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Recommended Citation
Seo, Dong-Jun; Rafieei Nasab, Arezoo; Nazari, Behzad; Norouzi, Amir; Mathew, Thomas; Chen, Haonan; Chandrasekar, V.; and Jangyodsuk, Piraporn, "High-Resolution Flash Flood Forecasting For Large Urban Areas – Sensitivity To Scale Of Precipitation Input And Model Resolution" (2014). CUNY Academic Works.
http://academicworks.cuny.edu/cc_conf_hic/431

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HIGH-RESOLUTION FLASH FLOOD FORECASTING FOR LARGE URBAN AREAS – SENSITIVITY TO SCALE OF PRECIPITATION INPUT AND MODEL RESOLUTION

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Introduction

Urban flash flooding is a serious problem in large, highly populated areas such as the Dallas-Fort Worth Metroplex (DFW). Being able to monitor and predict flash flooding at a high spatiotemporal resolution is critical to mitigating its threat and cost-effective emergency management. In general, the higher the resolution of the model and the precipitation input is, the better the spatiotemporal specificity of the model output is. Due to the errors in the precipitation input, model parameters and model itself, however, there are practical limits to the resolution of modeling. In this work, we assess the dependence of accuracy in streamflow simulation on modeling resolution using the National Weather Service (NWS) Hydrology Laboratory’s Distributed Hydrologic Model (HL-RDHM) for a large part of DFW. The spatiotemporal resolutions considered range from ~250 m to ~4 km and from 1 min to 1 hr. The high-resolution precipitation input comes from the DFW Demonstration Network of CASA radars. The model simulation results are evaluated using the water level observations from the Cities of Fort Worth, Arlington and Grand Prairie in DFW.

Introduction

To take full advantage of high-resolution radar precipitation information, it is necessary to operate hydrologic models at a scale commensurate to the scale of the quantitative precipitation information (QPI). The NEXRAD experience has taught us that, in doing so, complexity must be balanced with practicality (Smith et al. [1], Reed et al. [2]). For urban flash flood forecasting, variability in runoff and streamflow can conceptually be captured by employing hydrologic and hydraulic models and precipitation input of sufficiently high resolution. In reality, however, all models and precipitation input have errors of varying nature and magnitude. Because the errors are nonlinearly transformed by the models in a scale-dependent way, the accuracy of simulated runoff and flow are generally not proportional to the resolution of modeling (Koren et al. [3], Berne and Krajewski [4]).
To illustrate, Fig 1 shows the relative error in runoff simulation as a function of the scale of sub-catchment delineation and the magnitude of error in the precipitation input under the assumption of a perfect hydrologic model (Koren et al. [3]). If the precipitation input is perfect, sub-catchment delineation at a finer scale would yield more accurate simulation of areal runoff and hence streamflow. If there are large errors in the precipitation input, however, the accuracy in simulated areal runoff may deteriorate due to the scale-dependent growth of nonlinear errors. For skillful flash flood forecasting, it is therefore necessary to identify the scale at which the relative error may be at minimum given the quality of radar QPE.

In this work, we design and perform two types of simulation experiments, synthetic and real-world to address the above question. For the synthetic experiment, we carry out experiments similar to Koren et al. [3] (see Fig 1) in which the distributed model is run at different resolutions and synthetic errors of varying magnitude are added to the precipitation input. In addition, we carry out resolution degradation experiments in which higher-resolution precipitation and/or selected model parameters are averaged over lower-resolution scales. This helps assess the marginal information content in higher-resolution precipitation input and/or model parameters.

**STUDY AREA**

The study area is a rectangular domain that encompasses the Cities of Fort Worth, Arlington and Grand Prairie in DFW in Texas. Currently, a network of CASA X-band radars, referred to as the DFW Demonstration Network, is being deployed in the area. The radar at UTA (XUTA) was installed in Oct 2012. The results presented here are from 5 catchments in the City of Grand Prairie. The catchment areas for the selected water level gauges are within the Cities of Arlington and Grand Prairie.

![Figure 1. Relative error in streamflow simulation at the catchment outlet as a function of the scale of sub-basin delineation and the magnitude of error in precipitation input (from Koren et al. [3]).](image)
Figure 2. Left: Study domain containing the Cities of Fort Worth, Arlington and Grand Prairie; the mesh shown is in the full HRAP resolution (~4km). Right: 5 selected basins in City of Grand Prairie.

