Enhanced Urban Rain Surveillance Systems for Smart city Solutions – EU-RainS⁴

Yann Dufournet[1*], Albert Oude Nijhuis[1], Igor Stepanov[1], Christine Unal[2] , Herman Russchenberg[2]

[1]SkyEcho VOF, Stationsplein 45, 4th floor, 3013AK Rotterdam;
[2]Delft University of Technology (TU Delft), Stevinweg 1, 2628CN Delft;
*Corresponding author: y.dufournet@sky-echo.eu

ABSTRACT

Europe is facing more frequent occurrence of severe and very local rain storms that mostly affect city's population and infrastructure at street-level. In the near future, an increasing number of city governments and corporates will be pushed to manage weather risks more pro-actively. However, current rainfall monitoring systems are not adapted for city observation, decreasing their potential benefit for weather resilience actions.
In this project, state-of-the-art X-band rain radar technology has been successfully upgraded to a new system that provide the most accurate rainfall information, fully adapted urban areas. A system demonstrator was created in the pilot city of Rotterdam.

Keywords: Radar; Weather resilience; Smart-City, Water management

1. INTRODUCTION

Europe is facing more frequent occurrence of severe and very local rain storms that mostly affect city's population and infrastructure at street level. High-resolution rainfall monitoring in city is an efficient way to improve urban weather resilience, the temporal and spatial resolutions of rainfall data required for urban applications exceeding those needed for rural catchments. However, current monitoring systems are not adapted and often inaccurate at city scale, making them ineffective for urban resilience.

EU-RAINS⁴ aims at improving the usability of rainfall data in cities by increasing their accuracy, trust and accessibility for operational water management.

This work is based on X-band radars, a technology widely used in atmospheric research to best study rainfall mechanisms at high-resolution on a regional scale. Yet, such a technology remains challenging for urban environments that are heavily cluttered and for which real-time management operation is required. A set of IT tools and filtering algorithms have been designed to drastically upgrade the X-band radar technology for cities.

The results were integrated within the first advanced X-band radar ever deployed in a European city, in Rotterdam, The Netherlands (Fig. 1). The project demonstrated that X-band radars can successfully be operated in cities. The project resulted in the following:

- a set of clutter filtering techniques were designed and deployed in the real-time processing of the radar to reduce unwanted echoes in the radar signal.
- A data merging strategy was explored to integrate the radar derived rainfall output within a network of additional rain sensors in the area. The goal is to improve representativity and coverage of the rain cells.
- A robust real-time data feed was developed to simplify data access for multi-purpose applications

Fig. 1 X-band Radar Rijnmond deployed and operated in Rotterdam

- An initial research on market analysis and business applications potential was investigated. The resulting HD rainfall data is already provided to early adopters (city and regional water managers).

A demonstrator of the technology is now running real-time in Rotterdam to evaluate the potential for water management.

2. STATE OF THE ART

Several sensor techniques are currently deployed in Europe to continuously monitor rainfall for weather surveillance and water management. One can mention:

- **Satellites** for large scale observation at low spatial and temporal resolutions
- **C-band radar network**: they are considered as the most optimum sensors to monitor rainfall at country scale. In Europe, a network of C-band radars (OPERA) is operated by the national weather services to cover the entire continent and part of the coastal area.
- **Automatic weather stations network**: This granular stations are mostly used to complement and validate the above larger scale rainfall data.

One of the key problems in urban studies is the lack of representative weather station observations at suitable spatial and temporal resolutions. Urban areas have distinct micro weather features attributable to their infrastructure and surface properties as well as associated anthropogenic activities such as transport and industry. The lack of coverage from a comprehensive city-wide network makes the representativeness of the rainfall situation at any given time difficult to retrieve.

Several innovative solutions are investigated to overcome this issue, such as the use of dense microwave links or crowd-sourced rainfall information (social media, cars's sensors …). Yet, their accuracy and representativeness for cities remain questionable.

