AN OCEAN IN YOUR COMPUTER

3.3 MODELLING OCEAN UPWELLING SYSTEMS

VIDEO DURATION– 06:40

Ocean Upwelling is one of the key processes by which deep, nutrient-rich waters are brought to its sunlit surface.

This lecture was written by Dr Katya Popova from the National Oceanography Centre in the UK. You will learn about the importance of upwelling systems for our planet and the life on it; about the main types of upwelling; about the rich and productive ecosystems that upwelling sustains, and how we use ocean models and remote sensing data to study it.

Upwelling is an upward movement of water, which is maintained long enough to lift water parcels over a vertical distance of about 100 meters or more. To achieve such a displacement in the ocean, this period of vertical movement needs to last from several days to weeks.

There are many mechanisms driving upwelling systems. The largest, most persistent, and most productive upwelling regions in the world ocean are those driven by the wind, and include coastal and equatorial upwelling.

Coastal upwelling occurs when wind blows alongshore - that is, parallel to the coast - northward in the northern hemisphere and southward in the southern hemisphere. Due to the rotation of the Earth, the Coriolis force acts to move water 90o to the direction of the wind, away from the coast. To compensate for this movement, upwelling occurs, replacing the surface water with deeper, colder and more nutrient-rich waters.

Depending upon the typical wind conditions in a region, coastal upwelling systems can be either permanent, forming major upwelling systems; or it can only occur during part of the year, forming seasonal upwelling systems.

The major upwelling systems are found along the west coasts of the main continents, and are called Eastern Boundary Upwelling Systems. They sustain the most productive ecosystems in the world. While accounting for only 1% of the ocean's surface area, they produce around 20% of the total global fish catch.

There are four such systems on Earth, we can see them very clearly in this animation of modelled surface chlorophyll:

- the Californian upwelling in the North Pacific;
- the Peruvian upwelling in the South Pacific;
- the Canary upwelling in the North Atlantic and
- the Benguela upwelling off the west coast of Africa.

In this animation, you can see these areas in dark red colours, indicating the high nutrient concentrations brought up to the surface from the deeper ocean.

Because the upwelled deep waters are cooler than the surface waters they are replacing, areas of strong upwelling can readily be spotted from space. They are characterised by lower sea surface temperatures and elevated chlorophyll.

In contrast to the major eastern boundary systems where upwelling occurs all year around, seasonal upwelling systems experience upwelling during only some parts of the year. Despite this seasonality, these upwelling systems can still be highly productive and are very important for regional fisheries.

One of the most intense upwelling systems in this category is that in Northern Indian Ocean, which occurs during the south west monsoon along the Somali and eastern Arabian coast. Examples of other significant regional systems include upwelling off the coast of India; Java and Sumatra; and the East China Sea – all of which support major industrial fisheries.

All seasonal upwelling systems have unique features in terms of their complex ecosystems; the fisheries they support, the intricate social fabric of their supply chains, conflicts of interest, and cultures rooted in the marine environment. They are also experiencing the first signs of climate change impacts.

Later in this MOOC we will tell you more about three regionally important seasonal upwelling systems of the Western Indian Ocean: the North Kenya Banks, the Tanzanian upwelling and the Agulhas Bank. Each of these have their own complex stories of fishery collapses and food security issues, as well as the artisanal fishermen so dependent on the sustainable use of these systems.

Now we need to mention a darker side of the high biological production in upwelling systems – the oxygen minimum zones that occur at depth beneath them. Oxygen is consumed when the high quantities of organic material produced in the upwelling systems decompose, as they sink to the ocean bottom. This decomposition results in areas which are low in oxygen, and sometimes being completely depleted of it. Although some marine life forms have evolved to live in low oxygen conditions, such conditions are often deadly for higher trophic level organisms such as fish and shellfish.

Equatorial upwelling is another type of large-scale and productive upwelling that we can see in our animation of surface chlorophyll. Easterly trade winds blowing along the equator, drag the surface water westward. The rotation of the Earth deflects these currents towards the right in the Northern hemisphere, and towards the left in the Southern hemisphere. This drives the surface water away from the equator, bringing up nutrient-rich water from below.

Another interesting feature of both coastal and equatorial upwelling, is their role as intense sources of CO_2 from the ocean to the atmosphere. This is driven by the high concentrations of dissolved inorganic carbon brought to the surface by upwelling. You can see these areas on this animation of air-sea exchange, with red colours indicating CO_2 sources to the atmosphere and blue colours indicating ocean sinks of atmospheric CO_2.

There are many other types of upwelling we have not covered in this short lecture. These include:

- large-scale wind-driven upwellings in the ocean interior;
- the upwelling associated with mesoscale ocean features such as eddies and meanders;
- topographically-driven upwelling such as that occurring around seamounts;
- broad diffusive upwelling in the ocean interior;
- ice-edge upwelling;
- "dynamic uplift" or the shelf-edge upwelling which occurs when a current flowing along the shelf accelerates;
- tidally-induced upwelling; and
- the upwelling found in the wake of islands, which is usually well-known to local fishermen.

In this lecture we have learned about the main types of ocean upwelling features, their role in maintaining highly productive ecosystems and rich fisheries, but also about the important oxygen minimum zones which are often formed underneath them.