SaWaM: Seasonal water resource management for semiarid areas: Regionalized Global Data and transfer to practice

Using seasonal forecasts to support climate proofing and water management in semi-arid regions

Christof Lorenz, Harald Kunstmann, Tanja Portele, Anita Bayer, Patrick Laux, Anne Müller, Gerd Bürger, Axel Bronstert, Nazli Turini, Boris Thies, Anna Smetanova, Eva Paton, Pallav Kumar-Shrestha, Luis Samaniego, Saskia Förster, Robert Behling, Siegrid Roessner, Sajedeh Behnia, Nico Sneeuw, Berhon Dibrani, Thomas Kukuk

Keywords: *Seasonal forecasts, semi-arid regions, sustainable water management, climate proofing*

ABSTRACT

In our project Seasonal Water Resources Management: Regionalized Global Data and Transfer to Practise (SaWaM), we analyse the potential of global hydrometeorological information for supporting the regional water management, particularly reservoir operation. Special focus is on seasonal forecasts, with which we aim to predict the availability of freshwater resources and the state of the ecosystem for up to 6 months in advance. This is achieved by a strongly interlinked model and data chain. After an in-depth evaluation during the period 1981 to 2010, global data sets are processed for regional water management purposes through dynamical and statistical downscaling approaches, hydrological and ecosystem modelling as well as the combination with remote-sensing-based information. To assess the transferability of our tools and products, we focus on eight different semi-arid basins in Iran, Sudan, Brazil, Ecuador, and West-Africa. The transfer into practice is ensured through the close cooperation with regional stakeholders, decision makers, research institutes, and water managers as well as the joint development of a tailor-made online decision support system for regional water management. The project also serves as a benchmark for the application of state-of-the-art seasonal forecast products. In-depth comparisons with reference datasets show a promising forecast skill, which allows e.g. for the prediction of the intensity of rainy seasons and droughts. The project is therefore strongly contributing to climate proofing and the accomplishment of SDG 6, that is to ensure the availability and sustainable management of water and sanitation for all, in particular in semi-arid regions.

INTRODUCTION

While weather forecasts are used for flood warnings and while climate projections are used for long-term climate adaptation measures, it is the knowledge of the climate of the coming months (Siegmund et al., 2015) that is crucial for the management and control of water reservoirs, e.g. for power generation or for irrigation in agriculture. This is particularly relevant in dry regions, i.e. arid and semi-arid areas. In semi-arid regions, unlike in arid regions, much can be achieved with sustainable and science-based water resource management. It is therefore of utmost importance to understand the local climate system including the dynamics and interactions of different water-related variables. However, due to the significant decrease in the number of hydrometeorological in situ stations (Lorenz and Kunstmann, 2012) and high uncertainties in estimates for the current and future water supply (Pilgrim et al., 1988), this is getting increasingly difficult. Scientists and decision makers may therefore rely their planning more and more on global hydrometeorological data sets, remote-sensing products, or global model systems. It is SaWaM's goal to investigate the performance of such global information and, in particular, global seasonal forecasts for which we develop methods and tools for the regionalization, the processing and, in the end, the transfer into practice for the regional water management in semi-arid regions. We focus on semi-arid regions in Brazil (Rio São Francisco basin), Iran (Karun and Lake Urmia basins), Sudan (Blue Nile and Atbara basins), Ecuador (Catamayo-Chira basin), and West-Africa (Niger and Volta basins). We further aim at the direct transfer to practice through a close cooperation with regional stakeholders, decision makers, and scientists. In the end, this cooperation shall demonstrate the potential of seasonal forecasts for climate proofing and for regional water management even beyond the project duration and our study regions.

METHODS

In SaWaM, we follow an interlinked chain of models and data in order to process global seasonal forecasts and other information for regional water management. While each sub-project requires specific data (e.g. runoff observations for hydrological modelling), all sub-projects use seasonal forecasts from the European Centre for Medium-Range Weather Forecasts (ECMWF), namely Version 5 of ECMWFs Seasonal Forecasting System (SEAS5).

Regionalization: Small scale precipitation variability cannot be resolved at the initial resolution of the global seasonal forecasts. For improving this resolution, we follow two regionalization approaches. High-resolution information is modelled with the Weather Research and Forecasting model (WRF). After finding a suitable parametrization for e.g. model physics of convection or radiation for each target region, this model allows us to provide information about precipitation and temperature down to a resolution of 3km, i.e. convection permitting scales. As this so-called dynamical downscaling requires huge computational resources, we also apply statistical approaches, where the interpolation of precipitation and other climatic variables to a higher resolution is based on statistical relationships between the coarse-scale global forecasts and either a gridded high-resolution reference dataset or in-situ observations. For the latter, we use the Expanded Downscaling (XDS, Bürger, 1996), which assumes that local climate covariance is linked bilinearly to the global circulation covariance. We also apply uni- and multivariate bias-correction and spatial disaggregation (BCSD, e.g. Lorenz et al., 2018) techniques, which are a compromise between the computationally expensive dynamical downscaling approaches and XDS, which provides information at selected stations only.

