

# SURFACE FILMS

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## Introduction

Surface films floating on the sea surface are usually attributed to anthropogenic sources. Such films consist, for example, of crude oil discharged from tankers during cleaning operations or accidents. However, much more frequently surface films that are of natural origin are encountered at the sea surface. These natural surface films consist of surface-active compounds that are secreted by marine plants or animals. According to their physico-chemical characteristics the film-forming substances tend to be either enriched at the sea surface (more hydrophobic character, sometimes referred to as 'dry surfactants') or they prevail within the upper water layer (more hydrophobic character 'wet surfactants'). The first type of surface-active substances ('dry surfactants') are able to form monomolecular slicks at the air-water interface and damp the short-scale surface waves (short-gravity capillary waves) much more strongly than the second type. This implies that they have a strong effect on the mass, energy, and momentum transfer processes at the air-water interface. They also affect these transfer processes by reducing the turbulence in the sub-surface layer which is instrumental in transporting water from below to the surface.

Both types of surface films are easily detectable by radars because radars are roughness sensors and surface films strongly reduce the short-scale sea surface roughness.

## Origin of Surface Films

Surface films at the sea surface can be either of anthropogenic or natural origin. Anthropogenic surface films consist, e.g., of crude or petroleum oil spilled from ships or oil platforms ('spills'), or of surface-active substances discharged from municipal or industrial plants ('slicks'). Natural surface films may also consist of crude oil which is leaking from oil seeps on the seafloor, but usually they consist of surface-active substances, which are produced by biogenic processes in the sea ('biogenic slicks'). In general, the biogenic surface slicks consisting of suf-

ficiently hydrophobic substances ('dry surfactants') are only one molecular layer thick (approximately 3 nm). This implies that it needs only few liters of surface-active material to cover an area of 1 km<sup>2</sup>. The prime biological producers of natural surface films in the sea are algae and some bacteria. Also zooplankton and fish produce surface-active materials, but the amount is usually small in comparison with the primary biological production. Primary production depends on the quantity of light energy available to the organism and the availability of inorganic nutrients. In the higher latitudes light energy depends strongly on the season of the year which results in a seasonal variation of the primary biological production in the ocean and thus of the slick coverage by natural surface films. At times when the biological productivity is high, i.e., during plankton blooms, the probability of encountering natural biogenic surface films is strongly enhanced.

In other regions of the world's ocean where the primary production is not mainly determined by the quantity of light energy available to the organisms, but by the nutrient levels, the seasonal variation of the slick coverage is smaller, however, still observable. Surface slicks of biogenic origin are mainly encountered in sea regions where the nutrition factor favors productivity. This is the case on continental shelves, slopes, and in upwelling regions where nutrition-rich cold water is transported to the sea surface.

The areal extent, the concentration and the composition of the surface films vary strongly with time. At high wind speeds (typically above 8–10 m s<sup>-1</sup>) breaking waves disperse the films by entrainment into the underlying water such that they disappear from the sea surface. In general, the probability of encountering surface films of biogenic origin decreases with wind speed. Furthermore, after storms, enhanced coverage of the sea surface with biogenic slicks consisting of 'dry surfactants' is often observed which is due to the fact that, firstly, the secretion of surface-active material by plankton is being increased during higher wind speed periods, and secondly, the surface-active substances are being transported to the sea surface from below by turbulence and rising air bubbles generated by breaking waves. The composition of the sea slicks varies also with time because constituents of the surface films are selectively removed by dissolution, evaporation, enzymatic degradation and photocatalytic oxidation.

## Modifications of Air–Sea Interaction by Surface Films

Numerous processes that take place at the air–sea interface are affected by surface films. Among other things, surface films: (1) attenuate the surface waves; (2) reduce wave breaking; (3) reduce gas transfer; (4) increase the sea-surface temperature; (5) change the reflection of sunlight; and (6) reduce the intensity of the radar backscatter.

### Attenuation of Surface Waves

Two main factors contribute to the damping of short-scale surface waves by surface films:

1. the enhanced viscous dissipation in a thin water layer below the water surface caused by strong velocity gradients induced by the presence of viscoelastic films at the water surface; and
2. the decrease in energy transfer from the wind to the waves due to the reduction of the aerodynamic roughness of the sea surface.

The enhanced viscous dissipation caused by the surface films results from the fact that, due to the different boundary condition imposed by the film at the sea surface, strong vertical velocity gradients are encountered in a thin layer below the water surface. This layer, also called shear layer, has a thickness of the order of  $10^{-4}$  m. Here strong viscous dissipation takes place. In the case of mineral oil films floating on the sea surface, the shear layer may lie completely within the oil layer, but more often it extends also into the upper water layer since the thickness of mineral oil films is typically in the range of  $10^{-3}$ – $10^{-6}$  m.

In the case of biogenic monomolecular surface films accumulating at a rough sea surface, the surface films are compressed and dilated periodically, causing variations of the concentration of the molecules and thus of the surface tension. In this case not only the well-known gravity-capillary waves (surface waves) are excited, but also the so-called Marangoni waves. The Marangoni waves are predominantly longitudinal waves in the shear layer. They are heavily damped by viscous dissipation; at a distance of only one wavelength from their source their amplitude has already decreased to less than one-tenth of the original value. This is the reason why Marangoni waves escaped detection until 1968. When these gravity-capillary waves and Marangoni waves are in resonance as given by linear wave theory, the surface waves experience maximum damping. Depending on the viscoelastic properties of the surface film, maximum damping of the surface waves usually occurs in the centimeter to decimeter wavelength region.

