Regional MPAS-Atmosphere

NCAR/MMM

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MPAS
Model for Prediction Across Scales

Outline

1. Introduction
2. System overview
3. Defining regional domains

5 minute break

4. Preparing atmospheric data
5. Creating a vertical grid
6. Preparing ICs
7. Preparing LBCs
8. Model configuration
9. Regional testing and comparison

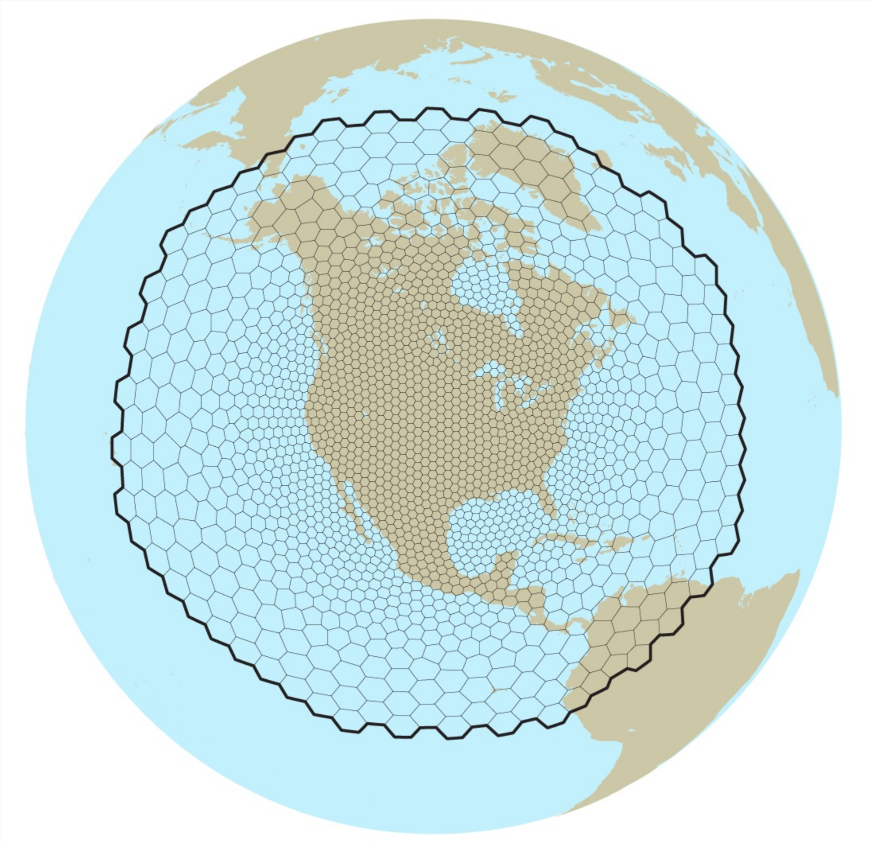
MPAS
Model for Prediction Across Scales

Outline

Regional MPAS

Introduction

What is regional MPAS and similarities with WRF



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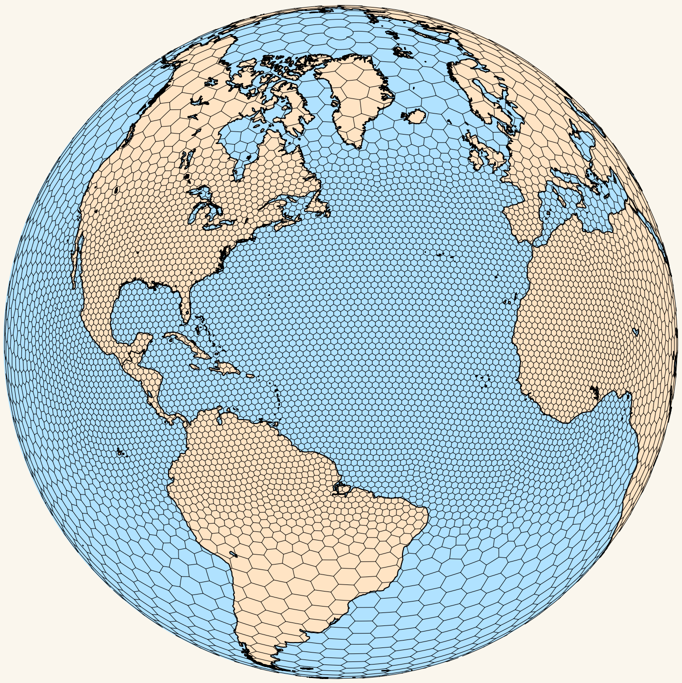
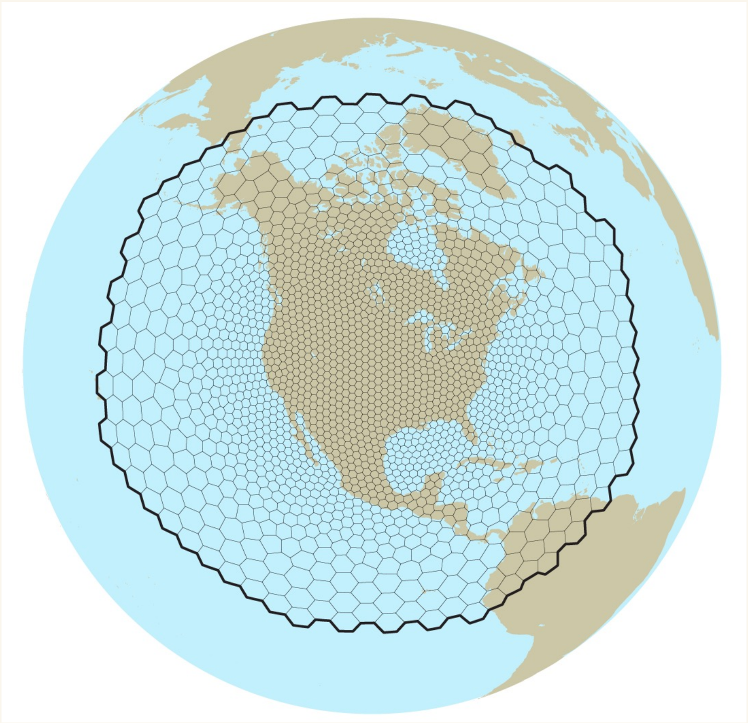
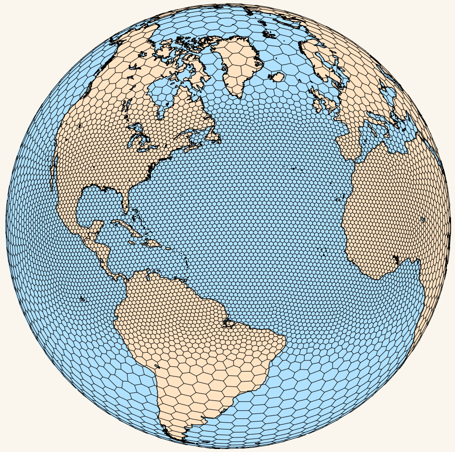
MPAS Tutorials





- A complete online tutorial covering both regional and global applications for MPAS can be found at
  https://www.mmm.ucar.edu/mpas-tutorial-agenda (April 2021 virtual tutorial)
  This link points to pdfs and recorded lectures.
- The next MPAS tutorial is tentatively scheduled for spring of 2022.

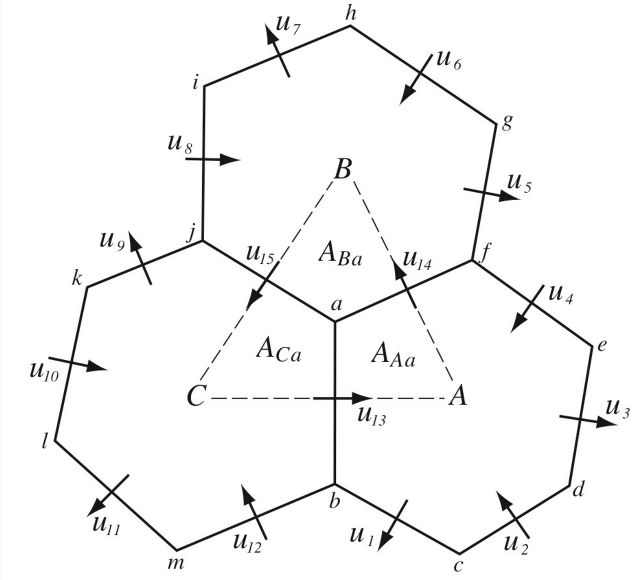
MPAS-Atmosphere



MPAS-Atmosphere solves the fully-compressible nonhydrostatic equations

<u>Unstructured spherical centroidal Voronoi meshes</u>

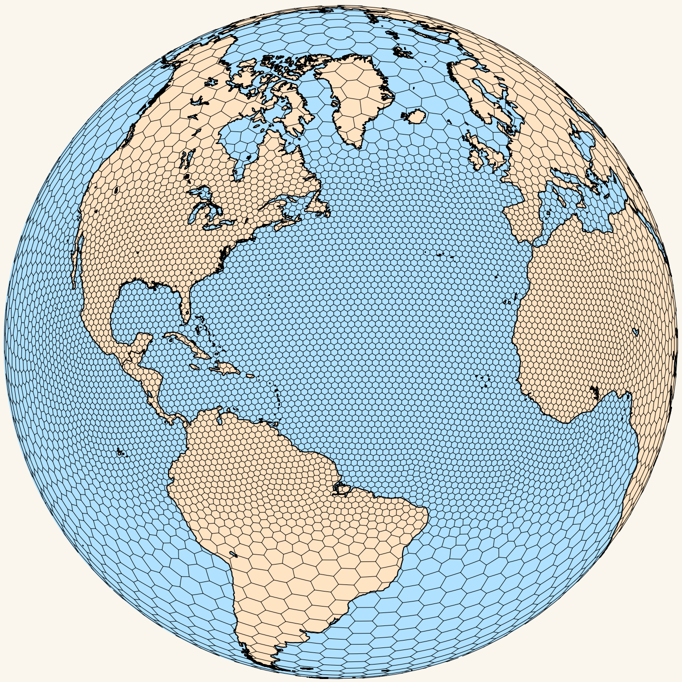
- Mostly *hexagons*, some pentagons and 7-sided cells
- Cell centers are at cell center-of-mass (centroidal).
- Cell edges bisect lines connecting cell centers; perpendicular.
- Uniform resolution – traditional icosahedral mesh.

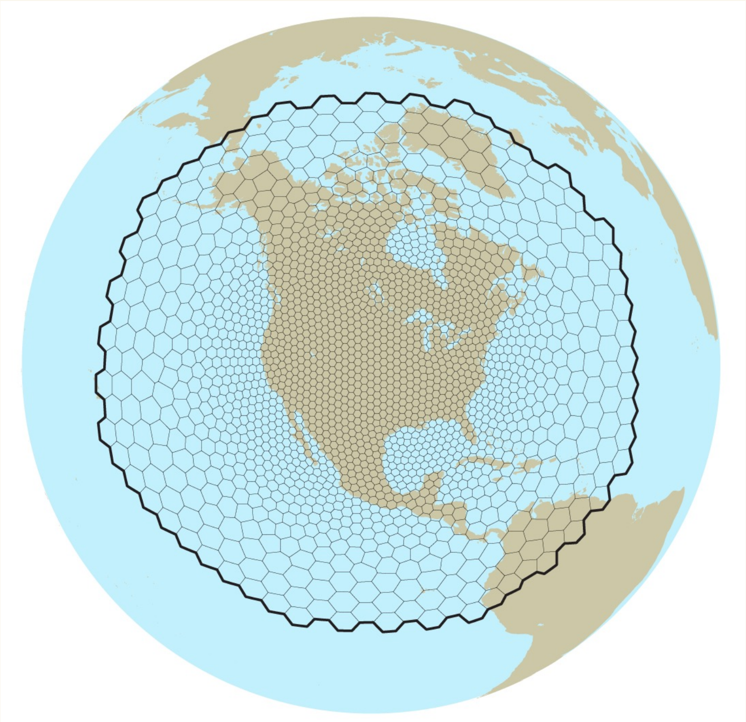


Time integration scheme as in Advanced Research WRF: Split-explicit Runge-Kutta (3rd order)

- Prognostic equations for coupled variables.
- Generalized height coordinate.

Global and Regional





- MPAS global and regional meshes differ in that the regional meshes do not cover the entire sphere and integration using the regional meshes require lateral boundary conditions.
- The MPAS model (dynamical core and physics) integrates both global and regional meshes by making use of a few boundary adjustment routines and boundary masks.

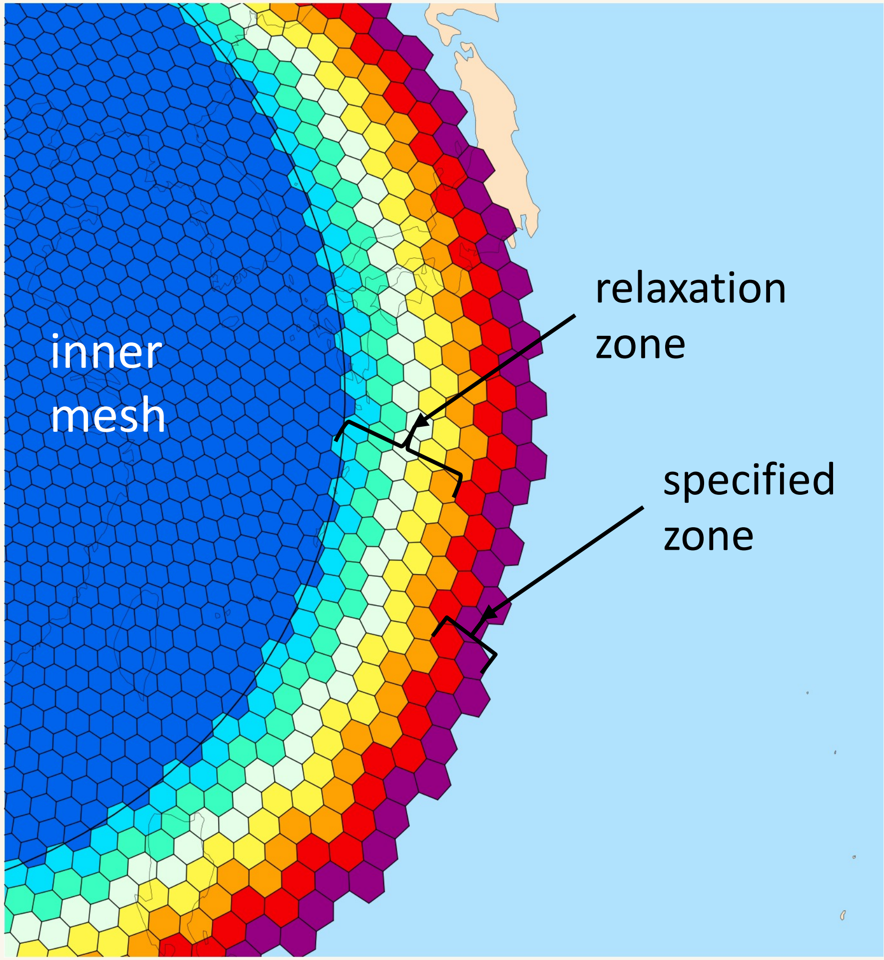
MPAS Model for Prediction Across Scales

Global and Regional

Global MPAS time integration	Regional MPAS time integration
Call physics	*Call physics*
Do dynamics_split_steps	Do dynamics_split_steps
Do rk3_step = 1, 3	Do rk3_step = 1, 3
compute large-time-step tendency	*compute large-time-step tendency*
	adjust boundary tendencies
Do acoustic_steps	Do acoustic_steps
update u	*update u*
update rho, theta and w	*update rho, theta and w*
End acoustic_steps	End acoustic_steps
	adjust boundary velocities (u and w)
End rk3_step	End rk3_step
End dynamics_split_steps	End dynamics_split_steps
Do scalar_rk3_step = 1, 3	Do scalar_rk3_step = 1, 3
scalar RK3 transport	*scalar RK3 transport*
	adjust scalar boundary tendencies
End scalar_rk3_step	End scalar_rk3_step
Call microphysics	*Call microphysics*

Regional MPAS

The regional MPAS meshes have a relaxation zone and specified zone at their outer edge, with boundary and relaxation zone numerics treated the same way as in WRF.



Relaxation Zone Specification

Filters in the relaxation zone

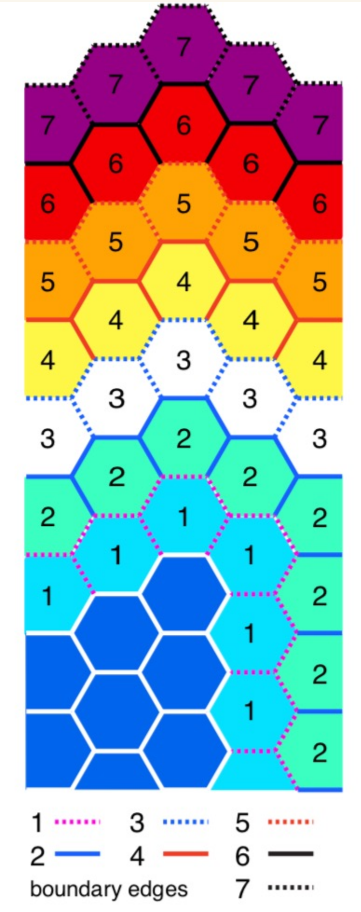
$$\frac{\partial \psi}{\partial t} = RHS_{\psi} + F_1(\psi_{LS} - \psi) - F_2 \Delta x^2 \nabla^2 (\psi_{LS} - \psi)$$

Rayleigh damping to the large-scale (LS) value

2nd-order spatial damping of the perturbation from the (LS) value

$$F_1 = \gamma_1 (i-1)/m, \quad F_2 = \gamma_2 (i-1)/m$$

These are the same filters used in WRF



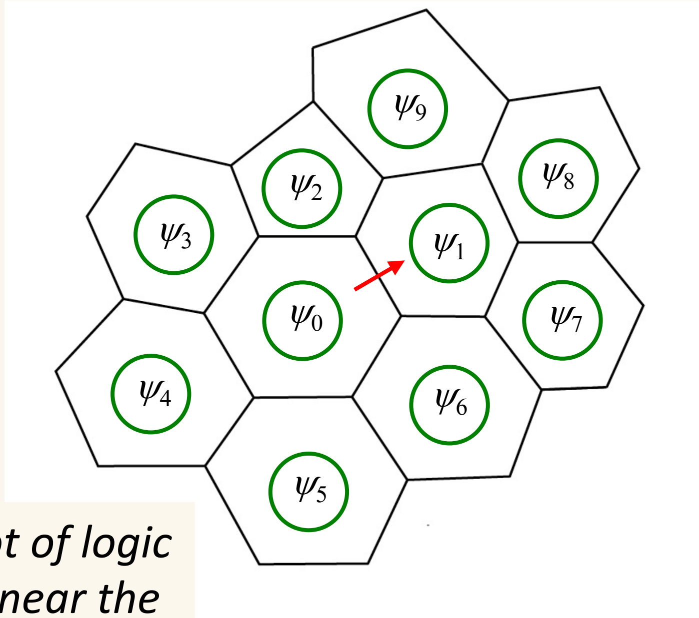
Boundary Zone Specification

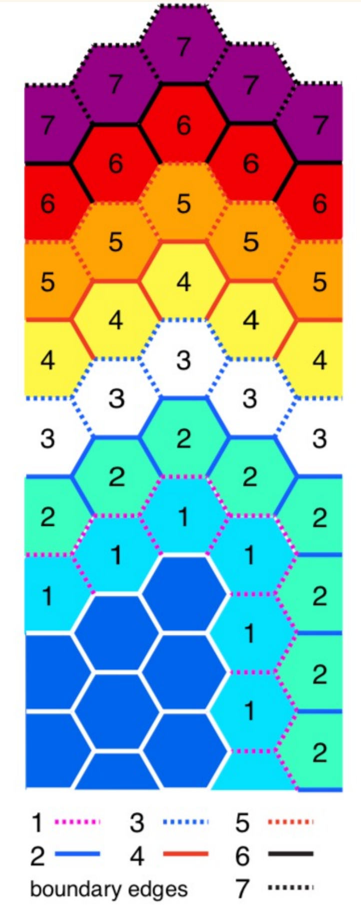
Why *two* specified cell rows?

Largest horizontal operator stencils are for the horizontal transport and the 4rth-order filter. Both need two rows to fill out their stencil. *No tests for boundaries in the MPAS solver!*

Example: fluxes in the transport scheme.

Cell-values needed to compute the 3rd order 4th order flux across an edge

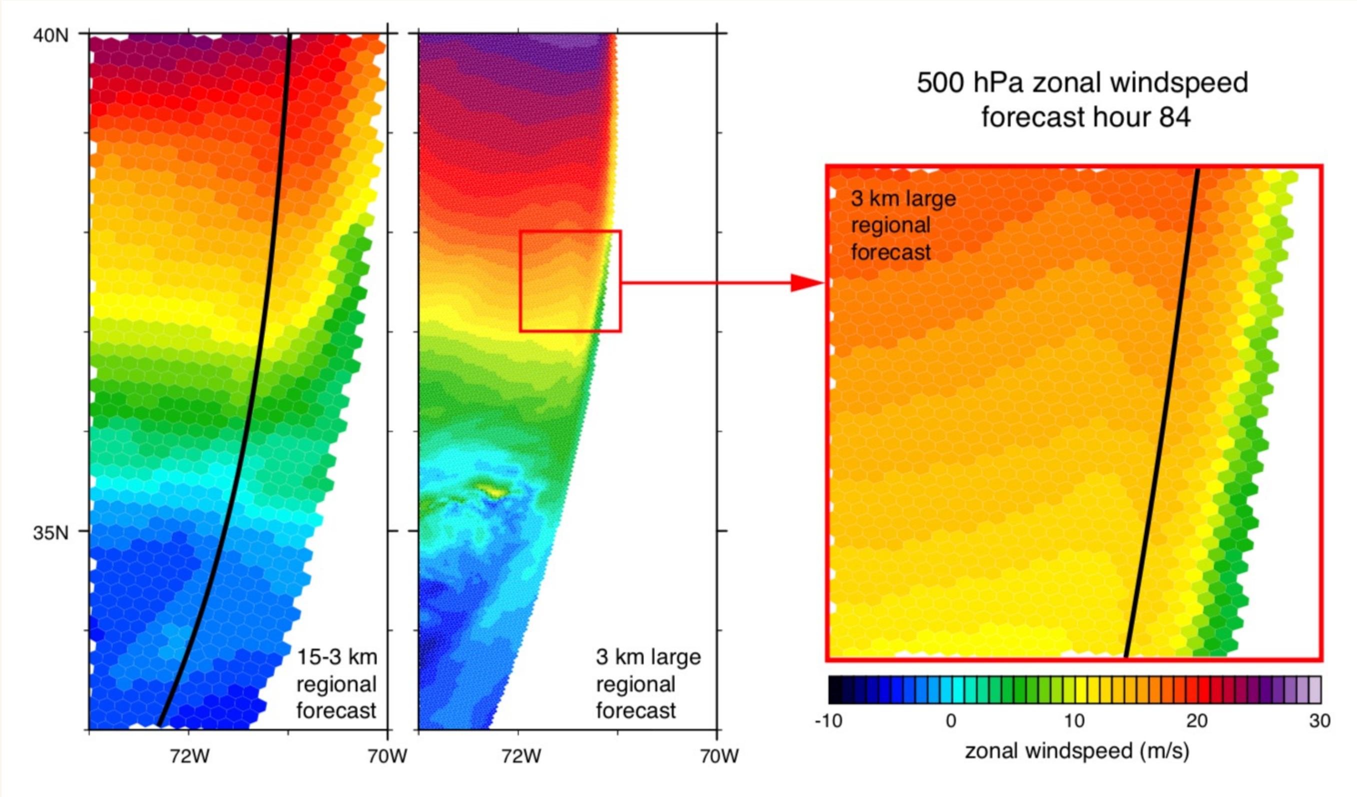




WRF uses 1 specified row and a lot of logic in the solver to change operators near the boundaries!

