7.5A Estimation of Upstream Discharge in Data-Deprived Riverine Environments

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1. The Challenge for the US Navy

There are over 900,000 rivers and 224 major river basins in the world. The US Navy has recently increased its focus on riverine environments. This activity has seen an exponential rise since the Global War on Terror ensued and is expected to grow as Special Warfare assumes an ever-increasing role in Navy operations. To meet this operational demand the Navy created the Navy Expeditionary Combat Command (NECC) with its two newly formed River Squadrons along with the existing capabilities of the Navy SEAL (NSW) and Special Boat Teams (SBT) (Fig. 1).

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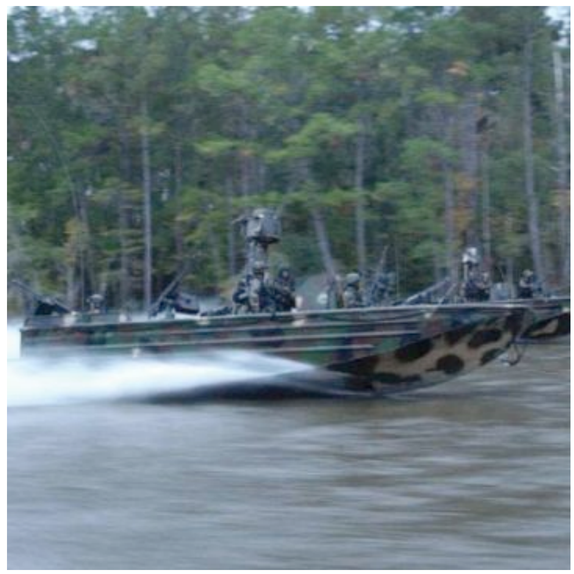
Fig. 1 SBT-22, based at Stennis Space Center, exercises on the Pearl River.



Rivers pose one of the most challenging environments to quantify as they contain elements of both land and water, they are small in size relative to normal (deep and coastal ocean) Navy operations, and are ever-changing in their position and character. To compound the problem, Navy operations are targeted at inaccessible or denied river environments that typically have very little, if any, known information.

In the past, Navy analysis of the river environment has relied heavily on imagery-based information. For all its utility, imagery cannot provide detailed spatial/temporal information on river dynamics when imagery is not available. Predictive numerical modeling of rivers is extremely valuable in addressing these needs. However, the lack of detailed knowledge of an entire river system precludes the application of sophisticated hydrodynamic models.

2. Approach

Our approach is to bring together satellite remote sensing, hydrodynamic modeling, and hydrological modeling in a coupled fashion so that one can characterize any river reach of interest. One critical forcing component to any realistic numerical model of a stretch of river is its upstream discharge. But specification of the upstream discharge is very difficult as this information is not typically available for rivers of military interest. In order to obtain a reasonable estimate of upstream discharge an accurate representation of land surface processes is needed. We use NASA's Land Information System (LIS) (Fig. 2) to generate surface runoff and subsurface baseflow. We couple these parameters with a river routing model to produce upstream river discharge estimates as a necessary boundary condition to the hydrodynamic model. In general, the physics in such models have the capability to resolve local riverine features.

LIS was developed by the Hydrological Sciences Branch (Code 613.4) at NASA's Goddard Space Flight Center (GSFC) (Kumar et al. 2006).

LIS is a high performance land surface modeling and data assimilation system, based on GSFC's Global Land Data Assimilation System (Rodell et al. 2004).

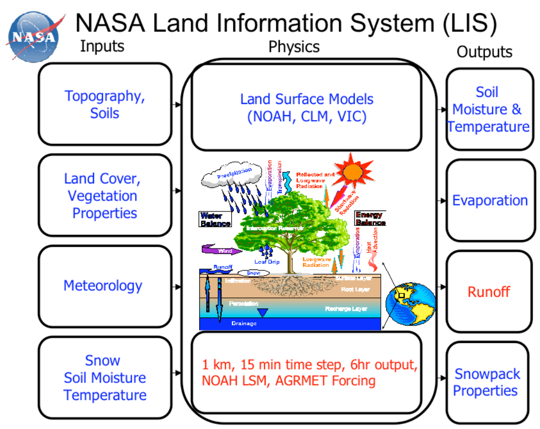


Fig. 2 NASA's Land Information System. The model configuration is shown in red. Output of interest is runoff.

In order to generate a streamflow hydrograph for comparison with observations it is necessary to route the runoff from each model grid cell to the basin outlet. We use the University of Washington's Variable Infiltration Curve (VIC) post-processor river routing model (Lohmann et al. 1996, 1998a,b) (Fig. 3).

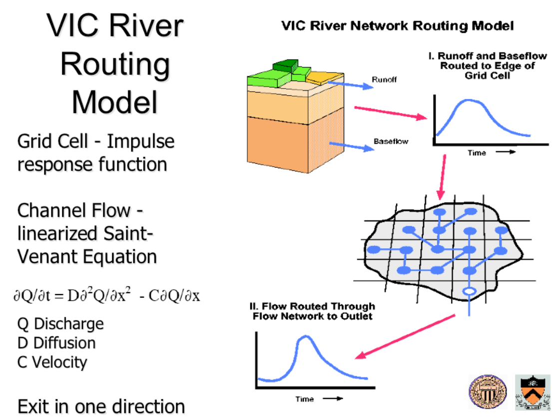


Fig. 3 University of Washington's VIC River Routing Model.

