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Review

CREST/EF5 capacity building to enhance resilience to hydrodynamic disasters in emerging regions

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Water and water-related disasters, e.g. flooding, landslide and droughts, are affecting the world and it is important for decision makers and experts to build the capacity of forecasting hydrodynamic disasters and safeguarding people's life and property. This study focuses on building capacity of decision makers and analysts with an aim to create and support a robust framework for decision makers in integrated water resource management. Capacity building training workshops has been conducted using Coupled Routing and Excess Storage (CREST) and Ensemble Framework for Flash Flood Forecasting (EF5) distributed hydrological modeling jointly developed by University of Oklahoma (OU) and National Aeronautics and Space Administration (NASA), involving Regional Center for Mapping of Resources for Development (RCMRD), ICPAC and Kenyan Meteorological department (KMD). The OU_Applied Science Team (AST) in collaboration with RCMRD provided an EF5 hydrologic model website to KMD to visualize and forecast streamflow. Further, an advanced EF5 training was conducted in East Africa and a system to collect citizen reports to gather observations of flooding was developed. This effort will improve awareness of and access to available services through providing user-tailored services to inform development of decision-making processes and build the capacity of SERVIR hubs and their partners to provide high quality services, creating a stronger network at the regional and international level. The study will guide users/forecasters on how to use EF5 operationally and enhances development of an impact-based flood early warning system with users, linking hydrologic forecasts with vulnerability assessment and risk analysis to mitigate the potential negative impact to the public and properties.

Key words: Capacity building, drought, flood, hydrologic model, landslide, streamflow.

INTRODUCTION

Uganda is at high risk from a variety of hazards, which have the potential to adversely affect progress on poverty reduction and economic growth. Landslides and floods are one of the most important disasters today with floods alone reported to account for 6.8 million deaths worldwide, estimates indicate that Asia and Africa are among the most vulnerable regions prone to disasters with Asia alone accounting for about 50% of flood related death (Jonkman and Kelman, 2005).

The World Bank has estimated that at least 200,000 Ugandans are affected by disasters each year. The Government of Uganda has identified drought as the most severe disaster affecting the lives and livelihoods of its citizens (Tsarouchi, 2018). Natural disasters can have significant impacts on the health and development of a region. Disasters such as floods, landslides, earthquakes, tropical cyclones, volcanic eruptions, and tsunamis have the potential to be catastrophic and lead to massive alterations in the lives of those affected; effects include loss of property and life, injury and morbidity, long-term displacement, disruptions in livelihoods, and widespread economic effects (Agrawal et al., 2013).

Flooding is another prominent feature of Kampala, frequent high intensity tropical rain storms almost inevitably generate extremely high run-off that quickly exceeds the capacity of the urban storm water drainage system, causing frequent flooding across the city, but especially in the low lying valleys and wetland areas that are typical of Kampala's environment and flooding impacts all socio-economic groups but those urban poor who are occupying the low lying lands and wetlands are most vulnerable (Sliuzas et al., 2013). Therefore knowledge about infiltration capacity in a catchment is extremely important for flooding analyses and common runoff fractions of rural catchments are between 5 and 10% for vegetated surfaces, while urban areas with sealed surfaces can have runoff percentages as high as 30-50%, depending on the soil hydrological properties (permeability and pore space) (Sliuzas et al., 2013).

The occurrence of landslides and floods in East Africa has increased over the past decades with enormous public health implications and massive alterations in the lives of those affected (Resilient Africa Network, 2015). Uganda is one of the African countries most prone to disasters. In 2010, flooding of the banks of river Manafwa and landslides in Bududa district in the Mt. Elgon region left 5,000 individuals displaced and over 400 killed (Atuyambe et al., 2011), the Mt. Elgon region of Uganda is reported to have the highest rates of landslides and floods in the country with devastating effects on the livelihood of people. In the current advent of climate change and the changing environment, it is anticipated that landslide and flood incidents will be on the increase within exposed communities in Mt Elgon region. Heavy rains in Eastern Uganda precipitated flooding in Butaleja District and landslides Bududa in February and March 2010 (Doocy et al., 2013). The Bududa landslides were among the ten deadliest disasters worldwide in 2010 with 385 deaths and the displacement of over 3,000 people (Center for Epidemiology in Disasters (CRED, 2009); landslides are often triggered by excessive rain in combination with other factors including increased groundwater content, steep slope gradients, land cover, and geologic composition. Landslides are particularly dangerous and often result in high numbers of casualties because of their rapid onset and limited lead-time for evacuation (Dore, 2003; Moe and Pathranarakul, 2006). In the case of the floods in Butaleja, widespread crop and infrastructure damage occurred with more than 33,000 people affected, however, there was little mortality (Butaleja District Government, 2009; UN OCHA, 2010a b). Moreover, floods caused more severe injuries than landslides and resulted in a higher degree of loss of function or disability, Landslides, on the other hand, caused a greater number of fractures and lacerations than floods (Agrawal et al., 2013). In late February of 2010, several consecutive days of heavy rains in the Butaleja and Bududa Districts of Eastern Uganda precipitated flooding and landslides which resulted in the destruction of crops, infrastructure, water and sanitation facilities; widespread displacement; and increased morbidity and mortality (WHO, 2010). However, Government of Uganda (GOU, 2007) indicates that the wetter areas of Uganda, around the Lake Victoria basin and the east and northwest are tending to become wetter, indicating an increase in rainfall in these areas. Temperature and rainfall simulations by Goulden (2008) indicate high percentage increases in rainfall for historically dry seasons for many parts of Uganda.