Regional MPAS

Variable resolution: coarsening the mesh towards the boundaries allows for more efficient filtering and less-abrupt solution mis-matches. Matching the resolution of the driving analysis is a good configuration policy.



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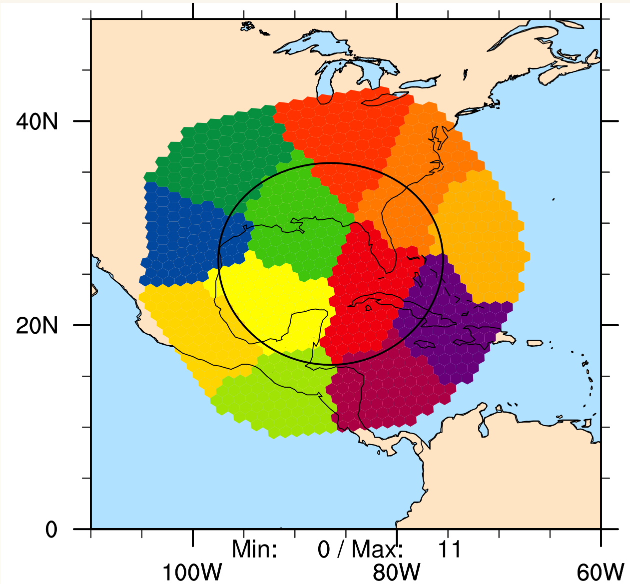
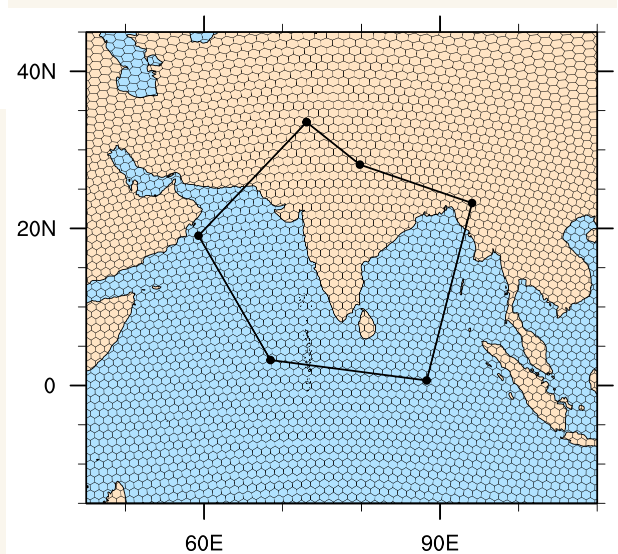
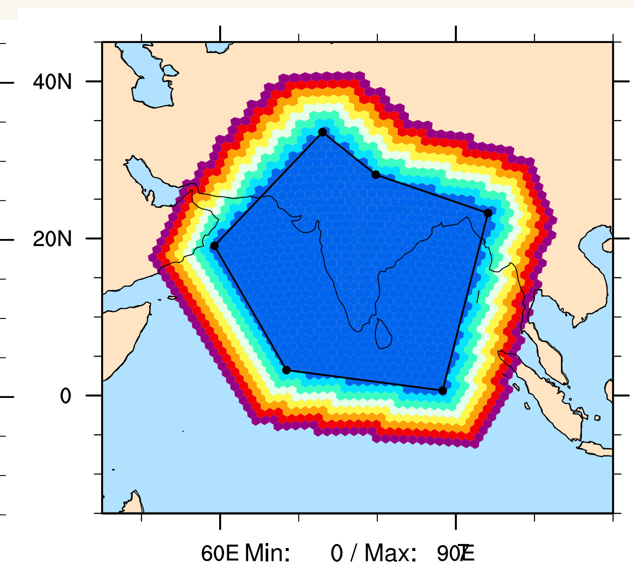
Regional MPAS



Parallelization by horizontal domain decomposition is accomplished the same way as in global MPAS

Existing tool allows regional zones to be specified as circles, ellipses, or polygons





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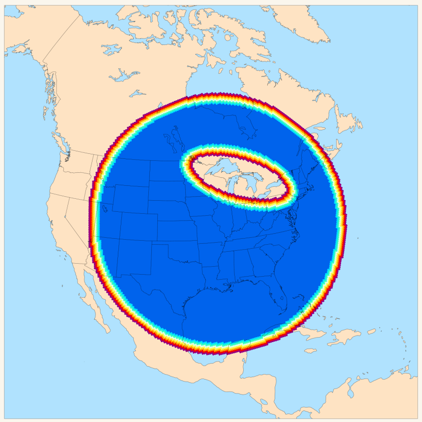
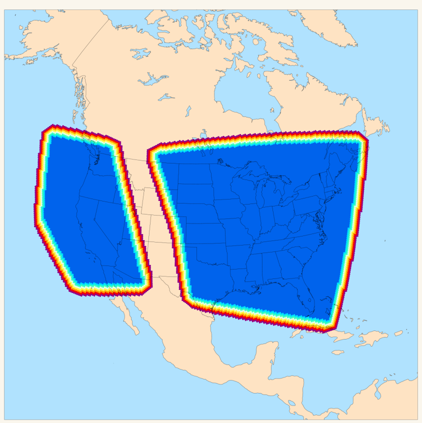
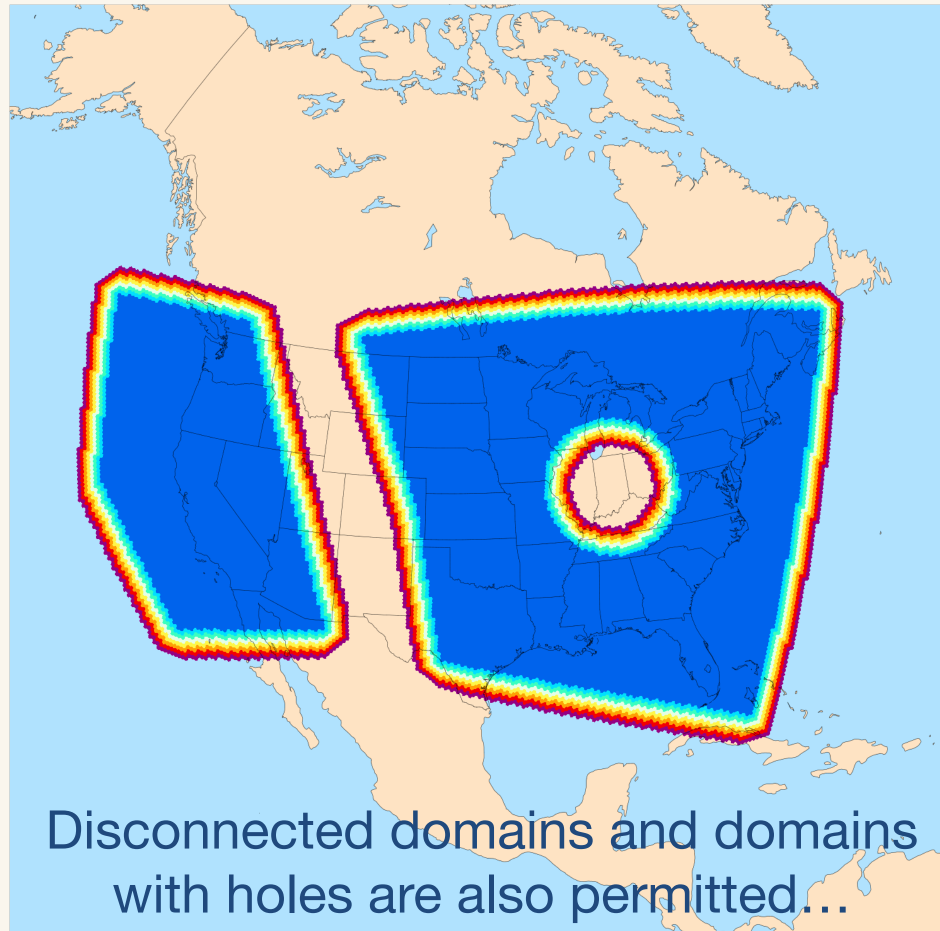
Regional MPAS

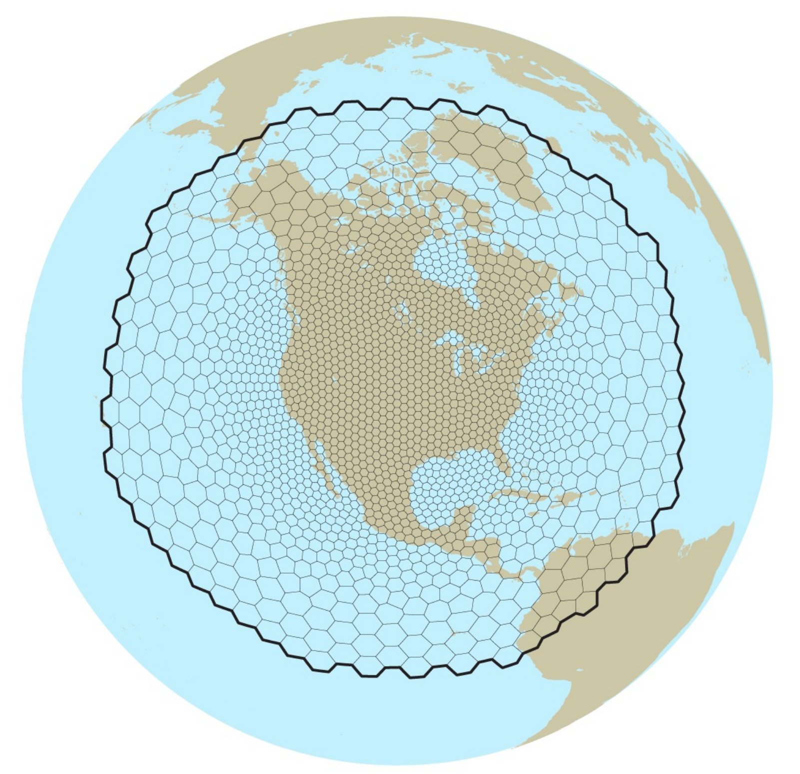
Significant flexibility in domain configuration is possible with the unstructured mesh and the LBC implementation







Regional MPAS



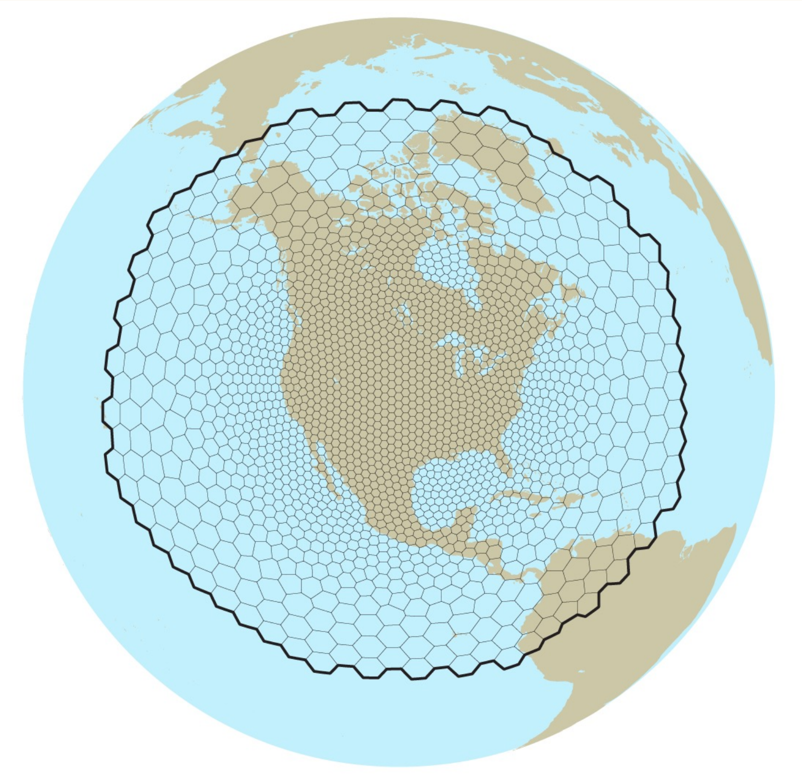
Why is there a regional version of MPAS given we have WRF?

- Provide a consistent (equations, mesh) regional solver to complement global MPAS.
- Allow for more efficient (less costly) testing of MPAS at high resolutions.
- Leverage MPAS development for next-generation architectures to regional applications.
- Enable regional atmospheric applications within MPAS-enabled coupled modeling systems (e.g. CESM).
- Employ variable resolution in regional applications to reduce LBC errors.

Regional MPAS

Why use MPAS instead of WRF?

- MPAS has clean local refinement capabilities using variable resolution mesh.
- MPAS is a much better global model – no polar filters or pole problems.
- MPAS regional code is a much cleaner implementation of LBCs compared to WRF.
- More extensive capabilities are under development.



More information:

(1) This short course, of course!

(2) Full MPAS tutorial - https://www.mmm.ucar.edu/mpas-tutorial-agenda

(3) Paper describing regional MPAS implementation and tests

W. C. Skamarock, M. G. Duda, S. Ha, and S.-H. Park, 2018: Limited-Area Atmospheric Modeling Using an Unstructured Mesh. Monthly Weather Review, doi:10.1175/MWR-D-18-0155.1

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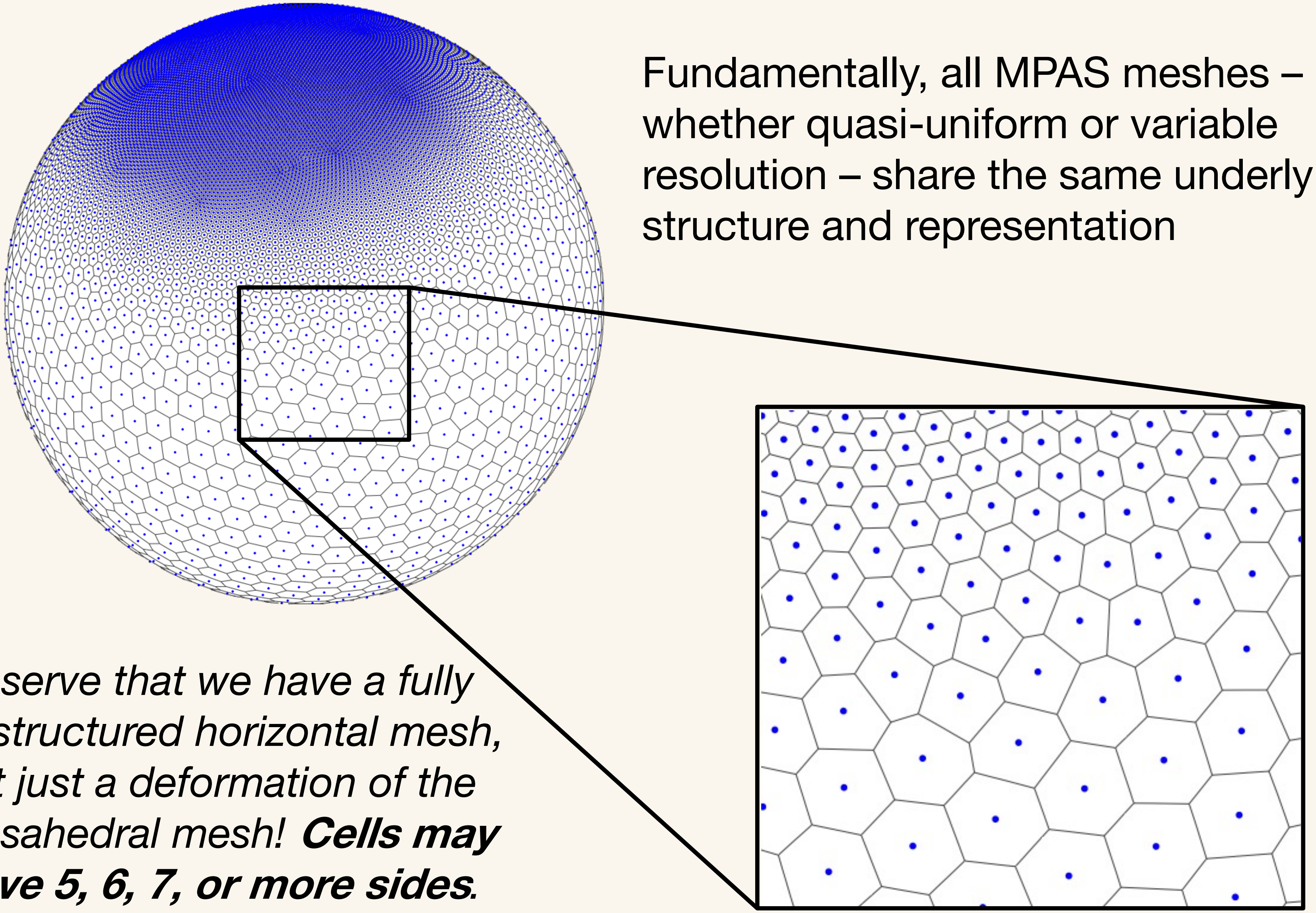
A few words about meshes

Fundamentally, all MPAS meshes – whether quasi-uniform or variable resolution – share the same underlying structure and representation

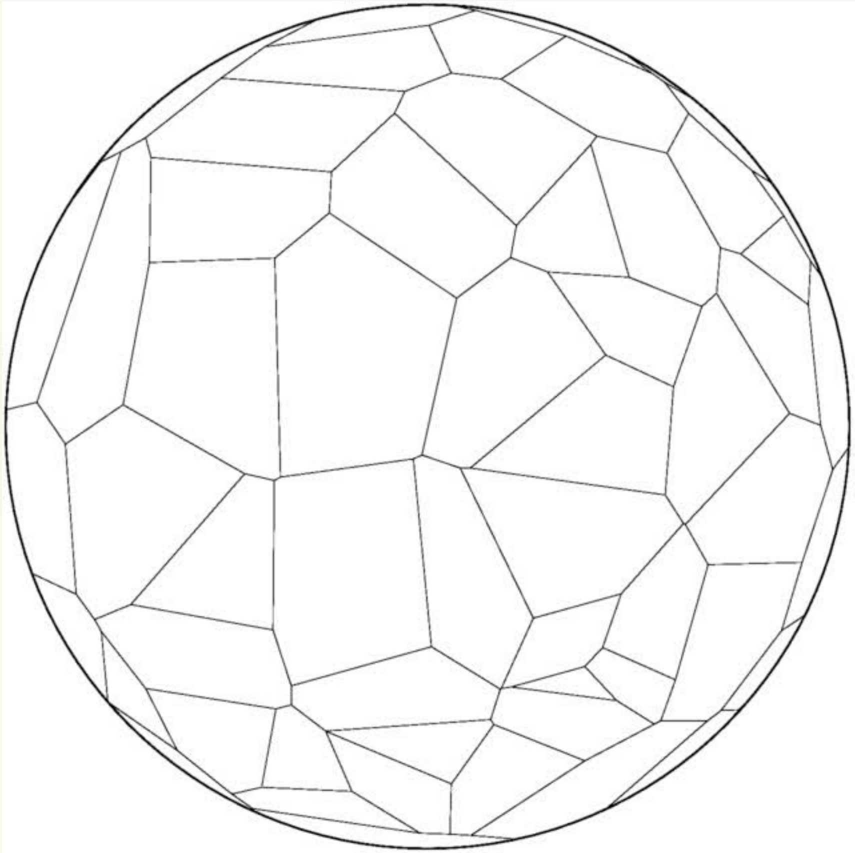


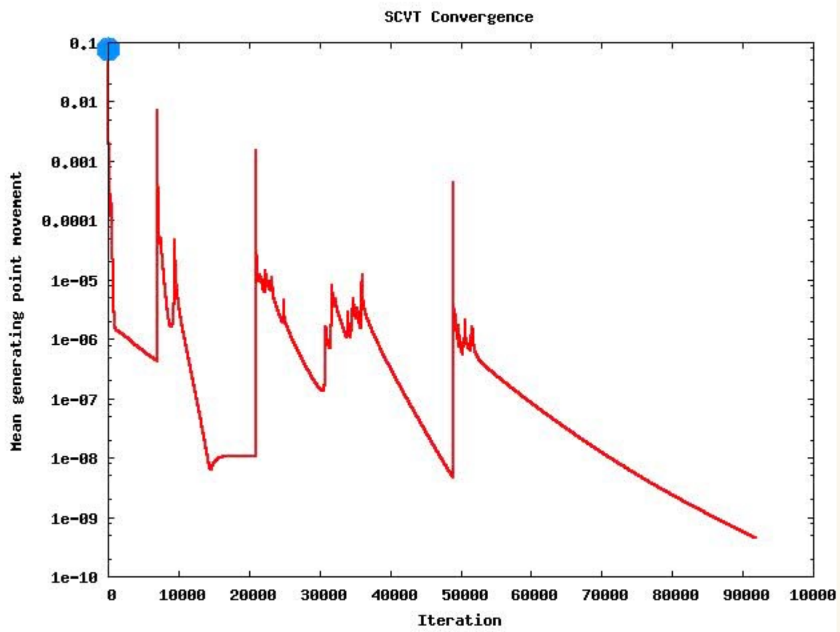
Observe that we have a fully unstructured horizontal mesh, not just a deformation of the icosahedral mesh! ***Cells may have 5, 6, 7, or more sides***.

