A large-scale and fine resolution SWAT model for an assessment of isolated climate change impact on unaltered flow regimes in Central Eastern Europe

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CHASE-PL project

- CHASE-PL: Climate change impact assessment for selected sectors in Poland
- Climate Change thematic area of the Polish Norwegian Research Programme
- Timeline 2014-2016
- Partners: Institute for Agricultural and Forest Environment PAS (lead), MET Norway, WULS-SGGW
Work packages

**WP1** - Change detection in observed climate of Poland, at a range of scales (IAFE)

**WP2** – Projections of climate variability and change for Poland, comparison with control period (MET.no)

**WP3** – Model-based assessment of climate change impacts in the Vistula and the Odra basins (WULS)

**WP4** – Index-based assessment of climate change impacts on ecosystems and agriculture (WULS)

**WP5** – Uncertainty in observations, understanding and projections – system framework (MET.no)

**WP6** – Promotion and dissemination (Integrated Web Mapping System)

**WP7** – Project management (IAFE)
GCM-RCM combinations of scenarios (EUROCORDEX)

- SMHI-RCA4__EC-EARTH
- SMHI-RCA4__CNRM-CERFACS-CNRM-CM5
- SMHI-RCA4__MPI-M-MPI-ESM
- SMHI-RCA4__MOHC-HadGEM2-ES
- SMHI-RCA4__IPSL-IPSL-CM5A-MR

- CLMcom-CCLM4-8-17__ICHEC-EC-EARTH
- CLMcom-CCLM4-8-17__CNRM-CERFACS-CNRM-CM5
- CLMcom-CCLM4-8-17__MPI-M-MPI-ESM-LR
- CLMcom-CCLM4-8-17__MOHC-HadGEM2-ES

- DMI-HIRHAM5__ICHEC-EC-EARTH
- KNMI-RACMO22E__ICHEC-EC-EARTH

Bias correction (quantile mapping method) ongoing!
WP3 main objective

• Model-based assessment of climate change impacts in the Vistula and the Odra basins
• Two-level approach of impact assessment
  • In large-scale focus on: water balance, river flows
  • In meso-scale focus additionally on: water quality, crop yields, environmental flows
  • In large-scale: broad spatial overview of impacts and identification of hot spots
  • In meso-scale: more in-depth process-oriented analysis + adaptation measures
• The SWAT model as the main modelling tool
Vistula and Odra: 2nd and 5th largest river basins in EU
Study area: Vistula and Odra river basins

<table>
<thead>
<tr>
<th>Catchment</th>
<th>Area $[10^3 \text{ km}^2]$</th>
<th>% in Poland</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Large-scale</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vistula</td>
<td>194</td>
<td>87</td>
</tr>
<tr>
<td>Odra</td>
<td>119</td>
<td>89</td>
</tr>
<tr>
<td>Total</td>
<td><strong>313</strong></td>
<td><strong>88</strong></td>
</tr>
<tr>
<td><strong>Meso-scale</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper Narew</td>
<td>4.3 (2.2% of the VRB)</td>
<td>73</td>
</tr>
<tr>
<td>Barycz</td>
<td>5.5 (4.6% of the ORB)</td>
<td>100</td>
</tr>
</tbody>
</table>
### Overview of data sources for model inputs

