NASA's Mid-Atlantic Communities and Areas at Intensive Risk Demonstration:

Translating Compounding Hazards to Societal Risk

Laura Rogers, David Borges, John Murray
Disasters Program
NASA Langley Research Center
Hampton, VA

J. Derek Loftis, Harry Wang
Virginia Institute of Marine Science
College of William and Mary
Gloucester Pt, VA

Andrew Molthan, Jordan Bell
SPoRT Center
NASA Marshall Space Flight Center
Huntsville, AL

Sagy Cohen
Surface Dynamics Modeling Lab
University of Alabama
Tuscaloosa, AL

Thomas Allen
Department of Political Science and Geography
Old Dominion University
Norfolk, VA

Donglian Sun
Geography and Geoinformation Science
George Mason University
Fairfax, VA

David Bekaert
Radar Science and Engineering Section
NASA Jet Propulsion Laboratory
Pasadena, CA

William Moore
Dept. of Atmospheric and Planetary Sciences
Hampton University
Hampton, VA

***Abstract*— Remote sensing provides a unique perspective on our dynamic planet, tracking changes and revealing the course of complex interactions. Long term monitoring and targeted observation combine with modeling and mapping to provide increased awareness of hydro-meteorological and geological hazards. Disasters often follow hazards and the goal of NASA's Disasters Program is to look at the earth as a highly coupled system to reduce risk and enable resilience. Remote sensing and geospatial science are used as tools to help answer critical questions that inform decisions. Data is not the same as information, nor does understanding of processes necessarily translate into decision support for disaster preparedness, response and recovery. Accordingly, NASA is engaging the scientific and decision-support communities to apply remote sensing, modeling, and related applications in Communities and Areas at Intensive Risk (CAIR).**

In 2017, NASA's Applied Sciences Disasters Program hosted a regional workshop to explore these issues with particular focus on coastal Virginia and North Carolina. The workshop brought together partners in academia, emergency management, and scientists from NASA and partnering federal agencies to explore capabilities among the team that could improve understanding of the physical processes related to these hazards, their potential impact to changing communities, and to identify methodologies for supporting emergency response and risk mitigation. The resulting initiative, the mid-Atlantic CAIR project, demonstrates the ability to integrate satellite derived earth observations and physical models into actionable, trusted knowledge. Severe storms and associated storm surge, sea level rise, and land subsidence coupled with increasing populations and densely populated, aging critical infrastructure often leave coastal regions and their communities extremely vulnerable. The integration of observations and models allow for a comprehensive understanding of the compounding risk experienced in coastal regions and enables individuals in all positions make risk-informed decisions. This initiative uses a representative storm surge case as a baseline to produce flood inundation maps. These maps predict building level impacts at current day and for sea level rise (SLR) and subsidence scenarios of the future in order to inform critical decisions at both the tactical and strategic levels.

To accomplish this analysis, the mid-Atlantic CAIR project brings together Federal research activities with academia to examine coastal hazards in multiple ways: 1) reanalysis of impacts from 2011 Hurricane Irene, using numerical weather modeling in combination with coastal surge and hydrodynamic, urban inundation modeling to evaluate combined impact scenarios considering SLR and subsidence, 2) remote sensing of flood extent from available optical imagery, 3) adding value to remotely sensed flood maps through depth predictions, and 4) examining coastal subsidence as measured through time-series analysis of synthetic aperture radar observations. Efforts and results are published via ArcGIS story maps to communicate neighborhoods and infrastructure most vulnerable to changing conditions. Story map features enable time-aware flood mapping using hydrodynamic models, photographic comparison of flooding following Hurricane Irene, as well as visualization of heightened risk in the future due to SLR and land subsidence.

Keywords—coastal resilience; compounding risk; SLR.

I. Introduction

Extreme storms are complex threats comprising a range of risks to coastal development including storm surge, severe wind, extreme rainfall, and recurrent tidal flooding. Severe storms, sea level rise, and land subsidence coupled with increasing populations and densely populated, aging critical infrastructure often leave coastal regions and their communities extremely vulnerable.

The 2017 hurricane season saw 17 tropical storms, 10 of which evolved into hurricanes. Hurricane Harvey struck Texas in late August, leaving more than 60 inches of rainfall, roughly 200,000 damaged homes and over 100 deaths, 68 from direct causes [1]. Some estimates found damage from the 2017 hurricane season alone exceeded $200 billion. Research from the scientific community suggests this was not an anomaly and more intense tropical storms will occur more frequently in the future.

