MicroRadarNet: an innovative wireless micro radar network for high resolution weather monitoring

MICRORADARNET:
AN INNOVATIVE WIRELESS MICRO RADAR NETWORK FOR HIGH RESOLUTION WEATHER MONITORING

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ABSTRACT:

This paper focuses on an innovative, wireless, low-cost, low-power consumption micro radar network for continuous, unattended meteorological monitoring. The key aspects of its radar elements are a short range strategy (about thirty kilometers) and the implementation of an effective sensor network approach. Raw spatial and temporal data are processed on-board in real-time, yielding a consistent evaluation of the information from the sensor and compressing the data to be transmitted. Network servers receive and merge data sets coming from each unit yielding a synthetic, high resolution plot of meteorological events (updated every minute).
This networked approach implies in turn a sensible reduction of the overall operational costs, including management and maintenance aspects, if compared to the traditional long range C-band approach.

1. INTRODUCTION

In the framework of the European INTERREG IIIB Alpine Space Programme, the FORALPS project ("Meteo-hydrological Forecast and Observations for improved water Resource management in the ALPS") promoted in 2004 the design and development of an innovative weather micro radar network. The Remote Sensing Group at the Politecnico di Torino has being developing this new network from its early ideation stages. The initial design scenario was specifically tailored to enable along-valley and vertical radar coverage for region exhibiting a complex orography (e.g. narrow valleys in the Alps). This suggested the adoption of a non-conventional vertical plane sounding to collect just 2 low elevation opposite rays and a vertical ray yielding the vertical reflectivity profile. To cover a broader range of operational needs, this initial design concept was then extended to collect the entire vertical plane and finally to include the more traditional horizontal scanning plane as well. Since from the early stages, the emerging sensor network concept suggested to design the apparatus as tightly related to a network of similar small unattended units. The result of the above approaches and suggestions is *MicroRadarNet®* (MRN): a low-cost low-consumption unmanned X-band micro radar network. MRN is already an operational entity, since a small number of MRN micro radars have been distributed on the territory. Operational units have been installed on the Politecnico di Torino roof (October 2006), on the roof of the Aosta Valley Civil Protection (March 2007), in an open field in Klagenfurt Airport (September 2007). An ever-growing database of meteorological case studies is being collecting providing a real-data test bench to refine assessment and data enhancements algorithms.

2. KEY ASPECTS AND MOTIVATION

C-band radar constellations are typically used for long range meteorological target detection. On the contrary, an X-band radar network works at short ranges. This prevents the shortcomings which typically occur when adopting C-band radar constellations within regions exhibiting a complex orography. Moreover, the availability on-the-shelves of low-cost portable X-band RF unit facilitated the development and deployment of an initial prototype sensor network.

Both the traditional horizontal scanning and the non-conventional vertical scanning approaches have been investigated. The vertical scanning mode has proven to be particularly effective when applied to the monitoring of orographically challenging regions, like Alpine Valleys. This scanning mode highly mitigates the effects of orography, thus enabling effective along-valley sounding and vertical profile retrieval. On the other hand, the horizontally scanning mode covers the more traditional weather monitoring needs.

High-performance embedded processing units directly interface to the radar RF unit, performing real-time on-board evaluations on the incoming instrumental data. The overall low power consumption may even allow powering through rechargeable solar cells. Each unit works remotely basing on well-assessed 2G cellular radio services (of course, satellite links could be optionally implemented). Unit installation is agile enough to allow for a fast distribution or relocation on the territory, if needed. Web-based network output is finally served to the end users for a timely and convenient content access and analysis, without any need for installing specific network access tools on the users side.

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3. NETWORK ARCHITECTURE

A number of MRN nodes (the micro radars) are distributed on the territory, collecting weather information and uploading it to the MRN server cluster. This validates and stores into a SQL database the received weather data. A subset of the MRN servers interface to the final users, to provide the data sets through regular Web pages.

