From the sensors to the models, integrated hydro-meteorological systems in NIMH – BAS, Bulgaria

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Abstract

The paper presents the actual development of the integrated hydro-meteorological systems at the National Institute of Meteorology and Hydrology (NIMH) in Bulgaria. Automatic measuring devices were used since 60ties, however until 1990 most of the recording devices used paper strips. First electronic automatic telemetric stations (ATS) were procured in 90ties within a WMO support program (MEDHYCOS). During the current century Bulgarian participation in European PHARE and INTERREG programs for regional flood forecasting permitted to implement reliable telemetry and more detailed measurements. Gradually the number of electronic measuring devices both in hydrology and meteorology increased. At the same time various data transmission options were implemented as UHF radio, CSD and GPRS. Implementation of regional models for atmospheric pollutant transport and for surface fluxes estimation, including water balance, required detailed and precise measurement and real-time transmission of data on liquid and solid precipitation, air temperature and moisture, solar radiation and wind speed and direction. Data is collected at hourly step, together with intra-hourly extremes, and stored in a relational database management system (RDBMS). Data checking is semi-automatic. As limits of probability for some variables are too large and automatic correction is not an option obviously erroneous data is stored with the corresponding (false) flag. Data is provided for scientific teams in NIMH in near-real time. Specific software interfaces are built to feed the diagnostic (initialization) part of the numerical models directly from the database. Such models are ISBA-Modcou (surface scheme and hydrological model), Mike11 (hydraulic and hydrological model), SURFEX-TOP land surface model (LSM), etc. Raw data from the sensors and that computed from the models is published at dynamic web pages.

Keywords: hydro-meteorological measurements

Introduction

The National Institute of Meteorology and Hydrology within the Academy of Sciences of Bulgaria (NIMH – BAS) is the authorized by law organization that provides meteorological and hydrological measurements, data management services and scientific expertise at national level. The economic transformation occurred in 90ties had long lasting negative impact on technological renewal. For instance hydrological measurement instruments till 1990 were most often imported from the former Soviet Union. These instruments, although with high quality, gradually deteriorated. Only after year 2к NIMH had the possibility with the help of external funding to implement automatic hydrological and meteorological stations and sensors from high quality manufacturers. Beside some tries to produce a Bulgarian water level station the first 4 hydrological automatic telemetric stations were delivered in the frame of MEDHYCOS project (Bolle, 2003) supported by WMO and funded by World Bank. Participation in European cooperation programs permitted to develop step by step strategy covering the main river basins, in South and North Bulgaria, with the required minimum of automatic telemetric stations (ATS) for water level, precipitation, air temperature & moisture and solar radiation sensors. These projects, mostly directed towards flood mitigation and forecasting, needed on-line systems of hydrological and meteorological measurements. Bulgaria's law on water includes a statement that NIMH has the obligation to maintain and further develop information systems on water resources including the monitoring and forecasting of stream flow, precipitation and evapo-transpiration. In the paper we will discuss the methods used to fulfill the requirements of those information systems mainly focusing on hydrological and rain-snow measurements, data gathering and dissemination.

Main objectives

Monitoring of surface and ground waters was the primary objective for the development of automatic measurement network for river water levels and for precipitations. Regarding water level measurements ATS provide irreplaceable data, especially for warning systems for floods. Regarding precipitations and other meteorological variables ATS data is required to feed natural disasters warning systems and for pollutant transport forecast systems. The target was not to replace manual measures but to ensure homogenous spatial data with sufficient quality, for the Land Surface Models (LSM), distributed hydrological models (DHM) and pollutant dispersion and transport models in real-time. To achieve satisfactory precipitation field the initial target was to achieve an average density of 1 sensor per 400 km^2. The underlying idea was to combine their data to the daily accumulated precipitation data coming from the former NIMH measuring network, thus enhancing the overall quality. Spatial coverage is extended following the gradual implementation of LSM and DHM over the country's largest river basins. Data flow from ATS network to the NIMH computing facilities must be uninterrupted 24 hours a day, 7 days a week. To achieve that NIMH staff had to learn how to install, maintain and repair separate ATS hardware parts and how to ensure round-the-clock software persistence.

