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The Scientific Committee on Antarctic Research (SCAR) Selected Science Highlights for 2014/15

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A Background paper submitted by SCAR

1. Background

This Background Paper highlights some recent key science papers published since the last Treaty meeting and should be read in conjunction with the Information Paper "*The Scientific Committee on Antarctic Research (SCAR) Annual Report for 2014/15*". Although not highlighted below, the latest ACCE update (see Information Paper) should also be consulted as it contains many pertinent references to climate change in the Antarctic region. Also see the two Kennicutt et al. (2014) papers on the SCAR Horizon Scan (see associated IP). It should also be noted that this is by no way a complete list (there have been many highly significant papers published over the last year) but represents a sample of key science papers highlighted by SCAR groups.

2. Selected Antarctic and Southern Ocean Science Highlights (2014/15)

Ice Sheet Mass Balance:

The floating ice shelves surrounding the Antarctic Ice Sheet restrain the grounded ice-sheet flow. Thinning of an ice shelf reduces this effect, leading to an increase in ice discharge to the ocean. Using 18 years of continuous satellite radar altimeter observations, the authors computed decadal-scale changes in ice-shelf thickness around the Antarctic continent. Overall, average ice-shelf volume change accelerated from negligible loss at 25 ± 64 cubic kilometers per year for 1994–2003 to rapid loss of 310 ± 74 cubic kilometers per year for 2003–2012. West Antarctic losses increased by ~70% in the past decade, and earlier volume gain by East Antarctic ice shelves ceased. In the Amundsen and Bellingshausen regions, some ice shelves have lost up to 18% of their thickness in less than two decades.
Paolo, F.S. Fricker, H.A. & Padman, L. 2015. Volume loss from Antarctic ice shelves is accelerating. Science, 348 (6232): 327-331 DOI: 10.1126/science.aaa0940

Thwaites Glacier is one of the West Antarctica's most prominent, rapidly evolving, and potentially unstable contributors to global sea level rise. Uncertainty in the amount and spatial pattern of geothermal flux and melting beneath this glacier is a major limitation in predicting its future behavior and sea level contribution. In this paper, a combination of radar sounding and subglacial water routing is used to show that large areas at the base of Thwaites Glacier are actively melting in response to geothermal flux consistent with rift-associated magma migration and volcanism. This supports the hypothesis that heterogeneous geothermal flux and local magmatic processes could be critical factors in determining the future behavior of the West Antarctic Ice Sheet.
Schroeder, D.M., Blankenship, D.D., Young, D.A. & Quartini, E. 2014. Evidence for elevated and spatially variable geothermal flux beneath the West Antarctic Ice Sheet. Proceedings of the National Academy of Sciences, 111(25): 9070–9072. doi:10.1073/pnas.1405184111

Past Climate:

The paper by Patterson et al (2014) reveals that before 3.5 million of years, under a warm climate state, the East Antarctic Ice Sheet demonstrates high sensitivity on orbital timescales to a relatively small increase in atmospheric CO2 concentration and mean global surface temperature. With atmospheric CO2 concentrations and global surface temperatures projected to remain above 400 ppm and >+2ºC beyond 2100, these results have implications for the equilibrium response of the Antarctic ice sheets, and suggest that the marine margins of the EAIS, as well as the marine-based West Antarctic Ice Sheet, may become increasingly susceptible to ocean warming, with the potential for widespread mass loss raising sea level by metres over

the coming centuries to millennia.
Patterson, M.O., McKay, R., Naish, T., Escutia, C., Jimenez-Espejo, F.J., Raymo, M.E., Meyers, S.R., Tauxe, L., Brinkhuis, H. & IODP Expedition 318 Scientists. 2014. Orbital Forcing of the East Antarctic Ice Sheet during the Pliocene and Early Pleistocene. Nature Geosciences, 7: 841-846.

