V. Kuzmin, A. Surkov, S. Eryomina, I. Gavrilov, K. Shemanaev

Stream flow modelling under Global Change: On stability and spatiotemporal continuity of multidimensional response surfaces

Prof. Vadim Kuzmin

Head of Department of Hydrogeology and Geodesy,
Russian State Hydrometeorological University
St Petersburg, Russia
www.rshu.ru

E-mail: vknoaa@hotmail.com

BACKGROUND

- RUSSIA: ~2,600,000 streams
- Up to 80% of them are poorly gauged or ungauged

(1/3 of population, 94% of gas and oil extraction)

- Global change: “old-fashioned”/classic forecasting

methods are inefficient

WHAT WE DO AT RSHU

- Automatic flood forecasting systems

- Improving stream flow forecasting by integrating satellite observations, radar data, NWP model output data, in situ data and catchment models using model-data assimilation methods

- Systems of customer-oriented hydrometeorological support (Russian Railways, hydropower industry etc)

- Automatic systems of environmental monitoring

AUTOMATED FLOOD FORECASTING SYSTEMS

- automatic acquisition and processing of data
- automatic calibration of operational models
- automatic issuance of warnings
- automatic decision-making

AUTOMATIC FLOOD FORECASTING SYSTEMS: STRATEGY

- Two-level forecasting:
  1) Background flood forecasting (exceeding thresholds → risk assessment)
  2) Enhanced flood forecasting in catchments where risk

- Automated decision support (PREDEFINED DECISION©)

AUTOMATIC FLOOD FORECASTING SYSTEMS: BACKGROUND FORECASTING

- Quite qualitative…
- Large areas are covered
- Saves resources
- Simple and robust , yet reliable models are used

MODEL CHOICE

Statistical models | **Conceptual models** | **Physically based models**

- Increasing complexity →
- ← Increasing sensitivity to data quality
- ← Increasing sensitivity to the process stability
- Increasing role of the process understanding →
- Increasing sensitivity to the calibration quality →

BACKGROUND FORECASTING: HYDROLOGICAL MODELS

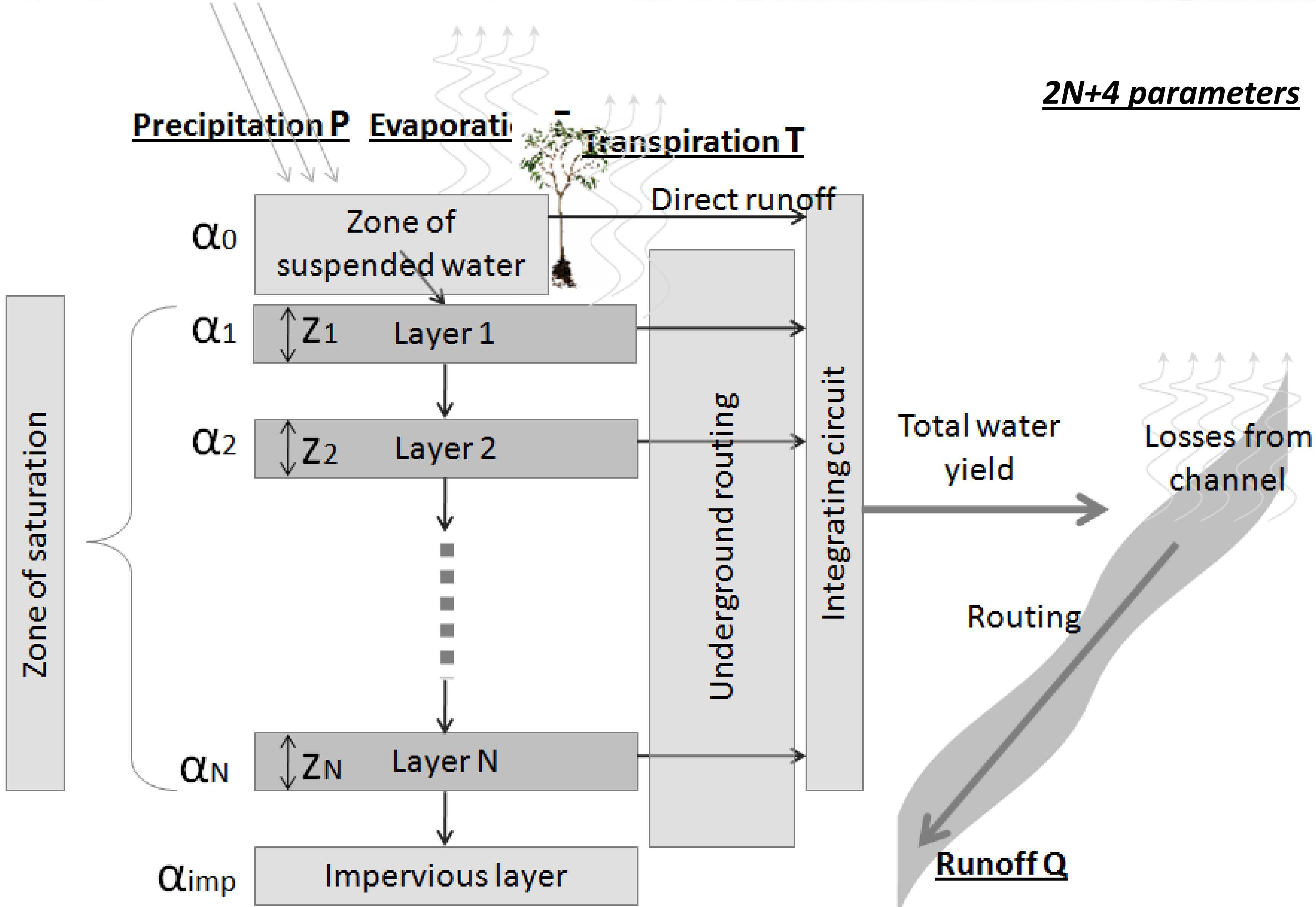
- **The SACRAMENTO soil moisture accounting model**

