One Ocean

Our ocean fan-assisted storage heater, by Philip C. Reid.

Until Aristotle, the world was viewed as a flat plane with a firmament comprising the sun, planets, and stars above, and it was thought that a voyager crossing the ocean might fall off the edge. Copernicus showed that we live on a spherical planet orbiting the sun, and space observations have since confirmed (see Fig. 1) that the Earth is blue due to Raleigh scattering of blue light by nitrogen and oxygen in the atmosphere, and in part due to the ocean covering 71 per cent of its surface. The ocean efficiently absorbs infrared, red, and other wavelengths of light from the sun that penetrate its surface, leaving only blue to be reflected back into space. The spatial and volume dominance of the ocean means that it is a major component of the Earth's life support system and has a huge influence on the terrestrial world, its ecosystems and human society. 'A healthy ocean makes all life on Earth possible, is essential to human existence and wellbeing and provides vital regulating and functioning services'.

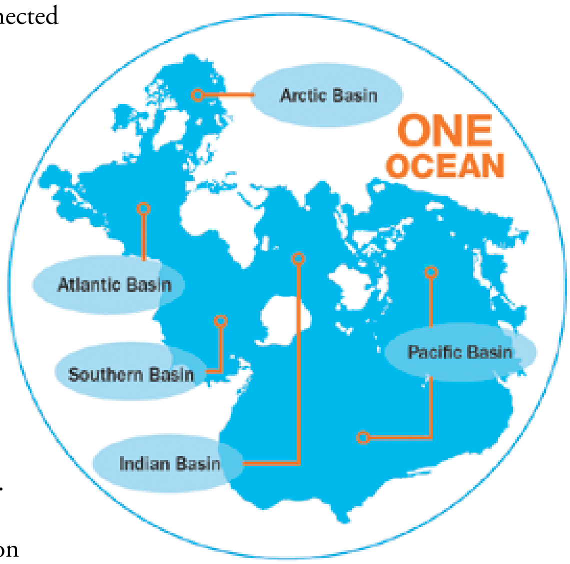
Figure 1 (Top). Earthrise: our blue planet rising above the Moon's surface and lunar horizon on 24 December 1968. Photograph taken by astronaut William A. Anders from the Apollo 8 spacecraft as it circled the Moon. This space mission was the first time that humans had orbited the Moon and seen the Earth from so far away. © William A. Anders.

Figure 2 (Right). One Ocean that is immense, interconnected, and heterogeneous, and provides immeasurable benefits to humanity and the planet. © Laffoley *et al.*, (2020).

Approximately 40 per cent of the human population lives within 100 km of the coast and it is estimated that possibly more than a third of these will never see the ocean in their lifetime. It is not surprising that it is difficult for most humans to recognize its importance to their lives and the massive contribution that they are making to the pronounced changes that are occurring in the regulatory processes that the ocean provides.

One Ocean

On a global scale there is only 'one Ocean', with five interconnected ocean basins: the Arctic, Atlantic, Indian, Pacific, and Southern (Fig. 2). Artificial boundaries for four of the basins have been defined by the International Hydrographic Organization with the fifth basin, the Southern—represented since 1937 as south of 60°S—still not recognized by all countries. The Intergovernmental Oceanographic Commission (IOC) of UNESCO has long campaigned to use the singular form 'ocean' rather than the common plural 'oceans'. Referring to the ocean in the singular is important as it reflects reality. It also helps reinforce the key importance of the ocean to human society and economies and the need to protect it and its ecosystems, which are vulnerable to overexploitation and pollution, never mind its crucial role in climate change. We can start to recognize its importance by referring to it in the singular and as a proper noun—our one **Ocean**—and replacing the word Ocean behind each of the Arctic, Atlantic, Indian, Pacific and Southern by the word Basin.



