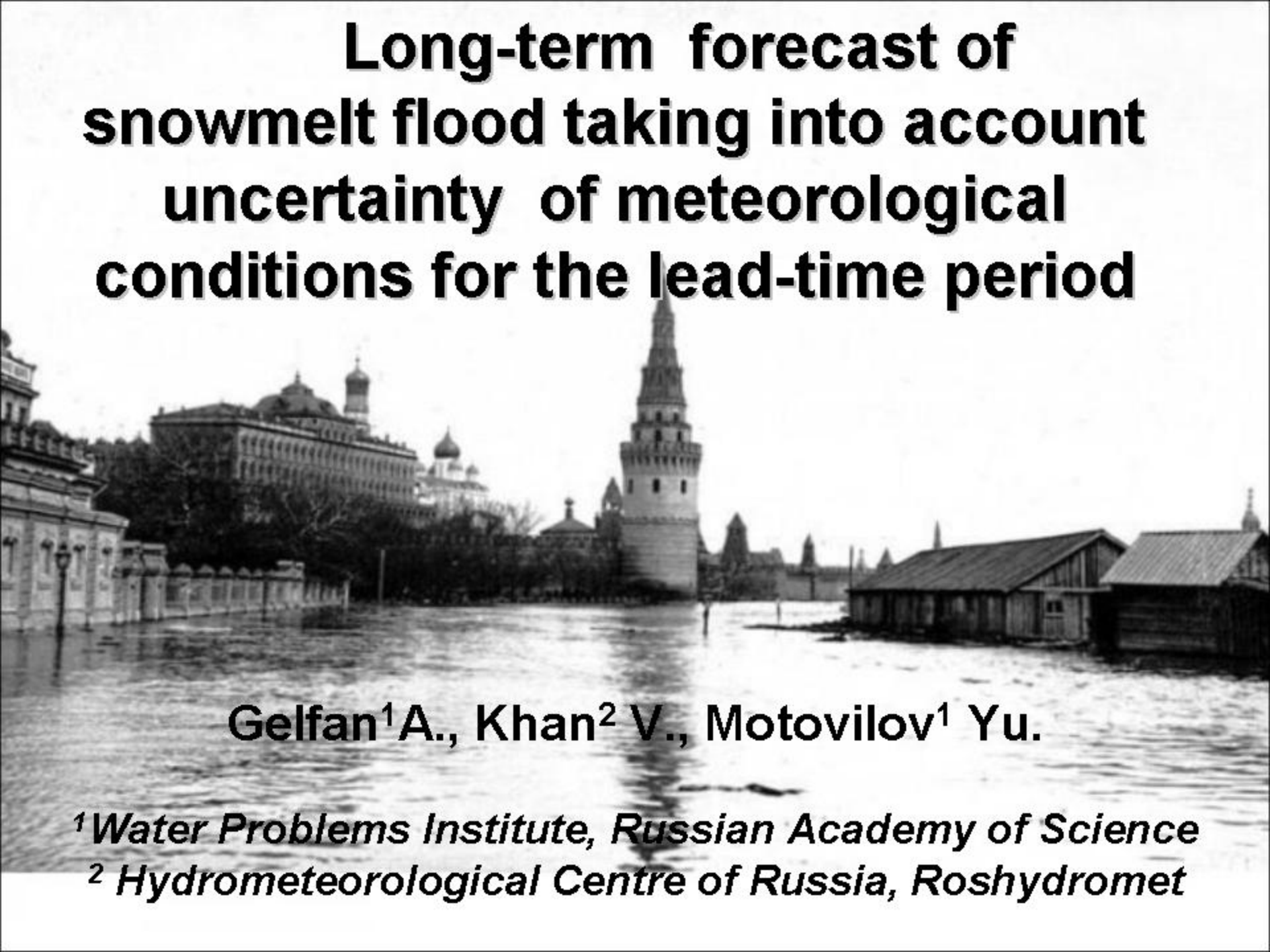
Long-term forecast of snowmelt flood taking into account uncertainty of meteorological conditions for the lead-time period



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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:

$$Y^*_{sum} = a + b_1 X_1 + b_2 X_2 \ldots\ldots + b_n X_n$$

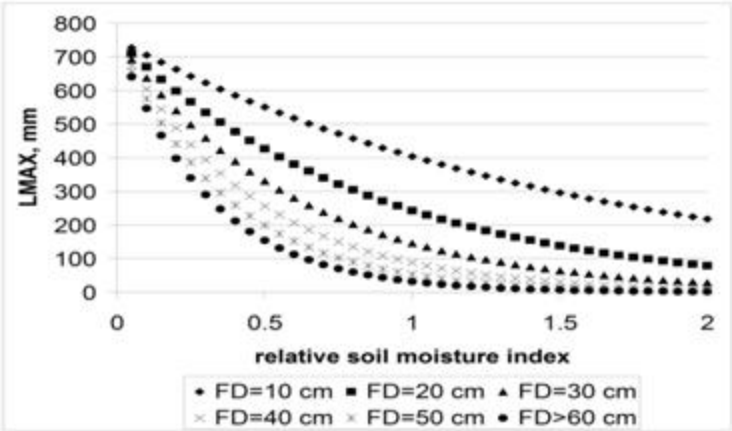
where $X_1, X_2 \ldots X_n$ are the runoff index variables

(e.g. autumn-precipitation index; winter-precipitation index; snow-water-equivalent index; spring-precipitation index (usually climatic mean)

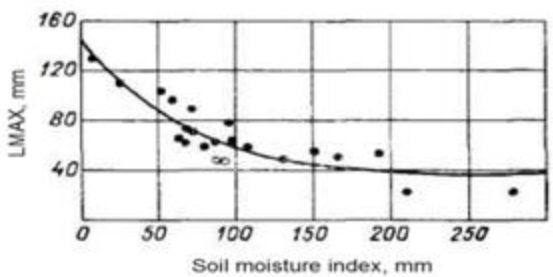
Physical-statistical methods (Russian practice)

$$Y^{*}_{sum} = \left(SWE + P^{*}_{sum}\right) - LMAX\left[1 - \exp\left(\frac{-\left(SWE + P^{*}_{sum}\right)}{LMAX}\right)\right]$$

a



b



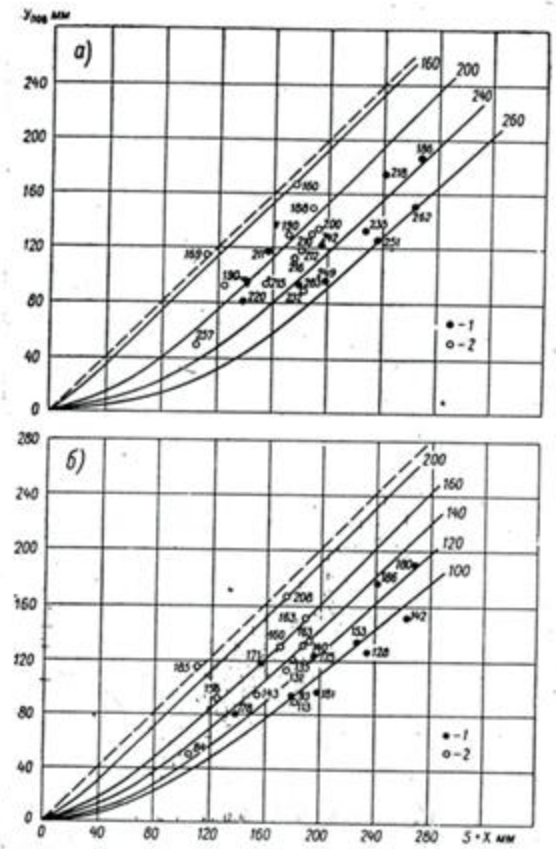


Рис. 20. Вятка до Вятских Полян. Зависимость весеннего стока ($Y_{пов}$) от величины максимальных запасов воды в снежном покрове и в ледяной корке (S) и осадков периода снеготаяния (X). Цифры около точек и линий: *а* — дефицит влаги в почве с учетом глубины ее промерзания, *б* — содержание продуктивной влаги в метровом слое почвы; *1* — глубина промерзания менее 80 *см*, *2* — глубина промерзания 80 *см* и более.

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

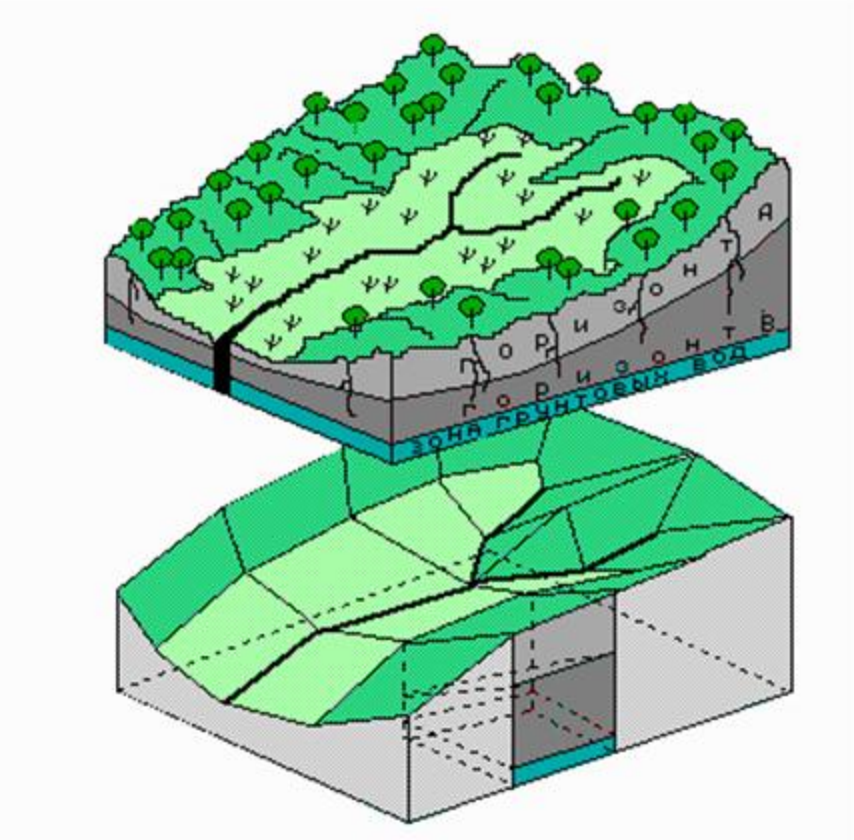
To present preliminary results on utilizing seasonal meteorological forecast for decreasing hydrological forecast uncertainty

