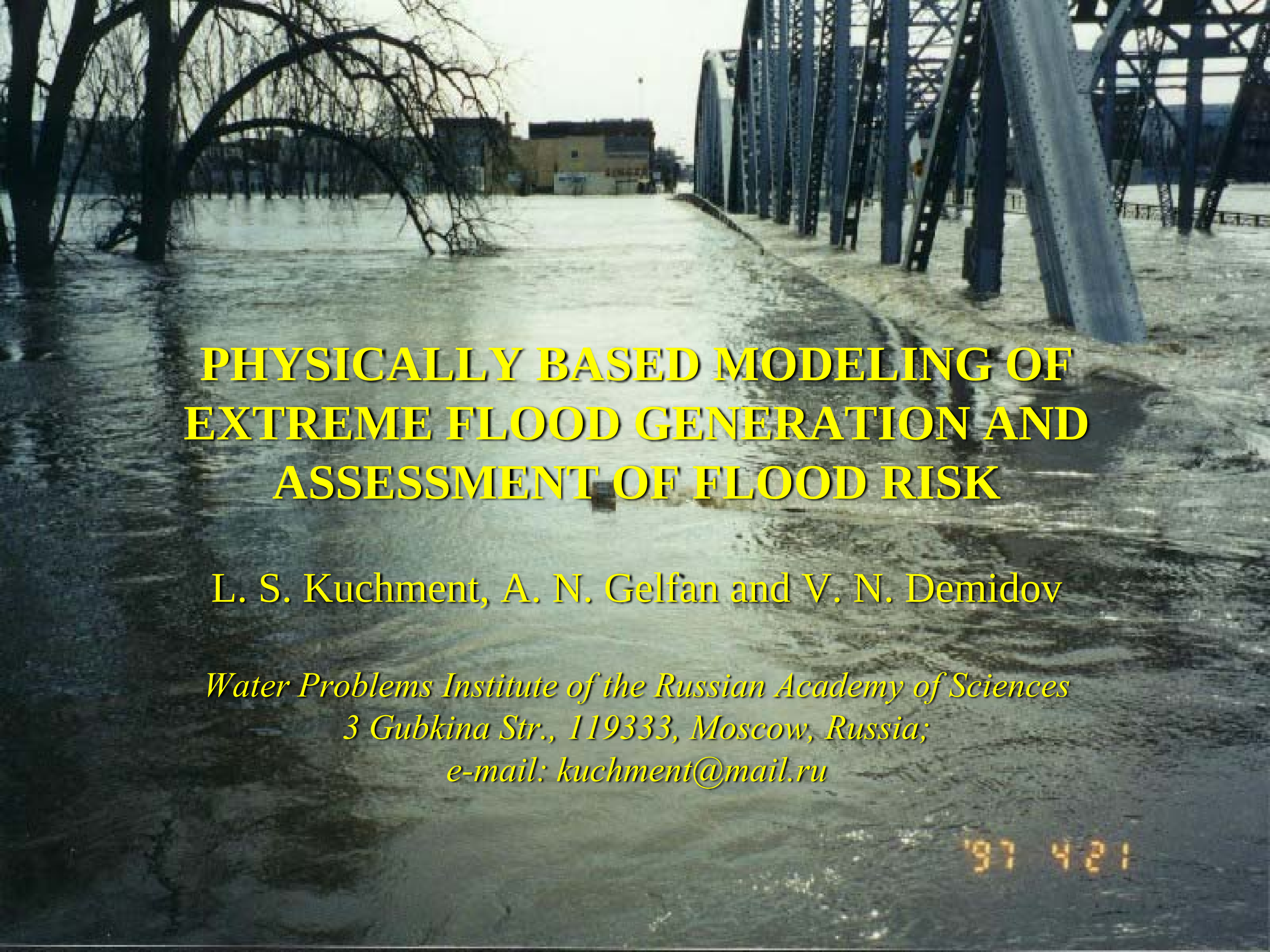

PHYSICALLY BASED MODELING OF EXTREME FLOOD GENERATION AND ASSESSMENT OF FLOOD RISK

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Main directions of investigating:

- Analysis of generation mechanisms of extreme floods using the Russian data
- Development of physically based models of flood generation mechanisms
- Developing a technique of estimating the probable maximum flood using physically based models
- Probabilistic characterization of extreme floods using dynamic-stochastic runoff generation models

