IDENTIFYING SCIENCE AND TECHNOLOGY OPPORTUNITIES FOR NATIONAL PREPAREDNESS (INTERNAL FEDERAL REPORT)

PRODUCT OF THE

National Preparedness Science and Technology Task Force of the Subcommittee on Disaster Reduction

January 2017

Report prepared by

NATIONAL SCIENCE AND TECHNOLOGY COUNCIL
COMMITTEE ON ENVIRONMENT, NATURAL RESOURCES, AND SUSTAINABILITY
SUBCOMMITTEE ON DISASTER REDUCTION
NATIONAL PREPAREDNESS SCIENCE AND TECHNOLOGY TASK FORCE

National Preparedness Science and Technology Task Force

Chairs

David Applegate
Associate Director for Natural Hazards
United States Geological Survey

Jacqueline Meszaros
Assistant Director for Natural Disaster Resilience
Office of Science and Technology Policy

Task Force Hazard Team Leadership

Thomas Breslin
Federal Emergency Management Agency

Patrick Brettell
National Nuclear Security Administration

Neil Christerson
National Oceanic and Atmospheric Administration

Kawana Cohen-Hopkins
Federal Emergency Management Agency

Gerald Epstein
Department of Homeland Security

Cyril Gay
Department of Agriculture

Chad Gorman
Federal Emergency Management Agency

Wayne Higgins
National Oceanic and Atmospheric Administration

Joselito Ignacio
Federal Emergency Management Agency

Bill Leith
United States Geological Survey

Leviticus Lewis
Federal Emergency Management Agency

Randy Long
Department of Homeland Security

Sarah Mahmood
Department of Homeland Security

Chris Maier
National Weather Service, National Oceanic and Atmospheric Administration

Greg Sayles
Environmental Protection Agency

Richard Vojtech
Department of Homeland Security

Table of Contents

Introduction

Federal science and technology investments ensure that the Nation has the necessary capabilities to prevent disasters, or in the event of a disaster, mitigate their impacts, protect life and property, and aid community recovery.

Presidential Policy Directive 8 (PPD-8) and the National Preparedness Goal establish the overarching principles for national preparedness policy, which aims to achieve "a secure and resilient nation with the capabilities required across the whole community to prevent, protect against, mitigate, respond to, and recover from the threats and hazards that pose the greatest risk." The National Preparedness Goal describes a set of critical elements, termed core capabilities, necessary for the achievement of all-hazard preparedness. Science and technology investments support the development and provision of these core capabilities by advancing fundamental understanding of how and why hazards occur, observation and monitoring capabilities to understand changes in the Earth system or the movement of dangerous materials or substances, technology to protect first responders and affected populations, and information to provide situational awareness during a disaster.

To employ a coordinated approach for future science and technology supporting national preparedness, the National Science and Technology Council's Subcommittee on Disaster Reduction formed the National Preparedness Science and Technology Task Force. The Subcommittee on Disaster Reduction worked closely with the Office of Science and Technology Policy and the National Security Council to develop a Charter for the Task Force that would ensure that science and technology insights would be explored in the context of preparedness protocol development needs. Collaboration between the Federal science and technology community and the National Preparedness community represents a new approach to joint planning that ensures science and technology outcomes are relevant to the needs of emergency mangers and decision makers responsible for protecting the Nation against all-hazards. Joint planning between these two Federal communities adds value toward meeting the respective mission of each participant agency, that would not achieved through independent planning efforts.

The Task Force assembled six teams of subject matter experts from across the Federal Government to assess science and technology opportunities to prepare for biological hazards, chemical hazards, radiological and nuclear hazards, geological hazards, meteorological hazards, and space hazards (including hazards from both space weather and Near Earth Objects). The Task Force analyzed the products of the six teams and identified a set of cross-cutting S&T development areas that were common to all six hazard teams. These areas were then used as a framework to classify S&T capabilities. The six cross-cutting S&T development areas identified by the Task Force are:

1. **Improve Public Communication of Warnings and Advisories:** S&T opportunities to advance public communication of warnings and advisories span a large area of scientific investment, including social science, risk communication, communications technology development, or education and outreach efforts to enhance two-way communication between communities and decision makers responsible for issuing warnings and advisories. These opportunities generally aim to support public communication rather than decision making by elected officials or other emergency management officials. S&T that hardens communications infrastructure or increases system redundancy are included in this category.

2. **Enhance Fundamental Understanding of Hazards:** Fundamental research advances understanding of the physical, chemical, or biological processes behind hazard phenomena, and how these process evolve within physical, living, and built environments. Technology developers

and applied researchers build on fundamental findings in order to produce tools for response and decision making, like detection and protection technologies, forecasts and projections, and response options.

3. **Improve Event Characterization and Risk Assessment:** S&T efforts that enable event characterization, forecast tracks, risk assessment, damage assessment, and related tools are essential to experts and emergency management officials in assessing hazards and associated risk. Applied research and technology development efforts that support event characterization or risk assessment prior to an event include hazard magnitude and frequency mapping, vulnerability assessment approaches or methodologies, and design standards. Research and development supporting post-event characterization include sampling protocols, modeling, and impact and damage assessment approaches that provide situational awareness and predict consequences.

4. **Enhance Observations, Modeling, and Data Management:** Earth observations; surveillance methods and technologies; models to understand and estimate effects; and management of data on hazards, infrastructure, and populations are all important supports for the preparedness mission areas. These observations, models, and data are the basis for sensing changes in the environment and translating those measurements into risk- and decision-relevant preparedness information. Long-term data management efforts are important so that scientists can understand trends and relationships associated with hazards that may take place over long timescales (e.g., drought, pandemics, and climate change).

5. **Develop Technology for Safer, Effective, and Timely Response and Recovery:** Response and recovery technology capabilities provide information, tools, and measures for emergency response officials to maintain situational awareness, to make informed decisions, and to ensure hazards are appropriately addressed. For example, these capabilities might include protocols for the collection and disposal of hazardous materials, standards for communications technology, or methods and technologies for detection and cleanup of environmental (chemical, biological, and radiological) contamination.

6. **Integrate Science into Preparedness Decisions:** Accurate, timely, and relevant science, delivered in ways that are readily understood and acted upon, are needed by emergency management officials, community decision makers, and the public in order to ensure appropriate actions are taken to protect lives and property. Opportunities in this category focus on supporting emergency management officials' or community officials' decisions before, during, or after an event. Opportunities in this category include outreach and education to train decision makers to understand warnings and advisories, and S&T leading to decision support tools that translate scientific input into locally decision-relevant information.

This report contains the results of joint efforts by Federal officials in both the S&T and the national preparedness communities to identify core S&T opportunities to enhance preparedness capabilities for all hazards, illustrating the value of joint planning between these two communities.

The following chapters present the S&T opportunities identified by each of the working groups. Each chapter is organized into the six cross-cutting S&T development areas. Appendices to this report include hazard area-specific lists of S&T gaps to meeting PPD-8 requirements and key Federal S&T programs that support preparedness.

Biological Hazard Science and Technology (Non-terrorism) Preparedness

Science and Technology Priorities to Counter Biological Hazards (Non-terrorism)

1. Improve Public Communication of Warnings and Advisories

Risk Communication: Advances in guidance, protocols, or other approaches to improve public communication about the risks of transmitting emerging infectious diseases (i.e. Zika Virus, Ebola Virus) are a necessary public health intervention. Approaches to messaging are needed to reduce the risk associated with disease transmission, support treatment decisions, triage, and waste management.)

Recommended Science and Technology Actions

S&T Opportunities

- Risk Communication
    - Enhance understanding of risk communication and risk perception research to improve understanding of most-trusted and well-received sources and forms of information for the public (adapted from Biological Response and Recovery Science and Technology Roadmap)
    - Public health officials and other emergency personnel should be trained in health crises related to public communication (Recommendation 4.2, HHS Ebola Response Improvement Plan)

2. Enhance Fundamental Understanding of Hazards

Transmission**:** Addressing emerging biological hazards such as emerging infectious diseases and antibiotic resistance requires a solid fundamental understanding of the processes related to human asymptomatic disease transmission, the role of vertical transmission, and associated virus routes of entry and shedding of the virus in infected individuals. Advances in understanding the transmission of antibiotic resistant bacteria to slow the emergence and prevent the spread of resistant infections in community and healthcare settings.

Environmental and Ecological Factors**:** Environmental and ecological factors are an important component affecting the overall risk posed by biological hazards, particularly infectious diseases. Developing a better understanding of the influence of these factors allows for capability development to detect aberrations or improve modeling and forecasting to predict the likelihood of disease outbreak.

Post-Infection Outcomes and Impacts: This category of science and technology for emerging infection diseases primarily relates to recent findings from initial public health and medical research priorities related to Zika Virus. Emerging infectious diseases, such as recent experience with Zika Virus, pose challenges for emergency managers and public health officials who have incomplete information about the range of potential adverse health outcomes and confounding factors associated a range of symptoms or potential confounding infections. In these cases where unknown or limited information is available on infectious disease outcomes, research is needed to better understand pathophysiology, immune response, susceptibilities and persistence of the agent.

Disease Emergence and Re-emergence: Anticipating risks posed by infectious diseases or antibiotic resistance requires capabilities that allow for scientists to better understand when changes take place within complex biological systems and developing a fundamental understanding of an agent's behavior within human or animal populations. With regard to risk posed by antibiotic resistance, research is needed to identify ecological determinants and environmental factors that are associated with antibiotic resistance.

Recommended Science and Technology Actions

S&T Opportunities

- Transmission
  - Enhance understanding of transmission epidemiology to develop accurate public health guidance on emerging diseases, such as the Ebola and Zika Viruses (adapted from IOM & NRC Research Priorities to Inform Public Health and Medical Practice for Ebola Virus Disease: Workshop in Brief)
  - Identify human-subjects qualified for enrollment in clinical trials of antibiotics to help treat resistant bacterial infections (adapted from Recommendation 4.1ii, National Strategy for Combating Antibiotic Resistant Bacteria)
- Environmental and Ecological Factors
  - Develop surveillance methodologies that integrate traditional monitoring (i.e., pathogen, environmental, health) with background data (i.e., meteorological and population dynamics) to strengthen capabilities to detect public health aberrations. (adapted from Recommendation from Chapter 2. Aberration Detection, National Biosurveillance Science & Technology Roadmap)
  - Enhance understanding of the nature of microbial communities, how antibiotics affect them, and how they can be harnessed to prevent disease. (adapted from Recommendation 4.2, National Strategy for Combating Antibiotic Resistant Bacteria)
- Post-Infection Outcomes and Impacts
  - Enhance understanding of emerging infectious diseases with limited knowledge about outcomes (e.g. Zika Virus) in order to better understand epidemiological characteristics associated with birth defects and enhancements in surveillance for indecent cases. (adapted from Potential Research Priorities to Inform Public Health and Medical Practice for Domestic Zika Virus: Workshop in Brief)
- Disease Emergence and Re-emergency (Epidemiology)
  - Enhance understanding of ecological and evolutionary factors that affect infectious disease agent's ability to move into new host-species, and for organisms, acquire antibiotic resistance. These research activities should include molecular approaches and explore molecular-level relationships and interactions between hosts and vectors. Applications of this research could support consideration of ecological and evolutionary drivers of disease

behavior in forecasting technology and models. (Adapted from National Biosurveillance Science and Technology Roadmap)

- Enhance understanding of Gram-negative pathogens and the nature of microbial communities and effects of antibiotics on them. (adapted from National Strategy for Combating Antibiotic-Resistant Bacteria)

3. Improve Event Characterization and Risk Assessment

Risk Assessment (e.g., risk of exposure, risk of infection): S&T can be used to both accurately assess risk of exposure and infection and also to reduce that risk. There are enormous uncertainties in modeling the risks and potential impact of infectious disease crises, which must be reduced in order to produce accurate risk assessments of infectious diseases. Clinical decisions on patient treatment require adequate information about environmental exposure risk.

Baseline Establishment and Aberration Detection: In order to determine the presence of a biohazard, aberrations from a baseline must be detected. The challenge is two-fold: first, one must characterize the baseline to understand the status quo, and second, one must recognize a deviation from that baseline. There are needed improvements in characterization of normal background and the ability to rapidly detect aberrations from the baseline, at different and changing spatial and temporal scales.

Threat Identification and Characterization (e.g., of resistant bacteria): The identification, with confidence, of known and unknown threats in complex samples requires improved sensitivity, specificity, and portability of multiplexed technologies.

Recommended Science and Technology Actions

S&T Opportunities

- Risk Assessment (e.g., risk of exposure, risk of infection)
    - Develop reliable estimates of risk of environmental exposure for a multitude of environments, matrices, and conditions associated with wide area release scenarios (Biological Response and Recovery Science and Technology Roadmap)
    - Develop reliable estimates of risk to humans, animals, and plants through various exposure and transmission routes (Biological Response and Recovery Science and Technology Roadmap)
    - Develop approaches and algorithms to assess risk of infection from environmental exposure, including food and water, to biological agents (Biological Response and Recovery Science and Technology Roadmap)
- Baseline Establishment and Aberration Detection
    - Establish baseline levels of community and ecosystem risks, threats, and health (National Biosurveillance Science and Technology Roadmap)
    - Enhance methods and tools to rapidly detect aberrations from the baseline (National Biosurveillance Science and Technology Roadmap)
    - Further characterize environmental background organisms over time and at various locations to validate standards (BioWatch PCR Assays)

- Threat Identification and Characterization
    - o Connect non-invasive data-gathering tools to other types of surveillance data to improve the ability to detect antecedent conditions and the earliest indications of a significant incident (National Biosurveillance Science and Technology Roadmap)
    - o Develop rapid and innovative diagnostic tests for identification and characterization of resistant bacteria (adapted from National Strategy for Combating Antibiotic-Resistant Bacteria)
    - o Develop instrumentation and large-data-set processing and capabilities to rapidly identify characteristics of known agents, rapidly detect changes in known agents, and/or discover the existence of unknown agents from samples in clinical or environmental matrices (adapted from National Biosurveillance Science and Technology Roadmap)

4. Enhance Observations, Modeling, and Data Management

Data Management (Availability, Discoverability, Integration, Security, and Sharing): There is a need for sustained and appropriate multilateral information sharing. Advancements are needed in data sharing and integration and communication technologies including assessment methods.

Modelling and Predictive Analytics: Currently, early indicators and recognized and visualized using remotely-sensed imagery, common operating pictures, and disease modeling/forecasting. Federally funded modeling research on specific, highly infectious diseases, such as novel respiratory diseases with pandemic potential, is currently most useful for mitigation and response. The current state of science does not allow for accurate predictions of the emergence of novel diseases or of the reemergence of diseases for which no regular cycle of emergence is known. Some success has been achieved in computationally assisted methods for predicting disease outbreaks in the realm of disease risk mapping (e.g., ecological niche modeling), typically of vector-borne disease where meteorological and environmental conditions are the principal drivers and the diseases recur with some regularity in the same general location.

Surveillance and Detection for Situational Awareness: Surveillance and detection of outbreaks enables early warning of incidents and increased situational awareness, and consequentially allows informed decisions to be made earlier. Biosurveillance may integrate information about disease incidents and reports of symptoms alongside data on specific populations and environments.

Recommended Science and Technology Actions

S&T Opportunities

- Data Management (Availability, Discoverability, Integration, Security, and Sharing)
    - o Improve data sharing and integration and communication technologies, including assessment methods (adapted from National Biosurveillance Science and Technology Roadmap)
    - o Improve diagnostic technologies and access to signatures, reagents, strains, and sequence data, and an informatics and computational capabilities (National Biosurveillance Science and Technology Roadmap)
    - o Harden pathogen and advanced biotechnology information from cyber attacks (A National Blueprint for Biodefense: Leadership and Major Reform Needed to Optimize Efforts)

  - Increase data sharing in the areas of epidemiological characteristics and virus vectors and reservoirs (adapted from Potential Research Priorities to Inform Public Health and Medical Practice for Domestic Zika Virus: Workshop in Brief)
- Modelling and Predictive Analytics
  - Enhance understanding of determinants of disease emergence and reemergence (adapted from National Biosurveillance Science and Technology Roadmap)
  - Improve forecasting technologies and models that consider ecological and evolutionary drivers of disease behavior (adapted from National Biosurveillance Science and Technology Roadmap)
  - Connect non-invasive data-gathering tools to other types of surveillance data to improve the ability to detect antecedent conditions and the earliest indications of a significant incident (National Biosurveillance Science and Technology Roadmap)
- Surveillance (Detection for Situational Awareness)
  - Improve surveillance of and planning for animal and zoonotic outbreaks by increasing opportunities for animal health data collection, increasing funding for the National Animal Health Laboratory Network, and developing guidance for the serious implications of companion animal and wildlife zoonoses (A National Blueprint for Biodefense: Leadership and Major Reform Needed to Optimize Efforts).

5. Develop Technology for Safer, Effective, and Timely Response and Recovery

Waste Management and Environmental Decontamination: Effective risk reduction strategies for a variety of biological threats must include procedures for agent-contaminated waste minimization and disposal. A national environmental decontamination capacity should be established to control and remove environmental contaminants generated in biohazard scenarios.

Medical Countermeasures (MCMs): MCMs may be used to diagnose, prevent, protect from, or treat conditions associated with a biological threat (FDA site). The development of MCMs can be improved, and a Medical Countermeasure Response Framework should be developed and implemented.

Personal Protective Equipment (PPE): The equipment worn to prevent the spread of infectious diseases and minimize exposure to biohazards is essential to protecting health care workers, their patients, and other contacts. Recommendations regarding the type and use of personal protective equipment (PPE) to protect against biological events are available, but most responders only possess the PPE necessary to operate within limited circumstances: in response to HIV and influenza within current community environments. Specific standards or guidelines for PPE are still needed, and their development will require special attention to unique requirements of the various emergency services subsectors (A National Blueprint for Biodefense: Leadership and Major Reform Needed to Optimize Efforts)

Diagnostics (Clinical Applications): Diagnostics are critical to a response to a biological threat by permitting medical professionals to identify the threat and provide appropriate treatment. In particular, new, rapid, simple, inexpensive, efficient and accurate point of care diagnostics could enable transformational changes in pathogen/resistance identification, prescription of medications, and clinical trial design.

Patient Treatment and Preventative Alternatives (Development of Nontraditional Care): Improving patient treatment requires the development of new therapeutics and vaccines before a biological incident, as well as more effective practices during patient interventions. Methods of treating antibiotic infections also have consequences on the evolution and proliferation of resistant bacteria, which motivates the development and use of nontraditional alternatives to antibiotics.

Recommended Science and Technology Actions

S&T Opportunities

- Waste Management and Environmental Decontamination
  - Develop tools to manage waste as part of an integrated response and recovery operation, including prioritization of infrastructure cleanup, waste segregation, recycling, staging, storage, treatment, transportation, disposal of wastes, and assessment of the impact of decontamination decisions on waste management practices (adapted from Recommendation 5.1.a, Biological Response and Recovery Science and Technology Roadmap)
  - Develop technologies and guidance for mass human, animal (including household pets), and plant decontamination or destruction (Recommendation 4.1.c, Biological Response and Recovery Science and Technology Roadmap)
  - Develop new approaches to decontaminate and evaluate efficacy for new and existing decontamination approaches and procedures (Recommendation 4.1.f, Biological Response and Recovery Science and Technology Roadmap)
- Medical Countermeasures
  - Produce a comprehensive framework to guide medical countermeasure distribution and dispensing planning (Recommendation 22.a, A National Blueprint for Biodefense: Leadership and Major Reforms Needed to Optimize Efforts)
- Personal Protective Equipment
  - Enhance understanding of how PPE elements work and interact with one another to inform more accurate donning and doffing strategies (adapted from Research Priorities to Inform Public Health and Medical Practice for Ebola Virus Disease: Workshop in Brief).
  - Establish reasonable personal protective equipment guidelines and requirements in advance of a biological event. (Recommendation 15.c, A National Blueprint for Biodefense: Leadership and Major Reform Needed to Optimize Efforts)
- Diagnostics (Clinical Applications)
  - Develop rapid, reliable next-generation detection and diagnostic capabilities (White House blog on National Biosurveillance Science and Technology Roadmap)
  - Develop rapid, point of care diagnostic tests that could enable more appropriate uses of antibacterial agents by changing the current widespread practice of prescribing after target pathogens have been identified (adapted from Time for a change: addressing R&D and commercialization challenges for antibacterials).
- Patient Treatment and Preventative Alternatives (Development of Nontraditional Care)

- Develop non-traditional therapeutics and innovative strategies to minimize outbreaks caused by resistant bacteria in human and animal populations (Recommendation 4.4, National Strategy for Combating Antibiotic-Resistant Bacteria).
- Develop vaccines, pharmaceuticals, and behavior management for emerging diseases such as Zika (adapted from Potential Research Priorities to Inform Public Health and Medical Practice for Domestic Zika Virus: Workshop in Brief)
- Explore and validate new approaches for treating bacterial infections, including alternative approaches for targeting the bacteria, other modalities, and targeting human target "host targets" (adapted from Time for a Change: Addressing R&D and Commercialization Challenges for Antibacterials).

6. Integrate Science into Preparedness Decisions

Reporting and Data Collection: Tracking the spread of disease is key to combating it. A capacity must be established to detect, analyze, and report the spread of pathogens such as antibiotic resistant bacteria in order to make available the information needed for evidence-based decision in each country and globally.

Uncertainty and Decision-making: Data on biohazards necessarily has error associated with it, and an understanding of this error is crucial to making informed decisions.

Science-based Infection Prevention Guidelines: Population infection prevention measures, such as quarantine, isolation, and social distancing, must be informed by a strong scientific basis (Biological Response and Recovery Science and Technology Roadmap).

Recommended Science and Technology Actions

S&T Opportunities

- Reporting and Data Collection
  - Develop a mechanism for international communication of critical events that may signify new pathogen trends with global public and animal health implications (adapted from Objective 5.3, National Strategy for Combating Antibiotic-Resistant Bacteria).
- Uncertainty and Decision-making
  - Formalize a means to effectively communicate uncertainty in biosurveillance data used for decision making (adapted from National Biosurveillance Science and Technology Roadmap).
- Science-based Infection Prevention Guidelines
  - Ascertain the risk associated with population movements during and after multiple disasters (adapted from Goal 4.2.a, Biological Response and Recovery Science and Technology Roadmap).
  - Develop expedient isolation methods and improved isolation capabilities to reduce exposure (Goal 4.2.c, Biological Response and Recovery Science and Technology Roadmap).
  - Conduct systems-based analysis and develop evidence-based, optimized MCM distribution constructs,), to supplement or enhance existing distribution mechanisms (e.g., stockpiles and points-of-distribution) (Goal 4.2.d, Biological Response and Recovery Science and Technology Roadmap).

Biological Hazard (Bioterrorism) Preparedness

The National Preparedness Science and Technology Task Force leveraged the efforts of the Biodefense Research and Development (BDRD) Subcommittee under the NSTC Committee on Homeland and National Security to conduct the Homeland Biodefense Science and Technology Capability Gap Review. The BDRD Subcommittee conducted a comprehensive evaluation of the Nation's biological defense capabilities to identify future priorities and actions to support them. The results of that study provide a blueprint for a future biodefense program that fully integrates the sustained efforts of the national and homeland security, medical, public health, intelligence, defense and law enforcement communities (Homeland Biodefense Science and Technology Capability Review[1]).

Chemical Hazard Science and Technology Preparedness

Science and Technology Priorities to Prepare for Chemical Events

A comprehensive review of Federal government programs, resources, capabilities, and priorities was performed by the team to evaluate current R&D gaps associated with chemical threats and hazards. Data from more than 20 Federal organizations were collected, analyzed, categorized, and discussed to determine gaps and priorities associated with future R&D requirements. The information resulting from this process is summarized below. Twelve priority gaps have been identified and clustered into four broad categories: Enhance Fundamental Understanding of Hazards (3 gaps); Improve Event Characterization and Risk Assessment (3 gaps); Safer Response or Recovery (including protocols and guidelines) (4 gaps); and Integrate Science into Preparedness Decisions (2 gaps). As some gaps cross-cut categories, they may be discussed in more than one category in the summaries presented below. No S&T gaps that necessitate investment were identified for the Improve Public Communication of Warnings and Advisories or the Enhance Observations, Modeling, and Data Management development areas.

1. Improve Public Communication of Warnings and Advisories

Chemical detection capabilities combined with improved decision support tools and protocols for local officials are supporting measures necessary to maintain public safety. The distribution of timely, credible, and actionable information to the public are important responsibilities for emergency managers. Science and technology opportunities discussed in section 6 on Integrate Science into Preparedness Decisions of this chapter are important prerequisites for public communications capabilities, including issuing warnings or advisories. For the purposes of this science and technology gap assessment, public communication of warnings and advisories were not a primary focus the assessment, however, opportunities in other categories may have cross-application for public communication needs.

2. Enhance Fundamental Understanding of Hazards

Effective response to and remediation of chemical hazards requires a complete understanding of the fundamental properties of materials or chemicals that may present a threat. As with biological hazards and unlike the relatively well-known set of radiological hazards, the world of chemical hazards is very large, with new potentially toxic chemicals easily created by synthetic methods. As a result, creating a fundamental understanding of the properties of such materials is a major task which will continue as an

[1] Biological Defense Research and Development Subcommittee, National Science and Technology Council. "Homeland Biodefense Science and Technology Capability Review". December 2016. Report can be accessed at: https://www.whitehouse.gov/sites/default/files/microsites/ostp/NSTC/biodefense_st_report_final.pdf

S&T need into the future. Information on fate, transport, and toxicity of chemicals in the environment are needed to inform operational decision-making, specifically evacuation, remediation, and public health decisions. Research and data collection on the stability, degradation, and toxicity of chemical substances in various media (e.g., atmosphere, soil, and groundwater) are essential for developing a fundamental understanding of potential chemical hazards.

Recommended Science and Technology Actions

Fundamental research leading to greater understanding of how potential chemical hazards interact with and travel through environmental media, and their effect on humans is needed for chemical hazard preparedness. Modeling the transport and dispersion of toxic substances, characterizing the adverse biological and health effects of exposure to toxic substances, and identifying novel approaches to identify chemical threats are areas of needed improvement. Advances in fundamental understanding of chemical hazards in these research fields would support chemical incident response requirements, such as threat identification, environmental response, and the provision of recovery-stage health services.

Short-Term Opportunities

- Improve data basing and data mining tools and services to enable sharing of knowledge on effects across federal, State, and Local Governments and the private sector.
- Identify and establish community consensus upon a set of priority scenarios to plan for and defend against through the use of currently accepted risk assessments.

Mid-Term Opportunities

- Improve estimates of hazards posed by exposure of humans, animals, plants, and equipment to high-risk chemicals through in vivo and in vitro experimentation and Physiological Based Pharmacokinetic (PBPK) modeling.
- Develop improved models to incorporate chemical exposure effects into assessments of risk.
- Develop improved hazard estimation capability to support decision analysis tools throughout policy development, planning, and preparedness.

Long-Term or Sustained Opportunities

- Characterize chemical and physical properties of an ever-evolving set of high-risk chemicals to account for the continually emerging chemical threat and hazard.
- Develop improved dispersion models for emerging chemical agents to develop better capabilities for estimating dosage and consequences, including investigating different routes of exposure.

3. Improve Event Characterization and Risk Assessment

Characterizing a chemical substance release is a necessary activity to activate response mission area capabilities. Complete characterization includes detection and recognition that a hazardous release has occurred, identification of the chemical released, and characterization of the extent of the release. Achieving complete characterization relies upon the timely distribution of accurate chemical detectors and monitors. Response actions are most effective when chemical characterization information is accurate and rapidly disseminated to emergency officials responsible for decisions regarding containment and decontamination actions. New research and development in detection technology are essential to advance the ability of the Nation to characterize chemical release events, and assess the risk of such releases.

