Validation of CCHE2D Model Using Digital Image Processing Techniques and Satellite Imagery

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ABSTRACT

This research validates the CCHE2D hydrodynamic model flood simulation results using a series of satellite imagery and several digital image processing techniques. Previously CCHE2D model simulation results have been validated using measured experiment and field channel flow data. In this study, remotely sensed data has been experimented to provide continuous truth data to evaluate the CCHE2D model simulation results for flood propagation due to levee breaching. Digital image processing based models were developed using satellite imagery acquired during the June 2008 US Midwest flood event and a time series of flood extent maps was generated for Alexandria, MO and Warsaw, IL areas along the Mississippi River. The flood maps were compared with the CCHE2D model simulation results and found in good agreement. This research shows that satellite imagery has the potential to provide continuous validation data for hydrodynamic models to develop and implement flood related emergency response plan.

Key Words: CCHE2D model, Simulation validation, Satellite imagery, Midwest flood.

INTRODUCTION

The CCHE2D model was developed by the National Center for Computational Hydroscience and Engineering (NCCHE), at The University of Mississippi to simulate two dimensional depth-averaged unsteady flow, sediment transport, flood inundation/propagation, levee breaching and pollutant transport (Jia and Wang, 1999, and Jia, et al., 2002). Usually computational models' hydrodynamic simulation results are validated using measured channel flow data from experiments or in the field. In case of a flood event, the flood propagation is very fast over the flood zone and it is not possible to measure the flow with conventional techniques. In this study, remote sensing data has been experimented to provide continuous truth data to evaluate the CCHE2D model simulation results for different scenarios of floods due to levee breaching.

In June, 2008, the Mississippi River in the Midwest USA experienced a 500 year flood. More than 22 breached levees flooded many areas along the Mississippi River in several days in 51 counties of 5 states (Illinois, Missouri, Wisconsin, Iowa, and Minnesota) with at least 24 fatalities. Thousands of people were affected and lost their homes, many industries and farmers lost their products and ability to recover from this disaster.

Remote sensing has been widely used as a proven tool to map and monitor flood and flood dynamics for many years. During a flood event near-real-time satellite imagery serves as a very useful management tool for authorities coping with the disaster (Hossain et al., 2007). Digital image processing based models were developed using satellite imagery acquired by different sensors and platforms during the June, 2008 US Midwest flood event and a time series of flood extent maps was generated for Alexandria, MO and Warsaw, IL areas along the Mississippi River. The satellite observed flood maps were compared with the CCHE2D model simulation results. Fig. 1 shows the location and extent of the current study site.

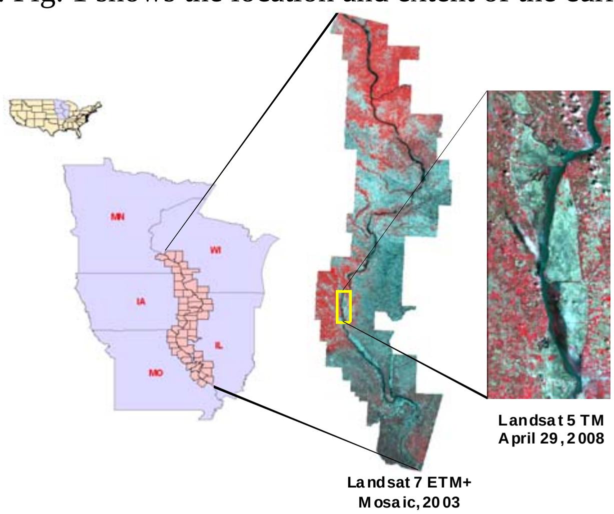


Figure 1. Location and extent of the current study site

DESCRIPTION OF SATELLITE IMAGERY USED

The Moderate Resolution Imaging Spectroradiometer (MODIS) reflective imagery (2 band data) at 250m resolution acquired on June 17 and 19, 2008 were obtained from USGS. Landsat 5 Thematic Mapper (TM) multispectral imagery (4 band data) at 30 m resolution acquired on April 29 and June 16, 2008 were obtained from NASA. Landsat 7 Enhanced Thematic Mapper Plus (ETM+) multispectral imagery (4 band data) at 30 m resolution acquired on June 17, 2008 was also obtained from NASA. Advance Land Observing Satellite (ALOS) Advance Visible and Near Infrared Radiometer type 2 (AVNIR 2) imagery (4 band data) at 10 m resolution and Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) at 2.5 m resolution were obtained from Alaska Satellite Facility (ASF). Fig. 2 shows the false color composite (4,3,2 band combination) of the processed imagery used for flood extent map generation.