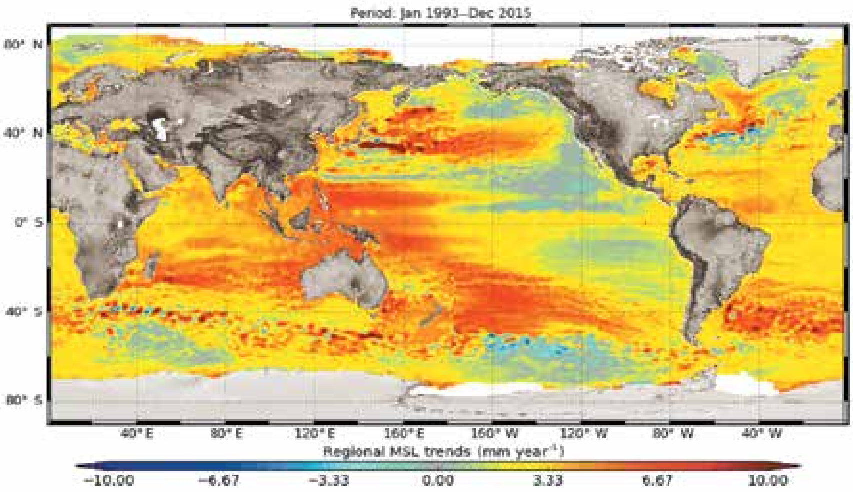


Figure 3. Regional mean sea level trends over the period 1993-2015 based on satellite altimetry from the European Space Agency. Larger increases, up to 10mm per year, in the tropical western Pacific reflect the increasing heat contribution to sea level rise in this area. © Legeais *et al.* (2018), *Earth Syst. Sci. Data.*

Distribution of heat by the ocean

In this article, I focus on ocean temperature, which has shown rapid and accelerating change over the last few decades with increased heat storage and expansion of stratified tropical and subtropical waters. The atmosphere and ocean are coupled and closely interacting systems with solar radiation as the primary source of the energy that powers motion in both. Of the two, the ocean—because of its size and the fact that water can incorporate more than 4,000 times as much heat energy per litre as air—is the main driver that powers weather and climate. It is also the main regulator of global temperature as well as moderating temperature on adjacent land.

Water also holds on to heat for longer than air and heat travels through water by convection around 20 times faster than through air as its molecules are much closer. Because the sun is vertically overhead at the equator, tropical waters absorb large amounts of heat. The ocean is a major distributor of this heat around the world from the tropics to the poles via ocean currents, a circulation that has accelerated. Increasing sea temperatures have contributed to altered wind patterns, an intensified hydrological cycle, more powerful and slower propagating tropical cyclones and rising sea levels (Fig. 3). There have also been more disasters, marked impacts on marine ecosystems and biogeochemistry, as well as effects on seasonal to long-term weather patterns.

Latent heat in atmospheric convection drives surface winds, which in turn drive ocean circulation. With a density of 997 kg/m^3 water is approximately 1,000 times denser than surface air at a mean global temperature and thus is capable of transporting approximately 1,000 times more heat. However, the rate of transport is proportional to speed and as currents are about a thousand times slower than mean winds, currents and wind approximately balance each other in heat distribution. Surface currents are primarily wind-driven as part of the ocean gyre circulation, and are reinforced by density differences—due to contrasting temperature and salt levels between the tropics and polar regions—and tidal currents, which are strongest in shallow shelf waters. Net ocean heat redistributed from warm equatorial waters towards the poles occurs primarily within basins with only limited exchange between them, and is dominated by the Pacific due to the wide band of tropical waters found there. In addition, the Atlantic Basin transfers heat across the equator to the north and the Indian Basin the same, but to the south. These recent results contrast with the traditional view of an interconnected global scale heat redistribution.

Influence of oceanic heat on land masses

I start with David Ellett's statement in 1993 that the ocean to the west of the British Isles is like a fan-assisted night storage heater and the oft-repeated comment that the UK's warmer climate is largely due to the warmth carried by the Gulf Stream. A proportion of heat energy, as infrared radiation from the ocean, heats molecules of air above. Heat is also transferred to the atmosphere when the air is in contact with warmer water by conduction. Lastly, latent heat is released to the atmosphere when water vapour evaporated from the ocean condenses as it rises to form cloud. The resulting heat-driven movement of molecules in the air generates winds that transfer the air over land. The night storage analogy is the heat stored and transported by currents from the tropics to the northern North Atlantic to the west of the UK. For an analysis of UK and global temperature change, see Osborne *et al.* (2018).

Heat transferred by warm currents has a strong moderating effect on the temperature of adjacent land, which reduces progressively towards more continental regions and deserts due to the differing specific heat capacity[1] of water and air. Maritime countries in the extratropics adjacent to a warmer ocean, like the UK, are warmer in winter and cooler in summer as a result, and maintain their heat into the autumn, ensuring that temperature over the land is warmer than would otherwise be the case. But, contrast this with the 10°C annual mean temperature difference between Goose Bay, Labrador (–0.5°C) with a cold ocean offshore, and Chester, England (9.4°C) at the same latitude.

