UNITED STATES ANTARCTIC PROGRAM

SUMMARY AND BACKGROUND

2003-2004 SEASON

Office of Polar Programs
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1. Antarctic mission

a. White House Memorandum 6646 (1982)[1]

i. United States will maintain an active and influential presence in Antarctica that supports the range of its interests under the Antarctic Treaty.

ii. National Science Foundation will budget for and manage the National program, including university and Federal research and logistics, as a single package.

iii. Departments of Defense and Transportation will provide logistics (reimbursed).

iv. NSF will use commercial support and management where cost effective and not detrimental to the National interest.

v. Other agencies may do short-term science when operations in Antarctica are coordinated with NSF.

b. Presidential Decision Directive NSC-26 (1994)

i. Protect antarctic environment.

ii. Protect opportunities for scientific research.

iii. Maintain Antarctica as an area of international cooperation for peaceful purposes.

iv. Conserve living resources in the oceans surrounding Antarctica.[2]

c. President's National Science and Technology Council review (1996)[3]

i. Presidential Memorandum 6646 continues to be appropriate at the current funding level.

ii. U.S. Antarctic Program is cost effective in advancing American scientific and geopolitical objectives.

iii. Continue three stations with year-round presence.

d. U.S. Antarctic Program External Panel (1997)[4]

i. Program is well managed, involves high quality science, and is important to the United States.

ii. An Optimized South Pole Station should replace the existing station.

2. Overall National achievement

a. **Peace.** Antarctica has been reserved for peace as a result of international cooperation stimulated in part by a 1948 U.S. international initiative, by U.S. leadership during the 1957–1958 International Geophysical Year, and by the Antarctic Treaty signed in 1959 by 12 nations in Washington, D.C.

b. **Knowledge.** Research since the IGY has provided the basic understanding of Antarctica and its key role in global processes. Antarctica is the last continent to be explored and studied; more than 90 percent of the world's antarctic research literature has been published in the 45 years since the IGY.

c. **Leadership.** Through its year-round presence in Antarctica and participation in international antarctic affairs, the United States has maintained scientific and political leadership and assured U.S. participation in future uses of the region.

3. Some reasons to perform scientific research in the Antarctic

a. **Largest ocean current.** The Antarctic Circumpolar Current transports 130 million cubic meters of water per second towards the east, making it the mightiest of the ocean's currents. It influences formation of cold, dense, and nutrient-rich bottom water that extends throughout much of the world ocean and is a key to understanding change in world ocean circulation and its influence on global climate.[5]

b. **Marine ecosystem.** Research on the marine ecosystem around Antarctica helps to understand levels of harvesting that can take place without damaging the ecosystem and is providing an understanding of the strong coupling in the Southern Ocean between climate processes and ecosystem dynamics.[6]

c. **Sea ice.** The annual eightfold growth and decay of sea ice around Antarctica has been termed the greatest seasonal event on Earth.[7] It affects regional climate and the global heat budget. Particularly near the edges, it nurtures some of the world's most productive ecosystems.[8]

d. **Ozone hole.** Starting in 1979, ozone in the stratosphere over Antarctica has been observed almost to disappear every austral spring. Everywhere else, stratospheric ozone depletions are only incremental. Stratospheric ozone keeps much of the Sun's harmful ultraviolet radiation from reaching the Earth's surface, and the ozone hole has received widespread attention.

i. Finding the cause. Research in Antarctica, particularly at McMurdo, was key to explaining how antarctic natural phenomena conspire with the global buildup of manmade chemicals to cause the ozone hole.[9]

ii. Removing the cause. The research led to an international decision (the Montreal Protocol) to reduce production of the destructive chemicals. Annual consumption of CFCs dropped from 1,100,000 tons in 1986 to 150,000 tons in 1999. Without the protocol, consumption would have reached 3,000,000 tons by 2010.[10]

iii. Monitoring the recovery. While atmospheric concentrations of the harmful manmade chemicals are in decline, it might take another 10 years of

observation before we can be sure the antarctic ozone hole is shrinking. Current antarctic research is providing further understanding of the ozone hole.[11]

iv. Effect on life. The ozone hole lets abnormally high levels of the Sun's ultraviolet-B radiation penetrate to the Earth's surface and into the sea. Scientists have documented how UV-B affects bacteria, phytoplankton, and the embryos of antarctic invertebrates and fish.[12]

v. Effect on climate. Research indicates that the ozone hole has increased the winds around Antarctica and reduced rainfall in Australia and elsewhere.[13]

vi. **Awards**.

