Executive summary:

HYDRORAD is the name of the project, positively evaluated by European Commission under Seventh Framework Programme (FP7), which lasted two years and three months and ended on November 30, 2011.

The primary goal of HYDRORAD project is the development of an innovative integrated decision support tool for weather monitoring and hydro-meteorological applications. The integrated system tool is based on an optimized polarimetric X-band mini-radar radar (i.e. low power, small-size), network, a software-based radar product generator for data quality control, rainfall estimation, nowcasting and precipitation classification coupled with a hydrological and meteorological models able to ingest precipitation data and mini-radar products.

The core of the decision support tool is the X-band polarimetric mini-radars which are are low cost, easy to deploy and, thus ideal for the setup of radar networksto cover areas with complex terrain. In order to test the integrated system an experimental campaign took place during autumn 2011 in Moldova. A network of three mini-radars was setup and tested against a state-of-the-art mobile polarimetric radar (XPOL) placed in the centre of the mini-radar network and against in-situ rain measurements from a video disdrometer and a network of raingauges. An integrated tool for short-to-medium-range forecast, using coupled hydrological and meteorological models and the mini-radar data network, has been tested during the Moldova campaign.

Weather and hydrologic hazards are among the most critical environmental issues world-wide, where weather radar observations have proven to be very useful in providing quantitative information on the spatial distribution of rainfall and floods, required by both the meteorological and hydrological communities. The combination of high-frequency and polarization-diversity radar technology, herein coupled with X-band radar-based products to be ingested into meteorological and hydrological models, constitutes a new challenge with respect to standard hydro-meteorological procedures.

The consortium's core competency lies on the scientific background and technical expertise of its world class experts in hydrometeorology, remote sensing technology and numerical modelling. These experts reside with seven European Partner Organizations and SMEs :

- HIMET (L'Aquila, Italy) a SME (Small and Medium-Sized Enterprises) that can exhibit a unique capability to implement operational meteorological modelling and remote sensing data processing;
- RST (Athens, Greece) a SME that has a long well-known experience in hydrological numerical modelling and water resources management;
- PROPLAN (Nicosia, Cyprus) a SME that can handle coordinated field instrumentation dealing with data analysis and radar algorithm development.
- ELDES (Florence, Italy), an international SME company fabricating X-band mini-radars and digital signal processors for weather radars;
- NOA (Athens, Greece), a well-known research Centre operating a state-of-the-art mobile weather observatory consisting of telemeter gauges, a 2-Dimensional video disdrometer and high-power / high-sensitivity Dual-Polarization and Doppler X-band radar (called XPOL);
- SHMS (Chisinau, Moldova), the national hydrological institute in charge of the hydrometric and rain-gauge network and major river basin management in Moldova.

- MICC (Chisinau, Moldova), the Moldova-Italy Chamber of Commerce that has experience on logistic aspect regarding radar installation and on administrative aspect toward Moldovan Institutions

The HYDRORAD lead partner is HIMET which is a SME established as a spin-off enterprise of the Centre of Excellence CETEMPS of the University of L'Aquila, Italy.

HYDRORAD results demonstrate that the network of mini-radars, developed in this project, can cover broader areas in complex terrain where large expensive systems may not be able to achieve, whereas on the other hand the decision support tool here developed offers a low-cost solution to the problem of hydro-meteorological forecasting and monitoring for weather surveillance, especially for hazard prevention and civil protection purposes.

Project Context and Objectives:

Weather and hydrologic hazards constitute two of the most critical environmental issues world-wide. Meteorological hazards like wind storms and convective outbreaks leading to torrential rain and flooding affect all of World. In fact, flooding causes the greatest loss of life of all the natural hazards. Convective storms, often accompanied by strong surface winds and torrential precipitation, can cause severe impacts particularly in mountain-ous areas. The urgency for development of reliable and accurate flash flood forecasts is growing, for a number of reasons.

In that context weather radar observations have proven to be very useful in providing information on the spatial distribution of rainfall and floods, which is required by both the meteorological and hydrological communities. However, radar rainfall estimations are subjected to many limitations and uncertainties due to radar calibration, beam occultation and shielding, ground and sea clutter, signal propagation conditions, precipitation variability, beam broadening and vertical profile effect increasing with the distance to radar. The use of polarization diversity in weather radar allows to address some of these problems including system miscalibration, drop size distribution estimation, hydrometeor type classification and attenuation correction. The latter is strongly pronounced in X-band radars limiting their application in operational mode. The use of dual-polarization technique in X-band has provided a solution to mitigate the impact of attenuation and explore the benefit of their low costs, easiness to transport and mount, and the high spatial and temporal resolution, which can be used to fill the observational gaps of the standard networks in regions with complex orography as well as to cover urban areas and small-scale flood-prone basins and coastal areas. New developments on X-band dual-polarization technology in recent years have revived the interest of scientific and operational communities in these systems so new enterprises are focussing on the advancement of mini-radar network technology, based on high-frequency (mainly X-band) and low-power/low-cost weather radar systems for weather monitoring and hydro-meteorological forecasting.

Within the above context the general aim of the HYDRORAD project was the development of an innovative system consisting of networks of small-size/low power dual-polarization X-band radars and an original and advanced system of radar retrieval algorithms and software-based tools for hydro-meteorological monitoring and nowcasting. Introducing X-band radar-based products generated by the developed algorithms into meteorological and hydrological models constitutes a new challenge with precedents or guideline. Such a tool is not currently readily available in the weather radar industry.

The motivation and vision of HYDRORAD project is to use innovative integrated decision support tool for weather monitoring and hydro-meteorological applications to handle severe weather, water resources and climate information in commercial and industrial sectors such as transportation (e.g., road, aviation, maritime), insurance, tourism, agriculture (e.g., water resources management) and government emergency management, in order to become a leader in those markets.

The core of the HYDRORAD decision support tool is the X-band polarimetric radar; this mini-radar is a low cost, easy to deploy system and, thus, ideal for the setup of radar networks to cover areas with complex terrain. This mini-radar system is probably the only economically feasible solution to providing nationwide weather radar coverage for developing countries. In fact these systems are inexpensive compared to the standard high-power operational radars, because they are designed to require smaller size antenna dish and very low power signal source to attain the requisite resolution and signal measurement of precipitation. Overall, the cost reduction of the proposed radar system, relative to existing operational radar units, can be in the range of 7 to 15 times depending on signal frequency and other radar characteristics.

