©2022 Published in 6th International Symposium on Natural Hazards and Disaster Management
21-23 October 2022 (ISHAD2022 Bursa - Turkey)
https://doi.org/10.33793/acperpro.XXXX

Weather Radars for Hydro-Meteorological Disaster Early Warning

[1*] Emre ÇİFTÇİBAŞI, [1]Yücel ÖZDEMİR, [1]Ergenekon HASSOY and [1]Murat BAŞARAN
[1] RST Inc., Ankara, Turkey

Abstract

In this paper, algorithm requirements of X-Band METRAD radar system in scope of Hydro-Meteorological Disaster Early Warning are described. Requirements for detection of low altitude smoke plumes caused by grass, brush and forest fires to locate the flame center is key to fire hazard early detection. Similarly, requirements of sensing flood clouds and calculation of flood risk from medium distance giving up to 1-hour is critical for flood warning systems. Conclusions section include how radar visualization of winds alert emergency teams for spread of fire/flood according to disaster maps and environmental parameters

Key words: Radar, emergency, disaster, warning, fire, flood

1. Introduction

RST Inc, established in 2012 is a technology developer company for radar, RF and electronic warfare systems. Company specializes in system design, hardware and software engineering, related test infrastructures and technical consultancy.

METRAD System is the X band polarimetric weather radar developed by RST Inc. under governmental support and named as national weather radar in Turkey. The entire METRAD system including all the software starting from RF and signal processing to meteorological products are sole property of RST. System is shown in Figure 1, sub-blocks are listed in Figure 2.

Figure 1. Transportable METRAD System

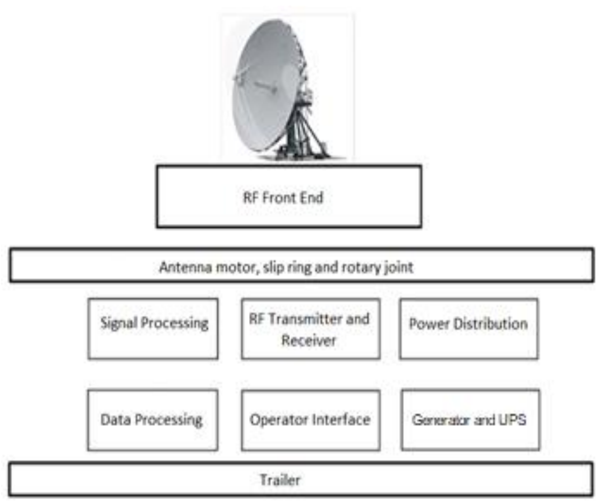

Figure 2. METRAD System Blocks

*Corresponding author: Emre Çiftçibaşı Address: RST A.Ş Hacettepe Üniversitesi Teknokent, Üniversiteler Mah. 1596. Cad. No: 95/6-7, 06800 Çankaya/Ankara. E-mail: eciftcibasi@rstteknoloji.com.tr Phone: +90 312 287 0115

