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RAINBO

Deliverable 2.2

Rainfall data based on Microwave links

Action C2 – Study, design and implementation of the new monitoring infrastructure

Comune di Bologna

lepida spa

arpae emilia-romagna

N:ER INGEGNERIA

MEEO Meteorological Environmental Earth Observation

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Document Summary

This document describes the procedure and algorithm implemented during the RainBO project in order to obtain rainfall estimation map by using microwave links data coming from Lepida and other telecommunication operators.

Summary

1. Introduction

Accurate and timely surface precipitation measurements are crucial for water resources management, weather prediction, climate research, as well as ground validation of satellite-based precipitation estimates. This technology wants to counteract the decline of the density of surface precipitation gauging networks observed in many parts of the world.

The microwave rainfall monitoring system proposed in the project exploits the Microwave links (MWL) used worldwide in commercial cellular communication networks. Along such links, radio signals propagate from a transmitting antenna at one base station to a receiving antenna at another base station. Rain-induced attenuation and, subsequently, path-averaged rainfall intensity can be retrieved from the signal's attenuation between transmitter and receiver by applying, almost in real-time, a rainfall retrieval algorithm.

The algorithm chosen for this purpose is the RAINLINK retrieval algorithm developed from Aart Overeem and Remko Uijlenhoet from Wageningen University (Wageningen, the Netherlands) and Hidde Leijnse from the Royal Netherlands Meteorological Institute (KNMI) in 2015. The code is an open source R package (https://www.r-project.org) available for free download on GitHub (https://github.com/overeem11/RAINLINK).

The implementation of the algorithm for the specific needs of the italian test areas, as well as code debugging and improving, is done by MEEO in close contact with the original authors.

2. State of the art

Regarding the existing available solutions, we learned through previous contacts in the telecom industry that Ericsson (telecom equipment provider) is developing a similar service called MINI-LINK, as shown on this interesting brochure of 2014 regarding Rain attenuation data from mini-link in Sweden http://www.ericsson.com/res/docs/2014/micro-weather.pdf

Ericsson seems to be collaborating with the Swedish meteorological institute. This is clearly showing that the telecom industry is aware of this technology.

First studies concentrated on algorithms for spatial–temporal interpolation (Goldshtein et al., 2009; Overeem et al., 2013; Zinevich et al., 2008) from the joint analysis of multiple Microwave links. Bianchi et al. (2013a, b) reported detection of malfunctioning RGs and improvement of radar observations by MWL links.

The great potential of MWL links for ungauged regions was demonstrated by the Burkina Faso application [Doumounia et al. (2014)] that represented the first test of this technology during the monsoon season in West Africa, where 95% of the rainy days were detected with a correlation of 0.8 in the daily precipitation amounts compared to rain gauge measurements.

In collaboration with one national cellular phone operator, Telecel Faso, the attenuation was monitored at 1 s time rate for the monsoon season 2012. The time series of attenuation (on a 29 km long microwave link operating at 7 GHz) is transformed into rain rates and compared with rain gauge data. The method is successful in quantifying rainfall: 95% of the rainy days are detected. The correlation with the daily rain gauge series is 0.8, and the season bias is 6% (http://onlinelibrary.wiley.com/doi/10.1002/2014GL060724/abstract).

Before that date, in 2012, Overeem et al. (2013) demonstrated that processing algorithms are capable of providing real time rainfall maps for an entire country, in this case the Netherlands.
http://www.pnas.org/content/110/8/2741

In experiments in the alpine and pre-alpine regions in southern Germany, Chwala et al. (2012) obtained correlations of 0.81 for the CML -rain gauge comparison and 0.85 for the MWlinks -rain radar comparison.

Such a network was already used also to retrieve the space–time dynamics of rainfall for an entire country, like in the case of The Netherlands (35,500 km2). The available data were minimum and maximum received powers over 15-min intervals with a precision of 1 dB, based on 10-Hz sampling. In general, power losses along links are measured and stored by cellular communication companies to monitor the stability of their link networks. In that case, 15 minutes rainfall maps were provided.
The limit of this technology is substantially related to the data availability by the telecommunication operators; in this case, however, we can exploit the market analysis results of the T-Rain project (funded by EIT Climate-KIC in 2015) in terms of telecommunication data availability assessment in Europe and in terms of feasibility study of a potential operational service to be used for the implementation of an advanced infrastructure for the rainfall monitoring and forecasting.
The great advantage of this technology is related to the high resolution 2D rainfall maps with 15 minutes and 1 KM2 resolution to monitor and forecast rainfall events even on geographical area not covered by traditional gauges network but equipped with mobile telecommunication antennas.
Regarding the city of Bologna, the RainBO future observation service represents a concrete adaptation service to improve the response of the city to climate change impacts, as pointed out in the vulnerability analysis and in the measures and actions described in the city Adaptation Plan edited within the Life BLUEAP project.

