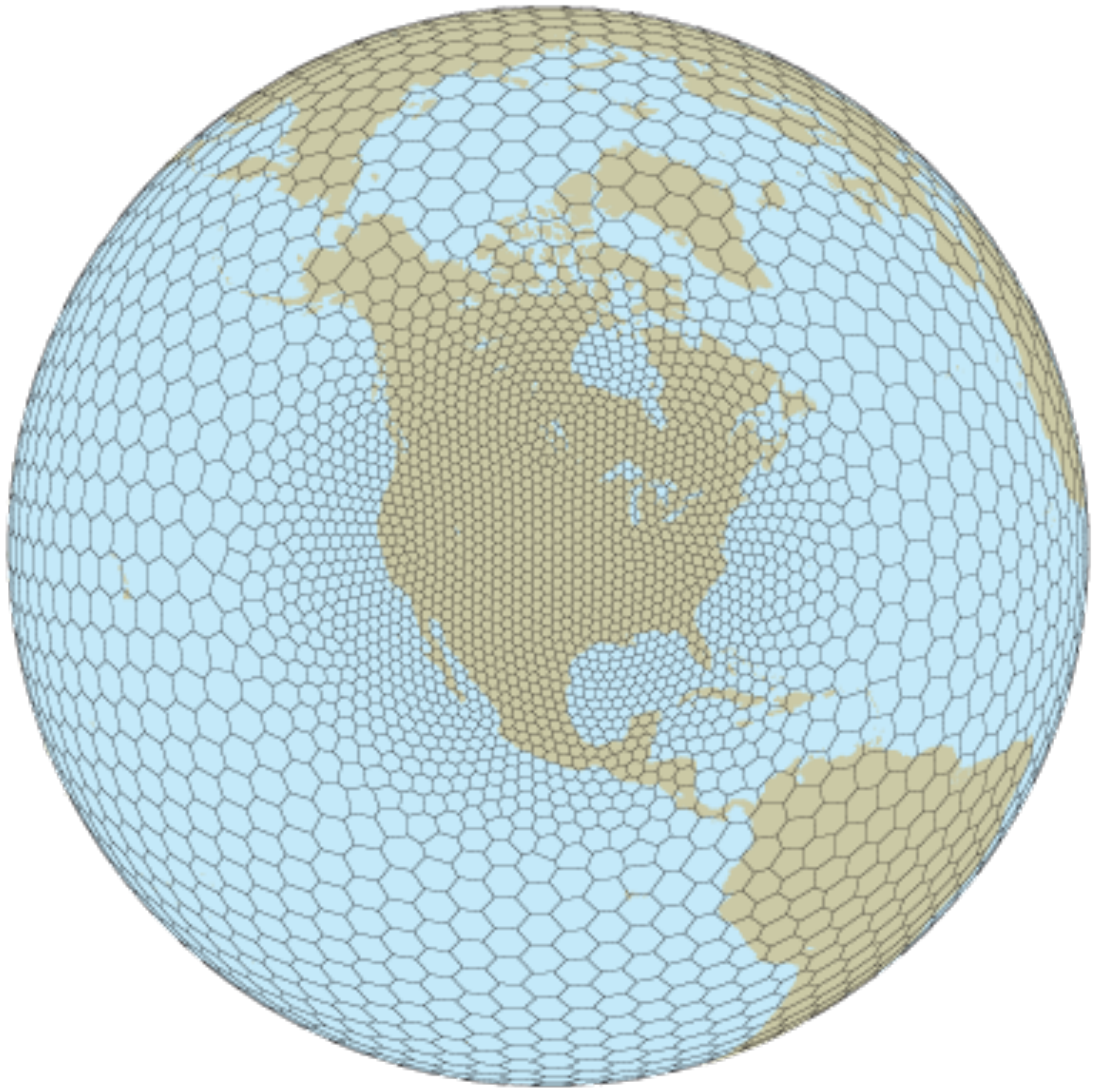
Universitat de les Illes Balears

Grup de Meteorologia

Exploring the Model for Predicction Across Scales (MPAS):

components and global applications



Maria Fca. Cardell

GOBIERNO DE ESPAÑA
MINISTERIO DE ECONOMÍA, INDUSTRIA Y COMPETITIVIDAD

EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND
"A way to make Europe"

TRAMPAS (PID2020-113036RB-I00 / AEI / 10.13039/501100011033)

MPAS

A collaborative project for developing atmosphere, ocean and other earth system simulation components for use in climate, regional climate and weather studies

- **MPAS Atmosphere**
- MPAS-Ocean
- MPAS-Albanyu Land Ice
- MPAS-Sea-ice

Development partners: the climate modeling group at Los Alamos National Laboratory (COSIM-LANL) and the National Center for Atmospheric Research.

MPAS-Atmosphere

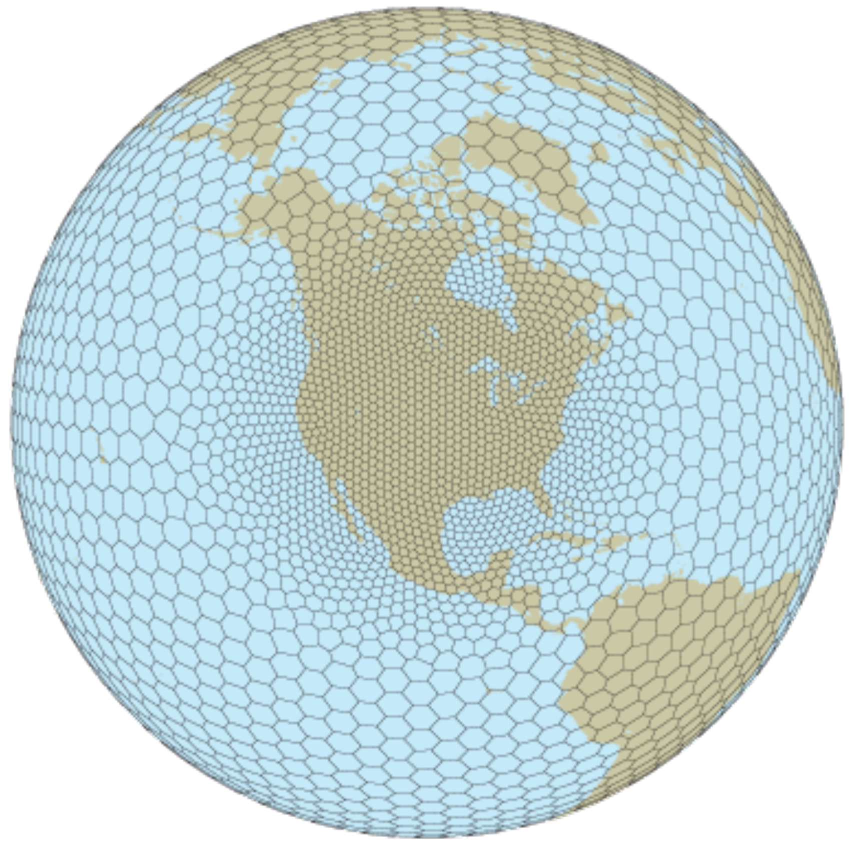
- **Effective modelling system for global applications:** in high resolution numerical weather prediction (NWP) and regional climate, and to global uniform-resolution NWP and climate applications.

- An atmospheric fluid-flow solver (the *dynamical core*) and, a **subset of the Advanced Research WRF** (ARW) model atmospheric physics.

- **Flexibility and capability of the MPAS Voroni mesh** to amend issues associated with the traditional refinement strategy of the one-way and two-way grid nesting with abrupt transitions.

- Work underway to provide **coupling between MPAS Ocean and MPAS Atmosphere,** and coupling to the Community Atmosphere Model (CAM) physics and other components of the Community Earth Systems Model CESM.

