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Weather and climate services for hydropower management

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Abstract

Predictions in hydroelectricity systems aim to help managers and stakeholders to guarantee people safety and dam security (in the case of reservoir-based systems) against extreme events, as well as to optimize energy production and the economic value of water resources. In a society moving towards a low-carbon economy, hydropower has the advantage of being a renewable source of energy that can be stored and reallocated in space and time and thus better handle the natural variability of hydrometeorological hazards and the occurrence of extreme events and/or peak demands. Hydropower water reservoirs may also be storage facilities to be operated in a sharing environment: not only for energy production purposes, but also for domestic and agriculture water supply, environment protection, tourism, flood protection, etc. Improved predictability of hydrometeorological events (reservoir inflows and extremes), and improved risk assessment techniques are crucial to the operational decisions taken at different time and space scales in hydropower operational systems. Examples in France, Italy, Spain, and Sweden illustrate the broad spectrum of potential collaborations between weather and climate services providers, water resources researchers and European energy production companies. In this short communication, we also highlight the challenges and open opportunities that may further strengthen the usefulness of climate and weather inputs for the hydropower sector.

1 Weather and climate services and the water sector

There are numerous enterprises in the water sector that are exposed to weather and climate variability and extremes, including energy generation and planning. It is therefore essential to promote actions that support and improve the uptake by weather-sensitive hydrological services of weather and climate (W&C) services. The Global Framework for Climate Services (GFCS), a United Nations initiative led by the World Meteorological Organization (WMO), was launched in 2009 "*to guide the development and application of science-based climate information and services in support of decision-making in climate sensitive sectors*". It acknowledges in its implementation plan that there are "*considerable benefits to be obtained through climate services in relation to the water sector on all time scales.*" [GRCS, 2014].

The EU research and innovation Roadmap for Climate Services [EC, 2015] also recognizes that "Climate services have the potential of becoming a supportive and flourishing market, where public and private operators provide a range of services and products that can better inform decision makers at all levels, from public administrations to business operators, when taking decisions for which the implications of a changing climate are an issue". Although the perceived importance of weather (several days to weeks) and climate (several months to decades) services is usually high [WMO, 2015], a number of challenges remain related to the provision of W&C services and the effective use by (and feedback from) the economic sectors. Some are listed below, just to name a few:

- The increasing complexity and amount of information produced by W&C services and requested by a diversity of stakeholders from contrasted geographic regions should not act as a disincentive for innovation in research and operations.
- At least two translating issues need special attention: translating users' needs into services and translating services into added socio-economic value. The production of increasingly skilful predictions in weather, climate and hydrology should translate into social benefits or economic added value to society and businesses, with a better understanding of the links between quality and usefulness of predictions.

- Progress requires transdisciplinary scientific approaches and inter-sectoral impact modelling, supported by more creative strategies to efficiently engage stakeholders in supporting and providing feedback to research and innovation.
- Improvements on the scientific understanding of natural processes and the prediction of high-impact events should go together with improvements on impact modelling and economic assessment, ensuring that one can continuously benefit and integrate knowledge from the other.
- Tailoring W&C information to the level of scale and detail needed by water systems is crucial to move from the stage of having predictions issued by a model available to the stage of having predictions integrated in the decision-making processes. For some users, tailoring comprises also the integration of W&C services from external providers to in-house products.
- Increasing professional capacity from both communities of providers and users of W&C services to communicate, access, understand and use services appropriately is essential. It goes hand in hand with building confidence and developing credibility in W&C services.

