NCM UAEREP

National Center of Meteorology
UAE Rain Enhancement Program

THE UAE RESEARCH PROGRAM FOR RAIN ENHANCEMENT SCIENCE

His Highness Sheikh

MANSOUR BIN ZAYED AL NAHYAN

Vice President, Deputy Prime Minister
and Chairman of Presidential Court

NCM
UAEREP
National Center of Meteorology
UAE Rain Enhancement Program

H.E. Dr. Abdulla Al Mandous
Director of NCM and President of WMO

THE UAE RESEARCH PROGRAM FOR RAIN ENHANCEMENT SCIENCE

United for water security

Under the leadership of H.H. Sheikh Mansour bin Zayed Al Nahyan, the UAE Vice President, Deputy Prime Minister and Chairman of Presidential Court, the UAE Research Program for Rain Enhancement Science is working to strengthen global water security by encouraging innovation and promoting global collaboration in the science and technology of rain enhancement.

Thanks to the efforts and vision of our wise leadership, the Program is already advancing scientific understanding while also fulfilling the equally important goal of developing local and global capacities through productive research collaboration.

This pioneering initiative is managed by the National Center of Meteorology (NCM), a leading regional hub for international scientific research and the advancement of research and development in the study of climatic and environmental phenomena. The Center is honored to play a leading role in managing this Program to help strengthen water security as one of the seven pillars of the UAE's National Innovation Strategy.

Since the Program's launch, its awardees have carried out a range of ground-breaking work that continues to give a real impetus to this field that has been relatively overlooked for too long.

To support the work of our awardees, the Program has built a global network with more than 1,811 researchers from over 806 prestigious global institutions including the European Organization for Nuclear Research (CERN), the European Space Agency (ESA), and NASA, as well as enduring links with institutions in over 70 countries ranging from the United States to the UK, Germany and Russia in Europe, and to China and Japan in East Asia. I cordially invite all scientists, researchers, and research centers globally to continue to contribute to this ground-breaking program through advancing innovative thinking and creative research strategies.
The NCM is confident that the program’s results will enhance the meteorological understanding of clouds and rainfall as the essential basis of international water security solutions. Now well established as the most prominent international scientific initiative of its kind, the UAE Research Program for Rain Enhancement Science will continue to drive innovation for the benefit of all those in arid regions at risk of water scarcity and the threat of drought.

By taking the lead in seeking innovations solutions to the global water security conundrum, the UAE has demonstrated the potential of its innovators to take a leading international role in promoting scientific advancement and research collaboration for the benefit of all humanity.

THE UAE RESEARCH PROGRAM FOR RAIN ENHANCEMENT SCIENCE

The United Arab Emirates Research Program for Rain Enhancement Science is an initiative of H.H. Sheikh Mansour bin Zayed Al Nahyan, Vice President, Deputy Prime Minister and Chairman of Presidential Court, under the management of the National Center of Meteorology (NCM).

Aligned with the National Innovation Strategy, the program demonstrates the UAE's leadership in tackling water security challenges by advancing the science of rain enhancement through research and development.

Aiming to expand global water security through promoting scientific best practices and collaboration in rain enhancement research, the program will identify scientifically verified and sustainably implementable methods of enhancing precipitation to increase rainfall in the UAE and beyond.

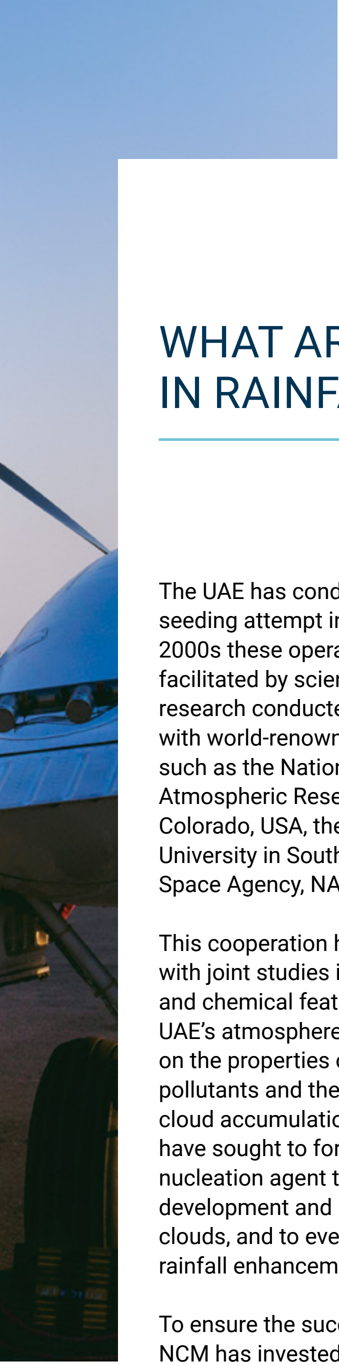
For more information on the program and its innovative research projects, please visit: www.uaerep.ae

To play the video please scan the QR Code

WHY IS THIS PROGRAM IMPORTANT TO THE UAE?

The UAE has an arid climate with less than 100 mm per year of rainfall, a high evaporation rate of surface water and a low groundwater recharge rate that is far less than the total annual water used in the country.

Furthermore, population increase and economic expansion will put additional pressure on existing water supplies and rainfall for food and water. This program was launched to address that concern and to advance the development of sustainable approaches to boost water security for the UAE and beyond.



WHAT ARE THE UAE'S ACHIEVEMENTS IN RAINFALL ENHANCEMENT?

The UAE has conducted its first cloud seeding attempt in 1982. By the early 2000s these operations were being facilitated by scientific and technical research conducted in cooperation with world-renowned organizations such as the National Center for Atmospheric Research (NCAR) in Colorado, USA, the Witwatersrand University in South Africa, and the US Space Agency, NASA.

This cooperation has continued with joint studies into the physical and chemical features of the UAE's atmosphere with a focus on the properties of aerosols and pollutants and their impact on cloud accumulation. These studies have sought to formulate a proper nucleation agent to ensure the development and augmentation of clouds, and to eventually achieve rainfall enhancement.

To ensure the success of the program, NCM has invested heavily in a cloud seeding infrastructure. The NCM has established a national network of 86 automatic weather stations (AWOS) for weather monitoring, six weather radars covering the entire UAE, and one upper air station. The Center has also created climate databases and assisted in the development of high precision Numerical Weather Predictions and simulation software in the UAE.

At present, the NCM operates 4 Beechcraft King Air C90 aircraft from Al Ain Airport equipped with the latest technologies and devices employed for cloud seeding and atmospheric research.

The NCM also exchanges data and information with other regional and international organizations, including the World Meteorological Organization (WMO) and the Standing Committee for Meteorology and Climate for the Gulf Cooperation Council (GCC), concerning new scientific research and developments in fields of mutual interest.

Today, cloud seeding operations are conducted by a permanent unit at the NCM's meteorological department, which conducts operations anywhere in the UAE where there are amenable clouds mostly along the eastern mountainous terrains. Importantly, no harmful chemicals are used in these operations, relying instead on natural salts such as potassium chloride and sodium chloride.

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GOALS OF THE UAE RESEARCH PROGRAM FOR RAIN ENHANCEMENT SCIENCE

1

To advance the science, technology and implementation of rain enhancement, and to spur additional investments in research funding and partnerships globally.

2

To increase rainfall in the UAE, and other arid and semi-arid regions.

PATHWAY TO GOALS

1

Enhance the level of research and innovation in the field

Increase the level of research activities and funding globally, including attracting diverse new researchers, technologists and entrepreneurs to the field, while leveraging program funding from participating entities.

2

Advance scientific understanding of rainfall enhancement

Obtain new scientific understandings of cloud physics and dynamics, cloud-cloud interactions, cloud systems, precipitation production, and other relevant physical processes. Additionally, consolidate current knowledge and understanding through the sharing of experimental data, sponsored symposia, and the like.

3

Advance state-of-the-art techniques in rainfall enhancement practices and operations

Make high-quality experimental data, current and historical, available to researchers and spur the analysis of that data with multiple, state-of-the-art techniques. Also, add to the technology base for cloud seeding with the testing of materials and delivery methods, demonstrating improved cloud modeling capabilities.

4

Enhance and further develop capacity in the field both locally and globally

Develop local and regional capacities for meteorology, water and environmental R&D and additional workforce capacity for scientific and technical fields in general. Spur global research collaborations in the region and the deployment of infrastructure for meteorology, water and environmental R&D.

RESEARCH IMPACTS

The following is a non-exhaustive list of the research areas that the UAE Research Program for Rain Enhancement Science intends to address:

Fundamental Understanding of Rain Enhancement

- Cloud microphysics
- Cloud dynamics and thermodynamics
- 3-dimensional characterization of clouds
- The physical chain of events leading to cloud formation and rainfall
- Aerosol (cloud condensation nuclei and ice nuclei)/cloud interactions and characterization of background aerosols
- Characterization of cloud seeding materials and delivery
- Impact of cloud seeding methods on cloud chemistry, physics and dynamics
- Nowcasting and forecasting of weather to support cloud seeding operations

Modeling and Data Analysis

- Data and analysis (comprehensive data bases, historical and new data, analysis and re-analysis of previous experiments to gain substantial new insights)
- Multiscale modeling of relevant atmospheric processes, including cloud microphysics and dynamics

Observations, Technologies, Instrumentation

- Production and characterization of cloud seeding materials
- Cloud seeding methodology assessments
- New technologies and approaches, other than cloud seeding, to stimulate rain enhancement
- Remote sensing and in-situ observation and technologies applied to rain enhancement
- Field experiments and campaigns

SUMMARY OF PROGRESS

Under the leadership of H.H. Sheikh Mansour bin Zayed Al Nahyan, Vice President, Deputy Prime Minister and Chairman of Presidential Court, the UAE Research Program for Rain Enhancement Science has already established a global reputation as a focal point for the ground-breaking innovation needed to tackle the challenge of global water stress.

The Program has pushed for breakthroughs in all directions, including in fields as diverse as nanotechnology, innovative algorithms, land cover modification, ice nucleation, optimization of aerosol seeding, electrical properties of clouds, artificial updrafts to produce rain, targeted use of unmanned aerial systems, and experimental-numerical approaches.

The ambitious and extensive outreach campaign undertaken by the Program since 2015 across four continents allowed us to continuously identify leading researchers and partners to join us on this quest for global water security innovation: the result was an increase in the number of participating researchers by 100% and in pre-proposal submissions by 121% for our Third Cycle in 2017.

In addition, worldwide outreach campaigns in recent years have built strong connections between the Program and leading researchers and partners working at the water-energy-food nexus. We now have a network with more than 1,811 researchers from over 806 global institutions including the European Organization for Nuclear Research (CERN), the European Space Agency (ESA), and NASA.

In cooperation with international experts from the World Meteorological Organisation (WMO), the program is currently reviewing its impressive achievements to date and formulating strategic goals to serve as guidelines for the next stage of its quest to advance rain enhancement science.

At the same time, we are continuing to support our eleven awardees and their teams across the world. Over the past years, we have carried out several ambitious roadshows across to the US, Brazil, Russia and China to strengthen and expand our comprehensive global scientific networks.

The Program, in collaboration with National Center of Meteorology (NCM), has also unveiled an imaginative new plan to integrate the Program's nine awardee projects, which are currently running in three program cycles, into an advanced model entitled "Integrating Schemes from UAEREP projects into a unified multi-component atmospheric model". Aimed at improving cloud seeding methods through leveraging the research findings of awardee projects, the collaborative scientific venture will increase the accuracy of weather forecasts related to clouds amenable to seeding operations in the UAE.

The program continues to build on the achievements of 1st Cycle awardee Prof. Linda Zou in the development of novel seeding material using nanotechnology. Airborne tests in clear air over Al Ain were conducted with a specialized research aircraft during August 2019, in preparation for in-cloud trials during May 2021 in collaboration with the West Texas Weather Modification Association.

Results showed an increase in the effective radius of the cloud droplet size distribution after seeding. Preliminary results encouraged the use of the novel seeding material in routine operational trials to generate enough cases for further statistical testing.

The program is engaging in a technology transfer process to locally produce this novel seeding material through the NCM Weather Enhancement Factory’s production line.

Also, the Program is continuing to run its prestigious International Rain Enhancement Forum in January once every two years. As a platform for international cooperation in this important field, the Forum raises global awareness about the potential of scientific advances to help reduce water scarcity.

