3B.7 THE U.S. GLOBAL CLIMATE OBSERVING SYSTEM (GCOS) PROGRAM: AN UPDATE ON CONTINUING EFFORTS TO IMPLEMENT REFERENCE CLIMATE OBSERVATION SITES

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1. INTRODUCTION

The U.S. GCOS Program [http://www.ncdc.noaa.gov/oa/usgcos/index.htm] at NOAA's National Climatic Data Center (NCDC) [http://www.ncdc.noaa.gov] is involved in working to implement a sustainable and robust GCOS observing network for international atmospheric, oceanographic, and terrestrial climate observing. The U.S. GCOS support philosophy is based upon a three-tiered approach involving a series of international, regional, and bi-lateral project efforts. One of the most active and important areas of involvement is in the Pacific Ocean region where we leverage support for this via formal climate bilateral agreements that the U.S. has with both Australia and New Zealand.

NCDC and the U.S. GCOS Program Manager serve as the NOAA and U.S. lead on these bilateral climate agreements. This paper will describe the efforts undertaken in the Pacific region towards developing a more sustainable and robust GCOS observing ground-based network for atmospheric, oceanographic, and terrestrial climate observing in the region. The paper will describe the actions to date, plans for the future, and how the efforts to date such as the establishment of a virtual Regional Climate Center for the region in order to, among other things, work towards improving data availability and access for and from the nations in the region in order to improve climate services across the region. NCDC is also interested in developing partnerships for installing U.S. Climate Reference Network [see http://www.ncdc.noaa.gov/crn] equipment to be part of a global long-term climate reference network for improving climate information from more data sparse tropical and high-elevation areas. In order to properly document this, a full description of the overall climate observations program in the U.S. is required.

2. BACKGROUND

Meteorological surface-based networks, utilized for climate purposes, make observations of important climate factors, atmospheric profiles, and pollutant emissions, aerosols, and ozone. These surface-based networks are intended to provide the basic observational set needed to define the status and trends in climate of the world, and also to calibrate and validate satellite-based observations. Although hundreds of millions of dollars are spent each year on developing and operating space-based observation systems, surface-based meteorological networks are "under reporting" their observations in many parts of the developing world.

This is because of declining economies and the lack of understanding of how these observations contribute to the global effort to monitor climate. Consequently, these networks are operating substantially below their design standards and important observations are either not being made, or are not being communicated to users. Workshops are being conducted to define GCOS deficiencies and, during the next several years, more detailed activities to improve the networks will be identified. The implementation of a GCOS Cooperation Mechanism (GCM) was begun in 2004 as a way of identifying resources (both financial and in-kind) to aid in improving the operation of GCOS monitoring stations in developing nations. The GCM is being used to implement an overall global GCOS Improvement Program. Support, both in funds and in-kind support, has been provided, in addition to the U.S. by Australia, New Zealand, South Africa, Spain, and the United Kingdom. International support for GCOS has been growing over the past couple of years and subsequent formal meetings of the GCM Donor Board have been held in Montreal in November 2005; Geneva in April 2007; and Bonn in June 2008.

The support for developing nations has primarily been for retrofitting surface and upper air observing stations that have up-to-now been silent but yet are key to global climate monitoring activities. Countries that have received new equipment and expendables over the past three years include: Argentina, Armenia, Congo, Cook Islands, Costa Rica, Ecuador, Ivory Coast, Kenya, Maldives, Namibia, the Philippines, and Zimbabwe. In addition to equipment, in cooperation with the U.S. State Department, a number of workshops for enhancing climate change monitoring in support of the Intergovernmental Panel on Climate Change (IPCC) have or are being staged in South Africa, southern South America, northern South America and Central America, Southwest Asia, and Southern Asia. These are all hands-on workshops involving seminars and hands-on work with data from the various countries in attendance. In addition, the State Department has been instrumental in aiding in the establishment of regional GCOS maintenance facilities which have been established in the Pacific and the Caribbean. Another one is being planned for Southern and Eastern Africa in order to further the sustainability of the GCOS network in the developing nations of that region.

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3. ORGANIZATION OF THE GCOS CLIMATE OBSERVATIONS PROGRAM IN THE U.S.

Climate observation activities in the U.S. are coordinated via a federal interagency organization known as the Climate Change Science Program Office (CCSPO). The CCSPO was created in 2001 as part of the President's Climate Change Research Initiative and includes membership from 17 U.S. federal Government agencies. More information on the CCSPO's efforts can be found via their web site at http://climatescience.gov. In its initial strategic plan published in 2003, one of the three main aims of the CCSP was to "Enhance and Expand Observations of the Earth System". The intent of this aim was to help "implement an international, integrated, sustained, and comprehensive global Earth observation system to minimize data gaps and maximize the utility of existing observing networks". This goal fits in quite nicely with the goals of GCOS, and as such an interagency Observations Working Group (OWG) was formed under the auspices of the CCSP to aid in that effort. The key agencies participating in the OWG are NOAA, the National Aeronautics and Space Administration (NASA), the Department of Energy (DOE), and the U.S. Geological Survey (USGS). While other agencies are members of the OWG, these 4 agencies form the basis for the bulk of sustained climate observing activities in the U.S. and on behalf of GCOS on an international basis. The OWG is co-chaired by NOAA and NASA, and is the coordinating body that helps set observing priorities, as well as in coordinating GCOS activities in the U.S.

In particular, the OWG is tasked with coordinating the development of strategies to:

- Design, develop, deploy, integrate and sustain the climate observational components of a comprehensive earth observing system;
- Develop and demonstrate new technology for the innovation of new observations;
- Accelerate the development and deployment of observing and monitoring elements needed for decision support;
- Integrate modeling requirements with the observing system;
- Coordinate the management of observing system components with an effective interagency structure;
- Provide data and information in a timely and seamless manner with a management and distribution system that employs interoperability and standards, and
- Foster international cooperation that contributes to a more robust global climate observing system.
- Systematic Observations

Long-term, high-quality observations of the global environmental system are essential for defining the current state of the Earth's system, its history, and its variability. This task requires both space- and surface-based observation systems. The term climate observations can encompass a broad range of environmental observations, including (1) routine weather observations, which, when collected consistently over a long period of time, can be used to help describe a region's climatology; (2) observations collected as part of research investigations to elucidate chemical, dynamic, biological, or radiative processes that contribute to maintaining climate patterns or to their variability; (3) highly precise, continuous observations of climate system variables collected for the express purpose of documenting long-term (decadal-to-centennial) change; and (4) observations of climate proxies, collected to extend the instrumental climate record to remote regions and back in time to provide information on climate change for millennial and longer time scales.

