

The UAE Research Program
For Rain Enhancement Science

STRATEGIC PLAN

2025-2030

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The UAE Research Program
For Rain Enhancement Science
UAERP

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A comprehensive strategy outlining the foundation, priorities, and enablers of the program—driving innovation, economic value, and impact through technology, partnerships, and strategic implementation

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SECTION ONE

UAEREP EXECUTIVE SUMMARY

VISION



To become the globally recognized model for rainfall enhancement research, development, demonstration and deployment of technologies and operations that enhance water security in the UAE and globally.

MISSION



To establish scientifically validated technology platforms and verification techniques that contribute to enhancing rainfall and water security in the UAE and globally.



To position the UAE as the global leader in the science, technology and implementation of rain enhancement.

*CF: Cloud Formation

*RE: Rainfall Enhancement

PILLARS



Managed Grant Assistance: Technical Oversight & Evaluation



International Collaboration: Industry-government-academia



Capacity Building and Knowledge Transfer



Multidisciplinary Research and Innovation

STRATEGIC ELEMENTS



Optimized Seeding Materials



Novel CF* and/or RE* Systems



Autonomous UAS Technology and Hardware



Limited-Area Climate Interventions



Advanced Models, Software and Data

Marking a Decade of Impact

Launched in 2015 under the patronage of His Highness Sheikh Mansour bin Zayed Al Nahyan, Vice President, Deputy Prime Minister, and Chairman of the Presidential Court, the UAE Research Program for Rain Enhancement Science (UAEREP) was born from a bold national commitment to addressing global water security through science and collaboration. A decade on, the UAEREP has grown into a globally respected model engaging over 1,800 researchers from 76+ countries, funding 14 breakthrough projects, and establishing the UAE as a hub for global leaders in water security.

Key Outcomes

Since its launch, the UAEREP has funded 14 pioneering projects across five cycles. These projects have collectively positioned the UAE as a global leader in applied rainfall enhancement research and innovation. Key outcomes include:

Nine new technologies demonstrated for rainfall enhancement, including:

3 Novel Materials

Nanotechnology-based seeding materials to enhance raindrop and ice formation, of which one material - core-shell NaCl-TiO2 (CSNT) - is locally manufactured and used in NCM cloud seeding operations.

2 Customized UAS

Unmanned Aerial Systems (UAS) for cloud measurements/seeding and atmospheric charge sensing/delivery.

3 Cloud Formation Enhancement Trials

- The Heliator (solar-heated balloon array),
- The Aerosol Layer Method (1 km² surface heating via aerosols),
- The Jet-Aerosol Method (using retrofitted aircraft engines with seeding injection).

1 High-Power Mobile Laser

Demonstrator in development for laser-induced rainfall enhancement trials in the UAE.

Other
Key Outcomes:

4 Cloud Chambers

Trials and a proposed facility design in the UAE, enabling controlled laboratory testing of cloud formation and seeding techniques.

1,000+ hrs

Research flight operations and atmospheric measurements in the UAE and abroad, including the first 3D profiling of clouds and winds over UAE mountain terrain using Doppler lidar and cloud radar systems.

300-meter Resolution

First-ever weather model deployed for the UAE, enabling high-precision landcover/terrain modification impact-analysis, cloud tracking and seeding decision support.

100+

Top-ranked journal articles and conference presentations.

10 Patents

Registered and obtained patents co-owned with NCM

17 Year Regional Climate Simulation

Run completed for the Arabian Peninsula, delivering critical insights into future precipitation trends and water security risks.

6 Physics-based Models

Upgraded or customized, simulating aerosol-cloud interactions and the impact of different seeding strategies, including secondary ice processes and electric charge mechanisms.

15 Field/Airborne Campaigns

Conducted in the UAE and abroad, generating a state-of-the-art NCM data repository for model testing and climate/weather technology evaluation.

AI/ML Models

Developed to identify seedable clouds and forecast rainfall up to six hours in advance, using real-time satellite and NCM radar data.

63 Students

Early-career scientists engaged in UAEREP projects in the UAE and globally.

UAEREP Executive Summary

Global Water Security: The Challenges We're Addressing



Water scarcity is a present, escalating global concern:

- **Rising Demand & Urbanization:** Global water demand is projected to increase by 55% by 2050 [1], driven by population growth, industrial use, and expanding cities.
- **Climate Disruption & Variability:** Extreme weather patterns and prolonged droughts are diminishing rainfall reliability, especially in arid and semi-arid regions [2].
- **Limited, Unequal Access:** Over two billion people already live in water-stressed areas, with lower-income and agricultural communities disproportionately affected [3].
- **High Costs of Conventional Solutions:** Desalination remains energy-intensive and costly, and groundwater depletion is accelerating beyond natural recharge rates.

2030 Targeted Goals



As we enter our second decade, UAEREP is scaling its ambition through three strategic goals:

1. Accelerate Innovation for Real-World Deployment

Develop and operationalize advanced technologies like AI-driven cloud forecasting and targeting systems, next-generation material science for optimized seeding agents, and autonomous Unmanned Aerial Systems (UAS) while also evaluating High-Risk/High-Reward (HRHR) science and applications to make rainfall enhancement more effective, scalable, and sustainable.

2. Strengthen Scientific Leadership & Global Collaboration

Expand UAEREP's role as a global hub by deepening collaboration with academic, industry, and policy leaders; increasing student capacity building and knowledge exchange; and ensuring research outcomes reflect both global standards and UAE-based value creation.

3. Contribute to a Resilient, Equitable Water Future

Embed rainfall enhancement technologies into integrated water resource management (IWRM) frameworks as a nature-based solution, and enable the transfer of scalable applications to vulnerable populations in arid ecosystems.

Looking Ahead



The ten-year milestone of the UAE Research Program for Rain Enhancement Science (UAEREP) marks not only a moment of reflection, but a renewed call to action. As the world confronts escalating climate variability and growing water insecurity, the UAE reaffirms its commitment to bold, science-driven leadership in sustainable water solutions. Guided by targeted research area roadmaps and supported by a growing global network of experts, UAEREP will continue to advance the frontiers of research, translating scientific innovation into operational impact and securing water for future generations.

SECTION TWO

FOUNDATIONS & FUTURE VISION



Introduction

The UAE Research Program for Rain Enhancement Science (UAERP) is an international research initiative designed to advance the science and technology of rainfall enhancement by offering managed grant assistance to selected teams of researchers who present innovative ideas and project proposals.

The Program is managed by the National Center of Meteorology (NCM) as part of its mission to support research in weather modification. Each awardee receives up to \$1.5 million over a three-year period and is selected through a multi-phase, merit-based review process.

NCM’s vision for the UAERP is to establish it as the globally recognized model for rainfall enhancement research, development, demonstration and deployment of technologies, and operations that enhance water security in the UAE and globally.

To achieve this vision, the UAERP is facilitating scientifically validated technology platforms and verification techniques that contribute to enhancing rainfall and water security in the UAE and globally.

The UAERP follows a clear strategic direction, prioritizing advanced technology and evolving research needs to drive the development of rainfall enhancement technologies and attract investment in practical applications that address not only water security but also the broader sustainability agenda and Water-Food-Energy Nexus.

Background

The UN predicts that almost half of the world's population will face high water stress by 2030 [IV]. Given the scale of the challenge posed by rising populations and diminishing resources, there is a need for new technologies and solutions to address this urgent challenge.

Cloud seeding is a decades-old approach used to modify specific cloud types to increase precipitation (rainfall and snowfall). First demonstrated in the 1940s by researchers at General Electric using dry ice and silver iodide to induce ice crystals in clouds, cloud seeding has been piloted by more than 60 countries to augment freshwater availability, supporting economic, environmental, and human well-being [v].

For arid and semi-arid regions, rainfall enhancement offers a viable, cost-effective supplement to existing water supplies. For instance, the Idaho Power program in the US reports a cost of \$3.22/acre-foot of water produced from cloud seeding, which is over 300 times less than US-based desalinated water production costs [vi]. The NCM in the UAE estimates a cost of ~ \$0.01 m³ of rainfall produced from cloud seeding, up to 30 times less than a unit volume produced from the most advanced reverse osmosis desalination plant (Hassyan) [vii]. Recent technological developments suggest that rainfall enhancement could offer an important supplement to existing sources of groundwater and desalinated water[viii].

Number of Aircraft	Number of Pilots	Flares per Aircraft	Type of Aircraft
4	12	48	King Air C90 GTI
Flight hours per operation	Ground Generator Unites	Flares per Ground Generator	Ground Generator Control Method
3	5	48	Via GSM from the control room

The UAE has long recognized the importance of water security and began its rainfall enhancement efforts in 1990 [ix], collaborating with international organizations such as the National Center for Atmospheric Research (NCAR) and the NASA Earth Science Programs. Today, the country operates over 100 weather stations, an integrated weather radar network, and four Beechcraft King Air aircraft instrumented for cloud seeding, managed by a skilled team of pilots and technical experts, mostly UAE nationals.

Beyond cloud seeding technology, the broader field of rainfall enhancement science encompasses multi-scale/physics interventions (airborne or ground-based) in rain-bearing clouds and their formation process. The most typical method of rainfall enhancement - cloud seeding - has often been applied through aircraft-based platforms. Research and technology in cloud seeding continues to advance through computational modeling, radar, and sensors, improving understanding of the processes and applications of this evolving science [x]. However, in a rapidly evolving technological landscape, there is a growing need for advanced research and development to utilize innovation and leverage new technologies such as nanotechnology, drones, lasers and Artificial Intelligence to explore applications beyond conventional approaches to cloud seeding [xi].

