The 7th Finnish Climate Modelling Seminar
4-5 December, 2018, Helsinki, Finland

Probabilistic hydrological mODEL MARCS (MARkov Chain System)

Elena Shevnina[1], Andrey Silaev[2] and Alexander Krasikov[3]

[1]Finnish Meteorological Institute, Helsinki, Finland.

[2]National Research University Higher School of Economics, Nizhny Novgorod, Russia.

[3]Infoproject Inc, Saint Petersburg, Russia.

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The mODEL overview

Aim: to support the Advanced Frequency Analysis approach on a climate scale hydrological prediction of river runoff in changing environment

Evolution steps: 2015: Shevnina E., Doctor of Science Thesis, Russian State Hydrometeorological Institute, St. Petersburg, Russia

2017: Shevnina E. and Gaidukova E., doi:10.1007/978-3-319-57532-2_8

2018: Shevnina E. and Krasikov A., doi:10.5281/zenodo.1220096

2018: Shevnina E. and Silaev A., doi: 10.5194/gmd-2018-108, discussion

Applications: 2017: Shevnina et al., doi: 10.5194/hess-21-2559-2017

2018: Shevnina et al., doi:10.5194/hess-2018-473, discussion

Location: https://github.com/ElenaShe000/MARCS

Code: mix of python, perl, netCDF, QGIS guided by Bash (Linux)

Challenges: the approach, the names of the model, the developing community

Support: Academy of Finland (TWASE project, contract 283101) and Ministry of Education and Science of the Russian Federation (01 2009 52622).

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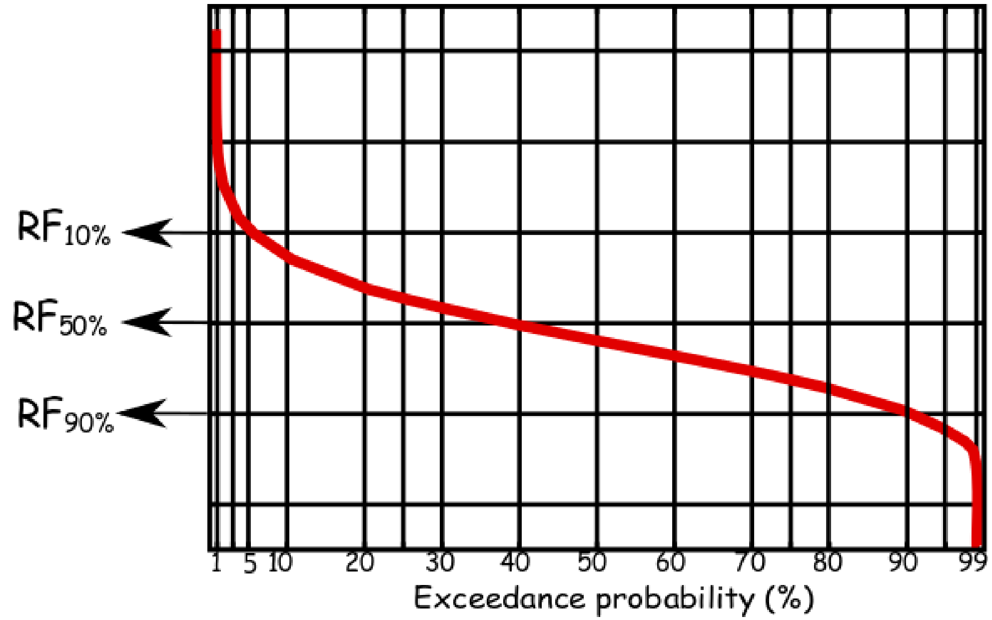
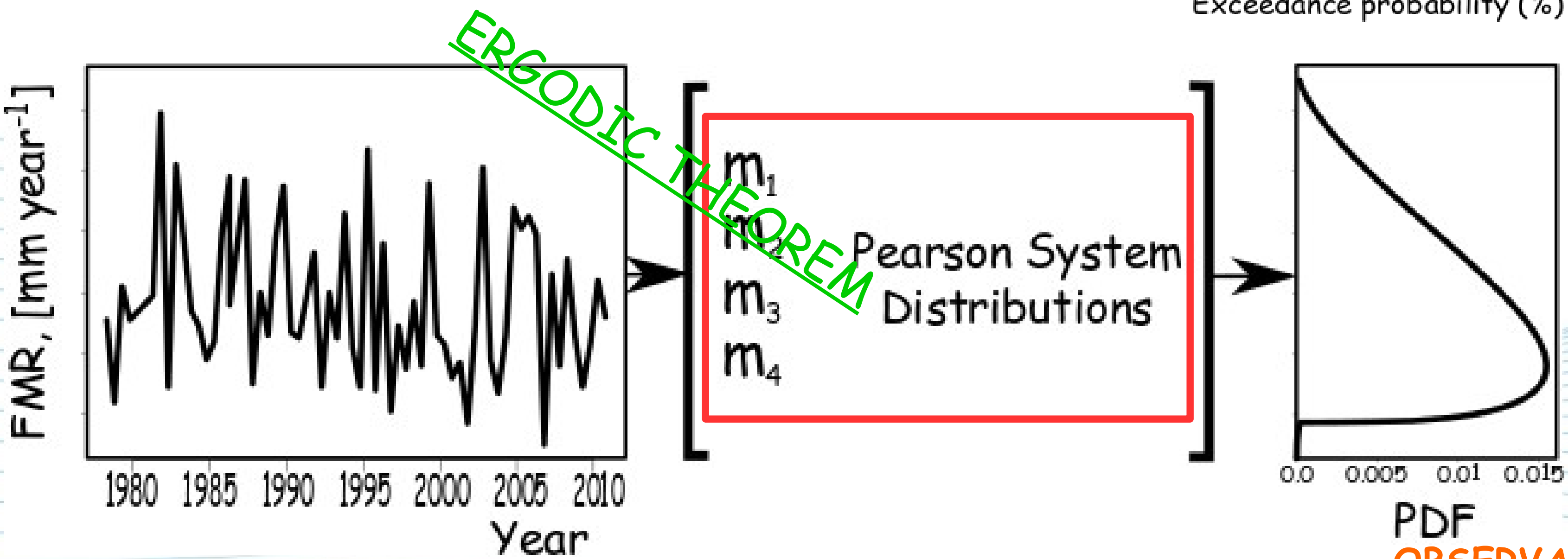
The ~~Advanced~~ Frequency Analysis: to estimate runoff extremes for a Civil Engineering

