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EARTH AND ITS RESOURCES
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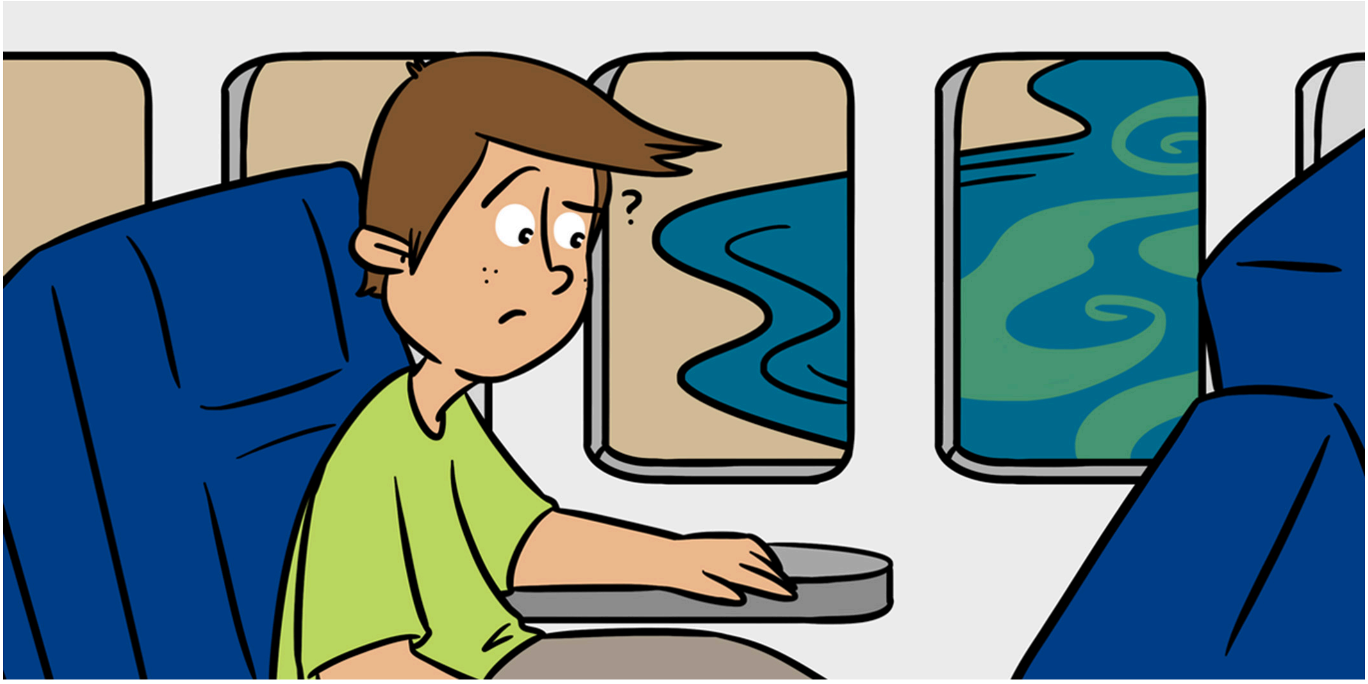

A SEA OF COLORS

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AGE: 10

IRENE
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AGE: 12

Although we always associate the oceans to the blue color, other colors such as green, brown, and even yellowish can be observed. The diverse color palette presented in the oceans and other water bodies is due to the presence of colored components that interact with the light in the water. Those components are, for instance, (1) the water itself, which gives a blue color to the oceans; (2) very tiny plants that can give a greenish color to the water; (3) dissolved compounds that turns the water into a brown-yellowish color; and (4) sediments, which gives a milky color to the oceans. In this article, we explain how those components change the color of the water and how marine scientists use satellites to capture those changes from space and convert them into information for their research.

INTRODUCTION

What is the first color that comes to mind when you think of the ocean? Blue, right? Pictures of the planet from space show that what we call Earth is mostly a blue ocean (if we knew this earlier, we may have named it Ocean rather than Earth!). But if we dig a little deeper, we find that the sea can have a range of colors, varying from blue to green or even yellowish-brownish. You can see some of these differences yourself the next time you take a plane trip. Near the coast, the water is often a different color from what it is out at sea. Have you ever wondered what those different colors mean? In this article, we will look at why the color of the sea changes, how this can be captured by satellites in space, and what it can tell scientists about the oceans.

FIRST, WHAT IS COLOR?

