TECHNICAL REFERENCE DOCUMENT

REDUCING LOSS OF LIFE AND PROPERTY FROM DISASTERS

1. 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. Within the U.S., disasters inflict many injuries and deaths, and cost the Nation $20 billion each year (SDR-03). Disasters in other countries can affect U.S. assets and interests overseas (e.g. as did 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 impact of disasters within the U.S. can be seen in Table 1, which gives a single, substantial example for each class of hazard reviewed in this report. Loss of life is relatively 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. Some hazards (large earthquakes, volcanic eruptions) are not annual events, but are devastating when they do occur. For other, more frequently occurring hazards, individual events may be small, but the average cost per year is high. Examples here include floods (averaging 80 deaths per year, with costs of $5.2 billion, NOAA-04a) and landslides (deaths 25-50 annually, with costs of $2 billion, USGS-03a).

The total impact on the U.S. for all hazards is difficult to determine, because there is no centralized or consistent accounting for costs. Also for certain hazards, such as landslides and coastal hazards, the costs are usually merged into the total for some other event (such as a hurricane or earthquake). Furthermore, one disaster may breed another (e.g., when disease outbreaks follow floods) and the costs of the aftermath events either not be tallied, or not attributed to the primary event. Nevertheless the costs of loss of life and property, of response and recovery, and of social or commercial disruption are conservatively estimated to be $20 billion a year (SDR-03). In addition to improved monitoring and forecasting, the U.S. needs to work toward more effective mitigation practices, to reduce our vulnerability to these events (BOND-99).

Table 1: Recent (5/31/04) Major Events for Each Hazard Type

HAZARD TYPE	EVENT	IMPACT (Reference)
Wildland fires	Southern California fires, October 2003	24 deaths, 750,000 acres burned, cost over $2 billion (CDFFP-04)
Earthquake	Northridge quake, 1994	67 deaths, $44 billion (BOND-99)
Volcanic eruption	Mt. St. Helens eruption, 1980	57 deaths, $1 billion (1980 dollars, Blong-84)
Landslides/debris flows	Thistle landslide, 1983	no deaths but buried a town, $400 million (USGS-03)
Floods	Mid-continent (Mississippi, Missouri) floods, 1993	44 deaths, $24 billion (Lott-00)
Extreme weather	Oklahoma City tornadoes, 1999	40 deaths, $1.6 billion (NOAA-04a)
Tropical cyclones	Hurricane Andrew, 1992	44 lives, $30 billion in Florida and Louisiana
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)

One specific benefit area of vigilant monitoring and good forecasting is enabling 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-03). 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. A related area of economic and social benefit is enabling 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 here 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 disaster.

In reviewing how best to enhance the Nation's use of Earth observations, this report will identify critical users of hazards information, review the observations needed, identify how those needs are met now, identify gaps in the presently deployed systems, and make recommendations on how to fill those gaps over the next 10 years. But first we should look at two events, one that illustrates the difficulties involved, and the other a success story.

Southern California Wildfires
A complex "natural" disaster: The intense and widespread wild fires that raged near Los Angeles and San Diego were widely foreseen but virtually unpreventable. Previous wet seasons had created tremendous fuel loads, so when the fall of 2003 was very hot, with strong Santa Ana winds, some level of wildfire activity was inevitable. Individual fires, started by lightning, human error, and arson, spread into towns and subdivisions as well as whipping through chaparral, forest and grasslands. Damage estimates and firefighting costs were at least $2 billion, and 24 people lost their lives (CDFFP-04). The resulting smoke was unusually hazardous because of anthropogenic components (3710 houses, plus other structures, garages, and vehicles) in the fuels. The fires denuded 750,000 acres of forest and scrub, much of it 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, killing 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 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% of U.S. domestic oil supply, with a daily value of over $25 million, so continuity of its operation is vital to the economy of Alaska and significant for the U.S. as a whole. This event, the largest onshore quake in the U.S. on record, did not break the pipeline because of elaborate engineering requirements based on geologic studies of the fault. The design was built to accommodate a magnitude 8.0 quake with 20 feet of horizontal and 5 feet of vertical displacement. The actual event was magnitude 7.9, 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-03b).