The Butaleja floods were concentrated in low-lying areas adjacent to the River Manafwa and affected more than 38,780 people (Butaleja District Local Government, 2010) while the Bududa landslides resulted in 388 deaths and was the deadliest disaster in Africa during 2010. (Guha-Sapir, 2010). In the flood-affected District of Butaleja, a sub-county level environmental vulnerability index was created with Geographic Information Systems (GIS) using administrative boundaries from the United Nations, regional rainfall data for the January to May time period, and spatially distributed population data from the Global Rural Urban Mapping Project (GRUMP) (DDGISST, 2010). In the landslide-affected area district of Bududa, a list of most-affected villages was compiled based on the United Nations interagency assessment

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report and discussions with the Bulecheke Camp Chairman, Fourteen villages were affected, with six classified as most affected (Agrawal et al., 2013). As a result, clusters assigned to the six most-affected communities were evenly divided between households in communities and those resettled in the camps, the remaining six clusters were assigned to camp residents from the other eight affected villages and the total affected population of each village as reported by the community leader was used to determine the sampling interval for systematic sampling of households (Agrawal et al., 2013). Local level studies conducted in Uganda have been based on the magnitudes of monthly and seasonal rainfall (Kigobe et al., 2011; Komutunga and Musiitwa, 2001) and the occurrence of dry and wet spells (Bamanya, 2007; Osbahr et al., 2011), with limited focus on the variability of rainfall within the year and seasons.

Boko et al. (2007) predict that Africa is likely to warm across all seasons during this century with annual mean surface air temperatures expected to increase between 3 and 4°C by 2099, roughly 1.5 times average global temperatures. Projections in East Africa suggest that increasing temperatures due to climate change will increase rainfall by 5 - 20% from December to February and decrease rainfall by 5-10% from June to August by 2050 (Hulme et al., 2001; IPCC, 2007). Non-governmental organizations working in Uganda also report that farmers recognize an increasingly erratic rainfall pattern in the first March to May rainy season, causing drought and crop failure, but also more intense rainfall, especially in the second rains at the end of the year, causing flooding and erosion (Oxfam, 2008). In comparison, the average long-term annual rainfall for Uganda is 1318 mm, which is considered adequate to support agricultural activities (Osbahr et al., 2011), this implies that Eastern Uganda receives adequate rainfall to support agriculture. Seasonal distribution of rainfall affects the decisions made by farming households on what type of crops to grow and land management practices to adopt (Komutunga and Musiitwa, 2001). In addition, excessive rains both in intensity and duration lead to water logging conditions that negatively affect crops and pasture (GOU, 2007; Komutunga and Musiitwa, 2001). For example, drought in 2008 caused an average reduction in yield of 50% of sorghum, groundnuts, cassava, and maize in Uganda (Ocowunb, 2009).

Floods, despite their slow onset and potential for early warning, are the most significant disaster worldwide in terms of frequency, affected population size, and deaths, in addition to their human impacts, floods damage livelihoods, property and infrastructure resulting and often result in widespread displacement and economic losses (Duclos et al., 1991). Heavy rainfall experienced between 2006 and 2010 is responsible for massive floods in the low land areas and numerous landslides in the mountainous regions in Eastern Uganda (GOU, 2009). This study explored underlying causes and coping strategies used to avert the effects of landslides and floods in Uganda. Therefore, findings on the strategies that have been used to mitigate, to cope positively, recover and learn from the landslides and floods could inform the design of appropriate innovative solutions that can strengthen the capacity of affected populations to become resilient.

History of CREST/EF5 hydrological modeling

To mitigate water and water-related disasters globally, the University of Oklahoma (OU) and the National Aeronautics and Space Administration (NASA) jointly developed the Coupled Routing and Excess Storage (CREST) hydrological model and the Ensemble Framework for Flash Flood Forecasting (EF5) software to run hydrological modeling using NASA data such as precipitation, evapotranspiration from FEWSNET and Stream flows from USGS websites. The EF5 hydrological modeling software was developed using the CREST (Wang et al., 2011) hydrological modeling as a basic source. The CREST model was initially developed to provide real-time regional and global hydrological prediction by running at fine spatiotemporal resolution with maintaining economical computational cost. CREST simulates the spatiotemporal variation of water, energy fluxes and storages on distributed grid cells of arbitrary user defined resolution, which enables multi-scale application. The scalability of CREST simulations is accomplished through the sub-grid scale representation of soil moisture storage capacity (using a variable infiltration curve), multi-scale runoff generation processes (using multi linear reservoirs) and a fully distributed routing scheme (using the fully distributed linear reservoir routing). The primary water fluxes such as infiltration and routing are physically affected by geographic variables land surface characteristics. Table 1 shows CREST distributed hydrological model parameters. The runoff generation and routing components are coupled; therefore, CREST includes more realistic interactions between lower atmospheric boundary layers, terrestrial surface, and subsurface water than another distributed hydrological model. The CREST/EF5 model is forced by gridded evapotranspiration (PET) precipitation datasets that are measured, estimated, and forecasted. The CREST hydrological model and EF5 hydrological model architecture are shown in Figures 1 and 2. The EF5 hydrological modeling software is being updated by Hydrometeorological and Remote Sensing Laboratory (HyDROS) research scientists including reservoir modeling, landslide, and dam to support water

Table 1. CREST distributed hydrological model parameters.

