Global Monitoring Division

Legislative and Scientific Drivers

Contents:

Document items of particular relevance to GMD are noted in Yellow.

Important GMD Legislative Drivers

- ***National Climate Program Act of 1978, 15 U.S.C. 2901-2908, at 2904(d) (4), et seq***.: …authorizes global data collection, monitoring, and analysis activities to provide reliable, useful and readily available information on a continuing basis, authorizes measures for increasing international cooperation.
- ***Clean Air Act 1990 Title IV and Title VI, 42 U.S.C. § 7401 et seq***.: Amendment to the Clean Air Act mandates that "…NOAA shall monitor, and not less often than every 3 years following November 15, 1990, submit a report to Congress on the current average tropospheric concentration of chlorine and bromine and on the level of stratospheric ozone depletion."
- ***Global Change Research Act of 1990, 15 U.S.C. 2921 et seq***.: Ensures the establishment of global measurements and worldwide observations…
- ***Global Climate Change Prevention Act of 1990, 7 U.S.C. § 6701 et seq.***: Requires research in climate change needed to protect the environment.
- ***U. N. Framework Convention on Climate Change (UNFCCC)***: Requires better quantification of the agents that force climate change by contributing research results and providing expertise to the assessments.
- ***Montreal Protocol on Substances that Deplete the Ozone Layer*** *(and subsequent amendments)*: Requires an assessment every four years of the state of the ozone layer, its recovery, and the amounts and origins of ozone depleting substances that drive the ozone layer changes.
- ***Global Earth Observation System of Systems (GEOSS)***: endorses the Global Earth Observation System of Systems (GEOSS) 10-Year Implementation Plan.
- ***Full List in Detail in the 3 following pages.***

Full List of Legislation / Drivers

Legislation:

- *Federal Records Act as amended, 44 U.S.C. §3101 et seq.*: Responsible for the establishment of the National Weather Records Center which archives and services U.S. weather and climate records.
- *Data Quality Act, Public Law 106-554, Section 515, 2001*: Requires that the U.S. government assure the quality of the information disseminated.
- *36 C.F.R., Chapter XII National Archive and Records Administration (NARA) Records and Guidelines*: Stipulates that data maintained for legal purposes and in the national interests must be archived using NARA standards.
- *National Weather Service Organic Act, 15 U.S.C. § 313*: Ensures there are atmospheric, oceanic, and terrestrial measurements suitable for establishing and recording U.S. Climate Conditions.
- *National Climate Program Act of 1978, 15 U.S.C. 2901-2908, at 2904(d) (4), et seq.*: Requires that one program element will be the provision of "useful and readily available information on a continuing basis." It authorizes global data collection, monitoring, and analysis activities to provide reliable, useful and readily available information on a continuing basis. In addition, the act authorizes measures for increasing international cooperation in climate research, monitoring, analysis, and data dissemination.
- *Global Change Research Act of 1990, 15 U.S.C. 2921 et seq.*: Ensures the establishment of global measurements and worldwide observations, and requires an early and continuing commitment to the establishment and maintenance of worldwide observations and related data and information systems.
- *Coastal Zone Management Act (CZMA) of 1972, 16 U.S.C. 1450 et seq. (amended 1990 and 1996)*: Requires understanding and predicting long-term climate change which may have large impacts in the Coastal zone such as global warming and associated sea level rise.
- *Clean Air Act 1990 Title IV and Title VI, 42 U.S.C. § 7401 et seq.*: Amendment to the Clean Air Act mandates that "the Administrators of the National Aeronautics and Space Administration and the National Oceanic and Atmospheric Administration shall monitor, and not less often than every 3 years following November 15, 1990, submit a report to Congress on the current average tropospheric concentration of chlorine and bromine and on the level of stratospheric ozone depletion."
- *Global Climate Change Prevention Act of 1990, 7 U.S.C. § 6701 et seq.*: Requires research in climate change needed to protect the environment.
- *Oceans Act 2000 (PL 106-256)*: Led to the Congressionally-mandated report of the U.S. Commission on Ocean Policy and the Executive response, the U. S. Ocean Action Plan of 2005: Requires federal agencies to participate in building a Global Earth Observation Network that includes integrated oceans observations. The U.S. is implementing this through the Integrated Ocean Observation System (IOOS), the Integrated Earth Observation System (IEOS), and participation in GEOSS.
- *Consolidated Appropriations Act, 2005, Public Law No. 108-447, 118 Stat. 2908 (Dec. 8, 2004), incorporates S. 1218, the Oceans and Human Health Act*: "Establish[es] a Federal research program that examines ocean resources and their applications to human health." The Act aims to "…ensure that any integrated ocean and Coastal observing system provides information necessary to monitor, predict and reduce marine public health problems including: (A) baseline observations of physical ocean properties to monitor climate variation; (B) measurement of oceanic and atmospheric variables to improve prediction of severe weather events; …"

Full List of Legislation / Drivers (con't)

U. S. Executive Branch and NOAA Directives and Other Guidelines:

- *Strategic Plan for the U. S. Integrated Earth Observations System (IEOS), USGEO Report, 2005*: This plan addresses the policy-related, technical, and fiscal components of a U.S. integrated Earth observation system.
- *President's Security and Prosperity Program of North America Initiative (SPP):* SPP is a trilateral agreement among the U.S., Canada, and Mexico signed in March 2005. One of the many facets of the agreement relevant to the Climate Program involves "enhancing the joint stewardship of our environment… through cooperation and information sharing."
- *U. S. Ocean Action Plan/ Charting the Course for Ocean Science for the United States for the Next Decade: An Ocean Research Priorities Plan and Implementation Strategy (2007):* Administration's response to the U.S. Commission on Ocean Policy Report: To accomplish actions within the Ocean Action Plan requires the access to and use of archived (new and historical) quality observations of essential climate and ocean variables. The ORPP calls for deployment of "a robust ocean observing system that can describe the actual state of the ocean."
- *Department Administrative Order (DAO) 212-2 Information Technology Handbook*: This handbook defines data management and related activities as: identifying the information needed; defining and documenting data requirements; coding and structuring the data; designing the database; selecting and using the most effective storage technology; collecting the data; processing the data; disseminating the information and facilitating user access; protecting the data against damage and unauthorized access; and archiving and disposing of the data.

Interagency and International Agreements:

- *International Council of Scientific Unions (ICSU) guidelines/policy regarding World Data Centers (WDC) – National Climatic Data Center WDC for Meteorology and Paleoclimatology*: Requires archiving and access to data collected by internationally sponsored observation and research programs. Allows for the active exchange of climate data with foreign countries to support research and other activities.
- *U. N. Framework Convention on Climate Change (UNFCCC)*: Requires better quantification of the agents that force climate change by contributing research results and providing expertise to the assessments.
- *Montreal Protocol on Substances that Deplete the Ozone Layer (and subsequent amendments)*: Requires an assessment every four years of the state of the ozone layer, its recovery, and the amounts and origins of ozone depleting substances that drive the ozone layer changes.
- *Global Earth Observation System of Systems (GEOSS*): Third Earth Observation Summit held in Brussels, 16 February 2005, endorsing the Global Earth Observation System of Systems (GEOSS) 10-Year Implementation Plan. Summarizes the essential steps to be undertaken over the next decade by nations, and intergovernmental, international, and regional organizations, to establish a coordinated and comprehensive sustained earth observations system and defines associated fundamental socio-economic benefits supported by a GEOSS approach to observations and monitoring.

Full List of Legislation / Drivers (con't)

Mission Requirements:

- Establish an Agency Records Center for U.S. Weather and Climate records. (*Federal Records Act)*
- Provide long-term preservation of the Nation's Climate Record. *(Federal Records Act, Data Quality Act, National Climate Program Act, NARA Records and Guidelines, ICSU World Data Center Guidelines & Policy, and U. S. Ocean Action Plan)*
- Provide climate data and information that meets rigorous scientific standards for quality.
- *(Data Quality Act, Coastal Zone Management Act, and U. S. Ocean Action Plan)*
- Provide NOAA customers access to Climate Data and Information (timely, easy, and convenient) related to the state and changing state of the climate system in a variety of formats. *(Federal Records Act, National Climate Program Act, NARA Records and Guidelines, ICSU World Data Center Guidelines & Policy, Consolidated Appropriations Act, and U.S. Ocean Action Plan)*
- Monitor and assess the climate system through adequate quality observations and measurements of atmospheric, ocean, and select terrestrial "essential climate (state) variables". (*Global Change Research Act, National Climate Program Act, National Weather Service Organic Act, Coastal Zone Management Act, and U. S. Ocean Action Plan)*
- Improve quantification of the forces and feedback systems bringing about changes in the earth's climate and related systems. (*Global Change Research Act, Global Climate Protection Act of 1990, Oceans Act 2000, Climate Change Science Program, U. N. Framework Convention on Climate Change, , Montreal Protocol, Global Earth Observation System of Systems)*

Scientific Questions Driving GMD Monitoring and Research

Climate Forcing

- ✓ How are atmospheric levels of greenhouse gases changing and what are their impacts on radiative forcing?
- ✓ What are the anthropogenic and natural sources and sinks of long-lived greenhouse gases and how are they changing over time?
- ✓ How sensitive are the large reservoirs of arctic and tropical terrestrial carbon to rising temperatures?
- ✓ What are the historic, present, and future drivers of upper tropospheric, lower stratospheric water vapor abundance?
- ✓ How do the means, variability, and trends of climatically important aerosol optical properties vary as a function of location, time, and atmospheric conditions?
- ✓ What changes in the worldwide radiation budget are we detecting at Earth's surface and what are the causes?
- ✓ How will spectral surface albedo measurements improve our understanding of long-term changes in cloud and aerosol optical properties?

Ozone Depletion

- ✓ Is the Montreal Protocol process successfully reducing the threat to stratospheric ozone posed by ozone depleting substances?
- ✓ Is stratospheric ozone recovering as expected?
- ✓ How does ozone variability affect the distribution and trends of UV radiation at Earth's surface?

Air Quality

- ✓ How is intercontinental transport of pollutants influencing air quality over the United States and adjacent oceans and how is it changing over time?
- ✓ How does the cleansing capacity of the global atmosphere vary over time and how sensitive is it to anthropogenic emissions?
- ✓ How does the production and extraction of fossil fuels affect air quality?

NOAA

national oceanic and atmospheric administration

20 YEAR RESEARCH VISION

UNDERSTANDING GLOBAL ECOSYSTEMS TO SUPPORT INFORMED DECISION-MAKING

Through research, we discover and improve our knowledge of Earth's oceans, coasts, and atmosphere.”

a message *from the* NOAA *administrator*

NOAA'S VISION:

"An informed society that uses a comprehensive understanding of the role of the oceans, coasts, and atmosphere in the global ecosystem to make the best social and economic decisions."

As NOAA works to realize its Vision for the future, it must confront a set of growing challenges in an ever-changing world. As science and technology progress, so too will the effects of globalization and a growing world population on local economies, human welfare, and the environment. NOAA must be able to adapt its posture and develop the necessary tools to support society's changing needs for information and services over the coming decades. Research is at the heart of turning NOAA's vision into reality. Through research, we discover and improve our knowledge of Earth's oceans, coasts, and atmosphere. This knowledge is the foundation for the products and services NOAA provides, and allows NOAA and the nation to make sound environmental and ecological management decisions.

The natural systems governing our planet are more complex and interconnected than even the most advanced models can currently depict, and shifting political, economic, and social factors limit our ability to pinpoint the state of this planet 20 years hence. In this challenging context, NOAA must maintain a commitment to pioneering research that will meet or exceed the evolving needs of resource managers, decision makers, and the American public in the years to come. Indeed, NOAA's ability to conduct research that targets critical national requirements is at the core of the present and future success of the agency.

For more than 30 years, NOAA has conducted and sponsored research to support a suite of products and services that span multiple temporal and spatial scales. These deliverables and the discoveries that generated them have been at the forefront of our scientific understanding and technological capabilities. This Vision document lays out a path to enhance NOAA products and services to meet the urgent demands of this new century by continuing to take advantage of discoveries in science and technology and recognizing the connection between our environment, our economic well-being, and human health. Integration of research across existing disciplines is a central theme of NOAA's future; the links among the ocean, atmosphere, and biosphere must be further explored, bolstering our nascent understanding of the complex interrelationships that comprise the global ecosystem.

The 20-Year Research Vision builds upon the NOAA 2005-2010 Strategic Plan which sets the stage for the short- and medium-term goals of NOAA's research enterprise. NOAA's Strategic Plan highlights focal areas for research in ecosystems, climate, weather and water, and commerce and transportation. The requirements for research in each of these areas determine the near-term activities and milestones described in the NOAA 5-Year Research Plan and point the way ahead for the agency's research agenda for the next two decades. The 20-year Research Vision provides the foundation for NOAA's longer-term approach to research. It will position NOAA to support society's changing needs for information and services over the next 20 years and beyond, and enable society to make the best social and economic decisions.

OUR WORLD IN 2025—A VISION OF NOAA AT THE FOREFRONT OF INFORMING DECISION-MAKERS

By 2025, the ubiquitous influence of NOAA's environmental forecasts on personal decision-making will span time scales from hours to months. Personal injuries from tornadoes and other extreme events will be almost unheard of, thanks to dramatic advances in forecast skill and the likelihood that virtually everyone will have a personal electronic assistant (PEA) that will include ample warnings of every kind of environmental hazard. Through their PEAs, boat captains will have easy access to the latest nautical, weather, and sea conditions and forecasts. Coupled with daily analyses of subsurface ocean fronts and eddies to identify the best fishing locations, captains will be able to limit the exposure of their crews to potentially dangerous conditions.

Forecasts will go beyond the simple weather predictions available at the turn of the century to incorporate air quality and risks of disease, which public health agencies will use to lessen adverse impacts. Emergency managers will have mitigation plans in place that will be selected and initiated based on forecasts. More confident outlooks of the weather seasons ahead will allow vacationers to choose between a beach holiday price that fluctuates with the short-term weather forecast and one that is locked in six months in advance.

Policy and decision makers at local to national levels will also increasingly factor environmental and ecological predictions and projections into their planning. Imagine, if you will, that on this date in 2025 local government leaders in Charleston, SC are meeting in special session. A new water desalination plant is about to come on line. The timing is critical. Population along the coast has doubled in the last twenty years. A three-year drought in the Southeast has depleted reservoirs. Damage to the local ecosystem is significant, but mitigation activities have lessened the adverse impacts. Fortunately, Charleston political leaders heeded long-range environmental predictions and built the desalination plant to mitigate future water supply challenges. This is a success story that major metropolitan areas around the globe will be rushing to emulate as they face their own water shortages.

On an international level, imagine that in 2025 the United States and Canada sign a landmark treaty covering use of fresh water stored in the Great Lakes. The focus of the treaty is to maintain ecosystem and environmental balance while tapping into the largest source of fresh water on the planet. The two-year climate projection indicates a likely decrease in precipitation over the middle of North America, making the treaty all the more timely.

By the end of the first quarter of the 21st century, the world will depend on NOAA's detailed and reliable environmental information and predictions to make the best social and economic decisions. These decisions will improve economies, enhance recreational opportunities, protect public health, reduce dramatically the likelihood of injuries from severe storms, and mitigate the harm from droughts and long-term climate changes.

SOCIETAL NEEDS AND NOAA IN THE 21ST CENTURY

Societal demand for information and integrated management solutions provided by NOAA on the state of the atmosphere and oceans, the condition of living marine resources, water rights, ocean navigation, and weather prediction will increase dramatically in extent and urgency during this century. The fundamental, overarching reality of growth in worldwide population will create many of these new demands as economies, human welfare, and the environment are affected. Impacts from globalization and associated trends will likewise result in increasing demands on society.

- Population growth — in the United States and globally — will increase the threat of severe weather impacts on human health, water rights, safety, and economic investments. The U.S. population will increase its expectations of, and reliance on, weather forecasts, and more sophisticated land planning will create a greater need for NOAA data and analyses.
- Fisheries resources will experience increasing stress in most regions until worldwide demand for protein creates financial incentives for society to insist on better management. This will result in a need for substantially improved description, understanding, and prediction of fisheries productivity. Increased marine aquaculture will be necessary to keep up with global demands for food protein, impacting economies and marine ecosystems.
- Threats to the oceans and human health will include infectious diseases. Increased monitoring of medical waste disposal and means of infectious agent transmission will be required. There will also be additional stresses on the oceans as their natural resources are explored in search of marine biomedicines and cures for noninfectious diseases such as cancer, multiple sclerosis, and Alzheimer's disease.
- Pollution will continue to increase as a result of normal human pursuits such as work, transportation, and recreation. Nitrogen and other by-products of human endeavor will continue to flow from the land into the oceans. Phenomena like harmful algal blooms (e.g. red and brown tides), will inhibit our use of ocean resources and will increase demand to monitor and moderate nutrient runoff from land. Increased introduction of invasive species due to ballast water exchange and recreational fishing will increase biological pollution. Atmospheric pollutants, originating both in the United States and off shore, will require enhanced monitoring, modeling, and tracking.
- Carbon and other greenhouse gas releases into the atmosphere will continue to increase on a worldwide basis even as industrialized countries, including the United States and Western Europe, reduce their emissions. As carbon and other greenhouse gas releases continue to promote global warming, the United States and other developed nations will put increased emphasis on atmospheric monitoring as a basis for providing economic incentives to reduce greenhouse gas releases.
- The potential for accidental or purposeful releases of biological, chemical, or radiation toxins into the environment has increased. This increase will create a need for enhanced observations and analyses incorporated into a quick response systems that coordinate with federal, state, and local emergency managers.
- Increasing international commerce will create a demand for more and larger ocean transport vessels and infrastructure improvements, such as larger and deeper channels. The larger vessels will operate more efficiently and safely by optimizing their routes using weather, wind, and current information. However, the larger and more numerous vessels will create congestion in ports with negative consequences on the economy and the environment as well as increased concerns for public safety. These increased risks will require location information that will allow vessel arrival times to be properly scheduled and coordinated, including an increased demand for real-time information on vessel location, sea state, weather, and ocean mapping.
- The economic significance of longer-term climate predictions for activities such as agriculture, manufacturing plant site location, and recreation industry decisions will grow substantially.
- Improved knowledge about ecosystems will demonstrate the need for society and government to adapt and respond to changes and demands in a more efficient manner than is possible today. This will demand understanding and improving the structure and functioning of NOAA with its fellow agencies, as well as academic, private sector, and international partners to support sustainable development of marine and other natural ecosystems.

TECHNOLOGY AND NOAA IN THE 21ST CENTURY

Accompanying society's increasing dependence on integrated ecological analyses and predictions will be the continuing introduction of new technologies in the marketplace that will enable NOAA to address these societal needs. There are four key technology sectors that NOAA depends on to describe, understand, and predict the environment — sensors, platforms, information technology, and telecommunications.

