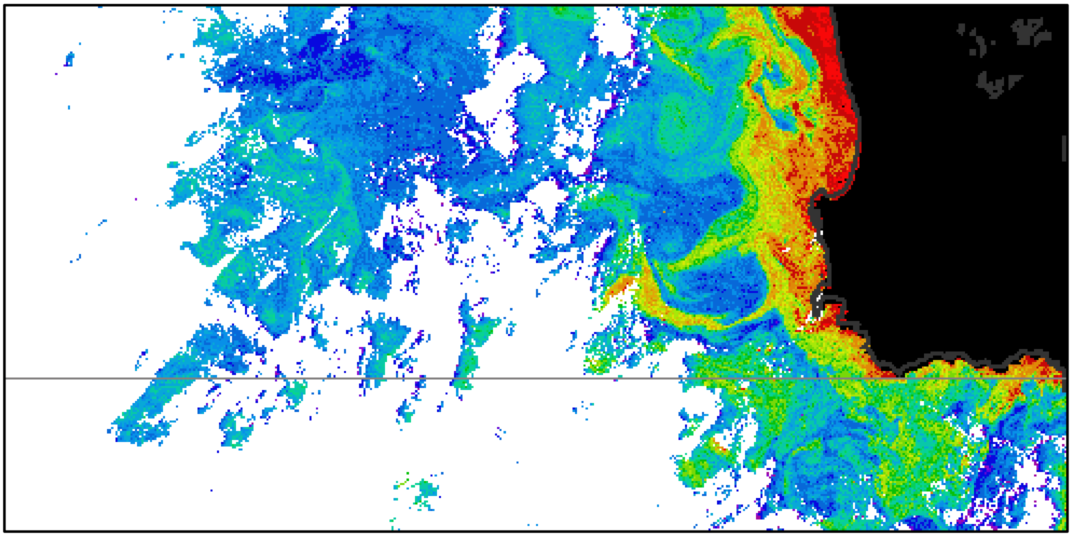
Chapter 2: The Benguela Upwelling Zone

In the first chapter, an image of the island of Tasmania illustrated the complex interactions that can result between the currents in the ocean (which are primarily studied in the field of physical oceanography) and the phytoplankton living in the ocean (which are part of the field of biological oceanography).

The CZCS image of Tasmania might make it seem impossible to figure out how such complex patterns are generated. In many regions of the ocean, however, the patterns are much simpler. There are some basic processes that cause patternsfound in many different areas of the ocean, all resulting from the same combination of winds, ocean currents, and the essential elements that allow life to exist in the ocean.

One of the basic realities of this research effort can be found in the name of the instrument that acquired the images -- the CZCS. The first two words in the name are "coastal zone". If you look at a CZCS image of the whole world, which is composed of many different smaller scenes obtained over the eight years the instrument operated, it is immediately obvious that the continents are surrounded by areas of higher productivity. While some of these areas can be very broad and others very thin, it is a general observation that there is more productivity near the coast. When the CZCS was first proposed, no one was sure that this type of remote sensing observation could actually be made from space! Yet the scientists did know that the best place to attempt such observations would be near the coast, where productivity was highest. So the "mission" of the CZCS was designed to look at various coastal regions. (The CZCS shared power on the satellite with other Earth observation instruments, and so it was not operated continuously. This factor makes the CZCS archive of images a little frustrating to use, because the instrument was always observing different oceanic regions, and many times these regions were covered by clouds. In many cases, to make a single image of one entire region of the ocean, several different images have to be combined. These images are called *composite* images, and some of them will be shown in later chapters.)

There is a reason that coastal areas usually have higher productivity than the open ocean. Besides sunlight and carbon dioxide from the atmosphere, plants also require certain elements, called nutrients, for growth. The supply of these nutrients is generally greater near the coast. The most important nutrients in the ocean are nitrate (NO_3^-) and phosphate (PO_4^-), though there are other necessary nutrients. Just as plants on land receive fertilizer with nitrogen and phosphorus to enhance growth, when phytoplankton receive more nitrate and phosphate, their growth rate will increase.



CZCS image of the southwest African coast, showing the high productivity of the Benguela upwelling zone and associated features of the Benguela current. This image was obtained on September 29, 1980.

