Appears in Proceeding of the Intl Geoscience and Remote Sensing Symposium, Vancouver, BC, July 2011.

COMBINING SPACE-BASED AND IN-SITU MEASUREMENTS TO TRACK FLOODING IN THAILAND

Steve Chien[1], Joshua Doubleday[1], David Mclaren[1], Daniel Tran[1]
Veerachai Tanpipat[2]
Royol Chitradon[3], Surajate Boonya-aroonnet[3], Porranee Thanapakpawin[3]
Chatchai Khunboa[4], Watis Leelapatra[4], Vichian Plermkamon[4]
Cauligi (Raghu) Raghavendra[5], Daniel Mandl[6]

[1]Jet Propulsion Laboratory, California Institute of Technology, USA
[2]National Park, Wildlife and Plant Conservation Department of Thailand
[3]Hydro Agro Informatics Institute, Thailand
[4]Khon Kaen University, Thailand
[5]University of Southern California, USA
[6]NASA Goddard Space Flight Center, USA

ABSTRACT

We describe efforts to integrate in-situ sensing, space-borne sensing, hydrological modeling, active control of sensing, and automatic data product generation to enhance monitoring and management of flooding. In our approach, broad coverage sensors and missions such as MODIS, TRMM, and weather satellite information and in-situ weather and river gauging information are all inputs to track flooding via river basin and sub-basin hydrological models. While these inputs can provide significant information as to the major flooding, targetable space measurements can provide better spatial resolution measurements of flooding extent. In order to leverage such assets we automatically task observations in response to automated analysis indications of major flooding. These new measurements are automatically processed and assimilated with the other flooding data. We describe our ongoing efforts to deploy this system to track major flooding events in Thailand.

Index Terms— Flooding, space-based remote sensing, in-situ sensing, hydrological modeling,

1. INTRODUCTION

Flooding has a tremendous impact in humanitarian and economic ($$) terms worldwide. Recent flooding in Thailand October-November 2010 [MCOT 2010, Bangkok Post 13 Nov 2010, Wikipedia 2010] was responsible for over 200 deaths, over $1.67 Billion USD damage, and affected over 7 million people [CNN 2010].

Flooding has a tremendous impact on humanity and are worldwide in scale. From p. 348, [NRC 2007] “Floods are among the most destructive of natural disasters. From a monetary standpoint, flood damages in the United States averaged around $5 billion per year in the 1990s in 1995 dollars (Table 3.1 in Pielke et al., 2002). Outside the United States, the impact is even more striking; flood losses globally increased 10-fold (inflation-corrected) over the second half of the 20th century to a total of around $300 billion in the decade of the 1990s (Kabat and van Schaik, 2003).”

Flooding is also a key part of the global hydrologic cycle. “The scientific challenge posed by the need to observe the global water cycle is to integrate in situ and space-borne observations to quantify the key water-cycle state variables and fluxes.” [NRC, 2007]).

Therefore the study of flooding at multiple scales: global, regional, river-basin, and sub-basin, is of great scientific and humanitarian importance. This paper describes an effort to combine several means of studying flooding: broad coverage satellite sensing of rainfall and surface water, targeted satellite sensing of surface water, in-situ sensing of weather (rainfall) and surface water flow, and hydrological modeling. It is hoped that by combining these methods better tracking of flooding events can be achieved.

2. TRACKING FLOODING

A number of satellites have been used to track flooding at a larger scale: most notably QuikSCAT (Quick Scatterometer), The Advanced Microwave Scanning Radiometer for Earth Observing System (AMSR-E), and Moderate Resolution Imaging Spectrometer (MODIS).

