J4.3 NATIONAL LONG-RANGE HYDROLOGIC PREDICTION SYSTEM

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1. INTRODUCTION

One of the primary objectives of the GEWEX Americas Prediction Project (GAPP) is "To interpret and facilitate the transfer of the results of improved seasonal predictions to users for the optimal management of water resources". Over the years, much progress has been made in developing climate predictions for lead times up to a year ahead. The National Weather Service (NWS) Climate Prediction Center (CPC), for example, has been routinely issuing monthly and seasonal temperature and precipitation outlook forecasts for the US and its territories. These forecasts have been shown to possess certain level of skills when they are evaluated against observations. Despite the progress made in climate predictions, hydrologists have yet to make full use of them for hydrologic predictions. The main reason is due to the fact that these outlook products are not in the form that can be used directly in hydrologic models. They are in fact given as probability of average temperature and precipitation total in three classes: below normal, normal and above normal. Procedures must be developed so these probability shifts can be translated into time series that are needed for hydrologic models. The skill level of the outlook products is dependent on the geographic locations and seasonality and it is not clear under what conditions these outlook products are most useful for hydrologic predictions. Therefore there is a need to demonstrate that climate predictions are useful for hydrologic predictions.

A National Long-range Hydrologic Prediction System (NLHPS) is proposed to examine how climate predictions such as CPC's monthly and seasonal outlooks can be used to produce national probabilistic hydrologic forecasts for lead times ranging from a month to a year. NLHPS is supported by NOAA Office of Global Programs (OGP), as part of the GAPP Core Project, and continues the parallel research and operational pathway strategy that has been the hallmark of GAPP and its predecessor GEWEX Continental-scale International Project (GCIP). It is led by the NWS Office of Hydrologic Development, in close collaboration with National Center for Environmental Prediction (NCEP) and the University community. This will also be an integral part of the NWS Advanced Hydrologic Prediction System (AHPS) program, whose aim is to develop the enhanced ability to deliver advanced hydrologic predictions for water resources applications. If it can be demonstrated that valid long-range runoff forecasts can be produced from NLHPS, a national NWS long-range runoff forecast product will be developed. This product will use RFC produced runoff forecasts where they are available and the results of the NHLPS where they are not. This paper is organized as follows. First an overview of the NLHPS is presented. We then discuss the science issues. Finally the research plan is outlined.

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2. OVERVIEW OF NLHPS

NLHPS is designed to demonstrate the ability to make national long-range predictions for 1-month to 1-year lead times. This system is to serve as a test-bed for hydrologic application of monthly and seasonal precipitation and temperature forecasts. In the beginning, NLHPS will use CPC monthly and seasonal temperature and precipitation outlook forecasts. Alternative climate predictions from other sources will be examined in the future. The initial focus is on producing experimental forecasts of natural runoff. It will test the limits of predictability of runoff over a wide range of space and time scales. The NHLPS will also provide alternative soil moisture fields for the continental US for CPC, who uses simulated soil moisture fields as one of the factors in developing climate predictions. The NLHPS will be executed based on climate divisions across the continental US. However, the system is flexible enough to run on any given modeling element.

NLHPS consists of three components: the pre-processor, the hydrologic model module and the post-processor. The pre-processor is the component that generates ensembles of hydrologic forcing time series needed by hydrologic models. This pre-processor is based on the existing AHPS ensemble temperature and precipitation pre-processors. The hydrologic modeling module ingests forcing time series and generates the runoff and soil moisture outputs. Considering that climate predictions are given as monthly or longer time scale products, the hydrologic module will be consisted of monthly hydrologic models at first. The use of daily or sub-daily models will be investigated at a later time. Because all hydrologic models are simplification of natural systems and therefore their outputs contain biases, a post-processor will be applied to the outputs from the hydrologic module to produce unbiased hydrologic predictions.

3. SCIENCE ISSUES

There are several critical science issues related to the development of NLHPS, including hydro meteorologic data, hydrologic models, ensemble implementation strategy and verification strategy. These issues are briefly discussed below.

Hydrometeorologic Data

A sufficiently long retrospective hydrometeorologic time series data set is needed to develop and validate NLHPS. They include at minimum many years of observed monthly temperature and precipitation time series and many years of retrospective monthly and seasonal temperature and precipitation outlook forecasts. Also needed are historical streamflow data for unregulated basins for thousands of hydrologic basins in the continental US. Observed monthly temperature and precipitation time series of all climate divisions in continental US dating back to 1931 have been obtained. Also obtained are the retrospective monthly and seasonal temperature and precipitation outlook forecasts from CPC dating back to 1994. To fully test the usefulness of CPC outlook forecasts, longer retrospective outlook forecasts are needed. We will work with CPC collaborators to develop ways to generate retrospective hindcasts of temperature and precipitation outlooks. Alternative climate predictions from other climate prediction centers will be tested at a later time. Historical streamflow records for 1861 basins in the US have been obtained. These streamflow records date back as far as the nineteenth century. They will be used for evaluating the ability of hydrologic models to simulate natural runoff.

