

Name:

Date:

TEACHER VERSION: Suggested Student Responses Included

Upwelling and Phytoplankton Productivity

Guiding Questions:

- How does nutrient concentration influence phytoplankton growth in coastal and open ocean waters?
- What and where are the upwelling zones, and what do they depend on?

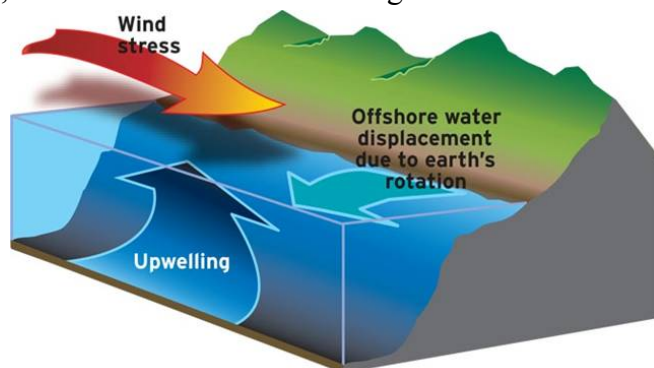
Introduction

Phytoplankton are microscopic plants that live in the surface layer of the oceans and form the base of the marine food chain. Though they are small, the energy they capture from the sun through photosynthesis (their **productivity**) helps to sustain almost all life in the ocean. In order to photosynthesize, phytoplankton contain a pigment called **chlorophyll-a** (the same as in land plants), which also gives the microscopic plants a greenish color. Like all plants, phytoplankton productivity depends on sunlight, water, carbon dioxide, and nutrients.

The nutrients needed by phytoplankton (primarily nitrate, phosphate and iron) quickly get depleted in the surface ocean unless replenished. One source of nutrient replenishment comes from runoff from the land (rivers). Another source of nutrients comes from deeper ocean water, which typically has high nutrient levels. These deeper waters need to be transported vertically into the surface layer. This happens during wind events, and during winter when surface ocean water gets cold (and denser) and sinks. This causes overturning and vertical mixing.

Another way in which deep ocean water gets to the surface is from a process called **upwelling**. Upwelling occurs when winds blowing across the ocean surface often push water away from an area. When this occurs, water rises up from beneath the surface to replace the diverging surface water. Subsurface water that rises to the surface as a result of upwelling is typically colder, rich in nutrients, and biologically productive. Therefore, good fishing grounds typically are found where upwelling is common. For example, the rich fishing grounds along the west coasts of Africa and South America are supported by year-round coastal upwelling.

The direction the surface water flows depends on the wind direction and hemisphere. Because of the rotation of the Earth, surface water moves at an angle to the wind direction. In the Northern Hemisphere, surface water moves to the right of the wind and in the Southern



Hemisphere, it moves to the left of the wind. This is why upwelling is dominant when winds are parallel to a coastline, although it occurs in the open ocean too.

The cold coastal water brought in by upwelling can easily be seen in sea surface temperature data, and the resulting phytoplankton productivity can be seen in chlorophyll concentration data. In this investigation, you will explore upwelling and phytoplankton productivity in the Benguela Upwelling Zone, which is located along the western coast of South Africa. The Benguela upwelling zone is rarely affected by oceanic variability, making it one of the most productive areas of the world ocean and one of the most prominent in remotely-sensed chlorophyll concentration data.



Part 1. Questions

1. What are the three ways nutrients can be replenished in ocean waters?

Nutrients can be replenished in ocean waters by: runoff from rivers, vertical mixing and overturning (for example, when cold, dense surface water sinks in the winter), and by upwelling.

2. Define upwelling.

Upwelling is when winds blow across the ocean surface, and push water away from one area. This allows the deeper, nutrient rich, water to rise and take its place.

3. In the Southern Hemisphere, if the wind is blowing to the North, which way will the water move?

The surface water would move west (to the left of the wind).

Part 2. Sea Surface Temperature

1. From the Student Climate Data website (<http://studentclimatedata.unh.edu>), click on the 'Ocean Data' tab at the top of the page.
2. Under 'Tools and Data' in the left panel, click 'DICCE Portal' to bring you out to the NASA DICCE data portal.
3. In the **Area of Interest** section (below the map), type in the coordinates for the Benguela upwelling area as shown below.

Area of Interest: West: North: South: East:

4. Click 'Update Map.' This should create a yellow bounding box off the western coast of South Africa.
5. Under the '**Ocean**' parameter section, click the box next to 'Sea Surface Temperature.'
6. In the '**Temporal**' section, set the Begin Date to Jan 2008 and the End Date to Dec 2008.

