Summary of good practices, recommendations in report format

WP5 - Deliverable D 5.2.1.

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Introduction

This technical report represent the Deliverable – D5.2.1. Summary of good practices, recommendations in report format, as result of the Activity 5.2. Elaboration of guidelines on data management related to forecasting activities.

The content is based on the summary of the main findings of other project activities: A3.1, A3.2 and A5.1., the country and regional systems factsheets, and representative results and finding from WP4.

The summary of good practices, recommendations of the project covers different aspects of data management in relation with the flood forecasting activities, starting from the stations networks, data collection, data management processes, data preprocessing and postprocessing modules used in relation with different flood forecasting models, data processing for generation of final products.

1 Monitoring networks

Most countries in the Danube River Basin have made a significant progress in the modernization of the meteorological and hydrological monitoring networks. The modern networks provide high quality data used in warning procedures, forecasting systems and other data processing.

In-situ monitoring of meteorological and hydrological variables are particularly crucial for reliable hydrological forecast. Additionally, data management processes (reliable data flow, data control and data processing) are extremely important for efficient hydrological forecasting activities. Countries use different transmission techniques in data flow and different software for data control and data processing.

Meteorological observations are an essential part of flood and ice warning and forecasting system. Generally, within the meteorological networks various data is collected. The most important variables are precipitation, air temperature, air humidity, wind speed, air pressure, solar radiation, sunshine duration, evaporation, soil moisture, snow depth and snow water equivalent.

In the frame of hydrological monitoring all countries collect data on hydrological parameters, i.e. water level, discharge and water temperature. Some of them collect also information about sediments and ice and there are practically no systematic measurements of water flow velocity. Bed load transport is hardly ever measured. There are also no systematic measurements of channel morphology, with the exception of navigable waterways along the Danube and its tributaries.

Measurements of river stages, and indirectly river discharges, are well developed in all hydrological services. However, the number of observation stations has unfortunately decreased over recent decades and we lost valuable information regarding the heterogeneity and dynamics of the phenomena measured.

The problem of hydrological as well as meteorological services is also the lack of financing and frequently reduced allocations of budgetary resources of individual countries. Consequently, the number of gauging stations in some countries is lower than several decades ago.

Germany

Flood Warning Service (Hochwassernachrichtendienst/HND) uses hydrological data from different sources:

- the official measuring network, characterized with a measuring station number (Figure 1 shows the network of these stations in whole Bavaria)
- additional stations from Federal Administration for Waterways and Shipping
- neighbouring countries and hydroelectric
- power plants

In the whole the HND uses 488 stations in the Bavarian Danube Catchment.

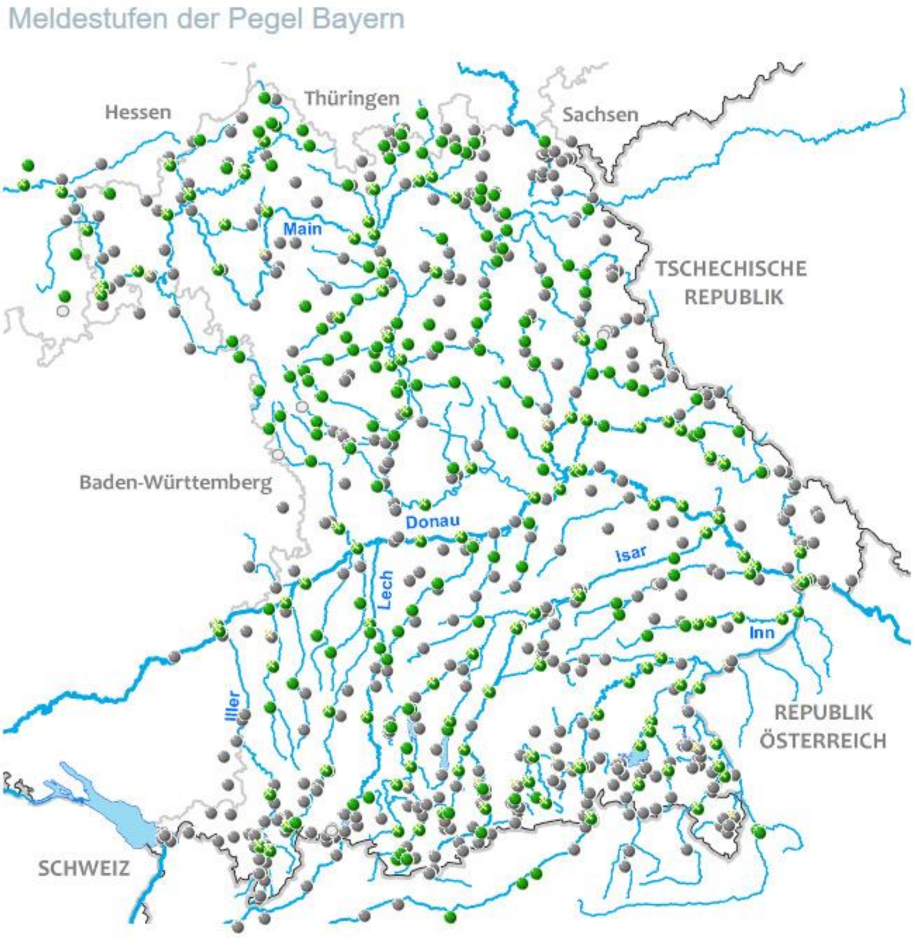

Figure 1: Level measuring stations in Bavaria

Measuring stations collect data about the water level, whereas the stations within the official measuring network collect data redundantly. Most stations also measure discharge and a few of them additional data about water temperature, sediments and water quality. The update interval for level data is 15 minutes, for other kinds of data it ranges from 15 to 60 minutes.

German Weather Service (Deutscher Wetterdienst/DWD) also uses meteorological data from different sources:

- stations from the DWD network
- stations from the LfU
- stations from external measuring networks

The most important data used by the HND are precipitation, snow depth and snow water equivalent. Further important data are temperature, humidity, wind speed, solar radiation and others. Figure 2 shows the network of precipitation stations in whole Bavaria.

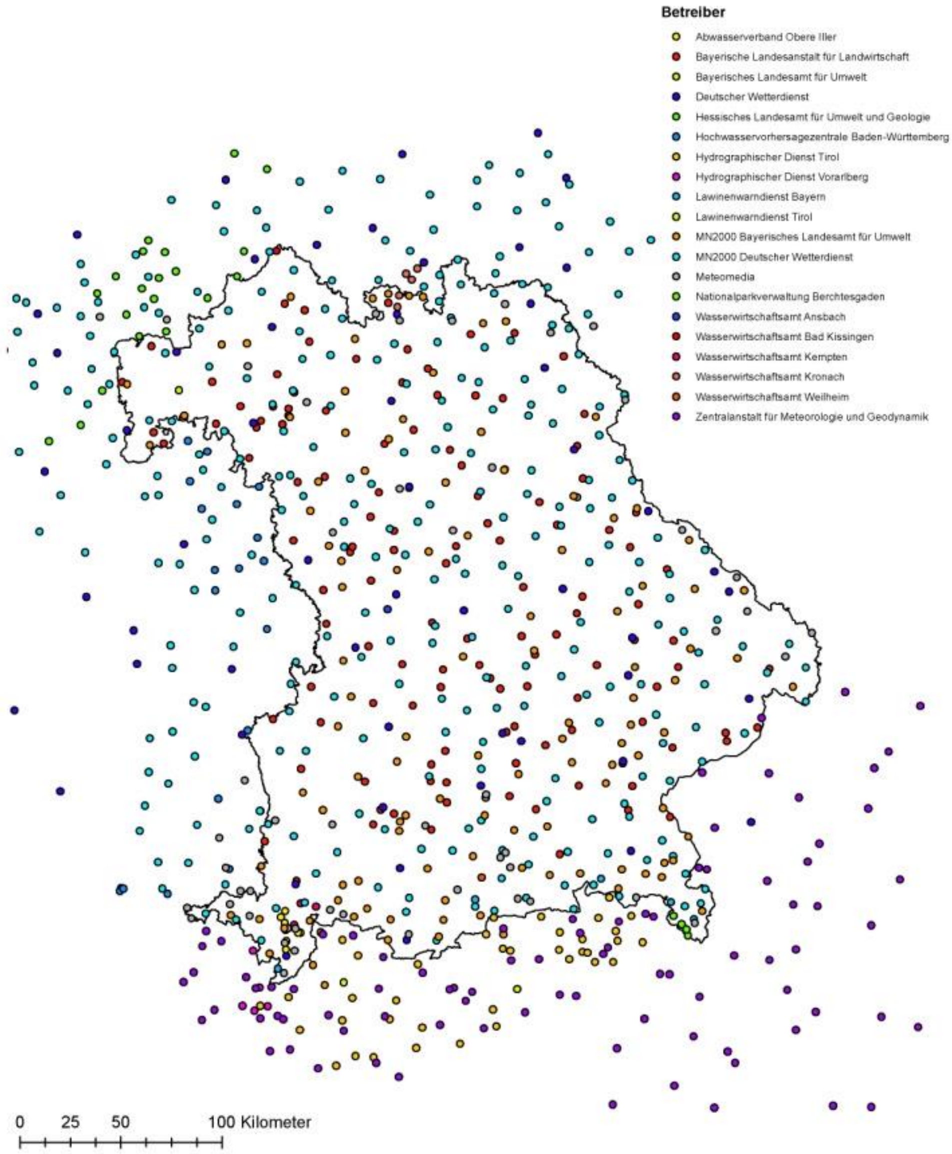

Figure 2: Stations for precipitation measurement in Bavaria

In case of Danube the HND includes precipitation data collected by 330 stations from the DWD and by 84 own stations. 82 of these own stations also measure snow depth and snow water equivalent. The update interval for precipitation data is 30 minutes, for snow depth and snow water equivalent it is 1.440 minutes.

Austria

The Hydrological Service of Austria has the task to maintain a basic network of surface water observations able to answer all actual questions concerning the water balance of Austria and to develop this network for future requirements. The basic network gauges should guarantee observations spanning the whole range of water levels and discharges, from low flows to extreme floods as well as long time homogenous data series. The gauges are therefore only installed at such sites where water levels and related discharges can be observed even during big floods.

In the year 2015 about 760 continuously recording water level gauges, 619 discharge and about 280 water temperature gauges are reported.

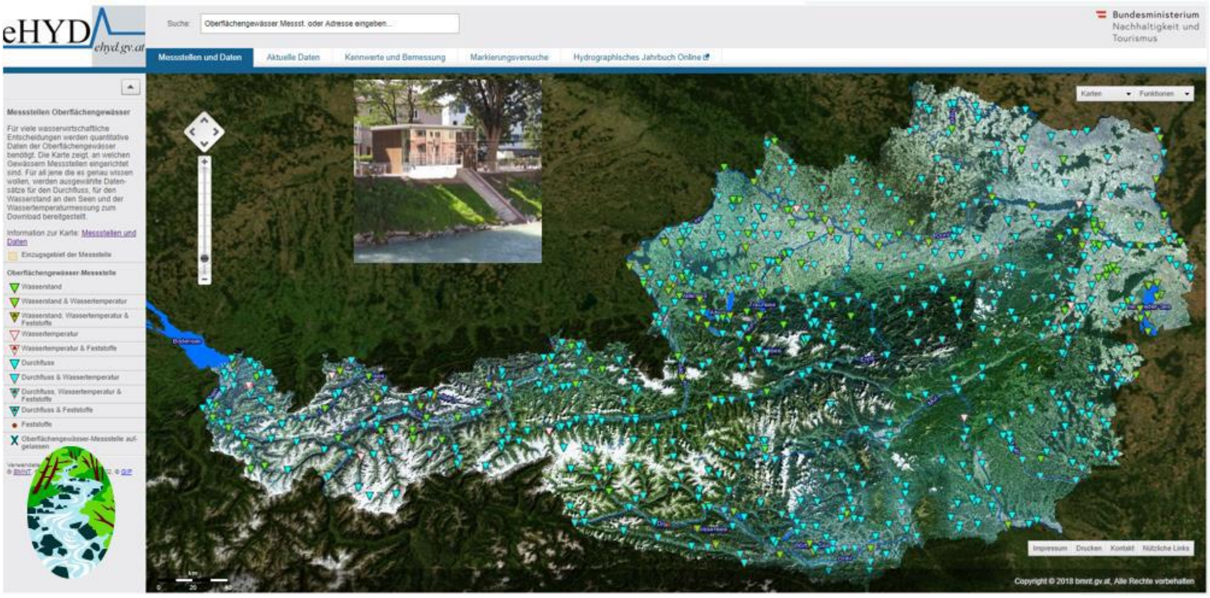

Figure 3: Hydrological monitoring sites in Austria

At a predominant number of observation stations, continuous recording of water levels is done by floats, pressure tubes and pneumatic devices. With these methods sensors are always situated in the water which in winter can cause failures due to formation of ice.

Data recording at water level gauges has been changed essentially by use of modern electronics. The development has progressed from the simple staff gauge, with values observed and noted in the 'water level booklet' only once a day, to continuously registering gauges, recording water level on paper, and finally to digitally measured values stored by data loggers. All of Austria's continuously recording observation stations, data loggers have been installed.

The aim of the state basis meteorological network for the observation of precipitation is to gain information about the spatial and temporal distribution of precipitation.

Several operators run networks in Austria. Beside the Hydrological Service the Central Institute for Meteorology and Geodynamics and the large power station companies are to be mentioned as main network operators.

Storage precipitation gauges, non-recording gauges and recording gauges are used to measure precipitation. Storage precipitation gauges are big containers collecting precipitation over a long period, typically one month. Non-recording gauges are standardized collecting devices, which store the daily precipitation. At least once a day an observer records the fallen amount. Recording precipitation gauges continuously register the fallen precipitation either analogue or digital with data loggers.

Out of the existing 1000 precipitation gauges in the year 2015, 151 were storage gauges, 883 were non-recording gauges and 514 were recording gauges. In addition to the measurement of precipitation the snow height or the fresh snow height is measured at 828 of the existing gauges. At 798 gauges the air temperature is recorded and at 36 gauges the potential evaporation is assessed.

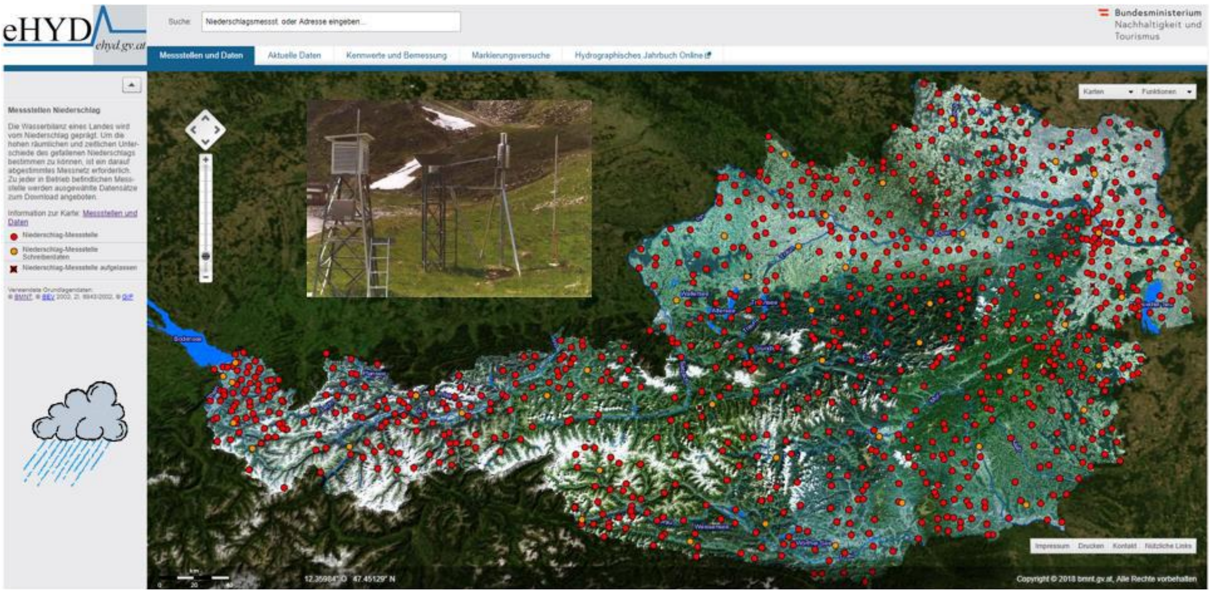

Figure 4: Overview of Precipitation monitoring gauges in Austria (2015)

Slovakia

In Slovakia, Water levels and discharges from gauging stations network are processed at SHMU in a so-called technological module. Special emphasis is applied in case of stations on border Rivers. The selection of monitoring stations, their distribution and technical equipment was designed in line with the purpose of their establishment – representativeness. The focus was oriented towards physical and geographical conditions of each basin and evaluation of development possibilities.

Gauging stations are projected on streams and at locations, where the network provides the most representative information on hydrological regime of Slovak rivers.

Currently, there are 366 hydrological stations in the Slovak part of the Danube basin, from which 306 are operative with continual data transmission and 46 with installed camera.