River runoff is a random value:
the values of river runoff ($RF_{n\%}$) together with their exceedance probabilities (n%).

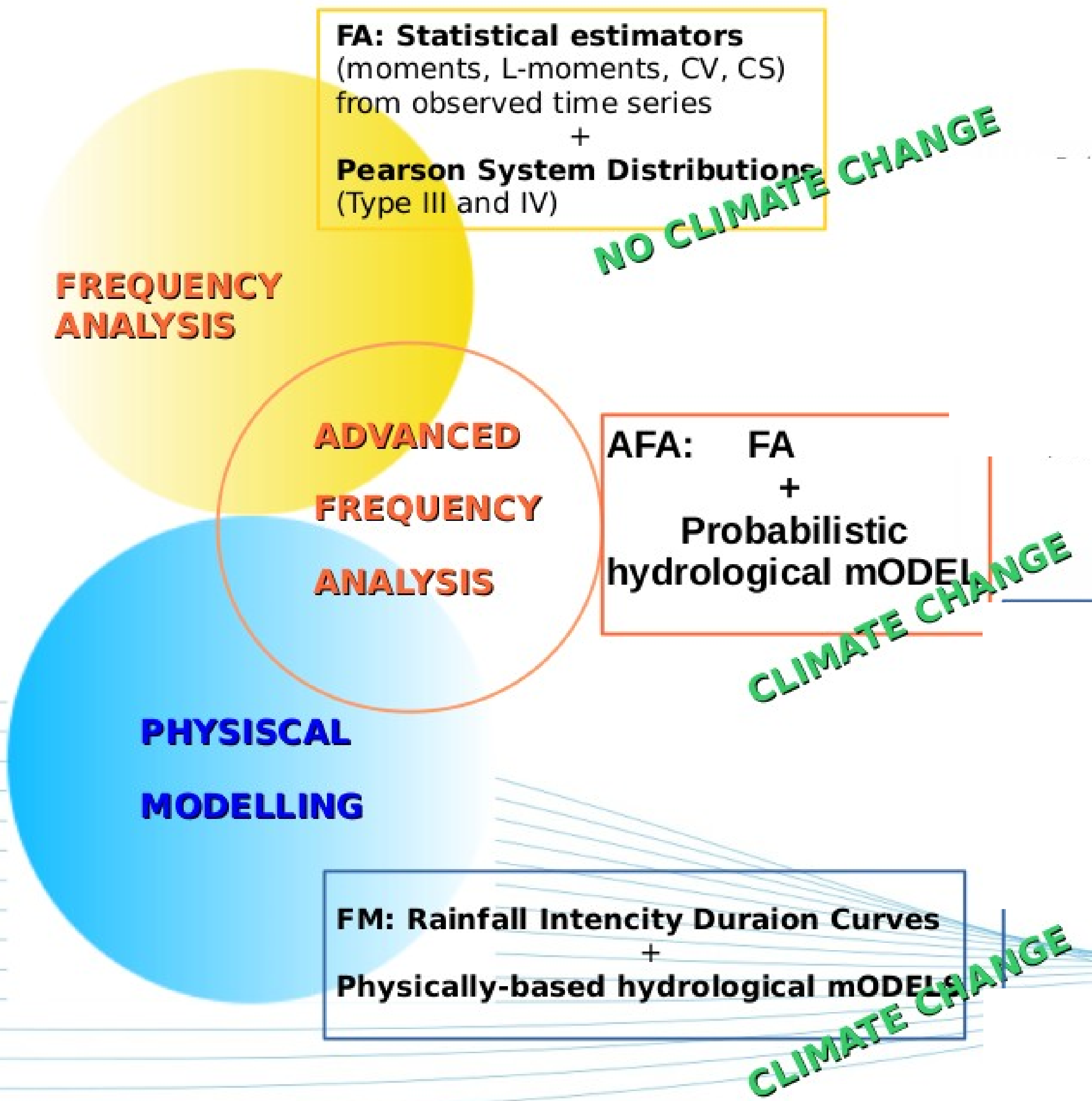
River runoff extremes:
the runoff value of low/high exceedance probability expressed as river streamflow discharge, [m^3 s^{-1}].