The X-band radar is another proven technology. Mainly used by research institutes, it is however rarely placed inside urban areas:

- The environment is heavy cluttered (radio interferences, high building reflections, non-meteorological echoes…) which strongly affect the quality of the radar signal.
- X-band radars suffer from saturation and attenuation issues that can impact monitoring of extreme rainfall events.
- X-band radars are mainly used for research and national weather services but not adapted for large scale business applications.

Tab.1 Comparison X-band Rijnmond radar with C-band radar from KNMI.

specifications	X-band Rijnmond radar	C-band national weather service radar (KNMI)
Frequency	X-band	C-band
Scanning mode	Horizontal*	Volumic
Polarisation	Quad-pol	Dual pol
Monitoring height	115m	1000m
Maximum range	30km	300km?
Time resolution	1 min	5 min
Spatial resolution	100x100 m	1x1 km

3. BREAKTHROUGH CHARACTER OF THE PROJECT

At EU-RAINS^4, we created a **radar system demonstrator** that is able to provide the most advanced high-resolution rainfall insights in Europe in real-time for various city operations.

The system demonstrator is based on the processing of an innovative city-wide X-band radar technology, that offers many advantages in city, compared to the national C-band weather radars. The main added values are, the observation altitude that is closer to the ground (and therefore more relevant) and higher spatial and temporal resolutions (see comparison in Tab. 1 and Fig. 2).

The major breakthrough comes from the way the demonstrator is further adapted for cities thanks to:

- Its successful integration into the Rijnmond radar, the first Quad-pol and Doppler X-band radar ever deployed in a European city, in Rotterdam - The Netherlands. The advanced capabilities of such a system, provides unique Doppler polarimetric information that can be added in the current software to further process and clean the signal in real-time.
- A unique merging of an urban-specific upgrade of the radar processing software with an innovative data management server architecture.

The system demonstrator is also part of the national Ruisdael observatory, a research infrastructure to study

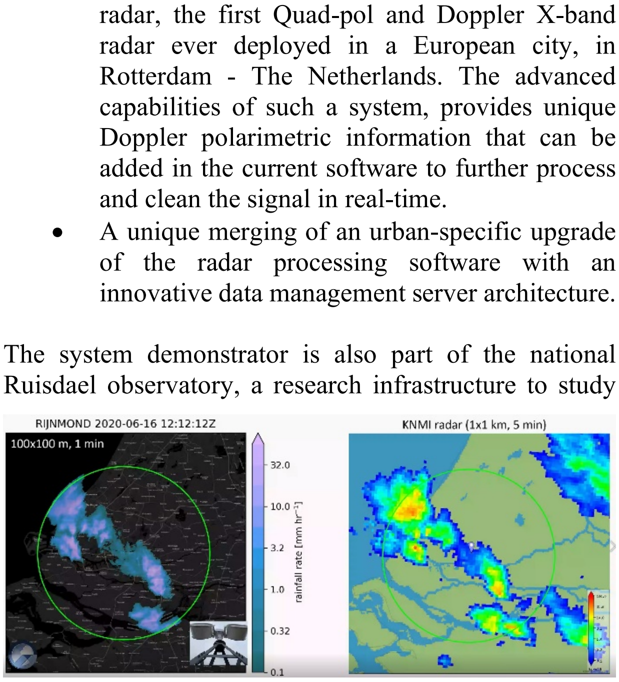

Fig. 2 Comparison of a similar rainfall event observed at high resolution with the Rijnmond radar (left) and at lower resolution with the radar from the national weather services (KNMI)

atmospheric processes, linking data and models for climate change, weather and air quality predictions. The project takes advantage of the multi-scale rain observation provided by Ruisdael.

4. PROJECT RESULTS

The development of the demonstrator has resulted in several milestones:

4.1. Result 1: New Clutter filtering for urban environment

One of the core features of the demonstrator is to drastically reduce any unwanted echoes within the radar signal and deliver the best rainfall quality. To do so, the following filters have specifically been developed for heavy urban cluttered environments:

- New noise estimation from activate copolar spectra has increased noise removal in the PPI signal.
- clutter filtering based on a set of spectral polarimetric parameters has improved the clutter removal from the signal
- Radar pixel discarding has been added based on Doppler, Saturation and spectral quality index to further improve clutter removal
- Pixel reconstructive process has finally been added to interpolate pixels which was too much affected by clutter and removed
- Automatic receiver attenuation control was finally implemented to reduce saturation issue of the system that produced signal distortions.

