Joint Virtual Workshop on “Connecting global to local hydrological modelling and forecasting: scientific advances and challenges”

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Virtual

Book of Abstracts

Contents

Pitch talks for poster session 1 / 7

A regional coupled approach to water cycle prediction during winter 2013/14 in the United Kingdom

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A regional coupled approach to water cycle prediction is demonstrated for winter 2013/14 in the UK through analysis of precipitation, soil moisture, river flow and coastal ocean simulations produced by a km-scale atmosphere-land-ocean coupled system, running with horizontal grid spacing of around 1.5 km across all components. The Unified Model atmosphere component, in which convection is explicitly simulated, reproduces the observed UK rainfall accumulation (r2 of 0.62 for daily accumulation), but there is a notable bias in its distribution – too dry over western upland areas and too wet further east. The JULES land surface model soil moisture state is shown to be in broad agreement with a limited number of cosmic-ray neutron probe observations. A comparison of observed and simulated river flow shows the coupled system is useful for predicting broad scale features, such as distinguishing high and low flow regions and times during the period of interest but are shown to be currently less accurate than optimised hydrological models. The impact of simulated river discharge on NEMO model simulations of coastal ocean state is explored in the coupled system, with comparisons provided relative to experiments using climatological river input and no river input around the UK coasts. Results show that the freshwater flux around the UK contributes of order 0.2 psu to the mean surface salinity, and comparisons to profile observations give evidence of an improved vertical structure when applying simulated flows. This study represents a baseline assessment of the coupled system performance, with priorities for future model developments discussed.

Keywords:

coupled prediction
regional modelling

Pitch talks for poster session 1 / 80

ULYSSES: a global multi-model hydrological prediction system

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The Copernicus Climate Change Service aims at facilitating the emergence of a downstream market of climate services with the ultimate goal of supporting the development of a climate-smart society. Central to this vision is the free and unrestricted distribution of high-quality climate data through the Climate Data Store, with seasonal meteorological predictions among them. Within this unique and challenging framework, ULYSSES [1] will provide the first seamless multi-model hydrological seasonal prediction system, with a global coverage at a spatial resolution of 0.1°. The ULYSSES

modeling chain is based on the successfully tested EDgE proof of concept [2] using four state-of-the-art hydrological models (Jules, HTESSEL, mHM, PCR-GLOBWB). A unique feature of this production chain consists of using the same physiographical datasets (e.g. DEM, soil properties) with identical spatio-temporal resolutions and forecast inputs for all HMS, as well as, for all the same multi-scale routing model (mRM).

The initial conditions of the production chain is based on ERA5-Land and the seasonal forecasts will be driven by a 25-member ensemble generated by the ECMWF-SEAS5 model. ULYSSES aims at generating six essential hydrological variables: snow-water equivalent, snowmelt, evapotranspiration, soil moisture, total runoff, and streamflow with a lead time up to six months. The seasonal forecast will be verified at 250+ gauges around the World during the hind-casting period from 1993 to 2019. The operational forecasting period -in testing phase- will start on Nov. 2020 and be extended until July 2021.

All input data sets (ERA5-Land), seasonal forecast and ULYSSES outputs will be ingested in the Copernicus Data Store C3S and will be completely open access. Currently, 60% of the reforecats are produced and we aim to have the first operational forecast by the 10th of April 2021. In this talk, the desing modeling chain concept with ecFlow and the first results will be presented.

[1] https://www.ufz.de/ulysses
[2] https://doi.org/10.1175/BAMS-D-17-0274.1
[3] https://cds.climate.copernicus.eu

Keywords:

Seasonal forecast, operational system, hydrological modeling

Pitch talks for poster session 1 / 37

Using ensemble reforecasts to generate flood thresholds for improved global flood forecasting

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Global flood forecasting systems rely on predefining flood thresholds to highlight potential upcoming flood events. Existing methods for flood threshold definition are often based on reanalysis datasets using a single threshold across all forecast lead times, such as in the Global Flood Awareness System. This leads to inconsistencies between how the extreme flood events are represented in the flood thresholds and the ensemble forecasts. This paper explores the potential benefits of using river flow ensemble reforecasts to generate flood thresholds that can deliver improved reliability and skill, increasing the confidence in the forecasts for humanitarian and civil protection partners. The choice of dataset and methods used to sample annual maxima in the threshold computation, both for reanalysis and reforecast, is analysed in terms of threshold magnitude, forecast reliability, and skill for different flood severity levels and lead times. The variability of threshold magnitudes, when estimated from the different annual maxima samples, can be extremely large, as can the subsequent impact on forecast skill. Reanalysis-based thresholds should only be used for the first few days, after which ensemble-reforecast-based thresholds, that vary with forecast lead time and can account for the forecast bias trends, provide more reliable and skilful flood forecasts.

Keywords:

ensemble reforecasts, flood forecasting, flood thresholds, forecast lead times, global predictions

Pitch talks for poster session 1 / 50

Deployment automation of hydrological forecasting systems on a global scale

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Hydrological forecasting systems represent an important decision-making tool for water and risk management. In this context, there is increasing development and implementation of such systems worldwide, which are commonly tailor-made: designed and configured according to the information and hydrological models available for a specific location and/or extent to answer to precise needs. Therefore, the concepts of setup automation and replicability of configuration of such systems are often overlooked, especially when they follow a model-centric approach.

However, in a global forecasting context such as the one adopted by Deltares' GLOFFIS (den Toom et al. 2020), the automation of hydrological forecasting systems' set up becomes an essential part for the development, as it enables the fast forward and constant addition of local specialized models where available in the system on a global extent, as well as by using local regional weather forecasts, reanalysis models or satellite data as forcing to produce estimates of various hydrological parameters, instead of focusing on a single model or NWP source.

In that sense, a prototype of a configuration production system for GLOFFIS was developed, which comprises two main components: (1) an external relational database holding the information regarding the set of hydrological models to be incorporated and weather data products used and, (2) a set of python scripts, that query the database and generate the configuration XML files needed for the system (as GLOFFIS is based on Delft-FEWS) to accomplish an automated deployment.

This new approach for system's configuration boosts the potential related to system maintenance, expansion, and replicability, which could be beneficial not only when developing large hydrological forecasting systems, but also for local systems developed using Delft-FEWS, as well as to encourage the distribution of forecasting systems worldwide.

Keywords:

global hydrological forecasting, forecast system automation, forecast system replicability

Pitch talks for poster session 1 / 89

Delivering Global Flood Awareness System (GloFAS) data operationally to the hydrological community

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Operational global-scale hydrological forecasting systems are widely used to help manage hydrological extremes such as floods and droughts. The Global Flood Awareness System (GloFAS; https://www.globalfloods.eu/) is the global flood forecasting and monitoring service of the European Commission's Copernicus Emergency Management Service (CEMS), with over 6000 registered users. While the post-processed forecast maps and graphics have always been openly available each day on the GloFAS web interface, the raw real-time reanalysis and forecast data have not - precluding their use in downstream applications and hampering scientific research and development. Further, a critical aspect of any forecasting system is the evaluation of ensemble forecast skill using reforecasts for a large set of past dates. However, it is a challenge to open these global data to users each time there is a model upgrade given the enormous volume of data involved. Further, for many users who require GloFAS data for their local scale forecast or evaluation purposes, a sub-set of the data needs to be downloadable rather than the full global domain. The GloFAS strategy for delivering data operationally to the hydrological community is based on the Copernicus Climate Data Store (CDS) and involves a full data support service. In addition to the technical solution, it requires i.) high quality model and metadata documentation, ii.) online tutorials on how to download, read and interact with GloFAS data, iii.) a list of Frequently Asked Questions (FAQs) to be continuously updated in response to the most common questions, and iv.) access to a data support service from technical and domain experts. Increasing the use and usability of GloFAS data for a broad range of end-users is at the centre of the GloFAS strategy.

Keywords:

Pitch talks for poster session 1 / 42

Advances and challenges in the past decade: from univariate to multivariate bias adjustment of climate models for impact studies

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Climate models are primary tools to reconstruct past and predict future climates. However, climate models face biases compared to observation. To overcome these biases, different statistical methods have been suggested in the scientific literature that employ a transformation algorithm to re-scale (or bias-correct) RCM outputs. Some of these methods (e.g. univariate methods) are comparatively easy to implement while others (e.g., multi-variate correction that guarantees consistency in spatiotemporal fields and different climate variables) that have been introduced lately to the field, are more complex and require advanced statistical knowledge and more computing power. Therefore, the need to further investigate the performance of the latest more complex bias-adjustment methods under different climatic conditions still exists and their added value still needs to be evaluated from different aspects.

Thus, we assessed the skill of two commonly used multivariate methods, namely copula based bias adjustment methods and non-parametric n-dimensional multivariate bias correction (MBCn). We further compared them with widely used univariate methods, i.e. the parametric distribution mapping (DS) and the non-parametric quantile delta mapping (QDM), to adjust RCM-simulated temperature and precipitation. We evaluated these methods over 55 Swedish catchments varying in size and climatic features using an ensemble of 10 different RCMs under varying climate conditions to

check multiple features that represent both probabilistic and temporal behavior. We further discuss potential issues and trade-offs of each of the applied methods and present an evaluation of each bias-corrected climate variable in terms of its (1) statistical properties, (2) temporal behavior utilizing cross correlation and autocorrelation measures, and (3) dependence structure to the other variable with help of copula-based dependence measures. Finally, we also examined how the four bias-adjustment methods influence the Clausius Clapeyron relation, which serves as an important climatic illustration of the relationship between extreme precipitation and temperature.

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Keywords:

climate models, multivariate bias adjustment, copula, Clausius-Clapeyron

Pitch talks for poster session 1 / 22

Global high-resolution regionalized parameter maps for LISFLOOD based on observed streamflow from over 4000 headwater catchments

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All hydrological models need to be calibrated to obtain satisfactory streamflow simulations. Here we present a novel parameter regionalization approach that involves the optimization of transfer equations linking model parameters to climate and landscape characteristics. We implement the approach, which has previously been tested using the simple hydrological model HBV, using the more complex LISFLOOD model underlying the Global Flood Awareness System (GloFAS), which is part of the Copernicus Emergency Management Service (EMS). The optimization was performed in a fully spatially distributed fashion at high resolution (0.05°), instead of at lumped catchment scale, using an unprecedented database of daily observed streamflow from over 4000 headwater catchments (<5000 km2) worldwide. The optimized equations were subsequently applied globally to produce parameter maps covering the entire land surface including ungauged regions. Four-fold cross-validation was used to evaluate the generalizability of the approach and to obtain an ensemble of parameter maps. We present the performance improvement due to the regionalization, discuss the spatial patterns in model parameters, and explore potential avenues forward.

Keywords:

global model calibration streamflow

Pitch talks for poster session 1 / 16

A few hundred catchments later – lessons from modelling large samples of catchments around the globe

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In recent years several data sets with hydrological data from a large sample of catchments have been made available. Using these data, we have simulated hundreds of catchments in the US, the UK, Chile and Brazil using a typical bucket-type model, namely the HBV model. Here we report on some of the lessons learnt from these modelling exercises:

• Upper and lower benchmarks are needed: reproducing observed streamflow with a model is often surprisingly easy. Therefore, for a useful assessment of model performance, it is important to compare model simulation to both what is possible at best and to what should be expected at the very least.

• Large sample hydrology helps to identify model structure issues: while we obtained good model fits for the majority of catchments, we found that unrealistic model parameters were needed for a number of catchments, especially in Brazil. This lead to the surprising finding that a simplified soil routine can lead to improved results in some catchments.

• Large sample hydrology helps to identify spatial patterns: Hydrological modelling is affected by uncertainties and equifinality. However, using many catchments and many calibration runs allows to obtain robust results and detect patterns that otherwise might have been hidden in the 'equifinality noise'.

• Regionalisation remains challenging: To simulate ungauged catchments, one could select a few suitable donor catchments and transfer (calibrated) model parameters from these catchments to the ungauged catchment. One would expect that spatial proximity or hydrological similarity might be a good basis to find suitable donor catchments. Surprisingly, however, many of the selection schemes we tested for the CAMELS-US data set did not lead to better simulations than using the ensemble with parameter sets from all 600 catchments.

Keywords:

large sample hydrology, camels, benchmarks

Pitch talks for poster session 1 / 71

Challenges of the European Flood Awareness System (EFAS) hydrological calibration

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EFAS is the operational pan-European flood forecasting system funded by the European Commission through its Copernicus programme with the aim to support preparatory measures against floods, particularly in large transnational river basins and throughout Europe in general.
Within EFAS, the distributed hydrological model LISFLOOD is implemented on an area of approximately 9Mil km2 at a 5km/6-hours spatial/temporal resolution and discharge data from approximately 1000 stations are available for model calibration.
The challenge of calibrating a large scale fully-distributed hydrological model for an operational system is threefold: one, the spatial extension of the modelling domain, the number of calibration points and the sub-daily temporal resolution of the model in EFAS require a fast converging calibration tool and large computation resources; two, the quality of the hydrological modelling performance needs to be acceptable and comparable across a variety of different hydrological situations where the dominant process often changes, and a variety of catchment sizes; three, the absence in EFAS of sub-daily discharge observational data for nearly 76% of the calibrated EFAS domain and the presence of hydrological records at both 6-hourly and daily time steps within nested catchments claim for an ad-hoc calibration strategy. Additionally, when calibrating an operational hydrological forecast system model, it is important that the calibration procedure uses the operational model configuration.
In EFAS, the temporal resolution of the system is finer than most available observational records. In order to optimise the available data, a dual time-step calibration strategy was developed, where simulations for all calibration steps were conducted at the operational temporal resolution (6-hourly) but the objective function was calculated on the observational temporal resolution (6-hourly or aggregated over a 24-hour period).

Keywords:

Model calibration
European Flood Awareness System (EFAS)
Distributed modelling

Pitch talks for poster session 1 / 40

Development of a global high resolution river routing model accounting for lake mass balance

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Land Surface Models (LSMs) are key tools to study the continental water cycle and can be used to better understand the main hydrological processes and their sensitivity to climate change. When coupled to River Routing Models (RRMs), they can simulate the propagation of water within the river network. With the increasing computing capacities and new available datasets from satellites, it has become possible to improve the spatial resolution of RRMs and then to finer represent rivers at the global scale. Besides, some LSMs include the representation of the energy balance in lakes to better simulate the fluxes at the land-atmosphere interface. Yet, although lakes act as a buffer zone within the river network and can significantly impact the propagation of water along the rivers, the lakes water mass balance is generally neglected in LSMs and RRMs. In this study, we present two main recent improvements of the CTRIP RRM developed at Météo-France. First, a new global scale river network has been developed at 1/12°, improving the spatial resolution from about 50 km (0.5°) to 8 km at mid-latitudes. This river network is derived from the 90 m resolution (1/1200°) MERIT-Hydro river network using an adapted Dominant River Tracing upscaling algorithm. Hydro-geomorphological parameters at 1/12° (including river width and depth, roughness, subgrid topography, soil characteristics) are then derived from ancillary datasets and empirical relationships, allowing global scale CTRIP simulations at the new resolution. Second, a new lake module (MLake) is implemented and integrated into CTRIP to simulate the water mass balance within lakes and the impacts on the river

discharge propagation. The main characteristics of lakes (localization, area and mean depth) are extracted from ECOCLIMAP-II and Global Lake DataBase. MLake solves the water mass balance using simulated inflows from upstream rivers and a weir equation to compute outflows. Finally, the new high resolution CTRIP model with MLake is validated at the global scale by comparing simulated and observed discharges over a large number of gauge stations. It is shown that CTRIP performs better at the new resolution and that MLake has a positive impact on simulated discharges. Future work will include the refinement of lakes bathymetry and the integration of water management strategies to simulate outflows from anthropized lakes and man-made reservoirs.

Keywords:

hydrology modelling
river network
river propagation
lake

Pitch talks for poster session 1 / 47

A sensitivity analysis of hydrological states and fluxes to groundwater representation in pan-European multimodel simulations

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High-resolution large-scale predictions of hydrologic states and fluxes are important for many regional-scale applications and water resource management. However, because of uncertainties related to forcing data, model structural errors arising from simplified representations of hydrological processes or uncertain model parameters, model simulations remain uncertain. To quantify this uncertainty, multi-model simulations were performed at 3km resolution over the European continent using the Community Land Model (CLM3.5) and the ParFlow hydrologic model. The ParFlow model simulates three-dimensional variably saturated groundwater flow solving Richards equation and overland flow with a two-dimensional kinematic wave approximation, whereas CLM3.5 applies a simple approach to simulate groundwater recharge and discharge processes via the connection of bottom soil layer and an unconfined aquifer. Over Europe with a lateral resolution of 3km, both models were driven with the COSMO-REA6 reanalysis dataset for the time period from 1997 to 2006 at an hourly time step using the same datasets for the static input variables (such as topography, vegetation and soil properties). Evaluation against independent observations including satellite-derived and in-situ soil moisture, evapotranspiration, and water table depth datasets show that both models capture the interannual and seasonal variations well at the regional scale, however ParFlow with dynamic groundwater representation performs better in simulating surface soil moisture in comparison with in-situ data. Simulations with ParFlow have overall wetter soil moisture than CLM, particularly in humid and cold regions and driest soil moisture in the arid and semi-arid regions. Moreover, the difference in ET between the two models shows that ParFlow produced overall higher ET over the regions with shallow water table and drier regions. This study helps to understand and quantify uncertainties in groundwater related processes in hydrologic simulations and resulting implications for water resources assessment at regional to continental scales.

Keywords:

groundwater, ParFlow, high-resolution, CLM

Pitch talks for poster session 1 / 83

Predicting the complete coupled terrestrial water and energy cycles

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Modelling and monitoring of the terrestrial water and energy cycles is not only relevant for weather prediction or climate projections, but also for many applications in the water and agricultural sectors. We developed the coupled Terrestrial Systems Modelling Platform (TSMP, www.terrsysmp.org), which simulates the water and energy cycles from deep subsurface to upper atmosphere across terrestrial compartments, with two-way couplings between the atmospheric model COSMO (or ICON), the land surface model CLM and the subsurface hydrologic model ParFlow. It is thereby important to simulate at a high spatial resolution in order to capture small-scale processes like runoff generation at hill slopes. TSMP is designed to achieve this by massively parallel computations, combining the use of CPUs and GPUs on the latest heterogeneous HPC systems. A particular interest of us lies in near-real time predictions with TSMP, taking into account the significant uncertainty. Data assimilation allows quantifying and reducing this uncertainty by assimilating observations and merging them with model predictions. The Parallel Data Assimilation Framework (PDAF) was coupled to TSMP for data assimilation and has been developed further to assimilate different data types like soil moisture contents (in situ and satellite), groundwater levels, river stages, land surface temperature, and air temperature. TSMP or its component models have been applied for different near real-time predictions. Examples are (i) forecasts of soil moisture content for agricultural applications like irrigation scheduling; (ii) seasonal forecasts of crop yield, using ECMWF seasonal forecasts as input; (iii) forecasts of flash floods from improved accuracy and nowcasts of precipitation fields derived from polarimetric radars; (iv) forecasts of all hydrological states and water fluxes of the terrestrial system over Europe, and at a higher resolution over North-Rhine-Westphalia, Germany with a lead time of up to 10 days.

