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A Bayesian Exploratory Approach to the Attribution of Changes in River Flows

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METHODOLOGY

The detection of changes in river flows does not give sufficient guidance for the design and operation of water resources projects. Upon detecting such changes, it is necessary to proceed to the attribution stage, i.e., to investigate the causes of these changes. In this paper we propose a Bayesian exploratory approach to the attribution of changes in river flows that concurrently examines the input, storage, and output variables of the basin system and does not assume that the variables and their relations are stationary. The proposed approach is applied to the Moisie River basin in the Quebec North Shore. In the last part of the paper, we give an overview of some studies of regional attribution and of the attribution of changes in the input variables (temperature and precipitation) of the river basin.

Several detection tests of change have been proposed in the meteorological and hydrological literature. The alternative hypotheses of these tests are based on some simple types of change. In the absence of information on the physical reasons for the change, the selection of a test for a particular application is usually based on the relative power of the test. Given that the changes of hydrometeorological variables do not necessarily have simple shapes, it would be preferable to use a more flexible statistical approach that follows the evolution of the changes. The method used in this paper is the Bayesian dynamic linear model in combination with the conceptual hydrological model CEQUEAU.

The analysis starts with the daily observations of the input and output variables of a river basin with a sufficiently long record. These observations are used to calibrate and verify a conceptual hydrological model, suitable for the conditions of the basin under study. Then, the monthly means of all variables including input, storage, observed and simulated flows are computed and, finally, each series of monthly values is analysed in order to determine the existence and type of changes using the dynamic linear model which decomposes each series in the following additive terms: trend, seasonal regression and residual.

APPLICATION TO THE MOISIE RIVER BASIN

The drainage basin of the Moisie River has an area of 19000 sq.km. An examination of the monthly hydrograph of this river shows a reduction of the flow in the mid-eighties. The size and timing of this reduction can be determined by one of the appropriate classical or Bayesian detection tests. However, for the attribution of these changes, it is necessary to examine the corresponding changes in all input, storage and output variables. From a supplementary analysis of the results of the conceptual model using a dynamic linear model we are further able to conclude that in the years 1986 to 1987 a reduction in snowfall and an early snowmelt resulted in a step reduction of the volume of the spring flood. The question remains, however, whether the observed

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changes are due to climate variability or to climate change. To answer this question we would have to extend the attribution of change to the entire region.

REGIONAL ATTRIBUTION OF CHANGES IN RIVER FLOWS

The method described above, while feasible for the study of an individual river is, of course, too elaborate for a regional attribution study. Three alternative approaches to this problem may be considered:

1) Use the principal component scores of the observed input and output variables (temperature, precipitation and river flow) of a region with the isolines of their correlation coefficients with the observed variables. Climatologists refer to this method as "empirical orthogonal functions (E.O.F.)"or
2) Use canonical correlation analysis of standardized or centered observations to analyze the combined input and output variables, a method known in climatology as "singular value decomposition" or
3) Use a simple water balance model to follow the changes of annual or seasonal input and output variables in a large region. This approach requires data on soil moisture, storage, potential evapotranspiration, precipitation, and runoff.

It must be noted that the first two alternatives use linear combinations of the observed variables which are difficult to interpret physically.

ATTRIBUTION OF CHANGES IN TEMPERATURE AND PRECIPITATION

The detection of changes in regional temperature, precipitation, and runoff has been the subject of several previous studies. To extend these studies to the attribution stage, it is necessary to analyze the entire chain of causative factors involved in the changes. The attribution of changes in river flow requires two scale transitions; starting from the global scale of the greenhouse gases, we must go to the relevant regional scale for the atmospheric variables, i.e., temperature, precipitation, and evapotranspiration and, finally to the basin scale relevant for river flow. These transitions result in a reduction in the proportion of the variance of the output variables as we progress along the causal chain. Many authors have investigated the relations between temperature, precipitation and forcing variables using statistical tests. But these tests are only one step towards the establishment of causal chains (attributions). We must also conduct major attribution studies of large regions or very large basins (e.g., the MacKenzie). for which the atmosphere–ocean system and the basin system are not very different. The results of these hydrological attribution studies must be combined with those of coupled atmosphere–ocean climatic models (GCM's) which deal with the attribution of changes in the input variables of the basin system. This combination of studies with concomitant studies of the impacts of climate change on human activities will provide guidance on the design of water resources projects and the long-term policy decisions concerning climate change.