Geological data indicate that global mean sea level has fluctuated during the last 25 million years, at times reaching 20 m or more above modern. Most climate and ice sheet models however, have not been able to simulate significant East Antarctic Ice Sheet from continental size, given that atmospheric CO2 levels were relatively low throughout this period. The paper by Pollard et al (2015) apply a simple Pliocene-like warming scenario incorporating the combined mechanisms of Marine Ice Sheet Instability, melt-driven hydrofracturing and cliff failure that cause a very rapid collapse of West Antarctic ice, on the order of decades. This is followed by retreat of East Antarctic basins within several hundred to a few thousand years. The total Antarctic ice loss corresponds to +17m sea-level rise, in good agreement with high-stands in geologic sea-level records, although uncertainty in the geologic records themselves should be considered.
Pollard, D., DeConto, R.M. & Alley, R.B. 2015. Potential Antarctic Ice Sheet retreat driven by hydrofracturing and ice cliff failure. Earth and Planetary Science Letters, 412: 112-121

The paper by Weber et al (2014) provide high-resolution Iceberg Rafted Debris (IBRD) records that capture a spatially integrated signal of Antarctic Ice Sheet (AIS) variability during the last deglaciation. They document eight events of increased iceberg flux from various parts of the AIS between 20,000 and 9,000 years ago, in marked contrast to previous scenarios which identified the main AIS retreat as occurring after meltwater pulse 1A, and continuing into the late Holocene epoch. The highest IBRD flux occurred 14,600 years ago, providing the first direct evidence for an Antarctic contribution to meltwater pulse 1A. Climate model simulations with AIS freshwater forcing identify a positive feedback between poleward transport of Circumpolar Deep Water, subsurface warming and AIS melt, suggesting that small perturbations to the ice sheet can be substantially enhanced, providing a possible mechanism for rapid sea-level rise.
Weber, M.E. , Clark, P.U., Kuhn, G., Timmermann, A., Sprenk, D., Gladstone, R. Zhang, X., Lohmann, G., Menviel, L., Chikamoto, M.O., Friedrich, T. & Ohlwein, C. 2014. Millennial-scale variability in Antarctic ice-sheet discharge during the last deglaciation. Nature, 510: 134-138

Earth sciences multidisciplinary:

The Special Issue of the journal *Global and Planetary Change* dedicated to the Scotia Arc, edited by Maldonado et al. (2014), is a significant contribution towards understanding this important region and its global influence. The Scotia Arc represents the last continental bridge in the process of the break-up of the supercontinent Gondwana. The rupture of this bridge facilitated the oceanographic connection between the Pacific and Atlantic oceans through Drake Passage and initiated the thermal isolation of Antarctica at about the Eocene/Oligocene transition, with profound effects on subsequent species evolution. The isolation of Antarctica facilitated the development of major ice-caps and eventually a continental ice sheet, which in turn increased the production of cold water that flowed northward and inundated the deep low latitude ocean basins. This Special Issue addresses some of these key issues through the work of an international, multidisciplinary group of authors.
Special Issue "Scotia Arc Evolution: Global Implications". Edited by A. Maldonado, I.W.D. Dalziel & P.T. Lead. Global and Planetary Change, 123-B: *151-413. 2014*

Permafrost and Periglacial Environments:

The special issue of the journal *Geomorphology* edited by Gugliemin et al. (2014) shows the main results from the SCAR Antarctic Permafrost, Periglacial Environments and Soils Group (ANTPAS) which were presented at the SCAR Open Science Conference in Portland in 2012. This Special Issue includes nine papers on a range of geomorphological issues, and reviews important contributions from the last two years.
Special Issue "Permafrost and periglacial research in Antarctica: new results and perspectives". Edited by M. Guglielmin, G. Vieira & A. Harvey. Geomorphology, 225: 1-100

Gugliemin et al. (2014) show that despite the lack of a clear warming trend in air temperatures in Continental Antarctica, there is an active layer thickening occurring in Victoria Land, as well as measurable ecosystem changes, with modifications in ground water associated with improved soil drainage conditions. Such changes in soil conditions will likely change the distribution of mosses and lichens. The authors support their observations with an observational dataset from the CALM network starting in 2000.

Guglielmin, M., Dalle Fratte, M., Cannone, N. 2014. Permafrost warming and vegetation changes in continental Antarctica, Environmental Research Letters, 9, 045001 (14pp).

