The Criterial Optics of Oceans and Glaciers with Technogenic Pollutions

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Abstract. Effective diagnostics of natural and technogenic pollutions of the ocean and forming snow-ice cover is considered on the basis of priority observation and registration of the changing optical characteristics of the seawater and glaciers. The paper discusses Influence of abnormal optical properties on overheating of the seawater subsurface layer and appearance of significant irradiated oceanic deep horizons up to 100 m. Additional heating of atmosphere, strengthening of hurricanes during a storm, tornadogenesis, generation of dehydrated convective air flows at a calm and effect of overcooling deep seawater is analyzed using the scheme of calculated heat budget and temperature distributions under combined solar and atmospheric exposure. The authors propose to use their unique deep hydrological multi-channel probe for synchronous and independent registration of optical, temperature and other standard hydro physical characteristics developed by Shirshov Institute of Oceanology. The paper presents calculation algorithm of real variability of spatial and temporal temperature field due to influence of registered concentration field of foreign substances in the seawater irrespective of its hydrodynamic conditions. Inphase or antiphase changes of fixed temperature gradients and transparency for polluted seawater has been explained as the result of the various contributions of scattering and absorption within attenuation processes of probing radiation for the local volume at a specified depth.

INTRODUCTION

The scales of anthropogenic and abnormal natural impact on the environment have become recently planetary. Technogenic catastrophes have become frequent; they are usually associated with the intensive technogenic pollution of the environment (especially the oceans, their marine and river basins) which is caused usually by the exploration and transport of considerable volumes of oil. That leads to the reduction of the stability of ecological and economic systems, irreversible and even sharp deviations in the dynamics of natural processes and changes habitual conditions of people's ability to live in vast territories [1, 2]. Therefore it is necessary to study the technogenic origin changes of natural situation as physical problem [3, 4]; in turn, it is necessary to understand many observed phenomena [5-7] caused by possible natural or technogenic climatic anomalies in aspects of our knowledge of environment.

In Mexico Gulf in April, 2010 half one million tons of crude oil was thrown out from the damaged bore hole within the period of three months [2, 6, 7]. The oil which has got to the seawater quickly spreads on a surface forming a thin oil film or water-oil emulsion (WOE). This process was theoretically simulated only as a dynamic process of change in velocity of sea currents [2, 6, 7]. The method of thermodynamic analysis regime may be based on theoretical evaluations for known thermal physical and optical parameters of pure and polluted seawater [8-10].

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Currently, the most common method of obtaining information on the condition of the World Ocean and the individual ocean basins is the distance sensing satellite. For verification of satellite data about the variability parameters of the hydro physical fields it is necessary to carry out in-Situ measurements using the submersible multi-channel probes at predetermined points for the sub-satellite polygons [11-13].

Features of solar and atmospheric radiation propagation in the ocean determine the character of heat transfer, the heating of seawater, sun exposure photic zone, as well as the level of technogenic pollution. This radiant - convective energy exchange and thermal regime of seawater area have a determining influence on the formation of the Earth's climate; insolation of the photic zone causes the productivity of the World Ocean.

PHYSICAL AND MATHEMATICAL MODELS OF POLLUTED SEAWATER

Optical properties of seawater are changing insignificantly versus variations of water physical state, but essentially depend on the number and composition of the impurities containing within seawater determining regime of penetrating heat radiation and, therefore, the formation of temperature fields.

Contemporary diagnostic methods allow fixing with high precision temperature-depth profile depending upon the composition of seawater and its dynamic parameters. Thus, radiant heating of the ocean at the same latitude can be determined by ambiguous thermal regime even at the similar level of natural or technogenic pollutions. It is of interest the emerging heating of atmosphere due to a model temperature profile *T(x,t)* calculated using optical properties of suspensions with measured concentrations in seawater at the absence of any oceanic currents.

For this purpose it is necessary to solute the inhomogeneous heat conductivity equation using the following thermal diffusivity equation with absorption energy function in two fluxes approximation (radiant thermal source with N spectral intervals) in one-dimensional approach for pure or polluted seawater:

$$c_p \cdot \rho \frac{\partial T(x,t)}{\partial t} = \frac{\partial}{\partial x}\left(K_T \frac{\partial T(x,t)}{\partial x} \right) + \sum_{i=1}^{N} \frac{q_0(\lambda_i,t)\cdot(1-A_i)\cdot b_i}{1-A_i^2 \cdot \exp(-2b_i \cdot H)} \times \left\{ \exp(-b_i \cdot x) - \exp\left[(2b_i \cdot (x-2H)\right] \right\} \quad (1)$$

with the condition of heat exchange on the exposed seawater surface $x=0$ – as impact of energy losses for phase transitions, air convective and thermoradiative fluxes:

$$-K_T \frac{\partial T(x,t)}{\partial t} = \alpha_T \cdot \left(T_A - T(x,t)\right) + \varepsilon_{ef} \cdot c_0 \cdot \left(T_A^4 - T(x,t)^4\right) + q_0^{UR} + q_0^{R} + q_0^{UV} - \rho \cdot L_v \cdot \frac{dx_v}{dt}, \quad (2)$$

where $\varepsilon_{ef} = \left(1/\varepsilon_A + 1/\varepsilon_S - 1\right)^{-1}$ - the effective blackness coefficient for the mutual radiated atmosphere and oceanic surface; $\varepsilon_A, \varepsilon_S$ - the blackness coefficients of atmosphere and seawater surface respectively in the long wavelength range of the solar radiation; q_0^{UV}, q_0^{R}, q_0^{UR}, - components of the solar radiation flux within ultraviolet, red and infrared diapasons (for these fluxes seawater is the nontransparent environment); T_A - temperature of atmosphere; α_T - the convective heat transfer coefficient on the boundary between the sea surface and atmosphere; c_o - the Stefan-Bolzman constant; c_p , K_T - specific heat capacity and thermal diffusivity coefficients; ρ - the seawater density; dx_v/dt - the velocity of the evaporation boundary displacement; L_v - the heat of seawater evaporation; $q_0(\lambda,t)$ - fallen radiate flux in N subbands within solar spectrum on the oceanic layer with thickness H; $b = \sqrt{\kappa^2 + 2\beta \cdot \sigma \cdot \kappa}$ - the effective attenuation coefficient; κ - absorption and σ - scattering indexes; $A = (b-\kappa)/(b+\kappa)$ - reflectance of semi-infinite layer; $\beta = 0.5$ - the share of penetrating radiation scattered toward along propagation of probing radiation.

Presented algorithm calculating the radiant and temperature fields requires accurate and correct evaluation of the absorption, scattering indexes and the phase function. This problem was solved by using of experience of numerous researches of the optical parameters of ceramics, composites, glass, ice and etc. Solid samples of these materials allow to estimate both reflection and transmission coefficients [8-10].

For liquids, seawater it is possible to be limited by registration transmission coefficients for different pathlengths (base light propagation) of laboratory and industrial transmissometers. Light attenuation coefficients are calculated using the Bouguer-Lambert law based on transmittance measuring of seawater layer with help of numerous types of multifunctional sensors and transmissometers ("Sea Oil-in-Water™ Locator", "C-Star" or Russian "PUM-A" [14-16]) with diagnostics different optical or fluorescence spectra. Additional laboratory spectrophotometric researches in-Situ of seawater samples with heterogeneous suspensions allow to carry out direct evaluation of absorption and scattering coefficients (or "indexes" – following classical terminology in Optics).

Thus inphase or antiphase changes of fixed temperature gradients and transparency for polluted seawater has been explained as the result of the various contributions of scattering and absorption within attenuation processes of probing radiation for the local volume at a specified depth [11-13, 17-18].

The scheme of the global redistribution of thermal fluxes in the atmosphere and ocean as a result of the large scale technogenic oil pollution on the seawater surface is shown in the Fig. 1.

