STOCHASTIC WEATHER GENERATORS

FOR HYDROLOGICAL APPLICATIONS

jointly organized by

Sciences de l'environnement Institut Pierre Simon Laplace

Freie Universität Berlin

18th-20th of September 2017
Berlin, Germany

Contents

1 Programme

1.1 Monday, September 18th

1:00pm

Registration and Coffee

2:00pm

Welcome

2:10pm

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abstract slides
2:10pm - 40min
Downscaling climate models for hydrology: Pitfalls and needs?
Prof. Florence Habets | CNRS, Université Pierre & Marie Curie | France

abstract slides
2:50pm - 40min
Weather generators - what properties of weather should be reproduced and what not?
Prof. Andras Bardossy | Stuttgart University | Germany

abstract slides
3:30pm - 30min
Comparing five weather generators in terms of entropy
Dirk Schlabing | Stuttgart University | Germany

4:00pm

Coffee break

4:30pm

Explorative and seasonal approaches

abstract slides
4:30pm - 30min
Explorative analysis of long time series of very high resolution spatial rainfall
Emma Dybro Thomassen | Technical University of Denmark | Denmark

abstract
5:00pm - 30min
A seasonal hidden Markov model for simulation of daily rainfall time series
Augustin Touron | EDF/R&D | France

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Ice-Breaker with snacks

1.2 Tuesday, September 19th

9:00am

Single-site models

abstract | slides
9:00am - 40min
Single-site rainfall generators: A look at some developments
Christian Onof, PhD | Imperial College London | United Kingdom

abstract | slides
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Extending clustered point process-based rainfall models to a non-stationary climate
Jo Kaczmarska, PhD | Risk Management Solutions | United Kingdom

abstract
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A multi-ensemble approach for precipitation projections: a case study based on 5 rainfall generators and 160 climate model runs
Els van Uytven | KU Leuven - University of Leuven | Belgium

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Resampling approaches

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Ensemble analogue downscaling of the twentieth century reanalysis over France for 140-year-long hydrological reconstructions
PhD Jean-Philippe Vidal | Irstea | France

abstract | slides
12:10am - 30min
A resampling based multivariate space-time simulator
Sara Martino, PhD | sintef energy research | Norway

abstract | slides
12:40am - 30min
SFRWG weather generator for hydrological applications: case studies for snow cover modelling and operational hydrological forecasting
Vsevolod Moreydo, PhD | Water Problems Institute of RAS | Russian Federation

1:10pm

Lunch

2:30pm

Multivariate models

abstract | slides

2:30pm - 30min
Multivariate statistical modeling of compound events via pair-copula constructions: analysis of floods in Ravenna (Italy)
Emanuele Bevacqua | Karl-Franzens University Graz | Austria

abstract

3:00pm - 30min
A multivariate statistical model describing the compound nature of soil moisture droughts
Collin Manning | University of Birmingham | United Kingdom

abstract | slides

3:30pm - 40min
Stochastic simulation of Sahelian storms. Recent developments and hydrological applications.
Theo Vischel, PhD | Institut des Géosciences de l'Environnement | France

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Poster Session

abstract | poster

The R-package CDVineCopulaConditional for modelling Compound Events
Emanuele Bevacqua | Karl-Franzens Universität Graz

abstract | poster

Daily spatio-temporal stochastic precipitation generator based on a censored and transformed latent Gaussian field
Komlan Agbéko Kpogo-Nuwoklo | Freie Universität Berlin

abstract | poster

Incorporating Dependencies between Rainfall Statistics and Rainfall Interannual Variability into Hourly Stochastic Rainfall Generator for Improved Extreme Value Reproduction
Jeongha Park | Hongik University Seou

abstract | poster

Partitioning spatial and temporal rainfall variability in urban drainage modelling
Nadav Peleg

abstract | poster

Assessing hydrological regime sensitivity to climate change in a convective rainfall environment: a case study of medium-sized eastern Mediterranean catchments
Nadav Peleg

abstract | poster

Precipitation extremes on multiple time scales - Original Bartlett-Lewis model and IDF curves
Christoph Ritschel | Freie Universität Berlin

abstract | poster

Intercomparison of statistical downscaling: from climate to hydrological point of view
Pradeebane Vaittinada Ayar | IGE

7:30pm

conference dinner at Tomasa - Bäkestr. 15, 12207 Berlin, see map

1.3 Wednesday, September 20th

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Space-time models for precipitation I

abstract slides
9:00am - 30min
Modeling Precipitation in Space and Time
Anastassia Baxevani, PhD | University of Cyprus | Cyprus

abstract slides
9:30am - 30min
Daily spatio-temporal stochastic precipitation generator based on a censored and transformed latent Gaussian field
Komlan Kpogo-Nuwoklo, PhD | Free University of Berlin | Germany

abstract slides
10:00am - 30min
A non-stationary spatial weather generator for statistical modelling of daily precipitation
Pradeebane Vaittinada Ayar, PhD | IGE | France

10:30am

Coffee break

11:00am

Space-time models for precipitation II

abstract slides
11:00am - 40min
Sub-kilometer-scale space-time stochastic rainfall simulation
Lionel Benoit | University of Lausanne | Switzerland

abstract slides
11:40am - 30min
AWE-GEN-2d: An advanced stochastic weather generator for simulating 2-D high-resolution climate variables
Nadav Peleg | Switzerland

12:10am
Discussion, closing remarks (max. until 1:00pm)

1:00pm

Lunch and farewell

2 Participants

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3 Abstracts

3.1 Motivation, aims and comparisons

Downscaling climate models for hydrology: Pitfalls and needs?

