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PLANNING RESOLUTION CHOICES FOR VARIABLE-RESOLUTION TROPICAL CYCLONE SIMULATION: DECISION-RELEVANT SYNTHESIS FROM SEVERE TROPICAL CYCLONE HINA (1985)

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Model-configuration choices in large-scale environmental simulation are planning decisions: they determine how computational resources are allocated, which physical processes are resolved, and whether outputs are credible enough for downstream risk interpretation. This paper develops a planning-oriented synthesis of published evidence for Severe Tropical Cyclone Hina (Southwest Pacific, March 1985), using the Conformal Cubic Atmospheric Model (CCAM) in both quasi-uniform and variable-resolution configurations as the empirical basis. Drawing on the original experimental design, we compare seven reported simulations spanning 50 km, 25 km, and 12.5 km grids, including a larger-domain 12.5 km stretched-grid experiment. The analysis shows that horizontal resolution is the strongest configuration lever among the tested options. The 50 km configuration behaves similarly to ERA5 and substantially under-resolves storm intensity, whereas 25 km improves the intensification phase but remains too weak at peak. The 12.5 km experiments most closely capture the observed intensity envelope and yield a more credible inner-core structure, including a radius of maximum wind near 30 km, stronger tangential and radial circulation, higher rainfall, and greater surface heat flux near the storm centre. Variable-resolution grids retain the main benefits of uniform high resolution while offering a more practical design pathway for regional applications. The paper's contribution is a decision framework that translates these published physical diagnostics into configuration guidance for simulation-based hazard studies.

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INTRODUCTION

In computational environmental research, model design is not merely a technical detail; it is a planning problem. Choices about domain structure, horizontal resolution, and resource allocation shape what a model can credibly represent and, in turn, what kinds of scientific or applied decisions can be based on its output. This is especially true for tropical cyclones, whose peak intensity, inner-core organization, and rapid intensification depend on multiscale interactions that are highly sensitive to grid spacing. For studies that seek to inform regional hazard assessment, the key practical question is not only whether a model can simulate an event, but which configuration yields evidence that is sufficiently reliable, proportionate, and operationally feasible for the intended use.

Severe Tropical Cyclone Hina (1985) provides an analytically useful case for this problem. Hina was one of the most intense storms in the Southwest Pacific satellite-era record and therefore represents a stringent test of simulation design. The underlying source study examined Hina using the Conformal Cubic Atmospheric Model (CCAM) in both quasi-uniform and stretched-grid configurations, with horizontal resolutions of 50 km, 25 km, and 12.5 km, and found that finer grids substantially improved intensity, wind structure, rainfall, and surface flux representation. Those reported results are directly relevant to planning-oriented research because they reveal which configuration choices generate decision-useful information and which choices suppress critical storm dynamics.

This manuscript positions that evidence within a planning framework and states explicitly that it is a synthesis, not a new numerical experiment. Rather than treating the study solely as a meteorological case analysis, it asks what the published Hina diagnostics imply for the *selection* of model configurations in computational hazard work. The central argument is that the source paper supports a clear configuration-planning logic: coarse grids are adequate for broad track placement, intermediate grids improve event evolution, and, within this case, 12.5 km is the first tested scale at which inner-core dynamics become consistently credible for higher-stakes interpretation.

Three research questions guide the paper:

1. Which reported configuration choices materially improve the simulation of an intense tropical cyclone?
2. How do structural storm diagnostics change as horizontal resolution increases?
3. What planning guidance can be inferred from the comparison between quasi-uniform and variable-resolution grids?

STUDY CONTEXT AND EMPIRICAL BASIS

Event chronology

Tropical Cyclone Hina formed over the South Pacific during the austral summer of 1984/85. Best-track data indicate that the system developed near Fiji at 00 UTC on 11 March 1985 and initially moved westward. On 14 March it turned cyclonically toward the southeast, after which it intensified rapidly from 55 to 105 knots within 24 hours between 14 and 15 March. Hina reached peak intensity at approximately 06 UTC on 16 March with a maximum sustained wind speed of 135 kt (69.5 m s^{-1}, 1-minute average) and a minimum sea-level pressure of 910 hPa. On the Australian/Fiji scale, the storm corresponded to Category 5 intensity (120 kt, 10-minute average). After peak intensity, Hina weakened while moving farther southeast.