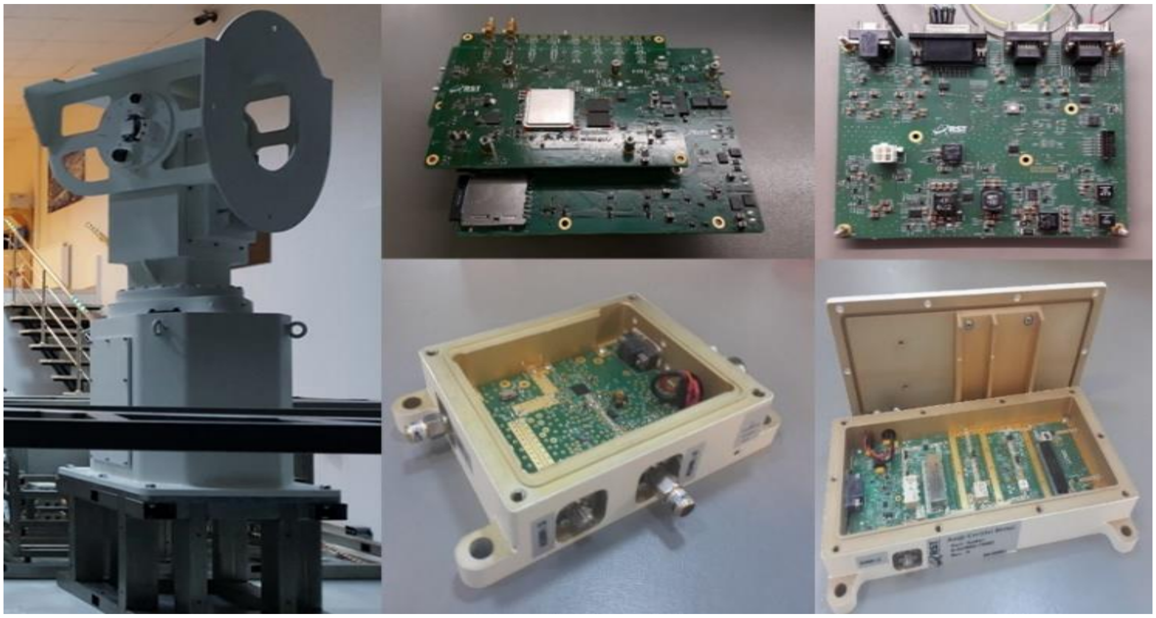

Figure 3. METRAD System Components

2. METRAD System Meteorological Capabilities

2.1. Meteorological Moment Generation

System provides the user with raw moments of meteorology regime such as reflectivity, velocity spectral width etc. which are produced from digital I/Q data produced by Signal Processing Unit from the received x-band radar signal reflections. Meteorological regime products to be used in emergency hazard detection and prevention are produced from these raw moments.

Table 1. Calculated Meteorological Base Moments after Signal Processing

Base Moment	Moment Description
Z	Reflectivity (clutter corrected)
T	Total Reflectivity (not clutter corrected)
ZDR	Differential Reflectivity
Vel	Radial Velocity
Width	Spectral Width
ØDP	Differential Phase Shift
KDP	Specific Differential Phase
TV/ZV	(Total) Reflectivity in vertical channel
Z	Reflectivity (clutter corrected)
T	Total Reflectivity (not clutter corrected)
ZDR	Differential Reflectivity
Vel	Radial Velocity
Width	Spectral Width
ØDP	Differential Phase Shift

2.2. Meteorological Product Generation

The hardware supplies the signals to custom developed signal processor cards shown in Figure 3, which transform the signals to base meteorological moments and then makes the following meteorological products available in METRAD user interface, as listed in tables below, as defined by Chandarsekar [1] and Zhang [2].

Table 2. Validated Meteorological Products Currently Operational in METRAD System

Meteo. Product	Product Description
PPI	The rate of precipitation received by horizontal scanning (reflectivity)
CAPPI	The amount of precipitation at a certain height
PCAPPI	The amount of precipitation at a certain height (with interpolation for regions with no signal)
MAX	The height with the heaviest precipitation, on the vertical axis for each coordinate
VIL	The total amount of precipitation between the two heights
RHI	The rate of precipitation of all elevation levels, received by a vertical scan

For validation of METRAD algorithms, we have performed many tests in the field, especially near the General Directorate of Meteorology (MGM) site in Elmadağ, Ankara. Transportable METRAD system if left for operation for months at Elmadağ radar site, and the data obtained is compared with MGM live radar data on the web. Results from standard C-band radars and METRAD are very similar, with METRAD giving much more in depth meteorological information as it is operating at a higher frequency band, namely X-Band.

3. Meteorological Radar Requirements for Hydro-Meteorological Disaster Early Warning

RST has performed years of hard work on developing the transportable meteorological solution. In the first phase of project, system hardware and meteorological baseline is established. Second phase added advanced software capabilities to METRAD System, most of which was a success. These advanced software algorithms are operational in X-band METRAD System, as of 2021.

