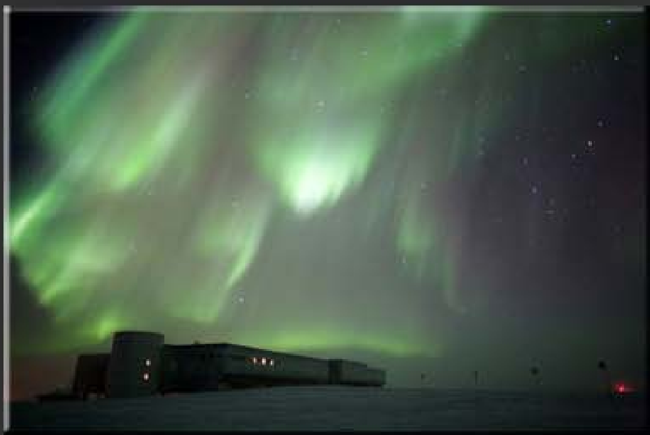
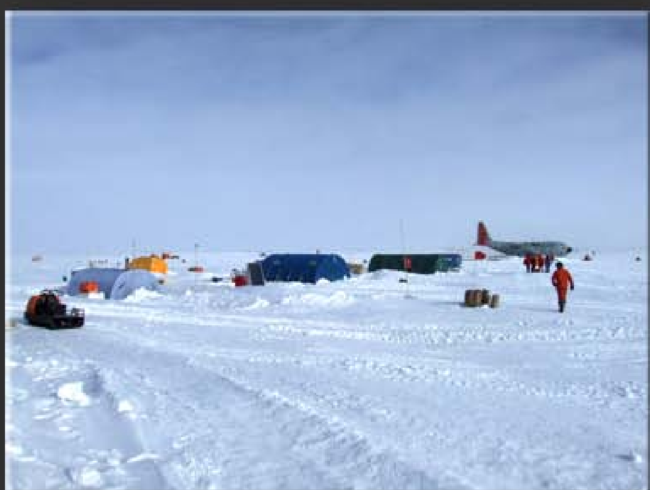
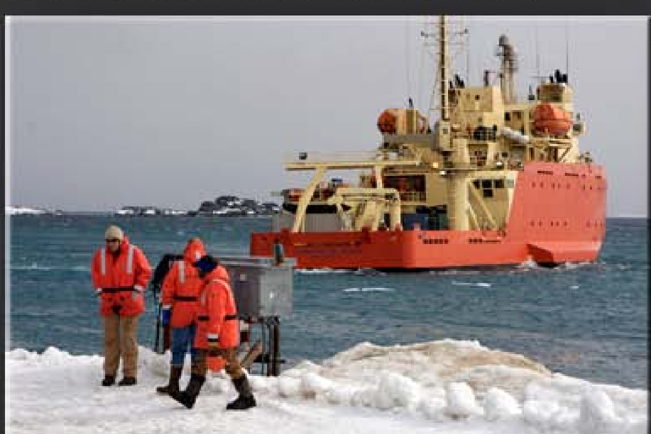
November 2009 Edition



The aurora australis over Amundsen-Scott South Pole Station on June 24, 2009. (Patrick Cullis, NSF/USAP)



The Antarctic Gamburtsev Province (AGAP) field camp is located in eastern Antarctica. The projects under the AGAP partnership are multi-national and multi-disciplinary and include aerogeophysics, passive seismic experiments and ice core and bedrock drilling. (Chad Naughton; NSF/USAP)



The Research Vessel LAURENCE M. GOULD departs Palmer Station. (John Brack; NSF/USAP

United States Antarctic Program

2009-2010 Season

Summary and Background

(revised 01/08/2010)

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1. Why 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 the world's ocean circulation and its influence on global climate.[1] Recent research has shown that understanding the carbon cycle in the Southern Ocean is critically important to understanding the global carbon cycle.

b. **Marine ecosystem.** Research on the marine ecosystem around Antarctica is providing an understanding of the strong coupling in the Southern Ocean between climate processes and ecosystem dynamics[2] and helps to understand levels at which harvesting can take place without damaging the ecosystem. Adding to that uncertainty is the problem of ocean acidification, a gradual change in oceanic chemistry due to uptake of atmospheric carbon dioxide by the sea. The extra carbon dioxide that is produced by anthropogenic activity lowers the oceanic pH, potentially affecting the physiology of marine organism and the ability to form shells. Due to its significant role in absorbing anthropogenic carbon dioxide, the Southern Ocean is predicted to be particularly vulnerable to ocean acidification.

c. **Sea ice.** The annual eightfold growth and decay of sea ice around Antarctica has been termed the greatest seasonal event on Earth.[3] It affects regional climate and the global heat budget. Particularly near the edges, it nurtures some of the world's most productive ecosystems.[4]

d. **Ozone hole.** One of the best examples of basic research about Earth's environment that led to important public policy decisions is the story surrounding the Antarctic ozone hole. The discovery of the annual Antarctic ozone depletion, the research that uncovered the cause of the ozone depleting reactions, and the subsequent decisions about phasing out ozone depleting CFC's is a compelling illustration of the value of science to society. Starting in 1979, ozone in the stratosphere over Antarctica has been observed almost to disappear every austral spring. In the 1990's seasonal ozone depletion in the Arctic was first observed. Elsewhere, stratospheric ozone depletions are only incremental. Stratospheric ozone keeps much of the Sun's harmful ultraviolet radiation from reaching the Earth's surface and therefore, 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.[5]

   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.[6]

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. The best estimates are that annual depletion will occur for another 50 years. Current Antarctic research continues to provide further understanding of the ozone hole.[7]

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 oceans. Scientists have documented how UV-B affects bacteria, phytoplankton, and the embryos of Antarctic invertebrates and fish.[8]

v. **Effect on climate.** Research indicates that the ozone hole has increased the winds around Antarctica and reduced rainfall in Australia and elsewhere.[9] Some research indicates that the annual ozone depletion allows additional heat loss from the earth resulting in the minor cooling observed in the Antarctic interior.

vi. **Delayed warming**. The ozone hole, by increasing winds over the Southern Ocean, has isolated Antarctica from the warming that’s happening elsewhere; in the last 30 years surface temperature over much of the continent has changed little.[10]

vii. **Economic impact.** Damage avoided through implementation of the Montreal Protocol’s measures to protect the ozone layer is valued at US$235-billion. The benefit of reduced damage to fisheries, agriculture, and materials is twice that amount. The benefit of reduced numbers of eye disorders and skin cancers is not expressed in economic terms. Without the Montreal Protocol, CFC consumption would have risen to 3 million tons by 2010 and 8 million tons by 2060, depleting 50 percent more of the ozone layer by 2035.[11]

viii. **Awards.**

a. The 1995 **Nobel Prize** in Chemistry was awarded to three professors who explained that the ozone layer is sensitive to anthropogenic emissions.[12]

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.