Hydrologic Models

NLHPS will rely on monthly hydrologic models to calculate water balance. Daily or sub-daily hydrologic models will be tested at a later time. A number of monthly hydrologic models are obtained for NLHPS, including the Leaky Bucket model running currently in CPC (Huang et al., 1996), the Simple Water Balance (SWB) model (Schaake, 1990), the USGS Monthly Water Balance Model (Winter, 1981), and the monthly water balance model developed by Xu and Vandewiele (1995). The two later models contain snow module, which has shown to be a very important component in hydrologic models. Figure 1 shows the effect of considering snow process on the Nash-Sutcliffe Efficiency of the SWB model simulation results. The Nash-Sutcliffe efficiency is shown to be higher for all snowy basins when snow effect is considered (the last four basins in the figure are snow-free basins).

An important issue in hydrologic modeling is parameter estimation. The NLHPS hydrologic modeling module has an automatic model calibration tool that determines the values of model parameters by matching simulated runoff values from hydrologic models with the observed runoff values. This should be an improvement over the current simulation results from the Leaky Bucket model which uses a constant set of model parameters over the entire US.

Ensemble Strategy

CPC monthly and seasonal outlook forecasts are in the form of probability of average temperature and precipitation total in three classes: below normal, normal and above normal conditions. These probability forecasts must be translated into hydrologic time series. The AHPS temperature and precipitation pre-processors will be used to construct unbiased temperature and precipitation ensembles. These ensembles will then be applied to the NLHPS hydrologic modeling module to generate hydrologic ensembles. A super ensemble strategy is envisioned for NLHPS that considers ensemble hydrologic predictions based on multiple hydrologic model outputs. This strategy is pursued because all hydrologic models are imperfect representation of the real world processes and different models may have strengths in representing different phases of the hydrologic processes. The results of hydrologic model outputs are also likely to be biased. A post-processor will be employed to remove the biases in hydrologic model outputs.

Validation of NLHPS Hydrologic Predictions

The NLHPS will be evaluated in two ways. First the NLHPS will be evaluated based on its ability to simulate historical runoff. Statistical analysis will be conducted to evaluate how well each hydrologic model simulate runoff in different regions. The second phase of the evaluation focus on NLHPS's ability to predict runoff using temperature and precipitation outlook forecasts. The predictive skill will be examined over different spatial and temporal scales. Critical attention will be paid to where climate predictions are shown to have relative skills.

4. RESEARCH STATUS AND PLAN

NLHPS is a collaborative project that involves a number of agencies and academic universities. Year 2003 activities included assembly of hydrometeorologic data and hydrologic models. A proto-type NLHPS is expected to be completed by the end of 2003. Year 2004 activities include running retrospective hydrologic simulations from 1948 to present. The simulation results will be analyzed and the soil moisture fields from NLHPS will be evaluated against those from current CPC setup. A error-model will be developed to post-process hydrologic model outputs. The capability to produce retrospective predictions will be developed. In Year 2005 and beyond, retrospective hydrologic predictions for the continental US will be made based on CPC outlook products. The CPC predictions and hydrologic predictions will be evaluated jointly. The space-time scale dependency of the predictions will be examined. Other issues of importance will also be explored. Those include the super ensemble strategy implementation, daily/hourly model testing, new downscaling and rescaling techniques to generate ensembles.

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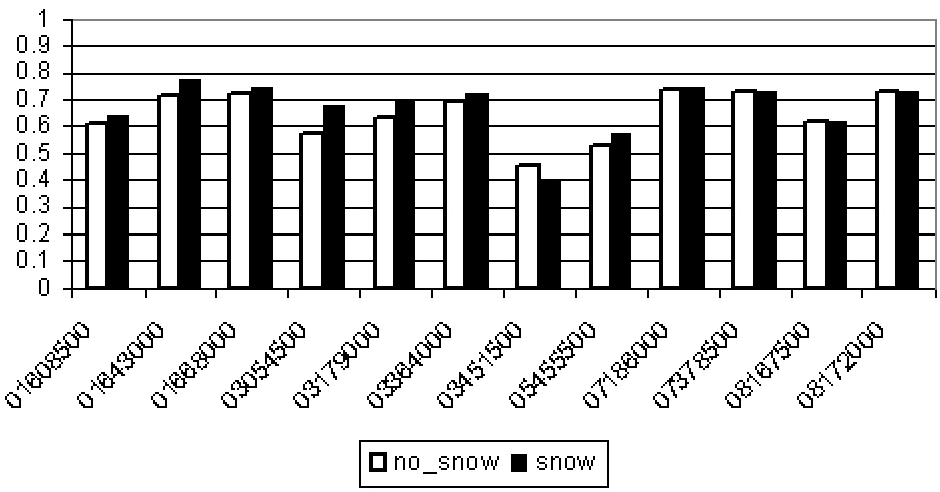

Figure 1. Comparison of Nash-Sutcliffe Efficiency of SWB model simulation when snow process is or is not considered (The higher value for Nash-Sutcliffe Efficiency is desired. The value of 1 indicates perfect model simulation).