Methods and Results

Gradual transition

At the end of 80ies, most of hydro-meteorological measurements in Bulgaria used either manual (non-recording) means as staff gauge, tin can rain-gages of type "Vild" and thermometers, or paper recording limnimeters as “Valday” for water level. Those methods, although proven by the time, relied on everyday human presence at the site and collected data, when needed the same day, had to be communicated by phone, telex or mail to the nearest data communication center. In the following years automated measures were introduced firstly as point sources of information to measure water levels and precipitation at certain river stations, and on the other hand few automatic meteorological stations (AMS) were installed to serve specific contracts of NIMH with state or private firms. Next step was to enlarge the measurement network (Tab. 1) and the number of measured variables in order to produce regional, basin level or country level digital maps at hourly step of some meteorological variables in real time. Automated measures are often differing from the manual measurements (Fig. 1) that are (regarding meteorological variables) still the official NIMH data. The reasons for that have to be assessed for each variable and often for each case (Tab. 2). Such a comparison is the first analysis of the ATS data series and helps understanding measurement discrepancies of both the manual readings and automated measures.

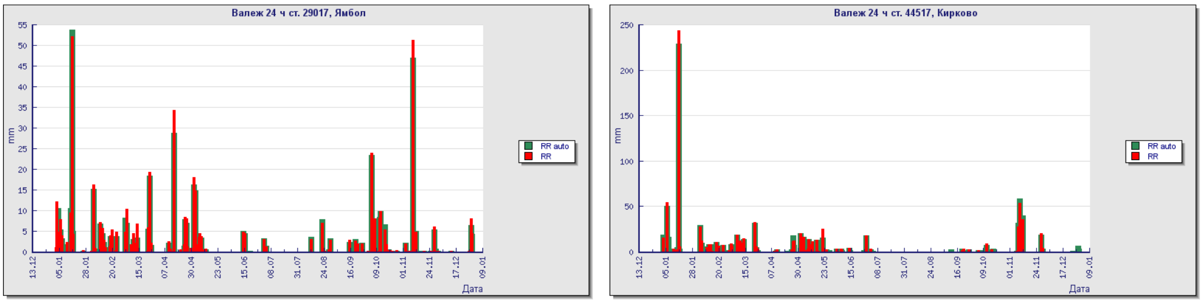

Fig. 1 Precipitation daily sums [mm] as recorder by an automatic sensor (green) compared to the manual measurements (red) for 2016 year at Yambol (left) and Kirkovo (right) stations.

Year	Water level sensors	Rain gauges	Temperature, rel. humidity	Solar radiation
2005	3	11	8	2
2008	21	60	42	8
2011	33	77	58	23
2014	73	154	91	47
2017	114	159	97	51

Tab. 1 Evolution of number of telemetry sensors in use since 2005.

Variable	**Water level**			**Precipitation**	
Characteristic	Time of measure	Measuring resolution	Missing measure, deviation	Time of measure	Wrong or missing measure
Manual reading	Around 8:00 am	2 cm	Visual obstacles, water level below staff-gauge min., water level above staff gauge max., illness or on leave	Around 7:30 am for the 24h sum	Observer fault, illness or observer on leave
Automated measurement	At the precise time e.g. 8:00 am	1 mm	Damaged, not calibrated equipment or broken communication, water level fallen below sensor minimum	Summed up at the precise time e.g. 8:00 am	Damaged, faulty equipment or broken communication link

Tab. 2 Main sources of deviations and missing measures as between manual measures and automated ones.

ATS network design

The position of hydrological ATS was determined mostly by the former hydrological network as it was set-up long time ago nearby riverside settlements. Other ATS' deployment had to ensure spatial and elevation homogeneity as a primary objective. It is known that elevated, forested areas receive more precipitations especially in winter months, so mountain area is very important for water resources assessment. Usually the lack of ATS in the mountain is explained with the settling of villages in valleys. Missing measures in the mountain affect mostly the quality of spatial air temperature and precipitation fields. Mountain area stations have also sensors to measure snow parameters that are important for the water resources estimation (Fig. 4b). Figure 2a shows that except for the belt 300-500 m a.s.l. the number of installed ATS corresponds roughly to the partitioning of the territory of Bulgaria into elevation belts given in Berov, 2012.