Recommended Science and Technology Actions

There is a need to improve our ability to estimate or determine the presence of a chemical hazard after a release, particularly for situations involving chemicals that may persist in the environment or cause widespread contamination. Characterization requires the acquisition and analysis of many samples from the environment and from exposed individuals to determine the full scope of the contamination. There is a need for research and technology development leading to improvements in sampling technology or protocols, and improvements in analysis protocols for the range of hazardous chemicals that could be released. Improvements in these protocols, including the development of field diagnostics, would expedite determinations of environmental contamination and of the level of exposure to affected individuals. These samples and analysis would also enable the establishment of exclusion zones that are needed to prevent further exposure and to provide a controlled area to begin recovery operations.

Advances in detection technology can also provide early warning capabilities. Chemical detection systems are currently utilized in limited situations as an early warning of a release of select toxic chemicals in important infrastructure systems. For example, DHS developed a networked chemical detection system for subways that has been in use in several transportation systems for some years. To enable early warning capabilities such as these, further research and development is needed to significantly reduce procurement and maintenance costs of detection technology. Sensors developed for early warning capabilities need to discriminate between specific hazardous chemicals in environments where many substances are present over operational life of the sensor.

Short-Term Opportunities

- Develop standards of performance for detection systems (standards of performance should be consensus-based and represent feasible technical goals).
- Provide guidance to the operational community on performance of commercially available detection systems.
- Develop doctrine to assist communities build a concept of operations plan to effectively respond to a chemical release, particularly involving stationary, autonomous chemical detection systems.
- Develop improved transport and dispersion models, incorporating consideration of the fate of hazardous chemicals in the environment.

Mid-Term Opportunities

- Identify and develop more selective and cost-effective detection technologies and detection algorithms for the highest risk scenarios involving release into the air (e.g., transportation systems).
- Develop and implement (establish) analytical capabilities and capacities for emerging chemicals of concern.
- Develop a comprehensive approach to defining re-occupancy after facility decontamination from chemical agents.
- Develop point-of-care diagnostics that can be used by medical personnel to evaluate potentially exposed individuals and serve as basis for treatment recommendations.

Long-Term or Sustained Opportunities

- Identify and develop more selective and cost-effective detection technologies and detection algorithms, for the highest-risk agents; these investments should consider chemical release into food supplies (e.g., during processing) and water systems.
- Develop detection capabilities to detect liquid and solid contamination on surfaces.
- Develop improved methods for sampling and analysis of hazardous chemicals in all media (air, soil, food, water), which should also consider the impact of decontamination agents.
- Develop assays and analytical platforms that can be used in the field to screen for potentially exposed individuals.

4. Enhance Observations, Modeling, and Data Management

Preparedness for chemical substance releases relies on the development and deployment of detection technologies that support the capabilities described in section 3 of this chapter, "Improve Event Characterization and Risk Assessment" section of this chapter. The detection technology needs described are a form of in-situ sensor that observe the environment, and provide useful information to emergency officials when the concentration of a chemical substance has reached a detectable threshold. Due to overlapping capability needs, these science and technology opportunities are discussed only in section 3 of the chapter. Science and technology needs common to both event characterization and observations and modeling needs include the development of new sensors, assays, and platforms to support detection capabilities and research leading to modeling advances, such as transport and dispersion modeling.

5. Develop Technology for Safer, Effective, and Timely Response and Recovery

A complete set of capabilities required for response and recovery mission areas includes detection, containment, decontamination, treatment, and attribution capabilities and technologies. The first stage of response to a chemical release involves accurate detection and characterization of a release. Science and technology opportunities to advance detection protocols, methods, and technologies are covered in section 3 of this chapter, "Improve Event Characterization and Risk Assessment. The remainder of response and recovery mission area chemical release capabilities (containment, decontamination, treatment, attribution) are discussed are covered in this section.

As described in section 3, "Improve Event Characterization and Risk Assessment, there is a natural link between the development and use of chemical detection technologies to inform further response capability requirements. After a hazardous substance release into the environment has been detected, emergency responders work to rapidly identify the chemical involved in the contamination, define and restrict the contaminated areas, limit the spread of contamination, and separate people to avoid potential exposure. Responders then require technological solutions to contain the release, decontaminate and treat affected individuals and environments, and attribute the source of the release. Officials also initiate early stage recovery operations to restore the contaminated area to a safe state, requiring hazardous waste and disposal capabilities. For individuals that are exposed to the hazardous substance, efforts are taken to decontaminate them and provide medical treatment to minimize the deleterious effects of the exposure. Investigation into the circumstances of the release will usually be initiated, especially if the release appears unusual or intentional, to begin to identify how the release occurred and who is responsible. Scientific attribution and forensic capabilities are essential successful apprehension and prosecution of responsible parties and prevent a recurrence of intentional releases.

Recommended Science and Technology Actions

For containment and decontamination capabilities, science and technology investments can improve capacity to respond to releases of a broad range of toxic chemicals, including toxic industrial chemicals (TICs), chemical warfare agents (CWAs), and other chemicals such as oils. Emergency officials and health professionals responsible for carrying out these containment and decontamination activities require personal protection equipment (PPE) to ensure safe and effective response. Additional research is needed to identify where current PPE technology may not provide sufficient protection. These research findings would enable PPE technological improvements and additional options to increase the protective capacity and range that PPE can afford emergency officials.

For attribution capabilities, research to improve forensic sampling and analytical procedures is needed. Improvements in these procedures would lead to increases in the efficacy of protocols designed to identify individuals or parties responsible for releases of highly toxic chemicals.

Short-Term Opportunities

- Contain and decontaminate exposed areas and individuals
  - Improve approaches to contain environmental transport of hazardous chemicals
  - Establish a science base and protocols for decontamination of exposed individuals, individually and en masse
- Improve personal protective equipment
  - Develop and implement standards for physical protective ensembles
  - Develop a database of the performance of physical protective ensembles to inform responder purchases

Mid-Term Opportunities

- Contain and decontaminate exposed areas and individuals
  - Develop technological options to remove, neutralize, or mitigate residual contamination hazards and persistent hazards on remains and personal effects
  - Develop a comprehensive approach to defining re-occupancy after facility decontamination from chemical agents
- Improve personal protective equipment
  - Develop improved suit technologies that reduces thermal burden to the wearer and provide percutaneous protection against emerging chemical threats
  - Develop improved respiratory protection that incorporates reliable indication of remaining filter life
- Improve treatment capabilities
  - Develop point-of-care diagnostics that can be used by medical personnel to evaluate potentially exposed individuals and serve as basis for treatment recommendations

- Develop and deploy definitive clinical diagnostic assays across laboratory response systems to enable high-capacity assessment of potentially exposed individuals as well as to facilitate long-term monitoring of exposed individuals

Long-Term or Sustained Opportunities

- Contain and decontaminate exposed areas and individuals: Develop technological options for removal and neutralization of material contaminated with emerging chemical agents
- Improve treatment capabilities
  - Develop point-of-care diagnostics that can be used by medical personnel to evaluate potentially exposed individuals and serve as basis for treatment recommendations
  - Develop therapeutic medical countermeasures for broad spectrum of established and emerging toxic chemicals

6. Integrate Science into Preparedness Decisions

Municipal-level experience implementing chemical release response and recovery operations often are based upon more frequent, common, small-scale releases. These types of events generally are well-understood, and may not be analogous to the types of decisions and actions necessary in larger-scale, more complex chemical releases (i.e. adversarial or human-caused chemical releases). Municipal government officials are the first-line decision makers when a chemical substance release takes place. Federal and state resources, assets, and aid will be provided to aid the response and recovery after a release has been detected, however the distribution of these resources will take hours or days to reach the affected area. Timely and informed decision making by local government officials and responders in the initial response period is necessary to limit the further spread and exposure to the hazardous substance, and ensure a rapid recovery process.

Up-to-date, accurate, and informative guidance is needed to maintain local capacity to respond to a chemical release. These guidance materials, including protocols and training materials, should be based upon best available scientific evidence and regularly updated as new scientific findings are made available and technological capabilities are developed.

Recommended Science and Technology Actions

Newly developed guidance materials for local government decision makers should be based on a set of valid, representative, high-risk scenarios that represent the diversity of decisions and capabilities local officials would be responsible for employing. The scenarios should represent a potential range of threats include procedures, countermeasures, and planning necessary to respond and recover to these potential threats. After these guidance materials are developed, to ensure that adequate countermeasures and mitigation protocols are deployed across the Nation, exercises and training events should test the readiness of coordinated local, state, and Federal chemical event response and recovery capabilities.

In order to identify appropriate high-risk scenarios that can be tailored to location-specific needs, the development of a "standardized" set of scenarios is needed. The library of scenarios would provide a common approach for selecting design scenarios across governmental organizations and agencies, and enable regular updates to scenarios based on known threats and risks. The use of standardized scenarios would allow for comparison of findings from multiple exercises and training sessions. These findings could inform updates to protocols and be analyzed to understand common response and recovery capability requirements that may be correlated with certain types of scenarios.

Short-Term Opportunities

- Develop comprehensive tools and protocols for local incident management to effectively manage a large-scale chemical incident, whether intentional or accidental in nature, aimed at saving lives.

Mid-Term Opportunities

- Develop guides to promote responder knowledge base on chemical threats, to include ready, as-necessary guidance on classified chemicals and scheme to disseminate in accordance with Security Classification Guides.

Long-Term Opportunities

- Develop formalized training curricula aimed at public health, first responders (e.g., fire, law enforcement, hazardous materials) and emergency managers based on the guides, and decision support tools.

Radiological and Nuclear Hazard Science and Technology Preparedness

Science and Technology Priorities to Prepare for Radiological/Nuclear Incidents

A comprehensive review of Federal government programs, resources, capabilities, and priorities was performed by the team to evaluate current R&D gaps associated with radiological and nuclear threats and risks. Data from more than 20 Federal organizations were collected, analyzed, categorized, and discussed to determine gaps and priorities associated with future R&D priorities. The information resulting from this process is summarized below. The 18 priority gaps identified are clustered into five the categories: Improve Public Communication of Warnings and Advisories (2 gaps); Improve Event Characterization and Risk Assessment (3 gaps); Enhance Observations, Modeling, and Data Management (4 gaps); Develop Technology for Safer, Effective, and Timely Response and Recovery (9 gaps); and Integrate Science into Preparedness Decisions (6 gaps). As some gaps cross-cut categories, they may be discussed in more than one category in the summaries presented below. No identified gaps are linked to the Enhance Fundamental Understanding of Hazards category.

1. Improve Public Communication of Warnings and Advisories

Successful preparedness for R&N incidents depends on the ability of local communities and officials to adequately understand and successfully comply with the 'shelter-in-place', evacuation, or other protective and response action decisions. Based on the current state of the capability, the Task Force determined the need for increased local capability for public communication and improved citizen awareness to effectively execute proper response actions following an R&N incident, and the need for a more robust risk communication program between the key decision-makers issuing the advisories and the communities affected by the incidents.

In addition, a low level of understanding of radiation science and risk among lay audiences can lead to disproportionate levels of concern—either excessive concern or a lack of vigilance about personal protection. An effective risk communication program can provide easy-to-understand information to the public to foster a basic understanding of radiation data, thereby increasing the federal government's communication during a response and informing the public.

Recommended Science and Technology Actions

Over the last five years, the federal community has made great progress in developing tools to present complicated radiological response data and information to key decision-makers and in enhancing communication with the public during a radiological response. For example, RadResponder Network, brought online by collaborative efforts of FEMA, DOE, NNSA, and EPA enables Federal, state, local, tribal, and territorial response organizations to rapidly and securely record, share, and aggregate large quantities of radiological data. The IND (Improvised Nuclear Device) –specific document "Improvised Nuclear Device Response and Recovery: Communicating in the immediate Aftermath" was developed to provide detailed guidance for general population and emergency responders, alongside with the related materials. Still, recent national-level exercises have exposed substantial gaps in our overall radiation communications preparedness. As a result, the development of communication tools that easily relay complicated radiological data to decision-makers and affected communities are key S&T opportunities. These investments should lead to decision support tools that provide actionable information and visual aids that are easily understood by the public. Since radiation science and protection are by their nature very complex subject matters, it is a challenge to develop tools that accurately, yet simplistically, convey complex radiological information. Therefore it will be necessary to evaluate the developed tools for their effectiveness with representative stakeholder groups.

Short-Term Opportunities

Short-term investment can help devise the accessible, easy-to-use, yet sufficiently accurate tools for communicating risk and broadcasting advisories.

- Integrate visual methods into improved communication system. Develop, test, and refine the adequate sets of visual representation (color coding, graphs, infographics, icons etc.) to effectively communicate the level of radiation danger to the population of affected areas. Develop tools for data visualization of complex radiological information to facilitate data analysis and decision-making by stakeholders.
- Apply existing communication methods and systems to real-world scenarios (including the outcomes of the recent nuclear/radiological events at home and abroad) to test their efficacy and develop lessons learned.
- Provide information to useful and actionable outreach and public awareness efforts.
- Encourage citizen awareness of proper preparation actions (e.g., shelter in place, evacuate) in the event of a radiological or nuclear incident. Examine the current level of penetration for existing preparedness materials aimed at the wide population; develop the strategy to effectively disseminate the core message before, during, and in the immediate aftermath of the incident.

Mid-Term Opportunities

- Design new and improve existing communication capabilities, devising better ways to use existing communication infrastructure, and to improve its resiliency
- Assess local capabilities to effectively execute the protection and response orders, and introduce improvements where necessary

Long-Term or Sustained Opportunities

- Enhance the ability of community members and community leaders to understand conveyed information regarding radiological risks and responses to successfully execute protective measures. Develop a nation-wide system that effectively engages Federal, state, local, tribal, and territorial organizations in the case of significant R&N incident, including damages and loss of power grid, communications infrastructure, and limitations to broadcasting venues for public information messaging. Reaching this goal incorporates successful implementation of the short-term and Mid-Term solutions described above. It also includes creating and sustaining a framework for continued investment in efficacy assessments and subsequent improvements, incorporation of the latest means of mass-communication (text messaging, Twitter, any new vehicles etc.), and coordination of effort on all administrative levels.

2. Enhance Fundamental Understanding of Hazards

A variety of Federal research and development efforts aim to improve our understanding of radiological and nuclear hazards. Advancements in our understanding of the physical and chemical behavior of nuclear and radiological materials are being made, and the fact that the task force identified no “gap” in this area is not to imply that current efforts are not important. The significant amount of knowledge gained from modern advancements in basic science, data gathered from government nuclear tests, and studies of incidents like the Fukushima disaster remain essential to promoting radiological and nuclear safety and risk reduction.

Basic research supporting efforts to detect, locate, track, and identify nuclear materials serves as the foundation for applied efforts to enhance capabilities. Such research not only serves as the starting point for efforts to enhance the capability of responders, but also serves to educate the next generation of scientists and engineers needed to support national security operations. Basic scientific research applicable to national security missions should be driven by technology gaps that have been identified through studies of existing capabilities and methods. For example, studies of the Global Nuclear Detection Architecture have found that the ability to detect threat objects at greater distances is needed. These studies have also identified the need to significantly increase the ability to detect threats with low signatures resulting from a material's composition, environmental masking, or an adversary's operational shielding of the threat.

While this task force report does not identify current substantive gaps related to enhancing fundamental understanding of nuclear and radiological hazards, continued research of the physical and chemical behavior of nuclear and radiological materials are an essential science and technology contribution to nuclear and radiological hazard preparedness.

3. Improve Event Characterization and Risk Assessment

Based on the current state of capabilities, the Task Force determined that priority R&D investments should be directed at integration of multi-purpose detection technologies and supporting equipment (specifically, incorporating detection of multi-purpose weapons of mass destruction and counter-smuggling technologies into R&D efforts); The most important aspects of R&D include forensic determination of origin and/or route of interdicted materials; identification of direction and speed of radioactive particles in the environment; prediction of the project areas with fallout and radiological contamination; and understanding the impacts of the urban environment on dispersion. In order to conduct forensic determination of origin and/or route of interdicted materials, data on the method and time of nuclear enrichment and data on the formation and production of the materials are needed.

The successful and early detection of materials that pose R&N threats has always been an essential part of the National Protection Framework. Science and technology advances are needed to ensure that detection technologies are effective for a reasonable cost. The following performance parameters should be considered in planning improvements in detection technology:

- Cost: reduce the cost of detection equipment components, especially the detector material, in order to achieve widespread deployment, resulting in a higher probability of successful threat detection.
- Ease of Use: reduce the operational cost of equipment, in order to achieve widespread deployment and more effective use.
- Sensitivity: improve the overall sensitivity of detectors, in order to enable detection of extremely weak signatures.

- Threat Discrimination: enhance the ability to distinguish between threats and non-threats, in order to reduce cost on stream-on commerce and reduce workload for operators responsible for decision-making.
- Multifunction: create a 'universal' detector, to simultaneously provide best possible energy resolution, high efficiency, and low size, weight, and power profile. The overall design should prioritize the high energy resolution and low weight to ensure the combination of efficiency and ubiquity. Such a detector would minimize the need for separate specialized equipment purchases and become a foundation block for the agile detection systems that can monitor, detect, and identify with equal effectiveness.

Recommended Science and Technology Actions

Increased detection capabilities are attainable through two distinct research and development pathways. The first pathway seeks to enhance the performance and production methods of detector materials and supporting components, in order to achieve the vision of cheaper, easier to use, and better detectors. The second pathway looks to optimize threat discrimination and mission flexibility, thereby providing lower overall operational, maintenance, and training cost to its users. In the long term those pathways should be viewed as mutually enhancing, since improvements in threat discrimination and other optimizations can later be translated into the cheaper materials and production methods. Short-term, Mid-Term, and long-term goals for both pathways are designed to achieve gradual progress in all criteria: improve efficiency (long-term goal of improving detection efficiency, defined as probability of detection for a single radiation quantum [[2]] to greater than 99%), improve energy resolution (several specific multi-level goals), and develop novel technologies (long-term goal of identifying 'game changing' innovations). The entire cost of ownership (e.g., procurement, operations and maintenance, etc.) needs to be considered when developing new technologies, particularly in "technology pushes."

Short-Term Opportunities

- Determine additional discriminating signatures to link measured data with models and archived data
- Develop models of special nuclear material production processes to better understand how the relevant stages of the nuclear cycle create, retain, or modify discriminating material characteristics
- Improve performance of analytical techniques to increase instrument efficiency and sensitivity, and to lower thresholds for detection ion low concentrations
- Develop laboratory-based technologies and methodologies for enabling the determination of morphological and microstructural signatures
- Collect and measure signatures of high priority samples
- Improve consistency of analytical results for nuclear materials across multiple experts, laboratories, etc.

- Explore the currently poorly understood morphological and microstructural characteristics landscape and determine the highest impact characteristics in terms of discrimination and accuracy
- Collect and organize information on novel and emerging laboratory-based methodologies

Mid-Term Opportunities

- Develop predictive chemical and kinetic models of the most relevant steps along the nuclear fuel cycle or weapons production
- Develop a set of model signature predictions
- Connect multiple steps to determine predicted persistence of model signatures, such as inclusions
- Extend models to larger portions of fuel cycle and weapons productions

Long-Term or Sustained Opportunities

Following on the results of Short-Term Opportunities, phased long-term science and technology opportunities may be focused on advancing predictive models for nuclear forensic material characterization. Advances in predictive modeling would allow scientists and decision-makers to obtain high probability characteristics (formation process, provenance, etc.) of any given nuclear material. This will enhance the ability to prevent and disrupt unauthorized procurement, enrichment, transportation and dissemination of nuclear materials, vastly improving public safety.

Accurate and reliable identification of the direction and speed of radioactive particles in the environment, and of project areas with fallout and radiological contamination, (including understanding the impacts of the urban environment on dispersion) is another important gap, which needs to be addressed. The objectives that need to be achieved are following:

- Understand and assess radiation-related measurements and interpret their impact on the response plan
- Identify particle type and radiation levels
- Determine potential effects of identified hazards on responders and the affected population.

The fast-developing field of mathematical modeling and continually improving computational capabilities to process extremely large bodies of data should be harnessed to achieve those objectives. Their successful implementation will result in improving community resilience prior to the R&N incident and in improved decision-making in the immediate aftermath.

4. Enhance Observations, Modeling, and Data Management

At this time, conventional radiation detection approaches are not well suited to detect nuclear and radiological threats that do not pass through a fixed location or checkpoint. This leaves transportation infrastructure vulnerable, especially across unattended borders and coastlines. These areas, covered by small vessel or general aviation aircraft, are too large to be covered by currently commercial dedicated mobile detection systems. For many of types of infrastructure that are challenging to monitor, current primary capabilities are not based on detection of radiological material and instead involve the detection of people or vehicles moving along the path using non-radiological electro-optical methods. Even when a threat object is detected, there may not be a nuclear or radiological detection system being able to be quickly deployed to the scene.

Improvements in observations sensors and deployment platforms are needed to develop the following capabilities: (1) the ability to determine potential effects of identified hazards on responders and the affected population; (2) the ability to collect real-time data on the damage of critical infrastructure and key resources (CIKR) to ascertain the continuing functionality for response operations; and (3) the ability to identify the direction and speed of radioactive particles in the environment and project fallout contamination.

Recommended Science and Technology Actions

Based on the current state of capabilities, the Task Force determined that priority R&D opportunities should also be directed at developing post-incident management capabilities, including population monitoring; increasing our ability to detect threat objects at greater distances; and increasing our ability to detect threats with low signatures resulting from the material's composition, environmental masking, or the adversary's operational shielding of the threat. Threat detection at greater distances is especially required in situations when the adversary is operating in a non-compliant manner and/or in a non-official or non-regulated pathway.

Improving these capabilities will involve research and development efforts to create more affordable equipment for wide spread utilization, increased detection range in object tracking, and improved ability to detect shielded threats. This should encompass all Wide Area Monitoring and Search (WAMS) segments, such as Airborne Radiological Enhanced-sensor system (ARES), Radiation Awareness and Interdiction Network (RAIN), and Mobile Urban Radiation Search (MURS).

Additionally, the task force established a need to identify and leverage technologies that are not primarily nuclear or radiological in nature to better characterize nuclear/radiological hazards, such as the use of radar and other sensing technologies to augment radiological atmospheric dispersion models. The use of these technologies can increase confidence in initial assessments and decision support products, thereby potentially increasing the effectiveness of resulting protective action decisions.

Short-Term Opportunities

- Assess the current state of research to identify and leverage currently existing non R&N technologies which can be used for incident characterization and threat assessment.
- Monitor the educational system to ensure continuous supply of R&N specialists, capable of supporting incident prevention and response measures.

Mid-Term Opportunities

- Develop capabilities to detect, localize, and identify static or dynamic radiologic or nuclear sources from an airborne platform(s).
- Develop capabilities to support the sensory networks and databases which provide detailed information about radiological status of complicated terrain and materials (including urban settings), enabling rapid response measures
- Provide enhanced data modeling, creation and testing of advanced radiation detection algorithms against the established benchmarks of radiological background
- Facilitate the processing, organization, analysis, and dissemination of radiological data within a data management framework

Long-Term or Sustained Opportunities

- Create and deploy a network of hardware (including radiation detectors, ancillary sensors, and image capture systems), communication capabilities, and data analysis software to detect, localize, and provide actionable information on a specific transport carrying radiological or nuclear materials.

5. Develop Technology for Safer, Effective, and Timely Response and Recovery

Response and recovery, as defined in PPD-8, are the most critical mission areas relevant to R&N incident preparedness. The response mission area includes the capabilities necessary to save lives, protect property and the environment, and meet most basic human needs after the incident had occurred. The recovery mission area encompasses the capabilities necessary to assist communities affected by an incident to recover effectively.

Based on the current state of capabilities, the Task Force determined that priority R&D investments should be directed at proactive, preparedness activities at all levels of government to understand critical actions in the first minutes, hours, and days of a radiological incident. These activities include incident characterization, decontamination and waste management, post-incident medical care, and population monitoring. Once an R&N incident occurs, it becomes critically important to quickly and accurately characterize the nature, level, and geographical spread of contaminating agent(s). This requires a successful interplay of several areas of capabilities, which depend on one another to provide the most effective outcome. These linked capabilities are:

- Forensic analyses: these capabilities are used to determine the origin and route of interdicted materials, guiding the development of tools for remediation operations for critical infrastructure and surrounding contaminated areas.
- Cleanup protocols: these operations ensure public safety and support the recovery of a contaminated location to functional use. Accurate information on the properties of the exposure are needed to inform decontamination and waste management operations.
- Public Health surveillance: expert public health knowledge helps monitor the population and provide post-incident medical care and management.

There are several important gaps identified for this area. One is a need for a common and complete understanding of how existing tools, models, briefing materials, and other decision support products will be used to support local and state decision making during a radiological/nuclear incident. Another significant gap is a need for development of scientifically sound, effective, and economical methods and strategies for decontamination of contaminated areas and management of contaminated waste. Potentially large number of affected people following R&N incident require improvement in current methods of treating health consequences of radiation exposure and establishment of firm guidelines for rapid diagnostics and triage.

Recommended Science and Technology Actions

Through comprehensive operational guidance and planning, and varying response and recovery capabilities such as communication systems, decision makers, law enforcement, and other emergency responders at the state and local levels can be better connected to specialized federal assets and programs for response and recovery.

R&N incident preparedness R&D should focus on forensic capabilities for determination of origin and/or route of interdicted materials. At the basis of quick and accurate characterization of the contaminating agent lies the development and refinement of scientific instruments, such as mathematical/statistical models of dynamic processes of contamination's initial dispersion; its subsequent diffusion and spread; and efficacy of different remediation techniques. Successful application of those models relies on timely availability and accuracy of underlying data. Therefore data collection/storage/interpretation procedures, technical means of collecting/transmitting of the relevant data streams become the matter of foremost importance.

Efforts are already underway to support this gap through the development of the Radiological Operations Support Specialist (ROSS) program. The ROSS is designed to establish a cadre of experts that would be available to State and local entities from the Governor to first responders to assist with understanding and developing actionable decisions and policies during response and recovery efforts. There would be continued benefit in promoting and enhancing the ROSS capability as a national and available asset.

Continued R&D efforts should be placed on leveraging preventative radiological/nuclear detection equipment currently used by law enforcement for interdiction and detection. Specifically, there is a need to develop a concept of operations outlining how non-response and recovery technology and responder tools can be altered and adapted for dual-use, saving cost and minimizing; and finally within this category, there is a need for technology that can be deployed in the non-regulated, non-official air, sea, and land border entries into the U.S. This technology must be capable of being deployed to an area where there is little direct control by law enforcement and that helps gain the advantage over the adversary in these pathways. For example, although evaluation of dual-use detectors is not currently planned, EPA believes having law enforcement equipment evaluated for characterization during remediation in the intermediate to late-phase recovery would potentially be helpful in increasing the overall environmental response capacity.

The Federal Government has no experience in the cleanup of urban areas and critical infrastructure after a wide area contamination incident like Fukushima. Therefore, within the cleanup operations component of the recovery mission area, there is a need to develop strategies, tools, technologies and guidance to perform remediation and waste management operations for both critical infrastructure (e.g., transportation, power, water/wastewater, communications, medical resources, and essential government services) and the surrounding contaminated areas. Within the remediation operations, there will be a need to measure and manage environmental hazards (including characterization of the extent of contamination), mitigate and contain contaminants, conduct gross decontamination, and manage contaminated waste and debris to reduce the public's exposure and to support whole community recovery efforts.

The waste management processes must account for the full cycle of the waste lifecycle – from its generation to the proper security at the final destination. Lastly, Lack of information on fate and transport of radionuclides in the environment creates challenges with regards to planning and implementing cleanup strategies and methods.

In addition prioritization should be placed on developing post-incident medical care and management capabilities, including population monitoring; developing a strategy for sharing international information and medical supplies, countermeasures, and expert public health and medical personnel.

Short-Term Opportunities

- Dual-use Interdiction/Detection Tools: Develop a concept of operations outlining how non-response and recovery technology and responder tools can be altered and adapted for dual-use.