Type	Parameter	Description	Min	Default	Max	Unit
	RainFact	The multiplier on the precipitation field	0.5	1.0	1.2	
	Ksat	The soil saturated hydraulic conductivity	0	500	3000	
	WM	The Mean Water Capacity	80	120	200	Mm/day
Physical parameter	B	The exponent of the variable infiltration curve	0.05	0.25	1.5	mm
	IM	The impervious area ratio	0	0.05	0.2	
	KE	The factor to convert the PET to local actual	0.1	0.95	1.5	
	CoeM	The overland runoff velocity coefficient	1	90	150	

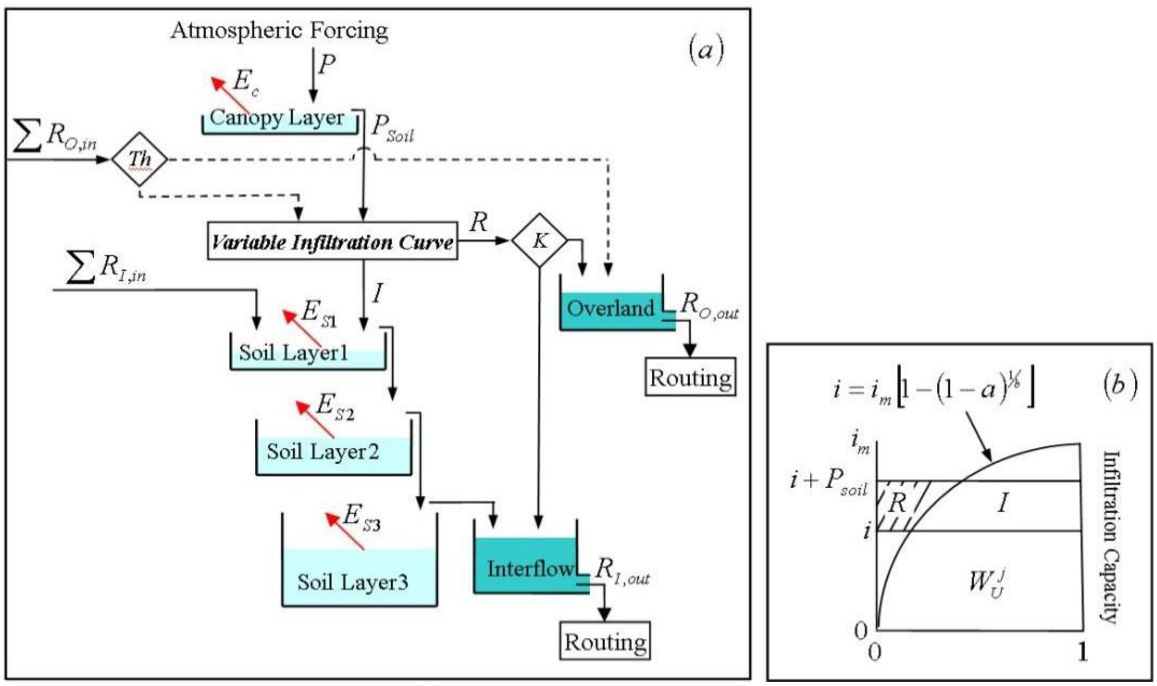

Figure 1. Core Components of the CREST model. The parameters are: Soil saturated hydraulic conductivity (Ksat), Mean water capacity (WM), Impervious area ratio (IM), PET to local actual (KE), Overland runoff velocity coefficient (CoeM).

management works globally (Figure 3).

Regionalized EF5 hydrological modeling in East Africa

A regionalized EF5 Hydrological modeling was developed based on the request from Regional Center for Mapping of Resources for Development (RCMRD) to communicate flood forecasts. Seven Eastern African countries were included in the regionalized hydrological model: Kenya, Uganda, Ethiopia, Rwanda, Tanzania, Burundi, and Malawi (Figure 4). Through several visits and online discussion, the OU Advanced Science Team (AST) has worked with RCMRD, Uganda Ministry of Water and Environment, and Uganda Meteorological Authority to develop a joint plan to expand the current hydrological system coupled with new upgraded modules to Uganda. The Uganda Ministry of Water and Environment has selected the focus areas of intervention in this project; Namatala, Mpologoma and Manafwa river basins (Figure 4) which shows the early results of the CREST/EF5 hydrological modeling conducted on the three basins.

Building upon RCMRD's expertise with the CREST model, EF5 provides several key improvements. First, EF5 can achieve useful results on ungauged basins