Ecology and Biology:

Subglacial:

Liquid water has been known to occur beneath the Antarctic ice sheet for more than 40 years, but only recently have these subglacial aqueous environments been recognized as microbial ecosystems that may influence biogeochemical transformations on a global scale. Here Christner et al (2014) present the first geomicrobiological description of water and surficial sediments obtained from direct sampling of a subglacial Ant- arctic lake. The water column of subglacial Lake Whillans (SLW) contained metabolically active microorganisms and was derived primarily from glacial ice melt with solute sources from lithogenic weathering and a minor seawater component. Heterotrophic and autotrophic production data together with small subunit ribosomal RNA gene sequencing and biogeochemical data indicate that SLW is a chemosynthetically driven ecosystem inhabited by a diverse assemblage of bacteria and archaea. Our results confirm that aquatic environments beneath the Antarctic ice sheet support viable microbial ecosystems, corroborating previous reports suggesting that they contain globally relevant pools of carbon and microbes that can mobilize elements from the lithosphere and influence Southern Ocean geochemical and biological systems.
Christner, B. C., Priscu,J.C., Achberger, A.M., Barbante, C., Carter, S.P., Christianson, K., Michaud, A.B., Mikucki, J.A., Mitchell, A.C., Skidmore, M.L., Vick-Majors, T.J. & the WISSARD Science Team. 2014. A microbial ecosystem beneath the West Antarctic ice sheet. Nature, 310 (512): 310-315

Marine:

The Biogeographic Atlas of the Southern Ocean provides the most thorough audit of marine life in the Southern Ocean. In an unprecedented international collaboration 147 scientists from 91 institutions across 22 countries (Australia, Belgium, Brazil, Canada, Chile, Denmark, France, Germany, Ireland, Italy, Japan, the Netherlands, New Zealand, Norway, Poland, Portugal, Russia, South Africa, Spain, Switzerland, the UK and the USA) combined their expertise and knowledge to produce the new Biogeographic Atlas of the Southern Ocean. More than 9000 species are recorded, ranging from microbes to whales. Hundreds of thousands of records show the extent of scientific knowledge on the distribution of life in the Southern Ocean. In 66 chapters, the scientists examine the evolution, physical environment, genetics and possible impact of climate change on marine organisms in the region. The data, and expert opinions, in the Atlas will help inform conservation policy, including the debate over whether or not to establish marine protected areas in the open ocean. Sophisticated environmental models coupled with existing species distribution data provide a valuable outlook on the possible future distribution of key species as they adapt to climate change.
De Broyer, C., Koubbi, P., Griffiths, H.J., Raymond, B., Udekem d'Acoz, C. d', Van de Putte, A.P., Danis, B., David, B., Grant, S., Gutt, J., Held, C., Hosie, G., Huettmann, F., Post, A. & Ropert-Coudert, Y. (eds.), 2014. Biogeographic Atlas of the Southern Ocean. Scientific Committee on Antarctic Research, Cambridge, 510 pp.

ANDEEP-SYSTCO (ANtarctic benthic DEEP-sea biodiversity: colonization history and recent community patterns - SYSTem COupling) aimed to uncover responses of the abyssal benthos to differences and longer-term changes in primary productivity. Investigations on pelagic-benthic coupling included the analysis of a phytoplankton bloom from the surface down to the abyssal seafloor at a single station in the South Polar Front. These analyses also suggested a strong benthic-pelagic coupling at certain stations. As expected, sediment oxygen consumption measurements revealed higher values after the bloom. The response of bacteria and metazoan meiofauna indicated that enhanced oxygen consumption was related to respiratory activity of the living benthic component. High relative nematode abundance in the top centimetre layer of sediment only after the phytodetritus had settled suggests an early stage of a meiofaunal response. The study also showed that foraminiferans collect a diluted and sparse food resource (phytoplankton) and concentrate it as they build up their cytoplasm. As benthic foraminiferans serve as a food source for many abyssal metazoans, this study highlights the link between the degraded food resources, phytodetritus and metazoan organisms.
Brandt, A. & Würzberg, L. 2014. Southern Ocean deep sea – a benthic view to pelagic processes. Deep Sea Research II: 108: 1-112.