To focus national and global efforts, the Presidential Court, under the patronage of His Highness Sheikh Mansour bin Zayed Al Nahyan, Vice President, Deputy Prime Minister and Chairman of the Presidential Court, established the UAE Research Program for Rain Enhancement Science (UAERP) and its grant-awarding functions in 2015. To this end, the UAERP aims to stimulate and promote scientific advancement and the

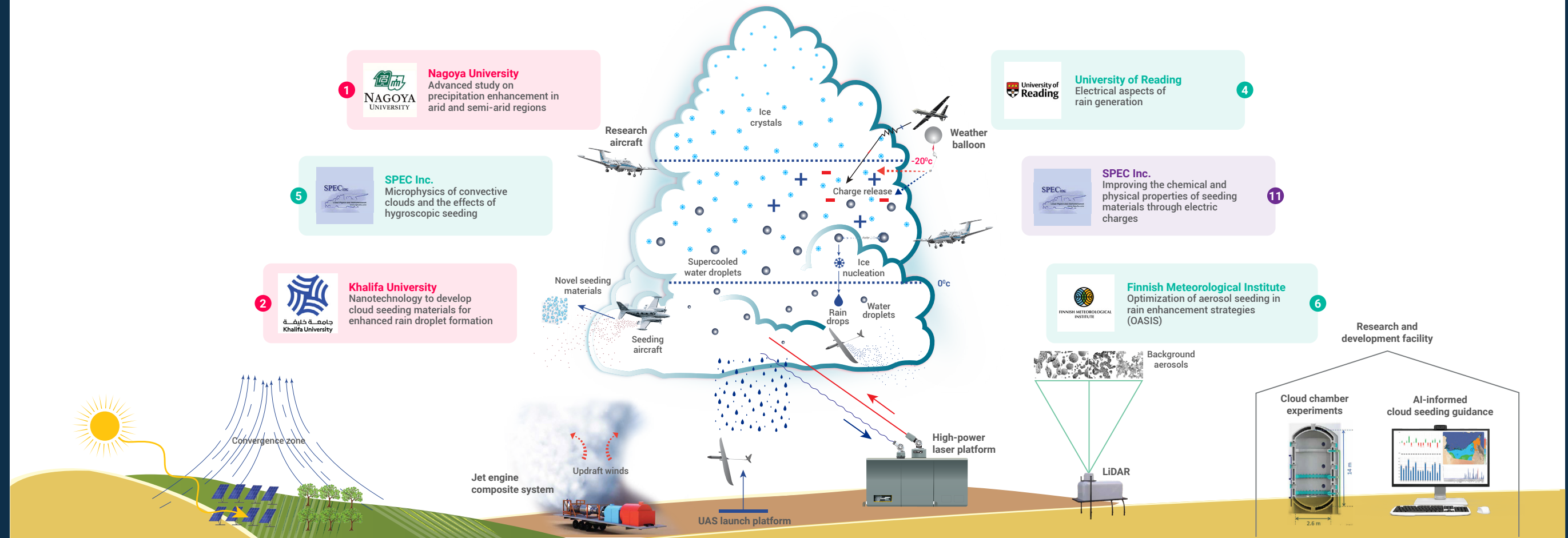
development of new methodologies and technologies in the field. The UAERP provides managed grant assistance to the international scientific community targeting innovative and interdisciplinary research on rainfall enhancement applications.

Since 2015, the UAERP has invested a total of \$22.5 million in rainfall enhancement research and development projects, including applied research and technology demonstrations. In each award cycle, the program offers a grant of up to \$1.5 million per awarded proposal, distributed over three years, with a maximum annual funding of \$550,000 for each winning proposal.

To date, the UAERP has awarded 14 research projects from nine countries over five cycles between 2016 and 2025. The sixth cycle, currently underway, will award up to three proposals. Awarded projects target multi-scale processes, including land-atmosphere feedbacks, bio-geo-engineering, aerosol-cloud-precipitation interactions, and mixed-phase cloud microphysics. The interdisciplinary nature of these projects leverages the latest advancements in material science and nanotechnology for the development of novel seeding materials [xii], autonomous unmanned aerial systems (UAS) [xiii] for more robust and cost-effective seeding missions, smart sensors for in-cloud electrification [xiv], reverse-engineered thermal systems [xv] to stimulate artificial updrafts and convection, and machine learning tools [xvi] for more efficient cloud forecasting and targeting systems. The infographic consolidates the intervention areas of the 14 UAERP projects awarded to date and their primary institutions.

UAEREP PROJECTS 2016 - 2024

● Cycle 1 | ● Cycle 2 | ● Cycle 3 | ● Cycle 4 | ● Cycle 5



Technology Landscape Shaping Rainfall Enhancement

The landscape of rainfall enhancement is being transformed by advances in several cutting-edge technologies. Innovations in materials science, such as computational materials design and the use of advanced substances including graphene and other 2D materials, are enabling the development of more efficient and eco-friendly seeding agents.

High-performance computing (HPC) systems are enhancing the precision and speed of numerical weather models, allowing researchers to simulate cloud microphysics and atmospheric conditions in fine detail. Artificial intelligence is also playing a crucial role in improving forecasting accuracy, integrating diverse data sources, and guiding real-time decision-making for cloud-scale monitoring and forecasting.

Autonomous systems, including drones and smart weather balloons, are increasing the precision and flexibility of seeding missions, especially in challenging environments. Meanwhile, satellite imaging, IoT sensor networks, and advanced remote sensing tools are providing high-resolution, real-time data needed to monitor atmospheric conditions and assess the impact of interventions. As these technologies converge, they are making rainfall enhancement more targeted, efficient, and scalable, with the potential for safer and more sustainable applications in water-stressed regions.

At the 7th International Rain Enhancement Forum (IREF) hosted in Abu Dhabi [\[xvii\]](#), discussions focused on advancements in hybrid AI-physics-based models for climate research, innovations in autonomous unmanned aerial systems for weather modification, the development of novel cloud seeding materials, limited-area climate interventions, and new approaches to rainfall enhancement. Previously in 2019, UAEREP led the first-ever Townhall meeting on rain enhancement during the EGU General Assembly. And at the AGU24, the annual general meeting of the American Geophysical Union, the UAEREP convened a session focusing on the intricate intersections of weather modification and climate intervention techniques [\[xviii\]](#). The session

presented 21 abstracts from 80+ authors across 40+ leading industry, government and academic entities.

Through the UAEREP, the UAE is leading the way in promoting innovation for the benefit of future generations facing water scarcity. In just over a decade, the program has established itself at the forefront of the UAE's mission to develop innovative and sustainable solutions addressing climate change and enhancing water security locally and globally. UAEREP's groundbreaking work in advancing rain enhancement science has been awarded the Future Fit Seal Award, part of the UAE Government Development Foundation's initiatives to honour entities that demonstrate excellence in contributing to sustainable development goals.

The UAEREP's Milestones



The UAE became a key platform for rain enhancement research as part of its global efforts in weather modification.



Led the first ever Townhall meeting on rain enhancement during EGU 2019.



Introduced innovations in rain enhancement such as AI and Nano technologies.



Featured on National Advanced Science Agenda 2031 and received the UAE's Future Fit seal.



Empowered the youth to actively participate in rain enhancement research projects.



Featured in the Nature magazine & received significant interest from international media (NY Times, AFP, and NBC TV).

3

SECTION THREE

STRATEGIC PRIORITIES & PATHWAYS

Strategic Thrust Areas

The Sixth Cycle's Five Strategic Thrust Areas aim to fulfill our vision of advancing rainfall enhancement in the UAE and across the world. These priorities were shaped and solidified during a Solicitation Assembly held on 5 June 2024 at the National Center of Meteorology (NCM) and hosted by UAEREP. The workshop brought together leading scientists and experts from world-class institutions including the World Meteorological Organization (WMO), the US National Center for Atmospheric Research (NCAR), Karlsruhe Institute of Technology (KIT), North-West University, and the Technology Innovation Institute (TII).

Participants included Ottmar Möhler (KIT, Germany), Will Cantrell (MTU, USA), James Mitchell, Imperial College London), Guillaume Matras (TII, UAE), Ali Abshaev (HSRC, Russia), Jennifer Simonjan (TII, UAE), Roelof Burger (NWU, South Africa), Dr. Fabian Hoffmann (Munich University, Germany), Jean-Francois, Lamarque (Silverlining), Lulin Xue (NCAR, USA), Jurg Luterbacher (WMO), Prashanth Marpu (Bayanat.AI, UAE), Lakmal Seneviratne (Khalifa University, UAE), and Marouane Temimi (Stevens Institute, USA), alongside members of the SDC: Steven Griffiths, Mahmoud Mohammed, Deon Terblanche, Richard Behnke, and Robert Robinson.

This highly focused technical workshop resulted in the formal definition of UAEREP's five Strategic Thrusts areas for its Sixth Cycle Solicitation Document, outlining both near-term research priorities and long-term innovation pathways for the program.



Strategic Thrust Areas

For its Sixth Cycle, the program is further focusing on the five Strategic Thrust areas to fulfil its vision of advancing rainfall enhancement in the UAE and across the world.

Optimized Seeding Materials

Optimized Seeding Materials research focuses on the development of new and advanced cloud seeding materials and methods to enhance rainfall. This includes material characterization and innovative delivery techniques to improve rainfall stimulation.

Key research focuses include understanding the potential of hygroscopic and glaciogenic seeding to enhance rainfall, evaluating the effectiveness of innovative materials, and deepening knowledge of natural precipitation processes.

Novel Cloud Formation and/or Rainfall Enhancement Systems

Novel Cloud Formation and/or Rainfall Enhancement Systems research targets multi-platform technologies such as UAVs and ground-based systems for enhanced cloud formation and rainfall generation. This thrust explores breakthrough physical methods and multi-platform technologies to stimulate cloud development and rainfall advancing beyond conventional seeding through energy, charge, and aerosol-based innovations.

Key research will explore new mechanisms for cloud formation, the transformation of aerosols into effective cloud condensation nuclei (CCN), and the influence of environmental conditions on particle growth. Studies will span from cloud chamber chemistry to field trials using sensor-equipped platforms to refine targeting and effectiveness.

Autonomous UAS Tech and Hardware

The Autonomous Unmanned Aircraft Systems strategic thrust emphasizes the use of autonomous UAVs for precise and real-time cloud seeding operations, with a focus on advanced decision-making technologies and beyond line-of-sight operations. With this thrust, we focus on building next-generation autonomous UAV platforms equipped with smart sensing, real-time decision-making, and multi-agent coordination to deliver faster, safer, and more precise cloud seeding operations.

Research will focus on enhancing UAS autonomy, optimizing real-time data integration, improving communication for multi-agent coordination, and developing scalable systems that can adapt dynamically to changing weather and operational conditions, while effectively covering 1–5 km² regions with short lead times.

Limited-Area Climate Interventions

Limited-Area Climate Intervention investigates localized geoengineering approaches like solar modulation, landform redesign, and sea breeze dynamics to test their potential for enhancing precipitation in a controlled, climate-sensitive way.

Priority research will investigate how regional solar radiation changes, sea breeze dynamics, and modified landforms influence cloud development and rainfall patterns. Additional focus areas include assessing potential risks, legal and governance frameworks, and cost-benefit analyses for scaling such interventions, with the ultimate aim of identifying synergistic strategies for rainfall enhancement.

Advanced Models, Software and Data

This thrust advances next-gen forecasting and decision-support tools by combining AI, data assimilation, and high-resolution modeling to enable faster, smarter, and more accurate cloud seeding operations.

Key research areas will focus on developing advanced software and algorithms, particularly those using AI and machine learning to model cloud microphysics, process large atmospheric datasets, and bridge the gap between lab-based cloud chamber data and real-world seeding operations. Emphasis will also be placed on integrating physics- and data-driven approaches, creating intuitive simulation tools, and establishing robust evaluation frameworks. Strengthening observational networks and building accessible data repositories will be essential to support research, operational effectiveness, and community collaboration in cloud seeding and weather forecasting.