Beyond the shocks to the coupled human-natural system caused by extreme events, long-term stressors or frequent events such as nuisance flooding caused by sea level rise could generate exposure comparable to, or larger than, extreme events. Further, in the face of climate change, land subsidence often exceeds the sea-level rise component and is the dominant contributor to relative sea level rise (RSLR) (relating to increased floods), yet it is rarely included in planning decisions.

As a society, we have a reached a decision point – we must either act now to better understand, adapt to, and mitigate the impact our changing environment will have on our communities or we must be willing to accept that loss when it comes.

II. Background

A. NASA's Communities and Areas at Intensive Risk Projects

NASA and the wider scientific community have a strong record of advancing applied science for practical uses such as early warning, risk reduction, situational awareness, and recovery. Disaster risk reduction and the building of community resilience have emerged as key priorities of governments, businesses (the insurance sector in particular), and national and international communities. While the increasing frequency and intensity of weather-related hazards share part of the responsibility for this emergence, it is also attributable to the increased exposure and vulnerability of communities. Factors contributing to this vulnerability and exposure arise from human choices, and therefore, may be mitigated by strategic planning. It is widely accepted that natural hazards do not create disasters without human risk and exposure. In other words, humans and human institutions can contribute greatly to their own risk – and to their protection – from disasters.

Earth observation science and technologies have become trusted sources in hazard monitoring, mitigation design, disaster risk prevention, and contingency planning. Providing heightened awareness of risk and vulnerability through improved understanding of communities, key infrastructure (e.g., oil and gas pipelines, roads and highways, bridges, electrical grids and networks, and hospitals), and the climate-related processes that contribute to risk can strengthen and support community-level interventions.

Data is not the same as information, nor does understanding of processes necessarily translate into decision support for hazard monitoring, mitigation design, disaster risk prevention, and contingency planning. Accordingly, NASA is engaging the scientific and decision-support communities to develop community groups focused on applying remote sensing, modeling, and related applications in areas at intensive risk – specifically coastal communities.

B. Mid-Atlantic Community and Area at Intensive Risk

A bustling hub of tourism, arts, and retail, the Hampton Roads region is home to 18 Federal facilities, to include NASA Langley, has the nation's third largest seaport, the world's largest naval base, and the country's second largest military presence. The region faces the fastest rates of sea level rise on the East Coast and has the second largest population center endangered by sea level rise in the nation. Subsidence (sinking of land) causes almost half of all relative sea level rise in Hampton Roads. The land in the area is expected to continue sinking, and the sea is expected to rise at faster rates. Home to 17 independent jurisdictions and 1.7 million people, the high rate of local sea level rise, the exposure to extreme weather events, and the complex socio-economic structure makes Hampton Roads a natural laboratory for climate change and sea level rise.

In 2014, an Inter-Governmental Pilot Project was kicked off sponsored by The White House Center on Environmental Quality, National Security Council, and the Office of Science Technology Policy. The mission of the Pilot Project is to develop a regional "whole of government" and "whole of community" approach to sea level rise preparedness and resilience planning in Hampton Roads that also can be used as a template for other regions. Recommendations as a result included the need to maintain, institutionalize and build relationships with each other in order to facilitate effective collaboration and information sharing among regional and local stakeholders. Further, they recommended while more data is needed, the methods by which that data is integrated and shared are equally important [2].

To build on the momentum created by this large, diverse group, the NASA Disasters Program held a workshop at NASA Langley in the spring of 2017. Participants included academic institutions, local and regional governments, and engaged federal entities looking to address flood concerns now and in the future. Discussion concluded that application-based scenarios based upon real flooding events impacting communities provided the most valuable basis for planning now and in the future. This workshop resulted in the formulation of the Mid-Atlantic Community and Area at Intensive Risk (CAIR) team.