The mini-radar network system, proposed for development and prototyped in the HYDRORAD project, could prove useful for:
1) facilitating the establishment of low-cost weather radar monitoring networks that would be particularly attractive to developing countries lacking the funds to implement and operate nationwide networks on the basis of high-power radar units;
2) developing small networks to provide in situ weather surveillance of small cities and flood prone areas not well covered by existing operational national radar networks, thus filling up the geographical gaps in the radar network coverage;
3) specialized applications such as agriculture/watershed management and weather modification programs (e.g., hail depression programs) that require localized precipitation measurements at very high resolution,
4) local deployment on small size platforms (mobile or fixed tower) requiring low power consumption and easily remotely controlled to facilitate specialized field observations in remote areas.

As mentioned before, the main aim of the HYDRORAD project is the development of an innovative integrated decision support tool for weather monitoring and hydro-meteorological applications. This has been carried out through seven Work Packages (WPs), subdivided into several Tasks. The philosophy behind the WP structure was to have a relatively agile organization of the work and to provide a leading role to each partner in relation to its major expertise. The articulation of WPs closely follows the breakdown of the project objectives.

The specific project objectives are listed below:
1. the customized design, production, deployment and set up of three polarimetric X-band mini-radar system characteristics in terms of the best trade-off between costs and performances;
2. the development, implementation and validation algorithms to process polarimetric X-band radar mini-radar system measurements;
3. the development and set up of an hydrological model, driven by the X-band radar network, gauges, disdrometer and flow meter data;
4. the development and set up of an integrated tool for short-to-medium-range forecasting using meteorological model and mini-radar data assimilation schemes;
5. the test of the integrated system tool and miniradars in a real-time setting within social and economical context of a developing country such as Moldova;
6. the analysis and validation of polarimetric X-band mini-radar system data collected during Moldova campaign utilizing available reference data taken from the other sensors and models;
7. the dissemination, communication and exploitation of the foregrounds;

Final outcome of HYDRORAD project is an innovative integrated prototype for weather monitoring and hydro-meteorological applications that the SME consortium will promote to the market. The HYDRORAD consortium has a unique geographic setting in the South-East Mediterranean that can reach a number of weather/flood prone countries in the area (e.g., South Asia and East Africa). This is considered to be a large market consisting of national weather services, agriculture and water management authorities as well as private companies specializing on weather and hydrological forecasting and water management applications. Advancing our consortium capability to develop weather radar systems and software-based business support tools would contribute to advance the position of Europe in the area of environmental technologies and further enhance exportation of goods and services relative to competitors in US and Japan.

Project Results:
The main objectives of the HYDRORAD project were the development of:
i) an innovative system consisting of a network of small-size/low power dual-polarization X-band radars for weather monitoring and an advanced system of radar retrieval algorithms and software-based tools for hydro-meteorological monitoring and nowcasting;
ii) a hydro-meteorological integrated forecasting system to predict weather and river outflows using the above mini-radar rainfall products as inputs.

The main foregrounds, achieved within HYDRORAD project, include:
1) Three upgraded X-band mini-radar called HYDROSYS
2) X-band rain retrieval algorithm suite and interface called HYDROALG
3) Moldova hydrological forecast numerical model tool called HYDROWAT
4) Moldova weather forecast numerical model tool called HYDROMET
5) Data post-processing integration/validation hardware and software called HYDRONET

The development and final state of the results products are explained below.

1) HYDROSYS

We recall that the primary goal of HYDRORAD is to develop a low cost, but robust, dual-polarization X-band radar to provide quantitative precipitation estimates with relatively high spatial and temporal resolution with limited range coverage equivalent to urban areas, small scale catchment basins or extended agricultural domains.
A point to note is that the weather radars' capability to monitor precipitation at high spatial and temporal scales stimulates great interest and support within the meteorological and hydrologic community. This is happening particularly because improving local flood and flash flood forecasting requires the accurate quantitative rainfall measurement at small scales. European meteorological and hydrological services have implemented standard operational weather radar systems to monitor precipitation and support a number of applications such as real-time forecasting of weather and river floods and flash floods.
The combination of high-frequency and polarization-diversity radar technology proposed herein uniquely addresses to the problem cited above. Such system can constitute a low-cost solution to the problem of hydrologic forecasting for urban and small-scale flood-prone basins and coastal areas, due to good sensitivity and spatial resolution.
In that context HYDROSYS result will advance radar sensor technology in terms of:
(1) design specifications and sensor characteristics that would maximize the system performances at minimum fabrication cost;
(2) signal processing techniques and retrieval algorithms aimed at optimizing the efficiency of the system to accurately measure precipitation parameters (snow, rain, hail, and hydrometeors' size distribution) and through integration with models, predict land surface hydrologic variables (soil and vegetation moisture, surface and river runoff, etc.).
(3) exploitation of these sensors in meteorological and hydrologic forecasting, water resources management application

HYDROSYS regards the design of system characteristics in terms of the best trade-off between costs and performances and the production of three polarimetric X-band mini-radars. To achieve this goal the design specification and the realization of the main subsystem of the new mini-radar system (called WR-25XP) has been carried out during the project lifecycle. The interfaces of the WR-25XP were carefully analyzed with the need of HYDRORAD project, taking into account some critical parts and carrying out design, specification and fabrication of the main subsystems. Each component has been fully tested before final system assembly.

