MNF Voyage Highlights

Voyage #:	IN2020_V08
Voyage title:	SOLACE - Southern Ocean Large Areal Carbon Export: quantifying carbon sequestration in subpolar and polar waters
Mobilisation:	Hobart, 0800 Monday 30 November to Tuesday 1 December 2020
Depart:	Hobart, 0800 Friday 4 December 2020
Return:	Hobart, 0800 Saturday 16 January 2021
Demobilisation:	Hobart, 0900 Saturday 16 January to Monday 19 January 2021
Voyage Manager:	Lisa Woodward
Chief Scientist:	Philip Boyd
Affiliation:	UTAS
Principal Investigators:	Michael Ellwood, Tom Trull, David Antoine, Rudy Kloser, Pere Masque
Project name:	
Affiliation:	ANU CSIRO Edith Cowan CSIRO Curtin University

VOYAGE HIGHLIGHTS

The SOLACE (Southern Ocean Large Areal Carbon Export) voyage made a series of comprehensive measurements of multiple particle pumps that naturally sequester carbon into the subpolar and polar waters of the Southern Ocean.

The suite of measurements were conducted at three contrasting sites, and preliminary measurements suggest that the roles of each of the particle pumps investigated differs between sites.

The deployment of robotic state-of-the-art profiling floats (and a glider) in both subpolar and polar waters will enable these particles pumps to be further investigated in the second phase of SOLACE after the research vessel returns to port. These autonomous measurements will be linked to satellite observations to provide the LA (Large Areal) component of SOLACE (Southern Ocean Large Areal Carbon Export).

SOLACE also has provided integration of measurements of C sequestration that straddle the ecology and biogeochemistry of the oceans' Twilight Zone. The shipboard measurements in conjunction with remote-sensing of the ocean (satellite, profiling floats, gliders) enables an assessment of the future role that research vessels can play in targeting key measurements needed to cross-link and interpret remotely sensed ecological and biogeochemical data obtained remotely.

The above overarching highlights can be readily expanded upon as illustrated by additional examples of highlights for the satellite remote sensing and mesopelagic ecology PI projects from PI's Antoine and Kloser. Thet are detailed below.

Satellite remote sensing

- Deployment of the Dynamic Above Water Radiance and Irradiance Collector (DALEC) radiometer for the first time in the Southern Ocean. This hyperspectral light sensor data will help us to improve ocean colour satellite algorithms for the monitoring of carbon and phytoplankton types. This data will also help us prepare for using data from the future hyperspectral PACE ocean colour satellite to be launched by NASA in 2022

- Successful deployment of the inherent optics package, (28 deployments) collecting information on the absorption and scattering properties of substances in the water. Of particular note is the data from two backscattering instruments which collectively provide data at 12 wavelengths - it is very rare to have these data collected at so many wavelengths and will be very useful for optically characterising particles, which enables us to better use optical tools for monitoring changes in particle size and composition.

- Collection of 66 profiles of particle abundance across a wide range of particle sizes using the underwater video profiler instruments version 5 and 6 deployed on the CTD rosette.

- Biogeochemical characterisation of phytoplankton pigments and carbon biomass from one CTD per cycle providing information on phytoplankton type and abundance and carbon content.

Mesopelagic Ecology

- Successfully sampled micronekton in the Southern Ocean using three complementary sampling tools (1) trawl, (2) acoustics and (3) optics.
- Successfully using these data to determine the migration patterns of the dominant micronekton taxa across three Southern Ocean sites.
- This was the first example of using the broadband capabilities of the PLAOS to distinguish between broad types of micronekton.
- For the first time we will depart from a voyage with a fully analysed dataset ready for inclusion in a scientific peer reviewed article.
- Established links with fellow researchers to progress this area of research within the Australian Antarctic Programme Partnership on return to Hobart.

Voyage Highlights

The Chief Scientist

Philip Boyd is a Professor of Marine Biogeochemistry who studies the sources, sinks and cycling of the major bioactive elements in the ocean – carbon, nitrogen, phosphorus and iron – and their role in setting marine productivity and in regulating global climate. He is based at the Institute for Marine and Antarctic Studies (IMAS) at the University of Tasmania (2013-Present). Prior to his current position he was with Univ. of Otago/NIWA (New Zealand, 1996-2013), University of British Columbia (Canada, 1993-1996) and Plymouth Marine Laboratory (1989-1993). He has conducted seagoing research in the N Atlantic, N Pacific, Arabian Sea,Mediterranean Sea, Southern Ocean (Atlantic and Pacific sectors) and the tropical Pacific Ocean. He has led 15 research voyages

including multiple ship studies, and logistically complex mesoscale ocean in situ iron enrichment experiments.

