

TABLE S-1. AUTHOR CONTACT INFORMATION AND CONTRIBUTION

(^a Members of the Horizon Scan International Steering Committee, ^b Members of Retreat Session Lead Discussion Teams, ^c Horizon Scan Session Technical Assistant, ^d Lead Writers of Cluster Summaries, ^e Did not attend the Horizon Scan Retreat)

Last name	First name	Email address	Contact Information
Kennicutt II ^{ab}	Mahlon C.	mckennicutt@gmail.com	Department of Oceanography, MS 3146, Texas A&M University, College Station, Texas 77843-3146
Chown ^{abd}	Steven L.	steven.chown@monash.edu	School of Biological Sciences, Monash University, Victoria 3800, Australia
Cassano ^{bd}	John J.	john.cassano@colorado.edu	Cooperative Institute for Research in Environmental Sciences, Department of Atmospheric and Oceanic Sciences, University of Colorado, Boulder, CO, 80309-0216 United States
Liggett ^{bd}	Daniela	daniela.liggett@canterbury.ac.nz	Gateway Antarctica, University of Canterbury, Private Bag 4800, Christchurch 8140, New Zealand
Massom ^d	Rob	Rob.Massom@aad.gov.au	Australian Antarctic Division and Antarctic Climate & Ecosystems CRC, Private Bag 80, Hobart, Tasmania 7001, Australia
Peck ^a	Lloyd S.	l.peck@bas.ac.uk	British Antarctic Survey, High Cross, Madingley Rd., Cambridge, CB3 0ET, United Kingdom
Rintoul ^{abd}	Stephen	Steve.Rintoul@csiro.au	CSIRO Ocean & Atmosphere Flagship and Antarctic Climate & Ecosystems Cooperative Research Centre, GPO Box 1538, Hobart, Tasmania 7001, Australia
Storey ^{bd}	John	j.storey@unsw.edu.au	School of Physics, University of NSW, Sydney NSW 2052, Australia
Vaughan ^d	David	dgv@bas.ac.uk	British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET, United Kingdom
Wilson ^{bd}	Terry J.	wilson.43@osu.edu	School of Earth Sciences, Ohio State University, 125 S Oval Mall, Columbus, OH 43210, United States
Sutherland ^{ab}	William J.	w.sutherland@zoo.cam.ac.uk	Conservation Science Group, Department of Zoology, University of Cambridge, Cambridge CB2 3EJ, United Kingdom
Allison ^b	Ian	Ian.Allison@utas.edu.au	Australian Antarctic Division and Antarctic Climate & Ecosystems CRC, Private Bag 80, Hobart, Tasmania 7001, Australia
Ayton ^b	Jeff	Jeff.Ayton@aad.gov.au	Australian Antarctic Division, 203 Channel Highway, Kingston Tasmania 7050, Australia
Badhe ^{ac}	Renuka	renuka@cantab.net	Scientific Committee on Antarctic Research (SCAR), SPRI, University of Cambridge, Lensfield Road, Cambridge CB2 1ER, United Kingdom
Baeseman	Jenny	jbaeseman@gmail.com	CliC International Project Office, Norwegian Polar Institute, Fram Centre, Hjalmar Johansens gate 14, NO-9296 Tromsø, Norway
Barrett	Peter J.	peter.barrett@vuw.ac.nz	Antarctic Research Centre, Victoria University of Wellington, P. O. Box 600, Wellington 6014, New Zealand
Bell	Robin	robinb@ldeo.columbia.edu	Lamont-Doherty Earth Observatory of Columbia University, 61 Rt. 9W, Palisades, NY 10964-8000, United States
Bertler	Nancy.	Nancy.Bertler@vuw.ac.nz N.Bertler@gns.cri.nz	Joint Antarctic Research Institute, Victoria University and GNS Science, PO Box 600, Wellington, New Zealand
Bo	Sun	sunbo@pric.gov.cn	Polar Research Institute of China, 451 Jinqiao Road, Pudong, Shanghai, 200136, PR China
Brandt	Angelika	Abbrandt@uni-hamburg.de	Biocentre Grindel and Zoological Museum, University of Hamburg, Martin-Luther-King-Platz 3, D-20146 Hamburg, Germany
Bromwich ^{ac}	David	bromwich.1@osu.edu	Byrd Polar Research Center, The Ohio State University, 1090 Carmack Road, Columbus, OH 43210, United States
Cary	Craig	caryc@waikato.ac.nz	The International Centre for Terrestrial Antarctic Research, University of Waikato, Hamilton, New Zealand
Clark ^b	Melody S.	mscl@bas.ac.uk	British Antarctic Survey, High Cross, Madingley Road, Cambridge, CB3 0ET, United Kingdom