2. User Requirements

The beneficiaries of improved hazard monitoring and disaster management will be society as a whole. However, in order to assess the efficacy of existing systems and identify gaps and future needs, we first must understand who the critical users are, and identify their needs. In the context of disaster management, these groups are:

End users
Users who are the authorities with responsibility for disaster management and/or mitigation. This category includes elected officials, Federal, State and local emergency managers, first responders (police, firefighters), 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 rather than actual Earth observation data, with typical products summarized in Table 2. A partial exception here is FEMA, 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 HAZUS.

Scientists in monitoring and advisory agencies
Scientists (responsible for geological surveys, weather, ocean and space agencies), who 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 and forecasts to the end users, often in near real time, in support of their decisions. The user requirements summarized in the various tables, whether for baseline information or monitoring data, are based on the needs of this group, to support their communications with the end users and with the public.

Research scientists
Personnel whose research is directed toward improving our understanding of the physical or chemical hazards considered here, or 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 EO systems, and so should be reflected in the tables.

The table on the following page outlines examples of requirements by end users.

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 fire	Clear, authoritative maps of fire perimeter, areas at risk for response planning, generated overnight for use the next day Timely alerts and updates to government officials, the affected population, and the media on fire location and status, effects on roads, possible evacuation routes Documentation of burned area, intensity of damage to vegetation and soils, at the watershed scale	Information on vegetation health, fuel loading, fire history. Needed for planning controlled burns, anticipating future fire activity.
Earthquakes	Clear, authoritative information on the location and magnitude of the shock and the time frame (in days) of aftershocks. Timely updates 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 for input to risk assessment models such as the earthquake module in FEMA's HAZUS program
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 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.

Landslides	Local, rapid mapping of affected areas, magnitude of instability, updated scenarios during ongoing instability, impact analysis. Early warning of heightened risk, if heavy rainfall is forecast for areas of known high hazard of landslides and debris flows	Regularly updated susceptibility and hazard zonation maps for landslides, debris flows, rock falls, subsidence (at appropriate scales).
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 Ground surveys, aerial photos and interviews for damage assessments	Flood hazard zonation maps, including accurate topographic maps; mapping of land use and land use changes; flood history of the area Data for input to 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). GIS 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.
Tropical cyclones	Timely and accurate landfall analyses in real time and forecasts (timing, location, intensity, outer wind radii, storm surge, sea state, rain quantity) GIS mapping , aerial photos for damage assessments.	Historical track and intensity information to generate hazard zonation maps. Input to building codes and standards for wind resistance and protection against storm surge. Land use policy in coastal areas, especially low-lying areas Data for input to risk assessment models such as the wind module in FEMA's HAZUS program

Sea and lake ice	Timely and accurate real time ice analyses and forecasts – short (days), medium (weeks), utilizing high-resolution imagery Charts in GIS and graphic format Meteorological model output (cloud cover, precipitation, snow cover, winds, temperature)	Seasonal ice analysis and forecasts (months, years) Charts in GIS and graphic formats Ice climatology (ice extents, probability of occurrence, presence of old ice, ice of land origin)
Coastal hazards, tsunami	Accurate information regarding the presence of tsunami, time of arrival, duration of event (all clear signal); boundaries of inundation area; evacuation routes. Post-event surveys to measure extent and height of inundation to validate/improve forecast models and inundation maps.	Inundation hazard maps for emergency response and land use planning; 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) Regularly updated high-resolution shoreline maps and dune erosion rate maps needed for mitigation policy 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). GIS 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) Death and injury counts and locations.	Accurate topographic maps; GIS mapping of land use and land use changes, (possibly based on aerial photos)

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	Maps showing areas of the Earth affected by particles, X-ray photons, and electrojet currents for use in configuring systems and operations vulnerable to space weather. These include satellites, electronic navigation systems and electric power grids.

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, we 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 eleven hazards reviewed here. In addition to the information products listed, there is a need for systematic accounting for casualties and costs. In the U.S., 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 hazards 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 against 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 (websites, pamphlets, fact sheets, videos) for public education and outreach. These products support longer-term planning and mitigation, as well as helping people 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.

