# The ADRIARadNet project: ADRIAtic integrated RADar-based and web-oriented information processing system NETwork to support hydro-meteorological monitoring and civil protection decision

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## 1 Introduction

"ADRIARadNet" is the name of the project positively evaluated by the European Commission under IPA Adriatic Cross Border Cooperation Programme (http://www.adriaticipacbc.org/) and currently ongoing. It is aimed at creating an innovative decision support system to enhance the response capacity to extreme weather events affecting the safety of people in the Adriatic areas. In this respect, the main four ADRIARadNet objectives are: 1) determination of Adriatic cross-border guidelines and policies to support warning emission and risk management; 2) testing of four new low-cost weather mini-radar systems to be installed in the Adriatic area; 3) development of an early warning system, based on coupled hydro-meteorological numerical modeling and observational data assimilation (satellite, radar and gauges network), tuned at local scale; 4) implementation of a flexible ICT (Information and Communication Technology) platform which integrates data from various sources, in order to assess hydro-meteorological risks over Adriatic area.

Two pilot areas (Marche/Abruzzo regions and Croatia/Albania territories) had been identified as test-beds where experimenting the decision support system in order to be exploited after the ADRIARadNet project accomplishment by Adriatic Civil Protection agencies. The two-months demonstration ADRIARadNet field experiment (AdriaFEx) campaign will start in the fall of 2014, once all four mini-radar systems will be installed.

To meet our goal **eight European Partners** have joined by sharing their complementary background and unique expertise. The ADRIARadNet partners are:
- **Centre of Excellence CETEMPS (L'Aquila, Italy)** with project management skills and expertise on hydro-meteorological remote sensing and models;
- **Branch of CIMA (Tirana, Albania)** a well-known research centre with expertise on ICT platform for data processing, visualization, integration and transmission;
- **Marche Region, Civil Protection Department (Ancona, Italy)** with an expertise for prevision and prevention activities about hydrological risk impending on Marche territory;
- **General Directorate of Civil Emergency (Tirana, Albania)** which is the public institution part of Ministry of Interior responsible for managing of civil emergencies in Albania;
- **Institute of GeoSciences, Energy, Water and Environment (Tirana, Albania)** with an expertise on meteorological data handling and major river basin management in Albania;
- **Beep Innovation Srl (Chieti, Italy),** a spinoff research agency whose activities deals with design, realization and service in ICT field. It has also an expertise on financial and administrative aspect;
- **Dubrovnik Neretva County (Dubrovnik, Croatia),** the regional institution that has long experience on administrative aspect and with the support of Croatian hydro-meteorological Institute with expertise on meteorological fields;
- **Abruzzo Region, Civil Protection Department (L'Aquila, Italy)** with expertise for prevision and prevention activities about hydrological risk impending on Abruzzo territory.

The ADRIARadNet lead partner is the Centre of Excellence CETEMPS of the University of L'Aquila (http://cetemps.aquila.infn.it) and its Director Frank S. Marzano is the Project Coordinator. More information about ADRIARadNet project are available in the devoted web page at http://cetemps.aquila.infn.it/adriaradnet/.

This article is organized as follows: section 2 gives the project background, sections 3, 4 and 5 describe the main components of the early warning system while section 6 gives shortly information about the developed ICT platform. Finally, a summary and outlook is given in section 7.

## 2 Progress beyond the state of the art

The understanding of natural processes, which cause hydro-meteorological hazards within the Adriatic areas, has made great progress in the last decades. This concerns meteorological conditions as well as hydrological mechanisms in relation to catchments, estuaries, coastal hydraulics and slope response. A new paradigm has recently emerged, giving rise to the concept of hydro-meteorological risk analysis and management by exploiting the new frontiers of ICT. Despite of progresses in research and practice, however, significant gaps still remain at operational level in terms of exploitation of data available from different sources as well as the capability to disseminate this information flow through interoperable and easy accessible system networks.

In this respect, the ADRIARadNet project aims to cover the “last mile” between hydro-meteorological community and regional agencies which are in charge of ground defense. Its major strength comes from the close cooperation among ICT engineers, meteorologists, hydrologists, and risk managers.