- Sensors that are capable of gathering most of the desired information about the biological, chemical, and physical components of the environment already exist. Many of these sensors are not deployed in the environment because of expense and fragility. Substantial improvements in both cost and ruggedness of sensors will occur in the next 20 years. This will allow the deployment of large numbers of biodegradable sensors in target environments that are cheap enough to simply be replaced rather than maintained. Adaptive technologies that can react dynamically to rapidly changing situations will be critical to NOAA in the next 20 years.
- Platforms: In addition to deployment of autonomous sensors on fixed platforms, NOAA will also exploit mobile sensor platforms (e.g., unmanned aerial vehicles and autonomous undersea vehicles) to monitor and observe the land, the atmosphere, and the ocean surface, depths, and floor. This approach will be particularly advantageous for deep ocean floor exploration and mapping. Of particular note, these advanced and sophisticated platforms, in conjunction with the sensors indicated above, will afford researchers and operators the capability for even more sophisticated adaptive sampling techniques; preprogrammed "smart" systems will take observations and measurements in a highly optimized fashion.
- Information Technology will continue to advance with computer processing speed doubling every 18 months. There will be better frameworks for constructing complex modeling systems, as well as better data management and analysis tools. This will allow NOAA to advance model-based analysis techniques (through data assimilation) that will exploit the data acquired from new sensors. NOAA will employ high resolution, holistic models that include information on land-based activities, estuaries, coasts, oceans, living marine resources, and the atmosphere. These holistic models will enable NOAA to describe, understand, and predict the interactions of all parts of the environment at increasingly finer resolution.
- Telecommunications will continue to improve in resolution, bandwidth content and availability. GPS, a critical telecommunications technology for support of sensor deployment, will achieve routine 1 cm resolution in the next five years. Global networks will have the capacity to link modeling and ecological information centers seamlessly and effortlessly with service providers and users. The wide availability of personal electronic assistants and enhanced data communications systems will give users the capability to "reach back" to powerful high performance computers, taking advantage of state-of-the-art modeling and forecasting, to meet their own, individual needs. As society becomes ever more dependent on telecommunications, NOAA's space weather forecasts will likewise become more critical to those who manage and depend upon the communication highway.

All of these technologies will be exploited in developing an integrated **Global Earth Observing System of Systems, GEOSS**. Our present observing system is composed of many individual pieces covering a wide range of environmental information needs. Many of these observing systems were built for a single purpose. They have connections to different networks and consist of a variety of data formats and dissemination methods. Integrating these observing systems will enable the analysis and prediction of the state of the atmosphere, land, streams, and oceans, placing special emphasis on the hydrological, biological, geological and chemical cycles that link these elements of the ecosystem.

A SAMPLING OF NOAA'S PRODUCTS AND SERVICES IN 2025

Fueled by dramatic improvements in the integration of NOAA's information, products, and services, NOAA will provide the American public with easy-to-use, seamless, integrated information products and services that will revolutionize, in heretofore unimaginable ways, how Americans lead their daily lives: we will dramatically improve severe event warnings and air quality forecasts; we will offer increasingly confident decadal predictions of climate; we will improve our man-

"More timely and region-specific forecasts, warnings, and use of information will save lives and billions of dollars."

agement of fisheries, estuaries, and protected resources based on ecosystem-level scientific information; and we will make critical environmental information available to individual land, air, and sea vehicles in real time. Highlights of these major advances are provided below.

- **Severe storm and event warnings will save more lives and property.** The enhanced information delivery systems of the future will be well coordinated and able to quickly disseminate severe storm and event warnings. The warnings themselves will see dramatic improvements. For example, tornado warning lead times will be on the order of one hour, rather than minutes. Technology like phased array radar, significant improvements in our under-standing of mesoscale weather processes, and the development of models that embody this understanding will enable this accomplishment. Improvements in storm surge forecasting and increased tsunami monitoring/warning capacity will also greatly minimize loss of life and property damage from these hazards. Our ability to protect the public from tsunami hazards, in particular, will be increased through the development and refinement of model-based propagation and inundation maps and the expansion of deep ocean warning systems.
- **Air quality forecasting will improve and expand nationwide.** Air quality models will include not only pollutants such as ozone, but also a whole range of species relevant to "chemical weather" as well as fine particles. The models will cover the entire nation but be adaptable to address local-to-regional health and visibility concerns. In the future, air-quality models will assimilate observations of chemical species, leading to greatly improved systems for protecting the public from emissions from specific point sources, and forecasts will extend out to several days and beyond.

  Improved air quality forecasts, in addition to extended prediction time horizons for severe storms, tsunamis, and flash floods will create substantial benefits for U.S. society. More timely and region-specific fore-casts, warnings, and use of information will save lives and billions of dollars.[1]
- **NOAA will make seasonal to decadal climate predictions with clearly stated levels of uncertainty**. This accomplishment will be enabled by increased observation data; improved understanding of the earth system; advances in the

[1] National Center or Atmospheric Research (NCAR), Environmental and Societal Impacts Group, and the Atmospheric Policy Program of the American Meteorological Society, 2001, Extreme Weather Sourcebook 2001: Economic and Other Societal Impacts Related to Hurricanes, Floods, Tornadoes, Lightning, and Other U.S. Weather Phenomena, National Center for Atmospheric Research, Boulder, CO.

speed, accessibility, and reduced cost of information technology; and the pervasiveness and reduced cost of telecommunications technology.

Climate-related products will move increasingly towards outlooks on regional scales that are accompanied by well-described uncertainties. NOAA will conduct and sponsor research to improve our understanding of key processes aimed at reducing uncertainty in predictions, as well as provide a better understanding of predictability and prediction limits. Probabilistic statements about climate outcomes will become standard, and they will be framed in ways that improve their utility for decision-makers and public use.

An improved appreciation of the applicability of seasonal climate forecasts will allow resource managers to better mitigate agricultural and other impacts from flood/drought, promote better water resource management, and combat temperature-sensitive disease propagation. Weather- and climate-sensitive industries account for nearly $3 trillion of the Nation's GDP annually, ranging from finance, insurance, and real estate services, to retail and wholesale trade manufacturing.[2] Other industries that rely either on consumptive or non-consumptive water use, such as agriculture, power generation, water supply and sanitation, flood control, and navigation are pillars of the economy, yet many of the country's large reservoirs are rarely used to full capacity, due in part to the limited accuracy of present-day seasonal climate and stream flow forecasts.

■ **NOAA will provide the scientific underpinning for an ecosystem approach to management of coastal and ocean resources, so that complex societal choices are informed by comprehensive and reliable scientific information.** Our vision includes a sound scientific basis for an array of ecosystem indicators with known meaning, a highly automated observing system to measure indicators, and models that evaluate tradeoffs between multiple sources of ecosystem stress and type of societal costs and benefits. In short, we envision the transition of research into a scientific-knowledge-rich, and technologically- and computationally-intense, system of decision support tools that provide relevant, responsive, and reliable scientific advice and information products, making an ecosystem approach to management operational.

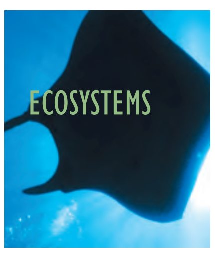
Ecosystem research will enhance understanding of physical/chemical/biological interactions and the ability to link ecosystem capacity and models to environmental variability and change. This understanding is critical to reducing uncertainties associated with ecosystem structure and function. Observing capability will be refined, and new models of physical/biological coupling at various space and time scales will be produced. Understanding of trophic, multi-species links will be advanced, and eventually fully coupled with climate variability and change. Building on this information, NOAA will produce operational forecasts for a suite of ecological conditions including fisheries, anoxia, harmful algal blooms, beach closings, and water quality.

Building better coastal and ocean decision support tools and exploring our vast ocean resources will support the nation's transformation to ecosystem-based management approaches. Key issues are to better manage coastal resources,

[2] Dutton, John A., Opportunities and priorities in a new era for weather and climate services, Bulletin of the American Meteorological Society, September 2002, volume 83, no. 9, pp 1303-1311.

a sample OF NOAA PRODUCTS AND SERVICES IN 2025

ecosystems



- Forecasts and mitigation strategies related to: anoxia/hypoxia, harmful algal blooms, beach closings, invasive species, waves, air/water quality and quantity
- Ecological assessments and predictions of impacts from climate change (e.g., coral bleaching)
- Decision support tools for adaptive, ecosystem-based management of fisheries, coastal development, and marine resources
- Improved assessments of sea level change on coastal resources and ecosystems
- Better integration of observing system data for coastal ecosystem manager use
- Fishery productivity forecasts that incorporate the effects of climate change

climate

- Improved intraseasonal to seasonal to decadal forecasts utilizing Earth System models
- Water resource & drought forecasts including nutrient runoff
- Weather-related disease forecasts (e.g., malaria, SARS, West-Nile virus)
- Projections of sea level change
- Scenarios for future climate mitigation and adaptation studies – including land use changes
- Decision support climate information and assessments

weather & water

- Work with partners to provide neighborhood-level weather forecasts and 10-14 day forecasts as accurate as current 7-10 day forecasts
- Severe thunderstorm and tornado track forecasts at the sub-county level with one hour or more lead time
- Sophisticated air-quality and chemical composition prediction models on regional- and continental-scale air quality and atmospheric chemistry predictions
- Improved stream flow forecasting models that cover flow levels from droughts to floods, including interactions with groundwater, water resources applications, estuaries, and coasts
- New soil moisture forecasting models for agricultural applications and mudslide warnings
- Improved systems for protecting the public from emissions from specific point sources

commerce & transportation

- Real-time atmospheric delay models (tropospheric and ionospheric) to improve real-time GPS positioning at cm-level accuracy
- Higher spatial resolution & accuracy for survey data to support safe navigation and ecosystem studies
- Vehicles/vessels that detect & respond to changing conditions; real-time access to weather information & route-planning tools
- Advanced real-time observational systems coupled with electronic charts, navigation systems, & forecast models
- New tools, technologies, and procedures enhancing safety & capacity in air traffic management practices
- Decision support tools to affect transit time, delivery reliability, efficiency, cost of goods transported, and the health of the environment

reduce/mitigate human impacts, ensure sustainability, and improve human health and quality of life. Improved science-based information will allow us to better manage problems such as variable seafood production, harmful algal blooms, coral reef bleaching events, and ecosystem deterioration by alien and invasive species.

- **NOAA will lead major programs in ocean exploration to benefit the nation.** The world's oceans remain a largely unexplored and unknown opportunity for mankind. Ocean exploration will increasingly characterize the unknown physical, chemical, biological, and geological aspects of our seas, providing new hypotheses in ecosystem and climate research. Discovery of lost shipwrecks and other submerged cultural resources will help modern civilization understand its past, and possibly resolve current mysteries. The oceans will present unexpected opportunities to benefit mankind — perhaps pharmaceuticals mined from ocean biota, new sources of energy generation, or new food resources. Ocean exploration will foster the testing and development of new sensors and platform technologies, and will continue to be on the frontier of our understanding of ocean processes and resources.
- **Weather, location, topographical, and other relevant environmental information will be made available to individual land, air, and sea vehicles in real time.** This accomplishment will be enabled by advances in information and telecommunications technologies including high resolution GPS. On our nation's roadways, adverse weather conditions are associated with over 1.5 million vehicular crashes, which result in 800,000 injuries and 7,000 deaths annually.[3] In addition to the tragic loss of life, significant delays in arrivals of travelers and goods (trucking, rail, transit, air, pipeline, ferry, and airport ground transportation factors) result in considerable economic costs. Adverse weather is responsible for about 70 percent of aviation delays — costing about $4.2 billion annually, much of which could be avoided with better observations and forecasts.[4] Improved transportation forecasts and guidance will not only help reduce accidents, but also save significant costs.

Research to address transportation needs will integrate real-time observations, atmospheric and oceanographic nowcasts/forecasts, and position-tracking information with enhanced interactive visual, electronic, and automated decision-support tools and services. Research will focus on improving the skill, applications, and uncertainty estimates of the models; positional accuracy; and data visualization methods, particularly in the development of new electronic navigational charting products.

Improved navigational tools, real-time observations, and nowcast/forecast oceanographic products coupled with GPS-assisted navigation will provide society with safer and more efficient ports, thus increasing capacity while not decreasing margins of safety to humans, port infrastructure, or to critical habitat and ecosystems.

CURRENT STATE OF NOAA RESEARCH

To place our vision for future research in context, it is worth examining the current state of research in NOAA as framed within NOAA's existing Mission Goal structure (ecosystems, climate, weather and water, commerce and transportation):

ECOSYSTEMS: Possibly our most under-appreciated challenge involves understanding ecosystems where human activity has a principal impact on their dynamics. NOAA has made dramatic strides in the ecosystems area: discovering new habitats (sea mounts, deep sea vents) and exciting new biota with unique chemistries, protecting marine mammals, reg-

[3] Lombardo, Louis, 2000, of the National Highway Traffic Safety Administration. Overview of U.S. Crashes & Environment. Presentation at the WIST II Forum, December 4–6, 2000. Available on the web site of the Office of the Federal Coordinator for Meteorology and Supporting Research, at: http://www.ofcm.gov/wist2/ presentationstartpage1.htm.

[4] 2002 State of the U.S. Airline Industry: A Report on Recent Trends for U.S. Carriers, Air Transport Association, Washington, DC, 2002.

The commercial fishing industry adds approximately $28.5 billion in economic value to the national economy every year

ulating fish stocks, managing coastal habitats, and raising the awareness of oceans and coasts by the American public. However, we need to better understand the cumulative effects on natural systems of unprecedented human growth and development and to create effective means of mitigation so as to sustain ecosystem function. NOAA presently supports or conducts numerous ecosystem-based studies ranging from physical modeling to ecosystem characterization and habitat restoration. Our predictive capability, though, is limited, as is the degree of integration across disciplines. The forcing mechanisms and links between the physical environment and the biosphere must be further explored, studied, and monitored to improve our understanding of fisheries productivity and our management of coastal resources.

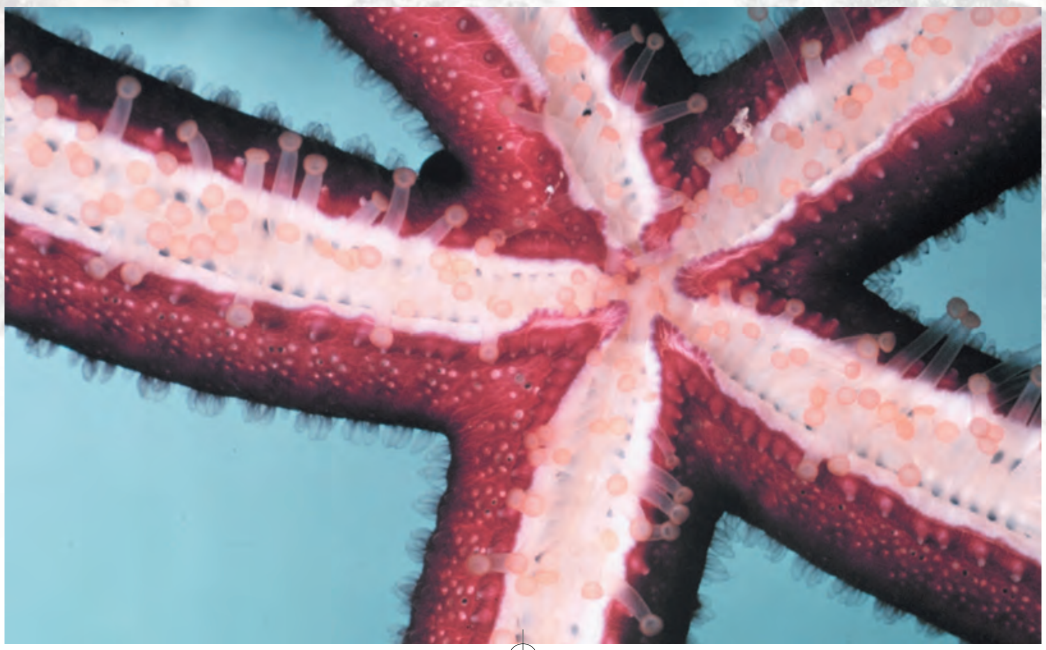
CLIMATE: Climate science has been revolutionized in the past decade. NOAA has helped plan and sponsor the world's most extensive program of scientific research, monitoring, data management, and assessment for climate change and variability. Results include the global characterization of important aspects of Earth's environment; the development of decadal-scale global observations; and significant improvement in the capability of models to project the future evolution of the Earth system, as evidenced by improvements in their ability to simulate variability in the present and recent past. We have made great strides in understanding the El Niño phenomenon, but we have a long way to go to make seasonal forecasts consistently accurate. NOAA uses its global climate models to project future climate change, but uncertainties remain large because of insufficient knowledge about the components of Earth's climate system and the interactions among them. The cycling of water and of carbon through the climate system, long known to be major factors in climate change, is poorly modeled today. Yet, this information is critical to America:[5] U.S. industries that are sensitive to weather and climate events account for one third of the Nation's Gross Domestic Product (GDP),[6] making future changes in climate of vital importance to project and account for in our social and economic planning. NOAA scientists made key contributions to understanding the cause of the depletion of the stratospheric ozone layer, but much remains to be done in predicting the future course of ozone depletion in the context of a changing future climate. Fundamental, long-term research on a broad range of global change issues is, therefore, called for in the next 20 years.

In addition to other benefits, worldwide agriculture benefits of better El Niño forecasts are at least $450 to $550 million per year

WEATHER AND WATER: One of the scientific success stories of the 20th century is the development of numerical weather prediction, and today NOAA produces weather forecasts of proven utility out to a week. On the other hand, tornado warnings are not issued on the basis of forecasts, but rather upon observed evidence. Today's science and technology do not allow scientists to describe the genesis of a tornado, model it, and predict its path — a capability that could save many additional lives. Similarly, while we have dramatically improved the prediction of the track of hurricanes in recent years, our forecasts of their intensity, storm surge, and associated rainfall are less skillful. We provide incipient forecasts of regional air quality in some locations, but we cannot yet predict atmospheric composition on continental scales. In addition, our forecasts of water resources are currently limited to flooding conditions. To be more effective, NOAA will need to enhance its system of information delivery and dissemination. With improved weather information that is effectively delivered in the future, NOAA can not only reduce the costs associated with weather disas-

[5] Weiher, Rodney, ed. Improving El Niño Forecasting: The Potential Economic Benefits, NOAA, U.S. Department of Commerce, 1997.

[6] Dutton, John A., Opportunities and priorities in a new era for weather and climate services, Bulletin of the American Meteorological Society, September 2002, volume 83, no. 9, pp1303-1311.



During the period of 1980-2003, the United States sustained 58 major weather or climate related disasters, with damages and costs exceeding $350 billion

ters, but also increase economic and human benefits, particularly through increasing the forecast accuracy of precipitation and water availability.

COMMERCE AND TRANSPORTATION: The development and implementation of new technologies in the recent past has led to significant advances in safety and efficiency by aircraft, shipping, and ground transportation. There has been a steady decline in weather-related air-craft accidents in the past two decades, in part due to improved understanding and prediction of hazardous weather such as microbursts and icing. The advent of Global Positioning System (GPS) technology has also helped, yet the ability to acquire and process sufficient quantities of timely survey data for ship and land transportation routes, as well as for ecosystem assessment, is severely lacking. Remote sensing technologies and data fusion techniques, although constantly evolving, are presently not able to provide timely updates for navigational products, which also limits the potential of habitat characterization studies. Currently unmet needs include well-organized infrastructure information, charts, maps, and environmental analyses required to handle the increased size and number of vehicles and vessels currently taxing the limits of existing roads, channels, and bridge and cable clearances. How these increased loads may affect the ecosystems being traversed is of increasing concern. These requirements demand advances in electronic navigational products; expanded mapping capabilities and operations; new visualization tools; transportation monitoring systems; and the use of hydrodynamic models using real-time and predicted water level, current, and water density fields.