2 Rainfall estimation method based on the Rainlink retrieval algorithm

In RainBO the adopted rainfall estimation method is based on the RAINLINK algorithm, which is already suited for a midlatitude flat land like the Netherlands and is easily portable to the Pianura Padana. We are still studying the algorithm capabilities over the mountainous areas of the Appennino (as shown later), but first results are encouraging.

Microwave links data comes from telecommunication operators (Lepida and Vodafone so far). High density network coverage is needed for best performances. The data consists in near real time receiving power readings, collected every one (Lepida) or fifteen (Vodafone) minutes. The algorithm works with 15-min maximum and minimum received powers, from which calculates signal attenuation estimations and, through informations about the link's pathlength, the instantaneous path-averaged rainfall depths.

The algorithm uses great care on distinguishing real rain signals from noise. This is done mainly by space correlation assessments and applying variable thresholds to remove outliers. The parameters that regulate these processes may be subjects of further scientific studies.

This data is then interpolated over a grid to obtain a rainfall map, applying an ordinary kriging which employs a spherical variogram model. The algorithm offers an easy setup for the interpolation parameters, allowing improvements after further studies on the precipitation mean characteristics.

The kriging interpolation is used but data are representative of the link between two points in space, as the first internal output of the algorithm is the rainfall estimation on the midpoint between the transmitter/receiver, derived from the power attenuation data measured on the antennas. The ordinary kriging interpolation is applied on these middles points of the links on a 1kmx1km grid, taking into account the other values and obtaining more reliable map of rainfall data, on a 5kmx5km.

The Algorithm evaluates the signal attenuation along the link and assigns the related rainfall intensity to its average point that we call, in this project, "Virtual rain-gauge".
In particular in RainBO we use Lepida data to produce Virtual rain-gauge map based on Lepida data. The Vodafone rain gauge data cannot be published as project output for data confidentiality issue.
Because of this feature of the algorithm, we expect an average interval of the errors that could be higher than the average length of the links, so around 5.5 Km. This interval can be larger than 5.5 Km in case the links are not very dense, so MEEO decided to increase the grid resolution from 1 Km (the original one used by Aart Overeem (WUR - https://www.wur.nl/en/Persons/dr.ir.-A-Aart-Overeem.htm) to 5 Km, in order to filter any possible interpolation artificial effect.
The interpolation grid adopted for RainBO project is the one already in use at Arpae for the meteorological interpolated maps and for the limited area models. This choice was done to simplify the validation of our data.
The transition from the 1 Km to 5 Km grid was managed by the following steps:

1) applying the 1 Km interpolation with kriging method;
2) calculating the average estimation inside the 5Km x 5 Km square;
3) assigning the result to the central point.

In the above manner, the estimation uncertainty was cancelled, at least partially, as there are not any relationship between the average points positions of the links and the interpolation grid points.

Rainfall maps are delivered every 15 min with a delay of a pair of minutes of processing time (still to be tested in real-time); a daily accumulation map is produced every day.

Please refer to the Microwave rainfall data validation analysis done in autumn 2017 by MEEO and ARPAE. The validation was done on 2016 historical data. The related activities and results are described in the C2_5 Deliverable regarding the validation activity of the Microwave links data.

2.1 Rainlink package customization

The RAINLINK package is free for download on GitHub (https://github.com/overeem11/RAINLINK) but is not ready for processing. Debugging and improvements were needed and performed by MEEO in order to make it working and fit for our purposes. Main bugs derived from a supervening incompatibility with the R software, which was updated after algorithm release. Other minor issues were making the software harder to manage (warning messages, discrepancies in variable names, ecc) and were also solved. This work was done in connection with the main author of the algorithm via the GitHub platform and via email. The Rainlink package was not itself modified, but corrected copies of the main functions was added to the code written from MEEO specifically for the RainBO project. This new version of the algorithm that improves the original one is named Rainlink4EMR (Rainlink for Emilia-Romagna).

