and south-east winds prevail, while north and south winds (due to orographic effect) prevail in the Absheron Peninsula area. In the southern part of the sea, north and north-east winds prevail in the southwest, northwest winds prevail in the extreme south-east in winter and south-east winds in summer. Above the sea, winds with speeds of up to 10 m/s prevail.

The Caspian Sea belongs to the seas with seasonal ice cover and is characterized by high spatial and temporal heterogeneity of ice processes development. The diversity of the ice cover in different parts of the sea is due to its large extent from north to south and significantly different climatic conditions.

In the Northern Caspian Sea, a rather powerful and stable ice cover is established annually. Already in mid-November, ice appears in the northeastern shallow waters, then in the northern coastal zone and gradually moves to the sea areas. In February, the ice cover is the most widespread, covering in fact the following areas.

Melting of ice usually starts in March and occurs more intensively (in a month) than its increase. The nature of ice conditions varies from year to year depending on thermal and dynamic factors. Only the coastal part of the sea is covered with ice during warm winters and the entire northern part of the sea during severe winters. Factors such as wind, waves, currents have a significant impact on the ice cover, as there is a breakage of fixed ice, resulting in a sharp decrease in its area and an increase in the area of floating ice. Pripai occupies a relatively narrow band 10-30 km wide. Its average thickness increases from 20 cm in the west to 50 cm in the north-east of the sea, but in abnormally cold winters it can reach 90 cm. The thickness of drifting ice is slightly less than solder. However, due to the rush of this ice, it can be over 2 m thick. In extremely icy winters, floating ice often takes place from the North Caspian Sea to the Middle Sea along the western coast to Makhachkala and further south-east to Absheron.

The current in the Caspian Sea is determined by the wind field, river runoff (Volga and Ural) and the distribution of the water density field. They depend on the depth, bottom topography and configuration of the sea coastline. According to observation data, wind currents predominate in the Northern Caspian Sea (70%) at floating beacons and multiday stations. In other cases, gradient currents (12%) caused by runoff-surge sea level fluctuations and weak, unstable currents (18%) prevail. Due to shallow water, there are abrupt changes in the direction and speed of wind currents due to abrupt changes in wind conditions. The velocity of surface currents at sea changes from 10 to 50 cm/s.

In the North Caspian Sea, the weakest waves are observed in May-July, and it is not uncommon for the whole water area of the sea to be completely calm. The spatial distribution of the waves in the Middle and Southern Caspian Sea is in good agreement with the Caspian Sea area in the prevailing wind. Thus, with north winds in the area of Makhachkala-Derbent, waves 2-3 m high prevail in the coastal zone and 4-6 m far from the shore. In this area, with east winds, there are quicksilver heights of over 3 m. In the Absheron archipelago area, the area with the maximum excursion is located to the north-west of the Oil Rocks. In case of strong storms to the north-east of the Absheron Peninsula, waves with a height of 7.5-8 m develop and up to 9-10 m in extreme storm conditions. In the area of Fort-Shevchenko the highest wave height (more than 4 m) is observed in the south-eastern storm winds. Off the coast of the southwestern and southeastern part of the sea during strong winds (10-15 m/s) the waves with the height of 2 m prevail, and only weak waves can be observed in some coastal areas. When the wind increases to 20 m/s, the wave height increases to 3 m, and when the storm is strong, it reaches 4 m or more. At the same time, in the central part of the Southern Caspian Sea the wave heights are approximately 2-3 m higher than at the coast. At the Turkmen coast, storm winds (16-20 m/sec) cause up to 3 m of wave height, and strong storms (21-25 m/sec) cause up to 4 m of wave height.

Natural griffins are natural inputs of hydrocarbons to the water surface in the Caspian Sea. In the north-western part of the South Caspian Depression there is the largest number of large underwater volcanoes (over 300). This part of the Caspian Sea water area is a unique and classical region of mud volcanism development. In terms of the number of volcanoes, their diversity and intensity, it has no analogues in the world.

Activation of submarine volcanoes and griffins in the places of hydrocarbon extraction leads to the appearance of mud and oil slicks on the water[4]. Such manifestations serve as direct indicators of oil and gas content of subsoil, so the mechanism of mud volcano formation and the frequency of their eruption attract the attention of researchers. Eruption of mud volcanoes is caused by earthquakes. Their epicenters are located at different distances from volcanoes, and seismic waves are transmitted with some delay, which leads to the awakening of the volcano not on the same day, but a few days or even weeks later, all depends on the distance between the volcano and the epicenter of the earthquake, its magnitude, and the depth of its origin. Both of these natural phenomena are related to the tectonic motion that accumulates in the Earth's crust, which causes their interaction.

Chapter 2. Description of physical and chemical properties of oil on water surface

2.1 Properties of oil on water surface

For a more successful and timely operation to eliminate oil products, we need to know a series of properties that oil acquires on the water surface. We will consider these properties.

Some time, after a spill, the dynamic viscosity of oil products changes[1]. After 24 hours, it increases many times. The viscosity values may vary depending on the origin of the oil. The higher the value of this factor, the faster oil is on the water surface.

Over time, the concentration of water in oil products increases, the oil becomes more fluid and begins to spread abundantly over the water surface. This leads to the formation of an oil film that prevents evaporation of water from the sea surface, changes in albedo and heat capacity of the upper layer. All this leads to a decrease in the solubility of gases in this layer, a decrease in the content of carbon dioxide in water (as most of it passes into the atmosphere), slowing down of photosynthesis and changes in the hydrogen index of the water environment.

The optical properties of the surface change, preventing solar radiation from penetrating the water column. Heating of the upper layer occurs, which affects the vital functions of marine organisms. The formation of a difference between the water and air environment can lead to climate change in the area.

When an accident occurs on a drilling platform on the sea shelf, the oil and gas mixture is released into the air and, before reaching the water, much of it evaporates in the air environment as the process is very intense[1]. Atmospheric temperature, sea turbulence and wind speed all influence how fast oil products evaporate. Oil components that have a boiling point below 200 degrees Celsius evaporate in a 24-hour period.

The faster an oil slick spreads, the larger its surface area, the faster lighter its components evaporate. Light oil evaporates by half its volume in the first 24 hours after a spill. If a spill of such oil occurs in a limited area, there is a risk of fire and explosion. In the case of heavy oil, there is a risk of fire because the evaporation is negligible and all burning substances remain on the water surface. Oil evaporates much faster as the slick increases in size than as the wind increases in speed. Evaporation rate also depends on the percentage of low boiling fractions in oil products. For oil slicks floating on the water surface, the vapor pressure drops sharply as the volatile components evaporate.

In the case of turbulent diffusion, the presence of oil in the water column is determined, and thus dangerous effects on marine life. Together with evaporation, this process determines the time of oil slick existence on the water surface, its distribution limits and thickness. In these processes, it is possible that the slick will reach the shore[1]. In the water column, oil only exists as a drop. In order to transfer a drop of oil from the slick to the water column, a certain amount of energy has to be used. This energy comes from water particles that are in a turbulent state. One important point is the size spectrum of the resulting droplets. The droplets produced by the dispersion of the oil film are broken down into smaller droplets in a turbulent stream until they reach a diameter at which the energy required to break the droplet does not exceed that which can be transmitted to the drop by the stream. The minimum droplet diameter shall be 50 µm. The thickness of the oil film is usually uneven: in the middle, the droplet size will be larger than the droplet at the periphery. Once the droplets have entered the water column, they may surface under the action of lift force and combine with the oil film. The process of droplet floating can be seen as a balance between the lifting speed of the droplet and random swirling speeds. The penetration depth of oil droplets into the water column can be between one and ten meters or more. It all depends on the characteristics of the oil and the flow in which the droplet resides.

2.2 Hydraulic processes of oil products distribution in water areas

2.2.1 Spreading of petroleum products by gravity, viscosity and surface tension forces

One of the main processes of oil and oil slick spreading on the water surface can be considered the action of gravity, viscosity and surface tension forces[1,24],. There are models that include the effects of these physical forces in the calculation. The Fairy model involves three phases in which the radius of an oil slick spreading over a water surface changes: in the first phase, the propagation is caused by gravity and inertia; in the second phase, the viscosity forces of oil are added; and in the third phase, the propagation is caused by surface tension forces.

Each phase lasts a certain time, which depends on the volume of oil spilled. One of the components of this model is the calculation of the flow coefficient, which requires the values of surface tension at the border of "water-air", "water-oil" and "oil-air" phases, time, relative water density, density of oil and petroleum products (t/m^3); total surface tension (n/m); - free fall acceleration; kinematic coefficient of water viscosity (10-4 m/s); volume of spilled oil (m^3); values of constants determined experimentally: Ki = 1.14; Кν = 1.45; Kt = 2.30.

At the same time, it should be noted that these coefficients depend on the type of oil. Conducting practical calculations revealed the need to expand the index coefficient of spreading, namely, the account at its definition of the values of the surface tension of sea water, depending on its solenosti and temperature. It should be noted, however, that this formula can serve only for an approximate estimation of the slick area, as it does not take into account the characteristics of oil products.

The following is a model of axially symmetric distribution relative to an instantaneous point source. This model is used taking into account the fact that the oil slick, which is on the water surface under the action of gravity and surface tension, has the shape of a circle. For example, according to the Blocker model, the radius of the oil slick will increase monotonically with time. For this purpose, we need to know the Blocker constant (K=216), oil product density, water density, time, initial slick radius and its volume.