By 2010, air passenger traffic is expected to increase to one billion annually, a 50 percent increase from 2001

A NEW PARADIGM FOR PREDICTING CHANGES IN GLOBAL ECOSYSTEMS

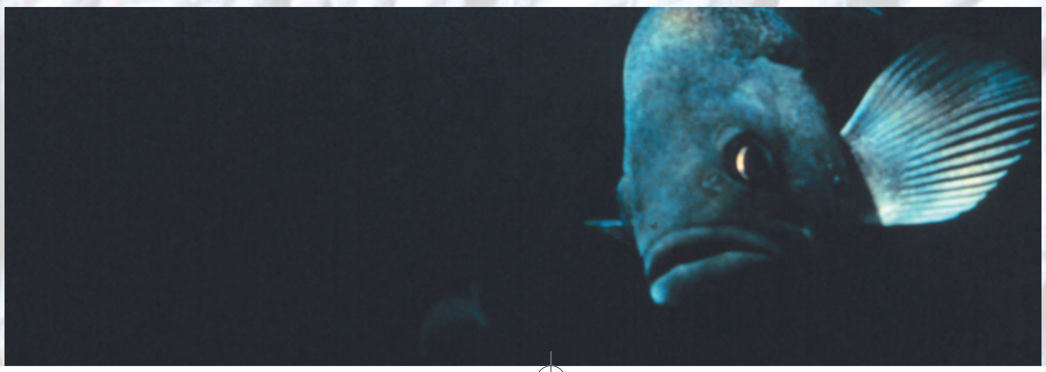
Given the current state of research, our vision for the products and services that NOAA will provide in 2025 requires significant advances in the activities that support our mission:

- Monitor and Observe the land, sea, atmosphere, and space to create an observational and data collection network that tracks Earth's changing systems.
- Understand and Describe how natural systems work together through investigation and interpretation of information.
- Assess and Predict the changes of natural systems and provide information about the future.

v Engage, Advise, and Inform individuals, partners, communities, and industries to facilitate information flow, assure coordination and cooperation, and provide assistance in the use, evaluation, and application of information.

- Manage coastal and ocean resources to optimize benefits to the environment, the economy, and public safety.

As we move further into the 21st century, a substantive integration of research across the current mission goal structure is paramount. The weaving together of NOAA's research for predicting changes in global ecosystems will largely be accomplished through data assimilation and models. NOAA uses models that depict the initial state of a system and project future states (forecasts) based on the laws of physics and thermodynamics or similar principles, along with an estimate of the forces or boundary conditions operating on the system. At present, models have been developed for the atmosphere, oceans, and to a lesser extent the biosphere. Although some success is being achieved in linking these models together to forecast the evolution of the full Earth system, truly holistic models that account for the interactions among all the components of the planet's ecosystems still elude us. These kinds of models and the forecasts they will produce are substantially different from what NOAA now provides the nation, and the creation of such holistic, Earth system models is a major goal of NOAA research in the next 20 years.



PARTNERS IN ACHIEVING THE NOAA VISION

NOAA is committed to collaborating with its current partners and seeking new partners to achieve its vision. With future advances in NOAA's high performance computing capabilities, models will be easily accessible to NOAA's research partners in universities, the private sector, other federal agencies and the international community. Advances in computer technology will allow more distributed modeling activity. This widespread computing and model accessibility (whether centralized or not) will create a rich intellectual environment that will accelerate our ability to understand, describe, assess and predict
the environment.

OPERATIONAL PARTNERS

- At the federal level NOAA will continue to work with the National Aeronautics and Space Administration, the Departments of Defense, Interior, Homeland Security and Energy, the Environmental Protection Agency, and others to gather, analyze, and share environmental data.
- At the state and local level, NOAA will continue to work with emergency managers, water resource managers, fisheries conservation managers, coastal zone managers, and pollution monitoring and abatement experts.
- NOAA will work with non-governmental organizations that are committed to land, estuary, ocean, and living marine resource management.
- NOAA will continue to provide research products and information for collaborative use by the Private Sector.

RESEARCH PARTNERS

- NOAA's federal research partners will continue to include NASA, NSF, EPA, DOE, DOD, and many others.
- NOAA will continue to have broad and symbiotic research relationships with universities through the National Sea Grant College Program, the National Undersea Research Centers, the system of National Estuarine Research Reserves, Cooperative Institutes, and substantial research grants.

- NOAA will also work with the private sector through computing and contracts to create and deploy new environmental sensors.
- NOAA will also collaborate with international partners both to learn and to share research results and techniques.

EDUCATIONAL PARTNERS

- NOAA will continue to depend on its collaborations with universities to advance mission-critical ideas through research and to train the environmental scientists and mangers needed by NOAA and the rest of the nation.
- NOAA will explore establishing a postdoctoral research program for oceans and the atmosphere to increase the availability of environmental researchers. The National Sea Grant College Program, the Coastal Zone Management Act, and the National Marine Sanctuaries Act provide formalized opportunities for NOAA to support educational institutions and learn from them.
- NOAA will continue to provide lesson plans and other tools for teachers to bring the excitement of oceans, coasts, the atmosphere, and the global ecosystem to the classroom.
- NOAA will expand its formal and informal education resources offered to the public and K-12 schools to increase awareness of the importance of healthy oceans and atmosphere.

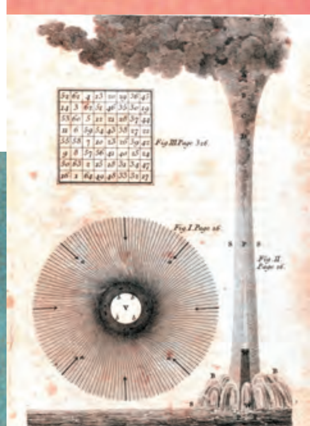
"The oceans will present unexpected opportunities to benefit mankind..."

NOAA Partners for Success: The design and deployment of NOAA Doppler radar in the mid-1990s illustrates the critical dependence of operational advances on research and partnership collaborations. The NOAA Doppler radar was developed jointly by NOAA, the Department of Defense (DOD), and the Department of Transportation (DOT) and was based on research supported primarily by the National Science Foundation and the Department of Defense in the 1970s and 1980s. The specific design and operating parameters of the NOAA Doppler unit was a result of research within NOAA and on contract to private sector organizations. Deployment of the NOAA Doppler radars to NOAA, DOD, and DOT locations provided a more detailed and richer description of the weather. These descriptions energized research in NOAA and universities that enabled enhanced understanding and allowed significantly better predictions of the weather. From 1994 to 1999, NOAA improved its average advance warning time for tornados from 6 to 11 minutes. In that same 5-year period, NOAA was able to improve its average advance warning for flash floods from 18 to 42 minutes.

REFINING THE NOAA 20-YEAR RESEARCH VISION

This document has been designed to present a 20-Year Research Vision of NOAA based on how NOAA advances its ability to predict the global ecosystem, the current state of NOAA research, an assessment of external influences on NOAA, and an assessment of technical opportunities for NOAA.

The 20-Year Research Vision will be updated in the future, in conjunction with NOAA's planning process. As part of this process, NOAA will solicit comments to improve this document. NOAA believes that its Research Vision will benefit greatly from the active participation of our partners in its further development, and NOAA welcomes your ideas, opinions, and inspiration.

"NOAA believes
that its Research Vision

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FOR MORE INFORMATION, PLEASE VISIT THE
NOAA RESEARCH COUNCIL AT:
WWW.NRC.NOAA.GOV

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DEPARTMENT OF COMMERCE
UNITED STATES OF AMERICA

CHART THE future

NOAA's Next Generation Strategic Plan Executive Summary

U.S. DEPARTMENT OF COMMERCE | NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION


NOAA - PMEL
RESCUE AND WORK BOAT LOCKER

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letter FROM THE NOAA ADMINISTRATOR

NOAA's mission is central to many of today's greatest challenges. The state of the economy. Jobs. Climate change. Severe weather. Ocean acidification. Natural and human-induced disasters. Declining biodiversity. Threatened or degraded oceans and coasts. These challenges convey a common message: Human health, prosperity, and well-being depend upon the health and resilience of both managed and unmanaged ecosystems. Combined with the capabilities of our many partners in Government, universities, and the private and nonprofit sectors, NOAA's science, service, and stewardship capabilities can help transition to a future where societies and the world's ecosystems reinforce each other and are mutually resilient in the face of sudden and prolonged change.

We clearly have a long way to go in order to realize this vision. We know much about the steep rise of global greenhouse gases and their current and potential impacts on the environment and on society. But our level of uncertainty about many of these impacts is far too high, particularly at regional to local scales. Our society's ability to mitigate and adapt to a changing climate will require far greater knowledge of climate trends and their impacts than we can deliver currently. At the same level, our ability to sustainably use and protect ocean and coastal resources will drive, in substantial measure, the prosperity, health, and safety of future generations—as will our ability to forecast and predict a wide range of environmental events, from hurricanes and tornados, to regional water supplies and pollutants along our coasts.

All of these challenges entail problems at the intersection of society, economy, and the environment—where NOAA's mission has its greatest impact. My optimism about the future is rooted in NOAA's long-standing record of science, service, and stewardship. We must address challenges and opportunities proactively and shape a better future for generations to come. This is the purpose of NOAA's Next Generation Strategic Plan.

The Plan conveys NOAA's mission and vision of the future, the national and global issues NOAA must address, the specific outcomes NOAA aims to help society realize, and the actions that the Agency must undertake. It emerged from extensive consultations with NOAA employees and our stakeholders—the extended community of partners and collaborators in the public, private, and academic sectors who contribute to NOAA's mission. In stakeholder forums across the country; a national forum in Washington, DC; as well as in Web-based engagement and idea generation, we took a fresh look at the major trends facing the Nation to stimulate our best thinking on how NOAA might respond.

Informed by these consultations, the Plan represents our assessment of the highest priority opportunities for NOAA to contribute substantially to the advancement of society. The availability and quality of fresh water, the exposure of people and communities to high impact weather, stresses of urbanization of the coasts, the exploitation of ocean and coastal resources, and above all the pervasive effects of climate change on society and the environment—these are the central challenges we must face if we are to improve human welfare and sustain the ecosystems upon which we depend. These are the challenges that define NOAA's strategic goals. Through the concerted efforts of NOAA and many other organizations, we can navigate our way toward a future where people, communities, and ecosystems prosper and are resilient in the face of change.

Thank you for engaging in NOAA's strategy. Your continued interest and involvement in NOAA is vital to the work of the Agency and to the health of our society, economy, and environment.

Jane Lubchenco, Ph.D.
UNDERSECRETARY OF COMMERCE FOR OCEANS AND ATMOSPHERE

NOAA'S mission

- To understand and predict changes in climate, weather, oceans, and coasts,
- To share that knowledge and information with others, and
- To conserve and manage coastal and marine ecosystems and resources.

NOAA generates tremendous value for the Nation—and the world—by advancing our ability to understand and anticipate changes in the Earth's environment, improving society's ability to make scientifically informed decisions, and by conserving and managing ocean and coastal ecosystems and resources. NOAA's world-class research and information services continuously advance our scientific understanding of a changing climate and its impacts. NOAA monitors and models the environment to forecast daily weather; warn us of hurricanes, tornados, and tsunamis; and support private enterprise with the information necessary to sustain economic growth. NOAA manages the Nation's fisheries and supports the responsible management of coastal habitats and species. NOAA makes key contributions to our understanding of the processes by which ecosystems provide services crucial for human survival on Earth, and in helping to educate businesses and Federal, State, and local decision makers about how the health of human society and the health of the environment are interconnected. These functions require satellite systems, ships, buoys, aircraft, research facilities, high-performance computing, and information management and distribution systems. NOAA provides research-to-application capabilities that recognize and apply significant new understanding to questions, develop research products and methods, and apply emerging science and technology to user needs. NOAA invests in and depends heavily on the science, management, and engagement capabilities of its partners. NOAA's organizational enterprise—its people, infrastructure, research, and partnerships—are essential for NOAA to achieve its vision, mission, and long-term goals.

Science at NOAA is the systematic study of the structure and behavior of the ocean, atmosphere, and related ecosystems; integration of research and analysis; observations and monitoring; and environmental modeling. Science provides the foundation and future promise of the service and stewardship elements of NOAA's mission.

Service is the communication of NOAA's research, data, information, and knowledge for use by the Nation's businesses, communities, and people's daily lives.

Stewardship is NOAA's direct use of its knowledge to protect people and the environment, as the Agency exercises its authority to regulate and sustain marine fisheries and their ecosystems, protect endangered marine and anadromous species, protect and restore habitats and ecosystems, conserve marine sanctuaries and other protected places, respond to environmental emergencies, and aid in disaster recovery.

NOAA'S vision of the future

Healthy ecosystems, communities, and economies that are resilient in the face of change

Earth's ecosystems support people, communities, and economies. Our own human health, prosperity, and well-being depend upon the health and resilience of natural and social ecosystems. Managing this interdependence requires timely and usable scientific information to make decisions. Human well-being requires preparing for and responding to changes within these natural systems. NOAA's mission of science, service, and stewardship is directed to a vision of the future where societies and their ecosystems are healthy and resilient in the face of sudden or prolonged change.

A vision of resilience will guide NOAA and its partners in a collective effort to reduce the vulnerability of communities and ecological systems in the short-term, while helping society avoid or adapt to potential long-term environmental, social, and economic changes. To achieve this vision we must understand current Earth system conditions, project future changes, and help people make informed decisions that reduce their vulnerability to environmental hazards and stresses that emerge over time, while at the same time increase their ability to cope with them.

Resilient human communities and economies maintain or improve their health and vitality over time by anticipating, absorbing, diffusing, and adapting to change. Resilient communities and institutions derive goods from ecosystems in a way that does not compromise ecosystem integrity, yet is economically feasible and socially just for future generations. To this end, NOAA will focus on four long-term goals that are central determinants of resilient ecosystems, communities, and economies—and that cannot be achieved without the Agency's distinctive mission and capabilities.

The objectives identified in the Plan are the basis for NOAA's corporate planning, performance management, and stakeholder engagement over the next five years. Objectives are specific outcomes NOAA can achieve on the path to broader, long-term goals and toward a more capable, flexible enterprise. They are measureable and can be affected by specified activities over a 5-year period. Evidence of Progress for each Objective—found in the full version of this Plan—form the basis of outcome-oriented performance measures. NOAA's Line Offices and Staff Offices are be accountable for executing the strategy laid out in this document through implementation plans at a tactical (rather than strategic) level of detail. Where there are shared capabilities to achieve an objective, there is also joint accountability for budgeting, executing, and performing toward that objective.

long-term goal

CLIMATE ADAPTATION AND MITIGATION

An informed society anticipating and responding to climate and its impacts

Projected future climate-related changes include increased global temperatures, melting sea ice and glaciers, rising sea levels, increased frequency of extreme precipitation events, acidification of the oceans, modifications of growing seasons, changes in storm frequency and intensity, air quality, alterations in species' ranges and migration patterns, earlier snowmelt, increased drought, and altered river flow volumes. Impacts from these changes are regionally diverse, and affect numerous sectors related to water, energy, transportation, forestry, tourism, fisheries, agriculture, and human health.

These changes already have profound implications for society, underscoring the need for scientific information to aid decision makers develop and evaluate options that mitigate the human causes of climate change and adapt to foreseeable climate impacts. While the Nation has made significant progress in understanding climate change and variability, more work is needed to identify causes and effects of these changes, produce accurate predictions, identify risks and vulnerabilities, and inform decision making. No single organization can accomplish these tasks alone. NOAA will advance this long-term goal of climate adaptation and mitigation as it builds upon a strong scientific foundation and decades of engagement with interagency, academic, and private sector partners.

NOAA is a national leader on the Intergovernmental Panel on Climate Change and, at the Federal level works with the Interagency Climate Change Adaptation Task Force and the U.S. Global Change Research Program. Recipients of NOAA's climate science and services include the Environmental Protection Agency and Agencies within the U.S. Departments of Energy, State, Agriculture, Transportation, Interior, Health and Human Services, Homeland Security, and Defense. NOAA also partners with the National Aeronautics and Space Administration to develop satellite technology that detects climate trends. Sustained partnerships among Federal Agencies, international, State, local and tribal governments, academia, non-governmental organizations, and the private sector are required to meet the objectives of this goal.

objectives

Improved scientific understanding of the changing climate system and its impacts

Assessments of current and future states of the climate system that identify potential impacts and inform science, service, and stewardship decisions

Mitigation and adaptation choices supported by sustained, reliable, and timely climate services

A climate-literate public that understands its vulnerabilities to a changing climate and makes informed decisions

long-term goal

WEATHER-READY NATION

Society is prepared for and responds to weather-related events

A weather-ready nation is a society that is able to prepare for and respond to environmental events that affect safety, health, the environment, economy, and homeland security. Urbanization and a growing population increasingly put people and businesses at greater risk to the impacts of weather, water, and climate-related hazards. NOAA's capacity to provide relevant information can help create a society that is more adaptive to its environment; experiences fewer disruptions, dislocation, and injuries; and that operates a more efficient economy.

Over the long-term, climate change may increase the intensity and even the frequency of adverse weather events, which range from drought and floods, to wildfires, heat waves, storms, and hurricanes. Changing weather, water, and climate conditions affect the economic vitality of communities and commercial industries, including the energy, transportation, and agriculture sectors. Environmental information aligned with user needs will become ever more critical to the safety and well-being of those exposed to sudden or prolonged hazards and is essential to sustain competitive advantage, expand economic growth, and to secure the Nation.

Achieving a weather-ready nation requires the work of NOAA, and the combined efforts of numerous public, private, and academic partners. The dissemination, communication, and validation of NOAA forecasts and warnings depend on the media, the emergency management community, and the U.S. weather and climate industry. NOAA views this diverse and growing industry of companies, media outlets, and others that create weather programming, provide consulting services, and deliver information to American society as a key strategic partner, which provides valuable services to many businesses while also being an important economic sector in its own right.

objectives

Reduced loss of life, property, and disruption from high-impact events

Improved freshwater resource management

Improved transportation efficiency and safety

Healthy people and communities due to improved air and water quality services

A more productive and efficient economy through environmental information relevant to key sectors of the U.S. economy

long-term goal

HEALTHY OCEANS

Marine fisheries, habitats, and biodiversity sustained within healthy and productive ecosystems

Ocean ecosystems provide many benefits to humans. Yet our marine, coastal, and Great Lakes environments are already stressed by human uses. Habitat changes have depleted fish and shellfish stocks, put more species at-risk, and reduced biodiversity. As long-term environmental, climate, and population trends continue, global demands for seafood and energy, recreational use of aquatic environments, and other pressures on habitats and over-exploited species will increase. Depleted fish stocks and declines in iconic species (such as killer whales, salmon, and sea turtles) result in lost opportunities for employment, economic growth, and recreation along the coasts. In addition, climate change impacts to the ocean, including sea level rise, acidification, and warming, will alter habitats and the relative abundance and distribution of species. Climate change poses serious risks to coastal and marine ecosystems productivity, which, in turn, affects recreational, economic, and conservation activities.

A strong understanding of ocean, estuarine and related ecosystems—and the species that inhabit them—supports NOAA's approach to management, and accounts for the complex connections among organisms (including humans); their physical, biotic, cultural, and economic environments; and the wide range of processes that control their dynamics. An ecosystem-based approach will assist policy makers to weigh trade-offs between alternative courses of action. By working toward the long-term sustainability of all species, NOAA will also help ensure for present and future generations that seafood is a safe, reliable, and affordable food source; that seafood harvest and production, recreational fishing opportunities, and non-consumptive uses of living marine resources continue to support vibrant coastal communities and economies; and that species of cultural and economic value can flourish.

