Project: **1500**

Project title: **TRR181 subproject L4 (Multiscale Ocean-Atmosphere Coupling): Investigating the triggering of tropical deep convection by mesoscale SST features in global coupled km-scale simulations**

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Report period: **2025-05-01 to 2026-04-30**

The project 1500 is part of phase 3 of the collaborative research center TRR 181 on „Energy transfers in atmosphere and ocean“ under the subproject L4 on „Energy-consistent ocean-atmosphere coupling“ (see www.trr-energytransfers.de) and takes place at the Max Planck Institute for Meteorology in Hamburg, the GEOMAR in Kiel, and the Leibniz Institute for Baltic Sea Research in Warnemünde. The overall goal of the project is to clarify the role of mesoscale air-sea interactions for upper-ocean and atmospheric dynamics in the tropics, with a particular focus on tropical deep convection. The planned work for the report period was to run several simulations at different horizontal grid spacings in the atmosphere and ocean components of the km-scale atmosphere-ocean model ICON at HRLE-4 „Levante“. With these simulations, we planned to investigate two main research topics:

1. Analysis of a baseline simulation at a grid spacing of 5 km in the atmosphere and ocean to investigate the relevance and the dominant mechanisms by which mesoscale gradients in sea surface temperature (SST) and associated mesoscale air-sea interactions modify tropical deep convection. To do so, we planned to run a tracking algorithm for mesoscale convective systems (MCSs), TOOCAN (Fiolleau and Roca, 2013), on this simulation.
2. Investigating potential upscale effects of mesoscale air-sea interactions on the tropical rainbelt as a whole by comparing the simulated tropical rainbelt in the simulations at different grid spacings in the atmosphere and ocean. This work also aimed at clarifying the root causes of remaining biases in the representation of the tropical rainbelt in km-scale climate models.

We have successfully conducted and postprocessed various coupled ICON simulations as planned. The following simulations with a length of two simulated months have been performed:

hfr0008: Δx_{atm} = 5.0 km, Δx_{oc} = 5.0 km
hfr0009: Δx_{atm} = 2.5 km, Δx_{oc} = 2.5 km
hfr0010: Δx_{atm} = 5.0 km, Δx_{oc} = 2.5 km
hfr0012: Δx_{atm} = 2.5 km, Δx_{oc} = 5.0 km
hfr0013: Δx_{atm} = 5.0 km, Δx_{oc} = 1.2 km
hfr0014: Δx_{atm} = 10.0 km, Δx_{oc} = 5.0 km
hfr0015: Δx_{atm} = 10.0 km, Δx_{oc} = 10.0 km
hfr0016: Δx_{atm} = 5.0 km, Δx_{oc} = 10.0 km

Furthermore, the MCS tracking algorithm TOOCAN has been successfully applied to all of the simulations. Consequently, we have generated all the necessary data to answer our research question in the report period. Additionally, we used some resources of project 1500 to analyze the coupled ICON simulation *ngc5004* that was performed in the context of the nextGEMS project and has a grid spacing of 2.5 km in both the atmosphere and ocean.

This analysis of the simulation *ngc5004* aimed at addressing the first research topic. We showed that small-scale warm patches in the tropical oceans with an area-equivalent diameter of about 15 — 100 km enhance precipitation on their downwind side by up to 5% of the large-scale background value. We could further show that this precipitation enhancement is predominantly driven by the so-called pressure adjustment mechanism as suggested by Li and Carbone (2012). The pressure adjustment mechanism works via a hydrostatic pressure reduction within the boundary layer above the SST warm patch that drives convergent winds. These give rise to ascent, and ultimately clouds and precipitation. A similar analysis for two coupled IFS simulations — one with a parameterization of deep convection and one without — showed further that the magnitude of the precipitation response to an SST warm patch depends on the treatment of deep convection: if deep convection is treated explicitly, the response of precipitation to the SST warm patch is stronger. We attribute this behaviour to a more direct coupling between circulation and convection. A publication of these results is currently in preparation (Franke et al., 2026).

So far, we haven't started working on the analysis related to research topic 2, i.e. potential upscale effects of mesoscale air-sea interaction on the tropical rainbelt. However, given that the required coupled ICON simulations for this analysis have been finished in the report period, we will conduct this analysis and prepare a corresponding publication in the first half of the upcoming allocation period (07/2026 — 06/2027). Related to this research topic, project partners from Geomar will use the ICON simulations to investigate how submesoscale processes, enabled by increasingly higher resolution, influence the coupling strength and energy distribution at scales related to these processes. Further, they will analyse whether these processes show an upscale effect on large-scale variability within the ocean mixed layer and beyond. Project partners from the Leibnitz Institute for Baltic Sea Research will use these simulations to investigate small-scale upper-ocean processes, the downward transport of heat, and potential atmosphere–ocean feedbacks in the tropical ocean, with a special focus on deep-cycle turbulence.

Right now, we already use the ICON simulations to investigate how the morphology of tropical MCSs depends on the horizontal grid spacing in the atmosphere and the ocean. We have already found a systematic dependency of the relationship between MCS intensity and anvil size on atmospheric grid spacing. Testing the impact of the ocean grid spacing on MCS properties will be the next step. This will help to uncover the relevance of mesoscale air-sea interactions for triggering deep convective systems further.

Publications

Franke, H., C. Hohenegger, X. Chen, 2026: Local modification of tropical precipitation by small-scale air-sea interactions in km-scale climate models, *in preparation for submission to the Journal of the Atmospheric Sciences*.

References

Fiolleau, T., R. Roca, 2013: An Algorithm for the Detection and Tracking of Tropical Mesoscale Convective Systems Using Infrared Images From Geostationary Satellite, *IEEE Transactions on Geoscience and Remote Sensing*, **51**, 4302-4315, doi: https://doi.org/10.1109/TGRS.2012.2227762.

Li, Y., R. E. Carbone, 2012: Excitation of Rainfall over the Tropical Western Pacific, *Journal of the Atmospheric Sciences,* **69**, 2983-2994, doi: https://doi.org/10.1175/JAS-D-11-0245.1.