Linking small-scale circulation dynamics with large-scale seasonal production (phytoplankton) in the Southern Ocean

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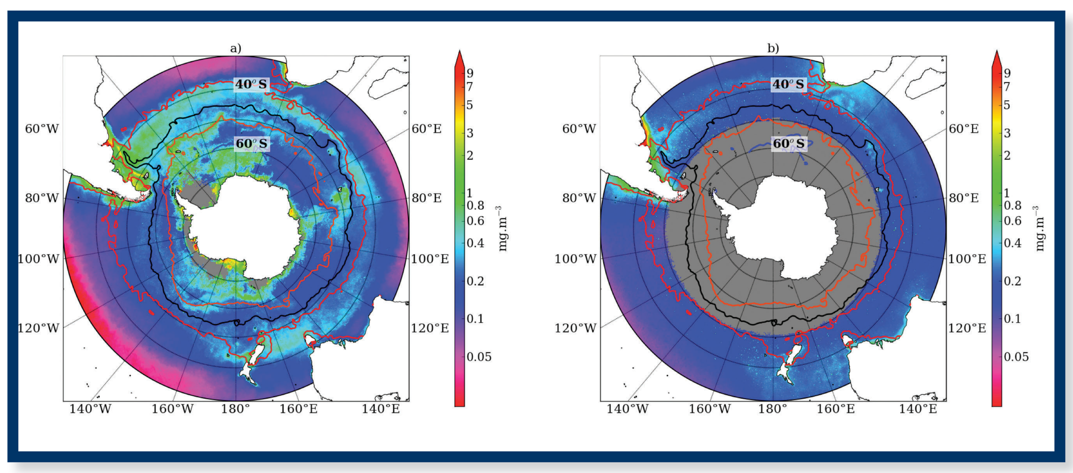
INTRODUCTION

The ocean has significant controls on the composition of the atmosphere through air-sea exchanges. Of most relevance today is the ocean's ability to moderate atmospheric carbon dioxide (CO_2) and store carbon, but this ability is strongly dependent on primary production. Primary production is the creation of organic matter from inorganic nutrients and primary producers are called phytoplankton (single celled plants). Two key ingredients are required for production to occur: sunlight and nutrients.

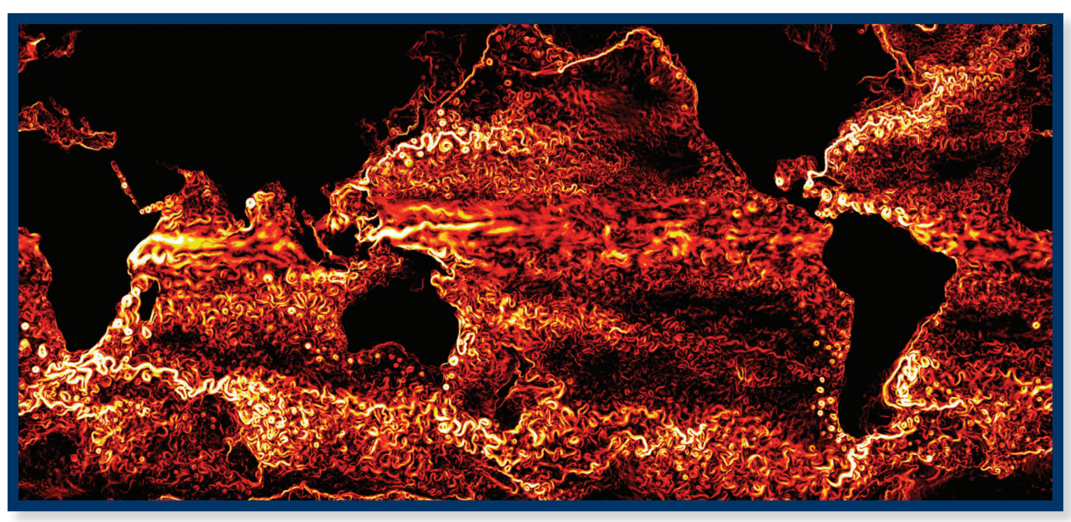
In the Southern Ocean, productivity is influenced by the seasonal cycle, which couples climate forcing with ecosystem responses in production and carbon transfer (Thomalla et al., 2011). The seasonal change of surface forcing (wind and sunlight) in the Southern Ocean has a direct impact on the physical structure of the water column. During winter, the decrease in solar radiation and an increase in wind stress (storminess) results in deeper mixing. This means phytoplankton are unable to stay in the shallower, well-lit upper layers and therefore struggle to reproduce or stay healthy. In contrast, during summer months less wind and more heat results in less mixing in the upper ocean and phytoplankton stay near the surface where sunlight is bountiful. This leads to increased populations of phytoplankton.