QuikSCAT has been used by the Dartmouth flood observatory [DFO] to track major flooding events. This method uses the change in backscatter to distinguish surface water from normal land areas. Averaging over longer time intervals (days) and comparisons against baseline data from prior years enables more accurate detections. While the use of scatterometer backscatter data enables detections even in the presence of clouds (a common difficulty as flooding, rain, and clouds all co-occur), this methods reliance on a

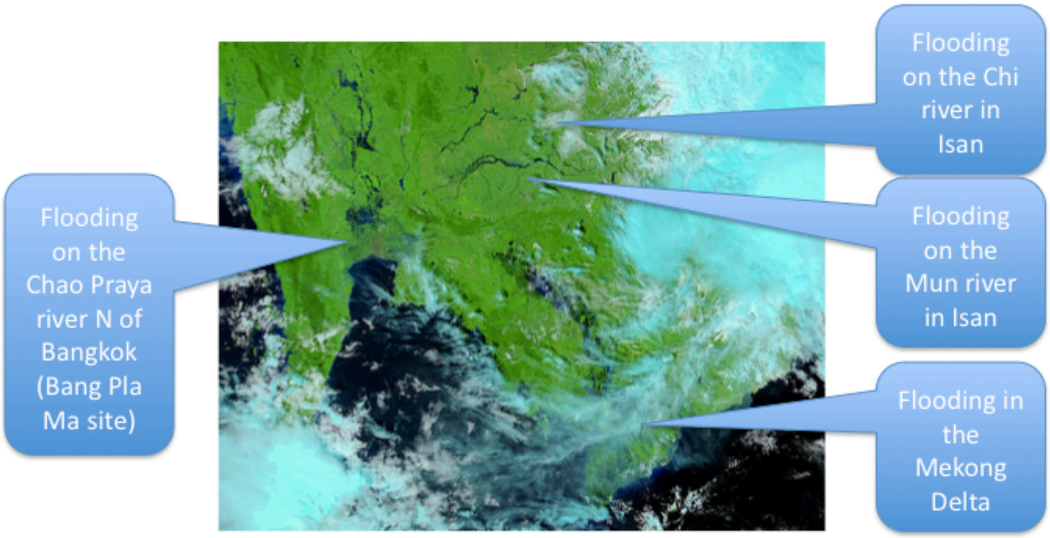


Figure 1: Aqua/MODIS 28 Nov 2010 Imagery of Thailand Flooding (band 7-2-1)

running average reduced the timeliness of the detection (days) and the instrument also allowed only moderate (km-scale) spatial resolution for flooding events.

AMSR-E has also been used to track global flooding by the Dartmouth Flood Observatory [DFO]. While AMSR-E does provide a useful flood tracking capability its moderate spatial resolution (km-scale) mean that it can only detect major flooding events.

Significant efforts have utilized MODIS to monitor flooding worldwide [Brakenridge 2005, Carroll et al. 2009]. Again MODIS has moderate spatial resolution (250m-1000m/pixel) so that its flood products are typically generated at a 500m per pixel resolution. However sub-pixel surface water extent has been demonstrated. MODIS flood tracking can be hampered by cloud cover that often occurs with flooding. These MODIS based flood tracking methods utilize the MODIS multispectral capability. Flooded areas exhibit very low spectral response across a number of spectral wavelengths whereas clouds and land typically reflect more sunlight at certain wavelengths. Cloud shadows can often be hard to distinguish from surface water. MODIS based surface water detection methods often look at several overflights of data to address both cloud and cloud shadow difficulties. However using this temporal technique causes a delay in detections.

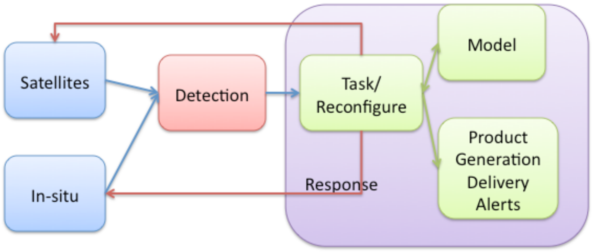


Figure 2: Sensorweb Paradigm – Autonomous Detection and Response Tasking, Reconfiguration, Modeling, Product Generation & Delivery & Alerts

Environnmental Satellite (ENVISAT)/Advanced Synthetic Aperture Radar (ASAR) and Advanced Land Observation Satellite (ALOS) / Phased Array type L-band Synthetic Aperture Radar (PALSAR) have both been used to detect surface water extent from flooding. Synthetic aperture radar can distinguish between surface water and land areas due to the change in backscatter. Depending on the wavelength of the radar, surface roughness condition of the water (e.g. wind causing waves on the water surface) can cause difficulty in flood detection.