- Cleanup Operations: Identify, develop, and evaluate indoor and outdoor decontamination techniques and procedures considering the entire environmental response system (e.g. subsequent waste streams.) Determine the effects of decontaminant residues (from chemical-based decontaminants) on rapid analytical methods for high priority radionuclides.
- Post-Incident Medical Care: Develop a strategy for sharing international information and medical supplies, countermeasures, and expert public health and medical personnel.

Mid-Term Opportunities

- Chemical Modeling Data: Improve data collection, storage, and interpretation procedures for chemical dispersion, diffusion, and remediation models.
- Dual-use Interdiction/Detection Tools: Deploy technology in the non-regulated, non-official air, sea, and land border entries into the U.S. in areas where there is little direct control by law enforcement.
- Cleanup Operations: Improve remediation capacity through the development of effective techniques for managing waste, including technologies for waste minimization, and through development and evaluation of self-help methods and strategies for indoor environments.
- Cleanup Operations: Understand and predict the fate and transport of radionuclides in the environment, including in rural environments (e.g., forest fires) and water infrastructure.

Long-Term or Sustained Opportunities

- Multi-Purpose Detection Tools: Develop integrated, multi-purpose detection technologies and supporting equipment. Multi-purpose weapons of mass destruction and counter-smuggling technologies must be incorporated into R&D efforts.
- Post-Incident Medical Care: Develop post-incident medical care and management capabilities, including population monitoring.
- Cleanup Operations: Improve remediation capacity through development and evaluation of approaches for managing large volumes of contaminated water, methods for decontamination of critical infrastructure, and self-help methods and strategies for outdoor environments. Improve environmental response with tools that support training, situational awareness, decision-making, and waste management.

6. Integrate Science into Preparedness Decisions

Based on the current state of capabilities, the Task Force determined that priority R&D investments should be directed at (1) proactive, preparedness activities at all levels of government to resolve the lack of guidance on how to integrate scientific information into decision-making support; and (2) improving the speed, accuracy, and understanding of data collected during an incident and provided to decision-makers in the aftermath of an incident. Specific R&D investments could focus on:

- determination of origin and/or route of interdicted materials;

- remediation operations guidance for contaminated critical infrastructure (e.g., transportation, power, water/wastewater, communications, medical resources, and essential government services) and surrounding areas;
- rapid integration of health physics and radiological safety professionals (e.g., including the initiation, credentialing and training of a cadre of Radiological Operations Support Specialists (ROSS) who can integrate their knowledge of health physics and radiological safety into emergency operations and incident command support) into response operations, public messaging, and decision making; and
- tool development that enhances ability to assess and model scenarios; collection analyze, and report data as useful information; and expand capacity of resources for incidents.

Recommended Science and Technology Actions

The team recommends the development of an accessible, yet scientifically accurate risk communication program, which will include visual coding of risk levels. This program will have applications for both sides of the communications process: from the scientific/responder community to the general public and from the public to the decision-making authorities. If fully implemented, the pilot ROSS program would provide tremendous short-, medium, and long-term benefits for improved decision-making at the State and local level. Having trained personnel, experts in health physics and with understanding of Federal response and recovery frameworks (e.g., NRF, NIMS, ICS, UCS), would expedite the flow of scientific data in a manner that can be translated and acted upon to protect lives, improve safety, and enhance response and recovery effectiveness, specific to a radiological or nuclear incident. Continued R&D for supporting the ROSS and comparable resources for improved decision-making would focus on tool and resource development, such as software and deployable applications for modeling, data collection, analysis and reporting; specialized resource teams; access to science and technical data; and the ability to translate science data into actionable intelligence.

Short-Term Opportunities

- Continue focus on existing first responder awareness and training, applying science, modeling, and technology to improve responders' abilities to plan and act in a safer and more effective manner. In addition, continue existing multi-agency expert team building and enhancing and maximizing science and technology modeling collaboration and information management tools and software

Mid-Term Opportunities

- Assist decision-makers to better understand the data and information associated with radiological and nuclear incidents in order to identify prudent actions to take
- Promote better planning, mitigation, and resiliency in the context of potentially limited available resources

Long-Term or Sustained Opportunities

- Develop and provide new tools, applications, and resources in a manner consistent with a decision-making framework, to enable informed decision-making based on realisms, rather than on impulse or guess work stemming from limited knowledge or understanding of risks and needed actions to address those risks.

Geological Hazard Science and Technology Preparedness

Science and Technology Priorities to Prepare for Geologic Hazard Events

1. Improve Public Communication of Warnings and Advisories

In this area, public education is a significant gap that is common to all the geohazards. Despite being aware of a recommended set of actions in case of an earthquake or a tsunami, for example, people often increase their peril by taking actions contrary to those recommended. For example, it is not uncommon for people who run out of a building during an earthquake to be injured or killed by falling debris. By contrast, scenarios of potential disasters and certain hazardous events have proved to be particularly useful in helping users understand the results of research and consider the information in the decision-making process.

A second significant gap is inadequate infrastructure for public alerts and communication during emergencies. Clear language and graphics need to be used for public warnings. Alerts must integrate improvements to forecasts by expanding the use of probabilistic geohazard information required to communicate geohazard impacts.

A particular challenge is how to address the need for information, not just about hazards but also about vulnerability and risk. Quantitative understanding of societal vulnerability to hazards requires interdisciplinary studies combining physical science, engineering, and social and behavioral sciences. Likewise, risk assessment combines hazard with vulnerability through the combination of these sciences to evaluate the probability of losses. The relevant scientific understanding may reside in parts of the Federal Government, in the academic sector, or in the private sector. A consistent message from stakeholders is that the science agencies should take a larger role in ensuring that hazards information results in accurate risk assessments that have broader use by decision makers and society. Because many aspects of vulnerability and risk analysis can be done in partnership with others, risk must be treated as an integral part of hazards science that necessitates development of risk assessments.

Recommended Science and Technology Actions

The Federal Government must invest in activities that facilitate its responsibility to inform the public about risks and impacts of geohazards.

Short-Term Opportunities

- There are opportunities to reduce message delivery latencies in Federal, State and local warning communication systems to shorten warning communication times. Current Federal alerting systems, such as Integrated Public Alert and Warning System (IPAWS), cannot deliver warnings in time for protective actions to be taken (e.g., earthquake early warning, local tsunami warning, and lahar and debris flow warnings).
- Gain public attention to boost awareness of Federal hazards information and promote risk-wise behavior through collaborative develop of hazard and risk communication products. Examples of Federal efforts in this area are the National Tsunami Hazard Mitigation Program (NTHMP), the National Earthquake Hazard Reduction Program (NEHRP), the National Landslide Loss Reduction Act, and the USGS Science Application for Risk Reduction Project (SAFRR).
- Develop hazard-event and disaster scenarios and other strategic assessments. Expand the range of hazard, vulnerability and risk assessments and conduct tabletop exercises for a range of events that vary in the extent of their disruption to the public. Such assessments could be

conducted in partnership with current and potential users to meet their needs in advance of hazardous events.

- Issue earthquake early warnings and operational forecasting of earthquake sequences.

Mid-Term Opportunities

- Provide educational materials that include interactive hazards education and training in the use of assessments and are aligned to the needs of known and potential users.
- Assess and improve the effectiveness of educational and situational awareness products for warnings and response decisions and to guide the presentation and dissemination of hazard information. Such collaboration is being fostered through, for example, the USGS Science Application for Risk Reduction (SAFRR) project. Lessons learned should be developed by evaluating the effectiveness of risk communication, accuracy of interpretation, understanding of uncertainty, and appropriateness of response to disseminated hazard maps and scenarios.

Long-Term or Sustained Opportunities

- Promote citizen science activities such as Did You Feel It? (for earthquakes), Did You See It? (for landslides), Is Ash Falling? (for volcanoes) and Pacific Wave" (for tsunamis). It will be important to ensure the scientific integrity in these activities.
- Train scientists to improve interactions with the public and media, and give professional recognition to scientists who devote time and resources to effective public interactions.

2. Enhance Fundamental Understanding of Hazards

The work of Federal scientists has improved the scientific understanding of geohazards, leading to important improvements in hazard monitoring, assessment, and warning capabilities. Despite these improvements, identified science and technology gaps in the basic understanding of geohazards present the largest obstacle to national preparedness. Limited knowledge of earthquake initiation processes limits the ability to make accurate short-term forecasts, as does limited understanding of the frequent triggering and interaction of multiple hazard processes, the combination of which often carries unforeseen implications. Gaps include:

- Large uncertainties in the expected sizes and frequencies of tsunami;
- Inadequate assessment of onshore and offshore landslide location and mobility to support hazard and risk assessments, early warning, and other mitigation measures;
- Inability to predict the durations, sizes, and styles of volcanic eruptions from pre-eruption signals;
- Large uncertainties in earthquake ground motions in earthquake-prone regions.

Some of these gaps directly threaten the resilience of the Nation's critical infrastructure. For example, the lack of earthquake records of nonlinear, damaging motions in buildings, bridges and other structures, or even free-field recordings of ground shaking at damaged-building sites, results in unacceptable uncertainty in seismic design and mitigation methods, including many untested building, bridge, and pipeline designs.

Recommended Science and Technology Actions

Many of the gaps in fundamental understanding of geohazards are closely connected to gaps in critical observations. In the past several decades, the Federal Government has invested heavily in much-needed improvements to monitoring and data collection, but investment in research has become a priority, as well. The following are key research priorities:

Short-Term Opportunities

- Reduce the uncertainty in geologic hazard and risk assessments (e.g., earthquake ground motion prediction equations).

Mid-Term Opportunities

- Improve understanding of geohazard initiation processes (e.g., the role of earthquake ground-shaking on triggering landslides).
- Improve understanding of extreme events, which, although rare, are the events that have the greatest potential for societal disruption.

Long-Term or Sustained Opportunities

- Increase understanding of the underlying physical processes and necessary conditions for the occurrence of geologic hazards.
- Foster scientific expertise for advice in crisis response (through the Incident Command Structure) and non-crisis situations.
- Publish peer-reviewed science and results in jargon-free formats through easy-access mechanisms.
- Encourage interchange of ideas in research about the role of fluids in Earth processes, an essential topic to understanding a broad range of geohazard phenomena.
- Increase understanding of the triggering and interaction of multiple hazard processes (e.g., earthquakes triggering submarine landslides that trigger local tsunami).

3. Improve Event Characterization and Risk Assessment

The Federal Government develops assessments of geological hazards, vulnerability, and risk to inform decisions that can mitigate adverse consequences and increase risk-wise behavior. Assessments are a means for communicating about hazard science and the basis for investment in risk mitigation and increases in national, State, and community resilience.

During the lead up to and following geohazard events, Federal operational centers produce forecasts, alerts, warnings, and situational awareness products that are the basis for actions taken by emergency response officials and organizations, by government officials, and by the public.

Because societally significant geologic events occur rarely (and therefore data on past events is sparse), modeling is critical to project both the hazard and the risks. Geohazard assessments identify what is known and what is uncertain about past, ongoing, and future hazardous events. Hazard assessments can describe recurrence intervals and probabilities of occurrence, speed of onset, magnitude, duration, and spatial extent. For some hazards, assessments can provide information (e.g., maps) to answer specific questions that are often constrained by time-frame (e.g., event probabilities of hazardous event on various timescales), and location (e.g., regional variations in hazard exposure). Society benefits by using hazard assessments to understand and minimize vulnerabilities and risks, and by using them to inform strategies to enhance resilience to geohazards. Risk assessments combine hazard and vulnerability assessments to describe the economic and social impact of possible future hazardous events.

Recommended Science and Technology Actions

Seven significant gaps were identified in the area of Improve Event Characterization and Risk Assessment. The identified gaps are of several types: unacceptable uncertainty in assessment; lack of accurate loss modeling; insufficient data for modeling; and inadequate inventories of hazard. Gaps related to offshore processes are particularly large because of sparse observational data due to the difficulty and cost of data collection.

Short-Term Opportunities

- Evaluate warning and response products to improve their accuracy, timeliness, and communication. For example, this would include developing a comprehensive, national-scale inventory of landslide locations and potential activity to assess the extent of the hazard and to prioritize mitigation efforts.
- Expand investment in modeling for all geohazards, including increased access to supercomputers.
- Exploit worldwide databases on specific geohazards to support probabilistic, long-term hazard assessments and short-term forecasts and warnings.

Mid-Term Opportunities

- Improve the formulation and scope of scientific assessments:
    - Implement a robust process to rapidly incorporate new data and scientific understanding to update and improve assessment resolution, accuracy, and timeliness.
    - Develop probabilistic approaches and quantification of uncertainties where possible (e.g., probabilistic tsunami hazard modeling).
    - Incorporate secondary effects to provide more comprehensive estimations of the consequences of geohazard events (e.g., basin amplification of seismic shaking, post-eruption lahars from volcanoes and secondary explosions after initial long eruptions, landslides triggered by earthquakes, and water-quality impacts from hazardous events).
- Develop a consistent methodology for geohazard assessments of urban areas, where the density of people, buildings, and infrastructure that are at risk pose problems of societal and economic importance. This effort includes adapting hazard assessments to provide information relevant to building codes (e.g., seismic hazard maps) across the Nation.
- Create and improve the distribution and communication of effective multimedia assessments of geologic hazards and risks. These assessments could be developed through partnerships with users, social and behavioral researchers, and educators. For example, delivery of assessments by multiple media and according to user needs would improve the uptake of the information and its use in decision making.
- Encourage collaboration among scientists, engineers, social and behavioral scientific experts, planners, and emergency managers to enable tradeoffs and decisions on investing in

improvements in accuracy, resolution, and timeliness of scientific hazard assessments and engagement needs with broader non-scientific user communities.

Long-Term or Sustained Opportunities

- Develop multi-hazard assessments that compare the relative threat of different hazards or assess the combined threat of multiple hazards (e.g., earthquake data that provide information about volcanoes and tsunamis).
- Develop event and disaster scenarios and other targeted or strategic assessments to incorporate research results into planning and decision-making processes.
- Improve data systems critical to situational awareness responsibilities, including making monitoring networks more robust, expanding monitoring coverage as needed, and delivering information in usable formats.
- Translate hazard assessments into decision support methods and tools, in partnership with end-users, in those cases where the observational base and level of hazard understanding is mature and effort is likely to have significant societal benefit.

4. Enhance Observations, Modeling, and Data Management

Reducing the impacts of geohazards begins with observations, and the largest number of gaps was identified in this area. The Federal Government observes hazardous events across a large range of spatial and temporal scales. Monitoring networks are used to continuously observe a wide variety of phenomena with sensors located across the landscape. The data they collect can be used to create catalogs of events over time, providing critical information for scientific studies, assessments, and warnings.

In contrast, surveys are discrete recordings of events in space and time, updated as required with improvements in technology or understanding. Bedrock and surficial geologic mapping help to determine the geological setting for a variety of hazards and provide key understanding of earthquake and tsunami hazard sources, ground shaking, and landslide initiation and travel, and the tectonic setting and long-term record of volcanism. Aeromagnetic, magnetotelluric, gravity, and active-source seismic surveys provide unique constraints on subsurface geological structures and hazard sources.

Long-term hazard chronologies are developed from historical and paleo-hazard studies to recognize individual events. This broad spectrum of observations is critical to the accurate description of the hazard and the assessment of the chance of future events.

Recommended Science and Technology Actions

The first and highest priority is to maintain the basic observations and communication mechanisms that support forecasts and warnings, which are the core responsibilities of the agencies and areas of activity that must be safeguarded in times of decreased funding. A critical need is to ensure that the *existing* monitoring and alerting systems that the Federal Government operates are robust, well-maintained—and, in many cases, expanded to increase data density (and therefore product accuracy) or to cover high-risk areas that are not currently served. Information (data, nowcasts, forecasts, and interpretive geospatial products) also must be delivered in formats that are useful to a broad range of users, including partner agencies, fellow scientists, emergency managers, and the public.

As new understanding is developed through research, new tools and products should evolve to inform and advise the public, partner agencies, and the emergency-response community during hazardous events. This will require maintaining partnerships to define the products and activities needed for planning, response, and recovery efforts and define the delivery mechanism that will most effectively get critical information into the hands of planners and responders.

A major challenge to achieving these goals and objectives is that of recruiting and retaining software developers, data center managers and other information technology professionals. Because there is competition for these skills across business and government, Federal pay has not kept up with private-sector compensation, and science agencies are significantly challenged to recruit and retain staff with the expertise needed. This specific human resource gap affects many, if not all, of the opportunities below.

Short-Term Opportunities

- Monitoring network management opportunities:
  - Ensure robustness of existing Federal geohazard monitoring systems and associated data centers.
  - Ensure adequacy of equipment maintenance and replacement schedules that ensure network readiness.
  - Ensure adequacy of network provision of spatial and temporal data density.
  - Ensure availability of appropriate levels of redundancy in sensors and telemetry in critical locations.
- Ensure reliability and timeliness of systems (hardware and software) that convert field sensor data into an understandable product.
- Maintain and enhance data portals, archives, and web-based distribution systems.
- Establish operational alarm systems to detect volcanic unrest, eruptions, and ash clouds emanating from all high- and very high-threat volcanoes in the United States and its territories.
- Establish landslide situational awareness capabilities akin to those available for other geohazards by expanding on the NOAA-USGS partnership for post-wildfire debris-flow warning in southern California.
- Expand coverage and availability of real-time, continuous GPS data.
- Ensure that the United States has rapid and easy access to high-resolution topographic (e.g., light detection and ranging [LiDAR]) and synthetic aperture radar data.

Mid-Term Opportunities

- Ensure that the critical parts of the National Science Foundation's EarthScope facility are successfully transitioned to the relevant science agencies, including the EarthScope seismic and geodetic monitoring networks and associated data centers.
- Improve global seismic networks, which lack adequate coverage in broad ocean areas and in the southern hemisphere.
- Measure or model near-field tsunamis in real-time. Establish local tsunami warning along the U.S. coasts most prone to rapid inundation from geologic events.
- Develop and deploy instrumentation to monitor hazards in the submarine environment (e.g., geodetic instruments, mobile seismometers, mobile gravimeters, etc.), a goal that is both technologically challenging and very expensive.

Long-Term or Sustained Opportunities

- Support implementation and maintenance of existing geohazard monitoring systems: the Advanced National Seismic System and Global Seismographic Network; the National Tsunami Warning System; and the National Volcano Early Warning System.
- Improve overall data quality standards governing quality assurance, metadata, additions, curation, and timeliness.
- Expand observations of geologic settings, including geological mapping and geophysical data acquisition, which are essential to understanding the frequency, physical mechanisms, and impacts of events.
- Improve data collection during and after hazardous events to protect public safety and gather critical, ephemeral information. Examples are clearinghouse efforts set up by Federal agencies and the States after earthquake disasters.
- Use geological and historical methods to expand data on hazard chronologies and size/magnitude distribution studies needed to define probabilities of occurrence.

5. Develop Technology for Safer, Effective, and Timely Response and Recovery

Geologic events can be of long duration. Earthquake aftershocks, volcanic eruptions, and even landslides may continue to threaten the local community well beyond an initial “event.” Thus, for all the geohazards, continuing alerts, forecasts, warnings, and other situational awareness products are needed in the recovery phase, and it is necessary to provide timely assessments of rapidly changing hazard situations to inform tactical response and strategic recovery decisions.

Recommended Science and Technology Actions

Short-Term Opportunities

- Collect post-disaster ephemeral data such as tsunami inundation, earthquake damage to the built environment, landslide locations, ash fall, extent of run out of pyroclastic flow and surge deposits, and other data to provide situational awareness to response and recovery teams.
- Improve the accuracy and timeliness of alerts, forecasts, nowcasts, and interpretive geospatial products, focusing on the specific goal of better supporting search-and-rescue (SAR) and urban SAR operations.
- Foster crucial coordination of remote sensing and other assets for the rapid provision of geospatial information for geohazard event response operation.

Mid-Term Opportunities

- Build better models and collect better data on the response and recovery of systems, populations, and individuals from significant geologic events in order to minimize the chance of hazard events becoming disasters. For example, the seismic performance of most lifeline structures (i.e., power, water, sewer, etc.) is typically neither modeled nor monitored, leading to poor knowledge of earthquake threats to lifelines and little availability of situational awareness in the time of a disaster.

- Expand stakeholder science and technology outreach efforts that build working relationships among experts and across Federal agencies and State governments to exercise during disaster response and recovery.
- Conduct catastrophic event exercises to help response organizations plan a robust interdisciplinary response.
- Coordinate learning from national and international disasters and identify and promote hazard research that can best inform response operations during crises.

Long-Term or Sustained Opportunities

- Incorporate current and potential user needs in support of tabletop exercises and in the expansion of hazard, vulnerability, and risk assessment products. These products should include scenario-based tools and processes for use during post-event recovery, including events that lead to crises and widespread destruction and more common events leading to general levels of disruption to the infrastructure and daily activities.

6. Integrate Science into Preparedness Decisions

For the geohazards, gaps in scientific integration for decision making are manifest in two ways: (1) unrealized benefits and improvements because useful but distinct and separate data or information streams are not being combined, either due to technology hurdles or inadequate development and integration resources; and (2) unmet research needs on multiple or triggered hazards (such as earthquake-triggered landslides or landslide-caused floods.) For example, highlighting the combined effectiveness of multiple data streams, volcanologists combine seismic and geodetic networks in an effort to detect unrest and then selectively use other data sources to track volcanic activity.

Recommended Science and Technology Actions

Short-Term Opportunities

- Integrate seismic and GPS data into rapid earthquake and tsunami characterization and volcano monitoring.
- Integrate onshore and offshore monitoring data with geologic and geophysical data for improved estimates of hazard events. If done effectively, integration would help address knowledge gaps of the poorly understood processes occurring in the swath of the seafloor extending from the shoreline out a few hundred kilometers.
- Develop geospatial analysis of variations in community exposure to multiple hazards, in terms of the built environment, populations, businesses, and economic assets. The outcome of such analyses could be used by local and State emergency managers for outreach, scenario development, prioritization of hazard mapping, and response planning.

Mid-Term Opportunities

- Develop multi-hazard assessments of the relative risk of multiple hazards or the combined risk of multiple hazards (such as earthquake data that provides information about volcanoes and tsunamis). (Cross-listed with “Improve Event Characterization and Risk Assessment.”)

Long-Term or Sustained Opportunities

- Expand research in triggering and interaction of multiple hazard processes, which occur frequently in nature and have distinct probabilities of occurrence and potential impacts. Each hazard is governed by physical processes that can trigger other hazards and amplify effects (e.g., earthquakes trigger landslides that can set off tsunamis or cause liquefaction that destroys more buildings). (Cross-listed with "Enhance Fundamental Understanding of Hazards.")

Meteorological Hazard Science and Technology Preparedness

Science and Technology Priorities to Prepare for Meteorological Events

1. Improve Public Communication of Warnings and Advisories

The delivery of timely, credible, and actionable information, warnings, and advisories is essential for saving lives and avoiding other types of losses prior to, during, and following meteorological hazard events. Advances in the public communication of hazards information and warnings are most effective when coordinated and consistent messaging across Federal agencies is provided. Federal agencies that support this goal should follow guidance in the National Preparedness Frameworks and Federal interagency operational plans. An interdisciplinary approach—employing evidence from both physical and social sciences—is required for success.

Recommended Science and Technology Actions

Priority investments are required in communicating scientific uncertainty, communicating risk, developing communications technology, and building a resilient communications infrastructure for the Nation to be more robustly prepared within each of the national preparedness mission areas. Research and development (R&D) within these priority areas of investment will contribute directly to advancing early warning and advisory capabilities. Projects that strengthen the communications infrastructure will directly enhance our Nation's overall critical infrastructure resilience and, ultimately, save lives. These actions have been identified as those that are the greatest need and will deliver the most improvement in making warnings and advisories more effective.

Short-Term Opportunities

Sound Short-Term Opportunities are those that develop new or refine ongoing projects that align with the above-mentioned communications need and can be implemented in the next two fiscal years.

The meteorological hazards team's top priority is social science projects that improve the communication of scientific uncertainty and risk communication for weather and climate hazards. Federal agencies that originate weather and climate warnings and advisories that target the public should continue to coordinate these projects to ensure that investments in them are effective and efficient. Consistent messaging is critical to the success of the Federal interagency effort to maximize national preparedness for public information and warning.

A second priority is ongoing Federal agency projects that focus on improving communications technology and the Nation's communications infrastructure. It is unlikely that a new project in these important areas will be completed in the near future; it is for this reason that the team prioritized existing efforts that can be improved through alignment with ongoing efforts.

Mid-Term Opportunities

As with Short-Term Opportunities, Mid-Term Opportunities should also prioritize projects that address communicating scientific uncertainty, communicating risk, developing communications technology, and building a resilient communications infrastructure.

The meteorological hazard team identified some specific project areas related to risk communication that should be priorities for Federal investments. These include science and technology investments to enable:

- High-resolution, grid-based, probabilistic hazard information products that can improve whole-community decision making and better inform resilient building strategies.
- National codes, standards, and guidance for the creation and dissemination of clear, consistent, and accurate emergency communications for tornadoes. It is likely that other weather hazards that have little to no warning lead times can also benefit from advances related to tornadoes.
- New communications technology that supports public information and warning within the Federal Emergency Management Agency (FEMA) Integrated Public Alert and Warning System (IPAWS). This includes science and technology that has potential to enable modernization or transition from legacy public warning dissemination systems such as the Emergency Alert System and the NOAA Weather Radio transmitter network. Science and technology with potential to improve Wireless Emergency Alerts (WEAs) is also a priority, consistent with the recommendations of Federal Communications Commission-led working groups and research supported by DHS Science and Technology Directorate.

Long-Term or Sustained Opportunities

The team identified no Long-Term or Sustained Opportunities in the area of public communication of warnings or advisories.

2. Enhance Fundamental Understanding of Hazards

The Nation's preparedness for meteorological hazards requires advances in the fundamental understanding of meteorological processes and severe weather events, including research on Earth system processes (e.g., environmental, chemical, and physical processes), emerging technology, and social and behavioral dimensions of the applications of information (e.g., how scientific information is used to support decision making). Fundamental research improves basic understanding of ocean, climate, and meteorological processes, which, when coupled with observations (discussed in a later section of this chapter), enables advances in models and, ultimately, forecasts of high-impact events. The gaps and actions in the other categories in this chapter are all dependent on fundamental research.

Key fundamental research gaps include the need for research in: Earth system processes; diagnostic analysis and evaluation of forecasts, predictions, and vulnerability/risk; mechanisms associated with high-impact weather and climate extreme events, including cascading hazards (e.g., a wind storm leading to power outages during a heat wave, resulting in increased mortality due to lack of air conditioning); and modeling of streamflow, groundwater, storm surge, and coastal waves.

Recommended Science and Technology Actions

By implementing the recommended actions below, the Nation will help ensure its leadership role in state-of-the-art science and technology on which national preparedness rests. For example, advancing the fundamental understanding of meteorological hazards requires research across a continuum from analysis of atmospheric and oceanic physical processes to climate variability and change to modeling and prediction of processes that drive weather and climate extremes. The following actions have been identified as those that should be emphasized to most effectively and efficiently advance the Nation's preparedness for meteorological hazards.

Short-Term Opportunities

Short-term investment is needed to coordinate data and tools (including models) between agencies, with emphasis on vulnerability assessments and community resilience that span geographies and meteorological hazards.

