The universal model “Hydrograph”: modelling across climates, landscapes, and space scales, with specific implementation to Russian Arctic

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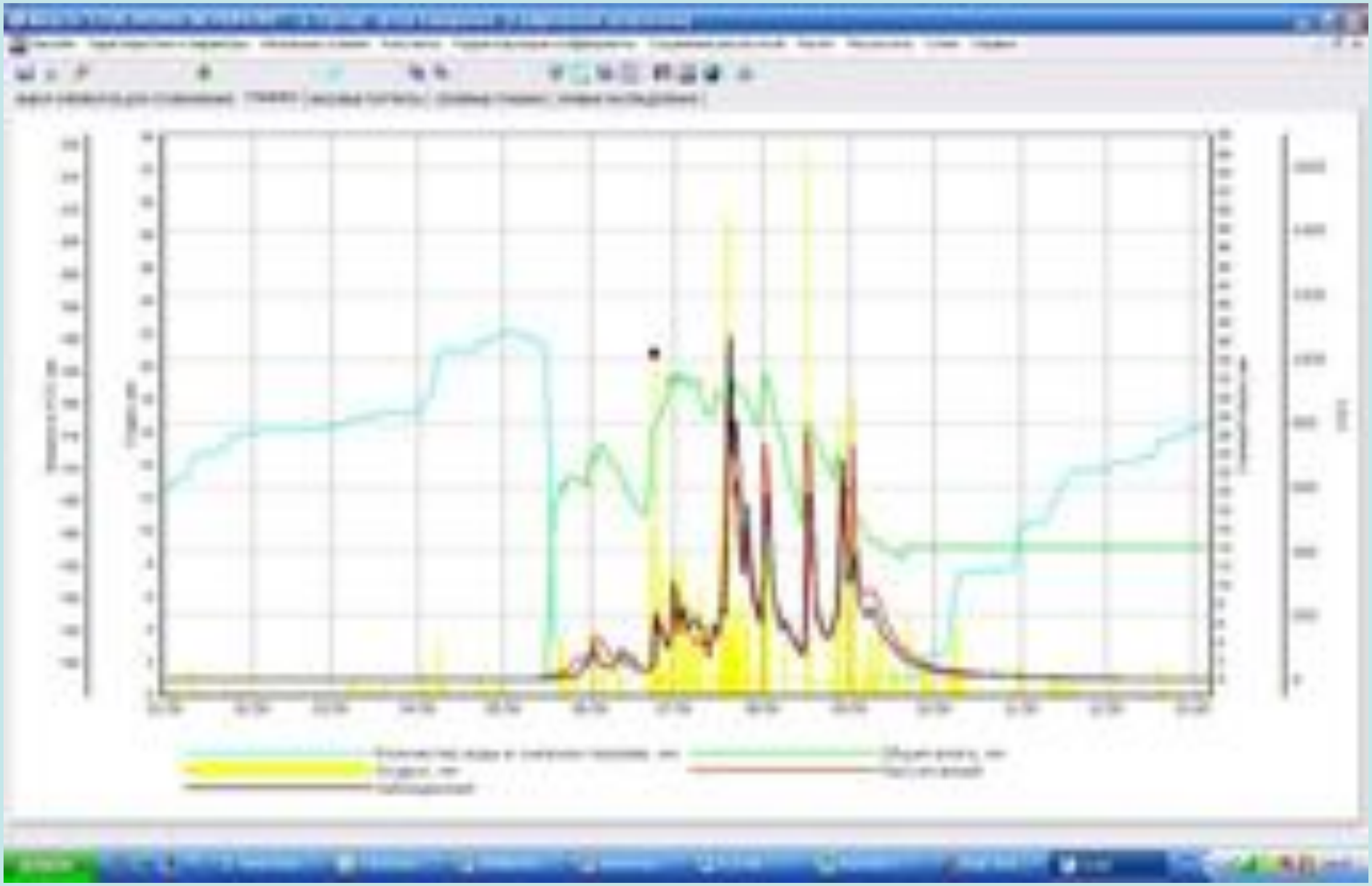
"Hydrograph" model

- Distributed
- Physically-based



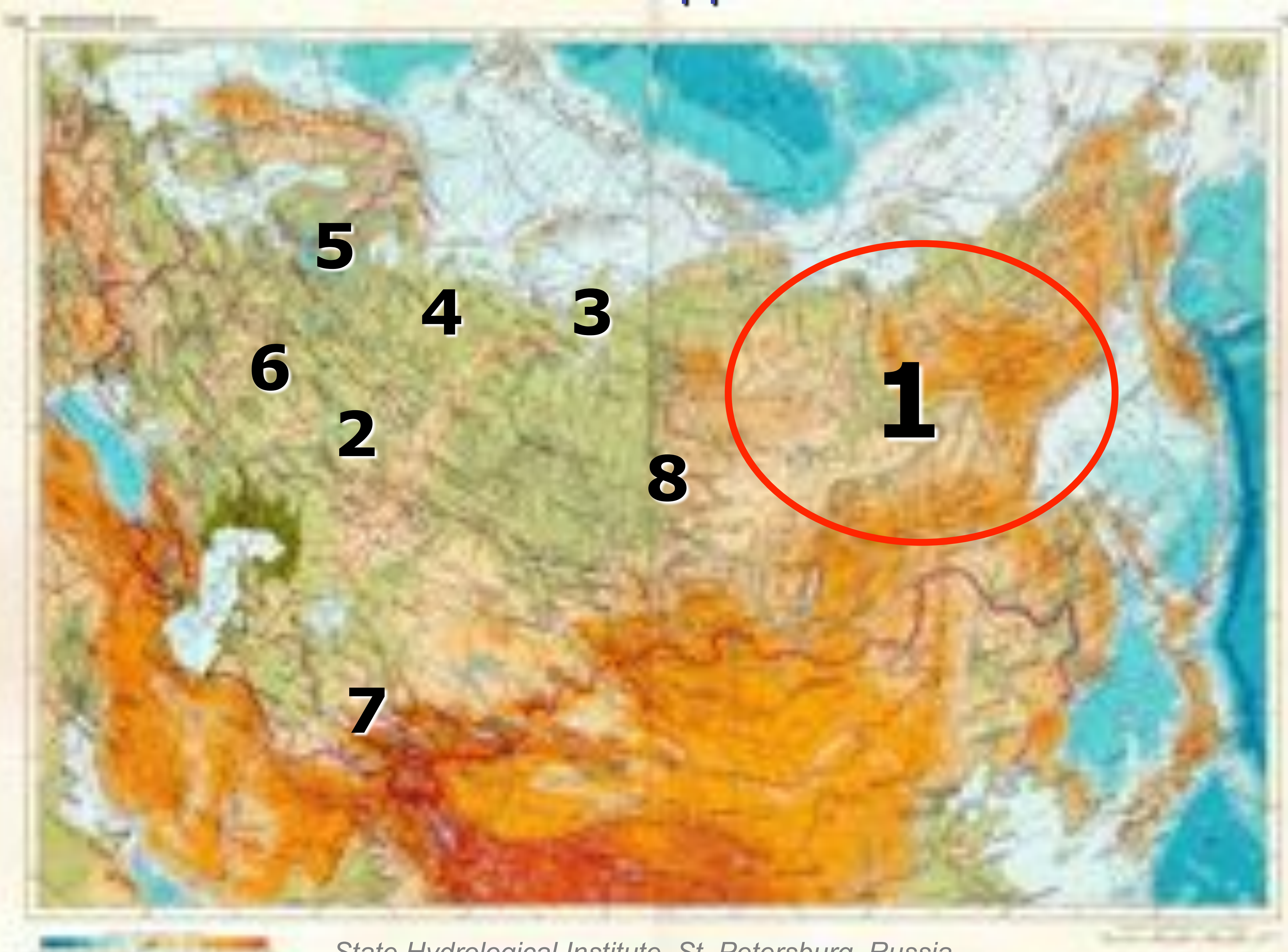
Developed by Prof. Vinogradov

State Hydrological Institute, St. Petersburg, Russia

Some results…

Observed (black)
against
simulated (red)
hydrograps

The model application



Study area – Eastern Siberia

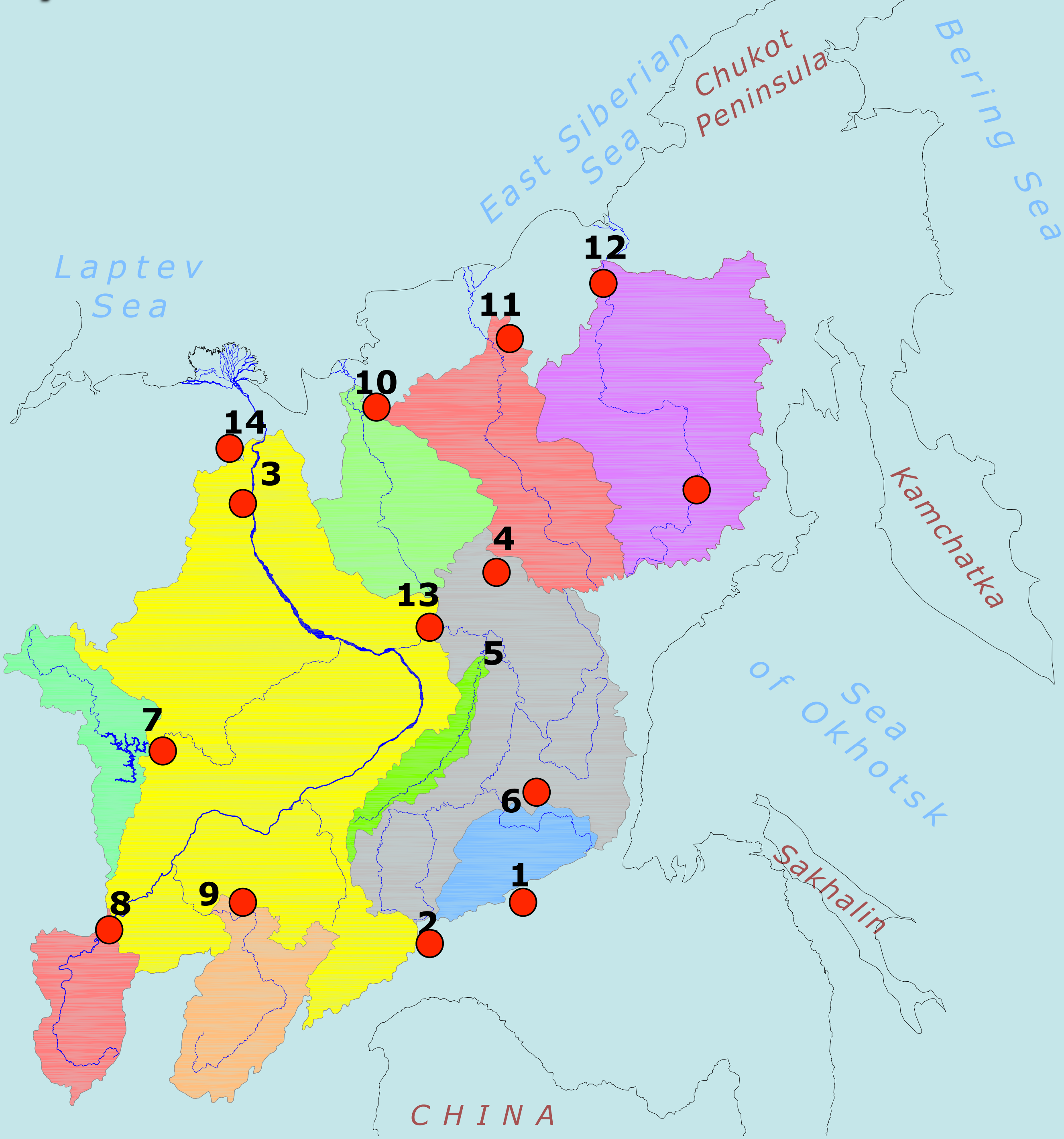
SMALL

1 Katyryk
40

2 Timpton
613

3 Ebetiem
1000

4 Suntar
7680



MIDDLE

5 Amga
65000

6 Uchur
108000

7 Viluy
136000

8 Lena (Zmeinovo)
140000

9 Vitim
186000

LARGE

10 Yana
216000

11 Indigirka
305000

12 Kolyma
526000

13 Aldan
696000

14 Lena
2430000

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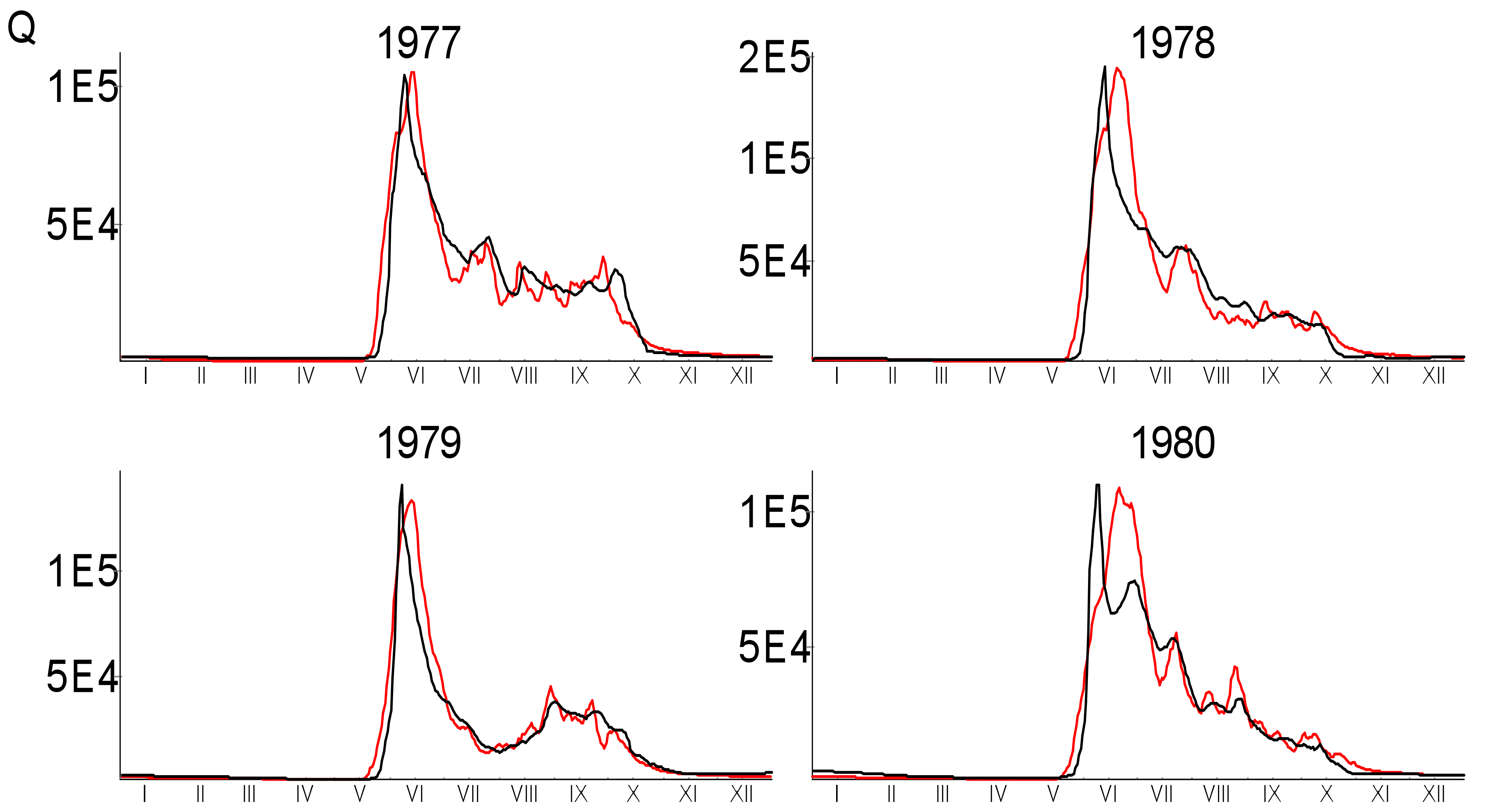
LARGE-SCALE BASINS

Lena at Kusur
basin area 2,4 million km^2



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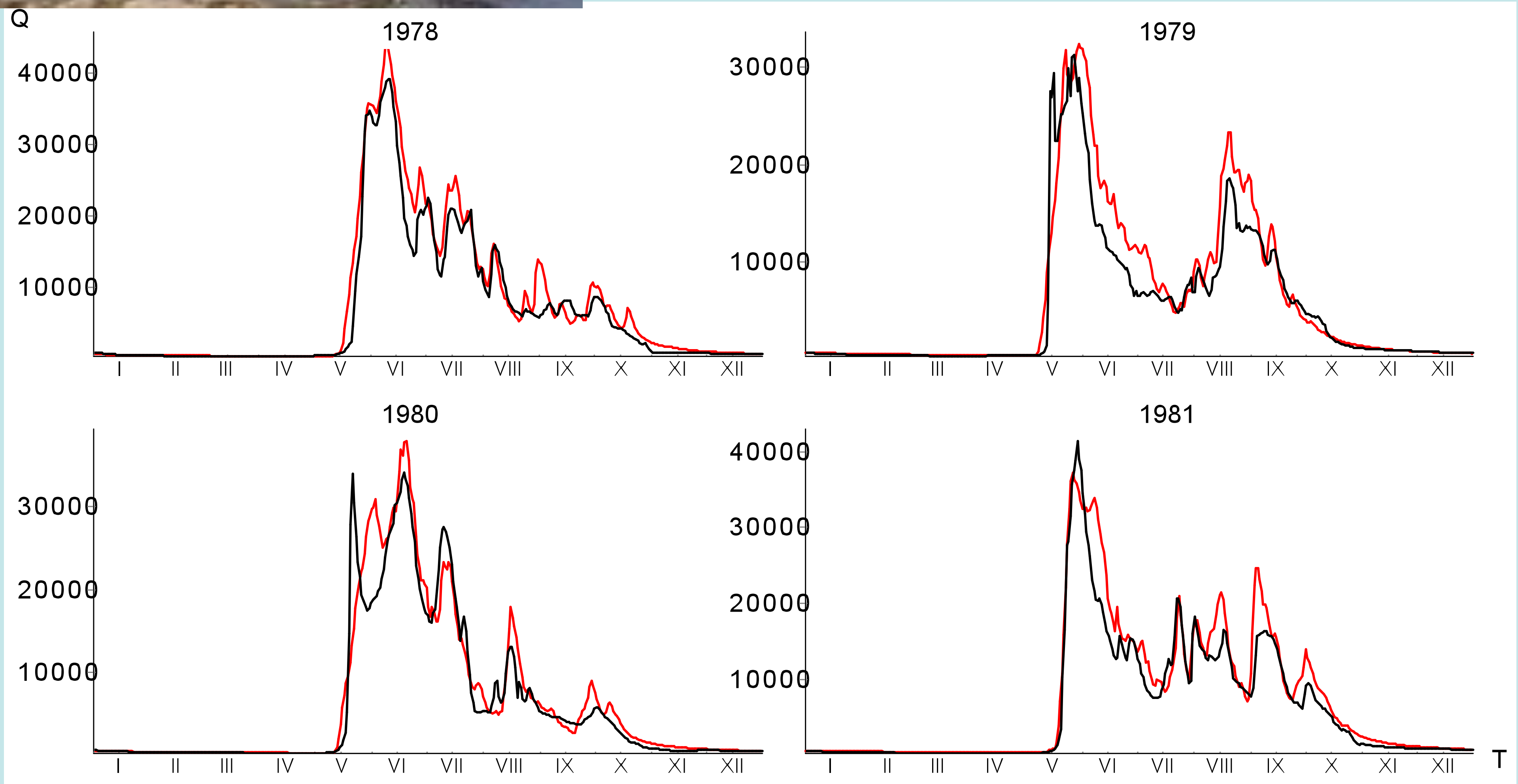
Aldan at Verkhoyansky Perevoz
basin area 696000 km²