Keywords:

integrated terrestrial systems modelling; data assimilation; high performance computing

Pitch talks for poster session 1 / 110

Introduction to poster session 1

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Pitch talks for poster session 2 / 48

Enabling hydrological (ensemble) verification as part of standard operational practice at operational centers around the world

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Information about forecast quality is an essential part in forecast based decision making. However, forecast verification is not routinely included in many hydrological forecasting systems. Instead, verification is often seen as a lengthy and costly task with the most effort in getting the data required. Additionally, decoupling operational practice and verification efforts increase the risk that the verification study does not answer the questions that the client has and do not result in better informed decision making.
In our work, we aimed to introduce operational forecast verification as a way to think about forecast quality and to integrate forecast verification into daily forecasting practice.
For this purpose, we coupled the Delft-FEWS forecasting system and the Deltares Open Archive, containing past forecast products, with the Ensemble Verification System (EVS) to produce verification statistics. Although plenty of steps remain, this successfully removed technical hurdles to perform verification exercises: enabling direct verification from the forecasting GUI. An equal important result are the discussions that ensued during the implementation: a two-way conversation about the interpretation of verification metrics and how to make this information on forecast quality relevant in operational practice.

Keywords:

hydrological ensemble verification, operational practice

Pitch talks for poster session 2 / 84

Development of a medium-range ensemble streamflow forecasting system in a suite of Andean catchments

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Data scarcity is an extended constraint for mountain regions across the world, hindering the development of hydrometeorological operational systems. In this work, we take advantage of recent developments of local products and global reanalyses to build a medium-range ensemble streamflow forecasting framework, based on: (i) an ensemble-based retrospective dataset with daily precipitation and temperature time series, (ii) a conceptual rainfall-runoff model with a snow module, (iii) pre-processed meteorological forecasts, and (iv) post-processed 1-7 day streamflow forecasts. The retrospective meteorological dataset is built upon a modified Schaake Shuffle and analog-based approach to produce ensemble time series for the period 1979-2018, using ERA5 temperature and precipitation as inputs, and the CR2MET local gridded product as the reference. We calibrate the GR6J-CemaNeige model for the period 1998-2011 using streamflow records, SWE from local reanalysis, evaporation from GLEAM and soil moisture from ESA-CCI; and validate the model for the period 2012-2018 (which covers the ongoing Chilean megadrought). Calibration results demonstrate the benefits of adding additional sources of information (besides streamflow); further, for the validation period we obtain split-KGE and split-NSE close to 0.7 and 0.6, respectively, and a relatively small positive bias (ranging from 1% up to 14%). Ongoing work is focused on coupling GEFS preprocessed forecasts to produce an ensemble of medium-range streamflow forecasts, implementing alternative post-processing techniques to improve forecast quality attributes. The availability of local and global products has allowed to develop a modeling approach with satisfactory results for operational systems, and remarkably, suitable for upscaling to a regional extent.

Keywords:

Andean, forecasting system, catchment scale

Pitch talks for poster session 2 / 90

Benchmarking hydrological model performance of GloFAS v3 against GloFAS v2

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The Global Flood Awareness System (GloFAS; https://www.globalfloods.eu/) is the global flood service of the European Commission, an operational system monitoring and forecasting floods across the world. The aim of the service, operational since 2018, is to complement national and regional authorities flood forecasting services and support international organisations in decision making and preparatory measures before major flood events.
In May 2021 GloFAS will be upgraded to version 3.1, replacing GloFAS v2.2 currently operational. The main difference between the two systems is a major change in the hydrological model component. GloFAS v2 is a coupled model chain formed by the land surface model HTESSEL (Hydrology Tiled ECMWF Scheme for Surface Exchanges over Land) and the LISFLOOD hydrological and channel routing model. GloFAS v3 is based on the full LISFLOOD distributed semi-physically based model developed at the Joint Research Centre (JRC) of the European Commission.
In this study, we evaluated the overall performance of both models against observed river discharge from 1281 stations globally using standard hydrological metrics such as the KGE and its constituent components (correlation, bias and variability ratios), as well as the KGE skill score (KGESS). Moreover, we evaluated the high flow performance of the two models to better understand how well they could reproduce a range of high flow conditions compared to observations using contingency table-based skill scores. This analysis will help users understand the main differences in performance between GloFAS v3 and GloFAS v2.

Keywords:

Pitch talks for poster session 2 / 8

GloFAS as fundamental tool in the Madeira River Crisis Room

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Since the unprecedented flood reported in the Madeira river basin, during the 2014 summer (December-March) where the discharge reached a peak at 58,000 m3s-1, Brazilian government included in its political agenda the need for a risk management system that can assist the stakeholders. From this, the Madeira River Crisis Room was established in 2015, under coordination of Brazilian Water Agency (ANA), focused on the management of critical drought and flood events. This room brings together representatives of ANA, Hydrological/meteorological and water resource management agencies, energy and transport sectors, civil protection and early warnings institutions, water users and other

regulatory agencies related. Another important point was the development of the contingency plan, which aims to establish the procedures in case of flooding in Madeira River, taking into account the flooding possibilities in urban areas located in Rondônia State and total or partial interruption of traffic by the highway BR364, between Rio Branco/AC and Porto Velho/RO. This work aims to show the importance of a hydrological forecasting system as a tool for decision making in the Madeira Crisis Room and thus avoid loss of human life as well as damage to structures, as well as presenting the efficiency of the forecasts so that the stakeholders can have confidence in the actions that should be taken in face of possible flood event.

Keywords:

Madeira, Crisis Room, Forecasting, Flooding

Pitch talks for poster session 2 / 19

Integrating hydrological ensemble forecasts into decision support tools for operation of the electric system in Uruguay

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The contribution of the renewable energy to the electric matrix in Uruguay has been increasing steadily during the last decades, with hydroelectric, wind and solar components that have different inherent variability and predictability. This poses both a challenge and an opportunity to optimize planning at different embedded timescales and ultimately dispatch. The interconnected Electric System Simulator (SimSEE) is used for these purposes.
This work presents a methodology for the generation and processing of a hydrological ensemble forecast for the largest hydroelectric reservoir of the Uruguayan system (Gabriel Terra plant located in the upper Rio Negro basin), based on a coupled hydrological and electric system modelling approach.
To generate the hydrological inflows, we use a daily hydrological model (GR4J) coupled with a hydrological transit model (Muskingum). The initial state of the system is determined by combining rain gauge observations and satellite precipitation estimates (GSMaP and IMERG) in near-real-time. The streamflow forecast ensemble is obtained from the GEFS-NOAA ensemble precipitation forecast. It is then integrated to the existing model of the interconnected electric system, particularly into the synthesizer model (CEGH), through biases and noise attenuators per time step adjusted through maximum likelihood.
The model was integrated into the operational version of SimSEE at the Electricity Market Administration (ADME) of Uruguay in June 2019, it updates and executes on a daily basis in order to obtain the dispatch of the following seven days. This result is published automatically on: https://www.adme.com.uy/.
The results obtained indicate that, for the operational implementation of the model, the assimilation of streamflow data in near-real-time is critical. We are currently working in the implementation of a relaxation (nudging) of the state variables of the hydrological model based on the relative error of the simulated streamflow.

Keywords:

Hydrological forecasting, ensemble forecast, hydropower generation, electricity-system simulation

Pitch talks for poster session 2 / 53

An ensemble-based method for investigating the predictability of fluvial flooding from tropical cyclones

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This work investigates the predictability of fluvial flooding associated with tropical cyclones, using forecasts from the Global Flood Awareness System (GloFAS), which produces probabilistic river discharge forecasts worldwide driven by ECMWF ensemble forecasts. A methodology is being developed to evaluate the influence on the predictability and uncertainty of the GloFAS fluvial flood forecasts for tropical cyclones from each component of the forecasting chain, including the tropical cyclone track, intensity, precipitation, and hydrological forecasts. A new score is introduced to assess the flood forecasts across the area affected in a tropical cyclone case, in terms of the amplitude and timing of the river discharge peaks. This score can assess the GloFAS ensemble's hydrological performance for a certain river point, or across all affected river points in a tropical cyclone case, for all forecast runs in the lead up to an event. It can also be used to identify 'good' and 'bad' forecast members in a particular run. The reasons behind the variations in predictability between members and between forecast runs can then be investigated. The methodology will be illustrated using the case study of Hurricane Iota in Central America, and has also been applied to other case studies such as Cyclone Eloise in Mozambique and Cyclone Nivar in India. The study adds a new perspective to the more traditional track and intensity-based methods of verifying global ensemble forecast performance for tropical cyclones, by looking at tropical cyclone forecasts specifically through a hazard-based hydrological lens.

Keywords:

GloFAS, tropical cyclone, predictability, ensemble

Pitch talks for poster session 2 / 95

Which precipitation forecasts to use? Deterministic versus coarser-resolution ensemble NWP models

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There are increasing needs for precipitation forecasts that are accurate and reliable, especially in countries with a diverse climate like Australia. Such forecasts can provide critical information for people to utilize water resources and prepare for natural hazards. In practice, deterministic numerical weather prediction (NWP) models and ensemble NWP models are routinely run worldwide to assist short-term precipitation forecasting. Deterministic forecasts are capable of capturing more detailed spatial features, while ensemble forecasts, often with a coarser resolution, have the ability to predict uncertainty in future conditions. As both forecasts are widely deployed by weather forecasting centers, it is essential to have a comparative understanding of the performance of these two

types of forecasts. Forecasting service providers would want to know how much resource to invest in each type of the forecasts; and forecast users would want to know which forecast products are better to use. However, past published comparisons tended to be limited in scope, for example, for only specific locations and weather events, and involving only raw forecasts.

In this work, we conduct a comprehensive comparison of the performance of a deterministic model and an ensemble model of the Australian Bureau of Meteorology in forecasting daily precipitation across Australia over a period of 3 years. The deterministic model has a horizontal grid spacing of approximately 25 km, and the ensemble model 60 km. Despite the coarser resolution, the ensemble forecasts are found to be superior by a number of measures, including correlation, accuracy, and reliability. This finding holds true for both raw forecasts from the NWP models and forecasts post-processed using the recently developed seasonally coherent calibration (SCC) model. Post-processing is shown to greatly improve the forecasts from both models; however, the improvement is greater for the deterministic model, narrowing the performance gap between the two models. This work adds strong evidence to the general notion that coarser-resolution ensemble NWP forecasts perform better than deterministic forecasts.

Keywords:

Pitch talks for poster session 2 / 54

Predicting river flow level categories using SMOS soil moisture within a machine learning approach

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Soil moisture is a key component of the terrestrial water cycle and runoff generation. Hence, we explore if it is a good predictor for anticipating episodes of high/low river flow. We built a machine learning ensemble classifier; Random Forest model which uses 15 dynamic and 10 static features for predicting river flow categories expressed as quintiles based on the re-analysis derived climatology. The model is designed to give predictions up to 10 days in advance. It is built using data in over 608 European catchments during the period March 2017 to May 2018. We demonstrate the predictability of river flow category and the relative importance of the SMOS soil moisture feature. A first model was constructed and validated using predictors from observations, results were promising achieving an accuracy score for test data of 83%, 74%, 67% and 59% for 10-, 5-, 3-, and 1-day lead time models respectively. We rebuilt the model using predictors from the ECMWF IFS ensemble forecast. The new model has been tested against operational forecasts from the European Flood Awareness System (EFAS) - the state of the art operational flood forecasting system which is part of the Copernicus Emergency Management Service (CEMS).

Keywords:

Machine learning, SMOS, ensemble forecast, EFAS

Pitch talks for poster session 2 / 21

Evaluating the post-processing of the European Flood Awareness System's continental scale streamflow forecasts

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Uncertainties are inevitably introduced throughout streamflow forecasting systems and untreated they can limit the value of the forecasts to end-users. In recent decades several post-processing methods have been introduced and shown to improve forecast skill through bias and spread correction. The European Flood Awareness System, part of the European Commission's Copernicus Emergency Management Service, post-processes its medium-range ensemble flood forecasts at over a thousand stations across Europe where historic and near real-time observations are available. A combination of different techniques, namely the Model Conditional Processor, Ensemble Model Output Statistics, and the Kalman Filter are used to account for hydrological and meteorological uncertainties using recent observations and forecasts. Evaluation of the post-processing method is performed using two years of twice-weekly reforecasts. In general, the skill of the forecasts is improved, but the magnitude of this improvement decreases at longer lead-times as recent observations become less impactful. The improvement from post-processing is found to vary substantially between the stations and the continuous ranked probability skill score is used to investigate the impact of different station characteristics. Low-lying large catchments are shown to have the greatest increase in skill from post-processing whereas small high-elevation catchments are harder to correct. Additionally, it was found that the flood magnitudes observed in the historic record are of greater importance than the length of the record itself for determining the effectiveness of the post-processing method.

Keywords:

post-processing, continental-scale, uncertainties, forecast evaluation

Pitch talks for poster session 2 / 82

Verifying precipitation from the Global Ensemble Forecast System in Maule, Chile

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Medium range (1-7 days) meteorological forecasts are critical to produce hydrological predictions that support decision-making in water resources management. In this work, we assess the quality of precipitation and temperature reforecasts obtained from the Global Ensemble Forecast System (GEFS) for the period 1985-2018, using the national gridded product CR2MET as the historical reference dataset. Our study domain is the Maule River Basin in Chile which is well-known for agricultural and hydropower production. We evaluate different attributes that describe the quality of raw forecasts at the catchment scale for 1-7 day lead times. Additionally, we apply Ensemble Model Output Statistics (EMOS) and Bayesian Model Averaging (BMA) to enhance the forecast quality at different lead times. The raw GEFS forecasts provide acceptable skill, especially for short lead times (1-3 days). The post-processing reduces the probabilistic error of precipitation forecasts, especially during the summer season (November-March), whereas the continuous ranked probability skill score (CRPSS) from EMOS, with raw GEFS as the reference, remains almost invariable from

April to October.The post-processed BMA dataset significantly improves the reliability of the forecast compared to EMOS, but presents an inferior CRPSS in the April-December period. Overall, these results demonstrate the importance of post-processing to obtain better predictions of meteorological forcing in mountain regions.

Keywords:

verification, forecast, GEFS, scores, Andes

Pitch talks for poster session 2 / 46

Real time flood forecasting in the Chenab basin in Pakistan

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The Chenab river a tributary of the Indus is extremely vulnerable to floods. It is a transboundary river with the upper catchments in India. In September 2014 the Jammu and Kashmir region received heavy rainfall which triggered floods and landslides in India and Pakistan. Nearly 277 people in India and around 280 people in Pakistan were killed due to the floods. Considering the high vulnerability to flood disasters in the Chenab basin timely flood forecasts is necessary to save lives and livelihoods. However, the availability of real-time data from upper catchments is limited providing an opportunity for use of satellite data for flood prediction.
A real time flood forecasting system was developed using globally available datasets. The system was developed using a precipitation-runoff model for basin catchments integrated with a hydrodynamic model for computing flood propagation along major rivers utilizing the freely available global satellite meteorological forcing. The hydrological model was set up using the 30 m SRTM DEM, satellite rainfall data using GPM Imerg and calibrated using the observed discharge data at Marala and Akhnoor from 2013 to 2015. The model was validated using the discharge data of 2017. The system was piloted in 2019 using the GPM data along with GFS 50 km resolution providing a 3 days forecast. The model was found to capture the occurrence of the floods and its trends and is a promising tool to be used for flood forecasting.

Keywords:

flood forecasting, satellite data, transboundary catchment, hydrological model, Chenab river

Pitch talks for poster session 2 / 5

Towards a seamless combination of short-term deterministic with mid-term probabilistic hydrological forecasts

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CNR is the concessionary of the French part of the Rhône river, operating and managing the river in accordance with its three missions: electricity production, river navigation development, and irrigation supplying. To optimize the management operations, two operational hydrological forecasting

tools – that have been developed internally – are used daily. They provide, on the different sub-catchments: (1) deterministic hourly forecasts, up to 4 days and (2) probabilistic daily forecasts, up to 14 days. The results of these tools are then independently assessed by the forecasters, to deliver an optimized forecast for the management of the operations.

To facilitate the forecaster’s task, and to homogenize the forecasts, a combination of the two tools has been developed. Both tools use a 365-days assimilation period with past observations to initialize the model parameters. The deterministic hourly forecasts with human expertise are used as observations in the assimilation scheme of the probabilistic daily forecasts, up to 4 days, and the probabilistic daily forecasts are only run between the 5th and 14th next days. This way, the probabilistic daily forecasts begin in coherence with the results of the deterministic hourly forecasts from the 5th day. Improving the coherence between these tools results in a better understanding of the long-term processes for the forecasters.

The overall quality of the probabilistic daily forecasts is improved thanks to the human expertise on the deterministic hourly forecasts, leading to finer forecasts, with a better accuracy, for the first 4 days. This eases the work of the forecasters, as they do not need to adjust the probabilistic forecasts in accordance to their previous expertise on the deterministic forecasts. As a result, operations for flow management are easier to optimize.

Keywords:

Combination of tools; hydrological forecasts; coherence of forecasts; deterministic and probabilistic

Pitch talks for poster session 2 / 63

Flood risk assessment on small catchment with ECMWF ensemble forecasts in operational conditions

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We evaluate the ability to assess a flood risk up to 5 days on small catchments (<2000km²) with ensemble rainfall forecasts from ECMWF and the tools available to Vigicrues network in operational conditions.
The study covers several catchment from various regions of France. The discharges are computed with GRP rainfall-runoff and post-processed with a non parametric method.
The GRP model is a continuous, lumped storage-type model designed for flood forecasting. It uses catchment areal rainfall as inputs. In this study, the calibration used for each catchment is the same as in operational setup.
The meteorological input is total precipitations field from ECMWF ensemble. The quality of the precipitation forecasts are evaluated on 12 hours accumulations.
Each member of the ensemble is transformed in catchment areal rainfall and used as an input of GRP model to generate a discharge ensemble forecast. Since GRP time step is 1 hour, we use hourly precipitation fields from 1 to 90 hours and 3-hourly divided by 3 from 90 to 120 hours.
The hydrological model uncertainties are assessed with a non-parametric method which provides an empirical distribution of relative errors. These errors will be applied to each member of the hydrological ensemble. The obtained values are pooled together to estimate a cumulative distribution.
We evaluate the accuracy and the reliability of the forecasts with and without a post-processing.