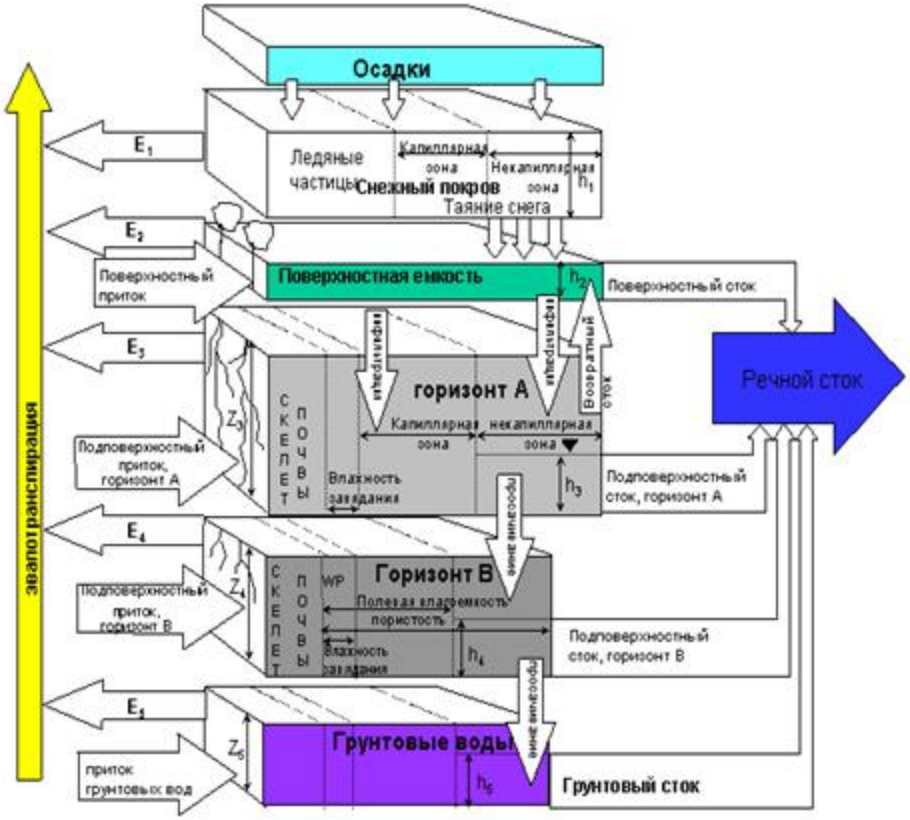
Distributed physically based model ECOMAG (Ecological Model for Applied Geophysics)

Motovilov, Yu., Gottschalk, L., Engeland K. & Rodhe A. (1999) Validation of a distributed hydrological model against spatial observation. *Agric. For. Meteorol.* 98–99, 257–277.

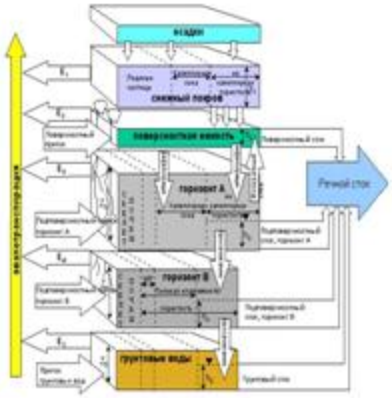
Motovilov, Yu., Gottschalk, L., Engeland, K., & Belokurov, A. (1999) ECOMAG – regional model of hydrological cycle. Application to the NOPEX region. Department of Geophysics, University of Oslo, Institute Report Series no. 105.

Gottschalk, L., Beldring, S., Engeland, K., Tallaksen, L., Salthun, N. R., Kolberg, S. & Motovilov, Yu. (2001) Regional/macroscale hydrological modelling: a Scandinavian experience. *Hydrol. Sci. J.* 46(6), 963–982





Vertical structure of ECOMAG



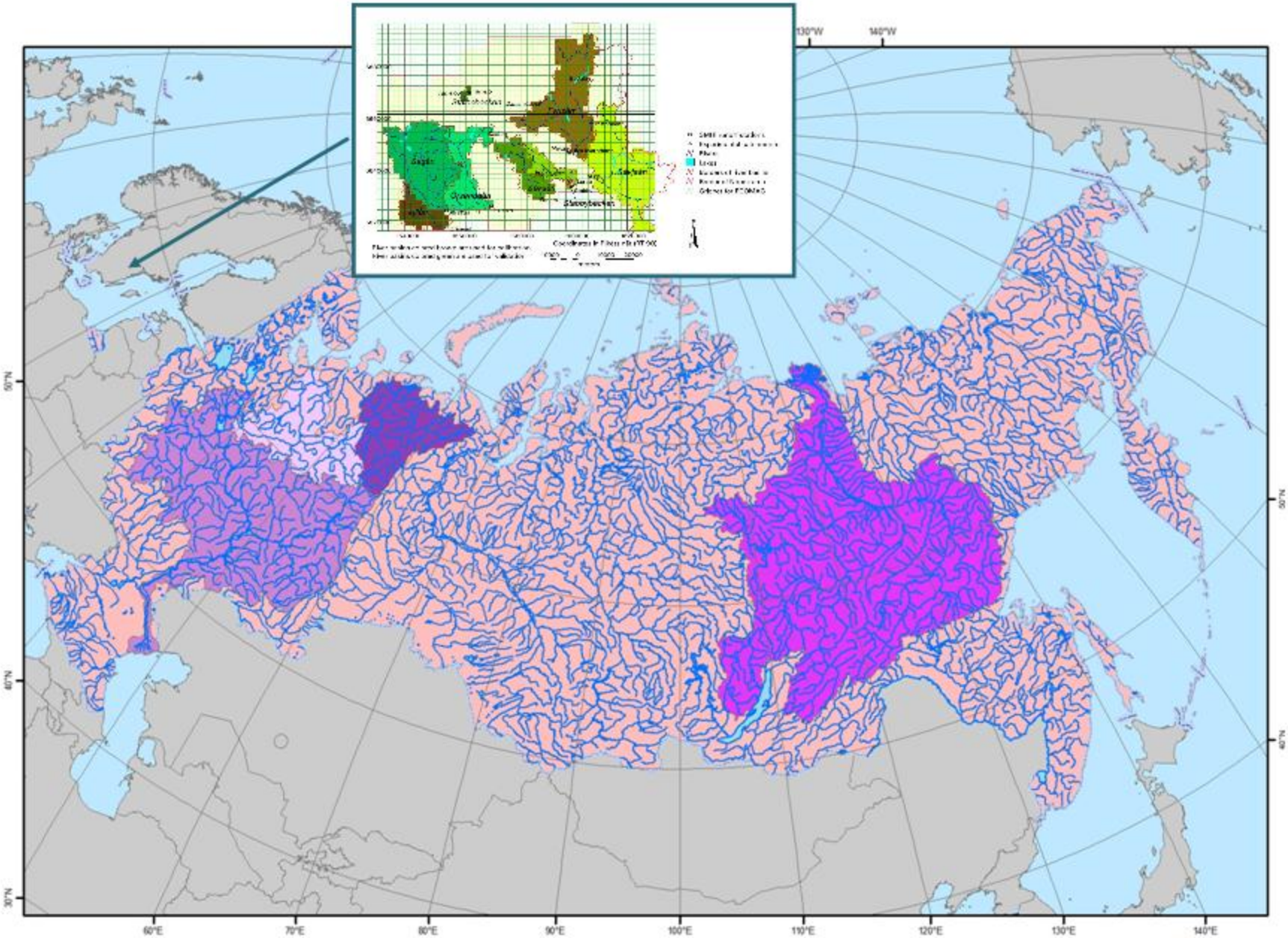
Input variables:

Daily precipitation

Daily air temperature

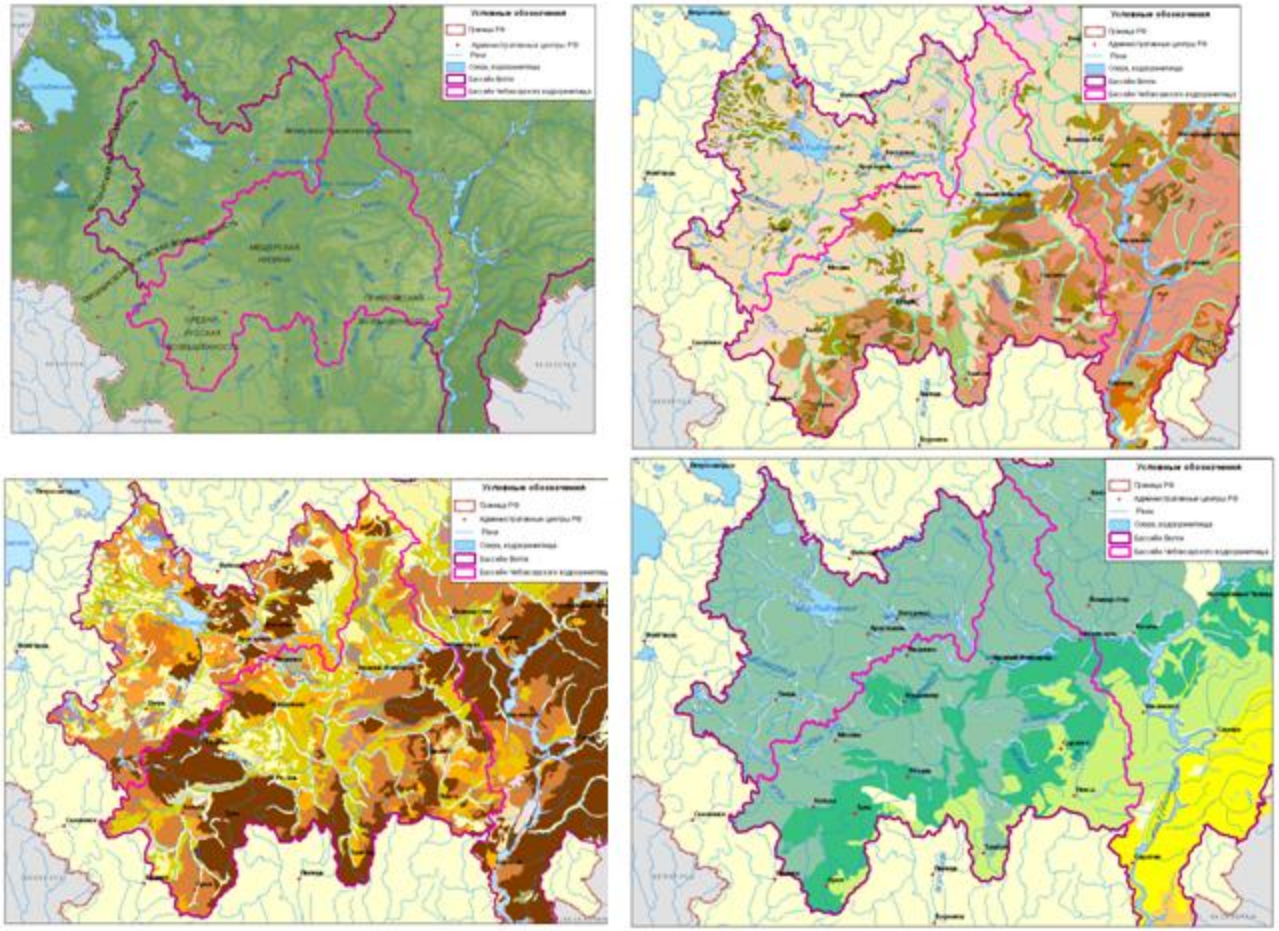
Daily air humidity

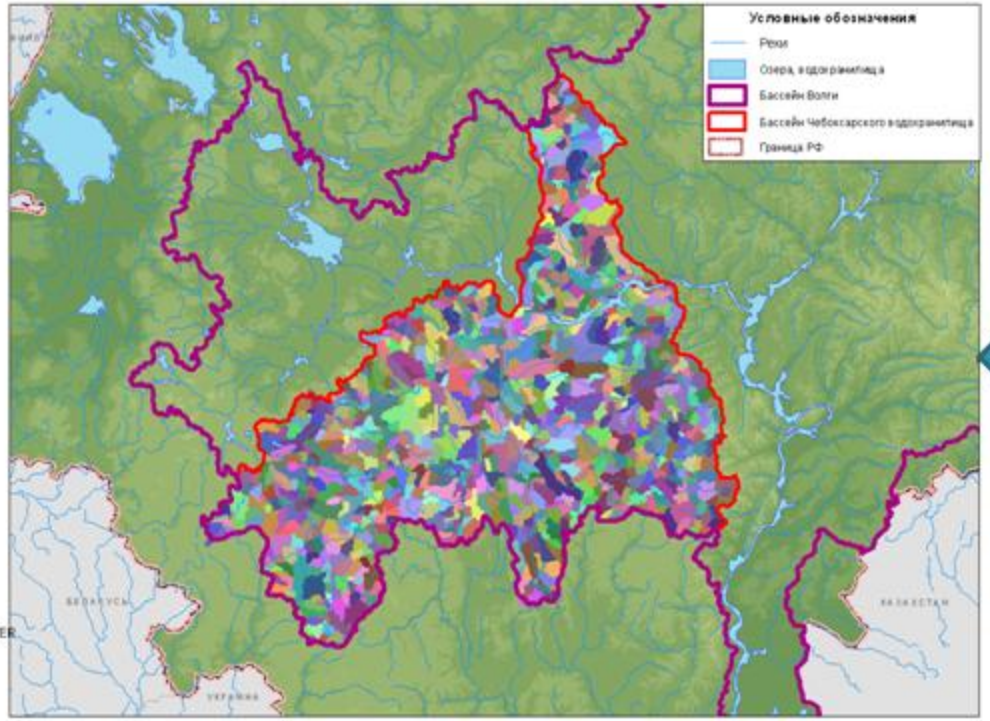
Examples of ECOMAG applications



Case Study: Cheboksary Reservoir

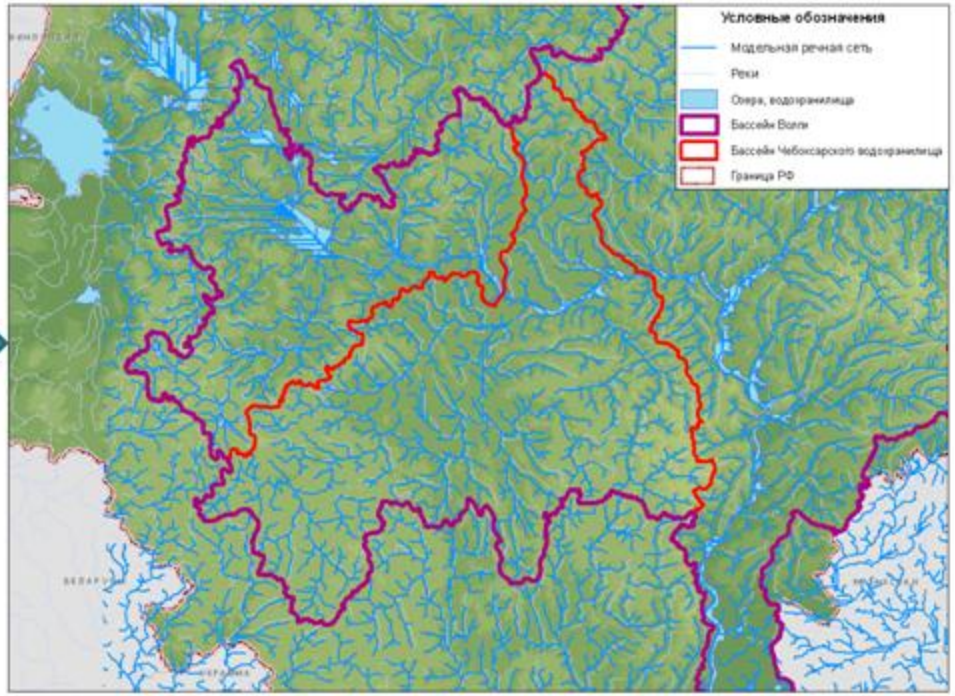
Basic GIS information for ECOMAG



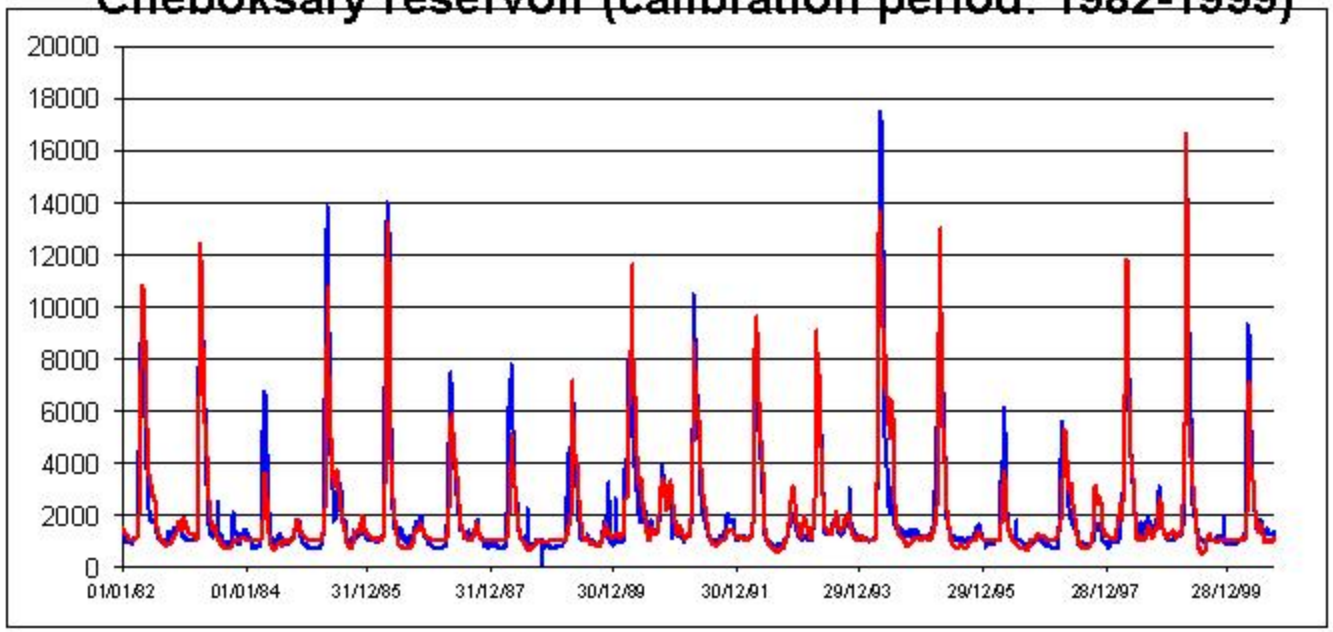


Spatial discretization of the Chrboksary res. basin onto calculation elements (elementary basins)