## 3 Mini-radar systems installation and developed algorithms

One of the primary goal of ADRIARadNet is to install and testing four low cost, X-band mini-radar to provide quantitative precipitation estimation with relatively high spatial and temporal resolution. Two dual-polarization systems will be installed in Abruzzo and Marche regions while two single-polarization systems will be installed in Croatian and Albanian territories: see figure 5, right panel, for the planned locations and the expected coverage. In Italy there are areas which are not fully covered by the national radar network yet, such as the Marche Region, due to lack of installations and such as the Abruzzo Region, although well instrumented, due to complex orography. In Croatia only two weather radars exists, installed inland, leaving the Dalmatian coastline basically uncovered, while there are no weather radar installations so far available in Albania.

The use of radar with high frequency (i.e. X-band) has proven particularly useful for mitigating some of the limitations of traditional operational systems by exploiting the benefit of easiness to transport and deploy and the reduced cost for maintenance. The drawback is that X-band signals may be heavily attenuated in intense rainfall and hail, as it may happen within convective systems. Thus, radar algorithms able to process raw data, enhance their quality, extract from them accurate and useful hydro-meteorological products are active parts of a radar system.

In this respect, advanced algorithms for X band radar have been developed and optimized within the ADRIARadNet project for single and dual polarization systems. These Radar Advanced Processing (RAP) algorithms will be used for mini-radar data analysis during and after the two-months AdriaFEx campaign foreseen in the project. Various operative aspects have to be examined to be able to extract quantitative information from mini-radar data and to provide reliable products. In particular, data quality verification, path-attenuation correction, hydrometeor classification, nowcasting and rain-rate estimation (see figure 1, left panel) deserve attention being the core of any hydro-meteorological application.

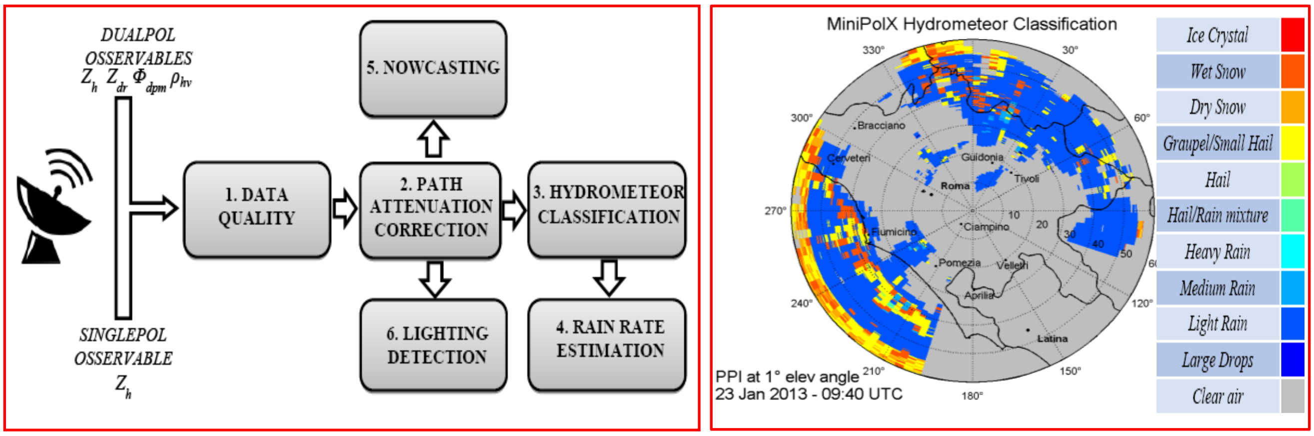


*Figure 1: Dual and single polarization processed chain scheme (left) and hydrometeor classification product for a case study (right)*

Specific results, which have been achieved during the first year of the project, are:

1) the development of a **quality check methodology** to flag radar observables as "good" or "bad". Data quality has been estimated through polarimetric self-consistency (*Straka et al. 2000*), while ground-clutter, anomalous propagation and WLAN interference has been removed by exploiting the textural spatial correlation of meteorological targets with respect to artifacts. Also a $\Phi_{dp}$ filtering and $K_{dp}$ estimation procedures *(Vulpiani et al. 2012)* has been devised for polarimetric systems.

