SYMPOSIUM OP'24

ADVANCING OCEAN PREDICTION SCIENCE FOR SOCIETAL BENEFITS

Local grid refinement within ICON based Earth System Model at DWD

A. Bevrnja(1), R. Potthast(1), G. Zängl(1), H. Haak(2), L. Linardakis (2), K. Logemann(3)

(1) Deutscher Wetterdienst
(2) Max-Planck-Institute for Meteorology
(3) Helmholtz-Zentrum Hereon

The project "Earth System Modelling at the Weather scale" (ESM-W) by DWD in cooperation with GeoInfoDienst BW aims to develop a coupled ocean-atmosphere forecasting system based on ICON-O[1] for the ocean model and ICON-NWP[2] for the atmosphere.

To obtain high-resolution regional results without having to use very expensive global grids, a coastal grid refinement algorithm[3] is applied and tested on a non-coastal region. Compared to Limited Area Mode (LAM), this approach preserves the globality of the model and requires only a single model run. Although a simple region is presented here, the algorithm accepts multiple refinement criteria such that complex refinement is possible while also retaining the coastal refinement capability. This poster presents first results alongside challenges that have to be solved in order for this approach to be practically viable. The main one is appearance of numerical artefacts due to the grid resolution gradient which is a consequence of fast grid-size transition. These artefacts seem to develop in velocity based quantities and then spread to other parameters as well. After fixing this issue, an improved refinement strategy could be sought out.

I. Intro

One of the goals of ESM-W project at DWD is developing regional simulation capabilities for coupled atmosphere-ocean model, for which its ocean component ICON-O[*] has to be extended. Aside from Limited Area Mode (LAM) which is being implemented, another interesting option is to use local grid refinement for this purpose. This means part of the domain gets populated with smaller cells through local grid refinement process, and while the grid is still global, most of the computational resources are used for this smaller part of the domain, effectively producing high-resolution regional results.

ICON uses icosahedral base grid, the grid cells are triangular and the grid is unstructured. This allows for simple yet effective grid refinement options.

II. Grid refinement

The algorithm relies on cell bi- and quadrisection. The cells in the region of interest are cut into 4 smaller triangles, and the cells between coarse and fine regions are bisected such that the edges match. This produces a topologically consistent grid and can be used without any code adaptations. The process can be repeated any number of times to achieve multiple refinement levels, allowing for very high refinements. Afterwards, a spring relaxation algorithm is applied to improve the angles of grid triangles. This approach has already been used to refine coastal regions in ICON-O[3]. Now we apply the same procedure, but instead of using shore-distance as the refinement criterion, we use a predefined latitude-longitude region.

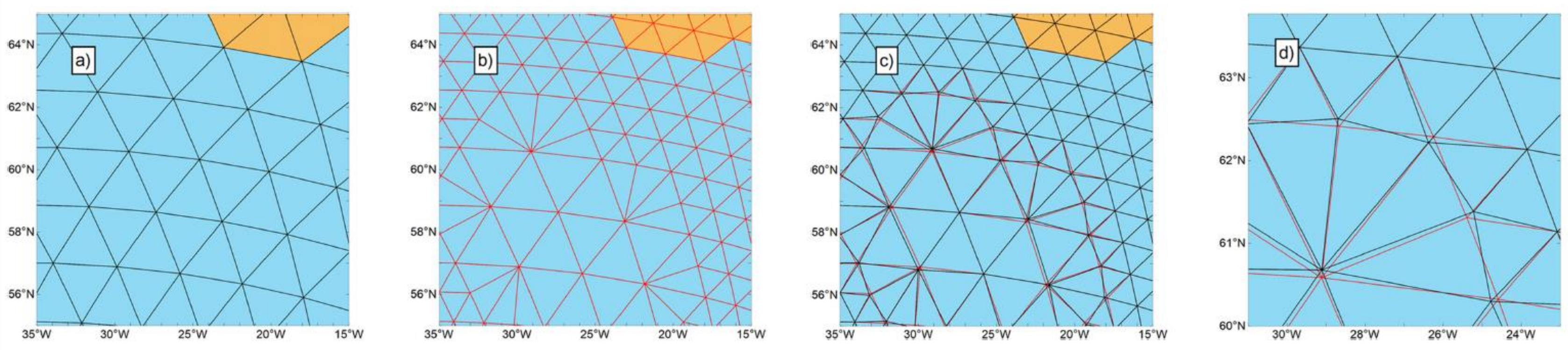


Figure 1: grid refinement process by steps, a) initial grid, b) refined grid after quadri- and bisections, c) refined grid before and after spring relaxation, d) detail view of (c) showing improvement for critical (big) angles