To meet the long-term needs for the documentation of global changes, the United States integrates observations from both research and operational systems. The United States supports the need to improve global observing systems for climate, and to exchange information on national plans and programs that contribute to the global capacity in this area. Providing for wide access to information from the Global Earth Observation System of Systems (GEOSS) for applications that benefit society has been a focus of efforts coordinated by the intergovernmental Group on Earth Observations (GEO) and the U.S. Group on Earth Observation (USGEO). An international framework for open access to GEOSS data was established, and a U.S. strategic plan was drafted to provide a basis for international cooperation. At the third Earth Observation Summit in February 2005, the United States joined over 75 countries and the European Commission in endorsing to a plan that, over the next 10 years, will revolutionize the understanding of Earth system processes.

A key regional effort of GEOSS in the Western Hemisphere is known as GEOSS in the Americas. The vision of this effort is to build partnerships with countries and organizations in the Americas and the Caribbean to strengthen the ability to utilize each other's research and operational Earth observations. The first significant GEOSS in the Americas project involved the shifting of the GOES-10 satellite in December 2006 to a new orbit, to greatly improve environmental satellite coverage of the Western Hemisphere, especially over South America. By significantly enhancing satellite detection of such natural hazards as severe storms, floods, drought, landslides, and wildfires, the shift will help protect lives and property in both South America and the United States, and will allow for improved prediction, response, and follow-up and expanded understanding of Earth system processes [see http://www.strategies.org/EOPA.html]. Since 2002, the United States has entered into a number of important bilateral climate agreements, funding projects with Australia, China, New Zealand, and South Africa. These wide-ranging projects deal with climate prediction, ocean observation, stratospheric detection, water vapor measurements, capacity building and training, and communication of information, and focus the attention and resources of these countries on developing a more sustainable and robust GCOS program. Much of the following information is incorporated in the most recent "*U.S. Report on Systematic Observations for Climate – 2008"* which was submitted to the United Nations Framework Convention on Climate Change in September 2008, and can be found on-line at http://www.climatescience.gov/Library/UNFCCC-report.htm.

4. DOCUMENTATION OF U.S. CLIMATE OBSERVATIONS

The U.S. supports a broad network of in-situ global atmospheric, ocean, and terrestrial observation systems, as well as a large number of remote sensing satellite platforms that are essential to climate monitoring.

4.1 *In-Situ Atmospheric Observations*

The U.S. supports 75 stations in the Global Climate Observing System (GCOS) Surface Network (GSN), 21 stations in the GCOS Upper Air Network (GUAN), and 4 stations in the Global Atmospheric Watch (GAW). These stations are distributed geographically as prescribed in the GCOS and GAW network designs. The data (metadata and observations) from these stations are shared according to GCOS and GAW protocols. Since publishing its last report to the UNFCCC, the United States has begun fielding and commissioning a system known as the U.S. Climate Reference Network (USCRN). The USCRN is designed to answer the question: How has the U.S. climate changed over the past 50 years at national, regional, and local levels? Since beginning in 2002, the full complement of 114 sites was completely implemented in September 2008 in the Continental U.S. [see http://www.ncdc.noaa.gov/oa/climate/uscrn]. Beginning in 2008, the USCRN program began expanding into Alaska with an eventual plan for 29 sites (to date 4 pilot sites have already been installed). A prime emphasis of the U.S. GCOS program centers on reference observations for both surface and upper air sites. As such, the USCRN system also forms the basis for a number of U.S. efforts to pursue the installation of reference surface observing in unique high latitude, high elevation, and tropical sites with partners from the World Bank, various universities, and the Smithsonian Tropical Research Institute. Finally, planning activities will continue on developing a GCOS Reference Upper Air Network (GRUAN) to aid in enhancing the quality of upper tropospheric and lower stratospheric water vapor measurements at a subset of present GCOS Upper Air Network stations and the U.S. has been a large supporter of the work done to date by the AOPC's Working Group on Atmospheric Reference Observations.

Since water vapor is the most important greenhouse gas in our atmosphere, exhibiting large gradients in concentration and mixing ratio between the Earth's surface and the upper troposphere/lower stratosphere (UT/LS). Fitting in with the GRUAN planning work outlined above, understanding changes in the distribution of water vapor, whether due to natural or anthropogenic causes, is essential to understanding the potential for climate change. Even small increases in stratospheric water vapor (1% per year) could cause significant surface radiative forcing and stratospheric cooling. Stratospheric water vapor amounts are controlled by dehydration processes driven by low temperatures in the tropopause region of the tropics. Our understanding of the dehydration process and its variability is incomplete. Of particular importance is the extent and frequency of ice-supersaturated conditions in the UT/LS. These shortfalls in our knowledge have made accurate and precise water vapor measurements in the tropopause region a required component of future climate research, particularly at the low water vapor mixing ratios in the UT/LS where measurement discrepancies currently exist. A number of research efforts will be continued or initiated to help resolve the observed discrepancies in *in-situ* water vapor observations. These activities are being conducted jointly by NASA and NOAA with the involvement of US and international investigators from a wide range of government and academic institutions. The planned efforts include: (1) single instrument laboratory studies designed to better characterize and understand instrument performance and calibration under a variety of atmospheric conditions; (2) the possible selection and use of a water vapor calibration standard to establish and/or confirm measurement accuracy and precision; and (3) multiple-instrument intercomparisons in the laboratory and field involving an independent referee to coordinate and presents the results of each formal laboratory and flight intercomparison that includes instruments from different research groups. Field intercomparisons will include aircraft-borne, balloon-borne, and satellite instruments.

The U.S. GCOS program supports a number of climate observing systems and projects in developing nations. In 2002, there were 20 non-transmitting GUAN stations around the globe. Through focused projects, the number of non-transmitting stations has dropped to 1 as of September 2008. The GCOS program continues to ensure the long-term sustainability of all stations through the establishment of regional technical and maintenance support centers for southern and eastern Africa, the Caribbean, and the Pacific Islands. Related to this capacity-building activity, the program will be supporting an intensive upper-air campaign as part of the African Monsoon Multidisciplinary Analysis, with the installation of a new hydrogen generator at the upper-air site in Dakar, Senegal.