(Burnash, 1973 (USA)): 11—16 parameters

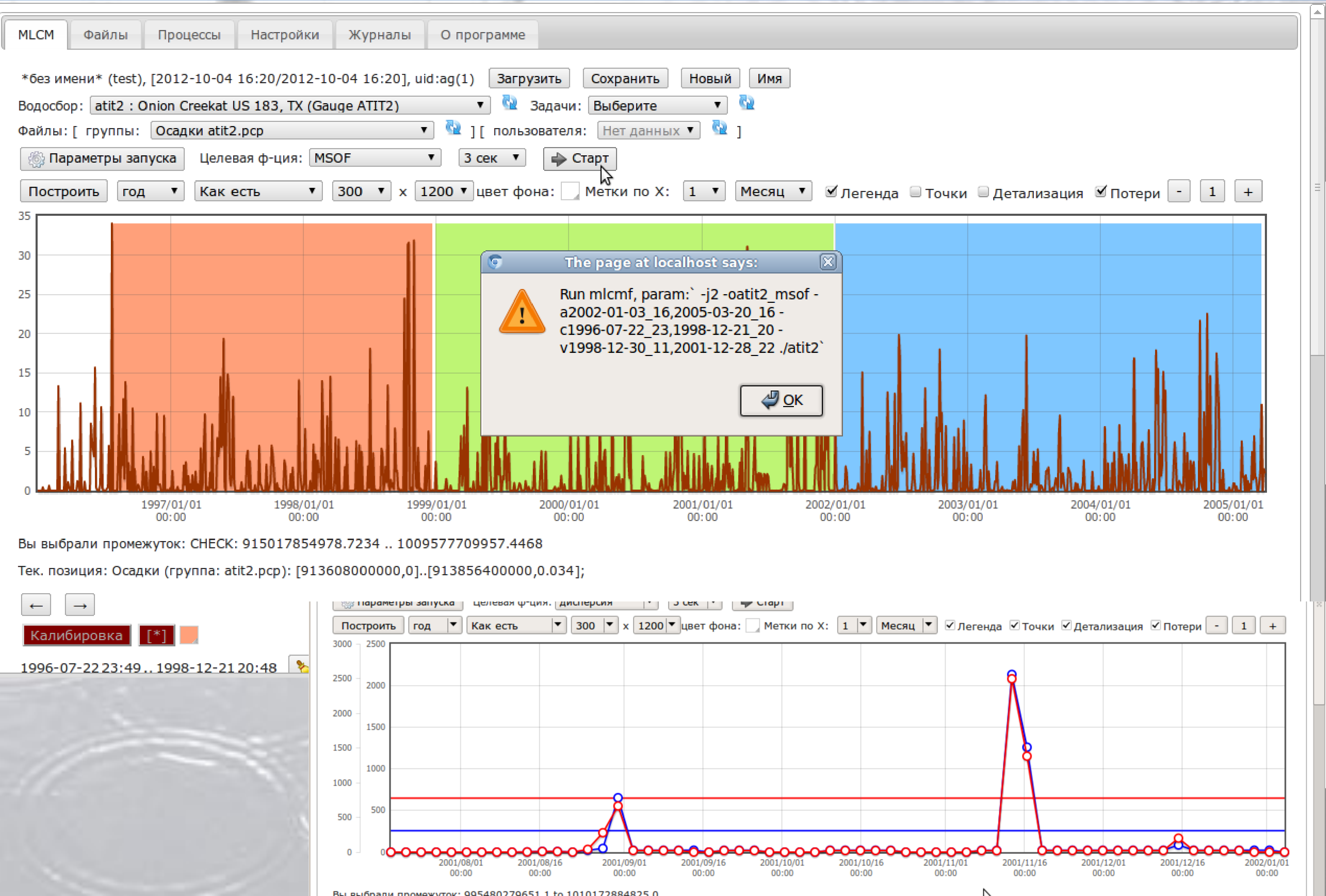
- **The Multi-Layer Conceptual Model (MLCM)**

(Kuzmin, 2010 (Russia)) – 2N+4 parameters (0—20…)

MULTI-LAYER CONCEPTUAL MODEL (MLCM)



MLCM: SOFTWARE FOR ONLINE MODELING



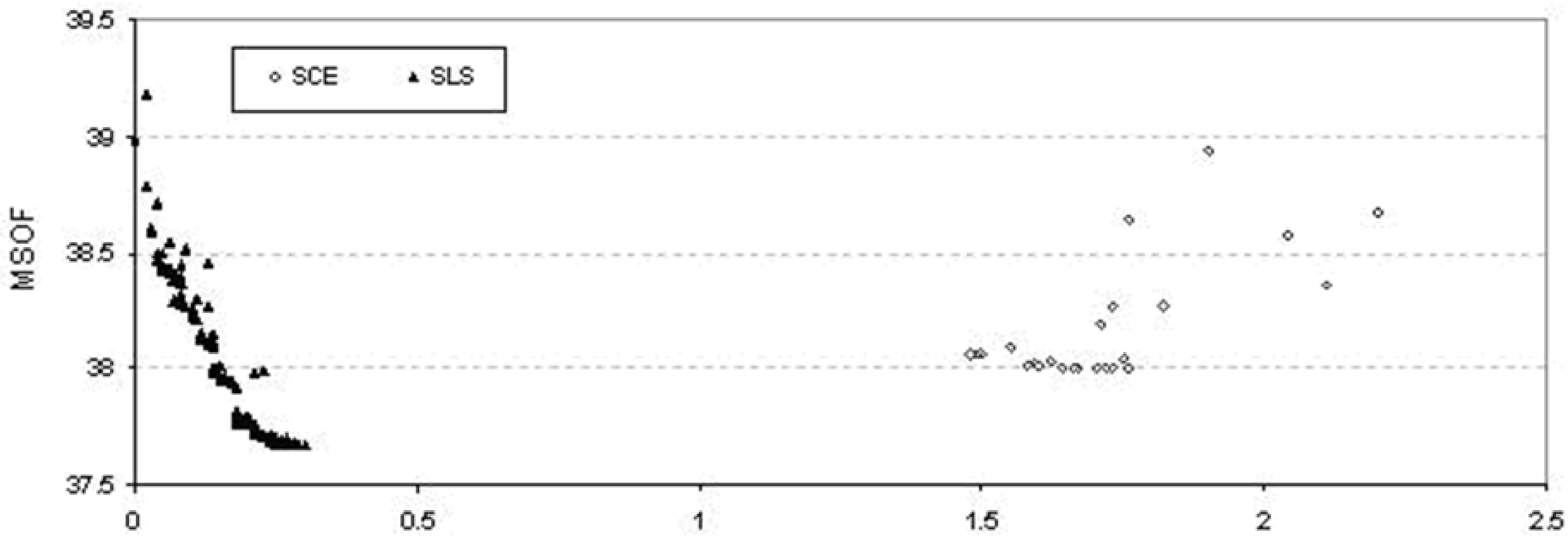
AUTOMATIC MODEL CALIBRATION: SAC-SMA

- **Quasi-global algorithm SCE (Shuffled Complex Evolution)** is computationally "expensive" and sensitive to a number of parameters, needs well defined boundaries

- **Quasi-local algorithm SLS (Stepwise Line Search) is computationally efficient, but** quite sensitive to an initial point for pattern search

KEY ISSUES OF HYDROLOGICAL MODELS CALIBRATION

Disadvantages of “global” calibration



Distance from the initial point (a priori parameter set)

WHAT WE DO TO RESOLVE THE PROBLEM OF MODELS CALIBRATION

Simultaneous random generation of the model input ensembles and quasi-local model calibration