2.2.2 Distribution of petroleum products under the influence of the wind

When the wind interacts with the oil slick floating on the water surface, the wind energy is transferred to the spill by tangential forces, so that the slick acquires some speed, which depends on the wind speed. The concept of speed and direction of movement refers to the center of mass of the slick, because with significant horizontal dimensions, individual parts of the slick can move at different speeds and in different directions. The direction of the spot movement is usually different from that of the wind. It is considered that the deviation of the spot direction from the wind direction is caused by Coriolis forces, i.e. it depends on the geographical latitude of a place. It is possible to divide the movement of oil floating on the water surface under the action of the wind into two components:

1) The movement of the surface layer (up to 10 m thick) of water at a speed of 2.5% of wind speed and 14° to the right of the wind line;

2) The movement of oil relative to the surface layer at a speed of 1.1% of the wind speed in the direction coinciding with the direction of the wind[1].

According to the data of aerial photography in the area of Neftdashlary during emergency oil spills in the presence of weak winds of different directions, there was a decrease in the total area of oil spills when the wind direction was changing, for example, from north to east, south and west.

Sometimes, under equal conditions, the speed factor becomes decisive or, conversely, the direction of the active wind. There may be a decrease in the mass and film thickness of a spilled oil by increasing the wind speed, or, depending on the location of the source of pollution, the wind direction with respect to the object of the oil spill becomes decisive, but at the same wind speed. The strength and duration of the wind determine the time the slick is located on the water surface, which also depends on its strength.

The efficiency of wind action on oil spills depends on their duration. If the wind direction coincides with the direction of the current, it increases the speed of the slick, and vice versa, the speed of the slick decreases.

2.2.3 Distribution of petroleum products under the influence of wind waves

At low wind speeds (less than 0.8 m/sec), wave motion increases wind drift[1]. At high wind speeds, the presence of waves leads to a reduction in total drift velocity. In reality, the spot is in the form of a strip of more or less wide, with a significant difference in thickness on the surface of the spot. The main reason for this is the physical processes of wave interaction with the oil slick. In particular, the slick is exposed to the action of waves. In this case, waves of ziby (in the absence of wind) practically affect only the speed and direction of the slick. Wind waves, or rather 10-15% of the ridges of these waves at wind speeds exceeding 7m / s, have white ridges.

These white ridges, which are turbulent streams of water, affect the film, transmitting some of its energy to it. The energy is also transmitted to the oil particles in the slick, separating them from the main slick and drawing them into the water column at different depths. In doing so, large droplets are lowered to a lower depth and smaller droplets to a greater depth. After some time, after the wave crest shape has recovered, the droplets begin to float. This process is mainly driven by gravity and viscosity. The force of Archimedes (gravity) acts on a drop of oil, forcing it to float. The larger the droplet, the greater the force of Archimedes. As a drop of oil moves towards the water surface, it also experiences resistance forces due to the viscosity of the water. For larger droplets - 1mm in diameter or larger - the force of Archimedes is much greater than the resistance, and the drop rises steadily upwards. For small droplets as well as high density oil droplets, the forces of Archimedes and Stokes are close and the drop remains in a neutral buoyancy state.

Once the wind and waves have calmed down, the droplets will float back to the surface where they form a film again. This phenomenon is possible and often observed in the coastal sea zone. As submarine drift clouds can travel considerable distances under the influence of currents, the appearance of an oil slick is often unexpected as there are no sources of pollution nearby. Droplet splashes are possible if they are more or less significant in size. For example, if a film of oil has only been exposed to the crumbling crest of waves, the droplet sizes are sufficient to support the floating process. If an oil-water mixture that has been pumped through complex piping systems is considered, then the droplet sizes are too small to ensure floating.

Thicker films do not allow tangential stresses to increase the speed of particles in a wave due to two factors:

1) When the film is very thick, oil particles in the film begin to move, which dramatically reduces the efficiency of energy transfer to the water particles in the wave.

2) The friction coefficient on the air-oil surface is smaller than on the air-water surface, which reduces the tangential stresses.

Thus, each drill hole on the crest of the wave will tear a piece of oil from the film. As a result of the ripple velocities of water particles, the oil film will be converted into a cloud of oil droplets in the water. These droplets have different sizes and are fascinated.

If a drop does not surface, it moves with the mass of water in a neutral buoyancy state (drop size 0.1mm or less). Oil film transformed into such droplets has the most dangerous effect on sea water quality. Oxidation processes (oxygen absorption from the water column) are accelerated by increasing the surface area of oil-water contact. The processes of dissolution of light fractions in water - polycyclic aromatic hydrocarbons (PAH) - are also accelerated. Thus, oil participates in all chemical reactions typical for oil in the water environment, but these reactions are faster and with more unpleasant consequences for the environment.

In this case, oil particles (drops) have different sizes depending on the parameters of the wave, characteristics of oil products, etc. Having plunged to the depth and released from the action of turbulence, the particles start to surface again. This process is quite complicated, as the droplets have different sizes and, consequently, different rates of floating, followed by the first wave, others collapse, which affect the floating process.

At the same time, large droplets with a high floating rate have time to join the main part of the moving spot, while medium and small droplets do not. When they float up to a clean surface, they form a secondary film, less thick, which adjoins the main one, forming a loop or tail of the main stain.

In nature, the rate of droplet pop-up is a variable value. It depends not only on the size and density of petroleum products, but also changes over time. Thus, immediately after liberation, a drop moves with acceleration under the constant force of Archimedes. However, as the rate of ascent increases, the force of frontal resistance increases, which counteracts the force of Archimedes. As a result, the climbing speed is equalized and becomes constant.

Thus, it is possible to determine what part of the volume of oil will pop up by the time the second wave with a crumbling crest occurs. It should be reminded that not every wave collapses in the water column. Oil refineries involved in the water column move in a different direction from the primary slick, both in the direction and in the value of speed. These differences depend on the characteristics of the NP as well as the parameters of the waves.

2.2.4 Destruction of oil products

NPs that have entered the aquatic environment for some reason are destroyed over time by natural factors, breaking down into separate elements that are relatively harmless to the environment. NP destruction in water basins occurs under the influence of abiogenic oxidation - disintegration as a result of photochemical and thermochemical reactions with low activation energy, as well as under the influence of biological self-cleaning - utilization of oil products by living organisms in the process of life activities[1].

According to the law of matter conservation, toxic substances that have entered the aquatic environment do not disappear, but simply transfer to another form less active in relation to this environment. The energy for these reactions comes from the Sun. On the boundary of the Earth's atmosphere it comes in the form of electromagnetic oscillations in the range of wavelengths λ=0.1 - 7 μm, with a concentration of 0.132 W/sm^2. At the same time, ultraviolet radiation (λ=10 - 400 nm), which has the largest impact on the oil products photooxidation process, is 9%; radiation in the visible area (λ=400 -760 nm) - 45% and in the infrared area (λ>760 nm) - 46%.

Variable cloudiness of 3-7 points reduces UV radiation flux by almost 50%. An approximate estimate of the rate of oil slick decomposition in sunlight gives 200 (mkg/sm^2) per 8-hour sunny day. The rate of photochemical oxidation depends on the type of oil product: heavy metals contained in small amounts in oil accelerate the oxidation process, and sulfur compounds, on the contrary, act as process inhibitors.

In natural bodies of water, oil products decompose faster than in laboratory conditions, because along with chemical decomposition, they also biodegrade under the influence of microorganisms that use NP as food, decomposing them into substances harmless to biota. The microorganisms that decompose NP have been found in waters at almost all latitudes. The amount of them is sharply increasing in waters subject to chronic contamination of NPs, near industrial enterprises, on ship routes. Under favorable conditions, in water saturated with oxygen, microorganisms can oxidize oil and petroleum products at a rate of up to 2 g per 1 m2 of water surface per day at a water temperature of 20-30° C. In terms of film thickness, this means that due to biological oxidation it can be reduced by 2 μm per day. Under favorable conditions, microorganisms can process almost all hydrocarbons; the most actively they process hydrocarbons with the number of carbon atoms from 12 to 22.

The efficiency of biological oxidation of oil and petroleum products varies for different natural zones. Thus, in Arctic waters the efficiency of biological destruction of oil products during the polar night is close to zero and only in the short summer period reaches several percent of possible under favorable conditions. It is practically impossible to stimulate this process, as it is impossible to eliminate the limiting factor - low water temperature. Obviously, the role of biological factor increases with increasing water temperature. The number of microorganisms can be increased by increasing the content of nitrogen and phosphorus in water.

2.2.5 Interaction of oil products with ice

An important factor in the interaction between ice and oil is the diversity of ice forms, their change over time and the dependence on water and air temperature. When the characteristics of ice change, its interaction with oil products also changes. Of particular importance are the processes of ice drift melting and freezing and its interaction with currents[25].

Another important factor is the ice structure. When seawater freezes, salt is squeezed out of the ice crystals. The separated crystals are shaped like vertical columns, which are set at a distance of 0.5-1.0 mm from each other. These intervals are called brine channels. They can only form in sea water. If oil has low viscosity, it can escape through these channels together with sea water. When the melting season starts, the brine channels increase in size and the oil gets out to form oil slicks, which reduce the albedo of the ice, thus accelerating its melting.

The rate of ice growth changes, as the thermal conductivity of oil is 0.75 less than that of ice. When oil comes to the surface, individual droplets of oil products may freeze into the ice. The following process takes place: the ice begins to grow intensively around the oil accumulation, in places where the thermal conductivity is higher, ice thickening begins to form, which form an ice dome and the oil turns frozen into ice.