Defining features



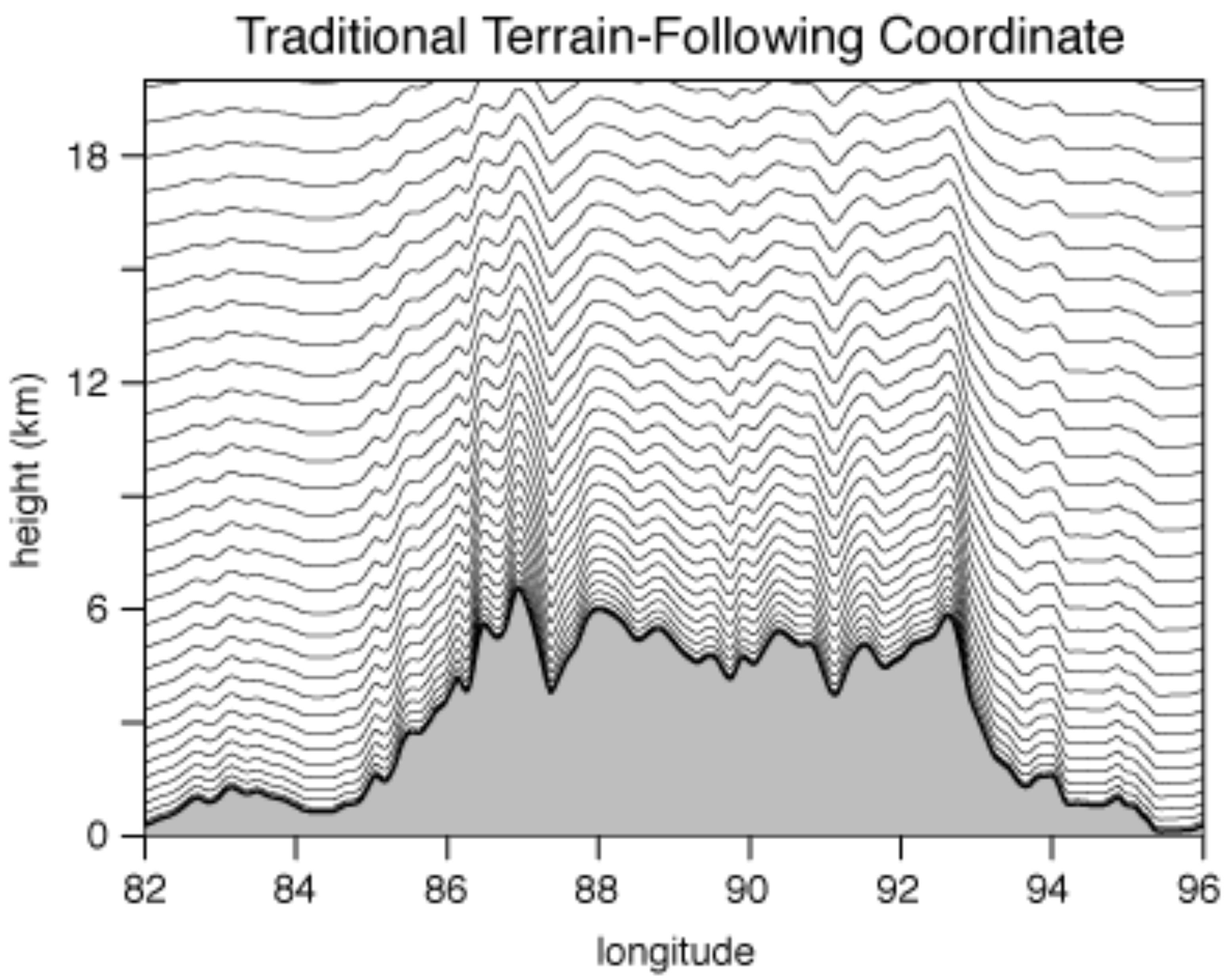
- Fully-compressible, **non-hydrostatic** dynamics.
- Split-explicit **Runge-Kutta** time integration.
- Exact **conservation** of dry-air mass and scalar mass.
- Positive-de nite and monotonic **transport** options.
- Generalized **terrain-following height coordinate**.
- Support for **unstructured variable-resolution** (horizontal) mesh integrations for the sphere and Cartesian planes.
- Support for **global and limited-area** simulation domains (MPAS v7.0).

Defining features

Atmospheric physics

-Physics suite from the Advanced Research WRF model

- **Surface Layer**: Monin-Obukhov and MYNN.
- **PBL:** YSU and MYNN.
- **Land Surface Model:** Noah (4-layers).
- **Gravity Wave Drag:** YSU GWDO as in WRF 3.6.1.
- **Convection**: Kain-Fritsch; Tiedtke; New Tiedtke (WRF 3.8.1); modified version of scale-aware Grell-Freitas (WRF 3.6.1).
- **Microphysics:** WSM6 as in WRF 3.8.1; Thompson (non-aerosol aware) as in WRF 3.8.1; Kessler.
- **Radiation:** CAM and RRTMG long-wave and short-wave radiation schemes.



MPAS cross section through the Himalayas at 28 degrees N latitude for a 15 km (mean cell-center spacing) uniform mesh. Model top at 30 km

