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Sentries in the Sky
Using Space Technologies for Disaster Response

POLICY BRIEF

By Will Rogers

U.S. policymakers can make better use of space technologies to improve disaster warning and response. As Japan's March 2011 earthquake, tsunami and nuclear accident demonstrated, the magnitude of some crises can overwhelm even the most advanced ground-based disaster warning and response services. Meanwhile, those charged with disaster response have not yet used space technologies to their full potential. Furthermore, planned budget cuts to ground-based sensors, as well as the technological limitations of existing space-based services, could leave America less prepared to manage future crises.

Space technologies offer fruitful avenues for enhancing disaster warning by relying on new modes of data collection that, together with existing capabilities, will help save lives. To illustrate how space systems can improve disaster warning and response, this policy brief analyzes the potential for space technologies to improve the detection of tsunamis. The U.S. government should take several steps to realize that potential: increase funding for government and university research into space-based tsunami detection, leverage public- and private-sector infrastructure to employ existing tsunami detection tools in space (such as satellite-based altimeter sensors that can monitor changes in wave height) and integrate tsunami detection into efforts to promote international space cooperation with U.S. allies.

Japan's Triple Disaster

U.S. agencies like the National Oceanic Atmospheric Administration (NOAA) and the Departments of Defense and Energy provided important services during and after the disaster in Japan, particularly in tsunami forewarning and radiation monitoring. This response to Japan's "triple disaster" in March 2011 provides a useful case study of the importance of U.S. disaster warning and response services and an opportunity to examine how space technologies could improve existing capabilities.

NOAA's Deep-Ocean Assessment and Reporting of Tsunamis (DART) program provided a real-time response to the 9.0-magntitude earthquake off Japan. The DART program uses a sophisticated array of 39 buoys to measure changes in wave height – in centimeters – and the direction and speed of approaching waves. That information is relayed to satellites and delivered to U.S. tsunami early warning centers in Hawaii and Alaska for near-real-time analysis. Within minutes, scientists can share the information with their counterparts around the world, as they did with the Japanese Meteorological Agency after the March 2011 earthquake.

In addition to the DART program, the French Jason-1 and Jason-2 satellite systems (jointly administered with NASA) provided information about the tsunami off the coast of Japan. Both satellites contain altimetry instruments that measure changes in sea level – again, in centimeters – and use that information to determine the height of ocean waves. The data was then relayed to scientists who input the information into advanced models to determine the strength of the tsunami.[1]

The United States also helped monitor radiation levels through aerial- and ground-based surveys after the triple disaster. In particular, the Department of Energy and Department of Defense (DOD) used airborne radiation monitoring equipment to measure ground contamination around the Fukushima plant; combined with data from ground-based surveys, this provides the most effective way to monitor residual radioactivity.

The Department of Energy's National Nuclear Security Administration (NNSA) – the U.S. agency charged with responding to nuclear and radiological emergencies in the United States and abroad – sent Consequence Management Response Teams to support the Japanese government's radiation monitoring efforts. NNSA also deployed its Aerial Measuring System (AMS) in the spring and summer of 2011 to provide airborne measurements of ground contamination.[2] According to a NNSA brief, the AMS contributed more than 500 flight hours to these operations.[3] Before the NNSA teams returned to the United States, they loaned their AMS to the Japanese government and trained Japanese experts on the equipment.

DOD also supported radiation monitoring operations. After the nuclear accident, the U.S. Air Force dispatched a WC-135 Constant Phoenix to collect and analyze radiation emissions around the Fukushima nuclear station.[4] The WC-135 – designed to verify compliance with the Limited Nuclear Test Ban Treaty of 1963 – includes a special filtration system that allows it to detect radioactive contamination – or "radioactive clouds" – in real time.[5] According to reports, the WC-135 also generated more than 500 flight hours of data.[6] The Air Force also deployed the Global Hawk drone to support search-and-rescue and surveillance efforts, such as photographing the damaged Fukushima reactors in order to help experts evaluate the damage to the nuclear facilities.[7]

Potential Challenges to U.S. Disaster Response Efforts

The very tools and techniques that enabled the U.S. response to Japan's triple disaster face three major challenges: budget cuts, technological limitations, and problems with existing platforms and personnel.