These techniques have been integrated in real-time in the demonstrator (Fig. 3). A drastic urban clutter reduction and a better management of surrounding noise (up to 25% increase noise detection) are initially observed.

4.2. Result 2: New Data integration

Radar data merging addresses the need for forecast of the rain for the coming 1-2 hours. Alone, the high-resolution measurements are, drifting with the wind, and typically only valid for 30 minutes in the radar area.

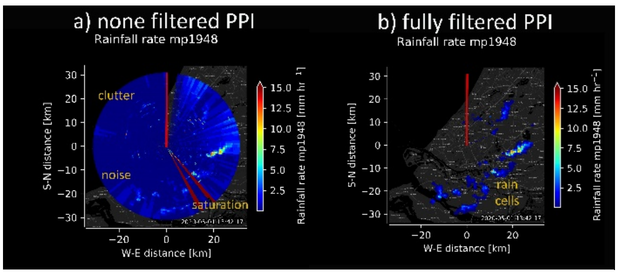

Fig. 3 Result of signal filtering processing achieved on the Rijnmond radar: a) no filter applied; b) all new filters applied with only rain cells remaining.

For this issue, composition techniques are investigated to merge the national C-band radar data (with high coverage) with the X-band radar data (high-resolution), in order to provide the best end-product to potential users. The techniques analysed are based on:

- Data gridding techniques, to homogenise the rainfall field to the same grid system
- Data interpolation: to take into account scaling and time differences. Three types of interpolation have been tested: nearest neighbour, bilinear and rtb, the last one providing the best results so far.

It is still under development as we write this article.

4.3. Result 3: New data feed management

The data management was designed with robustness, versatility and security in mind. The data-management framework for operational radar-data is deployed on top of a fully serverless AWS architecture.

Data flow: The rainfall data is initially generated directly on the radar processing-unit. This unit runs an AWS agent, which monitors the newly created rain-files. The AWS agent then uploads them instantly to a dedicated S3-bucket on AWS. This S3-bucket is the main storage for radar-files, in NetCDF format.

Infrastructure: A lambda function is triggered upon a new real-time radar-file in the S3-bucket. This function extracts the rainfall-rate values, and stores them in a MySQL database, for easier and robust programmatic access of third parties. The interface between MySQL database and clients is the API-Gateway[1].
The same API endpoints can be used for any visualization purposes, or even embedded system triggering. This opens many possibilities of usage, as any mobile or web apps can use this type of access.

Additionally, some clients still require NetCDF file access. A fully managed sFTP service was then deployed, with which user permissions are issued. In this case, clients have instant access to NetCDF files, as soon as they become available in S3-bucket, distributed via sFTP custom AWS access policies.
Since May, the HD rainfall data are integrated within the water management systems of the local authorities for testing.

4.4. Result 4: Student program: Pre-analysis of business and societal application potential

SkyEcho invested in several product design's programs within ATTRACT. We supported three different groups of students to ideate and prototype potential applications that demonstrates the applicability of the innovation for different urban applications:

