Prepared in cooperation with the Earth Observations Task Group of the Subcommittee for Disaster Reduction

Reducing Loss of Life and Property from Disasters: A Societal Benefit Area of the Strategic Plan for U.S. Integrated Earth Observation System (IEOS)

By Rosalind L. Helz and John E. Gaynor

Open-File Report 2007–1147

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Suggested citation:
Helz, R. L. and Gaynor, J. E., 2007, Reducing Loss of Life and Property from Disasters: A Societal Benefit Area of the Strategic Plan for the U.S. Integrated Earth Observation System (IEOS) :Reston VA, US Geological Survey, OFR 2007-1147, 67 pp.

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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
Length		
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
meter (m)	1.094	yard (yd)
Area		
square meter (m^2)	0.0002471	acre

Inch/Pound to SI

Multiply	By	To obtain
Length		
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
yard (yd)	0.9144	meter (m)
Area		
acre	4,047	square meter (m^2)

Foreword

On July 31, 2003, representatives of more than thirty nations met in Washington, D.C. at the first Earth Observation Summit, to begin work on a proposal for improving global Earth observations. This effort culminated in 2005 with the adoption and publication of two reports (GEO, 2005a; 2005b). The U.S. component of this global effort, the Interagency Working Group on Earth Observations (IWGEO), now the U. S. Group on Earth Observations (USGEO) was established in August 2003 under the Committee for Environmental and Natural Resources (CENR) of the White House National Science and Technology Council (NSTC). The NSTC Subcommittee for Disaster Reduction (SDR) subsequently set up a task group to assist the IWGEO by identifying U.S. capabilities and needs in the area of observing and predicting hazards and disasters.

This report documents the work of the Earth Observation Task Group (EOTG) of the SDR. This report and the tables that accompany it have served as the basis for those sections in both the U.S. national plan (CENR/IWGEO, 2005) and the international GEO plan (GEO, 2005b) that cover the area of hazards and disasters.

The EOTG began its work in the fall of 2003, first by establishing which hazards to cover and then by providing detailed lists of the critical observations known at present to be needed to deal effectively with the selected hazards. The group also identified the most critical users and their needs, to ensure effective disaster reduction, identified the users and their needs. All of these data were summarized in tabular form and are presented here in Appendices 1 and 2.

By early 2004, the U.S. Global Earth Observations team had formulated an outline for the U.S. national plan, which presented the need for improved observations in terms of nine "Societal Benefit" areas. The first draft of the present report was written in spring of 2004, following the outline specified for all nine Societal Benefit areas. The draft Societal Benefit documents were presented and discussed at a public workshop sponsored by the IWGEO, which was held in June 2004 at the U.S. Geological Survey, in Reston, VA. In July 2004, a second draft was prepared, incorporating suggestions received at the June workshop, and the revised document was submitted on behalf of the SDR to the IWGEO. That second draft, along with the Technical Reference Documents for other Societal Benefit areas, was cleared by CENR and posted on the Federal Register from Nov 8-30, 2004, again for public comment.

The U.S. strategic plan for integrated earth observations was published in April 2005 (CENR/IWGEO, 2005); the Disasters component of that document is based on this Technical Reference Document. After release of the strategic plan, the IWGEO held another public workshop (May 9-10, 2005, at the Reagan Building in Washington, D.C.) to obtain comments on that document, on the various Technical Reference Documents, and to seek general input on how implementation of the IEOS might proceed. The current version of the Technical Reference Document uses the second draft (posted on the Federal Register Web site) as a point of departure. It incorporates as many of the comments received at the May 2005 workshop as possible, and includes references to the various GEO documents that had been published by the May 2005 workshop, or have come out of that workshop, specifically the recently released near-term opportunity plan for disaster reduction (CENR/USGEO, 2006). Most importantly, and in response to consistent requests from technical experts at both the June 2004 and May 2005 workshops, this version includes all of the source tables assembled by the EOTG, and thus gives a full accounting of the EOTG's work.

The text below provides an overview of agencies responsible for the various hazards, and the Observational Requirements tables give fairly complete consensus summaries of what the participating experts regard as essential observations for the eleven hazards covered. However, neither provides an inventory of current existing observing systems. Such an inventory is urgently needed, particularly for the many surface-based networks that form the backbone of our national observing capacity. The need for that inventory, and the need for a plan to improve those systems, is identified in the IEOS plan (CENR/IWGEO, 2005, p. 90) and in the report below as a particularly urgent next step as we move toward implementation of the IEOS.

Members of the Earth Observations Task Group and other contributors

Members of the Earth Observation Task Group and other contributors to this report are listed below. They are identified by the agency they represent, and by specific area of expertise.

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Reducing Loss of Life and Property from Disasters: A Societal Benefit Area of the Strategic Plan for U.S. Integrated Earth Observation System (IEOS)

By Rosalind L. Helz and John Gaynor

Introduction

Natural and technological disasters, such as hurricanes and other extreme weather events, earthquakes, volcanic eruptions, landslides and debris flows, wildland and urban-interface fires, floods, oil spills, and space-weather storms, impose a significant burden on society. Throughout the United States, disasters inflict many injuries and deaths, and cost the nation $20 billion each year (SDR, 2003). Disasters in other countries can affect U.S. assets and interests overseas (e.g. the eruption of Mt. Pinatubo in the Philippines, which effectively destroyed Clark Air Force Base). Also, because they have a disproportionate impact on developing countries, disasters are major barriers to sustainable development. Improving our ability to assess, predict, monitor, and respond to hazardous events is a key factor in reducing the occurrence and severity of disasters, and relies heavily on the use of information from well-designed and integrated Earth observation systems. To fully realize the benefits gained from the observation systems, the information derived must be disseminated through effective warning systems and networks, with products tailored to the needs of the end users and the general public.

The pattern of disaster impact within the United States is illustrated in Table 1, which gives a single, substantial example for each class of hazard reviewed in this report. Loss of life is generally low, even for very large events, a testimony to the effectiveness of disaster management systems already in place in this country, but the economic costs are staggering. One recent exception was Hurricane Katrina, where over 1300 people lost their lives in New Orleans alone. Some hazards (*e. g*., large earthquakes, volcanic eruptions) are not annual events, but are devastating when they do occur. For other, more frequently occurring hazards, even when individual events are small, their total costs per year are high. Examples include floods (averaging 80 deaths per year, with costs of $5.2 billion, NOAA, 2004) and landslides (deaths 25-50 annually, with costs of $2 billion, USGS, 2003a).

The total impact on the United States from all hazards is difficult to determine, because no centralized or consistent means of accounting for costs exists. This problem is compounded by the fact that for certain hazards, such as landslides and coastal hazards, the costs are usually merged into the total cost compiled for some other event (such as a hurricane or earthquake). In addition, one disaster may breed another (e.g., when disease outbreaks follow floods) and the costs of the aftermath events may either not be tallied, or not attributed to the primary event. The costs of loss of life and property, of response and recovery, and of social or commercial disruption are conservatively estimated to average $20 billion a year (SDR, 2003). In addition to improved monitoring and forecasting, the United States needs to develop and implement more effective mitigation practices, to reduce our vulnerability to these events (BOND, 1999).

One specific societal benefit area of vigilant monitoring and good forecasting is the ability to ensure safe transport, of all sorts and at all scales, including private and commercial automotive traffic, railroads, passenger and freight air traffic, recreational boating and ships at sea (DOT, 2003). Most of the hazards considered below (extreme weather and hurricanes, earthquakes, volcanic ash, landslides, wildland fires, floods, coastal hazards and sea ice) endanger safe transport. Another economic and social benefit is the ability to ensure continuity and safe operation of critical infrastructure, which include not just transportation facilities, such as roads, rail lines, tunnels, port facilities and airport runways, but also pipelines, electric grids, dams and reservoirs, and underground mines. Relevant hazards in these cases include: earthquakes, volcanic eruptions, landslides, severe weather and hurricanes, sea ice, and space weather. Successful monitoring, timely warnings and effective mitigation practices cannot prevent hazards but can often prevent a hazardous event from becoming a major disaster.

Table 1. RECENT MAJOR U.S. EVENTS FOR EACH TYPE OF HAZARD

HAZARD TYPE	EVENT	IMPACT (Reference)
Wildland fires	Southern California fires, October 2003	24 deaths, 750,000 acres burned, cost over $2 billion (CDFFP, 2004)
Earthquake	Northridge quake, 1994	67 deaths, $44 billion (BOND, 1999)
Volcanic eruption	Mt. St. Helens eruption, 1980	57 deaths, $1 billion (1980 dollars, Blong, 1984)
Landslides/debris flows	Thistle landslide, 1983	No deaths but buried a town, $400 million (USGS, 2003a)
Floods	Mid-continent (Mississippi, Missouri River) floods, 1993	44 deaths, $24 billion (Lott, 2000)
Extreme weather	Oklahoma City tornadoes, 1999	40 deaths, $1.6 billion (NOAA/NWS, 2004a)
Tropical cyclones	Hurricane Katrina, 2005	1,353 lives, $40.6 billion insured losses in Mississippi and Louisiana (NOAA/NWS, 2005)
Sea and lake ice	*Magdalena Oldendorf* trapped in Antarctic sea ice, 2002	No deaths, but costs of rescue, support for wintering over, spring egress were several million dollars
Coastal hazards (incl. tsunami)	Beach replenishment following storms	No deaths, $3 billion to replenish 33 miles of New Jersey coastline (Heinz, 2000)
Pollution events	Exxon Valdez oil spill, 1989	No human deaths, cost for ship repairs, loss of cargo $28 million; clean-up costs, reimbursements to Federal, State and local governments $11.2 billion so far; recreational fishing losses $580 million; environmental impact is ongoing
Space weather	January 6, 1997 storm	Destroyed AT&T Telstar satellite (cost $200 million)

In reviewing how best to enhance the nation's use of earth observations, this report identifies critical users of hazards information, reviews the observations needed, identifies how those needs are met now, identifies gaps in the presently deployed systems, and makes suggestions on how to fill those gaps over the next 10 years. But first we examine two events: one that illustrates the difficulties involved, and the other, a success story.

Southern California Wildfires of 2003: A Complex Natural Disaster

The intense and widespread wildfires that raged near Los Angeles and San Diego were widely foreseen but virtually unpreventable. Previous wet seasons had created tremendous fuel loads. The fall of 2003 was very hot, with strong Santa Ana winds, which made some level of wildfire activity inevitable. Individual fires, started by lightning, human error, or arson, spread into towns and subdivisions and whipped through chaparral, forest and grasslands. Damage estimates and firefighting costs came to at least $2 billion, and 24 people lost their lives (CDFFP, 2004). The resulting smoke was unusually hazardous because of anthropogenic components (3710 houses, plus additional structures, garages, and vehicles) consumed by the fires. The fires burned 750,000 acres of forest and scrub, much of it on very steep terrain, leaving the area vulnerable to severe erosion, with authorities warning that there was a high probability for debris flow generation. Torrential rainstorms on Christmas Day produced the anticipated debris flows, which killed 16 people, as reported in the San Bernardino County Sun-News. This series of events illustrates vividly how one disaster can breed another, and how “natural” disasters may have significant anthropogenic components, either as causes or as effects.

Denali Earthquake in Alaska: Successful Mitigation of a Major Event

The Denali Earthquake of November 3, 2002, in central Alaska, caused surface ruptures for a distance of 209 miles along the Denali Fault, which passes beneath the Trans-Alaska Oil Pipeline. The pipeline carries 17 percent of the nation’s domestic oil supply, with a daily value of over $25 million; thus continuity of its operation is vital to the economy of Alaska and significant for the country as a whole. This event, the largest onshore quake in the historical record for the United States, did not break the pipeline, thanks to elaborate engineering requirements based on geologic studies of the fault. The pipeline was designed to accommodate a magnitude 8.0 quake with 20 feet of horizontal and 5 feet of vertical displacement. The actual event was a magnitude 7.9 quake, with 14 feet of horizontal and 2.5 feet of vertical displacement where the pipeline crossed the fault. These successful mitigation measures forestalled a major economic and ecological disaster on the scale of the Exxon Valdez disaster (USGS, 2003b).

Users and User Requirements

Society as a whole will benefit from improved hazard monitoring and disaster management. To assess the efficacy of existing systems and identify gaps and future needs, however, we first must understand who the critical users are, and identify their needs. In the context of disaster management, these groups are:

End users

These users are the authorities with responsibility for disaster management and/or mitigation. This category includes elected officials, Federal, State and local emergency managers, first responders (such as police, firefighters, other emergency response personnel), public health officials, land-use planners, insurance companies, engineers, building-code developers, and managers of critical private-sector facilities. End users usually need derived information, including decision support systems, rather than actual Earth observation (EO) data, with typical products summarized in

Table 2 below, and in Appendix 1. A partial exception here is the Federal Emergency Management Agency (FEMA, 1999), which, because of its mitigation responsibilities, needs baseline and monitoring data as input for flood hazard maps and the various modules of the risk assessment program Hazards-U.S. (HAZUS).

Scientists in monitoring and advisory agencies

These users are scientists, typically those on the staff of geological surveys, plus weather, ocean and space agencies. They collect earth observation data, design and maintain the observing systems, and interpret the results. These users analyze and interpret continuous data streams, delivering information, evaluations, forecasts and results of decision support systems to the end users, often in near real time, in support of their decisions. The information needs of this class of users are listed in the tables in Appendix 1. The observational requirements summarized in Appendix 2, whether for baseline information or monitoring data, are based primarily on the needs of this group, to support their communications with the end users and with the public.

Research scientists

These users are scientists whose research is directed toward improving our understanding of the physical or chemical hazards considered here, toward mitigating their effects, or toward improving our capacity to forecast events. Researchers do not normally operate under the time constraints of the first group of scientists, nor do they have responsibility for communicating with public officials and emergency managers. However their role is critical and their requirements will often shape the development of future Earth observation systems, and so are reflected in the tables in Appendices 1 and 2.

Table 2 summarizes the major information requirements of the first of these classes of users. Satisfying their needs is the key to effective disaster response and mitigation.