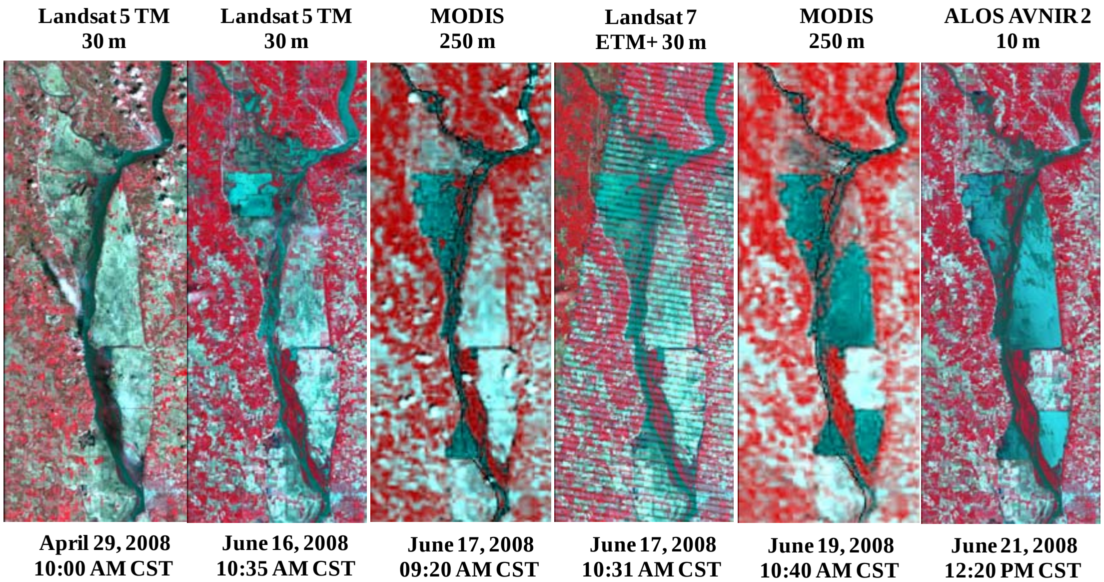


Figure 2. Satellite imagery used for the current study

METHODS AND RESULTS

The CCHE2D flood model simulated the flood in the Mississippi River in Alexandria, MO and Warsaw, IL areas during the June, 2008 flood event. The simulation was done for six days starting on June 14, 2008. The satellite data that were acquired within this time period were collected and processed to produce flood extent maps covering the same area of the computational domain. The simulation results were compared with the satellite imagery derived flood maps to validate the CCHE2D Flood model.

Generation of satellite imagery derived flood maps

Acquired satellite imagery were processed and classified into water and non-water classes to separate the areas occupied by different water bodies in the study site. ISODATA clustering algorithm (Jensen, 2007; Lillesand and Kiefer, 2000) and density slicing technique (Campbel, 2002; Hossain and Easson, 2007) were used to generate the classified land-water imagery. The areas covered by water bodies in the dry season were subtracted from the areas covered by water bodies in the wet season to derive the flooded areas in the given time. In this study Landsat 5 TM imagery acquired on April 29, 2008 was used to extract the location and extent of the dry season water bodies.

