1st SCAR
Antarctic and Southern Ocean Science

“A roadmap for Antarctic and Southern Ocean Science for the next two decades and beyond”
Horizon Scan Supporters
What is a Horizon Scan?

A Horizon Scan is the systematic search for opportunities, which are then articulated as a vision for future directions.
The 1st SCAR Antarctic and Southern Ocean Science Horizon Scan

The international Antarctic community came together to “scan the horizon” to identify the highest priority scientific questions that researchers should aspire to answer in the next two decades and beyond.
Intensive planning over a two-year period
An inclusive process

• Community-wide question solicitations
  – Round 1 – 751 questions
  – Round 2 – 115 questions

• Retreat invitation nominations
  – 789 nominations of 510 individuals

• Scientists, Program Directors/Managers, policy makers, decision makers and early career scientists.

• 75 Retreat attendees from 22 countries
• 6-8 Observers (Nature, MFAT, Tinker Foundation, Media)
Question criteria

• Answerable by an achievable research design.
• Have a factual answer independent of value judgments.
• Address important gaps in knowledge.
• Of a spatial and temporal scale that could be addressed by a research team.
• Specifically formulated - not a general topical area.
• If related to impact and interventions, contain a subject, an intervention and a measurable outcome.
• Clearly-worded, simple and concise.
• Addressable in the next two decades and beyond.

Questions best addressed by research in the southern polar regions or where studies in the Antarctic provide insights unobtainable elsewhere.
The Horizon Scan Retreat

Millbrook Resort, Queenstown, NZ
April 20-23, 2014
The Horizon Scan Retreat
Lots of thinking!
The Horizon Scan Retreat
Lots of discussion and debate!
The Horizon Scan Retreat
Coming to collective agreement on the top questions
Horizon Scan Outcomes

From nearly 1000 ideas, the 80 most important scientific questions were identified through structured debate, discussion, revision and voting.
### DAY 1

1. Southern Ocean Physics, Geology, and Chemistry
2. Southern Ocean Life and Ecology
3. The Solid Earth
4. The Atmosphere, Near Earth Space and Beyond
5. Land Ice
6. Biotic Responses to Change
7. The Marine Biosphere and the Physical Environment
8. Humankind in Antarctica
9. The Past - A Window on the Future
10. Terrestrial Life and Ecology

### DAY 2

- The Southern Ocean (1,2,7)
- Land Ice and Terrestrial Life (5,10)
- The Southern Ocean (3,4)
- Predicting Future Change (6,8,9)

### DAY 3

- Antarctic Atmosphere and Global Connections
- Southern Ocean and Sea Ice in a Warming World
- The Dynamic Earth Beneath the Antarctic Ice
- Antarctic Ice Sheet and Sea Level
- Antartic Life on the Precipice
- Human Presence in Antarctica
- Near Earth Space and Beyond - Eyes on the Sky

**Question Clusters**
50% of the questions cross-cut other topical clusters
SCIENCE PRIORITIES FOR...

DEFINE
the global reach of the Antarctic atmosphere and Southern Ocean

UNDERSTAND
how, where and why ice sheets lose mass

REVEAL
Antarctica’s history

RECOGNIZE AND MITIGATE
human influences

OBSERVE
space and the Universe

LEARN
how Antarctic life evolved and survived

SCIENCE
PRIORITIES FOR...

NASA/LIMA
Stieg et al 2009
Antarctic Atmosphere and Global Connections

Tele-connections

Processes and interfaces

Greenhouse gases

Regional variations

Observations

1979-2003

temperature trend (°C/decade)
Antarctic climate change has a pronounced regional signature

What drives the regional patterns of climate change in Antarctica?

Steig et al. 2009 (Nature)
Lower latitudes force Antarctic climate

The impact of Antarctic climate change on lower latitudes is unknown.

Ding et al. 2011 (Nature Climate Change)

Li et al. 2014 (Nature)
Role of ozone and GHG on Antarctic climate

How will future changes in ozone and GHGs impact Antarctic climate?

What impact will changes in atmospheric circulation have on the ocean and sea ice?

Polvani et al. 2011 (Journal of Climate)
Understand the processes that drive Antarctic climate

Atmosphere (Clouds, precipitation, radiation, turbulence)

Sea and land ice (Ice extent, thickness, snow cover, melting)

Ocean (Currents, SST, trace gas fluxes, biology)

Process level understanding is critical for climate projections.
The Southern Ocean and Sea Ice in a Warming World

- Human role in ocean change
- Heat, energy, carbon dioxide, carbon, oxygen and nutrient cycles and budgets
- Sea ice variability
- Improved climate forecasts
Global warming is ocean warming … and the Southern Ocean takes up more heat than other ocean regions.
Southern Ocean stores more anthropogenic carbon dioxide than other ocean latitudes

Sabine et al. (2004)
Pace of climate change and sea level rise is strongly influenced by Southern Ocean processes

US National Research Council (2011)
Human activities are driving change in the Southern Ocean

Southern Ocean is:
• warming
• freshening
• melting ice shelves
• acidifying

Both the ozone hole and greenhouse gases have contributed to observed changes.

