THE OCEAN, OUR ALMOST UNKNOWN HELPER

Photo: Marina Boyarkina/ Adobe Stock

The ocean is a natural sink that takes up about a quarter of fossil fuel emissions each year. However, the ocean's ability to absorb carbon changes from year to year, season to season, and between locations. Generally, the CO_2 exchange between the ocean and the atmosphere varies much more in the coastal areas than in the open ocean. Some areas can even release CO_2. Yet we know too little about the ocean: There are simply not enough observations to fully understand the reasons for the variations in the ocean's ability to absorb carbon, especially when it comes to its future response to climate change.

by **Dr Meike Becker** (lead writer),
Dr Carolina Cantoni, Dr Thanos Gkritzalis,
Dr Anna Luchetta, Prof. Dr Gregor Rehder,
Prof. Anna Rutgersson

The uptake of CO_2 by the oceans is not homogeneously distributed and some ocean areas are even a source of CO_2 (Figure 1). CO_2 fluxes vary from one location to another based on different ecosystems and climatic conditions. The sink also changes during a year with the length of daylight, with temperature and nutrient concentration. These factors determine the growth of algae and thus primary production throughout the year. Additionally, CO_2 fluxes between the ocean and the atmosphere vary from year to year.

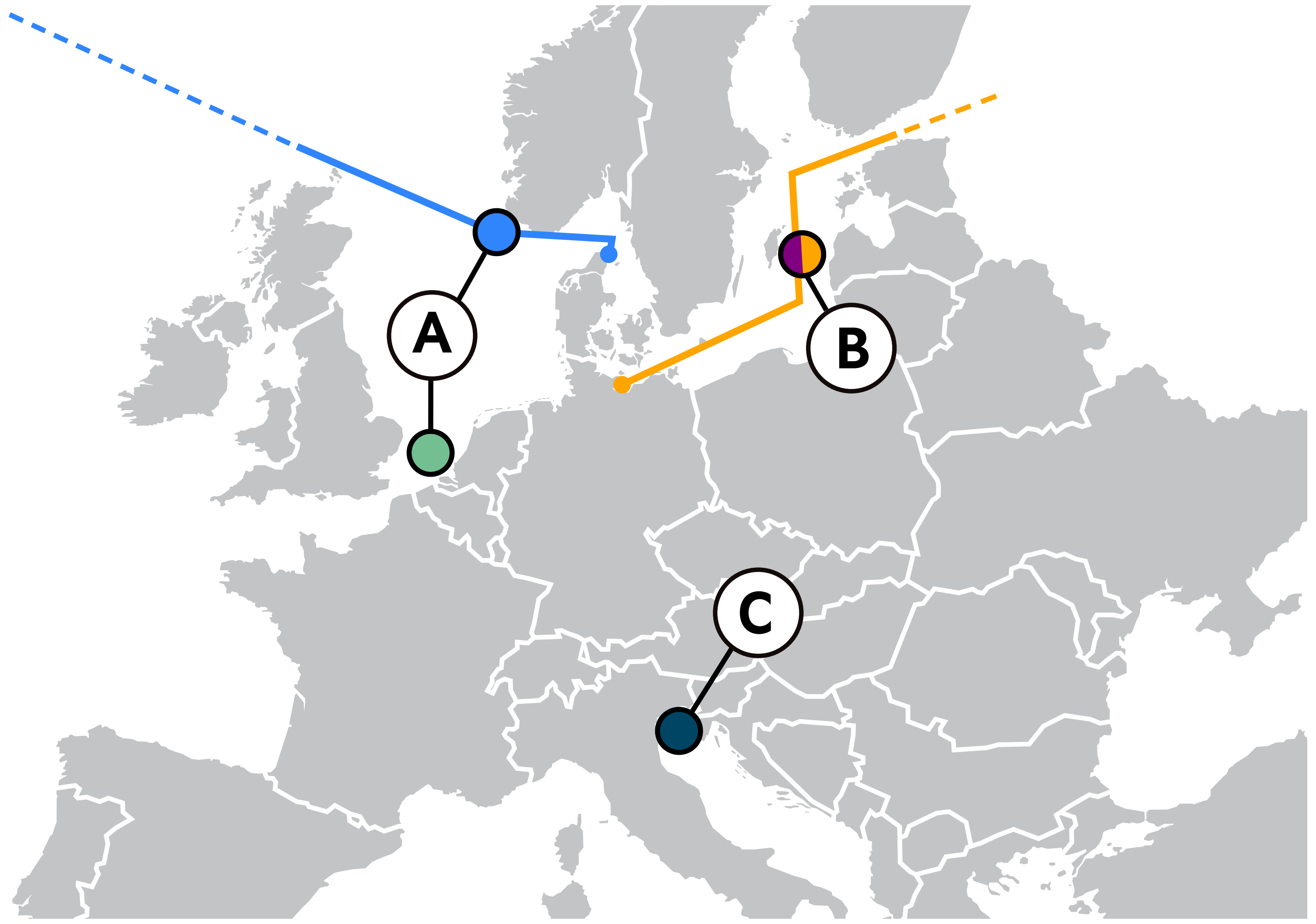
This variability tends to be larger in coastal regions than in the open waters. One reason for this is the stronger influence of rivers transporting carbon and nutrients to the coasts. Organic carbon deposited by rivers in coastal areas may be mineralised by bacteria, forming CO_2 that finds its way to the atmosphere. On the other hand, nutrient inputs result in increased algae growth, which increases photosynthesis, which in turn increases the uptake of CO_2 by surface waters. On top of these biogeochemical patterns, temperature is a very important driver, since colder water can store more CO_2.