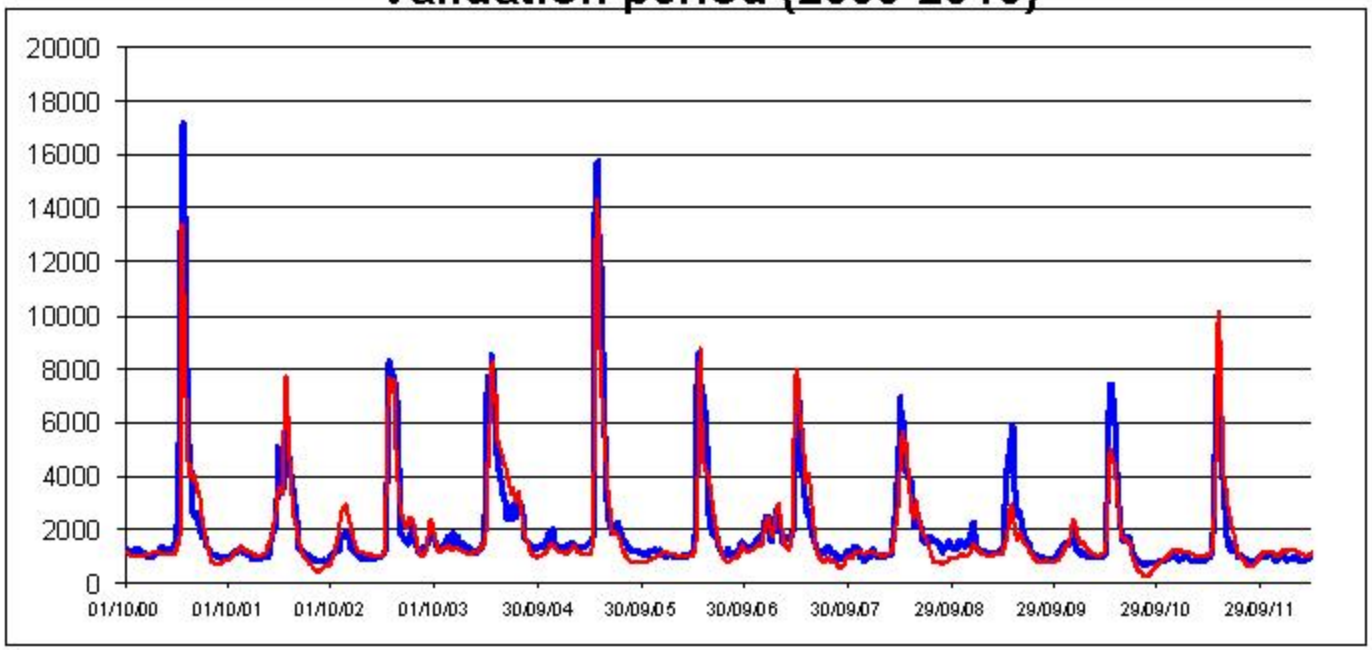
Modelled river network



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



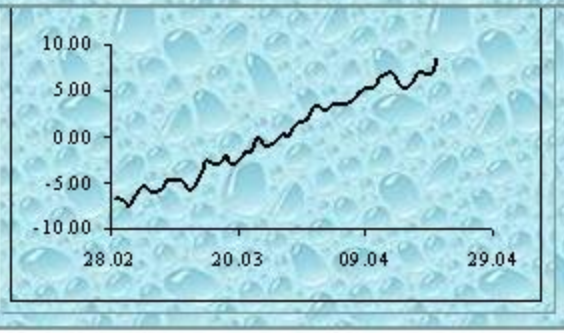
Validation period (2000-2010)

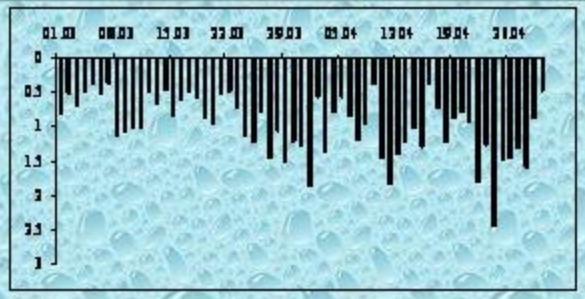


Deterministic long-term forecast

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)



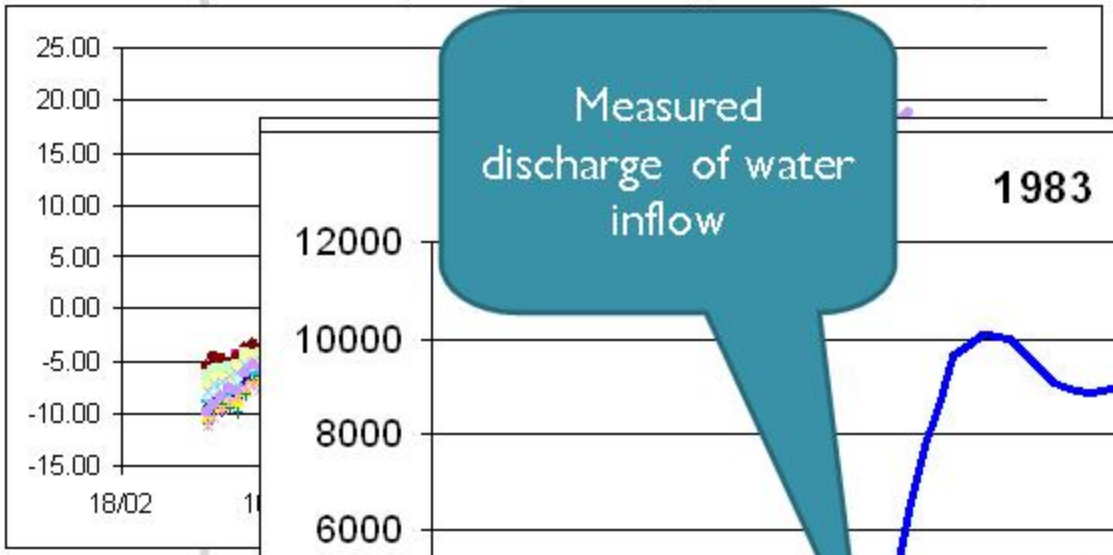


ECOMAG

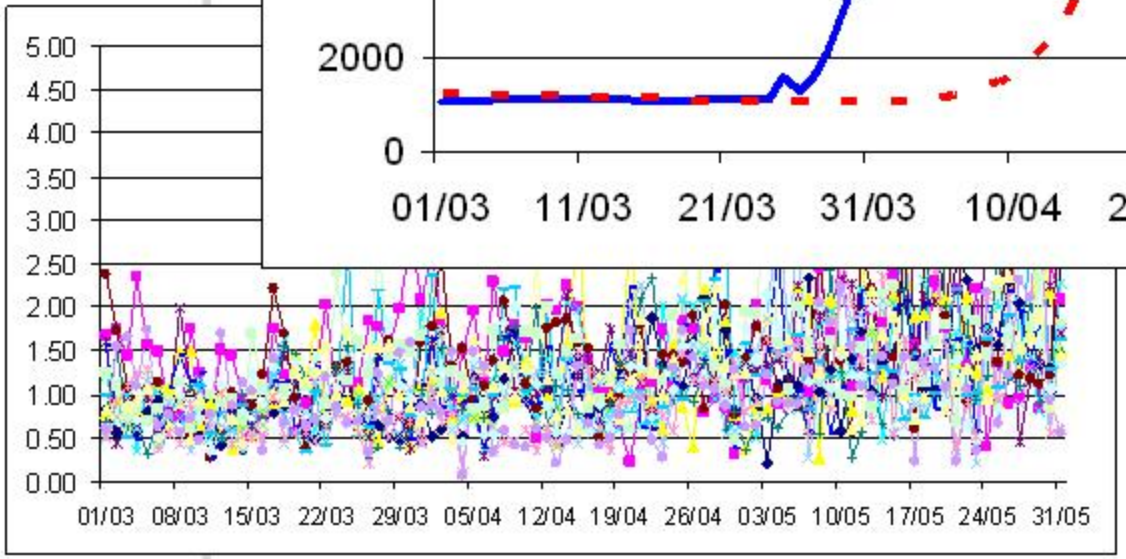
Deterministic Forecast of flood characteristic

