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THE GLOBAL

The global water cycle and global climate interactions.

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Water is a unique substance without which our world could not exist as it is. Unlike other chemical compounds, at the temperatures standardly found on Earth water can be found in all three physical states – as a solid, liquid, and gas. Water vapor in the atmosphere, the gaseous form of water, is the main contributor to the natural greenhouse effect which creates the conditions supporting life. Our planet has been described as a blue marble by those who have seen it from space; however, if it were not for the greenhouse effect, Earth would instead resemble a snowball, since the average surface temperature would be 30°C or more degrees cooler. As it is, oceans – comprising water in its liquid state – cover over 70% of the globe's surface, providing habitats for countless organisms and acting as a vast storehouse of energy. Ocean currents distribute this energy throughout the globe, reducing temperature differences between latitudes. Polar ice caps and permafrost in high moun-

Water Cycle

tain ranges store the vast majority of fresh water. The presence of ice (water in its solid state) also affects the volume of sunlight absorbed and reflected by the planet's surface.

The ways in which water circulates around Earth and changes from one state to another are severely affected by global warming. Emissions of greenhouse gases, in particular carbon dioxide, as a result of rapidly growing industry and agriculture are bolstering the greenhouse effect and leading to increasing average temperatures.

Oceans

The oceans are reservoirs that store most of the energy accumulated on Earth as a result of warming. As ocean temperatures increase, so do rates of evaporation, which in turn cause more violent tropical cyclones to form and create large low-pressure areas in temperate regions, for example those bringing air from over the Atlantic to Poland. This results in increased wind speeds and more intense rainfall, which in turns increases the risk of flash-floods. Due to climate change, events such as 2017's Hurricane Harvey (which brought over 1,000 mm of rain to Houston over the course of three days) are now three times more likely, and the frequency of storms such as Desmond (which brought record volumes of rain to the British Isles in 2015 and 2016) goes up by around 60%. Dr. Friederike Otto, member of the World Weather Attribution initiative conducting real-time analysis of extreme weather events around the globe, writes extensively on the subject in her book *Angry Weather*.

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As well as causing more violent storms, rising ocean temperatures also result in elevated sea levels. The simple thermal expansion of water plays an important role in the process, even though it is not a factor we generally consider. In the meantime, close to 700 million people live in regions at elevations close to the sea level; according to the Intergovernmental Panel on Climate Change (IPCC) report published in 2019, that figure is likely to exceed a billion by the mid-21st century. Many coastal regions of Poland are now already at increased risk of annual flooding caused by storms. And we would do well to remember that an area does not have to be entirely and permanently submerged to become uninhabitable and/or unusable to humans. Even occasional sea floods cause widespread destruction, salination of soil and contamination of potable water sources, all of which can force people living or working on such lands to relocate.

Wind

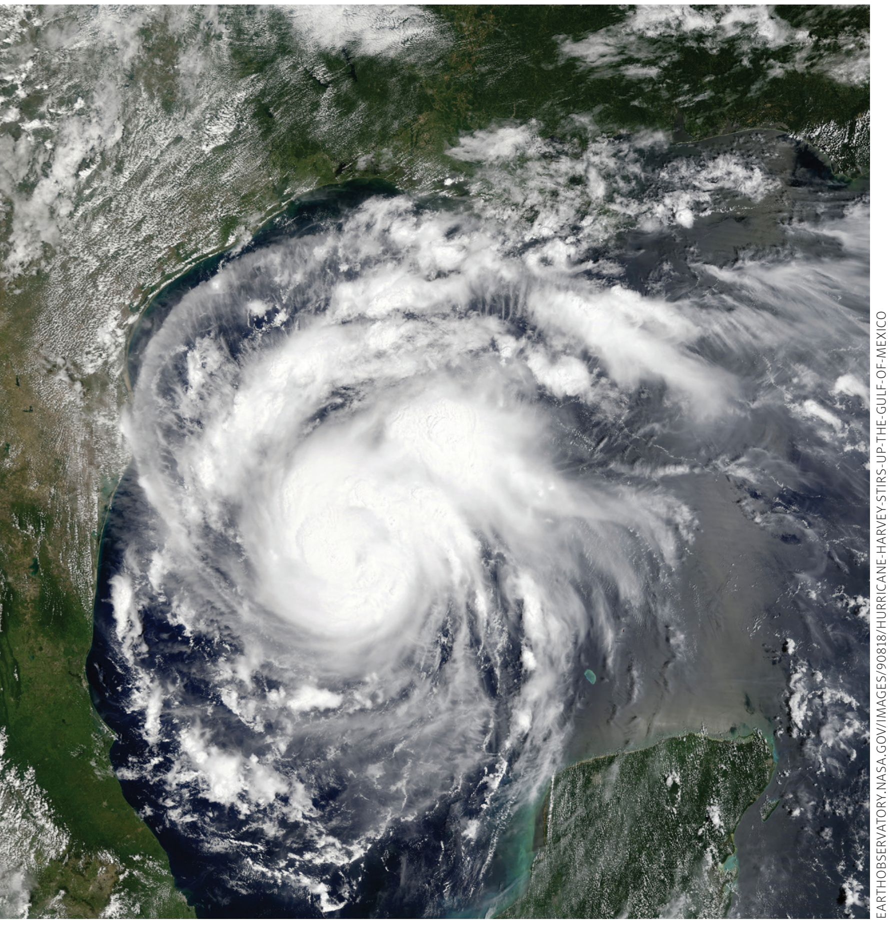
Having constant access to fresh water is essential to our very survival, since without it all living organisms on Earth would cease to function. Water is used to irrigate fields where we grow food for ourselves and for our livestock; it is essential in maintaining hygiene and in a range of industrial processes, including generation of electricity which makes modern civilization possible. Although the overall volume of water on Earth is not diminishing, we are increasingly struggling to maintain a safe, steady supply of that most precious of resources: clean fresh water.