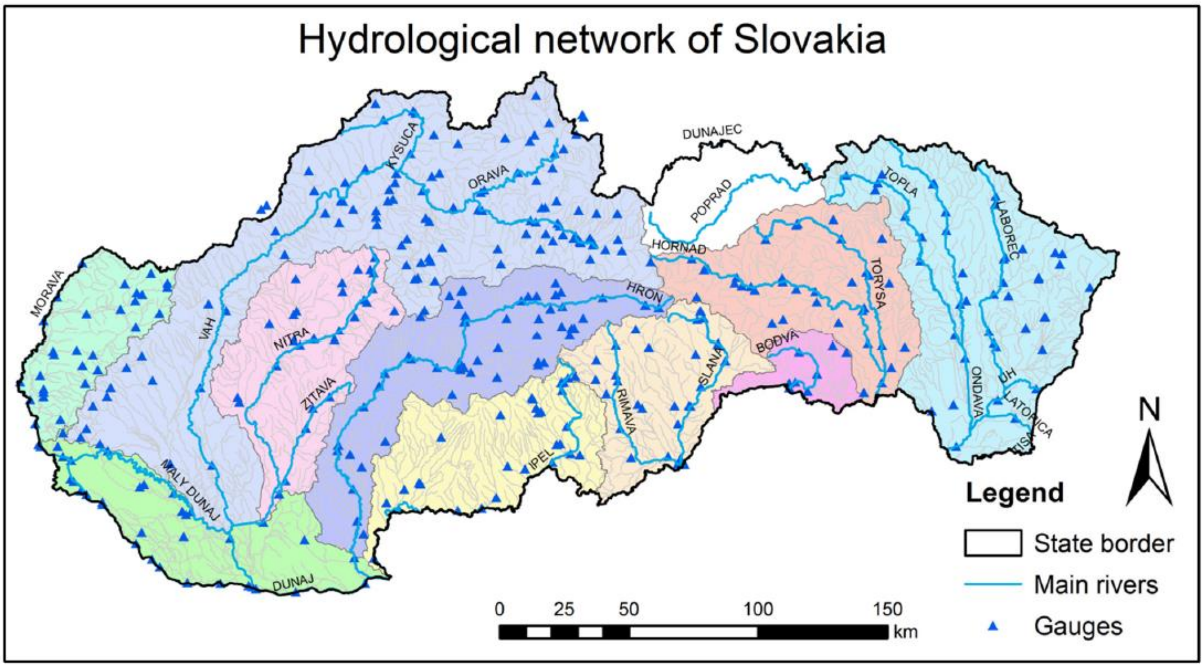

Figure 5: Hydrological network of Slovakia

MARS (Measuring And Registration Station) stations use a pressure sensor that reads a water level which is digitally recorded. Devices of specification MARS 5 and MARS 5i are used for operative stations, MARS 4 and MARS 4i devices are used for regime stations.

Following hydrological parameters are observed in the hydrological monitoring of surface waters:

• MARS 5i measure water level, water temperature, air temperature, precipitation and through rating curve they calculate flow. The device measures and records data on continual basis and dispatches them every 15 minutes. MARS 5i devices allow online data transfer using mobile network GSM or GSM – GPRS. Operative stations are used in operative service for evaluation and forecast of hydrological situations development for 24 hours.

• MARS 4 and MARS 4i measure water level and water temperature. They have a memory card, from which the data is downloaded to a magnetic card (ca. every two months). Discharge is calculated later on PC. Stations in regime mode are used for assessment of hydrological regime and hydrological processes.

An important part of SHMU´s monitoring system is composed by the meteorological observation network collecting data mainly for weather forecasting and climatology. This data is within SHMU used for needs of operational meteorological and hydrological services, especially for analysis of atmosphere´s and hydrosphere´s status and for forecasting and warning of dangerous synoptic phenomena, including ones that may trigger floods.

Current types of meteorological stations can be divided into following groups:

- **Synoptic meteorological stations - p**rofessional meteorological stations, which provide hourly data and measure: air temperature, air pressure, relative humidity, wind, precipitation, cloudiness, snow depth and other phenomena.
- **Automatic weather stations (AWS) -** provide data with minute frequency of measurement and measure: air temperature, ground temperature, air pressure, humidity, wind direction and speed, precipitation amount, duration of precipitation, sunshine, soil temperature, visibility and snow.
- **Climatological stations** measure three times a day parameters: air temperature, maximum and minimum air temperature, relative air humidity, stormy phenomena, wind direction and speed, cloudiness, precipitation, sunshine, snow cover depth and water equivalent, soil surface condition and other atmospheric phenomena.

- **Rain gauge stations** are operated by voluntary observers and provide data about precipitation and atmospheric phenomena on daily basis.
- **Automatic precipitation stations** (APS) provide data on precipitation amount with a minute frequency of measurement.

The network of precipitation stations in Slovak part of the Danube basin consists of 18 synoptic meteorological stations, 84 automatic weather stations, 50 climatological stations, 512 rain gauges and 187 automatic precipitation stations, numbers valid from 2017.

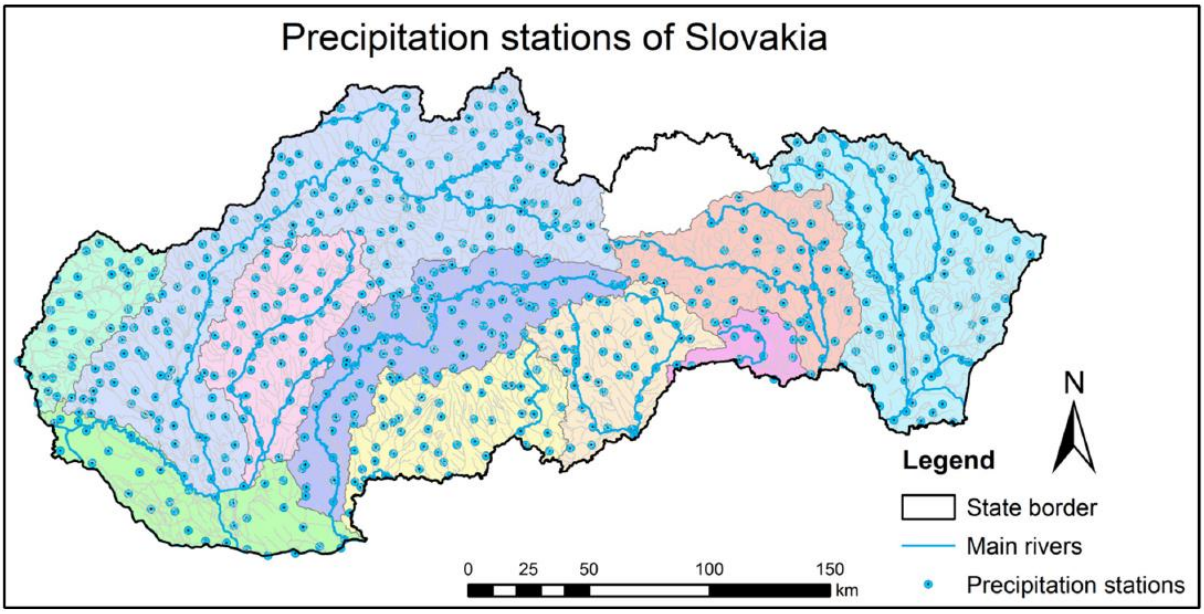

Figure 6: Precipitation stations network of Slovakia

Within the framework of the POVAPSYS project, in years 2014 to 2016, a network of ground station was established. In this period, 137 automatic precipitation stations (APS2), 78 automatic weather stations (AWS2) and two new radar towers on Kubinska Hoľa and Špani Laz were supplied, installed and put into service. On the two old previous radar towers on Maly Javornik and Kojšovska Hoľa new radars were also installed.

Meteorological radars in SHMU measure the following basic variables: radar reflectivity, Doppler radial velocity, velocity spectra, differential reflectance (horizontal and vertical polarization reflection difference), correlation coefficient of received signal with horizontal and vertical polarization, phase difference of received signal with horizontal and vertical polarization and specific phase difference of the received signal with horizontal and vertical polarization. Measurements are performed every 5 minutes.

Slovenia

It the territory of Slovenia the existing hydrological network since 2016 consists of 193 measuring sites on rivers, lakes and sea, of which 182 are automatic stations. In the Danube River basin there are 149 gauging stations, of which 139 are automatic stations.

In BOBER project, the hydrological measurement network has been almost completely renovated and represents a modern system of automatic stations with real-time data transfer.

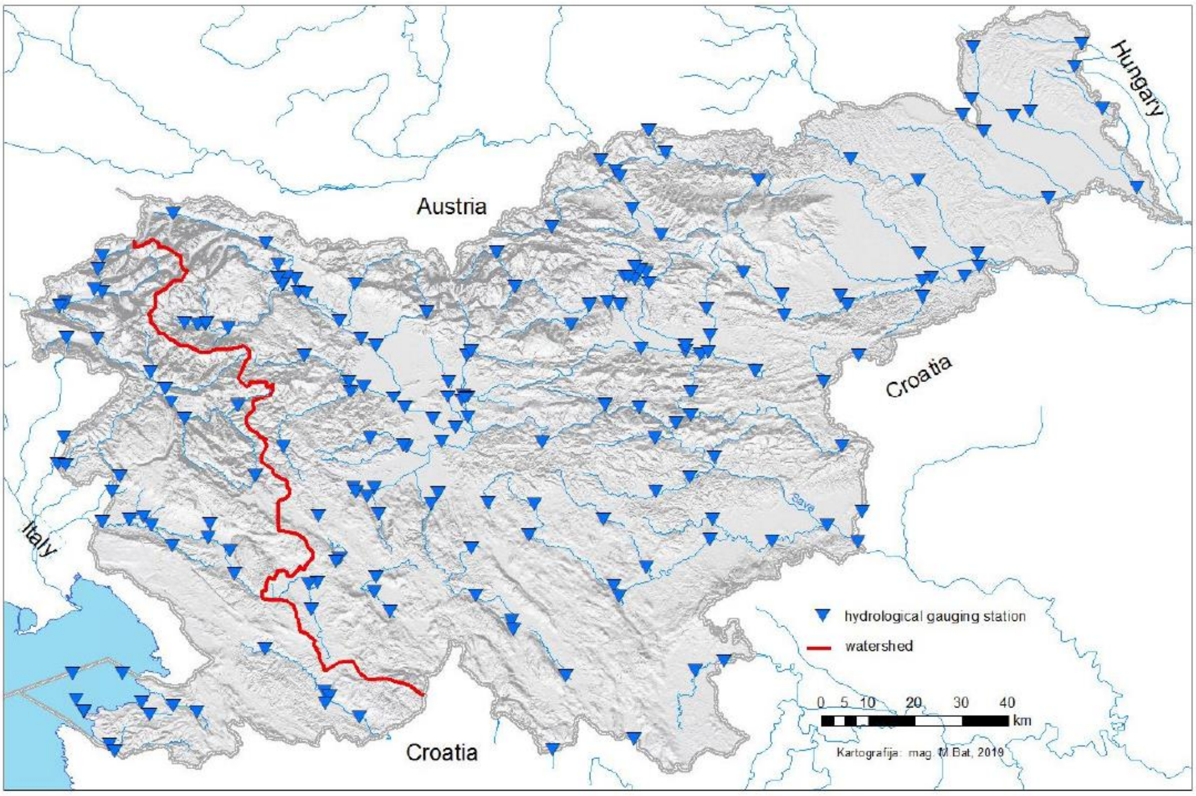

Figure 7: Hydrological monitoring sites on surface waters in Slovenia.
Red line represents the boundary between the Adriatic and the Black Sea basin

The hydrological parameters which are observed in the hydrological monitoring of surface waters include the measurements of water level, water velocity, discharge, water temperature and suspended sediment load. Measurements are carried out in accordance with recommendations of the World Meteorological Organization and international standards.

Nearly 200 meteorological stations are in operation for the time being in Slovenia. Within the framework of the BOBER project, the existing network of meteorological stations has been extended with 90 new automated meteorological stations set up throughout Slovenia and a new meteorological radar installed on Pasja Ravan.

The upgraded and extended meteorological measuring network provides a modern system for monitoring the weather in Slovenia's diverse climate conditions. In addition to the increased number of measuring sites, we have also expanded the range of the observed meteorological quantities and the frequency of measurements. Information about the weather in Slovenia, obtained through new automated meteorological stations every 10 minutes, are immediately and freely accessible to the public.

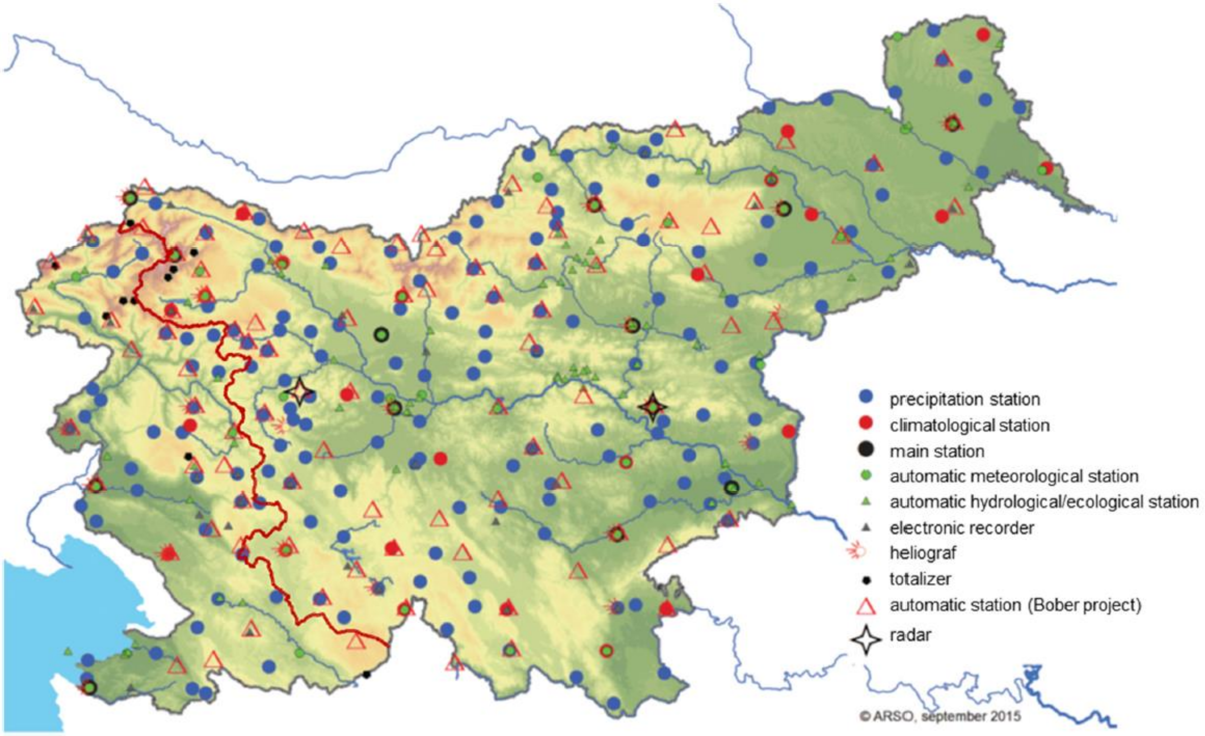

Figure 8: Slovenia - The entire network of meteorological stations including two weather radars at the end of 2015

Slovenia has been receiving from the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) high resolution satellite images since 1996. In 2008, Slovenia became a full member of EUMETSAT.

Croatia

The network of surface water station includes over 450 active hydrological stations, and the available data may be:

- Water levels (daily or hourly values),
- Calculated discharges (daily or hourly values),
- Stage-discharge curves,
- Results of water metering (measured discharge),
- Water temperature (daily or hourly values),
- Suspended sediment concentrations (daily values),
- Suspended sediment transfers (daily values),
- Results of riverbed cross-section surveys (profile sketches and chainage-depth value pairs).

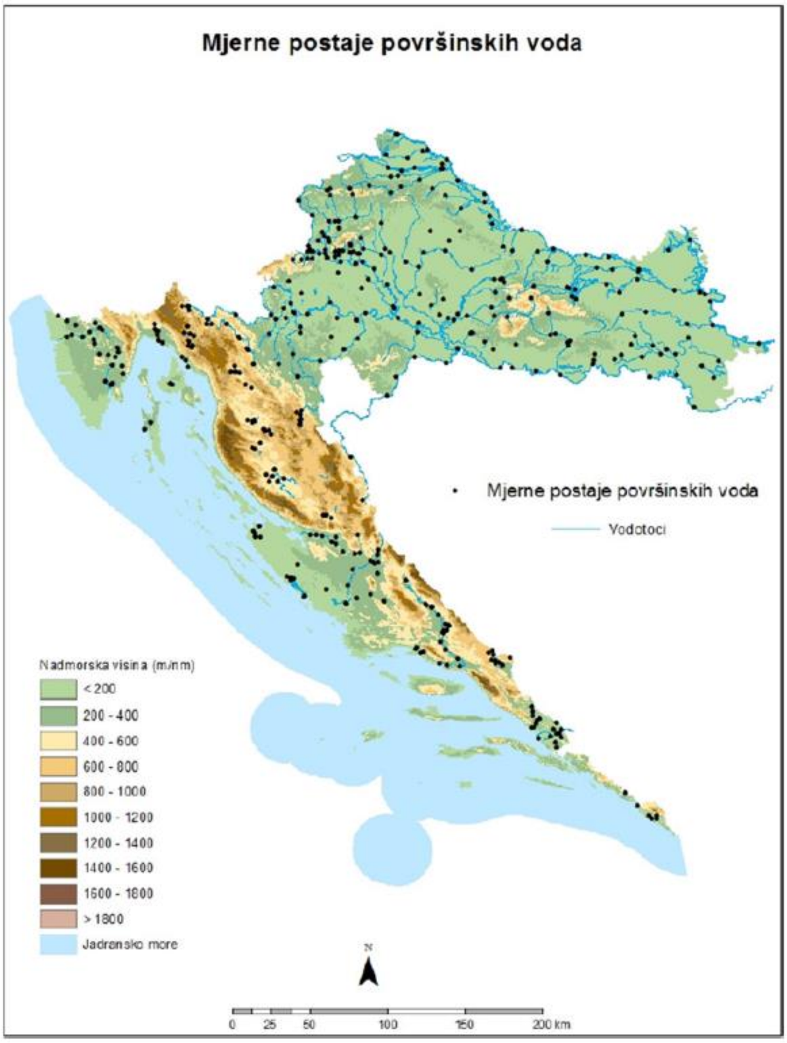

Figure 9: Map of surface waters stations in Croatia

In 2017, the Danube river basin district contained approximately 280 active stations for surface waters monitoring, of which about 170 automatic stations, i.e. those equipped with an alarm system. The network of groundwater stations includes about 700 active hydrological stations. They monitor groundwater levels, mostly by biweekly measurements (Mondays and Thursdays), while the measurements at about a hundred monitoring sites are continuous and performed with electronic limnigraphs. The available data are groundwater levels (daily values for two days in a week or mean daily values for each day).

