Running Regional MPAS: Preparing limited-area meshes and lateral boundary conditions

Wei Wang and Michael Duda
NCAR/MMM

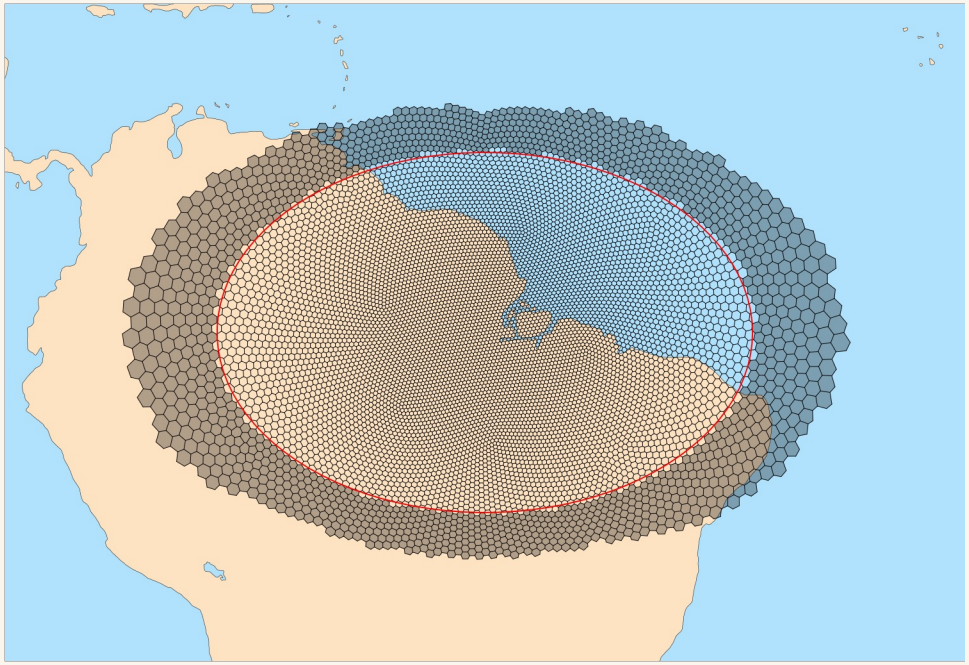
This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

MPAS
Model for Prediction Across Scales

Overview

Running limited-area simulations with MPAS-Atmosphere involves only small variations on the process of running global simulations:

1) A limited area domain must be defined, and a mesh must be created for that domain
2) In addition to ICs, lateral boundary conditions (LBCs) must be generated with the *init_atmosphere* core
3) LBCs must be enabled when running the *atmosphere* core

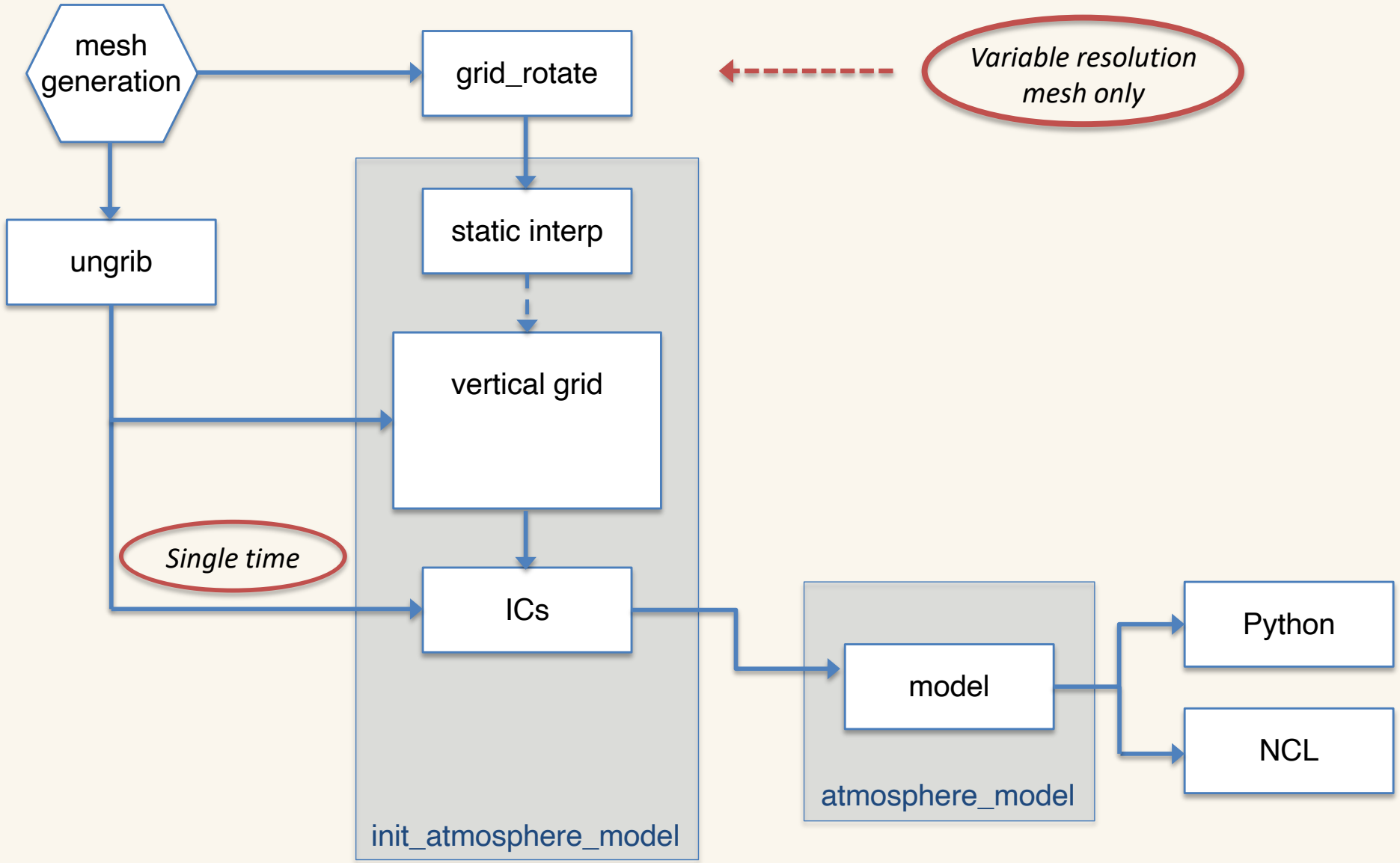


Above: A variable-resolution, limited-area MPAS mesh. Relaxation zone and specified zone cells are shaded gray.

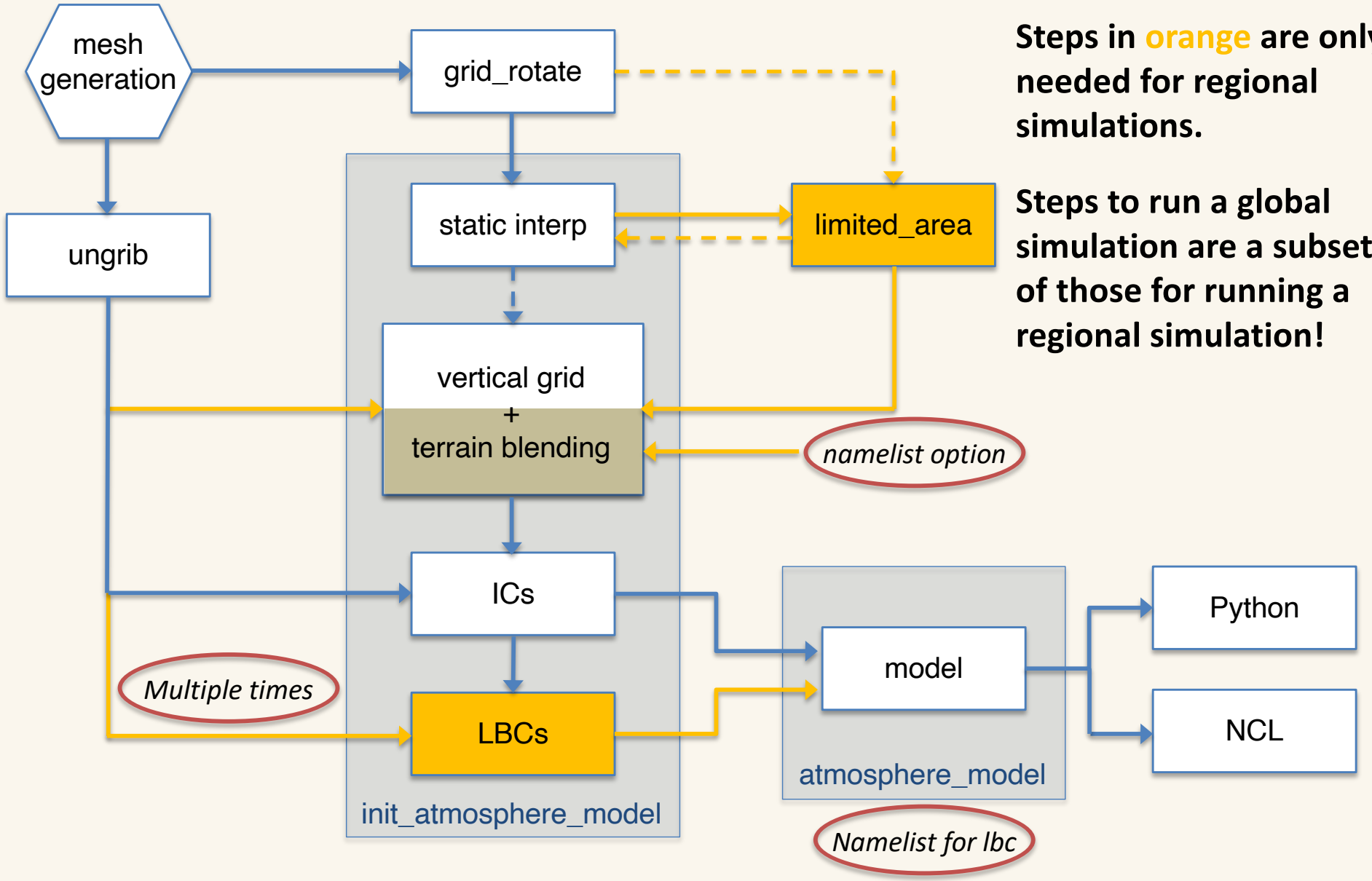
See Sections 4.3 and 8.2 in the User's Guide

