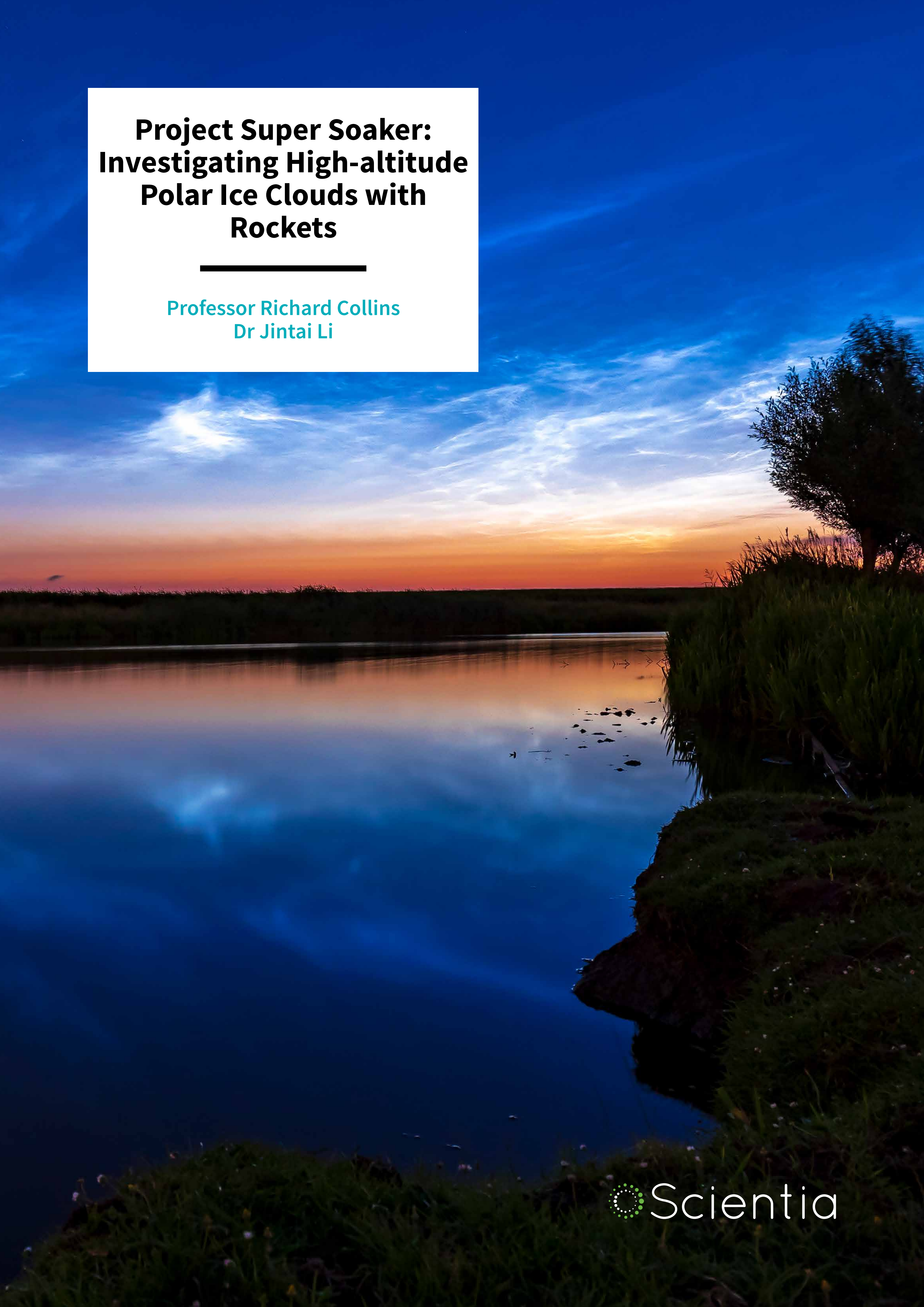
Project Super Soaker: Investigating High-altitude Polar Ice Clouds with Rockets