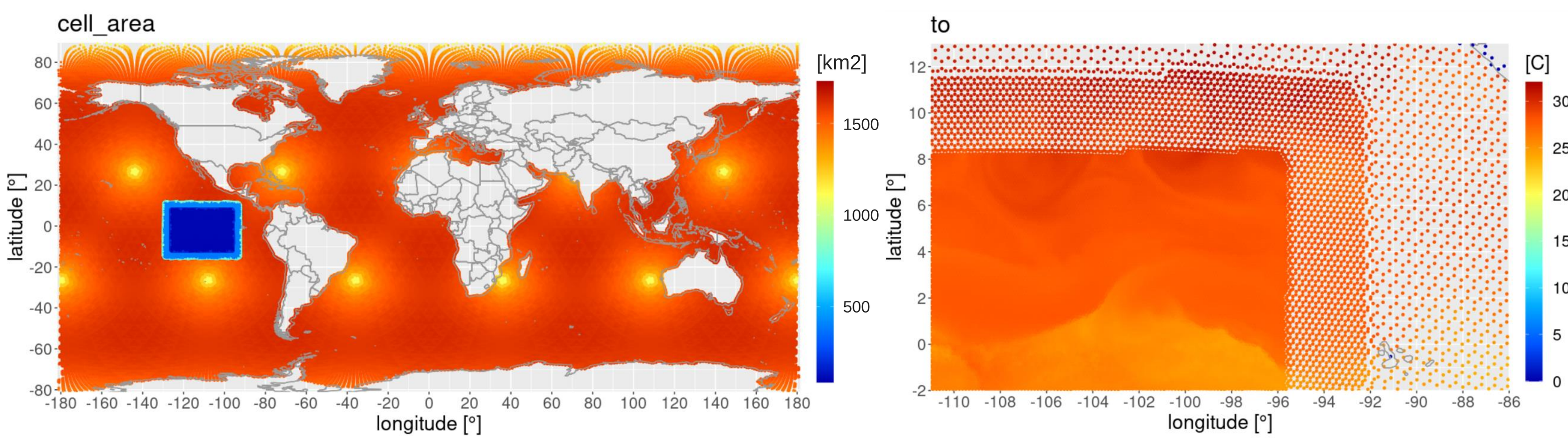


Figure 2: (left) grid cell area as countour plot, (right) an example variable (temperature) over different resolution levels

For analyzed region of eastern Pacific, we used two refinement levels, going from the original global R2B6 resolution (40km) over R2B7 (20km) to R2B8 (10km) in the core of region of interest. It is important to note that no special treatment is applied to the transition zone between the resolutions.

Test region was chosen based on strong surface convective activity in the region, which should help detect any anomalies that appear due to sudden grid resolution change. Also, leaving the shores out of the equation enables us to focus on the grid-induced effects. However, we plan to test more complex configurations once the issues presented here have been solved.

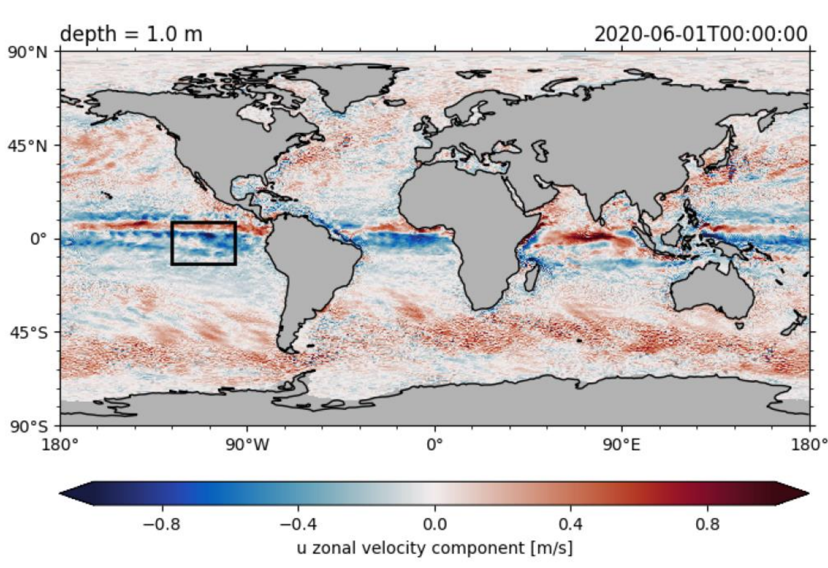


Figure 3: u-velocity plot and region of interest

III. Experiments

The ocean model was run alone, for ten simulated days, using ERA5 hourly forcing, as a replacement for the atmospheric influence, with a 5 minute timestep. These short range results seem to show good agreement with our other regional model, the ICON-O-LAM, and both agree well with the reference case. Here we show only one against the other. There are only slight differences when looking at velocity based quantities even though they are the most sensitive ones.