MPAS
Model for Prediction Across Scales

Global MPAS Flowchart



Regional MPAS Flowchart: Global v. Regional



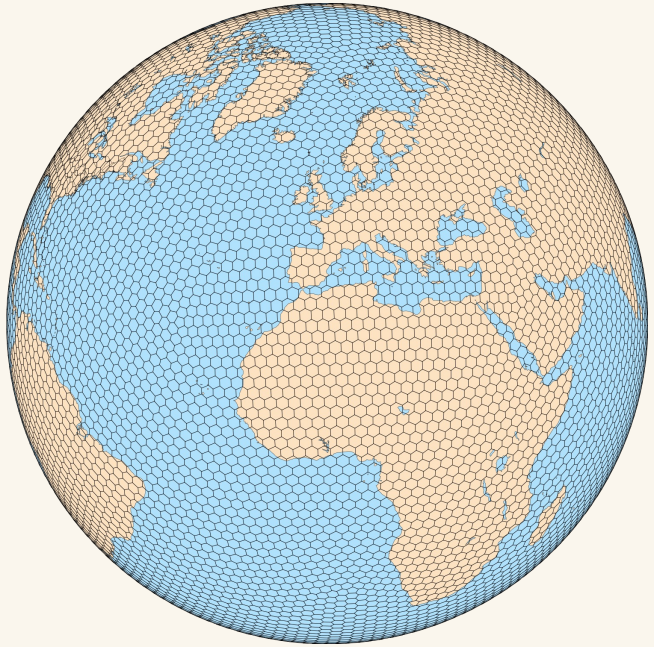
Steps in orange are only needed for regional simulations.

Steps to run a global simulation are a subset of those for running a regional simulation!

Creating limited-area meshes

As mentioned elsewhere, generating new CVT meshes can be quite time consuming

- At present, limited-area meshes are created by subsetting existing meshes with the MPAS-Limited-Area tool



Each cell in the limited-area mesh is exactly coincident with a cell in the ”parent” mesh

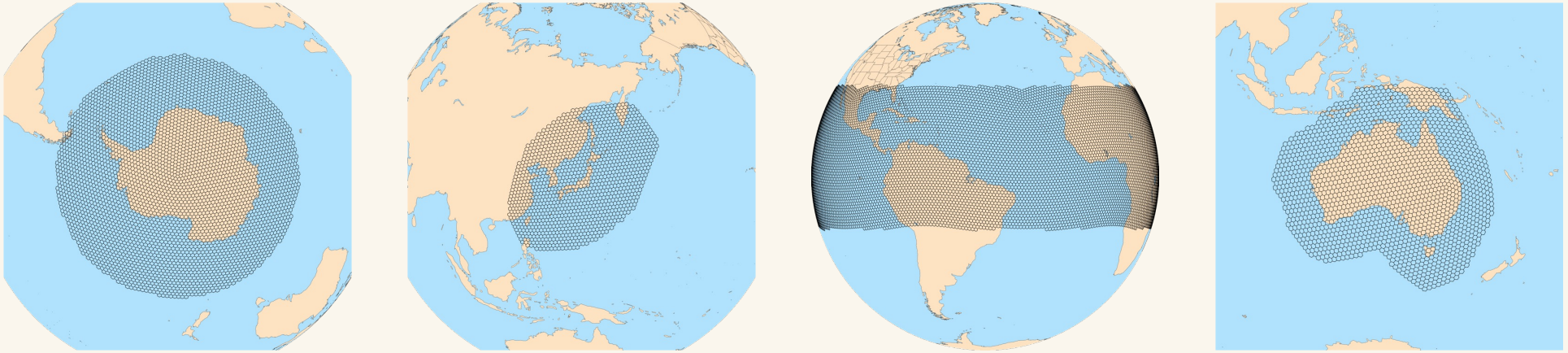
- The key point is that subsetting mesh is computational trivial, while generating a new mesh is not!

MPAS
Model for Prediction Across Scales

Creating limited-area meshes

MPAS-Limited-Area is a simple (~1300 lines) Python tool

- The Python NumPy, and NetCDF4 modules are required
- A “parent” mesh and a region definition file are the only inputs



Various region types are supported for defining regions: circles, ellipses, channels, and general polygons

- With some Python knowledge, adding new region types should be easy

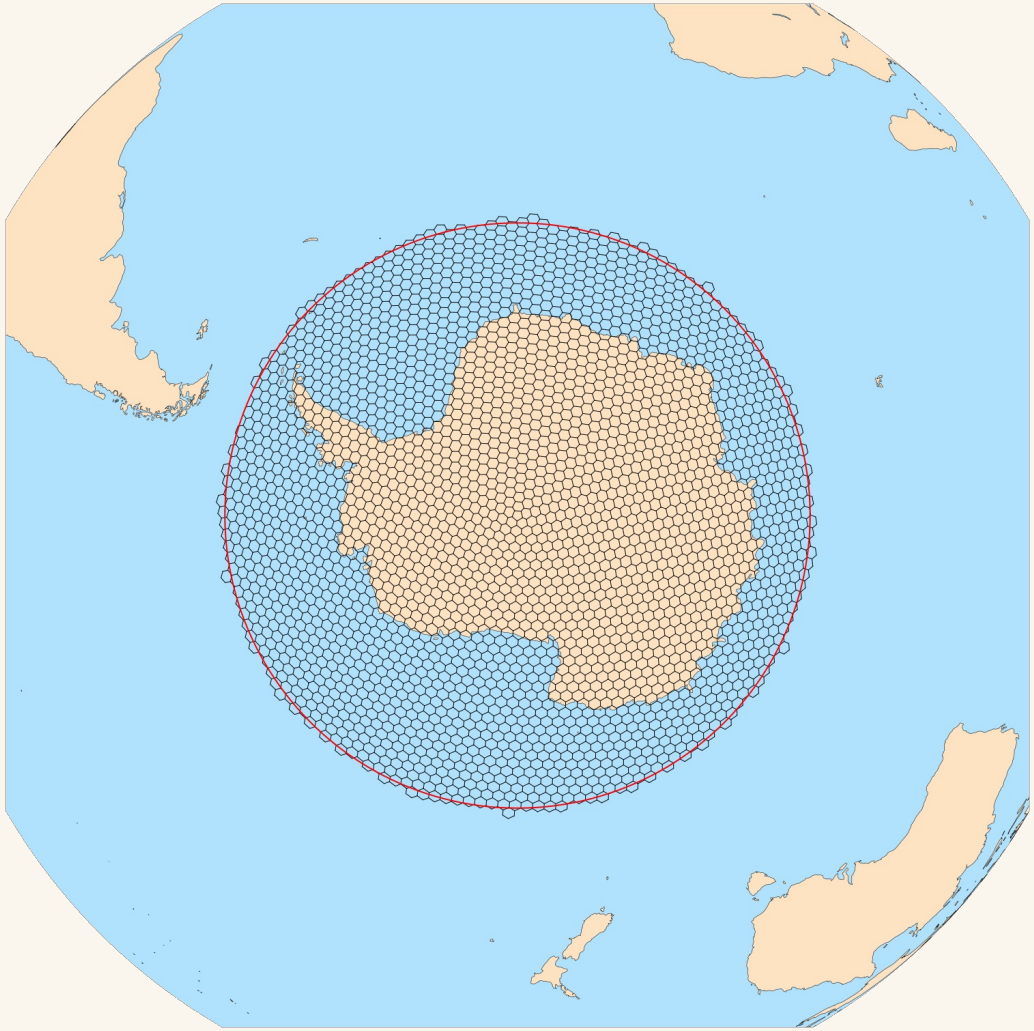
https://github.com/MPAS-dev/MPAS-Limited-Area

