X-band mini weather radar network and other wireless sensor networks for environmental monitoring

X-band mini weather radar network (and other wireless sensor networks for environmental monitoring)

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POLITECNICO DI TORINO

DET
Department of Electronics and Telecommunications

Outline

- Introduction on my Ph. D. program in “Alto Apprendistato”

Radar activities

- X-band mini weather radar
  - Why X-band mini weather radars can be useful?
  - The X-band mini weather radar network
- Quantitative Precipitation Estimation (QPE)
  - CAL/VAL Procedure
- Clutter analysis to control the X-band radar stability

Other activities

- Brief description of other Wireless Sensor Networks (WSNs)

- Research partners and projects
- Special formation activities

Ph. D. Program in “Alto Apprendistato”

Ph. D. Program in "Alto Apprendistato"

- Since 2010 the Regione Piemonte has started the experimentation for the "**Alta Formazione in Apprendistato**" which include some Ph. D. programs.

- Aim of the experimentation is:
  - to offer to the Ph. D student the possibility to **work with high level technologies** offered by a private company.
  - to attend **high level formation activities** offered from both Politecnico di Torino and also from other institutions thanks to additional fund provided by Regione Piemonte.

- **I was selected to be employed at Envisens Technologies s.r.l.**
- **The main project was "Monitoraggio Radar Ambientale" (2012-2013)**

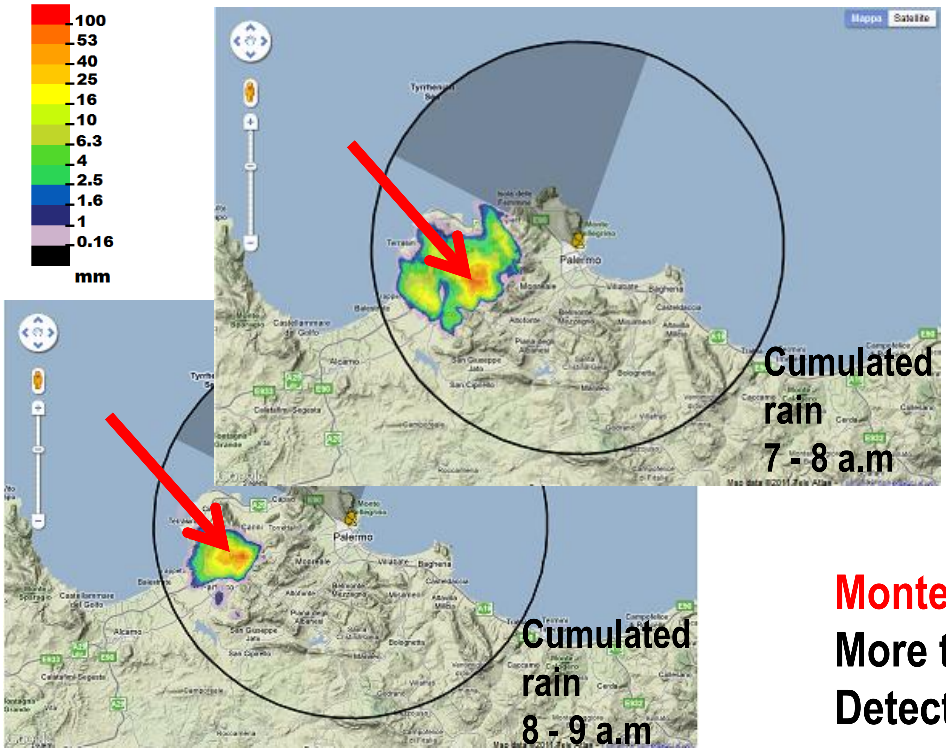
The X-band mini weather radar network

X-band mini weather radar activities

- Installation of X-band radars
- Radar software development (both on radars and network server)
- Conception and realization of different services
- Radar network management activities
- Improving X-band mini weather radar performances and functionalities
  - → QPE (Quantitative Precipitation Estimation) techniques
  - → Clutter analysis to control the radar stability

Why X-band mini weather radar could be useful?

To monitor a very intense rainfall with limited temporal duration and limited extension of the rain cell thanks to its high spatial resolution. With common rain gauges an extreme dense and unrealistic rain gauge network should be needed.



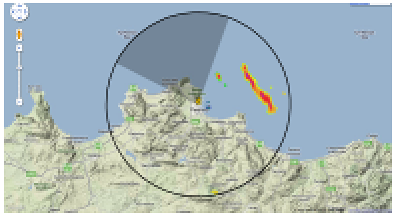
Courtesy of Protezione Civile della Provincia Regionale di Palermo

Montelepre (PA), Italy, 18th February 2011
More than 50 mm of rain in less than 2 hours!
Detected by a radar installed in Palermo (Italy).

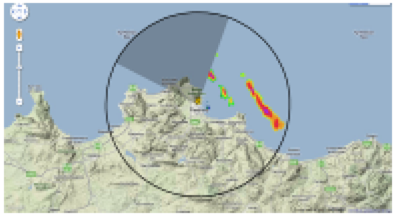
Why X-band mini weather radar coul be useful?

To detect rain field in rapid movement. With common S-Band or C-Band weather radars, the mechanics of the system and the signal processing make it difficult to monitor rapid rain fields.

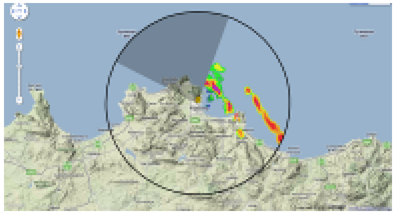
Instantaneous maps acquired by the radar in Palermo (Italy), 11.02.2011



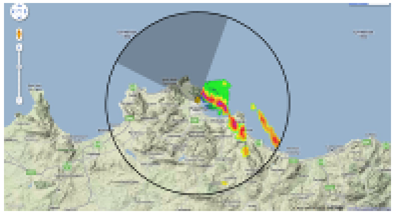
h. 17.05



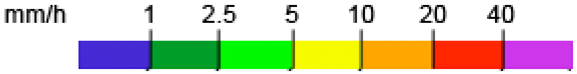
h. 17.10



h. 17.15



h. 17.20



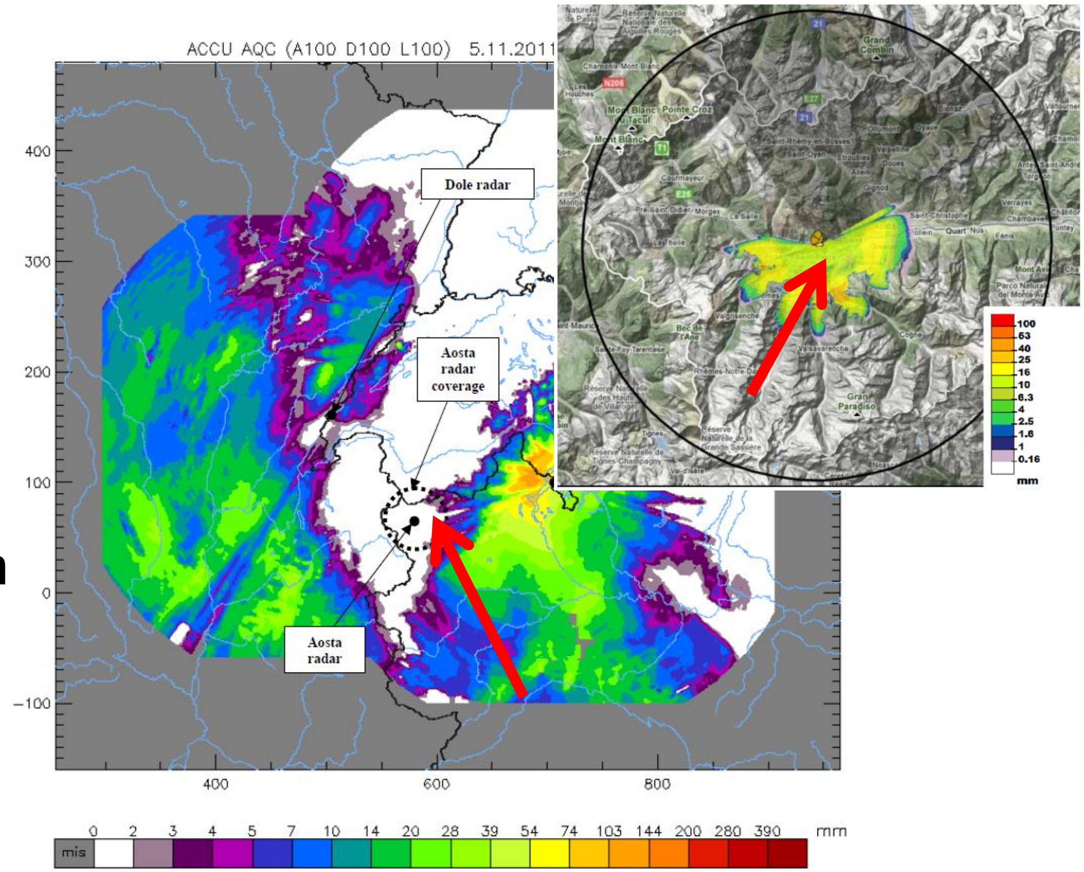
In less than 15 minutes the intense rainfall event took place. A rate of more than 20 mm/h has been measured with the radar. **X-band mini radars are able to detect such rain fields thanks to their high temporal resolution**.