III. Mid-Atlantic Demonstration

The mid-Atlantic CAIR project demonstrates the ability to integrate satellite derived earth observations and physical

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Project Needs, Goals and Objectives

Need: Decision makers at strategic and tactical levels lack comprehensive, integrated decision support tools needed to identify areas of heightened vulnerability as a result of compounding hazards

Goals:

- Demonstrate the ability to integrate satellite derived Earth Observations and physical models into actionable, trusted knowledge
- Create comprehensive understanding of compounding risk
- Enable risk-informed decisions

Objectives:

- Produce building level (1m resolution) impact analyses for tactical (emergency management) and strategic (city planning, resilience) decision making
- Quantify spatially-variable subsidence rates and associated uncertainty in the Hampton Roads region at 3-5km resolution using Interferometric Synthetic Aperture Radar (InSAR) data

Fig. 1. Mid-Atlantic CAIR project needs goals, and objectives

models into actionable, trusted knowledge. The integration of observations and models allow for a comprehensive understanding of the compounding risk experienced in coastal regions and enables individuals in all positions make risk-informed decisions. In order to identify gaps and strategic opportunities for NASA to pursue coastal resilience, this project analyzed Hurricane Irene in 2011 as a case study coastal disaster. The event posed a severe threat and challenged the hurricane forecasting, storm surge modeling, and geospatial communities. Decision makers and emergency management lacked the data required to make informed decisions related to response and recovery. Accordingly, this study uses a representative storm surge case as a baseline to produce flood inundation maps. These maps predict building level impacts at current day as well as for SLR and subsidence scenarios of the future with the intent of informing critical decisions at both the tactical and strategic levels. Specific study needs, goals and objectives are detailed in Figure 1.

A. Study Component Interaction and Integration

The mid-Atlantic CAIR project brought together Federal research activities with academia to examine coastal hazards in a number of ways, including: 1) reanalysis of impacts from 2011 Hurricane Irene, using numerical weather modeling in combination with coastal surge and hydrodynamic, urban inundation modeling to evaluate combined impact scenarios considering sea level rise and subsidence, 2) remote sensing analysis of flood extent from available optical imagery, useful for identifying storm impacts and as precursors for future response efforts, 3) adding value to remotely sensed flood maps through depth predictions, and 4) examining coastal subsidence as measured through time-series analysis of synthetic aperture radar observations. The interaction and interdependencies between the various components are detailed in Figure 2.

NASA SPoRT at Marshall Space Flight Center simulated a Hurricane Irene-like storm (2011) in the Middle Atlantic region using the NASA Unified – Weather Research and Forecasting (NU-WRF) model [3]. The NU-WRF was configured for a 9-3-1 km nested set-up with initial boundary conditions supplied by 3-hourly Global Forecast System (GFS) final analyses available from the National Center for Environmental Information. This storm re-analysis served as