Creating limited-area meshes: circular region

For circular regions, the region definition looks like the following

```
Name: Antarctic
Type: circle
Point: -90.0, 0.0
radius: 3300
```

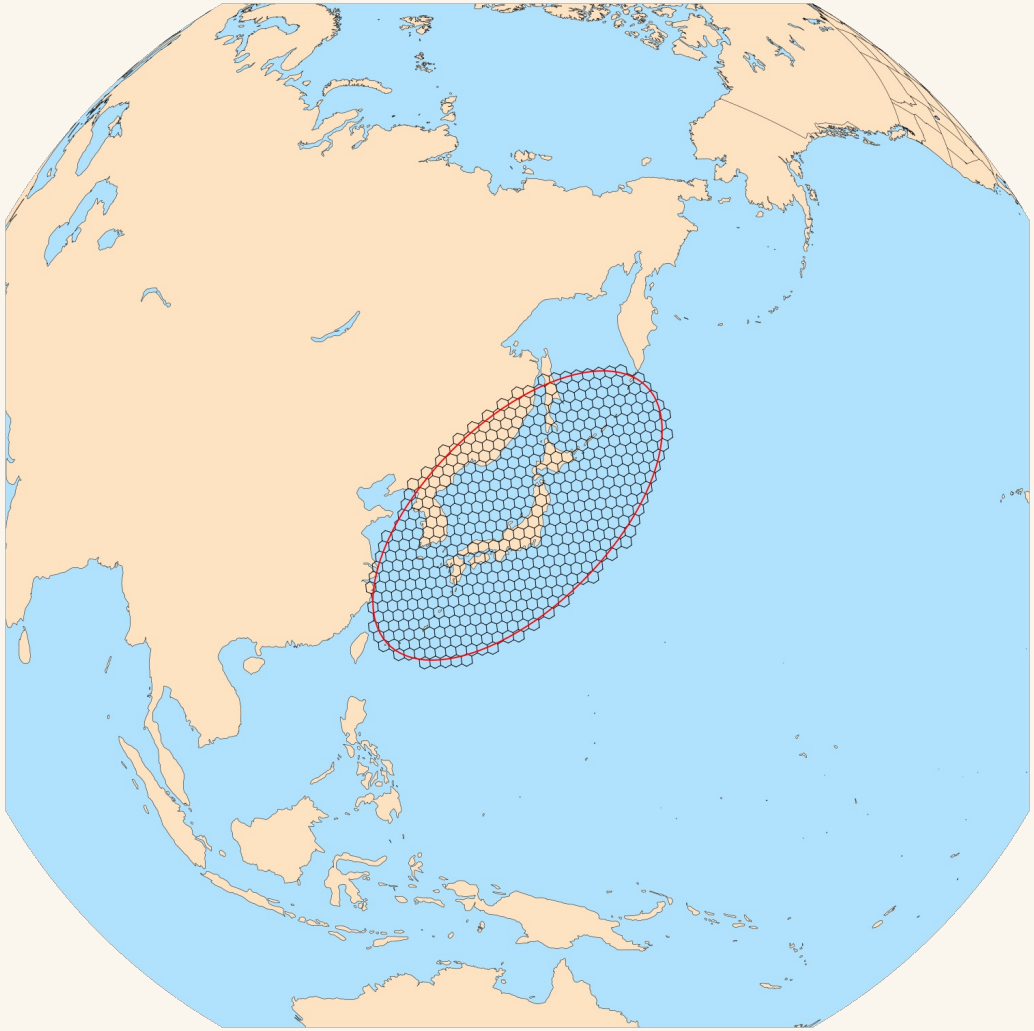
”Point” gives the latitude and longitude at the center of the circle, and “radius” gives the radius in km



Creating limited-area meshes: elliptical region

For elliptical regions, the region definition looks like the following

```
Name: Japan
Type: ellipse
Point: 38.0, 138.0
Semi-major-axis: 2000000
Semi-minor-axis: 1000000
Orientation-angle: 45
```

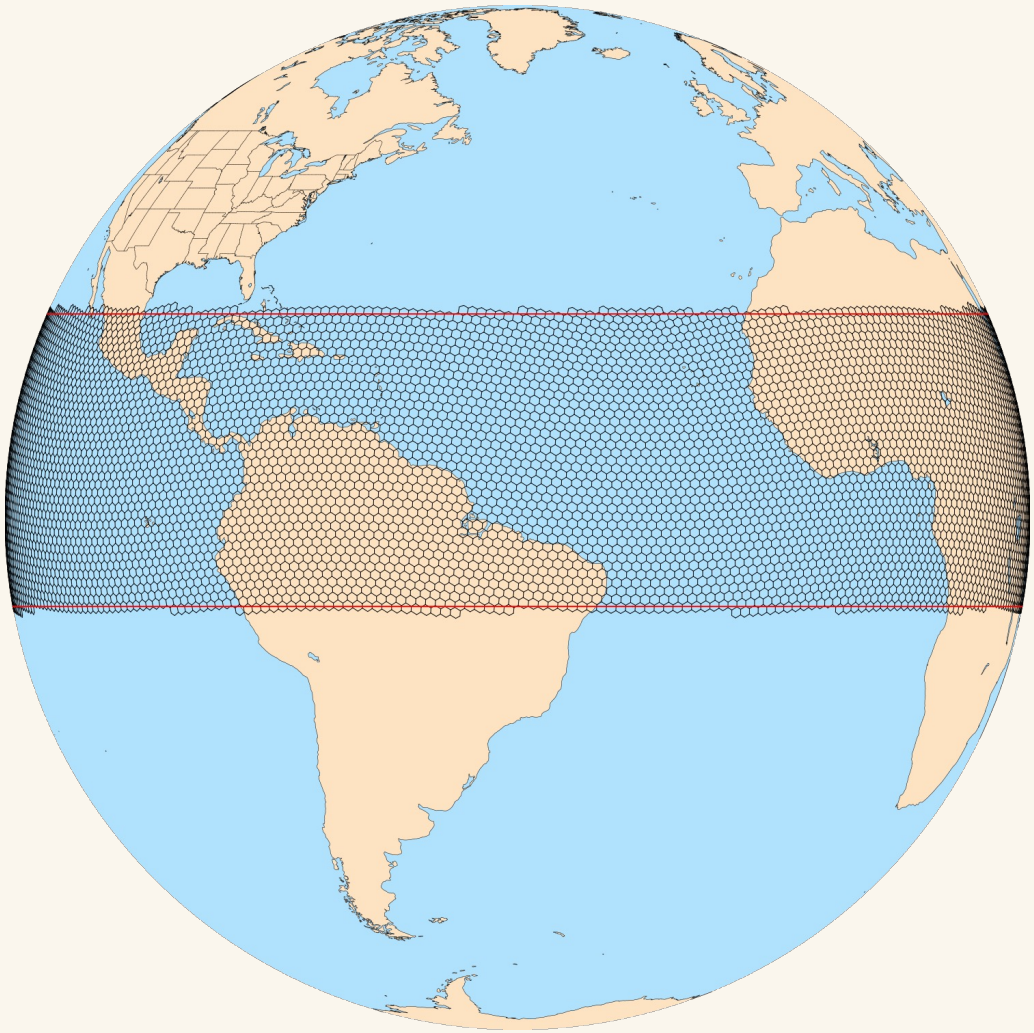


”Point” gives the latitude and longitude at the center of the ellipse, ”Semi-major-axis” and “Semi-minor-axis” are in meters, and “Orientation-angle” gives the rotation of the axes of the ellipse

Creating limited-area meshes: channel region

For channel regions, the region definition looks like the following

```
Name: Tropics
Type: channel
ulat: 23.4
llat: -10.0
```