Synoptic setting

The source analysis shows that the moisture feeding Hina primarily originated from the northeast of the domain. At 00 UTC on 14 March, the highest specific humidity at the storm centre was 15.1 g kg^{-1} at 850 hPa and 6.2 g kg^{-1} at 500 hPa. By 12 UTC on 16 March, these values increased to 16.1 g kg^{-1} and 7.2 g kg^{-1}, respectively. The same analysis also identified an extratropical cyclone near 35°S, 176°E in the southeastern part of the domain, while tropical moisture extended southeastward and later drew additional moisture from northern Australia.

These details matter for planning because they establish that the case is not a weak or marginal storm; it is an extreme-event test of whether configuration choices preserve the storm's moisture supply, intensification pathway, and inner-core organization.

DATA, MODEL, AND CONFIGURATION DESIGN

ERA5 and IBTrACS

The study uses ERA5 reanalysis and IBTrACS best-track data as the empirical basis for evaluation. ERA5 provides hourly atmospheric fields at approximately 31 km horizontal resolution with 137 vertical levels extending from the surface to 0.01 hPa. The variables used in the source analysis include geopotential, wind speed, temperature, specific humidity, and mean sea-level pressure. IBTrACS provides the best available estimates of storm position, minimum sea-level pressure, and maximum sustained wind speed for Tropical Cyclone Hina.

CCAM configuration

The Conformal Cubic Atmospheric Model (CCAM) is an open-source global stretched-grid non-hydrostatic atmospheric model developed by CSIRO. It can be run either as a quasi-uniform global grid or as a stretched-grid system with local refinement over a target region. In the source study, all simulations used 54 vertical layers, with the lowest model level approximately 22 m above the displacement height and the upper model top at 35 km.

A common spectral-nudging configuration was applied across runs: temperature and winds above 850 hPa, together with surface pressure, were nudged at scales above 3,000 km to maintain consistency with ERA5 large-scale fields. No moisture nudging was applied. Simulations were initialized at 00 UTC on 4 March 1985, integrated for 16 days, and used a 7-day spin-up period. Sea-surface temperature evolution was also driven from ERA5.

Experimental structure

The core design comprised seven experiments: three quasi-uniform runs, three variable-resolution runs at matching target resolution, and one larger-domain 12.5 km stretched-grid run. Table 1 reproduces the experiment structure reported in the source study.

From a planning perspective, this experimental design is valuable because it isolates the effect of grid spacing while also testing whether variable-resolution layouts can preserve the main high-resolution benefits through targeted refinement. The source paper does not report explicit runtime or cost statistics, so the efficiency claim

Table 1: CCAM experiment design used in the Hina case study.

Experiment	Horizontal resolution	Schmidt factor
U50 (Ctrl)	50-km quasi-uniform	1.0
U25	25-km quasi-uniform	1.0
U12	12.5-km quasi-uniform	1.0
VR50	Variable grid with 50-km target area	2.1
VR25	Variable grid with 25-km target area	2.1
VR12	Variable grid with 12.5-km target area	2.1
VR12c	Variable grid with 12.5-km target area (larger high-resolution domain)	1.4

Algorithm 1 Configuration evaluation workflow for the Hina case study

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Require: ERA5 fields, IBTrACS best-track data, and reported CCAM outputs from all seven experiments
Ensure: Comparative evidence synthesized across track realism, intensity, inner-core structure, precipitation,
    and surface fluxes
Identify storm position over time from the best track and from each model simulation
Compare simulated and observed track evolution from 11–20 March 1985
Extract time series of maximum near-surface wind speed and minimum sea-level pressure
Assess whether simulated onset, peak intensity, and decay align with the best-track chronology
Compute storm-centred azimuthal averages of tangential wind, radial wind, and vertical velocity
Diagnose radius of maximum wind and the compactness of the inner-core circulation
Compare azimuthally averaged rainfall profiles across experiments
Compare total, latent, and sensible surface heat fluxes near the storm centre
Synthesize how reported changes in horizontal resolution alter physical realism and practical suitability
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remains qualitative, but the design still supports a disciplined comparison of where finer grid cells matter most.