- Low sensitivity to setting of the random generator
- Possibility to calibrate models in data scarce regions
- Use of the Stepwise Line Search algorithm (modified pattern search)
- Possibility to obtain unbiased parameters

AUTOMATIC MODEL CALIBRATION: MLCM

A special calibration algorithm is implemented:

- For 0, 1 or 2 layers: all possible parameter sets are examined (step size: 5 or 10%)
- For 3 and more layers: SCE

AUTOMATIC MODEL CALIBRATION: MOST CRITICAL ISSUES

- Parameter stability in **time** → their reliability
- Parameter stability in **space** → possibility to be used in ungauged basins

KEY ISSUES OF HYDROLOGICAL MODELS CALIBRATION

Need to identify many interdependent parameters

Irregularity of the multi-dimensional response surface

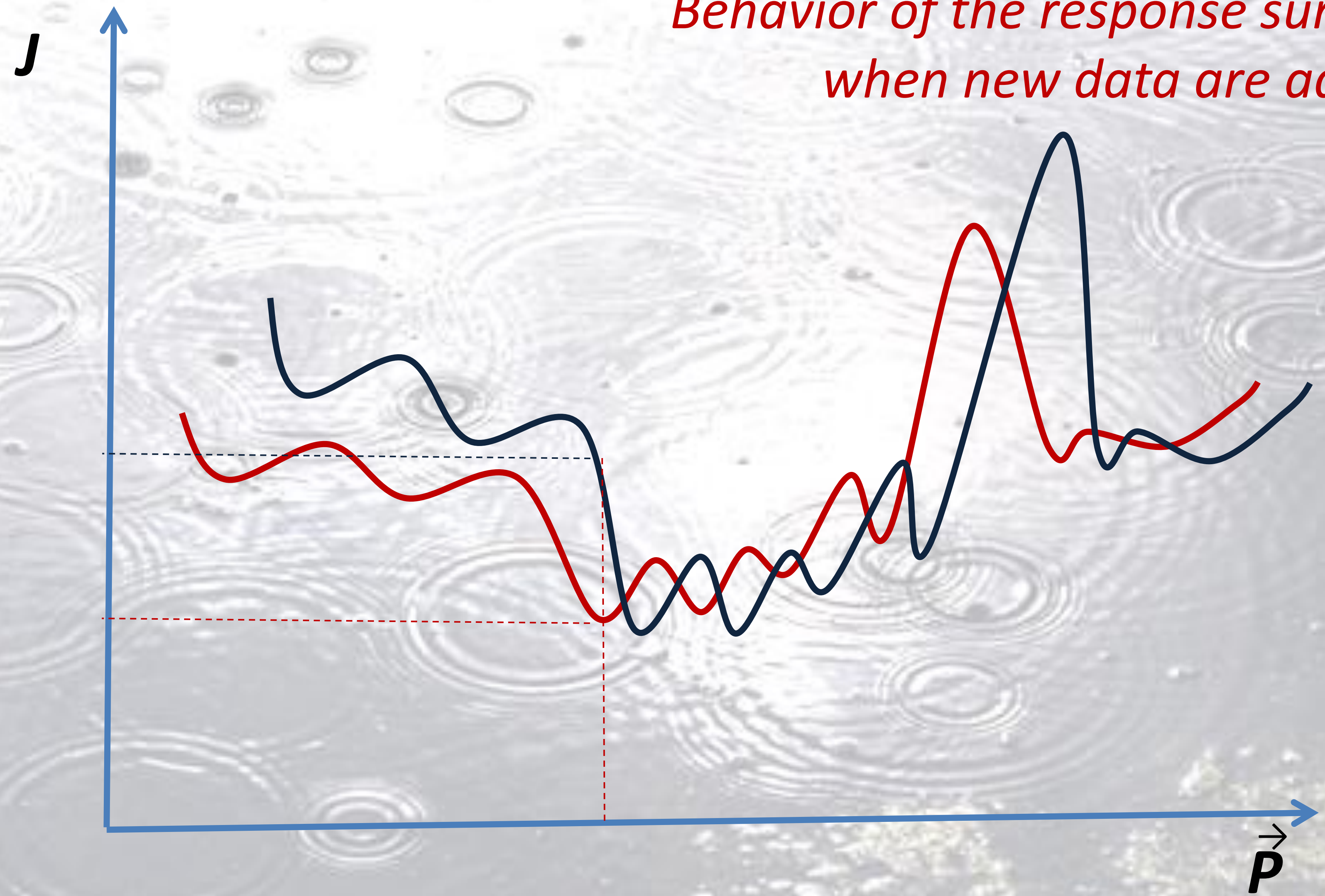
Low stability of the response surface

Selection of appropriate objective function

Possibility to calibrate models in realistic time

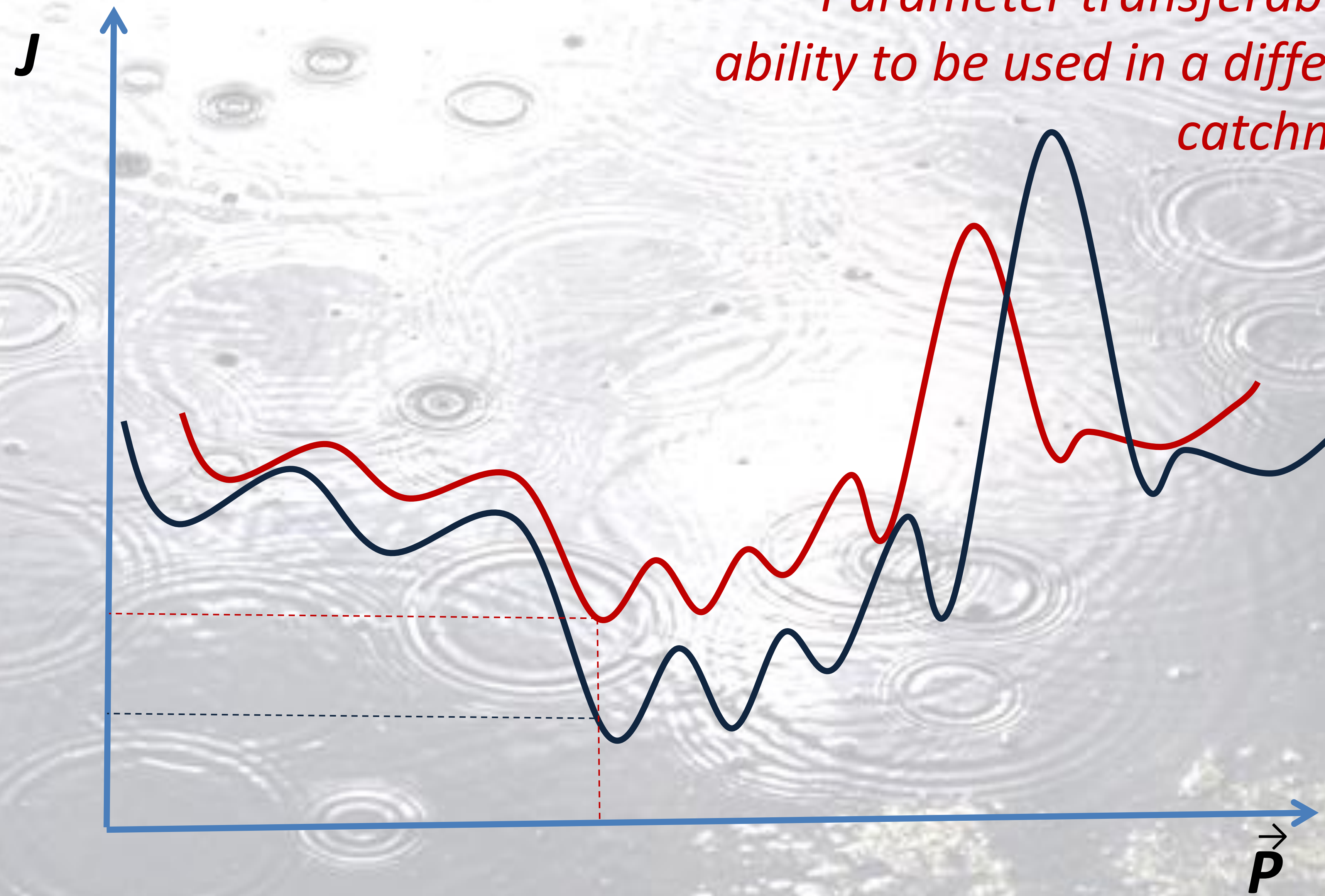
PARAMETER STABILITY IN TIME

Behavior of the response surface when new data are added



PARAMETER STABILITY IN SPACE

Parameter transferability: ability to be used in a different catchment



WHAT WE MEAN BY PARAMETER CONTINUITY

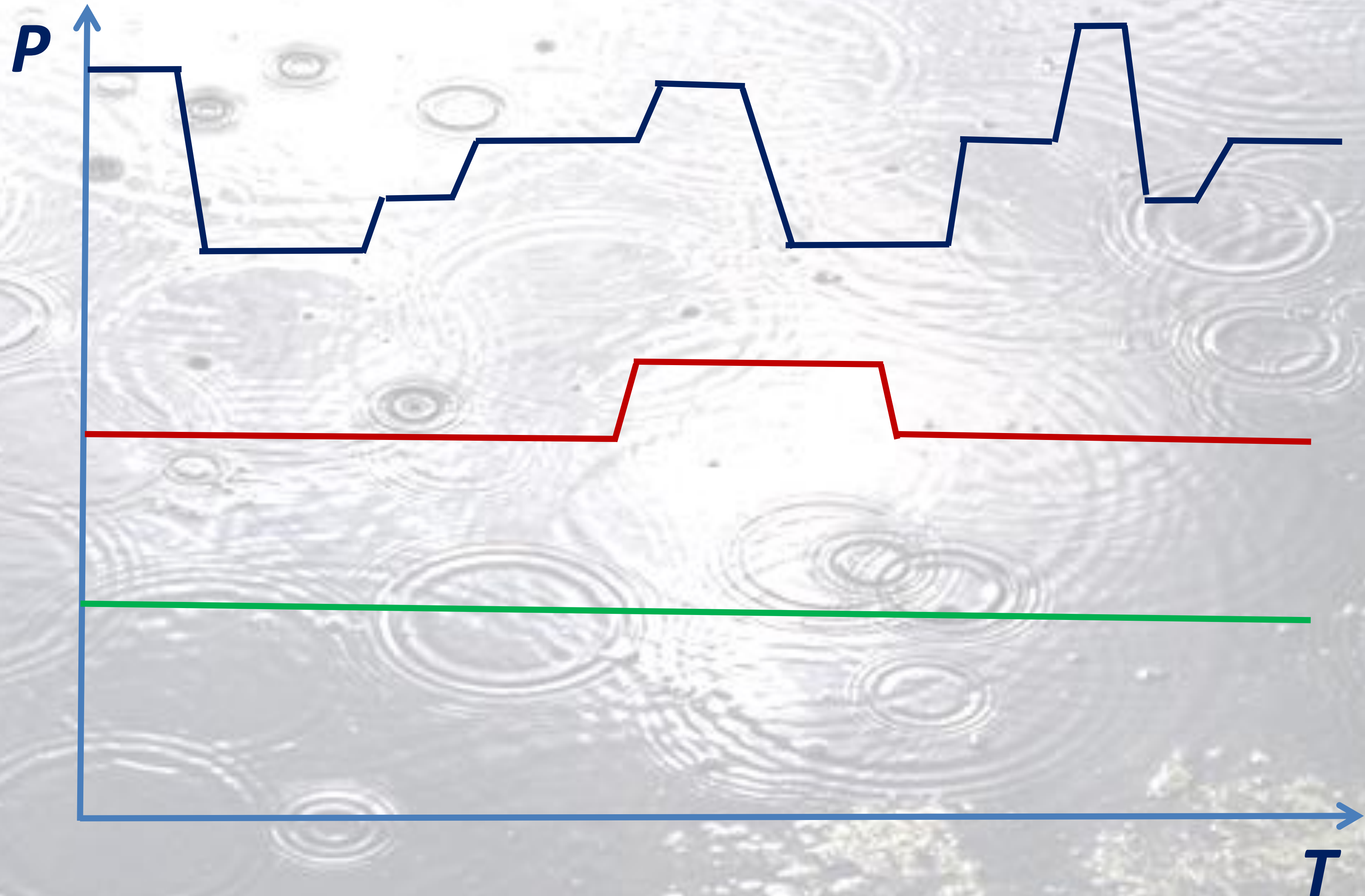
GENERAL PATTERNS OF THE RESPONSE SURFACES

- **for the same basin and different time intervals → parameter/forecast reliability**
- **for different basins → parameter transferability**