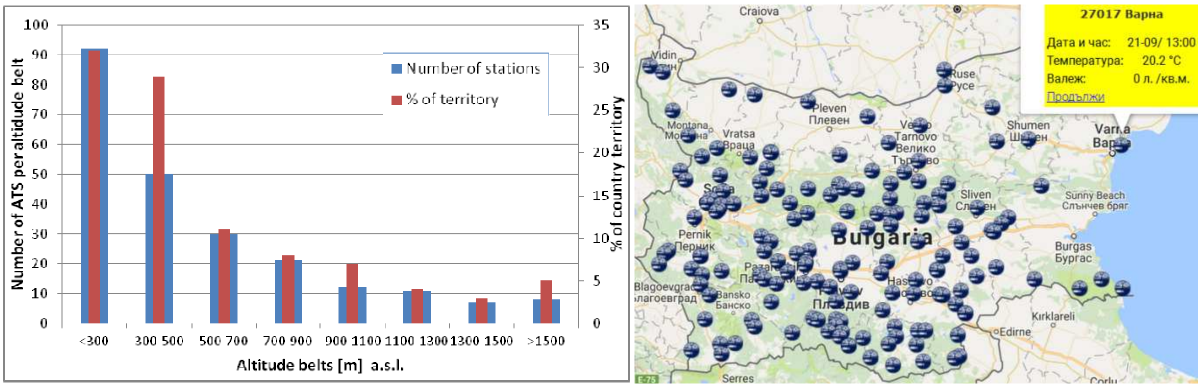

Fig. 2ab At the left (a) partition of ATS per altitude belts. The homogenous partition is important for the good estimate of precipitations and other meteorological variables over the country. On the right (b): interactive map of precipitation sensors over the country.

Procurement, installation, set-up, maintenance

Deployment of ATS network in Bulgaria is performed gradually depending on the development of international projects funded by EU or specific national projects funded by the Ministry of Environment and Waters (MOEW). Maintenance of already working ATS relies on funds received from MOEWs annual budget. Public procurements of ATS are prepared by the NIMH staff. That guarantees that the characteristics of ATS devices that finally determine their overall robustness, efficiency and longevity are specified precisely. Installation and set-up of the measurement equipment, with some exceptions, is made by the NIMH staff (Fig. 4a) with the remote support of equipment manufacturers. This helped the employees to better understand ATS construction, functioning and data collection processes. That knowledge is important for the faster and efficient reaction in case of ATS or communication systems failure. The objective is to minimize data gaps and to ensure uninterrupted operation of warning systems for floods, pollutant transport systems etc. Maintenance process is performed at regular basis every year and additionally when a failure of a sensor, a communication device or other part of the ATS is registered.

Communication and data storage

Data communication and initial data storage are made with the software of respective equipment manufacturer. In the initial stages of ATS deployment in Bulgaria Meteosat Data Collection Services

(DCS), Circuit Switched Data (GSM-CSD) and Ultra-high frequency (UHF) radio modems were used. All of them were superseded by General Packet Radio Service (GPRS) communication devices. The later proved to be more effective with lower overall communication cost. Proprietary software applications that are used to download ATS data to the data collecting center (DCC) are often an issue because their round-the–clock operation is not guaranteed. This problem had to be addressed in case there is no 24h a day on-call duty. Final storage for the data coming from ATS at hourly step is ensured from a system of programs and databases built on the top of MySQL Relational Database Management System (RDBMS). The system takes care of some basic data checking, computing of secondary time steps as 3h and daily precipitation sums, daily temperature averages, computing of streamflow discharges based on sensor measured water levels and preliminary introduced rating curves, computing of composite variables as specific air moisture, daily potential evapo-transpiration (ETo) etc.