Achieving healthy and sustainable ocean ecosystems will require strong coordination and integration across NOAA and with Federal, State, local, and tribal stakeholders. Collaboration with academic institutions, non-governmental organizations, Federal agencies, and NOAA's operational and research programs will help to provide the scientific foundation for ocean resource management decisions and strengthen ecosystem science.

objectives

Improved understanding of ecosystems to inform resource management decisions

Recovered and healthy marine and coastal species

Healthy habitats that sustain resilient and thriving marine resources and communities

Sustainable fisheries and safe seafood for healthy populations and vibrant communities

long-term goal

RESILIENT COASTAL COMMUNITIES AND ECONOMIES

Coastal and Great Lakes communities are environmentally and economically sustainable

The complex interdependence of ecosystems and economies will grow with increasing uses of land, marine, and coastal resources, resulting in particularly heavy economic and environmental pressures on the Nation's coastal communities. Continued growth in coastal populations, economic expansion, and global trade will further increase the need for safe and efficient maritime transportation. Similarly, the Nation's profound need for conventional and alternative energy presents many economic opportunities, but will also result in greater competition for ocean space, challenging our ability to make informed decisions that balance conflicting demands as well as economic and environmental considerations. At the same time, the interdependence of ecosystems and economies makes coastal and Great Lakes communities increasingly vulnerable to chronic—and potentially catastrophic—impacts of natural and human-induced hazards, including climate change, oil spills, harmful algal blooms and pathogen outbreaks, and severe weather hazards.

NOAA envisions invigorated coastal communities and economies, with increased resiliency and productivity. Comprehensive planning will help protect coastal communities and resources from the impacts of hazards and land-based pollution to vulnerable ecosystems by addressing competing uses, improving water quality, and fostering integrated management for sustainable uses. Geospatial services will support communities, navigation, and economic efficiency with accurate, useful characterizations, charts and maps, assessments, tools, and methods. Coastal decision makers will have the capacity to adaptively manage coastal communities and ecosystems with the best natural and social science available.

Resilient coastal communities and economies cannot be achieved without strong partnerships. NOAA will build on existing strategic partnerships in our coastal communities with other Federal Agencies (such as the U.S. Coast Guard) to help provide services to adapt to coastal hazards and provide safe conditions in the Arctic, the DOI to conserve and manage special marine and coastal places, and the EPA and USDA to improve coastal water quality and encourage smart growth. Comprehensive ocean and coastal planning also will require an unprecedented level of engagement and collaboration with state, local and tribal partners, as well as a wide range of stakeholders in the private and academic sectors.

objectives

Resilient coastal communities that can adapt to the impacts of hazards and climate change

Comprehensive ocean and coastal planning and management

Safe, efficient and environmentally sound marine transportation

Improved coastal water quality supporting human health and coastal ecosystem services

Safe, environmentally sound Arctic access and resource management

NOAA'S

enterprise-wide capabilities

NOAA's strategy would be incomplete without detailing the enterprise-wide capabilities that will be required to achieve the environmental, social, and economic outcomes targeted by NOAA's strategic goals. NOAA's enterprise-wide capabilities consist of three groups:

- **Science and technology**—NOAA's vision centers on a holistic understanding of the interdependencies between human health and prosperity, and the intricacies of the Earth system. Achieving this level of understanding presents an overarching, long-term scientific and technical challenge to NOAA: *to develop and apply holistic, integrated Earth system approaches to understand the processes that connect changes in the atmosphere, ocean, space, land surface, and cryosphere with ecosystems, organisms, and humans over different scales.*
- **Engagement**—The best way for NOAA to meet the increasingly complex needs of its stakeholders is often to deliver data and knowledge to those who have not yet accessed it. NOAA must understand these needs at all levels—within the U.S. and abroad—and respond to them. Conversely, NOAA's next breakthrough in research, development, operational improvement, or policy action may depend on the unique knowledge or needs of a partner or customer.
- **Organization and administration**—NOAA's managers, at headquarters and in the field, have common responsibilities to manage the investment of taxpayer dollars, deploy physical infrastructure, and retain a qualified workforce. NOAA's managerial efforts provide the rest of the Agency with the staff, the infrastructure, and the financial capital needed to get the job done. Effective management of these resources fosters an organizational environment in which core competencies are used most effectively and final products and services have the greatest impact.

These capabilities represent cross-cutting requirements that support NOAA's strategic goals as a whole.

enterprise-wide capability

SCIENCE AND TECHNOLOGY

Over the long-term, drawing upon its world-class research, observation, and modeling capabilities, NOAA is uniquely positioned to:

- Acquire and incorporate knowledge of human behavior to enhance understanding of the interaction between human activities and the Earth system.
- Understand and quantify the interactions between atmospheric composition and climate variations and change.
- Understand and characterize the role of the oceans in climate change, and variability and the effects of climate change on the ocean and coasts.
- Assess and understand the roles of ecosystem processes and biodiversity in sustaining ecosystem services.
- Improve understanding and predictions of the water cycle from global to local scales.
- Develop and evaluate approaches to substantially reduce environmental degradation.
- Sustain and enhance atmosphere-ocean-land-biology and human observing systems.
- Characterize the uncertainties associated with scientific information.
- Communicate scientific information and its associated uncertainties accurately and effectively to policy makers, the media, and the public at large.

To address this long-term challenge and meet the near-term science requirements within and across its strategic goals, NOAA must simultaneously pursue three objectives within its core scientific and technical enterprise: a holistic understanding of the Earth system, accurate and reliable data from sustained and integrated Earth observing systems, and an integrated environmental modeling framework.

objectives

A holistic understanding of the Earth system through research

Accurate and reliable data from sustained and integrated Earth observing systems

An integrated environmental modeling system

enterprise-wide capability

ENGAGEMENT

Achieving NOAA's goals involves garnering support from domestic and international partners through engagement.

NOAA's capacity to engage individuals and other organizations effectively will determine its long-term success. It is not sufficient for NOAA to conduct, fund, and direct science. NOAA must be aware of science conducted, funded, and directed by others and must integrate and convert that scientific information into applications used within the Agency, and accepted and recognized by the scientific community world-wide, then harness its stewardship responsibilities by meeting society's broader needs for more information. Scientists must solicit management needs as early as possible in the design of research with a constant eye toward management's potential use of research results. Scientists must engage with their peers, but also with colleagues around the world, in other disciplines, and with the public at large. Managers of NOAA's environmental data and information services must engage with decision makers in local governments and industries. Regulators must engage with communities they regulate, as well as with their regulatory counterparts in other nations. NOAA must also engage with constituents, educators, and communicators to share knowledge and information.

objectives

An engaged and educated public with an improved capacity to make scientifically informed environmental decisions

Integrated services meeting the evolving demands of regional stakeholders

Full and effective use of international partnerships and policy leadership to achieve NOAA's mission objectives

enterprise-wide capability

ORGANIZATION AND ADMINISTRATION

At the heart of NOAA operations is the creative work of scientists, engineers, technicians, managers, NOAA Corps Officers, and administrative staff. Only by investing in this stock of intellectual capital can NOAA achieve its strategic goals to provide the public with scientific knowledge, information services, incident response, and environmental stewardship capabilities.

NOAA's mission also requires a transformed, agile, service-oriented, and secure IT infrastructure to propel its scientific and operational goals with advanced computing capabilities. World-class delivery of reliable and scalable IT services is essential to meet growing demands and to process and disseminate ever-increasing volumes and types of environmental information efficiently.

NOAA's research, operations, and management functions are conducted in specialized facilities located across the Nation and internationally. From highly-specialized laboratories to state-of-the-art data and computing centers, from satellite operations to energy-efficient offices, NOAA must ensure its facilities provide modern, sustainable, and safe environments to fulfill its mission successfully and to attract and retain a high-performance workforce.

NOAA's unique mission is particularly resource intensive, requiring diverse investments in land, structures, satellites, ships, aircraft, unmanned systems, sensors, equipment, software, and IT. In addition to its physical infrastructure, a large part of NOAA's mission requires investing in the capabilities of its partners through grants, cooperative agreements, and contracts. Successfully managing these systems and partnerships to operate efficiently and effectively over their entire life cycle requires a long-term perspective.

objectives

Diverse and constantly evolving capabilities in NOAA's workforce

A modern IT infrastructure for a scientific enterprise

Modern, safe, and sustainable facilities

A high-performing organization with integrated, efficient, and effective business systems and management processes

NOAA'S strategy execution and evaluation

The Next Generation Strategic Plan identifies what NOAA should produce in the future (i.e., outputs), and why those outputs are important (i.e., outcomes). Distinguishing between outputs and outcomes gives NOAA the flexibility to evolve while staying true to its ultimate mission and vision. The Plan will facilitate:

- Well-reasoned, transparent decision-making and investment choices based on priorities,
- Alignment of requirements for resources with requirements for products and services,
- Monitoring the effectiveness of outputs in contributing to societal outcomes, and
- Common understanding of roles, responsibilities, and the meaning of "success."

NOAA will systematically monitor and evaluate its performance toward the outcome-oriented goals and objectives in the Plan. Evaluating performance will allow NOAA to learn from its successes and failures, improve continually as an organization, and deliver better on the promise of its mission of science, service, and stewardship. NOAA's performance measures, including those required under the Government Performance and Results Act, are published annually in the NOAA Annual Performance Plan and Performance Accountability Report.

NOAA's Next Generation Strategic Plan supports the U.S Department of Commerce (DoC) Strategic Plan and Annual Performance Plan. A direct relationship between NOAA's goals, objectives and performance measures is included in the annual budget submission to DoC. DoC uses this information for its Annual Performance Plan and Performance and Accountability Report, which integrate outcomes and performance measures across the Department.

For further information on the analyses used in developing the Plan, including NOAA's *Scenarios for 2035 and the results of NOAA's extensive stakeholder consultations, please visit:* www.noaa.gov/ngsp.


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acknowledgements

NOAA's Next Generation Strategic Plan emerged from extensive consultations with NOAA employees and our stakeholders. NOAA acknowledges the valuable input that staff and stakeholders provided in public forums and online. We also thank NOAA's Federal Advisory Committees and our partners in numerous trade associations for their input and feedback on early drafts of the Plan. And we thank the representatives from NOAA Line and Staff Offices who served on the Scenario Team, Plan Steering Committee, Working Group, and Communications Team.

RESILIENCE IN THE FACE OF CHANGE

NOAA's Next Generation Strategic Plan
Executive Summary

www.noaa.gov/ngsp

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Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC

Executive Summary

1. Introduction

The Global Climate Observing System (GCOS), in consultation with its partners, has prepared an implementation plan that addresses the requirements identified in the Second Report[1] on the Adequacy of Global Observing Systems for Climate in Support of the United Nations Framework Convention on Climate Change (UNFCCC) (hereafter called the 'Second Adequacy Report'). This plan specifically responds to the request of the Conference of the Parties (COP) to the UNFCCC in its decision 11/CP.9 to develop a 5- to 10-year implementation plan. As requested, the implementation plan (the Plan):

- Builds on the Second Adequacy Report and draws on the expressed views of Parties with respect to that report;
- Takes into consideration existing global, regional and national plans, programmes and initiatives, including those of the European Global Monitoring for Environment and Security programme and the Integrated Global Observing Strategy Partnership, as well as the plans of the Group on Earth Observations;
- Is based on extensive consultations with a broad and representative range of scientists and data users, including an open review of the Plan before its completion;
- Includes indicators for measuring its implementation;
- Identifies implementation priorities and resource requirements.

2. Meeting the Needs of the UNFCCC for Climate Information

This Plan, if fully implemented by the Parties both individually and collectively, will provide those global observations of the Essential Climate Variables and their associated products, to assist the Parties in meeting their responsibilities under Articles 4 and 5 of the UNFCCC. In addition, it will provide many of the essential observations required by the World Climate Research Programme and Intergovernmental Panel on Climate Change. Specifically the proposed system would provide information to:

- Characterize the state of the global climate system and its variability;
- Monitor the forcing of the climate system, including both natural and anthropogenic contributions;
- Support the attribution of the causes of climate change;
- Support the prediction of global climate change;
- Enable projection of global climate change information down to regional and local scales;
- Enable characterization of extreme events important in impact assessment and adaptation, and to the assessment of risk and vulnerability.

As noted in the Second Adequacy Report, **"Without urgent action and clear commitment of additional resources by the Parties, the UNFCCC and intergovernmental and international agencies, the Parties will lack the information necessary to effectively plan for and manage their response to climate change"**.

[1] The Second Report on the Adequacy of the Global Observing Systems for Climate in Support of the UNFCCC, GCOS-82, April 2003 (WMO/TD No. 1143).

2.1. Essential Climate Variables

The Second Adequacy Report established a list of the Essential Climate Variables (ECVs) (see Table 1) that are both currently feasible for global implementation and have a high impact on the requirements of the UNFCCC. Clearly, there are additional climate variables that are important to a full understanding of the climate system. Many of these are the subjects of current on-going research, but are not currently ready for global implementation on a systematic basis. As our knowledge and capabilities develop, it is expected that some of these variables will be added to the list of ECVs.

Table 1. Essential Climate Variables that are both currently feasible for global implementation and have a high impact on UNFCCC requirements.

Domain	Essential Climate Variables
Atmospheric (over land, sea and ice)	**Surface:** Air temperature, Precipitation, Air pressure, Surface radiation budget, Wind speed and direction, Water vapour. **Upper-air:** Earth radiation budget (including solar irradiance), Upper-air temperature (including MSU radiances), Wind speed and direction, Water vapour, Cloud properties. **Composition:** Carbon dioxide, Methane, Ozone, Other long-lived greenhouse gases[2], Aerosol properties.
Oceanic	**Surface:** Sea-surface temperature, Sea-surface salinity, Sea level, Sea state, Sea ice, Current, Ocean colour (for biological activity), Carbon dioxide partial pressure. **Sub-surface:** Temperature, Salinity, Current, Nutrients, Carbon, Ocean tracers, Phytoplankton.
Terrestrial[3]	River discharge, Water use, Ground water, Lake levels, Snow cover, Glaciers and ice caps, Permafrost and seasonally-frozen ground, Albedo, Land cover (including vegetation type), Fraction of absorbed photosynthetically active radiation (fAPAR), Leaf area index (LAI), Biomass, Fire disturbance.

2.2. Implementation Actions and Associated Cost Implications

The Plan includes over a hundred specific actions to be undertaken over the next 10 years, across the three domains. Many of the proposed actions are already underway, at the least as part of research activities, and most of the required coordination mechanisms have been identified. The costs of undertaking these actions are summarized in Table 2 by cost and type of action. Priority should be given over the first 5 years to those actions that will address the critical issues identified within the Second Adequacy Report, specifically improving access to high-quality global climate data; generating integrated global analysis products; improving key satellite and *in situ* networks; and strengthening national and international infrastructure, including the enhancing of the full participation of least-developed countries and small island developing states.

[2] Including nitrous oxide (N_2O), chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6), and perfluorocarbons (PFCs).

[3] Includes runoff ($m^3\ s^{-1}$), ground water extraction rates ($m^3\ yr^{-1}$) and location, snow cover extent (km^2) and duration, snow depth (cm), glacier/ice cap inventory and mass balance ($kg\ m^{-2}\ yr^{-1}$), glacier length (m), ice sheet mass balance ($kg\ m^{-2} yr^{-1}$) and extent (km^2), permafrost extent (km^2), temperature profiles and active layer thickness, above ground biomass (t/ha), burnt area (ha), date and location of active fire, burn efficiency (%vegetation burned/unit area).

The Plan is both technically feasible and cost-effective in light of the societal and economic importance of climate observations to the considerations of the UNFCCC. It involves global extension and improved operating practices for observing systems that are currently supported and functioning for other purposes. While its implementation is dependent on national efforts, success will be achieved only with international cooperation, coordination and in some cases, sustained technical and financial support for the key global reference observation sites in least-developed countries. While the Plan focuses on meeting global requirements, such global data and products are also relevant to regional and local needs. In the case of extreme events, which are usually of a small scale and/or short-lived, the Plan provides for global estimates of many such phenomena. Finally, the Plan will be updated over time as networks and systems become operational and as new knowledge and techniques become available.

Table 2. Summary of incremental annually recurring costs (in US-$).

Cost Category*	Number of Common Actions	Number of Atmospheric Actions	Number of Oceanic Actions	Number of Terrestrial Actions	Total
I – <100K	4	8	7	11	30
II – 100K-1M	8	4	11	13	34
III – 1M-10M	2	11	17	11	42
IV – 10M-30M	1	8	6	2	17
V – 30M-100M	0	1	0	0	1
Uncosted Actions[4]	6	-	-	-	6
Total Number	21	32	41	37	131
Estimated total cost profile[5]	**34.4M**	**282.8M**	**211.2M**	**102.6M**	**631.0M**

*K: 1000s of US-$, while M: 1 000 000s of US-$.

The estimated costs are incremental to the expected future support of the current observing systems and associated infrastructure. The cost estimates include both the costs of transition of current systems from research to operations as well as those wholly associated with new systems. The new observations and infrastructure for climate will serve many applications other than just the climate needs of the Parties. For example, as the climate component of the proposed Global Earth Observation System of Systems (GEOSS), they would meet the needs of many other GEOSS applications. Satellites, though a major cost item accounting for some 40% of the total cost profile, provide unique global coverage. In all cases the costs noted are simply indicative and would need to be refined by those charged with executing the actions.

Key Action 1: Parties need, both individually and collectively, to commit to the full implementation of the global observing system for climate, sustained on the basis of a mix of high-quality satellite measurements, ground-based and airborne *in situ* and remote-sensing measurements, dedicated analysis infrastructure, and targeted capacity-building.

3. Agents for Implementation

The global observing system for climate requires observations from all domains – terrestrial, oceanic, and atmospheric – which are then transformed into products and information through analysis and integration in both time and space. Since no single technology or source can provide all the needed observations, the ECVs will be provided by a composite system of *in situ* instruments on the ground, on ships, buoys, floats, ocean profilers, balloons, samplers, and aircraft, as well as from all forms of remote sensing including satellites. Meta-data (i.e., information on where and how the observations are taken) are absolutely essential, as are historical and palaeo-climatic records that set the context

[4] Costs covered in domain actions.

[5] Estimated total cost profile assumes average costs (in US-$) of 0.1M for Category I actions, 0.5M for Category II, 5.0M for Category III, 20.0M for Category IV, and 65.0M for Category V.

for the interpretation of current trends and variability. Although these individual activities are to be coordinated internationally through a variety of programmes, organizations and agencies, success will depend mainly on national and regional entities that will translate the Plan into reality. Collectively, all of these entities are referred to in the Plan as the 'Agents for Implementation'.

The Plan outlines a comprehensive programme that marshals contributions from virtually all countries and organizations dealing with Earth observations and requires continuing and strengthened coordination and performance monitoring. An International Project Office is needed to help coordinate the activities of the component elements of the system, to interact with regional bodies addressing aspects of the Plan, to monitor the performance of the system, to identify deficiencies in the system, and to coordinate measures to correct such deficiencies. It could also oversee the implementation of the GCOS Cooperation Mechanism (see Section 3.4 in the Executive Summary).

Key Action 2: Parties need to provide support for an International Project Office to provide overall coordination, to monitor performance, to report regularly on implementation, to initiate corrective actions, and to oversee the GCOS Cooperation Mechanism.