Research and Development Plan

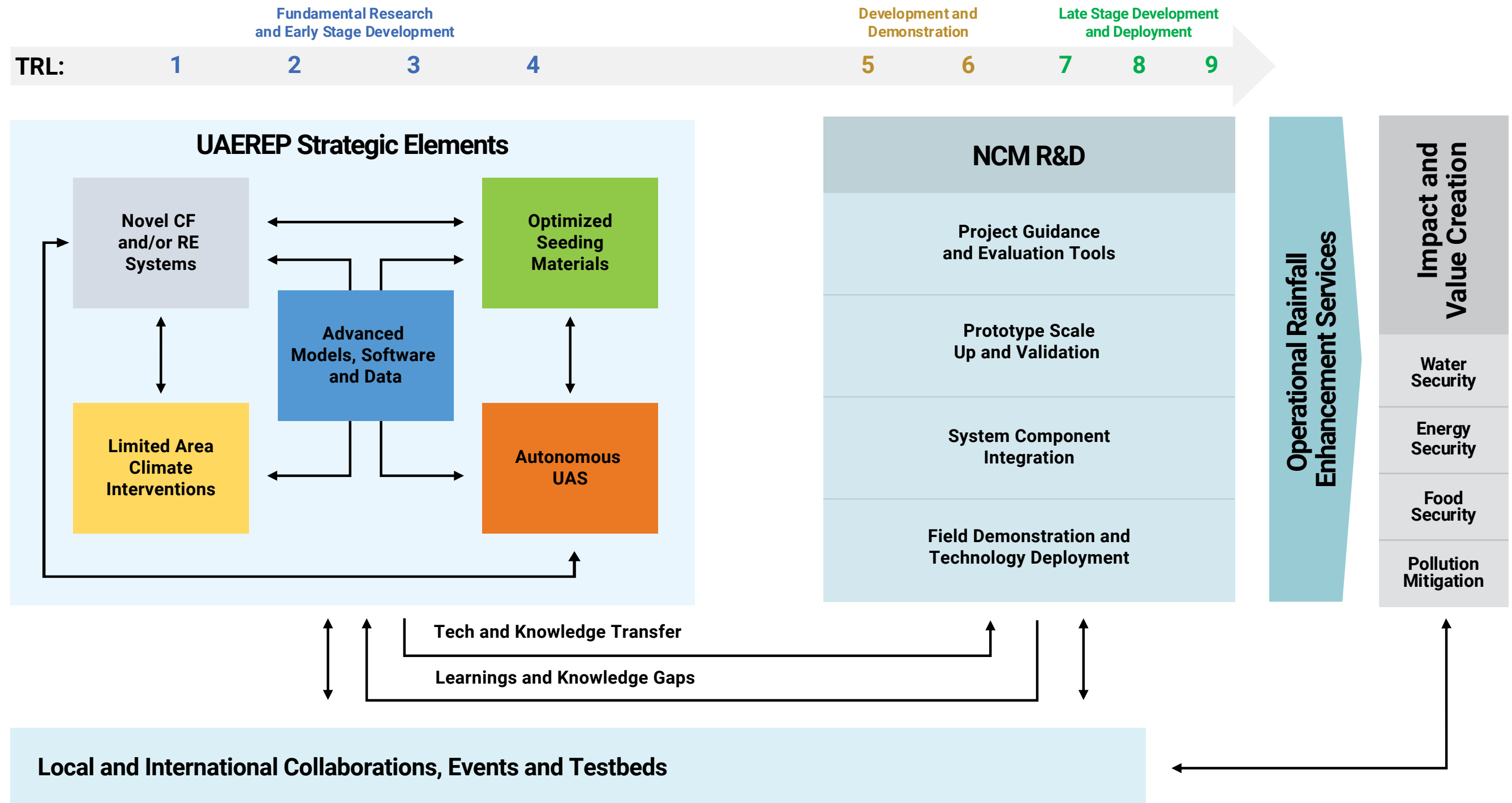
Each of the five strategic thrust areas have defined roadmaps and specific end points for the research applications, building on the progress of previous cycle projects.

Strategic Thrust	2030 Goal	5-Year KPIs
1. Optimized Seeding Materials	Develop, demonstrate and commercialize cost-effective seeding materials (glaciogenic, hygroscopic or hybrid) tailored to specific cloud regimes and regional conditions—targeting performance levels that exceed conventional, non-specific materials, which currently achieve up to 15% precipitation enhancement rates.	• Model material performance across cloud types and conditions. • Synthesize lab-scale seeding materials for cloud-specific conditions and explore scale-up feasibility. • Standardize testing via cloud chambers and field/airborne validation.
2. Novel Cloud Formation & Rainfall Enhancement Systems	Deploy high-risk, high-reward integrated systems that combine multiple platforms to trigger or enhance rain-bearing cloud formation and favorable precursor conditions.	• Develop lab-scale devices and/or system components/processes. • Cloud chamber experimental setup (verification mechanisms). • Prototype development and testing in the operational environment.
3. Autonomous UAS Tech & Hardware	Deliver 20-60 kg of seeding material to a 2-10 km² area confirmed as ideal for seeding through a forecast lead time of 10-30 minutes, augmented by real-time sensing with minimal human supervision.	• Validate real-time sensing and onboard targeting. • Enable multi-UAV coordination in cloud conditions Beyond-Visual-Line-of-Sight (BVLOS). • Achieve 1–5 km² dynamic coverage (10 kg payloads) within 1-hour windows.

For more in-depth information on the strategic thrusts and the research process, please see the Appendix.

Strategic Thrust	2030 Goal	5-Year KPIs
4. Limited-Area Climate Interventions	Pilot kilometer-scale climate interventions (e.g., landcover, terrain, solar radiation modification) to stimulate rainfall and cloud formation.	• Model UAE-specific rainfall enhancement output, risks, and cost-benefit trade-offs from climate intervention strategies. • Generate high-resolution datasets on sea breeze dynamics and their role in cloud formation in the UAE. • Evaluate past and future land changes on moisture flux, sea breeze interaction, and rainfall outcomes.
5. Advanced Models, Software & Data	Operationalize real-time, AI-enhanced cloud forecasting and targeting decision-support tools.	• Build high-resolution, real-time models integrating cloud chamber and field data to simulate seeding impacts. • Apply ML to atmospheric datasets to identify key drivers, improve forecasts, and refine seeding tactics. • Deliver validated platforms, visual tools, and frameworks for research use and decision support.

The Role of NCM R&D in Demonstration and Deployment



SECTION FOUR

ENABLING SUCCESS & SCALING IMPACT

The Role of NCM R&D in Demonstration and Deployment

The program spans the full innovation lifecycle from early-stage fundamental research to late-stage development, field demonstration, and operational deployment. Each stage is mapped against Technology Readiness Levels (TRL 1–9). It also integrates system components through structured evaluation tools, prototype validation, and technology scale-up.

The ultimate aim is to deliver impactful rainfall enhancement technologies that sustainably address water and food security and co-benefits through air quality improvement. A strong emphasis is placed on collaborative development, testbed integration, knowledge transfer, and continuous feedback to address existing gaps and advance innovation in rainfall enhancement technologies.

The National Center of Meteorology (NCM) provides a robust technological and operational foundation that directly supports awardees and researchers in rainfall enhancement. Central to this infrastructure is the ATMOSPHERE High-Performance Computing (HPC) system, a pioneering platform in the region designed to accelerate the development of advanced modeling software, data-driven optimization strategies, and simulation tools for cloud microphysics, seeding efficacy, and precipitation forecasting. With 2.8 petaFLOPS of processing power, 64,000 CPU cores, 220,000 GPU cores, and vast storage capacity, ATMOSPHERE enables real-time, high-resolution atmospheric simulations, AI-driven analysis, and integration of big data crucial to driving innovation across all UAEREP research themes. All modeling results, parameterization schemes, and data from UAEREP projects including aerial and ground-based field campaigns are compiled and integrated on the NCM's HPC. This allows for consistent testing and refinement across projects. Additionally, a decision tree-based algorithm was developed to guide cloud seeding operations, showing up to 67% alignment with actual seeding decisions [xix]. Ongoing testing and case studies continue at NCM and are shared with current UAEREP projects.

UAE'S RAIN ENHANCEMENT PROGRAM COMPONENTS



The National Center of Meteorology operates ATMOSPHERE

Key Goals:

Enhance the computing system for the numerical predictions.

Increase the accuracy and effectiveness of numerical prediction outputs.

Speed up current system performance by 300%.

A supercomputer equipped with the latest processors, memory, and advanced networking to ensure faster and larger data processing.

Processor cores:
64k
Cores

System speed:
2.8
Petaflops

Graphics Cores:
220k
GPU cores

Storage Capacity:
5.7
Petaflops

Local Network:
200
GB interconnect

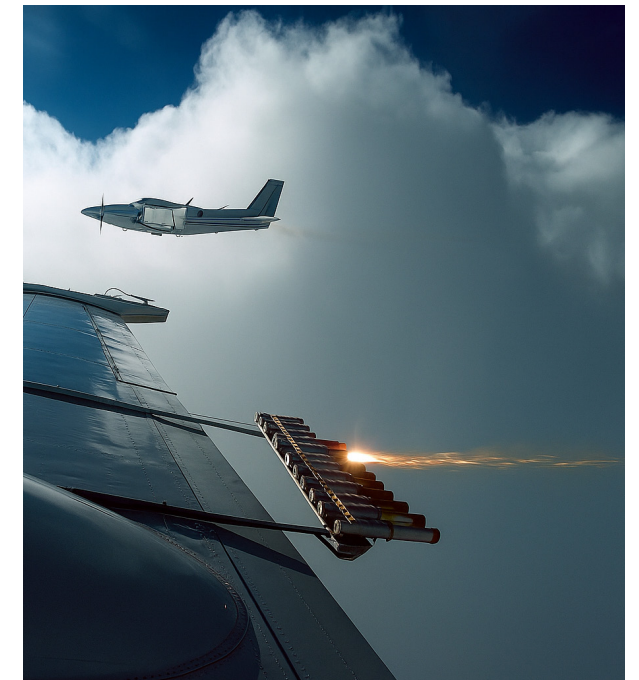
Powered by:

Hewlett Packard
Enterprise

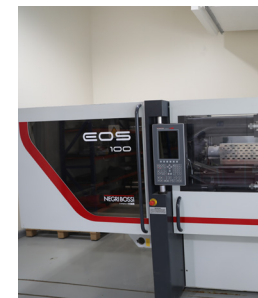
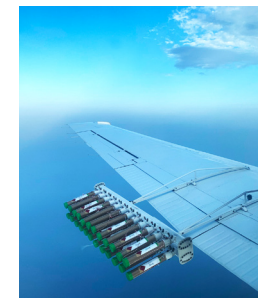
Complementing this computational capability is the Weather Enhancement Technology (WET) Factory, established in 2018 and based at Tawazun Industrial Park (TIP) in Abu Dhabi. The facility provides the physical tools and materials including hygroscopic, nano-enhanced, and ground generator flares required to implement and validate cloud seeding strategies developed through simulation and modeling efforts. The factory's precision-engineered flares are essential for experimental testing, model validation, and advancing the scientific understanding of seeding mechanisms, bridging laboratory research with real-world application. The WET Factory was expanded in 2023 through a technology transfer collaboration with particle manufacturing company, AVEKA Inc. (USA). The expansion focuses on nano-scale particle processing for the local production and commercialization of novel core-shell NaCl-TiO₂ (CSNT) cloud seeding material with joint ownership of the intellectual property by NCM.