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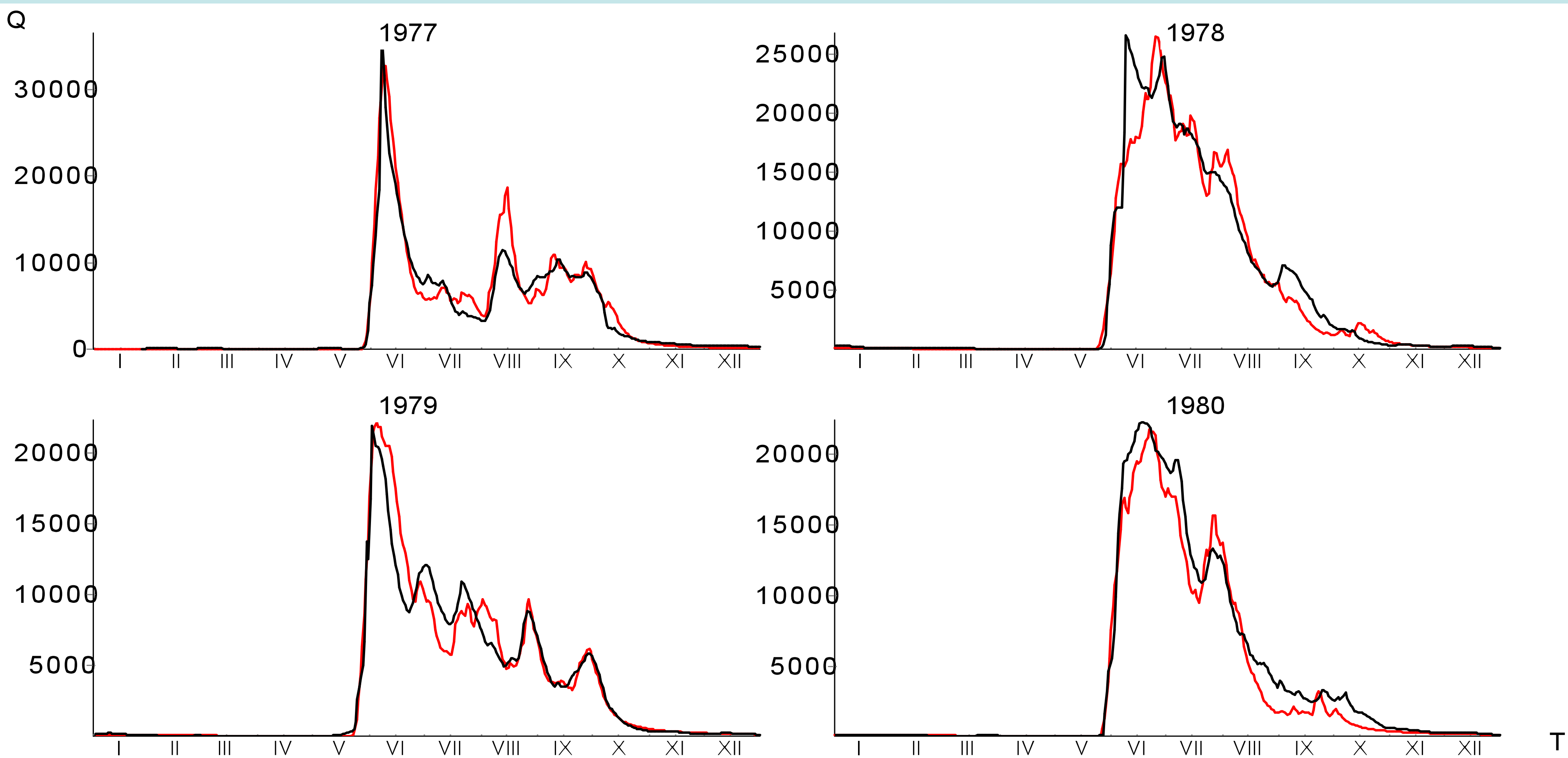
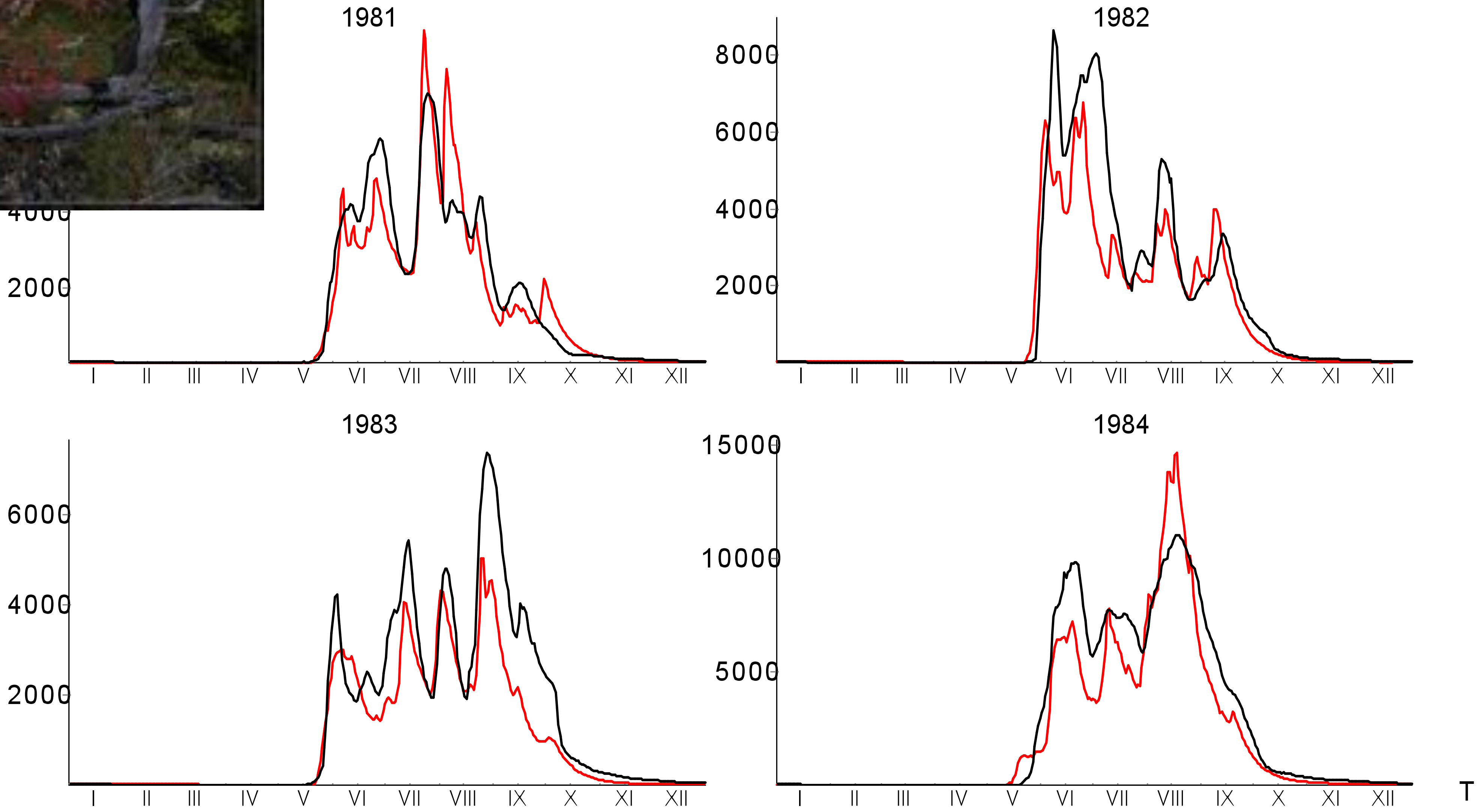
Kolyma at Kolymskoye, basin area 526000 km^2



Indigirka at Vorontsovo basin area <u>315000</u> km²



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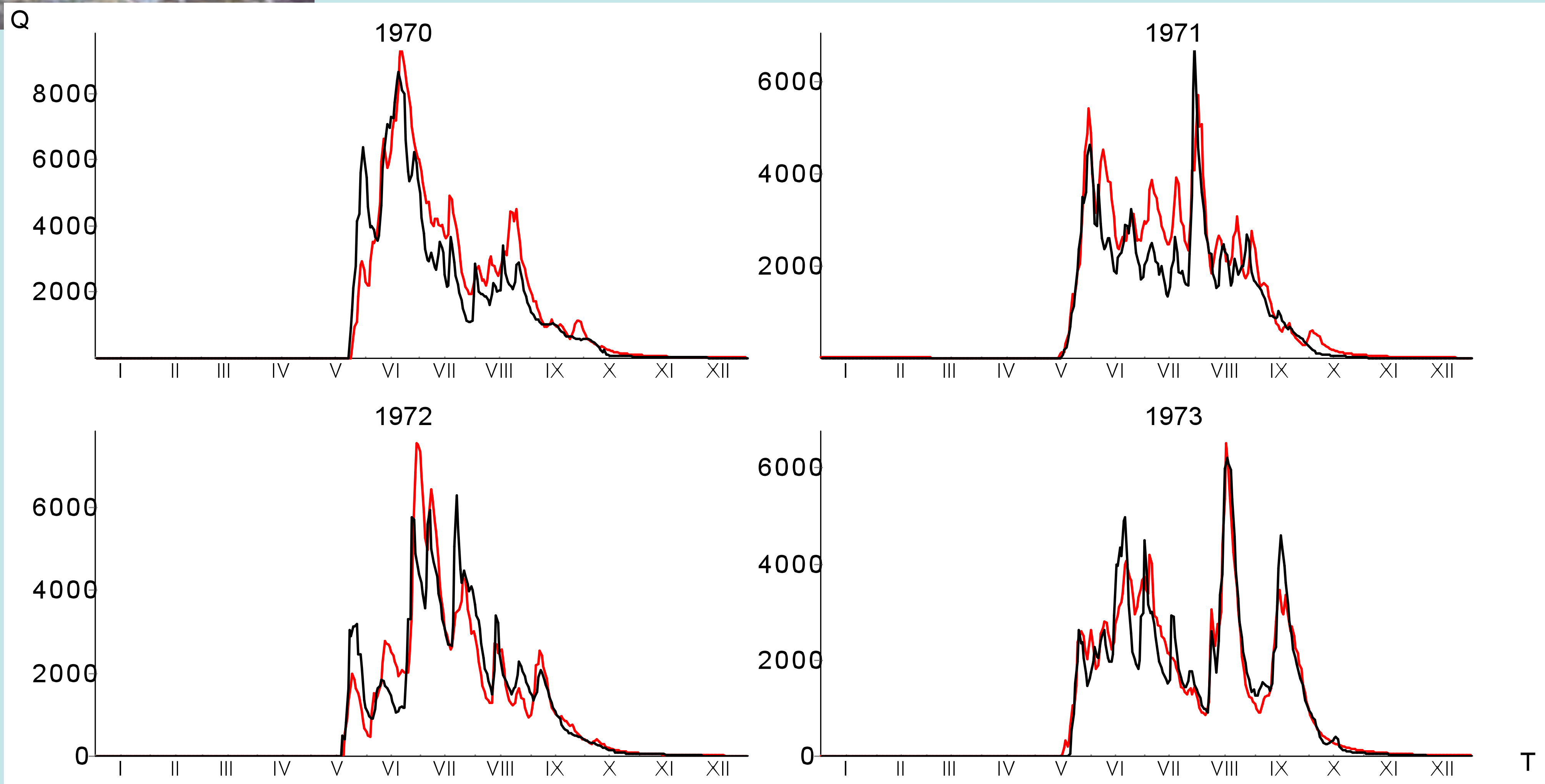
Yana at Dgangky, basin area 216000 km²



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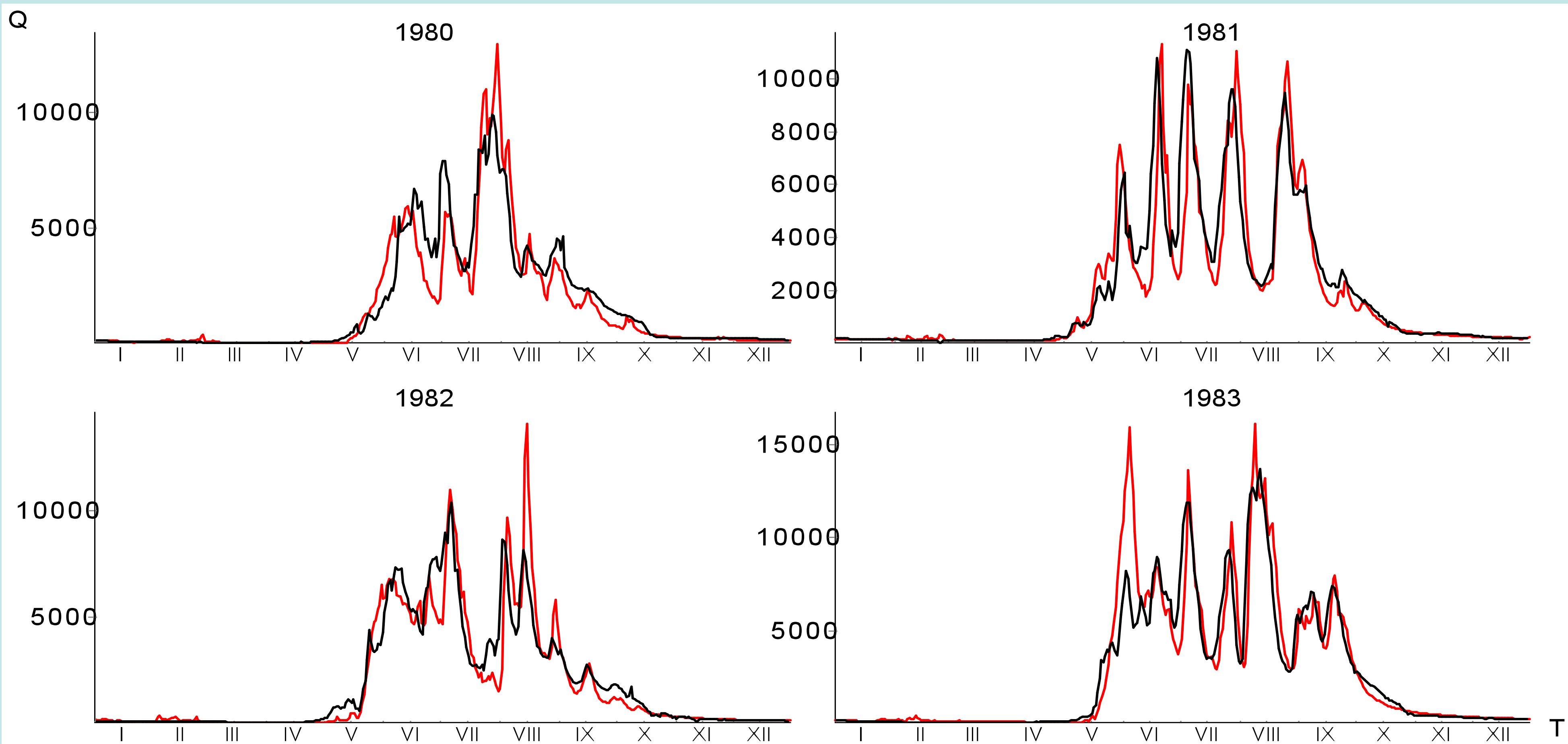
MIDDLE-SCALE BASINS

Vitim at Bodaybo, basin area 186000 km^2



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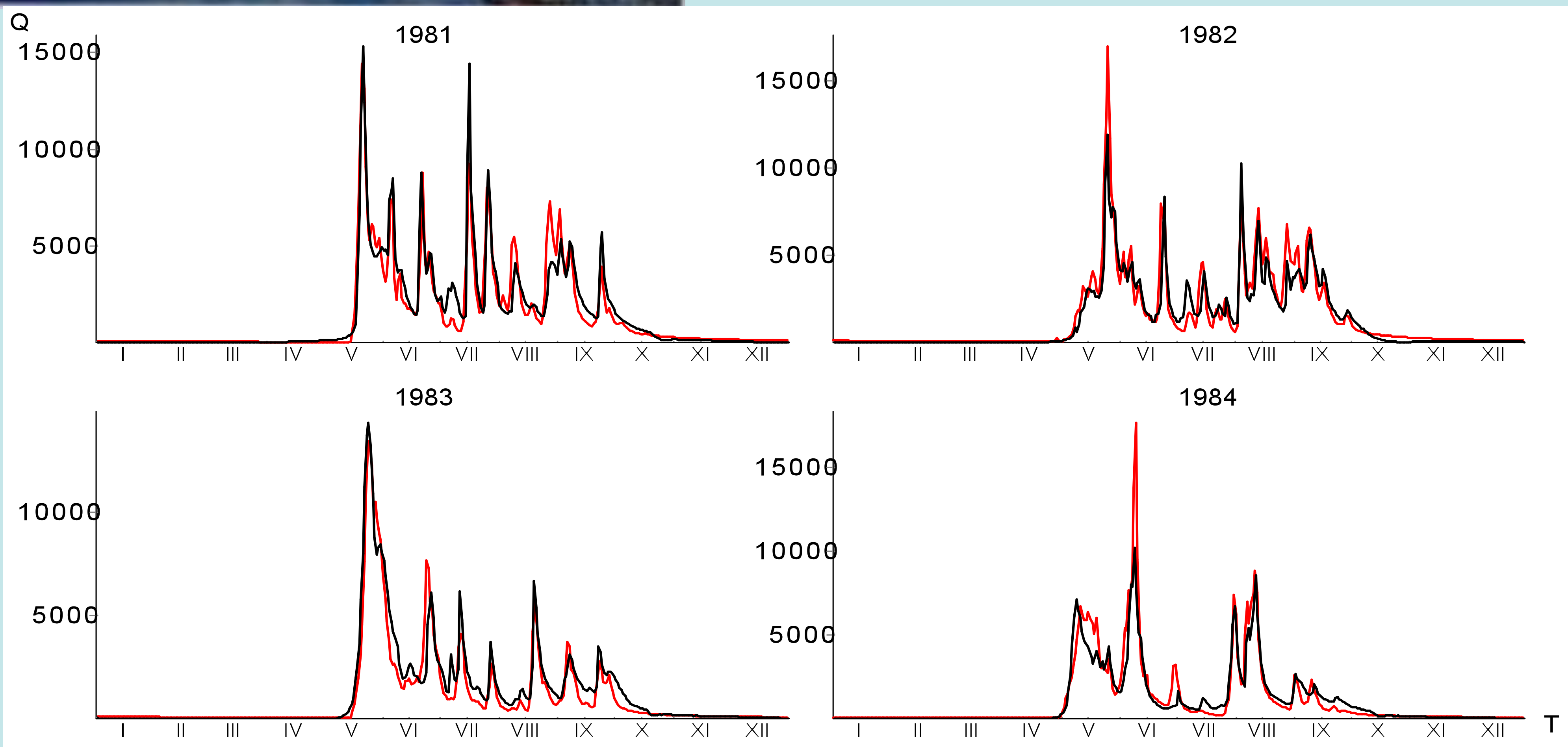
Uchur at Chyul'bu, basin area 108000 km^2