3.1. International Agents

The networks, systems, data centres and analysis centres identified within this Plan are almost all funded, managed and operated by national entities within their own requirements, plans, procedures, standards and regulations. This Plan calls on all contributing networks and systems to respond to the actions contained in it and, where appropriate, to adjust their plans, procedures and operations to address the specified climate observing requirements. GCOS will continue to emphasize with all relevant international and intergovernmental organizations the need for their Members to: (a) undertake coordination and planning for systematic climate observations where this is not currently being undertaken; and (b) produce and update on a regular basis plans for their contributions to the global observing system for climate, taking into account the actions included in this Plan. For this to be effective, it will also be essential for the Parties to ensure that their requirements for climate observations are communicated to these international and intergovernmental organizations.

Key Action 3: The international and intergovernmental organizations need to incorporate the relevant actions in this Plan within their own plans and actions.

3.2. Regional Agents

For some observations, regional planning and implementation of climate observing system components is particularly effective as a means of sharing workloads and addressing common issues. The GCOS Regional Workshop Programme has established a framework for interested nations to work together to optimize their networks and to identify both national and GCOS network needs in each region. Regional Action Plans, one of the outputs of these workshops, are being developed and some elements of them are finding support from member nations and/or donors for implementation.

Key Action 4: Parties need to complete development and alignment of Regional Action Plans for observations in the context of this Plan.

3.3. National Agents

The needs of the UNFCCC and other users for global climate observations and products can be addressed only if plans are developed and implemented in a coordinated manner by national organizations. As noted in the Second Adequacy Report, with the exception of the main meteorological networks and the planning for individual activities, most climate-observing system activities are poorly coordinated, planned and integrated at the national level. All Parties need national coordination mechanisms and national plans for the provision of systematic observation of the climate system. Such mechanisms are usually best sustained when national coordinators or focal points[6] are designated and assigned responsibility to coordinate planning and implementation of systematic climate observing systems across the many departments and agencies involved with their provision.

[6] The GCOS Steering Committee has developed guidelines for such functions.

Key Action 5: Parties are requested to undertake national coordination and planning and produce national plans on their climate observing, archiving and analysis activities that address this Plan.

Reporting by the Parties[7] on systematic climate observation activities as part of their National Communications under the UNFCCC is essential for planning and monitoring the implementation of the global observing system for climate. The response by Parties to the Second Adequacy Report emphasized that accurate and credible information relative to all aspects of climate observations must be exchanged, according to the relevant guidelines (decisions 4/CP.5 and 11/CP.9).

Key Action 6: Parties are requested to submit information on their activities with respect to systematic observation of all ECVs as part of their national communications to the UNFCCC utilizing an updated Supplementary Reporting Format.

3.4. Participation by all Parties

Recognizing the common requirement for information on climate variability and change, the need for all Parties to improve global observing systems for climate in developing countries has been a consistent theme in the considerations by COP on systematic observation. There are many ways that systems can be improved, including for example through developed-country agencies working with organizations and personnel from developing countries, and the donation of equipment and the training of personnel. The GCOS Cooperation Mechanism has been established by a core set of countries to provide a coordinated, multigovernmental approach to address the high-priority needs for stable long-term funding for key elements of the global observing system for climate, especially in least-developed countries, small island developing states and some countries with economies in transition. It will complement and work in cooperation with existing funding and implementation mechanisms (e.g., the World Meteorological Organization (WMO) Voluntary Cooperation Programme, the United Nations Development Programme, and the many national aid agencies), many of which deal with climate-related activities and support capacity-building in particular.

Key Action 7: Parties are requested to address the needs of least-developed countries, small island developing states and some countries with economies in transition for taking systematic climate observations by encouraging multilateral and bilateral technical cooperation programmes to support global observing systems for climate and by participating in the GCOS Cooperation Mechanism.

4. Access to Climate Data

4.1. High-Quality Climate Data

Ensuring that high-quality climate data records are collected, retained and made accessible for use by current and future generations of scientists and decision-makers is a key objective of this Plan. As a result, investment in the data management and analysis components of the system is as important as the acquisition of the data. The Plan calls for strengthening the current International Data Centres[8] and seeking commitments for new Centres so that all ECVs have an appropriate infrastructure.

Key Action 8: Parties need to ensure that International Data Centres are established and/or strengthened for all ECVs.

The flow of data to the user community and to the International Data Centres is not adequate for many ECVs, especially for those of the terrestrial observing networks. Lack of national engagement and/or resources, restrictive data policies, and inadequate national and international data-system infrastructure are the main causes of the inadequacy.

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[7] Reports are available through the UNFCCC Secretariat.

[8] International Data Centres are responsible for monitoring, product preparation and dissemination as well as archiving.

In decision 14/CP.4, the COP urged Parties to undertake free and unrestricted exchange of data to meet the needs of the Convention, recognizing the various policies on data exchange of relevant intergovernmental and international organizations. Yet, as the Second Adequacy Report points out repeatedly with respect to almost all of the variables, the record of many Parties in providing full access to their data is poor. This Plan is based on the free and unrestricted exchange of all data and products and incorporates actions to: develop standards and procedures for meta-data and its storage and exchange; to ensure timely, efficient and quality-controlled flow of all ECV data to climate monitoring and analysis centres and international archives, and to ensure that data policies facilitate the exchange and archiving of all ECV data and associated meta-data.

4.1.1. International Standards and Guidance

The international programmes and Technical Commissions of WMO and the Intergovernmental Oceanographic Commission (IOC) exist to provide the standards, regulatory material and guidelines for the collection of climate data in the Atmospheric and Oceanic Domains. There is at present no equivalent international body or technical commission for climate observations for the Terrestrial Domain. A key requirement for successful implementation of this Plan is the urgent establishment of such an international body by the relevant international organizations, including WMO, the Food and Agriculture Organization of the United Nations (FAO), the United Nations Environment Programme (UNEP), and the International Council for Science (ICSU).

Key Action 9: The relevant intergovernmental organizations including WMO, FAO, UNEP, and ICSU need to create a mechanism for establishing standards, regulatory material and guidelines for terrestrial observing systems.

4.1.2. GCOS Climate Monitoring Principles

The GCOS Climate Monitoring Principles (GCMPs) provide basic guidance regarding the planning, operation and management of observing networks and systems, including satellites, to ensure that high-quality climate data are available and contribute to effective climate information. The GCMPs address issues such as the effective incorporation of new systems and networks; the importance of calibration, validation and data homogeneity; the uninterrupted operation of individual stations and systems; the importance of additional observations in data-poor regions and regions sensitive to change; and the crucial importance of data management systems that facilitate access, use and interpretation of the data. These principles have been adopted or agreed by the UNFCCC, WMO, Committee on Earth Observation Satellites (CEOS) and other bodies. The implementation actions now call on all data providers to adhere to the GCMPs and to initiate effective programmes of data quality control.

Key Action 10: Parties need to ensure that their climate-observing activities which contribute to GCOS adhere to the GCMPs.

4.1.3. Data Stewardship and Management

Climate observations that are well documented, and have good meta-data about the systems and networks used to make them, become more valuable with time. The creation of climate-quality data records is a fundamental objective of the global observing system for climate. International standards and procedures for the storage and exchange of meta-data need to be developed and implemented for many climate observing system components, including those of the operational satellite community. It is essential that all such data be properly archived and managed with the full expectation that they will be reused many times over in the future, often as a part of reprocessing or reanalysis activities. Good stewardship of the data also requires that data be migrated to new media as technology changes, be accessible to users, and be made available with minimal incremental costs.

Key Action 11: International standards for meta-data for all ECVs need to be established and adopted by the Parties in creation and archiving of climate data records.

4.2. Domain-Specific Observing Networks and Systems

The global observing system for climate is an integrated system comprised of complementary satellite and *in situ* components. With greater attention to climate monitoring issues, satellites are expected to become an increasingly more important means of obtaining observations globally for comparing climate variability and change over different parts of the Earth. Therefore, a system of satellites and satellite sensors implemented and operated in a manner that ensures the long-term accuracy and homogeneity of the data through the adoption of the GCMPs, is a high priority within the Plan. At the same time, some ECVs will remain dependent on *in situ* observations for long-term trend information, for calibration and validation of satellite records, and for measuring variables not amenable to direct satellite measurement (e.g., sub-surface oceanic ECVs). Consistent with the role of satellites, the Plan details the substantial effort required to ensure the operation and refinement of *in situ* networks.

Some of the key domain-specific components merit highlighting.

4.2.1. Atmospheric Domain

Many atmospheric networks and systems, including some satellite components, are relatively mature, having been in existence for several decades, albeit generally for non-climate purposes. As a result, a key action for this domain is to ensure the full global implementation of these networks and systems for climate purposes. Other key actions respond to the need for additional baseline observations to enable full use of existing measurements, improvements relating to a few important but poorly-observed variables, and the use of reanalysis techniques to generate needed climate information products.

The GCOS Surface Network (GSN), together with the other surface atmospheric networks, provides the basic observations of the surface climate in which we live. The GCOS Upper-Air Network (GUAN), together with related satellite observations, provides a baseline for the upper atmosphere. Network and system improvements are proposed in many areas, including the extension of the GSN to include all relevant surface ECVs. Indeed, the advantages of collocated measurements imply that greater efforts should be made to establish sites where many of the ECVs for both the Atmospheric and Terrestrial Domains are observed. In the upper atmosphere, water vapour plays a critical role in climate feedback, and supplements to the current baseline observations are needed from reference networks and GPS-based techniques.

Key Action 12: Parties need to: (a) ensure the implementation and full operation of the baseline networks and systems contained in Table 3 in accordance with the GCMPs, in order to specifically resolve reported problems, to ensure the exchange of these data with the international community, and to recover and exchange historical records; (b) establish a high-quality reference network of about 30 precision radiosonde stations and other collocated observations; and (c) exploit emerging new technology including the use of radio-occultation techniques and ground-based Global Positioning System (GPS) sensing of the total water column.

Table 3. Existing atmospheric baseline networks and systems.

- GCOS Surface Network (GSN).
- The atmospheric component of the composite surface ocean observation system including sea-level pressure (see Key Actions 17 and 18).
- GCOS Upper-Air Network (GUAN).
- Global Atmosphere Watch (GAW) global CO_2 network.
- MSU-like radiance satellite observations.
- Total solar irradiance and Earth radiation budget satellite observations.

With the societal importance of precipitation, there is further urgent need for improved global analyses including unbiased estimation of precipitation over the oceans and at high latitudes and further development and understanding of the implications of automation on precipitation measurements.

Key Action 13: Parties are urged to: (a) establish a reference network of precipitation stations on key islands and moored buoys around the globe and at high latitudes; (b) submit national precipitation data (preferably hourly data) to the International Data Centres; and (c) support the further refinement of satellite precipitation measurement techniques.

The total solar irradiance and Earth radiation budget measurements provide overall monitoring of the solar radiation and the net greenhouse effect within the atmosphere. Clouds, as well as water vapour, strongly affect this Earth radiation budget and provide the most uncertain feedbacks in the climate system. It is vital to maintain long-term records concerning the overall radiation of the Earth. Cloud properties are of particular importance and research, some of which is in progress, is needed to improve the monitoring of clouds. Surface radiation measurements over land are an important complementary observation and the baseline surface radiation network needs to be extended to achieve global coverage.

Key Action 14: Parties need to: (a) ensure the continued operation of satellite measurements of the Earth radiation budget and solar irradiance (e.g., the NASA Earth Radiation Budget Experiment); and (b) support research to extend and improve current capabilities for monitoring clouds as a high priority.

Greenhouse gases and aerosols are the primary agents in forcing climate change; continuous observations that are spatially and temporally homogeneous are therefore required. For the greenhouse gases, elements of the needed networks are in place but extension and improved attention to calibration are needed. Aerosols are a complex variable and the Plan proposes a key action in the establishment of an improved reference network and a global network for the aerosol-related optical depth variable.

Key Action 15: Parties need to: (a) fully establish a baseline network for key greenhouse gases; (b) improve selected satellite observations of atmospheric constituents; and (c) extend existing networks to establish a global baseline network for atmospheric optical depth.

4.2.2. Oceanic Domain

New technology, developed and proven by the oceanic climate research programmes of the 1990's, has allowed the ocean community to design, and commence implementation of, an initial oceanic climate observing system. The first action of the initial system is the global implementation of the surface and sub-surface networks, including the establishment of data analysis systems. This will allow for a composite system of satellite and *in situ* observations collected by operational and research groups to be synthesized into information products. Sustaining this system will require national designation of and support for Agents for Implementation, and the establishment of effective collaboration between research and operational groups. This will also require the continuity of existing and predominantly research-based *in situ* and satellite activities.

Key Action 16: Parties need to: (a) complete and sustain the initial oceanic observing system for climate; (b) designate and support national Agents for Implementation for implementing this system; (c) establish effective partnerships between their ocean research and operational communities towards implementation; and (d) engage in timely, free and unrestricted data exchange.

The surface ocean network will provide information about the patterns of ocean surface temperature, pressure, winds, salinity, sea level, waves and sea ice that are important both to the global climate and its regional distribution and to marine resources and coastal societies. In particular, sea ice, which plays a key and complex role in climate feedback, requires continued research into improved *in situ* and satellite measurements.

The surface observing network depends critically on the continuity of satellite observations, most of which are in research rather than operational status (Table 4), and on the full implementation of the *in situ* activities identified in this Plan.

Key Action 17: Parties need to ensure climate quality and continuity for essential ocean satellite observations (see Table 4).

Table 4. Essential ocean satellite systems.

• Sustained support for vector-wind (scatterometer), sea-ice, sea-surface temperature (microwave and infra-red) and ocean-colour measurements. • Continuous coverage from altimeters to provide high-precision and high-resolution sea-level measurements (1 high-precision and 2 lower-precision altimeters).

Key Action 18: Parties need to provide global coverage of the surface network by implementing and sustaining: (a) the GCOS baseline network of tide gauges; (b) an enhanced drifting buoy array; (c) an enhanced Tropical Moored Buoy network; (d) an enhanced Voluntary Observing Ships Climatology (VOSClim) network; and (e) a globally-distributed reference mooring network.

The sub-surface ocean network will provide critical information on ocean climate variability and change. The network will provide a capacity for monitoring the regional oceanic uptake of heat, freshwater and carbon, and identification of abrupt climate change arising from changes in the planetary hydrological cycle processes. In association with the surface observations, they also provide the basis for seasonal-to-interannual predictions that can be critical in giving forecasts of the likelihood of extreme climatic events.

Key Action 19: Parties need to provide global coverage of the sub-surface network by implementing and sustaining: (a) the Argo profiling float array; (b) the systematic sampling of the global ocean full-depth water column; (c) the Ship-of-Opportunity Expendable Bathythermograph (XBT) trans-oceanic sections; and (d) the Tropical Moored Buoy and reference mooring networks referred to in Key Action 18 above, as well as the satellite altimetry system described in Table 4.

In recognition of the importance of potential changes to the ocean carbon cycle and marine ecosystems, the Plan contains a number of important research and implementation actions dealing with the establishment of an observing network for the partial pressure of carbon dioxide (pCO_2) and the measurement of the state and change of carbon sources and sinks in the oceans.

Finally, continuing climate research and technology programmes for the oceans are needed to enhance the efficiency and effectiveness of observing efforts, and to develop capabilities for important climate variables that cannot currently be observed globally. This need for enhanced capability is particularly acute for remote locations, for improved understanding of the ocean ecosystems, for improving the estimates of uncertainty, and for understanding the mechanisms of climate change.

4.2.3. Terrestrial Domain

The climate observing system in the Terrestrial Domain remains the least well-developed component of the global system, whilst at the same time there is increasing significance being placed on terrestrial data for climate forcing and understanding, as well as for impact and mitigation assessment.

The Plan proposes actions designed to achieve an initial coordinated and comprehensive observational programme for all terrestrial ECVs. The nature of the Terrestrial Domain is such that priority is being placed on obtaining global products for all ECVs from a range of research-level satellite sensors supported by an increasing number of reference and baseline *in situ* networks.

Key Action 20: Parties are urged to support the operational continuation of the satellite-based products given in Table 5.

Table 5. Priority terrestrial satellite products.

- Daily global albedo from geostationary and polar orbiting satellites.
- LAI and fAPAR products to be made available as gridded products.
- Gridded fire and burnt area products through a single International Data Centre.
- Snow cover of both hemispheres.
- Digital elevation maps of the ice sheet surfaces and full glacier inventory from current spaceborne cryosphere missions.
- Specification and production of land-cover characterization data sets.

A coordinated reference network is needed for: *in situ* observations of the fullest possible range of terrestrial ECVs and associated details relevant to their application in model validation; process studies; validation of observations derived from Earth observation satellites; and to address intrinsic limitations in some of these, such as the saturation of LAI measurements. Opportunities for collocation of Atmospheric and Terrestrial Domain reference network sites should be sought whenever possible.

Key Action 21: Parties are urged to develop a global network of at least 30 reference sites (collocated with atmospheric sites if possible) to monitor key biomes and to provide the observations required in the calibration and validation of satellite data.

The hydrological variables are of critical societal importance. Many are observed but not well exchanged for the purposes of assessing global climate change. The proposed international body (Key Action 9 above) is intended to establish standards for, and to facilitate the exchange of, terrestrial data for climate and other purposes. The Plan proposes specific actions to continue with the implementation of the Global Terrestrial Networks (GTNs) for hydrology (including specific lakes and rivers components), for glaciers and for permafrost.

Key Action 22: Parties are urged to: (a) fill the identified gaps in the global networks for permafrost, glaciers, rivers and lakes; (b) provide support for the designated International Data Centres; and (c) submit current and historical data to the International Data Centres.

5. Availability of Climate Products

Use of observations for policy and planning purposes depends on access to information beyond the basic observations. To meet the needs of all nations for climate information, the global observing system for climate must generate useful climate products. The preparation of climate products almost invariably involves the integration of data in time and space, as well as the blending of data from different sources. Some products, such as reanalysis to climate standards, involve extensive data set preparation and significant computing and data management resources, and implicitly require estimation of uncertainties. Providing access to climate information for all Parties will involve significant information technology infrastructure. The best use of available resources will come via international coordination of these activities. Therefore, a sustained and coordinated application of reanalysis is one of the key actions of this Plan for all domains.

Key Action 23: Parties are urged to adopt an internationally-coordinated approach to the development of integrated global climate products and to make them accessible to all Parties. As far as possible, these products should incorporate past data covering at least the last 30 years in order to serve as a reference for climate variability and change studies.

Key Action 24: Parties are urged to give high priority to establishing a sustained capacity for global climate reanalysis, to develop improved methods for such reanalysis, and to ensure coordination and collaboration among centres conducting reanalyses.

6. Improving the System

Our ability to measure some key and emerging ECVs from *in situ* and remote sensing systems (both surface- and satellite-based) is limited by the lack of suitable instruments and techniques. The limitation can vary all the way from difficulties with the fundamental observing technique to those associated with instrumentation, algorithms, suitable calibration/validation techniques, spatial and/or temporal resolution, ease of operation, and cost.

The development, demonstration, and validation of existing and new techniques are vital to the future success of the global observing system for climate. It is critically important that as new global satellite-based observations of environmental variables are made, the validation of both the measurements themselves (e.g., radiances) and the retrieval algorithms be carried out under a sufficiently broad range of conditions that they can be confidently applied in the creation of a global data sets.

Research is needed to improve the ability to blend different data sets and/or data sources into integrated products. As new types of data are assimilated into models, it will also be important to understand the error characteristics of the new data and the models used. Data assimilation for climate purposes is still in an early stage of development and requires continued research support. As these developments occur, reprocessing of data to take advantage of the new knowledge will be vital to sustained long-term records.