Once frozen in the ice, its movement under the influence of external factors becomes impossible. There is a question about the speed at which oil moves relative to the lower surface of the ice. Low viscosity grades of oil at a flow rate of 3.5 m/s begin to move under the ice. The higher the viscosity, the higher the flow speed is required for the oil products to start spreading.

In the event that oil and gas are released under the ice, there are two options for its behavior. If the spreading pressure is positive, gas and oil can combine to form gas bubbles inside the oil bubble. The thickness of the layer can reach 5-10 mm. The thicker the film becomes, the faster the bubbles will divide. At negative spreading pressure, oil and gas will exist separately. Oil also rises to the fault zones and blends with the water surface.

Ice floes rise about half their thickness above the water surface, so they act as a barrier to oil proliferation. Further movement of oil will depend on its viscosity. Viscous grades of oil remain within the area bounded by broken ice, while light, low-viscosity grades quickly spread across the free surface of water between floating ice floes and reach a thickness corresponding to the thickness of the oil film on the surface free of ice. Oil products + ice - this ratio is possible only in the presence of water, as ice in relation to oil is a non-soaky surface. Either if oil is poured on dry ice or oil products are frozen in ice. The energy of interaction between the molecules of oil is greater than between the molecules of ice and oil.

Chapter 3. Elimination of oil spill consequences.

3.1 Methods for cleaning the water surface

Oil spill response depends on the spill conditions. Usually, oil spill response means collecting a film of oil products floating on the water surface. However, if the slick has come ashore, these measures are complemented by coastal soil treatment, evacuation and processing of petroleum products.

With few exceptions, modern international agreements imply that oil spilled by an accident must be collected and evacuated outside the water area[1]. In some cases, this term is replaced by removal of oil from the water surface. This involves the use of both modern technologies, such as the use of biosorbents, and traditional technologies such as sinking, burning and dispersion by chemical means. The latter make it possible to get rid of the film on the water surface with little effort and means. In most cases such technologies cause more damage to the environment than the oil slick itself would have done without human intervention.

1) Oil sinking - this procedure is carried out using small vessels on which rotary diffusers are installed. The vessel passes through the slick and scatters coarse sand, which is used as a material for sinking oil products. Sand grains of sand, when hitting the oil film, are enveloped by oil and go to the bottom under the force of gravity, where they remain, disturbing the ecosystem of the seabed, which in turn leads to the death of aquatic life. It can be concluded that this method is not ecological and causes irreparable damage to the environment. Consider the following method.

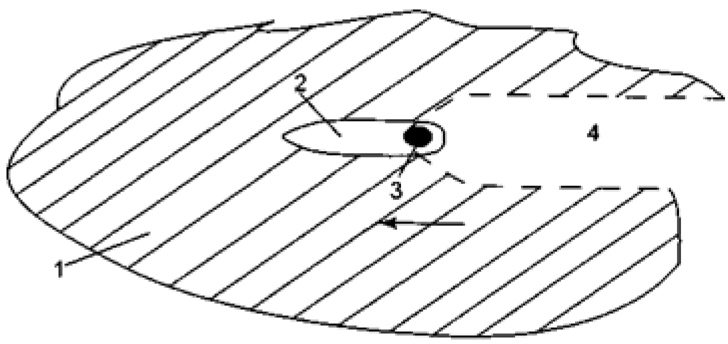

Figure 2. Sinking of oil floating on water surface

1 - oil spill; 2 - vessel; 3 - rotary sand spreader;

4 - clean surface

2) Burning oil - the oil slick itself can only be ignited after a short period of time before all the combustible components have evaporated. If the spill has been in the water for a long time, special means are required to burn the oil. For example, special bags are used which, when in contact with water, release oxygen for better ignition and combustion. They are discarded from various vehicles such as airplanes,

ships and so on. The method itself is very dangerous because burning is an uncontrolled process and poses a danger to ships and coastal facilities. Changing the direction of the wind also contributes to the danger, as a burning spot can go towards seaports or ships themselves.

3) Chemical treatment of slicks - chemical agents are used together with mechanical means of oil gathering. They are applied from aircraft to the water surface. The obstacles are high wind speed and lack of precipitation.

a) Solvents - used to remove oil from shores, bridge pillars, etc. They dissolve crude oil and viscous oil products in water. They are used in small doses so as not to degrade water quality[1].

b) Flocculants - used to form stable flakes from oil, which can be easily collected by mechanical means and transferred to shore for further processing.

c) Surfactants - these substances affect the oil film in such a way that the surface tension of the oil products changes, the surface of the slick decreases many times, and at the same time the film thickens. This allows for more efficient collection of oil with the help of technology and reduces the length of the fence.

d) Hardeners - give the oil film properties close to the solid substance. This helps to collect the oil. When applied around the perimeter of a stain, it can act as a fence.

Sorbents are substances that absorb oil well and as little water as possible[1]. They are made from different materials. For example: dried peat, sawdust or cotton balls. They are used for oil spills of limited size. Sorbents can be treated to increase their sorption capacity. Sorption is the absorption of a substance from the environment by a solid substance. Sorbate is a body absorbed by sorbent. Sorption capacity - ratio of mass of retained sorbate to the mass of sorbent. Sorbate retention capacity - time during which the sorbate is retained. An important characteristic of a sorbent is the sorbent time. It depends on a number of factors, including such factors as the nature of sorbent, characteristics of oil products, the degree of turbulence of oil-containing liquid. Sorbents themselves are used to help in oil gathering by mechanical means.

There are biosorbents - they combine the properties of sorbents and biological decomposition of oil. They are presented in the form of flakes, made of organic mass, on their surface are applied bacteria. They are capable of processing oil products, resulting in a neutral appearance. They can be stored for a long time without any activity. During oil refining, the base on which the bacteria are located absorbs the oil and the bacteria themselves interact with the oil products until the slick is removed, after which the bacteria stop their life activity.

3.2 Mechanical means for collecting oil from the water surface.

Booms are mechanical devices designed to contain spills and prevent them from spreading further over the water surface. The thicker an oil slick, the more efficient its collection is. Some booms are attached to the nose of the oil collector, or stretched in line at an angle of 38 degrees in the direction of water movement.

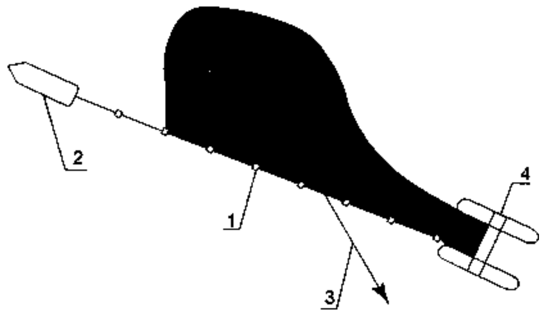

Figure 3. Scheme of staging the boom fence in the current.

1-bore fence; 2-vessel towing booms; 3-vector of spot center motion; 4-oil collector[1].

The floatation of the entire structure is provided by the floats. The entire length of the coupons is held in place by a web that holds the oil product in place. The power elements at the bottom of the sheet allow to hold or move the booms. The fabric of the fabric consists of nylon and is covered with polyurethane rubber, which allows to use the fence in a wide temperature range. Inside the coupons are flexible frames that are connected to each other. They are preloaded with stainless steel springs. In addition, the fences are equipped with warning lights to avoid damage by vessels at night.

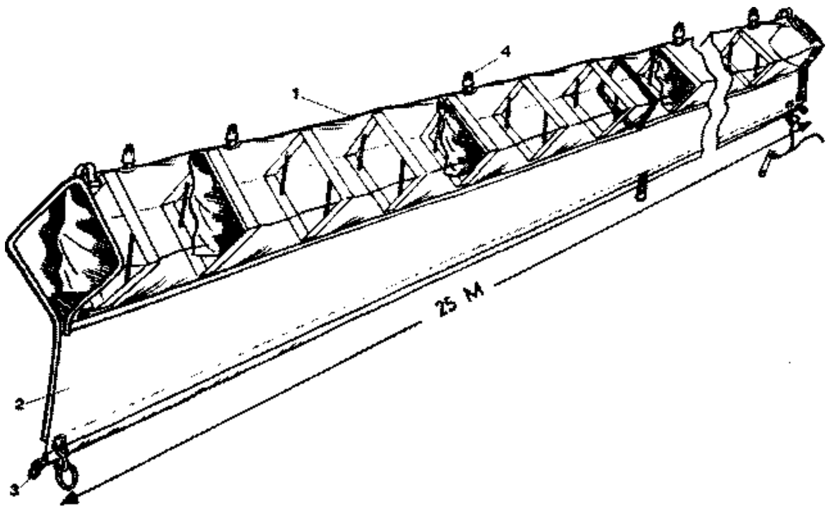

Figure 4. Scheme of a typical boom fence.

1 - the float; 2 – canvas; 3 - power parts; 4 - warning lights[1].

The purpose and design of the boom fence is divided into: Locating agents - keep oil in the specified area while treatment works are carried out. Guides - direct the oil film to the oil collector.

There are, however, a number of challenges in working with booms:

1) Difficulties in gathering oil when it is impossible to withstand strong waves and currents.

2) Difficulty in deployment during storms.

3) Prevention of oil products with different characteristics.

Therefore, more practical booms for solving these problems are still being created.

Petrolers[1]. This equipment can be roughly divided into three groups: oil gathering equipment for disposal and liquidation of accidents, storage equipment and oil collectors themselves.