Specific results achieved during this project within HYDROSYS are:
- a study for the optimization of antenna performances that has been carried out as result that the "offset-Cassegrain" type antenna is the best choice to find the best compromise between costs and performances. Furthermore the design and fabrication of the antenna unit has been carried out.
- the design and the fabrication of radome unit ensure to have attenuation limit around the transmission frequency and ensure a small change of the antenna characteristics
- the design, the fabrication and the assembly of trans-receiver unit, which, for HYDRORAD purposes, has been directly mounted behind the antenna so as to minimise losses in the waveguide. Each component has been tested on laboratory.
- the fabrication and the assembly of the Ambient monitoring unit able to monitoring environment parameters and system functioning.
- the fabrication and the assembly of radar control and signal processor able to processing and integration of radar data and to generate polarimetric moments.
- improving and adapting software for data analysis. The Software system (called Metranet) runs on Linux workstations and servers to ensure the fastest available data processing, easy upgrade paths to accommodate future enhancements to the system.
- definition of the structure of WR-25XP polar data volume to accommodate both reflectivity and polarimetric quantities. A volume contains a number of files depending on the configuration of the scan. Each file, which is referred to as a sweep, contains data from one elevation of scan and is composed by a number of rays depending on the radar data integration scheme and azimuth angular sampling.
- definition of the system interface to implement all the X-band radar retrieval algorithm developed in HYDROALG into Metranet software. The choice is to utilize executable programs applications.
- factory tests of the prototypes with outdoor measurements (by exploiting ELDES Italian test-bed and verification of system requirements), carried out from three months. During that period data quality assessment of radar measurements has been carried out and some hardware/software problems resolved.
- production of three WR-25XP mini-radars, according to the design specification in Annex 1 of GA. This issue includes all the industrial phases that are needed to build the radars (i.e. material procurement, assembling, testing, etc.). All the activities were carried out following the ELDES Quality Manual Procedures that is normally used at ELDES for production. One of the WR-25XP is a tow-mobile radar, this unit makes possible to deploy the radar in different locations and thus optimize the radar coverage according to any possible future need, it is securely fastened to a trailer that can be easily moved by a car or a small truck.The other two radar systems are fixed tower-based radar units.

During the factory test a preliminary assessment was carried out with respect to polarimetric radar parameters self-consistency, based on the correlation between different polarimetric observables and texture signatures. Results are satisfactory as the correlation diagrams between polarimetric observables are well consistent with those expected from simulated atmospheric scatterers. Differential reflectivity was well calibrated with zenithal scans test, a bias was found and then compensated. The differential propagation phase shift (PHIDP) seems to has a standard deviation below 1°/km and its value are in agreement with reflectivity values for the different kind of precipitation caught during this preliminary test. Sometime we noted some anomalous behavior as function on the range: along some rays where PHIDP shows up like a bump (a hill). This behavior is probably due to the high values of backscattering phase shift (delta) in areas with large droplets or due to prolate particles. The copolar correlation coefficient exhibits values, which are not always in line with expectations, being values less than 0.9 in rainfall due probably to the low signal-to-noise ratio or H/V signals synchronization problem. Overall speaking, data quality check, based on the comparison between the expected simulated signatures and the measured ones for both dual-polarized amplitude and phase returns, seems confirm the capability of the system to measure polarimetric parameter within an acceptable error.

The three radar systems were fully tested during the Moldova Operational Field (MOF) campaign. MOF study was performed to assess the strengths and weaknesses of the radar systems, newly developed within HYDRORAD. For MOF purposes deployment and set-up activities were carried out and the three radars were left in continuous operational mode, basic antenna scan mode was the volume scan, with a 5-minute repetition. WR-25XP scanned in a 360° sector and for 0.5°, 1.5°, 2.5° and 3.5° elevation sweep. The two upper elevation sweeps were selected to avoid ground clutter and beam blockage in the western direction of scan horizon. The pulse repetition frequency was 500 Hz with 250 m range resolution (gate length). Antenna rotation rate was 20 (°/s) and the time period for a full volume scan was about 3minutes. The maximum range was set to 60 km for a conservative choice although maximum range is 80 km.

The rainy events during MOF were well monitored from all three deployed radars although in a few times some problems (due to some minor system bugs) was found, they were solved by MICC-SHMS operators with remotely helps by ELDES technical people. One time was necessary the on-site maintenance operation directly by ELDES technicians to solve a key system fault in Baltata site.

However the three radars system worked properly most of time during MOF campaign, even though the logistics posed some inevitable constraints and limited the full exploitation of the network.

An interesting feature is that, even though not all the 3 WR25XP mini-radars were always operating during the campaign, the network configuration ensured a continuous coverage of the Bic basin thus showing the robustness of the network concept with respect to the single system choice.

2) HYDROALG

The increasing importance of dual-polarized X-band weather radar systems is undoubted. As mentioned, the combination of high-frequency and polarization-diversity radar technology proposed herein can constitute a low-cost solution to the problem of hydrologic forecasting for urban and small-scale flood-prone basins and coastal areas, due to good sensitivity and high spatial resolution provided by locally deployed mini-radar systems.

These enhanced radar features derive by the transmission of dual-polarized energy signals and phase detection capabilities. Sophisticated radar systems are needed to fully exploit the benefits of the dual – polarized systems in a optimal way. The use of X-band weather radars have advanced to the level that can have direct implications to meteorological and hydrological forecasting. However, the use of sophisticated hardware systems, even though of essential importance, is not enough. Radar algorithms able to process row radar data, enhance their quality, can extract from them accurate products useful for example for initializing hydrological as well as meteorological models, are active parts of the radar system.

The HYDROALG objective is to develop an original X-band polarimetric integrated retrieval algorithm. It is worth mentioning that the capability to invert the X band polarimetric radar measurements into useful hydro-meteorological products is crucial for the full exploitation of the mini radar system, developed within HYDROSYS and for any other radar system. Various operative aspects have to be examined to be able to extract quantitative information from radar data and to provide reliable products. In particular data quality verification, hydrometeor classification, water content, path-attenuation correction, vertical profile correction, rain-rate estimation and nowcasting deserve attention.