Mid-Term Opportunities

Investments in the midterm should focus on the following activities:

- Continue Earth system research that advances understanding of fundamental physical, dynamical, and biogeochemical processes; identifies sources of predictability; and improves models and predictions of meteorological hazards, including high-impact weather and climate events.
- Improve understanding of streamflow dynamics and groundwater/surface water interactions to better forecast and prepare for flooding and other streamflow impacts, including updating streamflow statistics for gaged and ungaged streams with methodology for accounting for climate change-driven streamflow that changes over time (nonstationarity) and guidance for decision makers; improved understanding of groundwater/surface water interactions and groundwater quantity through better measurements and analysis; and evaluating changes in stream temperature attributable to climate change.
- Improve understanding of coastal wave and storm surge dynamics and their interactions with the atmosphere, including air-sea exchanges, wave-current interaction, wave-driven setup contribution to storm surge, and overland wave propagation.
- Quantify/verify models through measurements.
- Evaluate changes in storm tracks and intensities due to climate change and the impacts of these changes on coastal risk and resilience.
- Improve understanding of the meteotsunami hazard (weather-driven extreme water-level changes) in the Great Lakes and other bodies of water in order to develop a potential warning system.

Long-Term or Sustained Opportunities

In terms of Long-Term Opportunities, recommended activities are:

- Perform measurements and analysis of vulnerability to hazards based on physical parameters and climate change projections.
- Assess natural and nature-based protection strategies (e.g., coastal wetland and dune restoration) by means of field, laboratory, and numerical research as well as ecological, economic, and social evaluation.

3. Improve Event Characterization and Risk Assessment

Event characterization, including forecasts, and risk assessments are foundational for both mitigation and response. Forecasts and risk assessments inform planning efforts and design standards, both of which are used to reduce impacts and speed recovery from weather-related events. Appropriately designed infrastructure protections, for example, are particularly important for effective and rapid recovery. Improved event characterization would also enable improvements in early warning capabilities and, of course, planning and execution of response operations.

Recommended Science and Technology Actions

For meteorological hazards, needs related to Improve Event Characterization and Risk Assessment fall into two main areas: improving forecasts and sector-specific applications. Better forecasting is needed as it relates to windstorms (thunderstorms and tornadoes) and precipitation. In particular, improvements are necessary in (1) forecasting precipitation events; (2) in estimating flash flooding and debris flow; (3) in measuring precipitation frequency and intensity; hurricane frequency, intensity, and track information (especially frequency of storms that make landfall); frequency and intensity of thunderstorms and tornadoes; occurrence and intensity of freezing rain and winter storms; and (4) in predicting fire weather. Computer capacity to enable higher-resolution model output would enable better forecast granularity in space, longer forecast ranges, and more forecasts tailored to sector-specific areas (such as aviation, land transportation, renewable energy, wildfires, and building design).

Forecasting improvements for the suite of weather hazards is one of the areas with the greatest need in this category. Accomplishing these improvements will require an improved Earth-observing system and more advanced Earth system models (discussed in the next section) to bolster efforts to identify sources of predictability and, ultimately, improve the accuracy of predictions. At present, the scientific community foresees potential forecast improvements related to precipitation (including forecasts for coastal tropical and extratropical events, river flooding, wind and storm surges); improved wind forecasts for tornadoes and severe thunderstorms; improved wildfire models and decision support tools; and enhanced weather-event predictions and projections (precipitation, flooding, and wind) for engineering and building professionals.

Short-Term Opportunities

In the short-term, Federal agencies should continue to facilitate communication among water-observation data managers and modelers to help resolve methodological differences and better tailor observational data to calibrate and verify model results.

Mid-Term Opportunities

The following activities are priorities for midterm investment by Federal agencies:

- Improve precipitation modeling and forecasting, and the computing capacity to produce them, for short time periods (24, 48 and 72 hours) and longer time periods (15- and 30-day); improve accuracy of forecasts, including the communication of uncertainty ranges.
- Develop and implement scientific and technological capabilities for 1) river and flood forecasting and 2) tropical and extratropical storm surge and wave forecasting.
- Research and develop methods for windstorm impacts characterization, including hazard quantification and mapping, modeling of wind loads and wind structure interaction, and more accurate estimation of windstorm disaster losses.
- Increase R&D of integrated fire weather modeling and forecasting.
  - Simulation of fire in complex terrain, especially the wildland-urban interface.
  - High resolution forecasts of humidity, wind, and precipitation for fire prediction.

Long-Term or Sustained Opportunities

The team identified no Long-Term or Sustained Opportunities in the area of Improve Event Characterization and Risk Assessment.

4. Enhance Observations, Modeling, and Data Management

Observations, data, and models are the basis for sensing changes in the environment, characterizing events, assessing risk, and deriving other decision-relevant preparedness information. Long-term data sets are especially important for understanding hazards that may take place over long timescales (e.g., drought, climate change impacts). The highest priority gaps and themes follow for observations and data management together and for modeling and predictions.

Observations and Data Management

Additional observations and well-managed data sets are needed to fill the gaps for key meteorological hazards and site-specific event characterizations related to tropical cyclones, drought, and extreme precipitation. Key gaps include observations and measurements for mesoscale monitoring; for improved tropical cyclone forecasting; for monitoring of soil moisture for drought; for watershed supply and demand associated with climate change; on hazard, load, and response for buildings and infrastructure in coastal or riverine floods; fire weather forecasts and decision support for wildfire planning and operations; and, generally, probabilistic forecasting information, data, and evaluation. Also, gaps listed in the other sections of this chapter are typically interdependent with observations; for example, improved forecasts are possible with improved observations and fundamental research can be conducted to advance the observational network.

Modeling and Predictions

Improved modeling is needed in the areas of tropical cyclone predictions, with emphasis on cyclone intensification; winter storms, especially in polar regions; short- and long-term drought prediction; modeling for prediction of atmospheric convection across all scales; and hydrological services for extreme event precipitation forecasting. Further, errors need to be eradicated in numerical weather prediction formulae in weather models that produce unreliable and overconfident probabilistic forecasts as well as poor representation of large anomalies such as extreme weather events. Efforts to fill several gaps listed in other sections of this chapter would support these modeling needs, including fundamental research that leads to better Earth analysis and forecasting.

Recommended Science and Technology Actions

Observations and modeling are essential for situational awareness and successful understanding that leads to better protection and mitigation. Investments in modeling and the computing infrastructure that supports them will result in better decisions across the preparedness mission areas. Observations, models, and data are the foundation for sensing change in the environment and translating those measurements into risk and decision-relevant preparedness information.

Short-Term Opportunities

Activities for short-term investment are:

- Continue to identify sources of predictability and improve predictions for the leading patterns of climate variability on timescales from subseasonal (e.g., blocking, atmospheric rivers, and Madden–Julian oscillation) to seasonal-to-interannual (e.g., El Niño–Southern Oscillation) through improved observations and modeling.
- Pursue seamless weather-to-climate prediction, including links between the frequency and intensity of weather events (including extremes) and the leading patterns of climate variability.

Mid-Term Opportunities

The priorities for investment by Federal agencies should focus on these recommended midterm actions, including those listed in the appendices of this report.

- Enhance observations and modeling for tropical cyclones
  - Increase satellite scatterometer ocean surface vector wind observations.
  - Annually monitor tropical cyclones using aircraft where X-band tail Doppler radar data are collected and ingested in forecast models.
  - Conduct Observing System Simulation Experiments (OSSEs) and Observing System Experiments (OSEs) [3] to optimize observing systems that improve monitoring and prediction of tropical cyclones.
  - Perform research and modeling studies to improve understanding of the complex interactions of tropical cyclone intensity, structure, track, and environmental forcing.
  - Improve current ocean schemes in the coupled tropical cyclone modeling systems to perform comprehensive evaluation and improvement of ocean-atmosphere interaction processes in regional coupled hurricane prediction systems.
  - Improve storm surge prediction capabilities.
- Winter hazard prediction
  - Enhance multi-model ensemble systems for prediction of probabilistic winter weather phenomena.
  - Improve numerical weather prediction (NWP) across Alaska and the Arctic to downscale winter hazards and provide more targeted impacts.
- Observations, modeling, data assimilation, and high-performance-computing needs
  - Employ "testbeds" for applied R&D to evaluate and integrate national mesoscale observing systems to address deficiencies in areas with unique requirements (e.g., cities, mountainous terrain, and coastal zones).
  - Improve data assimilation of available observations for improved modeling and prediction.
  - Research and develop techniques that will reduce errors in numerical weather prediction and improve model accuracy.
  - Drought: Coordinate Federal Activities to improve monitoring of soil moisture; add soil moisture sensors to all Climate Reference Network sites.
  - Floods: Develop technologies or measurement systems where buildings are located so information can be captured on water velocity, wave, and sediment supply to inform design approaches.

[3] Observing System Simulation Experiments (OSSEs) are numerical model based experiments designed to test hypothesized impacts of future observing systems on subsequent predictions and forecasts. OSSEs provide a rigorous, cost-effective approach to evaluate the potential impact of new observing systems and alternate deployments of existing systems, and to optimize observing strategies. OSSEs are an extension of Observing System Experiments (OSEs), which are data denial experiments to determine the impact of existing observing systems. OSEs allow for the objective assessment and comparison of existing operational observing systems in a controlled software environment.

Long-Term or Sustained Opportunities

Among the highest priority long-term observational investment is developing water body reference monitoring networks to detect watershed changes driven by climate change. Prioritized investments in modeling include performing modeling studies for improved understanding of interactions between tropical cyclone intensity, structure, track, and environmental forcing; and also the need for scale awareness parameterizations for the prediction of extremes. Additional recommended actions are listed below and in the appendices.

- Observations
  - Collect and employ Earth observation data, imagery, and reference measurements with higher temporal, spatial, and spectral resolution through sustained observations and better reuse of related data for land imaging, boundary layer observations, air quality measurements, natural hazards, hydrology, and severe-weather forecasting.
  - Federal agencies and partners should deploy LIDAR and radio frequency profilers nationwide at approximately 400 sites to continually monitor lower tropospheric conditions.
  - There are opportunities to seek the improvement of the quality of geo-stationary satellite water vapor and temperature soundings within the contiguous United States.
- Modeling
  - Improve weather and climate models' physics and numerical schemes to more accurately depict unresolved processes in the atmosphere and oceans.

5. Develop Technology for Safer, Effective, and Timely Response and Recovery

While there is a strong role for science and technology to support meteorological event preparedness, the meteorological needs for response and recovery technology, as defined in this report, specifically are minimal. The main roles that science and technology supports have to do with forecasting, observation, and modeling; the delivery of the resulting information, and the gaps and needs for these are primarily covered in the other sections. As discussed in other development areas, meteorological information and data products can inform the design of scenarios, plans, and hazard-agnostic technologies that can be used in the response or recovery phase of a meteorological event. The meteorological and climatological information needs highlighted in this chapter provide the information that is used to choose the best strategies for national and community preparedness. This information, in turn, better situates the Nation to respond to events more effectively and recover from them more rapidly.

6. Integrate Science into Preparedness Decisions

Improved decision making for meteorological hazard events requires the integration of scientific information with enabling technologies such as decision support tools for hazard impact modeling and risk analysis, situational-awareness tools that improve operations, and tools that increase community resilience. For example, NOAA's Weather-Ready Nation initiative is about building community resilience in the face of increasing vulnerability to extreme weather and water events. As part of the Weather-Ready Nation initiative, NOAA, along with partners such as FEMA, helps communities take actions that will prepare them for a weather disaster. The first step to becoming weather-ready is to understand the type of hazardous weather that can affect a community and then respond accordingly when a forecast or warning is provided.

For meteorological hazards, the development of decision support tools and the associated training are priority gaps that cross-cut the preparedness mission areas. Situational awareness tools and training that enhance operational communications will contribute to advance early-warning capabilities. Decision support tools that model meteorological hazards, assess the associated risks, and inform design standards and infrastructure strengthening strategies will enhance critical infrastructure resilience.

Recommended Science and Technology Actions

To protect life and property from meteorological hazards requires a whole-of-community approach to preparedness. Scientific agencies must effectively communicate hazard information to decision-makers that include emergency management, community officials and the public in ways that enable them to play their important roles in protection, mitigation, response, and recovery. Thus, for each mission area, decision support tools that translate the relevant scientific information are necessary. R&D efforts for these tools should ensure they have value to the targeted decision-makers. Also, training and outreach are essential for the successful use of these tools. Investments in these actions will result in better decisions across the preparedness mission areas.

Short-Term Opportunities

Training and outreach for decision support tools on meteorological hazards are the investments that will be most readily achieved. Investments should be made in strengthening existing decision support tools that lack guidance, training, and outreach, as well as in implementing tools that are still in the development cycle. Effective decision support relies on a solid base of information which can be enhanced through the execution of the top short-term actions outlined earlier in this chapter. Top decision making investments include R&D, training, and outreach investments in decision support tools that integrate:

- Social/behavioral science research to inform effective means of communicating hazardous weather information to the public and
- Research and model development to improve the prediction of high-impact weather and climate events.

Mid-Term Opportunities

Federal agencies should work toward developing decision support tools and associated training that transition meteorological hazards research to operations with a focus on better decision making by emergency management, community officials, and the public. Best practices of utilizing testbeds to evaluate these tools and providing training should be considered.

The following focus areas are deemed to be the highest priorities for midterm investment:

- Tropical cyclone forecasting systems.
- Tools and training that enhance decision makers' ability to act on climate change.
- Ensemble prediction systems with probabilistic forecast products. (Precipitation products were identified as the most important.)
- Flood inundation mapping.
- Tools and training that relate data from previous high impact events or worst case scenario events (e.g., wind and water velocities, waves, and sediment supply) back into built infrastructure approaches.

Long-Term or Sustained Opportunities

The team identified no Long-Term or Sustained Opportunities in the area of technology delivery for response and recovery.

Space Hazard Science and Technology Preparedness

The space hazards team considered both hazards from space weather events and hazards from Near Earth Objects (NEOs). The team's analyses for these two distinct types of hazards are presented in this chapter separately, beginning with preparedness for space weather hazards.

Space Weather Hazard Preparedness

Science and Technology Priorities to Prepare for Space Weather Events

1. Improve Public Communication of Warnings and Advisories

Public communications of U.S. Government space weather warnings and advisories are handled through the NOAA Space Weather Prediction Center. These responsibilities include the delivery of real-time monitoring and forecasting data that various agencies and industries use.

The science and technology priorities for space weather hazards do not deal directly with the front-end mechanisms and channels for public communication of space weather warnings and advisories. Rather, they deal with the back-end capabilities that feed into existing warning and advisory systems employed by centers like the NOAA Space Weather Prediction Center. These back-end capabilities can range from observational space assets to data forecasting models and tools. Although the space hazards team has identified no specific gaps in this area, a concerted effort is needed to integrate new back-end capabilities with existing warning and advisory systems in order to enable delivery of new or improved capabilities to users as quickly as possible.

In addition, SWAP Objective 4.4, "Improve Operational Impact Operational Forecasting and Communications," lists two actions related to public communication of warnings or advisories: (1) survey operators and emergency managers to develop functional forecasting capabilities and alert products and (2) develop new or improved forecasting models and relevant tools to ensure the operational execution and dissemination of forecasts.

2. Enhance Fundamental Understanding of Hazards

Fundamental understanding of the Sun-Earth domain and the dynamic processes of space weather phenomena as they originate from the Sun and travel to Earth through the heliosphere, magnetosphere, and ionosphere are critical to the development of models and actionable tools and capabilities for predicting space weather events and their impacts on Earth. The limited understanding of these processes is a high-priority gap. Furthering this understanding will improve the development of forecasting tools and enhance capabilities to protect, mitigate, and respond to space weather events.

A consequence of the limited understanding of solar-terrestrial physics is limited capability to provide geographically specific space weather information. Current models and tools that enable space-weather forecasting capabilities are generally focused on large-scale regional (e.g., hemispheric) or global effects. Greater localization of forecasting capabilities, in addition to greater lead times and accuracy, is highly sought after by critical infrastructure owners and operators, such as electric utility services.

Recommended Science and Technology Actions

The objectives of the actions recommended below are to improve the fundamental understanding of the Sun-Earth domain and to extend forecast modeling capabilities to geographically-specific and localized areas. These objectives would be achieved through the refinement of existing models as well as the development of new models to facilitate model chain coverage from the Sun to the surface of Earth. These models would then be able to support the development of better forecasting tools that are both more accurate and more geographically specific. The below actions map to SWAP objective 5.5: Enhance Fundamental Understanding of Space Weather and Its Drivers to Develop and Continually Improve Predictive Models.

Short-Term Opportunities

Thorough and accurate models are needed to capture the dynamic processes of space weather phenomena as they travel through the domains between the Sun and Earth (e.g., heliosphere, magnetosphere, ionosphere, etc.). The first action is therefore to identify domain-modeling gaps in the set of existing and in-development space weather models and to create a plan for strategic investments to ensure a robust set of models throughout the Sun-Earth domain. This should extend to the surface of Earth and include models to enable geographically specific forecasting capabilities (SWAP Action 5.5.1).

Mid-Term Opportunities

Once the domain gaps are identified and a strategic investment plan is created, the opportunities exist to support the development of new and existing models. A key set of models to support the development of localized forecasting tools and capabilities should be completed in the midterm.

Long-Term or Sustained Opportunities

Refinement and expansion of the modeling library should be a sustained effort. Other sustained investments identified in the National Space Weather Action Plan include regional magnetotelluric surveys of geographic regions having the highest induction hazards (SWAP Action 5.5.5).

3. Improve Event Characterization and Risk Assessment

Benchmarks serve as inputs to risk assessment processes by helping to characterize events through a set of physical characteristics and conditions against which space weather events can be measured. The current lack of necessary benchmarks against which to baseline and identify events, in partially due to complexities in defining such benchmarks, such as a lack of historical data. Without benchmarks to characterize events and standardize metrics, developing tools, techniques, and processes to protect and mitigate space weather events will continue to pose a challenge.

Another high-priority gap is the lack of tools for decision support and risk management to support assessments of risk and vulnerability of critical infrastructure to the effects of space weather. Models, tools, and capabilities to enable this would allow critical infrastructure owners to understand their vulnerabilities and enable them to protect and mitigate, thereby improving critical infrastructure resilience.

Recommended Science and Technology Actions

The objectives of the actions below are to enable characterization and risk and vulnerability assessments of space weather events. These objectives will be achieved by establishing space weather benchmarks (*National Space Weather Strategy* Goal 1), improving the understanding of space weather impacts to critical infrastructure, and developing models, tools, and capabilities (*National Space Weather Strategy* Goal 4).

The development of benchmarks and models will serve as input into forecasting and assessment tools, which will help improve situational awareness and event characterization, improve response, and reduce risk and vulnerabilities of critical infrastructure to space weather events.

Short-Term Opportunities

Benchmarking programs should be funded and created within the lead agencies identified in Goal 1 of the National Space Weather Action Plan. The benchmarks to be created should include benchmarks for induced geo-electric fields, ionizing radiation, ionospheric disturbances, solar radio bursts (SRBs), and upper atmospheric expansion (SWAP Objectives 1.1–1.5).

To support the development of risk and vulnerability assessment tools (SWAP Actions 3.2.1, 3.2.2), the first step is to monitor, catalog, and model the impacts of space weather events on critical infrastructure systems (SWAP Objective 4.3). As understanding of these impacts improves, associated operational forecasting models should also be refined and developed (SWAP Action 4.4.2). In addition, outreach will need to be conducted with critical infrastructure owners and operators to collect requirements for the development of necessary operational tools (SWAP Action 4.4.1).

These actions are high-priority short-term items because they are tied to the ability to identify and characterize space weather events and understand their impacts on critical infrastructure. Once these impacts are understood and quantified, risk and vulnerability assessment tools and techniques should be developed not only for use at the Federal, State, and local levels but also for owners and operators of private sector critical infrastructure.

Mid-Term Opportunities

No opportunities identified.

Long-Term or Sustained Opportunities

No opportunities identified.

4. Enhance Observations, Modeling, and Data Management

Forecasting and early warning capabilities rely on real-time monitoring and detection of space weather events, which are provided by an array of space-based and ground-based observational sensors. Space-based observational capabilities are particularly important for early detection and warning capabilities, but some observations currently depend on aging deep-space satellites such as NASA's Solar and Heliospheric Observatory.

Despite the essential role these satellites play in collecting essential operational data, significant gaps remain in long-term strategic plans to fund and maintain these observational capabilities. Loss of these capabilities would prevent forecasting and early warnings and jeopardize the Nation's ability to protect, mitigate, and respond to space weather events.

Recommended Science and Technology Actions

The objectives of the recommended actions below are to maintain current observational capabilities, expand capabilities where necessary, and increase their diversity, resulting in greater resilience (SWAP Objectives 5.3, 5.4, 6.2). These actions not only ensure preservation of forecasting and early warning capabilities, but also facilitate basic research to further fundamental understanding of the Sun-Earth domain.

Short-Term Opportunities

Numerous operational capabilities for monitoring space weather events are beyond their operational life span, and sustaining and enhancing these operational capabilities is essential. A technology roadmap should be developed that includes not only traditional technologies but also alternative and emerging technologies evaluated in the short-term actions below. In addition, development of a dedicated satellite for space weather observation should be incorporated into this roadmap (SWAP Actions 5.3.1, 5.3.2).

To increase the diversity of space weather sensors, alternative and emerging technologies need to be evaluated for their maturity and capability in monitoring and detecting space hazards. Examples of such technologies include microsatellites, miniaturized sensors, and ground-based technologies. Evaluations should detail the type of operational data that each technology collects to facilitate decision making that ensures sufficient coverage of data types (SWAP Actions 5.4.2, 5.4.3).

Mid-Term Opportunities

The development of supporting arrays of ground-based instruments with real-time data capabilities for use in space weather forecasting is recommended to execute the strategy identified in the previous section on Short-Term Opportunities. Alternative technologies to replace these capabilities should be considered, and the existing United States Geological Survey/NSF EarthScope program, should be expanded to provide coverage of the continental United States (SWAP Actions 5.3.4, 5.3.6, 5.3.8, 5.3.9, 6.2.1).

Long-Term or Sustained Opportunities

Observational systems require periodic replacement of space-based and ground-based systems to maintain operational capabilities is an area of needed ongoing maintenance.

5. Develop Technology for Safer, Effective, and Timely Response and Recovery

Space weather events can disrupt critical infrastructure systems and permanently damage system components, as occurred during the March 1989 geomagnetic storm. The electric grid is of particular concern, and a major event could permanently damage power transformers, cause voltage collapses, and affect other critical infrastructure sectors that rely on the power grid. Improved capabilities, standards, and technologies for critical infrastructure will enable their protection, mitigation, response, resilience, and recovery from significant space weather events.

Recommended Science and Technology Actions

The objective of the actions below is to increase critical infrastructure resilience against space weather events, which requires a comprehensive approach through the development and implementation of standards, plans, technologies, and capabilities to respond and recover from significant space weather events.

Short-Term Opportunities

An immediate short-term action is to develop a Power Outage Incident Annex to the Federal Interagency Operational Plans that includes responding to and recovering from space weather events (SWAP, Objective 2.1). In addition, plans should be developed for stockpiling replacements of critical infrastructure components sensitive to space weather damage, with priority given to components that are difficult to procure or have long manufacturing lead times. Engineering standards for systems should be developed to improve resilience against space weather events (SWAP Action 6.4.6).

Development of technologies and capabilities that will allow critical infrastructure owners and operators to reduce the vulnerabilities of their systems to space weather events is recommended.

6. Integrate Science into Preparedness Decisions

As discussed previously, existing forecasting capabilities are focused at the regional level, but many affected sectors, such as electric utilities, require localized forecasts to take mitigation actions in response to space weather events. Therefore, there is a need for decision support tools that are not only accurate and reliable, but also actionable. In addition, outreach to and education of critical infrastructure owners and operators will increase awareness of the risk of space weather events and spur adoption of critical infrastructure resilience measures.

Recommended Science and Technology Actions

The objective of the recommended actions is not just to develop tools and capabilities, but to ensure these capabilities are relevant and actionable for critical infrastructure owners and operators to improve adoption rates (SWAP Objective 5.2). The benefits of successful implementation are that relevant tools will be available, owners and operators will be aware of the hazards of space weather, and successful adoption of developed tools and capabilities, resulting in improved critical infrastructure resilience against space weather events.

Short-Term Opportunities

Programs to survey user needs and define user requirements for forecasting lead-times, accuracy goals, and guidelines for intelligible and actionable information should be created within the lead agencies identified in the SWAP, Actions 4.4.1, 5.1.1, and 5.4.1–3.

Decision support tools can provide actionable information to serve as input to operational procedures and processes such as the Federal Emergency Regulatory Commission-approved North American Electric Reliability Corporation (NERC) Emergency Preparedness and Operations (EOP) standard for geomagnetic disturbance operations (EOP-010-1), which coordinates operating procedures and processes to mitigate the effect of geomagnetic events. The development of these decision support tools for critical infrastructure owners and operators should incorporate user requirements developed from the requirements programs previously mentioned.

Mid-Term Opportunities

No opportunities identified.

Long-Term or Sustained Opportunities

Ongoing efforts should be made to enhance awareness across the Federal Government, the scientific and technical communities, and the general public to promote familiarity with space weather hazards and hazard prevention. Heightened awareness can be achieved through publicly released fact sheets, best practices, or other documents. In addition, outreach to and education of the private sector and critical infrastructure owners and operators to increase their understanding of the economic and social benefits of critical infrastructure resilience to space weather events (SWAP Goal 6.1.1). These efforts will improve adoption rates of protection, mitigation, response, and recovery technologies and capabilities.

Near Earth Object Hazard Preparedness

Science and Technology Priorities to Prepare for Near-Earth Objects

1. Advanced Public Communication of Impact Advisories or Warnings

No public communication protocols are available for a possible NEO impact warning. Due to the lack of an agreed-to plan for communication among agencies and with the public, OSTP has directed NASA and FEMA to establish notification processes for a potential NEO impact. The Planetary Impact Emergency Response Working Group (PIERWG) was established by FEMA and NASA to develop guidance to prepare for any potential NEO impact. Because no overarching agreement exists on managing this type of event, the PIERWG will coordinate responsibilities and resolve preparedness and operational issues relating to interagency response and recovery activities at the national level.

Recommended Science and Technology Actions

Short-Term Opportunities:

- Establish threat notification protocols to alert relevant agencies when an impact threat is detected.
- Leverage existing interagency, international, and public communication pathways for use in agency protocols when a NEO impact threat is detected.

Mid-Term Opportunities:

- Enhance understanding of risk communication and risk perception research to improve current communication approaches related to probability, impact location, and predicted effects. This could include communicating uncertainties related to lack of knowledge about the object's behavior and impact effects.

Long-Term or Sustained Opportunities:

- Update communication protocols as needed, specifically, as advancements are made in detecting and tracking NEOs and modeling impact behaviors.

2. Enhanced Fundamental Understanding of Impact Hazards

There are considerable uncertainties about the behavior of asteroids after they enter Earth's atmosphere and about the effects of their impact. Few investments have been made thus far in accurately modeling impact consequences, including analyzing the threat to life and communicating how these models and analyses integrate across a range of activities. The resulting information would be used throughout all phases of a response, including evaluating the efficacy and risks of prevention efforts, planning for emergency preparation and response, and estimating casualty and property losses. Because of the reliance on modeling throughout the national planetary-defense effort, integration, coordination, and communication of the modeling needs and results are critical.

A new area of scientific investigation relates to tsunamis generated by a NEO impact. These tsunamis are hypothesized to be different than those generated by earthquakes, and as a result, current understanding of the propagation and modes of impact is insufficient to inform planning and response decisions. Currently, the lack of qualitative and quantitative models hinders further development of forecasting capabilities. Furthermore, the area of prevention capabilities (i.e., how to deflect or disrupt an approaching NEO) has only recently been a focus of study, and considerable uncertainties remain in the models currently in use.

Recommended Science and Technology Actions

Short-Term Opportunities

- Improve current airburst models to better predict asteroid behavior and effects.
- Refine models for simulating tsunamis generated by asteroid impact to enable basic predictive capabilities.
- Conduct a comprehensive review of modeling and analysis needs from across stakeholders for purposes of planetary defense to inform an assessment of current capabilities and identify strengths and gaps.

Mid-Term Opportunities

- Integrate NEO-impact warnings into the tsunami warning system.
- Improve predictive models for various space-based mitigation options to better understand requirements and consequences.

