

Glacier Studies

SUMMARY:

The cumulative impact of 6.4 billion humans (a global population which is increasing about 90 million each year) is affecting, to a lesser or greater degree, every component of the Earth System and related processes and cycles: its Geosphere (Atmosphere, Hydrosphere, Lithosphere, and Cryosphere), Biosphere, Climatic Processes, Hydrologic Cycle, and Biogeochemical Cycles. The two key scientific questions that must be answered for each of these components, processes, and cycles are: (1) What is the natural variability of each; and (2) Are human activities causing changes that exceed natural variability? For example, direct measurements of carbon dioxide composition of the Earth's atmosphere (since 1958), coupled with measurements of carbon dioxide contained in glacier ice cores from Antarctica proves that the current composition of carbon dioxide in the Earth's atmosphere is now more than 35.7 percent higher than natural variability of the past 800,000 years. The cryosphere is an element of the Earth System that is extremely sensitive to changes in regional and global temperature, especially so in the polar regions. (See the Arctic Climate Impact Assessment (ACIA) report published by Cambridge University Press in 2004).

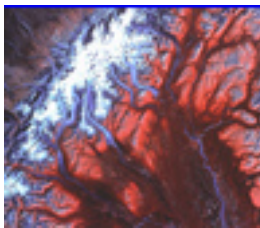


photo of glaciers

INVESTIGATORS:

Principal: Richard S. Williams (rswilliams@usgs.gov)

Associate: Jane G. Ferrigno (jferrigno@usgs.gov)

DESCRIPTION:

The multi-Federal agency U.S. Climate Change Science Program is directed at achieving a better understanding of natural variability and human impact on the Earth System through studies of past, present, and projected changes in the geosphere and biosphere. The Glacier Studies Project, a part of the U.S. Geological Survey's contribution to the national effort, is directed at studying changes in the glacier component of the Earth's cryosphere, one of the four elements of the geosphere. The cryosphere (composed of glaciers; sea, lake, and river ice; snow cover; and permafrost) is particularly sensitive to changes in regional and global climate. Temperature changes in the Arctic are decreasing the areal distribution of discontinuous and continuous permafrost in the northern hemisphere. Seasonal changes in sea ice and snow cover and annual and decadal changes in glacier areas can be monitored regionally and globally with image and other data from Earth-orbiting satellites. To stay at the leading edge of satellite and airborne remote sensing technology and data analysis of glaciers (and other dynamic landforms), USGS and NASA Goddard Space Flight Center Earth Science Enterprise scientists are collaborating on analysis of satellite images from new satellite systems and with geodetic airborne and satellite laser altimetry surveys of glaciers to detect changes in area and surface elevation of glaciers. The overall objective of the project is to use past, present, and future remotely sensed data, supplemented with ground-based observational data, including historical data such as maps and photographs, where available, to construct and analyze long-term data sets of fluctuations of glaciers from a regional and global perspective. The 11-volume Satellite Image Atlas of Glaciers of the World Task 1 uses Landsat images from 1972 to 1981 to establish a global baseline of glacier area. The 24-map Coastal-Change and Glaciological Maps of Antarctica Task 2 uses two sets of Landsat images (mid-1970's and late 1980's/early 1990's), September/October 1997 RADARSAT images, Landsat 7 ETM+ images, and other satellite data, where available, to define precisely grounded or floating glacier ice. Task 2 is directed at mapping changes in the coast of Antarctica, using ArcGIS, ERDAS Imagine, and available geodetic ground-control information (unclassified and classified source materials) derived from the RADARSAT image mosaic and associated DEM of Antarctica, in formal cooperation with the British Antarctic Survey and Antarctic survey institutions in other Antarctic Treaty nations.