Figure source: https://mpas-dev.github.io

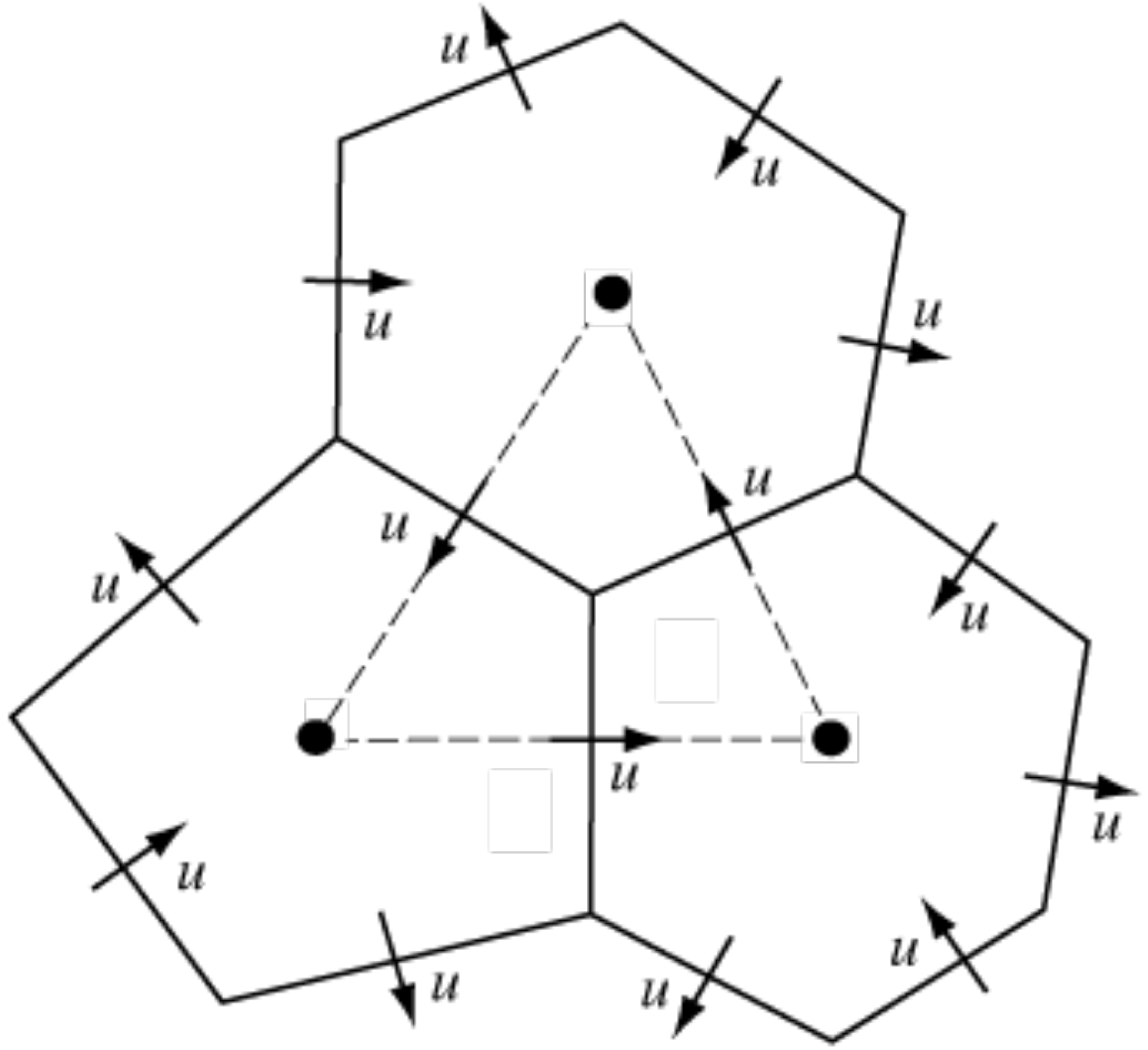
Defining features

Centroidal Voroni mesh and the C-grid staggering

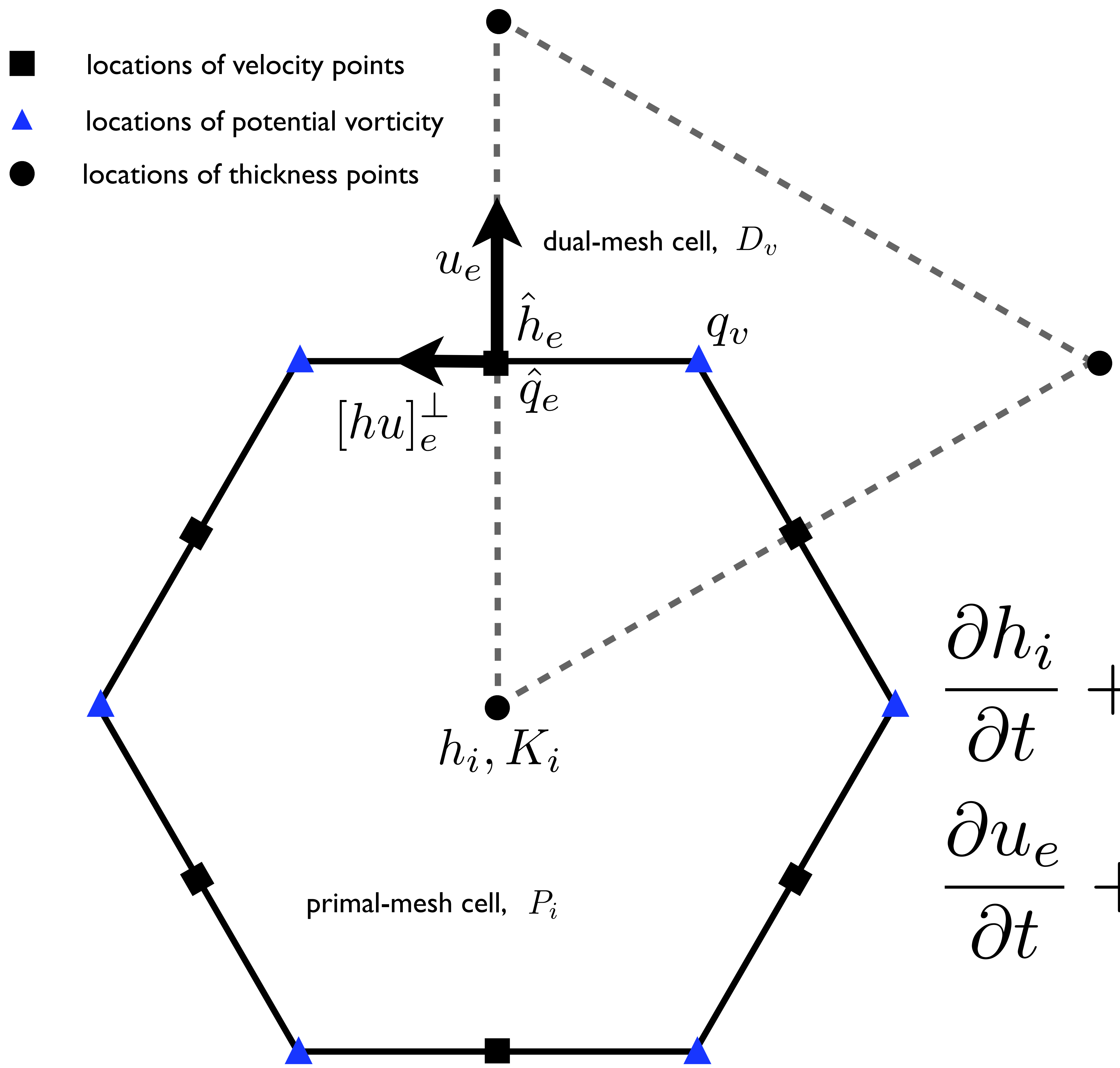
Allow for both quasi-uniform discretization of the sphere and local refinement.

The unstructured variable resolution meshes can be generated having smoothly-varying mesh transitions.

The C-grid discretization: the normal component of velocity on cell edges is prognosed, is especially well-suited for higher-resolution, mesoscale atmosphere and ocean simulations.



The C-grid Staggering



When using a C-grid staggering, the component of velocity normal to cell edges (u_e) is retained as a prognostic equation.

The tangential component of the velocity ($u_e^\perp$) must be reconstructed from the normal components of velocity in order to compute the nonlinear Coriolis force.

$$\frac{\partial h_i}{\partial t} + \left[\nabla \cdot \left(\widehat{h}_e u_e\right)\right]_i = 0$$

$$\frac{\partial u_e}{\partial t} + \widehat{q}_e \left[hu\right]_e^\perp = \left[\nabla \left(g h_i + K_i\right)\right]_e$$

MPAS-A components

- **Two main components** built as cores: the model (atmospheric dynamic and physics), and an initialization component.
- Same driver programme and software infrastructure but each component compiled as a separate executable.