3. Existing Capabilities and Commonalities

The current observing systems in use for wildland fires, earthquakes, volcanic activity, landslides, floods, extreme weather, tropical cyclones, sea and lake ice, coastal hazards, pollution events and space weather are summarized in a series of tables. These tables draw on user requirements for satellite data documented in the the CEOS DMSG report (CEOS-02) for most of the hazards considered. Other sources include the Geohazards IGOS report (ESA-03), and the many agency-specific plans from NOAA, NASA, USGS, and others listed in the references. Some categories of hazard are covered elsewhere: drought and its effects are considered separately in the section on Agriculture, and most health-related issues are covered in the section on environmental effects on human health. In the following tables, 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.

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, described in general in section 5.1, is the most mature hazard monitoring system in the U.S. 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.

Flood hazards. Severe flooding occurs each year, and the patterns of many kinds of flooding events are predictable. Hence the monitoring, evaluation, and forecasting of floods, such as those produced near large rivers, whether by large storms or spring snow melt, is relatively mature, and depends 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, and effective snow melt forecasting. [Refs include FEMA-03a, NOAA-02, NOAA-04e, USGS-99b]

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 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 FEMA, working in partnership with the USGS, NIST and NSF (WSSPC-03). 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 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-02, ESA-03). 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 SESWG report (NASA-02), the Advanced National Seismic System (ANSS) Report to Congress (USGS-99a), national landslide strategy documents (USGS-03b, NRC-04), and EarthScope documents (EWG-01, NRC-01].

Wildland and urban-interface fires are extremely complex events, requiring weather information support (at various time scales and spatial resolutions), plus specialized IR imagery, and very rapid response time for all aspects of fire response. Because of the range of latitudes and climates within the U.S., there are few months of the year when there are no wildfires burning anywhere. 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 DOI. Fire response activities are coordinated through the National Interagency Fire Center (NIFC) in Boise, ID. 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 in 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-03, USFS-02, WFLC-02)

Coastal hazards, tsunami, and sea ice hazards. This varied set of hazards, with meteorological, hydrological, geological and human-induced components, impact our heavily developed and populated coast lines, and pose 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-00). Accurate forecasting of storm surge and coastal flooding depends on coordination between NOAA-NWS (for e.g. hurricane landfall forecasts), the USGS (for stream flow information), and NOAA's National Ocean Service or 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 [EPA-03, additional EPA references?]. 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 (Helz-03).

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-99). 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 sections of this document.

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 no consequence to human society a century ago, can 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 networks, supported by NASA. These ground-based networks monitor the Earth's reference frame and track the orbits of satellites within that frame. These networks, by defining the precise orbits of the GPS satellite constellation, enable 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.

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. In constructing this cross-walk table, the list of individual observational requirements has been condensed from 107 to 37. Some lumping of observational requirements was inevitable, but the data/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, in more detail than in the individual hazards tables, what base-line data are needed for disaster management.

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.

Lastly, Table 3 shows extensive commonality between the observational needs for pollution events, such as oil spills, and those for the natural hazards. This fact, combined with experience that most 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 does not include the required observations for Space Weather, because they do not cross-walk with other categories of data. 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-03a, NSWP-00).

Table 3: CROSSWALK FOR GAPS – HAZARDS AND DISASTERS

(X= 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**	**Land Slides**	**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	gap (S, processing)	gap (S, processing)	gap (S, processing)	gap (G, S, processing)	gaps (A, S, need updates)	X	X	gap (A, S) annual	gap (A, S, processing, G for bathymetry)	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, dating		gap (G)	gap (G, S)	X						
Detailed mapping, dating of surficial deposits, including fill, dumps		gap (G)	gap (G, S)	gap (G)	X			gap (A, S) annual	X	gap (G)
Documentation/ assessment of effects and area affected during and after event	gap (A, S= Landsat)	X	X	X	X	X	X	X	X	X
Seismicity, seismic monitoring		gap (G)	gap (G)	X					X	
Strong ground		gap (G)		X					X	

