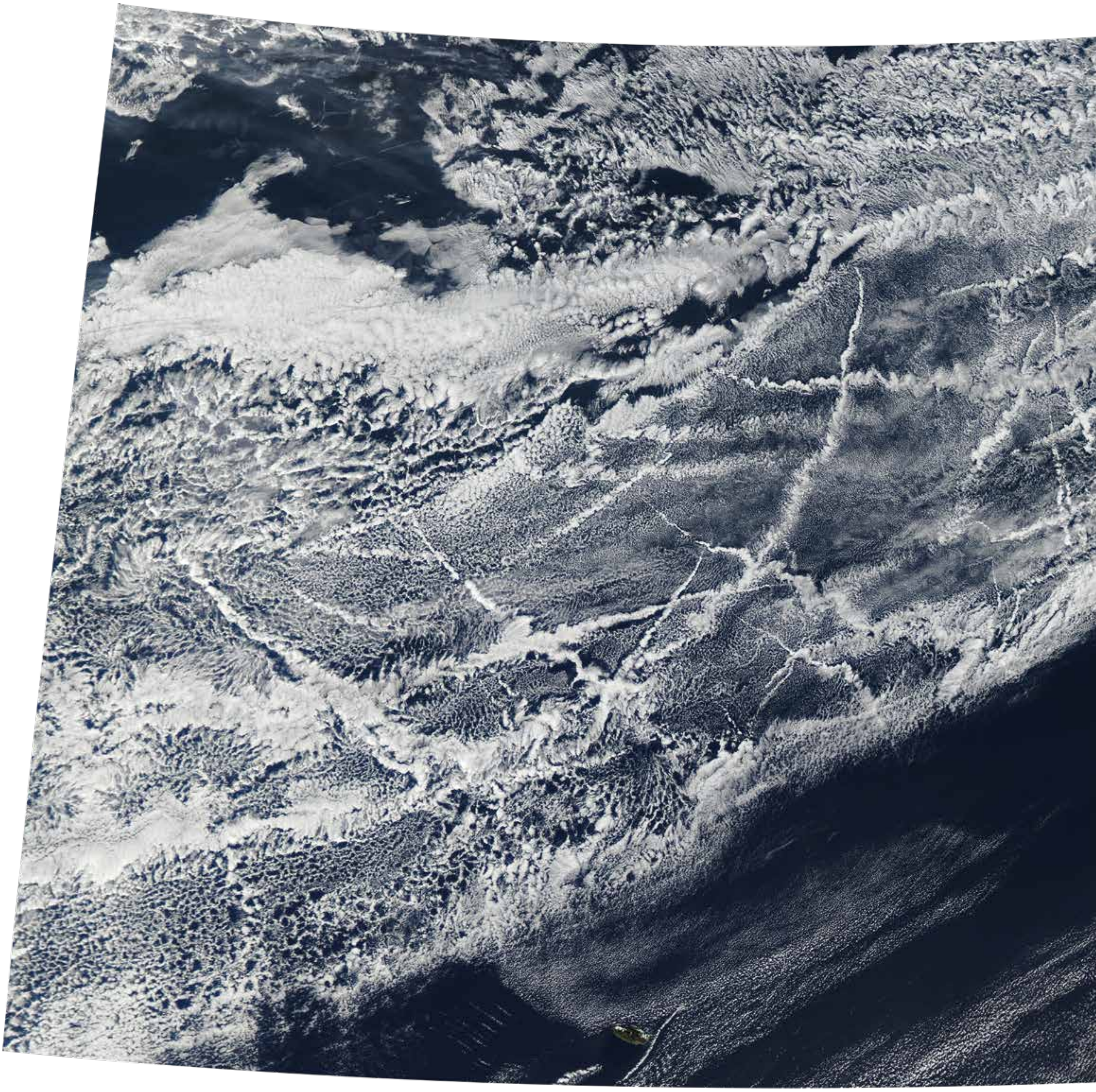

# Ocean sunshade

## How clouds influence climate change

*By Andreas Lorenz-Meyer*


As far as global warming is concerned, whether we are heading more towards +2 or rather +5 °C is decided to a quite significant extent over the oceans. It is there that vast layers of low, flat clouds shade the ocean surface below, cooling it down in the process. Will that be the case in future too?

