

10 April 2008 18:00

Report to the SCAR Delegates on the Scientific Research Programme**Antarctica and the Global Climate System (AGCS)****THE RATIONALE FOR THE PROGRAMME**

AGCS is a cross-disciplinary science programme that focuses on the atmospheric, oceanic and cryospheric linkages between the Antarctic and the rest of the Earth system. It uses a very wide range of observations from the Antarctic continent and the Southern Ocean to investigate natural climate variability and possible anthropogenic signatures of change. The in-situ meteorological and oceanic observations provide high quality data for recent decades, but these are supplemented with proxy data from deep and shallow ice cores that extend the records back into the pre-instrumental period. The programme also uses a range of satellite data and the output of climate and numerical weather prediction models to investigate the mechanisms of change and how climate signals are transferred to and from mid-latitudes and the tropics to the Antarctic. Our focus is on climate change over roughly the last 10,000 years, although we work closely with the ACE programme, which is looking deeper into the past.

AGCS consists of four science themes concerned with:

1. Decadal time scale variability in the Antarctic climate system
2. Global and regional climate signals in ice cores
3. Natural and anthropogenic forcing on the Antarctic climate system
4. The export of Antarctic climate signals.

This document reports on progress with the implementation of the programme since our report to the SCAR Executive in July 2007. It provides details of progress with the science and lists outputs.

FIVE SCIENTIFIC HIGHLIGHTS

1. Improved projections of how the climate of the Antarctic and Southern Ocean will evolve over the Twenty First Century have been produced. The work was based on the output of the models used in the Fourth Assessment Report of the IPCC. Since the models have a wide range of skills in simulating the Antarctic climate their output was weighted according to their ability to reproduce the mean climate of the late 20th century. The models suggest an increase in the circumpolar westerlies, which is largest (27%) in the autumn. The surface warming averaged over the continent is projected to be 0.34 deg C per decade. More rapid warming of 0.5 deg C per decade is expected during the winter in areas where there will be sea ice loss around the coast of East Antarctica. Approximately 33% of the sea ice area is expected to be lost by the end of the century, while there will be an increase of precipitation onto the continent. The work has been published in the Journal of Geophysical Research
2. An oceanographic section across the eastern Scotia Sea occupied in 1995, 1999 and 2005 revealed significant variability in the deep and bottom waters of Southern Ocean origin. Warming (~0.1°C) of the warm mid-layer waters in the Scotia Sea between 1995 and 1999 reversed through to 2005, reflecting changes seen earlier upstream in the Weddell Sea. The volume of deep waters with potential temperature less than 0°C decreased during 1995-2005, though such a reduction was only clear between 1995 and 1999 at the southern end of the section. The abyssal waters of the eastern Scotia Sea apparently changed circulation between 1995 and 1999, with the dominant point of their entry to the basin shifting from the south to the northeast; by 2005, the former route had regained dominance. These changes

are best explained by interannual variations in the deep waters exiting the Weddell Sea, superimposed on a longer-term (decadal) warming trend. The interannual variations are related to changes in the strength of the Weddell Gyre, reflecting large-scale atmospheric variability that may include the El Niño / Southern Oscillation phenomenon. The Scotia Sea is the most direct pathway for dense waters of the overturning circulation emanating from the Weddell Sea to fill much of the world ocean abyss. The regional changes reported have the potential to affect the climatically significant ventilation of the global ocean abyss.

3. A first assessment has been made of the circumpolar distribution of sea ice and snow thickness distribution around the Antarctic continent. Results are presented on seasonal and regional variability of the sea ice (and snow cover) thickness distribution based on the SCAR Antarctic Sea Ice Processes and Climate (ASPeCt) climatology of ship observations from 1980 to 2005. The work has been accepted for publication in the *J. Geophys. Res.*
4. A new medium depth (136 m) ice core has been drilled in a high accumulation site on the south-western Antarctic Peninsula during 2007. The Gomez record reveals a doubling of accumulation since the 1850s, from a decadal average of 0.49 m (water equivalent) per year in 1855–1864 to 1.10 m per year in 1997–2006, with acceleration in recent decades. Comparison with published accumulation records indicates that this rapid increase is the largest observed across the region. Evaluation of the relationships between Gomez accumulation and the primary modes of atmospheric circulation variability reveals a strong, temporally stable and positive relationship with the Southern Annular Mode (SAM).
5. A first assessment has been made of the “State of the Antarctic and Southern Ocean Climate System (SASOCS) covering the last 10,000 years and the next century. This major report has been submitted to *Reviews of Geophysics*.