START DATE OF PROJECT:

October 1, 2002

END DATE OF PROJECT:

September 30, 2007

TOPIC:

changes in the glacier component of the Earth's cryosphere

APPROACH:

The U.S. Geological Survey has played the lead national and international role in using satellite image data to provide baseline data and other information about glaciers from a global perspective. In Task 1, 7 volumes have been published of the 11-volume Satellite Image Atlas of Glaciers of the World (USGS Professional Paper 1386-A-K): B Antarctica, C, Greenland; E, Glaciers of Europe; G, Glaciers of the Middle East and Africa; H, Glaciers of Irian Jaya, Indonesia, and New Zealand; I, Glaciers of South America; and J, Glaciers of North America. Completion of the remaining 4 volumes remains the project's highest priority. The 4 remaining volumes in order of production (e.g., editing, technical reviews, preparation of computer graphics, page formatting, printing) are as follows: 1386-K, Glaciers of Alaska [in final preparation (graphics and page formatting); to be published in late 2005 or early 2006]; 1386-D, Glaciers of Iceland (in initial preparation; to be published in late 2006); 1386-F, Glaciers of Asia (in final preparation, to be published in early or mid-2006); 1386-A, State of the Earth's Cryosphere at the Beginning of the 21st Century: Glaciers, Snow Cover, Floating Ice, and Permafrost, including 1:50,000,000-scale Map of the Earth's Dynamic Cryosphere (to be written in late 2005; to be published in early 2006). The 11 volumes are published in two formats: printed books and digital (accessible via the USGS website). For Task 2, completion and publication of the Coastal-Change and Glaciological Maps of Antarctica series (USGS Geologic Investigations Maps I-2600-A-Y) will provide critical baseline glaciologic and basic cartographic information about changes in both the grounded and floating ice margins of Antarctica. More than 700 Landsat 1-5 MSS and/or TM, RADARSAT, and other satellite data have been analyzed to provide, for the first time, advanced GIS and image processing technologies to: 1. Prepare 1:1,000,000-scale baseline maps (in both printed and digital formats) of the coast of Antarctica, using accurate Landsat MSS, TM, RADARSAT, Landsat 7 ETM+ images, and other satellite images. 2. Compile 23 accurate coastal-change and glaciological maps [9 maps (A-I) (in both printed and digital formats; 14 maps (J-X) in digital format] which show coastal changes in floating (ice fronts) and grounded (ice walls) glacier ice during the past 30 years. 3. Determine selected glacier-ice velocities in selected coastal regions. 4. Compile a comprehensive inventory of named and unnamed outlet glaciers and ice streams. 5. Compile a 1:5,000,000-scale map (in both printed and digital formats) of the continent of Antarctica. A prototype map of the series was published in 1997 (I-2600-F). Two maps [I-2600-F (2d ed.) and I-2600-G] were published (paper and digital formats) in 2003. One map (I-2600-E) was published in 2004. Map I-2600-D is in press. Five more maps (I-2600-A-C and H-I) are currently in production. The three maps of the Antarctic Peninsula (I-2600-A-C) are being done as a joint effort with the British Antarctic Survey. The current production schedule is to ready all remaining maps (I-2600-J-X) for publication, in digital format (pubs.usgs.gov website), and the 1:5,000,000-scale map (in both printed and digital formats) by the end of FY2007.

IMPACT/RESULTS:

The 13-Federal agency U.S. Climate Change Science Program (CCSP), the successor program to the 9 Federal agency U.S. Global Change Research Program, and Federal Government decisionmakers are the primary clients for the results of the research. The CCSP will link national programs in a multinational effort to better understand natural and human-induced changes in the Earth System. Glaciers are important indicators of global climate change because of their response, both areally and volumetrically, to changes in regional and global climate. In addition, approximately 75 m of potential sea-level rise is currently sequestered from the global hydrologic cycle by glacier ice "stored" on land. A rise in sea level, from both the melting of glaciers and steric increase, is a predicted consequence of global climate warming. (cf. Fitzharris, B.B., author-editor, 1996, *The cryosphere: Changes and their impacts*; in *Climate Change 1995. Impacts, adaptations and mitigation of climate change: IPCC Report*, p. 241-265). One of the more robust predictions of the latest global circulation models (GCMs), is that warming trends during the next 50-100 years will be strongly amplified in both polar regions [see National Research Council, 2001, *Climate Change Science. An analysis of some key questions*: Washington, D.C., Committee on the Science of Climate Change, National Academy Press, 28 p. (Prepared at the request of the Bush Administration) (see especially Chapter 5, *Observed Climate Change During the Industrial Era*, p. 16-17), and the Arctic Climate Impact Assessment (2005).]. Given the potential impact of this prediction on the sensitive polar regions, it is crucial to monitor the cryosphere for changes during the next 100 years or more. The results of this project will provide substantive evidence of changes in the cryosphere based on systematic, long-term monitoring and will be useful in establishing a credible scientific baseline necessary in reducing the uncertainty contained in climate models. The breadth of information generated provides ample evidence of the long-term natural variability that affects the cryosphere and global climate processes. The research responds to the Director's FY2006 science objectives (integrated landscape monitoring) and the Assoc. Dir. for Geology's FY2006 science objectives: Goal 4, Element 4.2, Activity 4.2.1 (Monitoring, Modeling, and Forecasting of Ecosystem and Climate Change).

