A glimpse of the future Web:

Forecasting storm damage on the Maine coast

by Philip Bogden, John Cannon, Riley Young Morse, Ian Ogilvie, Brian Blanton and William Perrie

Introduction

The Internet has helped globalize the economy and change social interactions, but the full impact on coastal science has yet to be realized. This essay provides a glimpse of the future. We demonstrate how Web 2.0 technologies can streamline the transition from research to practical applications. Our partners at the National Weather Service (NWS) are meteorologists whose forecast warnings save lives and livelihoods. Our research partners work on the most advanced technologies on the planet for environmental prediction. Gulf of Maine Ocean Observing System (GoMOOS), Inc. (www.GoMOOS.org) has brought these two communities together to prototype new ways to mitigate the impact of coastal storms in New England. A case study tells the story.

The Patriots' Day Storm, 2007 – A Case Study

On April 16, 2007, an intense (966 mb) low-pressure system became quasi-stationary near Long Island. The storm brought hurricane force winds up to 139 kph (75 kts) to the Gulf of Maine. GoMOOS buoys near the coast registered wave heights of 9.75 m (32 ft).

Excessive rainfall over 20 cm (8 in) combined with rapid snowmelt to produce widespread terrestrial (fresh water) flooding. Five rivers recorded all-time record flows in southern Maine and southeast New Hampshire [USGS, 2008]. Storm damage seemed especially intense wherever terrestrial freshwater flooding coincided with the incoming storm tide, which occurred along many marsh roads.

Along the coast, intense winds and large, battering waves produced severe coastal flooding, splash-over and beach erosion. Homes were swept out to sea and new river inlets formed. The region was declared a disaster area and required assistance from the National Guard. In Portland Harbor, the now infamous Patriots' Day Storm combined with tides to exceed flood stage six consecutive times in 72 hours.

A Practical Problem – Forecasting Storm Damage

New England NWS meteorologists face their biggest challenge when they produce the forecast warnings for coastal communities. Emergency response managers use these warnings for disaster preparedness and mitigation. Costs of responding to a warning are formidable and the implications of inappropriate responses can be life threatening.

Storm damage comes from many sources. Flooding from storm surge is not always the biggest problem. Beach erosion is one of the most significant impacts of coastal storms. Storm tide, wave energy and duration are three primary factors that determine storm erosion potential. Exactly how these environmental factors combine to produce damage is not fully understood. Some research has shown that the erosion potential during severe winter storms (nor'easters) depends more on storm tide than wave energy and duration. However, significant damage can occur with water levels below flood stage during splash-over events. Splash-over occurs when large waves "over-top" obstacles, driving substantial beach erosion distinct from coastal flooding. Threats magnify as populations swell near vulnerable beaches and as global sea level rises. Coastal storms significantly impact the marine community and pose billions of dollars in risk to personal property.

Forecasters rely on all the available statistical and dynamical guidance, but these can have large numerical and temporal errors and they are only available in select locations. Complicating matters, coastal inundation in New England is rare, but damage produced by large, battering waves is not.

Storm-surge guidance and visualization techniques are being developed with a focus on damage caused by the combined effects of waves and flooding. New forecast schemes seem promising. However, there are no forecast models for predicting the various categories of damage due to the combined influence of coastal flooding in the presence of large waves. This creates a special challenge for NWS meteorologists, who are charged with producing detailed warnings describing storm impact.

A Practical and Operational Solution

In Gray, Maine, NWS meteorologists have developed their own visualization techniques to predict coastal damage. One of these tools — a "Splash-Over Nomogram" — combines the synergistic effects of storm surge and large battering waves. This semi-empirical tool increases their confidence in predictions made during the operational warning process.

The type of plot shown in Figure 1 can be created for any location that has nearby monitoring of water level and waves. The background on the plot is "calibrated" empirically for specific locations based on climatological records of storm damage, water level and wave height. A region in the upper right marks the most severe beach erosion associated with damaging storm tides.

The horizontal red line on the nomogram denotes the magnitude of the storm tide associated with the onset of coastal inundation. This benchmark represents the 3.77 m (12 ft) flood stage in Portland Harbor, Maine, and was produced by examining a robust catalogue of coastal flood events (1914-2007) along south coastal Maine and the New Hampshire seacoast.

