**PLATFORMS AND MODELS FOR DROUGHT AND FLOOD FORECASTING**

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# Overview of technical aspects

**Event**

* **Here** the term event is used to refer to the meteorological or hydrological conditions or phenomenon generally linked with precipitations that can trigger flood situation. (e.g storm precipitation, continuous precipitation, flash floods, flooding,…)

**Monitoring**

* Continuous or frequent standardized observation, measurement and evaluation of phenomena occurring in the environment, used for warning or control. It could be done through manual or automatic methods.
* The monitoring of hydrological and meteorological variables provides knowledge of both spatial and temporal variability. This information could be used to describe the behaviour and the trends of one event in real time or for the preparation of forecasts.
* Ensuring adequate variables monitoring help to analyze better the nature of an event.

**Forecasting**

* A forecasting is the anticipation of the future behaviour of a phenomenon. It is generally estimated from a set of observed/monitored or predicted variables using numerical and/or probabilistic methods/models, sometimes it could include historical data.
* The meteorological or hydrological forecasting is generated from the prediction of variables in a particular location and time.
* The main objective of a meteorological/hydrological forecasting is to provide information for planning and preparation of future human, social, agricultural, and industrial activities.
* In-situ observations are key information in the generation of forecasting provided by numerical weather, radar or satellite, because it allows to validate the indirect weather estimation. Nevertheless, this information is limited to analyse an event and particularly to capture its spatial-temporal variability.

**Prediction**

* It is the assumption of something that could happen through the interpretation of indicators.
* The prediction term is mainly used for hydrological scenarios, generally futures scenarios however it is possible to predict past situations.
* Monitoring of variables, historical information, numerical and probabilistic methods/models are used for hydrological predictions.
* The hydrological prediction is a terminology originally used for anticipating the basin response in a longer time than the lead time of the catchment.

**Platform**

* It is an environment integrated by software and hardware that execute a series of program codes to display information.
* A forecasting/monitoring platform is able to get data/information from different sources, which could be displayed, classified or analyzed by analytical, empirical, statistical methods/models, and the results are generally shown in a friendly interface (graphics, tables…). Sometimes, the platform is also named portal, web server for forecasting, etc...
* Drought and flood forecasting platform are tools that provide meteorological/hydrological monitoring or forecasting, at several time and spatial scales, which are used for decision making. The data of the platform could come from manual/real time stations, numerical weather, radar, and satellite; this data is usually used as inputs for hydrological models, who provides surface response such as, runoff, streamflow, etc.
* The conception of a platform for drought and flood prevention is closely linked with the user’s needs, the available resources in terms of: technology, financing, technical structure,…
* A platform is used by national services to inform communities about drought or flood warning. It could be also used by users to monitor real time flooding situation, or to plan activities during drought season.
* Delivering forecasting and warning about a possible future scenario could contribute to minimize risks of communities, infrastructure and environment.

**Models for flood forecasting**

It corresponds to a set of operational numerical models that could be used by National Hydrological Services for flood forecasting, according to the basin characteristics and needs of the population.

According to the catchment dynamic the flood prevention models could be of the following type:

* **Hydrological models**, it is a simplified numerical representation of the rainfall-runoff process in a catchment. These types of models are not usually able to simulate hydraulics structures (dams…) in the catchment and hydrological system integrated by reservoirs.
* **Reservoir models**,this type of hydrological model are used to simulate catchment response which is composed of reservoirs used for water storage or other purposes. The reservoir models could simulate all basin response or could be linked with others hydrological models.
* **Hydraulics models**, it is a numerical model to calculate the river dynamic integrated by hydraulic structures (dams, flood plain…)

\*\*\* The models for flood foresting should be adapted to the criteria indicated by the Tasks Team of Community of Practice (CoP).