PUBLICATIONS:

- ◆ A modern Earth narrative: What will be the fate of the biosphere?: *Technology in Society*, v. 22, p. 303-339
- ◆ Allison, Ian, and Peterson, J.A., 1989, *Glaciers of Irian Jaya, Indonesia (H-1)*, and Chinn, T.J., 1989, *Glaciers of New Zealand (H-2)*; in Williams, R.S., Jr., and Ferrigno, J.G., editors, *Satellite image atlas of glaciers of the world: U.S. Professional Paper 1386-H (Glaciers of Irian Jaya, Indonesia, and New Zealand)*, 48 p. ISBN 0-607-71457-3. (<http://pubs.usgs.gov/prof/p1386h/>)
- ◆ Analysis of coastal change in Marie Byrd Land and Ellsworth Land, West Antarctica using Landsat imagery: *Annals of Glaciology*, v. 27, p. 33-40
- ◆ Analysis of glacier facies using satellite techniques: *Journal of Glaciology*, v. 37, no. 125, p. 120-128
- ◆ Antarctic glacier velocities from Landsat images: *Antarctic Journal of the United States*, v. 24, no. 5, p. 106-107
- ◆ *Antarctica, with sections on the "Dry Valleys" of Victoria Land*, by Chinn, T.J., and *Landsat images of Antarctica*, by

Williams, R.S., Jr., and Ferrigno, J.G., *Satellite image atlas of glaciers of the world* (Williams, R.S., Jr., and Ferrigno, J.G., editors): U.S. Geological Survey Professional Paper 1386-B, 278 p. (<http://pubs.usgs.gov/prof/p1386b>) ISBN 0-607-71453-0