State of the hydrosystem: In order to get information about hydrological variables like streamflow and soil moisture but also the transport and entry of sediments, we use the downscaled seasonal forecasts as driving data for two hydrological models, namely the mesoscale Hydrological Model (mHM, Samaniego et al., 2010) and the Water Availability in Semi-Arid environments – SEDiments (WASA-SED, Mueller et al., 2010) model. The mHM-model with its different modules allows for a straightforward modelling of the catchments even if only limited local information is available. This is possible through mHMs multi-scale parameter regionalization technique, with which we assimilate and incorporate different satellite- and station-based observation datasets with different spatial resolutions. The WASA-SED-model, on the other hand, requires detailed information about the catchment. Then, by including the description of processes for erosion at the hillslope scale, for transport of suspended and bedload fluxes at the river scale and the retention and remobilisation of sediments in large reservoirs, it provides all relevant information for the regional water management especially in semi-arid regions.

State of the ecosystem: In order to predict the state and functionality of the ecosystem including indicators for ecosystem services for the next season, the global dynamic vegetation model LPJ-GUESS is modified for the application on the

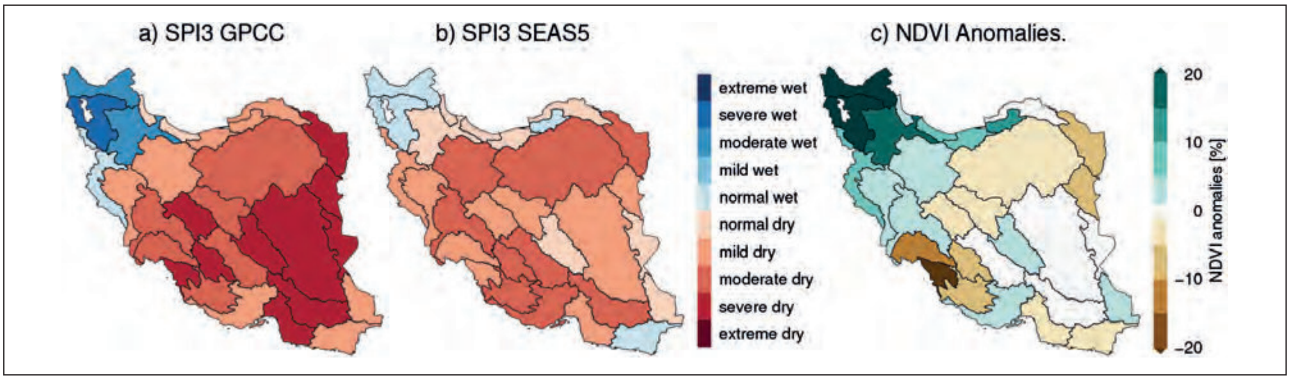

Figure 1: The drought in Iran from winter 2017/2018 picked up by different methods applied in the SaWaM project: (a) Drought index SPI3 from Monitoring (GPCC v6.0 for Dec 2017 to Feb 2018), (b) SPI3 from seasonal forecast system (ECMWF SEAS5, for Dec 2017 to Feb 2018) and (c) as detected by remote sensing (relative NDVI Anomaly from MODIS during the period Dec 2017 to Feb 2018 with respect to the long-term mean for 2001 to 2018). For the SEAS5-forecast, only the SPI-category with the most ensemble members is shown.

regional scale. Ensemble simulations will identify how uncertainties in the amount of precipitation and its temporal and spatial distribution are reflected in crucial ecosystem services, such as crop yields, carbon sequestration and ecosystem water balance. A semi-parametric approach is used to identify areas with degraded vegetation and soils, which contribute significantly to the infilling of reservoirs by sediments. In particular, sediment transport is approximated through a function of precipitation, connectivity, soil and vegetation properties. This allows us to prepare and test land management scenarios in degraded areas in order to prevent siltation.

Validation: We develop and apply several remote-sensing based approaches for validating the different derived products. In particular, we use data from the Global Precipitation Measurement (GPM) mission, which is combined with information from high-resolution optical sensors on board of geostationary satellite systems like the Meteosat Second Generation. A newly developed rainfall retrieval technique, based on a random forest machine learning approach, allows for a quasi-continuous observation of rainfall distribution in near–real time and in high spatial and temporal resolutions. Runoff is estimated from spaceborne altimetry sensors by computing a statistical relationship between altimetry-based water level time-series and observed runoff. Water levels can then be transformed into runoff even if the gauge-based observations are discontinued. Finally, time series of optical remote sensing data of varying spatial (Sentinel-2, Landsat, MODIS at 10m – 1000m pixel size) and temporal scales (decades to seasons) are used to derive long-term and seasonal vegetation dynamics patterns.