Landsat-5, Landsat-7, and Earth Observing One (EO-1)/Advanced Land Imager (ALI) can all be used to detect surface water using spectral methods. While these sensors provide higher resolution data (30m/pixel) their infrequent revisit rate and challenge with clouds limit their utility for global flood mapping.

The Tropical Rainfall Measurement Mission (TRMM) satellite provides timely rainfall information for equatorial and middle latitude regions. TRMM provides averaged rainfall data for periods as short as 6 hours at moderate (km-scale) resolution.

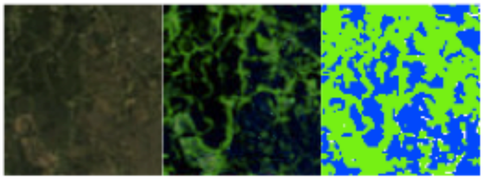
In-situ sensors can also provide valuable information. In-situ sensors can provide point estimates of rainfall, water levels, and in some cases flow rates.

Hydrological modeling is an essential part of flood management. Hydrological models are typically grid-based water balance models that track incoming water from rainfall or from upslope, water lossage from evaporation or absorption, and outflow (downslope). All of the sources of data we have described in this section (e.g. satellite, in-situ) can be considered inputs to the hydrological models.

3. A SENSORWEB FOR FLOODING – INTEGRATING, RESPONDING AND UPDATING FLOOD MODELS

3.1. Sensorweb – The Concept

In our sensorweb concept, the sensorweb constantly assimilates available data from any and all available sources to track flooding. This may be as easy as downloading the available data. Or it may mean active querying to determine if potentially contributing satellites are acquiring data and acquiring the data form relevant servers when available.



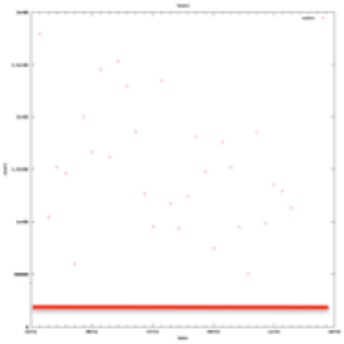


Figure 3a: True color, band 7-2-1, and flood classified MODIS imagery from 5 Nov 2010 of Bang Pla Ma Site
Figure 3b: Flood score for same site, 150,000 score threshold marked, dry baseline score is 5000.
Figure 3c: average and std. dev. spectra for each class

Data acquisition may also involve downloading in situ data from the web. This data is used to constantly update our model of the flood state. All of these data can then be combined with hydrological models to perform hindcasting (estimation of flood parameters in the past to fill in missing times or areas), nowcasting (estimating the current flood state by using the model to fill in spatial gaps), and forecasting (using the model to predict which areas are at risk for future flooding).

When appropriate, this raw data and model are used to generate specific flood products for end users such as local, regional, and national authorities. These products may include surface water extent maps, flood alerts for already inundated areas, and alerts for areas at future risk. When targetable satellite assets are potentially available, the sensorweb can automatically request data.

3.2. Thailand Flood Sensorweb – a Sensorweb in Implementation

We are currently implementing such a sensorweb to monitor flooding in Thailand. We have begun with a core system that leverages prior work with MODIS and EO-1/ALI and are working to better integrate this system with additional components including: TRMM, river basin and sub-basin hydrological models, in-situ sensing, and additional satellite assets.

MODIS sensing provides excellent temporal coverage (2x per day daylight overflights), spectral range (0.62-14.3 μ m), and spatial coverage (coverage of the majority of Thailand each overflight). We draw the subsetted FAS Indochina MODIS data as geotiff from the site http://rapidfire.sci.gsfc.nasa.gov/ and utilize the band 7-2-1 combination to feed both threshold and Support Vector Machine [Schölkopf, B., & Smola 2002] methods to classify scenes into: water, land, and clouds.