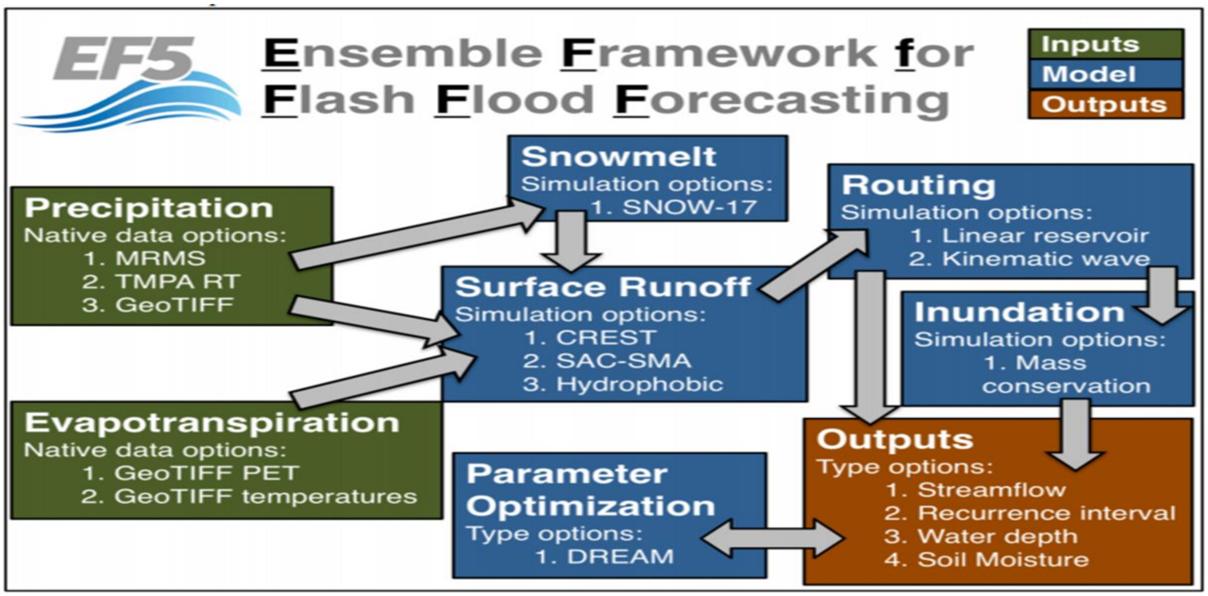

Figure 2. Ensemble Framework for flash flood Forecasting (EF5) Hydrological modeling architecture.

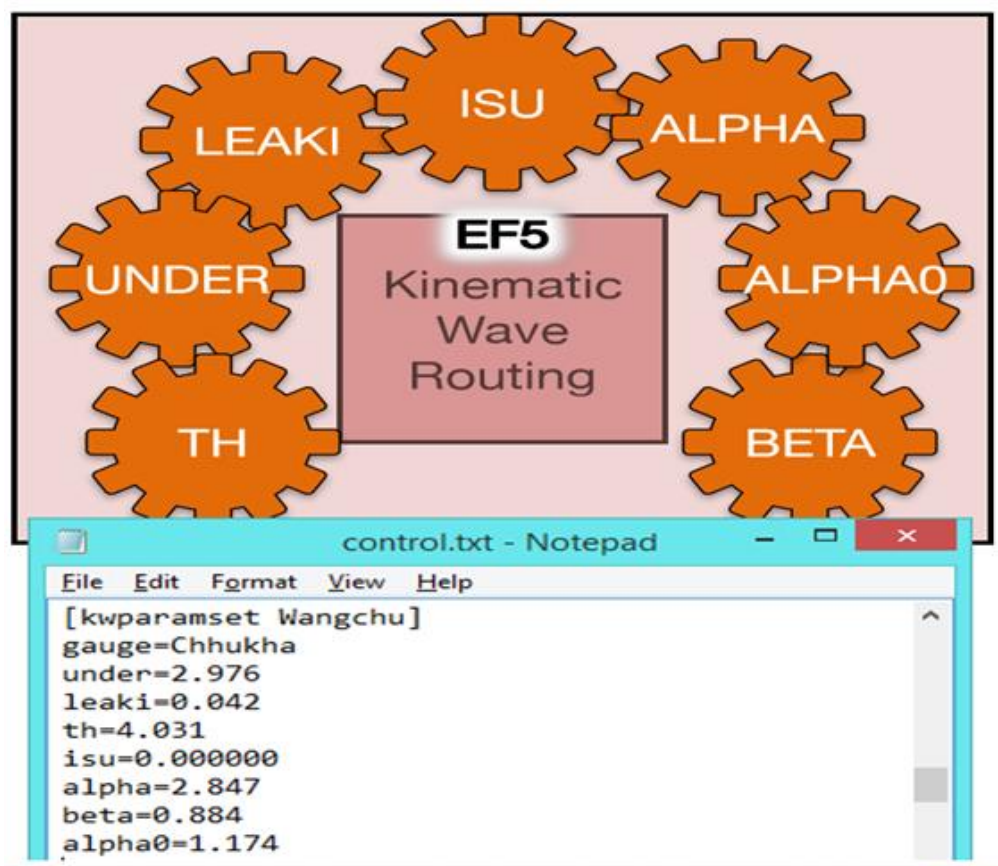

Figure 3. EF5 hydrological model kinematic wave routing parameters.