Why X-band mini weather radar coul be useful?

To monitoring rain in complex orography environment, even to supplement long range weather radar information.

24 hour cumulative rainfall amount from 12 UTC of 4th November to 12 UTC of 5th November, 2011.

ON AOSTA TOWN
Monte Lema radar: < 2 mm
Aosta gauges: 44.2 and 40.2 mm
X-band radars: 25 mm



Courtesy of MeteoSwiss

The X-band mini weather radar

Non coherent – Non doppler – Pulsed
One polarization (Vertical)
Trasmitted power: 10 kW peak
PRF: 800 Hz (but configurable)
Pulse Duration: 400 ns (but configurable)
Antenna Gain: 34 dB – HPBW: 3.6° – 2.5° elevation
Maximun Range: 30 km
Space resolution of real time processed maps: 60 m
Time resolution for real time processed maps: 1 min

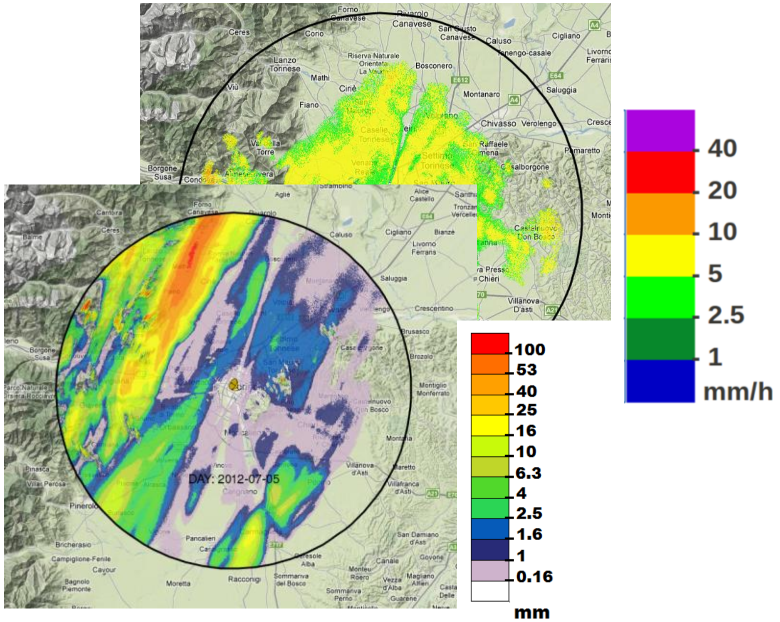
Exclusively devoted to rain measurement!

The X-band mini weather radar network

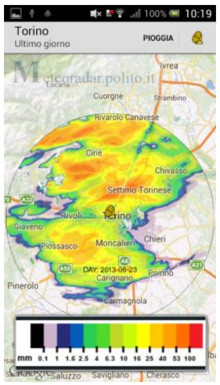
First operative installation in Turin, 2010

Developed applications and services

- Real time maps representation.
- Last hour cumulated rain.
- Last 6, 12 hours cumulated rain.
- Last day cumulated rain.
- Last 15 minutes rain evolution.
- Last 7 days cumulated rain.



Android© App available for free (**Meteoradar-IT**)



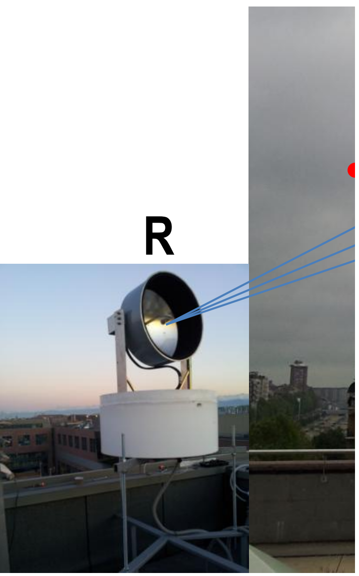
WEB SITE: http://meteoradar.polito.it

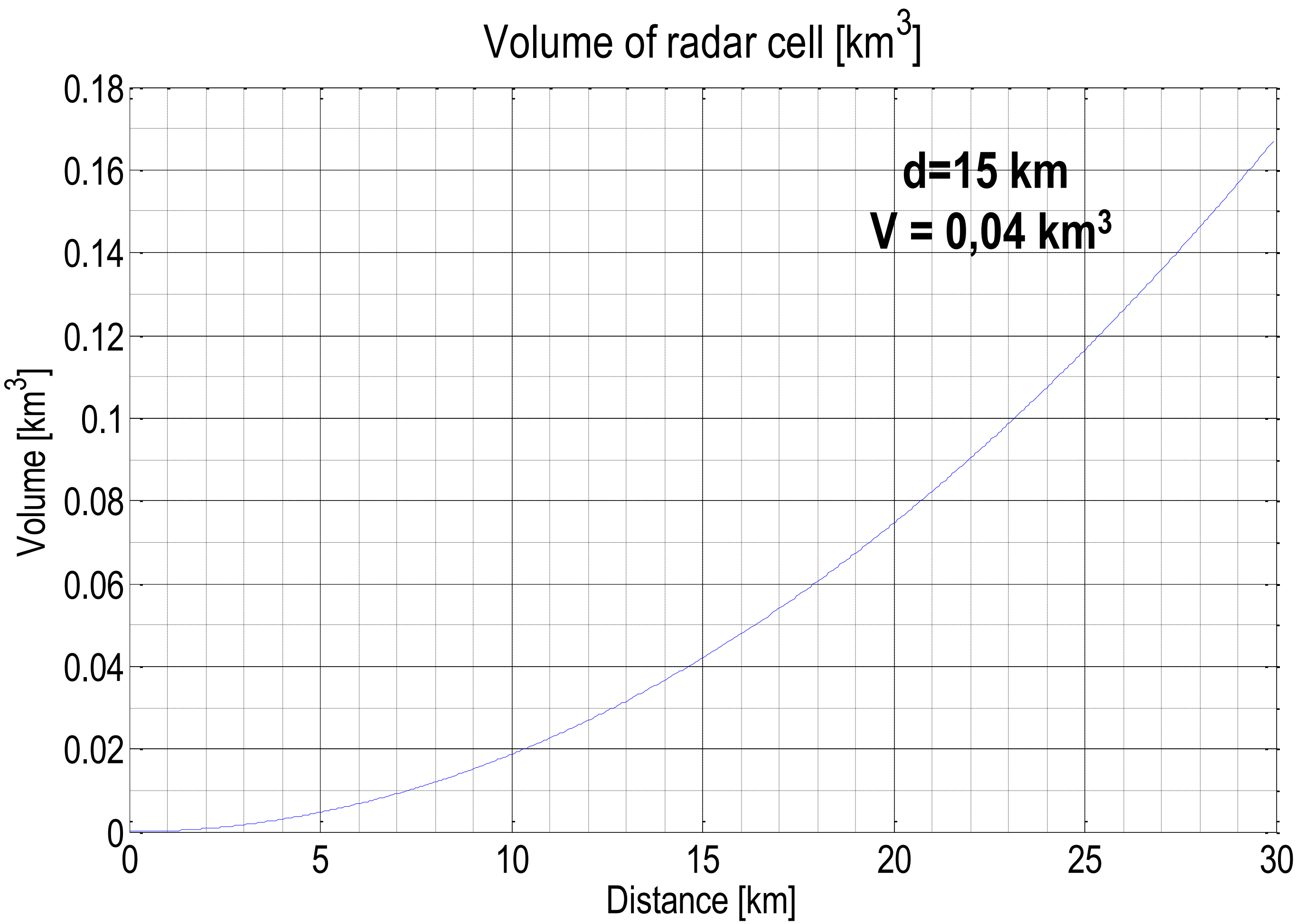
Also mobile version of the site!