We are currently tracking a number of sites on the Chao Praya River in western Thailand North of Bangkok as well as eight (8) sites along the Chi river in northeastern Thailand. For each test site we examine a 20 x 20 km area and compare the current flooded extent by counting flood classified pixels and examining prior pixels up to 3 days prior to address cloud cover occlusions.

For each test site, the flood score is compared to a baseline score from the dry season. If the current flood score exceeds the baseline by a manually tuned threshold a flood alert is issued for the site. Flood alerts can also generate an associated magnitude score which is based on the degree which the flood classifier score exceeds the dry season baseline.

Figure 3 shows the true color, band 7-2-1, surface water extent maps, and flooding scores (flooded and dry) for the Bang Pla Ma area NW of Bangkok near the Chao Praya river. The flood classification score for the October – December 2010 timeframe is consistently greater than 500,000 and easily distinguishable from the dry season baseline score of 5000.

The Earth Observing One spacecraft has automated tasking capability [Chien 2005] and is integrated with this alert system to automatically task to image flooded areas using the Advanced Land Imager (ALI) Instrument (30km wide swath, 30m spatial resolution multispectral, 9 bands 0.4-2.4 μ m spectral range).

This imagery is automatically processed to derive surface water extent maps using both SVM and ratio (0.55/0.86 μ) threshold methods [Ip et al. 2006]. Figure 4 shows ALI imagery and associated surface water extent maps for the Ayutthaya-Chao-Praya Test site.

We have also been investigating the possibility of bringing in other satellites including Digital Globe's Worldview-2 which offers 1.5m spatial resolution 8 band

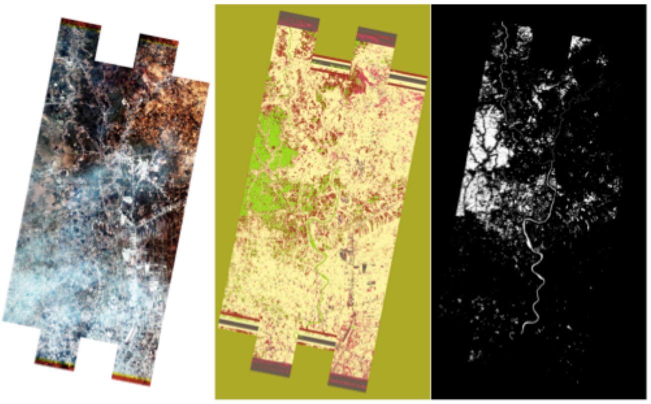


Figure 4: ALI Imagery – Color, SVM classified flood, and band ratio classified flood for Ayutthaya-Chao-Praya Site acquired 03 December 2010

0.4-1.05 μ m multispectral imagery. We have experimented with generation of surface water extent maps using spectral classification via band ration and SVM on WV-2 imagery derived for test sites on the Chao Praya and Eastern Thailand. Additionally, we are investigating the potential use of Landsat-5 data which is automatically acquired and downlinked via Thai groundstations.

We currently are developing mechanisms to automatically deliver the satellite data and in-situ sensor data to drive hydrological models to provide data for decision support in flood response. Currently the satellite data and products are provided over the internet to interested parties.

We are also working to integrate available in-situ data. Thailand's Hydro Agro Informatics Institute (HAII) processes data from over 200 in-situ stations including numerous rainfall, water level, and flow rate sensors (e.g. for the Mun river basin see http://www.thaiwater.net/DATA/REPORT/php/mun_scada/mun_scada.php). Additionally, Khon Kaen University is in the process of developing and deploying further in-situ sensors to the Huay Sa Batt and Chi river basins.

The current status of the Thailand Flood Sensorweb is shown in Figure 5. Implemented systems and products are shown in regular type and those in implementation are shown in *italics and underline*.

10. CONCLUSIONS

We have described a general method of sensorweb operations in which data assimilated from a wide range of sensors (space, in-situ) is used to feed a model. This model is then used to task/reconfigure the sensor network to acquire further data, as well as generate and deliver relevant products and alerts to end users. We describe the how a sensorweb of this type is being developed to track flooding in Thailand. This network will eventually link together space and in-situ sensors to track flooding and deliver flood status and products to relevant institutions.