Objects that are black absorb (extinguish) all light, so you could say they have no color, because what our eyes actually see as color is the light that is reflected back from an object. White light (like sunlight) consists of a mixture of light of all colors. Milk is white because it contains lots of very small fat particles that reflect all colors equally well. Similarly, a sheet of white paper reflects all colors. Some objects appear a certain color to our eyes because they absorb specific colors, meaning that they actually remove certain colors of light. Light is absorbed by **pigments**, which are chemical compounds that can be found in living organisms (such as green plants) and inanimate objects (such as paints). The colors that are not absorbed by an object are reflected by the object, and that is what we see or measure with scientific instruments. So, what we see is, in fact, the light that is *reflected* by the object we are looking at.

PIGMENTS

Chemicals that add color to a material.

WHAT CONTROLS THE COLOR OF THE SEA?

Some of the sunlight that shines on the sea surface is absorbed by the water and by pigments that can be found in it, and the rest is reflected, creating the blue, green, and yellowish-brownish colors we see when looking at the ocean (Figure 1). Which colors are reflected depends on what is in the water and the properties of water [1]. Water naturally absorbs most red light and reflects a lot of blue light (Figures 1B, 2), which is the one that penetrates deepest into the water and is the most reflected (Figure 2). This can be observed, for instance, in the clearest blue-water tropical oceans (and mountain lakes). Other colors of water result from three things: dissolved compounds, plants, and very fine grains of sand.

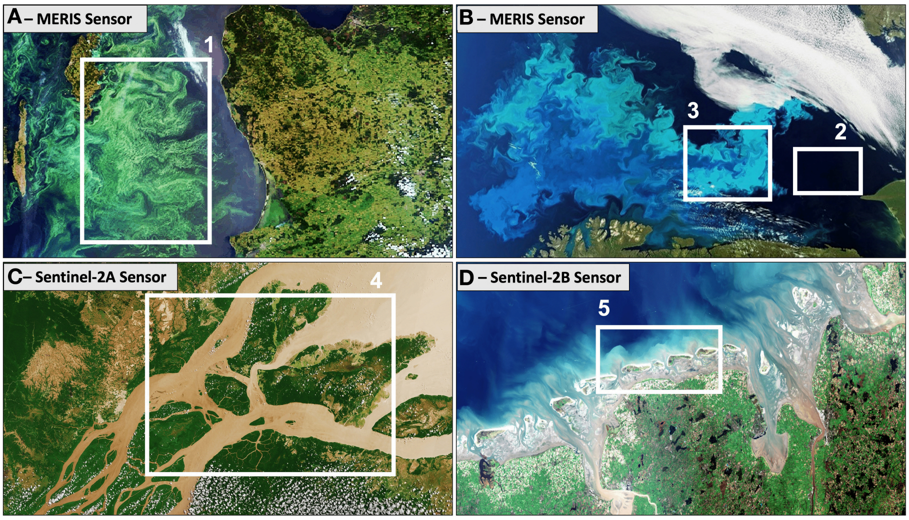

Figure 1

Figure 1

The color of water seen from space, using sensors on board satellites from the European Space Agency. **(A)** The Baltic Sea, showing green waters with lots of phytoplankton (1). **(B)** The Barents Sea, with dark blue open ocean (2) and light blue waters caused by blooms of coccolithophores (3). **(C)** The Amazon, showing the yellowish-brownish coastal waters with river discharge (4). **(D)** The German Bight in the North Sea, highlighting the milky waters full of sediments (5).

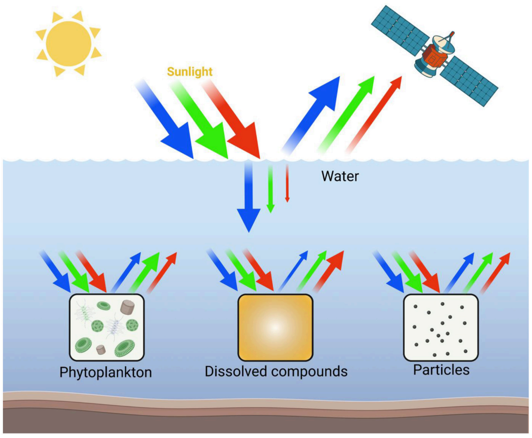

Figure 2

Figure 2

OCRS uses sensors on satellites to monitor the color of the oceans. Sunlight is represented by red, green, and blue arrows that vary in intensity (shown by arrow width). Upward arrows show the light reflected back from the ocean after interacting with water itself (which reflects blue light), phytoplankton (which reflect mostly green light), dissolved compounds (which reflect green and red light), and particles (which mostly scatter light).