<table>
<thead>
<tr>
<th>Type of input</th>
<th>Poland</th>
<th>Outside Poland</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEM</td>
<td>Created based on contour lines, scale 1:25,000, 40m res.</td>
<td>SRTM v4.1 90 m res.</td>
</tr>
<tr>
<td>Hydrographic network</td>
<td>MPHP (Hydrographic Map of Poland), scale 1:50,000</td>
<td>CCM River and Catchment Database, version 2.1</td>
</tr>
<tr>
<td>Land cover</td>
<td>CLC2006, Imperviousness2012 (EEA), district-level crop statistics (GUS)</td>
<td>CLC2006, MODIS Land Cover &amp; Imperviousness2012 (EEA)</td>
</tr>
<tr>
<td>Soils</td>
<td>Soil map from IUNG-PIB, scale 1:500,000</td>
<td>Harmonized World Soil Database v 1.2</td>
</tr>
<tr>
<td>Climate data 1</td>
<td><strong>Observed data from IMGW-PIB 1951-2013</strong></td>
<td><strong>Observed data from DWD, ECAD, NOAA NCDC 1951-2013</strong></td>
</tr>
<tr>
<td>Climate data 2</td>
<td>WATCH WFD (ERA-40) 1900-1978</td>
<td>WFDEI (ERA Interim) 1979-2012</td>
</tr>
</tbody>
</table>

Development of high-resolution gridded temperature and precipitation datasets for modelling
Input maps

**DEM**

- **2633 subbasins**

**Slopes**

- Slope [%]
  - 0-4
  - >4

**Land cover**

**Soils**

- **21311 HRUs**
Land cover refinement: main crops (2000 Census data)
Development of gridded temperature and precipitation datasets for modelling - overview

<table>
<thead>
<tr>
<th>Item</th>
<th>Minimum and maximum temperature</th>
<th>Precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>Poland + Vistula and Odra basins</td>
<td></td>
</tr>
<tr>
<td>Data sources</td>
<td>• IMGW-PIB – Polish stations</td>
<td>Quality assessment</td>
</tr>
<tr>
<td></td>
<td>• DWD - German and Czech stations</td>
<td>Richter correction for precipitation undercatch</td>
</tr>
<tr>
<td></td>
<td>• ECAD, NOAA-NCDC – Slovak, Ukrainian and Belarusian stations</td>
<td></td>
</tr>
<tr>
<td>Preprocessing</td>
<td>Quality assessment</td>
<td>Quality assessment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Richter correction for precipitation undercatch</td>
</tr>
<tr>
<td>Interpolation</td>
<td>Kriging with elevation as external drift</td>
<td>Combination of Universal Kriging and Indicator Kriging (for wet day probability estimation)</td>
</tr>
<tr>
<td>method</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Library</td>
<td>R gstat</td>
<td></td>
</tr>
<tr>
<td>Time frame</td>
<td>1951-2013</td>
<td></td>
</tr>
<tr>
<td>Resolution</td>
<td>5 km grid in the projected coordinate system PUWG1992</td>
<td></td>
</tr>
<tr>
<td>Output format</td>
<td>.tiff files (one file per variable per day)</td>
<td></td>
</tr>
<tr>
<td>Cross validation</td>
<td>All stations, for each day. Both temporal and spatial scale</td>
<td></td>
</tr>
<tr>
<td>SWAT input</td>
<td>Aggregation at subbasin level</td>
<td></td>
</tr>
</tbody>
</table>
Temperature and precipitation stations network

Station type
- Climate
- Precipitation
- Polish national border
- Vistula and Odra Catchments
Number of stations with data: annual variability

Precipitation

- Range: 300-700

Temperature

- Range: 80-180

30-year baseline with the best coverage: 1982-2011
Cross validation of precipitation: standardized RMSE

- Median range 0.7-0.8, with more than 85% of RMSE values not exceeding one standard deviation.

- Negative correlation with the number of available stations.

- Errors depend on the density of the observation network.
Calibration of large-scale models

- Unavoidable problem in calibration of large-scale models: water management
- In the context of climate change impact modelling, water management effects may distort pure climate change effects!
Large-scale model calibration approach

• The goal: investigate pure climate change effects (i.e. isolated from water management effects that can amplify or damp CC signal) in order to enable **fair spatial comparison of CC impacts**
• The approach: to focus model calibration on near-natural sub-catchments => develop a model simulating “natural” flows
  1. Water management not considered in the model setup
  2. “Benchmark” (gauged) catchments selected for calibration/validation
  3. Optimising the multi-site calibration effort by a statistical approach involving the Indicators of Hydrologic Alteration, Principal Component Analysis and Cluster Analysis
  4. Regionalisation of optimal parameter values in order to simulate “natural” flows across the whole basin (future step)
Selection of „benchmark” catchments