a. The 1995 **Nobel Prize** in Chemistry was awarded to three professors who explained that the ozone layer is sensitive to anthropogenic emissions.[14]

b. The 1999 **National Medal of Science** (the Nation's highest scientific honor) was awarded to Dr. Susan Solomon, who led U.S. Antarctic Program expeditions in 1986 and 1987 giving the first direct evidence that anthropogenic chlorine depletes stratospheric ozone.[15]

c. The 2002 **National Medal of Technology** (the Nation's highest honor for technological innovation) was awarded to the Dupont Company for leadership in the phaseout and replacement of chlorofluorocarbons (CFCs).[16]

e. **Polar adaptations of biota.** Antarctic cold, desert conditions, and annual light cycles have led to molecular, biochemical, and physiological adaptations that have enabled biota to survive, reproduce, and indeed thrive under environmental extremes not experienced elsewhere. Studies provide basic understanding of these unique adaptations and are leading to understanding how changes in populations can shed insight into changing climate.[17]

f. **Atmospheric background levels.** Antarctica is the planet’s farthest region from human population centers and records the world’s background levels of atmospheric constituents. Measurements since 1956 at the geographic South Pole have documented changes in world levels of greenhouse gases such as carbon dioxide and methane. Measurements in the data-sparse Southern Hemisphere are important to understanding and predicting world levels of these gases and their impact on (or forerunner to) climate change.[18]

g. **Weather and climate.** The unbroken collection of weather data from manned and unmanned stations in Antarctica, now exceeding 40 years for some locations, provides a data base and real-time information from which to make operational forecasts, study the dynamics of the antarctic atmosphere, and chart the progress of human-induced global warming.[19]

h. **Ice sheets and ice shelves.** Antarctica’s ice sheets contain 90 percent of the world’s ice. This ice is 70 percent of the world’s fresh water. Melted, it would raise sea level 65 meters (200 feet).

i. **Global process.** Antarctica's ice—the world's largest area of cold (the Arctic is 35°F warmer)—affects and responds to world climate change. Just 20,000 years ago, for example, the ice sheet was far larger. Sea level was 11 meters (36 feet) lower, that much water having been evaporated from the world's oceans and precipitated onto Antarctica.[20]

ii. **Climate history.** The ice, deposited annually as snow over millions of years, traps past atmospheric constituents that tell a climate history with a precision not equaled by other proxies such as ocean sediments and tree rings. The world's deepest ice core (3,650 meters) and another core containing the world's oldest ice (possibly 1 million years old) both were drilled in Antarctica.[21]

iii. **West Antarctic Ice Sheet**. The West Antarctic Ice Sheet if melted would raise sea level 5 meters. It is less stable than the eastern one because its base is below sea level. Its low-probability/high-impact collapse has stimulated vigorous research over the last 30 years indicating that it has largely or completely disappeared after it formed, but at an unknown rate. Portions of it are changing rapidly now, while averages over the whole ice sheet show little change. Some models project stability, while others suggest the possibility of rapid change.[22]

iv. **Ice shelf dynamics.** Ice shelves—extensions of continental ice sheets that are afloat on the ocean—can control the rate at which their parent ice sheets or glaciers move into the sea and can respond quicker than ice sheets to environmental change. The Larsen Ice Shelf on the east coast of the Antarctic Peninsula lost massive sections in 1995 and 2002, possibly in response to atmospheric and oceanic warming over the last several decades. Some scientists call it a model for what could happen to larger ice shelves farther south.[23]

v. **Meteorites.** Since 1969, teams from the United States, Japan, and the European Council have collected 30,000 meteorite specimens from the surface of the ice sheet representing many meteorite classes (including some from the Moon and Mars) and extending our knowledge of the solar system. Antarctica has yielded four-fifths of the meteorites known to science.[24]