Table 2. PRODUCTS REQUIRED BY END USERS

Hazard	Information/ products needed for crisis response (during and after)	Information/ products needed for hazard mitigation (between)
Wildland and urban- interface fires	For initial attack/extended attack: rapid access to geospatial data, including active fire front position, fire origin, fire fuels, spot fires, fire weather, emergency access routes, terrain, structures and other improvements in the area of the incident. Relative geolocational accuracy can be favored over absolute accuracy. For larger incidents (100+ acres): rapid access to the above plus smoke monitoring. Full suite of products need to be available at major shift change times (generally 0600 and 1800 hours local time). For post-fire burn recovery: geospatial data includes extent and characterization of vegetation burn severity, soils observations, and all structures and other improvements in the affected area. Timely alerts and updates to government officials, affected population, and media on fire location and status, effects on roads, possible evacuation routes	Information on vegetation health, vegetation fire fuels, fuel moisture, fire history, structures and other infrastructure adjacent to wildland areas, atmospheric transport of smoke, and access routes. Needed for planning prescribed burns, anticipating future fire activity, land use policy and planning in or near wildland areas. Often there is a need for greater information in wildland -- urban interface areas.

Hazard	Information/ products needed for crisis response (during and after)	Information/ products needed for hazard mitigation (between)
Earthquakes	Clear, authoritative information on the location and magnitude of the shock and the time frame (in days) of aftershocks. Timely updates and precise geolocation data are critical for activating shutdown of critical facilities (power plants, trains, etc.) Post-event maps (shake maps, damaged/affected areas, identification of safe areas) also needed.	Hazard zonation maps: paper maps or GIS data bases showing areas of lower vs. higher intensity of ground motions. Maps for various secondary effects of seismic hazards (landslides, liquefaction, etc.) are also needed. . Data support land use planning, building standards regulations. Decision support tools for seismic risk assessment (*e.g.* FEMA's HAZUS)
Volcanoes, volcanic ash and aerosols	Clear, authoritative information on most likely course of the unrest/eruption, whether ash explosions may occur. Includes best estimates on when and what type of eruption, possible size, which areas or air routes will be affected and which will be safe. Timely updates and adequate geolocation data are critical.	Need hazard zonation maps: paper maps or GIS data bases showing areas of lower vs. higher risk, for future eruptions. The maps for various major hazards (lava flows, lahars, ash fall, etc.) will be different. Data provide input for land use planning, ash response plans and community volcanic eruption response plans.
Landslides	Local, rapid mapping of affected areas, magnitude of instability, updated scenarios during ongoing instability, including known and expected locations of ground failure and runout, and impact analysis. Early warning of heightened risk, if rainfall intensity or duration exceed thresholds, for areas of known high hazard of landslides and debris flows, including burned areas	Regularly updated susceptibility and hazard zonation maps for landslides, debris flows, rock falls, subsidence (at appropriate scales). Data support decisions on land use, siting of critical facilities.
Floods	Timely and accurate short through extended range forecasts and warnings which quantify certainty and convey risk (time, discharge, stage, area inundated) for both river and flash flood events. Includes accurate locations of areas, infrastructure (roads, bridges, etc.) affected. Ground surveys, aerial photos and interviews for damage assessments.	Flood hazard zonation maps, accurate topographic base maps; updated maps of land use, showing land use changes; flood history of the area Decision support tools for flood risk assessment models such as the flood module in FEMA's HAZUS program
Extreme weather	Timely and accurate forecasts (time, location, intensity and nature of severe weather). Accurate and comprehensive real-time data during the event (e.g. location of strong winds, heavy precipitation, hail and direction of propagation). Mapping, ground surveys, interviews, aerial photos for damage assessments.	Historical data for the area (e.g. frequency of tornadoes, strong winds, heavy snows, hail) Needed for input to land use planning, building codes and standards, such as wind resistance, roof loading, materials resistant to hail, and tornado safe rooms.

Hazard	Information/ products needed for crisis response (during and after)	Information/ products needed for hazard mitigation (between)
Tropical cyclones	Timely and accurate landfall analyses in real time and forecasts (timing, location, intensity, outer wind radii, storm surge, sea state, rain quantity) Mapping, aerial photos for damage assessments. Models that show and permit analysis of behavior and impact of storms.	Historical track and intensity information to generate hazard zonation maps. Data serve as the basis for appropriate land use policy in coastal areas, especially low-lying areas.
Sea and lake ice	Timely and accurate real time ice analyses and forecasts – short (days), medium (weeks), utilizing high-resolution imagery. Accurate geolocation of icebergs in shipping lanes. Charts showing ice extent in GIS and graphic format	Seasonal ice analysis and forecasts (months, years) Charts showing ice extent, seasonal patterns.
Coastal hazards, tsunami	Accurate information regarding potential storm surge or tsunami: includes time of arrival, duration of event (all clear signal); boundaries of inundation area; evacuation routes. Mapping, aerial photos for response, damage assessments	Inundation hazard maps for emergency response and land use planning on high-resolution DEM base maps, and showing critical infrastructure at risk. Regularly updated high-resolution shoreline maps and dune erosion rate maps needed for mitigation such as establishing setback lines
Pollution events	Clear, authoritative information on the location, compound(s) or chemical(s) released, magnitude of the technological release and the media in which the release occurred (air, land and/or water). Geolocation and other information to support public notifications. Timely updates are critical for activating shutdown of potentially affected facilities (water treatment plants, transportation networks, etc.) Post-event maps (release maps showing damaged/affected areas, identification of safe areas)	Accurate topographic and geologic maps, especially maps of surficial geology; GIS mapping of land use and land use changes, Data serve as basis for land use policy, decisions on siting critical facilities or potentially hazardous but essential facilities
Space weather	Clear, authoritiative information on the timing and magnitude of solar X-ray flares, solar energetic particle events, and geomagnetic storms Timely updates are critical for commercial airlines flying polar routes, all satellite operators (civil, military, or commercial) and electrical power companies Post-event summaries to allow affected technologies and services to return to normal operating modes	Real-time maps showing areas of the Earth affected by particles, X-ray photos and electrojet currents, for use in configuring systems and operations vulnerable to space weather. These include satellite, electronic navigation systems, and electric power grids. Complete records of past events so that planners and system designers know what they must design to in order to mitigate or minimize future storm impacts.

Products needed by the end users fall into two broad categories, reflecting the two distinct time scales involved in dealing with hazards and disasters. First, they need rapid generation of forecasts, assessments and other information products in response to events, whether before, during or in the aftermath. Table 2 articulates these needs for the 11 hazards reviewed here. In addition to the information products listed, there is a need for systematic accounting for casualties and costs. In the United States, this responsibility is dispersed: state and local governments usually provide data on deaths and injuries. Damage estimates may come from state and local governments, FEMA, or the private sector (insurance companies, utilities, etc.).

Over the long term, however, mitigation measures provide the best means of reducing loss of life and property from disasters. Such efforts depend on the second category of products described in Table 2: namely hazard zonation maps, probabilistic hazard zonation maps, and GIS-based risk assessments such as FEMA's HAZUS program. Producing such maps requires documentation of the historical and geologically recognizable record of hazard events, characterization of those events, and their integration with other data (topography, bathymetry, present status of the area, including vegetation cover, known long-term deformation, etc.). The products are a series of maps, or GIS layers, that display the past and potential hazard together with the human population and material infrastructure at risk. These studies usually require a broader range of research and modeling tools than are needed for rapid response to hazards.

Effective disaster response and mitigation also require the production of a wide range of products (Web sites, pamphlets, fact sheets, videos) for public education and outreach. These products support longer-term planning and mitigation and help people to respond appropriately in emergencies. They may be distributed by federal agencies, state governments or other organizations such as the Red Cross, or in the case of web-based products, be accessed directly by the general public.

Overarching requirements for all categories of users, across all hazards, are for (1) continuity of operations, (2) continuous, real-time data streams, (3) rapid tasking of other data sources, (4) global coordination of resources, (5) rapid generation of accurate information and forecasts, and (6) efficient sharing of information products, in formats that are adapted to users' needs.

Existing Capabilities and Commonalities

The current required observations and generic descriptions of the means by which those observations are obtained are summarized in eleven tables in Appendix 2. Hazards covered include wildland fires, earthquakes, volcanic activity, landslides, floods, extreme weather, tropical cyclones, sea and lake ice, coastal hazards, pollution events and space weather. These tables, which were put together by members of the Earth Observation Task Group, draw on user requirements for satellite data documented in the CEOS Disaster Management Support Group report (CEOS, 2002) for most of the hazards considered. Other sources include the Geohazards Integrated Global Observing Strategy (IGOS) report (ESA, 2004), and the many agency specific plans from NOAA, NASA, USGS, and others listed in the references. In the tables in Appendix 2, the left-hand column describes the required data or observations, and the next three columns identify how the requirement is met by (1) surface-based, or (2) airborne, or (3) satellite-based observing systems. The "Gaps" column allows present or anticipated deficiencies to be specified. The final "Comments" column adds information on why the information is needed, or how it is processed or disseminated, or how it relates to other required observations.

It should be noted that some additional types of hazard are covered under other societal benefit areas in the Integrated Earth Observation System (IEOS) strategic plan (CENR/IWGEO, 2005) and supporting documents. For example, drought and its effects are considered separately in the technical report on sustainable agriculture, and most health-related issues are covered in the report on environmental factors affecting human health.

Agency responsibility for the operation of the currently deployed observing systems is summarized below, beginning with the most mature efforts:

Extreme Weather, Tropical Cyclones. The weather monitoring system is described in general in the Societal Benefit Reference Document on Weather and is the most mature hazard monitoring system in the United States. It includes large arrays of ground-based monitoring instruments, satellite systems specifically designed to support *e.g.* hurricane tracking, dedicated facilities (the National Hurricane Center, Storm Prediction Center) and dedicated communications networks, including NOAA weather radio and agreements with media outlets for weather warning dissemination. A unique feature of this area is that the economic and social benefits are strong enough to support systematic plans for future satellites (NPOESS, GOES-R). Satellite systems, ground-based remote sensors and most *in situ* systems operated by the U. S. National Weather Service (NWS) function in the same fashion, whether providing observations for benign or extreme weather. However, there are special observing strategies for some operational observing platforms when severe weather is imminent. For example, for hurricanes, and more recently for significant winter storms, NOAA and Air Force aircraft are deployed to collect data for real-time analysis, as input into operational hurricane or winter storm forecast models. For severe or potentially severe thunderstorms, capable of generating tornadoes, flash floods, hail or many lighting strikes, special Doppler radar modes are activated. In some cases, satellite tasking may be modified to provide higher temporal and spatial resolution, in support of better forecasts. (Multiple NOAA documents are listed in the references.)

Flood hazards. Severe flooding occurs each year, and the patterns of many kinds of flooding events are fairly predictable. Hence the monitoring, evaluation, and forecasting of floods, such as those that occur near large rivers, whether caused by large storms or spring snow melt, are relatively mature, and depend on a combination of ground-based and remotely sensed data streams. Problem areas include inundation forecasting, especially in heavily developed areas, sufficiently rapid modeling and warnings for flash flooding, especially in small watersheds, and effective snow melt forecasting. (References include FEMA, 2003; NOAA, 2003; NOAA/NWS, 2002 and 2004a; USGS, 1999b.)

The solid earth hazards include earthquakes, volcanic eruptions, landslides and other types of ground instability. Critical monitoring of these hazards is mostly ground-based, but with increasing utilization of selected satellite capabilities, especially GPS, LiDAR, and interferometric SAR (InSAR) for deformation monitoring. U.S. Federal activities related to earthquakes are coordinated through the National Earthquake Hazard Reduction Program (NEHRP), which is headed by NIST, working in partnership with the USGS, FEMA and NSF (WSSPC, 2003). The reporting of earthquakes is centralized at the USGS National Earthquake Information Center (NEIC), which coordinates both national and regional networks. Archiving of seismic records (by the USGS and the Incorporated Research Institutions for Seismology, or IRIS) is systematic and more mature than for most other kinds of solid earth hazard data. Monitoring volcanic activity, including volcanic ash and aerosols, requires a wide range of airborne or satellite support, as documented in many reports (CEOS, 2002; ESA, 2004). Monitoring of volcanic hazards is done at dedicated facilities, such as the five volcano observatories maintained by the USGS or the two Volcanic Ash Advisory Centers (the Washington and Anchorage VAACs) maintained by NOAA. The monitoring needs of these hazards and the earth processes (e.g. plate tectonics) that control them are reviewed in many reports, including the report of NASA's Solid Earth Sciences Working Group (SESWG) (NASA, 2002), the

Advanced National Seismic System (ANSS) Report to Congress (USGS, 1999a), the National Volcano Early Warning System (NVEWS) report (USGS, 2005), national landslide strategy documents (USGS, 2003b; NRC, 2004), and EarthScope documents (EWG, 2001; NRC, 2001].

Wildland and urban-interface fires are extremely complex events, requiring weather information support (at various time scales and spatial resolutions), plus specialized infrared imagery, and very rapid response time for all aspects of fire response. Because of the range of latitudes and climates within the United States, there are few months of the year when the country is free of wildfires. Responsibility for responding to wildfires at the Federal level is borne jointly by the U.S. Forest Service (USFS) and the land management agencies in the Department of the Interior (DOI). Fire response activities are coordinated through the National Interagency Fire Center (NIFC) in Boise, Idaho. Fire research is conducted by the USFS, in cooperation with the USGS (especially the EROS Data Center and various projects within the Biological Resources Discipline). High- resolution satellite and airborne imagery support is barely adequate for wildfire response during a severe fire season, leaving little support for needed pre-fire studies to characterize the health and types of vegetation, and fuel loading. Such studies are essential to assess areas at highest risk of fire in the immediate future, to enable land management agencies and communities to determine where best to invest mitigation resources and to monitor reduction in fire hazard. (References include CEOS, 2002; USFS, 2002; WFLC, 2002; USGS, 1997)

Coastal hazards, tsunami, and sea ice hazards. This varied set of hazards, with its meteorological, hydrological, geological and human-induced components, impacts our heavily developed and populated coast lines, and poses major threats to port facilities and to navigation. Because coastal areas fall in the transition zone between terrestrial and ocean processes, this class of hazards often falls in the cracks between existing programs and systems, and the costs associated with these hazards are not broken out cleanly (Heinz, 2000). Accurate forecasting of storm surge and coastal flooding depends on coordination between NOAA-NWS (*e.g.* hurricane landfall forecasts), the USGS (for stream flow information), and NOAA's National Ocean Service (NOS), for tidal and wave height information. Tsunami forecasting involves coordination between the USGS (for seismic or other geological information) and NOAA, with the forecasts being issued by NOAA's Tsunami Warning Centers. Cleanup after a storm involves FEMA, which includes flood insurance for flooding from coastal storms in its National Flood Insurance Program, and the U.S. Army Corps of Engineers (USACE), which maintains and restores navigation channels. The National Ice Center (NIC), a joint activity of the U.S. Navy, NOAA, and the U.S. Coast Guard, provides operational ice analyses for sea and lake ice for the Great Lakes and U.S. coastlines.