Automatic data checking and spatial interpolation

Data verification is made semi-automatically before and visually after the spatial interpolation of meteorological variables. Min-max filters are applied to air temperature and relative moisture sensor data series to ensure that obviously wrong values will not enter the system. Where manual readings are collected for the same location the deviations can be analyzed case by case. For the precipitation only a rough maximum filter is applied for the hourly values. Some sensor errors can be seen only after mapping the variable that permits to compare adjacent stations data. Regarding hydrological variables specific min-max filter for each hydrometric station is applied on ATS collected data series of water level. In any case wrong data can't be corrected automatically but only by the authorized NIMH personnel. Spatial interpolation is performed using different methods for each variable (Artinyan et al., 2017). Mapping of variables is needed to provide gridded input to LSMs: precipitation, air temperature (Fig. 3a), relative humidity (Fig. 3b) and global solar radiation. It is important to emphasize that most of the maps are prepared using more than one data source. For instance the map of air temperature with 3h step is prepared using the point measures but also the grid of the altitude gradient from the "first guess" computed by the regional version of ALADIN short range high resolution atmospheric model. Precipitation maps with 3h step integrate manual 24h measures too, which permits to have credible information in areas where ATS are scarce (Artinyan et al., 2016). These methods partially overcome the issue of missing detailed measures over the mountain area where the maintenance cost of ATS is higher than in the valley.

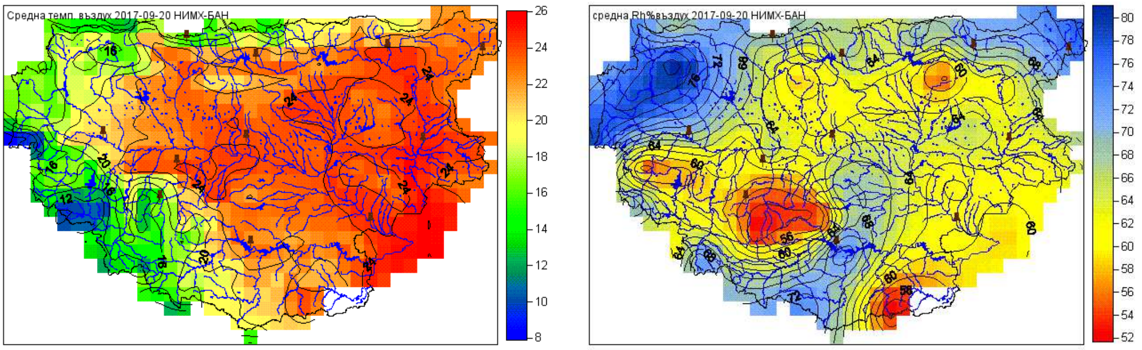

Fig. 3ab Example of spatial data: air temperature (a-left) and relative humidity (b-right) sensor values used to produce digital maps of the variables over the East Aegean River Basin domain (34000 km^2) in South Bulgaria.

Data visualization and dissemination

Data is visualized on-line and in near-real time using Apache web server software. Currently NIMH network users are allowed to interactively visualize and copy operational data from the sensors and to see data in concrete locations as graphs (Fig. 1), spatial maps (Fig. 3) or in hourly tables. Several functions are included showing problematic sensors or ATS failure. Such examples are “Low voltage warning” procedure, “Straight line sensor data check” procedure, “Failed sensors” page, “Missing data check” etc. Other web pages show data for different purposes: cases of sudden rise of water levels, extreme precipitation events etc.