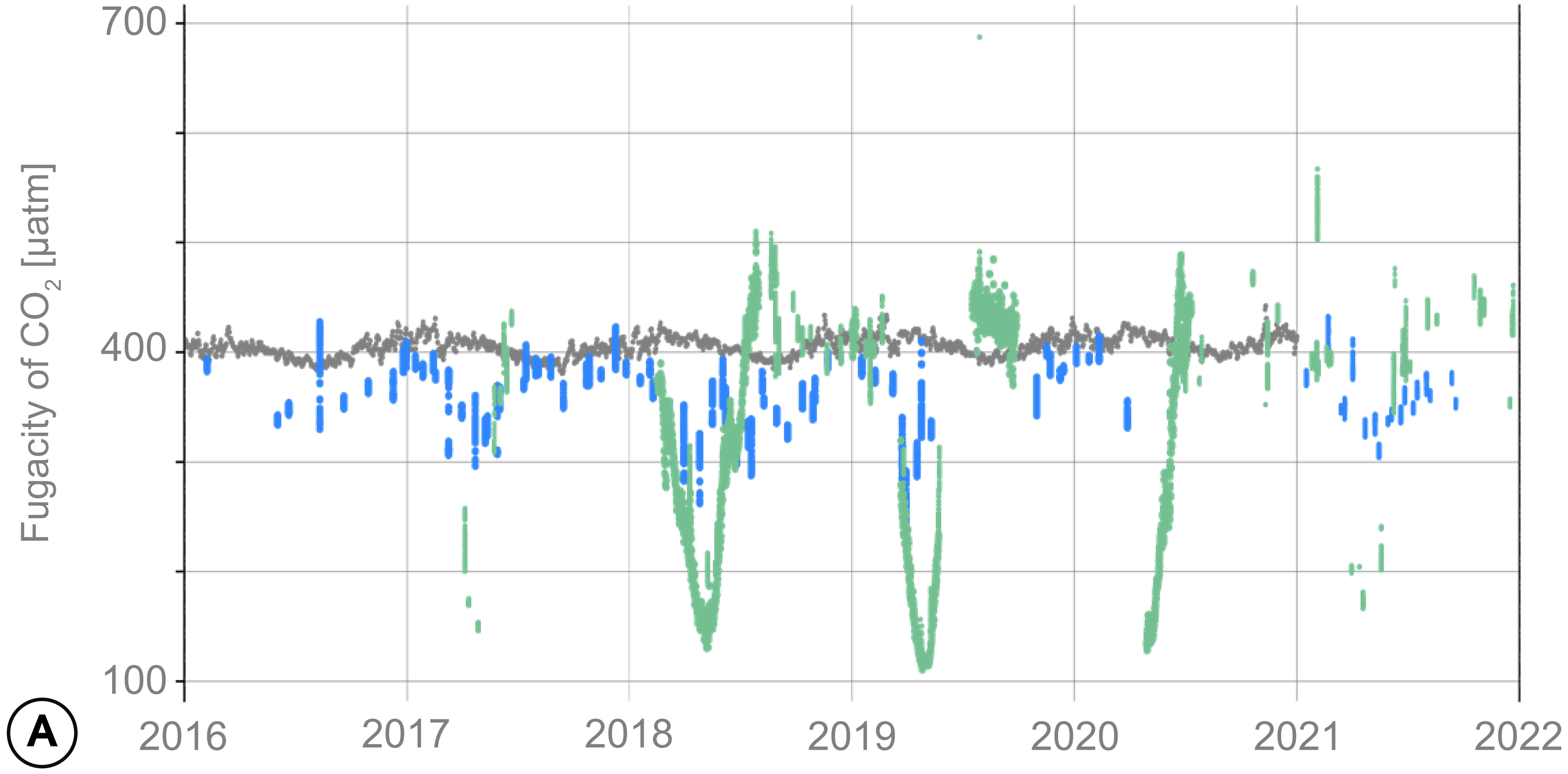
Data from different measurement stations across European coastal or inland seas show the variability in fugacity around Europe (Figure 9): in the northern North Sea (NO-SOOP-Nuka Arctica and NO-SOOP Tukuma Arctica), the southern North Sea (BE-SOOP-Simon Stevin, BE-FOS-Thornton Buoy), the Baltic Sea (DE-SOOP-Finnmaid, SE-FOS-Östergarnsholm) and the Mediterranean Sea (IT-FOS-PALOMA).