The image shown above is a single CZCS 2-minute scene (the area scanned by the CZCS in two minutes as it orbited the Earth) of the southern African coast on September 30, 1980. Along the western coast is an area of very high primary productivity, as seen by the large areas of red and yellow in the false color image. The high productivity of this area is due to a fundamental process in physical oceanography called *upwelling*. This area is called the Benguela upwelling zone, because it is located where winds and currents combine to bring cold ocean waters rich with nutrients from the ocean depths to the surface. Upwelled waters have high nutrient concentrations because when organisms living in the lighted surface waters die, the organic matter that is in their cells sinks into the deep ocean. Very slowly, the cells are decomposed by bacteria. This process enriches these deep waters with nutrients.

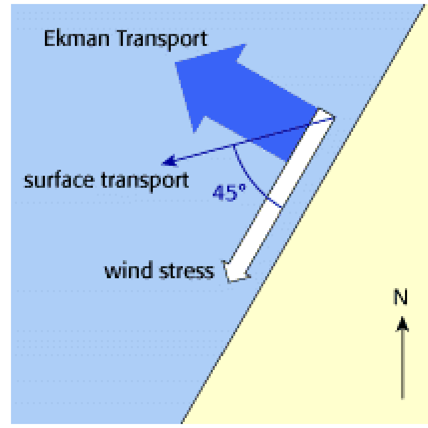
Visible light photograph taken from space of a plankton bloom in the Benguela upwelling zone. The air masses near the coast originate over desert areas and are therefore very dry, which helps to keep the nearshore area cloud-free.

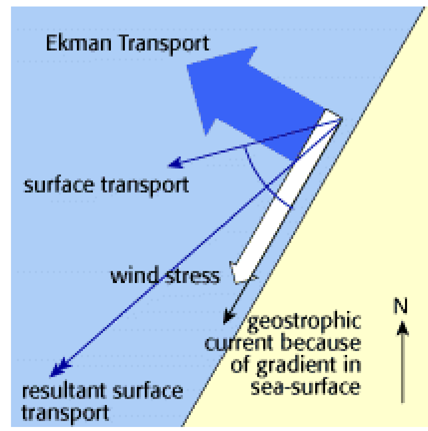
Note: This image is probably not a plankton bloom, but is more likely a related geophysical phenomenon that is explained in the *Science Focus*! article A Bloom By Any Other Name... Might Never Be a Bloom At All.

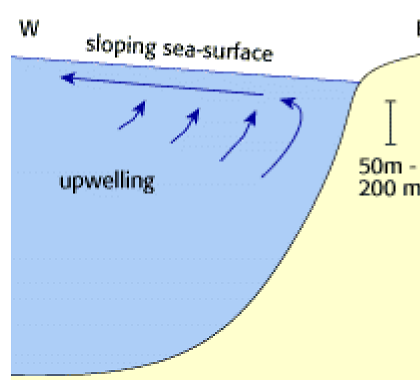
The flow of most surface currents in the ocean is induced by the wind, and these currents are therefore called wind-driven currents. The northward direction of the Benguela current is part of the *geostrophic* flow of the world ocean, the currents which flow due to the Coriolis force, the force that results from the rotation of the Earth. One result of the interaction between the prevailing winds and the Coriolis force is the large-scale rotational circulation in major ocean basins. These large rotational patterns are called *gyres*, and they result from the necessary balance between the Coriolis force and pressure gradients in the ocean produced by winds. In the South Atlantic, the north-flowing Benguela is part of a counterclockwise gyre; on the South American side of the gyre, the Brazil Current flows south.

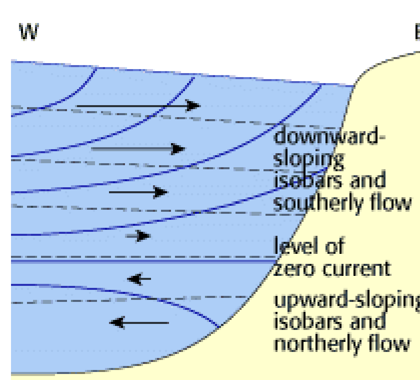
However, the productivity of the Benguela upwelling zone results from a different principle that is also related to the Coriolis force. This principle, one of the most important principles of physical oceanography was determined by physicist V.W. Ekman, who examined the frictional effects of wind moving over a surface. The net effect is that wind does not make a current flow in the exact same direction that the wind is blowing. What actually happens is that the resulting current moves to the right side of the wind direction in the Northern Hemisphere and to the left of the wind direction in the Southern Hemisphere At the surface, the current moves about 45 degrees to the right (or left, in the Southern Hemisphere) of the wind direction. If the movement of the water is integrated over the entire depth that wind influences the movement of the water, the resulting motion of the water is at roughly a right angle (90 degrees) from the direction of the wind. This movement of water is called *Ekman transport* or *Ekman flow*.