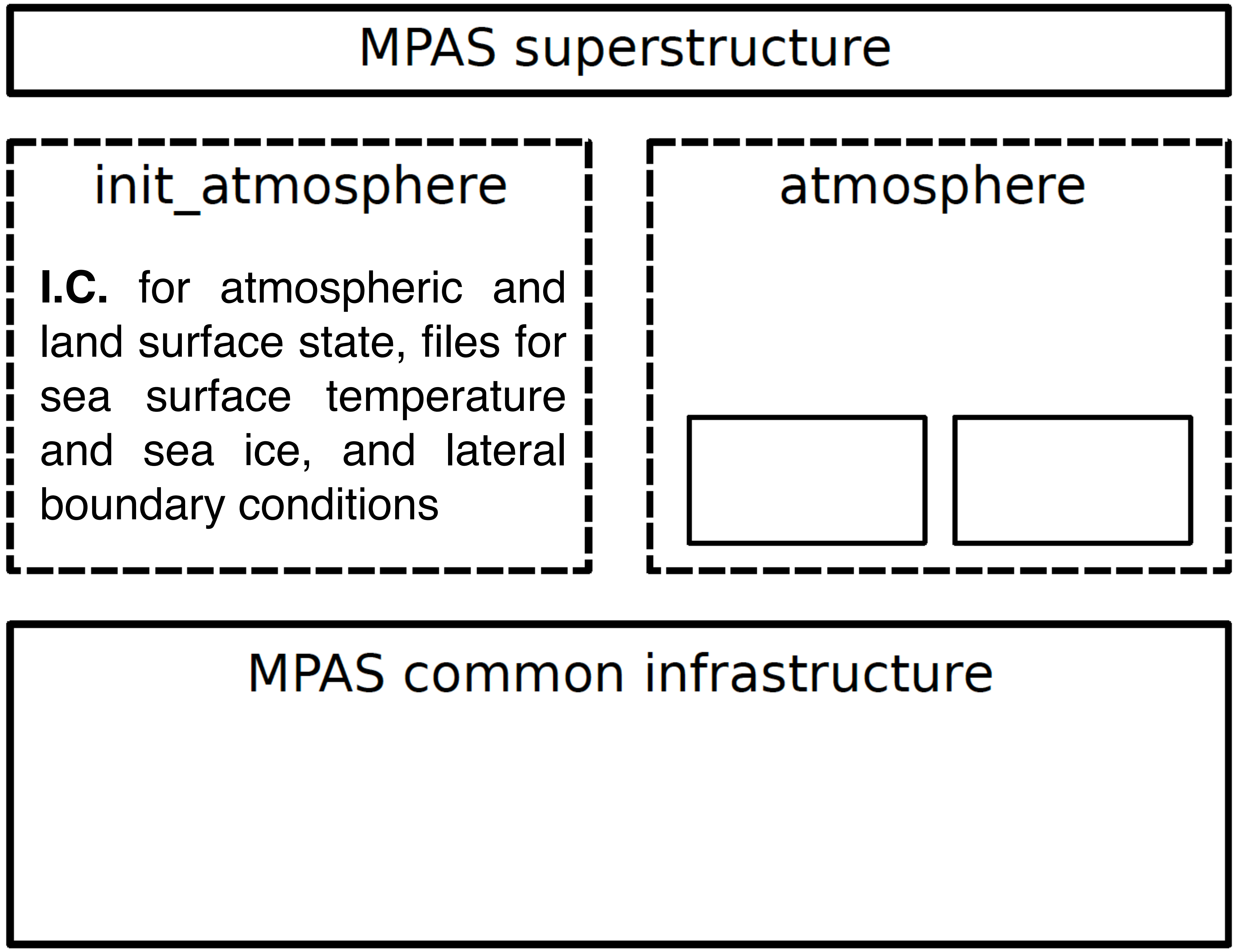


Figure source: http://www2.mmm.ucar.edu/projects/mpas/mpas_atmosphere_users_guide_7.0.pdf

Installing and running the MPAS-A

1. *Building MPAS: MPI implementation (MPICH, OpenMPI …), netCDF library, parallel-netCDF library, Parallel I/O (PIO) library, MPAS-Model source code, the init_atmosphere and atmosphere cores.*
2. Prepare meshes for simulation.
   - For quasi-uniform meshes: mesh descomposition across processors (METIS)/ MPI tasks.
   - Relocating refinement regions on the sphere (grid_rotate programme)
   - Creating limited-area meshes. Configuring model input and output.
3. Physics Suites (mesoscale_reference, convection permitting, individual physics parameterizations).
4. Running the model (idealized ICs, real-data ICs)
5. Model Options (periodic SST and Sea-ice Updates).
6. Visualization (input and output files in netCDF format).

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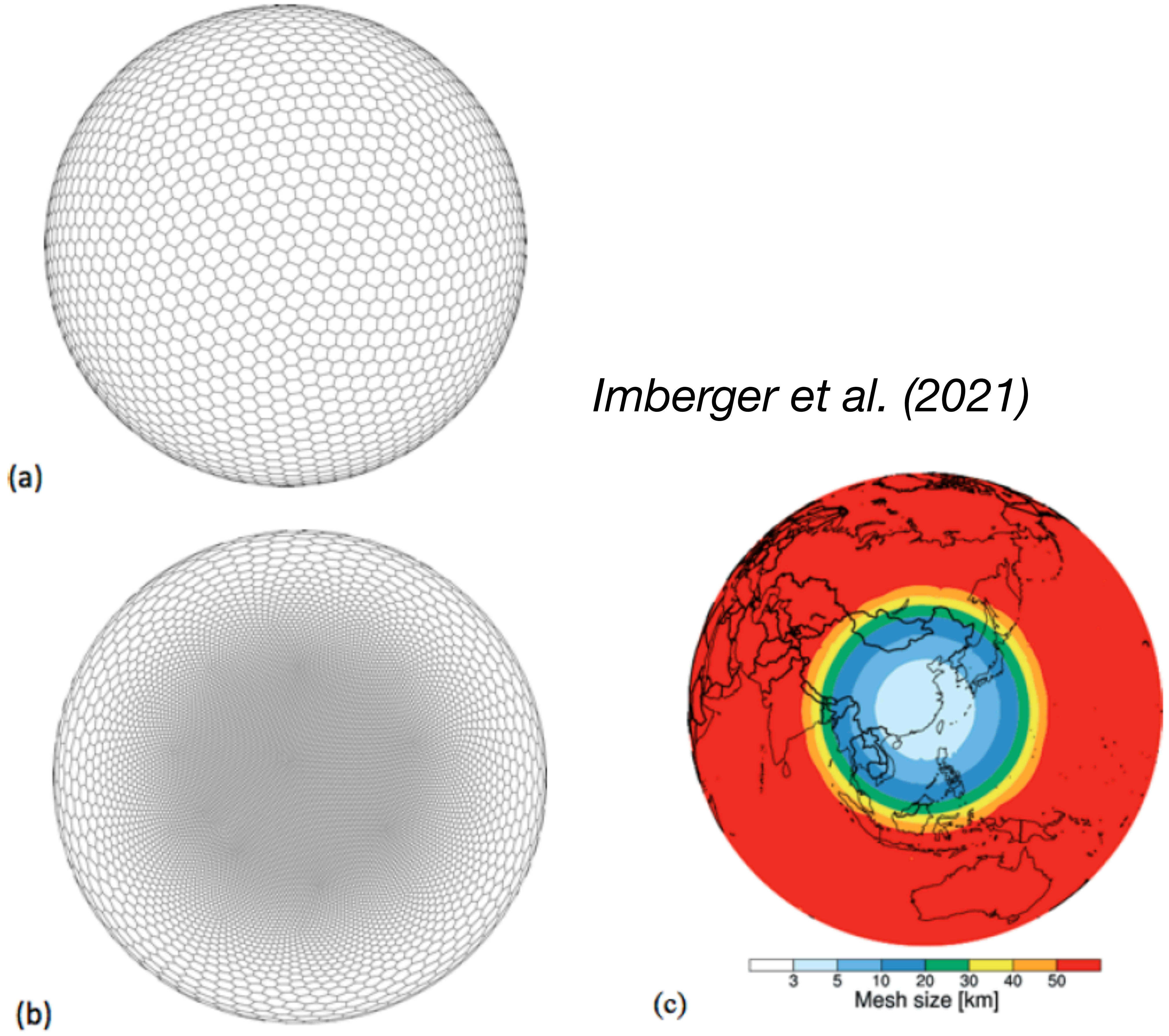
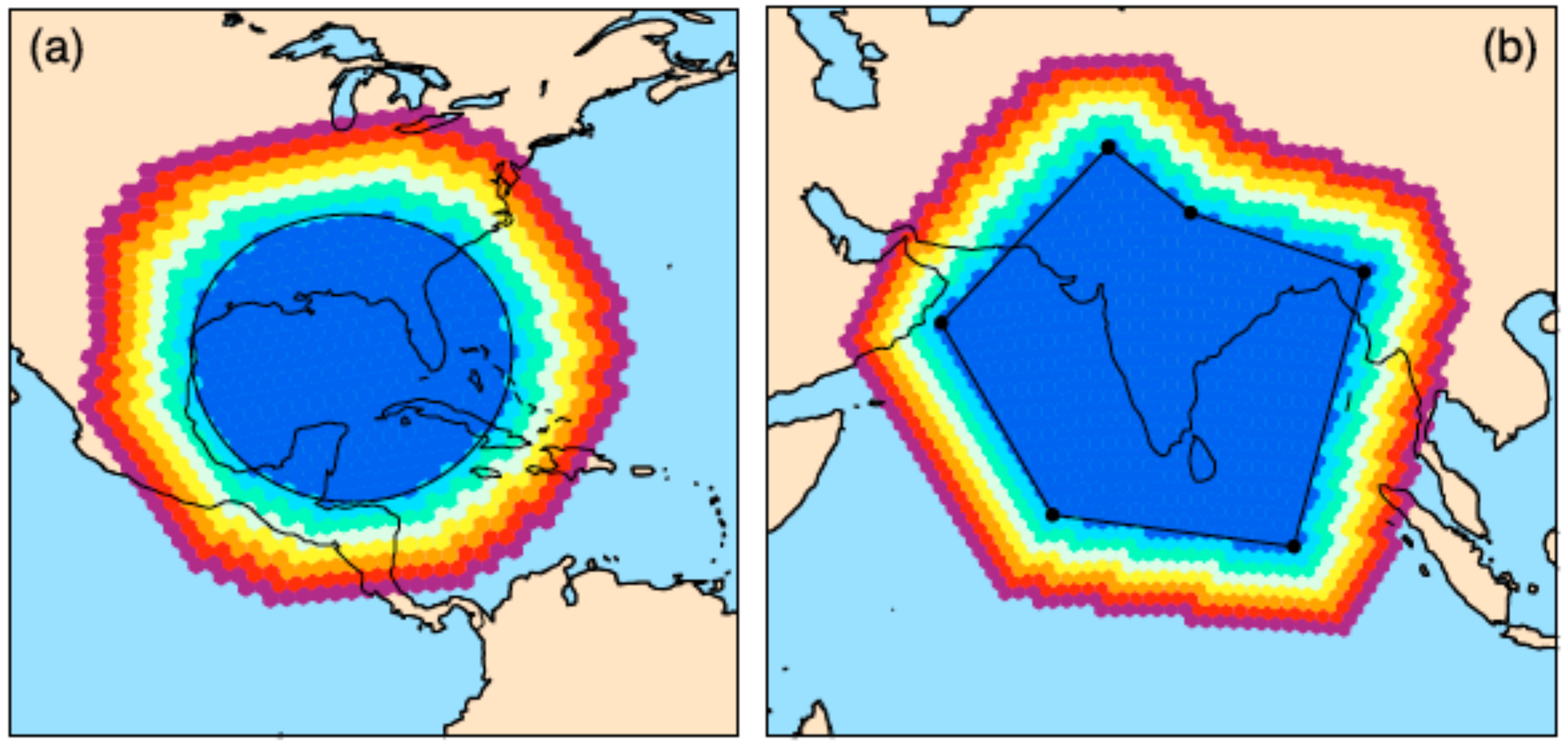