This comprehensive infrastructure is further supported by a fleet of four cloud seeding aircraft, six radar stations, 100 automatic weather stations, and a network of air quality and dust monitoring stations, all of which facilitate data collection, model validation, and operational deployment. The cloud seeding aircraft have played a vital role in all UAERP airborne research campaigns. The aircraft have been instrumental in the work of 1st Cycle Awardee, Prof. Masataka Murakami from the Institute for Space-Earth Environmental Research, Nagoya University, Japan. The NCM cloud seeding aircraft flew in coordination with a fully-instrumented Japanese research aircraft for cloud physics research in UAE airspace during the Advanced Study on Precipitation Enhancement in Arid and Semi-Arid Regions project [xx]. Additionally, the NCM cloud seeding aircraft flew in coordination with a US-based cloud physics research jet (Learjet 35A) during the 2nd Cycle Awardee, Dr. Paul Lawson's project entitled Microphysics of Convective Clouds and the Effects of Hygroscopic Seeding [xxi]. This allowed for the first open-atmosphere operational trials of the novel CSNT material in summer 2019.



The Evolution of Nanomaterials in Rain Enhancement



2015



- Prof. Linda Zou of Khalifa University submits a nanotechnology-based cloud seeding material proposal in UAEREP's 1st cycle.

2016



- Prof. Zou awarded a grant of \$1.5 million for her project on core-shell nanotechnology (CSNT) material to enhance rain droplet formation.
- CSNT patent is filed.

2017



- Laboratory testing for the production and characterization of the first CSNT samples.
- Simulations and laboratory tests verify that CSNT material outperforms conventional seeding material.
- CSNT material successfully tested in a semi-operational environment of a cloud chamber facility in Russia.

2018



- Cost-effective, large-scale production options explored with particle manufacturing industries in Japan and USA.

2019



- Verification of large-scale production methodology begins with US-based AVEKA Inc.
- Environment Agency Abu Dhabi (EAD) approves open-atmosphere CSNT testing during a UAEREP research aircraft campaign.
- Airborne tests in clear-air conditions completed, in preparation for in-cloud testing.

2021



- Airborne tests conducted over West Texas through coordinated flights between a research and cloud seeding aircraft operated by the West Texas Weather Modification Association (WTWMA).
- Test results reveal an increase in numbers of large cloud droplet effective radius.
- WTWMA ground-based radar reports a cloud echo attributed to CSNT seeding.
- UAEREP peer-review study using modeling and aircraft observations, showing superior seeding effects of CSNT compared to other materials.
- Routine use of CSNT particles in NCM cloud seeding operations.

2023



- Initiation of Technology Transfer Program between the NCM Emirates Weather Enhancement Factory and AVEKA Inc. for localizing CSNT production in the UAE.

2024



- Completion of Technology Transfer Program and CSNT flare production line.
- Ongoing local production of CSNT at NCM Emirates Weather Enhancement Factory.

Partnerships and Collaborations

The UAERP has emerged as a global leader in advancing rainfall enhancement technologies. In just 10 years, the program has brought together over 1,800 researchers from more than 800 institutions across 70 countries. By fostering collaboration among academia, industry, and government, the UAERP is raising awareness of the importance of rainfall enhancement as a vital tool in addressing water security challenges.

To date, the UAERP 63 students and early-career scientists awarded projects in the UAE and globally, disseminated more than 105 scientific publications in top-tier scientific journals, secured 10 patents, and contributed to over 150 conferences worldwide. The UAERP's global network includes prestigious institutions such as the World Meteorological Organization (WMO), the US National Center for Atmospheric Research (NCAR), Russian Academy of Sciences, Chinese Academy of Sciences and top universities, research centers and industry leaders across six continents. With over 3,700 stakeholders engaged and ongoing partnerships with 720 researchers, the program continues to drive innovation in weather modification. The UAERP actively invites public and private sector entities to join its mission and encourages researchers to collaborate with leading UAE institutions such as Khalifa University, NYU Abu Dhabi, and the Technology Innovation Institute (TII).

105

Peer-reviewed Journal Articles

10

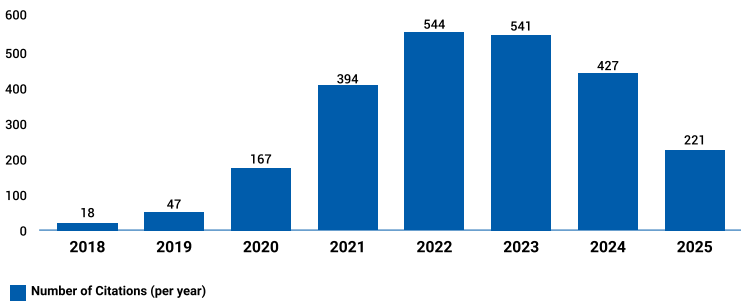
Patents

150+

Conference Presentations

2,586

Total Citations



UAERP Global Outreach 2015-2024



76+
Countries Involved

3700
Stakeholders Involved

1800
Researchers Engaged

\$22.5m
Provided as grants since 2016

45
Research Institutes

14
Awardees

208
Researchers Involved

Funding and Resources

The UAEREP offers research grants of up to \$1.5 million over three years (capped at \$550,000 annually) to support innovative research proposals in the field of rainfall enhancement.

The UAEREP offers research grants of up to \$1.5 million over three years (capped at \$550,000 annually) to support innovative research proposals in the field of rainfall enhancement.

To date, the program has invested \$22.5 million across five grant cycles, funding projects that span applied research, technology development, and field demonstrations. All proposals undergo a rigorous two-stage review process led by the program's International Technical Review Committee, in alignment with its vision to become a globally recognized model for rainfall enhancement research, development, demonstration and the deployment of technologies and operations.

In the current cycle, projects will be selected based on their potential to contribute to the UAEREP's 2030 targeted outcomes, particularly by advancing technologies toward deployment or introducing novel scientific insights. Proposals must demonstrate a clear pathway to operational readiness, avoid redundancy with previously funded work, and are encouraged to involve collaboration with the UAE research community.



Monitoring and Evaluation

The UAEREP Strategic Directions Committee (SDC) is responsible for the technical, financial, and research monitoring of awardees’ projects through progress reports and site visits to ensure successful project completion within a three-year time scale.

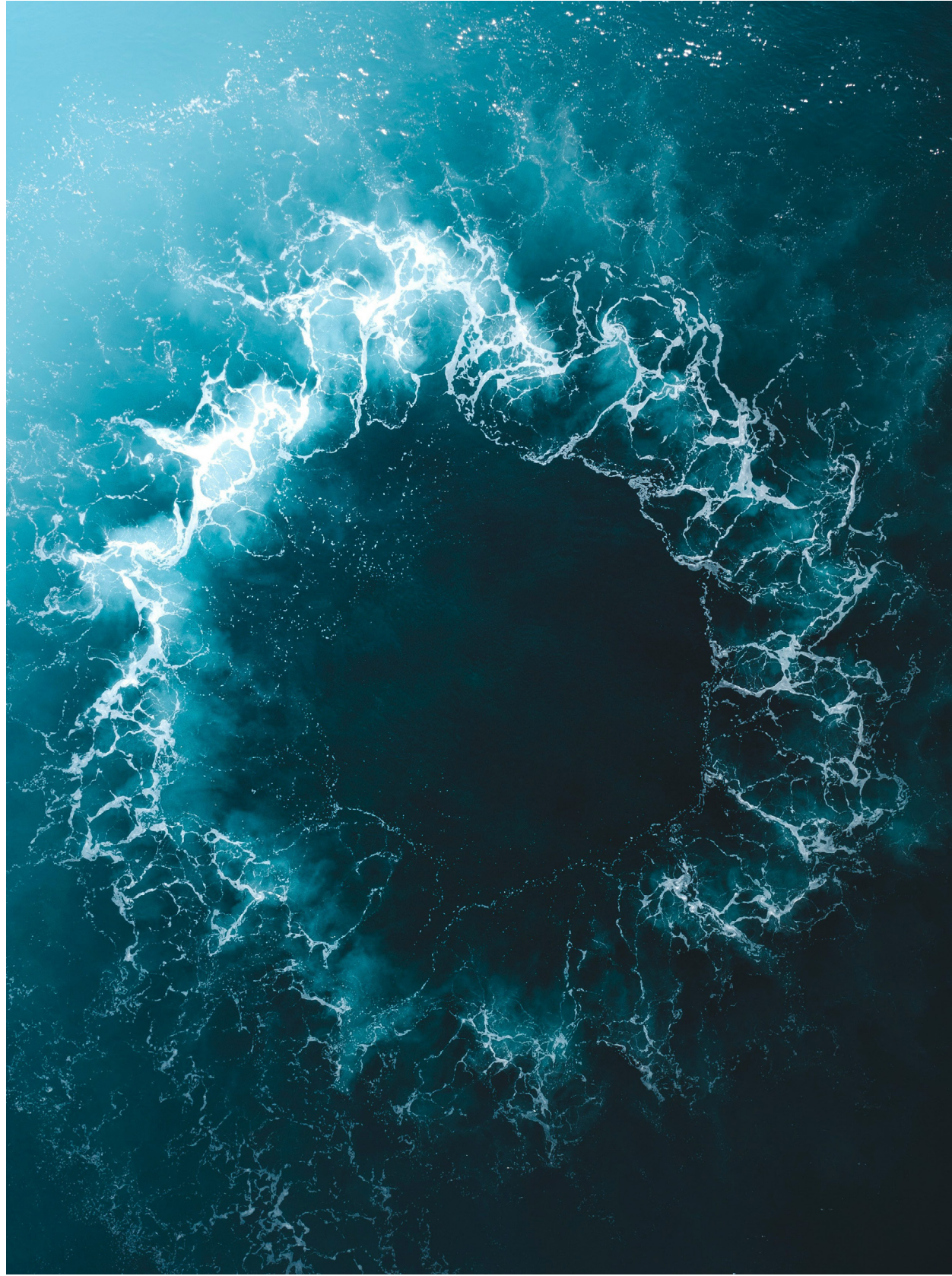
The UAEREP oversight process for project monitoring and evaluation consists of the following structured stages followed during synchronous semi-annual reporting periods (February and September) for all awarded projects:



Importantly, a three-day in-person site visit is conducted midway through the award period. The agenda includes PI and institutional leadership briefings, technical presentations, lab tours, and student engagement. A written summary is shared with the PI to document strengths, gaps, and required follow-up.

All reporting periods evaluate the following KPIs:





Conclusion

As the global demand for water continues to rise, it is increasingly imperative for countries to strengthen their water resilience by promoting research and development, investing in new technologies, improving resource conservation and building effective international partnerships.

With a mission to advance weather modification research to strengthen water resilience, the overall vision of the UAEREP is to become the globally recognized model for rainfall enhancement research, development, demonstration and deployment of technologies and operations in the UAE and globally.

By establishing scientifically validated technology platforms and verification techniques that contribute to enhancing rainfall in the UAE and globally, and by positioning the UAE as the global leader in the science, technology, and implementation of rainfall enhancement, the UAEREP is actively advancing its vision to lead international efforts in water security research. Through managed grant assistance, international collaboration, capacity building, knowledge transfer and multidisciplinary research and innovation, the program pursues a comprehensive strategy to ensure this vision has a long-term and sustainable impact on augmenting water security for the UAE and the world.

5

SECTION FIVE

APPENDIX

Thrust Area Roadmaps

Optimized Seeding Materials

Each of the strategic thrust areas have defined roadmaps and specific end points for the research applications, building on the progress of previous cycle projects.