Prof. Florence Habets[1], Pascal Viennot[2]
(1) CNRS, Universite Pierre & Marie Curie, (2) Mines Paris Tech PSL

back slides

There are many uncertainties with weather forecasts or climate projections, with one exception: precipitations are biased. For this reason, hydrologists are accustomed to using certain types of methods to regionalize and reduce biases in weather and climate models. However, as climate change is becoming more sensitive, it is now asked to hydrologists to address more complex questions such as the estimation of the long term evolution of the groundwater diffuse contamination or the estimation of the potential of some natural or artificial structures that could be adaptation solutions. To do so, it is required to have complex modeling systems, that integrate several processes that are sensitive to most atmospheric variables (radiation, wind speed, humidity, temperature, precipitation), and need consistent temporal and spatial variations. Therefore, it is required to have downscaling or bias correcting methods that are able to manage several variables consistently. Most of these methods are not able to fully bias correct the atmospheric forcing, which leads to some bias that are not easy to interpret, especially when projected in the future climate change. Indeed, it is becoming difficult to disentangle the part of the projected results which is assumed being caused by the remaining part of the bias, by the climate model, greenhouse gas scenario, or even caused by the natural variability. This makes it complicated to interpret the results, unless being able to run a large number of simulations, which is becoming resource-demanding since the models are increasingly complex. Therefore, to address such topics, more powerful methods should be used. Among them, the stochastics weather generators will certainly have an important place. The talk will take examples from regional hydrological studies in France.

Weather generators - what properties of weather should be reproduced and what not?

Prof. Andras Bardossy - University of Stuttgart

back slides

Weather generators (WG) are frequently used for different purposes such as the quantification of uncertainties of complex non-linear systems, estimation of climate change effects, extending time series for partly observed or unobserved sites etc. They are supposed to reproduce natural (or expected) variability of climate variables on different temporal scales. One of the serious difficulties in developing a WG is the selection of statistics, which the simulation should reproduce. These properties can include distributional properties on different time scales, temporal dependence characteristics for one or more variables. The dependence between different variables (for example precipitation and temperature) is often complicated and requires specific statistical tools. An additional challenge is the extension of WGs to spatial or multi site models. The application of WGs shows that the importance of these properties may vary strongly depending on application and the system under investigation. In this contribution, some examples of the scale dependent relations between variables are discussed. The importance of extremes and their specific properties are demonstrated for precipitation simulation. Copulas are introduced for a flexible modelling of dependencies. The possibility to generate series via step-wise disaggregation is also presented. The importance of properties is discussed using examples of urban hydrology and lake ecology.

Comparing five weather generators in terms of entropy

Dirk Schlabing, Prof. Andras Bardossy - University of Stuttgart

back slides

There are fundamental differences in the concepts underlying parametric and non-parametric weather generators. Despite these differences, common performance criteria are in general met, yet differing ways in which dependencies are modelled result in different entropy. Entropy has been used in hydrological applications since the early 1960s and continues to be a relevant concept. As entropy calculations can be used to quantify the uncertainty of - possibly multivariate - probability distributions, it lends itself naturally to evaluate the output of weather generators. We chose 5 measurement stations with daily precipitation amounts and mean temperature from diverse climates in Europe. These time series exhibit trends which we exploit to test weather generators for their ability to project bivariate distributions from a calibration to a validation period. The weather generators studied are SDSM, LARS-WG, a KNN resampler, a trans-Gaussian vector-autoregressive weather generator and a model based on copulas.

3.2 Explorative and seasonal approaches

Explorative analysis of long time series of very high resolution spatial rainfall

Emma Dybro Thomassen[1], Hjalte Jomo Danielsen Sorup[1], Marc Scheibel[2], Thomas Einfalt[3], Karsten Arnbjerg-Nielsen[1]
(1) Technical University of Denmark, (2) Wupperverband, (3) hydro & meteo GmbH&Co.KG

back slides

We examine rainfall characteristics of convective and front extreme events in high spatio-temporal resolution (5 minutes, 1x1 km) over an area of 1824 km^2 covering the catchment of the Wupperverband, North Rhine-Westphalia. The main focus of the analysis is a description of the complexity of hourly and daily extreme rainfall with the purpose of identifying suitable characteristics that can be used in a spatial weather generator of similar resolution. The spatial and temporal properties of the extreme events are explored by means of principal component analysis, cluster analysis, and linear models. For each method a set of 17 variables are used to describe the properties of each event, e.g. duration, maximum volumes, spatial coverage and heterogeneity, and movement of cells. A total of 5-9 dimensions can be found in the data, which can be interpreted as a rough indication of how many independent variables a weather generator should employ. Both principal component analysis and cluster analysis show patterns that are in accordance with our understanding of physical properties of rainfall. In particular it seems that the differences between hourly and daily extremes can be described by relatively simple scaling across the set of variables, i.e. the level of each variable varies significantly, but not the overall structure of the spatial precipitation. The analysis show that there is a good potential for making a spatial weather generator for high spatio-temporal precipitation for precipitation extremes. Before the method can be employed further work is necessary to describe non-linear correlation between the variables and also the tracking algorithm employed needs to be improved.