Imberger et al. (2021)



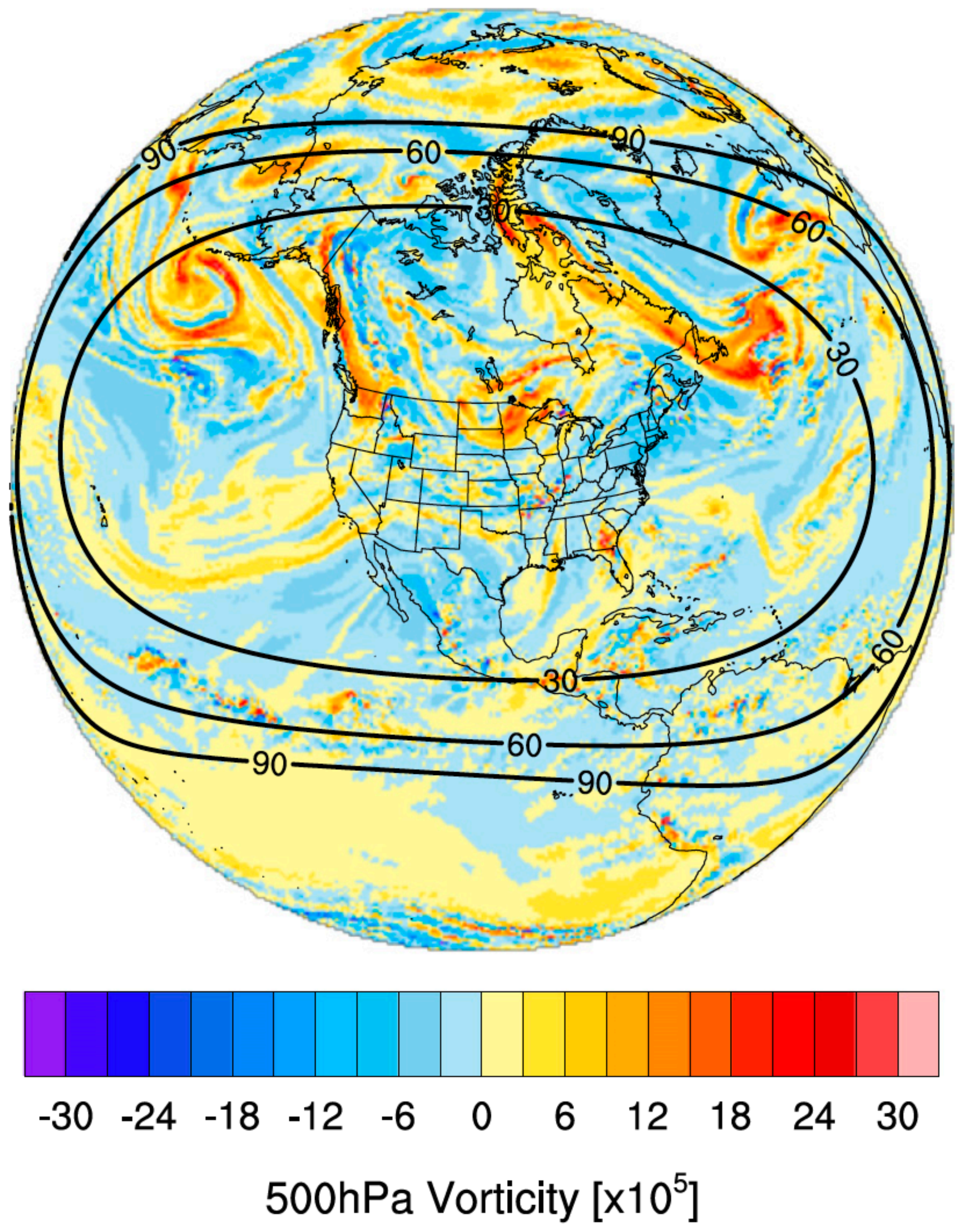
Skamarock et al. (2018)

Relevant publications

Ha, S., Snyder, C., Skamarock, W. C., Anderson, J., & Collins, N. (2017). Ensemble Kalman filter data assimilation for the Model for Prediction Across Scales (MPAS). Monthly Weather Review, 145(11), 4673-4692.

Global atmospheric analysis and forecast system using the MPAS-A and the Data Assimilation Research Testbed (DART) ensemble Kalman filter.