Oil gathering equipment for waste disposal and accident management. This equipment can be divided into two categories: disposal equipment (centrifuges, separators, incinerators) and oil gathering equipment for emergency response. The former is needed to reduce negative environmental impacts, and the latter are needed to address the causes of water or soil accidents in a timely manner.

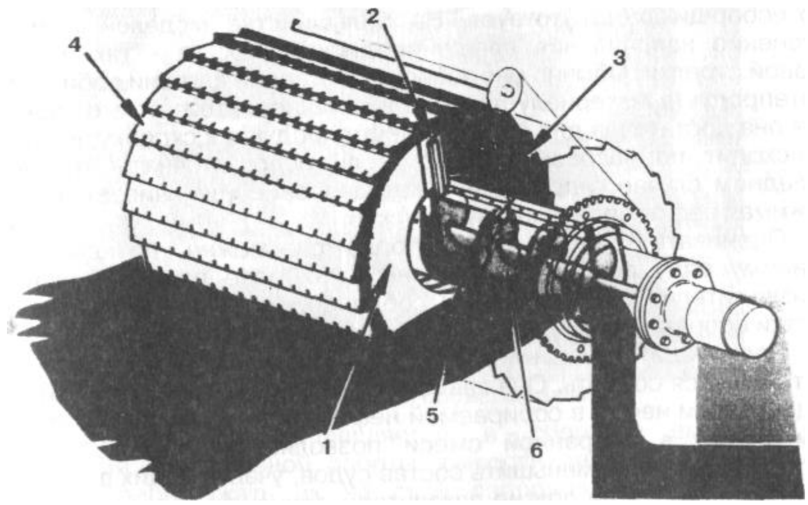

Figure 5. Collector scheme using the principle of adhesion.

1 - rotating disks; 2 - scrapers; 3 - sticking oil; 4 - protective cover protecting the discs from damage by floating objects or individual ice floes; 5 - tray for transportation of collected oil; 6 - auger for transporting the oil into collecting tanks.

Emergency oil collectors are prefabricated equipment, booms, temporary tanks of various types, and dispersing plants for emergency spraying of chemicals.

The issue of oil storage is also very serious. The next oil gathering equipment is as important as the gathering equipment. These are different types of tanks for storage of oil products, both temporary and permanent. Oil gathering equipment for temporary storage - is a cushion-shaped tanks, folding pools and much more, which allows you to collect and leave for temporary storage of oil and sorbents, for example, in case of emergency spreading. Typically, these tanks are made of strong materials and are sufficiently resistant to corrosion and oil. Permanent storage tanks are large in size, but the materials used are almost the same.

Perhaps the central place among the oil-gathering equipment is occupied by oil-gatherers working in normal mode. They are called skimmers in a different way. Skimmers are different from each other by their working principle. There are several types of skimmers.

Skimmers[11]. The latter, so-called mechanical devices for collecting oil and petroleum products, or skimmers, are based on the use of the difference in water and oil densities. The following methods can be used to remove oil products from the water surface:

1. Adhesion: oil products adhere well to oleophilic surfaces. Oleophilic skimmers with rotating discs, brushes or continuous strips, from which stuck oil products are removed mechanically. Skimmers of this type are characterized by a small amount of water collected together with oil, low sensitivity to the oil grade and the possibility of collecting oil in shallow waters, in submerged areas, ponds in the presence of thick algae.

2. Threshold: a thin surface layer of water and petroleum products flows through the threshold, after which petroleum products are separated from the water and pumped out of the tank. Threshold skimmers are notable for their simplicity and operational reliability. Threshold skimmer is able to serve for many years without breakage.

3. Cyclones: creates a whirlpool with lowering the level in the center, from where the oil is pumped out. Skimmer - cyclone is designed to collect oil from the water surface during accidents at underwater crossings of main oil pipelines through navigable rivers.

4. Vacuum: the surface water layer is absorbed and the oil is then separated from the water. The principle of vacuum skimmer operation is as follows. A vacuum pump creates a vacuum in the sump-vacuum tank. Under the influence of vacuum, a film of oil is sucked together with water by means of an oil collecting device. The mixture of oil and water entering the tank is defended and pumped back into the river, if it is water, and if it is oil, into a specially prepared container. A type of vacuum oil skimmer is a manual brush skimmer designed to remove heavy and

viscous oil from hard surfaces, to clean the shoreline and work in hard-to-reach places.

According to the method of movement (fastening), skimmers are divided into:

- Self-propelled skimmers;

- Stationary skimmers;

- Towed and carried on various swimming aids[11].

Specialists believe that the best way to remove oil from the water surface is mechanical treatment. Depending on the type and quantity of spilled oil products and weather conditions, different types of skimmers are used, both in terms of design and principle of operation. Collection of oil from the water surface with the help of the device type "skimmer" is widely used due to the simplicity of implementation, the possibility of elimination of emergency spills of various types of oil products and all-season use of the method.

3.3 Collection of spilled oil if there is ice on the water surface

The presence of ice in the water areas significantly reduces the efficiency of oil gathering. If the ice is thick and not cracked, the chances of finding a spill are very slim.

Unfortunately, nowadays there are no ways to collect oil from under the ice. But in the late '80s, there was a way to collect oil from under the ice.

The icebreaker comes to the location of the oil slick under the ice, becomes on the ice anchors and starts to work with the screws, remaining in place. The propellers work under the ice to create a flow of water that carries the oil away. The oil is then captured by standard bonuses and skimmers. Calculations have shown that this way it is possible to collect oil that is up to 200m away from the icebreaker.

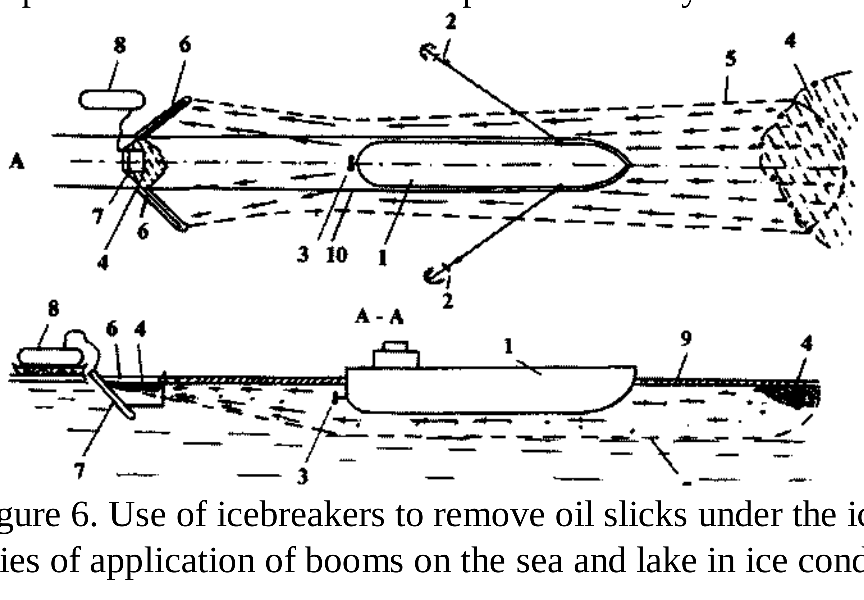

Figure 6. Use of icebreakers to remove oil slicks under the ice.

Peculiarities of application of booms on the sea and lake in ice conditions:

When the ice concentration exceeds 30%, booms are practically useless, as they can only hold small pieces of ice;

coupons can be damaged by small pieces of ice if wind speeds of more than 35 km/h (10 m/s) are encountered;

the most resistant are thixotropic fabric (conveyor material) booms; PVC and polyurethane are less durable;

their main characteristic is the strength, wave stability and buoyancy of the booms;

anchorage in ice conditions is difficult or meaningless[1].

3.4 Elimination of the consequences of accidental oil spills in the Caspian Sea

The region under study applies the liquidation measures described in previous paragraphs.

The list of measures used includes:

1) Timely reporting of an oil spill;

2) The use of ships to transport booms to the accident site, respectively, and the location of the oil spill;

3) Use of vessels for transportation of oil gathering vessels, or use of oil gathering vessels themselves;

4) Use of chemical agents and sorbents to ensure oil gathering;

5) Ensuring the safety of nearby areas, and signals to mark the accident area.

In today's world, such measures must be carried out quickly and clearly, so in all areas of oil production a rescue team is on duty and emergency response drills are conducted.

Chapter 4. RGB models

These are models that can be processed using channels across the entire spectrum, from visible and infrared to passive microwave. As a result, RGB models are often called multispectral models. They are suitable for describing colors displayed by monitors, scanners and color filters, but not printers. A color model is an abstract mathematical model that describes a way in which colors are represented as n-dimensional values, may consist of three or four components or colors.

Mixing the three basic colors is called the three-component theory. Originally it was based on the assumption that it is possible to get any shade by mixing the three "basic" colors red (R), green (G), blue (B), in different proportions. Thanks to spectral studies of the retinal receptor absorption spectra, several maxima of absorption in the visible area have been revealed. Based on this, it was suggested that there were three types of ranges - red, green and blue. They analyze the limited areas of the spectrum so that each range can receive signals only in its spectral zone (but in reality, these zones overlap significantly), on the basis of which a sense of color is formed in the brain.

The RGB scale was proposed in the twenties of the twentieth century[9]. Any color in this scale represents a vector with three components: Red-Green-Blue which length defines brightness, and its angular position - its colorfulness. Color scale allows to solve the main task - to calculate the results of interaction of color vectors analytically.

Obviously, one and the same object considered in daylight will be different in color when added to its palette of artificial lighting. Conversely, when lighting changes, close shades of the same color may appear identical.

