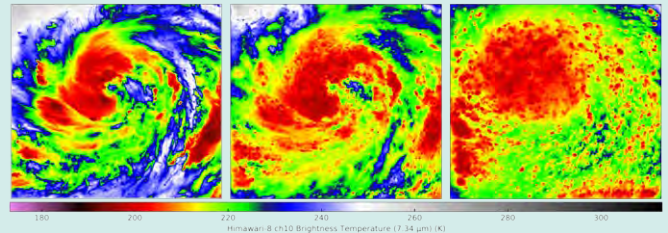


A New Frontier in Tropical Cyclone Prediction: All-Sky Data Assimilation of Geostationary Satellite Observations

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Case Overview

Tropical cyclone genesis and rapid intensification are governed by the "butterfly effect," in which even slight atmospheric disturbances are amplified, and have long been difficult to predict. This study developed a new technique enabling stable numerical weather prediction assimilation of cloud observation data from geostationary meteorological satellites, which had previously been difficult to utilize, achieving approximately a 20% reduction in tropical cyclone intensity forecast error. By unlocking the potential of geostationary meteorological satellites, it demonstrates improved accuracy in forecasting extreme weather, establishes a new frontier in tropical cyclone prediction, and contributes to disaster risk reduction.



Super Typhoon Nanmadol (2022) during its development phase observed by Himawari-8 (left) and simulation results (center: satellite plus conventional observations assimilation; right: conventional observations assimilation only). (Based on Minamide & Posselt, 2025)

Key points regarding receiving the award (Comments from the selection committee)

This research is highly valued for its scientific merit, and for demonstrating that integrating its results into operational forecasting can consistently improve tropical cyclone intensity prediction, thereby enhancing the value of weather forecasts and contributing to disaster risk reduction.

The development and verification of a new technique for stable assimilation into numerical weather prediction, achieving an approximately 20% reduction in forecast error, is particularly commendable for unlocking the potential of geostationary meteorological satellites and significantly advancing the accuracy of extreme weather prediction.

Concrete Results

1. Contribution to creating new areas for space development and utilization

Extreme weather events such as tropical cyclones and heavy rains develop rapidly in a short period of time and cause great damage to society, are inherently difficult to predict. Behind this lies the chaotic nature of the atmosphere, in which slight disturbances can be rapidly amplified. Overcoming this limitation in prediction requires precise representation of the inner-core structure of tropical cyclones and its assimilation into numerical weather prediction models. However, many of the typhoons that have a particularly large impact on Japan develop over the ocean, beyond the reach of ground-based observation networks, making direct observation of their inner-core structure difficult.

Geostationary meteorological satellites are in many cases the only means to fill these observational gaps. However, due to the limitation that infrared observations cannot penetrate clouds, observation information on cloud areas has not been fully utilized in numerical weather prediction. This study addresses this long-standing challenge by developing a new method to stably incorporate satellite data into numerical weather prediction while statistically correcting for cloud effects. By extracting and utilizing information that can be reliably inferred even in regions where direct observation is hindered by clouds, it demonstrates the feasibility of stable assimilation into numerical weather prediction systems. The novelty of this work lies in redefining cloud-affected observations from geostationary meteorological satellites, previously excluded, as a valuable resource for numerical weather prediction.

2. Contribution to expanding the space development and utilization market

This result demonstrates the usability of cloud-affected observations from geostationary meteorological satellites, which had not been fully utilized in numerical weather forecasting, and extends the value of existing satellite observation infrastructure. Geostationary meteorological satellites cover the entire globe as an observation platform, and this method is expected to be applicable across countries and operational forecasting centers worldwide, regardless of specific regions, phenomena, or satellite generations. By transforming previously underutilized large volumes of observational data into actionable resources, it broadens the scope of space data utilization and provides a foundation for future market expansion, including private weather and disaster prevention related services.

3. Contribution to the advancement of the economy and society

Tropical cyclones are particularly difficult to predict in their early stages, with conventional numerical forecasts tending to underestimate their development and often failing to predict them until just before intensification onset. This study

established a new method that assimilates all-sky observations from geostationary meteorological satellites, including cloud-affected areas, enabling more accurate representation of the inner-core structure of tropical cyclones from their early stages. As a result, the average error in tropical cyclones intensity forecasts has been reduced by approximately 20%, allowing earlier detection of signs of rapid intensification. This is expected to enhance both the confidence and lead time of decision-making in disaster response and societal operations, contributing to more rational disaster mitigation by reducing both under- and over-response.

4. Contribution to technology

"All-sky satellite data assimilation", which incorporates satellite data into numerical weather prediction models regardless of atmospheric conditions, has long been one of the most difficult challenges. This is because the presence of clouds causes nonlinear amplification of discrepancies between observations and model states, making calculations unstable under conventional error settings. This study redefined this problem from the perspective of error treatment and proposes two complementary approaches: Adaptive Observation Error Inflation (AOEI), which dynamically adjusts the reliability of observations, and Adaptive Background Error Inflation (ABEI), which expands model uncertainty according to conditions. By combining these approaches, a numerical weather prediction and data assimilation system capable of stable operation under all-sky conditions, including cloud-affected areas, was established and demonstrated.

This framework has broad applicability beyond geostationary meteorological satellites, as it systematically addresses the impact of observational operator nonlinearity on error. It is expected to extend to other satellite sensors and next-generation observation networks, expanding the utilization of satellite observation data and contributing to the advancement of numerical prediction and data assimilation methods.

5. Contribution to promoting public understanding and human resource development

Guided by the principle that "advancing space exploration deepens our understanding of Earth," the awardee has actively communicated the link between space technology and meteorological research to society. Through lectures, research supervision, and seminars both inside and outside the university, he has introduced the mechanisms of weather forecasting and the role of satellites in disaster prevention and everyday safety. By highlighting the connection between space technology and familiar meteorological phenomena, it fosters public interest in science and promotes greater awareness of disaster prevention across a wide range of generations.