Ocean
 The Physical Ocean(2002/07/01 - 2012/03/31)
Parameter
 Euphotic depth
 Sea Surface Temperature (11 micron day)

Begin Date Year Month
End Date Year Month

7. Using the '**Select Visualization**' drop-down menu, select 'Lat-Lon map, Time-averaged.'
8. Click and set the **Color Bar Mode** to 'Dynamic.'
9. Click
10. It may take a few minutes for DICCE to create the map. Once the map loads, take some time to observe the patterns in sea surface temperature.
11. Where is the upwelling occurring on the map? How do you know?

Upwelling occurs right off the coast of Africa. I can tell because that is area with the lowest sea surface temperature.

12. Why is the upwelling occurring in this location?

The upwelling is likely occurring due to wind and the Earth's rotation. The surface water is being pushed away from the coast allowing the deeper, colder ocean water to take its place.

13. Based on your knowledge from the Introduction and your observations of sea surface temperature, where do you expect the chlorophyll concentrations to be the highest? Why?

I would expect chlorophyll concentrations to be highest in the area of upwelling (where the sea surface temperature are the lowest), because that would have the most nutrient dense water.

Part 3. Chlorophyll

1. Return to the data portal page by clicking the [Home](#) tab on the top-left of the page.
2. Click *off* the Sea Surface Temperature box, and click *on* the box next to ‘Chlorophyll a concentration.’

| Ocean Biosphere(1997/09/01 - 2014/12/31) | | |
|---|-------------------|------------|
| Parameter | Data Product Info | |
| <input checked="" type="checkbox"/> Chlorophyll a concentration | SWFMO_CHLO.CR | SeaWIFS |
| <input type="checkbox"/> Chlorophyll a concentration | MAMO_CHLO_9km.CR | MODIS-Aqua |

3. Click [Edit Preferences](#) and set the **Color Bar Mode** back to ‘Pre-Defined.’
4. Keep all other parameters the same.
5. Click [Generate Visualization](#)
6. Once the map loads, take a few minutes to observe the patterns in Chlorophyll.
7. Where is the highest chlorophyll concentration occurring on the map? How can you tell? Is this the location you predicted?

The highest chlorophyll concentration is off the coast of Africa, in the area that I predicted. I can tell because the values are high, between 1 and 10 mg/m³, as opposed to the 0.1 mg/m³ values farther off the coast.

8. Why is the highest chlorophyll concentration in this location?

The highest chlorophyll concentration is in this location because upwelling, as seen from the sea surface temperature map, has brought up nutrient-rich water, so phytoplankton productivity is high, leading to a high chlorophyll concentration.

Part 4. Is there a relationship between Chlorophyll and Sea Surface Temperature?

1. Return to the data portal page by clicking the [Home](#) tab on the top-left of the page.
2. Click *on* the Sea Surface Temperature box, and keep Chlorophyll a concentration on.
3. In the ‘**Temporal**’ section, keep the Begin Date the same, but set the End Date to Dec 2010.
4. Using the ‘**Select Visualization**’ drop-down menu, select ‘Time series.’
5. Click [Edit Preferences](#) and set the **Overlay Flag** to ‘Yes’ (this will plot both variables on the same graph).
6. Click [Generate Visualization](#)
7. What color are the sea surface temperature data? What color are the chlorophyll data?
Sea surface temperature data are red; chlorophyll data are blue.

8. What is the range of chlorophyll concentration for this area?

There is a range from 0.3 to 1.1 mg/m³.

9. What time of year is sea surface temperature generally the highest? What time of year is chlorophyll the highest?

Sea surface temperature is generally highest in June to August, whereas the chlorophyll concentration is generally highest from February to March.

10. Is there a relationship between sea surface temperature and chlorophyll concentration off the coast of South Africa? Explain why or why not.

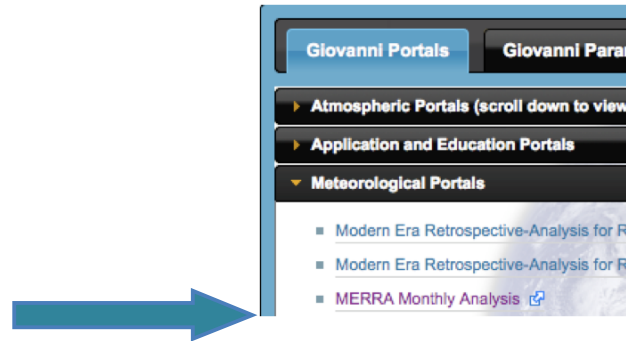
There seems to be an inverse relationship between sea surface temperature and chlorophyll concentration. When sea surface temperature is lowest, chlorophyll concentration is highest. This could be because when sea surface temperature is lowest, it signifies greater upwelling, causing a spike in chlorophyll concentration due to phytoplankton productivity.