To find out where our climate stands – just look up at the clouds! They play an important role in Earth's radiation budget. On the one hand, clouds reflect short-wave solar radiation and send it back into space – the cooling effect also known as cloud albedo. On the other hand, they absorb long-wave thermal radiation emitted from Earth's surface, preventing it from leaving the atmosphere – the warming effect.

Altogether, clouds currently have a global net radiative effect of $-20\,Wm^2$, meaning that their cooling effect is greater than their warming effect, and Earth is about five degrees cooler as a result. However, this initial value of minus 20 watts will not necessarily stay the same since clouds' radiation properties change. One reason is cloud feedback, the direct response of clouds to human-induced global warming. The other reason is anthropogenic aerosols, that is, the minute suspended particles produced by waste gases that play a direct role in cloud formation.

### Clouds influence climate change

How these two effects, which occur separately, have an impact is something that Anna Possner, physicist at the Institute for Atmospheric and Environmental Sciences, is investigating. For her, clouds are "the greatest source of physical uncertainty in climate change projections". It is mostly down to them that we still do not know exactly what temperature increase we can expect at which $CO_2$ concentration. This has to do with the fact that clouds are complex structures, "the end products of many individual process chains within the atmosphere". Radiation, dynamics, turbulence, surface fluxes of heat and moisture, microphysics and atmospheric chemistry – they all contribute to cloud formation. "They influence at what height clouds develop, how much radiation they reflect or absorb, whether they produce rain or snow, or simply evaporate. In each stage of the process, the uncertainties overlap – and that makes it difficult to quantify the effect of clouds in a changing climate."

Ship tracks over the North Atlantic off Portugal and Morocco: ships emit aerosols that produce characteristic contrails.

Although the "gaps in our understanding of the process" are shrinking, and increasingly efficient, higher resolution models are available, Possner wants to understand the processes in the clouds and their interaction with the climate system even better and map them in climate models with even greater precision. "Only then will it be possible to pinpoint climate sensitivity more accurately." Climate sensitivity reveals how much warmer it will become if the concentration of greenhouse gases in the atmosphere doubles from the pre-industrial level of 280 ppm to 560 ppm. The Intergovernmental Panel on Climate Change (IPCC) recently predicted global warming of between 2.5 and 4 °C in such a case.

As far as future living conditions are concerned, there are worlds between. To calculate this down to the last degree, we need to know more about clouds.

### Low clouds as sunshade

To achieve this, Possner is looking at very specific types: flat, low stratus and stratocumulus clouds over the oceans. Stratus clouds, similar to a thick layer of fog, have no structure whatsoever, their water content is homogenous. In stratocumuli, by contrast, water content varies. Together, both types of cloud form a semipermeable "sunshade" that has a cooling effect. This is because with these low clouds the short-wave effect predominates wherever the sun shines, in the tropics just as in the Arctic during summer, meaning that more short-wave solar radiation is reflected than long-wave thermal radiation absorbed. The cooling sunshade over the oceans is huge: it spans more than a fifth of all ocean surface. If its properties change in any way, the consequences for Earth's climate are particularly dramatic, as Possner explains: "Oceans cover 71 percent of Earth's surface. They are extremely dark and on average absorb 99.3 percent of incoming solar radiation. This is considerably higher onshore, where different land surfaces reflect between 10 to 40 percent. In terms of global warming, the sunshade's effectiveness over the oceans is therefore much more important than over land. It makes a tremendous difference whether or not there is a layer of cloud over the dark ocean surface that reflects between 20 and 40 percent of irradiation."

### Ship emissions make clouds brighter

And now for the bad news: because of global warming, the sunshade over the oceans is shrinking, its material thinning. "The low clouds are literally burning off and reflecting less solar radiation as a result." But there is a counterforce with a cooling effect: anthropogenic aerosols. The same applies for these too: the effects are much more dramatic at sea than on land. Possner is looking closely at the impact of exhaust plumes from merchant ships that journey back and forth across the oceans, blowing vast quantities of minute particles into the atmosphere as they go. Under certain conditions, "ship tracks" form, which can be spotted clearly on satellite pictures. "They look like contrails behind a passing aircraft. Only they form far lower down, within the lowest kilometre of the atmosphere." How much brighter clouds become due to these particles can be measured with great accuracy within these tracks.