SELECTED INTERIM RESULTS AND DISCUSSION

Evaluation of the SEAS5 seasonal forecasts: For evaluating the performance and the forecast skill of SEAS5 seasonal predictions, we have compared the precipitation forecasts against gridded observation-based datasets from the Global Precipitation Climatology Centre (GPCC) in terms of accuracy, overall performance, sharpness, and reliability, which is expressed in the so-called Unified Skillscore. After a basic multiplicative bias correction, we can observe skilful predictions for the seasonal precipitation sums during the rainy season already two months (São Francisco, Karun, Urmia, Catamayo-Chira, Blue Nile) or one month ahead (Atbara, Niger, Volta).

The 2017/2018 drought in Iran: For testing the potential as regional decision support for water management, we evaluated the performance of our different tools and products during the 2017/2018 drought in Iran. Besides the evaluation of the performance of the precipitation forecasts, we are interested in the implications of such a drought on the ecosystem. While the prediction of ecosystem states is still work in progress, we can already use satellite-based information in order to assess the condition of the vegetation during this season. Figure 1 therefore shows the Standardized Precipitation Index (SPI), an index for meteorological droughts, and the differences between the vegetation climatology and the conditions during the rainy season 2017/2018. Comparing the GPCC-Monitoring product (Figure 1a) with the SEAS5-forecasts (Figure 1b) clearly shows that the low amount of precipitation was successfully predicted by the seasonal forecasts. The impact on the vegetation, however, shows a dry signal especially in the regions which are dominated by natural vegetation or low population (Figure 1c). In heavily irrigated areas like the Karun basin, vegetation is even slightly increasing, which indicates that despite the low freshwater resources, the available water has been used for irrigation in order to maintain food supply. This caused water shortages for other sectors like, e.g. drinking water, leading to protests and revolts especially in the Southern parts of Iran at that time.

Atmospheric, hydrological and ecosystem modelling: For all modelling approaches, we finalized the initial setups and first parametrization experiments. The hydrological modelling for the headwaters of the river basins using mHM shows already highly promising results and will be used in an operational setup after the implementation of a lake module. The LPJ-GUESS model has been used for modelling the ecosystem of the Rio São Francisco basin in particular during dry periods in order to assess the implications on the vegetation. First runs show a significant drought signal in both the vegetation parameters and also the excess water, which already indicates the potential of the LPJ-GUESS-model to assess changes in the vegetation that are driven by water availability.

Public relations: Due to the strong focus on the involvement of stakeholders, decision makers, and other potential users, we have organized workshops in our study regions in Brasília (Brazil), Ahvaz and Teheran (Iran), and Khartoum (Sudan). With up to 100 participants, these workshops have shown the great interest not only in our tools and methods, but in seasonal forecasts and climate proofing approaches in general. Besides site visits in the different basins, we also organized training courses e.g. for dynamical and statistical downscaling. Special highlights have been the presentation of SaWaM at side events both at the 8th World Water Forum in Brasília, Brazil, and the 24th Conference of the Parties (COP24) in Katowice, Poland.

CONCLUSIONS & OUTLOOK

In the SaWaM-project, we evaluate the performance of global hydrometeorological information and, in particular, seasonal forecasts, for the regional water management in semi-arid regions. Since the project start we have made significant progress especially in the understanding both the potential and the limitations of seasonal forecast products and their usage in different modelling approaches. While the regional adaptation especially for the hydrological and ecosystem models is still ongoing, the production of statistically corrected seasonal precipitation forecasts as well as the remote-sensing based monitoring of precipitation, runoff and vegetation parameters is almost in an operational status. Besides that, we follow the collection of regional data with a high effort, because, even if the project also includes the regional application of globally available data, the detailed evaluation of our products as well as the quantitative analysis of regional climate systems still require in-situ information which, however, is often hard to obtain and/or inconsistent.

During the kick-off workshops in our study regions and several side events, we have learned that regionalized seasonal forecasts and the derived products for the hydrological systems and ecosystems have a huge potential for predicting and therefore mitigating the impact of extreme events like droughts. The products, tools and methods that are developed in SaWaM are a benchmark for the application of seasonal forecasts for the regional water management and therefore contribute to climate proofing in particular in semi-arid regions.