BUDGET CUTS

Although the U.S. tsunami early warning system provided advanced warning for residents in Japan, Hawaii and elsewhere, recent budget cuts to the NOAA DART program could take up to one-third of the tsunami detection buoys offline at any one time. Although NOAA officials argue that the system will still provide a robust detection capability, academics and other experts remain concerned that the budget cuts could create gaps in the system and undermine the accuracy of the warnings.[8]

TECHNOLOGICAL LIMITATIONS

Current space technologies, although valuable, have limitations. Existing satellite systems with advanced altimetry equipment provide useful data for recording tsunamis but have only a limited area of coverage. For example, the French Jason-1 and -2 satellites were only able to provide the sea-level measurements necessary to detect the March 2011 tsunami because they happened to be in the right place at the right time.[9] Satellites equipped with altimetry must cross the path of a tsunami at the right moment in order to accurately read changes in wave height.[10] Given the vastness of the Pacific Ocean, limited satellite coverage cannot provide consistent and reliable advanced warning. Moreover, limited on-board data-processing speeds do not allow existing satellites to be used for tsunami alert systems due to the time required to measure and analyze the data.

PROBLEMS WITH PLATFORMS AND PERSONNEL

In addition to the limits of the technologies themselves, their support platforms and personnel are not suited for all disaster contingencies. According to NNSA, for example, aerial collection and analysis of ground contamination was incomplete because low-flying aircraft could not reach some mountainous communities.[11] Additionally, aerial monitoring of ground contamination directly over the Fukushima accident site was inconsistent, in part due to concerns about exposing personnel to potentially hazardous conditions. Although advanced modeling of contamination and ground samples can provide some measure of assurance, additional aerial radiation monitoring tools could help close existing monitoring gaps.

The Case for Space

While not all disaster-related missions can be performed in space, a better use of space-based technologies can improve U.S. disaster warning and response capabilities. America currently relies on a number of satellite systems for managing the unconventional challenges of the 21st century, including monitoring environmental change in the Arctic and tracking urbanization, migration patterns and other demographic trends that have implications for security and development professionals.[12] In addition, the 2010 U.S. *National Space Policy* noted that space systems have already helped the United States "save lives by warning us of natural disasters … making recovery efforts faster and more effective."[13]

The United States should improve existing systems and invest in new ones so that U.S. space capabilities can both produce and relay data to first responders and others charged with protecting the nation.

These technologies have the potential to further improve disaster response efforts. Today's space systems primarily relay seismic data and other land-based environmental indicators that aid countries in preparing for and responding to disasters, but they could also be used to collect data. The United States should improve existing systems and invest in new ones so that U.S. space capabilities can both produce and relay data to first responders and others charged with protecting the nation, bridging capability gaps where they exist.

Space systems are currently used in several tsunami early warning and response systems and can be better employed in such efforts in the future.

The March 2011 triple disaster demonstrated that, although infrequent, tsunamis have a scale and impact that deserve attention from those responsible for safeguarding vulnerable U.S. infrastructure, especially coastal communities. The United States has already incorporated some space-based technologies in its tsunami early warning network. In addition to the satellites that serve as relay nodes for information from NOAA's DART buoys, other satellites have successfully employed specialized instruments that allow scientists to detect changes in wave height and other ocean and atmospheric characteristics associated with tsunamis. Yet these specialized instruments are in limited use today, and the tsunami early warning network contains a number of vulnerabilities. For example, a 2011 National Academies of Science report concluded that "many coastal communities in the United States still face challenges in responding to a tsunami that arrives in less than an hour after the triggering event."[14]

Space systems offer solutions to such vulnerabilities. Two promising examples involve using altimetry sensors to measure changes in sea levels and using GPS sensors to detect tsunamis.