PROGRESS AGAINST PRIOR WORK PLAN

What were the planned milestones and deliverables? What were the achievements against these?

All the AGCS milestones and deliverables are listed in the AGCS Implementation Plan available at <http://www.scar.org/researchgroups/physicalscience/agcs/>, and in the minutes of the AGCS Steering Committee. Because of space restrictions only selected achievements are listed below. We do not duplicate the work described in the highlights above.

- Theme 1. Increasing Antarctic sea ice. Work is underway to understand why Antarctic sea ice extent has been increasing since the late 1970s. The greatest increase has been in the Ross Sea sector during the autumn. Model runs have suggested that the ice extent has increased because of anthropogenic factors - principally atmospheric circulation changes brought about by stratospheric ozone losses, and by increasing greenhouse gases to a lesser extent.
- Theme 2. The SAM. Good progress has been made into understanding the factors that control the variability of the Southern Hemisphere Annular Mode (SAM) and its influence on the atmospheric and oceanic conditions of the Antarctic and Southern Ocean. Changes in the SAM are now understood to be largely responsible for the significant summer season warming on the eastern side of the Antarctic Peninsula and the increase in wind speeds over the Southern Ocean
- Theme 3. The mid-tropospheric warming. A paper linking the warming to increasing amounts of polar stratospheric clouds (PSCs) above the continent is under revision for *Geophys. Res. Letters*.
- Theme 2. Exciting new data on snow accumulation, temperature and ice thickness have been obtained from Dome A. They suggest that a deep ice core collected at the location could provide the oldest ice from the Antarctic and provide a climate record extending back more than a million years. Excess deuterium data from Dome A shallow ice cores show an increasing trend during the past ~4000 years, implying that the average moisture sources of Dome A in the southern hemisphere are moving equatorwards.

- The SCAR Delegates asked AGCS to lead the preparation of a report on Antarctic Climate Change and the Environment (ACCE). Good progress has been made on this task, which has involved scientists from all the SCAR SSGs and several of the science programmes, as well as people who have had little involvement with SCAR to date. The editors met in Cambridge to review progress in January 2008. A draft of the review will be presented to the SCAR Delegates in Moscow.
- Investigation of the current state of the Antarctic climate in the context of the last several hundred years. Much of the progress related to this goal is summarized in the SASOCS paper.
- Teleconnections between Austral-mid-latitudes and the Antarctic – Shallow ice cores collected by ITASE that cover the last 200-1000 years reveal associations between changes in solar variability and strength of the westerlies. A new ice core drilled by a Brazilian-Chilean-US team on the Detroit Plateau, Antarctic Peninsula, plans to investigate changes in the strength of the westerlies in the region encompassing the Antarctic Peninsula and South America.
- Contribution to the reanalysis effort. AGCS funded the digitisation of surface pressure data from South Georgia.
- Sea ice thickness. A recommendation of the International Workshop on Antarctic Sea Ice Thickness, co-sponsored by SCAR in Hobart in July 2006, was to establish a sea ice data portal for in situ sea ice data (such as drilled measurements, core and snow pit analyses etc). The Australian Antarctic Data Centre agreed to facilitate this and has made a great deal of progress in establishing it. SCAR funding to the ASPeCt programme has been used to fund a student to source and enter data from a number of national Antarctic programmes, which have so far contributed almost 150 files from the Australian, US, German and Japanese programmes.
- An array of 200-1000+ year long coastal ice cores is in progress by teams from Brazil, Chile, New Zealand and the US in East Antarctica and the Antarctic Peninsula.
- Marine productivity to understand sea ice extent in proxy records. Ice core records of methanesulfonic acid (MSA) from three sites around the Weddell Sea have been investigated for their potential as sea ice proxies. It was found that the amount of MSA reaching the ice core sites decreased following years of increased winter sea ice in the Weddell Sea; opposite to the expected relationship if MSA is to be used as a sea ice proxy.
- Theme 4. Funding has been obtained to conduct observational work that will quantify the fluxes of heat, volume and freshwater from the Weddell Gyre into the global ocean. Two linked proposals, led by AGCS scientists, were written and approved, and the fieldwork will be conducted in early 2009. This work will also assess the role of the Weddell Gyre in the global carbon cycle, and will be a major advance in our quantitative understanding of the Southern Ocean's role in the global climate system.
- Theme 4. Significant progress was made in understanding the role of the Southern Ocean in closing the global ocean overturning circulation. A high-profile paper was written, which used observational tracer data to elucidate the relative roles of mixing and upwelling in the Scotia Sea, and which identified a "short circuit" in the overturning. This work serves as an excellent precursor to the international DIMES (Diapycnal and Isopycnal Mixing in the Southern Ocean) programme, to which AGCS is contributing strongly.
- Theme 4. AGCS scientists at the National Oceanography Centre, UK, have progressed our understanding of how signals occurring in the high-latitude southern regions can be rapidly transmitted to the equator, and further into the northern hemisphere. Using a range of coupled and ocean-only models, anomalies in sea ice in the Southern Ocean were observed to trigger both oceanic and atmospheric teleconnections that rapidly propagated to lower latitudes. This ongoing work is seeking to further elucidate the mechanisms involved, and to determine whether these signals can be detected in observational data.
- Theme 4. Much AGCS activity has focussed on understanding the observed warming of the circumpolar Southern Ocean, and determining to what extent it is anthropogenic in origin. A