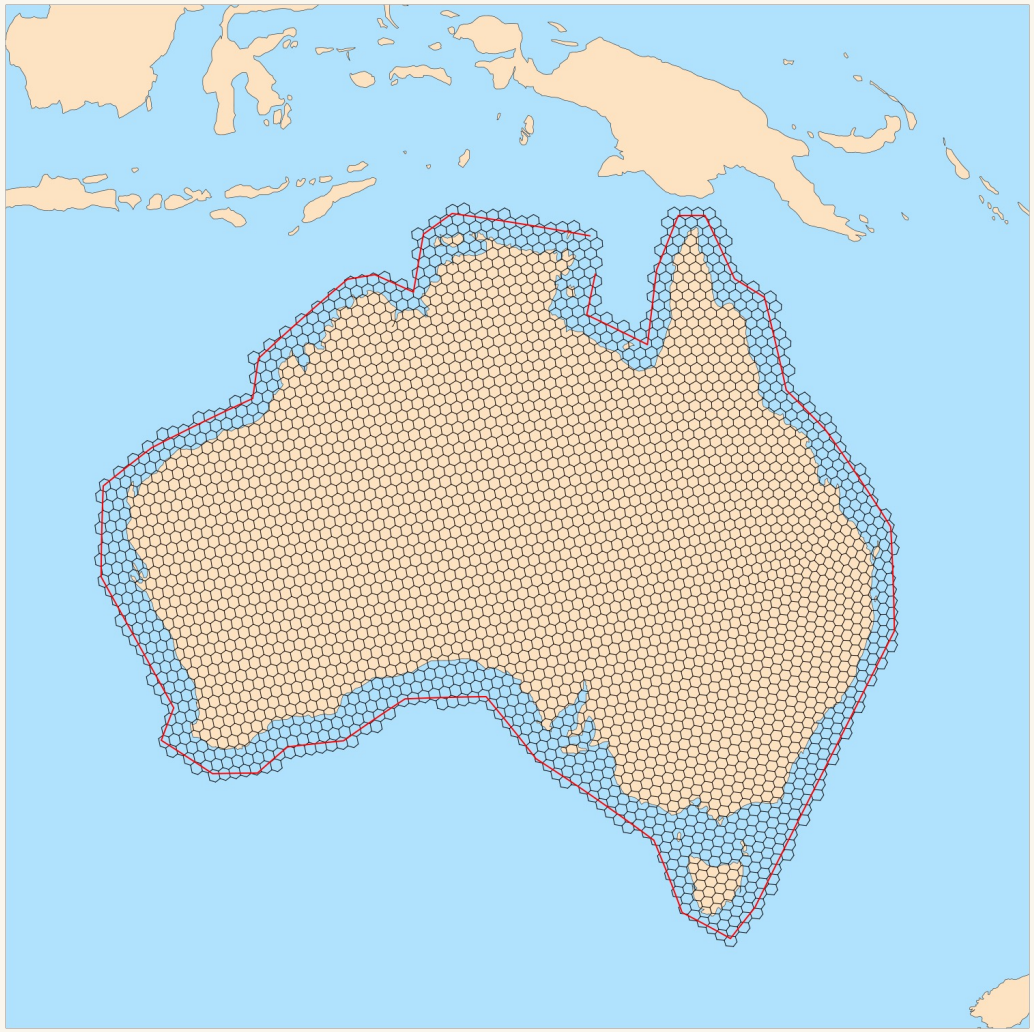
”ulat” gives the upper latitude of the channel, and “llat” gives the lower latitude of the channel

Creating limited-area meshes: polygon region

For polygon regions, the region definition looks like the following

```
Name: Aus
Type: Custom
Point: -24.0, 134.0
-11.36, 137.50
-10.27, 130.85
-11.24, 129.46
...
-15.17, 137.40
-13.20, 137.78
```

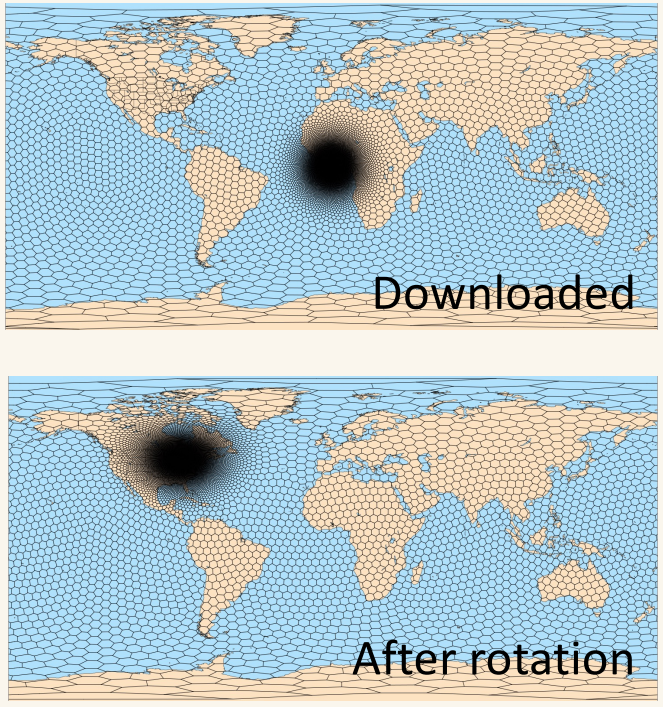
"Point" gives the latitude and longitude of a point that is interior to the polygon, and it is followed by a list of latitude, longitude boundary points



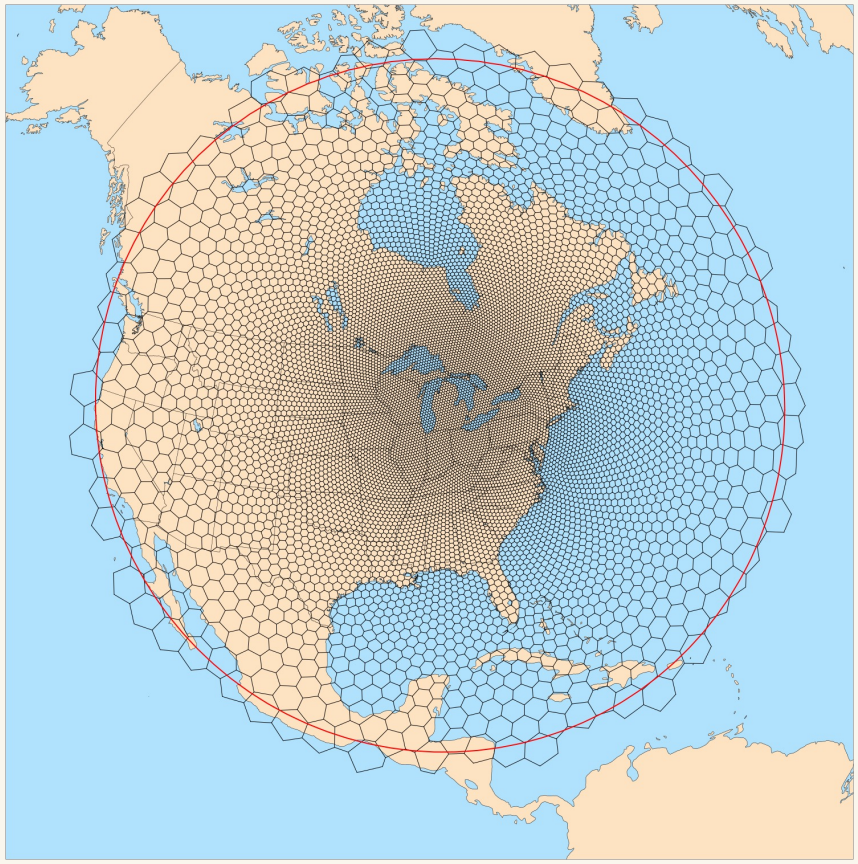
Creating limited-area meshes: refinement

Creating limited-area meshes from variable-resolution “parent” meshes works equally well…

1) Rotate the refinement to a region of interest using the *grid_rotate* tool described earlier



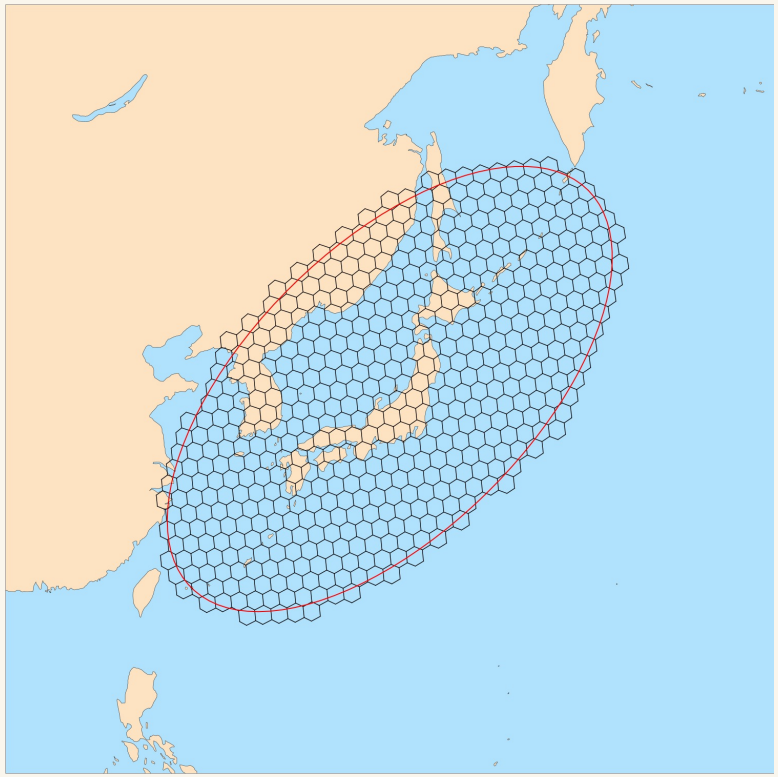
2) Extract a limited-area mesh using MPAS-Limited-Area tool



