Improved Flood Prediction through Air/Sea/Land-River Monitoring and Modeling

A Fulbright Scholar proposal for Research/Teaching award to the Philippines

Area: Environmental Science
Specialization: Environmental sustainability/climate science

Background:

Floods from typhoons and extreme rain events are a common occurrence in the Philippines. These weather events now lead to frequent landslides and evacuations throughout the Philippines (Soria et al. 2016). Indeed the Philippines ranks in the top 10 countries impacted by weather-related disasters (CRED 2015). A nation-wide warning system has been designed to enhance the ability to monitor and predict these natural hazards. As part of its deployment, a network of rainfall and river monitors is being accelerated throughout the country. The campaign, known as the Nationwide Operational Assessment of Hazards (Project NOAH), includes the Philippines Department of Science and Technology (DOST) and weather service (PAGASA), in partnership with University of the Philippines-Diliman (UPD) researchers.

The scientists of Project NOAH are focused on the implementation of state-of-the-science coupled air/sea models with the express purpose of developing the capability to anticipate hazards in a changing climate. The emphasis on rainfall-induced flooding comes at a time when international attention is focused on monitoring and predicting extreme events in the Maritime Continent. It also coincides with a growing recognition of the need to train the next generation or research scientists to utilize the state-of-the-science modeling tools and datasets, and employ advanced statistical techniques.

Hypotheses:

- River flooding in the mountains and coasts varies spatially and is modulated by weather events that occur across multiple timescales throughout the year.
- The relationship between weather events and river flooding can be predicted by sophisticated coupled earth systems models and measured across different environmental datasets.
- River discharge from the islands modifies upper ocean features (temperature, salinity), thereby influencing weather pattern propagation and characteristics.

Objectives:

- Access and combine diverse datasets (e.g., rain gauge, river gauge, satellite precipitation, soil moisture, meteorological station and sounding data)
- Evaluate the correlation between different sensing modalities (land-based, satellite, coastal/ship-based) and the values predicted by model simulations
- Recommend additional sites for sensors to best capture the patterns of rainfall indicated by the combined modeling and sensing modalities
- Prepare datasets for use by U.S. and Philippine coupled air/sea models
- Assist Philippine colleagues with coupled model implementation and evaluation

- Develop new UPD course offering in meteorology (with Olivia Cabrera, Ph.D, Assistant Professor at Institute of Environmental Science and Meteorology), and assist student research and mentoring

The hypotheses and objectives nest within a larger international project, described below.

Impact:
The coming years (2017-2019) will bring an unprecedented coordinated focus on the meteorology, oceanography, and hydrology of the "Maritime Continent" (including Philippines, Indonesia, Malaysia, Papua New Guinea and Singapore). Multi-country measurement and modeling campaigns are being undertaken (http://www.jamstec.go.jp/ymc/). In the "Year/s of the Maritime Continent" (YMC), scientists will measure the ocean and atmosphere in an attempt to better understand how the planet transports heat from the tropics to the poles (Gordon and Fine, 1996), and propagates weather patterns along the tropical belt. The YMC particularly highlights the need to develop an ability to predict the rainfall and flooding that pose hazards in a changing climate.

I co-authored the U.S. Science Plan for YMC (Zhang et al. 2015) and am a principal investigator on the U.S. Office Naval Research (ONR) project (2016-2019) with planned fieldwork in July-September 2018. The fieldwork will involve extensive air, sea and land measurements of the Philippines tropical region and will utilize ships from the U.S. and the Philippines. The ONR effort, "Propagation of Intra-Seasonal Tropical Oscillations" (PISTON), is currently undergoing designation as a joint project under a Science and Technology Agreement (STA) between the U.S. and Philippine governments in Working Group 3 on Climate Change/Disaster Resilience. The Philippines YMC contribution is coordinated through UPD and is to be funded by DOST (Project title: "Philippines Sea-air-land interaction in the context of archipelago", SALICA, lead: Olivia Cabrera, Ph.D).