OBSERVATIONS >

The Advanced Frequency Analysis (AFA): to estimate runoff extremes in the changing climate



Statistical moments estimates
+ Pearson System

Simulated statistical
moments estimates
+ Pearson System

Simulated time series of
river discharges (seasonal,
monthly or daily)

OBSERVATIONS + CLIMATE CHANGE PROJECTIONS >

The theoretical basis of the AFA approach

Simple “Black Box” Model, WMO: 2009.

$$a_n(t)\frac{d^nQ}{dt^n}+a_{n-1}(t)\frac{d^{n-1}Q}{dt^{n-1}}+...+a_1(t)\frac{dQ}{dt}+a_0(t)Q=$$
$$=b_n(t)\frac{d^nP}{dt^n}+b_{n-1}(t)\frac{d^{n-1}P}{dt^{n-1}}+...+b_1(t)\frac{dP}{dt}+b_0(t)P$$

where, Q is model output (runoff), P is model input (precipitation), an and bn are parameters connceted to catchment physiograpy and meteology.

WMO, 2009: WMO No.168: the Guide to Hydrological Practices. Volume II: Management of Water Resources and Application of Hydrological Practices, Chapter 6: Modelling of hydrological system. web: http://www.whycos.org/hwrp/guide/

“Linear filter with stochastic component” Model, Pugachev et al.: 1974.

$$\frac{dY}{dt}=f(Y,t)+g(Y,t)\xi(t)+h(Y,t)\eta(t)$$

where, is Y model output, $\xi(t)$ and $\eta(t)$ are Gaussian noise signals with zero means and intensities D_ξ and D_η ; the signals are mutually correlated and their correlation function:

$$K_{\xi\eta}(\tau)=E(\xi(t)\eta(t+\tau))=D_{\xi\eta}\delta(\tau)$$

Pugachev V.S., Kazakov I.E., Yevlanov L.G., 1974: Basics of statistical theory of automatic systems. Chapter 9: Stochastic systems. Moscow, Mashinostroenie.

“Pearson Distributions” Model (System), Pearson: 1895.

$$\frac{dp(Q)}{dQ}=\frac{Q-a}{b_0+b_1Q+b_2Q^2}p(Q)$$

where: a, b_0, b_1 and b_2 are parameters of Pearson System.

Pearson K., 1895. Memoir on Skew Variation in Homogeneous Material, Philosophical Transactions of the Royal Society, A186, pp. 323-414.

Statistical Estimation Methods for Engineering, see review in Van Gelder, 2004.

Van Gelder, P.H.A.J.M., Statistical Estimation Methods in Hydrological Engineering, Proc. Intern. Semin. “Analysis and Stochastic Modeling of Extreme Runoff in Eurasian Rivers Under Conditions of Climate Change,” Irkutsk: Publishing House of the Institute of Geography SB RAS, 2004, pp. 11–57.

$$m_{n-1}b_0n+m_n[b_1(n+1)-a]+m_{n+1}[(n+2)b_2+1]=0$$

Kovalenko V.V, 1993. Modelling of hydrological processes. Leningrad, Hydrometizdat.

More details in Shevnina E. and Silaev A., 2018: doi: 10.5194/gmd-2018-108, discussion

First challenge of the MARCS mODEL:

It is not easy to understand the approach, which used methods and terms mainly from two scientific disciplines: Hydrology and Statistical Radiophysics

https://doi.org/10.5194/gmd-2018-108

Discussion papers

Abstract | Assets | **Discussion** | Metrics

Model description paper

09 Jul 2018

The probabilistic hydrological model MARCS (MARkov Chain System): the theoretical basis for the core version 0.2

Elena Shevnina and Andrey Silaev

Review status

This discussion paper is a preprint. It is a manuscript under review for the journal Geoscientific Model Development (GMD).