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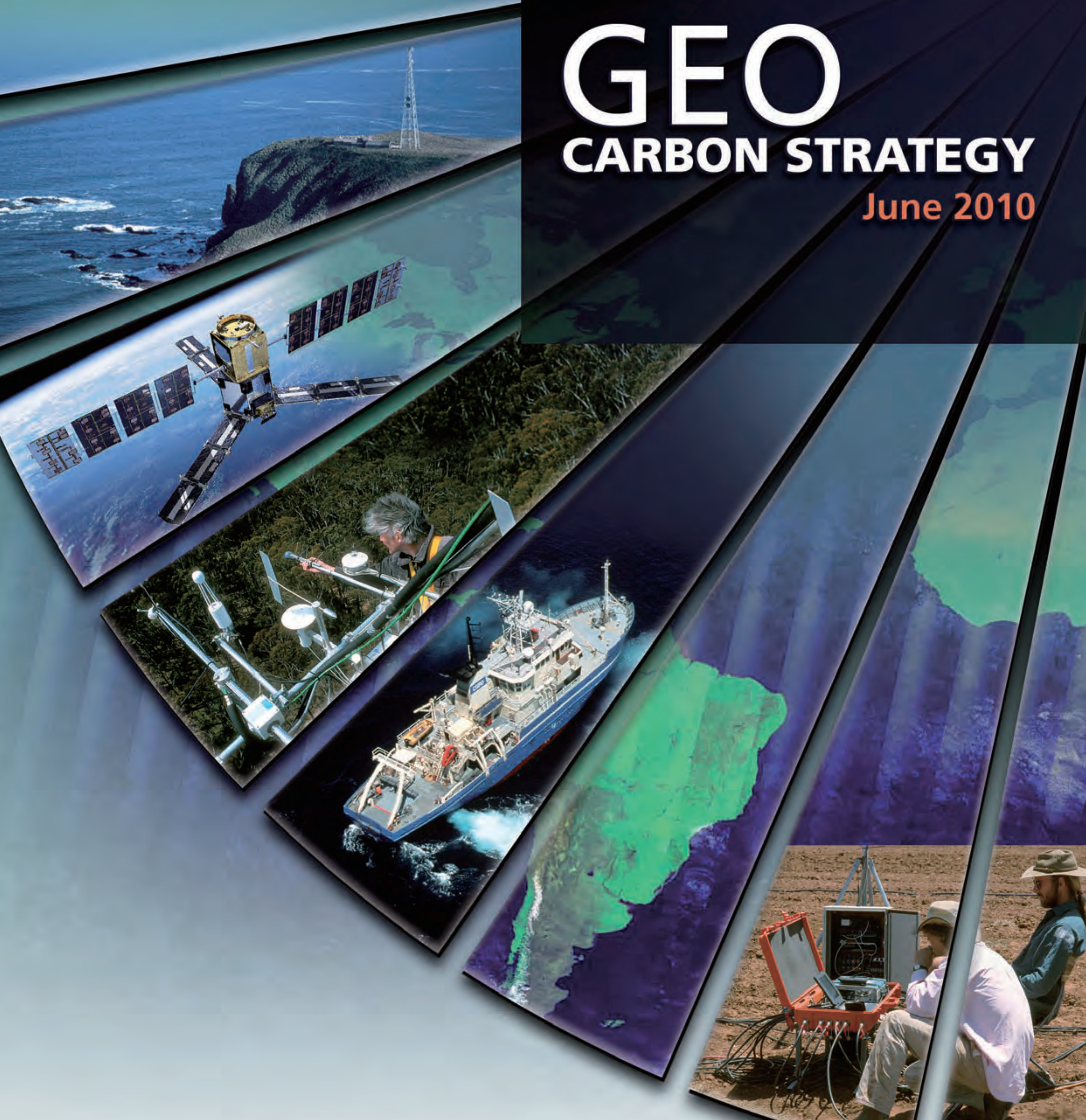
GEO
CARBON STRATEGY
June 2010



GROUP ON
EARTH OBSERVATIONS

GEO Carbon Strategy

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Preface

Recognizing the growing need for improved Earth observations, over 130 governments and leading international organizations are collaborating through the Group on Earth Observations (GEO) to establish a Global Earth Observation System of Systems (GEOSS) by the year 2015. They are contributing their respective Earth monitoring systems to GEOSS and interlinking these systems so that they work together better. They are developing common technical standards to make it possible to pool information, and they are promoting the free sharing and dissemination of Earth observations and data. This expanding coalition of countries and organizations has already transformed the ability of governments to manage natural resources and promote the safety and well-being of their citizens.

GEO plans to produce globally harmonized data sets on global, national and local scales, using common algorithms, variables and units; as well as, to develop an integrated model that stitches all carbon observations together. The IGOS-P, through their leadership and implementation plans have now been fully integrated into GEO and are the foundation for the Communities of Practice. The new GEO Carbon Community of Practice will implement a plan for an Integrated Carbon Observation program.

GEO through its Members and Participating Organizations, has begun work to implement a global carbon observation and analysis system addressing the three components of the carbon cycle (atmosphere, land and ocean) to provide high quality information on carbon dioxide (CO_2) and methane (CH_4) concentrations, and emission variations. By combining observations, reanalysis and product development we will be able to develop tools for carbon tracking and carbon storage evaluation, including improved global networks of atmospheric CO_2 observations, air-surface exchange flux networks, as well as surface ocean CO_2 and related marine biochemistry observations.

GEO Members and Participating Organizations: Australia, Canada, France, Japan, Netherlands, Norway, UK, Italy, USA (NASA,NOAA,USGS,USDA), Carbon Community of Practice (formerly IGOS-P), Committee on Earth Observation Satellites (CEOS), European Space Agency (ESA), Food and Agriculture Organization (FAO) Global Climate Observing System (GCOS), Global Terrestrial Observing System (GTOS), World Meteorological Organization (WMO), the World Climate Research Program (WCRP) and The William J. Clinton Foundation are supporting the development of an integrated global carbon observation system. GEO encourages the development of high-resolution global and regional data-assimilation and modeling systems to enhance the utility of the spatial and temporal resolution of those observations and provide relevant regional-scale information.

Through GEO, coordinated Earth Observations can provide the capability and capacity to support the monitoring, reporting, and verification (MRV) information required by future regulatory frameworks for the inclusion of forests in post-Kyoto climate agreements. This would ensure assessment of permanence, additionality and leakage to support Forest Carbon Tracking. This builds upon existing and planned GEO efforts in forest monitoring, associated modeling and use of these tools for timely provision of observations required for their routine use world-wide. In close collaboration with national governments, space agencies, and relevant technical experts, GEO will demonstrate this capability through the establishment of robust methodologies, satellite acquisition plans and a series of regional pilot studies, which will provide a template for a consistent and reliable global carbon monitoring system.

Activities include: (i) establishment of several regional reference test-sites; (ii) consolidation of observational requirements and associated products; (iii) coordination of observations, including their long-term continuity; (iv) coordinated assessment of tools and methodologies at these sites, (v) coordination of the production of reference data sets,and (vi) improved access to observations, data sets, tools and expertise.

One other major activity is to foster the use of space-based greenhouse gas (GHG) observations and consolidate data requirements for the next-generation GHG monitoring missions. By establishing close cooperation with CEOS and the GEO Carbon Community of Practice plans will be implemented for the end-to-end utilization of space-based GHG data, particularly those of Japan's GOSAT mission and NASA's replacement OCO mission, and other GHG-observation missions being prepared in Europe.

The global carbon cycle determines the amount of carbon dioxide and methane that accumulates in the atmosphere, increasing the Earth's greenhouse effect. It is therefore a key component of the global climate system. The carbon cycle also responds to climate change, and understanding the ability of the carbon cycle to continue to act as a partial sink of fossil fuel emissions into the future will be a vital factor in determining the "allowable" fossil fuel emissions, while keeping concentration below certain levels.

Current uncertainties on the space-time distribution of CO_2 and CH_4 fluxes are very large. For well informed policy action aiming to curve down the future increase of CO_2 and CH_4, these uncertainties must be reduced, by establishing an Integrated Global Carbon Observing system (IGCO). The main goal of this report is to describe the building blocks and coordinated implementation of such an Integrated Global Carbon Observing system.

It is anticipated that this document will become a live document, subject to frequent updates and available online. As actions are completed, the following steps will become clear, necessitating new actions and new directions. IGCO will be a service provider to the practitioners of the carbon community, facilitating the flow of information and the coordinated implementation of new observations.

Executive summary

Understanding the global carbon cycle, and predicting its evolution under future climate scenarios is one of the biggest challenges facing science today; there are huge societal implications. The uncertainty in the natural sinks of the carbon cycle is a major contributor to the uncertainty in climate predictions. The feedbacks between climate change and the carbon reservoirs are not well known or understood. The spatial and temporal distribution of natural sinks over land and oceans remains elusive, which precludes better quantification of their underlying mechanisms and drivers. In addition to natural sinks, anthropogenic emissions from fossil fuel burning and land use change need to be known at regional level and with better accuracy. These uncertainties must be reduced to underpin well-informed, evidence-based policy action.

A key reason for our lack of understanding of the global carbon cycle is the dearth of global observations. An increased, improved and coordinated observing system for observing the carbon cycle is a prerequisite to gaining that understanding.

This report sets out a number of key actions that build on a strategy to expand the current observations into a fully integrated observation system measuring the essential parameters and variables. Some actions are already being carried out, while others still need to be addressed and implemented.

Completing an Integrated Global Carbon Observing system (IGCO) within the Group on Earth Observation (GEO) and the Global Climate Observing System (GCOS) will involve thousands of scientists, technicians, agency representatives and policy makers. One key element of an Integrated Global Carbon Observing system is the provision of communication points to facilitate the flow of information from the data providers to the data users. These communication points will also acts as nodes for summarizing and disseminating the current state-of-the-art information.

The main recommendations are to:

i) increase the density of in situ networks, in particular for stations and aircraft atmospheric observations, ocean pCO2 observing systems using Voluntary Observing Ships, and eddy covariance terrestrial ecosystem flux measurement networks.

ii) develop space measurements of global CO_2 and CH_4 distributions, to fill the gap after GOSAT and SCIAMACHY;

iii) develop spatial scaling techniques for pCO_2 and land flux observations for application to wider regions, using satellite information;

iv) undertake a decadal full basin survey of ocean carbon state, together with regular inventories of forest biomass and soil carbon pools;

v) improve access to a continuous supply of mid-resolution Earth observing satellitedata (i.e., LAI, FAPAR, disturbance, land cover change), to monitor areas of forest;

vi) develop space measurements of vegetation 3-dimensional structure to improve estimates of global terrestrial aboveground biomass and carbon stocks and continue the observational data streams started with JERS-1, ALOS PALSAR, and ICESat;

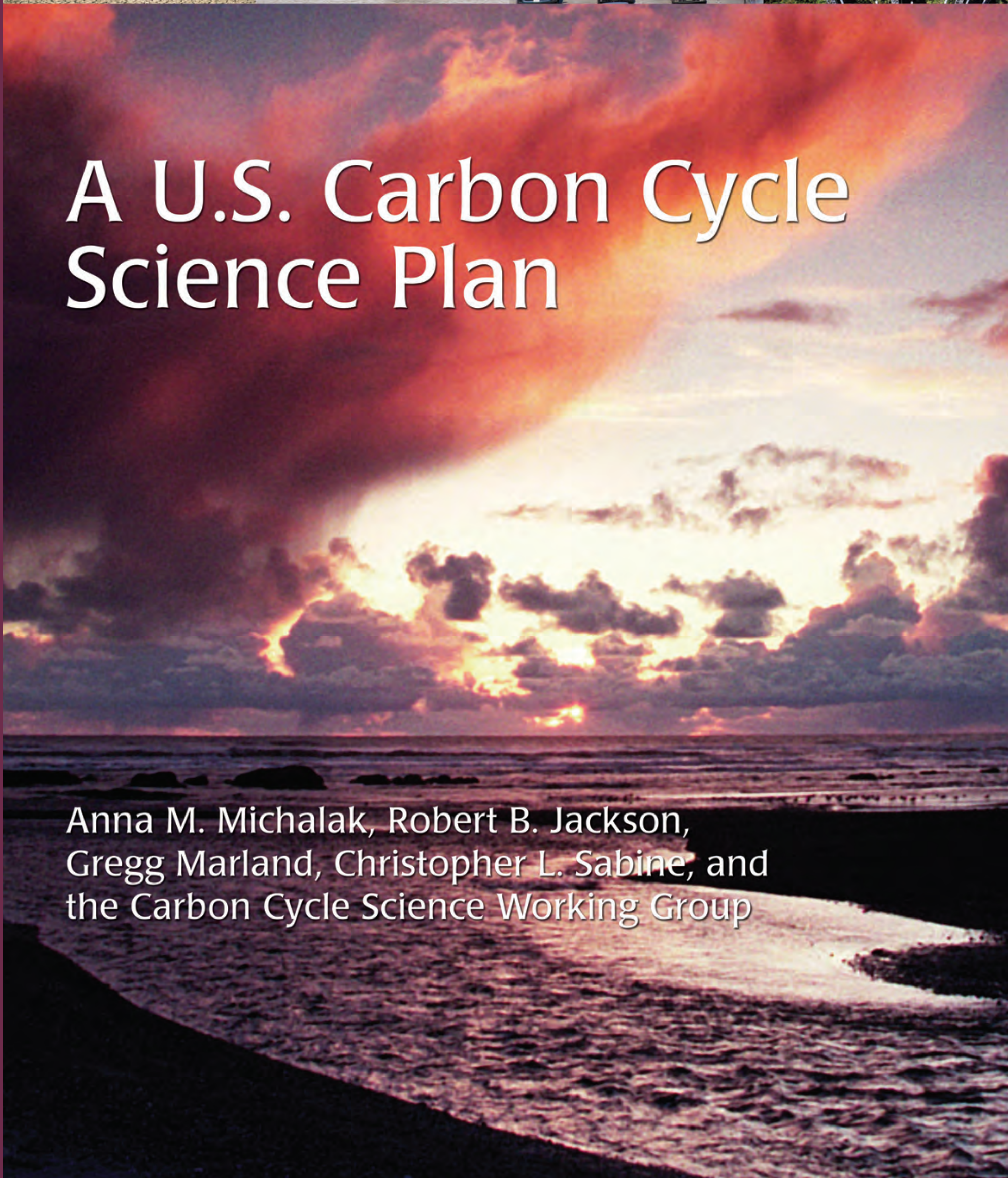
vii) develop new space missions and satellite products to improve estimation of carbon capture and export in the ocean;

viii) improve access to geospatial and temporal fossil fuel emission information, including spatial-data infrastructure;

ix) assemble geospatial information about use of wood and food products, and continuously monitored dissolved and particulate carbon, if possible with age information, for relevant rivers;

x) implement a data architecture that facilitates the combination of different data-streams;

xi) establish an International Carbon Office to operate a program to produce annually updated regional and global carbon budgets.



A U.S. Carbon Cycle Science Plan

Anna M. Michalak, Robert B. Jackson, Gregg Marland, Christopher L. Sabine, and the Carbon Cycle Science Working Group

Executive Summary

Understanding of the Earth's carbon cycle is an urgent societal need as well as a challenging intellectual problem. The impacts of human-caused changes on the global carbon cycle will be felt for hundreds to thousands of years. Direct observations of carbon stocks and flows, process-based understanding, data synthesis, and careful modeling are needed to determine how the carbon cycle is being modified, what the consequences are of these modifications, and how best to mitigate and adapt to changes in the carbon cycle and climate. The importance of the carbon cycle is accentuated by its complex interplay with other geochemical cycles (such as nitrogen and water), its critical role in economic and other human systems, and the global scale of its interactions.

The need for improved understanding of the global carbon cycle and better research coordination led to the development of the first U.S. Carbon Cycle Science Plan, published more than a decade ago. That document outlined a plan for land, atmosphere, and ocean observations; manipulative experiments; and Earth-system modeling to improve our understanding of the contemporary carbon cycle and our ability to predict its future.

The development of a new Plan was initiated by the U.S. Carbon Cycle Interagency Working Group (CCIWG) and the Carbon Cycle Science Steering Group (CCSSG), and outlines a strategy for refocusing U.S. carbon cycle research based on the current state of the science. The development of this Plan was led by a committee of 25 active members of the carbon cycle research community, and the result is intended to provide U.S. funding agencies with information on community-based research priorities for carbon cycle science over the next decade. The Plan emphasizes the long-lived, carbon-based greenhouse gases, carbon dioxide (CO_2) and methane (CH_4), and the major pools and fluxes of the global carbon cycle. The recommended research is global in scale, and there is therefore a strong need for international cooperation and collaboration.

While many of the research goals in the 1999 Science Plan remain important for the coming decade, new research thrusts are also needed. These thrusts include a more comprehensive look at the effects of humans on carbon cycling, including the consequences of carbon management activities; the direct impacts of CO_2 on ecosystems and their vulnerability or resilience to changes in carbon and climate; a quantitative understanding of the uncertainties associated with the carbon cycle; and the need to coordinate researchers from the natural and social sciences to address societal concerns.

The Plan is organized around three overarching questions:

Question 1. *How do natural processes and human actions affect the carbon cycle on land, in the atmosphere, and in the oceans?*

Question 2. *How do policy and management decisions affect the levels of the primary carbon-containing gases, carbon dioxide and methane, in the atmosphere?*

Question 3. *How are ecosystems, species, and natural resources impacted by increasing greenhouse gas concentrations, the associated changes in climate, and by carbon management decisions?*

In addition, the Plan recognizes the central role of sustained observations that underlie all of the outlined science objectives. There is need for an optimally designed and integrated system for long-term observations, data collection, and data management.

Incomplete representations of the carbon cycle cause large uncertainties in estimates of future changes in the climate system. Conversely, uncertainties about future climate also make it more difficult to predict future changes in the carbon cycle. In balancing the global carbon cycle and gaining a process-level understanding of its components, it is important to evaluate, understand, and deal with the uncertainty that arises through measurements, models, analyses, and projections, and the complex interdependence of the carbon, climate, and socioeconomic systems.

The overriding science questions provide basic long-term direction for guiding carbon cycle research. To make progress toward answering the questions, and to provide guidance for continuing research, we have outlined six science goals that should be pursued over the next decade. These six goals (together with references to the overriding questions they are primarily designed to address), are:

Goal 1 (Q1, Q2): *Provide clear and timely explanation of past and current variations observed in atmospheric* CO_2 *and* CH_4 *– and the uncertainties surrounding them.*

The scientific community needs to be able to provide the broader public with a clear and timely explanation of past and current variations observed in atmospheric CO_2 and CH_4, as well as the uncertainties surrounding these explanations. We note that 'timely' is an important part of this goal. To serve public policy needs, atmospheric observations and clear analyses are needed in close to real time. To address this goal, we need to develop the capability to accurately estimate variability in carbon sources and sinks as well as the processes controlling that variability.

Goal 2 (Q1, Q2): *Understand and quantify the socioeconomic drivers of carbon emissions, and develop transparent methods to monitor and verify those emissions.*

This goal seeks to derive process-level understanding of the human processes and motivations that determine carbon emissions from energy use, industrial activity, and land use. Improved understanding will enable better evaluations of current emissions levels and better projections of future emissions, including the implications of alternative policy scenarios. Atmosphere-based measurements, remotely-sensed observations, evaluation of socioeconomic parameters, and other tools need to be developed to provide confirmation and confidence in mitigation commitments. The institutions and infrastructure for monitoring and verification of international agreements must come from the national and international political processes, but the tools and methods need to be developed by science.

