Organizers: Zanna Chase, Andrew Bowie and Philip Boyd

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Southern Ocean Biogeochemistry

Institute for Marine and Antarctic Studies, 12 & 13 September 2019

Flex Space on the ground floor of the Institute for Marine and Antarctic Studies (IMAS) Building, 20 Castray Esplanade, Hobart Tasmania

Thursday 12th September 2019

08:30– 09:00 – Coffee
09:00 – 09:20 – Bill Landing
09:20 – 09:40 – Tina van der Fliert
09:40 – 10:00 – Pier van der Merwe
10:00 – 10:20 – Suzanne Fietz (invited)
10:20 – 10:30 – Discussion
10:30 – 11:00 – Coffee Break

11:00 – 11:20 – Al Tagliabue (invited)
11:20 – 11:40 – Matthieu Bressac
11:40 – 12:00 – Michael Ellwood
12:00 – 12:20 – Pete Strutton
12:20 – 12:30 – Discussion
12:30 – 14:00 – Lunch at IMAS

14:00 – 14:20 – Elizabeth Shadwick
14:20 – 14:40 – Maeve Lohan (invited)
14:40 – 15:00 – Viena Puigcorbe Lacueva
15:00 – 15:20 – Pamela Barrett
15:20 – 15:40 – Sunil Kumar Singh
15:40 – 16:00 – Discussion
16:00 Free discussion time, drinks ~~and nibbles~~ available upstairs in IMAS Galley
17:00 Conference BBQ gets underway upstairs in IMAS Galley

Friday 13th September 2019

08:30– 09:00 – Coffee
09:00 – 09:20 – Rob Middag
09:20 – 09:40 – Christina Schallenberg
09:40 – 10:00 – Taryn Noble
10:00 – 10:20 – Bob Anderson (invited)
10:20 – 10:30 – Discussion
10:30 – 11:00 – Coffee Break

11:00 – 11:20 – Antonio Tovar Sanchez
11:20 – 11:40 – Marina Kravchishina
11:40 – 12:00 – Lennart Bach
12:00 – 12:20 – Delphine Lannuzel
12:20 – 12:40 – Rob Sherrell
12:40 – 13:00 – Lightning talks (e.g. 2 x 5mins; Halfter; Raes)
13:00 End of workshop, self-catered lunch
15:00 AUS-GEOTRACES discussions

Speakers Titles and Abstracts

Speaker slots are 15 minutes, with 5 minutes for a discussion and transition.

SPEAKERS

Bob Anderson

Evidence from oxygen-sensitive proxies for late-Pleistocene variability in ventilation of the Southern Ocean

Ice core records have informed us that atmospheric CO_2 levels dropped by 80-100 ppm during each of the late Pleistocene ice ages. It was proposed more than three decades ago that glacial-interglacial variability of atmospheric CO_2 must reflect changes in carbon storage in the deep sea. A growing body of evidence indicates that the dissolved oxygen concentration in the deep ocean was much lower during the last ice age than during interglacial periods, confirming a role for the biological pump in increasing the storage of CO_2 in the ocean during the ice ages. However, indicators of biological productivity and of nutrient utilization inform us that greater ice-age CO_2 storage reflects more the changes in dynamics of ventilation of the Southern Ocean than changes in the strength of the biological carbon pump. This presentation will challenge physical oceanographers to consider water mass structures and patterns of ventilation in the ice-age Southern Ocean that could account for greater carbon storage and reduced oxygen levels in the deep sea.

Lennart Bach

Will there be a 'NextGen Ocean Iron Fertilization scheme' for climate intervention?

Pamela Barrett

Constraining iron sources to the East Australian Current and examining its role in seasonal bloom development in HNLC waters south of Tasmania

The East Australian Current (EAC) is a major western boundary current that entrains iron from a variety of potential sources including riverine, sediment resuspension, lateral exchange of shelf waters, and atmospheric dust inputs as it flows south along the eastern margin of Australia. In waters southwest of Tasmania, large spring phytoplankton blooms are associated with mixing of iron-enriched EAC waters with nutrient-rich, iron-depleted (HNLC) Southern Ocean waters in the vicinity of the Subtropical Front (STF), playing an important role in the drawdown of CO_2 in this region. To assess sources of new iron to the southern branch of the EAC and evaluate the role of this Fe delivery to seasonal bloom productivity near the STF, we will examine trace metal concentrations and Fe and Zn stable isotope signatures of dissolved and particulate phases to compare Fe and Zn biogeochemistry in southern EAC waters, in seasonal bloom conditions near the STF, and in HNLC waters near SOTS.