\*\*\*\* *It could be interesting to define later some technical aspects useful for CoP glossary*

*Example:*

*Flood Forecasting or hydrological forecasting*

*Flood Prediction or hydrological prediction*

*Flood Monitoring or hydrological monitoring*

For more definition we can consult WMO hydrologic glossary

<http://www.wmo.int/pages/prog/hwrp/publications/international_glossary/385_IGH_2012.pdf>

# CoP criteria to choose the platforms / models for flood forecasting

In the meeting of Community of Practice for Flood Forecasting (CoP FF) held in November 2017, it was agreed that the selection of platforms or models will be based on the following criteria

1. It **must** be:

- Operationally used

- Freely available

- Available of training material

- Institutional support

- Low hardware requirements

- Sustainable technology and software

- Available in one of the official UN languages

- Peer reviewed or case studies

1. It **should** be:

- Open source

- Easily Updated (modelling only)

- Easy to use (simplicity - calibration)

- Data Format (model)

1. It **could** be:

- Pre-existing CoP (m&p)

- Internet-based system

- Redundancy capacity

This criteria have been defined by Mr William Scharffenberg and disseminated for a review by the other experts of the Task Team.

# Review of operational drought and flood forecasting platforms

This is a review of operational drought and flood forecasting platforms that showcase its main precipitation product, the linked hydrological models and its outputs. Later it could be possible to choose or classify the platforms according to the CoP’s criteria.

## Platforms description contains following points

* **Overview**
* **Tools for flood monitoring and forecasting**
* Hydro-meteorological data(*rain gauge / hydrometric station in RT, Radar…)*
* Numerical models (*hydrological, hydraulic, reservoir, etc...)*
* **Related to platform outputs (variables)**
  + Precipitation from different sources …
  + Streamflow, water levels, soil moisture…
* **Formats**
  + Graphics, time series, netcdf file…
* **Others**
* **Application / uses**
* **Ilustration of the platform**
* **Evalution of CoP’s criteria**

## African Flood and Drought Monitor – AFDM

<http://stream.princeton.edu/AWCM/WEBPAGE/interface.php>

* **Overview**

This platform was developed by Princeton University in collaboration with UNESCO [IHP](https://en.unesco.org/themes/water-security/hydrology), [G-WADI](https://en.unesco.org/themes/water-security/hydrology/programmes/g-wadi) and [ICWarM](https://iciwarm.info/)[[1]](#footnote-1). The AFDM monitors and forecasts meteorological, agricultural and hydrological drought at various temporal and spatial scales for the whole Africa region. It also has a multi-decadal, historical reconstruction of the terrestrial water cycle against which current conditions can be compared.

* **Tools for flood monitoring and forecasting**

Precipitation from satellite products and weather numerical models are used as main inputs to simulate through a macro-scale hydrological model which generates the surface response.

Numerical models

**VIC (Variable Infiltration Capacity),** a macroscale semi-distributed hydrologic model that solves full water and energy balance. It was developed by Xu Ling in University of Washington in 1994 and is an open source code.

* **Related to platform outputs**

\*\*\* Main meteorological products in daily time step and 0.25°

* Global Forecasting System – GFS: precipitation, temperature and wind
* TRMM 3B42RT precipitation(It is only used for monitoring)
* Others satellite product such as NDVI-vegetation, SMAP-soil moisture are also used for monitoring.

\*\*\* Main hydrological products from VIC model in daily time step

* Evapotranspiration, streamflow, baseflow, runoff, soil moisture at 2 level
* In addition, for modeling are calculated the surface fluxes..

\*\*\*\* Those hydrological product for monitoring are derived from TRMM 3B42RT, and for forecasting from GFS, which is calculated over 7 days.

\*\*\* It provides drought indices such as, SPI, Drought Index, NDVI percentile, Streamflow percentile

* **Formats**

The information is delivered as

* Raster animation over all domain and in numerical format (Arc ASCII or NETCDF)
* Point data by graphs and time series.
* **Others**

AFDM provides monitoring of historical information, at monthly and yearly time step, from a dataset product developed by Princeton university. The monthly forecasting could be derived from different monthly precipitation products.

* **Application / uses**

In 2016 and 2017, AFDM data and information have been used for:

* Drought resilience
* Health and epidemiology
* Impact of irrigation dams
* Human migration

\*\*\* It could be deepened by a research of case studies

* **Ilustration of the AFDM platform**
* **Evaluation of CoP’s criteria**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  |  |  |  |
| Operationally used | Y |  | Open source |  |
| Freely available |  |  | Updating (modelling only) | Y |
| Available training material | Y |  | Easy to use (simplicity - calibration) |  |
| Institutional support |  |  | Data Format (model) |  |
| Low hardware requirements |  |  |  |  |
| Sustainable technology, software |  |  | Pre-existing CoP (m&p) | N |
| Be available 1 of the official UN languages | Y |  | Internet-based system | Y |
| Peer review OR case studies | Y |  | Redundancy capacity |  |
|  |  |  |  |  |
| Color |  |  | Classification |  |
| Red = must |  |  | Y = Yes |  |
| Green = should |  |  | N = Not |  |
| Black = could |  |  | - = Unknown |  |