variety of model-based studies have been conducted, and a range of potential processes identified, including enhanced air-sea heat fluxes, southward shifting of the circumpolar current, and enhanced eddy activity in response to the strengthening circumpolar winds. The work is ongoing, though it seems increasingly likely that a significant part of the observed warming is due to humanity's activities.

- Theme 4. Monitoring of the water mass properties in the Weddell Sea has continued, led by German AGCS scientists. The mid-level warming in the Weddell Sea was observed to peak in the mid-1990s, following which a cooling has entailed. The abyssal waters have shown a persistent warming since the 1980s, whereas the deep waters that are readily exported to lower latitudes show a more complex signal, with little change overall but some spatially-complex areas of warming and cooling. Many of these waters are exported to lower latitudes as part of the global ocean overturning, this continuing work is an important part of understanding the response of the Southern Ocean to climate change, and its role in determining climate over a much larger area.

What deviations were made from the work plan, and why?

There were no major deviations from the work plan.

What SCAR funds were allocated to the activity?

How were the SCAR funds spent?

AGCS had a budget of \$22,367.08 in 2007, including the carry forward from 2006. The 2007 spend was:

| Activity | Spent |
|---|--------------------|
| ASPECT | \$4K |
| High Lat Clim W'shop | \$4305.29 |
| Page charges for JGR re-analysis paper. | \$2K |
| SOOS Workshop, Bremen | \$750 |
| FI & S Georgia data digitisation | \$1K |
| Printing of IGOS report | \$2K |
| Currency conversion | -\$18.54 |
| Total | \$14,036.75 |

Most of the funds go to support the attendance of individuals at workshops. We have a carry forward of \$8,330.33 to 2008, which when combined with the 2008 allocation of \$21,000, gives a budget of \$29,330.

We anticipate spending this sum as follows:

| | Allocation |
|-----------------------------|-------------------|
| ASPECT | \$4K |
| Ocean READER | \$2K |
| AGCS graphics and publicity | \$1K |
| Maine ITASE workshop | \$10K |
| Page charges | \$3K |
| SASOCS page changes | \$3K |
| Oceanography Expert | \$3K |

| | |
|---|----------|
| Group | |
| Workshop on High Resolution Modelling of the Cryosphere | \$3K |
| | |
| Total | \$29,000 |

OUTPUTS/DELIVERABLES

(a) Publications in peer reviewed literature (including articles “in press”) – selected papers

Abram, N. J., Mulvaney, R., Wolff, E. W. and Mudelsee, M. 2007. Ice core records as sea ice proxies: An evaluation from the Weddell Sea region of Antarctica. *Journal of Geophysical Research* 112: D15101, doi:10.1029/2006JD008139.

Worby, A. P., Geiger, C. A., Paget, M. J., Van Woert, M. L., Ackley, S. F. and DeLiberty, T. L. 2008. The thickness distribution of Antarctic sea ice. *Journal of Geophysical Research* .

Bracegirdle, T. J., Connolley, W. M. and Turner, J. 2008. Antarctic climate change over the Twenty First Century. *Journal of Geophysical Research* 113: D03103, doi:10.1029/2007JD008933.

Thomas, E. R., Marshall, G. J. and McConnell, J. R. 2008. A doubling in snow accumulation in the western Antarctic Peninsula since 1850. *Geophysics Research Letters* 35: L01706, doi:10.1029/2007GL032529.

Connolley, W. M. and Bracegirdle, T. J. 2007. An Antarctic assessment of IPCC AR4 coupled models. *Geophysics Research Letters* 34: L22505, doi:10.1029/2007GL031648.

Hill, S. L., Watters, G. L., Punt, A. E., McAllister, M. K., LeQuere, C. and Turner, J. 2007. Model uncertainty in the ecosystem approach to fisheries. *Fish and Fisheries* 8: 315-336.