My university partners in the Philippines have a history of working closely with PAGASA. Our prior collaborative research analyzed rainfall patterns using satellite and PAGASA rain gauges in the Philippines during an extremely wet winter (Pullen et al. 2015). The rain led to many floods and evacuations on the islands (NDCC 2008). Our unique modeling and measurement approach revealed the correspondence of intense deluges in the Philippines mountains with particular wintertime weather patterns that occur on short (cold surges) and medium (Madden-Julian oscillation, MJO) timescales (Figure 1). Other recent work has shown that the MJO signal dominates rainfall measured in catchment areas of Papua New Guinea in the Maritime Continent (Mathews et al. 2013). Our research contributed to the published work targeting these tropical weather events for international fieldwork and lends support to the growing belief that such events have ramifications that extend across the globe (Zhang 2013).

My role in this area of research has grown now that the high-fidelity coupled air/sea model I helped develop for the U.S. Navy (COAMPS, described in Hodur et al. 2002 and Pullen et al. 2006) has the ability to represent the rain unleashed in the Philippines by the passage of multiple weather patterns (Pullen et al. 2015). Specifically, the demonstrated ability of a coupled air/sea model to anticipate complex precipitation events heralds the potential to warn populations in mountainous areas most at risk for flooding, and mitigate associated flood risks.

The coastal mountainous Maritime Continent region motivates a focus on the linkages between the air, land/rivers, and ocean. The nature and significance of the linkages have not been sufficiently measured and modeled, and are highly dependent on timescale. The synergies with the larger YMC project and associated U.S. (PISTON) and Philippines (SALICA) projects guide the timing of my proposed Fulbright award (January to May 2018) to be ahead of the primary field season (July to September 2018), so the insights from my work can be of maximal value.

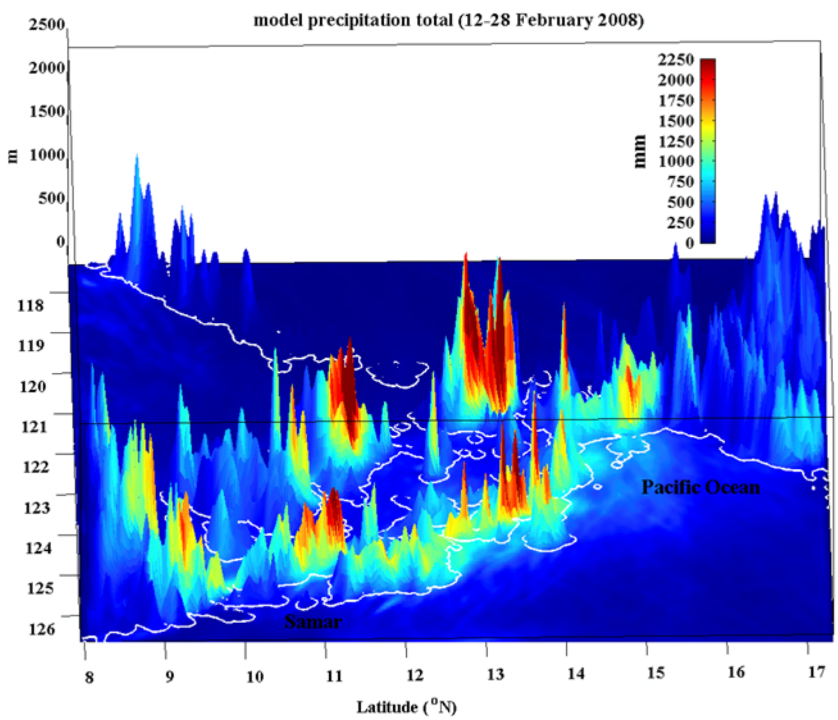

Figure 1: The winter of 2007-2008 was the rainiest winter in the Philippines in 40 years. Philippines 3-km coupled air/sea model rainfall totals during the February 2008 MJO event and cold surge are contoured in color. The view is from the east toward the west. Terrain is shown in relief, and the land/ocean boundary is outlined in white. (from Pullen et al. 2015). Regions where the model shows highest rainfall were areas that experienced river flooding and evacuations.