EVALUATION WORKFLOW

The published study followed a process-oriented diagnostic logic. For clarity, transparency, and replicability of interpretation, the main analysis sequence is restated below as an explicit workflow.

RESULTS

Track fidelity and intensity representation

A consistent planning-relevant result is that *track* is comparatively robust across configurations, whereas *intensity* and inner-core realism are much more resolution-dependent.

ERA5 reproduces the observed track well, including the southeastward turn on 14 March, but substantially underestimates intensity. The reanalysis begins to strengthen the storm at 00 UTC on 12 March, then stalls near 40 kt while the best track intensifies sharply. ERA5 reaches peak intensity at 18 UTC on 17 March, roughly 36 hours later than the best track, and at that point differs from IBTrACS by about 75 kt in maximum wind and 65 hPa in minimum pressure.

The coarse quasi-uniform CCAM control run (U50) behaves similarly to ERA5. It reaches peak intensity at 12 UTC on 17 March with a minimum sea-level pressure of 960 hPa, and its discrepancy relative to the best track is about 75 kt in maximum wind and 50 hPa in minimum pressure. Although U50 reproduces storm onset and dissipation timing reasonably well, it still lags peak intensity by about 24 hours.

The 25 km run (U25) substantially improves on U50. It intensifies from the beginning of the simulation and follows IBTrACS closely from 00 UTC on 12 March to 12 UTC on 14 March, reaching peak intensity around 06 UTC on 16 March. Even so, it fails to intensify enough after 12 UTC on 14 March and remains too weak at peak, with a reported maximum wind of 110 kt and minimum sea-level pressure of 928 hPa.

The 12.5 km run (U12) performs best among the quasi-uniform configurations. The source study does not report a single tabulated peak value for U12 in the text, which limits exact point-by-point comparison, but it states directly that U12 better captures both intensity and intensity changes than the coarser runs. That conclusion is strengthened because the structural, rainfall, and flux diagnostics presented below point in the same direction.

The variable-resolution results are especially important for planning. VR50, VR25, and VR12 closely reproduce the track while showing time series of maximum wind and minimum pressure that are broadly comparable to their quasi-uniform counterparts. The source paper emphasizes that VR12 and U12 differ only slightly in intensity over the main intensification period and both capture peak intensity reasonably well. The larger-domain VR12c experiment remains comparable to VR12, indicating that expanding the high-resolution region does not degrade the main intensity result. Additional tests with different spin-up times for 12.5 km runs produced a mean minimum pressure of 928 ± 5 hPa, which the authors describe as consistent with observation. Although no direct runtime benchmark is reported, this cross-check provides the strongest available practical validation for the stretched-grid design.

Why resolution changes the structure of the storm

The source paper shows that increasing resolution does more than raise peak intensity; it changes the *geometry* of the storm in a way that independently corroborates the intensity comparison.

Across simulations, tangential wind maxima are located off-centre, but the radius of maximum wind (RMW) contracts sharply as the grid is refined. In the 50 km simulations (U50 and VR50), the RMW is about 100 km. At 25 km (U25 and VR25), it moves inward to about 60 km. At 12.5 km (U12 and VR12), it contracts further to about 30 km. This is qualitatively much closer to observed intense tropical cyclone structure and is consistent with prior size estimates for Hina, whose eye has been reported at approximately 22 km diameter.

The magnitude of the resolved circulation also strengthens with resolution. In the quasi-uniform runs, the maximum azimuthally averaged tangential wind increases from 44 m s^{-1} in U50 to 63 m s^{-1} in U25 and 70 m s^{-1} in U12. The overturning secondary circulation intensifies similarly: maximum low-level radial inflow increases from 15 m s^{-1} (U50) to 21 m s^{-1} (U25) and 24 m s^{-1} (U12). The source paper reports comparable magnitudes for the variable-resolution versions at the same nominal resolution. Taken together, these structural diagnostics provide an independent validation layer rather than a simple restatement of the peak-intensity curves.

These changes are not cosmetic. They indicate that finer grids begin to reproduce the compact inner-core wind field associated with major storm intensification. For planning purposes, this means that horizontal resolution is directly linked to whether the simulation can support interpretation of storm structure rather than only storm track, thereby validating the configuration choice across multiple metrics.