While it is difficult to list all observing campaigns and systems, there are several others that need to be noted here for their global climate significance. The Southern Hemisphere ADditional OZonesondes (SHADOZ) [see http://croc.gsfc.nasa.gov/shadoz/] provides a consistent dataset from balloon-borne ozonesondes for ground verification of satellite tropospheric ozone measurements at 12 sites across the tropical and subtropical regions of the southern hemisphere. Another key system along these lines is the Aerosol Robotic NETwork (AERONET) [see http://aeronet.gsfc.nasa.gov/data_frame.html] which is a federation of ground based remote sensing aerosol networks established in part by NASA and France's CNRS. AERONET provides a long-term, continuous and readily accessible public domain database of aerosol optical properties for research and characterization of aerosols, validation of satellite retrievals, and provides synergy with other databases. Aeronet collaboration provides a series of globally distributed observations of spectral aerosol optical depth, inversion products, and precipitable water in diverse aerosol regimes. . The collaborative effort between NASA's Advanced Global Atmospheric Gases Experiment (AGAGE) and NOAA's Flask Monitoring Network has been instrumental in measuring the composition of the global atmosphere continuously since 1978. The AGAGE is distinguished by its capability to measure over the globe at high frequency almost all of the important species in the Montreal Protocol to protect the ozone layer and almost all of the significant non-CO_2 gases in the Kyoto Protocol to mitigate climate change, and both NASA and NOAA demonstrate great collaborative research efforts in this key climate monitoring activity [see http://agage.eas.gatech.edu/ and http://www.esrl.noaa.gov/].

The primary goal of the Atmospheric Radiation Measurement (ARM) Climate Research Facility (ACRF) is to provide the infrastructure needed for studies investigating atmospheric processes in several climatic regimes and for climate model development and evaluation. The ACRF consists of three stationary facilities, an ARM Mobile Facility (AMF), and the ARM Aerial Vehicles Program (AAVP). The stationary sites provide scientific testbeds in three climatically significant regions (mid-latitude, polar, and tropical), and the AMF provides a capability to address high priority scientific questions in regions other than the stationary sites. The AAVP provides a capability to obtain in situ cloud and radiation measurements that complement the ground measurements. Data streams produced by the ACRF will be available to the atmospheric community for use in testing and improving parameterizations in global climate models. The AMF was deployed in Niamey, Niger in 2006 measuring radiation, cloud, and aerosol properties during the monsoon and dry seasons.

The Micro Pulse Lidar (MPL) Network (MPLNET) [see http://mplnet.gsfc.nasa.gov] is a federated network of MPL systems designed to measure aerosol and cloud vertical structure continuously, day and night, over long time periods required to contribute to climate change studies and provide validation for models and satellite sensors in NASA's Earth Observing System. At present, thirteen permanent sites are operational worldwide, and five more to be completed soon. Numerous temporary sites have been established in support of various field campaigns. Most MPLNET sites are co-located with sites in NASA's AERONET to provide both column and vertically resolved aerosol and cloud data, such as: optical depth, absorption, size distribution, aerosol and cloud heights, planetary boundary layer structure and evolution. Recent MPLNET accomplishments include contributions to the development of a novel approach to retrieve the height and optical depth of low, thick cloud layers (such as stratus). Such clouds can contain vast amounts of water and reflect significant amounts of sunlight. However, these clouds are extremely difficult to analyze from space due to their low altitude and high drop concentration (opaque). In another recent study, MPLNET contributed to the most comprehensive assessment of aerosol profiling capability to date. The study concluded that measured aerosol extinction profile uncertainty is approximately 20% on average. The profile of aerosol extinction is used to determine aerosol radiative effects. The accuracy with which are able to estimate aerosol extinction translates directly to our ability to quantify aerosol impacts on climate understand impacts on climate.

4.2 *In-Situ Ocean Observations*

The climate requirements of the Global Ocean Observing System (GOOS) are the same as those for GCOS. Also like GCOS, GOOS is based on a number of in situ and space-based observing components. The United States supports the Integrated Ocean Observing System's surface and marine observations through a variety of components, including fixed and surface-drifting buoys, subsurface floats, and volunteer observing ships. It also supports the Global Sea Level Observing System through a network of sea level tidal gauges.

The U.S. currently provides satellite coverage of the global oceans for sea-surface temperatures, surface elevation, ocean-surface vector winds, sea ice, ocean color, and other climate variables. The first element of the climate portion of GOOS, completed in September 2005, is the global drifting buoy array, which is a network of 1,250 drifting buoys measuring sea-surface temperature and other variables as they flow in the ocean currents. Continued upgrading of the Global Sea Level Observing System (GLOSS) tidal gauge network from 43 to 170 stations is planned for 2006–14. Ocean carbon inventory surveys in a 10-year repeat survey cycle help determine the anthropogenic intake of carbon into the oceans. Plans for advancement of the global Tropical–Atmosphere–Ocean (TAO) network of ocean buoys include an expansion of the network into the Indian Ocean (the Pacific Ocean has a current array of 70 TAO buoys). During 2005-07, 8 new TAO buoys were installed in the Indian Ocean in collaboration with partners from India, Indonesia, and France. Plans call for a total of 39 TAO buoys in the Indian Ocean by 2013. These moorings will enhance the tropical networks currently monitoring above-surface, surface, and subsurface conditions in the Pacific and Atlantic Oceans. As of the end of 2008, 60 percent of the GOOS suite of ocean climate observing platforms had been fielded; the full system of ocean climate sensors is scheduled for completion by 2014.

The Integrated Ocean Observing System (IOOS) is the U.S. coastal observing component of the Global Ocean Observing System and is envisioned as a coordinated national and international network of observations, data management and analyses that systematically acquires and disseminates data and information on past, present and future states of the oceans. A coordinated IOOS effort is being established by NOAA via a national IOOS Program Office collocated with the Ocean.US [http://www.ocean.us/] consortium of offices consisting of NASA, NSF, NOAA, and the Navy. The IOOS observing subsystem employs both remote and in situ sensing. Remote sensing includes satellite-, aircraft- and land-based sensors, power sources and transmitters. In situ sensing includes platforms (ships, buoys, gliders, etc.), in situ sensors, power sources, sampling devices, laboratory-based measurements, and transmitters.