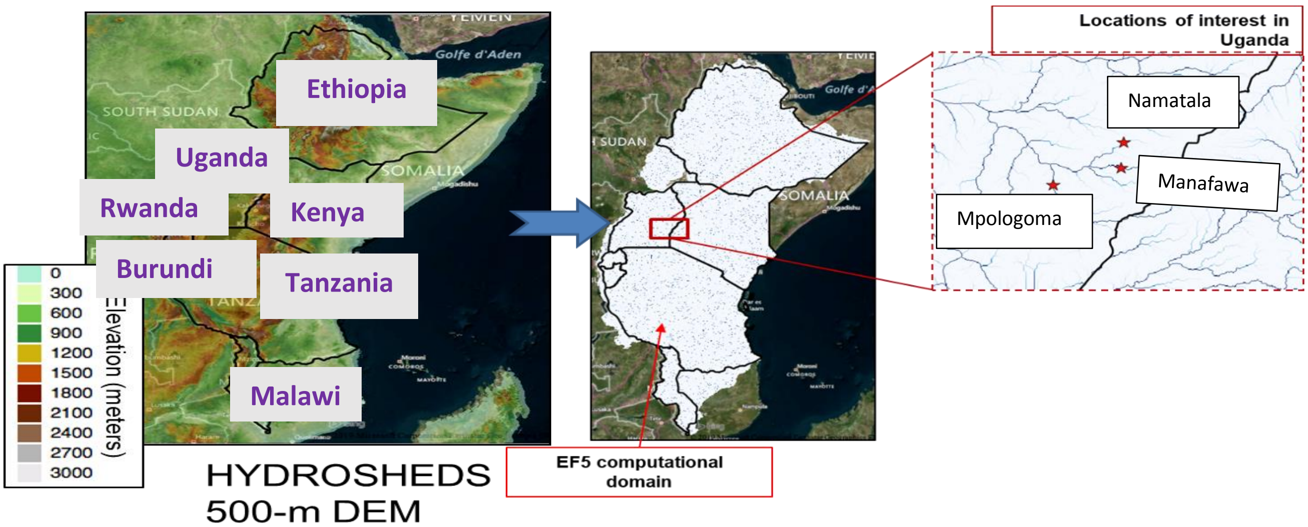

Figure 4. The regionalized hydrological model for Eastern Africa.

where calibration is impossible or gauged basins without calibrations (Gourley et al., 2016). This is achieved by using remotely sensed estimates of soil type, soil texture, and other variables to generate a priori hydrologic model parameters. Second, EF5 enables fast and accurate automatic calibration with the use of the Differential Evolution Adaptive Metropolis (DREAM) parameter optimization scheme. Third, the last major category of improvements in EF5 involve usability and user interface. This includes informative error-handling and long-term technical support and continued improvement and development by virtue of its adoption by a major U.S. government agency. We further cross-evaluate the EF5/CREST simulation with the Global Reach-Level a Priori Discharge Estimates for SWOT (Lin et al., 2019).

Forcing parameters; the earth observation satellites provide the potential to estimate precipitation on a global scale. One such unprecedented effort, the NASA Global Precipitation Measurement (GPM) mission was launched in 2014 by building upon the success of previous Tropical Rainfall Measuring Mission (TRMM) from 1997. To date, the global precipitation measurement (GPM) mission has used the Integrated Multi-satellite Retrievals for GPM (IMERG) algorithm to generate the quasi-global precipitation products at 0.1 by 0.1 arc-degree spatial resolution and 30 min temporal resolution. The GPM IMERG system runs twice in near-real-time to produce early run and late run results, where the early run has the morphing scheme only propagated forward, and the late run has the morphing scheme applied both forward and backward. Precipitation forcing to EF5/CREST in East Africa is provided by the IMERG early run products due to the near-real-time feature. Potential evapotranspiration (PET) forcing is from the USAID's FEWS NET (Famine Early Warning System Network), where PET estimates are generated using the Penman-Monteith equations. In East Africa, EF5/CREST is forced with monthly mean gridded PET estimates at 0.25 latitude by 0.25 longitude.

Cross-evaluation of longer-term simulation; any good hydrologic model relies on stream observations for calibration and validation. We are partnering with the RCMRD to deploy *in-situ* measurements in this region. However, the existing historical stream observations provided by our partners are limited in the following aspects: 1) all stream gauges are concentrated in small portions of Uganda; 2) it is unclear which daily statistics (min, max or mean) the observed values represent; 3) the observations are susceptible for underestimation as they correspond to very small unit-discharge values. Because of these limitations, we determined to pursue other sources of validation instead. Global reach-level a-Priori discharge estimates for SWOT (Lin et al. 2019) provides 35-year daily flow simulation for all rivers globally and are used for cross-evaluation. The GRADES reach has full coverage over the EF5/CREST simulation domain as shown in Figure 5. Because GRADES and EF5/CREST are developed using different DEM datasets, their stream networks do not align with each other completely. To overcome with this technical issue, we conducted two sets of cross-evaluations, that is, reach-scale and basin-scale.

For reach-scale cross-evaluation, the reaches in GRADES are paired with channel pixels in the EF5/CREST model when they share 1) similar reach length, 2) similar spatial location, 3) similar contributing drainage area. This ends up generating 124 pairs, and 10

Figure 5. GRADES Reaches overplayed on EF5/CREST Domain.

years (2001 to 2011) of their corresponding daily-mean flow values are compared. Results show that the EF5/CREST simulation based on IMERG-early satellite rainfall shows good correlation with the GRADES simulation, but higher runoff volume (Figure 6).

CREST/EF5 CAPACITY BUILDING EVENTS

In March 2018, the OU Advanced Science Team (AST) group travelled to Nairobi, Kenya and Kampala, Uganda to present the EF5 advanced training workshop and foundation EF5 training. The advanced training workshop is the follow up to the EF5 fundamental workshop. The fundamental EF5 training workshop focuses on creating a fundamental knowledge of hydrology, creating, and gathering the data needed for EF5, running and calibrating EF5, and teaching the methods to interpret the model output. The Advanced EF5 workshop training focuses on using the tools learning from the fundamental training and applying them to access advanced features in EF5. The participants were taught how to use all the ensemble outputs available. In the fundamental EF5 workshop, only the CREST water balance model was used; however, there are two other water balance models that are included in the EF5 framework. Other topics included is using distributed parameters, precipitation forcing using numerical weather predication, inundation modeling, multiple gauges, and learning Jupyter notebook to create computer generated hydrographs from the EF5 output.