Convey	Peter	pcon@bas.ac.uk	British Antarctic Survey, High Cross, Madingley Road., Cambridge CB3 0ET, United Kingdom
Costa	Erli S.	costaerli@gmail.com	Laboratório de Radioisótopos Eduardo Penna Franca. Universidade Federal do Rio de Janeiro. Av Carlos Chagas Filho, 373. CCS. Rio de Janeiro. Brasil. CEP: 21941-902
Cowan ^b	Don	Don.Cowan@up.ac.za	Centre for Microbial Ecology and Genomics, University of Pretoria, Pretoria 0002, South Africa
DeConto	Robert	deconto@geo.umass.edu	Department of Geosciences, 611 North Pleasant St., 233 Morrill Science Center, University of Massachusetts Amherst, MA 01003-9297, United States
Dunbar ^b	Robert	dunbar@stanford.edu	Environmental Earth System Science, Stanford University, Stanford, CA 94306, United States
Elfring ^{ac}	Chris	CElfring@nas.edu	US National Academy of Sciences, The National Academies (K-636), 500 Fifth Street NW, Washington DC 20001, United States
Escutia	Carlota	cescutia@ugr.es	Instituto Andaluz de Ciencias de la Tierra, CSIC-UGR, 18100 Armilla, Spain
Francis ^b	Jane	janefr@bas.ac.uk	British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET, United Kingdom
Fricker ^{ae}	Helen A.	Hafricker@ucsd.edu	Institute of Geophysics & Planetary Physics, Scripps Institution of Oceanography, University of California, San Diego, 9500 Gilman Dr, La Jolla, CA 92093-0225
Fukuchi	Mituso	fukuchi@nipr.ac.jp , fukuchi@general.hokudai.ac.jp	Director of Tokyo Office, Hokkaido University, Sapia Tower 10F, 1-7-12, Marunouchi, Chiyoda-ku, Tokyo 100-0005, Japan
Gilbert	Neil	enviroconsultant@antarcticanz.govt.nz	Antarctica New Zealand, Private Bag 4745, Christchurch, New Zealand
Gutt ^b	Julian	julian.gutt@awi.de	Alfred-Wegener-Institut, Helmholtz Zentrum für Polar- und Meeresforschung, Am Alten Hafen 26, 27568 Bremerhaven, Germany
Havermans ^c	Charlotte	chavermans@naturalsciences.be	Royal Belgian Institute of Natural Sciences, OD Natural Environment, Rue Vautier 29 1000 Brussels, Belgium
Hik	David	dhik@ualberta.ca	Department of Biological Sciences, University of Alberta, , Edmonton, AB, Canada, T5N 0R5
Hosie ^a	Graham	graham.hosie@inet.net.au	Not available
Jones ^b	Christopher	chris.d.jones@noaa.gov	Antarctic Ecosystem Research Division , NOAA Southwest Fisheries Science Center 8901 La Jolla Shores Dr., La Jolla, CA 92037 USA
Kim ^{ae}	Yeadong	ydkim@kopri.re.kr	Korea Polar Research Institute , 26 Songdomirae-ro, , Yeonsu-gu , Incheon 406-840, Korea
Le Maho	Yvon	yvon.lemaho@iphc.cnrs.fr	Institut Pluridisciplinaire Hubert Curien, CNRS and Strasbourg University, 23, rue Becquerel, F-67087 Strasbourg Cedex 2, France
Lee	SangHoon	shlee@kopri.re.kr	Korea Polar Research Institute, Incheon 406-840 , Korea
Leppe	Marcelo	mleppe@inach.cl	Instituto Antártico Chileno, Plaza Muñoz Gamero 1055, Punta Arenas, Chile
Leichenkov ^a	German	german_l@mail.ru	Research Institute for Geology and Mineral, Resources of the World Ocean, VNIIOkeangeologia, 1, Angliysky Ave., 190 121 St.- Petersburg, Russia
Li	Xichen	xichenslc@gmail.com	New York University, , Courant Institute of Math Sciences, 251 Mercer Street, RM912, New York, NY 10012, United States
Lipenkov	Vladimir	lipenkov@aari.nw.ru	Arctic and Antarctic Research Institute (AARI), 38, Bering St., , St. Petersburg 199397, Russia
Lochte ^{ab}	Karin	karin.lochte@awi.de	Alfred-Wegener-Institut, Helmholtz Zentrum für Polar- und Meeresforschung, Am Handelshafen 12, 27570 Bremerhaven, Germany
López-Martínez ^a	Jerónimo	jeronimo.lopez@uam.es	Dept. Geología y Geoquímica, Facultad de Ciencias, Universidad Autónoma de Madrid 28049 Madrid, Spain