Hazard	**Wildland Fire**	**Earthquakes**	**Volcanoes Volcanic ash and aerosols**	**Land Slides**	**Floods**	**Extreme weather**	**Tropical cyclones**	**Sea and Lake Ice**	**Coastal hazards, tsunami**	**Pollution events (oil spills, etc.)**
shaking, ground failure, liquefaction effects										
Deformation monitoring, 3-D, over broad areas		gap (G, S = InSAR)	gaps (G, S = InSAR)	X					gap (S = InSAR)	
Strain and creep monitoring, specific features or structures		gap (G, S = InSAR)	X	gap (G, S = InSAR)						
High-resolution measurements of gravity, magnetic and electrical fields		X	X							
Physical properties of Earth materials (surface and subsurface)		gap (G, L)	X	gap (G, L)					X	
Characterize regional thermal emissions, flux – all time scales	gap (S= 3.96 micron band)	X	X							
Detect and characterize local thermal features at varying time scales	gap (A, S=3.96 micron band)		gaps (A, S = ASTER)							gap (S=3.96 micron band)
Characterize gas emissions by species and flux		X	gaps (G, S) CO2, SO2 monitors							gap (S) – no hyper-spectral
Detect and monitor smoke or ash clouds, acid and other aerosols	gap (S)		gap (S – no split window)							X
Water chemistry, natural and contaminated		X	X		X				X	X
Detect and monitor	X		X		X				X	gap (S) SAR,

Hazard	**Wildland Fire**	**Earthquakes**	**Volcanoes Volcanic ash and aerosols**	**Land Slides**	**Floods**	**Extreme weather**	**Tropical cyclones**	**Sea and Lake Ice**	**Coastal hazards, tsunami**	**Pollution events (oil spills, etc.)**
sediment, other discharges (oil, etc.) into water										inadequate revisits
Water levels (groundwater) and pore pressure		X		X	X					
Stream flow: stage, discharge and volume	X			X	gap (G)	gap (G)	gap (G)		X	X
Inundation area (floods, storm surge, tsunami)				X	X	X	X		gap (S= InSAR)	X
Soil moisture	X	X		gap (A ,S) passive microwave	gap (G, S) passive microwave	gap (G, S) passive microwave	gap (G, S) passive microwave		X	
Precipitation	X		X	gap (G, S)	gap (G, S)	gap (G)	gap (G)		X	X
Characterize snow cover or ice cover: area, concentration, thickness, water content, etc.				X	gap (G)	gap (?)		gap (A,S)		
Observe snow melt, ice break up, ice jams					gap (G)	X		gap (A, S)	X	
Navigational hazards or obstructions, including ice								gap (G, S)	X	
Waves, heights and patterns (ocean, large lakes), currents						X	gap (G= buoys)	gap G=buoys	gap (G=buoys)	X
Tides/ coastal water levels					X	X	X	X	X	X
Wind velocity and direction, wind profile	X		X			gap (G)	gap (A, S)	gap (G=buoys)	gap (G= buoys)	X
Atmospheric temperature, profile	X					gap (G, S) microwave profilers	gap (A, S)	X		
Surface and near-surface temperature	X	X	X	gap (G)		X	X	gap G=buoys		

Hazard	**Wildland Fire**	**Earthquakes**	**Volcanoes Volcanic ash and aerosols**	**Land Slides**	**Floods**	**Extreme weather**	**Tropical cyclones**	**Sea and Lake Ice**	**Coastal hazards, tsunami**	**Pollution events (oil spills, etc.)**
(ground, ice and ocean)										
Airmass differences and boundaries	X					gap (G= Doppler)				
Moisture content of atmosphere	X		X			gap (G)	gap (G, A, S)			
Vegetation (high-resolution)	gap (S – Landsat)			X	X					
Fuel characteristics: structure, load, moisture content	gap (S – Landsat, InSAR)									

4. Major Gaps and Challenges

There are still many significant gaps, whether in instrumentation, temporal and spatial coverage, baseline data and models, communications networks, and decision support tools. These have been identified in many reports (SDR-03, 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, which mostly identify gaps in instrumentation, are summarized in Table 3 with the individual gaps identified.

In Table 3, high-resolution digital topography emerges as a key unmet need for 7 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 as too sparse, or as 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.

Airborne infrared capability, for wildland fires, volcano monitoring, or some technological disaster, is cited as inadequate, as is moderate-resolution satellite IR imagery. The inadequacy of Landsat 7 data, in its current impaired state, and the apparent complete 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. SAR or InSAR is mentioned as sparse or lacking for all the geohazards, sea ice, coastal hazards and pollution events. The SAR data stream is so limited that some basic applications of SAR imagery, such as documentation of inundation patterns during floods, or assessing coastal wind patterns (Helz-03, Cunningham-03) were not cited as applications in the corresponding tables. 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 represented in Table 3, 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 government or private-sector. These are essential activities that must be continued, if the U.S. is to continue or expand its dependence on satellite-based information.