The major advantages to using LIS and the VIC river routing models are that they are well-established, widely-adopted, rely on readily available satellite data sets and are suited to supercomputer processing.

3. Application to the Tactical Scale

Runoff generated must be routed through a river network. In one example of continental scale modeling Brown (2007) used the University of New Hampshire's Simulated Topological Network at 30-minute resolution (STN-

30) (Vörömarty et al. 2000) to generate daily discharge estimates for major rivers draining into the Bay of Bengal. Figure 4 shows the STN-30 network for our test case – the Pearl River, USA watershed.

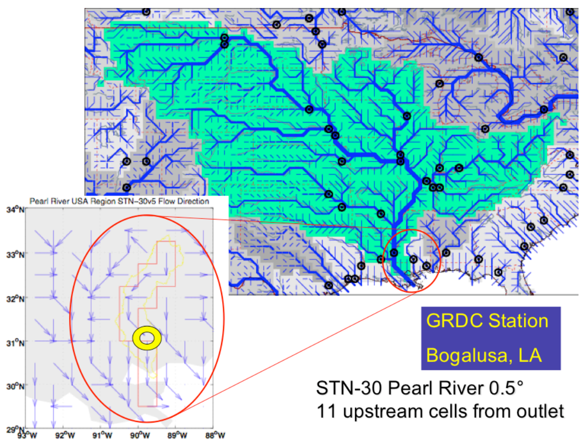


Fig. 4 STN-30 network for the Pearl River basin

At the 0.5° scale there are only 11 upstream cells from the river outlet with only one gauge station in the Global Runoff Data Center climatology. In our test case we apply the same techniques on the tactical scale. NASA's LIS produces output at a nominal 1 km scale and we find a suitable river network with the United States Geological Survey's (USGS) HYDRO1K 1 km flow-direction data set. However, first we must match the HYDRO1K network to the LIS 1 km grid so that the surface runoff and subsurface baseflow grid values can be routed along their correct flow paths. One challenge is that the USGS HYDRO1K data is in a Lambert Azimuthal Equal Area projection while the NASA LIS data are in a rectangular/Mercator projection. A further complication is that in the HYDRO1K data 1km = 0.009009° while in the NASA LIS data 1km = 0.01°. The adjustment process resulted in a river network that embedded several flow-direction errors that had to be manually corrected to allow the river routing model to work. These errors can generally be grouped as crossed vectors, double-backs, and triangles (Fig. 5).

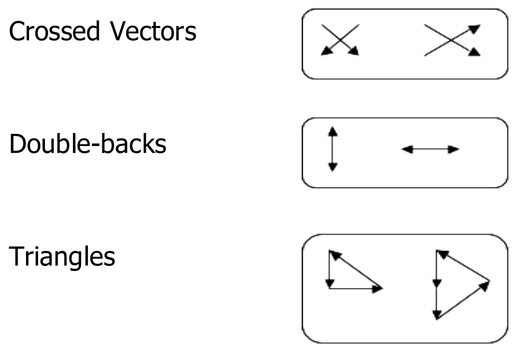


Fig. 5 Types of flow-direction errors after network adjustment

We leverage off the research efforts of NASA and the US Air Force Weather Agency (AFWA) who run LIS on the high performance supercomputer at the Naval Oceanographic Office (NAVO). The AFWA LIS was configured with the NOAH land surface model and forced by AFWA's own Agricultural Meteorology (AGRMET) model which incorporates unique precipitation, radiation and surface forcing algorithms. For our test case LIS was run at 15-minute time-steps with 6-hourly output. The entire LIS run covers the whole Pearl River domain: 30°-33.5° N & 88°-91.5° W or 351 x 351 1 km grid cells (not shown) from December 2005 to August 2007. At this resolution there are 20,530 upstream cells from the outlet. A total of 361 flow-direction errors were found in and around the USGS delineated Pearl River boundary, or an error rate of 1.5%-2.0%. In comparison there are only 576 upstream cells for the entire Ganges/Brahmaputra Basin in the quality-controlled STN-30 network.

Another factor complicating the application of these methods to the tactical scale are the differing formats of the LIS output and the VIC routing model data input. LIS output is given as 6-hourly files covering a domain versus VIC routing input given as 0.01° files of runoff and baseflow time-series data. For the Bay of Bengal study region in Brown (2007) there were 3721 total grid cells (61 x 61 0.5° grid cells). Converting from the LIS output format to a VIC routing compatible format was a process that took one weekend of MATLAB processing time on a single workstation. For this test case the time required to convert a domain of 351 x 351 would take two weeks MATLAB processing time on a single workstation.