2) the development of two techniques for the **correction of two-way path attenuation** which is, as mentioned before, a critical issue for X-band radars: the first uses polarimetric observations and is mostly based on $\Phi_{dp}$ measurements *(Bringi and Chandrasekar 2001)* while the second one technique exploits the radar returns by close mountains to estimate the path integrated attenuation (PIA) along suitable rays *(Serrar et al., 2000).* Only the latter technique can be applied to the single-polarization radars.

3) the development of a technique for **hydrometeor classification** aimed at partitioning the radar volume in terms of microphysical hydrometeor types. The algorithm provides a hydrometeor class index for each radar bin using a Bayesian decision rule starting from radar observables and temperature information (*Marzano et al. 2008*); an example of output is shown in figure 1 (right panel). As for single-polarization radar a method for hail detection has been developed using the altitude at which a reflectivity of 45 dBZ is measured with respect to the height of the freezing level (*Holleman 2001*).

4) the development of a technique for **rain rate estimation**, based on a new rainfall microphysics algorithm, developed from T-matrix simulations at X band using a method based on the Rayleigh limit with the addition of a rational polynomial dependence on median volume due to Mie scattering effects *(Kalogiros et. al 2013).*

5) the development of a **short-term nowcasting techniques**, able to identify and forecast convective cells. The basic principle of the Spectral Pyramidal Advection Radar Estimator (SPARE) is to perform spatial correlation on filtered radar images in the spectral domain and, by means of the estimated displacement vectors, to define how different rainy structures moves. The procedures take a temporal sequence of available radar maps and propagate the last available one in the future *(Montopoli et al. 2012).*

6) the development of a new technique **to detect lightning event** in terms of probability of lightning (POL) for a given geographical area of interest. Single-polarization weather radars with their three-dimensional volume scan capability have been used for several decades to detect the atmospheric conditions favorable to the lightning formation during rainstorms *(e.g., Watson et al.,1995).* Dual-polarization radar capabilities are also being studied even if their operational use has to be still demonstrated *(Carey and Rutledge 2000).*

The adaptation of the RAP algorithms, developed within the project, will be performed and tested during the AdriaFEx demonstration campaign. The assessment of the processing chain will be carried out by using available reference data such as raingauges, disdrometer and other available radars measurement taken as a benchmark.

## 4 Precipitation estimation from geostationary satellite

A procedure for extracting surface rain estimation from satellite-based observations has been developed. In particular, surface rain is estimated from infrared radiometric observations or brightness temperature (BT), collected by Meteosat Second Generation (MSG) geostationary satellite, and calibrated by using ground-based available weather radar data. The general idea behind the procedure is to combine the appealing coverage and spatial/temporal resolution of geostationary BT observations with more accurate rain rate estimates from radars which suffer of a limited spatial/temporal resolution and coverage *(Marzano et al 2004)*. For ADRIARadNet purpose, the Italian weather radar network has been chosen to be the source of surface rain intensity (SRI in mm/h), with its high accuracy and resolution. Thus, the correlation between satellite-based BT observations and radar-derived SRI is used to extend the SRI product from the weather radar network to the whole Adriatic region.

The statistical integration technique is built within a procedure that runs continuously over the Adriatic domain. This procedure, hereafter called MICRAdria (Microwave Infrared Combined Rainfall Algorithm for Adriatic regions), is based on a background process and a foreground process. During the background process, the latest nearly-simultaneous SRI product from the weather radar network and BT observations are spatially collocated. The set of SRI-BT matchups is then used to calibrate a SRI-BT relationship through a statistical integration technique. During the foreground process, the latest coefficients are applied to estimate the rain rate from the next BT observations over the entire Adriatic domain. The process is iterated every time step (either 15 or 30 minutes) and it is continuously ongoing, since new SRI and BT data are continuously ingested. An example of output is shown in figure 2 where the SRI product (in mm/h) is color-coded according to the horizontal bar. Once available, mini-radar data of the four new installations within Central Italy, Dalmatia and Albania will be ingested in the process to have better accurate SRI estimations.