DISSOLVED COMPOUNDS: THE OCEAN AS A CUP OF TEA

Make yourself a cup of tea and you will see the water in your cup become yellow or brown, as the pigments in the tea leaves dissolve into the water. The pigments from the dried tea leaves absorb blue light, and the light reflected ends up being yellow or brown. This example helps to explain why seawater can be yellow or brown near places where rivers flow out into the sea. The same way water dissolves compounds in tea leaves, falling rain dissolves soil, which drains into rivers and finally makes its way to the ocean (Figure 1C).

PLANTS: JUST DRIFTING AROUND

Just like plants on land, plants in the ocean have a green color. Plants have pigments that they use to capture sunlight as a source of energy, through photosynthesis. Most plants in the ocean are part of a group of organisms called **phytoplankton**, which are very tiny—the width of human hair or even smaller (see this Young Minds article for some examples). Because of their size, phytoplankton cells mostly drift around with the ocean currents. When there are lots of phytoplankton cells in the water the ocean (called a **bloom**), the ocean becomes green (Figures 1A, 2), which can often be seen in spring and summer. Some groups of phytoplankton have certain red pigments, making the ocean look red when those phytoplankton bloom. This phenomenon is called a red tide.

PHYTOPLANKTON

Single-celled organisms of water environments that make their own food from sunlight through photosynthesis.

BLOOM

When phytoplankton density increases rapidly due to lots of nutrients and sunlight available in the water. It generally happens during Spring season.

SEDIMENTS: THE OCEANS' "MILKY WAY"

As rocks and soils experience the effects of wind, rain, and erosion over the years, they are broken into smaller pieces, ranging from coarse sand grains to very fine silt that forms clay. These products from eroded rocks and soils are called **sediments**. The very fine grains sink so slowly that they remain suspended in the water for a long time. Near the coasts, these grains are either supplied by rivers or whirled up from the seafloor by storms. Although sediments can be pigmented (colored), they mainly change the color of the water by reflecting (scattering) light in all directions (Figure 2). This is similar to what the fat particles in milk do—making the water become what we often call "milky" (Figure 1D). Some phytoplankton called coccolithophores have white plates made of chalk, which also scatter the light. When these phytoplankton bloom, the ocean water can become light blue or even white (Figure 1B).

SEDIMENTS

Fragments of material that have been broken down. Those materials can be organic (for example, soil) and inorganic (for example, rocks).

MEASURING THE COLOR OF WATER

We can see a lot using only our eyes: the blue of the open ocean, the brown and milky river waters flowing to the sea, and the green phytoplankton blooms at the beach in summer. But with instruments called sensors, we can turn the colors we see into precise numbers. We can use those numbers to follow very small changes in water color, which are invisible to the naked eye. These sensors are called **radiometers**. Some radiometers only measure a specific color, whereas others can measure lots of colors at the same time—either individually or by combining the total signal across several colors (see this Young Minds article for some examples).

RADIOMETER

Instrument to detect and measure the intensity of light.

SATELLITES: SENTINELS FROM SPACE

A satellite is any man-made or natural object that orbits another, larger object. Often, satellites with a range of sensors are intentionally placed into orbit around the Earth. These sensors can include radiometers used to monitor water color, among other things. This technique is called **ocean color remote sensing** (OCRS) and, although it has "ocean" in its name, it can be used to monitor the color of water in lakes, rivers, and other aquatic environments, too. The OCRS technique has been running since the 1970s, when the first ocean color sensor, the Coastal Zone Color Scanner, was integrated into the satellite Nimbus 7. A sensor on board a satellite acts like a camera that takes several pictures of the Earth's surface during its orbit around the planet. That means these sensors capture the sunlight reflected by ocean water after that light is absorbed and/or scattered by dissolved compounds, phytoplankton, and sediments (Figure 2). The individual pictures are then combined into a mosaic, which represents a global map of how and why ocean color changes. This mosaic can be produced once a day, every day! The daily mosaics can be combined over several years to form a time series. Scientists use time series images to study how the color of the oceans varies regionally (for example, across different seas or in coastal vs. open sea areas) and over time (year to year, month to month), and to evaluate if ocean conditions are changing [2].

OCEAN COLOR REMOTE SENSING (OCRS)

A method to collect information on the color of the ocean's surface and further transform it into information (data) which can be used by scientists to study the oceans.