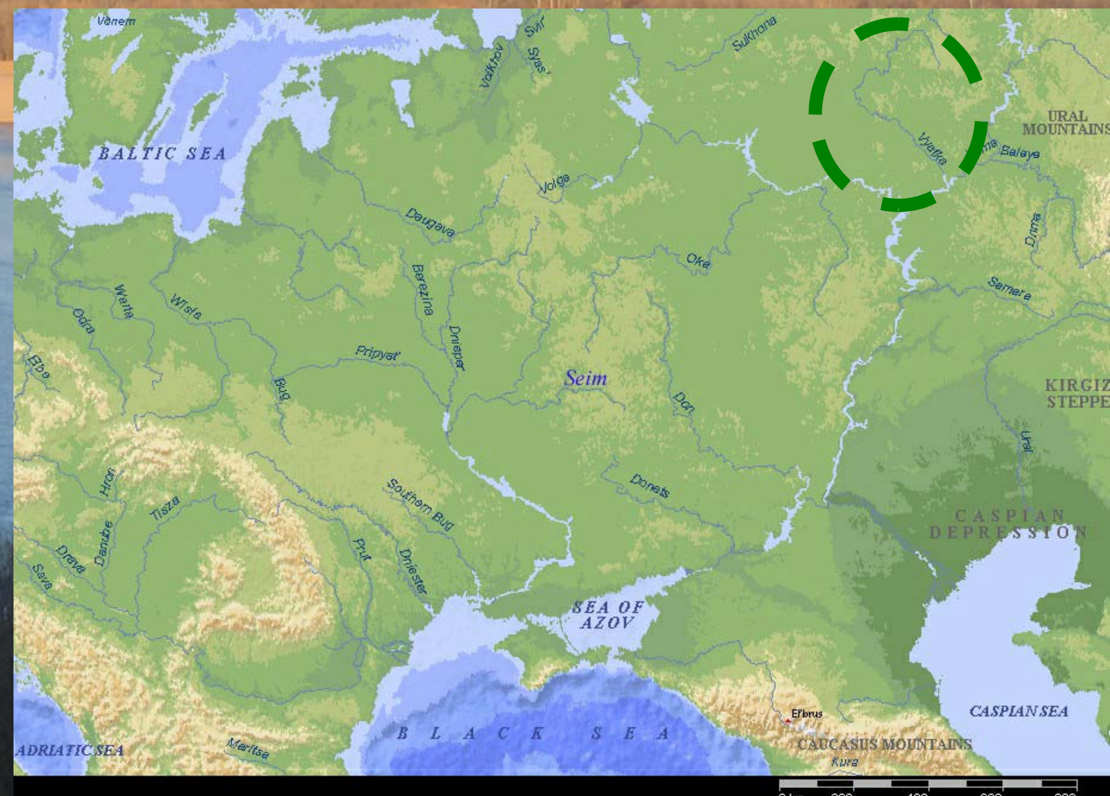
In many cases, the extreme floods can be resulted from unusual combinations of hydrometeorological factors that may be unobserved in the historical data. At the same time, because of nonlinearity of hydrological processes, the physical mechanisms of extreme flood generation are often quite different from such mechanisms for usual floods.

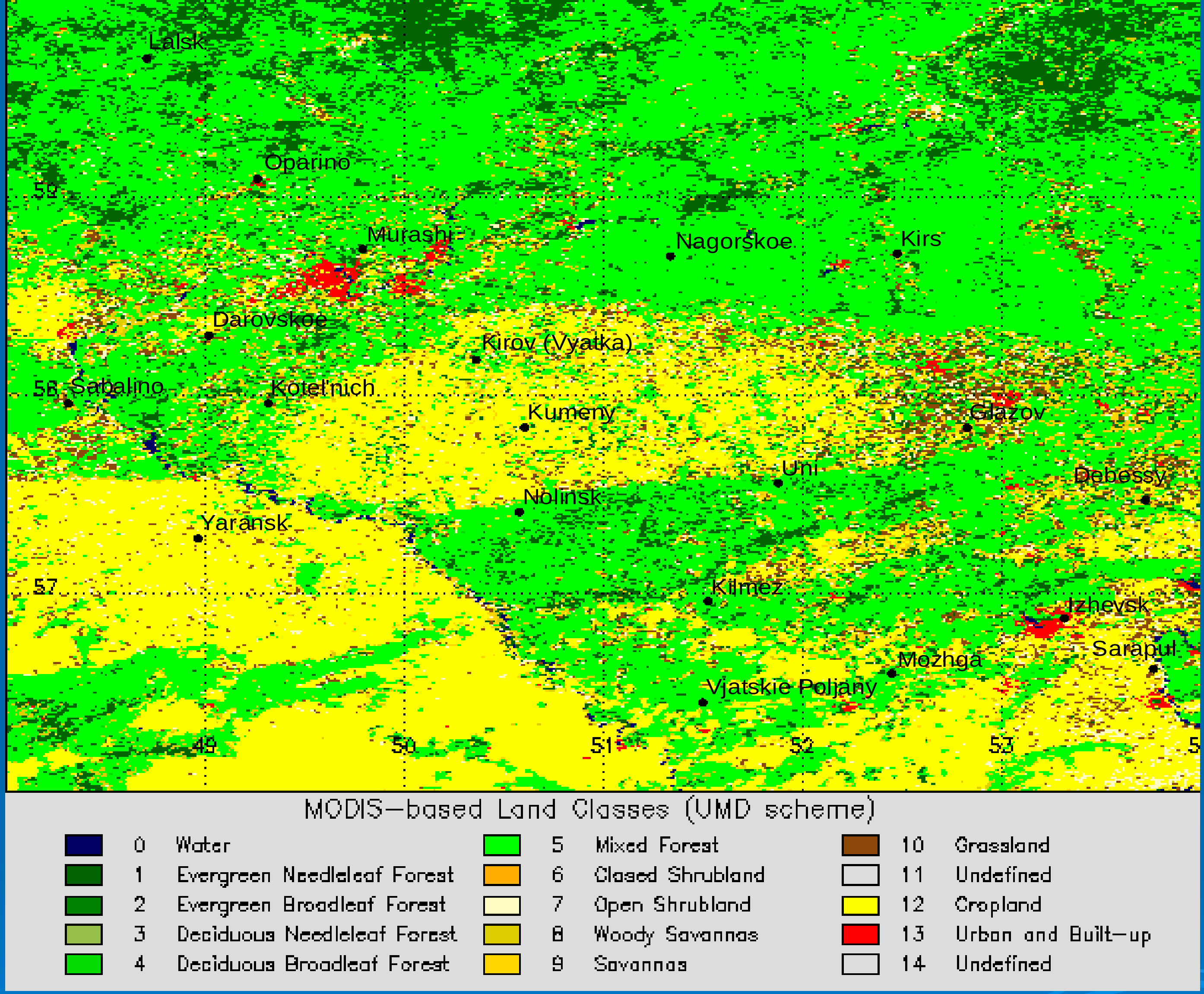
The detailed physically based models of runoff generation give opportunities to estimate the hydrographs of floods for possible combinations of meteorological and hydrological conditions, taking into account the specific physical mechanisms of extreme flood generation and the change of drainage basin characteristics. At the same time, coupling these models with stochastic models of meteorological inputs (weather generators) and with the Monte Carlo procedure of simulation of meteorological series allows one to estimate the risk of floods through the probabilities of flood peak discharges and volumes.