The specific results that have been achieved during this project within HYDROALG are:

a) the development of a quality check methodology applied to flag radar observables as good or bad quality using the self consistency test, based on scattering model simulations of radar response. They are used to define a proper mask on the radar observable multi-dimensional space where data are considered qualitatively acceptable. The originality of the adopted approach relies on the use of a large number of checks to continuously monitor the quality of produced data.

b) development of a technique for hydrometeor classification aimed at partitioning a radar volume in terms of microphysical hydrometeor types. The algorithm provides hydrometeor class index for each radar range bin using a Bayesian decision rule starting from radar observables and temperature information. The temperature information is essential to identify the existing hydrometeor classes within an environmental scenario and then help the individuation of the most likely hydrometeor class by radar observables. The hydrometeor classification technique is trained with a radar backscattering-model simulation, based on the T matrix code where liquid, ice and mixed phase hydrometeors are simulated. Simulations take into account the composition, shape, size, canting angle and dielectric properties of hydrometeors in different phases. Thus, radar observables for each type of hydrometeor is simulated and functional relations among radar observables and different classes of precipitation regime is found.

c) development of a technique for water content estimation, based on a parametric algorithm, trained by radar backscattering simulations and constrained to the hydrometeor classification product. The applied methodology is based on two steps: the classification and water content estimation. In this way we can take into account the prevailing hydrometeor type intercepted by the radar beam, and provide optimal water content estimations. The inversion of WR-25XP radar data into water content estimates can be performed using, for each detected hydrometeor class, a specific power-law regression previously outlined.

d) development of a technique for the correction of two-way path attenuation which is a critical issues for X-band radar; the approach followed is original and is based on the use of relations between attenuation parameters Ahh, Adp, and backscattering phase shifts and radar observables Zhh, Zdr and Kdp. The approach followed is original with respect to past techniques since the below mentioned relations are found using radar backscattering simulations at X band, trained by microphysical 2D-video disdrometer (2DVD) measured size spectra, and their use allow to avoid time-consuming minimization approaches.

e) development of a technique for VPR (vertical profile reflectivity) correction, based on the melting layer identification, VPR normalization, extrapolation and corrections. The method used to correct for the BB (bright band) and mixed phase precipitation effect is called VPR correction algorithm which uses the polarimetric information (i.e., Rhv and Zhh) to identify the properties of the melting layer. In a stratiform type event the reflectivity by itself is enhanced in the melting layer region. However, the detection of BB along a ray is challenging due to its horizontal variability which is often significant and complicates the determination of melting layer boundaries. The co-polar correlation coefficient Rhv is a very useful polarimetric parameter that can be used for identifying the upper and lower boundaries of BB because it allows for a robust discrimination among the regions of rain, melting layer and snow region.

f) development of a technique for rain rate estimation, based on a new rainfall microphysics-based algorithm. The herein proposed rainfall algorithm is 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 diameter D0 due to Mie scattering effects. A point to note is that our algorithm is based on the consideration that Gamma distribution model (or a similar model such as lognormal distribution) can adequately describe many of the natural variations in the shape of raindrop size distribution. The raindrop size distribution model used here is the 'normalized Gamma distribution' function as presented in many polarimetric radar rainfall studies. The governing parameters that characterize the size distribution are related to algorithm parameters. Specifically, the algorithm is given in terms of parametric relationships.

g) development of a short-term nowcasting techniques, called SPARE, able to identify and forecast convective cells. The basic principle of 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. The principle is based on the cross correlation between portions of two consecutive radar maps to compute the displacement vector between them. The segmentation of each available radar field (also regarded as a special case of spatial decomposition) is a fundamental step which allows computing the displacement vectors for each identified portion of the radar maps. This implies that the resulting motion filed is composed by several vector components (one for each identified portion of the radar map) that in principle are different each other. Thus, vortex or multiple system movements can be in principle caught.

HYDROALG tools were applied to WR-25XP data collected during MOF campaign. Anyway, although developed for WR-25XP validation, HYDROALG algorithm set can be applied to any X-band weather radar and therefore suitable to be exploited as project foreground.

As a matter of fact, the overall assessment results of developed HYDROALG has been carried out using reference data taken from previous field campaigns (e.g., IHOP in USA, XPOL in Athens and Crete, Greece). From these tests, we have assessed that the hydrometeor classification at X band provides a score of accuracy of about 76%, when tests are performed comparing X band and S band retrievals. For the path attenuation compensation procedure, the standard error is around 2 dBZ and 0.5 dB for copolar Zhh and differential Zdr reflectivity, respectively, whereas the rain estimation algorithm have a mean relative error that does not exceed in absolute values the 2-3 (%) with high correlation values ranging from 0.6 – 0.9 and RMSE ranging from 10 to 38 (%). The nowcasting algorithm provides a Critical Success Index (CSI) of about 50% after 30 minutes forecast time. This implies a probability of detection (POD) of about 70% with associated false alarm of 30%.

All algorithms, described in HYDROALG, have been implemented with Matlab® and ANSI "C", whereas the software design was carried out with the goal to maximize speed of execution and minimize the program size.

3) HYDROWAT

The specific results that have been achieved during this project within HYDROWAT consist of the development, implementation and set up of a hydrological model able to ingest the X-band radar high-resolution rainfall products, weather forecast numerical model outputs and in situ rain-gauge measurements to predict river runoff.
The main purpose of integrating X band radar data in hydrologic modeling is to assess the improvements that can be obtained in flood risk and flood emergency management using WR-25XP network rain able of reducing the uncertainty relative to sparse network of rain gauges.

The developed Hydrological system was tested during Moldova Operational Field (MOF) campaign. The hydrological model implemented on Moldova region is based on semi-distributed parametric schemes such the HEC-HMS (Hydrologic Engineering Center - Hydrologic Modeling System) and HEC-RAS (Hydrologic Engineering Center - River Analysis System) hydraulic modelling chain. Both models was set up using historical data from Bic basin in Moldova about geology, land surface characteristic (terrain, soil, vegetation) and atmospheric forcing (radar, model and in situ data).

The Bic River is an important resource in central Moldova for which the central government is looking for a better management system. A main goal of river management is the prevention of damage from flooding. This can be carried out by means of integration of the hydrologic model of the basin with the (i) mini-radar network estimated and (ii) numerical weather prediction model forecasted rainfall data as well as meteorological data from the area aimed to predict the timing and magnitude of flooding, which consequently can be a key tool in flood management.

To assess the hydrologic error propagation for the mini radar network we performed the following hydrologic experiments:
- the hydrologic model was forced with rainfall from the rain gauge network to simulate the reference runoff;
- the hydrologic model was then forced with rainfall from the mini radar network at hourly time resolution and 1-km spatial resolution to simulate the radar-predicted runoff;
- the hydrologic model was finally forced with rainfall from MM5 atmospheric model rainfall forecasts to simulate forecasted runoff.