Moving beyond the gaps in instrumentation, reducing loss of life and property to extreme weather events requires timely (3-6 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 set up to 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.

Forecasting for wildland fire or for the solid Earth hazards lags behind weather forecasting. 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 forecasting (which implies the ability to give reasonably accurate information on the time, place and size of such events) remains a major challenge for these hazards.

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 U.S., 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 (Hazards-U.S.) model.

Plans to address gaps include two new satellite systems – the NPOESS and GOES-R. These systems will replace current polar and geostationary satellites in 2009 and 2012, respectively. Both satellites 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 the fundamental research on these processes and events. Onboard instruments will have improved spatial and temporal resolution, and will include a wider range of spectral bands than instruments on 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 increased use of local carriers, expanded deployment of surface-based radar wind profilers to observe the atmospheric boundary layer, development and deployment of arrays of phased-array radars to significantly increase the quantity, quality and timeliness of weather information in extreme weather, and operational deployment of high-altitude unmanned aerial vehicles such as NASA's Global Hawk.

Most of the gaps in disaster-related Earth observations systems require further analysis and planning. Many land-based systems, such as stream flow monitoring and seismic monitoring, exist but need to be expanded and upgraded. Satellite observations of thermal emissions via infrared imagery, which could make a significant contribution to our ability to forecast and manage fires and volcanoes, must be expanded and improved.

For disaster-related Earth observations, the two overarching considerations for future Earth observation systems 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 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 basic 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. Earth surface observations are essential for both operational purposes and basic research on geographically distributed natural processes. For a more in-depth look at the state of Earth observations in the Reducing Loss of Life and Property from Disasters arena, as well as for a list of references, please see the Reducing Loss of Life and Property From Disasters Reference Document on the IWGEO website at http://iwgeo.ssc.nasa.gov .

5. 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-99), deformation monitoring (EWG-01, ESA-03), stream gages (USGS-99b), and ocean buoys (NOAA-04d). Globally, existing monitoring networks (such as the global geodetic networks, Global Seismograph 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.

Two new satellite systems – the NPOESS (NOAA-04b) and GOES-R (NOAA-04c) – 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. These 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.

Easier access to SAR data would address a need identified for most of the hazards reviewed [CEOS-03, ESA-04, Helz-03, Cunningham-03, the SESWG report (NASA-02)]. The need for SAR is also mentioned in Earthscope documents (EWG-01, NRC-01). Currently this means seeking easier access to Canadian and European C-band SAR satellite imagery. In addition, Japan plans to launch a new L-band SAR (the PALSAR sensor on the ALOS satellite) in early 2006. That will be 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 6-8 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-03, USFS-02), also for volcano monitoring (CEOS-03, ESA-04). High-resolution imagery needs for volcanoes, plus rapid, tactical IR imagery support for wildfire response, would be better met airborne IR cameras, as there will be less interference from clouds.

Other weather-related future solutions 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, development and deployment of arrays of phased-array radars to significantly increase the quantity, quality and timeliness of weather information in extreme weather, and operational deployment of high-altitude UAVs such as NASA's Global Hawk. The need to integrate these observations to make optimum use of each and enhance information content is key.

NASA Earth Science Enterprise (NASA-00) 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 for new and additional satellites to monitor the interplanetary solar wind.

6. Interagency and International Partnerships

The SDR report (SDR-03) 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-03). Dealing with the hazards posed by volcanic ash clouds to air traffic involves coordination between NOAA (both the NWS and NESDIS), the USGS, the USAF, and the FAA. Wildfire response (WFLC-02) is coordinated through NIFC (the National Interagency Fire Center, consisting of the U.S. Forest Service, the National Park Service, the Bureau of Land Management, Fish and Wildlife 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-99) and works with numerous other Federal agencies, such as FAA, NASA and USGS.

In addition to the partnerships between agencies with operational roles, there are some major interagency collaboration that focus on research in the area of Earth observations. One prominent example is the Earthscope initiative (EWG-01, NRC-01), which includes active seismic experiments (USArray), deep drilling of the San Andreas fault zone (SAFOD), and geodetic studies of motion at plate boundaries and other deformation (PBO). This effort primarily involves NSF and the academic community, but other agencies (NASA, USGS) are coordinating with Earthscope activities. 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 (USWRP) 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.