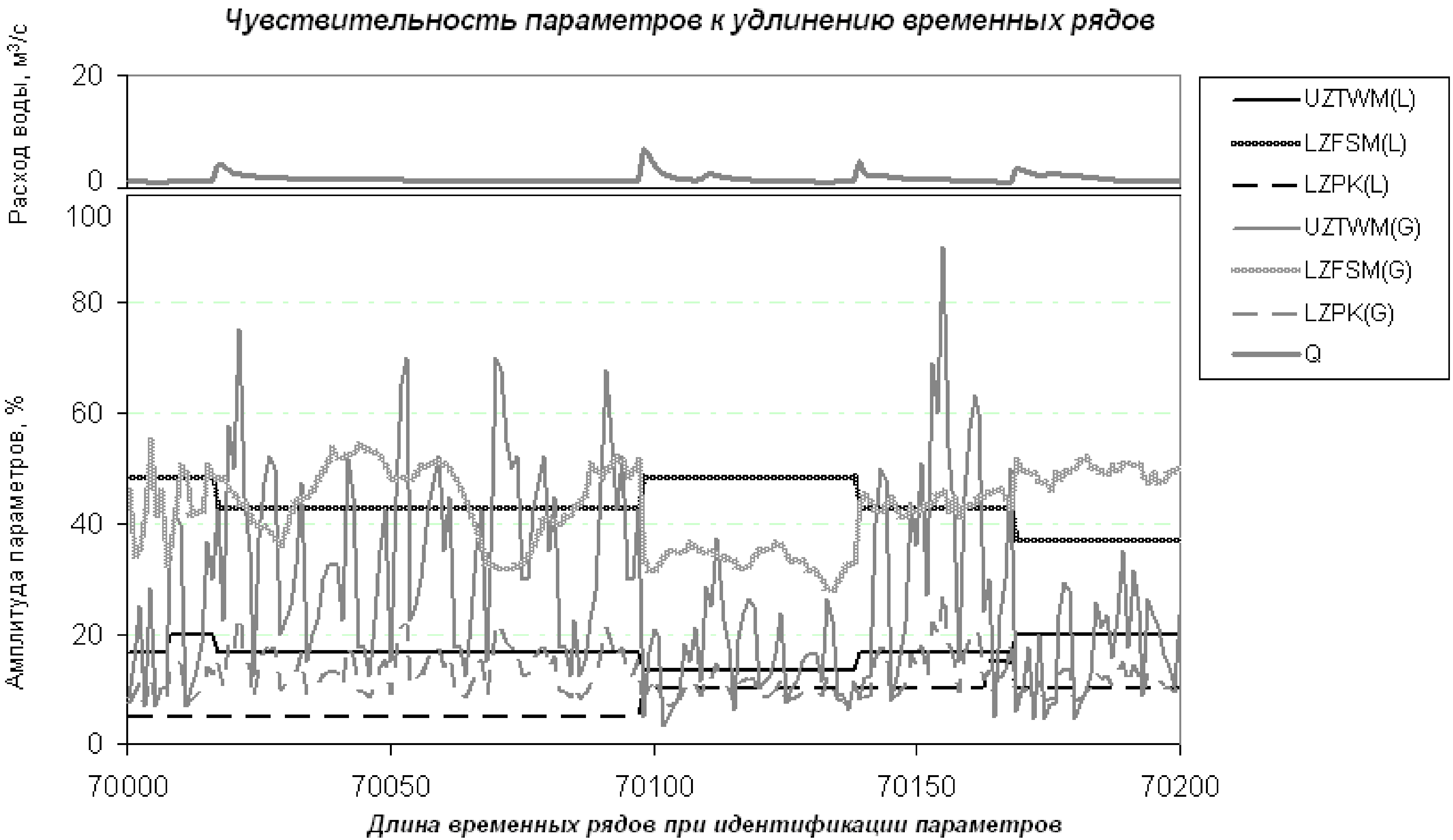
HOW TO ASSESS PARAMETER CONTINUITY?

Temporal stability	slightly change the initial point for pattern search
Spatial stability	calibrate a (semi)distributed model using various cells or sub-basins of the same basin

STABILITY IN TIME



STABILITY IN TIME

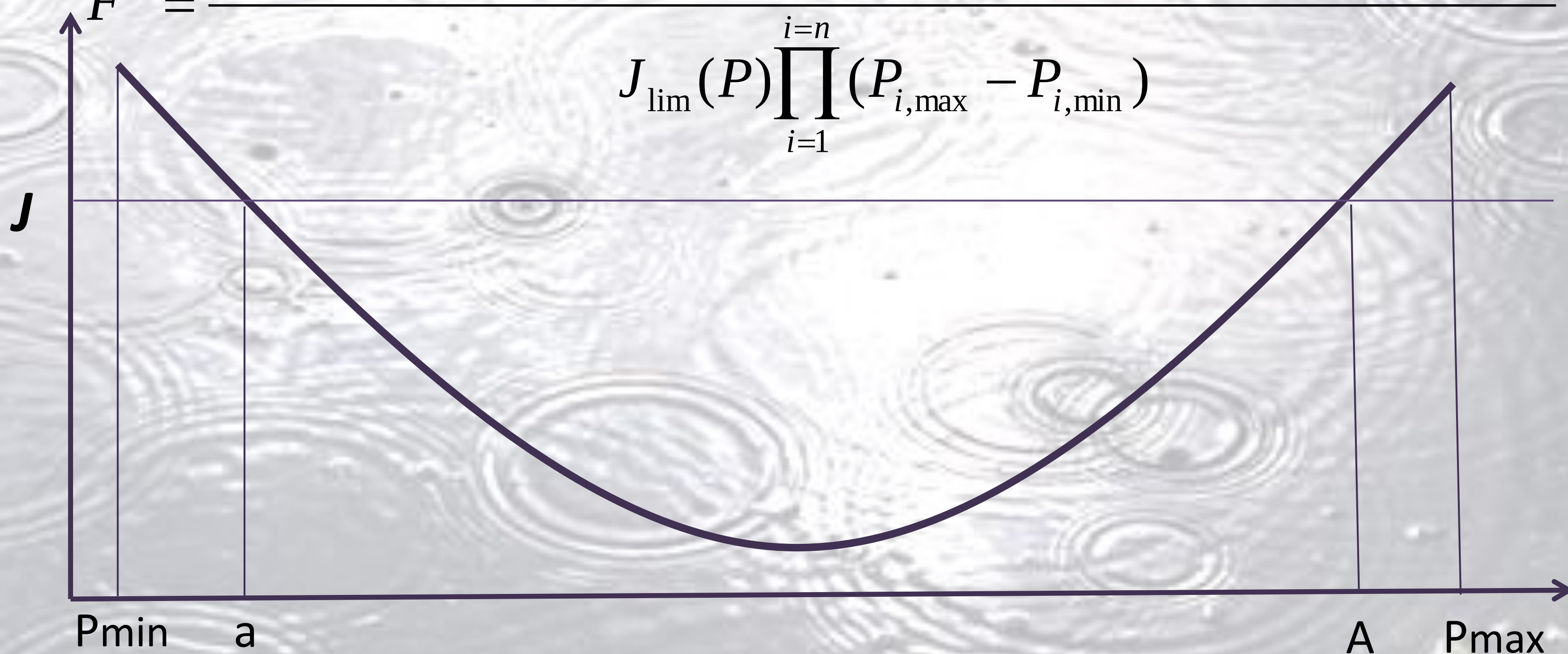


STABILITY IN SPACE…

F-transformation of the response surface

$$J(\vec{P}_n) \to F(\vec{P}_n)$$

$$F^n = \frac{\int_{a_1}^{A_1} \ldots \int_{a_n}^{A_n} J(P)\,dP_1 \ldots dP_n + J_{\lim}(P)\left(\prod_{i=1}^{i=n}(P_{i,\max} - P_{i,\min}) - \prod_{i=1}^{i=n}(A_i - a_i)\right)}{J_{\lim}(P)\prod_{i=1}^{i=n}(P_{i,\max} - P_{i,\min})}$$