Meredith, M.P., E.J. Murphy, E.J. Hawker, J.C. King and M.I. Wallace. “On the interannual variability of ocean temperatures around South Georgia, Southern Ocean: forcing by El Niño/Southern Oscillation and the Southern Annular Mode”. *Deep-Sea Research II* (Palmer LTER Special Issue), accepted, 2008.

Meredith, M.P., A.C. Naveira Garabato, A.L. Gordon and G.C. Johnson. “Evolution of the Deep and Bottom Waters of the Scotia Sea, Southern Ocean, 1995-2005”. *Journal of Climate*, accepted, 2008.

Hogg, A.McC., M.P. Meredith, J.R. Blundell and C. Wilson. “Eddy Heat Flux in the Southern Ocean: Response to Variable Wind Forcing”. *Journal of Climate*, 21, 4, 608-620, 2008.

(b) Other Publications (e.g. institution reports, articles in the grey literature, maps, atlases, CDs, Newsletters or contributions to newsletters)

Several articles on AGCS science appeared in conference proceedings.

The second issue of the AGCS Newsletter ‘Notus’ was issued in July 2007. It is available at http://www.antarctica.ac.uk/met/SCAR_ssg_ps/agcs_newsletter_issue2.pdf. It was edited by Dr Mike Meredith, UK.

(c) Brochures, posters, press/media articles and similar PR material

There has been a lot of press interest in the papers published on the warming across the Antarctic Peninsula and the increase in precipitation over the region.

(d) creation of a web site, and number of hits per web site

- An AGCS web site (http://www.antarctica.ac.uk/met/SCAR_ssg_ps/AGCS.htm) is available that describes the research programme and our goals. At present we don't have any information on the number of hits.

(e) creation of database(s), and amount of use of database(s) (e.g. as measured by hits on a web version)

- The frequently used MET-READER data base of monthly mean Antarctic climate data (<http://www.antarctica.ac.uk/met/READER/>) has continued to be developed and kept up to date with recent observations.
- The ICE-READER (<http://www2.umaine.edu/itase/content/icereader/>) data base has been updated to include additional ice core records.
- A portal for Southern Ocean data (OCEAN-READER) was created and is being maintained by AGCS (http://www.antarctica.ac.uk/met/SCAR_ssg_ps/OceanREADER/). In due course, it is intended that this will be replaced by a "Southern Ocean Observatory", to be created to handle data flowing from the Southern Ocean Observing System (SOOS), which AGCS is helping to design.

(f) number and type of education/training and other capacity building activities;

Numerous public outreach talks were given by AGCS scientists.

(g) new technology/model developments;

A priority is the development of high resolution, coupled climate models for the Antarctic that are capable of representing the small scale atmospheric and oceanic processes that are important in the Antarctic climate system. Work is in progress to develop these complex models.

(h) contributions to IPY

- As the first expedition of the Chinese IPY programme, PANDA, there was a successful traverse to Dome-A. There were investigations of ice layers, bedrock, snow accumulation rates and ice flow, which were measured over a wider area than the first investigation in January 2005.
- Ice cores were collected near Maïtri station as part of the Indian ITASE (2006-2007) collaborative programme between the National Centre for Antarctic & Ocean Research (NCAOR), Goa and the Geological Survey of India (GSI).
- There was joint Brazilian-Chilean-US ice core drilling on the Detroit Plateau, Antarctic Peninsula as part of the Climate of the Antarctic and South America (CASA) programme. During two expeditions CASA collected a total of 155m of ice core (including the deepest 133 meters ice core), conducted GPS and GPR based measurements of ice flow and accumulation rates, and installed an automatic telemetric weather station.
- The US ITASE team arrived at South Pole on 24 December 2007 after completing their second traverse to the Pole. Since 1999 US ITASE has traversed more than 8000 km throughout West and East Antarctica and collected a total of 3945m of ice core.
- The Norwegian – US Scientific Traverse of East Antarctica involved scientific investigation along an overland traverse in East Antarctica going from the Norwegian Troll Station to the vicinity of the United States South Pole Station in 2007-2008.