Title

SOLACE - Southern Ocean Large Areal Carbon Export: quantifying carbon sequestration in subpolar and polar waters

Purpose

The SOLACE (Southern Ocean Large Areal Carbon Export) voyage consisted of four main aims

1. To improve water column measurement of the downward export flux of carbon of the biological pump using an integrated suite of new technological advances – from particle decomposition to mesopelagic vertical migrations.

2. To integrate these improved estimates of the functioning of the biological export with bio-optical properties, used as proxies of biogeochemical (BGC) properties, and which can be remotely sensed using satellite sensors. A combination of conventional passive "ocean colour radiometry" and active "CALIOP" LIDAR (that 'sees through clouds' and also senses below the surface) will be validated on SOLACE to provide a comprehensive regional extrapolation of carbon export fluxes.

3. To cross-link larger scale estimates of the biological pump (termed the BGP – biological gravitational pump - in a Review paper at Nature by Boyd, Claustre, Levy, Siegel and Weber, under revision) with those of PIPs (Particle Injection Pumps, Boyd et al., 2019, Nature) such as the Mixed Layer Pump (Llort et al., 2018) than can be assessed using profiling biological-floats (i.e., BGC-ARGO) as part of the US S. Ocean SOCCOM mission (www.soccom.edu), as well as the individual programmes of France, Australia and others.

4. To link these S. Ocean findings with those of international programmes on this topic, working on N. Hemisphere analogues, via data synthesis and modelling (co-collaborator Dave Siegel, UCSB) to produce large areal maps of carbon export by both the BGP and PIPs. These programmes sit under the JETZON umbrella - http://jetzon.org/ .

Voyage objectives

The voyage had four main objectives:

1) A modular 3.5 day cycle of diverse water column activities from deployment and recovery of surface tethered free floating moorings (RESPIRE, particle sediment traps), to deployment from the ship of CTD, profiling cameras, net tows, ISP's, and water sampling to run lab based experiments. This cycle will be repeated 3 times at the subantarctic site (lower productivity and particle export) and 4 times at the polar site (bloom/bust and higher productivity and particle export). The mooring deployment / recovery is the most weather dependent event. Weather days will be factored in and may result in a modification of the number of cycles or their duration. In order to fully meet the multiple aims of the voyage we will carry out

additional sampling (to add to our time series) on 'weather days' that we do not use for bad weather.

2) Land-based satellite oceanography will be linked to shipboard bio-optical and optical sampling for validation (within the 3.5 day cycle of 1) above). It will be further underpinned by the deployment of gliders (from collaborators at CALTEC, USA) – one at each site (recovered post voyage downstream off New Zealand by another vessel). Weather should be of little influence for these deployment activities across the 45 day voyage.
3) Deployment of two state-of-the-art BGC-ARGO profiling floats with miniaturised UVP (Underwater Vision Profiler) on a 5 year mission. The floats telemeter datasets and their output will be modelled by collaborators in Spain.
4) SOLACE sits under the JETZON umbrella - http://jetzon.org/ . The site is currently being developed and we are already (in anticipation of our voyage) contributing to metadata development and modelling initiatives.

In addition there were four additional objectives:

5) Conduct aerosol and rain sampling:
    a. ASP to provide advance notice of incineration events and a final record of incineration events for the voyage to both the aerosols and atmospheric teams.
    b. Require access to aerosol sampling lab.
6) Cosmic ray measurements from underway instrument (Dr Grahame Rosolen, CSIRO).
7) Cloud Aerosol Precipitation Radiation Interactions eXperiment (CAPRIX) (Dr Alain Protat, BOM).
8) Completion of noise signature testing (MNF).
    a. This will be completed in Storm Bay immediately following departure and will be structured so as not to impact science equipment testing in Storm Bay and the voyage schedule.
9) To complement the CTD casts and regular BGC Argo floats, underway instrumentation will be running and will require some estimate of the mixed layer depth to support these observations. To give subsurface temperature structure while the ship is in transit, deployment of 12 x XBTs to observe subsurface properties while the ship is in transit between the 2 sites will be undertaken. These deployments are not permitted occur within Australian Marine Parks (AMPs).

Contribution to the nation

The waters of the Southern Ocean, to the South of Australia, represent an important natural sink of carbon that helps set atmospheric levels of carbon dioxide. The SOLACE voyage by studying the downward export flux of carbon by both ocean biological and physical processes will provide the first accurate baseline for this carbon sink for the subpolar and polar Southern Ocean. These shipboard estimates can be extrapolated over a larger region using using an integrated suite of additional measurements – satellite remote sensing, ocean glider surveys and profiling robotic floats with multiple sensors – to provide a 4D view of this carbon sink.