Interactive discussion

Status: open (extended)

AC: Author comment | **RC**: Referee comment | **SC**: Short comment | **EC**: Editor comment | : Report abuse

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SC1: 'Comments on paper "The probabilistic hydrological model MARCS (MARkov ChainSystem): the theoretical basis for the core version 0.2" by Elena Shevnina and Andrey Silaev', Anatoly Frolov, 05 Aug 2018 **[reply]**

└ **AC1**: 'Answers to comments and conclusion given by A. Frolov', Elena Shevnina, 15 Aug 2018 **[reply]**

RC1: 'Potntial reviion', Anonymous Referee #1, 08 Nov 2018 **[reply]**

└ **AC2**: 'Answers to the potential review of the Anonymous Referee #1', Elena Shevnina, 29 Nov 2018 **[reply]**

The hydrological mODEL MARCS: the core version 0.2

$$m_{n-1} b_0 n + m_n [b_1 (n+1) - a] + m_{n+1} [(n+2) b_2 + 1] = 0$$

Core Model: Linear filter with stochastic component

$$a = \frac{G_{\tilde{c}\tilde{N}} + 2\bar{N}}{2\bar{c} + G_{\tilde{c}}} \quad b_0 = -\frac{G_{\tilde{N}}}{2\bar{c} + G_{\tilde{c}}} \quad b_1 = \frac{2G_{\tilde{c}\tilde{N}}}{2\bar{c} + G_{\tilde{c}}} \quad b_2 = -\frac{G_{\tilde{c}}}{2\bar{c} + G_{\tilde{c}}}$$

$$-k(\bar{c} - 0.5 k G_{\tilde{c}}) m_k + k \bar{N} m_{k-1} - k(k-0.5) G_{\tilde{c}\tilde{N}} m_{k-1} + 0.5 k (k-1) G_{\tilde{N}} m_{k-2} = 0$$

Regime type: quasi-stationary period

$$m_1 (2b_2 + 1) - a + b_1 = 0$$
$$(3 b_2 + 1) m_2 + (2 b_1 - a) m_1 + b_0 = 0$$
$$(4 b_2 + 1) m_3 + (3 b_1 - a) m_2 + 2 b_0 m_1 = 0$$
$$(5 b_2 + 1) m_4 + (4 b_1 - a) m_3 + 3 b_0 m_2 = 0$$

Distribution type: the Pearson Type III

$G_{\tilde{c}} << \bar{c}$ $\quad b_2 = -G_{\tilde{c}} / (2\bar{c} + G_{\tilde{c}}) \approx 0 \quad (4 b_2 + 1) \approx 1 \quad (2 b_2 + 1) \approx 1$

$$-a + b_1 = -m_1$$
$$b_0 + 2 m_1 b_1 - a m_1 = -m_2$$
$$2 m_1 b_0 + 3 m_2 b_1 - a m_2 = -m_3$$

m_1 ==> *Norm*, $\bar{Q} = m_1$

m_1, m_2 ==> *Coefficient of variation*, $CV = \sqrt{(m_2 - m_1^2)} / m_1$

m_1, m_2, m_3 ==> *Coefficient of skewness*, $CS = (m_3 - 3 m_2 m_1 + 2 m_1^3) / (CV^3 m_1^3)$

$$\bar{c}_r = \bar{N}_r / (a_r - b_{1r}/2)$$
$$G_{\tilde{N} r} = -2 b_{0r} \bar{N}_r / (a_r - b_{1r}/2)$$
$$G_{\tilde{c}\tilde{N} r} = b_{1r} \bar{N}_r / (a_r - b_{1r}/2)$$

$$m_k = 1/n \sum_{i=1}^{n} Q_i^k$$
$$\bar{N} = 1/n \sum_{1}^{n} PRE$$

Statistical estimator for runoff: initial moments

... for climate: mean values

$$\bar{c}_r = \bar{c}_{pr}, G_{\tilde{N} r} = G_{\tilde{N} pr}, G_{\tilde{c}\tilde{N} r} = G_{\tilde{c}\tilde{N} pr}$$

Options: No changes on the variability of catchment physiography (VCP), No changes on the variability of precipitation (VP), No changes on the mutual variability of VCP and VP.

2018: Shevnina E. and Krasikov A., doi:10.5281/zenodo.1220096

2018: Shevnina E. and Silaev A., doi: 10.5194/gmd-2018-108, discussion

https://doi.org/10.5194/hess-2018-473

Discussion papers

Abstract | **Discussion** | Metrics

Research article

19 Sep 2018

Climate change will increase potential hydropower production in six Arctic Council member countries based on probabilistic hydrological projections

Elena Shevnina et al.