Matthieu Bressac

Mesopelagic recycling reveals particle composition sets dissolved iron distributions

Dissolved iron supply controls half of ocean primary productivity. Resupply by remineralization of sinking particles, and subsequent vertical mixing, largely sustains this productivity. However, hypotheses on what controls sub-surface iron remineralization remain untested due to difficulties in studying mesopelagic biogeochemistry. Here, we present innovative *in situ* mesopelagic estimates of particulate transformations to dissolved iron, concurrent oxygen consumption and iron-binding ligand replenishment. Dissolved iron regeneration efficiencies (i.e., replenishment/oxygen consumption) were ten- to one hundred-fold higher in low-dust Subantarctic waters relative to higher-dust Mediterranean sites, revealing the complex nature of dissolved iron replenishment across oceanic provinces. Regeneration efficiencies are heavily influenced by how particle composition dictates ligand release, scavenging, differential remineralization of biogenic versus lithogenic iron, and ballasting. At high-dust sites these processes together deepen the ferricline, altering vertical patterns of dissolved iron replenishment, and setting its redistribution at the global scale.

Michael Elwood

Biogeochemical metrics reveal a distinctive iron cycle within a Southern Ocean eddy

Mesoscale eddies are ubiquitous in the Southern Ocean and play a major role in the transfer of heat and carbon between the atmosphere. Southern Ocean cold-core eddies are typically defined by strong clockwise rotation and by cooler temperatures and negative sea-surface height anomalies. These eddies typically have closed circulation leading to distinct biogeochemical properties compared to external waters. The concentration of dissolved iron in remote Southern Ocean surface waters, away from continental and island input sources, is typically sub-nanomolar (60-200 pmol kg-1). Here, we probed the biogeochemical cycling of iron within a subantarctic cyclonic cold-core eddy during the austral autumn in 2016. In-eddy dissolved iron concentrations were low with concentrations ranging between 18 and 33 pmol kg-1 between 15 and 200 m. Out-eddy dissolved iron concentrations were higher with concentrations ranging between 35 to 68 pmol kg 1 across a similar depth range. In-eddy primary production was also low. However, phytoplankton iron to carbon uptake (Fe:C) ratios were elevated 2-6 fold compared to populations in surrounding waters. These higher Fe:C ratios were indicative of up-regulation of iron acquisition processes by phytoplankton to enhance iron bioavailability. This is supported by measured (+1.3‰ at 40 m cf. 0‰ at 150 m) and modelled iron isotope values, which are isotopically heavy in the euphotic zone. Below the euphotic zone, in-eddy microbial recycling of iron was evident and coincided with maxima in heterotrophic bacteria and recycled nutrients. Because eddies are omnipresent within the Southern Ocean, iron limitation of phytoplankton be more severe than previously measured or modelled.

Svenja Halfter

SINKING DEAD – How zooplankton carcasses affect the particulate organic carbon flux in the subantarctic Southern Ocean

The subantarctic Southern Ocean carbon cycle are largely understudied regarding the role of mesozooplankton though the area is regarded as important carbon sink. Zooplankton contribute to the passive carbon flux by producing faecal pellets, moults and carcasses. Currently, the carcass production is rarely included in estimates of the carbon export due to the lack of data. During a field campaign on the RV Investigator in early October 2018, the dominant copepod *Neocalanus tonsus* was collected before the start of the spring bloom at two sites south of Tasmania. Our aim was to determine if copepod carcasses can serve as food source for deep Southern Ocean biota, therefore we estimated carbon content and sinking speed of *N. tonsus* carcasses and conducted bacterial degradation experiments. High average sinking velocities (0.5 ± 0.13 m min^{-1}) and oxygen consumption by bacteria (5.86 ±1.19 to 7.52 ±1.48 µmol L^{-1} h^{-1}, at 11.5 ˚C) indicate that carcasses act as microbial hotspots and can potentially serve as food source for deeper water layers. The results indicate that non-consumptive mortality of zooplankton can lead to a significant downward flux of carcass carbon, which affects the oceanic carbon sequestration and, hence, should be included in the global biogeochemical models