Through the UAE Research Program for Rain Enhancement Science, the UAE will continue to use its immense knowledge capacities to provide solutions to ensure a better quality of life in arid regions and beyond around the world. By leading the world in advancing rain enhancement science, the UAE has once again demonstrated its inspiring and generous vision and commitment to making a real difference by finding answers to the global threat of water stress.

ABOUT NCM

The National Center of Meteorology (NCM) supports the study of a broad range of atmospheric phenomena and processes through methods ranging from mathematical analysis to field experimentation. Research projects range in size from basic studies involving individual scientists to national and international programs involving teams of scientists. The center is concerned with:

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Synoptic Meteorology:
which is the analysis and prediction of weather systems, such as cyclones high and low pressure fronts, and jet streams.

Mesoscale Meteorology:
which includes most weather phenomena directly impacting human activity, such as thunderstorms, gap winds, down slope windstorms, land-sea breezes, and squall lines.

Atmospheric Dynamics:
which examines atmospheric phenomena as impacted by natural events along with biological and anthropogenic activities.

Boundary Layer Research:
which looks at the structure and dynamics of the lowest layer of our atmosphere and its vital importance to our understanding of weather and climate.

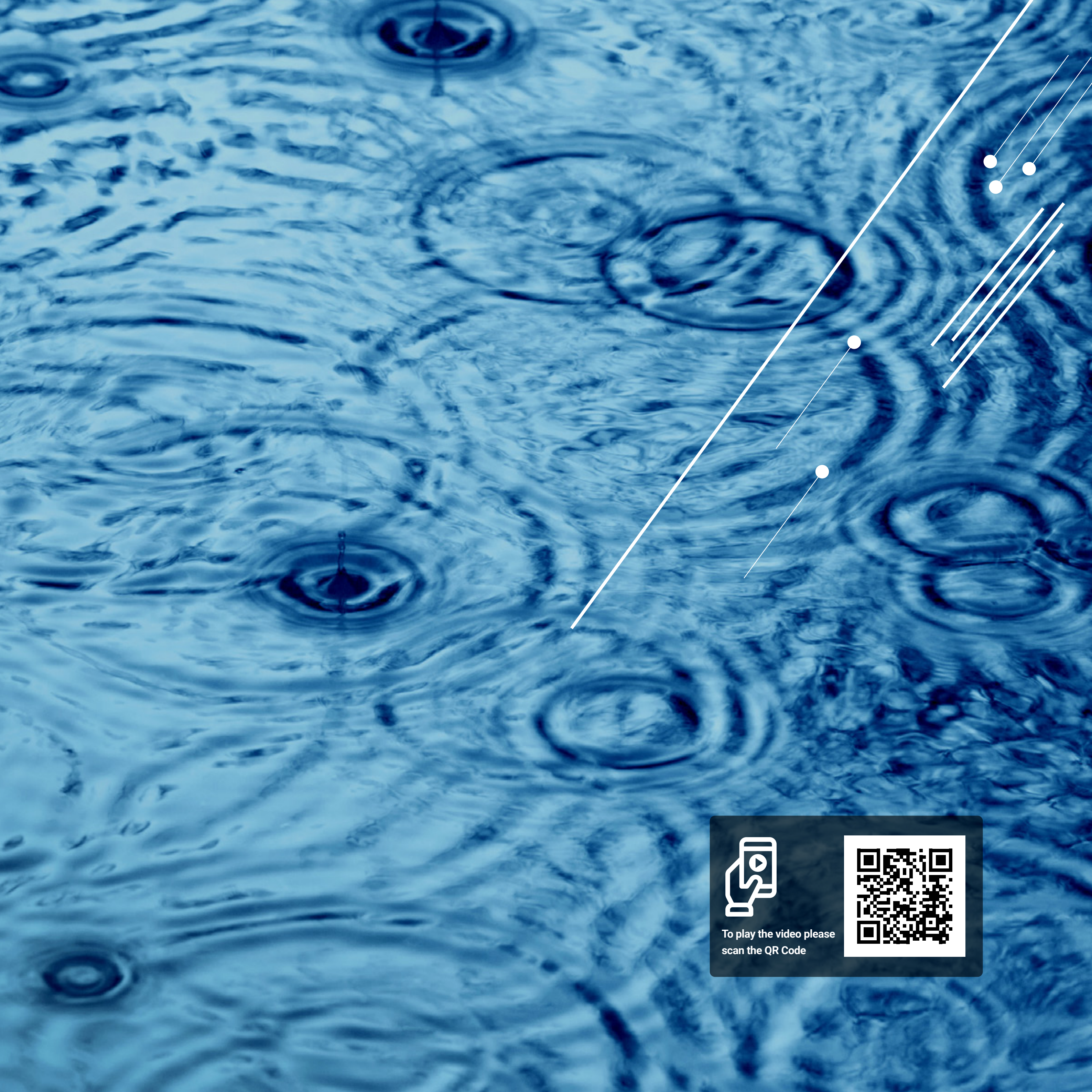
Cloud Dynamics Precipitation Processes and Storms:
which examines atmospheric phenomena as impacted by natural events along with biological and anthropogenic activities.

Cloud and Aerosol Research:
which is concerned with the origins of various particles and gases in the air and their effects on the atmosphere locally.

14 AWARDESS
9 COUNTRIES
1 AIM

- Dr. Lulin Xue
- Prof. Hannele Korhonen
- Prof. Volker Wulfmeyer
- Prof. Masataka Murakami
- Dr. Ali Abshaev
- Prof. Giles Harrison
- Prof. Linda Zou
- Dr. Paul Lawson
- Prof. Eric Frew
- Dr. Bradley Baker
- Dr. Luca Delle Monache
- Prof. Will Cantrell
- Prof. Daniel Rosenfeld
- Dr. Guillaume Matras

CYCLE 1
AWARDEES
PROJECTS UPDATE



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CYCLE 1 AWARDEES

PROF. MASATAKA MURAKAMI

BIOGRAPHY

Prof. Murakami is a Professor at the Institute for Space-Earth Environmental Research, Nagoya University and a visiting scientist at the Japan Meteorological Research Institute (MRI). Masataka Murakami had also been a scientist in the Cloud Physics section of the Meteorological Research Institute, Japan Meteorological Agency since 1984, including the last 21 years as Section Head, and involved in cloud physics, precipitation systems and numerical modelling.

He served as a member of the International Commission on Clouds and Precipitation from 1992 to 2000. Prof. Murakami is chair of American Meteorological Society (AMS) Planned and Inadvertent Weather Modification Committee, as well as a member of the World Meteorological Organization (WMO) Expert Team on Weather Modification.

PROJECT BRIEF

“Advanced study on precipitation enhancement in arid and semi-arid regions”

Prof. Masataka Murakami’s project focuses on innovative algorithms and sensors dedicated to identifying the clouds most suitable for seeding and their frequency of occurrence.

Prof. Murakami’s project team developed optimal seeding methods and new statistical evaluation methods to study the effects of long-term seeding through accurate numerical models.

Researchers from Nagoya University, the University of Tokyo and the Japan Meteorological Agency also contributed to this research project.

RESEARCH PROGRESS

Satellite data analysis over the UAE has long been subject to errors and uncertainties.

To support the selection of the field measurement site candidates by the Japanese team, solar radiation and rain gauge data were analyzed to map the occurrence frequency of potentially seedable clouds.

This occurrence frequency was investigated in 2017 and validated against year-round ground-based observations at Al Ain Airport.

The observational campaign was conducted from February 2017 through January 2018.

Customized NWP models were tested over the UAE and land surface processes were tuned to accurately reproduce cloud formation and precipitation developments over the

desert and mountain regions during 2021. The developed model schemes were transferred to the UAEREP data repository and hosted on the NCM Cray supercomputer during 2022.

In parallel, cloud chamber experiments were conducted in Japan and the properties of salt micro-powder, hygroscopic flare, AgI flare, hybrid flare particles were investigated.

During September 2017, an instrumented cloud physics research aircraft from the Japanese Meteorological Research Institute was ferried to the UAE and collected measurements in seeded and unseeded clouds over the eastern region of the UAE. The campaign results were documented in a journal article entitled “In Situ Measurements of Cloud and Aerosol Microphysical Properties in Summertime Convective Clouds over Eastern United Arab Emirates” published in the journal of Scientific Online Letters on the Atmosphere (SOLA).

The processed aircraft and ground-based datasets were archived in the UAEREP data repository and are being made available to other project teams for model verification and testing, including the UAV-based cloud seeding decision algorithm developed in Prof. Frew’s 3rd Cycle project.

In the last year of the Japanese project and following the UAE flight campaign, the work focused on the assessment of seedability, evaluation of seeding effects, development of optimal seeding methods, and a new statistical evaluation method of long-term seeding effects.

A 6-week aircraft observation campaign was carried out from August 22 to October 1, 2017 in cooperation with NCM's cloud seeding aircraft.

For more information
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CYCLE 1 AWARDEES

PROJECT RESULTS

The team submitted their final report in February 2020. The aircraft measurements indicated that drizzle freezes through the nucleation of dust particles and forms larger ice particles which can favor a secondary ice multiplication process through hygroscopic seeding.

Consequently, this secondary ice process was then investigated in detail by one of the Program's 2nd cycle projects led by Dr. Paul Lawson.

Three NWP models have been developed with optimized land surface processes that realistically reproduce convective cloud development over the UAE.

A hygroscopic seeding scheme was developed and customized for UAE weather conditions.

Cloud chamber experiments at the Meteorological Research Institute were conducted for the characterization of seeding material.

The team published 6 scientific articles examining different stages of the project progress.


エーロゾルバッファータンク
Ice nucleation instrument

CYCLE 1 AWARDEES

PROF. LINDA ZOU

BIOGRAPHY

Prof. Linda Zou joined Masdar Institute, now Khalifa University of Science and Technology, as a Full Professor in October 2014.

Her research interests include applying nanotechnology and membrane science to the development of low energy and high efficiency novel desalination and water purification solutions. Her research outcomes have been published in more than 150 journal articles and conference presentations (with Google Scholar H-index 46 and 7000 citations).

Her cloud seeding research has been reported by New York Times in 2017.

She is the chief investigator of many frontier research projects sponsored by Australian Research Council. She is also the recipient of the UK-Gulf Institutional Links 2016 grants awarded by the British Council.

PROJECT BRIEF

"Nanotechnology to Develop Novel Cloud Seeding Materials for Rain Enhancement"

Prof. Linda Zou's project intends to improve the effectiveness of cloud seeding technologies used to increase rain precipitation, through engineering nanostructured properties of the cloud seeding materials to help water vapor in clouds condense, which is the necessary process needed for raindrops to form.

The goal of the project is to explore state of art knowledge of nanotechnology to fabricate innovative cloud seeding materials, to increase the efficiency of rain droplet formation. Linda Zou's project has also developed innovative in-situ observation method to evaluate water adsorption and condensation of cloud seeding materials using a scanning electron microscope (SEM).

The numerical cloud models have been developed first for the inclusion of new cloud seeding materials and second to predict rainfall formation and precipitation.

Prof. Zou collaborated with the University of Belgrade for her project.

The goal of the project is to explore state of art knowledge of nanotechnology to fabricate innovative cloud seeding materials, to increase the efficiency of rain droplet formation.

RESEARCH PROGRESS

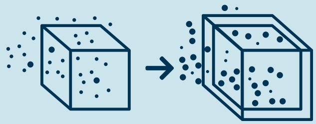
Prof. Zou designed and synthesized novel cloud seeding materials that can successfully absorb much more water vapor than pure salt. These novel cloud seeding materials can help to form much larger water droplets, hence increasing the chance of rainfall. By using scanning electron microscope (SEM) observations, as well as cloud chamber experiments, the efficiency of these novel materials was systematically evaluated and validated.

Prof. Zou collaborated with the Russian High-Mountain Geophysical Institute for her cloud chamber experiments. Those experiments were conducted to evaluate the performance of the novel materials in a 3-dimensional environment, under controlled temperature and humidity conditions.

Results demonstrated that, at 100% humidity condition, the novel seeding materials formed 300% more numbers of larger water droplets compared to those resulting from conventional seeding materials. The success of Prof. Zou's research project is demonstrated by the team's filing of a worldwide patent with the United States Patent and Trademark Office (USPTO) in 2017 for a new application of cloud seeding through nanotechnology, with NCM joint-ownership of the intellectual property.

