Abstracts from the SCAR Open Science Session 401:
Integrating Climate and Ecosystem Dynamics in the Southern Ocean (ICED)

Contents

Integrating analyses of circumpolar Climate interactions and Ecosystem Dynamics.

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The Integrating Climate interactions and Ecosystem Dynamics in the Southern Ocean (ICED) program will address the need to understand how climate and anthropogenic forcings may affect the ecosystems of the Southern Ocean. The three major themes for ICED are: 1) to understand how climate processes affect the structure and dynamics of ecosystems in the Southern Ocean; 2) to understand how ecosystem structure and dynamics affect biogeochemical cycles in the Southern Ocean; and 3) to determine how ecosystem structure and dynamics should be incorporated into management approaches to sustainable exploitation of Southern Ocean species. To achieve this ICED will bring together climatologists, oceanographers, biogeochemists, ecologists and fisheries scientists in a single circumpolar research effort. The ICED program is proposed as part of the new joint International Geosphere-Biosphere Program (IGBP) and Scientific Committee on Scientific Research (SCOR) initiative entitled Integrating Marine Biogeochemistry and Ecosystem Research (IMBER) and will build on the results of the Southern Ocean Global Ocean Ecosystems Dynamics Program. The ICED program also has the support of the European Network of Excellence for Ocean Ecosystems Analysis (EUR-OCEANS) and the Scientific Committee on Antarctic Research (SCAR). This presentation will provide an overview of the current status of the ICED Program, and its involvement in the International Polar Year (IPY) activities.

Spatial and Temporal Operation of the Scotia Sea: Integrated Analyses and Circumpolar Links.

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The Scotia Sea is the most physically energetic and productive region of the Southern Ocean. Here we review the operation of the Scotia Sea ecosystem and consider the wider Southern Ocean links. The Antarctic Circumpolar Current (ACC) and its interaction with the Scotia Arc dominate the physics and chemistry of the region. The ecosystem is highly heterogeneous, maintained by the generation and dispersal of energy across the Scotia Sea in the current systems and up through trophic levels. The flow of the ACC is deflected north by the Scotia Arc, pushing polar waters to the lower latitudes. The interaction with the bathymetry generates intense mixing, introducing micronutrients into surface waters, and fuelling phytoplankton blooms that at times extend over more than 0.5 million km2. Within the zooplankton communities, copepods may consume substantially more phytoplankton than Antarctic krill. However, krill are the key species in transferring energy to higher trophic levels. Krill grow and develop more rapidly in areas of high phytoplankton concentration but in the more northern regions higher summer temperatures limit their growth. The flows of the ACC and associated currents carry the krill to areas around South Georgia and the northern Scotia Arc where they subsidize local food webs. During summer upper trophic level predators forage across the region bringing back prey to breeding colonies, highlighting the localised concentration of consumption in the food web. During winter the spatial distribution and trophic links in the food web change dramatically and many of the upper trophic level predators leave the Southern Ocean. The effect is a dynamic mosaic of areas with changing balances of autochtonous and allocthonous production. Interannual variation in winter sea ice distribution and sea surface temperatures is linked to southern hemisphere-scale climate related processes. This variation also affects regional primary and secondary production, biogeochemistry and food web dynamics. There is also clear evidence of marked decadal changes across the region that have led to major changes in the operation of this ecosystem. Developing integrated analyses of the Scotia Sea ecosystem requires understanding of the circumpolar operation of Southern Ocean ecosystems.

Differing Marine Ecological Regimes Over A Meso-Scale Distance In The Southwest Atlantic Sector Of Southern Ocean; Response To Sea Ice Retreat Or Eddies?

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Significantly different marine ecological regimes were observed over only a meso-scale distance in the Southwest Atlantic Sector of Southern Ocean. This was apparent during early summer with Shackleton Fracture Zone as a natural boundary and it does not seem to be an isolated case to a single year. In the vicinity of South Shetland Islands, mostly to the west of Elephant Island, chlorophyll level as well as krill abundance was low. On the other hand, chlorophyll biomass was at an enhanced level and there were substantial concentrations of krill to the east of Elephant Island, which is the northwestern part of the Weddell Sea. In this biologically richer part of study area, open-water to ice-line gradient was seen in a number of aspects including the size composition of phytoplankton assemblage and krill aggregation characteristics. This area is more strongly affected by the annual cycle of sea ice retreat and also by the influence of Weddell Sea water than the other, western part of the study area. Krill concentrations found in this richer area are likely to have come from nearby under-ice habitat, which developed during the preceding winter, rather than having been transported by eastward-flowing water currents. This does not support the prevailing concept of krill distribution that greatly resorts to krill being moved on circum-Antarctic flow. The process that often promotes and maintains elevated biological activity in this area, not long away from typical unproductive waters, appears to be related to the timing of sea ice retreat and subsequent weather conditions in the area. Bottom topography-induced turbulence and the resultant nutrient supply may also play a role. The relative importance of different processes deserves to be a focus of future study.