4.3 *In-Situ Terrestrial Observations*

For terrestrial observations, GCOS and the Global Terrestrial Observing System (GTOS) have identified permafrost thermal state and permafrost active layer as key variables for monitoring the state of the cryosphere. The United States operates a long-term "benchmark" glacier program to intensively monitor climate, glacier motion, glacier mass balance, glacier geometry, and stream runoff at a few select sites. The data collected are used to understand glacier-related hydrologic processes and improve the quantitative prediction of water resources, glacier-related hazards, and the consequences of climate change. Long-term, mass-balance monitoring programs have been established at three widely spaced U.S. glacier basins that clearly sample different climate-glacier-runoff regimes.

SNOTEL and SCAN Networks—The SNOTEL (SNOpack TELemetry) and SCAN (Soil Climate Analysis Network) monitoring networks provide automated comprehensive snowpack, soil moisture, and related climate information designed to support natural resource assessments. SNOTEL operates more than 660 remote sites in mountain snowpack zones of the western United States. SCAN, which began as a pilot program, now consists of more than 120 sites. These networks collect and disseminate continuous, standardized soil moisture and other climate data in publicly available databases and climate reports. Uses for these data include inputs to global circulation models, verifying and ground truthing satellite data, monitoring drought development, forecasting water supply, and predicting sustainability for cropping systems.

Polar Climate Observations—Polar climate observations will continue to be a focus of U.S. activities as preparations are made for the International Polar Year beginning in 2007. Currently, the United States maintains soil-moisture climate stations in both Alaska and Antarctica, and plans to increase efforts on observations of the Arctic atmosphere, sea ice, and ocean. Working with a number of Arctic nations via the International Arctic Systems for Observing the Atmosphere (IASOA), the United States will deploy and/or participate in a number of observing activities to produce a higher-resolution characterization of clouds and aerosols and of both incoming and outgoing radiation, to provide the high-quality records needed to detect climate change and to improve calibration of broad-scale satellite observations in the Arctic. For example, through the IASOA process, the United States will be working with its international partners in establishing a super-site climate observatory in the Russian Arctic in Tiksi, north of the Arctic Circle at latitude 71.5º North in the boreal summer 2009 timeframe.

The AmeriFLUX Network—The AmeriFLUX network endeavors to establish an infrastructure for guiding, collecting, synthesizing, and disseminating long-term measurements of CO_2, water, and energy exchange from a variety of ecosystems. Its objectives are to collect critical new information to help define the current global CO_2 budget, enable improved projections of future concentrations of atmospheric CO_2, and enhance the understanding of carbon fluxes, net ecosystem production, and carbon sequestration in the terrestrial biosphere. The North American Carbon Program (NACP)—The NACP is a major focus of the US CCSP, to measure and understand the source and sinks of CO_2, CH_4, and CO in North America and in adjacent ocean regions.

4.4 *Space-Based Observations*

Space-based, remote-sensing observations of the atmosphere–ocean–land system have evolved substantially since the early 1970s, when the first operational weather satellite systems were launched. Over the last decade satellites have proven their observational capability to accurately monitor nearly all aspects of the total Earth system on a global basis. Currently, satellite systems monitor the evolution and impacts of El Niño and La Niña, weather phenomena, natural hazards, and vegetation cycles; the ozone hole; solar fluctuations; changes in snow cover, sea ice and ice sheets, ocean surface temperatures, and biological activity; coastal zones and algal blooms; deforestation and forest fires; urban development; volcanic activity; tectonic plate motions; aerosol and 3-dimensional cloud distributions; water distribution; and other climate-related information.

One critical challenge to the Earth observation field is to maintain existing observation capabilities in a variety of areas. For example, maintaining the observational record of stratospheric ozone is essential in discerning the effects of climate change on the nature and timing of ozone recovery. Other key areas include radiative energy fluxes of the Sun and Earth, atmospheric carbon dioxide, and global surface temperature. Efforts to create a long-term record of global land cover, started by Landsat in the 1970s, are currently being prepared for the transition to a Landsat Data Continuity Mission (LDCM) being planned by the National Aeronautics and Space Administration (NASA) and the U.S. Geological Survey [see http://landsat.gsfc.nasa.gov/]. The LDCM is expected to have a 5-year mission life with 10-year expendable provisions.

Planning continues on deploying the National Polar-orbiting Operational Environmental Satellite System (NPOESS). Prior to the launch of NPOESS in 2013, the NPP satellite will serve as a bridge mission between the NASA Earth Observing System (EOS) program and NPOESS. The mission of NPP is to demonstrate advanced technology for atmospheric sounding, continuing observations of global change after EOS-Terra and EOS-Aqua. It will supply data on atmospheric and sea surface temperatures, humidity soundings, land and ocean biological productivity, and cloud and aerosol properties. NPP will contribute to instrument risk reduction by offering early instrument and system level testing and lessons learned for design modifications in time to ensure NPOESS launch readiness, ground system risk reduction, and early user evaluation of NPOESS data products, such as algorithms, and instrument verification, and opportunities for instrument calibration.

A number of U.S. satellite operational and research missions form the basis of a robust national remote-sensing program that fully supports the requirements of GCOS. These include instruments on the Geostationary Operational Environmental Satellites (GOES) and Polar Operational Environmental Satellites (POES), the series of Earth Observing Satellites (EOS), the Landsats 5 and 7, and the Jason satellite measuring sea-surface height, winds, and waves. Additional satellite missions in support of GCOS include (1) the Active Cavity Radiometer Irradiance Monitor for measuring solar irradiance; (2) QuickSCAT; (3) the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) for studying ocean and productivity, as well as aerosols; (4) the Shuttle Radar Topography Mission (SRTM); (5) the Tropical Rainfall Measuring Mission for measuring rainfall, clouds, sea-surface temperature, radiation, and lightning; (6) the Ocean Surface Topography Mission (OSTM), an altimetry mission to provide sea surface heights for determining ocean circulation, climate change and sea-level rise; (7) ICESat, and the Gravity Recovery and Climate Experiment (GRACE) that measure the transport of mass between the cryosphere, oceans and land; (8) Tropical Rainfall Measuring Mission (TRMM); and (9) Laser Geodynamics Satellite (LAGEOS), Global Position Satellites (GPS) and other geodetic satellites that provide for an accurate Terrestrial Reference Frame for the measurement of sea level change.