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 phase-out and replacement of chlorofluorocarbons (CFCs).[13]

e. **Polar adaptations of biota.** Antarctica's cold, desert conditions, and annual light cycles have led to molecular, biochemical, and physiological adaptations that enable biota to survive, reproduce, and indeed thrive under environmental extremes not experienced elsewhere. Unique chemical reactions that provide energy to microbes and consequently, ecosystems, have been uncovered in lakes and under glaciers. Studies provide a basic understanding of these unique adaptations and help us understand how life evolved and may respond to environmental change.[14]

f. **Atmospheric background levels.** Antarctica is the planet's farthest region from human population centers and is ideal for recording the world's background levels of atmospheric constituents. Measurements since 1956 at the geographic South Pole have documented changes in worldwide levels of greenhouse gases such as carbon dioxide and methane. Measurements in the data-sparse Southern Hemisphere are important to understanding and predicting global levels of these gases and their impact on (or forerunner to) climate change.[15]

g. **Weather and climate.** The unbroken collection of weather data from manned and unmanned stations in Antarctica, now 50 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.[16]

h. **Ice sheets and ice shelves.** Antarctica's ice sheets contain 90 percent of the world's ice and 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^{o}F warmer)—affects and responds to world climate change. Just 20,000 years ago, the ice sheet was far larger, and correspondingly, sea level was 11 meters (36 feet) lower, as the water was locked up in Antarctic ice.[17]

    ii. **Climate history.** The ice, deposited as snow over millions of years, traps past atmospheric constituents that reveal 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) were both drilled in Antarctica.[18]

    iii. **West Antarctic Ice Sheet**. The West Antarctic Ice Sheet if melted would raise sea level 5 meters. It is less stable than the East Antarctic Ice Sheet because its base is below sea level. Its low-probability/high-impact collapse has stimulated vigorous research over the last 30 years, revealing that it has largely or completely disappeared in the past 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.[19]

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 more quickly 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, 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.[20] Recently observed excursions of intermediate depth water from the Antarctic Circumpolar Current have the potential to deliver tremendous thermal energy to the underside of the floating ice shelves. Current research is aimed at quantifying the amount of energy delivered and developing models to understand the physical processes of ocean-ice shelf interactions.[21]

v. **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 likely oligotrophic—an environment with low nutrient levels and low standing stocks of organisms. Life there may depend on alternative energy sources and survival strategies.[22]

vi. **Monitoring Ice Mass Change and Sea Level Rise.** The Gravity Recovery and Climate Experiment (GRACE) satellite mission offers important observations about changes in mass in the Antarctic region. This mass change is predominantly due to two interwoven processes; 1) changes in ice mass and 2) the response of the lithosphere beneath the ice sheet to change in ice loading. However, GRACE observations alone cannot separate these processes. Consequently, the ground observations of crustal response to changes in ice loading that will be provided by the Polar Earth Observing Network (PoleNet) are essential to fully understanding how total ice mass is changing.[23]

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 high-altitude balloons.** 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 relatively inexpensive way to get scientific experiments into near-space.[24]

i. The 2006 Balzan Prize for Astrophysics (one of four 1-million-Swiss-Franks awards made annually with the stipulation that half of each award must be used to support research of young investigators) was awarded to Dr. Andrew Lange of CalTech and his co-investigator Dr. Paolo de Bernardis of Italy in recognition of their contributions to cosmology, in particular the BOOMERANG Antarctic Long Duration Balloon experiment that produced the first images of structure in the Cosmic Microwave Background.[25]

ii. In 2008 NSF and the National Aeronautics and Space Administration (NASA) jointly achieved a new milestone in the almost 20-year history of scientific ballooning in Antarctica, by launching and operating three long-duration, sub-orbital flights within a single Southern-Hemisphere summer. Scientists from the United States, Japan, South Korea, France and other international collaborators concurrently used the high balloons to investigate the nature of ultra-high-energy cosmic rays and searched for anti-matter, as air currents that circle Antarctica carried the balloons and their instruments at the edge of space.[26]

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. Amundsen-Scott South Pole Station has become a major astronomy and astrophysics center. [27]

i. **Cosmic Microwave Background Radiation (CMBR)** has been studied at the South Pole with unprecedented accuracy. Predicted in 1980s, the CMBR polarization was revealed for the first time in experimental data obtained by the University of Chicago Degree Angular Scale Interferometer (DASI)[28] in 2002. Current studies are trying to detect the B-mode polarization with the Caltech small telescope BICEP[29]. The 10-m South Pole Telescope[30] received its first light in February 2007, and now focuses on determining the nature of dark energy and dark matter and tests cosmological models aimed at explaining the origin of the Universe.

