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Deltares

Development of a Flood Early Warning System for The Gambia

FEWS-Gambia

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Author(s)		
Marc van Dijk	Flood Forecasting Specialist at Deltares	
Matthijs Lemans	Flood Forecasting Specialist at Deltares	

Doc. version	**Author**	**Reviewer**	**Approver**	**Publish**
0.1	Marc van Dijk	Matthijs Lemans	Nadine Slootjes	

Summary

The overall goal of the project is to support the Department of Water Resources of the Gambia with the National Disaster Management Agency of the Gambia in the development of a pilot flood early warning forecasting system. The Gambian forecasters are trained, and guidance provided in further evolution of a pilot flood forecasting system into a fully operational flood early warning system. In the project period, from August 2021 to December 2021, several activities were completed:

- Establishing of a database with GIS data and historic time series data for the Gambia
- Development of a FEWS-Gambia pilot flood forecasting system
- Full set of training webinars that covered the use, development and maintenance of a pilot forecasting system for The Gambia

This document is the final document in this project for the development of a pilot flood forecasting system for the Gambia. It covers all the steps in the development of a pilot system, the training provided to the forecasters and an advice for next steps in developing an operational flood forecasting system for the Gambia.

Since the project was run during the COVID-19 pandemic period the project team was forced to move from providing offline courses to an online environment. All training courses and meetings were provided online through MS Teams meetings and a customized online training curriculum for the Gambia Forecasters was setup.

Contents

1 Introduction

1.1 Background

The country of the Gambia is centred around the Gambia river, with the capital of the Gambia, Banjul, situated at the mouth of the Gambia River. This makes the river of strategic importance to the country. The Gambia river itself originates in Senegal, before entering the Gambia to form a wide estuary, and subsequently flowing into the Atlantic Ocean. There are several challenges that the Gambia faces related to the water resources of the river, including the occurrence of floods and droughts. For the context of flooding, there are also several sources of flooding. This includes riverine floods originating from the basin of the Gambia, estuarine floods, as well as flash flood events due to high intensity rain storms, in particular over the urban areas of Banjul. These challenges have prompted UNESCO West Africa (situated in Senegal) in collaboration with the Department of Water Resources of the Gambia and the National Disaster Management Agency of the Gambia to initiate the development of early warning forecasting capabilities. In this project Deltares has been working with the Department of Water Resources of the Gambia to establish a pilot forecasting system as a first step to such forecasting capabilities, including the provision of training and guidance of the Gambian forecasters. This initial step should lead to a vision on how a fully operational service to the people of the Gambia can be established.

In this project the focus was to establish technical and human capacities in operational forecasting in the Gambia, there are still several challenges as to the reliability with which forecasts for the important sources of floods can be provided. As with many countries in the region, the Gambia is challenged with the availability of data, particularly real time that would be required. An alternative data source is the availability of global datasets from international data and modelling efforts, such as through Copernicus Climate Services and other sources. This data is comprehensive in its coverage and availability, but it is not clear if the reliability of forecast and models developed with such datasets is sufficient to meet the needs. Improvement to the current pilot forecasting system could be achieved through integration of these global datasets with locally available data and models.

1.2 Goal of the project

The overall goal of the project is to support the Department of Water Resources of the Gambia with the National Disaster Management Agency of the Gambia in the development of a pilot flood early warning forecasting system. The Gambian forecasters are trained, and guidance provided in further evolution of a pilot flood forecasting system into a fully operational flood early warning system. In the project period, from August 2021 to December 2021, the following activities were completed:

- A database is developed that contains all provided hydrological and meteorological observations for the Gambia. This database also includes some global and regional datasets that can be used to calibrate flood forecasting models, and server as operational observations and forecasts. (Chapter 2)
- A pilot flood forecasting system is developed that will serve as a proof-of-concept to demonstrate the technical capabilities of an operational forecasting system for the Gambia. (Chapter 3)
- A flood forecasting toolkit for Gambian forecasters is developed to process and analyse data and integrate models. (Chapter 3)
- A hydrologic and a flooding model is developed for the Gambia river basin and for the Greater Banjul Area. (Chapter 4)

- The Gambian forecasters are trained in the development, maintenance and use of the pilot flood forecasting system. An overview of the training material and training sessions is provided in Chapter 5.
- A plan is made for further evolution of a fully operational warning system for the Gambia. (Chapter 6)

1.3 Delft-FEWS and development of a Flood Forecasting System

The pilot flood forecasting system is developed for the Department of Water Resources of the Gambia using the Delft-FEWS software platform. Delft-FEWS is an integrated platform that facilitates users to better manage data, which includes collecting and displaying real-time monitoring information, processing data and integrating with simulation models, and propagating and disseminating forecasting information. The general concept of Delft-FEWS is illustrated in the figure below.

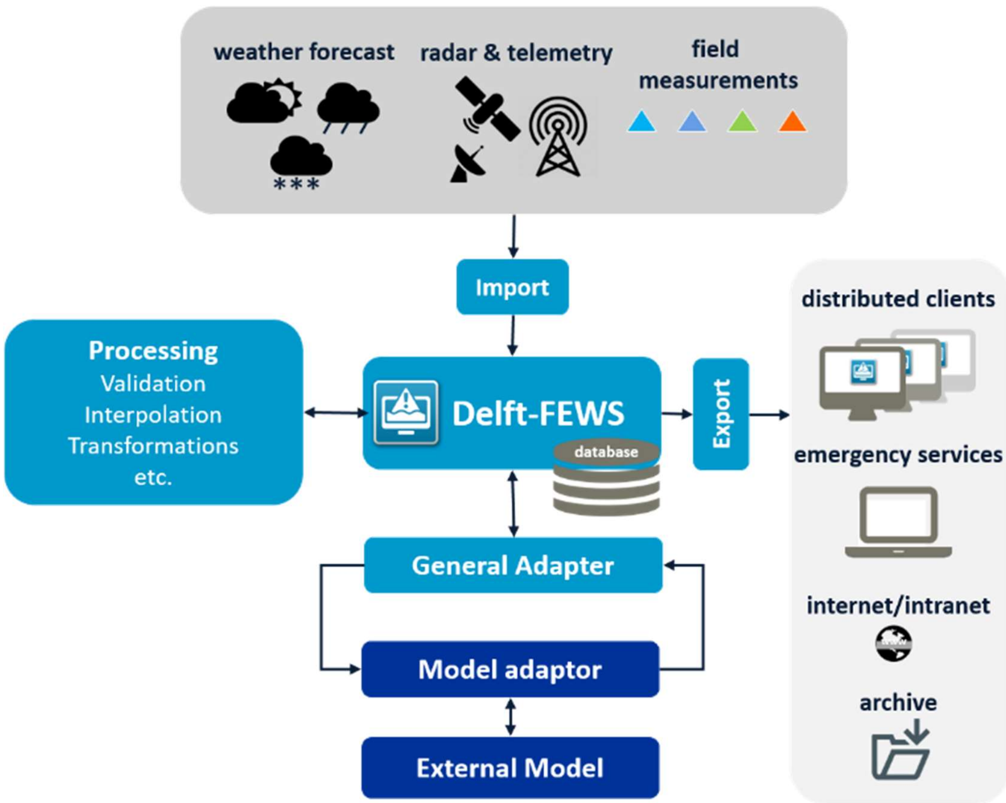


Figure 1 Delft-FEWS general concept

The development of Delft-FEWS pilot system for the Department of Water Resources of the Gambia (FEWS-Gambia) was an interactive process where Deltares took the lead in the system development and forecasters in the Gambia were trained in improving and extending the FEWS-Gambia pilot. This development process was though building FEWS-Gambia prototypes and providing Delft-FEWS configuration training courses. The prototype developed resulted in a final FEWS-Gambia pilot forecasting system capable of importing real-time data, processing and displaying this data, running a hydrologic and flooding model, presenting the model results and exporting forecast information to the Department to support the provision of warnings to end-users. The warning process could include further dissemination in for example internal or external web pages, documents or Mobile Apps.

1.4 Guide to the reader

This document is the final document in this project for the development of a pilot flood forecasting system for the Gambia. It covers all the steps in the development of a pilot system, the training provided to the forecasters and an advice for next steps in developing an operational flood forecasting system for the Gambia.

Since the project was run during the COVID-19 pandemic period the project team was forced to move from providing offline courses to an online environment. All training courses and meetings were provided online through MS Teams meetings and a customized online training curriculum for the Gambia Forecasters was setup. During the training sessions the team has realized that internet connection in the Gambia was not always of good quality, therefore not all forecasters were able to follow the online training in a way we expected at the start of the project. To help the trainees that could not attend all training sessions, the training material is made available as MS PowerPoint presentations with supporting videos where a Deltares trainer presents the training courses.

The original project plan proposed to have two workshops where non-technical issues would be discussed with a larger forecasting community in the Gambia. These workshops would lead to a comprehensive plan for the institutional embedding of a full operational forecasting and early warning system for the Gambia. Due to the COVID-19 pandemic and the bad internet connection these workshops did not happen. We still feel that it is very important to organize these workshops before going to a next phase in the development of a flood forecasting and early warning system for the Gambia. We advise to have these workshops in the Gambia and not as online meetings.

1.5 Project deliverables

This document contains references to the FEWS-Gambia pilot application and training material that is made available during and shortly after the training courses. All the training material is made available by email including surfFileSender links to download the material. All presentations, videos and other training material is downloaded by the trainees, we expect these are shared with the larger forecasting team and archived for later use.

The following deliverables are made available for download:

- A pilot flood early warning forecasting system based that is sustainable and scalable, based on the Delft-FEWS software.
- A database with local meta data, GIS data and meteorological and hydrological observations provided by the Department of Water Resources. The database also contains global datasets to fill gaps in the necessary data for a pilot flood forecasting system.
- A set of tools for the development, use and scaling up of the flood forecasting system. These tools are third party products that are provided at the start of the training.
- A hydrologic and flooding model for the Gambia basin and the Greater Banjul Area that show the use of models in the flood forecasting process.
- A full set of training sessions, including Microsoft PowerPoint presentations and supporting videos, to create a well-trained team of Gambian forecasters in using and maintaining the FEWS-Gambia pilot.
- This document with an overview of what is covered in the training and an advise for next steps in the development of a fully operational flood forecasting and early warning system.

2 Development of a database with local and international observation and forecast data

2.1 Set-up of a database management system (DBMS)

One of the central components in the development of a flood forecasting system is a database with historical time series data, real-time data, local meta data of observation networks and Digital Elevation Models for the construction of detailed hydrological forecasting models. The Delft FEWS database is capable of storing all these meta data, import the time series as well as model results. A Delft-FEWS database is therefore created with all provided data for the Gambia as well as some freely available global and regional datasets.

In this chapter the activities for data collection and data storage in the Delft-FEWS database are described. The steps needed to import, store and present these data in the Delft-FEWS database are covered in the training modules and in the FEWS-Gambia pilot presentations listed in Chapter 3 and 5.

2.2 Collection of local meta data and GIS data

For the development of hydrologic and flooding models, but also for the development of the FEWS-Gambia forecasting system local meta data and GIS data is used. Where available, the Department of Water Resources provided local information and local data for the development of the FEWS-Gambia pilot. The following local meta data and GIS data is required for the development of an operational FEWS-Gambia forecasting system. Only some of these datasets were available and provided for building the FEWS-Gambia pilot. It is expected that the Department of Water Resources will make more data available when a fully operational forecasting system will be developed.

The following local meta data and GIS data is required for the development of an operational flood forecasting system:

1) Map layers with critical infrastructure (preferably in shape file format)
2) Local detailed DEM/DTM of the greater Banjul area
3) List with hydrological gauging stations; the following meta data is required:
    - X, Y, Z coordinates of gauges
    - Location ID and Location Name of gauges
    - Data owner and data provider
    - Parameters that are measured at the gauges
    - Critical levels for validation or warning at the gauges
    - Time step the data can be provided at (5, 10, 15, 30, hour, daily intervals)
    - Historical and real time data
4) List with meteorological gauging stations
    - Same type of meta data as for the hydrological gauges
5) List with rating curves or structure functions to calculate flow from observed water levels

From this data requirement items 3) and 4) were provided and implemented in the FEWS-Gambia pilot. The gaps in accurate local data were complement with global datasets in the FEWS-Gambia pilot.

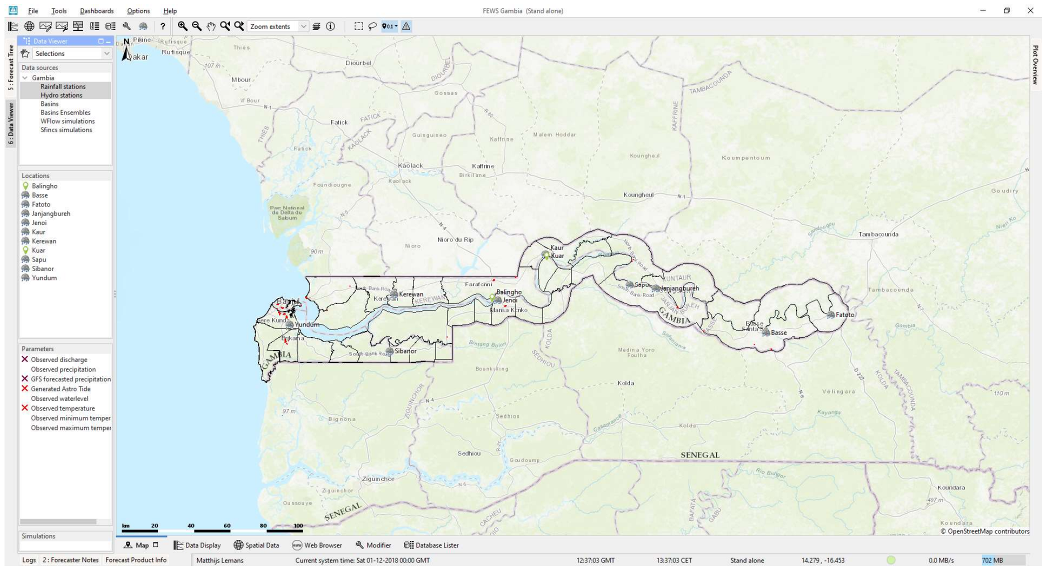


Figure 2 Example of the main display of the FEWS-Gambia system with locations where observed rainfall and water levels are provided.

