



Regionalization of ICON-o

Alija Bevrnja



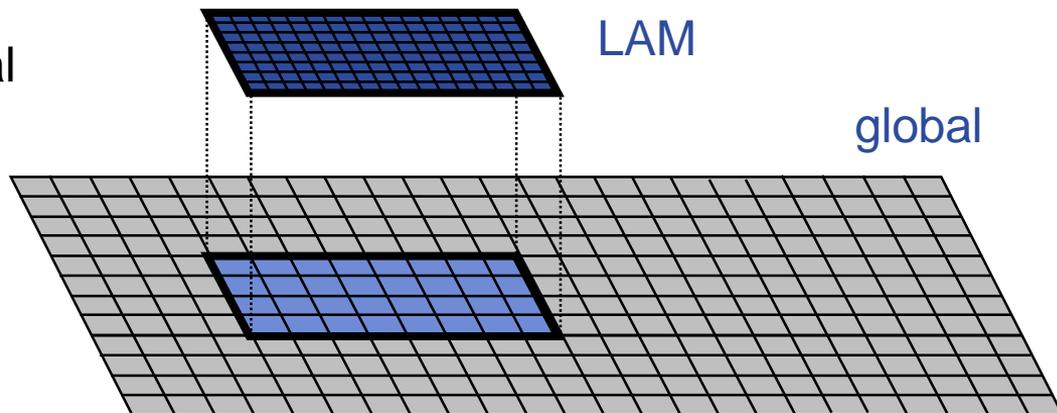


Outline

- Motivation
- ICON-O-LAM short intro
- Implementation status
- Results and performance
- Further ideas

ICON-O-LAM

- ICON-O Limited Area Mode
- Higher local resolution
- Based on LAM for ICON-A
- Does not couple back to global
 - no nesting
 - instead ICON-O-ZOOM
- global results prescribed to LAM as initial and boundary conditions





ICON-O-LAM

Global simulation



Data output



Initial data interpolation

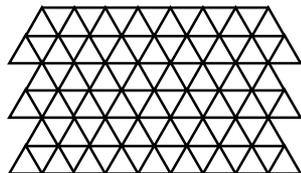


External data

+

const

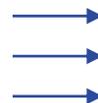
||



LAM grid



Boundary data interpolation

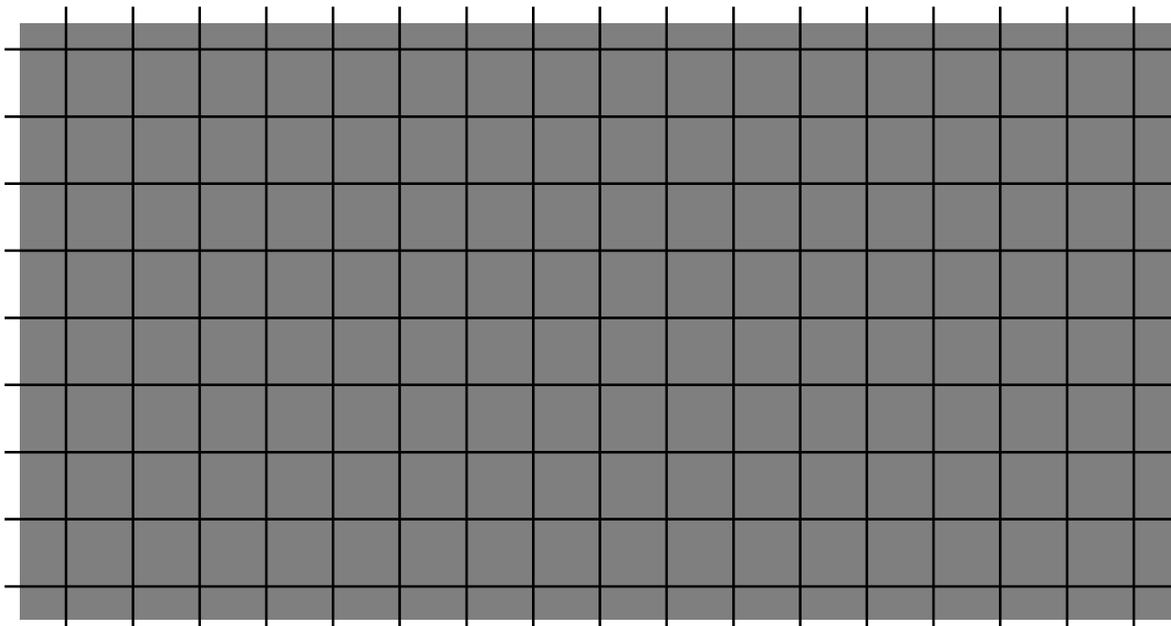


Local simulation



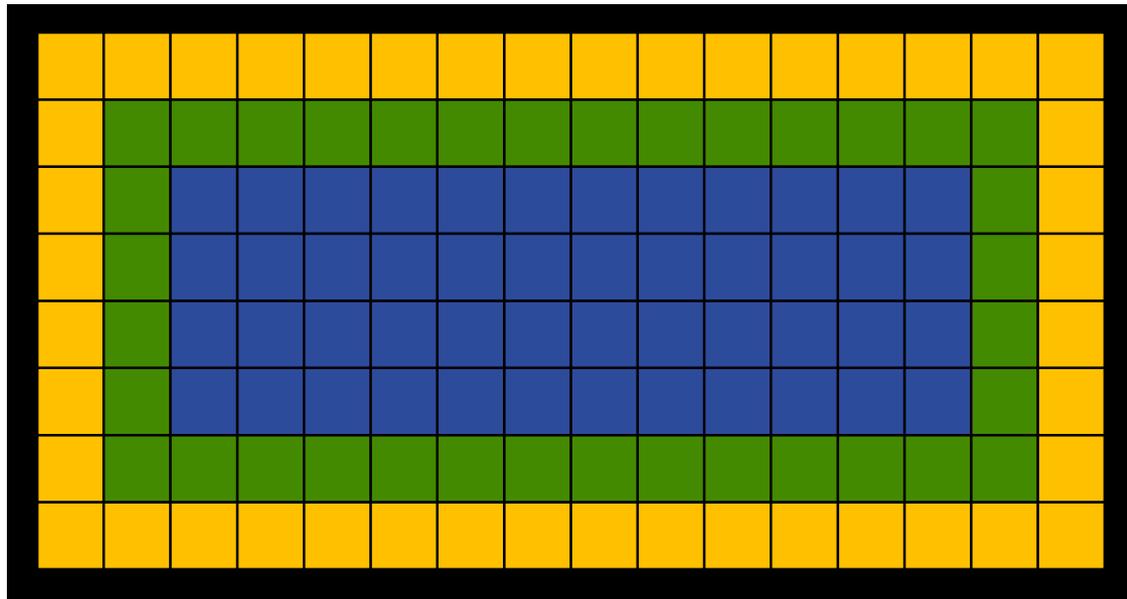
Implementation status (grid)

→ Create LAM by cutting global grid (by Leonidas Linardakis of MPI-M)



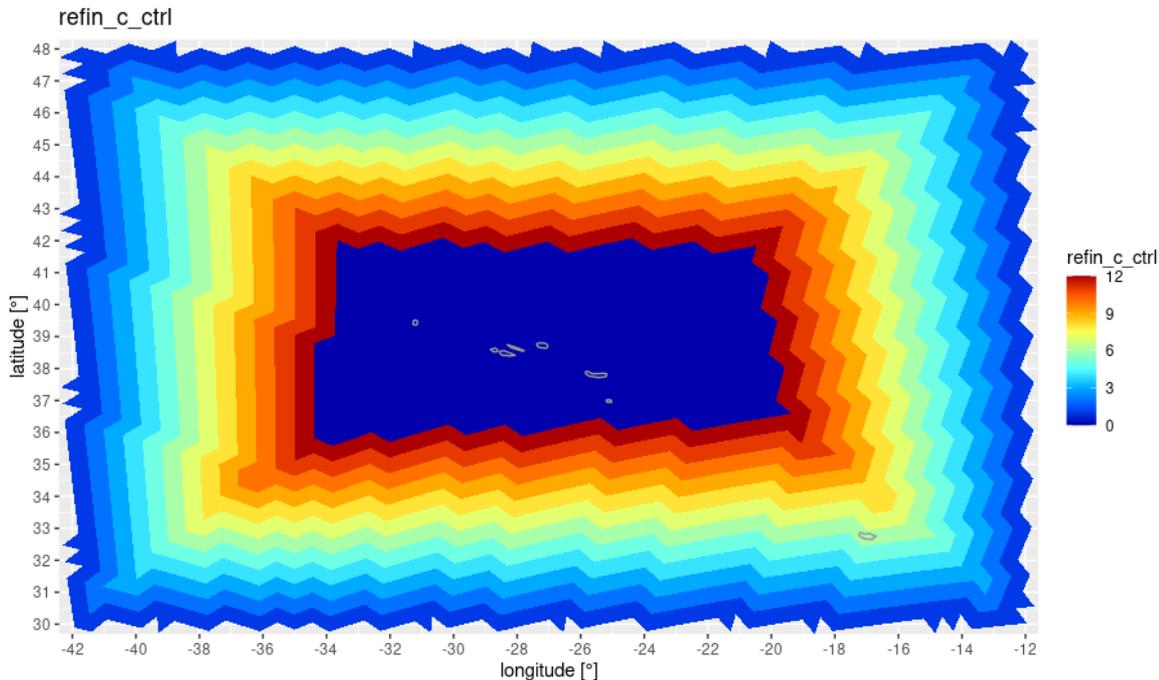
Implementation status (grid)

- Create LAM by cutting global grid (by Leonidas Linardakis of MPI-M)
- Dummy cell closure (also by Linardakis)
 - Outer cells see **fake land**
- Zones:
 - **Boundary interpolation**
 - **Nudging**
 - **Prognostic**



Implementation status (grid)

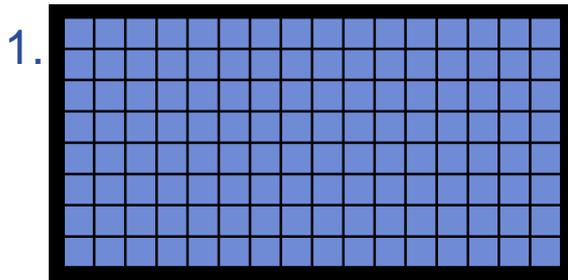
- Region definitions
 - Based on distance from the boundary
 - 1 to 4: Boundary interpolation zone
 - 5 to 8: Nudging zone
- Zones can be wider (if needed)
- Similar for the edges



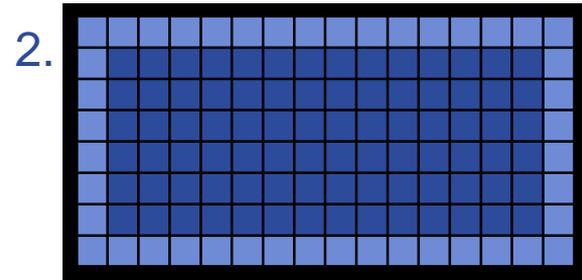
Implementation status (BC)