The network of meteorological and phenological stations consists of the following:

- 40 main meteorological stations,
- 41 automatic meteorological stations,
- 104 climatological stations,
- 339 rainfall stations,
- 22 totalisers,
- 57 phenological stations,
- 2 aerological (radiosonde) stations.

The network of air quality monitoring stations consists of 21 stations within the National network for permanent air quality monitoring and 15 stations for precipitation sampling within the DHMZ meteorological stations network.

National network for permanent air quality monitoring includes 12 rural stations and 9 urban stations.

Remote measurements are performed by 3 radars and 1 sodar.

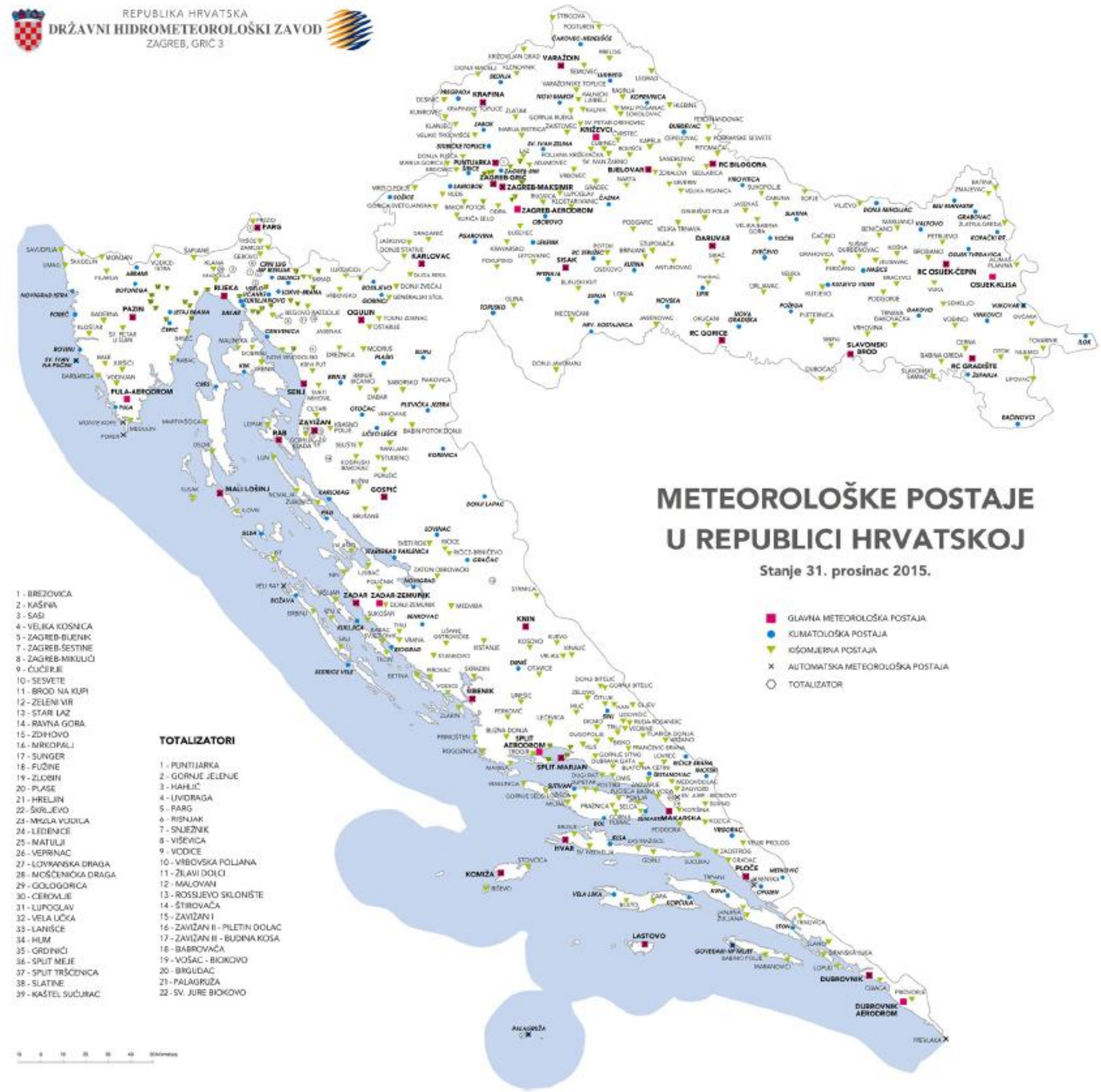

Figure 10: Network of meteorological stations in Croatia

Meteorological measurements include:

- air temperature at 2 m above ground,
- extreme (maximum and minimum) air temperatures at 2 m above ground,
- minimum air temperature at 5 cm above ground,
- soil temperature at depths of 2, 5, 10, 20, 30, 50 and 100 cm,
- relative air humidity at 2 m above ground,
- wind velocity at 10 m above ground,
- wind direction at 10 m above ground,
- air pressure at barometer level,

- air pressure tendencies, characteristics of air pressure tendencies,
- precipitation (quantity, type, intensity and characteristics),
- snow cover (height of total snow cover, height of new snow, extent of soil coverage with snow, snow density),
- sea temperature,
- sunshine duration,
- free water surface evaporation,
- solar radiation (global, diffuse).

Meteorological observations include:

- description of current weather
- description of past weather
- cloud cover (quantity, cloud genus, type and subtype, height of cloud floor)
- visibility
- wind force
- dominant wind direction
- soil status
- sea status (at costal stations)
- atmospheric phenomena during the day (type, intensity and duration)
- daily weather description.

Hungary

Currently, operation, maintenance, upgrading and development of about 8,000 stations are carried out by the 12 Regional Water Directorates under the supervision of General Directorate of Water Management (OVF). Hydrological observations and measurements take place at national and regional scale master and operational control stations. Nearly 350 surface stations and more than 1,700 operating stations exist and operate, with continuous water level detection, of which more than 410 are automatic stations. In addition, there are more than 800 other water status stations (flood operation stations, study stations, etc.). The number of water discharge stations currently exceeds 380, and the number of continuous water temperature measurement stations is around 150. There are nearly 500 hydrometeorological stations in the country with continuous precipitation measurement. Gauges are installed based on national specifications. Frequencies of hydrological data are hourly and daily.

The hydrological parameters which are observed in the hydrological monitoring of surface waters are water level, discharge, water temperature.

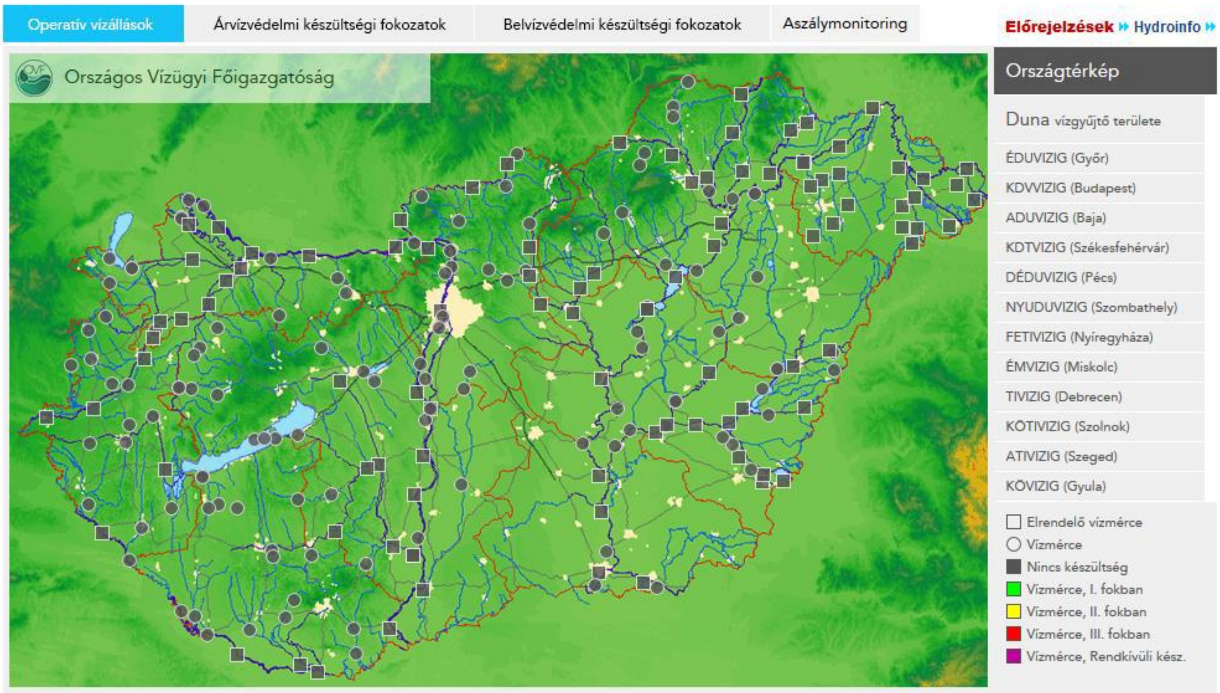

Figure 11: Hydrological monitoring sites on surface waters in Hungary

According to the more than 140 years' tradition, OMSZ fulfils such duties as collecting, processing and (in the last few decades) providing meteorological data and information. Next to running nationwide monitoring network, OMSZ provides radiosonde upper air measurements, operates meteorological radar system as well as lightning localization system, and guarantees the continuous collection, verification and assimilation of the above information, as well as the maintenance of the meteorological data base. OMSZ analyses and calculates weather development by using its own numerical model runs as well as up to date forecast products issued by international weather forecast centers.

Approximately 300 meteorological stations are operates in Hungary.

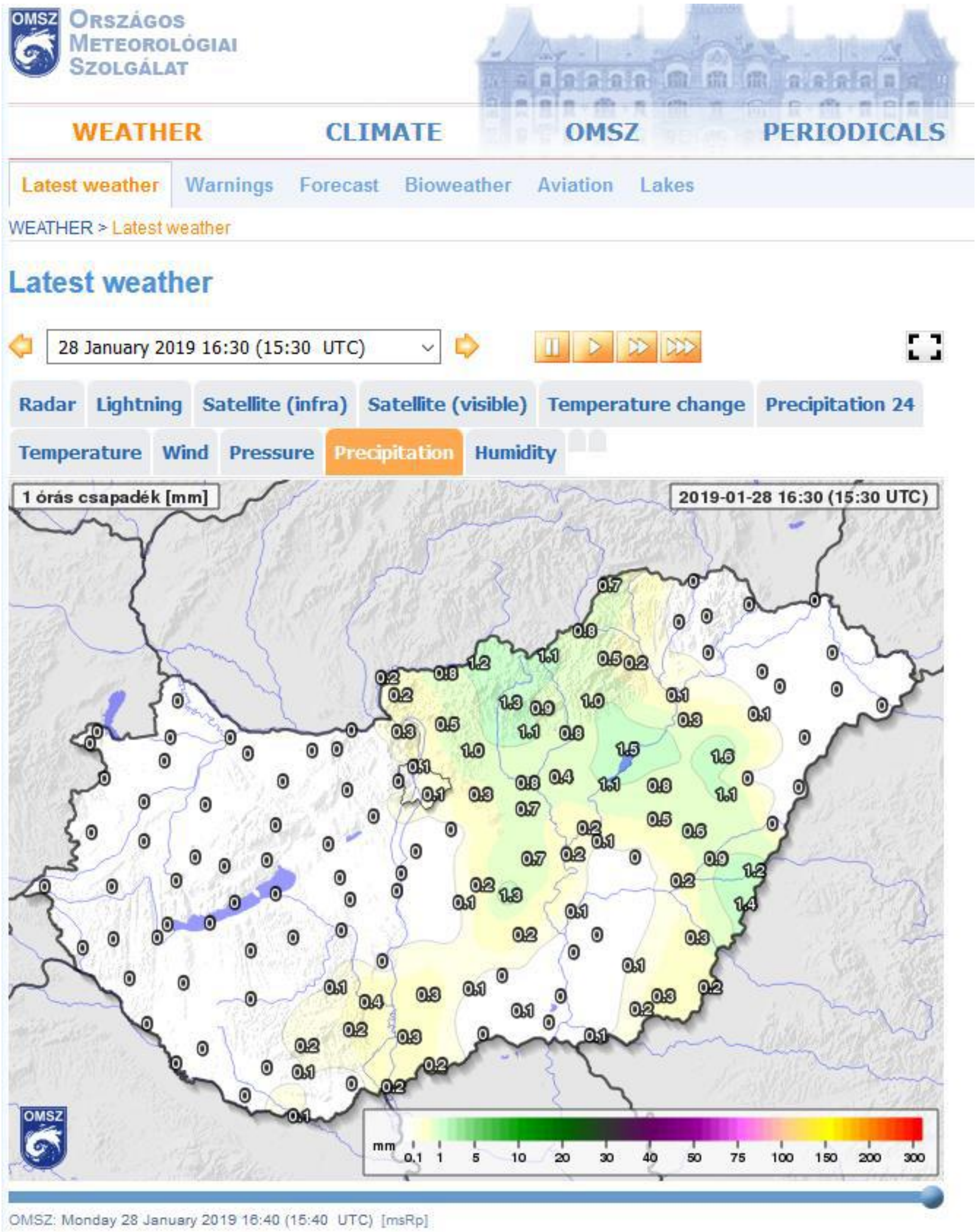

Figure 12: Precipitation stations in Hungary

Surface measurements are supplemented with radar measurements. As a result of developments, a new radar was installed in 2014, already a total of 4 radars are covering the entire country. Data provided by radars are of key importance for very short-term and accurate forecasts of extreme weather events accompanied by large quantities of precipitation over a very short time period, which normally result in dangerous weather conditions and hydrological events.

Measurements are carried out in accordance with recommendations of the World Meteorological Organization and international standards.

Hungary has been receiving high resolution satellite images from the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) since 1996. In 2008, Hungary became a full member of EUMETSAT.

Serbia

At present the RHMSS hydrological network consists of 5 regional centers, which operate 183 surface water and 344 groundwater stations. New technology is adopted during the latest years for discharge and water level measurements. Hydrological data observed by RHMSS are water level, water temperature, ice phenomena for surface water, and water level and water temperature for groundwater. The data from 97 surface water stations are available in near real-time, out of 113 equipped with data loggers. The data from 32 groundwater station is available in near real-time, out of 62 supplied with data loggers.

The general program of the hydrological network is the following:

- hydrological data acquisition, observation and reporting;
- hydrometric measurements (water and sediment);
- zero gage leveling and surveying of cross section;
- maintenance of the network;
- collecting, processing and archiving of the observed and measured data;
- optimization of the hydrological network;
- standardization of the measurement and observation methods;
- introduction of new methods, equipment and instruments;
- Providing guidance and training.

Majority of the hydrological station belongs to the Danube River catchment, 179 stations in total.

Figure 13: Hydrological network, water level observing stations in Serbia

At present the RHMSS meteorological network consists of 28 principal meteorological stations, about 90 climatological stations and about 420 precipitation stations. Data from all principal meteorological stations is available online, hourly, in real time and published on website. Measuring and observation at the principal meteorological stations are performed according to the synoptic program. All principal meteorological stations equipped with automatic weather stations as well as additionally 11 automatic weather stations.

Meteorological data from climatological and precipitation stations are available once per day. Measurement are performed three times per day on climatological and once per day on precipitation stations.