• “Benchmark” = near-natural, relatively undisturbed flow regime
• Initial pool contains 100+ non-nested gauged catchments (areas 500 – 3,000 km²) with available (> 10 years) discharge data
• Selection of relatively unimpacted catchments using two approaches
  • Potential predictors of flow alterations selected and calculated in GIS, e.g. dam density; reservoir storage index, volume of water withdrawals, volume of point source discharges
  • Hydrograph screening (visual inspection)
• 80 “benchmark” catchments selected
Selection of “benchmark” catchments

Investigated catchments

Removed
“Benchmark”
Spatial calibration (parametrisation) approaches

**All the same**

Regions

Clusters

Catchments divided into clusters of similar flow regime

Assumption: different clusters have the same calibration parameter values

Unique
An approach for flow regime clustering for optimising calibration process

1. Major components of the flow regime (magnitude, extremes, duration, timing, rate of change) quantified using 67 Indicators of Hydrologic Alteration (IHAs) for 80 “benchmark” catchments for the period 1990-2009

2. Principal Component Analysis (PCA) applied in order to derive a parsimonious set of non-correlated synthetic indices that represent several uncorrelated dimensions of hydrological variability

3. Tree clustering applied to selected PCAs in order to join gauges into groups having similar flow regimes

4. Each cluster randomly divided into calibration and validation subsets

5. SWAT calibration/validation performed using SWAT-CUP SUFI2 separately for each cluster
Flow regime clusters
• Median (+/- IQR) monthly standardized flows
• One catchment per cluster
Mean annual precipitation at subbasin level

Mean annual precipitation [mm], 1991-2000

km
Model inputs/outputs – before calibration

Winter PCP

Snow melt

Summer PCP

PET (Hargreaves)
Initial results: single gauge vs multi-gauge

- What is the objective function value at 80 „benchmark“ catchments when the model is calibrated at the watershed outlets?
- Compare these values with the situation when the model is calibrated independently for every „benchmark“ catchments.
- One SUFI-2 run
- KGE (Kling-Gupta Efficiency) used as an OF
Initial results: objective function (clusters)

- KGE after the first SUFI-2 iteration for 6 out of 8 clusters (mean values across clusters)
Initial results: 95PPU uncertainty measures

- p- and r-factors after the first SUFI-2 iteration for 6 out of 8 clusters
Initial results: calibration plots

R. Drawa, cluster 1 (Cal)

Plots for the first SUFI-2 iteration

R. Krutynia, cluster 1 (Val)
Initial results: calibration plots

R. Mierzawa, cluster 4 (Cal)

R. Por, cluster 4 (Val)

Plots for the first SUFI-2 iteration

**R. Mierzawa, cluster 4 (Cal)**

- p-fact: 0.98
- r-fact: 2.32
- KGE: 0.83
- PBIAS: 3.4

**R. Por, cluster 4 (Val)**

- p-fact: 0.86
- r-fact: 1.94
- KGE: 0.50
- PBIAS: 35.1
Summary

- A framework for spatial calibration of large-scale SWAT models has been presented. It can be applied elsewhere provided that a sufficient number of gauged “benchmark” catchments exists.
- Preliminary calibration results are “quite promising”.
- The SWAT model of the Vistula and Odra basins will deliver “natural” daily flows simulated for the period 1951-2013.
- Projections simulated using this model will enable disentangling pure climate change effects from other effects not related to climate.
- In the nearby future projections of future streamflow (along with other projections) will be made available through an Interactive Web Mapping System (http://climateimpact.sggw.pl - under construction)
Acknowledgements

CHASE-PL
Climate change impact assessment for selected sectors in Poland

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Thank you!