ACKNOWLEDGEMENTS

Portions of this work were performed by the Jet Propulsion Laboratory, California Institute of Technology, under contract from the National Aeronautics and Space Administration. The Khon Kaen University team acknowledges the support of the Telecommunications Research and Industrial Development Institute, National Telecommunications Commission, Thailand.

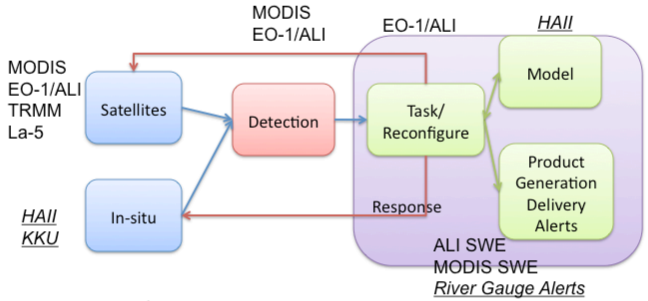


Figure 5: Sensorweb Implementation Progress
Regular Type – Implemented *Italics and Underline* – In Progress

REFERENCES

G.R. Brakenridge and E. Anderson, "MODIS-Based Flood Detection, Mapping, and Measurement: The Potential for Operational Hydrological Applications," Transboundary Floods, Proc. NATO Adv. Rsch Wkshp, Springer, 2005, pp. 1–12.

M. Carroll et al., "A New Global Raster Water Mask at 250 Meter Resolution," Int'l J. Digital Earth, vol. 2, no. 4, 2009.

"FTI: Damage tally B50bn". Bangkok Post. http://www.bangkokpost.com/business/economics/204512/fti-damage-tally-b50bn. Retreived 13Nov2010.

Carroll, M.L., DiMiceli, C.M., Townshend, J.R.G., Sohlberg, R.A., Noojipady, P. (ongoing), MODIS Flood Maps, University of Maryland, College Park, Maryland.

Chien, S., B. Cichy, A. G. Davies, D. Tran, G. Rabideau, R. Castano, R. Sherwood, D. Mandl, S. Frye, S. Schulman, J. Jones and S. Grosvenor (2005a) An Autonomous Earth-Observing Sensorweb, IEEE Intelligent Systems, 20, no. 3, 16-24.

CNN. "Death toll in Thailand flooding rises to 206". CNN. http://edition.cnn.com/2010/WORLD/asiapcf/11/13/thailand.flooding.toll/. Retrieved 14 Nov 2010.

EOS - Earth Observatory Image of the day, http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=46693

Ip, F., J. M. Dohm, V. R. Baker, T. Doggett, A. G. Davies, R. Castano, S. Chien, B. Cichy, R. Greeley, and R. Sherwood (2005) Development and Testing of the Autonomous Spacecraft Experiment (ASE) floodwater classifiers: Real-time Smart Reconnaissance of Transient Flooding. Remote Sensing of Environment, Vol. 101, Issue 4, pp. 463-481.

Kabat, P, and H. van Schaik, (co-ordinating lead authors), (2003). Climate changes the water rules: How water managers can cope with today's climate variability and tomorrow's climate change. Synthesis Report of the Intl Dialogue on Water and Climate, ISBN 9032703218, 106pp

MCOT – Ministry of Communication of Thailand, 19 November 2010, http://www.mcot.net/cfcustom/cache_page/131902.html http://en.wikipedia.org/wiki/2010_Thai_floods

National Research Council (NRC), "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond," National Academy of Science Press, 2007.

Pielke, Jr., RA, MW Downton, and JZ Barnard Miller, 2002: Flood Damage in the United States, 1926–2000: A Reanalysis of National Weather Service Estimates. Boulder, CO: UCAR. Downloadable from flooddamagedata.org

Schölkopf, B., & Smola, A. J. (2002). Learning with kernels. Cambridge, MA: MIT Press.

United Nations Office for the Coordination of Humanitarian Affairs (OCHA), 10 July 2008, http://www.reliefweb.int/rw/rwb.nsf/db900SID/MUMA-7GF2TG?OpenDocument