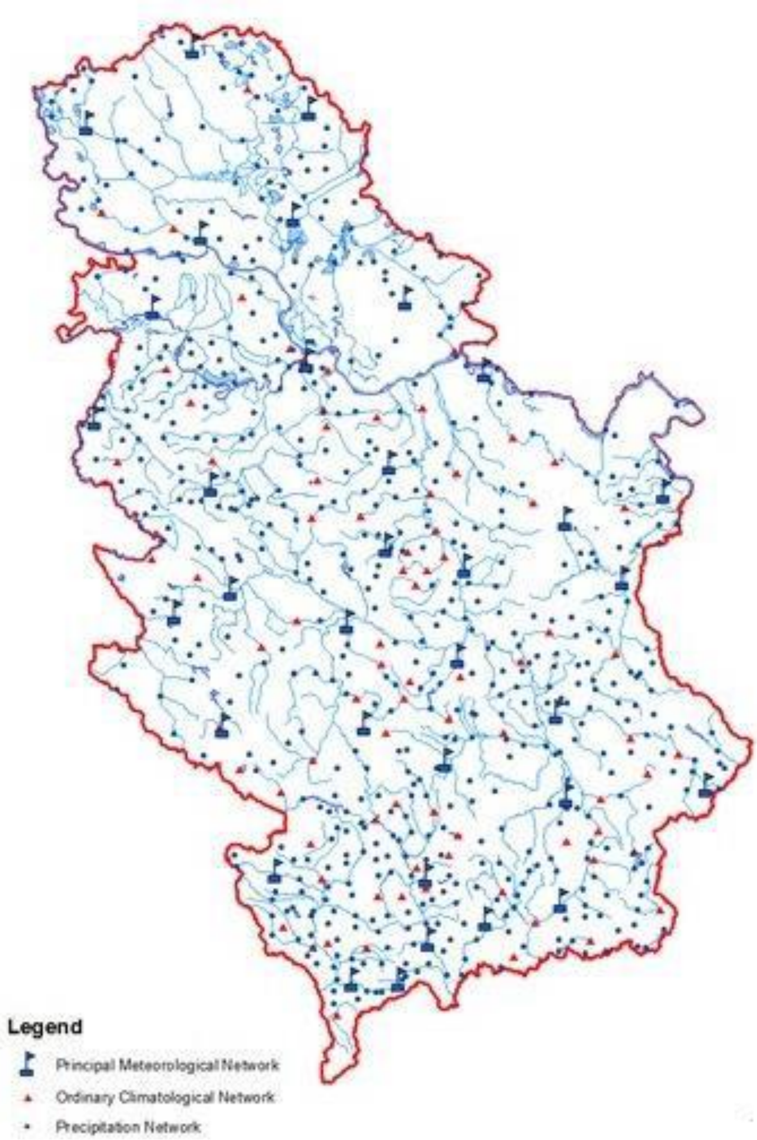

Figure 14: Meteorological Network in Serbia

Radar network of RHMSS consist: 4 Gematronik, Doppler radars (S band, two with dual polarization), 10 Mitsubishi radars (S band), MRL5 radar (S and C band) and LAWR (X band). Satellite data available through collaboration with EUMETSAT (European Agency for the Exploitation of Meteorological Satellites).

Bulgaria

On the territory of Bulgaria the existing hydrological network consist of 194 measuring sites on rivers, of which 109 are automatic stations and 68 operational. In the Danube River basin there are 66 hydrometric stations, of which 28 are automatic hydrometric stations. Daily measurements of the water level, the temperature of the water and information about the available of ice phenomena in the conventional stations are made at 8:00 am and at 08:00 pm. From the automatic stations information on the water level is sent every hour. For each value of the water level the respective water quantity of temporary rating curves is reported.

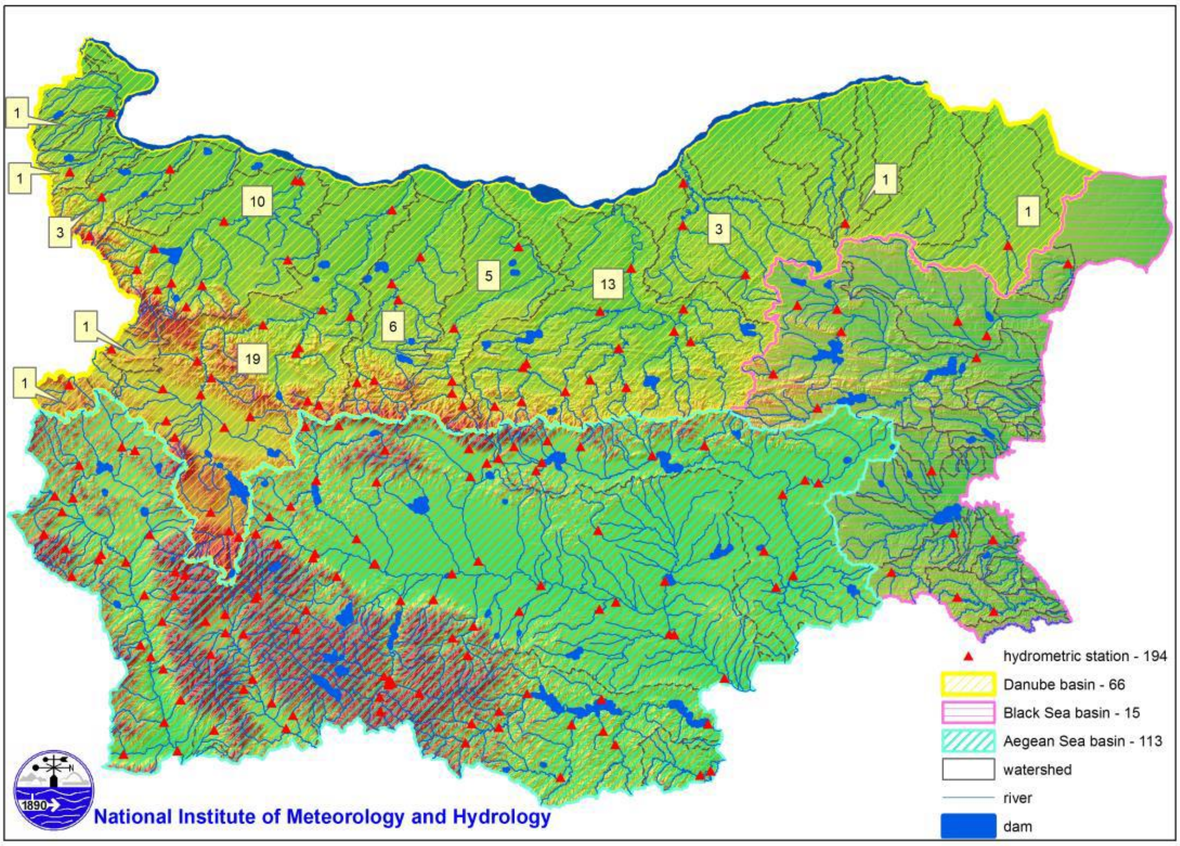

Figure 15: Hydrological network in Bulgaria

The meteorological network of NIMH consists of 367 stations. At 116 locations are installed also automatic stations with different sensors. There are 251 precipitation stations, 78 climate stations and 38 synoptic stations. Meteorological measurements are made according to WMO standards. Measurements in Weather Station: every 3 hours at 00, 03, 06, 09, 12, 15, 18, 21 GMT. Climate station measurements: local time at 07, 14, 21 hours. Measurements in precipitation stations: once daily at 07:30.

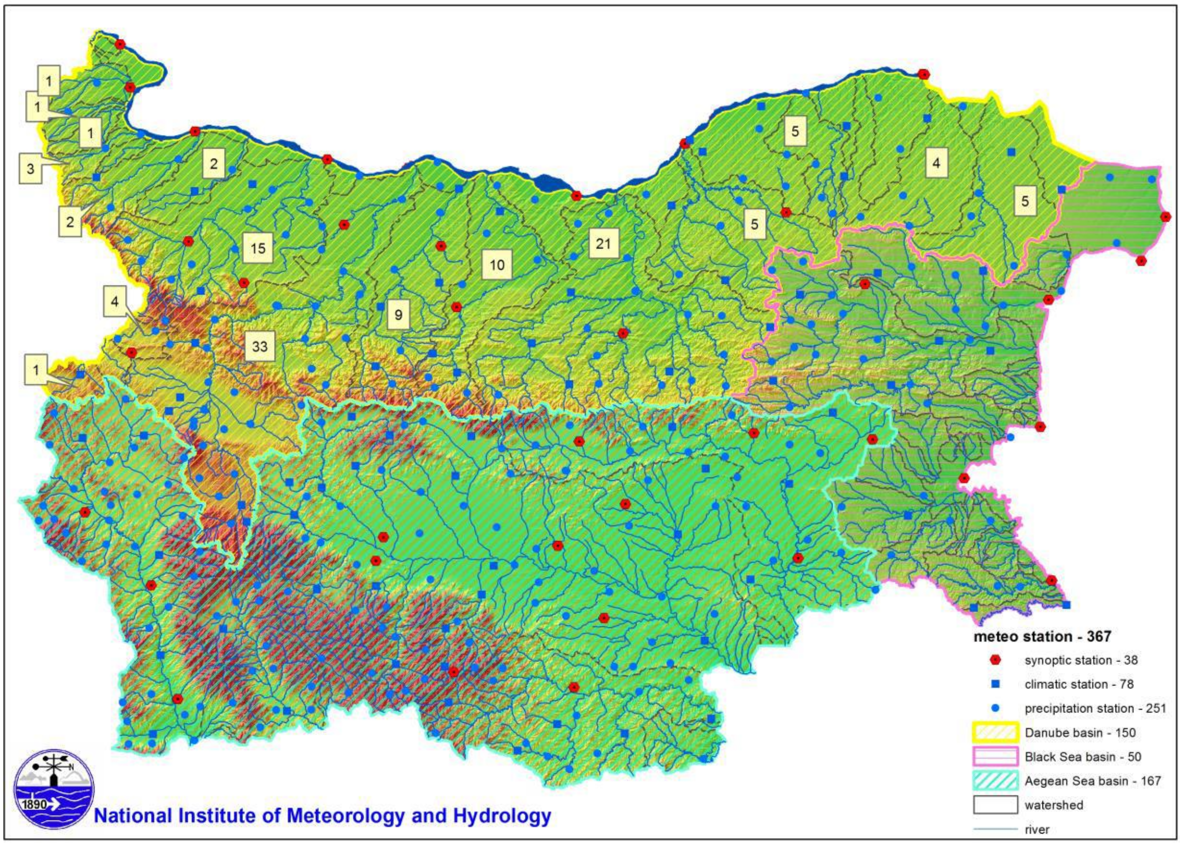

Figure 16: Meteorological network in Bulgaria

On the territory of Bulgaria there are two radars, owned by Sofia Airport and Varna Airport. Access to their information is provided to NIMH for use if necessary.

The stations located along the Danube River in the Bulgarian section of the river are outside of the responsibility of NIMH:

- 6 conventional hydrometeorological stations with an observer.
- 9 automatic hydrometeorological stations

Measured parameters in automatic stations are water level, water temperature, air temperature, atmospheric pressure, humidity, visibility, wind speed and direction, rainfall and sunshine duration. At conventional stations, the observer also reports cloudiness and other phenomena.

Measurements from automatic stations are every 15 minutes and from conventional as follows: Water level and water temperature are measured every 24 hours at 8:00 local time.

At stations in Novo Selo and Lom, additional measurements are made at 13:00 and 17:00. If necessary, increase the number of measurements. The remaining parameters are measured by the NIMH manual - the weather forecasts at 3 o'clock, the climate three times a day.

Romania

The National Hydrological Network within the Romanian Water National Administration is administrated by the eleven Water Basin Administrations, organized based on the main River Basins as follows: Somes-Tisa, Crisuri, Mures, Banat, Jiu, Olt, Arges-Vedea, Buzau-Ialomita, Siret, Prut, and Dobrogea-Litoral.

On the Romanian sector of the Danube, there are 28 main hydrometric stations.

The general statistics for the hydrometric stations on the interior rivers, are presented in Table1.

Table1: General statistics of national hydrologic network per main interior River Basin and upstream basin area

River Bazin Administration		Somes-Tisa	Cris	Mures	Banat	Jiu	Olt	Arges-Vedea	Ialomita - Buzau	Siret	Prut	Dobrogea	**TOTAL**
No. of hydrometrical stations		103	88	113	80	79	104	65	51	131	80	50	944
Hydrological parameters	Level (only)	11	-	4	-	-	-	2	-	4	2	37	60
	Level, discharge	92	88	109	80	79	104	63	51	127	78	13	884
	Precipitations	139	79	103	71	42	104	72	104	133	77	49	973
No of stations with a basin area	< 100 km²	30	43	32	28	27	45	13	16	34	14	13	295
	Between 100 km² and 500 km²	45	29	46	30	26	42	22	20	61	36	13	370
	Between 500 km² and 2000 km²	20	10	14	17	10	10	14	10	15	14	30	164
	Between 2000 km² and 10000 km²	5	6	9	4	4	5	7	7	16	9	-	72
	> 10000 km²	3	-	8	-	8	2	9	1	5	7	-	43

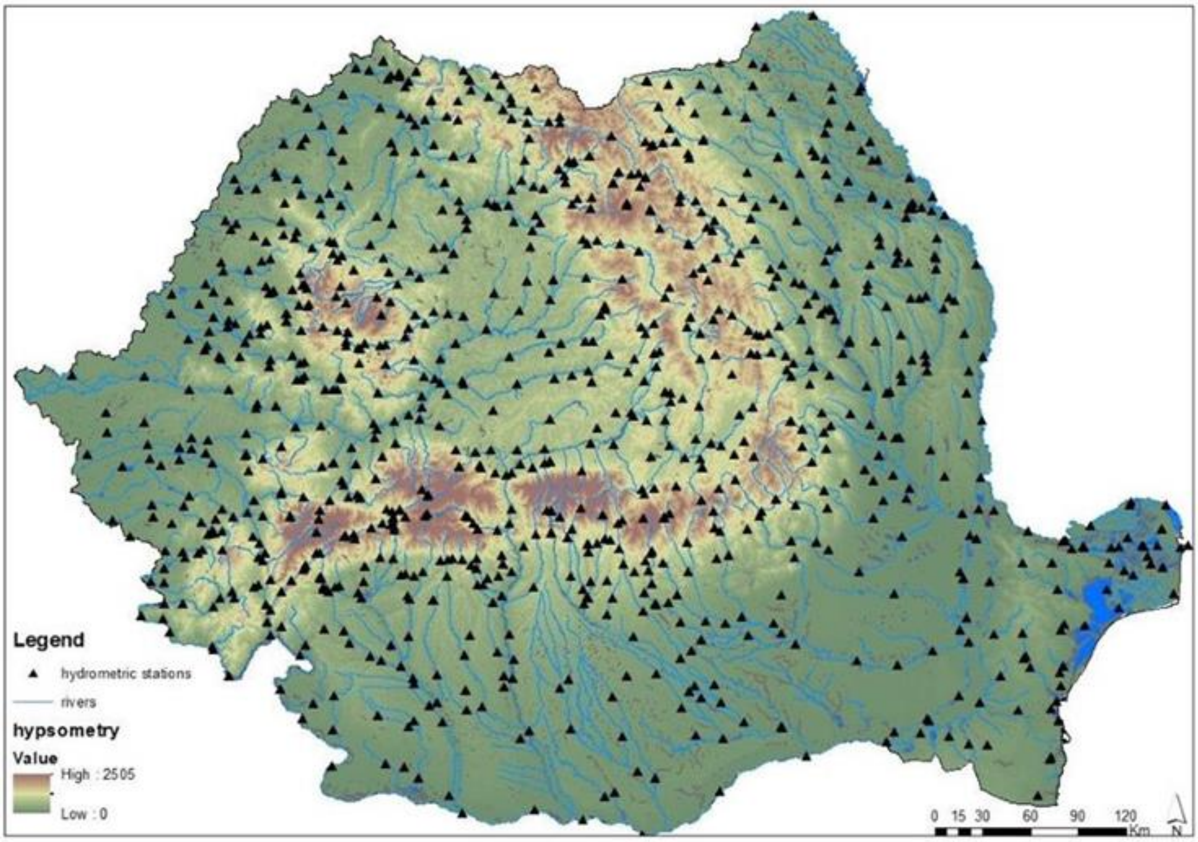

Figure 17: Romania National hydrological monitoring network general spatial distribution

The Romanian national surface meteorological network consists of 160 stations, most of them equipped with automatic weather stations (AWS). All AWS have sensors for air temperature, pressure, relative humidity, liquid atmospheric precipitation, wind speed and direction, and some of them measure soil surface and depth temperature, net radiation, global and diffuse solar radiation, and sunshine duration. In SYNOP reports there are included also observations about visibility, cloudiness, cloud types, height of the lowest clouds, meteorological phenomena, depth and density of the snow cover, snow water equivalent. In special cases, supplementary information can be provided automatically from AWS every 10 minutes with elements measured by its sensors. For hazardous meteorological phenomena such as strong wind, low visibility, precipitation, thunderstorm, hail, early and late frost, meteorological warnings are transmitted.

The national weather radar network provides important information regarding cloud and precipitation systems (extent, vertical development, direction and speed, evolution) as well as the related severe phenomena such as hail, heavy rain, wind gusts and tornadoes.

Figure 18: National meteorological monitoring network in Romania

Meteo Romania is currently operating a network of 7 Doppler radars: 2 C-band and 5 S-band. The radars of Romanian National Network produce many type of data:

- The Level II data are the digital radial base data (Reflectivity, Mean Radial Velocity, and Spectrum Width) output from the signal processor;
- The Level III data are the output product data of the Radar Product Generator. The products assist forecasters and others in weather analysis, forecasts, warnings and weather tracking. The pre-defined list of products are provided electronically in near real-time to the Central Operations Facility Bucharest (COF), to all Regional Forecast Center (RFC) and to other external beneficiaries.

