SCIENCE FOCUS: Ocean Circulation

A Very Cold Warm-Core Eddy in the Southern Ocean

Part 1

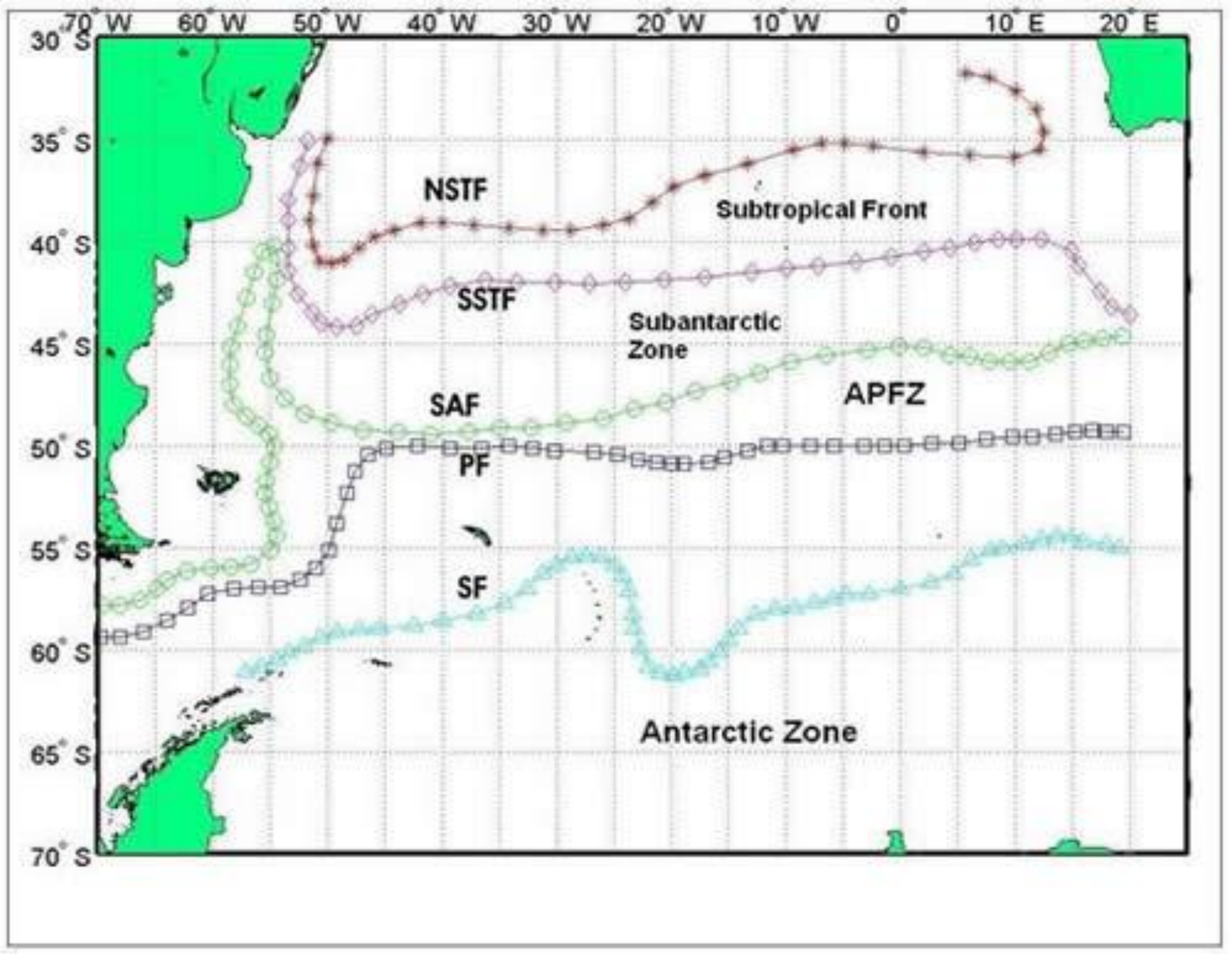
Warm-core eddies are a famous feature of the Gulf Stream and Sargasso Sea region. They have been extensively studied by shipboard research, and they are highly discernible features in both sea surface temperature (SST) and ocean color (chlorophyll) data. The *CZCS Classic Scenes* chapter entitled "Gulf Stream Rings" provides a general overview of these types of eddies and how they form.

When a Gulf stream warm-core eddy forms, the water in the warm core is usually quite warm, because it was extracted from the surface waters of the Sargasso Sea. The Sargasso Sea is a tropical water body that is very warm year-round, in the range of 27-30 °C. So it isn't difficult to call the core of a Gulf Stream warm core eddy "warm"—or even hot.

However, such eddies do not always form where the water is tropical. The example examined in this *Science Focus!* article is decidedly non-tropical—it is found in the chilling waters of the Southern Ocean. And this example also illustrates how a few fortuitous observations can provide significant information about the physical and biological dynamics of this region.