Lüdecke	Cornelia	C.Luedecke@lrz.uni-muenchen.de	University of Hamburg, Fernpaßstraße 3 81373 Munich, Germany
Lyons ^a	W. Berry	lyons.142@osu.edu	School of Earth Sciences, The Ohio State University, , Columbus, OH 43210-1398 United States
Marensi ^{ab}	Sergio	smarensi@hotmail.com	IGeBA (Universidad de Buenos Aires – CONICET), Dto. Ciencias Geológicas – FCEyN, Ciudad, Universitaria-Pabellón 2, 1° piso, , Buenos Aires, Argentina C1428EHA
Miller	Heinz	Heinrich.Miller@awi.de	Alfred-Wegener-Institut, Helmholtz Zentrum für Polar- und Meeresforschung, Am Alten Hafen 26, 27568 Bremerhaven, Germany
Morozova	Polina	morozova_polina@mail.ru	Institute of Geography, Russian Academy of Sciences 119017, Staromonetny pereulok 29, Moscow, Russia
Naish ^b	Tim	Timothy.Naish@vuw.ac.nz	Antarctic Research Centre, Victoria University of Wellington, PO Box 600, Wellington, 6140, New Zealand
Nayak ^a	Shailesh	secretary@moes.gov.in	Earth System Science Organization and Prithvi Bhavan, Lodi Road, New Delhi 110023, India
Ravindra	Rasik	rasikravindra@gmail.com	Earth System Science Organization, Ministry of Earth Sciences., Lodi Road, New Delhi 110 003, India
Retamales	José	jretamales@inach.cl	Chilean Antarctic Institute , Plaza Muñoz Gamero 1055 , Punta Arenas, Chile
Ricci	Carlo A.	carloalberto.ricci@unisi.it	University of Siena, Museo Nazionale dell'Antartide, Via del Laterino 8, 53100, Siena, Italy
Rogan-Finnemore	Michelle	michelle.finnemore@comnap.aq	COMNAP Secretariat, Private Bag 4800, Christchurch, New Zealand
Ropert-Coudert	Yan	docyaounde@gmail.com	Institut Pluridisciplinaire Hubert Curien – DEPE, CNRS UMR7178 23, rue Becquerel 67087 Strasbourg, France
Samah ^b	Azizan A.	azizans@um.edu.my	National Antarctic Research Center, University of Malaya, 50603 Kuala Lumpur, Malaysia
Sanson ^a	Lou	lsanson@doc.govt.nz	Department of Conservation, P.O. Box 10420, Wellington, New Zealand
Scambos	Ted	teds@nsidc.org	National Snow and Ice Data Center, University of Colorado at Boulder, Boulder CO, 80303, United States
Schloss	Irene R.	ireschloss@gmail.com ischloss@dna.gov.ar	Instituto Antártico Argentino, Balcarce 290 (C1064AAF), Ciudad Autónoma de Buenos Aires, Argentina and Institut des sciences de la mer de Rimouski, Rimouski, Quebec, Canada
Shiraishi ^a	Kazuyuki	kshiraishi@nipr.ac.jp	National Institute of Polar Research (NIPR), 10-3 Midori-cho, Tachikawa, 190-8518 , Tokyo, Japan
Siegert ^a	Martin J.	m.siegert@imperial.ac.uk	Grantham Institute, and Department of Earth Sciences and Engineering, Imperial College London, South Kensington, London, SW7 2AZ, United Kingdom
Simões ^{ab}	Jefferson C.	jefferson.simoies@ufrgs.br	Centro Polar e Climático, Instituto de Geociências, Universidade Federal do Rio Grande do Sul – UFRGS Porto Alegre, RS, Brazil
Sparrow ^{ac}	Michael D.	mds68@cam.ac.uk	Scientific Committee on Antarctic Research (SCAR), SPRI, University of Cambridge, Lensfield Road Cambridge CB2 1ER, United Kingdom
Storey ^a	Bryan	bryan.storey@canterbury.ac.nz	University of Canterbury, Private Bag 4800, Christchurch, New Zealand
Wall ^b	Diana H.	Diana.Wall@colostate.edu	School of Global Environmental Sustainability, Colorado State University, Fort Collins, CO 80523-1036, United States
Walsh ^c	Jessica C.	j.walsh@zoo.cam.ac.uk	University of Cambridge, Department of Zoology, Downing Street, Cambridge, CB2 3EJ, United Kingdom.
Wilson	Gary	gary.wilson@otago.ac.nz	New Zealand Antarctic Research Institute, Private Bag 4745, Christchurch 8140, New Zealand
Winther ^e	Jan-Gunnar	jan.gunnar.winther@npolar.no	Norwegian Polar Institute, Fram Centre, NO-9296 Tromsø, Norway
Xavier ^{ab}	Jose C.	jccx@cantab.net	Institute of Marine Research, Department of Life Sciences, University of Coimbra, 3001-401 Coimbra, Portugal
Yang ^{ab}	Huigen	Huigen_yang@pric.gov.cn	Polar Research Institute of China, 451 Jinqiao Road, Pudong, , Shanghai 200136, P.R. China