Long-Term or Sustained Opportunities

No opportunities identified.

3. Improve Event Characterization and Risk Assessment

NEO impacts cannot be predicted unless the asteroid has been detected, so it is important to continue event characterization and risk assessment activities. Early detection is critical to enabling decisions for emergency response (including the ability to prevent an impact); the earlier the threat is detected the more time there is to prepare a response. NASA has a requirement to complete a catalog of NEOs 140 meters in size and greater by 2020. The agency will not be able to meet this goal with existing ground-based facilities. Several studies, including one by the National Research Council, have identified the value of a space-based observatory that would not be hindered by daylight and weather and that could complete a comprehensive survey of new objects much more rapidly than could be done with existing facilities.

NASA's aging observatory infrastructure does not provide sufficient coverage, resolution, or analytic capabilities. For example, delays in critical infrastructure maintenance of the Goldstone 70-meter observatory resulted in a significant observation gap when the observatory was shut down for several months. Current monitoring capabilities also lack sufficient continuous monitoring and detection to provide warning of NEO impacts, particularly for the smaller, more frequent events (e.g., NEOs <40 meters are expected to disintegrate in the atmosphere but do occasionally impact Earth; these objects have been difficult to detect and thus the population is relatively unknown). In addition, technology capability investments to improve detection data analysis and modeling, along with associated infrastructure updates, were identified as lagging. Finally, current planetary radar capabilities (which are critical for refining orbits and thus impact locations) are not adequately supported to conduct rapid, real-time observations of newly detected potentially hazardous objects while still observable to improve orbit characterization and threat analysis.

Recommended Science and Technology Actions

Short-Term Opportunities:

- Update relevant observatory infrastructure to take advantage of improvements in observational and analytic capabilities.
- Augment and upgrade existing planetary radar facilities and work with FAA to streamline authorization response time.

Mid-Term Opportunities

- Develop new detection data analysis and modeling capabilities to ensure rapid characterization of NEOs as well as in capabilities that can improve spatial and temporal range of current and future systems by revising algorithms to detect smaller objects.

Long-Term Opportunities

- Develop and implement a space-based observatory that will be capable of fully cataloging smaller objects (<140 meters in diameter), as well as larger objects, to ensure that the full range of the hazard is understood and that potential impactors are cataloged.

4. Enhance Observations, Modeling, and Data Management

As noted above, an earlier impact warning increases the options that can be implemented to either prevent the impact or mitigate the damage on Earth. In addition, in order, data about the specific asteroid may be needed to successfully prevent an asteroid impact and inform the decision to launch a deflector or disruption mission. The data may not be obtainable by ground-based observation and may require, time permitting, an in-space reconnaissance mission to get the data, especially as the asteroid population is very diverse in composition and structure, as well as in size.

As the space hazards team worked through the gap analysis, the definition of *prevention* received intense discussion. Although science and technology investments to understand asteroid structure and composition can depend on improved modeling techniques of existing data sets, upgrades of observatory infrastructure, or spacecraft missions to take detailed measurements of the threatening object (all discussed above), actually preventing a NEO impact will require a space-based capability. Depending on the amount of time until impact, technologies to deflect (alter the object's orbit either instantaneously or more slowly) or disrupt (high-energy technologies to rapidly break-up the object and distribute the mass) may be key to reducing regional, national, or global threats.

Another critical area would be to develop a deflection capability for a variety of size/mass objects. The notion that an approaching asteroid could be diverted from hitting Earth has been extensively studied and appears to be feasible. The technologies have not yet been tested and their applicability to certain types of asteroids is unknown. Inherent in these capabilities is the need for a set of benchmarks or guidelines to aid decisions in whether to implement deflection or disruption missions. In such an event, furthermore, it is expected that such a mission might require international agreements before implementation. There are currently no specific decision protocols in place to inform long-term technology investment strategies to deflect or disrupt asteroids, either intra- or internationally.

Science and Technology Opportunities

Short-Term Opportunities

- Develop specific recommendations on a minimal set of measurements and instruments for a reconnaissance mission to obtain required data about a NEO to inform response decision-making and to shorten the required time to build and fly such a mission.
- Develop a reconnaissance mission concept to ensure rapid response in the event that a potential impactor is detected only a few years in advance.

Mid-Term Opportunities

- Develop space-based technology demonstration missions to test capabilities of various technologies for deflecting or disrupting asteroids.
- Model and test high-energy disruption capabilities that may be required to prevent a large object from making impact with Earth, or disrupting a smaller object with only short warning.

Long-Term or Sustained Opportunities

- Develop and sustain an inventory of relevant activities worldwide to include ground-based observations, space-based demonstrations, and launch capabilities, to be used as a discussion basis for development of international protocols and agreements.

5. Develop Technology for Safer, Effective, and Timely Response and Recovery

The opportunities discussed above would ensure improvements in response and recovery through better modeling and perhaps even prevention of an impact event.

6. Integrate Science into Preparedness Decisions

NEOs represent a unique, though low-probability hazard for which the United States must prepare. Our limited state of understanding of asteroid impacts would hinder decision-making in emergency situations. Unlike for other large-scale natural hazards, such as volcanic eruptions or earthquakes, asteroid impact is potentially preventable if action is taken quickly. But the population of NEOs is quite diverse, some may present a severe threat while others may be expected to cause minimal damage. The United States may therefore decide not to try to prevent particular asteroid impacts. In addition, design reference missions to deflect or disrupt an asteroid have not been used to inform decisions in the past. Responses must be carefully coordinated and balanced with other risks and hazards.

Recommended Science and Technology Actions:

Short-Term Opportunities

- Develop a set of real-world scenarios based on credible impact threats with observable parameters that can be used to inform planning and investments. The scenarios could be used at various levels, from local to national, to inform emergency response planning.
- Develop an agreed-to set of threshold parameters (i.e., asteroid size, velocity, possible composition, projected impact location), which would trigger action and frame recommendations for a subsequent response.
- Refine the Torino scale or develop a new impact hazard scale to better illustrate and communicate

the risks of potential impact objects.

- Develop a set of representative deflection or disruption missions to provide a basis for decision making, to include technology development and ground-based options development. This would inform Federal response planning and be the basis for international discussions.

Mid-Term Opportunities

No opportunities identified.

Long-Term or Sustained Opportunities

No opportunities identified.

Appendix 1.A – Chemical Hazards – Science and Technology Preparedness Gaps and Alignment with PPD-8 Mission Areas

Table 1. S&T Gaps—Chemical Hazard—Improve Public Communication of Warnings and Advisories

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
NO GAPS DESCRIBED FOR THIS S&T DEVELOPMENT AREA							

Table 2. S&T Gaps—Chemical Hazard—Enhance Fundamental Understanding of Hazards

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
2.1	Lack of information on fate, transport, and toxicity of certain chemicals in the environment that would better inform operational decision making	NA	NA				

Table 3. S&T Gaps—Chemical Hazard—Improve Event Characterization and Risk Assessment

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
NO GAPS DESCRIBED FOR THIS S&T DEVELOPMENT AREA							

Table 4. S&T Gaps—Chemical Hazard—Improve Event Characterization and Risk Assessment

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery

3.1	Need for prioritizing high-risk scenarios for the development of countermeasures and efficient use of resources	NA	NA				
3.2	Need to improve ability to estimate or determine the presence of a chemical hazard after a release. This will improve our ability to establish exclusion zones, identify exposed individuals, and streamline clean-up processes	NA	NA				
3.3	Need for fast and accurate screening protocol for determining individuals who have been exposed to toxic chemicals.	NA	NA				

Table 4. S&T Gaps—Chemical Hazard—Enhance Observations, Modeling, and Data Management

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
		NO GAPS DESCRIBED FOR THIS S&T DEVELOPMENT AREA					

Table 5. S&T Gaps—Chemical Hazard—Develop Technology for Safer, Effective, and Timely Response and Recovery

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
5.1	Lack of adequate monitoring capabilities for alerting first responders and the public about the presence of harmful chemicals.	NA	NA				
5.2	Need to improve ability to mitigate the spread of hazardous chemicals.	NA	NA				
5.3	Lack of adequate, non-obtrusive materials and operational safety measures necessary to safely and effectively conduct operations in contaminated environments.	NA	NA				

5.4	Need to better integrate forensic science during the response and recovery of a chemical incident to better support the apprehension and prosecution of perpetrators	NA	NA				

Table 6. S&T Gaps—Chemical Hazard—Integrate Science into Preparedness Decisions

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
6.1	First responders do not have adequate information about potential threats.	NA	NA				

Appendix 1.B – Chemical Hazards – Science and Technology Programs and Alignment with PPD-8 Mission Areas

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
Chemical Security Analysis Center	DHS	Analysis and scientific assessment of current and evolving chemical threats against American public and American homeland.					
Advanced Detectors	DHS	Initiate exploration of novel and/or improved chemical detection technologies					
Standoff Detection	DHS	Explore application of standoff detectors in transit system testbed					
Chemical Forensics	DHS	Develop improved methods for processing and collecting samples from crime or terrorist scenes and develop analytical methods to support forensic investigations					
Chemical Defense Program (OHA)	DHS	Provides health and medical expertise related to chemical preparedness, detection, response, and resilience to provide a comprehensive approach to chemical defense.					
Office of Research and Development's Homeland Security Research Program	EPA	Develops 1)standardized sample collection and analysis methods and strategies for characterization of contamination so that risk can be assessed and cleanup approaches considered; 2) approaches for preparing water systems for disasters and responding to catastrophes successfully so that access to drinking water by the public and business is maintained or restored quickly; and, 3) approaches for cleanup of outdoor areas and buildings so that the impact of disasters on commerce and our personal lives is minimized. The program also provides expert technical advice and hands-on assistance as needed by the response community.					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
ASPR/BARDA/CBRN Chemical MCM program	HHS	Advanced development of MCMs including drugs and response paradigms to improve health outcome after chemical exposure.					
NIH/NINDS & NIAID/ Countermeasures Against Chemical Threats (CounterACT) Program and IAAs	HHS	Basic and translational research on chemical threat agents and MCMs including toxicology and natural history studies, drug discovery and preclinical development.					
Life Sciences Basic Research	DoD	Fundamental efforts to understand living systems' response to biological or chemical agents, in order to support detection, protection, diagnostics, and medical treatment.					
Physical Sciences Basic Research	DoD	Focuses on fundamental scientific knowledge in physical science areas that include chemistry, physics, materials science, environmental science, and nanotechnology that could potentially lead to transformational CB defensive capabilities enhancing warfighter performance and safety.					
Nanoscale/Bio-Inspired and MetaMaterials	DoD	Exploits advances in nano/microscale and bio-inspired materials; includes materials that can respond for soldier protection against chemical and biological threats					
Material Contamination Mitigation	DoD	Development and analysis of non-traditional decontamination technologies and approaches which significantly improved effectiveness by complementary application.					
Respiratory and Ocular Protection	DoD	Development and analysis of design alternatives for chemical and biological air-purifying respirators to provide enhanced protection with lower physiological burden and improved interface with mission equipment.					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
Detection	DoD	Emphasis on the detection and identification of chemical and biological threats. Objectives include development of miniaturized detector for sensing of chemical and biological agents, design for prototype whole pathogen genome sequencing system.					
Hazard Prediction	DoD	Improve battlespace awareness by accurately predicting hazardous material releases, atmospheric transport and dispersion, and resulting human effects. Develop capability for predicting the source term of releases of chemical, biological, and industrial materials.					
Data Analysis	DoD	Develop CBRN data sharing capabilities and simulation tools. Develop chapters of the Chemical and Biological Agent Effects Manual Number 1 (CB-1), an authoritative source capturing analytical methods for evaluating the effects of CB agents on equipment, personnel, and operations.					
Operational Effects & Planning	DoD	Develop decision support tools and information management capabilities for planning and real-time analysis to determine and assess operational effects, risks, and impacts of CBRN incidents on decision making. Focus areas include consequence management, population modeling, and human knowledge management.					
Filtration	DoD	Development and integration of novel filtration media into a lightweight, low-profile, and low-burden individual protective filter, which has enhanced performance against a broader range of challenges that includes toxic industrial chemicals.					
Lightweight Integrated Fabric	DoD	Development of lightweight chemical and biological protective textiles that can be used as an integrated combat duty uniform.					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
Personnel Decontamination	DoD	Development of new technologies to alleviate the risk associated with contaminated human remains and personal effects (materials) exposed to and contaminated by chemical, biological, and radiological agents by neutralizing and/or physically removing the residual agent.					
LUSTER	DoD	Develop Laser UV Sources for Tactical Efficient Raman; applications include chemical agent sensing					
Threat Agent Science	DoD	Defensive countermeasure development against current and emerging chemical and biological threats by delivering scientific understanding and relevant estimates of hazards posted to humans by exposure to agents.					
NTA Material Contamination Mitigation	DoD	Study and assessment of decontamination technologies against NTAs, including emerging threats.					
NTA Chemical Diagnostics - Med	DoD	Development of state-of-the-art laboratory/fieldable methods to detect exposure to NTA samples. Identifies biomolecular targets that can be leveraged as analytical methodologies, as well as laboratory and animal studies characterizing time-course and longevity of a particular analyte/biomarker. Supports the analytics for traditional agent diagnostics and hand-held diagnostic technologies that might be applied to NTA diagnostics.					
NTA Chemical Pretreatments - Med	DoD	Development of pretreatments that provide protection against NTAs. Enzymes should have the ability to rapidly bind and detoxify nerve agents, and have broad binding specificity and high catalytic efficiency for the destruction of agents.					
NTA Chemical Therapeutics - Med	DoD	Investigates common mechanisms of agent injury. Determines the toxic effects of agents by probable routes of field exposure, as well as standard experimental routes. Physiological parameters and					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
		pathological assessment will be used to establish the general mode and mechanism(s) of toxicity. Develops, assesses, evaluates, and validates therapeutics for treatment resulting from exposure to NTAs.					
NTA Detection	DoD	Primary focus is to assess the potential of multiple technologies to meet the needs of NTA detection.					
NTA Modeling & Simulation	DoD	Modeling of NTA materials for hazard prediction. Investigation of NTA agent fate for secondary effects, environmental/atmospheric chemistry, atmospheric and waterborne transport and dispersion, human effects, model Validation and Verification (V&V), scaled testing, casualty estimation, and supporting data management.					
NTA Air Purification	DoD	Study and assessment of filter technologies against NTAs.					
NTA Respirator	DoD	Development and analysis of design alternatives for chemical and biological air-purifying respirators to provide enhanced protection against NTAs with lower physiological burden and improved interface with mission equipment.					
NTA Percutaneous Protection	DoD	Study and assessment of percutaneous protective technologies.					
NTA Threat Agent Sciences	DoD	Provide enabling S&T on current and emerging threat agents, which informs development and testing of NTA defense technology such as detection, decontamination, protection, hazard assessment, and more. This preliminary assessment of new threats informs decision makers and provides the basis for all countermeasure development and assessment.					
Chemical Diagnostics	DoD	Development of state-of-the-art laboratory/fieldable methods to detect exposure to chemical warfare agents (e.g. nerve agents and vesicants) or radiological agents in clinical samples. Identifies biomolecular					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
		targets that can be leveraged as analytical methodologies, as well as laboratory and animal studies characterizing time-course and longevity of a particular analyte/biomarker.					
Medical Countermeasures Initiative	DoD	Integrate the regulatory science and manufacturing technologies and processes developed into the DoD Medical Countermeasures Advanced Development and Manufacturing (MCM-ADM) as enablers of the advanced development and flexible manufacturing.					
Pretreatments, Nerve Agents	DoD	Development of pretreatments that provide protection against all organophosphorus nerve agents.					
Chemical Therapeutics	DoD	Focuses on therapeutic strategies to effectively minimize neurologic injuries resulting from exposure to CWAs. Designed to develop potential candidates for submission to FDA licensure or new indications for previously licensed products for use in the treatment of chemical warfare casualties.					
In vivo Nanoplatforms	DoD	Develop the nanoscale systems necessary for in vivo sensing and physiological monitoring and delivery vehicles for targeted biological therapeutics against chemical and biological threat agents					
Medical Countermeasures	DoD	Further develop an expedited medical countermeasure capability, integrating emerging technologies to address safety and efficacy considerations to counter biological, chemical, and radiological threats					
Material Contamination Mitigation	DoD	Demonstration of non-traditional decontamination technologies and approaches that gain significantly improved effectiveness by complementary application.					
Respiratory and Ocular Protection	DoD	Demonstration of design alternatives for chemical and biosocial air-purifying respirators to provide enhanced protection with lower physiological burden and improved interface with mission equipment.					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
Detection	DoD	Detection and identification of chemical and biological threats in near real-time at a distance from the detector. Future programs focus on the improvement of algorithms, excitations sources, and detector elements to increase range, reduce false positives, increase sensitivity, and reduce cost.					
Hazard Prediction	DoD	Improve battlespace awareness by accurately predicting hazardous material releases, atmospheric transport and dispersion, and resulting human effects. Develop capability for predicting the source term of releases of chemical, biological, and toxic industrial materials.					
Data Analysis	DoD	Development of chemical, biological, radiological, and nuclear data-sharing capabilities. Development of chapters of the Chemical and Biological Warfare Agent Effects Manual Number 1 (CB-1), an authoritative source capturing analytical methods for evaluating the effects of CB warfare agents on equipment, personnel, and operations.					
Operational Effects	DoD	Development of decision support tools and information management capabilities for planning and real-time analysis to determine and assess operational effects, risks, and overall impacts of CBRN incidents on decision-making. Focus areas include consequence management, population modeling, and knowledge management.					
Filtration	DoD	Demonstration of novel filtration media into a lightweight, low-profile, and low-burden individual protective filter, which has enhanced performance against a broader range of challenges that includes toxic industrial chemicals.					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
Fabrics	DoD	Demonstration of lightweight chemical and biological protective textiles that can be used as an integrated combat duty uniform.					
CBRNE Combating Terrorism Technology	DoD	Rapid research, development, test and evaluation on threat characterization; materials attribution; personal protective equipment; detection of CBRNE materials; information resources and decision support tools; and consequence management					
NTA Diagnostics - Medical	DoD	Focuses on state-of-the-art laboratory/fieldable methods that detect exposure to NTAs in clinical samples. Targets identification of biomolecular targets that can be leveraged as analytical methodologies, as well as laboratory and animal studies characterizing time-course and longevity of a particularly analyte/biomarker.					
NTA Material Contamination Mitigation	DoD	Study and assessment of decontamination technologies against NTAs, including emerging threats. Enhancement of NTA-related understanding and capability, and development of additional processes for NTA hazard mitigation.					
NTA Pretreatments - Medical	DoD	Develop nerve agent enzyme treatments that provide protection against NTAs.					
NTA Therapeutics - Medical	DoD	Determine toxic effects of agents by probable routes of field exposure and refine standard experimental routes. Physiological parameters and pathological assessment will be used to establish the general mode and mechanisms of toxicity required for Medical Countermeasure (MCM) development.					
NTA Detection	DoD	Focuses on technologies to provide NTA detection capabilities.					
NTA Modeling & Simulation	DoD	Develops NTA technology advancements for joint service application in the area of information systems					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
		and modeling and simulation technologies. Information systems advanced technology focuses on areas of advanced warning and reporting, hazard prediction and assessment, simulation analysis and planning, and systems performance modeling.					
NTA Air Purification	DoD	Study and assessment of filter technologies against NTAs.					
NTA Percutaneous Protection	DoD	Study and assessment of protective technologies against NTAs.					
NTA Test & Evaluation	DoD	Develops test and evaluation technologies and processes in support of NTA activities.					
Chemical Diagnostics	DoD	Focuses on state-of-the-art laboratory/fieldable methods that detect exposure to chemical warfare agents in clinical samples. Also targets the identification of biomolecular targets that can be leveraged as analytical methodologies, as well as laboratory and animal studies characterizing time-course and longevity of a particular analyte/biomarker.					
Medical Countermeasures Initiative	DoD	Integrate the regulatory science and manufacturing technologies and processes developed into the DoD Medical Countermeasures Advanced Development and Manufacturing (MCM-ADM) as enablers of the advanced development and flexible manufacturing. Development of human in vitro immune mimetic assays for FDA acceptance to enable rapid and accurate prediction of the human response to experimental vaccines and other MCMs.					
Neurologic Therapeutics	DoD	Focuses on therapeutic strategies to effectively minimize neurologic injuries resulting from exposure to chemical warfare agents.					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
Experiment & Technology Demonstrations	DoD	Validates high-risk/high-payoff technologies and concepts-of-operations through the use of the Advanced Technology Demonstration and Rapid Military Utility Assessment (RMUA) processes. This project addresses four family of product areas: Biological Resiliency, to include Biosurveillance; Early Warning and Remote Detection; Small Scale CBW Agent Defeat; and Hazard Mitigation.					

Appendix 2.A – Radiological and Nuclear Hazards – Science and Technology Preparedness Gaps and Alignment with PPD-8 Mission Areas

Table 1. S&T Gaps—Radiological/Nuclear Hazard— Improve Public Communication of Warnings and Advisories

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
NO GAPS DESCRIBED FOR THIS S&T DEVELOPMENT AREA							

Table 2. S&T Gaps—Radiological/Nuclear Hazard—Enhance Fundamental Understanding of Hazards

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
NO GAPS DESCRIBED FOR THIS S&T DEVELOPMENT AREA							

Table 3. S&T Gaps—Radiological/Nuclear Hazard—Improve Event Characterization and Risk Assessment

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
3.1	There is a need to be able to identify the direction and speed of radioactive particles in the environment, project areas with fallout and radiological contamination, including understanding the impacts of the urban environment on dispersion.	2014 DHS S&T Radiological and Nuclear Response and Recovery Research and Development Investment Plan (HSSAI)	NA				
3.2	There is a need to significantly increase our ability to detect threat objects at greater distances. Specifically, this ability is required where the adversary is operating in a non-compliant manner and/or in a non-official or non-regulated pathway.	DNDO 2015 Stage Gate Zero Report	NA				

3.3	There is a need to significantly increase our ability to detect threats with low signatures resulting from the material's composition, environmental masking, or the adversary's operational shielding of the threat.	DNDO 2015 Stage Gate Zero Report	NA				
3.4	Forensic determination of origin and/or route of interdicted materials	National Technical Nuclear Forensics Center	NA				

Table 4. S&T Gaps—Radiological/Nuclear Hazard—Enhance Observations, Modeling, and Data Management

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
NO GAPS DESCRIBED FOR THIS S&T DEVELOPMENT AREA							

Table 5. S&T Gaps—Radiological/Nuclear Hazard—Develop Technology for Safer, Effective, and Timely Response and Recovery

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
5.1	There is a need to measure and manage environmental hazards, mitigate and contain contaminants, conduct gross decontamination, and manage contaminated waste and debris to reduce the public's exposure and to support whole community recovery efforts.	2014 DHS S&T Radiological and Nuclear Response and Recovery Research and Development Investment Plan (HSSAI)	NA				
5.2	There is a need for technology that can be deployed in the non-regulated, non-official air, sea, and land border entries into the U.S. This technology must be capable of being deployed to an area where there is little direct control by law enforcement and that helps gain the advantage over the adversary in these pathways.	DNDO 2015 Stage Gate Zero Report	NA				

5.3	There is a need for integrated, multi-purpose detection technologies and supporting equipment. Multi-purpose weapons of mass destruction and counter-smuggling technologies must be incorporated into R&D efforts.	DNDO 2015 Stage Gate Zero Report	NA				
5.4	Develop and make available new and improved rapid diagnostics and therapeutics for radiation injury.	Nuclear Defense Research and Development Roadmap, Fiscal Years 2013–2017	NA				
5.5**	Develop tools, technologies and guidance to perform cleanup operations for both critical infrastructure (e.g., transportation, power, water/wastewater, communications, medical resources, and essential government services) and the surrounding contaminated areas. (This gap covers characterization and mitigation of the spread of contamination, indoor/outdoor are decontamination, water infrastructure decontamination, and waste management)	Nuclear Defense Research and Development Roadmap, Fiscal Years 2013–2017	NA				

**Critical Infrastructure Resilience

Table 6. S&T Gaps—Radiological/Nuclear Hazard—Integrate Science into Preparedness Decisions

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
6.1	There is a need for a common and complete understanding of when and how models, data tools, briefing materials and other decision support products will be used to support local and state decision making during a radiological/nuclear incident.	2014 DHS S&T Radiological and Nuclear Response and Recovery Research and Development Investment Plan (HSSAI)	NA				
6.2	There is a need for response and recovery protocols and procedures that leverage preventative radiological/nuclear detection equipment currently used by law enforcement for interdiction and detection. Specifically, there is a need to develop a concept of operations outlining	NA	NA				

	how non-response and recovery technology and responder tools can be altered and adapted for dual-use, saving cost and minimizing						
6.3	Develop increased local capability and improved citizen awareness to effectively execute shelter-in-place, evacuation, or other protective and response action decisions following an RN incident.	Nuclear Defense Research and Development Roadmap, Fiscal Years 2013–2017	NA				
6.4	Develop post-incident medical care and management capabilities, including population monitoring.	Nuclear Defense Research and Development Roadmap, Fiscal Years 2013–2017	NA				
6.5	Develop a risk communication program for key decision-makers.	Nuclear Defense Research and Development Roadmap, Fiscal Years 2013–2017	NA				

Appendix 2.B – Radiological and Nuclear Hazards – Science and Technology Programs and Alignment with PPD-8 Mission Areas