Raymond et al. 2014 uses two decades of satellite tracking data for Adélie and emperor penguins, light-mantled albatross, Antarctic fur seals, southern elephant seals and Weddell seals. Statistical modelling techniques were used to identify the preferred habitat of each species. The overlap amongst the foraging areas of individual species identified six major hotspots of important marine habitat. These areas were generally over the Antarctic shelf and waters immediately to its north, excluding deep, open oceanic areas, and were characterized by proximity to breeding colonies and by sea-ice dynamics, particularly locations of winter polynyas.
Raymond, B., Lea, M.-A., Patterson, T., Andrews-Goff, V., Sharples, R., Charrassin, J.-B., Cottin, M., Emmerson, L., Gales, N., Gales, R., Goldsworthy, S.D., Harcourt, R., Kato, A., Kirkwood, R., Lawton, K., Ropert-Coudert, Y., Southwell, C., van den Hoff, J., Wienecke, B., Woehler, E.J., Wotherspoon, S. & Hindell, M.A. 2014. Important marine habitat off east Antarctica revealed by two decades of multi-species predator tracking. Ecography 38: 121-129. doi: 10.1111/ecog.01021

Antarctic marine ecosystems have been changing for at least the past 30 years. This article reviews current and expected changes in physical habitats in response to climate change. It then reviews how these changes may impact the autecology of marine biota of this polar region. The general prognosis for the physical environment is for an overall warming, and freshening and strengthening of westerly winds. A potential pole-ward movement of those winds and the frontal systems, and an increase in ocean eddy activity is also predicted. Many habitat parameters will have regionally specific changes, particularly relating to sea ice dynamics.
Constable, A.J., Melbourne-Thomas, J., Corney, S.P. et al. 2014. Change in Southern Ocean ecosystems I: How changes in physical habitats directly affect marine biota. Global Change Biology, 20(10):3004-25. doi: 10.1111/gcb.12623.

Human impacts threaten not only species, but also entire ecosystems. Ecosystems under stress can collapse or transition into different states, potentially reducing biodiversity at multiple scales. This study highlighted the vulnerability of Antarctic shallow invertebrate-dominated ecosystems, through the identification of several threatening processes. Climate change is likely to cause early breakout of seasonal sea ice in parts of Antarctica, which will dramatically increase the amount of light reaching shallow seabed. This is predicted to result in ecological regime shifts, in which invertebrate-dominated communities are replaced by macroalgal beds. Habitat for these endemic Antarctic ecosystems is globally rare, and the fragmented nature of their distribution along Antarctic coast increases their sensitivity to change. The authors estimate their spatial distribution around Antarctica using sea ice and bathymetric data, and apply the International Union for Conservation of Nature Red List of Ecosystems criteria to assess their vulnerability. Best available data suggest that shallow ice-covered ecosystems are likely Near Threatened to Vulnerable in places, although the magnitude of risk is spatially variable and requires additional data to strengthen the assessment.
Clark, G.F., Raymond, B., Riddle, M.J., Stark, J.S. & Johnston, E.L. 2015. Vulnerability of Antarctic shallow invertebrate- dominated ecosystems Austral Ecology, doi:10.1111/aec.12237

Terrestrial:

In the very first metaviromics survey of an Antarctic soil habitat, these authors demonstrate, among other things, that there is an extremely wide diversity of bacteriophage and eukaryotic viruses present in Dry Valley soils. The identification of a number of highly novel phage sequences, including an entire virophage genome (comprising portions of both prokaryotic and eukaryotic origin), reflects the novelty of this environment.
Zablocki, O., van Zyl, L., Adriaenssens, E.M., Rubagotti, E., Tuffin, M., Craig Cary, S. & Cowan, D.. 2014. Level Diversity of Tailed Phages, Eukaryote-Associated Viruses, and Virophage-Like Elements in the Metaviromes of Antarctic Soils. Appl. Environ. Microbiol., 80(22):6888. DOI: 10.1128/AEM.01525-14.