METRAD system is in a third phase of development as of 2022, in which phase disaster early warning capabilities and decision support tools for disaster teams are being added to the system. “Seeing the wind” as performed by Istanbul Technical University [3] is the most essential capability for emergency early detection and decision support to be added to METRAD system in near future. But in near future other signal processing capabilities currently available in Wind Shear Detection Systems as explained by John Y. N Cho, Robert G. Hallowel, Mask E. Weber in [4] will be added to METRAD system making METRAD an essential tool in airports, allowing safe landing of commercial aircraft in case of dangerous wind conditions.

In this third phase of our system development, we are currently adding wind visualization to the system. With artificial intelligence, meteorological algorithms are not only enabling emergency early detection but also “seeing” the wind and knowing the digital map vegetation/urbanization/flood map details, system can “predict” the areas that the fire/flood will spread, which alerts emergency firefighting and flood rescue teams for near future dangers of emergency event, which will save many lives. The capabilities currently added to the system are listed below.

3.1. Hydro-Meteorological Disaster Early Warning System Requirements

- Precise wind detection and visualization
- Early warning and emergency detection algorithms
    - Forest and agricultural fires early warning (smoke detection)
    - Flood prediction and early warning (algorithm design suppresses noise where rain starts/ends)
- Representation of all algorithm outputs on real land and sea maps
- Inter-changeable hydrometeor classification parameters
- Remote control of the system with standard software
- Ability to save screenshots / visual 3D radar display videos.

Also, one of the main objectives of this work is to ensure that meteorology engineers directly participate in algorithm design and development activities. For this purpose, a wide range of university-industry cooperation and remote access capabilities are planned for data recording and playback including scenario studies on laboratory hardware prototypes for algorithm and software development.

3.2. Precise Wind Vector Detection via X-Band Radar

For sensitive wind detection algorithms/software, the ICAO 9817 Low-Level Wind Shear standard has been examined and it has been seen that the main system and software architecture of the METRAD System is suitable for producing these products in future.

Due to the fact that the project target is early warning of disasters, ICAO requirements will not be directly targeted in this project, but studies that can be made to ensure that the sensitive detection capability meets ICAO requirements will be especially evaluated.

Wind speed change, wind speed loss and gain values for sensitive wind detection are planned to be adjusted by the user, and early notification will be provided in cases within these limits. A subcomponent of the software will be developed in such a way that enlargement, reduction and scrolling can be done on the imaging software, and notifications can be presented as text and graphics. Warnings will be presented by being visualized with colors according to their severity.

3.3. Flash Flood Detection via X-Band Radar

Detection of dense clouds as well as the calculation of flood risk of clouds from a medium distance is also of utmost importance for flood warning systems.

It is aimed to collect data for early detection in flood environments by making measurements at the seaside areas from a safe distance close to real disaster locations.

Detection of dense clouds, movement prediction of dense clouds into mountainous areas and detection of possible future combinations of small clouds into dense clouds for the possibility of flooding from a medium distance and before the high-altitude meteorological radars reach the detection height is the first target in this context.

The objectives of the project include the detection of the areas where the disaster can occur, which requires the radar's wind vision, to respond to the flood in a short time and to make the flood prediction with high accuracy before the flood occurs, which requires a thorough assessment of wind and cloud formations as described in Figure 4 in the past time from the relevant meteorological data of the area with flash flood risk.