The adaptation to the RainBo needs includes graphic tweaks like map positioning and zoom setup and general appearance settings like data-scale colors and font styles.

The input data was formatted to the required format, which includes many informations about the links characteristics (as shown later) which were not always easy accessible. The code used to add these informations to the dataset is included in the Rainlink4EMR package.

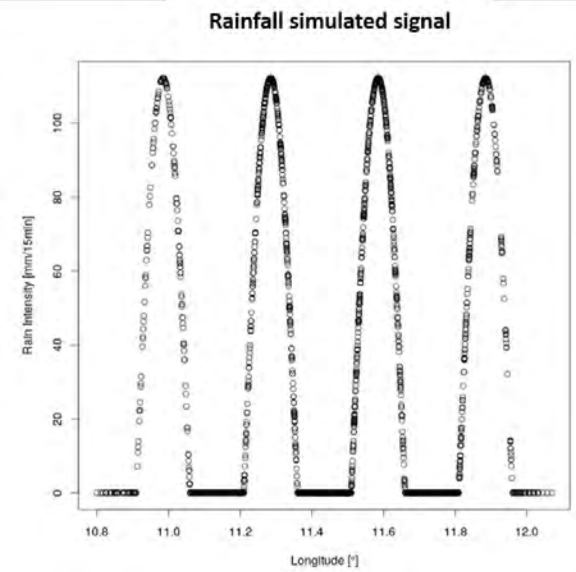
A shell script was written from scratch to control all the processing procedure: it automatically downloads and formats the available data, sends them to the algorithm and prints the graphical outputs. This script is called *service.sh and* is the core of the Rainlink4EMR module.

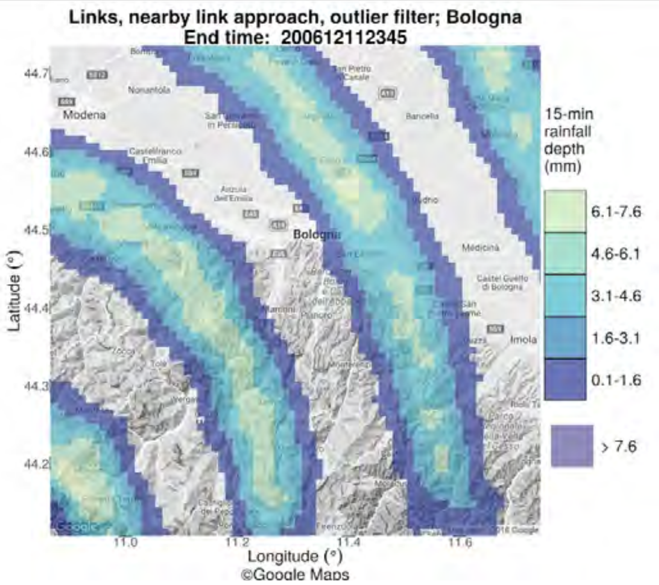
2.2 Rainlink algorithm tuning and calibration

The algorithm allows many physical parameters which are related to precipitation characteristics to be adjusted to the local atmospheric conditions. The parameters consists in: 1) thresholds and ranges to discriminate real rain from other attenuating phenomena (fog, frost, dew, snow, ecc..), 2) constants which weigh the means over 15 mins and 3) semivariogram parameters that lead the ordinary-kriging-interpolation procedure. This study will be done in the future, in parallel to the RainBO project, during a related research activity that will represent a follow-up of the MWL data validation activity, in the framework of a current scientific research study that will be completed in 2019 by a Earth Physics Master Student at the University of Bologna, Trainee at MEEO srl. Please refer to the chapter 6 "Suggested improvements" of the C2_5 deliverable on the validation of the Microwave links data.

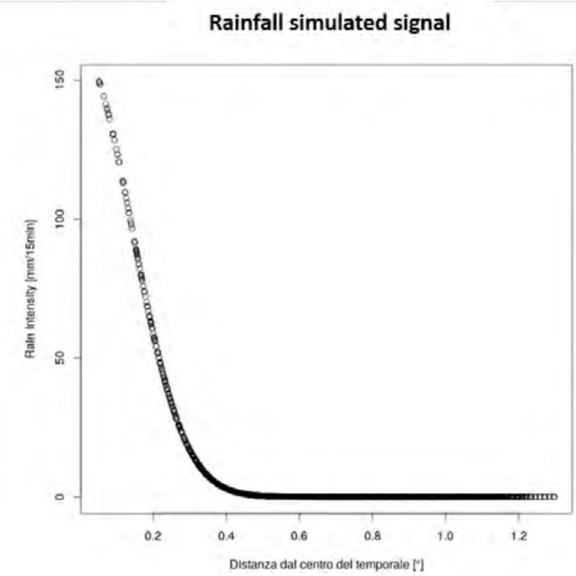
We expect to find different behaviors over land and over mountain, so different calibrations may be choosed.