First of all, some context. The region being examined is the Southern Ocean in the vicinity of South Georgia Island. (For more on this region, read the Science Focus! article "**South Georgia: A View Through the Clouds**". Clouds will be an important aspect of this article, too.)

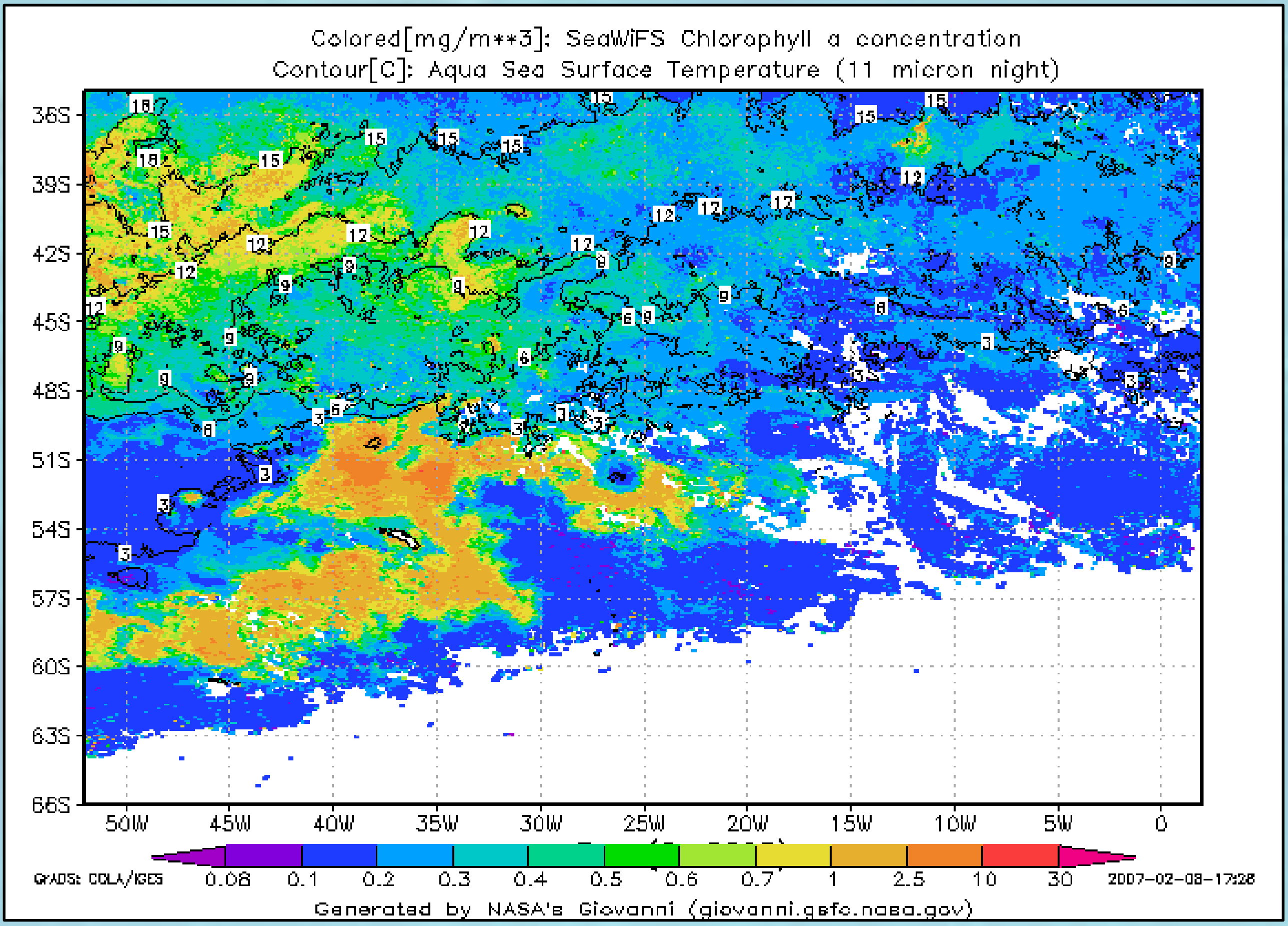
On the next page is a diagram of the South Atlantic and Antarctic Ocean, showing the various oceanic fronts in the region. A front is a region where two currents, or two distinct water bodies, meet. The acronyms stand for the following: NSTF: North Subtropical Front; SSTF: South Subtropical Front; SAF: Subantarctic Front; APFZ: Antarctic Polar Frontal Zone; PF: Polar Front; SF: Scotia Front. In the map below, South Georgia Island is the crescent-shaped island between the "PF" and "SF" labels on the fronts.



Fronts in the Southern Atlantic Ocean and Southern Ocean. See previous page for acronym expansion. Permission to use this image was obtained from Igor Belkin, URI/GSO, image author.