A seasonal hidden Markov model for simulation of daily rainfall time series

Augustin Touron - EDF/R&D

back

In order to reach the supply/demand balance, EDF needs to control the consumption and production of electricity at different time scales. This implies the need of modeling weather variables such as temperature, wind speed, solar radiation and precipitation. This work is dedicated to a daily rainfall generator at a local scale. It is based on a hidden Markov model integrating seaonalities in both occurrence and intensity of precipitations, with gamma distributions as emission laws. The model is able to produce arbitrarily long daily rainfall simulations that reproduce closely different features of observed time series at a single site, including seasonality, rainfall occurrence, daily distributions of rainfall, dry and rainy spells. The model was fit and validated on data from several weather stations across Germany.

3.3 Single-site models

Single-site rainfall generators: A look at some developments

Chris Onof[1], David Cross[1], Dongkyun Kim[2], Lipen Wang[1]
(1) Imperial College London, (2) Hongik University, Seoul

back slides

This year marks the 30th anniversary of a milestone in the history of rainfall modelling, namely the publication of Ignacio Rodriguez-Iturbe, David Cox and Valerie Isham's paper with the unassuming title of 'Some models of rainfall based on stochastic point processes'. In the present paper, we situate that approach to the modelling of rainfall time-series among possible alternatives and identify some of the problems that these types of models have encountered. The paper then reviews important developments in particular in trying to make the generated rainfall more realistic, since we last reviewed this modelling approach in 2000 and 2005. The final section of the paper looks in more detail at very recent or ongoing developments insofar as they directly address some of the problems flagged earlier. These are a censoring approach, the use of nearest climatological neighbours to fit the model, the combination of such a model for hourly rainfall with a coarser-scale model either for the rainfall statistics or directly the rainfall depths (e.g. a GLM), as well as the possibility of combining such a model with a weather type model.

Extending clustered point process-based rainfall models to a non-stationary climate

Jo Kaczmarska, Valerie Isham, Paul Northrop - Risk Management Solutions

back slides

Generating realistic artificial rainfall series for a changing climate, at a sub-daily time scale, poses a particularly difficult challenge. Such data may be required at point locations for hydrological applications, such as urban drainage design. One of the most important categories of stochastic weather generator for sub-daily rainfall series consists of the clustered point process-based rainfall models. These are fitted to rain-gauge data using the Generalised Method of Moments (GMM). However, in their basic form, the only non-stationary feature that the models can incorporate is seasonality, which is achieved by fitting separate models for each calendar month or season. To date, the most common approach to address this limitation has been to rescale the rainfall statistics used to fit the model, using climate model output. We propose an alternative, more coherent approach, that extends the existing fitting method. The new approach allows the discrete covariate, calendar month, to be replaced or supplemented with continuous covariates that are more directly related to the incidence and nature of rainfall, thereby allowing the models to be used for climate impact studies. The covariate-dependent model parameters are estimated for each time interval using a kernel-based nonparametric approach within the GMM framework ("local GMM"). An empirical study demonstrates the new methodology at a single site, using a time series of five-minute rainfall data.

A multi-ensemble approach for precipitation projections: a case study based on 5 rainfall generators and 160 climate model runs

Els van Uytven, Jan de Niel, Patrick Willems - KU Leuven University of Leuven

back

Recent studies indicate the increased availability of regional and limited area climate models (De Troch, 2014; Jacob et al, 2014; Kjellström et al., 2016; Tabari et al., 2016). The spatial and temporal resolutions of these models range between 2.8 – 50 km and 15 minutes - 3 hours. Although these resolutions fulfill the requirements for hydrological impact modelling, biased model outputs (Kotlarski et al., 2014, Teutschbein and Seibert, 2012) hinder the direct use. Moreover, compared to the ensemble size of global climate model (GCM) runs, the total ensemble size is rather small. These facts considered, statistical downscaling of a large ensemble of GCM runs remains appealing. GCM runs have a daily resolution and their spatial resolution varies in the range 100 – 300 km. Hence, spatial downscaling is required, whereas the need of temporal downscaling depends on the application considered. Over the years many statistical downscaling methods have been developed. Maraun et al. (2010) classify them as model outputs methods, weather generators and perfect prognosis based methods. Each of these methods involves general and specific assumptions and limitations. Thereupon statistical downscaling adds up to the total uncertainty in climate change projections. An ensemble of statistical downscaling methods accounts for this uncertainty contribution (Chen et al., 2011; Maraun et al., 2010; Sunyer et al., 2015). As part of an inter-comparison study between statistical downscaling methods for hydrological climate change impact modelling, we will present point precipitation projections for Belgium, based on an ensemble of 5 rainfall generators and a total of 160 CMIP5 global climate model runs for the 4 representative concentration pathways. The ensemble of rainfall generators includes a spell length model (Semenov and Stratonovitch, 2010), a general linearized model (Furrer and Catz, 2007), an event-based model (Thorndahl et al., 2017) and two Markov chain models. Different precipitation intensity processes are considered for the Markov chain models: one model accounts for the long term variability (Chowdhury et al., 2017), while the other accounts for the convective and stratiform nature of summer precipitation (Willems, 2000). The rainfall generators are defined at daily time scale and calibrated using the 100-years time series for the Uccle station of the Royal Meteorological Institute. By applying change factors to the variables of the rainfall generators, projected time series are obtained. The current and projected time series are evaluated on seasonal basis, using precipitation accumulation metrics, intensity-duration-frequency (IDF) relations and spell length metrics. By means of variance decomposition, the total uncertainty in the change signals is decomposed in contributions explained by differences in greenhouse gas scenarios, climate models, statistical downscaling approaches (rainfall generators) and their interaction terms. The results demonstrate how assumptions and limitations of statistical downscaling methods introduce uncertainties in precipitation projections.