### Reduction of Wave Breaking

Since surface films reduce roughness of the sea surface, the stress exerted by the wind on the sea surface is reduced. Furthermore, the steepness of the short-scale waves is decreased which leads to less wave breaking.

### Reduction of Gas Transfer

Biogenic surface films do not constitute a direct resistance for gas transfer. However, they do have a major effect on the structure of subsurface turbulence and thus on the rate at which surface water is renewed by water from below. Furthermore, surface films reduce the air turbulence above the ocean surface and thus also the surface renewal. As a consequence, the gas transfer rate across the air–sea interface is reduced in the presence of surface films.

### Change of Sea Surface Temperature

In infrared images the sea surface areas covered with biogenic surface films usually appear slightly warmer than the adjacent slick-free sea areas (typical temperature increase 0.2–0.5 K). This is due to the fact that surface films reduce the mobility of the near-surface water molecules and thus slow down the conventional overturn of the surface layer by evaporation.

### Change of Reflection of Sunlight

Slick-covered areas of the sea surface are easily visible by eye when they lie in the sun-glitter area. This is an area where facets on the rough sea surface are encountered that have orientations that reflect the sunlight to the observer. When the surface is covered with a surface film, the sea surface becomes smoother and thus the orientation of the facets is changed such that the amount of light reflected to the observer is increased. Thus surface slicks become detectable in sun-glitter areas as areas of increased brightness. Outside the sun-glitter area they are sometimes also visible, but with a much fainter contrast. In this case they appear as areas of reduced brightness relative to the surrounding.

### Radar Backscattering

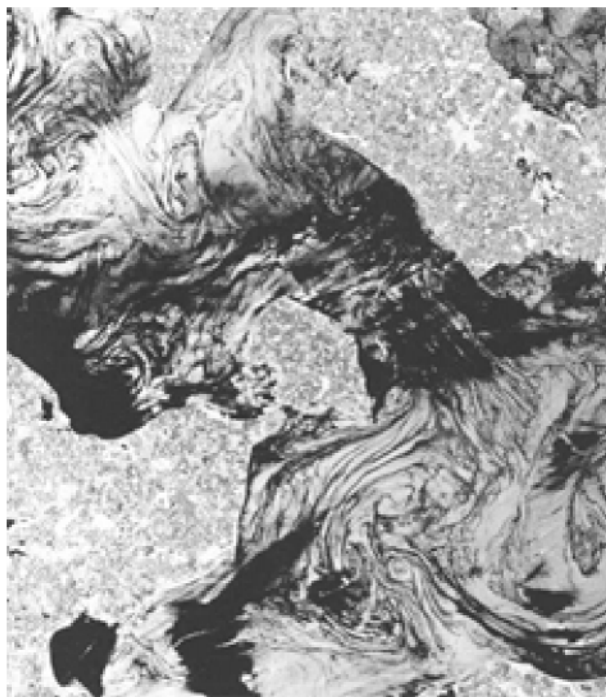
Surface slicks floating on the sea surface also become visible on radar images because they reduce the short-scale sea surface roughness. Since the intensity of the radar backscatter is determined by the amplitude of short-scale surface waves, slick-covered sea surfaces appear on radar images as areas of reduced radar backscattering. Since radars have their own illumination source and transmit electromagnetic waves with wavelengths in the centimeter to decimeter range, radar images of the sea surface



**Figure 1** Radar image acquired by the synthetic aperture radar (SAR) aboard the First European Remote Sensing satellite (ERS-1) on 20 May 1994 over the coastal waters east of Taiwan. The imaged area is 70 km  $\times$  90 km. It shows a ship (the bright spot at the front of the black trail) discharging oil. The oil trail, which is approximately 80 km long, widens towards the rear because the oil disperses with time. Copyright © 2000, European Space Agency.

can be obtained independent of the time of the day and independent of cloud conditions. This makes radar an ideal instrument for detecting oil pollution and natural surface films at the sea surface. Consequently, most oil pollution surveillance aircraft which patrol coastal waters for locating illegal discharges of oil from ships are equipped with imaging radars.

Unfortunately the reduction in backscattered radar intensity caused by mineral oil films is often of the same order (typically 5–10 decibels) as that of natural surface films. This makes it difficult by using the information contained in the reduction of the backscattered radar intensity to differentiate whether the black patches visible on radar images of the sea surface originate from one or the other type of film. However, in many cases the shape of the black patches on the radar images can be used for discrimination. A long elongated dark patch is indicative of an oil spill originating from a travelling ship. Examples of radar images on which both types of surface films are visible are shown in **Figures 1 and 2**.



**Figure 2** Radar image acquired by the SAR aboard the Second European Remote Sensing satellite (ERS-2) on 10 May 1998 over the Western Baltic Sea which includes the Bight of Lübeck (Germany). The imaged area is 90 km  $\times$  100 km. Visible are the lower left coastal areas of Schleswig-Holstein with the island of Fehmarn (Germany) and in the upper right part of the Danish island of Lolland. The black areas are sea areas covered with biogenic slicks which are particularly abundant in this region during the time of the spring plankton bloom. The slicks follow the motions of the sea surface and thus render oceanic eddies visible on the radar image. Copyright © 2000, European Space Agency.

## See also

**Air–Sea Gas Exchange. Oil Pollution. Phytoplankton Blooms. Satellite Remote Sensing of Sea Surface Temperatures. Surface, Gravity and Capillary Waves.**

## Further Reading

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