vi. **Neutrino detection.** The ice sheet beneath the South Pole is 2,900 meters deep and is homogeneous and clear. Investigators buried downward-looking detectors to observe light produced by neutrinos (ultra-high-energy particles created by cataclysmic collisions in deep space) when they on rare occasions collide with ice molecules after they pass through the Earth. The data help in descriptions of galactic centers, dark matter, and supernovae. The observatory in March 2001 became the first in the world to detect neutrinos. A larger project, called IceCube, is getting under way.[25]

vii. **Subglacial lakes.** More than 70 lakes lie beneath the ice sheet, most of them several kilometers long. One, Vostok Subglacial Lake, is an order of magnitude larger and represents the closest analog to both Europa (a moon of Jupiter) and a Neoproterozoic ("Snowball Earth") subglacial environment. Lake Vostok is oligotrophic—an environment with low nutrient levels and

low standing stocks of organisms. Life there may depend on alternative energy sources and survival strategies.[26]

i. **Polar landmass.** Almost 10 percent of the Earth's continental crust resides in Antarctica. The continent is old and stable and has been in a near-polar position for over 100 million years. It thus contains unique high latitude environmental records of a time when Earth changed from greenhouse to icehouse conditions. The landmass is different from the other continents in that Antarctica's crustal structure—or its underlying mantle—has allowed the continent to remain essentially fixed on Earth's surface for a long time.

j. **Astronomy by balloon.** Antarctica's summer weather provides a stable ride for instruments suspended from a balloon, which floats around Antarctica at a steady height above most of the atmosphere, providing a cheap way to get scientific experiments into near-space.[27]

k. **Astrophysics and astronomy from the surface.** The cold, clean, dry atmosphere over the South Pole provides viewing conditions that in some wavelengths are equal to those in space. South Pole Station has become a major astronomy and astrophysics center.[28]

4. 2003-2004 season project highlights

a. **Number of research projects.** Research and related activities are being supported in Antarctica and the Southern Ocean in the following areas.[29] A few of these projects are described in this section. There are 156 projects. In the table, the columns do not sum because a few projects are active at more than one location.

Discipline	1	2	3	4	5	6
McMurdo and camps	13	30	18	14	7	6
Ships	0	22	4	0	4	0
South Pole	23	1	1	1	4	1
Palmer	1	5	2	0	4	1
Other	0	6	0	0	0	0

1 Aeronomy, astrophysics 2 Biology, medicine 3 Geology, geophysics
4 Glaciology 5 Climate, ocean sciences 6 Artists, writers

b. **Long-term ecological research (LTER).** Two sites in Antarctica—in the McMurdo Dry Valleys and along the west coast of the Antarctic Peninsula centered on Palmer Station—are among the world's 25 NSF-sponsored LTER sites being

investigated to increase understanding of ecological phenomena over long temporal and large spatial scales (all but one of the other sites are in the United States).[30]

c. **West Antarctica GPS Network.** Researchers are deploying Global Positioning System transceivers across the West Antarctic Ice Sheet—an area the size of the United States from the Rockies to the Pacific. Measurements of motions of the Earth's crust in the bedrock around and under the West Antarctic Ice Sheet are critical to understanding the dynamics of the ice sheet and its potential role in global change, and they improve understanding of Antarctica's role in global plate motions. WAGN complements existing GPS projects by filling a gap in coverage among crustal blocks that make up West Antarctica.[31]

d. **Latitudinal Gradient Project.** In Victoria Land, investigators will examine marine, freshwater, and terrestrial habitats from 72^{o} to 86^{o}S, studying the relationship of linear and nonlinear changes and how they affect the creatures that live through them, and then how the life forms will be affected as climate changes in the region.[32]

e. **South Pole astrophysics.** Telescopes at the South Pole are continuing investigations of the origins of the universe.[33] For example, the degree angular scale interferometer (DASI) has been measuring the cosmic microwave background at the South Pole since 1999-2000 and has precisely measured minuscule variations in afterglow of the Big Bang, verifying the theoretical framework that underlies the modern scientific concept of how the universe came into being. The discovery is so fundamental that it also may provide a key to an even keener understanding of the origins of the universe.[34] In 2003, DASI will measure the currently undetected polarization of the CMB anisotropy to test the standard theory of the early universe. Team members are reconfiguring DASI from 30 giga-Hertz (GHz) to 100 GHz for intensity and polarization measurements of the fine-scale CMB anisotropy power spectrum. [35]

