The role of surface active agents in the processes of heat / mass transfer in the system “ocean-atmosphere”

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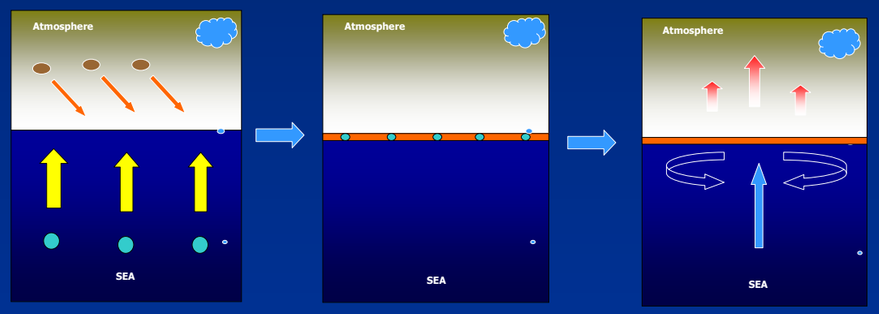
Phenomenon

More than half of the heat balance in the system "ocean-atmosphere" is governed by hidden heat, which is supplied from the oceanic micro layer to the atmosphere. In this process the role of gravity-capillary convection is relatively poorly understood. The situation becomes even more complicated in the case of the presence of Surface Active Agents (SAAs), which have biogenic and anthropogenic origin. SAAs change the rheology of matter and introduce an additional physical process - adsorption, which leads to the gathering of SAAs at the free surface.

Intensification of heat/mass exchange between ocean and atmospere



Surface Active Agents (SAAs) are the product of human activity, erosion of soil and rocks, blowing sand from the deserts, etc. They get from the atmosphere and sea water into surface layer.

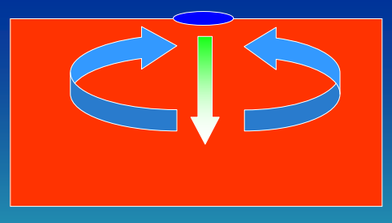
SAAs tend to gather at the free surface; such process is called adsorption. The presence of SAAs at the water surface reduces the surface tension, which in turn reduses the surface energy.

The prosess of adsorption changes the reology of matter and causes convective prosesses. An additional heat flow and highly concentrated SAAs penetrate from the ocean into the atmosphere.

Mechanism

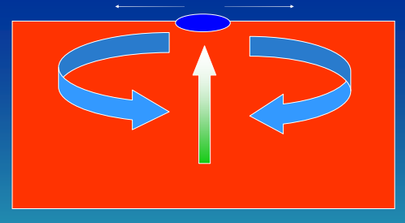
The presence of SAAs results in two types of convection

Gravity convection



Mechanism of the gravity convection caused by the density excess at the free surface. SAAs play a secondary role.

Capilarry convection



Capillary convection originates due to the change of the surface tension, caused by the fluctuation of surface concentration of SAAs.

Problem statement

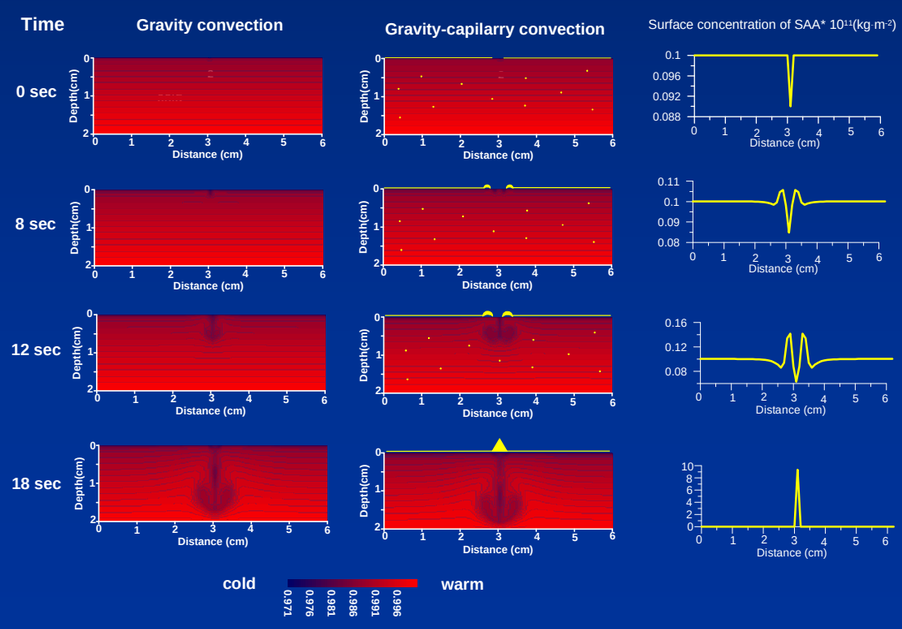
The principal aim is to study the dynamical processes developing in a thin surface layer in the presence of Surface Active Agents and to quantify the role, which SAAs can play in the process of heat/mass exchange between ocean and atmosphere.