Professor Richard Collins
Dr Jintai Li



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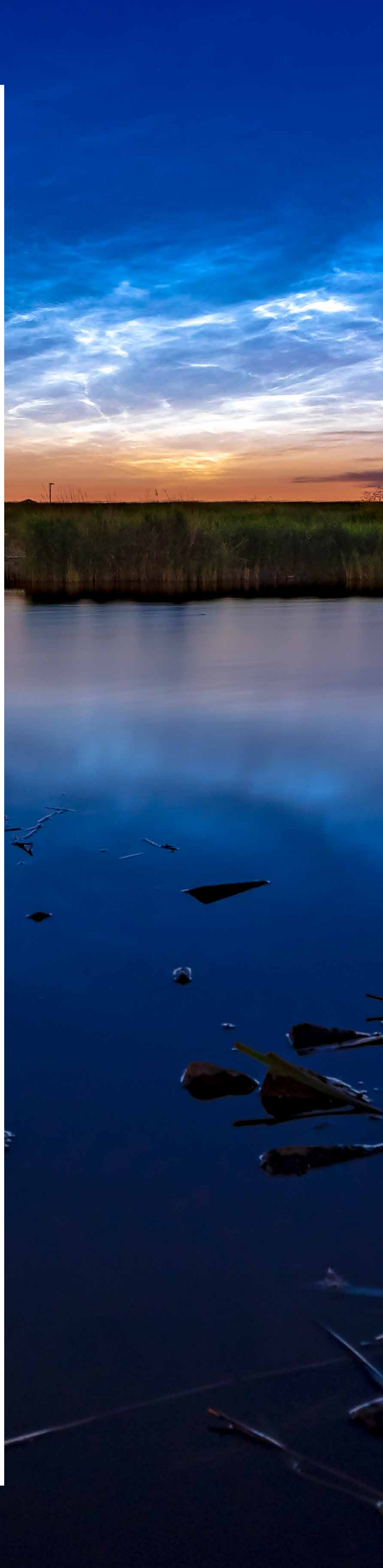


PROJECT SUPER SOAKER: INVESTIGATING HIGH-ALTITUDE POLAR ICE CLOUDS WITH ROCKETS

Phenomena in the upper atmosphere are difficult to study for several reasons – some rarely form, others are difficult to see, and all are incredibly high up. Polar Mesospheric Clouds (PMCs) are no exception, forming at around 80 kilometres up into the sky, only under specific atmospheric conditions, and only visible to the naked eye during twilight. PMCs are also called noctilucent or 'night-shining' clouds, as they appear to glow in the summer nighttime sky. **Professor Richard Collins** from the University of Alaska Fairbanks is using rockets to seed these clouds, allowing better investigations of both PMCs and the effects of space traffic on our upper atmosphere.

Some Clouds in the Sky

When a space vehicle launches, a long tail of clouds forms behind it. This cloud is formed of water vapour from the exhaust of the rocket, in the same way as contrails form behind high-flying aircraft. As the rockets ascend, they travel through all layers of the atmosphere. One such layer is the mesosphere. Lying between 50 and 80 kilometres, the mesosphere is far beyond the reach of aircraft and only the lowest few kilometres are accessible to balloons. This makes it tricky to study, although many of the phenomena that exist within it are of considerable interest to researchers.

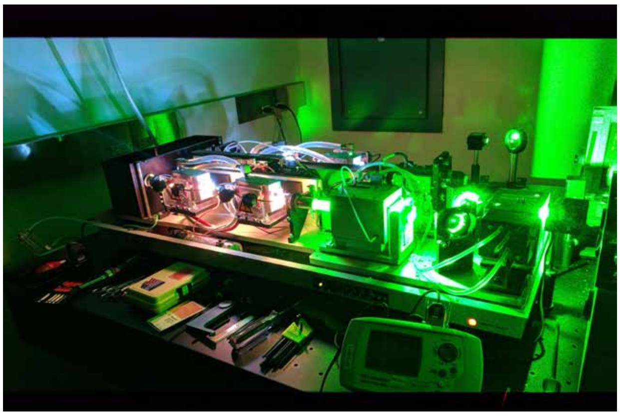
Polar mesospheric clouds (PMCs) are a fascinating example of mesosphere phenomena. These clouds of water ice particles form during the polar summer on the upper edges of the mesosphere, in extremely cold and dry conditions. They are much less likely to form in the winter when the mesosphere above the poles is warmer than the summer temperature. The sensitivity of these clouds to temperature and humidity variations makes them an ideal candidate to study the meteorological conditions and processes of the upper atmosphere.

Previous research has shown more PMCs form when the number of space vehicles travelling through the mesosphere increases, but the mechanisms behind this have remained elusive until recently. To solve the mystery, Professor Richard Collins and Dr Jintai Li at the University of Alaska Fairbanks and their colleagues from seven labs and universities across the USA developed 'Project Super Soaker' with support from NASA. The plan was to deliver a payload of water vapour into the upper atmosphere to form an artificial polar mesospheric cloud (PMC), which could then be investigated to determine the effects of concentrated water vapour on the atmosphere.

Cloud Technology

Professor Collins' team constructed three sounding rockets to carry out Project Super Soaker. Two rockets

Time lapse of the Super Soaker launch. Three rockets launched with the mission, two using vapour tracers to track wind movement and one releasing a water canister to seed a polar mesospheric cloud. The green laser beam visible at the top left is the lidar beam used to measure the artificial cloud. Credits: NASA's Wallops Flight Facility/Poker Flat Research Range/ Zayn Roohi https://www.nasa.gov/feature/goddard/2021/nasa-mission-seeks-to-understand-bright-night-shining-clouds-by-creating-one



Credit: Jintai Li, 2018

contained tracers to calibrate atmospheric conditions; the third carried a payload of 220 kilograms of liquid water set to detonate at 85 kilometres. By releasing a large amount of water vapour at once, the team would soak the region with water and more easily measure the effects. The mission was carried out in January when PMCs are less likely to naturally form, meaning only the artificially created PMC was present.