f. **Arcminute Cosmology Bolometer Array Receiver.** This instrument, installed at the South Pole in late 2000, is measuring temperature differences in the cosmic microwave background—the faint afterglow of the Big Bang. By December 2002 the project had the most detailed images of the early Universe ever recorded—evidence supporting the favored model in which 30 percent of all energy is dark matter that doesn't interact with light and 65 percent is dark energy accelerating the expansion of the Universe. The instrument's sensitivity rivals that of balloon-borne experiments, and it has an angular resolution they cannot hope to achieve.[36]

g. **Snow megadunes.** Megadunes of the East Antarctic Ice Sheet are subtle features, 2 to 4 meters in amplitude over a 2 to 4 kilometer wavelength and just recently receiving significant research attention, that may affect the interpretation of climate in deep ice cores. Investigators are conducting ground penetrating radar surveys, global positioning surveys, firn cores, pit sampling, automatic weather station installation, and snow permeability experiments to determine physical and chemical characteristics of the dunes to help understand their significance, including the effect on ice cores.[37]

h. **Planet search.** Using an optical telescope and a photometer, scientists at South Pole Station are searching for the periodic dimming that happens when a planet transits its parent star. Because the geographic South Pole features constant altitude of a stellar field and does not have large daily variations in the atmosphere, the investigators hope to detect 10 to 15 extrasolar planets over the next two winters, and they see the potential for a tenfold increase in the number of extrasolar planets for which transits are observed.[38]

i. **Infrared measurement of the atmosphere.** Winter measurements of atmospheric chemistry will provide data for predicting ozone depletion and climate change. Since most satellites do not sample polar regions in winter, these ground-based measurements are expected to make important contributions.[39]

j. **Weddell seal population dynamics.** Weddell seals in McMurdo Sound have been studied since 1968—one of the longest intensive field investigations of long-lived mammals anywhere. More than 15,000 animals have been tagged, and 145,000 resightings have been recorded. The project is a resource for understanding the population dynamics of not only Weddell seals, but also other species of terrestrial and marine mammals. New work this season includes assessing the role of food resources in limiting the populations.[40]

k. **Foraminifera studies by remote control.** Research divers have detailed summer "snapshots" of the ecology of giant (>1mm) foraminifera in McMurdo Sound, but winter observations are needed when algae are not growing. This project will install an unmanned underwater observatory, connect it to shore by fiber optic cable, and link it through the Internet to a lab in the United States for operation and data collection all year long.[41]

l. **Genomic study of invertebrates.** Cold-ocean ecosystems are 72 percent of Earth's biosphere by volume, yet they are sparsely inhabited and relatively unexploited. Environmental adaptations of the few animals that manage to exist on this verge of intracellular freezing are ideal subjects for exploration at the genomic level. This project will quantify gene expression in sea stars and sea urchins to find out if it is more or less difficult for an organism to grow in a polar extreme. To interest students in the developing field of environmental genomics, the project will have an intern program for minority students and a K-12 education program.[42]

m. **Seismograph.** The world's quietest earthquake detector is 8 kilometers from the South Pole, 300 meters beneath the ice sheet surface. Completed in 2002, the station is detecting vibrations four times smaller than those recorded previously. Other seismographs have been there since 1957, and long-term, high-latitude data have helped to prove that the Earth's solid inner core spins faster than the rest of the planet. Also, Antarctica is the continent with the fewest earthquakes, so the new station will record small regional earthquakes, leading to new insights into the Antarctic Plate.[43]

n. **Dinosaurs in the Transantarctic Mountains.** A study of fossil dinosaurs from the Triassic and the Jurassic is under way along with related studies by other

investigators at sites near the Hanson Formation in the southern Transantarctic Mountains. The area is the only location in Antarctica that has yielded dinosaur fossils. Antarctic vertebrates such as these will provide a unique opportunity to study the evolution of high-latitude fauna.[44]

o. **Reedy Glacier history.** A two-season effort at Reedy Glacier in the southern Transantarctic Mountains should help to establish whether the West Antarctic Ice Sheet stopped retreating thousands of years ago or still is getting smaller. The Reedy Glacier is above the grounding line (where land ice goes afloat on the ocean), so its surface slope and elevation should record changes in the thickness of grounded ice in the Ross Sea up to the present, whereas previous work was on other glaciers north of the grounding line, where size-change data up to the present cannot be obtained.[45]