Goal 3 (Q1, Q2, Q3): *Determine and evaluate the vulnerability of carbon stocks and flows to future climate change and human activities, emphasizing potential positive feedbacks to sources or sinks that make climate stabilization more critical or more difficult.*

All carbon reservoirs and carbon processes are not equally vulnerable to change, resilient to stress, responsive to management, or susceptible to unintended side effects of management decisions. We need to be able to identify which carbon pools and flows are most vulnerable and to understand the physical, chemical, and biological processes important in determining the degree of vulnerability of these pools and flows. We also need to predict the consequences of carbon management and sequestration schemes on vulnerable pools and to support carbon management goals by prioritizing the resources that are needed to assure the stability of the most vulnerable stocks and flows.

Goal 4 (Q3): *Predict how ecosystems, biodiversity, and natural resources will change under different* CO_2 *and climate change scenarios.*

The direct effects of elevated greenhouse gas levels, along with the accompanying changes in climate, are likely to alter ecosystems profoundly on land and in marine and freshwater environments. Beyond the interaction with climate change, there is a need to assess the direct impact of increasing atmospheric greenhouse gas concentrations on ecosystems, beyond their potential role as carbon reservoirs or sinks. Three examples of such impacts are altered marine ecosystem structure due to ocean acidification, biodiversity impacts on land and in the ocean, and the potential stimulation of net primary productivity due to additional CO_2. The interacting effects of climate and biogeochemistry need to be understood.

Goal 5 (Q1, Q2, Q3): *Determine the likelihood of success and the potential for side effects of carbon management pathways that might be undertaken to achieve a low-carbon future.*

This goal is especially important as concerns increase over anthropogenic impacts on the atmospheric concentrations of greenhouse gases and their impacts on the global carbon cycle. There is a need to understand interlinked natural and managed systems sufficiently for individuals, corporations, and governments to make rational and well-informed decisions on how best to manage the global carbon cycle, and especially the anthropogenic impacts on this cycle.

Goal 6 (Q1, Q2, Q3): *Address decision maker needs for current and future carbon cycle information and provide data and projections that are relevant, credible, and legitimate for their decisions.*

The scientific community needs to provide carbon cycle information needed by decision makers and other stakeholders, understand how decision making affects the evolution of the carbon cycle, and determine how information about the carbon cycle can be relevant to policy decisions. Meeting the needs of decision makers requires an interactive process in order to understand those needs. This goal also recognizes the need to be anticipatory. The needs of decision makers a decade from now will not necessarily be the same as the needs they confront now and a goal of research is to anticipate and probe creatively so that we are prepared to confront tomorrow's questions.

A number of key cross-cutting research components comprise the central core for advancing carbon cycle science over the next decade, and these have been grouped into four high-priority elements. These elements embody the action items of carbon cycle research, with each of them contributing to all six research goals. The first element encompasses sustained and focused observations, which include atmospheric, ocean/coastal/inland water, terrestrial ecosystem, demographic/social, and remote-sensing observations. The second element includes studies of system dynamics and function across scales, including intensive process studies and field campaigns, manipulative laboratory experiments, and manipulative field studies. This work should be designed as coordinated, integrative studies across traditional disciplinary boundaries where appropriate and possible. The third element focuses on modeling, prediction, and synthesis, including improving existing models, adding human dimensions to Earth system models, and augmenting synthesis activities. Finally, the fourth element centers on communication and dissemination, including improving dialogue among the decision-making community, general public, and scientific community, developing appropriate tools for communicating scientific knowledge to decision makers, and evaluating the impact of scientific uncertainty on decision making.

Interdisciplinary studies and improvements in both inclusion of, and collaboration with, the social and political sciences are essential to the success of this Plan. Visions of the future need to be strengthened through interactions with integrated assessment efforts and studies of carbon management. Similarly, the increasing importance of international collaboration is also apparent. U.S. scientists need to participate and take leadership roles in international assessments and syntheses, field campaigns, model inter-comparisons, and observational networks. Such international participation offers opportunities to leverage investments in resources and to contribute the knowledge and creativity of U.S. scientists to coordinated research.

The conduct of science depends on the institutions and structures that support the research. Institutional structures and opportunities to improve coordination and to ensure the achievement of the Plan's research goals include:

- Providing more opportunities for sustained, long-term funding.
- Enhancing carbon cycle data management.
- Encouraging directed calls for integrated topics in carbon cycle research, including research in the social sciences.
- Facilitating efforts to contribute to integrated, interdisciplinary efforts such as the assessments of the Intergovernmental Panel on Climate Change.

The National Global Change Research Plan 2012-2021

A Strategic Plan for the U.S. Global Change Research Program (USGCRP)

Global change is having important and immediate impacts on society. Increases in world population, industrialization, and other human activities are altering the atmosphere, oceans, land, ice cover, ecosystems, and distribution of species over the planet. People working in agriculture, energy, health, coastal management and other sectors are grappling with how these changes may affect decisions both today and in years to come. Understanding the science of global change and its impacts on society is essential to ensuring these decisions are well-informed.

Recognizing this imperative, Congress passed the Global Change Research Act of 1990, which mandated the USGCRP to coordinate the work of 13 agencies that fund scientific research on global change. This coordination optimizes efforts across the Federal government, leverages synergies, and facilitates communication among member agencies, partners in industry, academia, and state, local, and foreign governments.

Vision
The USGCRP's vision is for a Nation, globally engaged and guided by science, meeting the challenges of climate and global change.

Mission
The Program's mission is to build a knowledge base that informs human responses to climate and global change through coordinated and integrated Federal programs of research, education, communication, and decision support.

Over two decades, USGCRP's research has helped uncover the potential risks and opportunities associated with global change and contributed to the advancement and application of global change knowledge. For example, mathematical models of the general circulation of the atmosphere and ocean now can reproduce major features of the global temperature record of the 20th century, providing confidence that climate projections accurately reflect the link between rising levels of greenhouse gases in the atmosphere and planetary warming. Despite this important progress, more research is needed to better understand the underlying processes and variability of the Earth system and the complex causes and consequences of human-induced global change. At the same time, increased publicly accessible, durable data and information is also needed to support partnerships among all sectors of society to foster sound decisions for a sustainable future.

USGCRP's new ten-year strategic plan addresses these needs and reflects recommendations and input from reports by the National Academies, stakeholder listening sessions, public comments, and collaborative planning among Federal agencies. It charts an ambitious course to advance the Program's legislative mandate by deepening basic scientific understanding and providing information and tools to support the Nation's preparation for and response to global change.

The Program will coordinate Federal research efforts through four strategic goals:

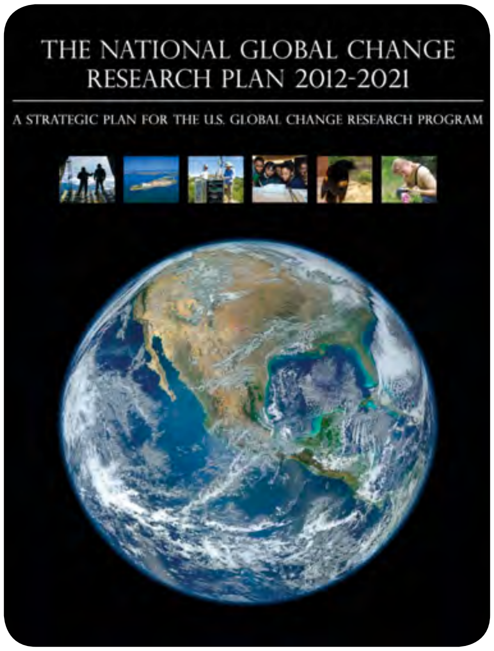
Goal 1. Advance Science: Advance scientific knowledge of the integrated natural and human components of the Earth system.

Goal 2. Inform Decisions: Provide the scientific basis to inform and enable timely decisions on adaptation and mitigation.

Goal 3. Conduct Sustained Assessments: Build sustained assessment capacity that improves the Nation's ability to understand, anticipate, and respond to global change impacts and vulnerabilities.

Goal 4. Communicate and Educate: Advance communications and education to broaden public understanding of global change and develop the scientific workforce of the future.

The Plan recognizes that effective responses to global change require a deep understanding of the integrated Earth system and the incorporation of information from the physical, chemical, biological, and social sciences. USGCRP will strengthen its integrated framework through the use of advanced computing, integrated large data sets, and modeling capabilities that can span scientific disciplines. It will increase use of research findings from the biological, social, and economic sciences to assist in understanding the implications of policy and development decisions.



To help inform decision-makers with the best available information on global change, USGCRP is strengthening the engagement between the science and decision-making communities, developing user-friendly information tools, and improving its assessment capabilities. These will enable a critical synthesis and evaluation of climate- and global-change science, with a focus on vulnerability assessment and evaluating progress in responding to change, while providing decision-makers with access to relevant and accurate science. USGCRP will continue to coordinate ongoing, comprehensive assessment efforts across regions and sectors at multiple scales. It will build a sustained, collaborative network of public and private partners and stakeholders, to link and align Federal capacity with a wide range of interested communities.

To be fully effective, USGCRP must effectively communicate its findings and engage in two-way dialogue about global change with a diverse set of audiences. By integrating communication and education into the Program's core research activities over the next decade, USGCRP will serve as a credible and authoritative source of global change scientific information. The Program's education efforts will support the critical goal of developing a scientific workforce capable of bridging the physical, chemical, biological, and social sciences, and coordinating that integrated knowledge-base with the engineering and planning skills needed to respond to global change challenges.

Effective preparation for and response to global change also requires international research and cooperation. USGCRP will continue to collaborate with counterparts around the globe to coordinate data collection and delivery, build robust models and assessments, and understand processes and trends that link the continents, oceans, and atmosphere. Observations across the globe are crucial to develop the long-term data sets needed to leverage and build upon U.S. investments.

This Strategic Plan acknowledges several looming challenges in global change research. Among them, the Nation is at risk of experiencing observational gaps that would affect the ability to monitor and understand natural and human-induced variability, due to developmental and launch delays of replacements for aging systems (e.g., Earth Observing System satellites). Understanding global change is an inherently data-rich and long-term process. This plan recognizes the need to maintain and enhance consistent data collection and processing capabilities.

This Strategic Plan envisions an ambitious research program that coordinates the work of Federal agencies to bring scientific insights to bear on timely, relevant decision-making for the benefit of the Nation.

United States
Global Change
Research Program

Executive Summary

The environment is changing rapidly. Increases in world population, accompanied by industrialization and other human activities, are altering the atmosphere, ocean, land, ice cover, ecosystems, and the distribution of species over the planet. Understanding these and other global changes, including climate change, is critical to our Nation's health and economic vitality. Scientific research is critical to gaining this understanding. Research, along with an array of increasingly sophisticated tools for collecting and analyzing data, can provide essential knowledge to governments, businesses, and communities as they plan for and respond to the myriad manifestations of global change, including sea-level rise and ocean acidification, heat waves and drought, and the severe storms, floods, and forest fires that pose an ever-growing risk to life, property, and agriculture.

To help fill this need, President Ronald Reagan created—and Congress in 1990 codified—the United States Global Change Research Program (USGCRP or Program), charged with providing a "comprehensive and integrated United States research program to assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change."[1] The Program coordinates the work of 13 agencies that fund research on global change, maximizing efforts and taking advantage of synergies while facilitating communication not only among member agencies but also with partners in industry, academia, and state, local, and foreign governments. Since USGCRP's inception, Federal research programs have created and maintained a robust mix of atmospheric, oceanic, and land- and space-based observing systems; gained new theoretical understanding of Earth-system processes; developed sophisticated predictive models; supported advances in data management and sharing; and helped develop an expert scientific workforce.

These research accomplishments have had far-reaching and significant impacts on the advancement and application of global change knowledge. For example, seasonal climate forecasts are now significantly more accurate and have longer lead times, often giving farmers critical and timely information for crop management. In addition, mathematical models of the general circulation of the atmosphere and ocean now can reproduce major features of the global temperature record of the 20th century, providing confidence that climate projections accurately reflect the link between rising levels of greenhouse gases in the atmosphere and planetary warming. These abilities are on display in a series of USGCRP publications that, over the years, have provided practical information about global change trends—in some cases sorted by geographic region and economic sector—to assist city and regional planners and others as they make decisions about upcoming investments in, for example, infrastructure and projected energy needs.

Today, new technological capacities and growing demands from a range of stakeholders for practical insights about global change require that USGCRP strengthen its role as both a generator and distributor of reliable, evidence-based climate change information. This Strategic Plan aims to facilitate this timely programmatic advancement. While the Program's first two decades focused largely on observations, process research, and modeling of the physical climate system, it is now poised to more fully integrate important dimensions to our understanding of the Earth system by incorporating such complex and critical components as the roles of ecosystems and human communities.

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1. The Global Change Research Act of 1990 (Public Law 101-606)

This ten-year Strategic Plan—which reflects recommendations from multiple reports of the National Academies, dozens of listening sessions with stakeholders around the country, public comments on a draft plan, and collaborative planning among the USGCRP agencies—charts a course that will advance the Program's legislative mandate to deepen basic scientific understanding while providing information and tools to support the Nation's preparation for and response to global change. In particular, the Program will coordinate Federal research efforts through the following four strategic goals:

Goal 1. Advance Science: Advance scientific knowledge of the integrated natural and human components of the Earth system.

Goal 2. Inform Decisions: Provide the scientific basis to inform and enable timely decisions on adaptation and mitigation.

Goal 3. Conduct Sustained Assessments: Build sustained assessment capacity that improves the Nation's ability to understand, anticipate, and respond to global change impacts and vulnerabilities.

Goal 4. Communicate and Educate: Advance communications and education to broaden public understanding of global change and develop the scientific workforce of the future.

These four goals and their related objectives (**Box 1**) recognize that to respond effectively to global change will require a deep understanding of the integrated Earth system—an understanding that incorporates physical, chemical, biological, and behavioral information. Looking forward, USGCRP will accomplish this by supporting the use of advanced computing science and analytic technologies capable of spanning traditional scientific disciplines and also integrating research findings from the ecological, social, and economic sciences, with ongoing coordinated emphases on observations and modeling.

In furtherance of its mission to inform decision makers with the best global change-related information available, USGCRP is also committed under its new Strategic Plan to improving its assessment—and ensuring its fulfillment—of stakeholder needs. Farmers, as previously noted, depend on USGCRP-generated information to manage planting decisions as growing zones, pest and weed ranges, and seasonal boundaries shift. Health care providers need predictive models to prepare for anticipated increases in severe weather events and outbreaks of diseases previously uncommon in their regions. Insurers must account for the increased likelihood of weather extremes as they assess future financial risk. Inhabitants of coastal cities need to understand the implications of sea-level rise, especially in the context of novel storm patterns and other pending changes. Water resources, energy, and infrastructure planners need to address accelerating changes in the availability of freshwater, demands for energy, and needs to divert stormwater runoff. By considering and responding to these societal needs, the Program will not only enhance its immediate value to the Nation but also improve its ability to make wise decisions about future research directions.

Providing decision makers with timely and relevant information requires regular evaluations and assessments. As part of its mandate to perform periodic assessments, USGCRP will implement a long-term, consistent, and ongoing process for evaluating global change risks and opportunities across diverse regions and sectors. Specifically, rather than conducting such assessments periodically, as was the case during the Program's first decades, USGCRP will work to establish a sustained assessment capacity focused on evaluating the state of scientific knowledge related to impacts and trends, and on informing the Nation's activities in adaptation and mitigation.

But to be fully effective, USGCRP must communicate with more than just decision makers; engagement with the public is also essential. By integrating communication, education, and engagement into the Program's core research activities over the next decade, USGCRP and its member agencies will serve as an unprecedentedly important gateway to credible and authoritative global change scientific information. The Program's education efforts will also support the critical goal of developing a home-grown scientific workforce capable of bridging the physical, chemical, biological, and social sciences, and coordinating that integrated knowledge-base with the engineering skills that are needed to respond to global change challenges and cultivate future research advances.

This Strategic Plan acknowledges several looming challenges in global change research. Among them, the Nation is at risk of experiencing observational gaps that would affect the ability to monitor and understand natural and human-induced variability, due to developmental and launch delays of replacements for aging systems (e.g., Earth Observing System satellites). Also, to achieve the new heights of multimodal integration recommended in this Plan, scientists and engineers will have to overcome the technical challenges of integrating observing and data systems focused on the physical environment with the range of social and ecological observations collected by other means.

Finally, this Plan recognizes that global change is an international concern. Across the Nation and around the world, people are increasingly becoming aware of the need to mitigate effectively the impacts of global change and adapt to those changes that cannot be prevented. The global nature of today's economy—and the speed with which challenges faced in one part of the world can affect others—reinforce the need for a global response based upon the best available science. Social, economic, and political upheaval can result from such manifestations of global change as decreased availability of water, food, and other critical resources that can sweep across regional and national boundaries. Understanding global change and the options for minimizing and managing its risks is important for U.S. national security and for maintaining regional and global stability.

A worldwide issue such as global change also requires international research cooperation. Observations across the globe are crucial to develop the long-term data sets needed to leverage and build upon U.S. investments. Networks of satellite, ocean, atmosphere, and land-based observations are essential to producing the data necessary to test models and advance research that can ultimately protect livelihoods and the environment.

To summarize, looking forward, the USGCRP will work to integrate the physical, chemical, biological, and social sciences; interact with decision makers about research results relevant to their needs; advance communication and interdisciplinary education in global change research; and make effective use of assessment results to inform future research activities. Broadening Federal participation in the Program is also needed, as current agency participants may lack the direct links to and experience with stakeholder communities that are key to developing viable adaptation and mitigation options. The implementation strategy section of the Strategic Plan outlines a path forward to address these and other challenging aspects of the new strategic goals and objectives.

Taken together, the Program envisioned through this Strategic Plan will coordinate the work of Federal agencies more productively than ever, ensuring a more effective global change research effort for the benefit of the Nation.

Box 1. USGCRP Strategic Goals and Objectives

Goal 1. Advance Science: Advance scientific knowledge of the integrated natural and human components of the Earth system.

- ***Objective 1.1. Earth System Understanding:*** Advance fundamental understanding of the physical, chemical, biological, and human components of the Earth system, and the interactions among them, to improve knowledge of the causes and consequences of global change.
- ***Objective 1.2. Science for Adaptation and Mitigation:*** Advance understanding of the vulnerability and resilience of integrated human-natural systems and enhance the usability of scientific knowledge in supporting responses to global change.
- ***Objective 1.3. Integrated Observations:*** Advance capabilities to observe the physical, chemical, biological, and human components of the Earth system over multiple space and time scales to gain fundamental scientific understanding and monitor important variations and trends.
- ***Objective 1.4. Integrated Modeling:*** Improve and develop advanced models that integrate across the physical, chemical, biological, and human components of the Earth system, including the feedbacks among them, to represent more comprehensively and predict more realistically global change processes.
- ***Objective 1.5. Information Management and Sharing:*** Advance the capability to collect, store, access, visualize, and share data and information about the integrated Earth system, the vulnerabilities of integrated human-natural systems to global change, and the responses to these vulnerabilities.

Goal 2. Inform Decisions: Provide the scientific basis to inform and enable timely decisions on adaptation and mitigation.

- ***Objective 2.1. Inform Adaptation Decisions:*** Improve the deployment and accessibility of science to inform adaptation decisions.
- ***Objective 2.2. Inform Mitigation Decisions:*** Improve the deployment and accessibility of science to inform decisions on mitigation and the mitigation-adaptation interface.
- ***Objective 2.3. Enhance Global Change Information:*** Develop the tools and scientific basis to enable an integrated system of global change information, informed by sustained, relevant, and timely data to support decision making.