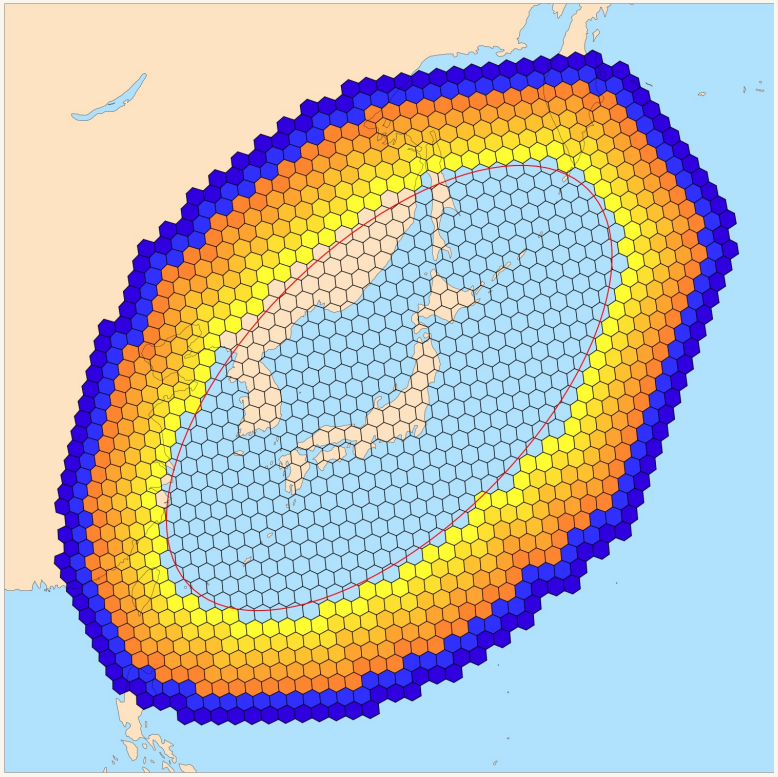
MPAS
Model for Prediction Across Scales

Creating limited-area meshes: boundary cells

After cells inside the region have been identified, layers of *relaxation* and *specified* cells are added



Above: An elliptical region (red) with cells identified as being in the region



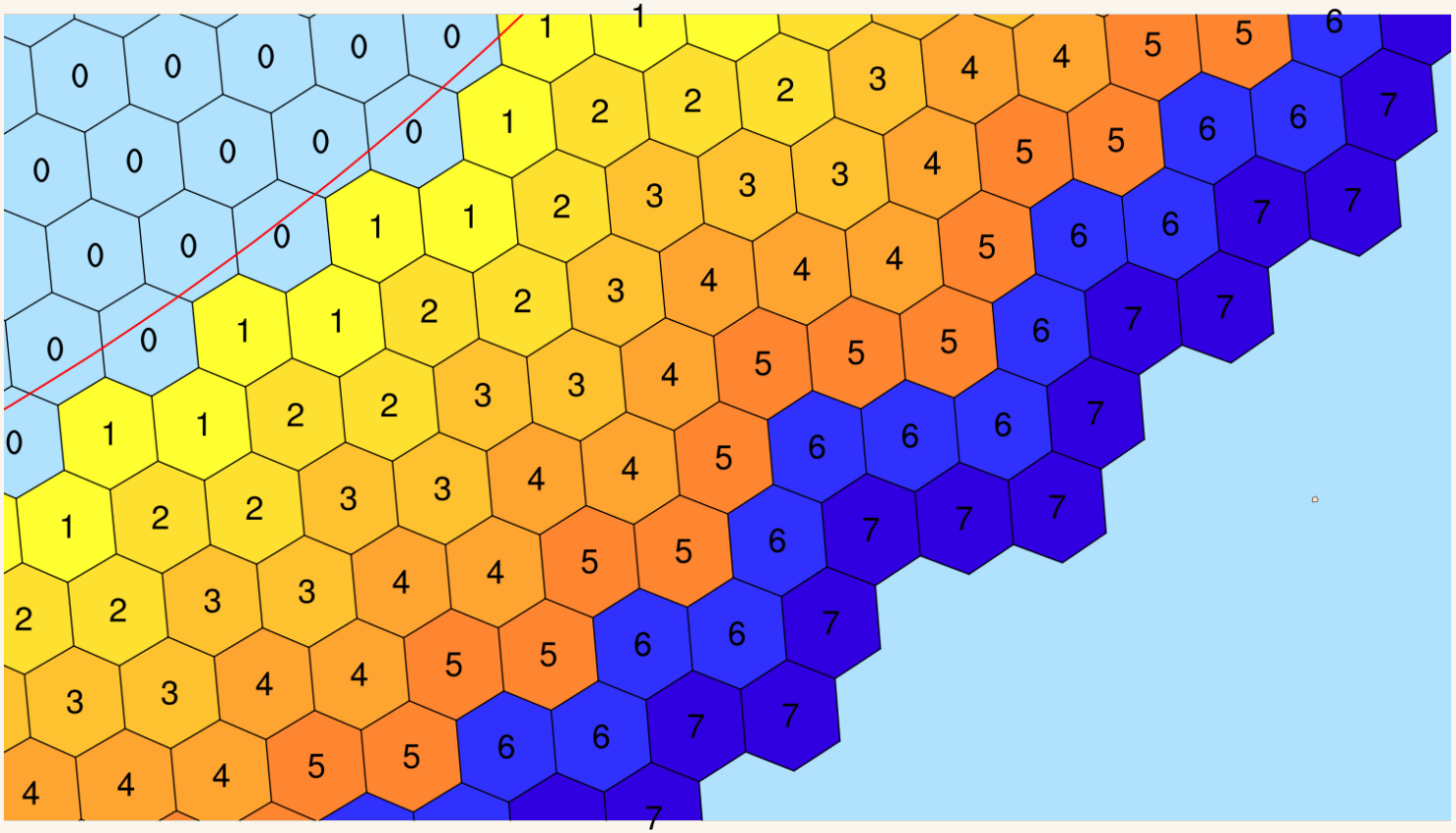
Above: Layers of relaxation zone cells (yellow-orange) and layers of specified zone cells (blue-purple) are added

Creating limited-area meshes: boundary cells

In MPAS v7.0 or later versions, we have

- Five layers of relaxation-zone cells
- Two layers of specified-zone cells

An integer field, `bdyMaskCell`, identifies boundary cell types in the regional mesh file



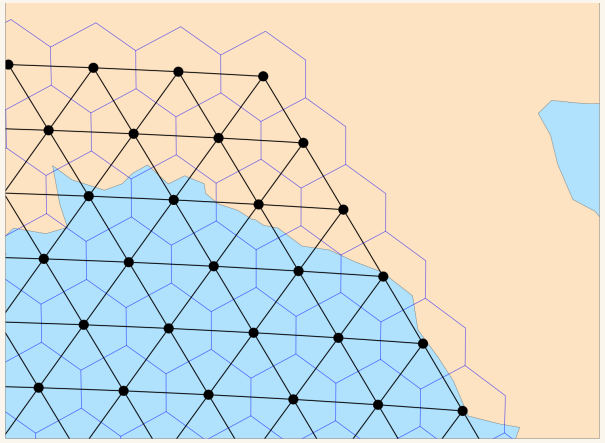
Left: Values of the `bdyMaskCell` field at the lateral boundary

MPAS
Model for Prediction Across Scales

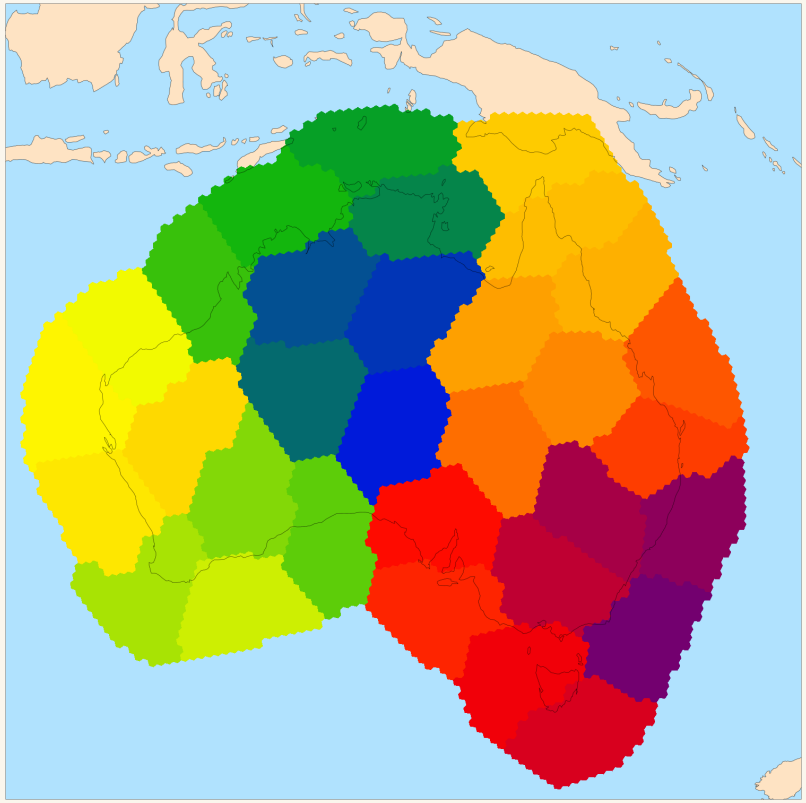
Creating limited-area meshes: partitioning