Quantitative Precipitation Estimation (QPE)

Quantitative Precipitation Estimation (QPE)

QPE is necessa
measure the righ
Common techni
Gauges compa





Radar equation and Z-R equation

- **Equation for weather radar**

$$P_r = \left(\frac{P_t \pi^3 G_0^2 \theta_{3dB} \phi_{3dB} c\tau}{\lambda^2 1024 \ln 2} \right) L^2 |K|^2 \frac{Z}{r^2} \longrightarrow P_r \cong K \frac{Z}{r^2}$$

- **Digital Number on the Cartesian radar maps** are represented as:

$$DN = (100 + P_{r,[dBm]} + 20 \cdot \log_{10} r_{[km]}) \cdot 2.55$$

$$P_r \cong K \frac{Z}{r^2}$$

Z = Reflectivity due to the rain cell [mm^{6}mm^{-3}].

$$Z_{[mm^6 m^{-3}]} = a \cdot R^b$$

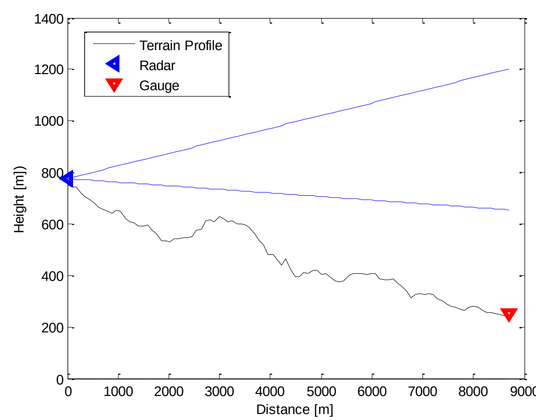
R = Rainfall rate [mm/h].
a and ***b*** depends on the precipitation type, in our case ***a*= 316, *b*= 1.5**
(**Marshall and Palmer Equation or Z-R equation**, 1948)

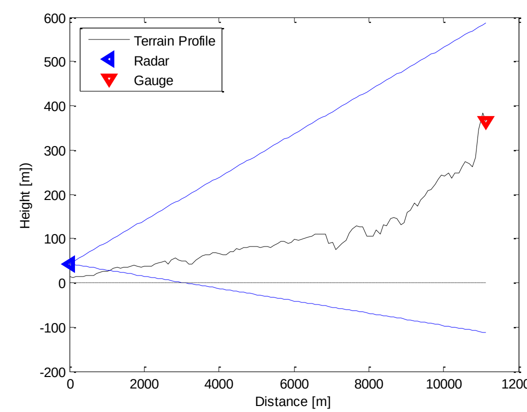
Radar and Rain Gauge

R ← COMPARISON → G

- Radar maps available with a sample time of 1 min
- **Rain maps are cumulated over 1 hour time interval → R**
- The value of rain is spatially averaged over a 1 km x 1 km (19 pixels by 19 pixels) area around the position of each rain gauge

- Rain data available with sample time of 15 min
- Selection of **Rain Gauges** avoiding clutter zone (Urban, mointaunous, hill) → avoiding beam shielding
- **Estimated hourly cumulated rain → G**





CALibration and VALidation procedure (CAL/VAL)

CAL/VAL is a QPE PROCEDURE:

Co-located R and G couples are divided into 2 datasets: 1° for CALibration - 2° for VALidation

CALIBRATION

- Considering the (R,G) **CAL** couples, the **overall bias** is computed, following a procedure normally identified as **Bulk Adjustment:**

$$BA = \frac{\sum_{storms\_CAL} \sum_{places\_CAL} R}{\sum_{storms\_CAL} \sum_{places\_CAL} G}$$

VALIDATION

- Necessary to evaluate the effectiveness of this Bulk Adjustment procedure:

$$R_{BA} = R_{VAL} \cdot (1/BA)$$

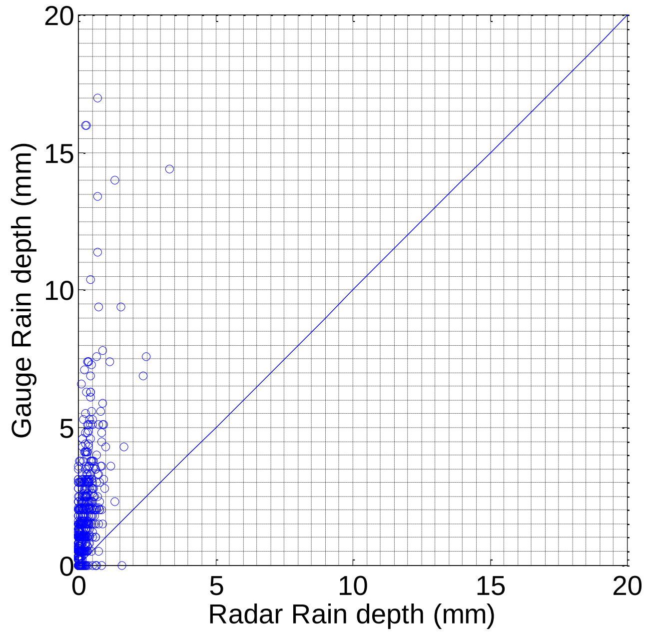
- Considering the couples (R_{BA}, G) of the VAL dataset some statistical indicator are computed:

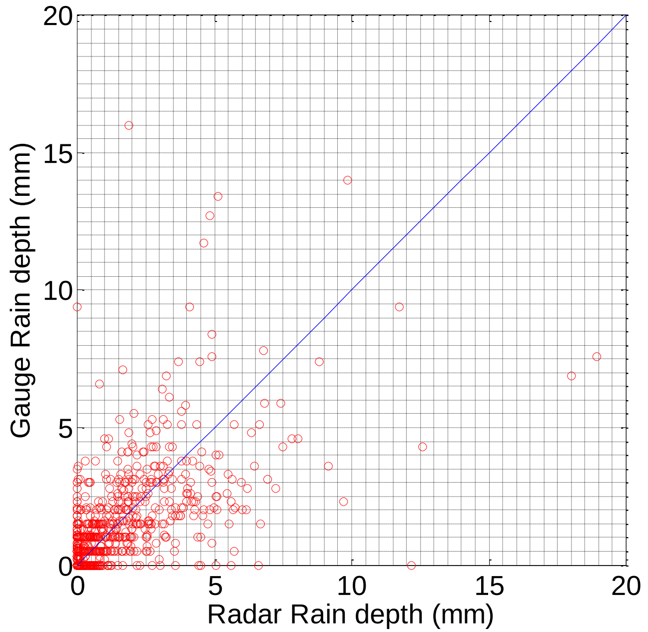
$$corr = \frac{\mathrm{cov}(R_{BA}, G)}{\sigma_{R_{BA}} \sigma_G} \qquad bias = \frac{\sum_{storms\_VAL} \sum_{places\_VAL} R_{BA}}{\sum_{storms\_VAL} \sum_{places\_VAL} G} \qquad rmsd = \sqrt{\frac{\sum_{gouges} \sum_{stroms} (G - R_{BA})^2}{N}}$$