Marina Kravchishina

Distribution of particulate matter and some organic compounds in snow and ice cores of East Antarctica

Our understanding of Southern Ocean biogeochemical processes has improved considerably in recent years; the sediments as well as flora and fauna of sea ice and the biogeochemical cycles of carbon and metals at the snow-ice-water interfaces remain poorly understood in generaland in East Antarctica especially. The Antarctic sea ice cover differs in structure from its analogue in the Arctic basin owing to the differences in oceanographic and meteorological conditions of their formation. The conditions of the snow–ice cover formation significantly control the distribution of the physical, biological, and geochemical parameters in the Southern Ocean adjacent Antarctica. The thickness of snow and ice influences the concentration of particulate matter and organic compounds at the snow–ice and ice–water interfaces, and throughout the ice core as well. Climate warming resulted in a significant decrease in the ice thickness in the Arctic, whereas sea ice breaking up along the East Antarctic shoreline was not observed in many areas in recent years.

Samples of slush ice, sludge ice, and nilas were taken onboard using a special triangular mesh screen (mesh size of 1 mm^2). The ice cores were collected using a titanium drill (d = 14.5 cm) in several sites of the Cooperation Sea (Prydz Bay), Lazarev Sea / King Haakon VII Sea (Leningradskii Bay), and Davis Sea. The researches were carried out by IO RAS during Russian Antarctic Expeditions onboard the *RV Akademik Fedorov*and *RV Akademik Treshnikov*in 2010–2014. The cores' length varied from 0.3 to 3.3 m. We studied sea salt content, total concentration and composition (including particulate organic and inorganic carbon, chloropigments, hydrocarbons, lipids, *n*-alkanes, lithogenic particles, and some other properties indicative particles origin) of particulate matter in ice cores.

The accumulation of particulate matter and related organic compounds starts in the sludge ice. The concentrations of particulate matter are higher in the rapidly growing ice as compared to the slowly growing ice. This determines also the amount of organic matter in the ice. The concentration of particulate matter including organic matter increased significantly at the ice–water interface. The accumulation of the particulate matter in the bottom of the ice cores depended on ice "age", cryobiological response of algae, quantity of photosynthetically available radiation, ice crystal structure, snow cover thickness, ice bottom topography etc.

We observed the H_2S contamination in the ice core (3.3 m length) from the Lazarev Sea in March 2012. This unusual phenomenon was related to the significant thickness of firn (1.2 m) carved the ice and the extremely high concentrations of organic compounds in the lower part (2–3 m) of the ice core. The decomposition of autochthonous organic matter accompanied by intense oxidation contributed to the H_2S formation in the multiyear sea ice. Anoxic conditions may also be a critical factor affecting chloropigment preservation. Concentration of chlorophyll "a" reached 112 $\mu g \cdot l^{-1}$in the lower layer (2–3m) of the ice core. Thus the intensive accumulation of organic matter due to the photosynthesis of ice microalgae and fast organic matter remineralization in such low temperature environment occurred in the sea ice of East Antarctica, which play an important role in biogeochemical processes in this region of the Southern Ocean.

William M. Landing

Quantifying the atmospheric deposition of bio-essential trace elements

We know that the balance of macro and micro nutrients along with physical environmental factors controls which microbes grow and how fast. As the base of the marine food web, their productivity affects growth and success at all other trophic levels in marine food webs. Micronutrients (like Mn, Fe, Co, Ni, Cu, Zn) are delivered to the open ocean by dust deposition, therefore quantifying their flux is important for understanding microbial productivity and for modeling trace element cycling in the global oceans. There are many models that try to estimate aerosol concentrations and deposition rates. How accurate are they? What is the relationship between aerosol concentration and aerosol flux?