Dynamics of Surface Layer

Gravity-capillary convection developing in a thin sea surface layer is studied numerically in the framework of the two-dimensional Navier-Stokes equations. The specific feature of the model is in its ability to reproduce the gravity and capillary convection in the presence of adsorption. Besides the ordinary mass, heat and momentum balance equations, the model also includes the equations for the concentration of SAAs at the free surface.

Numerical simulations of gravity-capillary convection without (left) and with (right) SAA at the free surface

Evolution of surface concentration of SAA



Capillary convection is at least twice as fast as the gravity one. At the initial stage it works as a “trigger” initiating the gravity convection (note the “pole-axe” structure at the 12-th second as an intermediate stage in transformation of the capillary convection into the gravity convection). On a long temporal scale the influence of the capillary convection decreases.

Ocean-Atmosphere Interaction

Heat transfer in the system “ocean-atmosphere” is described by the formula:

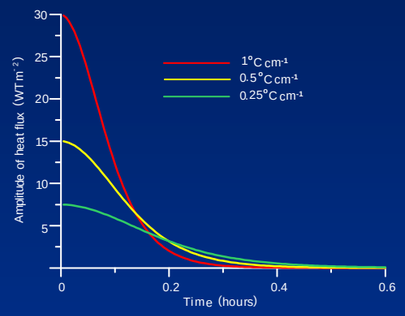
$$Q(\delta\Gamma,\nabla T,t)=(1+7\cdot10^{-5}\nabla T)(e^{-\delta\Gamma^2}\log(16/\delta\Gamma)+e^{-(\delta\Gamma/2.5-1)^2}(5-\delta\Gamma)+e^{-(\delta\Gamma/5)^4})Q(1,2,t)$$

Here T is the temperature of water; Γ denotes the surface concentration of SAAs; δΓ is the fluctuation of concentration; Q denotes the heat capacity. This formula is valid for a short period of time when the magnitude and type of fluctuation are significant. On a long temporal scale the heat flux does not depend on magnitude and type of fluctuation, and following formula is valid:

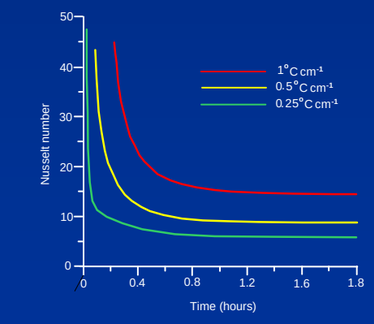
$$Q(\delta\Gamma,\nabla T,t)=(1+7\cdot10^{-5}\nabla T)Q(1,2,t)$$

Ascending Heat Flux

Temporal dependence of the ascending heat flux for three initial temperature gradients



The dependence of the Nusselt number vs. time for three initial temperature gradients



Summary

Most Surface Active Agents (SAAs) are harmful to human health, and understanding the mechanism of SAAs adsorption, which greatly increases their surface concentration with respect to the bulky concentration, is very important. Being gathered at the free surface, SAAs give rise to the capillary convection.

The capillary convection is many times weaker than its gravity counterpart; it becomes a starting mechanism for the gravity convection. This, in turn, leads to the considerable increase in the heat flux from the ocean to the atmosphere (several times) in comparison with the simple heat exchange provided by only diffusion. Thus SAAs introduce an additional effect into ocean-atmosphere interaction, which can also affect the climate change.