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2A.10 A COUPLED MODELING SYSTEM TO SIMULATE WATER RESOURCES IN THE RIO GRANDE BASIN

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1. INTRODUCTION

Limited availability of fresh water in arid and semi-arid regions of the world requires prudent management strategies from accurate, science-based assessments. These assessments demand a thorough understanding of the hydrologic cycle over long time periods within the individual watersheds that comprise large river basins. Measurement and simulation of the hydrologic cycle is a tremendous challenge, involving a coupling between global to regional-scale atmospheric precipitation processes with regional to local-scale land surface and subsurface water transport.

Los Alamos National Laboratory is developing a detailed modeling system of the hydrologic cycle and applying this tool at high resolution to assess the water balance within the upper Rio Grande river basin. The Rio Grande is a prime example of a river system in a semiarid environment, with a high demand from agricultural, industrial, recreational, and municipal interests for its water supply. Within this river basin, groundwater supplies often augment surface water. With increasing growth projected throughout the river basin, however, these multiple water users have the potential to significantly deplete groundwater resources, thereby increasing the dependence on surface water resources.

The waters of the Rio Grande are strongly influenced by regional climate and could be vulnerable to climate change. The headwaters of the Rio Grande are located in the San Juan Mountains of southwestern Colorado, fed primarily by spring melting of the snowpack deposited by winter storms (see Fig. 1). In contrast, runoff accumulates primarily from thunderstorms of the summer monsoon season in southern New Mexico and the Texas/Mexican border. Any change in this precipitation distribution due to climate change could greatly affect seasonal water availability along the entire Rio Grande.

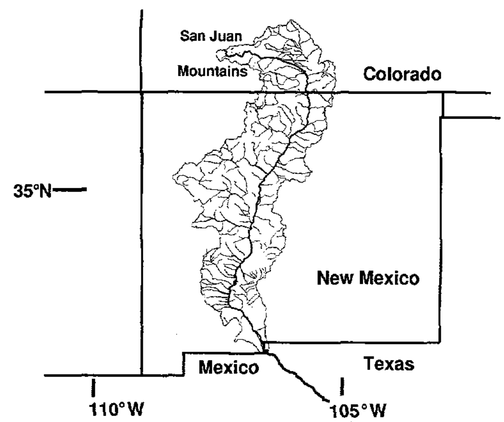

Figure 1. The Upper Rio Grande river drainage basin within Colorado and New Mexico.

2. MODELING SYSTEM

2.1 Overview

The water resources project at Los Alamos is constructing a coupled model of the water balance of the Rio Grande that includes atmospheric, surface/subsurface runoff, river flow, and groundwater transport models. The individual components of the coupled model system are shown in Fig. 2. These include the Regional Atmospheric Modeling System (RAMS), which provides meteorological variables and precipitation to a high resolution land surface model, the Simulator for Processes of Landscapes, Surface/Subsurface Hydrology (SPLASH). SPLASH partitions precipitation into evaporation,

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transpiration, soil water storage, surface runoff, and subsurface recharge. The runoff is routed through a river channel model (DWOPER) and a subsurface hydrology model (FEHM), that is also linked to the land surface model and simulates saturated and unsaturated groundwater flow.

2.2 Computing Hardware

The wide range of temporal and spatial scales included within the modeling system require an enormous amount of computational resources that few facilities can provide. At Los Alamos, ongoing development of a massively parallel supercomputer from SGI/Cray, acquired under the Department of Energy's Accelerated Strategic Computing Initiative (ASCI), High Performance Computing and Communications Program (HPCC), and Computing Hardware Advanced Mathematics and Model Physics (CHAMMP) programs, has provided a framework with sufficient processing power to make this coupled modeling project feasible.

2.3 Large-Scale Atmosphere

The coupled modeling approach shown in Fig. 2 needs global-to-local scale data sets or model output for initialization and specification of boundary conditions. Large-scale weather is currently obtained from the National Center for Environmental Prediction's (NCEP) 2.5^o global reanalysis for recent climate conditions. After sufficient testing and validation of the modeling system, we intend to use simulation results from a coupled atmosphere/ocean model (CCM3/POP) to assess the water resources over the upper Rio Grande basin for a future climate scenario, such as a doubling of carbon dioxide. The large-scale reanalysis data set presently used includes the essential variables that describe the state of the atmosphere via twice-daily temperature, pressure, winds, and humidity.