Figure 3. Left: An example MPE field, Right: Matching 1-hr aggregated field of 1 minute CASA QPE.

CASA QPE

The CASA radar QPE used is KDP-based (R=18.15 KDP 0.791 where R and KDP denote the rainrate in mm/hr and specific differential phase in deg/km, respectively, applicable for southern Oklahoma and North Texas) (Chandrasekar and Lim [5]). Currently, the spatiotemporal resolution of the QPE is ~500 m and ~1 min. Because the CASA radars operate only during events, the CASA QPE is available only for significant precipitation events. We use the MPE data for all other periods. Figure 3 shows examples of hourly MPE (left panel) and hourly CASA QPE (right panel).

HYDROLOGIC MODELING

HL-RDHM is used as the hydrologic model. The Sacramento Soil Moisture Accounting Model, or SAC-SMA, is used for rainfall-runoff and kinematic wave is used for routing. HL-RDHM has been used operationally on a ~4 km grid forced by hourly precipitation. To the best of the
authors’ knowledge, this is the first application of HL-RDHM at a resolution of ~500 m and 1 min. The a priori grids of the SAC-SMA and kinematic-wave routing parameters are provided by NWS for the continental US at a 4km x 4km resolution. Since impervious areas play a critical role in rainfall-runoff processes in urban areas, high-resolution maps of fractional imperviousness are generated at different spatial resolutions based on the information obtained from the Cities of Fort Worth, Arlington and Grand Prairie. The routing parameters such as hillslope and specific discharge are generated at different spatial resolutions as well. The routing results provide a city-wide view of flooding threats which may be drilled down for more detailed information via locations-specific hydraulic modeling and inundation mapping (Nazari and Seo [6]).

SPATIOTEMPORAL SCALE SENSITIVITY

The hydrologic model is run at different spatiotemporal resolutions ranging from 1 min to 1 hr and from ~250 m to ~4 km. To ensure mass balance across all spatial resolutions, the cell area in HL-RDHM is adjusted such that the total catchment area depicted at all resolutions equals the actual area. Water level data are available for comparison with simulated flow. There are, however, no rating curves available. We use the conditional bias-penalized regression to derive a relationship between the observed stage and simulated flow above the 90th percentile of the observed stage for each resolution. Using the derived relationships, we estimate the pseudo streamflow observations, which are then used to calculate the error statistics. Here we present only a subset of the preliminary results.

Fig 4 show the root mean square error (RMSE), mean error and correlation coefficient of simulated flow at temporal resolutions of 1, 5, 15, 30 and 60 minutes at spatial resolution of 1/8 HRAP (~500 m) for the 5 selected basins. Fig 5 shows the RMSE, mean error and correlation coefficient for spatial resolutions of full, 1/2, 1/4, 1/8 and 1/16 HRAP at temporal resolution of 1 min for the 5 basins.

RESULTS AND FUTURE WORK

For the analyses carried out thus far, the smallest RMSE is observed at a temporal resolution of 15 min while the best ME and correlation coefficients are observed at 30-min temporal resolution. For spatial scale sensitivity, however, no clear pattern is seen among all basins. For example, the simulated results get better as the resolution gets finer for Cottonwood Creek at Carrier while the opposite is true for Fish Creek at GSWP. It is suspected that the considerable timing errors (see Fig 6) may cloud the sensitivity of streamflow simulation on the spatial resolution of modeling. Reducing timing errors via, e.g., optimization of distributed parameters is beyond the scope of this work. The above suggests that other performance measures that are less susceptible to timing errors, such as the Relative Operating Characteristic (ROC) curves, be used. The results will be presented at the conference.

ACKNOWLEDGMENT

This work is supported by the Accelerating Innovation Research (AIR) Program of the National Science Foundation, the City of Fort Worth and the Office of Science and Technology of the National Weather Service. These supports are gratefully acknowledged.
Figure 4. RMSE, mean error and correlation coefficient for temporal resolutions of 1, 5, 15, 30 and 60 minutes at spatial resolution of 1/8 HRAP for the 5 basins.
Figure 5. RMSE, mean error and correlation coefficient for spatial resolution of full, 1/2, 1/4, 1/8 and 1/16 HRAP at temporal resolution of 1 min for the 5 basins.
Figure 6. Scatter plot of simulated streamflow versus the pseudo observed flow

REFERENCES