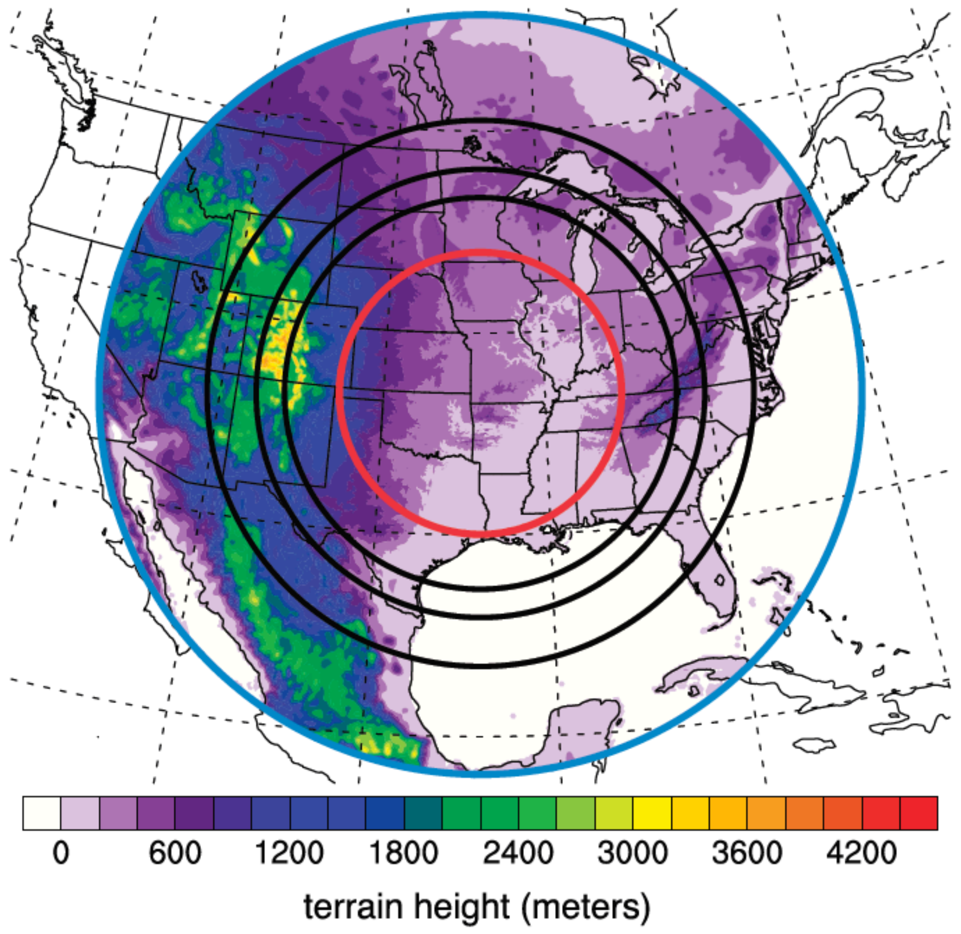
- Cycling experiments with the assimilation of real observations show that the global ensemble system is robust and reliable throughout a one-month period for both quasi-uniform and variable-resolution meshes. The **variable-mesh assimilation system** provides **higher-quality analyses** than those from the coarse uniform mesh, in addition to the benefits of the higher-resolution forecasts, which leads to substantial improvements in 5-day forecasts.



Grid resolutions in 120-30 km variable mesh, contouring every 30 km in solid lines, superimposed over relative vorticity at 500 hPa (coloured) at 36-h forecast valid 1200UTC 29 May 2012

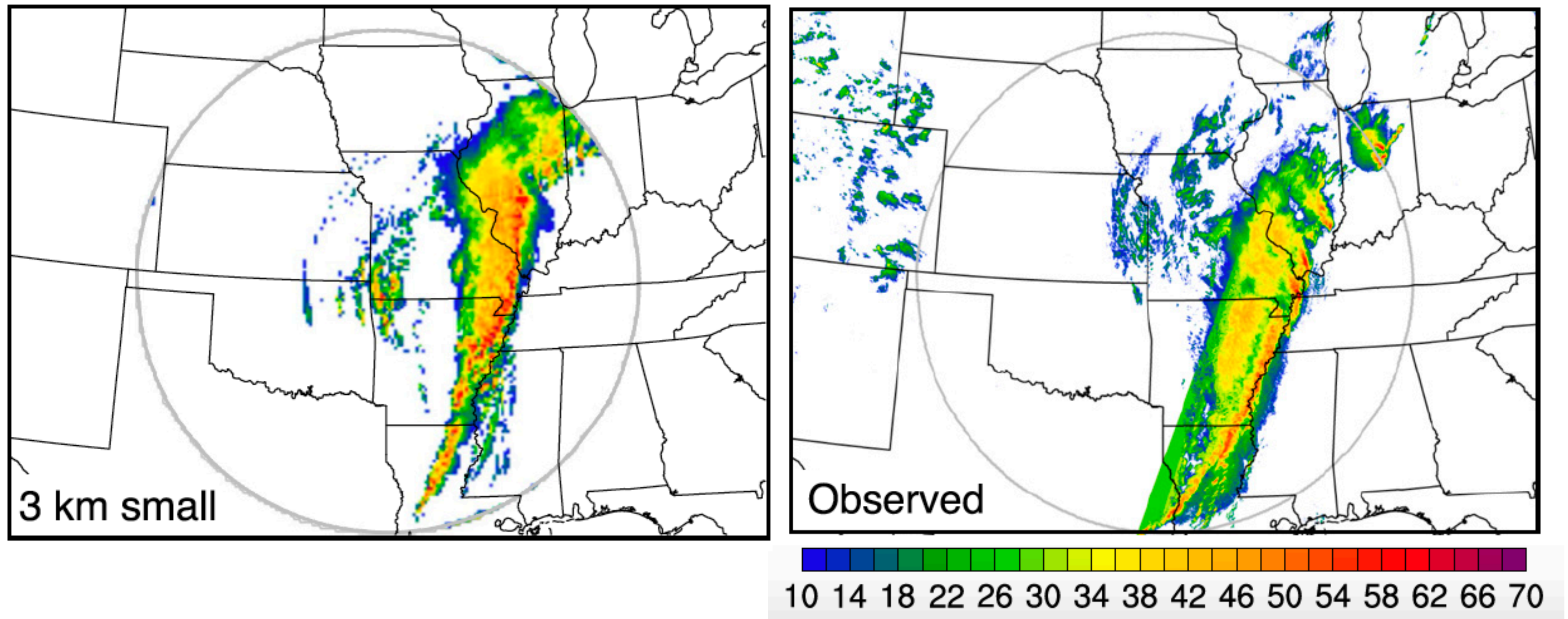
Relevant publications

Skamarock, W. C., Duda, M. G., Ha, S., & Park, S. H. (2018). Limited-area atmospheric modeling using an unstructured mesh. Monthly Weather Review, 146(10), 3445-3460.



Regional configuration of the (MPAS-A) supporting variable-resolution meshes

- Variable-resolution configurations **recover most of the error reduction** compared to uniform high resolution configurations, and at **much-reduced cost.** The wider relaxation-zone region also helps reconcile differences near the lateral boundary that evolve between the regional the driving solution, and the **configuration** is **more stable** than one using a uniform high-resolution regional mesh.