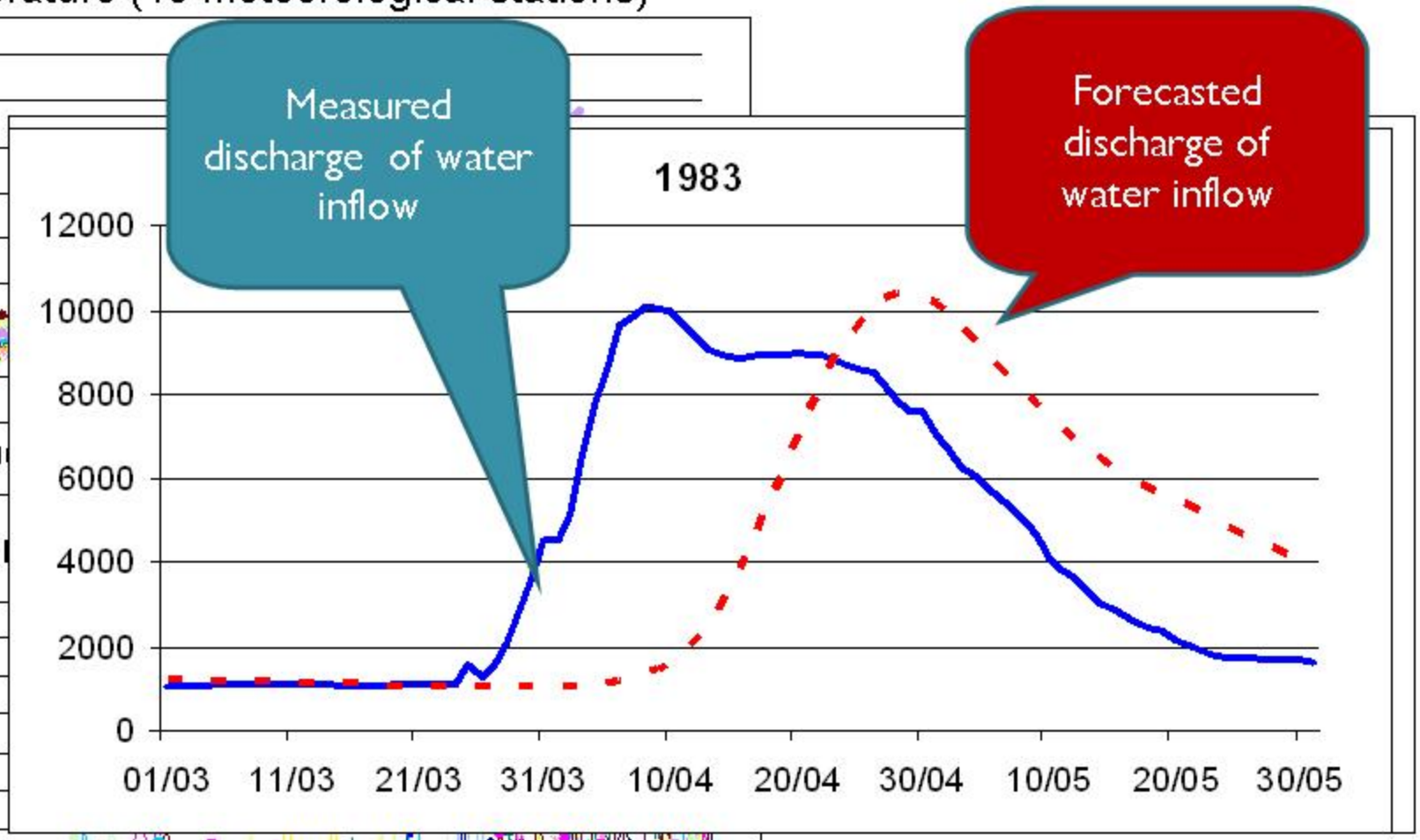
Example of a deterministic forecast using climatic mean as inputs into ECOMAG

Air temperature (15 meteorological stations)