Meteo Romania is part of the OPERA programme (Operational Programme for the Exchange of weather RAdar information) within EUMETNET, and contributes with radar volume data to the European radar Mosaic. The volume files are sent operationally (24h/24h) to Odyssey, the OPERA Data Centre, where composite products, from raw single site radar data using common pre-processing and compositing algorithms, are generated.

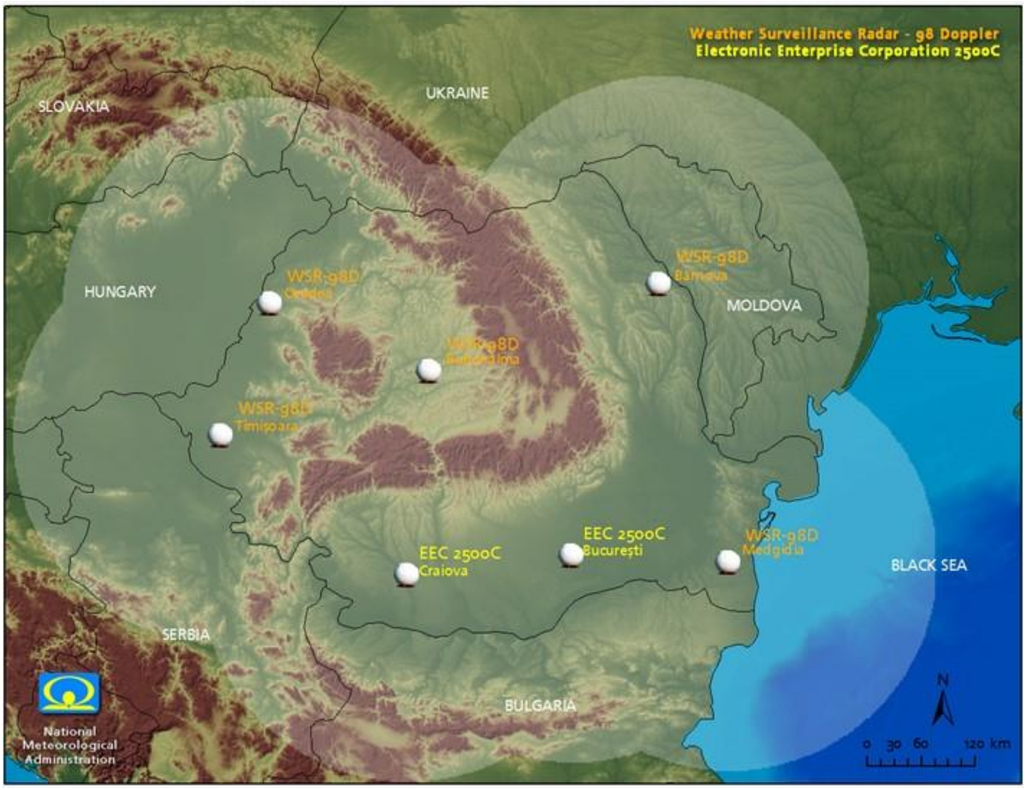

Figure 19: National weather radar network in Romania

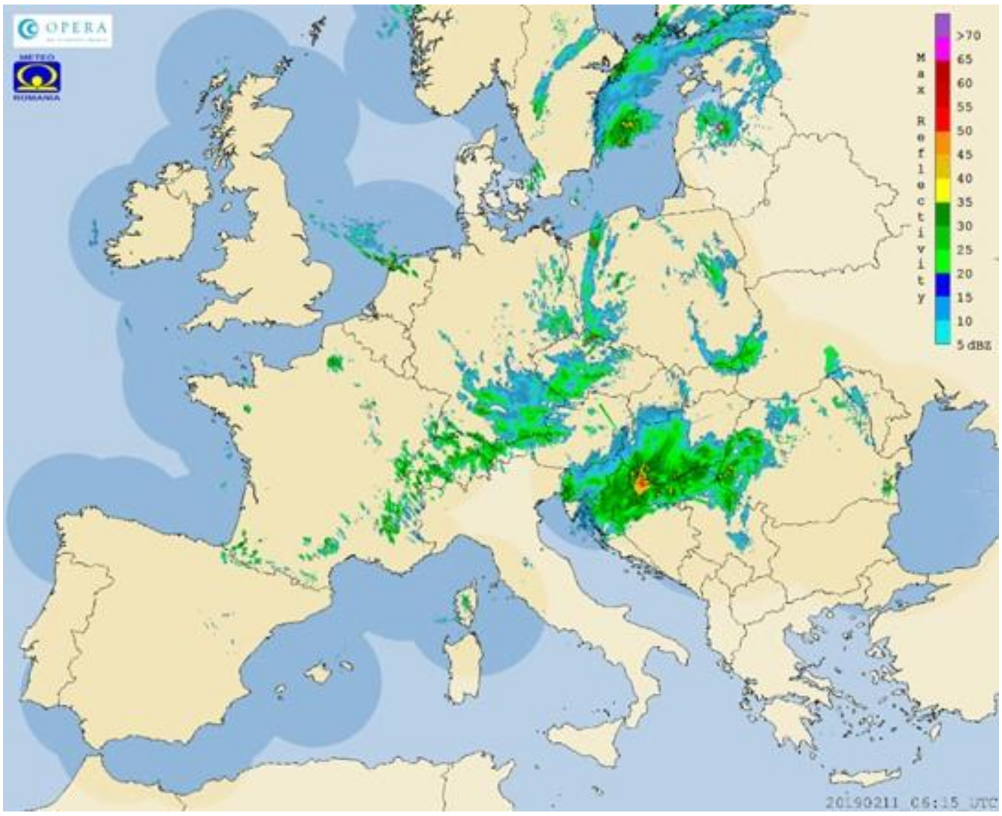

Figure 20: Example of integrated OPERA programme radar product

2 Primary data management systems – experience from the national flood forecasting and warning systems

Table 2 provides the information about operating system of the server that collects the data from the stations in individual countries in the Danube river catchment. Additionally, Table 3 shows the information about a database the hydrological data are stored in.

Table 2: Information about operating system of the server that collects the data from the stations

Country / Region	Operating system of the server (Microsoft Windows Server, Red Hat Enterprise Linux, Ubuntu Server, SUSE Enterprise Linux Server, Oracle Linux Server, Debian Linux)					
Austria (Lower Austria)	Microsoft Windows Server					
Bosnia and Herzegovina	Microsoft Windows Server					
Bulgaria						Debian Linux
Croatia	Microsoft Windows Server					
Czech Republic	Microsoft Windows Server	Red Hat Enterprise Linux			Oracle Linux Server	
Germany			Ubuntu Server	SUSE Enterprise Linux Server		
Hungary	Microsoft					Debian

	Windows Server					Linux
Moldova	Microsoft Windows Server					
Romania	Microsoft Windows Server	Red Hat Enterprise Linux	Ubuntu Server			
Serbia	Microsoft Windows Server					
Slovakia					Oracle Linux Server	
Slovenia					Oracle Linux Server	
Ukraine						Debian Linux

Table 3 Information about the used Database Management System Softwares

Country	**Database** (Relational Database Management System (e.g. MS SQL Server, Oracle, PostGreSQL), other)	
Austria (Lower Austria)	Relational Database Management System (MS SQL Server, Oracle, PostGreSQL, other)	
Bosnia and Herzegovina	Relational Database Management System (MS SQL Server, Oracle, PostGreSQL, other)	
Bulgaria	Relational Database Management System	

	(MS SQL Server, Oracle, PostGreSQL, other)	
Croatia	Relational Database Management System (MS SQL Server, Oracle, PostGreSQL, other)	
Czech Republic	Relational Database Management System (MS SQL Server, Oracle, PostGreSQL, other)	
Germany	Relational Database Management System (MS SQL Server, Oracle, PostGreSQL, other)	MySQL, (MariaDB)
Hungary	Relational Database Management System (MS SQL Server, Oracle, PostGreSQL, other)	Unique Binary Database
Romania	Relational Database Management System (MS SQL Server, Oracle, PostGreSQL, other)	
Serbia	Relational Database Management System (MS SQL Server, Oracle, PostGreSQL, other)	
Slovakia	Relational Database Management System (MS SQL Server, Oracle, PostGreSQL, other)	
Slovenia	Relational Database Management System (MS SQL Server, Oracle, PostGreSQL, other)	

Based on the particularities and characteristics of data management approach, several examples of good practice have been selected, and are shortly presented in this chapter.

In Germany, all collected data is transmitted to internal servers of the HND. Data from the official measuring stations for water levels, own stations for water levels and own stations for precipitation data is transmitted automatically. Data from the DWD is transmitted by an FTP-Server.

For the water level stations, every measuring station has a data collector which stores the level data with an update interval of 15 minutes. Level data is transmitted to several so called SODA servers, each for a certain catchment area.

SODA is a system developed by Kisters company for the special purpose of data storage of level measurement data. The SODA servers are industrial PCs with Linux operating system. The transmission works via phone lines (analog, ISDN, D-Kanal, currently switching to IP transmission) and mobile networks (GPRS, GSM). These servers transmit the data to a central LAMP server at the LfU which stores the data in a MariaDB data base. The MariaDB data base is mirrored by three additional LAMP servers at different locations to protect against failure in case of a flood.

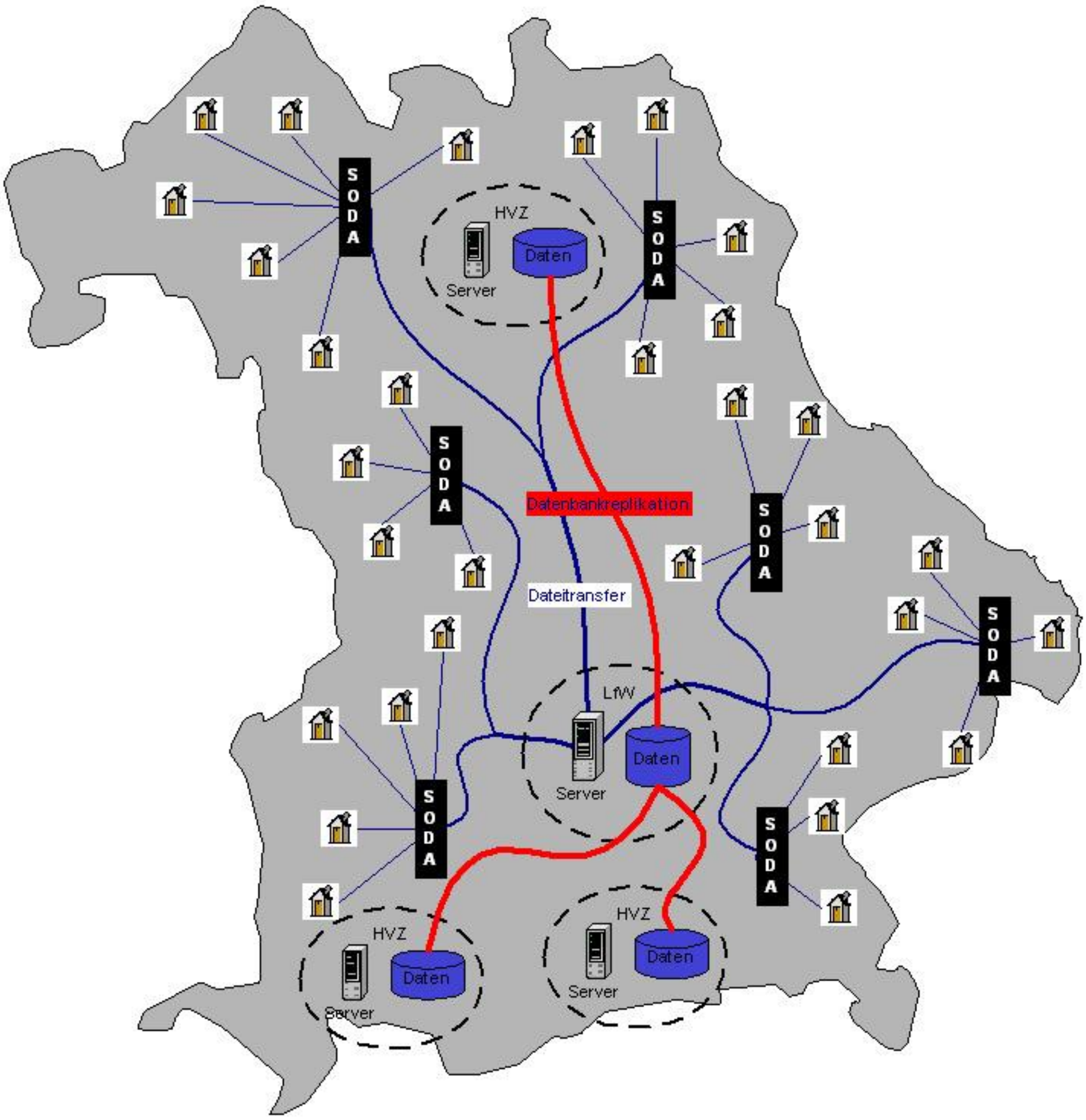

Figure 21: Data management for level measurement data in Germany

In Austria, the data from all measuring points are entered in the hydrographical database called HyDaMS. Acquisition, processing and controlling of hydrological data is be done consistent in all Provinces and in the Central Office. The Provinces as well as the Central

Office are using the Hydrographisches Daten-Management-System (HyDaMS). There is a well defined data flow from measuring to analysis with regular controlling measurements, equipment checks and quality controls. Data controlling is first be done in the Province´s offices, then again in the Central office before publishing. The evaluation of the yearbook pages and many different data analyzes are carried out with the program HyDaMS. The system combines the subsystems of the national network for monitoring precipitation, groundwater, springs and surface water.

In Slovakia, data from automatic gauging stations are transmitted into the SHMU´s database directly from measurement points. Data from MARS stations are mostly transmitted to the internal MARS database by GSM, GPRS mobile network every 15 minutes. Data are copied to operative database that is used in operative hydrology processes (hydrological forecasts by models).

All hydrological data are corrected offline and are uploaded to a regime database. These data are used for model calibration and verification.

In Slovenia, data from automatic gauging stations come into the database of Slovenian Environment Agency directly through transmission from measuring points. Data from the BOBER automatic stations are transmitted to the database mostly via mobile network every 10 minutes, from the oldest automatic stations which have not been upgraded yet every 30 minutes with 10 minute data blocks.

Data control is provided by a three-level system. First level control is automatic and comprises a basic control about the meaningfulness of the data and the operation of the device. The second-level control includes manual control of data and data correction. The second-level control is carried out in the Kolomon tool, which was developed in Slovenia for this purpose.

Further processing and data analyses are performed in the information system of the national hydrology service named HIDROLOG. The system combines the subsystems of the national network for monitoring groundwater, springs, surface water and the sea.

In Croatia, Hydrological data on water levels are collected from several sources (DHMZ, Hrvatske Vode, National parks, HEP) into the data management software Hydras 3 (Ott). Data from automatic stations are sent through a mobile network via ftp in hourly, half-hourly or 15-minute intervals (depending on the settings at each individual station) whereas data from limnigraphs are collected from the stations every three months.

Control readings of water levels are performed during visits to the stations and results are entered directly into the Hydras 3 and serve during the subsequent data analysis.

The basic processing of water levels is conducted periodically through the Hydras, and the verified series are stored in the information system "HIS2000", which is developed by the Hydrology Department, whereas the database is developed as relational, under the InterBase RDBMS.

Meteorological data are stored in separate databases.

The relational database of type PostgreSQL serves for storing climatological data, precipitation data, sea temperatures, soil temperatures, data on evaporation and data on the stations. Some measured values are daily, some are interval ones for 07, 14, 21 hours.

Data from the automatic stations are stored in the Database of the automatic meteorological stations.

In Hungary, all hydrological data are stored in MS SQL database. The manual observed data are recorded on data sheet, and are processed monthly. The automatic station recorded data are hourly transmitted by URH and GPRS to Regional Water Directorates.

Data control is provided by several steps. First step is automatic and comprises a basic control about realness of data and operation of device. The second-level control includes manual control of data and data correction. Data are added to the Operational Hydrological Module (OHM) and Hungarian Hydrological Database (MAHAB). Data are controlled one more time automatically and manually straight before hydrological forecasting.

For hydrological data management purposes, RHMS of Serbia uses a information system WISKI (Water Information System Kisters) from Kisters. WISKI provides information transfer: from water resources area to computer data and information area. WISKI uses time series technology which enable storage of data and information describing the state and changes in water resources while ensuring high performance and system efficiency. Also, post-processing, analysis, synthesis and decision-making is based on reliable and verified information.

WISKI basic characteristics are:

- Ability to handle large amounts of data
- Flexibility and extensibility of the system
- Security and reliability of the system
- Knowledge Base - Thesaurus: 540+ experts
- Customer base: 700+ worldwide
- Reliable, scalable and adaptable system - multi-tier (multilayer) modular architecture
- Provides an environment for intelligent time management (agents) for all types of parameters in hydrology and meteorology
- Provides requirements: manage metadata, acquisition, storage, validation, analysis, integration and dissemination
- Possibility of preparing different types of reports, graphics ...
- Data transfer (import <-> export), scripting
- Manage data quality and manage users
- Tools for hydrometric measurement processing and flow calculation, advanced statistical processing and analysis in hydrology
- Data is stored in a relational database - Oracle

WISKI is currently used for the processing of hydrological data of surface waters and meteorological data for the needs of hydrology. The implementation of groundwater data is in plan for a future period.

