The Basque Hydrologic Nowcasting project

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Abstract

We present different aspects in relation to a project developed in order to implement an operational hydrological nowcasting system for the Basque Country. The project begins in mid 2021 and ends in 2024. This project covers different issues associated with flash floods forecasting and will be an essential contribution to improve local warning effectiveness at very short and short term in our territory .

We describe the main project phases, including the specifications, the development and the operational tasks, summarizing key aspects We introduce the general scheme of the system, describing the functionalities of the main modules and detailing the technical solutions adopted to deal with the different hydrological and meteorological analysis and prediction needs at different espatial-temporal scales. Finally, we summarized our experience in specification and development phases and present some conclusions from workshops and other joint hydro-meteorological working sessions that have taken place during the project.

Main project phases

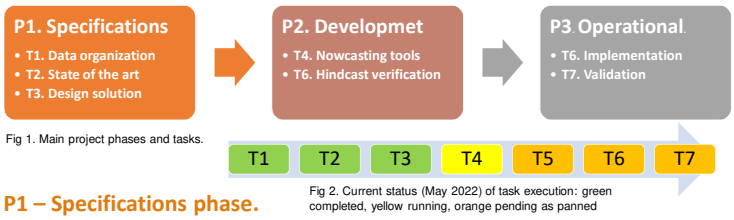

Fig 1. Main project phases and tasks.

Fig 2. Current status (May 2022) of task execution: green completed, yellow running, orange pending as panned

P1 – Specifications phase.

In this first phase we proceed with a detailed specification of the problem and to design the solution based on: the instrumentation and data availability, the Basque operational context and the hydro-meteorological characteristics of Basque Country. As a result we obtain a detailed specifications set and a general design of the tools and components to be developed in next phase. Such aspects are included in Task 1, 2 and 3.

- In T1 we proceed to **data collection and organization**, all the data and metadata are collected and organized for its use along the project. Basque multipurpose network (e.g. Gaztelumendi et al 2018) precipitation, temperature, river level data, etc. Kapildui radar reflectivity data (Aranda et al 2008, Gaztelumendi et al 2006). Numerical weather forecasts (ENSGFS). Calibrated hydrological models (TETIS, HBV, M04 and M07) for all the basins in the CAV (see Fig 4), Local Area Meteorological Models (Gaztelumendi et al 2007, Gelpi et al 2006,2015,2019), Meteosat images (e.g. Gaztelumendi et al 2010, 2021, 2022). Since some of this information consists of raw data, we proceed to depuration and validation prior to its use in the following phases of the project.
- In T2 we analyzed the **state of the art** in Nowcasting, very-short and short term forecasting in the hydrological and meteorological side. Making an in-depth review of the existing techniques and methodologies both in the field of Radar image processing that enable the estimation of the observed precipitation fields (QPE), very short-term and short-term prediction techniques that allow determining predicted precipitation fields (QPF), as well as the most suitable hydrological models for their incorporation into flood prediction systems.
- In T3 we proceed to **design** the most suitable and appropriate methodologies for their application in Basque Country case. For this purpose we consider the meteo-climatic and orographic characteristics of the territory, the type of severity in relation to precipitation and river basins characteristics, the available instrumentation and observation networks, the URA/DAEM operational context (integration, automation, human factor...), the usability of the system (availability of products, post-processing , etc.) and open-source requirements, among other aspects.

P2 – Development phase

Based on the conclusions of the previous phase in P2 we proceed to the development of the hydro-meteorological nowcasting system (see Fig 3) executing Tasks 4 and 5.

- In T4 we proceed to the **development** of numerical and computer tools for hydro-meteo very short-term and short terms predictions. The system is developed in a modular way, based on Python and collaborative/open source tools in order to provide Quantitative Precipitation Estimation (QPE) and Forecast (QPF) to feed hydrological models providing relevant information on river levels and flows for flooding prediction and different temporal horizons. The information transmitted throughout the chain of models and the final results will be probabilistic.
- In T5 we proceed with the **verification in hindcast mode** of the predictive capacity of the chain of models. In this task, the whole system will be executed in different selected episodes of the recent past (historical mode or hindcast). With this objective, we proceed to the selection of different representative episodes of different typical situations that allow us to verify the weaknesses and strengths of the system in an offline context. For such purpose different metrics are selected for hydrological and meteorological results verifications. Indicators and verification metrics are calculated on every available hydrological station (see Fig 4).