For newly created limited-area meshes, one must partition the mesh for parallel execution

MPAS-Limited-Area tool writes not only the netCDF mesh file, but also a *graph.info* file



An illustration of the mesh connectivity information contained in a graph.info file



Cells in a regional mesh colored according to their partition in a graph.info.part file

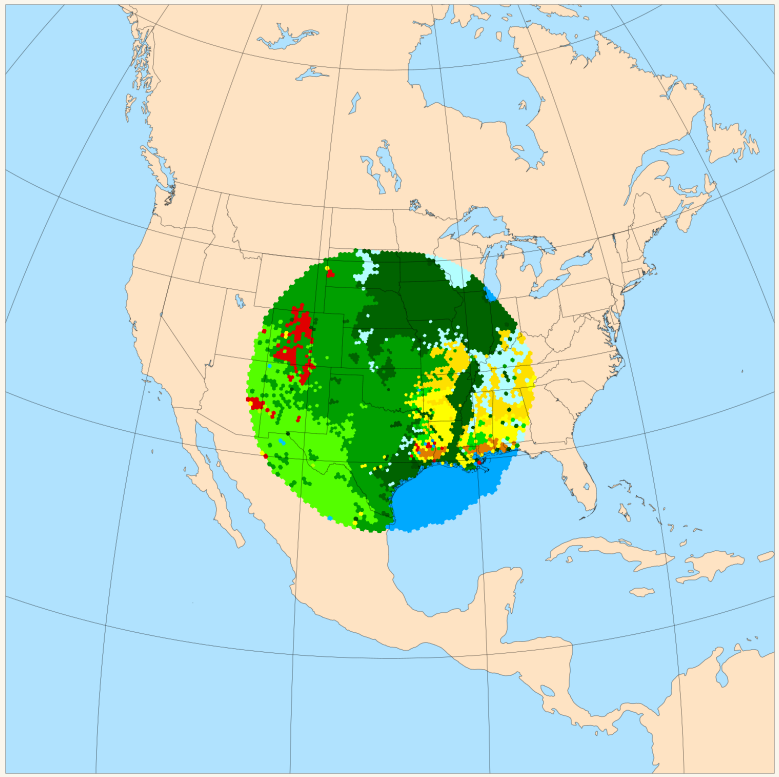
See Section 4.1 in the User's Guide

Creating limited-area meshes: static fields

If no rotation needs to be applied, the MPAS-Limited-Area tool can also subset "static" files

- This can save time, e.g., if a global, uniform static file already exists!

Above: A global, variable-resolution static file that took ~34 minutes to produce



Above: A limited-area subset of the static file that took <5 seconds to subset

MPAS
Model for Prediction Across Scales

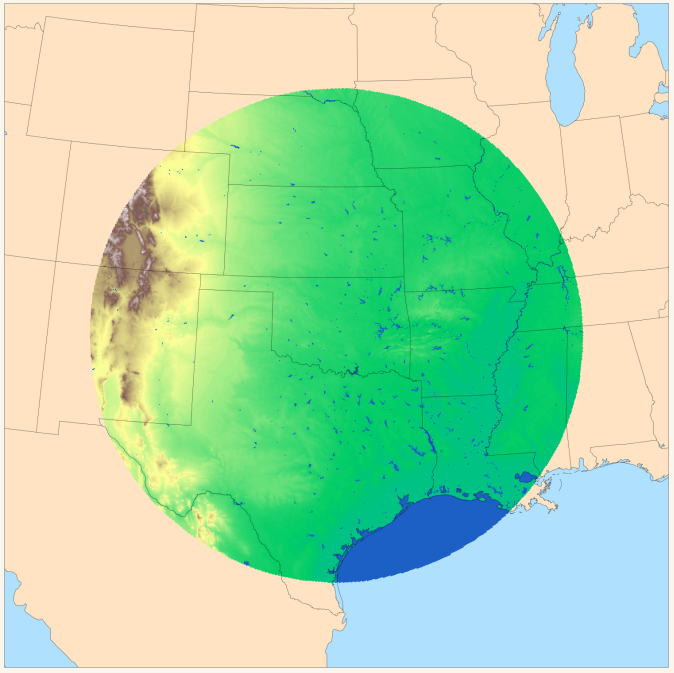
Regional Initial Conditions

Generating limited-area initial conditions works exactly as for global initial conditions, with one exception:

The terrain height in boundary cells is generally averaged with the terrain height from the first-guess dataset

```
&vertical_grid
    config_ztop = 30000.
    config_nsmterrain = 1
    config_smooth_surfaces = true
    config_dzmin = 0.3
    config_nsm = 30
    config_tc_vertical_grid = true
    config_blend_bdy_terrain = true
/
```

Above: When config_vertical_grid=true, config_blend_bdy_terrain should be 'true' as well

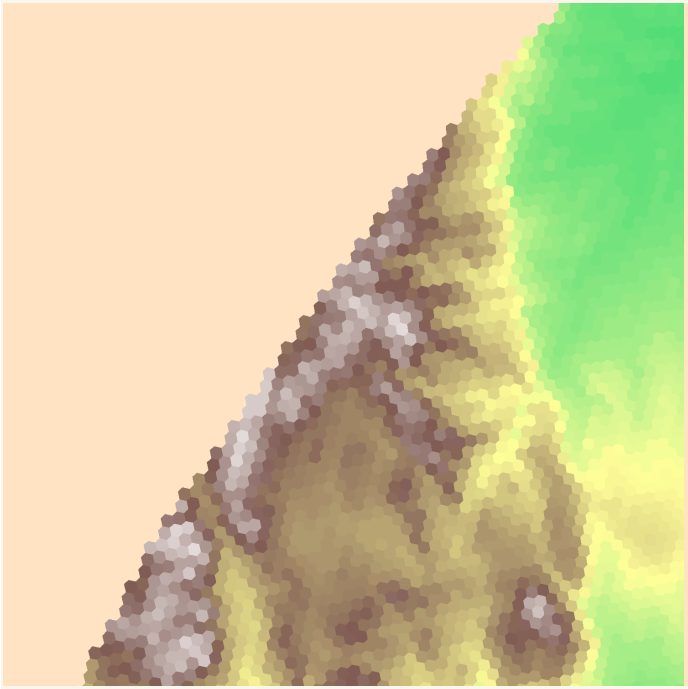


Above: The terrain field in a ~3-km regional mesh

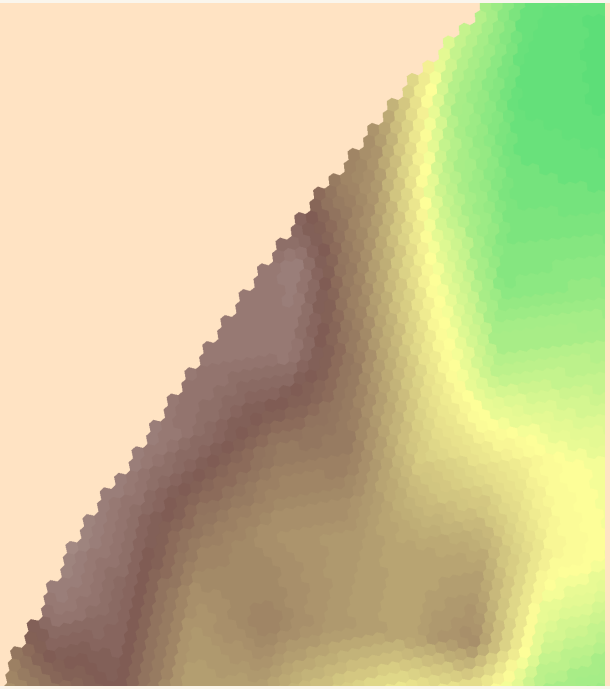
MPAS
Model for Prediction Across Scales

Regional ICs: blending boundary terrain

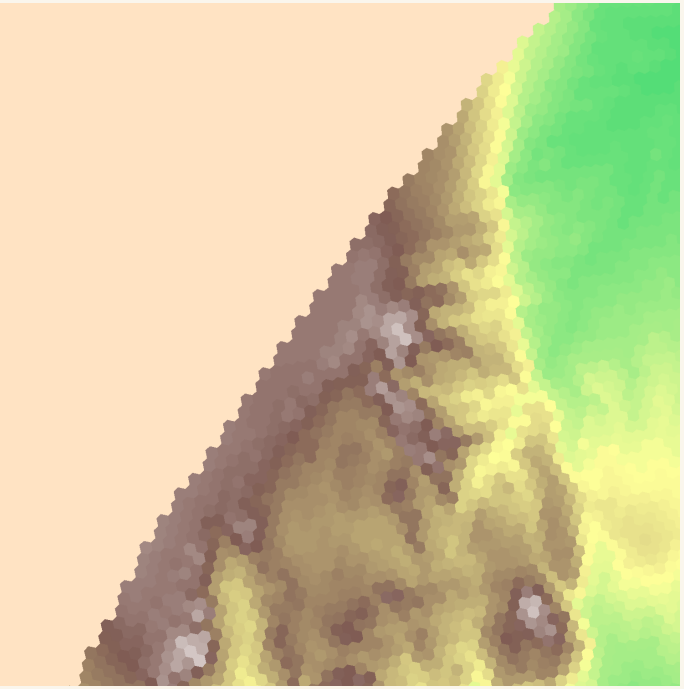
The `config_blend_bdy_terrain` option only affects terrain in the boundary cells (where `bdyMaskCell` > 0)