A few words about meshes

Variable-resolution meshes are generated through an iterative process that distributes cells in the mesh according to a *mesh density* function

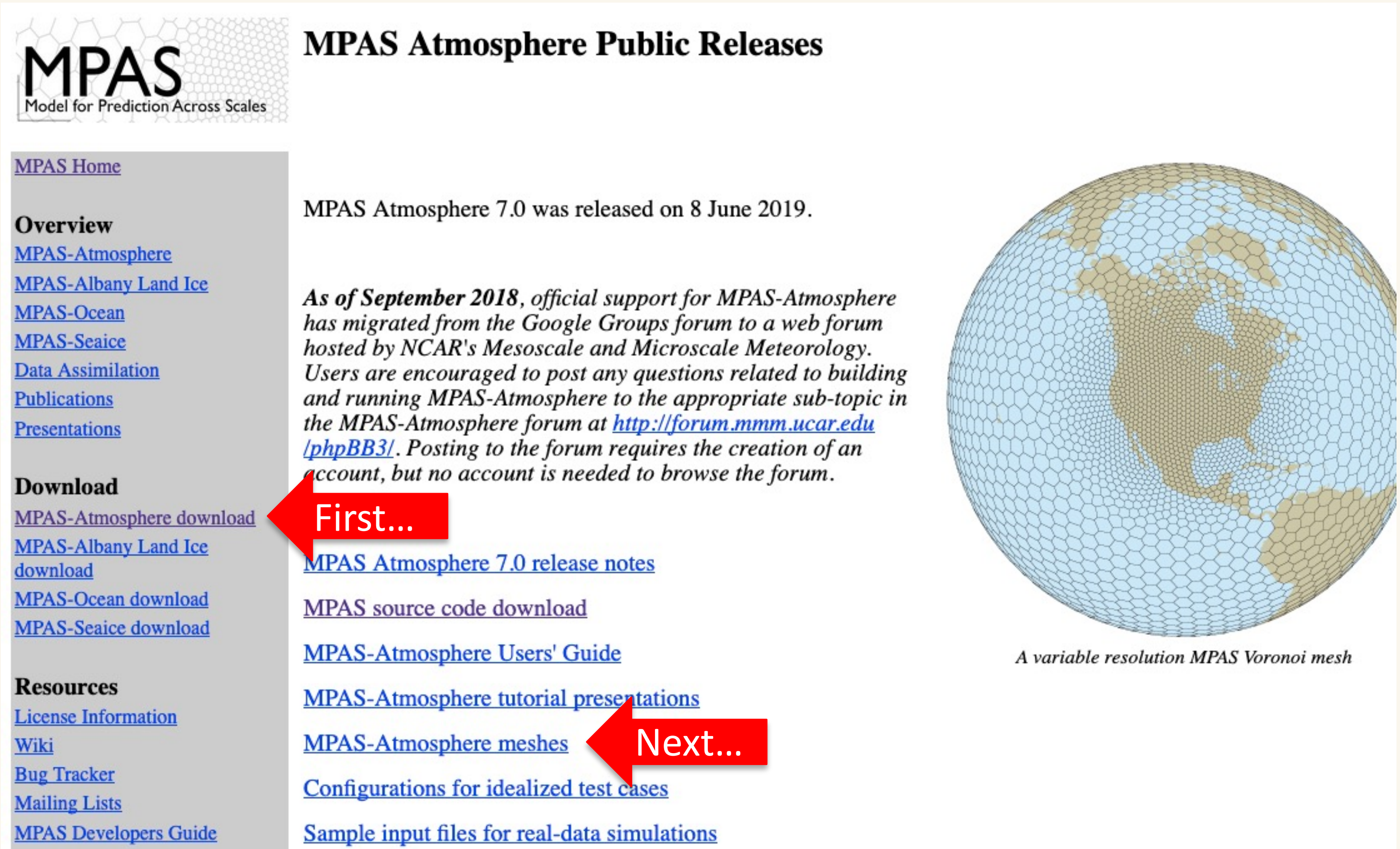
- *For dense variable-resolution meshes, this process can take weeks or more!*





A few words about meshes

Whether you intend to run a global simulation or a regional simulation, the starting point is always the mesh download page:



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MPAS Atmosphere 7.0 was released on 8 June 2019.

__As of September 2018__, official support for MPAS-Atmosphere has migrated from the Google Groups forum to a web forum hosted by NCAR's Mesoscale and Microscale Meteorology. Users are encouraged to post any questions related to building and running MPAS-Atmosphere to the appropriate sub-topic in the MPAS-Atmosphere forum at http://forum.mmm.ucar.edu/phpBB3/. Posting to the forum requires the creation of an account, but no account is needed to browse the forum.

MPAS Atmosphere 7.0 release notes

MPAS source code download

MPAS-Atmosphere Users' Guide

MPAS-Atmosphere tutorial presentations

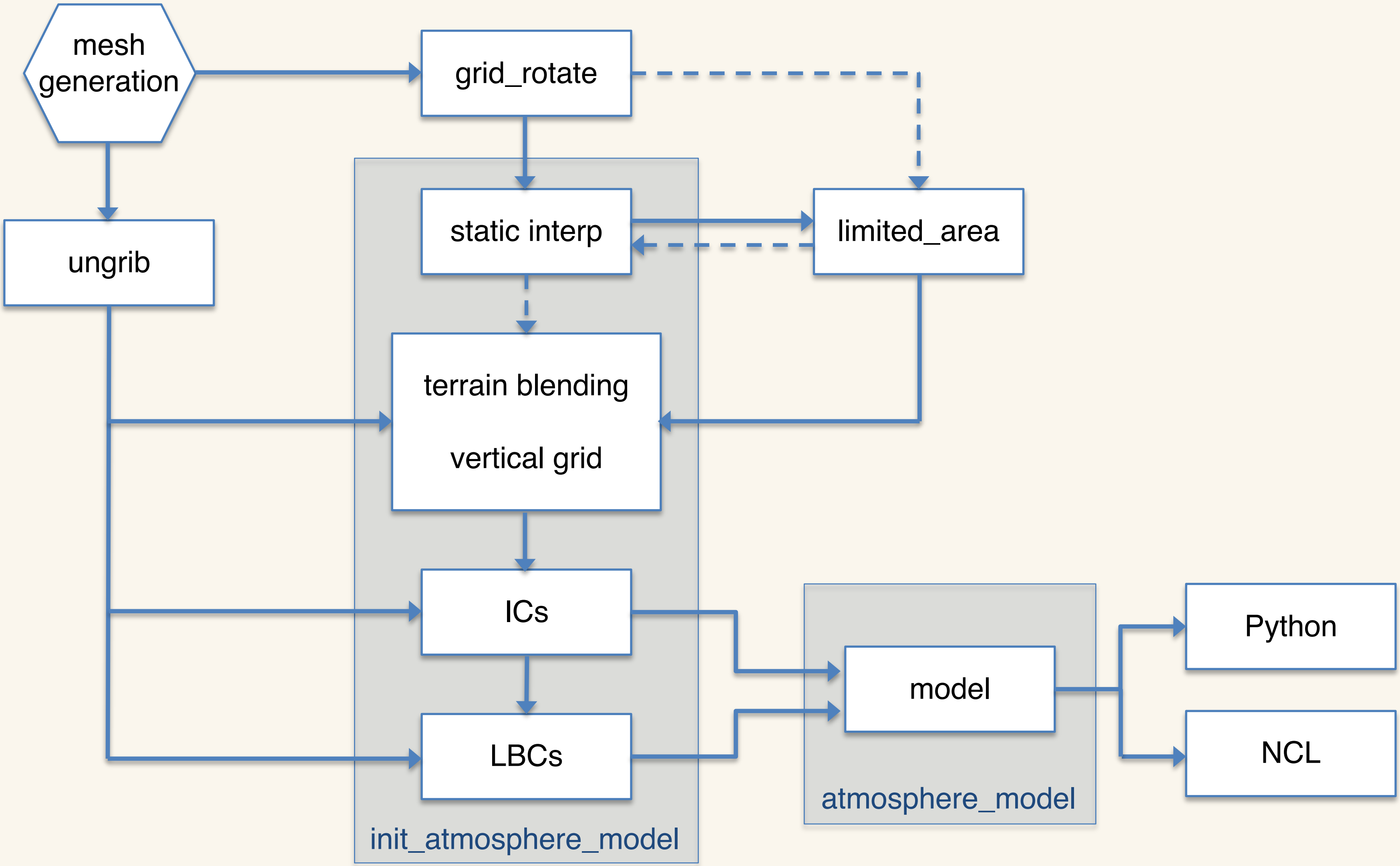
MPAS-Atmosphere meshes

Configurations for idealized test cases

Sample input files for real-data simulations

A variable resolution MPAS Voronoi mesh

Regional MPAS Flowchart



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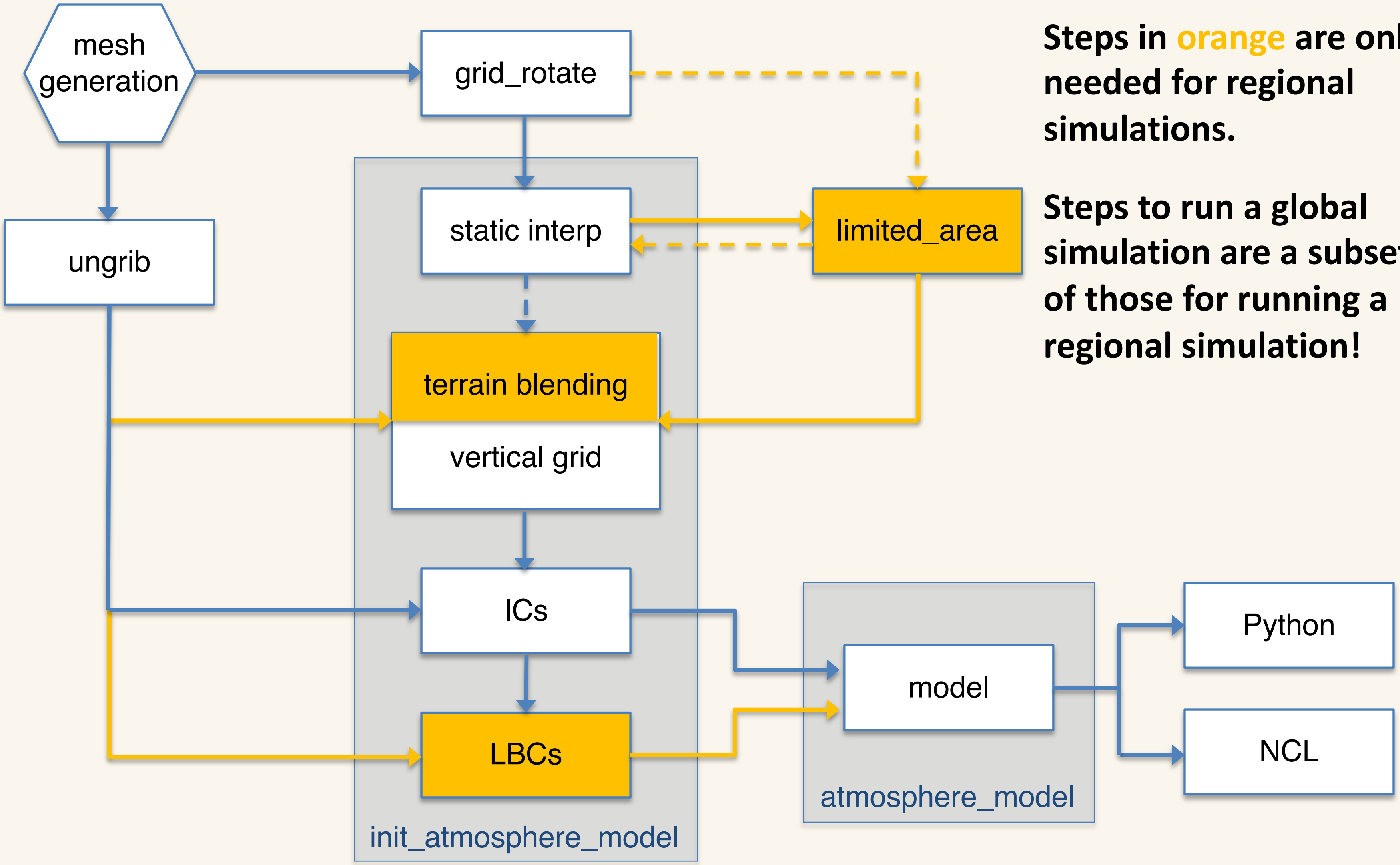
Regional MPAS Flowchart: Global v. Regional

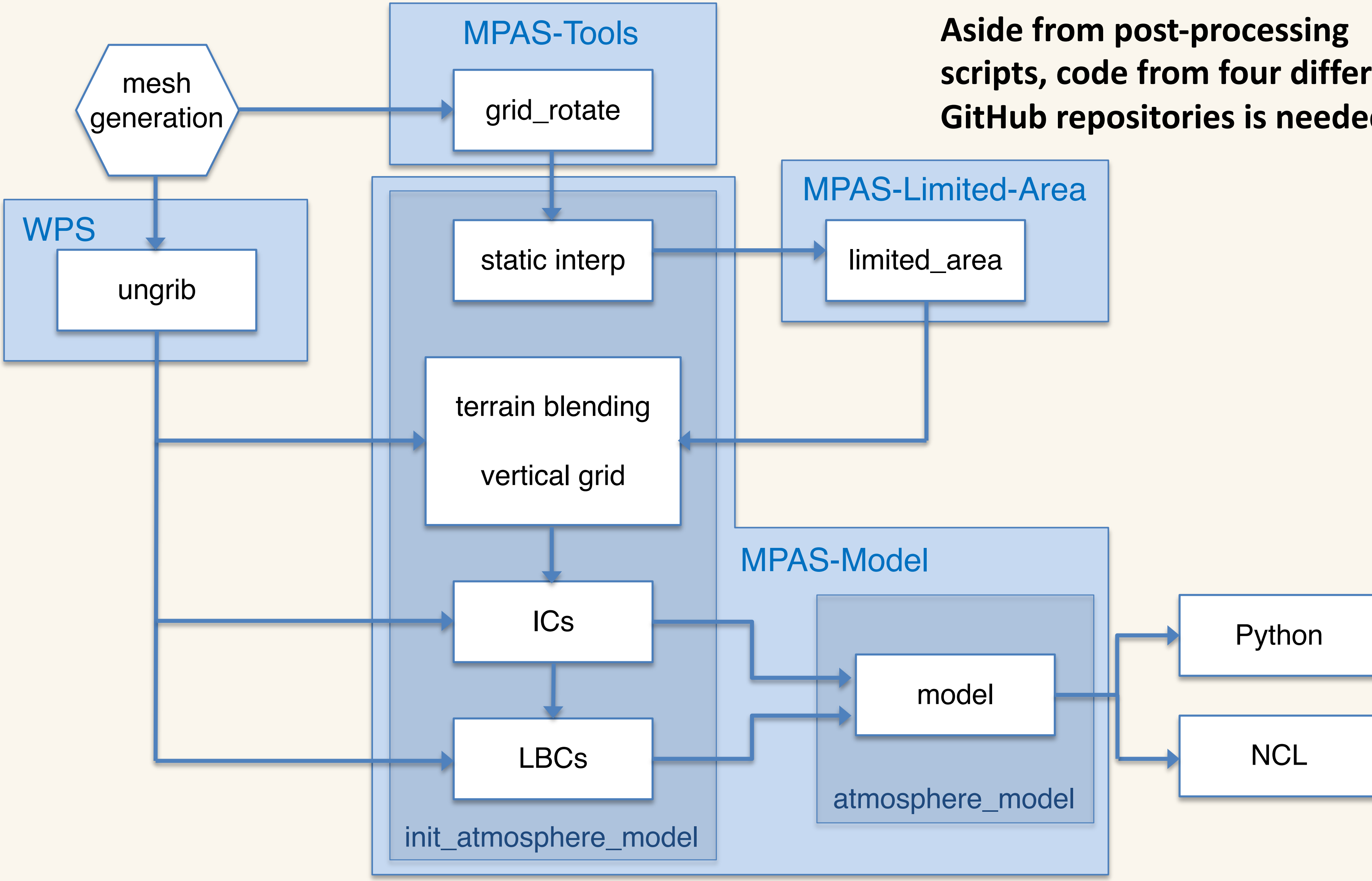


Steps in orange are only needed for regional simulations.

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

Regional MPAS Flowchart: Repositories

Aside from post-processing scripts, code from four different GitHub repositories is needed.



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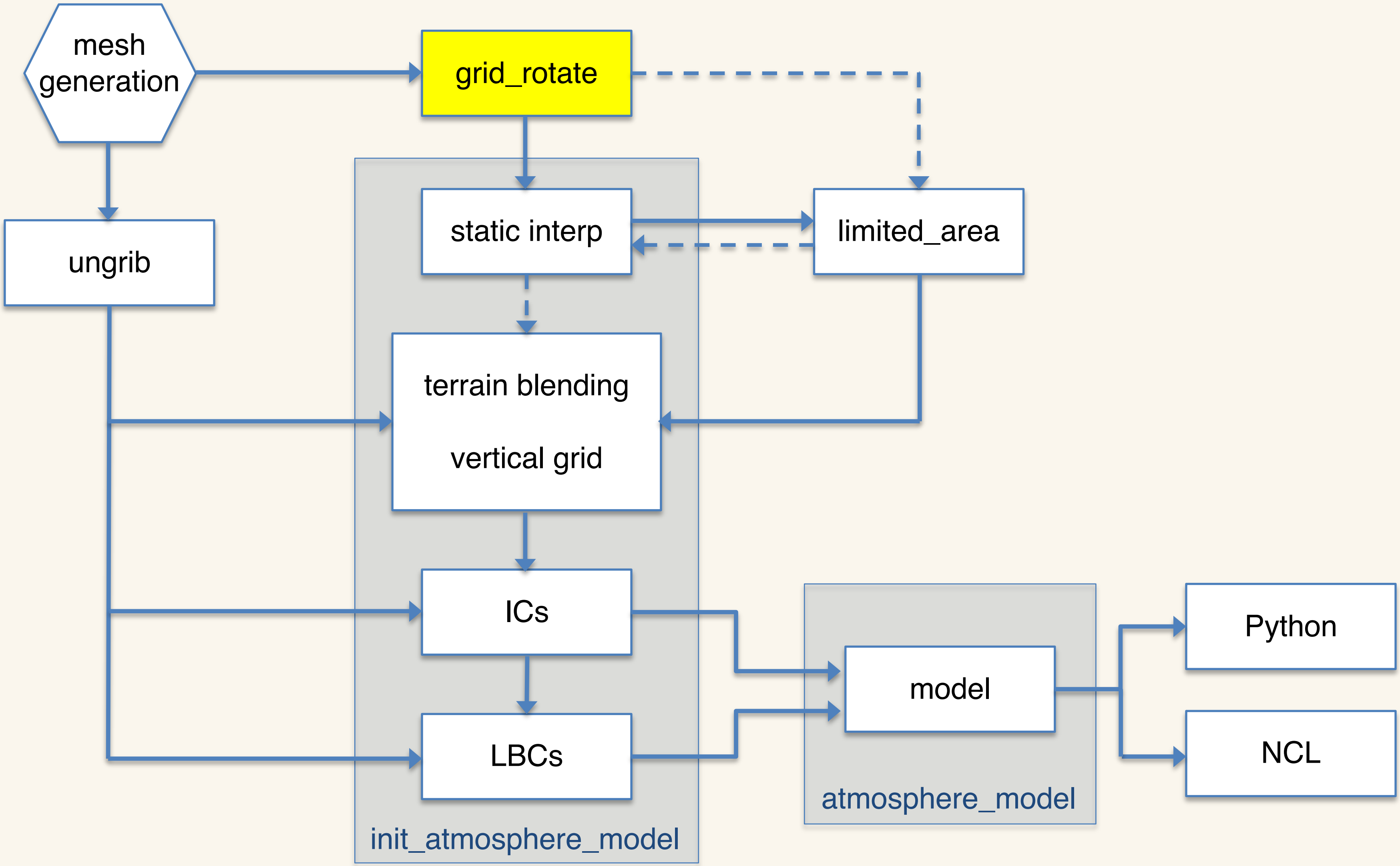
Regional MPAS Flowchart



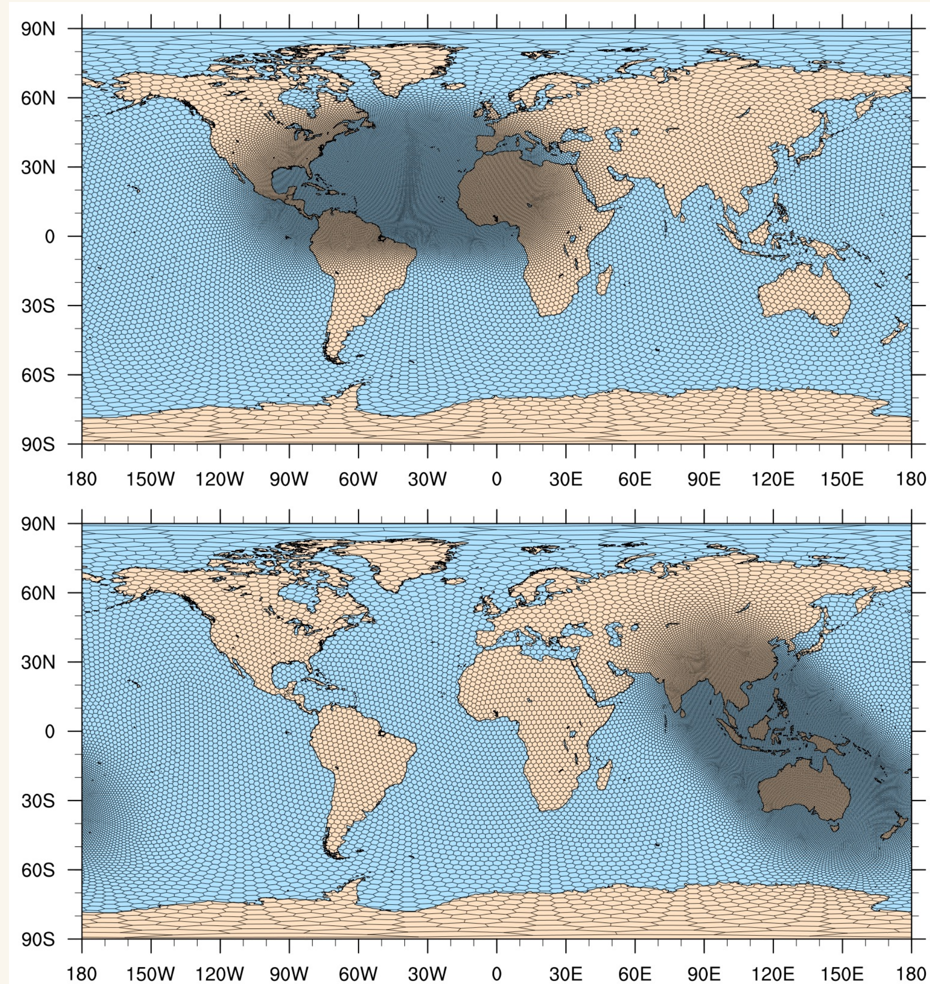
Variable-resolution meshes

The key idea for re-using variable-resolution meshes is to rotate the refined region

This may be accomplished easily (and quickly!) using the "grid_rotate" tool

- Implements two solid-body rotations for spherical meshes:

1. Move center of refined region from one location to another
2. Rotate the relocated refinement about its center to change orientation



Above: A refinement region originally centered at 25N, 40W has been shifted to 7S, 125E and rotated by -45 degrees.

