Long-term forecast of snowmelt flood taking into account uncertainty of meteorological conditions for the lead-time period

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OUTLINE

1. The present-day practice of the long-term forecasting of snowmelt runoff

2. Physically based modeling offers scope for extend of physical and informational content of the forecast and improvement of the forecast accuracy

3. Transition from deterministic to probabilistic forecast opens up opportunity to take into account uncertainty of the forecast

4. Development of deterministic and probabilistic forecasts on the basis of the ECOMAG hydrological model (by the example Cheboksarsky reservoir)

5. Preliminary results on utilizing seasonal meteorological forecast for decreasing hydrological forecast uncertainty
Some terms used in hydrological forecasting

Short-term forecasting is defined as prediction several days ahead (usually up to 10) using observed and forecasted weather conditions.

Long-term forecasting is defined as all forecasting that extends beyond this short-term definition. For example, this includes subseasonal and seasonal runoff forecasts.
Why the snowmelt flood?

Any opportunity for lengthening the forecast window (assuming that the forecast remains valid) depends, among other factors, on the influence of the initial watershed conditions on the predicted runoff. The long-term storage features of accumulated snow result in a clear association with river runoff several months afterwards, and thus create the opportunity to increase a lead time of the runoff forecast by as much as a month or even a whole season.

“...Snowmelt runoff is one of the few natural phenomena for which relatively accurate long-term forecast can be made”

Lettenmaier & Waddle (1978)
The present-day practice of the long-term forecasting of snowmelt runoff volume

Between the 1930s and the 1950s, general approaches and specific methods of long-term forecasting of runoff volume were developed, which underlay (and still underpin) the approaches of agencies charged with runoff forecasting in Russia, the United States, Canada, Norway, and other countries in cold regions.

Index method (US practice)

The total runoff volume for a specific forecasting period is usually written as a function of independent variables in the form of a multiple linear regression equation:

\[ Y_{sum}^* = a + b_1 X_1 + b_2 X_2 + \ldots + b_n X_n \]

where \( X_1, X_2, \ldots, X_n \) are the runoff index variables (e.g. autumn-precipitation index; winter-precipitation index; snow-water-equivalent index; spring-precipitation index (usually climatic mean))
Physical-statistical methods (Russian practice)

\[ Y_{sum}^* = (SWE + P_{sum}^*) - LMAX \left[ 1 - \exp \left( \frac{-(SWE + P_{sum}^*)}{LMAX} \right) \right] \]

Dependence of on index variables for the Sosna River basin (a; forest-steppe vegetation zone) and Yuga River basin (b; forest vegetation zone). FD is the depth of soil freezing. (After Apollov et al., 1974).
Refinement of the regression-based forecasts can be expected through the use of ever longer homogeneous time series of observations and thus longer calibration periods.

But this is not the case... Why?

1. The available observation series are non-homogeneous as a consequence of changes in land use, modernisation of data collection techniques, and so on.

2. Some data obtained using modern technologies (e.g. satellite observations) cannot be incorporated into the existing regression relationships, which are based on traditional ground-truth observations.

3. The accuracy of the forecasts turns out to be insufficient to satisfy the growing demands of its users.
Physically based hydrological modeling offers scope for improvement of a forecast accuracy

For what reasons?

1. Models are based on physical principles. This means that they generally reproduce the main processes of runoff generation that allows extending physical content of the forecast and overcoming the restrictions inherent in regression-based methods.

2. It may be possible to widen informational basis of the forecast by using modern measurement technologies (including satellite data).

3. Using the model, it may be possible to obtain the predicted hydrographs, rather than just the runoff volume, thus resulting in increased potential benefits for decision makers.
Deterministic forecast vs. Probabilistic one

For many years, the prevailing techniques were deterministic. These methods used a single set of input values to produce a single set of predicted outcomes (runoff volume, river discharges, etc.), which were then assumed to represent the most likely conditions of runoff. Increasingly, users of hydrologic forecasts are interested in quantitative estimations of forecast uncertainty rather than simply the most probable scenario. In long-term hydrological forecasting, wherein a forecaster attempts to predict conditions far into the future, estimates of forecast uncertainty assume a greater significance.