A major upgrade to the GOES system, known as GOES-R, is under development, with a first launch currently planned for 2015. It should also be noted that a number of new missions will be launched over the next several years as follows [launch year in brackets]: (1) Orbiting Carbon Observatory (OCO) [2009] mission to measure CO_2; (2) Glory mission [2009] that will measure black carbon soot and other aerosols, as well as total solar irradiance; (3) Aquarius [2010] intended to measure global sea surface salinity; and (4) Global Precipitation Measurement (GPM) mission [2013].

The accurate, climate-quality record of sea surface topography measurements, started in 1992 with TOPEX/POSEIDON and continued in 2001 with the Jason satellite mission, will be extended with the OSTM. These missions have provided accurate estimates of regional sea-level change and of global sea-level rise unbiased by the uneven distribution of tide gauges. Ocean topography measurements from these missions have elucidated the role of tides in ocean mixing and maintaining deep ocean circulation. Further, quantitative determination of ocean heat storage from satellite measurements have confirmed climate model predictions of the Earth's energy imbalance which is primarily due to greenhouse gas forcing. The high levels of absolute accuracy and cross calibration make these missions uniquely suited for climate change studies. OSTM, launched in 2008, is a collaborative effort among NASA, NOAA, the French space agency Centre National d'Etudes Spatiales (CNES), and the European meteorological agency EUMETSAT.

The Glory mission is planned to launch in 2009. It will carry a Total Irradiance Monitor (TIM) based on the SORCE TIM design, with the same high-precision phase-sensitive detection capability. Glory will also carry an Aerosol Polarimeter Sensor (APS), which will improve our ability to distinguish among aerosol types by measuring the polarization state of reflected sunlight. Both TIM and APS will provide key measurements beginning in 2009, a period of expected low solar activity. This less-active portion of the 11-year solar cycle is especially crucial in estimating any long-term trends in solar output – a key to understanding the 20th-century context of global change, as the Sun is the single entirely “external” forcing of the climate system that is unaffected by climate change itself.

The Aquarius satellite mission will measure changes in sea surface salinity over the global oceans to a precision of 2 parts in 10,000 (equivalent to about 1/6 of a teaspoon of salt in 1 gallon of water). By measuring global sea surface salinity with good spatial and temporal resolution, Aquarius will answer long-standing questions about how our oceans respond to climate change and the water cycle, including changes in precipitation, evaporation, ice melting, and river runoff. Aquarius is a collaborative effort between NASA and Comisión Nacional de Actividades Espaciales (CONAE), the Argentine space agency, with an expected launch date in 2010.

The "A-Train" is a sun-synchronous earth-orbiting satellite formation that studies the atmosphere. The "A" in "A-Train" stands for “Atmosphere” and is a collaboration between NASA and the space agencies of Canada and France. The A-Train constellation consists of five satellites flying in close proximity to each other, with a 6th satellite, the Orbiting Carbon Observatory (OCO), due to be added late in early 2009. The first satellite in the A-Train constellation, Aqua, was launched in 2002. The second satellite, Aura, was launched in June 2004, while the CloudSAT, CALIPSO and PARASOL satellites were launched in October 2004. The A-Train satellites cross the equator within a few minutes of one another at around 1:30 p.m. local solar time. By combining the different sets of observations from the A-Train, a better understanding of atmospheric composition, clouds, and aerosols has resulted that has led and is leading to major advances in atmospheric knowledge. More details on the six A-Train components are as follows:

- The NASA Aura satellite was launched in July 2004 with 4 instruments to extensively monitor the composition of the atmosphere. Two of these instruments, the Microwave Limb Sounder (MLS) and High Resolution Dynamics Limb Sounder (HIRDLS), obtain limb viewing observations to obtain highly resolved altitude profiles of the stratosphere and upper troposphere for understanding photochemical and dynamical processes in these altitude ranges. The Tropospheric Emission Spectrometer (TES) obtains column and partial altitude profiles for ozone and tropospheric trace gases, while the Ozone Monitoring Instrument (OMI) obtains nearly daily global ozone column maps as well as columns for other important air quality parameters. Aura observes the atmosphere to answer the following three high-priority environmental questions: (1) is the Earth's ozone layer recovering; (2) is air quality getting worse; and (3) how is the Earth's climate changing.

- PARASOL is a French CNES microsatellite project. It has improved the characterization of cloud and aerosol microphysical and radiative properties. This has led to a substantial increase in our understanding of the radiative impact of clouds and aerosols that in turn has led to improving numerical modeling of these processes in general circulation models.

- The NASA Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) and NASA CloudSat satellites were successfully launched in April 2006. CALIPSO and CloudSat are highly complementary and together provide new, three-dimensional perspectives of how clouds and aerosols form, evolve, and affect weather and climate. Both CALIPSO and CloudSat fly in formation as part of the NASA A-Train constellation (e.g., Aqua, Aura, and the French PARASOL spacecraft), providing the benefits of near simultaneity and thus the opportunity for synergistic measurements made with complementary techniques. After the launch of NASA's OCO satellite in 2009, it will join the A-Train.

- The NASA Aqua satellite is designed to acquire precise atmospheric and oceanic measurements that provide a greater understanding of these components in the Earth's climate. Other instruments on Aqua, such as the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument, provide regional to global land cover, sea surface temperature, and ocean color. Data from the A-Train instruments will help answer these important questions: (1) what are the aerosol types and how do satellite observations match global emission and transport models; (2) how do aerosols contribute to the Earth Radiation Budget and to what extent are they a climate forcing; (3) how does cloud layering affect the Earth Radiation Budget; (4) what is the vertical distribution of cloud water/ice in cloud systems; and (5) what is the role of Polar Stratospheric Clouds in ozone loss and de-nitrification of the Arctic vortex.

- NASA's OCO is a new mission, expected to launch in early 2009, which will provide the first dedicated, space-based measurements of atmospheric CO_2 (total column) with the precision, resolution, and coverage needed to characterize carbon sources and sinks on regional scales and to quantify their variability. Analyses of OCO data will regularly produce precise global maps of CO_2 in the Earth's atmosphere. These maps will enable more reliable projections of future changes in the abundance and distribution of atmospheric CO_2 and enhance understanding of the effect these changes may have on the Earth's climate.