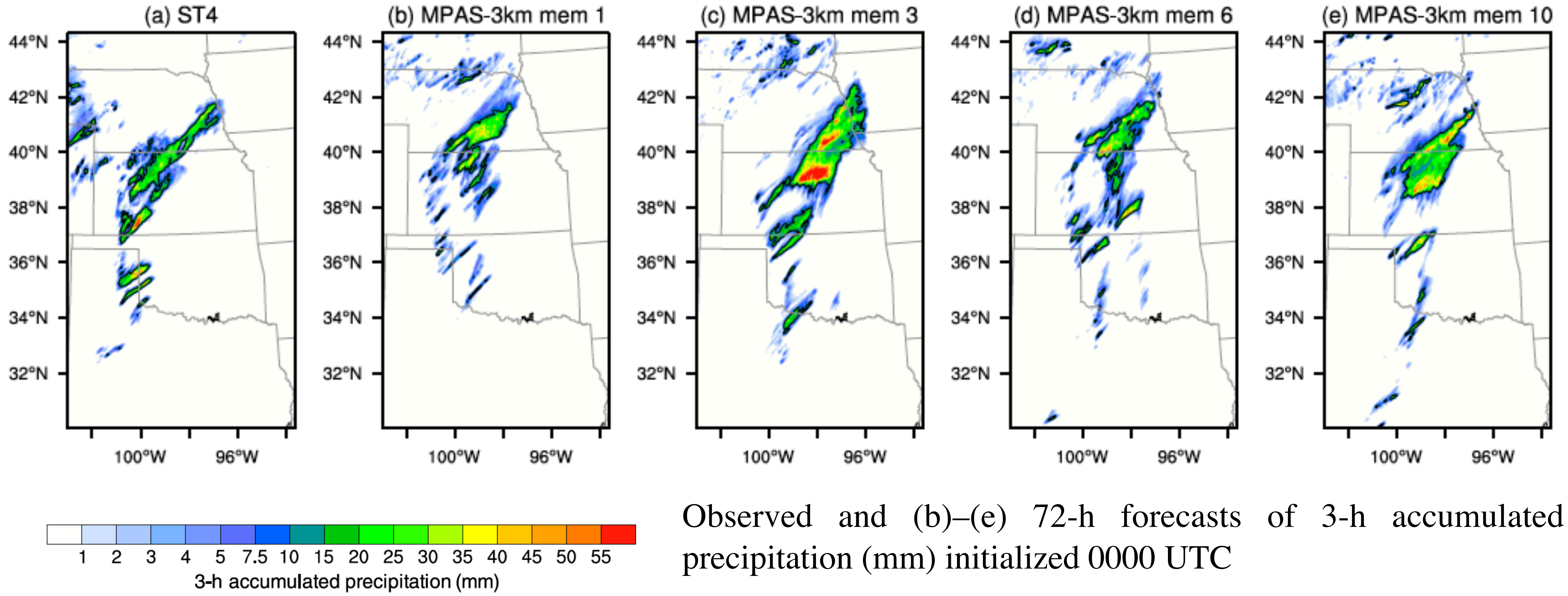
Simulated column maximum reflectivity (dBZ) 3-km small region simulation with the observed composite reflectivity from the NOAA MRMS data.

Relevant publications

Schwartz, C. S. (2019). Medium-range convection-allowing ensemble forecasts with a variable-resolution global model. Monthly Weather Review, 147(8), 2997-3023.

<u>Configuring MPAS with a 3-km mesh refinement region for medium-range forecasts</u>

Faithful reproduction of the observed diurnal cycle of precipitation throughout the 132-h forecasts and good precipitation skill and reliability over the first 48 h.



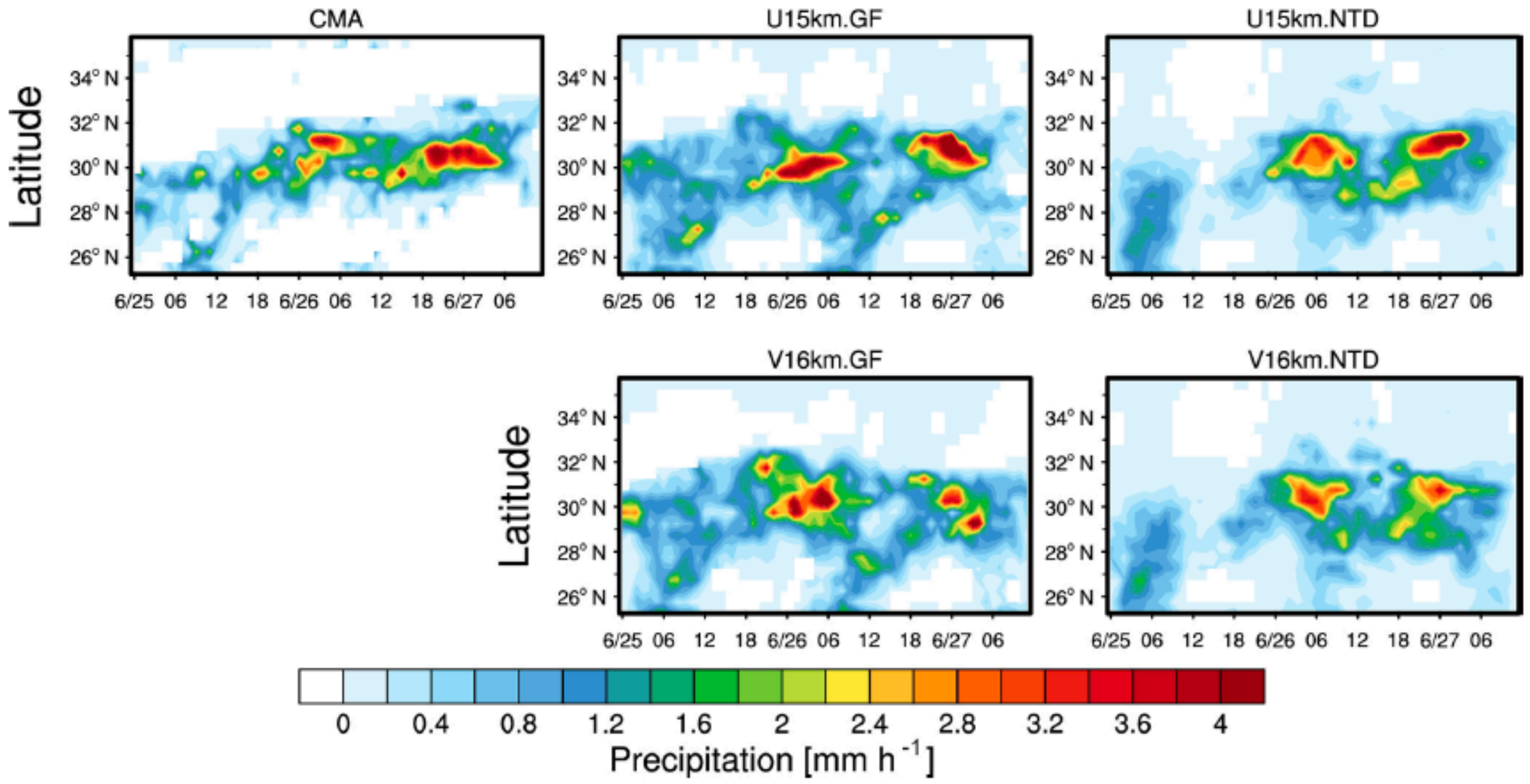
Observed and (b)–(e) 72-h forecasts of 3-h accumulated precipitation (mm) initialized 0000 UTC

Relevant publications

Zhao, C., Xu, M., Wang, Y.,…& Skamarock, W. (2019). Modeling extreme precipitation over East China with a global variable-resolution modeling framework (MPASv5. 2): impacts of resolution and physics. Geoscientific Model Development, 12(7), 2707-2726.

Simulation of extreme precipitation events using MPAS global variables resolution at a range from hydrostatic (60, 30, 16 km) to non-hydrostatic (4 km) scales, and regional refinement over East Asia.

- Similar characteristics of precipitation and wind using using global uniform-resolution and variable resolution meshes.
- Significant impacts of resolution on simulating the distribution and intensity of precipitation and updrafts.