To the west of the UK, the subpolar

1 https://en.wikipedia.org/wiki/Specific_heat_capacity

gyre is a region of the ocean where heat from warm surface water, originating from the Gulf Stream/North Atlantic Drift, is released to the atmosphere, chilling the water, which sinks and is convected to form deep water. Large quantities of heat released by an exceptional formation of this cold water in 2015—the 'cold blob' or 2015CA— has been associated with a change in the position of the jet stream, linked to extreme heat waves in Europe and even modulation of the North Atlantic Oscillation.

The contrast in warming between ocean and land

By 2019 global mean sea surface temperature had warmed at approximately half the rate of land surface temperature (Fig. 4). Land has a much smaller heat capacity than water, partly explaining why, on average, land warms up by half as much again as the ocean (a factor of 1.5). However, the main reason, is that there is no constraint on evaporation over the ocean to cool the surface in a warming climate, whereas land surfaces have limited water available to evaporate and have to increase their temperature to compensate the ocean/land contrast. The key to the discovery is that the rate at which temperature decreases with height above the surface due to evaporation (the lapse rate) is much faster over the ocean than over land. The theory also explains why relative humidity has been declining over land in recent years, and does not augur well for future dry and subtropical land surfaces as warming increases in the future.

The large increase in global temperature that characterizes El Niño events is caused by a similar process. Water vapour from strong evaporation over the warm tropical eastern Pacific during El Niño rises in tropical moist convection to high altitudes, where it condenses as rain and releases latent heat to the upper troposphere. This high warmer air easily encircles the tropics and spreads towards the poles.

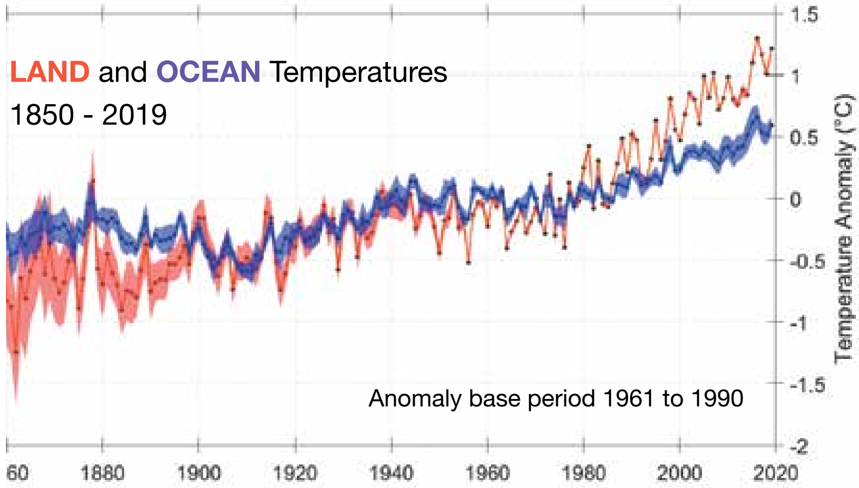


Figure 4. Annual global land and ocean temperature anomalies relative to a 1961–1990 average using Berkeley Earth and HadSST4 datasets. The 95% confidence intervals on the data - shaded. Note the much higher potential error in the 19th century data and the higher confidence in more recent land versus ocean data. Access to the datasets from Berkeley Earth and the Met Office Hadley Centre are gratefully acknowledged. © Guillaume Signoret and Philip C. Reid.

Surface air over land adjusts to these upper level higher temperatures, but has to warm even more, as it is not able to achieve a balance because of a limited ability to cool by evaporation.

A way forward for a threatened ocean

Through its interactions with the atmosphere and land, in heat distribution, in the water cycle and gas exchange, and in other essential Earth regulatory processes the ocean is the beating heart of the world (see also https://youtu.be/I8l6_vGDc_U). All of these regulatory processes are changing rapidly due to human activities, and the ocean and the benefits it provides are under threat. A way forward to recover and restore the state of the ocean in a post Covid-19 world is outlined by Laffoley *et al.* (2020) based on a six-point narrative:

- All life is dependent on the ocean
- By harming the ocean, we harm ourselves
- By protecting the ocean, we protect ourselves
- Humans, the ocean, biodiversity, and climate are inextricably linked
- Ocean and climate action must be undertaken together
- Reversing ocean change needs action now

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Further reading:

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