At the International workshop on non-structural measures for water management problems carried out in London, Ontario, Canada in October 2001, we presented our results in developing a methodology of estimation of risk and characteristics of extreme floods based on coupling the WPI models of runoff generation and the Monte Carlo simulation of meteorological input (Kuchment and Gelfan, 2002). In that presentation the Seim River basin with the drainage area of 7460 km^2 situated in the forest-steppe zone of Russia (in the Dnieper River basin) was chosen as the case study area. In following investigations we continue to advance this methodology using several other case study areas. In this paper we present our results obtained for the Vyatka River basin situated in the forest zone of Russia.

Case study: Vyatka River

The Vyatka River starts in the foothills of the central Urals and continues into the East European Plain. The drainage area of the Vyatka River basin is 124000 km^2.





Land cover classes and location of meteorological stations

WPI System of Runoff Generation Models

The model of runoff generation is based on the finite-element schematization of the river basin and describes the following main processes: snow cover formation and snowmelt, soil freezing and thawing, infiltration into frozen and unfrozen soil, vertical water transfer in an unfrozen soil, evaporation, overland and channel flow.

Channel Flow

$$\frac{1}{C}\frac{\partial Q}{\partial t}+\frac{\partial Q}{\partial x}=\frac{D}{C}\left(\frac{\partial^2 Q}{\partial x^2}-\frac{\partial q}{\partial x}\right)+q$$

Overland Flow

$$\frac{\partial(hB)}{\partial t}+\frac{\partial(qB)}{\partial x}=q_c$$

$$q=i^{0.5}h^{1.67}Bn^{-1}$$

Subsurface Flow

$$\left(\theta_m-\theta_f\right)\frac{\partial h}{\partial t}+\frac{\partial q}{\partial x}=G$$

$$q=K(H)i_0h$$

$$K=K_0\exp(-\varphi H)$$

Finite-element schematization of the Vyatka River basin

Snow cover formation and snowmelt

$$\frac{dH}{dt} = \rho_w \left[X_s \rho_0^{-1} - (S + E_s)(\rho_i I)^{-1} \right] - V$$

$$\frac{d}{dt}(\rho_i I H_s) = \rho_w (X_s - S - E_s) + S_i$$

$$\frac{d}{dt}(\rho_w w_s H_s) = \rho_w (X_l + S - R_s) - S_i$$

Water and heat transfer in a frozen soil

$$\frac{\partial \theta}{\partial t} = -\frac{\rho_i}{\rho_w} \frac{\partial I}{\partial t} + \frac{\partial}{\partial z}\left(D \frac{\partial \theta}{\partial z} + D_I \frac{\partial I}{\partial z} - K \right)$$

$$c_T \frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(\lambda \frac{\partial T}{\partial z}\right) + \rho_w c_w \left(D \frac{\partial \theta}{\partial z} + D_I \frac{\partial I}{\partial z} - K\right) \frac{\partial T}{\partial z} + \rho_w \chi \frac{\partial W}{\partial t}$$

