2025
ANNUAL REPORT

PHARA

At a Glance

Executive Summary

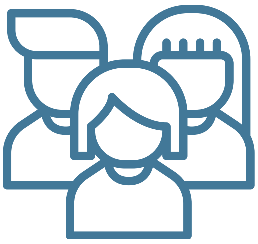
Prof. DSc. Alexander Yarovoy
PROJECT COORDINATOR

"Despite the manufacturing setbacks, PHARA continues to advance cutting-edge radar technology through strong collaboration and dedicated teamwork."

Building on a productive 2024, in which the PHARA consortium was established and the manufacturing contracted to Robin Radar Systems, 2025 focussed on manufacturing, raising visibility, and extending the PHARA research cloud. While subsystem design was successfully completed and manufacturing initiated, progress has been significantly impacted by component supply chain disruptions and capacity constraints. These delays are closely monitored and carefully managed, but an extension of the project runtime will be required to ensure successful completion of the manufacturing phase. Organizationally, PHARA strengthened its research capacity with the appointment of three PostDocs. The user community remained actively engaged through online consultations, ensuring alignment between development progress and stakeholder needs. International visibility grew substantially in 2025, with a dedicated session at European Microwave Week 2025, presentations at three major conferences and successful delivery of an international PhD summer school on phased arrays, contributing to knowledge dissemination and capacity building in this specialized field. Despite the manufacturing setbacks, we remain fully committed to to advance the development of cutting-edge radar technology through strong collaboration and dedicated teamwork, and look forward to completing the subsystem manufacturing in the period ahead.

Highlights

Completion of Final Design Review. The PHARA Subsystem Design Documents have been delivered, detailing the design solutions for both the transmit and receive arrays, including the specifics for the mobile platform with the mount, the embedded software for signal processing and radar control.



Filling of all postdoctoral positions. **Linda Bogerd** focuses on cloud and precipitation retrieval using phased array radar, **Pilar Castillo Tapia** works as an antenna engineer reducing cross-polarisation in phased-array antennas, and **Tworit Dash** adresses precipitation parameter estimation to bridge the gap between target tracking and reliable meteorological observations.

PHARA at European Microwave Week 2025 Our team contributed to several sessions on phased array radar for weather applications, highlighting how PHARA advances atmospheric observation and severe weather prediction through international collaboration between academia and industry.

TU Delft International Summer School on Phased Array Systems From 29 September to 3 October 2025, TU Delft hosted the International School on Phased Array Systems, bringing together nearly 40 researchers for an intensive programme on phased array technologies for 6G, radar, and wireless communications.

Expansion of PHARA Research Cloud with Wind Field Study. The first externally funded research project using PHARA has launched, led by PhD student Alberto Frizzera at TU Delft. With support from Robin Radar, the project will use PHARA to create 3D maps of wind patterns in the atmosphere.

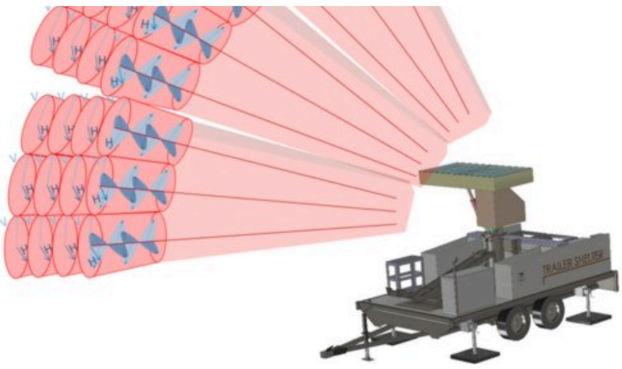
PHARA User Committee Meeting to Discuss Progress and Data Requirements On 4 November, 2025, the PHARA project hosted an online meeting with its user committee to share progress updates and gather input on desired data outputs.

Introduction

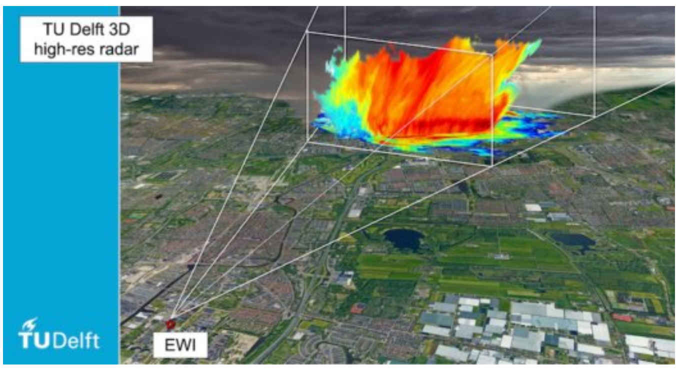
Building on the foundations laid in 2025, in 2026 PHARA is making steady progress towards realization. The development of this fast-scanning phased-array radar in Ku-band continues, with the consortium of TU Delft, KNMI, ASTRON, TU Eindhoven, RU Groningen, TNO, and Robin Radar Systems working together to overcome the many technical and scientific challenges that come with building a truly novel instrument. While there is still much work ahead, the project is advancing with dedication and growing expertise, following our ambition to bridge the gap between traditional precipitation radars and cloud profilers, and enable to advances in atmospheric science, weather forecasting, hydrology, and beyond.