P3 – Operational phase

In this phase we proceed with the operational implementation of the system and the operational execution in real world conditions. Once the pre-operational capacity of the proposed system has been tested in hindcast mode, we proceed with the operational implementation and "online" operation that includes verification during real time flash-floods episodes. Those aspects are covered in Tasks 6 and 7.

- In T6 we proceed to the **implementation and operation of the system.** In the case of inundation risk, when predefined thresholds are exceeded in rainfall, in river levels or in river level change rates, or when the general conditions are compatible with inundations, the system will be fully activated providing all defined nowcasting products to URA. Such products, including those for surveillance are going to be accessible in different tools for analysis and monitoring including a dedicated flash-flood extranet.
- In T7 we proceed with **final operational verification**, documentation and tranfer. After an alert, a detailed analysis report of the episode and the operation of the system will be made, an automatic validation set of products will be available.

Introduction

Floods are among the world's deadliest natural disasters with significant social, economic and environmental impacts. In Basque Country (e.g. Gaztelumendi et al 2016a, 2017), as in other parts of the World with similar geomorphological and hydro-meteorological characteristics, flooding events are produced on relatively short spatial and temporal scales (flash floods) making flood modeling a particularly difficult challenge. Major flash floods episodes in Basque Country are produced when rivers react to intense and persistent rainfall that are produced on saturated soils scenarios, occasionally with extra water from snow-melting processes (e.g. Mugerza et al 2005, Egaña et al 2009, 2010, 2013, 2015, 2016, 2018, Gaztelumendi et al 2009, 2011). In this context, nowcasting and very short term forecasting tools (up to 12 hours) are essential in order to manage impact events in real time and to provide different operational products and warning guidance for hydrological, meteorological and civil protection authorities (e.g. GV 2018. Gaztelumendi et al 2012, 2016b)

This project is promoted by Basque Government and financed with Basque Water Agency (URA) funds in collaboration with Emergencies and Meteorology Directorate (DAEM) in Basque Government Security Department. Technical development is performed by meteorological and hydrological experts from Tecnalia and IHCantabria. Experts in operational meteorology from the Basque Meteorology Agency (Euskalmet) are also involved.

One of the aims of this project is to improve modeling capabilities pushing meteorological operational tools (e.g. Gaztelumendi et al 2007, Gelpi et al 2006, 2015, 2019) to very short term forecast and including hydrological capabilities with a full explotation of local observational systems (e.g. Aranda et al 2006, Gaztelumendi et al 2003, 2006, 2018, 2022, Gelpi et al 2022, Diaz de Arcaya et al 2022). Another important point is the generation of hydro-meteorological synergies. In this context experts from both disciplines can join forces, combining expertise, and accelerating the implementation process of local hydrometeorological operational systems.