Vertical profiles of ^{7}Be in the upper ocean are mostly governed by the atmospheric deposition flux, the intensity of vertical turbulent mixing, and radioactive decay. The inventory of ^{7}Be activity in the upper ocean (0-200m) should be equivalent to the atmospheric flux of ^{7}Be to the ocean. Using the ^{7}Be decay inventory and ^{7}Be activity in aerosols, we can derive a "bulk deposition velocity". Can we estimate the atmospheric flux of Fe (or any other TEI) by multiplying the bulk deposition velocity for ^{7}Be by the aerosol concentrations of any other tracer? So far, the answer seems to be **"YES"**! (better than ±30%).

Delphine Lannuzel

Ocean fertilisation: a positive effect from Antarctica's great thaw?

Artificial iron fertilisation experiments conducted in the Southern Ocean confirmed that iron addition stimulates phytoplankton growth. The focus eventually moved away from large scale artificial experiments conducted in the 90s to now studying naturally-fertilized areas, with an emphasis on continental shelf sediments, atmospheric dust and hydrothermal plumes. The scientific community recognises that natural fertilisation events will be subject to rapid changes in the near future, both in the mode and magnitude of iron fluxes to our oceans. This is especially true for iron-rich and climate-sensitive environments, such as sea ice, ice shelves and icebergs, with large speculations on how these dramatic changes to the icescape will affect the capacity of the Southern Ocean to absorb CO_2. This talk will give an overview on the current role of the Antarctic cryosphere as an ocean fertiliser and how this may change in the future.

Taryn Noble

Southern Ocean ventilation at glacial terminations

The production of Antarctic Bottom Water (AABW) today is restricted to four main locations on the Antarctic margin. AABW originates as dense shelf water (DSW), which is exported down the continental slope where it mixes with ambient water to ventilate the deep ocean. The production of AABW is dictated by the strength of sea-ice production, ocean/ice shelf interactions and the geometry of the continental shelf. Modern observations and modelling indicate a recent reduction of AABW production, in response to ocean freshening and warming, and changes in the icescape along the continental shelves. However, the response of AABW formation to past climate forcing is uncertain, due to a paucity of suitable proxy records. Here we use authigenic Mn measured in two sediment cores (2600 m depth), to track the delivery of well-oxygenated DSW on the continental slope near Adélie Land, East Antarctica. We find increasing concentrations of aMn early during the last and penultimate deglaciations, coincident with increases in Th-normalised opal and excess Ba fluxes. We infer that the formation of DSW was reduced during glacial maxima, and was reinitiated when ice retreated and productivity ramped up early in the Southern Hemisphere deglacial sequence. Our results have implications for deep ocean circulation during glacial periods and suggest a tight coupling between ocean circulation-ice sheet dynamics during deglacial warming.

Viena Puigcorbé

Sampling device-dependence of prokaryotic community structure developing on marine particles

The effectiveness of the biological carbon pump depends largely on the ability of prokaryotic communities to degrade and remineralise the sinking particles and either convert them back to CO2 or rework them so that they are basically recalcitrant and can accumulate and remain for long periods of time at depth. Sampling of marine particles is mostly done with sediment traps, in situ pumps, of filtration of material collected from Niskin/oceanographic bottles. We compared microbial community structure on small (1-53 μm) and large (>53 μm) particles collected from the mesopelagic of two Antarctic polynyas. In situ pumps recovered more diversity than Niskin bottles, in particular groups such as Planctomycetes, Deltaproteobacteria and Marine group I Thamarchaeota were more prevalent in the pumps than in the Niskin samples, which were basically composed by Alpha- and Gammaproteobacteria, as well as Flavobacteria. This difference was more evident for large than for small particles. In situ pumps had a larger amount of unique (i.e. not occurring in the Niskin samples) OTUs, yet those represented a smaller fraction of the community. These results leave open a number of questions that we should explore if we are to properly understand the efficiency of the biological carbon pump in the open ocean

Antonio Tovar Sanchez

The Pimetan project: The role of penguins in the biogeochemical cycles of trace metals in the Southern Ocean

