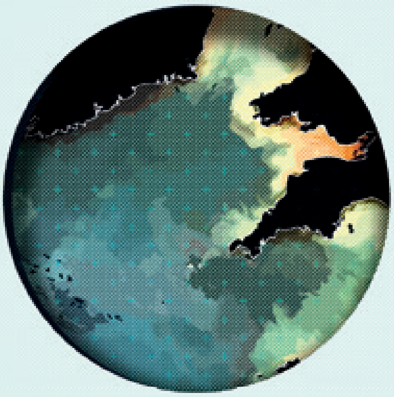
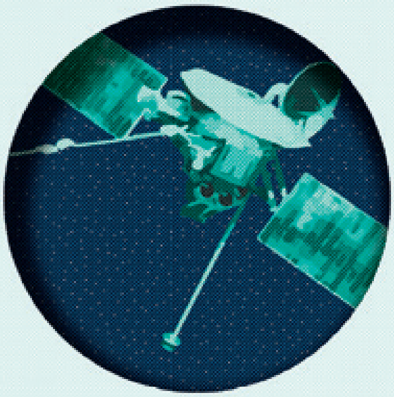
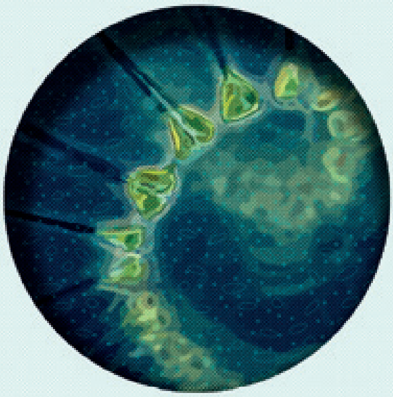






The power of **three**

Drs Cécile S Rousseaux and **Watson W Gregg** explain how enhanced modelling, satellite and *in situ* derived data of the oceans' carbon cycle can help contribute towards more accurate climate impact assessments

Can you explain why phytoplankton composition plays such a major role in the biogeochemical cycle of the oceans?

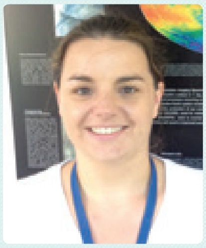
Phytoplankton are tiny ubiquitous organisms that represent the first level of the food chain, so not only do they feed higher trophic levels but, because they are photosynthetic organisms, they take up carbon dioxide and release oxygen too. They have provided oxygen to the Earth for millions of years, taking up over a quarter of the carbon dioxide produced by humans and feeding higher levels of the food chain.

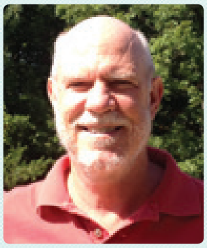
What are the objectives of your current work?

We combine the highest quality datasets and models currently available to assess the effects climate variability and change have on oceans. As part of this effort we also look out for significant increases or decreases in phytoplankton levels that may affect higher trophic levels and carbon dioxide. As such, state-of-the-art models represent a key tool to assess the sensitivity of the environment to factors related to climate change. If we are to understand the effects climate change may have, and start predicting when climate events such as El Niño may occur and what their impact may be, the use of models is unavoidable.

Why is the combination of satellite, *in situ* and model-derived data so important to this line of research?

Each of these datasets has its advantages and disadvantages. A lot of effort is put into collecting highly valuable *in situ* data from boats around the world. These are the highest quality data





and accurately represent a specific location at a precise time but as we know, the conditions can change pretty quickly. By integrating *in situ* data and satellite data, we were able to build the longest time series of ocean colour data – approximately 15 years.

Satellite data provide a bigger picture of the world but clouds, dust and darkness prevent us from seeing the oceans all the time. Regions like the Southern Ocean are dark for almost half the year and remain very cloudy the rest of the time. By using satellite data in our model, we are able to correct for these atmospheric contaminants and obtain data in these areas, thereby providing global coverage of different key variables. Once this process is complete we use the *in situ* data again to validate our results.

How are phenomena such as El Niño and La Niña linked to changes in phytoplankton composition and primary production and how does your work help to better understand this relationship?

El Niño and La Niña events can dramatically affect the weather in many parts of the world. During these events the temperature of the Equatorial Pacific also changes as a result of intensified (La Niña) or reduced (El Niño) upwelling. This upwelling, which generally brings deep, cold and nutrient rich water to the surface, can have significant effects on the phytoplankton composition and primary production.