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
DHS S&T RNRR: Manage the Response	DHS	Supporting first responders and local agencies on managing catastrophic incidents by providing guidance on decision making with limited information, and, as technical data is collected, integrating radiation levels and health physics into incident command decisions.					
DHS S&T RNRR: Characterize the Incident	DHS	Development of responder guidance on scientifically validated methods of using widely available preventative radiological detection and interdiction equipment for consequence management operations.					
DHS S&T RNRR: Initial Response	DHS	Identifying the type of emergency operations and response decisions required in the first minutes and hours of a radiological incident, and developing guidance, tools, and materials that support local agencies in initiating a successful initial response.					
DHS S&T RNRR: Site Cleanup and Restoration of Essential Functions	DHS	Research into responder tools and techniques for radiological contamination containment, gross mitigation of hazard for responder/public safety, and early phase waste management strategies.					
Radiological Detection System	JPEO-CBD	modernized radiological survey meter to detect alpha, beta, gamma, neutron and low energy x-rays to address Operation TOMODACHI lessons learned					
Joint Personal Dosimiter	JPEO-CBD	Modernize dosimeter by providing NVLP accredited dose of record for service member radiation exposure					
Man-portable Radiological Detection System	JPEO-CBD	Man-portable isotope detection system of systems capability to search and find materials of interest					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
Radioisotope Identification Detection (RIID) Family of Systems	JPEO-CBD	Modernize RIIDs for DoD by providing medium and low resolution RIIDS along with visual and cell phone size capability					
Vehicle, Installation, Ship, aircraft Radiac	JPEO-CBD	Develop radiological detector that can be integrated onto manned platforms					
Advanced Radiological and Nuclear Detection Family of Systems	JPEO-CBD	Develop aerial and ground radiological detection systems capable of detection materials of interest at distances up to 100m					
DTRA J9 NTS	DTRA	DTRA's Nuclear Survivability Program is the center of excellence for applied science needed to address DoD survivability requirements and serves as an enabler for DoD program offices and U.S. atomic veterans. Provide support to ASD (NCB) on implementation of DoDI 3150.09, "The Chemical, Biological, Radiological, and Nuclear (CBRN) Survivability Policy. Provide support to USSTRATCOM certification process. Execute DTRA strategic deterrence mission.					
DTRA J9 NTV	DTRA	Research, develop and provide operational tools, technologies, and methods to DoD customers, for monitoring & verification of arms control treaties & agreements through sensing, analysis, and knowledge management.					
DTRA J9 ISR	DTRA	The Technical Reachback Division (J9ISR) provides 24/7 CBRNE decision support capability for planning, operations, and post-event analysis to COCOMs, OSD, JS, IC, and other USG agencies and first responders as required. J9ISR serves as the Department of Homeland Security's IMAAC Operations Hub.					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
DTRA J9 CXS	DTRA	The Counterforce Systems Division (J9CXS) develops, integrates, demonstrates, and transitions emerging and innovative technologies to support the conduct and assessment of operations to counter the threat of WMD. J9CXS provides DoD with advanced sensor, surveillance, and data-processing technologies; state-of-the-art weapons effects planning tools and operational expertise supporting CWMD missions; state-of-the-art threat-effects models and planning tools for force protection; new sensor techniques and procedures to support the WMD kill chain; and advanced, energetic approaches to achieve orders of magnitude improvement in counter-WMD weapons performance.					
DTRA J9 CXA	DTRA	The Target Assessment Technologies Office (J9CXA) develops and applies technologies to find, characterize, and assess hardened and deeply buried targets and related WMD facilities for the IC and COCOMs.					
DTRA J9 CXW	DTRA	The Weapons and Capabilities Office (J9CXW), located at Eglin AFB, FL supports the COCOMs through research, development, and transition of offensive weapons and other capabilities to combat WMD while mitigating collateral contamination effects.					
DTRA J9 CXC	DTRA	The Combating Terrorism Division (J9CXC) provides CCDRs with improved offensive capabilities in support of counter-terrorism and counter-proliferation missions to combat WMD.					
DTRA J9 CXQ	DTRA	The Special Programs Office (J9CXQ) provides oversight and management of special and sensitive programs.					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
DTRA J9 CXT	DTRA	The Test Support Division (J9CXT), located at Kirtland AFB, NM provides end-to-end test event planning, management, safe execution, and results analysis supporting the DoD, Federal agencies, and friendly nations' programs to counter proliferation of WMD.					
DHS DNDO Transformational & Applied Research: Academic Research Initiative	DHS	The ARI Program has two primary objectives: 1) Engage the academic community to advance fundamental knowledge for rad/nuc threat detection and related sciences with emphasis on fundamental research to solve long-term, high-risk challenges; and 2) Develop human capital in the nuclear science and engineering professions and related fields. Further, the program works to sustain a long-term commitment to basic research in these fields and coordinates these research efforts with other federally sponsored research in industry and at the national laboratories.					
DHS DNDO Transformational & Applied Research: Exploratory Research Program	DHS	The Exploratory Research Program explores innovative, high-risk, early to later-stage technologies, concepts, and ideas that can make transformational contributions to support the GNDA and reduce the risk of nuclear terrorism. Specifically, the ER program researches technologies and techniques that address capability gaps and weaknesses in the GNDA, provide substantial performance improvement and/or cost reduction of rad/nuc detection capabilities and improve nuclear forensics capabilities.					
DHS DNDO Transformational & Applied Research: Advanced Technology Demonstrations	DHS	The Advanced Technology Demonstration (ATD) program performs accelerated development, characterization, and demonstration of leading-edge technologies that address critical gaps in nuclear detection capabilities. It builds on technology concepts previously demonstrated under the ER program, research conducted by interagency partners, or privately funded research.					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
DHS DNDO Transformational & Applied Research: Small Business Innovative Research (SBIR)	DHS	The statutory purpose of the SBIR Program is to stimulate technological innovation by strengthening the role of innovative small business concerns (SBCs) in federally funded R&D. This program is implemented by the Policy Directive as administered by the Small Business Administration (SBA).					
ASPECT	EPA	ASPECT provides infrared and photographic images coupled with geospatial, chemical and radiological information within minutes to the first responder and to those supporting the response (e.g., On-Scene Coordinators, the Environmental Unit in the ICS). This enables efficient assessment of the extent and severity of damages to critical infrastructure during emergencies as well as the extent of radiological /nuclear contamination.					
Decontamination and Consequence Management	EPA	Develops methods and best practices for mitigation of radiological and nuclear contamination.					
Decontamination and Consequence Management	EPA	Evaluates decontamination methods and solid and liquid waste management options for radiological and nuclear contamination for indoor and outdoor areas including critical infrastructure. This includes performing scientific studies to inform recommendations for waste minimization, siting, and handling practices for waste triage, staging, temporary storage, and disposal sites. This is included in documents and training related to R/N waste management.					
Water Infrastructure Protection	EPA	Develops methods for decontaminating water infrastructure and evaluates options for managing large volumes of contaminated water.					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
Radiological Laboratory Services and Field Operations	EPA	Develop methods for characterization of radiological/nuclear contamination in environmental matrices (including building and outdoor materials).					
Radiological Laboratory Services and Field Operations	EPA	Placeholder Monitoring - Mobile Environmental Radiation Lab, National Analytical Radiation Environmental Lab (includes RadNet), & National Center for Radiation Field Operations					
Radiological Laboratory Services and Field Operations	EPA	Placeholder Communication of Radiation Risk					
CBRN Consequence Management Advisory Team (CMAT)	EPA	Consequence Management Advisory Team (CMAT) offers radiological training and guidance materials for EPA first responders and partnering department and agencies (WMD CSTs, HRFs, etc.) to prepare for and respond to rad/nuc incidents. CMAT also offers training to non-technical personnel for use as a force multiplier when large amounts of federal personnel are required to respond to large scale/wide area events.					

Appendix 3.A – Geological Hazards – Science and Technology Preparedness Gaps and Alignment with PPD-8 Mission Areas

Table 1. S&T Gaps—Geological Hazard—Improve Public Communication of Warnings and Advisories

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
1.1	Many people don't take the most protective actions during a hazard or crisis event. (e.g., "drop, cover, hold on" when the warning comes, rather than running out of the building or otherwise panicking (or doing nothing).	NA	NA				
1.2	Increase public notice and awareness and minimize risk to public safety and first responders through improved understanding of landslide hazards and strategies for hazard mitigation	USGS - Landslide Hazards Program					

Table 2. S&T Gaps—Geological Hazard—Enhance Fundamental Understanding of Hazards

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
2.1	How do earthquakes initiate? What controls branching of rupture or the triggering of one fault by another rupture? Why does a rupture stop? Can rupture attributes be anticipated based on geodetic determinations of prior fault locking and strain accumulation?	New Research Opportunities in the Earth Sciences (NRC); Earthscope planning documents; SAFOD Science plan	NA				
2.2	It is not known what governs the size, location and frequency of great subduction zone earthquakes and how is this related to the spatial and temporal variation of slip behaviors observed along subduction faults; this strongly effects estimates of earthquake and tsunami hazard and risk	The GeoPRISMS Science and Implementation Plan	NA				

2.3	There are large uncertainties in earthquake ground motions in most earthquake-prone regions. The tradeoff between natural variability in ground motion and simple uncertainty is not well established.	USGS ANSS Requirements Circular; COSMOS review of earthquake engineering challenges	NA				
2.4	In areas of low seismicity, we have poor understanding of past earthquakes, those that occurred prior to any instrumental and human records. In low seismicity regions, such as the central and eastern United States, large earthquakes do occur, however, because their occurrence rates are relatively low (on the orders of hundreds and thousands of years), knowledge is not complete and some large earthquakes may have gone unnoticed. The need to increase our understanding of past large earthquakes using geologic records, such as paleoliquefaction features is high. Understating historical earthquakes and their occurrence rates has an impact in seismic hazard analyses and risk studies for critical facilities.	US NRC's regulatory guidance (RG 1.208) document the need to use paleo earthquake data in seismic hazard calculations.	NA				
2.5	The instrumental record of earthquakes in low-seismic areas is inadequate to establish seismic hazard, even though historical and prehistoric studies provide evidence that large earthquake have occurred.	USGS ANSS Requirements Circular; and other documents	NA				
2.6	There are extremely few records of non-linear, damaging motions in buildings, or even free-field recordings of ground shaking at damaged-building sites. This results in unacceptable uncertainty in seismic design and mitigation methods, including many untested designs	USGS ANSS Requirements Circular; and other documents	NA				
2.7	We do not understand the behavior of a subduction zone fault along its entire length. Just seaward of the trench and up-dip of the zone of active faulting is a zone that is very poorly understood. Is this area capable of producing earthquakes and if not how is the movement of	The GeoPRISMS Science & Implementation Plan	NA				

	the fault accommodated? Below the zone of active faulting is the region of episodic tremor and slip, a process still poorly understood.						
2.8	Understanding of landslide mobility, for all landslide types, is inadequate to support hazard and risk assessments, early warning and other mitigation measures.	National Research Council (NRC), “Partnerships for Reducing Landslide Risk”.	NA				
2.9	Controls on the frequency and magnitude of debris flows are insufficiently known to assess hazard and risk.	National Research Council (NRC), "Partnerships for Reducing Landslide Risk".	NA				
2.10	Knowledge of the factors controlling the distribution and frequency of bedrock landslides is insufficient to assess hazard and risk.	USGS Circular 1244, National Landslide Hazards Mitigation Strategy – A Framework for Loss Reduction; National Research Council (NRC), “Partnerships for Reducing Landslide Risk”.	NA				
2.11	Hydrological criteria defining the onset of landslides are insufficiently accurate for early warning.	USGS Circular 1244, National Landslide Hazards Mitigation Strategy – A Framework for Loss Reduction; National Research Council (NRC), “Partnerships for Reducing Landslide Risk”; Baum and Godt (2010).	NA				
2.12	The big unknowns for submarine landslides are their triggers, frequency, and sizes. It has been proposed that gas hydrates promote land sliding but how to determine if they do is still being debated. Landslides affect both coastlines of the U.S.	The GeoPRISMS Science & Implementation Plan	NA				
2.13	Frequency of submarine mass movements is insufficiently known for hazard and risk	National Research Council (NRC), “Partnerships for	NA				

	assessment (see also Tsunami loss reduction section).	Reducing Landslide Risk"; Locat and Lee (2002).					
2.14	Techniques and methods to obtain physical properties of sediments are insufficient to adequately model submarine landslides for hazard assessment.	National Research Council (NRC), "Partnerships for Reducing Landslide Risk"; Locat and Lee (2002).	NA				
2.15	Understanding of submarine mass movement mechanics is insufficient to predict travel distances and impacts needed for hazard and risk assessment.	National Research Council (NRC), "Partnerships for Reducing Landslide Risk"; Locat and Lee (2002).	NA				
2.16	The processes occurring in the swath of seafloor extending from the shoreline out a few 100 km are very poorly understood;	Sea Change 2015-2025 Decadal Survey (NRC)	NA				
2.17	Currently unable to either measure or infer near-field tsunami waves in real-time. Currently limited in both seismic and sea-level analysis capabilities.	FY16 NOAA Science-based Operational Needs--Tsunami	NA				
2.18	There are large uncertainties in the expected sizes and frequencies of tsunami	Sea Change 2015-2025 Decadal Survey (NRC)	NA				
2.19	Currently unable to either measure or infer near-field tsunami waves in real-time. Currently limited in both seismic and sea-level analysis capabilities.	FY16 NOAA Science-based Operational Needs--Tsunami	NA				
2.20	How are dynamic volcano systems integrated (short and long range, seismic, infrasound, geodetic, geochemical) and how can we utilize that integration to enhance eruption prediction? Can the duration and style of an eruption be predicted from pre-eruption signals? (e.g., can we link gas and direct mineralogy/glass measurement of volatiles to eruption behavior?) Why do supervolcanoes exist? What processes govern the speed and distance traveled by pyroclastic density currents? What processes govern the speed and distance traveled by high-elevation ash?	New Research Opportunities in the Earth Sciences (NRC) and The GeoPRISMS Science and Implementation Plan	NA				

2.21	Our understanding of earthquake hazard would be improved by better constraints on mineral and rock physics under fault conditions, longer records of earthquake behavior worldwide, and better constraints on wave propagation through realistic Earth media. We also need better models of the fault distribution, input stresses as a function of time, and distribution of materials in a given region of interest. All of these are scientific limitations.						
2.22	Since we can only get longer records of EQ behavior by waiting, the other way to attack it is better models of earthquake initiation, rupture, and termination. This is both a scientific limitation (we need more constraints on the input parameters for the models and a better understanding of the physics underlying them to allow us to get to higher frequency/finer resolution) and a technical limitation (we need more powerful computers to run the models under more realistic conditions to get to the frequencies of interest).						
2.23	Need to advance the scientific understanding of volcanic processes in order to lessen the harmful impacts of volcanic activity. The Volcano Hazards Program addresses this gap by monitoring active and potentially harmful impacts of volcanic activity.	USGS - Volcano Hazards Program					
2.24	Increase knowledge of the impact of climate change on infrastructure and communities, including the ability to predict climate, weather, and natural hazards.	NASA - Applied Sciences Program/Earth Science					
2.25	*Deep earth hazard drivers* -- Understand what are the mechanical properties of the crust and mantle that control surface deformation.	Solid Earth Science Working Group (SESWG)					

Table 3. S&T Gaps—Geological Hazard—Improve Event Characterization and Risk Assessment

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
3.1	Earthquakes cannot be accurately located in broad ocean areas, including much of the southern hemisphere	GSN planning and scientific review documents	NA				
3.2	Landslides losses are not known with sufficient accuracy or detail to inform risk assessments.	National Research Council (NRC), "Partnerships for Reducing Landslide Risk".	NA				
3.3	Comprehensive, national-scale inventory identifying landslide locations and activity does not exist and is needed to assess extent of hazard and to prioritize mitigation efforts.	USGS Circular 1244, National Landslide Hazards Mitigation Strategy – A Framework for Loss Reduction; National Research Council (NRC), "Partnerships for Reducing Landslide Risk".	NA				
3.4	We need better models and better data on how individuals and populations respond to and recover from the event in order to minimize the chance of it becoming a disaster.	NA	NA				
3.5	Developing instrumentation to monitor hazards in the submarine environment (e.g., geodetic instruments, mobile seismometers, mobile gravimeters, etc.) is technologically challenging and very expensive. This last point could be considered a technological gap	Sea Change 2015-2025 Decadal Survey (NRC)	NA				

Table 4. S&T Gaps—Geological Hazard—Enhance Observations, Modeling, and Data Management

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery

4.1	The sizes of the largest earthquakes and the lengths of the largest fault ruptures can't be quickly determined (seconds) with current seismic-only) techniques. This can be solved by integrating geodetic data into EEW systems, and then to apply those techniques to existing networks. The first is a scientific and technical limitation; the second is really a funding and management limitation.	USGS ANSS Requirements Circular; USGS EEW Implementation Plan; USGS NHMA Strategic Plan	NA				
4.2	The seismic performance of most lifeline structures (power, water, sewer, etc.) is typically neither modeled nor monitored. Hence earthquake risks to lifelines are poorly known.	USGS ANSS Requirements Circular; NEHRP Strategic Plan; NAS evaluation of NEHRP	NA				
4.3	The distribution of absolute stress in space and time at a subduction zone is an unknown quantity. More detailed observations of small earthquakes and their fault plane orientations in these regions are needed and require seafloor seismic sensors. Seafloor geodetic measurements would be able to capture the strain associated with changing stress, but these instruments need to be designed, tested and deployed. Of interest is that a new area of study on what portions of the subduction zone generate the very largest earthquakes suggests that contrary to what we traditionally have thought, the largest earthquakes occur along weak sections of the faults rather than strong sections	The GeoPRISMS Science & Implementation Plan, various Subduction Zone Observatory-related documents	NA				
4.4	Digital topographic data sufficient for landslide and debris-flow susceptibility and hazard mapping exist for a small fraction of the landslide-prone areas of the US.	USGS Circular 1399, The 3D Elevation Program initiative - A Call to Action.	NA				
4.5	System to integrate near-real-time in-situ landslide observations with remote sensing data is needed for emergency response and early warning.	USGS Circular 1244, National Landslide Hazards Mitigation Strategy – A Framework for Loss Reduction; National Research Council (NRC),	NA				

		"Partnerships for Reducing Landslide Risk".					
4.6*	Significant monitoring gaps presently exist at several Very-High-Threat and High-Threat volcanoes including Glacier Peak, Mt. Adams, and Mt. Baker in Washington state, Mt. Hood, in Oregon, Lassen, and Mt. Shasta in California. Additionally, the lahar warning system for Mt. Rainier in Washington state is at the end of its expected service and needs to be replaced with a new generation lahar warning system encompassing all major drainages of Mt. Rainier.	USGS Scientific Investigative Report SIR2008-5114, "Instrumentation Recommendations for Volcano Monitoring at U.S. Volcanoes Under the National Volcano Early Warning System"; Also USGS Open-File Report 2005-1164, "An Assessment of Volcanic Threat and Monitoring Capabilities in the United States: Framework for a National Volcano Early Warning System".	NA				
4.7	New generations of campaign deployable or permanent UV camera systems and /or compact MultiGas Sensors capable of measuring volcanic gas discharge in real time have been developed in the past five years and have been utilized in eruption forecasting with great success at a number of the world's most active volcanoes, yet we have only two such systems currently deployed on U.S. volcanoes. Widespread implementation of new generation gas sensors will allow for earlier detection of volcano unrest manifest as changes in gas emission that can be integrated with changes in volcano deformation and seismicity.	Kern, Christoph, Sutton, Jeff, Elias, Tamar, Lee, Lopaka, Kamibayashi, Kevan, Antolik, Loren, and Werner, Cynthia, 2015, An automated SO2 camera system for continuous, real-time monitoring of gas emissions from Kilauea Volcano's summit Overlook Crater: Journal of Volcanology and Geothermal Research, v. 300, p. 81–94. Also see: Kern, Christoph, de Moor, J.M., and Galle, Bo, 2015, Monitoring gas emissions can help forecast volcanic eruptions—5th Meeting of the Network for Observation of Volcanic and Atmospheric Change; Turrialba Volcano, Costa Rica, 27 April to 1 May 2015: EOS Earth & Space Science News, v. 96, no.	NA				

		17, p. 6, doi:10.1029/2015EO034081.					
4.8	The U.S. currently does not have operational access to Synthetic Aperture Radar (SAR) data over almost all active volcanoes in the U.S. even though surface deformation as delineated by SAR data is usually an eruption precursor and clearly showing up as much as months to years before volcano unrest or eruption.	USGS Scientific Investigative Report SIR2008-5114, "Instrumentation Recommendations for Volcano Monitoring at U.S. Volcanoes Under the National Volcano Early Warning System"; Also USGS Open-File Report 2005-1164, "An Assessment of Volcanic Threat and Monitoring Capabilities in the United States: Framework for a National Volcano Early Warning System". See also Poland, M, 2015, Volcano monitoring from space, chap. 17 of Loughlin, S.C., Sparks, Steve, Brown, S.K., Jenkins, S.F., and Vye-Brown, Charlotte, eds., Global volcanic hazards and risk: Cambridge University Press, p. 311–315.	NA				
4.9	The U.S. does not currently have high-resolution Light Distance And Ranging (LiDAR) coverage of all Very-High-Threat and High-Threat volcanoes. These high resolution LiDAR surveys allow VHP to successfully model runout of hazardous lahars (volcanic mudflows) and debris flows sourced from volcanos, and the problem is particularly acute at Alaskan volcanoes.	USGS Volcano Hazards Program Office, and USGS National Geospatial Program.	NA				

4.10	We need to improve the distribution of strong-motion accelerometers, harden stations and comms so that systems stay up during strong shaking, and improve data processing systems. All of these are technical limitations, as well as management -- they are limited by available funding.						
4.11	We also need better earthquake simulators -- codes that can run for millions of simulated years to produce "realistic" catalogs of earthquakes to test our theories and models. This is both a scientific and technical limitation.						
4.12	*Intraplate deformation* -- Global measurements of vertical intraplate deformation at mm/yr accuracy.	Solid Earth Science Working Group (SESWG); C79+C69					
4.13	*Time-variable topography* -- Topography influences how natural hazards (such as landslides, floods, and earthquakes) are distributed across the landscape. High-resolution topographic time-series data are needed to better understand the fundamental physics that drive many natural hazards. Course resolution topographic data has been a major impediment to understanding the forces and dynamics processes associated with many natural and anthropogenic process that shape the Earth's surface. Topographic time series data from a uniform 5 meter - sub-decimeter accuracy digital elevation of the US and the world for better assess and model gravity and fluvial driven hazards (landslides, floods) and the ability to track dynamic topographic changes associated with earthquakes and volcanic activity.	Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond (Decadal Survey); Solid Earth Science Working Group (SESWG); A Foundation for Innovation: Grand Challenges in Geodesy					

4.14	Optical change detection -- Acquisition of high-spatial-resolution panchromatic imagery in conjunction with imaging spectroscopy measurements will support the ability to measure and monitor small-scale surface displacements in a manner complementary to InSAR observations. Significant improvements in accuracy over what can be achieved with current NASA imagery require resolution of 1-5 m/pixel.	Solid Earth Science Working Group (SESWG)					
4.15	*Forecasting landslides* -- Landslides threaten life and property in many parts of the US and the world. Steep slopes, soil conditions, soil moisture, and rainfall patterns are all parameters that contribute to slope movement and landslides. Accurate landslide forecasts rely on detailed knowledge of the location of the landslides, hill slope topography (LS-02, LS-03), soil conditions/rock type, soil moisture preconditioning, the ability to measure and track down-slope motion at the millimeter to centimeter level in a variety of land use types - including heavily vegetated, and the ability to detect landslide precursors. *The SDR Grand Challenges for Disaster Reduction - Landslide elements: develop better rainfall threshold models for landslides in areas routinely threatened by hurricanes and winter rainy seasons; research landslide initiation processes to better understand the interaction between soil type, texture, terrain grade, weather, fire, and other hazards; better integrate models that evaluate post-wildfire debris flow and landslide potential with near real-time rainfall estimates that blend in situ, radar, and satellite observations.*	Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond (Decadal Survey)					

4.16	*Global high-resolution topographic data* -- Predicting the location and timing of landslides depends on precise topographic data. Develop a 5-m global topographic survey with decimeter precision to identify and map landslides and flood hazards on a scale small enough to be useful for site-specific land-use decisions and advance the science on which such risk assessments are based. *The SDR Grand Challenges for Disaster Reduction - Landslide elements: Increase the use of Interferometric Synthetic Aperture Radar as well as airborne and groundbased side-looking LiDAR for more accurate landslide hazard assessments, susceptibility mapping, and to determine the volumes of susceptible material and possible runout distances;*	Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond (Decadal Survey); A Foundation for Innovation: Grand Challenges in Geodesy					
4.17	*Time-variable topography* -- Topography influences how natural hazards (such as landslides, floods, and earthquakes are distributed across the landscape. High-resolution topographic time series data are needed to better understand the fundamental physics that drive many natural hazards including landslides. Course resolution topographic data has been a major impediment to understanding the forces and dynamics processes associated with many natural and anthropogenic process that shape the Earth's surface. Topographic time series data from a uniform 5 meter - sub-decimeter accuracy digital elevation of the US and the world for better assess and model gravity and fluvial driven hazards (landslides, floods) and the ability to track dynamic topographic changes.	Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond (Decadal Survey); Solid Earth Science Working Group (SESWG); A Foundation for Innovation: Grand Challenges in Geodesy					

4.18	*Landslide deformation* -- Identify and measure surface displacements associated with landslides at 1 mm/yr over 50 km horizontal extents. *The SDR Grand Challenges for Disaster Reduction - Landslide elements: Increase the use of Interferometric Synthetic Aperture Radar as well as airborne and groundbased side-looking LiDAR for more accurate landslide hazard assessments, susceptibility mapping, and to determine the volumes of susceptible material and possible runout distances.*	Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond (Decadal Survey)					
4.19	*Hyperspectral identification and mapping of landslides* -- Identify and map landslides based on soil type, vegetation, and geomorphology from high-resolution hyperspectral imaging.	Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond (Decadal Survey); Solid Earth Science Working Group (SESWG)					
4.20	*Soil moisture* -- Soil moisture in mountainous areas is one of the most important determinants of landslides, a hazard that could be better predicted with consistent spatial and temporal soil moisture observations. The ability to map temporal and spatial variability of soil moisture every 3-days will advance our ability to assess landslide triggers, develop more accurate models, and significantly improve landslide and flood forecasts.	Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond (Decadal Survey)					
4.21	*Automated landslide parameterization* -- Automate the measurement of landslide areas and volumes using difference in topographic observations prior to and after each landslide event.	Solid Earth Science Working Group (SESWG)					

4.22	*Landslide precursors* -- Landslides often have precursors, but the ability to detect and interpret these precursors is severely limited by a lack of observations.	Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond (Decadal Survey)					
4.23	*Forecasting tsunamis wave heights and timing* -- Tsunamis can impact the coastal regions of the US and the world with great risk to life, property, and the ecosystem. Accurate tsunami forecasts rely on the ability to quickly characterize the earthquake, assess the tsunamigenic potential, model the tsunami energy as it propagates across the ocean interacting with the sea floor bathymetry and forecast onshore inundation from high resolution topographic data. *The SDR Grand Challenges for Disaster Reduction - Tsunami elements: Understand the natural processes that produce hazards; develop improved and sustained monitoring and research of both the generating mechanisms and the physical characteristics of the tsunami and more accurate description of the sites at risk.*	Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond (Decadal Survey)					
4.24	*Ocean bathymetry* -- Doubling the spatial resolution of data on seafloor topography would improve understanding of the geologic processes responsible for ocean-floor features, including abyssal hills, seamounts, microplates, and propagating rifts. It would improve tsunami hazard forecast accuracy by mapping the near-field ocean topography that steers tsunami wave energy.	Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond (Decadal Survey); Review of Solid Earth Science Working Group (SESWG)					

4.25	*Tsunami runup* -- Predicting the location and timing of tsunami runup depends on precise topographic data. The Decadal Survey determined that proposed 5-m global topographic survey at decimeter precision would permit improve global tsunami inundation modeling a scale small enough to be useful for site-specific land-use decisions. High-resolution topographic data would also advance the science on which such risk assessments are based.	Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond (Decadal Survey)					
4.26	*Volcanic deformation* -- Measure surface displacements associated with volcanic unrest 1 mm/yr over 50 km horizontal extents. *The SDR Grand Challenges for Disaster Reduction - Volcano elements: Launch a United States civilian Synthetic Aperture Radar satellite; Expand monitoring tool box to include emerging technologies such as Interferometric Synthetic Aperture Radar, and self-organizing, event-driven, smart monitoring networks; and expand efforts to improve monitoring capability at under-monitored volcanoes*	Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond (Decadal Survey); A Foundation for Innovation: Grand Challenges in Geodesy					
4.27	*Thermal production* -- The ability to identify and track thermal signatures associated with volcanic unreset from space. The combined, pointable hyperspectral and infrared sensors would greatly improve volcano monitoring and eruption prediction. *A thermal imaging spectrometer (3–5 µm and 8–12 µm with 30-nm spectral sampling) having high signal-to-noise ratio, good calibration stability. The SDR Grand Challenges for Disaster Reduction - Volcano elements: Increase satellite remote sensing capability for thermal imaging, detection of ash clouds by splitwindow technique, and detection of volcanic gas; provide accurate forecasts of ash fall and air quality to emergency managers and health officials in affected*	Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond (Decadal Survey)					

	communities; and Provide accurate forecasts of future ash cloud locations to aircraft controllers.						
4.28	*Volcanic gasses and ash detection* -- The ability to identify and track gasses and ash from volcanic activity with sufficient resolution. Gases from within Earth, such as CO2 or SO2, are sensitive indicators of impending volcanic hazards, and plume ejecta themselves pose risks to aircraft and to those downwind. These gases have distinctive spectra in the optical and near-infrared (IR) regions. An improved-precision solar-reflected spaceborne imaging spectrometer with a 100-km swath and 30-m spatial resolution. *The SDR Grand Challenges for Disaster Reduction - Volcano elements: Increase satellite remote sensing capability for thermal imaging, detection of ash clouds by splitwindow technique, and detection of volcanic gas; provide accurate forecasts of ash fall and air quality to emergency managers and health officials in affected communities; provide accurate forecasts of future ash cloud locations to aircraft controllers; test utility of unmanned aerial vehicle platform based analysis of volcanic gases (CO2, SO2, and others), and thermal, visual, and radar imaging; improve source and transport terms for ash cloud models to better understand the movement, separation, and gas necessary to form the clouds.*	Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond (Decadal Survey)					

4.29	*Volcanic mapping and modeling with high-resolution topographic data* -- high-precision topographic data would provide the basis for detecting and modeling incipient hazards from volcanic eruptions, lahars, pyroclastic flows, and mudflows. Develop a 5-m or better global topographic survey with decimeter precision that would aid volcanic hazard assessment and would greatly improve provide geodetic control for other space-based measurements including InSAR.	Solid Earth Science Working Group (SESWG)					
4.30	*Time-variable topography* -- Volcanic eruption can significantly change the landscape over time scales of minutes, to months and years. Up-to-date time-series of high-precision topographic provide invaluable data for assessing and modeling evolving volcanic hazards throughout an eruption sequence and provide the current modeling data to forecast the likelihood of lave flow extents as well as potential hazards associated with ash fall, lahars, pyroclastic flows, and mudflows. The Decadal Survey recommended a satellite mission with global coverage - 5-m horizontal and 10 cm vertical accuracy.	Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond (Decadal Survey); A Foundation for Innovation: Grand Challenges in Geodesy					
4.31	*Integrated science* -- Need to develop an improved understanding on the relationship among volcanic surface deformation, induced seismicity, volcanic intrusion, and volcanic eruptions. *The SDR Grand Challenges for Disaster Reduction - Volcano elements: understand the natural processes that produce hazards; and improve eruption forecasts for high-threat volcanoes and improve understanding of magmatic processes beneath volcanoes based on long-term patterns of eruptive behavior as well as monitoring observations.*	Solid Earth Science Working Group (SESWG); Grand Challenges in Geodesy					

4.32	*Early warning* -- Develop a volcanic activity warning system that integrates multi-satellite based measurements including the development of ash and plume products. *The SDR Grand Challenges for Disaster Reduction - Volcano elements: Provide hazard and disaster information where and when it is needed; and deploy a National Volcano Early Warning System, working with the Consortium of U.S. Volcano Observatories, Federal, state, and local emergency managers, and land-management agencies*	Solid Earth Science Working Group (SESWG)						
4.33	*Global volcanic inventory* -- Help develop an up-to-date global inventory of active terrestrial volcanoes. *The SDR Grand Challenges for Disaster Reduction - Volcano elements: Expand efforts to improve monitoring capability at under-monitored volcanoes; and develop a worldwide database on volcanic activity by working with national and international partners.*	Solid Earth Science Working Group (SESWG)						
4.34	*Volcanic triggers* -- Understand how dynamic and static stress changes associated with earthquake affect magmatic systems. *The SDR Grand Challenges for Disaster Reduction - Volcano elements: understand the natural processes that produce hazards; and improve eruption forecasts for high-threat volcanoes and improve understanding of magmatic processes beneath volcanoes based on long-term patterns of eruptive behavior as well as monitoring observations.*	A Foundation for Innovation: Grand Challenges in Geodesy						
4.35	*Volcanic interactions* -- Understand how volcanoes interact with each other.	A Foundation for Innovation: Grand Challenges in Geodesy						

4.36	The sharing of US Government purchased data that can support hazard science and response among all agencies. There are many datasets (i.e. RadarSAT, TerraSAR-X) where each agency purchases the same datasets. Data purchased by one agency should be available to all. Effort needs to be spent in minimizing the duplicate purchasing of data by the US Government.							