Comparisons of the above hydrologic model simulations provided a qualitative indication of the use of mini radars in hydrologic prediction. From MOF case study analysis we have obtained an overall underestimation of what measured by the raingauge network of the order to about 8%. This underestimation may be corrected by a bias-adjustment, as carried out for most radar systems. The error propagation in runoff simulations exhibited error enhancement (overall bias increased to about 30%). The error for each basin scattered significantly from -55% to about 45%. Overall results show that mini-radars can produce high quality and accurate rain fields for hydrological purpose in difficult to cover complex terrain areas. Networks of mini-radars can cover broader areas in complex terrain where large expensive systems cannot achieve this goal.

Although the developed hydrological system was adapted for Moldovan characteristics land, the HYDROWAT tool can be applied to any country and therefore it is suitable for exploiting project foregrounds.

5) HYDROMET

The specific results that have been achieved during this project within HYDROMET consist of the development, implementation and set up of the weather forecast model system for short-to-medium range predictions able to ingest X-band radar high-resolution products and to interface with the hydrological model, developed within HYDROWAT.

The operational weather forecast has been performed using the Mesoscale Model 5 (MM5), a Limited Area Model (LAM), developed by Pennsylvania State University and National Center for Atmospheric Research (PSU/NCAR). This numerical weather prediction is continuously improved by contributions from users of several universities and government laboratories and its current evolution for research applications is the Weather Research Forecast (WRF) model.

The developed Meteorological system was tested during Moldova Operational Field (MOF) campaign. The model was set up on three domains two-way nested (with a grid spatial resolution of 27, 9 and 3 km respectively), the highest resolution domain (3 km) are able to covering the whole Moldova state.

The main purpose of integrating X band radar data in meteorological modeling is to assess the improvements that can be obtained in flood risk and flood emergency management using WR-25XP network estimate rain. We implemented a new alternative and simpler technique respect to the 3DVAR and NUDGING: the operational MM5 version includes some microphysical parameters derived from WR-25XP radar observations. Radar-data has been ingested within the model forecast assessment and the microphysical module optimization. Preliminary tests confirm that radar observed measures seem to improve MM5 microphysics output.

A public web interface for access to 7-days operative weather forecast on Moldova region has also been developed. This section has been integrated into HYDRORAD web site using Open Source CMS (Content Management System) technology authorized and released for free use under GNU/GPL licence. Same MM5 model outputs was used as input for the hydrological model described in HYDROWAT section.

Although the developed meteorological system was adapted for Moldovan characteristics HYDROMET concept can be applied to any country and therefore suitable for exploiting of foreground.

6) HYDRONET

The specific results that have been achieved during this project within HYDRONET consist of the analysis and validation of mini radar-network products, aimed at extracting a sort of quality certification for the mini-radar network prototype.

It worth mentioning that the HYDROALG tool was applied to WR-25XP data collected during MOF campaign and the performance was checked out with available reference data such as rainguages, disdrometer and X-POL radar. The latter set has been used in several studies and field campaigns over the past five years, carried out to provide accurate estimates of rainfall and precipitation microphysics (rainfall drop size distributions, precipitation classification) as reported in a stream of definitive publications.

To reach our purpose the first step was to organize and perform a demonstration campaign in the Moldova region called MOF, Moldova Operational Field campaign:

- the area centred on the Bic river basin that is located in the center of the State of Moldova, was selected as MOF study area being an important resource in central Moldova for which the central government is looking for a better management system.
- three WR-25XP radar sand the XPOL radar sites were selected and properly arranged (infrastructures, power, internet line, license, security);
- in situ hydrological (stream gauge, Doppler flow) and meteorological stations (gauges, disdrometer) sites were selected and properly arranged;
- all data were properly collected and stored.

The three WR-25XP (two fixed and one mobile) mini radars were deployed around the basin between 20-30 km apart from each other, while the X-POL was deployed in the middle of this triangle as a reference instrument which is at the outskirts of the capital city of Chisinau. The meteorological stations were deployed homogeneously within Bic basin.

As already mentioned, once data were collected, the WR-25XP assessment was carried out with respect to:
- data quality: The differential reflectivity may show a significant difference from XPOL data at the highest elevation and ranges longer than 45 km, which probably has to do with the extension of the beam well above

the rain layer at these distances. The copolar correlation coefficient shows a significant reduction with range at low elevations and less at the highest elevation probably due to signal decorrelation by the reflection from the terrain ground. The specific differential phase shift is about 30% of XPOL measurements at the low elevation angle and very small at the higher elevation. However, the low specific differential phase shift maybe also due to noise problems in the mini-radars as there was no trend in the differences in XPOL data versus range. In general, we can state that WR25XP mini-radars can be usefully employed for quantitative estimation up to 36 km and within this range their performances are comparable with the current state-of-the-art high-power/high-resolution X-band dual-polarization radars such as XPOL.

- polarimetric radar parameters self-consistency, based on the correlation between different polarimetric observables and texture signatures. Generally speaking, results are satisfactory as the correlation diagrams between polarimetric observables are well consistent with those expected from simulated atmospheric scatteres. This feature is crucial to perform a model-based hydrometeor classification at X band. Texture polarimetric signatures are affected by the large beamwidth (greater than 3°) at medium-long ranges, as expected.
- rain-path path attenuation correction, based on the estimate of specific attenuation including Mie effects at X band. Results shows that most rain profiling techniques, such as ZPHI, Final Value and -attenuation-adjustment, can be applied to WR25XP measurements and corrected polarimetric observables are comparable with those obtained by XPOL radar.
- rainfall estimation, based on new scattering model-based parameterizations and exploiting all polarimetric observables. The newly developed algorithms can be applied to XPOL and to WR25XP radars with the latter showing a smoothing effect due to the intrinsic lower spatial resolution. The correlation of rainfall estimates by mini-radar with XPOL is statistically significant with relatively small biases and the observed scatter and differences can be justified by beam blockage effects by the terrain and the temporal and spatial separation of radar volume measurements
- nowcasting of the reflectivity field, based on a spectra-pyramidal approach and the capability to anticipate the evolution of field up to 2 hours. Results show that, till 1 hour in advance, a probability of detection (POD) of about 0.6 is obtainable whit a critical success index (CSI) of about 40%. These values are comparable to what got from fixed and high-performance systems.