The project objectives of designing and fabricating novel cloud seeding materials were achieved. These novel cloud seeding materials were characterized for their size, chemical composition, elemental distribution, then their hygroscopic performance was evaluated by water vapor adsorption analysis. A new approach of observing the real-time change in size of the novel materials in a two-dimensional environment was developed.

The findings of the research project were used in authoring and publishing a total of 8 scientific articles, as well as obtaining 3 patents.



At 100% humidity condition, the novel seeding materials formed 300% more numbers of larger water droplets -a critical size for rainfall compared to the conventional seeding materials.

CYCLE 1 AWARDEES

PROJECT RESULTS

Following the laboratory-scale results involving flat surface experiments, cloud chamber tests, and numerical modeling, the novel core–shell NaCl–TiO2 (CSNT) nanomaterial outperformed the bio-inspired graphene-based material, and the conventional seeding salts. Large-scale production alternatives from outsourced vendors were assessed during 2018 – 2019.

Large-scale production trials of the nanomaterial were conducted using two distinct processes: (1) Benchtop V-blending and (2) Magnetically Assisted Impact Coating (MAIC). on June 11, 2019, samples of these materials were received by Prof. Zou for verification. All samples passed the quality check: size ranges of 1-10 μm, successful coating with TiO2 nanoparticles, and water vapor adsorption improvement compared to uncoated NaCl. Based on the results, the V-blending process alone was recommended for cost-effective and quality-controlled large-scale production.

After sample verification, a larger quantity was received on August 5, 2019; in time to conduct airborne tests by leveraging the US team's (Cycle 2) aircraft campaign, equipped with advanced microphysics instruments, in coordinated flights with an NCM seeding aircraft.

NCM is currently executing a technology transfer project to locally manufacture the novel CSNT nanomaterial within its Weather Enhancement Factory production line during 2024.

As a secondary objective of the project, the design and fabrication of novel glaciogenic (ice-nucleating) cloud seeding material was also completed.

During September 2019, the Karlsruhe Institute of Technology (KIT), Germany supported the analysis of micro ice nucleation measurements at their cloud chamber facility. Preliminary results showed accelerated deposition and nucleation of ice crystals and rapid growth.

For more information
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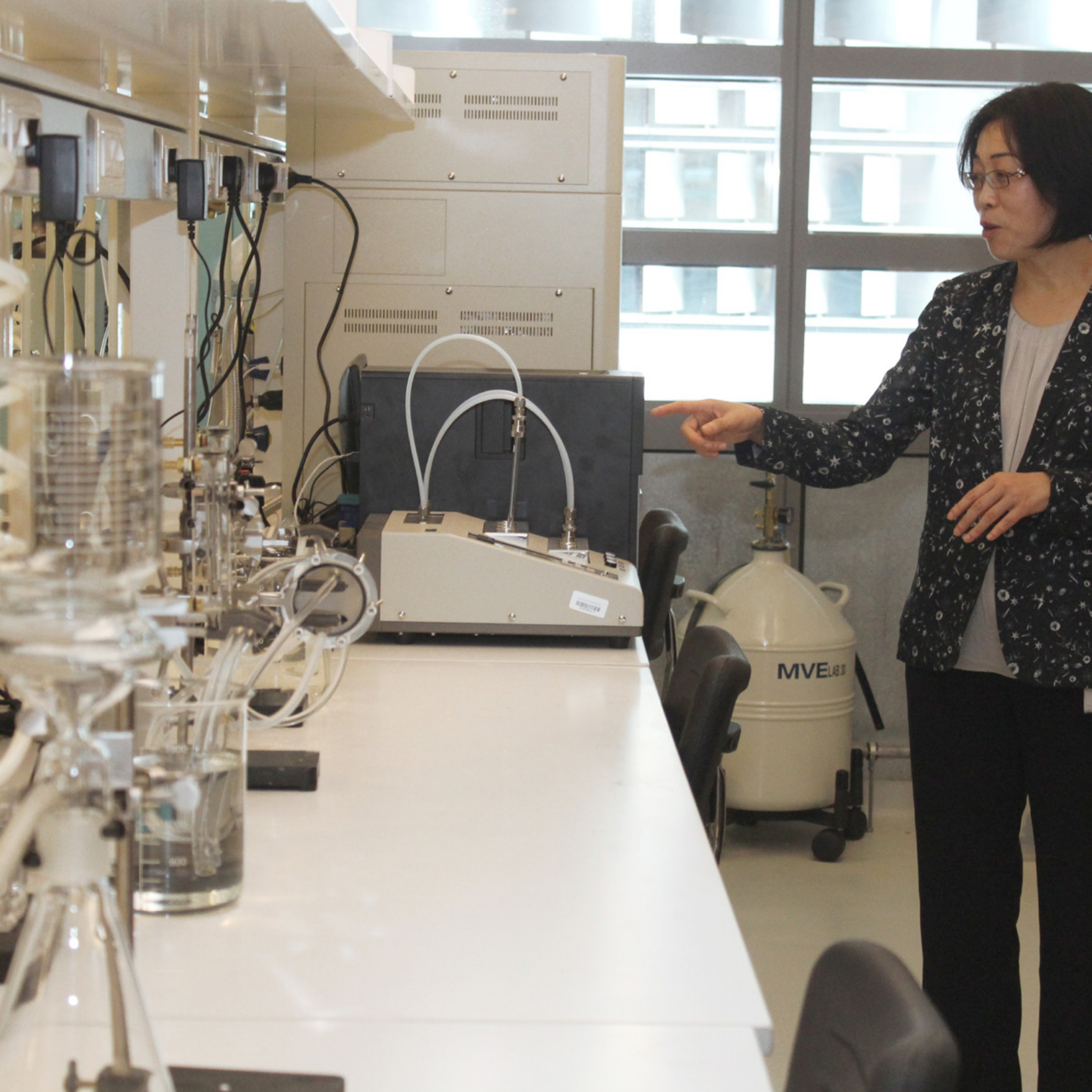
Large-scale production of the glaciogenic nanomaterial was found to be more challenging and less cost-effective than the warm cloud seeding material, but alternatives may continue to be assessed as part of future work.


MVE LAB 30

CYCLE 1 AWARDEES

PROF. VOLKER WULFMEYER

BIOGRAPHY

Prof. Volker Wulfmeyer is a University Professor, Managing Director and Chair of Physics and Meteorology at the Institute of Physics and Meteorology of the University of Hohenheim in Stuttgart, and member of the Heidelberg Academy of Sciences and Humanities.

Prior to his current affiliation, Prof. Wulfmeyer worked for the United States National Center for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (NOAA), and the Max Planck Institute for Meteorology of Hamburg. He currently participates in a working group of the World Climate Research Programme of the World Meteorological Organisation (WMO).

In February 2018, Prof. Wulfmeyer was announced as the Chair of the UAEREP Awardee team. In this function, he coordinated coordinating the scientific exchange of all groups in order to combine the results achieved and the approaches pursued by the nine groups to a big picture for the utmost benefits of rain enhancement science in the UAE.

The combination of large plantations with an additional heat source at the convergence zones has the potential to induce the development of clouds and precipitation, also it can be combined with seeding efforts for further amplification.

PROJECT BRIEF

“Optimizing cloud seeding by advanced remote sensing and land cover modification”

Prof. Volker Wulfmeyer’s project aims to specifically study convergence zones and the modification of land surface for the amplification of clouds and precipitation.

For optimal cloud seeding deployment, these convergence zones need to be identified prior to the development of clouds. Prof. Wulfmeyer’s work focused on the improved detection and forecasting of convergence zones, a key to precipitation enhancement and cloud seeding guidance.
This was conducted through new-generation active remote sensing, particularly Doppler lidar and cloud radar as well as advanced high-resolution modelling in combination with sophisticated data assimilation techniques.

RESEARCH PROGRESS

Within Prof. Wulfmeyer's project, the first mountain observatory for studying aerosol particles, wind fields, and clouds in 3D was established in the UAE.

A synergy of remote sensing instruments (the first Doppler lidar system for 3D wind measurements and the first Doppler cloud radar for 3D cloud studies) operated continuously during the summer of 2018 in the Al Hajar Mountains providing previously unavailable, ultra-high-resolution observations of convection initiation.

Additionally, Prof. Wulfmeyer's team performed the first eddy covariance measurements in the UAE over a desert site. A unique, long-term data set of surface energy flux measurements in Al Ain (April 2017-January 2019) was produced for model verification as well as for case studies to improve model physics.

Prof. Wulfmeyer's team has not only simulated the effect of large plantations and their feedback with respect to convection initiation, but also a combination of this approach with an additional heat source.

Their results demonstrate that this combination has the potential to induce the development of clouds and precipitation. This way, precipitation events can be generated even without cloud seeding and can also be combined with seeding efforts for further amplification.

In the last year of their project, Prof. Wulfmeyer's team came to the following conclusions:

a) The first reliable method to generate and enhance clouds and rain over the UAE was identified: the Cloud and Precipitation Reactor (CPR). The beneficial side effects of CPR include its contribution to carbon mitigation, thus helping the UAE to achieve its climate objectives in accordance to the Paris Agreement, as well as the co-generation of solar energy and the sustainment of JoJoba plantations.

b) As only a small percentage of all clouds have the potential to generate rainfall, and as even these clouds only respond to cloud seeding efforts during a very limited time period, a Cloud Seeding Alert System (CSAS), which can already be realized based on the atmospheric data currently available in the UAE, was proposed to identify these clouds and to predict their formation well ahead of time. This way, all cloud seeding efforts can be planned ahead and can focus exclusively on the right clouds in the right moment.

PROJECT RESULTS

The project team submitted their final report in February 2019.

The team developed an ensemble forecast model customized for UAE weather and surface conditions, with results published in the Quarterly Journal of the Royal Meteorological Society.

During 2021, the developed model schemes were transferred to the UAEREP data repository and were made available to other UAEREP project teams for their modeling studies.

The model system is transferred to the NCM Cray supercomputer during 2022.

The project's final report identified suitable plantation locations across the UAE, including their size, shape and crop types for inducing additional rainfall.

A follow-on proof-of-concept or pilot project in the UAE, in the form of a large-scale plantation integrated with solar photovoltaic panels, remains contingent on additional cross-agency funding and support. Intellectual property filing may also be pursued depending on further development.

Over the course of the project, the team authored and published 5 scientific peer-reviewed journal articles.

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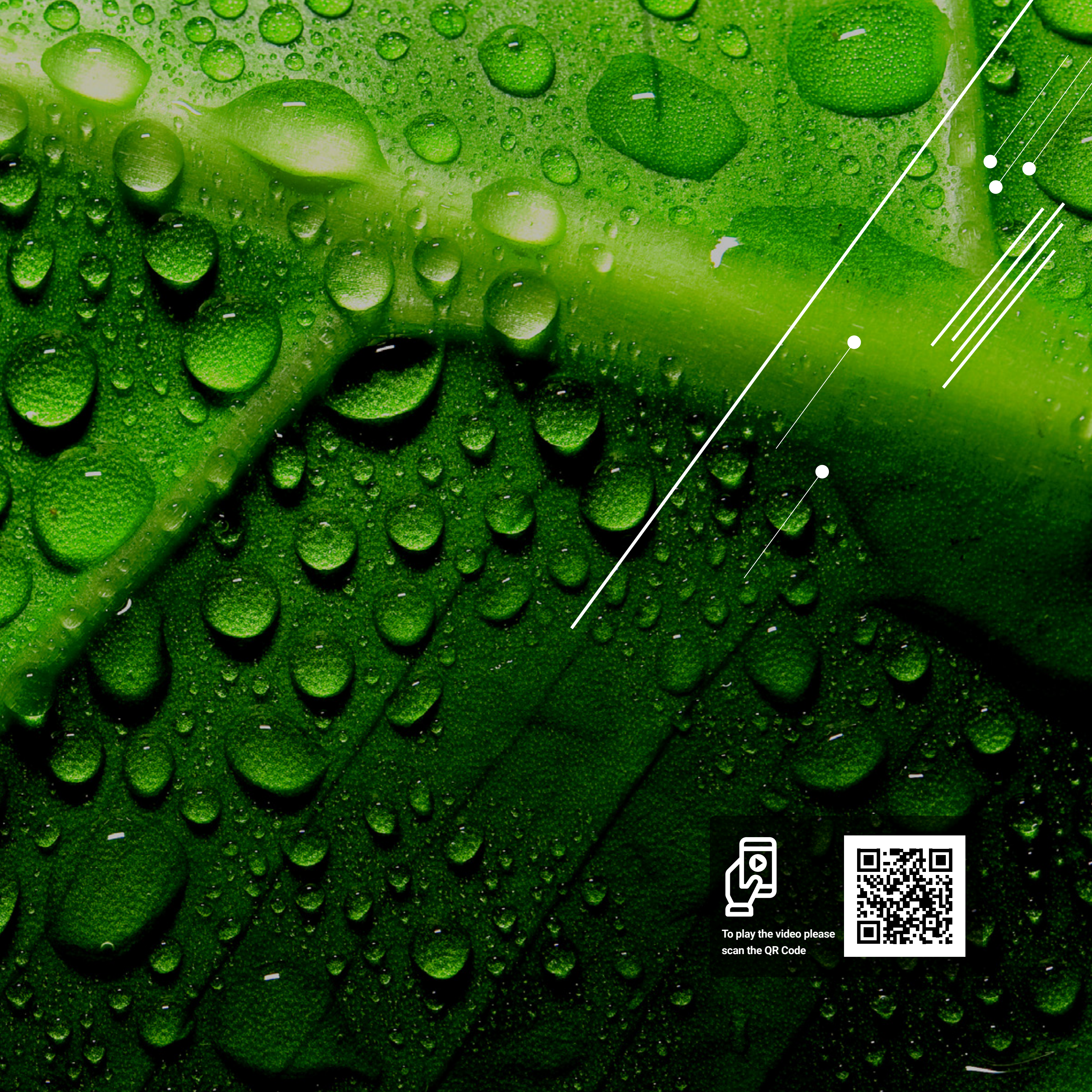
CYCLE 2
AWARDEES
PROJECTS UPDATE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CYCLE 2 AWARDEES

