University of Natural Resources and Life Sciences, Vienna
Department of Spatial-, Landscape- and Infrastructure- Sciences

Institute of Applied Statistics and Computing

Symposium on Climate Impacts on Low Flows and Droughts Vienna 2012

1st and 2nd March 2012

Abstracts

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Foreword

Low stream flows and associated streamflow droughts have major economic implications in Europe. Current global change scenarios suggest that the magnitude and frequency of droughts may increase in the next decades with important ramifications for water quality, the ecological status of European water bodies, irrigation, navigation and power production.

The International Symposium on Climate Impacts on Low Flows and Droughts, held from 1-2 March 2012 in Vienna, was jointly organised by three Viennese research institutions: The University of Natural Resources and Applied Life Sciences Vienna (BOKU), the Vienna University of Technology (TU Vienna), and the Central Institute of Meteorology and Geodynamics (ZAMG), as a contribution to the research project *Climate Impacts on Low flows and Droughts (CILFAD)*, funded by the Austrian Climate Research Program ACRP of the Klima- und Energiefonds. The aim of the symposium was to bring together drought experts from various disciplines to compare the current status of drought research and the implications for water resources management. The symposium focuses on the European continent and provides a platform for discussing large-scale studies in a regional context, and national/regional studies in the European context.

A focus was to discuss the following *questions*:

- What are the main climate drivers of hydrological change related to droughts?
- What is the state-of-the-art of drought modelling, including scenarios, downscaling and coupling models?
- What is known about the time patterns of droughts from observed, reconstructed and projected time series in streamflow and climate variables?
- What are the predictions of future low flows and droughts, and how reliable are such predictions in the light of all the uncertainties involved?
- How do regional assessments fit into Europe-wide analyses, and vice versa?
- What are the lessons on climate impacts on low flows and droughts to be learned for science and water resources management?

This volume contains the abstracts from 22 presentations (keynote presentations and oral presentations selected from an open call) from over 12 European countries which reflect the international dimension of the low flow and drought topic. We hope that the symposium will stimulate international cooperation and initiatives, crossing national boundaries and disciplines and, thereby, will contribute to a better assessment of European water resources under current and future environmental conditions.

Gregor Laaha

Schedule

Thursday, 1st March

8^{00} - 9^{00}	Registration
9^{00} - 9^{30}	Welcome and Opening
Welcome	Univ.Prof. Dr. phil. Josef Glößl, Vice Rector for Research and International Cooperation
Welcome	Univ.Prof. Dipl.-Ing. Dr.techn. Friedrich Leisch, Head of the Institite of Applied Statistics
Introduction	Gregor Laaha
9^{30} - 11^{00}	Drought processes (Chair: Bodo Ahrens)
Sonia Seneviratne	*Keynote:* Droughts in present and future climate: Perspectives on seasonal predictions to multi-decadal projections
Christian Reszler	Low flow characteristics - the influence of geological conditions
Adriaan Teuling	The role of evapotranspiration and runoff in the development of recent droughts in Central Europe
Björn THOMAS	Which catchment properties determine runoff behavior in small catchments?
11^{00} - 11^{30}	Coffee break and poster session
11^{30} - 13^{00}	Trends and patterns of droughts (Chair: Sonia Seneviratne)
Lena M. Tallaksen	*Keynote:* Drought and Low Flow in Europe: Observations and Multi-model simulations
Jamie Hannaford	European hydrological drought patterns: simulations by Global Hydrological Models and future projections
Jorge Lorenzo-Lacruz	Regional assesment of streamflow response to drought at different time scales in the Iberian Peninsula
Vesselin Alexandrov	Droughts in Bulgaria and SE Europe - changes and management
13^{00} - 14^{00}	Lunch break
14^{00} - 15^{10}	Reconstruction of historic droughts (Chair: Wolfgang Schöner)
Emmanuel Garnier	*Keynote:* The historic approach of the droughts and its perspectives for the research
Neil Macdonald	A millennial scale drought history for NW England
Sandra Karanitsch-Ackerl	Can tree rings of black pine (Pinus nigra) be used as a proxy for low flow?
15^{10} - 15^{30}	Discussion of the previous sessions (Chair: Günter Blöschl)
	Sonia Seneviratne, Lena Tallaksen, Emmanuel Garnier
15^{30} - 16^{00}	Coffee break and poster session
16^{00} - 17^{30}	Modelling low flows and droughts (Chair: Jamie Hannaford)
Benjamin Renard	Low flows in France and their relationship to large scale climate indices
Wojciech Jakubowski	Estimated distributions of low flow characteristic - some remarks about their instabilities
Maria Staudinger	Persistence of the actual hydrological state in streamflow prediction
Gregor Laaha	*Keynote:* A synthesis of low flow prediction at ungauged basins - PUB report and beyond
19^{00} - 22^{30}	Social event and conference dinner
	Wine tasting @ Winery Cobenzl
	Conference dinner @ Waldgrill Cobenzl

Friday, 2nd March

8^{00} - 8^{45}	Coffee reception
8^{45} - 10^{00}	Climate models and scenarios (Chair: Günter Blöschl)
Bodo Ahrens	*Keynote:* Meteorological dry and wet spells in Europe: observed and simulated by climate models
Shaochun Huang	Projection of low flow condition in Germany under climate change by combining three RCMs and a regional hydrological model
Jean-Phillipe Vidal	Effect of climate change adaptation and mitigation scenarios on spatio-temporal drought characteristics
10^{00} - 10^{30}	Coffee break and poster session
10^{30} - 11^{40}	Implications for water resources management (Chair: Miriam Fendekova)
Christian Kopeinig	*Keynote:* The early warning system for drinking water supply in Carinthia
Mikhail Bolgov	Low flow risk assessment for water management
Raphael Meyer	The implications of projected climate change on summer low flow in the Swiss Plateau based on a multi-variable calibration of the hydrological modeling system PREVAH
11^{40} - 12^{00}	Discussion of the previous sessions (Chair: Lena Tallaksen)
	Gregor Laaha, Bodo Ahrens, Christian Kopeinig
12^{00} - 12^{20}	Short break
12^{20} - 13^{00}	Closing Session
Karl Schwaiger	*Keynote:* Climate impacts on low flows and droughts - first responses at European level

Accepted Posters

Taha Al-Salim	Rainwater Harvesting of Wadi Al-Kassab Basin W. of Mosul City / N. of Iraq; Case Study Facing Drought
Daniel Alexandru	Recommendation and development of management options for an improved land use system of the agricultural crops in the Western part of the Romanian Mures Basin
Judit Bartholy	Projections of drought index tendencies for Central/Eastern Europe in the 21st century
Mathias Deutsch	Low water events on the Elbe and Weser River with special focus on the year 1911
Hadi Donyadoost	Study probaility climate change of Markazie province
Ahmad Fatehi Marj	Streamflow forecasting using climatic signals and artificial neural network
Miriam Fendekova	Groundwater drought in the Nitra River basin - identification and classification
Felix Fundel	Monthly Forecasts of Hydrological Droughts
Borbala Galos	Impacts of the increasing drought frequency on the lower limit of forest distribution in Central Europe
Sandra Garcia-Galiano	Assessing drought risk in West Mediterranean basin from non-stationary PDF ensemble
Georg HEINRICH	The future of dry and wet spells in Europe: A comprehensive study based on the ENSEMBLES regional climate models
Nosrati Kazem	Regional low flow frequency analysis using hybrid regression method
Silvia Kohnova	tba.
Masoud Moradi	Survey of the affective parameters on the stream flow using the Artificial neural network in dehgolan catchment, Kurdistan, Iran
Abolfazi Mosaedi	Investigation and evaluation of different methods of appropriate drought index
Argentina Teodora Nertan	Vegetation state assessment based on satellite derived products for drought monitoring in the Mures Basin
Rita Pongracz	Analysis of projected changes in climate index CDD for Hungary using ENSEMBLES simulations
Stanislava Radeva	Drought in Bulgaria
Eric Sauquet	Climate and hydrological uncertainties in future low-flows in France
Andreas Schaumberger	Modelling and Analysing Spatio-Temporal Patterns of Drought in GIS
Gerhard Soja	Climate impacts on water level of Lake Neusiedl and Flow of River Wulka
Philipp Stanzel	Climate change impact on low flows in Austria: changes in runoff and seasonality
Beverley Todd	Reconstructing a 300 Year Drought Record for Southern Britain
Koen Verbist	Development of an operational drought risk management system for the Chilean Drylands
Sergio M. Vicente-Serrano	Performance of drought indices for ecological, agricultural and hydrological applications
Mehrez Zribi	Analysis of drought events in a North Africa semi-arid region, Using SPOT-VEGETATION and C band scatterometer satellite Data

1 Drought processes

Sonia Seneviratne: Droughts in present and future climate: Perspectives on seasonal predictions to multi-decadal projections (Keynote)

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In this presentation, I will provide an overview of recent research on drought processes in present and future climate. In particular, I will review current assessments on the role of land-climate interactions for drought dynamics (e.g. Seneviratne et al. 2010) and the impact of droughts on temperature extremes (e.g. Seneviratne et al. 2006, Teuling et al. 2010, Hirschi et al. 2011), as well as analysis frameworks for the investigation of soil moisture memory characteristics and their implications for seasonal forecasting (e.g. Seneviratne and Koster 2012, Orth and Seneviratne 2012). In addition, I will review current projections of changes in drought characteristics in the context of global warming (e.g. Orlowsky and Seneviratne 2012), including the recent assessment of the IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) regarding past and future changes in droughts at the global scale (Seneviratne et al. 2012).