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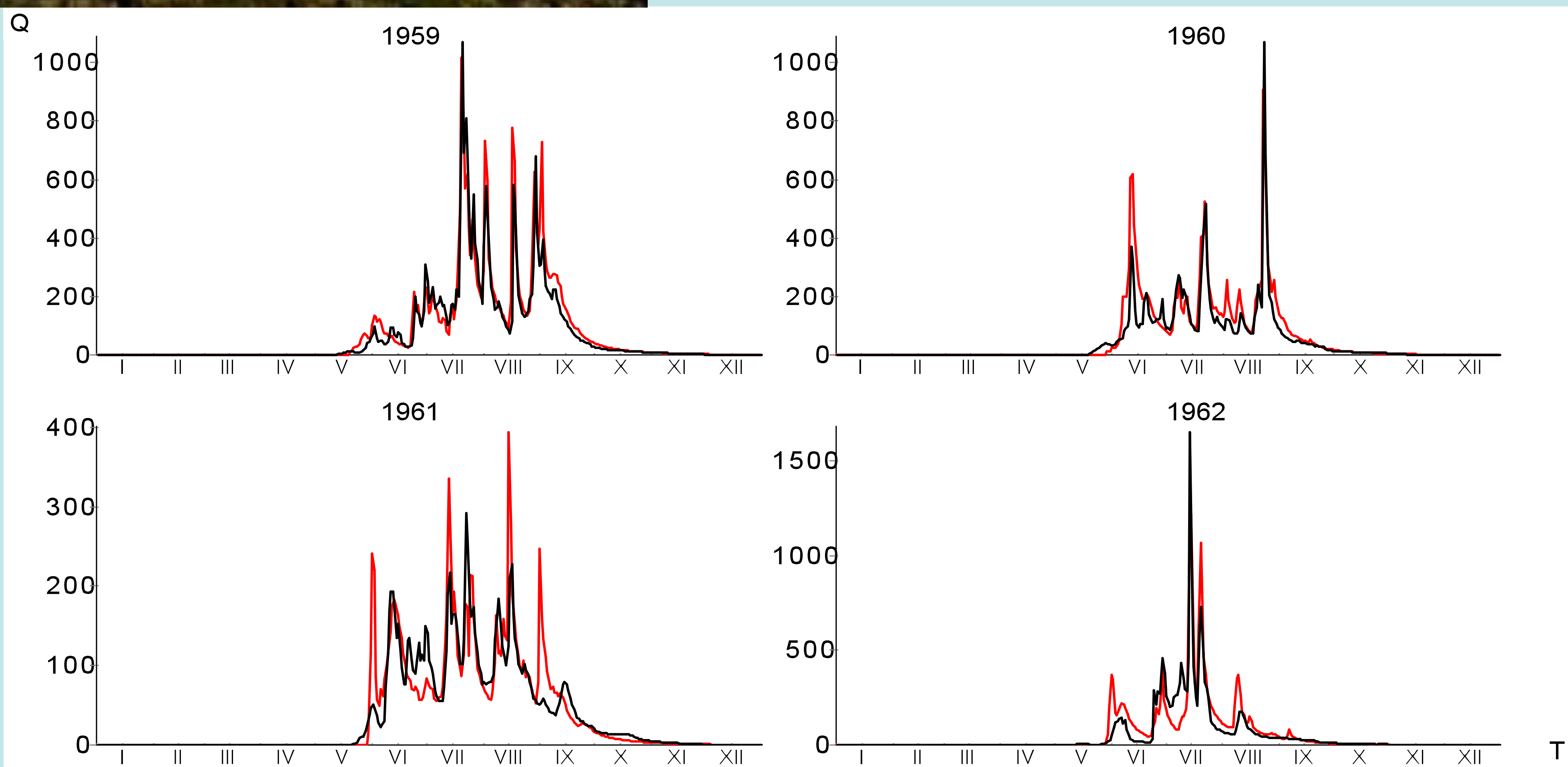
SMALL-SCALE BASINS

Suntar at Sakharynia river mouth, basin area 7680 km^2



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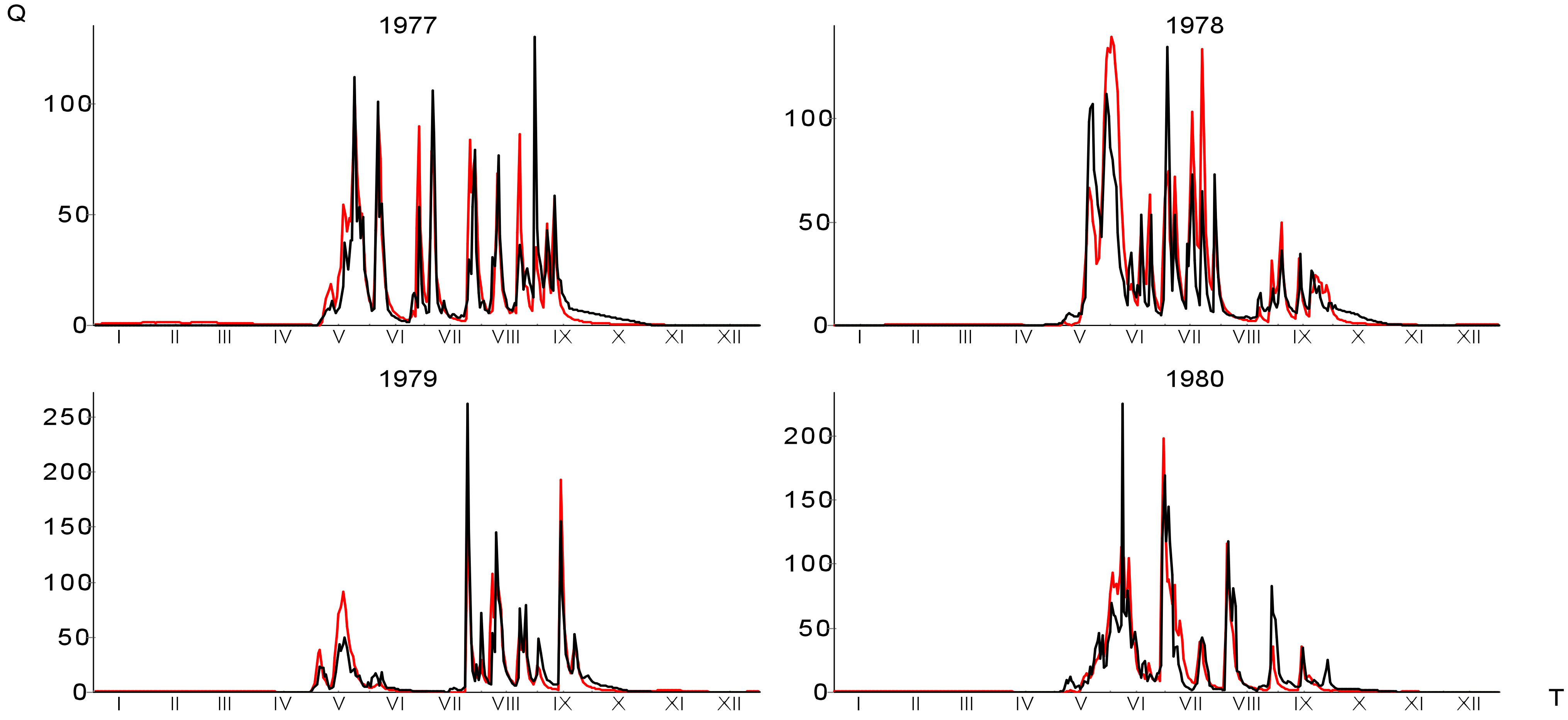
Timpton at Nagorny, basin area 613 km²



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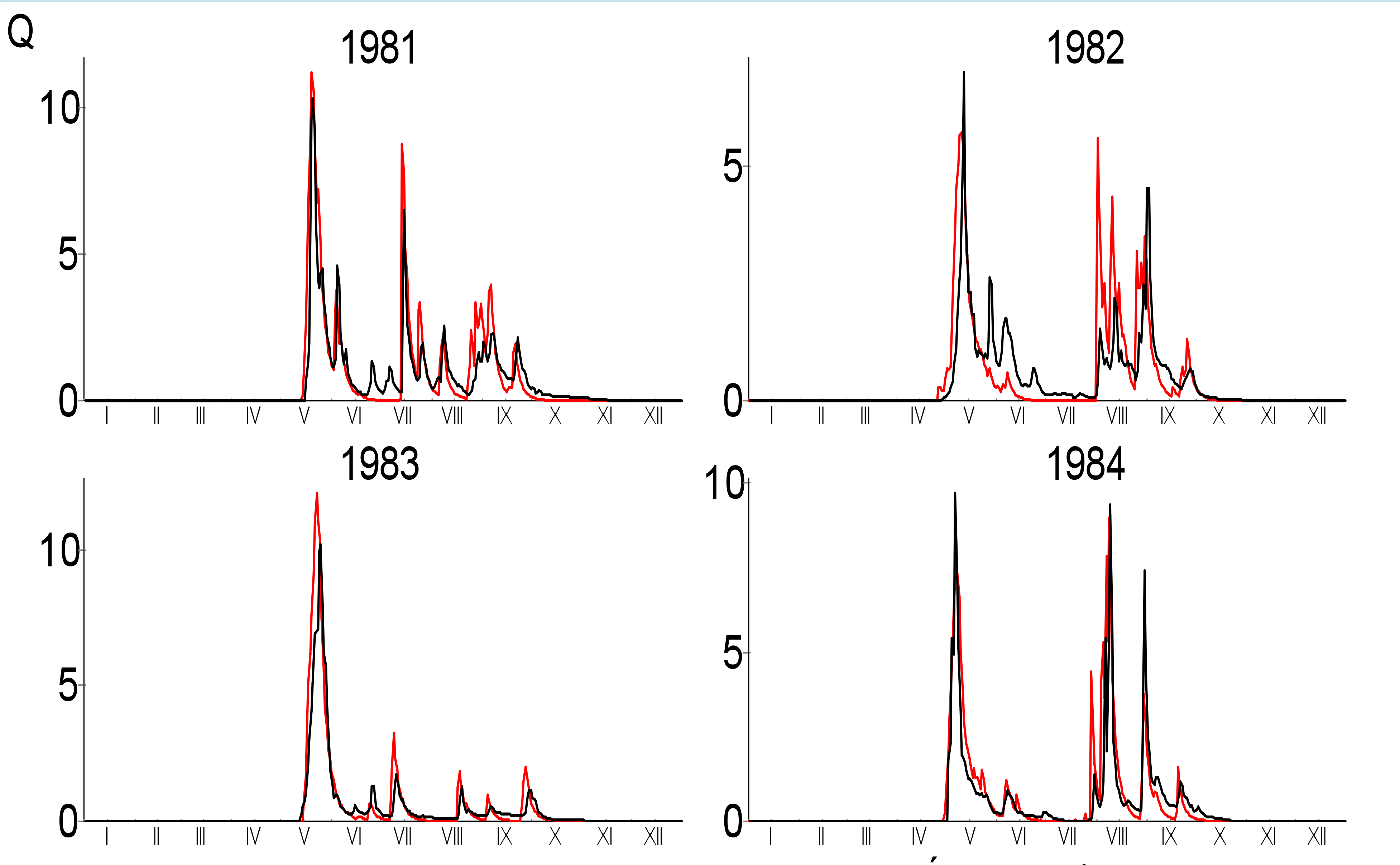
Katyryk at Toko, basin area <u>40.2</u> km²



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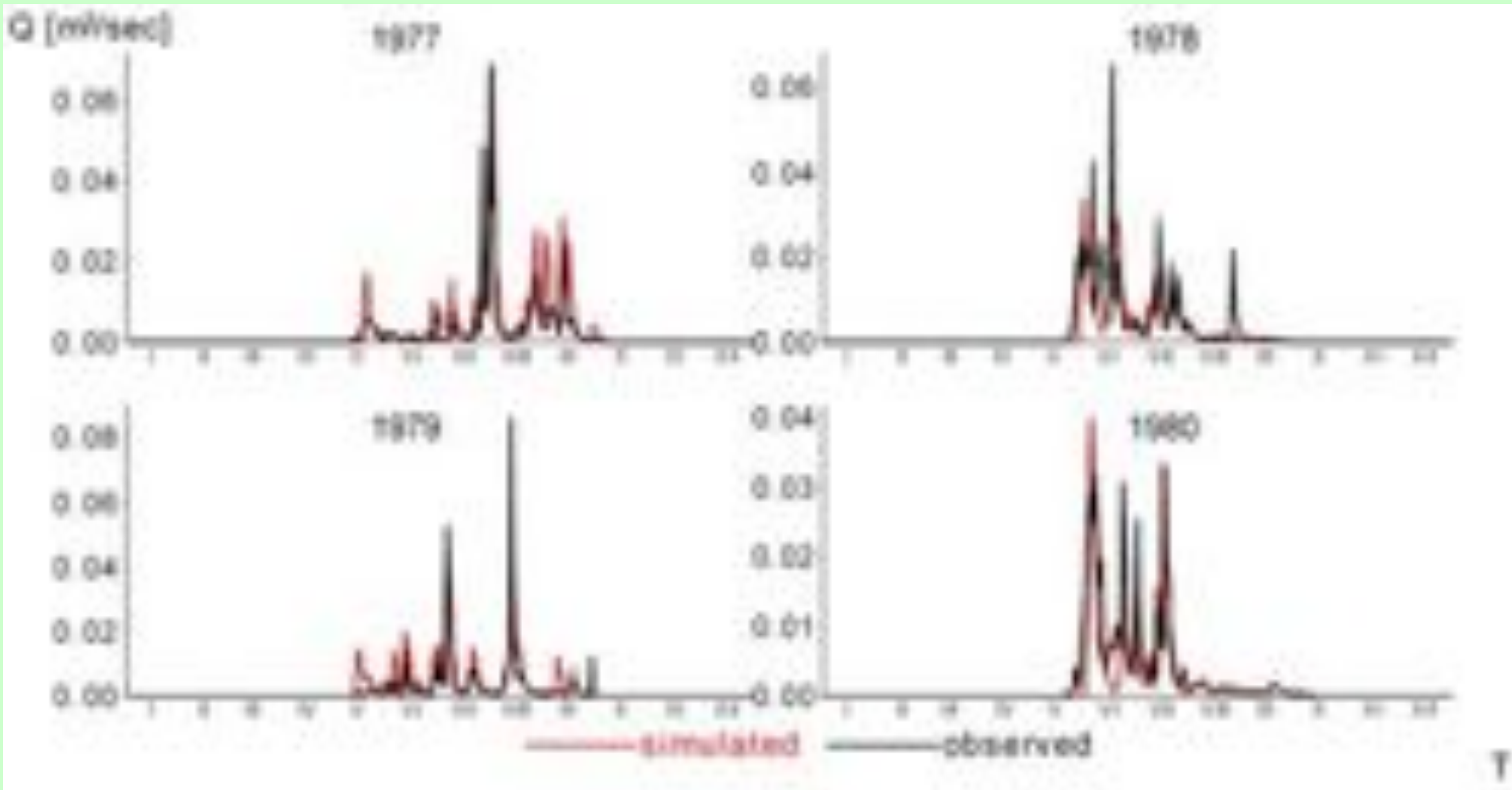
SLOPE SCALE