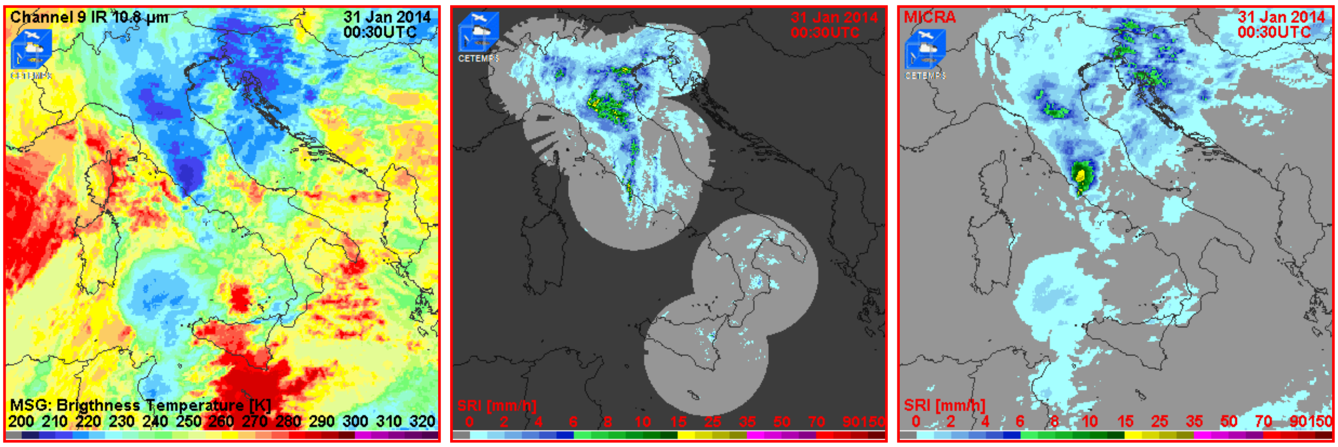


*Figure 2: MICRAdria application for January 31, 2014 case study. In the left panel BT measured by MSG channel 9, in the central panel the SRI product from the Italian radar network and in the right panel the SRI derived from MICRAdria procedure.*

## 5 Hydro-meteorological forecast tool

An integrated tool for short-to-medium-range forecasting using coupled hydrological models, meteorological model and radar, satellite, gauges data assimilation schemes has been developed. The various meteorological forcing variables (either retrieved from available instrumental observations or predicted by numerical weather models) have been integrated within a hydrological model for the prediction of the hydrological variables at the watershed scale.

The meteorological model adopted to forecast the future state of weather over Central-Southern Adriatic area is the WRF (Weather Research Forecasting). The WRF model is designed to be a flexible, state-of-the-art atmospheric simulation system that is portable and efficient on available parallel computing platforms. It is suitable for use in a broad range of applications across scales ranging from meters to thousands of kilometers; finally, it is a fully compressible and non hydrostatic model, whose vertical coordinate is a terrain-following hydrostatic pressure coordinate.

A pre-operative chain, named WRFAdria, was built for meteorological forecasting over Adriatic area, a single domain at a spatial resolution of 3 km centered over the whole central-southern Adriatic region is used. The initial and boundary conditions (BCs) are produced by using a previous simulation performed by WRF at 12 km (initialized by ECMWF analysis and BCs upgraded every 6 hours) as first guess and able to assimilate radar data via 3DVAR *(Maiello et al., 2013).* Data assimilation is the technique by which observations are combined with a Numerical Weather Prediction (NWP) product (the first guess or background forecast) and their respective error statistics to provide an improved estimate (the analysis) of the atmospheric state, through the iterative solution that minimize a cost function.

In the ADRIARadNet project web-site all the available WRF outputs can be found. In figure 3 (left panel) an example of the 12hr accumulated rainfall forecasted by the 12km domain is shown.