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Christian Reszler:
Low flow characteristics - the influence of geological conditions

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In this study the influence of geological conditions on the low flow characteristics as an example of regional case studies in southern Austria is assessed. For this purpose, discharge dynamics of springs and stream gauges are analysed that are located in regions with climatologically comparable conditions. Thus, the influence of the climatic boundary conditions is reduced and the differences in the discharge dynamics can be explained by the predominant geological (and morphological) conditions. The interpretation of the geology/storage relation, i.e. amount of stored water and recession characteristics, is illustrated by different hydrogeological examples, e.g. karst and fissured/porous aquifer zones in the Karawanken and Sattnitz massif, weathered schist and gneiss zones at the Koralpe or the tertiary region with predominating less permeable loamy sands and silts in Eastern Styria. In a next step, geologically homogeneous units were defined assisting in regionalising flow depletion characteristics. In this context, certain springs can be selected as an indicator of possible critical low flow conditions in a region. The study also illustrates the benefit of the geological analyses for hydrological modelling. In most of the regions a distributed hydrological model is set up, where the groundwater system is represented by a system of linear reservoirs. Runoff generation and water balance is calibrated on spring and runoff data, focusing on baseflow and low flow periods. The hydrogeological information assists in identification and interpretation of the necessary parameter values for the time constants and exchange rates, as well as enables the detection of differences between the orographic and hydrographic recharge areas. The models are used as tools for simulating scenarios with different climatic conditions to analyse the impact of a possible climate change on groundwater flow. However, by understanding the geological and hydrogeological system and the corresponding groundwater flow mechanisms, the vulnerability of a particular area on severe low flow conditions is also assessed in a rather qualitative way. In this context, the presented procedure also points out the importance of the combination of different disciplines for understanding the hydraulic dynamics and setting up a realistic hydrological model leading to more reliable low flow simulations or forecasts in an investigated area.

Adriaan Teuling:
The role of evapotranspiration and runoff in the development of recent droughts in Central Europe

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Traditionally, droughts are often seen as periods with below-average rainfall. However, when drought is viewed as the below-average availability of subsurface storage instead, it becomes clear that drought evolution is not only controlled by the reduced input of rainfall into the land surface system, but also (as dictated by the subsurface water budget) by the way the drought conditions themselves alter the outgoing hydrological fluxes, in particular evapotranspiration and runoff. The way in which these fluxes respond to drought is not straightforward to predict, and depends on many factors such as soil moisture, land use, and subsurface conditions.

In this study we investigate how the different components of the land surface water budget have contributed to recent droughts in Central Europe. Given the difficulties to predict these fluxes, we focus on observational records instead. The natural unit for such analysis is the (small) catchment scale, at which topography-driven flow convergence facilitates the monitoring of runoff. Here we study the drought development over three catchments in Belgium, Germany and Switzerland, for which concomitant and long-term (decadal) records of precipitation, actual evapotranspiration (by means of eddy covariance or lysimeter) and runoff are available.

Our analysis suggests that runoff and evapotranspiration dynamics have a much larger role in drought evolution than previously thought. In particular, an inverse relation is found between monthly precipitation and evapotranspiration, with evapotranspiration increasing on average with 10% of the precipitation decrease. Whereas evapotranspiration acts to amplify drought with anomalies of up to 1 mm/d, runoff limits the magnitude of drought by reducing at a rate similar to the precipitation anomalies. In addition, we find that GRACE satellite estimates of storage anomaly dynamics can be reproduced based on the catchment water balance, but only when taking into account the positive evapotranspiration anomalies.

Björn THOMAS:
Which catchment properties determine runoff behaviour in small catchments?

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The complexity of Pleistocene landscape and various anthropogenic influences complicate the classification of runoff characteristics of small catchments in northeast Germany. Such a classification would be of use for scientists and water managers in order to estimate the catchments' vulnerability regarding floods and low flows, transfer results to ungauged catchments as well as planning of measures to adapt to climate change. The objective of our study is the use of dimensional reduction technique solely on discharge time series in order to classify runoff behaviour of small catchments (< 500 km²) of Brandenburg, Germany.

The study is based on data of daily discharge at 37 gauges from 1991 to 2006. Data was provided by the State Office of Environment, Health and Consumer Protection of the Federal State of Brandenburg. Principal Component Analysis was applied to reduce dimensionality to as few principal components as possible explaining still most of the variance in the data. Additionally, meteorological data and catchment properties derived from hydrogeologic, soil and land use maps were included to better understand the results and to check hypotheses about underlying processes and driving forces.

The first six components exhibited an eigenvalue exceeding one and explained 72% of the total variance. Analysis of the loadings and comparison with meteorological and catchment properties allowed assigning runoff generating processes to the principal components. The first principal component represented the mean runoff behaviour of the time series from all catchments. Further components could be related to precipitation patterns that exhibited a northwest-southeast and southwest-northeast gradient, short term damping according to thickness of the unsaturated zone, long term damping visible in the annual behaviour of discharge and specific behaviour or measurement errors at single gauges. Despite our hypothesis that soil, groundwater and land use properties are crucial to understand discharge patterns at small catchments the results show that precipitation patterns explain most of the variance in our data set. Our method was suited to extract common patterns in catchments and related them to low flow statistics. Further, we used this classification to estimate catchments' vulnerability to extremes, especially low flows, and formulate key concerns for water managers.

2 Trends and patterns of droughts

Lena M. Tallaksen: Drought and Low Flow in Europe: Observations and Multi-model simulations (Keynote)

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Observations suggest that drought in Europe has occurred more frequently in the latter part of the 20th century, however the scientific understanding of the driving forces behind large-scale droughts is incomplete. Climate change projections for Europe further indicate that drought is likely to become more frequent and more severe due to warmer northern winters and a warmer and drier Mediterranean region.
The EU-funded WATCH project (2007-2011) aimed to advance our knowledge on the impact of global change on water resources. The project brought together the hydrological and climate communities to analyse, quantify and predict the components of the current and future global water cycle, and hydrological extremes in particular. In this presentation focus is on hydrological drought on the European scale based on both observed and simulated time series. Observations stem from a newly assembled dataset of near-natural daily streamflow records, consisting of more than 400 stations (1962-2004). In a major interdisciplinary effort the simulation results of eight large-scale hydrological models were compared with respect to their ability to reproduce the hydrological regime, extremes and observed trends in streamflow. All models were run using the WATCH Forcing Data on a half-degree resolution.
Evidence from the observed dataset revealed a regional coherent picture of annual streamflow trends, with negative trends in Southern and Eastern Europe, and generally positive trends elsewhere (especially in northern latitudes). Low flow has decreased in most regions with a summer minimum, whereas positive trends were found in the winter months in most catchments. A marked shift towards negative trends was observed in April, gradually spreading across Europe to reach a maximum extent in August. In general, the large regional scale patterns of change agree with the hydrological responses as projected by climate models. Regional patterns of trends in annual runoff were also well reproduced by the large-scale models, however, seasonal trends and trends in extremes were less well represented and differed substantially among the models. Negative trends, which dominate in the summer months, were generally less reliable modelled, suggesting that the models do not satisfactory represent catchment storage and release important for the generation of low flow.
A benchmark framework was introduced to allow comparison across different catchments, large-scale models and runoff indices. The model performance differed significantly between models and hydrological regime. Overall, high flows were better captured than low flows, indicating that models perform better under wet conditions, although less so in snow dominated regimes. The large spread in model performance was contrasted by the overall good performance of the ensemble mean. The model were also evaluated in their ability to capture the spatial characteristics of large-scale droughts and a consistent behaviour among the models in their ability to capture annual indices, such as the mean drought area, was found. However, considerable differences were revealed for event characteristics with some models producing about twice as many events as observed. This can likely be related to the conceptualization of hydrological processes such as the depletion and replenishment of catchment stores.

Jamie Hannaford:
European hydrological drought patterns: simulations by Global Hydrological Models and future projections

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Droughts are extreme climatic and hydrological episodes, which typically develop slowly, over large areas (several hundreds of square kilometres). They are characterised by prolonged water deficit; when considering hydrological drought, this deficit refers to river flow. Often, the duration and the spatial extent of water deficits are the two most important measures used to define a drought as an exceptional event.
The Regional Deficit Index (RDI) is a time series that measures the proportion of a region where a river flow deficit occurs – as a proxy for the spatial extent of a drought event. From a set of about 500 river basins, twenty three European regions were defined according to the timing of their water deficit which, for any one region, is used to generate a daily Regional Deficit Index for 1961 to 2004. The totality of the twenty three RDI series forms the European Drought Catalogue.
Using the same method, seven gridded global models (GHMs– both hydrological and land surface) from the Water-MIP and the EU-WATCH projects, run with the WATCH Forcing Data (WFD), were analysed; daily RDI series from the twenty three regions were derived from modelled total runoff estimates. The ability of GHMs to reproduce drought events across Europe was assessed by comparing the European Drought Catalogue benchmark RDI time series and the GHM-RDI time series. Results showed mixed ability of GHMs to reproduce droughts in different European regions, with some models tending to simulate long, spatially consistent events (e.g. JULES, HTESSEL) while others generate very short droughts (e.g. MPI-HM, H08).
Total runoff simulated by the same GHMs driven by three Global Climate Model GCM projections were used to derive transient GHM-RDI series for the period 1961-2100 for each GCM-GHM combination. GHM-RDI for the control period (1961-2000) shows that uncertainty in drought simulation due to the GHM is large, and for some regions as large as that due to GCMs. However, most GCM/GHM combinations are able to reproduce similar drought characteristics to those obtained when the GHMs are driven by WFD. The models were run into the future, to generate RDI time series extending to 2100, to allow changes in drought characteristics to be quantified and compared between the various GHM/GCM combinations. In the future, signal of change and strength of changes in drought characteristics vary regionally, and the consistency of signal for all GCM/GHM depends on the region of interest.
The results show that the uncertainty from GHM in the quantification of the impact of climate change on drought is as large as that due to GCM projections for most parts of Europe. It is therefore recommended that climate change impact studies on hydrology consider several hydrological models as well as several climate models.