Environmental objects emit light, or are sources of reflected light. The former is colored by an additive synthesis process, which is a process of color reproduction due to the optical mixing of the emissions of the main colors. The latter acquire color through a process called subtractive color synthesis. In this case the color is obtained by subtracting individual spectral components from white light, when illuminating a colored surface. In addition, the light is subtracted by a colorful layer, and the remaining part, reflected, falls into the eye of the observer.

The human eye is unable to recognize the smallest differences between similar shades, so increasing or decreasing the number of color errors affects the perception of the image as a whole, forcing us to consider the image obtained on the optical device in terms of the characteristics of the device itself[20]. From this assumption we can conclude that the RGB model is hardware dependent. Perception of each subject is individual according to the image obtained as a result of the object modeling process. The next feature of additive model object visualization is the impossibility to reproduce some pure colors, for example, blue. Depending on the technical characteristics of the monitors, the programmed colors will differ, which should be taken into account when developing the models.

A set of colors, when mixing which can produce the full range of possible shades, is called basic colors. Main additive colors are secondary colors, which are most often used in subtractive main colors and vice versa.

Identification of colors different by nature occurs because of imperfect work of peripheral department of a retina. Under condition of influence of various streams of radiation, the person can receive the color model which does not correspond to the reality and does not coincide with the image received as a result of use of optical devices for effective work with the information. The presence of such differences is due to the reflective properties of materials that are not available to the human eye, which is responsible for the color sensation.

The principle of obtaining colors in an additive model is to add to black. At crossing of projections of light beams of the basic colors on the screen, secondary colors are created in a place of their crossing. White color turns out at superposition on each other of all basic colors of equal intensity. When two layers of paint of basic colors are put on the screen, secondary colors are created. Black light turns out at superposition of all three layers of basic colors.

CMY model is a description of reflected paints that occur when subtracting part of the spectrum of incident light on a surface. It consists of green-blue (Cyan), magenta and yellow (Yellow) colors. K - black (blacK) - is the last component in CMYK model, which describes the process of color printing.

There is a tool created using the RGB model, which provides visualization of combinations between all possible colors. It is called the RGB color wheel. It is occupied by the basic colors, equally located on three segments, each segment has an angle of 120 degrees. The arrangement of the initial color is arbitrary, as well as the order of the remaining two. It can be either clockwise or counterclockwise. In this circle between basic colors secondary colors with shift in 60 degrees are located.

The basic colors cannot be created at mixing of any other colors, but their uniqueness consists that at their mixing it is possible to receive a huge quantity of colors and shades. All occurs as follows: at mixing in equal quantity of three basic colors, three new colors which make CMY model - turquoise (blue + green), magenta (red + blue) and yellow (red + green) receive. After mixing the primary and secondary colors are obtained tertiary colors. Gradually mixing received at each new color mixing, in the end we receive RGB a circle filled with color transitions.

Additional colors - pairs of colors, at which additive mixing white color turns out. At subtractive mixing of additional colors, it turns out neutrally grey or black color. In RGB circle pairs of additional colors are opposite each other.

RGB models in three-dimensional space

Three-dimensional color space has three axes, only instead of x, y, z axes will indicate the intensity of basic colors that are perpendicular to each other. The intensity of each of the colors starts at the beginning of the coordinates and increases along its axis. Since each color has values between zero and maximum intensity, which is 255 for a depth of 8 bits, we have a cube structure. The coordinates have the form of a triad of red, green and blue intensities.

The colors are obtained by specifying the coordinates of each of the colors. For example, black color has coordinates (0, 0, 0), as it has zero intensity in the basic colors. Accordingly, white color will have coordinates (255, 255,255), and grey color will have coordinates (128. 128, 128), that is in the very center of the cube. Red, green and blue colors will be located on corners of a cube with coordinates (255, 0, 0), (0, 255, 0) and (0, 0, 255).

The main colors of the subtractive model will be located on the coordinates: (255, 255, 0) - yellow, (0, 255, 255) - turquoise, (255, 0, 255) - magenta.

To obtain each color in the cube uses an eight-bit code that allows you to integrate values from 0 to 255. This system can synthesize 256*256*256 = 16777216 different colors.

By combining the three main wavelengths of light output, a color image is generated, which is displayed on the monitor screen and will be understandable to the human eye. When these images are synthesized, halftone satellite images are displayed, which correspond to different channels in the main colors.

To synthesize a color image of the selection of different details, you need to take three steps:

1) Selecting three halftone images that correspond to three channels.

2) Stressing the relative contrasts between the three images by displaying the first channel in blue, the second in green, and red in the third.

3) Combination of these three colors.

To increase the intensity of reflection in remotely sensed data and to see areas of the electromagnetic spectrum that are unable to distinguish the human eye, images in natural colors are used. For grayscale images, color filters are applied that match the color of the channels.

But there are cases when for each channel a filter that does not match its color is used. Thus, images in pseudo colors are obtained.

Advantages of using RGB models:

They combine different channels to highlight atmospheric and surface features that are difficult to distinguish in images in the same channel; each channel usually represents a certain wavelength, although combinations of channels are also used.

RGB technology produces intuitive, realistic looking products that can reduce ambiguity and simplify interpretation, making them useful for a wide range of users.

Future satellite sensors will have more channels, making RGB models even more useful for image analysis.

Chapter 5. Index methods

5.1 Oil spill index

Calculation of the amount of oil spilled from the pipeline is performed in 3 stages, determined by different expiration modes:

- the expiration of the oil from the moment of damage to the pumping stop;
- the flow of oil from the pipeline from the moment the pumping is stopped until the valves are closed;
- oil flow from the pipeline from the moment the valves are closed until the leak stops.

The volume of V_1 of oil, which has flowed out of the pipeline from the moment of τ_a accident till the moment of τ_0 pumping stop, is determined by the following ratio

$$V_1 = Q_1 * \tau_1 = Q1(\tau_0 - \tau_a) \quad (5.1)$$

Damage time of τ_a and stop time of τ_0 pumps is fixed by automatic control of pumping modes.

Oil flow through the damaged area Q_1 is determined from expression:

$$Q_1 = Q' - Q_0 \left\{ 1/(l - x^*) \left[Z_1 - Z_2 + \frac{P' - P''}{pg} - i_0 x * (Q'/Q_0)^{2-m_0} \right] / i_0 \right\}^{\frac{1}{2} - m_0} \quad (5.2)$$

Oil consumption in a serviceable oil pipeline at working pumping stations Q_0 is determined by the mode of loading the pipeline and is fixed by the readings of devices at oil pumping stations (OPS).

The length of the damaged section of the oil pipeline l enclosed between 2 OPS, the length of the oil pipeline section from the OPS to the point of damage x*, geodetic marks of the beginning of Z_1 and the end of Z_2 of the section l are determined by the profile of the oil pipeline route.

The flow rate Q', pressure at the beginning P' and at the end P" of section l in the damaged oil pipeline at the operating oil recovery unit are determined by the readings of instruments at the oil recovery unit at the moment of the accident.

Particular cases of Q_1 determination:

a) at Q' = Q_0 (when the leak rate is so low that it is not detected by the instruments at the oil recovery unit)

$$Q_1 = \mu\omega \sqrt{(2gh^*)} \quad (5.3)$$

The area of the defective opening ω, depending on the shape of the rupture of the wall of the oil pipeline.

The flow coefficient μ through the defective opening with a diameter $d_{op.}$ inevitable is determined according to Reynolds Re number according to Table 1.1

Table 1.1

Re	<25	25...400	400...10000	10000...300000	>300000
Flow coefficient μ	Re/48	Re/(1.5+1.4Re)	0.592+0.27/√Re	0.592+5.5/√Re	0.595

Reynolds Re's number is calculated by the formula

$$Re = d_{op} \sqrt{2gh^*})/v. \quad (5.4)$$

To determine the flow coefficient μ of holes whose shape differs from that of a round, the equivalent diameter is calculated.

$$d_{eqv} = \sqrt{4\omega/\pi}. \quad (5.5)$$

In this case, the formula (2.4) is substituted. $d_{op.} = d_{eqv}$

The pressure drop h* at the point of expiry depends on the pressure P' at the beginning of the section l, the hydraulic slope I', the distance of the fault location from the oil pump, the depth h_T of the oil pipeline, the pressure ha created by the atmospheric pressure, and is determined from the expression

$$h^*P'/pg - I'x^* - h_T =; \quad (5.6)$$

b) if P" = 0, or P" < (Z_n - Z_2) ρg, or P" < (Z_m - Z_2) ρg, then Q_1 = Q' (5.7)

External signs of oil film	Mass of oil on 1 m^2 of water surface, gr.
Pure water surface	0
Separate iridescent stripes are observed	0.1
Separate stains and grey films of silver plaque	0.2
Stains and films with bright colored stripes	0.4
Oil in the form of stains and film	1.2
The surface of the water is covered with a continuous layer of oil	2.4

5.2 Vegetation indices.

Spectral indices used to study and evaluate vegetation have been given a common name for vegetation indices.

A numerical index used for the visible and near infrared ranges of the electromagnetic spectrum. It analyzes the results of measurements using remote sensing and assesses whether the object under study contains live green vegetation or not[7].

Generally, healthy vegetation absorbs most of the visible light falling on it and reflects most of the near infrared radiation. Unhealthy or rare vegetation reflects more visible light and less near infrared. Naked vegetation reflects moderately in both the red and infrared parts of the electromagnetic spectrum.