- Two major IPY sea ice programmes were conducted in Spring 2007. These were the Australian Sea Ice Physics and Ecosystem eXperiment (SIPEX) and the US Sea Ice Mass Balance of Antarctica (SIMBA) campaign. Both programmes focussed on improving our understanding of the physical sea ice environment and links to the associated biology and biogeochemistry of the sea ice. The Geoscience Laser Altimeter System (GLAS) aboard NASA's ICESat satellite was turned on for 33 days to coincide with the field campaigns in an effort to improve the calibration and validation of the satellite data.
- (i) key achievements (see details earlier)
 - Publications in the peer reviewed literature (see above)
 - The development of the ASPECT sea ice thickness data base
 - The Antarctic traverses that have contributed to IPY

(a) number, gender and country of participating scientists

The AGCS Steering Committee consists of:

- Dr. John Turner, British Antarctic Survey, UK (Chair) (J.Turner@bas.ac.uk) M
- Prof. David Bromwich, Byrd Polar Research Center, Ohio State University, USA (bromwich.1@osu.edu) M
- Dr. Mike Meredith, British Antarctic Survey, UK (M.Meredith@bas.ac.uk) M
- Prof. Paul Mayewski, Climate Change Institute, University of Maine, USA (paul.mayewski@maine.edu) M
- Dr. Alberto C. Naveira Garabato, National Oceanography Centre, UK (acng@noc.soton.ac.uk) M
- Dr. Tony Worby, University of Tasmania, Australia (a.worby@utas.edu.au) M
- Dr. Nancy Bertler, Victoria University of Wellington, New Zealand (nancy.bertler@vuw.ac.nz) F
- Dr. Cunde Xiao, Chinese Meteorological Administration, Beijing (cdxiao@cma.cma.gov.cn) M
- Dr. Gino Casassa, Centro de Estudios Científicos, Chile (GC@cecs.cl) M
- Dr. Shigeru Aoki, Low Temperature Institute, Hokkaido University, Japan (shigeru@lowtem.hokudai.ac.jp) M
- Dr. Tas van Ommen, ACE CRC and Australian Government Antarctic Division, Australia (tas.van.ommen@utas.edu.au) M
- Ms Helen Campbell, British Antarctic Survey, UK (HCAMP@bas.ac.uk) (JCADM rep) F

The Implementation Plan explicitly names 64 scientists (52 male and 12 female) working on AGCS activities, but there are many other people involved in the project, including co-workers and students.

(b) number and type of meetings/workshops, and numbers, genders and countries represented in their attendees.

A symposium on Antarctica and the Global Climate System was held at the European Geosciences Union General assembly in Vienna, Austria in April 2007. There were approximately 50-60 attendees, although we have no information on the gender and nationality of those attending.

A workshop, jointly organised with CliC, on Global Prediction of the Cryosphere was held at the British Antarctic Survey in October 2007. The meeting reviewed our ability to predict the evolution of various aspects of the cryosphere over the coming century. There were attendees from the UK, Canada, Sweden and Belgium. All male.

AGCS took the lead in organising the second workshop on Recent High Latitude Climate Change, which was held in Seattle, USA over 22-24 October 2007. The workshop was organised in conjunction with the WCRP/SCAR/IASC Climate and the Cryosphere (CliC) project, along with IASC themselves. It considered atmospheric, oceanic and cryospheric changes that had taken place during the last 50 years in the Arctic and Antarctic. A report on the meeting will appear in EOS.

(c) links to other SCAR SRPs or Action or Expert Groups

There is frequent discussion with the Expert Group on Operational Meteorology over operational meteorological observations from the Antarctic, since these form the basis of the Met-READER data base. We are also working with the group over the production of a supplement to the Antarctic Weather Forecasting handbook.

AGCS has membership on the SCAR Oceanography Expert Group, to ensure that the group's activities are fully aligned with the science requirements of AGCS. Through this, AGCS is involved in the design of the Southern Ocean Observing System (SOOS). AGCS also has representation on the SCAR Action Group for Antarctic Fuel Spills, providing physical oceanographic expertise for this interdisciplinary action group.

AGCS has worked closely with the SSGS and the other SRPs over the drafting of the AGCS document.

(d) links to other ICSU bodies or to other scientific groups

Close links have been established with the World Climate Research Programme Climate and Cryosphere (CliC) project and especially the CliC Project on Global Prediction of the Cryosphere. SCAR and CliC have co-sponsored several meetings and symposia, including the workshop, jointly organised with CliC, on Global Prediction of the Cryosphere that was held at the British Antarctic Survey in October 2007. Also the second workshop on Recent High Latitude Climate Change, which was held in Seattle, USA over 22-24 October 2007.

(e) development and staffing of a project office or other administrative support

AGCS does not have a formal project office. However, some secretarial support is obtained from the British Antarctic Survey.

(f) sources and amounts of income for project activities

Besides the funds provided by SCAR, the activities of AGCS have been funded by national Antarctic programmes, research grants and university funds.

(g) expenditure on project activities

See the breakdown of the usage of SCAR funds.