It might seem that increased evaporation from the planet's surface should translate into increased rainfall; however, the distribution and timing of precipitation also depend on the terrain and the dynamics of atmospheric circulation, which in turn is affected by factors such as sea currents. For example, when temperatures in the North Atlantic are abnormally high, the region of equatorial rainfall shifts slightly northwards, and vice versa, when temperatures are low it shifts southward (when observed over several years). Unfortunately we are seeing that climate change is bringing more droughts to regions which are already suffering from low rainfall levels, such as around the Mediterranean coast.

In Central Europe, the main problem we are seeing is irregular patterns of rainfall. This is the result of the rapid rise (in comparison with the rest of the globe) of average temperatures in the Arctic, driving a phenomenon known as Arctic amplification. Increasing global temperatures also result in reduced sea ice cover; this means that white ice surfaces which are effective at dispersing sunlight are being replaced by dark patches of liquid water which absorb it. The feedback loop further accelerates ocean warming in the given region, resulting in a more rapid melting of sea ice. As a result, the Arctic region is experiencing the highest rate of warming around the globe.

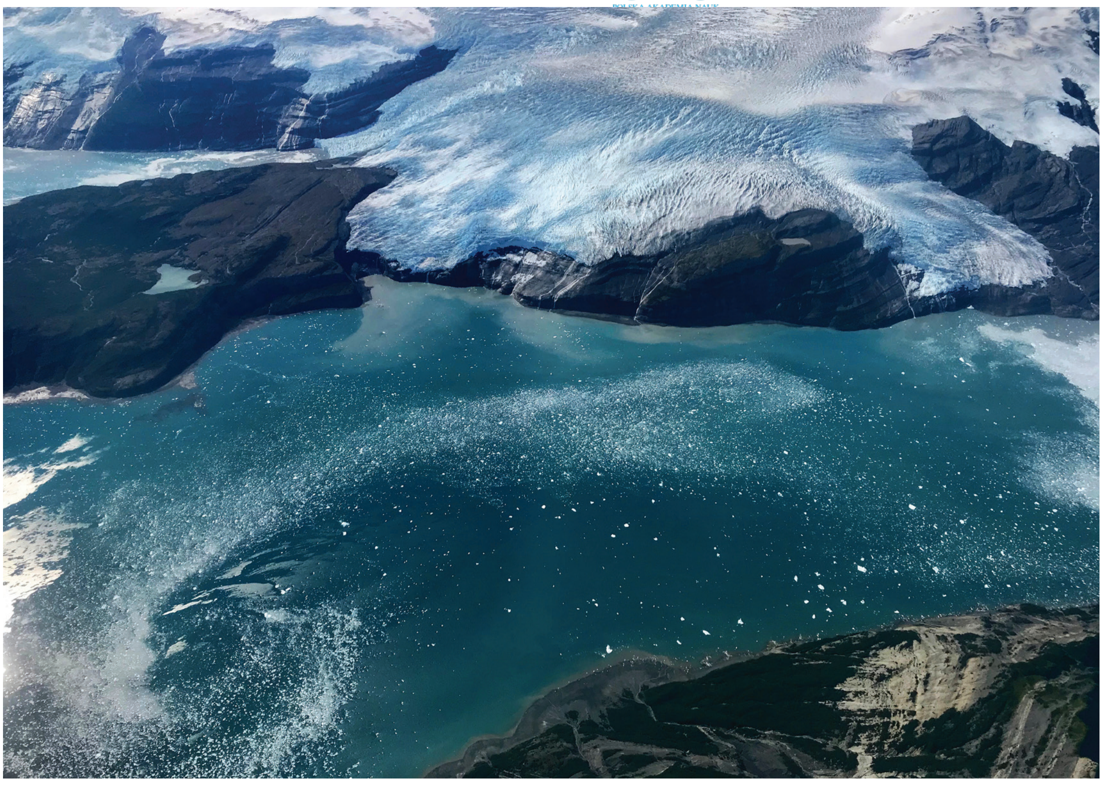
The reduction of the temperature difference between polar and equatorial regions is also likely to weaken the jet stream – the fast-flowing air current at around 10 km above sea level which bring moist air to Europe from over the Atlantic. The slower jetstream becomes more meandering, which means that instead of Atlantic air Poland is now increasingly experiencing a long-term influx of continental air, with masses of air arriving from the north and south. Additionally, the typical routes of low-pressure areas in temperate latitudes are shifting northwards, and instead of crossing Poland they are increasingly moving as far north as Scandinavia. All this contributes to prolonged periods with no rainfall, lasting as long as several weeks.