2.4 Regional Atmosphere

The large-scale data are used as initial and boundary conditions to the Regional Atmospheric Modeling System (RAMS - see Pielke et al. 1992). The data are first interpolated onto a limited domain grid mesh both spatially and temporally within RAMS to initialize information about precipitating large-scale, transient weather systems in the atmosphere. The RAMS model resolves these weather systems at progressively smaller scales with nested grids. This allows the model to accurately simulate synoptic-scale flow features that produce weather over the entire western United States at relatively coarse resolution (80 km) while simultaneously capturing the effects of topography on orographic precipitation over the Rio Grande headwaters on the highest resolution grid (5 km).

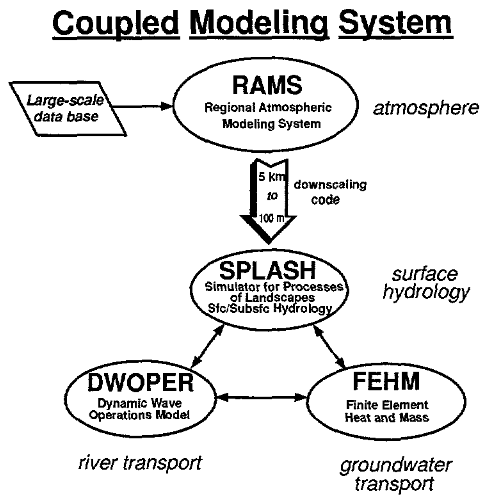

Figure 2. Schematic of the Los Alamos coupled modeling system to address water resources.

Precipitation processes are parameterized using a partial two-moment microphysics scheme which includes eight water species [see Stalker and Bossert (1998) for a description]. An investigation of the results from month-long simulations with the RAMS model is provided in this session (Costigan et al. 1999).

2.5 Surface Hydrology

The Simulator for Processes of Landscapes, Surface/Subsurface Hydrology (SPLASH) is a landscape-scale distributed simulation model that incorporates coupled surface-subsurface hydrology, simulation of evapotranspiration from a vegetation canopy, and an energy balance approach for snowpack calculations (Martens et al. 1999). It can simulate these processes over periods of minutes to years. The landscape is represented as square grid cells within which most properties are considered to be homogeneous. SPLASH's initial input requirements include a digital elevation model (DEM), six soil physical parameters, and a leaf area index. Driving variables are temperature, precipitation, wind speed, relative humidity, and solar radiation which are obtained from the RAMS simulation at 5 km resolution. Prognostic variables output are evaporation of intercepted precipitation, snowmelt, transpiration, soil evaporation, surface water velocity (x and y directions), surface head, infiltration rate, subsurface velocity (x and y directions), exfiltration, and recharge to groundwater.

2.6 River

The lateral surface and subsurface runoff is collected within a simple river channel model, known as the Dynamic Wave Operations Model (DWOPER - Fread 1978) that takes into account the network of streams within the complex watersheds that encompass the upper Rio Grande basin (URGB see Fig. 1). DWOPER routes unsteady flow using the dynamic wave method. The model is based on the complete one-dimensional St. Venant equations and uses a weighted four-point nonlinear implicit finite difference scheme for solution. The model is designed to accommodate various boundary conditions and irregular cross-sections located at unequal distances along a a complex network of bifurcating channels and tributaries. For this study, we are using the Strahler classification scheme (Strahler 1964) to define the Rio Grande river network with a 3-arc-second digital elevation model (DEM) from the U.S. Geological Survey. DWOPER allows for roughness parameters to vary with location, temporally varying lateral inflows, and wind effects. Input parameters include lateral inflow, obtained from the SPLASH code, and cross-section location and geometry in the form of channel widths versus elevation that are determined from the DEM. The model produces hydraulic properties at each cross-section including water surface elevation discharge and velocity. Man-made water diversions and storage facilities will eventually be incorporated into a river model, but are being ignored in the present testing phase of the project.

2.7 Groundwater

The pressure head associated with river channel flow from DWOPER and the infiltration to the subsurface from SPLASH serve as input boundary conditions to the Finite Element Heat and Mass (FEHM) code for groundwater flow and transport. FEHM is a non-isothermal, multi-phase flow and transport code developed at Los Alamos (Zyvoloski et al. 1997). It simulates the flow of water and air and the transport of heat and solutes in two and three-dimensional saturated or partially saturated heterogeneous porous media. The code calculates recharge, discharge to streams, stream-aquifer interactions, and human impacts such as groundwater pumping.