*Enable Early Warning Capabilities

Table 5. S&T Gaps—Geological Hazard—Develop Technology for Safer, Effective, and Timely Response and Recovery

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
5.1*	In the U.S. (and all but a few countries), no warnings are provided of imminent earthquake shaking, yet early warnings are possible with existing techniques, and warning systems are in place in Japan, Taiwan and elsewhere	USGS ANSS Requirements Circular; USGS EEW Implementation Plan; USGS NHMA Strategic Plan	NA				
5.2	Need to develop cost-effective measures to reduce earthquake impacts on individuals, the built environment, and society-at-large	NIST, FEMA, USGS, NSF - National Earthquake Hazards Reduction Program (NEHRP)					
5.3	Improve scientific processes within recovery process, which will lead to faster resumption of normal services and continuity of governments.	NASA - Applied Sciences Program/Earth Science					
5.4	Technologies to support survivors during a disaster, such as Assistive Technologies and demographic technologies to determine population types.	FEMA Office of Disability Integration and Coordination					

*Enable Early Warning Capabilities

Table 6. S&T Gaps— Geological Hazard—Integrate Science into Preparedness Decisions

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery

6.1	Guidelines or standards for landslide mapping and hazard assessment are not available.	USGS Circular 1244, National Landslide Hazards Mitigation Strategy – A Framework for Loss Reduction; National Research Council (NRC), "Partnerships for Reducing Landslide Risk".	NA				
6.2	Improve geological hazards intelligence in order to provide policymakers and first responders with actionable and timely information.	National Geospatial-Intelligence Agency					
6.3	There needs to be improved information sharing and public awareness. This program helps State and local agencies by providing resources for State tsunami inundation evacuation mapping, which provides a basis for preparedness and mitigation planning.	FEMA, FIMA - National Tsunami Hazard Mitigation Program (NTHMP)					
6.4	In order to mitigate consequences from geological hazards, there is a need for improved building codes and structures. NEHRP focuses on building code standards, technical guidance, and education. The NEHRP agencies work together to reduce the Nation's vulnerability to earthquakes. The agencies research the causes and effects of earthquakes to produce technical guidance; develop earthquake-resistant design, construction standards, and techniques; and educate the public about earthquake hazards and mitigation.	FEMA, FIMA - National Earthquake Hazards Reduction Program (NEHRP)					

Appendix 3.B – Geological Hazards – Science and Technology Programs and Alignment with PPD-8 Mission Areas

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
Earthquake Hazards	USGS/NH	The USGS Earthquake Hazards Program is part of the National Earthquake Hazards Reduction Program (NEHRP), established by Congress in 1977. We monitor and report earthquakes, assess earthquake impacts and hazards, and research the causes and effects of earthquakes.					
Volcano Hazards	USGS/NH	The USGS Volcano Hazards Program (VHP) monitors and studies active and potentially active volcanoes, assesses their hazards, and conducts research on how volcanoes work in order for the USGS to issue "timely warnings" of potential volcanic hazards to emergency-management professionals and the public.					
Landslide Hazards	USGS/NH	The primary objective of the National Landslide Hazards Program (LHP) is to reduce long-term losses from landslide hazards by improving our understanding of the causes of ground failure and suggesting mitigation strategies.					
Tsunami Hazards	NOAA/NWS	In 1995, recognizing the threat, the U.S. Congress directed the National Oceanic and Atmospheric Administration (NOAA) to form and lead a federal/state working group to develop a plan for reducing tsunami risk to U.S. coastal communities. This group formed what has become a model for federal/state partnerships—the National Tsunami Hazard Mitigation Program (NTHMP).					
Earth Science	NSF/GEO/EAR	The Division of Earth Sciences supports proposals for research geared toward improving the understanding of the structure, composition, and evolution of the Earth, the life it supports, and the processes that					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
		govern the formation and behavior of the Earth's materials. The results of this research will create a better understanding of the Earth's changing environments, and the natural distribution of its mineral, water, biota, and energy resources and provide methods for predicting and mitigating the effects of geologic hazards such as earthquakes, volcanic eruptions, floods, landslides.					
Earth Surface & Interior	NASA/ESD	NASA's Earth Surface and Interior focus area (ESI) supports research and analysis of solid-Earth processes and properties from crust to core. The overarching goal of ESI is to use NASA's unique capabilities and observational resources to better understand core, mantle, and lithospheric structure and dynamics, and interactions between these processes and Earth's fluid envelopes.					
Disaster Science	NASA/ESD/AS	The Disasters Applications area promotes the use of Earth observations to improve prediction of, preparation for, response to, and recovery from natural and technological disasters. The Disasters area supports projects to enhance management practices and disaster reduction across disaster types, including floods, earthquakes, volcanoes, and landslides.					
Humanitarian Assistance & Disaster Response	NGA	The National Geospatial-Intelligence Agency delivers geospatial intelligence to provide advantages to policymakers, warfighters, intelligence professionals, and first responders. The NGA has provided analytical support or public access to its information to aid response and recovery efforts for major disasters and biological incidents, including the 2015 Nepal earthquake and recent outbreak of the Ebola virus disease.					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
Office of Foreign Disaster Assistance	USAID/OFDA	The Office of U.S. Foreign Disaster Assistance (OFDA) is responsible for leading and coordinating the U.S. government's response to disasters overseas.					
HMA - Pre-Disaster Mitigation (PDM) and Hazard Mitigation Grant Program (HMGP)	FEMA	Non-structural Retrofitting of Existing Buildings and Facilities: Modifications to the non-structural elements of a building or facility to reduce or eliminate the risk of future damage and to protect inhabitants. Non-structural retrofits may include bracing of building contents to prevent earthquake damage or the elevation of utilities.					
HMA - Pre-Disaster Mitigation (PDM) and Hazard Mitigation Grant Program (HMGP)	FEMA	Soil Stabilization: Projects to reduce risk to structures or infrastructure from erosion and landslides, including installing geotextiles, stabilizing sod, installing vegetative buffer strips, preserving mature vegetation, decreasing slope angles, and stabilizing with rip rap and other means of slope anchoring. These projects must not duplicate the activities of other Federal agencies.					
PER-306 HURRIPLAN: Resilient Building Design for Coastal Communities	FEMA	The two day performance-level course will provide professionals with the training necessary to integrate resilient community planning and building design strategies with civic and commercial projects located in hurricane-prone areas.					
PER-305 Coastal Flood Risk Reduction	FEMA	This is a one-day performance level training course that develops participants' abilities to apply coastal risk reduction and opportunity enhancement measures to coastal floodplain management.					
AWR-322 Natural Disaster Awareness for Security Professionals	FEMA	This course will familiarize participants with a range of natural hazards, the disaster-specific risks they pose (including likelihood and consequences), different factors that contribute to or reduce vulnerability.					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
PER-304 Social Media for Natural Disaster Response and Recovery	FEMA	This course enhances the participants' abilities to build up an organization's communication strategy for disaster preparedness, response, and recovery.					
AWR-326 Tornado Awareness	FEMA	This eight hour is course is designed to provide emergency managers, first responders, and community members across all sectors with a basic understanding of the latest knowledge in tornado science, forecasting, warning, and preparedness.					
Office of Disability Integration and Coordination	FEMA	ODIC uses various technologies to support survivors during a disaster. Notably, ODIC uses numerous Assistive Technologies and demographic technologies to determine population types.					
Office of Disability Integration and Coordination	FEMA	ODIC uses various technologies to support survivors during a disaster. Notably, ODIC uses numerous Assistive Technologies and demographic technologies to determine population types.					
National Tsunami Hazard Mitigation Program (NTHMP)	FEMA	Supports State and local agencies to use their State tsunami inundation evacuation mapping as the basis for preparedness and mitigation planning and to improve public awareness					
National Earthquake Hazards Reduction Program (NEHRP)	FEMA	NEHRP focuses on building code standards, technical guidance, and education. The NEHRP agencies work together to reduce the Nation's vulnerability to earthquakes. The agencies research the causes and effects of earthquakes to produce technical guidance; develop earthquake-resistant design, construction standards, and techniques; and educate the public about earthquake hazards and mitigation.					
USNRC - Regulatory Activities	USNRC	USNRC uses geologic and meteorological natural hazards in its regulatory activities of nuclear reactors, nuclear materials and radioactive waste					

Appendix 4.A – Meteorological Hazards – Science and Technology Preparedness Gaps and Alignment with PPD-8 Mission Areas

Table 1. S&T Gaps—Meteorological Hazard—Advance Public Communication of Warnings or Advisories

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
1.1	Prediction Gap Area: Need for improvements in communicating winter storm impacts and expanding the use of probabilistic winter storm information.	Weather Ready Nation V2 Services Plan	NA				
1.2	Public Warning, Wireless Emergency Alerts Gap Area: Lack of clear language and graphics enabling public warnings of emergencies	NA	NA				
1.3	Public Warning Gap Area: Lack of infrastructure for public alerts and communication around emergencies	NA	NA				

Table 2. S&T Gaps—Meteorological Hazard—Enhance Fundamental Understanding of Hazards

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
2.1	Forecasting Gap Area: Need for better short- and long-term predictions of drought	Drought.Gov website	NA				

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
2.2	Modeling Groundwater Gap Area: Need for better information about the interactions between groundwater (quantity) and surface water	National Action Plan: Priorities for Managing Freshwater Resources in a Changing Climate; https://www.whitehouse.gov/sites/default/files/microsites/ceq/2011_national_action_plan.pdf	NA				
2.3	Earth Analysis and Forecast Gap Area: (1) lack of analysis to improve understanding of the air quality and health effects from wildfires, (2) lack of knowledge of link between weather and fire dynamics, and (3) lack of ability to link fire scars and debris flow	Federal budget requests	NA				
2.4**	Transportation and Operations Gap Area: Need for better visibility and freezing precipitation studies and measurements to enhance operations during winter storms	Lack of readily available surface temperature observations in AWIPS 2	NA				
2.5	Climate Change and Extreme Weather Gap Area: Lack of prediction capability and research to improve forecasting for: (1) high-impact weather & climate extreme events to support policy development, decision-making, and resource management; (2) air chemistry research that improves extreme weather forecasting; and (3) meteotsunami warnings along the coast of the Great Lakes	NA	NA				
2.6	Climate Change and Extreme Weather Gap Area: Lack of prediction capability and research to improve forecasting for: (1) high-impact weather & climate extreme events to support policy development, decision-making, and resource management; (2) air chemistry research that improves extreme weather forecasting; (3) meteotsunami warnings along the coast of the Great Lakes	President's FY 2016 Budget Submitted to Congress	NA				

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
2.7	Climate Change and Extreme Weather Gap Area: Lack of prediction capability and research to improve forecasting for: (1) high-impact weather & climate extreme events to support policy development, decision-making, and resource management; (2) air chemistry research that improves extreme weather forecasting; (3) meteotsunami warnings along the coast of the Great Lakes	National Academy of Science reports, severe weather assessments, budget requests	NA				

**Critical Infrastructure Resilience

Table 3. S&T Gaps—Meteorological Hazard—Improve Event Characterization and Risk Assessment

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
3.1	Tropical Cyclones Observations and Predictions Gap Area #2: Advance and improve our understanding of tropical cyclone intensity, structure and track	2007 Interagency Strategic Research plan for Tropical Cyclones - The Way Ahead; http://www.ofcm.gov/p36-isrtc/fcm-p36.htm	NA				
3.2	Modeling and Forecasting Precipitation Gap Area: Need for higher resolution model output, shorter to longer-term precipitation forecasts, and improved flood estimates	National Action Plan: Priorities for Managing Freshwater Resources in a Changing Climate - https://www.whitehouse.gov/sites/default/files/microsites/ceq/2011_national_action_plan.pdf	NA				

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
3.3	Modeling Precipitation Change Gap Area: Need for improvements in statistical methodologies and data to model precipitation	National Action Plan: Priorities for Managing Freshwater Resources in a Changing Climate - https://www.whitehouse.gov/sites/default/files/microsites/ceq/2011_national_action_plan.pdf	NA				
3.4	Hydrological Services Gap Area: The current suite of hydrological services does not provide adequate information to provide the following services: • Extreme event precipitation forecasting • Estimation of flash flooding and debris flow	National Research Council, (2005): Flash flood forecasting over complex terrain: With an assessment of the Sulphur Mountain NEXRAD in Southern California. National Academy Press, Washington, D.C.; http://www.nap.edu/catalog/11128/flash-flood-forecasting-over-complex-terrain-with-an-assessment-of National Weather Service's Service Assessment on The Record Front Range and Eastern Colorado Floods of September 11 – 17, 2013; http://www.nws.noaa.gov/om/assessments/pdfs/14colorado_floods.pdf	NA				
3.5	Engineering Design Gap Area: Need for improved probabilistic windstorm hazard mapping during high intensity severe thunderstorms and tornadoes	Measurement Science R&D Roadmap for Windstorm and Coastal Inundation Impact Reduction; http://www.nist.gov/customcf/get_pdf.cfm?pub_id=915541	NA				

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
3.6	Aviation Weather Gap Area: Need to improve short-term weather prediction of severe thunderstorms and tornadoes	FAA NextGen Weather (http://www.faa.gov/nextgen/programs/weather/), ICAO Aviation Service Block Upgrades; http://www.icao.int/airnavigation/IMP/Documents/ASBU%20Document%202015-01-08.pdf	NA				
3.7	Building Design Gap Area: Buildings are currently not designed adequately to reduce vulnerability to wind hazards due to deficiencies in: • Vulnerability assessment methodologies • Adequate engineering design standards	Measurement Science R&D Roadmap for Windstorm and Coastal Inundation Impact Reduction; http://www.nist.gov/customcf/get_pdf.cfm?pub_id=915541	NA				
3.8	Climate analysis, forecasting and uncertainty Gap Area: Lack of understanding of vulnerability assessments, resilience work, and models	NA	NA				
3.9	Modeling and Stream Flow Stats Gap Area: Need for improved understanding of stream flow for gaged and ungaged streams.	National Action Plan: Priorities for Managing Freshwater Resources in a Changing Climate - https://www.whitehouse.gov/sites/default/files/microsites/ceq/2011_national_action_plan.pdf	NA				

Table 4. S&T Gaps—Meteorological Hazard—Enhance Observations, Modeling, and Data Management

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
4.1	Tropical Cyclones Observations and Predictions Gap Area #1: Lack of atmospheric and oceanic observations and measurements to improve Tropical Cyclone forecasts, including in areas over the open ocean where manned (with X-Band Tail Doppler radar) and unmanned aircraft can be used as well as satellites as well as adding additional coastal surface platforms (C-MAN stations)	Internal expert input within the USACE Coastal and Hydraulics Laboratory	NA				
4.2	Tropical Cyclones Observations and Predictions Gap Area #3: Lack in a realistic version of the ocean-atmosphere interaction in tropical cyclone regional models	Hurricane Forecasting Improvement Program (http://www.hfip.org)	NA				
4.3	Monitoring Gap Area: Need for improvements in the monitoring of soil moisture for drought	National Academy of Sciences report: Observing Weather and Climate from the Ground Up: A Nationwide Network of Networks (2009) http://www.nap.edu/catalog/12540/observing-weather-and-climate-from-the-ground-up-a-nationwide	NA				

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
4.4	Wildfire Planning and Operations Gap Area: The current suite of planning and operations does not provide adequate information to provide the following services: (1) high-resolution analysis of current surface and upper air conditions around fire zones, (2) fire weather forecasts and forecast maps, (3) fire simulations and behavior, and (4) decision support tools	2008 NOAA SAB Fire Weather Research report: A Burning Agenda for NOAA; http://www.sab.noaa.gov/Reports/2008/FWRWGreportFINALfromSABtoNOAA_11_03_08.pdf National Cohesive Wildland Fire Management Strategy; http://www.forestsandrangelands.gov/ strategy; and, the NOAA Science Advisory Board Report on wildland fire weather research - found here: http://www.sab.noaa.gov/reports/2008/FWRWGreportFINALfromSABtoNOAA_11_03_08.pdf	NA				
4.5	Winter Storm Modeling and Predictions Gap Area: The current suite of modeling and prediction training and resources for winter storms are inadequate to create successful deterministic and probabilistic forecasting based on coupled models	Internal expert input within the USACE Coastal and Hydraulics Laboratory	NA				
4.6	Polar Storm Modeling Gap Area: There is need for better impact modeling in high-latitude regions from wind/wave/ice motions during winter storm events	USACE Cold Regions Lab, NSF Office Polar Programs	NA				
4.7	Modeling Gap Area: The current suite of modeling and parameterization efforts does not enable prediction of atmospheric convection across all scales	Holloway, C E., et al. (2014). Understanding and representing atmospheric convection across scales: recommendations from the meeting held at Dartington Hall, Devon, UK, 28–30 January 201(3) Atmospheric Science Letters.	NA				

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
4.8	Observation Gap: Need for measured hazard, load, and response data for buildings and infrastructure in coastal or riverine floods.		NA				
4.9	Observing System Gap Area: The current suite of weather services does not provide adequate information to provide the following service: Support of fundamental infrastructure for Mesoscale Monitoring		NA				
4.10	Operations Gap Area: Gap in Probabilistic Forecasting information, data, and evaluation		NA				
4.11	Monitoring Water Body Changes Gap Area: Lack of information on watershed demand and supply resulting of climate change		NA	x			

Table 5. S&T Gaps—Meteorological Hazard—Develop Technology for Safer, Effective, and Timely Response and Recovery

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
NO GAPS DESCRIBED FOR THIS S&T DEVELOPMENT AREA							

Table 6. S&T Gaps—Meteorological Hazard—Integrate Science into Preparedness Decisions

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
6.1	Prediction and Communication Gap Area: Need for improved numerical guidance by forecasters and delivery of forecast services to partners	UCACN 2014 Annual Report, WRN v2 Strategic Plan	NA				
6.2	Training Gap Area: need for additional training in Met Hazards gap areas	Other Meteorological source documents listed	NA				
6.3	Community Resilience Gap Area: Lack of plans, strategies, tools, and awareness to guide communities	President's Climate Action Plan, June 2013, https://www.whitehouse.gov/sites/default/files/image/president27sclimateactionplan.pdf	NA				

Appendix 4.B – Meteorological Hazards – Science and Technology Programs and Alignment with PPD-8 Mission Areas