In a comprehensive review of climate change impacts in polar region, Royles and Griffiths (2015) describe how moss bank archives provide insights into long term environmental change in the region. By looking at moss form and function in these long term deposits, these authors provide a framework in which the potential impact of climate change on Antarctic terrestrial habitats can be assessed.
Royles, J. & Griffiths, H. 2015. Invited review: climate change impacts in polar regions: lessons from Antarctic moss bank archives. Global Change Biology, 21: 1041-1057

The current status of biological invasions in terrestrial Antarctica was documented by Hughes et al. (2015) who also look at the capacity to respond to these incursions. They provide an up- to-date inventory of known

terrestrial non-native species introductions on the Antarctic continent and Peninsula. They conclude that practical management action is more likely to succeed with improved co-operation, communication and engagement by nations and industries operating across the region.
Hughes, K.A., Perierra, L.R., Molina-Montenegro, M.A. & Convey, P. 2015. Biological invasions in terrestrial Antarctica: what is the current status and can we respond. Biodiversity Conservation, DOI 10.1007/s10531-015-0896-6

Herbold et al. (2014) present evidence in aerobiology that challenges the assumption that geographical isolation is an effective barrier to microbial transport. However, given the uncertainty with which aerobiological organisms are recruited into existing communities, the ultimate impact of microbial dispersal is difficult to assess. Here the authors use molecular genetic approaches to examine microbial communities inhabiting fumarolic soils on Mount Erebus, the southern- most geothermal site on Earth, to evaluate the ecological significance of global-scale microbial dispersal. There, hot, fumarolic soils provide an effective environmental filter to test the viability of organisms that have been distributed via aeolian transport over geological time. We find that cosmopolitan thermophiles dominate the surface, whereas endemic Archaea and members of poorly understood Bacterial candidate divisions dominate the immediate subsurface. These results imply that aeolian processes readily disperse viable organisms globally, where they are incorporated into pre-existing complex communities of endemic and cosmopolitan taxa.
Herbold, C., Herbold, W., Lee, C.K., McDonald, I.R. & Cary, S.C. 2014. Evidence of global-scale aeolian dispersal and endemism in isolated geothermal microbial communities of Antarctica. Nature Communications, 5:3875. DOI: 10.1038/ncomms4875

This study by LaRue et al. (2014) explored the hypothesis that emperor penguins are strictly philopatric using satellite imagery, counts from aerial photography, and literature reports on emperor penguin distributions. There were six instances over three years in which emperor penguins did not return to the same location to breed, and there was also one newly discovered colony on the Antarctic Peninsula that may represent the relocation of penguins from the Dion Islands. This study is the first to use remote sensing to suggest that emperor penguins move between and establish new colonies, and suggests that emigration may have been partly responsible for the population decline at Pointe Géologie during the 1970s. Metapopulation dynamics of emperor penguins have not been previously considered and represent an important avenue for future research. Life history plasticity may be an important aspect of climate change adaptation, and our study offers new insight for the long-term future of emperor penguins.
LaRue, M.A., Kooyman, G., Heather, J. Lynch, H.J. & Fretwell. 2015. Emigration in emperor penguins: implications for interpretation of long-term studies. Ecography, 38: 114–120.

The paper by Lynch and LaRue (2014) reports on the first global census of the Adélie penguin, achieved using a combination of ground counts and satellite imagery, finding a breeding population 53% larger (3.79 million breeding pairs) than the last estimate in 1993. This global population assessment, which provides the first abundance estimates for 41 previously unsurveyed colonies and reports on 17 previously unknown colonies, provides a robust baseline for understanding future changes in abundance and distribution and finds that Adélie Penguin declines on the Antarctic Peninsula are more than offset by increases in East Antarctica. These results represent a critically-needed contribution to ongoing negotiations regarding the design and implementation of Marine Protected Areas for the Southern Ocean
Lynch, H.J. & LaRue, M.A. 2014. First global survey of Adélie penguin populations. The Auk, 131(4): 457-466, doi: http://dx.doi.org/10.1642/AUK-14-31.1

Astronomy and Astrophysics:

The possible detection of the signature of gravity waves from the early Universe in early 2014 caused great excitement across the scientific world. However, a joint analysis of 150 GHz data from two telescopes at South Pole (BICEP2 and Keck) with data from the Planck satellite at (principally) 353 GHz shows that somewhere between half and all of the signal observed at 150 GHz is due to polarized emission from dust in our own galaxy. Once this is accounted for there is no significant evidence for an inflationary gravitational wave component.
Ade P.A.R. et al. 2015. A Joint Analysis of BICEP2/Keck Array and Planck Data, Physical Review Letters, 114: 101301. DOI: 10.1103/PhysRevLett.114.101301

The detection and study of transiting extrasolar planets (i.e., those whose orbits momentarily eclipse their host star when viewed from the earth) is one of the most important elements in the search for habitable

extrasolar planets and the possible existence of extraterrestrial life. This study compared the best observing sites in Chile with Dome C, Antarctica. Two weeks of observations at Dome C yield a transit detection efficiency that typically requires a whole observing season in Chile. Combination of data from both continents improves detection yield by a further 12 to 18%.
Fruth, T. et al. 2014. Transit Search from Antarctica and Chile -Comparison and Combination, Publications of the Astronomical Society of the Pacific, 126: 227 - 242. DOI: 10.1086/675684

Humanities and Social Sciences:

The Consultative Parties to the Antarctic Treaty have frequently declared their collective ambition to manage Antarctica "in the interest of all mankind". However, the concrete implications of these declarations are not clear. As part of an international research project, the authors asked people from different parts of the world to respond to a questionnaire about Antarctica, its values, and the way it should be managed. Notwithstanding differences in respondents' nationalities, ages and the time of data collection, our results indicate that a significant proportion of the public values Antarctica both as a scientific laboratory and as one of the world's last wildernesses. Is this 'public's dream' of co-existence of science and wilderness a Mission Impossible? In this article, we contend that: 1) in theory, it is a Possible Mission that would connect well with the recognition of science and wilderness in the Antarctic Treaty System (ATS) instruments; 2) in practice, science in Antarctica has gradual and cumulative impacts on all three main wilderness qualities of Antarctica (absence of permanent infrastructure, naturalness and large size); 3) currently, the co- existence of science and wilderness is not an important consideration in the management of human activities in Antarctica; and 4) in the future, unless a proactive and concerted effort is taken by the Consultative Parties, it appears to be a Mission Impossible, as the expansion of scientific activities and associated logistics remains uncontrolled, inexorably eroding the Antarctic wilderness. The authors propose the adoption of principles providing clear and concrete guidance on scientific facilities and international cooperation as a constructive step forward in realising the 'public's dream' of coexistence of science and wilderness in Antarctica.
Bastmeijer, K. & Tin, T. 2015. Antarctica - A Wilderness Continent for Science: The 'Public's Dream' as a Mission Impossible? The Yearbook of Polar Law VI. 559-597. DOI 10.1163/1876-8814_020.

This book discusses concerns for the sensitive environments and ecosystems of Antarctica and looks ahead to the state of the continent as it might be in 2060. At the beginning of the 21st century, Antarctica stands at the edge of a warmer and busier world. The editors have gathered leading researchers to examine the challenges of Antarctic environmental governance, and to address such important questions as: What future will Business-As-Usual bring to the Antarctic environment? Will a Business-As-Usual future be compatible with the objectives set out under the Antarctic Treaty, especially its Protocol on Environmental Protection? What actions are necessary to bring about alternative futures for the next 50 years? In three main sections the authors a) examine the future state of Antarctic ecosystems in general, and specifically focuses on baleen whales, fisheries, introduction of non-native species, and the consequences of human trampling on soils; b) provide regional case studies with detailed summaries of human activities and environmental management in three regions as microcosms of current practice from which lessons can be learned and c) provide a diverse set of perspectives from representatives of environmental non-governmental organizations and governmental institutions as well as from tourism and sustainability researchers on how Antarctica is used, valued and governed, and how strategic thinking can assist in exploring, and potentially reaching, desirable futures for the Antarctic environment.
Tin, T., Liggett, D., Maher, P.T. & Lamers, M. (Eds.). 2014. Antarctic Futures: Human Engagement with the Antarctic Environment. Dordrecht, Heidelberg, Berlin, London: Springer.