2.3 Collection of local time series observations

An operational flood forecasting system is very much dependent on historic and real-time time series data. The time series data will have to be collected by Delft-FEWS from the different local data providers. The FEWS-Gambia pilot imports observed rainfall, temperature and water level time series for the locations provided by the Department of Water Resources. This is no real-time data but historic data collected and stored in Microsoft Excel files and CSV files. For an operational flood forecasting system for the Gambia we expect the following time series data to be provided as historic time series as well as real-time time series.

1. Observed rainfall data: this data is collected by telemetry or SCADA systems.
2. Observed water levels: this data is collected by telemetry or SCADA systems.
3. Observed discharges: this data is collected by telemetry or SCADA systems.
4. Forecasted rainfall data from local NWP rainfall forecasts or global NWP rainfall forecasts like ECMWF, Alladin.
5. Forecasted Water Levels and Discharges from existing local forecasting systems or global forecasting systems.

For the development of the historic database all provided local observation time series are imported and stored in the FEWS-Gambia database.

2.4 Collection of international earth observation and forecast time series

As with many countries in the region, the Gambia is challenged with the availability of data, particularly real time that would be required. In the FEWS-Gambia pilot several global datasets are collected, imported and stored in the FEWS-Gambia database. Most of these data sources were covered in the online training courses, some additional data sources that are integrated in the FEWS-Gambia pilot are listed below. It must be stated that this is not an extensive list of data sources, but it covers the most common international datasets for fluvial operational flood forecasting and modelling.

2.4.1 GFS – Global Forecasting System

The Global Forecast System (GFS) is a National Centers for Environmental Prediction (NCEP) weather forecast model that generates data for dozens of atmospheric and land-soil variables, including temperatures, winds, precipitation, soil moisture, and atmospheric ozone concentration. The system couples four separate models (atmosphere, ocean model, land/soil model, and sea ice) that work together to accurately depict weather conditions.

https://www.ncei.noaa.gov/products/weather-climate-models/global-forecast

The GFS parameters imported include forecast of rainfall, temperature and wind with timesteps of 1hour and 3-hours for forecast periods of 5 to 10 days. These forecasts can be imported in the FEWS-Gambia database when an internet connection is available. The period that is available on-line at the NOAA servers covers the last 7 days only prior to the current time.

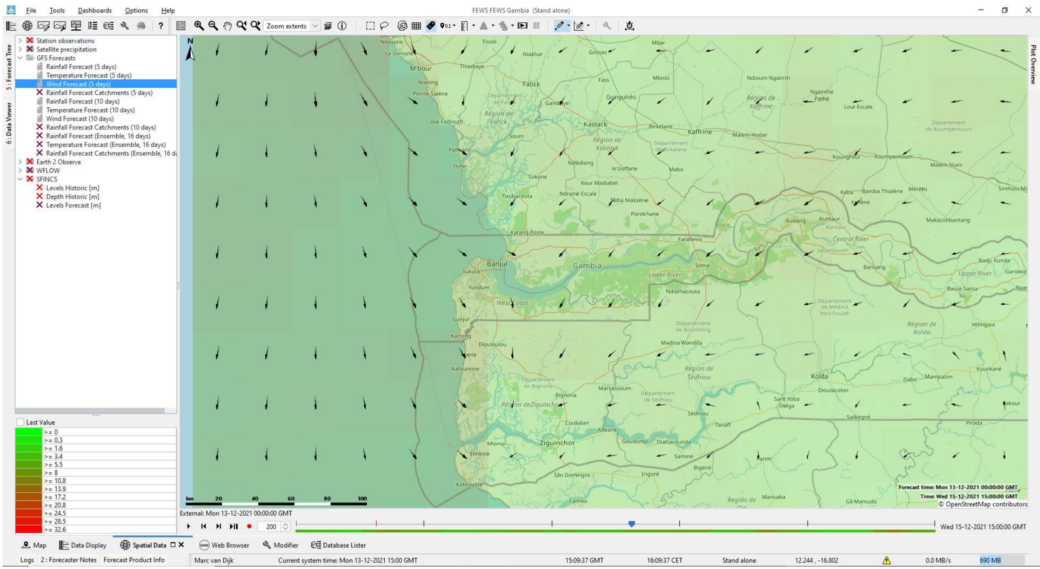


Figure 3 Example of imported GFS Wind Forecast in the FEWS-Gambia pilot.

2.4.2 GEFS – Global Ensemble Forecast System

The Global Ensemble Forecast System (GEFS) is a weather model created by the National Centers for Environmental Prediction (NCEP) that generates 21 separate forecasts (ensemble members) to address underlying uncertainties in the input data such limited coverage, instruments or observing systems biases, and the limitations of the model itself. GEFS quantifies these uncertainties by generating multiple forecasts, which in turn produce a range of potential outcomes based on differences or perturbations applied to the data after it has been incorporated into the model. Each forecast compensates for a different set of uncertainties.

https://www.ncei.noaa.gov/products/weather-climate-models/global-ensemble-forecast

The GEFS parameters imported include forecast of rainfall and temperature with timesteps of 6-hours and a forecast period of 15 days. These ensemble forecasts can be imported in the FEWS-Gambia database when an internet connection is available. The period that is available on-line at the NOAA servers covers the last 7 days only prior to the current time.

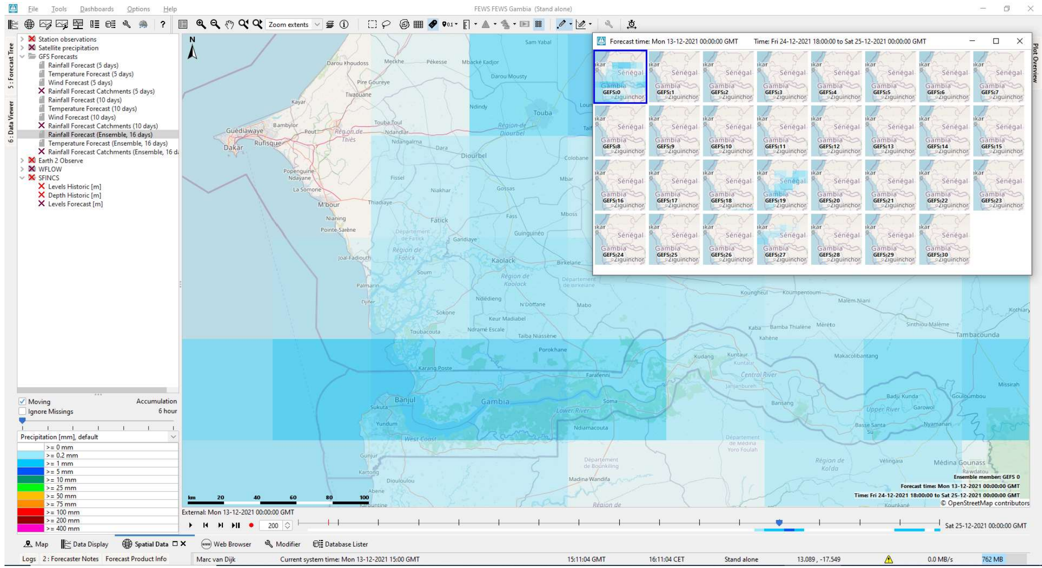


Figure 4 Example of imported GEFS Rainfall Forecast in the FEWS-Gambia pilot.

2.4.3 IMERG: Integrated Multi-satellitE Retrievals for GPM

The Integrated Multi-satellitE Retrievals for GPM (IMERG) algorithm combines information from the GPM satellite constellation to estimate precipitation over the majority of the Earth's surface. This algorithm is particularly valuable over the majority of the Earth's surface that lacks precipitation-measuring instruments on the ground. Now in the latest Version 06 release of IMERG the algorithm fuses the early precipitation estimates collected during the operation of the TRMM satellite (2000 - 2015) with more recent precipitation estimates collected during operation of the GPM satellite (2014 - present).

The IMERG data is imported in the FEWS-Gambia database and has time steps of 30 minutes; this means that every 30 minute these is a new satellite derived rainfall image available.

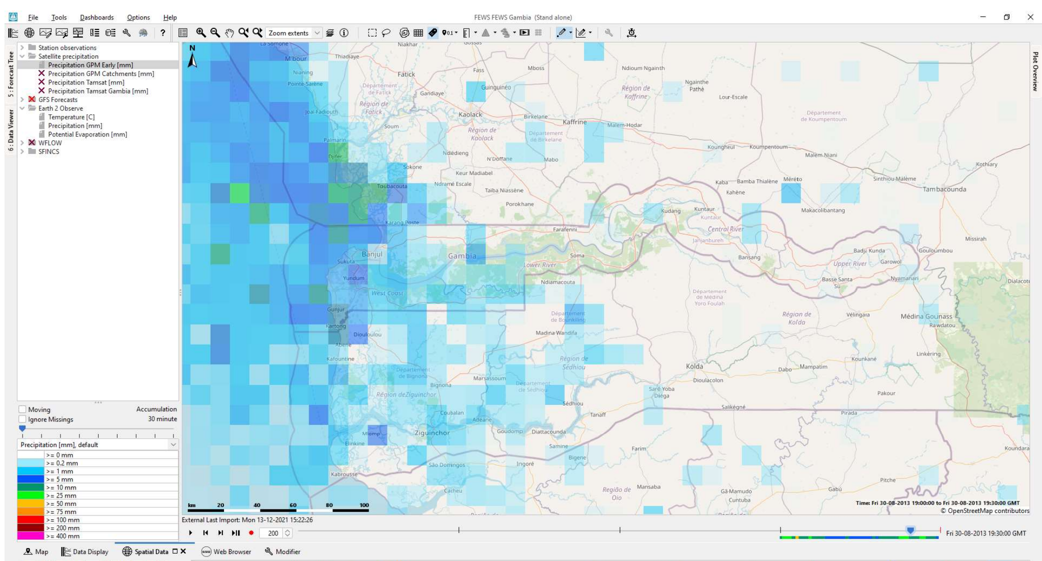


Figure 5 Example of imported IMERG Rainfall observations in the FEWS-Gambia pilot.

2.4.4 TAMSAT: Tropical Applications of Meteorology using SATellite data

TAMSAT stands for Tropical Applications of Meteorology using SATellite data and ground-based observations. TAMSAT enhances the capacity of African meteorological agencies and other organizations by providing and supporting the use of satellite-based rainfall estimates and related data products. TAMSAT produces daily rainfall estimates for all of Africa at 4km resolution. The TAMSAT archive spans 1983 to the delayed present. The longevity of the dataset makes it especially suitable for risk assessment. Applications of the data include famine early warning, drought insurance and agricultural decision support. Rainfall estimates and other TAMSAT products are issued on the 1st, 6th, 11th, 16th, 21st, and 26th of the month. All TAMSAT data are released for operational, research and commercial use under a creative commons license.

https://www.tamsat.org.uk/

The TAMSAT data is imported in the FEWS-Gambia database and has time steps of 1-day.

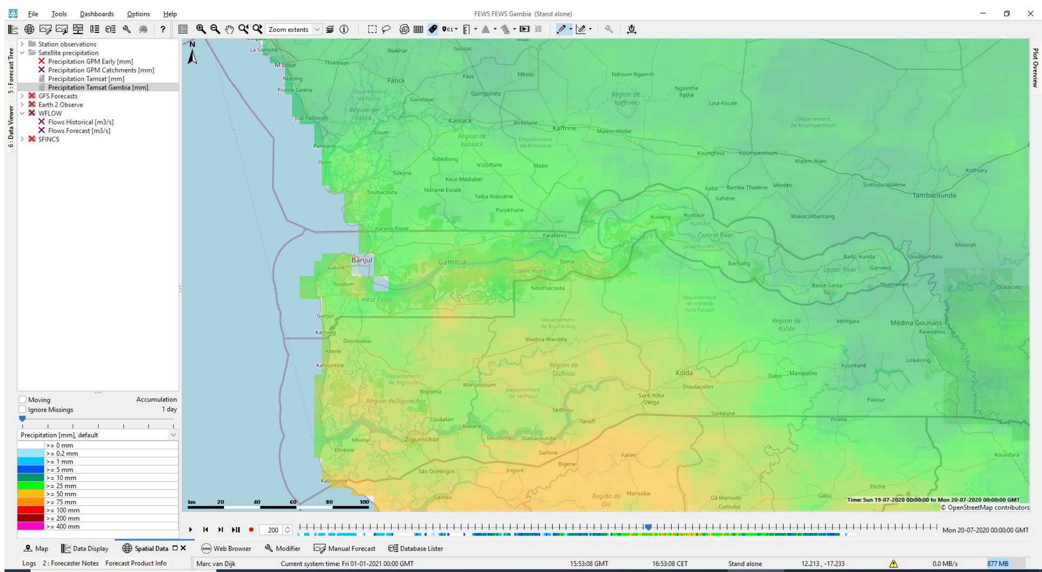


Figure 6 Example of imported TAMSAT Rainfall observations in the FEWS-Gambia pilot.