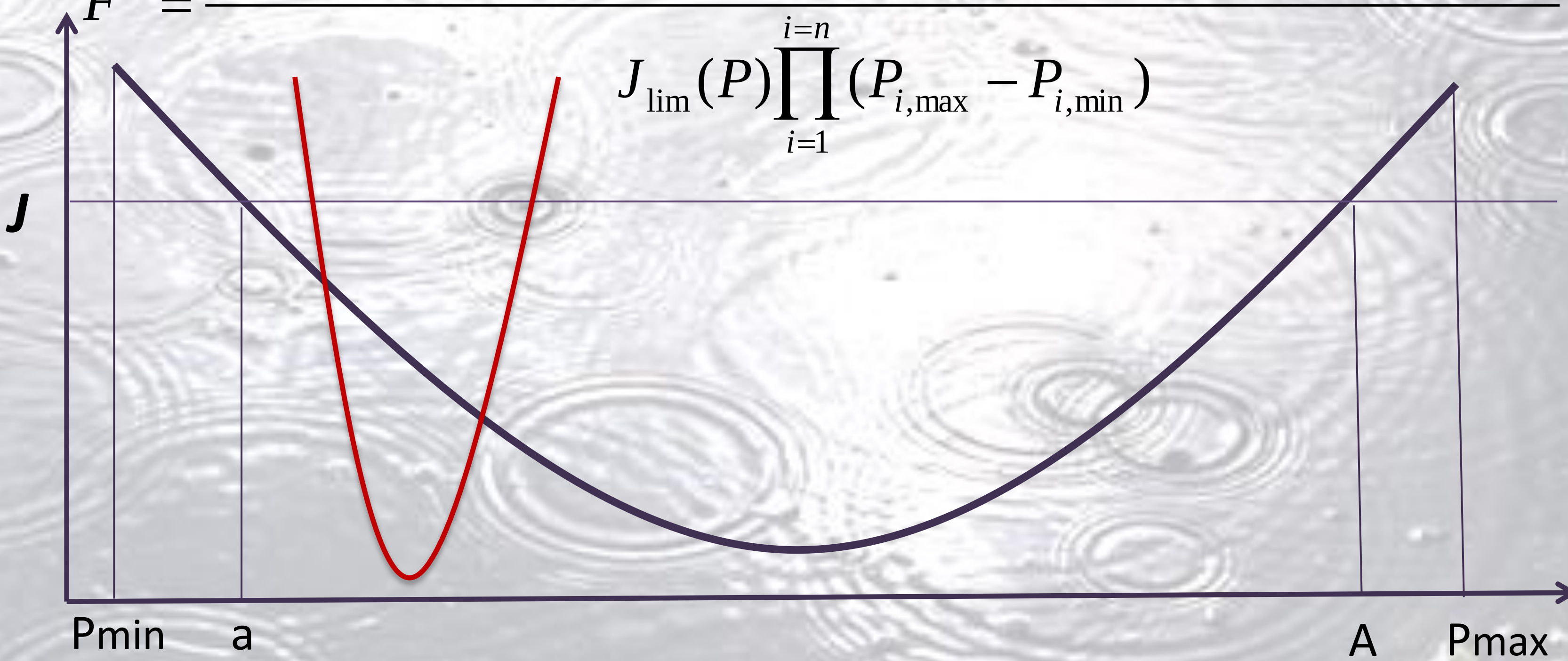
…AND TIME!

INTERCOMPARISON OF OPTIMA

F-transformation of the response surface

$$J(\vec{P}_n) \to F(\vec{P}_n)$$

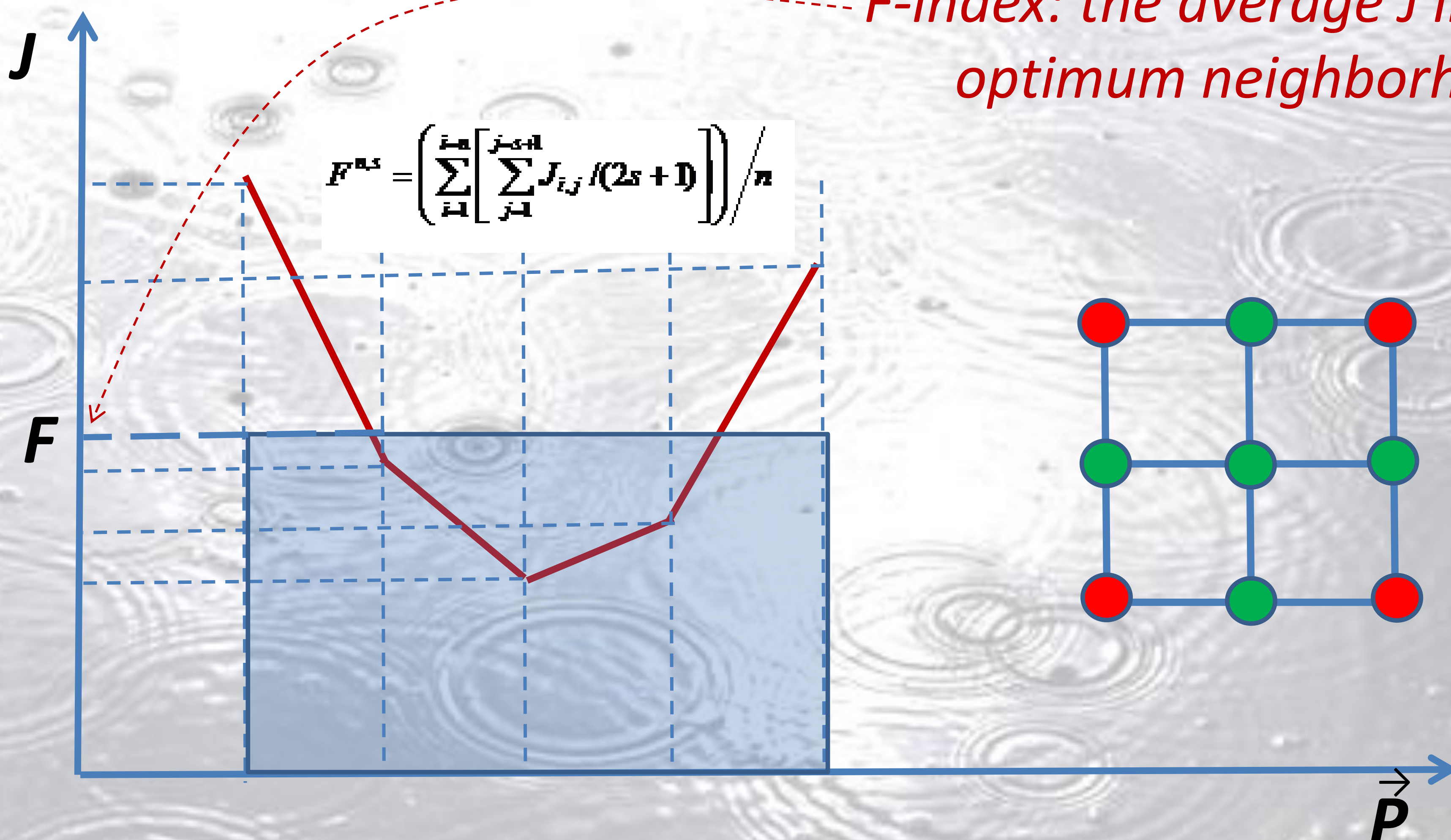
$$F^n = \frac{\int_{a_1}^{A_1}\dots\int_{a_n}^{A_n} J(P)dP_1...dP_n + J_{\lim}(P)\left(\prod_{i=1}^{i=n}(P_{i,\max} - P_{i,\min}) - \prod_{i=1}^{i=n}(A_i - a_i)\right)}{J_{\lim}(P)\prod_{i=1}^{i=n}(P_{i,\max} - P_{i,\min})}$$