## Mekong River Commission - MRC Data and Information Services Portal

<http://portal.mrcmekong.org/river-monitoring>

* **Overview**

This portal continuously monitors water level and provides observation and forecast data. This information is delivered as a service to the government of the each country in Lower Mekong Basin (Cambodia, Lao PDR, Thailand, and Vietnam). This portal allows communities to better understand water trends in the national rivers, water-related event across borders.

* **Tools for flood monitoring and forecasting**

MRC Information System provides ready to access or use environmental and socio-economic models and data which support in regional planning of the basin area. Real time water level data is also available in this portal.

Hydrometric network (Real time)

The MRC is integrated by a vast hydrological network that reliably provides daily hydrological information during flood season. The data is provided every 15 minutes to the national data centers and the MRC data terminal in order to prepare communities in the event of floods and droughts.

Numerical models

In the [MRC Toolbox](http://portal.mrcmekong.org/assets/documents/att-MRC-Toolbox-DSF.pdf), it is mentioned that the MRC modelling system include a chain of numerical models for hydrodynamic, soil analysis, water balance, integrated water resource and erosion (SWAT, IQQM, ISSSI, HEC-Res Sim, DMS 3D), which could be used for informed decision-making.

The MRC Toolbox was developed in 2010 from initiatives started in 2001 under Work Bank funds.

* **Related to platform outputs**
* Mean precipitation estimates comes from the United States Geological Survey USGS
  + NOAA (National Oceanic & Atmospheric Administration) provides rainfall data based on satellite imagery
  + MM5 (5 Generation Mesoscale Model) gives three rainfall forecast, one for 24-h the others for 48-h and 72-h, respectively.
* Water level observation (from real time hydrometric stations), and forecasting (how is it done?)
* **Formats**

The information is delivered through

* Graphics and tables of hydrometric stations and average precipitation in the basins
* **Others**

\*\*\*It is necessary to check if the models are still operational because some problems were encountered while accessing the portal. (how does it works?)

\*\*\* Flash Flood Guidance System was a product of this portal, which is not available since the end of 2017…

* **Application / uses**
* Planning for crop irrigation, navigation accessibility and fishiers.
* Health and epidemiology
* **Ilustration of the MRC Portal**

## Flood and Drought Monitor Tools - FDMT

<http://www.flooddroughtmonitor.com/home?showLogin=true&redirect=flood>

* **Overview**

The Flood and Drought Management Tools project provides a methodology with a online tool to facilitate the inclusion of information on floods and droughts, and future scenarios for Integrated Water Resources Management planning, Water Safety Planning and Transboundary Diagnostic Analyses and Strategic Action Plans. These approaches are used to support planning from the transboundary basin to water utility level.

The project is funded by the [Global Environment Facility](https://www.thegef.org/), implemented by [UNEP](https://www.unenvironment.org/) and executed by [DHI](https://www.dhigroup.com/) and the [International Water Association](http://www.iwa-network.org/).

The project **is developing a methodology** (2014 -2018) for basin organisations and local users (specifically water utilities) to provide guidance on both short-term (operational) and long-term (strategic) planning. Currently, the FDMT methodology and tools are being tested and validated in three pilot basins, Chao Phraya Basin (Thailand), Lake Victoria Basin and Volta Basin.

* **Tools for flood monitoring and forecasting**

This project **plans** to integrate into the portal a linkage with hydrological models using satellite-based and global information.

Numerical Model

It is **planned** to have available output from [MIKE powered](https://www.mikepoweredbydhi.com/) by DHI. MIKE system integrates a set of rivers models such as: MIKE SHE for hydrological modelling or MIKE RIVER (11) for hydraulics calculations.

* **Relate to platform outputs**

\*\*\* The following meteorological products are available in the platform, some of them (GPM) are only showed in the demo version.

* Satellite-based precipitationfrom:

CHIRPS (Climate Hazards Group Infrared Precipitation with Station Data)

TRMM (*it is not indicated which product*)

CRU (Climatic Research Unit monthly precipitation),

GPM –Global precipitation measurement.