ii. **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.[31]

iii. **BICEP Telescope at South Pole makes first maps of CMB Polarization on the angular scales that probe the physics of Inflation.** Observations of the Cosmic Microwave Background (CMB) radiation from telescopes at high-altitude sites and on satellites have produced information about our Universe on its largest scales, precisely measuring the Universe's age, composition, and the seeds of its structure. BICEP is a novel mm-wave telescope designed to test theories of the origin of the Big Bang by using precise measurements of the CMB polarization. While making these observations, BICEP measured polarization originating closer to home and mapped the polarized emission from dust and free electrons that trace our own Galaxy's magnetic fields. Between March 2006 and December 2008, BICEP observed nearly continuously, targeting CMB polarization in a region of the Southern sky that is uniquely free of Galactic emission, and dedicated 15% of its time to mapping polarized emission from the Milky Way Galaxy. The resulting maps trace the large-scale magnetic fields essential to understanding the dynamics of star formation in our Galaxy. They also provide feedback to models that predict levels of Galactic foreground emission and their impact on future CMB missions like the Planck satellite. Finally, because BICEP's polarization response has been precisely referenced to artificial sources, these maps offer a unique astronomical calibration standard and will ultimately specify the orientation of polarized Galactic emission at three frequencies (100, 150, and 220 GHz) to the level of precision required for Planck to use this emission for in-flight calibration.

l. **Meteorites.** Meteorites offer important information about the origin of our solar system and Antarctica is the principal source of meteorites for science. Since 1969, teams from the United States, Japan, and Europe have collected more than 30,000 meteorite specimens from the surface of the ice sheet and represent many meteorite classes (including some from the Moon and Mars), extending our knowledge of the solar system. Antarctica has yielded four-fifths of the meteorites known to science.[32] Martian and lunar meteorites provide information about processes that helped form the crust of these bodies. The large numbers of meteorites available from the Antarctic collections have allowed unprecedented discoveries because more material has been available for destructive analysis. For example, common chondrites have yielded diamonds and other highly refractory grains that are remnants of the dust clouds that coalesced to form our solar system.

m. **Mount Erebus — one of Earth’s few long-lived lava lakes.** The world’s southern-most active volcano, Mount Erebus is one of the few volcanoes in the world with a long-lived (decades or more) convecting lava lake. Although the volcano was discovered by James Ross in 1841, scientists still know relatively little about its geology because of extensive snow and ice cover, its remoteness, the extreme environment, and the short field season for study.[33]

n. **Interpreting the glacial history of Mars from research in Antarctica**. Based on their experience working in the McMurdo Dry Valleys of Antarctica, researchers were able to interpret images of the Martian landscape to show that Mars has experienced varied glaciation. These include large ice sheets followed by small scale alpine glaciers in a single location. They also showed that some areas may harbor icy remnants of the final glacial episode, some hundreds of meters thick. These would be prime targets for future exploration for both life and climate records.

2. Season Project Highlights

The table shows this year's number of U.S. Antarctic Program research projects and related activities in Antarctica and the Southern Ocean.[34] Projects range in size from one person to tens of people, and time in the Antarctic ranges from a few days to years. Some of these 124 science and technical projects are active at more than one location. A few are described below.

Program	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
McMurdo and camps	13	23	13	11	5	2	4	6	1
South Pole	15	0	1	0	2	0	1	0	1
Palmer	1	7	1	0	2	0	0	2	2
Ships (*LMG* and *NBP*)	2	7	0	0	8	3	0	0	0
Support by non-USAP resources*	2	3	6	1	1	1	0	0	0

*Includes support at stations and research ships of other national programs, e.g. the Swedish icebreaker *Oden.*

Programs

1. Aeronomy, astrophysics
2. Organisms, ecosystems
3. Earth Sciences
4. Glaciology
5. Ocean and Atmospheric Sciences
6. Integrated System Science
7. Artists, writers
8. Technical Projects
9. IPY Education and Outreach

a. **10-meter telescope**. Construction of the 10-meter telescope, or South Pole Telescope (SPT), was completed as planned with the first light achieved in February 2007.[35] By surveying 4,000 square degrees of the sky with high sensitivity in three wavelength bands, the SPT can detect galaxy clusters through the spectral distortion they impart on the Cosmic Microwave Background (CMB), called the Sunyaev-Zel'dovich Effect (SZE). The first tow winters of observations proved the planned observational capabilities of the telescope with detection for the first time of early galaxy clusters via their SZE in the CMB. . The resulting catalog of galaxy clusters will be used to set constraints on the mysterious dark energy that dominates the mass-energy density of the Universe and is causing the expansion of the Universe to accelerate.

b. **IceCube**. Work continues on the world's largest neutrino detector, which—after 7 years of work—will occupy a cubic kilometer of ice beneath the South Pole Station, deploying more than 5,000 photomultiplier detectors into 86 holes that the Enhanced Hot Water Drill (EHWD) makes in the ice. Neutrinos are special but hard to detect astronomical messengers that can carry information from violent cosmological events at the edge of the Universe or from the hearts of black holes. Historically, astronomical work in new energy regions has invariably discovered unexpected phenomena. By peering through a new window on the Universe, IceCube could open new frontiers of understanding. Currently, IceCube operates 59 strings collecting data that are already in scientific analyses. This austral summer researchers plan to install 18-20 strings and trench and install 14 IceTop stations. They will replace components of the EHWD system as needed and perform sub system tests on electrical and plumbing systems.[36]

c. **Searching for the Universe's beginning.** Mounting evidence indicates that the observable Universe began in a dramatic superluminal inflation of a sub-nuclear volume (known as the "Big Bang"). This violent acceleration of matter would have produced a Cosmic Gravitational-wave Background (CGB), the amplitude of which measures the energy scale at which inflation occurred. The CGB imprints a signature, which can be measured directly or indirectly, in the polarization of the Cosmic Microwave Background (CMB). At the South Pole, the BICEP1 (Background Imaging of Cosmic Extragalactic Polarization) telescope will be upgraded to increase the telescope's mapping speed almost 10 times. Researchers hope to detect the polarization signature of the CGB, gravitational lensing of CMB polarization on scales of less than 1°, characterize the galactic foregrounds in the cleanest field on the sky, and prepare for an even more sensitive search for the CGB from South Pole Station that will use six compact, mechanically-cooled receivers deployed simultaneously on the DASI mount. [37]

d. **Long-term ecological research (LTER)**. Two sites in Antarctica — the McMurdo Dry Valleys and the marine environment on the west coast of the Antarctic Peninsula— are among 26 NSF-sponsored LTER sites dedicated to understanding ecological phenomena over long temporal and large spatial scales (most of the other sites are in the continental United States).[38] These sites are providing important data regarding global change (and annual variability) impacts on oceanic ecosystems, and how extreme cold terrestrial and aquatic ecosystems support unusual life forms.