5. Construction highlights

a. **Science support center.** Phase 1 of a new science support center entered operation in 2002.

b. **Building 58 demolition.** The old science support facility (building 58), one of McMurdo's oldest and least efficient structures, is being removed**.**

c. **Waste-heat recapture.** A multiyear project is under way to capture McMurdo power plant waste heat for:

i. heating of feedwater to reverse-osmosis water plant.

ii. space-heating science laboratory, dormitories, and other buildings.

d. **Joint Space Operations Center.** This multistory building near the center of McMurdo, funded by NASA and NSF, has been erected and when complete will enable consolidation of much of McMurdo's satellite ground station activities.

e. **McMurdo power plant upgrade.** Design is complete, and procurement is underway, for replacement of generators and improvements to electrical distribution systems. The upgrade will move some equipment to the water plant to permit redundancy in the case of loss of one of the buildings.

f. **McMurdo gasoline tanks.** Site preparation will begin for two new 250,000-gallon gasoline storage tanks scheduled for assembly next year.

g. **South Pole Modernization Project.** Major renovation is under way to replace most of the 26-year-old South Pole Station's central facilities, which have exceeded their design life, and cannot meet projected science demands. Construction to date has included a new fuel storage facility, a new garage and shop, a new electric power plant, some of the living facilities, station services, medical facilities, and science labs. Additional wings are being erected this season. The station is scheduled for completion in 2007.

h. **Palmer Station improvements.** An upgrade, lasting several years, of the two major buildings at Palmer Station essentially has been completed, increasing the effectiveness of science support and living facilities. A ground station installed in

2002 has extended the station's Internet communications to 24 hours per day. Replacement of, or major repair to, the station's pier is being studied.

6. Environmental protection; waste management

a. Cradle-to-grave management of supply/waste stream

b. Source-point sorting and removal of all solid and hazardous waste from Antarctica, of which approximately 65 percent is recycled

c. Environmental monitoring and research

d. Comprehensive spill prevention and cleanup program (e.g., fuel lines and hoses, double-walled or bermed fuel tanks, cleanup training and equipment)

e. Permitting system in place for all scientific and other activities involving antarctic fauna and flora

f. Educational and enforcement procedures for waste management and environmental protection

g. Sewage treatment plant at McMurdo, now fully operational

h. Improvement of management plans for Specially Protected Areas, in cooperation with other Antarctic Treaty nations

i. In compliance with all applicable treaties and U.S. laws[46]

7. Personnel, 2003-2004 austral summer

a. Total number of people (Antarctica and ships): +/-3,000

b. Station winter population in 2004 will be about 282—202 at McMurdo, 60 at South Pole, and 20 at Palmer. Additional science and operations personnel will be aboard the research ships *Gould* and *Palmer*, which operate year-round.

c. Approximately 70 percent of U.S. Antarctic Program science personnel and >90 percent of operations personnel transit New Zealand and McMurdo

d. About one-fourth of science personnel and <10 percent of operations personnel transit South America to Antarctic Peninsula

8. Year-round research stations

a. **Palmer** (65°S 64°W), Anvers Island, west coast of Antarctic Peninsula

b. **McMurdo** (78°S 168°E), Ross Island, southwest corner of Ross Sea

c. **Amundsen-Scott South Pole** (90° S), continental interior at geographic South Pole

9. Major summer research camps

a. **Siple Dome** (Siple Coast, West Antarctica). Geophysics[47] including a GPS array; automatic weather stations.[19]

b. **Byrd Surface** (West Antarctica). Automatic weather stations; GPS monitoring of bedrock motion.

c. **Beardmore Glacier (southern Transantarctic Mountains). Eight geology and paleontology projects with helicopter and Twin Otter support.**

d. **Mount Moulton** (northern Marie Byrd Land). Two projects studying ice conditions and climate.

e. **Megadunes** (East Antarctica). Two projects investigating possible effect of dunes on interpretation of ice cores.[48]

f. **Moody Nunatak** (Transantarctic Mountains). Aeromagnetics and geology using helicopters and Twin Otters.

g. Numerous smaller camps.