Because plant behaviour is known throughout the electromagnetic spectrum, NDVI information can be obtained by focusing on the satellite ranges that are most sensitive to vegetation information (near infrared and red). The greater the difference between infrared and red reflection, the more vegetation must be.

The NDVI algorithm subtracts the red reflection values from the near infrared and divides it by the sum of the near infrared and red bands.

This formulation makes it possible to cope with the fact that two identical areas of vegetation may have different values if one is located, for example, under a cloudy sky and the other in a bright sun. Bright pixels will have large values, and therefore a large absolute difference between stripes. This can be avoided by dividing it by the sum of reflections.

One of the main signs of vegetation and its condition is the spectral reflectivity, characterized by large differences in the reflection of radiation of different wavelengths. Knowledge about the relationship between the structure and state of vegetation and its spectral reflectivity makes it possible to use aerospace imagery for mapping and identification of vegetation types.

To work with spectral information, "index" images are often used. On the basis of combination of brightness values in certain channels, informative for selection of the object under investigation, and calculation of the "spectral index" of the object on the basis of these values, an image, corresponding to the index value in each pixel, is built, which allows to select the object under investigation or to estimate its condition.

Calculation of the most part of vegetative indices is based on two most stable (not depending on other factors) sections of the curve of spectral reflectivity of plants:

The red zone of the spectrum (0.62-0.75 µm) accounts for the maximum absorption of solar radiation by chlorophyll, while the near infrared zone (0.75-1.3 µm) accounts for the maximum reflection of energy by the cellular structure of the leaf. I.e. high activity of photosynthesis, which is associated with a large phytomass of vegetation, leads to lower reflection coefficient values in the red zone of the spectrum and higher values in the near infrared zone. As it is well known, the ratio of these indicators to each other allows a clear separation of vegetation from other natural objects.

The calculation of the NDVI (Normalized Difference Vegetation Index) is additionally put into a separate ENVI tool. NDVI - Normalized Difference Vegetation Index, a simple quantitative index of the amount of phytomass. The index is calculated by the following formula:

$$NDVI = (NIR - RED) / (NIR + RED) \quad (5.8)$$

The following table shows the values of the NDVI index:

Table 1.2 NDVI value for different natural objects

Object type	NDVI value (µm)
Thick vegetation	0.7
Discharged vegetation	0.5
Open soil	0.025
Cloud	0
Snow and ice	-0.05
Water	-0.25
Artificial materials (concrete, asphalt)	-0.5

The NDVI Index takes positive values for vegetation, and the greener the phytomass, the higher it is. The NDVI Index values are influenced by.

Also, species composition of vegetation, its closedness, condition, exposure and angle of surface inclination, soil color under thin vegetation. The index is moderately sensitive to changes in soil background, except when the density of vegetation cover is below 30%.

The index can take values from _1 to 1. For green vegetation, the index usually takes values between 0.2 and 0.8. It should be noted that any vegetation indices do not give absolute quantitative indices of the investigated property, and their values depend on the sensor characteristics (spectral channel width, resolution), imaging conditions, illumination, atmosphere state. They give only relative estimates of vegetation cover properties, which can be interpreted and recalculated into absolute values using field data.

Soil adjusted vegetation index SAVI is calculated according to the equation:

$$SAVI = [(NIR - RED) (1 + l)] / (NIR + RED + l), \quad (5.9)$$

where, l is the soil factor, the value is in the range from 0 to 1. Choose a value equal to 0.5 to exclude the influence of different backgrounds in the following way

of sinfulness.

This index minimizes the effect of soil brightness on vegetation spectral indices such as red and near infrared (NIR) wavelengths.

The use of such characteristics as spectral brightness coefficients R (λ) and vegetation indices I(λ) in the tasks of thematic interpretation of cosmic spectrozonal images of natural objects is based on the traditional assumption of combination invariance:

$$I(\lambda_i, \lambda_k) = \frac{R(\lambda_i) - R(\lambda_k)}{R(\lambda_i) + R(\lambda_k)}$$

are essentially incident radiation relations to obtain characteristics that are invariant with respect to the variability of the energy flow.

Chapter 6. Image Analysis

Imagery database.

First of all, a database of images to be used in the analysis will be compiled. Satellite multispectral images will be provided. The data are taken from the satellite. MOD021KM, sensor – MODIS: Terra, source: ladsweb.modaps.eosdis.nasa.gov.

Table 1. List of multispectral images.

№	Image name	Location	Date	Time
1	MOD021KM.A2016238.0940.061. 2018061165340	Zhiloy island OPP «Neftynie kamni»	23.08.2016	09:40
2	MOD021KM.A2015232.0730.061. 2017322012815	Zhiloy island OPP «Neftynie kamni»	20.08.2015	07:30
3	MOD021KM.A2016185.0740.061. 2017326184245	Zhiloy island OPP «Neftynie kamni»	03.07.2016	07:40
4	MOD021KM.A2015163.0710.061. 2017320215321	Zhiloy island OPP «Neftynie kamni»	12.06.2015	07:10
5	MOD021KM.A2010127.0745.061. 2017255001108	Zhiloy island OPP «Neftynie kamni»	07.05.2010	07:45
6	MOD02HKM.A2010129.0735.061. 2017251224524	Zhiloy island OPP «Neftynie kamni»	09.05.2010	07:35
7	MOD02HKM.A2010175.0745.061. 2017255125928	Zhiloy island OPP «Neftynie kamni»	24.06.2010	07:45
8	MOD021KM.A2015153.0810.061. 2017320195156	South-Western part of the Caspian Sea	02.06.2015	08:10
9	MOD021KM.A2015216.0730.061. 2017321212846	South-Western part of the Caspian Sea	04.08.2015	07:30
10	MOD021KM.A2015155.0800.061. 2017320201958	South-Western part of the Caspian Sea	04.06.2015	08:00
11	MOD021KM.A2015156.0705.061. 2017320222305	South-Western part of the Caspian Sea	05.06.2015	07:05

After reviewing each case, it turned out that not every multispectral image can detect an oil spill. This is due to a number of reasons, such as: dense cloud cover, heavy rainfall, strong wind, strong waves at sea. Poor resolution of the satellite lens may cause inability to detect oil spills on images.

In case number one, which will be considered further, was clear weather, wind is weak, 2-3 meters per second, visibility 10 km or more. The data was taken from website rp5.ru, from near Baku weather station for 23 August 2016 in the period from 9 to 10 hours.

Images from this case will be presented in IR, visible ranges of the RGB model and in pseudocolors. Changes in each image will be detected and conclusions will be drawn about the convenience of each image.

Zhiloy island, OPP «Neftynie kamni». Date 23.08.2016 time 09:40.

Infrared channel.

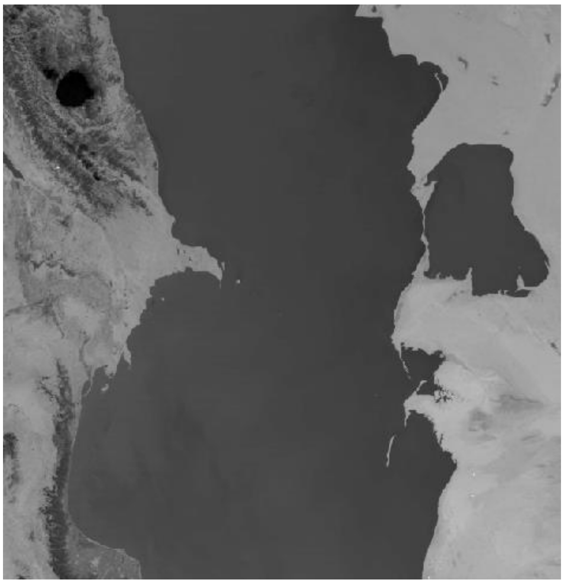

Figure 7. An oil spill near OPP «Neftynie kamni». (3750 nm)

The residential island is located in the center of the image. No spill can be seen at first glance on the image. But as the image grows, the northern part of the island shows a dark elongated silhouette, which may well be a spill caught by the current and spilled over the sea. This cannot be a shadow from the cloud, as the sky above the island and its immediate surroundings is clear.

If you take a closer look, you can see a barely visible silhouette of an oil production platform near the island. Such blurring of the image is related to the satellite resolution but if it is possible to distinguish objects on the image we can already speak about the multispectral image efficiency.

Figure 8. Approximate image. (3750 nm)

Now let's look at the image in the visible range.

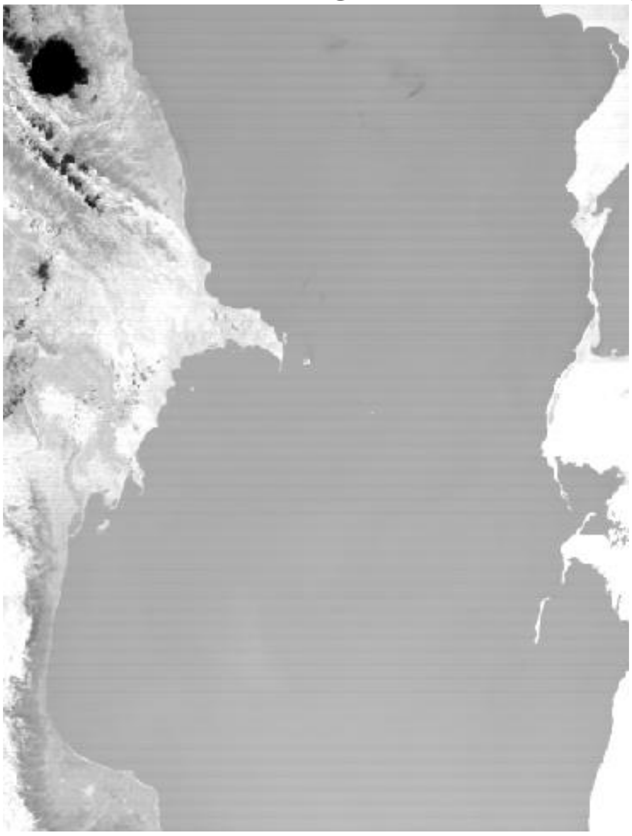

Figure 9. An oil spill near OPP «Neftynie kamni». (4515 nm)

This picture is duller than the last one, and even the island is barely visible. However, as we approach, we can see two dark stripes stretching from south to north that were not visible on the symphony in infrared mode. The "spill" near the island is almost inv isible.