2.4.5 EartH2Observe

EartH2Observe “Global Earth Observation for Integrated Water Resource Assessment” is a collaborative project funded under the DG Research FP7 programme. The project begun in January 2014 and ended in 2017. The overall objective of this project was to contribute to the assessment of global water resources through the use of new Earth Observation datasets and techniques. For this purpose, the project integrated available earth observations, in-situ datasets and models, to construct a consistent global water resources reanalysis dataset of sufficient length (at least 30 years). The resulting datasets are made available through an open Water Cycle Integrator data portal: the European contribution to the GEOSS/WCI approach. The datasets are downscaled for application in case-studies at regional and local levels, and optimized based on identified European and local needs supporting water management and decision making.

http://www.earth2observe.eu/

The E2O parameters imported include observed rainfall, temperature and evaporation with timesteps of 3-hours and 1-day for a historic period of 36 years. The time series are imported in the FEWS-Gambia database and used in the WFLOW model for Gambia basin.

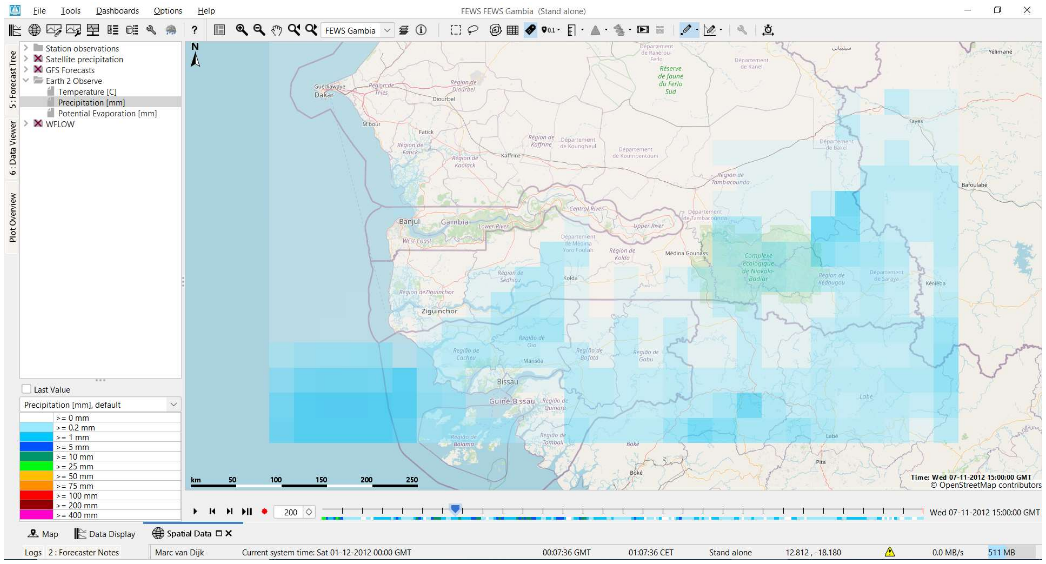


Figure 7 EartH2Observe time series in FEWS-Gambia pilot.

2.4.6 Tidal Boundary

For making a flooding model for Greater Banjul area it is important to have the tidal water levels for the Gambia river mouth. These tidal time series (astronomical harmonics) can be computed with globally generated astronomical harmonics. A first estimate of these astronomical harmonics is added to the FEWS-Gambia system for Banjul gauging station. With these harmonics the tidal water level series can be computed as a coastal boundary for the overland flooding models. For a fully operational flood forecasting system these harmonics must be reviewed and updated by the Department of Water Resources. The actual water level for Banjul can be computed with the tidal harmonics and forecasted surge time series caused by wind set-up.

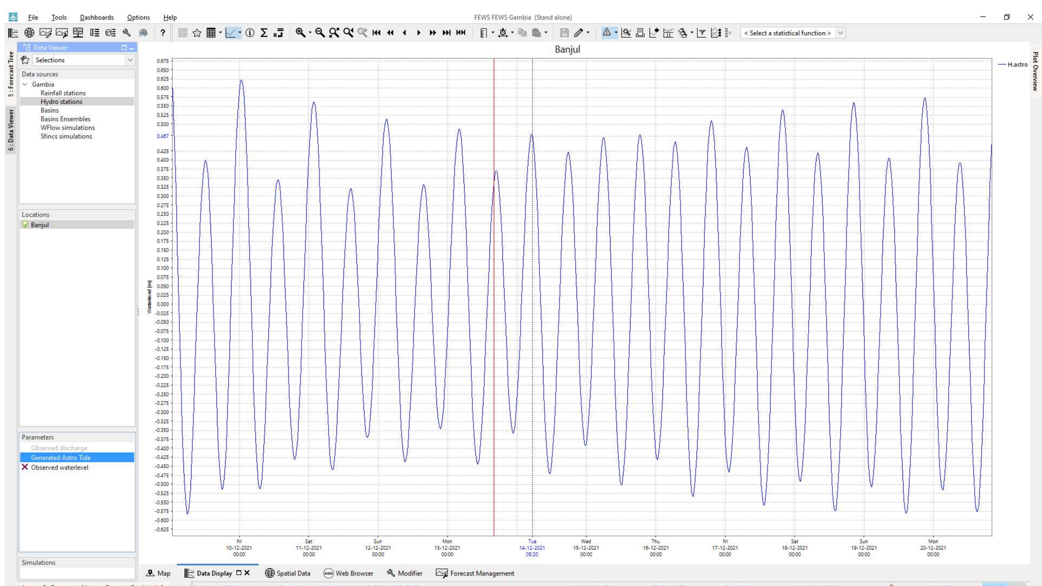


Figure 8 Tidal boundary for Banjul in the FEWS-Gambia pilot.

2.5 Overview of data in FEWS-Gambia database

The FEWS-Gambia database produced in this project contains the following datasets. Most of the data consist of global datasets that can be used for initial model testing for the Gambia river and Greater Banjul Area. It is strongly advised to make more detailed local datasets available before using the FEWS-Gambia system as a fully operational forecasting system.

Dataset	Type of data	Local / Global	Historic Period	Real Time
Background map layers	GIS / WMS	Global		
DEM	GIS	Global		
Flooding Hotspots	GIS	Local		
List of meteo gauges	Meta data	Local		
List of Hydro gauges	Meta data	Local		
Observed rainfall	Time Series	Local	1-1-1980 to 31-12-2020	No
Observed water levels	Time Series	Local	June 2012 to Aug 2019	No
E2O satellite meteo	Time Series	Global	1979 to 2014	No
Tamsat satellite rainfall	Time Series	Global	1983 - 2020	Near-realtime
IMERGE satellite rainfall	Time Series	Global	No historic data stored	Yes
GFS NWP	Time Series	Global	No historic data stored	Yes
GEFS NWP	Time Series	Global	No historic data stored	Yes
Tidal Harmonics	Meta data	Global		Yes

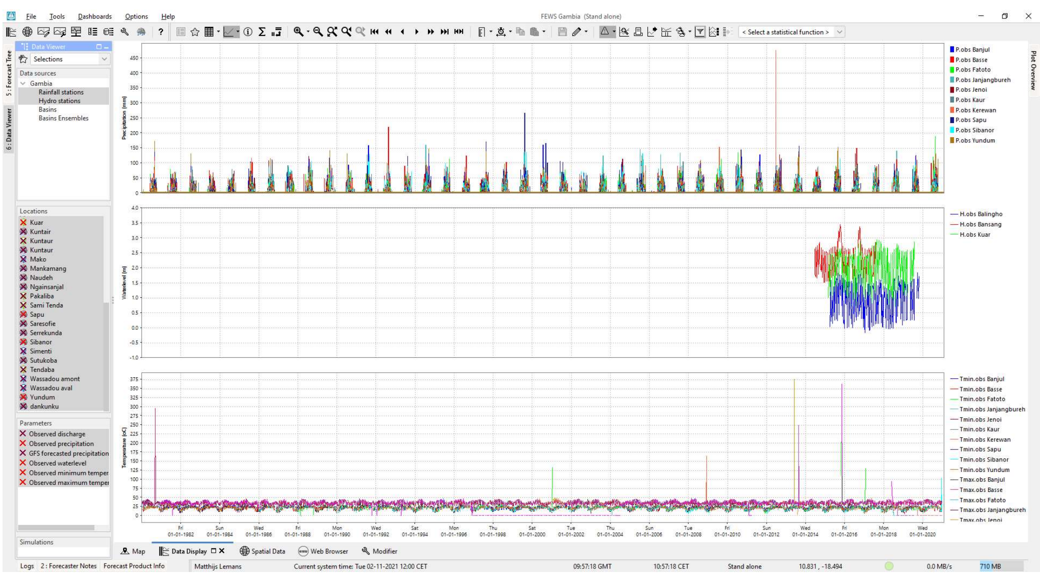


Figure 9 Overview of current local time series in the FEWS-Gambia database.

3 Development of a pilot flood forecasting and early warning system for the Gambia

3.1 From Prototype to a pilot forecasting system

A first prototype of the FEWS-Gambia forecasting system was developed at the start of the project implementation phase. This prototype is used in FEWS configuration and user training sessions and in discussions with the Gambia forecasters to gain familiarity with the Delft-FEWS software and its functionality. Working with prototypes is also very useful to understand the requirements for an operational FEWS-Gambia forecasting system. The initial FEWS-Gambia prototype was developed with the Delft-FEWS software in combination with open data that can be downloaded from the internet.

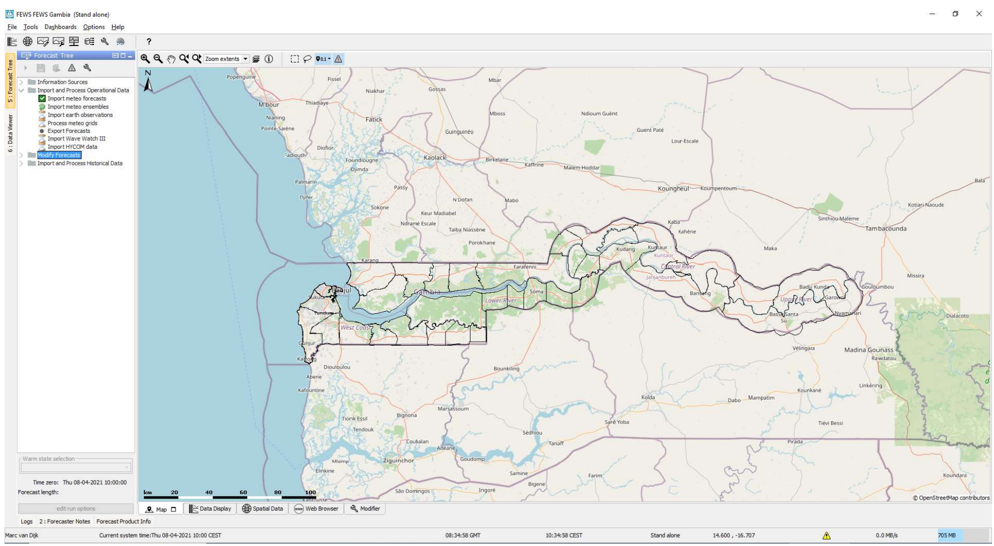


Figure 10 Example of the main display of the Delft FEWS system in an initial set up for the Gambia

The development of the final FEWS-Gambia pilot forecasting system has been evolved during the training webinars, where each prototype contained more functionality. This additional functionality was added to the system following the delivery of collected local data and the implementation of user requirements that were discussed at the webinars. The forecasters in Gambia from the Department of Water Resources were actively involved in this prototype development and trained in all aspects of the FEWS-Gambia configuration. At the end of this implementation phase, the Gambia forecasters are knowledgeable Delft-FEWS users capable of extending FEWS-Gambia with new data and models and add new Delft-FEWS functionality without or with minor support of Deltares.

This agile development of the FEWS-Gambia prototypes included the following activities:

1. Collection of local meta data and GIS data and adding this data to the FEWS-Gambia database
2. Collection and implementation of hydro-meteorological gauging stations
3. Collection and implementation of historical and real-time data sources
4. Processing of historic and real-time data
5. Development of hydrological and hydraulic models
6. Integration and running of hydrological and hydraulic models in FEWS-Gambia
7. Display of real-time data and model results

8. Export of forecasts to support warning processes

All these steps have been introduced, explained, configured and exercised during the Training webinars. A more detailed over view with all delivered training material is included in Chapter 5.2 of this report.

3.2 Overview of what is in the system

An overview of the final FEWS-Gambia pilot application is schematized in the figure below, showing the data flows between the various components. Time series data are imported from several sources (Chapter 2.3 and 2.4) using Delft-FEWS workflows that can be submitted by the user in the FEWS-Gambia pilot. The data is validated against configured rules (quality control) and stored the FEWS-Gambia database. Other workflows process the data for visualization purposes or prepare the data for input to the hydrological and flooding models. The model workflows export data to the WFLOW and SFINCS models and import the generated simulated time series back to the FEWS-Gambia database where it is further postprocessed for visualization or reporting. The FEWS-Gambia forecaster duty officer (FDO) can visualize all the data in the FEWS-Gambia displays, and copy graphs and images to a word template file for creating a daily report (Appendix B). There is no automatic import, export or report configured yet in the pilot application.