We found an important shift in the composition of phytoplankton during transitions from El Niño to La Niña events. One group of phytoplankton called diatoms benefited significantly from these strong upwelling conditions during a La Niña event. These are the largest and fastest-growing of the phytoplankton groups. On the other hand, during El Niño some smaller phytoplankton groups such as cyanobacteria and coccolithophores, who rely on less nutrients but need more light, were favoured.

Finally, what would you highlight as the team's primary achievement to date?

We have developed a model that, with data assimilation, is able to represent the spatial and temporal variability that occurs in the oceans. We are always amazed when we validate our results with *in situ* data, demonstrating that the model can reflect spatial and temporal variability. There is still much to improve, such as representing small-scale variability and understanding the interactions between the oceans, land and atmosphere, but establishing these tools among climate scientists and seeing people worldwide use our data is the ultimate achievement for us.

Marine modelling: the phytoplankton community

By completing the most comprehensive analysis of phytoplankton distribution to date, scientists at NASA's **Goddard Space Flight Center** hope to answer unresolved questions about the ocean's biogeochemical variability

EARTH'S CLIMATE STRONGLY impacts the biological dynamics of our oceans. Key to the study of the mechanics of this phenomenon are microscopic phytoplankton; organisms that comprise only a fraction of the global carbon biomass but are in fact responsible for more than half of its primary production on Earth. As such, advancing knowledge of the processes involved in phytoplankton distributions and their relationship with climate will ultimately help improve understanding of the uptake, cycling and transformation of carbon and nutrients by marine ecosystems.

At present, ocean biology is a huge subject area that remains underrepresented in climate impact assessments. Models produced by atmospheric scientists at the fore of climate research are therefore in danger of omitting a wealth of interrelated data produced by the oceanographic community. To fully grasp the nature of climate variability, change and its consequences, research conducted by scientists at NASA is attempting to understand and tie in the complex interactions of ocean biology with the atmosphere and the physical ocean environment.

COMPREHENSIVE COVERAGE

Dr Cécile Rousseaux has worked as a Research Scientist at NASA's Goddard Space Flight Center since 2011. With a background in the biology of organisms, oceanography and environmental engineering, Rousseaux's work spans projects that aim to understand and predict the evolution of global carbon sources. In 2011 she received the World Climate Research Programme (WCRP) Presentation Award and shortly after joining NASA's Global Modelling and Assimilation Office (GMAO) received the Award for Outstanding Contribution by a new GMAO member.

With funding from several NASA programmes, Rousseaux is currently working closely with Dr Watson W Gregg. Using a novel combination of state-of-the-art data collection techniques, their efforts feed into other projects around the world, such as the MARine Ecosystem Intercomparison Project (MAREMIP), which aims to provide comprehensive information on phytoplankton through the inter-comparison of devoted models worldwide. "This allows us to see how the different models match up in terms of estimating parameters related to the phytoplankton community," states Rousseaux. This broad perspective is invaluable for the development of the team's own models.

One way of studying the phytoplankton community is direct observation; analysing samples of ocean water. The number of observations is limited in time and space, but the advent of ocean colour satellites has augmented this methodology providing global measurements of chlorophyll – an indicator of the total phytoplankton community.

In fact, phytoplankton has been monitored globally since the launch of the Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) in 1997. However, satellites cannot solve all observation challenges; indeed, much of the Southern Ocean for example is shrouded in darkness or cloud cover for much of the year. In order to achieve the clearest view of the global phytoplankton community, Rousseaux therefore employs a combination of *in situ* data, satellite coverage and cutting-edge modelling for global coverage of the oceans' biogeochemical variability.

SEPARATING THE ROLES

Rousseaux and Gregg's three-pronged attack on data collection is based on the NASA ocean biogeochemical model (NOBM). Data from ocean colour satellites are directly assimilated into the model and *in situ* data is used to validate and calibrate the model further. First built by personnel at GMAO, the NASA model is presently coupled with the Poseidon ocean general circulation model (OGCM) to account for four phytoplankton groups (diatoms, coccolithophores, chlorophytes and

MODELLING THE PHYTOPLANKTON COMMUNITY

OBJECTIVE

To improve knowledge of ocean biology dynamics using state-of-the-art models.