e. **Weddell seal population dynamics.** Weddell seals in McMurdo Sound have been studied since 1968—providing one of the longest intensive field investigations of long-lived mammals in the world. More than 15,000 animals have been tagged, and 145,000 re-sightings have been recorded. The project is a resource for understanding the life history and population dynamics of not only Weddell seals, but also other species of terrestrial and marine mammals. Data collected this austral summer will be correlated with variables including sea ice conditions, colony, age, time of year, survival, and reproduction to understand the role of climate, local colony characteristics, and individual characteristics on body mass and population dynamics.[39] Other projects focused on Weddell seals will determine how Weddell seals locate and capture prey and then relocate breathing holes in the ice under low, ambient light levels and determine how behavioral and physiological-metabolic responses to minimal low ambient light level and seasonality influence energetic costs, benefits and efficiency of foraging. In an interesting twist, researchers will use seals to understand physical oceanographic processes, by instrumenting individuals with small oceanographic sensor that take data, and transmit information to researchers via satellite, while seals forage.

f. **Adelie penguin populations and climate change.** The Adelie penguin is tied to sea ice, a key environmental variable affected by rapid climate change. Researchers will investigate the populations of Adelie penguins on Ross and Beaufort Islands, where colonies have recently expanded, relative to colonies at Cape Crozier that declined during the 1960s and 1970s. The information will be related to sea ice, as quantified by satellite images, and other climatic variables. This study is an important counterpoint to another project in the West Antarctic Peninsula, where sea ice extent and Adelie penguin populations are shrinking due to warming trends. Understanding the mechanisms behind this sensitivity will contribute greatly to predicting the effects of climate change on Antarctic food webs, as the Adelie penguin is an important predator in the marine ecosystem.

g. **LARISSA (Larsen Ice Shelf System Antarctica)** is a multidisciplinary project to study the region of the spectacular Larsen Ice Shelf collapse in 2002. The project combines ice-core paleoclimate science, marine geology, glaciology, oceanography, and marine ecology to address the changing environment in the past and present with an eye to understanding what lies ahead in the rapidly warming Antarctic Peninsula region. The emplacement of high-precision GPS stations in the bedrock at locations on the western side of the Peninsula this year will set the stage for a major ship- and aircraft-based field effort next year. Data from the GPS stations will allow determination of the rates of rebound of the Earth's surface since the large glacial mass believed to have been centered on the Peninsula has retreated. This, in turn, will aid in understanding the past climate of the region in addition to reducing uncertainties in GRACE satellite gravity-based measurements of current ice loss from the region that contributes to sea-level rise. This element of the LARISSA project is synergistic with the international POLENET project.[40]

h. **Pine Island Glacier Ice Shelf**. The Pine Island Glacier is thinning and accelerating. The hypothesized cause is that warm ocean water is melting the underside of the ice shelf. This decreases the "back pressure" from the ice shelf that helps to hold the glacier in place. This project seeks to directly measure the interaction between ocean water and the underside of the floating ice shelf at the end of the glacier. Researchers hope that by monitoring the evolution of various water masses beneath this ice shelf and by simultaneously measuring atmospheric conditions and ice motion, a more detailed cause-and-effect analysis of the observed glacial degradation can be developed.[41]

i. **West Antarctic Ice Sheet (WAIS) Divide.** This project, a collaboration among several research teams, will collect a 3,400-meter-deep ice core in West Antarctica. The main objectives are to develop the most detailed record of greenhouse gases possible for the last 100,000 years; to determine if the climate changes during the last 100,000 years were initiated by changes in the Northern or Southern Hemisphere; investigate the past and future stability of the West Antarctic Ice Sheet; and to investigate the biology of deep ice. This is the third season of deep drilling with the DISC Drill. The project will drill 24 hours per day, 6 days per week. The project team will resume drilling at 1,500 meters and will pack the brittle ice collected last season and prepare it for transport back to McMurdo where it will be stored until it is shipped north on the resupply vessel.[42]

j. **The Center for Remote Sensing of Ice Sheets (CReSIS)** is a multi-year program designed to develop special sensors and research platforms for investigating ice thickness and to use these sensors and platforms to produce ice-thickness data. Researchers will survey along and across the Thwaites Glacier flow in three regions of interest – the transition from interior ice-sheet flow to rapid basal sliding; one or two locations in the main body of the glacier; and at the grounding line of the glacier. They also will conduct high-resolution, three-dimensional surveys above the transition and within the main body of the glacier. These surveys will be repeated within a season and, if possible, repeated after 1 year to monitor changes in bed properties. Starting at the WAIS Divide camp, the research team will conduct an oversnow traverse along the Thwaites Glacier. Using snowmobiles, they will tow sleds containing camp and science equipment. A Tucker Sno-Cat will tow sleds, a shothole drill, and a compressor. A full geophysical characterization, including sediment properties and thickness, water layer thickness, and possibly bed roughness will aid in the numerical modeling. The work will take place at two locations on the glacier, where researchers hope to collect enough data to generate a three-dimensional image of the bed and its properties. After three years of design, development, and manufacturing efforts, CReSIS will conduct field trials of their newly-developed Uncrewed Aerial Vehicle (UAV). This activity will be accomplished at McMurdo Station (Pegasus Field). Pending successful field trails, the UAV may also be used to a limited extent, for some aerial survey work.[43]

k. **AGAP (Antarctica's Gamburtsev Province).** This project explores the Gamburtsev Subglacial Mountains, the world's last unknown mountain range. Buried beneath miles-thick East Antarctic Ice Sheet, the mountains will be mapped and characterized with aerogeophysical and seismic methods. The project's goal is to understand how the mountains formed and their relationship to development of the ice sheet. The project is led by the United States and involves scientists and logistics support from the United Kingdom, Australia, Germany, China, and Japan. During the last two field seasons, 26 stations have been deployed. Airborne geophysical data from the