- Computing 2 indexes from the contingency tables:
  - **POD** (probability of detection)
  - **MISS** (probability of missing observation)

Turin radar: calibration results

n° storms	n° couples	n° gauges Cal	n° gauges Val	data set date
13	1872	4	5	10-12 /2012



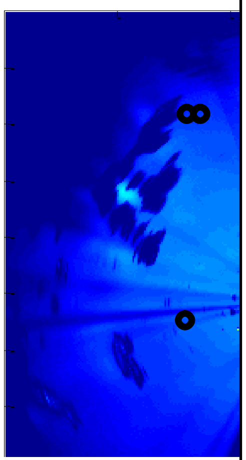


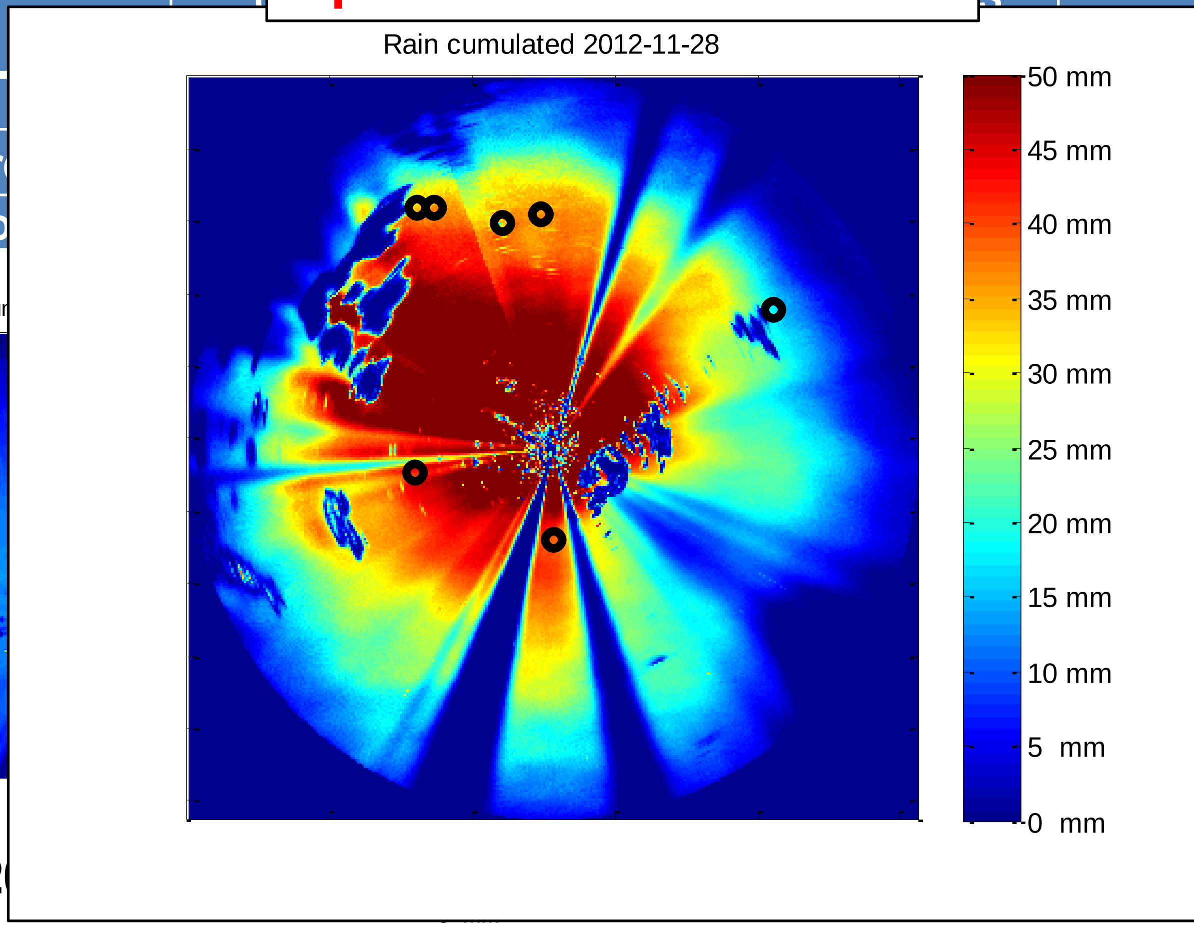
Turin radar: calibration results

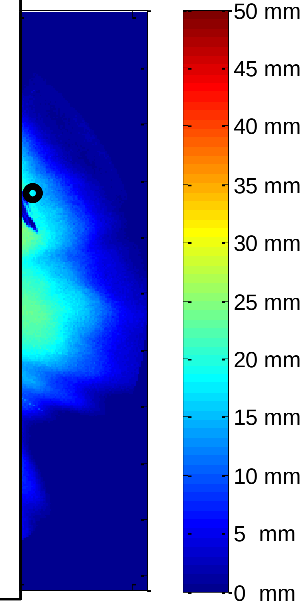
Open issue: attenuation!

		rmsd
Pr		
Po		

Rain cu







Before BA

Less than 2

Clutter analysis to control the radar stability

Radar calibration and control using ground clutter echoes

- Each radar sub-systems may suffer for some degradations due to:
  - external factors (e.g. temperature fluctuations, humidity) .
  - equipment related issues (e.g. frequency drift of the magnetron, de-tuning of the receiver filter).
- To assure good performances in detection and measurement of rain, it is important to control the stability of the overall radar system components.

- **IDEA: use ground clutter echoes during clear sky days to check the radar calibration and control if any equipment failures occurred (also RCA algorithm, Silberstein 2008).**

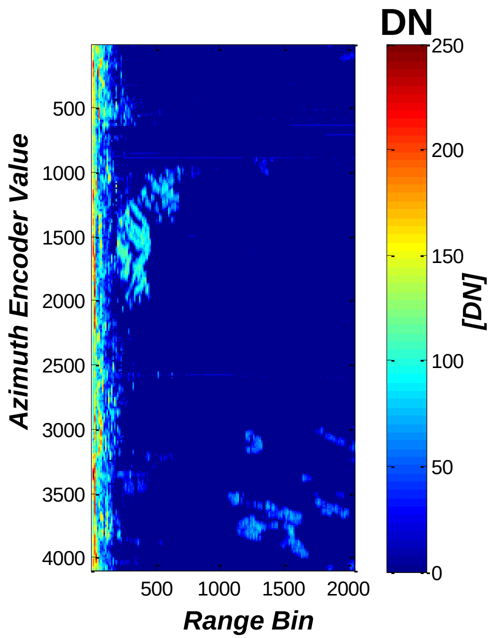
$$P_r \cong K \frac{Z}{r^2}$$

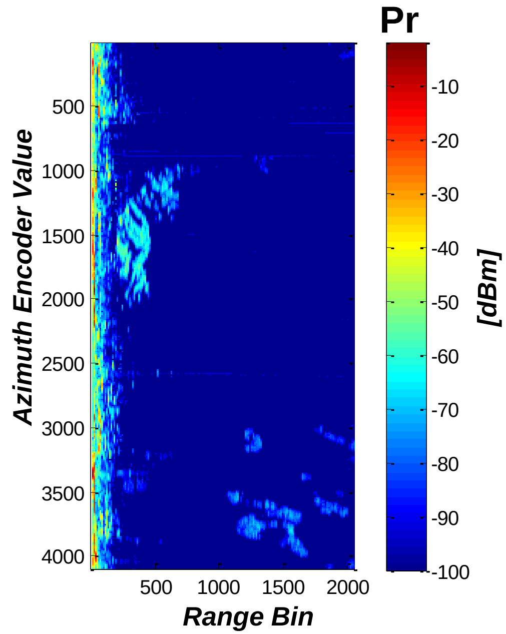
Z = Reflectivity due to the back scattering cross section of a portion of ground clutter, in case of no rain during clear sky days.