This brightening causes the clouds to reflect more sunlight because the more aerosols there are, the greater the number of condensation nuclei for cloud droplets. This means that the same amount of cloud water is now dispersed among several smaller droplets. These, in turn, occupy a larger total surface area for the same water content, which increases cloud albedo. "The disturbed cloud therefore provides more shade than the undisturbed cloud," says Possner.

### Major global impact

She discovered the extent of this effect in a study with American colleagues. "We succeeded for the first time in corroborating and quantifying, by means of satellite observations, a brightening effect caused by ship emissions. We looked at a shipping corridor on the west coast of Africa. In this corridor, the wind blows for parts of the year in such a way that individual exhaust plumes overlap. As a result, the signal was stronger compared to the overall variability, and we were thus able to isolate it."

This robust and unambiguous finding was described in the scientific article "Substantial Cloud Brightening from Shipping in Subtropical Low Clouds", published in 2020 and extrapolated on a global scale. According to this, particles from ship emissions worldwide reflect around 1 watt of incident sunlight per $m^2$ by brightening marine stratus clouds. "Compared to current global warming through anthropogenic greenhouse gases, which is 4 watts per $m^2$, this is sizeable. It means that about a quarter of human-induced global warming is offset by the cooling cloud effect of anthropogenic aerosols over the oceans."

### Ice crystals reduce cooling effect

Possner is currently looking at low clouds in the Southern Ocean beyond the $40^{th}$ parallel south, where anthropogenic aerosols are insignificant because there is little shipping traffic in that area. There, too, stratocumulus decks stretch

## ABOUT ANNA POSSNER

**Anna Possner**, 34, came from prestigious Stanford University in the USA to Frankfurt in 2018 to set up the "Atmospheric Physics and Climate" research group, which is looking at the role of clouds in climate change. Financial support comes from the German-French research initiative "Make our planet great again". It was through programming work in the course of her mathematical physics studies in Edinburgh, Scotland, that she turned her attention to clouds. Possner enjoys solving problems by building and running models. After an internship at the Max Planck Institute for Meteorology in Hamburg, Possner worked for several years at ETH Zurich in Switzerland before moving to the USA.

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Photo: Avigator Fortuner/Shutterstock; Graphics after Possner, A. in Nature News and Views Vol. 572, p.35; Montage: P. Kiefer

Aerosols from ship emissions lead to the formation of smaller and more numerous water droplets (small circles) than usual in the low clouds over the ocean. Such clouds are brighter and therefore reflect more sunlight (yellow). At the same time, they shed less rain because of their lower water content.

over hundreds of kilometres, cooling the almost undisturbed ocean surface beneath. In contrast to the subtropics, it is so cold in the Southern Ocean that 40 to 70 percent of the low clouds are composed of a mixture of water droplets and ice crystals. A fraction of all cloud droplets freeze – and this reduces cloud albedo. This is because cloud droplets are smaller than ice crystals and occupy more surface area with the same water content, meaning that cloud droplets are far more efficient at reflecting sunlight than ice crystals. Or conversely: the more condensate that enters the ice phase, the lower cloud albedo is.

But as far as clouds are concerned, things can quickly become rather complicated, and there is therefore something else that also determines radiative properties: the cloud's internal organisational structure. The stratocumuli in the Southern Ocean display regular patterns that resemble honeycombs. There are "full" and "empty" ones. "Full" means cloud formation starts at the centre of the honeycomb while "empty" means it begins at the edges. "Two dynamically different systems with different radiative properties. Closed, or "full", cell structures have higher cloud albedo than open, or "empty", ones at the edge of the cloud, so they have a greater cooling effect." At the present time, Possner is looking closely at a specific detail: Does ice crystal formation change this internal organisation? Does a "full" honeycomb with a greater radiative effect then become an "empty", less radiative one? That would mean an additional warming effect. According to a first statistical analysis, however, that does not seem to be the case: "So far, we've no evidence that ice crystal formation propels stratocumuli into a less radiative organisational regime." Meaning that "full" combs stay that way. Should further studies confirm this preliminary result, that would be a little bit of good news as far as global warming is concerned. ●


**The author**

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