Yuzhny stream, area 0.27 km²



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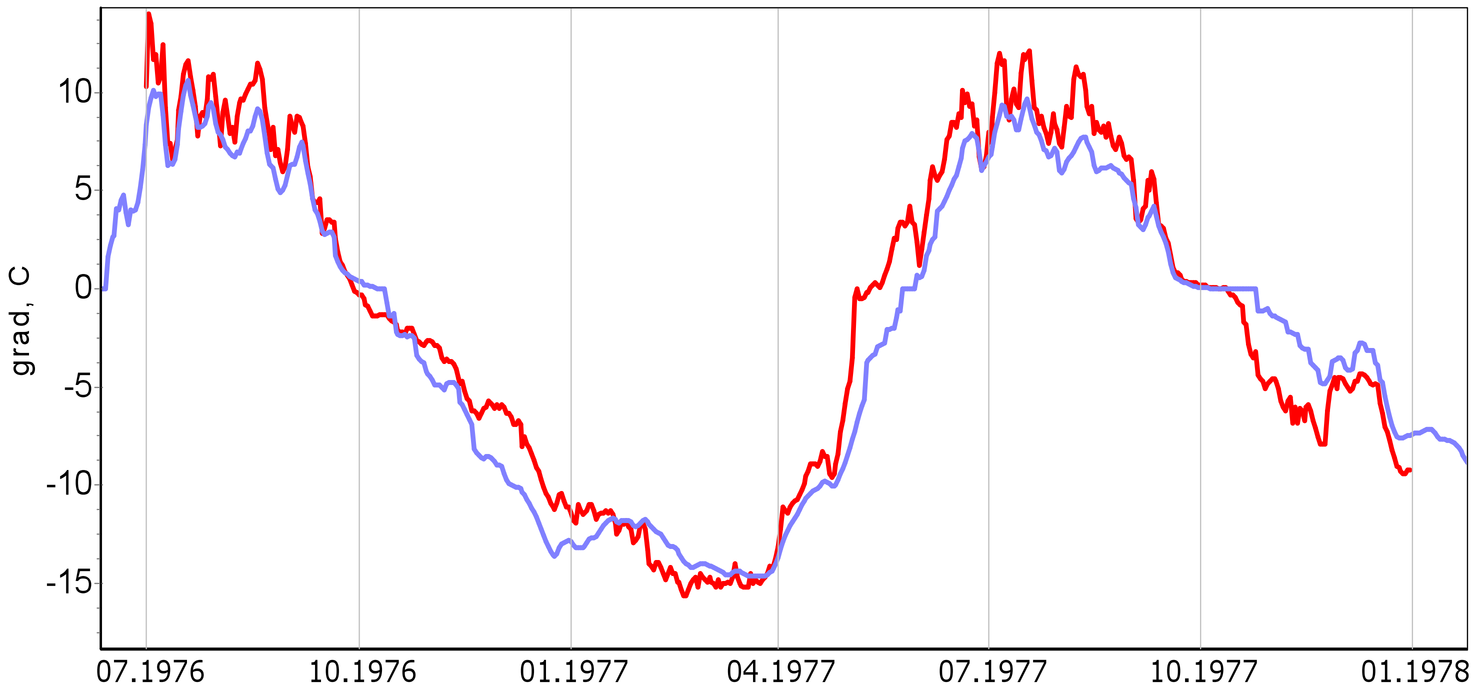
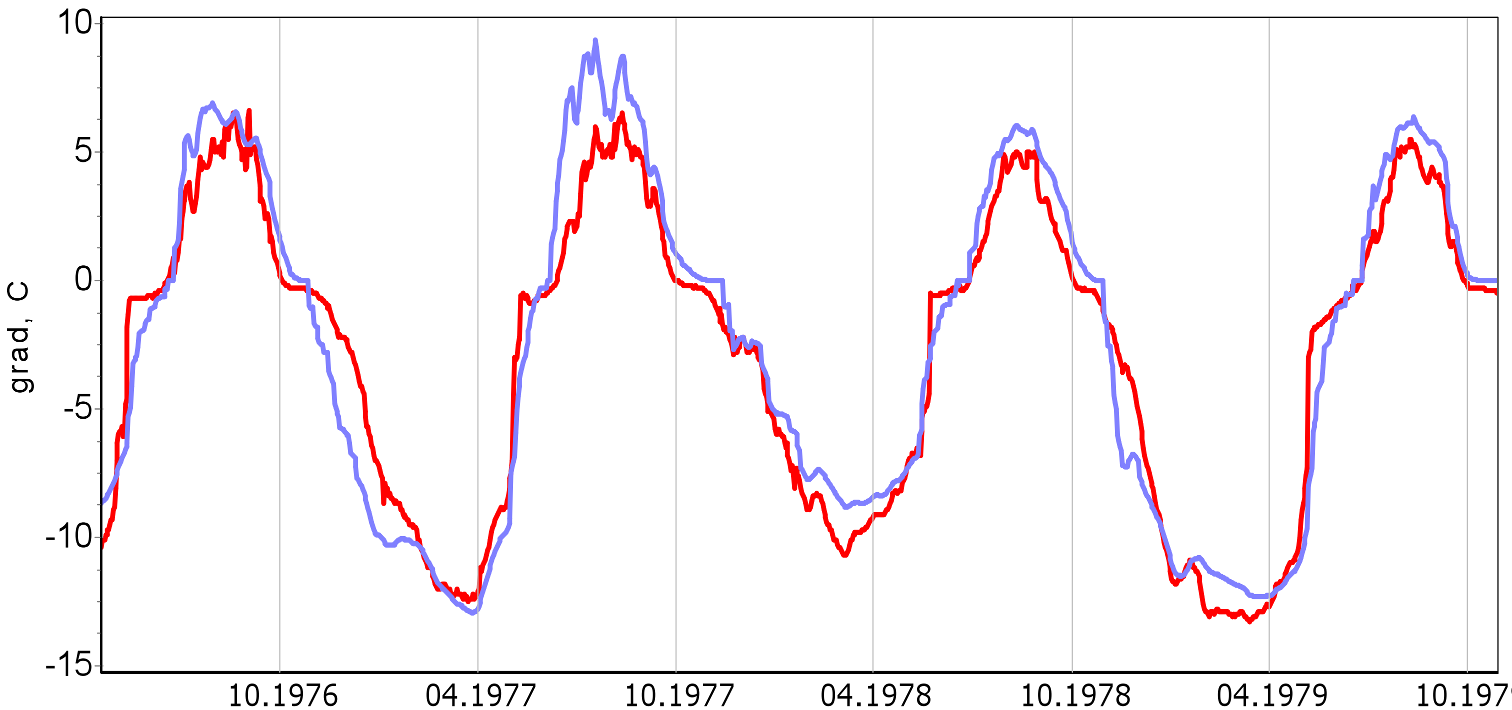
Meteorological Plot (Kolyma water balance station)



SOIL TEMPERATURE

0.4 m

0.8 m



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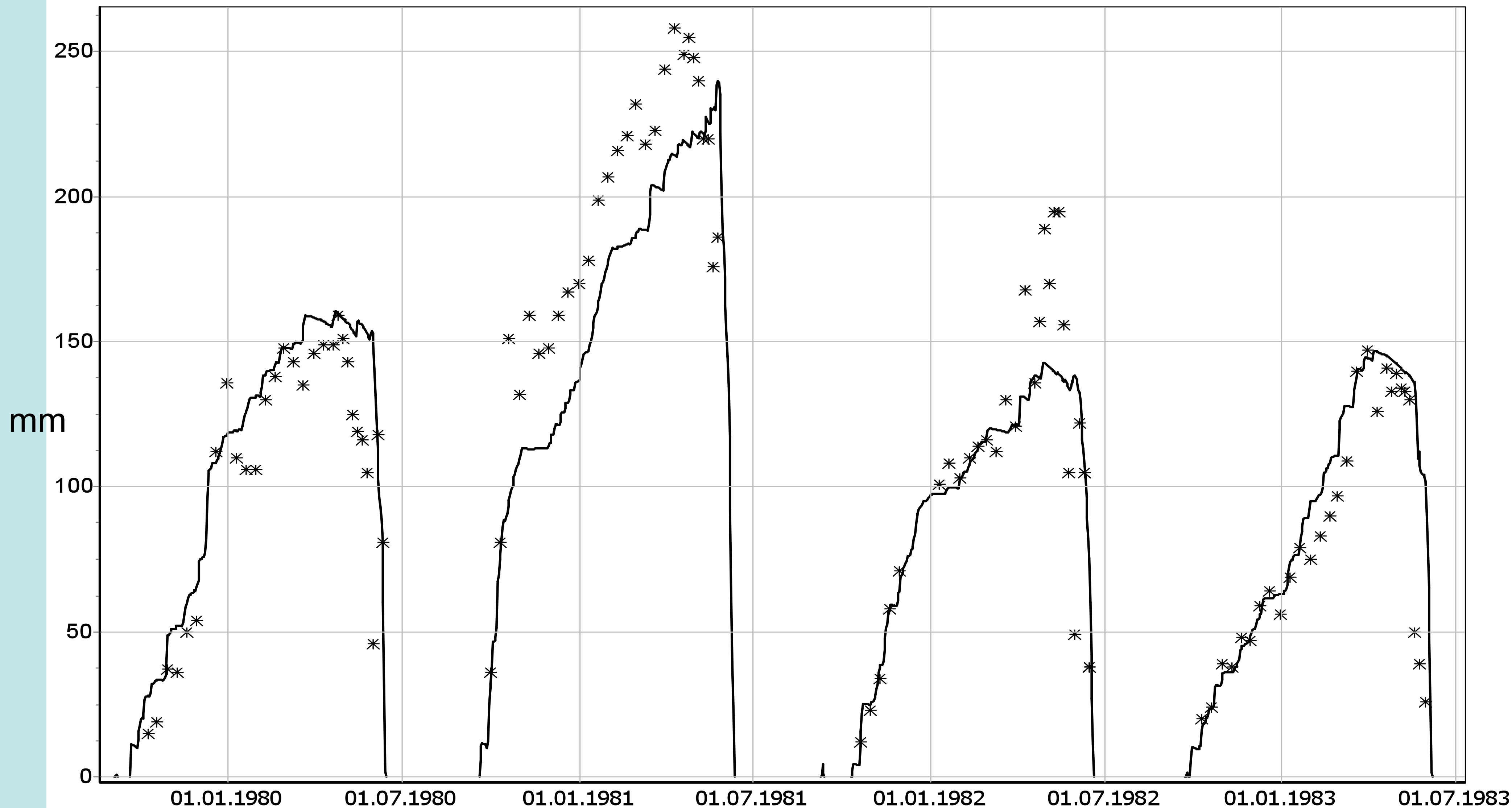
Snow water equivalent (meteorological station Kusur) (1980 – 1983)



------------- calculated at meteorological station

************ observed at snow surveys near station

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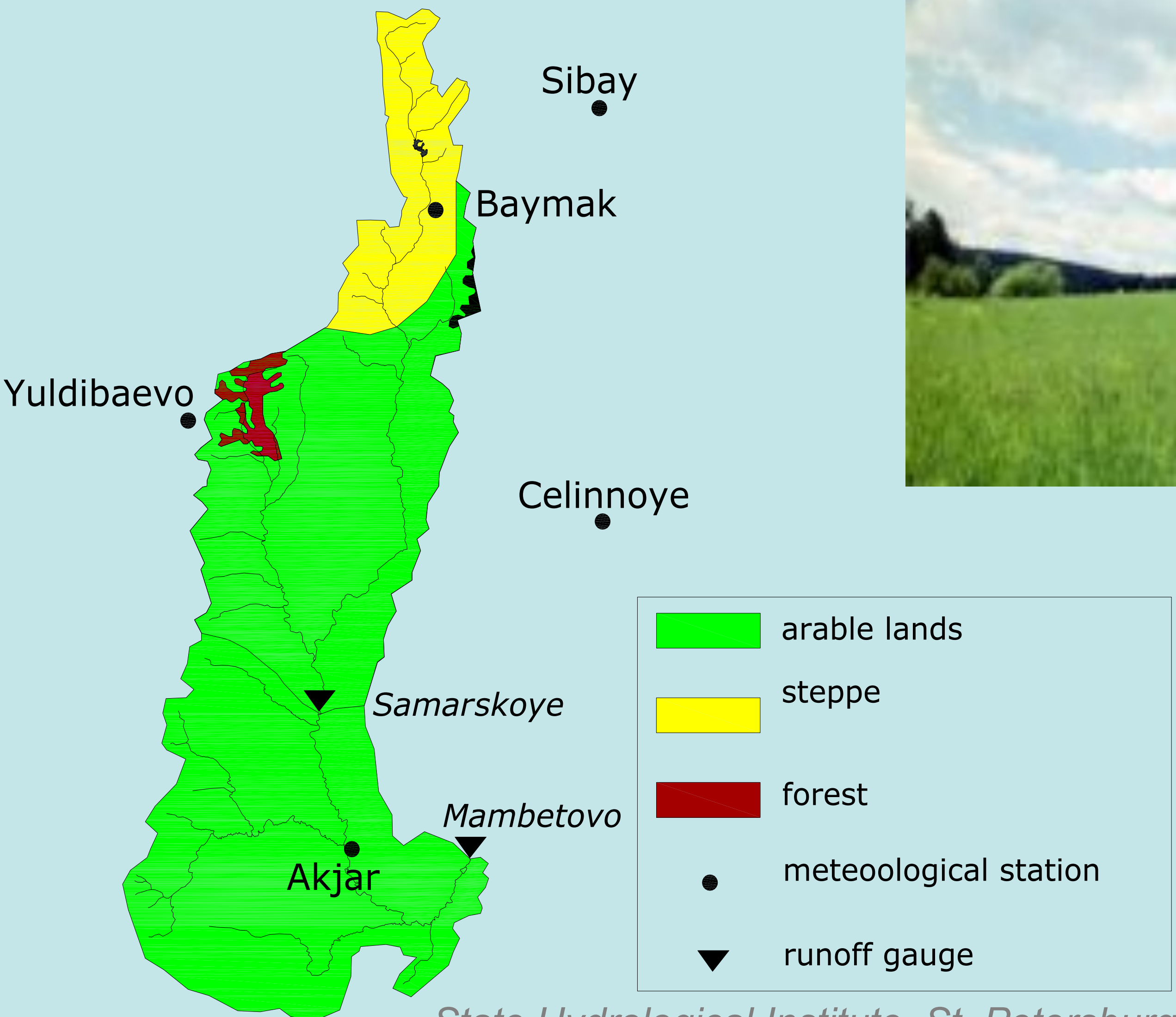
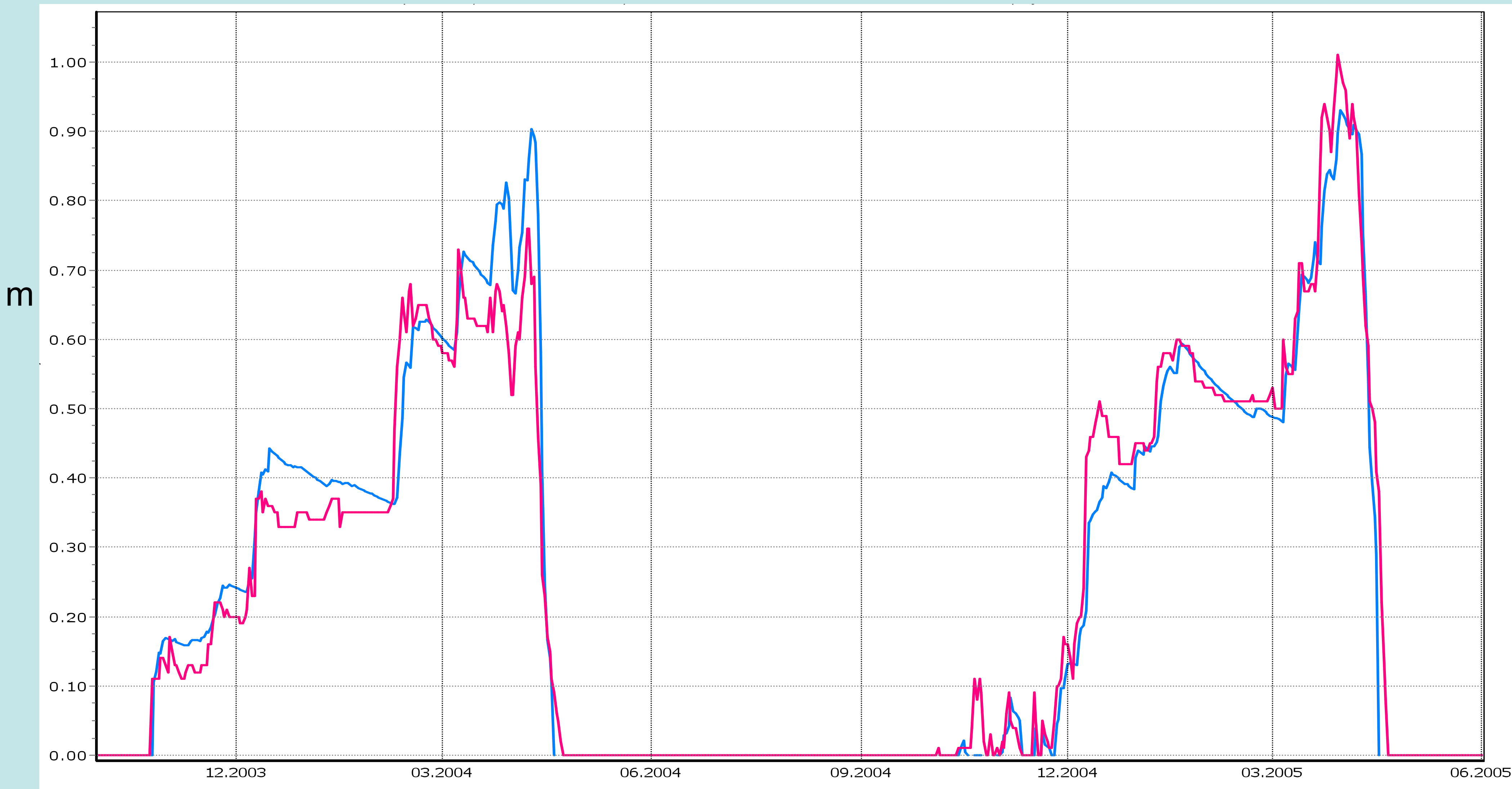
Bashkiriya – steppe landscapes

Tanalyk, Samarskoy, basin area 1350 km^2



State variables of soil and snow

Snow height, meteorological station Zilair, 2004 – 2005



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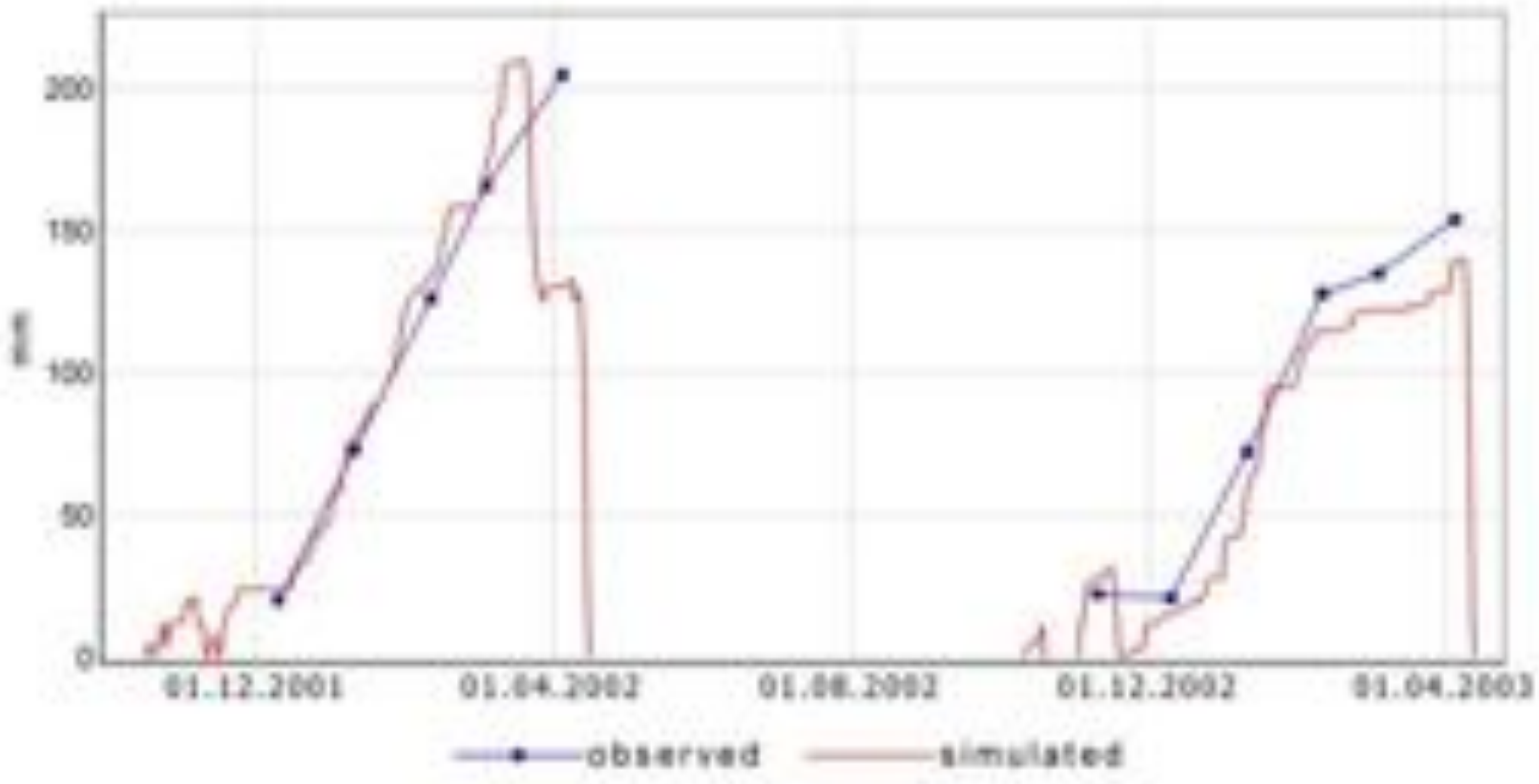
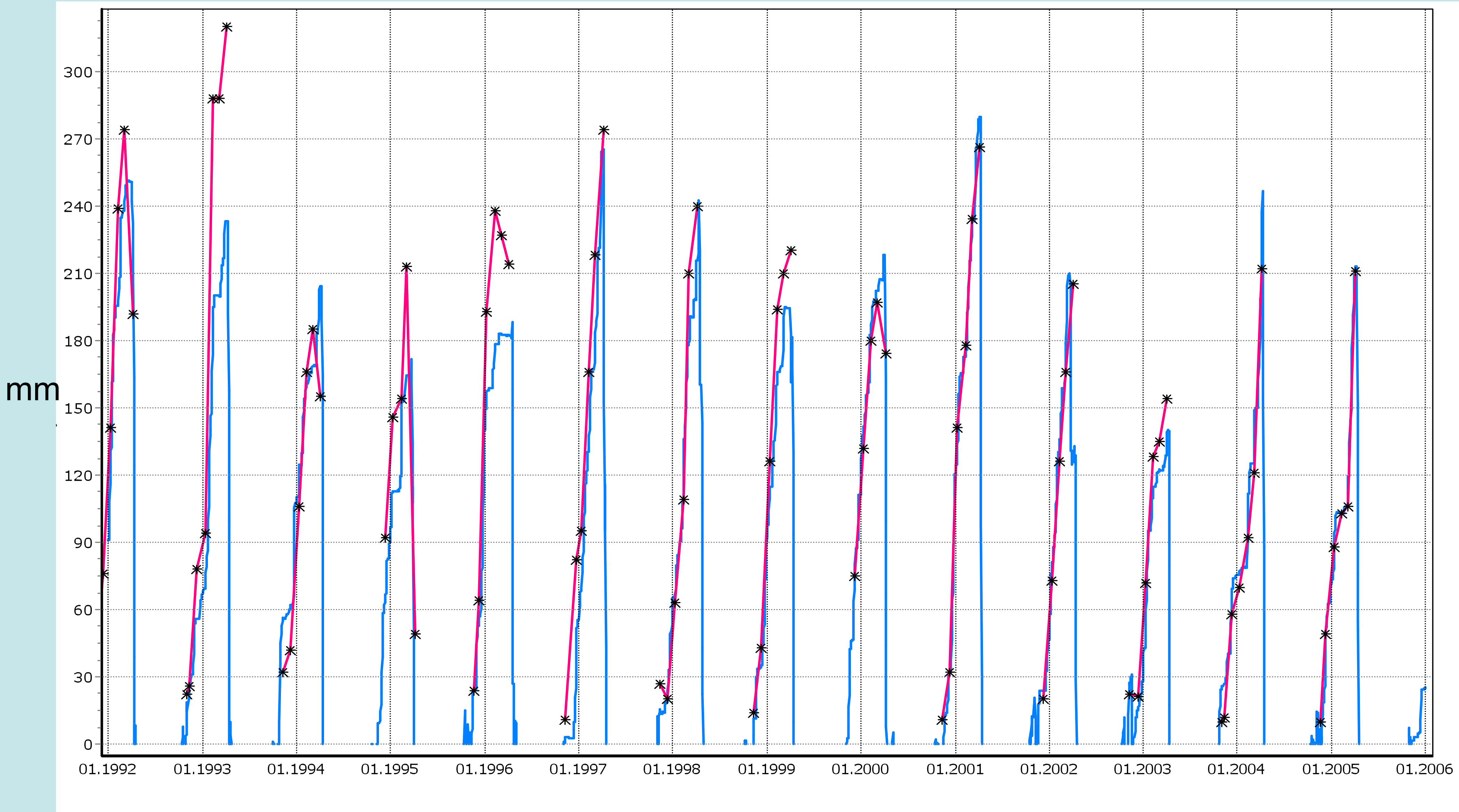
SWE, snow survey near the meteorological station Zilair, 2001 – 2003