Methodology:

This work will draw on remotely sensed observations (e.g., satellite rainfall, cloud cover), *in situ* data (river and rain gauges, soil moisture and other meteorological station and sounding data) acquired through the UPD/DOST initiative SALICA, led by Dr. Cabrera, and others. Data reside at DOST, PAGASA, Philippines public/water works, Manila Observatory, YMC partner institutions, and non-profits such as Oceana and World Wildlife Fund (WWF).

For example since 2013 Project NOAH (http://noah.dost.gov.ph), has unveiled more rain and flood sensor sites across the Philippines. There are >80 Automated Weather Stations (AWS) stations and >80 Automated Rain Gauges (ARGs) that transmit data at 15 minute interval to the Project NOAH "disaster risk reduction and management online platform" (Langmay, 2012). Another 600 AWS sensor deployments are planned. Stream gauge data are likewise being expanded.

Other datasets from organizations such as WWF-Manila (soil moisture from watersheds studied for agriculture purposes) and Oceana Philippines (ocean measurements) will be pursued for their potential utility in contributing to the larger project aims.

The Philippines has 412 principal river basins, with 19 categorized as major global rivers. The major rivers have mostly been gauged, while the water/public works department only intermittently gauges many other rivers prone to flooding. These data will be used to refine the models currently in use. For example, the current model does not account for river discharge and thus consistently over-predicts salinity by ~0.5psu in the upper 75m of the water column (Pullen et al. 2015). This missed salinity effect has an equivalent impact of >1ºC temperature change, which is significant for the tropical ocean. Such a deficiency in the model can be addressed with the new data.

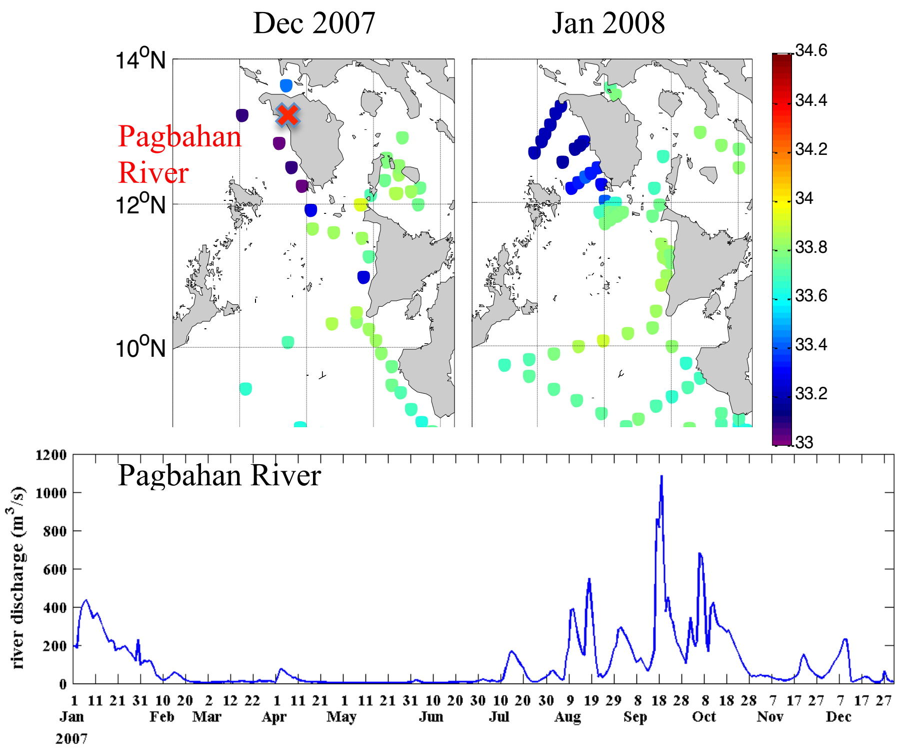

Figure 2: Top: measured 10m salinity from CTD casts during two ONR research cruises (December 2007 and January 2008) from Pullen et al. (2015). The location of Pagbahan River is indicated with a red cross. Bottom: measured discharge for 2007 from Pagbahan River, one of the rivers draining northwestern Mindoro. (Data courtesy of Cesar Villanoy.)