Numerous biogeochemical studies in the Southern Ocean have focused on the importance of trace metals in controlling primary production (e.g. Fe, Co) or as potentially toxic to the ecosystem (e.g. Ag, Cd). However, the reasons why Fe limitation is prevalent in the Southern Ocean or the concentrations of non-biogenic elements in surface waters are higher than those reported in other oceans are not fully understood. As the Southern Ocean is not influenced by direct anthropogenic inputs and trace metal additions do not occur naturally, special attention is being allocated to the recycling processes that control trace metal cycling in the ecosystem. Yet, the importance of penguins, one of the most abundant animals in the Southern Ocean, in trace metals cycling has not been addressed. The working hypothesis of PiMetAn project is that penguins play a fundamental role in delivery of recycle metals to the Antarctic surface waters, influencing their environmental concentrations and ecological functioning. The aim of PiMetAn is to characterize the trace metal composition, biochemical behavior, bioavailability and toxicity of guano from the three most abundant penguin's species living in Antarctica (the Chinstrap: Pygoscelis antarctica, Adélie: Pygoscelis adeliae and Papua: Pygoscelis papua).

Christina Schallenberg

Diel fluctuations in Southern Ocean phytoplankton fluorescence reflect photosynthetic competency related to iron limitation

Evaluation of photosynthetic competency in time and space is critical for better estimates and models of oceanic primary productivity. This is especially true for areas where the lack of iron is limiting phytoplankton productivity, such as the Southern Ocean. Phytoplankton chlorophyll a fluorescence (ChlF) is affected by, and consequently provides information about, the photosynthetic efficiency of the organism. A second process affecting the ChlF signal is heat dissipation of absorbed light energy, referred to as non-photochemical quenching (NPQ). NPQ is triggered under conditions of excess absorbed energy, i.e. when more light is absorbed than can be used directly for photosynthetic carbon fixation. The effect of NPQ on the ChlF signal complicates its interpretation in terms of photosynthetic efficiency, necessitating correction procedures. Here, we propose that NPQ itself holds potential as an easily acquired optical signal indicative of phytoplankton physiological state.

We present data from a research voyage to the Subantarctic Zone south of Australia. Incubation experiments confirmed that resident phytoplankton were iron-limited, as the maximum quantum yield of primary photochemistry, Fv/Fm, measured with a Fast Repetition Rate fluorometer (FRRf), increased significantly with iron addition. The NPQ "capacity" of the phytoplankton also showed sensitivity to iron addition, decreasing with increased iron availability. The fortuitous presence of a remnant warm-core eddy in the vicinity of the study area allowed comparison of fluorescence behaviour between two distinct water masses, with the colder water showing significantly lower Fv/Fm than the warmer eddy waters, suggesting a difference in iron limitation status. Again, NPQ capacity measured with the FRRf mirrored the behaviour observed in Fv/Fm, decreasing as Fv/Fm increased in the warmer water mass. We went on to analyse the diel fluctuations in underway fluorescence measured with a standard fluorometer, such as is frequently used to monitor ambient chlorophyll-a concentrations, and found a significant difference in behaviour between the two water masses. This difference was quantified by defining an NPQ parameter akin to the Stern-Volmer parameterization of NPQ, exploiting the fluorescence quenching induced by diel fluctuations in incident irradiance. We propose that monitoring of this novel NPQ parameter may enable assessment of phytoplankton physiological status based on measurements made with standard fluorometers, such as are ubiquitously used on moorings, ships, floats and gliders.

Elizabeth Shadwick

Southern Ocean CO2 fluxes: an evolving view of winter conditions from autonomous sensors

Our understanding of Antarctic coastal systems is heavily biased by observations restricted to the summer where open water primary production dominates CO_2-system variability. Changes in the physical and biogeochemical state of coastal Antarctic waters are already underway: warming, freshening and onshore intrusion of carbon-rich circumpolar deep water, are all processes with associated feedbacks to the CO_2 system that are expected to influence contemporary rates of air-sea CO_2 exchange. Resolving the dominant drivers of variability requires sustained observations; given the challenges of working in remote Antarctic coastal waters, acquiring observations outside of the summer season necessitates the use of autonomous platforms. New high-frequency data from a moored CO_2 system observatory in the West Antarctic Peninsula reveals both open water and winter season CO_2 supersaturation with respect to atmospheric CO_2. These observations reinforce the emerging view of wintertime outgassing in the Southern Ocean, and a need to better understand variability in air-sea exchange at seasonal and shorter timescales.