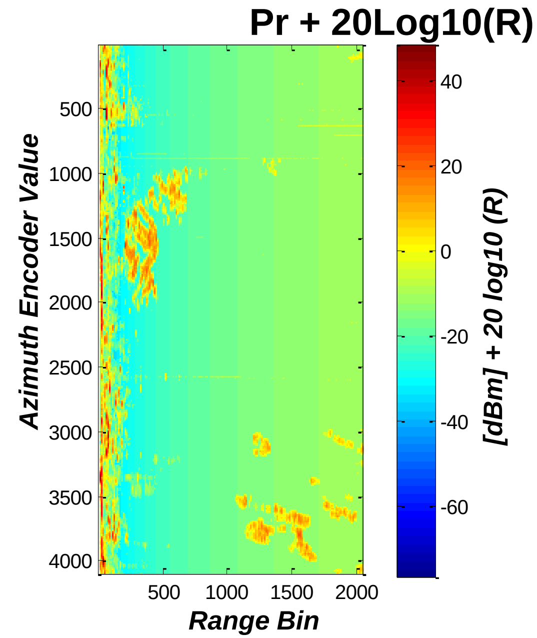
Experiment Description

- The X-band radar receiver filter is controlled by a 8-bit register which control the filter central frequency.
- **To simulate a radar failure, the radar receiver filter has been intentionally detuned**.
- The radar central frequency, in tuned conditions (measured in laboratory) corresponds to a register value of 210.
- 11 different datasets of polar clutter maps have been acquired considering register code number between 160 to 255 with a step size of 10 units.
- For each register value the acquisition period lasted 2 hours and 15 minutes, and correponds to 135 maps (1 map each minute).
- **The acquisitions have been performed in clear sky conditions in order to detect only clutter echoes and do not acquire echoes coming from meteorological targets**.
- **A statistical analysis have been performed on the maps.**
- Some statistical indicators have been computed
  - **16^{th} percentile, 84^{th} percentile, 90^{th} percentile, Mean, Median**

Clutter maps processing







The radar acquired original cartesian map is in Digital Number (DN), values from 0 to 255.

$$DN = \left(100 + P_r^{[dBm]}\right) \cdot 2.55$$

DN are transformed into received power exploting the receiver law. Received power can be expressed considering the radar equation for meteorological target:

$$P_r = k \cdot \frac{Z}{R^2}$$

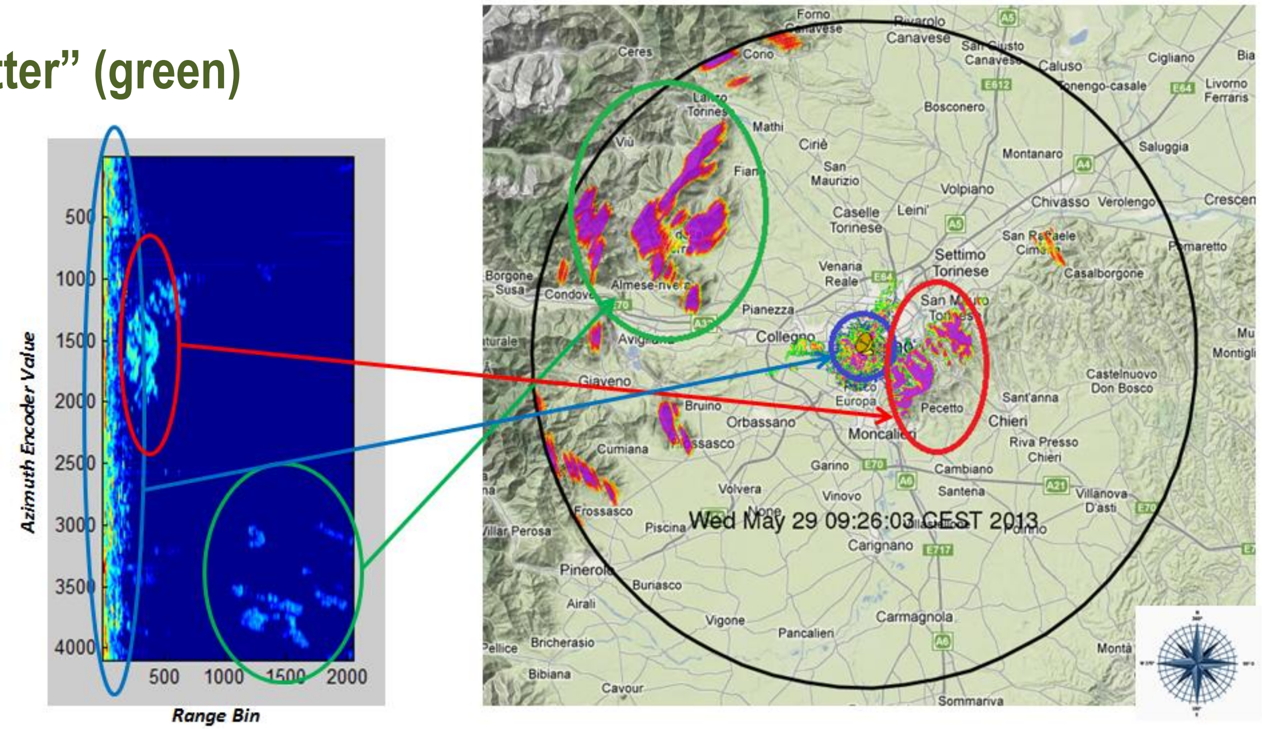
The backscattered power contribution (in dBm) coming from each ground clutter pixel is then compensated for space attenuation due to distance (R).

$$P_r + 20 \cdot \log_{10} R$$

Clutter maps

- 3 different areas can be observed considering a single clutter map acquired by the radar in Turin. Each area has a homogeneous type of ground clutter:

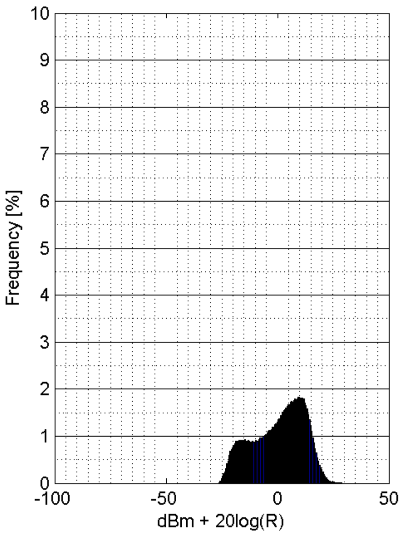
- **“Urban Clutter” (blue)**
- **“Hill clutter” (red)**
- **“Mountainous clutter” (green)**



Clutter maps

- The echoes power distribution from the 3 different clutter areas has been computed
- As example, the following PDFs have been computed for the filter code value equal to 210, the tuning condition.

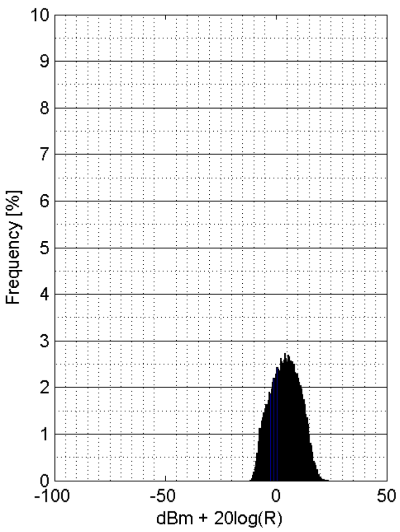
Hill clutter



"Two modal"

2 different clutter sub-areas

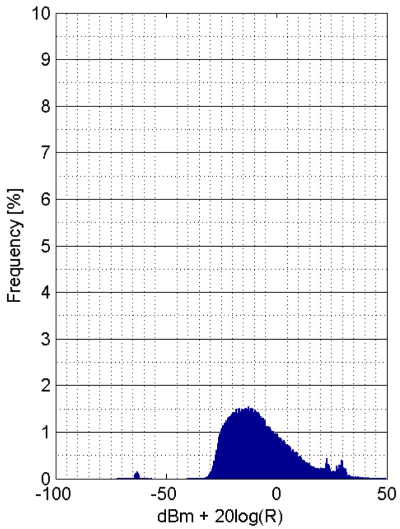
Mountain clutter



"Normal distribution"