→ Assigning the lateral BC to the grid cells

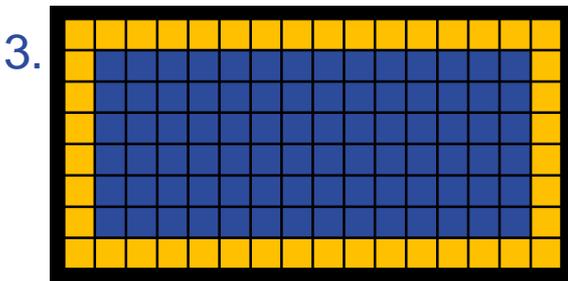
1. Load initial conditions



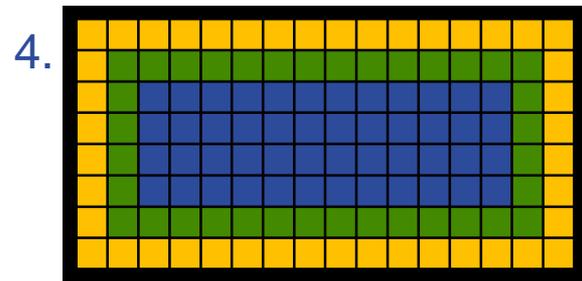
2. Perform prognostic calculations inside for variable x



3. Update boundary for x



4. Apply nudging for x



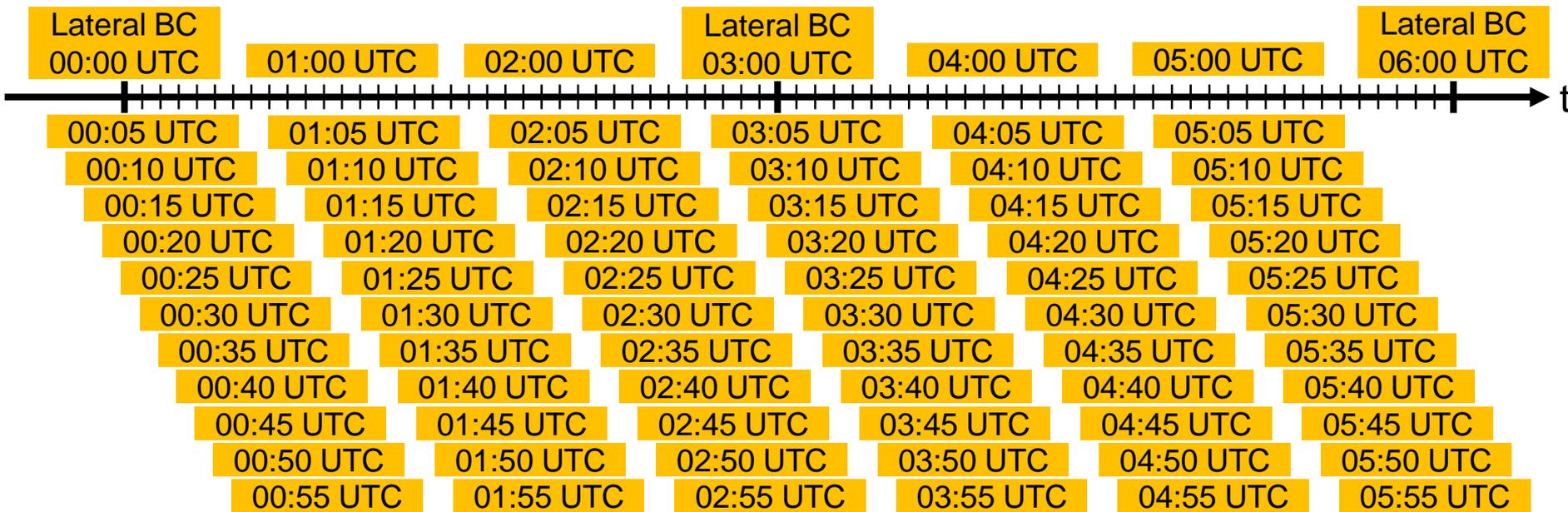
5. Repeat from 2 for the next variable



Implementation status (time interp.)

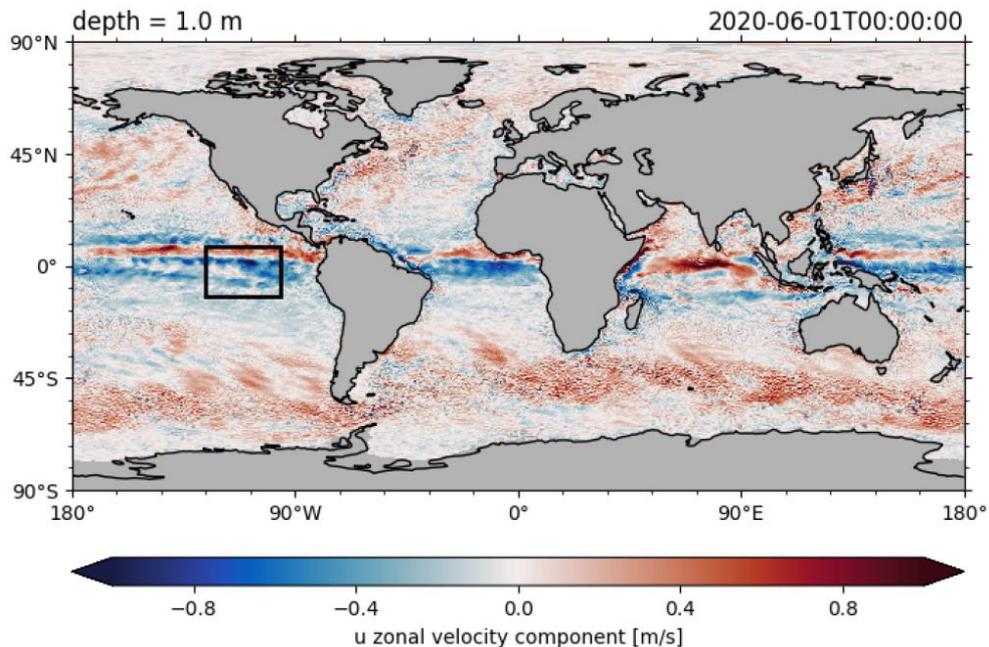
➔ Temporal lateral boundary data interpolation

- Lateral BC period
- Simulation timestep



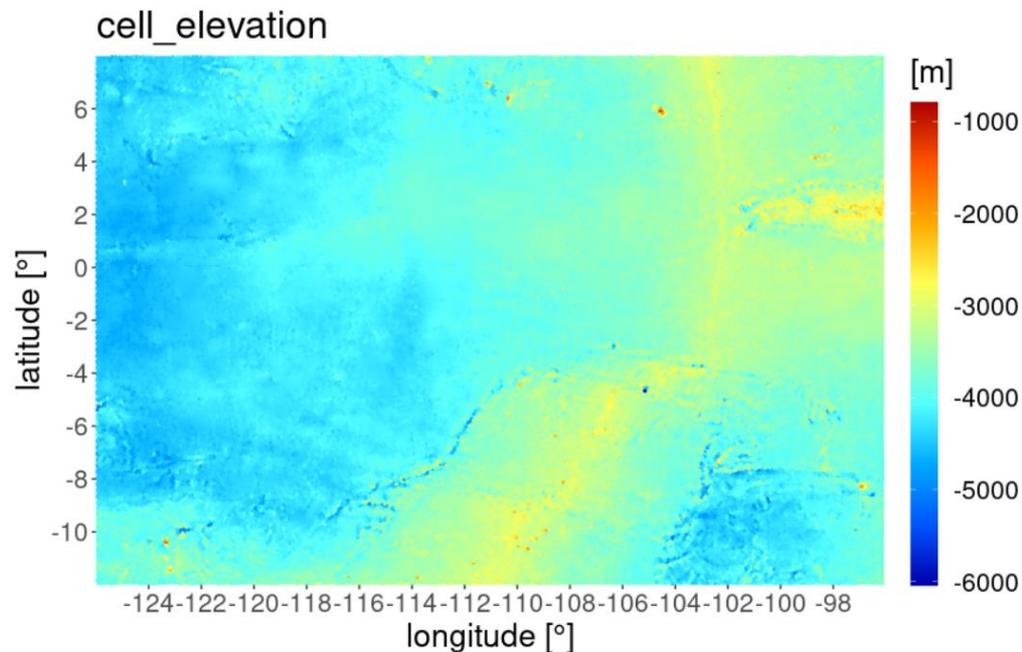


Results (region selection)





Results (region selection)





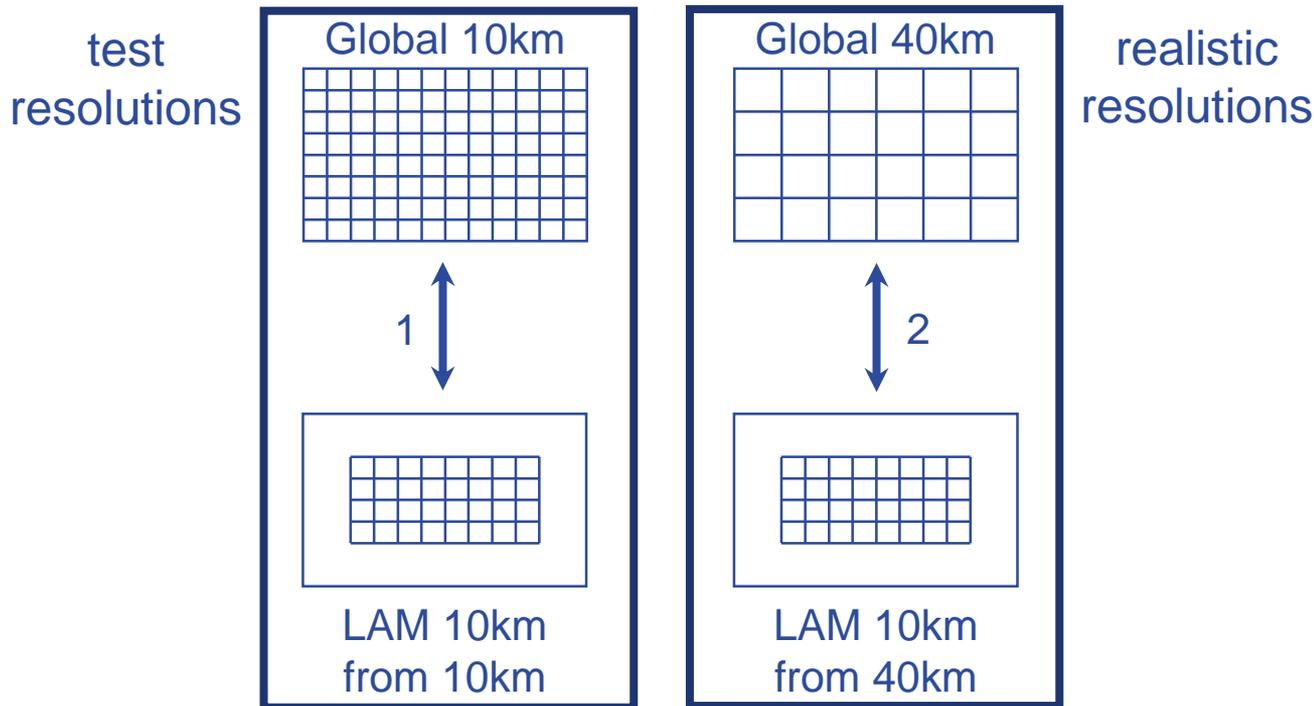
Results (setup)