Jorge Lorenzo-Lacruz:
Regional assesment of streamflow response to drought at different time scales in the Iberian Peninsula

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This work analyses the response of hydrological variability to precedent climatic conditions at different accumulated time-scales (1 to 48 months) in 187 streamflow series distributed across the Iberian Peninsula. The Standardized Precipitation Index (SPI) was used to summarize the climatic conditions related to precipitation of each drainage basin and it was correlated with a Standardized Streamflow Index (SSI) by means of the Pearson R correlation index. Based on the obtained correlations at each time scale (1-48 months) in all gauging stations, we performed a Principal Component Analysis in S mode to extract the general patterns of the delayed response of the hydrological systems to climatic drought throughout the Iberian Peninsula. This methodology was applied to the gauging stations classified into 3 groups according to the degree of water regulation: non-regulated rivers, rivers impounded bv dams during the study period (1945-2005) and rivers regulated before the beginning of the data series.
Results for the non-regulated rivers showed two main patters of response to climatic droughts: basins distributed across the study area with high correlations at short time-scales, from 1 to 3 months (67% of the variance), and those with the strongest relationship at longer time- scales, 12 months (20% of the variance), located in specific permeable catchments.
The analysis classified the basins regulated during the study period into three main patterns: a first group of basins (32% of the variance) which did not experienced a significant change in the response after the damming. A second group (31% of the variance) composed by basins where water regulation have modified the short response of the basins, 2 to 4 months, and delayed it to longer time-scales, 11 to 24 months. The third pattern (19% of the variance) summarized the basins where the response have changed from high correlations at long time-scales (20 to 24 months) to more smoothed but sustained response along all time scales.
Finally, the basins regulated before 1945 showed two main patterns which are very similar to those of the non-regulated rivers: A group of basins (70% of the variance) with short-responses located in the central and northern part of the study area and other group (21% of the variance) which showed a delayed response at medium time-scales (10 to 12 months).
The implications of the impact of water management are diverse. In concrete catchments regulation was useful to smooth the dependence of streamflow on climate droughts, which seems like an appropriate and successful management strategie. However, in other basins water management caused the enhancement of the response and its sustainment over medium and long time scales, threatening the consumptive uses established within them.

Vesselin Alexandrov:
Droughts in Bulgaria and SE Europe - changes and management

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During the last decades an increase of the number of extreme natural events has been observed all over the world. Drought should be considered as an extreme event. It is related to a decrease of precipitation frequency both in regions marked as ones with profusion of rains and areas where the scarce of precipitation is assumed as normal conditions. Historical soil, meteorological, agrometeorlogical, and hydrological data provide us with information for a large number of dry periods observed over South-eastern Europe during the 20th century. Drought is a natural part of the climatic cycle of the Balkan Peninsula. But the processes getting deeper in any new coming dry periods should be considered as warning signals.

The Drought Management Centre for Southeastern Europe (DMCSEE) joins the efforts of scientists for regional drought monitoring, assessment and risk management. DMCSEE coordinate development and application of drought risk management tools and policies with the goal of improving preparedness and reducing drought impact. Using common methodology in drought analysis and impact assessment the project obtains regionally comparable results enabling better overview of drought situation for sectors economically dependant on water availability, such as agriculture, energy and tourism. Quality assessments of drought occurrence risk and possible drought impacts provided by DMCSEE and disseminated to decisions makers and general public allows effective and timely decisions to reduce drought related damages.

Reconstruction of historic droughts

Emmanuel Garnier:
The historic approach of the droughts and its perspectives for the research*(Keynote)*

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The droughts are a factor of historic durability and because of their impacts on societies, they left multiple milestones in the archives of the last 500 years. For the record, it is necessary to remind that the general term of 'drought' recovers different notions. In its most frequent meaning of a word, it is synonymic of pluviometric deficit and extreme climate event.
In this perspective, and for lack of being able to take into account the criterion of its deviation with regard to the mean or normal values of the pluviometry, non-existent before the beginning of the 19th century, the historian uses the other present quantitative elements in sources as duration, period of occurrence, the geographical extension of the phenomenon and finally his effects on societies.

Before the middle of the 19th century, the historian has to open at most the corpus of sources. Marginal and hidden at random some documentation, it requires to neglect no type of archives if we want to hope to reconstruct long and relatively reliable chronologies. Diaries drafted by private persons, the municipal chronicles are particularly useful. Besides the private, economic and political events, they are often very sensitive to the extreme events which engender a disaster. The catholic church is faithful ally of the historian to study the droughts. Thanks to the religious processions, the historian has relatively homogeneous series on the archival and historic plans. These religious ceremonies allow the reconstruction of historic series included generally between 1500 and 1800. There where the wars spared cities, the historian has very precious municipal archives. Deliberations and municipal accounts constitute an inexhaustible deposit of climatic data. Unlike the data of temperatures which appear around 1700s, it is necessary to wait for the beginning of the 19th century to have instrumental data on the pluviometry or the water flows. They result from the creation of scientific societies as the Royal Academy of the sciences of Paris or the Societas meteorologica palatina of Mannheim in Germany.

For lack of having reliable instrumental data before 1800, the contents of archives offer two methodological solutions to estimate these natural events for which we arrange only textual descriptions. The first solution is to use all the chronological mentions of a drought appearing in archives. Thereof, the drought of the historian indicates rather a very dry and long episode with very important economic and human impacts to appear in the archives of the men. Other methodological choice which can complete the evaluation by duration consists in creating an indexed scale of severity directly built according to the descriptive contents of the drought. The geographical comparison also shows that periods of unusually dry and warm affected to the whole of Europe, particularly in the second half of the 16th century to early 18th century and finally since the 1960s.

Neil Macdonald:
A millennial scale drought history for NW England

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Drought is one of the major natural hazards experienced worldwide; they are complex with both causes and multifaceted impacts poorly understood. Few studies of drought events from a long-term perspective have been undertaken in the UK. This presents problems in determining important drought characteristics such as duration, frequency and severity. In order to undertake robust drought analyses reliable long-term data are required. Historical records have long been recognised as valuable data sources within historical climatology; however, the application of historical records in drought analysis is in its infancy, with few historical studies considering drought. This paper presents a reconstruction of drought events for NW England, from around AD 1000 to 2009, drawing upon instrumental, historical and sedimentary records. The drought record is extended to a millennial timescale by coupling the long, continuous instrumental meteorological records available for this area since the late 18th century, with descriptive historical accounts of droughts (since c.AD 1600) and a sedimentary peat sequences from an ombrotrophic mire (Butterburn Flow), with water table variation history inferred from sub-fossil testate amoebae. The high resolution testate amoebae analysis is presented at 3mm sampling resolution, providing near annual (1-5 year) values. Calibration of the sedimentary sequences to the instrument series over the last c.250 years reveals a detailed millennial drought-dry phase history, with a near basal 14C date (860±19 BP) for the core. The results identify a number of severe droughts - dry phases that have been of longer duration and of greater severity than the 1976 drought, the most memorable drought in living memory in the UK. The results of this work illustrate that current water resource management plans within the UK would struggle to maintain potable water supplies, indicating the need for greater resilience within current water management plans.

Sandra Karanitsch-Ackerl:
Can tree rings of black pine (Pinus nigra) be used as a proxy for low flow?

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Annual increments of trees growing in temperate forests of the northern hemisphere have been widely used for climate reconstructions. Most frequently, tree rings of high alpine or high latitude sites serve as a proxy for past summer temperatures. Over the past years, several reconstructions of precipitation from tree rings in Central Europe have been published. Black or Austrian pine (Pinus nigra var. nigra) has proven to be a valuable proxy for precipitation several times already. The field of dendrohydrology – using tree rings as a proxy for hydrological parameters – is less common in Europe, though widespread in the US.

The aim of the present study is to find out, if it is possible to use tree rings of black pine as a proxy for river runoff to reconstruct low flows and drought in dry regions of eastern Austria.

As a first step, chronologies of Black pine from five different sites in northeastern Austria (Staatz, Eichhorn, Strasshof an der Nordbahn, Oberweiden and Markhof) were simply correlated with monthly data of five gauging stations – Niederabsdorf (Zaya), Bad Pirawarth (Weidenbach), Zwingendorf (Pulkau), Obermallebarn (Pulkau) and Hollenstein (Schmida) – data provided by Hydrographic Service Austria.

For every site, data of at least 11 up to 15 trees were used to calculate three chronologies: ring-width index, earlywood-index and latewood index. All chronologies were correlated with monthly mean river runoff and monthly minimum runoff of every gauging station for the time period 1977 to 2008.

Best correlation coefficients were achieved with July mean runoff and latewood chronologies (highest value for latewood chronology Staatz and July mean runoff Zaya: r = 0,669). Correlation coefficients with monthly minimum runoff are generally lower.

Not surprisingly, the correlation coefficients decrease with distance between tree site and river and also seem to be dependent on site conditions of the trees. Staatz – a site with extremely shallow immature soil – shows the highest correlation coefficients with all five analysed rivers.