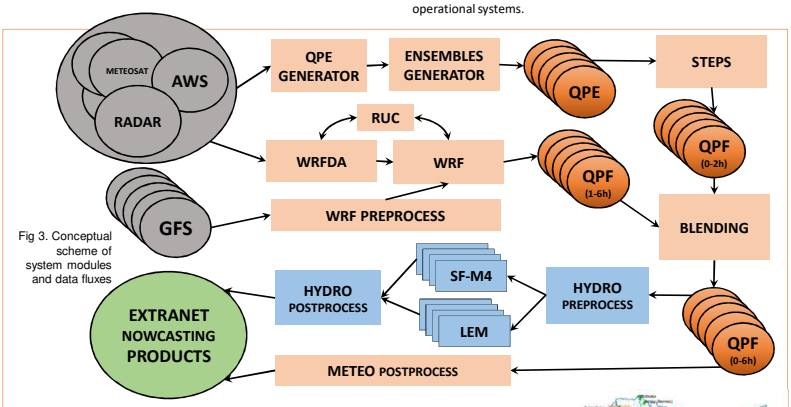

Fig 3. Conceptual scheme of system modules and data fluxes

Hydrological Nowcasting Components

The system is developed in a modular way with probabilistic capabilities and mainly based on open source tools. The system will contain all the necessary modules to provide QPE fields based on the available remote sensing (mainly Euskalmet Radar) and surface information, as well as different very short-term and short-term prediction modules, including blending solutions that allow us to have seamless QPF information feeding hydrological module. Post-processing modules and extranet capabilities guarantee that relevant nowcasting information on river levels and flows are available during potential flooding risk events. The information transmitted throughout the chain of models and the final results will be probabilistic.

The models chain and tools are:

(i) a set of probabilistic precipitation models capable of extrapolating the evolution of precipitation from radar observations (STEP)

(ii) a set of high resolution non-hydrostatic numerical weather prediction (NWP) models with fast assimilation cycle (RUC), running in ensemble mode (WRF, WRFDA, GFS).

(iii) a blending tool that allows the effective combination of the generated weather information.

(iv) a set of aggregate hydrological models (Superflex-M4, LEM, ...) that will provide us with predictions of river flow and level in more than 50 control points (Fig 4).

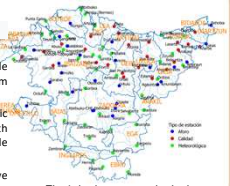

Fig 4. hydro-meteorological network. Blue and red dots with river level and precipitation, green dots just precipitation.

Project Workshops

Workshops sessions (see Fig 5) are planed as joint sessions where the hydrological and meteorological experts (URA, DAEM, Euskalmet, Tecnalia and IHC) have exchanged impressions, forging a joint vision, defining specifications and agreeing on the characteristics that must have a fully useful system for the operational needs in meteo and hydro side in the Basque Country. Note that other different project meetings are held routinely (each 1-2 months). Seven workshops sessions are done or planned during the first and second phase of the project (third phase not detailed here):

WS1: Hydro modeling. Hydrological experts from IHC present the main characteristics of the hydrological modeling systems applicable to flash flood problems, focusing on main operational characteristics, data needs, outputs, etc. most adequate for Basque Country application. Open discussion is stablished between URA, DAEM, Euskalmet, Tecnalia and IHC experts, around different modeling approximations (particularly around convenience of conceptual models). Some conclusions and consensus is reached in hydro specifications.

WS2: Radar Application. Experts from remote sensing and data quality from Tecnalia introduce Radar operation capabilities, products available and quality procedures applied to Euskalmet Radar. This session is intended to encourage open discussion and debate on those issues relevant for the inclusion of remote sensing data in the project. Consensus is reached about procedures for full exploitation of radar data capabilities available in the territory.

WS3: Meteo modeling. Meteorological experts from Tecnalia present state of the art in very short-term and short-term forecasting, focusing on most suitable numerical and statistical techniques for nowcasting and data assimilation for Basque Country context. Open discussion is stablished between URA, DAEM, Euskalmet, Tecnalia and IHC experts about the use of Numerical Limited Area Models with data assimilation capabilities for 1-6 hours and data flow techniques based on Radar for shorter periods and the importance of blending. Conclusions and consensus is reached for meteo specifications considering the hydro-meteo forecast necessities.

WS4: Hydro Pre and Post- processing. Hydro and meteo experts from Tecnalia, IHC and URA discuss about the post-process and pre-process requirements to be included in the system for its operational exploitation. Focusing on the modular requirements and the structuration of Python algorithms needed to adequately incorporate bridges between hydrological and meteo side.

WS5: Products ideation. This workshop is developed as an ideation sessions where experts from Tecnalia, URA, DAEM and Euskalmet think, discuss and pre-design the products that are needed for the correct operation of the system from the perspective of their different responsibilities , in a collaborative way. A consensus is reached on the requirement of some basic and advanced operational products that are needed for the communication, analysis and monitoring of severe flood events at different severity levels, under different operational circumstances and responsibilities.