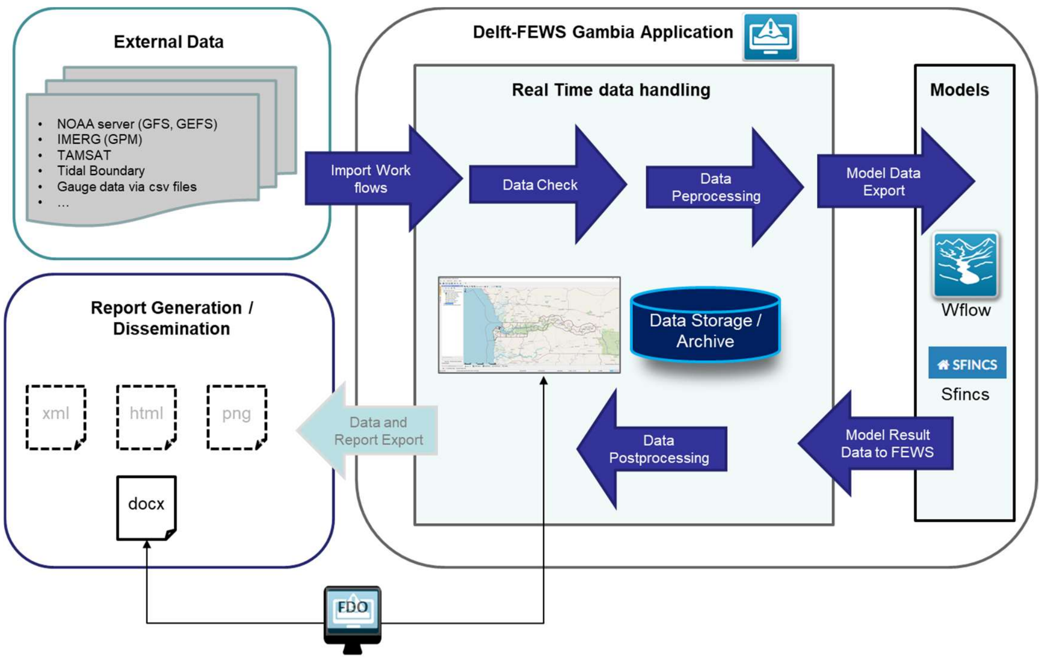


Figure 11 Overview of the FEWS Gambia pilot processes in a data flow diagram

3.3 FEWS-Gambia User Guide

There is no detailed FEWS-Gambia user guide created. All steps in starting the FEWS-Gambia pilot, importing data, running models and displaying data are included in the training material. The Microsoft PowerPoint presentations and videos included in the training material provide a good visual guidance to the Gambia forecaster in using the FEWS-Gambia pilot.

The following presentations provide a good overview of the activities in using the FEWs-Gambia pilot:

- **Module 01 Delft-FEWS Pilot for The Gambia.pptx**
  - Start of the FEWS-Gambia pilot.

– Import of operational satellite rainfall data
– Import of operational weather forecasts

- **Module 09C Importing Real Meteo Data.pptx**
  – Visualising and editing observation data
- **Module 10 Validating Data.pptx**
  – Data validation, automated and manual quality control
- **Module 13 WFLOW Model Integration.pptx**
  – Running the Gambia basin hydrologic model and analyse results
- **Module 14 SFINCS Model Integration.pptx**
  – Running the Greater Banjul Area flooding model and analyse results

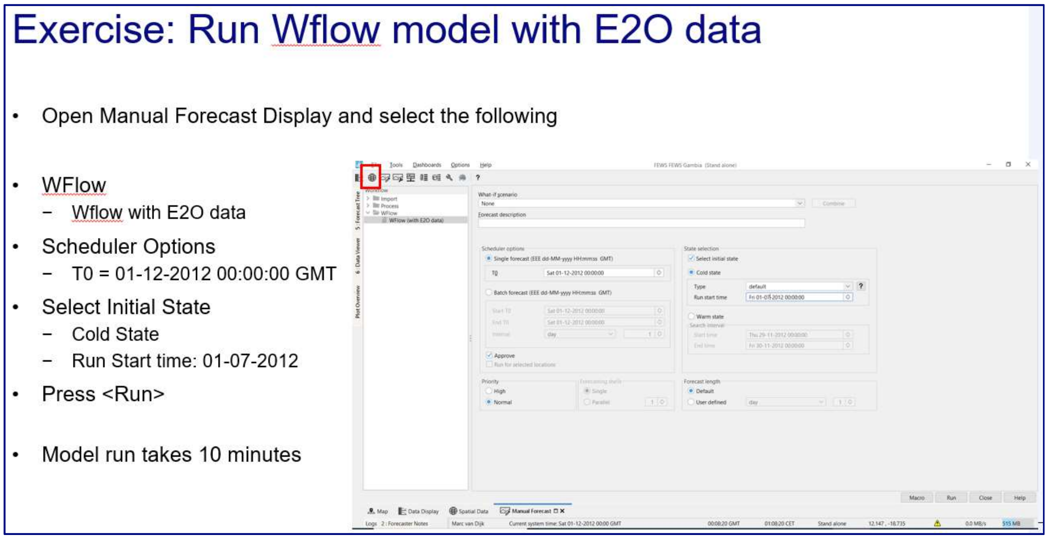


Figure 12 Example of a training sheet to run the hydrologic WFLOW model

4 Development of hydrological models for the Gambia

4.1 Introduction

Operational forecasting and warning capabilities have been developed in many river basins across the world. Although a wide variety of approaches can be found, the key elements of the flood forecasting and warning process can be summarised as four main steps; (i) Detection, (ii) Forecasting, (iii) Dissemination and Warning, and (iv) Response. Within the forecasting step, hydrological and hydraulic models may be used to develop a prediction, and the forecasting system needs to support the operation of these models in real-time. These models use real-time input data that has been processed to an appropriate spatial and temporal scale. To increase lead time, meteorological forecast data from for example Numerical Weather Prediction models is increasingly being used. This requires the forecasting system to import and process the data from these to serve as future precipitation inputs for the hydrological and hydraulic model chain.

The approach to the integration of models to be run as a part of the forecast process in Delft-FEWS has been chosen to be simple yet effective. Typically a forecasting process may use a cascade of models such as a snowmelt model, a rainfall-runoff model and a routing model. These models are often independent, with the forcing of each downstream model being the result of the model upstream of it. This means the models can be run sequentially, and independently, with data being passed to and from the database at each step in the model cascade.

When setting up a model to run from a forecasting system, a good understanding of the model itself is required. It is therefore important that a forecasting system uses model concepts that are used and or developed by the local forecasting agencies. In the FEWS-Gambia training webinars the Gambia forecasters were asked to provide (when available) the following model types:

- Regression curves or correlation functions that are available for the Gambia rivers or basins.
- Hydrological models developed for the Gambia in other projects
- Hydraulic models developed for the Gambia in other projects

In the FEWS-Gambia training webinars it turned out that the Gambia forecasters did not have experience with these types of local models or had these models developed in previous projects. It was therefore decided to use open source model concepts that can be set-up in a semi-automated procedure and can be customized by the forecasters with some minimal training.

This project did not include any specialised hydrologic or flooding model training. It is advised to have this type of training organised, such that the Gambia forecasters become familiar with modelling concepts and are capable of developing and improving the models that they intent to use operationally.

4.2 Integration of hydrological models in FEWS-Gambia

The philosophy of Delft-FEWS is to provide an open system that allows a wide range of existing forecasting models to be used. This concept is supported by a Delft-FEWS module called the General Adapter, which communicates to external models through an open XML or NetCDF based interface. This interface allows plugging-in of any forecasting model, algorithm or script in the FEWS-Gambia pilot. The XML or NetCDF based interface is linked with a Model Adapter which converts input data into model inputs and converts model output data back to XML or NetCDF format that can be imported to Delft-FEWS.

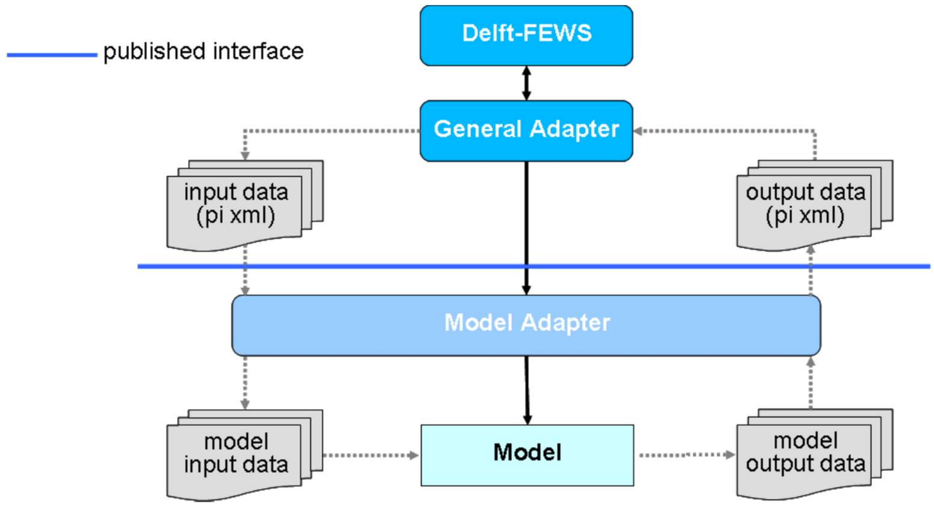


Figure 13 Delft-FEWS Model Adapter concept for integrating hydrological and hydraulic models.

The Delft-FEWS configuration for integrating external models is added to the FEWS-Gambia pilot by Deltares and presented to the Gambia forecasters in the configuration training webinars.

Within the FEWS-Gambia pilot system a WFLOW hydrological model is developed for the Gambia basin and a SFINCS overland flooding model is developed for the greater Banjul Area. These models are part of the proof-of-concept to demonstrate the technical capabilities of the flood early warning forecasting system. The models will simulate the hydrological processes, the models will not be detailed flooding models taking into account sewer systems or detailed road networks.

4.3 Set-up of a WFLOW Rainfall Runoff model

4.3.1 WFLOW Model background

WFLOW is the Deltares open-source modelling framework for distributed rainfall-runoff modelling. It maximizes the use of recent-day Earth observation data and calculates all hydrological fluxes at any given location and time step, using high-resolution distributed meteorological forcing data. Examples of major processes that can be included are snow and glacier accumulation and melt, rainfall interception, soil moisture accounting, runoff generating processes and river flow. WFLOW is programmed in the state-of-the-art Julia programming language. A main benefit of WFLOW as compared to many other distributed hydrological models is that consists of a library of different hydrological concepts and the possibility to link it with other model components (like water quality, sediment, crop growth, reservoirs) directly or by using the basic model interface (BMI), the integration with Delft-FEWS for flood and or drought forecasting, and the coupling with OpenDA for data assimilation of point and spatial observations.

WFLOW has been successfully applied across the world for flood and drought forecasting as well as evaluating the impacts of climate change (including drought conditions) or (land) management strategies. It is also used as an instrument to provide uniform flow simulation for river basin management studies and for the assessment of water availability for the design of irrigation schemes. A global WFLOW model has been identified as a major component in the provision of hydrological data services via the GLOFFIS system for forecast data and in the project GLOW for historic data.

WFLOW models maximise the use of available spatial data by linking parameter values to soil or land use types and by using gridded meteorological products (see figure below**Error! Reference source not found.**). The distributed nature of the model implies that the model is run on each grid cell and that water flows from one grid cell to another either through the kinematic wave routine and/or through lateral groundwater flow. For each grid cell, WFLOW provides continuous simulated values of the hydrological state variables (channel flow, overland flow saturated zone storage etc.). The model output can be visualized as a sequence of spatial maps (gridded raster data) of hydrological variables. For any location in the catchment, time series of hydrological variables such as discharge or soil saturation can be generated.

The input data required to execute a simulation in WFLOW can be separated into i) static data concerning the description of the land surface, and ii) dynamic data, represented by the hydro-meteorological forcing of the model. Main input maps are generally available spatial datasets:

- Digital elevation map (DEM)
- River network map (can be generated from the DEM)
- Land use map
- Soil type map

Based on the DEM, and the river network map, the WFLOW model requires a local drain direction map, which forms the basis for the hydrological routing calculations.

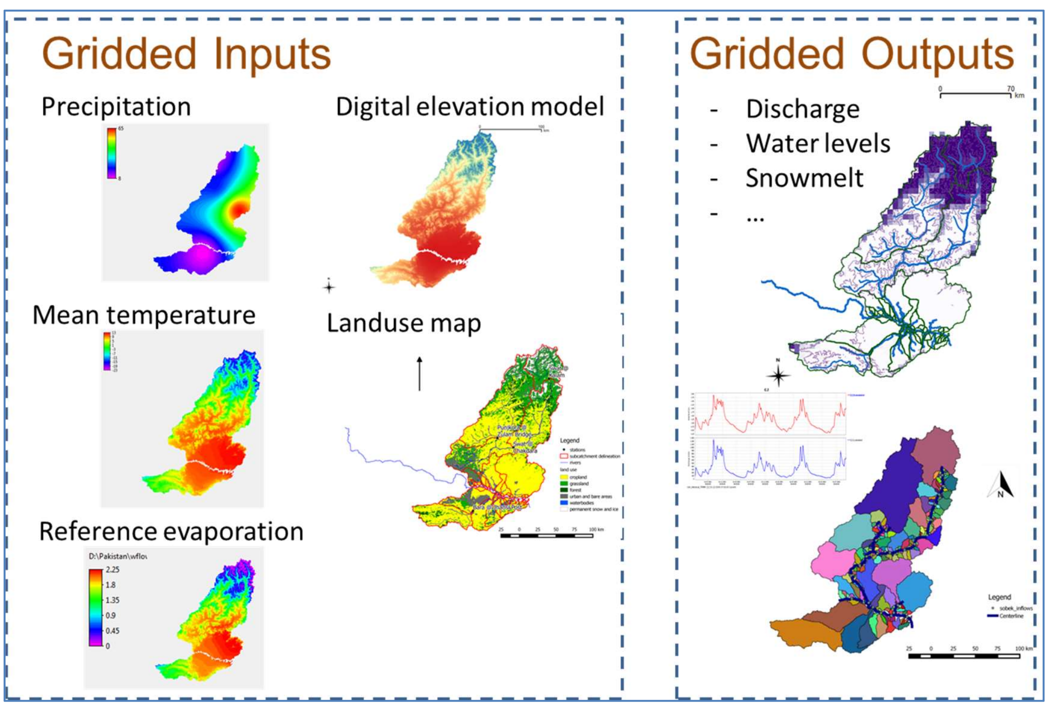


Figure 14 Gridded in- and outputs of WFLOW

Deltares' ongoing research on WFLOW focusses on the further development of the WFLOW_sbm concept (loosely based on Topog_sbm concept (Vertessy and Elsenbeer (1999). WFLOW_sbm is a physically based model, that makes use of a simplified representation of the Richards equation (gravity-based infiltration and vertical flow through the soil column as well as capillary rise), and kinematic wave for lateral flow through the subsurface (making it comparable to the closed source G2G (Bell et al., 2007) and TopKapi (Todini and Ciarapica, 2002) models), on top of the land surface (overland flow) and the river network in downstream direction. This way the run time performance is faster than more complex physically based hydrological models that solve the Richards equation and the shallow water equations for overland flow and through the river network. WFLOW_sbm model parameters have a clear physical meaning (e.g., saturated and residual water content and saturated hydraulic conductivity) and can be derived from available large-scale digital elevation models, soil texture data and land cover information. This combination allows for comprehensive model estimation using pedo-transfer functions and seamless calibrations across large domains or for the possibility of detailed land use change scenario analyses.