This leads to rapidly growing risks of agricultural droughts and shortages of water for all applications. When regular, moderate rainfall is replaced by long dry periods with intermittent heavy downpours, water resources continually get used up and are difficult to replenish. In the event of short but intensive rainfall (whose incidence has unfortunately increased), the soil simply has insufficient time to absorb water. Instead, large volumes flow over the surface to drainage



Hurricane Harvey over the Gulf of Mexico

EARTHOBSERVATORY.NASA.GOV/IMAGES/90818/HURRICANE-HARVEY-STIRS-UP-THE-GULF-OF-MEXICO



Glacier Bay in the Wrangell-St. Elias National Park & Preserve, Alaska, August 2018. A century ago the whole bay was covered with ice

systems or rivers and then into the sea, where the fresh rainwater mixes with seawater rendering it unsuitable for drinking or irrigation.

Glaciers

Melting mountain glaciers also contribute to problems with fresh water supply. These vast masses of ice expand in size every winter (when snow falls) and decrease in summer when ice and snow melt. As the global climate warms, we are seeing that in most cases the winter precipitation is no longer sufficient to balance out the summertime melting.

As still-extant glaciers continue to melt rapidly, the volumes of rivers they supply increase, which in turn increases the risk of flooding. There are various reasons for this. The accumulation of vast volumes of water at reservoirs at the foot of glaciers may simply break through the natural dam formed by a moraine. Alternatively, water can be displaced from the reservoir by falling lumps of ice or avalanches. The likelihood of such events increases with the progressing melting of ice and permafrost on slopes as glaciers recede. In 2000, an outburst flood caused by a landslide into the Yigong River in Tibet, killing dozens of people and causing extensive damage in China and India.

Additionally, once a glacier melts away entirely, water levels in mountain streams will depend purely on rainfall. When this is low, water shortages will not be supplemented by melting snow and ice accumulated from previous years. If anthropogenic greenhouse gas emissions are not halted, we can expect up to 80% of all alpine glaciers to disappear by the end of the 21st century.

While rivers in Poland are not supplied by glaciers, the changing climate also affects average flows at different times of year. As average winter temperatures are increasing, snowfall is being replaced by rain, and we are gradually seeing less accumulation of water in its solid state to be released in spring to feed rivers and irrigate soil.

Melting glaciers, ice sheets and sea ice do not just increase sea levels and change the volumes of sunlight absorbed by our planet; they also drive major changes in the global circulation of ocean water. This is caused by differences in water salinity, with melting ice introducing large volumes of fresh water at specific ocean locations. Changes in sea current systems are reflected in new patterns of rainfall, drought or violent storms in different regions around the globe.

Numeric simulations of Earth's climate in the future, taking into account a range of possible scenarios, indicate that it will be very difficult to reverse anthropogenic climate change caused by increased concentrations of greenhouse gases in the atmosphere. Halting ongoing emissions of carbon dioxide, methane and nitrogen oxides alone will be insufficient. Unless we actively remove carbon dioxide from the atmosphere, it may take natural processes hundreds or even thousands of years to reduce its concentration. In any case, this will only be possible if average temperatures do not pass too many tipping points, triggering positive feedback loops which drive anthropogenic changes to the point when they cannot be reversed. Even though we are striving to halt climate change at the level of 1.5–2°C with respect to the preindustrial era (as defined by the Paris Agreement in 2015), we must accept and adapt to changes which are already happening around us and prepare for those coming in the future.

Further reading:

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