Science & Engineering

Summary PHARA is being developed to address the need for high-resolution data on the microphysical processes inside clouds and precipitation, which current instruments cannot adequately provide. PHARA addresses this by combining two powerful technologies: phased-array radar, which can scan the atmosphere in multiple directions simultaneously, and polarization diversity, which reveals information about the shape, orientation, and phase of particles in clouds. By going beyond combining these two approaches, PHARA achieves a tenfold increase in update rate compared to conventional radars, while maintaining both range and Doppler resolution, enabling accurate tracking of rapidly evolving weather systems. Operating in Ku-band, it fills the observational gap between traditional precipitation radars and cloud profilers. Key innovations include polarimetric waveform agility, multi-beam management, agile 3D beamforming, multiple operating modes (cloud and precipitation), and integration with multi-frequency radar systems. The ultimate scientific goal is to understand exactly how particles inside clouds develop and grow into raindrops, particularly during severe weather. By providing fast scanning rates, 3D imaging of rainfall, height-resolved developmental data, and the ability to focus its attention to key areas of interest, PHARA will be a valuable addition to the diverse network of atmospheric sensors operated by the Ruisdael observatory, and advance both fundamental atmospheric science and applied fields such as weather forecasting, hydrology, water management, and communication technologies.



TU Delft Phara radar



TU Delft 3D high-res radar

Manufacturing Progress In 2025 we completed the subsystem design phase, marking an important milestone in PHARA's development. The design encompasses three main components: The transport platform houses the main power supply unit, server racks, and a liquid cooling subsystem, and is built to carry the full radar system in a mobile configuration. The radar system itself will feature 360° rotation in azimuth and 20°–90° tilt in elevation, enabling full hemispheric coverage of the atmosphere. At the heart of the system is the tile, the smallest functional unit, comprising antenna modules, an analog board, and digital board. While the first prototypes of the tile, including the antenna modules, analog board, and digital board were successfully produced, the progress has been impacted by component supply chain disruptions and capacity constraints. The team is currently engaged in prototype tile verification, a critical step before full-scale production. These challenges have necessitated a revision of the original project timeline, with full-scale production spread out over a two-year period, targeted to start in Q3 2026 and comprising gradual assembly of the antenna system and RF front-end, digital backend, power supply, cooling system and trailer.

Research and Publications To date, PHARA research has been done on two themes: millimeter-wave phased array antenna design and weather radar signal processing. Two **ultrawide-angle antenna array** designs were developed for millimeter-wave frequencies, targeting next-generation 5G/6G applications [1, 2]. Both designs use antenna elements that can switch between two radiation modes, allowing the antenna beam to cover a very wide range of directions with minimal signal loss. Both operate in the 27–29.5 GHz frequency range commonly used for high-speed wireless communications. On the radar side, an **adaptive radar framework** was proposed that dynamically adjusts key transmission settings in real time on a per-scan basis, allowing the radar to respond more accurately to rapidly changing and localized weather conditions such as turbulence [3]. In addition, a novel method called **Latent Moment Beamforming (LAMB)** was developed to measure the velocity and spread of rain and snow particles at different heights, without needing to steer the radar beam [4]. By treating the full vertical profile as a single statistical problem, the method delivers more accurate atmospheric measurements even with a small antenna or when fast updates are required, supporting applications such as aviation safety and climate monitoring.

1. R. Ansems, G. Federico, A. B. Smolders and D. Caratelli, "Multimode Phased Antenna Array for mm-Wave User Terminals With Ultrawide-Angle Scanning Capabilities," *IEEE Transactions on Antennas and Propagation*, vol. 72, no. 1, pp. 1021-1026, 2024
2. G. Federico, Z. Song, G. Theis, D. Caratelli and A. B. Smolders, "Multi-Mode Antennas for Ultra-Wide-Angle Scanning Millimeter-Wave Arrays," *IEEE Open Journal of Antennas and Propagation*, vol. 4, pp. 912-923, 2023
3. A. Pappas, T. Dash, A. Yarovoy, F. Fioranelli, S. Sardar, and M. Schleiss, "Adaptive Radar Approaches for Doppler Moment Estimation," *IEEE Geoscience and Remote Sensing Letters*, preprint, 2025
4. T. Dash, S. Yuan, J. Heylen and A. Yarovoy, "Doppler Moments Estimation for Precipitation with a Phased Array Radar using Latent Beamforming," *IEEE Transactions on Geoscience and Remote Sensing*, preprint, 2025

Organisation & Team

The NDA and CA were signed, and the governing bodies (MT, Governing board, International Advisory Board) are in place. The progress with the radar manufacturing was monitored during bi-weekly

Management Team meetings. With the delivery of the first prototype subsystems coming up, a Technical Team was installed to discuss and align on technical and operational aspects related to the PHARA system.