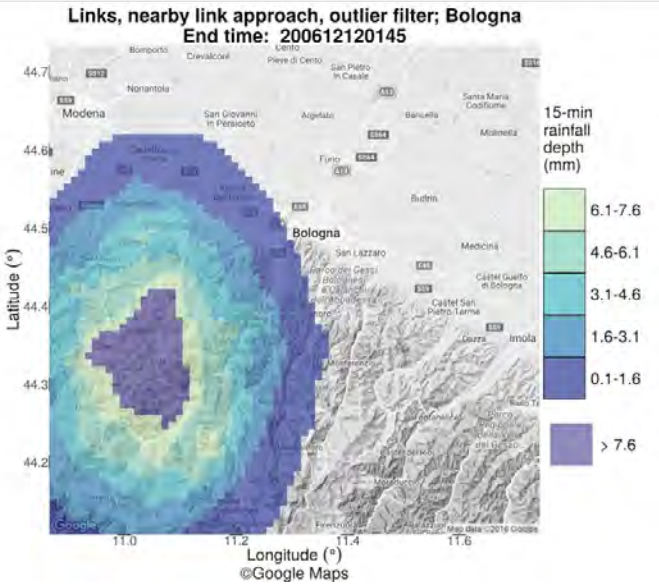
When data was not yet available, a simulation on fake data has been carried out to test the algorithm capabilities and solve the bugs (see before). The rain signal was built first as a sine wave, and then as a thunderstorm-like spot fading like a normal distribution (Gauss), both moving across the target area. The signal was added with some random noise to gain a more realistic shape and then inversely processed to become an attenuation in power received from a network of imaginary antennas (also created by the algorithm). This simulated dataset was then correctly formatted and given to the Rainlink4EMR algorithm as real rain. This helped to gain informations about how rain retrieval and interpolation work. The code used for these simulation is not included in the package but can become a spin-off.





Thunderstorm simulation





3. Area of Interest

The area of interest considered in the implementation of the procedure is a square about 90 km wide which covers all the province of Bologna. Another quite similar over Parma is ready and waiting for data from Vodafone.

Adjusting the algorithm to the target area was done by MEEO by creating a grid for the interpolation of the same type and density of the one used for Netherlands and provided with the algorithm package. That is, the interpolation points are about 1 km apart and the shape is nearly a square. Along with the grid, a series of polygons is also generated to allow the printing of shapes over the geographical map. All the code written by MEEO for this purpose is provided inside the new Rainlink4EMR package.