The oldest trees used for this study are more than 150 years old. So they bear the potential to reconstruct summer runoff back to the middle of the 19th century. In the project WALD-WASSER-WEINviertel (SPA03-015) performed within the framework of the research program Sparkling Science, funded by the Austrian Federal Ministry of Science and Research, a pine chronology dating back to 1578 AD consisting of more than 200 trees has been established. This could serve as a tool to gain insight in river runoff of the past.

3 Modelling low flows and droughts

Benjamin Renard: Low flows in France and their relationship to large scale climate indices

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This study explores the relationship between low flows in France and large scale climate variability. To this aim, a national low flows reference network of near-natural catchments called R2SE was set up. It consists of 220 French gauging stations suited to the monitoring of low flow evolution in France. Daily streamflow records for the period 1968-2008 were used to detect trends in several drought indices: three severity indices (mean annual flow, annual minimum flow and volume deficit) and three timing indices (drought start, center and end). In addition to testing for trend with respect to time, four climate indices were used as covariates: the North Atlantic Oscillation (NAO), the Atlantic Multidecadal Oscillation (AMO) and the frequency of two Weather Patterns corresponding to circulation types associated to wet (WP2) and dry (WP8) conditions over France. Due to their specific dynamics, NAO and WPs were also analyzed seasonally.

Results first show a consistent increase of drought severity in southern France with respect to time, NAO and AMO. Additionally, significant relationships with WPs are found throughout France, with the exception of the Mediterranean coast. Timing indices appear to be less related to large scale climate indices, whereas some evidence of a negative association with time is found (i.e. an earlier start of the annual low flow period). Seasonal climate indices appear to have stronger links with low flow indices than their annual counterparts. The summer (JJA) NAO shows a strong link with severity indices in the northern half of France. This link is found again for the winter (DJF) WP2. Lastly, significant links are detected between timing indices and seasonal WP8, while these links could not be detected at the annual scale.

In order to assess the robustness of the above relationships, a subset of 28 stations with a longer record period is studied on three different periods: 1948-1988, 1968-2008, and on the whole period 1948-2008. Importantly, trends with respect to time clearly lack robustness: trends of opposite sign are found in the first and second period, and no compelling trends are found in the whole period 1948-2008. Conversely, the relationship between low flow indices and climate indices remain stable across all three time periods.

The above result demonstrates that time cannot be used beyond purely descriptive purposes. In particular, this lack of stability precludes the use of time as a covariate for forecasting purposes: extrapolating a temporal trend in the future could lead to misleading predictions. On the other hand, the stability of the relationships between low flow and climate indices provides confidence that these relationships result from physical mechanisms linking atmospheric circulation and surface hydrology. Moreover, it paves the way for useful seasonal forecasting applications. As an illustration, information about drought severity could be inferred several months ahead from either a forecasted summer NAO or more directly from the WP2 frequency observed during the previous winter.

Wojciech Jakubowski:
Estimated distributions of low flow characteristic - some remarks about their instabilities

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At some profile consider the low flows obtained by POT method. Each observed low flow can be described by three characteristics: deficit – D, duration – T and lowest outflow – M. The values of triple (D;T;M) depends on threshold level Q_g – POT method parameter. For perennial rivers the thresholds in the range from Q_70 to Q_95 can be considered reasonable – Tallaksen and van Lanen [2004]. However for practical estimation the Q_g value is set on some chosen values - mainly on Q_70 or Q_90. This value is mostly selected because of hydrological (no statistical) point of view. In this article the impact of threshold level on estimated distributions is taken into consideration. To describe statistics of the low flow characteristics the following distributions were tested:
– GEV (Generalized Extreme Value) and GP (Generalized Pareto) for the extremes;
– log-normal at non extreme cases.

The following algorithm is used:
– from the flow duration curve two values Q_90 and Q_55 are selected;
– for each observed flow from the interval (Q_90,Q_55) the three dimensional low flow sequence is extracted, the Zelenhasic and Salvai [1987] method is applied;
– for each one dimensional sequence of observed characteristic an estimation of above distributions is performed.

As a result for chosen characteristic, distribution and threshold level Q_g the return level z_pg associated with return period 1/p is estimated. Furthermore, by the delta method [Coles, 2001] the variance Var(z_p) is calculated. Consider two threshold levels Q_g1, Q_g2 and |Q_g1-Q_g2| is close to 0. One would expect that z_pg2 should belong to 50% confidence interval for z_pg1 or symmetrically z_pg1 should belong to 50% confidence interval for z_pg2.
If these conditions are fulfilled we will say that examined characteristic is stable, otherwise it is instable.
The examples of stability and instability of low flows characteristics for polish and worldwide profiles will be presented.

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Maria Staudinger:
Persistence of the actual hydrological state in streamflow prediction

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Since the extreme summer of 2003 early warning of droughts and low flows is increasingly recognized as being important also for European countries. Most recently, the year 2011 provided additional examples of drought conditions, which might be expected to be more frequent in the future. So far little has been done regarding drought forecasting in Europe. A fundamental question related to drought forecasting is, how long before a drought actually occurs, can it be predicted. This study is assessing the relative importance of the current hydrological state and weather during the prediction period. 15 Swiss meso-scale catchments were selected and the HBV model was calibrated to each catchment leading to an ensemble of 100 suitable parameter sets per catchment. Each catchment was then studied with a twofold procedure: First, the streamflow was simulated using the hydrological state and the observed preceding weather conditions as starting conditions and weather series from the different years as 'predictions'. Second, the streamflow was simulated using different hydrological starting states corresponding to preceding weather conditions of the different years and only one observed weather series in the 'prediction mode'. By this the influence of persistence of a certain hydrological state on the prediction could be evaluated. Preliminary results indicated that the estimated persistence is varying between different catchments. However, the variation in the estimation of the persistence from using different parameter sets for one catchment is smaller than the variation between several catchments. The preliminary results indicated a range of 50 to 200 days for the persistence of a certain hydrological state in the prediction period.

Gregor Laaha:
A synthesis of low flow prediction at ungauged basins – PUB report and beyond *(Keynote)*

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The prediction of runoff in ungauged basins (PUB) is one of the key challenges of water resources management. A synthesis report is currently being compiled which summarises the state of hydrological predictions for ungauged basins, focussing of various runoff signatures. The chapter on low flows is jointly compiled by members from the EURO-FRIEND-Water Low Flow and Drought Group and experts from the PUB initiative. The chapter summarizes findings of about 28 individual assessments in 15 studies from all over the world, to assess the state of the art of low flow prediction in ungauged basins for various regions and regimes. In this talk we give an outline of the study and present the preliminary results. We also give an outlook about a proposed COST network activity from the FRIEND-Water program which aims to continue the research of the PUB report and extend it to a pan-European assessment of low flows and droughts under climate change.

4 Climate models and scenarios

Bodo Ahrens*:*
Meteorological dry and wet spells in Europe: observed and simulated by climate models (*Keynote)*

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Projecting dry and wet spell characteristics into the future is of major interest. This paper discusses the ability of two global and two regional climate models to simulate the statistics of meteorological dry and wet spells over Europe. Using the self-calibrating effective drought index as measure for spell characteristics the model evaluation shows that the spatial patterns of the spell characteristics are well represented, that the regional models add value to the global model projections, but also that the uncertainty of the evaluation is large due to the large decadal variability of spell characteristics. The projections indicate, that the intensity and length of spells in the period 2061–2100 changes substantially in south (more extreme dry spells) and north (more extreme wet spells) of Europe if determined with respect to the control climate in 1961–2000, but not if determined with respect to the mean climate in 2061–2100. This indicates that the models project a change in the mean annual cycle of precipitation, but less a change in the relative extremes. Changes in spell characteristics in West and Central Europe are projected to be relatively small.

Shaochun Huang
Projection of low flow condition in Germany under climate change by combining three RCMs and a regional hydrological model

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More frequent and intense extreme events are expected as a consequence of climate change in many regions. In this study, the aim is twofold: a) to project the future low flow conditions in the five large river basins in Germany (Rhine, upper Danube, Elbe, Weser and Ems) and b) to account for uncertainty of the low flow projections due to various climate scenarios generated by three regional climate models (RCMs). The eco-hydrological model SWIM was applied to simulate the daily river discharges and it was intensively calibrated and validated in terms of Logarithmic Nash-Sutcliffe Efficiency, low flow trends and the low flow frequency curves. The simulated discharges using observed climate data show a good agreement with the observed ones for the control period (1961 – 2000) for 20 gauges. Climate scenarios from two dynamical regional climate models (REMO and CCLM) and one statistical-empirical model (Wettreg) were used as input data for SWIM to simulate the future river discharges. The Generalized Extreme Value distributions were fitted to the annual minimum 7-day mean flow series for the control and two scenario periods (2021 – 2060 and 2061 – 2100). The occurrence of the 50-year low flow values from the control period were estimated for the two scenario periods using the same climate models (no bias correction). The 50-year low flow is likely to occur more frequently in western, southern and central Germany during the second scenario period as suggested by more than or equal to 80% of all model runs. The current low flow period (from August to September) may be extended until the late autumn at the end of this century. Compared with the study of flood projections using the same models, the signal of severer low flows is more pronounced and consistent between models. Therefore, the uncertainty of projected changes is also lower.

Jean-Phillipe Vidal:
Effect of climate change adaptation and mitigation scenarios on spatio-temporal drought characteristics

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Drought events develop in both space and time and they are therefore best described through summary joint spatio-temporal characteristics, like mean duration, mean affected area and total magnitude. This study addresses the issue of future projections of such characteristics of drought events over France through three main research questions: (1) Are downscaled climate projections able to reproduce spatio-temporal characteristics of meteorological and agricultural droughts in France over a present-day period? (2) How such characteristics will evolve over the 21st century under different emissions/mitigation scenarios? (3) How would perceived drought characteristics evolve under theoretical adaptation scenarios?