Pollution hazards. These include a very complex set of hazards, which may be triggered by other hazards events (such as an earthquake or flood), or be induced by human activity. Releases of chemicals, including crude petroleum, on land, into fresh-water systems, or into the atmosphere are dealt with by EPA [e. g., EPA, 2003]. Radiation hazards are the responsibility of DoE and EPA. Spills in the coastal zone or at sea are the responsibility of NOAA-NOS and the EPA. Monitoring often depends initially on direct reports of eyewitnesses, with a wide range of sensors and techniques coming into play, once an event is recognized. Oil spills can be tracked with satellite imagery, in particular with synthetic aperture radar imagery (Cunningham and others, 2003; Helz and others, 2003).

Space Weather Monitoring and other critical satellite support activities. Capabilities in this area include space-based and ground-based sensors that monitor solar and geomagnetic storms. These storms, of limited consequence to human society a century ago, can now cause major disruptions in satellite navigation, radio communication, satellites' operations, and electric power grids. The economic impact of a major geomagnetic storm on the electric utility industries can be equivalent to that of a major hurricane.

Another vital set of networks are the **global geodetic reference networks**, supported by NASA. These ground-based networks monitor the Earth's reference frame and track the orbits of satellites within that frame. These reference networks, by defining the precise orbits of the GPS satellite constellation, permit the use of GPS for precise geolocation for all applications, which range from precise determination of topography (whether for ice, land or ocean surfaces), to monitoring of plate motions and deformation associated with the geohazards, to facilitating search and rescue operations. Needs for rapid and accurate geolocation, whether for tracking the hazard or for humanitarian response, are identified where appropriate in Table 2 and in Appendix 1.

There are many other hazards, not formally documented here, such as avalanches and fog, which are not well- monitored or consistently reported, but which may nevertheless cause significant casualties and expense (Mileti, 1999). In addition, there are other ramifications of these hazards, such as disease outbreaks following floods, or the ecological impacts of wildfires, that are covered in other societal benefit sections of the IEOS strategic plan and supporting documents.

Commonalities across the Hazards

Many of the data and observational needs described in the individual hazards tables are common to more than one hazard, as summarized in Table 3. A blank in Table 3 means that there is no requirement for the individual observation for that hazard. In constructing this crosswalk table, the list of individual observational requirements has been condensed from 107 to 37. Some lumping of observational requirements was inevitable, but the data or requirement descriptions in the left-hand column have been expanded to clarify what is covered for each. In addition, the first eight data requirements in Table 3 spell out what baseline data are needed for disaster management, in more detail than in most of the individual hazards tables.

Inspection of Table 3 shows the expected extensive overlap among the weather or weather-driven hazards. There is a similar level of overlap among the solid earth hazards, and in certain areas, among floods, sea ice and coastal hazards. However there are other significant commonalities that may be less widely appreciated: wildland fires, volcanoes and some pollution events have overlaps for thermal signals, gas emissions, smoke and aerosols, and sediment and other discharges into water. Seven of the individual hazards listed require information on soil moisture.

Finally, Table 3 shows extensive commonality between the observational needs for pollution events, such as oil spills, and those for the natural hazards. These commonalities, combined with experience showing that many large natural disasters (especially wildland fires, earthquakes and floods) result in significant pollution as part of the event, illustrate the validity and importance of treating pollution events as part of the continuum of physical and chemical disasters.

Table 3. CROSSWALK FOR REQUIRED OBSERVATIONS

(X = requirement for the particular hazard; blank =no requirement)

Hazard	Wildland Fire	Earthquakes	Volcanoes Volcanic ash and aerosols	Landslides	Floods	Extreme weather	Tropical cyclones	Sea and Lake Ice	Coastal hazards, tsunami	Pollution events (oil spills, etc.)
Digital topography – broad, regional	X	X	X	X	X	X	X		X	X
Digital topography– detailed or high-resolution	X	X	X	X	X	X	X	X	X	X
Maps (terrain, water features, geographic names)	X	X	X	X	X	X	X	X	X	X
Location of infrastructure, transportation routes	X	X	X	X	X	X	X	X	X	X
Exposure: structure inventory, engineering properties, response to hazards	X	X	X	X	X	X	X	X	X	X
Detailed bedrock geologic mapping, age dating		X	X	X						
Detailed mapping, dating of surficial deposits, including fill, dumps, paleohydrology		X	X	X	X			X	X	X
Document/ assess effects and area affected during and after event	X	X	X	X	X	X	X	X	X	X
Seismicity, seismic monitoring		X	X	X					X	
Strong ground shaking, ground failure, liquefaction effects		X		X					X	
Deformation monitoring, 3-D, over broad areas		X	X	X					X	
Strain and creep monitoring, specific features or structures		X	X	X						

Hazard	Wildland Fire	Earthquakes	Volcanoes Volcanic ash and aerosols	Landslides	Floods	Extreme weather	Tropical cyclones	Sea and Lake Ice	Coastal hazards, tsunami	Pollution events (oil spills, etc.)
High-resolution measurements of gravity, magnetic and electrical fields		X	X							
Physical properties of earth materials (surface and subsurface)		X	X	X					X	
Characterize regional thermal emissions, flux – all time scales	X	X	X							
Detect and characterize local thermal features at varying time scales	X		X							X
Characterize gas emissions by species and flux		X	X							X
Detect and monitor smoke or ash clouds, acid and other aerosols	X		X							X
Water chemistry, natural and contaminated		X	X		X				X	X
Detect and monitor sediment, discharges (oil, etc.) into water	X		X	X	X				X	X
Water levels (groundwater) and pore pressure		X		X	X					
Stream flow: stage, discharge and volume	X			X	X	X	X		X	X
Inundation area (floods, storm surge, tsunami)				X	X	X	X		X	X
Soil moisture	X	X		X	X	X	X		X	
Precipitation	X		X	X	X	X	X		X	X
Characterize snow cover or ice cover: area, concentration, thickness, water content				X	X	X		X		
Observe snow melt, ice break up, ice jams					X	X		X	X	

Hazard	Wildland Fire	Earthquakes	Volcanoes Volcanic ash and aerosols	Landslides	Floods	Extreme weather	Tropical cyclones	Sea and Lake Ice	Coastal hazards, tsunami	Pollution events (oil spills, etc.)
Navigational hazards or obstructions, including ice								X	X	
Waves, heights and patterns (ocean, large lakes), currents						X	X	X	X	X
Tides/ coastal water levels					X	X	X	X	X	X
Wind velocity and direction, wind profile	X		X			X	X	X	X	X
Atmospheric temperature, profile	X					X	X	X		
Surface and near-surface temperature (ground, ice and ocean)	X	X	X	X		X	X	X		
Airmass differences and boundaries	X					X				
Moisture content of atmosphere	X		X			X	X			
Vegetation -- high-resolution	X			X	X					
Fuel characteristics: structure, load, moisture content	X									

Table 3 does not include the required observations for Space Weather, because they do not crosswalk with other categories of data, as can be seen by comparing the Space Weather table with others in Appendix 2. However, as societies around the world become more dependent on continuity of operation of satellites and large electric grids, and thus more vulnerable to space weather storms, it is imperative that these monitoring capabilities be maintained and improved (NOAA/OAR, 2003; NSWP, 2000).

Major Gaps and Challenges

There are still many significant gaps, in instrumentation, temporal and spatial coverage, baseline data and models, communications networks, and decision support tools. These have been identified in many reports (SDR, 2003, all reports previously cited). In addition, some existing capabilities are degrading, or will be lost within 10 years. The gaps identified in the individual hazards tables in Appendix 2, which mostly identify gaps in instrumentation, are summarized in Table 4 with the individual gaps identified. For the most part, the authors of the individual hazards tables specified gaps only where the gap is important for that hazard. Sometimes a requirement exists for a particular type of observation, but no gap was identified in the corresponding table in Appendix 2. This situation, indicated by a dash in Table 4, should not be interpreted to mean that our ability to observe that variable for the particular hazard is adequate.

Examination of Table 4 shows that high-resolution digital topography emerges as a key unmet need for seven of the 10 hazards considered, with detailed mapping of surficial deposits (including landfill and dumps) also widely lacking. In some cases the need for better topography may be met with satellite data, but in areas of low relief, extensive LIDAR or airborne SAR support is needed.

In general, big ground-based networks have consistently been identified as either not extensive enough, or too sparse, or in danger of serious deterioration over the next 10 years. This is true for seismic and deformation (GPS) networks as well as weather monitoring systems, stream gages, and coastal and ocean buoy systems. Undersea seismometers and tsunami detecting buoys in particular are lacking, both for the United States and globally (SDR, 2005b, c), although the recent (December 2005) tsunami in Indonesia has stimulated progress in this area.

Airborne infrared capability, for wildland fires, volcano monitoring, or some technological disaster, is cited as inadequate, as is moderate-resolution satellite infrared imagery. The inadequacy of Landsat 7 data, in its current impaired state, and the present lack of sponsorship for a follow-on ASTER sensor are of concern as well.

The most widely cited inadequacy in satellite data is for increased access to synthetic aperture radar (SAR) data. Table 4 shows SAR or interferometric SAR (InSAR) as sparse or lacking for all the geohazards, floods, wind hazards, sea ice, coastal hazards and pollution events. Because of its all-weather, day-night imaging capability, SAR offers support to a very wide range of disasters, including near-real time inundation patterns during floods, or assessing coastal wind patterns (Cunningham and others, 2003; Helz and others, 2003). A related gap in satellite capability is the absence of a passive microwave sensor for determining soil moisture. Lastly, the detection of anthropogenic contaminants in the atmosphere or in plumes will require expanded hyperspectral capability, either airborne or possibly satellite-based.

Although not separately represented in Table 4, both the global geodetic networks and the satellite and ground-based systems that monitor solar and geomagnetic storms provide essential support to the world's constellation of satellites as a whole, whether those satellites are owned by the government or the private sector. These are essential activities that must be continued, if the United States is to continue or expand its dependence on satellite-based information.

Beyond the gaps in instrumentation emphasized in Table 4, the reduction of loss of life and property to extreme weather events requires timely (three to six hour forecasts, if there is skill in predicting the event), reliable and specific information. In many cases, the time resolution of observations is inadequate to support such forecast requirements. In addition, better forecasts require regional solutions, which may be difficult to achieve with models that can deal with the global scale. Finally, there are different observing requirements in different regions, due to terrain differences or whether a location is coastal or inland.

Table 4. CROSSWALK FOR GAPS IN OBSERVATIONS

(Dash = requirement, no gap identified; G= gap in ground-based systems,

A= gap in airborne coverage, S= gap in satellite systems, L = gap in lab data)

Hazard	**Wildland Fire**	**Earthquakes**	**Volcanoes Volcanic ash and aerosols**	**Landslides**	**Floods**	**Extreme weather**	**Tropical cyclones**	**Sea and Lake Ice**	**Coastal hazards, tsunami**	**Pollution events (oil spills, etc.)**
Digital topography (broad, regional)	--	--	--	--	--	--	--		--	--
Digital topography–detailed or high-resolution	gap in S, processing	gap in S, processing	gap in S, processing	gaps in G, S, processing	gaps in A, S, need updates	--	--	gaps in A, S--annual updates	gap in A, S, processing, G for bathymetry	--
Maps (terrain, water features, geographic names)	--	--	--	--	--	--	--	--	--	--
Location of infrastructure, transportation routes	--	--	--	--	--	--	--	--	--	--
Exposure: structure inventory, engineering properties, response to hazards	--	--	--	--	--	--	--	--	--	--
Detailed bedrock geologic mapping, age dating		gap in G	gaps in G, S	--						
Detailed mapping, dating of surficial deposits, including fill, dumps, paleohydrology		gap in G	gaps in G, S	gap in G	--			gaps in A, S -- annual updates	--	gap in G
Document/ assess effects and area affected during and after event	gaps in A, S (Landsat)	--	--	--	--	--	--	--	--	--
Seismicity, seismic monitoring		gap in G	gap in G	--					--	
Strong ground shaking, ground failure, liquefaction effects		gap in G		--					--	
Deformation monitoring (3-D) over broad areas		gaps in G, S = InSAR	gaps in G, S = InSAR	--					gap in S = InSAR	
Strain and creep monitoring, specific features, structures		gap in G, S = InSAR	--	gaps in G, S = InSAR						
High-resolution measurements of gravity, magnetic and electrical fields		--	--							
Physical properties of earth materials (surface and subsurface)		gaps in G, L	--	gaps in G, L					--	