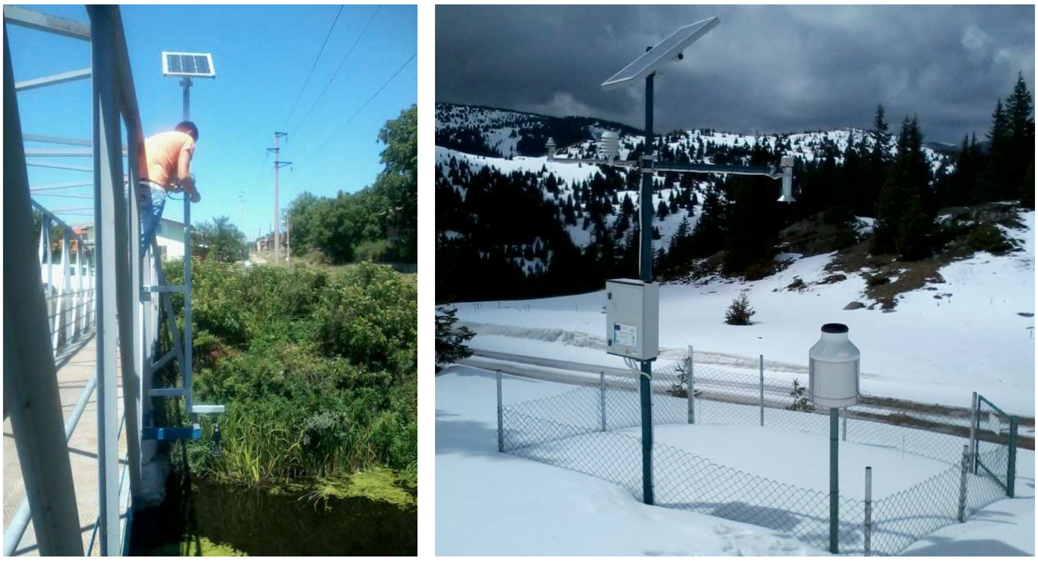

Fig. 4a (left) Installation of an ATS with radar water level sensor over the river. 4b (right) An ATS for snow parameter measurements: snow height and water content sensors are included.

From the beginning ATS were deployed to be used for specific projects e.g. warning systems for floods, pollutant transport models etc. These systems are running on the top of the corresponding physical or data driven models at regular time intervals e.g. every 12 hours. Therefore data from ATS have to be provided automatically to each of these systems. This is done via procedures directly taking data from the MySQL RDBMS. Such systems are “Flood forecasting and early warning system for Maritsa and Tundzha rivers” (Roelevink et al., 2010), “Flood warning system in Arda river basin - Ardaforecast” (Artinyan et al., 2016), “Danube Water” (Nedkov et al., 2015). Additionally users in NIMH receive newest data from ATS at regular basis via FTP protocol or by data transfer into their separate RDBMS. Such users are from “Forecasts and Information Service” department, “Hydrology” and “Meteorology” departments etc. Further this data is used to prepare maps of precipitation over the country for a given period, to assess snow accumulation and to monitor forecasts performance.

Discussion and Conclusions

NIMH accumulated steady expertise in installation, maintenance and operation of ATS network. ATS data series are used successfully for NIMH scientific projects however not solved standardization and methodological issues are slowing down their implementation. Different sources of deviations between manual readings and automatic ones exist. For instance the manual temperature reading is performed using a standard wooden shelter for thermometers while automatic sensors are protected with solar radiation shields, with or without forced air flow. Although comparison between daily average temperatures by the two methods gives good results and standard error of 0.32 °C (Fig. 5a), comparing the values at 14:00 am results in a higher deviation and standard error of 1.07 °C (Fig. 5b). Therefore transition between manual readings and automatic measures could reflect in non-homogenous data series. The transition process from manual to automatic measures is much easier in hydrology where water levels have to be measured.

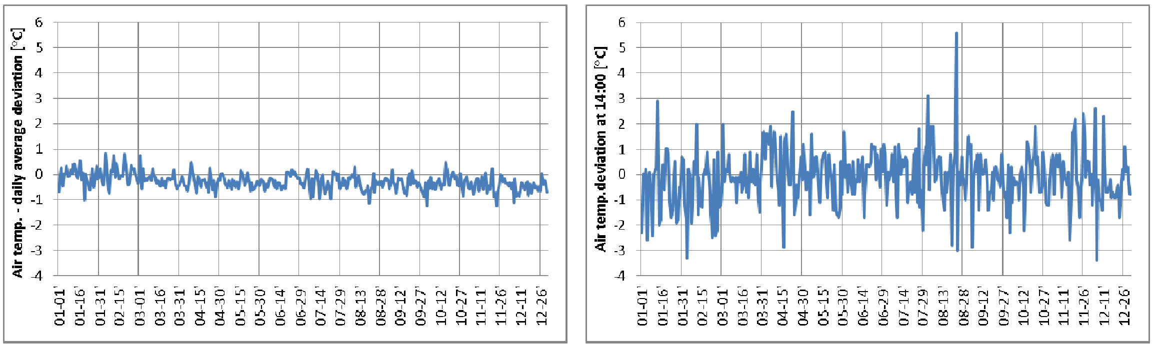

Fig. 5ab Comparison between air temperature data series deviation of manually measured against ATS data for Rozhen station for year 2016: at the left (a) daily averages and on the right (b) measured at 14:00 am.

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