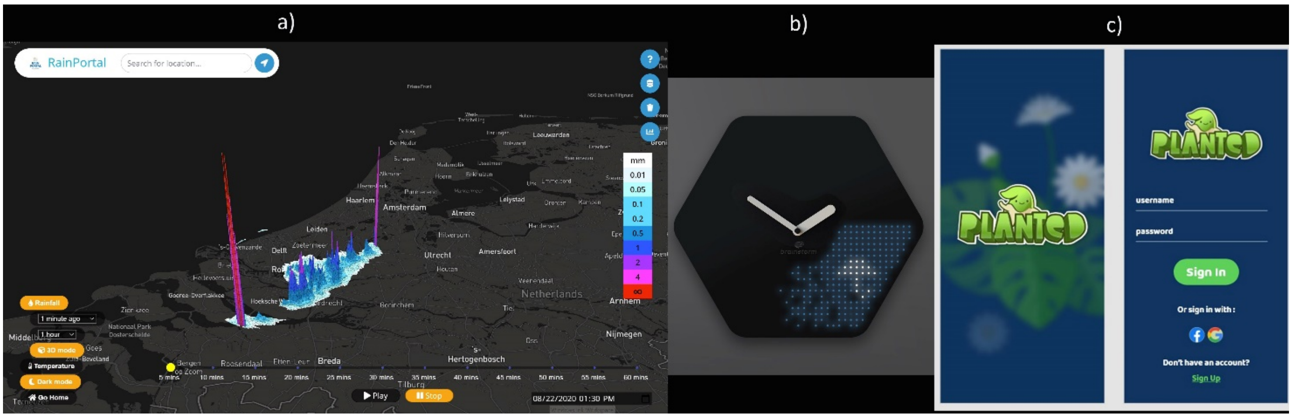

Fig. 4 - Example of technological applications developed in 4.4: a) prototype of webapp to visualise rainfall for water management, b) design of an smart IoT 'weather clock', c) Prototype of an app game to increase public awareness of rainfall variation in cities.

- <u>Rainfall warning and public awarenes</u> - Aalto PDP program (9 months – 6 students) – Fig.4b and 4c. The students focused on prototyping a digital solution based on gamification activism, market research and speculative design theory[2].
- <u>Innovation on the way to vizualize HD rainfall insights</u> - Aalto Summer internship program (3 months - 4 students) – Fig. 4a. A user-centric webapp is currently being developed to improve the data management experience.
- <u>Use of the technology to retrieve other type of information and increase the added value of the system</u> - Ideasquare – CERN/TU Delft summer school (1 month – 3 students) – The students focused on the alternative market potential of the technology for Hay fever monitoring.

5. FUTURE PROJECT VISION

5.1. Technology Scaling

Phase 1 of EU-RainS4 has just reached TRL 5, thanks to the deployment of the demonstrator in Rotterdam.

<u>To reach TRL6,</u> **potential limitations and biases** of the new technology need to be further **investigated** against different weather conditions and other available rainfall measurement techniques. A particular attention will be given to better estimate rainfall rate in partial beam blocking areas.

<u>To reach TRL 7,</u> **phase 2 will be <u>application-driven</u> to turn the project into a pre-commercial scale.** To achieve that, we want to create a **cutting-edge innovation platform**, mixing both, low-code and agile web structures. The platform will act as **application catalyser** by adding several **original and multidisciplinary** toolboxes to support application development.

5.2. Project Synergies and Outreach

To get a step closer to commercialisation, the expanded consortium in Phase 2 shall reflect and support this application's development need. The size of the consortium is expected to grow from 2 to 7-8 members, **with interdisciplinary profiles**:

- <u>Early adopters</u>: We particularly search for public partners (city or city-scale programs) and businesses working on weather resilience, that can already benefit from our solution.
- <u>Organisation with **expertise**</u> on environmental applications in the field of AI, augmented/virtual realities, IoT and 3D printing (see section 5.3).

We seek collaboration with ATTRACT projects working on environmental monitoring as well as the project DEBARE on augmented reality.
The platform will integrate a collaborative ecosystem architecture (Fig. 5), where project partners and external contributors can jointly access a common virtual working space. This will allow a single access point for an **efficient project content-making** that can be extracted for any public dissemination and outreach.

5.3. Technology application and demonstration cases

HD rainfall obtained in Phase 1 unleashes an infinity of new smart applications in cities. In the platform, tailored toolboxes will be engineered to demonstrate the use of the technology for the following application challenges:

Research challenge: Outputs obtained in Phase 1 will be used to improve our understanding of the urban climate and develop **the most accurate HD rain nowcast (2 hours forecast)** for cities, based on AI and sensor merging. A partnership with the national Ruisdael observatory, will be considered to integrate the results of Phase 2 in their research plan.