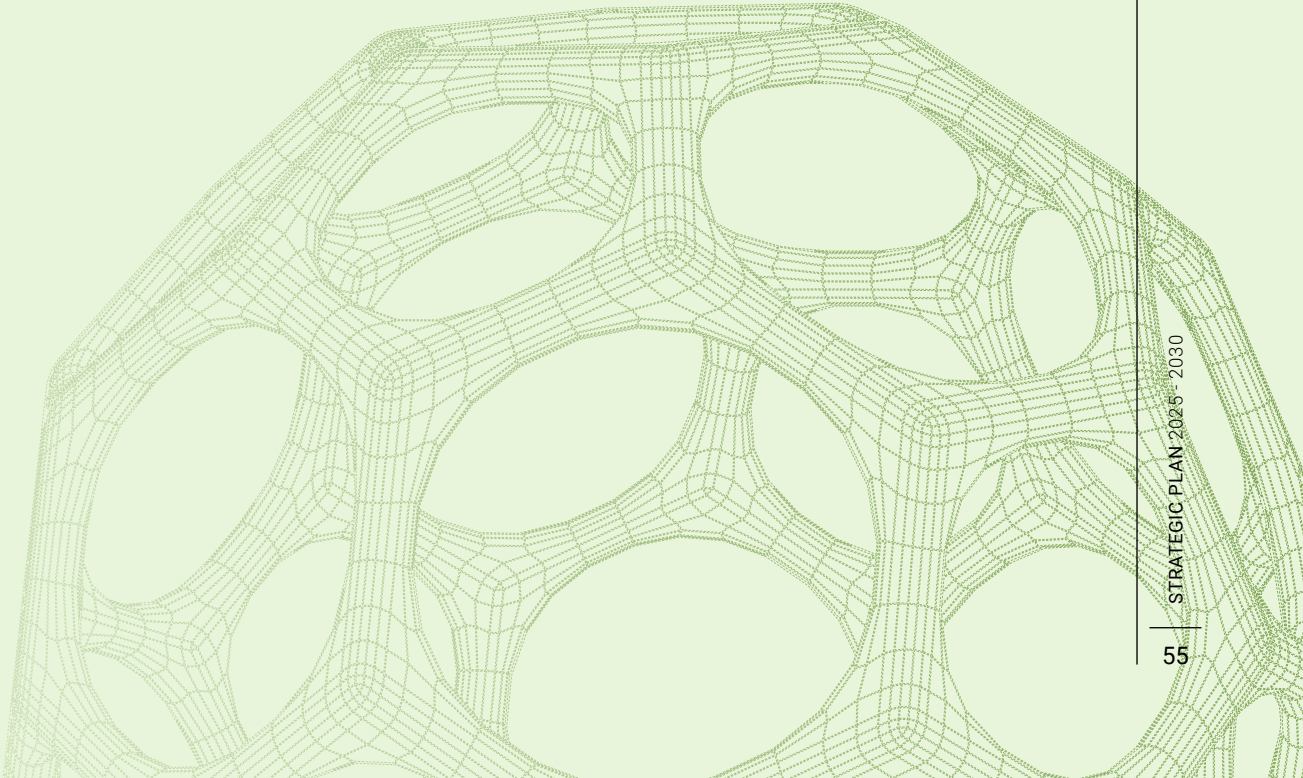
By 2030, the goal is to establish standardized methods for assessing cloud seeding materials through laboratory and field studies, supported by advanced modeling to evaluate various seeding strategies under diverse cloud conditions. This will lead to evidence-based recommendations for optimal materials and techniques tailored to specific environments, particularly arid regions such as the UAE.

There is growing interest in the development of novel high-performance and cost-effective materials, including both hygroscopic material and ice nucleation agents. For example, Prof. Linda Zou of Khalifa University has submitted three patents [xxii] in relation to her publication, Nanotechnology to Develop Novel Cloud Seeding Materials for Rain Enhancement [xxiii]. With the support of UAEREP, Prof. Zou has submitted patents for core-shell NaCl-TiO2 (CSNT), 3D Reduced graphene oxide/SiO2 for cold cloud ice nucleation and Sodium chloride/graphene particles and methods; all to increase precipitation formation.

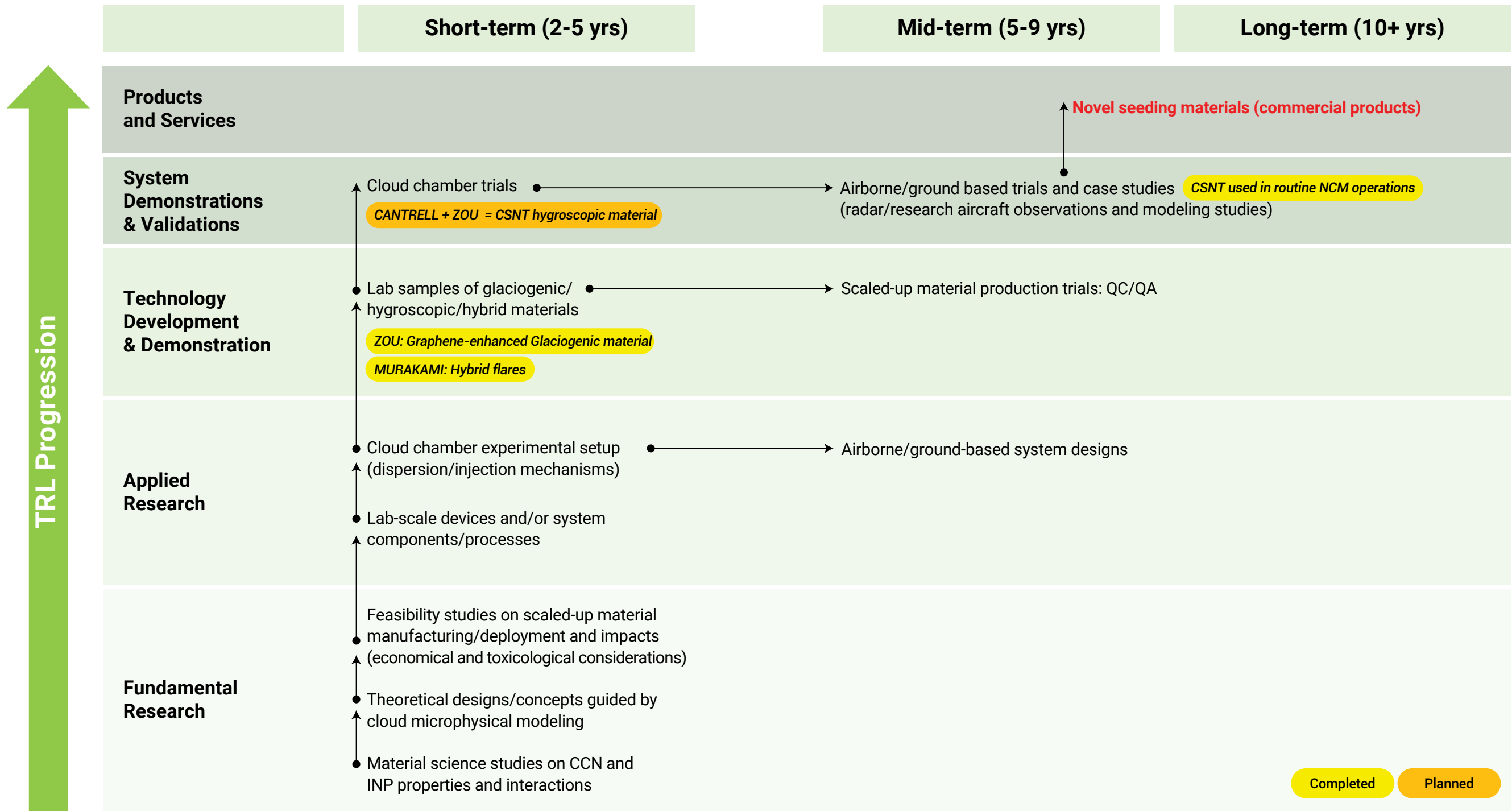
Additionally, novel methods for facilitating precipitation including bacterial intervention [xxiv] for ice nucleation could have important implications for enhancing snowfall. Existing products on the market such as Snowmax [xxv] demonstrate similar interventions for commercial use and adapting these organic technologies at scale could produce positive outcomes.

Five-year KPIs:

- Establish standardized methodologies for quantifying seeding material properties through cloud chamber measurements and validate these through comprehensive field observations.
- Develop and implement advanced cloud seeding modeling scenarios to evaluate various seeding materials, strategies, and dispersion methodologies under different cloud conditions.
- Produce evidence-based recommendations for optimal seeding materials and methodologies tailored to specific cloud conditions, synthesizing insights from laboratory studies, modeling, and field validations.



Optimized Seeding Materials



Thrust Area Roadmaps

Novel Cloud Formation and/or
Rainfall Enhancement Systems

By 2030, the objective is to develop advanced, multi-platform rainfall enhancement systems integrating aircraft, UAVs, and ground-based technologies customized for the UAE's climate and guided by high-resolution radar and satellite data.

Research has also shown that cloud droplet growth may be accelerated by electric charge, which increases the collision-coalescence probability of small droplets in certain controlled conditions. A custom UAV was developed to deliver positive and negative charges into clouds, showing observable changes in fog properties. Prof. Giles Harrison's research at the University of Reading explored how electric charge influences rain formation [xxvii], particularly in non-thunderstorm clouds. Supported by the UAERP, his team developed computer models and conducted field experiments using drones and balloons to release electric charges into clouds. These studies demonstrated that introducing charge can increase the number and size of water droplets in fog, as a type of low clouds.