The Antarctic sea ice ecosystems: comparative analysis.

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Sea ice biota production during the austral winter in the extensive Antarctic sea ice zone is recently considered as an important contribution to the phytoplankton production in the Southern Ocean where sea-ice covers more than 80% of its surface. It is important to know the contribution of different types of sea ice to biological production in both pelagic and coastal ecosystems.

Coastal ice. On the basis of round-year materials from the coastal zone of Admiralty Bay (King George Island, 1987-1988), it has been shown that sea ice algae biomass (in terms of chlorophyll a concentration), is 2-3 orders of magnitude higher than in the underlying seawater. Mean POC/chlorophyll a ratio is of 220 in the young-formed ice, 109 in the anchored ice and 23 in the fast ice. Maximum coastal chlorophyll a concentrations were up to 210 2g/l but POC concentrations were up to 6000 2g/l. Total list of diatoms identified in the coastal sea ice consists of 119 species. Only 6 diatoms are dominated by numbers during the winter period in the anchored ice: *Navicula gelida var. parvula*, *Nitzschia lecointei, N. prologatoides*, *N. barbieri*, *Fragilariopsis cylindrus* and *F. curta* reaching more 95% of the total list of identified diatoms. *Navicula gelida*, *Nitzschia lecointei*, *N. barbieri*, *Corethron criophilum, Fragilariopsis cylindrus* and *F. curta* were dominated in the fast ice (more 90% of the total list of species).

Pelagic ice. The values of chlorophyll a concentrations of the one-year sea ice from the western part of Weddell Sea (Ice Station Weddell, Feb-Jun 1992) were hundreds times higher than in the seawater below ice. High chlorophyll a concentrations, in the range 20-50 2g/l, testify to very intensive biological processes within the thickness of multi-year, one-year and young growing sea ice during the early austral winter in the pelagic system. 88 and 89 taxa of diatoms were identified, correspondingly, within the old and one-year ice interior in the western Weddell Sea, Feb-Jun 1992. Two diatoms were dominated by numbers during the winter period: large size *Fragilariopsis cylindrus* and *Archaeomonas areolata* (more 80% of the total algae list of species) in the old sea ice and *F. cylindrus* (more 90%) in the one-year ice). The infiltration community consists mostly of small-size cells of *Fragilariopsis cylindrus* reaching up to 90% of the total cell number. Diatoms: *Chaetoceros deflandrei*, *Ch. debilis* and *Ch. socialis* were dominant species during the late winter but *Corethron criophilum* and *Eucampia antarctica* dominated in the early spring bloom. POC/chlorophyll a ratio shows very high correlation for the old- and one-year ice in the pelagic system (R2=0,94) as well as for the fast ice in the coastal region (R2=0,96). During the winter season both in coastal and pelagic ecosystems, a large amount of living and dead organic materials are released from the sea ice down to the underlying seawater providing food sources for invertebrates associated with ice-water interface such as copepods, fish larvae and krill. These results indicate that sea ice algae developing during the austral winter in the Antarctic sea ice zone should be considered as an important factor in Southern Ocean biological models.

Modelling the Circulation on the West Antarctic Peninsula: The Effect of Buoyancy Forcing.