Some other significant existing missions include the following:

- NASA's Ice, Cloud, and Land Elevation Satellite (ICESat), launched in 2003, has been measuring surface elevations of ice and land, vertical distributions of clouds and aerosols, vegetation-canopy heights, and other features with unprecedented accuracy and sensitivity. The primary purpose of ICESat has been to acquire time series of ice-sheet elevation changes for determining the present-day mass balance of the ice sheets, to study associations between observed ice changes and polar climate, and to improve estimates of the present and future contributions to global sea level rise.

- NASA's Solar Radiation and Climate Experiment (SORCE) satellite, launched in 2003, is equipped with four instruments that measure variations in solar radiation much more accurately than previous measurements and observe some of the spectral properties of solar radiation for the first time.

- NASA's Gravity Recovery and Climate Experiment (GRACE) twin satellites celebrated their sixth anniversary on orbit in March 2008, completing a successful primary mission which has provided improved estimates of the Earth's gravity field on an on-going basis. In conjunction with other data and models, GRACE has provided observations of terrestrial water storage changes, ice-mass variations, ocean bottom pressure changes and sea-level variations.

- The US-Taiwan Constellation Observing System for Meteorology, Ionosphere and Climate (COSMIC) GPS Radio Occultation (GPSRO) constellation, and the NASA supported GPSRO Occultation devices aboard the Challenging Minisatellite Payload (CHAMP), GRACE, and SAC-C satellite missions are providing absolute measurements of atmospheric and ionospheric refractivity related to atmospheric temperature and water vapor and ionospheric electron content. GPSRO is inherently a stable measurement because of its sole reliance upon the transfer of time which and be achieve with superb accuracy.

In 2007, the U.S. National Academy of Sciences' National Research Council's (NRC) Committee on Earth Science and Applications from Space published a study entitled, "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond" [see http://books.nap.edu/catalog.php?record_id=11820] which recommended four satellite missions for launch in the 2010-2013[1] time frame as follows:

- The Climate Absolute Radiance and Refractivity Observatory (CLARREO) mission is one in which NASA and NOAA share responsibility. The NOAA component involves the continuity of measurements of incident solar irradiance and Earth energy budget by flying the TSIS and CERES sensors. The NASA portion involves the measurement of spectrally resolved thermal IR and reflected solar radiation at high absolute accuracy. Coupled with measurements from on-board GPS radio occultation receivers, these measurements will provide a long-term benchmarking data record for the detection, projection, and attribution of changes in the climate system. In addition, the SI traceable radiances will provide a source of absolute calibration for a wide range of visible and infrared Earth observing sensors, greatly increasing their value for climate monitoring.

- The Deformation Ecosystem Structure and Dynamics of Ice (DESDynI) is a dedicated Interferometric Synthetic Aperture Radar (InSAR) and LIDAR mission optimized for studying hazards and global environmental change. The mission objectives are to (1) determine the likelihood of earthquakes, volcanic eruptions, and landslides; (2) predict the response of ice sheets to climate change and impact on the sea level; (3) characterize the effects of changing climate and land use on species habitats and carbon budget; and (4) monitor the migration of fluids associated with hydrocarbon production and groundwater resources. This mission combines two sensors that, taken together, provide observations important for solid-Earth (surface deformation), ecosystems (terrestrial biomass structure) and climate (ice dynamics).

- The ICESat-II mission is to deploy an ICESat follow-on satellite to continue the assessment of polar ice changes. ICESat-II is also expected to measure vegetation canopy heights, allowing estimates of biomass and carbon in aboveground vegetation in conjunction with related missions, and allow measurements of solid earth properties. ICESat-II is expected to launch in 2015.

- The Soil Moisture Active and Passive (SMAP) mission is one of four missions recommended by the SMAP will use a combined radiometer and high-resolution radar to measure surface soil moisture and freeze-thaw state, providing new opportunities for scientific advances and societal benefits. Direct measurements of soil moisture and freeze/thaw state will aid understanding of regional and global water cycles, ecosystem productivity and the processes that link the water, energy, and carbon cycles. Soil moisture and freeze/thaw state information provided by SMAP at high resolution will enable improvements to weather and climate forecasts, flood prediction and drought monitoring, and measurement of net CO_2 uptake in forested regions.

The U.S. recognizes the critical role that satellite data play in contributing to the long-term climate record; such remotely sensed data must be part of a system implemented and operated so as to ensure that these data are highly accurate, well calibrated and sustained for the duration of the climate phenomenon being studied. Finally, in addition to meeting the needs of the UNFCCC, the real-time and near-real-time information obtained through such a system would provide an equally large benefit to the needs of many other key societal benefit areas, and as such, the US strives to lead the implementation of such satellite climate requirements as documented in GCOS' satellite requirements document at http://www.wmo.int/pages/prog/gcos/Publications/gcos-107.pdf.

4.5 *Data Management*

Data management is an important aspect of any systematic observing effort. U.S. agencies have unique mandates for climate-focused and -related systematic observations, and for the attendant data processing,

[1] Chapter 2 of the NRC report details several other missions recommended for the periods of 2013-2016 and 2016-2020.

archiving, and use of the important information from these observing systems. Cooperative efforts by the various federal agencies that make up the U.S. Climate Change Science Program (CCSP) are moving towards providing integrated and more easily accessible Earth observations. Currently operating CCSP systems for data management and distribution highlighted in the 2009 Our Changing Planet report [http://www.usgcrp.gov/usgcrp/Library/ocp2009/ocp2009.pdf] include NASA's Global Change Master Directory and Earth Observing System Data and Information System, and DOE's Carbon Dioxide Information Analysis Center; NOAA NCDC's Climate Data Online site provides climate data from multiple stations around the world.

Plans for 2009 and beyond include the participation in IPY through a focus on polar climate observations. Finally, efforts are being explored to improve climate data integration in the Pacific Islands region and produce more useful, end-user-driven climate products. NOAA's recently created IDEA Center is developing more customer-focused, integrated environmental products. Operating under the auspices of NOAA's NCDC, the IDEA Center is partnering with academic institutions and other federal and local agencies in the region to provide information on (1) issues related to Pacific islands, including past, current, and future trends in patterns of climate- and weather-related extreme events (e.g., tropical cyclones, flooding, drought, and ocean temperature extremes); (2) their implications for key sectors of the economy, such as agriculture, tourism, and fisheries; and (3) options for coastal communities and marine ecosystem managers to adapt to and manage the effects of variable and changing environmental conditions.