Table 2: Key reported intensity benchmarks used in this synthesis. Exact values are shown where explicitly stated in the source paper; other entries are reported qualitatively when the paper does not provide a single exact peak number in the body text.

Case	Reported peak metric	Interpretation
IBTrACS	135 kt; 910 hPa at 06 UTC 16 Mar	Reference event intensity
ERA5	36-h late peak; about 75 kt and 65 hPa weaker than IBTrACS at 18 UTC 17 Mar	Track realistic, intensity strongly underestimated
U50	960 hPa at 12 UTC 17 Mar; about 75 kt and 50 hPa weaker than IBTrACS	Similar to ERA5; too weak and late
U25	110 kt; 928 hPa at about 06 UTC 16 Mar	Improved timing; under-resolved peak intensity
U12	Best-performing quasi-uniform run	Captures intensity evolution more credibly than U50 and U25 in the reported comparisons
VR12 / VR12c	Comparable to U12; 12.5-km tests gave mean SLP_{min} of 928 ± 5 hPa across spin-up sensitivity tests	High-resolution stretched-grid design remains stable across the reported sensitivity checks

Large-scale fields and variable-resolution performance

The source paper also compares snapshots of the variable-resolution simulations against ERA5. At 12 UTC on 16 March 1985, the maximum 10 m wind speed reaches about 30 m s^{-1} in VR50, 57 m s^{-1} in VR25, and 67 m s^{-1} in VR12. The analysis further notes that specific humidity within a $3^\circ \times 3^\circ$ box around the storm centre increases with horizontal resolution. Because no moisture nudging is applied, the model retains some boundary-layer independence from ERA5 and is able to represent the storm's northeast moisture source more strongly as the grid is refined. This provides a second consistency check that the higher-resolution gains are not confined to a single diagnostic family.

For planning-oriented model design, this is a crucial result: a stretched-grid system can preserve large-scale realism while still delivering substantial gains near the region of interest within the reported experiment set.

Table 3: Resolution-dependent structural diagnostics reported in the source study and used here as cross-diagnostic validation.

Diagnostic	**50-km runs**	**25-km runs**	**12.5-km runs**
Radius of maximum wind (RMW)	∼100 km	∼60 km	∼30 km
Maximum tangential wind (quasi-uniform)	44 m s^{-1}	63 m s^{-1}	70 m s^{-1}
Maximum low-level radial inflow (quasi-uniform)	15 m s^{-1}	21 m s^{-1}	24 m s^{-1}
Inner-core compactness	Broad	More focused	Most realistic / compact

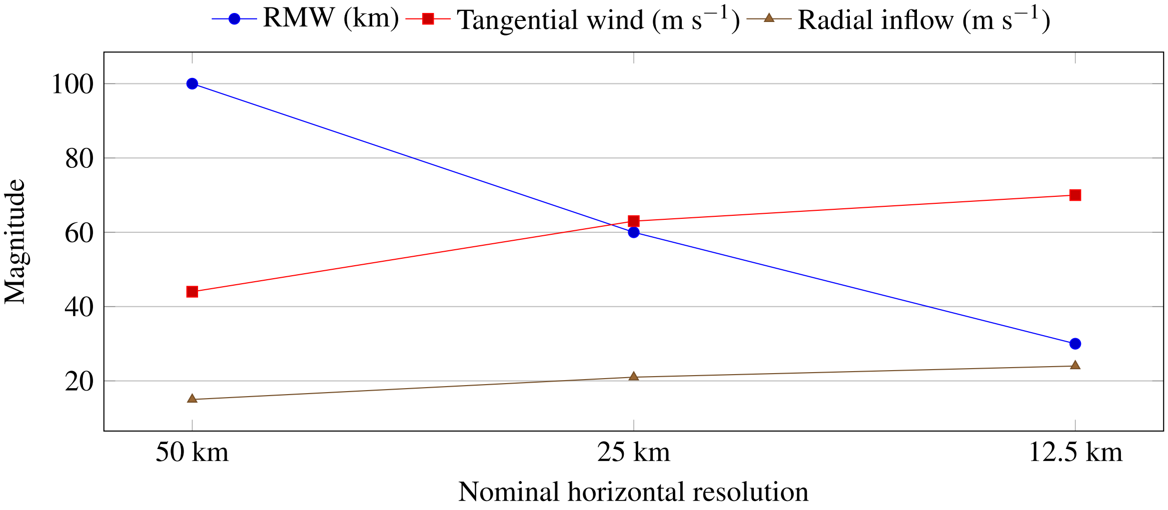

Figure 1: Reported structural changes in the quasi-uniform simulations as horizontal resolution increases. The compacting radius of maximum wind and strengthening circulation show why 12.5 km begins to diverge materially from the coarser designs.

