Manuscript egusphere-2026-512

Comments from CC1 (Saeed Hariri, 21 May 2026):

https://doi.org/10.5194/egusphere-2026-512-CC1

Dear Authors,

Please find attached my review report. The report contains my detailed comments and recommendations regarding the manuscript.

Recommendation: Major Revisions

General assessment

This manuscript presents numerical experiments with the intermediate-complexity moist-convective Thermal Rotating Shallow Water (mcTRSW) model Aeolus 2.0 to investigate the evolution of imposed subtropical buoyancy anomalies under dry and moist-convective conditions. The study explores the emergence of cyclonic/anticyclonic structures, wave adjustment, rainband-like features, and barotropic/baroclinic differences. The topic is relevant to the GMD community because it concerns the development and application of an idealized atmospheric model framework designed to bridge conceptual theory and more comprehensive climate models. The manuscript also provides open code/data access and builds upon earlier Aeolus/mcTRSW developments.

The manuscript contains potentially interesting dynamical results, especially regarding moist-convective adjustment and the role of imposed buoyancy anomalies. However, in its current form, it does not yet meet the standards expected for publication in GMD. The main issue is that the paper reads primarily as a physical interpretation study rather than a rigorous model development paper. Critical methodological details, validation procedures, numerical configuration information, reproducibility elements, and quantitative diagnostics are insufficiently documented. Furthermore, the manuscript contains substantial language issues, conceptual ambiguities, notation inconsistencies, and several claims that are overstated relative to the evidence presented.

I therefore recommend **major revisions** before the manuscript can be considered further.

> **Author response**:
>
> Dear Reviewer,
>
> We appreciate the time and effort you have dedicated to providing feedback on our manuscript, and we are grateful for your insightful comments and valuable suggestions for improving our paper.

Major Comments:

1. Insufficient focus on model development for GMD

GMD papers require strong emphasis on:

- model formulation,
- numerical implementation,
- evaluation/verification,

- reproducibility,
- limitations,
- technical innovation.

At present, the manuscript is dominated by qualitative interpretation of atmospheric phenomena, while the actual advances in Aeolus 2.0 are not sufficiently demonstrated.

For example, the manuscript states that:

“Including background effects in addition to the anomaly forcing is a new development relative to Rostami et al. (2023)”

However, this innovation is not rigorously documented. The manuscript does not clearly explain:

- what exact equations were modified,
- how ERA5 forcing/background fields are incorporated,
- whether initialization is balanced,
- how topography is numerically represented,
- whether conservation properties are preserved,
- how stability constraints are handled,
- whether the implementation changes numerical behavior.

A GMD paper requires a dedicated section clearly distinguishing:

1. inherited mcTRSW equations,
2. new Aeolus 2.0 developments,
3. new additions introduced specifically in this paper.

At present these distinctions are blurred.

Author response:

The foundational model formulation is extensively detailed across the Aeolus development history in Rostami et al. (2023; 2024; 2025a; 2025b). In addition to the governing equations presented in the primary manuscript, the recently implemented flux-form formulation is mathematically documented in the Supplementary Material, the first section of which explicitly details the model setup and numerical discretization schemes.

Furthermore, the Zenodo repository containing all required physical routines and initialization datasets (available at https://zenodo.org/records/18065000) provides a thorough explanation regarding reproducibility, as noted in the 'Code and data availability' section of the manuscript. The complete suite of model features, physical constants, moist-convective parametrizations, configuration parameters, and installation guides are fully housed within the repository, which features extensive inline code documentation clarifying the numerical implementation. Finally, the validation and test cases evaluating the numerical core have been largely published in the peer-reviewed journals cited above.