3.4 Resampling approaches

Ensemble analogue downscaling of the twentieth century reanalysis over France for 140-year-long hydrological reconstructions

Jean-Philippe Vidal[1], Laurie Caillouet[1], Eric Sauquet[1], Benjamin Graff[2]
(1) Irstea, (2) Compagnie Nationale du Rhône (CNR)

back slides

The record length of streamflow observations is generally limited to the last 50 years even in data-rich countries like France. This is not enough to properly explore the long-term hydrometeorological variability, which is a key to better disentangle the effects of anthropogenic climate change from natural variability. In order to overcome this limit, the SCOPE (Spatially COherent Probabilistic Extension) ensemble analogue downscaling method is used to bridge the scale gap between the large-scale Twentieth Century Reanalysis and local meteorological variables relevant for catchment-scale hydrology.

SCOPE extends the SANDHY method (Stepwise Analogue Downscaling Method for Hydrology) originally developed for daily quantitative precipitation forecast. SCOPE consists in refining analogues dates and associated predictand values found by applying SANDHY with locally optimized predictor domains over France. SCOPE first includes two additional analogy levels with large-scale 2m-temperature and sea surface temperature as predictors. The driest analogue dates are then removed to correct for the remaining wet bias. Finally, the Schaake Shuffle procedure ensures the spatial coherence of 8-km precipitation and temperature fields for each of the 25 ensemble members of this meteorological reconstruction called SCOPE Climate. SCOPE Climate presents very little bias in comparison to the reference Safran surface reanalysis on their common period (1958-2012). There is a slight overestimation of precipitation in spring (around 10%), and an underestimation/overestimation (within 1 degC) in summer/winter mean temperature, respectively. SCOPE Climate is able to capture the seasonal variability of precipitation and temperature as well as the increasing trend in temperature since the 1990s. It also highlights the large multidecadal variability in precipitation that occurred over the last 140 years.

A continuous hydrological modelling using SCOPE Climate as forcings then allowed reconstructing 25-member ensembles of daily streamflow time series for more than 600 near-natural catchments in France over the 1871-2012 period. The resulting SCOPE Hydro reconstruction dataset was recently used to identify and characterize spatio-temporal extreme low-flow events in a homogeneous way over France and over a 140-year period. This analysis built on innovative aspects for defining local extreme low-flow events and for matching events across the whole country. On top of recent events like 1976 or 1989-1990, it brought forward the outstanding 1921 and 1940s events but also older and less known ones that still are the most severe ones to date in specific regions, like 1893 in the North-East of France and 1878 around the Mediterranean coast.

The SCOPE Climate and SCOPE Hydro thus pave the way for further analyses of long-term meteorological and hydrological variability and trends in a comprehensive way over the whole France.

A resampling based multivariate space-time simulator

Thomas Nipen[1], Sara Martino [2], Cristian Lussana[1]
(1) Norwegian Meteorological Institute, (2)sintef energy research

back slides

In the current energy market, solar and wind power have become important beside other, more traditional, energy sources, such as thermal and hydro power. This requires that the weather generators used in the energy sector are able to jointly simulate different meteorological variables such as temperature, precipitation, wind and solar radiation. It is also important that such simulators take into account the complex spatio-temporal structures of these variables and the interaction between them. Building a stochastic model that captures all of these characteristics has proven to be extremely challenging. On the other hand, many of these characteristics are embedded in deterministic models used in numerical weather prediction. In recent years, more and more operational forecasts are stored and, in some cases, operational models are also re-run for past days. Resampling from these large (and increasing in size) databases constitutes an alternative to a fully stochastic model where all dependencies (in space, time and inter-variable) would have to be learned from data. We propose a spatio-temporal multivariate weather generator based on resampling 10-day segments from the ECMWF medium-range ensemble reforecasts dataset. The basic idea is to join the 10-day segments into arbitrary long time series by matching the state of the last day of one segment with the first day of a different segment. The simulator uses separate databases for each month of the year to ensure that the resulting long time-series captures seasonal variations. We have tested several metrics to define how distant two states are. The weather generator can provide gridded datasets of precipitation, wind, temperature, surface pressure, on the same grid of the ECMWF medium-range ensemble reforecasts. Preliminary results show that the resulting simulated time series of multivariate gridded fields honour covariance in time, space and between variables. Moreover, the climatology of the simulated time series are consistent with the climatology of the original ECMWF medium-range ensemble reforecasts. The simulated time series tend to slightly underestimate the variability over larger accumulation time. The method has been applied on a domain covering the South of Norway. However, potentially the method could be applied in any area covered by the ensemble forecast making it a good method to build weather simulators in areas where climate data are scarcely available.