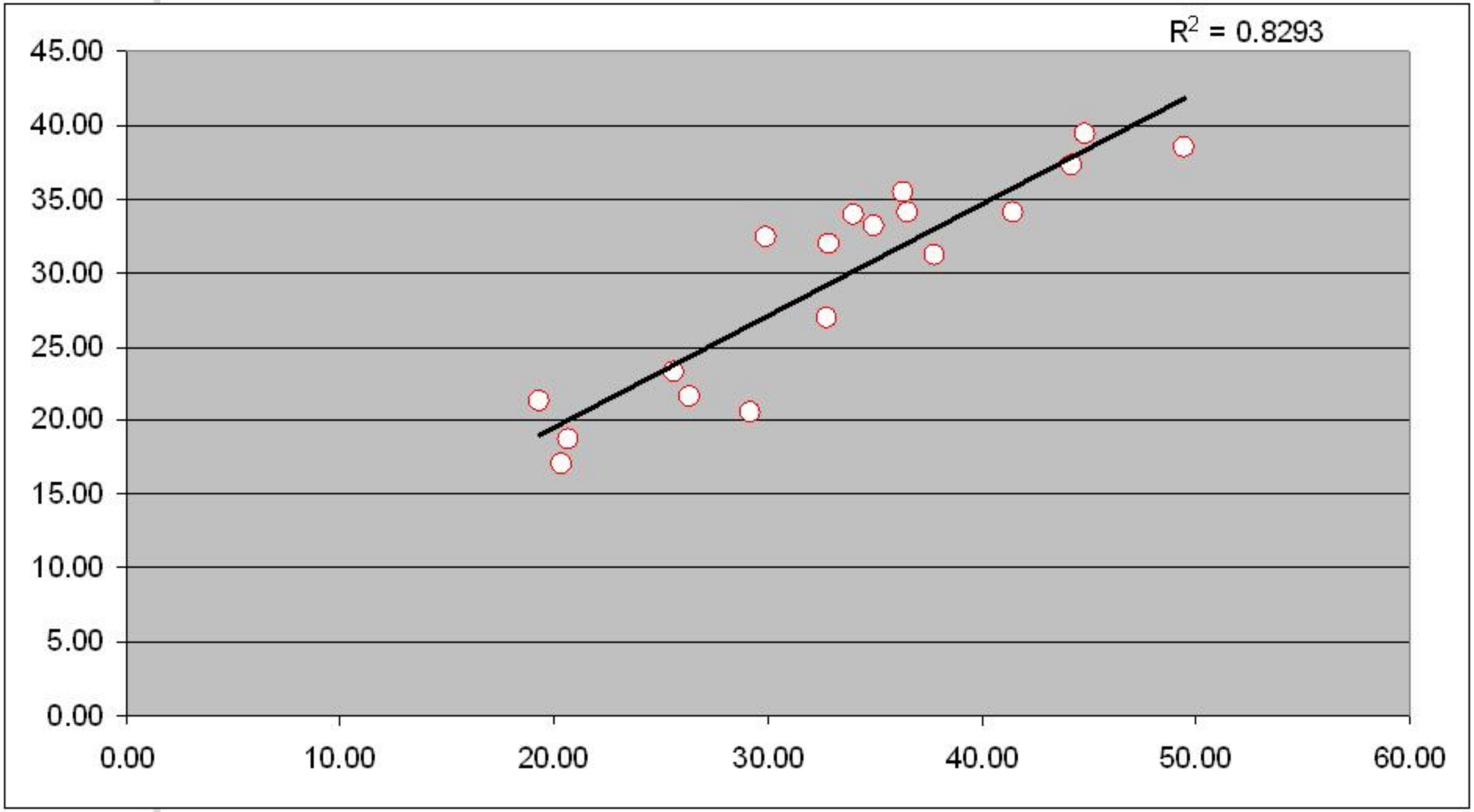


Precipitatio

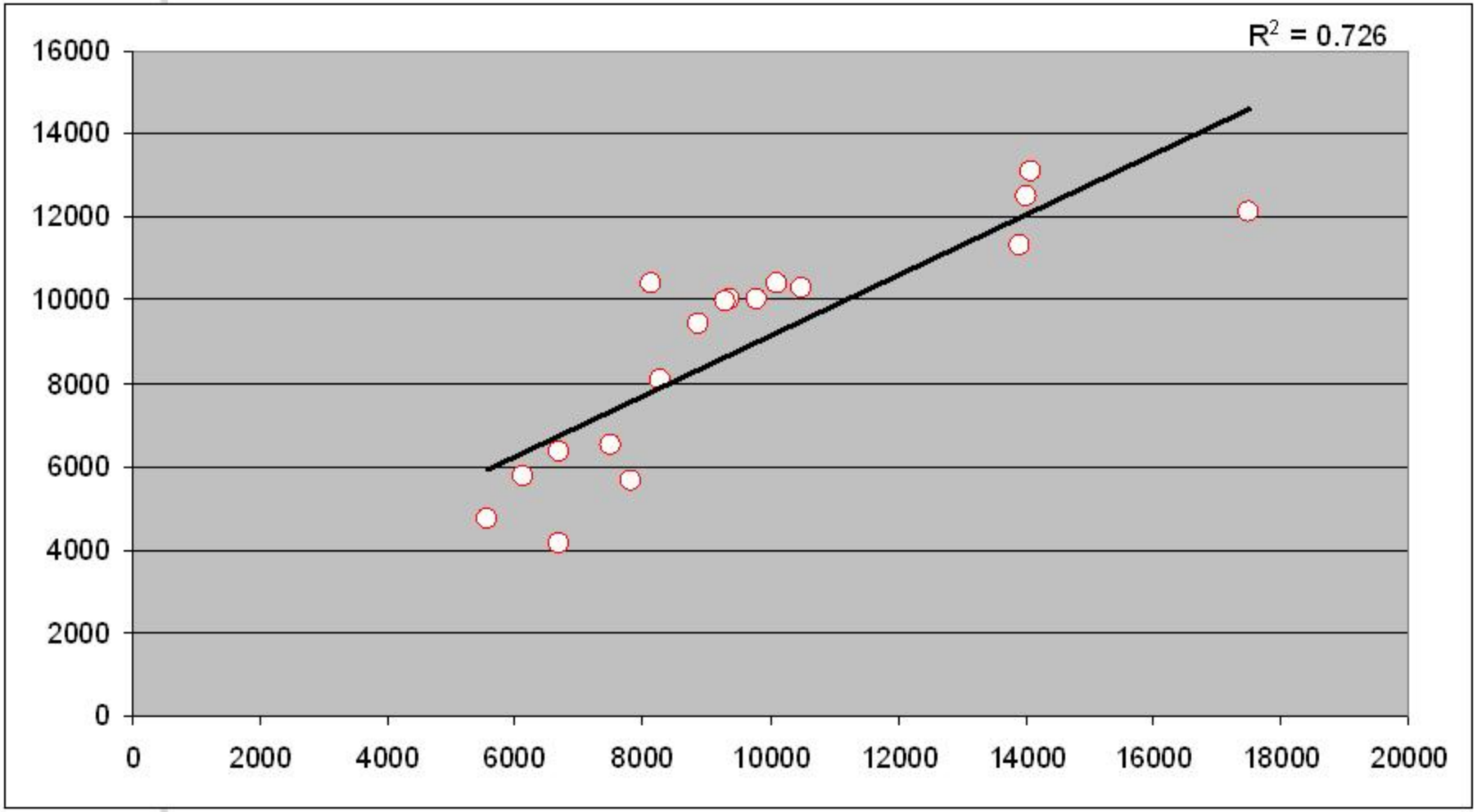




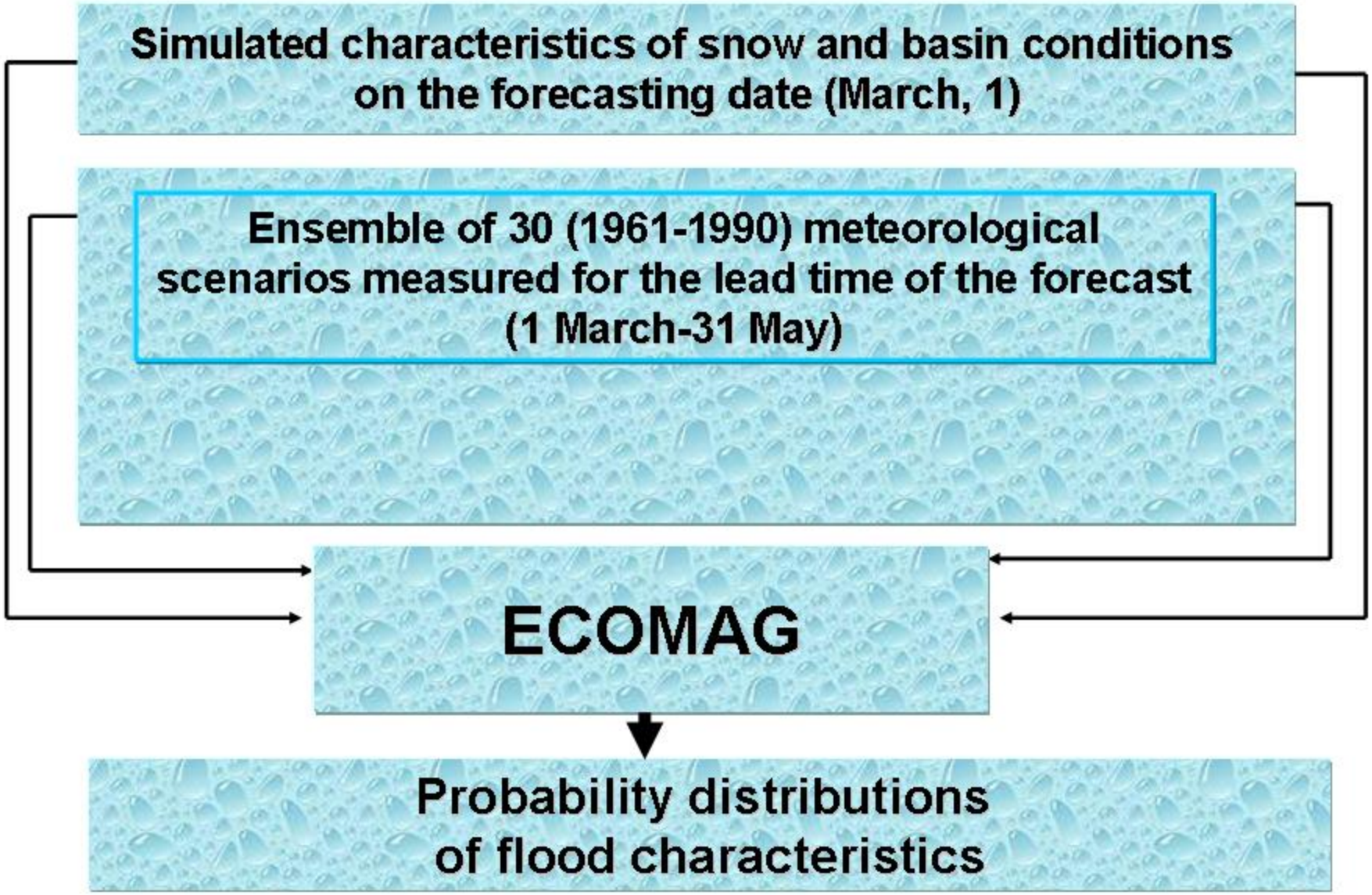
Forecasted vs. Measured flood volume (km^3)



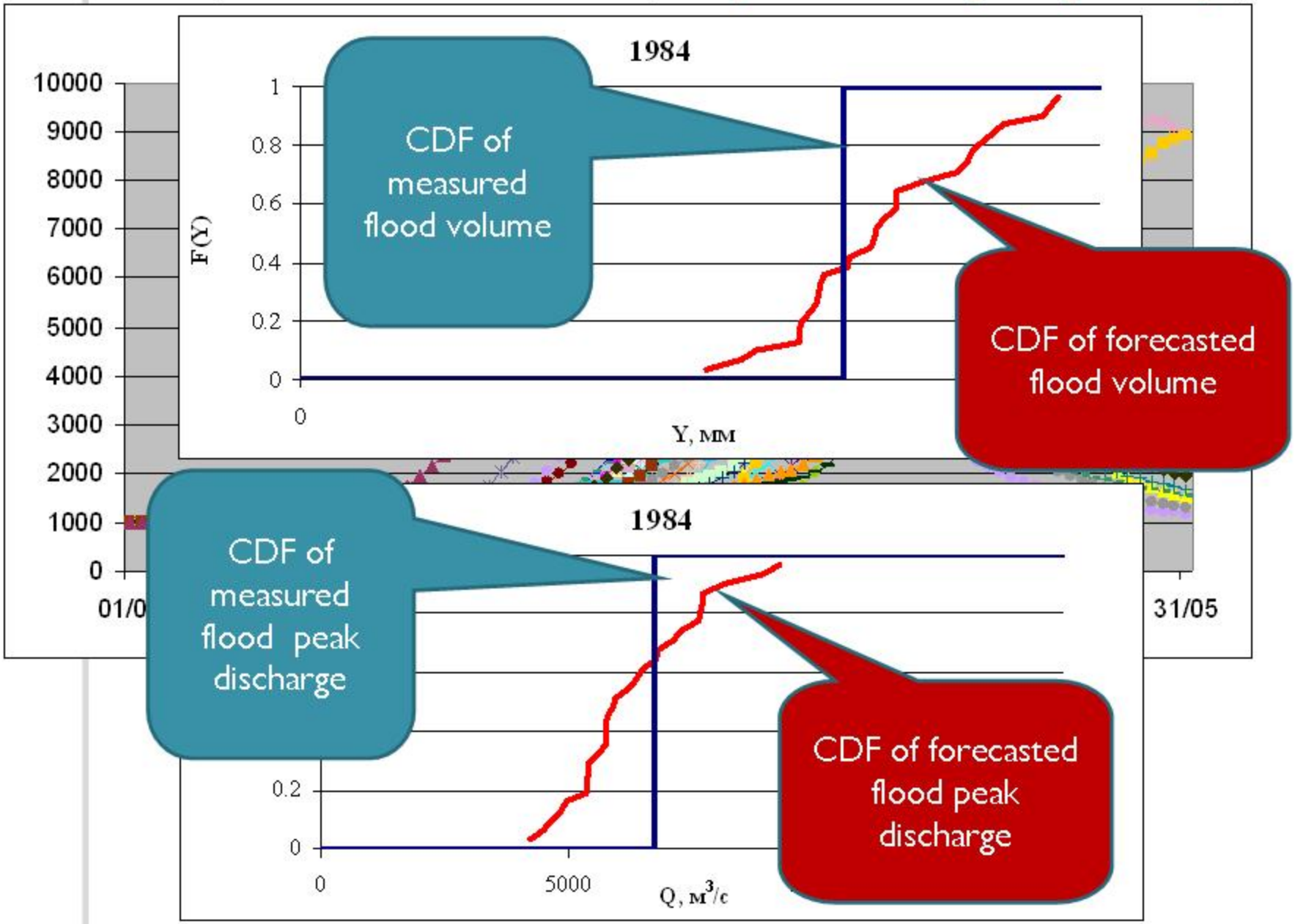
Forecasted vs. Measured flood peak discharge (m^3/s)