Summer–January mean (left) and winter–February mean (right) in chlorophyll (indication of phytoplankton) in the Southern Ocean (Thomalla et al., 2011)

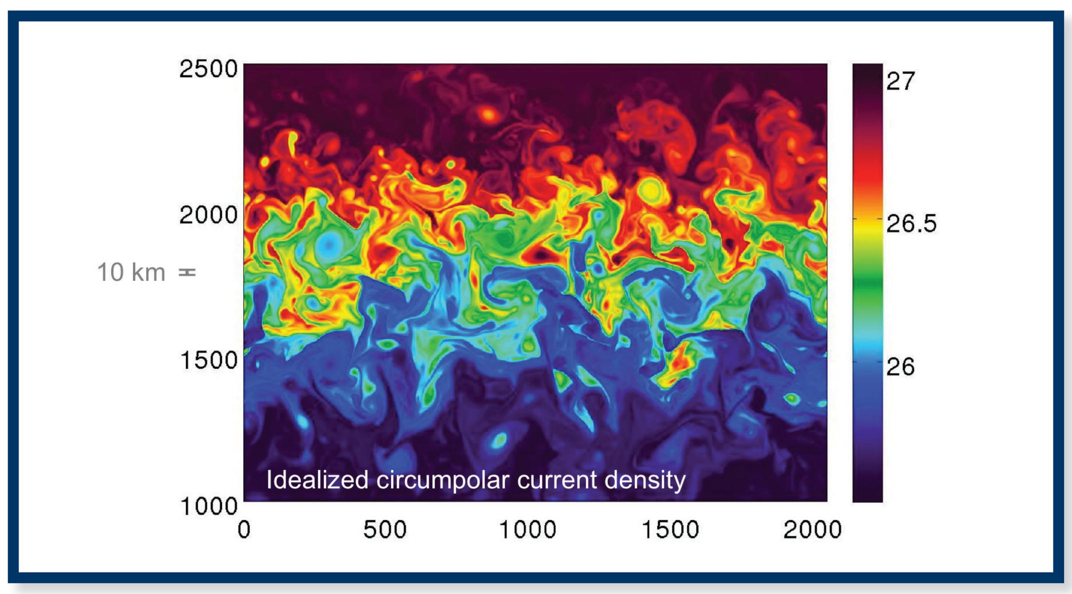
WHAT IS MISSING?

In addition to changes of seasonal forcing in the Southern Ocean, the transport of nutrients from ocean depths (light limited) into the upper sunlit layers of the ocean is believed to be driven by what is known as ocean eddies or storms that are generally the size of ~100 km. These eddies are rotational features that drive upwelling and downwelling, as well as transporting water properties horizontally over great distances. The interaction of eddies with the seasonal cycle may explain some of this variability. However, research has shown that eddies alone do not provide the nutrients to support the observed populations of phytoplankton (Oschlies, 2002; Martin and Pondaven, 2003).



The oceans are crowded with these mesoscale eddies (with 100 km scales). Image of ocean surface currents from a global ocean computer model (OGCM) (Courtesy of Raf Ferrari, MIT, USA)