Key international partnerships and coordinating bodies include the 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, which has a number of monitoring systems, the International Space Environment Service (ISES), etc. Within the WMO there is a key emerging international activity called THORPEX: A Global Atmospheric Research Program designed to accelerate the improvement of global weather forecasting out to 14 days. It will link to EOS through its efforts to determine optimal observing systems for global weather forecasting. Lastly, the NIC collaborates internationally through the WMO/IOC; the International Ice Chart Working Group, formed in 1999, provides operational cooperation amongst national ice services, with regional (North American) collaboration handled by the U.S.-Canadian Joint Ice Working Group.

Another category of international partnerships 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.

7. U.S. Capacity Building Needs

The need to increase capacity to withstand and recover from natural and man-made disasters with minimum loss of life, injuries, damage to homes and other structures, and impact on the economy is clearly recognized. 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 dissemination of accurate and timely warnings.

There is also a need to maintain existing capacity. Several 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 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 then the world. Lessons learned in one region can be applied to the development and expansion of observing capabilities in another region. For example, an instrument developed for one region any be used with no additional development in another region; this comment is applicable to many types of hazards and of instrumentation.

Other needs include the expansion of emergency airborne capabilities including UAVs (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/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 U.S. needs to improve its ability to issue targeted warnings for local hazards such as tornadoes, fog on highways, flash floods [NDIS-02, Mileti-99].

U.S. scientists can learn a good deal through the study of major natural disasters in foreign countries, as large events are relatively uncommon, and their impacts on other societies can carry lessons either for scientific understanding of the hazard or for more effective mitigation practices, that subsequently may be applied in the U.S.

8. Conclusions

In reviewing the status of hazards related monitoring, existing deficiencies and gaps, and new systems on the verge of deployment, the disasters team recognizes two overarching summary considerations for future Earth observation systems. The team will continue to discuss:

(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 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.

(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 have no home.

(3) More systematic acquisition of high-resolution digital topography (identified as a need for almost all hazards, and probably essential to many other societal benefit areas 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 ice monitoring, for vegetation/canopy characterization, for oil slick detection, etc.

(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, so 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.

References

1. Blong, R. J., 1984. Volcanic Hazards: A Sourcebook on the Effects of Eruptions. Academic Press, 424 pages.

2. Board on Natural Disasters, 1999. Mitigation Emerges as Major Strategy for Reducing Losses Caused by Natural Disasters. (Report of the National Academy Board on Natural Disasters) Science, vol. 284, pp 1943-1947.

3. California Department of Forestry & Fire Protection, 2004, California Fire Siege 2003 – The Story. Web document at <http://www.fire.ca.gov/php/fire_er_siege.php>

4. Committee on Earth Observation Satellites (CEOS), 2002, The Use of Earth Observing Satellites for Hazard Support: Assessments and Scenarios, Final Report of the CEOS Disaster Management Support Group, 218 pp, is posted at <http://disaster.ceos.org>

5. Cunningham, J.D., Chambers, D. Davis, C.O., Gerber, A., Helz, R., McGuire, J. P., 2003, Ocean Observer Study: A proposed National Asset to Augment the Future U.S. Operational Satellite System. Marine Technology Science vol. 37, pp. 142-157.

6. Earthscope Working Group, 2001, Earthscope: A New View into Earth. Project Plan. 36 pages. <http://www.earthscope.org/linkpubs.html>

7. European Space Agency, 2003. IGOS Geohazards Theme Report 2003. Available for download at http://dup.esrin.esa.it/igos-geohazards/schedule.asp .

8. Federal Emergency Management Agency, 2003a. Map Modernization Objective: Automated Hydrology and Hydraulics (H&H). Flood Hazard Mapping, June 9, 2003. http://www.fema.gov/fhm/mm_ahh1.shtm

9. Federal Emergency Management Agency, 2003b. A Nation Prepared: Federal Emergency Management Agency Strategic Plan, Fiscal Years 2003 - 2008. 67 pp. http://www.fema.gov/pdf/library/fema_strat_plan_fy03-08(append).pdf

10. Federal Emergency Management Agency, 1999. Remote Sensing in Federal Disaster Operations: Standard Operating Procedures. 9321.1-PR, June 1999. 45 pp. http://www.fema.gov/pdf/library/remotes.pdf .