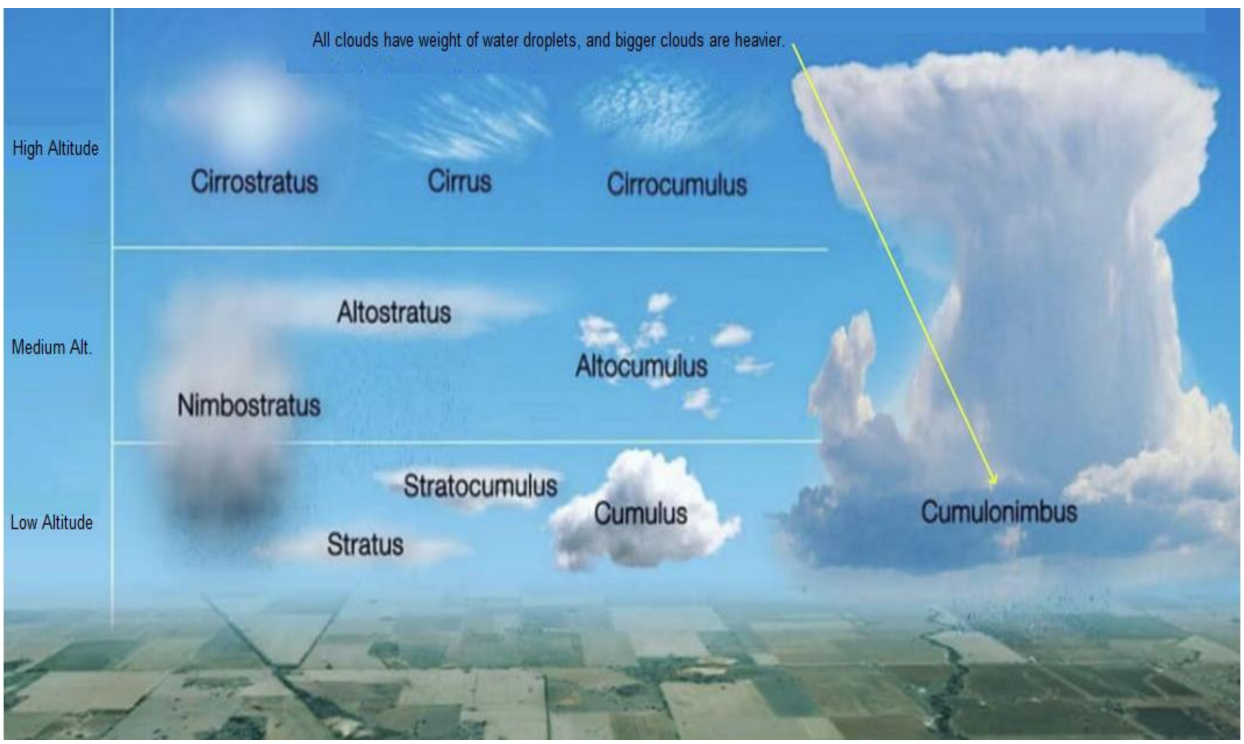

Figure 4. Standard Clouds compared to Cumulonimbus Flood Clouds

In cases such as the news that the possibility of flooding is increasing in agricultural areas, data can be collected also by taking the radar system to the field.

By combining detected dense clouds and "wind vision", a decision support system will be developed by making predictions about the flash flood detections.

Since high frequency will be advantageous with the use of X-band radar in flood forecasts, and meteorological field knowledge will be required due to factors such as temperature, pressure and humidity, it is planned to receive support in operational scenarios with field expertise from meteorological engineers who are experts in their fields, as in [5] and [6].

3.4. Smoke and Fire Detection via X-Band Radar

While trying to detect the smoke plumes caused by grass fire, brush fire, and forest fire, locating the flame center of fire is key to fire hazard early detection and elimination. Detection of the flame center of a forest fire from a medium distance before the fire is spread is a challenging research area. The smoke plumes are usually not detected by the high-altitude meteorological radars as the smoke did not reach the detection height of new targets for standard meteorological radars, but is easy for transportable meteorological X-Band radars, as described in [7] and [8].

Other objectives of the project are to detect the areas where the fire disaster can spread with the radar's wind vision, to intervene in the fire in a short time, to prevent new fires.

Figure 5 shows an example coverage of two METRAD radars to protect a touristic area of Turkey with 200 forest and agricultural fires in last 10 years, compliant with the requirements stated in this paper.

Adding the necessary functions for the system to precisely monitor the movement of smoke, precipitation and accumulated water in the air. Meteorological moments ZH, ZE, ZDR, Correlation Coefficient of previous scans and RHI are for default to be inspected.

Within the scope of sensitive wind detection, the aim is to monitor the precipitation regime, smoke and accumulated water separately and make direction predictions. Because these events are effective at the lower atmospheric level, they cannot be detected sensitively by long range meteorological radars in high positions in most cases with radial velocity values.