Soil moisture redistribution in an unfrozen soil and evaporation

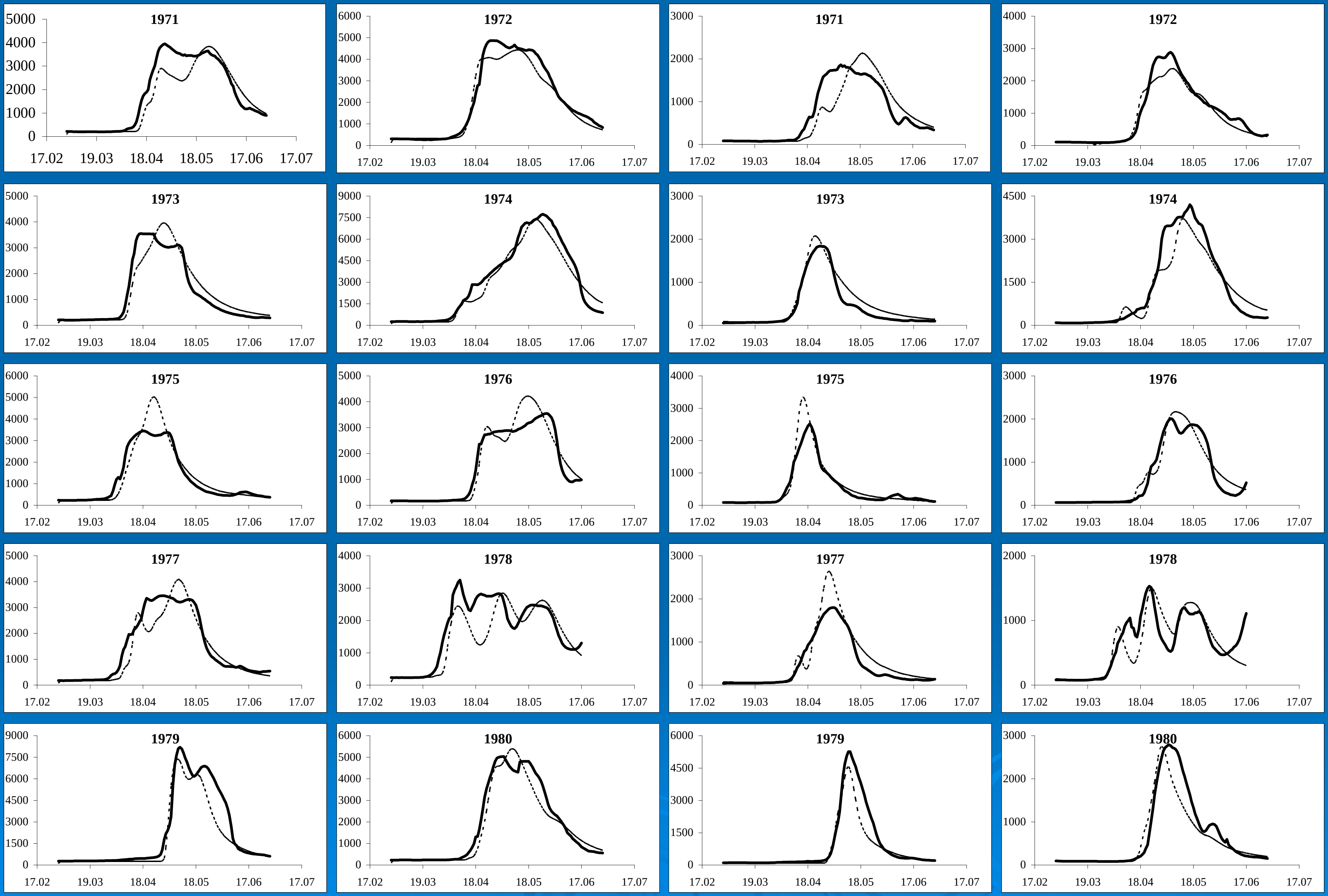
$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left[K \frac{\partial \psi}{\partial z} - K \right];$$