These questions are addressed using the Isba land surface model, downscaled climate projections from the ARPEGE General Circulation Model under three emissions scenarios, as well as results from a previously performed 50-year multilevel and multiscale drought reanalysis over France (Vidal et al., 2010). Spatio-temporal characteristics of meteorological and agricultural drought events are computed using the Standardized Precipitation Index (SPI) and the Standardized Soil Wetness Index (SSWI), respectively, and for time scales of 3 and 12 months. Results first show that the distributions of joint spatio-temporal characteristics of observed events are well reproduced by the downscaled hydroclimate projections over a present-day period. All spatio-temporal characteristics of drought events are then found to dramatically increase over the 21st century under all considered emissions scenarios, with stronger changes for agricultural droughts.

Two theoretical adaptation scenarios are eventually built based on hypotheses of adaptation to evolving climate and hydrological normals. The two scenarios differ by the way the transient adaptation is performed for a given date in the future, with reference to the normals over either the previous 30-year window ("retrospective" adaptation) or over a 30-year period centred around the date considered ("prospective" adaptation). These adaptation scenarios are translated into local-scale transient drought thresholds, as opposed to a non-adaptation scenario where the drought threshold remains constant. The perceived spatio-temporal characteristics derived from the theoretical adaptation scenarios show much reduced changes, but they call for more realistic scenarios at both the catchment and national scale in order to accurately assess the combined effect of local-scale adaptation and global-scale mitigation.

This study thus proposes a proof of concept for using standardized drought indices for (1) assessing projections of spatio-temporal drought characteristics and (2) building theoretical adaptation scenarios and associated perceived changes in hydrological impact studies (Vidal et al., 2012).

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5 Implications for water resources management

Christian Kopeinig: The early warning system for drinking water supply in Carinthia *(Keynote)*

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Seasonal decrease in precipitation or re-distribution of precipitation and groundwater recharge pattern is already the case in parts of Carinthia. In the Austrian Alps long time series analyses over 200 years indicate increasing temperatures and partly decreasing precipitation as well as significant decrease of groundwater recharge up to 25% in the last 100 years. This is why measures for developing water management strategies and an early warning system on water scarcity were enforced.
The early warning system concentrates on official communal drinking water suppliers in Austria's southern province Carinthia. Each of this water supplying organisations has water sources like springs, wells or deliveries from other organisations and water demands of their customers. The structure of these water sources and water demands were collected and mapped to a database of water management data.
For the entire province of Carinthia a very dense network of measurement sites is in operation. A large amount of hydro-meteorological data provides the basis for the development of an appropriate hydrological modelling system. Springs with a high temporal sampling resolution or a long monitored period are simulated and used as reference springs. By cross-correlations about 900 springs used for drinking water supply were assigned to suitable reference springs.
If we take a look at the early warning system as a whole we have to distinguish two different time horizons: At the near horizon of three month the so called "operational early-warning-system" works on the basis of weather scenarios for the following three month. It should give the possibility to activate timely measures to enable a proactive water management for expected drought periods.
On the other side the scenario catalogue for drought conditions and the climate change scenarios provide information for long time strategic water management planning.
To create the scenario catalogue for drought and scarcity conditions time series of discharge from 1970 – 2010 were simulated for every reference spring. Statistical analyses of the simulated time series delivered the annuality of different low flow conditions. A "normal" state was defined as the medium available water resources of an organisation, a "dry" state was defined as the minimum available resources with an annuality of approximately 10 years, and a "very dry" state was defined as the minimum available resources with an annuality of around 40 years.
For organisations with sufficient data the monthly available resources of all springs, wells and deliveries from other organisations as well as all water demands were summarized and displayed in a report.
In order to assess the long time future development of spring discharge 16 different climate change scenarios with modifications in temperature and different precipitation forcing are analysed. As a reference scenario the simulated spring discharges at the sixty reference spring sites in the last 40 years are used.
The early warning system for drinking water supply is already working for water supplier with sufficient datasets. These are approximately 30 percent of all organisations. With appropriate data quality up to 80% of the Carinthian population could be achieved with the early warning system.

Mikhail Bolgov:
Low flow risk assessment for water management

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Risk assessments related to increasing aridity of climate are important in particular for sustained water systems operating and optimization of water resources management. For this purpose several approaches for regionalization and evaluation of parameters of long-term river flow fluctuations are considered and the method of simulation of synthetic time series of inflow to reservoirs is proposed. To validate the applicability of the Markov stochastic model to description of probability of cycling of dry and wet years, the characteristics of distribution of excursions which are below defined thresholds and the minima in the time series of fluvial discharge smoothed regarding N-years were calculated. This approach has been used for assessment of reliability of the complex water system in the Volga River basin under drought conditions and can be applied to evaluation of probability of long periods of low flows on the rivers in Siberia and in the Far East.

Raphael Meyer:
The implications of projected climate change on summer low flow in the Swiss Plateau based on a multi-variable calibration of the hydrological modelling system PREVAH

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Daring a view into the possible future of summer low flow behavior is desirable for water re-sources management purposes. Nowadays climate models in combination with hydrological models make such an impact analysis feasible. The adventure of a hydrological projection, however, bears a number of risks. Especially for low flow conditions generating reliable projections is challenging.

Nevertheless, within the interdisciplinary research project Climate Change and Hydrology in Switzerland CCHydro (Volken, 2010) such projections are claimed. Therefore, a novel multi-variable calibration specification for the hydrological modeling system PREVAH (Viviroli, 2009) was conceived (Meyer et al., submitted). Multi-variable calibration is a calibration of a model against more than one output variable. Therewith, multi-variable calibration offers the opportunity to enlarge the likeliness to correctly simulate low flow generation processes, which are more likely valid in a future far from the validation period.

In this contribution, the multi-variable calibration procedure is presented that makes use of the two runoff components (1) total flow and (2) base flow according to Wittenberg (1999) (Meyer et al. 2011). This novel specification of the hydrological modeling system PREVAH was successfully applied to 29 catchments in the Swiss Plateau. With the new model specification significantly better simulation of base flow were achieved without a decrease in total flow efficiency. 10 GCM-RCM climate model chains (Bosshard et al., 2011) were used to make projections of the possible low flow changes under future climates. The results of this assessment confirm quantitatively what was presumed by earlier qualitative studies. Gener-ally, runoff is expected to decrease during summer low flow periods in the Swiss Plateau. The expected changes are more pronounced for the far future (2070 to 2099) than for the near future (2021 to 2050). Mean annual minimum 7 day flow (MAM7) of summer months (May to October) of the control period was used as threshold level to define low flow events.

The implications for water resources management are obvious. Less water during a longer time period decreases its availability and increases the conflict potential between different stream flow water users. In Switzerland nowadays legal practice for residual water is based on the runoff which is reached at least at 95% of the days (Q347). In catchments where the runoff value Q347 is caused by summer low flows, i.e. in most catchments in the Swiss Plat-eau, less water can be used under future climate.

6 Closing Session

Karl Schwaiger: Climate impacts on low flows and droughts - first responses at European level (Keynote)

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This contribution provides an overview of actions taken, respectively ongoing at EU level. Actions taken by Austria are equally covered.

Starting point for action at EU level was 2003, which was seen as first alarming sign of a changing climate.

2003 was the year with unprecedented high temperatures and severe droughts nearly all over Europe with a wide range of negative impacts (such as an enhanced death toll among aged persons in France, a shutdown of thermal energy production in plants due to lack of cooling water and exceptional low flow in rivers, heavily impacted inland navigation, losses in agricultural production, unprecedented melting of glaciers…). This triggered action at EU level in particular in the field of climate change and water, but soon the issue of water scarcity and droughts moved in.

The major steps taken – based on a number of studies, conferences and research results - with regard to - climate change were the „White Paper on Adapting to Climate Change" COM (2009)147 final (highlighting the need to promote strategies which increase the resilience to climate change inter alia by improving the management of water resources and ecosystems), respectively a guidance adopted by the European Commission and EU Water Directors on „Adaptation to climate change in water management" to ensure that River Basin Management Plans are climate proof, - water scarcity and droughts was the Communication (COM (2007) 414 final) based on an in depth assessment of water scarcity and droughts. Seven policy options were identified i.a. „water pricing - putting the right price tag on water" and „improving drought risk management". So far 3 reports were published by the Commission on this basis; the main message of the last report COM (2011) 133 final was that water scarcity and droughts are a growing issue across the EU not limited to Mediterranean countries.

Actually the European Commission is working on a „Blue Print to Safeguard Europe's Waters" to be published end 2012. Main aim will be to ensure good quality water in sufficient quantities for all legitimate uses.

Basis for this Blue Print and its policy options are

1. The assessment of river basin management plans under the EU WFD;

2. A review of EU Action on „Water Scarcity and Droughts" with the additional help of studies covering

- A gap analysis,
- Water efficiency activities (in buildings, in distribution networks, …),
- Water use in agriculture (with focus on pricing and potential for savings),
- Instruments for better planning.

3. An assessment of the „vulnerability of water resources to climate change and other man made pressures",

4. A fitness check addressing the entire EU water policy.

Actions are envisaged in 7 specific areas, i.a. on

- Water-related green infrastructure measures (such as restoration of wetlands…) to reactivate ecosystem services benefical to lessen impacts,
- Internalisation of costs from water use and water pollution, as well as on

- Enhancement of water efficiency including water efficiency targets for river basins based on „water and ecosystem accounts (developed by EEA)“ and indicators such as the „Water Exploitation Index“.