ISODATA Clustering Algorithm

Probably the most common unsupervised classification scheme in remote sensing is the Iterative Self-Organizing Data Analysis Technique (ISODATA). ISODATA is an iterative unsupervised classification scheme. The objective of this algorithm is to minimize the within cluster variability. The objective function (which is to be minimized) is the sums of squares distances between each pixel and its assigned cluster center. Minimizing the $SS_{distances}$ is equivalent to minimizing the Mean Squared Error (MSE). The MSE is a measure of the within cluster variability.

$$SS_{distances} = \sum_{\forall x}[x - C(x)]^2 \qquad 1$$

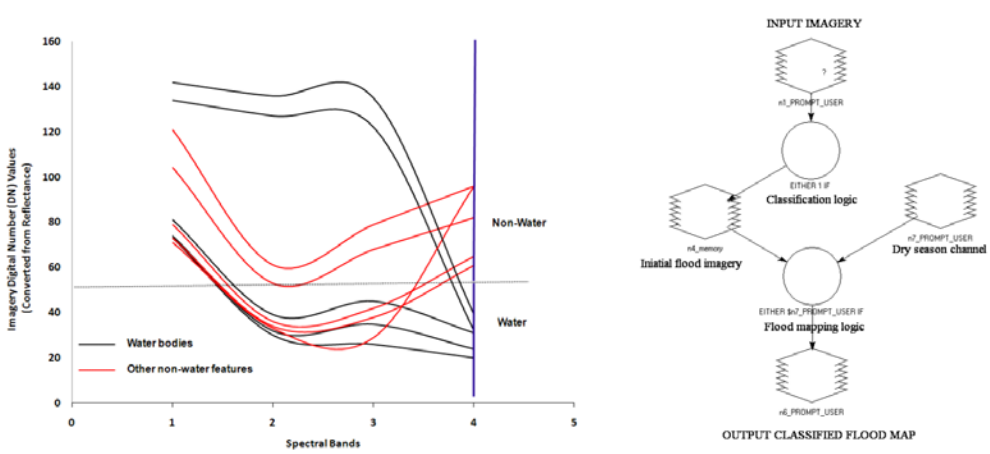
$$MSE = \frac{\sum_{\forall x}[x - C(x)]^2}{(N-c)b} = \frac{SS_{distances}}{(N-c)b} \qquad 2$$

where $C(x)$ is the mean of the cluster that pixel x is assigned to, N is the number of pixels, c indicates the number of clusters, and b is the number of spectral bands.

<u>Density Slicing</u>

Density slicing is a digital data interpretation method used in analysis of remotely sensed imagery to enhance the information gathered from an individual brightness band. Density slicing is done by dividing the range of brightness in a single band into intervals, then assigning each interval to a color (Campbell, 2002). In the near infra-red (NIR) spectral channel water usually absorbs most of the incident energy of sunlight (Hossain and Easson, 2007). This concept was applied in this study (Fig. 3a) and we subset the band 4 (NIR) of Landsat 5/7 and AVNIR 2 imagery and band 2 (NIR) of MODIS imagery to generate the land-water classified imagery.

The NIR band was sliced into 256 levels of brightness and a threshold value was obtained to separate water from all non-water features in the study site. The threshold value was determined by using the thematic clusters derived from unsupervised classification scheme using the ISODATA clustering algorithm. The obtained threshold values are 40 and 51 for Landsat 5 TM imagery acquired on April 29 and June 16, 2008; 45 and 32 for MODIS imagery acquired on June 17 and 19, 2008; and 45 for ALOS AVNIR2 imagery acquired on June 21, 2008 respectively. Using these threshold values a spatial model (Fig 3b) was developed in ERDAS Imagine 9.2 image processing software to generate the flood maps, and flood extent maps were produced for each image acquisition dates during flood event. Fig. 4 shows the generated flood extent imagery displayed on the Landsat 7 ETM+ imagery acquired in June, 2003.



(a) (b)

Figure 3. (a) Spectral profiles of NIR band in different imagery in the study site; (b) Spatial model for flood map generation developed in ERDAS Imagine 9.2