The two-day advanced training on March 12-13, 2018 at RCMRD went successfully; according to the evaluations, the participants were pleased with the modules and materials of the workshop. The participants were from various occupations, including private companies, academic institutions, and government positions. Many of the participants attended the foundation EF5 training at RCMRD in March 2017 (Figure 7).

The EF5 training workshop focused on creating a fundamental knowledge of hydrology, creating, and gathering the data needed for EF5, running and calibrating EF5, and teaching the methods to interpret the model output. Specifically, the two-day EF5 workshop focused on the background and motivation of EF5, introduction to hydrologic models, EF5 overview, rainfall and PET, manual calibration, automatic calibration, interpreting and using model output, DEM practice, calibration practice, and using EF5 to monitor drought.

EF5 training focuses on a hands-on technique to teach participants how to use the EF5 modeling software. The workshop contains about eight modules that cover two full working days. The successful implementation of these

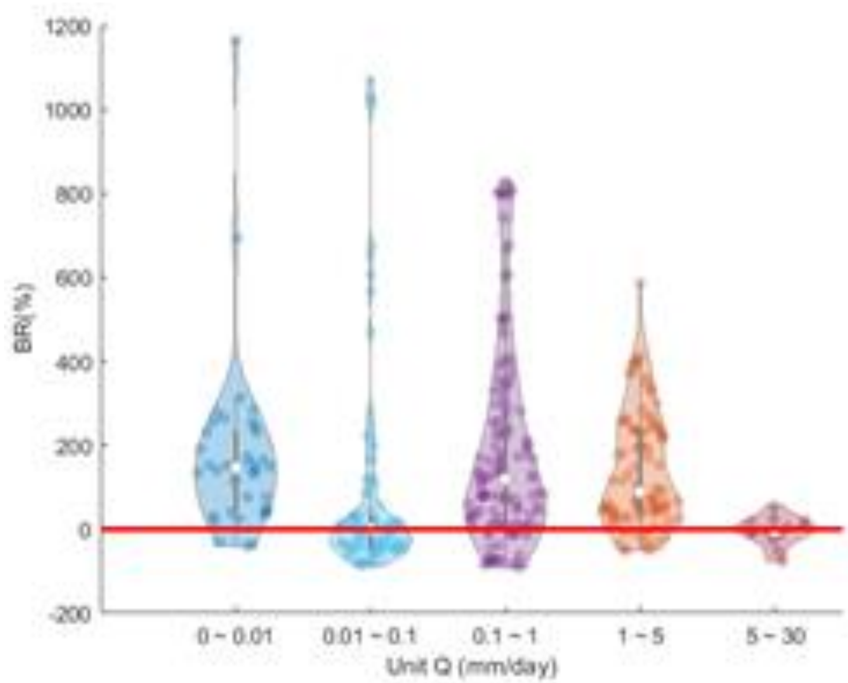

Figure 6. Relative difference of EF5/CREST and GRADES conditioned on unit flow.

Figure 7. EF5 workshop in Kampala, Uganda in March 2018.

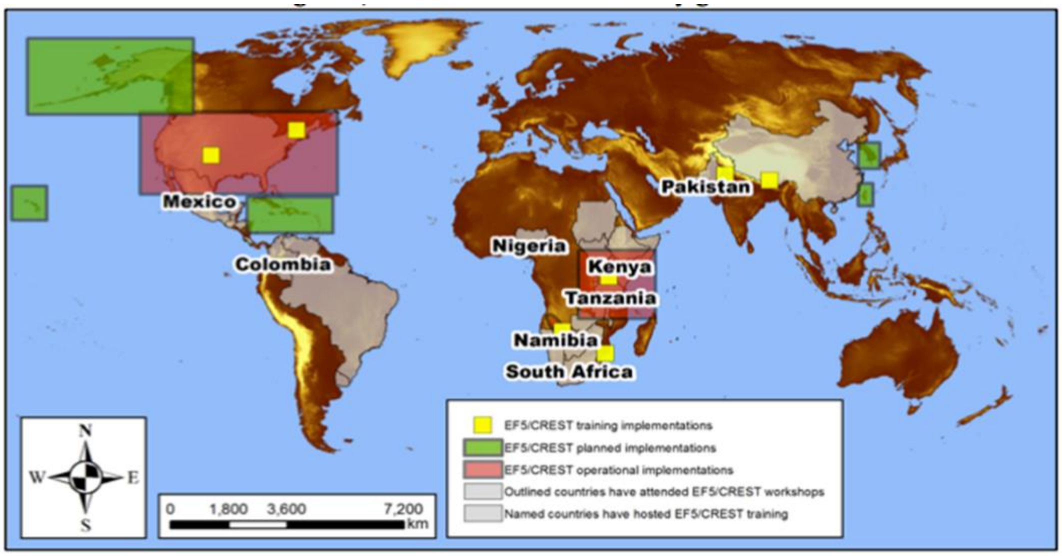

Figure 8. CREST/EF5 capacity building activities conducted across the world.

modules has been conducted over a dozen times throughout the United States, Mexico, Pakistan, Namibia, and Kenya since 2014. The advantage of this training workshop is the utilization of open source software. EF5 and QGIS, the software demonstrated in the training, are free to download and available to anyone with a computer around the world (Figure 8).