TABLE S.2 FINAL LIST OF QUESTIONS^{1,2}

Antarctic Atmosphere and Global Connections

1. How is climate change and variability in the high southern latitudes connected to lower latitudes including the Tropical Ocean and monsoon systems?
2. How do Antarctic processes affect mid-latitude weather and extreme events?
3. How have teleconnections, feedbacks, and thresholds in decadal and longer term climate variability affected ice sheet response since the Last Glacial Maximum, and how can this inform future climate projections?
4. What drives change in the strength and position of Westerly winds, and what are their effects on ocean circulation, carbon uptake and global teleconnections?
5. How did the climate and atmospheric composition vary prior to the oldest ice records?
6. What controls regional patterns of atmospheric and oceanic warming and cooling in the Antarctic and Southern Ocean? (*Cross-cuts "Southern Ocean"*)
7. How can coupling and feedbacks between the atmosphere and the surface (land ice, sea ice and ocean) be better represented in weather and climate models? (*Cross-cuts "Southern Ocean" and "Antarctic Ice Sheet"*)
8. Does past amplified warming of Antarctica provide insight into the effects of future warming on climate and ice sheets? (*Cross-cuts "Antarctica Ice Sheet"*)
9. Are there CO₂ equivalent thresholds that foretell collapse of all or part of the Antarctic Ice Sheet? (*Cross-cuts "Antarctic Ice Sheet"*)
10. Will there be release of greenhouse gases stored in Antarctic and Southern Ocean clathrates, sediments, soils, and permafrost as climate changes? (*Cross-cuts "Dynamic Earth"*)
11. Is the recovery of the ozone hole proceeding as expected and how will its recovery affect regional and global atmospheric circulation, climate and ecosystems? (*Cross-cuts "Antarctic Life" and "Human"*)

Southern Ocean and Sea Ice In A Warming World

12. Will changes in the Southern Ocean result in feedbacks that accelerate or slow the pace of climate change?
13. Why are the properties and volume of Antarctic Bottom Water changing, and what are the consequences for global ocean circulation and climate?
14. How does Southern Ocean circulation, including exchange with lower latitudes, respond to climate forcing?
15. What processes and feedbacks drive changes in the mass, properties and distribution of Antarctic sea ice?
16. How do changes in iceberg numbers and size distribution affect Antarctica and the Southern Ocean?
17. How has Antarctic sea ice extent and volume varied over decadal to millennial time scales?
18. How will changes in ocean surface waves influence Antarctic sea ice and floating glacial ice?
19. How do changes in sea ice extent, seasonality and properties affect Antarctic atmospheric and oceanic circulation? (*Cross-cuts "Antarctic Atmosphere"*)
20. How do extreme events affect the Antarctic cryosphere and Southern Ocean? (*Cross-cuts "Antarctic Ice Sheet"*)
21. How did the Antarctic cryosphere and the Southern Ocean contribute to glacial-interglacial cycles? (*Cross-cuts "Antarctic Ice Sheet"*)
22. How will climate change affect the physical and biological uptake of CO₂ by the Southern Ocean? (*Cross-cuts "Antarctic Life"*)
23. How will changes in freshwater inputs affect ocean circulation and ecosystem processes? (*Cross-cuts "Antarctic Life"*)