Hazard	Wildland Fire	Earthquakes	Volcanoes Volcanic ash and aerosols	Landslides	Floods	Extreme weather	Tropical cyclones	Sea and Lake Ice	Coastal hazards, tsunami	Pollution events (oil spills, etc.)
Characterize regional thermal emissions, flux at all time scales	gap in S= 3.96 micron band	--	--							
Detect and characterize local thermal features at varying time scales	gaps in A, S=3.96 micron band		gaps in A, S = ASTER							gap in S=3.96 micron band
Characterize gas emissions by species and flux		--	gaps in G, S, CO2, SO2 monitors							gap in S little hyperspectral
Detect and monitor smoke or ash clouds, acid and other aerosols	gap in S		gap in S if split window in thermal IR absent							--
Water chemistry, natural and contaminated		--	--		--				--	--
Detect and monitor sediment, discharges (oil, etc.) into water	--		--		--				--	gap in S, esp . SAR
Water levels (groundwater) and pore pressure		--		--	--					
Stream flow: stage, discharge and volume	--			--	gap in G	gap in G	gap in G		--	--
Inundation area (floods, storm surge, tsunami)				--	gap in S SAR and InSAR	--	--		gap in S SAR and InSAR	gap in S SAR and InSAR
Soil moisture	--	--		gap in A ,S passive microwave	gap in G, S passive microwave	gap in G, S passive microwave	gap in G, S passive microwave		--	
Precipitation	--		--	gaps in G, S	gaps in G, S	gap in G	gap in G		--	--
Characterize snow cover or ice cover: area, concentration, thickness, water content				--	gap in G	gap (?)		gaps in A,S, esp. SAR		
Observe snow melt, ice break up, ice jams					gap in G	--		gaps in A, S, esp. SAR	--	
Navigational hazards or obstructions, including ice								gaps in G, S, esp. SAR	--	
Waves, heights and patterns (ocean, large lakes), currents						--	gap in G (buoys)	gap in G (buoys)	gap in G (buoys)	--

Hazard	Wildland Fire	Earthquakes	Volcanoes Volcanic ash and aerosols	Landslides	Floods	Extreme weather	Tropical cyclones	Sea and Lake Ice	Coastal hazards, tsunami	Pollution events (oil spills, etc.)
Tides/ coastal water levels					--	--	--	--	--	--
Wind velocity and direction, wind profile	--		--			gap in G	gap s in A, S, esp. SAR	gaps in G (buoys) S (SAR)	gaps in G (buoys) S (SAR)	--
Atmospheric temperature, profile	--					gaps in G, S (micro-wave profilers)	gaps in A, S	--		
Surface and near-surface temperature (ground, ice, ocean)	--	--	--	gap in G		--	--	gap in G (buoys)		
Airmass differences and boundaries	--					gap in G= Doppler radar				
Moisture content of atmosphere	--		--			gap in G	gaps in G, A, S			
Vegetation -- high-resolution	gap in S = Landsat			--	gap in S = Landsat					
Fuel characteristics: structure, load, moisture content	gap in S = Landsat, InSAR									

Our ability to issue forecasts for wildland fire or for the solid earth hazards lags behind our success in forecasting the weather. It is possible to identify areas of high hazard, and sometimes (for fires, volcanic activity, landslides, or tsunami) to issue statements of higher probability of an impending event. But hazard forecasting (which implies the ability to give reasonably accurate information on the time, place and size of such events) remains a major challenge for most of these hazards.

Modeling is another area that poses significant challenges. In the domain of predictive hazard models, for hazardous weather or any other hazard, it is imperative, as we seek to optimize operational models, that the research community work with the same model used in operations. The same is true of risk assessment models that seek to predict the impact of hazards on the built environment. A common modeling architecture, sometimes referred to as a community model, enhances the transition of new capabilities into the operational model. For regional weather, such a capability is emerging in the United States, through the Weather Research and Forecasting (WRF) model, but coordination between researchers and operations must be greatly enhanced. Predictive hazard models are in turn an essential component of predictive risk assessment models, such as FEMA’s GIS-based HAZUS loss estimation model.

Future Earth Observation Systems that May Fill Gaps

Robust, modern national networks are essential for *in situ* monitoring, for example: seismic monitoring and notification (USGS, 1999a), deformation monitoring (EWG, 2001; ESA, 2004), volcano monitoring (USGS, 2005), stream gages (USGS, 1999b), and ocean buoys (NOAA,NWS, 2004b). In the wake of the Indian Ocean disaster, the U.S. government has focused on better tsunami detection systems for U.S. coastal areas as a priority (SDR, 2005c). Globally, existing monitoring networks (such as the global geodetic networks, Global Seismographic Network and International Monitoring System) provide both the communications infrastructure and distributed coverage needed to support enhanced Earth observation, improved disaster response and better international collaboration for multiple sensors.

Two new satellite systems – the NPOESS (NOAA/NESDIS, 2003 and 2004a) and GOES-R (NOAA/NESDIS, 2004b) – will replace NOAA's current polar and geostationary satellites in 2009 and 2012, respectively. Both will provide improved technologies to support the detection and monitoring of severe weather, tropical cyclones, volcanic eruptions and ash clouds, and will provide data essential to support research on these events. Onboard instruments will have improved spatial and temporal resolution, and will include a wider range of spectral bands than current POES systems, although some bands currently available and used for fire detection will either be absent or too sensitive on the NPOESS equivalent for fire detection in daytime. In addition the GEO Lightning Mapper will monitor lightning in support of better extreme-weather assessment.

Future weather-related solutions also include expansion of the commercial-aircraft Meteorological Data Collecting and Reporting System (MDCRS) globally, and more use of local carriers. Expanded deployment of surface-based radar wind profilers to observe the atmospheric boundary layer is also envisioned. The development and deployment of strategically located phased-array radars will significantly increase the quantity, quality and timeliness of weather information in extreme weather, as will the operational deployment of high-altitude unmanned aerial systems (UAS). The need to integrate these observations into an optimal observing system is vital to realize the benefits of these investments in improved observations.

Easier access to SAR data would address a need identified for most of the hazards reviewed [CEOS, 2002; ESA, 2004; Cunningham and others, 2003; Helz and others, 2003; the SESWG report (NASA, 2002)]. The need for SAR is also mentioned in Earthscope documents (EWG, 2001; NRC, 2001). Currently the only course is to seek easier access to Canadian and European C-band SAR satellite imagery. In addition, Japan launched its new L-band SAR (the PALSAR sensor on the ALOS satellite) in January 2006. That is a welcome development, but PALSAR and other SAR sensors are designed as research instruments, and share power and downlink capabilities with other sensors on the same satellites. Consequently the amount of SAR data available is severely limited now and will be for the next six to eight years. Specifically, it is inadequate for both routine ice monitoring (the principal use of the Canadian Radarsat) and for monitoring solid-earth deformation on a continental or global scale. A C-band (or X-band) and L-band SAR capability, to generate all-weather imagery for a wide range of hazards, could address this gap.

Improved access to moderate to high-resolution near IR and short-wave IR imagery is needed, especially for fire response (CEOS, 2002; USFS, 2002), but also for volcano monitoring (CEOS, 2002; ESA, 2004). High-resolution imagery needs for volcanoes, plus rapid, tactical IR imagery support for wildfire response, would be better met through the use of airborne IR cameras, as there will be less interference from clouds.

NASA Earth Science Enterprise (NASA, 2000) covers a wide range of applications, including sensors that would be useful for hazards applications, to the extent that they can be run as operational systems. There will be a need, however, for new and additional satellites to monitor the interplanetary solar wind.

6. Interagency and International Partnerships

The SDR report cited earlier (SDR, 2003) identifies the many existing interagency partnerships that deal with particular hazards. Flood monitoring and response involves coordination among the NWS, USGS, FEMA and USACE. Activities related to earthquakes are coordinated through NEHRP (WSSPC, 2003). Dealing with the hazards posed by volcanic ash clouds to air traffic involves coordination among NOAA (both the NWS and NESDIS), the USGS, the USAF, and the FAA. Wildfire response (WFLC, 2002) is coordinated through NIFC (the National Interagency Fire Center, which consists of the U.S. Forest Service, the National Park Service, the Bureau of Land Management, U.S. Fish and Wildlife Service and other land management bureaus). U.S. agency activities that support development of improved hazard and risk models are also listed in the SDR report, as are the existing national-level response plans. In addition, the NOAA/NWS/Space Environment Center is an integral part of the DOD space weather operation (NSSA, 1999) and works with other federal agencies, such as the FAA, NASA and USGS through the National Space Weather Program.

In addition to the partnerships between agencies with operational roles, there are some major interagency collaborations that focus on research in the area of Earth observations. One prominent example is the NSF Earthscope initiative (EWG, 2001; NRC, 2001), which includes active seismic experiments, deep drilling of the San Andreas fault zone, and geodetic studies of motion at plate boundaries and other deformation. This effort primarily involves the academic community, in collaboration with NASA and the USGS. Other areas of collaboration between Federal agencies and academia are represented by IRIS (seismic data archiving) and UNAVCO (GPS studies, equipment and data archiving). The U.S. Weather Research Program is an interagency activity focusing on accelerating improvement in forecasts of high- impact weather. Its member agencies include NOAA, NSF, NASA, the U.S. Navy and the U.S. Air Force. The National Tsunami Hazard Mitigation Program involves collaboration among NOAA, FEMA, the USGS and the coastal states.

Key international partnerships and coordinating bodies include the World Meteorological Organization (WMO) and the associated Meteorological Watch Offices (MWOs), the nine Volcanic Ash Advisory Centers (VAACs), the International Charter for Space and Major Disasters (ESA, CNES, CSA, NOAA, ISRO, etc.), the Preparatory Commission for the Comprehensive Nuclear Test Ban Organization (CTBTO), which has a number of monitoring systems, and the International Space Environment Service (ISES), among many others. Tsunami information is coordinated internationally through the UNESCO Intergovernmental Oceanographic Commission. Within the WMO there is a key international activity called THORPEX, a Global Atmospheric Research Program designed to accelerate the improvement of global weather forecasting out to 14 days. WMO also houses the International Ice Chart Working Group, under the WMO/IOC, which provides operational cooperation amongst national ice services, with regional (North American) collaboration handled by the U.S. -- Canadian Joint Ice Working Group. Many of these organizations, in particular those under the WMO, will feed into the Global Earth Observation (GEO) System of Systems (GEO, 2005a, b), which is the international equivalent of the U.S. national IEOS (CENR/IWGEO, 2005)

Another category of international partnerships that are focused more on capacity-building than on information gathering includes programs such as the USGS Volcano Disaster Assistance

Program (cosponsored by the USGS and USAID/OFDA) and the Civil Military Emergency Preparedness program of the USACE.

U.S. Capacity-Building Needs

Recent experience (notably the aftermath of Hurricane Katrina) underlines the need to increase capacity to withstand and recover from natural and anthropogenic disasters with minimum loss of life, injuries, damage to homes and other structures, and impact on the economy. This can be accomplished by educating the public through distribution of information on potential disasters and their impacts, by preparing our society through effective mitigation strategies, by improving and encouraging the use of predictive risk assessment tools such as HAZUS, and by disseminating of accurate and timely alerts and warnings. Some of these issues, which go beyond the scope of this report, are the main focus of many other institutions, such as the National Hazards Research and Information Center (NHRAIC) at the University of Colorado (Boulder). These aspects of disaster response are also explored in the recent Grand Challenges report of the SDR (SDR, 2005a).

There is also a clear need to maintain existing monitoring capacity. Many of our major surface-based monitoring networks are incomplete or aging: these include the national seismic monitoring system, the global geodetic networks, regional GPS networks, the more local networks that monitor seismicity and deformation at active volcanoes, various meteorological and stream-gaging networks, and various ocean buoy systems.

Both nationally and globally, there is an overall need to expand and improve coordination of IT infrastructure to support research, expanded hazards monitoring, risk assessment, and communication activities. Existing and developing global networks could support dramatically expanded Earth observations on a common communications backbone.

There is a need to integrate regional observations beginning with one or two regions and expanding to regions covering the entire nation and eventually the world. Experience in one region, or with one system, such as NOAA's Meteorological Assimilation Data Ingest System (MADIS), can be applied to the development and expansion of observation capabilities in another region. Also, of course, an instrument developed for one region can be used with no additional development in another region.

Other needs include the expansion of emergency airborne capabilities including UASs for severe weather, fire/fuels mapping, volcano observation, characterization of airborne contaminant plumes, and expansion of capabilities for airborne LiDAR and SAR (to support detailed observation of topography and topographic changes). We should also support research into new instrumentation (cheap, portable, sensitive, accurate, and quickly deployable) to identify and monitor a wide range of trace gases, toxic chemicals, or explosives in soil, water, and the atmosphere. Remotely controllable sensors that can function in extreme or unusual environments (near erupting volcanoes, in wildfires, or in malfunctioning nuclear reactors) will be needed.

In the area of public hazard communication, the United States needs to improve its ability to issue targeted warnings for local hazards such as tornadoes, fog on highways, and flash floods [SDR, 2000; Mileti, 1999]. Two means for improved hazard communication in general are the use of CAP (Common Alerting Protocol) procedures, and expanded use of electronic clearinghouses, such as the Disaster Management e-Government initiative (OMB, 2004). Because large events are relatively uncommon, U.S. scientists can learn a good deal through the study of major natural disasters in foreign countries; the impacts of such events on other societies can carry lessons either for scientific understanding of the hazard or for more effective mitigation practices, which may be applied in the

United States. A recent report *Science and Technology Lessons Learned from the December 26, 2004 Indian Ocean Disaster* (SDR, 2005b) is a case in point.

Conclusions

In reviewing the status of (1) monitoring of natural and certain manmade hazards, (2) existing deficiencies and gaps, and (3) new systems on the verge of deployment, the disasters team recognizes two overarching areas of immediate concern for future discussions on Earth observation systems. These are:

(1) The development of a process whereby the unmet needs for expansion and modernization of the vast array of surface-based monitoring systems can be dealt with in the 10-year time span of the IEOS plan. This work is essential to maintain the benefits of the status quo, to define the needed communications infrastructure, and to prepare for the future expansion of population and infrastructure into areas of high risk. This deployment can be incremental, but it should be systematic, for all critical systems. This array of surface-based monitoring systems will provide the landscape-scale observations needed for research to understand natural hazards and their root processes, and to improve modeling and forecasting of hazard events.

(2) The clarification of responsibility for designing, building, launching and operating satellites that are intended to observe the solid surface of the Earth at moderate spatial resolution, with temporal resolution and spectral capabilities adequate for the range of natural hazards discussed here. NOAA/NESDIS covers weather and other atmospheric observational requirements, and many ocean requirements, but operational satellites for solid-Earth surface observations currently have no home. This class of satellite observations is essential for both operational purposes and for basic research on natural hazards and other processes.

More specific needs or areas of observational deficiencies that have been identified in this report are:

(3) More systematic acquisition of high-resolution digital topography (which has been identified as a kind of information needed to support response for almost all hazards and is probably essential to many other societal benefit areas of the IEOS as well).

