Physics Sensitivity of All-Sky Infrared Radiance Assimilation in HAFS-JEDI and Its Impact on Tropical Cyclogenesis Forecasts

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NOAA

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Introduction

Hurricane Beryl provides a valuable case for investigating tropical cyclone genesis prediction because its formation occurred earlier than indicated by much of the operational guidance. The National Hurricane Center noted that Beryl's genesis was forecast with less-than-average lead time: although the general formation region was identified correctly, a high probability of development was issued only shortly before genesis. This case highlights continuing challenges in representing the multiscale interactions among moist convection, cloud processes, environmental moisture, and mesoscale circulation development during tropical cyclogenesis.

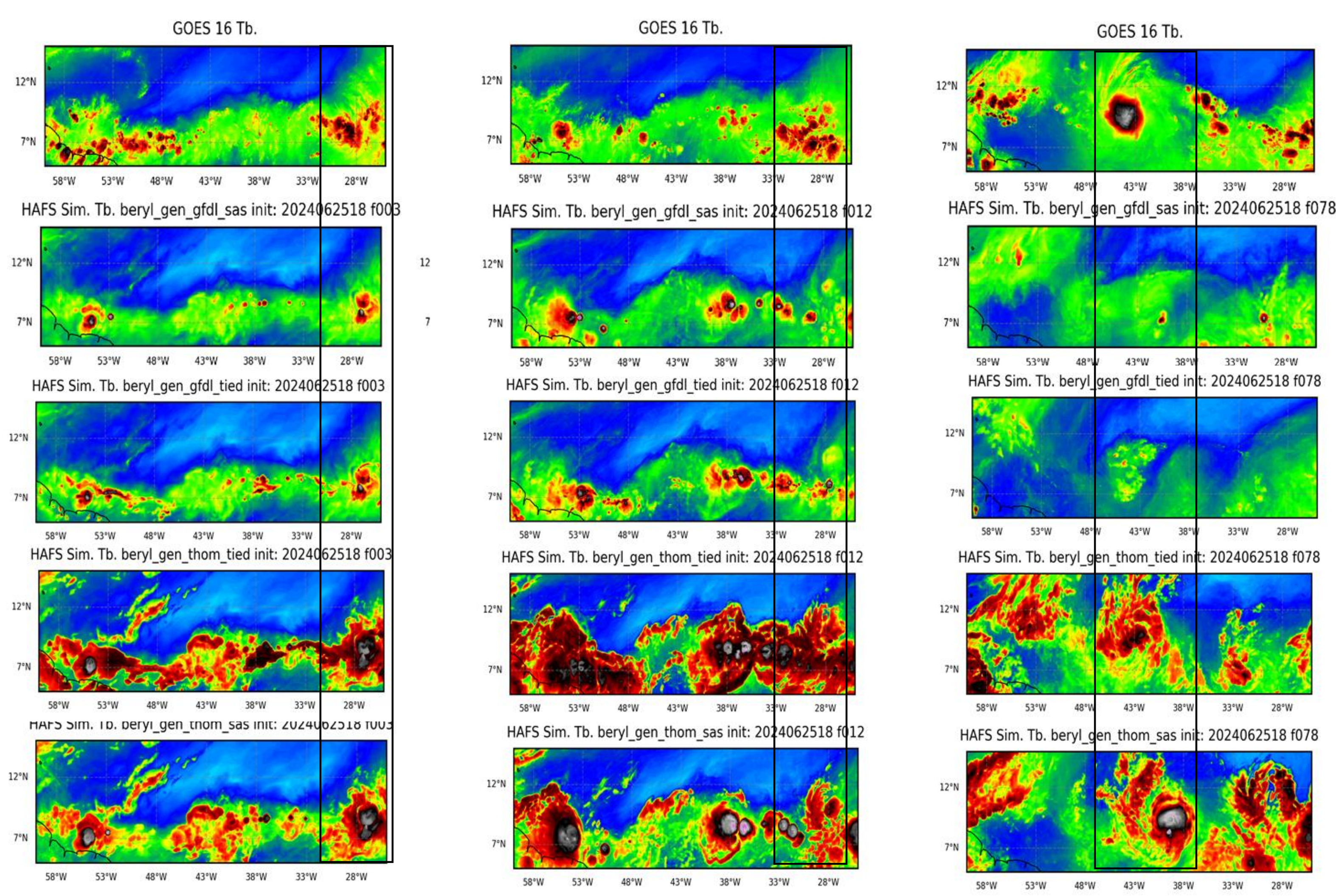
This study examines how cumulus and microphysics parameterizations affect all-sky infrared radiance assimilation and subsequent forecasts of Beryl's genesis using HAFS–JEDI. Experiments are conducted over a basin-wide domain at 6-km grid spacing, within the convective gray zone where convection is neither fully parameterized nor explicitly resolved. At this resolution, physics choices can substantially alter moisture, hydrometeor distributions, cloud structures, latent heating, and simulated radiances, thereby influencing radiance innovations, analysis increments, and the evolution of the pre-genesis disturbance. The objective is to determine which physics configurations improve cloud representation, satellite radiance assimilation, and prediction of the timing and structure of cyclogenesis.