10. Ships (research and support)

a. R/V *Nathaniel B. Palmer*, length 94 meters, icebreaker, purpose-built in 1992 for long-term charter to U.S. Antarctic Program.[49] The ship supports research throughout the Southern Ocean the year-round. Current work, though, is focused on the Ross Sea, and *Palmer* will call at McMurdo three times in January-February 2004.

b. R/V *Laurence M. Gould*, 71 meters, ice strengthened, purpose-built in 1997 for long-term charter to U.S. Antarctic Program[49] (replaces R/V *Polar Duke*, chartered 1984-1997). Year-round research and Palmer Station support.

c. *Polar*-class, 122 meters, U.S. Coast Guard icebreaker(s).[50] Annual summer channel break-in to McMurdo and some summer-season research support.

d. *American Tern*, 159 meters, Military Sealift Command chartered ice-classed cargo ship.[51] Annual cargo delivery to, and waste retrograde from, McMurdo.

e. Tanker, Military Sealift Command (MSC) chartered. Annual fuel delivery to McMurdo.

11. U.S. antarctic runways (wheeled operations near McMurdo)

a. McMurdo Sound (78°S), annual sea ice, October–December

b. Pegasus (78°S), prepared glacial ice; previously not used in the warmer summer months, this runway was groomed for year-round use in 2001.

12. U.S. antarctic skiways (ski operations only)

a. Williams Field (78°S), near McMurdo, available year-round

b. South Pole (90°S)

c. Open field (various locations)

13. National Science Foundation[52]

a. **Mission.** The National Science Foundation is a catalyst for progress through investment in science, mathematics and engineering. The agency is guided by its longstanding commitment to excellence in the support of discovery and learning. NSF provides leadership and stewardship to sustain and strengthen the Nation's science, mathematics, and engineering capabilities and to promote the use of those capabilities in service to society.

b. **Organization.** NSF, a U.S. Government agency established in 1950, has a staff of 1,200. Science is supported in these major areas: mathematics and physical sciences (including chemistry and astronomy); geosciences (earth, atmosphere, ocean); biological sciences; sociological, behavioral, and economic sciences; engineering; computer sciences and information systems; and polar programs.

c. **Primary activity.** Scientists, engineers, and educators at U.S. institutions compete for support by submitting proposals that respond to NSF program areas.[53] Annually:

i. 30,000 proposals competitively reviewed

ii. 10,000 new awards to 2,000 institutions

d. **Budget (NSF overall).** The National Science Foundation requests $5.48-billion for FY 2004, $453-million or 9 percent over the FY 2003 request of $5.03 billion.[54]

e. **Budget (NSF antarctic).** NSF spending in FY 2003 for the U.S. Antarctic Program was $254.95-million, of which $42.56-million was for research grants, $143.84-million was for operations and science support, and $68.55-million was for logistics. NSF funds about 97 percent of all Federally supported antarctic research and research support.

U.S. Antarctic Program aircraft and supply ship operations, 2003-2004 season

LC-130 missions (round trips) within Antarctica	
Amundsen-Scott South Pole Station	331
Beardmore Glacier area, Transantarctic Mountains	13
Moody Nunatak	9
Vostok	3
Other field science	48
Total LC-130 within Antarctica (USAF/109th)	401
Twin Otter missions within Antarctica	122
AS-350-B2 and Bell 212 helicopter operations within Antarctica	
2,321.3 flight hours in support of 112 groups or activities (PHI)	
Christchurch/McMurdo round trips	
C-17 (USAF/AMC, August/October)	3/12
C-141 (USAF/AMC, October-December/January-February)	26/19
LC-130 (USAF/109th, Oct.–Feb.)	60
C-130 (RNZAF, November-December)	15
Cargo ship *American Tern* (Military Sealift Command, February)	1
Tanker (Military Sealift Command ship, January)	1