The nomogram includes other benchmarks for minor versus moderate and severe coastal flooding. These categories were established from the height of the peak storm tide in Portland Harbor of 3.66 m (12 ft), 3.81 m (12.5 ft) and 3.96 m (13.0 ft) respectively. Unfortunately, there is little documentation or consistency in the NWS for categorizing coastal flood severity along the east coast. This is significant as it forces highly subjective interpretations of various damage levels.

Finally, a yellow line on the nomogram depicts the benchmark for the onset of splash-over. The empirical relationship between storm tides, large ocean waves and

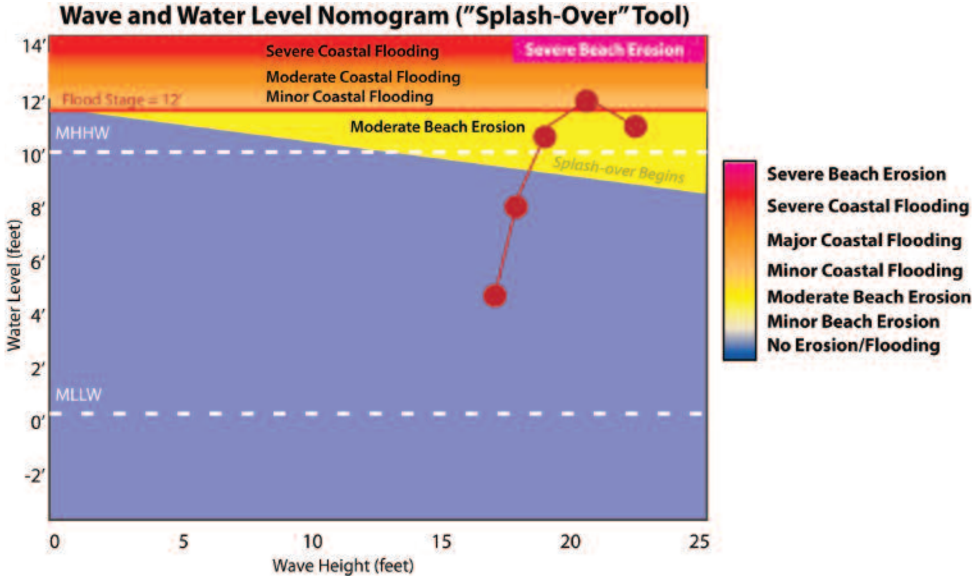

Figure 1: Snap shot from a time loop of the Web-based "Splash-Over" Nomogram during the 2007 Patriots' Day Storm. Forecast hourly storm tides are plotted against predicted near-shore waves. Forecasts of increasing storm tides and large battering waves result in the prediction of severe coastal flooding and beach erosion. The entire retrospective time sequence is available at www.OpenIOOS.org and www.GoMOOS.org.

splash-over was derived using the storm data publication database. These records show that as wave heights increase, there is an increased risk of localized splash-over damage or coastal inundation along exposed sandy beaches south of Portland. Damage can occur before tide heights exceed flood stage in Portland Harbor. During minor coastal flood events (when storm tides exceed flood stage), seawater submerges near-shore roads and low lying properties. Damage and water levels may increase locally due to the presence of large, battering waves. In these events, sand, rocks and other debris may be tossed onto washed out coastal roads. During moderate coastal flood events, damage will be magnified and become increasingly widespread. Seawalls crumble, massive cement barriers are moved by the tide and most piers and wharfs become submerged. Some residents are evacuated and "reverse 911" procedures go into effect. The most severe coastal flooding events are rare. Beachfront homes are lost to the sea and buoys are ripped from their moorings. Coastal flooding spreads inland and may occur for more than an hour either side of high tide. Mammoth waves strike lighthouses. Severe financial strife occurs within the marine community, which may prompt a state of emergency.