Terrain field from 3-km static file, interpolated directly from GMTED2010



0.25-deg GFS terrain field interpolated to 3-km mesh

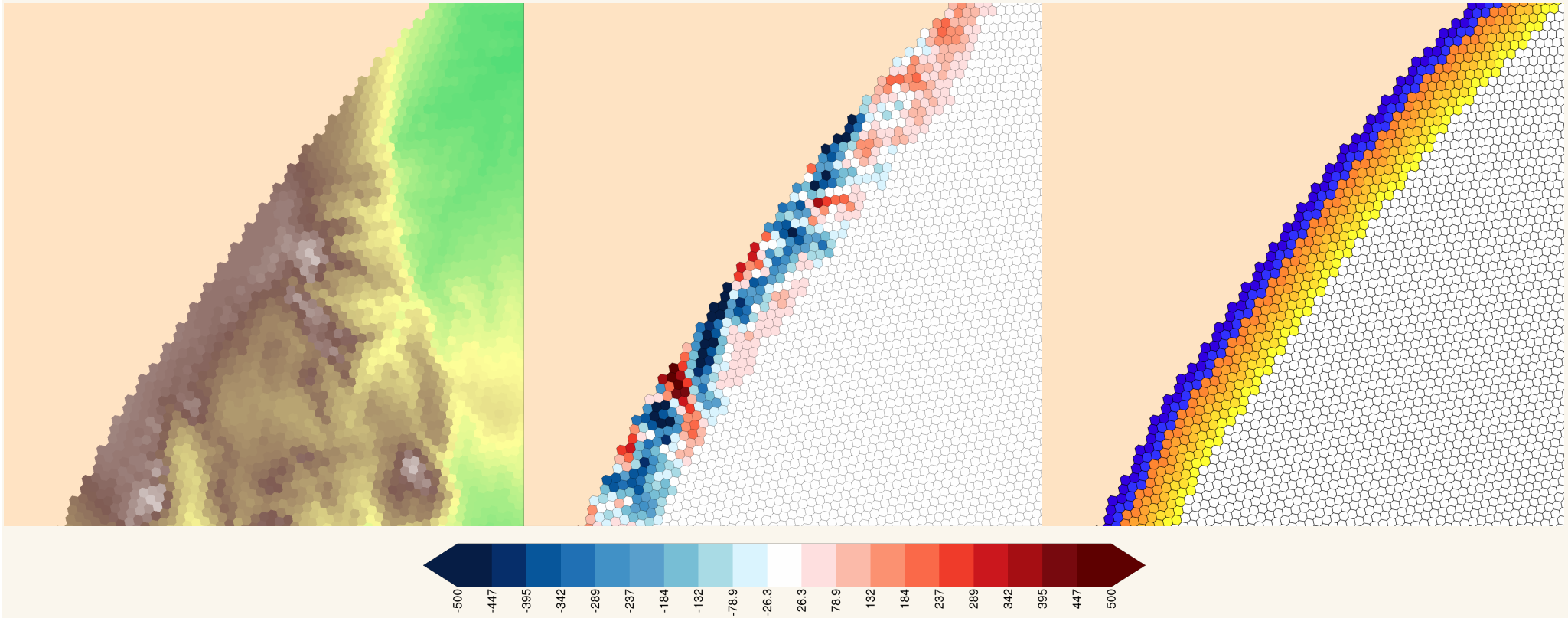


Blended terrain field used in the generation of vertical coordinate surfaces

MPAS
Model for Prediction Across Scales

Regional ICs: blending boundary terrain

The `config_blend_bdy_terrain` option only affects terrain in the boundary cells (where `bdyMaskCell` > 0)



Blended terrain field

Diff between blended terrain field and original terrain field

bdyMaskCell (>0 for yellow-orange and blue-purple cells)

Generating regional LBCs

Lateral Boundary Conditions (LBCs) for limited-area simulations are created by the *init_atmosphere* core with "init case" 9:

```
&nhyd_model
    config_init_case = 9
    config_start_time = '2019-08-31_00:00:00'
    config_stop_time = '2019-09-03_00:00:00'
/
&data_sources
    config_met_prefix = 'GFS'
    config_fg_interval = 10800
    config_use_spechumd = false
/
&interpolation_control
    config_extrap_airtemp = 'linear'
/
```

Left: The key namelist options to be set when generating lateral boundary conditions with the init_atmosphere core

See Section 8.2 in the User's Guide

MPAS
Model for Prediction Across Scales

Generating regional LBCs

The “input” stream must be set up to read from a file with vertical grid information

- Typically, this done by setting the `filename_template` to the name of the initial conditions file

```
<immutable_stream name="input"
                  type="input"
                  filename_template=”CONUS.init.nc"
                  input_interval="initial_only" />
```

- Also use a different file name for output `filename_template`

```
<immutable_stream name=”output"
                  type=”output"
                  filename_template=”other.init.nc"
                  input_interval="initial_only" />
```

MPAS
Model for Prediction Across Scales

Generating regional LBCs

The “output_interval” for the “lbc” stream must also be set in the streams.init_atmosphere file

- This interval must match config_fg_interval from the namelist.init_atmosphere file, as well as data processed by ungrib

```
<immutable_stream name="lbc"
                  type="output"
                  filename_template="lbc.$Y-$M-$D_$h.$m.$s.nc"
                  filename_interval="output_interval"
                  packages="lbcs"
                  output_interval="3:00:00" />
```

Above: A typical “lbc” stream definition for the init_atmosphere core. Besides the output_interval, one may also change the filename_template.

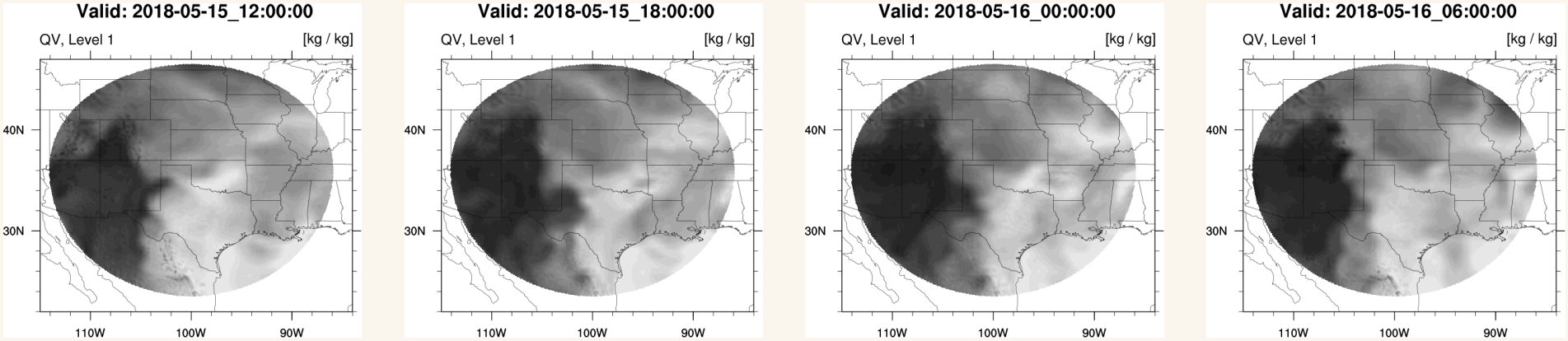
```
lbc.2019-08-31.00.00.00.nc
```

MPAS
Model for Prediction Across Scales

What's in an LBC file?

The individual LBC netCDF files contain *full, uncoupled fields* of:

- Potential temperature (`lbc_theta`)
- Dry density (`lbc_rho`)
- Normal component of horizontal winds on edges (`lbc_u`)
- Vertical velocity on vertical cell interfaces (`lbc_w`)
- Scalars (`lbc_qv`, `lbc_qc`, `lbc_qr`, etc.)
- Valid time of fields (`xtime`)



These fields are interpolated and written at:

T_0, $T_0+\Delta t_{LBC}$, $T_0+2\Delta t_{LBC}$, $T_0+3\Delta t_{LBC}$, …

Applying LBCs during the simulation

When running the atmosphere core (i.e., the model itself), enable the enforcement of LBCs in the `namelist.atmosphere` file:

```
&limited_area
    config_apply_lbcs = true
/
```

Above: The only namelist option needed to "activate" a regional simulation in MPAS v7.0

If `config_apply_lbcs` is not set to true for a regional simulation, the model will stop with the following error:

```
ERROR: Boundary cells found in the bdyMaskCell field, but config_apply_lbcs = false.
ERROR: Please ensure that config_apply_lbcs = true for limited-area simulations.
ERROR: Please correct issues with the model input fields and/or namelist.
```

MPAS
Model for Prediction Across Scales

Applying LBCs during the simulation

Additionally, set the “input_interval” for the “lbc_in” stream in the streams.atmosphere file

- The interval *must not be higher in frequency* than the interval at which LBC files were produced!