2008-2009 season imaged in detail the complete Gamburtsev range, an area approximately 2 million square kilometers. Although analysis of this data is ongoing, initial images show that the mountain chain has a remarkably rugged, glacier-scarred topography. This season, they will service 8 stations, move two USAP stations and demobilize 16 stations so that they can be moved to Byrd Field Camp to be used by the POLENET project.[44]

l. **PoleNet (Polar Observing Network)**. This project measures current motion of the antarctic plate in response to tectonic forces and ice sheet loading. The project will ultimately lead to more precise measurement of the changes in the mass of the antarctic ice sheet in response to global warming. The project is led by the United States and involves scientists and logistics support from 20 other countries including New Zealand, the United Kingdom, Italy, China, and Germany. This austral summer GPS/Seismic and GPS-only stations will be installed along the southern Transantarctic Mountains, in Marie Byrd Land, and in the Thurston Islands sectors of West Antarctica. Besides visiting some sites to collect data, they will deploy a transect of seismic sensors on the ice sheet between Marie Byrd Land and the Whitmore Mountains.[45]

m. **Surface carbon dioxide in the Drake Passage.** The Southern Ocean is an important part of the global carbon budget, and the Drake Passage is the narrowest place through which the Antarctic Circumpolar Current travels. This chokepoint is an efficient site to measure the latitudinal gradients of gas exchange, and the research icebreaker *Laurence M. Gould* will support a project to measure dissolved and total CO_2, providing data that, with satellite images, will enable estimates of the net production and export of carbon by oceanic biota.[46]

n. **CONCORDIASI.** CONCORDIASI, part of the International Polar Year/The Observing System Research and Predictability Experiment (IPY/THORPEX) cluster of research activities, is composed of ten projects with researchers from Canada, France, Germany, Iceland, Norway, United Kingdom, and the U.S. The goals of the project are to document the state of the climate system and the nature and extent of climate change and to improve understanding and models of the forcing mechanisms, thresholds, and feedbacks that control the climate system. Twenty long-duration stratospheric balloons will be launched near McMurdo Station by the French space agency and will carry instruments to perform *in situ* and remote measurements of the atmosphere. These measurements will be performed in conjunction with those taken by satellite-borne instruments and radiosonde observations at various antarctic stations.[47]

o. **Atmosphere-Ocean-Ice Interaction in a coastal polynya.** Polynyas are ice-free areas that often persist in the sea ice surrounding Antarctica. To gain a more detailed understanding of the role that a polynya has in producing latent-heat type sea ice and in forming dense ocean bottom waters, researchers will characterize the lower atmosphere properties, air-sea surface heat fluxes and corresponding ocean depth profiles in polynyas, especially when winds are strong. To do this they will use an instrumented uninhabited aircraft system to observe safely the interaction of light and strong katabatic wind fields with the Terra Nova Bay polynya waters during the late winter and early summer.[48]

p. **Antarctic Artists and Writers Program.** Five artists and writers will deploy to Antarctica this season between November and February. Four projects will based in the McMurdo area and one will travel to South Pole Station.[49]

q. **International Polar Year Education Projects.** Three projects, funded under the IPY education program, will work in Antarctica during 2009-2010 austral summer. Two will work in and around Palmer Station. The remaining project, a film project making a documentary for Discovery Channel and the British Broadcasting Company, will be based at McMurdo and will film at field camps and the South Pole.

r. **Ice Coring Drilling Services.** This project, one of the technical services in support of Antarctic science, provides ice core drilling to the U.S. Antarctic Program and NSF's Arctic Research Program.[50]

3. Construction Highlights

a. **American Recovery and Reinvestment Act (ARRA).** NSF will spend about $18.5 million in ARRA funds for infrastructure improvements to save energy and create jobs, as well as for major transportation and safety initiatives. About $7.5 million, will purchase new equipment for the South Pole traverse, an overland tractor train that transports fuel and supplies on a snow-compacted route between the McMurdo and South Pole stations — a distance of about 1,000 miles. The traverse, accomplished by a 10-person team, uses Case and Caterpillar tractors to pull specially designed sleds loaded with fuel, along with other cargo and a sleeping/cooking module. This method saves fuel and the associated carbon footprint over using ski-equipped C-130 airplanes flown by the New York Air National Guard. One roundtrip swing by the South Pole Traverse saves about 32 LC-130 flights.

   Three million dollars will be used to purchase equipment somewhat similar to the South Pole traverse, but with the intent of supporting a major scientific campaign in the coming years, with modules for labs, ice-core drilling, and other scientific equipment.

   Another $3 million will pay for a new McMurdo Station heat-trace system, an electrical system that carries heat along the length of a plumbing system to keep the water from freezing in the pipes — an obvious concern in Antarctica. In the current system, there is no way to regulate the temperature, so it remains on all the time. The new system will be thermostatically controlled along six miles of pipeline.

   Finally, $5 million will be invested in new airfield vehicles ($3.3 million) for transporting cargo and people, and emergency vehicles and fire suppression equipment ($1.7 million), including two ambulances.

b. **McMurdo Power and Water Plant Upgrade.** The current McMurdo Power Plant was completed and brought on line in 1982 with equipment that was specified in the 1970's design of the new facility. The facility is presently the only centralized power generation plant for McMurdo Station with emergency power provided by distributed units. The distributed units are not capable of providing power to all facilities. Therefore, any significant failure in the present power plant could require shutting down a portion of the station.

   The plant upgrades will add redundancy to the power and the water systems by placing both power generation and water production in each of the water and the power plants, eliminating the single point of failure scenario for both systems without increasing the footprint on the station. The use of more efficient engines and the addition of heat recovery from both the engine jacket and exhaust gases will decrease the fuel required to operate the station.