- global 10km, global 40km, then LAMs on 10km
- hourly forcing data, for each grid
- 72 vertical levels
- 5 months spin-up on global → interpolate to LAM → run 10 days
- 5 min timestep, 3-hourly output
- more details: conjugate gradient solver, biharmonic viscosity for horizontal diffusion of velocity, TKE for vertical mixing scheme





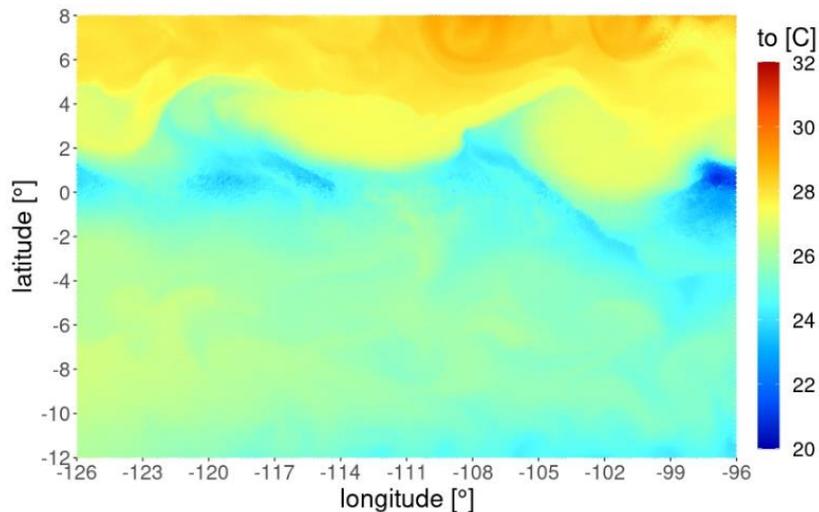
Results (experiments overview)



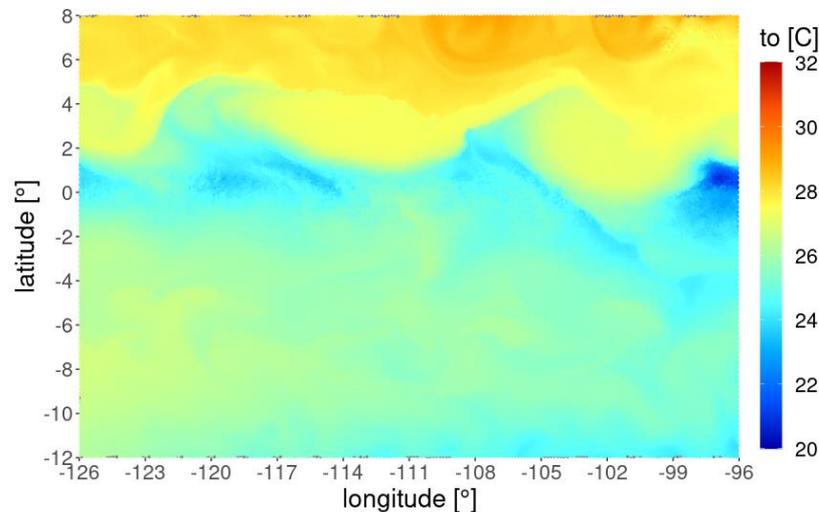
Results (comparison, 10km global, 10km LAM case)

→ surface temperature after 10 days

global results



LAM results

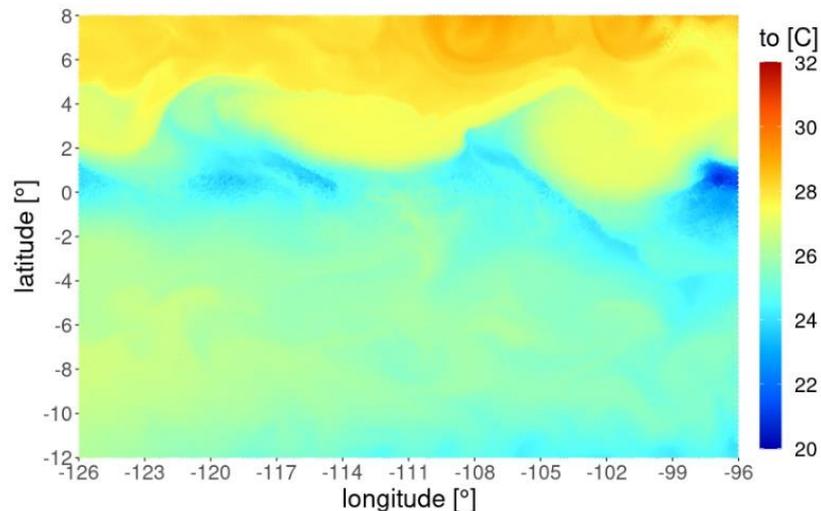




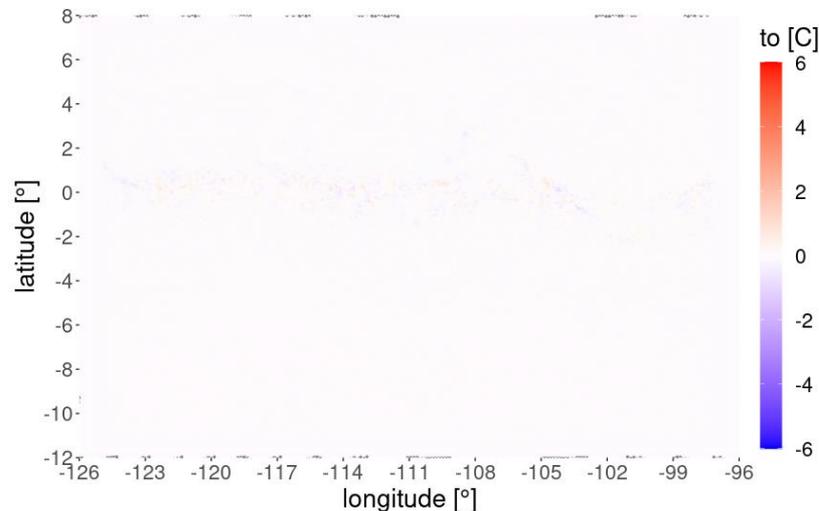
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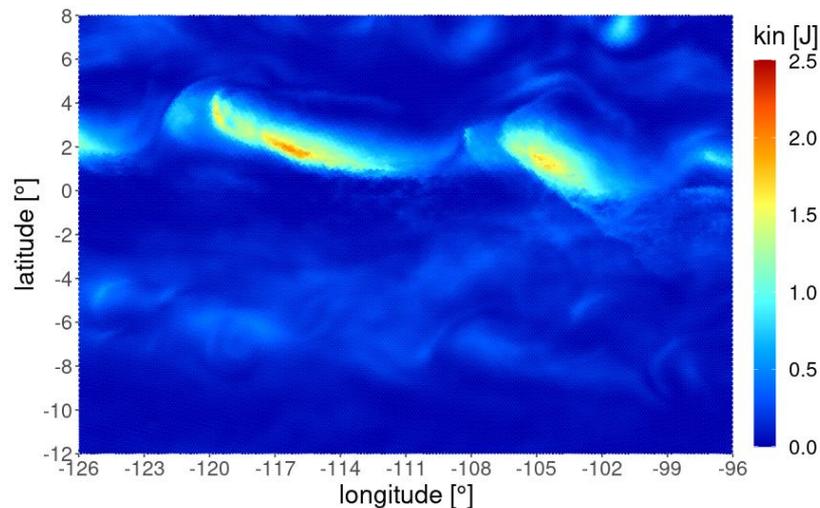
LAM difference



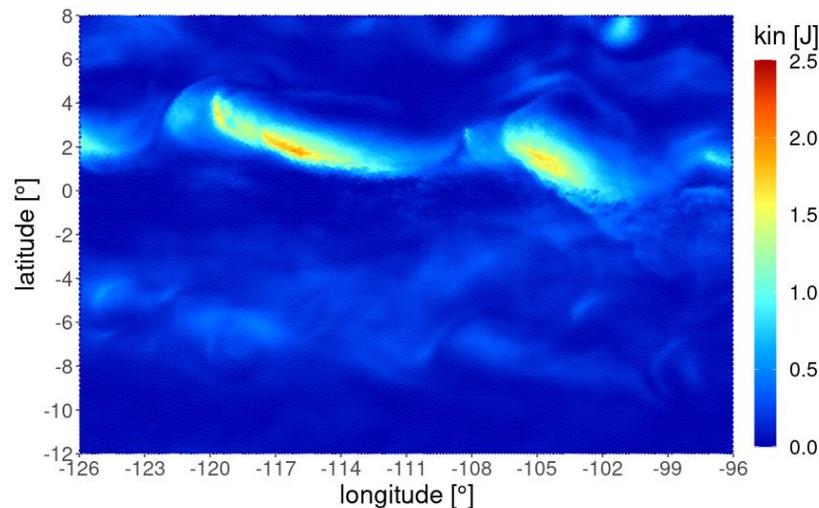
Results (comparison, 10km global, 10km LAM case)