Rainfall and surface heat fluxes as decision-relevant outputs

The strongest cross-diagnostic evidence that the 12.5 km configurations add practical value comes from precipitation and surface flux diagnostics.

The source study reports that peak inner-core rainfall increases systematically as horizontal resolution becomes finer. U12 and VR12 produce peak rainfall rates of 17.5–19 mm h^{-1}, whereas U25 and VR25 produce 12.5–14 mm h^{-1} and the 50 km simulations produce only 10–11 mm h^{-1}. Rainfall maxima remain off-centre in all simulations, aligned with peak vertical motion, but the coarse runs display broader and less focused inner-core maxima.

Surface heat fluxes show the same monotonic dependence on resolution. The source paper reports peak total surface heat flux values of about 640 W m^{-2} in U12 and 740 W m^{-2} in VR12, compared with 500–550 W m^{-2} in the 25 km simulations and about 400 W m^{-2} in the 50 km runs. The peak flux occurs near the radius of maximum wind and shifts radially inward as resolution increases.

The physical interpretation offered in the source paper is straightforward and important: stronger near-surface winds at higher resolution increase moisture content at the lowest model level, which raises latent heat flux, increases precipitation and diabatic heating near the storm centre, and thereby supports further intensification. In planning terms, finer resolution changes not only the appearance of the storm but also the causal chain represented in the simulation. That matters because the configuration decision is being validated not just by

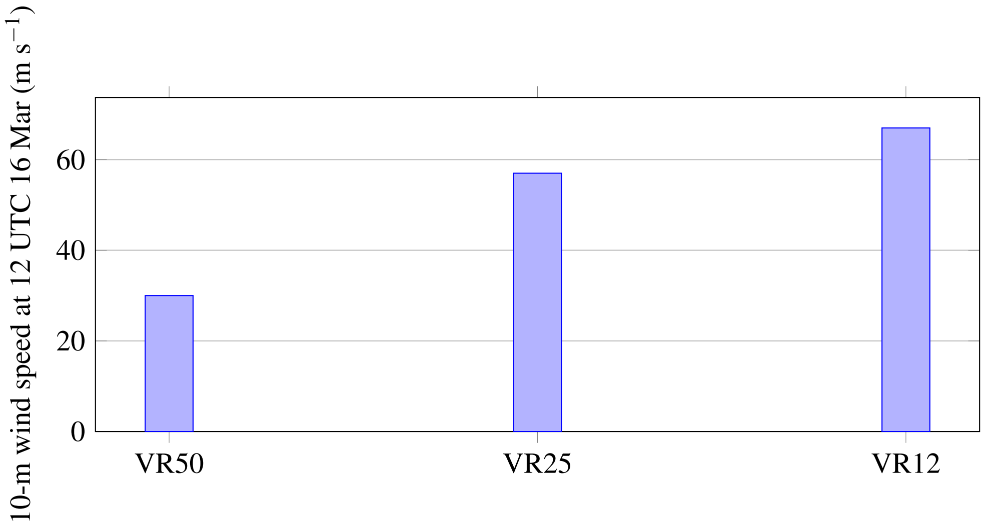

Figure 2: Reported maximum near-surface wind speed in the variable-resolution experiments at 12 UTC on 16 March 1985. The large increase from VR50 to VR12 illustrates the practical significance of target-area refinement.

Table 4: Resolution-dependent rainfall and total surface heat flux reported for the Hina inner core and used as process-level validation.

Resolution group	**Peak rainfall (mm h^{-1})**	**Peak total SHF (W m^{-2})**
50-km runs (U50 / VR50)	10–11	∼400
25-km runs (U25 / VR25)	12.5–14	500–550
12.5-km runs (U12 / VR12)	17.5–19	640 (U12) / 740 (VR12)

endpoint intensity, but by the process pathway linking wind, moisture, fluxes, and rainfall.