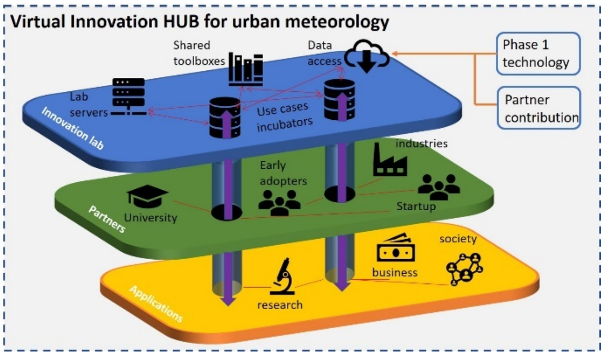

Fig. 5 – example of the multi-layered innovation platform structured to support new application incubation.

Societal challenges: Climate awareness - The spatial resolution provided via the new technology helps regain trust on rainfall information and weather warnings at street-level for outdoor activities. In Phase 2, research will be conducted to **integrate physical rainfall triggered embedded system products in the urban space** to warn the public about potential rainfall threat and improve city resilience. This work package shall make use of advanced IoT and 3D printing technics to allow for fast prototyping of smart products adapted to specific uses.

Industry challenges: Although 70% of businesses are affected by rainfall worldwide no clear mitigation solutions currently exist. Thanks to the accuracy achieved in Phase 1, business processes and supply chain indicators can better be evaluated against the rainfall insight at high resolution. **In Phase 2, we want to develop statistical and AI-based algorithms to support such analysis**. Innovative AR and VR technologies will also be investigated to improve data manipulation. Businesses will become more aware of the rainfall impact, allowing tailored mitigation actions.

5.4. Technology commercialization

The steps to reach the full commercialisation potential of the technology are:

Go-to-Market Phase (2 years): EU-RainS^4 is falling under the concept of 'blue oceans', a technology-push innovation with high development risk combined to high potential return. For such innovations, the biggest challenge is to **reach investor readiness**, i.e. become less risky. Within phase 2, a strong emphasis shall be given on full market research using business canvas, client interviews, pricing and marketing strategies. The goal is to determine beachhead markets and the related flagship solutions that will drive the early business development. **A particular attention will be given to the development of application demonstrations** integrated in the innovation platform.
In Phase 2, a budget of 1,2-1,7 million Euros for application deployment and go-to-market phase preparation will be requested.

Scale-up phase: To start the business, scalability is crucial, so that the technology can be adapted to different locations and needs. Additional investment will be needed to develop a legal, commercial and technical upscale, in order to achieve a commercially viable weather-data-as-a-service business model.

5.5. Envisioned risks

- Lack of expertise (especially in the business sectors) – such a risk will be mitigated by integrating business incubator (possibility to integrate Climate KIC – Phase 2) and hiring third-party experts when deemed necessary.

- The lack of profitability of the technology: the initial cost of the new technology is high, forcing the revenues to be spread over many segments. If needed, new applications and new market segments will be added to boost the attractivity.

5.6. Liaison with Student Teams and Socio-Economic Study

EU-RainS^4 was lucky to have 14 motivated students participating in Phase 1, providing valuable feedbacks on the collaboration with students. In Phase 2, we plan to continue this collaboration effort via the innovation platform where communication tool and necessary content will be accessible. On-site workshops shall also be organised (if possible) to create the initial connection with the project team.
The platform will also include socio-economic indicators to monitor the development and potential of the initiative.

6. ACKNOWLEDGEMENT

The Authors would like to express their gratitude to all the students, university program organisers and ATTRACT management team that supported the project. We also would like to warmly thanks ESADE for the business initiation and their support for online dissemination. A final thanks to the city of Rotterdam that provided us the opportunity to use the Rijnmond radar and acted as first data testers.
This project has received funding from the ATTRACT project funded by the EC under Grant Agreement 777222.

7. REFERENCES

[1] Example result API-Gateway: https://dmhlfqz1u8.execute-api.eu-central-1.amazonaws.com/dev/latest-rainfall-rate/
[2] Brainstorm – Building the resilient city of Tomorrow – Final PDP report, Aalto university - link