Contact

Coordinator: Prof Harald Kunstmann
Karlsruhe Institute of Technology
Institute of Meteorology and Climate Research
Tel.: +49 8821 183 208
E-mail: Harald.Kunstmann@kit.edu
Website: www.grow-sawam.org
BMBF Project ID: 02WGR1421A-I

LIST OF REFERENCES

Bürger, G. (1996). Expanded downscaling for generating local weather scenarios. Climate Res., 7, 111–128, doi: 10.3354/cr007111

Lorenz, C., H. Kunstmann (2012). The Hydrological Cycle in Three State-of-the-Art Reanalyses: Intercomparison and Performance Analysis, Journal of Hydrometeorology, 13, 1397 - 1420 doi: 10.1175/JHM-D-11-088.1

Lorenz, C., C. Montzka, T. Jagdhuber, P. Laux, H. Kunstmann (2018). Long-Term and High-Resolution Global Time Series of Brightness Temperature from Copula-Based Fusion of SMAP Enhanced and SMOS Data. Remote Sens., 10, 1842, doi: 10.3390/rs10111842

Mueller, E., A. Güntner, T. Francke (2010). Modelling sediment export, retention and reservoir sedimentation in drylands with the WASA-SED model, Geosci. Model Dev., 3, 275-291, doi: 10.5194/gmd-3-275-2010

Pilgrim, H. D., G. Chapman, D. G. Doran (1988). Problems of rainfall-runoff modelling in arid and semiarid regions. Hydrological Sciences Journal, 33, 379-400, doi: 10.1080/02626668809491261

Samaniego L., R. Kumar, S. Attinger (2010). Multiscale parameter regionalization of a grid-based hydrologic model at the mesoscale. Water Resour. Res., 46, W05523, doi: 10.1029/2008WR007327.

Siegmund, J., Bliefernicht, J., Laux, P., Kunstmann, H. (2015). Toward a seasonal precipitation prediction system for West Africa: Performance of CFSv2 and high-resolution dynamical downscaling, Journal of Geophysical Research-Atmospheres, 120, 7316–7339, doi: 10.1002/2014JD022692

Contacts

SaWaM

Institution	Contact person
Karlsruhe Institute for Technology, **Institute of Meteorology and Climate Research –** **Division Regional Climate and Hydrology** Kreuzeckbahnstraße 19 82467 Garmisch-Partenkirchen	**Prof Harald Kunstmann** harald.kunstmann@kit.edu **Dr Christof Lorenz** christof. lorenz@kit.edu **Tanja Portele**
Karlsruhe Institute for Technology, **Institute of Meteorology and Climate Research,** **Division Ecosystem-Atmosphere Interactions** Kreuzeckbahnstraße 19 82467 Garmisch-Partenkirchen	**Prof Almut Arneth** almut.arneth@kit.edu **Dr Anita Bayer** anita.bayer@kit.edu **Dr Patrick Laux**
University of Potsdam, **Institute of Geosciences, Hydrology and Climatology** Karl-Liebknecht-Straße 24-25 14476 Potsdam-Golm	**Prof Axel Bronstert** axel.bronstert@uni-potsdam.de **Dr Gerd Bürger** **Anne Müller**
University of Stuttgart, **Institute of Geodesy** Geschwister-Scholl-Str. 24 70174 Stuttgart	**Prof Nico Sneeuw** sneeuw@gis.uni-stuttgart.de **Sajedeh Behnia**
Philipps-Universität Marburg, **Department of Geography** Deutschhausstraße 12 35037 Marburg	**Prof Jörg Bendix** bendix@staff.uni-marburg.de **Dr Boris Thies** **Nazli Turini**
Helmholtz Centre Potsdam, **GFZ German Research Centre for Geosciences,** **Section Remote Sensing** Telegrafenberg Haus A 17 14473 Potsdam	**Dr Sigrid Rössner** sigrid.roessner@gfz-potsdam.de **Dr Saskia Förster** saskia.foerster@gfz-potsdam.de **Dr Robert Behling**
Helmholtz Centre for Environmental Research – **UFZ, Department of Computational Hydrosystems** Permoserstr. 15 04318 Leipzig	**Prof Sabine Attinger** sabine.attinger@ufz.de **Dr Luis Samaniego** luis.samaniego@ufz.de **Pallav Kumar Shrestha**
Technische Universität Berlin, Institute of Ecology, **Chair of Ecohydrology and Landscape Evaluation** Ernst-Reuter-Platz 1 10587 Berlin	**Prof Eva Paton** eva.paton@tu-berlin.de **Anna Smetanova**

SaWaM

Institution	Contact person
Lahmeyer International GmbH Friedberger Straße 173 61118 Bad Vilbel	**Berhon Dibrani** berhon.dibrani@de.lahmeyer.com
GFA AG Arnulfstr. 199 80634 München	**Thomas Kukuk** thomas.kukuk@gaf.de