SFRWG weather generator for hydrological applications: case studies for snow cover modelling and operational hydrological forecasting

Vsevolod Moreydo, Alexander Gelfan - Water Problems Institute of RAS

back slides

Simultaneous multi-site generation of weather variables has been a challenge for many researchers in the field of stochastic weather simulation. Numerous approaches, such as hidden Markov chains, cluster analysis and time-series resampling, chain-dependent methods etc. have been presented over recent decades to preserve the spatial structure of weather variables, which is crucial for description of discontinuous variables, such as precipitation events. We introduce the Multi-Site Fragment-based stochastic Weather Generator (MSFR_WG) – a stochastic model producing Monte-Carlo simulated time-series of daily weather variables (precipitation, air temperature and air humidity deficit), retaining statistical properties, both spatial and temporal, of the corresponding observed variables. The MSFR_WG's modeling procedure is based on so-called 'spatial fragments' (SFR) resampling method" initially presented by Gelfan et al (2015). The model has been designed for hydrological applications to provide daily weather data for hydrological models. The model was identified and tested using multi-year observations on the European part of Russia. Good performance in reproducing temporal and spatial statistics of observed data was demonstrated. Next, we used it for two case studies. The first case study was to create a dynamic-stochastic snow cover model to assess probabilistic properties of the snow water equivalent and snow height on multiple sites in the European Russia. The model was capable to both reproduce pointwise snow properties and semivariograms of the snow water equivalent and snow height. The second case study was to generate a 1000-member weather ensemble to be used in an ensemble hydrological forecasting application in the Middle Volga river basin. We show the advantages of this approach for operational use in water management and decision-making. Acknowledgements: this research was financially supported by the Russian Foundation for Basic Researches grant No. 16-05-00599. References: Gelfan, A., Motovilov Yu., Moreido, V. (2015) Ensemble seasonal forecast of extreme water inflow into a large reservoir. Proc. IAHS, 369, 115–120 proc-iahs.net/369/115/2015/ doi:10.5194/piahs-369-115-2015

3.5 Multivariate models

Multivariate statistical modeling of compound events via pair-copula constructions: analysis of floods in Ravenna (Italy)

Emanuele Bevacqua[1], Douglas Maraun, Ingrid Hobaek Haff, Martin Widmann, Mathieu Vrac
(1)Karl-Franzens University of Graz

back slides

Compound events (CEs) are multivariate extreme events in which the individual contributing variables may not be extreme themselves, but their joint – dependent – occurrence causes an extreme impact. Conventional univariate statistical analysis cannot give accurate information regarding the multivariate nature of these events. We develop a conceptual model, implemented via pair-copula constructions, which allows for the quantification of the risk associated with compound events in present-day and future climate, as well as the uncertainty estimates around such risk. The model includes predictors, which could represent for instance meteorological processes that provide insight into both the involved physical mechanisms and the temporal variability of compound events. Moreover, this model enables multivariate statistical downscaling of compound events. Downscaling is required to extend the compound events' risk assessment to the past or future climate, where climate models either do not simulate realistic values of the local variables driving the events or do not simulate them at all. Based on the developed model, we study compound floods, i.e. joint storm surge and high river runoff, in Ravenna (Italy). To explicitly quantify the risk, we define the impact of compound floods as a function of sea and river levels. We use meteorological predictors to extend the analysis to the past, and get a more robust risk analysis. We quantify the uncertainties of the risk analysis, observing that they are very large due to the shortness of the available data, though this may also be the case in other studies where they have not been estimated. Ignoring the dependence between sea and river levels would result in an underestimation of risk; in particular, the expected return period of the highest compound flood observed increases from about 20 to 32 years when switching from the dependent to the independent case.

A multivariate statistical model describing the compound nature of soil moisture droughts

Colin Manning[1], Martin Widmann[1], Emanuele Bevacqua[2], Douglas Maraun[2], Anne van Loon[1], Mathieu Vrac[3]
(1) University of Birmingham, (2) Karl-Franzens University of Graz, (3)LSCE

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Compound events are multivariate extreme events involving the combination of two or more contributing variables or events which in themselves may not be extreme but through their joint occurrence produce an extreme impact. We analyse soil moisture (SM) drought as a compound event of meteorological drought and heat waves in Europe where a reinforcement of drought and heat wave conditions through land-atmosphere interactions can arise as a result of their concurrence. Our main focus is the relevance of contributing meteorological variables and their dependence structure to the estimation of soil moisture across various locations in Europe in dry, transitional and wet climate regimes. We use a conceptual framework implemented via Pair Copula Constructions (PCCs) to study SM drought as a compound event in the summer months June, July and August (JJA). The model is constructed in such a way to allow us to capture both the dependence between the contributing meteorological variables and soil moisture as well as the dependence amongst the meteorological variables themselves. In particular we look to explicitly capture the increased probability of extreme temperatures in dry conditions due to antecedent precipitation deficits. The model is composed of four variables; daily soil moisture (h); a short term and a long term accumulated precipitation variable (Y_1 and Y_2) that account for the propagation of meteorological drought to SM drought; and accumulated Potential Evapotranspiration (PET) (Y_3)

that represents the effect of extreme temperatures on soil conditions. Copula are multivariate distribution functions that allow one to model the dependence structure of given variables separately from their marginal behaviour. PCCs allow for the formulation of a multivariate distribution of any dimension that is decomposed into a product of marginal probability density functions and two-dimensional copula, of which some are conditional. PCC provides flexibility in modelling heterogeneous dependence structures and when specifying the decomposition of the PCC, one can obtain a quantile function that allows for the estimation of an impact h from the multivariate conditional cumulative distribution function $F_{h|Y1Y2Y3}(h|Y_1\ Y_2\ Y_3\ )$ conditioning on the Y. Applying the model to various Fluxnet sites across Europe, we find it has good skill in the representation of SM but note the wide uncertainties that can exist around the estimation of SM using meteorological variables alone. We apply the model in various sensitivity experiments to test the relevance of the Y variables and their dependence structure. At wet sites we find precipitation exerts the main control over SM drought while PET can explain the severity of the drought as well as the persistence of SM drought that would otherwise be underestimated using precipitation alone. We also show that low values of SM would be underrepresented when not accounting for tail dependencies between precipitation deficits and PET in transitional climates. At dry sites we see little relevance of PET in the estimation of SM where overestimations of drought severity may occur through its incorporation leading to questions over its suitability in drought analysis at such locations.