→ surface turbulent kinetic energy after 10 days

global results



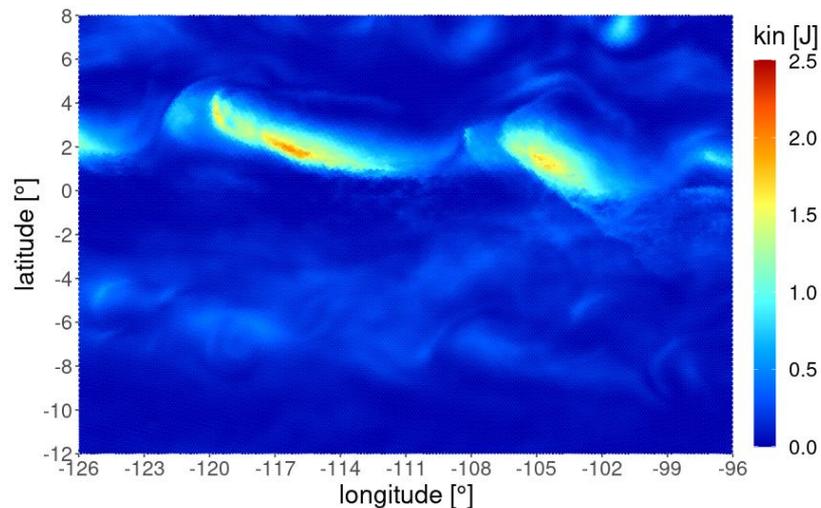
LAM results



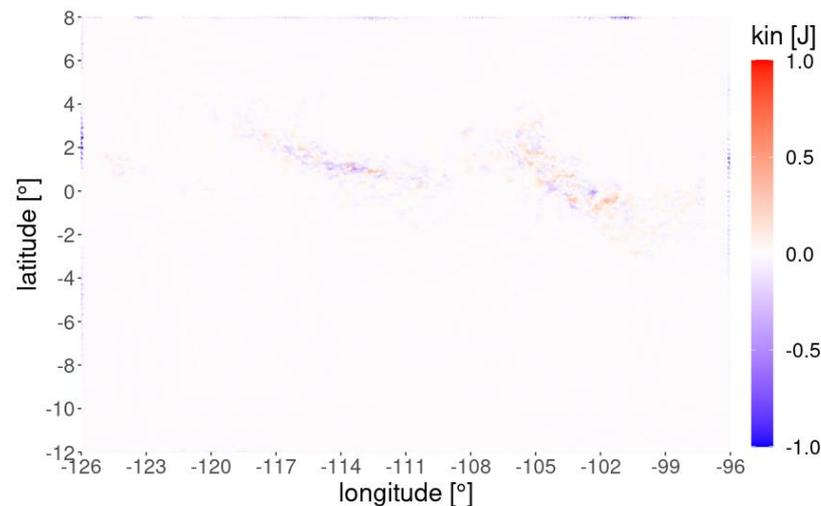
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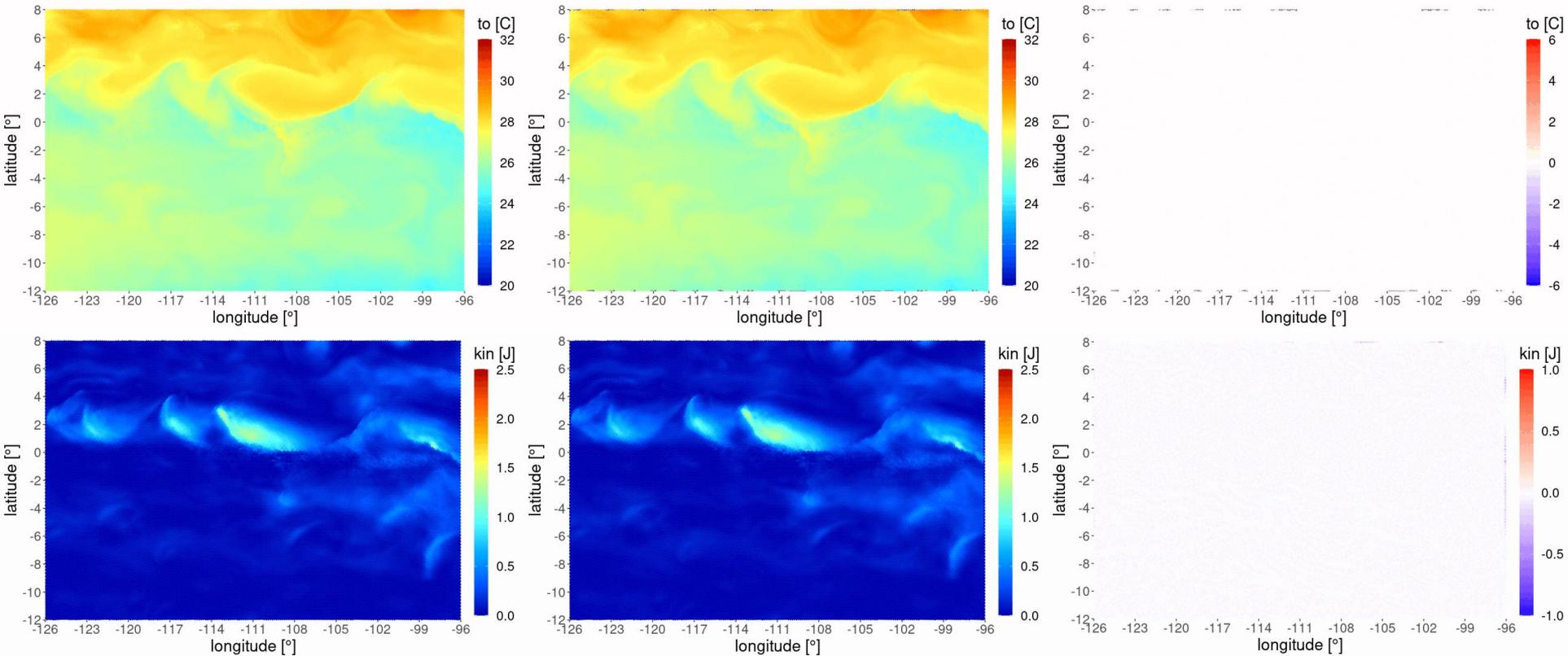


LAM difference





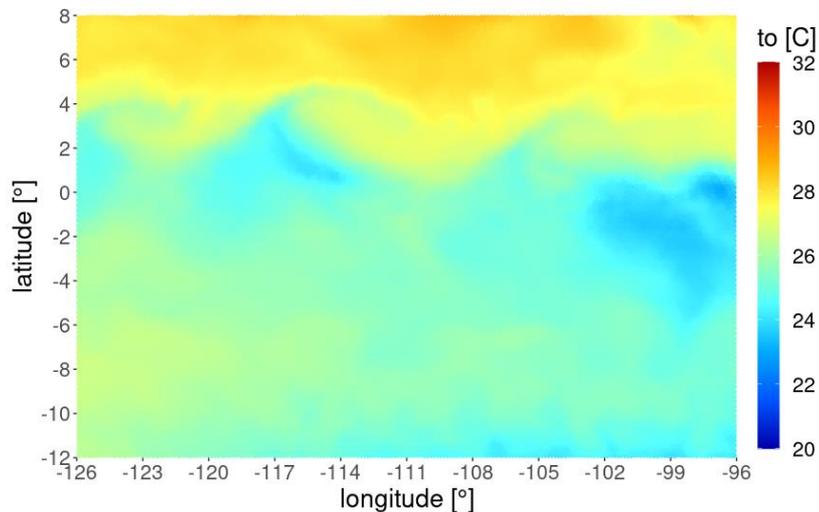
Results (comparison, 10km global, 10km LAM case)



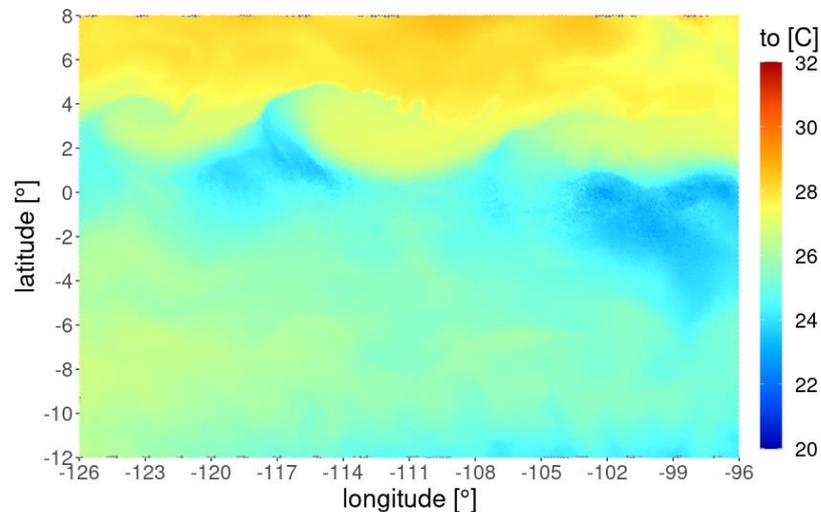
Results (comparison, 40km global, 10km LAM case)

→ surface temperature after 10 days

global results



LAM results

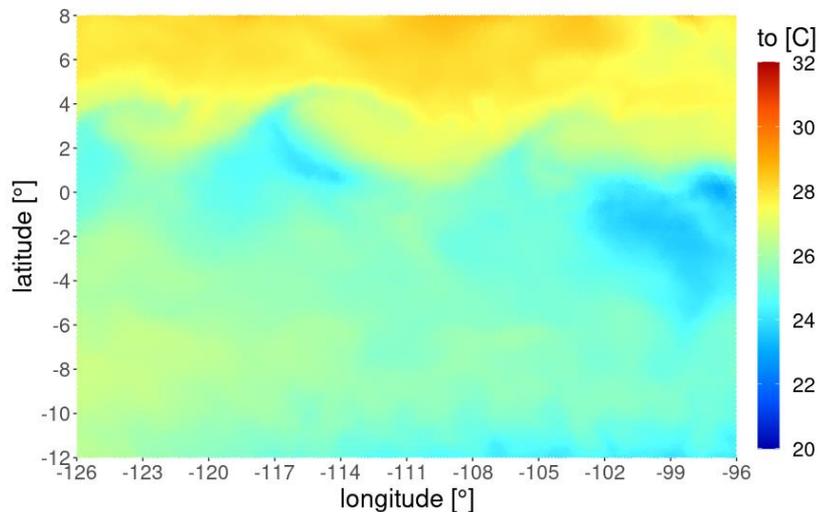




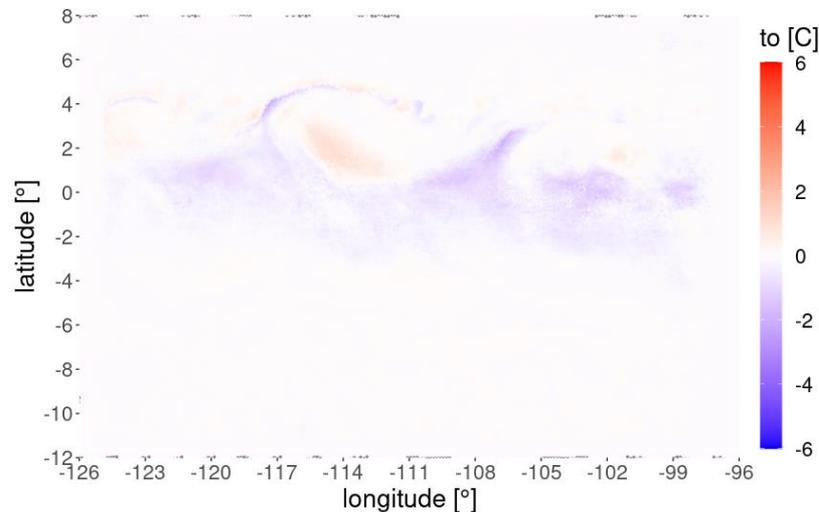
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→ surface temperature after 10 days

global results

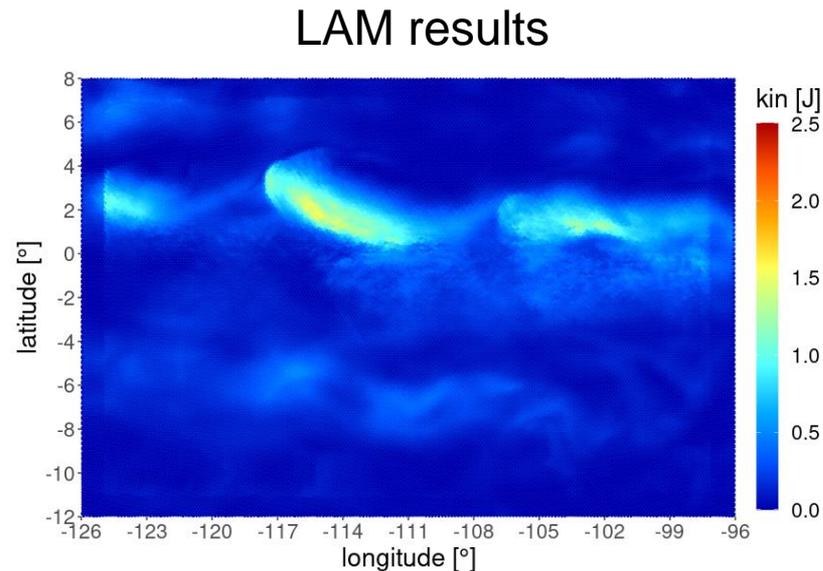
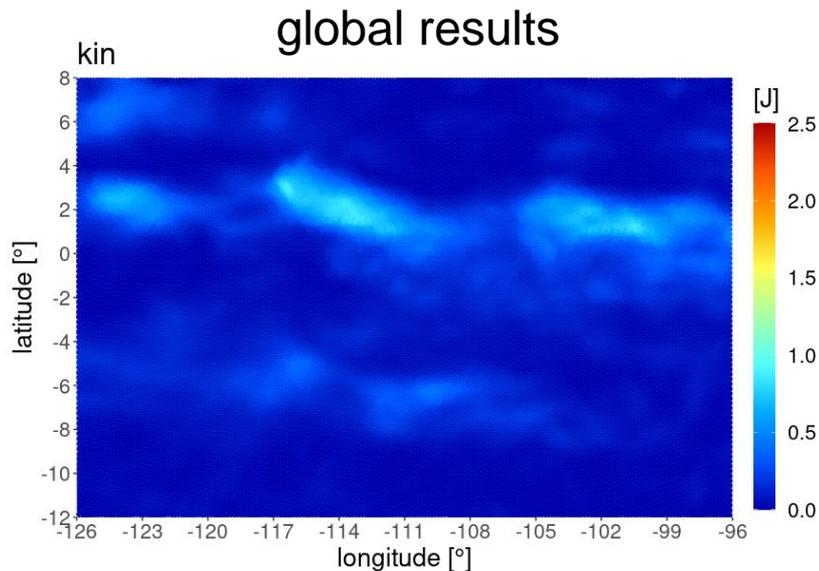