Keywords:

ensemble
lumped model
operational

Pitch talks for poster session 2 / 41

Short-Range Streamflow Forecasting Using Multi-Models Over Snow Dominated Basin In Turkey

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Transferring theory to short-term operational practice is challenging especially for snowmelt runoff forecasting due to harsh topography and complex response of basins. There are many uncertainties arising from temporal and spatial variability of snow cover, forcings, modelling structure and initial states. This study attempts to combine different techniques for reducing and estimating hydrological predictive uncertainty such as the use of multi-prediction data (deterministic and probabilistic), multi models and error correction. Snow dominated mountainous headwater basin in Turkey (upper Euphrates), are selected due to high runoff potential, extensive snow cover and the need of an operational forecast system. Probabilistic and deterministic numerical weather forecasts are obtained from Ensemble Prediction Systems (EPS, 9-day lead-time) and Weather Research and Forecast (WRF, 2-day lead-time). The basin is simulated using HBV and SRM conceptual hydrological models having different snowmelt routines. The first one produces snow cover extent by means of calculating snow water equivalent in the model itself and the latter directly takes satellite snow data as an input to the model. Snow depletion curves are acquired from MODIS cloud-filtered daily snow cover images. Both models are calibrated and validated for 2001-2008, 2009-2014 periods, respectively, with acceptable Nash-Sutcliffe efficiency. The developed multi-model structure is evaluated under hindcasting experiment set-up for 2011-2015 period with various verification metrics (hit and false alarm rate, bias, Brier Skill Score). In the end, pros and cons of using different forcings and multi-model structure are discussed in detail for exploiting uncertainty in the snowmelt processes.

Keywords:

snowmelt runoff, Euphrates River, hydrological models, ensemble forecasting

Pitch talks for poster session 2 / 115

Introduction to poster session 2

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Pitch talks for poster session 2 / 107

Q & A

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Pitch talks for poster session 3 / 81

Flood monitoring using passive microwave remote sensing in the Senegal River, Western Mali

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Accurate flood forecasting and early warning are critical for disaster risk management. Detecting and forecasting floods at an early stage is certainly relevant for Mali, and crucial in order to prevent a hazard from turning into a disaster. Remotely sensed river monitoring can be an effective, systematic and time-efficient technique to detect and forecast extreme floods. Conventional flood forecasting systems require extensive data inputs and software to model floods. Moreover, most models rely on discharge data, which is not always available and is less accurate in overbank flow conditions. There is a need for an alternative method which detects riverine inundation, while making use of the available state-of-the-art.

This research investigates the use of passive microwave remote sensing with different spatial resolutions for the detection and forecasting of flooding. Brightness temperatures from two different downscaled spatial resolutions (1x1 & 10x10 km) are extracted from sensors and converted into discharge estimators: CM & CMc ratio. Surface water has a low emission, thus let the CM ratio increase while surface water percentage in the pixel increases. Sharp increases are observed for over-bank flow conditions.

Overall, passive microwave remote sensing model results of the different spatial resolutions are compared with rating curves and TLCC. The passive microwave remote sensing model does not require extensive input data when used as an Early Warning System (EWS), as many smaller-scale EWS do, we suggest that when improved, the passive microwave remote sensing method is implemented as part of an integrative EWS solution, including a passive microwave remote sensing model and various other models. This would allow for early warnings in data-scarce regions and at a variety of lead times. In order for this to be effective, we suggest that more research be done on correctly setting trigger thresholds, and into the potential spatial interpretation of CMc.

Keywords:

Flood monitoring
Passive Microwave Remote Sensing
CM ratio
CMc ratio

Pitch talks for poster session 3 / 145

Blue-green roofs with forecast-based operation to reduce the impact of climate extremes in cities

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In the coming decades, climate change will increase the intensity and frequency of extreme summer precipitation events as well as heatwaves. Green infrastructure (e.g. parks and green roofs) is generally seen as an effective adaptation measure to address these challenges, especially in the urban setting. Green roofs, however, are often criticized for having a limited water retention capacity during high-intensity rainfall events. In response to this concern, the city of Amsterdam has started a project (RESILIO, https://resilio.amsterdam/en/smart-blue-green-roofs) to investigate a new innovation in this field: smart blue-green roofs. These roofs have an extra water retention layer underneath the green roof, which can be used to buffer extreme rainfall volumes or as a capillary irrigation system for the plant layer on hot and dry summer days. The smart valve on the roof can be opened when extreme precipitation is predicted to create enough capacity to capture and retain the incoming rainfall. It is yet unknown if the accuracy of the forecasts used to trigger drainage is sufficient enough to provide added value. This is because false alarms in the forecast can lead to a reduction of water availability, and therefore a reduction in evaporative cooling and plant health.
To test the magnitude of this trade-off, we evaluate the performance of ensemble precipitation forecasts from the European Centre for Medium-Range Weather Forecasts (ECMWF) to trigger drainage from blue-green roofs. We simulate blue-green roofs in a hydrological model on 28 locations over the Netherlands, using hourly meteorological observations over the last 11 years and different quantiles of the ECMWF ensemble precipitation forecasts. They are used to trigger drainage from the roof if an extreme precipitation event is predicted. We show that this forecast-based drainage creates enough buffer capacity to capture 70-97% of extreme rainfall (>20mm/hr), without major losses in water availability, and therefore evaporative cooling, on hot summer days (>25 degrees Celsius).
We conclude that blue-green roofs are much more effective in reducing pluvial flood risk and heat stress than green roofs, and that relatively low-resolution ECWMF precipitation forecasts can increase the effectiveness of these local-scale nature-based solutions. Initial results of a suitability analysis to upscale this solution in Amsterdam showed that approximately 14km2 of roof surface is potentially suitable for blue-green roof application, which is on average 10% of the area of urban catchments. These results show that blue-green roofs can help to make Amsterdam and perhaps other cities more resilient to the extreme weather events of the future.

Keywords:

Pitch talks for poster session 3 / 143

Emulation of 2D hydrodynamic flood inundation model using deep learning with spatial reduction and reconstruction

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The computational complexity of 2D hydrodynamic models has limited their applications to real-time ensemble flood forecasting and uncertainty analysis. In this study, we introduce a novel framework using deep learning (DL) with spatial reduction and reconstruction (SRR) to emulate 2D-hydrodynamic models for flood inundation simulation. In the framework, we identify representative locations using the SRR method and simulate the water levels at these locations with DL models. The simulated water levels are then passed back to the SRR method to map flood inundation. The DL models include a built-in input selection layer and the Long Short-Term Memory architecture for time series modelling. They are trained with pre-computed 2D hydrodynamic model results. In our application to a real-world river system, the framework detects flood inundation with over 99% accuracy and the Relative RMSEs of predicted water levels are below 20% for over 80% of the grid cells in our model domain. With the developed methods, it takes less than 4 seconds to simulate flood inundation at any time step for a model domain with over 3 million grid cells. Therefore, the proposed framework can potentially be used as an emulator of 2D hydrodynamic flood inundation model for characterizing uncertainty in applications.

Keywords:

Pitch talks for poster session 3 / 134

Introduction to poster session 3

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Pitch talks for poster session 3 / 61

Combining pan-European flood hazard forecasts with exposure information to enhance local decision making

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As part of the TAMIR project (tamir-project.eu), flood hazard forecasts are being combined with exposure data at the pan-European level to derive flood impact forecasts. These will provide local emergency responders with forecasts that can be used to make decisions at local scales. This talk describes the creation of the TAMIR exposure data through end user engagement and open source datasets, and how the paucity of constituent data available at this large scale makes this a challenging exercise. The talk will also present the verification of this data through comparison with local exposure information, and conclude by discussing the ongoing incorporation of final facet of impact/risk to be considered, vulnerability.

Keywords:

Impacts; Exposure; Flood forecasts; TAMIR

Pitch talks for poster session 3 / 9

Unravelling the interplay between flood model selection, simulations outcomes, and resulting flood risk – a case study in the Ganges-Brahmaputra delta

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Fluvial flood events are and will remain a major threat to people and infrastructure along rivers world-wide. Global Flood Hazard Models (GFHMs) can be applied to simulate flood hazard for various return periods, informing the planning of disaster risk reduction measures.
Within GFHMs, hydrological processes are simulated by, for example, global hydrologic models (GHMs). As such, GFHM and consequently GHM selection strongly determines how well flood hazard can be simulated. Depending on the selection, obtained discharge and flood maps can vary and, in turn, can have major implications for the analysis of flood risk. Understanding the role of model selection in the flood risk modelling process is thus of great importance in assessing flood risk estimates and their uncertainty.
By means of GLOFRIM, it is possible to do not use the GHMs 'as is', but align their forcing through a spatially explicit model coupling cascade. Consequently, evaluation and benchmark of models' output is better comparable and not distorted by the influence of different meteorological input data sets as it is oftentimes the case in similar studies.
For this study, the models PCR-GLOBWB, CaMa-Flood, and Lisflood-FP were applied. While using higher-order routing schemes do, rather counter-intuitively, not improve discharge estimates, flood maps obtained with two-dimensional Lisflood-FP model improved flood extent simulations. Combining the obtained flood maps with actual population data gives subsequently a first-order estimate how GHM selection translates into actual flood risk.
The research shows that model selection and its interplay with forcing data are important drivers of uncertainty of simulated flood risk. As such, it is detrimental that the various characteristics of a model are known not only to modelers, but also 'data users' to facilitate the optimal model selection depending on model purpose.

Keywords:

flood risk, hydrology, model benchmark, global flood model

Pitch talks for poster session 3 / 65

Challenges of event-based evaluation of flash floods: example of the October 2018 flood event in the Aude catchment in France

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Flash floods can cause extensive social and economic damages. They are a particular type of event difficult to forecast since they develop quickly, as a combined result of intense and localized convective storms falling over reactive catchments. The French Mediterranean region is particularly prone to flash floods given its proximity to the Mediterranean Sea and the presence of mountain chains near the shore. In this context, flash flood forecasting systems play a key role in accurately detecting such events in space and time and activating early warnings in advance to prevent fatalities and economic damage. There has been increased interest in using ensemble forecasts to better quantify the risk of flash floods and inform decision making. These mainly come from applying statistical perturbations to real-time radar data, building ensembles from time-lagged deterministic forecasts from numerical weather prediction (NWP) models, using small scale convection-permitting numerical prediction models, or a combination of these alternatives. However, the evaluation of the performance of flash flood forecasting and warning systems presents many challenges. It has many facets

depending on the system's characteristics and purposes, as well as on the hydrological response of the catchments.

In this study we focus on the challenges of event-based evaluation of flash floods. We evaluate five ensemble precipitation forecast products recently developed by the French meteorological service (Météo-France) for an extreme flash flood event that took place on 14-15 October 2018 in the Aude River in the south of France. These products are based on the AROME NWP model, on a combination of the AROME forecasts with nowcasting AROME products or the AROME-IFS product which is based on AROME NWP model with boundary conditions are determined by IFS model from ECMWF. They are used as input to a semi-distributed rainfall-runoff model previously calibrated over 10 years of hourly hydrometeorological data (2008-2018). Our aim is to investigate, from a hydrological perspective, how well these ensemble forecast products can capture the extreme flood event at the sub-catchment scale and how ensemble forecast verification can be applied given the magnitude and short duration of the event (less than 48 hours). Hydrological ensemble forecasts are compared to simulated discharges (using observed precipitation) and to peak discharges estimated at ungauged sites during the HyMeX post-event survey. The evaluation focuses on forecast discrimination (ROC curve), the spread-skill relationship score, diagrams of forecast accuracy, and visual inspection of hydrographs for specific lead times. The results show that the differences among the products in terms of discrimination are small. Only detailed evaluation based on the visual inspection of hydrographs and the spread-skill relationship provide enough information to identify the best ensemble precipitation forecast product for flash flood forecasting.

This work is part of the French national project ANR PICS (contract number: ANR-17-CE03-767 0011); https://pics.ifsttar.fr/.

Keywords:

event-based forecast evaluation, flash floods, ensemble forecasts

Pitch talks for poster session 3 / 57

The challenges of making seamless pan-European flash flood impact forecasts useful for local decision making

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Seamless 1 km pan-European flash flood impact forecasts have been developed within the TAMIR project. An impact matrix is used to combine flash flood hazard forecasts, derived by blending hourly radar based nowcasts and medium range numerical weather predictions, with exposure information regarding population and critical infrastructure. The impact forecasts are intended to help end users, such as civil protection agencies, to make local decisions. However, ensuring these forecasts can be used for such purposes is challenging due to the scale disconnect between a continental forecast system and the local scale at which decisions are made.

We will introduce the seamless pan-European flash flood impact forecast system and the ongoing efforts to ensure its usefulness. These efforts include end user engagement and verification by computing the skill against flood impacts derived from radar based re-analysis and benchmarking against persistence. We also present the development of web services to deliver the flood impact products. These allow end users to integrate and customise the products to meet their specific requirements.

Keywords:

Impacts; Flash floods; Forecasts; Verification

Pitch talks for poster session 3 / 34

Ensemble Flash Flood Predictions Using a High-Resolution Nationwide Distributed Rainfall-Runoff Model: Case Study of the Heavy Rain Event of July 2018 and Typhoon Hagibis in 2019

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The heavy rain event of July 2018 and Typhoon Hagibis in October 2019 caused severe flash flood disasters in numerous parts of western and eastern Japan. Flash floods need to be predicted over a wide range with long forecasting lead time for effective evacuation. The predictability of flash floods caused by the two extreme events are investigated by using a high-resolution (~150 m) nationwide distributed rainfall-runoff model forced by ensemble precipitation forecasts with 39-h lead time. Results of the deterministic simulation at nowcasting mode with radar and gauge composite rainfall could reasonably simulate the storm runoff hydrographs at many dam reservoirs over western Japan for the case of heavy rainfall in 2018 (F18) with the default parameter setting. For the case of Typhoon Hagibis in 2019 (T19), a similar performance was obtained by incorporating unsaturated flow effect in the model applied to Kanto region. The performance of the ensemble forecast was evaluated based on the bias ratios and the relative operating characteristic curves, which suggested the higher predictability in peak runoff for T19. For the F18, the uncertainty arises due to the difficulty in accurately forecasting the storm positions by the frontal zone; as a result, the actual distribution of the peak runoff could not be well forecasted. Overall, this study showed that the predictability of flash floods was different between the two extreme events. The ensemble spreads contain quantitative information of predictive uncertainty, which can be utilized for the decision making of emergency responses against flash floods.

Keywords:

Flash floods, Rainfall-Runoff-Inundation model, Meso-scale Ensemble Prediction System (MEPS)

Pitch talks for poster session 3 / 17

Using the GEOGloWS ECMWF Streamflow Services for forecasting inundations and urban flooding in Israel

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Urban inundations and flooding are a major and growing concern for many places. Previous studies have shown increased precipitation intensities trend in the medtrianain region mostly, during

summer and transition seasons convective storms due to increase in SST. Together with land use changes and rapid increase in urbanization that leads to decrease in infiltration, runoff generation is higher and urban flooding becomes more common and intense.
The medtrianain coast of Israel is densely populated, mostly the Tel Aviv metropolitan area. Statistical analysis shows sharp increase in precipitation intiticities for different time durations (10 min, 60min and 24h) for the last 50 years and future projections suggest that this trend will continue in the coming decade due to climate change. The Israli Fire and Rescue Authority reports reveal that rescue operations due to urban flooding in the central coast doubled itself from 15,000 calls a year to 30,000 during the recent years in respect to the long term average. During the last two years there were several rare extreme urban flooding events with damage to properties and casualties.
It is clear that there is a growing need to develop more advanced tools for improving preparation before extreme weather events and providing the "First responders" Authorities the possibility to take proactive approach and make better decisions.
In this paper, we will present the urban flooding forecasting system for coastal Israel. It includes both streamflow predictions based on the GEOGloWS ECMWF Streamflow Service and precipitation thresholds that were for each city in the domain, based on output from the local high resolution (1 km) WRF model for Israel.
Urban flooding can result both from high streamflow discharges (river banks over spill), from direct heavy rainfall or from the combination of both of them at the same time: streamflow together with direct rainfall. The city urban runoff network drainage the runoff to the lowest place in the city. It can be the Ocean/sea in some cases or rivers that flow inside/near the city. However, when the water level in the River is high, above the drainage outlets, the runoff is unable to flow into the river and the outcome is severe city inundations.
In order to be ready and to be able to take early actions like pumping or even evacuations, the city needs to know in advance the combined effect of the water level in the river and the direct rainfall in the city itself. Data regarding just streamflow or precipitation itself would not allow the city managers to get the full picture and to be better prepared.
The streamflow-precipitation threshold modeling system outputs described in this paper was used seccsuffly in the rainy season of 2020/21 by the IFRA and several municipalities in Israel like the city of Tel Aviv, Ramat Gan, Ashdod and Nes Ziona.

Keywords:

GEOGloWS ECMWF Streamflow Services, Urban flooding, city-wide Innudations.

Pitch talks for poster session 3 / 55

Rainfall nowcasting using commercial microwave links from cellular communication networks

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Rainfall nowcasting can play an important role in improving the forecasts of the timing and location of rainfall events up to several hours in advance. Although nowcasting algorithms were initially developed for radar-based quantitative precipitation estimates (QPE), alternative rainfall estimation sources can be of interest in the absence of, or complementary to, weather radars. The use of signal level data from the roughly four million commercial microwave links (CMLs) worldwide is a promising option. CMLs are close to the ground radio connections used in cellular communication networks. Rain attenuates the signal between the transmitter and receiver. When the signal attenuation is known, path-averaged rainfall intensities can be derived.

As a proof of concept, we demonstrate the use of country-wide rainfall maps from CML QPE for rainfall nowcasting in the Netherlands. With the pySTEPS algorithm, we created ensemble nowcasts with both CML and real-time radar QPE for twelve summer days in 2011.

The CML nowcasts compare well to the radar rainfall nowcasts for most events. The interpolation of the path-averaged rainfall intensities to country-wide rainfall maps leads to rainfall fields that are not as accurately represented as in the radar QPE, which also affects the nowcast quality. Rainfall volumes of the CML QPE are, however, closer to the observed amounts than the real-time non-bias-corrected radar QPE, which results in better forecasts of high-intensity rainfall events.

We see potential for rainfall nowcasting with CML data, especially for areas without radar coverage but with high CML density, like urban areas in developing regions. A main limitation that can be improved in future work is the rainfall advection derivation, which can be heavily impacted by regions with limited CML data coverage. Most nowcasting algorithms rely on these advection derivations. The use of motion fields from for instance satellite imagery can potentially overcome this issue.