SWE, snow survey near the meteorological station Zilair, 1992 – 2005



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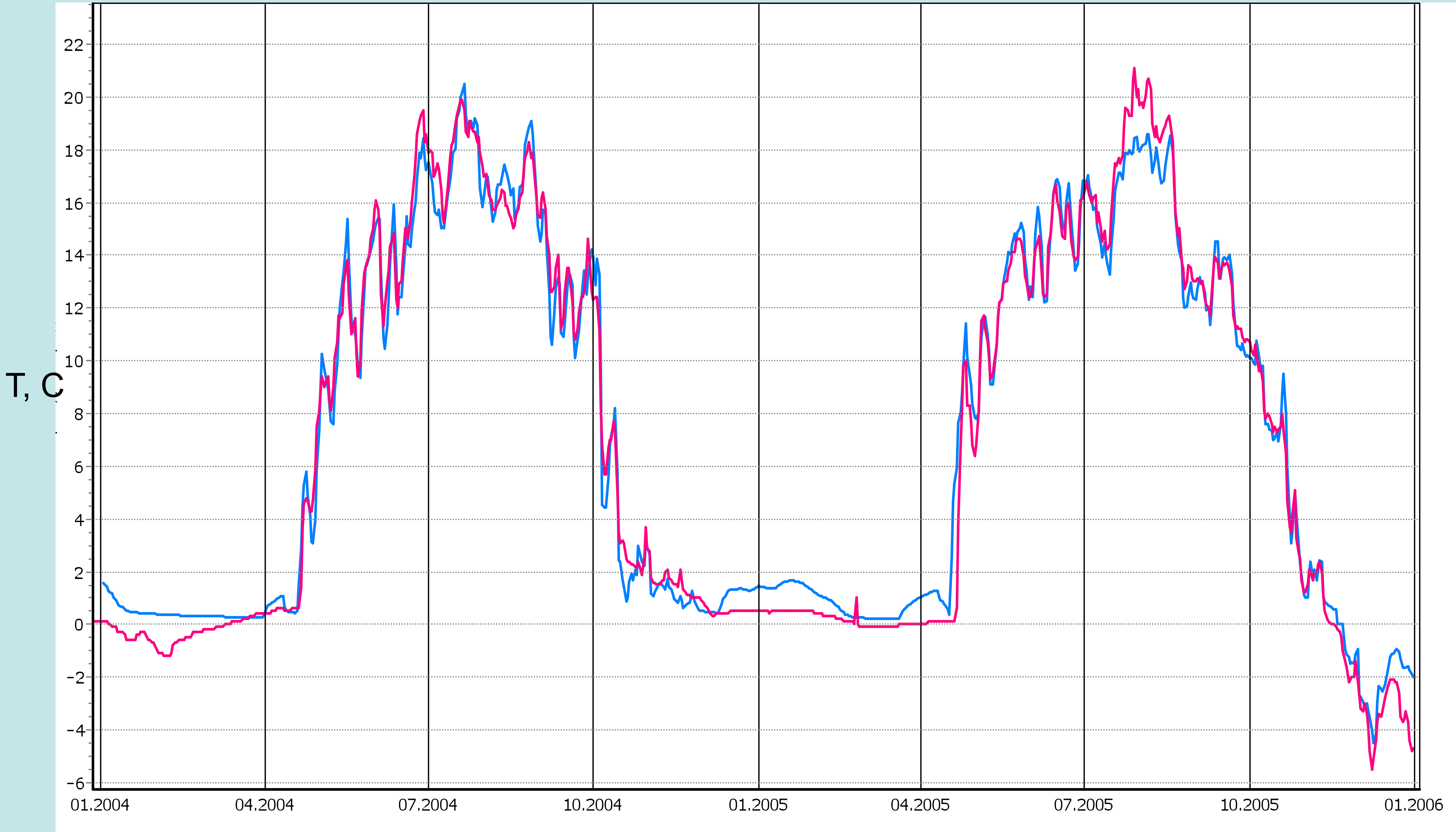
Soil temperature at 0.2 m, meteorological station Zilair, 2004 – 2005



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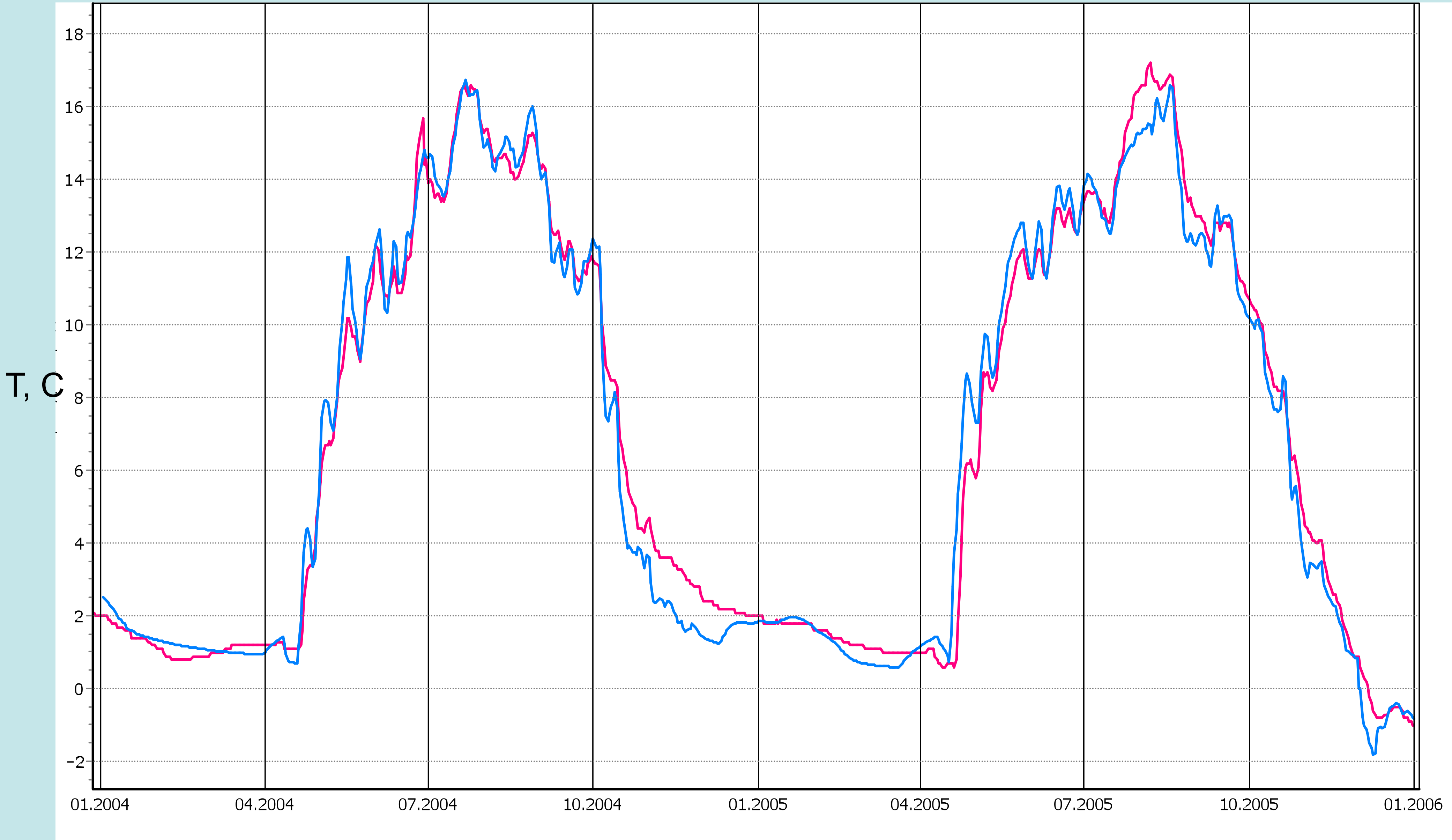
Soil temperature at 0.4 m, meteorological station Zilair, 2004 – 2005



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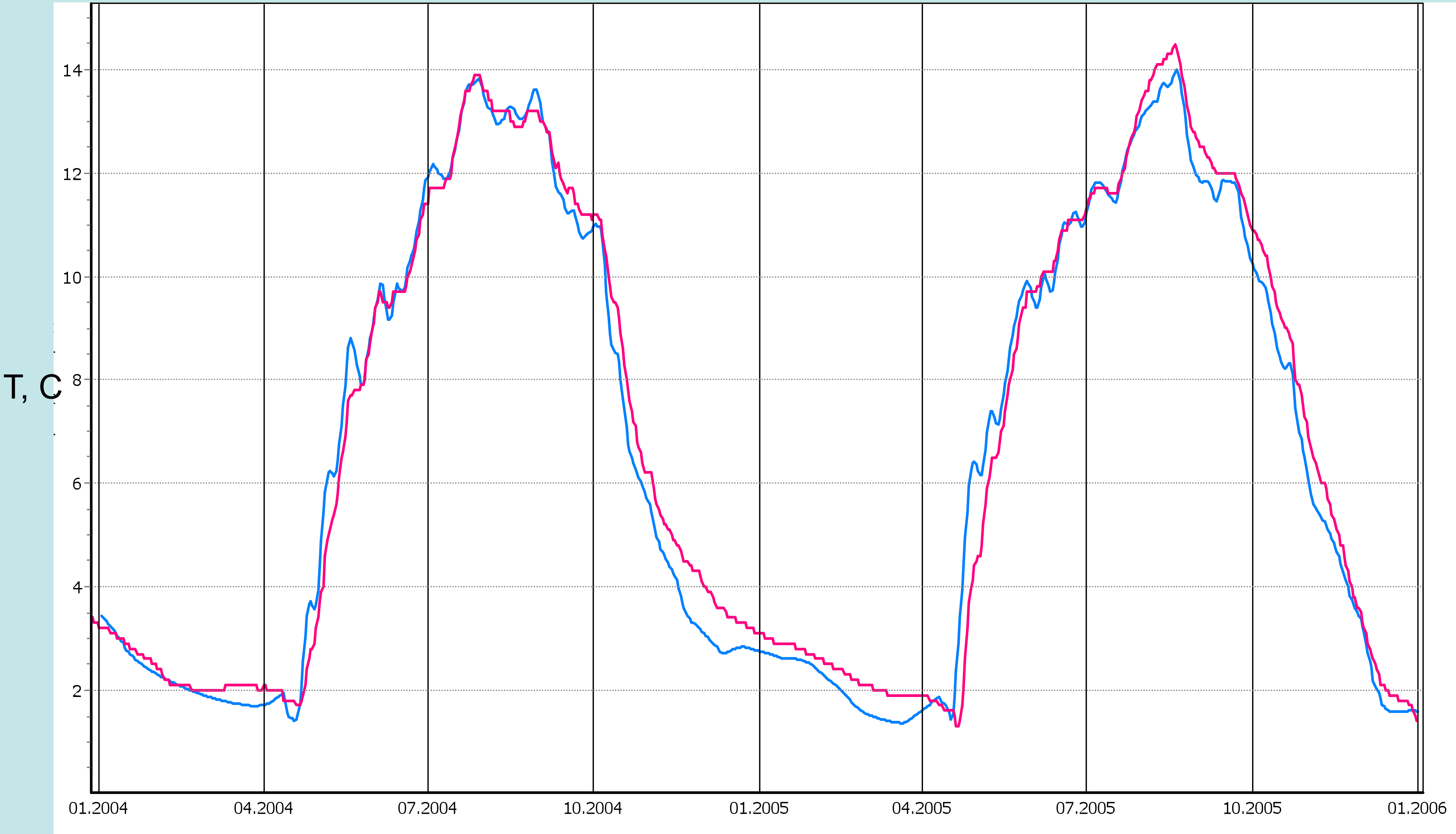
Soil temperature at 0.8 m, meteorological station Zilair, 2004 – 2005