Phase II of Power Plant construction began in the austral summer of FY08 with final acceptance scheduled for January 2010.

c. **McMurdo Fuel Storage Upgrade.** This project, which will provide $5.0 million to complete the construction of two two-million gallon fuel tanks, is part of the effort to double the fuel storage capacity at McMurdo Station to mitigate against a failed ship-borne resupply. This funding will complete the line piping and upgrades required to connect existing tanks and to bring the infrastructure into compliance with the USAP Spill Control and Countermeasures Plan. Because of recent and planned energy and fuel conservation initiatives, an assessment will be done to determine how many additional tanks will be required to support the strategic resupply initiative. It may be possible to reduce the number of tanks from the five that were initially thought to be needed.

d. **U.S.-New Zealand Wind Power Project**. USAP and Antarctic New Zealand are collaborating on the construction of Antarctica's first wind farm with three 330-kilowatt wind turbines on Crater Hill, which overlooks New Zealand's Scott Base. The project, started in November 2008, will cut fuel consumption by about 463,000 liters per year (an 11% savings). Electricity from the turbines will feed into the McMurdo distribution system. To meet part of the combined McMurdo-Scott Base, annual 1.7-megawatt demand for electricity, the electricity will be distributed to Scott Base and then to McMurdo. The wind-generated electricity will meet 15% of McMurdo's annual demand and about 87% of the smaller Scott Base demand. The wind farm is expected to be operational in February 2010. Antarctica New Zealand, the lead for the $10-million (New Zealand dollars) project, will cover the largest part of the costs as an enhanced contribution to the shared logistics pool with USAP, which transport most of the fuel, people, and materials for the two programs.

e. **South Pole Station Modernization Project.** Major construction and renovation have replaced the 30-year-old South Pole Station's central facilities, which exceeded their design life and could not meet projected science demands. Construction of the Logistics Facility was completed and the facility will be occupied in FY09. The new station was formally dedicated in January 2008.

During the 2009-2010 austral summer, the Geodesic Dome will be deconstructed and removed from Antarctica.

f. **National Polar-orbiting Operational Environmental Satellite System (NPOESS) Receptors, 60/20 Mb/s Communications.** The second field component of the NSF-NPOESS collaboration to install NPOESS satellite weather-data-receptor earth stations will begin during the 2009-2010 austral summer at McMurdo Station. This second phase continues the upgrade of McMurdo broadband satellite communications from 10 Mb/s to 60 Mb/s outbound and 20 Mb/s inbound. This will be accomplished by NPOESS and NSF-funded upgrades to the NSF-owned, 11-meter satellite earth station antenna located at the Black Island Telecommunications Facility (BITF). The location of Black Island, approximately 22 miles south of McMurdo Station, allows unobstructed view to the low elevations of geosynchronous communications satellites. The BITF supports the current operational satellite earth station (7.2-meter antenna, providing the current 10 Mb/s service on a provisional basis) and the permanent earth station (11-meter antenna, presently undergoing refurbishment). The refurbished earth station will operate at Ku-Band identical to the current provisional service and will initiate a new shared satellite communications service obtained via a NPOESS service contract on the OPTUS D1 satellite.   This shared service will support NPOESS mission requirements, NASA requirements for its satellite tracking activity in McMurdo, and NSF.   Provisional service (NSF only) at 10 Mb/s will continue during 2010 on the 7.2-meter antenna while the 11-meter antenna is tested and certified at the higher data rates and while NPOESS tests network traffic management equipment. A third phase during the 2010-2011 austral summer will conclude the communications upgrade by permanently shifting McMurdo communications from the 7.2-meter system to the 11-meter system and de-activating the 7.2-meter system. The resulting final configuration will provide NSF with a dedicated 10 Mb/s outbound and 19 Mb/s inbound services, with the remainder of the bandwidth managed by NPOESS for NPOESS receptor service and NASA ground-station service. In addition to the communications work, foundation installation for one of the two NPOESS receptors will be completed in preparation for an early-opportunity for receptor earth station installation in the 2010-2011 austral summer.

g. **NASA McMurdo Ground Station Depot Level Maintenance Site Survey.**   As part of the on-going host-tenant support for the NASA McMurdo Ground Station, NSF will host a site survey team that will inspect the current 10-meter McMurdo Ground Station antenna system (to be renamed "MG1") for detailed logistical planning in preparation for a major depot level maintenance activity scheduled by NASA for the 2010-2011 austral summer. NASA must execute major preventative maintenance repairs of the motorized antenna tracking pedestal that will require opening the radome protecting the antenna, removing the 10-meter dish reflector, and replacing a major portion of the motorized pedestal. Detailed site planning is required this austral summer to plan the details and validate the feasibility for radome work, antenna dish stowage while dismounted, heavy equipment (e.g., lattice boom crane) lift plans.

h. **NASA Antarctic Interactive Launch Support System (NAILS) Preventative Maintenance and Upgrade Survey.** The NASA Goddard Space Flight Center program office supporting the NOAA polar operational environmental satellites (POES) maintains a small S-Band telemetry/command system at McMurdo used for engineering support to NOAA for POE's satellite operations. A technical team from NASA will deploy during the 2009-2010 austral summer to perform routine preventative and corrective maintenance and will conduct a survey for requirements and feasibility to upgrade the existing system to L-Band receive to process POE's satellite telemetry data. NASA anticipates future support to NOAA to assist in satellite health monitoring and to facilitate rapid-response protective countermeasures to protect the U.S.'s current operational weather satellites from an ever increasing threat of damage from space debris.

i. **Satellite Communications Engineering Assessment for South Pole Station.** In support of NSF, SPAWAR Systems Center Charleston and its contractor LJT & Associates will deploy an engineering team to South Pole Station during January 2010 to conduct transmission/reception tests to a potentially new satellite communications resource for South Pole Station that is marketed via Intelsat. The Skynet-4C satellite has the potential to provide broadband communications suitable for high quality Internet service throughout the upcoming decade, with daily service duration increasing with each passing year. An important component of the field team's work is to conduct a site survey for potential earth station locations. Results of the survey will be used for systems engineering planning for implementing service in either the 2010-2011 or 2011-2012 season.