The Network Solution – A Glimpse of the Future

GoMOOS staff worked with the NWS meteorologists on the Web-based prototype of the splash-over nomogram (Figure 1). For the first time, the Web version will make the information available to emergency management, coastal zone managers and home owners in the affected area on a 24/7 basis. This tool is finding value even during non-storm conditions, such as water level predictions during extreme low-water periods, and to assist shippers and pilots in planning movement of big ships in and out of Portland Harbor.

Software developers easily prototyped the Web version using technology created by GoMOOS and the Southeastern Universities Research Association (SURA) as part of the SURA Coastal Ocean Observing and Prediction (SCOOP) program. The SCOOP system has prototyped a distributed system for predicting and analyzing coastal inundation and ocean waves. With the Web-based nomogram, we used Web services to "plug in" the available forecasts. The standardized web-service interfaces had already been applied to the models for other research applications (e.g., model-data and model-model comparisons), many of which appear on

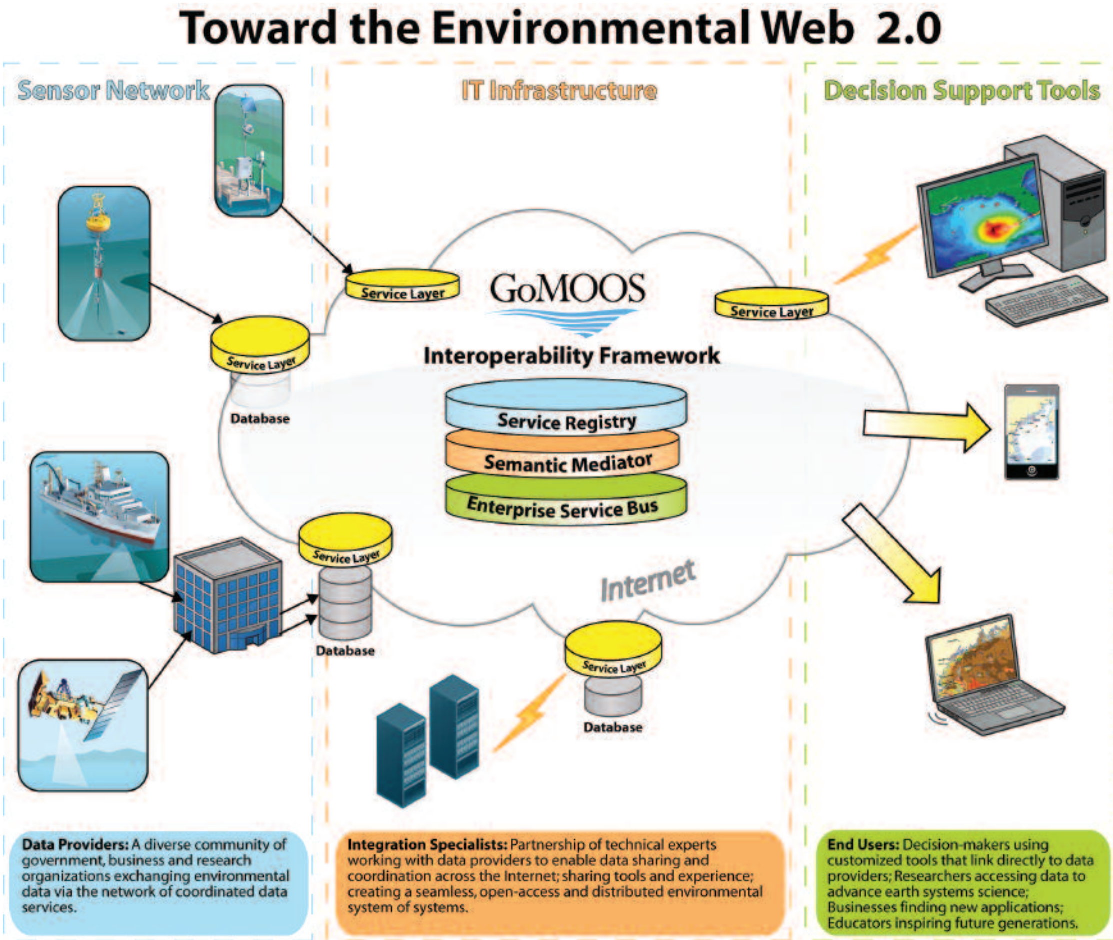

Figure 2: Conceptual design of the SCOOP infrastructure with GoMOOS operating in the "cloud space."

www.OpenIOOS.org. As a result, the data from the Web services were easily and readily accessible for the splash-over tool – an application that hadn't been anticipated when SCOOP partners created the infrastructure. This example demonstrates a basic tenet of the Web 2.0 and standards-based interoperability, namely, standards enable innovation.