“A deterministic format forces the forecaster to suppress information and judgment about uncertainty” and “...may create the illusion of certainty in a user’s mind” (Krzysztofowicz, 2001).
Objectives

To present a long-term hydrological forecasting technique based on the ECOMAG model

To present an approach for taking into account the hydrological forecast uncertainty resulted from the uncertainty of meteorological conditions for the lead-time period

To present preliminary results on utilizing seasonal meteorological forecast for decreasing hydrological forecast uncertainty
Distributed physically based model ECOMAG (Ecological Model for Applied Geophysics)


Input variables:

- Daily precipitation
- Daily air temperature
- Daily air humidity

Vertical structure of ECOMAG

Base GIS information

Digital elevation model

Soil

Vegetation

Simulation

Discharges in river network

Layer of runoff

Hydrographes

Data base

GIS - analysis of simulated results

Climate

Layer of runoff

Soil moisture

Evapotranspiration
Case Study: Cheboksary Reservoir

Basic GIS information for ECOMAG
Spatial discretization of the Chrboksary res. basin onto calculation elements (elementary basins)

Modelled river network
Prediction (using observed meteorological inputs) spring water inflow into Cheboksary reservoir (calibration period: 1982-1999)

Validation period (2000-2010)
Deterministic long-term forecast

Simulated characteristics of snow and basin conditions on the forecasting date (March, 1)

Mean (climatology) time series of meteorological variables for the lead-time period (1 March-31 May)

ECOMAG

Deterministic Forecast of flood characteristic
Example of a deterministic forecast using climatic mean as inputs into ECOMAG

Air temperature (15 meteorological stations)

- Measured discharge of water inflow
- Forecasted discharge of water inflow
Forecasted vs. Measured flood volume (km³)
Forecasted vs. Measured flood peak discharge (m$^3$/s)

$R^2 = 0.726$
Probabilistic long-term forecast

Simulated characteristics of snow and basin conditions on the forecasting date (March, 1)

Ensemble of 30 (1961-1990) meteorological scenarios measured for the lead time of the forecast (1 March-31 May)

ECOMAG

Probability distributions of flood characteristics
Example of a probabilistic forecast using ensemble of historical inputs into ECOMAG (outputs are equally likely!)

- CDF of measured flood volume
- CDF of forecasted flood volume
- CDF of measured flood peak discharge
- CDF of forecasted flood peak discharge
RPS (Ranked Probability Score) Formulation

The smaller the blue area, the “better” the forecast is.
Preliminary results on utilizing seasonal meteorological forecast for decreasing hydrological forecast uncertainty

SL-AV model

The Semi-implicit semi-Lagrangian vorticity-divergence (SL-AV) atmospheric prognostic global model developed at the Hydrometeorological centre of Russia and the Institute of Numerical Mathematics of the Russian Academy of Sciences (Tolstykh 2010)

Dynamical core of the model has been developed by M.Tolstykh (Tolstykh 2010), ALADIN/LACE parameterizations were used

The spatial resolution of the model is: 1.125 lat x 1.40625 lon., 28- vertical levels.
Seasonal hindcasts set-up

Set-up according to SMIP-2/HFP protocol
Forecast period – 4 months
Ensemble size – 10 members, perturbed initial conditions from NCEP/NCAR Reanalysis-2
Hindcast period – 1981-2010

Interpolated SST anomalies
Output fields are available at resolution: 2.5 lat x 2.5 lon.

Source of atmospheric initial conditions for operational forecasts is HMC data assimilation system

Ensemble size for the operational forecasts is 20
Preparation of SL-AV data for input to hydrological model

Precipitation (P) and air temperature (T2m) data were extracted from SL-AV global hindcast fields.

The region of interest is limited: 33E - 48.5E, 52N - 60N. Considered season is: March-April-May
Period: 1981-2010

Regionally averaged seasonal values for P and T2m were calculated separately for each member of ensemble.

Uncertainty of atmospheric data served as input for hydrological model is represented by ensemble.
Mean ensemble temperature: III-V forecast vs. observation (1981-2009)

Mean ensemble precipitation sum: III-V forecast vs. observation (1981-2009)
Post-adjustment technique (Werner et al., 2005)

Post-adjustment technique allows to weight the predicted hydrological traces according to how well their particular weather forcing agrees with a particular seasonal meteorological forecast. **Hydrological model outputs are NOT equally likely!**

Weights are assigned taking into account probability distribution of errors of meteorological forecast.
Example of a probabilistic forecast using ensemble of historical inputs into ECOMAG

1984

Post-adjustment using meteorological forecast (outputs are NOT equally likely)

SD = 3.5 km³

1984

Equally likely outputs

SD = 2.9 km³
Conclusions

Long-term hydrological forecasting technique is developed on the basis of the ECOMAG model.

An approach is presented for taking into account the hydrological forecast uncertainty resulted from the uncertainty of meteorological conditions for the lead-time period.

An approach is developed for utilizing seasonal meteorological forecast for decreasing hydrological forecast uncertainty.