Variable-resolution meshes

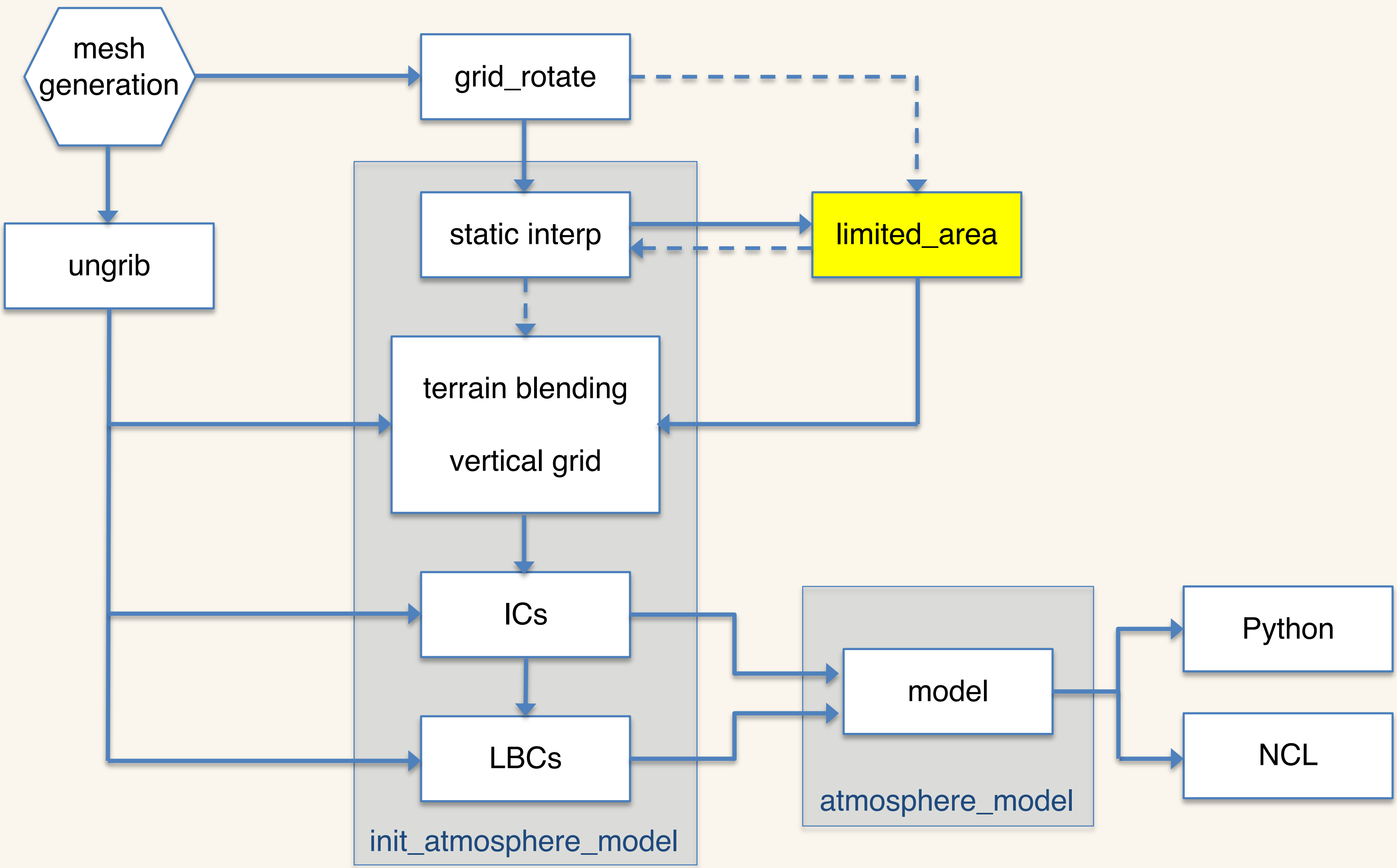
The grid_rotate tool uses a Fortran namelist file to control rotation of the mesh:

```
&input
   config_original_latitude_degrees = 0
   config_original_longitude_degrees = 0

   config_new_latitude_degrees = -19.5
   config_new_longitude_degrees = -62
   config_birdseye_rotation_counter_clockwise_degrees = 90
/
```

Typical usage might look like:

```
grid_rotate x5.30210.grid.nc SouthAmerica.grid.nc
```

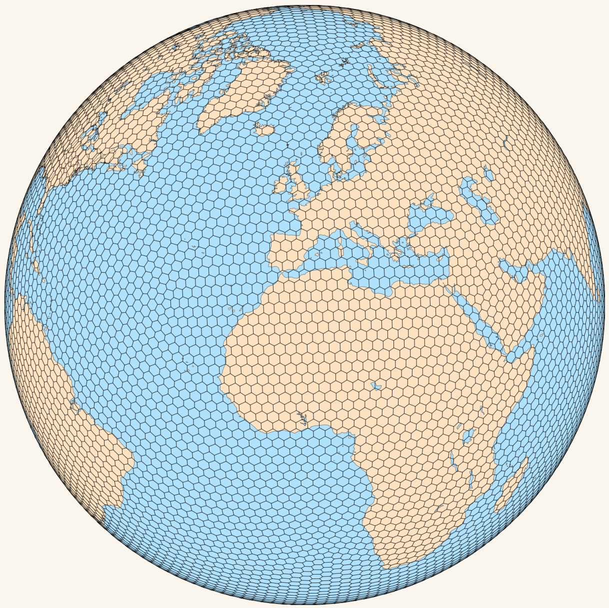
Regional MPAS Flowchart



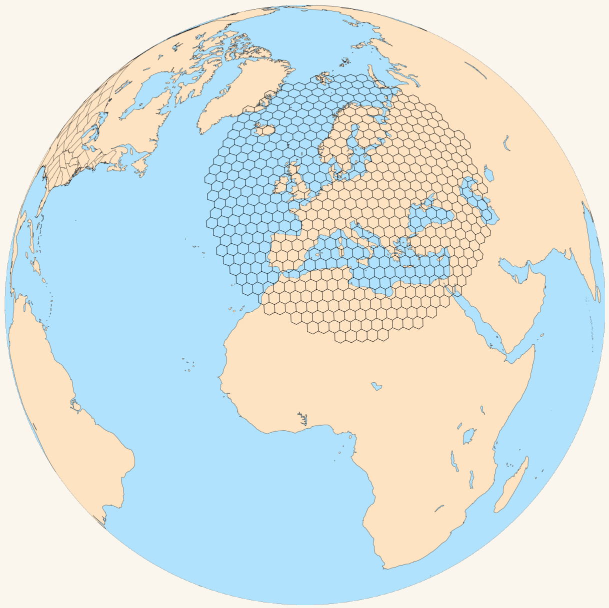
MPAS Model for Prediction Across Scales

Creating limited-area meshes

Given a global, "parent" mesh, limited-area meshes are created by subsetting the cells in the parent mesh with the MPAS-Limited-Area tool



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

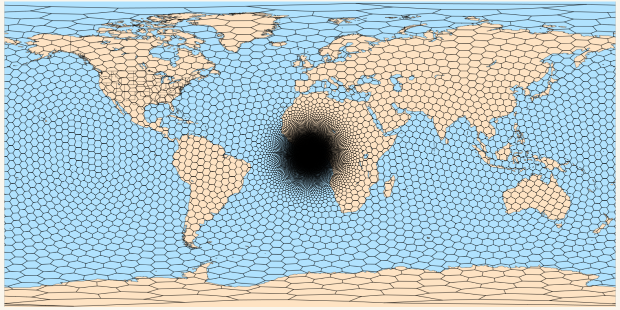


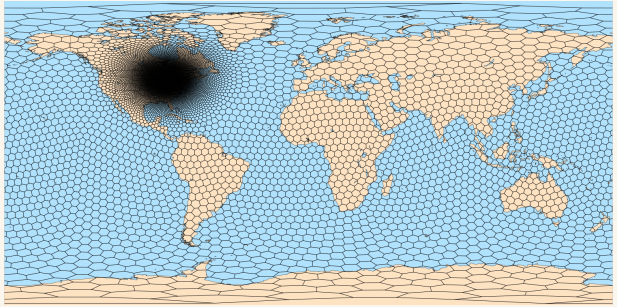
- The key point is that subsetting mesh is computational trivial, while generating a new mesh is not!

Variable-resolution, limited-area meshes

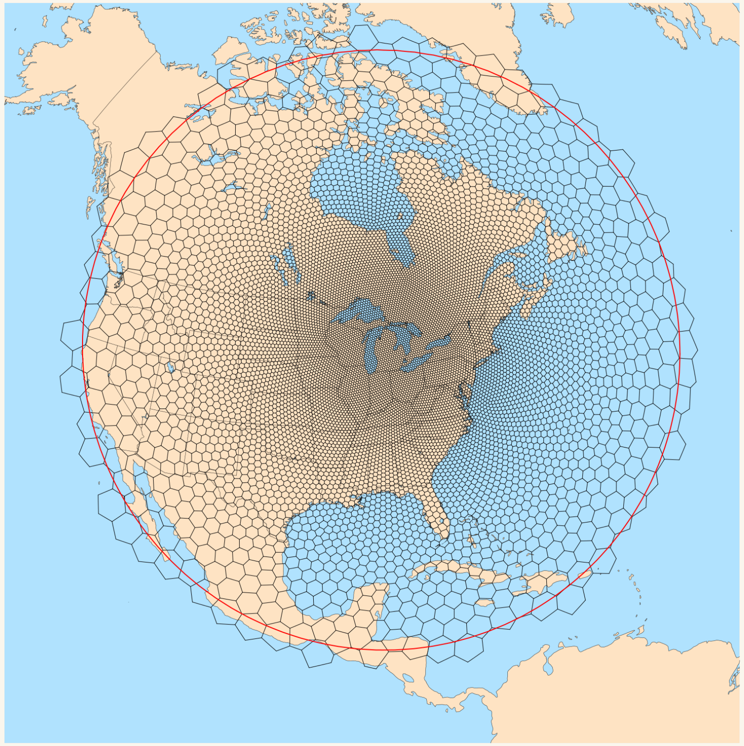
Aside from the relocation of refinement, creating variable-resolution, limited-area meshes works the same as for uniform-resolution

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





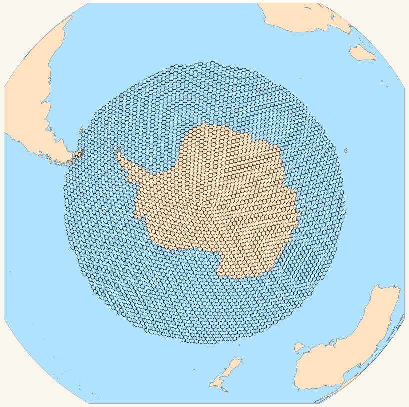
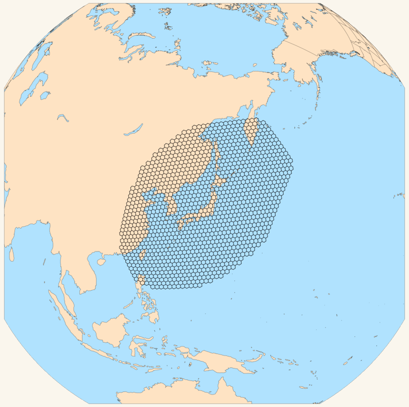
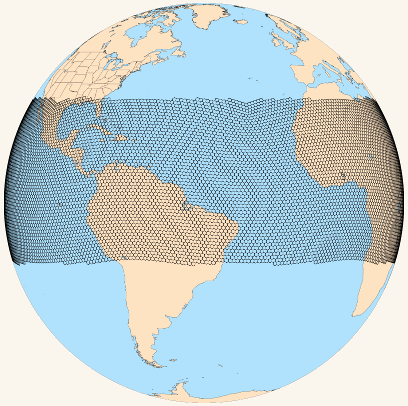
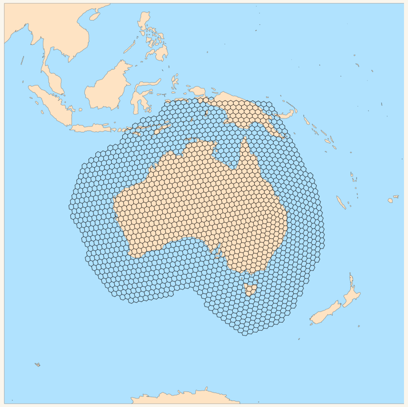
2) Extract a limited-area mesh using MPAS-Limited-Area



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

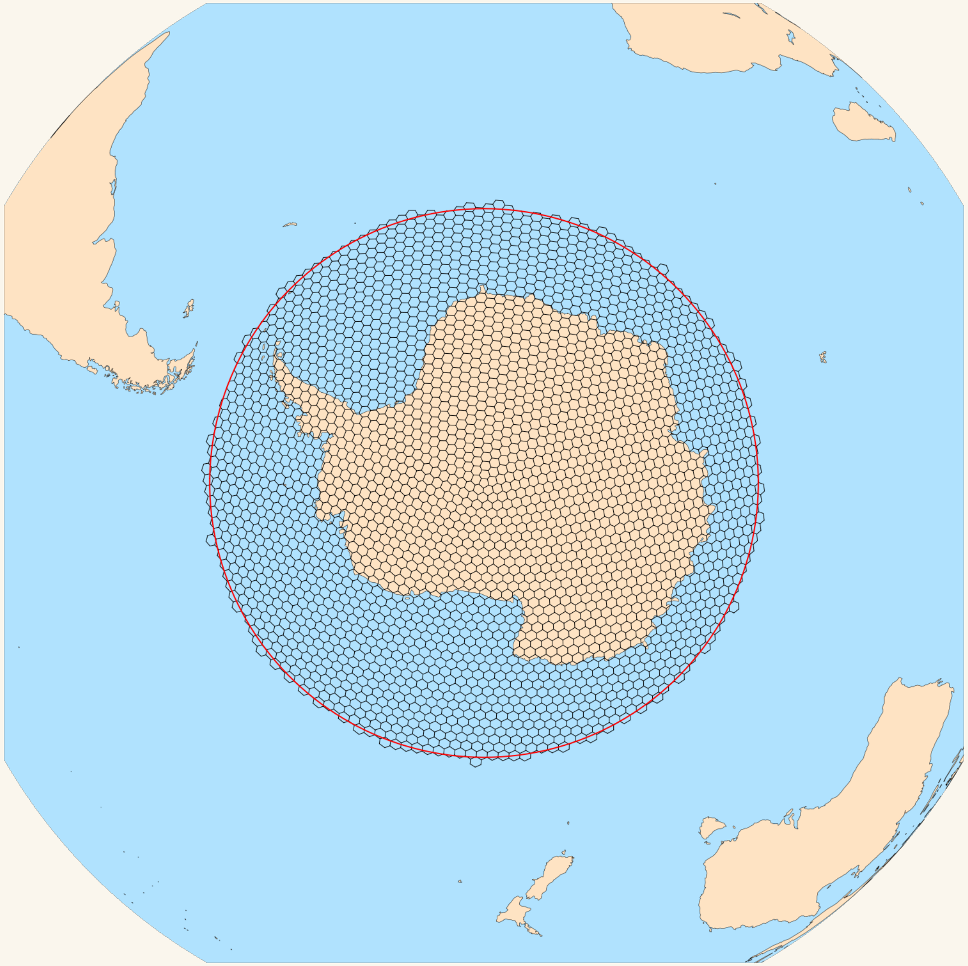
https://github.com/MiCurry/MPAS-Limited-Area

Circular regions

For circular regions, the region definition looks like the following

```
Name: Antarctic
Type: circle
Point: -90.0, 0.0
radius: 3300000
```

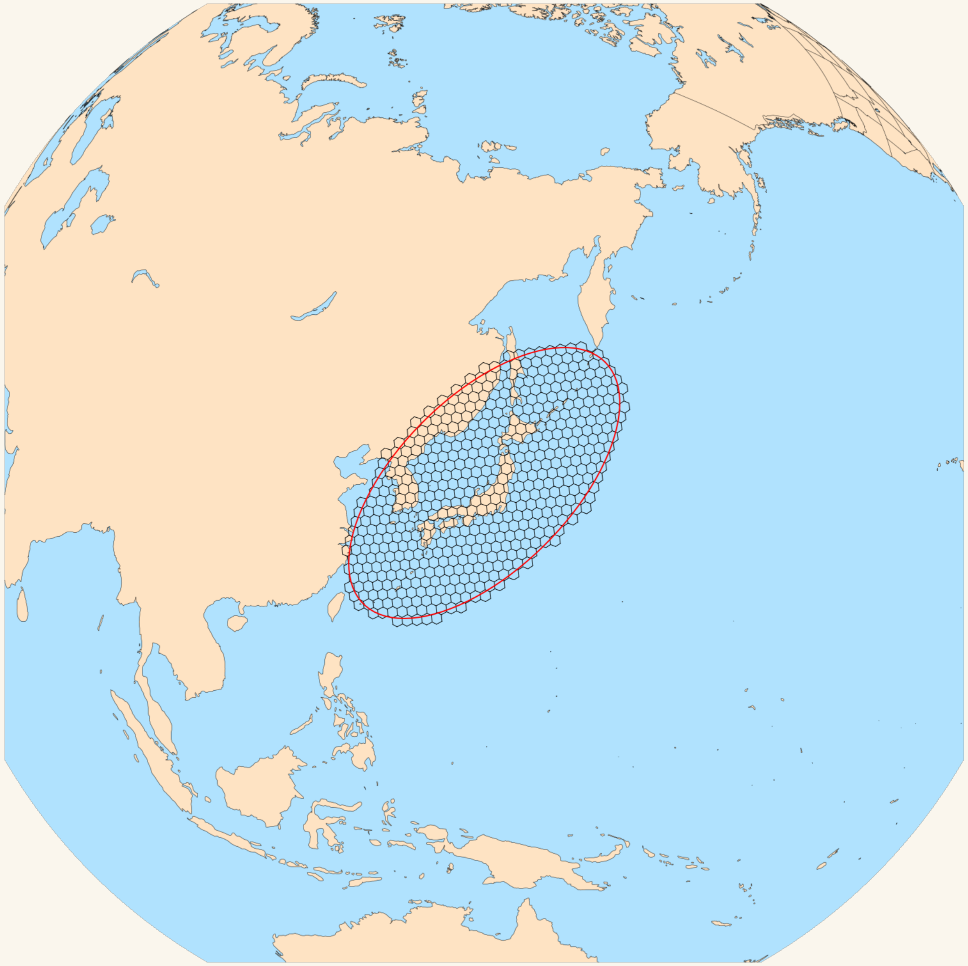
"Point" gives the latitude and longitude at the center of the circle, and "radius" gives the radius in meters