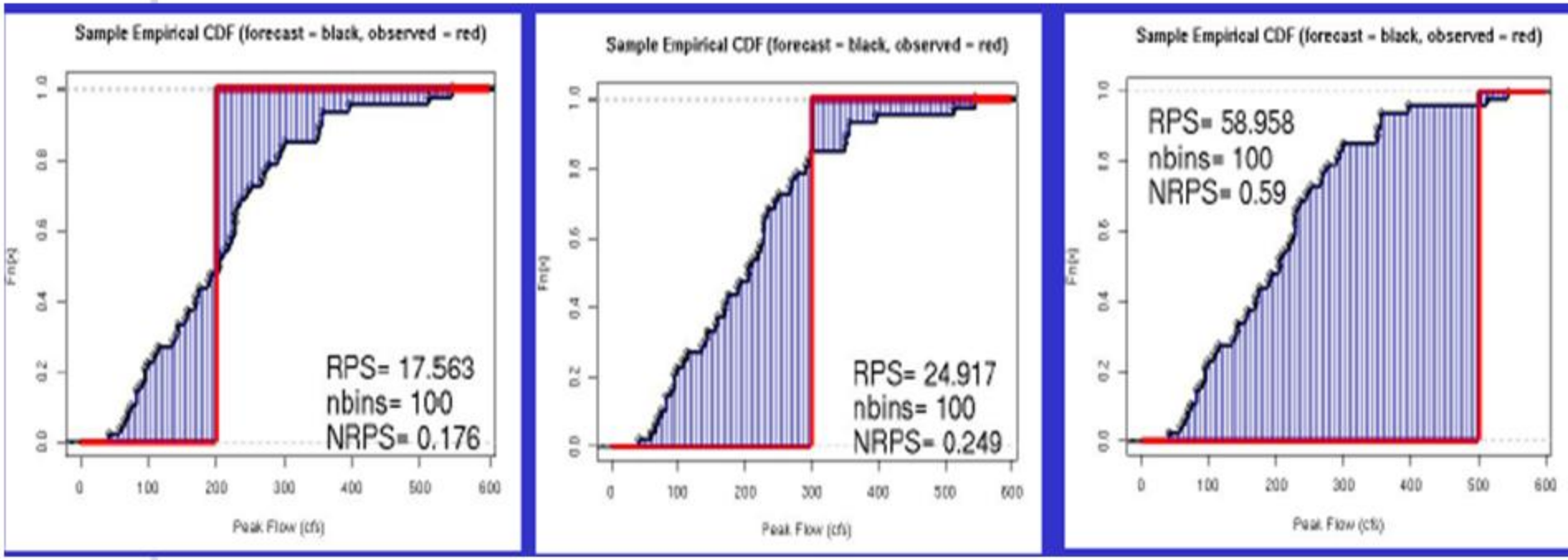
Probabilistic long-term forecast



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



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.Tolstyh (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

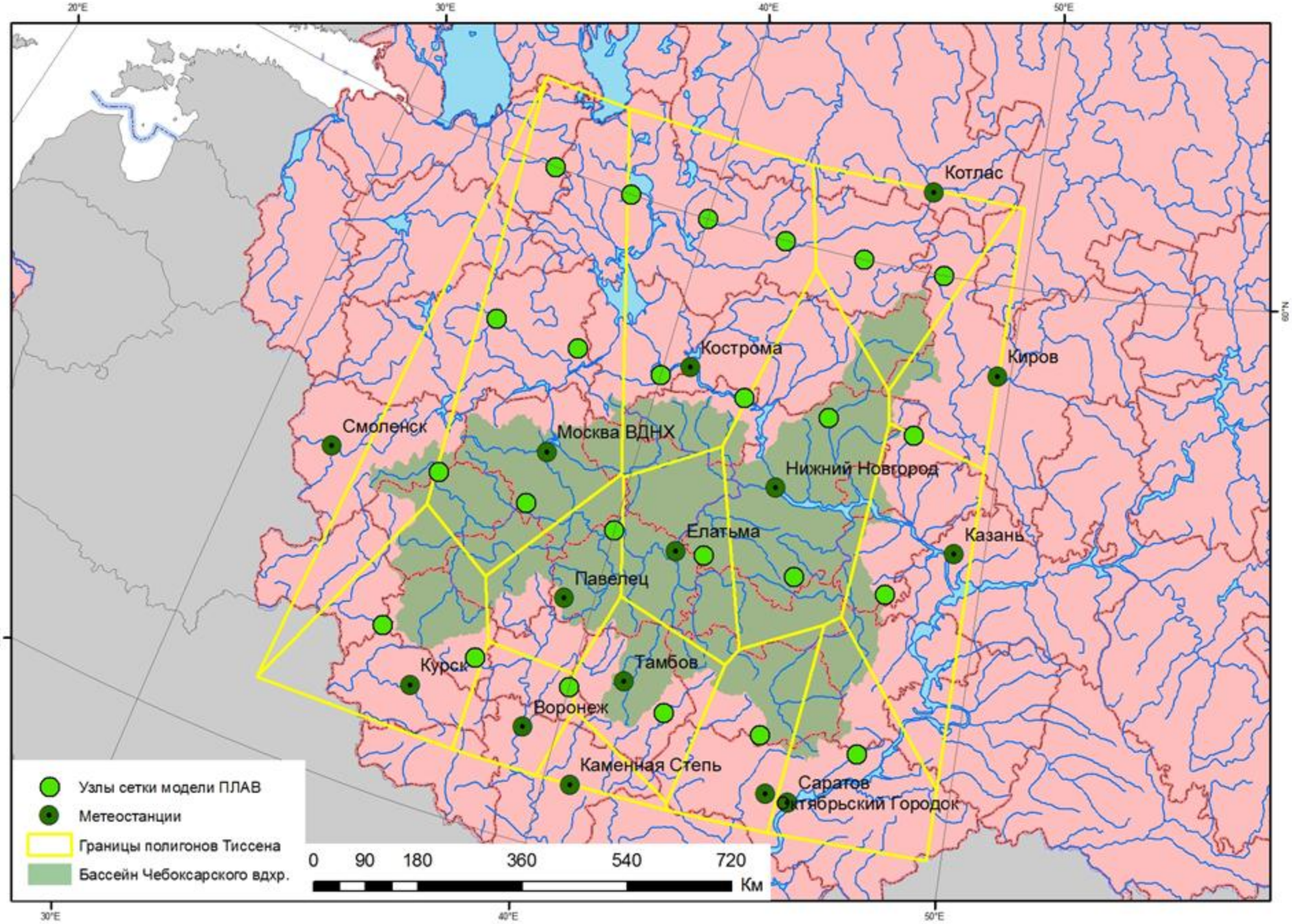
Preparation of SL-AV data for input to hydrological model

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

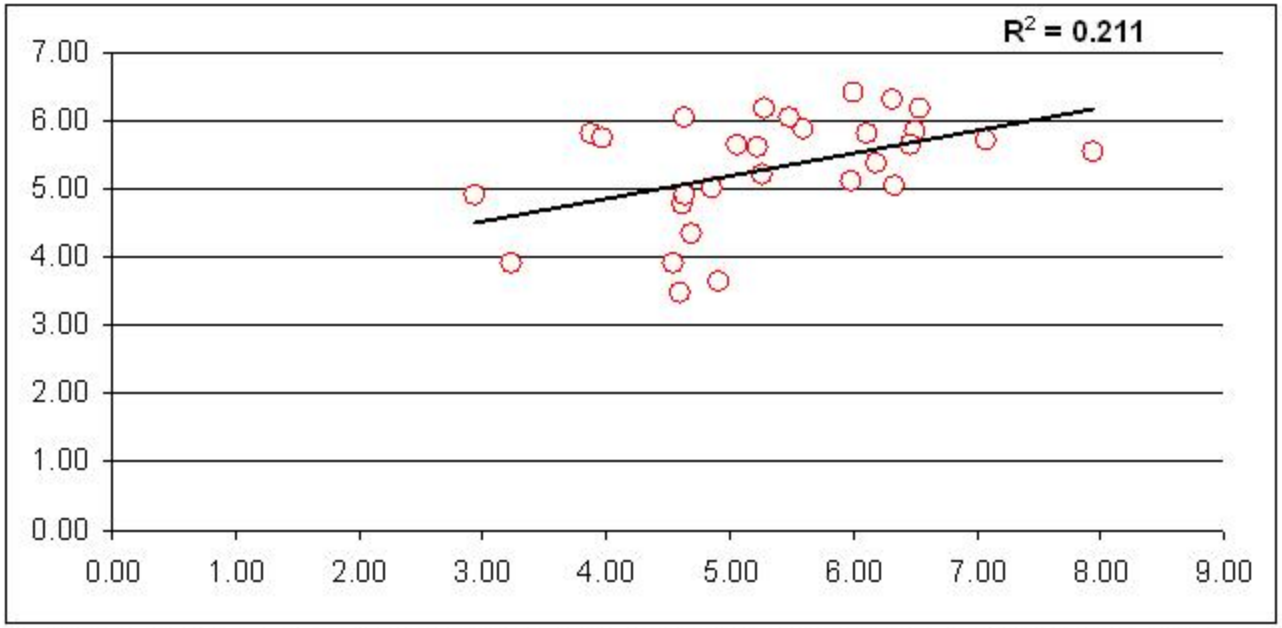
The region of interest is limited: 33E - 48.5E, 52N - 60N.
Considered season is: March-April-May
Period: 1981-2010

