National Aeronautics and Space Administration

NASA's Science Mission Directorate supports various research programs in the Arctic that emphasize space-based and airborne remote sensing studies to characterize, understand, and predict changes in the Arctic and to examine their interactions with the rest of the Earth System.

A glacier feeding the floating ice tongue of the Petermann Glacier in northwestern Greenland, in an image taken from a twin-otter aircraft during a joint NASA/NSF field campaign.

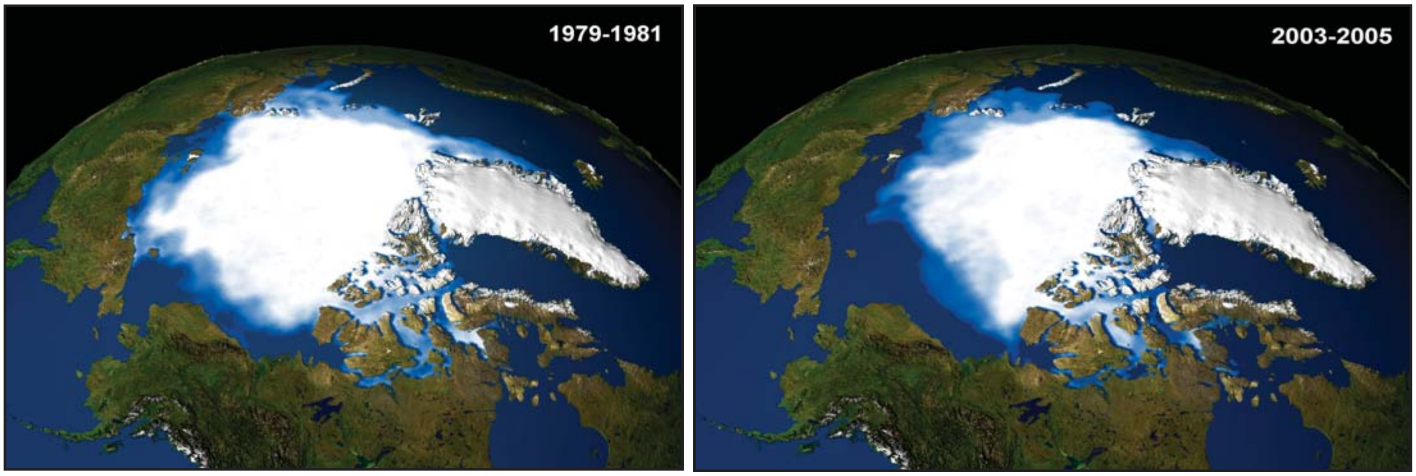
	Funding (thousands)	
	FY 04	FY 05
Polar Ice Interactions	4,000	4,700
Terrestrial Ecology	1,400	1,000
Solid Earth Sciences	4,200	4,200
Hydrological Science	700	700
Modeling	500	500
Atmospheric Chemistry	300	3,400
Clouds and Radiation	500	600
Suborbital Sciences	2,500	2,500
Physical Oceanography	400	400
Biological Oceanography	100	100
Satellite Algorithms/Data Analysis	6,000	6,000
Data Systems	13,200	12,500
Exploration Habitat	400	400
Total	34,200	37,000

By taking advantage of the unique vantage from space, NASA achieves the perspective, sampling, and context needed to study the Arctic as an entire region. Combining these observations with modeling efforts and measurements on the ground and from the air enables NASA to continue to support advances in understanding the Arctic system. These efforts complement those of its interagency partners, such as NSF and NOAA, to provide an integrated understanding of the Arctic as a whole.

Cryospheric Science Research

NASA's investments in cryospheric science research have led to significant advances in our understanding of the Arctic ice, as satellite data have revealed remarkable behavior of the Greenland ice sheet and Arctic sea ice. In Greenland, passive microwave satellite data have shown that the melt on the ice sheet has increased by about 30% since 1979, contributing to the thinning of the margins of the ice sheet. At the same time, satellite radar altimetry data are showing that the ice sheet is growing at its higher and colder interior, presumably as a result of increased snow accumulation. These findings are consistent with predictions for both increased snowfall and increased melt in a warming climate. What is especially significant about Greenland, however, is that many of its outlet glaciers that drain the ice from the ice sheet and dump it into the ocean in the form of calving icebergs have accelerated in speed. In some cases, the speed has doubled, hastening the loss of Greenland's ice to the sea. This acceleration is largely a result of the melting and break-up of floating ice "tongues" at the front of these glaciers, which have historically been buttressing the ice and slowing its discharge.

There has been a wide range of estimates for the current rate of loss of Greenland ice that have been derived from the Gravity Recovery and Cli-



Three-year average extent of the perennial Arctic ice cover for the start of the passive microwave satellite record, 1979–1981, and for the most recent period, 2003–2005.

mate Experiment (GRACE), radar altimetry, aircraft laser altimetry, and interferometric synthetic aperture radar, and while they vary considerably in magnitude, they all tell a consistent story of an ice sheet that is losing mass much more rapidly in the last few years than in the past.

In addition to ice sheet research, NASA continues to invest in research in understanding changes in glaciers and ice caps to assess their mass balance characteristics, including support of airborne surveys of elevation changes of the Canadian ice caps and interpretation of observed changes in Alaskan glaciers. Most recently, results from the GRACE mission have provided estimates of the seasonal and interannual mass loss from Alaskan glaciers and the glacier systems of northwest Canada by monitoring changes in the gravitational signal. This new approach is the first direct measurement of ice mass change over these smaller glacier systems.