Methodology

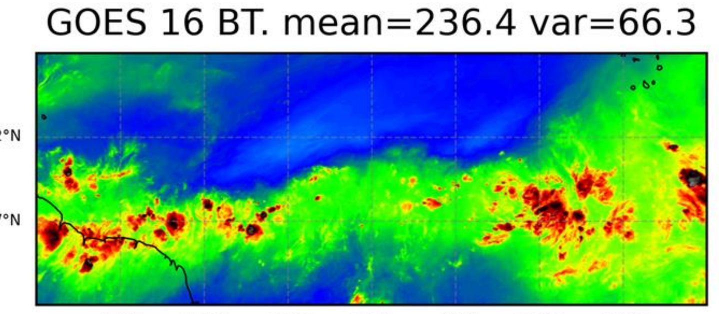
HAFS-JEDI experiments were conducted for Hurricane Beryl (2024) over a basin-wide, approximately 6-km domain. A 2X2 experimental matrix combined the GFDL or Thompson microphysics scheme with the scale-aware SAS or New Tiedtke cumulus scheme. Free forecasts initialized from the 0.25° GFS analysis were first used to isolate physics sensitivities in cloud structure, hydrometeor distributions, convection, and vortex development.

The same four physics configurations were then evaluated using HAFS-JEDI 3DEnVar with a 40-member ensemble. Each experiment assimilated identical conventional GTS observations and GOES-16 ABI channel-8 all-sky brightness temperatures using CRTM. Physics-dependent changes were assessed through prior and posterior radiances, departures, and thermodynamic, dynamical, and hydrometeor increments. Deterministic forecasts were evaluated against the NHC best track using genesis timing and location, track, intensity, and storm-structure metrics.