As a result of analysis, we can assess that the WR-25XP polarimetric mini-radars have the expected performances in terms of capturing the vertical and horizontal distribution of moderate and convective precipitation with features that are consistent with the ones derived from the high-power and high-resolution XPOL radar, taken as a benchmark.

HYDRONET results can demonstrate ways to efficiently interface data from various sources providing integrating observations and predictions for a range of hydro-meteorological variables. Experience gained from this project will help us propose future systems for other agencies and operational organizations.

Potential Impact:

1) Potential impact

The main aim of the HYDRORAD project is to develop an innovative dual-polarization X-band mini-radar system network and software-based support tools for regional hydro-meteorological applications. The overall system has been demonstrated and tested during two months Moldova Operational Field (MOF) campaign.

The final results of the HYDRORAD project are the development of:
i) an innovative system consisting of a network of small-size/low power dual-polarization X-band radars for weather monitoring (called WR-25XP) and an advanced system of radar retrieval algorithms and software-based tools for hydro-meteorological monitoring and nowcasting;
ii) a hydro-meteorological integrated forecasting system to predict weather and river outflows using the above WR-25XP rainfall products as inputs.

The investment of the 3 SMEs in the HYDRORAD has solid and tangible revenues. The HYDRORAD consortium will own the 3 mini-radars and the hydro-meteorological forecasting software package and will foresee strategies to demonstrate the system prototype in various countries and for various local, national and international agencies.

Socio-economic impacts and wider societal implications of HYDRORAD are significant as extreme weather and floods or droughts constitute the most critical environmental hazard world-wide. Activities in the HYDRORAD project will place the consortium in a high technological potential and competitive edge within the environmental market.

At present, there is a global weather services market in the billions of dollars with an economic impact in the trillions. This market is set to continue to expand. This is particularly true for developed countries such as the United States of America (USA), Canada, Western Europe and Australia. South and East Europe lag in such weather services mainly due to lack of appropriate infrastructure and integrated meteorological observing systems (e.g., weather radar network). However, this is set to change as several of those countries have already started implementing weather radar system in an effort to provide better baseline weather and climate services to the public. Thus, there are expanding opportunities for weather and climate information companies in Europe to work with end users as the need for focused and integrated information increases.

The HYDRORAD business solution targets a niche strategy, which, based on specialized hardware and software features, would provide integrated hydro-meteorological forecasting solutions at costs that are competitively lower than current operational systems. The availability of a low-cost radar systems will hopefully open new radar deployment requests from developing countries that otherwise would not afford acquiring traditional C or S band radar system.

There are few radar manufacturing companies around the globe, but, none of them currently specialize in developing integrated systems consisting of the radar instrument and advanced software packages for deriving hydro-meteorological products. Furthermore, none of the current radar manufacturing companies seek to advance the use of mini radar systems in weather and hydrological applications.

Potential competitors to the HYDRORAD consortium would be individual research groups from the USA (e.g., Colorado State University and University of Massachusetts under CASA consortium) and from Europe (e.g., CNRS-Novimet) that can develop similar mini-radar systems. Nevertheless, there is no research group that we know to have developed a fully integrated observations-modelling system based on mini-radar networks. Furthermore, the research and development to be conducted in this project will help us advance the current state-of-the-art in mini-radar technology by incorporating polarization diversity and identifying the optimal design that maximizes performance at minimum cost. Those aspects will give a competitive edge to our consortium especially relative to US efforts in the international market arena.

2) Exploitation of results

Successful completion of the proposed project will position our consortium in a unique situation to develop such a cost effective hydro-meteorological monitoring and forecasting system that would fit the needs of a number of clients worldwide. Those clients can be:
- National Weather Services in seek of economic solutions to establish national hydro-meteorological monitoring and forecasting facilities; in this respect, contacts have been already established with the Moldova Weather Service, Ethiopian Weather Service, Cyprus Weather Service, Italy and Greek regional weather service.
- Research Institutes and Universities in need of small radar systems to support weather, hydrological and climate research programs; in this respect, contacts have been already established with Italian, Cypriot and Greek research centres.
- Water Authorities and Management Agencies worldwide in need of localized monitoring systems; in this respect, contacts have been already established with the Italian CESI R&D centre, related to ENEL group that manages many water basins in Italy and with the Italian LUCAS company in Sicily that deals with electrical trading. In addition, contacts have been established with Ethiopia, Brasil and Tanzania for the development of an economical weather monitoring system based on the mini-radar technology
- TV Broadcasting companies aiming at providing advanced weather and hydrologic prediction news to their audience; in this respect, examples are the Italian private company Mediaset, the international group SKY, several local TVs especially in central-north Italy, and the Antenna TV channel in Greece.
- Local authorities in charge of urban area management for civil protection purposed and Geographic Information System (GIS)-based weather information collection; in this respect, contacts have been already established with the Civil Protection Departmens of Abruzzo Region, Lazio Region and Molise Region in Italy, the Araxova region in Central Greece and Evros international basin in the North East of Greece.
- Logistics companies involved within tourist and public event managements (sport, music, conferences, events); in this respect, contacts have been already established with some Italian companies such as Formula car-racing and motorbike-racing teams.
- Insurance companies interested in services aimed to monitor and estimate the hazardous weather risk in specified regions; examples are the international Generali Insurance company in Italy where contacts are in place.
- Various industrial sectors (e.g., transportation, power plants, civil construction, agriculture); in this respect contacts have been established with the Hellenic Ministry of Transportation for the

development of a GIS based forecasting system for the road conditions in Greece.

Furthermore, our results will be presented at international conferences and will be published in peer reviewed journals. In fact, with the conclusion of the project and the scientific synthesis of our project results, additional opportunities for scientific publications will emerge for the project partners. Preparing submissions for conferences and/or scientific magazines therefore establishes an important part of the dissemination strategy after the end of the project that will facilitate networking with other researchers and professionals in the area aiming collaborations in the RTD sector.

Among others, the main hydro-meteorological topic conferences are: American Geophysical Union (AGU), American Meteorological Society (AMS), European Geophysical Union (EGU), EUMETSAT, International Association of Hydrological Sciences (IAHS), International Association of Hydraulic Engineering and Research (IAHR), International Association of Meteorology and Atmospheric Sciences (IAMAS), International Society for Optical Engineering (SPIE), International Union of Geodesy, Geophysics (IUGG), Royal Meteorological Society (RMS), European Conference on Radar in Meteorology and Hydrology (ERAD), Conference on Mediterranean Storm - Disaster and Climate Change (PLINIUS) and International Conference on Meteorology, Climatology and Atmospheric Physics (COMECAP).

