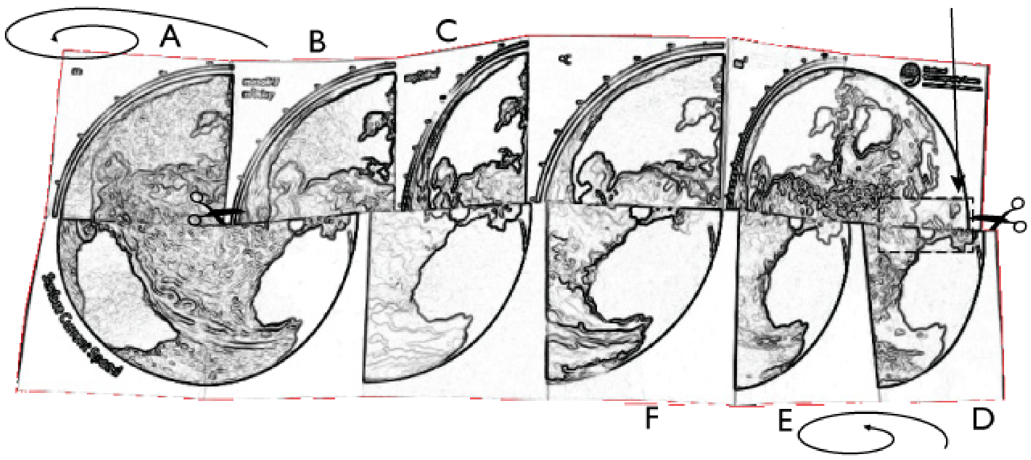
How to construct a flexagon

The Marine Systems Modelling Group showcase our models every year at the NOC Open Day. We regularly provide additional activities with our younger visitors in mind involving some form of papercraft. This year we will be offering the opportunity to construct a flexagon showing six different model fields over the Atlantic ocean. Each colourful image can be selected in turn by successively folding and unfolding the completed flexagon. Space constraints mean there isn't room to provide an explanation of each field on the images other than a title, units and a colourscale. We encourage anyone wishing to know more to approach our staff with questions which we will always do our best to answer. However, we have also included some information here for anyone too shy or too late to ask.

First, here are some instructions and guide images to help you construct your flexagon:

1. Cut centre-line between the points indicated (i.e. leaving one pair of quadrants connected).
2. Roll up top strip. Start by folding face B behind A. Next bring face C in front of A and keep going until you complete the current speed image.
3. Roll up bottom strip. Start by folding face D behind E then E behind F and keep going.
4. Finish by taping these two quadrants after rolling up the strips. Face D will now be on the inside so it will be easier to unroll the bottom strip. Apply tape across the top edge of D (sticky side dow), re-roll bottom strip and attach to top strip



When folded correctly the flexagon can be manipulated to show six different distributions of oceanic properties over the Atlantic Ocean. The following sections explain what these properties are and the roles they play in the Earth system.

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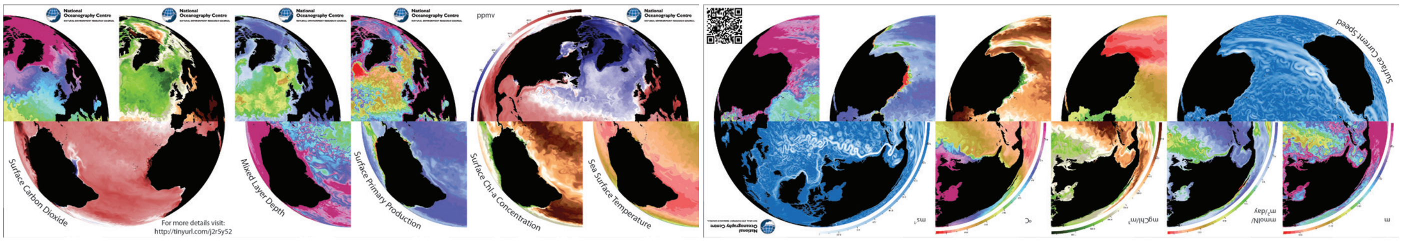

Introduction

Ocean properties vary in both space and time. These variations arise from both external influences and internal variability. External influences include atmospheric conditions at the surface such as temperature and wind speed, but the relationship is complex because the ocean surface also affects the atmosphere. To help understand these processes we investigate the ocean response to atmospheric conditions by running ocean models forced by realistic atmospheric conditions. The resulting computer simulations of the ocean give us insight into its relationship with the atmosphere, as well as how different processes – both physical and biological – work within the ocean's interior.

The images shown on your flexagon are a selection of 5-day mean states taken from such an integration of our highest resolution ocean model. For this integration, the model has been integrated forward in time from a "best guess" of how the ocean was in 1958 through to the present day. This occurs under atmospheric forcing provided by what's known as "reanalysis" runs of modern Numerical Weather Prediction programs. These are essentially the same weather prediction programs that supply daily weather forecasts but are re-run and constrained with all available historical observations. The result is a detailed description of a possible ocean state that is consistent with the atmospheric forcing. This predicted state is unlikely to exactly match the current state of the ocean because the chaotic nature of the ocean means that small variations or errors in the initial conditions or forcing can lead to different final states – this is sometimes known as the "butterfly effect". However, the predicted state is still consistent with our understanding of the physical processes that form the mathematical basis of the model, and so it provides a comprehensive framework for studying the interactions between these processes and how their relative importance may be changing over time.