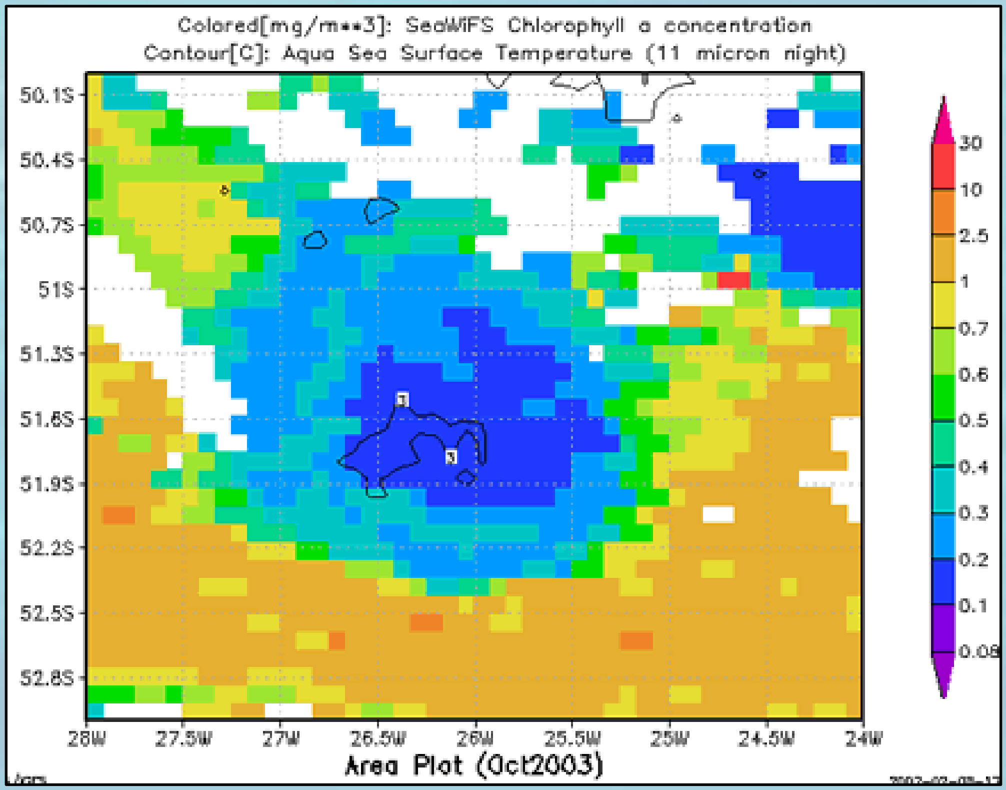
What this diagram doesn't show is the distribution of sea surface temperature (SST) and phytoplankton chlorophyll. Of course, these are constantly changing, but the particular month shown below, October 2003, was very interesting. This image was generated with the Giovanni Ocean Color Multi-dataset Intercomparison Interface*. The color scale is for chlorophyll concentration; the numbers are for contour lines of SST. The Polar Front follows the 3 °C contour fairly closely; moving northward, the proximity of the 9 °C and 12 °C contours indicates the approximate position of the Sub-Antarctic Front. The occurrence of higher chlorophyll concentrations is also an indicator.

* No longer available.

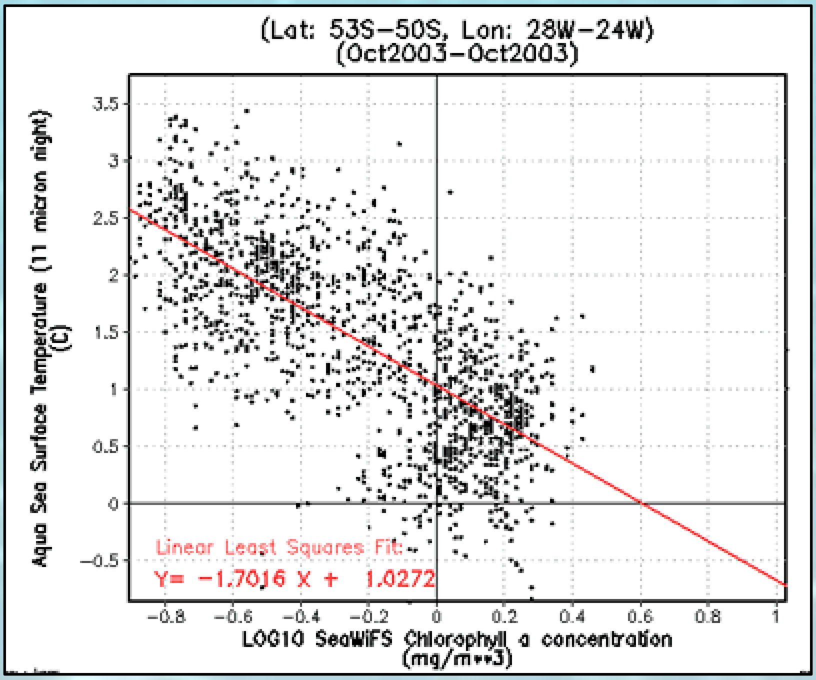


The most prominent feature in this image is a circular eddy northeast of South Georgia Island, approximately 25 °W, 51 °S. By its circular appearance, we would presume that this is an eddy. But we can confirm the diagnosis using Giovanni.