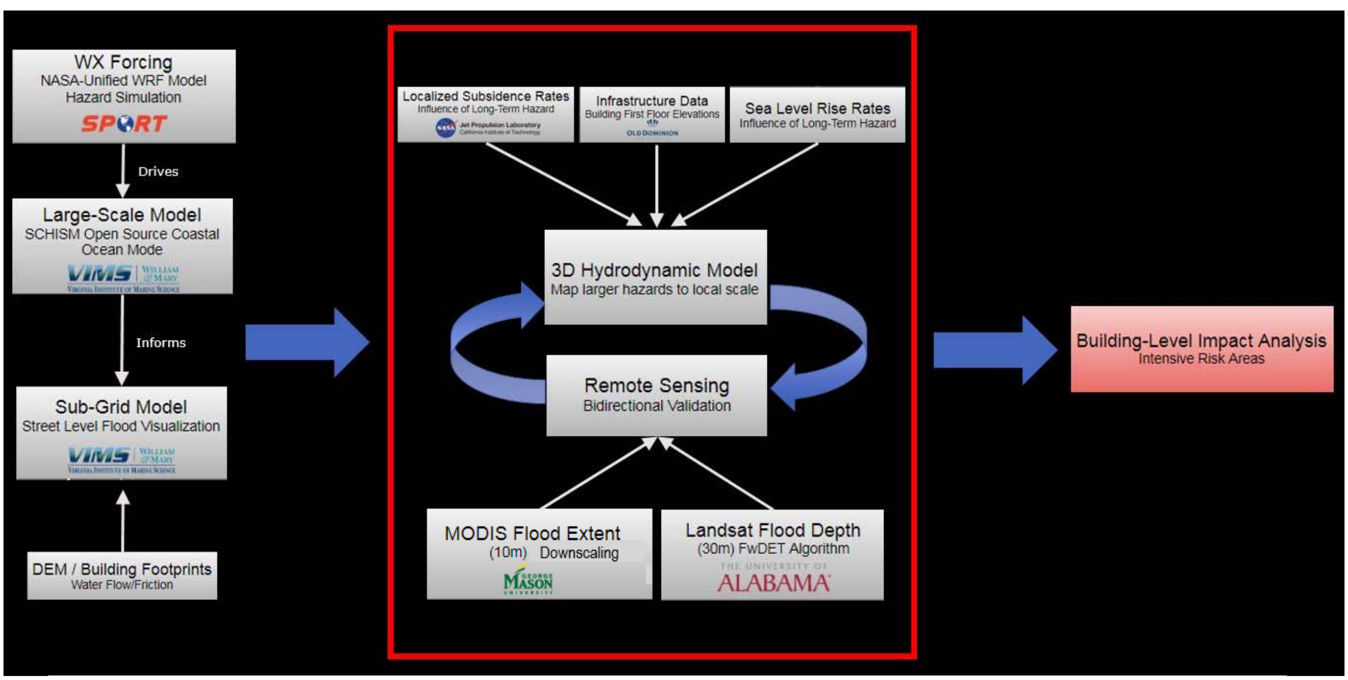

Fig. 2. Components were brought together according to the flow chart to demonstrate the ability to produce building level impact analyses for today and 2045 for a Hurricane Irene-like storm

the driver of the large-scale ocean model to inform the hydrodynamic model. The hydrodynamic model produced building-level flood maps, in turn validated by remoted sensing efforts conducted at the University of Alabama and George Mason University.

The large-scale ocean tidal model (SCHISM) [4], developed and run at the Virginia Institute of Marine Sciences, is used to inform the sub-grid model (UnTRIM) [5]. The sub-grid model, also developed and run at the Virginia Institute of Marine Sciences, produced time-aware floodwater depths and extent throughout the simulated storm using SCHISM predicted storm surge values. High resolution data to include digital elevation models and building footprints, provided by Old Dominion University, allows the sub-grid model to account for varying friction values caused by buildings, curbs and impervious surfaces. The inclusion of high resolution data produces a more accurate representation of water movement and velocity.

The unique component of this demonstration is the addition of remotely sensed data. The data is used to validate the hydrodynamic model and the hydrodynamic model is used to validate the identification of flooding in remotely sensed imagery. Two approaches are used in this study 1) a coastal flood water depth tool developed at the University of Alabama used to determine flood depth and 2) down-scaled MODIS imagery to identify flood water extent done at George Mason University. For this work, an existing flood water depth tool (FwDET) [6] was adapted for coastal regions [7] and existing VIIRS downscaling and terrain shadow removal algorithms were applied to MODIS imagery [8,9]. This dual process approach created a 3-dimensional understanding of inundation to compare with model results.

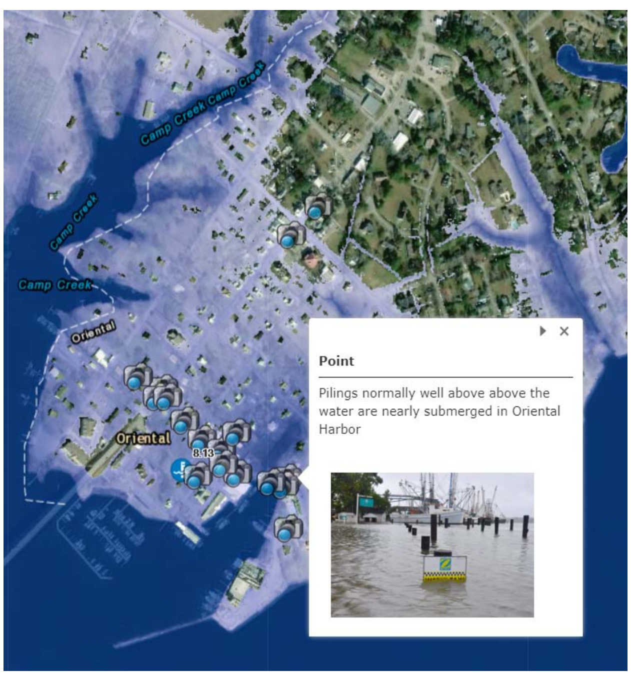

Fig. 3. Screen capture of story map feature displaying photographed water depth relative to modeled water depth