(4) Continued access to visible/IR imagery at moderate resolution (10-100 m pixels, like Landsat or SPOT or ASTER), but with better temporal resolution than Landsat, etc. This would support a wide range of land-observation needs in other focus areas.

(5) SAR satellite capability, both C-band (or X-) and L-band, for monitoring deformation, for topography, for inundation and sea ice monitoring, for vegetation/canopy characterization, and for oil slick detection, among many other applications.

(6) Community predictive hazard-assessment and risk-assessment models, that is, model architecture shared between the research community and the operations community, to facilitate model improvements through research. Hazard models involved include weather hazards, chemical or radiological spills, wild fire and smoke spread, among others. Interoperability of models, to ensure that hazard prediction outputs can be transferred rapidly to risk assessment models, is essential to providing information to decision makers in a timely manner.

(7) Evaluating the potential for expanding global ground-based observations by expanding the suite of sensors deployed in the global monitoring networks, (e.g. adding meteorological (barometric) and geomagnetic sensors at Global Seismographic Network station sites), to take advantage of the existing communications infrastructure.

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APPENDIX 1. USER REQUIREMENTS for INFORMATION on INDIVIDUAL HAZARDS

Table 1a. USER NEEDS for WILDLAND FIRE INFORMATION

Type of user	Needs for response to an event	Needs for hazard assessment and mitigation
Responsible authorities **("end users")**	For initial attack/extended attack: rapid access to geospatial data, including active fire front position, fire origin, fire fuels, spot fires, fire weather, emergency access routes, terrain, structures and other improvements in the area of the incident. Relative geolocational accuracy can be favored over absolute accuracy. For larger incidents (100+ acres): rapid access to the above plus smoke monitoring. Full suite of products need to be available at major shift change times (generally 0600 and 1800 hours local time). For post-fire burn recovery: geospatial data includes extent and characterization of vegetation burn severity, soils observations, and all structures and other improvements in the affected area. Timely alerts and updates to government officials, the affected population, and the media on fire location and status, effects on public health, roads, and possible evacuation routes	Information on vegetation health, vegetation fire fuels, fuel moisture, fire history, structures and other infrastructure adjacent to wildland areas, atmospheric transport of smoke, and access routes. Needed for planning prescribed burns, anticipating future fire activity, land use policy and planning in or near wildland areas. Often there is a need for greater information in wildland -- urban interface areas.
Scientific and technical staff in monitoring and advisory agencies	All environmental data related to fire starts (fuels, weather), location, and anticipated fire duration, plus accurate geolocation data.	Detailed in-situ, airborne, and satellite based observations of fire fuels and climate change to anticipate future conditions.
Research scientists	All available data relevant to their research, collected in real time, but accessed when needed. Feedback on the performance of models and scenarios	Same as for scientists above. Feedback on the performance of models and scenarios

Table 1b. USER NEEDS for EARTHQUAKE HAZARD INFORMATION

Type of user	Needs for response to an event	Needs for hazard assessment and mitigation
Responsible authorities **(“end users”)**	Clear, authoritative information on the location and magnitude of the shock and the timeframe (in days) of aftershocks. Rapid maps of effects for situational awareness (shake maps, damaged/affected areas, identification of safe areas) Timely updates and precise geolocation data are critical for activating shutdown of critical facilities (power plants, trains, etc.)	Hazard zonation maps: paper maps or GIS data bases showing areas of lower vs. higher intensity of foreseeable ground motions. Maps for various secondary effects of seismic hazards (landslides, liquefaction, etc.) are also needed. Data support land use planning, building standards regulations. Decision support tools for seismic risk assessment (e.g. FEMA’s HAZUS)
Scientific and technical staff in monitoring and advisory agencies	All available data, in as near to real-time as possible, in particular the following: Seismicity, intensity of ground shaking, strain, precise location data, digital elevation models (DEMs), soil type, moisture conditions, infrastructure and population.	Seismic history, archives of data on seismicity. Continuous monitoring of seismicity, deformation, and other geophysical and geochemical parameters, to recognize active faults Base maps (geological, soil, active faults, hydrological, and DEMs), and conceptual models. Data for input to risk assessment models such as the earthquake module in FEMA’s HAZUS program.
Research scientists	All available data relevant to their research, collected in real time, but accessed when needed. Feedback on the performance of models and scenarios	Same as above. Continuity of observations of all relevant geophysical and geochemical data. Feedback on the performance of models and scenarios

Table 1c. USER NEEDS for VOLCANO HAZARD INFORMATION

Type of user	Needs for response to an event	Needs for hazard assessment and mitigation
Responsible authorities **("end users")**	Clear, authoritative information on most likely course of the unrest/eruption, whether ash explosions may occur Includes best estimates on when and what type of eruption, possible size, which areas or air routes will be affected and which will be safe. Timely updates and adequate geolocation data are critical	Need hazard zonation maps: paper maps or GIS data bases showing areas of lower vs. higher risk, for future eruptions. The maps for various major hazards (lava flows, lahars, ash fall, etc.) will be different. Data provide input for land use planning, ash response plans, and community volcanic eruption response plans.
Scientific and technical staff in monitoring and advisory agencies	All available data relevant to the hazard (seismic, deformation, gas, and thermal, both ground-based and EO), plus location of activity or ash clouds, wind speed and weather conditions, collected in real time or near real-time, and accessed as needed. Digital elevation models (DEMs) to help predict distribution of pyroclastic or lava flows, or lahars, to identify both areas of high risk and safe areas Wind direction, models for dispersal of ash clouds	Base maps and DEMs. Maps showing distribution of all young volcanic deposits, with dates, to determine type, size and recurrence intervals of eruptions over significant time (10,000 years or more). 3D models of volcanic structure. Continuous monitoring of seismicity, deformation, and other geophysical and geochemical parameters
Research scientists	All available data relevant to their research Feedback on the performance of models and scenarios	Same as above Feedback on the performance of models and scenarios

Table 1d. USER NEEDS for LANDSLIDE HAZARD INFORMATION

Type of user	**Needs for response to an event**	**Needs for hazard mitigation**
Responsible authorities ("end users")	Local, rapid mapping of affected areas, magnitude of instability, updated scenarios during ongoing instability, including known and expected locations of ground failure and runout, and impact analysis. Early warning of heightened risk, if rainfall intensity or duration exceed thresholds, for areas of known high hazard of landslides and debris flows, including burned areas	Regularly updated susceptibility and hazard zonation maps for landslides, debris flows, rock falls, subsidence (at appropriate scales). Data support decisions on land use, siting of critical facilities
Scientific and technical staff in monitoring and advisory organizations and agencies	Near real-time observational tools Needs as for mitigation, plus seismic data or weather forecasts, depending on the nature of the triggering event.	Data on: landslide inventory, DEMs, ongoing ground deformation, hydrology, geology, soils, plus geotechnical, climatic and seismic zonation maps, and data on present and historical land use, at appropriate scales. Methods and models for susceptibility and hazard evaluation. Data from well-observed past events
Research scientists	All available data relevant to their research Feedback on the performance of models and scenarios	Continuity of observations, appropriate data as above, for understanding process, and for development of models and observational tools. Data from well-observed past events

Table 1e. USER NEEDS for FLOOD HAZARD INFORMATION

Type of user	Needs for response to an event	Needs for hazard assessment and mitigation
Responsible authorities (“end users”)	Timely and accurate short through extended range forecasts and warnings that quantify certainty and convey risk (time, discharge, stage, area inundated) for both river and flash flood events. Includes accurate locations of areas, infrastructure (roads, bridges, etc.) affected (contained in FEMA’s HAZUS data base). Ground surveys, aerial photos and interviews for damage assessments.	Flood hazard zonation maps, accurate topographic base maps; updated maps of land use, showing land use changes; flood history of the area Decision support tools for flood risk assessment models such as the flood module in FEMA’s HAZUS program
Scientific and technical staff in monitoring and advisory organizations and agencies	Real-time in-situ and remotely-sensed environmental data (including rainfall, upstream discharges, snowmelt rates, inundation areas). Event/storm direction, type, intensity, and speed. Needed to produce analyses and forecast model products.	Accurate topographic data (DEMs). Long-term precipitation and stream gage records. Historical data related to flood inundation areas and discharges; information on alterations to watersheds (dams; levees, etc.); information on land-use changes. Data for input to risk assessment models such as the flood module in FEMA’s HAZUS program. Includes information related to hydraulic structures (dams, levees, etc.); hydraulic models to route flood flows.
Research scientists	Capture & archive all data in high temporal and spatial resolution (4 dimensions)	Same as above.

Table 1f. USER NEEDS for EXTREME WEATHER INFORMATION

Type of user	Needs for response to an event	Needs for hazard assessment and mitigation
Responsible authorities (“end users”)	Timely and accurate forecasts (time, location, intensity and nature of severe weather). Accurate and comprehensive real-time data during the event (e.g. location of strong winds, heavy precipitation, hail and direction of propagation). Mapping, ground surveys, intervies, aerial photos for damage assessments.	Historical data for the area (e.g. frequency of tornadoes, strong winds, heavy shows, hail). Needed for input to land use planning, building codes and standards, such as wind resistance, roof loading, materials resistant to hail, and tornado safe rooms.
Scientific and technical staff in monitoring and advisory organizations and agencies	Real-time environmental data (e.g., winds, moisture, temperature, cloud fields, and synoptic/sub-synoptic flow fields). Needed for analyses and forecast model products. Radar and research aircraft in special cases during which field studies are occurring. GIS mapping, ground surveys, interviews, aerial photos for damage assessments.	Historical data for the area, as above. Needed for input to land use planning, building standards, including roof loading, materials resistant to hail, and tornado safe rooms. Input to wind module in FEMA’s HAZUS program.
Research scientists	Capture all data in great temporal and spatial detail (4 dimensions), including special data sets, such as the full complement of satellite data at highest spatial and temporal resolution.	Historical data as above. Needed to improve forecasting models.

Table 1g. USER NEEDS for TROPICAL CYCLONE INFORMATION

Type of user	Needs for response to an event	Needs for hazard assessment and mitigation
Responsible authorities (“end users”)	Timely and accurate landfall analyses and forecasts (time, location, intensity, outer wind radii, storm surge, sea state, amount of rainfall) Mapping, aerial photos for damage assessments, models that show and permit analysis of behavior, impact of storm	Historical track and intensity information; hazard zonation maps for storm surge, wind, flooding. Data serve as the basis for appropriate land use policy in coastal areas, especially low-lying areas.
Scientific and technical staff in monitoring and advisory organizations and agencies	Real-time environmental data (moisture, winds, temperature, precipitation rates, clouds), mostly from satellite. Storm direction and speed. Radar wind from Doppler . Needed to produce analyses and forecast products, including sea state and storm surge forecasts. Analyses of all surface and remote-sensed wind, surge, wave, and precipitation data at and after landfall.	Historical track and intensity information, to generate hazard zonation maps, including maps for storm surge, flooding. Input to building codes and standards for wind resistance, as input to the wind module in FEMA’s HAZUS program, also for resistance to storm surge.
Research scientists	All data in great temporal and spatial detail, including research data. Aircraft, in situ (buoys and land surface data), full complement of satellite data at highest spatial and temporal resolution.	Detailed analyzed track information. Analyses of all data streams. Needed to improve forecasting models.

Table 1h. USER NEEDS for SEA and LAKE ICE HAZARD INFORMATION

Type of user	Needs for response to an event	Needs for hazard assessment and mitigation
Responsible authorities (“end users”)	Timely and accurate real time ice analyses and forecasts – short (days), medium (weeks) – using high resolution imagery. Accurate geolocation of icebergs in shipping lanes. Charts showing ice extent in GIS and graphic format	Seasonal ice analyses and forecasts (months, years) Charts showing ice extent, seasonal patterns.
Scientific and technical staff in monitoring and advisory organizations	Information on ice cover, thickness, etc. using high-resolution imagery, Meteorological information and model output (cloud cover, precipitation, snow cover, winds, temperature)	Seasonal, historical information on ice extent, thickness, etc. Ice climatology, (ice extents, probability of occurrence, presence of old ice, ice of land origin).
Research scientists	All data in great temporal and spatial detail, including research data.	As above, plus climate models

Table 1i. USER NEEDS for INFORMATION on COASTAL HAZARDS, INCLUDING TSUNAMI

Type of user	Needs for response to an event	Needs for hazard assessment and mitigation
Responsible authorities ("end users")	Accurate information regarding potential storm surge or tsunami: includes time of arrival, duration of event (all clear signal); boundaries of inundation area; evacuation routes. Mapping, aerial photos for response, damage assessments	Inundation hazard maps for emergency response and land use planning, on high-resolution DEM base maps, and showing critical infrastructure at risk Regularly updated high-resolution shoreline maps and dune erosion rate maps needed for mitigation policy, such as establishing setback lines
Scientific and technical staff in monitoring and advisory organizations	All necessary data streams (meteorological, water levels, seismic data, DART buoy data, satellite imagery) in real time, to produce analyses and forecast products, including storm surge or tsunami run-up forecasts. Post-event surveys to measure extent and height of inundation to validate/improve forecast models and inundation maps.	Inundation hazard maps require 100% coverage bathymetric surveys from ships and/or LIDAR (from shoreline to the continental shelf break); accurate topographic information in the potential run-up area (heights to 25 meters above sea level) Archives of previous coastal topography, shoreline positions, major inundation events including tsunami, as input for hazard zonation maps.
Research scientists	All data in great temporal and spatial detail, including research data. Aircraft, in situ (buoys and land surface data), full complement of satellite data at highest spatial and temporal resolution.	Data as above, in support of development of models of inundation, plus coastal retreat, erosion and deposition

Table 1j. USER NEEDS for INFORMATION on POLLUTION EVENTS

Type of user	Needs for response to an event	Needs for hazard assessment and mitigation
Responsible authorities ("end users")	Clear, authoritative information on the location, compound(s) or chemical(s) released, magnitude of the technological release and the media in which the release occurred (air, land and/or water). Geolocation and other information to support public notifications. Timely updates are critical for activating shutdown of potentially affected facilities (water treatment plants, transportation networks, etc.) Post-event maps (release maps, damaged/affected areas, identification of safe areas)	Accurate topographic and geologic maps, especially maps of surficial geology; GIS mapping of land use and land use changes. Data serve as basis for land use policy, decisions on siting critical facilities or potentially hazardous but essential facilities.
Scientific and technical staff in monitoring and advisory organizations	Real-time in-situ and remotely-sensed environmental data (surface water, ground water, wind, etc.) needed to produce analyses and forecast model products. GIS mapping, ground surveys, interviews, aerial photos for damage assessments.	Updated geologic and topographic maps, including information on recent geologic events and any land-use changes, e.g., location of new chemical plants, landfill sites, reservoirs, population centers. Need hydrologic information (surface water and groundwater). Needed for input to land use policy and siting decisions.
Research scientists	Capture & archive all data in high temporal and spatial resolution (4 dimensions)	Same as above, plus data on well-observed past events Feedback on performance of dispersion models and response scenarios.