MEASURING SEA LEVELS THROUGH ALTIMETRY SENSORS

Improving the use of space-based altimetry sensors may be a cost-effective way of complementing existing ground-based sensors by providing scientists and disaster management professionals with a wider area of coverage to monitor for tsunamis.

Altimetry sensors are currently deployed on a range of space-based remote sensing systems, particularly meteorological satellites. NOAA, the European Organisation for the Exploitation of Meteorological Satellites and others rely on altimetry tools to measure atmospheric, weather and climate conditions. The sensors determine the distance between the satellite and the surface of the ocean by measuring the time it takes for a pulse sent from the satellite to hit the ocean surface and return to the sensor. These data help scientists detect changes in sea level, which can be input into advanced models for everything from forecasting weather to projecting rises in sea level resulting from climate change.

After the March 2011 earthquake and tsunami, the scientists who initially analyzed the data challenged the accuracy of the information provided by the Jason-1 and Jason-2 satellites. The initial measurements, taken at different locations of the tsunami, varied dramatically; Jason-1 measured the wave height at 28 centimeters and Jason-2 measured the wave height at 8 centimeters. As a result, there was some confusion about the tsunami wave height. After later re-analyzing the data, however, scientists determined that the earthquake actually produced two separate tsunamis, and thus the satellites were measuring two different waves.[15]

Despite the value of altimetry sensors, three specific challenges exist in using satellite altimeters for advanced tsunami warning systems:

Real-time data processing. Many current satellite altimeters take three to five hours to deliver data – which is too slow to provide adequate warning of a tsunami. The Jason-2 satellite, for example, is equipped with a specially designed Operational Geophysical Data Record that relies on an on-board processor to provide users with "near-real-time data on surface wind speed and wave features along with a first estimate of sea surface height."[16] This information, however, takes several hours to generate and disseminate. NOAA's DART program, in contrast, delivers information to scientists in minutes rather than hours and thus offers a much better alternative.

Sensor limitations. Altimeter sensors have limitations in deep oceans. Some tsunamis, for example, may go undetected in deep oceans because the wave amplitude is not significant enough to measure against normal sea-level height of the surrounding ocean.[17]

Limited coverage of the Earth's oceans. As noted previously, altimetry satellites must be in the right position at the right time to be effective. The 2011 National Academies study states that: "making satellite altimetry operational for tsunami warning requires geostationary satellites over the ocean basins of interest, or a dense array of low-earth-orbit (LEO) satellites, with either set-up providing data availability in near-real time."[18] However, the United States does not have this type of broad coverage, and budget constraints will likely prevent the government from deploying a constellation of satellites for this purpose.

Private-sector efforts to develop new constellations of satellites could mitigate this challenge. Iridium Communications, for example, plans to replace its existing constellation of 66 LEO satellites beginning in 2015 with new communication satellites that can host additional sensor payloads, including altimeters that measure sea-level height.[19] The 2011 National Academies study found that "[t]he planned constellation of 66 satellites suggests that a tsunami created anywhere in the world could be observed close to the moment of inception."[20] However, it is unclear whether the U.S. government will rely on commercial infrastructure to build a constellation of satellite altimetry given that budget constraints are also limiting satellite contracts between the public and private sectors.[21]

DETECTING TSUNAMIS THROUGH GPS SENSORS

Integrating GPS satellite technology into U.S. tsunami early warning systems could enhance disaster prevention by reducing the time it takes to measure the strength of an earthquake at sea, thereby improving alert systems for coastal communities that could be impacted by a tsunami in less than an hour.

GPS satellites could potentially detect atmospheric changes that accompany tsunami formations. One novel approach involves measuring the effects of tsunami-induced atmospheric disturbances on GPS receivers.[22] "The detection methodology uses dense arrays of GPS receivers because large-scale fluctuations of the ionosphere affect the propagation of the electromagnetic waves from the GPS satellites, thus distorting the signals recorded at the receivers," reported the 2011 National Academies study.[23] This process has been successfully tested using recorded data from previous earthquake and tsunami events.