11. Heinz Center, 2000, The Hidden Costs of Coastal Hazards: Implications for Risk Assessment and Mitigation, The H. John Heinz III Center for Science, Economics and the Environment, Island Press, Washington D. C., 220 pp.

12. Helz, R.T., LaBrecque, J. and Pichel, W.G., 2003, SAR: A Versatile New Tool for Earth Science. Geotimes vol. 48, pp. 14-17.

13. Knabb, Richard D., 2003. The United States Weather Research Program's Joint Hurricane Test Bed (JHT). Proceedings of the Mid-Atlantic Regional Conference on the Inland Effects of Tropical Weather Systems, May 11-13, 2003, Raleigh, NC. 27 pp. http://www.nc-climate.ncsu.edu/ams/conference/pdf/knabb.pdf .

14. Lott, N. and Ross, T., 2000, A Climatology of Recent Extreme Weather and Climate Events, NCDC Technical Report 2000-02, Asheville, N.C., NOAA National Climatic Data Center.

15. Mileti, D. S.,1999. Disasters by Design: A Reassessment of Natural Hazards in the United States, Joseph Henry Press, Washington D.C., 351 pages.

16. NASA Earth Science Enterprise, 2000. Understanding Earth System Change: NASA's Earth Science Enterprise Research Strategy for 2000-2010. http://www.earth.nasa.gov/visions/researchstrat/Research_Strategy.htm .

17. NASA Solid Earth Science Working Group, 2002. Living on a Restless Planet: Solid Earth Science Working Group Report 2002. Jet Propulsion Laboratory, California Institute of Technology. JPL 400-1040. November 2002. 68 pp. http://solidearth.jpl.nasa.gov/PDF/SESWG_final_combined.pdf .

18. National Oceanic and Atmospheric Administration, 2003. New Priorities for the 21st Century: NOAA's Strategic Plan for FY 2003 - 2008 and Beyond. March 31, 2003. 23 pp. http://www.spo.noaa.gov/pdfs/FinalMarch31st.pdf .

19. NOAA, 2004a, Economic Statistics for NOAA, April 2004 – Third Edition, 51 pp. <http://www.publicaffairs.noaa.gov/pdf/economic-statistics2004.pdf>

20. NOAA National Environmental Satellite, Data, and Information Service, 2003. Priorities for the 21st Century: A Strategic Plan for NOAA's Satellite and Information Service For FY 2003-2008 and Beyond. October 2003. 17 pp. http://www.spo.noaa.gov/pdfs/LO Strat Plans 2003 Final/1_NESDIS Strategic Plan Oct2.pdf .

21. NOAA National Environmental Satellite, Data and Information Services, 2004b, National Polar-orbiting Operational Environmental Satellite System (NPOESS). <http://www.ipo.noaa.gov/>

22. NOAA National Environmental Satellite, Data and Information Services, 2004c, Selected Activities Related to the GOES R Series <http://www.osd.noaa.gov/goes R/>

23. NOAA National Weather Service, 2002. Advanced Hydrologic Prediction Services: Concept of Services and Operations. Hydrologic Services Division, Office of Climate, Water, and Weather Services, April 2002. 14 pp. http://www.nws.noaa.gov/om/water/AHPSconcept.pdf .

24. NOAA National Weather Service, 2003. NOAA's National Weather Service Science and Technology Infusion Plan. Final Draft. October 17, 2003. http://review.oar.noaa.gov/Docs/Meetings/Oct_22-23/STIP_Glossy_finaldraft_031017.pdf .

25. NOAA National Weather Service, 2003. Working Together to Save Lives: National Weather Service Strategic Plan for FY 2003 - FY 2008. October 20, 2003. 36 pp. http://www.spo.noaa.gov/pdfs/LO Strat Plans 2003 Final/newnwssp 10-01-03 final.pdf (accessed February 20, 2004).

26. NOAA Office of Oceanic and Atmospheric Research, 2003. NOAA Research Strategic Plan for FY 2003 - FY 2008 and Beyond: Understanding the Environment from the Bottom of the Ocean to the Surface of the Sun. June 27, 2003. 20 pp. http://www.spo.noaa.gov/pdfs/LO Strat Plans 2003 Final/OAR SP final03.pdf (accessed February 20, 2004).