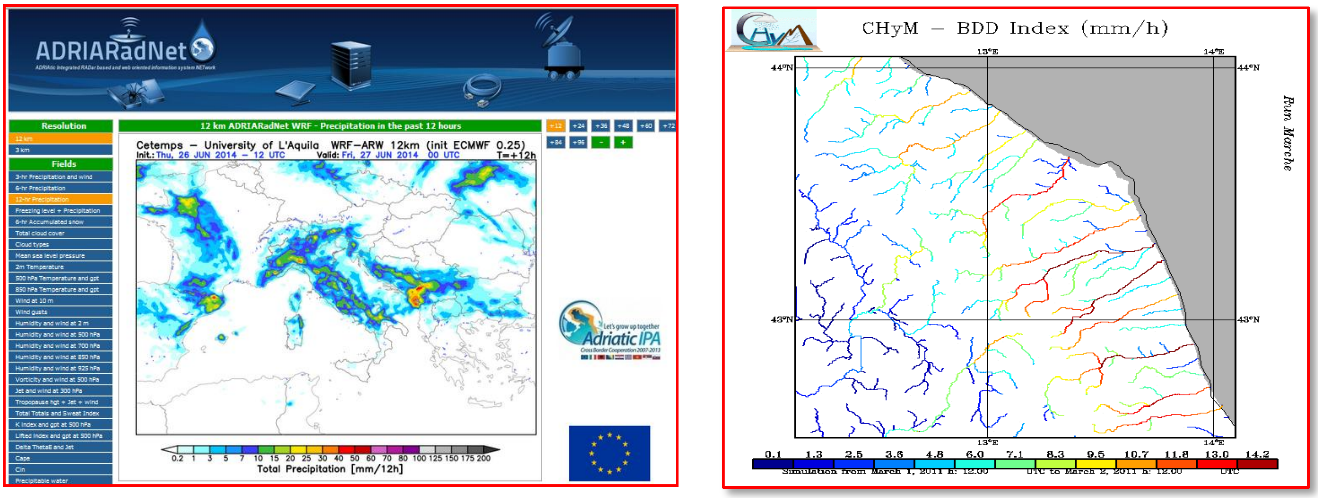


*Figure 3: In the left panel an example of WRFAdria 24-hr accumulated precipitation selected from the forecast model menu. In the right panel the CHyM stress index BDD for a case study in Marche territory.*

The CHyM hydrological model used and adapted for the project was developed since 2003 within the activities of CETEMPS with the aim to assimilate different precipitation data set in order to operationally predict possible critical stress of hydrological drainage network (*Verdecchia et al. 2008*). CHyM model is a grid distributed, physical based hydrological model. All the relevant physical quantity are defined on an equally-spaced grid. The model can be used to simulate the hydrological cycle in any geographical domain with any spatial resolution up to the resolution of implemented Digital Elevation Model (DEM), namely 300 meters in the current version of the model. As for operational purpose, the capability to simulate an arbitrary domain corresponds to the need to run the model for those river basins that are more stressed by the current meteorological event. The CHyM model is in a pre-operational configuration on the three target areas (Central Italy, covering Marche and Abruzzo Regions, Neretva basin and Drin basin) using, as rain field input, the Italian rain gauges network, the available rainfall estimation from radars, satellite and from the WRF meteorological model at 3 km horizontal resolution over Italy, Albanian and Croatia territory.

In the ADRIARadNet project web-site the results of daily CHyM simulations are provided by means of a devoted web-page where two stress indexes are displayed, CAI (CHyM Alert Index) and BDD (Best Discharge-based Drainage). The first index represent the ratio between the total rain drained by a cell and the total area drained by the same cell; namely it represent the average precipitation drained by a cell during a time interval corresponding to the runoff time. The second index is calculated as the ratio between maximum value of the discharge during the simulation and the hydraulic radius of the considered grid point. According to many other authors the hydraulic radius can be computed as a function of drained area. These two indexes, currently applied to all the operational domain of CHyM model, have been tested and calibrated in a large number of case studies. An example of CHyM output is shown in the right panel of the figure 3.

## 6 The integrated platform DewetraNet

It is worth mentioning that information and communication technology (ICT) has proved to be an essential tool to develop and finalize applications of public usefulness due to its capability to handle complex scenarios and integrate inhomogeneous components. It will enhance the staff capabilities to handle data and processes for hydro-meteorological hazards prevention and assessment. The existence of geographic information systems (GISs) on the market is not sufficient to set up a specific tool devoted to hydro-meteorological decision support, as the quality and quantity of the information content and layer features is the critical aspect of the whole infrastructure.