NASA's Earth Observing System Data and Information System (EOSDIS) provides convenient mechanisms for locating and accessing products of interest either electronically or via orders for data on media. EOSDIS facilitates collaborative science by providing sets of tools and capabilities such that investigators may provide access to special products (or research products) from their own computing facilities. EOSDIS has an operational EOS Data Gateway (EDG) that provides access to the data holdings at all the Distributed Active Archive Centers (DAAC) and participating data centers from other U.S. and international agencies. Currently, there are14 EDGs around the world which permit users to access Earth science data archives, browse data holdings, select data products, and place data orders.

Eight NASA DAACs, representing a wide range of Earth science disciplines, comprise the data archival and distribution functions of EOSDIS. The DAACs carry out the responsibilities for processing certain data products from instrument data, archiving and distributing NASA's Earth science data, and providing a full range of user support. There are more than 2,100 distinct data products archived at and distributed from the DAACs. These institutions are custodians of Earth science mission data until the data are moved to long-term archives. They ensure that data will be easily accessible to users. NASA and NOAA have initiated a pilot project to develop a prototype system for testing candidate approaches for moving MODIS data into long-term NOAA archives. This pilot project is part of the evolution of the Comprehensive Large Array-data Stewardship System (CLASS) developed by NOAA. Acting in concert with their users, DAACs provide reliable, robust services to those whose needs may cross traditional discipline boundaries, while continuing to support the particular needs of their respective discipline communities. The DAACs are currently serving a broad and growing user community at an increasing rate. CLASS is NOAA's on-line facility for the distribution of NOAA and U.S. Department of Defense POES data, NASA mission data, as well as NOAA GOES data, and derived data. CLASS is an electronic library of NOAA environmental data, and provides capabilities for finding and obtaining such satellite data, and can be found at the following web site at: http://www.nsof.class.noaa.gov/saa/products/welcome.

The USGS' Landsat 35-year record of the Earth's surface will soon be available to users at no charge. Under a transition towards the NLIP, the USGS is pursuing an aggressive schedule to provide users with electronic access to any Landsat scene held in the USGS-managed national archive of global scenes dating back to Landsat 1, launched in 1972. By February 2009, any Landsat archive scene selected by a user will be automatically processed, at no charge; in addition, newly acquired scenes meeting a cloud cover threshold of 20% or below will be processed and placed on-line for at least 3 months, after which time they will remain available for selection from the archive. More details on this are available at http://landsat.usgs.gov.

NASA's Global Change Master Directory (GCMD) is an extensive directory of descriptive and spatial information about data sets relevant to global change research. The GCMD provides a comprehensive resource where a researcher, student, or interested individual can access sources of Earth science data and related tools and services. At present the GCMD database contains over 21,000 metadata descriptions of data sets and data-related services from approximately 2,800 government agencies, research institutions, archives, and universities worldwide; updates are made at the rate of over 1000 descriptions per month. The GCMD contains descriptions of data sets covering all disciplines that produce and use data to help understand our changing planet. Although much research is focused on climate change, the GCMD includes metadata from disciplines including atmospheric science, oceanography, ecology, geology, hydrology, and human dimensions of climate change. This interdisciplinary approach is aimed at researchers exploring the interconnections and interrelations of multidisciplinary global change variables (e.g., how climate change may affect human health). The GCMD has made it easier for such data users to locate the information they desire. The latest version of the GCMD software was released in March 2008 as MD9.8. Software upgrades are made in response to user needs and to capitalize on new technology. Several virtual subsets, also known as "portals" have been created in support of the tasks that are part of GEOSS; see http://globalchange.nasa.gov or http://gcmd.nasa.gov.

The Arctic Observing Network (AON) is a developing system of 34 land, atmosphere and ocean observation programs, some already operating and some newly funded by the National Science Foundation. This International Polar Year initiative is acquiring much of the data needed to drive the interagency Study of Environmental Arctic Change (SEARCH). AON will succeed in supporting the science envisioned by its planners only if it functions as a system and not as a collection of independent observation programs. Data management plays an essential role. AON planners envision an ideal data management system that includes a portal through which scientists can find all data relevant to a location or process; all data have browse imagery and complete documentation; time series or fields can be plotted online, and all metadata are in a relational database so that multiple data sets and sources can be queried.

DOE's Carbon Dioxide Information Analysis Center (CDIAC) provides comprehensive, long-term data management support, analysis, and information services to the global climate change research programs, the global climate research community, and the general public. The CDIAC data collection is designed to answer questions pertinent to both the present-day carbon budget and temporal changes in carbon sources and sinks. The data sets provide quantitative estimates of anthropogenic CO_2 emission rates, atmospheric concentration levels, land–atmosphere fluxes, ocean–atmosphere fluxes, and oceanic concentrations and inventories. In 2008, CDIAC will augment its ocean holdings by offering CO_2 measurements from buoys, research cruises, and Volunteer Observing Ships lines along U.S. coastlines to support the NACP. In 2008, CDIAC also released the final CARbon dioxide In the North Atlantic ocean (CARINA) synthesis database including both discrete and underway measurements. CDIAC will release of the final North Pacific Marine Science Organization (PICES) synthesis database, which will replace the previous North Pacific discrete measurement component of the Global Ocean Data Analysis Project.

Precipitation chemistry remains as a major environmental issue due to concerns over eutrophication, ecosystem health, biogeochemical cycling, and global climate change. Although global modeling assessments require data of high and known quality, many of the laboratories supporting the approximately 200 site global network require expert assistance and ongoing oversight. As such, the quality assurance for the GAW Precipitation Chemistry Program that is performed by NOAA's Air Resources Laboratory, in close cooperation with the State University of New York at Albany, Environment Canada, European, East Asian, South African, and other scientists, has been an important component in addressing these problems through the development and provision of a guidance manual for program participants, and the development of a tool for rapid assessment of laboratory quality by data users. Global laboratory intercomparison data are presently posted at http://www.qasac-americas.org/ and may be displayed by clicking on the "Data" link and then on "Ring Diagram Assessments". Intercomparisons have been conducted annually beginning in 1985 and biannually beginning in 2001. In addition to complete quality assurance information, it is the goal of this program to make all GAW precipitation chemistry data freely downloadable on the Web.