LAM difference



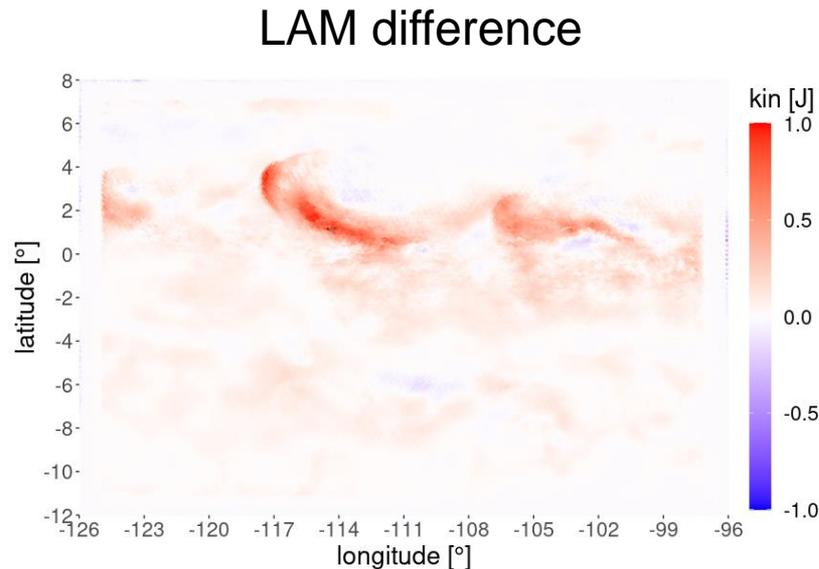
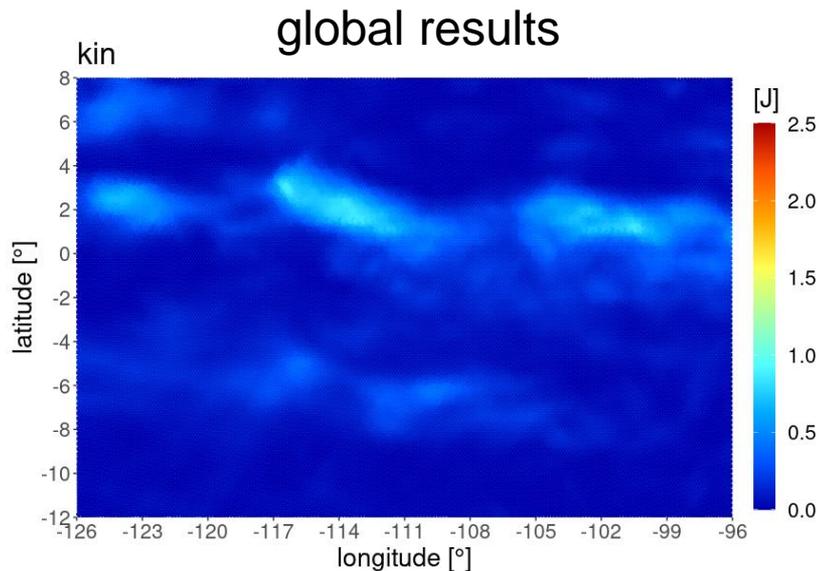
Results (comparison, 40km global, 10km LAM case)

→ surface turbulent kinetic energy after 10 days



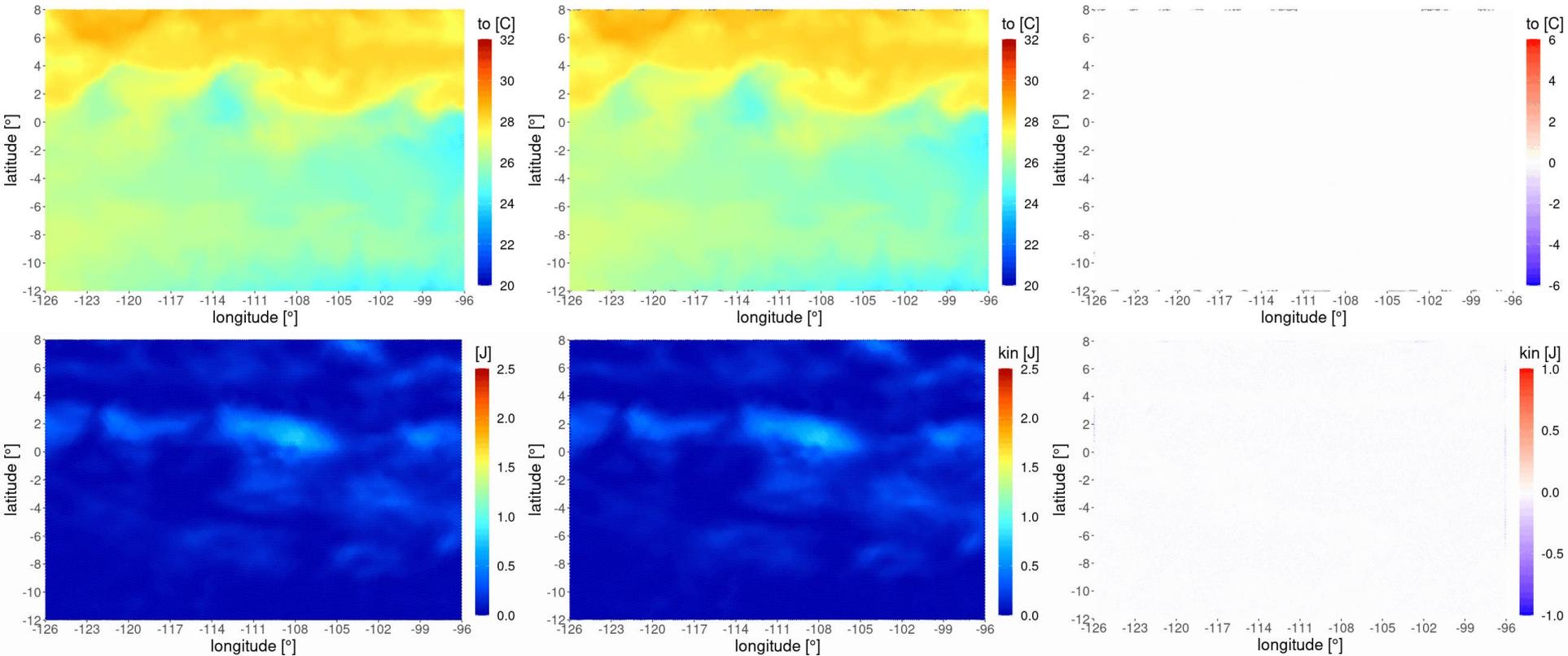
Results (comparison, 40km global, 10km LAM case)

→ surface turbulent kinetic energy after 10 days





Results (comparison, 40km global, 10km LAM case)





Results (some conclusions)

- LAM on same resolution almost identical to global – implementation working
- LAM on higher resolution resolves much finer structure – as expected
- LAM needs little time to start developing finer structures – good potential
- 40km initial state is visibly not fully developed (from 10km perspective)
- can we improve upon 40km based initial and boundary data (DA?)



Results (performance)

→ Experiment size

Experiment	Global 10km	Global 40km	LAM 10km
Number of cells	3,73 M	235 k	76 k
Number of edges	5,61 M	357 k	114 k
Number of vertices	1,88 M	121 k	38 k

→ Storage for 3-hourly data

Experiment	Global 10km	Global 40km	LAM 10km
Single file (MB)	9216	581	166
One day (GB)	72	5,67	1,62
10 days (GB)	720	56,7	16,2
30 days (GB)	2160	170,1	48,6



Results (performance)

→ Simulation speed

Experiment	Global 10km	Global 40km	LAM 10km
Used nodes	40	16	6
Used VEs	320	128	48
Single timestep	2,5 sec	1,3 sec	0,4 sec
Single day	12 min	6 min 12 sec	2 min
10 days	120 min	62 min	20 min
30 days	6 h	3 h 6 min	1 h

→ Simulation speed normalized to 100 VEs

Single timestep	8 sec	1,7 sec	0,2 sec
Single day	38 min 24 sec	7 min 56 sec	58 sec



Special thanks

→ Contributors

- Günther Zängl
- Roland Potthast
- Helmuth Haak
- Leonidas Linardakis
- Peter Korn
- Nora Schenk

→ Institutional involvement

- DWD
- MPI-M
- GeoInfo BW



Outlook (summary)

- Merge the changes into masters
- Increase complexity of test cases
- Implement asynchronous lateral boundary read
- Implement sparse lateral boundary conditions
- Couple ICON-O-LAM with atmospheric LAM
- Implement variational DA into ICON-O-LAM in the next year