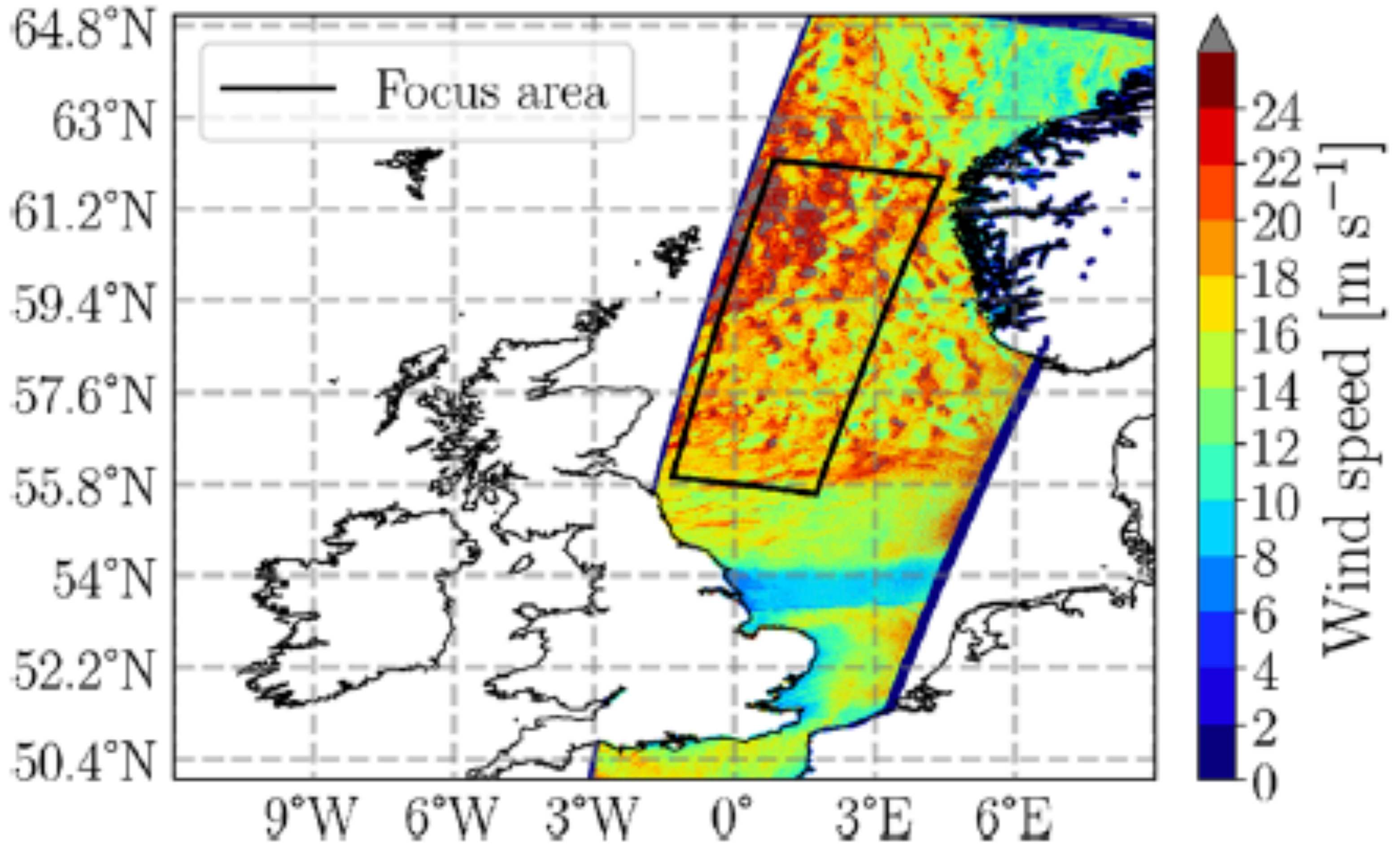
Time–latitude cross section of precipitation from the CMA station observations and the simulations with global uniform and variable resolutions with two convective parameterizations

Relevant publications

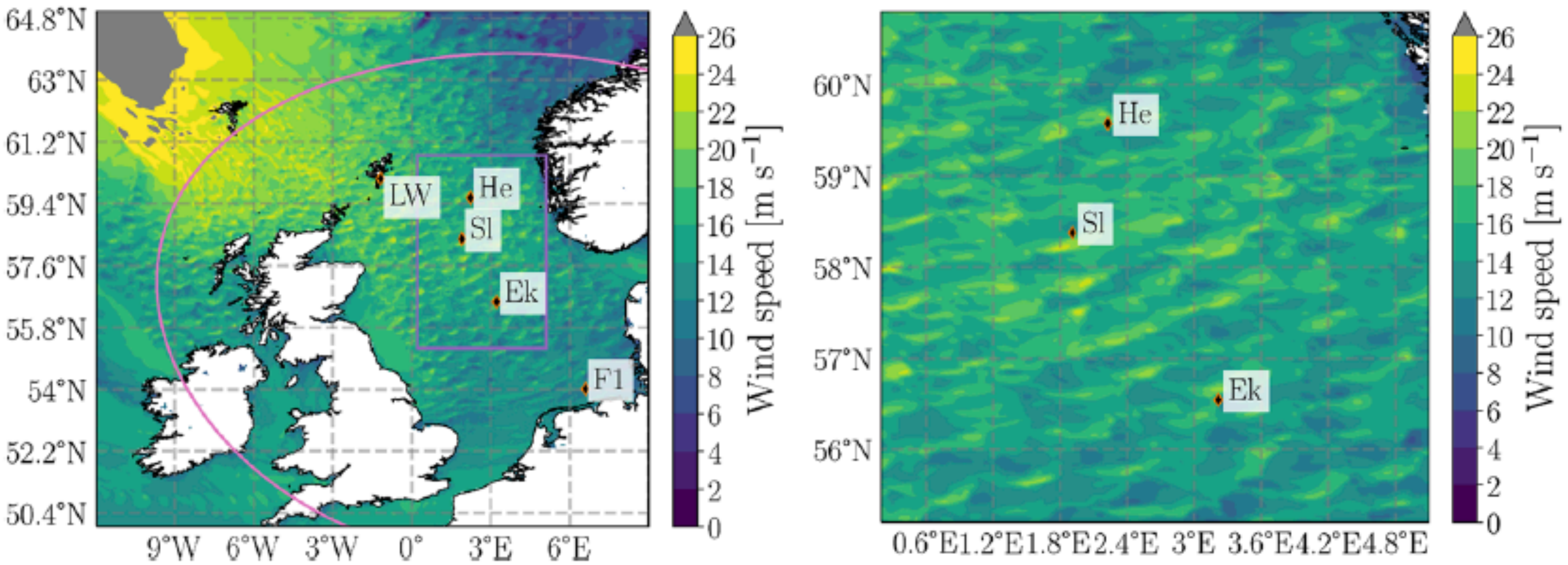
Imberger, M., Larsén, X. G., & Davis, N. (2021). Investigation of Spatial and Temporal Wind-Speed Variability During Open Cellular Convection with the Model for Prediction Across Scales in Comparison with Measurements. Boundary-Layer Meteorology, 179(2), 291-312.

<u>Regional mesh refinement down to convection-permitting scales of 2 km.</u>

- Realistic simulation of OCC structures and mesoscale wind-speed variability over the North-Sea within the limits set by the effective model resolution. The modelled wind speed and vertical velocity component show that the model is able to create cell patterns that resemble those seen in the cloud and the SAR image.



Wind speed at 10 m from the Environmental Satellite synthetic aperture radar at 16 December 2010



Wind speed over water at 10 m and amplified version from the model output at 16 December

Work plan

- **Train** for a smooth transition from WRF to MPAS.
- **Unify TRAM and MPAS** applications and evolve and **integrate** in the new models the team **own numerical techniques**: ingredients-based diagnosis, PV-inversion, model verification, ensemble generation, hydrological coupling and visualization and analysis tools.
- **Inter-comparison and validations** (Bencharmark tests): MPAS, TRAM, WRF, CM1 cloud model and the operational version of HARMONIE-AROME.
- Investigate the climate of the **Mediterranean and the evolution of extreme events** focusing on **precipitation and wind-related** Mediterranean extreme weather, and on two strategic sectors: wind and photovoltaic energy planning, and flood early warning for civil protection.
- **Operational implementation**.

THANK YOU !!!

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COASTEPS CGL2017-82868-R (AEI/FEDER, UE)

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