Peter Strutton

The role of eddies in Southern Ocean biogeochemistry

At any given time, there are about 1200 eddies in the Southern Ocean. They are detectable from satellites because they cause anomalies of lower (cyclones) or higher (anticyclones) sea surface elevation. This presentation will describe work at IMAS/UTas that is quantifying the surface temperature and chlorophyll signatures of eddies from satellite, and their subsurface biogeochemical structure from ships and Argo floats

Alessandro Tagliabue

What will end of century Southern Ocean primary production look like?

The Southern Ocean environment will be greatly modified by ongoing climate change, which will alter net primary production (NPP), mainly via modulation of light and nutrient supply. Understanding future changes is important if we are to constrain their impact on the carbon cycle and marine ecosystems, both locally and remotely. Prior work as part of CMIP6 has examined the zonal asymmetry in the response of NPP to climate change, but these models had simple representations of iron cycling and microbial iron limitation. Here we use a new version of the PISCES biogeochemical model to conduct climate change experiments under the RCP8.5 scenario to examine how iron supply and demand interact to shape future Southern Ocean NPP.   Additional experiments highlight how model assumptions regarding cellular iron stoichiometry and the extent of iron storage, as well as the iron demand of grazers can play an important role in altering projections of NPP change over the coming century, highlighting the need for better observational constraints.

Tina van de Flierdt

Pathways and processes controlling the distribution of anthropogenic lead in the interior of the Southern Ocean

Over the last century, anthropogenic emissions from mining, smelting and fossil fuel combustion have greatly perturbed the lead (Pb) inventory of the modern ocean. The spatiotemporal variability of anthropogenic Pb fluxes, and their distinct isotope fingerprints, enable tracing anthropogenic inputs to seawater. Few data have yet been presented for the Southern Ocean. I will present preliminary results for dissolved Pb isotopes and concentrations from GEOTRACES section GS01, which sailed in 2018 along the SR3 transect from Hobart to Antarctica and back. Antarctic Bottom Waters in the south of the transect carry a largely natural Pb isotope signature, whilst mode waters in the north of the transect are the most polluted. Their signature is however not easily explained by lateral advection or diapycnal mixing, and requires processes such as reversible scavenging and equilibrium exchange to dominate the vertical transport of anthropogenic Pb in the area.

Pier van der Merwe

Beyond shipboard sampling: moored water samplers for time series studies and sampling previously inaccessible waters using autonomous underwater vehicles.

Trace element research has always been tightly linked with technical and methodological advances. It was not until the advent of clean sampling techniques and instrumentation that quantification of open ocean trace elements was even possible. Today, with the success of the GEOTRACES program, shipboard sampling for trace elements across full ocean transects has become routine. However, shipboard sampling is limited, both in observational duration and access within ice covered seas.

The fundamental role of the micronutrient Fe in controlling phytoplankton growth in large parts of Earth’s oceans and a lack of information on seasonal transitions in remote regions motivated us to create a moored, autonomous water sampler capable of collecting uncontaminated open-ocean sea water samples with monthly resolution over a full annual cycle. This capability is particularly important in the Southern Ocean where Fe limitation is wide-spread, and access is difficult especially in winter. Testing of the new system during a GEOTRACES section (SR3 line, GS01) in 2018 alongside an industry standard, trace metal clean rosette revealed no significant difference in Fe concentrations in the 50 pM range.

In a follow-up project, a custom, trace metal clean water sampler is being built for the $5 million IMAS/AMC autonomous underwater vehicle, named nupiri muka. This novel water sampling system will allow a rare glimpse into the trace elements and isotope cycling under major ice shelves. During an upcoming voyage with Korean colleagues, we plan to deploy the system under the highly unstable and rapidly retreating Thwaits glacier in the West Antarctic Ice Shelf (WAIS) as part of the International Thwaits Glacier Collaboration. We are only beginning to understand how ice-shelves and subglacial biogeochemical processes effect the wider Southern Ocean while simultaneously major instabilities exist particularly in the WAIS and thus, accurate sampling of these environments is of high importance.