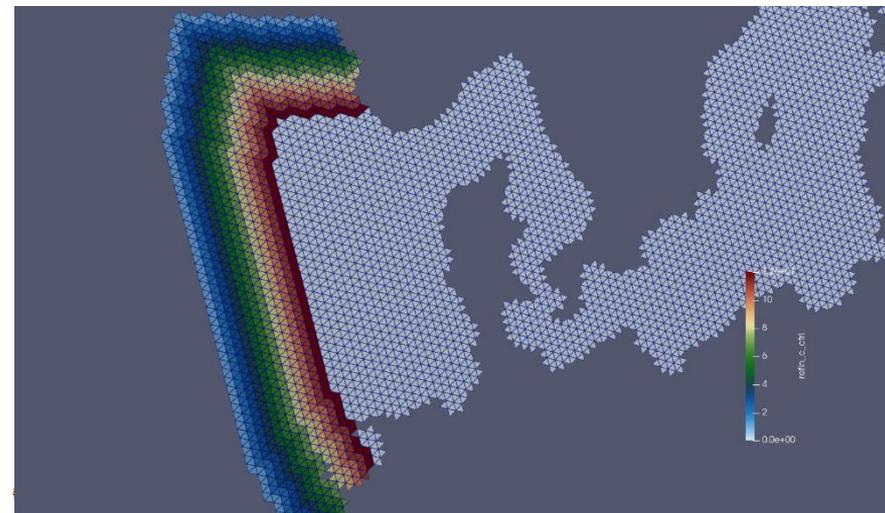
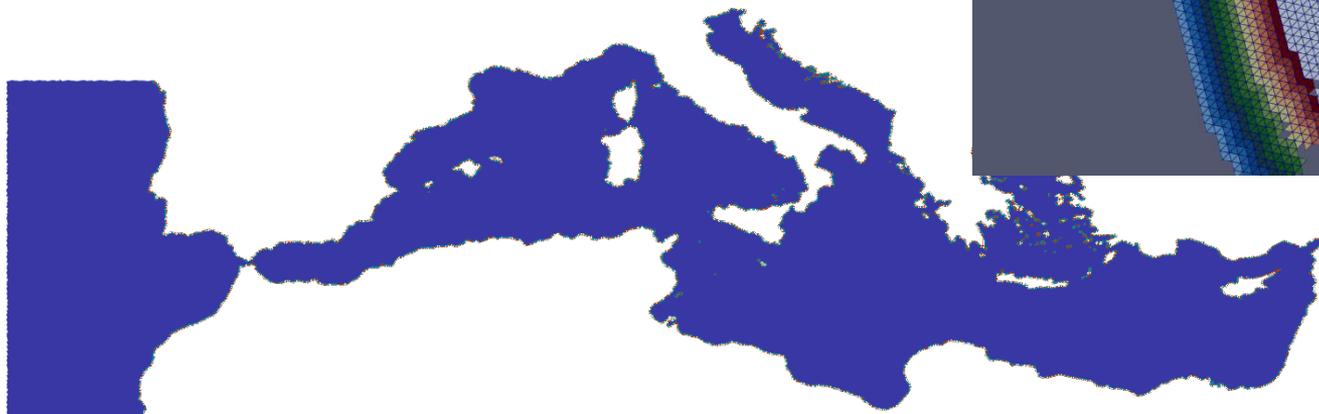
Questions – comments – remarks





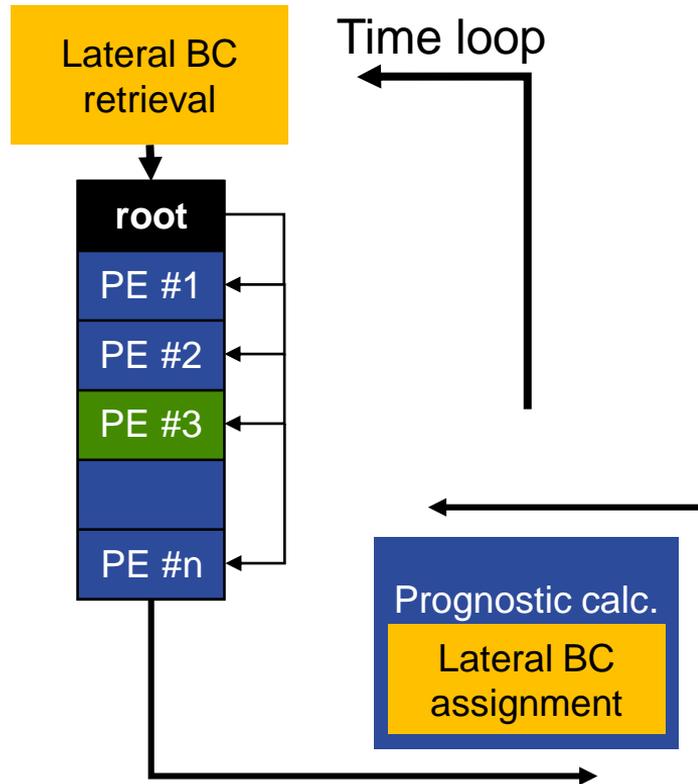
Outlook (complexity)

→ More complex cases



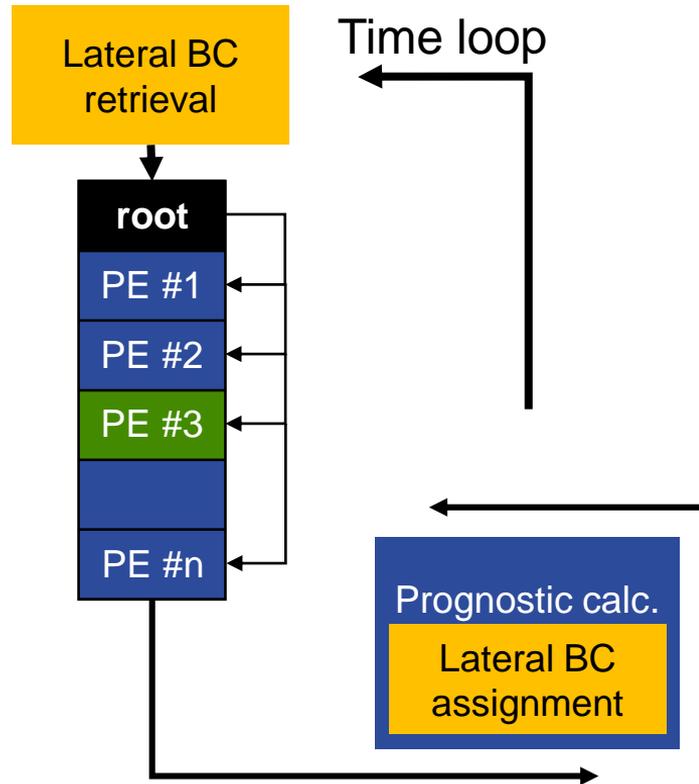
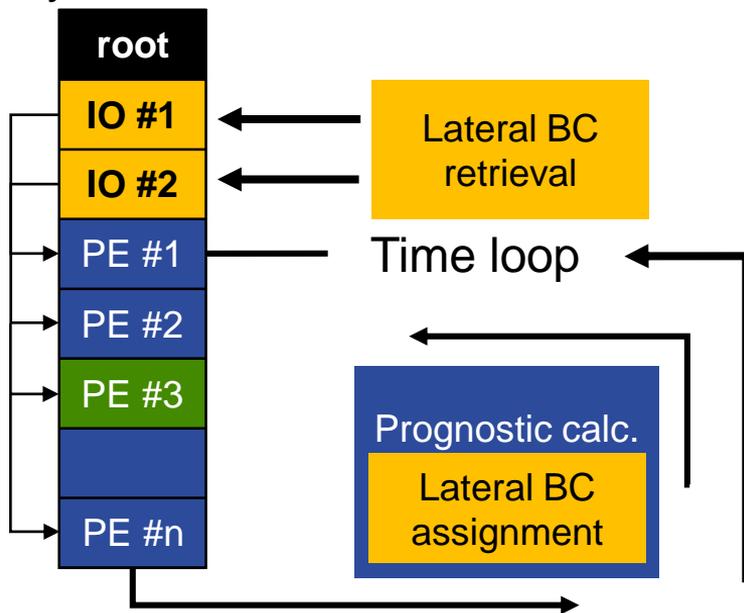
Outlook (async IO)

→ Current synchronous IO read for LAM



Outlook (async IO)

→ Asynchronous IO read for LAM

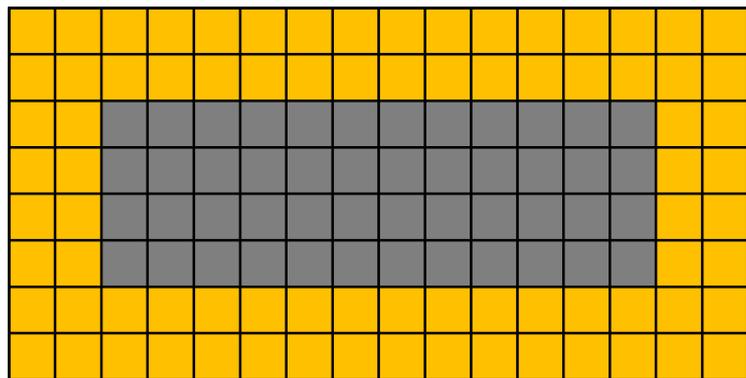




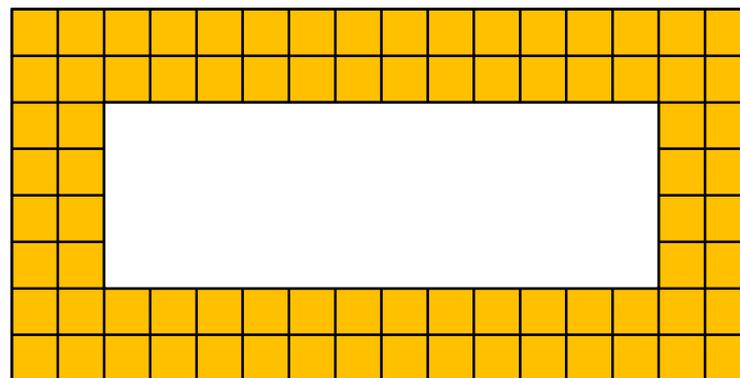
Outlook (sparse lateral BC)

→ Sparse lateral boundary data

replace

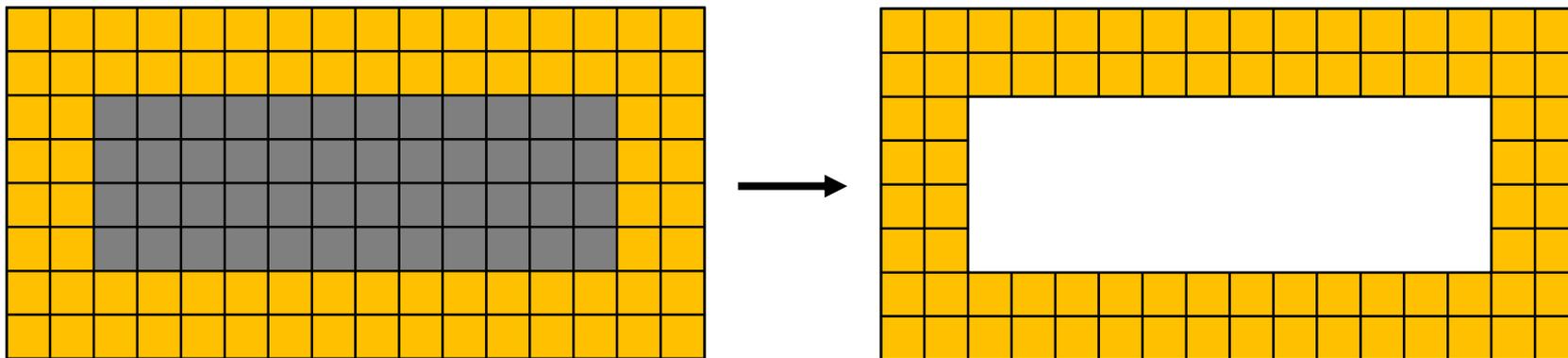


with



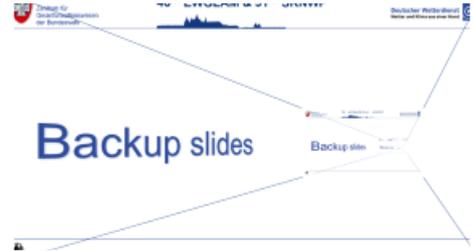
Outlook (sparse lateral BC)