Review status

This discussion paper is a preprint. It is a manuscript under review for the journal Hydrology and Earth System Sciences (HESS).

Interactive discussion

Status: final response (author comments only)

AC: Author comment | **RC**: Referee comment | **SC**: Short comment | **EC**: Editor comment | : Report abuse

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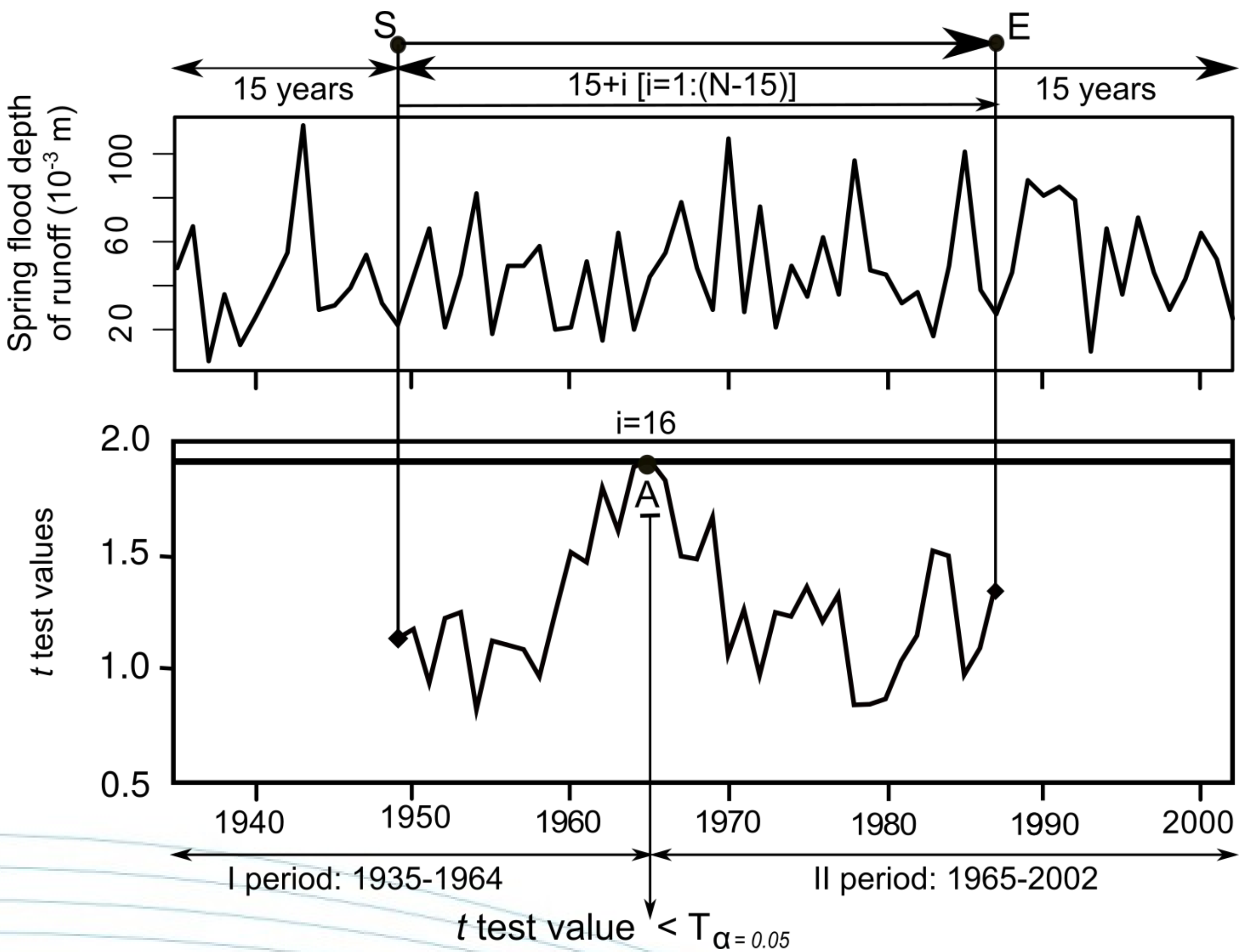
RC1: 'Review of study into climate impacts on hydropower in Arctic Council countries', Anonymous Referee #1, 20 Oct 2018