Passive microwave observations of perennial sea ice in the Arctic reveal that its extent has continued to decline at a rate of about 10% per decade, while the total ice cover has diminished by about 3% per decade. This significantly higher percentage for the perennial ice cover is especially important because this is the ice that survives the summer melt season. It is generally thicker than the seasonal ice cover, so even if it grows back, it will take multiple years of sustained growth before new ice can develop to a similar thickness. The implications for the energy exchanges between the ocean and atmosphere are significant. In addition, the melting of perennial sea ice results in a significant input of relatively fresh water to the Arctic Ocean, which has uncertain implications for ocean circulation.

As a result, there is a very strong interest in measuring thickness changes on large scales, as can potentially be done from space. NASA's Ice Cloud and Land Elevation Satellite (ICESat) mission has demonstrated a new capability to estimate sea ice thickness from measured freeboard height (the portion of the floating ice cover that extends above water). A challenge remains in identifying the thickness of snow that might be on the sea ice, but efforts continue in improving the microwave-derived snow depth on sea ice in the Arctic. These thickness measurements, which have been a major goal since the first satellite observations of sea ice, will provide essential information for understanding the interactions between the ice, ocean, and atmosphere and for predicting the rate and consequences of sea ice decay.

Arctic Hydrologic Change

NASA is making investments in improving our understanding of variability and change in the Arctic hydrologic system. A key tool in support of this effort is the Arctic Rapid Integrating Monitoring System (Arctic-RIMS), which synthesizes station precipitation, river discharge, and information from NASA satellite platforms, along with output from hydrologic, thermal, and numerical weather prediction models. The Arctic-RIMS web site (rims.unh.edu/) contains background material, a tutorial for site navigation, and visualization and analysis tools. Current research foci include understanding recent increases in river discharge to the Arctic Ocean, variability in the freeze–thaw state of the Arctic surface, changes in active-layer depth in permafrost regions, and changes in lake levels and glacier mass balance. A major study, to appear in a forthcoming issue of the *Journal of Geophysical Research*, has synthesized available information to quantify the large-scale freshwater cycle of the Arctic, “following the water” through the atmospheric, terrestrial, and oceanic branches of the hydrologic system.

Arctic Climate Modeling

NASA makes significant investments in improving the representation of the Arctic in climate models and understanding its interactions with the rest of the Earth System through the inclusion of satellite data for assimilation, initialization, and validation. One focus of these efforts has been examining the Goddard Institute for Space Studies (GISS) coupled atmosphere–ocean models for Arctic sea ice from the runs performed for the Intergovernmental Panel on Climate Change. Two ocean models are being run with GISS Model E: the Russell et al. model and the HYCOM model. In the control run simulations, the sea ice distribution is generally realistic in both models. The primary discrepancies are that sea ice concentrations tend to be too large in the northeast North Atlantic, and polar sea ice is too thick (especially in the Russell et al. model). Model simulations for the past few decades have been compared with observations. Both models underestimate the reduction in northern hemisphere sea ice. Sea ice changes are also small in simulations of the future climate. Warming at high northern latitudes is also underestimated, perhaps in conjunction with the lack of sea ice response. Part of the problem may be associated with a weaker change in high-latitude atmospheric circulation. Current efforts are focusing on whether finer-resolution models produce a more realistic atmospheric response. Efforts continue toward improving model physics as a result of what is learned through these studies.

Atmospheric Chemistry

NASA continues its support of high-quality, long-term measurements of atmospheric trace gases, particles, and physical parameters via a suite of globally distributed research stations under the international Network for the Detection of Stratospheric Change (NDSC), recently changed to the Network for the Detection of Atmospheric Composition Change (NDACC). In the Arctic, NASA supports the operation of a high-resolution, FTIR (Fourier-transform infrared) spectrometer operated at Thule, Greenland, by investigators from the National Center for Atmospheric Research.

The Polar Aura Validation Experiment (PAVE) was conducted by NASA in January 2005 as an international science mission to acquire critical, high-quality measurements of the polar region in support of the Aura satellite. PAVE was the third of a series of Aura validation missions designed to provide correlative measurements to help understand the transport of gases and aerosols in the troposphere and their exchange with the lower stratosphere. The measurements from the Aura satellite are helping to improve modeling of global-scale air quality and climate change predictions.

Utilizing the NASA DC-8 and high-altitude balloons, PAVE aimed to collect valuable science data from a suite of atmospheric remote sensing and in situ instruments. Based at the Pease Tradeport in New Hampshire and the ESRANGE balloon facility in Sweden, approximately 80 scientists, managers, and support personnel were deployed to perform the science flights in the Arctic. The DC-8 component of PAVE was very successful in fulfilling the mission objectives of:

- Obtaining high-quality in situ and remote sensing measurements of the polar region for validation of Aura satellite measurements;
- Making observations of the influx of material from the troposphere into the stratosphere;
- Characterizing the high gradients of stratospheric trace gases both in and outside the polar vortex; and
- Measuring outflow from the North American continent.

The balloon component suffered a launch failure of the large remote sensing instrument package, and instrument damage prevented another launch attempt. The balloon measurements (with a larger suite of instruments) are rescheduled for January 2007.