First we'll zoom in on the eddy, still using the Multi-dataset Intercomparison Interface. Right in the middle of the eddy, we can see that the low chlorophyll concentration center coincides with water temperatures that are above 3° C. Because warm water is buoyant, if we had sea surface height data from an altimeter like Jason or TOPEX/Poseidon, the center of the eddy would also be an area where the sea surface is elevated.



To ultimately confirm our diagnosis that this is a warm-core eddy (even though warm is only 3 degrees above the freezing point of pure water!) we can now generate a scatter plot of the SST and chlorophyll concentrations for this image.



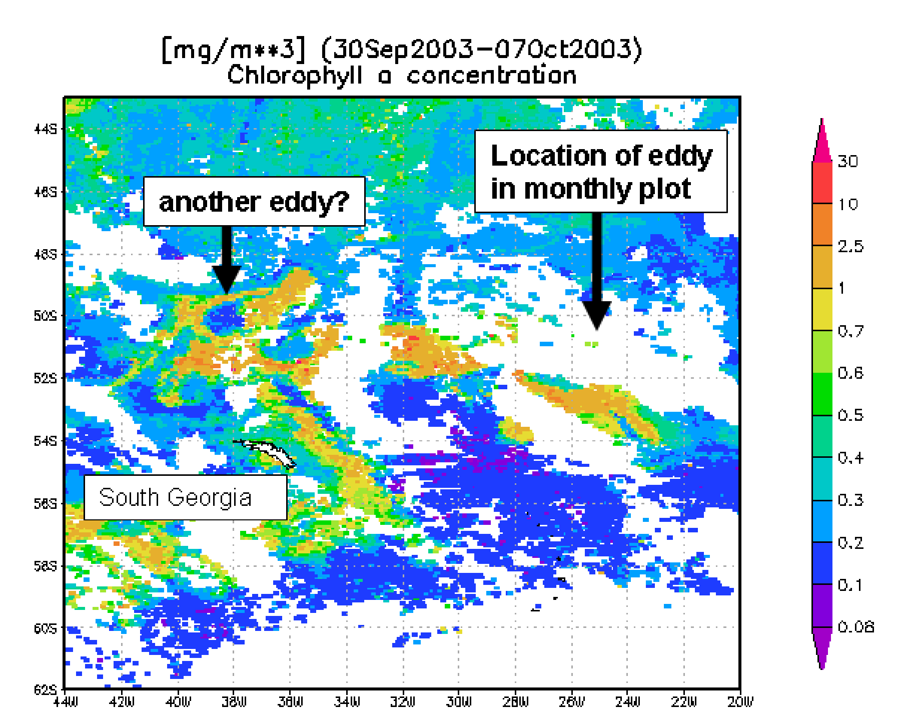
The scatter plot on the previous page demonstrates that the circular feature certainly is a warm-core eddy. The "warmest" water temperatures, in the range of 2.5 to 3 °C, are associated with the lowest chlorophyll concentrations, less than 0.2 milligrams per cubic meter. And the lowest temperatures, sometimes even below 0 °C (seawater freezes at a lower temperature than pure water because of its salt content), are associated with the higher chlorophyll concentrations around the eddy.

It's very unusual to see such a well defined eddy in an image of monthly averaged chlorophyll concentrations, because eddies, along with the currents and fronts that create them, are constantly moving. Because a monthly average plot takes all of the observations for a given month, if a lot of observations are obtained, this will "blur" or "smear" a distinct feature (like an eddy) that moves. So examination of this image made us suspect that the eddy was easy to see because there were probably very few observations of it in October 2003. As noted earlier, clouds are an important part of this article, because the Southern Ocean tends to be VERY cloudy.