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
Aviation Weather Center	NOAA National Weather Service	The Aviation Weather Center uses Science and Technology to prepare aviation weather and safety of flight warnings for the United States as well as for large expanses of oceanic airspace within its international Meteorological Watch Office domain.					
Climate Prediction Center	NOAA National Weather Service	The Climate Prediction Center delivers real-time products and information that predict and describe climate variations on timescales from weeks to years thereby promoting effective management of climate risk and a climate-resilient society					
Storm Prediction Center	NOAA National Weather Service	The Storm Prediction Center uses innovative science and technology to deliver timely and accurate watch and forecast information dealing with tornadoes, severe thunderstorms, lightning, wildfires, and winter weather.					
National Hurricane Center	NOAA National Weather Service	NHC issues official watches, warnings, forecasts, and analyses of hazardous tropical weather.					
Central Pacific Hurricane Center	NOAA National Weather Service	CPHC issues official watches, warnings, forecasts, and analyses of hazardous tropical weather.					
Weather Prediction Center	NOAA National Weather Service	The Weather Prediction Center is a center of excellence in the prediction of high-impact precipitation events. In the cool season these events include blizzards, snowstorms, ice storms,					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
		and lake-effect snows. Precipitation associated with hurricanes, mesoscale convective complexes, and squall lines are warm season examples.					
Meteorological Development Laboratory (MDL)	NOAA National Weather Service	MDL develops and transitions interpretive model guidance, decision support applications and digital forecast services that enable NWS forecasters and partners to be more effective in protecting life and property and enhancing the national economy					
NWS Regional Science Services Division (SSDs), Science Operations Officers (SOOs), and Development Operational Hydrologists (DOHs)	NOAA National Weather Service	The SOOs/DOHs/SSDs lead the field innovation and science to operations transition activities to meet emerging requirements for service enhancements, integrating and transitioning science and technology advancements into operational services and providing local science and training expertise to ensure effective service delivery by the workforce.					
NWS/Alaska Region/ Environmental and Scientific Services/Arctic Test Bed (ATB)	NOAA National Weather Service	The Arctic Test Bed has been designed to transform our scientific services to meet the emerging requirements in the Arctic, as well as enable the Alaska Region to be an effective component of the NWS integrated field structure, improved focus is needed on operational science and technology advances relevant to this region and enable the fulfillment of NOAA's science, service, and stewardship mission in Alaska and the Arctic.					
National Integrated Drought Information System (NIDIS)	NOAA OAR	Produces US Drought Portal; US Drought Monitor (weekly since 1999), a composite indicator to monitor drought					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
NWS Office of the Chief Learning Officer	NOAA National Weather Service	The NWS Learning Office trains forecasters and hydrologists to predict and effectively communicate critical forecasts and warnings to key partners and the public					
NWS Fire Weather program	NOAA National Weather Service	The NWS Fire Weather Program provides effective leadership and Innovative operational support of fire management, firefighters, and the public through a suite of decision support information.					
NWS Public Weather Program	NOAA National Weather Service	The Public Weather Program provides a wide range of products and services that impact the public, including wind, heat, cold, air quality and ultraviolet radiation. The Program articulates policy for provision of generalized weather forecasts and information in textual, graphical and digital form. The Program leads efforts to promote spatial and temporal consistency among products issued across the scope of the Program. In addition, the Program is leading efforts to both simplify and clarify NWS hazard messaging and to deliver operational web-based requirements.					
NWS Winter Weather Program	NOAA National Weather Service	Winter storms including heavy snow, ice storms and blizzards, as well as life threatening wind chill and extreme cold are a coast-to-coast threat to the United States and its territories. The Winter Weather Program provides a wide range of products and services that impact the public. The Program leads the policy and provision of winter weather hazards in textual, graphical and digital form.					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
NWS Severe Weather Program	NOAA National Weather Service	The NWS provides forecasts of tornado and severe thunderstorms up to 8 days in advance, continually refining and increasing the specificity of these forecasts to issuing watches in the hours prior to events, and tornado warnings, severe thunderstorm warnings, and frequent update statements during the event. There is close coordination on policy and procedures with national and regional headquarters, the Storm Prediction Center, WFOs, and key partners.					
Office for Coastal Management	NOAA National Ocean Service	OCM helps build coastal community capacity for hazard preparedness, mitigation, and recovery by providing an integrated suite of data, information, training, technical assistance, cooperative funding, and policy tools.					
StormReady®	NOAA National Weather Service	The StormReady® program recognizes emergency managers and their programs for attaining a minimal level of preparedness for weather and flood hazards.					
SKYWARN®	NOAA National Weather Service	The SKYWARN® program trains volunteers as severe weather spotters. These dedicated citizen scientists help fill-in observing system gaps by reporting hail, wind damage, flooding, heavy snow, tornadoes and other hazardous weather impacts in order to help NOAA scientists make life-saving warning decisions.					
NWS Operations Proving Ground	NOAA National Weather Service	OPG evaluates new tools and capabilities in a realistic operations setting to assess readiness for field deployment					
Ocean Prediction Center	NOAA National Weather Service	The Ocean Prediction Center is responsible for accurate and timely warnings and forecasts of high winds and waves over the Offshore and High					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
		Seas waters of the North Atlantic and North Pacific					
National Integrated Drought Information System (NIDIS)	Multiagency; NOAA Office of Oceanic and Atmospheric Research (lead)	Produces US Drought Portal; US Drought Monitor (weekly since 1999), a composite indicator to monitor drought					
Regionally Integrated Sciences and Assessment Program (RISA)	Multiagency; NOAA Office of Oceanic and Atmospheric Research (lead)	Supports research teams that help expand and build the nation's capacity to prepare for and adapt to climate variability and change.					
Climate Program Office	NOAA/OAR	The Climate Program Office (CPO) manages competitive research programs in which NOAA funds high-priority climate science, assessments, decision support research, outreach, education, and capacity-building activities designed to advance our understanding of Earth's climate system, and to foster the application of this knowledge in risk management and adaptation efforts. CPO-supported research is conducted in regions across the United States, at national and international scales, and globally.					
National Sea Grant College Program	NOAA/OAR	Sea Grant's mission is to enhance the practical use and conservation of coastal, marine and Great Lakes resources in order to create a sustainable economy and environment.					
Office of Weather and Air Quality	NOAA/OAR	The Office of Weather and Air Quality (OWAQ) helps improve weather forecast information and products for the Nation by supporting high-impact weather and air quality research that ultimately leads to improvements in NOAA's operational forecasts that help save lives and reduce property damage.					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
NOAA Unmanned Aircraft Systems	NOAA/OAR	Unmanned Aircraft Systems (UAS) can revolutionize NOAA's ability to monitor and understand the global environment. There is a key information gap today between instruments on Earth's surface and on satellites - UAS can bridge that gap. Operated by remote pilots and ranging in wingspan from less than six feet to more than 115 feet, UAS can also collect data from dangerous or remote areas, such as the poles, oceans, wildlands, volcanic islands, and wildfires. Better data and observations improve understanding and forecasts, save lives, property, and resources, advancing NOAA's mission goals.					
Air Resources Laboratory	NOAA/OAR	Scientists at the Air Resources Laboratory (ARL) conduct research to gain new insights into atmospheric dispersion, atmospheric chemistry, climate change, and the complex behavior of the atmosphere near the Earth's surface, called the atmospheric boundary layer.					
Atlantic Oceanographic and Meteorological Laboratory	NOAA/OAR	AOML, a federal research laboratory, is part of NOAA's Office of Oceanic and Atmospheric Research, located in Miami, Florida. AOML's research spans hurricanes, coastal ecosystems, oceans and human health, climate studies, global carbon systems, and ocean observations.					
Earth System Research Laboratory, Directors Office	NOAA/OAR	ESRL was formed to pursue a broad and comprehensive understanding of the Earth system. This system comprises many physical, chemical and biological processes that need to be dynamically integrated to better predict their behavior over scales from local to global and periods of minutes to millennia. ESRL-DO					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
		coordinates across ESRL Divisions and incubates programs into Divisions or elsewhere in NOAA.					
Earth System Research Laboratory, Global Monitoring Division	NOAA/OAR	ESRL's Global Monitoring Division conducts sustained observations and research related to global distributions, trends, sources and sinks of atmospheric constituents that are capable of forcing change in the climate of the Earth. This research will advance climate projections and provide scientific policy-relevant, decision support information to enhance society's ability to plan and respond.					
Earth System Research Laboratory, Physical Sciences Division	NOAA/OAR	The Physical Sciences Division (PSD) conducts weather and climate research to observe and understand Earth's physical environment, and to improve weather and climate predictions on global-to-local scales					
Earth System Research Laboratory, Chemical Sciences Division	NOAA/OAR	Our mission is to advance scientific understanding of three major environmental and societal issues of our time: climate change, air quality, and stratospheric ozone layer CSD scientific research and the interconnections through atmospheric research on the chemical and related physical processes that affect Earth's atmospheric composition.					
Earth System Research Laboratory, Global Systems Division	NOAA/OAR	The Global Systems Division (GSD) of the Earth System Research Laboratory (ESRL) conducts research and development to provide NOAA and the nation with observing, prediction, computer, and information systems that deliver environmental products ranging from local to global predictions of short-range, high impact					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
		weather and air quality events to longer-term intraseasonal climate forecasts.					
National Severe Storms Laboratory	NOAA/OAR	The National Severe Storms Laboratory serves the nation by working to improve the leadtime and accuracy of severe weather warnings and forecasts in order to save lives and reduce property damage. NSSL scientists are committed to their mission to understand the causes of severe weather and explore new ways to use weather information to assist National Weather Service forecasters and federal, university and private sector partners.					
Geophysical Fluid Dynamics Laboratory	NOAA/OAR	The Geophysical Fluid Dynamics Laboratory (GFDL) is engaged in comprehensive long lead-time research fundamental to NOAA's mission. Scientists at GFDL develop and use mathematical models and computer simulations to improve our understanding and prediction of the behavior of the atmosphere, the oceans, and climate. GFDL scientists focus on model-building relevant for society, such as hurricane research, prediction, and seasonal forecasting, and understanding global and regional climate change.					
National Water Center	NOAA/National Weather Service	The National Water Center (NWC) collaboratively researches, develops and delivers state-of-the-science national hydrologic analyses, forecast information, data, decision-support services and guidance to support and inform essential emergency services and water management decisions. In partnership with NWS national, regional, and local offices, the NWC coordinates,					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
		integrates and supports consistent water prediction activities from global to local levels.					
National Earth System Prediction Capability	Multiagency, NOAA NWS and OAR lead	National ESPC is an interagency partnership (NOAA, DoD, NASA, DoE, NSF) to develop/implement a common or coordinated prediction technology through an affiliation of existing Programs, Projects, Laboratories, and Centers. Its goal is to meet broad federal needs through coordinated R&D and operations to create a more accurate, longer range, global ocean and atmosphere forecast system for decision support.					
Center for Weather and Climate	NOAA National Environmental Satellite Data and Information Service	The Center for Weather and Climate delivers near real time and archived products and data that document and describe climate and its variations to allow proactive management of risk to inform a climate-resilient society					
Environmental Modeling Center	NOAA National Weather Service	EMC maintains, enhances and transitions-to-operations numerical forecast systems for weather, ocean, climate, land surface and hydrology, hurricanes, and air quality for the Nation and the global community and for the protection of life and property and the enhancement of the economy.					
U.S. Integrated Ocean Observing System (IOOS®)	NOAA/NOS	The U.S. Integrated Ocean Observing System (IOOS®) coordinates national, international, regional, and local ocean and coastal observation networks, modeling efforts, and data management and communications services to provide the Nation with information to safeguard life and property, to protect valuable					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
		ecosystems, and sustain our Nation's economic vitality.					
U.S. National Ice Center	NOAA/NESDIS/OSPO	The U.S. National Ice Center (USNIC) provides global to tactical scale ice and snow products, ice forecasting, and other environmental intelligence services for the United States government.					
NESDIS/OSPO/Satellite Analysis Branch	NOAA/NESDIS	24 x 7 satellite imagery analysts provide information about a variety of hazards including potentials for flooding, the intensity and location of tropical storms and the location of fires					
(STAR) Center for Satellite Applications & Research	NOAA/NESDIS	Develops advanced satellite-derived measurements of atmospheric and oceanic processes for use in weather prediction models, and providing near real time observations and analyses used in forecasting and other environmental decision support.					
Office of Observations	NOAA National Weather Service	The Office of Observations (OBS) serves as the primary office responsible for the collection of space, atmosphere, water, and climate observational data owned or leveraged by NWS.					
Naval Oceanography Program	Dept of the Navy	Provides operational environmental support to the Navy and Marine Corps					
Air Force Weather Program	Dept of the Air Force	Provides operational environmental support to the Air Force and Army					
High Impact Weather Prediction Program (HIWPP)	NOAA/OAR	Improve time-zero to two-week weather prediction of nature's most dangerous storms such as hurricanes, floods, and blizzards/					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
Hurricane Forecast Improvement Program (HFIP)	NOAA/NWS	Reduce the average errors of hurricane track and intensity forecasts by 20% within five years and 50% in ten years with a forecast period out to 7 days					
FHWA Emergency Relief Program	Federal Highway Administration	Funds the repair and reconstruction of Federal-aid highways and roads on federal lands which have suffered serious damage as a result of natural disasters or catastrophic failure due to an external cause.					
FHWA Road Weather Management Program	Federal Highway Administration	Seeks to better understand the impacts of weather on roadways, and promote strategies and tools to mitigate those impacts. Envisioned is a system that provides "Anytime, Anywhere Road Weather Information" for road users and road operating agencies, as well as a robust, competitive market for road weather services.					
FTA Public Transportation Emergency Relief Program	Federal Transit Administration	Helps States and public transportation systems pay for protecting, repairing, and/or replacing equipment and facilities that may suffer or have suffered serious damage as a result of an emergency, including natural disasters such as floods, hurricanes, and tornadoes. The program can fund capital projects to protect, repair, or replace facilities or equipment that are in danger of suffering serious damage, or have suffered serious damage as a result of an emergency. The program can also fund the operating costs of evacuation, rescue operations, temporary public transportation service, or reestablishing, expanding, or relocating service before, during or after an emergency.					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
FHWA Hydraulic Engineering	Federal Highway Administration	Provides FHWA offices with technical expertise in matters of the hydraulic discipline					
Community Resilience Program	NIST	The Community Resilience Program provides tools to measure resilience at the community scale and support investment decisions on measures to improve resilience. The program also produces planning and implementation guidance developed through broad engagement of resilience stakeholders.					
Water Management Mission (USACE)	USACE	USACE operates over 700 dams within US for flood risk management purpose and other Congressionally authorized proposes.					
Emergency Management Mission (USACE)	USACE	Emergency Management is USACE one of the main mission areas					
Civil Works Research & Development (USACE)	USACE	Research & Development serves the technology needs of the Civil Works missions of USACE					
Hydrologic Engineering Center (HEC), USACE	USACE	The HEC develops Hydrology, Hydraulics, Revoir Systems, Flood Damage, and Real Time River and Reservoir Forecasting software.					
Joint Agricultural Weather Facility	USDA Office of the Chief Economist	Operational products include: World Agricultural Supply and Demand Estimates, Weekly Weather and Crop Bulletin, U.S. and North American Drought Monitor					
Regional Climate Hubs	USDA Office of the Chief Economist	The Climate Hubs will deliver science-based knowledge, practical information and program support for decision-making related to climate change.					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
Strategic Data Acquisition and Analysis	USDA Risk Management Agency	Uses PRISM to help improve their climate and weather data for underwriting and compliance purposes in the Federal Crop Insurance Program					
Federal Crop Insurance Corporation	USDA Risk Management Agency	Develop pilots using Weather Data and Satellite Imagery for purpose of defining risk					
Water Availability and Watershed Management	USDA Agricultural Research Service	The goal is to manage water resources while protecting the environment and human and animal health (key element: Long-Term Agro-Ecosystem Research)					
Climate Change, Soils, and Emissions	USDA Agricultural Research Service	Mission: to improve the quality of atmosphere and soil resources affected by, and having an effect on agriculture, and to understand the effects of, and prepare agriculture for, adaptation to climate change (key product: Agricultural Model Intercomparison and Improvement Project)					
Agriculture and Food Research Initiative	USDA National Institute for Food and Agriculture	Charged with funding research, education, and extension grants and integrated research, extension, and education grants that address key problems of national, regional, and multi-state importance in sustaining all components of agriculture.					
National Water and Climate Center	USDA Natural Resources Conservation Service	The Center is the technical lead for the Snow Survey and Water Supply Forecasting Program, the NRCS national Soil Climate Analysis Network (SCAN), and a large number of water and climate activities.					
National Water Management Center	USDA Natural Resources Conservation Service	Provides expertise in and guidance with the application of water resource technologies to assess watershed health and plan watershed-scale solutions (programs include: Hydrology and					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
		hydraulics, Watershed and dam rehabilitation, DAMWATCH)					
National Interagency Fire Center	USDA Forest Service	Nation's support center for wildland firefighting. Programs include: Predictive Services Program, Fire and Aviation Management (RAWS Network), Satellite Telemetry Interagency Working Group					
National Windstorm Impact Reduction Program (NWIRP)	NIST	NIST's NWIRP activities support R&D to improve building codes, standards and practices for design and construction of buildings, structures, and lifelines to reduce the impacts of windstorms.					
National Windstorm Impact Reduction Program (NWIRP)	NOAA	NOAA's NWIRP activities support atmospheric sciences research to improve the understanding of the behavior of windstorms and their impact on buildings, structures, and lifelines.					
National Windstorm Impact Reduction Program (NWIRP)	FEMA FIMA	FEMA's NWIRP activities support the development of risk assessment tools and mitigation techniques, windstorm-related data collection and analysis, public outreach, information dissemination, and implementation of mitigation measures consistent with the Agency's all-hazards approach.					
National Windstorm Impact Reduction Program (NWIRP)	NSF	NSF's NWIRP activities support research in engineering and the atmospheric sciences to improve the understanding of the behavior of windstorms and their impact on buildings, structures, and lifelines.					

Appendix 5.1.A – Space Weather Hazards – Science and Technology Preparedness Gaps and Alignment with PPD-8 Mission Areas

Table 1. S&T Gaps— Space Weather Hazard — Improve Public Communication of Warnings and Advisories

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
NO GAPS DESCRIBED FOR THIS S&T DEVELOPMENT AREA							

Table 2. S&T Gaps—Space Weather Hazard—Enhance Fundamental Understanding of Hazards

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
2.1	Limited understanding of Sun-Earth domain, which impacts ability to develop models tools, and capabilities.	Space Weather Action Plan	NA				
2.2	Need for greater accuracy and lead time of space weather forecasting.	Grand Challenges 2010 Space Weather Action Plan 5.4 Space Weather Action Plan 4.3 (Develop or refine operational models) Space Weather Action Plan 4.4 (Identify requirements and seek development of relevant tools)	NA				

Table 3. S&T Gaps—Space Weather Hazard—Improve Event Characterization and Risk Assessment

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
3.1	Need for benchmarking of space weather events to enable reference points for vulnerability and risk assessment.	Space Weather Action Plan	NA				
3.2**	Require better understanding of space weather impacts to critical infrastructure in order to inform protection and mitigation needs.	Grand Challenges 2010 Space Weather Action Plan 4.2 (Develop Real-Time Infrastructure Assessment and Reporting Capability) Space Weather Action Plan: 2.2.5 (Integrate into national preparedness plans) Space Weather Action Plan: 3.2.2 (Develop guidance on tools for assessment replacement systems)	NA				

**Critical Infrastructure Resilience

Table 4. S&T Gaps—Space Weather Hazard—Increased Observations, Enhanced Modeling, Data Management

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
4.1	Stable and long-term space-based and ground-based capabilities and measurements to enable real-time monitoring and detection of space hazard events.	Grand Challenges 2010 Space Weather Action Plan 5.3	NA	X	X	X	

Table 5. S&T Gaps—Space Weather Hazard—Response or Recovery Research and Technology Needs

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
5.1**	Need for improved critical infrastructure response and recovery capabilities for significant space weather events.	Grand Challenges 2010 Space Weather Action Plan 2.0 Space Weather Action Plan: 3.2.2 (Federal resilience guidance) Space Weather Action Plan: 2.6 (Training materials + exercise objectives for evaluation response)	NA				

**Critical Infrastructure Resilience

Table 6. S&T Gaps—Space Weather Hazard—Integrate Science into Preparedness Decisions

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
6.1	End-user need for actionable, reliable, and accurate space weather information to enable decision support of mitigation and response actions.	Space Weather Action Plan 4.0 & 5.0	NA				
6.2**	Need for educate and inform CI operators to the risk of space weather events and spur adoption of resilience measures.	Grand Challenges 2010 Space Weather Action Plan 2.3	NA				

**Critical Infrastructure Resilience

Appendix 5.1.B – Space Weather Hazards – Science and Technology Programs and Alignment with PPD-8 Mission Areas

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
557th Weather Wing Note: Air Force Weather Agency (AFWA) was redesignated to this name on March 2015	USAF	Within the 557th Weather Wing, the 2nd Weather Squadron is responsible for solar observation and forecasting. The squadron also has a Space Weather Flight and its key functions include space situational awareness, solar event forecasting and warning, and satellite anomaly assessments. They coordinate daily with NOAA's SWPC. Additional details on this fact sheet (see page 20, Operations section): http://www.557weatherwing.af.mil/shared/media/document/AFD-150325-016.pdf					
Space Weather Prediction Center (SWPC)	NOAA	The Space Weather Prediction Center (SWPC) is one of the nine National Centers for Environmental Prediction (NCEP) within the National Weather Service (NWS) and is the Nation's office civilian source of space weather alerts and warnings. SWPC provides real-time monitoring and forecasting of solar and geophysical events, conducts research in solar-terrestrial physics, and develops techniques for forecasting solar and geophysical disturbances. SWPC works with many national and international partners who contribute data and observations.					
NextGen Weather	FAA	NextGen Weather is one of the programs within the Next Generation Air Transportation (NextGen) System. NextGen Weather will help reduce weather impact by producing and delivering tailored aviation weather products via SWIM, helping controllers and operators develop reliable flight plans, make better decisions, and improve on-time performance. NextGen Weather is accomplished through collaboration between FAA, NOAA and NASA. NextGen is being rolled out in stages from					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
		2012 to 2025. Question: To what extent will NextGen Weather produce products? The National Space Weather Program website refers to NextGen as mostly being an integration product.					
Geomagnetism Program	USGS	Geomagnetism Program provides high-quality, ground-based magnetometer data continuously from 13 observatories distributed across the United States and its territories. The Program collects, transports, and can disseminate these data in near-real time, and it also has significant data-processing and data-management capacities. Working through the INTERMAGNET organization, and with other national geomagnetism programs, the USGS Geomagnetism Program assists in the coordinated, global-scale monitoring of the Earth's magnetic field. The Geomagnetism Program also supports research on magnetic field activity, magnetic storms, and magnetic climatology, and it is currently developing a real-time storm-time disturbance (Dst) service. Question: Where can more information be found on the real-time storm disturbance (Dst) service and its status (in development, operational, enhancements, etc.)?					
FEMA Center of Excellence for Space Weather	FEMA	Question: This COE should be related to FEMA R8 and the Denver MERS Detachment. It is not mentioned on the FEMA website. Where can information be found on this COE and the work being performed?					
NAIRAS	NASA	Nowcast of Atmospheric Ionizing Radiation for Aviation Safety (NAIRAS) uses real-time data and modeling to estimate radiation exposure for airline crews and passengers.					
NASA Solar Shield	NASA GSFC	The solar shield project helps protect electric power companies from the extremes of space weather through improved forecasting. Power grids rely on high-voltage transformers that are vulnerable to surging electric currents ultimately caused by incoming solar material blasted off the sun. Solar Shield helps map out where and					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
		how strongly such currents, called geomagnetically induced currents (GICs), may impact Earth, thus giving power companies enough warning to protect their systems.					
Solar Storm Mitigation: GIC Forecasting (Solar Shield Extension)	DHS S&T	This GIC forecasting project will provide utilities with actionable information by enabling more localized and precise GIC forecast levels that are specific to a utility's location and infrastructure. This will help utility operators to make better informed operational decisions to mitigate the impacts from solar storms on critical grid infrastructure.					
Resilience Dispatch for Electric Power Grids under Geomagnetic Disturbances	DHS S&T	To protect against voltage instability impacts to the grid, the Resilient Dispatch project will work with PJM Interconnection to develop a process for analyzing and quantifying the resilience of a power grid to solar storms. A methodology will also be created for optimizing generation dispatching to protect/mitigate against voltage collapse during solar storms.					
Recovery Transformer (RecX) Program	DHS S&T	RecX is a mobile spare EHV transformer designed to be rapidly deployed in the event of a transformer failure					
EPRI SUNBURST network	EPRI	The Electrical Power Research Institute's (EPRI) Sunburst network is both an organized method for measuring geomagnetically induced currents (GICs) and their effects, and a source of data for continuing research studying the cause, effects and mitigation of GIC impacts on electrical power systems.					
NOAA Space Weather Follow-On	NOAA	DSCOVR follow-on satellite for real-time monitoring and forecasting of geomagnetic storms that can affect critical infrastructure and the bulk power system. The Space Weather Follow-On will maintain or improve the current observations provided by SOHO (coronograph) and ACE/DSCOVR (in-situ solar wind).					
Space Weather Enterprise Forum (SWEF)	Interagency	The SWEF has been held almost yearly since 2007 and began as a method for government agencies and academia to educate and inform a broad range of space weather users, policy makers, and					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
		decision makers on the importance of space weather preparedness.					
National Space Weather Program (NSWP)	Interagency	The NSWP is an interagency initiative to speed improvement in space weather services and prepare the country to deal with technological vulnerabilities associated with the space environment.					
NASA Space Weather Research Center	NASA	Experimental research information and products and forecasting of space weather for NASA's robotic mission operators.					
SWPC Geospace Modeling	NOAA	SWPC's Geospace modeling efforts will provide regional geomagnetic storm short term forecasts in support of the electric power industry. This work is a collaborative effort with NASA's Community Coordinated Modeling Center as well as supporting contracted work from the University of Michigan (model developer).					
SWPC Induced Electric Field Modeling	NOAA	SWPC's Induced Electric Field (Induced-E) efforts will provide nowcasts of the Induced-E from a geomagnetic storm, a valuable input for directly evaluating the impacts and induced currents on the bulk power system. This work is a collaborative effort with the USGS, NASA, and Natural Resources Canada.					
SWPC Integrated Dynamics in Earth's Atmosphere (IDEA) Modeling	NOAA	SWPC Integrated Dynamics in Earth's Atmosphere (IDEA) modeling effort will predict the lower atmosphere impact on ionospheric space weather (and vice versa). This will result in improved forecasts/lead times for ionospheric conditions that can disrupt GPS services & communications as well as improved terrestrial weather forecasts from upper atmosphere coupling. This work is a collaborative effort with the University of Colorado (CIRES).					
NASA/NSF Collaborative Space Weather	NASA	This program is funding eight large efforts (6 of which listed below) that are working towards development of one or more deliverables that address a significant and specific need for					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
Modeling: Overview		achieving Living With A Star and National Space Weather Program goals.					
NASA/NSF Collaborative Space Weather Modeling: Effort 2	NASA	Integration of Extended MHD and Kinetic Effects in Global Magnetosphere Models					
NASA/NSF Collaborative Space Weather Modeling: Effort 3	NASA	The Coronal Global Evolutionary Model (CGEM)					
NASA/NSF Collaborative Space Weather Modeling: Effort 4	NASA	Medium Range Thermosphere Ionosphere Storm Forecasts					
NASA/NSF Collaborative Space Weather Modeling: Effort 6	NASA	Integrated Real-Time Modeling System for Heliospheric Space Weather Forecasting					
NASA/NSF Collaborative Space Weather Modeling: Effort 7	NASA	Physical Processes Governing Energy and Momentum Flows on Multiple Scales in Near-Earth Space Using a First-Principles-Based Data Assimilation System for the Global Ionosphere-Thermosphere-Electrodynamics					
NASA/NSF Collaborative Space Weather	NASA	Corona-Solar Wind Energetic Particle Acceleration (C-SWEPA) Modules					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
Modeling: Effort 8							

Appendix 5.2.A – Near Earth Object Hazards – Science and Technology Preparedness Gaps and Alignment with PPD-8 Mission Areas

Table 1. S&T Gaps— Space Weather Hazard — Improve Public Communication of Warnings and Advisories

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
NO GAPS DESCRIBED FOR THIS S&T DEVELOPMENT AREA							

Table 2. S&T Gaps—Near Earth Object Hazard—Enhance Fundamental Understanding of Hazards

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
2.1	Lack of tsunami impact models specific to asteroid impacts are insufficient to inform planning and response decisions.	NOAA, NRC Defending Planet Earth	NA				
2.2	Current deflection models (i.e., attempts to prevent impacts by moving the PHO away from Earth) are insufficient to inform technology development.	Space Mission Planning Advisory Group; NRC, Defending Planet Earth	NA				

Table 3. S&T Gaps— Near Earth Object Hazard — Improve Event Characterization and Risk Assessment

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
NO GAPS DESCRIBED FOR THIS S&T DEVELOPMENT AREA							

Table 4. S&T Gaps—Near Earth Object Hazard—Increased Observations, Enhanced Modeling, Data Management

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
4.1	Lack of asteroid data required to inform decision making hinders emergency response. Critical strategic knowledge gaps need to be filled to inform programmatic decisions.	International Asteroid Warning Network; Space Mission Planning Advisory Group; OSTP guidance; NASA Strategic Knowledge Gaps	NA				
4.2*	Current monitoring capabilities lack sufficient continuous monitoring and detection to provide warning of NEO impacts, particularly for the smaller, more frequent events.	International Asteroid Warning Network; NRC Defending Planet Earth	NA				
4.3	Current impact effects modeling capabilities are insufficient to inform planning and response decisions.	NRC, Defending Planet Earth	NA				

*Enable Early Warning Capabilities

Table 5. S&T Gaps— Near Earth Object Hazard — Response or Recovery Research and Technology Needs

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
NO GAPS DESCRIBED FOR THIS S&T DEVELOPMENT AREA							

Table 6. S&T Gaps—Near Earth Object Hazard—Integrate Science into Preparedness Decisions

ID	Team Provided Gap Description	Gap Source	Prevention	Protection	Mitigation	Response	Recovery
6.1	Insufficient protocols exist for effective emergency response and interagency planning efforts.	FEMA	NA				

6.2	Limited state of understanding of asteroid impacts hinders decision making in emergency situations. There is a need for asteroid impact scenario reference sets to inform government planning and response.	International Asteroid Warning Network; National Research Council (NRC) "Defending Planet Earth"	NA				
6.3	Decision thresholds (i.e., asteroid size, velocity, possible composition, projected impact location) that would trigger response or action do not currently exist.	International Asteroid Warning Network; OSTP guidance	NA				
6.4	Reference missions (i.e., mission analyses and architectures) to be used to inform programmatic decisions do not currently exist.	International Asteroid Warning Network, Space Mission Planning Advisory Group; OSTP guidance	NA				

Appendix 5.2.B – Near Earth Object Hazards – Science and Technology Programs and Alignment with PPD-8 Mission Areas

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
United States Space Surveillance Network (SSN)	USSTRATCOM	The United States Space Surveillance Network detects, tracks, catalogs and identifies artificial objects orbiting Earth, i.e. active/inactive satellites, spent rocket bodies, or fragmentation debris. The system is used by USSTRATCOM Space Control and Space Surveillance and is managed by USSTRATCOM's Joint Functional Component Command for Space (JFCC Space).					
Joint Space Operations Center (JSpOC)	USAF	JSpOC maintains the catalog of all artificial Earth-orbiting objects, uses it to ensure orbital safety, and predicts re-entry of objects into the Earth's atmosphere. JSpOC tasks SSN to carry out about 400,000 observations per day in order to track debris and keep up with changes due to atmospheric drag.					
NNSA Planetary-Defense Activities	NNSA	NNSA Labs' analysis of asteroid deflection/disruption, atmospheric entry, airbursts, land/water impacts, and infrastructure effects					
Planetary Defense Coordination Office	NASA HQ	Office responsible for communication regarding potential threats and managing NASA's Near-Earth Object Observation Program					
Near-Earth Object Observation (NEOO) Program	NASA HQ	Office responsible with detecting, characterizing, and tracking - and assessing the threats from - NEOs within NASA. Program includes integration of global observations, automated orbit computation and hazard analysis. Includes the Minor Planet Center, the JPL Center for Near-Earth Object Studies, and extensive international partnerships and agreements.					

Program Name	Agency	Brief Description of Program Purpose	Prevention	Protection	Mitigation	Response	Recovery
Near Earth Object Program JPL Center for Near-Earth Object Studies (CNEOS)	NASA	Set of NASA programs with goal of identifying near-earth objects of various sizes, distances.					
Mino Planet Center of the International Astronomical Union (MPC)	NASA	The Minor Planet Center, or MPC, is the single worldwide location for receipt and distribution of positional measurements of minor planets, comets and outer irregular natural satellites of the major planets. The MPC is responsible for the identification, designation and orbit computation for all of these objects. This involves maintaining the master files of observations and orbits, keeping track of the discoverer of each object, and announcing discoveries to the rest of the world via electronic circulars and an extensive website. The MPC operates at the Smithsonian Astrophysical Observatory, under the auspices of Division F of the International Astronomical Union (IAU).					
Planetary Impact Emergency Response Working Group (PIERWG)	FEMA NASA	The Planetary Impact Emergency Response Working Group (PIERWG) is established by the partnership of the Federal Emergency Management Agency (FEMA) and National Aeronautics and Space Administration (NASA) to develop guidance to prepare for any potential impact of our planet by a large natural object. This charter provides the framework for the structure and processes of this interagency team. The PIERWG will coordinate responsibilities and resolve preparedness and operational issues relating to interagency response and recovery activities at the national level in preparation for a predicted or actual impact of an asteroid or comet in the United States or its territories.					