- ◆ Ascent of Oraefajokull; Excerpt from "A Physical, geographical, and historical description of Iceland's glaciers on the basis of a journey to the most prominent of them in 1792-1794 (including four plan and [eight] perspective drawings)" by Sveinn Pálsson (1795) Translated into English and edited, with annotations (Endnotes), by Richard S. Williams, Jr., and Oddur Sigurdsson, *Jokull*, v. 45, p. 29-33
- ◆ Calculation and error analysis of a digital elevation model of Hofsjokull, Iceland, from SAR interferometry: 56th Eastern Snow Conference (Fredericton, NB, 2-4 June 1999) Proceedings, p. 5-12
- ◆ Coastal-change and glaciological map of the Bakutis Coast, Antarctica: 1972-1990: USGS Geologic Investigations Series Map I-2600-F, with accompanying booklet, 12 p.
- ◆ Coastal-change and glaciological maps of Antarctica: *Annals of Glaciology*, v. 21, p. 284-290
- ◆ [Coastal-change and glaciological maps of Antarctica: U.S. Geological Fact Sheet, FS050-98, 2 p.](http://pubs.usgs.gov/factsheet/fs50-98) (<http://pubs.usgs.gov/factsheet/fs50-98>)
- ◆ Collaboration between USGS, NASA, and NEA in glacier research: *Ice* (New Bulletin of the International Glaciological Society), no. 119, p. 3
- ◆ Comparison of satellite-derived with ground-based measurements of the fluctuations of the margins of Vatnajokull, Iceland: *Annals of Glaciology*, v. 24, p. 72-80
- ◆ Evaluation of remote-sensing techniques to measure decadal-scale changes of Hofsjokull ice cap, Iceland: *Journal of Glaciology*, v. 46, no. 154, p. 375-388
- ◆ [Final Report of the workshop on long-term monitoring fluctuations of glaciers of North America and northwestern Europe: Open-File Report 98-31, 144 p.](http://pubs.usgs.gov/of/of98-31) (<http://pubs.usgs.gov/of/of98-31>)
- ◆ Geodetic airborne laser altimetry of Breidamerkurjokull and Skeidararjokull, Iceland, and Jakobshavn Isbrae, West Greenland: *Annals of Glaciology*, v. 17, p. 379-385
- ◆ Glacier recession in Iceland and Austria as observed from space: *EOS*, v. 73, no. 12, p. 129
- ◆ Glaciers, in chapter on the cryosphere, in Gurney, R.J., Foster, J.L., and Parkinson, C.L., eds, *Atlas of Earth Observations Related to Global Change: Atlas of Earth Observations Related to Global Change*, p. 401-422
- ◆ Glaciological delineation of the dynamic coastline of Antarctica: *Antarctic Journal of the United States*, v. 32, no. 2. Also in paper format: 1998, v. 32, no. 5 (1997 Review Issue), p. 225-227
- ◆ Glaciological observations on Bruarjokull, Iceland, using Landsat TM and ERS-1 SAR data: *Annals of Glaciology*, v. 21, p. 271-276
- ◆ Global environmental changes, natural, in Dasch, E.J., editor-in-chief, *Encyclopedia of Earth Sciences: Encyclopedia of Earth Sciences*, v. 1, p. 425-432
- ◆ Greenland, with a section on Landsat images of Greenland, by Williams, R.S., Jr., and Ferrigno, J.G., *Satellite image atlas of glaciers of the world* (Williams, R.S., Jr., and Ferrigno, J.G., editors): U.S. Geological Survey Professional Paper 1386-C, 141 p. ISBN 0-607-71454-9
- ◆ [Icelandic-English glossary of selected geoscience terms: Open-File Report 95-807, 31 p.](http://pubs.usgs.gov/of/of95-807) (<http://pubs.usgs.gov/of/of95-807>)
- ◆ Inventory of North American glaciers, in Williams, R.S., Jr., Final Report on the Polar Research Program Strategies Workshop, USGS Open-File Report 95-247, p. 47
- ◆ Kurter, Ajun, 1991, *Glaciers of Turkey (G-1)*; Ferrigno, J.G., 1991, *Glaciers of Iran (G-2)*; and Young, J.A.T., and Hastenrath, S.L., 1991, *Glaciers of Africa (G-3)*; in Williams, R.S., Jr., and Ferrigno, J.G. editors, *Satellite image atlas of glaciers of the world: U.S. Geological Survey Professional Paper 1386-G (Glaciers of the Middle East and Africa)*, 70 p. ISBN 0-607-71456-5 (<http://pubs.usgs.gov/prof/p1386g>)
- ◆ Lava-cooling operations during the 1973 eruption of Eldfell Volcano, Heimaey, Vestmannaeyjar, Iceland: *Open-File Report 97-724, 73 p.* (<http://pubs.usgs.gov/of/of97-724>)
- ◆ Measurement of changes in the area and volume of the Earth's large glaciers with satellite sensor, in Williams, R.S., and Ferrigno, J.G., workshop coordinators, *Final Report of the Workshop on Long-Term Monitoring of Glaciers of North America and Northwestern Europe: U.S. Geological Survey Open-File Report 98-31, p. 74-76* (<http://pubs.usgs.gov/of/of98-31>)
- ◆ Monitoring the dynamics of the Antarctic coastline with Landsat images: *Antarctic Journal of the United States*, v. 27, no. 5, p. 316-317
- ◆ *Restless Earth*, p. 8-11
- ◆ Rott, Helmut (The Austrian Alps), Scherler, K.E. (The Swiss Alps), Reynaud, L. (The French Alps), and Barbero, R.S.,