Typically, MRN units connect to the MRN servers via commercial GSM providers. The newest technologies enabling wireless data transmission have been investigated. However, well-assessed second generation services (GPRS and EDGE) have been chosen as the preferred radio-link for both MRN node control and data exchange. These radio data services are commonly supplied by most GSM service providers worldwide and were found to provide a robust communication channel for the low bit rate needs of the network. All other MRN connections are Web based.

Authorized MRN users can remotely control their apparatus through the GSM network (by sending SMS commands). This mechanisms assures both a high availability of the apparatus and a smart card level security environment. MRN exposes a password-protected Web site as its basic way of interaction with its final users. MRN users can select a certain MRN session, observe its contents via a specialized Web viewer and store locally the session data set.

Actually, MRN adopts two kinds of node configurations: a vertical plane scanner (the so called MRN *Weather WindMill®*) and a more conventional horizontal plane scanner (the MRN *SuperGauge®*). The low power consumption of both sensors may also permit feeding through rechargeable power cells.

The *Weather WindMill®* is specifically suitable to perform high-resolution vertical sections of clouds, to precisely detect the bright band level (the freezing level) and to measure precipitation along linear structures (like narrow valleys, highways or even airport glide paths).

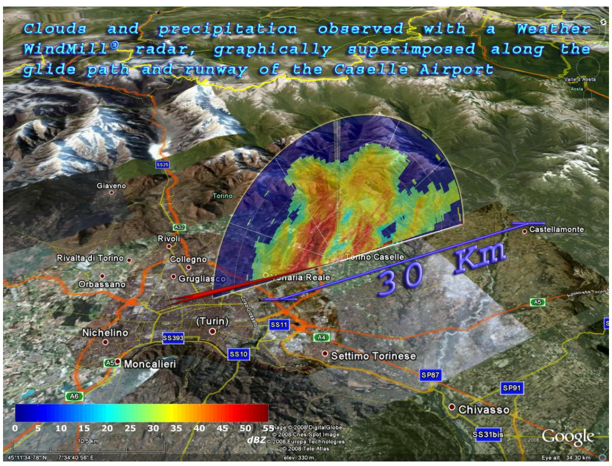

Figure 1: *A vertical section by the Weather WindMill® graphically superimposed along the glide path of the Turin Caselle Airport.*

On the other hand, the MRN *SuperGauge®* performs the typical measurements of horizontal precipitation fields with high sensitivity and resolution up to 30 Km range. It is designed to cover wide plains, urban areas, airports. Optionally, it can also operate as a vertical reflectivity profiler. Safety concerns are eased by the lack of any moving part.

4. CASE STUDIES

4.1 A typical Western Alps winter event

A typical operational output of MRN is depicted as follows by means of a recent light rainy event over the Piedmont area on November 8th 2009.

An Atlantic weather system has been moving up out to the Eastern Europe and a cold-core barotropic low is forming over Ligurian Sea. This pressure situation is causing wet South-eastern winds blowing over Northwest Italy. The cold front connected with the spreading of the Atlantic weather is getting to occlusion over Ligurian Sea.

Light rain, moderate at times, in the morning over Turin area. Cold-core barotropic low is moving away out to Adriatic Sea in the afternoon. Backing winds from Northern, Alpine sectors get weather to ease. Freezing level is around 2700-2900 meters (810-870 ft).