Antarctic Ice Sheet and Sea Level

24. How does small-scale morphology in subglacial and continental shelf bathymetry affect Antarctic Ice Sheet response to changing environmental conditions? (*Cross-cuts "Dynamic Earth"*)
25. What are the processes and properties that control the form and flow of the Antarctic Ice Sheet?

¹ Questions are assigned numbers for ease of referencing and do not indicate relative importance or rank-order within or between clusters.

² *Questions that cross-cut clusters are indicated in red.*

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26. How does subglacial hydrology affect ice sheet dynamics, and how important is it? (*Cross-cuts “Dynamic Earth”*)
27. How do the characteristics of the ice sheet bed, such as geothermal heat flux and sediment distribution, affect ice flow and ice sheet stability? (*Cross-cuts “Dynamic Earth”*)
28. What are the thresholds that lead to irreversible loss of all or part of the Antarctic ice sheet?
29. How will changes in surface melt over the ice shelves and ice sheet evolve, and what will be the impact of these changes?
30. How do oceanic processes beneath ice shelves vary in space and time, how are they modified by sea ice, and do they affect ice loss and ice sheet mass balance? (*Cross-cuts “Southern Ocean”*)
31. How will large-scale processes in the Southern Ocean and atmosphere affect the Antarctic Ice Sheet, particularly the rapid disintegration of ice shelves and ice sheet margins? (*Cross-cuts “Antarctic Atmosphere” and “Southern Ocean”*)
32. How fast has the Antarctic Ice Sheet changed in the past and what does that tell us about the future?
33. How did marine-based Antarctic ice sheets change during previous inter-glacial periods?
34. How will the sedimentary record beneath the ice sheet inform our knowledge of the presence or absence of continental ice? (*Cross-cuts “Dynamic Earth”*)

Dynamic Earth - Probing Beneath Antarctic Ice

35. How does the bedrock geology under the Antarctic Ice Sheet inform our understanding of supercontinent assembly and break-up through Earth history?
36. Do variations in geothermal heat flux in Antarctica provide a diagnostic signature of sub-ice geology?
37. What is the crust and mantle structure of Antarctica and the Southern Ocean, and how do they affect surface motions due to glacial isostatic adjustment?
38. How does volcanism affect the evolution of the Antarctic lithosphere, ice sheet dynamics, and global climate? (*Cross-cuts “Antarctic Atmosphere” and “Antarctic Ice Sheet”*)
39. What are and have been the rates of geomorphic change in different Antarctic regions, and what are the ages of preserved landscapes?
40. How do tectonics, dynamic topography, ice loading and isostatic adjustment affect the spatial pattern of sea level change on all time scales? (*Cross-cuts “Antarctic Ice Sheet”*)
41. Will increased deformation and volcanism characterize Antarctica when ice mass is reduced in a warmer world, and if so, how will glacial- and ecosystems be affected? (*Cross-cuts “Antarctic Life”*)
42. How will permafrost, the active layer and water availability in Antarctic soils and marine sediments change in a warming climate, and what are the effects on ecosystems and biogeochemical cycles? (*Cross-cuts “Antarctic Life”*)