As an example, Dr. Villanoy of the UPD has recently acquired limited river discharge data from the island of Mindoro (Figure 2). Mindoro's Pagbahan River peak fall 2007 discharge reached over 1000 m^3/s. By contrast, the climatological discharge for this river is under 100 m^3/s throughout the year, suggesting that the representation of this river in current models under-estimates the episodic flooding by a factor of 10. In the same timeframe, December 2007 shipboard measurements showed excessively fresh water west of Mindoro Island (Figure 2). While more extensive measurements conducted in January 2008 revealed that the fresher water filled Mindoro Strait to the west. It is expected that the modified ocean surface properties feedback via air-sea interaction to affect the propagation of weather systems (DeMott et al. 2015). This synthesis shows significant impacts to the coastal ocean caused by river discharge, and is an example of how the different sensing modalities will be brought together in the proposed Fulbright work.

Our prior study covered wintertime monsoon conditions. River flooding in the Philippines peaks in the summer monsoon, and is also exacerbated by tropical cyclones in this season. Therefore the upcoming focus is on monitoring and simulating flood hazards in the most dangerous summer/fall monsoon season.

The proposed effort will synthesize and analyze these data, prepare datasets for use by coupled models, and evaluate the various sensing modalities using statistical approaches such as cluster and wavelet analysis (Schulte 2015). (We have been applying these techniques in our lab with postdoctoral associate Justin Schulte.) In addition, this project will investigate the associated land surface and hydrology responses during several case studies of extreme rainfall events. The results will be prepared with Philippine colleagues for joint publication.

Benefits to country:

The Philippines is experiencing an unprecedented growth in environmental science monitoring and modeling for flood hazards. My presence in the Philippines will facilitate the augmentation of the datasets, leading to inquiry-driven model/data aggregation and analysis for science purposes. My ocean/atmosphere modeling expertise is valuable for setting up the UPD coupled model simulations, comparing with observations, and training students in these tools.

The country would benefit greatly from enhanced interaction with the international community conducting YMC projects. One of my aims is to strengthen integration and coordination with international field campaigns, as detailed above. To that end, I will be a key organizer and participant in the 4th international YMC workshop scheduled to be held in Manila in spring 2018. I will also conduct seminars at university and government facilities (e.g., at PAGASA and Manila Observatory) and conference presentations to facilitate these aims. Outcomes of my work will include recommendations to PAGASA on additional sites for sensors in order to fill potential gaps and gather information on weather impacts. These efforts will enhance the resilience of the Philippines.

I will engage in Meteorology curriculum development and teaching of a new UPD course in Tropical Air/Sea Interactions (with Dr. Cabrera, Assistant Professor at Institute of Environmental Science and Meteorology). I have co-taught Oceanography and Meteorology courses at my university and developed two new courses (Tropical Air/Sea Interactions; Urban Meteorology) scheduled to be piloted in 2016-2017 at my home institution. In my teaching I strive to inspire and cultivate curiosity and deep learning in students. I aim to explain concepts from several different perspectives in order to connect with different types of learners. I have fielded project-based and active inquiry approaches and found that they lead to co-discovery and sustained connective learning in students. I will bring my research background to the classroom and to student advising, and build continuity by working with Professor Cabrera to ensure the new course is sustained in subsequent years.

In my lab at Stevens we continue to build out our real-time New York/New Jersey regional air/sea/river/sewer prediction system as a tool to address extreme events in a changing climate (Saleh et al. 2016). There are strong avenues for future faculty and student exchanges with the Philippines around these topics of mutual interest, as monitoring and prediction systems are strengthened to enhance national resilience to floods.