4. 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, fully operational as of January 2003

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

i. Established area management and environmental protection plans for Antarctic Specially Managed Areas (ASMA):

    i. McMurdo Dry Valleys, Southern Victoria Land, ASMA No. 2 (2004): management plan written and submitted to the Antarctic Treaty by the United States and New Zealand

    ii. Amundsen-Scott South Pole Station, ASMA No. 5 (2006): management plan written and submitted to the Antarctic Treaty by the United States

    iii. Southwest Anvers Island and Palmer Basin, ASMA No. 7 (2008): management plan written and submitted to the Antarctic Treaty by the United States

j. In compliance with all applicable treaties and U.S. laws.[51]

5. **Personnel**

a. The total number of people entering and leaving Antarctica and USAP research ships over the course of the summer will be about 3,000. The U.S. Antarctic Program peak population at any given moment will be about 1,600 on land and 300 on the ships.

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

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

6. **Year-round research stations**

a. **Palmer** (65°S 64°W), Anvers Island, west coast of Antarctic Peninsula—marine biology and other disciplines, population 10 to 44

b. **McMurdo** (78°S 168°E), Ross Island, southwest corner of Ross Sea—all research disciplines, operational hub, logistics center, population 160 to about 1,100

c. **Amundsen-Scott South Pole** (90° S), geographic South Pole—astronomy and astrophysics, meteorology and climate studies, population 60 to 240

7. **Summer research camps**

a. **Siple Dome** (Siple Coast, West Antarctica). Two field camp personnel will provide daily weather observations for airplanes operating in West Antarctica and will support transiting Kenn Borek Air flight crews. (automatic weather stations[52])

b. **Western Antarctic Ice Sheet (WAIS) Divide Camp** (West Antarctica). Glaciology, including ice-core sampling, radar surveys, and installation of a magnetometer; automatic weather stations; GPS monitoring of bedrock motion. Nine projects will work at the camp, including a team (I-477) that will collect a 3,400-meter ice core. [53]

c. **AGAP South Field Camp** (Gamburtsev Mountain range, East Antarctica). Seismic and aerial geophysical surveys of the Gamburtsev Mountain range; passive seismic experiment and retrieve a seismometer array

d. **CReSIS Traverse (1,084 nm from McMurdo Station; 160 nm from WAIS Divide).** Two projects (I-199-M and I-205-M) will traverse from WAIS Divide to the Thwaites Glacier and back to conduct reflection seismic experiments and study flow dynamics and glacier subsurface.[54]

e. **Byrd Field Camp (West Antarctica)**. Five Projects will work from the field camp, including one installing a GPS array throughout West Antarctica and two projects collecting aerial radar data in the Pine Island Glacier area. Two other projects will depart from Bryd Camp for the Pine Island Glacier.[55]

f. Small field camps at Beardmore Glacier (Transantarctic Mountains) and at remote sites supported by other national antarctic programs.

g. Numerous camps in the McMurdo Dry Valleys, on sea ice, and on Ross Island.

8. Logistics Traverse

Extending prior work, two South Pole Traverses are planned from McMurdo to South Pole and back between 20 October 2008 and 8 February 2009. The traverses will move fuel and cargo between the two stations, reducing the demand on LC-130 airplanes.

9. Ships (research and support)

a. RV *Nathaniel B. Palmer*, length 94 meters, icebreaker, purpose-built in 1992 for long-term charter to U.S. Antarctic Program.[56] The ship supports research throughout the Southern Ocean the year-round.

b. RV *Laurence M. Gould*, 71 meters, ice-strengthened, purpose-built in 1997 for long-term charter to U.S. Antarctic Program (replaces RV *Polar Duke*, chartered 1984-1997). Year-round research and Palmer Station support.[57]

c. *Oden*, 107.8 meters, Swedish Maritime Administration with the annual summer channel break-in to McMurdo and escort of the *Tern* and the tanker.[58]

d. *American Tern*, 159 meters, Military Sealift Command chartered ice-classed cargo ship.[59] Annual cargo delivery to and waste retrograde from McMurdo.

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

10. Runways (wheeled operations near McMurdo)

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

11. Skiways (ski operations only)

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

b. South Pole (90°S)

c. Open field (various locations)

12. Antarctic Mission and Policy

a. White House Memorandum 6646 (1982)[60]

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.[61]

c. President's National Science and Technology Council review (1996)[62]

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)[63]

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.

13. 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.** Antarctic research has enabled discoveries of fundamental societal importance that could not have been achieved without a substantial scientific and operational presence in Antarctica and the Southern Ocean. 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 50 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.

14. National Science Foundation[64]

a. **Mission.** The National Science Foundation is a catalyst for progress in discovery and learning. NSF provides leadership, stewardship, and funds to sustain and strengthen the Nation's science, mathematics, and engineering capabilities and education 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 and directorates or offices for 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; education; international activities; environmental studies; crosscutting programs; 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.[65] Annually:

   i. 40,000 proposals competitively reviewed

   ii. 11,000 new awards to 2,000 institutions

d. **Budget (NSF Overall).** The National Science Foundation requests $7.045 billion for FY 2010, $555 million or 8.5 percent over the FY 2009 plan of $6.49 billion. In addition, since investments in science and technology foster economic growth and create high-tech, high-wage jobs, NSF received a one-time appropriation of $3.0 billion from the American Recovery and Reinvestment Act of 2009 (ARRA), raising the agency's overall FY 2009 appropriation to $9.49 billion.[66]

e. **Budget (NSF Antarctic).** NSF spending in FY 2008 for the U.S. Antarctic Program was $355.94 million, of which $59.06 million was for research grants and Science & Technology Center, $240.008 million was for operations and science support, $5.91 million was for Environment, Health & Safety, $67.63 million was for logistics, and $50.89 million was for USCG polar icebreakers operating in the Arctic and the Antarctic. NSF funds about 97 percent of all Federally supported antarctic research and research support. For FY 2009, NSF estimates that it spent $372.41 million, of which $65.25 million was for research grants and the Science & Technology Center, $246.87 million for operations and science support, $6.29 million for Environment, Safety & Health, and $67.52 million for logistics. NSF also budgeted $54 million for operation and maintenance of the USCG polar icebreakers. In addition to its regular funding, NSF received $174 million for polar research and support as part of the funding for the ARRA. Of these funds, $66.50 million was for Antarctic research grants and $15.50 million was for Antarctic Infrastructure and Logistics. For FY 2010, NSF has requested $407.30 million, of which $72.50 is for research grants and the Science & Technology Center, $273.60 million is for operations and science support, $7.20 million is for Environment, Safety & Health, and $67.52million is for logistics. NSF also budgeted $54 million for operation and maintenance of the USCG polar icebreakers.[67]