The topography formulation is described in the Model Description section (lines 125–129 of the manuscript):

“To define the structure of the pressure gradient terms in the governing equations, we specify the relevant velocity and pressure-related quantities for each model layer. In this formulation, $\langle \nabla p_i \rangle = \nabla \tilde{p}_i - \tilde{h}_i \nabla b_i$ represents the vertically-averaged horizontal gradient of the pressure field. For the 2 layers schema, the lower layer gradient is $\langle \nabla p_1 \rangle = (1/2)h_1 \nabla b_1 + b_1 \nabla (h_b + h_1 + h_2)$, and in the upper layer $\langle \nabla p_2 \rangle = \nabla (h_1 b_1) + (1/2)h_2 \nabla b_2 + b_2 \nabla (h_b + h_2)$, where h_b is a bottom topography height, $\tilde{p}_1 = (h_b + h_1 + h_2)b_1$, $\tilde{p}_2 = h_1 b_1 + (h_b + h_2)b_2$, $\tilde{h}_1 = h_b + (1/2)h_1 + h_2$, and $\tilde{h}_2 = h_b + (1/2)h_2$."

The gradient of the pressure term ($\langle \nabla p_i \rangle$) carries the bottom topography effects, calculated for the two layers schema using the bottom topography height (h_b) in the formulation, to represent its contribution into the governing equations - **Equations (1a-b)** and **(3a-b)**.

In addition to the dynamic equations, the thermodynamic terms $\mathcal{C}$ (condensed liquid water) and $\mathcal{D}$ (downward convective flux) were also parametrized in this version to account for the influence of topography.

The explicit implementation of topography within the model equations can be found in the **`aeolus2main.py`** (https://zenodo.org/records/18065000 > Aeolus2.0_model/aeolus2main.py > lines 1460-1464) under the variable name **`Dh10`**.

In the previous study conducted by Rostami et al. (2023; DOI: 10.1002/asl.1188) introducing the Aeolus framework, the conceptual experiments were performed in an atmosphere initially at rest, without the inclusion of background flow or topography. In contrast, the present work incorporates these factors, allowing us to evaluate how topography interacts with the background zonal flow and vertical wind shear to distort the developing pressure systems. Consequently, the upper-level anticyclonic ridges and surface low-pressure anomalies develop non-uniform, elongated geometries similar to real-world atmospheric blocking configurations. Furthermore, the background velocity field interacts dynamically with the imposed buoyancy anomalies, generating more realistic, comma-shaped water vapor signatures and complex spiral rainbands. This highlights how a localized thermal anomaly propagates through a moving atmosphere, shedding inertia-gravity waves that redistribute heat and momentum far from the initial heatwave center; by comparison, the configurations in Rostami et al. (2023) present a more stable, centered evolution.

The comments will be thoroughly evaluated, and the text will be enhanced.

2. Lack of numerical configuration details

The manuscript lacks critical numerical information required for reproducibility. Missing details include

- horizontal resolution,
- spectral truncation,
- timestep,
- diffusion/hyperdiffusion,
- filters,
- boundary treatment,
- conservation properties,
- CFL conditions,
- runtime performance,
- sensitivity to resolution,

- initialization procedure,
- spin-up rationale,
- convergence tests.

The paper mentions Dedalus usage but provides no implementation details sufficient for reproducibility.

A dedicated subsection on numerical implementation is required.

Author response:

The Aeolus 2.0 Stand-alone atmospheric model was configured following similar approach as Rostami et al. (2024; 2025).

The grid used is regular with 384 latitudes by 768 longitudes (~0.5 degrees), passed to Dedalus in a Cartesian domain, to then be processed into Spectral domain using Fourier series. The frequency is every 1 minute (numerical time-step), outputted 4 times per day.

The simulation was performed under 16 cores and 16 GB ram, running for 102 numerical-days (4x per day = 408 time-steps), spending approximately 3hs to complete, for each case studied. The output size by case is 20 GB.

Dedalus framework details are found in Rostami et al. (2024) and in Dedalus Project homepage (dedalus-project.org, Burns et al., 2020). We used Dedalus version 2.2207.3, running in Python 3.10.14.

Other libraries used: Climlab (0.8.2), C-Extensions for Python (cython 3.0.10), NumPy (1.26.4), Scipy (1.13.1), MPI for Python (mpi4py 3.1.6), and HDF5 for Python (h5py 3.11.0).