$$E = k_E d_a \theta(0, t)$$

Detention by a basin storage

$$DET = D_0 \left[1 - \exp\left(-\frac{R_t}{D_0} \right) \right]$$

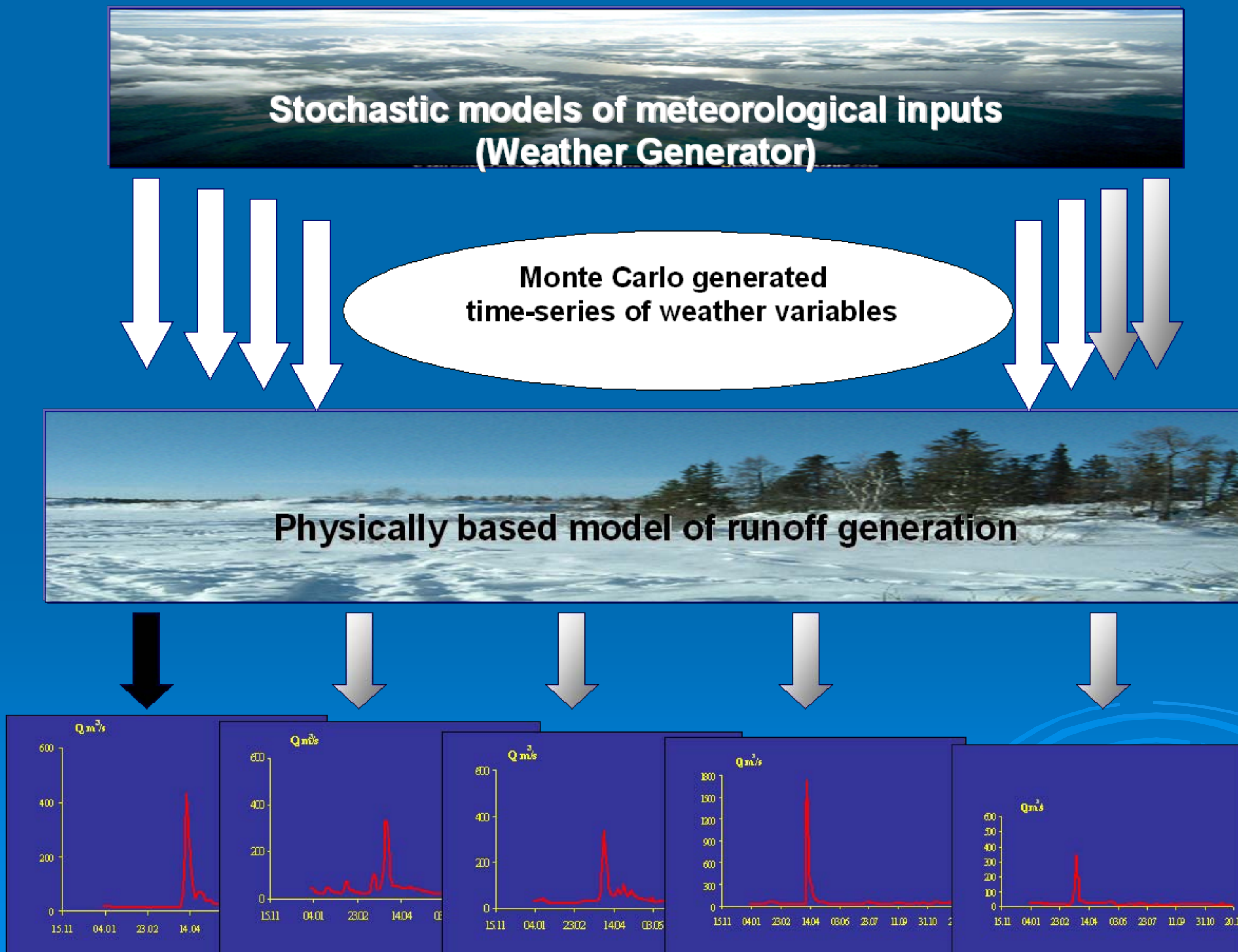
Validation of the model (1960-1980 гг.)



Vyatka (Vyatskie Polyany; 124,000 km^2)

Vyatka (Kirov; 48,000 km^2)

Schematic Diagram of the Dynamic-Stochastic Model



Weather Generator

Precipitation:

wet-dry day sequence –

1st-order Markov chain

wet-day precipitation sum –

gamma-distributed variable

Air Temperature:

method of "fragments"