27. NOAA National Weather Service, 2004. Advanced Hydrologic Prediction Service. http://www.nws.noaa.gov/oh/ahps/ahps.htm (accessed March 17, 2004).

28. NOAA National Weather Service, 2004d. National Data Buoy Center. Http://www.ndbc.noaa.gov/

29. National Research Council, 2001. Review of EarthScope Integrated Science. Washington, DC: National Academy Press. 61 pp. http://www.nap.edu/books/0309076447/html/

30. National Research Council, 2004, Partnerships for Reducing Landslide Risk: Assessment of the National Landslide Hazards Mitigation Strategy, The National Academies Press, Washington, D.C.

31. National Security Space Architect, 1999, Space Weather Architecture Study Final Report, 27 pages. <http://schnarff.com/SpaceWeather/PDF/Reports/P-IIB/01.pdf>

32. National Space Weather Program Council, 2000. The National Space Weather Program: The Implementation Plan, 2nd Edition, 196 pages. <http://www.ofcm.gov/nswp-ip/pdf/nswpip.pdf>

33. Office of Management and Budget, 2004. Disaster Management e-Government Initiative. https://disasterhelp.gov/portal/jhtml/aboutus.jhtml .

34. Subcommittee for Disaster Reduction, 2003. Reducing Disaster Vulnerability Through Science and Technology, NSTC CENR Report, 36 pp, <http://www.sdr.gov/SDR_Report_ReducingDisasterVulnerability2003.pdf>

35. USDA Forest Service, 2002. WFAS - Wildland Fire Assessment System. August 9, 2002. http://www.fs.fed.us/land/wfas/ .

36. U.S. Department of Agriculture, 2002. USDA Strategic Plan for FY 2002-2007. September 2002. 42 pp. http://www.usda.gov/ocfo/sp2002/sp2002.pdf .

37. U.S. Department of Transportation, 2003. Department of Transportation Strategic Plan, 2003 B 2008: Safer, Simpler, Smarter Transportation Solutions. September 2003. http://www.dot.gov/stratplan2008/strategic_plan.htm .

38. U.S. Environmental Protection Agency, 2003. 2003-2008 EPA Strategic Plan: Direction for the Future. September 30, 2003. 239 pp. http://www.epa.gov/ocfo/plan/2003sp.pdf .

39. U. S. Geological Survey, 1998. Geology for a Changing World – A Science Strategy for the Geologic Division of the U.S.Geological Survey, 2000-2010. U.S. Geological Survey Circular 1172. http://pubs.usgs.gov/circ/c1172/ .

40. U.S. Geological Survey, 1999a. Requirement for an Advanced National Seismic System: An Assessment of Seismic Monitoring in the United States. U.S. Geological Survey Circular 1188, 55 pp.

41. U. S Geological Survey, 1999b. Strategic Directions for the Water Resources Division, 1998-2008. U. S. Geological Survey Open-File Report 99-249, 27 pages.

42. U.S. Geological Survey, 2000. U.S. Geological Survey Strategic Plan 2000-2005. 25 pp. http://www.usgs.gov/stratplan/stratplan_rev.pdf .

43. U. S. Geological Survey, 2003b. Rupture in South-Central Alaska–The Denali Fault Earthquake of 2002. USGS Fact Sheet fs014-13. <http://geopubs.wr.usgs.gov/fact-sheet/fs014-03>

44. U.S. Geological Survey, 2003a, National Landslide Hazards Mitigation Strategy-- A Framework for Loss Reduction. U.S. Geological Survey Circular 1244, 56 pp.

45. U.S. Weather Research Program, 200?. Implementation Plans and Reports. http://box.mmm.ucar.edu/uswrp/reports/reports.html

46. Western States Seismic Policy Council, 2003. National Earthquake Hazards Reduction Program (NEHRP). http://www.wsspc.org/links/nehrp.html .

47. Wildland Fire Leadership Council, 2002?, National Fire Plan. Web address is <http://www.fireplan.gov/content/home>

48. Working Group on NDIS, 2000. Effective Disaster Warnings, Report by the Working Group on Natural Disaster Information Systems, Subcommittee on Natural Disaster Reduction, November 2000, 56 pages, <http://www.sdr.gov/NDIS_rev_Oct27.pdf>