Table 1k. USER NEEDS for INFORMATION on SPACE WEATHER

Type of user	Needs for response to an event	Needs for hazard assessment and mitigation
Responsible authorities (“end users” , including engineers and designers of systems affected by severe space weather)	Clear, authoritative information the timing and magnitude of solar X-ray flares, solar energetic particle events, and geomagnetic storms Timely updates are critical for commercial airlines flying polar routes, all satellite operators (civil, military or commercial) and electric power companies. Post-event summaries to allow affected technologies and services to return to normal operating modes	Real-time maps showing areas of the Earth affected by particles, X-ray photos and electrojet currents, for use in configuring systems and operations vulnerable to space weather. These include satellite, electronic navigation systems, and electric power grids. Complete records of past events so that planners and system designers know what they must design to in order to mitigate or minimize future storm impacts
Scientific and technical staff in monitoring and advisory organizations (e.g., forecasters)	Real time access to data including solar x-ray flare information, solar energetic particle events, geomagnetic fields, solar x-ray, white-light, and coronal imagery, solar magnetograms, interplanetary particles and fields, energetic particles at GEO and LEO, magnetic field at GEO, Solar radio data, ground based geomagnetic field data, neutron monitors.	Same as above Historical data for all of the records described. Predictive space weather models
Research scientists	Capture & archive all data in high temporal and spatial resolution.	Same as above including complete metadata Archives of real-time data for model testing and development

APPENDIX 2. REQUIRED OBSERVATIONS for INDIVIDUAL HAZARDS

Table 2a. REQUIRED OBSERVATIONS for WILDLAND FIRE

Required Observations	Ground based systems	Airborne	Satellite sensors	Gaps	Comments
Terrain features—topography, rivers, lakes, etc.				High-resolution DEMs mostly lacking	DEM's at best available resolution. Base layer for multiple purposes listed below.
Infrastructure (roads, homes, etc.)—protection, access, evaluation of social/economic values at risk.	Map products; census data bases	Valuable where other data are not available	DMSP—city lights; high resolution imagery such as IKONOS		For incident response, planning, monitoring changes over time
Vegetation at scales of 30-m or better	Intensive ground-based (plot) sampling to characterize vegetation and link with remote sensing data		Landsat, ASTER or higher - resolution panchromatic or multispectral imagery	Landsat availability impaired Hyperspectral scarce	Hyperspectral helps characterize, discriminate vegetation types
Fuel structural characteristics at scales of 30-m or better	Intensive ground-based (plot) sampling to characterize fuels and link with remote sensing data	Waveform or multi-return LIDAR to help characterize vertical and horizontal structure of fuel layers	Landsat, ASTER or higher - resolution panchromatic or multispectral imagery to develop regional to national-scale products	Landsat availability impaired Vegetation-penetrating SAR (L-band) not available	Necessary input data for fire behavior models, fire incident response, and prescribed fire planning
Fuel condition (seasonal and year to year changes in fuel moisture, fuel loads, etc.) –30-m to 250-m resolution	Intensive ground-based (plot) sampling to link with remote sensing data and biophysical models	Some potential for radar?	Landsat, ASTER, MODIS, or higher-resolution panchromatic or multispectral imagery	Landsat availability impaired	Necessary input data for fire behavior models, fire incident response, and prescribed fire planning
Active fire detection-Within 15 minutes of ignition for populated areas to within several to 24 hours in remote areas	Field validation of methods is critical to improve algorithms, maximize detections, and minimize false alarms. Almost all of current detection is ground-based.	Fire detection flights - spotters and thermal sensors, commercial and general aviation reports	Geostationary satellites for short time frames; AVHRR, MODIS, ASTER, others for regional views at longer time frames.	Satellite systems lack spatial and temporal resolutions necessary for rapid detection. Means of rapid transmission of reports also lacking. Fire channel (3.96 microns) lacking on NPOESS	Current fire detection in the US is very good. Satellites most promising for detection in remote areas, at night, and as a confirming validation of public reports.
Active fire monitoring and mapping—several meter to 1-km resolution. Multiple times per day; rapid data analysis and transmission to the field are critical	Field validation requires a combination of ground based sampling during and after fires. Once validated, aircraft data can be used to validate satellite data and algorithms.	Variety of aircraft based thermal sensors are available. Systems that produce high-resolution unsaturated images with large area coverage and MWIR and LWIR bands are desirable. Must be georectified to meet operational needs	AVHRR, MODIS, useful for strategic information on multiple fires, but lack detail required for tactical firefighting on individual incidents.	Not enough appropriate aircraft sensors available, adequate validation lacking Need faster communication, data analysis and transmission. Need detectors that will not saturate, including in daytime	Current suite of satellite sensors do not have high resolution (15 meter or better) thermal bands. Ideal configurations would have both MWIR and LWIR capabilities. Cloud cover and dense smoke can inhibit observations
Fire scar mapping—100-m to 1-km resolution	Ground-based sampling for field validation		Landsat, SPOT or higher resolution commercial satellites for small fires and for validation of observations from MODIS etc. for larger fires	Landsat impaired or lacking from 2004-2010, if only Landsat follow-on is part of NPOESS	May need a combination of active fire products and pre and post fire products due to rapid recovery of vegetation after some fires and problems obtaining cloud-free images

Required Observations	**Ground based systems**	**Airborne**	**Satellite sensors**	**Gaps**	**Comments**
Fire Severity mapping—critical for post fire response and for estimating emissions and ecosystem impacts.	Ground-based sampling of fuel consumption, soils, and fire effects for determination of burn severity. Also, field validation of methods in a range of fuel types	Various airborne color infrared digital sensors are available for use. Spatial resolution tends to be more resolute than required for the airborne reflectance product.	Same as above. VIS/NIR essential. SWIR band beneficial for smoke penetration and rock/bare soil identification.	Satellite revisit times (14 days for Landsat) are too long. Additional bands needed.	Rapid response severity maps are needed for decision-making on post-fire emergency rehabilitation of burned areas. Evaluation of effects on vegetation and carbon cycling can be accomplished with lower data frequency.
Smoke from wildland fire	Ground-based sampling of smoke chemistry and aerosols; observations of regional haze	Aircraft-based sampling of smoke plumes and regional haze; smoke and aerosol chemistry in plumes; optical measurements of haze, particulate (aerosol) densities, distributions.	Observations of smoke plumes and inversion layers from AVHRR, MODIS, etc. Atmospheric soundings	Moderate to high-resolution satellite revisit times too long to be of use	
High-resolution weather data (0.1-1 km) for fire behavior, smoke predictions: wind fields; vertical soundings	Current Remote Area Weather Systems (RAWS) deployed to measure fire weather. Individual reports made at each incident.				
Moderate resolution weather data (20-100's km)—temperatures, dew point/humidity, precipitation, winds	Ground-based weather networks; data need to be accessible, compiled into regional/national/global data bases		AVHRR, TOVS?? Linked to MM-5 and other weather models		
Medium to long-term regional weather forecasts—eg based on sea surface temperature models					Strategic planning for fire and fuels management and fire suppression resources-
1-7 (14) day regional and local forecasts					Tactical planning for fire suppression, prescribed fire, etc.
Streamflow and water quality	Surface monitoring networks—stream and precipitation gages, weather radar		Weather observations and predictions		Prediction and modeling of hydrologic response to fires—flooding, sedimentation, impacts on water quality, etc.

Table 2b. REQUIRED OBSERVATIONS for EARTHQUAKE HAZARDS

Required Observations	Ground based systems	Airborne	Satellite sensors	Gaps	Comments
Monitor seismicity nationwide to magnitude 3.0, to magnitude 2.0 in seismically active areas	National and regional scale seismic networks			Needs upgrading and expansion under Advanced National Seismic System (ANSS) Plan (10% complete)	ANSS is an effort to expand and modernize earthquake monitoring nationwide. Current appropriations are10% of authorized level.
Monitor strong ground shaking in all urban areas subject to moderate to high earthquake risk	Dense seismic networks (with high dynamic range seismometers, also known as "strong-motion detectors")			Needs upgrading and expansion under Advanced National Seismic System (ANSS) Plan (10% complete)	See above.
Monitor response of critical facilities, and of typical buildings of different classes of construction in urban areas subject to moderate to high earthquake risk	Seismic instruments in critical facilities and in typical buildings			Needs upgrading and expansion under Advanced National Seismic System (ANSS) Plan (10% complete)	See above.
High-resolution topographic mapping in seismically active areas		Comprehensive LIDAR surveys or stereo aerial photography		Availability of high-resolution DEMs is limited	
Detailed geologic mapping in seismically active areas for slip and recurrence rate	Comprehensive ground-based mapping at scales of 1:5000 to 1:12,000	Low-level aerial photography	Moderate to high resolution panchromatic or multispectral imagery	.	Geologic studies of fault zones (paleoseismology) indicate past earthquake activity – necessary to forecast future activity.
Detailed mapping of surficial deposits in urban areas subject to moderate to high earthquake risk	Comprehensive ground-based mapping at scales of 1:5000 to 1:12,000	Low-level aerial photography	Moderate to high resolution panchromatic or multispectral imagery		Surface studies are needed to determine the amplification of ground shaking due to local soil and rock conditions.
High-resolution deformation monitoring in seismically active areas	Comprehensive GPS networks and surveys		GPS satellites SAR imagery for InSAR	SAR data stream limited	GPS networks to be expanded under Earthscope (PBO)

Required Observations	Ground based systems	Airborne	Satellite sensors	Gaps	Comments
Strain and slow movement (creep) measurements along active faults and near fault zones	Arrays of creep meters, dilatometers and tensor strain meters		SAR imagery for InSAR	SAR data stream limited	Wider installation of tensor strain meters under Earthscope (PBO)
Ground water levels and water chemistry measurements along active faults and near fault zones	Extensive instrumentation of fault zones, including water well monitors				Case studies for specific fault zones are needed to build up earthquake forecasting and prediction experience and credibility.
High-resolution measurements of the Earth's gravity, magnetic and electric fields along active faults and near fault zones	Campaign surveys of established networks, using gravimeters, etc.	Airborne surveys at various scales	GRACE (regional scale gravity anomalies)		
Determine soil or rock strength parameters and physical properties of near-surface materials in and near fault zones	Field reconnaissance and sampling; laboratory testing of materials				
Deep (2-10 km) physical measurements of the material and physical properties of fault zones	Drilling, direct sampling and down-hole measurements				SAFOD/EarthScope will provide first deep fault samples.

Table 2c. REQUIRED OBSERVATIONS for VOLCANO HAZARDS

Required Observations	Ground based systems	Airborne	Satellite sensors	Gaps	Comments
Characterize seismicity of volcano(es) or group of volcanoes [magnitude, 3-D location, type of earthquake(s)]	Individual volcanoes require 3-6 seismometers, to detect and locate quakes of $M \leq 0.5$; data relayed and processed in real time			Many high-threat volcanoes unmonitored or under-monitored	Upgrades (additional short period, 3-component instruments needed at all volcanoes with minimal or no seismic networks. More broadband seismometers desirable
Monitor deformation of volcanic edifice (horizontal, vertical and tilt)	GPS networks and/or EDM, leveling and tilt monitoring networks Borehole strainmeters (continuous recording)		SAR interferometry (frequency determined by level of volcano's activity)	Most high-threat volcanoes are not actively monitored for deformation C-band SAR data stream inadequate to monitor all volcanoes of interest; L-band SAR completely lacking	Continuous recording and relay of in-situ data desirable.
Monitor changes in local gravity	Gravimeter surveys (every 1-5 years, more frequently if volcano actively deforming)				Gravity surveys sporadic, local
Characterize gas emissions of volcano(es) by species (SO2 and CO2) and flux (tons per day)	COSPEC, LICOR surveys at regular intervals (days, weeks, months) – fixed stations or vehicle mounted FTIR measurements, direct sampling of gases	COSPEC, LICOR surveys at regular intervals – helicopter or fixed-wing aircraft	Regular checks of satellite imagery with appropriate IR bands (7.3, 8.3 microns) at moderate resolution	Few active volcanoes routinely monitored Appropriate imagery (ASTER) scarce, no successor mission known.	This requirement is for near-surface and tropospheric gas plumes. New, small, cheap instruments (FLYSPEC, MiniDOAS) would facilitate SO2 monitoring
Characterize local thermal features of volcanoes (nature, number, location, temperature)	Field observations, plus use of thermocouples, visible and IR pyrometers (fixed stations or portable), with measurements taken at hot springs, fumaroles, crater lakes, fissure systems	High-resolution imagery obtainable with digital IR cameras – helicopter or fixed-wing Moderate resolution airborne IR imagery (TIMS)	Moderate-resolution (Landsat, ASTER) imagery may allow recognition of larger features	Landsat 7 impaired; no successor to ASTER identifiable	Thermal IR bands critical for active hazard mapping. Needed resolution not possible in most satellite imagery
Monitor volcanoes for hot spots (eruptions) or changes in regional heat flux			IR imagery from meteorological satellites (GOES, MODIS)	NPOESS lacks the 3.96 micron channel, will saturate in daylight, preventing hotspot detection	Global coverage with MODIS. Interference from clouds common.