* Temperature, PET, NDVI

\*\*\* Main hydrological products

* The main outputs of this platforms should be: runoff, evapotranspiration, recharge
* **Formats**

The information is provided as:

* Raster animation over all the surface
* Tables and graphs (mean information – scale?)
* **Others**
* The platform includes a set of functions for decision support
* It is provided an user’s training to learn how the platform works
* **Application / uses**
* For flood and drought assessment and monitoring
* For basin planning
* **Ilustration of the FDM tool portal**

## European Drought Observatory - EDO

<http://edo.jrc.ec.europa.eu/edov2/php/index.php?id=1000>

* **Overview**

The EDO system provides drought-relevant information such as maps of indicators derived from different data sources (e.g., precipitation measurements, satellite measurements, modelled soil moisture content). It is a service of the European Commission Joint Research Centre (JRC).

EDO is directly or indirectly linked with Global Water Partnership, EUROCLIMA, DEWFORA, CARPATCLIM, EuroGEOSS projects.

* **Tools for drought monitoring and forecasting**

The system provides soil moisture forecasting by hydrological modelling using satellite and pluviometry data.

Hydro-meteorological data

* Regional meteorological station network
* Satellite rainfall product

Numerical models

**Lisflood,** it is ahydrological rainfall-runoff model developed by JCR which can be used in large and trans-national catchments.

* **Related to platform outputs**
* Monthly precipitation from different sources and temperature
* Low flow indicator, soil moisture (by modelling)
* Others: vegetation response, fire danger
* **Formats**

Raster image, graphics, time series,

* **Others**
* **Application / uses**

Delivering real-time drought forecasting to help the linked national services to plan their activities.

* **Ilustration of the MRC Portal**

## Global facilities for Disaster Reduction and Recovery - GFDRR

<https://www.gfdrr.org/en/gfdrr-engagements>

* **Overview**

GFDRR is a global partnership program administered by the World Bank Group. It supports developing countries to: (i) mainstream disaster risk management and climate change adaptation in development strategies and investment programs, and (ii) improve the quality and timeliness of resilient recovery and reconstruction following a disaster.

The GFDRR portal contents information about the main hazards in the world such as: river flood, urban flood, coastal flood. That could be useful to characterize the natural hazards in different regions of the world. The information comes from World Bank projects and regional organizations.

Information about river flood, urban flood and costal flood around the world is available in this platform.

# Platforms proposed in the CoP Report

## Hydrological Engineer Corps – Real Time Simulation - HEC-RTS (3.0.3)

<http://www.hec.usace.army.mil/software/hec-rts/features.aspx>

* **Overview**

HEC-RTS is the public version of the Corps Water Management System (CWMS). It is a system which is able to receive, process and forecast meteorological data in real–time, in order to provide real-time hydrological/hydraulic simulations for short-term decision support.

HEC-RTS is a Windows based and free available but the technical assist is only provided to USACE customers. The mainly components including an interface of control and visualization for data processing, a set of linked models for hydraulic and hydrological calculations and a RAS Mapper for computing flood inundation maps in real-time.

* **Tools for flood monitoring and forecasting**

This system is integrated by a sets of HEC models which are able to represent hydrological and hydraulic watershed behaviour.

Numerical models

* HEC-HMS (4.2.1), rainfall-runoff model to develop hydrographs
* HEC-ResSim (3.3.1), reservoir operation model
* HEC-RAS (5.0.3), hydraulics model to predict river stages
* HEC-FIA (3.0.1), flood impact analysis (CHECK)

**HEC-HMS** simulates flow hydrographs at points in the watershed where flows are not controlled by dams or other structures. If necessary HEC-RTS allows switching with:

**HEC-Res.Sim** simulates reservoir operations (using the inflow and local downstream hydrographs generated from HEC-HMS). This model computes pools elevation and storage time series, and flow hydrographs at control structures and downstream locations;

**HEC-RAS** compute rivers hydraulics from the hydrographs produced by HEC-HMS or HEC-ResSim. It simulates river stages and water surface profiles also provide inundation boundary and depth map of water in the flood plain.

In addition, the **HEC-FIA** is included to lead an economic analysis and impact. It calculates agricultural and urban damages and project benefits by impact area.

