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A Model Quest [1]

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Researchers develop a hydrologic model that can be applied from basin to basin without recalibration, and test it on the Mackenzie River Basin.

"The holy grail of hydrology," said University of Waterloo engineer E. D. Soulis, "has been to come up with a generic model that doesn't require recalibration from watershed to watershed."

Such a model could solve many water resources problems. For example, unlike conventional hydrologic models such a model could be coupled with atmospheric models, thereby allowing modelers to better balance the water budget so important to large-scale climate simulations.

Soulis compares conventional hydrologic models to black boxes in which essential watershed details are lost. Modelers historically built hydrologic models on the only information available: empirical rainfall-runoff relationships identified using hydrographs, the bell-like plots of a river's response to precipitation. Having little other choice, modelers built mathematical descriptions deduced from hydrographs into models that characterize basins. But, because hydrographs only summarize the response of physically complex areas, modelers effectively lumped together all physical processes at work in the watershed.

"You couldn't really worry about the details of the processes at all," said Nick Kouwen, Soulis's colleague at Waterloo. "What you could say was, 'If you get so many millimeters of precipitation in a storm you get so many cubic meters of flow.' And that's about all."

Using the conventional approach, modelers have been moderately successful at simulating the behavior of individual watersheds. However, huge watersheds such as Canada's Mackenzie River Basin, which drains an area slightly larger than all of Alaska, test the limits of the hydrograph approach. Moreover, conventional models cannot be easily transferred or applied from basin to basin without significant recalibration.

Over the last 20 years, hydrologic modelers have sought to develop "distributed" models to solve this problem, said Soulis. Distributed models are built on the internal physical characteristics of a watershed and attempt to use fundamental physical laws to predict the response of a basin to precipitation.

Since 1972, Kouwen has been working on WATFLOOD, one of the world's first distributed hydrologic models. With WATFLOOD, satellite data and numerical weather model output provide the detail lost in the black boxes of conventional models. Because both pieces of information are in electronic form, WATFLOOD can easily generate them for different watersheds, thereby significantly reducing the recalibration problem and allowing the model to be easily transferred in both time and place.

Weather model output supplies the spatial detail for precipitation, temperature, and radiation, and the other information necessary to model physical processes, like evaporation, infiltration, and fluid flow. Satellite data provide information about land cover, which along with topography, determines a watershed's "hydrological response" to precipitation events.

Kouwen's model also builds on a basic fact about hydrological response: though the land cover mix may vary by basin, similarly vegetated areas will respond in similar ways. For example, though the hydrological responses of developed land and dense forests differ greatly within a given watershed, dense forests in different basins will respond to similar weather in the same way.

Using this concept and taking what is known as the Grouped Response Unit approach, WATFLOOD ties geo-referenced satellite data to specific land cover types. The model might first, for instance, count the forested data pixels for a given area and calculate the hydrologic response. The model then does the same for each pixel

Feedback

type representing a distinct land cover parameter. Once the model has covered everything from barren ground to glacier, it groups all responses and calculates the collective hydrological response for the entire watershed.

Because the Waterloo model ties hydrological responses to land cover as represented by data pixels, it can be easily adjusted to reflect land cover changes without recalibration. "When a place is logged, we can change pixels from forest to whatever comes after, and the model will reflect the change," said Kouwen. Additionally, modelers can change the land cover in the abstract to project a watershed's response, Soulis said, giving WATFLOOD environmental assessment and flood forecasting potential.

Also, this strong land cover basis means WATFLOOD can be easily applied to different basins. For this reason, the model is a candidate for coupling with larger-scale atmospheric models that require hydrological accounting over very large areas. "This is particularly critical if you're going to do numerical weather prediction work because you need one model that's going to work over large areas and everywhere," said Soulis. "This is a major thrust of our work."

"With climate models and numerical weather prediction models, you don't really close the water balance unless you take runoff into account," said Soulis. "With a model like WATFLOOD that you can latch onto the bottom of atmospheric models, you're in a position to properly close the water balance."

As yet, hydrologic models have not been coupled with global atmospheric models. The Waterloo researchers are currently running regional tests of WATFLOOD with various models in an uncoupled mode. "Ultimately we'll go global, but we have to start at the regional level. If everything goes well, we will be participating in global runs with the Canadian General Circulation Model early next year," said Soulis.

"In the future, we hope to incorporate the hydrologic models in the weather models so that the weather models calculate flows directly," said Kouwen. "Then, when they make forecasts of weather, they will make forecasts of flows as well. There will be one package."

Modeling the Mackenzie River Basin

The Mackenzie River collects rain and snow from dense forests in British Columbia, low agricultural land in Alberta, high glaciers in the Yukon, and barren ground in Canada's Northwest Territories. Accurately characterizing the topography of such a large basin historically has been no easy task for hydrologic modelers. Before remotely sensed topography data became widely available, modelers manually extracted the accurate elevation data necessary for regional hydrologic models from topographic maps, a tedious and time-consuming task.

WATFLOOD uses the Global 30 Arc-Second Elevation Data Set distributed by the EROS Data Center (EDC) Land Processes DAAC. "It's the best high resolution data set we've got," said E. D. Soulis. "The real power of it is that it lets us even attempt the regional-scale problem. We couldn't do it without it. It's really opened the door to the possibility of regional-and global-scale linking of hydrologic and atmospheric models."

With the high resolution digital elevation data, modelers are able to identify slope details and delineate boundaries for large watersheds like the Mackenzie River Basin. The modelers use routines that count contour lines within model elements and automatically trace the extent of rivers to recreate watershed divides. "That's very important because it saves us from having to do that by hand," said Soulis. "Because you've got to be able to do this over very large areas, we couldn't even consider the possibility of linking to the atmospheric models without the digital data." Using EDC's topography data, Soulis's engineer delineated all the significant boundaries for the Mackenzie Basin in about six weeks, saving the modelers about six months.

Resource(s)

Kouwen, N., E. D. Soulis, A. Pietroniro, J. Donald, and R. A. Harrington. 1993. Grouped response units for distributed hydrologic modeling. Journal of Water Resources Planning and Management. 119(3):289-305.

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