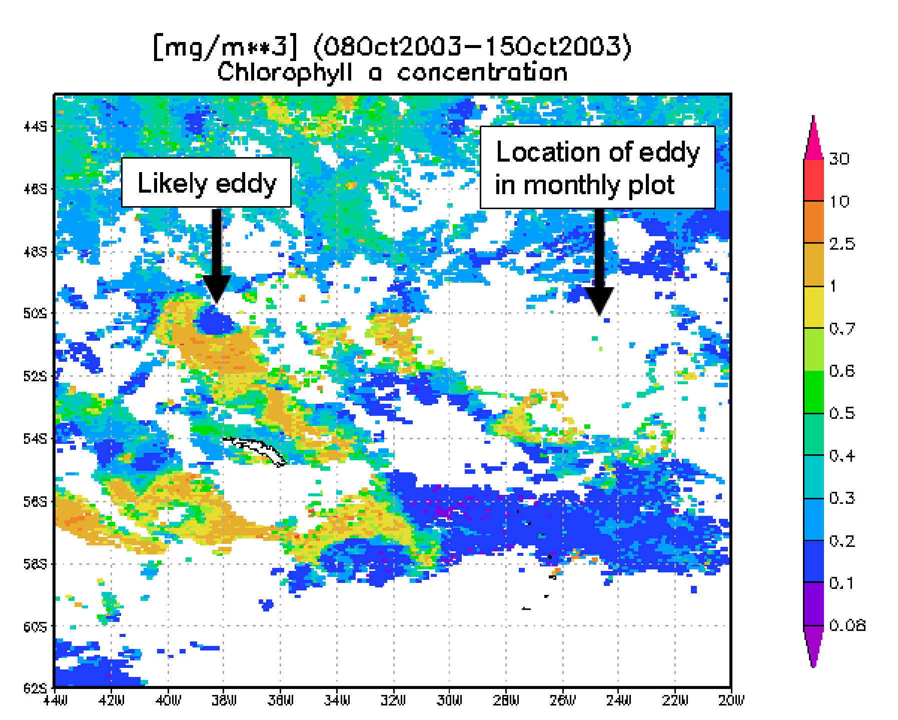
Part 2

We just examined an image of the Southern Ocean in October 2003, observed an eddy, and determined that this was indeed a warm-core (where 3 °C is warm compared to the surrounding waters). We also suspected that the reason this eddy was so easy to see in the monthly data plot was due to a limited number of observations in this particularly cloudy oceanic region. Now we'll check to see if our suspicion is correct.

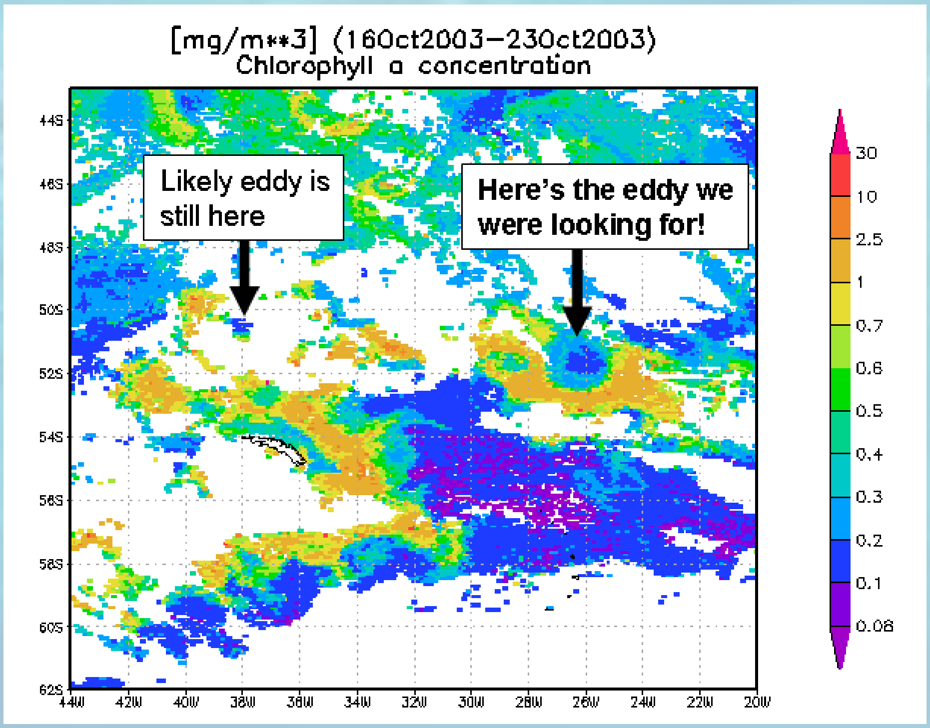
The first thing we will do is to look at the four 8-day SeaWiFS images of this region for the month of October 2003.