- Sparse lateral boundary data
- This requires cell remapping each time new data is read, but
 - Computations are faster than IO
 - Heaviest remapping part can be precomputed



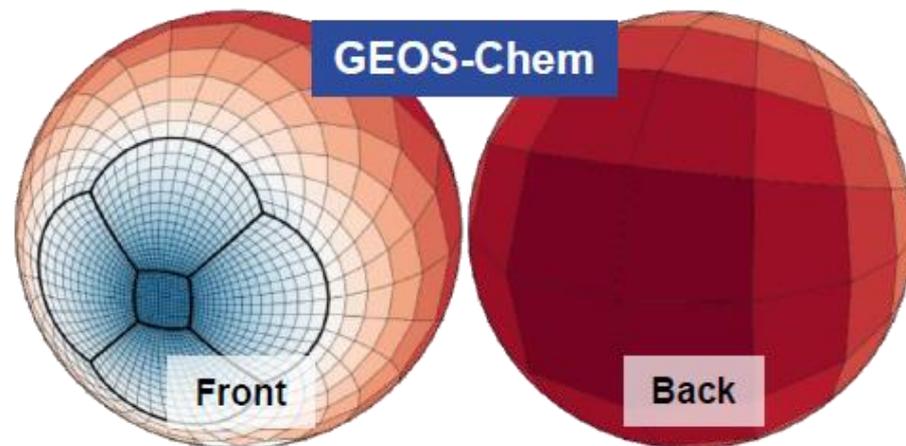


Backup slides



Grid refinement

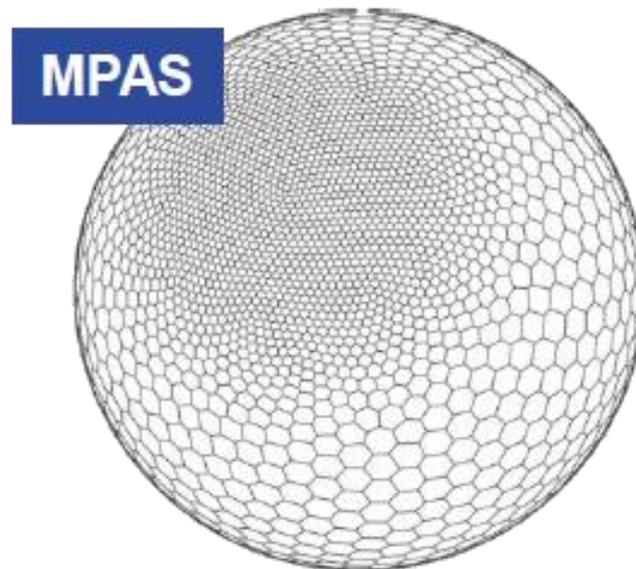
- Different options
- Telescoping (stretching)
 - Same topology and problem size
 - Good aspect ratios
 - Bad resolution elsewhere



Bindle et al., 2018

Grid refinement

- Different options
- Irregular (arbitrary)
 - High meshing flexibility
 - Good aspect ratios
 - Difficulties with multigrid
 - Complex topology

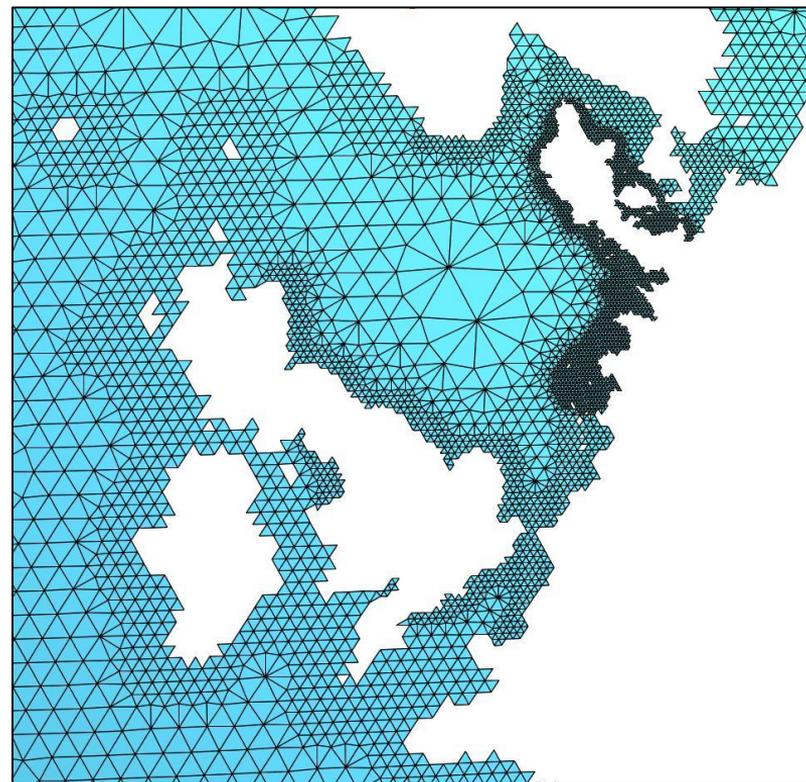


Ullrich et al., 2018



Grid refinement

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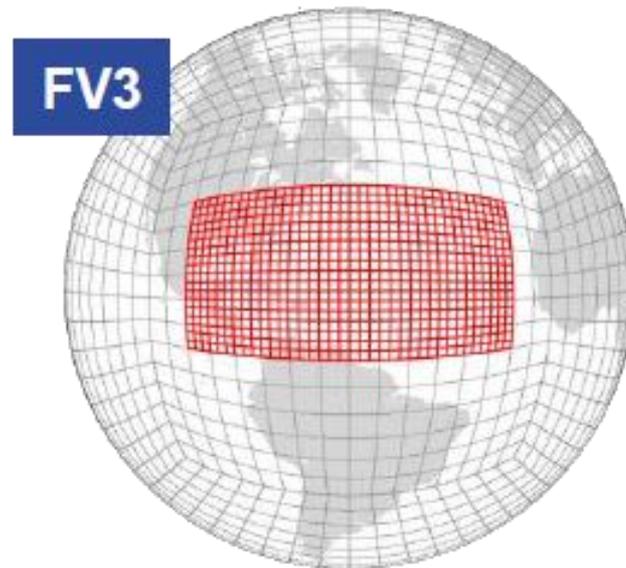


Logemann



Grid refinement

- Different options
- Stepwise refinement
 - Easy multigrid
 - Good topology
 - Fine aspect ratios
 - Fine meshing flexibility

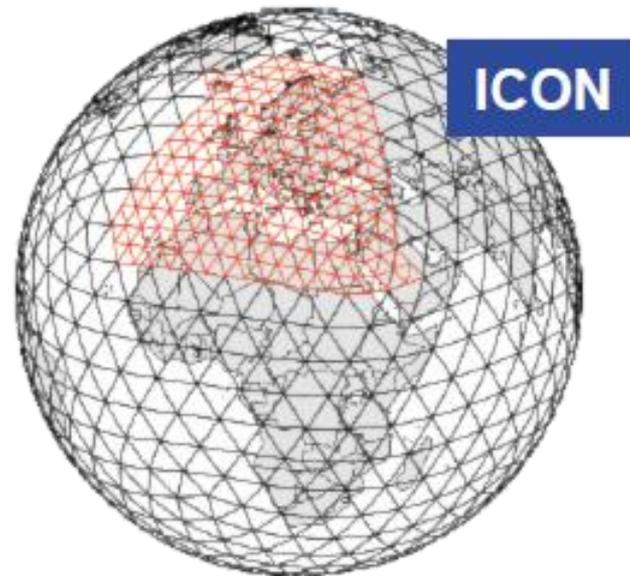


Gao et al., 2018



Grid refinement

- Different options
- Stepwise refinement
 - Easy multigrid
 - Good topology
 - Fine aspect ratios
 - Fine meshing flexibility





Ocean equations

- Horizontal velocity:
$$\frac{\partial v_n}{\partial t} + \frac{\partial K_h}{\partial t} + (\zeta + f)v_t + w \frac{\partial v_n}{\partial z} = -c_{pd}\theta_v \frac{\partial \pi}{\partial n} + F(v_n)$$
- Vertical velocity:
$$\frac{\partial w}{\partial t} + \mathbf{v}_h \cdot \nabla w + w \frac{\partial w}{\partial z} = -c_{pd}\theta_v \frac{\partial \pi}{\partial z} - g$$
- Mass:
$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\mathbf{v} \rho) = 0$$
- Energy:
$$\frac{\partial p\theta_v}{\partial t} + \nabla \cdot (\mathbf{v} \rho\theta_v) = \tilde{Q}$$



Sea surface height

→ The differential equation for sea surface height:

$$\frac{\partial \eta}{\partial t} + \text{div}_h \int_{-B}^{\eta} v \, dz = 0$$

→ Once expanded:

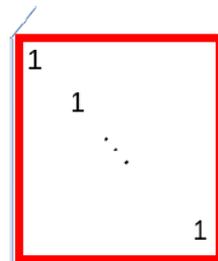
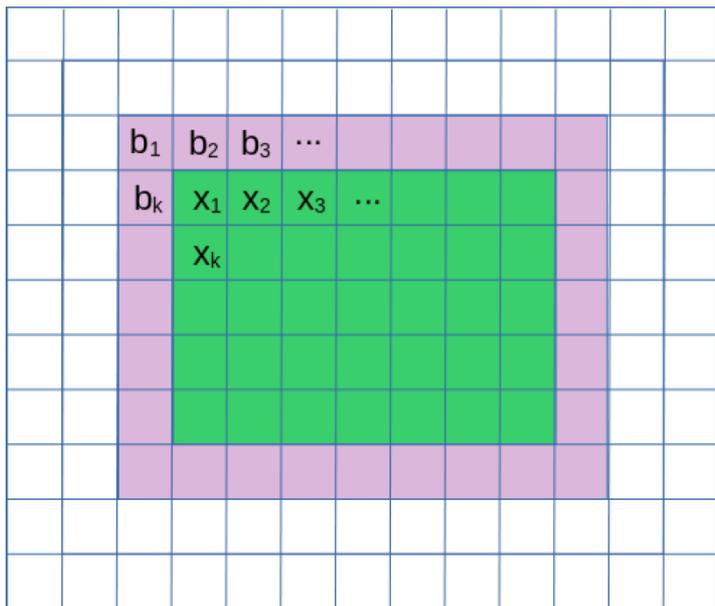
$$\eta_K^{n+1} - \Delta^2 g \beta \gamma \mathbf{div}[\mathcal{M}_G[(\eta^n + B), \nabla \eta^{n+1}]]_K = \eta_K^n - \Delta t \sum_{k=1}^{k_{bot}} \mathbf{div}[\mathcal{M}_G[\Delta z_k, (\gamma v_k^{**} + \gamma' v_k^n)]]$$