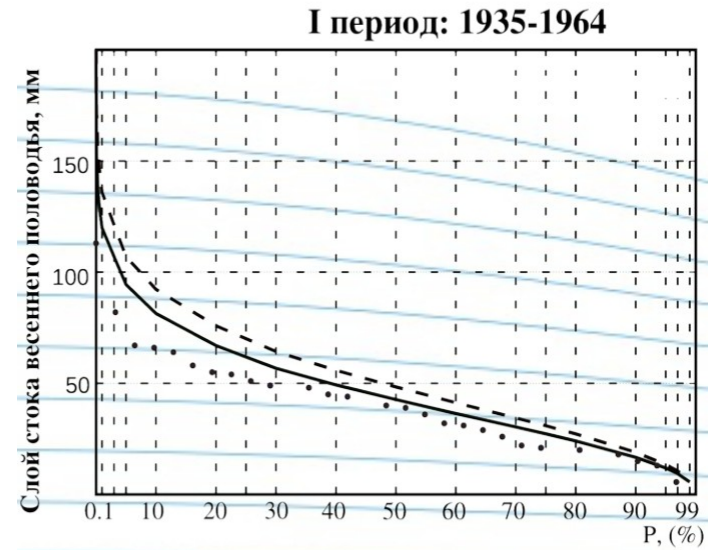
RC2: 'Review HESS-2018-473', Anonymous Referee #2, 20 Oct 2018

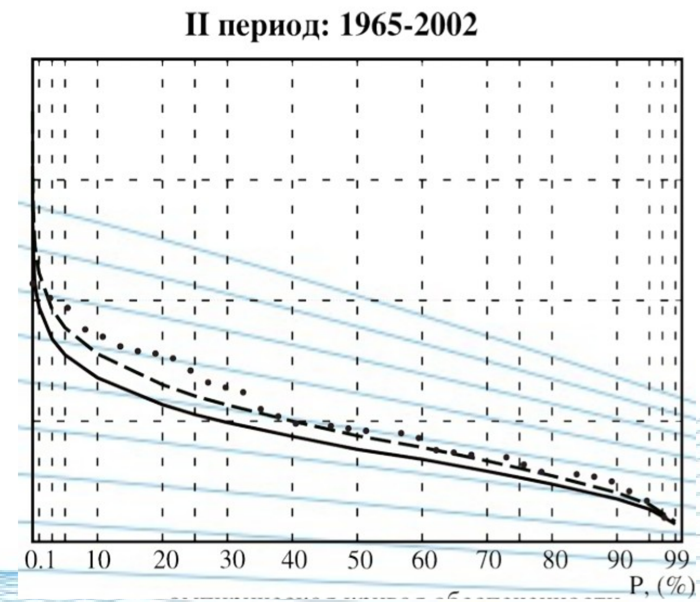
RC3: 'Review comments', Anonymous Referee #3, 21 Oct 2018