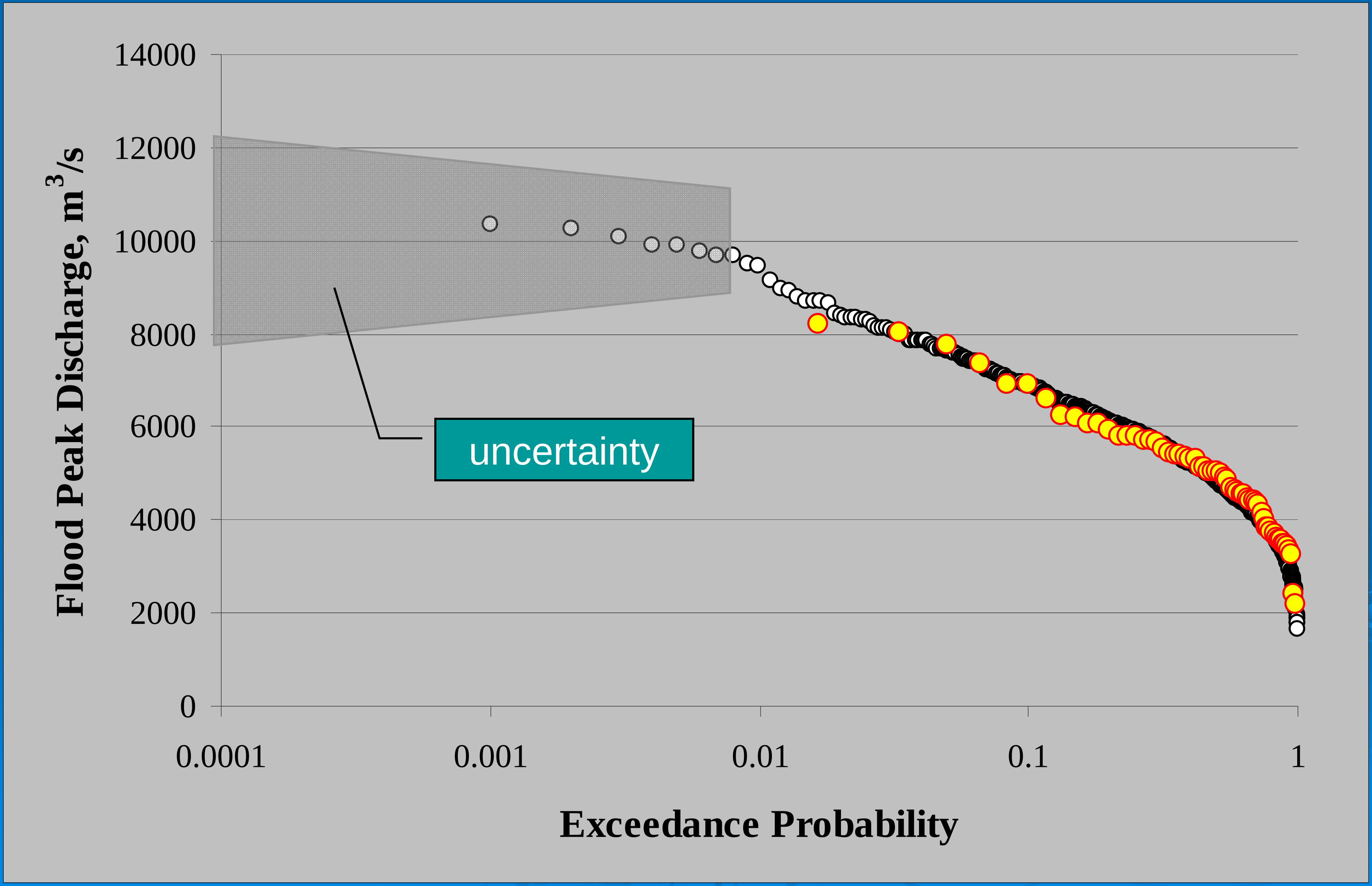
Air Humidity Deficit

lognormal distributed variables for dry days

Exceedance probabilities of the snowmelt flood peak discharges of the Vyatka River:

yellow points show observed peak discharges;

white points represent peak discharges simulated by the dynamic-stochastic model



Estimation of Probable Maximum Snowmelt Flood Discharge (PMD)

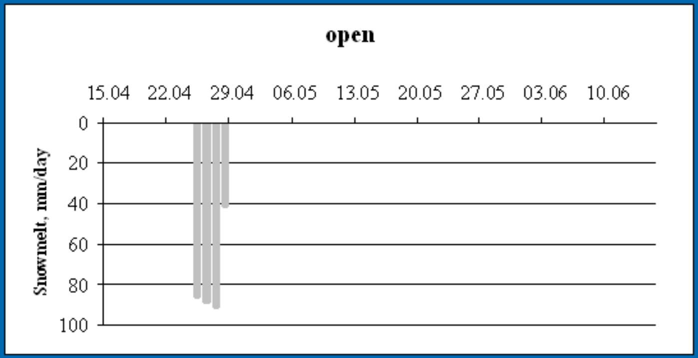
Probable maximum melt rate (mm/day)

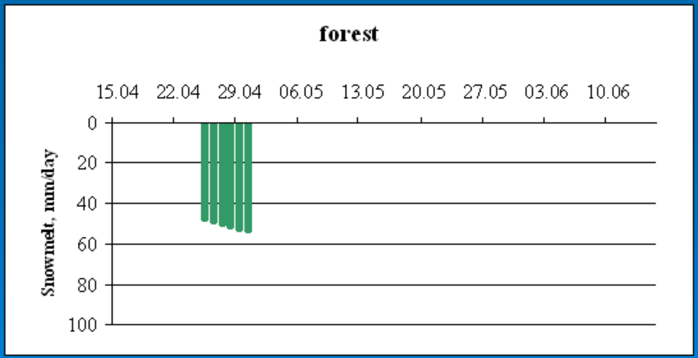
$$S_{\max} = 0.125 Q^{*}_{sw}(1-\alpha_s) + 4.86 T_{\max}(0.18 + 0.098\overline{U})$$

Q^{*}_{sw} **is the input solar radiation under cloudless ski, cal/cm²/day**

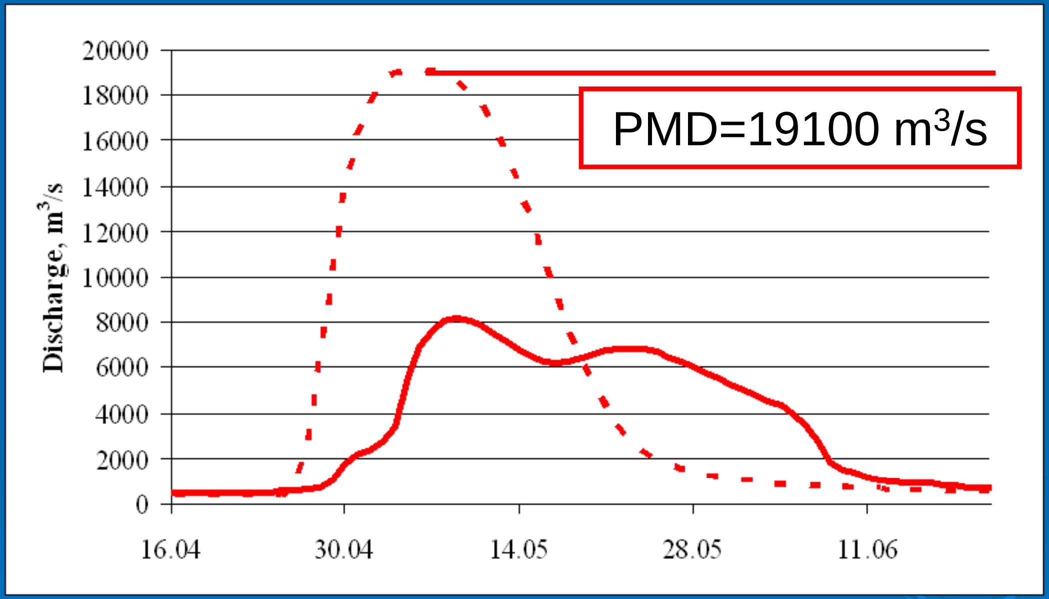
α_s **is the minimum snow-surface albedo (=0.5)** $\overline{U}$ **is the wind speed, m/s**