Stochastic simulation of Sahelian storms. Recent developments and hydrological applications.

Theo Vischel, Claire Aly, Juliette Blanchet
Institut des Géosciences de l'Environnement

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Assessing the impact of climate and environmental changes on water availability and flood hazards has become a major challenge for decision makers to define suitable water management strategies over the long term. The West African Sahel is a very critical region in this regard. This semi-arid region has experienced devastating droughts in the 70s and 80s, intensifying the stress on already limited water resources. The last two decades have seen a growing number of extreme storms causing damaging floods concurrent with ongoing episodes of water shortages. This great climate variability has major impacts on populations whose livelihood is heavily dependent on rainfed agriculture and whose adaptive capacities are notoriously low. Sahelian rainfall is mainly produced by mesoscale convective systems (MCSs) generated during the West African monsoon season. MCS frequency, intensity and size are key factors of the hydrological variability from local to regional scales. They are controlled by multiscale processes which are not well represented in GCMs. Consequently the predictive skills of climate scenarios regarding possible changes in the Sahelian hydrology are quite low. Long time series of rainfall observations at mesoscale are often lacking in the region, limiting the possibility to document past hydrological changes. The use of stochastic MCS generators to simulate long rainfall series at scales relevant for the Sahelian hydrology is thus an efficient alternative to explore hydrological scenarios both in the past and the future. Here we present a stochastic model of MCS rainelds. The model uses the frame of meta-gaussian random functions to simulate event cumulative rainfall. A simple hyetograph shape coupled with a kinematic model is used to disaggregate the rainfields into sub-event scales. In its initial versions (Guillot and Lebel 1999; Vischel et al. 2009) the model was intended for dealing with big MCSs only (covering at least 30% of the simulation domain), leaving aside the local convective systems representing about 10% of the annual rainfall. The model assumed the passage of a MCS but did not simulate its occurrence. There was no distinction between average and extreme MCS intensity. A new version of the model is presented here, characterized by the following improvements: (1) the separate description of big and small MCSs, (2) the simulation of MCS occurrence through the distribution of inter-event time, (3) the explicit simulation of extreme precipitation by using an extreme value distribution. All occurrence and intensity distribution parameters are seasonally variable by including temporal covariates. Two hydrological applications are shown. The model is first conditioned by raingauge measurements over the densely instrumented AMMA-CATCH Niger observatory (1deg x1deg) to assess the rainfall sensitivity of the water and energy budget simulated by a land surface model (Sethys-Savannah). In a second application the stochastic model parameter are derived from three years of MCS simulations made by a high resolution convective permitting atmospheric model (model CP4). We will evaluate here the relevance of coupling a deterministic and a stochastic MCS modelling approach to produce future flood scenarios in the Sahel.

3.6 Space-time models for precipitation

Modeling Precipitation in Space and Time

Anastassia Baxevani - University of Cyprus

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We discuss the patio-temporal modeling of daily precipitation using two different models. The first one is the so-called two-stage model and the second one is a truncated and transformed Gaussian field. In the first case, the occurrence process is modeled at each site separately, using Markov chains of high orders and the intensity process is modeled using a hybrid model consisting of the empirical pdf stitched together with the Generalized Pareto distribution. Gaussian copulas are used for the spatial correlation. In the second case, we use a transformed Gaussian random field to model simultaneously both the occurrence and intensity process. Performance of both models is judged through their ability to accurately reproduce a series of dependence measures and weather indices.

Daily spatio-temporal stochastic precipitation generator based on a censored and transformed latent Gaussian field

Komland Agbeko Kpogo-Nuwokol, Henning Rust, Uwe Ulbrich, Edmund Meredith, Christos Vagenas
Free University of Berlin

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Since recent decades, there is an increasing demand for high-resolution precipitation data for hydrological impact studies. Rainfall data are generally collected at coarser scales than required, hence the need for a spatio-temporal model which allows simulation of rainfall at fines scales, yet consistent with observations. Stochastic precipitation generators have been key features of climate impact studies for a number of decades. They are able to reproduce accurately the spatio-temporal dynamics as well as the natural variability of the rainfall distribution. Compare to numerical climate models, stochastic generators generally have a low computational cost and provide relatively fast simulations. They allow simulation of large ensembles of precipitation sequences and thus allow uncertainty assessment. In the context of the HORIZON 2020 project BINGO (Bringing INnovation to onGOing water management) we have developed a spatio-temporal stochastic precipitation generator based on a censored and transformed latent Gaussian field. More precisely, we use a Gaussian field to model the occurrence process of precipitation and transform the same latent field to model the positive rainfall amounts. The model takes into account the seasonality and the dependence of rainfall on large-scale atmospheric conditions. Results show a good agreements between simulations and observations.

A non-stationary spatial weather generator for statistical modelling of daily precipi- tation

Pradeebane Vaitinada Ayar, Juliette Blanchet - Univ. Grenoble Alpes

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Simulation methods for design flood analyses and dam dimensioning require good precipitation data. Thus, fine scale precipitation data are needed to provide quality input for hydrological models which leads to use statistical models such as stochastic weather generators. The aim here is to develop a generic stochastic model working on different kind of catchments over the French Alps and accounting for spatial dependencies in daily precipitation fields. To achieve this goal the framework of spatial random processes is adopted here.