For the purpose of controlling the operation of the equipment and observers (data accuracy and data quality), control measurements are performed at all hydrological gauging stations.

Quality control of hydrological data and information obtained through the implementation of hydrological measurement and monitoring programs at hydrological stations (data control) are carried out in order to establish reliability and international comparability of data, removing detected errors and bringing data and information into a form suitable for storage, sharing, use, processing, publishing, and permanent storage. Control of hydrological data are performed by using manual and / or automatic control methods. Control are carried out in accordance with the relevant technical regulations of the World Meteorological Organization, WMO No. 168, 2008 Sixth Edition, International Standards.

In Bulgaria, the Regional Telecommunication Hub – Sofia (RTH - Sofia) is among the 15 regional telecommunication hubs worldwide that are based on the Main Telecommunication Network (MTN) of the Global Telecommunication System (GTS) of WMO.
RTH - Sofia’s zone of responsibility are: Albania, Bulgaria, Cyprus, Montenegro, Republic of North Macedonia, Romania, Serbia and Syrian Arab Republic.
Hydrometeorological data flows through the RTH – Sofia and is further disseminated worldwide. All data is encrypted according to WMO’ standards. Exact formatting is available on WMO website: http://www.wmo.int/pages/prog/sat/formatsandstandards_en.php
The Hydrological Forecast section within the National Institute of Meteorology and Hydrology has various international agreements regarding hydrological and meteorological data exchange. NRT data on water levels and discharges at the outlet stations of the six main Danube tributaries is being processed and sent daily to the telecommunication hubs in Bucharest, Romania, Belgrade, Serbia and Bratislava, Slovakia.
Data from the outlet stations of 10 rivers in the Danube basin, 2 hydrometric stations on Maritsa river are sanded to EFAS that collects near-real-time water level and river discharge observations for LISFLOOD simulations

3 Data management for hydrological forecasting activities

National meteorological and hydrological services are obliged to meet national needs for meteorological, hydrological and related data and services, as well as to maintain networks, equipment and other supporting infrastructure. Furthermore, they need to cover the international obligations and initiatives. They also provide services in order to satisfy other varied end-user needs.

Germany

The model used for general forecasts is LARSIM (Large Area Runoff Simulation Model). For the execution of the models LARSIM, WAVOS and FLUX/FLORIS the HND uses an internally developed user interface called HUGO (Hochwasservorhersage Unterstützende Grafische Oberfläche/Flood Forecast Visual Support Interface) which is applied for data processing, control, visualization and publication.

Slovakia

The Hydrological Forecasting Service of SHMU operates with help of a customized fully automated Hydrological Forecasting System (HYPOS) (Figure 8). HYPOS is designed as a modular system with intranet applications. Its partial modules are interconnected and they are in the state of a continual expanding and improving.

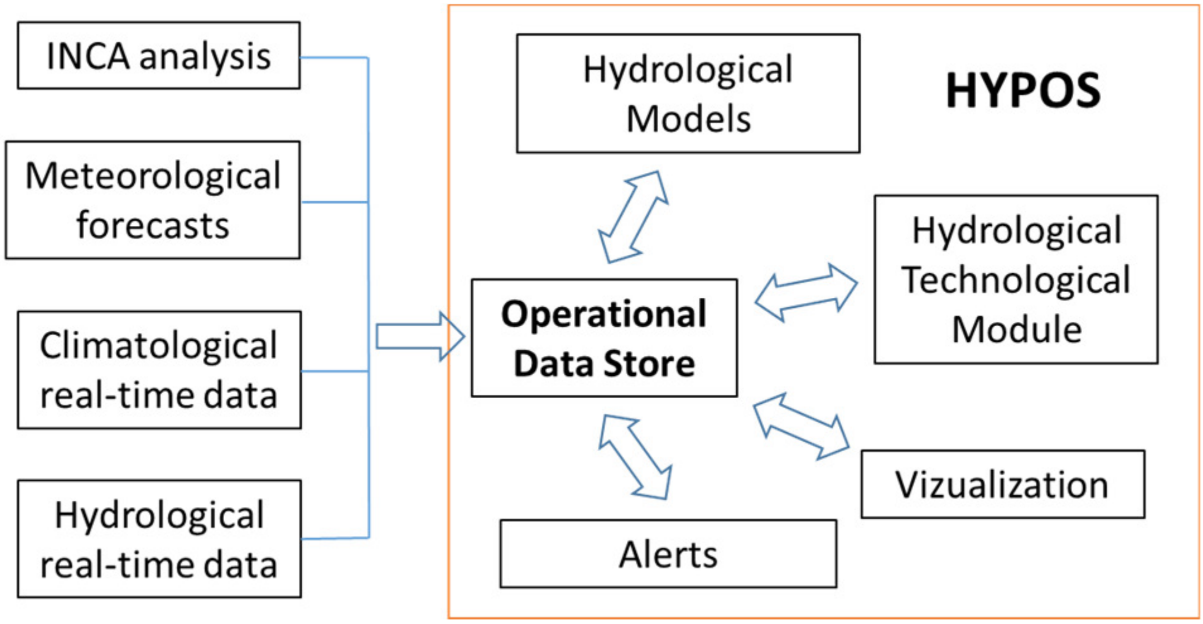

Figure 22: Diagram of HYPOS

The modules of Operational Data Store (ODS) and System of Hydrological Models (SHM) form the core of HYPOS. The ODS is a **database** designed to integrate data from multiple sources (meteorological, hydrological, climatological) for additional operations on the data – for hydrological modelling, reporting, visualization, controls and operational decision support.

To analyze meteorological situation (precipitation and air temperature fields) in real-time, INCA system is applied. It merges point measurements from ground stations with spatial information from meteorological radars.

The Hydrological Information System (IS HIPS) is a tailor-made information system designed for the operative practices of the Hydrological Forecasting Service of SHMU. It is a web platform communicating with HYPOS and allowing management of hydrological real-time data, forecasts published on the web, dissemination of daily hydrological situation and text forecasts as well.

Moreover, HYPOS allows users to download input data and model setups of the catchment and thus working with model in offline mode as well.

Systems HYPOS and IS HIPS are also designed for automatic alerting of hydrologists on duty. Alerts on extraordinary events within the climatological (precipitation) and hydrological (water stages) observation networks and within modelling outputs (exceedance of the warning threshold levels) are sent in real-time via SMS and email notifications.

Forecasters use also information received through the European Flood Awareness System (EFAS) web platform, data and notifications are considered as supporting information during the decision making processes. Moreover, SHMU is through its Hydrological Forecasting Service also a member of the EFAS Dissemination Centre.

Slovenia

The hydrological forecasting service of ARSO is using mostly self-developed informational and modelling systems. The following four systems are used in the daily operational practices:

- VISPRO – meteorological data and NWP visualization platform,
- HFS – the hydrological forecasting (modelling) system,
- VodePro – hydrological information and dissemination platform,
- SAP – system for automatic alerting.

The VISPRO viewer is one of the oldest systems that is still being used by the meteorological and the hydrological forecasting services. It is a comprehensive system with the latest data and information collected from the observational networks, reported by the observers and acquired with the remote sensing instruments. It also contains NWP results from several meteorological models and the nowcasting system running at the computation centre of ARSO. It also provides the data and the modelling results received from the international organizations (ECMWF, EUMETSAT, HSAF, Copernicus).

From the aspect of hydrological forecasting, the most important are the following simulation results:

- medium range weather forecasts from the global ECMWF NWP model;
- short range weather forecasts of two Slovenian versions of the Aladin NWP model;
- nowcasting system INCA;
- LAEF and ECMWF ensemble forecasts.

VodePro is informational platform dedicated to the operative practices of the hydrological forecasting service at ARSO. The first VodePro version was launched in 2016 and it has been updated with additional features several times already. It is designed as web platform that integrates all hydrological and meteorological real-time data, grids, forecasts and products used in the daily practice of the forecasting service. It is the tool also used for data management of the surface waters real-time data public web page (http://www.arso.gov.si/vode/podatki/amp/) of ARSO as well as for dissemination of the daily hydrological forecast.

SAP is the system for automatic alerting of the hydrological forecasters on extraordinary events within the observational networks, the modelling and nowcasting systems of ARSO. It is a comprehensive tool that performs real-time data analyses at high frequency (10 minutes update) and notifies the forecasters in case any event fits within the predefined categories of interest. It was introduced in 2018 mostly for supporting the flash flood detection during the convective season.

Croatia

DHMZ hydrological forecasters use five visualization platforms. Two of them (EFAS – European Flood Awareness System and SEEFFGS – South East Europe Flash Flood Guidance System) are run and maintained out of DHMZ. Three of them were developed within or for the DHMZ tasks and are maintained by DHMZ. DHMZ’s three platforms are presented in short as follows:

1. Operational meteorological forecasting web interface;

2. Sava SM model web interface;
3. Danube model web interface.

Operational meteorological DHMZ “black screen” password protected web interface that consists of all approachable weather forecasting and measured meteorological parameters. It helps in regular screening weather situation at territory of Croatia and surroundings.

Sava SM model web interface could be open from any internet connected place by usage of username and password. At its screen the user can choose the one of seven parameter’s visualization to be shown at the chosen hydrological station or at the catchment (discharge, water level, water level at cross section, precipitation, temperature, soil moisture, snow water equivalent), and for the period -48 h to + 120 h from the time of forecast. The chosen parameter is shown in the map, at the graph and in the table.

Danube model web interface web interface could be open from any internet connected place by usage of username and password. At its screen the user can choose the location of hydrodynamic and meteorological forecast. For one or more hydrological station one can choose discharge, temperature or water level, measured and forecasted (not for water temperature) data. For meteorological stations one can choose temperature, precipitation in form of liquid, total precipitation, snow-measured and forecasted data. The data are shown for the period -48 h to + 120h from the time of forecast within tables, graphs and cross-section at the chosen hydrological station.

Hungary

Hungarian Hydrological Forecasting Service is using mostly self-developed informational and hydrological modelling systems. The following systems are used in the daily operational practices:

- ArcGIS – meteorological and hydrological data visualization;
- OLSER – hydrological modelling system (Operative Runoff Simulation and Forecasting System, OLSER);
- www.hydroinfo.hu, HYDROINFO mobile app. – hydrological information and dissemination platforms.

ArcGIS is used for visualization of observed and forecasted meteorological data in map format. HHFS using ArcView for map display, for example measured and forecasted

(ECMWF) precipitation, temperature, surface water income, snow depth and snow water equivalent.

Serbia

The basic element of the System for operational hydrological real time data processing is the program „FORECAST“. Program runs under the WINDOWS environment, it is accessible through the dialog box and it allows efficient, interactive and easy operation with hydrological and meteorological data as well as graphic support. Data used for operational processing is linked through local Ethernet network with Central Telecommunication Data which enables communication and access to GTS (Global Telecommunications System) network.

The main program includes the following options:

- Hydrological and meteorological data;
- Hydrological bulletins;
- Forecast models;
- Hydrological and weather forecast;
- Data reception;
- Data transmission;
- Graphic support;
- Additional programs.

Program allows performance of the following procedures:

- Data reception-transmission;
- Direct data input and overview;
- Data processing;
- Preparation of the data (bulletins) for distribution.

4 Best practice example of data management from the regional flood forecasting and warning systems

European Flood Awareness System (EFAS)

EFAS European Flood Awareness System is the first operational European system monitoring and forecasting floods across Europe and the first operational European warning system.

An EFAS partner is any national, regional or local authority that is legally obliged to provide flood forecasting services or has a national role in flood risk management within its country and the European Commission Services, i.e. DG ECHO-ERCC, DG ENTR-COPERNICUS and DG JRC.

All EFAS partners:

- sign a Condition of access (CoA) agreement with the EFAS DC;
- have REAL-TIME ACCESS TO THE EUROPEAN FLOOD AWARENESS SYSTEM (EFAS) products through the EFAS Information System (EFAS-IS), as well as the right to attend and get one vote at the Annual EFAS Partners Meeting;
- gain free of charge, password protected, web access to the EFAS Information System (EFAS-IS) from which the Partner can retrieve early flood information products for the river basins agreed upon.

Archived EFAS forecasts (older than 1 month) are freely available.

EFAS provides complementary, flood early warning information up to 10 days in advance to its partners: the National/Regional Hydrological Services and the European Response and Coordination Centre (ERCC).

The operational EFAS organization consists of four centres:

EFAS Hydrological data collection centre - REDIAM and SOOLOGIC is responsible for collecting historic and real-time discharge and water level data.

EFAS Meteorological data collection centre - KISTERS AG and the German Weather Service (DWD) collecting historic and real-time meteorological data across Europe.

EFAS Computational centre - European Centre for Medium-Range Weather Forecasts (ECMWF) - runs the forecasts and post-processing calculations as well as the web interface of the EFAS-Information System.

EFAS Dissemination centre - Swedish Meteorological and Hydrological Institute, Slovak Hydrometeorological Institute and Dutch Rijkswaterstaat - analyses EFAS results on a daily basis, disseminates information to the EFAS partners, organizes user meetings and provides training.

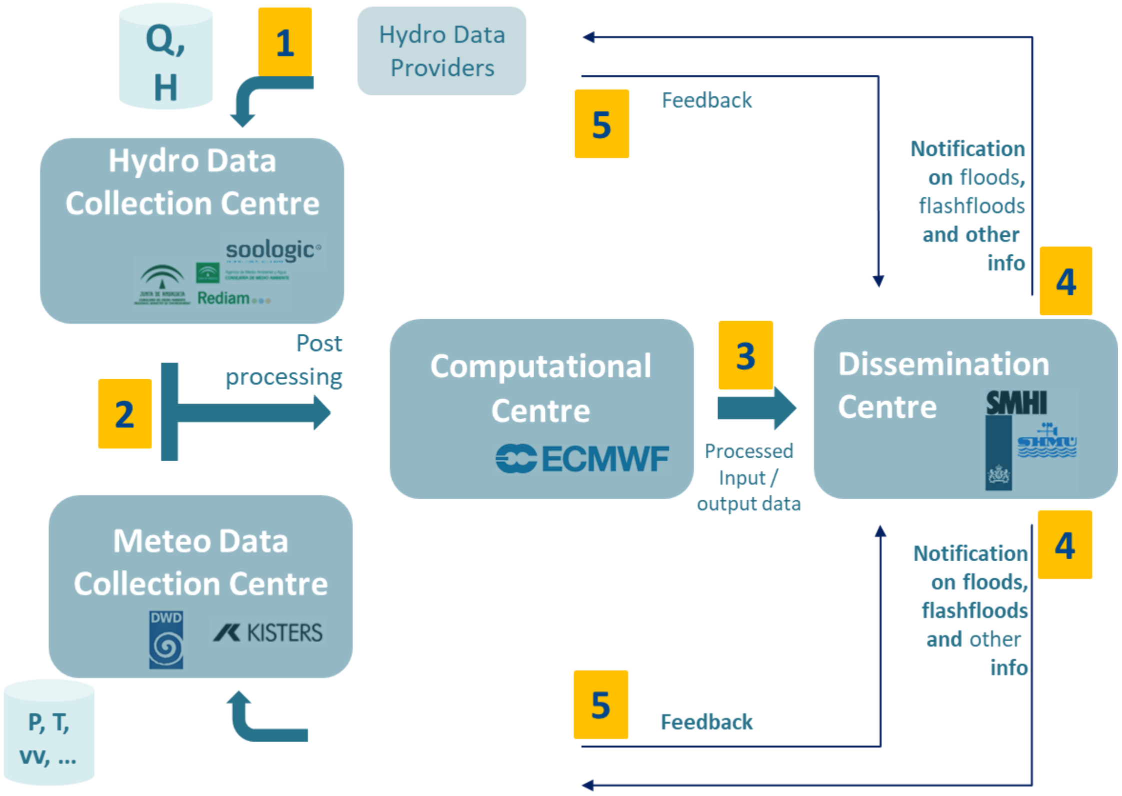

Figure 23: EFAS structure

Early flood warning to EFAS partners aims to draw attention to an upcoming event so a country can make proper preparations regarding for example: equipment, put team and responsible officers on standby, consult local information regularly (MetService, observations). EFAS provides a congregated picture on a larger scale to decision makers at EU level.