Keywords:

Nowcasting, Rainfall, Radar, Commerical Microwave Links

Pitch talks for poster session 3 / 66

Google's Flood Forecasting Initiative: Globally-Scalable Models for Hyper-Local Information

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Google's operational flood forecasting system was developed to provide accurate real-time flood warnings to agencies and the public, with a focus on riverine floods in large, gauged rivers. This forecasting system consists of four components: partnering with local governments and agencies for historical and real-time data sharing, river stage forecasting, inundation mapping, and alert distribution. Scalable and computationally efficient machine learning models are used for stage forecasting and inundation modeling. The flood warning system was operational in India and Bangladesh during the 2020 monsoon season, covering flood-prone regions that are home to more than 220M people. During this operational period the stage forecast model yielded a median NSE of 0.97 and the inundation model yielded a median F1 of 66%. Flood alerts were sent to approximately 10M individuals, and to relevant authorities and emergency organizations. Ongoing work includes extending the models to global coverage including ungauged basins (based on recent ML results), alternative dissemination options including a publicly accessible data hub, and post-hoc analysis of the effectiveness of Google's alerting system.

Keywords:

Flood Forecasting, Operational System, Global Scale, Machine Learning

Pitch talks for poster session 3 / 33

Development of nationwide 150m high-resolution Rainfall-Runoff-Inundation model for flood forecasting: Integration of 26,000 cross-

section data to improve flood predictions

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As a basis of wide-area and high-resolution flood forecasting, we have been developing a nationwide 150m resolution Rainfall-Runoff-Inundation (RRI) model for whole Japan. This model analyses runoff and inundation at all once, and therefore is able to simulate basin-scale flood disasters. We have confirmed the applicability of this model to real flood disasters by case studies of 2018 West Japan Heavy Rainfall and 2019 Typhoon Hagibis.
When we analyse floods with distributed hydrological model, including RRI, setting and parametarisation of river channel have a big impact on the results. In the past case-studies, we have used simplified rectangular-shape cross-section, and estimated width and depth parametres based on upstream basin area. In this study, we have introduced a nationwide river cross-section survey database in the whole-Japan RRI model, and integrated around 26,000 cross-sections in the model. For investigating the effect of river cross-section introduction, we conducted a flood simulation of 2018 West Japan Heavy Rain with and without real river cross-sections, and compared the result of these 2 cases with observed discharge and waterlevel data at around 300 observation points in Kyushu, Shikoku, and Chugoku regions, in west Japan. As a result, we confirmed that at each observation point 1) flood peak time tends to delay around 1 to 2 hours, 2) peak discharge tends to decrease, and 3) peak waterlevel tend to increase, by introducing cross-section database. We could also confirm that Relative Peak, NSE, and KGE indices of discharge and waterlevel tend to improve by introducing cross-section database.
In the presentation, we will discuss further analysis and quantification of result improvement.

Keywords:

Flood Predictions, Distributed Hydrological Model, River Geometry, River Cross Section

Pitch talks for poster session 3 / 64

A first evaluation of the future CEMS systematic global flood monitoring product.

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The Global Flood Monitoring (GFM) system of the Copernicus Emergency Management Service (CEMS) will soon deliver global, near-real time flood extent maps for each newly acquired Sentinel-1 Interferometric Wide Swath image. The GFM product will be available within a maximum of 8 hours following image acquisition. It will comprise 11 layers including maps of observed water and flood

extents with classification uncertainty. Layers describing reference water bodies, exclusion areas, affected populations and land covers will be generated along with product quality flags and Sentinel-1 metadata, which includes schedules of subsequent observations and respective image footprints. In this study, we evaluate the observed flood extent layer with the associated classification uncertainty information. These two layers are generated based on the combination of three independently developed flood mapping algorithms, that individually derive the flood information from the Sentinel-1 data and its archive, therefore increasing the GFM's accuracy and robustness. The flood extent is calculated from a combination of the three binary maps based on a majority decision, where a pixel is considered to be flooded when there is classification agreement with at least two algorithms. The classification uncertainty layer is computed as the product of the uncertainty values estimated by the three algorithms. The evaluation is carried out over three test sites in different parts of the world, namely in Texas, in Greece, and in Myanmar. The sites were affected by flood events that occurred in 2017, 2018 and 2019, respectively. The evaluation is performed with reference flood extent maps derived from optical Sentinel-2 images, acquired within an accepted timeframe of a maximum of one day from the acquisition of the corresponding Sentinel-1 images. The flood extent maps are evaluated based on Critical Success Index and Overall Accuracy metrics. Classification uncertainty is evaluated using reliability diagrams, also known as quantile-quantile-plots.

Keywords:

Global and near-real time flood mapping, Sentinel-1 images, Copernicus Emergency Management Service.

Pitch talks for poster session 3 / 13

Floodwater detection in urban areas using Sentinel-1 and WorldDEM data

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Remote sensing using SAR is an important tool for emergency flood incident management. At present operational services are mainly aimed at flood mapping in rural areas, as mapping in urban areas is hampered by the complicated backscattering mechanisms occurring there.
A method for detecting flooding in urban areas that may contain dense housing is presented. This largely uses data sets that are readily available on a global basis, including open-access Sentinel-1 data, the WorldDEM DSM, and open-access World Settlement Footprint data.
The method is a change detection one that estimates flood levels using pre-flood and post-flood S-1 images. In urban areas, it searches for strong double scattering backscatter from wall-ground structures in the pre-flood image, where the wall is aligned within 30° to the satellite direction of travel. If such double scatterers have high backscatter ratios in the post-flood compared to the pre-flood image, they are likely to be flooded, while those having ratios close to 1 are likely unflooded. Flooded double scatterers are paired with nearby unflooded ones, and the associated ground heights averaged to estimate local flood levels.
Rural flooding adjacent to the urban areas will often have a reduced SAR backscatter in the post-flood image due to specular reflection away from the sensor, and rural flood regions are identified using adaptive backscatter thresholding. Water levels are estimated locally at region boundaries by intersecting them with the DSM. The levels in the urban and rural areas are interpolated over the domain to form a flood level surface. Areas of urban flooding are detected by comparing this surface to the DSM.
Results will be shown for two flood events that occurred in the UK during the storms of Winter 2019-20.
The method has potential for operational use for detecting urban flooding in near real-time on a global basis.

Keywords:

flood, hydrology, urban, SAR

Pitch talks for poster session 3 / 20

An evaluation of ensemble flood inundation mapping spatial skill

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An ensemble of forecast flood inundation maps has the potential to represent the uncertainty in the flood forecast and provides a location specific, probabilistic, likelihood of flooding. This gives valuable information to flood forecasters, flood risk managers and insurers and will ultimately benefit people living in flood prone areas. The selection of spatial scale for presenting the flood maps is important as it should reflect the spatial uncertainty of the forecast. High resolution digital terrain models can be used to produce very detailed forecast inundation maps. It is an open question whether such detailed forecast flood maps are skilful at accurately capturing this level of spatial detail.

We investigate a method of evaluation of the spatial spread-skill for forecast ensemble flood inundation maps from the Flood Foresight system. The Flood Foresight system utilises a hydrodynamic model to create a simulation library of potential flood inundation maps. The forecast flood map is selected using GloFAS output and compared to flood maps derived from Sentinel-1 Synthetic Aperture Radar (SAR) satellite data. The spatial spread-skill method, previously applied to convective precipitation forecasts, computes an agreement scale (at grid level) between each unique pair of ensemble flood maps and between each ensemble flood map with the SAR derived flood map. The resulting agreement scale maps tell us the spatial predictability of the ensemble flood inundation forecast and provide an evaluation of the spatial spread-skill performance.

Keywords:

Ensemble flood maps
Synthetic Aperture Radar
Spatial spread-skill

Pitch talks for poster session 4 / 11

From Global to Local: Validating Forecast High Flow Events from GEOGloWS ECMWF Streamflow Services

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The disruption of the paradigm for how streamflow information is created and disseminated is one of the most important contributions of the GEOGloWS ECMWF Streamflow Services (GESS) to the water resources and decision-making community. Through web services, actionable streamflow forecasting information created and run on proven global systems is provided in scales meaningful to local water organizations. This new capability helps local communities become more competitive and effective but highlights the need for locally collected streamflow observations to validate the forecast and to ensure the quality of information at the local level.
The GEOGloWS ECMWF Streamflow Services (GESS) is a global streamflow prediction system (GSPS) that uses the gridded surface runoff results calculated by ECMWF using the HTESSEL model before the resampled and performs an area-weighted grid-to-vector downscaling for the runoff. GESS computes this cumulative runoff volume at each time step as an incremental contribution for each sub-basin. The Routing Application for Parallel computation of Discharge (RAPID) model is then used to route these inputs through the stream network. GESS provides a 40-year historic simulation based on ERA-5 reanalysis precipitation, a 15-day 51-member ensemble forecast, and a 10-day high-resolution forecast. The streamflow services are accessible through an Application Programming Interface (API) which is transforming the way globally derived information can be accessible and usable by local river and flood management agencies who need better data to make more informed decisions. The API makes it possible for a broader community to participate in validation studies and understand how to better apply and improve accuracy and skill.
In this paper, we will present a methodology that uses the API along with locally collected streamflow observations to evaluate the performance of the GESS historical simulations and short-term forecast for any river in the world. This methodology requires the record of forecast during the flood event, the observed streamflow during the flood event, the historical simulated streamflow, and the historical observed streamflow for the place of interest. For any event, in particular, we can estimate how many days in advance the GESS was capable of predicting the flood event and a measure of how accurate it was. This methodology was tested for different events with different hydrological conditions around the world, including in Central America, Israel, United States, and Colombia. Documentation and Python notebooks are provided as a template for similar analysis for any event on any river where observed data are available. Because the GESS provides free and open access the analysis can be done by anyone in the larger community who has an interest or need.

Keywords:

High Flow Events, GEOGloWS, global streamflow prediction system, local scale, global scale

Pitch talks for poster session 4 / 12

From Global to Local: Development of a Bias correction method for the GEOGloWS ECMWF Streamflow Services global model

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The GEOGloWS ECMWF Streamflow Services (GESS) is a global streamflow prediction system (GSPS) that uses the gridded surface runoff results calculated by ECMWF using the HTESSEL model before the resampled and performs an area-weighted grid-to-vector downscaling for the runoff. GESS computes this cumulative runoff volume at each time step as an incremental contribution for each sub-basin. The Routing Application for Parallel computation of Discharge (RAPID) model is then used to route these inputs through the stream network. GESS provides a 40-year historic simulation

based on ERA-5 reanalysis precipitation, a 15-day 51-member ensemble forecast, and a 10-day high-resolution forecast.
Decision-makers are rightfully concerned about the accuracy and uncertainty of hydrologic model predictions. Results, as with any model, do not need to be perfect, but they need to be reliable and accurate enough to give decision-makers confidence to use them. This uncertainty is due to the challenge of gathering and processing the needed local data to validate these large-scale models. For global models, this is a challenge as the ability to perform validation over large domains is limited by both data and human resources.
In this paper, we will describe a method to correct the bias in the GEOGloWS historical and forecast simulated streamflow. The method is based on the flow duration curves of the observed and simulated data. We present case studies in the Amazon Region countries where observed data were available for demonstration. We can apply this approach to bias correction using monthly flow duration curves to account for temporal variations in bias that may result. Temporal variations mean that both high and low biases can occur at different times of the year at the same stations. For each case study, we demonstrate an improvement in the bias-corrected historical and forecasted data.

Keywords:

GEOGloWS, hydrology, observed data, simulated data, ERA5, Bias Correction, global streamflow prediction system, global scale, local scale

Pitch talks for poster session 4 / 88

Challenges in setting up a multi-model hydrometeorological forecasting system

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Southeastern Europe has in recent years experienced several extreme hydrometeorological events that have led to severe economic damage and human losses. These events have triggered not only floods, but also forest fires and lead to extreme heat and cold waves. There are several forecasting systems in place for warnings in the region, but there is a need for better tools for collaboration among the national and regional authorities as well as for providing a comprehensive platform for multirisk assessment and potential warning for the region. WMO therefore initiated the South-East European Multi-Hazard Early Warning Advisory System (SEE-MHEWS-A) to strengthen the existing early warning capacity in the region. The project is creating and testing a prototype of a flood early warning system using local information and multiple NWP and hydrological models. The aims of the project are: (1) to strengthen co-operation between national, regional and global authorities; (2) to enhance national multi-hazard early warning systems by making tools and data available to the participating countries and other beneficiaries; (3) to implement impact-based forecasts and risk-based warnings using a multi-model hydrometeorological forecasting system to support all actors in their decision-making and actions, and (4) to harmonize forecasts and warnings in trans-boundary catchments. This presentation will focus on the challenges of setting up the system, preliminary results from the hydrometeorological forecasts and a quick demonstration of the system.

Keywords:

Pitch talks for poster session 4 / 93

Forecasting seasonal water demand across Australia's southern Murray Darling Basin

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The Murray–Darling Basin (MDB) in Australia has experienced a wide range of climate, water market, irrigation efficiency and policy changes over the last two decades. Water management agencies across the MDB have thus faced the challenge of making water delivery decisions within this highly dynamic system. Forecasts of future water demand can be used to support these agencies as they consider the many moving parts of the system. Through interviews conducted over 2020, water management agencies located across the MDB identified the multiple objectives they must balance when managing water resources. These include the timely release of water from storages, preventing storage spills, and managing the degradation of the river channels during water delivery – all while considering the influence of ever-changing commodity pricing, water trade and associated restrictions. Within this project, we partner with several water management agencies to incorporate their management requirements into the development of a seasonal water demand forecasting model, suited for the southern MDB (sMDB).

The model under development is designed to shift water throughout the basin, mimicking the movement of water induced by changes in water availability. The model is designed to operate on a monthly time step and is dependent upon a series of demand functions that are developed for key regions of the sMBD. The model builds upon the already existing annual water demand model developed by the Australian Bureau of Agriculture and Resource Economics and Sciences (ABARES). This work is one part of a greater whole - the larger Linkage Project is titled 'Water availability and demand: better forecasts, better management'. Here we present the design of the model, interesting relationships gleaned from the data and modeling framework, as well as the role of this work within the larger Linkage Project.

Keywords:

Pitch talks for poster session 4 / 94

Improving irrigation water availability forecasting: A case study involving Australia's largest rural water corporation

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Within Australia, water managers are responsible for delivering water at the appropriate time and amount according to water ordered by irrigators, whilst managing the water delivery system in a safe and sustainable manner. An underpinning factor that determines the behavior of irrigators, and thus drives much of their system operations, is the amount of water available for ordering, otherwise known as water allocation. Water managers provide seasonal outlooks (i.e. forecasts) of water allocation, which help guide irrigators as to what their likely water allowance will be in the coming season. The common practice across the Murray Darling Basin in Australia is to provide allocation outlooks with a range of climatic scenarios for the upcoming irrigation season, based on observations of historical streamflow entering different storages. Irrigators then suppose the likelihood of these different scenarios to make farm decisions (e.g. such as the decision to plant specific crops, or whether to buy or sell water). However, the range of scenarios does not incorporate probabilistic information based on current climatic conditions.

This work aims to narrow the uncertainty and improve the accuracy of the allocation outlooks for Australia's largest rural water corporation – Goulburn Murray Water (GMW). Through interviews and meetings with GMW conducted over 2020, it was identified that improved allocation outlooks could help irrigators plan with greater confidence throughout the irrigation season. To achieve this goal, we built upon GMW's current methods for allocating water for their systems. Here we utilize seasonal streamflow forecasts to inform the allocation outlooks as a replacement for the historical climate scenarios used by GMW. Results show that the uncertainty and accuracy of the allocation outlooks have been significantly improved when our methods are validated over the last three irrigation seasons. This work demonstrates the potential of improving water availability forecasts by combining hydroclimatic forecasting expertise together with local system knowledge.

Keywords:

Pitch talks for poster session 4 / 14

Estimating the benefits brought by seasonal forecasts on the management of the Water-Energy-Food nexus in the Jucar river system

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Multipurpose water systems are subject to trade-offs among competing uses that should be identified to estimate the impact of water allocation and avoid undesirable consequences. Hydrometeorological forecasts can support improved operation acknowledging these interlinkages. In this regard, the benefits brought by forecast-based water allocation need to be assessed per sector (e.g. urban, agriculture, hydropower).

This study analyses the economic benefits associated with forecast-based allocation rules on the Jucar river system in Spain. The revenues are calculated by combining Stochastic Dual Dynamic Programming (SDDP) with Model Predictive Control (MPC) forced with the following hydrometeorological forecasts: (1) the current system operating rules forced by historical observations, (2) SMHI's pan-European E-HYPE hydrological forecasting system forced with bias-adjusted ECMWF SEAS5 seasonal meteorological forecasts, (3) five bias-adjusted seasonal meteorological forecasting systems from the Copernicus Climate Change Service (ECMWF SEAS5, UKMO GloSEA5, MétéoFrance System6, DWD GCFS and CMCC SPS3) combined with locally-adjusted hydrological models, and (4) an ensemble system based on local observations of past river discharge.

Results show that forecast-based allocation rules improve the revenues obtained by the current policies forced by historical observations. This demonstrates the potential of adopting forecast-based operating rules without requiring a particular forecasting system. For agriculture, the benefits obtained depend on the forecasting system used, while hydropower's economic returns are similar regardless of the forecast product used. This means that for hydropower the benefits are driven by the integration of forecasts in reservoir operation instead of adopting a particular forecasting system. Results show that both agriculture and hydropower benefit from forecast-based water allocation, creating cooperation opportunities to achieve win-win solutions.

Acknowledgements:

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Keywords:

Seasonal forecasts; water-food-energy nexus; E-HYPE; stochastic programming

Pitch talks for poster session 4 / 44

Development of a web-based decision support system (DSS) for water resources management in Vietnam and Mekong region

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GIS-based web portal has been widely used for sharing data and supporting watershed management in different scales. These tasks, supported by a decision-support system that integrates data from various sources, help to make decision processes more effective and transparent. This paper presents the design and development of the Asean Water Portal (http://waterportal.vaci.org.vn/) which provides access and visualization for historical and forecasted high-resolution data for the entire Vietnam and Mekong region. Current essential water variables include precipitation, temperature, ET, streamflow, soil moisture, water level, reservoir inflow/outflow, sediment concentration etc. at different time scale. Forcing data (i.e., precipitation, temperature) at the resolution of 0.25 deg is merged from multi-sources (i.e., satellite, reanalysis, in-situ) using weighted-ensemble method while the other water variables are generated using Greater Mekong HYPE model (Du et al 2019) and other satellite techniques. The historical data since 1979 is updated once per year to help users understand the characteristics and monitor the variation of the water resources. The forecasting data provides short-term (16-day ahead) and seasonal forecasts (up to 6-month ahead) are updated in near real-time manner to assist decision makers, reservoir operators, and citizens in making plans. The projected impacts of climate change on these water variables are also integrated in the portal for long-term planning application. The portal also provides model performance in different metrics to show the quality control of the provided data and guidance for wider uptake of the data by end users.