Required Observations	Ground based systems	Airborne	Satellite sensors	Gaps	Comments
Monitor, characterize and document eruptions in real time. Detect and monitor explosions, eruption columns. Determine speed, direction, thickness of flows, lahars or other deposits, areas covered and threatened.	Documentation includes video, visible/ IR photography; sampling in real time. Doppler radar,to assess eruption column height and density; cloud-to-cloud lightning detectors useful Acoustic flow monitors (lahar detection)	Document eruptions, including eruption columns and plumes, plus all surficial deposits using overflights to get visible and IR photography, video, etc.)	Documentation may use moderate-resolution multispectral satellite imagery as available	Deployment of specialized systems (Doppler radar, acoustic flow monitors) very limited	High-resolution commercial imagery may also be available
Detect and monitor high-altitude volcanic ash clouds and aerosol plumes			Meteorological satellites (geostationary, polar-orbiting) plus TOMS, MODIS	Split-window (separate 10.5 and 12 micron bands) lacking on some satellites	Especially useful after cloud has moved away from the source volcano
Monitor precipitation	Rain gages, Doppler radar		Meteorological satellites		Affects probability of lahar formation during eruption
Monitor wind at range of altitudes		Radiosondes, profilers	Meteorological satellites		Models required: VAFTAD, PUFF
Monitor atmospheric moisture content	Ground based radar/LIDAR	Radiosondes	Meteorological satellites, microwave sensor (AMSU)		Needed to correct ash cloud detection in tropical regions
Acquire baseline topography of volcano(es)		Aerial photography (stereo), LiDAR	DEMs from SRTM or ASTER imagery	Data still not processed or released for many active volcanoes	
Make geologic and structural maps of volcano(es), in order to characterize eruptive style and eruptive history of volcano(es). Update as necessary	Characterize, map and date all young (especially <10,000 years BP) eruptive deposits	Aerial photography, AVIRIS surveys	Moderate-resolution multispectral imagery	Landsat 7 impaired; no successor to ASTER identifiable	Includes inventory of ground cracks, so that new cracking or changes can be recognized.

Table 2d. REQUIRED OBSERVATIONS for LANDSLIDE HAZARDS

Required Observations	Ground based systems	Airborne	Satellite sensors	Gaps	Comments
Detect and monitor slope movement rate and depth with high accuracy and frequency (horizontal and vertical)	Extensometers, inclinometers, or GPS networks	Temporally document slope movement with helicopter or fixed-wing overflights to get low level, large scale stereo aerial photography	SAR interferometry at various wavelengths, at appropriate time intervals	SAR data stream limited, specific tasking usually required	Changing rates of movement often indicate whether a landslide may stop or accelerate to catastrophic movement
Prepare high-resolution topographic mapping of slopes in areas of high landslide susceptibility including elevation, slope angle, curvature	Detailed GPS field surveys	High quality DEMs from LiDAR surveys or stereo aerial photography	High resolution satellite imagery, updated as necessary	Availability of DEMs limited	
Determine soil or rock strength parameters and physical properties in areas of instability (including fracture and rock-joint orientation and spacing)	Field reconnaissance and sampling, including drilling for subsurface samples; laboratory testing				Slope stability models require detailed data on topography, depth, material strength values, pore-water pressure and joint fracture discontinuities
Monitor weather data, including amount, intensity, and duration of precipitation and temperature	Regional rain gage networks to confirm remote sensing data; Doppler radar for very localized, short interval rainfall data		Meteorological satellites (GOES)	Spatial and temporal resolution of rainfall data not always adequate for landslide forecasting	Thresholds for triggering landslides based on rainfall intensity and duration have been developed for some regions around the world
Monitor seismicity in areas of high landslide susceptibility	Dense seismic networks (with high dynamic range seismometers)				Forecasting possible landslide movement based on seismological data and dynamic landslide models
Monitor groundwater level and pore pressure	Piezometers, tensiometers, well monitors				Subsurface-water conditions constitute a major factor in slope instability and rates of landslide movement
Monitor stream flow	Stream gages				

Required Observations	Ground based systems	Airborne	Satellite sensors	Gaps	Comments
Monitor soil moisture	Piezometers and tensiometers		Infrared imagery to detect variation in temporal and spatial ground surface moisture	No passive microwave available	Subsurface-water conditions constitute a major factor in slope instability and rates of landslide movement
Document the distribution, kinds, and magnitudes of landslides that result from a major storm, earthquake or other landslide-triggering event	Field reconnaissance including subsurface drilling to determine depth of sliding and variation in materials	Low-altitude, large scale (1:5000-1:12,000) aerial photography as soon as possible after the landslides occur	High resolution satellite imagery		Documenting actual events forms a basis for testing forecasts and hazard maps, and extending the capabilities of empirical and analytical predictive tools or methods

Table 2e. REQUIRED OBSERVATIONS for FLOOD HAZARDS

Required Observations	Ground based systems	Airborne	Satellite sensors	Gap	Comments
Stage, Discharge and Volume	Stream gages and direct flow measurements with hydroacoustics		Retrievals (GOES DCP) Radar altimetry	Shortage of stream gages. The total number has been reduced significantly over the past decade	Stage and discharge relationships are needed to construct rating curves; need more hydroacoustics training
Inundation area	Ground surveys, GPS	Aerial photography	SAR imagery, visible and IR imagery if area is cloud-free	SAR data stream inadequate; multidimensional modeling capability inadequate	SAR provides all-weather imaging; flow models could provide real-time data on flooding characteristics
Topography	Surveys, GPS	Aerial photography, LiDAR surveys	SRTM, ASTER for DEMs	Surveys not done often enough to document changes in topography, especially in urban areas	Critical to flood forecast and warning operations.
Soil moisture	Ground stations		Passive microwave	Shortage of soil moisture monitoring sites. No passive microwave sensors available	Supports flood forecast and warning capabilities. The lack of reporting locations impacts both flood and drought monitoring.
Precipitation	Buoys, ground stations, Doppler radar (polarized), profilers, sub-millimeter radars, mesonets	IR, radar, SFMR rain, in situ, microwave radiometers	Microwave, radar (TRMM/PR) Retrievals (GOES DCP	Spatial distribution is not sufficient to adequately support all operational activities of the hydrologic community	Microwave resolution limited but not cloud limited. Polarized radar, profilers and Millimeter radars are experimental.
Snowmelt monitoring: includes snow cover, depth, and liquid water equivalent, air temperature and humidity, wind speed snowpack, and solar influx	Surface measurements	Aerial snow surveys	Retrievals (GOES DCP) Visible, IR Imagery Imager/Radiometer	Not enough reporting sites.	Information critical to river stage and inundation forecasts as well as addressing water resource management during drought periods.

Required Observations	Ground based systems	Airborne	Satellite sensors	Gap	Comments
Observe snow properties: cover extent, depth, wetness, temperature	Surface based measurements	aerial snow surveys	Visible IR Imagery Imager/Radiometer	Not enough reporting sites.	
Observe frozen –soil Properties: soil moisture prior to Winter freezing, freezing depth, soil temperature	Surface based measurements		Visible IR Imagery Imager/Radiometer	Not enough reporting sites.	
Observe river ice and lake ice properties: location, thickness		aerial snow surveys	Visible IR Imagery Imager/Radiometer	Not enough reporting sites.	
Observe ice-breakup in rivers and lakes, and ice jams in rivers	Stream gages	Aerial snow surveys	Visible IR Imagery Imager/Radiometer	Not enough reporting sites. Stream gages destroyed in major ice jam events.	

Table 2f. REQUIRED OBSERVATIONS for EXTREME WEATHER HAZARDS

Required Observations	**Ground based systems**	**Airborne**	**Satellite**	**Gaps**	**Comments**
Moisture	Surface stations Radiosondes GPS systems Lidar Microwave and interferometer systems	ACARS (AMDAR, MDCRS & TAMDAR) Flight level hygrometer Radar Dropsondes DIAL	Microwave sounder DPI Retrievals	Surface mesonet with horizontal grid spacing of 25 km and 10 km in many regions. Four dimensional moisture fields in the vertical (includes fluxes). Critical in the boundary layer (variable thickness of 3-5 km). Horizontal spacing 25 km for vertical measurements	Lidars, microwave and interferometer experimental systems are experimental. GPS systems are coming on line.
Wind	Surface stations Radiosondes Buoys Doppler radar Wind profilers Doppler lidar	ACARS (AMDAR, MDCRS & TAMDAR) Doppler radar Flight level pressure/wind UAVs Driftsondes Dropwindsondes	Cloud and vapor tracking winds QuikSCAT Lidar winds	Surface mesonet with 25 km horizontal grid nationally, and 10 km in many regions. Wind in boundary layer for both moisture flux and wind shear. Horizontal grid spacing of 3-5 km in boundary layer.	Doppler lidars, UAVs, Driftsondes and wind profilers are experimental instruments and would require development and considerable investment before operational deployment
Atmospheric Temperature	Surface stations Radiosondes Surface IR	ACARS (AMDAR, MDCRS & TAMDAR) Flight level temperature Dropsondes	IR sounder	Surface mesonet. 25 km grid nationally, and 10 km in many regions. Microwave sounders on satellites to penetrate clouds.	RASS is experimental and most useful for atmospheric boundary layer temperature profiles.
Ground surface: Heat & Moisture Content	Ground surface measurements Below ground profiles	Passive microwave IR	Passive microwave IR	Long term measurements of sub-surface temperature and moisture.	Ground surface temperature and moisture are critical to drought monitoring
Airmass differences /Boundaries (e.g. Cloud Fields)	Surface stations Doppler radar	Doppler radar	GOES Imagery	Doppler radar to view more of the boundary layer (i.e. lower antenna elevation angles and gap fillers)	

Required Observations	Ground based systems	Airborne	Satellite	Gaps	Comments
Synoptic/Sub-synoptic flow fields (e.g., extratropical cyclones, shortwave troughs, etc)	Radiosondes Surface stations Doppler radar	ACARS (AMDAR, MDCRS & TAMDAR) Doppler radar Dropwindsondes	GOES Imagery	Doppler radar coverage for events such as bow echo, gust fronts, and demarcation of precipitation types (liquid, freezing, frozen).	
Precipitation	Doppler radar Surface stations Lightning network Surface mesonets including the cooperative network	Radar Cloud physical properties and liquid water determinations SFMR rain (over water)	Infrared (e.g. wet vs. dry ground)	Surface mesonet with horizontal grid spacing of 25 km nationally and 10 km in many regions. Measurements of snow and water equivalent. Indications of type of precipitation. Ice accumulation.	
Stream Flow	Stream gauges			Recording and transmitting gages on secondary watersheds.	Comprehensive assessments recently conducted by ACWI Stream Gauge Task Force http://water.usgs.gov/wicp/acwi/streams/ http://water.usgs.gov/wicp/acwi/streams/minutes/StreamTF-Rpt.html
Snow (aerial coverage, depth and water equivalent)	Surface Stations	Snow survey aircraft	GOES Imagery	Snow depth and water equivalent	

Table 2g. REQUIRED OBSERVATIONS for TROPICAL CYCLONE HAZARDS

Required Observations	Ground based systems	Airborne	Satellite	Gaps	Comments
	Tropical	**Cyclone**	**Envirommment**		
Moisture	Rawinsondes Surface stations GPS-met	ACARS Flight level hygrometer Radar Dropsondes	Microwave radiometers (AMSU, AMSR) Interferometers	Four dimensional moisture fields at all levels from the surface to the tropopause in vertical increments of 100 meters and areal grids of 100 km.	GPS-met and satellite interferometers need development. Volumetric measurements of radars and other indirect sensors need to be integrated.
Wind	Radiosondes Buoys Surface stations (ASOS, C-MAN) Doppler radar (WSR-88D)	Doppler radar, LiDAR Dropwindsonde Flight level pressure/wind Scatterometers Stepped frequency radiometer (SFMR)	Cloud and vapor Microwave radiometers Scatterometers Lidar winds	Four dimensional wind fields, including wind shear and for determining moisture flux. Vertical increments of 100 meters and horizontal grids of 100 km.	Satellite and airborne Doppler lidar needs development. Airborne system development supported by the NOAA G-IV aircraft upgrade.
Atmospheric Temperature	Rawindsondes Buoys Surface stations	ACARS Flight level temperature Dropsondes	IR and microwave radiometers Interferometers	Vertical increments of 100 meters and horizontal grids of 100 km.	Satellite interferometers need development.
Ocean Temperature and Heat Content	XBTs/drifters Buoys	AXBT AXCP, AXCTD Drifters, Microwave radiometers	IR radiomenters Altimetry Microwave radiometers	Microwave for sea surface temperatures and altimetry for heat content.	
Sea State	Buoys Tide gages	Visual Scanning radar altimeter (SRA) SFMR	SAR Microwave radiometers	Buoy network along Gulf and Atlantic Coasts. Sea state in tropical cyclone environment.	
	Tropical	**Cyclone**	**Core**		

Required Observations	**Ground based systems**	**Airborne**	**Satellite**	**Gaps**	**Comments**
Moisture	Rawinsondes GPS-met ACARS Surface stations Buoys	Dropsondes ACARS Microwave radiometry Flight level hygrometer Interferometry DIAL	Microwave radiometry Interferometry	Moisture measurements in the core: 100 meter height and 10-20 km horizontal resolution.	GPS-met and airborne/satellite interferometers need development. DIAL needs development – NASA has flown LASE in TCs.
Wind	Doppler radar Buoys Surface stations Rawsinsondes	Doppler radar, LiDAR Flight level pressure/wind Dropwindsondes Scatterometer SFMR	Scatterometer SAR, Cloud drift Microwave radiometers	SAR data stream inadequate 3 dimensional wind structure (0.5-1km horizontal resolution and 100 meter height resolution) is not available.	Airborne Doppler lidar needs development and is supported by the NOAA G-IV aircraft upgrade.
Atmospheric Temperature	Rawinsondes ACARS Surface stations Buoys	Dropsondes ACARS IR Interferometry Flight level temperature Microwave radiometry	IR Microwave radiometry Interferometry	Need 100 meter height and 10-20 km horizontal resolution. Especially important for verification.	Airborne/satellite interferometers need development.
Ocean Temperature and Heat Content	Drifters XBTs Buoys	AXBT AXCP, AXCTD Drifters Microwave radiometers	Altimetry IR Microwave radiometers	Sea spray and sea state measurements. 20 m resolution in the ocean mixed layer. Ocean waves and currents with at least a radial structure of 20-50 km.	
Precipitation	Ground stations (gages) Radar (polarized) Buoys Profilers Sub-millimeter radars	Cloud physical properties and liquid water determinations Radar, IR SFMR rain Microwave radiometers	Microwave radiometers Radar (TRMM/PR) IR	Precipitation rate and amount in the core.	Microwave may be resolution limited but not cloud limited. Polarized radar, profilers and millimeter radars are experimental.