More uniform reflection geometry

Urban clutter

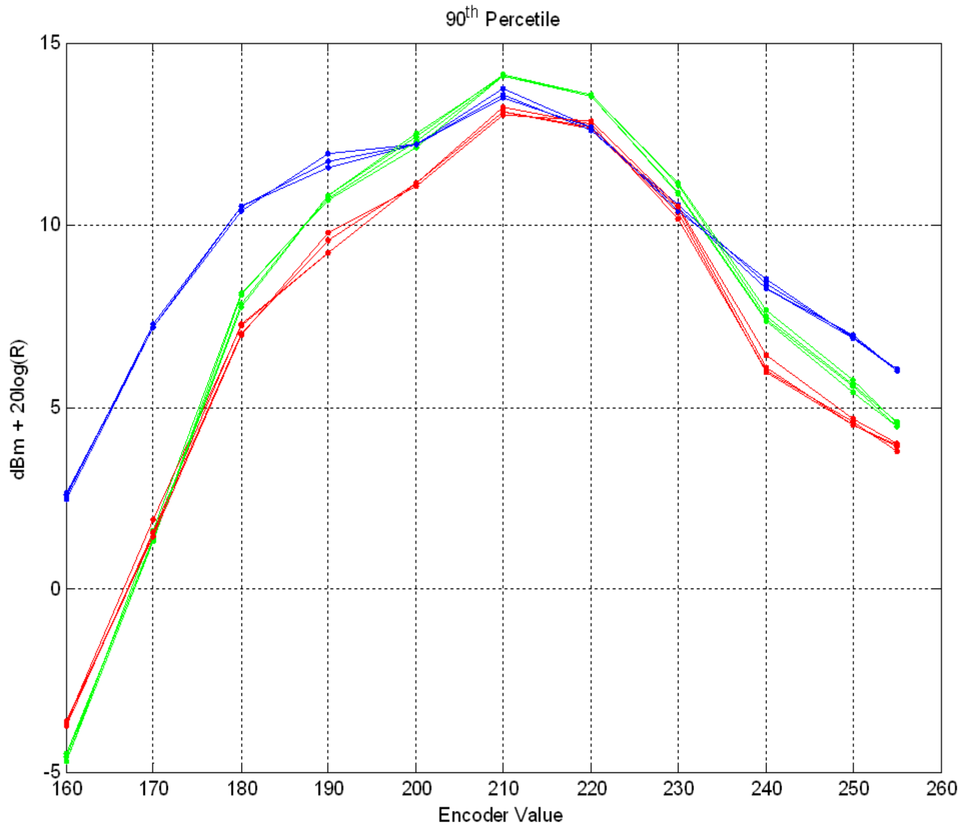


"Rayleigh"

Absence, in average, of dominant scatterers

Detect a possible equipment failure

- Among all the statistical indicators, **90th percentile** is the best indicator to detect a possible radar equipment failure or modification, or a filter de-tuning condition.

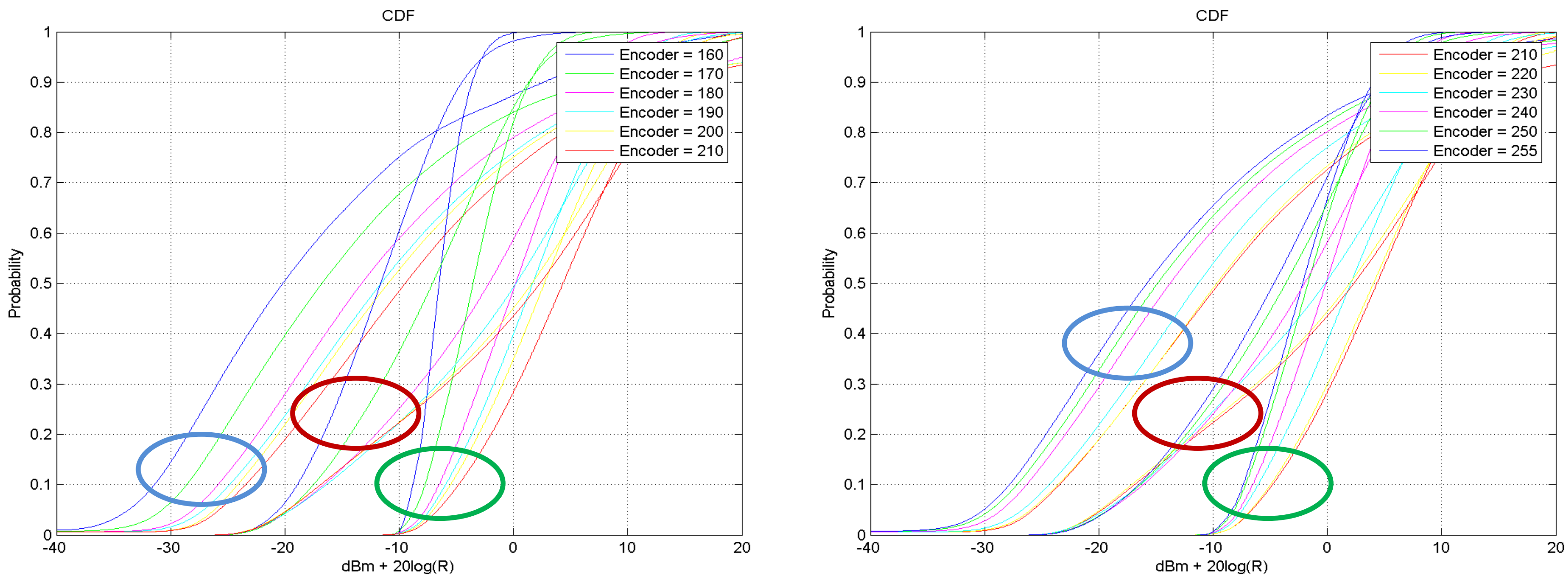


Variation of the clutter power 90th percentile indicator in function of the receiver filter code value for three different data subsets.

-"Urban Clutter" (blue)
-"Hill clutter" (red)
-"Mountainous clutter" (green)

Cumulative Distribution Functions (CDFs)

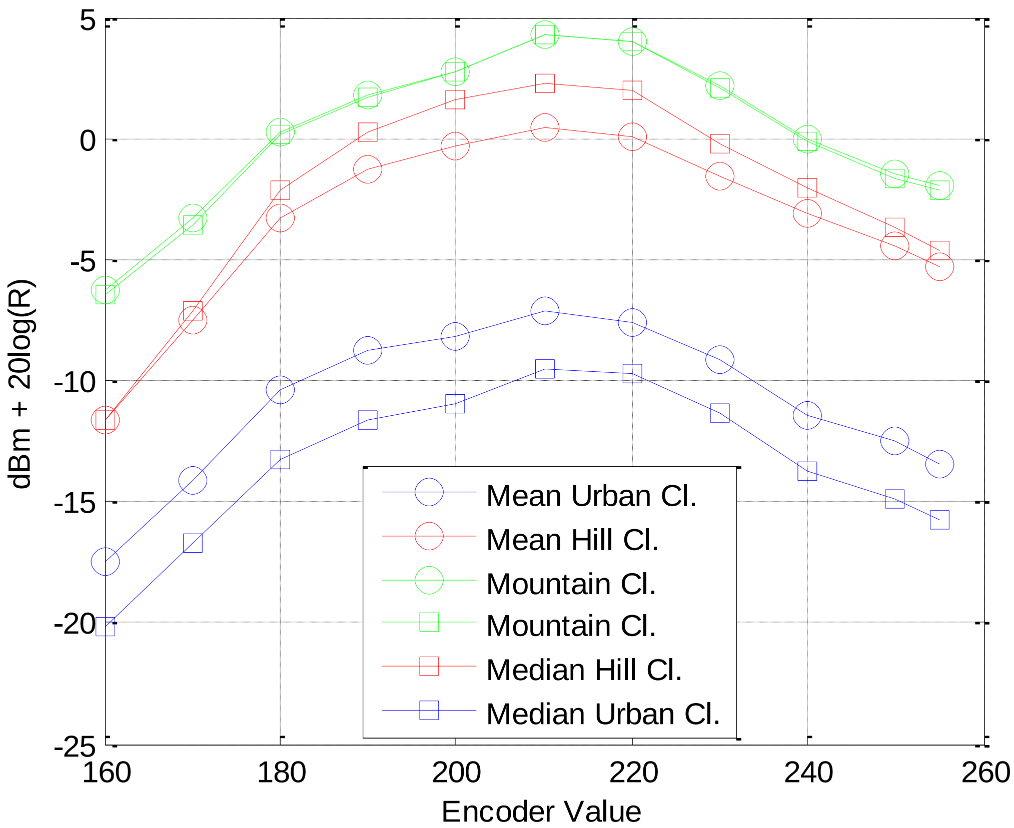
- Considering a specific receiver filter code value:
- The 90th percentile is almost in correspondance of the same backscattered power value for different type of clutter.
- CDFs have different "growth" for different type of clutter.