Keywords:

Mekong region; decision support system (DSS); water resources management

Pitch talks for poster session 4 / 39

Application of HYPE Model in Simulating Streamflow and Suspended Sediment Concentration at Upper Srepok River Basin in Vietnam

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Vietnam has been facing many challenges related to water resources, such as transboundary water resources management, increasing water demand, degradation of water quality and quantity due to climate change and human activities, among others. One of the most important transboundary river basins in Vietnam is the Srepok River Basin- a main branch of Mekong river basin. We focus our study on the Upper Srepok River Basin (USRB) which is the portion of the Srepok River Basin located within Vietnam. In this study, the HYPE model was applied to the USRB in Simulating River Discharge and Suspended Sediment Concentration (SSC). The HYPE model is an open-source model that simulates hydrological processes and water resources development, such as reservoir operation, irrigation, water use, and wastewater discharge in a river basin (Lindström, G. et al., 2010). The model was calibrated and validated (2000–2015) at a daily time step. Firstly, the daily discharge in USRB has simulated two scenarios with and without reservoirs. Modeling the presence of reservoirs apparently improves the model performance across all stations, RMSE value achieves better results in this case. This approach can show a significant alteration in the natural runoff in the case which has an existence of reservoirs. Secondly, the HYPE model was applied to estimate SSC. The simulated and observed sediment yields (2001–2002) showed a similar tendency. The initial results of the simulated SSC show that the HYPE model has great potential in predicting the sediment yields and impacts of reservoirs on streamflow and sediment regimes in catchment scales.

Keywords:

Upper Srepok River Basin, HYPE Model, River Discharge, Suspended Sediment Concentration

Pitch talks for poster session 4 / 75

Continental versus regional scale flood inundation modelling estimates for southern South America

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Over the last few years, the large scale hydrological model for South America has been developed by the Large Scale Hydrology research group at IPH (Instituto de Pesquisas Hidráulicas)/UFRGS (Universidade Federal do Rio Grande do Sul), Brazil (https://www.ufrgs.br/lsh/). This model is based on the MGB (Modelo de Grandes Bacias) hydrological-hydrodynamic model and it has been used for several studies in the continent. MGB flood inundation estimates have been mostly used and accessed in studies related to large wetlands. However, there are still open questions related to flood mapping with the model: 1) How reliable the flood mapping capabilities of the proposed continental modelling framework are in the context of local relevance for societal applications? 2) How comparable are the continental model results to a standard local approach, based on a regional version of MGB? In a recent partnership between the Brazilian National Water Resources Agency (ANA – Agência Nacional de Águas e Saneamento Básico) and IPH/UFRGS this topic has been addressed for Uruguay, Jacuí, Caí and Sinos rivers, placed in southern Brazil, South America. The flood maps generated from both models (continental and regional) were compared to estimates based on satellite imagery (Landsat, Sentinel 1 and 2, PlanetScope) for selected flood events. Results suggested that both models are in good agreement with observed satellite images and that the continental scale flood inundation results are comparable to the regional scale model, with fit-metric values ranging between 0.2 and 0.7 for the studied rivers and floods.

Acknowledges: this work presents part of the results obtained during the research project under development by the Hydraulic Research Institute (IPH) from the Federal University of Rio Grande do Sul (UFRGS) and the Brazilian National Water Resources Agency (ANA), under project ID "TED 05/2019/ANA - COOPERAÇÃO EM TECNOLOGIAS PARA ANÁLISES HIDROLÓGICAS EM ESCALA NACIONAL".

Keywords:

Flood, hydrological-hydrodynamic model, South America, MGB

Pitch talks for poster session 4 / 49

Towards globally applicable and locally relevant compound flood simulations

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Many delta areas in the world are densely populated and have large exposure. These areas are prone to fluvial, pluvial and coastal flood drivers. Cyclone Idai in March 2019 is an example where the combination of these drivers (i.e. compound flooding) led to extensive flooding and large impacts: over $1 billion worth of damage to infrastructure, more than 100,000 houses damaged and over 1000 people killed in Mozambique, Zimbabwe and Malawi combined.

Capturing the spatial and temporal dynamics of compound floods requires a detailed description of floodplains and relevant flood processes for each driver and their interactions. Furthermore, the models need to be computationally efficient to simulate the many plausible combinations of drivers. While global compound flood models have proven useful for large-scale assessments, these lack detail to be locally relevant. On the other hand, many local models exist which provide great detail, but often take many person hours to setup and are therefore not very scalable and hard to reproduce.

We are therefore developing an open-source globally-applicable framework to rapidly build nested hydrodynamic models from a command line interface. The hydrodynamic models are built for floodplains and nested in a hydrological model for riverine boundary conditions and, if at the coast, a global tide and surge model for downstream sea level boundary conditions. The framework uses global datasets as a starting point to setup model schematizations and can incorporate detailed local data if available. The model setup is configured in a single file which makes it easy to operate and reproduce. We will highlight some key components of the framework and present a case study for Cyclone Idai for which we validated the model framework with good results.

Keywords:

floods,
compound events,
modelling framework,
open source

Pitch talks for poster session 4 / 38

Seasonal hydrological forecasting across scales: similarity patterns and attribution of forecast quality

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Up until now, most studies have assessed the performance of hydrological forecasts at a single or limited number of catchments. Although these investigations can provide in-depth knowledge on the local conditions that affect forecast quality, the potential to scale up the underlying hydrometeorological hypotheses is limited. Here, we present new insights drawn from two large-sample seasonal hydrological forecast investigations in Sweden and Europe, containing about 39,500 and 35,400 basins in their model domains, respectively. These large-sample analyses not only cover a strong hydro-climatic gradient, but they also allow to further broaden our knowledge of river behaviour, ultimately leading towards the identification of the drivers that control the quality of hydrological forecasts. Using machine-learning clustering techniques, we identify emerging spatiotemporal patterns indicating that forecast performance can be attributed to different regional physiographic characteristics. Seasonal streamflow forecast quality can thus be clustered and regionalized based on a priori knowledge of the local hydroclimatic and physiographic descriptors whose relative importance varies with the initialization month and lead time. Finally, we conclude that while seasonal river flow can generally be successfully predicted in river systems with slow hydrological responses, predictability tends to be poor in cold and semiarid climates in which river systems have a short response time to precipitation signals.

Keywords:

Seasonal hydrological forecasting, large-sample hydrology, performance attribution, machine-learning

Pitch talks for poster session 4 / 60

Exploiting SEAS5 (re-)forecasts to support risk-based decision making (UNSEEN)

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Climate extreme events are causing high socio-economic impact. We can prepare and adapt to extreme events by learning from past extreme events. However, what about events that we have not yet seen?

To assess what kind of extreme events we could expect beyond what we can see in the observed records, the UNprecedented Simulated Extreme ENsemble (UNSEEN) approach might be used. Instead of the 'single realization' of reality, ensemble approaches can be exploited to better assess the likelihood of infrequent events, which only have a limited chance of occurring in observed records.

In this talk, we will explain how the ECMWF seasonal prediction system SEAS5 can be used to generate an UNSEEN ensemble. Through various examples, we will discuss when and where UNSEEN can be best used. We introduce an open and transferable UNSEEN workflow developed during the ECMWF summer of weather code 2020. We will show that the increased sample size helps in risk estimates, detecting trends in 100-year extremes (Kelder et al., 2020) as well as explaining drivers of extreme events that could not be explained from the observed record alone.

Keywords:

Seasonal predictions, risk estimates, GEV

Pitch talks for poster session 4 / 18

Bayesian merging of large scale and local hydrological forecasts

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With the development of hydrological forecasting systems at different spatial scales ranging from local to global, it is increasingly common to have access to forecasts from different systems at a given site. A framework that would merge those forecasts while considering the skill and uncertainty of each system seems to be appealing, especially given the growing popularity of global forecasting systems and their co-existence with local forecasting systems.

In this study, a Bayesian post-processor used to estimate the uncertainty of a forecast is adapted to perform the fusion of two sets of forecasts: one implemented on a large spatial scale and one implemented locally. The approach is tested in Quebec (eastern Canada), where two forecasting systems from the federal and provincial governments are operational since 2019. In the basic configuration, the prior distribution is built based on the large-scale forecasting system and then refined using a likelihood function and the local forecasts. Alternative prior distributions (climatology, Markov chain) are considered. Also, since both forecasting systems include ungauged sites, a version of this Bayesian merging framework based on regional statistics is developed and tested using cross-validation.

The results suggest that the merged forecasts perform at least as well as the best individual system and can even outperform it for longer lead-times where both systems are more competitive.

Keywords:

Hydrological forecasting; Bayesian; forecasts merging; post-processing

Pitch talks for poster session 4 / 24

Understanding the current gaps between global and catchment scale seasonal and short-term streamflow forecasts

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Forecasts of streamflow for seasonal and shorter forecast time-scales are produced using a range of methods. Global and continental scale models are used to produce operational streamflow forecasts by a number of forecasting centres around the world. These models tend to use universal parameterisations that seek to either represent the best a priori knowledge of physical processes or produce best average performance across multiple variables of interest all data available for calibration. In contrast, many National Meteorological and Hydrological Services use locally-calibrated models that seek to achieve the best simulation or forecast performance at individual locations, by adopting calibration and modelling strategies that use local data to fit models and update predictions in real-time. While operational forecasts have been produced using both approaches for many years, there have been few studies that seek to characterise the strengths and weakness of the different approaches.

In this presentation, we compare the performance of operational seasonal and short-term (7-day) ensemble streamflow forecasts produced using global (GloFAS, www.globalfloods.eu/) and locally-calibrated (Bureau of Meteorology, www.bom.gov.au/water/7daystreamflow/, www.bom.gov.au/water/ssf/) modelling methods for many imporatant water supply catchments across Australia that cover a wide range of hydro-climatic conditions. Unsurprisingly, we find that on-average the locally-calibrated forecasts outperform forecasts produced using a global model for a range of verification measures. However, we also find that under particular circumstances the global forecasts can be more skilful than the locally-calibrated forecasts. We explore the reasons for the differences in the performance of forecasts, including the impact of the forecast ensemble size, and identify opportunities for improving the performance of both global and locally-calibrated forecasting approaches.

Keywords:

Forecast verification, global streamflow forecasts, catchment streamflow forecasts, forecast comparision

Pitch talks for poster session 4 / 23

Comparative Suitability of the Global Flood Awareness System and a Catchment-based Model to Simulate and Predict Floods in Uganda

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This study aims to assess the comparative suitability of a global hydrological forecasting system, the Copernicus-EMS Global Flood Awareness System (GloFAS), and a catchment-based model (GR4J) as possible alternative or complementary flood forecasting tools in Uganda. This would help local relevant authorities understand whether global flood forecasts can be relied on as one of the tools to inform flood-preparedness actions in Uganda, or whether other ready-to-use models that can be set up more easily at the catchment scale provide advantages in particular areas. While GloFAS provides probabilistic extended-range forecasts, it has not been calibrated at any location in Uganda yet. A simpler catchment-based model could be calibrated more easily using observed hydrological data.

Results are presented for four catchments across Uganda with different morphological and hydrological characteristics (areas between 500-13000 km2). An evaluation of both GloFAS reanalysis (GloFAS-ERA5) and extended-range forecast has been carried out against observed streamflow data, analysing performance statistics including the Kling-Gupta Efficiency (KGE) for the reanalysis, and the False Alarm Ratio and Probability of Detection for forecasts at different lead times. The GR4J model simulations were run using the ERA5 meteorological reanalysis as input. In both calibration and validation mode, the calibrated GR4J model provides better KGE scores than GloFAS, especially for the smaller catchments. However, GloFAS performance is relatively good for the two largest basins (>2200 km2) and is acceptable with respect to a mean flow benchmark for all catchments, except the smallest (500 km2). Our results suggest that in small- to medium-size basins in Uganda, a simple lumped catchment-based model may outperform GloFAS, but even without calibration GloFAS performs satisfactorily in larger basins. Thus, GloFAS can be relied on as interim solution for flood forecasting in Uganda, especially for larger river catchments and at longer lead times.

Keywords:

Hydrological modeling
GloFAS
Flood forecasting
Global reanalysis

Pitch talks for poster session 4 / 58

Assessment of Global Reanalysis Datasets for Catchment modelling Across Kenya

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Information about monitoring of hydrological extremes, agricultural yields and irrigation may be informed by early warning, forecasts, and flood management advice through appropriate modelling skills. However hydrological modelling is a challenging task in poorly gauged catchments, especially in developing countries like Kenya. Open access global precipitation and temperature reanalysis datasets with different spatial and temporal resolutions provide alternative sources in data-scarce regions but, individual reanalysis precipitation datasets have significant uncertainties. Inspired by data scarcity issues, significant spatial and temporal gaps in gauge observations, and poor performance of individual reanalysis in hydrological models, this study assess the performance of four new-era reanalysis datasets (ERA5, ERA-Interim, Climate Forecast System Reanalysis (CFSR) and Japanese 55-year Reanalysis Project(JRA55)) to simulate daily streamflow using the GR4J model across the 20 catchments in Kenya. Deviating from the modelling normality of calculating the model performance statistics for the calibration and validation periods to investigate whether a model serves as satisfactory representations of the natural hydrologic phenomenon, we couple with sensitivity analysis (SA) to unveil model structural uncertainty and suitability when forced with the different reanalysis products. In this study we use the reanalysis precipitation, maximum (T max) and minimum (T min) temperatures against the observations from the Climate Hazards group Precipitation (CHIRPS) for 1981–2016 to calculate performance statistics, streamflow simulations and sensitivity analysis. In addition, we develop model suitability index (MSI) by coupling the performance statistics with the sensitivity results across the different reanalysis products for our study catchments. MSI developed in this study is a quantitative measure that can be used for the comparison of reanalysis products for different catchments, thus useful for application to modelling to assess the suitability of both the modelling tools and catchment response to alternative forcing for early warning and inform early action.

Keywords:

Reanalysis, model calibration, sensitivity analysis

Pitch talks for poster session 4 / 78

Evaluating the forecast skill of GloFAS ensemble river discharge hindcasts for different lead times using impact data; a case study for Ethiopia

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Flooding in Ethiopia occurs on almost an annual basis greatly affecting the livelihoods of communities. Early action can mitigate its impact but requires a pre-defined trigger level of a flood forecast, that is linked to the expected humanitarian impact. The 510 data team at the Netherlands Red Cross is

developing with the Red Cross Red Crescent Climate Centre, Ethiopian Red Cross Society, Ethiopian National Disaster Risk Management Commission, and other stakeholders such a trigger methodology for floods with a return period of 5 years or more.
In this study, we used anomalously high values of river discharge hindcasts from the Global Flood Awareness System (GloFAS) as predictors of a flood. We evaluated thresholds based on the return period of the river discharge distribution at multiple GloFAS virtual gauge stations in Ethiopia for several flood events and for lead times from zero up to seven days for the period of 1997 to 2020. We created a flood-impact database from Desinventar, EM-DAT, and disaster reports to identify historical flood events. We calculated 2,5,10 and 20 year return period discharge values for the selected GloFAS stations. We also calculated the probability of exceedance based on the ensemble members of GloFAS. Based on the respective return period values calculated for each lead time we quantified the number of events for which GLOFAS forecasted discharge exceeded the selected threshold.
Our results show there a variation in magnitudes of return period values for the different lead times, therefore we recommend for each GloFAS station return period values were calculated per lead time. We also showed how to define a threshold by taking into account the frequency of triggering early actions at a national scale.

Keywords:

EAP; Trigger Threshold; Flood forecasting

Pitch talks for poster session 4 / 31

Assessing the role of global datasets for flood risk management at national and catchment scales

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The last decade has seen the development of several different global river flood hazard models. These models, when combined with data of human population and globally consistent methods for calculating vulnerability, have been used to quantify global flood risk. In recent years, the datasets used in global flood risk studies have become sufficiently detailed that they can be relevant at national and catchment scales. The use of these datasets at these more local levels could have an enormous benefit in areas lacking existing flood risk information and allow better flood management decisions and disaster response.
In this study we evaluate the usefulness of global data for assessing flood risk in five countries: Colombia, Ethiopia, India, Malaysia, and the UK. National flood risk assessments are carried out for each of the five countries using global datasets and methodologies. We use 5 different global flood models, 7 different global population datasets, and 3 different methods for calculating vulnerability that have been used in previous global studies of flood risk. We assess the implications of using these datasets interchangeably at the national scale by quantifying the uncertainty in national flood risk calculations arising from the use of the different global datasets. We also explore the local credibility and applicability of these datasets with an understanding of the local flood management context and capacity to use the data within each country.

Keywords:

Global Flood Models
Global Population Data
Global Flood Vulnerability
Global Flood Risk

Pitch talks for poster session 4 / 136

Introduction to poster session 4

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Pitch talks for poster session 5 / 144

Evaluating the performance of a data-driven short-term irrigation demand forecasting model under different levels of data availability

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Reliable short-term Irrigation Water Demand (IWD) forecasts can help water supply system operators with day to day operating decisions. IWD forecasting is a very challenging task due to uncertainties related to natural variability (soil, water, crop and climate interactions) and irrigators' behavior in the irrigation process. Many of the existing studies have considered weather variables as the main driving factors of IWD. To simplify the modelling process, Data-Driven (DD) approaches such as Artificial Neural Networks (ANN) have been developed and applied to map the relationship between these factors and IWD. However, the performance of these models is highly dependent on data-availability and thus can be constrained by limited information on previous demands or weather variables. In this study, the performance of an Artificial Neural Network (ANN) model has been evaluated under different calibration length to see how sensitive the model is to data availability. The developed model has been tested to estimate IWD in the Redcliffs irrigation district in Victoria, Australia for different periods from 2012 to 2020. The predictive performance of developed models has been quantified using the Root Mean Squared Error (RMSE), Nash–Sutcliffe model Efficiency coefficient (NSE), Anomaly Correlation Coefficient (ACC) and Mean Square Skill Score (MSSS). Here we present the design of the ANN models as well as interesting relationships between calibration length and model performance gleaned from the data and modeling. Preliminary results are consistent with the fact that the developed DD models perform better when validated over time periods with similar conditions as the calibration period. Therefore, DD models should be applied carefully as they are unable to replicate IWD when conditions are substantially different from their calibration period.