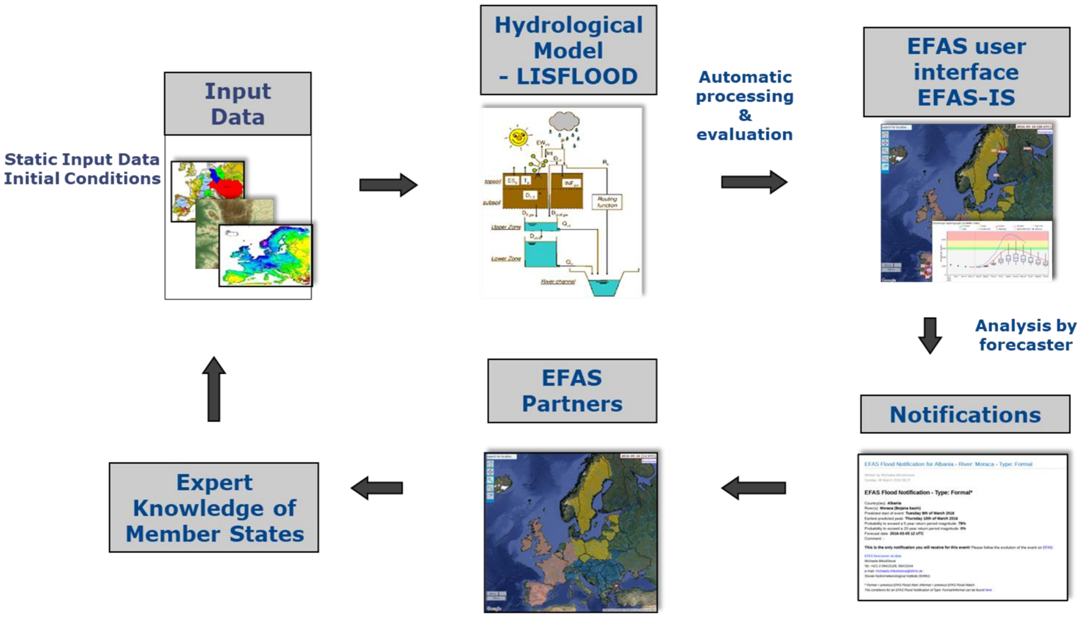

Figure 24: Process chain in EFAS

EFAS has two main data services:

- A **data access service** that provides direct access to hydrological time series simulation (medium-range forecasts and historical runs) data files. The way and type of files accessible depends on EFAS user credentials;
- **A web service**, that provides direct access to EFAS forecast products (maps and associated graphical outputs). The type of information accessible depends on EFAS user credentials.

EFAS has a dedicated data service enabling users (public or EFAS registered users) to access hydrological simulation time series produced by the system. Two types of hydrological time series datasets are available: operational medium-range forecasts and historical hydrological simulations. More information on the available datasets and accessible variables can be found in the EFAS available data pages.

Access to EFAS data depends on their release date:

- Near real-time data. This is a restricted service only available to registered authorised EFAS users, providing access to operational hydrological time series data within 30 days of their release date. Access is possible through a dedicated password-protected ftp service.

- Archived data. This is a service open to all, conditional to license conditions acceptance, providing access to operational hydrological time series data after 30 days of their release date, and to reference historical hydrological time series data. Access is possible through the Copernicus Climate Data Store and the ECMWF MARS archive server.

Climate Data Store - The Copernicus Climate Data Store (CDS) is an easy way for users to access climate-related data, including EFAS data. It offers a web interface service where users can select which data to access or view.

FTP services - Registered EFAS users with access to EFAS real-time information can access real-time EFAS hydrological forecasts through the ECMWF's production Data Store (ECPDS).

MARS archive - MARS is ECMWF's Meteorological Archival and Retrieval System. The system has the following features:

- Facilities to archive and retrieve environmental data
- 24/7 service
- Batch and interactive modes
- Large amount of data, both in size and number of items stored
- Large number of users with different requirements.
- Access to the MARS archive requires being an ECMWF registered user.

Static data files - EFAS orography, EFAS upstream area, soil moisture index. These data are part of the EFAS setup of the LISFLOOD model.

EFAS provides OGC (Open Geospatial Consortium) compliant web services of selected products. This includes a Web Map Service – Time (WMS-T) for geospatial products as well as a Sensor Observation Service (SOS) for post-processed river discharge forecasts at selected locations.

A Web Map Service (WMS) is a standard protocol for serving geo-referenced map images over the Internet that are generated by a Map Server.

A WMS server can provide support to temporal requests (WMS-T), this is done by providing a TIME parameter with a time value in the request.

WMS is a way for a client (web browser, GIS application etc.) to request map images from a server. The client sends a request to a map server, then the map server generates an image based on parameters passed to the server in the request and the server returns an image.

The WMS server generates an image from whatever source material, which could be vector data, raster data, or a combination of the two.

The EFAS - Sensor Observation Service is an web-based api that allows access to the EFAS post-processes forecasts via web based query, allowing users to download real time data from stations on the EFAS River Network.

Sava Flood Forecasting and Warning System (Sava FFWS)

The development of a joint Flood Forecasting and Warning System in the Sava River Basin (Sava FFWS) was launched in June 2016, as a component of the project Improvement of Joint Actions in Flood Management in the Sava River Basin, funded by the Western Balkans Investment Framework and implemented by the World Bank.

After two years of development period, in October 2018 the Sava countries, coordinated by the Sava Commission successfully established Sava FFWS which is now operational. The Sava FFWS has been established in line with the Article 9 of the Protocol on Flood Protection to the FASRB .

The Sava FFWS is based on the Delft-FEWS platform, which has also been applied in a number of basins across the world. The Sava FFWS is implemented as an open shell for managing the data handling and forecasting process, allowing a wide range of external data and models to be integrated.

This concept is particularly important for the five cooperating Sava countries (Bosnia and Herzegovina, Croatia, Montenegro, Serbia and Slovenia), and each country has its own models, monitoring systems, forecasting systems, water authorities and interests.

The Sava FFWS integrates various numerical weather prediction models, available weather radar and satellite imagery, outputs of the existing national forecasting systems, different meteorological, hydrological and hydraulic models which are easily ‘plugged’ into a common platform.

One of the main aim of Sava FFWS is to bridge differences and supports collaboration in the field of hydrological forecasting (current focus are floods) keeping the countries’ own autonomy in monitoring, modelling and forecasting and remain open to developing its own models and supplementary forecasting initiatives.

The regional system is assessed as added value to existing or developing systems, expecting that a common forecasting platform with well trained staff should provide better preparedness and optimized mitigation measures to significantly help reduce adverse consequences from floods, and in future from droughts, and ice hazards.

Sava FFWS integrates Sava HIS, as a data hub for the collection of real-time hydrological and meteorological data, as well as various Numerical Weather Prediction models, available weather radar and satellite products, outputs of the existing national forecasting systems, different meteorological, hydrological and hydraulic models which all are ‘plugged’ into a common platform.

The Delft-FEWS application is used as backbone for data integration and user interface. The system runs hydrological and hydraulic simulation models, like HEC-HMS, Mike11 etc.

The Delft-FEWS software comprises the several components as illustrated in Figure 25. Note that this figure just shows the components of one single duty system. These components can be separated in two groups: components on the server and components on the client.

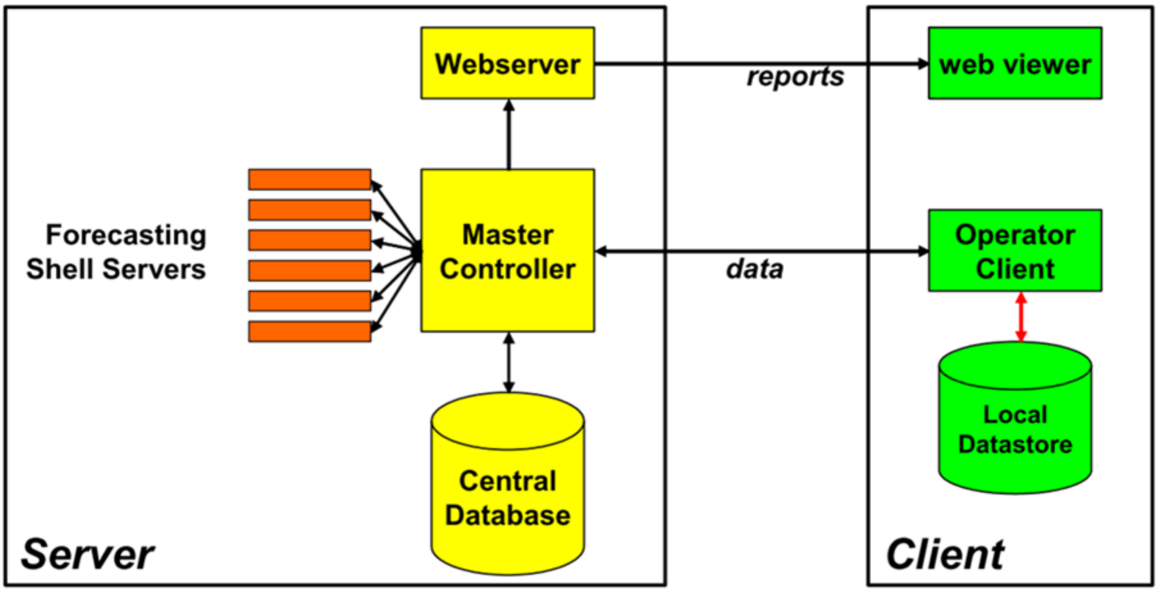

Figure 25: Functional Components in a Delft-FEWS client-server application

On the server side the main component is the Master Controller (MC). This is in fact the agent that monitors status of all components and distributes tasks to the so-called Forecasting Shell Servers (FSS).

Actual tasks, like importing data or running of models are performed on the FSS. The system uses a central database which can be of Oracle, MS SQL Server or PostgreSQL. We use PostgreSQL as it is free of charge available.

On the client (a laptop or PC where the users use the system), the so-called Operator Client (OC) is run. This is a thick-client, Java based application, that connects to the Master Controller through https over the internet. Data is read and cached in a local data repository (referred to as the LocalDataStore).

Also a web portal is available that can be easily viewed in any web browser.

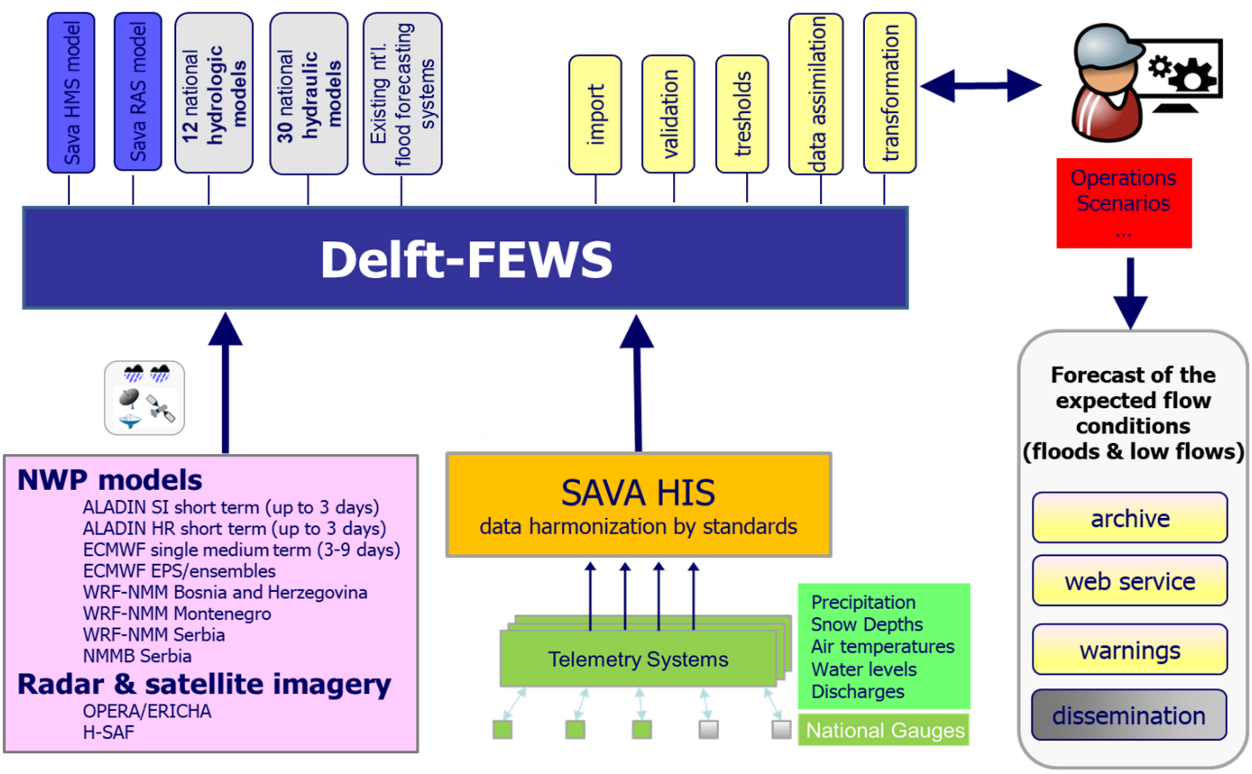

Figure 26: Schematic overview of Sava FFWS approach

Sava FFWS consists of five hosting locations, i.e. one Primary and three Backup server locations as well as Archive and Web server. Under normal conditions, the Backup systems will retrieve data from the Primary system through an automatic data synchronization process. The Primary system is the only system that is used to carry out operational tasks under normal circumstances, such as the running of forecasts or the uploading of changes to the configuration.

For purpose of developments and testing a 100% independent stand-alone application of Sava FFWS is available, which runs at any computer and has no interaction with any other application or the live system.

Currently, Sava HIS is collecting observed data from 310 hydrologic and 220 meteorological stations. Since the Water ML 2.0 format (WMO's standard) is implemented in Sava HIS, the system enables storage of countries' observations in a standard format and supports data sharing and publication via web services for further use in the Sava FFWS.

Grids are used to import data from Numeric Weather Prediction (NWP) models and import, export and process grid data from simulation models. Within the Sava FFWS, 8 NWP models are used as meteorological inputs:

- model ALADIN Croatia;
- model ALADIN Slovenia;
- model ECMWF;
- model ECMWF ensemble;
- model WRF Bosnia and Herzegovina;
- model WRF Montenegro;
- model WRF Serbia;
- model NMMB Serbia.

Along with the NWPs, the Sava FFWS is prepared to extrapolate radar or satellite imagery in order to provide a very accurate short-term hydrological forecast (nowcasting) for several hours in advance based on measured values.

Nowcasting products are currently not available within the Sava basin. The first step towards nowcast is to have a radar based composite rainfall image (precipitation field), corrected with observed ground rain gauge data. The radars in the Sava basin are currently not able to produce accurate rainfall images.

Considering the importance of providing a nowcasting hydrological forecast and raising the awareness of experts to this meteorological input, in the Sava FFWS the Lisca radar data from ARSO (Slovenia) are implemented, next to Opera radar composite images. These images are only displayed within the system, but are not connected to any of the hydrological or hydraulic models implemented in the Sava FFWS. This approach is also used for the H-SAF satellite images products.

South East Europe Flash Flood Guidance System (SEE-FFGS)

The South East Europe Flash Flood Guidance System (SEEFFGS) is developed as one of the Flash Flood Guidance Systems (FFGS) implemented around the world by the Hydrologic Research Center (HRC) in collaboration with the World Meteorological Organization (WMO), the US Agency for International Development Office of Foreign Disaster Assistance (USAID/OFDA), and the US National Oceanic and Atmospheric Administration (NOAA).

FFGS products provide up-to-date information to National Meteorological and Hydrological Services (NMHSs) for their use in rapid assessment of current flash flood risk and to enable NMHSs to issue timely and location specific flash flood alerts, watches or warning. The primary purpose of the FFGS is to provide real-time guidance products pertaining to the threat of potential flash floods in relatively small basins. The system provides the necessary products to support the development of warnings for flash floods from rainfall events through the use of remote sensing-based rainfall estimates.

The system products are made available to forecasters as a diagnostic tool to analyze weather-related events that can initiate flash floods (e.g. heavy rainfall, rainfall on saturated soils) and then to make a rapid evaluation for a flash flood occurrence at a location.

To assess the threat of a local flash flood, the FFGS is designed to allow product adjustments based on the forecaster's experience with local conditions, incorporation of other information (e.g. Numerical Weather Prediction output) and last minute local observations (e.g. non-traditional rain gauge data), or local observer report.

The regional system incorporated remotely-sensed precipitation with the local but relatively sparse surface observation network, and semi-distributed hydrologic modelling with high spatial resolution to produce guidance products pertaining to the threat of small scale flash flooding.

Evaluations of the threat of flash flooding are done over hourly to six-hourly time scales for basins from 100-300 km^2 in size. Satellite precipitation estimates are used together with available regional in-situ precipitation gauge data to obtain bias-corrected estimates of current rainfall volume over the region.

These precipitation data are also used as input to hydrologic models that update soil moisture conditions.