4. Data Procurements and interaction with data providers

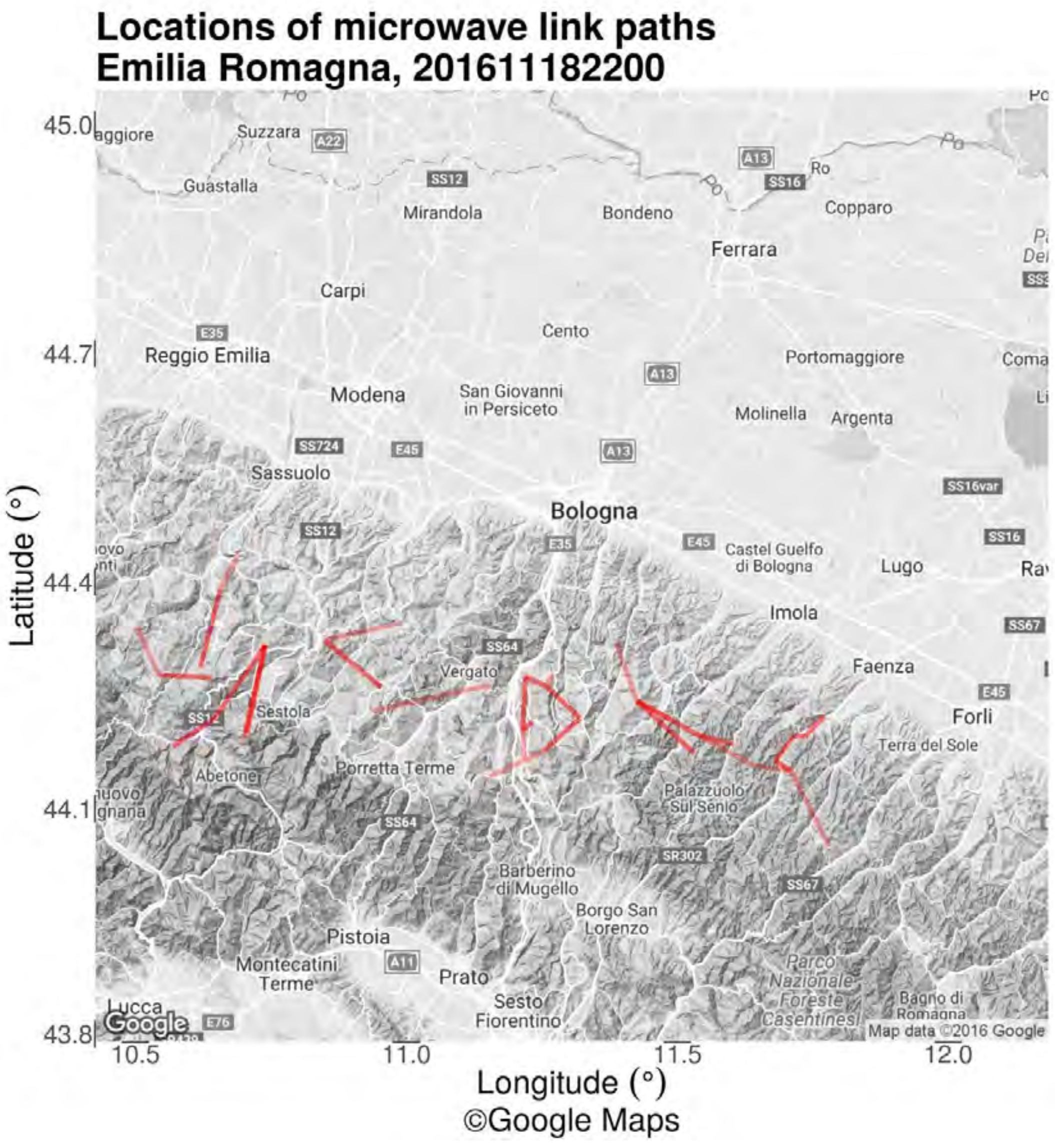
Data requirements for the algorithm to work properly: continuity in time (at least 24h before the interested time), high density of links (not met yet), dry periods in the past 24 hours long enough (3-6 hours) to calibrate the reference dry level of the link.

MEEO asked for Microwave links data for the project to the following telecommunication operators:

1) Lepida: they provided data on the Apennine area of the Emilia Romagna Region
2) Telecom: they did not provide any data as it would have required a huge effort not in line with the deadline of the project.
3) Vodafone: they provided data on the metropolitan areas of Bologna and Parma.

In the document RainBO_C2_5_deliverable_ValidationPrecipitation.pdf, the requirements necessary for the collection of the Microwave links data to the telecommunication operators are reported. Aside from time and power readings, informations needed unconditionally are the location of both sides of the link (geographical coordinates) and microwave working frequencies.

Following the map with the Microwave link data already provided by Lepida, covering the Apennine area of Bologna:

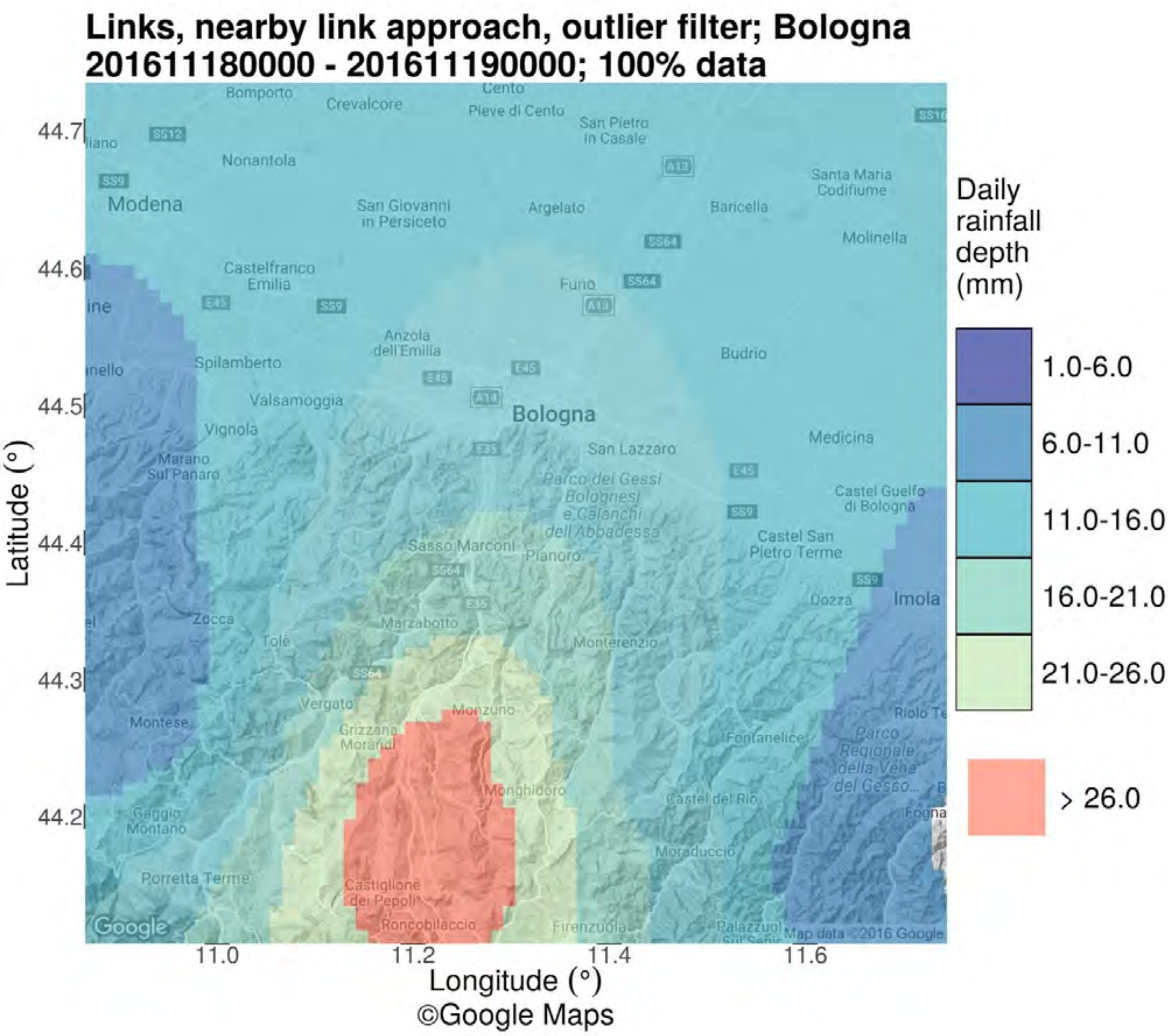


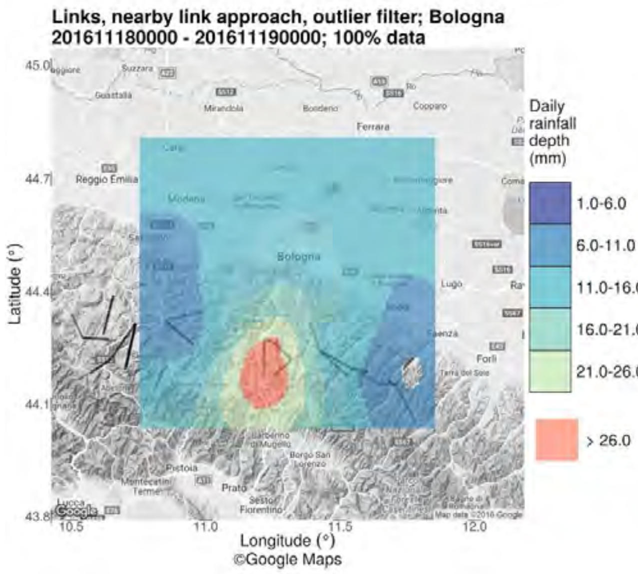
In 2017 we received further data from Lepida, covering Parma Apennine area and data from Vodafone to cover the whole Bologna and Parma urban areas. The Dec 2017 deliverable C2_5 on the Microwave data validation refers to Lepida and Vodafone data on Bologna.