Keywords:

Pitch talks for poster session 5 / 142

Effective calibration of precipitation forecasts across Australia using the Seasonally Coherent Calibration (SCC) model

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Inadequate representation of precipitation seasonality in calibration models has limited the effective calibration of forecasts from Numerical Weather Prediction (NWP) models. In recognition of this challenge, we develop the Seasonally Coherent Calibration (SCC) model to improve the post-processing of NWP precipitation forecasts. The SCC model is capable of generating high-quality calibrated forecasts which are coherent in climatology, including seasonality, consistent with observations, despite only a short period of forecasts being available. In this study, we calibrate deterministic precipitation forecasts from the Australian Bureau of Meteorology's Australian Community Climate and Earth System Simulator G2 version (ACCESS-G2) model to generate calibrated ensemble forecasts across Australia. Compared with raw forecasters, calibrated forecasts demonstrate significant improvements in precipitation seasonality. The calibration also effectively corrects bias in raw forecasts and improves forecast skills. Through this continental-scale investigation, the statistical assumptions and reparameterization algorithms of the SCC model are confirmed to be effective and robust. The SCC model is being adopted to support operational landscape water balance forecasting across Australia. Post-processing of NWP precipitation forecasts with the SCC model is anticipated to benefit a broad range of forecast users by providing accurate, skillful, and reliable ensemble forecasts.

Keywords:

Pitch talks for poster session 5 / 86

Error modelling for long-range ensemble forecasts of flow in highly ephemeral rivers

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Generating reliable ensemble forecasts in ephemeral rivers remains a major challenge for continental scale forecasting systems. This is particularly true of highly ephemeral rivers that do not flow >50% of the time at certain times of the year. In this study, we revise our error model for generating Forecast Guided Stochastic Scenarios (FoGSS) to produce statistically reliable long-range (12-month) forecasts for ephemeral rivers. FoGSS features an error model with four stages: data transformation, bias-correction, an autoregressive error model and the statistical distribution of residuals. We revise the fourth stage of FoGSS with a parameter estimation method that uses data censoring to account for zero values in both observations and forecasts. This allows FoGSS to produce statistically reliable ensemble forecasts in even highly ephemeral streams (with >50% zero flows).

FoGSS can be applied to any forecasting system to produce reliable forecasts at streamflow gauges. We apply FoGSS to conventional ensemble hydrological prediction (ESP) forecasts for 50 Australian catchments, including 26 ephemeral rivers. FoGSS improves the accuracy of ESP forecasts at short lead times, while at long lead times FoGSS forecasts transition to climatology-like forecasts. FoGSS forecasts are reliable in ensemble spread at individual lead times and for volumes aggregated over lead times, even in highly ephemeral rivers. FoGSS forecasts pave the way for operational long-range forecasts in ephemeral rivers, meeting a key need for improved water management.

Keywords:

Key words: ephemeral rivers; long-range forecasting; error modelling

Pitch talks for poster session 5 / 97

Integrated chain for the hydrometeorological forecasting of low flows and droughts in France – The CIPRHES project

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There has been a growing interest in extending forecast lead times to facilitate water resources planning and management during droughts and low-flow events. This can be partly achieved by improving integrated hydrometeorological forecasting systems, which offer forecasts of future meteorological and hydrological conditions over continuous space and time scales. Several initiatives have been recently carried out at continental or global scales, in Europe and worldwide, to set up forecasting chains that run with numerical weather and climate model predictions as input to distributed hydrological models. Overall, these systems have been developed in response to a call for seamless forecasts in time (from short-, to medium- and long-ranges) and space (at well-monitored and partially-monitored or ungauged catchments). These systems usually have to deal with limited calibration and evaluation against local data.

In France, the CIPRHES project (2021-2025) aims at building an efficient and integrated methodology and an online operational service for a country-wide hydrological drought and low-flow forecasting system, based on the proof-of-concept PREMHYCE platform. The first step focuses on producing seamless atmospheric forecasts, combining information from climatology, weather predictions and seasonal forecasts. Then forecasts are post-processed and tailored for hydrological purposes of drought and low-flow forecasting.

In this presentation, we introduce the main scientific challenges of the project to provide short- to long-term seamless hydrological forecasts at gauged and ungauged locations, while accounting for human influences and assimilating various observation sources. We present a national prototype co-developed with a group of users, based on a multi-model approach, and a 'crash-testing' framework, developed to better evaluate the performance, robustness and usefulness of low-flow forecasts and products at various time and spatial scales, and for different objectives of water management.

The CIPRHES project is funded by the French National Research Agency (grant ANR-20-CE04-0009-03).

Keywords:

Pitch talks for poster session 5 / **69**

Forecasting soil moisture at 600m resolution over Germany using the hydrologic model ParFlow/CLM with ECMWF atmospheric forcing

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Monitoring and forecasting the terrestrial water budget at stakeholder-relevant high spatial resolutions becomes increasingly important as stressed by the repeated droughts that have affected Europe since 2018. In this context, we have established and operate a new model experiment at 500m horizontal resolution to forecast primarily the soil moisture evolution over Germany and the neighbouring regions. We use the hydrologic model ParFlow (www.parflow.org), which simulates the complete 2D/3D surface and subsurface water budget, as well as the atmosphere-surface-subsurface interactions through its surface module CLM (Common Land Model).

The simulations are driven hourly by eight surface and near-surface atmospheric variables. 9-day soil moisture forecasts are produced once per day on the basis of the deterministic high resolution

weather forecast HRES from ECMWF. They are complemented by an ensemble of ParFlow/CLM simulations forced by several ECMWF ENS members to account for the impact of the uncertainty of the forecast, especially precipitation, on soil moisture. Finally, we run once every three months a 4-month seasonal prediction soil moisture ensemble on the basis of the ECMWF SEAS long-term forecasts.
To be able to relate the daily forecasts to past system states and fluxes and for continuously monitoring the state of the terrestrial hydrosphere, the first 24 hours of each daily HRES run since 2007 have been used as forcing to hindcast a 14-year time series.
A prototypical application of these experiments is the ADAPTER project (www.adapter-projekt.de). In this framework, the monitoring and forecasting of relevant soil moisture-related diagnostics is meant to provide support for agricultural and water resources management, e.g., against droughts.

Keywords:

soil moisture, Germany, ParFlow/CLM, medium and long range forecast

Pitch talks for poster session 5 / 72

Seasonal Hydrological Forecasts for the Yacyretá Hydropower Facility

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The Yacyretá Hydropower complex is a large transboundary facility (installed capacity 3000 MW, average flow 14,500 m3/s) located at the outlet of the Upper Paraná River Basin (UPRB); a large and extensively intervened basin with multiple upstream hydropower reservoirs. The facility is operated as a run-of-the-river power station. With the operator we identified the main needs for seasonal forecasts as energy generation planning and maintenance scheduling, with required lead times of up to 15 months. This extensive lead time, and the operation of upstream reservoirs means obtaining acceptable hydrological predictions is challenging.

We develop seasonal hydrological forecast using the Ensemble Streamflow Prediction (ESP) approach. A wflow_sbm distributed hydrological model of the basin is established using CHIRPS precipitation and ERA5 reanalysis data, and calibrated against naturalised flow observations. Given the influence of the El Niño-Southern Oscillation (ENSO), the ESP procedure is conditioned using an ENSO index. This provides one seasonal inflow forecast using the uniformly weighted traditional ESP methodology (ESP_trad) and another with ensemble member weights conditioned with the ENSO index (ESP_CI). Forecasts to support energy planning with 15 months lead time were generated with initialization in October. Forecasts to support maintenance with 6 month lead time were generated with initialization in January, April and July.

Results show that ESP_trad has moderate skill only up to 1-2 months lead time for all initialization months. This indicates that the memory in the hydrology has limed contribution to predictability. For forecasts initialized in October and January, the variability of the wet season dominates the hydrological predictability. Little improvement of skill was found using the selected ENSO index, though results suggest that further research into the complex teleconnections of this large basin could improve that skill. A seasonal meteorological forecast (SMF) may help to capture this variability, and will be tested in further research.

Keywords:

Seasonal hydrological forecasting; Ensemble streamflow prediction; Large-scale basins; Hydropower.

Pitch talks for poster session 5 / 3

Understanding streamflow predictability on seasonal timescales across North America

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Sub-seasonal to seasonal (S2S) streamflow forecasts represent critical operational inputs for water sectors and society, for instance for spring flood early warning, water supply, hydropower generation, and irrigation scheduling. However, seasonal streamflow forecast skill is still limited despite recognizable advances in many relevant capabilities, including hydrologic modeling and S2S climate prediction. To build a continental-scale forecasting system that has value at the local scale, the sources and nature of streamflow predictability should be quantified and communicated.

As part of the Canadian Global Water Futures (GWF) programme, we are advancing capabilities for probabilistic streamflow forecasting over North America. The overall aim is to improve sub-seasonal to seasonal streamflow forecasts for a range of applications. We are implementing an array of probabilistic seasonal streamflow forecasting workflows that integrate state-of-the-art mechanistic models (e.g., using the ESP approach; Day, 1985) and statistical methods (i.e., based on the regression of snow observations). To guide forecast developments, we are quantifying streamflow predictability for different hydroclimatic regimes, forecast initializations and lead times, against streamflow simulations and observations. Building on the work from Arnal et al. (2017), we are additionally assessing the elasticity of predictability across North American watersheds - i.e., the increase in streamflow forecast skill achievable by improving the system's initial hydrological conditions or atmospheric forcings. The results will help to target science investments for tangible improvements in the sub-seasonal to seasonal streamflow forecasting skill.

Arnal, L., Wood, A. W., Stephens, E., Cloke, H. L., & Pappenberger, F. (2017). An efficient approach for estimating streamflow forecast skill elasticity. Journal of Hydrometeorology, 18(6), 1715-1729, doi:10.1175/JHM-D-16-0259.1

Day, G. N. (1985). Extended streamflow forecasting using NWSRFS. Journal of Water Resources Planning and Management, 111(2), 157-170, doi:10.1061/(ASCE)0733-9496(1985)111:2(157)

Keywords:

streamflow forecasting; seasonal predictability; North America

Pitch talks for poster session 5 / 29

The effects of post-processing on the performance of reservoir inflow at Itaipu (Brazil / Paraguay)

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By combining ECMWF's latest seasonal hindcasts SEAS5 with the Variable Infiltration Capacity (VIC) hydrological model we produced hindcasts of river discharge for the whole continent of South America. However, here we will focus on the hindcasts of the Parana River at Itaipu (1992-2015), the location of the largest hydro-power generation station in South America. The raw hindcasts, compared with naturalized observation, have considerable amounts of discrimination skill (measured by the correlation coefficient between the median of the forecasts and the observations, R), especially for target months November and December, with significant skill for all leads. Beyond the first two lead months, that skill is due to the meteorological forcing (SEAS5) and not to the initial hydrological conditions as shown by experiments with restricted hindcasts. The raw hindcasts for Itaipu were fraught with considerable biases. Therefore, they were post-processed with Ensemble Model Output Statistics (EMOS), which means that biases and errors in the spread of the hindcasts were corrected by comparing the hindcasts with observations. EMOS was indeed successful in making these corrections or, in other words, the hindcasts became much more reliable. However, discrimination skill decreased. This loss was caused by the leave-one-year-out procedure employed in the post-processing and is similar to the expected loss of skill when the procedure would be applied to operational forecasts. We found that after the post-processing R is almost one-to-one related to the Continued Ranked Probability Skill Score, a commonly used metric used to quantify the overall quality of ensemble forecasts. In cooperation with Brazil's Operator of the National Electricity System (ONS) our results will be compared with seasonal forecasts produced with statistical methods by ONS itself.

Keywords:

post-processing Parana "seasonal forecasts"

Pitch talks for poster session 5 / 92

An improved trend-aware post-processing method for GCM seasonal precipitation forecasts

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Climate trends have been observed in recent decades across many parts of the world, but current global climate models (GCMs) for seasonal climate forecasting often fail to capture these trends. Consequently, model forecasts may achieve lower forecast skill, and not always meet user requirements. Previous research developed a trend-aware forecast post-processing method to overcome this problem, which built on the Bayesian joint probability (BJP) modelling approach. This trend-aware method has shown effectiveness for embedding observed trend information into seasonal temperature forecasts. In this study, we aim to further develop the method for post-processing GCM seasonal precipitation forecasts. We modify the algorithm and introduce new evaluation tools to account for special characteristics of precipitation amounts, such as having a zero-lower bound, highly positive skewness, and greater temporal and spatial variability than temperature variables. We apply this advanced trend-aware method to calibrate ECMWF SEAS5 forecasts of seasonal precipitation for Australia and compare trend-aware calibrated forecasts with raw and BJP calibrated forecasts that do not have historical trend information embedded. Our evaluation shows that trend-aware calibrated forecasts properly capture observed trends and reproduce the magnitude of strong trends over the 36-year hindcast period (1981-2016), when raw and BJP calibrated forecasts fail to do so. Compared to the BJP model, the trend-aware calibration leads to marked skill improvement in the regions with statistically significant observed trends. In most regions, trend-aware calibrated forecasts substantially outperform raw forecasts in terms of bias, skill, reliability, and sharpness. Wider applications of the new trend-aware post-processing method have the potential to boost user confidence in seasonal precipitation forecasts.

Keywords:

Pitch talks for poster session 5 / 36

Post-processing hydro-meteorological tercile forecasts with weather regime data using machine learning

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There is an increasing interest in improving the predictability of sub-seasonal hydro-meteorological forecasts as they play a valuable role in medium- to long-term planning in many sectors such as agriculture, navigation, hydro-power production, and hazard warning. One way to report forecast results in order to cope with the high uncertainty associated with long range forecasts is through quantiles divided into three classes, such as "lower than normal", "normal" and "higher than normal", also known as terciles. The goal of this study is to improve the tercile forecast quality by post-processing the outputs (both raw and pre-processed) from the hydrological model PREVAH with weather regime data using a machine learning algorithm. The study area consists of 307 catchments covering the area of Switzerland. Five hydrological variables are investigated: total discharge, precipitation, baseflow, soil moisture and snow melt. In order to evaluate the added value of incorporating weather regime data, model outputs were also post-processed without weather regime data.

Comparing the accuracy of the post-processed forecasts with raw forecasts reveals the impact of the post-processing technique. We find that the ability of post-processing to improve forecast accuracy varies by catchment, lead time and variable. A benefit from adding WR data is observed but it is not consistent across the study area and among the different variables. Nevertheless, when applying a "best practice" with the highest accuracy among the proposed processing techniques to each individual catchment, the results indicate a clear improvement of forecast accuracy. Due to the small sample size, the conclusions should be considered preliminary, but this study highlights the potential of improving the skill of sub-seasonal hydro-meteorological forecasts utilizing weather regime data and machine learning in real-time.

Keywords:

Hydrological Forecasting, Weather Regimes, Machine Learning, Subseasonal

Pitch talks for poster session 5 / 56

Seasonal forecasts of winter and summer precipitation for the Island of Ireland from dynamical-statistical methods

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Seasonal precipitation forecasting is highly challenging for the northwest fringes of Europe. Statistical and dynamical methods have been developed in recent years, while hybrid statistical-dynamical approaches have been shown to play an important role in increasing forecast skill. In this research, dynamical hindcasts of mean sea level pressure [MSLP] from dynamical systems (GloSea5 and SEAS5) are used to derive two distinct sets of indices to forecast winter [DJF] and summer precipitation [JJA] at lead-times of one to four months. These indices are used as predictors of seasonal precipitation using a multiple linear regression model [MLR] and an artificial neural network [ANN] applied to four Irish rainfall regions and the island of Ireland as a whole. Forecast skill for each model, lead time, and region was benchmarked against bias corrected precipitation hindcasts from both GloSea5 and SEAS5, together with a zero-order forecast based on rainfall persistence. Results show that our hybrid method based on MSLP indices outperform direct use of dynamical forecasts in all cases. Although MLR and ANN models produced skillful precipitation forecasts of up to 4-month lead-times, the ANN model outperformed MLR in all seasons, regions, and lead-times. Forecast skill for summer was comparable to that for winter and for some regions/lead times even had better performance. We conclude that the hybrid statistical-dynamical approach developed here – by leveraging useful information on MSLP from the dynamical systems – offers a method for producing skillful seasonal precipitation forecasts for Ireland.

Keywords:

Dynamical systems, Precipitation, Forecasts, SEAS5, GloSea5

Pitch talks for poster session 5 / 15

Skill of seasonal meteorological forecasts from the Copernicus Climate Change Service to foresee groundwater pumping allocation in an overexploited Mediterranean aquifer

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The Requena-Utiel aquifer in the Jucar River Basin (Mediterranean Spain) is mined mainly for irrigation (vineyards, olive, nut trees). It has been recently declared as overexploited by the Jucar River Basin Agency. To control the water abstraction, a pumping quota has been established depending on the cumulative precipitation from December to April. Predicting this quota beforehand would be valuable for users to optimally define the irrigation schedule that maximizes the crop production according to its commercial strategy balancing production and quality.

This study analyses the ability of seasonal meteorological forecasts from the Copernicus Climate Change Service to anticipate pumping quotas. The following seasonal forecasting services were used: 1) ECMWF SEAS5; 2) UKMO GloSEA5; 3) MétéoFrance System 6; 4) DWD GCFS; 5) CMCC SPS. Seasonal forecasts issued between November 1st and April 1st were post-processed using linear scaling against historical records. The skill of seasonal forecasts was evaluated for the 1995-2015 period.

Results show that, on a broader view, the type of year cannot be safely anticipated before April 1st. However, some services can identify particular situations with higher anticipation times (e.g. dry years can be predicted by SEAS5 in November). Furthermore, we have found a direct relationship between the strength of the signal (number of ensemble members that predict the same type of year) and the forecasting skill, meaning that seasonal forecasts showing a strong signal, if properly identified, could offer valuable information months in advance to the beginning of the irrigation season.