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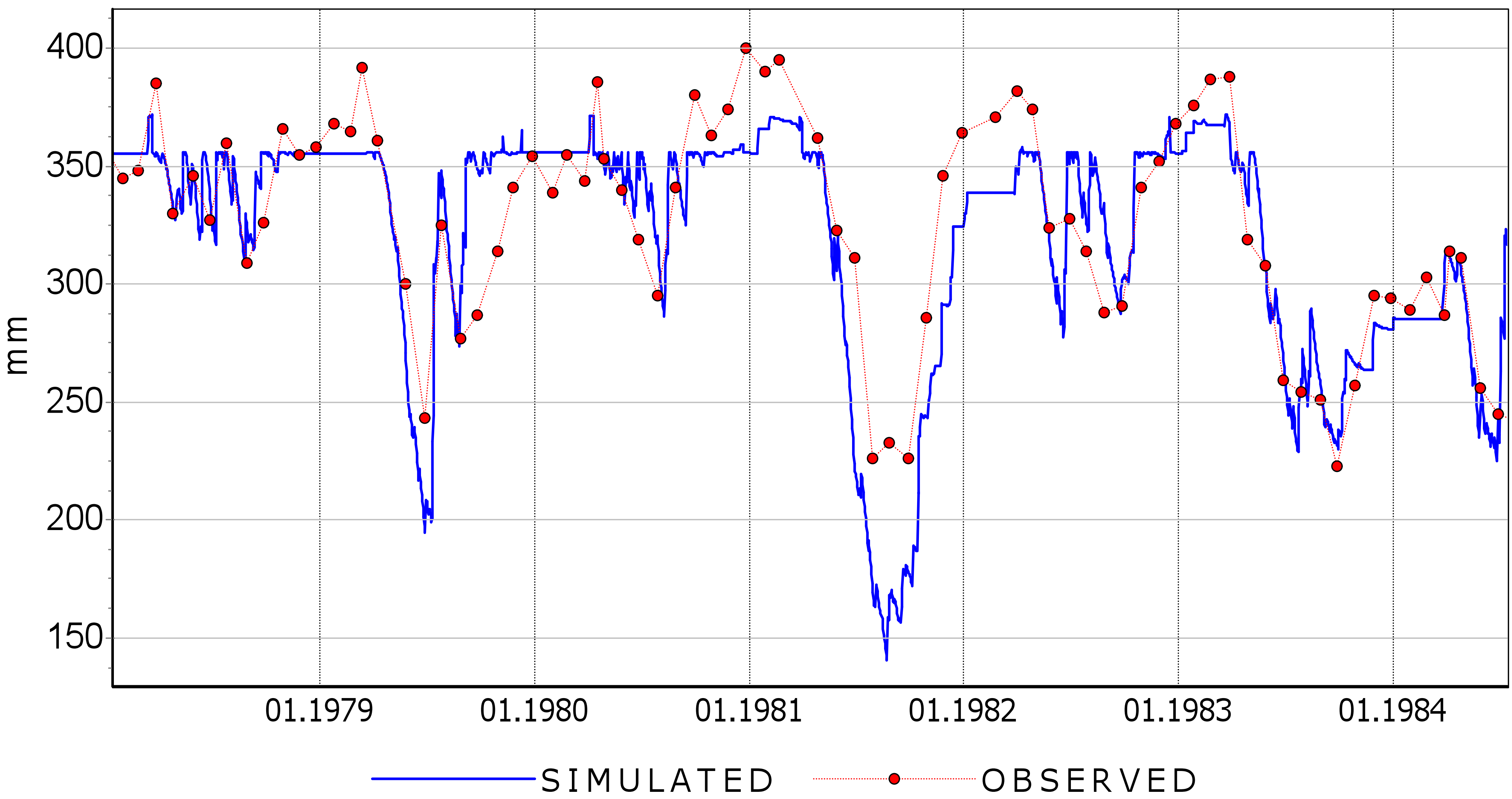
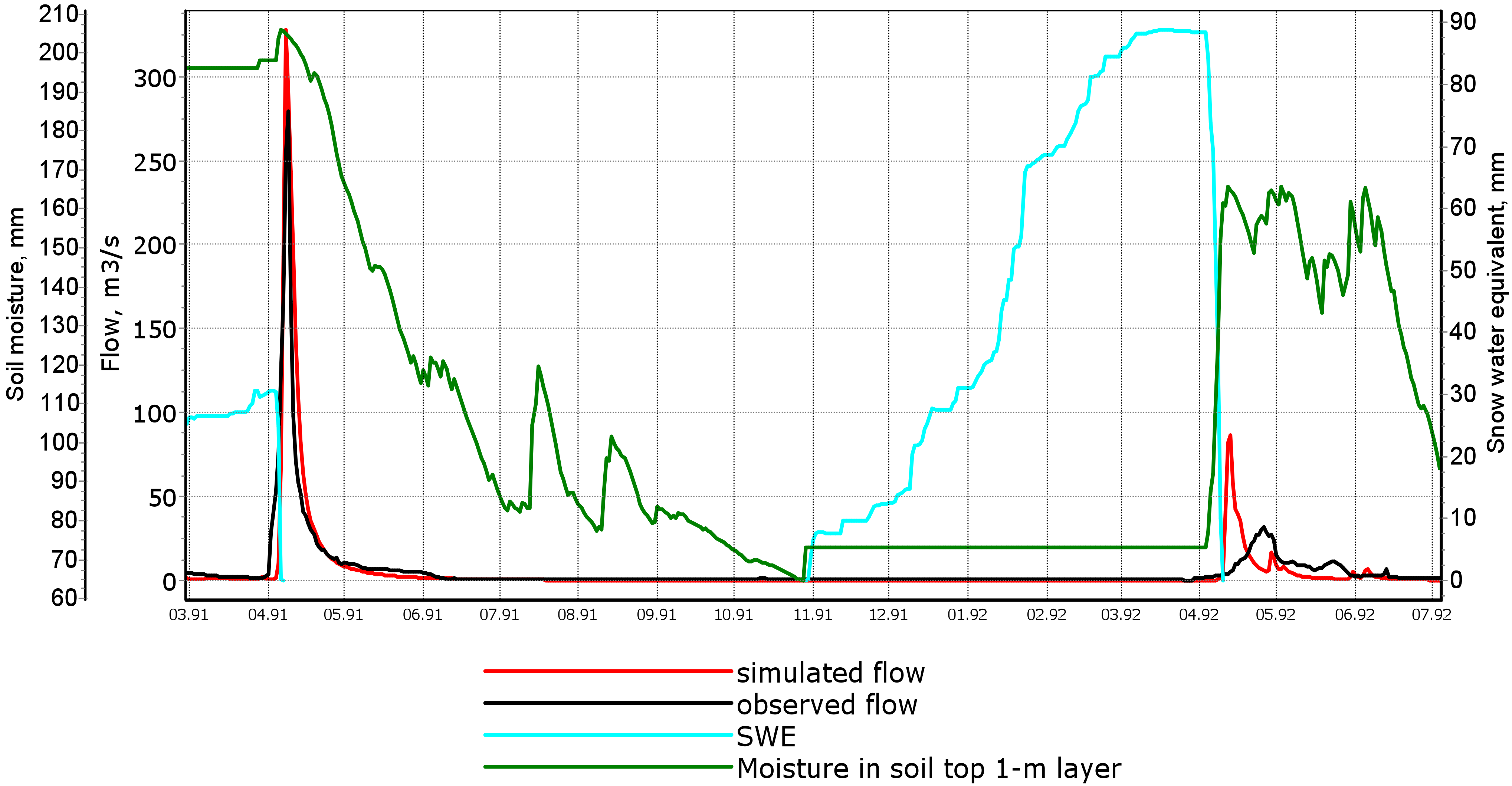
SOIL MOISTURE

Stream Dolgy, area 2.51 km², averaged content of moisture in 1-m layer Nizhnedevitskaya water balance station

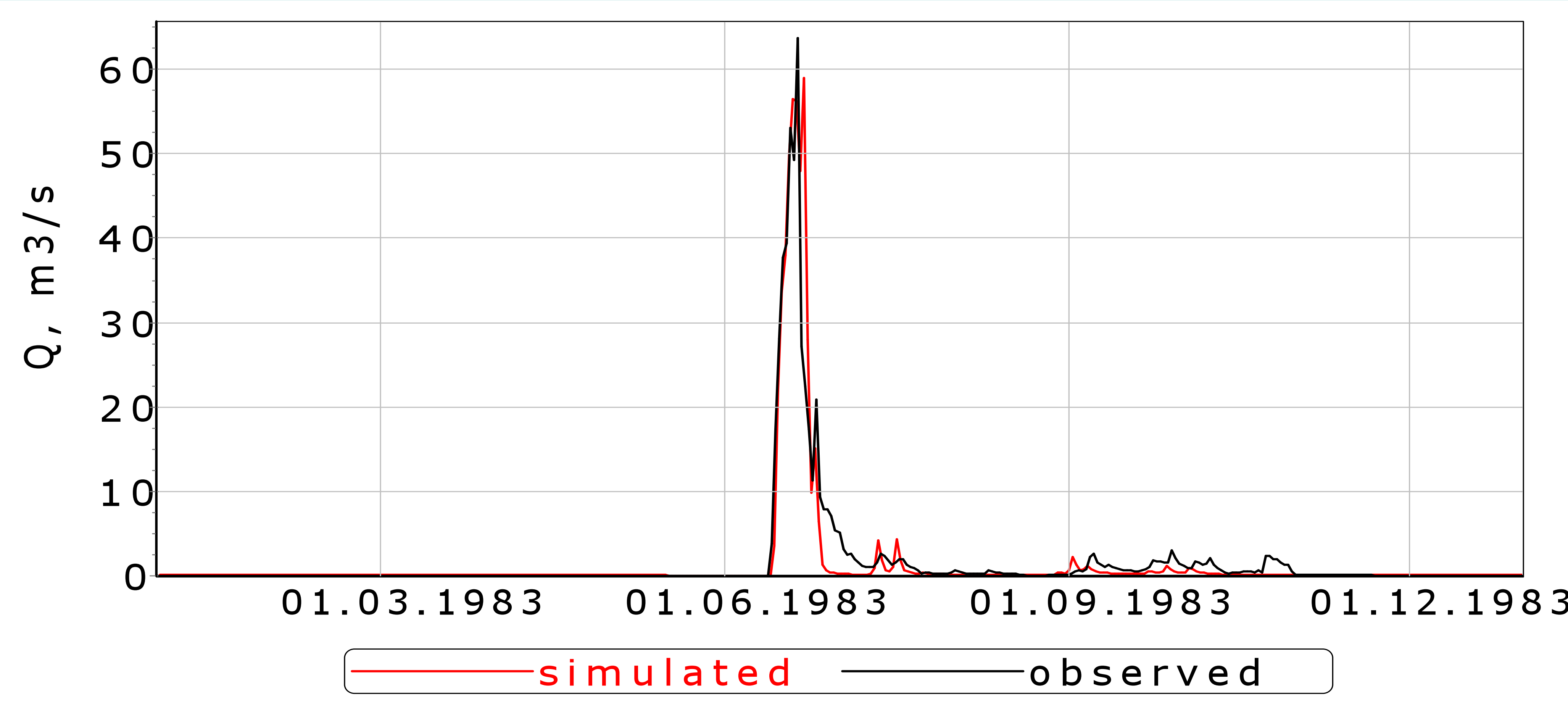


State variables of soil, snow and runoff



Yamal Peninsula

Pyasedey-Yaha, basin area 113.6 km^2



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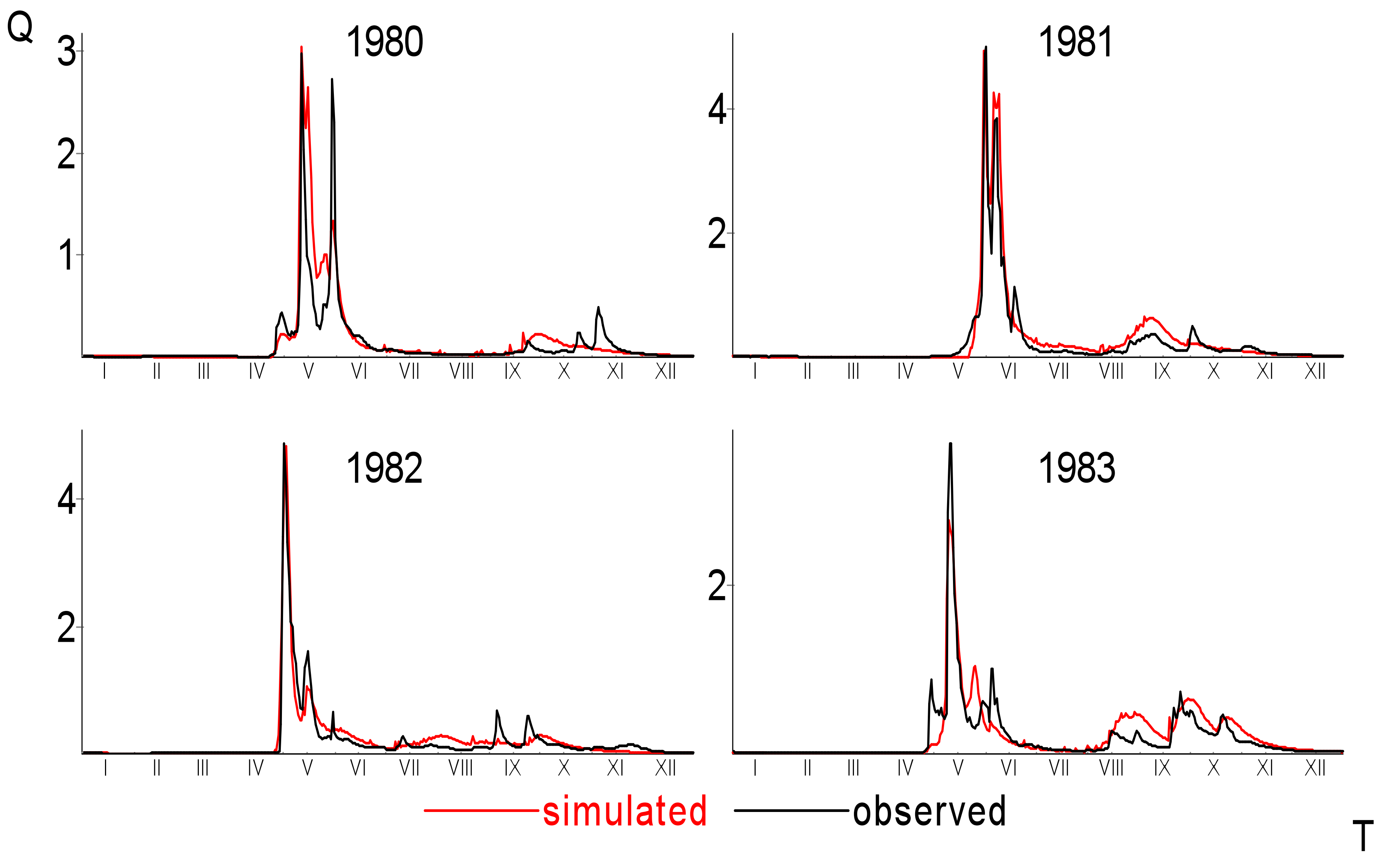
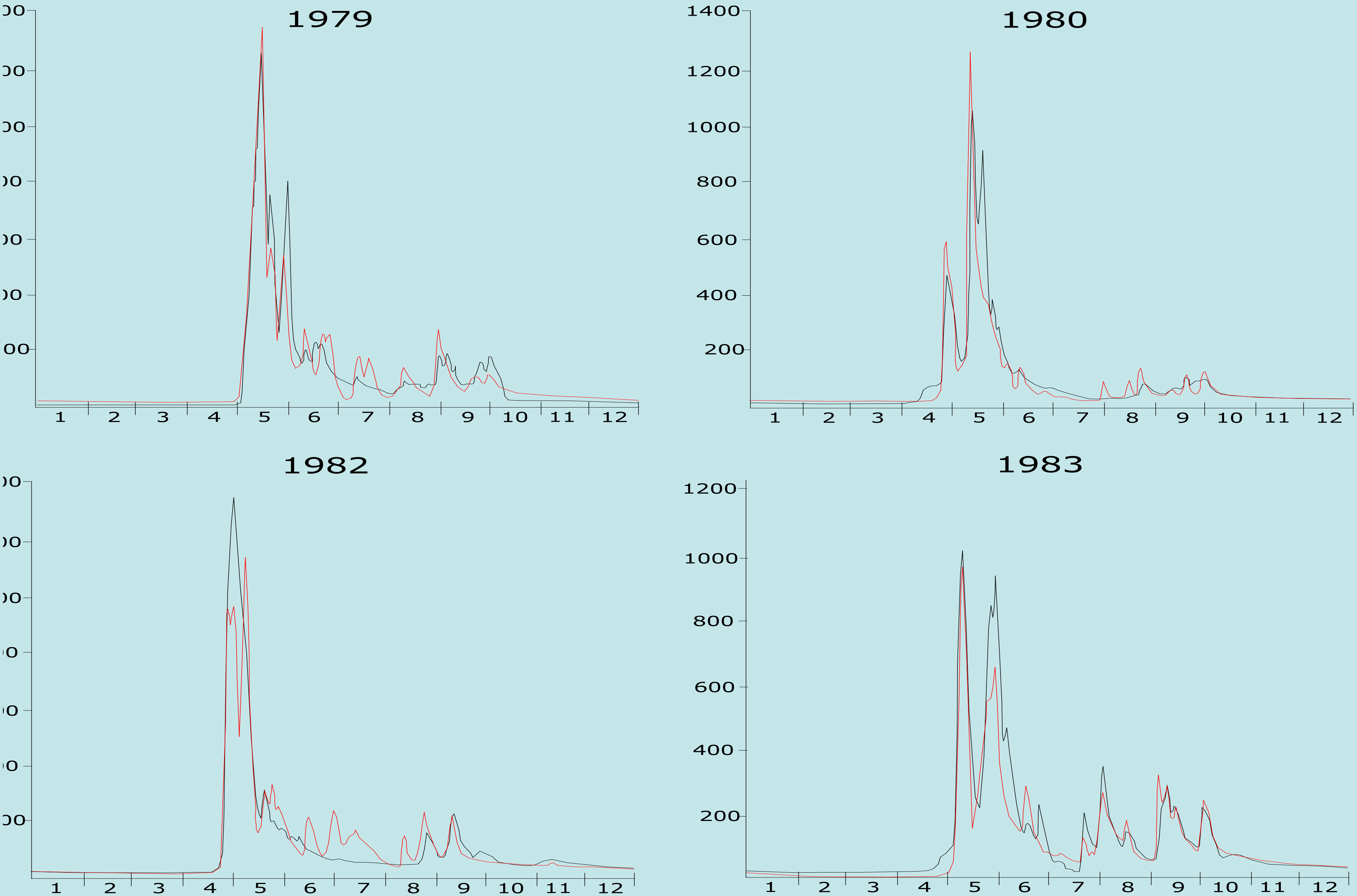
European North of Russia

Nyashenny stream at Kotkino, basin area 16.1 km²



Sula River at Sula, basin area 8500 km²



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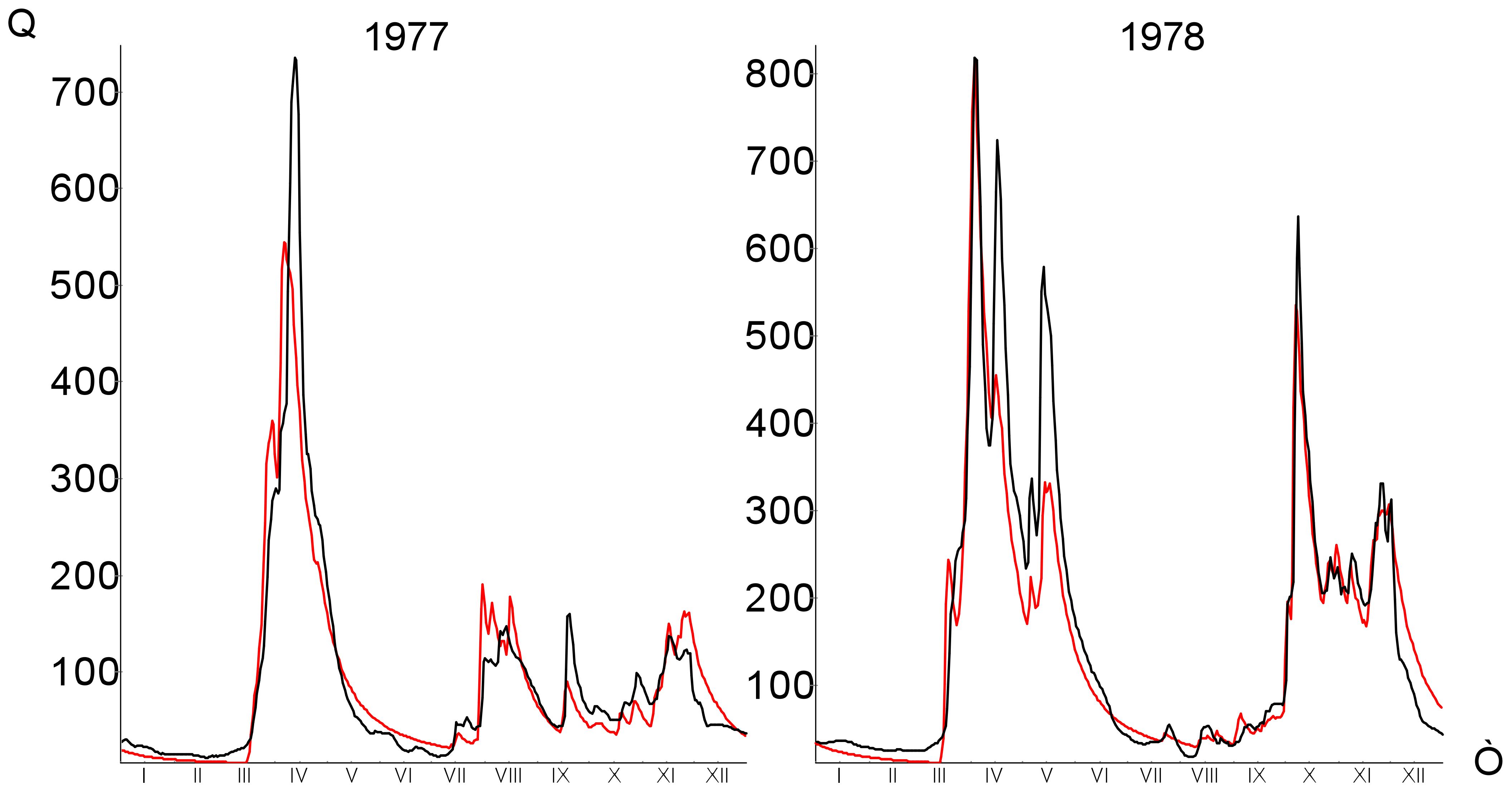
Baltic Sea Basin