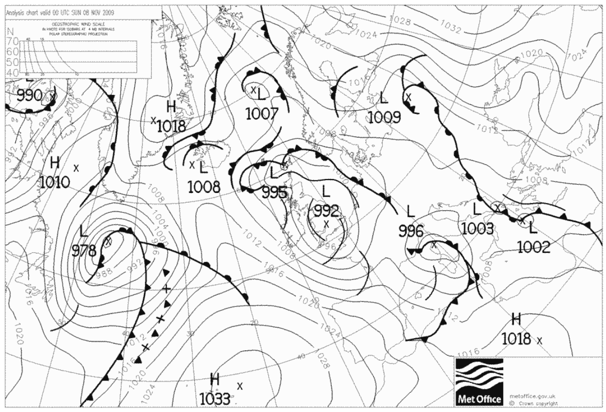

Figure 2: *November 8th 2009 @ 0am sea level map with fronts (by Met Office ©).*

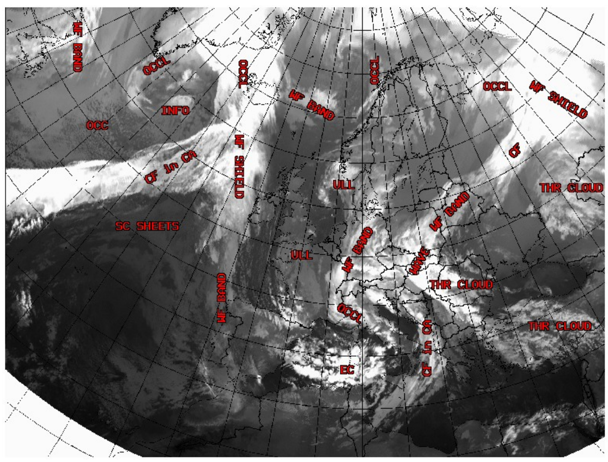

Figure 3: *MSG2 IR (ch.9) Map on November 8th 2009 @ 06pm by ZAMG ©.*

Micro radar rain estimations are compared with rain gauges readings as follows (red lines are water estimates).

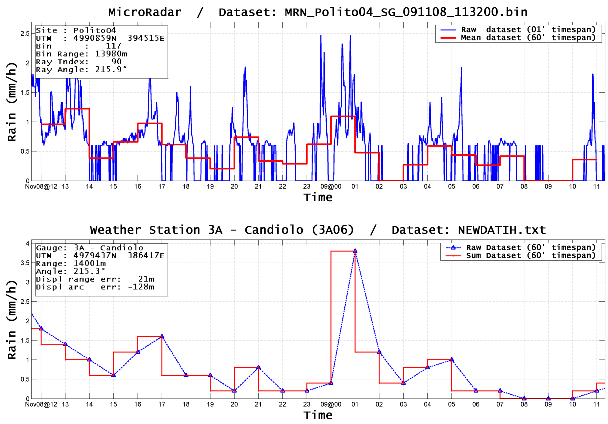

Figure 4: *Micro-radar / rain-gauge comparison over Candiolo (sited South-West of Turin, at 14Km range).*

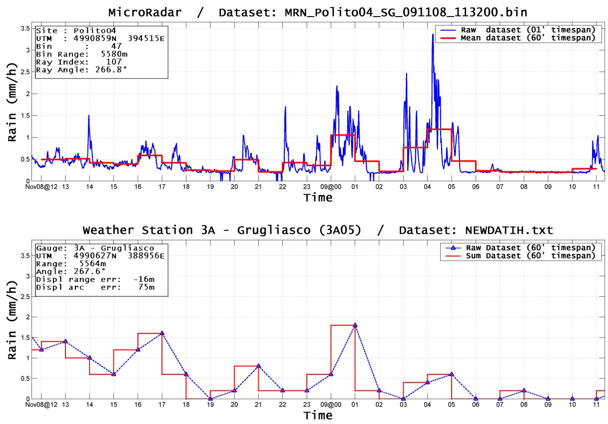

Figure 5: *Micro-radar / rain-gauge comparison over Grugliasco (sited West of Turin, at 5.5Km range).*

Even taking into account the intrinsic differences between the two sensors, a reasonable agreement (both in terms of timings and water estimates) may be inferred from the datasets above.

An overall picture of this light rain event is also streamed via the MRN Website.