Given its widespread applications and importance as a GCOS Essential Climate Variable (ECV), sea surface temperature (SST) observations and products are developed by numerous groups around the world. Global and near-global SST analyses are created using a wide range of statistical reconstructions and interpolations that are applied to data sets from a variety of input platforms. The result of these different analysis routines is a collection of products that can say subtly or significantly different things about the changing climate. The GCOS SST/Sea Ice (SI) Working Group seeks to gain an understanding of the differences between these SST analyses and recommend actions and criteria to ensure quality and consistency among them. Collaborating with members of the Working Group, NOAA's National Oceanographic Data Center (NODC) has created an online intercomparison framework at http://ghrsst.nodc.noaa.gov/intercomp.html. The website, an extension of the NODC Group for High Resolution Sea Surface Temperature (GHRSST) Long Term Stewardship and Reanalysis Facility, provides value-added access to a large collection of satellite, non-satellite, and blended SST analysis products.

The Global Observing Systems Information Center (GOSIC) at http://gosic.org serves as a central data integration facility for the data and information requirements related to global observing data access and retrieval. The GOSIC began as a developmental activity at the University of Delaware in 1997, and as of January 2007, has fully transitioned to an operational global data facility operated by NCDC on behalf of, and with the concurrence of, the global observing community. The GOSIC provides information, and associated tools, to facilitate better access to data and information produced by the Global Climate, Ocean, and Terrestrial Observing Systems (GCOS, GOOS and GTOS) and their partner programs. The distributed nature of this vast system of global and regional data and information systems is best served by such a single entry point for users. GOSIC provides that entry point by performing such functions as providing global data system documentation and metadata, providing an integrated overview of the various global observing programs, and facilitating on-line access to their data, information, and related data services. GOSIC offers a search capability across international data centers in order to better facilitate access to a worldwide set of observations and derived products that provide the end user with a consistent interface across all centers.

GOSIC is now a registered GEOSS data service at http://geossregistries.info/holdings.htm

5. ANNUAL STATE OF THE CLIMATE REPORT– USING EARTH OBSERVATIONS TO MONITOR THE GLOBAL CLIMATE.

NOAA, in partnership with numerous national and international partners, has established a State of the Climate program, which consists of operational monitoring, analysis, and reporting on atmosphere, ocean, and land surface conditions from the global to local scale. By combining historical data with current observations, this program places today's climate in historical context and provides perspectives on the extent to which the climate continues to vary and change as well as the effect that climate is having on societies and the environment. More than 150 scientists from over 30 countries are now part of an annual process of turning raw observations collected from the global array of observing systems into information that enhances the ability of decision makers to understand the state of the Earth's climate and its variation and change during the past year, with context provided by decades to centuries of climate information. Many observing and analysis systems are unique to countries or regions of the world, but through this effort, the information from each system is openly shared and has proven essential to transitioning data to operational use and filling critical gaps in current knowledge about the state of the global climate system. A State of the Climate report is distributed through publication in the Bulletin of the American Meteorological Society each year. The State of the Climate Report seeks to report on as many of the ECVs as possible as identified by GCOS Second Adequacy Report. The State of the Climate Report seeks to report on as many of the ECVs as possible as identified by GCOS Second Adequacy Report. The 2007 edition was published in July 2008, and an archive of these reports from 2000 through 2007 can be found at http://www.ncdc.noaa.gov/oa/climate/research/state-of-climate/. Since this report began the monitoring of ECVs in 2001, and in line with the recently published 2007 version of the report, we have now doubled the number of monitored ECVs to a total of 22.

6. CONCLUSION

The emphasis of the U.S. GCOS program is on high-quality, sustained, and robust reference observations (both satellite and non-satellite) to ensure that over the next 50 years, we can document with certainty the regional and national climate signatures and trends in surface air temperature and precipitation over the U.S. including maximums, minimums, and frequency of extreme events to characterize and document changes in climate. From a non-satellite point-of-view, the four most important efforts we see are: (1) the installation of soil moisture/soil temperature and relative humidity sensors at all 114 USCRN stations; (2) the expansion of the USCRN to Alaska, the Pacific, and other high latitude (e.g., polar), high elevation (e.g., Andes), and tropical locations; (3) the initiation of the GRUAN (including 7 U.S. sites) in order to better document the key climate forcing variables of upper tropospheric and lower stratospheric water vapor; and (4) the initiation of the Surface Radiation Budget Network which provides benchmark observing stations for measuring surface solar and infrared radiation, as well as energy budgets.

A sustained global observing system is the foundation for all climate services. The climate community needs, in particular, an integrated set of global, atmospheric reference observing systems to fulfill both its climate monitoring and services missions. Atmospheric observations are a key input to climate forecast models, and are essential in assessing the changing state of the climate. It is absolutely critical that we now establish a global atmospheric climate reference observing system and commit to sustaining it, so that future generations will have the tools necessary to resolve questions about long-term trends in climate observations.

A new generation of space-based instruments is planned on NOAA's suite of polar orbiting satellites. These instruments will be the raw data needed by all countries to adequately monitor global climate change. Specifically, observations from these instruments will provide the first step in a process to discriminate among one of the many possible trajectories of climate change now projected for the 21st Century. It is critical that ongoing efforts to sustain continuity in many records continue, and this must remain a major priority.

However, contingency plans for the inevitable gaps in the climate record must be developed as well. It is actually likely that a gap will occur even if the efforts to get the instruments into space are realized (such as from a vital instrument failure). For some measurements, such as solar irradiance, such a gap is disastrous for the climate record. But for other measurements it may be possible to bridge such gaps with other measurements. Such measurements must be of sufficient quality, accuracy and sampling that they can act as a transfer standard. An in-situ Reference Observing Network leveraging on existing or partially completed networks with reference sites taking multiple measurements (such as temperature, ozone, radiation, and water vapor) will minimize costs and increase efficiencies. Implementing these reference networks must take on a high priority to ensure the value of past and future space based observations. Several assessments by worldwide climate experts (e.g., GCOS, CCSP 1.1 Synthesis and Assessment Product[2]) have argued for the importance of such atmospheric reference networks.

As such, the continuing goal of the U.S. GCOS program will be in advocating the implementation, maintenance, and continuing need for high-quality and

[2] See Report at http://www.climatescience.gov/Library/sap/sap1-1/finalreport/default.htm

specific networks (satellite and non-satellite) that are designed expressly for maintaining a continuous and homogeneous climate record well into the future. As always the challenge will be resources devoted to this, but again, these are a necessary and vital infrastructure component to furthering the goals of understanding climate.