Load comparisons, Christchurch/McMurdo

Equipment	Maximum load	Passengers (RT)
Cargo ship	15,000,000 pounds	
Tanker	9,000,000 gallons	
C-5	150,000 pounds	73
C-17	120,000 pounds	102
C-141	42,000 pounds	140
C-130	20,000 pounds	50
LC-130 (ski or wheel)	10,500 pounds	36

KB Kenn Borek Air Ltd.[55]

MSC Military Sealift Command[56]

PHI Petroleum Helicopters Inc.[57]

RNZAF Royal N.Z. Air Force[58]

USAF/109th N.Y. Air Natl Guard, 109th Airlift Wing[59]

USAF/AMC U.S. Air Force, Air Mobility Command[60]

References

[1] For the full text, see appendix B in http://www.polar.org/hq/PGuide02_04/index.htm

[2] http://swfsc.ucsd.edu/antarctic.htm

[3] The 67-page report *United States Antarctic Program*, April 1996, is in the NSF web site at http://www.nsf.gov/pubs/1996/nstc96rp/start.htm

[4]The 94-page report *The United States in Antarctica*, April 1997, is at http://www.nsf.gov/cgi-bin/getpub?antpanel

[5] "The Southern Ocean," by Arnold L. Gordon, *Current* 15(3): 4-6, 1999. The bountiful recent literature on the topic includes "What drove past teleconnections?" by Frank Sirocko, p. 1336-1337, *Science*, 5 September 2003.

[6] http://www.ccpo.odu.edu/Research/globec_menu.html

[7] The area of sea ice around Antarctica varies between 1 and 8 million square miles annually. See images 4 and 5 in http://www.nsf.gov/od/opp/antarct/imageset/start.htm

[8] http://www.antcrc.utas.edu.au/aspect/

[9] "Overview of the polar ozone issue," by Solomon, S.; Schoeberl, M.R.(ed), *Geophysical Research Letters*, 15(8), p.845-846 (August 1988), introduces a special issue on polar ozone.

[10] "Montreal Protocol Benefits Cited," page 395, 30 September 2003 *EOS*.

[11] http://www.cmdl.noaa.gov/ozwv/ozsondes/spo/ozhole.html (historical significance of the ozone hole)

[12] Scroll down to "Ozone Hole Consequences" in http://www.solcomhouse.com/ozonehole.htm

[13] "Ozone and climate change," p. 236-237, and "Simulation of recent Southern Hemisphere climate change," p. 273-275, *Science*, 10 October 2003. www.sciencemag.org.

[14] http://www.nobel.se/chemistry/laureates/1995/

[15] http://www.nsf.gov/od/lpa/news/media/2000/mos_99vitalstats.htm

[16] http://www.commerce.gov/opa/press/2003_Releases/October/22_NationalMedalTechnology_release.htm

[17] See, for example, *The Adélie Penguin: Bellwether of Climate Change*," Columbia University Press, October 2002 http://www.columbia.edu/cu/cup/catalog/data/023112/023112306X.HTM

[18] The Climate Monitoring and Diagnostics Laboratory, National Oceanic and Atmospheric Administration, operates four baseline observatories worldwide, including the one at the South Pole in cooperation with NSF. See http://www.cmdl.noaa.gov/

[19] The automatic weather station project, University of Wisconsin, is described at http://uwamrc.ssec.wisc.edu/aws/awsproj.html

[20] http://igloo.gsfc.nasa.gov/science/perspective.html

[21] Russian, French, and U.S. investigators drilled and analyzed the world's deepest ice core (3,650 meters). The core spans four glacial-interglacial cycles, furnishing an unparalleled archive. "Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica," by J.R. Petit and others, *Nature* (London), 399(6735), 429-436. European coring at Dome C, East Antarctica, in 2003 reached 3,200 meters, yielding the world's oldest ice, possibly 1 million years old.