DISCUSSION: IMPLICATIONS FOR MANAGEMENT AND PLANNING RESEARCH

Resolution as a planning variable

The Hina case shows that horizontal resolution should be treated as a primary planning variable in simulation-based hazard work. If the research objective is limited to broad track placement or coarse regional context, a 50 km system may be sufficient. If the objective includes realistic timing of intensification, a 25 km design is a substantial improvement. However, if the goal is to support interpretation of inner-core wind structure, rainfall concentration, or coupled surface-flux processes, the evidence from this case strongly favors 12.5 km.

This is the core planning lesson: configuration choice must be matched to the intended use of the model output. The source study demonstrates that a single event can appear “acceptable” at coarse resolution for one metric (track), while remaining substantively inadequate for others that matter more for hazard-relevant interpretation. The resulting guidance is therefore case-bounded but still decision-relevant.

Why variable-resolution grids matter for design feasibility

A second planning lesson concerns the design feasibility of variable-resolution grids. The source paper explicitly notes that quasi-uniform high resolution is less practical for studies across the broader Australasia region, while variable-resolution grids offer a more computationally efficient alternative. Because explicit wall-clock or cost statistics are not reported, that efficiency claim should be interpreted qualitatively rather than as a formal cost analysis. Even so, the key result is that VR12 closely matches U12 in the main outcomes that matter most: track realism, peak-intensity behavior, and inner-core structural improvement.

That makes variable-resolution design strategically important. It allows investigators to preserve analytical fidelity in a target region without paying the full cost of a uniformly fine global mesh. For management and planning research, this is a classic resource-allocation problem: the question is how to deploy limited computational capacity where it yields the greatest informational return, while remaining explicit about the fact that the present paper infers efficiency from design logic rather than from direct runtime accounting.

Implications for domain planning

The source paper also issues an important caution. Even though variable-resolution is effective, grid deterioration outside the focal high-resolution area can still matter. The authors argue that a high-resolution (about 12 km) region should ideally encompass the entire lifecycle of a tropical cyclone if the aim is to represent intensity reliably. This is a direct planning constraint: local refinement is useful, but the refined domain must be designed around the storm's developmental pathway rather than around a narrow geographic convenience.

In other words, the question is not only *how fine* the grid should be, but also *where* that resolution should be placed. That moves the paper squarely into planning logic: spatial design and resource distribution determine analytical quality, especially when the target event evolves across a wide domain.

CONCLUSION

This paper has presented the Hina case study as a planning-oriented synthesis of published evidence on model configuration choices. The empirical record summarized above supports four main conclusions.

1. **Track realism alone is not enough.** Coarse configurations can reproduce the trajectory of a severe tropical cyclone while still severely underestimating intensity and inner-core dynamics.
2. **Horizontal resolution is the strongest design lever evaluated in this case.** Moving from 50 km to 25 km and then to 12.5 km systematically improves peak intensity, compactness of the wind field, rainfall concentration, and surface heat flux.
3. **Within this case, 12.5 km is the first tested scale at which physically meaningful inner-core behavior becomes consistently credible.** At this scale, the radius of maximum wind contracts to about 30 km, tangential and radial circulations strengthen sharply, and rainfall and heat-flux magnitudes better support realistic intensification.
4. **Variable-resolution layouts provide the most practical design pathway among the tested configurations.** They preserve the main benefits of high resolution in the target area while avoiding the cost of globally uniform refinement, provided the refined region is designed to encompass the storm lifecycle, although the efficiency advantage is inferred from grid design rather than from directly reported runtime statistics.

For management and planning research, the wider implication is clear: when simulation outputs are intended to support complex judgment, the planning of computational design cannot be treated as secondary. This article's contribution is to convert a published meteorological sensitivity study into explicit, decision-oriented guidance about adequacy, tradeoffs, and scope conditions in simulation-based analysis.

DATA AND CODE AVAILABILITY

This article does not introduce new numerical simulations or new code. ERA5 reanalysis is publicly available through ECMWF. IBTrACS best-track data are publicly available through NOAA/NCEI. CCAM is open source through CSIRO. Reproduction of the exact diagnostics discussed here requires access to the archived CCAM outputs used in the underlying study.

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