The Consortium will try to link HYDRORAD to other international projects at the highest possible level to ensure an adequate distribution of the project's results and an incoming flow of data and feedbacks. Also we plan to write articles for the most widespread journals and bulletins on the HYDRORAD system and associated applications.

3) Dissemination activities

The consortium is ensuring the highest diffusion of the technical/research results, both within and outside the consortium. The partners are committed to actively promote dissemination, at both Academic and Institutional levels, as well as towards standardization bodies, through contacts and links they have already established and new projects aimed at further developing the HYDRORAD project foregrounds during and after the project lifetime.

Dissemination activities have been already performed in several directions. The major tools and channels used for dissemination during the project's lifetime include the participation in international conferences, meetings and workshops, various publications and drafts, announcements about project news in web site, media and in press releases, liaison with other European projects and programs, project web site and the creation of the project brochures.

In more detail the main dissemination actions, already performed, are provided in the following items:
- The official conference presentation of the Project has been held in L'Aquila, Italy on October 14, 2009 It was attended by Moldovan Ambassador in Italy and several National and Regional authorities.
- Participation at 2010 Conference on Water Resources in Ethiopia co-organized by Addis Ababa University and the University of Connecticut that has been held in Addis Ababa, Ethiopia from 12 to 16 January 2010 (see http://www.engr.uconn.edu/waterworkshop/ online).

- Participation at Meeting at the Hellenic Meteorological Service has been held in Athens, Greece on February,10 2010 where Dr. Emmanouil Anagnostou discussed the use of WR-25XP mini-radars for filling up critical gaps in the Hellenic Meteorological Service network
- Participation at 4th GPM International Ground Validation Workshop (see http://gpm.fmi.fi/ online)
Co-organized by NASA and Finish Meteorological Institute that has been held in Helsinki, Finland from 21 to 23 June 2010 where Dr. Anagnostou presented a new hydrological experiment in the Mediterranean where the HYDRORAD mini radar systems will play a critical role

- Presentation at 6th European conference on radar in meteorology and hydrology ERAD 2010 (see http://www.erad2010.org online) that has been held in Sibiu, Romania on 6 to 13 September 2010.
Co-organized by Romanian National Meteorological Services
- Participation at 2011 Ethiopian Institute of Water Resources workshop in Addis Ababa, Ethiopia, 15 January 2011 where Dr Emmanouil Anagnostou presented the WR-25XP mini-radar concept at the kickoff meeting of the Ethiopian Institute of Water Resources in Addis Ababa, Ethiopia, 15 January 2011
- Participation at Meeting with the Region Abruzzo - Directorate of Civil Protection and Environment has been held in L'Aquila, Italy on February 22, 2011.
- Participation at Meeting with the Italian Department of Civil Protection (DPC) has been held in Rome, Italy on June 21, 2011 where Dr. Frank Marzano discussed the use of WR-25XP mini-radars within the field campaign in Central Italy, named IDRAX and to be held in the fall of 2012.
- Participation at 13th PLINIUS Conference on Mediterranean Storm - Disaster and Climate Change: know to adapt (see http://www.plinius.org online) that has been held in Savona, Italy on 7 to 9 September 2011.
- Meeting with the University of L'Aquila on September 22, 2011 where Dr. Frank Marzano discussed the installation and experimentation of mini-radars at the L'Aquila site for system demonstration..
- Meeting with the Region Abruzzo Civil Protection manager on November 24, 2011. where Dr. Frank Marzano discussed the installation and experimentation of mini-radars in L'Aquila for hydro-meteorological testing and civil protection purposes.
- Tele-meeting with the HyMeX Special Operation Period (SOP) group on November 30, 2011 where Dr. Frank Marzano discussed with the Special Operation Period (SOP) group of the international HYdrological cycle in the Mediterranean EXperiment (HyMeX) the possible installation and experimentation of the WR25XP mobile mini-radar in Central Italy (Rome) for supporting the field campaign.
- Meeting with the local authorities at Chisinau on November 29, 2011 where Dr. Roberto Pace (MICC) discussed the project results of test bed on Bic basin in Moldovan territory with the local authorities.
- Published Proceedings at the 6th European conference on radar in meteorology and hydrology ERAD 2010, Sibiu (Romania), pages 407-413. Marzano et al., "HYDRORAD project: integrating X-band mini-radar networks and hydro-meteorological forecast models in Moldova territory"
- Published Proceedings at the 13th PLINIUS Conference on Mediterranean Storm - Disaster and Climate Change: know to adapt (see http://www.plinius.org online), Savona, Italy on 7 to 9 September 2011. Marzano et al., "Coupling X-band dual-polarized mini-radar and hydro-meteorological forecast models: the HYDRORAD project",
- Published Proceedings at 11th International Conference on Meteorology, Climatology and Atmospheric Physics COMECAP 2012 (see

http://comecap2012.geol.uoa.gr/ online) to be held in Athens, Greece on 30 May to 01 June 2012. Kalogiros et al., "Mobile radar network measurements for flood applications during the field campaign of HYDRORAD project"

- During the final meeting was held in L'Aquila (IT) on November 17, 2011 RAI television troupe has been has realized a report on the HYDRORAD final meeting with images and interview with project coordination Frank Marzano.

The service was broadcasted by RAI TV (Italian National State TV) on November 24 during the evening news. At http://www.himet.it/HYDRORAD/media/tg3_HYDRORAD.wmv, you can see the full service.

