PRESS RELEASE

Antarctic Expedition Reveals Why Southern Ocean Clouds Remain One of Climate Science's Greatest Challenges

Researchers compare real-world observations with leading climate models to improve future climate predictions

The Southern Ocean is one of Earth's most important climate regulators, yet the clouds covering this remote region remain among the least understood features in atmospheric science. Their influence on the planet's energy balance makes accurate cloud representation essential for reliable weather forecasts and climate projections. A new study combines observations from an Antarctic expedition with advanced atmospheric datasets and climate models to investigate the processes behind this long-standing challenge in climate science.

The Southern Ocean plays a pivotal role in regulating Earth's climate, yet the clouds that blanket this remote region remain among the least understood features in atmospheric science. By controlling both incoming sunlight and outgoing heat, these clouds strongly influence Earth's energy balance. Even small errors in representing them can introduce significant uncertainties into weather forecasts, climate models, and projections of future global warming, making them a long-standing challenge for climate scientists.

To better understand why these clouds remain so difficult to simulate, researchers from the National Institute of Polar Research (Japan) and Nagoya University analyzed cloud observations collected during the 64th Japanese Antarctic Research Expedition (JARE64) aboard the research icebreaker *R/V Shirase*. Professor Jun Inoue explains, "*Numerical models have been reported to exhibit poor skill in reproducing clouds. In particular, over the Southern Ocean and Antarctica, where cloud representation remains especially challenging, cloud-related biases have been shown to increase errors in the surface energy budget through biases in the radiative budget*." Their findings were published in *Geophysical Research Letters* on 31 July 2026.

During December 2022 and March 2023, ship-based instruments continuously measured cloud properties, atmospheric temperature and humidity, surface radiation, and aerosol concentrations, providing a comprehensive benchmark for evaluating model performance. The team evaluated two widely used atmospheric reanalysis datasets, ERA5 and MERRA-2, alongside the CAM-ATRAS climate model using observations throughout the expedition.

Although all three datasets broadly captured cloud patterns over the Southern Ocean, important differences emerged. ERA5 and MERRA-2 consistently overestimated the occurrence of low-level clouds, whereas CAM-ATRAS most closely matched the observations, particularly in reproducing cloud occurrence and cloud phase. Surprisingly, despite simulating abundant low-level clouds, all three datasets underestimated the amount of downward longwave radiation reaching the surface. Comparison with observations showed that the reanalysis datasets contain higher aerosol concentrations than observed. Therefore, the researchers also conducted sensitivity experiments with CAM-ATRAS by increasing aerosol emissions over the Southern Hemisphere to examine how aerosols influence cloud formation and surface radiation. However, the aerosol sensitivity experiments further showed that increasing aerosol concentrations produced more low-level clouds but had only a limited effect on surface radiation.

The researchers traced this discrepancy to the physical properties of the simulated clouds rather than to cloud amount alone. In the models, clouds contained excessive ice, reducing the heat emitted toward the surface. However, these results demonstrate that biases in cloud representation alone cannot explain the underestimated DLW. Instead, the numerical models exhibit an inherent cold temperature bias, which also plays a role in the underestimation of DLW. These findings indicate that accurately representing both cloud phase and temperature is more important than simply reproducing cloud frequency when simulating the Southern Ocean's surface energy budget.

By identifying the processes responsible for persistent cloud biases, the study provides valuable guidance for improving weather and climate models. Better representation of cloud microphysics, aerosol–cloud interactions, and background environment will help reduce uncertainties in simulations of Earth's energy balance, leading to more reliable predictions of future warming, sea ice change, and climate variability.

The researchers emphasize that continued progress will require not only expanded observations of clouds across the Southern Ocean and Antarctica but also increased observations of fundamental atmospheric variables, particularly temperature, to reduce the cold bias in numerical models. As Assistant Professor Kazutoshi Sato notes, *"Because observations over Antarctica remain sparse, numerical models still contain substantial uncertainties in their representation of the Antarctic atmosphere. Therefore, incorporating existing but currently underutilized observations into numerical models may provide an effective solution. For example, assimilating observations from the PANSY radar at Japan's Syowa Station, which are not yet routinely used in numerical weather prediction systems, could help reduce model biases and improve forecast accuracy."*

This study represents one of the most comprehensive observational evaluations of cloud and radiation simulations over the Southern Ocean using data collected during the JARE64 expedition. By revealing why current models struggle to reproduce these clouds and identifying the processes responsible for long-standing biases, the findings provide an important step toward more accurate weather forecasts, improved climate models, and more confident projections of Earth's changing climate.