Lovat at Holm, basin area 14700 km²



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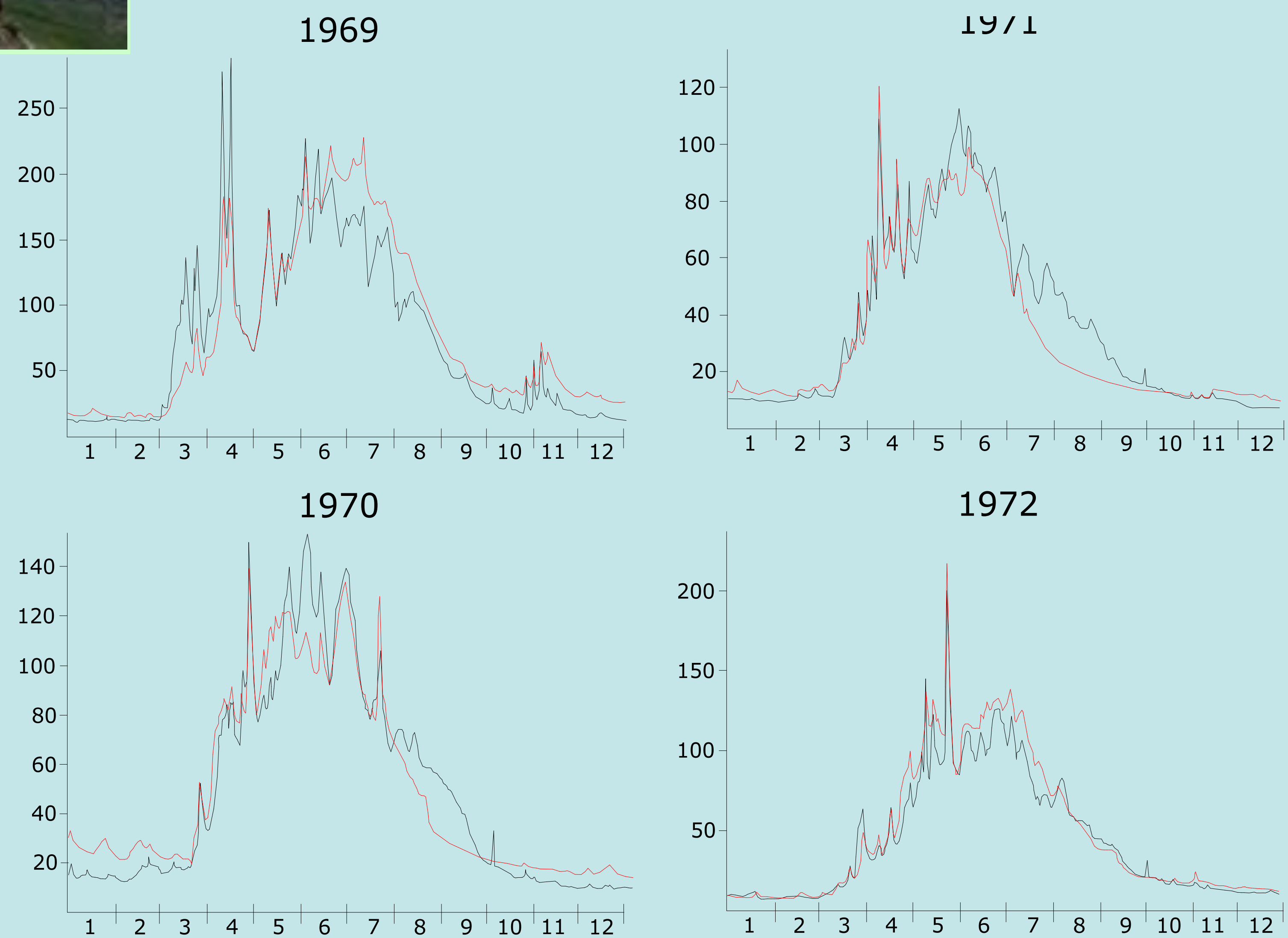
Varzob at Dagana,
basin area 1270km^2
Mountains, glaciers,
altitude range 1000-4880 m



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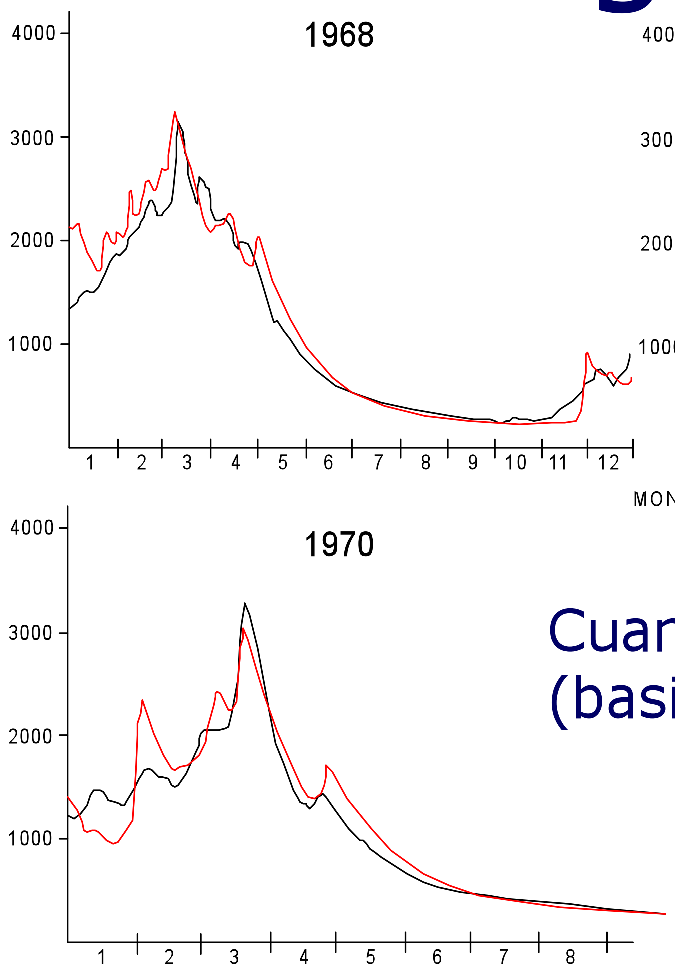
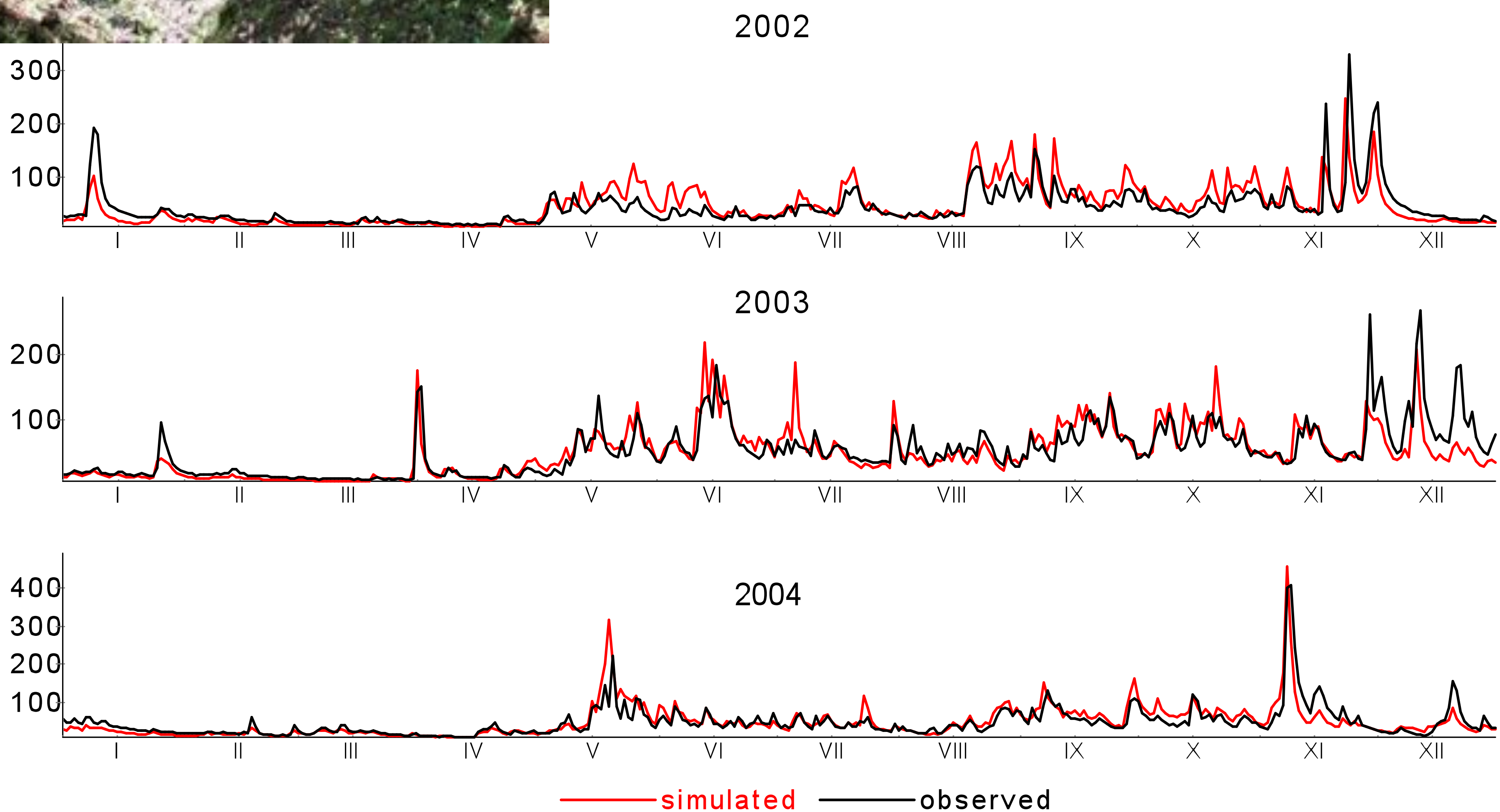
Angola, Africa



Tropical savanna

Cuanza River at Kambambe
(basin area 115500 sq. km)

Rio Reventazon-Parismina, Palome, Costa-Rica, basin area 371 km²: tropical forest



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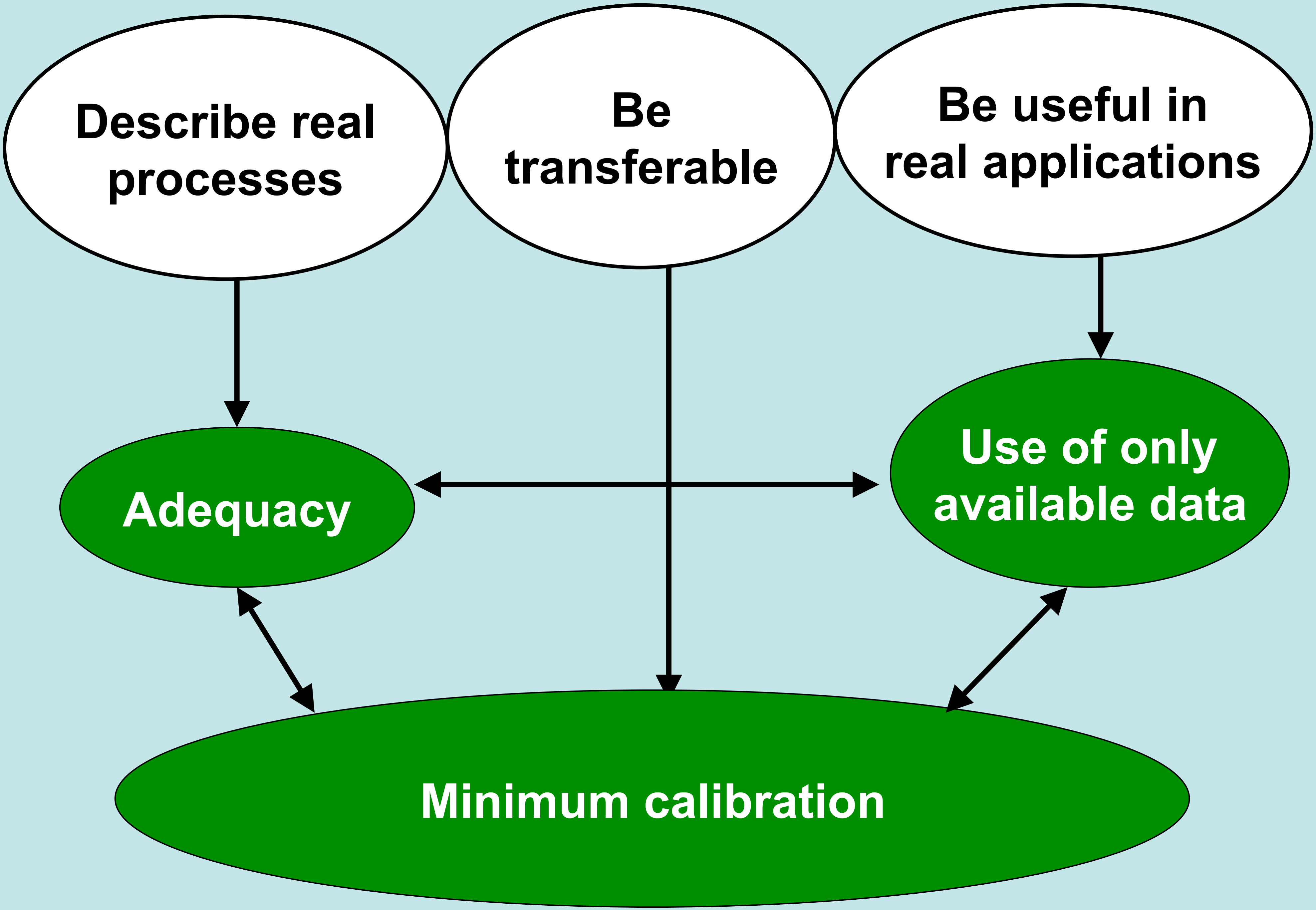
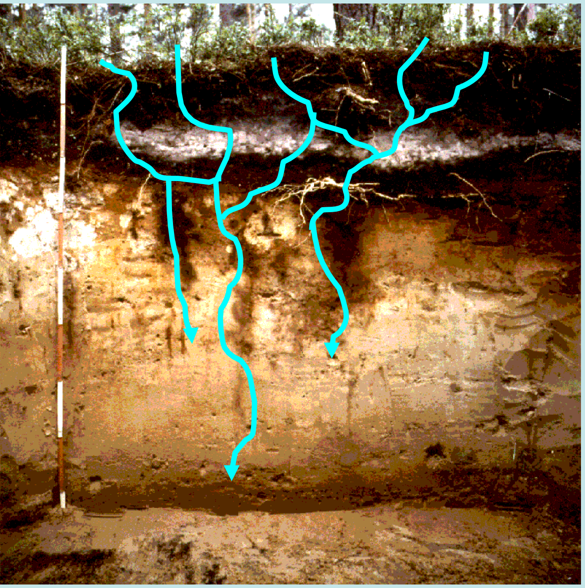
What we would like our models to be?

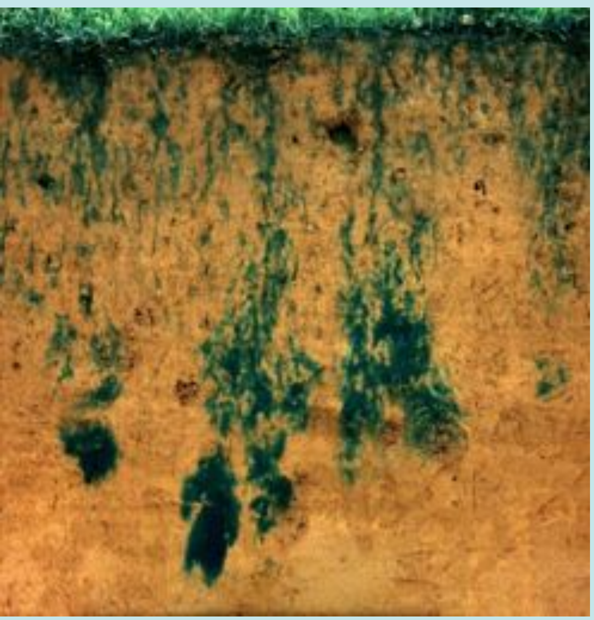


The Richard's equation (moisture diffusion/ conductivity)



$$\frac{\partial\theta}{\partial t}=\frac{\partial\left[D(\theta)\frac{\partial\theta}{\partial z}-K(\theta)\right]}{\partial z}$$

θ – volume moisture
$D(\theta)$ – diffusion coefficient
$K(\theta)$ – hydraulic conductivity
t – time, z – soil depth



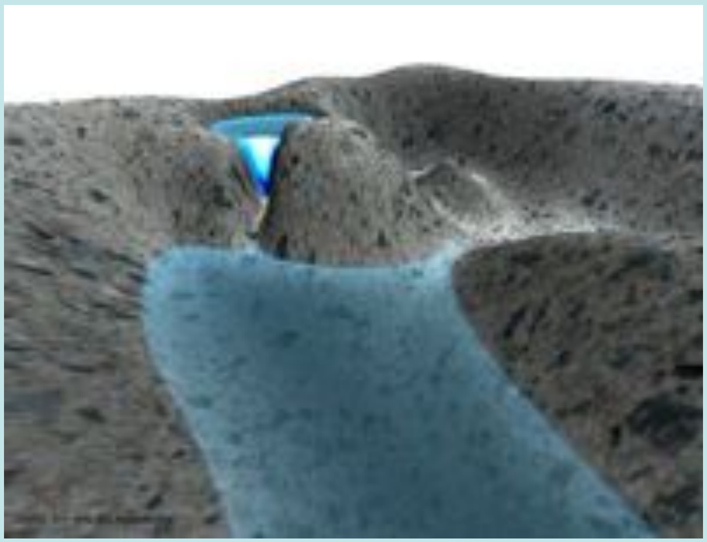
- Parallel between the "di sion of soil water" and heat cond ctivity
- Suspended moistu existence is impossible
- Nonlinearly depend nce of **D** and **K** on θ
- Change of **D** in 10^4 and **K** in 10^6 - 10^7 times corresponds to the range of natural variation of θ

[J. McDonnell lectures]

The equation of Saint-Venant (kinematic wave, etc…)

$$\alpha_1 \frac{\partial V}{\partial t} + \alpha_2 V \frac{\partial V}{\partial x} + g\frac{V|V|}{C^2 H} + \frac{Vq}{H} = g(\sin\alpha - \frac{\partial H}{\partial x}) \qquad \frac{\partial H}{\partial t} + V\frac{\partial H}{\partial x} + H\frac{\partial V}{\partial x} = q$$

t - time, x – distance, H – depth, V – velocity, q – inflow, C – Chezy coefficient,
α_1 α_2 – coefficients



[from http://www.math.sintef.no/ gpu/visualwave.html by Knut-Andreas Lie]

?