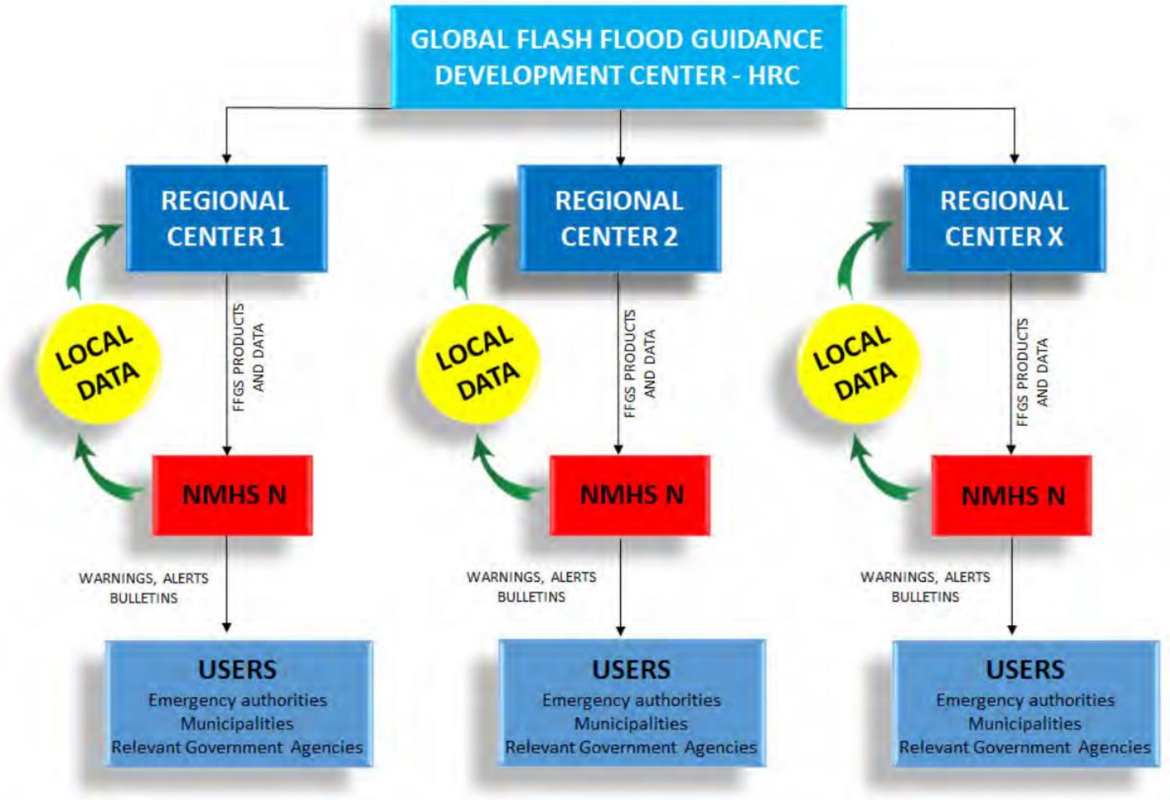

Figure 27: Global Flash Flood Guidance program concept (Source WMO)

The South East Europe Flash Flood Guidance System covers the countries of Albania, Bosnia and Herzegovina, Croatia, Moldova, Montenegro, Romania, Serbia, Slovenia and The former Yugoslav Republic of Macedonia. In January 2013, it was agreed to establish the Regional Center of the SEEFFGS at the Turkish State Meteorological Service (TSMS) in Ankara.

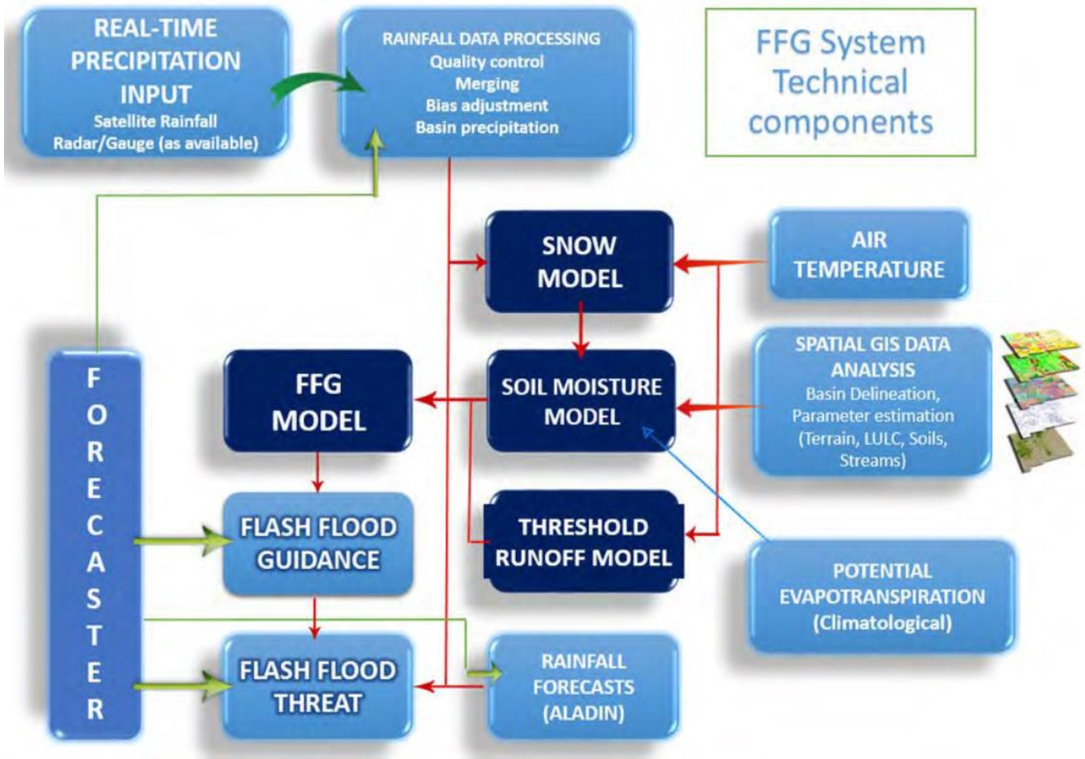

Figure 28: Flash flood guidance system technical components (Source WMO)

The processing and modeling components of the FFGS utilize the available real-time data from in-situ gauging stations and from remote sensing platforms, suitably adjusted to reduce bias, together with physically based soil water accounting models to produce flash flood guidance estimates of various durations over small flash flood prone catchments.

South-East European Multi-Hazard Early Warning Advisory System (SEE-MHEWS-A)

WMO initiated the 'South-East European Multi-Hazard Early Warning Advisory System (SEE-MHEWS-A)' project in 2016 to assist Members in the region to achieve these objectives. This project builds on the outcomes of several recent projects in the region related to disaster risk reduction that were implemented with funding from the European Union, United Nation agencies, the World Bank and a number of other international and national organizations.

The SEE-MHEWS-A project will benefit the National Meteorological and Hydrological Services of WMO Members from the region - that is Albania, Bosnia-Herzegovina, Bulgaria, Croatia, Cyprus, Greece, Hungary, Israel, Jordan, Lebanon, North Macedonia, Republic of Moldova, Montenegro, Romania, Serbia, Slovenia, Turkey and Ukraine. The Project Steering

Committee, composed of the Directors of the NMHSs of the WMO Member States listed above, will manage the advisory system developed under the project.

The development of the SEE-MHEWS-A will support the NMHSs in fulfilling their mandate to provide timely and accurate warnings in order to minimize the impacts on people, infrastructure and industry of hazardous weather events and to protect the lives and livelihoods of the people.

The main objectives of SEE-MHEWS-A are:

- Strengthened regional cooperation through leveraging of national, regional and global capacities to develop improved hydrometeorological forecasts, advisories and warnings, which will contribute to saving lives and reducing economic losses and damage;
- Strengthened national MHEWS systems by making regional and sub-regional observing, monitoring and forecasting tools and data available to the participating countries and other beneficiaries;
- To implement impact-based forecasts and risk-based warning capacities that contribute to better informed decision-making by national governments, disaster management authorities, humanitarian agencies, and NGOs;
- Harmonized forecasts and warnings among the NMHSs especially in transboundary areas of the region;
- Increased operational forecasting capabilities of NMHSs staff.

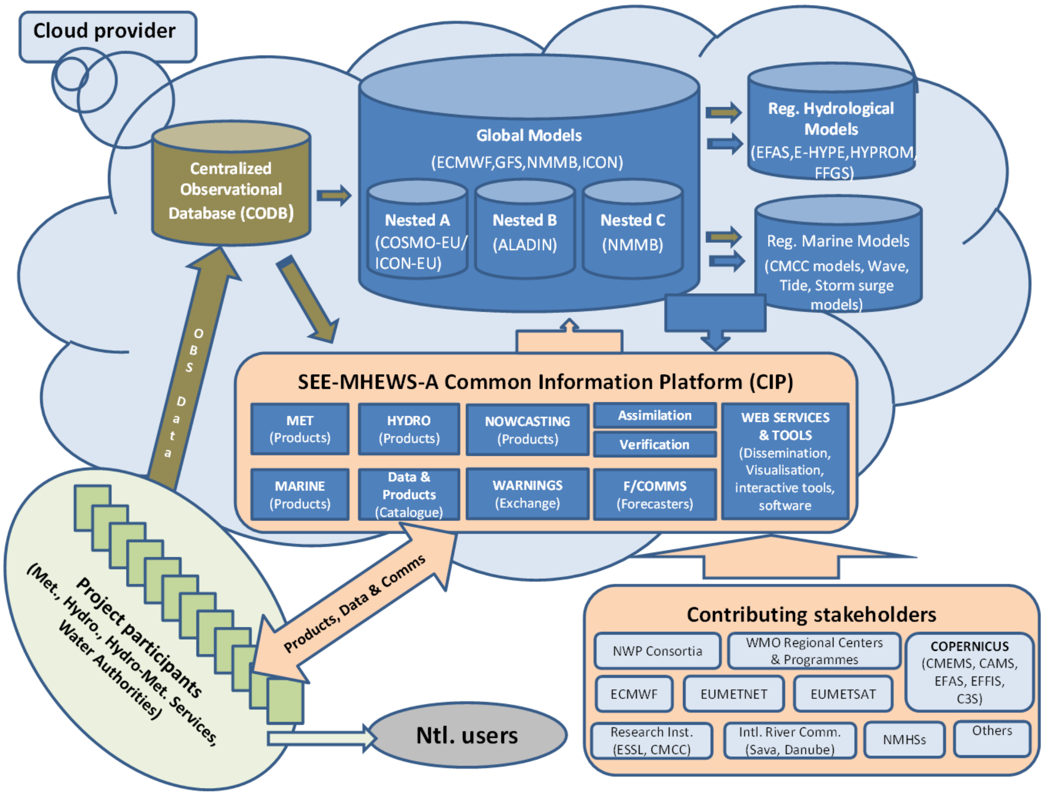

Figure 29: General architecture of the SEE-MHEWS-A System (Source WMO)

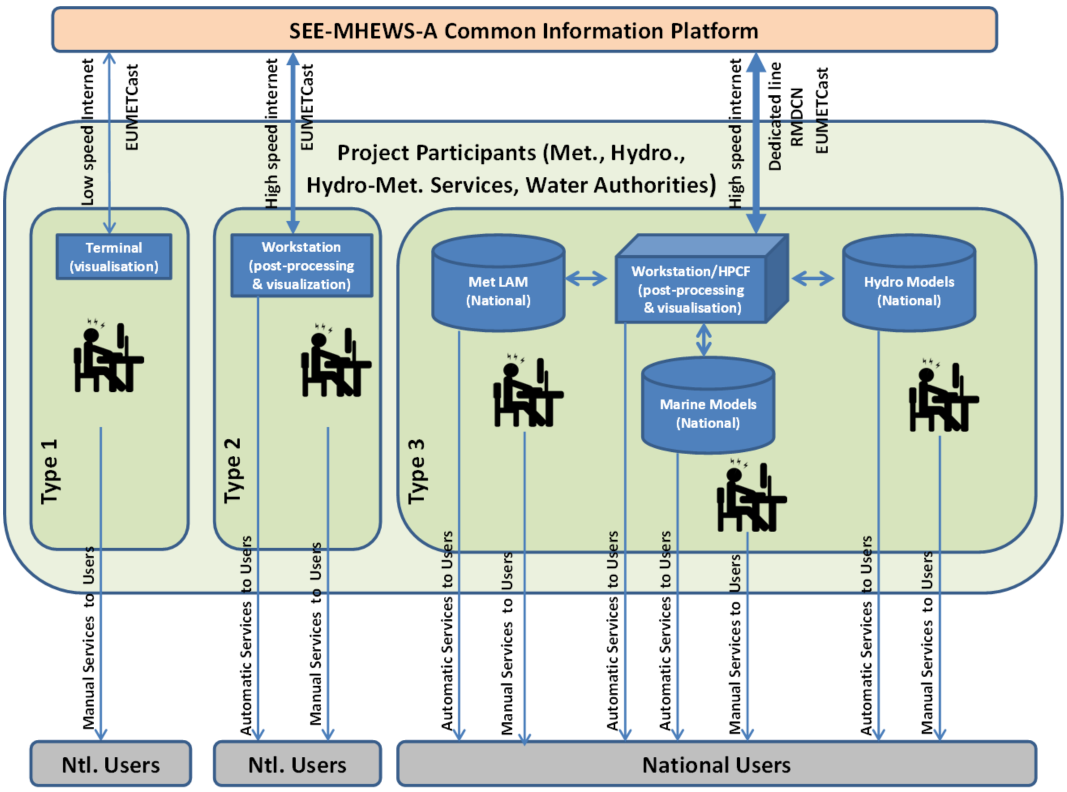

Figure 30: General concept of operation and collaboration within SEE-MHEWS-A System (Source WMO)

Currently, there is a lack of observational as well as high-resolution model data for many areas in the SEE region.

During the second phase of the project, current status of the observational networks including inventory of the data and recommendations for improvements to the existing observational networks supporting SEE-MHEWS-A was prepared.

In November 2019, the project countries agreed to extend their cooperation regarding data exchange with development and signing of the Policy on the Exchange of Hydrological and Meteorological Data, Information, Forecasts and Advisories under the South-East European Multi-Hazard Early Warning Advisory System.

This Policy provides technical and conceptual principles required to promote data, information, forecast, and warning exchange and interoperability within the SEE region.

This will allow access to a large quantity of additional observations, which are currently not shared regionally, to be utilized for various project purposes, such as numerical weather prediction data assimilation and verification, hydrological modelling and nowcasting.

The Data Policy has been signed by 15 NMHSs from the region as well as European Centre for Medium-Range Weather Forecasts (ECMWF), who is supporting the implementation of the Policy. The signatories of the Policy provide additional observations to those they routinely share via Global Telecommunication System (GTS).

These additional observations are collected in the Central Observational Database (CODB) for SEE-MHEWS-A hosted by the ECMWF.

Pilot version of the CODB was developed to facilitate data collection, assimilation, model verification, post-processing and nowcasting. By August 2020, over 13,000 additional daily observations are being provided regularly by the countries to ECMWF.

5 Data management in support of future developments of forecasting activities within Danube River Basin

An overview of the short- and long-term developments plans of the forecasting services are presented in Table 4.

One can see that future plans are relatively similar and forecasting services will work on models development (e.g., better calibration, enhanced model structure), gauging networks improvements (e.g., new stations, modern equipment, denser network), forecasting system development (e.g., use of additional data, use of ensemble forecasts, flash-flood forecasting improvements) and warning process improvement.

Moreover, some of the forecasting services also indicated that they will work on media relations (e.g., web-page development, data access, social media such as Twitter or Facebook).

Most of these development plans integrate also a component of further development on the data management side, that is needed in order to support the new functionalities of the Flood Forecasting and Warning Systems.

Table 4: Overview of future development plans of the Danube River forecasting services

Country / Organization	**Future plans**
Austria	IT system development
Bulgaria	Hydrological forecasting process development (new early warning system, model development), automatic hydrometric stations development (i.e. more stations))
Croatia	Models development, automatic hydrometric stations development (i.e. new modern stations (hydrological, meteorological, air quality, radar, oceanographic buoys,…))
Czech Republic	Models development, widening of the forecast portfolio, flash flood forecasting development, medium-term forecasts for drought events, optimization of gauging network (more stations, use of modern equipment)
Germany (Bavaria)	Use ensemble forecasts, use of supercomputer for hydrological modelling
Hungary	Hydrological forecasting system development (e.g., new 1D hydraulic model), ice forecasting development

Moldova	Monitoring enhancement and forecasting development
Romania	Flash flood forecasting and warning development, development of snow water equivalent and rainfall grid data, use of ensemble forecasting, hydrological model development, hydraulic model development
Serbia	Hydrological modelling of additional catchment, hydraulic model development, hydrological and meteorological gauging network development (e.g., number of stations)
Slovakia	Forecasting system development (e.g., hydrological models development, use of probabilistic models)
Slovenia	Models development (e.g., Drava, Mura), warning process upgrade, enhanced communication with general public via social media, web-page development
Ukraine	Forecasting system development (use of ALADIN model for prediction, models development), use of meteorological radars, hydrological and meteorological gauging stations development
EFAS	Forecasting system development (e.g., use of additional data, better calibration, model development, use of grand ensemble forecast, better seasonal forecasting, better flash-flood forecasting, increase of spatial resolution), improvement of forecast data access for the EFAS partners
ISRBC	Meteorological data improvement (e.g., spatial coverage improvement, -increase temporal resolution, establish a nowcast,…), hydrological models development (e.g., calibrate models for low and high flows by using observed hydro- meteorological data of sufficiently long record, improvement of the reservoir operation models with real-time data,..), hydraulic model development (e.g., couple the hydraulic model to a hydrological model, calibrate the model for both high and low flows, flood mapping improvement), improvement of computational time taking into consideration also model quality

As output from the stakeholders workshops consultations, among the most suggested recommendations for new hydrological information and forecast products or product enhancements, we could mention the following:

- Improved radar products for hydrological applications.
- Improved quantitative precipitations forecasting products, especially for high intensity rainfall events.
- Archives with historical data.
- Hydrological forecasts joint with flood risk maps products, and a portal at hydrological service website focusing on emergency events related to floods, droughts, forest fires, warnings.

The project is co-funded by the European Union

- Ensemble forecasts shared between countries, propose a unified definition and naming of the ensemble members in order to use the ensembles from upstream countries for forecasting in downstream countries.
- Improved hydrological diagnosis and forecasting ice on rivers phenomena products.
- Improved products for inflows into water reservoirs and better accuracy of forecasts for small river basins.
- Development of mobile applications for dissemination of monitoring and forecasting data.
- Creation of working groups on online platforms, for improving the cooperation between forecasting services and main stakeholders.