Different interpolation methods such as moving average, median filtering, smoothing methods etc. will be used to complete the missing and incorrect measurement values. Since wind speed variation is very important especially in adverse weathers, 1-dimensional and 2-dimensional derivatives over location. Pattern recognition will also be used on radar data.

Algorithms will be set up on a laboratory prototype setup for continuous development, and new radar data will be gathered from the field every day until the tests are finalized with near %100 guaranteed differentiation of smoke plume from precipitation regime and accumulated water, including clouds, rain and ice crystals.

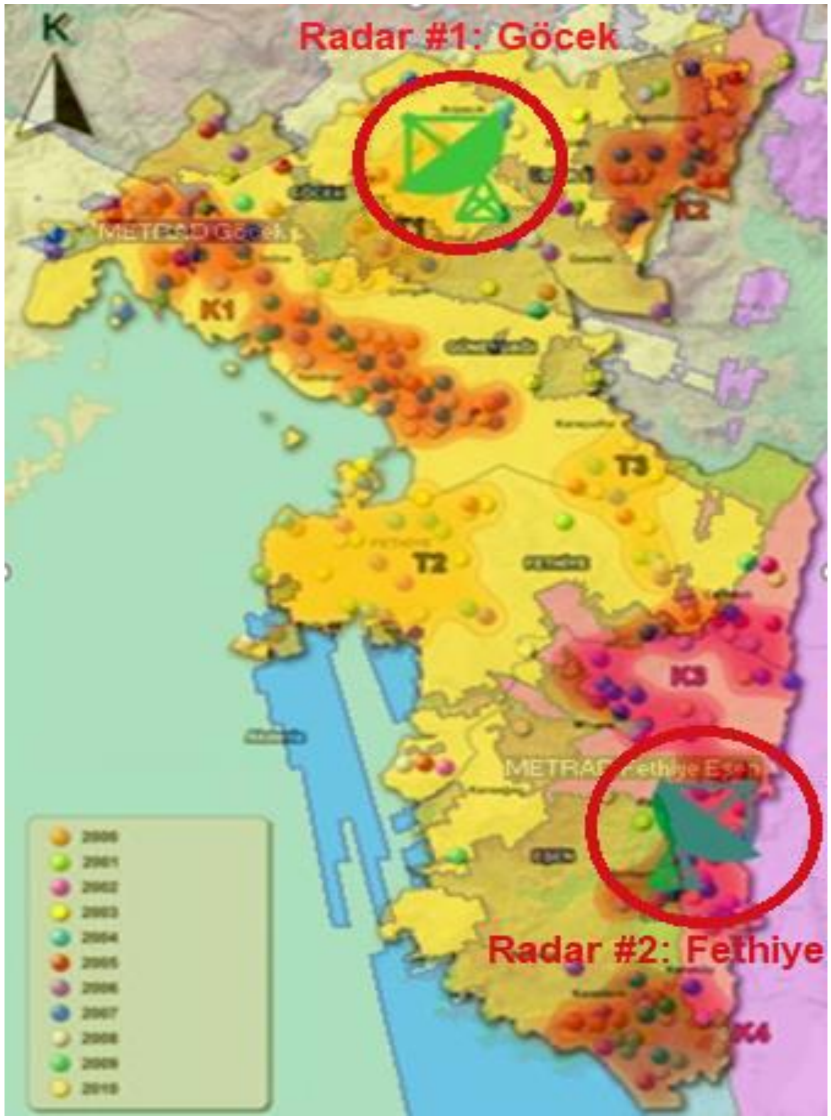

Fig. 5 Two METRAD Radars (Yellow coverage = Göcek radar, Pink coverage = Fethiye radar) is sufficient to protect a touristic area with 200 forest and agricultural fires in last 10 years

4. Discussion of Weather Radar Requirements of RST Metrad System Different From Products In International Market

The Process will have a standard Systems Engineering Lifecycle Process Structure, compliant with ISO/IEC/IEEE 15288:2015 - System life cycle processes as given in [9], but the Operational Concept Phase, Algorithm Development Phase, Software Development Phase (for User Interface) and Integration/Testing Phase will have more effect on final product than standard Meteorological Radars. Different approaches of our system development are listed below as weather radar requirements of disaster early warning.