WFLOW_sbm incorporates the most important processes of the hydrological cycle and has the option to divide the soil column into different layers, to allow for transfer of water within the unsaturated zone. Different components of the hydrological cycle are modelled through a combination of hydrological processes nested in the model code, including:

- Evapotranspiration (open water and soil evaporation and transpiration) and interception losses, interception is schematized by the Gash model (Gash, 1979,) on a daily timestep and the Modified Rutter interception model on a sub-daily timestep.
- A root water uptake reduction function (Feddes, 1978).
- Channel, overland, and lateral subsurface flow are modelled with the kinematic wave model.
- Infiltration (paved and unpaved areas per grid cell (fraction))
- Vertical flow through the unsaturated zone, and transfer to the saturated store.
- Saturated zone (Capillary rise to the unsaturated zone, kinematic lateral subsurface flow between grid cells).

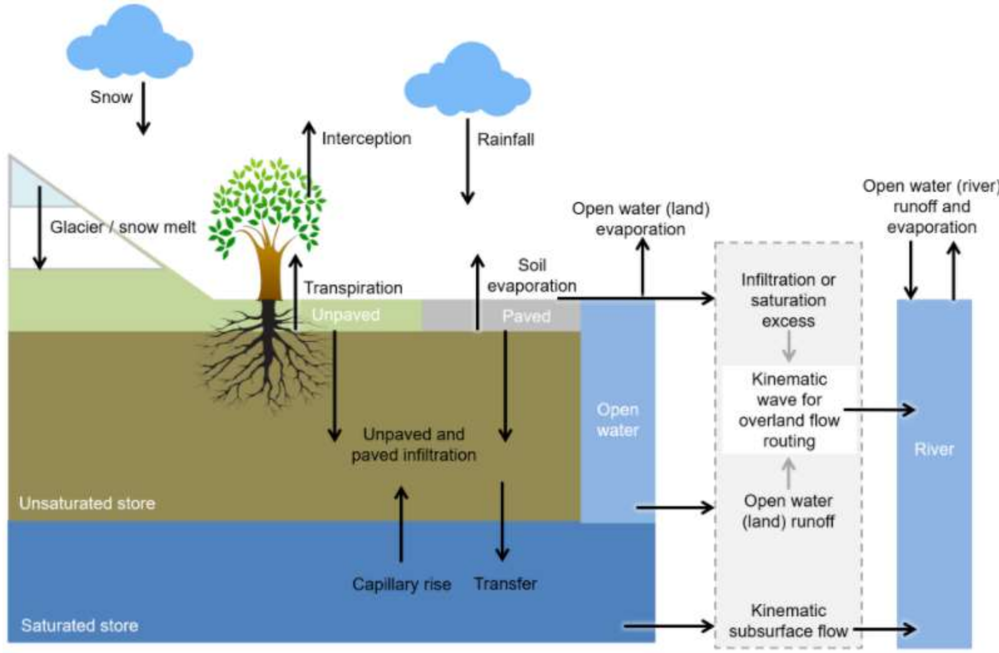


Figure 15 The Hydrological cycle

Within the kinematic wave for channel flow, natural lakes and reservoirs can be included. Both modules use a simple mass balance approach and need as inputs inflow, precipitation and potential evapotranspiration.

The reservoir module requires the model parameters surface area, maximum release below the spillway, the minimum environmental flow requirement downstream of the reservoir, a target fraction full (of the maximum reservoir storage) and a target minimum full fraction (of the maximum reservoir storage), and the maximum reservoir storage capacity. A sigmoid curve, based on the current storage fraction of the reservoir, the minimum environmental flow requirement downstream, and the target minimum full fraction controls the amount of the flow that the reservoir releases to fulfil the environmental flow requirement downstream. Furthermore, the reservoir releases water based on the maximum storage capacity (reservoir storage that exceeds the maximum storage capacity is always released), the target fraction full and maximum release below the spillway.

Both storage and outflow of the natural lake module are linked to the water level in the lake using a storage curve and rating curve respectively. More detailed information about these modules can be found here:

https://deltares.github.io/WFLOW.jl/dev/lateral/kinwave_params/#reservoir_params

More information (as well as the source code of the WFLOW model) can be found online.

- WFLOW: https://deltares.github.io/WFLOW.jl/dev/
- HydroMT: https://deltares.github.io/hydromt/latest/

4.3.2 WFLOW for the Gambia Basin

For the Gambia basin a WFLOW model is set-up that covers the complete river basin upstream of Banjul. The figure below shows the spatial domain of the WFLOW model that is integrated in the FEWS Gambia pilot.

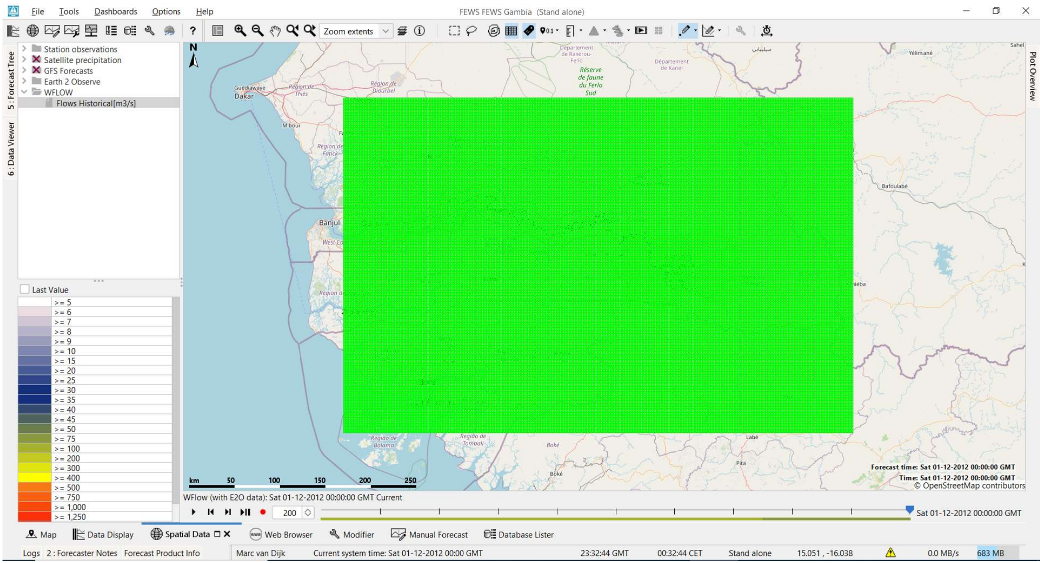


Figure 16 WFLOW model grid domain, visualized in the Delft FEWS system

The WFLOW model is run for several periods with high rainfall events, results of the model output can be visualized in the FEWS-Gambia Displays.

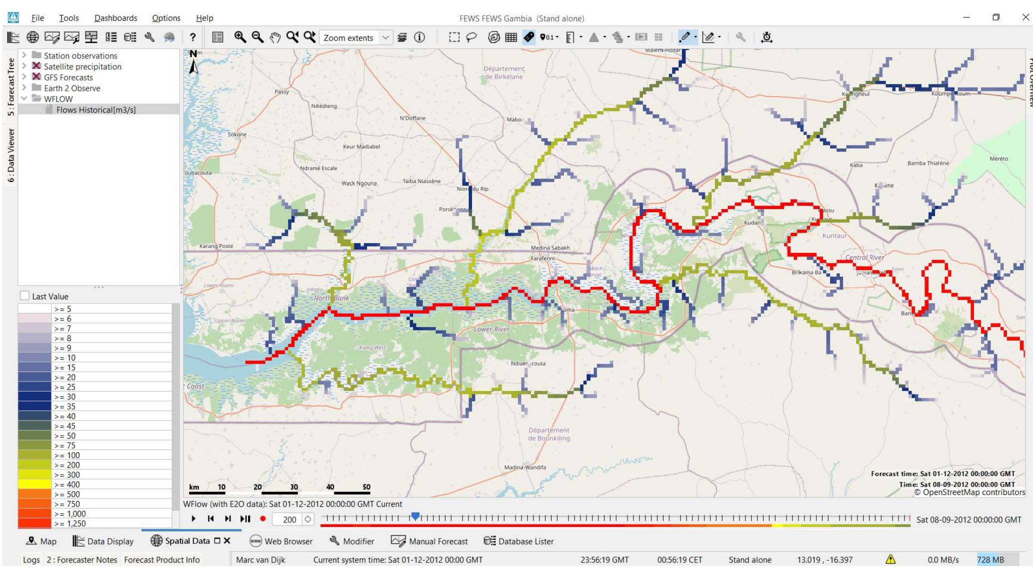


Figure 17 WFLOW model river network showing flows in the Gambia river

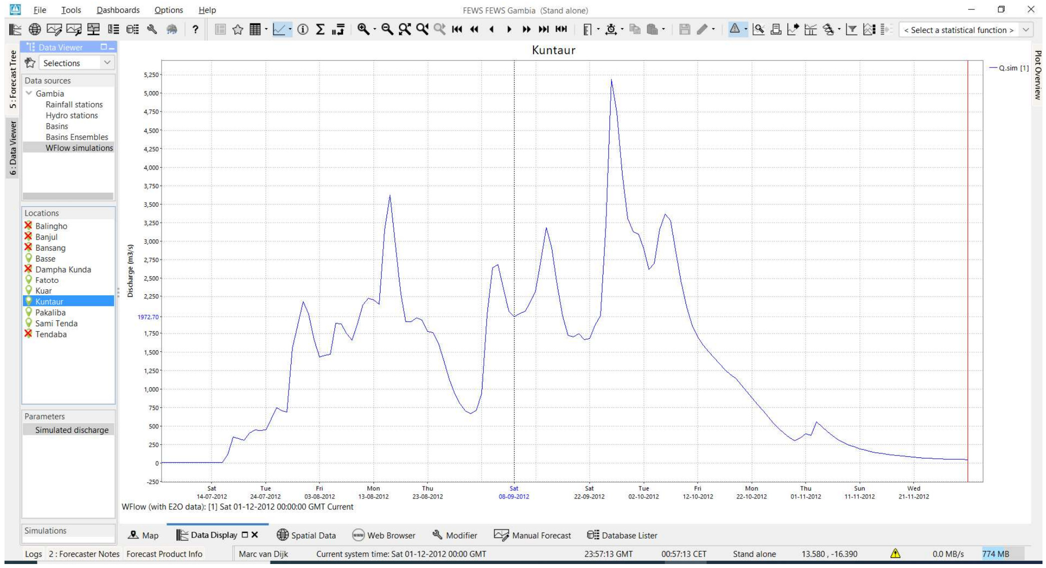


Figure 18 WFLOW discharges for some gauge locations

Unfortunately, there are no observations in the Gambia river to compare the model results with. It is therefore difficult to assess the quality of the WFLOW model for the Gambia basin.

4.4 Set-up of a SFINCS flood model

4.4.1 SFINCS Model background

SFINCS (Super-Fast INundation of CoastS) (Leijnse et al., 2020) is a time-dependent reduced-physics dynamic model which contains all the necessary physical processes to compute compound flooding with similar level of accuracy but at a much lower (50-100 times) computational cost than a full-physics model (like Delft3D-FM, ADCIRC, TU-FLOW or FV-COM) due to a sub-grid approach (see table below). This speed enables the user to perform a probabilistic flood risk with 100s of ensembles at a state-wide scale in a much shorter time and to evaluate the effect of various interventions in the system.

Includes physics of tides, storm surge, waves, precipitation, river discharge, ground water	The SFINCS Coastal Flood Model captures processes relevant for flooding of the New Hampshire coastline. As concluded by among others Wake et al. (2019) and the NHCRHC (2016), these processes include tides, storm surge, waves, river discharge, precipitation, and ground water influence.
Computationally-efficient	SFINCS is highly computationally efficient, which is required for probabilistic computations and ensemble modelling, as well as for a potential future extension to an early warning application. The sub-grid model feature uses the high resolution (3 – 15 ft) of the topographic data sets but computes the water level variations at a computationally-efficient wider grid (150 ft) while the model output is translated back to the high-resolution mesh grid (3-15 ft) to support decision-making at a parcel level.
Easily adaptable and extendable	The SFINCS model is an easily adaptable software code for future extensions (e.g., erosion modules) and can be coupled to other Deltares' software like Delft3D-FM, XBeach, and FIAT.
Consistent with recent flood risk assessments	Deltares has already created SFINCS models for the South East Atlantic and Gulf of Mexico coast, commissioned by clients such as the Department of Homeland Security, the U.S. Geological Survey and the Office of Naval Research.
User friendly	The SFINCS model software is very user-friendly, being integrated in the Delft Dashboard GUI for quick and easy model setup and model adaptations. SFINCS can also be included in Delft-FEWS which allows for interactive scenario modelling.
Low-maintenance	The SFINCS model is continuously updated and revised as it is used in a number of national and international research and consultancy projects. New versions will be compatible with old input statements, making the model low maintenance for its users.