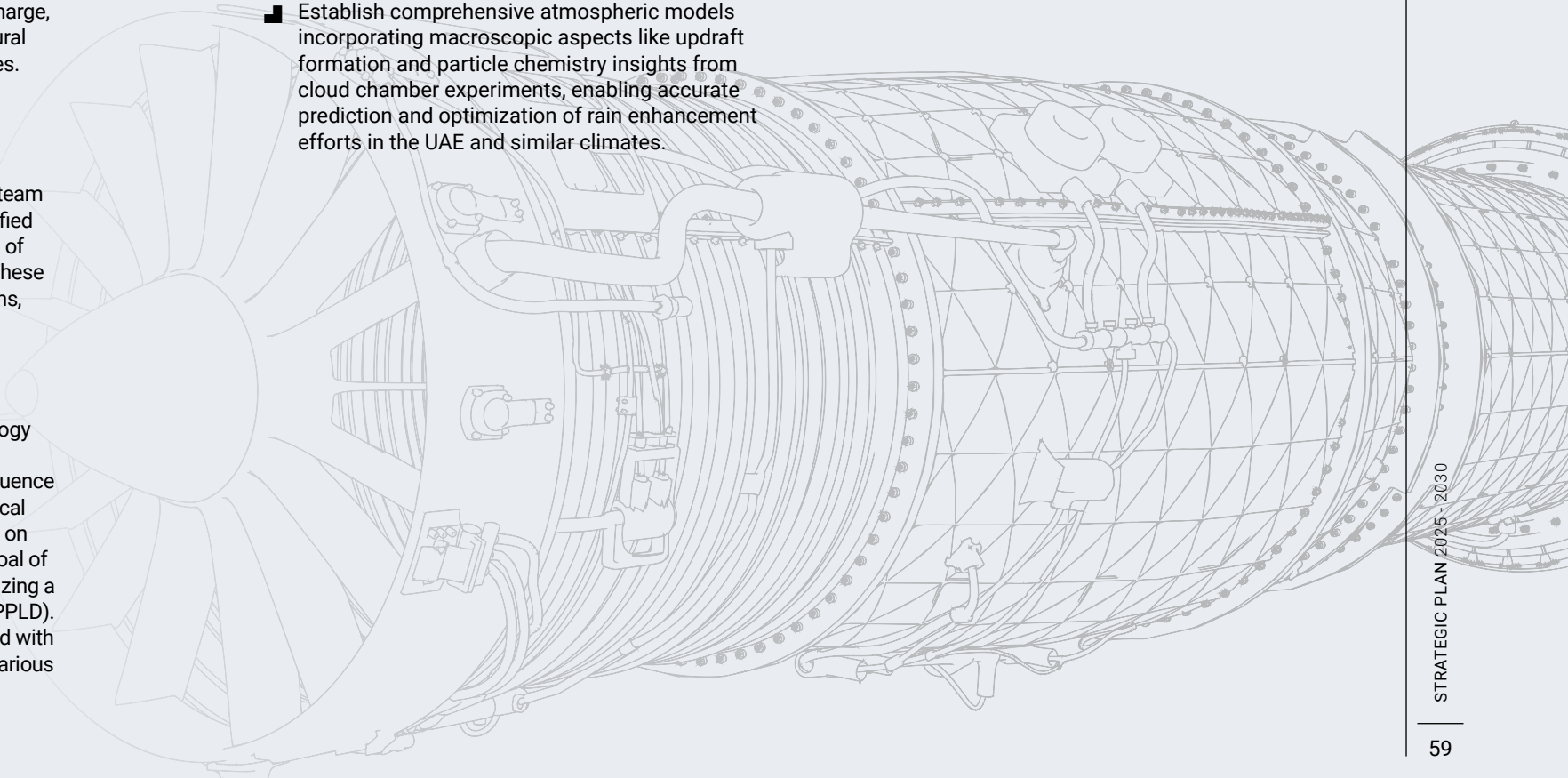
Additionally, a new measurement site in Al Ain was set up to monitor cloud properties, dust, and atmospheric charge, revealing that the UAE's dusty sea breeze carries natural electric charge, which could influence cloud processes.

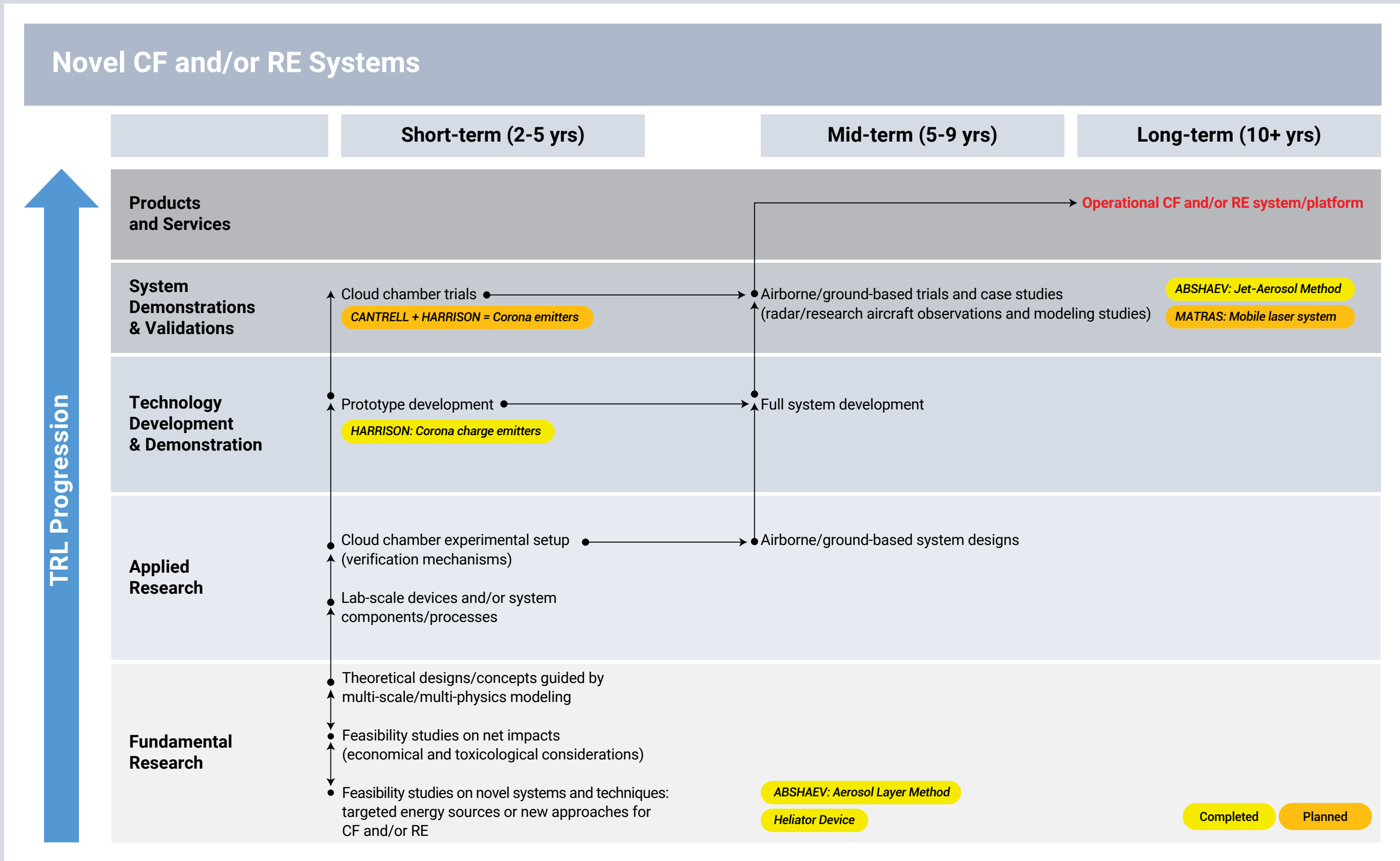
The project titled "On the creation of updrafts for the formation of artificial clouds and rainfall" [xxviii] by Dr. Ali Abshaev investigates cloud formation and rainfall generation by stimulating atmospheric updrafts. His team conducted field experiments in the UAE using a modified jet engine system that releases high-velocity streams of hygroscopic aerosols to create vertical air currents. These trials, performed under various atmospheric conditions, observed phenomena such as the formation of small aerosol-droplet clouds and short-term rainfall.

Dr. Guillaume Matras' research on Laser-based rain triggering demonstrator with remote sensing technology [xxviii] investigates the feasibility of using lasers for inducing controlled atmospheric modifications to influence and enhance precipitation processes through numerical simulations and laboratory experiments, with a focus on leveraging laser-induced wave shocks. The second goal of the project involves conducting field experiments utilizing a Mobile High-Power Pulsed Laser Demonstrator (MHPPLD). This demonstrator comprises a mobile laser equipped with a remote sensing system, allowing for relocation to various locations within the UAE.

Five-year KPIs:

- Building on current UAERP project outcomes, develop and implement advanced, multi-platform rain enhancement systems integrating aircraft, unmanned aerial vehicles, and ground-based technologies, optimized for UAE's climate conditions and backed by state-of-the-art radar and satellite data for precise targeting and delivery.
- Demonstrate novel, environmentally-friendly materials and/or directed energy sources and delivery systems, for enhanced particle growth and/or ionization yields, tailored to maximize precipitation in arid and semi-arid regions.
- Establish comprehensive atmospheric models incorporating macroscopic aspects like updraft formation and particle chemistry insights from cloud chamber experiments, enabling accurate prediction and optimization of rain enhancement efforts in the UAE and similar climates.





Thrust Area Roadmaps

Autonomous UAS Tech and Hardware

The goal is to demonstrate fully capable unmanned aerial systems (UAS) that can replicate precise, human-led cloud seeding operations with built-in safety and regulatory compliance by 2030.

These platforms will integrate real-time atmospheric sensing, nowcasting, and onboard decision-making tools to autonomously identify and target optimal seeding locations. The research so far has allowed for a range of advanced technologies to be developed to support autonomous cloud seeding and atmospheric research.

In a 3rd Cycle UAEREP project, led by Prof. Eric Frew at the University of Colorado, Boulder, miniaturized Cloud Droplet Probes (CDP) and Multi-hole Inertial Probes (MIP) were integrated into UAVs for autonomous missions, including real-time data collection and seeding operations. The project also developed specialized software tools such as the Cloud Seedability Algorithm (CSA), Rapid Evaluation of Convective Cell Environments for Seeding (RECCES) tracking system, and mission management software to enable more efficient cloud targeting and coordination across multiple UAVs, with successful field tests in the U.S. Great Plains [\[xxix\]](#).

The UAS and customized sensor payloads were transferred to NCM ownership during Q1 of 2023. The UAS includes two fully instrumented UAVs with miniaturized instruments for cloud measurements and 1 UAV to carry and dispense seeding material (payload ~2 kilograms; flight time ~3 hours). In 2024, NCM and the Khalifa University Center for Autonomous Robotic Systems (KUCARS) kicked-off a joint project to further develop the capabilities of the UAS and demonstrate them locally in the UAE. This project focused on validating the UAS in UAE operating conditions.