Decision Tools in a Service Oriented Architecture

The Web-based splash-over tool is one of several applications that leverage the IT infrastructure of the SCOOP program. This is how the Web 2.0 should work. A network of Web services enables creation of many more applications. In the Web 2.0, the individuals who provide the services are typically not those who create the applications.

The network was built with a Service Oriented Architecture (SOA). Service orientation is a design philosophy that underlies much of the World Wide Web, particularly the transaction-oriented Web 2.0. Service layers are standards-compliant, Web-service interfaces that can be used to interconnect disparate and heterogeneous data sources over the Internet. The conceptual design (Figure 2) shows these "service layers" applied to a variety of data systems, which can range from databases at large organizations to data loggers on buoy systems or stand-alone self-reporting smart sensors. In SCOOP, we applied service layers to forecast models as well.

Standards-compliant service layers provide easy access to the network. Communication over the Internet uses well established eXtensible Markup Language (XML) technologies that conform to standards from the Open Geospatial Consortium (OGC). These lightweight software components "attach" web-service interfaces to data-provider systems. We find that these service layers must be easy to install and maintain, otherwise data providers are not likely to participate. The service layers must also comply with established standards or the network will not scale up in size without becoming an information-management nightmare.

The "Interoperability Framework" includes other software components contributed by various partners around the country. These components coordinate a wide variety of messages, data flows and processes (including the numerical predictions and analyses). The service registry is a database that keeps track of all the services available on the network. The Semantic Mediator is a metadata catalogue that organizes and adds meaning to all the keywords used by the underlying data systems (a service provided by our partners in the Marine Metadata Interoperability project). The Enterprise Service Bus (ESB) is a middleware framework at GoMOOS for managing message traffic and data flows. These components have become common in e-business. GoMOOS hosts a website (www.OpenIOOS.org) that demonstrates various aggregation and visualization capabilities, including web-based mapping of Geographic Information System (GIS) data sources and images. Thus, the splash-over application is only one of many system components. A true SOA supports many applications, including desktop analysis tools, web browsers, cell phones or any other device that can connect to the Internet.

Conclusion

Our practical splash-over application is built upon three key ingredients for this kind of distributed information system: (1) IT standards, (2) a working system prototype and (3) communities of interest. We strongly endorse and adhere to standards from the Open Geospatial Consortium and other international organizations that create standards based on consensus among government, private sector and academic interests. These standards are often highly complex, which can be an impediment to their use. We have found that the second key ingredient — a working prototype — helps overcome the complexity and demonstrate the power of standards. Finally, the prototype supports the third key ingredient, namely, communities of interest (in this case, researchers and operational meteorologists) who adopt and leverage the standards. Even though they have never met in person, our international partners have used the Web to create a virtual collaboration and to prototype a new application. As a result, the best available research is directly helping to mitigate storm impacts in coastal New England.

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Dr. Philip Bogden is CEO of GoMOOS, the Gulf of Maine Ocean Observing System. GoMOOS, Inc. is a nonprofit membership organization, and a regional component of a national program designed to bring hourly oceanographic data to all those who need it. He leads several projects that will augment GoMOOS by establishing new levels of interoperability and integration between other regional systems like GoMOOS, as well as state and federal agencies that collect their own information about the coastal ocean.

The goal is an integrated set of interoperable and distributed observing systems producing top quality data and information products for both research and practical applications. For data integration and product services, GoMOOS implements and helps to advance open standards developed by the Open Geospatial Consortium.

Dr. Bogden also serves as Director of a major coastal science initiative at the Southeastern Universities Research Association (SURA) called the SURA Coastal Ocean Observing and Prediction (SCOOP) Program.


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