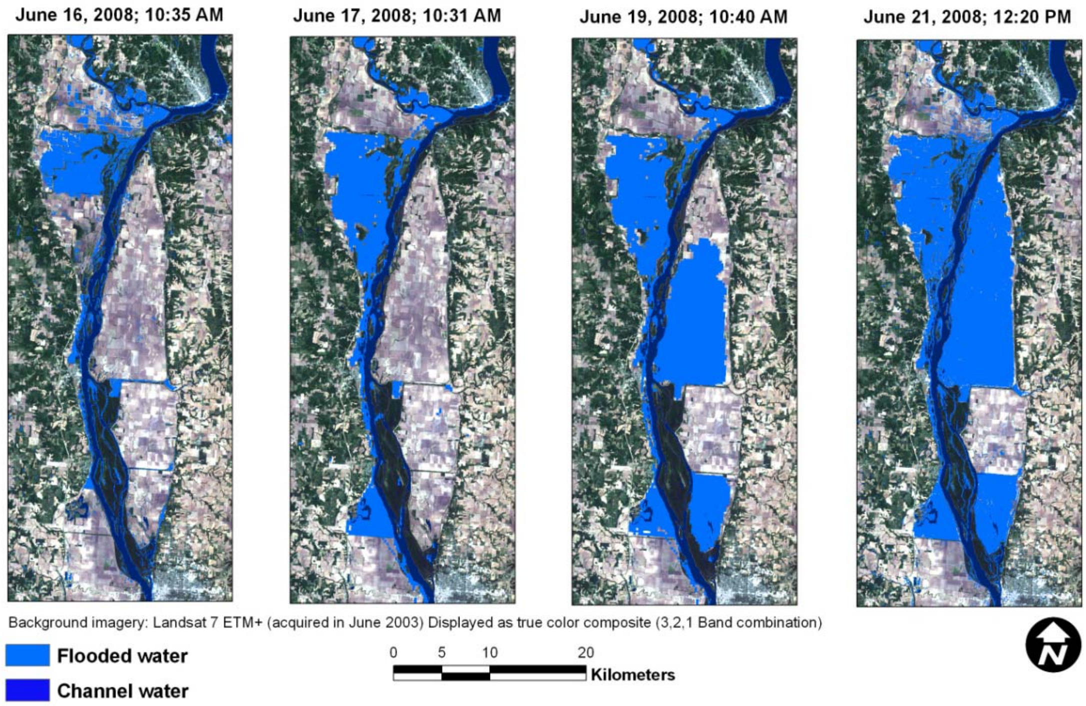
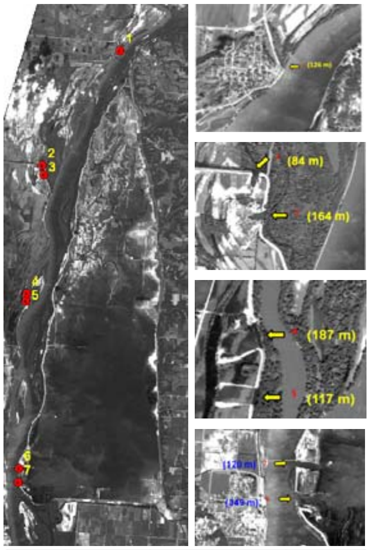


Figure 4. Imagery derived flood extent maps in the study site

Validation of CCHE2D simulation results

CCHE2D was applied to study the flood propagations of the Midwest flood 2008. The CCHE2D finite element model for free surface flows was modified to compute the flood propagation. Unlike most of the flood models that solve only the shallow water equations, terms for taking into account of turbulence effects are also included in the modified CCHE2D flood model, because the simulations have to deal with the subcritical channel flow in the main channel of the Mississippi River and the super critical levee breaching flows. The CCHE2D flood model is a special version of the general CCHE2D model using an explicit time marching scheme. The explicit computation is necessary to handle the levee breaching flow efficiently near breaching locations and around breaching time. However, after the breached levees are completely open, and the flows in its vicinity become less rapid, a more efficient implicit method should be applied to speed up the overall computation. In this study, the levee breaching and flood propagation were computed using a hybrid explicit/implicit solution method which greatly speeded up the computation and reduced the total computation time.