— HUH… COULD YOU SIMPLIFY IT?..

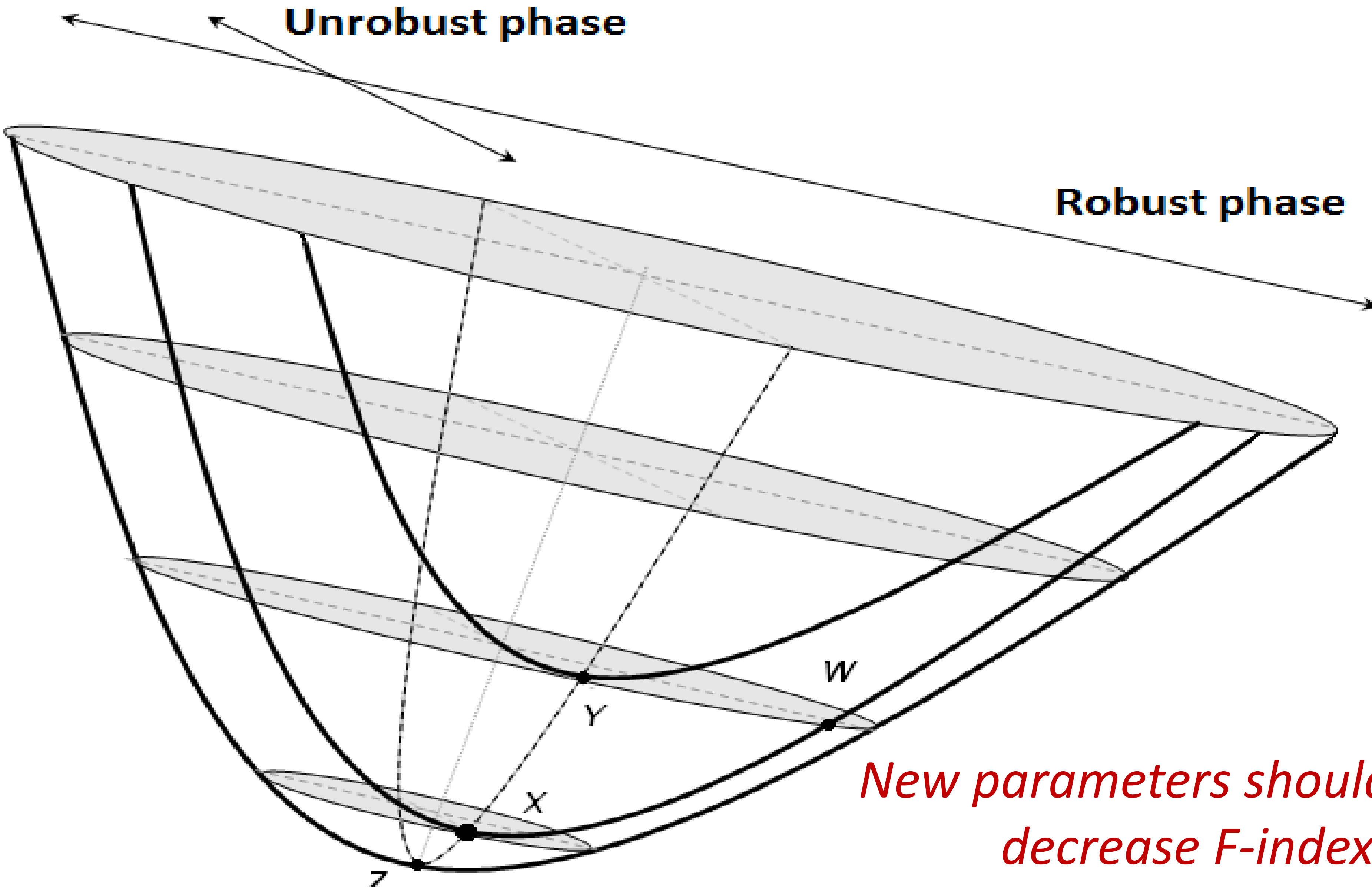
F-index: the average J in an optimum neighborhood

$$F^{n,s} = \left(\sum_{i=1}^{i=n} \left[\sum_{j=1}^{j=s+1} J_{i,j} / (2s+1) \right] \right) \Big/ n$$



— SURE!

DO YOU WANT EXTRA PARAMETERS?



New parameters should decrease F-index!

"NATURAL" SMOOTHING RESPONSE SURFACE

- Smoothing based on penalty functions x
- Smoothing through F-transformation v
- Smoothing through using special objective functions: v

 - Multi-Scale Objective Function (MSOF)
 - Most Informative Scales Objective Function (MISOF)
 - All Scales Objective Function (ASOF)

MULTI-SCALE OBJECTIVE FUNCTION

$$J = \sqrt{\sum_{k=1}^{n}\left(\frac{\sigma_1}{\sigma_k}\right)^2 \sum_{i=1}^{m_k}\left(q_{o,k,i} - q_{s,k,i}(X)\right)^2},$$