Due to various data storage, processing, and transfer issues we will only show results for December 2005 and January 2006 for a smaller subset domain (75 x 75 0.01° grid cells) covering the northeast corner of the Pearl River basin (Figs. 6 & 7). Model results are produced for USGS gauge stations Burnside, MS (upstream) and Edinburgh, MS (downstream).

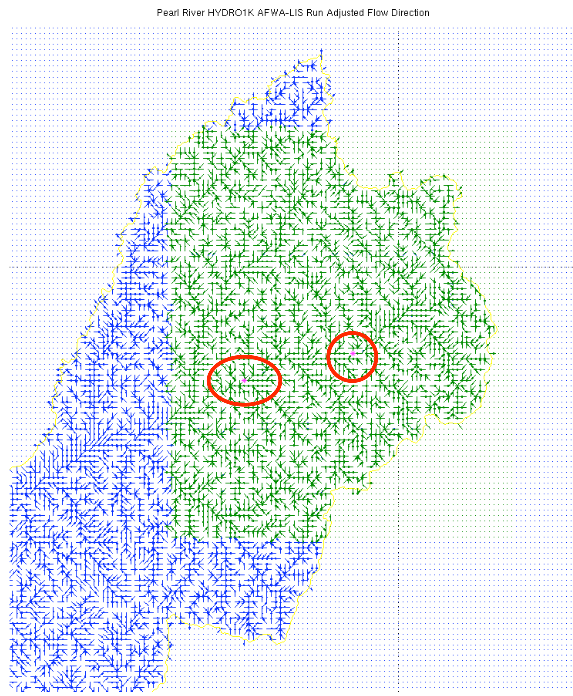


Fig. 6 Northeast corner of Pearl River domain (75 x 75 grid cells). Results are produced for USGS gauge stations Burnside, MS (magenta point in red circle) and Edinburgh, MS (magenta point inside red oval).

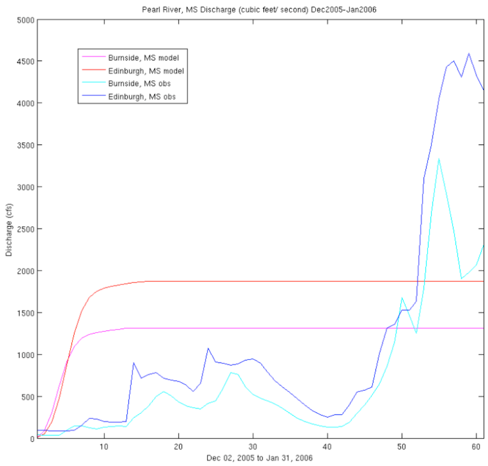


Fig. 7 Initial model results for the smaller domain. River discharge values for Burnside, MS (USGS observations in cyan, LIS/VIC-routed model in magenta) and Edinburgh, MS (USGS observations in blue, LIS/VIC-routed model in red).

At first glance we see that the LIS/VIC-routed model discharge is within the climatologically expected values, but do not show the natural variability of the USGS observations. Also one can see the so-called “start-up” effect that is documented on the VIC website. Conceptually, the problem is that the river channels are started “empty” because no state file is stored for the routing arrays. This effect soon corrects itself depending on travel time. Without an in-depth analysis of the AFWA forcing data one can see that the LIS/VIC-routed model did not pick up a noticeable precipitation event in late January 2006.

4. Way Forward

In order for NASA’s LIS and the University of Washington’s VIC river routing model to be adapted to the tactical scale a few issues need to be addressed. Due to the number of grid cells within a river basin at the 1 km scale as many steps as possible need to be automated. Thus, the process of adjusting the river routing network from one scale or projection to another needs to include algorithms for checking flow-direction errors. Additional scripting can transform the LIS model output of temporal files of a domain to the VIC river routing model format of grid cell files of time-series data. Currently, the VIC river routing model routs daily land surface model output. Ideally, upstream discharge as a boundary condition to the hydrodynamic model would need to have a 6-hourly (or finer) resolution capability.

Resolution of the forcing data (radiation, precipitation, wind, etc) as well as the land surface state parameter data (land cover, soil type, etc) is an issue. Land surface models are most sensitive to the precipitation forcing. At the tactical scale it is easy to understand how a local rain event could be missed within the targeted domain. Data quality checks of the LIS model output could also be automated with any bad values corrected or set to zero.

Since we are at the limits of applicability with these techniques other routing schemes and small-scale hydrological models such as the University of Washington's Distributed Hydrology Soil Vegetation Model may need to be adopted.

However, our goal is not to model an entire river basin at 1 km or finer scale, but rather to provide a set of workable and appropriate boundary conditions to the main hydrodynamic model for a given data-deprived environment.

Acknowledgement

This work was sponsored under a National Research Council Post-doctoral fellowship funded by an NRL Rapid Transition Project: Feature Extraction and Simulation of River Dynamics using Satellite-Derived Information. Many thanks to Mr. John Eylander, US Air Force Weather Agency and the NASA LIS project team directed by Dr. Christa-Peters Lidard.

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