Work in Austria‘s water sector has been focusing on looking into more detail into consequences of climate change, to design first adaption strategies to climate change , respectively to present the state of knowledge with regard to climate change and water scarcity and droughts within chapter 9 of the „National Water Management Plan“.

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7 Posters

Daniel Alexandru:
Recommendation and development of management options for an improved land use system of the agricultural crops in the Western part of the Romanian Mures Basin

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Objectives
- Modeling long-term observations and agro-climatic data in order to establish the risk factors and to spot the areas with high vulnerability and provide timely drought forecasts;
- Assessing impact of climate changes on soil water availability for wheat and maize crops cultivated in the most vulnerable area of Mures River basin to drought and water scarcity;
- Rainwater conservation in soil for optimizing the water availability according to the plant needs throughout the growing season and in the period with high deficit;

Activities and means involved
- Analysis of the agrometeorological potential and risk factors for the main crops in the forecasted climate conditions of Mures River Basin.
- Use of agrometeorological forecast products to improve monitoring, prediction and early warning capacity of the drought conditions.
- Use of simulation models for optimizing the best agricultural management practices and crop structure in the most vulnerable area to drought within Mures basin.
The main purpose of this paper is represented by agrometeorological bulletin which is done weekly, and containing diagnosis and prognosis, and users need expert advice in agriculture, according weather forecasting and meteorological developments in appropriate intervals according to the agricultural calendar.
Agrometeorological Bulletin are developed weekly and includes diagnosis and prognosis, containing information on climatic data in the period, the soil water supply for crops of winter wheat and corn, sown area of interest Pecica and state of vegetation (phenological data) field crops and fruit-growing in the area. They are also the main expert advice useful to farmers in the area according to the timetable agriculture.
Agrometeorological bulletins is disseminated to the main beneficiary, respectively Pecica Hall (Arad county).

Expected results
- Adaptation analyses and development options for improved land use systems in agricultural crop production under the water scarcity and drought conditions;
- Recommendations to improve effective use of water in the different production systems and specific measures to prevent land degradation and groundwater resources depletion;
- To raise awareness about the importance of effective drought preparedness and water management strategies in the affected drought area.
- Increase crop yields and its productivity by using efficiently the water either in irrigated or non-irrigated areas;
- Economic benefits by using appropriate agricultural management practices and crop structure in areas vulnerable to drought.
- The results of this study is the applicability, including the possibility of expansion to other areas affected by drought at regional level, and experts from the Drought Management Centre for Southeastern Europe will make recommendations for improving the methodology in comparison with neighboring countries which are affected by water scarcity and drought phenomenon.

Judit Bartholy:
Projections of drought index tendencies for Central/Eastern Europe in the 21st century

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Projected future changes (i.e., mean values, distributions, inter-annual variability and empirical probabilities) of several drought indices are analyzed for the period 2071-2100 (compared to 1961-1990, as a reference period). The comparison includes simple precipitation index, standardized precipitation anomaly index (SAI), De Martonne aridity index, Thornthwaite index, Lang's rainfall index, Ped's drought index, and Foley's anomaly index (FAI). The monthly time series have been calculated from different regional climate model simulations of the models PRECIS and RegCM adapted for Central/Eastern Europe at the Department of Meteorology, Eotvos Lorand University.
The model PRECIS is a hydrostatic regional climate model developed at the UK Met Office, Hadley Centre. The model uses 19 vertical levels with sigma coordinates for the atmosphere, and the horizontal grid is transposed to the Equator in order to avoid spurious results due to high latitudes. The horizontal resolution of PRECIS experiments is 25 km, which seems to be appropriate and fine enough to model the fine scale spatial patterns. The driving boundary conditions are provided by the outputs of global climate model HadCM3 taking into account the SRES A2, B2 and A1B emission scenarios.
The model RegCM is a 3-dimensional, sigma-coordinate, primitive equation model, and it was originally developed by Giorgi et al. Currently, it is available from the ICTP (International Centre for Theoretical Physics). The horizontal resolution of RegCM experiments is 10 km, and 18 atmospheric vertical levels have been used. The driving boundary conditions are provided by the outputs of global climate model ECHAM5 taking into account the SRES A1B emission scenarios.
According to the results the main finding emphasizes that significant drying is projected in the region, especially, in summer.

Miriam Fendekova:
Groundwater drought in the Nitra River basin - identification and classification

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Drought as a natural phenomenon becomes more often the subject of the research. It is also because of increasing frequency of extreme climatic events in mild climate conditions. Groundwater drought indices could be derived for different groundwater parameters, e.g. base flow, groundwater head stage, spring yield, or groundwater recharge values. Base flow drought assessment methods were proposed and applied in the Nitra River Basin. Threshold level method was used for groundwater drought analysis. Base flow values were separated from the discharge hydrograms using the HydroOffice 2010 statistical program package. The standardized base flow drought index was proposed, calculated as the value of the base flow drought deficit volume divided by the average long-term base flow value. Method was applied on identification of spatio-temporal propagation of groundwater drought in the study area.

Felix Fundel:
Monthly Forecasts of Hydrological Droughts

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Droughts can be defined by a variety of parameters and can occur on a wide temporal range. The large variety of drought definitions is a direct consequence of the numerous socioeconomic impacts for different interest groups. In the framework of this study, the quality of monthly forecast of hydrological droughts, characterized by low streamflow (low-flow) is assessed. Low-flow forecasts on a monthly time scale are potentially useful for hydropower generation, agriculture (irrigation), conventional power production (supply of heat exchange water), water quality, navigation or the recreational sector. Skillful forecasts of low-flows can therefore help to prevent or mitigate the consequences of water shortage for those applications.
Streamflow forecasts from coupled meteorological hydrological models have shown to provide useful information for the short- to medium-range when considering rapid events like peak runoff. Additional value can be expected when using ensemble prediction systems (EPS) or multi-model ensembles but, generally, so far no skillful forecast beyond two weeks seems possible. Yet, for low-flow predictions those forecast systems might be valuable, mainly out of interest in events of longer duration or cumulative parameters as e.g. the expected water deficit.
We consider monthly ensemble runoff forecast of low-flow duration, severity and magnitude in order to assess their potential in giving guidance for potential users. The study is performed for the river Thur, having its source in the Swiss Alps. The ECMWF VarEPS 5-member reforecast data over a period of 18 years is used as forcing for the hydrological model PREVAH. A thoroughly performed verification of monthly forecast of daily runoff shows, forecasts for hydrological low-flow indices are skillful and users could benefit by including them in a decision making process.

Borbala Galos:
Impacts of the increasing drought frequency on the lower limit of forest distribution in Central Europe

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In the Carpathian Basin, frequency of summer droughts increased in the last 50 years. Droughts have been shown to be the limiting factor of the health condition and presence of climate-dependent (zonal) tree species in this region at the lower limit of forest distribution (xeric forest limits). Recurrent droughts at the end of the 20th century and in the first years of the 21st resulted in loss of vitality and triggered the appearance of pests and pathogens in beech and oak stands at the forest/steppe limit.
According to regional climate projections, this tendency will continue, especially in the second half of the 21st century. Probability of summer droughts may increase, consecutive severe dry periods will last longer at the end of the century (for the decade 2090-2100, 8 extreme dry summers are projected). Results of regional impact studies show that these changes may cause growth decline and may lead to mass mortality events first of all in beech and spruce forests, both being especially sensitive to drought.
The stability loss of closed forest cover leads also to the decline of the ecological services of forests (biodiversity and soil protection, water supply regulation etc). Drought stress diminishes carbon fixation, increases soil respiration and may lead to a positive feedback in global warming at the forest/steppe limit in East-Central- and Southeast-European countries and in Southern Siberia. On the other hand, based on the results of REMO (regional climate model at the Max Planck Institute for Meteorology, Hamburg), the role of forest area increase through afforestation in mitigating climate change in the Carpathian Basin, is relatively small.
Our results emphasise the need of regional-scale information on probability, severity and duration of future droughts. International collaboration is essential in monitoring and research, to formulate long-term adaptation strategies to droughts in forest and water management and nature conservation.

Keywords:
regional climate modelling, drought frequency, xeric forest limit, climate sensitivity of forests

Georg HEINRICH:
The future of dry and wet spells in Europe: A comprehensive study based on the ENSEMBLES regional climate models

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Drought is a natural recurrent phenomenon which occurs in a variety of different temporal and spatial scales and significantly affects natural and socio-economic systems. Under the aspect of the human induced climate change it is of high interest to decision makers how drought conditions might change at regional scale in order to map out adequate mitigation and adaption strategies. For our study recent RCM simulations provided by the ENSEMBLES project are used to analyse projected changes in dry and wet conditions in Europe by the mid of the 21st century under the A1B emission scenario. Based on seasonal temperature and precipitation climate change signals, eight scenarios out of the entire ensemble are selected in order to capture the uncertainties of the projected changes. An empirical-statistical bias correction approach based on the E-OBS observational dataset is applied to modelled daily mean air temperature and precipitation amount to account for RCM errors, and commonly used drought indices—the Standardized Precipitation Index (SPI), the self calibrated Palmer Z-Index (scZI) and Palmer Drought Severity Index (scPDSI)—are calculated. Changes in the mean, in interannual variability, and in frequency, length, distance, magnitude, and area of dry and wet events are investigated. The statistical significance of the projected multi-model mean changes and the according uncertainties are analysed for nine European subregions. Furthermore, distributional changes of the dry and wet spell characteristics are assessed. The results show that changes in the mean, and in dry and wet event characteristics are most pronounced towards drier and wetter conditions in the southern- and northernmost European subregions, respectively. Here, the changes are highly significant and confident, while the projected changes are more dissonant for the other subregions. Severe changes in the extremes of event length, distance, magnitude, and area particularly arise in the southern- and northernmost European subregions. The projected changes in interannual variability are less significant and confident. However, significantly increasing interannual variability is projected in regions with pronounced changes in the mean towards.