Antarctic Life on the Precipice

43. What is the genomic basis of adaptation in Antarctic and Southern Ocean organisms and communities?
44. How fast are mutation rates and how extensive is gene flow in the Antarctic and the Southern Ocean?
45. How have ecosystems in the Antarctic and the Southern Ocean responded to warmer climate conditions in the past? (*Cross-cuts “Antarctic Atmosphere” and “Oceans”*)
46. How has life evolved in the Antarctic in response to dramatic events in the Earth’s history? (*Cross-cuts “Dynamic Earth”*)
47. How do subglacial systems inform models for the development of life on Earth and elsewhere? (*Cross-cuts “Eyes on the Sky”*)
48. Which ecosystems and food webs are most vulnerable in the Antarctic and Southern Ocean, and which organisms are most likely to go extinct?
49. How will threshold transitions vary over different spatial and temporal scales, and how will they impact ecosystem functioning under future environmental conditions?
50. What are the synergistic effects of multiple stressors and environmental change drivers on Antarctic and Southern Ocean biota?
51. How will organism and ecosystems respond to a changing soundscape in the Southern Ocean? (*Cross-cuts “Human”*)
52. How will next-generation contaminants affect Antarctic and Southern Ocean biota and ecosystems?

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53. What is the exposure and response of Antarctic organisms and ecosystems to atmospheric contaminants (e.g. black carbon, mercury, sulphur, etc.), and are the sources and distributions of these contaminants changing? (*Cross-cuts "Antarctic Atmosphere" and "Human"*)
54. How will the sources and mechanisms of dispersal of propagules into and around the Antarctic and Southern Ocean change in the future?
55. How will invasive species and range shifts of indigenous species change Antarctic and Southern Ocean ecosystems? (*Cross-cuts "Human"*)
56. How will climate change affect the risk of spreading emerging infectious diseases in Antarctica? (*Cross-cuts "Human"*)
57. How will increases in the ice-free Antarctic intertidal zone impact biodiversity and the likelihood of biological invasions?
58. How will climate change affect existing and future Southern Ocean fisheries, especially krill stocks? (*Cross-cuts "Human"*)
59. How will linkages between marine and terrestrial systems change in the future?
60. What are the impacts of changing seasonality and transitional events on Antarctic and Southern Ocean marine ecology, biogeochemistry, and energy flow?
61. How will increased marine resource harvesting impact Southern Ocean biogeochemical cycles? (*Cross-cuts "Human"*)
62. How will deep sea ecosystems respond to modifications of deep water formation, and how will deep sea species interact with shallow water ecosystems as the environment changes?
63. How can changes in the form and frequency of extreme events be used to improve biological understanding and forecasting? (*Cross-cuts "Antarctic Atmosphere"*)
64. How can temporal and spatial "omic-level" analyses of Antarctic and Southern Ocean biodiversity inform ecological forecasting?
65. What will key marine species tell us about trophic interactions and their oceanographic drivers such as future shifts in frontal dynamics and stratification?
66. How successful will Southern Ocean Marine Protected Areas be in meeting their protection objectives, and how will they affect ecosystem processes and resource extraction? (*Cross-cuts "Human"*)
67. What ex situ conservation measures, such as genetic repositories, are required for the Antarctic and Southern Ocean? (*Cross-cuts "Human"*)
68. How effective are Antarctic and Southern Ocean conservation measures for preserving evolutionary potential? (*Cross-cuts "Human"*)

Near-Earth Space and Beyond - Eyes on the Sky

69. What happened in the first second after the Universe began?
70. What is the nature of the dark Universe and how is it affecting us?
71. What are the differences in the inter-hemispheric conjugacy between the ionosphere and that in the lower, middle and upper atmospheres, and what causes those differences?
72. How does space weather influence the polar ionosphere and what are the wider implications for the global atmosphere? (*Cross-cuts "Antarctic Atmosphere"*)
73. How do the generation, propagation, variability and climatology of atmospheric waves affect atmospheric processes over Antarctica and the Southern Ocean? (*Cross-cuts "Antarctic Atmosphere"*)

Human Presence in Antarctica

74. How can natural and human-induced environmental changes be distinguished, and how will this knowledge affect Antarctic governance? (*Cross-cuts all other Clusters*)
75. What will be the impacts of large-scale, direct human modification of the Antarctic environment? (*Cross-cuts "Antarctic Life"*)
76. How will external pressures and changes in the geopolitical configurations of power affect Antarctic governance and science?
77. How will the use of Antarctica for peaceful purposes and science be maintained as barriers to access change?
78. How will regulatory mechanisms evolve to keep pace with Antarctic tourism?
79. What is the current and potential value of Antarctic ecosystem services?
80. How will humans, diseases and pathogens change, impact and adapt to the extreme Antarctic environment? (*Cross-cuts "Antarctic Life"*)