DR. PAUL LAWSON

BIOGRAPHY

Dr. Paul Lawson is a Senior Research Scientist at SPEC Incorporated.
H received a B.S. degree in Electrical Engineering from Michigan State University in 1969 and M.S. and Ph.D. degrees in Atmospheric Science from the University of Wyoming in 1972 and 1988.

He has been heavily involved in the development of instrumentation and analysis of meteorological data for more than three decades.

Dr. Lawson has also authored or co-authored over 100 peer-reviewed papers and has participated in over 50 meteorological field programs as scientist and/or Learjet pilot.

Dr. Lawson is a past member of the American Meteorological Society (AMS) committee on cloud physics, and a member of over twenty NASA and NSF science teams.

PROJECT BRIEF

"Microphysics of Convective Clouds and the Effects of Hygroscopic Seeding"

SPEC investigates a new approach to rain enhancement that leverages ice production processes in cumulus clouds.

When large "supercooled" drops – drops that remain unfrozen at temperatures below zero degrees Celsius - form in clouds and freeze, they emit tiny ice particles.

These tiny ice particles then collide with other large supercooled drops, producing an avalanche process that freezes the remaining large drops, producing small hail stones.

The hail stones then melt into rain after they fall into the warm sub-cloud layer.

Seeding in the updraft at cloud base with water attracting material can facilitate the development of large drops that are required to generate the natural secondary ice process.

Using sophisticated instrumented aircraft and radar, this experiment studies this process in cumulus clouds in the UAE, and evaluate the potential for rain enhancement.

The operations are conducted in collaboration with Dr. Hugh Morrison of the National Center for Atmospheric Research (NCAR) and Dr. Roelof Bruintjes of Advanced Radar Corporation (ARC).

NCAR is providing numerical modeling support for the project, while the ARC is assisting the researchers through the provision of a flight scientist and analysis of radar data.

RESEARCH PROGRESS

Since the start of his project, Dr. Lawson's research team has systematically investigated cumulus clouds with a large range of cloud base temperatures and drop distributions. In July and August 2017, the American team employed a Learjet research aircraft to study work convective clouds over the US with cloud base temperatures ranging between -6 and +12 C.

The research campaign saw a total of 108 cloud penetrations conducted with the important goal of determining what combination of temperatures and drop size distributions could potentially be treated by cloud seeding to produce large drops leading to enhanced rainfall.

The team also analyzed NCM radar data to identify optimal locations and times of day for a UAE flight campaign set to be conducted as part of a field project in 2019.

During August 2019, the SPEC Learjet 35A - a fully instrumented cloud physics research aircraft - was ferried from the US and collected measurements in seeded and unseeded clouds over the UAE.

A total of 12 research flights were conducted with more than 80 cloud penetrations in different portions of targeted clouds.

A theoretical and numerical modeling study of the ascent rate of cloud thermals was also carried out. The results from this work were published in the Journal of the Atmospheric Sciences.

The team developed an idealized 3D mixed-phase cloud microphysics scheme in collaboration with the National Center for Atmospheric Research (NCAR). Simulations targeted days of the UAE campaign to improve performance of the 3D cloud scheme using the aircraft measurements.

Seeding in the updraft at cloud base with water attracting material can facilitate the development of large drops that are required to generate the natural secondary ice nucleation process, leading to rain enhancement.

CYCLE 2 AWARDEES

PROJECT RESULTS

The team submitted their final report in September 2020.

The first-ever high resolution measurements of both liquid droplets and ice particles were collected in mixed-phase cumulus clouds over the UAE.

The project team produced a unique dataset to study precipitation evolution across 5 channels of particle size resolution from 0.1 micron cloud particles up to mm-sized rain drops.

The aircraft measurements indicate that cumulus clouds over the UAE experience very weak natural coalescence between cloud droplets, which is a necessary process for rainfall generation. Instead, most of the available cloud liquid water evaporates due to the dry ambient environment.

The modeling results indicate that increasing the concentration of drops, specifically in the 10 to 30 micrometer size range, by seeding clouds with the novel nanomaterial can enhance coalescence and rainfall generation.

The project team collaborated with the Finnish Meteorological Institute (Cycle 2) to assess the physiochemical properties of aerosols.

During 2021, the aircraft measurements and idealized cloud seeding scheme developed in the project were transferred to the UAEREP data repository. The modeling outcomes transferred to the NCM Cray supercomputer during 2022.

Over the course of the project, the team has published 9 scientific peer-reviewed journal articles discussing the developments of their research.

For more information
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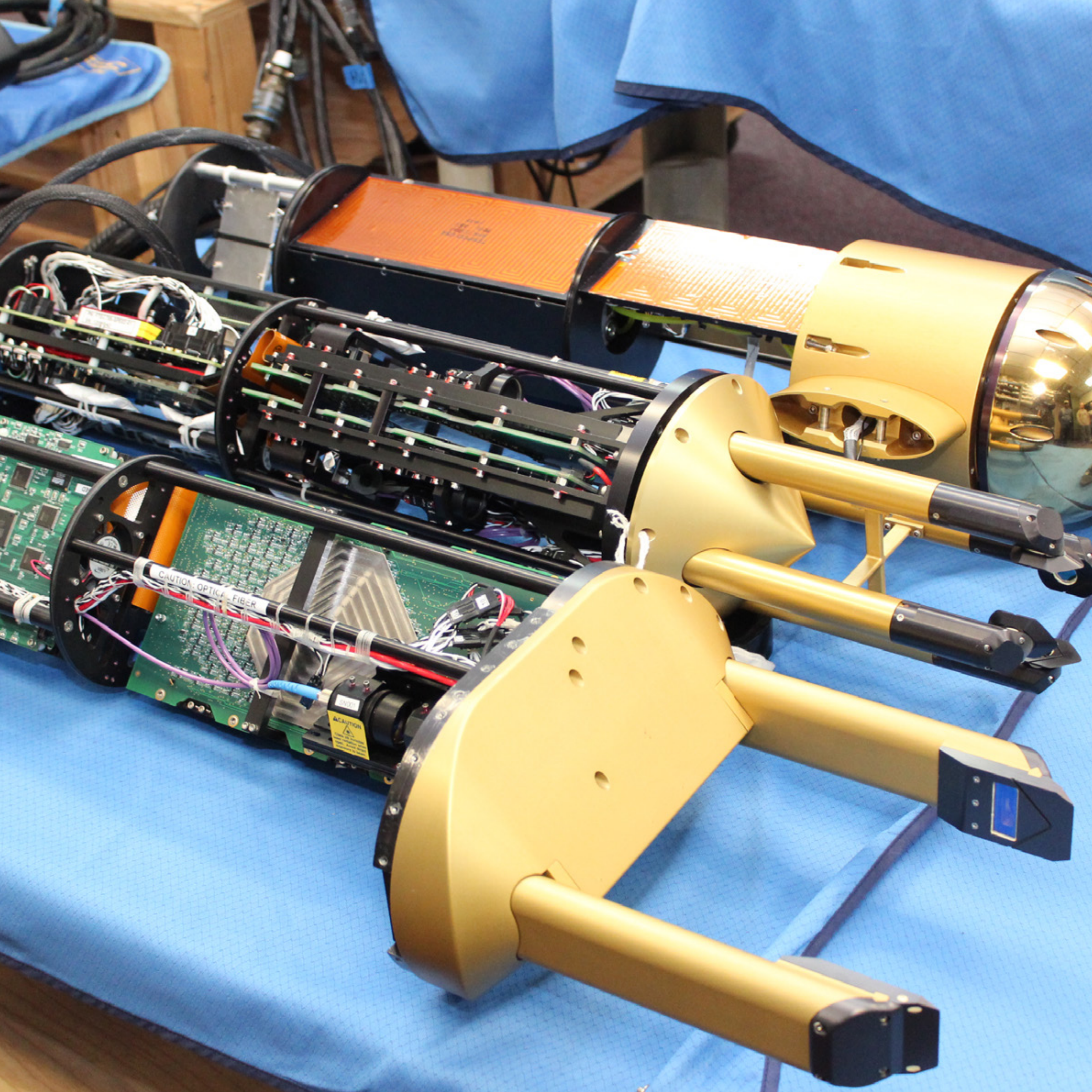
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CYCLE 2 AWARDEES

PROF. HANNELE KORHONEN

BIOGRAPHY

Prof. Hannele Korhonen is a Research Professor at the Finnish Meteorological Institute (FMI).

She was appointed as a Research Professor in Climate Modelling in 2014, and acts as the Director of the Climate Research Program at FMI since 2018.

She has nearly two decades of experience in research on atmospheric aerosol-cloud-precipitation interactions from process to global scales.

Her other current research interests include artificial cloud modification, and advanced statistical methods to enhance performance with complicated atmospheric models.

Prof. Korhonen gained her PhD from the University of Helsinki in 2004 and has since worked as a post-doctoral researcher at the Universities of Leeds (UK) and Kuopio (Finland).

PROJECT BRIEF

“Optimization of Aerosol Seeding In rain enhancement Strategies (OASIS)”

OASIS applies a multidisciplinary approach to provide a comprehensive quantification of the role of atmospheric aerosols in precipitation enhancement.

It aims to both advance the fundamental scientific understanding and to provide practical guidance for future field explorations.

The project goals were addressed through a 1-year field campaign to measure background aerosols and their cloud-precipitation interactions in the UAE, combined with simulations using a cloud-resolving model with highly advanced aerosol microphysics and quantum chemical calculations, along with innovative statistical approaches.

This research project is being carried out by the Finnish Meteorological Institute, the University of Helsinki and Tampere University of Technology, and in collaboration with UAE University.

Characterizing the background aerosols, clouds and boundary layer behavior, and ice nucleation will build an operational tool for predicting optimal conditions for cloud seeding.

RESEARCH PROGRESS

Prof. Korhonen's team completed a 1-year aerosol measurement campaign based in Al Dhaid, Sharjah (Feb.2018-2019).

The aerosol measurements contained both ground level (in-situ) and profile quantities (remote sensing). The observations served to characterize the complex background aerosol properties and their mineral composition over the UAE.

After consultation with NCM and the UAEREP's Strategic Directions Committe in December 2019, the focus of the statistical analysis was re-scoped to identify the most favorable cloud seeding conditions by leveraging AI methods.

The aim was to assess to what extent rain enhancement potential of mature clouds could be predicted using machine learning if atmospheric conditions and aerosol properties were known at the cloud initial stage, based on the team's cloud-scale model results.

In the final year of the project, the multi-scale modeling efforts were concluded by integrating their mesoscale and cloud-scale simulations to simulate seeding impacts on mixed-phase microphysical processes in clouds over the UAE.