Argentina Teodora Nertan:
Vegetation state assessment based on satellite derived products for drought monitoring in the Mures Basin

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Drought refers to a temporary decrease in water availability, for example, when it doesn't rain over a long period of time. On the other hand, water scarcity occurs when the demand for water exceeds the available sustainable resources. Most European countries are affected by the consequences of water scarcity, droughts and land degradation caused by water resources over-exploitation and exacerbated by climate change. An important objective of EU water policy is to ensure access to good quality water in sufficient quantity for all, and to ensure the good status of all water bodies across Europe. So, policies and actions are set up in order to prevent and to mitigate water scarcity and drought situations, with the priority to move towards a water-efficient and water-saving economy. As a consequence, a pilot project on development of prevention activities to halt desertification in Europe has been included in the EU budget. The pilot initiatives are demonstration projects aimed at testing specially designed technologies, techniques or practices.
In this framework the main objective of the MIDMURES (Mitigation drought in vulnerable area of the Mures Basin) project is to test specially designed technologies, techniques or practices in order to decrease the drought effect in the Mures River Basin. The priority issues are: conservation of rainwater and surface water; alternative forms of irrigation; water saving/water efficiency measures; crops consuming less water. The study area is focused on agricultural region situated in the western part of Romania, in the Romanian downstream of Mures River.
Collecting agrometeorological data is critical for running different crop weather-yield models in order to assess the actual crop vegetation state and make decisions on crop treatment and forecast their yields. In this regard, the satellite systems present a wide range of new capabilities that can be used to assess and monitor the actual conditions of agro-ecosystems since information can be obtained on remote, wide area, non-destructive and/or real-time bases. Remote sensing data with low spatial resolution and high temporal resolution provide a useful tool for the monitoring of the vegetation activity from global to regional and local scale. The agricultural vegetation condition monitoring is currently possible, ranging from medium spatial resolution satellite derived - products, with daily revisit (NOAA-AVHRR, SPOT-VEGETATION, etc.) to high and very-high spatial resolution, offered by environmental satellites (LANDSAT, SPOT, FORMOSAT, IKONOS, QuickScat etc.) with longer revisit period. The most important parameters are: vegetation indices (VI), maximum greenness during the growing season, total greenness during the growing season, fraction of photosynthetically active radiation (fAPAR) and leaf area index (LAI).
Crop vegetation indexes and biophysical parameters status at any particular stage in the growth cycle can be a consequence of several crop and soil variables, such as soil condition, nutrient imbalances, and disease. There spatial heterogeneity can be used as an indicator of the crop condition resulting from vegetation response to soil properties and specifically nutrients availability for given weather conditions.
The study is focused on vegetation state assessment based on satellite derived products for drought monitoring (drought duration and intensity). This paper is based on the analysis of several vegetation indexes (NDVI, NDWI, etc) and biophysical parameters (LAI, fAPAR, land surface temperature, etc).

Rita Pongracz:
Analysis of projected changes in climate index CDD for Hungary using ENSEMBLES simulations

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Global climate models (GCMs) provide a useful tool to describe and simulate large scale features of the changing climate. However, their spatial resolution is inappropriate to describe regional climate processes, especially, in case of precipitation, which is highly variable both in time and space. Therefore, GCM outputs may be misleading to compose regional climate change scenarios for the 21st century. In order to provide better estimations for regional climate parameters, fine resolution regional climate models (RCM) can be used. RCMs are limited area models nested in GCMs, i.e., the initial and the boundary conditions of RCMs are provided by the GCM outputs. In order to estimate the regional climate change projected for Hungary, outputs from several RCMs (from the completed EU-project ENSEMBLES) with 25 km horizontal resolution are summarized and analyzed for 1951-2100 using the SRES A1B emission scenario, according to which CO2 concentration by 2100 is estimated to exceed 700 ppm (more than twice of the preindustrial level).
In order to estimate the bias of the different RCM simulations, outputs from 1951-2000 are compared to the E-OBS datasets containing gridded daily precipitation values. The validation results suggest that the simulated values usually significantly overestimate the observations, except in summer when mostly underestimations are found. These biases of the raw RCM outputs are corrected using the monthly empirical distribution functions.
Annual and seasonal climate index values of consecutive dry days (CDD) are defined as the longest period in a year or a given season with daily precipitation less than 1 mm. Analysis of CDD trends provide useful information for agriculture on the critical dry periods. For the selected target region, composite maps of projected seasonal change in CDD are generated using the RCM simulations for the periods of 1961-1990 (as the reference period), 2021-2050, and 2071-2100. Furthermore, trend coefficients are compared for all the seasons for the entire 21st century. According to the results, the following main conclusions can be drawn.
(1) The largest change by 2021-2050 is projected for spring and summer: 5 and 3 simulations (respectively) of the evaluated 11 RCM runs project significant increase of CDD in Hungary, the projected change is 15-35% relative to 1961-1990.
(2) The largest change by 2071-2100 is projected for summer: 9 simulations out of 11 RCM runs project significant increase of CDD in Hungary, the projected change is 25-75 % relative to 1961-1990. The projected increase is larger in the southern part of the country than the northern regions.

Stanislava Radeva:
Drought Management Centre for Southeastern Europe

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During the last decades an increase of the number of extreme natural events has been observed all over the world. Drought should be considered as an extreme event. It is related to a decrease of precipitation frequency both in regions marked as ones with profusion of rains and areas where the scarce of precipitation is assumed as normal conditions. Historical soil, meteorological, agrometeorlogical, and hydrological data provide us with information for a large number of dry periods observed over South-eastern Europe during the 20th century. Drought is a natural part of the climatic cycle of the Balkan Peninsula. But the processes getting deeper in any new coming dry periods should be considered as warning signals.

The Drought Management Centre for Southeastern Europe (DMCSEE) joins the efforts of scientists for regional drought monitoring, assessment and risk management. DMCSEE coordinate development and application of drought risk management tools and policies with the goal of improving preparedness and reducing drought impact. Using common methodology in drought analysis and impact assessment the project obtains regionally comparable results enabling better overview of drought situation for sectors economically dependant on water availability, such as agriculture, energy and tourism. Quality assessments of drought occurrence risk and possible drought impacts provided by DMCSEE and disseminated to decisions makers and general public allows effective and timely decisions to reduce drought related damages.

Eric Sauquet:
Climate and hydrological uncertainties in future low-flows in France

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Future projections of low flows are associated with different types of uncertainties, due to an imperfect knowledge of both future climate and rainfall-runoff processes. Due to computational constraints, impact and adaptation studies unfortunately cannot always afford to perform a detailed analysis of all these uncertainties. In that case, the modelling efforts have to focus on the most relevant source of uncertainty in order to provide the best estimate of the overall uncertainty.

The present study thus aims at assessing the hierarchy of uncertainties in changes on low flows at the scale of France, within the national Explore2070 project. Amongst all possible sources of uncertainties, two are here considered: (1) the uncertainty in General Circulation Model (GCM) configuration, with 7 different models that adequately sample the range of changes as projected by the GCMs used in the IPCC AR4 over France, and (2) the uncertainty in hydrological model structure, with 2 quite different models: GR4J, a lumped conceptual model calibrated on each target catchment, and Isba-Modcou, a suite of a land surface scheme and a distributed hydrogeological model not fully calibrated at the catchment scale.

The hydrological models have been run at more than 1500 locations in France over the 1961-1990 baseline period with forcings from both the Safran near-surface atmospheric reanalysis and the GCM control runs statistically downscaled with a weather type method, and over the 2046-2065 period with forcings from all downscaled GCM runs under the A1B emissions scenario. Various low-flow indices have been computed for both periods: the annual minimum monthly flow with a 5-year return period (QMNA5, commonly used as a policy threshold in France), the annual minimum 10-day mean flow with a 2-year return period (VCN10-2), the daily flow value exceeded 95% of the time (Q95), as well as a seasonality index.

All low-flow indices show a dramatic increase in drought severity for the mid 21st century, with large uncertainties due to both future climate and associated hydrological response. An analysis of variance has been performed for each low-flow index and at all stations shared by the two hydrological models (around 550) in order to assess the two considered sources of uncertainty and their hierarchy. Results first show spatial differences over France in the amount of overall uncertainty due to both sub-regional climate change patterns and catchment properties. The analysis of hierarchy between climate and hydrological uncertainties shows a large spread over France for any single low-flow index, with the uncertainty in hydrological response appearing as important as the uncertainty in future climate. The large uncertainty in hydrological modelling partly comes from the difference in the way the two models simulate low flows and the way they are calibrated, which results in significant differences in their efficiency in low-flow simulation in the baseline period.

The results of this study will help to define the relevant hydrological scenarios to be used in the adaptation part of the Explore2070 project for deriving national-scale adaptation strategies.