- HYDRORAD project news and announcements, shown by several web-news agencies and other internet sites.
- HYDRORAD project topics was published by the Moldovan magazine "Il Ponte" on November 2009 and April 2010. This magazine is press in Moldova by Moldova-Italy Chamber of Commerce.
- The conclusion of the project and HYDRORAD topics has been published by Italian newspaper "Il Centro" on December, 23 2011. Il Centro served the Abruzzo regional area since 1986, local issues are extensive covered as well as sports. Il Centro is the newspaper most widespread in Abruzzo Region. having about 250.000 copies sold daily (see http://www.ilcentro.it online).
- We submitted on October, 20 2011 a joint project, called DAFFNE, within the FP7 Collaborative project under the call FP7-ENV-2012-two-stage.
- We submitted on November, 2 2011 the project ADRIARadNet under priority 3 of IPA Adriatic Cross-border Cooperation Programme 2nd call (see http://www.adriaticipacbc.org/).
- HYDRORAD Consortium has submitted a proposal, coordinated by the University of Sao Paolo, Brazil (Prof. Carlos Morales), to install in December 2012 two of the prototype mini radars in Sao Paolo, Brazil as part of a pilot project activity for real-time flood monitoring over the Sao Paolo urban area.
- The Internet represents at present one of the main communication media, allowing the dissemination of any kind of information to a wide audience, in a fast and accessible manner. According to this, the website has been intended as an immediate and easy-to-access entry point opened to any potentially interested external party, able to create awareness and interest on the project by making publicly available in a concise but exhaustive way the most important information.

The project has established a web site http://www.himet.it/HYDRORAD/ which was launched on September 2009 and supported by the project partners and maintained by the coordinator, to provide a unified view of the project and to present HYDRORAD to the international community. The project http://www-pages serve as a means for continuous dissemination of information about the project for the public awareness as well as internally for the project participants. It is structured in two major areas: a public section and a private section. The public section offers general information on the project, including all public documents produced in the framework of the project while the reserved area contains material accessible by project partners only, mainly working documents and any other material considered useful to the project partners.

- The project brochure was intended to be a dissemination tool with the purpose of providing general basic information on the project, to be addressed to potentially interested parties not being yet aware of the existence of the project. The brochures has been distributed both in electronic and paper format.

In more detail dissemination actions, already foreseen, are provided in the following items:

- Two comprehensive overview of the project's results will be submitted at the 7-th European conference on radar in meteorology and hydrology ERAD 2012 (see http://www.meteo.fr/cic/meetings/2012/ERAD/ online) that will be held in Toulouse, France on 25 to 29 June 2012. ERAD represents one of the most important radar conferences in the world.

- One WR-25XP radar prototype carried out from the project will be installed on the roof of the Physics Department of University of L'Aquila (Italy) as a demonstrator. All developed products will be available on HYDRORAD internet site allowing the dissemination of hydro-meteorological information to a wide audience. Local and National authorities will be invited to visit the radar site and WEB pages

- A second WR-25XP radar prototype carried out from the project would be installed side-to-side with the high-power/high-resolution X-band dual-polarization radar (XPOL) at the National Observatory of Athens hydro-meteorological observatory. Synergistic XPOL and WR-25XP radar observations based on several storm cases along with in situ raindrop size distribution measurements from a two-dimensional video disdrometer will be used to accurately determine the WR-25XP radar parameter calibration and evaluate some of the critical rainfall estimation algorithm components (e.g. attenuation correction, rain retrieval, DSD parameter retrieval, Vertical Reflectivity Profile correction).

- The HYDRORAD Project final press conference will be held in L'Aquila, Italy within April, 2012. Invitations to National and Regional authorities and government agencies will be sent. A final conference leaflet will be provided as well. The basic idea is to play the conference at Physics Department of University of L'Aquila so we can organize also a visit to the radar installation as well.

- The HYDRORAD web site will remain online, so it will continue to be one of the main dissemination tools for the project's results also in the future. WEB page will be maintained and updated by the partners based on new information useful to fulfill the objectives of intra-consortium dissemination as well as external dissemination.

- The partnership with academic institutions has provided the opportunity to disseminate research activities at the classroom level, through courses they are involved in. Specifically, in the following courses, currently running at University Departments, selected topics of HYDRORAD will be used during the classes of Remote Sensing at University of L'Aquila, Antennas on University La Sapienza of Rome and Engineering Dep. of Aquila and hydrometeorology at the Civil and Environmental Engineering of the University of Connecticut.

- A pilot project, that use WR-25XP radars, is under discussion with the Cyprus National Meteorological Agency. The agency is likely looking for two X-band dual-polarization radar systems to cover the complex terrain and surrounding waters of the island providing rainfall observations for flood warning and management of water resources.

- Dr. Frank Marzano will continue promoting the use of WR-25XP in the field campaign in Central Italy, within HyMeX program. HyMeX (HYdrological cycle in the Mediterranean EXperiment) aims at a better understanding and quantification of the hydrological cycle and related processes in the Mediterranean (see http://www.hymex.org/). Measurement over Central Italy is envisaged for September-December 2012

- HYDRORAD results and conclusion will be published by magazine "Il Ponte" and by newsletter on Moldovan territory by Moldova-Italy Chamber of Commerce (MICC) partner. Also the Moldovan Academy of Sciences (see http://www.akademos.asm.md online) will publish soon the results into its scientific press releases.

- Some papers, explicitly acknowledging the support of HYDRORAD project, have been submitted for publications and are still under review process, other paper are being submitted:
1) Kalogiros J, Anagnostou M, Anagnostou E, Montopoli M, Picciotti E, Marzano FS (2011) "Optimum estimation of rain microphysical parameters using X-band polarimetric radar measurements" Submitted to the IEEE Trans. Geosci. Remote Sens.
2) Kalogiros J, Anagnostou M, Anagnostou E, Montopoli M, Picciotti E, Marzano FS (2012) , "Evaluation of an iterative polarimetric algorithm at X-band for path attenuation correction in rain against disdrometer data". Submitted to the IEEE Trans. Geosci. Remote Sens. Letters
3) Kalogiros J, Anagnostou M, Anagnostou E, Montopoli M, Picciotti E, Marzano FS (2012) , "Rainfall correction due to vertical profile of reflectivity for X-band polarimetric radars."
To be submitted to the J. Appl. Meteorol. Clim.

- Dr. John Kalogiros (NOA) will present the HYDRORAD results at the 11th International Conference on Meteorology, Climatology and Atmospheric Physics COMECAP 2012 (see http://comecap2012.geol.uoa.gr/ online) to be held in Athens, Greece on 30 May to 01 June 2012. The presentation is entitled "Mobile radar network measurements for flood applications during the field campaign of HYDRORAD project"

List of Websites:
http://www.himet.it/hydrorad