Name:

Date:

Extension 1. Wind fields

1. Click **+ ABOUT GIOVANNI** at the top of the page.
2. Under ‘Giovanni Portals,’ click ‘Meteorological Portals’ and then ‘MERRA Monthly Analysis’



3. Under the ‘**Parameters**’ section, click the box next to ‘Northward wind component’. This variable is the speed of the wind moving in a northerly direction.
4. In the **Area of Interest** section (below the map), type in the coordinates for the Benguela upwelling area as shown below.

Area of Interest: West: North: South: East:

5. Click ‘Update Map.’ This should create a yellow bounding box off the western coast of South Africa.
6. Under the ‘**Vertical Profile**’ section, set the ‘Upper Level’ and ‘Lower Level’ values to 1000.0 hPa.

Upper Level hPa
Lower Level hPa

7. In the ‘**Temporal**’ section, set both the Begin Date to Jan 2008 and the End Date to Dec 2008.


Begin Date Year Month
End Date Year Month

8. Using the ‘**Select Visualization**’ drop-down menu, select ‘Lat-Lon map, Time-averaged.’
9. Click
10. Colors on the map indicate the intensity of the northward or southward wind component. Reds indicate a strong northward wind, and purple indicates a southward wind. Where is the strongest northward wind located?


The strongest northward wind is located at 26S, 14N, or just off the coast of Africa.

11. Using your knowledge from the Introduction, what direction is the surface water moving in relation to the wind in this hemisphere? What direction would the water move if this were in the northern hemisphere?

In this hemisphere, the surface water is moving to the left of the wind, so it would be moving west. In the northern hemisphere, the surface water would move to the right of the wind (east).

11. Return to the data portal page by clicking the  tab on the top-left of the page.

12. Using the ‘**Select Visualization**’ drop-down menu, select ‘Time-series.’

13. Click 

14. What time of year is northward wind generally the highest? What time of year is chlorophyll the highest (recorded in Part 4, Question 9)?

The northward wind is generally highest from November to January. The Chlorophyll concentrations are generally highest from February to March.

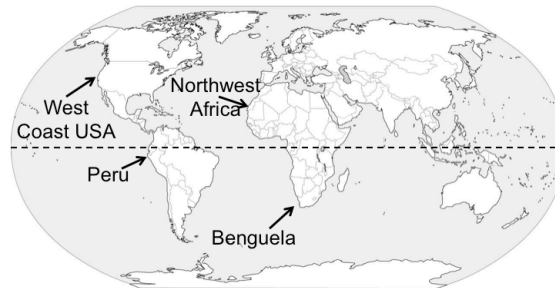
15. How does the northward wind component relate to chlorophyll throughout the year? Why do you think this is?

The strong northward wind from November to January causes upwelling to occur as surface waters are pushed away from the coast. This causes higher phytoplankton productivity, which can be seen in the resulting chlorophyll spike in February.

Name:

Date:

Extension 2. Upwelling Investigation in Other Regions



From the table below, choose a region or regions you would like to investigate, and using what you have now learned about the Benguela upwelling and the tools in Giovanni, look at the various indicators to see if the upwelling signatures can be seen in the remote sensing data. Explore the cycle over one or more years.

Table 1. Coordinates for selected regions.

| Region | West | North | South | East |
|------------------|-------------|--------------|--------------|-------------|
| Peru | -87 | 0 | -20 | -70 |
| Northwest Africa | -25 | 36 | 19 | -7 |
| West Coast USA | -130 | 50 | 35 | -120 |

Which region(s) did you choose?

Pose a **research question** that focuses on the effects of upwelling on sea surface temperature and chlorophyll concentration, and can be answered using the data available on the DICCE Data Portal page.

A research question should be concise, have a single or limited set of variables, and be answerable using data available on GIOVANNI.

Write a **hypothesis statement** that will either be supported or not supported by the results of your investigation. State your hypothesis:

The hypothesis statement should answer the research question and provide reasoning for their thinking.

What data/information do you need in order to test your hypothesis?

Information should include the variables they wish to study as well as the range of dates they will use in their investigation.

***Student responses on this page depend on the student developed research question.*

Use the coordinates from Table 1, and the data available on the DICCE portal, to investigate research question. Record your results in the table below or create your own table.

Table 2. Investigation Results

| Region | Year | Month | Sea Surface Temp(min) | Sea Surface Temp(max) | Chlorophyll (min) | Chlorophyll (max) |
|--------|------|-------|-----------------------|-----------------------|-------------------|-------------------|
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

Record other observations and findings using graphs, tables, or text below.



***Student responses on this page depend on the student developed research question.*

Analysis and Discussion

What are some notable outcomes of your investigation? Were the results of your investigation similar or different than the patterns observed in the Benguela upwelling zone?

Was your hypothesis supported by the data from your investigation? Why or why not?

Develop one new research questions you have after viewing your results. What information would you need to answer this new question?