-"Urban Clutter" (blue)
-"Hill clutter" (red)
-"Mountainous clutter" (green)

Measure the losses

The **mean** and the **median** indicators, are more sensitive to clutter types.



Taking into account the mean value when radar is tuned (encoder value 210) it is possible to observe:

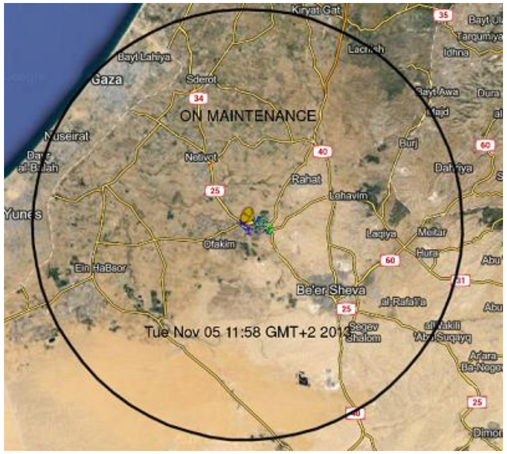
-5 dB difference between mean power coming from Mountainous Clutter and Hill Clutter

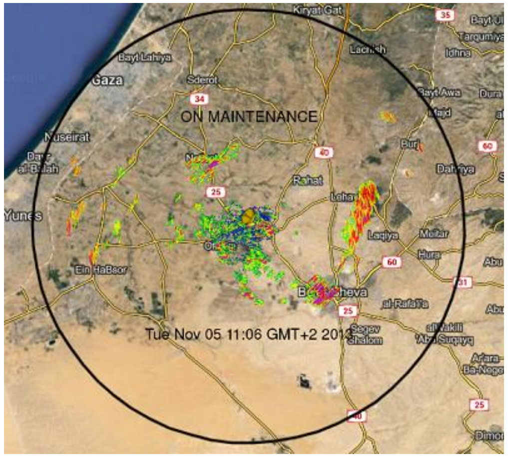
-about 12 dB from Mountainous and Urban clutter

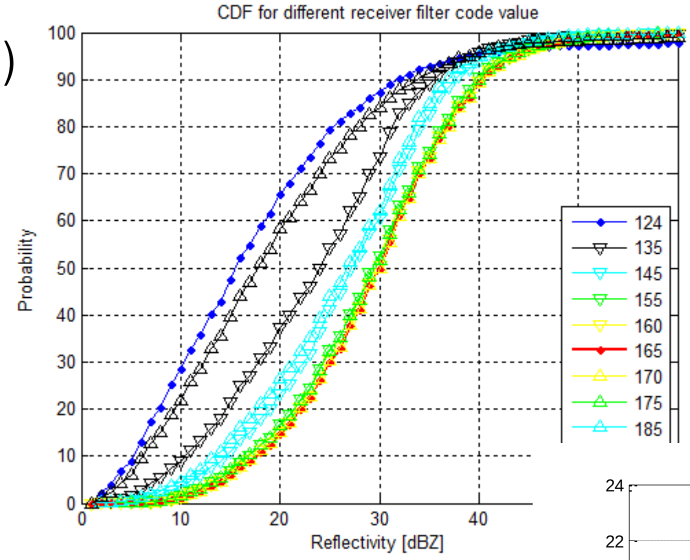
The same difference can be detected in detuning condition!

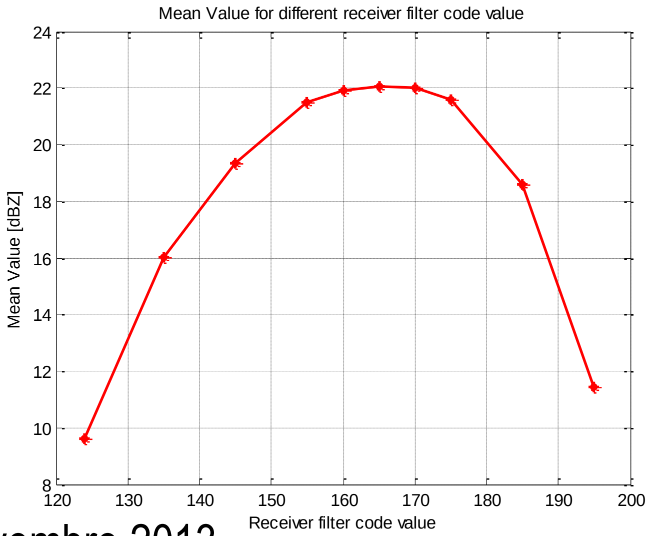
An example of remote re-tuning of radar

Radar installed in Gilat (Israel)









Installed in October 2012

Remotely retuned on 5th Novembre 2013

Radar activities: publications

1 Book Chapter

- Gabella M., Notarpietro R., **Bertoldo S.**, Prato A., Lucianaz C., Rorato O., Allegretti M., Perona G. (2012) *A Network of Portable, Low-Cost, X-Band Radars.* In: Doppler Radar Observations - Weather Radar, Wind Profiler, Ionospheric Radar, and Other Advanced Applications. Dr. Joan Bech and Dr Jorge Luis Chau (InTech), pp. 175-202. ISBN 9789535104964

2 Journal articles

- M. Allegretti, **S. Bertoldo**, A. Prato, C. Lucianaz, O. Rorato, R. Notarpietro, M. Gabella (2012) *X-Band Mini Radar for Observing and Monitoring Rainfall Events*. In: ATMOSPHERIC AND CLIMATE SCIENCE, vol. 2 n. 3, pp. 290-297. - ISSN 2160-0414
- **Bertoldo S.**, Lucianaz C., Rorato O., Allegretti M., Prato A., Perona G. (2012) *An operative X-band mini-radar network to monitor rainfall events with high time and space resolution.* In: ENGINEERING TECHNOLOGY AND APPLIED SCIENCE RESEARCH, vol. 2 n. 4, pp. 246-250. - ISSN 1792-8036

8 Conference contibutions

- **Bertoldo S**., Notarpietro R., Branca M., Dassano G., Lucianaz C., Rorato O., Allegretti M. (2013) *Characterization of the receiver filter of a X-band weather radar to improve the performance of an application to control the radar stability*. In: International Conference on Electromagnetics in Advanced Applications (ICEAA '13), Torino (Italy), 9-13 September 2013. pp. 935-938
- Notarpietro R., Branca M., Morin E., Lokshin A., Gabella M., De Vita P., Basso B., Bonfil D., **Bertoldo S**., Shah S., Lucianaz C., Rorato O., Allegretti M. (2013) *Towards sustainable agricultural management using high resolution X-band radar precipitation estimates*. In: International Conference on Electromagnetics in Advanced Applications (ICEAA '13), Torino (Italy), 9-13 September 2013. pp. 915-918