(a)



Breach #	Breach Width (m)	Breach Order	Breach Date	Breach Time (CST)
1	126	1	06/16/2008	10:35
2	84	2	06/17/2008	09:20
3	164	2	06/17/2008	09:20
4	187	3	06/17/2008	10:31
5	117	3	06/17/2008	10:31
6	120	4	06/19/2008	10:40
7	349	4	06/19/2008	10:40

(b) (c)

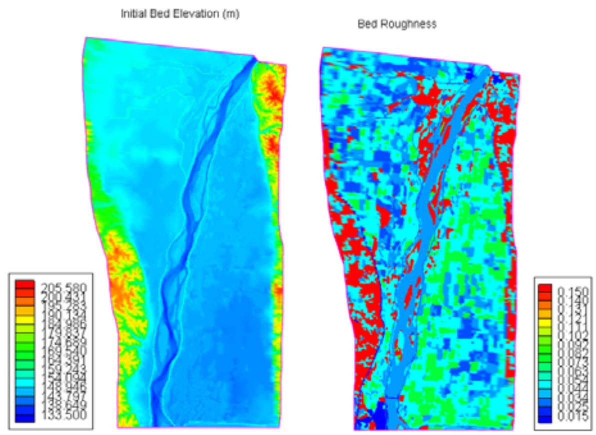


Figure 5 (a) Location, dimension and timing of levee breaching in the study site, (b) Initial boundary condition of the CCHE2D model, and (c) Distributed Manning's roughness coefficient values (Manning's n) determined using land use land cover information derive from satellite imagery

There were seven levee breaching observed in the studied flood zone. Five of them were along the right levee and two of them occurred on the left levee just downstream of the lock and dam 20 of the Mississippi River. ALOS PRISM imagery acquired at 2.5 m resolution was used to identify the locations and dimensions of these breaching (Fig. 5a), which were used for the flood simulation as input parameters. Lacking knowledge about how these levees were breached: overtopping, collapsing or due to piping, it was assumed all the beaching involved were due to overtopping which induced a vertical incision with a constant erosion rate. To make the computations more efficient, widths of the breaching observed with satellite imagery (Fig. 5a) were used for flood simulation. The computations were conducted using a 198x550 quadrilateral mesh. The topography of the simulation domain is shown in Fig 5b. The Manning's roughness coefficients in the main channel of the Mississippi River and over the flood plains were estimated using the land use and land cover information obtained from remote sensing data (Fig.5c). The levees along the river were represented with two lines of mesh. The observed unsteady flow discharge and water surface elevation were applied for boundary conditions.

The CCHE2D Flood simulation results were validated using the remote sensing derived flood extent imagery in both qualitative and quantitative ways. In qualitative validation the simulation results for the available image acquisition dates and time were extracted and displayed on the non-flooded imagery in conjunction with the satellite observed flood extent imagery at a constant scale and visually compared (Fig. 6). In quantitative validation 33 frames of the simulated flood scenarios were converted to vector data and the areas were calculated for flood inundation in each frame using the tools in ArcGIS 9.3. The calculated areas were plotted against simulation time steps. Areas of the satellite observed flood extent were also calculated and plotted in the same chart and compared. Fig. 7 shows the chart comparing the flooded areas computed by CCHE2D flood model and satellite observation.