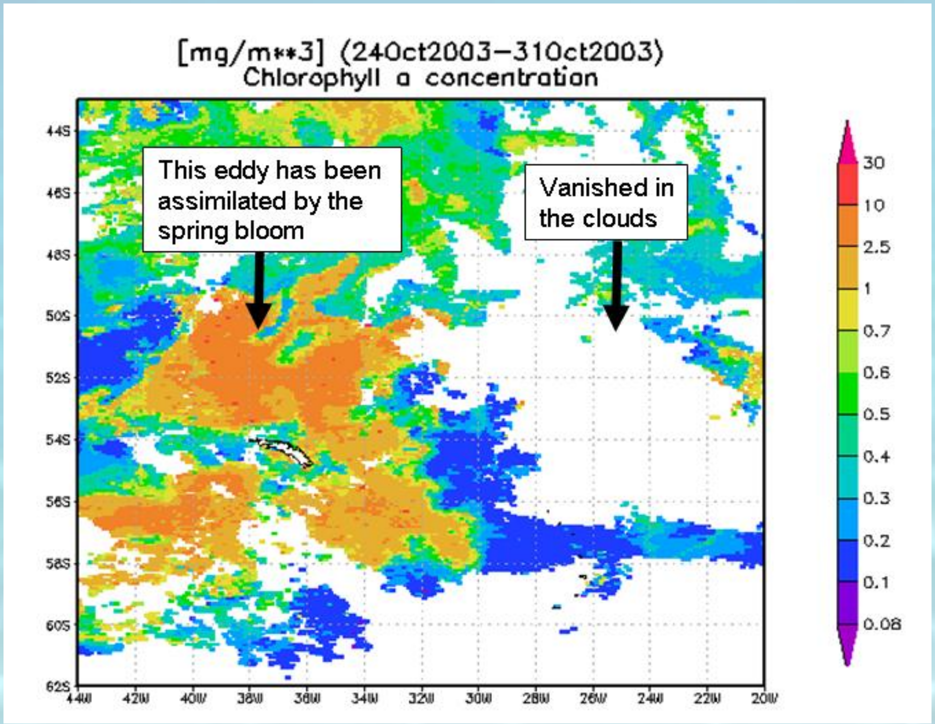
September 30 – October 7, 2003



October 8 – October 15, 2003



October 16 – October 23, 2003

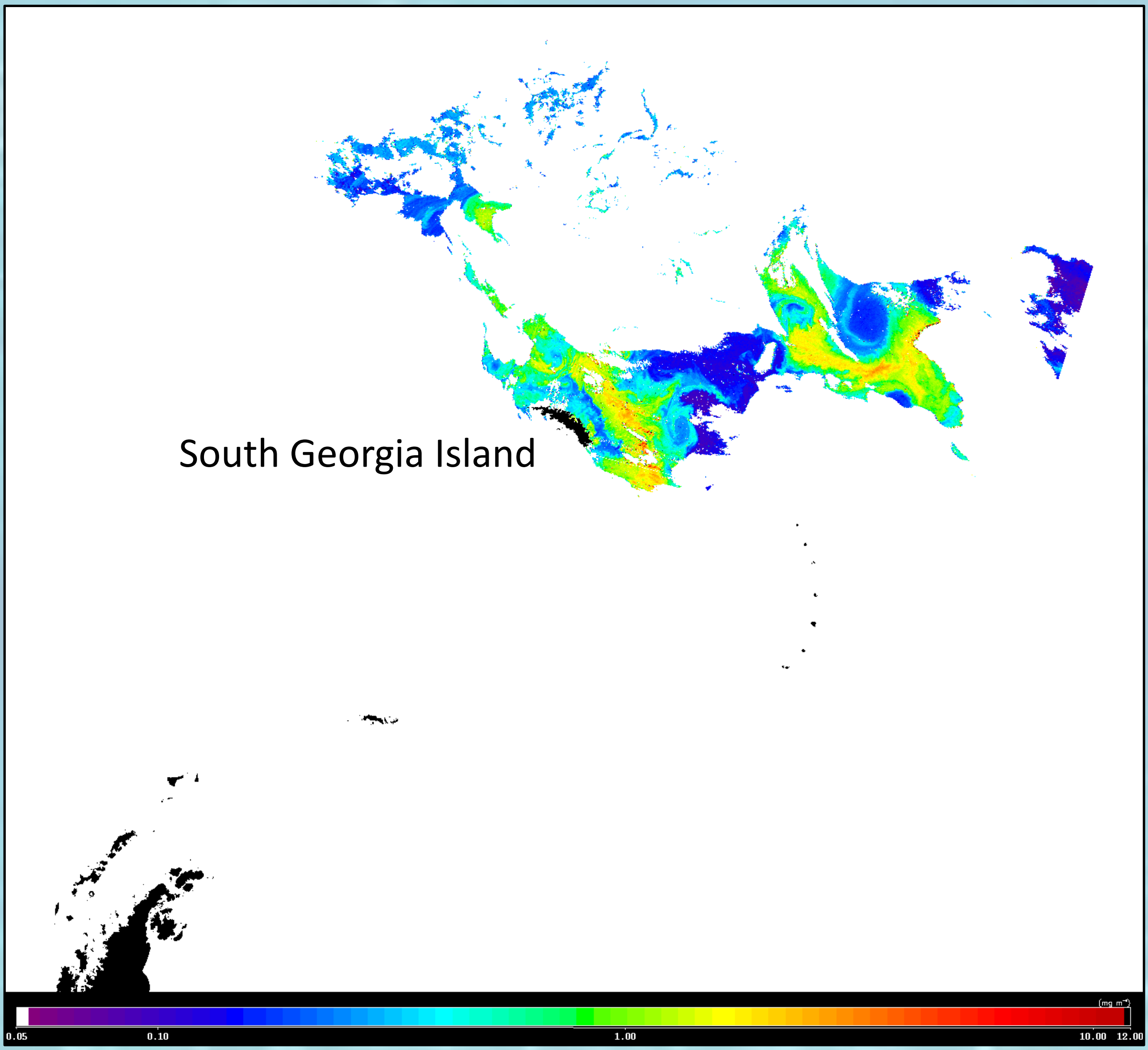


October 24 – October 31, 2003

(Happy Halloween!)

The images on the preceding pages demonstrate, clearly, that the only period when the eddy to the northeast of South Georgia Island was visible was October 16 to October 23. Even in the other 8-day images, the cloud cover was so pervasive that there are hardly any glimpses of the sea surface in the eddy location. However, the 8-day images also revealed another eddy, almost directly north of South Georgia. But as the spring bloom blossoms north of the island, it appears that the eddy gets torn apart by the shifting currents and the low productivity water in the center of that eddy is stirred into the higher productivity waters around it.

