AN OCEAN IN YOUR COMPUTER

3.2 MODELLING OCEAN BIOGEOCHEMISTRY: THE VIEW FROM THE BOTTOM OF THE FOOD CHAIN VIDEO DURATION– 07:39

In this lecture, you will learn about models of ocean biogeochemistry and ecosystems, and how they can be used to understand what factors control their dynamics. You will learn about the phytoplankton, which form the base of all marine food webs, how they change with the seasons and why their abundance differs across regions of the World Ocean.

This lecture was written by Dr Andrew Yool, a researcher at the National Oceanography Centre in the UK, who, like myself, is an ocean modeller studying in the field called marine biogeochemistry.

The subject of our work is marine ecosystems. We are trying to understand where and when they're productive, what controls this, and how this affects the ocean's carbon cycle and fisheries.

We develop and use numerical models - like the one you see on the globe behind me – to achieve this.

Models of marine biogeochemistry consist of numerical equations like the ones you see here on the screen. Like all models, it's not a perfect representation of the real world, but it captures most of the features that can be seen in the ocean.

Of course, the rules that govern the dynamics of marine ecosystems are not anywhere near as well-understood as those that control the physical properties of water, but we know enough of the basics to represent the main factors in the ocean that marine plankton, which are at the base of the food web, depend upon for life.

This movie shows one of our model simulations of surface chlorophyll changing through the seasons. This is an accelerated view of the annual cycle, with the clock showing which month and year are being displayed.

Chlorophyll is the pigment that phytoplankton – and plants on land – use to harvest light and grow. High concentrations of it appear as bright green here, while low concentrations appear as deep blue.

The first thing to notice is that chlorophyll is not distributed evenly or randomly over the World Ocean. There is a lot of variability both in location and time.

In this lecture we will take you on a modelling trip around the World Ocean to try to explain what drives these features.

One of the main features that's immediately obvious, is that there is a strong seasonal "pulse" in the distribution of phytoplankton in the ocean. This phenomenon is known as the "spring bloom", and is strongest in the North Atlantic.

During the winter, chlorophyll concentrations in the ocean are low, but as spring arrives, and into the summer, a "bloom" of algae occurs, spreading northwards, ultimately reaching the seasonally ice-free waters of the Arctic in the summer.

After reaching this peak, the bloom declines again into winter. As you can see in the movie here, the phenomenon repeats year on year.

The explanation behind it is as much physical as it is biological and the main mechanism controlling it is the vigorous mixing of the surface layers of the ocean.

To grow, phytoplankton in the ocean need two things: sunlight, which comes from the surface, and nutrients - most of which are mixed up from below where their concentrations are higher.

Deeper mixing brings up a lot of nutrients, but takes phytoplankton away from the sunlit surface. Meanwhile, shallow mixing keeps phytoplankton close to the sunlit surface, but limits the nutrient supply from below. Thus, only a narrow range of mixing conditions are optimal for driving phytoplankton blooms.

Have a look here at the complex patterns of the mixing in the upper ocean. The movie shows the depth of the upper ocean mixing and how it varies in location and time.

At the surface of the ocean, vigorous mixing occurs as a result of the interactions with the atmosphere. The action of wind transfers turbulent energy into the ocean and deepens the mixing. When the surface of the ocean cools in winter, the mixing penetrates even deeper. When the surface warms in summer, the mixing becomes more shallow. In some places, input of the fresh water from melting ice, rivers or rainfall can also reduce mixing.

For our story about the North Atlantic bloom it’s important to note that very deep mixing in winter brings up a lot of nutrients, and this is followed by shallow mixing in summer which creates stable conditions for phytoplankton to bloom.

Let’s now have a look at the surface nutrients. This movie is showing dissolved inorganic nitrogen. You’ve probably already noticed that in the areas characterised by deep winter mixing, the nutrients are high. You can see this most clearly in the North Atlantic.

However, as well as the nutrient-rich areas, there are regions where nutrient concentrations are very low. You can see those throughout the tropical oceans here. These are known as oligotrophic gyres, and they are the largest ecosystem in the World Ocean. Sometimes they are called “ecological deserts”, because the low nutrient conditions there lead to very poor growing conditions for phytoplankton.

Here we are back to chlorophyll and, as you can see, this is very low in the gyres in spite of the stable mixing regime and abundant sunlight. There are five oligotrophic gyre regions in the World Oceans: two in the Atlantic and Pacific, one per hemisphere, and one in the Indian Ocean.

Getting back to the Chlorophyll at the high latitudes, we discussed the North Atlantic bloom, but what about other places like the North Pacific or Southern Ocean? Blooms there are not as intense as in the North Atlantic. Why is that? Let's start with the North Pacific.

Nutrients in the Pacific are high, but ocean mixing in winter is not as deep as in the North Atlantic. This allows the zooplankton – the animals – that graze on phytoplankton, to survive through the winter and be ready in spring to graze on the growing phytoplankton and stop the sort of intense blooms we see in the North Atlantic from developing.

Moving to the Southern Ocean, here phytoplankton blooms are also not as intense as in the Atlantic. Part of the explanation is similar to the Pacific – here as well, zooplankton survival through the winter puts grazing pressure on the bloom. But there is another important factor at play: nutrient iron, which is needed for phytoplankton growth.

Although, like nitrogen, some of the dissolved iron comes from the deeper layers of the ocean, the main source of iron is the atmospheric dust deposition, driven by winds bringing it from the continents, especially from the deserts. This image shows an atmospheric dust deposition event captured over the Atlantic by NASA's satellite-based MODIS sensor.

https://twitter.com/CopernicusECMWF/status/1121030966733090818

https://atmosphere.copernicus.eu/europe-struck-desert-dust

https://visibleearth.nasa.gov/view.php?id=81864

Antarctica, the continent surrounded by the Southern Ocean, is largely covered by ice and, as such, is a poor source of iron dust. Rich sources of dust and iron, such as Sahara or Patagonia, are too far away from the Southern Ocean to provide much iron.

This remoteness is responsible for what we call an iron-limitation of the phytoplankton and its primary production. The movie shows dissolved iron concentrations at the surface of the ocean. You can see very low values away from the continents, most notably in the Southern Ocean but also in some remote areas of the Pacific.

In this lecture we showed you some of the most important features of the variability in phytoplankton which lies at the base of all marine food webs. We introduced you to the key factors ocean biogeochemical modellers are working with to describe this variability: ocean mixing, supply of nutrients and sunlight.

We use models like this to understand the dynamics of the marine ecosystems, their role in climate change and fisheries.

In the next lecture you will learn about Upwelling.