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Other proposals include using integrated GPS satellite and ground systems to predict whether an earthquake is large enough to produce a tsunami. This involves measuring the displacement of GPS ground stations by earthquakes and comparing their known locations with GPS satellites. The measurements could potentially measure the precise strength of an earthquake in as little as 15 minutes.[24] According to NASA experts, "[t]his magnitude is directly related to a quake's potential for generating tsunamis," which could advance real-time tsunami warning systems.[25] However, this approach is currently in the research and development phase and has not been tested in the field.

The Limits of Space: The Case of Radiation Detection

Although space-based technologies may improve many types of disaster prevention and relief capabilities – including tsunami detection, drought monitoring and sea-level rise tracking – they are not suitable for all types of disasters. Radiation detection, in particular, presents challenges that space-based technologies cannot overcome.

Three key physical challenges prevent accurate radiation measurement from space: distance, speed and shielding.

DISTANCE

The greater the distance of a radiation detector from the source of radioactive emissions being measured, the more difficult it is to develop an accurate measurement. During their decay, radioactive materials produce emissions that can be detected by various types of instruments. However, the signal strength of the radioactive emissions (that is, the energy of the emissions) is inversely proportional to the square of the distance from the source: the greater the distance from the source, the weaker the signal strength of the emissions being measured. Consequently, weak signals can remain undetected. Experts note that taking accurate measurements at even several hundred meters is difficult.[26] Measurements from radiation detectors on satellites in low-earth orbit (up to 2,000 kilometers) would not be reliable.

SPEED

Radiation detectors work best when they loiter over an observation site, giving the detector sufficient time to measure the radioactive emissions from the contamination site. However, orbiting satellite systems cannot provide persistent stationary detection of radiation. At low-earth orbit, satellite systems move at several miles per second. Placing radiation detectors on satellites in higher orbits (such as geosynchronous orbit, around 35,000 kilometers) would reduce their orbital speeds, but would further exacerbate the challenge of distance described above.

SHIELDING

Shielding – the obstruction of radiation concentrations due to physical or atmospheric barriers – can occur in several ways. For example, background radiation makes it difficult to distinguish low levels of radiation associated with nuclear accidents from radiation that occurs naturally or is produced by structures such as nuclear power plants. In principle, imaging detectors could help distinguish between normal and abnormal radiation readings, but developing accurate imaging detectors is challenging. For example, lenses that focus gamma rays change the energy of those rays and therefore produce a less accurate measurement.[27] Additionally, atmospheric conditions (e.g., cloud cover) can shield radiation signals and prevent them from reaching space-based sensors, and cosmic radiation (e.g., energy from the sun) can disrupt detection efforts in space.

Thus, space-based radiation detection remains unrealistic. However, the United States could improve its radiation detection capabilities through two key measures:

- **Equip remotely piloted aircraft (RPA) with radiation sensors.** Most RPAs cannot be fielded with current detectors because the weight of the detectors exceeds their payload capacity.[28] However, current research is exploring ways to decrease the size and weight of radiation detectors.
- **Build a U.S. network of radioecology expertise.** The Fukushima accident underscores the importance of studying radioecology – how radiation interacts with the natural environment, such as the food supply. Yet there are no formal radioecology training programs in the United States. Only a handful of U.S. scientists currently have formal radioecology training, partly because such training was seen as unnecessary after the ban on nuclear weapons testing. As a result, the United States is increasingly relying on the training programs of its allies and partners, including those in France and Ukraine, in order to retain the expertise in U.S. national labs and other government agencies.[29]

Improving Tsunami Detection through Space

The U.S. government should take three steps to enhance tsunami detection: find budget-conscious ways to improve government and university research into space-based tsunami detection, leverage public and private sector infrastructure to develop existing tsunami detection tools in space and integrate tsunami detection in international space cooperation efforts with like-minded allies.