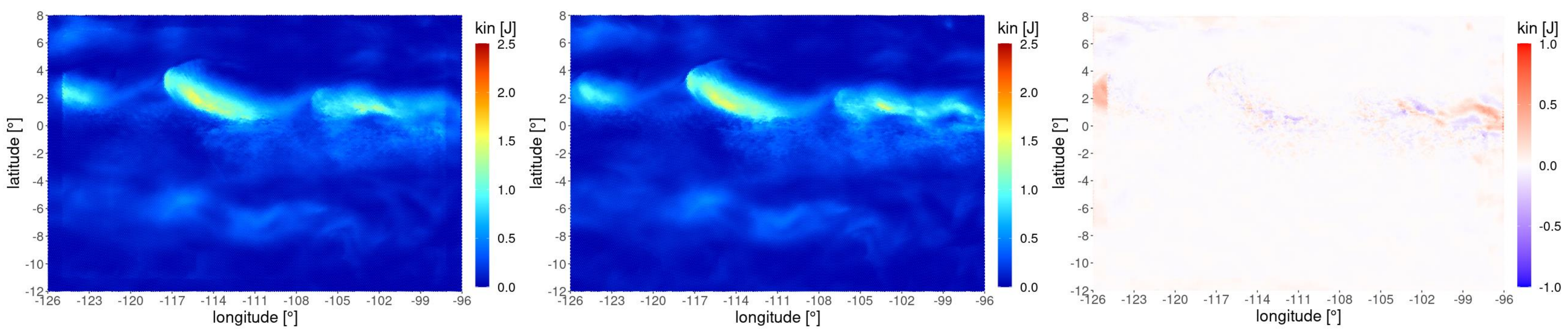


Figure 4: surface turbulent kinetic energy, (left) LAM, (middle) current model, (right) difference

Another run was made under the same conditions, that run for seven simulated months. The simulation took around 1300 core hours. Due to the longer period, the results are not supposed to stay convergent with the reference case, but the flow structures can still be compared against each.

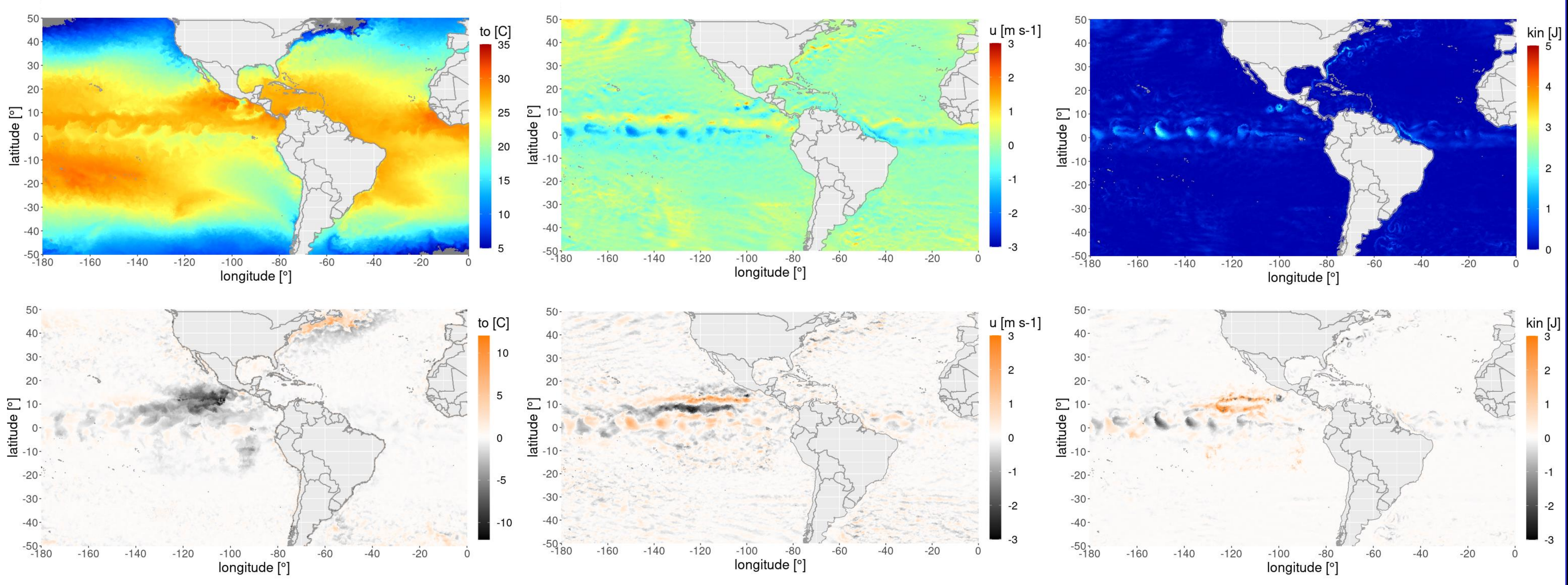
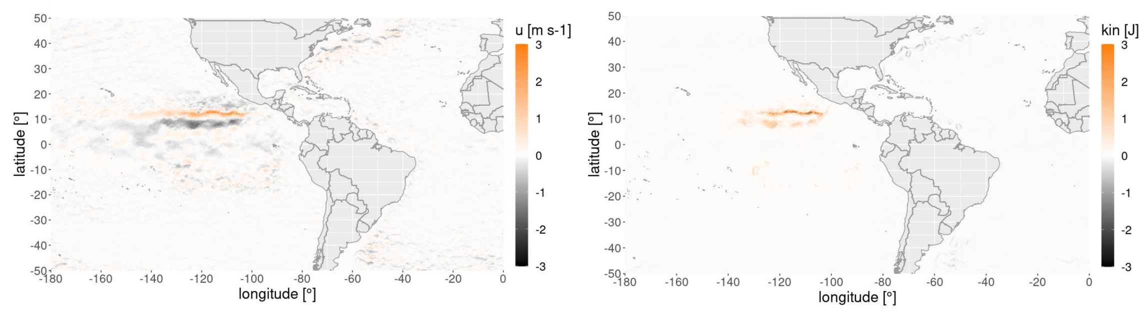