WS6: Hindcast scenarios and methodology. This session is planned in order to define and reach consensus on hindcast scenarios, methodologies and metrics.

WS7: pre-operational validation and verification. This session is planned in order to present results, analyze hindcast experiments and discuss improvements previous to operational ohase task development.

WS1 WS2 WS3 WS4 WS5 WS6 WS7 WS8 WS9 WS10

Fig 5. Current status (May 2022) of Workshops execution: green completed, orange pending as planned

Remarks and Conclusions

✓ In this contribution we have summarized the Basque Hydrological Nowcasting project including some technical aspects related with the nowcasting model chain and some considerations for the different project phases. We also include details from Workshops where meteorological and hydrological experts joint forces and focus on practical and pragmatic operational local solutions.

✓ Ciclo-iterative approach, continuous communication and specific technical workshops allow all the agents involved understand the scope of each stage and acquire a critical view of the system, facilitating early interventions and reorientation improving usability.

✓ Fully documented modular developments allow the evolution and, where appropriate, the replacement of complete modules for functional improvements that could occur in the long term, as a result of: (1) Future incorporation of new algorithms and/or improvement of existing ones. (2) Incorporation of new data sources (new stations, new disdrometers network (Gaztelumendi et al 2022a), future radars, new satellites, etc.) (3) Plausible modification of execution hardware environments.

✓ Operational design and code structuration may be robust against possible malfunctions due to observational inputs failures and other contingencies (e.g. lack of Radar data, poor quality, intermittencies, failures on surface stations, ...). Operational capabilities must be guaranteed in absence of Radar data, adopting Meteosat (Gaztelumendi et al 2022b)

✓ The system will allow the incorporation of local radar and surface rain-gauge observations synergistically, exploiting the information of each element to complement each other. To do this, on one hand observations from the precipitation field (radar+rain-gauges) are used as input for the tracking and advection for nowcasting and very short range. On the other hand, NWP framework with high frequency radar and surface data assimilation guide the very short and short term precipitation forecasting system. Both forecasts will be integrated through blending techniques, generating a set of rainfall scenarios used to feed the hydrological models chain, producing a prediction of river flows and levels, in terms of the probability of exceeding certain established thresholds.

✓ The combination between STEPS and NWP approximation seems to be useful in those situations with intense and/or persistent precipitation with a stratiform predominance. Note that STEPS will be especially effective in situations dominated by convective cells and intense upper-level flows common in summer where the convective cells usually move from southwest to northeast with southwesterly wind aloft under a trough configuration. In the case of weak upper flow but with directional shear, the convective cells can be quasi-stationary and/or have erratic-complex dynamics, in such cases the usefulness of STEPS will be more limited and high-resolution Limited Area Models (LAM) with short-cycle radar assimilation could, potentially, improve results.

✓ The choice of the hydrological models in the project is based on a comprehensive analysis of the catchments of the Basque Country, carried out by URA with the collaboration of IHCantabria. This includes the benchmarking of many popular models (such as the Superflex-M4) and also the development of new ones (Logistic equilibrium model - LEM), customized for the local conditions. It has been checked that aggregate hydrological models are highly reliable, parsimonious and numerically efficient in this context, even more than many distributed ones. On this basis, the M4 and LEM will be used for the initial versions of the nowcasting system, although in the near future we are planning to move towards fully distributed models, fed directly by the new precipitation fields without spatial averaging.

Acknowledgements

The Hydrological Nowcasting project (URA/023A/2021) is funded by the Basque Water Agency (URA).
The authors would like to thank the Department of Security of the Basque Government and particularly to the Directorate of Emergencies and Meteorology for operational service financial support. We also would like to thank all our colleagues from DAEM, EUSKALMET, URA and TECNALIA for their daily effort in promoting valuable research and services for the Basque Society.

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