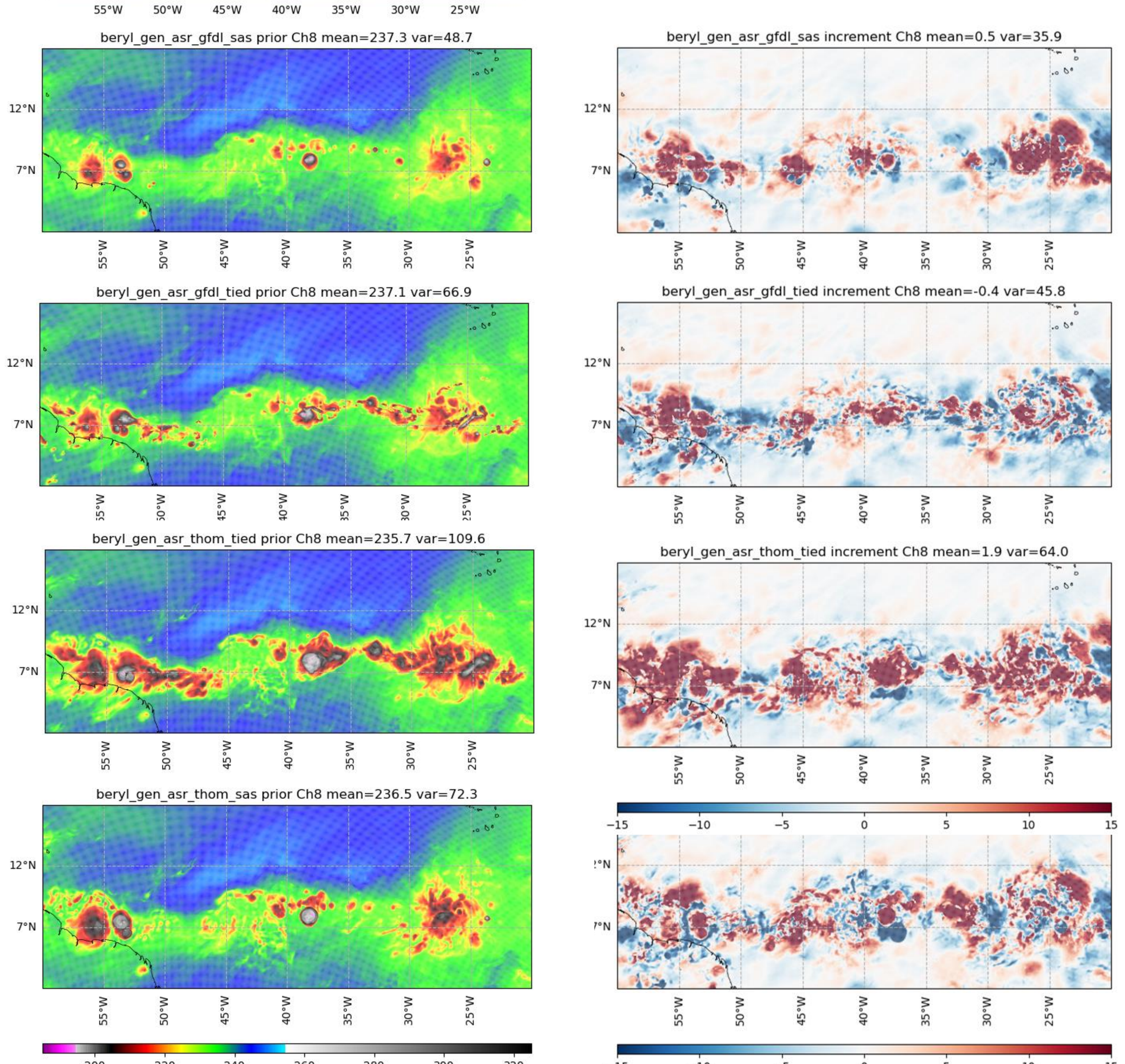
Results

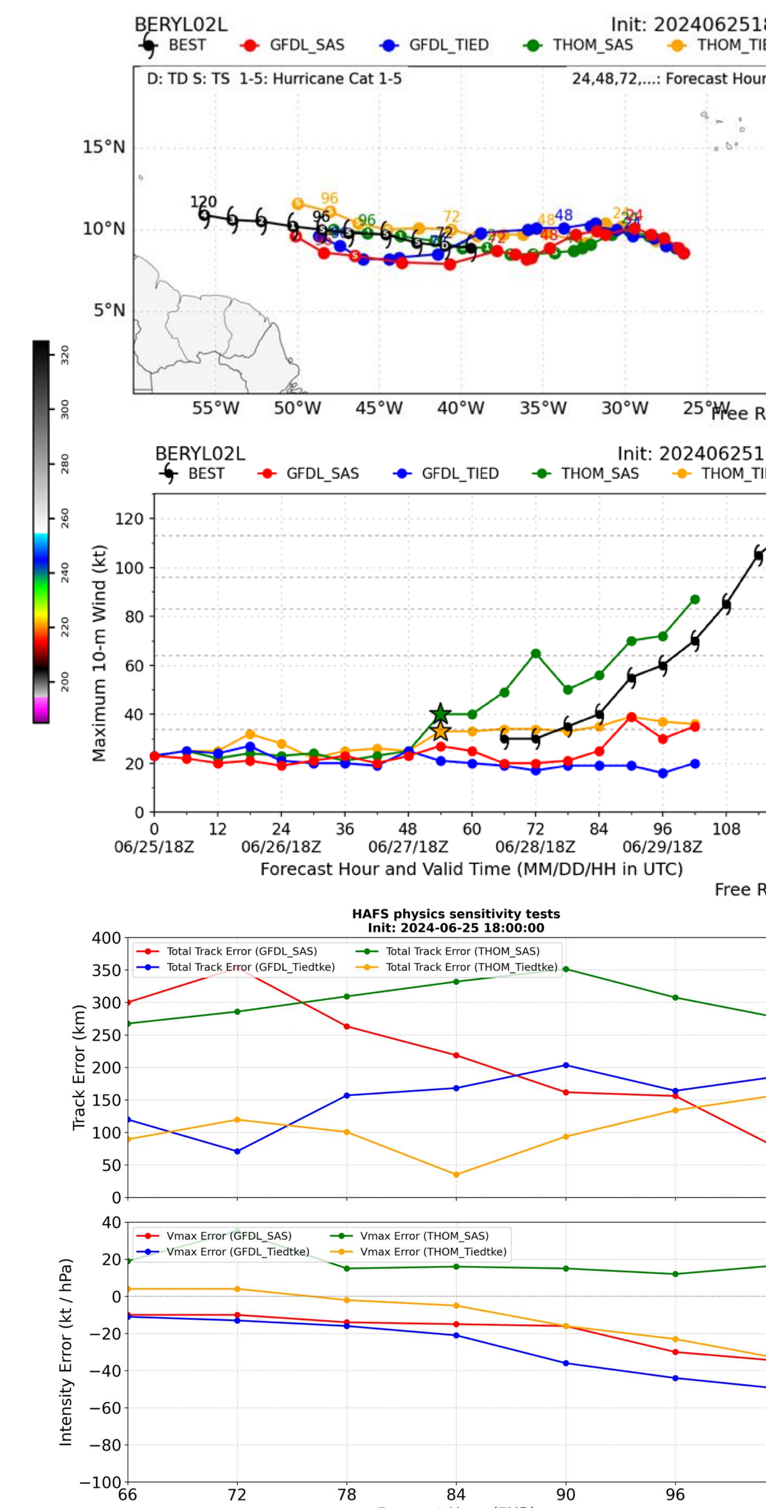


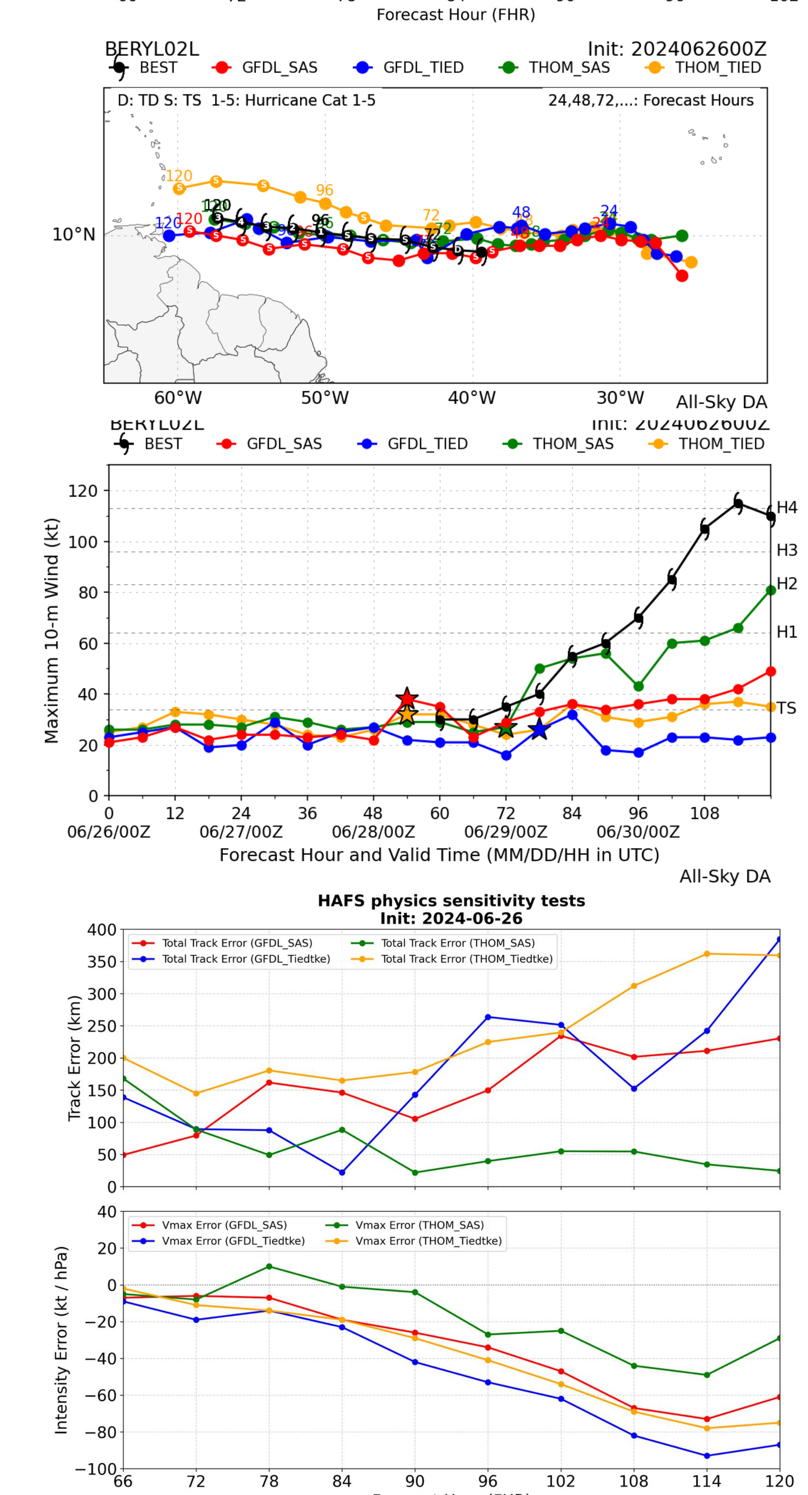
GOES 16 BT. mean=236.4 var=66.3



EXP	Microphysics	Convection
HFSBv1	Thompson	SAS
HFSAv1	GFDL	SAS
HFSBv2.01	Thompson	New Tiedtke
Exp. 1	GFDL	New Tiedtke







Findings

- Model physics strongly controls the cloud and hydrometeor background used by all-sky infrared radiance assimilation.
- Tiedtke produces broader, more diffuse convection and a weaker vortex, whereas scale-aware SAS favors compact cloud bands.
- Thompson generates colder and more extensive cloud fields than GFDL, likely associated with greater upper-level snow and ice (Wang et al. 2024).
- All-sky GOES-16 ABI assimilation reduces radiance departures, but the resulting thermodynamic, dynamical, and hydrometeor increments remain physics dependent.
- Thompson-SAS provides the best overall genesis and track forecast. All-sky assimilation also enables GFDL-SAS/GFDL-Tiedtke to capture genesis missed in the free run
- These results demonstrate that the benefit of all-sky radiance assimilation depends on the interaction between model physics and the initial cloud environment.

Future work

- Extend the evaluation to additional tropical cyclogenesis cases and forecast cycles to assess statistical robustness.
- Quantify relationships between assimilated brightness-temperature departures and state-vector increments, including temperature, moisture, winds, pressure, and hydrometeors.
- Diagnose how cloud-water, cloud-ice, snow, moisture, and circulation increments contribute to vortex formation and intensification.
- Test situation-dependent observation errors and correlated-error treatments for all-sky ABI radiances.

Acknowledgment

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