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Observations on the west Antarctic Peninsula (WAP) shelf show a persistent decrease in salinity of about 1.0 psu from the ocean to the shelf. Some low salinity water is trapped near the surface (~50 m thickness), which is clearly due to surface ice melt, coastal runoff and precipitation. However, the deep salinity at the coast is lower than offshore indicating a deeper source of fresher water. Two possibilities are water from Bransfield Strait through Gerlache Strait, or deep melting of ice shelves. A high resolution (5 km) regional circulation model (using the Rutgers/UCLA Regional Ocean Model System) creates reasonable flow in the offshore ocean and on the outer continental shelf, driven by winds and the oceanic flow (ACC). The near-shore model flow is only sometimes southward which is the flow direction indicated by surface drifters and moored current observations. Increasing model precipitation at the coast, due to the coastal mountains, creates a little better near-shore flow. Stronger flow into Bransfield Strait from the Weddell Sea (a model boundary condition) improves the southward flow on the WAP shelf indicating a dynamic connection through the Gerlache Strait. Model salinity within and south of Marguerite Bay is higher than observations. Meltwater from the George VI Ice shelf onto Marguerite Bay is estimated at 16 km3/yr and when this additional freshwater source is added, the circulation and salinity structure improve. In summary, this model study indicates that circulation on the WAP shelf is influenced by the oceanic intrusions, flow along the shelf break, surface winds, precipitation, coastal runoff, sea ice freezing and melting, flow through Gerlache Strait and basal melt of ice shelves.

Internal Melting in Antarctic Sea Ice: Development of "Gap" or "Freeboard" Layers

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Gap or freeboard layers consisting of a partially melted honey-comb like ice structure are found below a surface snow and ice layer in summer in Antarctic sea ice, are widespread there, but are not typically observed in the Arctic. A first explanation of these layers in previous work, because of the high concentration of biological material found within the observed layers, was suggested as a Physical-Biological Feedback process where concentrations of dark algal material accelerated melting by increased absorption of solar radiation. A second mechanism suggested the layer was formed by the incomplete refreezing of the surface slush layer as conditions warmed during summer. The surface ice layer, in this case was suggested to be Superimposed Ice Formation by the refreezing of fresh snowmelt on top of the unconsolidated slush layer below. No biological interaction was necessary in this case, however, sufficient snow melting to refreeze as superimposed ice was necessary as a cap on the unconsolidated slush layer. A thermal model is presented here, different from either of the previous models. This model takes into account the change in thermal properties of the upper layer of the sea ice when it warms and loses salinity through brine drainage. At temperatures still below the melting point for snow (0C) but above the freezing point of sea water (-1.8C), heat from the upper snow and sea ice can then be conducted, without melting the intermediate freshened layer, directly to the layer located near sea level and used to melt the ice in this (still saline)internal layer. A simple diffusive heat flux model using observed upper layer properties and temperature gradients in summer in Antarctic sea ice and snow covers gives a melting rate of 0.5 to 1.0cm/day. These values correspond reasonably with observations of gap layer thicknesses of 10 to 20 cm in Antarctic sea ice assuming 20 to 30 days of available heat flux in midsummer. This explanation avoids invoking the special conditions of the previous models, of biological growth in the first case, and of both flooding and snowmelt in the second, and is more generally applicable to the widespread observations of gap layers in Antarctic sea ice covers where these special conditions have not necessarily been observed concurrently.

Oceanography along East Antarctica (30 - 80º E) during the BROKE-West survey (CCAMLR Area 58.4.2) in the austral summer of 2006.

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A second East Antarctic Baseline Regional Oceanography Krill and Environment survey, termed BROKE-West, was conducted January 10th – February 25th 2006 and covered CCAMLR Area 58.4.2 west of the Princess Elizabeth Trough in the Weddell-Enderby Basin. This survey comprised 6 meridional Conductivity-Temperature-Depth (CTD) transects between 30 - 80º E from 62º S to the Antarctic coastal shelf, and a zonal CTD transect along 62º S. A ship-borne Acoustic Doppler Current Profile (ADCP) instrument and CTD-mounted Lowered ADCP were employed to measure surface and full-depth velocity profiles of the region. We describe the spatial variability in the properties of the Antarctic shelf and continental slope water masses: Antarctic Surface Water; Shelf Water; Tmin Water; Upper, Lower and Modified Circumpolar Deep Water and Antarctic Bottom Water. The position and properties of the major ocean fronts, i.e. the Antarctic Slope Front (ASF), Southern Boundary (SB) and Southern Antarctic Circumpolar Current Front (SACCF) are identified. These fronts, defined by sub-surface features, are examined with respect to the distribution of surface mixed layer properties from the CTD survey, including ship-based fluorometry and thermosalinograph data. Initial comparisons with preliminary results from the parallel biological and biogeochemical surveys demonstrate the importance of the physical environment to the structure of the marine ecosystem in this sector of East Antarctica.

Tracking the Antarctic Circumpolar Current fronts using penguin and seal dive data.