There is a wide variety of spatial models available in the literature. The model developed in this study relies on a single transformed and truncated Gaussian field to model daily rain fields (including both occurrences and intensities). In this context the use of stationary dependence structure (or covariance function) are quite common. The novelty of this work resides in : first the use of a censored likelihood in order to take into account the spatial and temporal intermitency of rainfall in the estimation of the covariance structure and second the use of a non-stationary covariance function allowing the introduction of spatial non-stationarities in the dependence structure.

The model is tested over the Ardèche Catchement at Sauze and is calibrated with stations data with at least 20 years of observations in the period 1948 – 2013. Geographical (latitude longitude and altitude) covariates are introduced in the dependence structure. The model is compared to observations and the model evaluation focuses on the added value of spatial non-stationarity in the dependence structure compared to classical stationary dependence structure.

Sub-kilometer-scale space-time stochastic rainfall simulation

Lionel Benoit[1], Gregoire Mariethoz[1], Denis Allard[2]
(1) University of Lausanne, (2) French National Institute for Agricultural Research

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The characterization and reproduction of rainfall spatial and temporal variability is a longstanding challenge. Since perceptible features of rainfall vary with the available measurement datasets, and because the features to transpose in model outputs are application dependent, a large variety of stochastic rainfall models have been developed to capture and reproduce different aspects of rain statistics. Stochastic rainfall models have continuously evolved in the last decades to fit instrumental improvements in resolution and accuracy. Data and models at the 1km x 1km x 5min resolution are nowadays available for applications where the local features of the rain field are important.

Here we take advantage of a network of closely spaced new in situ rain measurement devices with high resolution (0.01mm of rain height) to infer rainfall at fine spatial and temporal scales (i.e. 100m in space and 30sec in time) that have not been previously observed. Data are collected by 8 Driptych drop-counting rain gauges in an area of 1 km^2. This dense measurement network was set up almost two years ago on the Campus of the University of Lausanne (Switzerland), allowing to capture the local patterns of the rain field throughout the year. A stochastic rainfall model has been developed to account for the rainfall patterns emerging from these high resolution measurements and will be presented here. Its main feature is its ability to generate space-time and high resolution rain fields at the local scale, which can be interesting for hydrological applications dealing with small catchments (e.g. mountain or urban catchments).

AWE-GEN-2d: An advanced stochastic weather generator for simulating 2-D high-resolution climate variables

Nadav Peleg, Simone Fatichi, Athanasios Paschalis, Peter Molnar, Paolo Burlando

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AWE-GEN-2d is a new stochastic weather generator. The model combines physical and stochastic approaches to simulate key meteorological variables at high spatial and temporal resolution, e.g. 2 km x 2 km and 5 min for precipitation and cloud cover and 100 m x 100 m and 1 h for near-surface air temperature, solar radiation, vapor pressure, atmospheric pressure and near-surface wind. AWE-GEN-2d is fast and parsimonious in terms of computational demand.

3.7 Poster

The R-package CDVineCopulaConditional for modelling Compound Events

E. Bevacqua[1], D. Maraun[1], I. Hobaek Haff[2], M. Vrac[3], M. Widmann[4], C. Manning[4]
(1) University of Graz, (2) University of Oslo (3) LSCE (4) University of Birmingham

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Given a joint probability density function (pdf), copulas allows for modelling the dependence structure of the variables separately from their marginal pdfs. Copulas provide flexibility when modelling joint pdfs, and therefore have been largely used in science, e.g. in quantitative finance to model and minimize tail risk, in hydrology and more recently for modelling Compound Events (CEs). However, multivariate parametric copulas lack flexibility when modelling systems with high dimensionality, where "heterogeneous dependencies" exist among the different pairs. Pair-copula constructions (PCCs) decompose the pdf dependence structure in bivariate copulas and give greater flexibility in modelling generic high-dimensional systems compared to multivariate parametric copulas. Given the complex structure of some CEs, PCCs can be useful for their modelling. Moreover, joint conditional pdfs can be used to get information about the impact or the contributing variables of CEs, given proper predictors, which could represent for instance meteorological processes. The R-package CDVineCopulaConditional [Bevacqua (2017)] provides tools for modelling conditional joint pdfs decomposed via Pair-Copula Constructions.

Daily spatio-temporal stochastic precipitation generator based on a censored and transformed latent Gaussian field

K. A. Kpogo-Nuwoklo, H. W. Rust, U. Ulbrich, C. Vagenas, E. Meredith
Freie Universität Berlin

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Since recent decades, there is an increasing demand for high-resolution precipitation data for hydrological impact studies. Rainfall data are generally collected at coarser scales than required, hence the need for a spatio-temporal model which allows simulation of rainfall at fines scales, yet consistent with observations. Stochastic precipitation generators have been key features of climate impact studies for a number of decades. They are able to reproduce accurately the spatio-temporal dynamics as well as the natural variability of the rainfall distribution. Compare to numerical climate models, stochastic generators generally have a low computational cost and provide relatively fast simulations. They allow simulation of large ensembles of precipitation sequences and thus allow uncertainty assessment. In the context of the HORIZON 2020 project BINGO (Bringing INnovation to onGOing water management) we have developed a spatio-temporal stochastic precipitation generator based on a censored and transformed latent Gaussian field. More precisely, we use a Gaussian field to model the occurrence process of precipitation and transform the same latent field to model the positive rainfall amounts. The model takes into account the seasonality and the dependence of rainfall on large-scale atmospheric conditions. Results show a good agreements between simulations and observations.