By enabling high-performance and efficient execution, this framework supplies Dedalus with the essential functionality required for advanced scientific computations.

Simulations were performed in a computer Alienware M18 R1, Processor i9-13900HX (32 Threads, 24 cores, 36 MB L3-Cache, 5.4GHz), 32GB RAM DDR5 4.800MHz (2x16GB), with operational system Ubuntu 22.04.4 LTS.

The comments will be thoroughly evaluated, and the text will be enhanced.

3. Validation is inadequate

The manuscript repeatedly claims realism and consistency with observations:

- comma-cloud structures,
- mesoscale vortices,
- ridge-trough coupling,
- heatwave persistence,
- Rossby-wave behavior.

However, validation is qualitative and mostly anecdotal.

For example:

“The success in reproducing phenomena observed in nature like rainbands, comma-cloud patterns, ridged trough coupling validates the approach…”

This statement is too strong given the evidence shown.

The manuscript needs:

- quantitative diagnostics,
- comparison with theory,
- comparison with reanalysis metrics,
- scaling arguments,
- spectral characteristics,
- phase speeds,
- energy budgets,
- Rossby radius consistency,
- growth rates,
- conservation diagnostics.

Without these, many conclusions remain speculative.

Author response:

The suggestions are appreciated with thanks. The remaining comments will be thoroughly evaluated and carefully addressed via corresponding updates in the revised manuscript.

4. Heatwave terminology is conceptually problematic

The manuscript defines "heatwaves" as buoyancy anomalies:

- comma-cloud structures,
- mesoscale vortices,
- ridge-trough coupling,
- heatwave persistence,
- Rossby-wave behavior.

"the term heatwaves is used in a connotation to describe the phenomenon involving the gradual formation and sustained presence of large-scale, localized regions of positive buoyancy"

This is problematic because:

- real heatwaves involve land-atmosphere coupling,
- radiative processes,
- boundary layer physics,
- surface energy balance,
- persistence metrics,
- temperature thresholds.

The experiments instead impose idealized buoyancy perturbations in a reduced-order dynamical system.

The manuscript should substantially soften claims about "heatwaves" and instead frame the study as:

idealized buoyancy-anomaly dynamics relevant to subtropical blocking and heatwave-like circulation responses.

Currently the title and framing overstate applicability.

Author response:

The suggestions are appreciated with thanks. The remaining comments will be thoroughly evaluated and carefully addressed via corresponding updates in the revised manuscript.

5. Excessive qualitative interpretation

Many results sections contain speculative meteorological interpretation unsupported by diagnostics.

Examples:

- “mesoscale convective systems,”
- “frontal boundaries,”
- “rainfall organization,”
- “heatwave environment,”
- “persistent and stable weather conditions,”
- “ridge-trough coupling.”

These claims require diagnostics that are absent.

The figures mainly show anomaly fields and vectors, but not:

- PV evolution,
- vorticity,
- geopotential,
- precipitation,
- wave decomposition,
- energetics,
- instability diagnostics.

The discussion should be substantially tightened and better linked to what the model can actually resolve.

Author response:

The Supplementary Material includes additional plots illustrating how divergence evolves over time, along with the corresponding fields for the zonal and meridional wind components. We have also hosted comprehensive Hovmöller diagrams in the Zenodo repository (https://zenodo.org/records/18065000). These were derived from the Hamiltonian formulation to track key diagnostics such as wave energy propagation, group velocity, and nonlinear wave-wave interactions across all our simulation cases. Because of the sheer volume of these plots, we chose to keep them in the repository and use them selectively to back up the physical discussion in the text.

The remaining comments will be thoroughly evaluated and carefully addressed via corresponding updates in the revised manuscript.

6. Mathematical notation and presentation require major revision

Several equations contain formatting or notation problems.

Examples:

- Eq. (4b) appears incorrect/repeated.
- Some symbols are undefined or inconsistently rendered.
- Several equations appear corrupted during typesetting.
- Variables switch notation between sections.
- Equation references are sometimes unclear.