Table 2h. REQUIRED OBSERVATIONS for ICE HAZARDS

Required Observations	Ground/water based systems	Airborne	Satellite sensors	Gaps	Comments
Observe edge (extent of the ice coverage) of pack ice or fast ice in lakes, ports and other coastal areas and over the polar and sub-polar seas.	Land and marine observations, visual hull mounted radar systems	Side looking airborne radar (SLAR) or Synthetic Aperture Radar (SAR). Visual reconnaissance	Visible (optical), Infrared, SAR, Scatterometer and Passive Microwave	High-resolution SAR imagery with global coverage able to image ice features at the 30-100 meter scale or commercial imagery	Safety of navigation, search and rescue and military operations
Observe concentration (fraction of area covered) of ice pack or fast ice in lakes, ports and other coastal areas and over the polar and sub-polar seas.	Land and marine observations, visual or hull mounted radar systems	SLAR or SAR. Visual airborne reconnaissance	Visible (optical), Infrared, SAR, Scatterometer and Passive Microwave	As above	As above. To determine paths for easier navigation in the ice or areas for submarines to surface through ice.
Observe thickness of the ice pack or fast ice in areas as above. Stage of development or age of the ice is often a proxy for ice thickness.	Land and marine observations, plus taking physical measurements of the ice thickness (ice cores)	Radar altimeter or laser profiler. Visual airborne reconnaissance	Radar altimeter, laser profiler, plus visible, IR, SAR, Scatterometer and passive microwave	Radar altimeter and high-resolution SAR imagery with global coverage able to image ice features at the 30-100 meter scale or commercial imagery	As above
Observe the optimal conditions for the breakup of landfast and river ice	Land and marine observations, visual or hull mounted radar	SLAR or SAR . Visual airborne reconnaissance	Visible , IR, SAR, Scatterometer and Passive Microwave	High-resolution SAR imagery with global coverage able to image ice features at the 30-100 meter scale or commercial imagery	Safety of the public and organizations using the fast ice for hunting, fishing, transportation and other subsistence or recreational activities or for commercial activities.
Characterize form and topography of the ice. Includes shear zones, ridges, hummocks, the occurrence and orientations of leads, large fractures or polynyas	Land and marine observations, visual or hull mounted radar	SLAR or SAR. Visual airborne reconnaissance	Visible , IR, SAR, Scatterometer and Passive Microwave	As above	To determine paths for easier navigation in the ice or areas for submarines to surface through the ice.
Observe the stage of decay during the summer melt season	Land and marine observations, visual or hull mounted radar	Visual airborne reconnaissance	Visible, IR, SAR	As above	As above.

Required Observations	Ground/water based systems	Airborne	Satellite sensors	Gaps	Comments
Observe the presence of icebergs, bergy bits and growlers (ice of land origin)	Ship observations	Visual reconnaissance, forward looking radar, SLAR, Forward Looking Infrared (FLIR/IRDS)	SAR, visible and IR imagery	As above	Icebergs and free floating "floebergs" composed of old ice are a serious hazard to marine navigation and structures
Observe the motion of the sea ice and ice of land origin	Buoys dropped onto the ice or moored in the ice capable of real-time satellite communications		Passive microwave (Ex. SSM/I 85 Ghz) or SAR imagery	Global coverage of SAR, high-resolution imagery lacking; insufficient buoy coverage in Arctic and Antarctic waters	Estimate position of ice during periods of darkness or cloud cover, to forecast the position, convergence and divergence of ice
Observe surface temperature of sea ice	Buoys dropped onto the ice or moored in the ice capable of real-time satellite communications		Infrared and passive microwave imagery	Insufficient buoy coverage in Arctic and Antarctic waters	Aids in evaluation of ice thickness and especially icebergs
Observe sea surface temperature	Drifting buoy and ship observations		Infrared imagery	In-sufficient buoy coverage in Arctic and Antarctic waters	Allows for the identification of new ice formation and the onset of the melt season
Observe air temperature above the ice	Drifting buoys			Insufficient buoy coverage in Arctic and Antarctic waters	Aids in the determination of the onset of the freeze-up and melt season
Waves, heights and patterns	Buoys, CODAR		SAR and scatterometer imagery	Buoys give insufficient spatial resolution near shore. Insufficient buoy coverage in Arctic and Antarctic waters	
Currents	Buoys (e.g. with ADCP), CODAR		Altimeter	Buoys give insufficient spatial resolution near shore	Altimeter may be of limited use in coastal regions. Currents are a factor in sea ice motion and drive iceberg drift
Winds	Land and marine anemometers (e.g. buoys, CMAN stations, coastal wind profiler)		Scatterometer (QuickScat) + SAR imagery	Buoys give insufficient spatial resolution near shore. Insufficient buoy coverage over the polar seas	Winds are a factor in iceberg motion and drive pack ice motion

Table 2i. OBSERVATIONAL REQUIREMENTS for COASTAL HAZARDS, INCLUDING TSUNAMI

Required Observations	Ground/water based systems	Airborne	Satellite sensors	Gaps	Comments
Coastal high-resolution topography with 5-10 year revisit		Topographic LIDAR, InSAR	SRTM 30-m data	High-resolution topography does not exist for most coastal areas.	For storm surge, tsunami modeling, erosion evaluation. SRTM 30-m best available globally
Shallow water bathymetry with 5-10 year revisit; navigational obstructions	Ship surveys (e.g. multibeam)	Bathymetric LIDAR		Many areas not surveyed for over 50 years. Ability to determine bathymetry in turbid water is lacking	For storm surge, tsunami modeling, navigational hazards
Waves, heights and patterns, wave spectra	Buoys, coastal radar		SAR imagery	Buoys give insufficient spatial resolution near shore	
Tides/water levels, inundation patterns during storm surge, floods, tsunami	Tide gauges, river gauges		SAR imagery	Water level measurement methods outmoded; gage network inadequate; SAR data stream inadequate	Need normal (predicted) tide levels for comparison, inundation forecasting
Currents	Buoys (e.g. with ADCP), coastal radar		Radar altimeter	Buoys give insufficient spatial resolution near shore	Altimeter may be of limited use in coastal regions
Surface winds	Land and marine anemometers (e.g. buoys, CMAN stations, coastal wind profiler)		Scatterometer (QuickScat) + offshore SAR imagery	Buoys give insufficient spatial resolution near shore SAR data stream inadequate	
Earthquake information to evaluate location and likelihood of tsunami generation	Seismic networks, notification systems				
Deformation/subsidence of coastal areas			SAR/InSAR	Need GPS networks in coastal areas, more SAR including L-band SAR	
Deep-Ocean Assessment and Reporting of Tsunami to detect tsunami	DART buoy system		DART data transmitted via GOES satellites		Buoys relay data, to confirm/deny existence of inferred tsunami
Post-event damage assessment	Visits, interviews, photographic documentation	Aerial photography	High-resolution satellite imagery		

Table 2j. REQUIRED OBSERVATIONS for POLLUTION EVENTS

Required Observations	Ground based systems	Airborne	Satellite sensors	Gaps	Comments
Characterize chemical(s) or compounds released into the water (ie oil spills, chemicals)	TOC analyzers, electomagnetic absorption monitors, electrical conductivity and pH, direct sampling of liquids by AA, MS, Ion chromotography	SAR, hyperspectral sensors, UV sensors, aerial photography in fixed wing, helicopter platforms or UAV	SAR, hyperspectral sensors, high spatial resolution systems	satellite revisit times often preclude frequent observations, spatial resolution of spaceborne SAR	
Characterize chemical(s) or compound(s) released into the air	Open-path FTIR measurements, direct sampling of gases by OVA, GC/MS, remote passive monitors (selective filters), LiDAR	thermal or LWIR hyperspectral sensors, airborne FTIR, direct gas sampling via UAVs, LiDAR	hyperspectral and LWIR multispectral sensors (ie MODIS, DOE MTI)	no space-based LWIR hyperspectral sensor	
Characterize chemical(s) or compound(s) released on the land	direct soil sampling with GC/MS,	thermal or LWIR hyperspectral sensors, airborne FTIR,	hyperspectral and LWIR multispectral sensors (ie MODIS, DOE MTI), high spatial resolution sensors		
Characterize affected area to determine populations at risk to exposure	GIS base data of population centers, infrastructure,	aerial photography, archived and current (to determine changes), multispectral and hyperspectral sensors. Sensor platforms on fixed wing, helicopter or UAV	SAR, hyperspectral and LWIR multispectral sensors (ie MODIS, DOE MTI), high spatial resolution sensors		
Monitor affected area	active and passive monitors	long-dwell or loitering sensor plaforms (blimps, UAVs)	high temporal resolution imagery, continiously tasked collections for high spatial resolution systems		weather can prevent imagery acquisitions

Table 2k. REQUIRED OBSERVATIONS for SPACE WEATHER

Required Observations	Ground based systems	Airborne	Satellite sensors	Gaps	Comments
Solar X-ray imagery and fluxes			GOES solar X-ray imager GOES X-ray sensor		
Solar coronal observations			SOHO LASCO	Presently relying on NASA spacecraft for coronal imagery. A coronagraph is critical, yet no follow-on has been approved.	Coronagraphs important and effective for providing 1 to 4 day forecasts of major space weather storms
Solar white-light images Solar radio emissions	SOON sites				
Solar Magnetograms	Major solar telescopes		SOHO MDI	Neither ground-based or space-based data sources are operational.	
Solar Wind: Electrons and protons, magnetic fields	High latitude riometers		NASA Advanced Composition Explorer (ACE)	Presently relying on NASA spacecraft for solar wind data. No follow-on solar wind monitor mission has been approved.	Solar wind monitors have proven to be one of the most important and effective instruments for providing 30 minute forecasts of major space weather storms
GEO energetic particles and magnetic fields			GOES space environment monitor (SEM)		
LEO energetic particles			POES SEM		
Global geomagnetic field	Several magnetometer networks			Most magnetometers are non-operational (not supported 24/7). Most magnetometer data are not provided in real-time	Data are supplied through interagency and international agreements
Ground base neutron flux	Neutron monitors				

APPENDIX 3. GLOSSARY of ACRONYMS and NAMES

ACARS – AIRINC Communications Addressing and Reporting System (commercial aircraft data system)

ADCP – acoustic doppler current profiler

AMDAR – Aircraft Meteorological Data Relay

AMSR – Advanced Microwave Scanning Radiometer (satellite)

AMSU – Advanced Microwave Sounding Unit (satellite)

ANSS – Advanced National Seismic System

ASOS – Automated Surface Observing System

ASTER – Advanced Spaceborne Thermal Emission and Reflection Radiometer

AVHRR – Advanced Very High Resolution Radiometer

AVIRIS – Airborne Visible-Infrared Imaging Spectrometer

AXBT – Airborne Expendable Temperature (ocean)

AXCP – Airborne Expendable Current Probe

AXCTD – Airborne Expendable Conductivity Temperature Depth

CENR -- Committee for Environmental and Natural Resources

CEOS – Committee on Earth Observation Satellites

C-MAN – Coastal-Marine Automated Network

COSPEC – Correlation Spectrometer (to detect SO2)

DEM – Digital Elevation Model

DIAL– Differential Absorption Lidar

DMSP – Defense Meterological Satellite Program

DPI – Derived Product Imagery

EDM – Electronic Distance Measurement

ESA – European Space Agency

FTIR – Fourier Tranform InfraRed

GEO – Group on Earth Observations (producer of GEOSS reports)

GEOSS – Global Earth Observation System of Systems

GOES – Geostationary Operational Environmental Satellite

GPS -- Global Positioning System

IEOS – Integrated Earth Observation System (the U.S. component of GEO and GEOSS)

IGOS – Integrated Global Observing Strategy

IHO– International Hydrographic Office

Ikonos – high-resolution commercial satellite (not an acronym)

InSAR – Interferometric Synthetic Aperture Radar

IR -- Infra Red (spectrum); also Infrared Radiometer
LASCO – Large Angle Spectrometric Coronagraph
LEO — Low Earth Orbit
LICOR – small infrared analyser for CO2 (brand name)
LIDAR – LIght Detection And Ranging
LWIR – Long Wave Infra Red
MDCRS – Meteorological Data Collecting and Reporting System (commercial aircraft)
MDI – Michelson Doppler Imager
MODIS – Moderate Resolution Imaging Spectrometer
MWIR – Mid Wave Infra Red
NESDIS – National Environmental Satellite, Data and Information Service
NIR– Near Infra Red
PBO – Plate Boundary Observatory, a component of Earthscope
PUFF – high-resolution volcanic ash tracking model (not an acronym)
QuikSCAT-- Quick Scatterometer
RASS – Radio Acoustic Sounding System
RMSE -- root mean square error
SAFOD – San Andreas Fault Oblique Drillhole
SAR– Synthetic Aperture Radar.
SFMR – Stepped Frequency Microwave Radiometer
SLAR– side looking airborne radar
SOHO – Solar and Heliospheric Observatory
SOON -- Solar Observing Optical Network
SRA – Scanning Radar Altimeter
SWIR – Short Wave Infra Red
TAMDAR -- Tropospheric Airborne Meteorological Data Reports (commercial aircraft)
TIMS – Thermal Infrared Multispectral Scanner
TIR – Thermal Infra Red
TOMS -- Total Ozone Monitoring Spectrometer
TRMM/PR -- Tropical Rainfall Measuring Mission/Precipitation Radar
UAS -- Unmanned Aerial System
VAFTAD – Volcanic Ash Forecast Transport and Dispersion model
XBT – Expendable Bathythermograph