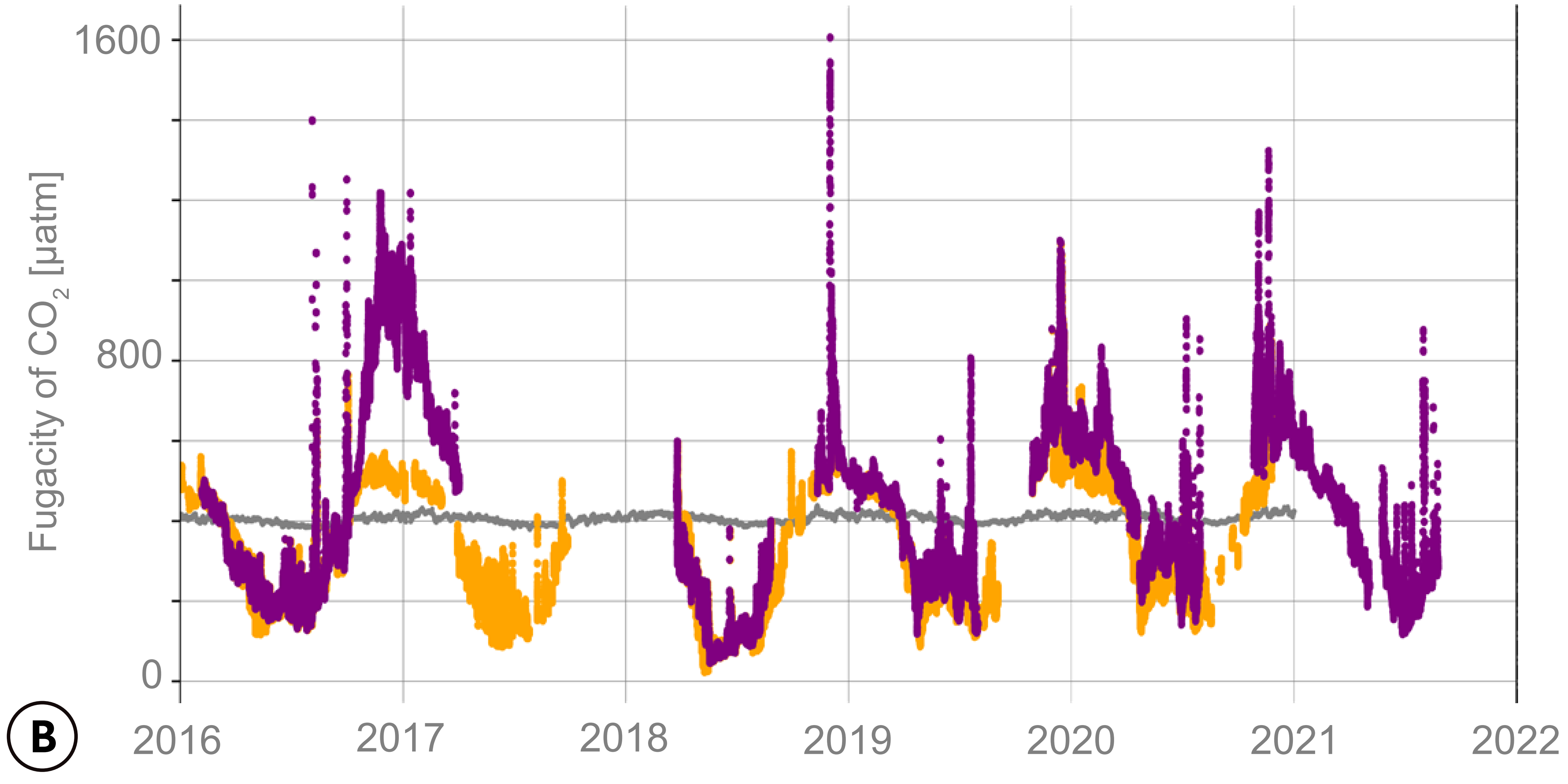
HOW DOES ICOS OBSERVE THE OCEAN?