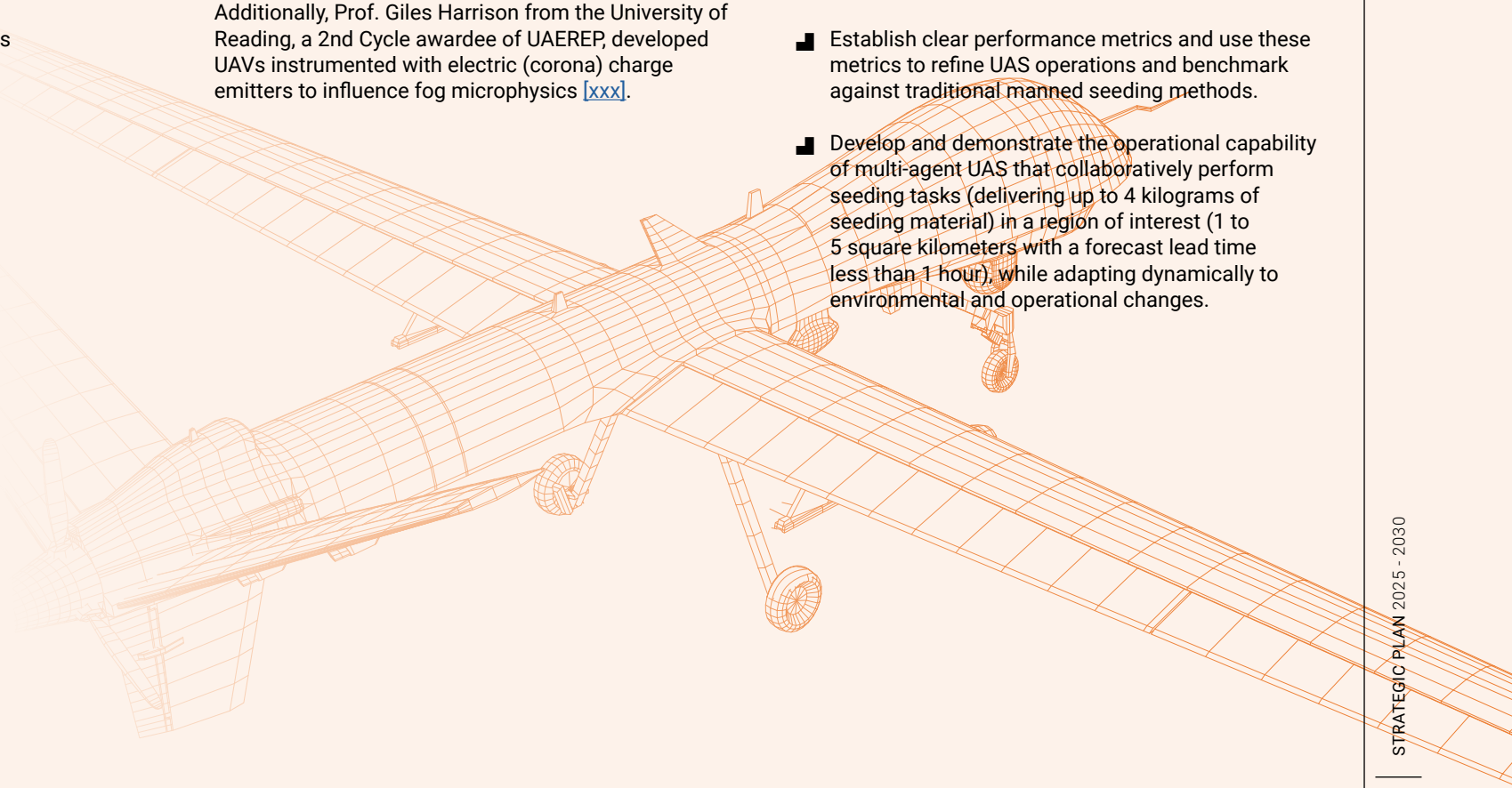
Key milestones achieved include:

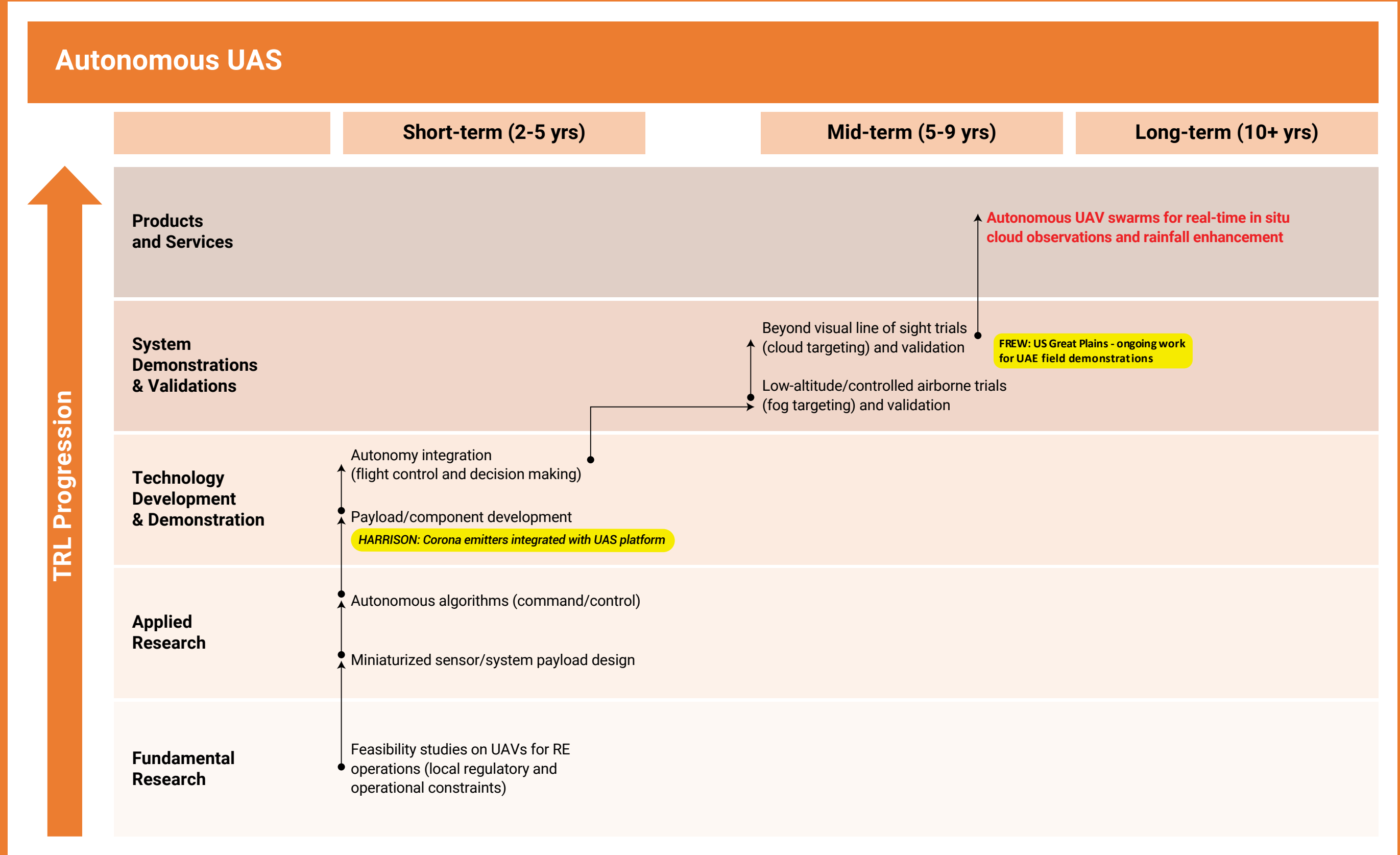
1. Assembly and indoor testing of the three UAS platforms;
2. Initial calibration of onboard meteorological sensors;
3. Establishment of communication protocols between the UAS and ground stations
4. Development of path-planning algorithms and autonomy modules, with advancements in software integration and environmental testing frameworks.

Additionally, Prof. Giles Harrison from the University of Reading, a 2nd Cycle awardee of UAEREP, developed UAVs instrumented with electric (corona) charge emitters to influence fog microphysics [\[xxx\]](#).

Five-year KPIs:

- Demonstrate a UAS platform capable of replicating precise human seeding operations, with integrated safety and regulatory compliance mechanisms.
- Integrate and validate real-time atmospheric sensing, nowcasting products, and onboard decision-making technologies that enable autonomous identification of seeding locations.
- Develop and test communication protocols that enable reliable Beyond Line-of-Sight (BLOS) operations for multi-agent UAS systems.
- Establish clear performance metrics and use these metrics to refine UAS operations and benchmark against traditional manned seeding methods.
- Develop and demonstrate the operational capability of multi-agent UAS that collaboratively perform seeding tasks (delivering up to 4 kilograms of seeding material) in a region of interest (1 to 5 square kilometers with a forecast lead time less than 1 hour), while adapting dynamically to environmental and operational changes.





Thrust Area Roadmaps

Limited-Area Climate Interventions

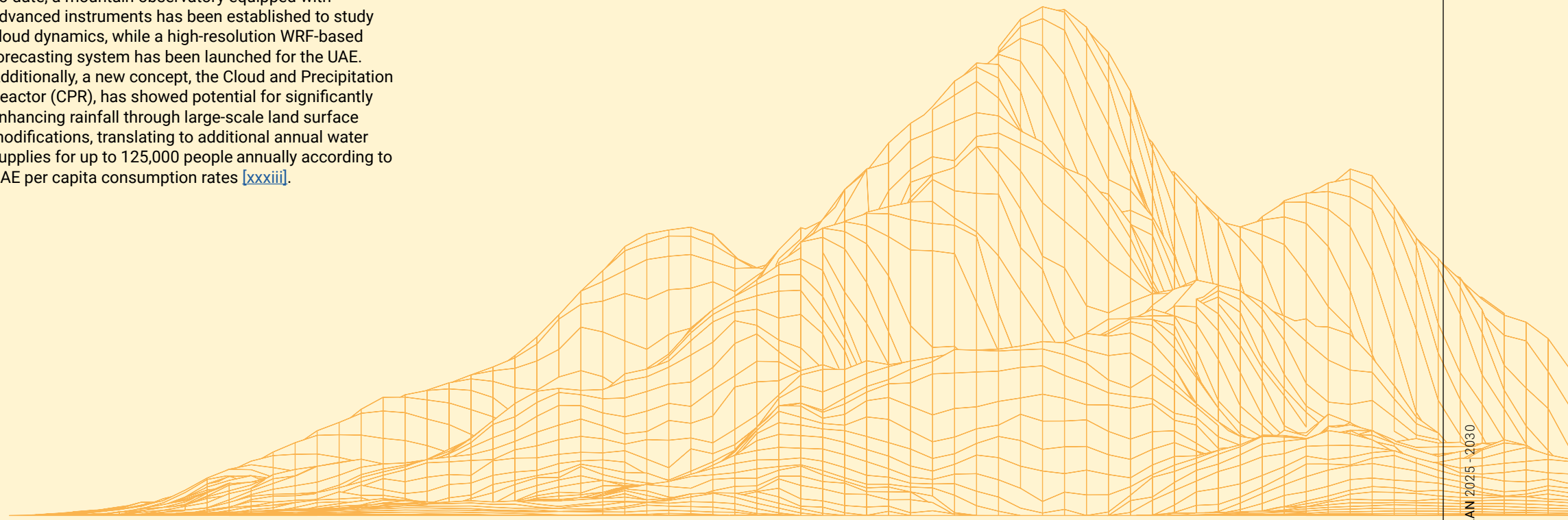
The objective is to explore and assess innovative, localized climate interventions such as solar radiation management, sea breeze funneling, and landform or topographical modifications to determine their potential for enhancing precipitation over the UAE. Through a combination of modeling, simulations, and limited field experiments, the goal is to evaluate the technical feasibility, environmental impact, and economic viability of these unconventional approaches.