The beginning of the training focuses on the basics of hydrology to accommodate every participant; this is designed to ensure that students coming from any background can be on track. These basics include fundamental concepts of the water cycle and its inclusion in hydrologic modeling. The modules contain various training methodologies for making adult learning sessions successful, including knowledge-based and skills-based learning sessions, through means of lecturing. The combination of these two learning techniques reinforces the information needed to know about the model and demonstrations that encourage independent use.

The knowledge-based lessons make up about half of the workshop. In this method of training, the coordinator presents the facts and information needed to understand the underlying processes that the modeling software uses. This gives the workshop participants a greater understanding of the processes that are involved in the EF5 hydrologic modeling software. The other half of the training workshop utilizes skills-based learning. Workshop attendees had the opportunity to download the software and run the model on their personal laptops or computers. This supports independent practice and future use for the participants. The participants also learn how to calculate and interpret the results from the model run.

Outline of CREST/EF5 capacity building

The Ensemble Framework for Flash Flood Forecasting (EF5), is hydrological modeling software that allows users to monitor and forecast hydrological phenomena such as floods and droughts. The proposed workshop involves introductions to hydrological concepts, GIS techniques, remote sensing, and the use of hydrological model outputs. The workshop is anticipated that users will be familiar with basic hydrological and modeling concepts. Table 2 shows the EF5 workshop outline. The workshop participants will be able to install and use the EF5 model for flooding and drought forecasting on river basins of interest. The workshop participants will provide feedback on the workshop, the modeling software, desired features, and future needs that could be addressed with our system.

Advanced CREST/EF5 capacity Building

The advanced EF5 was developed to improve the fundamental EF5 hydrological modeling by including additional parameters. For example, a multiple gauge analysis was included in the advanced EF5 starting with observation locations at the upstream and calibrate it first and then calibrate the next observation location downstream. A cascaded calibration of the gauge locations is being used preparing control files under Crest param set and KW param set. In advanced EF5, output Girds to help visualize stream flow, soil moisture, return period, precipitation, and PET. The advanced EF5 also

Table 2. EF5 workshop outline.

Session 1: Welcome
Training goals; system requirements; CREST/EF5 basics; training course contents and organization; OU, HyDROS, and NASA SERVIR and Installing QGIS and TauDEM.
Session 2: Ensemble Output
Ensemble outputs with EF5; CREST model; Sacramento Soil Moisture Accounting Model; Hydrophobic model; discussion of the resolution for topographical inputs.
Review creating Digital modeling (DEM), Flow direction (FDR), Flow accumulation (FAC); review DREAM calibration; Preparation of topographical datasets for three River examples (Manafwa, Mpologoma and Namatala).
Discussion of potential pitfalls and problems.
Create hydrographs with Ensemble output for three River basin examples.
Session 3: Destributed Parameters
Review of hydrological models: distributed and lumped parameters; topographical resolution for distributed parameters; global distributed parameters; distributed parameters in EF5
Example of using distributed parameters in EF5
Review and setting up TH EF5 parameter
Session 4: Precipitation Forcing
Numerical weather prediction introduction (NWP); Global Forecast System; Weather Research and forecast Model; EF5 control file set up; EF5 (NWP) options.
Example on preparing and Executing EF5 with NWP. Download and visualize (IMERG and TRMM rainfall) and PET data for three River basins.
Session 5: Inundation Modeling
Background of inundation modeling: description of rating curves; inundation in EF5; EF5 control file set up; interpreting and using model output and Run flood inundation on three river basins
Session 7: Introduction To Jupyter Notebook
Using Jupyter notebook to create hydrograph from the simulation output
Session 6: Multiple Guages
How to use multiple gauges in a basin; set up for cascading calibration on basin in Pakistan
Use EF5 for multiple gauges and evaluate cascading calibration

included the flood inundation modeling which is an important aspect to be cautious of when floods of any kind occur. During flood inundation, if the height of water is greater than the height of the DEM, the water will overflow into the neighboring cells. Additionally, calibration is conducted on coarser resolution grid and then run on the high -resolution Shuttle Radar Topography Mission (SRTM-2) grid to save time. The advanced EF5 modeling is a multi-model ensemble expandable with new model and physics improving model results through calibration such as automatic calibration, evaluation of model skill, and defining parameters. The interpretation, analysis and use of the model result helps in flood forecasting through high-resolution immediate modeling and confidence on uncertainty.

Further, a Juypter notebook is used in the advanced EF5 for plotting the hydrograph. Therefore, the advanced EF5 developed by the OU-HyDROS has been used to provide a capacity building training in Uganda in November 2019 (Figure 9).

Capacity building/training workshops for the RCMRD hub and SERVIR network

To-date, OU Advanced Science Team (AST) has provided capacity building training to over 250 hydrologists, geographers, meteorologists, computer scientists, GIS specialists, data scientists, and many others from around 30 countries in the use of CREST/EF5 software. The OU

Figure 9. EF5 advance training.

AST team, working together with NASA and RCMRD, will continue providing both fundamental and advanced CREST/EF5 training workshops: 1)

The fundamental training workshop focuses on creating a fundamental knowledge of hydrology, creating and gathering the data, running and calibrating the models. The workshop participants will have the opportunity to download the software and run the model on their personal computers to support independent practice and future use of the software; 2) The advanced training workshop is the follow up to the fundamental ones. The Advanced EF5 workshop training focuses on using the tools learning from the fundamental training and applying them to access advanced features in the suite of CREST/EF5 system with coupled modules of landslide and inundation mapping etc.