WHY IS IT IMPORTANT TO STUDY THE COLOR OF THE OCEANS?

The color of the oceans can provide scientists with lots of information. For instance, ocean color can tell us about the quantities and locations of phytoplankton, dissolved compounds, and sediments in different regions. What do those three components have in common? They all include the element carbon. That means the oceans are involved in the global **carbon cycle**. Carbon dioxide (CO_2) is a very important gas in the carbon cycle. CO_2 can influence global temperature and climate. Like other plants, phytoplankton use CO_2 during photosynthesis and therefore help to control the amount of CO_2 in the atmosphere (see more in this Young Minds article). Phytoplankton also represent the basis of the marine food chain, and changes in phytoplankton quantity and distribution may affect the overall life cycle in the oceans and can even impact humans, in terms of the availability of fish for us to eat (see more in this Young Minds article) [3]. Thus, the color of the oceans represents more than beautiful hues, it gives us information about fundamental elements that control life in the oceans and the climate of the entire Earth.

CARBON CYCLE

Process of how the element carbon travels from living to non-living objects.

DO YOU WANT TO HELP OCEAN SCIENTISTS COLLECT DATA?

Due to some impressive technological developments in the last decades, citizens (including you!) can help to advance this science through what are called **citizen science** projects. Using your smartphone, you can download applications that collect information about the color of waterbodies near you. This info is sent to scientists

CITIZEN SCIENCE

Science projects in which the public participates by collecting data. Some projects eventually also train the public to analyze data.

so they can, for instance, correct the data collected from the satellites. One example is called Project Citclops (Citizen's Observatory for Coast and Ocean Optical Monitoring), which has developed a smartphone app called Eye on Water. This app is fun and quite easy to use, and a great way for you to contribute to research and help the scientific community. So, get your hands dirty (or should we say wet) and help ocean-color science!

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

EVA, AGE: 10

My name is Eva and I am 10 years old. I like dancing. I like to dance the styles Jazz, Tap, and Ballet. I also like reading. I normally read Harry Potter, The Keeper of the Lost Cities, and any mythology series by Rick Riordan. I also like writing. I write fiction books. My favorite school subject is math.

IRENE, AGE: 10

My name is Irene. I am in fourth grade at elementary school. I love sweets and the book series Keeper Of The Lost Cities. I play piano and I am currently learning the cello. I love playing with my friends outside and swimming in the summer. I am also in the Student Council at my school. My favorite special is gym and writing. I joined this program because I am interested in science and our environment. I am worried about climate change and the glaciers that are melting.

KAVIN PORKO, AGE: 12

We as a team are excited and delighted in contributing to science by reaching young minds. Reviewing articles written by experts for young children is a wonderful opportunity to seek and learn various aspects of earth and its resources.

AUTHORS

RAFAEL GONÇALVES-ARAUJO

Dr. Rafael Gonçalves-Araujo is a Brazilian oceanographer with a Ph.D. in natural sciences from the University of Bremen in Germany in 2016. Rafa has been fascinated by the ocean since the first time he saw it in his childhood. He studies the carbon cycle, with a focus on the Arctic Ocean. In his research, he combines information from samples collected directly from the oceans with data from satellite remote sensing. Apart from enjoying expeditions to collect water samples, his work also involves lab work, scientific instrumentation, and a lot of time in front of the computer. *rafgo@aqua.dtu.dk

COLIN A. STEDMON

Prof. Colin A. Stedmon is a chemical oceanographer at the Technical University of Denmark. He obtained his Ph.D. from the University of Copenhagen in 2004. His current research focuses on Arctic marine biogeochemistry. This essentially involves studying the chemical composition of seawater and collaborating with experts in marine physics and biology to understand how the oceans function and, in particular, how the Arctic is changing. He most enjoys the detective work: looking for patterns in data, finding explanations for those patterns, and contributing to an understanding of how the oceans function.

ASTRID BRACHER

Prof. Astrid Bracher is a biologist by training who, after her Ph.D. in ocean optics in the Southern Ocean and her postdoc in atmospheric physics using satellite remote sensing, is now a professor in environmental physics focusing on ocean color, both from space and field measurements. She works on developing methods to obtain the concentrations and composition of phytoplankton and other optically active substances, from ocean-color measurements. Apart from that, she appreciates working occasionally in the field, sampling optical data. Overall, she enjoys the interdisciplinarity of her work and the interactions with many different scientists.