For a comprehensive understanding, a strategic planning component augmented the study. NASA's Jet Propulsion Laboratory completed a state-of-the-art study to add the subsidence factor of relative sea level rise. This work used interferometric synthetic aperture radar (InSAR) analysis applied to ALOS-1 synthetic aperture radar data acquired during 2007–2011 to generate high-spatial resolution (20–30 m) estimates of vertical land motion. Additional work was done with Sentinel-1, however, time-series was contaminated by high spatially variable tropospheric noise which propagated into subsidence rates and associated uncertainty. Although the results are limited by the uncertainty associated with the small set of available historical SAR data, they highlight both localized rates of high subsidence and a significant spatial variability in subsidence, emphasizing the need for further measurement. Further study detail is published in *Scientific Reports* [10].

B. *Visualization and Communication*

The resulting research is assimilated into one story map to enable decision-makers to make risk-informed decisions. A modified version is also available for social media communication. The map is interactive, incorporating geospatially enable features such as zoom, inundation point depth, embedded high-water marks and photos.

Within the story map, flood inundation is shown in time-aware layers to identify areas most vulnerable to sustained flooding. In Oriental, NC where first floor elevation data is available, buildings are shown in either red or green. Buildings colored red are locations where the water depth exceeded that of the building first floor elevation and are therefore likely to sustain substantial flood damage. Water depth did not exceed the first floor elevation for buildings shown in green.

Further analysis is done for strategic purposes comparing today's flood rates to 2045. After identifying highly vulnerable homes and businesses at current conditions, we added the compounding factors of sea level rise and land subsidence. The sea level rise rates chosen are simply trends seen at local gauges and do not include potential scenarios. Analysis of the town of Oriental determined an additional 28% of the community will experience flooding above the first floor elevations by the year 2045.

IV. Discussion

Long term monitoring and targeted observation combine with modeling and mapping to provide increased awareness of hydro-meteorological and geological hazards. Disasters often follow hazards and the goal of NASA's Disasters program is to look at the earth as a highly coupled system to reduce risk and enable resilience. Remote sensing provides a unique perspective on our dynamic planet, tracking changes and revealing the course of complex interactions. This work brings together diverse fields with the common goal of better understanding such complex interactions in order to provide trusted knowledge for tactical and strategic decision-making.

Further, this work strikes particular importance as the Leaders of the G7 release their Blueprint for Healthy Oceans, Seas and Resilient Coastal Communities, and President Trump announces the Executive Order Regarding the Ocean Policy to Advance the Economic, Security, and Environmental Interests of the United States. Each initiative builds on the Sendai Framework for Disaster Risk Reduction 2015-2030 strategy cite, which aims toward the substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries. This body of work signals an emerging global priority on coastal communities and their vulnerable populations.

V. Next Steps

Through Earth-observing capabilities unique to NASA, we aim to complement and augment the ongoing work being done across the Federal government and local communities to translate hazards to risk. In summer of 2018, a follow-up workshop was held to collect lessons learned, identify gaps in understanding and decision maker needs, and formulate next steps beyond the initial demonstration. Participants of the workshop included more than 60 in person and online contributors ranging from first responders, city and regional planners, NGOs, city and state resilience coordinators, and sister Federal Agencies in addition to four NASA centers and six universities. During the workshop, it was identified that all future efforts must meet the following criteria:

- Extensible – applicable to any at-risk coastal region with minor local tailoring
- Actionable – at a scale or resolution needed by decision-makers
- Understandable – easily comprehended by users without a deep science background

Initial strategic thrusts will focus on data accessibility and assimilation; understanding, visualizing and communication compounding hazards; and gaps in technology that can leverage cube-sats and constellation advancements.

Though this was a highly successful demonstration, this only marks the beginning. Throughout there was excellent participation with diverse representation. The next steps require taking this information and creating a path forward to enable the core capabilities discussed. This path forward will be shared and communicated with the broader coastal and marine communities and beyond. Together, we must understand the implications in order to minimize the vulnerability – we are translating hazards to risks to inform decisions, prepare for future risk and build resilience.

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