Radar activities: publications

8 Conference contibutions - continue –

- Shah S., Notarpietro R., **Bertoldo S.,** Branca M., Lucianaz C., Rorato O., Allegretti M., (2013) *Automatic Storm(s) Identification in High Resolution, Short Range, X-Band Radar Images*. In: International Conference on Electromagnetics in Advanced Applications (ICEAA '13), Torino, 9-13 September 2013. pp. 945-948
- Allegretti M., **Bertoldo S.,** Lucianaz C., Rorato O., Branca M., Shah S., Notarpietro R., Perona G. (2013) *Monitoring precipitation on mountain streams to optimize the hydroelectric power production*. In: 2nd International Conference Energy and Meteorology, Tolosa (FRA), 25-28 June 2013 (Only abstract in the proceedings).
- **Bertoldo S.**, Bracco L., Notarpietro R., Gabella M., Lucianaz C., Rorato O., Allegretti M., Perona G. *Clutter analysis to monitor the stability of a portable X-band mini weather radar* UrbanRain12, In: Urban Rain 2012 - 9th International Workshop on Precipitation in Urban Areas, Hotel Randolins, St. Moritz, Switzerland, 6 - 9 December 2012. pp. 171-176.
- **Bertoldo S.**, Bracco L., Notarpietro R., Lucianaz C., Rorato O., Allegretti M., Perona G. (2012) *A standalone application to monitor the stability of a low cost maintenance free X-band mini weather radar, using ground clutter echoes.* In: International Conference on Electromagnetics in Advanced Applications (ICEAA '12), Cape Town, WP, South Africa, 2-7 September 2012. pp. 1040-1043
- Paolella S., Prato A., Turso S., Notarpietro R., **Bertoldo S.**, Cucca M., Gabella M., Perona G., Ferrarese S., Richiardone R. (2011) *Identification, tracking, validation and forecast of local high resolution precipitation patterns observed through X-band micro radars.* In: ICEAA'11, Torino (ITA), September 12-16, 2011. pp. 1436-1439
- Lucianaz C., **Bertoldo S.**, Rorato O., Mamino M., Allegretti M., Perona G. (2011) *High temporal and spatial resolution X-band radar based system to monitor rainfall events and detect landslide risk in the Mediterranean area.* In: 13th Plinius Conference on Mediterranean Storms (EGU Topical Conference Series), Savona (ITA), September, 7-9, 2011

Other research activities: WSNs

Other Wireless Sensor Networks (WSNs)

Wireless Sensor Networks (WSNs) design and realization.

- DGPS Wireless Sensor Network for environmental monitoring: to monitor landslide and glaciers

- WSN as anti-theft alarm system for PV plant

- WSN for smart gas metering

WSNs and other research activities: publications

3 Journal articles

- O. Rorato, **S. Bertoldo**, C. Lucianaz, M. Allegretti, S. Bertoldo, R. Notarpietro (2013) *An Ad-Hoc Low Cost Wireless Sensor Network for Smart Gas Metering.* In: WIRELESS SENSOR NETWORK, vol. 5 n. 3, pp. 61-66. - ISSN 1945-3086
- **Bertoldo S.**, Rorato O., Lucianaz C., Allegretti M. (2012) *A Wireless Sensor Network Ad-Hoc Designed as Anti-Theft Alarm System for Photovoltaic Panels*. In: WIRELESS SENSOR NETWORK, vol. 4 n. 4, pp. 107-112. - ISSN 1945-3086
- Rorato O., Lucianaz C., Vittaz E., **Bertoldo S**., Allegretti M. (2012) *A wireless sensor network board for environmental monitoring using GNSS and analog triaxial accelerometer. In: International Journal of Embedded Systems and Applications*. In INTERNATIONAL JOURNAL OF EMBEDDED SYSTEMS AND APPLICATIONS, vol. 2 n. 4, pp. 35-43. - ISSN 1839-5171

4 Conference contibutions

- Rorato O., Lucianaz C., **Bertoldo S**., Allegretti M., Perona G. (2012) *A multipurpose node for low cost wireless sensor network*. In: 2012 IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC), Cape Town, WP, South Africa, 2-7 September 2012. pp. 247-250
- Losso A., Corgnati L., **Bertoldo S**., Allegretti M., Notarpietro R., Perona G. (2012) *SIRIO: an integrated forest fire monitoring, detection and decision support system - performance and results of the installation in Sanremo (Italy).* In: Forest Fire 2012, The New Forest, UK, 22-24 May 2012. pp. 79-90
- **Bertoldo S**., Corgnati L., Losso A., Perona G. (2012) *Safety in forest fire fighting action: a new radiometric model to evaluate the safety distance for firemen working with hand-operated systems.* In: Forest Fire 2012, The New Forest, UK, 22-24 May 2012. pp. 3-12. (INVITED PAPER).
- **Bertoldo S.**, Corgnati L., Perona G. (2011) *Un nuovo modello radiometrico per l'identificazione di hot spot di incendi boschivi e come strumento di valutazione delle performance dei sensori in ambienti ad orografia complessa*. In: 15a Conferenza Nazionale ASITA, Colorno, Parma (ITA), 15-18 Novembre 2011. pp. 325-334

1 Patent pending as inventor

- Allegretti M., Amici A., **Bertoldo S.**, Giorgi A., Norcini Pala G., Pacetti A., Rorato O.,*Rete di sensori wireless per la misura da remoto di consumi di gas da interfacciarsi con i tradizionali contatori in dotazione alle utenze*. Patent pending N. TO2013U000009, 23rd January 2013

Research partners, projects and formation activities

Research partners and projects

Projects for radar activities:

- **MONITORAGGIO RADAR AMBIENTALE**
  (January 2012 – December 2013)
- **Realizzazione di un progetto pilota per il monitoraggio delle precipitazioni con tecnologia radar ad alta risoluzione spaziale e temporale nel territorio della Provincia Regionale di Palermo.**
  (January 2011 – July 2011)
- **X-RADAG (Toward sustainable agricultural management using high-resolution X-band radar precision estimates).**
  (January 2012 – December 2013). The project will end in 2015.
- **PRESMAM (High-resolution PREcipitation eStimation using Multisensors system for improving Agricultural Management and environmental benefits).**
  (January 2012 – December 2013). The project will end in 2014.

Projects for other research activities (WSNs):

- **PICENOGAS** (June 2011 – December 2012)
- **ANKENERGIA** (June 2011 – December 2012)
- **RETI DI MONITORAGGIO AMBIENTALE** (January 2012 – March 2013)

Partners:

PROVINCIA REGIONALE DI PALERMO – PROTEZIONE CIVILE

CINFAI

CRA – CONSIGLIO PER LA RICERCA E LA SPERIMENTAZIONE IN AGRICOLTURA

האוניברסיטה העברית בירושלים
The Hebrew University of Jerusalem

Special formation activities

The PhD program in “Alto Apprendistato” gives to the students **more fund for further specialist formation activities** with respect to the high level formation already provided by Politecnico di Torino:

- **Spatial Multicriterial Analysis for Environmental Decision Making, SMCA 2012**, 10th – 21st September 2012, University of Trento (IT).

- **9th Inernational Worskhop on Precipitation in Urban Areas, Urban Rain 2012**, 6th – 9th December 2012, Hotel Randolins, St. Moritz (CH).
- **5th International Summer School on Radar/SAR,**12th – 19th July 2013, Fraunhofer FHR, Rolandseck, Bonn, (DEU).
- **International Summer School on Atmospheric and Oceanic Sciences on Weather Forecasting (ISSAOS 2013)**, 16th – 20th September 2013, CETEMPS, L’Aquila (IT).

… **Other than the formal PhD Politecnico training activity (52 credits)**

Thank you!

Questions?

RAIN EVENT DEMO

Radar: Parma

Date: 13th July 2013

Parmaonline
il quotidiano di Parma

Noceto, allagamenti per il temporale

sabato 13 luglio 2013 09:35

Pioggia intensa nel Parmense. Tante le chiamate ai vigili del fuoco per richieste d'intervento. Nella Bassa segnalate grandinate

GAZZETTA DI PARMA.it

Violento temporale: a Noceto allagamenti, decine di chiamate. E la grandine imbianca Boretto

13/07/2013 - 08:51