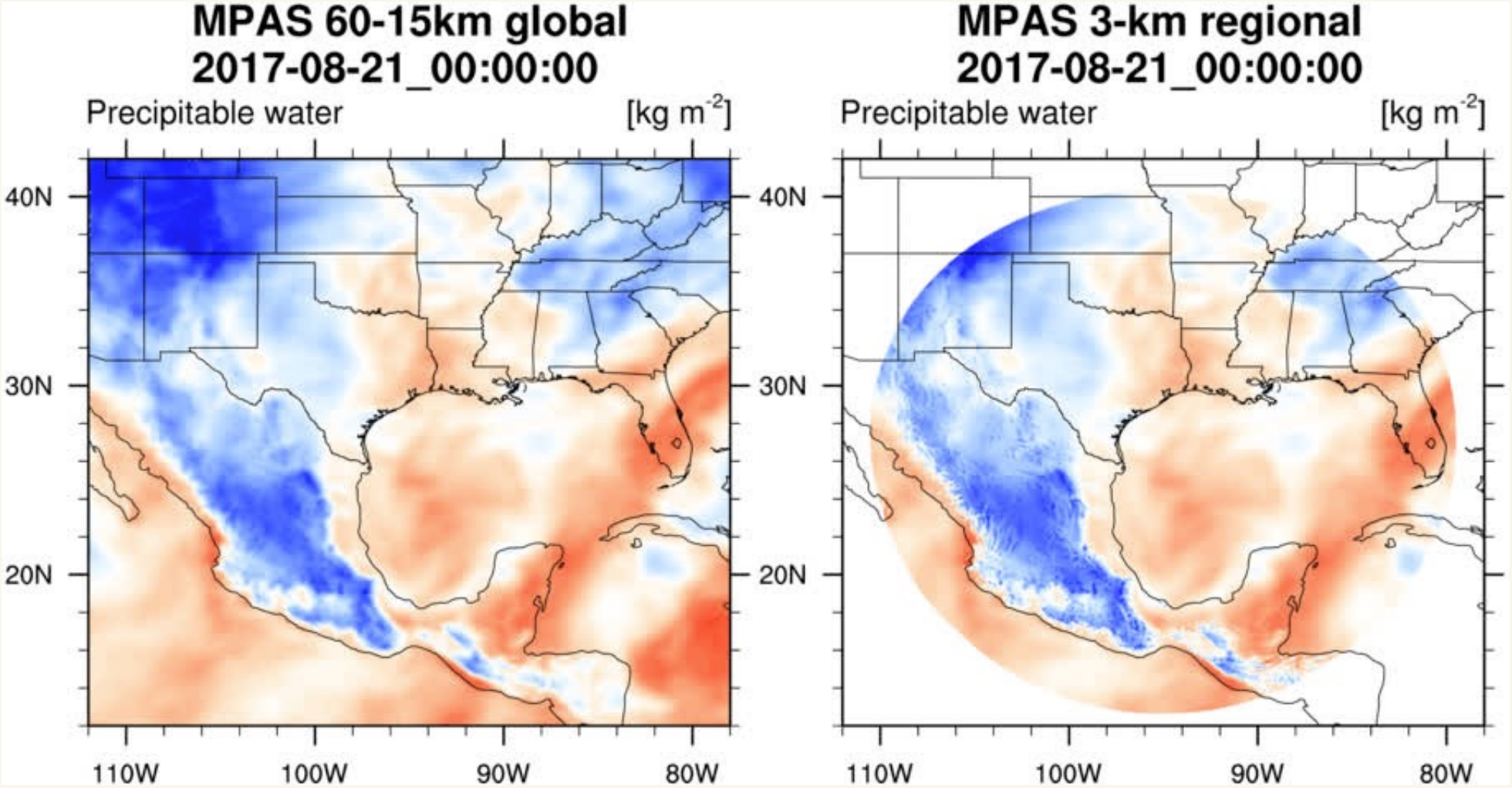
```
<immutable_stream name="lbc_in"
                  type="input"
                  filename_template="lbc.$Y-$M-$D_$h.$m.$s.nc"
                  filename_interval="input_interval"
                  packages="limited_area"
                  input_interval="3:00:00" />
```

If the “input_interval” is smaller than the interval of LBC files, the model will stop with an error like:

```
ERROR: Could not read from 'lbc_in' stream after the current date to update lateral
boundary tendencies
ERROR: Failed to process LBC data at next time after 2019-08-31_00:00:00
```

MPAS
Model for Prediction Across Scales

Example simulation: Hurricane Harvey



Above: Animation of the precipitable water field from a 6-day variable-resolution, global simulation alongside a 6-day regional simulation

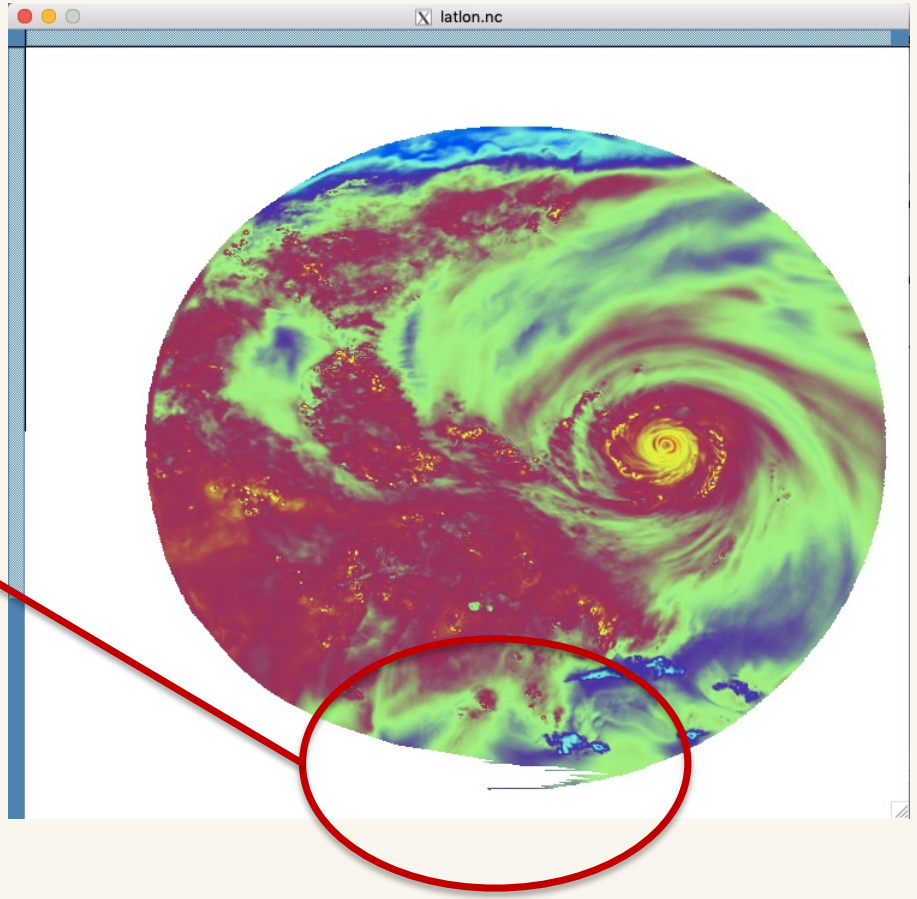
MPAS
Model for Prediction Across Scales

Post-processing concerns

As of today, the *convert_mpas* program doesn't handle limited-area meshes very well…

- "Smearing" or "streaking" is almost certainly an interpolation artifact and not a problem in your model fields
- We need to fix this!

These are interpolation artifacts produced by the convert_mpas program as of this tutorial…



MPAS
Model for Prediction Across Scales

Summary

Running limited-area simulations is only slightly more difficult than running a global simulation!

1) Create a subset of an existing mesh with the MPAS-Limited-Area tool
2) If subsetting a mesh, run init_atmosphere to produce static file
3) Generate initial conditions using “init case” 7 as usual, and set

```
&vertical_grid
    config_blend_bdy_terrain = true
/
```

4) Generate LBCs using “init case” 9
5) Run the model as usual, and set

```
&lbcs
    config_apply_lbcs = true
/
```

and set the input interval for the “lbc_in” stream in the `streams.atmosphere` file

MPAS
Model for Prediction Across Scales

About Configuring a Regional Simulation

Best practices are required:

1) Regional domain size should be large enough to allow true model solution to develop
2) Choose better horizontal and vertical resolution forcing data whenever possible
3) Choose higher time frequency forcing data for lateral boundary conditions

Other readings:

Skamarock, W. C., M. G. Duda, S. Ha, and S-H. Park, 2018: Limited-Area Atmospheric Modeling Using an Unstructured Mesh. Mon. Wea. Rev., 146, 3445-3460. doi: 10.1175/MWR-D-18-0155.1

https://www2.mmm.ucar.edu/wrf/users/workshops/WS2021/presentation_pdfs/regional_mpas.pdf