Further, we remain committed to training partners in other countries over the long-term. The joint OU-NASA-RCMRD team will extend the capacity building training workshops to the SERVIR East and South Africa countries (Kenya, Ethiopia, Tanzania, Rwanda Tanzania, Malawi and other RCMRD member nations). We have trained the trainers, three technical staff in RCMRD so they can lead the fundamental EF5/CREST training while the OU/NASA team will focus more on advanced training. The training participants will be encouraged to complete the online training using the recently developed CREST/EF5 video (http://ef5.ou.edu/videos/) prior to the workshop to enable optimize the use of the training time and spare time to answer questions, conduct advanced tasks such as parameter optimization and model operationalization.

CALIBRATION OF EF5 MODELING IN THREE BASINS IN UGANDA (MANAFAWA, MPOLOGOMA, NAMATALA)

Hydroclimatic disaster is an emerging major threat in Uganda (CRED, 2009). Meanwhile, a rapid population growth rate is anticipated to sharply increase demands for water and create challenges for the country in achieving its development goals. Uganda has been regularly affected by water and water-related hazards. For example, flooding caused largest risks particularly in the low-lying areas and repeats almost every year. The droughts occurred in Uganda affected close to 2.4 million people between 2004 and 2013, and drought conditions in 2010 and 2011 caused an estimated $1.2 billion property loss and damage. More frequently, cascading events such as heavy rains of 2010 in the Eastern part of Uganda caused flooding which affected 33000 people including crop and infrastructure damage (OCHA, 2010) and landslides which caused 385 deaths and displacement of over 3000 people.

Through several visits and online discussion, the OU AST has worked with RCMRD, Uganda Ministry of Water and Environment, and Uganda Meteorological Authority to develop a joint plan to expand the current hydrological system coupled with new upgraded modules to Uganda. The Uganda Ministry of Water and Environment has selected the focus areas of intervention in this project; Namatala, Mpologoma and Manafwa basins (Figure 9). Figure 10 shows the early results of the CREST/EF5 hydrological modeling conducted on the three basins.

The daily gauge data, IMERG daily and TRMM 3B42RT

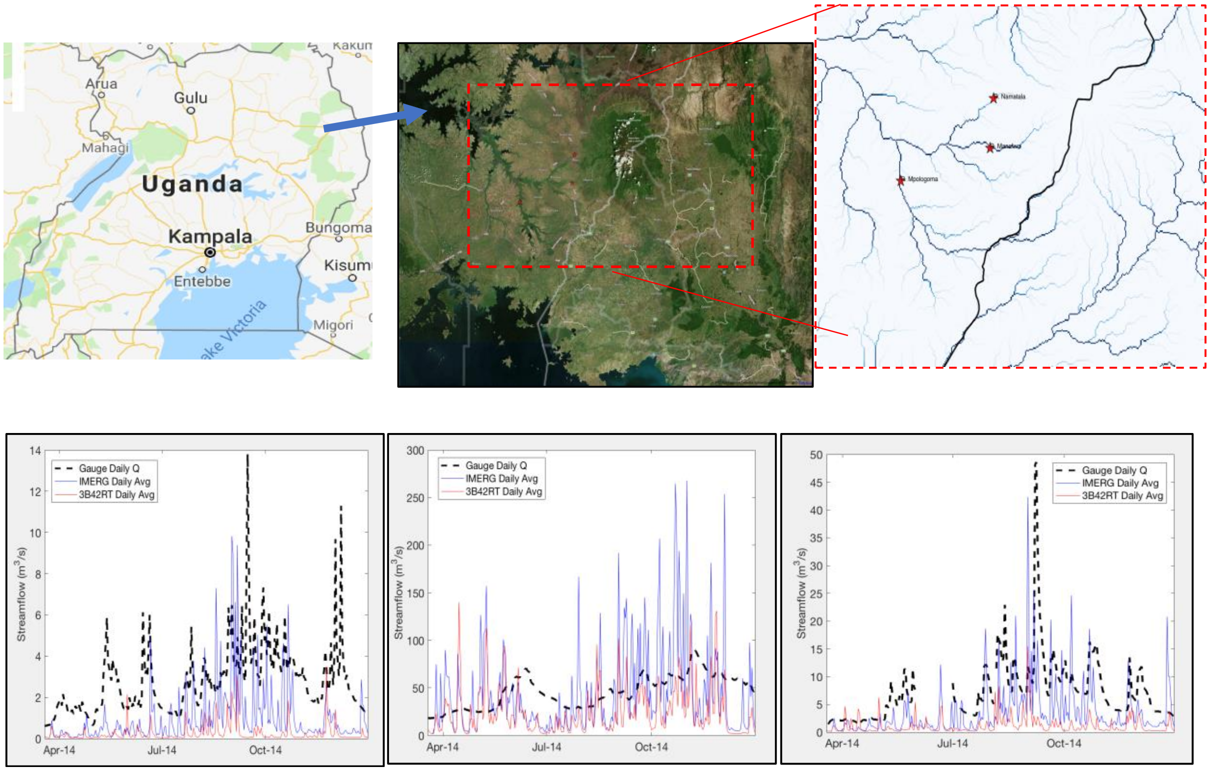

Figure 10. The EF5 hydrological modeling early results using the NASA GPM IMERG vs TRMM 3B42RT precipitation data on the three basins in Uganda.

daily precipitation data have been used to run the EF5 hydrological modeling on the three basins selected in this work. Additionally, potential evapotranspiration (PET) is a forcing parameter from the USAID's Famine Early Warning System Network (FEWS NET) where the PET is estimated using Pen-man-Monteith equations.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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