- Water m ment is resented by thin continu water lay
- Disagreement betw units of flow depth (mm) and grid si (km)
- Requirement fo NOT AVAILABLE information (m phology, roughness)
- No possibility to evaluate the described process excep runoff in the outlet

- Exaggeration of slope distances and underestimation of slope inclination in spatial schematization
- Need of calibration – different methods – different parameters

The Boussinesq equation

$$\mu \frac{\partial H}{\partial t} = K \frac{\partial \left(H \frac{\partial H}{\partial x} \right)}{\partial x}$$

K, – filtration and water yield coefficients of rock, *H* – of ground waters over the surface of impervious bed or piezometric head in the case of water ent due to differential head, *t* – tim *x* – dista

?

- True structure of the underground aquifers is unknown
- Information on quantity and stratigraphy of impervious beds and aquifers (capacity, inclinations, connection with underground and external channel system, filtration and water yield coefficients) is required and NOT AVAILABLE
- It does not account for the great groundwater storage
- It does not describe the fact of different water ages

N O T A D E Q U A T E

“Physically-based” models

Richard’s **Saint-Venant** **Boussinesq**

ь Nonlinear dependence of parameters on equation argument

ь Requirement for NOT AVAILABLE information

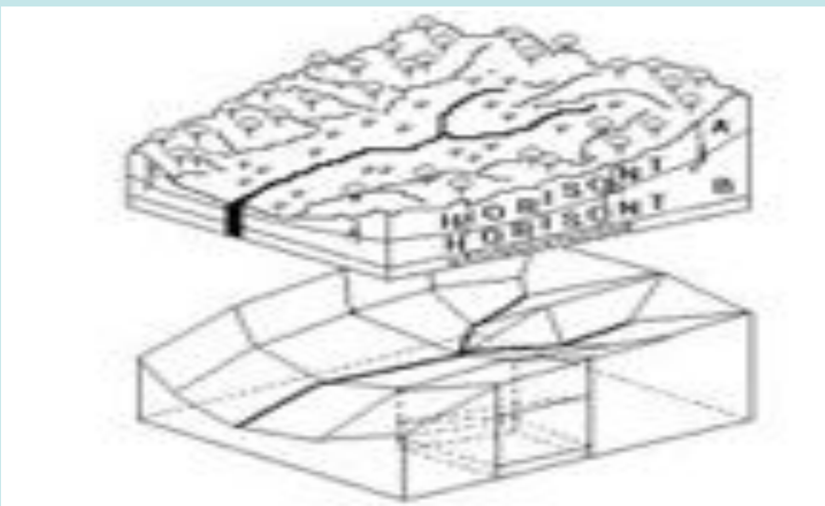
ь Need of calibration – different methods – different parameters

Nonlinearity **Uncertainty** **SCALE** **Uniqueness** **Equifinality**

The basin schematization

1) To make calculations for all elementary slopes of the basin = UTOPIAN

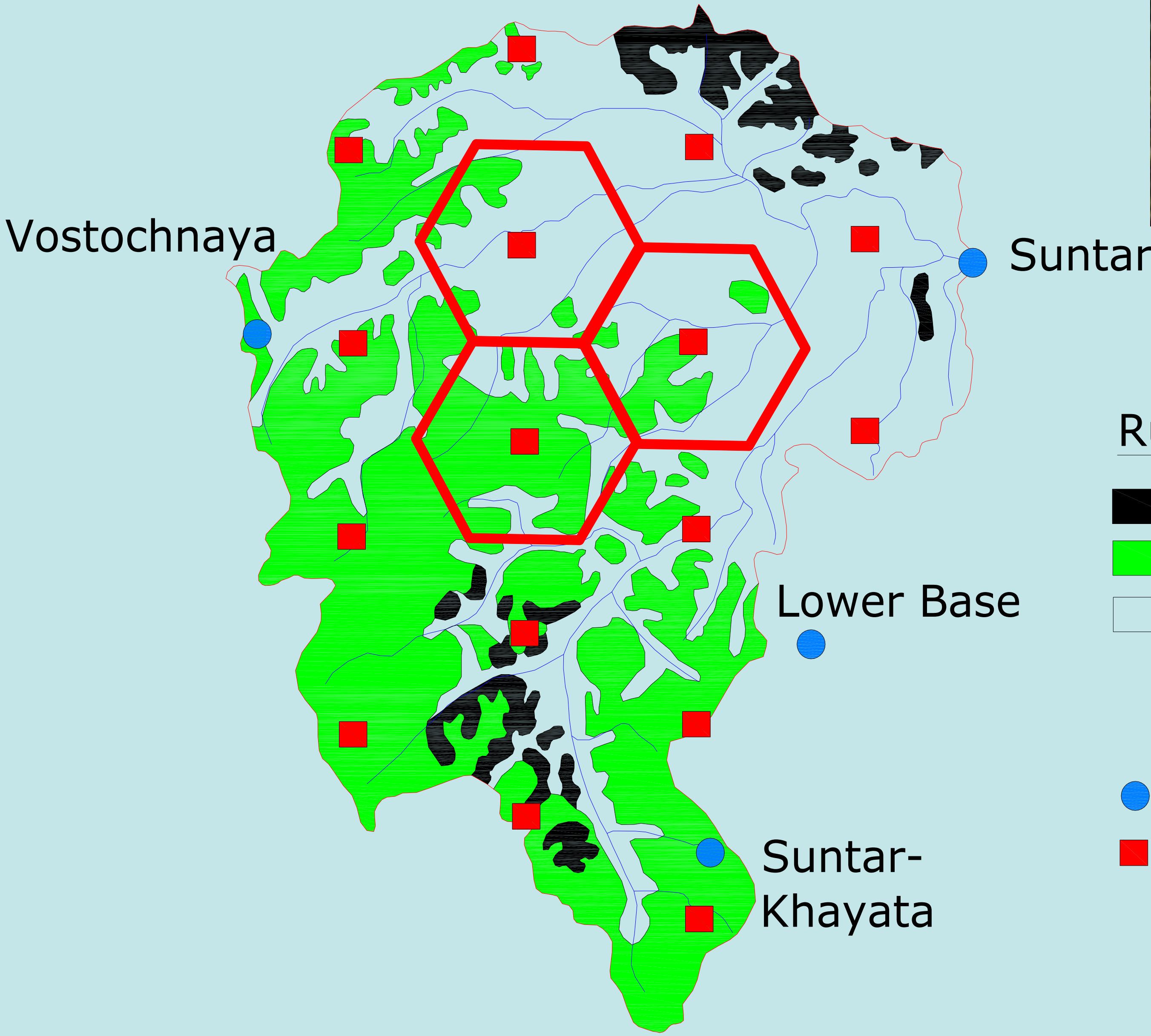
2) To ignore the existence of elementary slopes and to make calculations for integrated areas



- Partial differential equations
- Approximation of the basin surface by set of finite elements
- Exaggeration of slope lengths and underestimation of slope inclination

3) To conduct calculations selectively for the chosen elementary slopes

The spatial-computational schematization of the basin



Runoff formation complexes

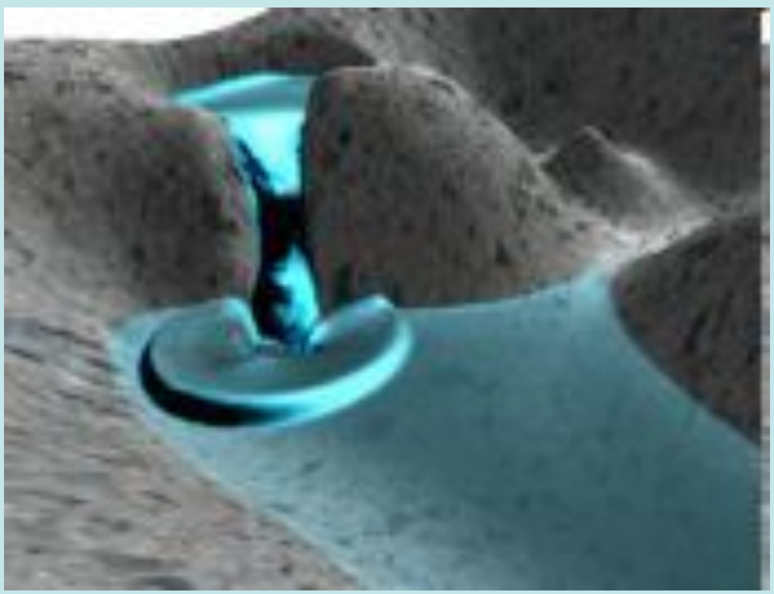
- "golets" area
- mountain tundra
- sparse mountain larsh forest

- meteorological station
- representative point

The concept of runoff elements

Watershed – elementary slope –
runoff elements system

Runoff element: a part of elementary slope limited by micro-divides directed with its open part to the slope non-channel or underground drainage system



- Surface, soil, underground

- The size depends on inclination and natural conditions

$$q = \beta\left[\exp(\alpha w) - 1\right]$$

W – water volume (m^3), q – outflow (m^3s^{-1})

$$\sum_{i=1}^{n} \beta_i \left[exp\left(\alpha_i W_i\right) - 1\right] = b\left[exp\left(a \sum_{i=1}^{n} W_i\right) - 1\right]$$

$$a = \alpha / n, \qquad b = n\beta$$

$$a = a^* / F, \quad b = b^* F$$

a^* [m^{-1}], b^* [ms^{-1}] – standardized hydraulic coefficients,
F – basin area

Typical outflow time
$T = 1/(a^* b^*)$

Water storage [mm]
$H = ln(q/b^*+1)/a^*$

System of runoff elements

	Type of runoff	a^*	T	H [mm]	Outflow intensity, [liter s^{-1} km^2]
-	Surface	1000	17 min	4.6	10^5
-	Soil	100	2.8 hours	24	10^4
1-3	Rapid ground	10 – 1	1.2–11.6 days	69.3–195	10^3 – 215
4-6	Ground	0.32 – 0.032	1.2months – 1 year	301–674	100 – 21.5
7-9	Upper underground	0.01 – 10^{-3}	3.2–32 years	995–2152	10 – 2.15
10-12	Deep underground	$3.2*10^{-4}$–$3.2*10^{-5}$	100–1000 years	3161–6812	1 – 0.215
13-15	Historical underground	10^{-5} – 10^{-6}	3200–32000 years	10000–21450	0.1 – 0.0215

parameter $b^* = 10^{-6}$

$$\sum = 67256$$

[different sources: 48000 – 70000]

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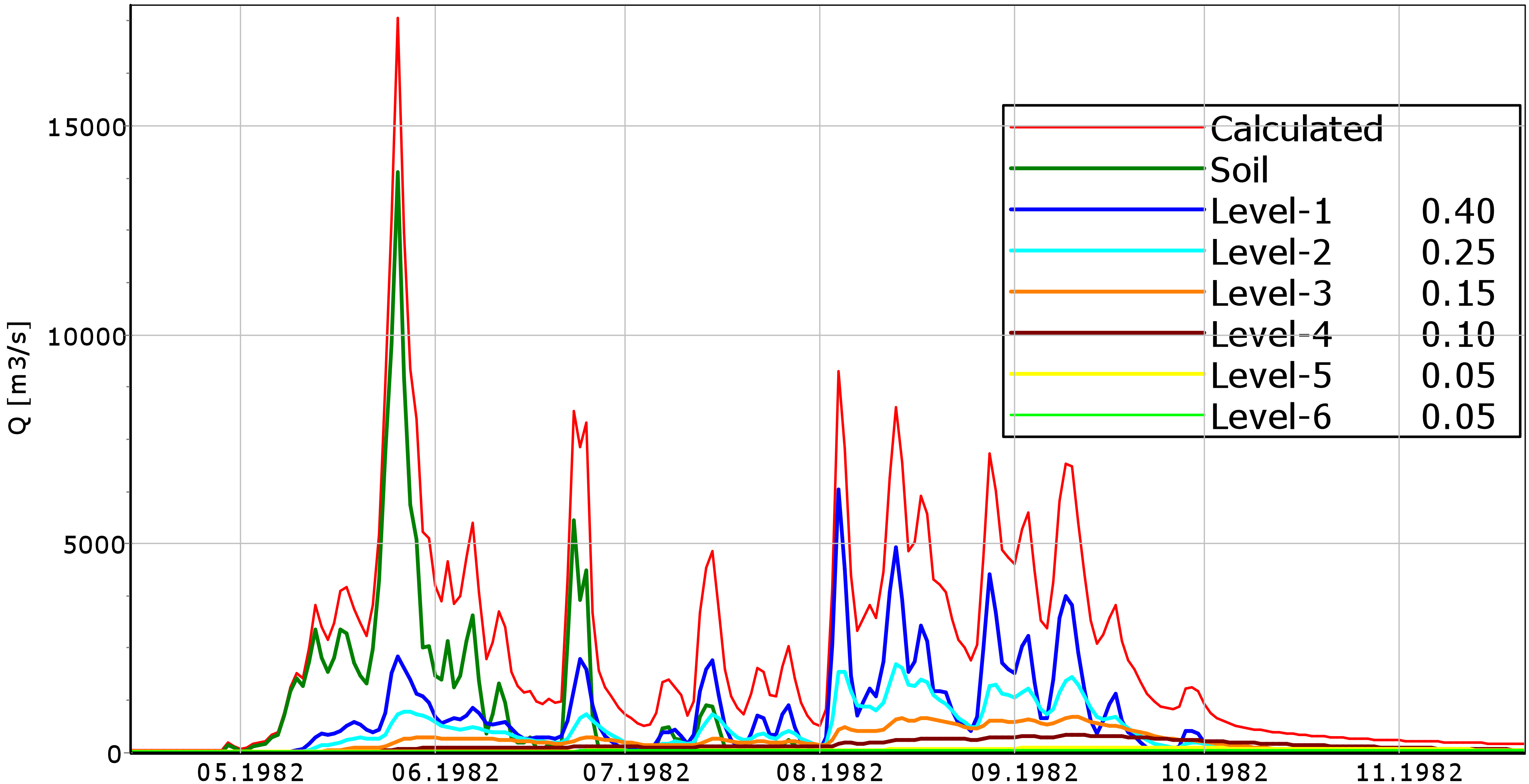
Runoff element system: parameters

- parameter a*
- parameter b*
- ratio of the distribution of incoming water content among modelling groundwater layers

	Lena, Kusur **2400000 km²**	Vitim, Bodaybo **186000 km²**	Katyryk, Toko **40.2 km²**
1	0.30	0.30	0.30
2	0.20	0.25	0.70
3	0.15	0.25	0
4	0.12	0.10	0
5	0.08	0.05	0
6	0.07	0.03	0
7	0.05	0.02	0
8	0.022	0	0
9	0.007	0	0
10	0.004	0	0
11	0.003	0	0
12	0.002	0	0
13	0.001	0	0
14	0.0005	0	0
15	0.0001	0	0

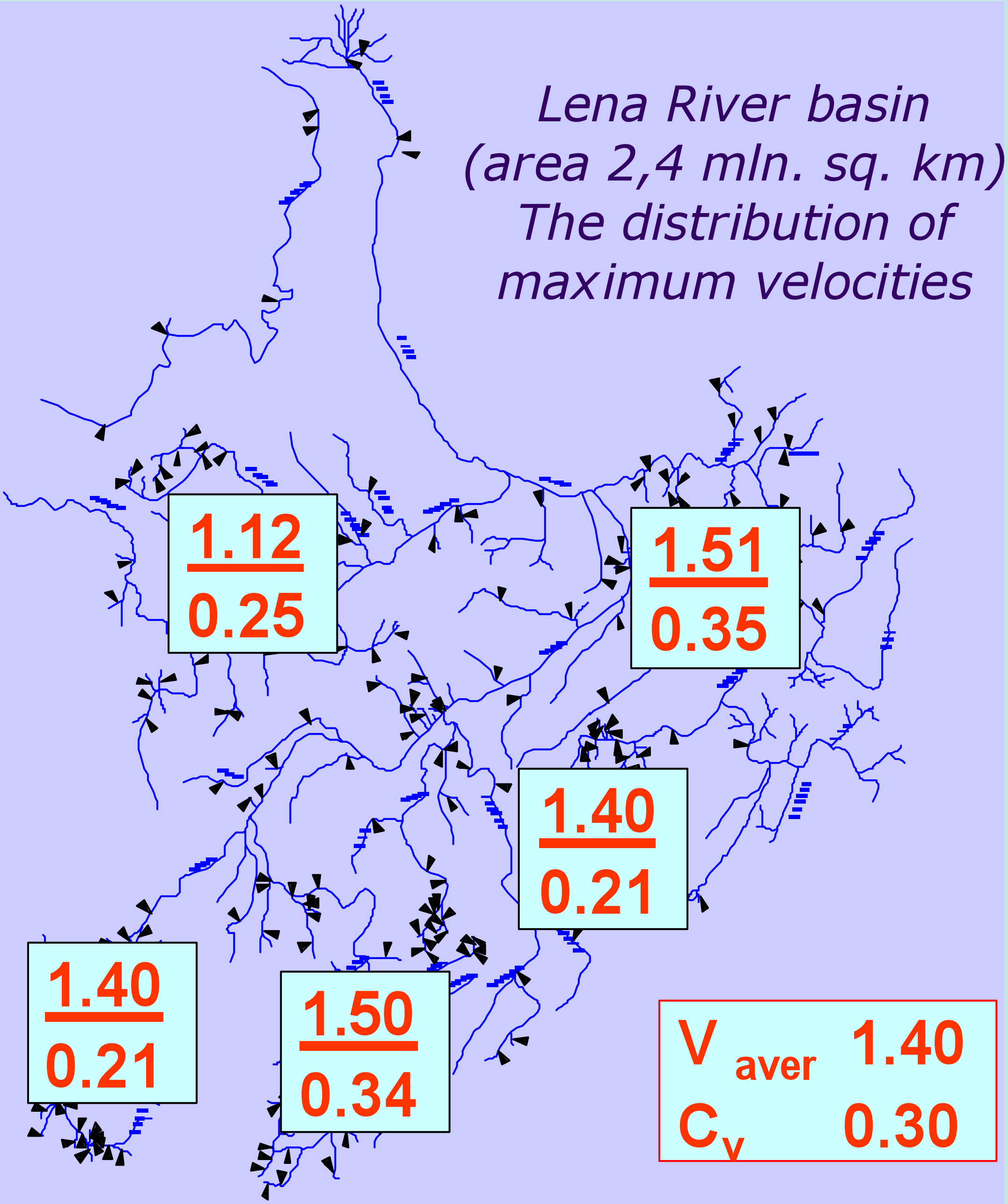
Uchur River basin, 108000 km²
mountainous, permafrost



The concept of runoff elements – what is that?

- It is a schematization in the conditions of full uncertainty.
- It doesn’t contradict the known hydro-geological items (structure and water storage).
- It corresponds to observed curves of runoff depletion for the basins of various sizes.
- It should correspond to the materials of tracers experiment on residence time (if not, should be changed!!!)
- It works for different scales and conditions…!
- It states the weakness of traditional “physically-based” approaches

The routing approach



1) transit velocity = flow velocity in the river

2) measured mean flow velocities can be used

3) constant lag time for each calculating point corresponds to 10-% range of the maximum velocities

Future…

- Not to be stuck to one model
- Not to be stuck to one basin
- Not to be stuck to the established approaches
- Multiple testing the approaches over the basins of any type, regardless of their scale and landscapes/climates

TRY TO MOVE BEYOND!