Elliptical regions

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
```



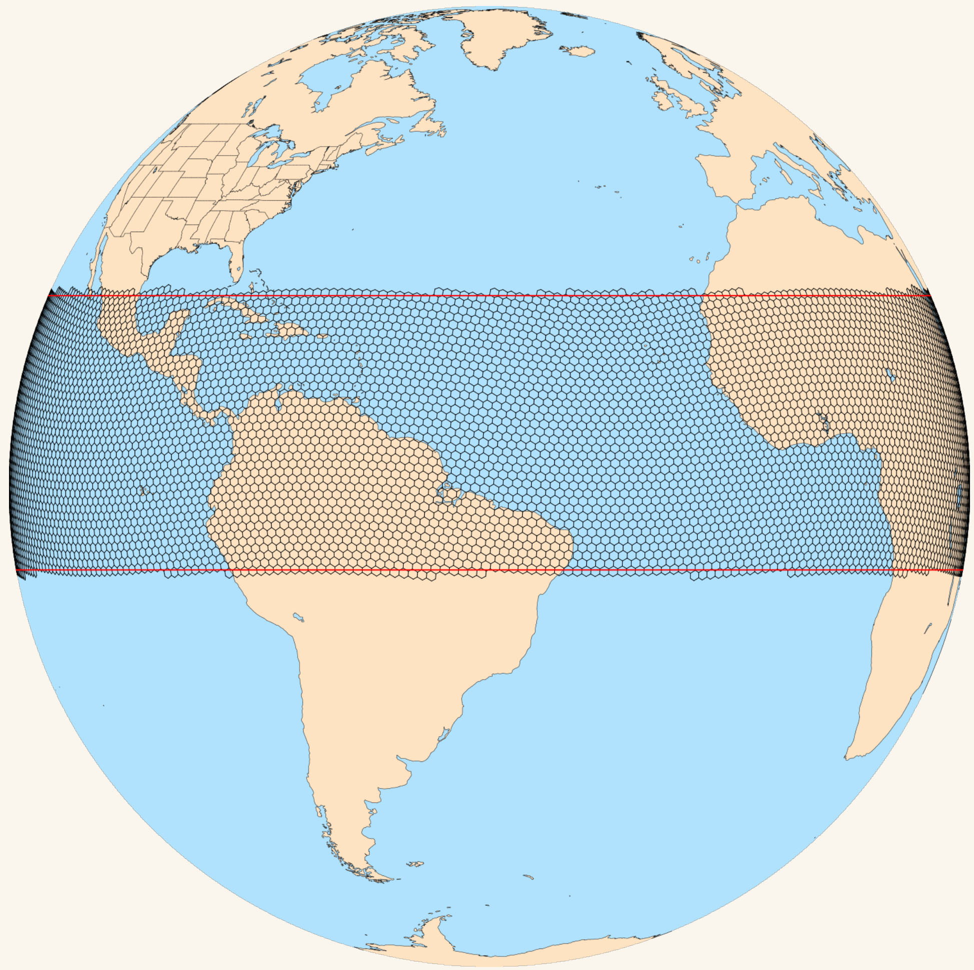
"Point" gives the latitude and longitude at the center of the ellipse, "Semi-major-axis" and "Semi-minor-axis" are in meters, and "Orientation-angle" gives the rotation of the axes of the ellipse

Channel regions

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

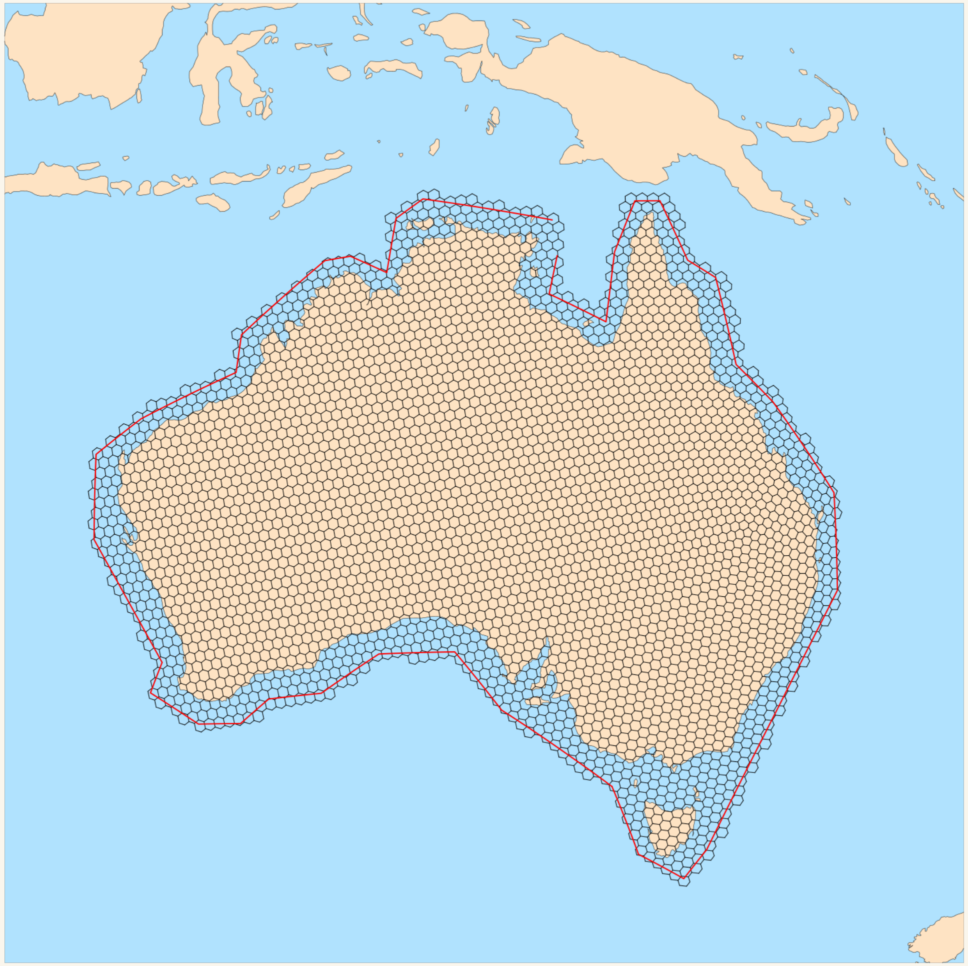


General polygon regions

For polygon regions, the region definition looks like the following

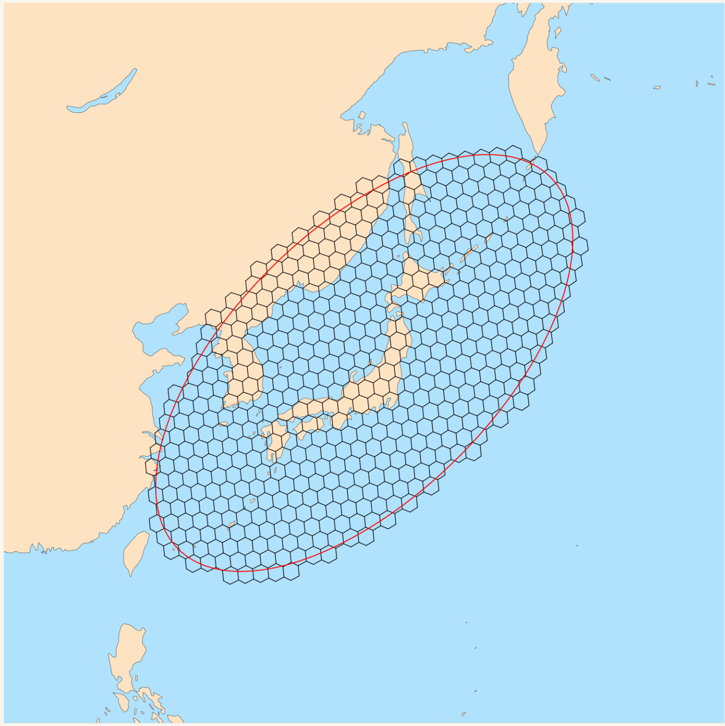
```
Name: Aus
Type: Custom
Point: -24.0, 134.0
-11.36, 137.50
-10.27, 130.85
-11.24, 129.46
...
-15.17, 137.40
-13.20, 137.78
```

"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

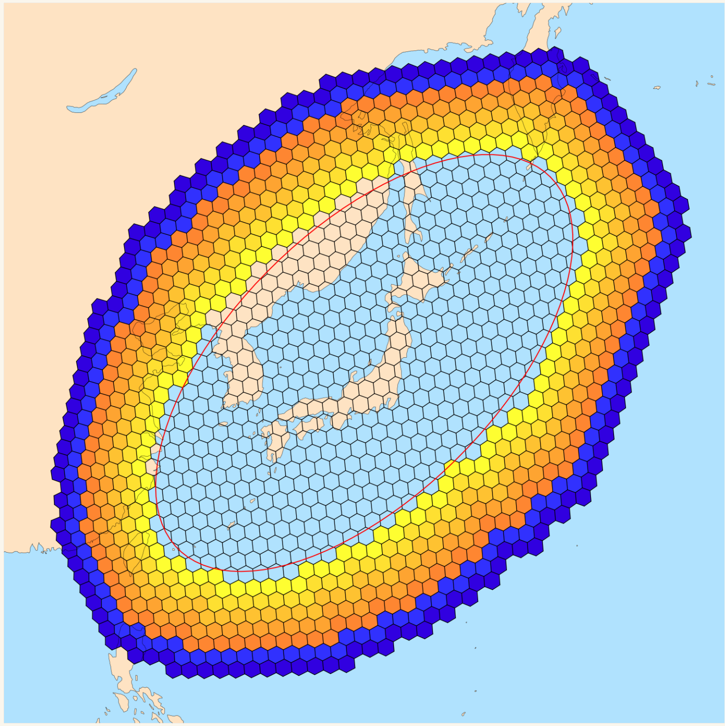


Boundary cells

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



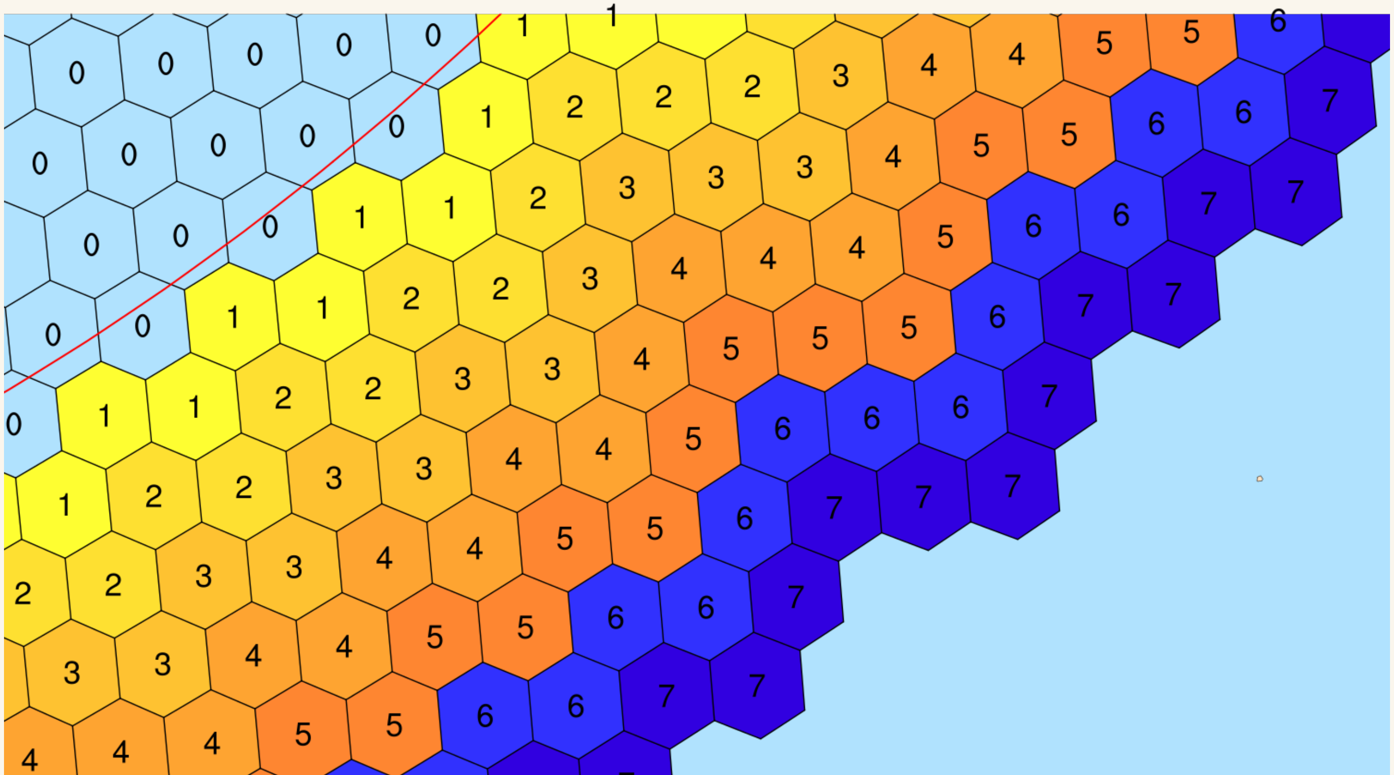
Above: Layers of relaxation zone cells (yellow-orange) and layers of specified zone cells (blue-purple) are added

Boundary cells

In MPAS v7.0, 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

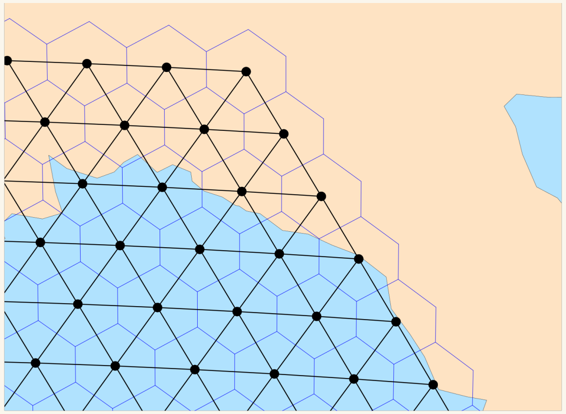


Left: Values of the `bdyMaskCell` *field at the lateral boundary*

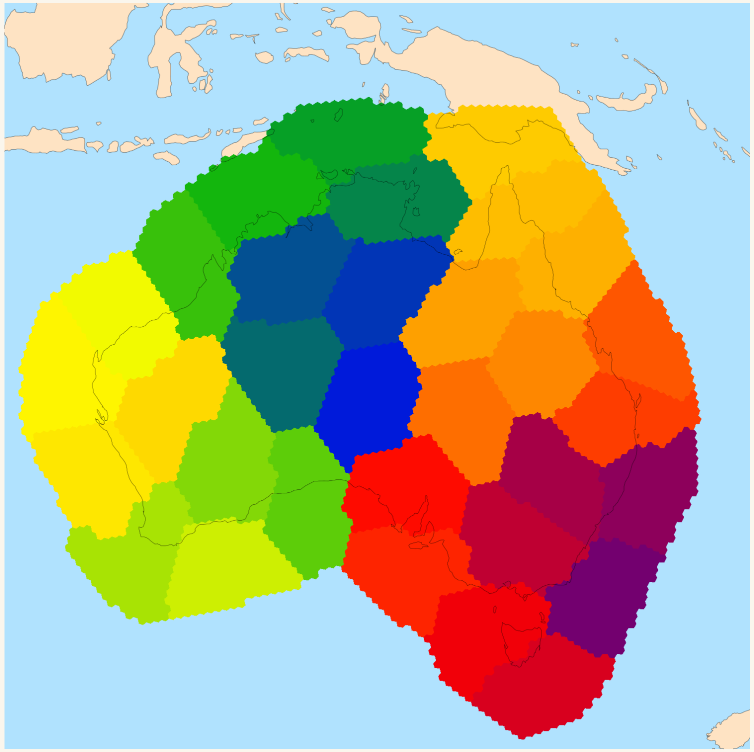
Partitioning regional meshes

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

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



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

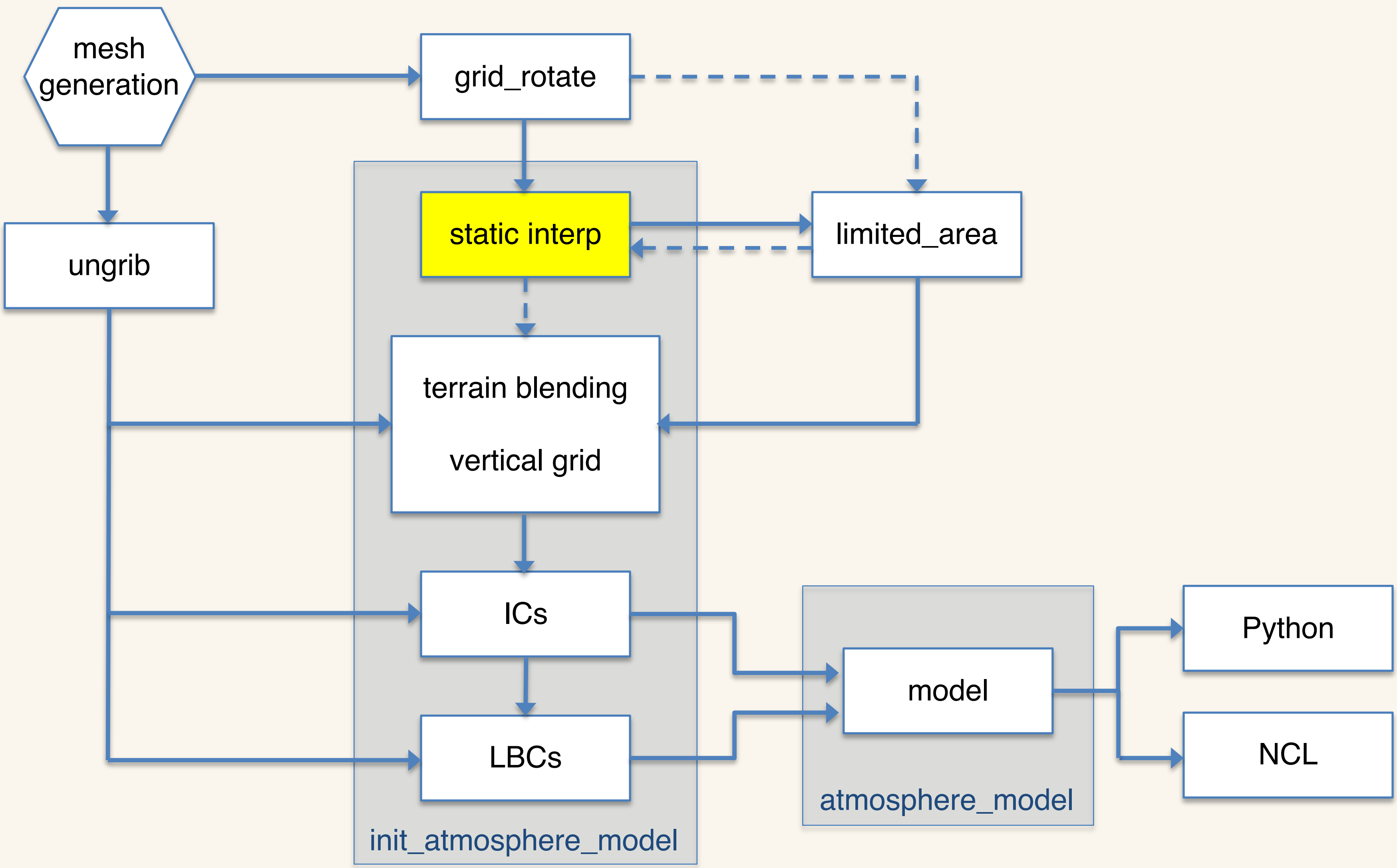


Above: Cells in a regional mesh colored according to their partition

See Section 4.1 in the User's Guide

MPAS Model for Prediction Across Scales

Regional MPAS Flowchart



Interpolating static, geographical fields

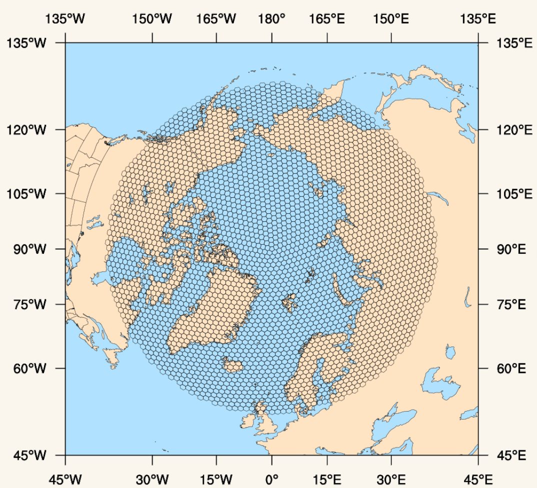
The interpolation of static, geographical fields to a mesh (global or regional) is performed using the MPAS-Model **init_atmosphere** core

`namelist.init_atmosphere`

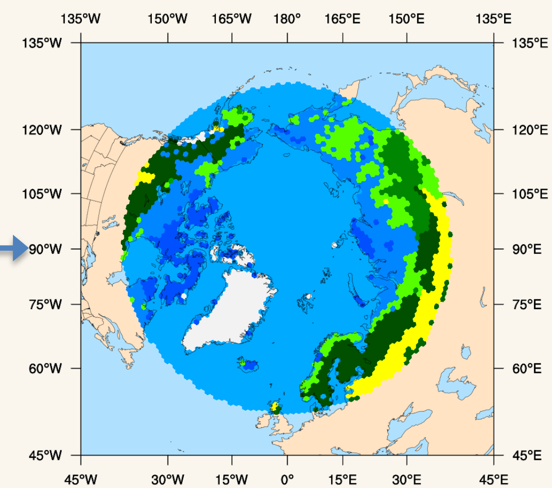
`streams.init_atmosphere`

`log.init_atmosphere.0000.out`

init_atmosphere_model



E.g., `arctic.grid.nc`



E.g., `arctic.static.nc`

Interpolating static, geographical fields

MPAS
Model for Prediction Across Scales

Key settings in the `namelist.init_atmosphere` file:

```
&nhyd_model
    config_init_case = 7
/
&data_sources
    config_geog_data_path = '/glade/work/wrfhelp/WPS_GEOG/'
    config_landuse_data = 'MODIFIED_IGBP_MODIS_NOAH'
    config_topo_data = 'GMTED2010'
    config_vegfrac_data = 'MODIS'
    config_albedo_data = 'MODIS'
    config_maxsnowalbedo_data = 'MODIS'
/
&preproc_stages
    config_static_interp = true
    config_native_gwd_static = true
    config_vertical_grid = false
    config_met_interp = false
    config_input_sst = false
    config_frac_seaice = false
/
```

MPAS
Model for Prediction Across Scales

Interpolating static, geographical fields

Key settings in the `streams.init_atmosphere` file:

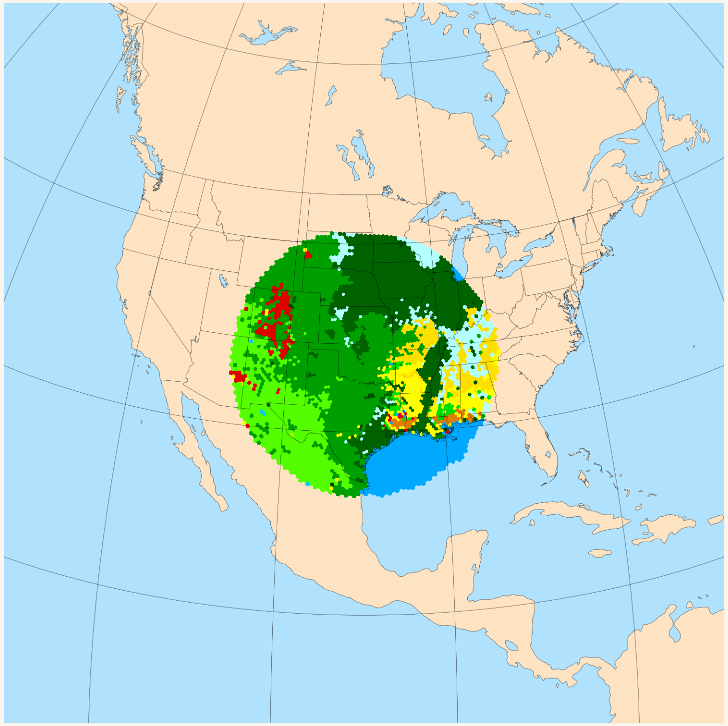
```
<immutable_stream name="input"
                  type="input"
                  filename_template="arctic.grid.nc"
                  input_interval="initial_only" />