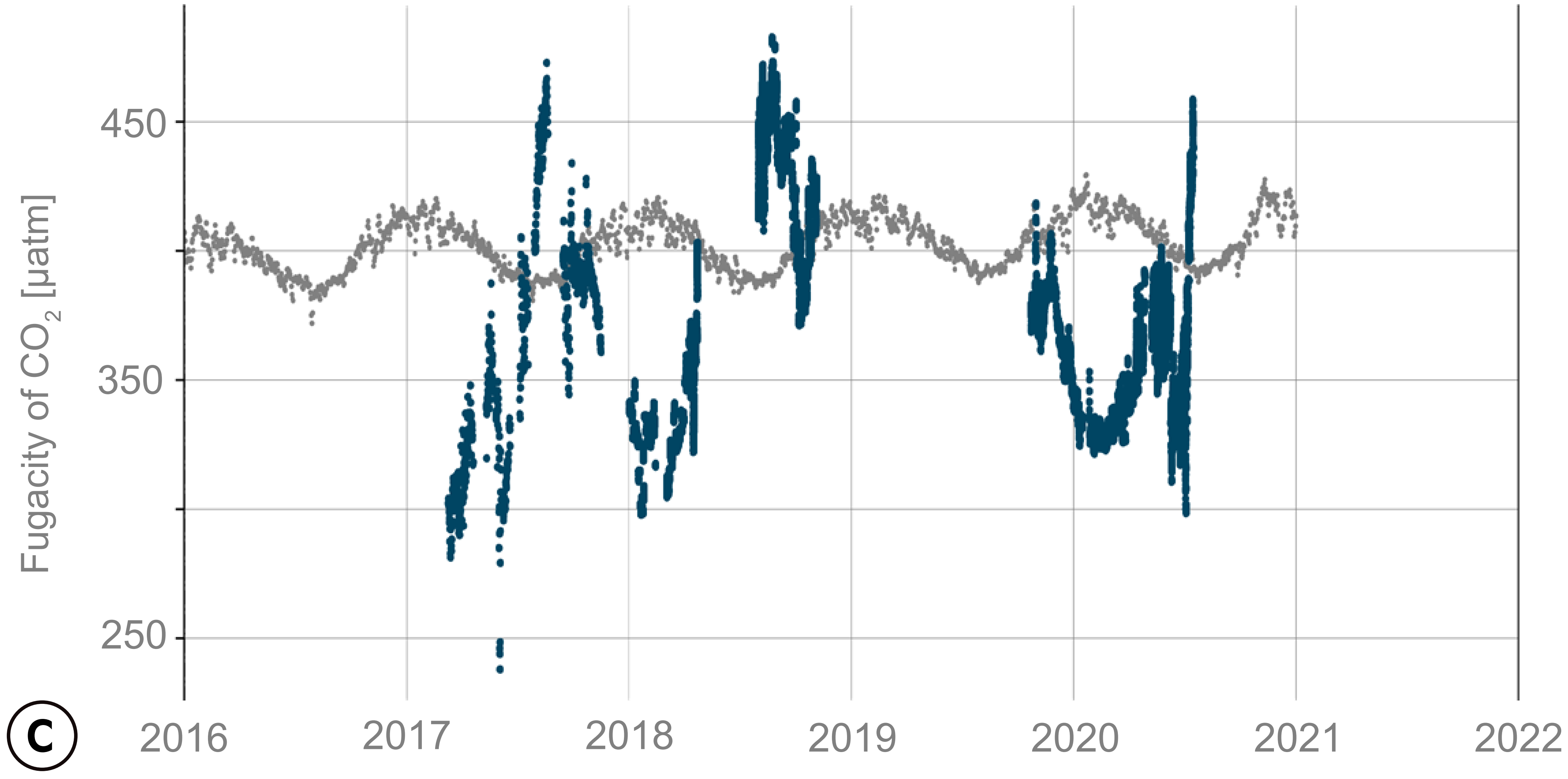
The ICOS Ocean observation network provides CO_2 flux data between the surface ocean and the atmosphere from fixed marine monitoring stations or from ships – either research vessels or 'Ships of Opportunity' (SOOPs): commercial ships that allow scientists to install their equipment on board. CO_2 fluxes between the ocean and the atmosphere are driven by the CO_2 gradient and the physical conditions at the sea surface. The respective scientific parameter that defines the flux is the difference in fugacity of CO_2 (fCO_2) between ocean and atmosphere. The fugacity describes the effective partial pressure and is calculated for the air above the ocean and for the seawater. The difference between fCO_2 in the air and in the water determines whether the seawater is releasing CO_2 or taking it up from the atmosphere. The ability of water to dissolve CO_2 and the fugacity are strongly dependent on temperature. Fixed stations and SOOPs cover only a small part of the ocean surface. The gaps between stations and SOOPs are filled in with statistical approaches ranging from simple multilinear regressions to more elaborated machine learning techniques such as neural networks and inverse modelling. The results are intermediate maps of fCO_2. The flux of CO_2 between the ocean and the atmosphere is calculated based on these maps and additional data on wind strength.