4.1. Operational Concept Phase Requirements of Weather Radar for Emergency Management

In Operational Concept Phase, at least two operational scenarios will be formed and documented, each different from each other, in the fields of wind detection, flood forecasting, smoke detection, fire spread forecasting. All scenarios in the X-band radar operational concept will be written as System Operation Scenarios in the Operational Concept Document (OCD) and trials will be performed on Laboratory Prototype.

4.2. Algorithm Development Phase Requirements of Weather Radar for Emergency Management

In Algorithm Development Phase, existing algorithms will be assessed and new algorithms will be developed for each new capability of METRAD System.

Assessment of Existing Algorithms

- Examining globally accepted algorithms in flood forecasting, smoke detection, fire spread forecasting
- Investigation of measurement and calculation parameters and models related to the algorithms in question
- Determination of performance criteria with basic algorithm inputs and outputs.

New Algorithm Development

- Within the scope of sensitive wind detection, it is aimed to monitor the precipitation regime, smoke and accumulated water separately and make direction predictions. Because these events are effective at the lower atmospheric level, they cannot be detected sensitively by long range meteorological radars in high altitudes in most cases.
- By developing a flood forecasting algorithm, it is aimed to gain an integrated disaster forecasting and early warning capability with environmental factors such as temperature, pressure and humidity.
- By developing a smoke detection algorithm, it is aimed to monitor the most densely smoky areas, which are the source of fires, and during the fire investigate the causes of the fire.
- With the development of fire spread algorithms and wind products, the software will have wind vision and will calculate the regions where the fire will spread, considering the geographical data of the wind and precipitation conditions. It is aimed that the geographical location and terrain situation can be integrated into the software in near future.
- As an original study, it is aimed to develop pattern recognition methods based on machine learning and to provide benefits in the detection of fire centers from smoke reflections and fire spread predictions according to wind vision. Whether supervised or unsupervised, the machine learning framework needs large amounts of data. Since the frequency of such

weather events is low, training machine learning-based decision makers will take longer than the project development time. Despite this, necessary studies are envisaged in order to make an original contribution to this subject.

4.3. User Interface Software Development Phase Requirements of Weather Radar for Emergency Management

- For precise wind detection, wind speed change, wind speed loss and gain values can be adjusted by the user, and early notification will be provided in cases within these limits.
- A subcomponent of the software will be developed in such a way that enlargement, reduction and scrolling can be done on the GIS interface, and notifications can be presented as text and graphics. Warnings will be presented by being visualized with colors according to their severity.
- Early warnings will be converted into similar warnings in flood and smoke detection, and the system will be able to generate new warnings in order to direct firefighters in real time, as soon as new fire centers occur due to environmental effects during a fire emergency.
- It will be possible to predict new locations where the flood/ fire can spread according to the wind view and update the flood / fire forecasts with similar calculations.
- The contact information of all flood rescue departments and fire departments to which emergency warnings will be sent.

4.4. Integration/Testing Phase Requirements of Weather Radar for Emergency Management

- X-Band Portable Polarimetric Weather Radar’s new algorithms for precise wind, fire and flood detection will need to be added to the pre-existing software from an intermediate point, as new capabilities will also use previous software libraries.
- New software libraries such as smoke detection, fire propagation according to wind vision and machine learning are not easy to integrate into existing software architecture of radar and will be a challenge for software developers and test engineers. This is a factor that will complicate the integration process of the interface of the Data Processing Software and Meteorological Product Creation Software in the main structure, and even their pre-integration at a certain level.
- After each module of software integration, a test will be carried out on the flow of the central software and it will be analyzed whether there is an effect in this direction. In this context, existing radar software and system integration tests will be repeated in general, with the addition of new software. In order to carry out these tests, a laboratory prototype will be used.
- Although we hope not to have any emergency events in the future of our safe planet, after the development of smoke detection and/or flood prediction algorithms if the METRAD

System is active and suitable for travel, in case of a fire in forest or agricultural areas and/or a flash flood risk, a trip will be planned to go to the fire area to collect radar data.