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

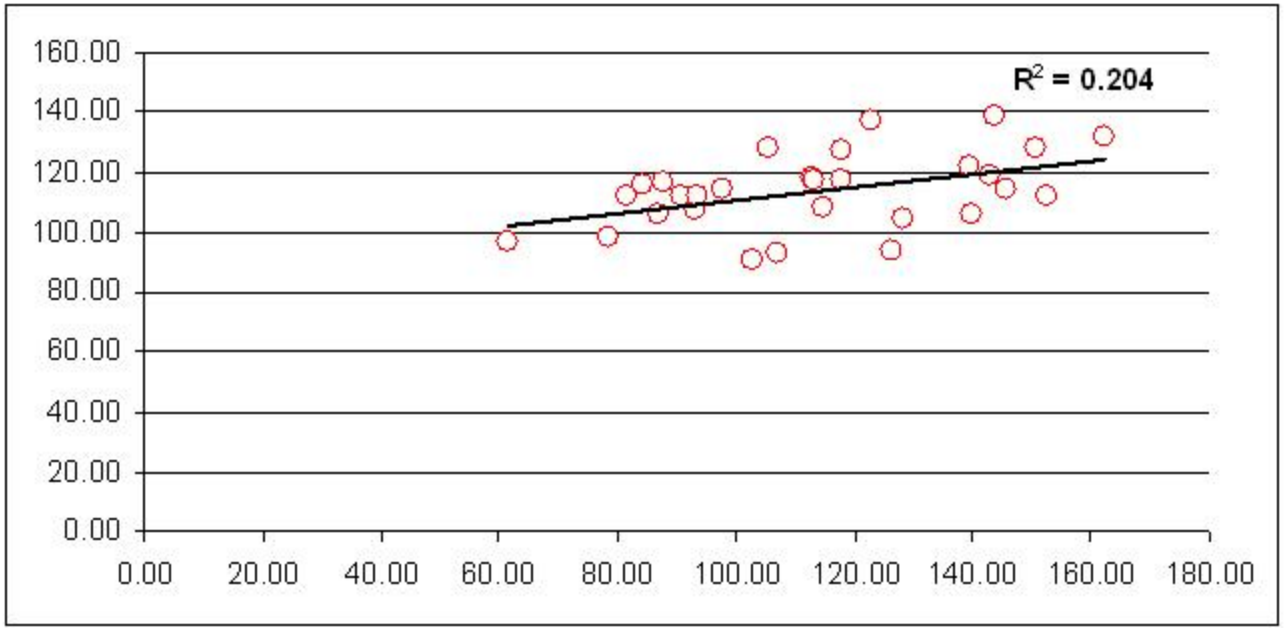
Uncertainty of atmospheric data served as input for hydrological model is represented by ensemble.


20°E
30°E
40°E
50°E
Котлас
Кострома
Киров
Смоленск
Москва ВДНХ
Нижний Новгород
Елатьма
Казань
Павелец
Курск
Тамбов
Воронеж
Каменная Степь
Саратов
Октябрьский Городок
Узлы сетки модели ПЛАВ
Метеостанции
Границы полигонов Тиссена
Бассейн Чебоксарского вдхр.
0 90 180 360 540 720
Км

Mean ensemble temperature: III-V forecast vs. observation (1981-2009)



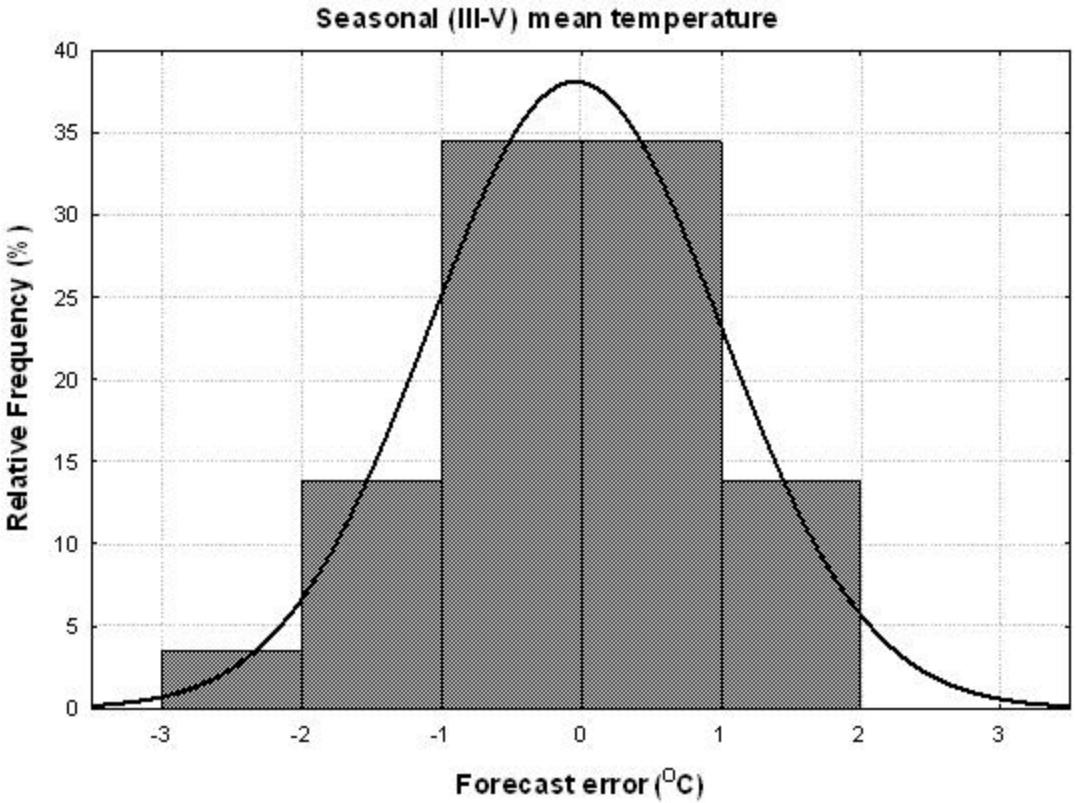
Mean ensemble precipitation sum: III-V forecast vs. observation (1981-2009)



Post-adjustment technique (Werner et al., 2005)

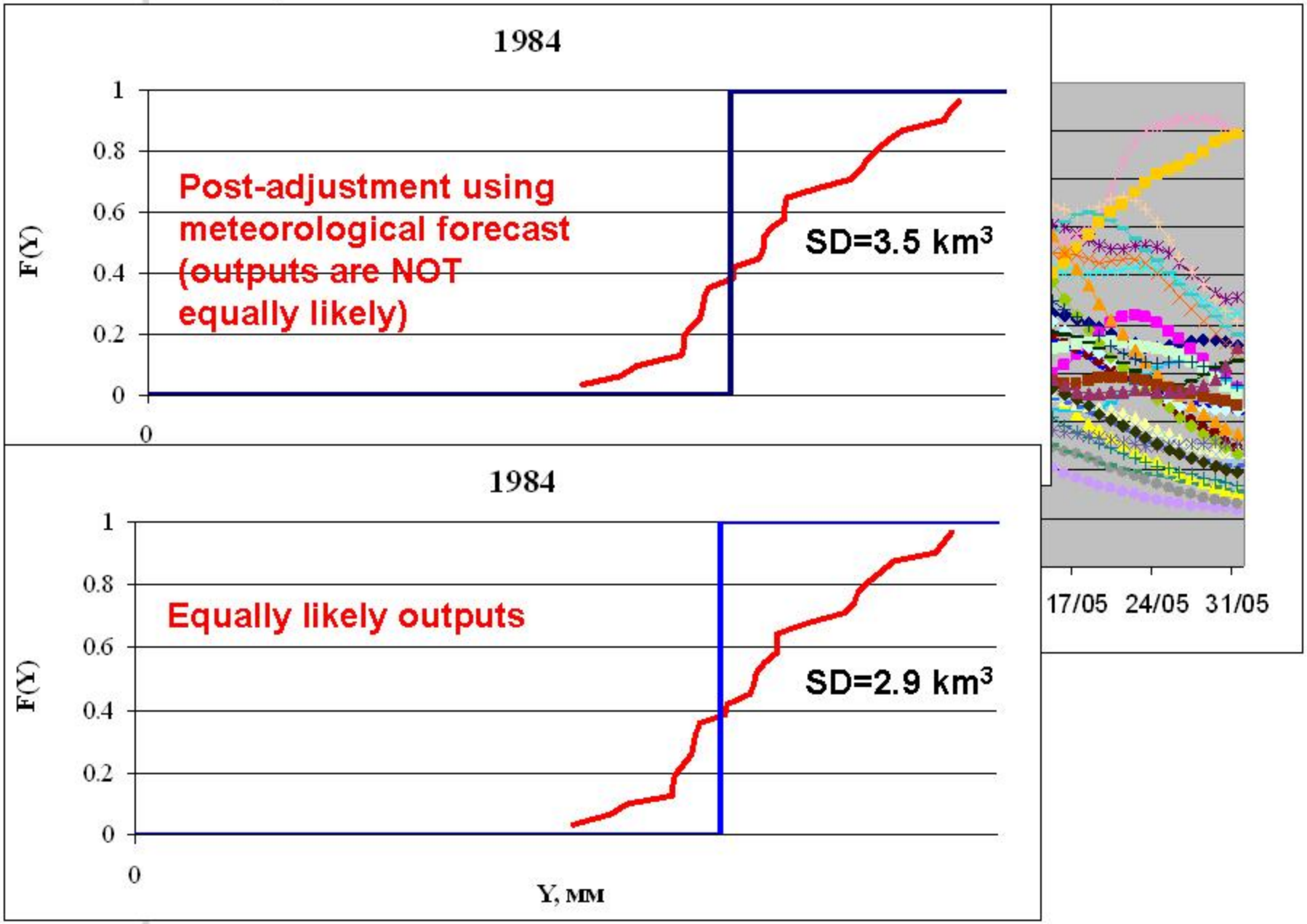
Post-adjustment technique allows to weight the predicted hydrological traces according to how well their particular weather forcing agrees with a particular seasonal meteorological forecast.

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



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