Meteorological input data

The system originally was developed to use rainfall inputs from NEXRAD (Next-Generation Radar[[2]](#footnote-2)) and GageInterp[[3]](#footnote-3). Both rainfall data sources are processed by the Meteorological Forecast Processor (MFP) of the system, which generates the rainfall forcing for HEC-HMS hydrologic model.

It possible to generate rainfall forcing from pluviometry data

Non-Meteorological data

Daily timeseries of land cover information: albedo, LAI and partial vegetation cover fraction.

* **Relate platform outputs**
* Levels, streamflows, etc…
* **Formats**
* Tables, graphs
* **Others**
* **Application / uses**

This platform is being developed in California as a tool for operational water activities from Merced Irrigation District (MID). MID owns several hydroelectric dams and reservoirs for irrigable land.

Dewberry is the private sing in charge to develop the real-time hydrologic operations models using the HEC-RTS . The objective is improving the ability to predict short-term and seasonal reservoir inflows due to precipitation and snowmelt.

* **Ilustration of the AFDM platform**

## PLATE-FORME OPÉRATIONNELLE DE MODÉLISATION (POM) – Vigicrues

<https://www.vigicrues.gouv.fr/>

* **Overview**

In France Vigicrues is the flood forecasting network, which is operated by the Service Central d’Hhydrométéorologie et d’Appui à la Prévision des Inondations (SCHAPI). This service is integrated by 28 hydrometric units, and it provides 24h a day hydrometeorological forecasting and monitoring on all watercourses.

Vigicrues is a national portal that provides real time monitoring of 1600 hydrometric station as well forecast for 600 of them. The flood forecasting is based on various decision support tools, and a network of numerical models that simulate the precipitation and its effect on runoff in streams.

This portal delivers flood warning bulletins to prevent the public and the authorities that there is a risk of flooding.

* **Tools for flood monitoring and forecasting**

Hydro-meteorological data

* Meteorological network (Rain gauge in real-time, meteo-france radar…)
* Hydrometric network in real-time

Numerical models

* **GRP** (Génie Rural pour la Prévision), it is a global hydrological model, like a conceptual model. GRP is a simple model that operates in a daily time step.
* **MASCARET**, it is a hydraulic model (1D)
* **TELEMAC**, that is a 2D hydraulic model

Vigicrues is developed at French national level and it is based on free and open tools.

* **Relate platform outputs**
* Water level in all station of the network (observed –RT and forecasted)
* Streamflow in gauged stations
* Station information (historical, coordinates, type, status,…)
* Bulletins
* **Formats**

The information is delivered as

* Graphics, tables
* **Others**

The flood forecasting is done by different models and methods according to the stream and basin characteristics. Vigicrues system has integrated a method for flood forecasting in ungaged streams.

* **Application / uses**

It is a currently and operational platform used for flood forecasting in France and used for planning of industrial activities, river navigation , ….

* **Ilustration of the AFDM platform**

## GREEN – KENUE

<https://www.nrc-cnrc.gc.ca/eng/solutions/advisory/green_kenue_index.html>

* **Overview**

It is a tool for hydrologic modeling used for forecasting and event simulation. It is composed of a user interface which prepares the data, perform analysis and visualize results. Green-Kenue was developed at the National Research Council Canada (NRC) and is a window of open source and currently used in various countries.

The system provides complete pre- and post-processing of different hydrologic models. It includes an application programming interface based on the python language that allows users to automate repetitive task or to integrate functionality into an operational system.

* **Tools for flood monitoring and forecasting**
* Hydro-meteorological data

Rain gauge / hydrometric station in RT, Radar…

* Numerical models

**Watflood** is an integrated set of computer programs for flood forecasting and modelling based on the CHARM (Canadian Hydrological and Routing Model) model. It was developed by University of Waterloo and it support remotely sensed data.

**HBV-EC** it is a hydrological transport model used to analyze river discharge and water pollution

* **Related to platform outputs (variables)**
* Precipitation from different sources, …
* Streamflow, water levels, soil moisture, …
* **Formats**
* Graphics, time series, netcdf file,…
* **Others**
* **Application / uses**
* **Ilustration of the Green-Kenue Portal**

\*\*\*\* Looking for information linked with this platforms

## AEGIR + HYFO

## K-EWS

## SWIFT

# Platforms that are widely used

## DEWETRA

<http://www.cimafoundation.org/en/cima-foundation/dewetra/>

* **Overview**

DEWETRA is an integrated operational system designed to forecast, monitor and prevent climate-related risks. It was created by CIMA foundation which is operated by the National Department for Italian Civil Protection (who has access to the platform).