Figure 10. Approximate image. (4515 nm)

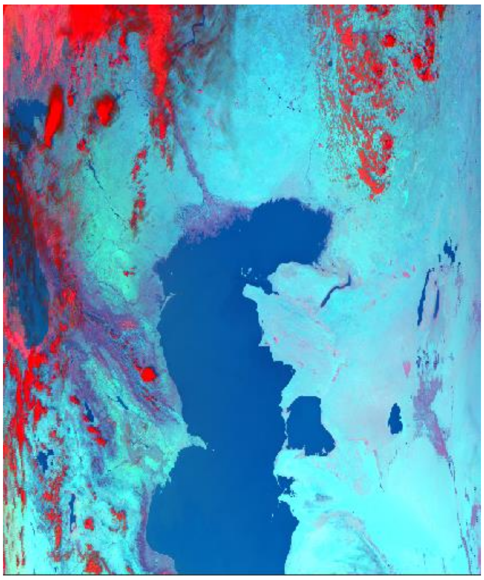

Figure 11. RGB model

When creating this model, the following filters were applied to the main channels:

Towards the red – EV_250_Aggr1km_RefSB_2;

Towards the green – EV_1KM_Emissive_22;

Towards the blue – EV_1KM_Emissive_31.

Figure 12. Approximate RGB model

On the resulting model the clouds became red, the water became dark blue, the land is bluish and the rivers became purple, which we see on the example of the Volga and its delta.

When we zoom in, the image above the island is still a spot, and it is not red, so we conclude that it is definitely not a cloud. We could say that it is a fog, but in previous images it did not show such properties.

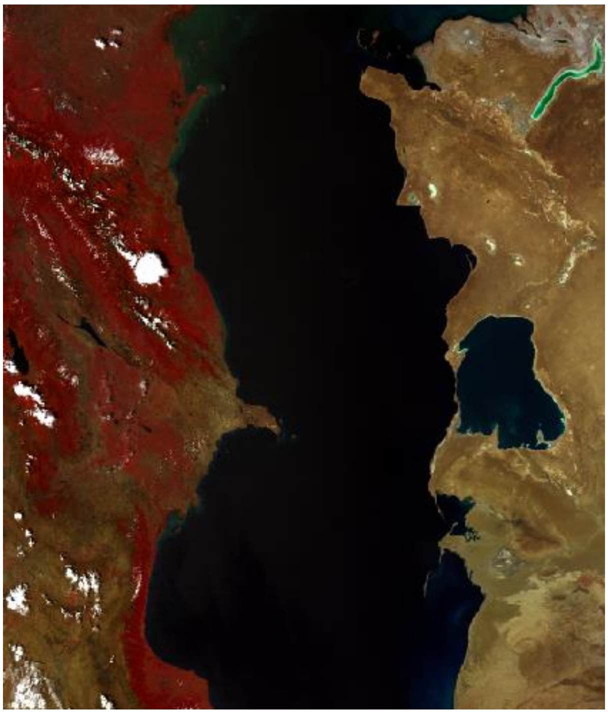

Figure 13. Natural color image.

This image has more pleasant shades for human eye.

Filters used:

Towards the red – EV_250_Aggr1km_RefSB_2;

Towards the green – EV_250_Aggr1km_RefSB_1;

Towards the blue – EV_250_Aggr1km_RefSB_3.

Figure 14. Approximate natural color image.

The dark elongated spot merges with the water surface, but if you look closely, you can see that this spot stands out against the green algae.