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Vertical temperature profiles collected by king penguins and elephant seals are used to map oceanographic fronts south of Australia and New Zealand. Independently, the Southern Ocean front locations are derived using satellite synoptic maps of sea surface height (SSH). There is good correspondence between Antarctic Circumpolar Current (ACC) front locations derived from temperatures sampled along the penguin and seal tracks and front positions inferred using SSH maps. Mesoscale features detected in the SSH maps from the eddy-rich regions are also reproduced in the individual temperature sections based on in situ dive data. The foraging strategy of Macquarie Island king penguins appears to be influenced strongly by oceanographic structure: almost all the penguin dives are confined to the region close to and between the northern and southern branches of the Polar Front. Surface chlorophyll distributions also reflect the influence of the ACC fronts, with the northern branch of the Polar Front marking a boundary between low surface chlorophyll to the north and elevated values to the south.

Rapid climate change in the ocean west of the Antarctic Peninsula during the second half of the 20th century.

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The climate of the Western Antarctic Peninsula (WAP) is the most rapidly changing in the Southern Hemisphere, with a rise in atmospheric temperature of nearly 3°C since 1951 and associated cryospheric impacts. We demonstrate here, for the first time, that the adjacent ocean showed profound coincident changes, with surface summer temperatures rising more than 1°C and a strong upper-layer salinification. Initially driven by atmospheric warming and reduced rates of sea ice production, these changes constitute positive feedbacks that will contribute significantly to the continued climate change. Marine species in this region have extreme sensitivities to their environment, with population and species removal predicted in response to very small increases in ocean temperature. The WAP region is an important breeding and nursery ground for Antarctic krill, a key species in the Southern Ocean foodweb with a known dependence on the physical environment. The changes observed thus have the potential to have significant impacts on the regional ecosystem.

Sensitivity of polar species to climatic changes: the case of Antarctic krill.

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High latitudes are the fastest warming regions of the planet, but their marine invertebrates are stenothermal, sensitive even to small temperature changes. For Antarctic species in a warming climate, the continent to the south could also block a compensating shift in their ranges. This talk focuses on one such species, *Euphausia superba*, which is potentially sensitive to such changes. We review firstly the major factors that control their present day distribution, and secondly some critical aspects of their biology that may be sensitive to change. Krill have an unusual circumpolar distribution, with over half of their total stocks concentrated into the SW Atlantic sector. We examine their distribution within this sector in relation to suitable habitat area (defined by water depth, temperature, ice cover, Chl a values) and compare with equivalent analyses from the Indian sectors. The Antarctic Peninsula region is changing in two ways that may affect krill. On one hand there is a reduction in winter sea ice, and on the other hand ocean temperatures have risen by ~1^{o}C since 1955. We examine some critical mechanisms by which both of these may affect krill, namely the requirement of sea ice for larval overwintering, and the limitation of postlarval growth at temperatures >2^{o}C. Analyses of critical mechanisms, coupled to an appreciation of what comprises good krill habitat, may help us to predict the future for this key species.

ENSO Drives Interannual Variability of the Antarctic Peninsula Pelagic Marine Ecosystem.

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The Drake Passage region off the West Antarctic Peninsula is a major source of Antarctic krill (*Euphausia superba*) for the entire Southern Ocean. This also is the domain where El Niño- Southern Oscillation (ENSO) variability in the tropics imposes its signature on climate variability in the Southern Ocean via meridional atmospheric teleconnections. The present study utilizes data collected in the South Shetland-Elephant Island area for 25 years, 1980 through 2004, to describe ecological response to interannual climate variability over six-to-seven ENSO cycles. Here we find interannual variations of elevated chlorophyll-a (Chl-a) and copepod concentrations and early krill spawning seasonality with increased reproductive and recruitment success that fluctuate in phase with poleward displacement of the Southern ACC Front (SACCF) and Southern Boundary of the Antarctic Circumpolar Current (SBACC) and retracted sea ice extent during the previous winter, variables that fluctuate in phase with La Niña in the eastern equatorial Pacific Ocean. El Niño conditions, in contrast, produce reduced copepod numbers, increased abundance of the salps *Salpa thompsoni* and *Ihlea racovitzai a*nd low krill reproductive success and recruitment, all with subsequent impacts on the pelagic marine ecosystem. We explain this in terms of the importance of climate variability on the krill-based food web and its implications for krill fishery management.