$T_{\max}$ **is the maximum air temperature, °C**





Maximum snowmelt rates calculated for open and forest areas of the Vyatka River basin

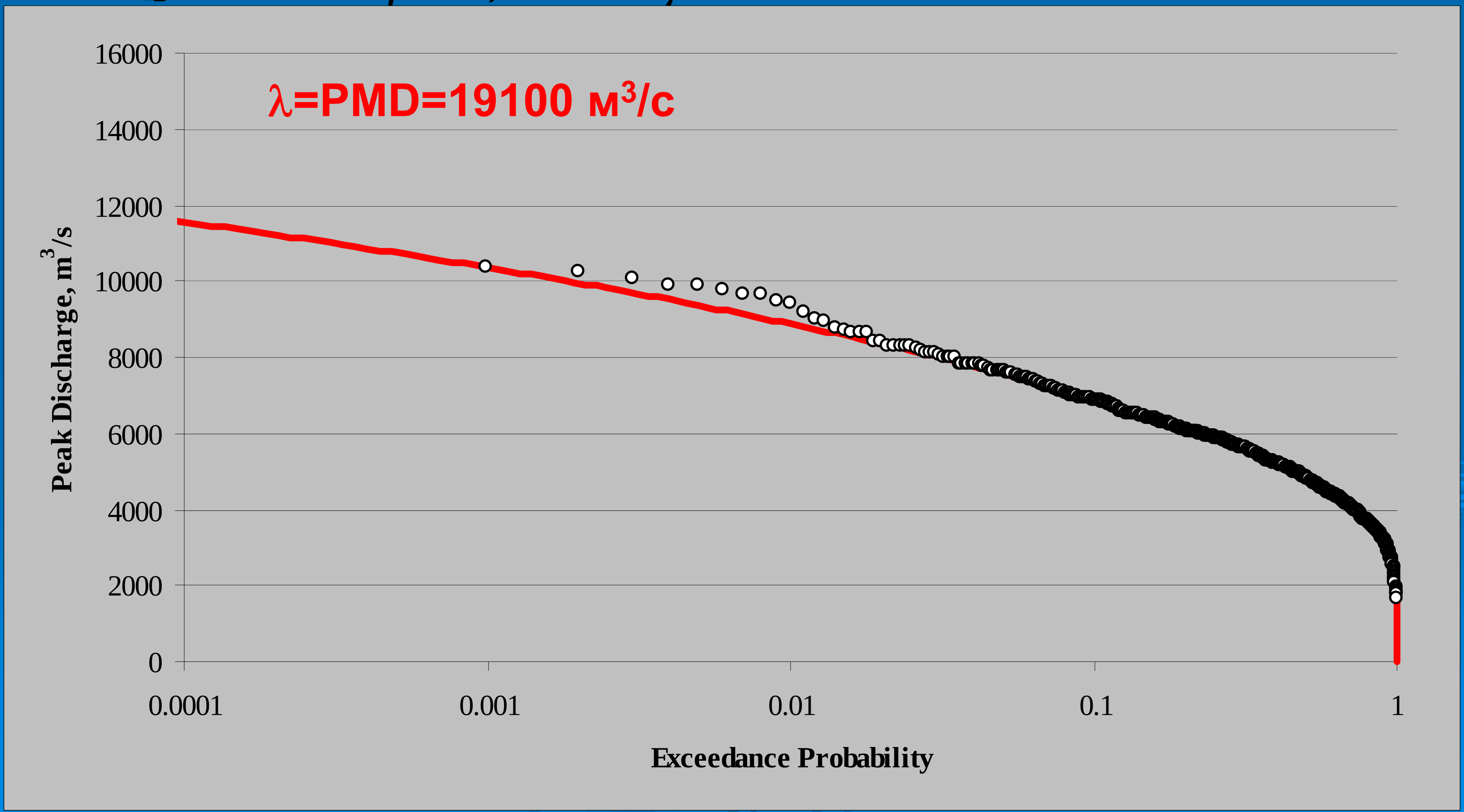


Simulated probable maximum flood hydrograph (dashed red line) and hydrograph of the largest observed flood in 1979 (continuous red line).