Policymakers should find budget-conscious ways to improve government and university research into space-based tsunami detection. The Obama administration's current Fiscal Year (FY) 2013 budget request reduces available funding for research grants that could be used to advance research, development and testing of space-based tsunami detection. NASA's Earth Science research budget, for example, would decline by 2.5 percent between FY 2012 and FY 2013, allowing fewer research grants "for the analysis and interpretation of data from satellites and field campaigns, as well as decreased effort by NASA investigators in predictive modeling designed to help scientists understand the future evolution of the earth system and its components."[30] This would limit funding for a broad research community, including NASA and university research programs, that could improve existing space-based sensors and develop other feasible space technologies.

Although today's budget environment remains constrained, the U.S. government should nevertheless find affordable ways to improve funding for government and university research programs that include space-based tsunami detection. Modest investments in research could pay dividends by improving current disaster management tools, such as on-board data-processing hardware and ground-based computer models that help disseminate information more rapidly to first responders, as well as applying GPS and other related technologies for tsunami warning systems. This could yield feasible technologies that could be fielded in a future, less constrained budget environment.

Policymakers should leverage public- and private-sector infrastructure to develop more space-based tsunami detection capabilities. The best way to improve space-based tsunami detection in the near term involves the advanced use of satellite altimetry, including fielding more sensors to cover a wider observation area.[31] However, given today's budget environment, the U.S. government is not likely to develop a constellation of altimetry satellites for such a narrow mission due to the costs of launching, operating and maintaining these systems.

Instead, policymakers should look for opportunities to leverage the existing public and private satellite infrastructure. NOAA's and NASA's Geostationary Operational Environmental Satellite R-Series, for example, is scheduled to launch the first of several satellites beginning in 2015. The satellite array is expected to provide coverage for most of the Atlantic and Pacific Oceans, the two oceans of greatest concern for U.S. disaster prevention officials.[32] Policymakers should look for ways to add altimeter instruments to these planned geostationary satellites to enhance tsunami detection. In addition, policymakers should seek to purchase excess payload capacity in new commercial satellite constellations array in order to develop a network of altimeter sensors. The next generation Iridium satellite constellation is one opportunity. Leveraging existing public- and private-sector satellite systems may prove to be a cost-effective way to enhance the use of satellite altimetry for tsunami detection.

Finally, the United States should integrate tsunami detection into existing international space cooperation with allies and partners. Both the U.S. *National Space Policy* and *National Security Space Strategy* call for the United States to leverage its alliance partnerships to support critical space missions, including those focused on disaster prevention and relief.[33] A number of foreign governments would likely be receptive to such efforts, including those with nascent and developed space programs that are vulnerable to tsunamis, such as India and Japan. The United States already maintains official science and technology ties with these governments aimed at fostering cooperation around space technologies.[34] U.S. foreign policy officials should pursue opportunities to incorporate space-based tsunami detection. Doing so would serve U.S. interests by enhancing the resiliency of U.S. partners to weather and recover from natural disasters, dampening the impact of these crises; and promoting new avenues of cooperation that can help develop and strengthen strategic partnerships.

Conclusion

Space technologies are a promising avenue to improve disaster warning and response. Though this paper has focused on advancing tsunami detection, this is just one of many potential applications of space technologies that can help save lives. Other possibilities include improvements in Earth-monitoring satellites to monitor environmental trends, such as severe droughts and violent storms, which can have devastating consequences. Despite the constrained budget environment, policymakers should increase investments in space technologies as cost-effective ways to complement existing terrestrial-based tools and enhance America's ability to respond to future crises.

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ENDNOTES

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11. U.S. Department of Energy and NNSA, "Radiological Assessment of effects from Fukushima Daiichi Nuclear Power Plant," slide 6.

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An artist concept of the Ocean Surface Topography Mission/Jason 2 Earth satellite.

(NASA)