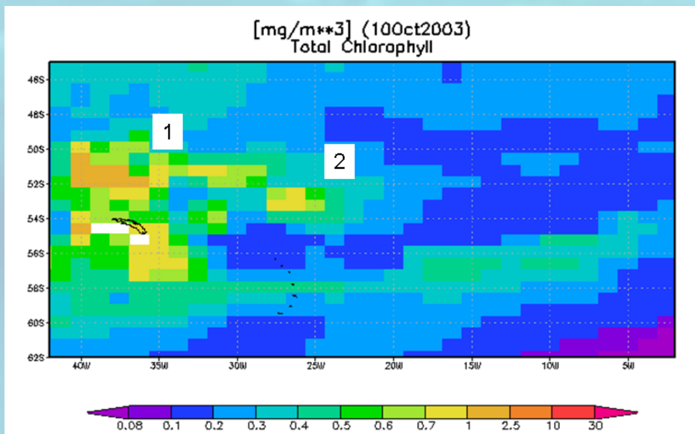
We then used Giovanni to browse the available high-resolution data for October 2003 — fortunately, a ground station on the Palmer Peninsula of Antarctica acquired the high resolution data from SeaWiFS. This search revealed that there was only one day, October 19, when the eddy was clearly visible—and it is the data from this day that makes the eddy so prominent in the 8-day and monthly images. The image shown on the next page was processed with SeaDAS to show how fortunate the observation of this eddy was. It's hard to see the color scale in the reduced-size image (click on it to see the stunning full-size version). The highest chlorophyll concentrations (orange to red) range from about 5 to 10 mg m^{-3}, and the lowest concentrations (dark blue to purple) are 0.05 to 0.1 mg m^{-3}.



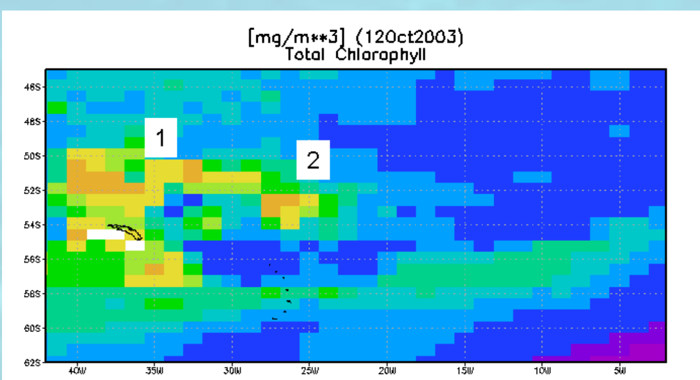
Now, there is a way to look under the clouds—in a sense. Giovanni also features data from the NASA Ocean Biogeochemical Model, NOBM. NOBM uses a model of ocean circulation and biology coupled to an "assimilation" of the available SeaWiFS data, to calculate chlorophyll concentrations and also the distributions of various kinds of phytoplankton, and it does this for every day of the year. The calculated output from the model, even though it is lower resolution than the SeaWiFS images, allows an observation of the daily changes happening in the ocean, even in cloudy areas like the Southern Ocean.

Below and on the next page are seven images from the NOBM output data for October 2003. The positions of the two eddies are labeled in each one; Number 1 is the eddy north of South Georgia Island, number 2 is the eddy to the northeast of South Georgia, the eddy that was examined in Part 1. The development of eddy number 2 and the disappearance of eddy number 2 can be observed in these images.

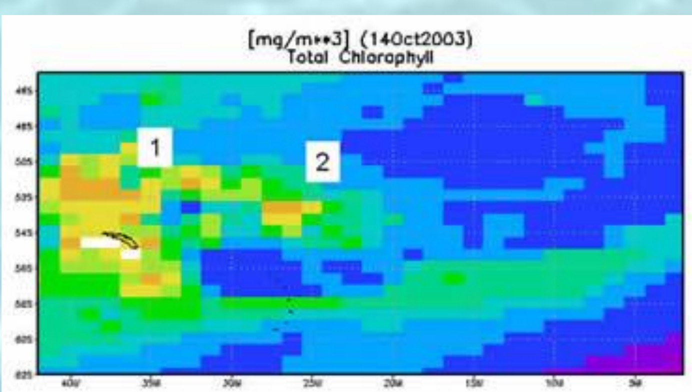
Also, observe how the spring bloom in the Southern Ocean slowly strengthens during this period, particularly north of South Georgia Island and along the Scotia Front south of the island.