3. MODELING STRATEGY

3.1 Data

Data from the Rio Grande basin are being collected into a data base to support model initialization and testing activities. Data sets are maintained and accessed within a GIS-based framework. Several data sets that were acquired and developed specifically for the project include monthly sea surface temperatures, 1-km land class/vegetation for the western hemisphere, digitized soil characteristics data for the United States from the STATSGO data base, leaf area index and greenness values for the United States from NOAA AVHRR, and hydrograph series for the Rio Grande river.

3.2 Computing Software

The design and development of the coupled modeling system includes a significant amount of software engineering. Specialized code is necessary to implement model components on parallel computers and to communicate model component interactions. The software framework is being built to address: 1) synchronizing the computations given the differences in the rates of various processes, e.g. precipitation versus groundwater flow; 2) allocating processors and memory to pass information efficiently among the codes; and 3) flow of data between the components.

3.3 Coupling Issues

3.3.1 Resolution

Coupling of the models at the interfaces between geophysical domains is particularly challenging, given the highly variable temporal and spatial scales at which each respective domain operates. For example, the RAMS model is being run down to 5-km resolution over the upper Rio Grande basin (URGB). The degree of resolution is defined by the desire to resolve explicitly the dominant terrain features within the URGB, and limited by the need to maintain reasonable calculation times for long-term (e.g., multi-year) simulations on a multi-processor computer. The SPLASH model, on the other hand, requires even higher resolution to define the runoff characteristics within the individual watersheds that comprise the URGB. Thus, SPLASH runs at 100 m resolution over the same domain as the 5-km resolution RAMS grid.

3.3.2 Downscaling

To couple the RAMS and SPLASH codes requires a statistical downscaling algorithm to disaggregate the RAMS precipitation, temperature, humidity, and solar radiation from 5-km down to 100-m for SPLASH's surface hydrology calculations. The algorithm currently in use is a linear prediction model, incorporating the basic concepts of kriging. The algorithm makes use of the spatial autocovariance of the meteorological fields, can incorporate spatial trends such as fixed effects, and can treat covariates such as elevation as a random effect. Prediction of random effects can then be biased to reflect the vertical trend calculated by RAMS, and conservation of mean or total quantities downscaled from the RAMS cells can be enforced. In the simplest case, with no elevational dependence, the variable calculated by RAMS at the center of a 5-km grid cell is interpolated smoothly to the centers of the 100-m grid cells. For variables with significant elevational dependence, elevation is treated as a random effect, whose coefficient (the "lapse function") satisfies an appropriate autocovariance model.

The SPLASH model routes the precipitation disaggregated from RAMS at 2-20 minutes timesteps (depending upon the precipitation rate) downgradient to a defined river channel, where the river model (DWOPER) then routes it into the main stem of the Rio Grande. Only the RAMS-SPLASH interface is fully operational at present. Results from preliminary RAMS-SPLASH calculations that describe the atmosphere-surface hydrology water transport and additional details on the surface hydrology-river network-groundwater transport cycle will be presented at the conference.

4. MODELING STUDIES

4.1 Testing

To fully test the coupled modeling system, a simulation of the 1992-93 water year over the URGB, that includes only a one-way coupling of RAMS to SPLASH, is presently underway. This includes the passing of RAMS generated precipitation, temperature, humidity, and radiation to SPLASH, as described above. Longer term simulations will be conducted after the initial year-long test simulation.

RAMS currently parameterizes the surface energy balance without any information from SPLASH. The next step will be to develop an appropriate aggregation scheme to include the feedback of evapotranspiration and sensible heat from SPLASH at 100-m resolution back to the RAMS 5-km grid. Comparison studies of the latent and sensible energy fluxes between SPLASH's aggregated 100-m results and RAMS' 5-km grid averaged results should provide some initial measure of the importance of high resolution in understanding the surface energy balance in highly complex terrain. Coupling and scaling issues are the core of the scientific work we hope to achieve within this study.

4.2 Implementation

The Rio Grande water resources project is being carried out in cooperation with federal, state, and university partners. Los Alamos will collaborate by complementing the capabilities of those agencies and organizations that have responsibility for water resource and climate modeling issues within the Rio Grande basin. Through this project, Los Alamos will provide the modeling tools, computing resources, and scientific basis for monitoring and modeling regional water resources. The capability developed within this project can eventually be used to examine water related issues in other arid/semi-arid river basins within developing countries. The modeling system can also be expanded to address ecosystem responses to climate change and other natural stresses.

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