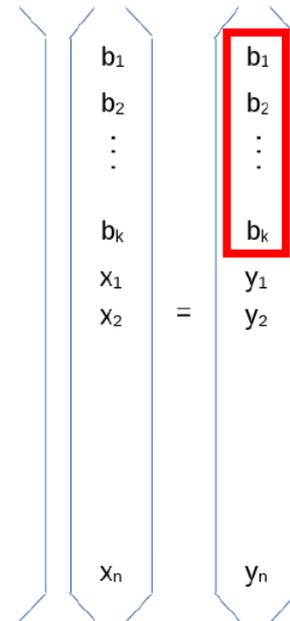


ICON-O-LAM SSH matrix

Linardakis, MPI-M



A



Interpolation operators

Zängl et al., 2022

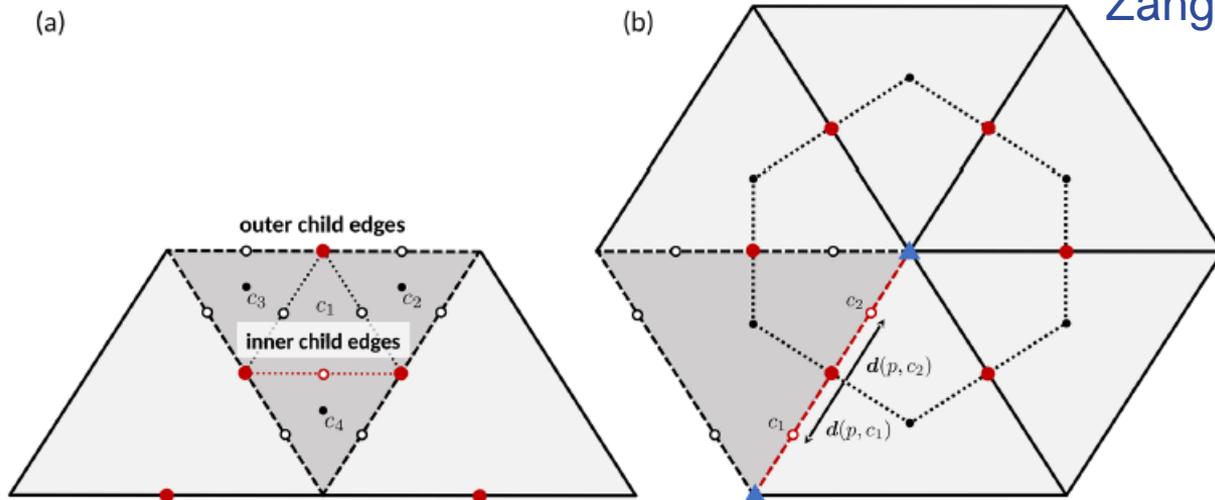
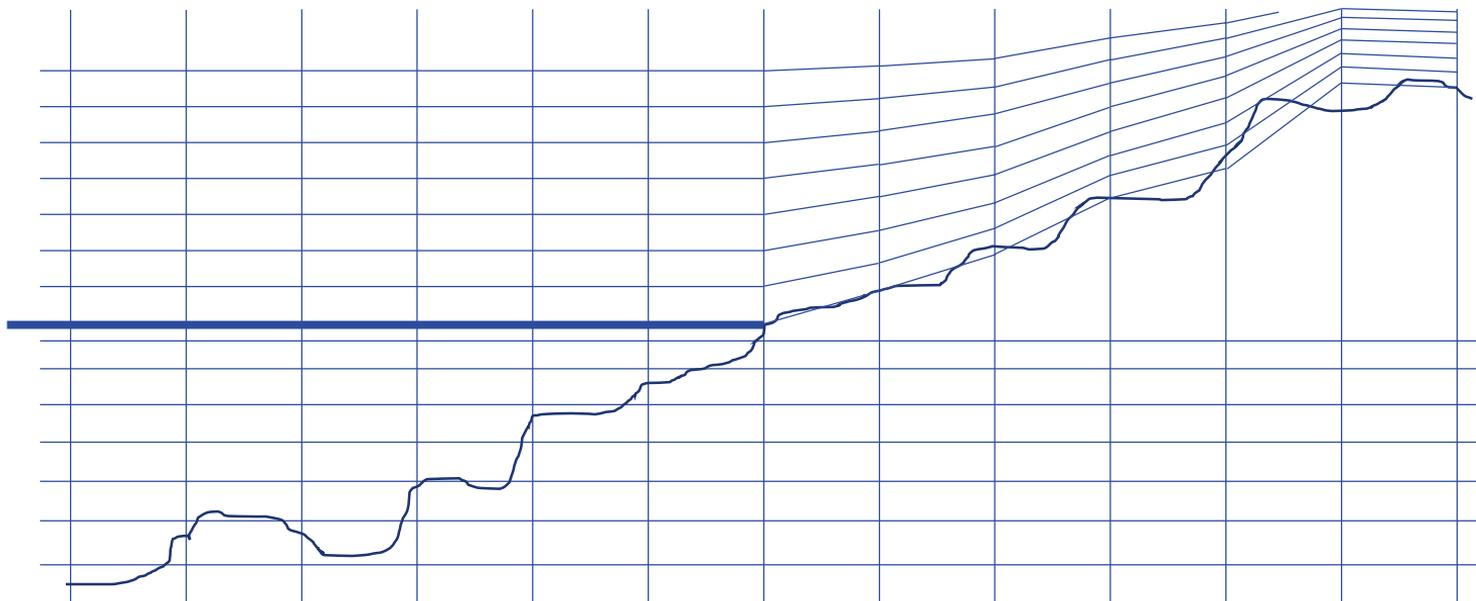


Figure 2. Horizontal reconstruction stencil for edge-normal vector components at (a) inner child edges and (b) outer child edges. The child edge under consideration is highlighted in red. Black open dots indicate child edge midpoints, while black solid dots indicate cell circumcenters. Solid red dots represent the reconstruction stencil, i.e., the location of the parent edge-normal vector components entering the reconstruction, and blue triangles in (b) indicate the location of the reconstructed 2D vectors. See the text for details.

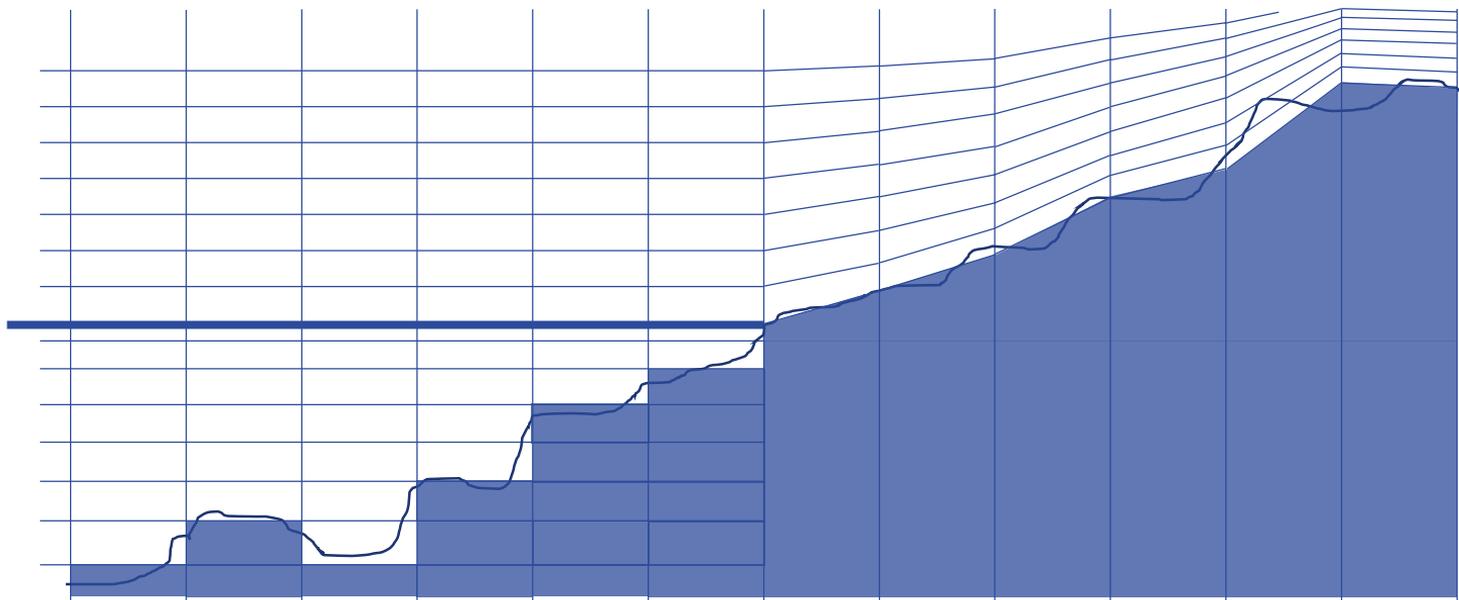


Ocean floor orography



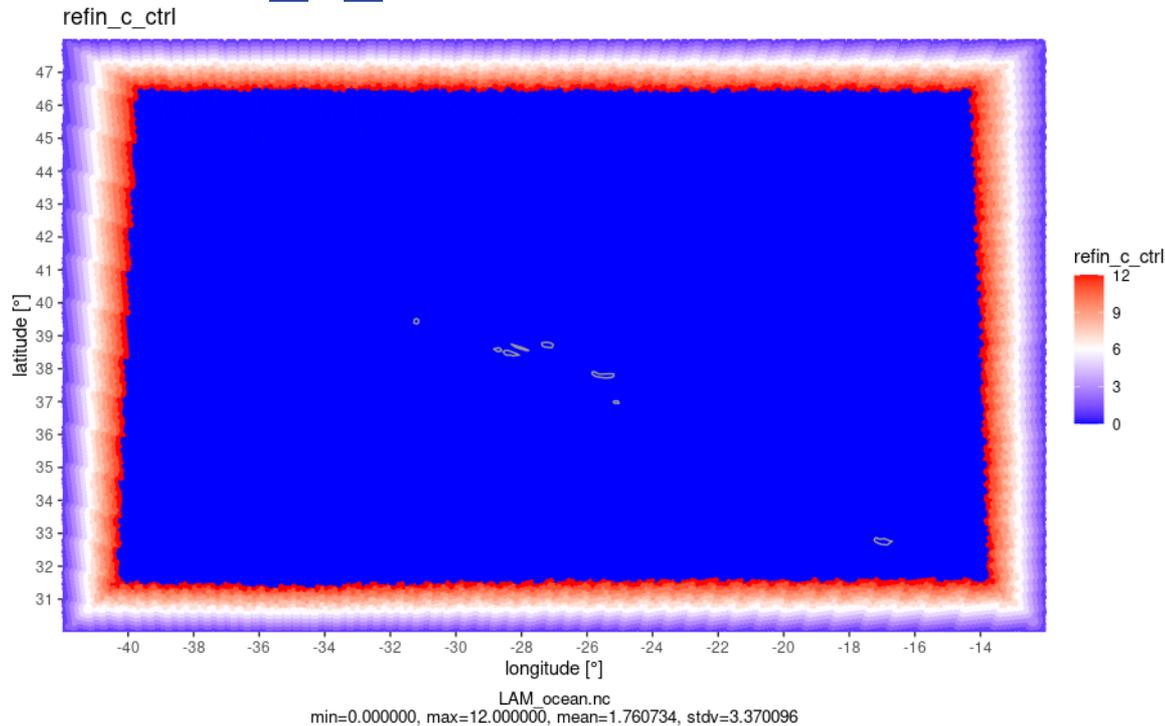


Ocean floor orography





ICON-O-LAM refin_c_ctrl





ICON-O-LAM cell indices