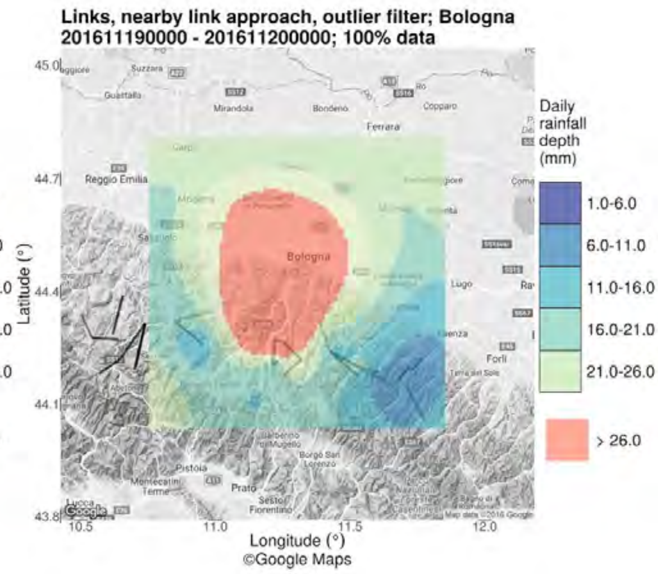
5. Results and Validation

The algorithm works fair over the target area. Current limitations in the accuracy of the estimations are caused solely by the lack of available data. Comparisons with hydrological informations and radar reflectivity maps show good correlation in time and raw correlation in space. Tests show that the algorithm works best with short high density links that cross each other. That is not the case of the network now available (Lepida only). The scarcity of links made available is clearly noticeable in the pictures.

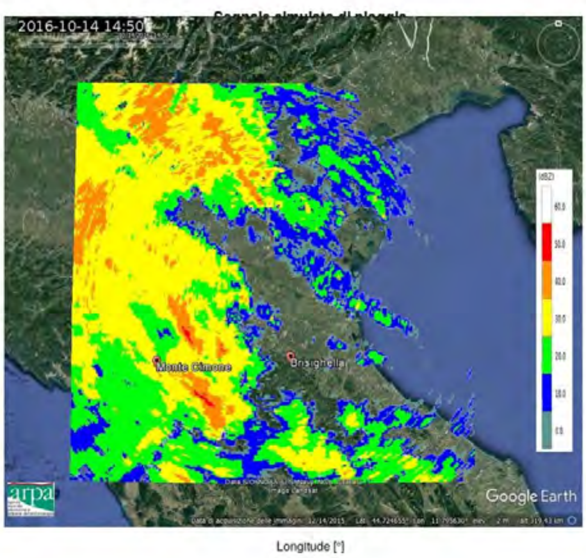
Following some pictures of the accumulated rainfall estimation maps obtained by applying the customized algorithm and the comparison with Radar images:

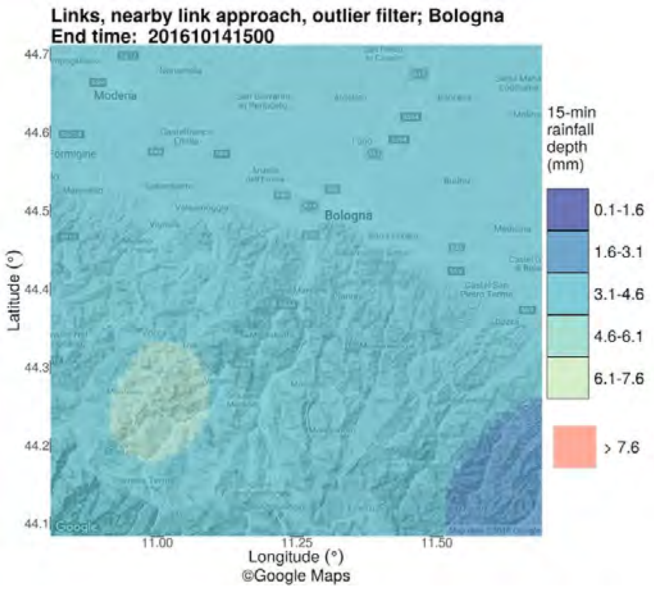


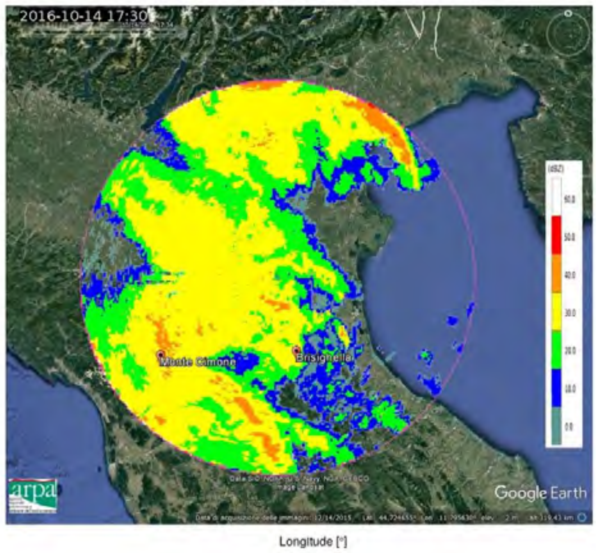


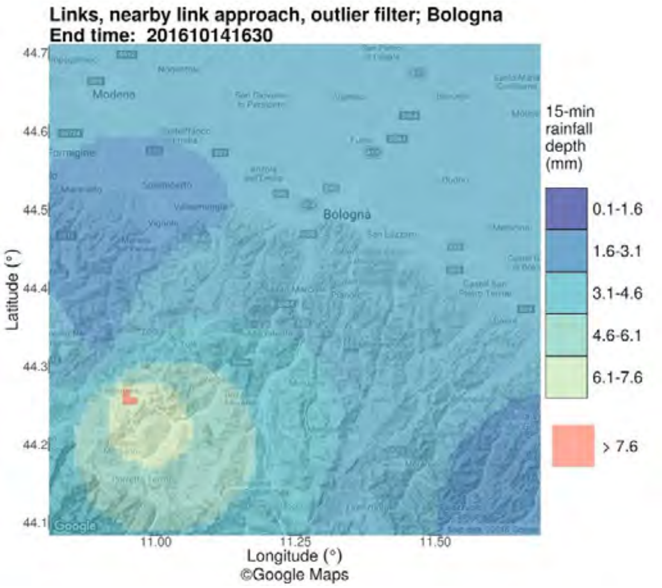


Comparison with Radar rainfall estimation maps (at 15:00 and 16:30 respectively)









6. Next steps

In the validation activity that will be done in the project to validate the Microwave links data, many comparisons will be done among Microwave links data, radar and ERG5 (interpolated rain gauges) ones, by carrying out qualitative and statistical analysis.

The deliverable C2_5 will describe in detail this activity and its results.

The package will be further implemented to retrieve on-line data automatically in a processing cluster equipped by Lepida.

The new monitoring infrastructures will later include a crowdsourcing component that makes possible the retrieval of citizens data and their sharing towards all the interested actors, like Comune di Bologna, Arpa Emilia-Romagna, Emilia-Romagna region etc, citizens included.

The app will allow moreover, the integration of the citizens data with other commercial applications that already collects data from non-conventional networks.or from existing crowd sourcing App (i.e).

7. Bibliography

Some literature information regarding microwave links rainfall monitoring systems:

(Overeem, A. , Leijnse, H. , Uijlenhoet, R. , 2011)

Water Resources Research 47 (2011). - ISSN 0043-1397 - 16 p.

Measuring urban rainfall using microwave links from commercial cellular communication networks

(Overeem, A., Leijnse, H., and Uijlenhoet, R., 2016)

Atmos. Meas. Tech., 9, 2425-2444, https://doi.org/10.5194/amt-9-2425-2016, 2016.

Retrieval algorithm for rainfall mapping from microwave links in a cellular communication network

MSc thesis at Hydrology and Quantitative Water Management Group of Wageningen University (WU) - Measuring rainfall using cell phone links: calibration and validation using a high-resolution X-band radar https://www.wageningenur.nl/en/show/Measuring-rainfall-using-cell-phone-links-calibration-and-validation-using-a-highresolution-Xband-radar.htm

8. Reference documents

In the document **RainBO_specification_of_requirements.pdf**, deliverable of the C1 action, with the requirements for the collection of the Microwave links data.

Please refer to the deliverable **RainBO_C2_5_deliverable_ValidationPrecipitation.pdf** for a final version of all the Microwave data that will be definitely provided by Vodafone and Lepida and that will be used in the validation activity.

Please refer to the deliverable **RainBO_C2_6_DataCollection.pdf** for details regarding the software package used to collect the Lepida and Vodafone data.