Andreas Schaumberger:
Modelling and Analysing Spatio-Temporal Patterns of Drought in GIS

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Sufficient water supply is one of the key factors for stable crop yield and successful cultivation. It primarily depends on precipitation, evapotranspiration rates and the ability of soil to buffer and store water. Drought constitutes continuing soil water depletion process and causes deepening water stress of plants with negative consequences for yield formation which increase with duration and severity. Persisting water deficit even causes complete crop failures with irreparable damages within the season. To identify spatio-temporal patterns of drought for the entire area of Austria a soil water balance model according to FAO was implemented in high resolution and integrated in an operational Geographic Information System (GIS).

Materials and Methods

The spatial implementation for large areas needs several simplifications in model complexity. The proposed soil water balance model takes into account the most important factors: reference evapotranspiration, precipitation and available water holding capacity.

The interpolation of reference evapotranspiration follows the concept “calculate then interpolate”. Firstly, it is calculated day by day at all weather station sites according to FAO-Penman-Monteith. Secondly, the results are interpolated by the state-of-the-art method “Residual Kriging”. The complex terrain with different impact of slope and aspect on evapotranspiration is considered by a correction factor which is derived from a radiation model. Daily precipitation is poorly influenced by external factors like elevation. Therefore the interpolation procedure is reduced to a simple geostatistical approach by using Ordinary Kriging based on about 1300 stations with mean nearest neighbour distance of 5 km. Daily surfaces of reference evapotranspiration and precipitation as well as information about available field capacity, derived from the Austrian Soil Map, are combined according to FAO soil water balance model. The actual evapotranspiration as the result of this process is adjusted to grassland by the appropriate FAO crop coefficients. The relation between actual and reference evapotranspiration provides information about the intensity of water stress. Short term water availability refers to an accumulation of this relation over the past six days, long term water availability from start of growing season to the given day. Both values are combined to a water availability factor which reflects the impact of drought on crop for each raster cell of the entire area of Austria day by day.

Results

The implemented soil water balance model is based on interpolated continuous surfaces of all input parameters in a resolution of 250 meters. The interpolation of reference evapotranspiration is the most important basis of the spatial model. Evaluation by a leave-one-out cross validation on selected surfaces shows a coefficient of determination of 0.91 and a RMSE of 0.4 mm. The system is prepared to calculate long time series, an important requirement for climatological applications. Historical data can easily be substituted with data from climate scenarios. The developed GIS is prepared to analyse climate impact on spatio-temporal patterns of drought in a very high spatial and temporal resolution. Detailed information about potential changes is a substantial precondition for development of climate adaption strategies.

Gerhard Soja:
Climate impacts on water level of Lake Neusiedl and Flow of River Wulka

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Lake Neusiedl is a dynamic lake that has changed its area between 0 and 500 km² several times in the course of the previous centuries. The water balance of Lake Neusiedl is mainly determined by precipitation (80%) and evapotranspiration. Evidence for a reduction of long term precipitation sums was clearer with a 14-years filter of annual means than without. This downward trend was more pronounced in winter, spring, and summer than in autumn. Changes in precipitation predicted by the regression derived from past precipitation changes were smaller than those predicted by a regional climate scenario that estimated changes of +11, -16, 0 and -2% for spring, summer, autumn and winter, respectively, for the period 2011-40. Lake water level is significantly influenced by precipitation of the actual year, the last, and the second last year.

The major surface water input to Lake Neusiedl is coming from river Wulka. The flow rate of Wulka is primarily depending on precipitation, temperature is of minor importance. For precipitation not only the studied year but also the year before significantly influences the water amount of Wulka. In contrast to precipitation which is highest in summer and lowest in winter, minimum flow rates of Wulka are characteristic for summer and autumn, maximum discharge can be observed during spring. The tributaries of Wulka are endangered of falling dry in summer, but flow rate is now also buffered by the inflow of three sewage treatment plants which have contributed nearly 40% of the water flow of Wulka over the past years. A negative trend for the amount of water over the years was observable after filtering the annual or seasonal means of flow rate of Wulka. Using the regression between precipitation and flow rate and the seasonal precipitation scenarios of the regional climate change model, flow rate of Wulka for the three decades 2011-40 was calculated to increase by 8% in spring and to decrease in all other seasons (-10, -5, and -2% for summer, autumn, and winter, resp.).

The water losses of the lake are mainly (>90%) due to evapotranspiration. Future climate conditions will favor meteorological conditions that enhance the evaporative losses. Even for the short period of 1994-2009 it was observed that the annual evapotranspiration of the lake is significantly increasing by 77±30 mm per decade. In the face of precipitation rates and natural inflows that are not similarly increasing, the risk of a negative water balance in several consecutive years, leading to water levels of <115 m a.s.l., becomes more realistic. Lower relative air humidity and higher water temperatures were identified as main drivers for the increasing evaporative water losses of Lake Neusiedl.

Significant correlations of precipitation sums and temperature means of Lake Neusiedl region with the large scale weather signals North Atlantic Oscillation, NAO, and the index of the Mediterranean Oscillation, MOI (for Gibraltar and Israel), were found. Relationship to large scale oscillation patterns was closer with temperature regime than with precipitation patterns. Water flow of Wulka was also significantly influenced.

Beverley Todd:
Reconstructing a 300 Year Drought Record for Southern Britain

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Drought is one of the major and most costly natural hazards experienced in Britain and across much of Europe. The analysis of drought events from a long-term perspective has rarely been undertaken in Britain, with no study extending back prior to 1800. Previous studies examining British droughts tend to focus either on single events or a cluster of drought years, drawing upon relatively short data series. Furthermore, these are often analysed from a water resources perspective, which fails to address the generating mechanisms. Our ability to identify trends in the frequency and severity of these extreme events is therefore limited. In order to identify patterns and examine the conditions giving rise to drought events, a long period of record and number of events is needed for analysis. Without reliable data on these events predictive models cannot be validated, possible causal relationships with climate change cannot be assessed and conventional drought risk estimates are likely to be unreliable.
This paper presents a methodology for constructing long, continuous time-series of past meteorological drought events for southern Britain. The study applies the widely used Palmer Drought Severity Index (PDSI, Palmer, 1965) to quantify and assess the severity of historic droughts. Applying this index enables other important drought characteristics, such as; onset, termination, duration and frequency, to be readily determined. Instrumental and historical meteorological data sources from three sites located across southern Britain are drawn upon to produce three reconstructed PDSI time series from 1697 to 2010.
Results show that drought is a recurring feature of Britain's climate; with severe events having a tendency to cluster together in time. The most extreme droughts on record are multi-year events punctuated with shorter, more intense periods. Analysis of input data demonstrates that precipitation has been the principal meteorological driver of drought events on record; however, recent rising global temperatures are likely to have played an intensifying role in the 20th century. The methodology presented has successfully identified historic British drought events since the late 17th century and improved understanding of both important drought characteristics and the principal climate generating mechanisms of droughts. The results of this research when coupled with information detailing drought impacts permits more robust drought mitigation measures to be achieved through improved (multi-) seasonal forecasting for example.

Koen Verbist:
Development of an operational drought risk management system for the Chilean Drylands

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Climate variability is characteristic for arid zones in Latin America, influencing dryland management and causing climate uncertainty and vulnerability for water users, especially those sectors that depend on annual rainfall (e.g., rainfed agriculture, multipurpose reservoir operations). Therefore, a case study was initiated in Central Chile to develop the building blocks of a climate risk management system, focusing primarily on climatic, hydrological and agricultural drought. Up till now, operational tools were developed that predict climatic conditions one season ahead, based on a successful statistical downscaling of a GCM (Climate Forecast System) onto 48 rainfall stations in the region. This was then further expanded through a non-Homogeneous Markov Model (nHMM) to allow generating probabilistic forecasts of daily rainfall characteristics, that are most relevant for agricultural drought prediction (f.e. using the Water Requirement Satisfaction Index). A similar approach was used to produce seasonal forecasts of discharge, which was coupled to the operational procedure of a multipurpose reservoir in the region and produced a set of probabilistic scenarios which were evaluated by the water users in order to take a decision on water allocation. An additional drought assessment product was developed, named Drought Atlas (http://www.cazalac.org/atlas_sequias_gm.html), that looks at drought recurrence intervals based on robust regionalization statistics using L-moments. This sheds light on drought in a spatially distributed way, identifying zones of higher drought risk potential. Finally, ongoing applied research focuses on the identification of drought risk in a near term climate change setting, creating stochastic decadal climate simulations to assess its probable impact on climatic, hydrological and agricultural drought in the region. As such, a climate risk management system is emerging, that could potentially be replicated in other dryland areas of Latin America.

Sergio M. Vicente-Serrano:
Performance of drought indices for ecological, agricultural and hydrological applications

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In this study we provide a global assessment of the performance of different drought indices for monitoring drought impacts to streamflows, soil moisture, forest growth and crop yields. For this purpose, we compare the Standardized Precipitation Index (SPI), four versions of the Palmer Drought Severity Index (PDSI) and the Standardized Precipitation Evapotranspiration Index (SPEI). Four different variables with hydrological, agricultural and ecological implications were used determine the performance of the different drought indices globally. We have found a higher capability of the drought indices that are calculated on different time-scales (the SPEI and the SPI) to correlate with the temporal variability of the different variables. The Palmer indices performed systematically worse to reproduce hydrological, agricultural and ecological droughts. We have found small differences in the performance of the SPI and the SPEI, but the SPEI has been the drought index that records the higher percentage of the cases in all the variables when the maximum correlations are obtained and in summer, the season in which more drought-related impacts are recorded and in which drought monitoring is more critical, the SPEI shows improved capability to identify drought impacts regarding the SPI. Given the results obtained, it seems reasonable to recommend the use of the SPEI if a priori we do not know the possible response to drought of the variable of interest.