<immutable_stream name="output"
                  type="output"
                  filename_template="arctic.static.nc"
                  packages="initial_conds"
                  output_interval="initial_only" />
```

Extracting static fields with MPAS-Limited-Area

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

Outline

1. Introduction
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3. Defining regional domains

---

5 minute break

4. Preparing atmospheric data
5. Creating a vertical grid
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7. Preparing LBCs
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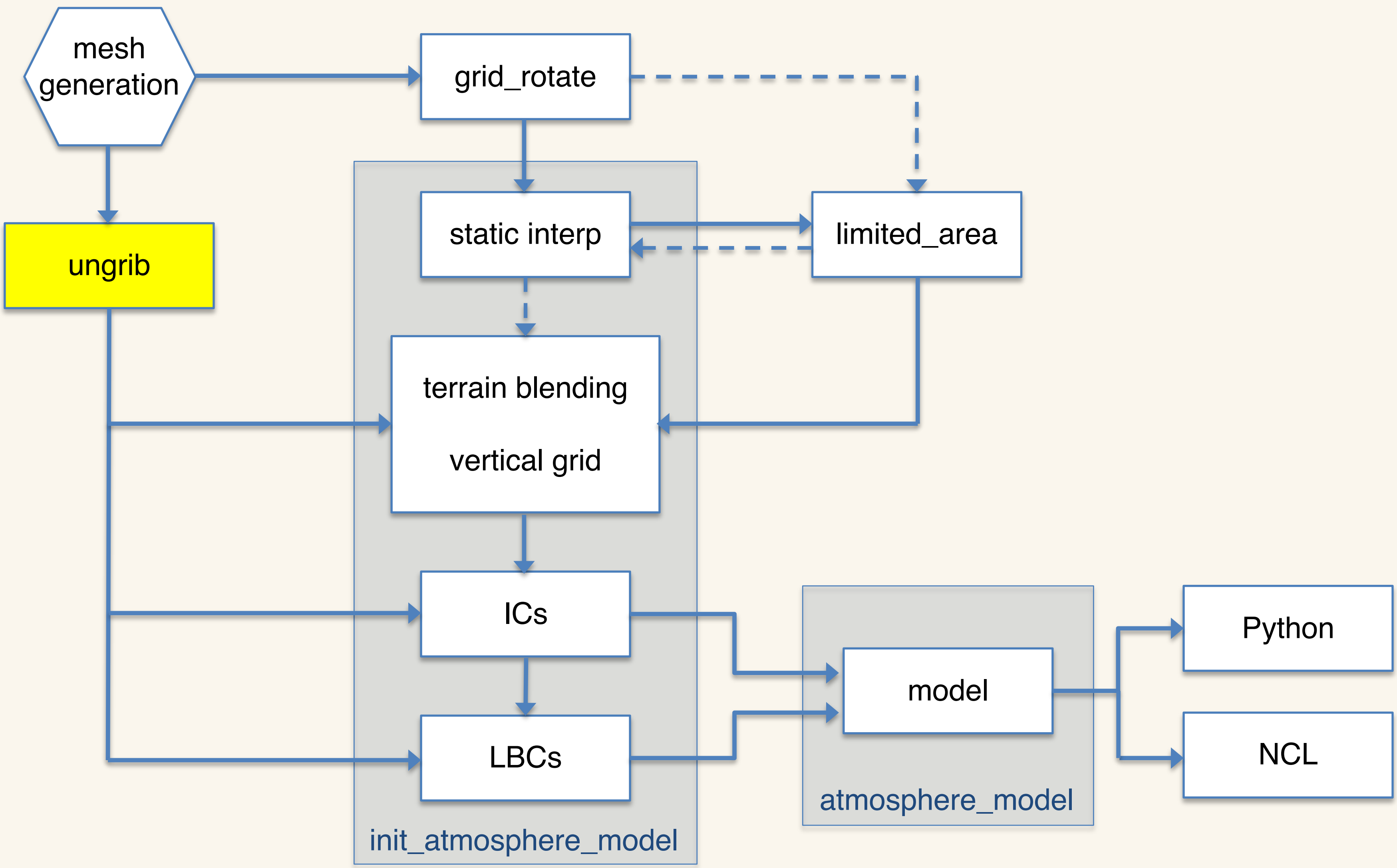
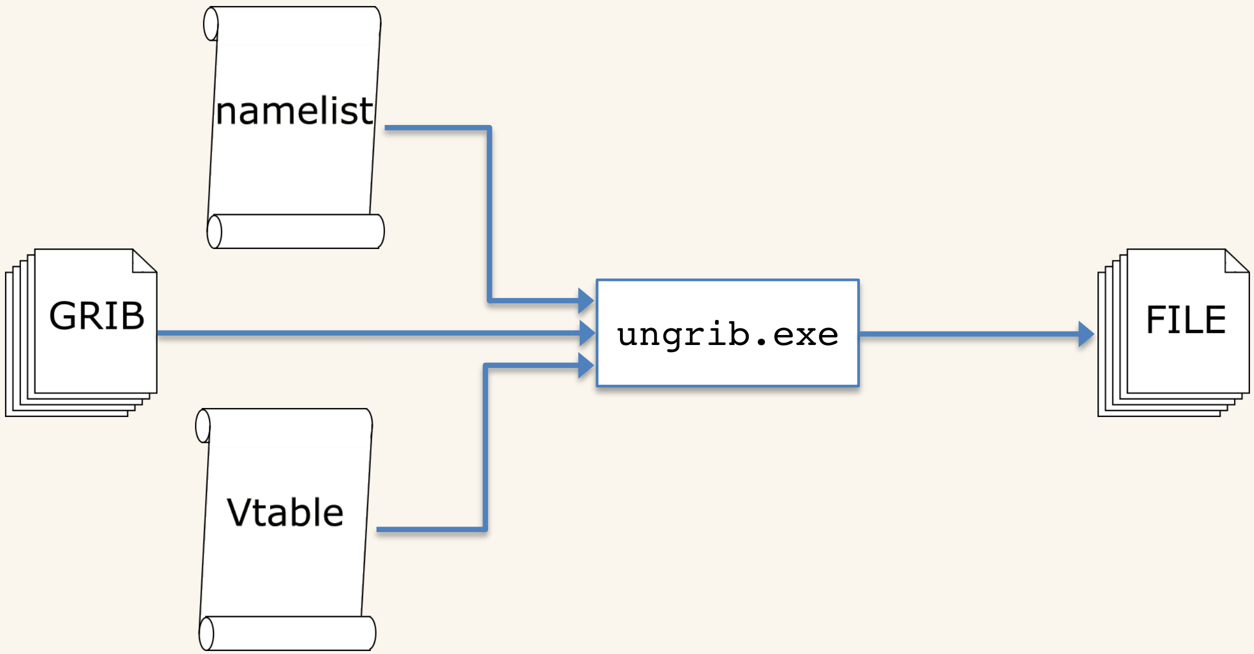
Regional MPAS Flowchart



Converting GRIB datasets

As in WRF, datasets for ICs and LBCs are often provided by datasets in GRIB format

For MPAS, use the WRF Preprocessing System's (WPS) *ungrib.exe*



Converting GRIB datasets

As in WRF, datasets for ICs and LBCs are often provided by datasets in GRIB format

For MPAS, use the WRF Preprocessing System's (WPS) *ungrib.exe*

New in the WPS v4.3 release is the ability to *configure* without referencing a compiled WRF model:

```
configure --nowrf
```

This is convenient if only the *ungrib* component of the WPS is needed!

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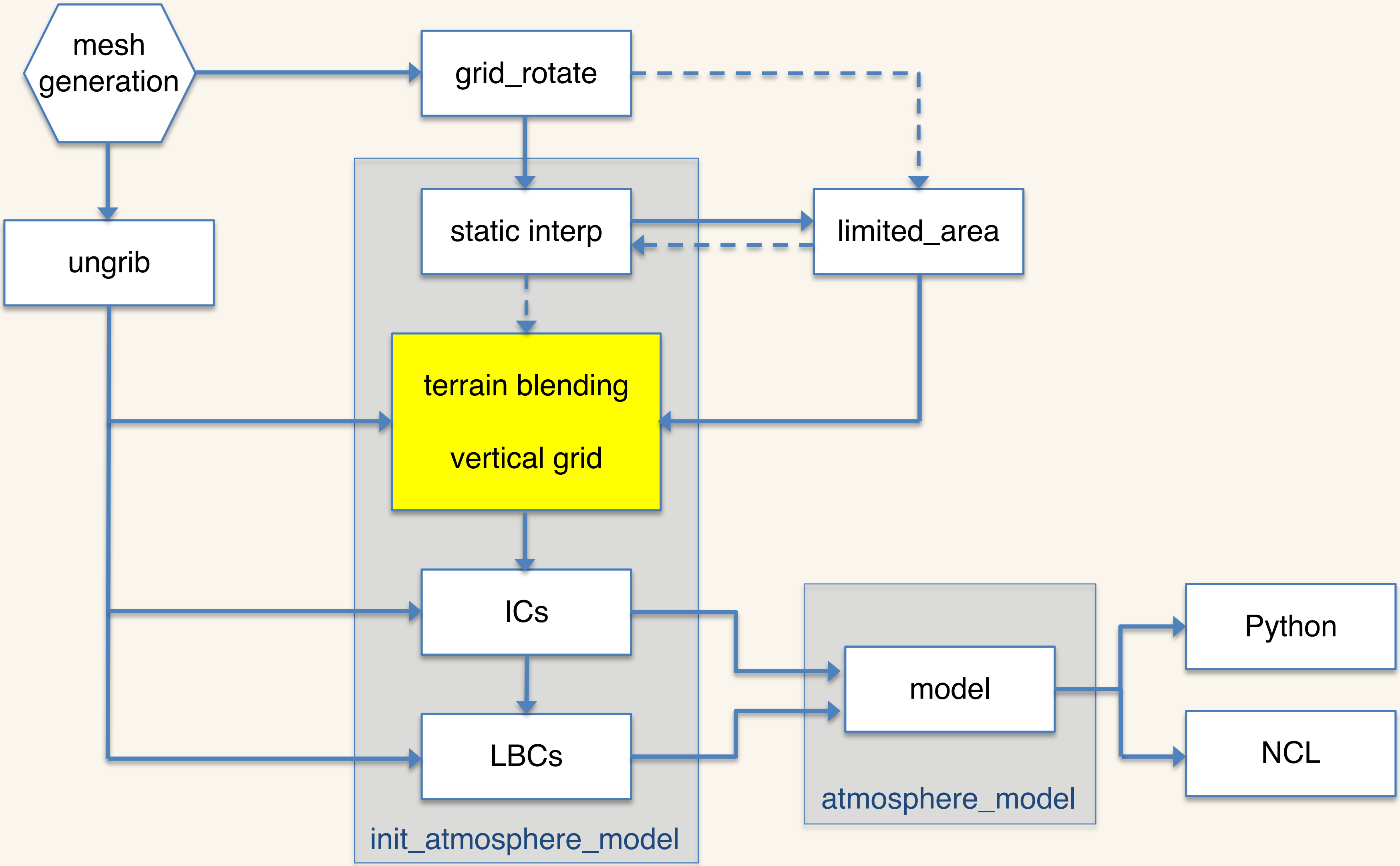
MPAS
Model for Prediction Across Scales

Regional MPAS Flowchart

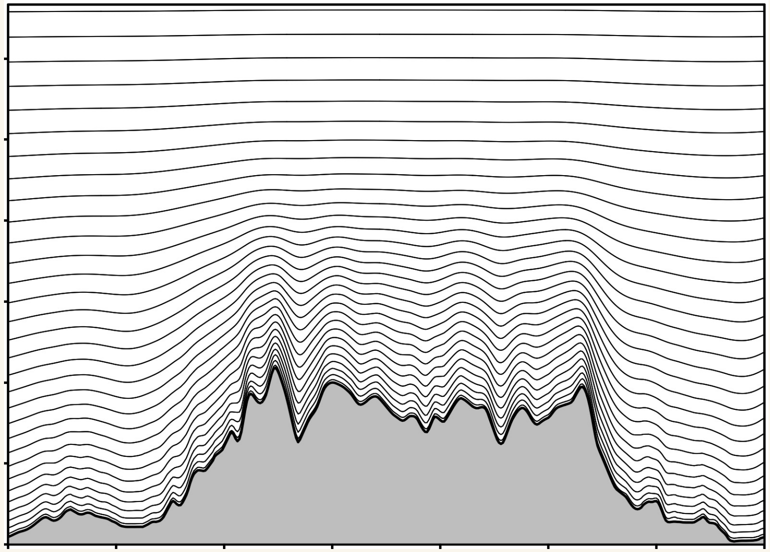


Vertical grid generation

Because MPAS-Atmosphere uses a smoothed terrain-following vertical coordinate (Klemp, *MWR* 2011), any modifications to the terrain field must be made before the vertical coordinate surfaces are produced

$$z = (z_t - A'h_s)\frac{\zeta}{z_t} + A'h_s = \zeta + Ah_s$$

$$h_s^{(n)} = h_s^{(n-1)} + \beta(\zeta)d^2\nabla_\zeta^2 h_s^{(n-1)}$$



Our experience suggests that it is beneficial to blend the terrain height in the boundary cells with the terrain height from the dataset used for ICs and LBCs

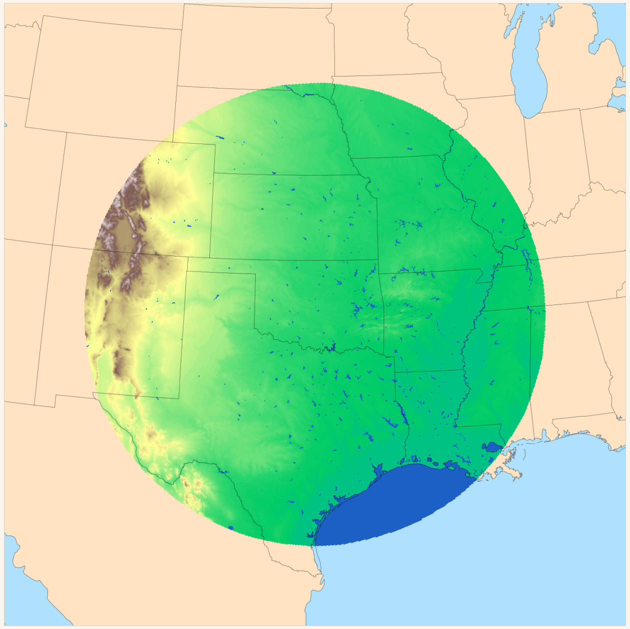
Vertical grid generation

Generating limited-area vertical grid works exactly as for global vertical grids, 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 = 30000.0
    config_nsmterrain = 1
    config_smooth_surfaces = true
    config_dzmin = 0.3
    config_nsm = 30
    config_tc_vertical_grid = true
    config_blend_bdy_terrain = true
/
```

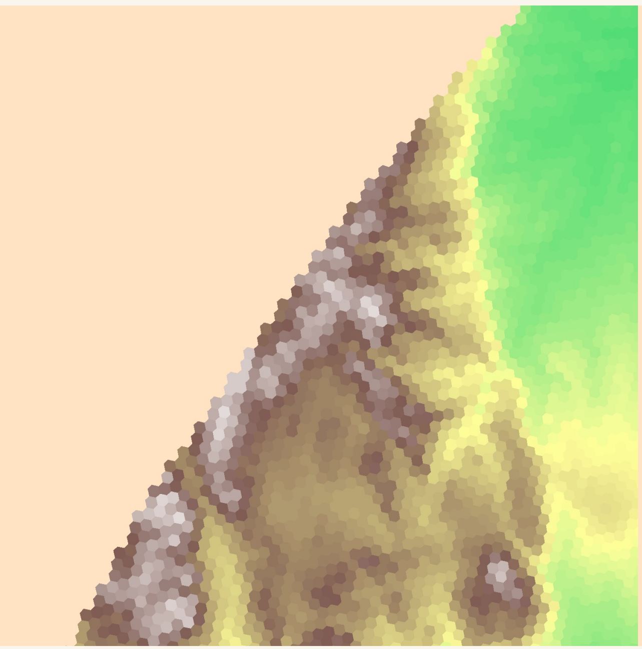
Above: When config_vertical_grid=true, config_blend_bdy_terrain should be 'true' as well



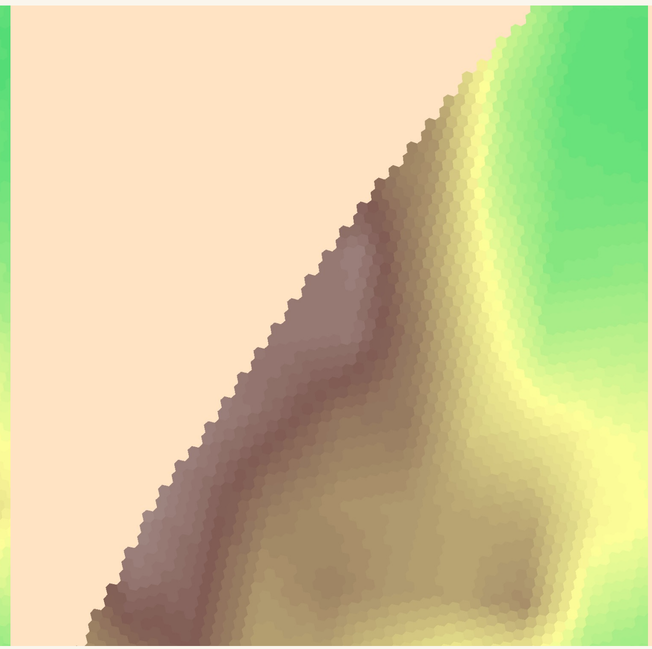
Above: The terrain field in a ~3-km regional mesh

Blending boundary terrain

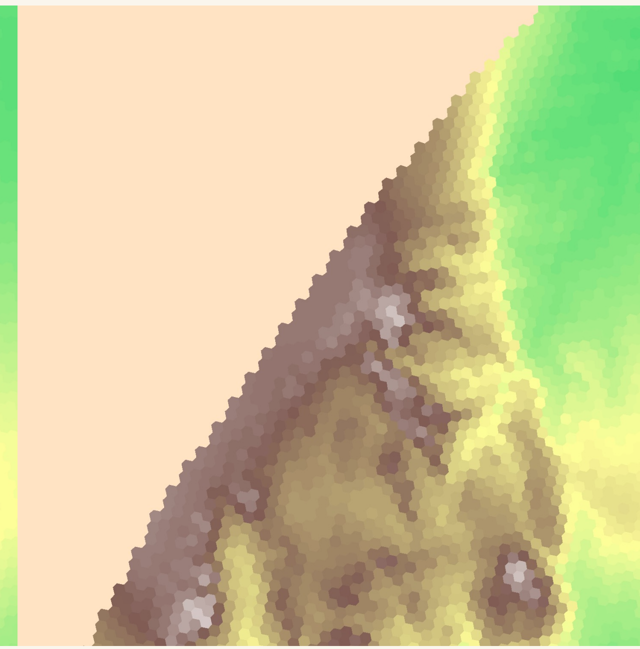
The `config_blend_bdy_terrain` option only affects terrain in the boundary cells (where `bdyMaskCell` > 0)



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



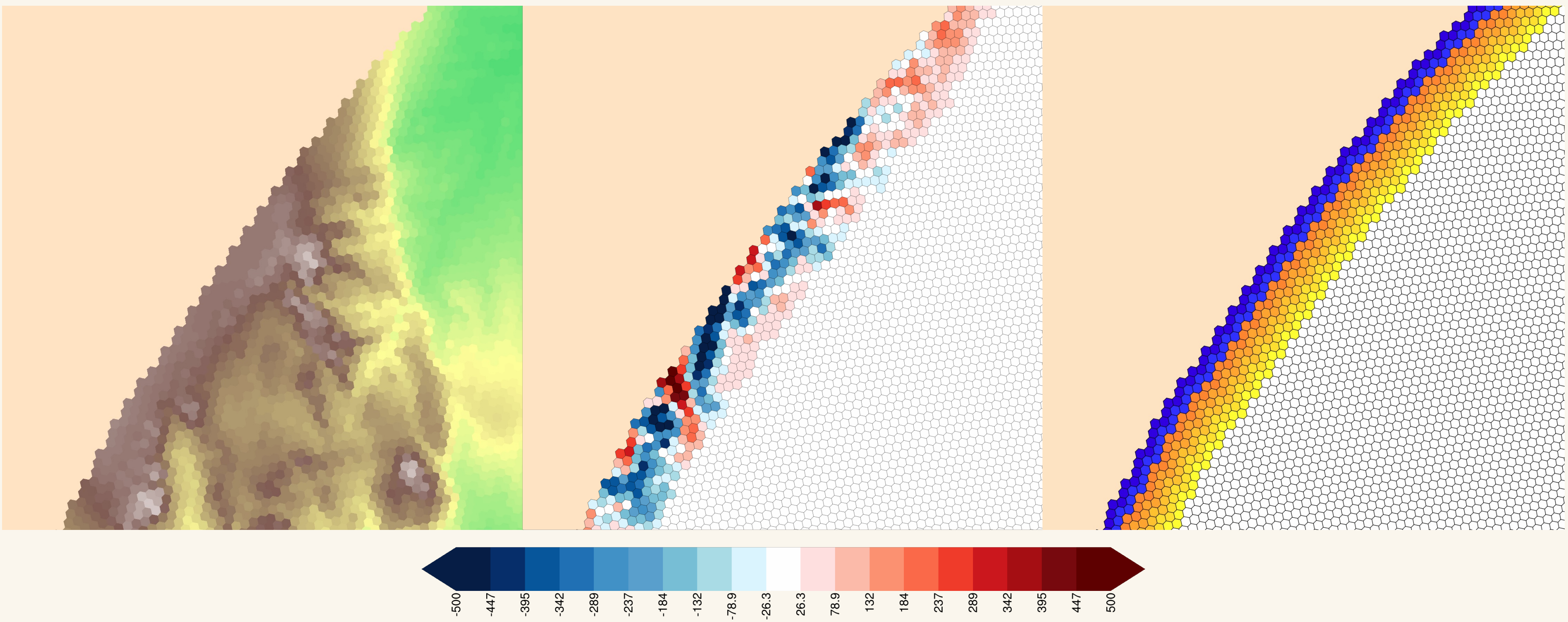
0.25-deg GFS terrain field interpolated to 3-km mesh



Blended terrain field used in the generation of vertical coordinate surfaces

Blending boundary terrain

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



Blended terrain field

Difference between blended terrain field and original terrain field

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

MPAS
Model for Prediction Across Scales

Generating vertical grids

The blending of boundary terrain and generation of vertical coordinate surfaces is performed using the MPAS-Model **init_atmosphere** core

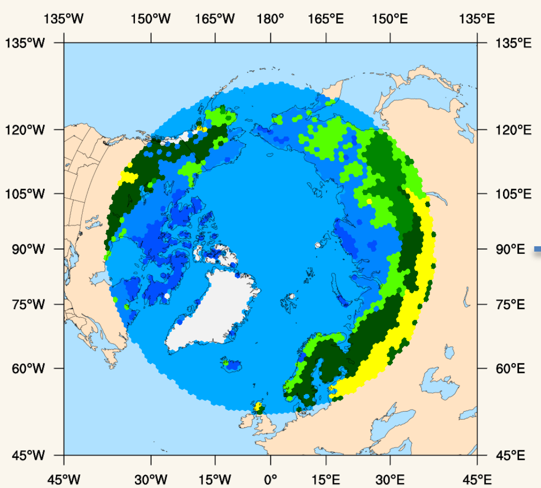
`namelist.init_atmosphere`

`streams.init_atmosphere`

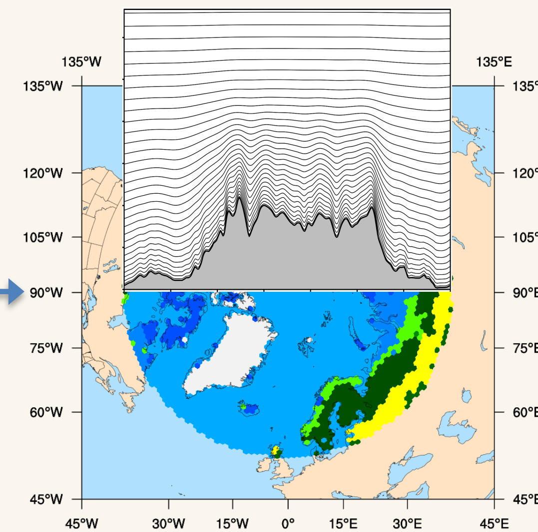
`log.init_atmosphere.0000.out`

init_atmosphere_model

FILE



E.g., `arctic.static.nc`



E.g., `arctic.vertical.nc`

MPAS
Model for Prediction Across Scales

Vertical grid generation

Several other applicable namelist options include:

- The number of vertical layers to generate
- The date and prefix of the intermediate file with first-guess topography

```
&nhyd_model
    config_init_case = 7
    config_start_time = '2020-12-21_12:00:00'
/
&dimensions
    config_nvertlevels = 55
/
&data_sources
    config_met_prefix = 'FILE'
/
```

MPAS
Model for Prediction Across Scales

Vertical grid generation

Several other applicable namelist options include:

- The **config_vertical_grid** preprocessing stage

```
&preproc_stages
    config_static_interp = false
    config_native_gwd_static = false
    config_vertical_grid = true
    config_met_interp = false
    config_input_sst = false
    config_frac_seaice = false
/
```

Vertical grid generation

Key settings in the `streams.init_atmosphere` file:

```
<immutable_stream name="input"
                  type="input"
                  filename_template="arctic.static.nc"
                  input_interval="initial_only" />


<immutable_stream name="output"
                  type="output"
                  filename_template="arctic.vertical.nc"
                  packages="initial_conds"
                  output_interval="initial_only" />
```

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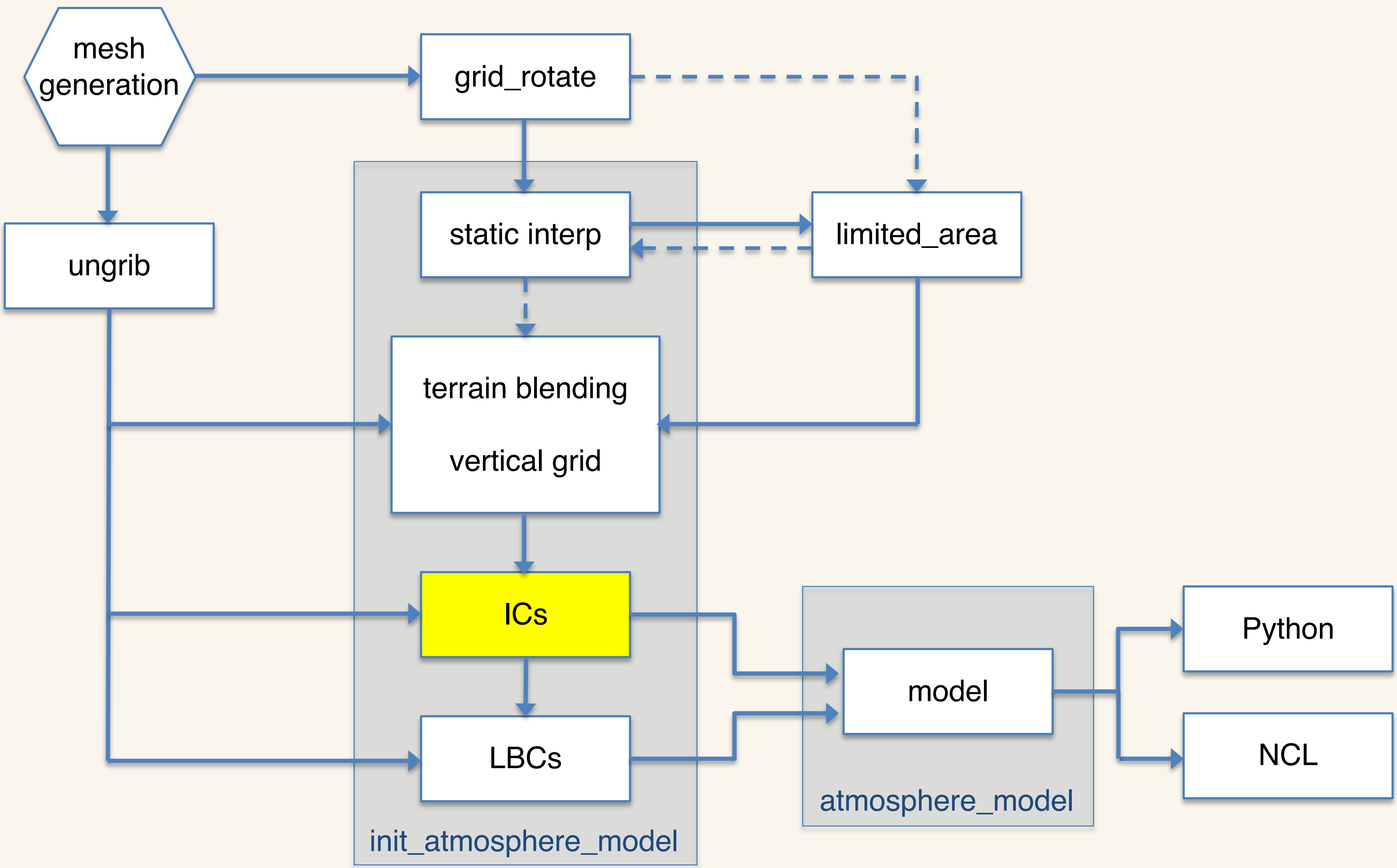
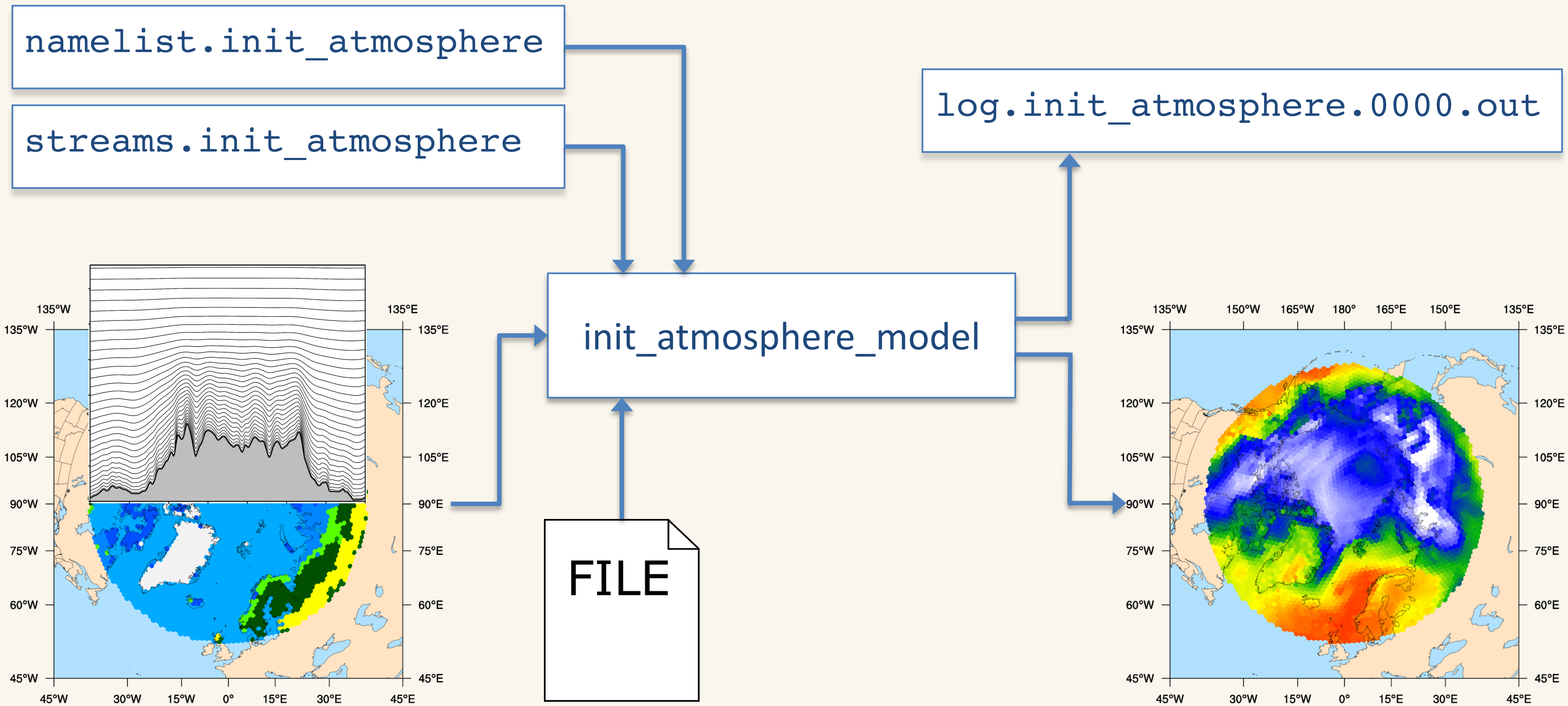
Regional MPAS Flowchart



MPAS
Model for Prediction Across Scales

Generating ICs

Initial Conditions (ICs) for limited-area simulations are created by the **init_atmosphere** core with "init case" 7:



E.g., arctic.vertical.nc

E.g., arctic.init.nc

MPAS
Model for Prediction Across Scales

Generating ICs

Key settings in the `namelist.init_atmosphere` file:

```
&nhyd_model
    config_init_case = 7
    config_start_time = '2020-12-21_12:00:00'
/
&dimensions
    config_nvertlevels = 55
    config_nsoillevels = 4
    config_nfglevels = 38
    config_nfgsoillevels = 4
/
&data_sources
    config_met_prefix = 'FILE'
    config_use_spechumd = true
/
```

Generating ICs

Key settings in the `namelist.init_atmosphere` file (*cont.*):

```
&preproc_stages
    config_static_interp = false
    config_native_gwd_static = false
    config_vertical_grid = false
    config_met_interp = true
    config_input_sst = false
    config_frac_seaice = true
/
```

MPAS
Model for Prediction Across Scales

Generating ICs

Key settings in the `streams.init_atmosphere` file:

```
<immutable_stream name="input"
                  type="input"
                  filename_template="arctic.vertical.nc"
                  input_interval="initial_only" />


<immutable_stream name="output"
                  type="output"
                  filename_template="arctic.init.nc"
                  packages="initial_conds"
                  output_interval="initial_only" />
```

Generating ICs

The result should be an “init” netCDF file with

- *<u>everything from the “vertical” file</u>*
- 3-d potential temperature (*theta*)
- 3-d winds (*u* and *w*)
- 3-d water vapor mixing ratio (q_v)
- 2-d soil moisture
- 2-d soil temperature

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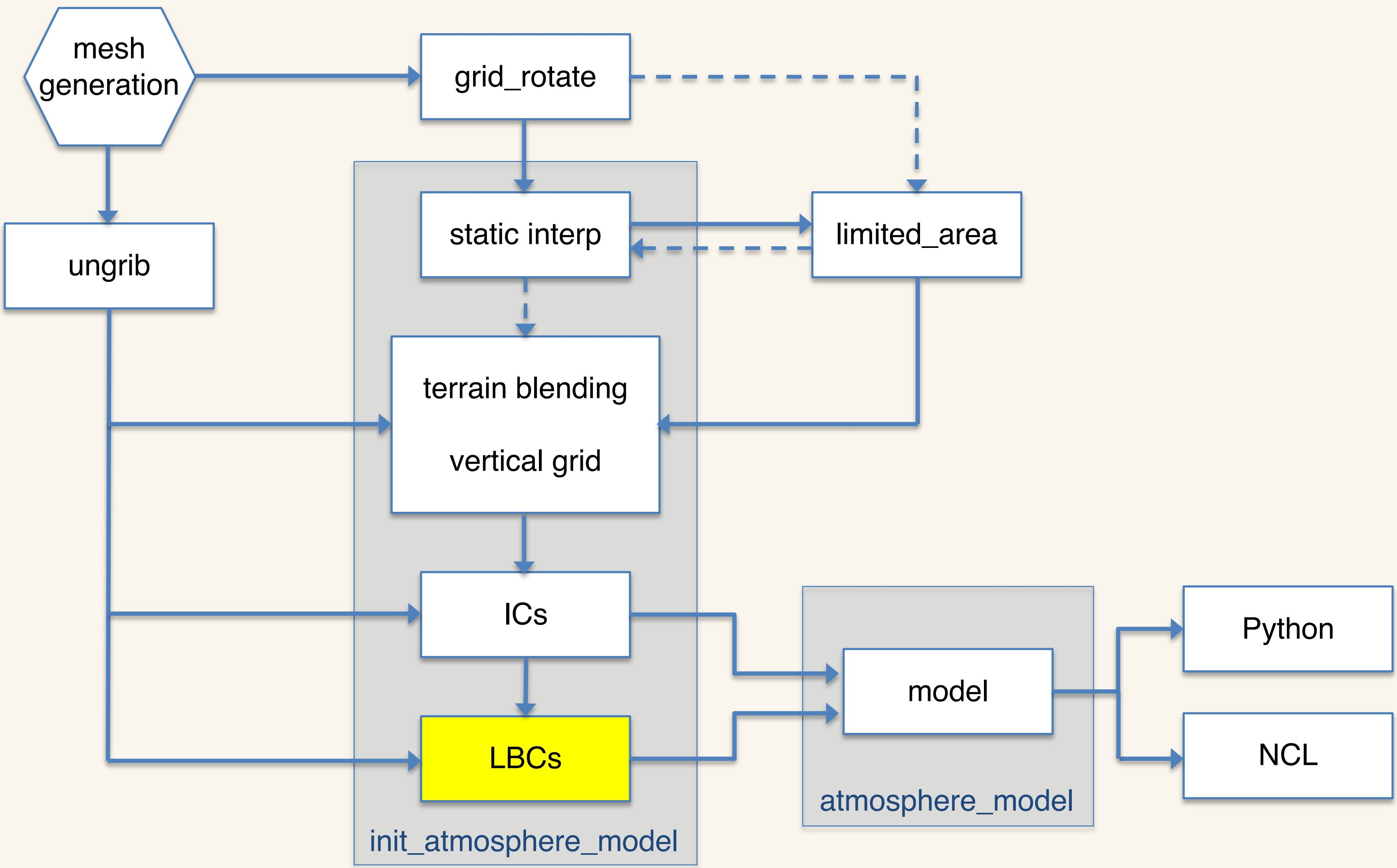
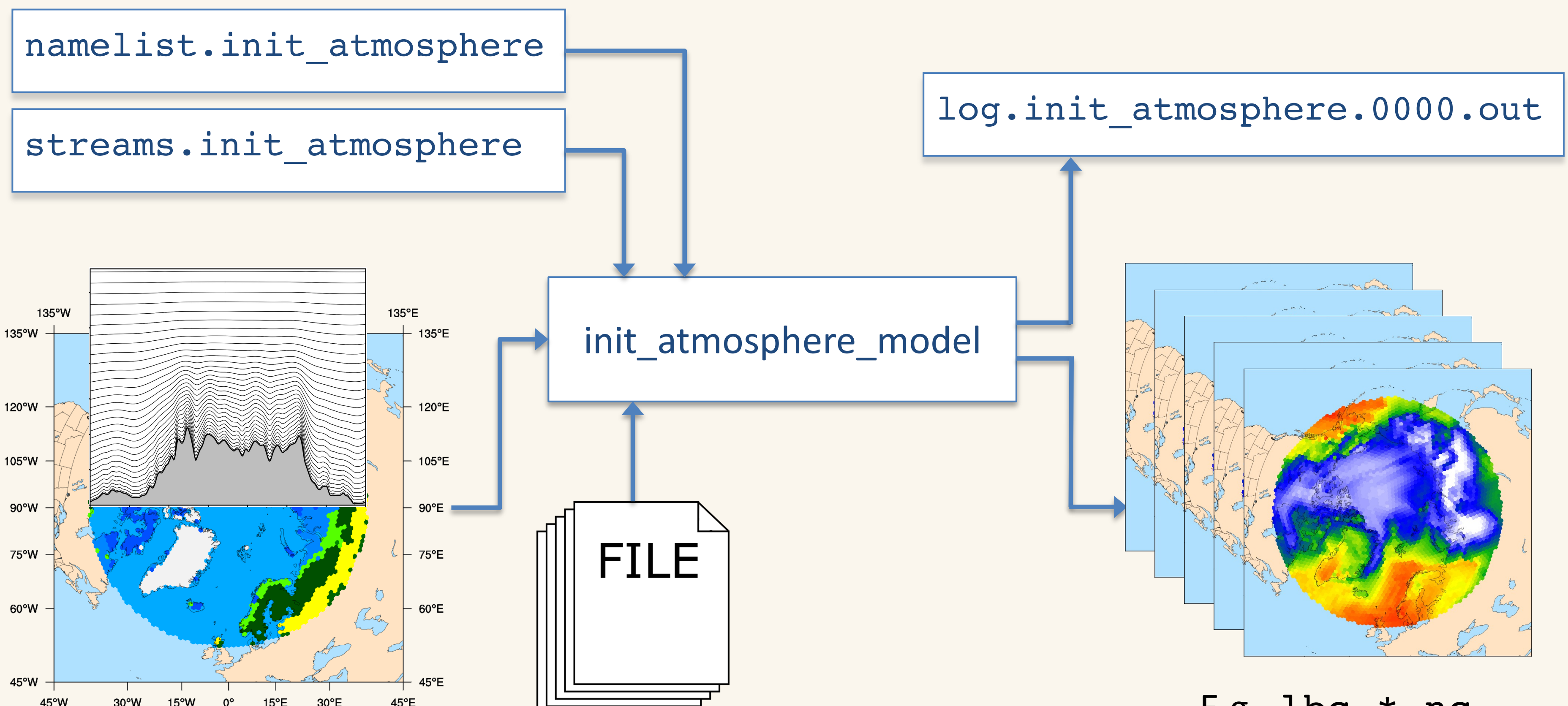
Regional MPAS Flowchart



Generating LBCs

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



E.g., arctic.vertical.nc

E.g., lbc.*.nc

MPAS
Model for Prediction Across Scales

Generating 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 = '2020-12-21_12:00:00'
    config_stop_time = '2020-12-22_12:00:00'
/
&data_sources
    config_met_prefix = 'FILE'
    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

Generating LBCs

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

- Note that, because the ICs also contain vertical grid info, setting the `filename_template` to the name of the initial conditions file also works!

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

MPAS
Model for Prediction Across Scales

Generating 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

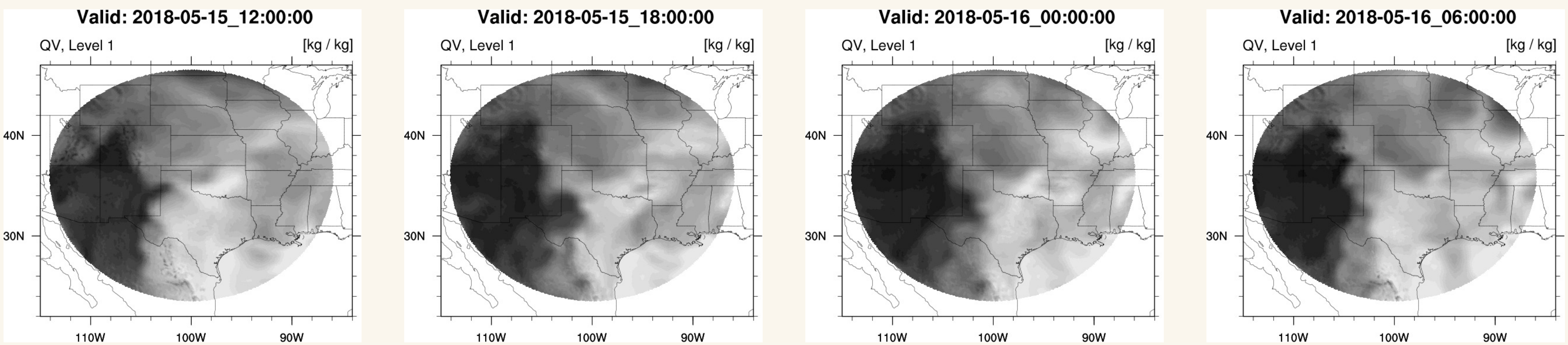
```
<immutable_stream name="lbc"
                  type="output"
                  filename_template="lbc.$Y-$M-$D_$h.$m.$s.nc"
                  filename_interval="output_interval"
                  packages="lbcs"
                  output_interval="3:00:00" />
```

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

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

MPAS
Model for Prediction Across Scales

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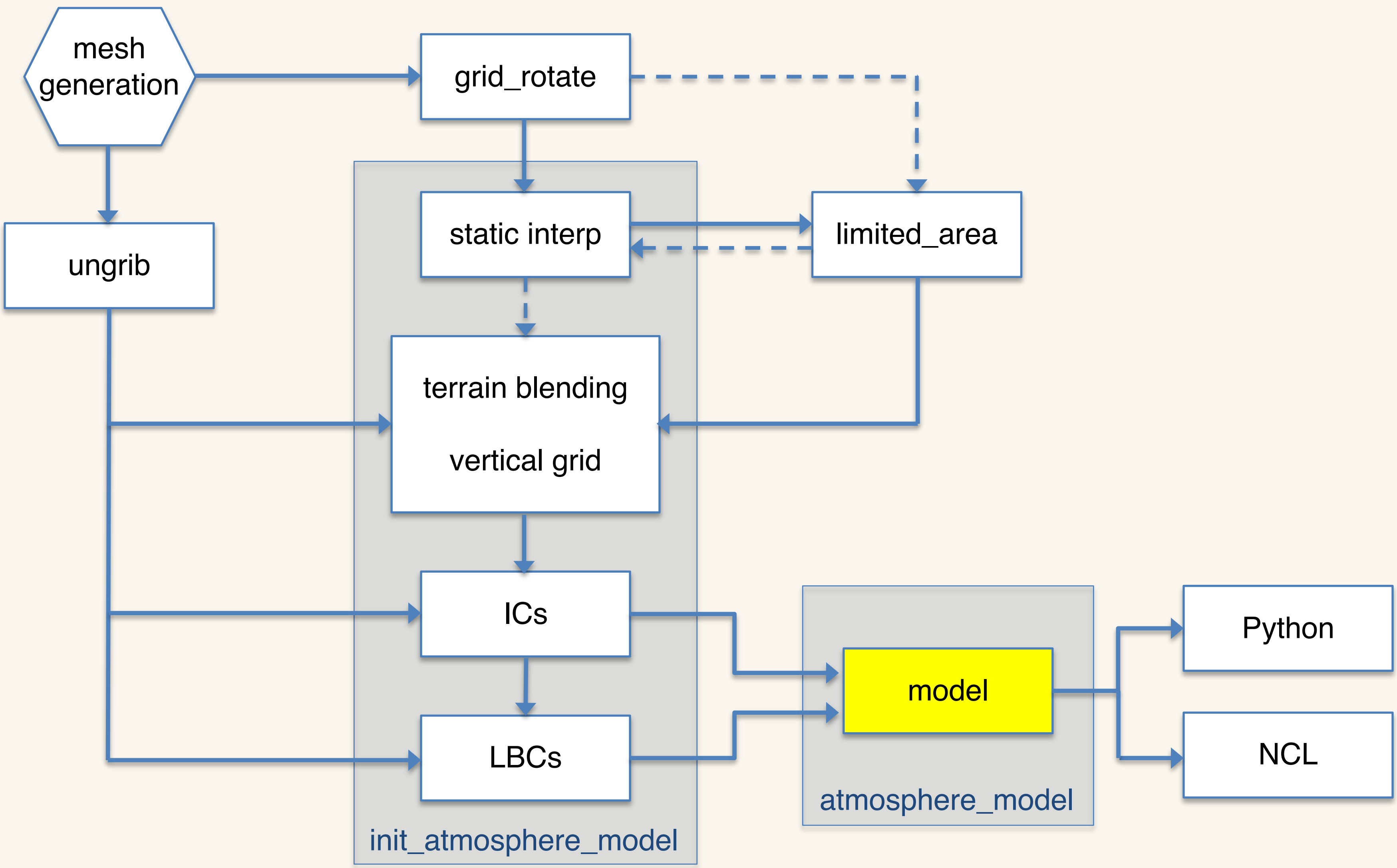
Regional MPAS Flowchart