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Keywords:

Seasonal forecasts; Copernicus Climate Change Service; groundwater allocation; Requena-Utiel aquifer

Pitch talks for poster session 5 / 91

Multi-temporal Hydrological Residual Error Modelling for Seamless Subseasonal Streamflow Forecasting

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Sub-seasonal streamflow forecasts (with lead times of 1-30 days) provide valuable information for many consequential water resource management decisions, including reservoir operation to meet environmental flow and irrigation demands, issuance of early flood warnings, and others. A key aim is to produce "seamless" forecasts, with high quality performance across the full range of lead times and time scales.
This presentation introduces the Multi-Temporal Hydrological Residual Error model (MuTHRE) to address the challenge of obtaining "seamless" sub-seasonal forecasts, i.e., daily forecasts with consistent high-quality performance over multiple lead times (1-30 days) and aggregation scales (daily to monthly). The model is designed to overcome common errors in streamflow forecasts:
• Seasonality,
• dynamic biases due to hydrological non-stationarity,
• extreme errors poorly represented by the common Gaussian distribution.
The model is evaluated comprehensively over 11 catchments in the southern Murray-Darling Basin, Australia, using multiple performance metrics to scrutinize forecast reliability, sharpness and bias, across a range of lead times, months and years, at daily and monthly time scales.
The MuTHRE model provides "high" improvements, in terms of reliability for:
• Short lead times (up to 10 days), due to representing non-Gaussian errors,
• Stratified by month, due to representing seasonality in hydrological errors,
• Dry years, due to representing dynamic biases in hydrological errors.
Forecast performance also improved in terms of sharpness, volumetric bias and CRPS skill score; Importantly, improvements are consistent across multiple time scales (daily and monthly).
This study highlights the benefits of modelling multiple temporal characteristics of hydrological errors, and demonstrates the power of the MuTHRE model for producing seamless sub-seasonal streamflow forecasts that can be utilized for a wide range of applications.

Keywords:

Pitch talks for poster session 5 / 77

Ensemble Forecasting of Drought over Germany at Sub-seasonal Time Scale

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Central Europe has faced several extreme hydrometerological events during recent years. A new hydroclimate forecasting system (HS2S) is developed over Germany to investigate drought forecast skill at sub-seasonal time scale. The HS2S benefits from more than 1500 station in-situ data collected everyday by the German weather service (DWD) to generate near-real-time hydrological initial conditions based on mHM (www.ufz.de/mhm) simulations. By using 51 ensemble forecasts from ECMWF sub-seasonal forecasting system, and mHM modeling, the forecasts of soil moisture to the depth of 2-meter are generated twice per week. Forecasts of Soil Moisture Index (SMI) are generated based on bias correction of daily atmospheric forecasts for the upcoming four calendar target weeks. A unique feature of HS2S is the possibility to verify drought events in near-real time based on the UFZ Drought monitoring system in addition to in-situ data records available from DWD and MOSES campaigns (https://www.ufz.de/moses), a data/research infrastructure which is not available in many other countries in Europe. The forecast information are still experimental and available online through the web-portal (https://www.ufz.de/moses/index.php?en=47304).

Keywords:

Ensemble forecasting, mHM, sub-seasonal forecasting, drought, Germany

Pitch talks for poster session 5 / 96

Operational multi-model hydrological seasonal forecasts for Europe: development, skill and challenges

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The Operational Water Service of C3S (developed by the Swedish Meteorological and Hydrological Institute (SMHI) and Wageningen University & Research (WUR)) aims to help a broad range of water managers in the fields of, for instance, water allocation, flood management, ecological status and industrial water use, to adapt their strategies in order to mitigate the effects of climate change. The service offers an interactive web application with refined data, guidance and practical showcases to water managers across Europe, to speed up the workflow in climate-change adaptation by using seasonal hydrological forecasts and climate-impact indicators. Policy makers will find a comprehensive overview for Europe with key messages and consultancy engineers will be helped in making their climate impact assessments.

The development of the current operational climate service for water management is based on the experience from two previous proof-of-concepts (PoCs) and will also be aligned with the hydrological model system of the Copernicus Emergency Management Service (CEMS). The service is only using data from the Climate Data Store and the operational hydrological seasonal forecasting system runs entirely in the European Centre for Medium range Weather Forecasts (ECMWF) technical environment, although developed by SMHI and WUR.

The operational Water Service of C3S will be launched during spring/summer 2021, and a series of activities and user interactions will take place to ensure that the applications developed for the service fulfil the users' needs. Here we present the development process of the operational seasonal forecasting system and application using two hydrological models (VIC-WUR & E-HYPE) at high-resolution (5km) driven by ECMWF Seasonal Forecasting System 5 (SEAS5) forcing. We highlight on i) our multi-model ensemble approach, ii) the evaluation and comparison of forecast skill in space and time, iii) (un)beaten challenges, iv) the resulting application.

Keywords:

Pitch talks for poster session 5 / 51

Ensemble forecasts for soil moisture, evapotranspiration and runoff across Australia – verification and applications

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The Bureau of Meteorology is currently developing a continental-scale hydrological ensemble forecasting system using the gridded water balance model (AWRA-L) forced with outputs from the Bureau's numerical weather prediction (NWP) and seasonal climate forecast systems. The short-term (1-9 day) and seasonal (1-3 month) hydrological forecasting systems produce ensemble forecasts of soil moisture, runoff, and evapotranspiration at 5km grid resolution.

The ability to forecast hydrological variables several days and months ahead can support improved decision making in many sectors (including water management, agriculture, energy production, emergency services and infrastructure). It can increase the resilience to and adaptation towards hydroclimatic variability and extremes by providing the opportunity to prepare for potentially harmful events and optimise decisions in advance.

We evaluated the hydrological forecasts relative to a historical reference simulation forced with observed climate inputs. The seasonal hindcasts were evaluated in terms of deterministic skill using the ensemble mean as well as probabilistically, assessing the accuracy and reliability of the forecast ensemble, with a specific focus on forecasts of hydrological extremes. The evaluation of the short-term hindcasts focuses on deterministic skill due to the comparatively short hindcast period of the NWP system.

This presentation will present the verification of the hydrological ensemble forecasts for Australia and describe potential use cases, such as in water management and agriculture. Overall, we find that the forecasting system shows sufficient skill for a wide range of applications and regions. We outline limitations of the presented systems and highlight potential future research directions.

Keywords:

Hydrological forecasting, ensemble forecasts, forecast verification

Pitch talks for poster session 5 / 52

Medium- to seasonal-range streamflow forecasting for the hydropower dams of the Brazilian National Interconnected System

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The Brazilian National Interconnected System (SIN) is composed of more than 150 hydropower plants and reservoirs located over a wide range of climate and hydrological conditions. It is responsible for more than 50% of the total electricity produced in the country. Whilst short to long-term streamflow forecasting is essential for the planning and operation of the SIN, the availability of high resolution and long-term rainfall for the whole country is also a matter of concern. In such context, a jointed research and development project was settled on June 2020 by multiple institutions. The main objective of this initiative is to investigate the use of medium-range, sub-seasonal, and seasonal ECMWF rainfall forecasts as input to a continental-scale, hydrologic-hydrodynamic model (MGB-SA) to produce streamflow forecasts for the SIN hydropower reservoirs. In this workshop, we will present ongoing research results, including analyses of pre-processing rainfall forecasts and first-run assessments at selected locations.

Acknowledges: this work presents part of the results obtained during the research project under development by the Paraná State electric company (COPEL GeT), the Meteorological System of Paraná (SIMEPAR) and the RHAMA Consulting company; Researchers of the Hydraulic Research Institute (IPH) from the Federal University of Rio Grande do Sul (UFRGS) participate in part of the project through an agreement with the RHAMA company. This project is granted by the Brazilian Agency of Electrical Energy (ANEEL) under its Research and Development program. Project PD 6491-0503/2018 – "Previsão Hidroclimática com Abrangência no Sistema Interligado Nacional de Energia Elétrica"

Keywords:

Medium-range forecasting, Sub Seasonal forecasting, Seasonal Forecasting, South America

Pitch talks for poster session 5 / 30

How can we extend the horizon of skillful hydrological predictions?

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Medium to subseasonal hydrological forecasts contain some important and gainful information for water and environmental management tasks (e.g. hydropower, agricultural production) in comparison to climatological or persistence based forecasts. The question remains how to extract this information and at what level of accuracy (e.g. temporal and spatial resolution). Most of the case studies show that the skill of extended range forecasts goes towards zero after 7 to 14 days looking at accurate daily predictions and small mountainous catchments. Even if highly sophisticated pre- and post-processing methods are applied, the gain is sometimes limited. Therefore, in this study the value of tercile forecasts of weekly aggregates is analysed for Switzerland. Thus, the objective is to analyse forecasts classified into three categories: below, above and normal conditions, which are derived from long-termsimulations and correspond approximately to climatological conditions. Possibilities of improvements are investigated by implementing different established Machine Learning (ML) based supervised classification models for correcting the hydrological model output. The results of these post-processed outputs are compared with pre-processing methods also, where the meteorological forecasts are statistically corrected before their usage in the hydrological model. For the verification of the forecast skill and possible improvements the Ranked Probability Score (RPS) and the Area under the Curve (AUC) of the Receiver Characteristic Operator (ROC) are used. The results show that looking at weekly aggregates and terciles skill can be achieved up to three weeks leadtime using the pre-processed input and even four weeks using the post-processing method based on the Gaussian Process (GP) model for classification.

Keywords:

Tercile forecasts, Machine Learning, Post-processing

Pitch talks for poster session 5 / 139

Introduction to poster session 5

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Keywords:

Pitch talks for poster session 6 / 73

Utilizing MODIS imagery and multi-platform microwave brightness temperature to constrain flood frequency

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Historical and current information regarding river discharge is essential, not only from a water management, energy, or global change perspective but also to better analyze, control and forecast flooding. However, globally the number of ground-based gauging stations declines, and data that is measured by ground-based gauging stations is often not, or shared with a considerable delay.
It has been demonstrated that existing satellite sensors can be utilized for useful discharge measurements without requiring ground-based information. The DFO – Flood Observatory uses the Advanced Microwave Scanning Radiometer band at 36.5 GHz (e.g. TRMM, AMSR-E, AMSR2, GMP), pre-processed by the JRC to estimate discharges. With a nearly-daily repeat interval, this microwave signal has been successfully applied to measure water discharge at a global scale, where the calibration of the microwave discharge signal to discharge units is accomplished by comparison to results

from a global hydrological numerical model, the Water Balance Model (WBM), for a calibration period. Once calibrated, daily discharge can be back calculated to January 1998, providing a daily discharge record for more than 20 years.
Here we present the methods used to utilize remote sensing to measure discharge. We indicate the challenges and how to overcome these when using a multiple sensor approach to capture daily discharges for over a 20-year period. And we show an example for the Amazon river, comparing the remote sensed discharge data with ground observations for multiple locations. Additionally, applications are shown on how this discharge can be combined with flood extent maps to analyze flood frequency.

Keywords:

Flood frequency; remote sensing; Remotely sensed water discharge

Pitch talks for poster session 6 / 70

Over-the-loop ensemble forecasting for risk-based reservoir operations in the US

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The adoption of ensemble streamflow forecasts for US reservoir operations is progressing, with several strategies for short range forecasts advancing in some regions, and traditional ESP remaining the dominant approach for seasonal prediction. Notwithstanding the growing interest about machine learning potential for reservoir management, a desire to strengthen the scientific foundations and practice of using process-based predictions continues. This talk highlights recent projects to connect over-the-loop ensemble forecasting with reservoir management and decision-making in several different river basins. The work is based on new process-oriented hydrologic modeling, analysis and prediction methods being developed in a collaboration between NCAR, federal water agencies, and several academic institutions. The SUMMA hydrologic modeling framework and MizuRoute channel routing model provide ensemble 50-year, 3-hour timestep retrospective simulations, real-time analyses and forecasts at the watershed scale (USGS HUC12) for the western US. Ensemble meteorological forcings enable the generation of initial forecast state uncertainty, and the ensemble forecast skill is enhanced further by using weather forecasts, conditioning on sub-seasonal climate forecasts and post-processing to compensate for hydrologic model bias. We present results and findings from efforts to use hindcasting to help design strategies for using real-time ensemble forecasts in risk-aware reservoir operations models in several basin contexts, including management in the Rio Grande, the Tuolumne and the Bighorn river basins.

Keywords:

hydrologic forecasting, ensemble forcings, large domain modeling, reservoir management, hindcasting

Pitch talks for poster session 6 / 87

Updating soil moisture and vegetation by assimilating Sentinel-1 backscatter: Impact on streamflow simulations

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Streamflow forecasts suffer from errors in the initial conditions of the catchment-scale soil moisture distribution. In this research, we evaluate the potential of improving streamflow simulations through the assimilation of Sentinel-1 backscatter data into a land surface model. Our modeling setup consists of the Noah-MP land surface model coupled to the HYMAP river routing model and the 'Water Cloud Model' (WCM), which acts as backscatter observation operator, integrated into the NASA Land Information System. The system was set up at 1 km resolution for two contrasting catchments in Belgium: i) the Demer catchment (1950 km2) dominated by agriculture and low topographic gradients, and ii) the Ourthe catchment (1616 km2) dominated by mixed forests and high topographic gradients. The land surface model was forced with MERRA-2 reanalysis meteorology. The evaluation of preliminary open-loop simulations from 2014 through 2020 against streamflow measurements at the outlets of the Demer and Ourthe catchments indicates a (relative) bias of 108 mm/yr (55%) and -44 mm/yr (-10%), and a correlation coefficient of 0.6 and 0.54, respectively. Surface soil moisture and leaf area index dynamically simulated by Noah-MP were used to calibrate the parameters of the WCM, separately for VV and VH polarization, using a Bayesian objective function and Sentinel-1 backscatter data processed to 1 km spatial resolution. We will present assimilation results obtained from an Ensemble Kalman filter that updates both soil moisture and leaf area index using backscatter data at VV and VH polarization either separately or combined. The analysis output will be evaluated with leaf area index from optical remote sensing and streamflow observations.

Keywords:

Pitch talks for poster session 6 / 79

Limits of predictability: a global-scale investigation of distribution and stochastic structure of key hydrological-cycle processes

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The limits of predictability of a natural process are defined by the strength of its variability, which is related to its intrinsic uncertainty. In this work, we measure the magnitude of the variability of key hydrological-cycle processes in the scale domain. Particularly, we analyze a collection of several billions of data values from thousands of worldwide stations for the near-surface hourly temperature, dew point, relative humidity, sea level pressure, atmospheric wind speed, streamflow and precipitation. Through the use of the second-order climacogram (i.e., variance of the averaged process vs. scale), we estimate the Hurst parameter for each process, and we conclude whether the examined processes exhibit short-term roughness and long-term persistence, both of which are indicative of a process behaviour with high variability, and thus, limited predictability.

Keywords:

stochastic similarities; hydrological cycle; global scale; long-term persistence

Pitch talks for poster session 6 / 2

Delineating groundwater occurrence and patterns within the Free State Province, South Africa

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In South Africa, the persistence of drought conditions has resulted in various water-adjustment policies in different provinces. The prolonged drought condition has created water stress environments affecting both crops and man. Across most provinces and municipalities, the provision of water has largely rested on groundwater. Water for drinking is purchased as commodities in bottled water while other conjunctive use of water rested on what the groundwater can offer. The distribution of groundwater across space is a natural resource and it is expected to be highly variable. This study aims at delineating groundwater occurrence in the Free State Province, South Africa. The study will use Geographic Information Systems and Remote Sensing Techniques to identify the occurrence of groundwater within the Free State Province. The datasets to be used include soil, geology, lineaments, slopes, rainfall, land use pattern, geomorphology and drainage. Geomorphology, drainage, slopes and lineaments were derived from Shuttle Radar Topography Mission (SRTM). Landsat series TM, ETM+, and OLI satellite imageries of Free State were obtained from the US Geological Survey (USGS) Landsat series of Earth Observation satellites accessible on the Google Earth Engine (GEE) platform. Supervised classification was done using a random forest (RF) machine learning classifier in the GEE platform. Rainfall, geology and soil are already available in needed formats. An overlay technique to identify zones of groundwater occurrence and abundance was performed using AHP. The occurrence distribution map was compared with groundwater data obtained from groundwater institutes and journal articles for cross-validation.

Keywords:

Groundwater, Google Earth Engine, Random Forest

Pitch talks for poster session 6 / 67

Ensemble Snow Data Assimilation Methods for Streamflow Forecasting

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Streamflow forecasts are produced by running a hydrological model up to the start of the forecast period to estimate basin initial conditions, and then running the model into the future forced by an ensemble of downscaled weather forecasts. Predictability is possible because of knowledge of basin initial conditions as well as knowledge of future weather and climate. Snow is a key initial condition for hydrological forecasting in cold regions.

Despite the importance of snow, accurate estimation of seasonal snow mass remains a technical and scientific challenge. This is due to large variation in the spatial and temporal patterns of snow,

complex physical processes and the difficulty measuring snow properties at the spatial scale of the model. To improve the physical fidelity of snowpack estimates, advances in both physically based modelling and measurement techniques are needed. Data assimilation provides a method to optimally combine modelled and measured information, improving snow state estimates and quantifying uncertainty. This improves initial hydrological conditions needed for forecasting snowmelt runoff and rain-on-snow events on a short to seasonal timescale.

This presentation describes proposed doctoral research in ensemble snow data assimilation methods for hydrological forecasting. Assimilation will focus on effective use of in-situ snow water equivalent and remotely sensed fractional snow cover area with Ensemble Kalman Filter and Particle Filter methods. This research applies data assimilation to physically based, multi-layer, energy balance snow model. This builds on recently developed North American domain hydrological modelling, probabilistic and forecasting efforts by the Computational Hydrology group at the University of Saskatchewan. The cold regions hydrological research is done in the context of a growing hydrological forecasting community of practice in Canada. Thoughtful development is needed to connect advances in large-domain forecasting to the provincial and territorial agencies responsible for issuing warnings.

Keywords:

SWE, Data Assimilation, Forecasting

Pitch talks for poster session 6 / 1

Remote Sensing of Global Daily Evapotranspiration based on Surface Energy Balance Method and Reanalysis data

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An accurate estimation of aerodynamic resistances is a major issue in most remote sensing ET models. An energy balance (EB) model using a column canopy-air turbulent heat diffusion method was developed to more realistically depict dynamic changes in aerodynamic resistance. In order to estimate global ET and land surface fluxes for all weather conditions, MODIS Aqua and Terra land surface temperature fields were combined and a nearest EF gap-filling method was merged into the EB model. A global evapotranspiration (ET) product covering the period 2003-2017 is produced by using the EB model. By combining thermal and optional information from MODIS satellites and surface meteorological forcing data from ERA-Interim reanalysis data, the EB model provides a 5×5 km resolution estimate of daily ET without spatial-temporal gaps at a global scale. Assessment of the daily EB ET at 238 flux sites shows that it has a mean bias of 0.05 mm/day. A global precipitation minus ET analysis demonstrated that EB ET has a relatively higher potential for agriculture water resource management than currently available global ET products, such as Landflux, GLEAM, MOD16, GLDAS, and ERA-Interim ET products. In addition, the EB model developed in this study can be applied to both polar and geostationary satellite thermal sensors.