Measuring the PMC had to be achieved from the ground, as the formation occurs too high for any aircraft, and the formed cloud is too small for satellite imaging. Professor Collins' team used an array of instruments to measure the conditions and clouds. A lidar (light detection and ranging) unit was designed to measure light scattering off the ice crystals forming the PMC, giving the team information on the cloud's size, shape, altitude, temperature, and density. A second lidar was calibrated to measure the wind and temperature, recording the critical meteorological conditions in which the cloud formed. Finally, an infra-red temperature mapper gave the temperature of a wide area around where the PMC forms. Armed with this array of rockets and measuring equipment Professor Collins' team launched their rockets on the night of the 25th of January 2019.

Formation and Measurement

Professor Collins and his team started detecting a potential PMC 18 seconds after detonation and were able to track the object for a further three minutes. Looking at the data, the team had several critical questions to be answered.

The first was whether a PMC had formed at all. The Lidar readings could originate from several sources; remaining liquid water from the detonation; debris from the payload; other rocket exhaust products; or a PMC. Looking at previous studies such as the 'High Water' experiments in the 1960s; calculating the trajectory of debris; and previously observed space vehicle mesospheric cloud formations, Professor Collins confirmed that the object formed was indeed a PMC, as hoped.
The second was that PMCs are only rarely seen at temperatures above 150 Kelvin (-123°C), but the initial temperature readings were around 200 (-73°C) Kelvin. Professor Collins explains that there are two mechanisms at play allowing such a cloud to form. First, the higher concentration of water lowers the frost point, allowing the cloud to form at a higher temperature. Second, the water vapour from the rocket forms a filamentary structure which drives a local cooling of the area. The rapid cooling of the local area and a reduced frost point allow the clouds to be formed out of season.

Finally, the cloud was seen to rapidly descend from its formation point, much faster than any winds or gravity would carry it. However, Professor Collins explains that this reading wasn't showing the whole picture; the cloud was instead expanding from the point of detonation. The Lidar measurement was only seeing the bottom edge of the cloud expanding downwards, while the rest of the cloud would have been expanding upwards and sideways.

Making a Splash…

Professor Collins and his team's work on Project Super Soaker has provided us with a wealth of information on the effects space vehicles have on the upper atmosphere. The water vapour introduced by space vehicles not only is a source for mesospheric clouds that raises the frost point but also simultaneously lowers the local temperature to induce the formation of PMCs.

Professor Collins states that whilst some further questions on the physics of mesospheric clouds may lie just beyond our current technological grasp, the area is primed for further investigation. With Project Super Soaker, Professor Collins and his team have shown that sometimes, the most interesting results come from making a big splash.

Meet the Researchers

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Professor Richard Collins earned his PhD in electrical engineering from the University of Illinois in 1994. Supported by his experience of Antarctic conditions from a previous visiting winter scientist position at the Amundsen-Scott South Pole Station, Professor Collins has gone on to contribute to many areas of atmospheric research. Having been based at the University of Alaska Fairbanks since 1994, Professor Collins' research utilises many methods to investigate the atmosphere, including rockets, lasers and radar. Professor Collins teaches both undergraduate and postgraduate students, lecturing on electrical engineering and atmospheric science and has received awards for his outstanding teaching and impactful research. He is the current treasurer of the Geoscience and Remote Sensing Society (part of the Institute of Electrical and Electronic Engineers), and has served as a member of the Living With a Star Program Advisory Panel.

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Dr Jintai Li completed his undergraduate studies at the University of Science and Technology of China. In 2019, he gained a PhD from the University of Alaska Fairbanks in atmospheric science for his thesis 'Lidar and Radar Studies of Turbulence and Waves in the Arctic Middle Atmosphere', and since then has continued to work studying our planet's atmosphere. After graduation, he worked as a postdoctoral fellow at Clemson University. Currently, Dr Li is an Assistant Professor at the Geophysical Institute of the University of Alaska Fairbanks. Dr Li has contributed to a large number of conference presentations and academic papers, concentrating on the application of lidar technology to atmospheric and space science.

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FURTHER READING

RL Collins, MH Stevens, I Azeem, et al., Cloud Formation From a Localized Water Release in the Upper Mesosphere: Indication of Rapid Cooling, Journal of Geophysical Research: Space Physics, 2021, 126(2), e2019JA027285. DOI: https://doi.org/10.1029/2019JA027285