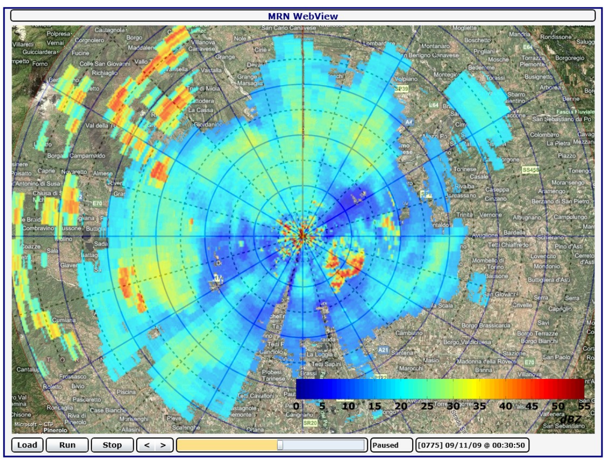

Figure 6: *A MRN Website screen shot on November 8th 2009 @ 00:30am, highlighting a moderate rain coverage over the Turin area.*

4.2 An heavy Summer event over Turin

In July 31st 2008, the persistence of Southern winds from Northern Africa towards Piedmont planes caused a unique, local atmospheric instability from the morning. A low was developing over the plane in the afternoon and causing local convergence over Turin area. As a consequence, unstable air masses gave an initial trigger action over an heavy convention, that implied heavy downpour from the evening. The weather was easing at night.

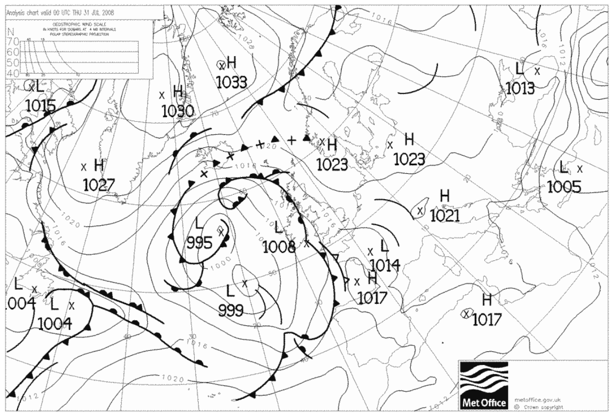

Figure 7: *July 31st 2008 @ 0am sea level map with fronts (by Met Office ©).*

Again this heavy event pattern is streamed by the Website and located over the city area with high spatial and temporal resolution.

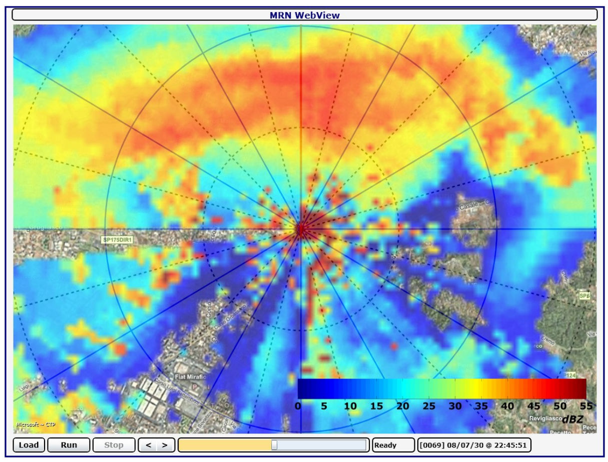

Figure 8: *A MRN Website screen shot on July 31st 2008 @ 10:45pm, showing an intense rain coverage right over Turin (blow up over the city area).*

5. CONCLUSIONS

A consistent amount of case studies clearly show that MicroRadarNet has enough potentialities to act as a fast-reacting weather monitoring tool.

The proposed strategy, based on a network of short range radars, shall effectively perform high resolution monitoring while lowering the overall operational costs. This could mitigate the shielding shortcomings which typically occur in orographically complex areas, while preventing, by design, the volumetric resolution loss at higher ranges, as well as the need for atmospheric corrections.

Moreover, being designed essentially as a network resource, MicroRadarNet could easily be integrated into already existing alerting infrastructures to play a role as an integrated weather data provider.

The rain gauges comparison here presented are based on the datasets made available by 3a Ltd, an agrometeorological operator that professionally handles more than 300 gauges in the Piedmont area. We strongly expect that MRN could greatly benefit from this recently started partnership, not only for what concern technical assessment aspects but especially in terms of being able to provide real weather monitoring services, well fitted around real user needs.

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