RSS 0.91
RSS 1.0
RSS 2.0
ATOM

The mODEL cross-validation procedure





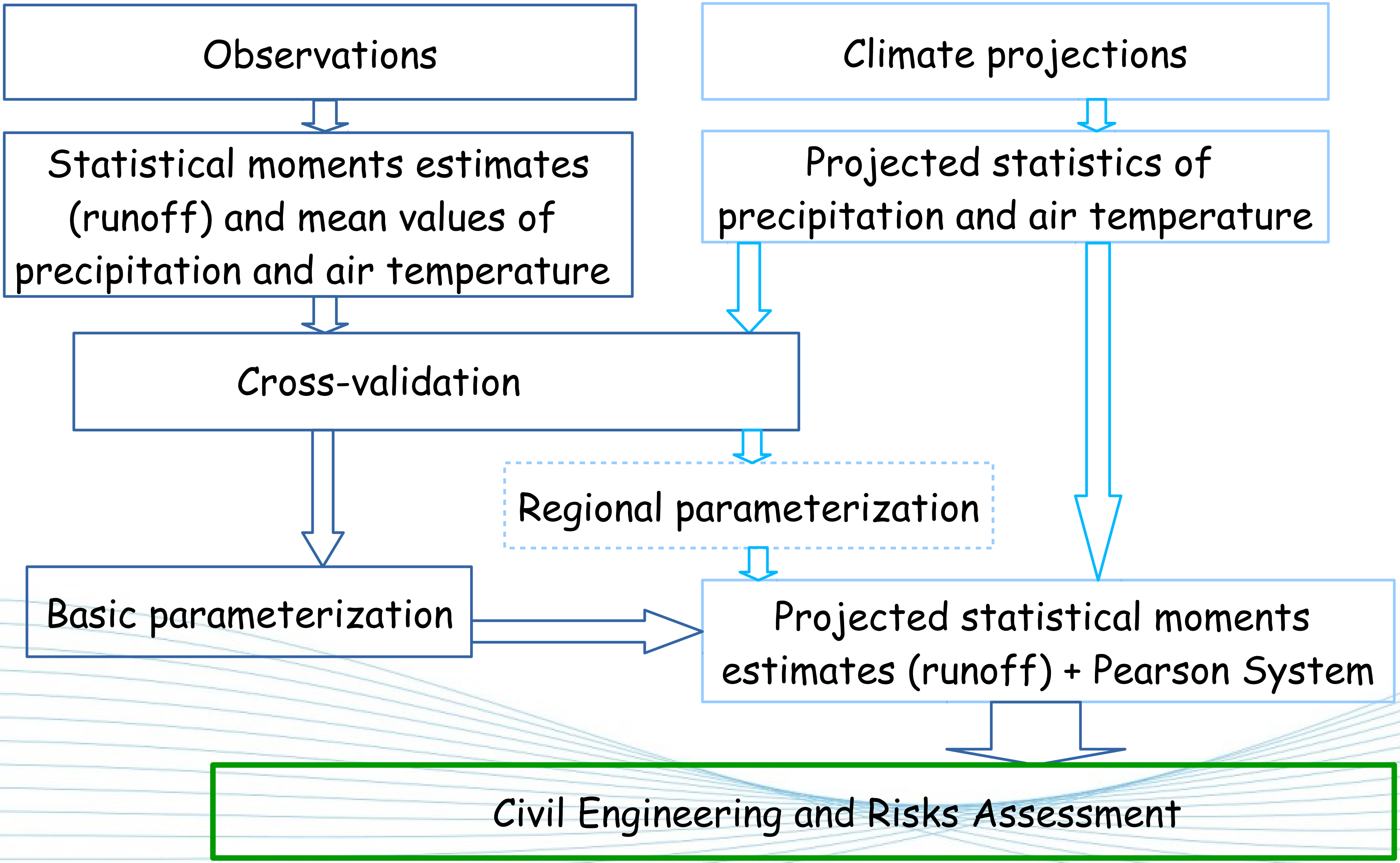


$$D = \sup \left| P(h)^{*} - P(h) \right|$$

$$\chi^{2} = N \sum_{i=1}^{N} \frac{P(h)^{*}_{i} - P(h)_{i}}{P(h)_{i}}$$

More details in Shevnina et al., 2017, doi: 10.5194/hess-21-2559-2017

The mODEL MARCS structure

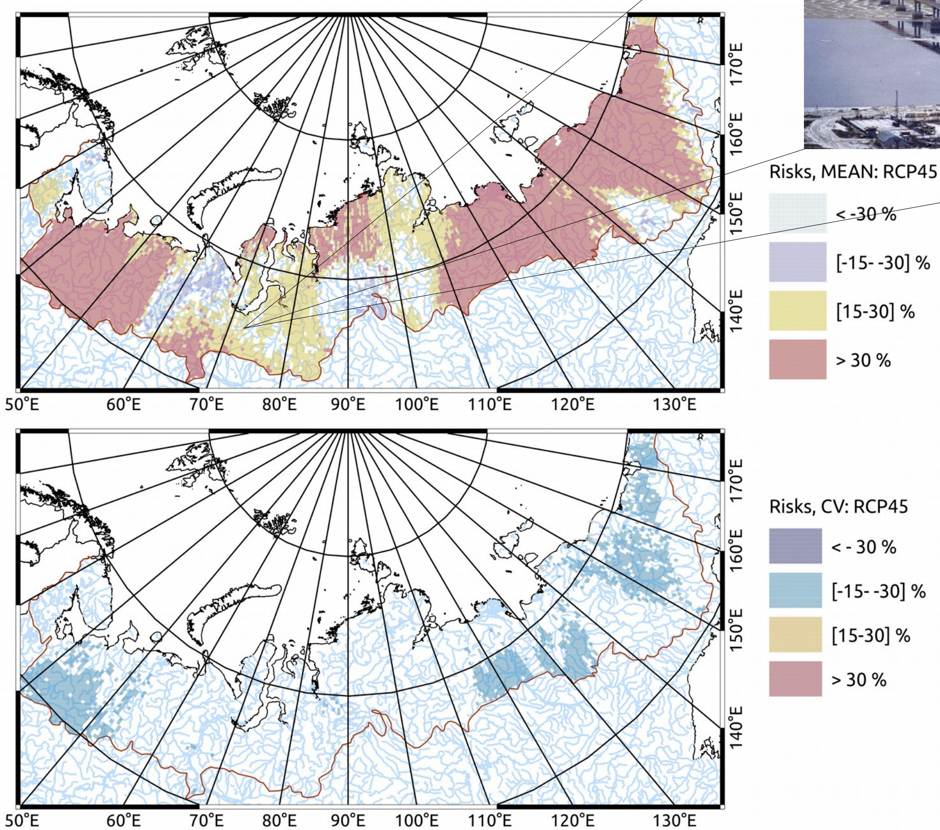


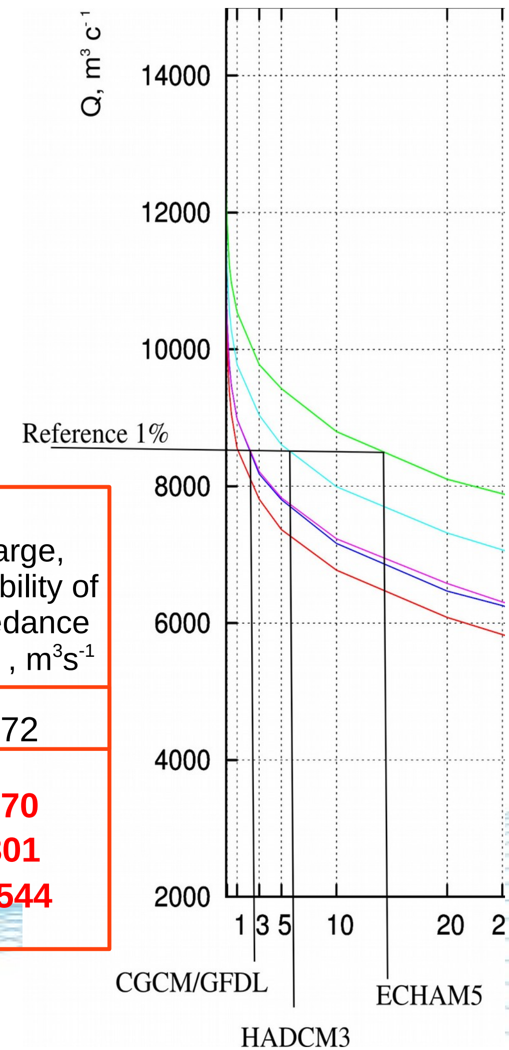
More details in Shevnina E. and Gaidukova E., 2017
doi:10.1007/978-3-319-57532-2_8

Civil Engineering:
on design of building constructions in the Russian Arctic

Aim: to define the regions, where the probability to get extreme floods is expected to change significantly. The future climate projections from the CMIP4/CMIP5 are used to generate the set of maps showing the risks of floods.

RCP4.5





Period	River discharge, probability of exceedance of 1% , m^3s^{-1}
1950–80	8572
2020-2050	**8970** **9801** **10544**

More details in Shevnina et al., 2017, doi: 10.5194/hess-21-2559-2017

Risks assessment: the potential hydropower production in the Arctic Council countries

CLIMATOLOGY

Observations + projections for precipitation

FA: 326 sites of national hydrological networks of the six countries: annual runoff time series with length 33-151 year; 11 projections of the future mean of precipitation classified into 2 types:"wet" and "dry"

HYDROLOGY

MARCS: core 0.1:

Projections of annual runoff with 10/50/90 % exceedance probabilities

AFA: 176 river catchments are aggregated on a country level (averaged)>> Exceedance Probability Curves (EPC) of annual runoff: Reference + 2 Projected EPC for the period of 2020-2050

HYDROPOWER

Simple relation of a potential hydropower production and annual runoff