Figure 5: top row shows results for reference global R2B6 case; bottom row shows differences of the approach with local grid refinement, relative to the reference case; all quantities are for 1m depth (first vertical layer); (left) temperature, (middle) u-velocity component, (right) turbulent kinetic energy

Figure 6: like fig. 5, but at 400m (32nd vertical level); showing only the differences between the grid refinement approach and reference case for (left) turbulent kinetic energy and (right) u-velocity



IV. Results

Numerical artefacts develop around the high-resolution region which is best seen for velocity-based quantities. The effects are also strongly reflected in scalar fields as well and this trend also holds for other depths.

ICON-O has been extensively tested for other ocean grids with non-uniform resolutions, so the model is not the source of these artefacts. Therefore, we conclude the sudden grid resolution change is the main culprit. First possible remedy is to use broader zones for intermediate resolutions (R2B7 region in this case), but a more long-term solution, and also more complex to implement, is to test out different refinement strategies[4] that allow for a more gradual resolution change.

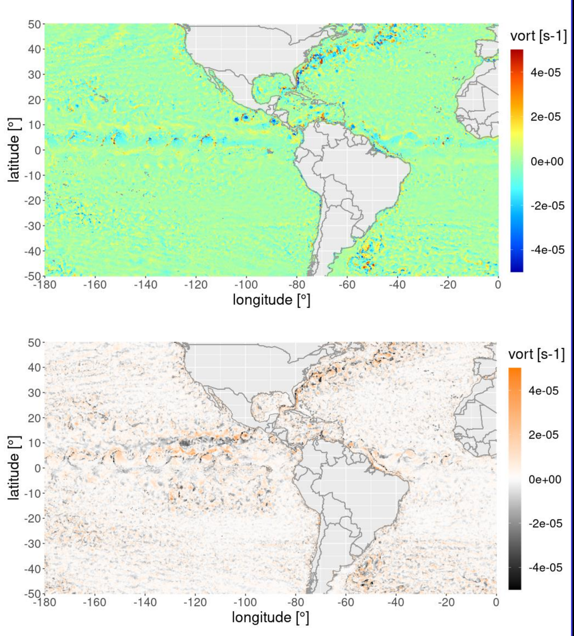


Figure 7: same as figure 5, but showing vorticity

1) P. Korn, 2017, Journal of Computational Physics, http://doi.org/10.1016/j.jcp.2017.03.009
2) G. Zängl, D. Reinert et al., 2014, Quarterly Journal of the Royal Meteorological Society, https://doi.org/10.1002/qj.2378
3) K. Logemann, L. Linardakis et al., 2020, Ocean Dynamics, https://doi.org/10.1007/s10236-020-01428-7
4) R. L. Walko, R. Avissar, 2011, Monthly Weather Review, https://doi.org/10.1175/MWR-D-11-00021.1

Many thanks to all who helped create this poster and work behind it, including Nora Schenk, for proofreading, tips and some of the plotting.

Contact: alija.bevrnja@dwd.de

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