For more information
Please scan the QR Code

CYCLE 2 AWARDEES

PROJECT RESULTS

Prof. Korhonen's team submitted their final project report in September 2020.

Based on the analysis of the collected aerosol measurements, results show that sulphate compounds dominated the aerosol chemical composition. Formation of new particles was also observed almost on a daily basis. However, aerosol size was shown to be more important than their chemical composition for their activation as cloud condensation nuclei in the UAE environment.

The developed models produced realistic simulations of winter-time stratiform precipitation systems as well as summer-time forced convection. Operational forecasting of the potential for cloud seeding is therefore feasible based on the modeling outcomes.

The modeling results revealed new insights regarding the importance of the cold precipitation process, especially rime fraction, when hygroscopic seeding is performed in convective clouds. The data shows that the seedability of a cloud can be best determined by examining the magnitude of the rime fraction in clouds.

A research-purposed neural network model was developed and showed skill in identifying optimal conditions for successful rain enhancement. Further work is needed to upgrade the AI-based tool for operational deployment – a new target area in the Program's 4th Cycle solicitation.

During 2021, the field campaign measurements, modeling packages and AI-based tool were transferred to the UAEREP data repository at NCM.

Prof. Korhonen and her research team authored and published 8 scientific peer-reviewed journal articles detailing the outcomes of the project's research strands.

CYCLE 2 AWARDEES

PROF. GILES HARRISON

BIOGRAPHY

Prof. Giles Harrison is Professor of Atmospheric Physics at the Department of Meteorology of the University of Reading.

His research work focuses on atmospheric electricity, a topic at the intersection of aerosol and cloud physics, solar-climate and internal climate interactions, scientific sensor development and the retrieval of quantitative data from historical sources.

His research includes development of new instruments and methods, particularly for exploiting meteorological balloon technologies, and generated some of the first airborne measurements in UK airspace of Icelandic volcanic ash from Eyjafjallajökull, during the April 2010 flight ban.

He has authored or co-authored about 275 articles and papers including a book on atmospheric measurements.

Prof. Harrison holds doctorates from Imperial College London (PhD 1992) and the University of Cambridge (ScD 2014).

He received the Appleton medal of the Institute of Physics in 2016.
Prof. Harrison chairs the Royal Meteorological Society's Special Interest Group on atmospheric electricity and serves on the Editorial Board of Environmental Research Letters.

> ***The efficacy of modifying the in-cloud charge can affect the cloud droplet size distribution, as an artificial influence on rainfall generation.***

PROJECT BRIEF

"Electrical aspects of rain generation"

Droplets even in non-thunderstorm clouds naturally carry electric charge. Recent work has shown that charges can modify the droplet growth rates. This can increase the rate at which rain droplets are formed. This research project seeks to evaluate the importance and significance of charge in affecting the cloud droplet size distribution, and with it the efficacy of modifying the in-cloud charge as an artificial influence on rainfall generation. The project follows a 3-way approach. Firstly, the team is developing an accurate computer model which can describe how large numbers of cloud drops can interact under the effect of electric forces. Secondly, they are characterizing and measuring the local electrical properties of clouds through state-of-the-art balloon-borne sensors as well as surface measurements.

RESEARCH PROGRESS

Thirdly, they are deploying UAVs to demonstrate charge delivery and in-situ measurement of electrical properties of the cloud. The UK team includes theoretical meteorologist Prof Maarten Ambaum and experimental scientist Dr. Keri Nicoll. They will investigate the electrical properties of clouds through a combination of theoretical and experimental work, firstly through modelling the growth of charged drops to raindrops, and secondly by measuring and modifying the charges present in clouds using balloons and aircraft. An innovative aspect is that the internal electrical properties of the clouds will be investigated using Unmanned Aerial Vehicles (UAVs) adapted to deliver charge into the clouds. A promising attribute of an electrical seeding approach is that it will leave no local environmental residues or pollution from delivery platform propulsion, as the UAVs are electrically powered.

Prof. Harrison's team employed a combination of surface and balloon measurements, and particle-scale supercomputing to fully represent the effect of turbulence on droplet growth.

Through their 8-month field campaign in Al Ain, the team collected the first ever atmospheric electricity measurements in the UAE, which revealed new insights on the electrical charging of dust in this region. Their paper entitled "Consistent dust electrification from Arabian Gulf sea breezes" was published in the prominent Journal of Environmental Research Letters.

For the theoretical aspects of the project, the UK team developed computer codes to represent droplet growth in order to test electrical modifications of interaction between drops with associated visualization software.

In the final year of the project, the focus was on the UAV flights over the UAE to demonstrate charge delivery and in situ measurement of electrical properties of clouds.

For more information
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PROJECT RESULTS

In April, 2017 site surveys were conducted around Al Ain to identify suitable areas for instrument installation in January, 2018. Radiosonde balloon launches for meteorological measurements and electrical field data acquisition during Jan-Mar, 2019 for selected fog events – led by NCM staff at AUH Airport.

A customized “flare-logger” for meteorological and cloud electrical field measurement has been designed and 3D printed. In December, 2019 the flare logger was sent to NCM to be equipped on their seeding aircraft.

In collaboration with FMI team, UAV tests in Pallas, Finland, occurred during October, 2019. The aim was to fully test the UAVs’ flight capability, electric charge delivery, and equipped sensors at high altitudes and inside clouds. Nine fully instrumented successful flights into clouds were performed during the campaign.

A 3D droplet growth model was fully developed and used to identify the optimal cloud conditions for artificial ion introduction.

The modeling work yielded a breakthrough in understanding the key processes underpinning cloud electrification. Results show that the presence of even a minimal amount of intermediate sized drops accelerates the rain formation process by a very substantial amount (3-times faster rain formation). This has important implications for developing new cloud seeding strategies combined with electric charge emission.

In March 2021, two customized UAVs and sensor packages were transferred and flight tested by their collaborators at Sanad Training Academy, Dubai.

The team conducted additional UAV trial flights in the UAE during Q1 of 2022. To date, the project team has authored and published a total of 5 scientific peer-reviewed journal articles.

CYCLE 3 AWARDEES
PROJECTS UPDATE


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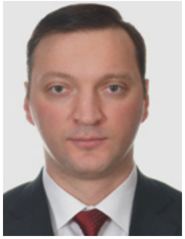
CYCLE 3 AWARDEES



DR. ALI ABSHAEV

BIOGRAPHY

Dr. Ali Abshaev is an Associate Professor at the Hail Suppression Research Center in Russia, and head of weather modification laboratory at the High Mountain Geophysical Institute of Russian Hydrometeorological Service. In 2004, he successfully defended his PhD degree on numerical simulation of dispersion of the seeding materials in hail clouds and optimization of their seeding, and in 2011 became Associate Professor in "meteorology, climatology and agricultural meteorology" at the High Mountain Geophysical Institute, where he conducts several scientific experiments related to hail suppression problem, precipitation enhancement.

In 2015, he defended his thesis on the creation of automated hail suppression technology and became a full Doctor of Sciences. Since 2016, he has also been a member of Expert Team on Weather Modification (ETWM) of the World Meteorological Organization (WMO).

Dr. Abshaev has participated in several scientific projects and supplies of special systems, technology and equipment applied by Hail Suppression Services, Meteorological Services and Airports in Russia, Armenia, Moldova, Ukraine, Tajikistan, Serbia and Macedonia. He has published with co-authors 148 articles on the physics of clouds, hail suppression and precipitation enhancement, fogs dissipation and frosts mitigation, radar meteorology and storms warning. He is also the coauthor of 9 patents of the Russian Federation and of 4 manuals on hail suppression.

PROJECT BRIEF

"On the creation of updrafts for the formation of artificial clouds and rainfall"

The aim of the project is to assess the possibilities of the creation of a new method of rain enhancement by stimulating convection and precipitation through the creation of artificial wind updrafts.

Preliminary studies using 3D models have demonstrated that artificial updrafts can be created by heating up layers of the local atmosphere.

RESEARCH PROGRESS

During 2018, Dr. Abshaev's team analyzed the validity of the theory and available field experiments related to the creation of artificial clouds.

New methods of generating artificial clouds were proposed and assessed.

The project team proposed and investigated three surface-based methods for the creation of artificial updrafts to trigger cloud formation using an (1) artificial aerosol layer, (2) a custom-built "Heliator" device, and (3) a vertically-directed jet engine composite system.

The aim was to stimulate thermal convection thereby leading to the development of artificial convective clouds.

All three methods were simulated using high-resolution 3D computational fluid dynamic models while accounting for variability in atmospheric conditions.

Horizontal wind speeds were shown to be a critical parameter to the success of the technology during field demonstrations.

Their modeling results were published in their article entitled "Investigating the feasibility of artificial convective cloud creation" in the Journal of Atmospheric Research.

In the final year of their project, the team are focusing on their technology demonstrations in the UAE.

> ***Solar radiation can be utilized to create an artificial updraft and reaching condensation level for developing convective clouds.***

For more information
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CYCLE 3 AWARDEES

PROJECT RESULTS

Based on the project's midterm evaluation in September, 2019, the jet engine method was recommended for field demonstrations in the UAE for having the most potential for success.

Two patents were filed with NCM joint ownership of the intellectual property, which outline the jet engine composite system for creating artificial updrafts to trigger clouds and precipitation generation.

The field demonstration in the UAE involved two phases. Phase 1 entailed the logistical preparations, engineering setup and testing of their jet engine composite system. To support the field experiments and gather key atmospheric measurements on updraft formation, the team also deployed advanced sensors and instruments, including a custom-made weather drone, microwave radiometer, wind lidar, fog cannon, and thermal infrared imager.

The team conducted a series of the three successful tests of their jet engine system and observed the creation of a strong vertical updraft in the shape of a vortex reaching between 500 to 1000 m above ground level. Phase 1 was completed during March 2021 at their campaign field site on Jebel Jais.

High humidity levels were found to be necessary to activate the injected aerosols within the jet stream and trigger cloud formation. Hence, Phase 2 was dedicated for the scientific demonstration of the system during the high humidity wintertime conditions in the UAE during Q1 of 2022.

After completing the field demonstrations at Jebel Jais, the jet engine system and associated equipment was transferred to NCM ownsership after providing on-site training and insturction manuals to NCM staff to conduct further trials.

Dr. Abshaev's team filed 4 patents and authored 9 peer-reviewed journal articles on their research outcomes to date. The team submitted their final project report in March 2022.

CYCLE 3 AWARDEES

PROF. ERIC FREW

BIOGRAPHY

Prof. Eric W. Frew is an Associate Professor in the Ann and H.J. Smead Aerospace Engineering Sciences Department, and Director of the Autonomous Systems Interdisciplinary Research Theme in the College of Engineering and Applies Sciences at the University of Colorado Boulder.
He received his B.S. in mechanical engineering from Cornell University in 1995 and his M.S and Ph.D. in aeronautics and astronautics from Stanford University in 1996 and 2003, respectively.
Prof. Frew has been designing and deploying unmanned aircraft systems for over twenty years. His research interests focus on autonomous flight of unmanned aircrafts; distributed information-gathering by mobile robots; miniature self-deploying systems; and guidance and control of unmanned aircraft in complex atmospheric environments.
Prof. Frew was co-leader of the team that performed the first-ever sampling of a severe supercell thunderstorm by an unmanned aircraft.

PROJECT BRIEF

"Targeted observation and seeding using autonomous unmanned aircraft systems"

This project pursues an innovative approach towards the enhancement of precipitation by developing and assessing an autonomous unmanned aircraft system (UAS) that utilizes in-situ real time data to sense and target suitable clouds for seeding.

Simple, calibrated and well-validated payloads designed to measure meteorological state parameters, wind, turbulence and aerosol-cloud microphysical properties in conditions conducive to seeding have been integrated into a new UAS platform.

Data assimilation algorithms and an associated observation simulation system, rapid enough to use for cloud seeding online decision-making, are also developed.

Finally, targeted observation and delivery strategies will be designed that guide the UAS towards suitable targets to implement successful seeding operations.

An innovative approach towards the enhancement of precipitation by developing and assessing an autonomous unmanned aircraft system (UAS) that utilizes in-situ real time data to sense and target suitable clouds for seeding.

RESEARCH PROGRESS

During the project's initial stages, the team assimilated data from previous field campaigns to identify cloud seedability conditions, begin integration of sensors into unmanned aircrafts, and create simulations to assess algorithms.
Prof. Frew's team has also focused on designing an unmanned aircraft platform, acquiring custom miniaturized versions of the sensors needed for missions, and integrating the sensors onto their customized UAVs.