U.S. ANTARCTIC PROGRAM AIRCRAFT AND SUPPLY SHIP OPERATIONS, 2009-2010 SEASON

LC-130 missions (round trips) within Antarctica	
Amundsen-Scott South Pole Station	260
WAIS Divide	52
AGAP South	12
AGO 1	3
Long Duration Balloon	3
Beardmore	2
Byrd Camp	44
Siple Dome	5
Shackleton Glacier	5
Patriot Hills	4
FAA missions	10
Total LC-130 (USAF/109th), Twin Otter, and Basler Operations within Antarctica	400
AS-350-B2 and Bell 212 helicopter operations within Antarctica	1,843 flight hours in support of 78 groups or activities (PHI)[1]
Christchurch/McMurdo round trips	
C-17 (USAF/AMC, August)	4
C-17 (USAF/AMC, October-February)	61
LC-130 (USAF/109th, Oct.–Feb.)	9
C-130 (RNZAF, November-December)	9
B-757 (RNZAF, December)	2
Airbus A-319 (Australian, February-March)	8
Cargo ship *American Tern* (Military Sealift Command, February)	
Tanker Paul Buck (Military Sealift Command ship, January)	

Load comparisons, Christchurch/McMurdo

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

[1] These amounts do not include flight-hours provided to Antarctica New Zealand as part of the logistics exchanged quid pro quo between the two national programs in Antarctica

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

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

[8] Scroll down to "Ozone Hole Consequences" in http://www.theozonehole.com/

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[10] Antarctic Climate Change and the Environment, Scientific Committee on Antarctic Research, 155 p., December 2009

[11] Montréal Protocol 1987-1997: Global Benefits and Costs of the Montréal Protocol on Substances that Deplete the Ozone Layer, Environment Canada, 80 p., 1997

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

[13] http://www.technology.gov/Medal/p_Recipients.htm#2002

[14] 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

[15] 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/

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

[17] http://igloo.gsfc.nasa.gov/wais/articles/perspective.html

[18] 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, 1999. European coring at Dome C, East Antarctica, in 2003 reached 3,200 meters, yielding some of the world’s oldest ice, possibly 1 million years old.

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[20] “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.

[21] http://pigiceshelf.gsfc.nasa.gov/

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

[23] http://www.polenet.org/

[24] 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

[25] See http://www.balzan.com/index_en.cfm

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http://www.csbf.nasa.gov/antarctica/ice0708.htm

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[29] http://www.astro.caltech.edu/~lgg/bicep_front.htm

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[32] http://geology.cwru.edu/~ansmet/

[33] http://www.ees.nmt.edu/Geop/mevo/mevo.html

[34] For each project with an NSF grant, a description including contact information and grant amount is in the Foundation's grants database, http://www.nsf.gov/awardsearch/. U.S. Antarctic Program participants also can request access to the *2009-2010 Science Planning Summary, United States Antarctic Program*, which describes all projects.

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[36] http://www.icecube.wisc.edu/

[37] http://bicep.caltech.edu/public/

[38] LTER network: http://lternet.edu/; McMurdo LTER: http://huey.colorado.edu/LTER/; Palmer LTER: http://iceflo.icess.ucsb.edu:8080/ice_hp.php?

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[49] http://www.nsf.gov/od/opp/antarct/artist_writer/fy09awards.jsp

[50] http://icedrill.org/

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

[53] Projects at the WAIS Divide Field Camp include:

- Kendrick Taylor (I-477-M), Investigation of climate, ice dynamics, and biology using a deep ice core from the West Antarctic Ice Sheet (http://www.nsf.gov/cgi-bin/good-bye? http://www.waisdivide.unh.edu)
- The National Ice Core Laboratory (I-478-M), National Ice Core Laboratory (NICL) (http://waisdivide.unh.edu)
- Richard Alley (I-168-M), Physical properties of the WAIS Divide deep core
- Charles Bentley–Ice Core Drilling Services (T-350-M), Ice Coring and Drilling Services (ICDS) Support for WAIS Divide (http://www.icedrill.org/)
- The AWS (automatic weather station) project team, O-283-M (Charles Stearns), Antarctic Automatic Weather Station Program (AWS), 2007-2010 (http://amrc.ssec.wisc.edu/aws.html)
- Eftyhia Zesta's team (A-357-M), South American Meridional B-Field Array (SAMBA): An American-Chilean chain (http://samba.atmos.ucla.edu)
- Lessard (A-105), Polar Experiment Network for Geospace Upper atmosphere Investigations (PENGUIn) - Advancing the vision for global studies
- Long Duration Balloon project (Mitchell A-147-M) will retrieve their BESS payload, launched in 2007-2008.
- Anna McKee will visit WAIS Divide as an artist and writer

[54] http://epsc.wustl.edu/seismology/GAMSEIS/index.html

[55] Byrd Field Camp Projects:

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- CReSIS (I-189, Gogineni), Center for Remote Sensing of Ice Sheets (CReSIS) (http://www.cresis.ku.edu)
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[59] http://www.msc.navy.mil/inventory/ships.asp?ship=180

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

[65] http://www.nsf.gov/funding/ (Browse NSF funding opportunities)

[66] NSF FY 10 Budget Request: http://www.nsf.gov/about/budget/fy2010/index.jsp

[67] Office of Polar Programs FY 10 Budget Request: http://www.nsf.gov/about/budget/fy2010/pdf/26_fy2010.pdf (PDF file, 283 KB)