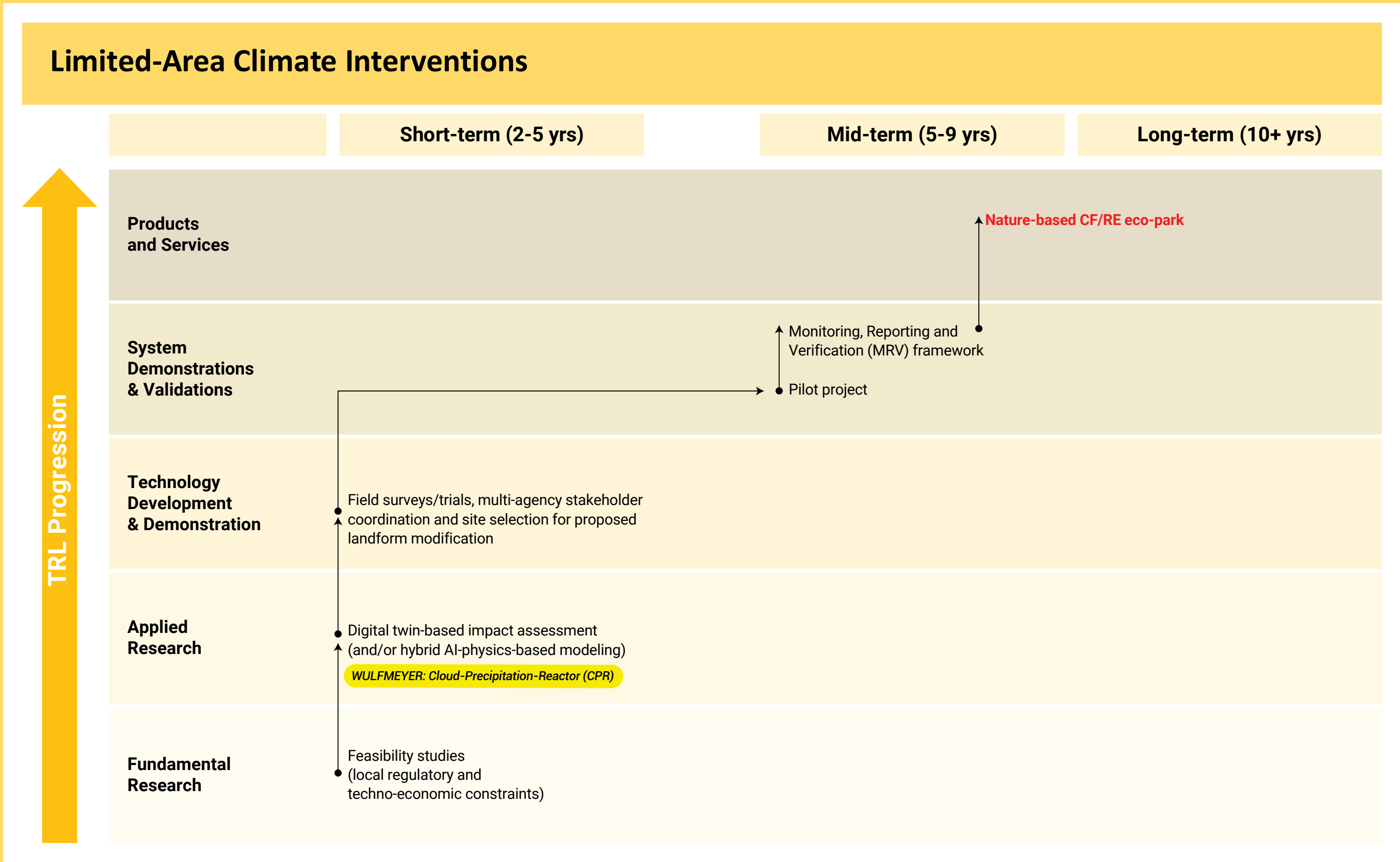
Prof. Volker Wulfmeyer from the University of Hohenheim, Germany, with support from UAEREP, has published a paper titled: “Optimizing Cloud Seeding by Advanced Remote Sensing and Land Cover Modification” [\[xxxii\]](#). His research used advanced remote sensing [\[xxxii\]](#) and high-resolution weather modeling to better identify cloud-forming zones in the UAE. It also introduced the “Cloud and Precipitation Reactor” concept, exploring how land surface changes could naturally enhance convection and rainfall, offering a potential alternative to traditional cloud seeding.

To date, a mountain observatory equipped with advanced instruments has been established to study cloud dynamics, while a high-resolution WRF-based forecasting system has been launched for the UAE. Additionally, a new concept, the Cloud and Precipitation Reactor (CPR), has showed potential for significantly enhancing rainfall through large-scale land surface modifications, translating to additional annual water supplies for up to 125,000 people annually according to UAE per capita consumption rates [\[xxxiii\]](#).

Five-year KPIs:

- Undertake modeling and experimental studies on solar radiation management, seabreeze funneling, landform modifications related to energy and humidity sources, topography modification, and localized climate interventions involving aerosols and/or other novel approaches.
- Determine via simulations and limited experiments if considered interventions show the technical and economic potential for further development.





Thrust Area Roadmaps

Advanced Models, Software and Data

The goal is to develop next-generation operational cloud-scale and seedability forecasting models, improving the accuracy of precipitation forecasts while increasing microphysical complexity without slowing down runtime. This includes expanding data assimilation with machine learning capabilities by incorporating advanced observation technologies and creating user-friendly visualization platforms to support faster and more effective planning and decision-making.

To this end, 4th Cycle UAERP Awardee, Dr. Luca Delle Monache, Deputy Director of the Center for Western Weather and Water Extremes (CW3E), Scripps Institute of Oceanography, University of California San Diego is working on a project titled: A Hybrid Machine Learning Framework for Enhanced Precipitation Nowcasting [xxxiv]. The project proposes to use artificial intelligence (AI) to improve precipitation estimates and pave the way for enhanced forecasting and cloud targeting by leveraging vast ground-based and spaceborne data sets and operational numerical weather prediction products from national meteorological centers worldwide.

Meanwhile, Prof. Daniel Rosenfeld, a 5th Cycle UAERP awardee and a leading expert on weather modification and climate change at the Institute of Earth Sciences, the Hebrew University of Jerusalem, is working on a project titled: "Identification of Clouds' Microphysical Seedability in an Actionable Manner" [xxxv]. His project, leveraging data produced from previous UAERP projects, aims to use a machine learning method for near real-time diagnosis of the seedability of cloud clusters in an actionable manner, based on operationally available meteorological and satellite data.

The training of the machine learning procedure will be based on model simulations of actual cases and the validation of the model by previously available aircraft and radar data. All completed project modeling outcomes (PIs: Murakami, Zou, Wulfmeyer, Harrison, Lawson, Korhonen, Xue, Abshaev, and Frew) are compiled and localized on the NCM HPC through a collaborative project between NCM and Khalifa University's ENGEOS lab. All modeling components were built into a single WRF-compatible code base test bed [xxxii].

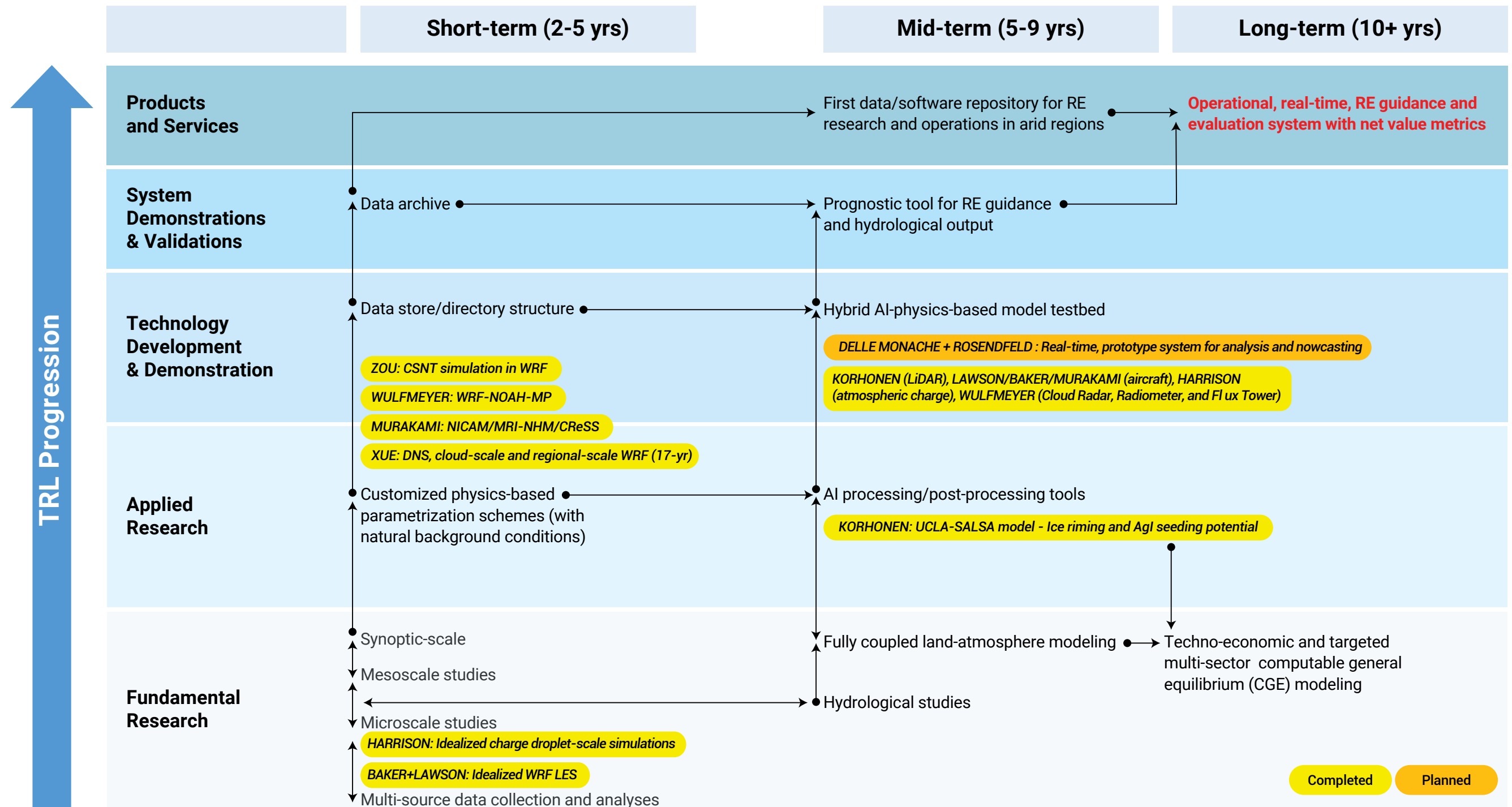
Over the next five years, the plan is to develop advanced, efficient software for high-resolution cloud microphysics modeling. The focus will be on integrating cutting-edge numerical techniques with ML/AI approaches to bridge laboratory cloud chamber data and real-world operations.

Key goals include creating physics-informed AI tools for simulating and visualizing precipitation processes, improving short-term forecasting, and developing user-friendly platforms for decision support. The roadmap also highlights enhancing observational networks, standardizing data, and establishing robust model evaluation and validation frameworks to support effective and scalable cloud seeding operations.

Five-year KPIs:

- Enhance current NCM/UAERP operational seeding planning models with improved accuracy in predicting location and timing of precipitation events, while increasing the complexity of operational microphysics without compromising model runtime.
- Expand data assimilation capabilities in operational cloud seeding models by incorporating new and future observation technologies, leading to a significant increase in the amount of data processed.
- Develop user-friendly visualization platforms for assessing and planning seeding operations, coupled with improved computational efficiency for faster and more effective decision-making processes.

Advanced Models, Software and Data



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