- Basic performance requirements for precise wind detection software will also be fulfilled by signal injection method with synthetic data produced according to test scenarios. In addition, the software results will be thoroughly compared with the output of existing radar network of the General Directorate of Meteorology and other sensors located in the area.

5. Conclusions

With this project, it is aimed that the system will gain the basic wind vision, which can be easily converted into disaster warning systems, as a decision support tool.

METRAD system not only gives alerts for fire/flood events, but also helps the emergency teams as a decision support tool about the regions where the disaster can spread with the radar's wind vision. Decision support helps emergency teams with firefighting location suggestions protecting team from dangers of fire spread. Alerting the joining of many clouds into a single Cumulonimbus clouds add a possible new flood event while the flood emergency teams are in the area can be taken as a similar system capability for flash flood events. As cumulonimbus travels up to 40 mph over mostly sea areas, and METRAD radar range is always bigger than 75 km, this corresponds to up to 1-hour of early warning for flash flood events. 1-hour is a long time for disaster prevention teams, so for a pre-disaster early warning time this long time can be a great breakthrough for saving lives and property.

Before METRAD system, agricultural and forest fires and flash flood events that may occur in our planet could only be detected by radars at a certain distance if there are no people in the immediate vicinity. By our X-Band meteorological radar on the other hand, have the advantages of both multi-polarization and high frequency in providing accurate information.

With the capabilities such as wind vision and clutter suppression, METRAD System will have early detection capability for flash flood and fire emergency events, up to 1-hour before flash floods, and less than 5 minutes after for new forest/agricultural fires.

METRAD System will also have decision support capability that can make spread predictions for fire and flood emergency events, helping the firefighters and flood rescue team in the emergency area by sending possible future coordinates of fire spread and new flash floods by the help of “Wind Vision”.

Acknowledgements

Authors hereby acknowledge all of the General Directorate of Meteorology (MGM) and the Disaster and Emergency Management Directorate (AFAD) personnel for their support through years.

References

[1] Chandarsekar V. (2004) Polarimetric Doppler Weather Radar.

[2] G. Zhang (2016) Weather Radar Polarimetry.

[3] https://uubf.itu.edu.tr/akademik/meteoroloji-muhendisligi

[4] John Y. N Cho, Robert G. Hallowel, Mask E. Weber (2008) Comparative analysis of terminal wind-shear detection systems.

[5] Witold F. Krajewski, Daniel Ceynar, Ibrahim Demir, Radoslaw Goska, Anton Kruger, Carmen Langel, Ricardo MantillLLa, James Niemeier, Felipe Quintero, Bong-Chul Seo, Scott J. SmallLL, Larry J. Weber, and Nathan C. Young, 2022, Bulletin of the American Meteorological Society, Real-Time Flood Forecasting And Information System For The State Of Iowa

[6] Jonathan J. Gourley, Zachary L. Flamig, Humberto Vergara, Pierre-Emmanuel Kirstetter, Robert A. Clark III , Elizabeth Argyle, Ami Arthur, Steven Martinaitis, Galateia Terti, Jessica M. Erlingis, Yang Hong, and Kenneth W. Howard, 2022, Bulletin of the American Meteorological Society, The FLASH Project Improving the Tools for Flash Flood Monitoring and Prediction across the United States

[7] Nicholas McCarthy, Hamish McGowan, Adrien Guyot, and Andrew Dowdy, 2022, Bulletin of the American Meteorological Society, Mobile X-Pol Radar A New Tool for Investigating Pyroconvection and Associated Wildfire Meteorology

[8] R. R. Rogers and W. O. J. Brown, 2022, Bulletin of the American Meteorological Society, Radar Observations of a Major Industrial Fire

[9] ISO/IEC/IEEE 15288:2015 Systems and software engineering — System life cycle processes