2 Challenges and opportunities in the hydropower sector

Energy systems search to optimize their production and improve their resilience to extreme weather events and climate changes. The needs of hydropower users for accurate and reliable weather forecasts cover a wide range of space and time scales: short-term forecasts (from few hours up to 2-3 days ahead) for flood protection of the population living downstream the facilities and for the security of installations, medium-range forecasts (up to 7-15 days ahead) for the optimisation of hydropower production, and long-term (months ahead) streamflow forecasts, for instance, for water resources management and environment protection measures during drought periods. Additionally, extreme hydrometeorological events affect their business activities not only in terms of water availability (power production), but also of water demand for power (load). Finally, the hydropower industry is also concerned by hydrological predictions based on future climate conditions and projected trends, as the effects of expected changes in precipitation and temperature may lead to changes in runoff volume, extremes and seasonality, directly affecting the potential for hydropower generation [Kumar et al., 2011]. Schaefli [2015] highlights the link between investing in real-time forecasting systems and new management strategies under future climates. Identifying future forecast needs today can play a key role in the capacity of hydropower systems to cope with climate change impacts tomorrow.

Links between W&C and hydropower also exist in the integration of hydropower production with other renewable, but intermittent, sources of energy [François et al., 2013]. In a society moving towards a low-carbon economy, hydropower production has the advantage of being a renewable source of energy that can be stored in space and time and thus better handle the natural variability of hydrometeorological hazards and the occurrence of extreme events and/or peak demands. Renewable energy integration draws focus to optimizing reservoir management strategies and anticipating W&C conditions for planning short- to long-term power supply and demand, distribution and transmission systems, as well as price trends in the energy market. With the expansion of intermittent solar and wind energy production, the optimized management of the water storage capacity of reservoirs for hydropower production is expected to play a major role in the future energy mix.

Furthermore, hydropower water reservoirs are often storage facilities that operate in a sharing environment. In this case, water resources are used not only for energy production, but also for domestic and agriculture water supply, environment protection, tourism, flood protection, etc. Conflicts of use may arise when resources are not abundant [e.g., Anghileri et al., 2013]. In this case, optimization tools and adaptive strategies may be required [Giuliani et al., 2014a,b; Tilmant et al., 2008]. These modelling tools use hydrologic inflows, parameterized (variable) reservoir capacities and constraints, together with information on energy prices to optimize management rules and evaluate potential economic gains of forecast information. New constraints may also be taken into account, which, in additional to the climate constraints of natural variability of water resources, rely on other users, legal/policy requirements, or socio-economic aspects.

Recently, a consortium has been formed in Europe to respond to a call for proposals of the H2020 programme of the European Commission within the Societal Challenge “Climate action, Environment, Resource efficiency and Raw Materials”. The project “Improvement of predictions and management of Hydrological Extremes (IMPREX)” was funded. It aims to improve prediction and foresighting capabilities of extreme weather events and their intake in strategic sectors, namely, flood damage, hydropower, transport, urban water, droughts and agriculture, and water economy.

In the hydropower sectoral survey proposed by IMPREX, four systems have been identified and will be studied during the project:

- South-eastern French catchments: specific attention will be paid to a set of catchments where the French energy company EDF operates hydropower reservoirs. At EDF, an expert-based semi-automatic hydrologic ensemble prediction system has been running operationally since December 2010 over several river catchments at the daily time step [Desaint et al., 2009; Ramos et al., 2010]. It is based on deterministic and ensemble weather forecasts integrated to a hydrological model. Post-processing approaches for statistical bias correction and a heuristic model for the optimisation of energy production have been recently investigated. They will be further evaluated to provide insights on how 7-day probabilistic forecasts of improved quality can impact economic gains of energy production [Zalachori et al., 2012; Zalachori, 2013].
- A typical snow-dominated Alpine basin, the Lake Como in Italy: this water system is heavily exploited for hydropower production in the upper catchment and with a multi-sectoral use in the lower part. It represents a large socioeconomic system where multiple, conflicting water-dependent activities coexist [Anghileri et al., 2013; Giacomelli et al., 2008]. This water system is a paradigmatic example of many Alpine watersheds: large storage capacity distributed in small reservoirs, mainly operated for hydropower production and located in the upper watershed region, regulated lakes in the middle region, and multiple water consumption users, mainly wide agricultural areas, in the lower region. Optimization tools will be applied to this densely populated large subalpine basin where increasingly high and frequent droughts are enhancing the conflict between energy (alpine hydropower) and food production (crop failure risk) also threatening the main ecosystem services and flood buffering capacity.
- A typical south Mediterranean basin with an important share of water for irrigated agriculture (80%) and conflicts on water allocation in a multi-reservoir system, the Jucar River basin in Spain: the basin has the now Europe's largest pumped-storage hydropower project (Cortes-La Muela) and, with its three main reservoirs, is an ideal case-study for in-depth analyses of water use optimization and impact assessment. Water scarcity, irregular hydrology and groundwater overdraft cause droughts to have significant economic, social and environmental consequences [Andreu et al., 2009]. The situation is expected to be exacerbated by the impacts of climate and socioeconomic (global) changes, and the increasing institutional impediments from political disputes. A range of different innovative solutions have been implemented, but coordination is still needed. It is expected that with the help of hydro-economic optimization models [Molina et al., 2013; Macian-Sorribes and Pulido-Velazquez, 2014], optimal coordination mechanisms at the basin scale can be designed and evaluated.
- The upper part of the River Umeälven in Sweden, a typical north European catchment: the study area includes four major reservoirs and hydropower stations, in a catchment that is highly influenced by snowmelt runoff and volumes for planning the hydropower production for the current and next winter seasons. The catchment is partly dominated by high mountains in the very upper parts and forest areas in the lower parts. Seasonal forecasts of snowmelt runoff volumes are key inputs to the decision models of the hydropower companies operating in the basin. Currently, the operational seasonal forecasts are based on hydrological model simulations using an ensemble of historical years of observations of precipitation and temperature as input data [Olsson et al., 2011]. Forecasts for the accumulated runoff volumes during April-July are issued once a month from January until the start of the snowmelt season in April. Intercomparison studies are planned to evaluate the added value of using climate model outputs of improved hydrometeorological predictions in comparison to the current operational methods.

3 Conclusion and way forward

The demand for weather and climate (W&C) services in the water sector, in general, and in the hydropower sector, in particular, has increased as forecasting and modelling capabilities have improved, and informed decisions have gained in social relevance and economic value. The hydropower sector is a user of W&C services with broad objectives along the chain of energy generation, management and planning. Its interests comprise: multi-use reservoir management, optimal space-time allocation of water resources for energy generation, flood and drought risk mitigation, integration with other, mainly intermittent, climate-related renewable energy sources (e.g., wind and solar power), climate adaptation, as well as strategic and sustainable energy planning to secure economic growth and environmental preservation. Such a rich context requires strong transdisciplinary collaborations and partnerships between science and actors, as well as between public and private organizations.

The IMPREX project, initiated in October 2015 and running for four years, proposes to investigate the value of improving predictions of hydrometeorological extremes at short-, medium- and long-range in a number of water sectors, including hydropower. The project's rationale is based on the fact that we can, and we should, learn from today's experience and practice to better anticipate the needs (and trigger the opportunities) of tomorrow. This is reflected in its ambition to bridge the gap between science and practice, operations and planning, as well as between past and future [Hurk et al., 2016]. Four hydropower systems will be investigated in the IMPREX project. They concern different geographical areas (south-east France, northern Italy, central-eastern part of the Iberian-Peninsula and northern Sweden) but share common goals: i) the evaluation of improved predictability of inflows and extreme events on hydropower decision models and, consequently, ii) the assessment of the operational value of forecasts, at short to medium up to seasonal time scales, or of the impacts of climate predictions on the adaptability of reservoir operation rules in a multi-sector perspective. Additionally, they are supported by close collaborations between scientists and operational modelling and forecasting centres of European energy production companies.

We expect that the current opportunities on improving the way weather and climate products can better service energy systems with reliable and valuable information will also trigger new forms of active and creative engagement of stakeholders in promoting innovations in science and technology. This should benefit not only practice and research, but also policy-making.

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