During 2021, the team focused on developing their autonomous UAV guidance algorithms which integrate real-time measurements, satellite/ radar observations and model reanalysis. They have also completed their UAV autonomy tests and air-worthiness certification flights, sensor integration, and communication system tests.

CYCLE 3 AWARDEES

PROJECT RESULTS

The physical quantities that best indicate cloud seedability have been identified from analyses of past data collected over the UAE (Cycle 1-Japan project) and Saudi Arabia.

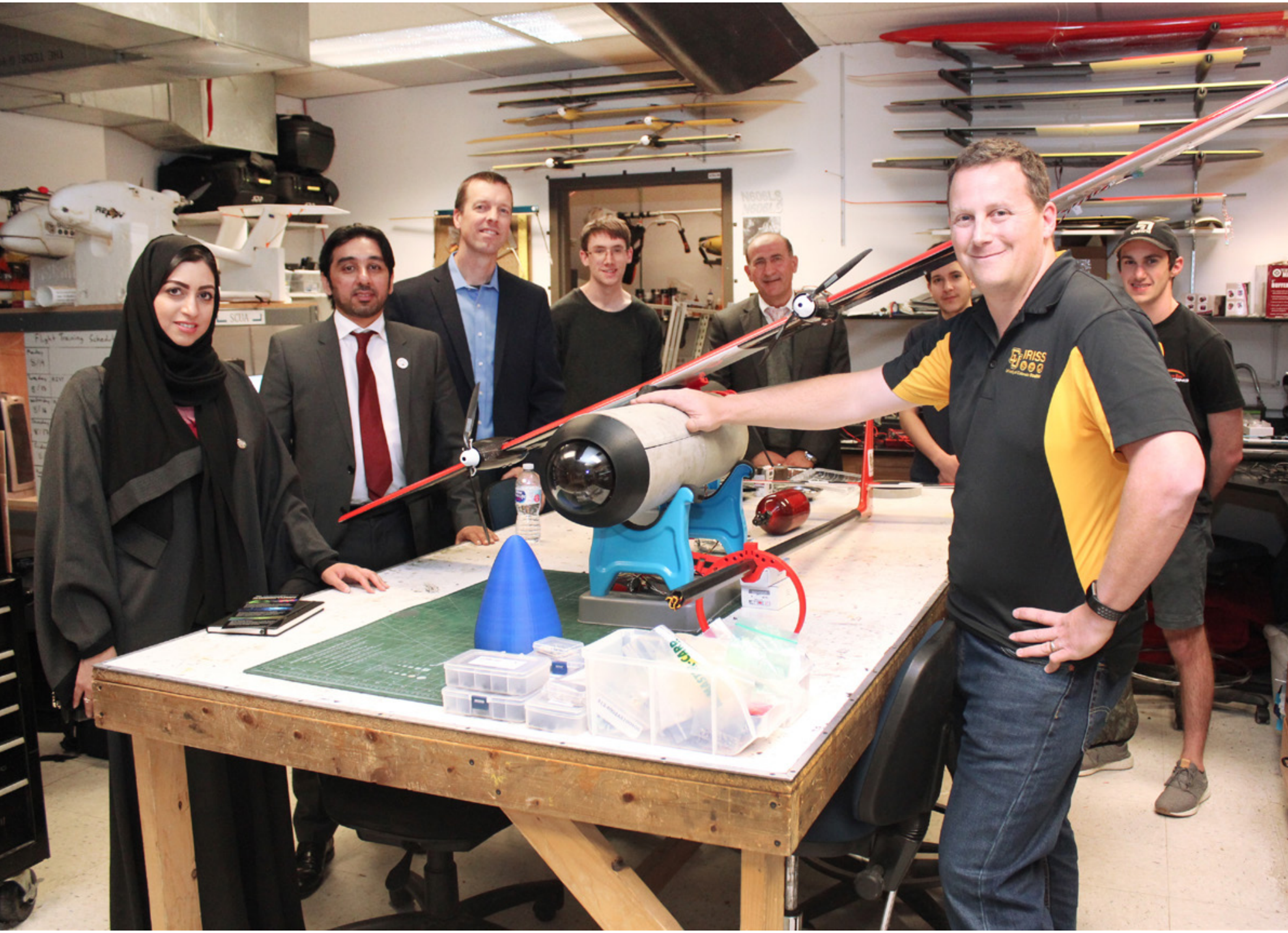
The UAV real-time measurements are being used to autonomously make seeding decisions.

A hierarchical search algorithm was developed to merge climate forecasts, satellite data, and radar data to predict regions of interest for cloud development for the UAVs to launch towards.
Once UAVs reach the ROI, the UAVs will autonomously scan (raster scan) the area and make seeding decisions.

Three UAVs were handed over to NCM after the project's completion: Two fully instrumented UAVs with miniaturized sensors for real-time microphysical measurements, and one UAV equipped with a delivery mechanism designed to disperse well-contained seeding material (payload > 2 kilograms; flight endurance of 3 hours). NCM is currently pursuing local development work to bring the UAVs to a higher technology readiness level in collaboration with Khalifa University.

In August 2021, Prof. Frew's team conducted a two-week field campaign to test their UAV-based cloud seeding approach in an operational environment over Colorado, USA. They flew 4 missions targeting 3 separate severe convective storms with tandem UAVs. The leading UAV collected and analyzed in-cloud measurements to relay a seed/no-seed decision to the trailing UAV carrying the seeding material.

The team submitted their final project report by September 2022.



CYCLE 3 AWARDEES

DR. LULIN XUE

BIOGRAPHY

Dr. Lulin Xue obtained his Ph.D. degree in Meteorology from Saint Louis University in 2009. He then joined the National Center for Atmospheric Research (NCAR) in the United States as an Advanced Study Program postdoctoral fellow. Dr. Xue joined the advisory panel of the Beijing Weather Modification Office in 2016 and became the Chief Scientist of Hua Xin Chuang Zhi Science and Technology LLC in 2017.

Dr. Xue has been the key scientist responsible for the numerical modeling aspect of several projects carried out at NCAR since 2009. He has conducted original and applied scientific research for a cloud seeding project in Saudi Arabia, a wintertime orographic cloud seeding project for the Idaho Power Company, and several programs in Wyoming.

Dr. Xue's areas of expertise are in aerosol-cloud-precipitation interactions, cloud microphysics and dynamics, boundary layer and mountain meteorology and numerical modeling. His research efforts have led to the development of a real-time cloud seeding forecasting system.

Improving the knowledge of hygroscopic seeding impacts on warm rain initiation lead to the achievement of rainfall enhancement.

PROJECT BRIEF

"Using Advanced Experimental - Numerical Approaches To Untangle Rain Enhancement (UAE-NATURE)"

This project involves a consortium of research institutes and universities from China, Hungary, UAE and USA collaborating on an innovative research approach to rain enhancement based on advanced laboratory experiments and state-of-the-art numerical models.

The core objectives of the proposed study are: 1) improve knowledge of hygroscopic seeding impacts on warm rain initiation; 2) discriminate the dynamical and microphysical processes by which natural and seeded precipitation forms and evolves within clouds; and 3) quantify potential seeding impacts on UAE rainfall in relation to climate variables over a 10-year period using high-resolution regional climate and ensemble seeding simulations. Additional objectives are to understand how cloud seeding affects cloud cover lifetimes, assess impacts on resultant groundwater availability, and quantify spatial and temporal rainfall distribution in the UAE.

Discriminate the dynamical and microphysical processes by which natural and seeded precipitation forms and evolves within clouds, are essential to understand rain enhancement.

RESEARCH PROGRESS

In the first year, the team conducted cloud chamber experiments on natural warm cloud formation and assessed hygroscopic seeding effects on warm cloud and precipitation formation.

Observations to validate a 10-year regional climate simulation were assembled, enabling the team to determine the optimal model configurations.

The model configurations were tested for the regional climate simulation over the UAE region using data relating to a two-month period in 2017.

In addition, the Beijing Aerosol Cloud Interaction Chamber (BACIC) has also been employed for continuous testing, improvement and measurement of instrumentation configurations needed for the warm-phase cloud experiments to emulate typical UAE weather conditions.

During 2021, the team's modeling efforts focused on simulating the effects of different cloud seeding materials on clouds and precipitation over the UAE, including the ICE-70 (USA) and NCM-produced flares, as well as the novel nanomaterial particles developed by Prof. Linda Zou's 1st Cycle Project

CYCLE 3 AWARDEES

PROJECT RESULTS

The team conducted state-of-the-art cloud chamber experiments to simulate cloud development under typical UAE conditions and to study aerosol concentration impact on cloud droplet sizes.

A first-of-its-kind Cloud Chamber Virtual Workshop was organized by Dr. Lulin during September 2021, involving different international groups and experts, including NCM representatives.

As a result of the workshop discussions, a conceptual design for a state-of-the-art cloud chamber facility was submitted to NCM in March 2022.

Direct Numerical Simulations of giant cloud condensation nuclei (CCN) and turbulent impacts on cloud particle size distribution were conducted for clean background aerosol condition. The team incorporated Dr. Paul Lawson's 2nd Cycle project aircraft measurements to realistically simulate the role of background aerosols during seeding operations over the UAE.

Their results show the novel nanomaterial (1st Cycle project outcome) produces more pronounced seeding effects compared to other seeding agents and can produce positive effects even in maritime influenced air masses.

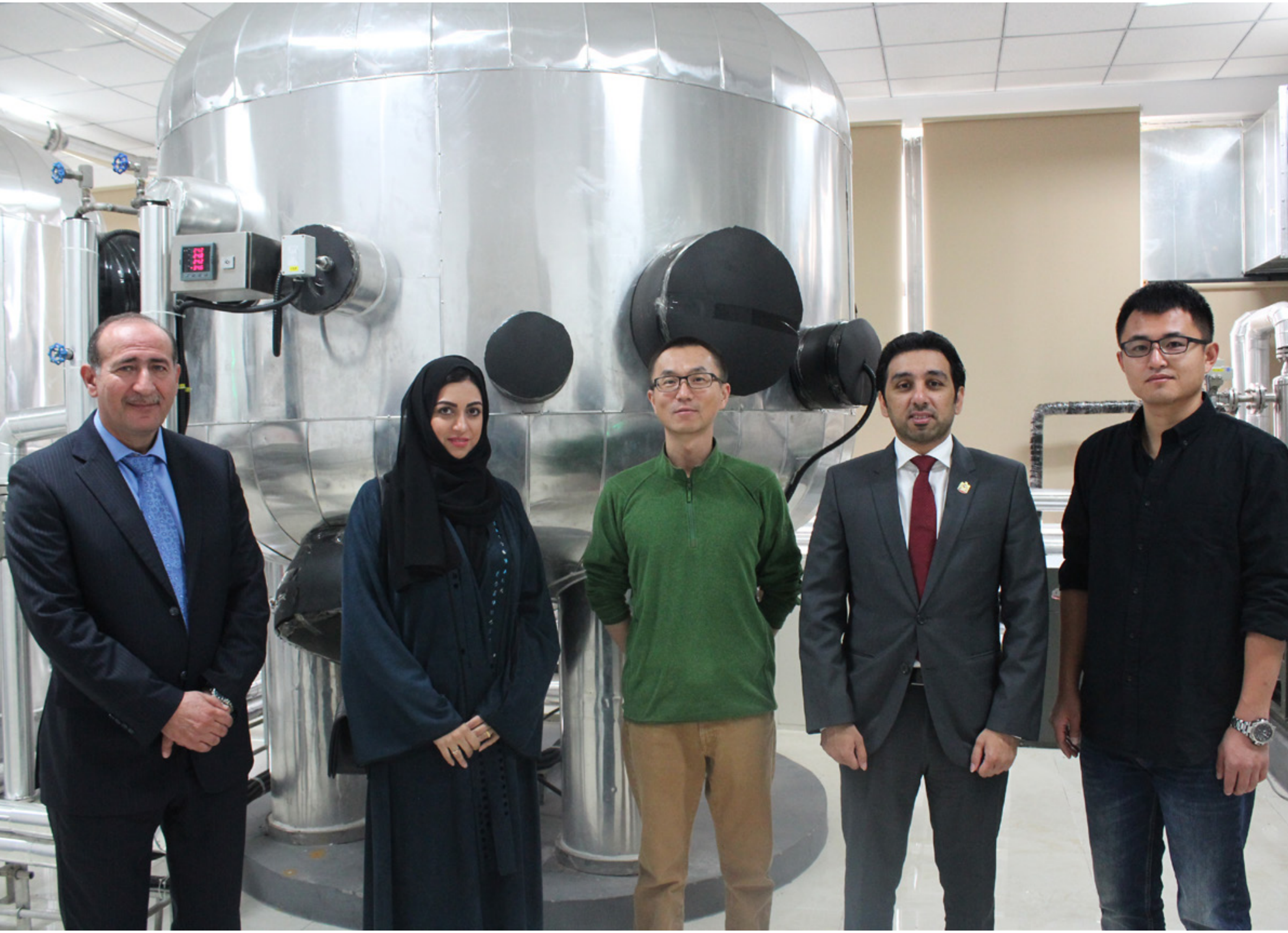
A cloud microphysics scheme was developed in collaboration with NCAR to incorporate sea salt emissions, which is of key importance for local UAE conditions.