Figures 9A, 9B, 9C
Time series of CO_2 concentrations from seven ICOS stations in three zones: North Sea (A), Baltic Sea (B) and Mediterranean Sea (C).









Oceanic observations from all stations highlight the variability of fCO_2 in these areas, and show that large differences between seasons and years can be found in the very same region.

The general pattern in fCO_2 is similar for most areas, i.e. a sharp decrease during the phytoplankton bloom in spring and a maximum during winter. The further south, the earlier the spring bloom starts and more common is a high fCO_2 during summer caused by seasonal heating of the surface ocean.

The fugacity of CO_2 in the atmosphere is shown as well. When fCO_2 in seawater is lower than in the atmosphere, the ocean absorbs CO_2. When it is higher, the ocean releases CO_2. In the North Sea, we see the difference between the coastal stations in the south (Thornton buoy, Simon Stevin) and open ocean stations in the north (Nuka Arctica, Tukuma Arctica). Both ocean regions are net sinks of carbon, but the variability in the coastal area is much larger, both on seasonal and inter-annual timescales.

The data from two stations in the Baltic Sea come from the same region but from two different types of station: one is a mooring (SE-FOS-Östergarnsholm) and the other one a ship that is passing by the mooring regularly (DE-SOOP-Finnmaid). Their data match nicely during spring and summer while the fCO_2 is low but can diverge largely during winter. The mooring station closer to the shore is more affected by local upwelling events where carbon-rich water is mixed to the surface, which leads to high fugacity.

> ***"The Earth's ocean is a natural sink that takes up about a quarter of human-induced carbon dioxide emissions each year.***

While the stations in the North Sea and Baltic Sea show a seasonal cycle with a minimum of fugacity during spring and summer, the station in the Mediterranean sea, IT-FOS-PALOMA, has its lowest fugacity during the winter season. In the south, the seasonal cycle is dominated by the temperature: when the water is warming, its ability to dissolve CO_2 decreases, while primary production and respiration, i.e. phytoplankton growth, is the main driver of seasonality further North.

Compared to other regions, at the Mediterranean station, inter-annual variability is driven by meteorological conditions and the changes in riverine inputs: mild and rainy winters lead to high fugacity while cold dry winters result in rather low fugacity.

The ocean is a huge carbon sink: it absorbs a quarter of fossil fuel emissions, thus keeping the world cooler. How long the ocean continues this uptake with the warming climate, we do not know. We have a blurry picture of the current ocean CO_2 exchanges, but not how global warming affects them. The marine ecosystems will react differently to changes in river runoff, nutrient availability, and temperature. Rising temperatures and changing climate also challenge the ocean's ability to dissolve CO_2. If we want to have any chance to understand the upcoming changes in the ocean carbon cycle, we need a stronger observation system, which also covers vulnerable ocean ecosystems.