Will the Southern Ocean continue to slow the rate of climate change by taking up heat and carbon dioxide?

Böning et al. (2008)
Antarctic sea ice is expanding
... regional changes rival those seen in the Arctic
Antarctic ice sheet and sea level

Controls and processes

Ice sheet thinning, retreat, and melt

Sea level

Improved climate and sea level forecasts
Understand how, where and why the ice sheets lose mass

- The ice sheet is thinning
- The ice sheet margin is retreating
- The ice shelves are melting

Rate of Ice Sheet melt and mass-loss

Ice Sheet thickness change 2002 - 2006

Rignot et al. 2013

Prichard et al., 2010
Ice sheets are losing mass at an accelerating rate

- Progressive increase in mass loss over the last years
- Approaching 6mm per year
- Mass loss doubled in the last 10 years
- Acceleration: yes, but the time series is short
- Implications for predictions?

Sources listed in Vaughan et al. IPCC (2013)
What are the implications for global sea-level rise?

Based on current understanding, only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea level to rise substantially above the likely range during the 21st century…IPCC AR5, 2013

But what about ice sheet surprises?!

Sources listed in Church et al. IPCC (2013)
What controls the rate of melt and their effect on sea-level rise?

- Ocean heat and circulation?
- The bedrock topography?
- Ice shelf buttressing?
- Marine ice sheet instability?
- Water at the bed?
Is the West Antarctic Ice Sheet on the brink of irreversible collapse?

Marine Ice Sheet Collapse Potentially Under Way for the Thwaites Glacier Basin, West Antarctica

Ian Joughin, Benjamin E. Smith, Brooke Medley

www.sciencemag.org  SCIENCE  VOL 344  16 MAY 2014
Is there an atmospheric CO₂ threshold beyond which ice sheets collapse and sea-level rises dramatically?

The last time the world saw 400 ppm CO₂ levels was 3 million years ago.
Dynamic earth – probing beneath Antarctic ice

Super continent assembly

Heat flux and volcanism

Cryospheric feedback

Deep Earth structure
Reveal Antarctica’s history

What lies beneath?
Dynamic Earth - Deep Time

Antarctic record of supercontinent assembly and dispersal?

Magmatism – influence on Antarctic lithosphere, ice sheet dynamics, global climate?

Dalziel et al. 2013
Dynamic Earth
Deep Earth structure

• Subglacial geology?
  • Heat flux?
• Impacts on ice sheet dynamics & isostatic rebound?

Becker, 2010, Science
Antarctica as the ice sheets shrink:

- Increasing volcanism & deformation?
- Greenhouse gas release?

.Active Volcano Found Under Antarctic Ice: Eruption Could Raise Sea Levels

Inevitable eruption will speed up ice loss on frozen continent, study says.

Antarctic Methane Could Escape, Worsen Warming

As glaciers melt, gas could belch into atmosphere, study suggests.
Dynamic Earth
Feedbacks with Cryosphere

Ice sheet dynamics: influences of bed morphology, subglacial hydrology, geothermal heat flux?
Antarctic life on the precipice

Ecosystem structure and function

Adaptation and biodiversity

Conservation science

Environmental drivers
## Antarctic Life on the Precipice

<table>
<thead>
<tr>
<th>Low diversity, isolated, recent, protected</th>
<th>Diverse, more connected, refugia, unprotected</th>
</tr>
</thead>
</table>

### Time and understanding

Exploring biological constraints on the glacial history of Antarctica

*Antarctica’s Protected Areas Are Inadequate, Unrepresentative, and at Risk*
Antarctic Life on the Precipice


Evidence of global-scale aeolian dispersal and endemism in isolated geothermal microbial communities of Antarctica
<table>
<thead>
<tr>
<th>Evolution</th>
<th>Thresholds</th>
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<tbody>
<tr>
<td>Adaptation</td>
<td>Species</td>
</tr>
<tr>
<td>History</td>
<td>Ecosystems</td>
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<tr>
<td>Genomics</td>
<td>Food webs</td>
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</tbody>
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Life on the Precipice
26 + 6 cross-cutting questions

<table>
<thead>
<tr>
<th>Climate</th>
<th>Conservation</th>
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<tbody>
<tr>
<td>Invasions</td>
<td>Evidence</td>
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<td>Contaminants</td>
<td>Indicators</td>
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<td>Disease</td>
<td>Policy</td>
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<td>Synergies</td>
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</table>
Antarctic Life on the Precipice
Antarctic Life on the Precipice

General Themes

• Genomics, evolutionary rates, adaptation
• Responses to change, extreme events and thresholds
• Dispersal characteristics of diseases, invasive species, indigenous groups
• Deep sea responses to changing environments
• Trophic interactions, resource harvesting, biological indicator efficacy
• Conservation both in situ and ex situ
• Evidence-based advice to conservation policy
• Sensing and data handling systems
Human presence in Antarctica

Tourism

Southern Ocean fisheries

The Future?