Reference

Title of original paper:	Evaluation of Low-Level Clouds, Temperature, and Surface Radiation Using a Model, Two Reanalyses, and Southern Ocean Observations
Journal:	*Geophysical Research Letters*
DOI:	10.1029/2026GL123000

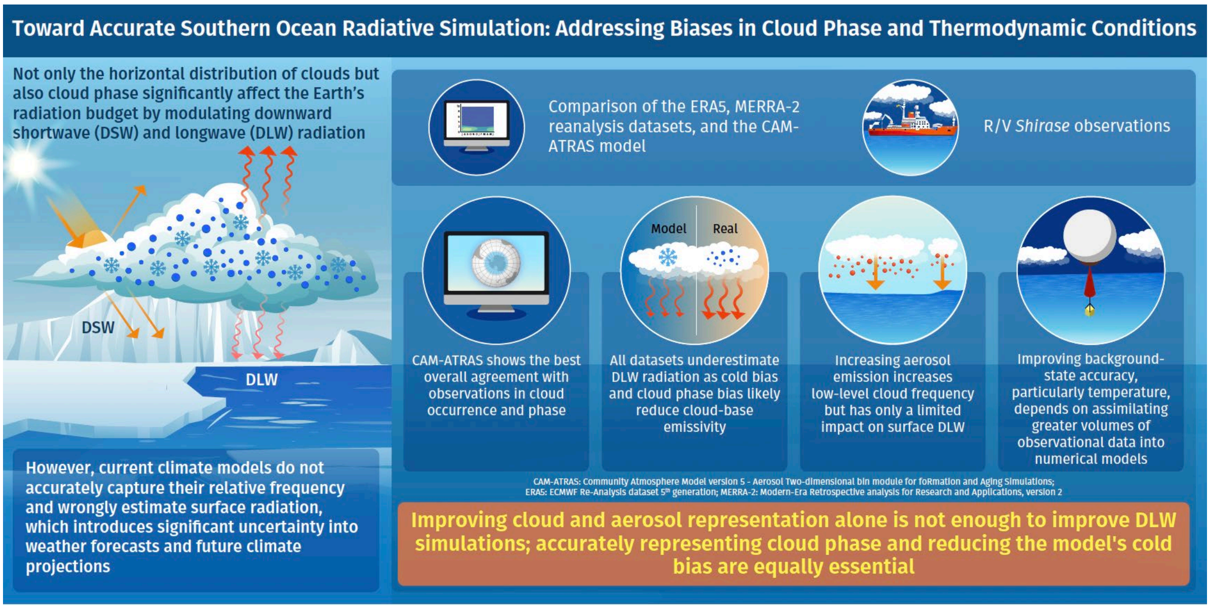
Additional information for EurekAlert
Article publication date: 31 July 2026
Method of research: Computational simulation/modeling
Subject of research: Not applicable
Conflicts of interest statement: The authors declare no conflicts of interest relevant to this study.

About National Institute of Polar Research, Japan
Founded in 1973, the National Institute of Polar Research (NIPR) is an inter-university research institute that conducts comprehensive scientific research and observations in the polar regions. NIPR is one of the four institutes constituting the Research Organization of Information and Systems (ROIS) and engages in comprehensive research via observation stations in the Arctic and Antarctica. It strives to promote polar science by soliciting collaboration research projects publicly, as well as by providing samples, materials, and information. NIPR plays a special role as the only institute in Japan that comprehensively pursues observations and research efforts in both the Antarctic and Arctic regions.

Website: https://www.nipr.ac.jp/english/

About Assistant Professor Kazutoshi Sato from National Institute of Polar Research, Japan
Kazutoshi Sato is an Assistant Professor at the National Institute of Polar Research. He studies climate phenomena that occur in the polar regions and explores how observational data affect numerical models. His research team mainly focuses on understanding the interaction between the atmosphere, the sea, and ice. His contributions to the field have gained recognition from *Nature Communications*, earning a place on the journal's Editors' Highlights page in 2021. Dr. Sato has an extensive portfolio of over 40 published papers. He is a member of the Meteorological Society of Japan, the Japan Geoscience Union, and the Oceanographic Society of Japan.

Funding information
This study was supported by the 64th Japanese Antarctic Research Expedition (JARE64 AJ1005), JSPS KAKENHI (JP18H05053, JP19K14802, JP20H04963, JP22H03722, JP22K14103, JP23H00515, JP23H00523, JP23K18519, JP23K24976, JP24H02225, JP24H02339, JP24H02341, JP25H00002, JP26K00780, and JP26K03065), the Japan Aerospace Exploration Agency (JAXA), the MEXT Arctic Challenge for Sustainability (ArCS II; JPMXD1420318865 and ArCS III; JPMXD1720251001) projects, the Environment Research and Technology Development Fund 2-2301 (JPMEERF20232001) and 2–2602 (JPMEERF20262002) of the Environmental Restoration and Conservation Agency (Japan) , and the National Institute of Polar Research (NIPR).



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Sato *et al.* (2026) | *Geophysical Research Letters* | DOI: 10.1029/2026GL123000

Title: Clouds over the Southern Ocean hold clues to Earth's future climate
Caption: Comparing real-world observations with climate models reveals key sources of uncertainty in Southern Ocean cloud simulations
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