Incorporating Dependencies between Rainfall Statistics and Rainfall Interannual Variability into Hourly Stochastic Rainfall Generator for Improved Extreme Value Reproduction

Dongkyun Kim[1], Christian Onof[2], Jeongha Park[1]
(1) Hongik University (2) Imperial College

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We present a method to improve the performance of Poisson cluster rainfall models to generate extreme rainfall values at hourly through daily temporal scale. First, we show that Poisson cluster rainfall mod els have a limitation to reproduce rainfall variability at monthly time scale, which is closely related to extreme rainfall values at sub - daily scale. Then, we present a methodology to incorporate this monthly rainfall variability into the existing framework of Poisson cluster rainfall generation model. This method is composed of the process of generating various rainfall statistics of an individual month considering their interdependencies, the process of parameter estimation of the Modified Bartlett-Lewis rectangular pulse model, and the process of generating rainfall statistics for a duration of a month based on the estimated parameter set. The entire process is repeated to obtain the rainfall time series with the desired length. The proposed approach performed well both in terms of reproducing the 1st, 2nd order statistics as well as the probability of zero rainfall and in terms of reproducing extreme design rainfall values of the observed rainfall time series. In addition, the proposed approach successfully reduced the bias of the runoff and the peak flow values when the synthetically generated rainfall time series were applied in some samplewatershed models.

Partitioning spatial and temporal rainfall variability in urban drainage modelling

Nadav Peleg[1], Frank Blumensaat[1,2], Peter Molnar[1], Simone Fatichi[1], Paolo Burlando[1]
(1) ETH Zurich (2) Swiss Federal Institute of Aquatic Science and Technology

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The goal of this study was to understand how climate variability and spatial rainfall varia- bility affect the response of a calibrated hydrodynamic urban drainage model. A stochastic spatially distributed rainfall generator was used to simulate many realizations of rainfall for a 30-year period. The generated rainfall ensemble was used as input into a calibrated hydro- dynamic model to simulate surface runoff and channel flow in a small urban catchment in the city of Lucerne, Switzerland.

Assessing hydrological regime sensitivity to climate change in a convective rainfall environment: a case study of medium-sized eastern Mediterranean catchments

N. Peleg[1], E. Shamir[2], K. P. Georgakakos[2,3], E. Morin[1]
(1) Hebrew University of Jerusalem (2) Hydrologic Research Center (3) University of California San Diego

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The hydrological sensitivity of two medium-sized Mediterranean catchments, strongly af- fected by convective rainfall, is explored by combining the HiReS-WG rainfall generator and the SAC-SMA hydrological model. The projected climate change impact on the hydro- logical regime was examined for the RCP4.5 and RCP8.5 emission scenarios, comparing the beginning of the 21st century and the mid-21st-century periods using data from three GCMs available from CMIP5.

Precipitation extremes on multiple time scales - Original Bartlett-Lewis model and IDF curves

Christoph Ritschel, Anette Müller, H. W. Rust, Peter Névir, Uwe Ulbrich
Freie Universität Berlin

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For several hydrological modelling tasks, precipitation time series with a high (i.e. sub-daily) resolution are indispensable. This data is, however, not always available and thus model simulations are used to compensate. A canonical class of stochastic models for sub-daily precipitation are Poisson-cluster processes, with the original Bartlett-Lewis (OBL) model as a prominent representative. The OBL model has been shown to well reproduce certain characteristics found in observations. Our focus is on intensity-duration-frequency relationship (IDF), which are of particular interest in risk assessment. Based on a high resolution precipitation time series (5-min) from Berlin-Dahlem, OBL model parameters are estimated and IDF curves are obtained on the one hand directly from the observations and on the other hand from OBL model simulations. Comparing the resulting IDF curves suggests that the OBL model is able to reproduce main features of IDF statistics across several durations but cannot capture rare events (here an event with a return period larger than 1000 years on the hourly time scale). Here, IDF curves are estimated based on a parametric model for the duration dependence of the scale parameter in the Generalised Extreme Value distribution; this allows to obtain a consistent set of curves over all durations.

Intercomparison of statistical downscaling: from climate to hydrological point of view

Pradeebane Vaittinada Ayar[1], Mathieu Vrac[2], Benjamin Grouillet[3], Denis Ruelland[3]
(1) IGE (2) LSCE (3) HSM

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Finer scale projections of variables affected by local-scale processes such as precipitation and temperature are often needed to drive impacts models, for example in hydrology or ecology among other fields. Statistical Downscaling Models (SDMs) are one way to achieve that. Here, several SDMs are compared from (i) the climate and (ii) the hydrological point of view. In both cases, an intercomparison experiment is designed. The chosen performance sriteria are expected to be able to correctly assess the quality of the simulations. The climatic intercomparison takes place under the CORDEX [GIORGI et al., 2009] initiave hindcast evaluation requirements and the simulations are compared to a reference dataset [E-OBS HAYLOCK et al. 2008]. In the hydrological intercomparison, the SDMs simulations are compared through the GR4j [PERRIN et al., 2003] hydrological model. The simulations driven by the SDMs are compared to a reference simulation.