Historical (1981-2005) and future (2060-2079) climate data analyses revealed that precipitation is expected to increase over ocean and decrease over land for the UAE and region.

The team worked with New York University - Abu Dhabi and Khalifa University on quantifying the effects of cloud seeding on clouds, rainfall and groundwater in the UAE over a historic 10-year period.

To date, Dr. Lulin's project team have published 10 peer-reviewed journal articles documenting the cloud chamber experiments and multi-scale modeling work.

The regional climate modeling outcomes were transferred to the UAEREP data repository. The comprehensive modeling deliverables from this project were transferred to the NCM Cray supercomputer during 2022. The team submitted their final project report in March 2022.




4
CYCLE 4
AWARDEES
PROJECTS UPDATE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CYCLE 4 AWARDEES

DR. BRADLEY BAKER

BIOGRAPHY

Dr. Baker is an expert in cloud physics with decades of experience in cloud physics and airborne, as well as radar, measurements of clouds.
He earned his undergraduate degree in mathematics at the University of Washington (UW) graduating with distinction (Phi Beta Kappa) in 1982. Two years later, he entered the graduate program in Geophysics at UW and earned his Ph.D. under Prof. Marcia Baker in 1990.
While a graduate student, he participated in his first, of what would become many, cloud physics research field projects, flying on the UW Convair research aircraft with Prof. Peter Hobbs and Art Rangno. The focus of that project was exploring the association of rapid ice formation with the presence of super-cooled large drops in cumulus clouds, an enigma that is central to the research that will be conducted during this 4th cycle field campaign.
Dr. Baker published four peer reviewed research articles based on his graduate work, including two on the subject of the aforementioned field project, and a seminal paper on thunderstorm electrification based on laboratory studies performed at the University of Manchester Institute of Technology, where he spent a year collaborating with the cloud physics research group led by Prof. John Latham.

After earning his Ph.D., Dr. Baker was invited to participate in the Advanced Study Program at the National Center for Atmospheric Research (NCAR), furthering his research on turbulence and the microphysical properties of clouds. Following the two-year program at NCAR, Dr. Baker accepted a position as Assistant Professor at the New Mexico Institute of Mining and Technology, where he taught courses in physics and atmospheric science.
In 1998, Dr. Baker joined SPEC Incorporated where he directed the company's participation in several international field campaigns, ranging from investigations of climate change in the Arctic in 1998, to the Rain in Cumulus over the Ocean (RICO) project in the Caribbean Sea in 2004 – 2005. He published four peer reviewed articles related to RICO, including one on the fundamentals of radar measurements and their comparison with aircraft in-situ measurements.
In 2012, Dr. Baker returned to teaching, becoming a Lecturer on Radar

> ***The main goals of our project are to make quality measurements in real clouds with and without the seeding materials to determine whether it leads to real rain enhancement***

Meteorology at the University of the West Indies and the Caribbean Institute for Meteorology and Hydrology until 2016. Dr. Baker returned to working on SPEC projects in 2018, as an independent contractor, transitioning to the position of Senior Scientist at SPEC in 2020. Dr. Baker's 30 years of experience in cloud physics and airborne measurements of cumulus clouds are valuable assets that will be applied to UAE Research Program for Rain Enhancement Science.

> ***The Learjet is well-suited to cloud physics studies, in particular its fast which allows you to get to the clouds you've identified to study before they've changed too much***

PROJECT BRIEF

"Enhancing Rain in the UAE via Hygroscopic Seeding with Nano-Seeding Material"

SPEC Incorporated will partner with two other 2nd Cycle Award winners, the Finnish Meteorological Institute (FMI) and the University of Reading, to build on results from previous studies in the UAE. The project will incorporate sophisticated numerical simulations of cumulus clouds with measurements using the SPEC Incorporated Learjet research aircraft in concert with the NCM King Air cloud seeding aircraft. FMI will simulate the effects of cloud seeding using hygroscopic nanomaterials previously developed at Khalifa University in the UAE. The University of Reading has developed miniature electric charge generators that will be attached to the King Air seeding aircraft. The charge generators have been shown to coagulate aerosol particles below cloud base into a size range that may enhance the effects of the hygroscopic nanomaterial seeding agents. FMI will run their numerical simulations of clouds with and without the nanomaterial seeding agent and the effects of the electric charge generators. The SPEC Learjet will make measurements in clouds with and without the nanomaterial seeding agent and electric charge generators. The measurements will be compared with the FMI numerical simulations.

> ***The Learjet is outfitted with instruments designed to measure the concentration of the small droplets and larger particles in precipitation when it forms***

CYCLE 4 AWARDEES

EXPECTED OUTCOMES

The overall goal of this project is to determine if the effects of the nanomaterial seeding agent and electric charge generators will stimulate a secondary ice process (SIP) that may potentially lead to rain enhancement. Previous observations indicate that the SIP occurs naturally in tropical cumulus clouds where cloud base temperatures are generally warmer than 20°C. The relatively warm cloud base temperatures result in ~ 3 km of cloud below the 0°C level, which produces an active coalescence process and development of millimeter-diameter drops at the 0°C level. Previous measurements suggest that the millimeter-diameter drops rise in an updraft, freeze and fracture, producing copious small ice particles that "seed" the cloud. Cumulus cloud base temperatures in the UAE are much colder, typically about 10°C. This results in about 1.5 km of cloud below the 0°C level, which is insufficient to naturally produce adequate concentrations of millimeter-diameter drops at the 0°C level and the natural SIP. This project will investigate the potential for the nanomaterial seeding agent and electric charge generators to stimulate the coalescence process and natural SIP that may lead to rain enhancement.

During summer 2023, the SPEC Learjet 35A research aircraft flew to the UAE to conduct the Cloud-Aerosol-Electrical Interactions Experiment (CLOUDIX) in collaboration with NCM. The Learjet was based out of Al Ain airport and gathered essential data on cloud and aerosol properties during both seeding and electric charge release at multiple altitudes within the boundary layer and mixed-phase clouds.

The data obtained from CLOUDIX are currently being analyzed in greater detail by the project team. Of particular interest is the comparison between the cloud microphysical properties observed during the 2019 campaign when in-situ measurements of unseeded natural clouds were taken and the recent 2023 CLOUDIX mission.

CYCLE 4 AWARDEES

DR. LUCA DELLE MONACHE

BIOGRAPHY

Dr. Luca Delle Monache is the Deputy Director of the Center for Western Weather and Water Extremes (CW3E), Scripps Institute of Oceanography, University of California San Diego. His goal is to provide support for the Director, Marty Ralph, in managing activities within the Center, and in developing new science and application directions to support CW3E's Vision and Mission.

Specifically, Dr. Delle Monache oversees the development of the Center's modeling, data assimilation, postprocessing, and artificial intelligence capabilities, with the goal of maintaining state-of-the-art models and tools while actively exploring innovative algorithms and approaches. In close coordination with the Center Director and the management team, he develops new scientific and programmatic strategies to maintain and further expand CW3E leadership on understanding, observing, and predicting extreme events in Western North America.

He earned a Laurea (~M.S.) in Mathematics from the University of Rome, Italy (1997), an M.S. in Meteorology from the San Jose State University, U.S. (2002), and a Ph.D. in Atmospheric Sciences from the University of British Columbia, Canada (2005). His interests include the design of ensemble methods, probabilistic prediction and uncertainty quantification, numerical weather prediction, data assimilation, inverse modeling, postprocessing methods including artificial intelligence algorithms, renewable energy, air quality and transport and dispersion modeling. Among his main scientific accomplishments, there is the development during his Ph.D. of the first ensemble for air quality prediction, and later in his career the design of the analog ensemble which has been applied successfully in several of the fields, and is based on a new paradigm for ensemble design.

> ***We are excited to push the envelope in machine learning for rain enhancement purposes***

Luca Delle Monache has been the principal investigator of several multi-institution multi-million projects funded by the National Science Foundation, the National Oceanic and Atmospheric Administration, the National Aeronautics and Space Administration, the Department of Energy, the

Department of Defense, and the private sector. Before joining CW3E, he was a postdoc and then a staff scientist at the Lawrence Livermore National Laboratory, Livermore, California (2006-2009), and a project scientist and then the Science Deputy Director of the National Security Applications Program at the National Center for Atmospheric Research, Boulder, Colorado (2009-2018).

> ***We are leveraging cutting edge machine learning algorithms to estimate the precipitation in the current time, the near future and cloud seedable features to enhance the precipitation over the UAE***

PROJECT BRIEF

"A Hybrid Machine Learning Framework for Enhanced Precipitation Nowcasting"

This 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 around the world. With the unprecedented abundance of data sets from diverse observations and models available to operational rainfall enhancement programs, the exploration of AI algorithms is already resulting in significantly improved weather forecasts.

This project aims to create an AI research and operations testbed in the UAE. This entails building a novel AI framework to blend satellite observations, ground-based weather radar data, rain gauges, and numerical weather prediction estimates to extract features and generate products to determine optimal cloud seeding timing and location, and to generate more accurate quantitative precipitation estimation for rainfall enhancement program evaluation.

> ***What we will do with the machine learning algorithm, we will blend all the information derived to generate the best estimate at the current time of precipitation***

CYCLE 4 AWARDEES

EXPECTED OUTCOMES

An advanced deep learning algorithm is proposed to learn from several thousands of examples from historical data how to effectively extract and extrapolate inputs and the required cloud features important to define cloud patches that are seedable.

These features and inputs, along with extrapolated satellite and radar data, as well as numerical weather prediction data and rain gauges, are utilized as input to an AI-based model to generate precipitation predictions six hours in the future.

To expand rain enhancement capabilities in the UAE through the use of AI and existing assets, this project assembled a multidisciplinary and diverse research team led by the Scripps Institution of Oceanography at University of California San Diego with collaborators from Khalifa University and Colorado State University. The main deliverable at the end of the project will consist of a high-resolution AI-based model for both precipitation and cloud seedability nowcasting over the UAE. The prototype will be deployed at the National Center for Meteorology (NCM) in the UAE through a research and operations partnership.

CYCLE 5 AWARDEES

PROJECTS UPDATE


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CYCLE 5 AWARDEES

PROF. WILL CANTRELL

BIOGRAPHY

Prof. Will Cantrell is the Associate Provost for Graduate Education and Dean of the Graduate School at Michigan Technological University. He holds an academic appointment as Professor in the Department of Physics. Over the last 20 years, Prof. Cantrell's research has primarily focused on laboratory investigations of ice nucleation and other aerosol-cloud interactions. He is one of the leaders of the Pi Chamber facility, a unique convection-cloud chamber, enabling studies of cloud droplet spectral broadening, mixed-phase clouds, the interaction of aerosol particles in a turbulent flow, and entrainment, among other topics.