The manuscript needs careful proofreading of all mathematical expressions.

Author response:

Thank you for these suggestions. We will carefully review them all before submitting the revised manuscript.

7. Figures require improvement

The figures are difficult to interpret because:

- color bars are not described sufficiently in captions,
- units are unclear,
- anomaly normalization is unclear,
- vector scaling is not explained,
- timestamps are difficult to follow,
- panel labeling is insufficient,
- quantitative interpretation is impossible.

For GMD, figures should better support:

- model evaluation,
- numerical behavior,
- process interpretation.

Author response:

Thank you for these suggestions. We will carefully review them all before submitting the revised manuscript.

Specific comments

Abstract

The abstract is too broad and overstates conclusions. Statements such as:

"provides new insight into the dynamics that sustain extreme heatwaves in a warming world"

are not demonstrated by the idealized experiments.

Please moderate such claims.

Author response:

Thank you for these suggestions. We will carefully review them all before submitting the revised manuscript.

Introduction

The introduction mixes:

- heatwaves,
- blocking,
- subtropical vortices,
- Rossby waves,
- moist convection,
- shallow-water theory,

without clearly defining the precise scientific question.

The scientific objectives should be reformulated more explicitly.

Author response:

Thank you for these suggestions. We will carefully review them all before submitting the revised manuscript.

Section 2.1

The model description is currently too compressed for GMD standards.

Please provide:

- a table of prognostic variables,
- parameter values,
- dimensional scales,
- nondimensionalization summary,
- conservation properties,
- solver details,
- computational cost,
- numerical scheme description.

Author response:

Thank you for these suggestions. We will carefully review them all before submitting the revised manuscript.

Equation system

The equations are central to the paper, yet several terms are insufficiently explained.

For example:

- entrainment,
- condensation closure,
- Newtonian relaxation,
- external forcing,
- evaporation parameterization.

A table summarizing all symbols and parameters is needed.

Author response:

Thank you for these suggestions. We will carefully review them all before submitting the revised manuscript.

Section 2.2

The anomaly forcing definition is difficult to follow.

Equation (5) is not clearly typeset.

Please rewrite carefully and define:

- α-Gaussian,
- normalization,
- dimensional amplitude,
- physical interpretation,
- relation to temperature perturbation.

Author response:

Thank you for these suggestions. We will carefully review them all before submitting the revised manuscript.

Results

The results rely too heavily on visual inspection.

Please add:

- quantitative diagnostics,
- timescale analysis,
- spectral decomposition,
- wave propagation speeds,
- energy partitioning,
- sensitivity experiments.

Author response:

Thank you for these suggestions. We will carefully review them all before submitting the revised manuscript.

Conclusions

The conclusions again overstate realism.

For example:

“validates the approach”

should be softened unless quantitative validation is added.

Author response:

Thank you for these suggestions. We will carefully review them all before submitting the revised manuscript.

Language and style

The manuscript requires substantial English editing.

Examples:

- grammatical inconsistencies,
- awkward phrasing,
- repetition,
- excessively long sentences,
- unclear terminology.

Examples include:

- “heatwaves is used in a connotation”
- “hold over multiple consecutive days”
- “performed the highest peak”
- “simulate an equal aspect”

A professional language revision is strongly recommended.

Author response:

Thank you for these suggestions. We will carefully review them all before submitting the revised manuscript.

Recommendation

The manuscript contains potentially valuable work on idealized moist-convective atmospheric dynamics using Aeolus 2.0, but major improvements are required before it is suitable for publication in GMD.

The most important revisions are:

1. strengthen the model-development focus,
2. provide full numerical implementation details,
3. add quantitative validation and diagnostics,
4. reduce speculative interpretation,
5. clarify mathematical notation,
6. substantially improve language quality,
7. moderate claims about real-world heatwaves.

Author response:

Thank you for the helpful feedback. The comments will be thoroughly evaluated, and the text will be enhanced.

Sincerely,

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