and Zanon, G. (The Italian Alps), 1993, *Glaciers of the Alps* (E-1); Serrat, D., and Ventura, J., 1993 *Glaciers of the Pyrenees, Spain and France* (E-2); Ostrem, G., and Haakensen, N., 1993, *Glaciers of Norway* (E-3); Schytt, V., 1993, *Glaciers of Sweden* (E-4), Liestol, O., 1993, *Glaciers of Svalbard, Norway, Norway* (E-5); and Orheim, O., 1993, *Glaciers of Jan Mayen, Norway* (E-6); in Williams, R.S., Jr., and Ferrigno, J.G., editors, *Satellite image atlas of glaciers of the world: U.S. Geological Survey Professional Paper 1386-E (Glaciers of Europe)*, 164 p. ISBN 0-067-71455-7

- ◆ [Satellite image atlas of glaciers of the world: U.S. Geological Survey Fact Sheet FS 130-02](http://pubs.usgs.gov/factsheet/fs/fs130-02), 2 p. (<http://pubs.usgs.gov/factsheet/fs/fs130-02>)
- ◆ Schubert, C., 1998, *Glaciers of Venezuela* (I-1); Hoyo-Atino, F., 1998, *Glaciers of Colombia* (I-2); Jordan, E., and Hastenrath, S., 1998, *Glaciers of Ecuador* (I-3); Morales Arnao, B., 1998, *Glaciers of Peru* (I-4), with a section on Quelccaya Ice Cap, by Hastenrath, S; Jordan, E., 1998, *Glaciers of Bolivia* (I-5); and Lliboutry, L., 1998, *Glaciers of Chile and Argentina* (I-6), with a section on Rock Glaciers by Corte, A.E.; in Williams, R.S., Jr., and Ferrigno, J.G., editors, *Satellite image atlas of glaciers of the world (Glaciers of South America)*, 206 p. ISBN 0-607-92475-6 (<http://pubs.usgs.gov/prof/p1386i/>)
- ◆ [Sea level and climate: U.S. Geological Survey Fact Sheet FS-002-00](http://pubs.usgs.gov/factsheet/fs002-00), 2 p. (<http://pubs.usgs.gov/factsheet/fs002-00>)
- ◆ The modern Earth narrative: Natural and human history of the Earth, in Frode, R., ed., *Earth matters. The Earth sciences, philosophy, and the claims of community*, New Jersey, Prentice-Hall, Inc., p. 35-49
- ◆ [U.S. Geological Survey Professional Paper 1386-J \(Glaciers of North America\)](http://pubs.usgs.gov/prof/p1386j/), 400+ p. ISBN 0-067-98290-X (<http://pubs.usgs.gov/prof/p1386j/>)
- ◆ Use of remote sensing techniques, in Haeberli, W., Hoelzle, M., and Suter, S., eds., *Into the 2nd century of world glacier monitoring: Prospects and strategies: A contribution to the International Hydrological Programme (IHP), and the Global Environmental Monitoring System (GEMS)*, World Glacier Monitoring Service, Paris, UNESCO Publishing, *Studies and Reports in Hydrology*, Publ. 56, p. 97-111
- ◆ Velocities of Antarctic outlet glaciers determined from sequential Landsat images: *Antarctic Journal of the United States*, v. 24, no. 5, p. 105-106
- ◆ Volumetric evolution of Surtsey, Iceland, from topographic maps and scanning airborne laser altimetry: 1968-1998: Reykjavik, Surtsey Research Society, v. 11, p. 127-134
- ◆ Williams, R.S., Jr., 2002, *Human impact on the planet: An Earth System perspective and ethical considerations*, USGS Open-File Report 02-349 (<http://pubs.usgs.gov/of/2002/of-02-349>)

RELATED:

- ◆ [Glacier Studies Project](#)