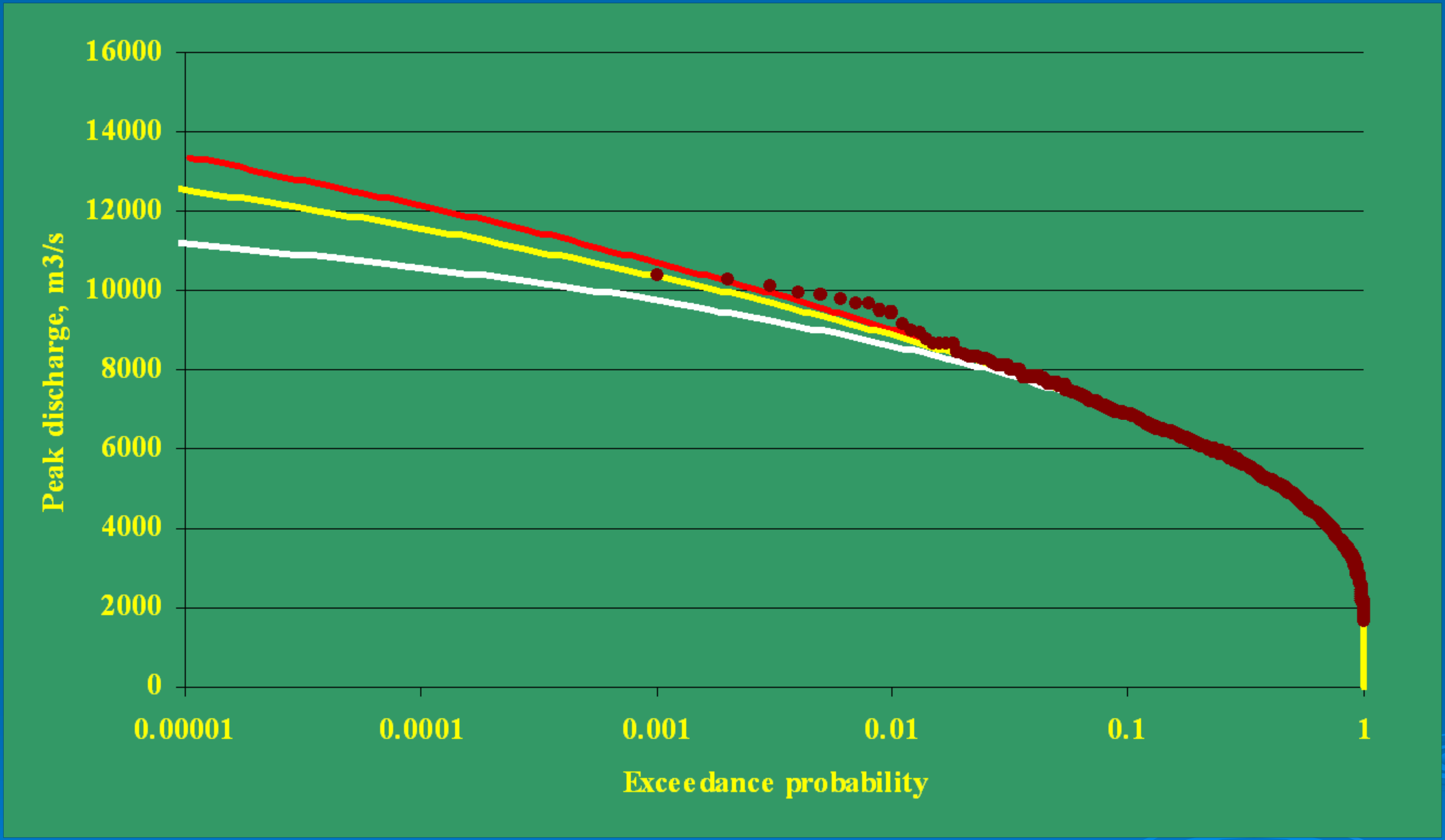
Exeedance probabilities of flood peak discharges simulated by the dynamic-stochastic model are fitted by SB Johnson distribution with the upper limit ($\lambda+\varepsilon$) =PMD=19100 m^3/s and the lower limit ε=0

$$f(Q)=\frac{\eta}{\sqrt{2\pi}}\frac{\lambda}{(Q-\varepsilon)(\lambda-Q-\varepsilon)}\exp\left\{-\frac{1}{2}\left[\gamma+\eta\ln\left(\frac{Q-\varepsilon}{\lambda-Q-\varepsilon}\right)\right]^2\right\}$$

$$\varepsilon\le Q\le\lambda+\varepsilon \quad \eta>0;\ -\infty<\gamma<\infty \quad \lambda>0 \quad -\infty<\varepsilon<\infty$$



Sensitivity of the derived flood frequencies to estimation of PMD



Comparison of the exceedance probabilities of simulated peak discharges (points) fitted by the Johnson distributions at different PMD values: white line: PMD=14000 m^3/s; yellow line: PMD=19100 m^3/s; red line: PMD=24000 m^3/s

Conclusions

✓A new approach has been developed to assessment of extreme floods of very large return intervals (1000 years and more). The developed approach is based on combination of probabilistic information on the derived flood frequencies and the deterministic information on calculated probable maximum peak discharge (PMD).

✓Flood frequencies are derived using the dynamic-stochastic model combining the physically based model of flood generation with the stochastic weather generator. PMD is calculated using physically based model forced by the maximum probable melt rate. Derived flood frequencies are fitted by SB Johnson distribution with the upper limit equals PMD


Thank you for