Integrable in existing flood risk platforms	The SFINCS model output is directly importable into the Delft-FEWS framework and other common frameworks.
Model limitations	Some advanced processes are not solved in SFINCS that can be solved with more computationally intensive models like Delft3D(-FM) or XBeach. This includes the modelling of water-quality and density driven flows (Delft3D), as well as nearshore wave processes like infra-gravity wave generation (XBeach). Prior modelling experiments have demonstrated these processes are not necessary for the planning-oriented compound flood modelling intended here.

More information on the SFINCS model can be found on the website:
https://sfincs.readthedocs.io/en/latest/overview.html

4.4.2 Compound flooding

Compound flooding is described as events occurring in coastal areas where the interaction of high sea levels, large river discharges and local precipitation causes (extreme) flooding (Wahl et al., 2015). To simulate compound flooding events, a model needs to be able to model all these types of forcing. Therefore, SFINCS includes fluvial, pluvial, tidal, wind- and wave-driven processes.

- **Coastal model:** A SFINCS model in coastal regions can be forced with marine forcing like tides, storm surge, local wind setup and wave driven processes. Generally, a model is setup with the offshore boundary in the swash zone, good practice is in about 2 meters water depth. In SFINCS it is possible to distinguish cells that are made inactive in the computation, so it will not slow your model down (in this case everywhere deeper than 2-meter water depth). In some cases, local rainfall might be relevant too for a coastal model.

- **Coral reef model**: SFINCS models have also been setup in coral reef type environments, where individual waves are forced to compute wave-driven flooding. This generally has a large contribution to flooding for Small Island Developing States (SIDS) or other coasts/islands with coral reef type coasts.

- **Tsunami model**: As an additional type of coastal model, SFINCS has also been used for modelling tsunami's. Generally, this would be an overland model forced with a tsunami wave as computed by an offshore hydrodynamic model. However, in the paper of Robke et al. 2021 SFINCS was also used for the first time to calculate the offshore propagation in a very short amount of time too. Get in touch to hear more about possibilities for tsunami modelling with SFINCS.

- **Storm surge model**: Since speed is wanted everywhere, also tests have been done to let SFINCS model offshore storm surge during tropical cyclones. Get in touch to hear more about possibilities for storm surge modelling with SFINCS.

- **Riverine model**: For inland riverine types of environments, boundary conditions are generally different than for coastal models. Generally, at the upstream end of rivers, one can provide discharge points with discharge time-series. At the downstream end of rivers, water level time-series need to be specified, which in case of sub-critical flow conditions will influence the flow upstream. Additionally, besides the general river discharge, local rainfall adding water to the river can be very relevant too.

- **Urban model**: For urban environments the local situation of varying land use conditions can heavily influence the local flow. Therefore, spatially varying input of manning roughness and infiltration is possible. The curve number method of infiltration will distinguish what part of falling precipitation can infiltrate or will run-off. To test out the effect of interventions, it is possible to insert different types of structures into the SFINCS model. These can be thin dams, levees, sea walls, simple drainage pumps or culverts.

- **Flash flood model**: In recent tests, SFINCS has also been used to model flash floods. In these events, a short but intense rainfall event falls onto a domain and together with a steep profile can lead to significant water depths and flow velocities. Get in touch to hear more about possibilities for fast flash-flood modelling with SFINCS.

- **Compound flooding model**: In a compound flooding model, all relevant types of forcing from either coastal, coral, riverine or urban models can be combined into 1 domain. Hereby the joint effect of multiple flood drivers that can enhance flooding can be taken into account.

4.4.3 Project experience

SFINCS has been applied in many projects in the USA, for clients like USGS, ONR and DHS; and elsewhere in the world, for example Denmark, Bangladesh, Liberia, Mozambique and the Marshall Islands. New projects where SFINCS will be used to model overland flooding in the complete East Coast of Australia are underway and will be completed in 2022. The WorldBank has developed a storymap using floodmaps simulated by SFINCS, info is available on https://storymaps.arcgis.com/stories/8c715dcc5781421ebff46f35ef34a04d.

In most of these projects the SFINCS model was created for flooding situations that were caused by a combination of coastal flooding and fluvial flash floods. The example below shows a typical situation where the SFINCS model covers the coast and tidal rivers. This is the same type of situation that is seen in Gambia.

Figure 19 SFINCS model for Charleston (South Carolina, USA)

4.4.4 SFINCS Model for Greater Banjul Area

Information provided by the Department of Water Resources show that most of the areas vulnerable to flooding are located in the Greater Banjul Area (see figure below). There are also some areas situated more upstream the Gambia river, but most of the vulnerable areas are located in the Greater Banjul Area. For testing the use of a flooding model in the FEWS-Gambia pilot a pilot SFINCS model is set-up for the Greater Banjul Area using global datasets. Unfortunately, the global datasets used do not include a detailed DEM, detailed bathymetry and information on canals or sewer systems in this area.

Figure 20 Areas vulnerable to flooding (in red)

The model should therefore only be used as a rough estimate of what can happen when there is intense rainfall in the area. Local GIS information is a prerequisite for developing accurate flooding models that include local information on dams, levees, sea walls, simple drainage pumps or culverts.

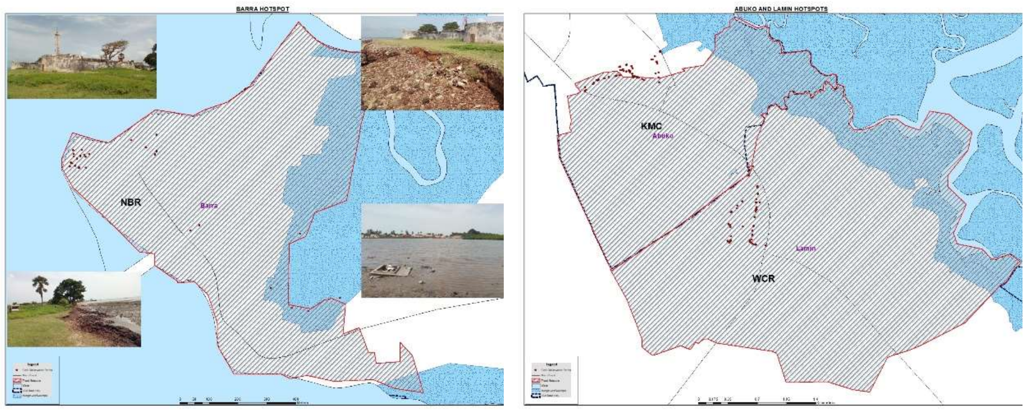


Figure 21 Examples of vulnerable areas provided by the Gambia Department of Water Resources

As the model area also contains some coastal stretches it is important to include a good bathymetry when building the model and information on tidal water levels when running the model in an operational environment.

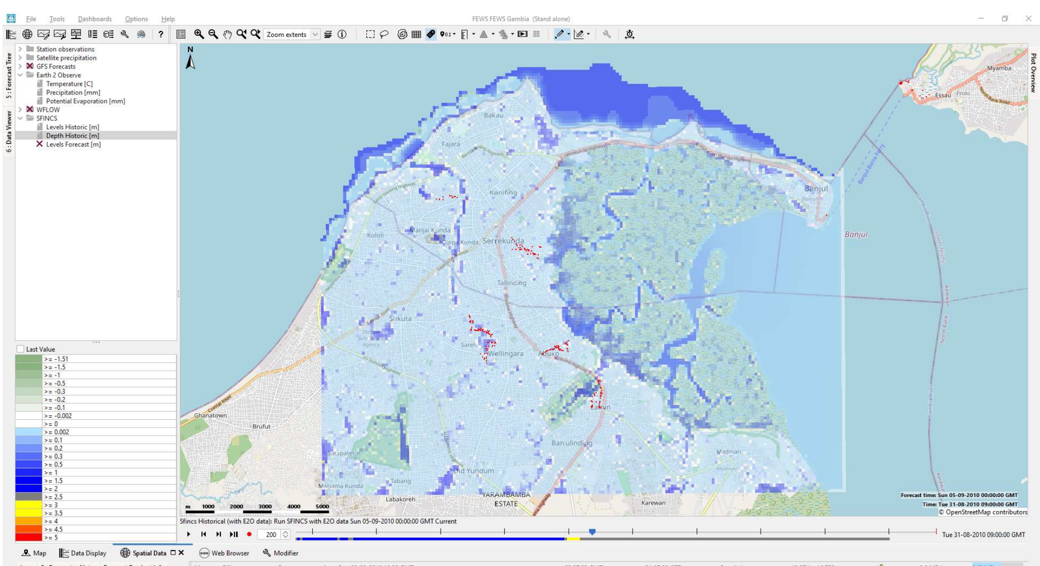


Figure 22 Water Depth of a historic model run with SFINCS for 5 September 2010

5 Training of the Gambia forecasters

5.1 Developing capacity with the Gambia forecasters

Training is an essential part in the development of an operational flood forecasting system, and thus forms an essential part in the development of the FEWS-Gambia pilot application. The training sessions are developed in the context of this FEWS-Gambia pilot application and focuses on the following components:

1. Formal training in the operational forecast process and the use of real time observations and forecast time series in the FEWS-Gambia pilot. This included training of the forecasters to run daily forecasting tasks using the FEWS-Gambia application, interpreting the results and generate daily concise forecasting reports.

2. Formal training in the configuration, set-up and maintenance of the FEWS-Gambia application, including the integration of observed time series, integration of NWP forecast, integration of models and in setting up forecast processes.

Because of the COVID-19 pandemic we were forced to provide the courses in an online environment, and not on-site. All meetings were facilitated through Microsoft Teams sessions where the Gambia forecast team could attend. During the training sessions the team has realized that internet connection in the Gambia was not always of good quality, therefore not all forecasters were able to follow the online training in a way we expected at the start of the project. To help the trainees that could not attend all training sessions, the training material is made available as MS PowerPoint presentations with supporting videos where a Deltares trainer presents the training courses. In between the training webinars questions from attendees were answered by email.

5.2 Training Program

The training program was executed as weekly webinars with homework assessments in between. The training sessions provided is summarized in Table 1 below.

Module	Topic	Type*	Files provided for download	Date
0	Training introduction	F	Module 00 FEWS-Gambia Training Introduction.pptx Training1_FEWS_Gambia_sept7.zip	Sept 7
1	FEWS Gambia introduction	F	Module 01 Delft-FEWS Pilot for The Gambia.pptx	Sept 7
2	Delft-FEWS and concepts of flood forecasting	F	Module 02 Introduction to Delft-FEWS.pptx	Sept 7
3	Customizing the FEWS Gambia application	F	Module 03 Customizing the FEWS-Gambia application.pptx FEWS Gambia Data Request.xlsx	Sept 7
4	Delft-FEWS Gambia configuration introduction	C	Module 04 Delft-FEWS Configuration Basics.pptx Module 04 Delft-FEWS Configuration Basics.mp4 Config_Training1_FEWS_Gambia_sept14.zip	Sept 14
5	Configuration: Explorer	C	Module 05 Delft-FEWS Explorer.pptx	Sept 14
6	Configuration: Locations	C	Module 06 Locations and LocationSets.pptx Module 06 Locations and LocationSets.mp4	Sept 14

7	Configuration: Time Series	C	Module 07 Time Series in Delft FEWS.pptx Module 07 Time Series in Delft FEWS.mp4 Config_Training2_FEWS_Gambia_sept21.zip	Sept 21
8	Configuration: Workflows, Modules and Forecast Tree	C	Module 08 Workflows, Modules and Forecast Tree.pptx	Sept 21
9	Configuration: Import module	C	Module 09 Importing Data.pptx Module 09 Importing Data.mp4	Sept 21
9B	Configuration: Import real hydro observations	C	Module 09B Importing Real Data.pptx Module 09B Importing Real Data.mp4	Nov 2
9C	Configuration: Import real meteo observations	C	Module 09C Importing Real Meteo Data.pptx Module 09C Importing Real Meteo Data.mp4	Nov 9
10	Configuration: Validating Data	C	Module 10 Validating Data.pptx Module 10 Validating Data.mp4 Config_Training3_FEWS_Gambia_sept28.zip	Sept 28
11	Configuration: Processing Data	C	Module 11 Processing Data.pptx Module 11 Processing Data.mp4	Sept 28 Oct 5
12	Hydrological Models	F	Module 12 Hydrological Models.pptx	Nov 16
13	Configuration: Wflow model integration	C/F	Module 13 WFlow Model Integration.pptx Module 13 WFlow Model Integration.mp4 Config_Training_FEWS_Gambia_Module13_nov23.zip	Nov 23
14	Configuration: SFINCS model integration	C/F	Module 14 SFINCS Model Integration.pptx Module 14 SFINCS Model Integration.mp4 Config_Training_FEWS_Gambia_Module14_dec21.zip	Dec 21

*Table 1 Overview of the training program with both the Forecasting (*F) and Configuration (*C) webinars*

Prior to the webinars all training material was provided to the trainees by email including surfFileSender links to download the material. All the presentations and videos are downloaded by the trainees, we expect these are shared with the larger forecasting team and archived for later use.

5.3 Training Exercises

The hands-on exercises that were included in the webinars and documented in the PowerPoint presentations, focused on both forecasting skills as well as Delft-FEWS configuration skills. Not all trainees were able to follow all configuration exercises, during the training we saw that a few champions were formed. These configuration champions will need to take the role to guide the other trainees that had more difficulties in the technical part of the training.