The ratio of reference/future water resources to the potential hydropower production of 10/50/90 % exceedance probabilities

More details in Shevnina et al., 2008: doi:10.5194/hess-2018-473, discussion

Second challenge of the mODEL MARCS

The name of the model is MARCS (MARkov Chain System), and the model with same name is already exist.

A&A 486, 951–970 (2008)
DOI: 10.1051/0004-6361:200809724

Astronomy & Astrophysics

A grid of MARCS model atmospheres for late-type stars

I. Methods and general properties

B. Gustafsson[1], B. Edvardsson[1], K. Eriksson[1], U. G. Jørgensen[2], Å. Nordlund[2], and B. Plez[3,1]

[1] Department of Physics and Astronomy, Uppsala Astronomical Observatory, Box 515, 751 20 Uppsala, Sweden
e-mail: [Bengt.Gustafsson;bg]@astro.uu.se
[2] Niels Bohr Institute for Astronomy, Physics and Geophysics, Copenhagen University, Blegdamsveg 17, Copenhagen Ø, 2100, Denmark
[3] GRAAL, Université de Montpellier II, 34095 Montpellier Cedex 05, France

Solutions:

1. the name of the hydrological probabilistic mODEL may be specify as the MARCS:hydro;
2. the mODEL MARCS may be incorporated to the HOPS hydrological model (in-house developed in the FMI).

Third challenge of the mODEL MARCS

Developing community is too small and too busy…

Andrey M. Silaev

Head of department of Mathematical Economics, Professor

Alexander I. Krasikov

Professional programmer with 15+ experience in the development

Elena Shevnina

Researcher, group of Polar Meteorology and Climatology, Finnish Meteorological Institute, PhD in Hydrology

Thank you for your attention!

Supported by Academy of Finland (TWASE project, contract 283101)

Linux to catch…

The Schirmacher oasis, East Antarctica, 2018. photo by D. Emelyanov