As well as the atmosphere, other external influences are also applied in models such as freshwater input from rivers, geothermal heating from the seabed and even iceberg calving from glaciers. However, while these are important, much of what the images on your flexigon display comes from the natural "internal" variability of the ocean. This arises from the turbulent nature of the ocean and the tendency for fronts and jets to become unstable. Jets such as the Gulf Stream, for example, will eventually meander to the extent that they can "pinch" off closed rings of seawater known as eddies. It isn't possible to see the time variation of such structures in the still images on your flexigon, but they do illustrate how widespread such small-scale structures are in the ocean. Hopefully you will have seen the animations on display at the Open Day which show this better; if not take a look at this YouTube clip of our model in action.

The fundamental physical state of the ocean is determined by its motion and local temperature and salinity (saltiness). Temperature and salinity are termed "active tracers" because they affect the density of seawater and how it moves within the stratified ocean. But seawater may also contain many other "passive tracers" that don't directly influence its movement but are, nevertheless, critical to the whole climate system. These include nutrients and dissolved gases such as oxygen and, most importantly, carbon dioxide, but in our models also living components such as microscopic "plants" (phytoplankton) and animals (zooplankton). These passive tracers interact to drive what we know as the great biogeochemical cycles of the ocean. Three of the images on your flexagon show examples from these components that allow us to investigate issues such as how the uptake of CO_2 from the atmosphere to the ocean may be changing over time.

Finally, remember that your flexagon is only showing conditions at the surface. The properties shown, and their variations, continue with depth. Our models fully represent this and provide detailed information in environments that are only rarely observed or are difficult to measure, such as the abyssal depths of the ocean.

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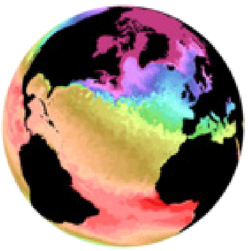
Images on the flexagon

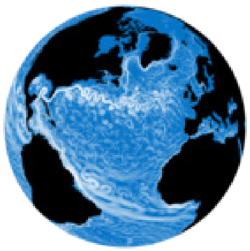
Each of the six images on the flexagon represents a 5-day mean view of one of the model variables at the surface of the Atlantic Ocean. The 5-day period chosen is actually early March in 2008. The year is not particularly significant but the date has been selected to show the onset of the 'spring bloom' in the biological mass of the surface ocean in the Northern hemisphere. The following sections provide a brief description of each field:

1. Sea Surface Temperature



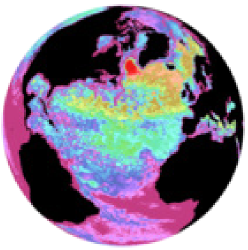
Animations of the Atlantic sea surface temperature would display a strong seasonal cycle with warmer conditions moving north during spring and summer and retreating south in autumn and winter. The advance northwards has started in this springtime image but note the influence of the Gulf Stream and North Atlantic drift which continuously transport warm waters northwards and across the basin helping to ensure that the seas of NW Europe experience warmer waters than equivalent latitudes on the opposite side of the Atlantic basin.

2. Surface current speed



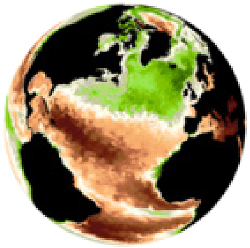
The Gulf Stream and North Atlantic drift are even more evident in this view of the surface current speed. The scale used is logarithmic in nature which allows many of the slower (but nevertheless important) currents and features to be seen also. Note the presence of cold return flows in the East Greenland and Labrador currents. Note also the fast dynamics in the equatorial band where features can move fast enough to be blurred over the five day averaging process.

3. Mixed layer depth



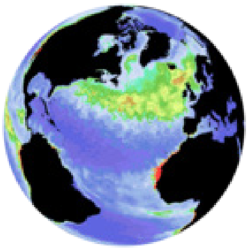
A key part of how the ocean works is how deeply it is mixed by the action of the wind and other surface processes. The effectiveness of any mixing sourced at the surface depends on the energy provided and the stratification of the subsurface waters. Here the spring sun is helping to stratify the ocean (by making the surface layers warmer and therefore lighter). This stratification is crucial to the microscopic biology which cannot grow if it is mixed out of the light-penetrated surface waters. Further north, deep mixing is still evident and is acting to take cold, dense, surface waters into the deep ocean.

4. Surface Chlorophyl-a concentration



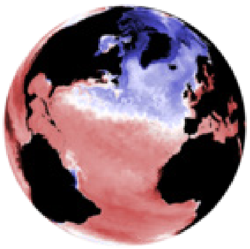
Almost all life in the ocean is ultimately fuelled by microscopic organisms known as phytoplankton. These live in surface waters and, like plants on land, absorb carbon dioxide (CO_2) and sunlight to grow. They form the base of the food cha in that ultimately leads to larger organisms such as fish. Also much like plants on land, many phytoplankton use chlorophyll (the green colour of plants) to "catch" light, and the ocean's colour can be seen to vary seasonally as phytoplankton numbers increase and decrease.

5. Surface primary production



Phytoplankton use light, carbon dioxide and nutrients to make food and allow them to grow. This is referred to as primary production, and is the source of almost all of the energy that drives marine ecosystems. Phytoplankton cells are eaten by tiny animals, zooplankton, who in turn are eaten by successively larger organisms, ultimately channelling the energy originally collected by the phytoplankton up the food web to animals as large as whales.

6. Surface carbon dioxide



The exchange of CO_2 between the ocean and atmosphere is related in part to its surface concentration, pCO_2. This is driven by a complex mixture of chemical, biological and physical processes, and is very variable geographically and seasonally. Here we show the exchange of CO_2 between the ocean and atmosphere. Blue indicates where CO_2 is going into the ocean, while red shows where it is coming out. As well as CO_2 concentration, this process is driven by winds, so strongly varies as weather systems and storms cross the Earth.

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