The Southern Ocean can also be divided into distinctive oceanic provinces where different water mass properties determine the ecology of the water column, which in turn can influence the degree to which carbon-rich sinking particles act as a vector to set the magnitude of this carbon sink. The SOLACE voyage integrated detailed ecological measurements using sophisticated camera systems and midwater trawls to provide new insights into how water mass properties set the ecology of the

Twilight Zone that underlies the sunlit part of the ocean. There has been growing interest globally in harvesting the marine life that resides in these waters from 100 to 1000 m, however we do not have a baseline on the stocks or who makes up the stocks. The SOLACE voyage will provide an inventory of the fauna of the Twilight Zone in different water masses, along with their biomass. These ecological measurements will be linked with biogeochemical observations to better understand the interplay of foodwebs and the elemental cycles of carbon, nitrogen and phosphorus.

The deployment of two state-of-the-art and profiling robotic floats with multiple sensors (termed BGC ARGO floats, which will have a 4-5 year observing mission) during the SOLACE voyage represents part of Australia's contribution to the biogeochemical ocean observing programme run through the BGC ARGO sub-module of IMOS (Integrated Marine Observing System). As a partner in this international observing programme this enables Australian reseachers open access to the rich datasets being collected by floats deployed by other nations in the Southern Ocean such as USA, France, Japan (for example see www.soccom.edu). Such access will help Australian programmes to devise better predictive models on a wide range of processes, some of which will help improve meteorological forecasting for example.

The datasets collected on SOLACE will provide a Southern Hemisphere / Southern Ocean contribution to a new international programme (Joint Exploration of the Twilight Zone Ocean Network (JETZON, see http://jetzon.org/). This will link our regional findings with on N. Hemisphere analogues, and using data synthesis and modelling we can jointly produce more accurate global maps of this natural carbon sink that will be taken up by the IPCC and other end-users.

As a result of this voyage

1. We have a better understanding of how midwater ecology and biogeochemistry interact to store particulate organic carbon in the oceans' interior.
2. We have found different midwater foodwebs that are associated with different water masses in both the subpolar and polar Southern Ocean, and are probably related to the productivity of each water mass in the upper ocean and the export of particles to depth.
3. We have mapped the phytoplankton, particle characteristics and productivity signatures at our three study sights, and they will be extrapolated to regional scales using shipboard validation of satellite remote-sensing products throughout our 42 day voyage.
4. We have commenced a program of ongoing monitoring of the multi-faceted ways in which the Southern Ocean stores particulate carbon by deploying two state-of-the-art profiling robotic floats with a sensor constellation that includes video imagery that will be sent to shore via satellite during their 4-5 year mission in the Southern Ocean.

Next steps

Samples from the voyage will be processed throughout 2021, some preliminary datasets such as from the CTD are already being checked for quality control, and in other cases, such as the PLAOS camera system (TB of data) analysis will continue via PhD studentships beyond 2021. Although the voyage is over, other related aspects of data collection continue in the Southern Ocean with one Konisberg glider (from Andrew Thompson's lab in CALTEC USA) and two profiling robotic floats (from

Philip Boyd's lab IMAS, but linked to the IMOS BGC-ARGO submodule in Hobart) extending the SOLACE mission in both subpolar and polar Southern Ocean waters. We currently have a SOLACE voyage www site that is embedded The datasets collected on SOLACE will provide a Southern www site that is embedded within the www site of a new international programme (Joint Exploration of the Twilight Zone Ocean Network (JETZON, see http://jetzon.org/). We will use this SOLACE www site to post future outputs as a result of the SOLACE voyage, and will also set up a password-protected section on this site where preliminary datasets will be collated, and where quality controls and quality assurance checks will be conducted before posting the final datasets. We anticipate that by mid 2022 all datasets both raw and processed, will be deposited and stored in publicly accessible databases, including CSIRO/MNF, the IMAS data portal, JETZON, SOCOMM (international partner programmes), and IMOS. (float datasets as part of the ongoing 4-5 year mission).

The next steps to communicate our main findings and to disseminate a suite of results will be via presentations/ or video presentations at the Australian Antarctic Programme Partnership (AAPP), arth Science, seminar talks around Australian universities, the AAD, CSIRO, and eventually (post 2021 due to COVID) at major international meetings such as the 2022 Ocean Sciences meeting in Honolulu.

As only Australian researchers could participate in SOLACE (due to COVID restrictions) we plan to run a voyage data and synthesis workshop in Hobart in late 2021 that will catalyse the publication of primary research and also facilitate synthesis and planned modelling activities.The findings from the voyage will be posted on the SOLACE www site (hotsed on the international JETZON wwww site – see link above). They will also be published in field-leading peer-reviewed journals such as Global Biogeochemical Cycles, Ecology, Marine Ecology Progress Series, Limnology and Oceanography. Based on our preliminary findings we are confident that some of our research will be suitable for publication in the leading scientific journals such as Nature, Nature Geoscience, Science, and Proceedings of the National Academy of Sciences.