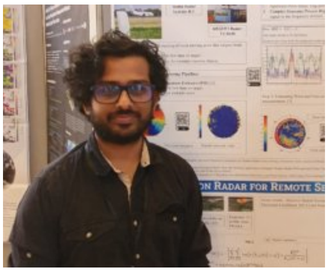
New PHARA members We welcomed new PHARA members from within the participating organisations:

- Robin Radar Systems (Project management): **Bruno Sochacki**
- TU/e (Antenna engineer): **Dr. Pilar Castillo Tapia**
- TUD (Signal processing): **Dr. ir. Tworit Dash**
- TUD (Cloud and precipitation microphysics): **Dr. Linda Bogerd.**

PostDocs

Linda Bogerd As a postdoctoral researcher within PHARA, Linda Bogerd works on retrieving cloud and precipitation properties from phased-array radar observations. Her research combines satellite data with ground-based measurements to improve the accuracy of precipitation estimation.

Pilar Castillo Tapia As Antenna Engineer within PHARA, Pilar Castillo Tapia focuses on improving phased array antenna performance by investigating methods to reduce cross-polarisation levels. Her work supports the development of high-quality antenna systems essential for advanced weather radar applications.



Tworit Dash As a postdoctoral researcher within PHARA, Dr. Tworit Kumar Dash works on advanced Doppler processing techniques for fast-scanning weather radars. He focuses on improving precipitation parameter estimation in multifunctional radar systems, such as those used at airports, where rapid azimuth scanning limits weather measurement accuracy, helping bridge the gap between target tracking and reliable meteorological observations.

Outreach

Conference visits PHARA members visited and presented at a several (inter)national conferences:

- **The PrePEP 2025 conference** (Bonn, March 16-21) was attended by PHARA team members *Remko Uijlenhoet, Marc Schleiss, and Tworit Dash*, who engaged with the international community on advances in precipitation estimation and prediction.

- **The 12th International Conference on Urban Climate** (ICUC12, Rotterdam, July 7–11) was attended by PHARA team member *Remko Uijlenhoet*, who presented a poster highlighting PHARA's potential for urban climate and extreme weather research.
- **The Ruisdael Science Day** (18 September) was attended by PHARA team members *Herman Russchenberg, Marc Schleiss, Remko Uijlenhoet,* and *Tworit Dash,* with contributions highlighting PHARA's role within the Ruisdael Observatory.
- **European Microwave Week 2025** (Utrecht, September 21–26) was attended by PHARA team members including *Alexander Yarovoy, Tworit Kumar Dash, and collaborators from TU Delft and TU Eindhoven,* who contributed to multiple sessions on phased array weather radar.
- **The 2025 IEEE Radar Conference** (Krakow, October 4–9) was attended by PHARA team members *Alexander Yarovoy, Marc Schleiss, Jonas Heylen, Tworit Dash, Rob van der Meer, Yankı Aslan, and Apostolos Pappas,* who contributed to a special session on polarimetric weather radar and presented two conference papers.

Website & Linkedin PHARA's website and LinkedIn page are live and provide a central platform to share project updates, research progress, and news with the PHARA community and beyond.

Meetings

Data Handling and Systems Engineering at ASTRON Workshop The consortium held a technical workshop at ASTRON, bringing together project partners to address key challenges in data processing and systems engineering. The discussions helped align design choices, data handling strategies, and next steps toward developing Europe's first fully polarimetric phased-array weather radar.

User Committee Meeting to Discuss Progress and Data Requirements On November 4, 2025, we held an online meeting with its user committee to share project progress and gather feedback on data needs. Updates covered achieved milestones, system development plans, and user requirements ranging from real-time operational data to advanced research applications, helping guide the next phase of radar development and data products.

Looking Ahead

We look forward to the year to come with high expectations: We anticipate the delivery of the first prototype subsystems and the acquisition of the first real measurement data from PHARA panels. In parallel, development of the PHARA digital backend will continue to progress, and full-scale manufacturing of the radar system is expected to commence. Beyond the core hardware programme, we will continue to seek opportunities to expand the PHARA research cloud with additional projects, and to grow PHARA's visibility within the research community.

Contact Us

For further information, please reach out to us at:
contact - PHased Array Radar for Atmospheric research

LinkedIn: Linkedin.com/company/phararadar/

Website: www.phara.tudelft.nl