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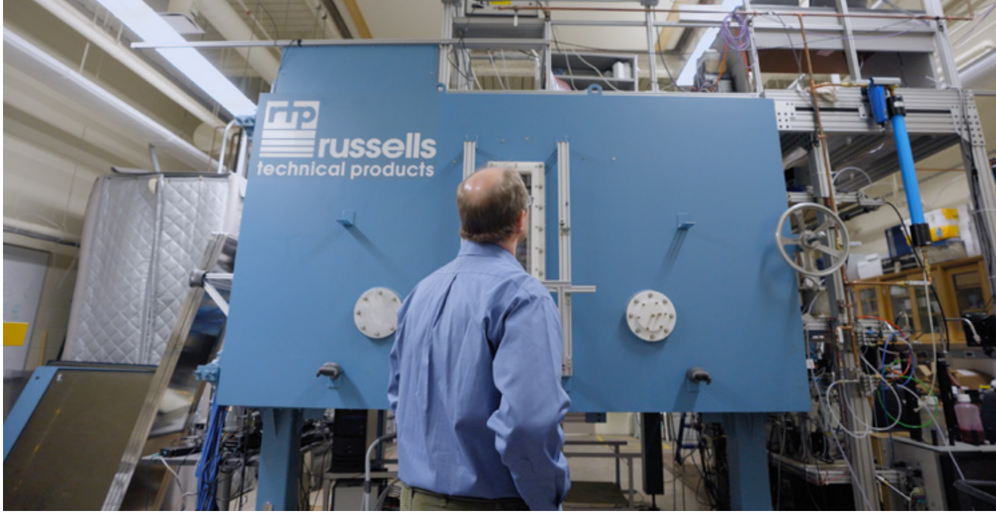
Prof. Cantrell joined Michigan Technological University in 2001, following a two-year postdoctoral role at Indiana University's Chemistry department. He received his PhD in Atmospheric Science from the University of Alaska Fairbanks in 1999, gaining extensive experience in field measurements of aerosol properties. Prof. Cantrell's current research not only contributes to the fundamental understanding of cloud physics, but also holds promise for practical applications in climate research and environmental sustainability.



PROJECT BRIEF

“Laboratory and Modeling Studies of Cloud Susceptibility to Hygroscopic Seeding”

The project aims to quantify the ‘modifiability’ of clouds through hygroscopic seeding or electrical charging effects. Clouds with low droplet concentrations (clean clouds) or high concentrations of small droplets (polluted clouds) are less likely to respond to seeding. Even clouds that are susceptible to seeding may be inadvertently overseeded, potentially hindering precipitation rather than enhancing it. The project aims to identify the specific cloud characteristics and conditions under which hygroscopic seeding or modification by electrical effects will produce changes in the cloud which lead to precipitation enhancement.

The project’s experimental approach is enabled by a unique facility at Michigan Tech known as the Pi Chamber, named for its 3.14 cubic meter internal volume. Using the Pi Chamber, the team aims to create and sustain steady cloud conditions over extended periods, enabling the collection of high-fidelity, high-resolution data on cloud characteristics. The investigation into cloud seeding involves creating a cloud in the chamber and introducing hygroscopic seeding material into that cloud to observe the changes in cloud characteristics produced by the seeding.

The seeding materials will include hygroscopic salts (including commercially used hygroscopic flare materials), dust, and the novel core-shell NaCl-TiO2 (CSNT) material from a previous UAEREP cycle. Furthermore, the project will investigate the effect of introducing charge into the cloud, either through ions from a corona discharge, or from highly charged aerosol particles. Changes in cloud characteristics include the number concentration of cloud droplets, the relative distribution of droplet sizes, and the number aerosol particles in the cloud that have not yet become droplets. The appearance of larger droplets is of particular interest.

The project’s experimental approach is closely integrated with modeling efforts, which will extend the range of scenarios that can be examined. Its hierarchy of models ranges from the explicit parcel-mixing model, which can run on a laptop to a large eddy simulation, requiring supercomputing resources. By combining results from experiments and simulations of the models, the project seeks to explore a wider range of conditions and more quickly determine the efficacy of seeding in different cloud conditions.

CYCLE 5 AWARDEES

EXPECTED OUTCOMES

The project team aims to establish a baseline through investigations of highly polluted clouds, which they expect be too costly to seed (meaning that the amount of seeding material required to enhance precipitation would be quite large). Once this baseline established, the amount of seeding material (or charge) introduced into the cloud will be adjusted, along with the cloud droplet number concentration, until a combination that leads to a broadening of the drop size distribution is identified. This will be the first step toward runaway collision-coalescence and rain formation. Furthermore, parallel simulations will provide additional context and pathways for scaling, facilitating adoption in operational contexts.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CYCLE 5 AWARDEES

PROF. DANIEL ROSENFELD

BIOGRAPHY

Prof. Daniel Rosenfeld is a leading expert on weather modification and climate change at the Institute of Earth Sciences, the Hebrew University of Jerusalem. He received his PhD from the Hebrew University in 1986 and later served as a postdoc at NASA before returning to the Hebrew University as a professor.

Prof. Rosenfeld has chaired the committee on weather modification of the American Meteorological Society and co-chaired the aerosol-cloud-precipitation Climate International initiative (ACPC). He also contributed as a lead author in the 6th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). With over 280 scientific papers and book chapters to his name, he has won recognition as a Fellow of the American Meteorological Society and the American Geophysical Union. He received numerous awards, including the Friendship Award from the Chinese Prime Minister, and the UAE/WMO Prize for weather modification.

Prof. Rosenfeld has chaired the committee on weather modification of the American Meteorological Society and co-chaired the aerosol-cloud-precipitation Climate International initiative (ACPC). He also contributed as a lead author in the 6th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).

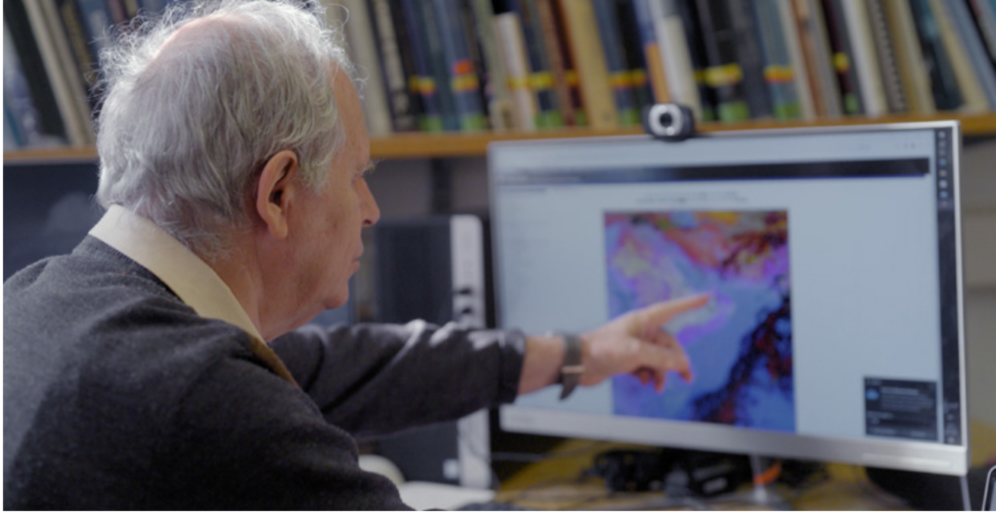
PROJECT BRIEF

"Identification of Clouds' Microphysical Seedability in an Actionable Manner"

Bringing together leading scientists from four different countries, the overall objective of this project is to develop the capability to diagnosis cloud seedability in near real-time at a spatial resolution of the convective cloud cluster, based on operationally available satellite and meteorological data.

The project's specific objectives include obtaining cloud microstructure in near real-time, retrieving precipitation forming processes in near real-time, obtaining cloud seedability in near real-time under various seeding methods and providing a decision tool on whether a given existing cloud system should be seeded, along with estimating the potential seeding effect if seeded.

The project will build on previous



UAEREP projects that measured the cloud properties with aircraft, developed novel seeding materials and methods and developed ways to predict accurately the locations of growing clouds, which is critical for effective seeding. Therefore, diagnosing cloud seedability in this project is highly complementary and synergistic with most of the previous UAEREP projects.

The machine learning procedure will be trained using model simulations of actual cases validated by aircraft and radar data. Simulated clouds will undergo seeding simulations to determine seedability using various methods. This machine learning procedure requires consistent datasets of meteorology, cloud properties, and their radar and satellite images for training input. While such data cannot be obtained observationally, it can be generated through validated simulations.

To obtain the simulated satellite imagery, a cloud radiative transfer model will operate on numerically simulated clouds and will produce simulated multispectral satellite images. Each simulated image of a cloud cluster will have its seedability. The machine learning procedure will be trained on meteorological and satellite data to estimate the seedability while accounting for potential differences between simulated and real images.

The machine learning procedure will be trained using model simulations of actual cases validated by aircraft and radar data. Simulated clouds will undergo seeding simulations to determine seedability using various methods

CYCLE 5 AWARDEES

EXPECTED OUTCOMES

The envisioned outcome of the project is an assessment of the seedability of a representative sample of clouds in the UAE. Furthermore, the machine-learning tool to be developed will allow NCM to perform such assessments in near real-time and guide cloud seeding flights, based on a combination of operational meteorological data and the new METEOSAT Third Generation geostationary satellite. This groundbreaking project has the potential to revolutionize the way cloud seeding is performed and evaluated.

CYCLE 5 AWARDEES

DR. GUILLAUME MATRAS

BIOGRAPHY

Dr. Guillaume Matras is the Senior Director of High Power Lasers and Applications at the Directed Energy Research Center (DERC), part of the Technology Innovation Institute (TII) in the UAE.

Prior to joining TII, Dr. Matras served as the Laser Expert and Project Manager at Thales LAS France, supervising multiple projects focused on state-of-the-art high-power laser sources, with a specific emphasis on ultrafast femtosecond laser systems. His key contributions to the advancement and administration of sophisticated laser systems led to their successful implementation at prestigious international research institutes.

A significant achievement in Dr. Matras's career was his role as the Technical Lead responsible for coordinating the development of the world's most powerful laser system at the Extreme Light Infrastructure - Nuclear Physics (ELI-NP) Research Institute in Romania, achieving unmatched peak powers of 2x10 Petawatts. This groundbreaking project serves as a testament to his outstanding technical leadership and expertise.

Dr. Matras served as the Laser Expert and Project Manager at Thales LAS France, supervising multiple projects focused on state-of-the-art high-power laser sources, with a specific emphasis on ultrafast femtosecond laser systems

PROJECT BRIEF

"Laser-based rain triggering demonstrator with remote sensing technology"

The primary objective of this research is to investigate 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.

The collaborative project will involve major international laboratories, each contributing specific and complementary expertise beneficial to

the initiative. The Weizmann Institute of Science will contribute its proficiency in cloud microphysics, Swiss Federal Laboratories for Material Science and Technology (EMPA) will bring expertise in acoustic system detection, and the Institute for Beam Tools (IFSW) at the University of Stuttgart will contribute specialized knowledge in high-power laser sources.

The project will commence with laboratory experiments involving a scientific understanding of the production of desired effects in the atmosphere that can be achieved using the MHPPLD in the clouds. A fundamental aspect involves in-depth characterization of laser filamentation within a controlled laboratory setting. Through systematic experimentation, the team will analyze the influence of various laser parameters such as pulse duration, energy, repetition rate, and wavelength on the formation and behavior of laser filaments. This characterization will provide valuable insights into the mechanisms underlying filament-induced perturbations in the atmosphere.

The project will commence with laboratory experiments involving a scientific understanding of the production of desired effects in the atmosphere that can be achieved using the MHPPLD in the clouds. A fundamental aspect involves in-depth characterization of laser filamentation within a controlled laboratory setting.

CYCLE 5 AWARDEES

EXPECTED OUTCOMES

To visualize the impact of laser filamentation on clouds microphysics and dynamics, the team will employ advanced visualization techniques, including laser shadowgraph and Schlieren imaging. These techniques enable the capture and visualization of shockwaves generated by laser filaments. By studying shockwave propagation patterns and density changes, the project aims to uncover potential links between laser-induced perturbations and atmospheric turbulence.

Building on the insights gained from filament characterization, the team will investigate the use of laser beam steering to induce turbulence in the atmosphere. This innovative approach could potentially create favorable conditions for precipitation initiation by enhancing the turbulence within the clouds and facilitating the coalescence of water and ice particles.

Furthermore, the research project will facilitate the establishment of atmospheric and laser science laboratories at the Technology Innovation Institute and local partner universities. The presence of such laboratories in the Emirate of Abu Dhabi will enable students from different levels to perform experimental works for their graduation projects and PhD theses without the need to go to laboratories outside the country, thereby enhancing the scientific sovereignty for the UAE. Additionally, a continuous education strategy can be implemented to promote periodic workshops and seminars in cloud microphysics, LIDAR technology, plasma diagnostics, and environmental monitoring. This interdisciplinary approach will encourage knowledge sharing, and the cultivation of innovative solutions.