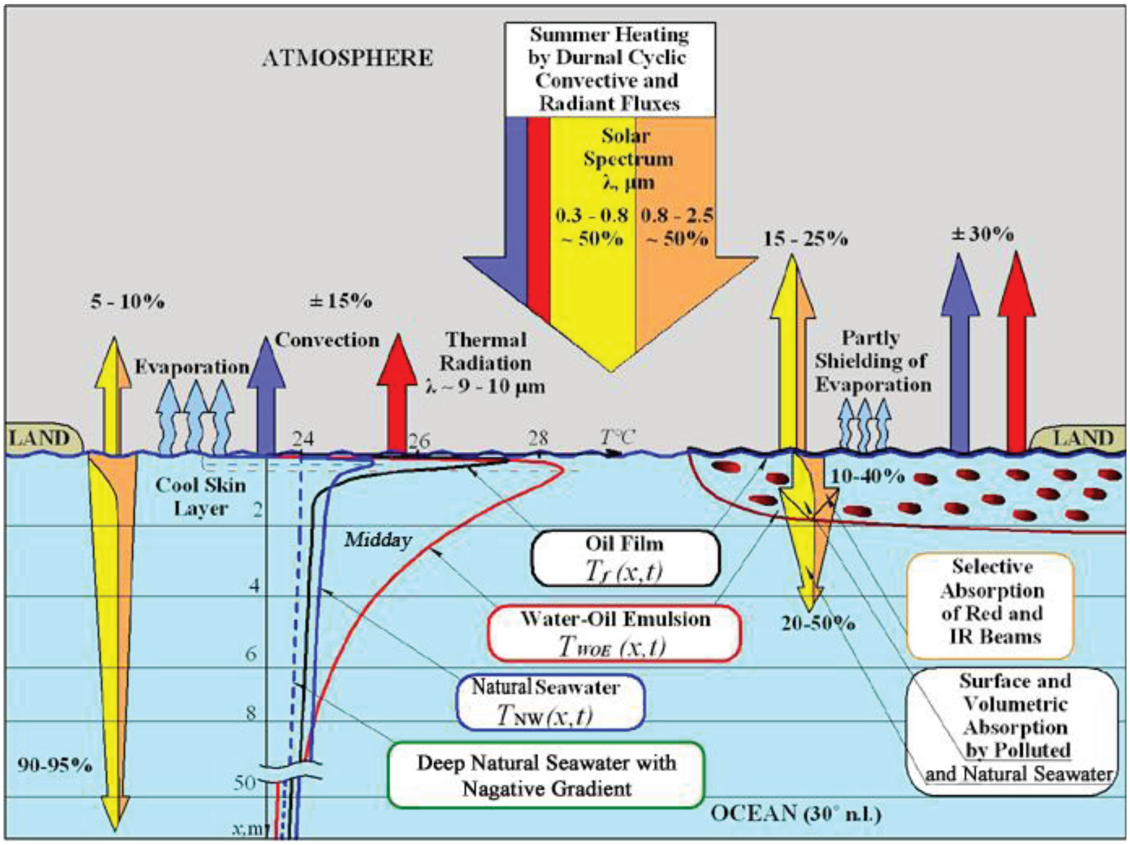

FIGURE 1. Model convective-radiative heat exchange at the ocean-atmosphere interface and simulated temperature distributions T (x,t) of natural seawater (NW) and water-oil emulsion (WOE)

Plots of simulated temperature distributions *T(x,t)* versus ocean thickness *x* are presented at astronomical midday in calm at complex radiant heat- and mass exchange, including spectral solar and atmospheric radiant fluxes, convective and evaporation thermal losses at daily cyclic inphase impact on natural (A =10%, κ_{NW} = 0.050 m^{-1} and scattering σ_{NW} = 0.01 m^{-1} indexes [19]) and oil-polluted (A =17%, κ_{WOE} = 0.50 m^{-1}, σ_{WOE} = 0.25 m^{-1} [20]) seawaters. Absorbed to 90-95 % solar flux (the narrowed yellow arrow directed downwards, in the left-hand of Fig. 1) proves the main contribution into the ocean heating under the conditions of weak scattering of pure seawater up to the depth ~ 100 m with surface reflectance up to ~ 5-10 %. Solar penetrating radiation ensures subsurface overheating with the formation maximum of temperature due to the surface cool skin layer.

In the case of the oil-polluted seawater (black drops of oil in subsurface area) the essential growth of the scattering and absorption of the sunlight occurs. It causes both the increase of the reflected solar radiation flux up to ~ 15 - 25% (on the right-hand of the Fig. 1) and the absorbed solar flux (up to 40% in the polluted subsurface area). No more than 60% of the solar flux extends within seawater, and heating of deep seawater decreases considerably.

Thus abnormal optical properties determine overheating of the subsurface layer seawater and appearance of significant irradiated ocean deep horizons. Additional heating of atmosphere, strengthening of hurricanes during a storm, tornadogenesis, generation of dehydrated convective air flows at a calm and effect of overcooling deep seawater require careful optical diagnostics in assessing the impact of absorption and scattering processes.

CONCLUSION

Changes in the optical properties of seawater caused by natural and technogenic pollutions (deposition of airborne dust, volcanic ash, oil spill and etc.) can induce subsurface overheating or overcooling of deep seawater due to disturbances of radiative-convective heat transfer at the boundary of the ocean with the atmosphere. Proposed theoretical approach and numerical modeling allowed calculating of complex heat transfer of marine and glacial environments with large pollution. The heat budget can be destroyed by redistribution of reflected, absorbed and emitted heat radiant fluxes, and also by changes in energy losses caused the anomalous evaporation (melting) at the boundary with the atmosphere. In this way an abnormal change in the optical properties becomes the criterion of meteorological characteristics of the ocean-atmosphere system.

To reveal above described factors resulting in technogenic disasters the authors propose to measure both optical and temperature characteristics with developed and tested on-board measuring system (with active depth of observation of sun exposure up to 300 m) [12, 14]. The measuring system has the interfaces of data transmission (4 channels Fast Ethernet 100 Mbit and RS485 channel); the hydrophysical module including registration of temperature (–5 ÷ +35 °C), attenuation coefficient (index) of directional light (0.03÷2 m^{-1}), using laser beam (530 nm) with base (pathlength) of light propagation up to 250 mm. Experimental distributions of sea suspended matter or pollution (fields of concentration) allows modeling and correcting of the parameters of the radiant field in the seawater regarding calculated estimation of absorption and scattering indexes, besides direct in-Situ measurement of attenuation coefficient for probing radiation.

So monitoring of Ocean Optics could be a criterion of quality forecast of the regime of anomalous overheating or overcooling of seawater for revealing natural and anthropogenic factors influencing climate change.

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