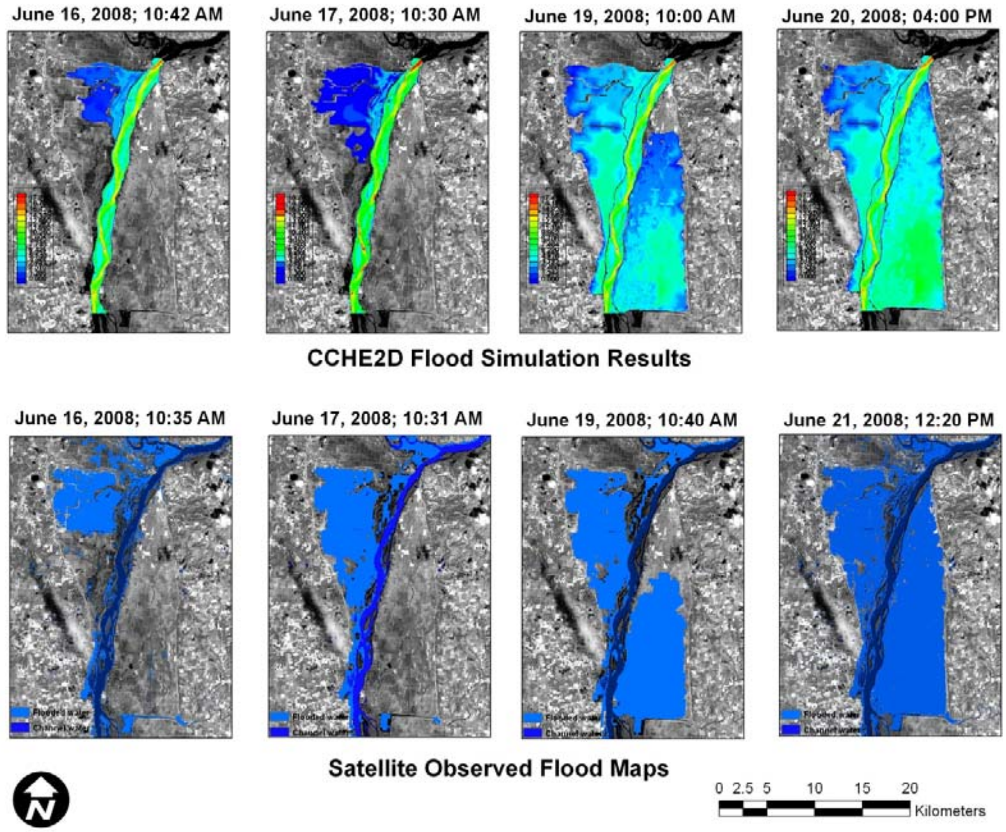


Figure 6. Qualitative validation of CCHE2D flood simulation

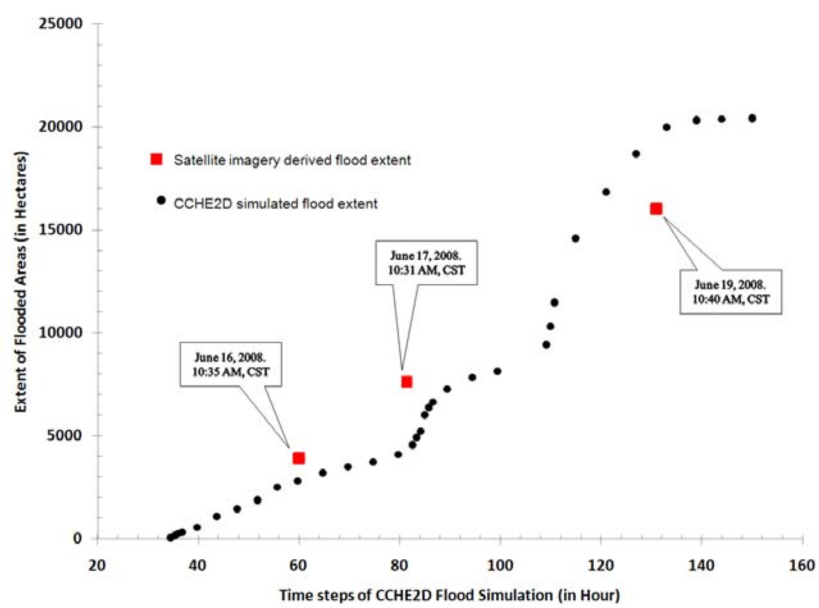


Figure 7. Quantitative validation of CCHE2D flood simulation

SUMMARY AND CONCLUSIONS

CCHE2D Flood hydrodynamic model developed at the National Center for Computational Hydroscience and Engineering (NCCHE), The University of Mississippi was applied to simulate the 2008 Midwest flooding event in the Mississippi River in Alexandria, MO and Warsaw, IL areas for 6 days starting on June 14, 2008. Landsat 5/7, MODIS reflective and ALOS AVNIR2 imagery were used to generate a time series of flood extent maps for the CCHE2D flood simulation model domain for the same flood event. Some parameters observed in satellite imagery such as Manning's coefficient, and levee breaching locations were used for computational simulation. The CCHE2D flood simulation results were compared with the satellite observed flood extent imagery for four time steps including June 16, 10:35 AM; June 17, 10:31 AM; June 19, 10:40 AM; and June 21, 12:20 PM. Both visual comparison and quantitative comparison show good general agreement between the computed (simulated) results and satellite observed data. This research indicates that space borne remotely sensed data has potential for providing continuous truth data for the validation of hydrodynamic model for flood dynamics simulation.

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