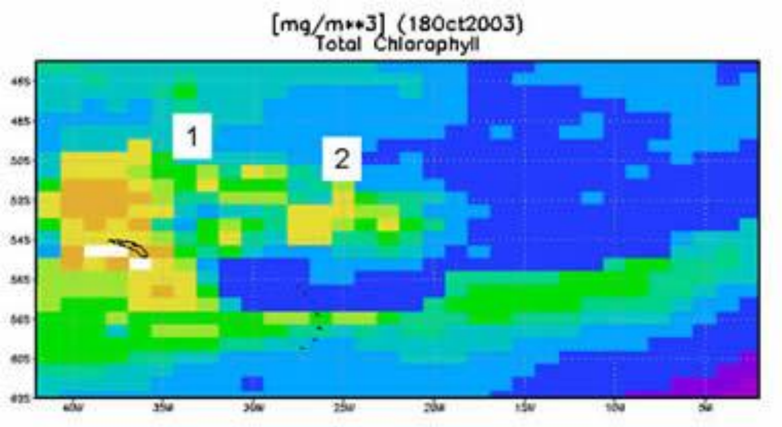
October 10



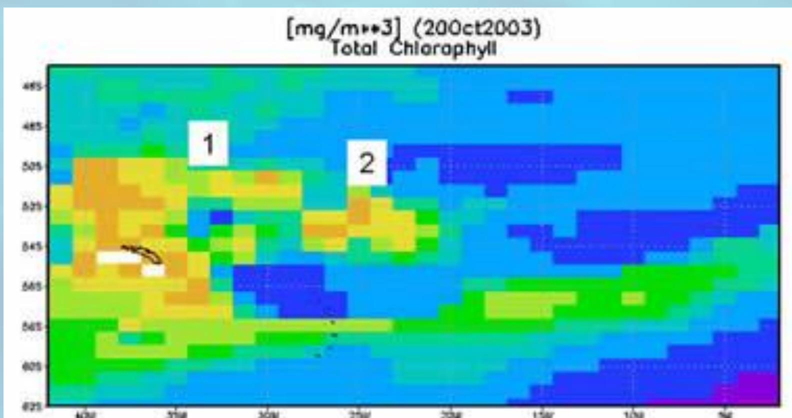
October 12



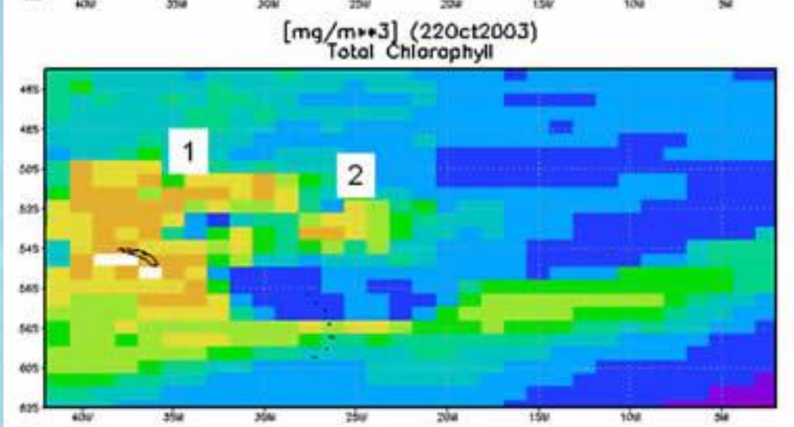
October 14



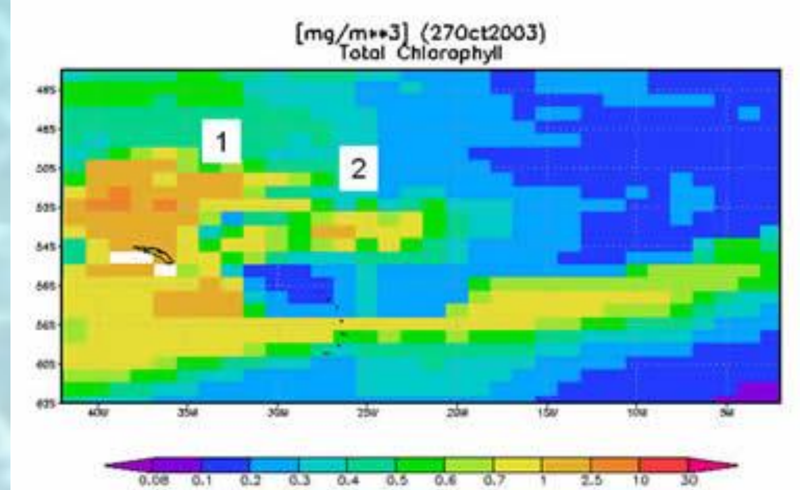
October 18



October 20



October 22



October 27

So now we've seen how the cold waters of the Southern Ocean can still produce a "warm" core eddy, and we have also seen how one break in the clouds can provide us with significant insight into the interaction of physical and biological factors in this dynamic oceanic region.

References for further information:

"Mesoscale eddies in the Subantarctic Front—Southwest Atlantic", Glorioso, Piola, and Leben, *Scientia Marina*, 69 (Suppl-2), pages 7-15, 2005.

"Southern elephant seal trajectories, fronts and eddies in the Brazil/Malvinas Confluence", Campagna, Piola, Marin, Lewis, and Fernandez, Deep-Sea Research, 53(12), 1907-1924, 2006.