[22] http://igloo.gsfc.nasa.gov/wais/

[23] "Warmer ocean could threaten antarctic ice shelves" (p. 759) and "Larsen Ice Shelf has progressively thinned" (p. 856-859), *Science*, 31 October 2003, www.sciencemag.org. See also http://nsidc.org/sotc/iceshelves.html.

[24] http://www.cwru.edu/affil/ansmet/index.html

[25]http://amanda.berkeley.edu/ (AMANDA, the initial experiment);
http://icecube.wisc.edu/science/ (IceCube, the newer and larger one)

[26] http://www.ldeo.columbia.edu/~mstuding/vostok.html

[27] A microwave telescope borne for 10½ days 120,000 feet over Antarctica provided detailed evidence that the large-scale geometry of the universe is flat (*Nature*, 27 April 2000). Following the Big Bang 12-15 billion years ago, the universe was smooth, dense, and hot. The intense heat still is detectable as a faint glow called cosmic microwave background radiation. Scientists had sought high-resolution images of the radiation since 1965, when a ground-based radio telescope discovered it. http://www.nsf.gov/od/lpa/news/press/00/pr0025.htm

[28] The University of Chicago (Yerkes Observatory) and 15 institutions from four nations installed telescopes at South Pole Station emphasizing infrared and submillimeter wavelengths. This large project, one of NSF's 24 Science & Technology Centers, in 2001 provided science with the strongest evidence to date for the theory of inflation, the leading model for the formation of the universe. http://www.nsf.gov/od/lpa/news/press/01/pr0138.htm

[29] For each project with an NSF research grant, further information including contact information and grant amount can be found in the Foundation's searchable grants database, http://www.fastlane.nsf.gov/a6/A6SrchAwdf.htm. U.S. Antarctic Program participants also can request access to the *2003-2004 Science Planning Summary, United States Antarctic Program*, which describes all projects.

[30] http://lternet.edu/

[31] http://www.ig.utexas.edu/research/projects/gps/wais_bedrock/wais_bedrock.htm

[32] http://seafloor.csumb.edu/

[33] http://astro.uchicago.edu/cara/

[34] John Carlstrom, S. Chandrasekhar Distinguished Service Professor in Astronomy & Astrophysics at the University of Chicago, announced the new findings 19 September 2002 at the COSMO-02 conference at Chicago's Adler Planetarium.

[35] http://astro.uchicago.edu/dasi/

[36] http://cosmology.berkeley.edu/group/swlh/acbar/

[37] http://nsidc.org/antarctica/megadunes/

[38] http://www-space.arc.nasa.gov/~vulcan/south/

[39] https://www.fastlane.nsf.gov/servlet/showaward?award=0230370

[40] http://www.homepage.montana.edu/~rgarrott/index.htm

[41] http://www.bowserlab.org

[42] http://www.ocean.udel.edu/cms/amarsh/

[43] http://www.iris.washington.edu/about/GSN/

[44] http://www.augustana.edu/academ/geology/antrctca.htm

[45] http://www.ume.maine.edu/iceage/Research/reedy.html

[46] The Antarctic Conservation Act, Public Law 95-541, authorizes U.S. regulations for compliance. See http://www.nsf.gov/od/opp/antarct/aca/aca.htm

[47] http://igloo.gsfc.nasa.gov/wais/

[48] http://nsidc.org/antarctica/megadunes/

[49] http://rpsc.raytheon.com/science/marine/index.html

[50] http://www.uscg.mil/pacarea/iceops/homeice.htm

[51] http://www.msc.navy.mil/N00p/pressrel/press02/press40.htm (MSC announcement); http://www.amo-union.org/Newspaper/Morgue/10-2002/Sections/News/newjobs.htm (*American Maritime Officer* news item)

[52] http://www.nsf.gov

[53] http://www.nsf.gov/cgi-bin/getpub?gp (NSF *Guide to Programs*)

[54] http://www.nsf.gov/home/budget/start.htm

[55] http://www.borekair.com/

[56] http://www.msc.navy.mil/

[57] http://131.103.214.67/

[58] http://www.airforce.mil.nz/

[59] http://www.dmna.state.ny.us/ang/109.html

[60] http://www.af.mil/news/factsheets/Air_Mobility_Command.html