The exercises to build-up forecasting skills included the following topics:

- Concepts of operational forecasting
- Combining data and models in a computational framework
- Concepts of hydrological modelling
- Installing and opening FEWS Gambia (Appendix A)
- Set Current System time in FEWS Gambia
- Use the FEWS-Gambia forecast tree to run import, process and model workflows
- Use Spatial data display to analyse different forecast products and assess model results

- Use Time Series data display to check station time series
- Create daily forecasting report using a MS Word template document

The more technical exercises were introduced to build-up Delft-FEWS configuration skills, these exercises included:

- Adding shape files as background layers (Figure 23)
- Adding map zoom extents (Figure 23)
- Adjusting system caption though settings in the global.properties file (Figure 23)
- Adding hydrological and meteorological stations (Figure 23)
- Adding nodes to the forecast tree panel
- Adding workflows to be launched from the forecast tree
- Configuring validation checks for imported data (Figure 24)
- Configuring FEWS import modules to import dummy and real station time series (Figure 24)
- Configuring FEWS transformation modules to interpolate station time series
- Configuring FEWS general adapter modules to run WFLOW and SFINCS models
- Configuring displays to visualize the data

Figure 23 Example of exercise results, in this case related to map and location components

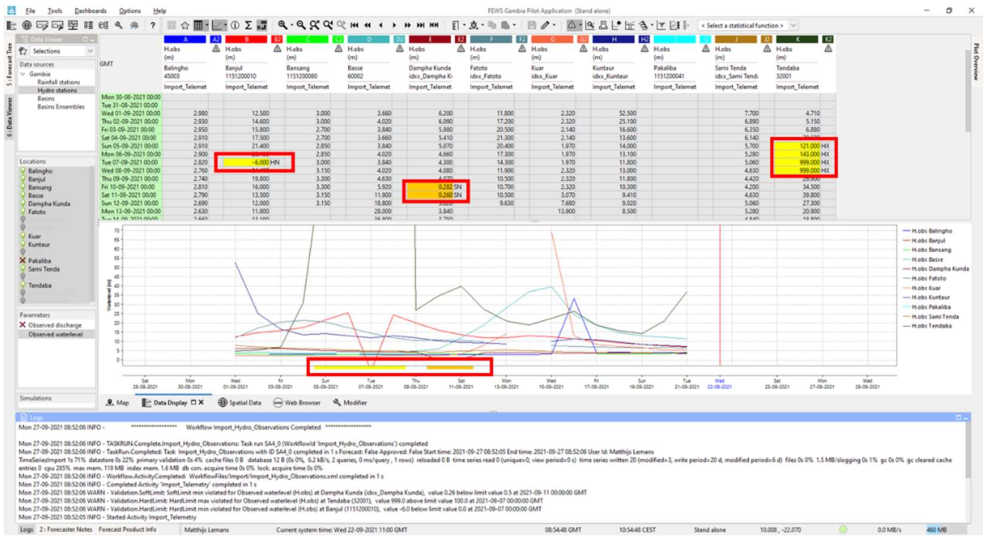


Figure 24 Example of exercise results, in this case related to data validation and associated visualisation

6 Development of a fully operational flood early warning forecasting system

6.1 Introduction

The development of the FEWS-Gambia pilot, and training of the Gambia forecasters is a first step in the development of a fully operational flood forecasting system for the Gambia. The FEWS-Gambia training webinars and efforts to collect data and real-time information made clear that there are still work to be done before a fully operational forecasting system can be developed for the Gambia that can be operated by the Department of Water Resources. This chapter will give a short overview of the required steps.

6.2 Availability of GIS data and real time information

As with many countries in the region, the Gambia is challenged with the availability of data, particularly real time that would be required. For the development of accurate flooding models and the initialisation of these models with information of the actual situation it is important to collect more detailed data.

1. In the FEWS-Gambia pilot system some historic data was provided. It is essential for an operational flood forecasting system that real time observations of water levels and rainfall is available. These data are normally collected by SCADA systems from local gauges and stored in a central database. No information was provided that such a system is functioning in the Gambia. It is therefore very important to understand what the status is of the current real-time data collection (SCADA) system in the Gambia for meteorology and hydrology. If the SCADA system is not functioning anymore, effort must be put in the rehabilitation of the current system. A second step is to make this real-time data available to the operational flood forecasting system.
2. Availability of meteorological forecast data. At the start of the project it was unclear if real time meteorological forecasts were available for the Gambia. During the project the forecasters explained that the Gambia has access to a PUMA system that provides meteorological forecasts from ECMWF and UK MetOffice. These forecasts are only available through a Website and can not be downloaded and used as input for hydrological models. The freely available GFS NWP is therefore used in the FEWS-Gambia pilot. Effort need to be put in getting more detailed NWP models available for the Gambia, especially for the coastal area near Banjul.
3. For the development of hydrological and especially for local flooding models, detailed DEM and infrastructure data sets are required. These data is currently not available for the Greater Banjul Area. Parallel to the FEWS configuration training webinars some of the Gambia forecasters were trained in developing a DEM for the Gambia. The status of this DEM is unclear, the DEM is therefore also not used in the development of the models. The FEWs Gambia pilot contains models to show the role of models in a flood forecasting system. Due to lack of local data these models could not be developed with the minimum required local information. For the development of models that can be used in an operational flood forecasting system it is important to have at least a good DEM of the Greater Banjul Area developed, including important infrastructure, pumps and other structures.
4. For the calibration of the WFLOW model for the Gambia basin the global datasets are enough to give a good estimate of the flows in the Gambia river. These models need some validation and calibration before the quality of the model results can be assessed. It is therefore important to not only collect water levels of the Gambia river, but also have

rating curves for the locations that have water level observations. These rating curves can be used to calculate the flows in the Gambia river.

6.3 Institutional embedding of the pilot forecasting system

Parallel to the establishing of the technical capabilities of an operational forecasting system, for which the FEWS-Gambia pilot forms the foundation, it is important to establish a comprehensive plan for the institutional embedding of the full operational forecasting system for the Gambia. In the proposal it was proposed to have several workshops organised that will lead to such a plan. It was proposed that the plan should include the following components:

1. Institutional mapping to establish the institutional responsibilities for the provision of operational forecasts and warnings for short term and long term hydro-meteorological hazards (floods and droughts), identifying the users of these forecasts and co-exploring their needs. The institutional relationships with other ministries and agencies, including with the disaster response agencies will need to be established. Also, the relationships at the international level (e.g. Senegal, The Gambia River Basin Organization), as well as with multi-lateral organizations (e.g. UNESCO, ECOWAS) will need to be defined.
2. Human capacity and capacity development plan. Specific training will be developed within the context of the development of the pilot. However, a clear plan for the further development of human capacity to ensure sustainable and continued operation of the forecasting system. This will include organizational needs for continued training, as well as establishing relationships with local and regional universities and identifying links with curricula and research agendas.
3. Technical and Financial sustainability. This plan will develop and outline the technical development towards a full operational forecasting and warning system in the Gambia, including the technical needs and the development of a plan to ensure sustainability beyond the implementation project, including provision for further development and support and maintenance.

The original project plan proposed to have two workshops where non-technical issues would be discussed with a larger forecasting community in the Gambia. These workshops would lead to a comprehensive plan for the institutional embedding of a full operational forecasting and early warning system for the Gambia. Due to the COVID-19 pandemic and the bad internet connection these workshops did not happen. We still feel that it is very important to organize these workshops before going to a next phase in the development of a flood forecasting and early warning system for the Gambia. We advise to have these workshops in the Gambia and not as online meetings.

6.4 Additional research on the integration of local data with global datasets

The objective of this project was amongst others to explore how the availability of local datasets and models in the Gambia can improve the reliability with which operational forecasts can be provided, within the framework of the pilot forecasting system that will be established. Unfortunately, there were not many local datasets available, especially the lack of real-time local datasets will have a negative impact on the accuracy of an operational forecasting system.

Additional research can be broken down into a number of underlying research objectives:

- Evaluate the needs for forecasts of flooding in the Gambia and the key processes that cause these floods (ie. riverine, pluvial, estuarine), and establish a baseline performance which forecasts can be provided using the globally available datasets and services.

- Review the local available real time data and models and evaluate how these contribute to and improve the performance of forecasts through a better/more detailed representation of key hydro-meteorological processes that cause floods.
- Evaluate the potential of additional data (i.e. new gauging locations, additional modelling) that would be most effective in improving forecast reliability.

This research can be a continuation of the developed offline version of the pilot operational forecasting system for the Gambia. This initial pilot will allow the researcher to evaluate the performance through applying common statistical assessments to evaluate forecast performance, either based on identified flood events, or through forecast verification experiments. To meet the second objective the researcher will incrementally update the models and data used, where applicable using innovative approaches to combine the different data sources and models. The incremental improvement of performance can then be assessed. The knowledge gained of the key hydro-meteorological processes that contribute to flooding in the Gambia can then form the basis of a critical assessment of data and modelling needs that would provide targeted improvement of forecast performance.

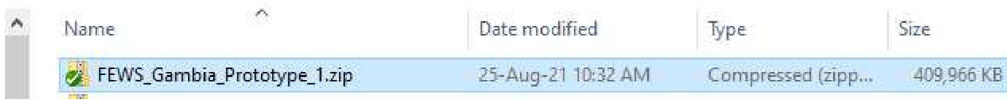
This type of research is especially suitable to be organised through universities. We therefore strongly advise to contact universities like IHE in Delft or universities in the Gambia or Senegal and organise this additional research with one or several students for their Master thesis.

A Installation of Delft-FEWS The Gambia Pilot

A.1 Installation of FEWS-Gambia pilot

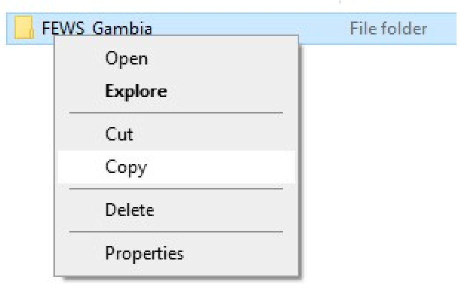
The FEWS-Gambia pilot application is provided as a zip file with all Delft-FEWS binaries and configuration included “FEWS_Gambia_Pilot.zip”. To install the FEWS-Gambia pilot application on your local Windows computer follow these steps.

1. Download the zip file and store the zip in a local folder on your laptop.
2. When using Windows Explorer, select the zip file and you will see the following.

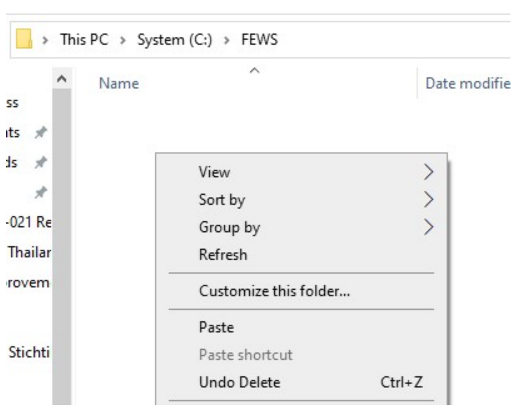


3. Double click on this file and Windows Explorer will show the content.

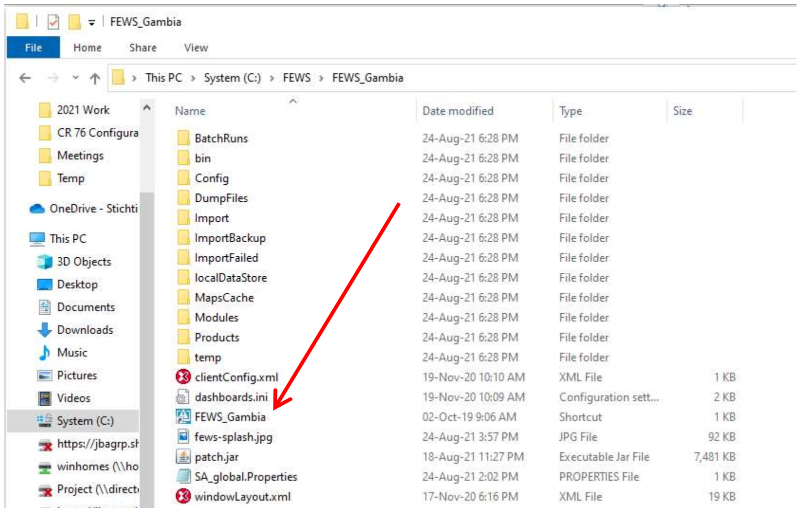
4. The folder FEWS_Gambia must be copied to a local folder on your desktop/laptop. For example, c:\FEWS. Copy the folder FEWS_Gambia using Windows Explorer (right-mouse button)



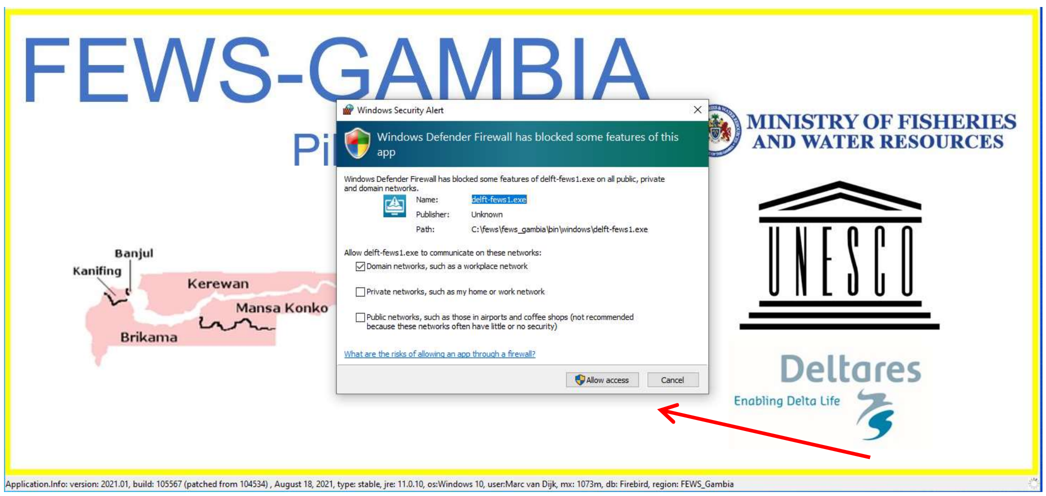
5. Then go to the C:\FEWS folder and select paste