PARTNERS

NASA Ocean Biology and Biogeochemistry

NASA Modeling, Analysis, and Prediction Program

MARine Ecosystem Model Intercomparison Project

NASA Carbon Monitoring System

FUNDING

NASA

CONTACT

Dr Cécile S Rousseaux
Research Scientist

NASA Goddard Space Flight Center
Building 33, Room G109, Code 610.1
Greenbelt
Maryland 20771
USA

T +1 301 614 5750
E cecile.s.rousseaux@nasa.gov

http://gmao.gsfc.nasa.gov/research/oceanbiology

DR CÉCILE S ROUSSEAUX is a research scientist of the Universities Space Research Association (USRA), working for the Global Modeling and Assimilation Office at the NASA Goddard Space Flight Center, USA. She uses *in situ* and satellite data, and a state-of-the-art model to represent the global ocean carbon cycle including phytoplankton composition.

DR WATSON W GREGG is a scientist working for the Global Modeling and Assimilation Office, NASA Goddard Space Flight Center. He served as Mission Operations Director for the SeaWiFS mission from 1991-97. He then transitioned to development and evaluation of global biogeochemical models and application of satellite data assimilation.

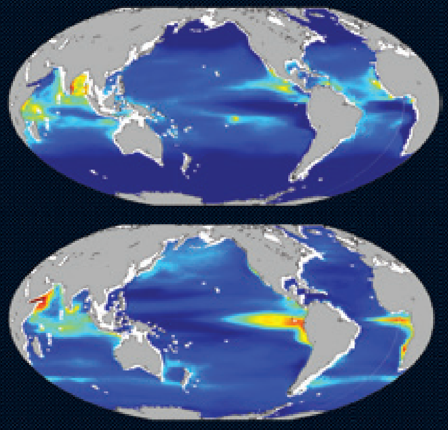
cyanobacteria), four nutrient groups (nitrate, regenerated ammonium, silica and iron), a single herbivore group and three detrital pools where organic material sinks and is stored until it returns to the food chain as usable nutrients.

To date, similar research has focused on total chlorophyll, which can only provide information on the phytoplankton community as a homogeneous mass, when in truth different groups are distinct in their growth rates, sink rates, nutrient requirements and optical properties. By observing the roles performed by four main groups, Rousseaux's research can begin to construct a picture of their role in the biogeochemical cycle of the oceans and their individual contribution to the primary production of organic carbon.

Looking for the greatest preponderance of climate variation effects in the Pacific Ocean, Rousseaux has identified a hotspot between 10°S and 10°N, the Equatorial Pacific, where it is known that reduced upwelling systems dramatically reduce the region's chlorophyll content. Exactly what this means for phytoplankton composition has, until now, remained unknown. "We are able for the first time to assess the contribution of each phytoplankton group to the carbon produced each year in the open ocean," states Rousseaux. In periods of reduced upwelling caused by El Niño events, the conditions of the nutrient poor water are favoured by the smaller, hardier cyanobacteria whilst being detrimental to the larger diatoms whose primary productions is highest in these equatorial latitudes. In fact, it is now known that diatoms contribute a substantial ~50 per cent of the total primary production in the oceans. Previously, cyanobacteria were thought to have a negligible role with the coccolithophores and chlorophytes accounting for 20 per cent each, but they in fact contribute around 10 per cent of the Earth's primary production.

COMPOSITION CORRELATIONS

Upwelling systems have visible effects on total chlorophyll, and these systems are heavily influenced by climate variability. Against this context, Rousseaux has been investigating the interannual variability of group-specific primary production between 1998 and 2011 to see if any fluctuations can be correlated to the variability in the region's climate. Using both global and regional climate indices, there are indeed strong associations between climate variability and interannual variability, most of which was recorded in the Equatorial Pacific. Most strikingly, Rousseaux's methods have established a probable chain of events stemming from changes in the primary production that travel up through the food chain. It now seems likely that in 1998, when the last major El Niño event was recorded, changes in the phytoplankton community were responsible for the simultaneous collapse of the region's fisheries.


Primary production by cyanobacteria (**top**) and diatoms (**bottom**).

> Phytoplankton are responsible for more than half of the primary production on Earth

Already, the combination of NOBM, satellite and *in situ* data has quite clearly demonstrated its reliability in helping oceanographers to understand the effects of climate variability on phytoplankton composition. However, there is always room for improvement. Having proven its compatibility with the Poseidon model, the staff at GMAO are currently in the process of coupling NOBM with the Goddard Earth Observing System Model (GEOS-5), allowing Rousseaux and Gregg to produce an entire new dataset. "GEOS-5 is a system of highly complex models that will allow us to achieve a much higher temporal and spatial resolution," explains Rousseaux.

Such enhancements are expected to maximise the impact of satellite observation, enabling model predictive capabilities and eventually sensitivity analyses. With a view of the ocean's biogeochemical variability finally coming into focus, perhaps now climate impact assessments take more notice.