Keywords:

Remote sensing, global ET estimation, energy balance

Pitch talks for poster session 6 / 28

Towards an operational forecasting system using altimetry assimilation : two case studies on the Niger and the Congo river basins

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The advent of new satellite missions providing high resolution observations of continental waters requires the implementation of systems that combine the benefits of multi-source hydro-meteorological observations and physical models. Such a system is essential to meet the need for operational hydrological forecasts over the world's major basins. This study is part of the initiative to develop a forecasting system, named HYdrological Forecasting system with Altimetry Assimilation (HYFAA), which manages the coupling between the MGB hydrological model and a data assimilation module of river flow observations. More specifically, the aim of this work is to quantify the contribution of data assimilation on the performance of the MGB model on two African basins: the Niger and the Congo river basins.
The MGB model, developed within the large-scale hydrology research group of the University of Rio Grande do Sul (Brazil), was calibrated independently for each basin against in situ discharge time series and validated against in situ discharges, satellite altimetry and flooded areas. It is coupled to an externalized Ensemble Kalman Filter (EnKF) which combines the uncertainties of the model and of the observations to give corrected estimates of the model state variables and parameters.
We assimilate water levels observations from the Hydroweb portal of the Théia-Land service that are converted into discharge using state/discharge rating curves. The main sources of modeling errors come from precipitation and three hydrodynamic parameters : the Manning coefficient, river depth and width. The EnKF also includes a localization algorithm to reduce the impact of spurious correlations induced by the finite size of the ensemble.
HYFAA is run in offline mode over a reanalysis period. The results show a general improvement of the discharge when assimilating Hydroweb water levels. The study ends with guidelines for future improvement, in the perspective of a possible operational system.

Keywords:

Hydrological modeling, data assimilation, altimetry

Pitch talks for poster session 6 / 74

Assimilation of backscatter radar observations in a hydrological model: a study for two catchments in Belgium

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Estimations of initial model states play a crucial role in hydrological modelling and forecasting in particular. We investigate the possibilities to improve hydrological simulations by assimilating active radar backscatter observations from the Advanced Scatterometer (ASCAT) in a hydrological model (SCHEME). In order to enable ASCAT data assimilation, the Water Cloud Model (WCM) must be coupled to the SCHEME model. In particular, the WCM is calibrated over two catchments in Belgium presenting different hydrological regimes. We explore a data assimilation system which is based on the Ensemble Kalman filter and the observation operator defined by the coupling of WCM and SCHEME models. This coupling underlines the advantage of using backscatter data for assimilation purposes instead of a soil moisture product carrying its own climatology. The present work is carried out in the context of the EODAHR project aiming at improving hydrological ensemble predictions over Belgium by assimilation of backscatter data.

Keywords:

hydrology, data assimilation, backscatter

Pitch talks for poster session 6 / 62

Applying the hydrological model framework HydPy for data assimilation in order to improve operational medium-range forecasts within the Rhine basin

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APPLYING THE HYDROLOGICAL MODEL FRAMEWORK HYDPY FOR DATA ASSIMILATION IN ORDER TO IMPROVE OPERATIONAL MEDIUM-RANGE FORECASTS WITHIN THE RHINE BASIN

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Abstract:
In cooperation with the Waterway and Shipping Administration, the Federal Institute of Hydrology (BfG) offers operational hydrological forecasting services for about 3.000 km of Germany's inland waterways. The corresponding river basins cover nearly 420.000 km². Their climatological and hydro-geological characteristics vary significantly from alpine regions to the lowland areas next to the North Sea and the Baltic Sea. Therefore, the applied hydrological forecasting models have to account for much heterogeneity, which requires a flexible and expandable modelling toolbox. In 2012, the BfG and the Ruhr-University Bochum started developing the open-source hydrological modelling framework HydPy (https://github.com/hydpy-dev). From a merely scientific tool, they subsequently developed it into a framework applicable in operational practice. This year the BfG will start applying HydPy, combined with OpenDA and Delft-FEWS, operationally for forecasting tasks in the Rhine basin.
HydPy is an interactive modelling framework developed in Python. Its main goal is the programmatic unification of conceptionally different hydrological models. All models implemented into the HydPy framework follow the same programming standards and subject to similar and rigorous testing. The unified design allows a single interface to connect one external methodology with multiple hydrological models. One example of such an interface is the OpenDA-HydPy wrapper. We use it

to apply the data assimilation approaches implemented in the OpenDA software (e.g. the Ensemble Kalman Filter) on HydPy-H and HydPy-L, which are functionally similar to HBV96 and LARSIM, respectively. HydPy provides direct runtime-access to all model states and fluxes, allowing for efficient and straightforward online-coupling with data assimilation techniques.
In this study, we demonstrate the effect of applying data assimilation techniques in combination with the HydPy framework. We focus on different sub-basins of the Rhine catchment representing different climate zones and basin scales. The different input datasets used as observations in the assimilation process are measured discharge, measured lake water levels, and simulated results of the SNOW4 model produced by the German Meteorological Service. Furthermore, we have scheduled to assimilate remotely sensed soil moisture data.

Keywords:

Hydrological Model Framework HydPy, data assimilation, hydrological forecasting, Rhine

Pitch talks for poster session 6 / 76

A High-Resolution Land Data Assimilation System Optimized for Drought Monitoring in the Western United States

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Numerical modeling of the land surface is a way to provide physically consistent, spatially and temporally continuous information about the water and energy budgets of the surface, subsurface, vegetation canopy, and snowpack. As much of the western United States exists in a near-constant state of freshwater scarcity, information about the amount of water available is critical for decision makers. The Western Land Data Assimilation System (WLDAS) is a custom instance of the National Aeronautics and Space Administration Land Information System that combines land surface parameters, meteorological forcing data, and satellite products within a land surface model to produce publicly-available 1-km daily estimates of the water and energy budget variables for the western United States using the Noah-Multiparameterization Land Surface Model. We discuss the configuration of WLDAS, including the assimilation of Moderate Resolution Imaging Spectroradiometer Leaf Area Index (LAI) and Gravity Recovery And Climate Experiment terrestrial water storage satellite products, and demonstrate applications of the system related to groundwater recharge and drought monitoring. The assimilation of LAI is shown to improve the model's estimation of evapotranspiration by constraining the dynamic vegetation scheme within the model, with the largest improvements occurring over agricultural areas during the warm season.

Keywords:

land surface modeling; drought; data assimilation

Pitch talks for poster session 6 / 32

Assimilation of streamflow into a distributed hydrological model using ConvLSTM

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Data assimilation allows for state updating of a hydrological model with observations to improve streamflow forecasting compared to the Open Loop simulation. Boucher et al. (2020) used neural networks to learn the relationship between simulated streamflow and corresponding state variables of a lumped model. This relationship was then used to update the states of the hydrological model with observed instead of simulated streamflow which successfully improved the forecast compared to the Open Loop simulation. This study uses the same concept but with two ConvLSTM models to learn the spatio-temporal state sequences of the distributed hydrological modelwflowsbm. One synthetic and two real world experiments are carried out for the Nahe Catchment, Germany. The results show that without introduced input error, state updating with both ConvLSTM models improved streamflow forecasts for peak flow discharge compared to Open Loop. For the synthetic experiment, streamflow forecasts deteriorated after state updating for both ConvLSTM architectures. In the second real world experiment, streamflow forecast improved after updating with one ConvLSTM model and deteriorated for the other. It is recommended to conduct further research with regards to measurement uncertainties and ConvLSTM model uncertainties.

Keywords:

state updating, distributed hydrological model

Pitch talks for poster session 6 / 27

Leveraging Earth Observation and Data Assimilation to Optimize Flood Inundation Forecasting

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As the climate crisis worsens, catastrophic flooding is expected to increase in frequency and magnitude, making reliable flood inundation forecasts absolutely critical to effectively prepare and respond. Research has demonstrated that assimilating Synthetic Aperture Radar (SAR) based flood inundation maps can mitigate the uncertainty of hydraulic model forecasts. The main challenges in this context have been (i) designing an adequately sensitive likelihood function for the assimilation and (ii) identifying the best observations to facilitate optimal forecast improvements. Indeed, since high resolution SAR images can often only provide partial catchment coverage, information on how location, timing, and frequency of flood extent assimilation influence flood forecast skill is vital for cost-effective acquisition planning. This study addresses these challenges through techniques developed based on identical twin experiments for the 2011 flood event in the Clarence Catchment, Australia. The truth simulation was setup with the two-dimensional hydraulic model LISFLOOD-FP at 90m grid resolution, using observed inflows, calibrated parameters, and LiDAR topography, while the open loop considered errors in inflows only. Synthetic SAR images generated based on empirical error estimates from COSMO-SkyMed SAR images available for the event, were subsequently converted to probabilistic flood extents for assimilation. Synthetic observations with full catchment

coverage were first used to develop a new flood extent assimilation algorithm based on particle filtering, which performed equivalently or better than the state-of-the-art. The synthetic observations were then assimilated into three catchment sub-regions, delineated by flow distances based on reach flow behavior and catchment morphology, to identify a targeted observation strategy for the catchment. Forecast performance was found to be more sensitive to observation coverage and timing with respect to the flood wave arrival time than frequency. Optimizing these acquisition parameters can thus lead to substantial forecast improvements, leading to more reliable insights for actionable decision-making during emergencies.

Keywords:

Flood forecasting, data assimilation, particle filters, targeted observation design

Pitch talks for poster session 6 / 35

Impacts of data assimilation on continental seasonal and short-term hydrological forecasts

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The Australian Bureau of Meteorology is currently developing a continental hydrological forecasting system using the gridded AWRA-L water balance model forced with continental-scale numerical weather prediction model outputs (up to nine days) and seasonal climate forecasts (up to three months).
We evaluated the potential of data assimilation to improve the short-term (1-9 day) and seasonal (1-3 month) forecast products including soil moisture, evapotranspiration, and runoff across Australia by updating model states. To this end, a triple collocation data assimilation scheme was developed and coupled with the AWRA-L model to integrate the Soil Moisture Active Passive (SMAP) and The Advanced Scatterometer (ASCAT) satellites data into the initialisation of the AWRA-L model. We assessed the impact of the data assimilation on short-term hindcasts (forced by the Bureau's numerical weather prediction model ACCESS-G2) over 2016-2019 and seasonal hindcasts (forced by the Bureau's climate forecasting system ACCESS-S1) over 2015-2020. The hindcasts using data assimilated initial states were evaluated against hindcasts with non-data assimilated states as well as an AWRA-L historical run forced with historical observed climate inputs.
Our results indicate that the data assimilation approach effectively improved the hindcasts by compensating the errors in model states. The improvements gained from data assimilation can persist for approximately 3 months in root-zone soil moisture hindcasts, 4 to 9 days in top-soil moisture estimates that demonstrate efficacy of this data assimilation for AWRA-L based forecasting framework.
This study demonstrated the benefit of implementing data assimilation into a hydrological model to improve land-based variable forecasting with potential application to real-time systems for agriculture and water management purposes.

Keywords:

Data assimilation, Continental model, Short-term and Seasonal forecasting, Soil moisture forecasts

Pitch talks for poster session 6 / 43

Does the assimilation of earth observations and in-situ data affect the seasonal hydrological forecast quality?

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Earth Observations (EO) have become popular in hydrological modelling because they provide fine information in space and time where direct measurements are either not available or prohibitively expensive to make. Recent scientific advances have enabled the assimilation of EO into models to improve the estimation of initial states and fluxes. This can further lead to improved forecasting for different hydro-meteorological variables. When assimilated, the data exert additional controls on the quality of the forecasts; it is hence important to apportion the effects according to model forcings and the assimilated datasets. Here, we investigate the seasonal hydrological predictions in the snowmelt-driven Umeälven catchment in northern Sweden. The E-HYPE hydrological model is driven by two meteorological forcings: (i) a downscaled GCM meteorological product based on the bias-adjusted ECMWF SEAS5 seasonal forecasts, and (ii) historical meteorological data based on the Ensemble Streamflow Prediction (ESP) approach. Six datasets are assimilated consisting of four EO (fractional snow cover, snow water equivalent, and actual and potential evapotranspiration) and two in-situ (discharge and reservoir inflow) datasets. We assess the impacts of the meteorological forcings and the assimilated EO and in-situ data on the quality of seasonal streamflow and inflow forecasts for the period 2001-2015. We show that all assimilations, which control the initial model conditions, generally improve the forecast quality but the improvement varies depending on the season and assimilated data. The lead times until when the data assimilations influence the forecast quality (assimilation versus no assimilation) are also different for different datasets and seasons. We finally show that the assimilated datasets exert more control on the forecast quality than the meteorological forcing data, highlighting the importance of initial hydrological conditions for this snow-dominated river system.

Keywords:

Earth observations, data assimilation, seasonal forecasting, snow-dominated river basins

Pitch talks for poster session 6 / 141

Introduction to poster session 6

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Session 1: Challenges and advances in modelling hydrologic variables at large scales / 99

Welcome

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Session 1: Challenges and advances in modelling hydrologic variables at large scales / 98

Virtual arrival - Session 1

Keywords:

Session 1: Challenges and advances in modelling hydrologic variables at large scales / 100

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Keywords:

Session 1: Challenges and advances in modelling hydrologic variables at large scales / 102

Pitch talks for posters - introduction by Chair: Peter Salamon

Session 1: Challenges and advances in modelling hydrologic variables at large scales / 101

Q&A (All participants)

Keywords:

Session 2: Catchment-scale hydrometeorological forecasting: from short-range to medium-range / 105

Welcome

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Keywords:

Session 2: Catchment-scale hydrometeorological forecasting: from short-range to medium-range / 104

Virtual arrival - Session 2

Keywords:

Session 2: Catchment-scale hydrometeorological forecasting: from short-range to medium-range / 108

From ensembles to uncertainty in hydrological prediction

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Keywords:

Session 2: Catchment-scale hydrometeorological forecasting: from short-range to medium-range / 109

Q & A (All participants)

Session 3: Monitoring, modelling and forecasting for flood risk, flash floods, inundation and impact assessments / 117

Welcome

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Keywords:

Session 3: Monitoring, modelling and forecasting for flood risk, flash floods, inundation and impact assessments / 116

Virtual arrival - Session 3

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Session 3: Monitoring, modelling and forecasting for flood risk, flash floods, inundation and impact assessments / 133

Q & A (All participants)

Session 3: Monitoring, modelling and forecasting for flood risk, flash floods, inundation and impact assessments / 132

Global flood forecasting for anticipatory humanitarian action

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Session 4: Connecting large scale water-cycle information to local needs, knowledge and decision making / 121

Welcome

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Session 4: Connecting large scale water-cycle information to local needs, knowledge and decision making / 135

Q & A (All participants)

Session 4: Connecting large scale water-cycle information to local needs, knowledge and decision making / 85

Connecting large scale climate services to the local context? Look out of the window

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Information provided through climate services, whether warnings to vulnerable communities of imminent hazards such as floods and droughts, or seasonal outlooks to support water resources planning, have a clear value proposition. This may be to inform timely action by those at risk, or to support better decisions in utilising scarce water resources. Research shows that a skilful forecast is a necessary ingredient in realizing the value proposition, but equally shows that it is not sufficient. Usage of climate services is challenged by several factors, including the difficulty in linking the information forecasts contain with the local needs, knowledges and policy contexts that frame the decisions users make.

Here we explore three examples from recent research where we use social sciences based methods and analysis of water allocation policies to reveal the local knowledge users have, the environmental cues that they observe to initiate actions, and the policy dimensions relevant to the decision making process. These three examples include flash flood warnings in Northern Malawi, drought warning in Southern Malawi and seasonal water allocation in Australia. Among the many rich insights we gain, a theme common to all three is the spatial and/or temporal dimension of hydro-meteorological information users identify as relevant to their decisions. We illustrate through these examples that this approach not only gives key insight into the local context of user needs and decision making, but also posit that it helps discern the relevance of information from large scale contemporary science-based forecasts. We argue that transdisciplinary research as used here contributes to connecting large scale scientific data to local needs and decision making through understanding the social and behavioural factors that govern user actions. A parallel could well be found in our own first instinct when receiving a severe weather warning for where we live. We look out of the window.

Keywords:

Climate Services, Local context, decision making, user needs

Session 5: Catchment-scale hydrometeorological forecasting: from medium-range to subseasonal-to-seasonal range / 125

Welcome

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Session 5: Catchment-scale hydrometeorological forecasting: from medium-range to subseasonal-to-seasonal range / 124

Virtual arrival - Session 5

Session 5: Catchment-scale hydrometeorological forecasting: from medium-range to subseasonal-to-seasonal range / 138

Q & A (All participants)

Session 5: Catchment-scale hydrometeorological forecasting: from medium-range to subseasonal-to-seasonal range / 137

Developments in hybrid hydrological forecasting

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Session 6: Use of Earth Observations and data assimiliation for hydrological forecasts and past reanalyses / 129

Welcome

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Keywords:

Session 6: Use of Earth Observations and data assimiliation for hydrological forecasts and past reanalyses / 128

Virtual arrival - Session 6

Session 6: Use of Earth Observations and data assimiliation for hydrological forecasts and past reanalyses / 140

Q & A (All participants)

Session 6: Use of Earth Observations and data assimiliation for hydrological forecasts and past reanalyses / 6

Advances in new EO technologies and computer modeling could soon enable better flood forecasting at impact-level scale

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With floods being a top-ranking disaster in terms of insured and uninsured losses, and with flood frequency and magnitude projected to increase in future, there is a clear need for high-quality, reliable flood forecasting. Given that floods are happening at the global scale but their impacts and consequences are truly felt at the local community level, flood forecasting needs to be at the highest resolution possible and multi-dimensional in space. Recent advances in Earth-observing technologies, in particular with the opening of the new space economy as well as considerable progress in computing architecture, interoperability and machine learning, have given rise to many opportunities but also many challenges. This talk will discuss some of these opportunities and associated challenges using recent examples of machine learning approaches to augment flood predictions with physical models and to enable precipitation prediction at local scale. The talk also examines new EO methods, such as radio occultation data and rapid processing of flood maps to enable immediate assimilation into NWP models and flood forecasting models, respectively.

Keywords:

Flood Forecasting; Earth Observation; Technology; ML

131

Activities in Gather.Town

130

Poster session 6 in Gather.Town - Visit the posters and chat with the authors

127

Activities in Gather.Town

126

Poster session 5 in Gather.Town - Visit the posters and chat with the authors

123

Activities in Gather.Town

122

Poster session 4 in Gather.Town - Visit the posters and chat with the authors

119

Activities in Gather.Town

118

Poster session 3 in Gather.Town - Visit the posters and chat with the authors

114

Activities in Gather.Town

113

Poster session 2 in Gather.Town - Visit the posters and chat with the authors

112

Activities in Gather.Town

111

Poster session 1 in Gather.Town - Visit the posters and chat with the authors

103

Poster Session 1 in Gather.Town - visit the posters and chat with the authors