This system or platform operates in real-time to collect different hydro-meteorological data that allow updating forecast models, analyse vulnerable areas and produce risk scenarios. Dewetra uses a software architecture that includes a Web-SIG interface to visualize the information such as real-time observations from automatic hydro-meteorological stations, weather radar and satellites. The streamflow forecasts are also added to the platform, and other model outputs, to support decision-making concerning the issuing of warning messages.

A cooperation agreement was signed in 2014 between WMO and the Italian Civil Protection Department in order to install and deploy Dewetra in countries requesting it.

* **Tools for flood monitoring and forecasting**

Hydro-meteorological data

* Precipitation from pluviometer-RT, radar, satellite rainfall (EUMETSAT-NASA)
* Temperature, wind
* Hydrometric stations in real-time

Numerical models

This system uses the hydrological model FloodPROOFS (Probabilistic Flood Forecasting Operational System) for flood forecasting.

* **Related platform outputs**
* Water level (observed –RT and forecasted)
* Streamflow in gauged stations
* Station information (historical, coordinates, type, status,…)
* Risk scenario
* Bulletins
* **Formats**

The information is delivered as

* Spatial image, graphics, tables
* **Others**

The Dewetra Platform is offered as an Open-Source tool to the WMO affiliated countries as an Italian contribution to the WMO programs on flood management and forecasting (FFI and APFM).

* **Application / uses**

According to CIMA, this platform is currently used by national-level forecasters and disaster managing authorities of different countries: Italy, Bolivia, Lebanon, Albania and the Caribbean at the regional level.

* **Ilustration of the Dewetra platform**

## DELFT-FEWSS flow forecasting system

<http://oss.deltares.nl/web/delft-fews/>

* **Overview**

Delft-FEWS is an operational platform developed for flood forecasting and warning system. It integrates real time data (rain, level, flow, temperature, etc), numerical weather predictions, radar data and climatological data to generate flood forecasting.

Deltares - Dutch Institute for applied research in the field of water and subsurface

Delft-FEWS is an open data handling platform which binds datafeeds and models together in an operational forecasting and early warning system. It has been applied in many operational forecasting centres all over the world. The platform offers flexibility in the integration of models and data. Delft-FEWS has contributed to changing the paradigm of flood forecasting systems from a model centric approach to a data centric approach.

* **Tools for flood monitoring and forecasting**

Hydro-meteorological data

* Precipitation from pluviometry network, radar, satellite products, numerical weather
* Hydrometric -RT

Numerical models

In the numerical modeling, this platform integrates different hydrologic and hydraulic models which may be different between the regions connected to the platform. Such are the case of: HEC-HMS, HEC-RAS, HEC-Res Sim, HBV, TOPKAPI, Sacramento.

* **Relate platform outputs**
* Water level
* Streamflow, soil moisture, …
* Bulletins
* **Formats**

The information is delivered as

* Graphics, tables, bulletins
* **Others**

<https://publicwiki.deltares.nl/display/FEWSDOC/Models+linked+to+Delft-Fews>

The information about several models linked to DELFT-FEWS is provided in the link above

* **Application / uses**

Flood forecasting

* **Ilustration of the AFDM platform**

1. <https://iciwarm.info/african-flood-and-drought-monitor-finding-applications-in-health-epidemiology-and-migration-studies/> [↑](#footnote-ref-1)
2. [NEXRAD](https://www.ncdc.noaa.gov/data-access/radar-data/nexrad), it is a radar product from NOAA which is available in 160 sites in United States and selects overseas locations. [↑](#footnote-ref-2)
3. [GageInterp](http://www.hec.usace.army.mil/training/CourseMaterials/Mongolia_Workshop/gageInterpUserManual.pdf), this is a component of generation of meteorological forcing (precipitation, temperature...). It provides gridded rain gages obtained through interpolation methods from observed precipitation. That represents the rainfall variation through the space varying through time at fixed locations. [↑](#footnote-ref-3)