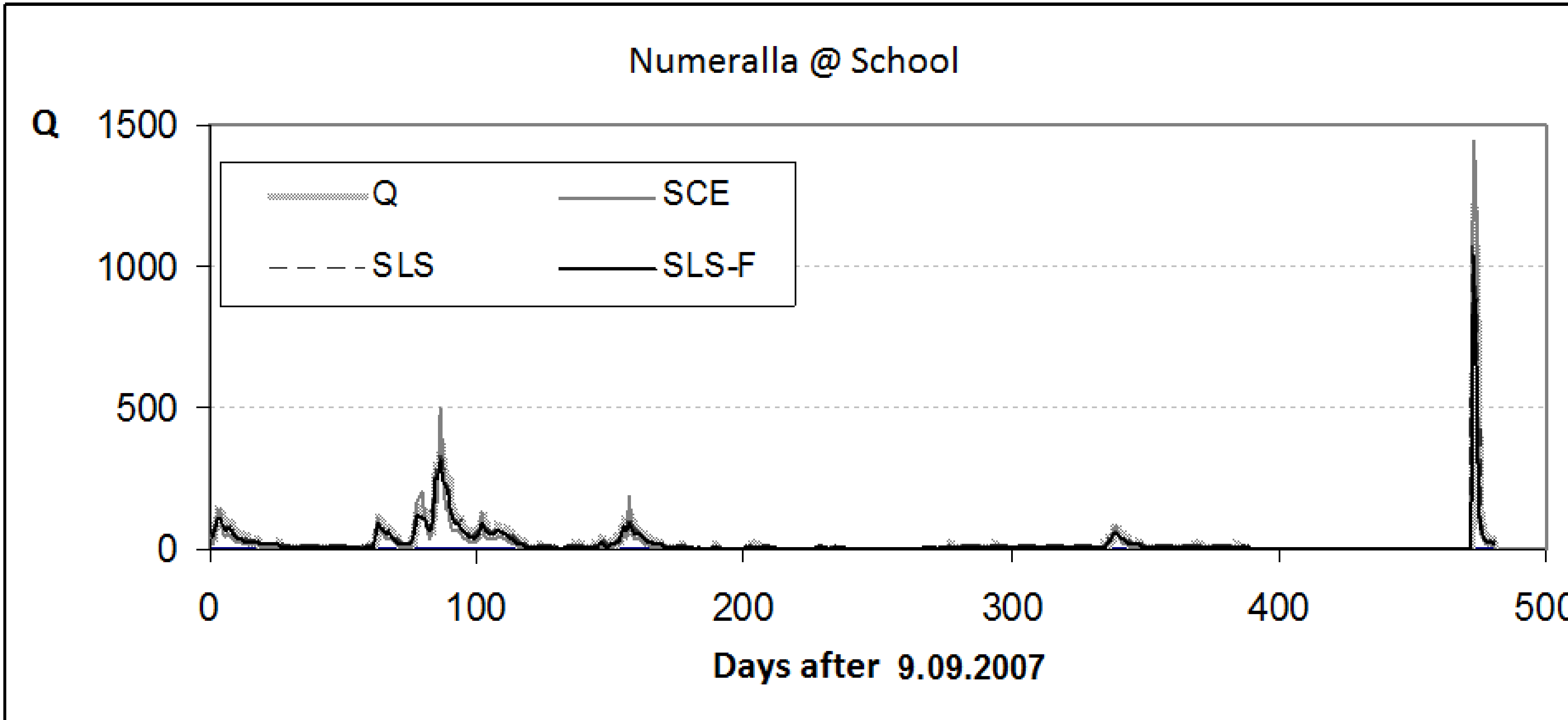
where $q_{o,k,i}$ and $q_{s,k,i}$ denote the observed and simulated flows averaged over time interval k (i.e. the k-th aggregation scale), σ_k denotes the standard deviation of discharge at that scale, n denotes the total number of scales used, and m_k is the number of ordinates at the scale k. In our experiments, we used hourly, daily, weekly and monthly scales corresponding to k = 1, 2, 3 and 4, respectively. The weight associated with each term is given by the inverse of the standard deviation of the flow at the respective scales. This weighting scheme assumes that the uncertainty in modeled streamflow at each scale is proportional to the variability of the observed flow at that scale. Another important motivation for using the multi-scale objective function (MSOF) is that it smoothes the objective function surface, and hence reduces the likelihood of the search getting stuck in tiny ‘pits.’

Kuzmin, Seo, Koren, “Fast and efficient…”, Journal of Hydrology, 2008

SLS BASED CALIBRATION ALGORITHMS

- Basic Stepwise Line Search (SLS) algorithm (needs a priori parameter set)
- SLS-F (F-indices + SLS)
- SLS-2L (two loops)
- SLS-E (ensembles of input + SLS)
- SLS-EF, SLS-2LE, SLS-2LF, SLS-2LEF

RESULTS: AN EXAMPLE FOR VISUAL LEARNERS



RESULTS: CALIBRATION

Catchments		Catchment area, км^2	INITIAL MSOF	FINAL MSOF				
				SCE	SLS	SLS-F	SLS-2L	SLS-E
Onion Creek –Austin	ATIT2	844	23.21	19.36	20.84	20.85	24.01	16.24
Denton Creek – Justin	DCJT2	1039	18.47	16.13	16.57	16.57	18.88	14.99
Greens Bayou – Houston	GBHT2	137	13.82	11.35	11.65	11.66	14.12	9.51
South Fork –	GETT2	334	17.39	16.22	16.52	16.54	17.32	16.03
Cowleech Creek – Greenville	GNVT2	212	16.89	14.39	14.60	14.60	17.90	11.72
Brays Bayou – Houston	HBMT2	246	35.69	27.02	28.52	28.53	42.48	24.18
Guadalupe River – Hunt	HNTT2	769	39.50	30.99	31.01	31.02	37.00	28.12
Double Mount Fork – Justiceburg	JTBT2	945	13.73	12.19	12.86	12.89	15.97	10.67
Sandy Creek – Kingsland	KNLT2	904	18.38	11.55	13.67	13.67	13.88	9.66
Davidson Creek – Lyons	LYNT2	508	10.51	10.22	10.37	10.37	10.41	9.10
East Fork Trinity – McKinney	MCKT2	427	16.84	13.87	14.18	14.19	15.31	12.42
Bedias Creek – Madisonville	MDST2	870	33.92	25.79	28.56	28.56	32.50	23.42
Midfield – Tres Palacios	MTPT2	435	35.43	33.92	33.83	33.83	34.00	29.45
Cowhouse Creek –Pidcoke	PICT2	1178	38.99	38.00	37.68	37.70	38.12	22.90
Navidad River – Sublime	SBMT2	896	56.66	53.92	54.57	54.57	55.73	48.83

RESULTS: TRANSFRABILITY

CALIBRATION	VALIDATION			
	1	2	3	4
	INITIAL MSOF			
	3.55	3.31	2.99	1.90
Kyeabma Creek – Book Book	*1.472*	1.320	1.659	1.118
Kyeamba Creek – Lady Smith	1.475	*1.272*	1.734	1.238
Hillis Creek – Mount Adrah	1.801	1.423	*1.045*	0.999
Billabong Creek – Aberfeldy	1.656	1.512	1.307	*0.800*

INTERESTED IN COLLABORATION?

WELCOME!!!

vknoaa@hotmail.com


Thank you!