(The diagrams to the right illustrate how Ekman transport causes coastal upwelling in the Northern Hemisphere for winds blowing south along the coast.)





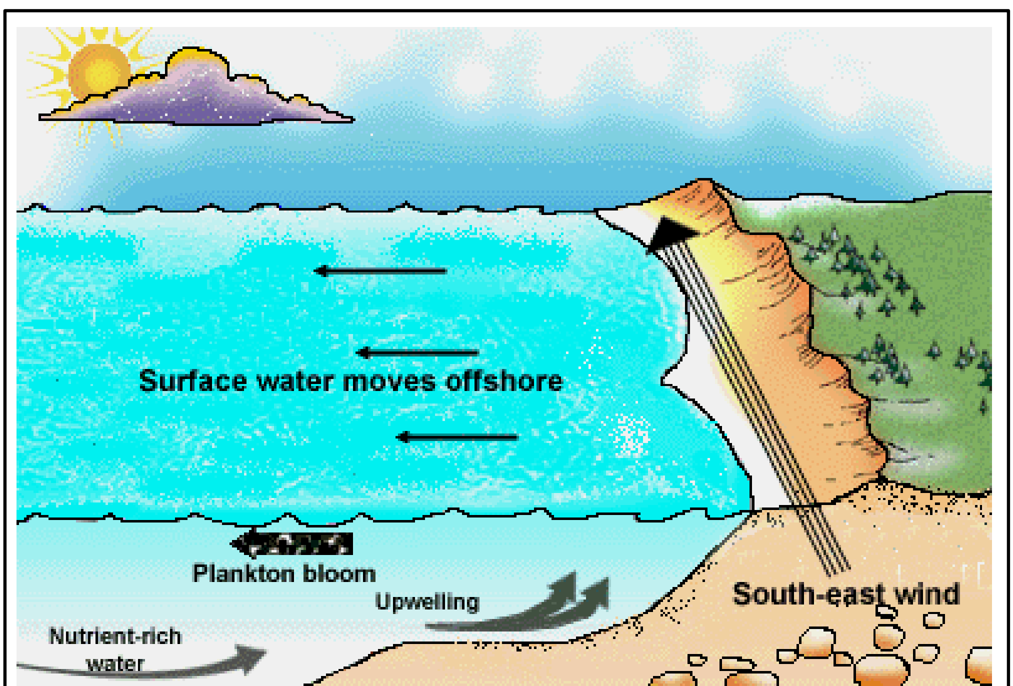




In the case of the Benguela Current upwelling in the Southern Hemisphere, the prevailing winds are from the southeast. These winds cause the nearshore Ekman flow to be directed away from the coast (westward), which brings cold surface waters to the surface right at the coast. This upward flow brings in the constant supply of nutrients that phytoplankton require for growth, which results in an area of particularly high productivity. The strong flow of the nearby Benguela Current sometimes causes the occurrence of offshore "jets" that capture some of the nearshore productivity and carry it offshore. The CZCS image shown earlier shows a prominent jet.

The image below depicts the interaction of winds, ocean upwelling, and nutrients that cause the Benguela Upwelling Zone to be one of the most productive oceanic regions in the world. (Just note that there are very few trees to the east of the Benguela Upwelling Zone – this region in Africa is the Namib Desert, one of the driest regions of the world. The cold ocean water that upwelling brings to the surface is also related to the lack of rainfall here.)

Knowing the location of major surface currents in the ocean should allow prediction of other similar upwelling zones. After such predictions are made, the CZCS archive can be searched to see if these predictions are correct.



Schematic diagram of the Benguela Upwelling Zone.