Figure 15. Pins on oil, water, land №1

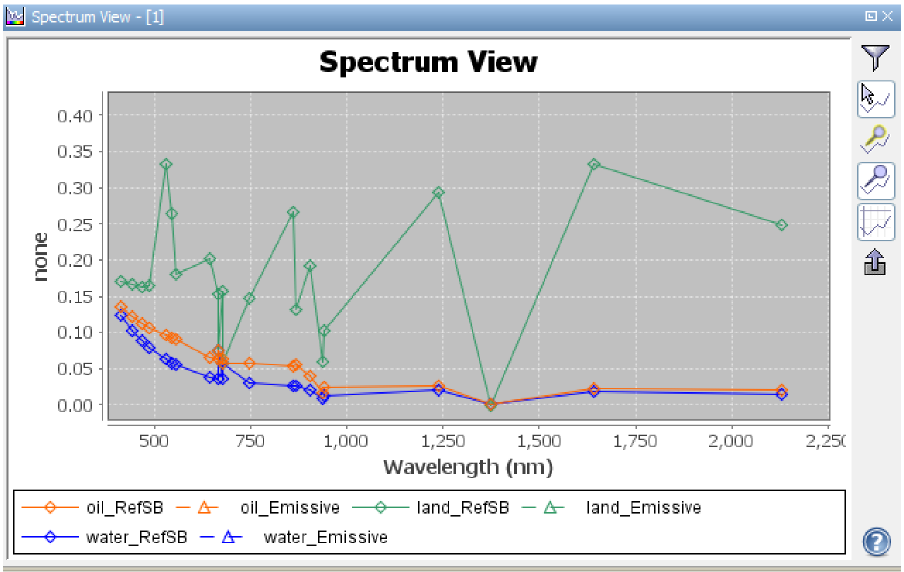

Figure 16. Spectrum View 0.5 – 2.0 µm

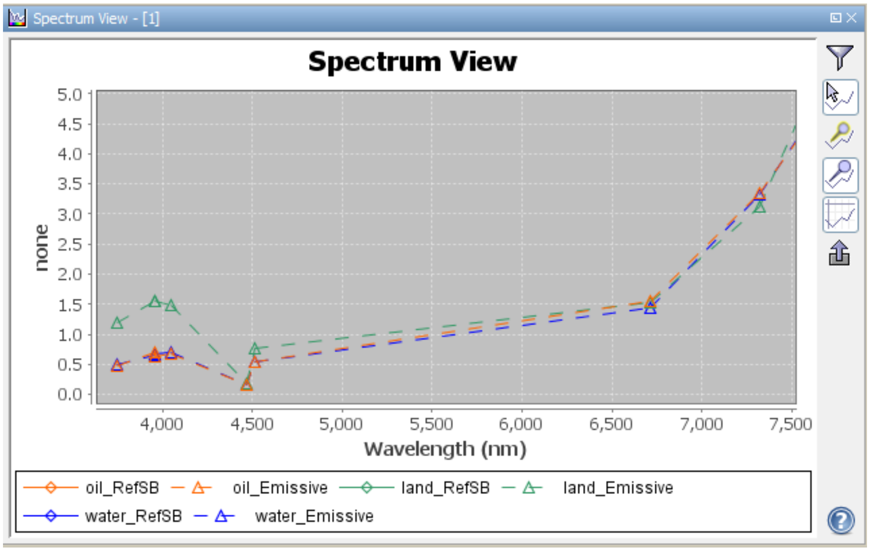

Figure 17. Spectrum View 4.0 – 7.0 µm

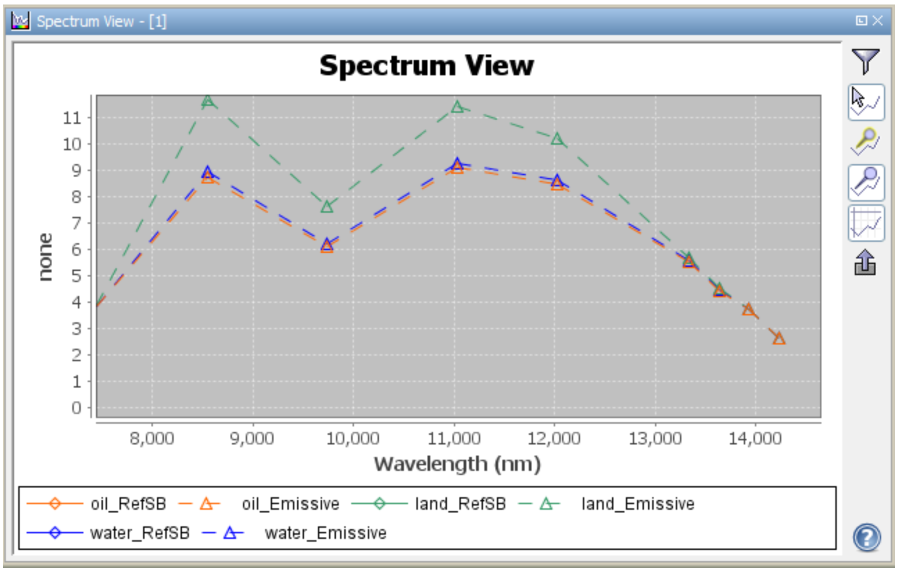

Figure 18. Spectrum View 7.5 – 14.0 µm

Figure 19. Pins on oil, water, land №2

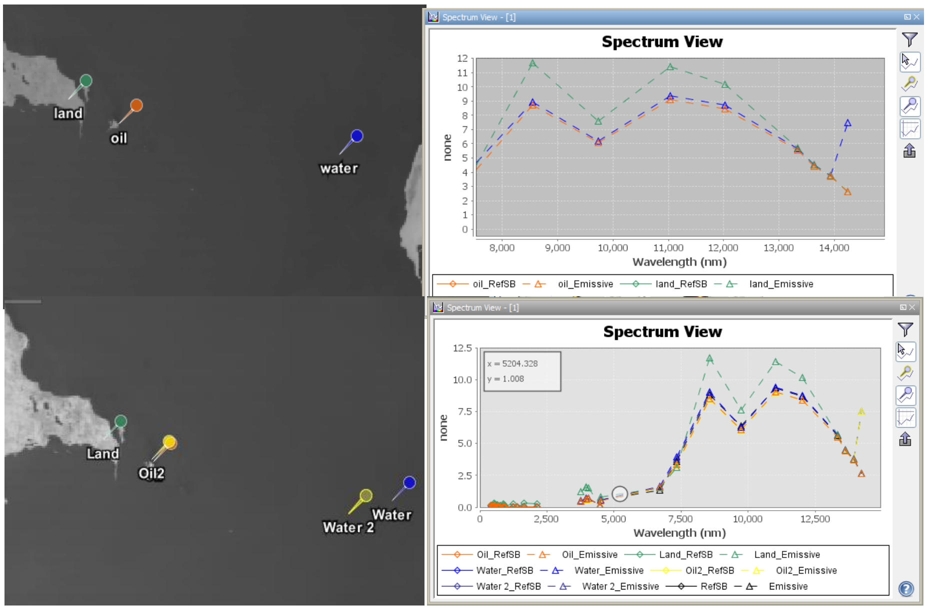

Figure 20. Spectrum View 7.5 – 14.0 μm

In this spectrogram, we see that the waves are parallel and only at the end of the water channel rises sharply.

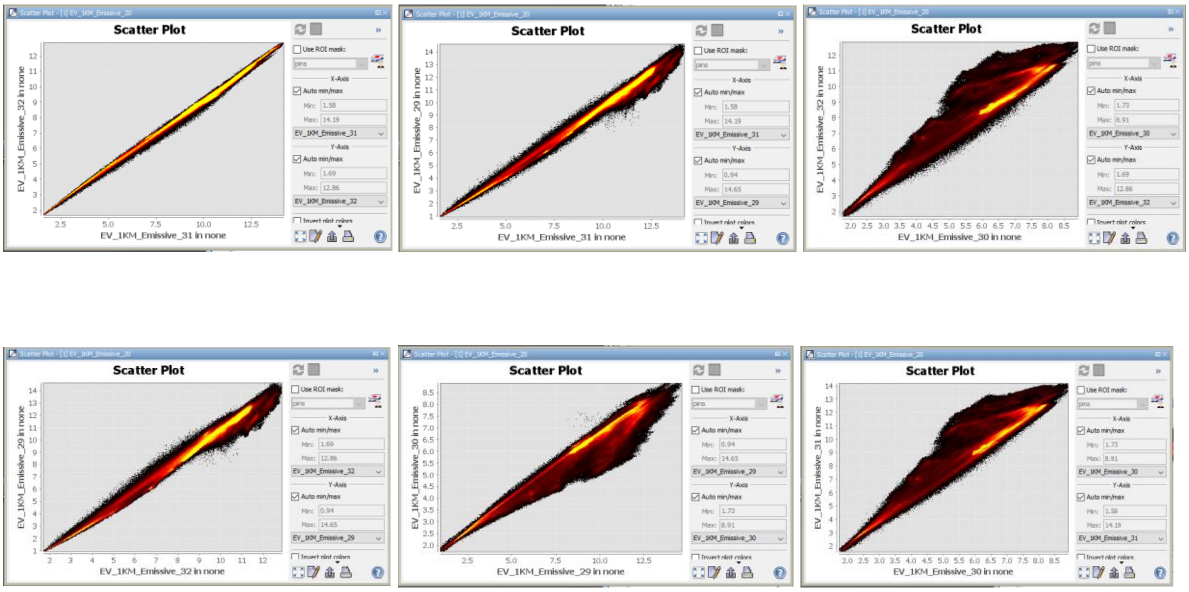

Figure 21. Scatter Plots of the image in different combinations of bands.

Bands: 29,30,31,32.

Conclusion

In carrying out this work, the following conclusions were drawn.

The Caspian Sea is rich in diverse terrain and meteorological conditions that determine the climate in each of its three parts. Its shelf is full of oil reserves and production will continue despite the environmental hazards.

The properties of oil on the surface are well studied, which helps to combat the spread of oil slicks when it spills. There are many ways to eliminate oil, but very few of them are environmentally friendly, for example, when cleaning up an oil spill ships themselves leave fuel waste, which also leads to a dangerous impact on the environment. It is worth paying attention to this factor and looking for cleaner ways to purify seawater from oil.

RGB models are a strength of multispectral analysis. However, even with their help it is not always possible to find spills on the water surface.

The development of index methods will help further study and improve oil spill response measures.

Meteorological phenomena or low resolution of the satellite lens may cause an oil spill to be impossible to find.

When cleaning the water surface from oil products, the ships themselves may leave traces of fuel emissions. There is a need to create a cleaner and more environmentally friendly way to get the cleaning equipment to the accident site.

Due to the oil film, there are temperature differences between the water and air surfaces, which can lead to cyclones.

While performing analysis of spectral images, various methods of their modification and spectrogram construction were considered. Undoubtedly, when studying and comparing indices at different wavelengths, we get important information on further development of oil spill detection.

References

1. Alchemenko. A. I., Emergency oil spills at sea and the struggle against them. Textbook. - SPb: OM-Press, 2004. - 113 pg.
2. ladsweb.modaps.eosdis.nasa.gov.
3. Lavrova O. U., Mityagina M. I., Kostyana A.G. Satellite methods of detection and monitoring of the ecological risk zones of the sea areas. - Moscow: IKI RAS, 2016. - 334 pg.
4. Guliyev A. Sh., Khlebnikova T.A., - Detection of offshore oil pollution sites based on space imagery data (on the example of Neftynie kamni (The Caspean Sea) water area), - 2019. – 13 pg.
5. Cherepanov A.S., Druzhinina E.G., Spectral properties / Vegetation and vegetation indices [Text], Geometika №3, 2009. – 5 pg.
6. www.elibrary.ru
7. Understanding the Normalized Diffrence Vegetation Index. – 2 pg.
8. James A. F., David P. H., Physical processes in the spread of oil on water surface. – Department of mechanical engineering Massachusetts Institute of Technology Cambridge, Massachusetts., - 1971. – 21 pg.
9. Klikushin U.N., RGB – Scale for measuring distributions / [Text], - Omsk State Technical University, - "JOURNAL OF RADIO ELECTRONICS" №3, 2008. – 9 pg.
10. Viktorovich B. V., Vagitovich A. Z., Vegetation indexes and their use for mapping mountainous landscapes of the Russian caucasus [Text], - Electronic scientific journal “Apriori. Series: Natural and technical sciences” №1, -2017. – 21 pg.
11. sorbenti.ru/sbor-nefti/skimmery.
12. ITOPF, The behaviour of marine oil spills [Text], Technical Information Document 2, UK, - 2011. – 12 pg.
13. Bakun O., Ivanov. A., Filimonova. N. – Multi-year satellite monitoring of the environmental situation in the northern part of the Caspian Sea [Text] – 2015. – 27-31 pg.
14. Zyryanov V.N., Shurganova S.V. – Oil spreading on sea surface with the weathering effect [Text]. – 7 pg.
15. Azigaliev M.D., Gubashev S.A., - Oil spill prevention and response plan related to the project for construction of an appraisal well ZT-2 on the Zhetysu structure., Book №4., - 2017. – 115 pg.
16. CHANG Luciang, Shenzhen tea star optoelectronics, - System and method of RGB to RGBW color conversion. – 2006. – 22 pg.
17. Yashchenko I.G., Peremitina T.O., Luchkova S.V., - Environmental impact of oil and gas companies / Integrated assessment of the environmental risks of oil spills. – 2004. – 9pg.

18. Avagimyan A.V., - Operational monitoring of oil spills and leaks offshore. – 7 pg.
19. Menshikov V.A., Menshikov V.V., Chursin O.B., - Investigation of efficiency of cosmic methods of monitoring potentially dangerous natural phenomena and technogenic objects in infrared thermal range ininstalling measuring remote sensing measures on a piloted space complex. – 2017. – 117 – 126 pg.
20. Donzova M. A., - Video coloristic features of metamere RGB color model, - 2013. – 2 pg.
21. Shichkin D. A., - Analysis and usage of dependences between components of RGB for tasks of objects selection on the images., - 2013. – 10 pg.
22. www.rp5.ru/ archive
23. Abdurakhmanov G.M., Teymurov A.A., Stun S.Y., Soltanmuradova Z.I., Huseynova S.A., - Predicting the dynamics of the oil slick and its impact on marine and coastal emissions middle Caspian ecosystem., - 2012. – 8 pg.
24.. Kurchenko A. B., Pecherskaya L. B., - System for collection and neutralization of oil wastes generated in the course of liquidation of consequences of emergency oil spills.
25. Zanozin V.V., Karelov A.V., Efimova V.V., - Methods of detection and recovery of the consequences of an oil spill in the Caspian Sea in the iced period, - 105-108 pg.