In this framework, CIMA Research Foundation developed, on behalf of the Italian Civil Protection Department, the integrated platform DEWETRA *(Pagliara et al. 2011)* as an operational tool that supports forecasters and decision makers in the daily operation of the Italian Early Warning System (EWS). The system is installed at the national and at each regional Functional Centre and contributes to create what is now establishing itself as the Italian System of Civil Protection.

DEWETRA is a decision system for building real-time risk scenarios and represents the modular web application of EWS. It is based on an environmental data presentation according to homogeneous and certificated procedures and fulfills the technical specifications prescribed by the terms of reference of the current call. The application allows any computer connected to the Internet to have all the data and the information available to the system, simply by using any commercial browser (e.g., Google Chrome, Mozilla Firefox, etc.) independently from operative system (OS) installed on the end-user workstation. DEWETRA is a Web 2.0 application, developed to display and use data from the GeoDatabase and interfaces with the Experience Platform to get the environmental monitoring data available on the user's browser. The use of a web application has known benefits as being accessible from anywhere and the rapidity to have updates available to anyone. In fact, updates can be directly published on the server making them immediately available to all connected clients.

Within the ADRIARadNet project, Branch of CIMA has extended the existing platform DEWETRA from centralized system to a decentralizes system of connected and federated databases. The new system (called DewetraNet) is an integrated system for the real-time monitoring of hydro-meteorological data, for the management of the hydro-meteorological risk forecasting, environmental monitoring and disaster risk mitigation. The system allows synthesis, integration and comparison of information necessary for instrumental monitoring, models forecasting and the assessment of risk scenarios and their possible evolution.

DewetraNet hardware and software architecture is fully compliant with the requirement of a flexible decision support system, which through a multi-layer Graphical User Interface (GUI) can provide decision makers with high resolution and rapid refresh information of the expected and observed risk. The access is via internet using the standard http protocol, through the web server the user has access to remote web services and  the layer is presently provided by the Google® server. DewetraNet can facilitates the access of operators to meteorological data observations from meteorological and hydrological models, radars, satellite and ground stations. During the prevention phase, DewetraNet shall provide Decision Makers with a quantitative detailed evaluation of the effects of the main atmospheric variables, along with the expected risk over the considered area and highlighting the zones denoted by the highest risk values. In the preparedness and response phases, DewetraNet can be used to forecast the dynamics of the expected events, taking into the whole risk scenario defined by the kind and the value of element at risk exposed to the effects of the considered variables. DewetraNet provides Civil Protection with an integrated approach to assess and forecast the risk over wide areas for a significative time horizon (up to 72 hours) basing on an up to date and complete information set.

The system can help decision makers for resource management and planning, suggesting the tactical deployment of the available squads and the adoption of some restrictive measures or limitations. Even more important, the broadcasting of alert messages to emergency services may strengthen the effectiveness and the promptness of the response. No specific skills are required for the proficient use of DewetraNet service/products. Two examples of DewetraNet graphics user interface outputs are shown in figure 4.