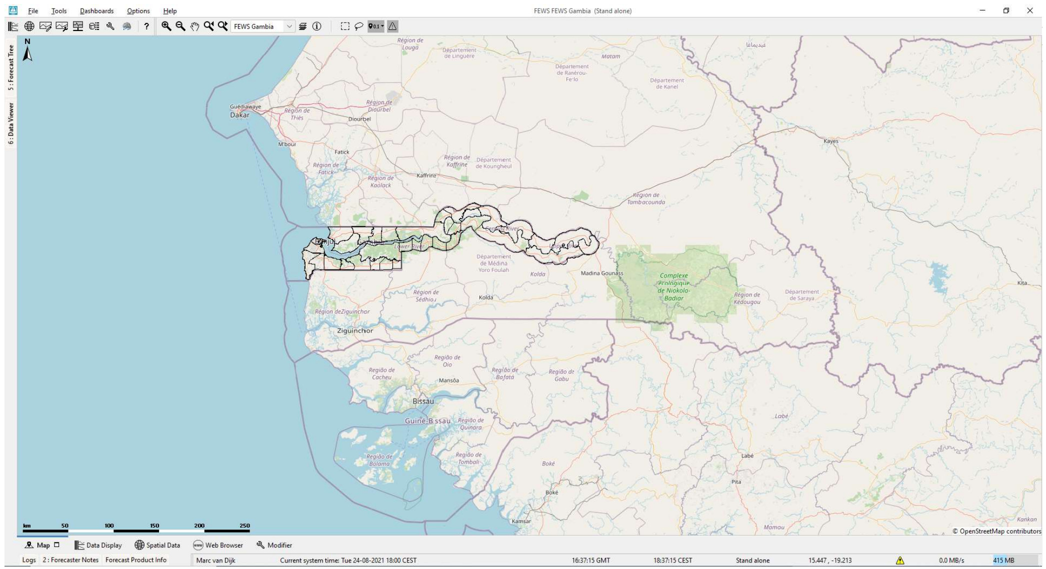
6. All the files from the folder will be copied the C:\FEWS folder
7. After Unzipping, start FEWS-Gambia with FEWS_Gambia.lnk Shortcut file



8. FEWS-Gambia will start with Splash-Screen and a Windows Security Alert will pop-up
9. Press <Allow Access> to continue. The message tells you would like to access external data



10. A Blue Screen will appear and select <Allow> or <OK>.
11. FEWS-Gambia will start and show the main Map Display.



A.2 Import of FEWS-Gambia collected data

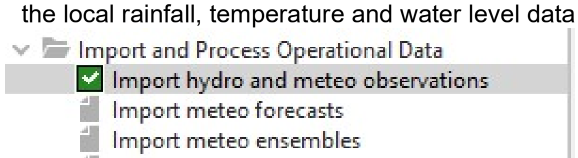
All local and global time series are made available as external files and databases in the FEWS_Gambia\Import folders:

- E2O: All EartH2Observe time series for the Gambia stored in an external database
- Meteo: All observed rainfall and temperature time series stored as CSV files
- Tamsat: All Tamsat time series for the Gambia stored in an external database
- Telemetry: All observed water level time series stored as CSV files

A special zip file with these data is made available for download with name “Import Gambia database.zip”. The files in this zip file need to be copied to the correct import folder in the FEWS-Gambia pilot application.

To import this data in the FEWS-Gambia system, follow these steps:

1. Install the FEWS Gambia Stand Alone as described in the previous paragraph.
2. Copy the files from the “Import Gambia database.zip” file to the correct import folders.
3. Delete or rename the \FEWS_Gambia\localDataStore\ folder. We will start the import with an empty database.
4. Start the FEWS-Gambia pilot application.
5. In the Forecast Tree, run the “Import hydro and meteo observations” workflow to import the local rainfall, temperature and water level data from CSV files.



6. In the Forecast Tree, run the “Import Database” workflow to import the satellite data from Tamsat and E2O databases.

More information on how to show the data in the FEWS-Gambia displays is provided in the training presentations.

B Daily Forecast Report

In one of the first training sessions the FEWS-Gambia pilot is presented as well as all steps in importing global observation and forecasting datasets.

- Module 01 Delft-FEWS Pilot for The Gambia.pptx

This presentation contains an exercise creating a daily forecast report with meteorological time series. All steps for importing processing and displaying this data in the FEWS-Gambia pilot is included.

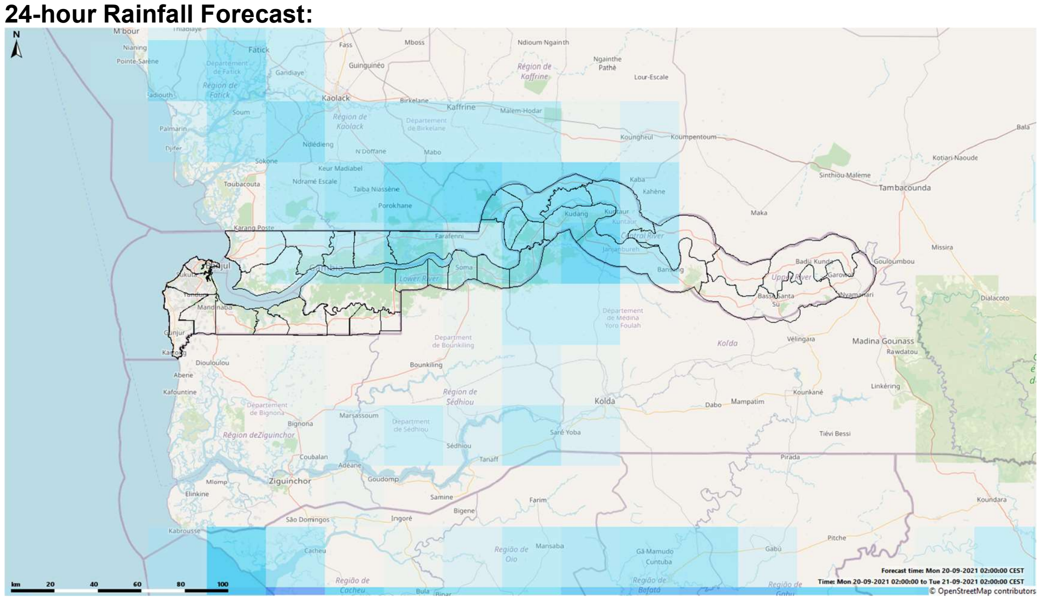
Daily steps to import, process and analyze NWP forecasts in the FEWS-Gambia pilot

1. Start the FEWS-Gambia Stand Alone
2. Set the Current System Time to today
3. Open Forecast Tree and run the:
    1. Import meteo forecasts workflow
    2. Import meteo ensembles workflow
    3. Import earth observations workflow
    4. Process meteo grids workflow
4. Open Spatial Data display and analyze the different forecast products
5. Open the Data Display and check the maximum rainfall for Banjul
6. Close the FEWS-Gambia Stand Alone

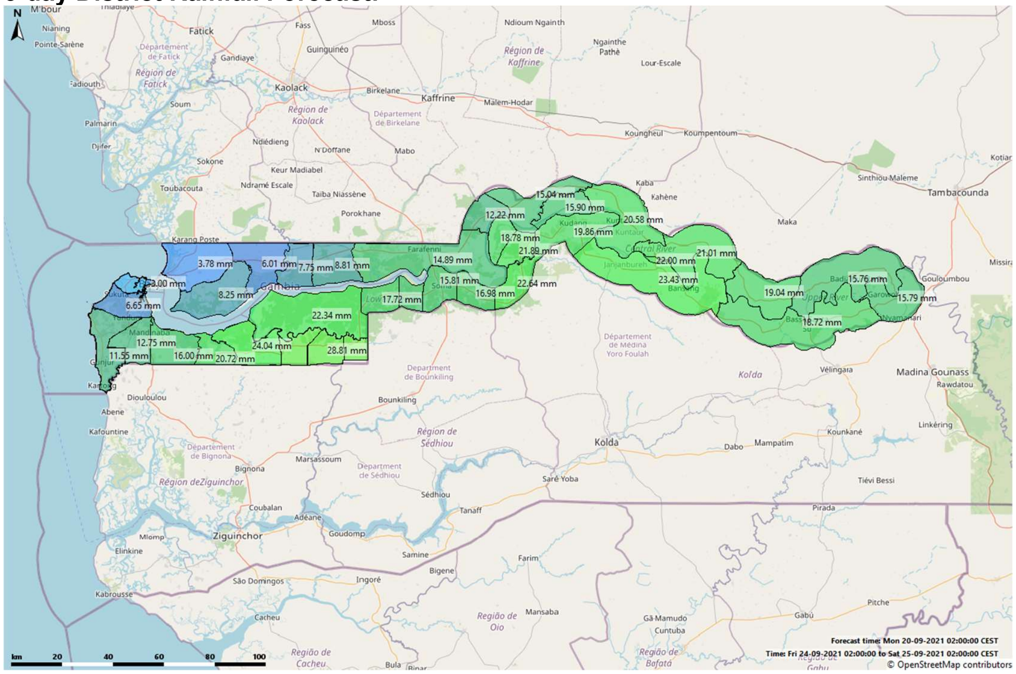
We strongly advise to use these daily steps in getting familiar with the FEWs-Gambia prototype. An example of a daily forecast reports is shown below.

Date: **20-09-2021**
Weather Forecast: **GFS**
Weather Forecast Forecast Time: **Monday 20-09-2021 02:00:00 CEST**

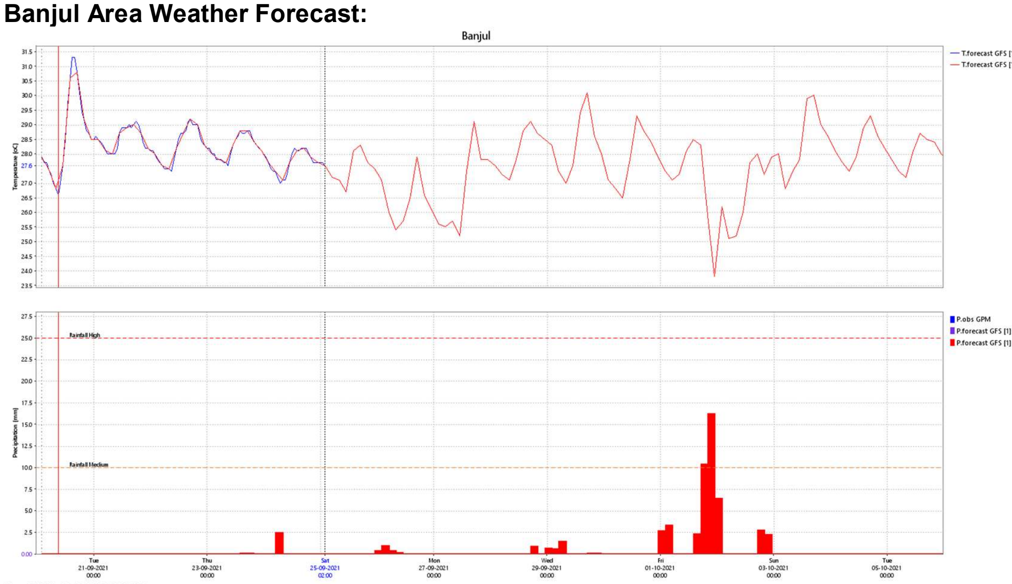
24-hour Rainfall Forecast:



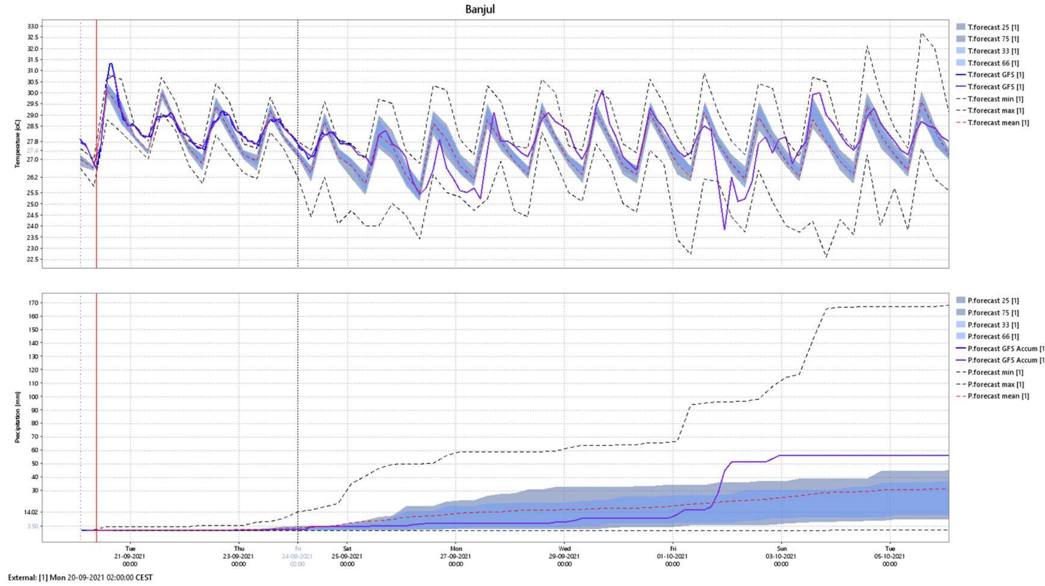
3-day District Rainfall Forecast:



Banjul Area Weather Forecast:



Banjul Area Weather Forecast Ensemble:



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