Goal 3. Conduct Sustained Assessments: Build sustained assessment capacity that improves the Nation's ability to understand, anticipate, and respond to global change impacts and vulnerabilities.

- ***Objective 3.1. Scientific Integration:*** Integrate emerging scientific understanding of the integrated Earth system into assessments and identify critical gaps and limitations in scientific understanding.
- ***Objective 3.2. Ongoing Capacity:*** Strengthen and evolve ongoing capacity to conduct assessments with accessible, transparent, and consistent processes and broad participation of stakeholders across regions and sectors.
- ***Objective 3.3. Inform Responses:*** Inform responses to global change with accurate, authoritative, and timely information that is accessible to multiple audiences in multiple formats.
- ***Objective 3.4. Evaluate Progress:*** Ensure ongoing evaluation of assessment processes and products, and incorporate the findings into an adaptive response for systemic improvement.

Goal 4. Communicate and Educate: Advance communications and education to broaden public understanding of global change and develop the scientific workforce of the future.

- ***Objective 4.1. Strengthen Communication and Education Research:*** Strengthen the effectiveness of global change communication and education research to enhance practices.
- ***Objective 4.2. Reach Diverse Audiences:*** Enhance existing and employ emerging tools and resources to inform and educate effectively, providing for information flow in multiple directions.
- ***Objective 4.3. Increase Engagement:*** Establish effective and sustained engagement to enable a responsive and wholly integrated Program.
- ***Objective 4.4. Cultivate Scientific Workforce:*** Cultivate a capable, diverse scientific workforce that is knowledgeable about global change.

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WMO Global Atmosphere Watch (GAW) Strategic Plan: 2008–2015

World Meteorological Organization

Weather • Climate • Water

WORLD METEOROLOGICAL ORGANIZATION
GLOBAL ATMOSPHERE WATCH

No. 172

WMO Global Atmosphere Watch (GAW) Strategic Plan: 2008 – 2015

A Contribution to the Implementation of the WMO Strategic Plan: 2008-2011

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FOREWORD

World Meteorological Organization (WMO) Members have long recognized the importance of atmospheric chemistry in their weather, climate and air quality programmes and activities. In 1989, this resulted in the establishment of the Global Atmosphere Watch (GAW) Programme by the forty-first session of the WMO Executive Council. In so doing, two long-term monitoring programmes dating back to the 1970s or earlier were merged: the Global Ozone Observing System (GO_3OS) and the Background Air Pollution Monitoring Network (BAPMoN).

In the report of its tenth session (Offenbach, 1990), the Commission for Atmospheric Sciences welcomed this decision and emphasized that "a fundamental concept of GAW was that atmospheric composition observations must be given the same importance as that given to the classical meteorological parameters such as temperature, wind and precipitation". In 1991, Eleventh World Meteorological Congress endorsed the GAW and, in 1992, the forty-fourth session of the Executive Council approved the GAW Technical Regulations.

Since that time, the GAW has evolved into a major programme in the context of WMO's leading efforts to implement an Integrated Global Atmospheric Chemistry Observations (IGACO) strategy and the monitoring needs for essential climate variables like ozone, aerosols and greenhouse gases.

It is a pleasure to introduce the third GAW Strategic Plan for the period 2008 to 2015, which is consistent with the WMO Strategic Plan: 2008 – 2011. I wish to thank all contributing experts of the Commission for Atmospheric Sciences' Open Programme Area Group for Environmental Pollution and Atmospheric Chemistry (CAS OPAG-EPAC), for their role in its development. The task involved a series of consultations within the international GAW community, including the Scientific Advisory Groups, as well as leaders of the Quality Assurance/Science Activity Centres, Central Calibration Laboratories, World or Regional Calibration Centres and World Data Centres. The Plan was reviewed and endorsed by the Joint Scientific Steering Committee of CAS OPAG-EPAC in April 2007.

The GAW Strategic Implementation Plan: 2008 - 2015 incorporates the successful aspects of previous plans and makes some positive changes in order to address future needs. By implementing the IGACO strategy, GAW rises to meet the atmospheric chemistry-related challenges of the next decade. The GAW 2008 - 2015 programme is a key component of the WMO observing system that, in turn, is a major contribution to the Global Earth Observation System of Systems (GEOSS). This strategic plan addresses a number of recent developments in numerical weather prediction that, no doubt, will require information on aerosols, ozone and greenhouse gases. This expands the community of practice of GAW, necessitates even stronger links to the WMO Information System (WIS) and brings GAW closer to the forecasting research activities of the World Weather Research Programme (WWRP), including THORPEX. The strategic plan sets GAW on a course that underscores its role as a unique international mechanism for applying systematic atmospheric chemistry observations and analysis in addressing societal needs under a constantly changing climate.

(M. Jarraud)

Secretary-General

EXECUTIVE SUMMARY

Based on an assessment of the programme status, this Global Atmosphere Watch (GAW) Strategic Plan is the foundation for developing the components of GAW over the next eight years (2008-2015). It is in line with a framework strategy, namely, the Theme Report of the International Global Observing Strategy (IGOS) on Integrated Global Atmospheric Chemistry Observations [*IGACO*, 2004]. Goals are formulated for the entire period while specific implementation tasks are defined for 2008 – 2011 only. For the remainder of the planning period, they will be developed in 2011 after assessing progress made.

This GAW Strategic Plan is the product of a joint effort of numerous key-players of the GAW community, reviewed and endorsed in its entirety by the Joint Scientific Steering Committee of the WMO Open Programme Area Group on Environmental Pollution and Atmospheric Chemistry (JSSC OPAG-EPAC) and acknowledged by the Fifteenth WMO Congress in 2007.

The GAW Strategic Plan addresses the GAW community, its partner programmes and interested scientists at large.

Rationale and Mission of GAW

The **rationale** for the Global Atmosphere Watch is the need to understand and control the increasing influence of human activity on the global atmosphere. Among the grand challenges are

- Stratospheric ozone depletion and the increase of ultraviolet (UV) radiation.
- Changes in the weather and climate related to human influence on atmospheric composition, particularly, greenhouse gases, ozone and aerosols
- Risk reduction of air pollution on human health and issues involving long-range transport and deposition of air pollution.

Many of these have socio-economic consequences affecting weather, climate, human and ecosystem health, water supply and quality, and agricultural production.

The **mission** of GAW, taking into account the Integrated Global Atmospheric Chemistry Observations (IGACO) strategy, is to

- Reduce environmental risks to society and meet the requirements of environmental conventions.
- Strengthen capabilities to predict climate, weather and air quality.
- Contribute to scientific assessments in support of environmental policy.

through

- Maintaining and applying global, long-term observations of the chemical composition and selected physical characteristics of the atmosphere.
- Emphasising quality assurance and quality control.
- Delivering integrated products and services of relevance to users.

GAW also fulfils a **mandate from WMO Members** by responding to the needs and clearly linking to the plans of national, regional, and international observing projects, programmes, systems and strategies, *e.g.*

- As a component of the WMO integrated global observing system, contributing to Global Monitoring for Environment and Security (GMES) in support of Global Earth Observation System of Systems (GEOSS).
- In supporting the United Nations Framework Convention on Climate Change (UNFCCC), especially by contributing to the implementation plan for the Global Climate Observing System (GCOS) [*WMO*, 2003a].

- In observing the Vienna Convention on the Protection of the Stratospheric Ozone Layer and follow-up protocols.
- In supporting the Convention on Long-Range Transboundary Air Pollution (CLRTAP).
- In providing a comprehensive set of observations of atmospheric composition in support of the Intergovernmental Panel on Climate Change (IPCC) process.

Programme Status

Since its inception in 1992, GAW has matured and developed into a programme with support from a large number of WMO Members. More than 100 countries have registered approximately 700 stations with the GAW Station Information System (GAWSIS). As of March 2007, each of the GAW World Data Centres (WDCs) have registered anywhere between 80 and 400 stations.

The **surface-based observational network** remains the back-bone of GAW. Twenty-four (24) stations (comprising one or several individual sites) constitute the network of Global GAW stations, with Jungfraujoch (Switzerland) and Danum Valley (Malaysia) being among the most recent additions. The remaining stations represent the GAW network of Regional and Contributing stations which add significantly to the global observing systems.

In the last decade, **airborne and space-based observations** have begun to contribute significantly to the characterization of the upper troposphere and lower stratosphere, in particular with regards to ozone, solar radiation, aerosols, and certain trace gases. Some aircraft measurements remain in continuous danger of being terminated because of insufficient funding. A new generation of satellite sensors have begun operation, in some cases adding to relatively long measurement series, in other cases beginning new measurement series (see IGACO report). During the last years, expertise has been built up to use satellite information to explore the composition of the lower and middle troposphere. Data access has been improving, but is still not optimal.

Various **GAW expert groups and central facilities** exist under the oversight of the WMO Commission for Atmospheric Sciences (CAS) and its Joint Scientific Steering Committee of the WMO Open Programme Area Group on Environmental Pollution and Atmospheric Chemistry (JSSC OPAG-EPAC). These comprise as of May 2007:

- 6 Scientific Advisory Groups (SAGs) to organise and co-ordinate GAW activities by parameter, and the Expert Teams on World Data Centres (ET-WDC) and Near-Real-Time Chemical Data Transfer (ET-NRT CDT).
- 4 Quality Assurance/Science Activity Centres (QA/SACs) perform network-wide data quality and science-related functions.
- 15 Central Calibration Laboratories (CCLs) and World and Regional Calibration Centres (WCCs, RCCs) maintain calibration standards and provide instrument calibrations and training to the stations.
- 5 World Data Centres archive the observational data and metadata, which are integrated by the GAW Station Information System (GAWSIS).

Main Long-Term Objectives

The **main long-term objectives** of GAW are in line with the WMO Strategic Plan 2008-2011 and identical with those expressed in the IGACO report [IGACO, 2004]. With respect to the last GAW Strategic Plan (2001-2007) [*WMO*, 2001b], the present version strives for the following main programme developments:

- Develop GAW into a three-dimensional global atmospheric chemistry measurement network through the **integration of observations** of surface-based, balloon-borne, aircraft, satellite and other remote sensing observations.

- Make certain sectors of GAW, such as total ozone, ozone sounding and aerosol observations, compatible with **near-real-time (NRT)**[1] **delivery of data**. Increase the usage of the WMO Global Telecommunication System/WMO Information System (GTS/WIS) for exchange of GAW data.
- Fuse observational systems, data assimilation and modelling, databases and product delivery, and quality assurance and validation into coherent data processing chains, related to a defined GAW **quality management system** within the WMO Quality Management Framework (QMF).
- Support research and development leading to **assimilation of the essential climate variables** – aerosols, ozone and greenhouse gases – in atmospheric transport and numerical weather prediction models and the production of related products and services.

Implementation Principles

The **implementation principles** for this GAW Strategic Plan are:

- Regularly **assess the status** of the GAW networks and projects on a biennial basis through the JSSC OPAG-EPAC.
- Establish and operate dedicated **IGACO offices** for the thematic foci on ozone/UV, aerosols, greenhouse gases and air quality/long-range transport of air pollution, to strengthen research and application activities in the focus area.
- Support continued operations and development of **existing GAW observatories** that have a solid record of achievement.
- Improve the collaboration between the NMHSs, environmental agencies and research organizations **in filling gaps** in the GAW three-dimensional observing network.
- Deliver in **near-real-time** total ozone, ozone sonde and aerosol optical depth data, making increasing use of the WMO GTS/WIS system.
- **Standardize** quality-related processes and procedures for the primary GAW variables: ozone, UV, greenhouse gases, aerosols, selected reactive gases and precipitation chemistry.
- Ensure that data collected and archived by WMO/GAW WDCs are of **known quality** and promote open access under a **'fair-use' data policy**.
- Continue to build up resident **expertise in developing countries** so that they are linked to strong science programmes.
- Increase **the visibility** of GAW through the quadrennial GAW Symposium and co-sponsoring specialized sessions at large conferences such as those of the American Geophysical Union (AGU) and the European Geosciences Union (EGU).

Development of the Focal Areas

The status and future development of the various GAW focal areas have been elaborated by the various SAGs and are detailed in Chapter 7 of this report. In summary:

Ozone (O_3) plays a central role in physical, chemical, and radiative processes in the atmosphere. The success of the Vienna Convention on Protection of the Ozone Layer and its Montreal Protocol is undisputed. However, the need to continue observations of stratospheric ozone has been re-enforced in the early 21st century with the occurrence of ozone holes of unprecedented dimensions. Trends, both in the stratosphere and in the troposphere remain a topic of scientific debate. A comprehensive network of Dobson and Brewer instruments for total ozone measurements needs to be continued with an emphasis on making QA/QC information including calibration histories publicly available. Satellite retrievals have become mature, and the focus

[1] *Defined through-out this document as being within 1-2 hours from time of observation*

should be on establishing good calibration histories for validation purposes and to enable the transition from one sensor to another. Further integration of the ozone sonde networks and other sources of vertical profile information (Umkehr, Lidar and microwave) into one global network is needed. Implementation of near-real-time data delivery capabilities will further increase the value of these observations for numerical weather prediction and model validation. The recognition of the GAW ozone networks as comprehensive GCOS networks is a priority.

Of the **greenhouse gases** that are directly affected by anthropogenic activities, carbon dioxide (CO_2) has the largest total radiative effect, followed by chlorofluorocarbons (CFCs), methane (CH_4), tropospheric ozone (O_3), and nitrous oxide (N_2O). Reliable long-term estimates of sources and sinks appropriate to particular emission management scenarios require very high accuracy and precision observations of the abundance and the vertical distribution of CO_2 and CH_4 as well as their isotopes. The global networks are still incomplete and should be augmented with continuous measurements on the continents, the Arctic, the tropics, and the oceans. A challenge and opportunity is the validation and use of satellite observations that are becoming available. Apart from the major greenhouse gases CO_2 and CH_4, the emergence of substitutes for chemicals banned under the Montreal Protocol and regulated under the Kyoto Protocol needs to be closely monitored. Calibration standards for some of these compounds still need to be harmonized and an accuracy of observations achieved that is sufficient to verify emission inventories. The GAW CO_2 and CH_4 networks have already been identified as comprehensive networks in GCOS and the incorporation of the GAW N_2O, CFCs and SF_6 networks is a priority.

The **reactive gases** as a group are very diverse and include surface ozone (O_3), carbon monoxide (CO), volatile organic compounds (VOCs), oxidised nitrogen compounds (NO_x, NO_y), hydrogen (H_2), and sulphur dioxide (SO_2). These compounds determine the oxidizing capacity of the atmosphere and influence the formation of tropospheric ozone and aerosols, and are therefore relevant to air quality and climate. The surface-based observational network for most of these compounds is totally inadequate and a continuous challenge for the development of the programme. A wealth of information has been obtained through aircraft programmes that are of high priority for GAW, and limited information has been derived from satellites. The global trends of most of these compounds are not sufficiently well understood, and are probably influenced by increasing emissions in Asia. The objectives are to expand the current networks and establish global networks, to further improve and institutionalise the quality assurance and control processes, and to better integrate various data sources. For surface ozone, near-real-time data delivery of the majority of Global and selected Regional GAW stations for inclusion in data assimilation efforts is foreseen.

Atmospheric deposition remains a major environmental issue in several parts of the world due to concerns over acid deposition, eutrophication, trace metal deposition, ecosystem health, biogeochemical cycling, and global climate change. In many areas reductions in emissions of sulphur dioxide have been reflected in precipitation chemistry, but it is increasingly evident that the deposition of nutrients (nitrogen and perhaps phosphorous) in precipitation is contributing to the eutrophication of ecosystems. In other parts of the world, increasing industrialisation has led to increasing emissions of reactive gases. The monitoring of precipitation chemistry worldwide remains, therefore, an important GAW contribution. Despite this, the GAW precipitation chemistry programme has only developed in areas where acid rain has been a major environmental concern. In other areas, the programme has been facing severe funding problems. The objectives, therefore, are primarily to maintain the existing networks, while expanding the observational base wherever possible. In addition, a major challenge is to maintain and improve the central facilities needed for quality control and data management.

The radiation component of GAW is concentrated on **UV radiation**. GAW shares stewardship for aspects of solar radiation with other WMO programmes. UV radiation is linked to several harmful effects on many forms of life, and there is a clear necessity for monitoring surface UV radiation and quantifying future changes. The global observational network is distributed irregularly. The main goals of the UV component of GAW are to expand the observational base in the Tropics and the Southern Hemisphere, to further improve the quality of UV data, to better integrate the ground-based networks with regards to data archiving and distribution of UV data, and to promote the use of UV data for satellite validation.

Aerosol activities are a core component of GAW because of the importance of aerosols to a wide range of issues including global climate change, weather prediction, and air quality/health. Aerosol-related concerns may frequently be equally or more important on the regional scale than on the global scale. For the future, it will be important to enhance the coverage, effectiveness, and application of long-term aerosol measurements within GAW and with cooperating networks worldwide. One important task will be the delivery of aerosol observations at selected stations in near-real-time for use in data assimilation to improve numerical weather prediction.

In addition to the parameters discussed above, a number of **ancillary variables** are important to exploit the chemical observations to the fullest. From the point of view of GAW, these ancillary variables mostly serve to characterise the origin of air masses or to directly characterise the radiative balance of the Earth. These ancillary variables include solar radiation, meteorological variables and radionuclides. Long-term observations of direct, diffuse and global **solar radiation** components at surface stations are important to answer questions on climate variability and climate change. The distribution and quality of the ground-based observations is very heterogeneous, and the main objective is to integrate surface-based and satellite measurements for the purpose of trend analysis. Local **meteorological information** is usually not satisfactory for advanced integration of meteorological and atmospheric chemistry, but it is essential to understand local transport processes and interactions between atmospheric thermodynamics and atmospheric chemistry. Meteorological measurements are usually made at GAW stations, however, they are not always easily available in sufficient temporal resolution. The primary objectives are therefore to enhance the availability, accessibility and use of meteorological information for better specification and understanding of atmospheric chemistry processes. The global distributions of the source-sink terms of the naturally occurring **radionuclides** (^{210}Pb and ^{222}Rn) and the anthropogenic radionuclide (^{85}Kr) are reasonably well known. They serve as ideal tools to assess large- and global-scale transport of gases and aerosols. Thus in future, the ability to monitor and measure atmospheric radionuclides at GAW stations should be improved.

The important cross-cutting area of urban air quality is the focus of the **GURME** project. National Meteorological and Hydrological Services (NMHSs) around the world are broadening their traditional roles to include air quality and related weather-sensitive public health threats. GURME addresses the end-to-end aspects of air quality, linking the observational capabilities of GAW with the needs of chemical weather prediction, with the goal of providing enhanced air quality services of high quality. Priority activities include: the improvement of observing systems and their integration with urban-scale models; the application of satellites in air quality; and capacity building/training initiatives focused on air quality.

Commitment

The coordination of joint activities of GAW with other relevant international and national organizations and programmes will continue to be very important. As all other WMO programmes, GAW is based on voluntary contributions by WMO Member countries, partners and the scientific community. WMO will take the lead but can only encourage rather than require regular contributions to the programme. Its objectives have to be realised bottom-up through a process of identification of individuals and organizations with the programme.

A new set of partnerships will be needed with the environmental agencies of Member countries. It is therefore important that NMHSs build bridges of cooperation with environmental monitoring agencies. GAW will help do this.