Scientific footprint

Conservation, protection, ecosystem services, and governance
Human Presence in Antarctica

- Increasing and diversifying
- Increasing pressures on resources & environment
- Drivers and motivations? => Future development?

- Impacts & challenges with regard to:
  - Antarctic ecosystems
  - Governance
  - Environmental management
  - Science logistics
Antarctic tourism

Number of tourists visiting Antarctica per season
(based on IAATO data)
Scientific footprint

Stations, airfields, camps and refuges in Antarctica

Source: Wratt 2013, pp. 200
Southern Ocean fisheries

Total krill catches reported to CCAMLR

Source: Miller 2014, p.69
Antarctic Protected Areas

Antarctica’s Protected Areas Are Inadequate, Unrepresentative, and at Risk

Justine D. Shaw¹,²*, Aleks Terauds², Martin J. Riddle², Hugh P. Possingham¹, Steven L. Chown³

Antarctica: 69th out of 84, between Mali and Kazakhstan
Human Presence in Antarctica
Research Requirements

• Understanding, evaluating and forecasting …
  – future human activities in the Antarctic
  – the impacts of large-scale human modifications
  – the effectiveness of Antarctic tourism regulation
  – the effect of state and non-state actors on Antarctic governance and the free conduct of science
  – the value of economic and non-economic Antarctic ecosystem services
  – the adaptation of humans, diseases and pathogens
  – the difference between anthropogenic & natural change
Near-Earth space and beyond – eyes on the sky

The origins of the Universe

Life beyond Earth

The nature of the dark Universe

Space weather
Antarctica—a special place for space scientists...

- The Earth’s magnetic field lines funnel high-energy charged particles to the poles.
- The poles represent unique points in the Earth’s atmospheric circulation system.

...and astronomers

- Antarctica has the clearest, most transparent and stable skies on the planet.
- Vast quantities of pure ice act as natural detectors for high energy particles.
Question #72. How does space weather influence the polar ionosphere and what are the wider implications for the global atmosphere?
Question #70: What is the nature of the dark Universe and how is it affecting us?
Question 69: What happened in the first second after the Universe began?

Keisler et al., 2011
Realizing the promise of Antarctic science

THE CHALLENGE...

COMMUNICATE with all stakeholders

ENHANCE INTERNATIONAL COOPERATION

SUSTAIN STABLE FUNDING

PROVIDE ACCESS Region-wide Year-round

APPLY EMERGING TECHNOLOGIES

STRENGTHEN ENVIRONMENTAL PROTECTION

Stieg et al 2009

NASA/LIMA

Enhance International Cooperation

Strengthen Environmental Protection

Communicate with all stakeholders

Produce Access Region-wide Year-round

Apply Emerging Technologies

Sustain Stable Funding

The Challenge...
Publications

7 August 2014 Issue

Six priorities for Antarctic science

Mahlon C. Kennicutt II, Steven L. Chown and colleagues outline the most pressing questions in southern polar research, and call for greater collaboration and environmental protection in the region.

Antarctica. The word conjures up images of mountains blanketed with glaciers, ice fields dotted with icebergs and ice caps, and icebergs floating somewhere. The continent is one of the centers of the planet’s land surface, nearly 98% of Earth’s ice and about 70% of its fresh water. Its encircling oceans support Pintingian toothfish and krill fisheries, and are crucial for regulating climate and the uptake of carbon dioxide by the oceans.

Antarctic scientists are addressing the complex interactions between climate and the Antarctic ecosystem. Emerging evidence indicates that changes in the Southern Ocean, such as warming and acidification, are influencing marine biodiversity and ecosystem processes. These changes have significant implications for the planet’s carbon cycle and climate system.

Online
August 2014

Process and Outcomes
Presentations

- **U.S. National Academies:** May 2014, Washington, DC
- **NZARI/Antarctica New Zealand:** June 2014, Christchurch, NZ
- **SCAR Biennial Meetings:** Open Science Conference, Special Event; Aug.-Sept. 2014, Auckland NZ
- **Polar Research Institute of China:** October 14-16, 2014 (Shanghai and Beijing, China)
- **UK SCAR National Committee:** October 27, 2014, London, UK
- **IASC ICARP III Executive Committee:** – November 2014, Potsdam, Germany
- **(National Polar Research Institute):** TBA 2015, Tokyo, Japan
- **World-wide Regional Meetings:** South America, Pacific Rim, Europe; TBA
To Reach the Horizon:

“A coordinated, portfolio of interdisciplinary science, based on enhanced international collaboration as no one scientist, program or nation can realize these aspirations alone.”

"The best way to predict the future is to invent it.”

A. Kay

"Tomorrow belongs to those who prepare for it today.”

paraphrase of an African proverb
QUESTIONS?