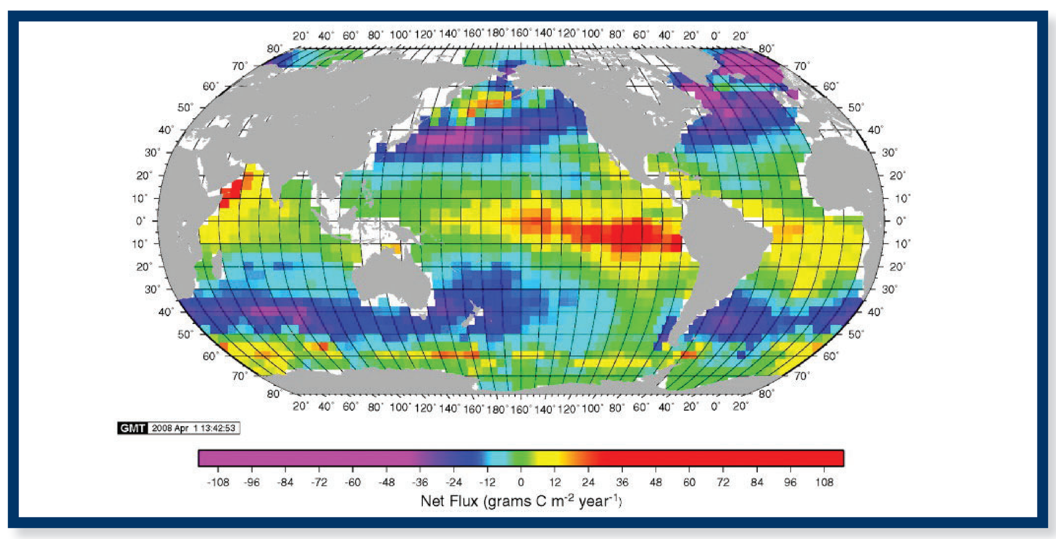
Recent research has revealed a new class of energetic circulation at much smaller scales known as sub-mesoscales (length scales of ~10 km). They have been shown to have large impacts on primary production, a result of the associated stronger vertical transfer of watermasses, which enhances communication between the ocean interior (nutrient rich) and the upper layers (light abundant, but generally nutrient poor) and reduction in mixing, which allows phytoplankton to be in the higher light zone for longer periods of time (Taylor et al., 2011). The importance of these sub-mesoscales features has not been well investigated in the Southern Ocean.



Numerically modelled sea surface temperatures of an idealised circumpolar current, showing sub-mesoscale features (X. Capet, Europole Mer 2010 Conference).

WHY THE SOUTHERN OCEAN?

The Southern Ocean, described as the ocean south of 30°S, is extremely good at regulating atmospheric CO_2 such that it stores about 50% of the entire oceans uptake of human produced CO_2 (Sabine et al., 2004).



The net CO_2 flux in and out of the oceans. Blue/purple colours show the uptake of CO_2 by the ocean. The SO is a large CO_2 sink, particularly noticeable south of Africa (Takahashi et al., 2009)

Understanding the seasonal and intra-seasonal (daily to weekly) changes of the upper ocean and the impact on the primary production in the Southern Ocean is key to better understanding the sensitivities of the global carbon cycle.

SUB-MESOSCALES?

Ocean circulation operates on vastly different scales, both in space and time. From large-scale circulations such as the Antarctic Circumpolar Current (ACC) to energetic mesoscales scale structures known as anticyclonic, and cyclonic eddies (or giant whirlpools) known as the weather of the ocean. Typically found at the edges of these eddies, where strong differences in water mass properties result in high strain rates and instabilities, are smaller sub-mesoscale features (size of ~10km) (Capet et al., 2008).

Sub-mesoscales observed from satellite imagery (NASA GSFC Gallery).

WHAT ARE THE GAPS IN OUR KNOWLEDGE?

What remains less known, is the impact of sub-mesoscale on the seasonal to intra-seasonal stratification dynamics. How these intra-seasonal impacts change the timing of phytoplankton blooms and what the large-scale effects of the sub-mesoscales are on seasonal stratification of the upper ocean. In the Southern Ocean (where there is strong seasonal variability), one could expect potential effects of the sub-mesoscales in modifying the seasonality, for example by inducing an earlier stratification.

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RESEARCH HYPOTHESIS

It is hypothesised that in the Southern Ocean, the effects of sub-mesoscale features on the physical environment of the upper-ocean will interact with phytoplankton bloom dynamics on both intra-seasonal and seasonal scales, effecting primary production and therefore carbon export. This research investigates the sensitivity of the seasonal cycle of primary productivity, to 1) the presence or absence of sub-mesoscale dynamics and 2) the interaction of intra-seasonal forcing with sub-mesoscale structures.

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