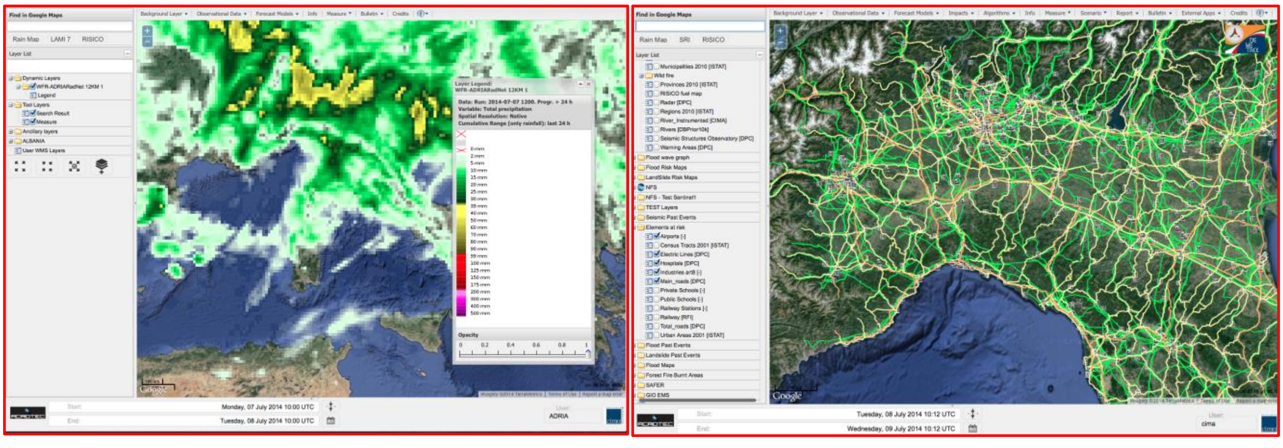

*Figure 4: Two example of DewetraNet outputs. WRF forecast for 24h cumulated precipitation (left) and element at risk (right)*

## 7 Conclusion and Outlook

We have presented the ADRIARadNet project whose purpose is to establish an innovative decision support system to enhance the response capacity to extreme weather events affecting the security of people in the Adriatic areas.

The ADRIARadNet activities cover a quite wide Adriatic geographical area, from Central Italy to Dalmatia and Albania regions. The available technological expertise and practice are not uniform within these countries, but hydro-meteorological disasters can occur without regards to national or regional boundaries. These issues will be approached thanks to the determination of common guidelines policies and best practices as well as sharing technologies as DewetraNet platform, hydro-meteorological models and advanced remote sensing instruments.

Two pilot areas (Marche/Abruzzo regions and Croatia/Albania territories) are identified as test-beds where experimenting the decision support system (see the overall scheme in figure 5, left panel) in order to be exploited after the ADRIARadNet project accomplishment by Civil Protection agencies. In these areas four new low-cost X-band mini-radar systems will be deployed and tested (see figure 5, right panel) with the aim to integrate or fill the available radar networks. The two-months AdriaFEx demonstration campaign is foreseen in the fall of 2014 once mini-radar systems will be installed and fully tested.

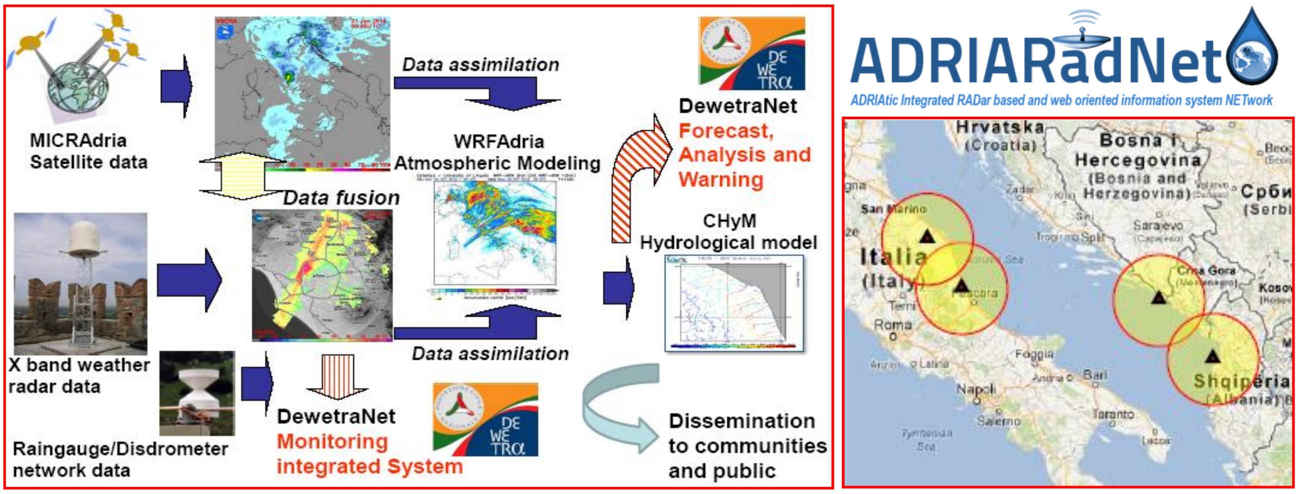


*Figure 5: Scheme of the decision support system developed within ADRIARadNet project (left) and planned locations and expected coverage of the four X-band radar installed within the project (right)*

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