Applying LBCs in a regional 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 in a regional 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

Regional log messages

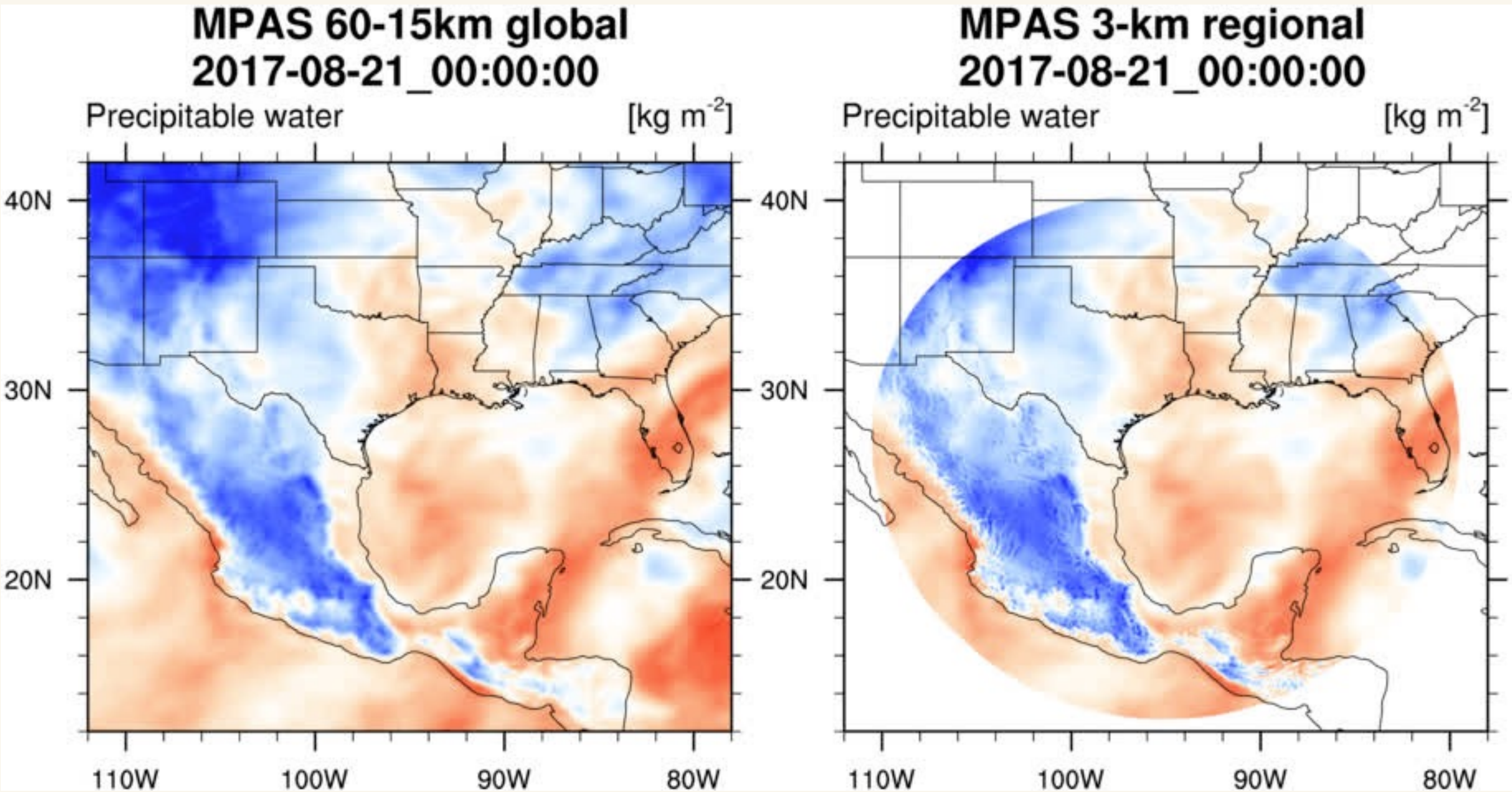
What regional simulation-specific messages should appear in the log files?

```
Checking consistency of limited-area settings...
 - config_apply_lbcs = T
 - Maximum value in bdyMaskCell = 7
 - Input interval for 'lbc_in' stream = '0000000000_003:000:000'
 ----- done checking limited-area settings -----
```

```
--------------------------------------------------------------------
Updated lateral boundary conditions. LBCs are now valid
from 2020-12-21_12:00:00 to 2020-12-21_15:00:00
--------------------------------------------------------------------
```

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

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MPAS
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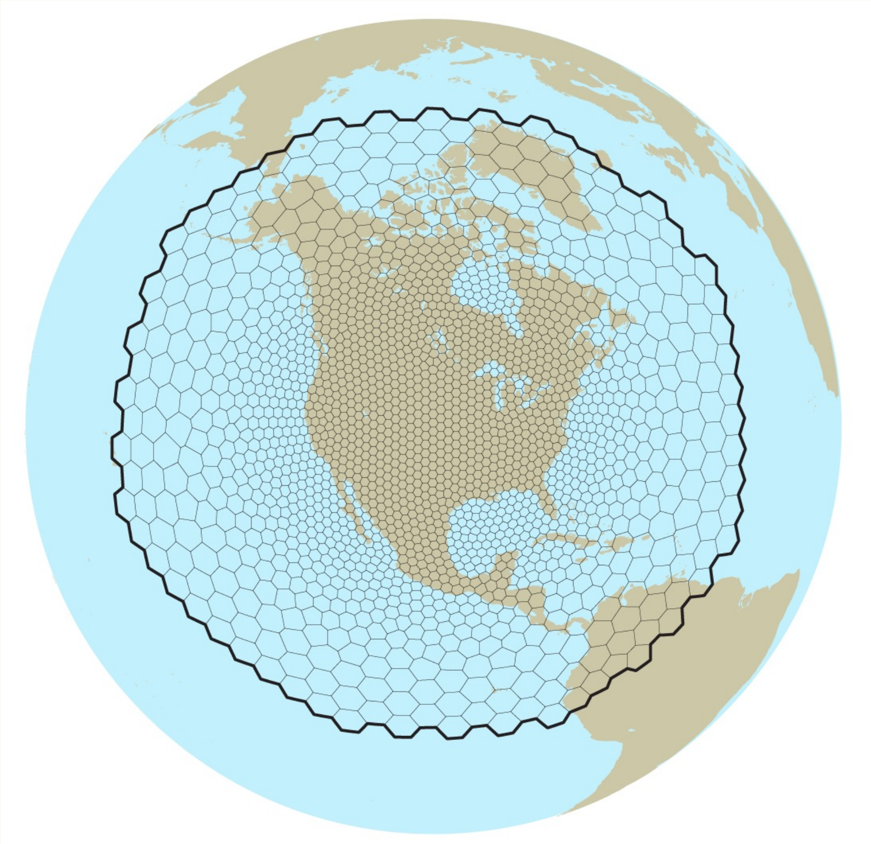
Regional MPAS

Results from regional-MPAS testing and comparisons with WRF

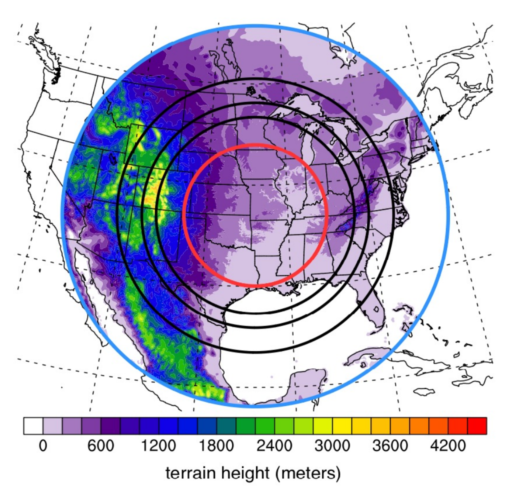


MPAS
Model for Prediction Across Scales

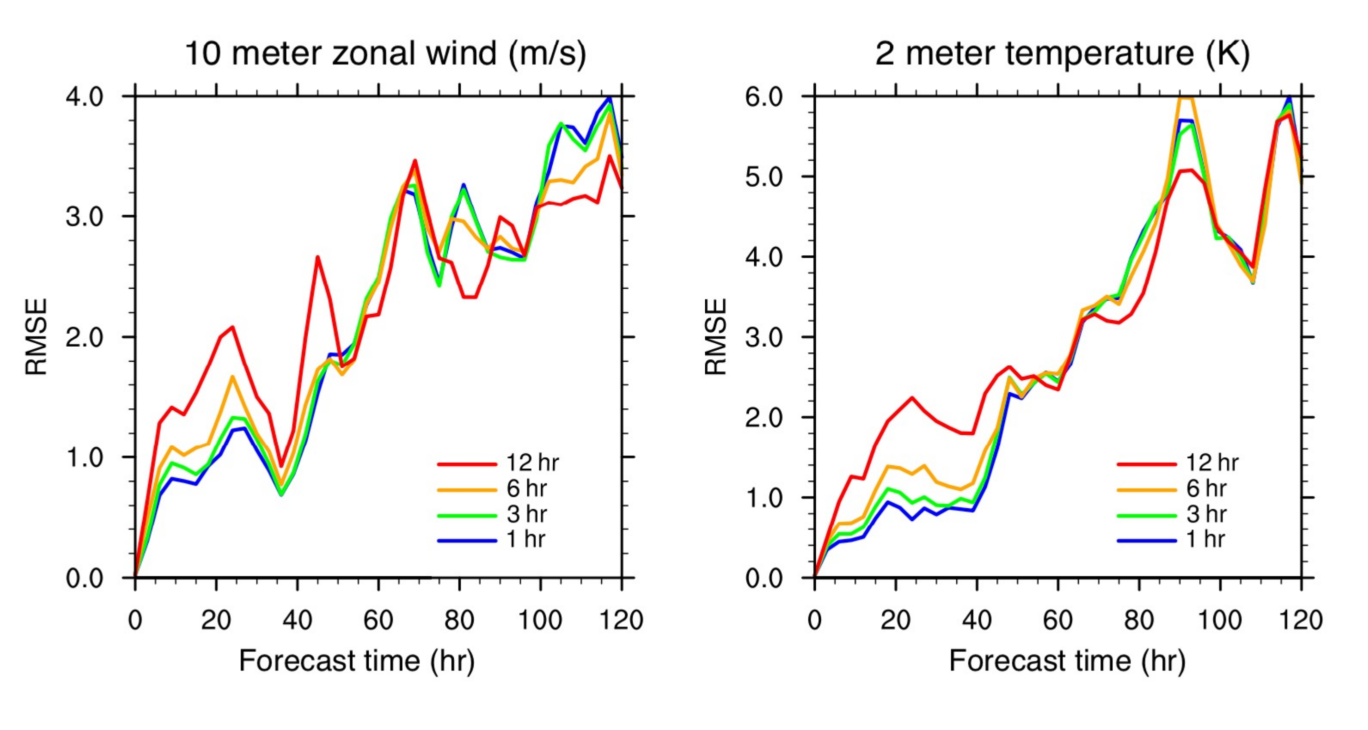
Regional MPAS

Configuration considerations

Boundary update frequency:
5-day regional MPAS integrations,
Red-circle region (3 km cell spacing),
different LBC update frequencies.
Global 3 km integration is truth.
More frequent updates are better.



26 April 2017
00 UTC init



*Verification over the small 3 km mesh (red circle)

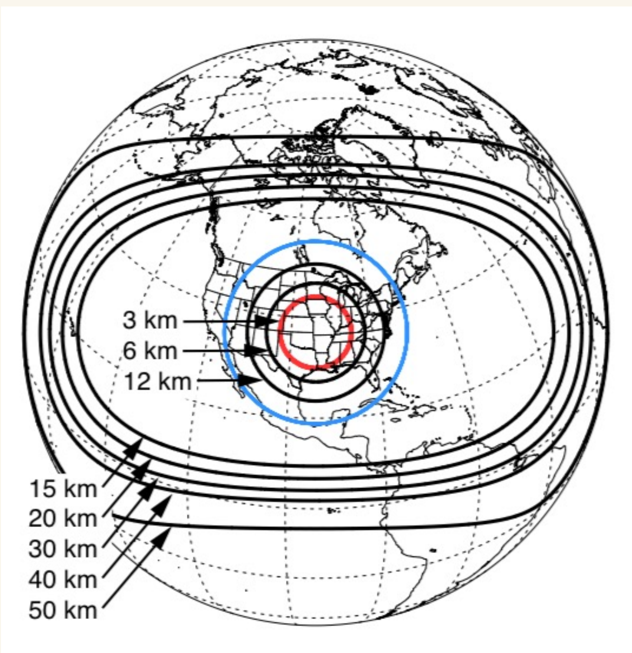
Regional MPAS

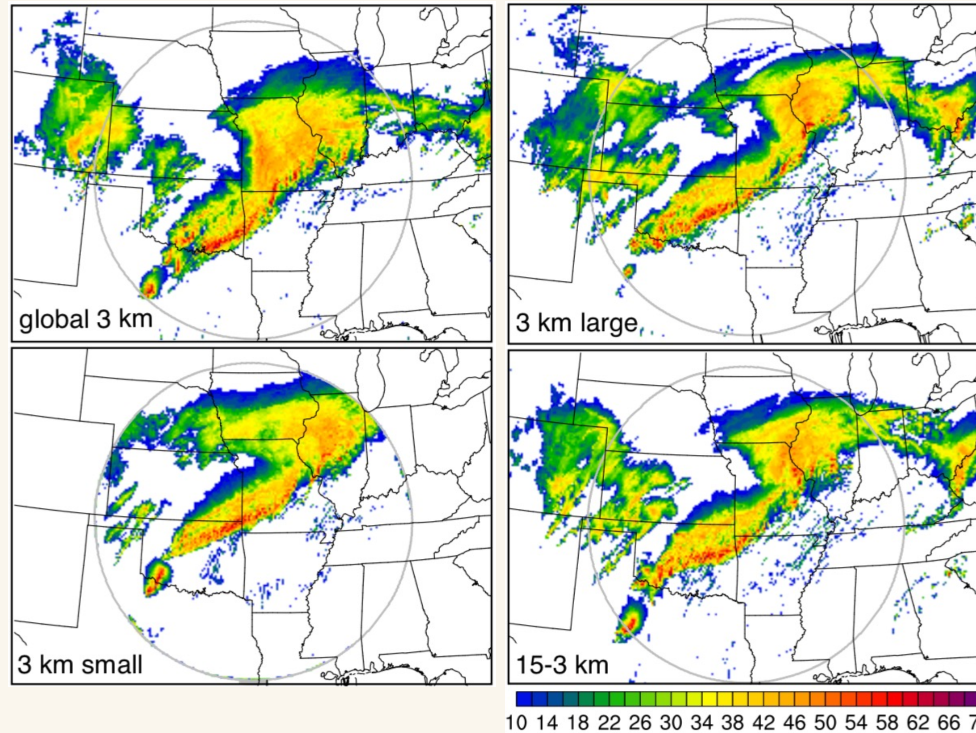
Configuration considerations

Domain size:

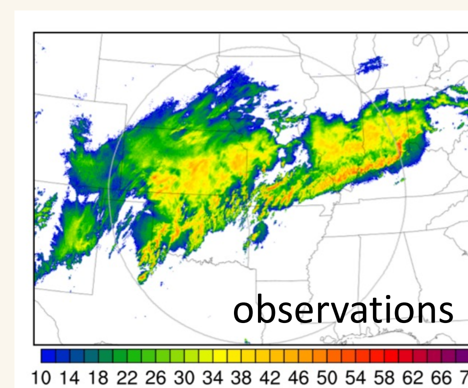
Larger is better.

Use variable-resolution capability to extend domain size but limit cost.





Column maximum reflectivity (dBZ)
84 h forecast
(12 UTC 29 April 2017)

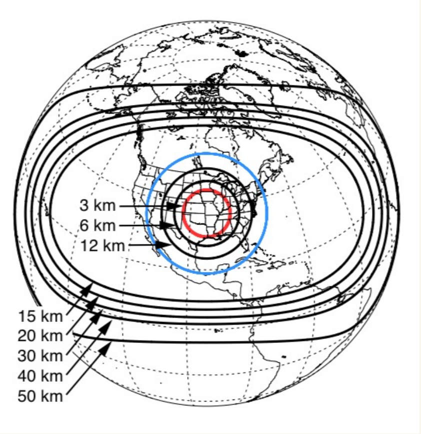


Regional MPAS

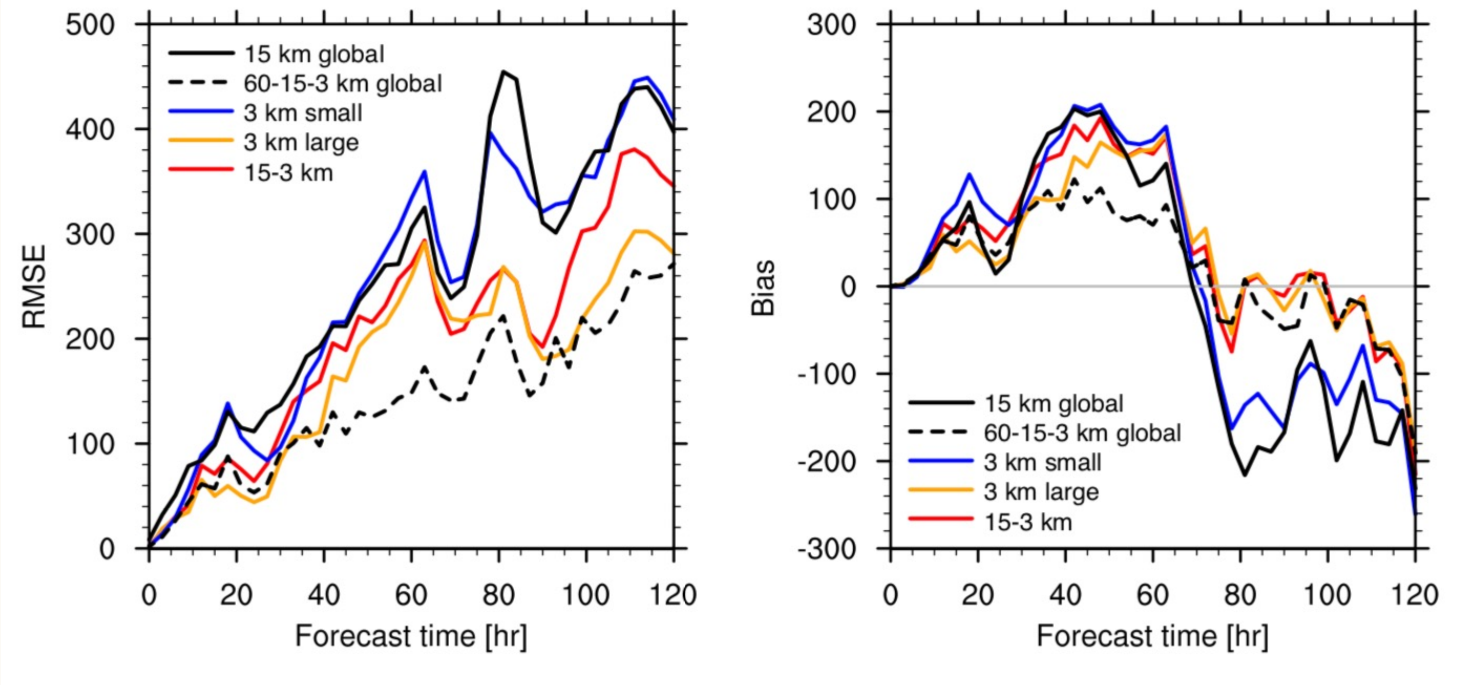
Configuration considerations

Domain size:
Larger is better.
Global is usually the best
(60-15-3 km result)

*Verification over the small 3 km mesh (red circle)



MSLP (Pa)



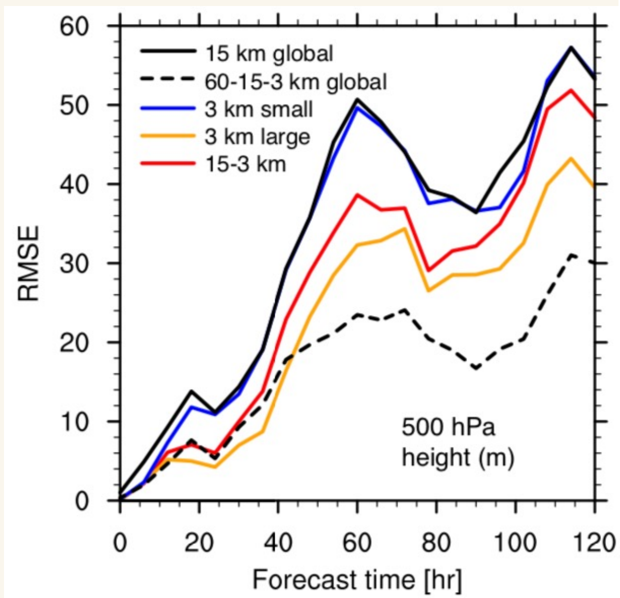
Regional MPAS

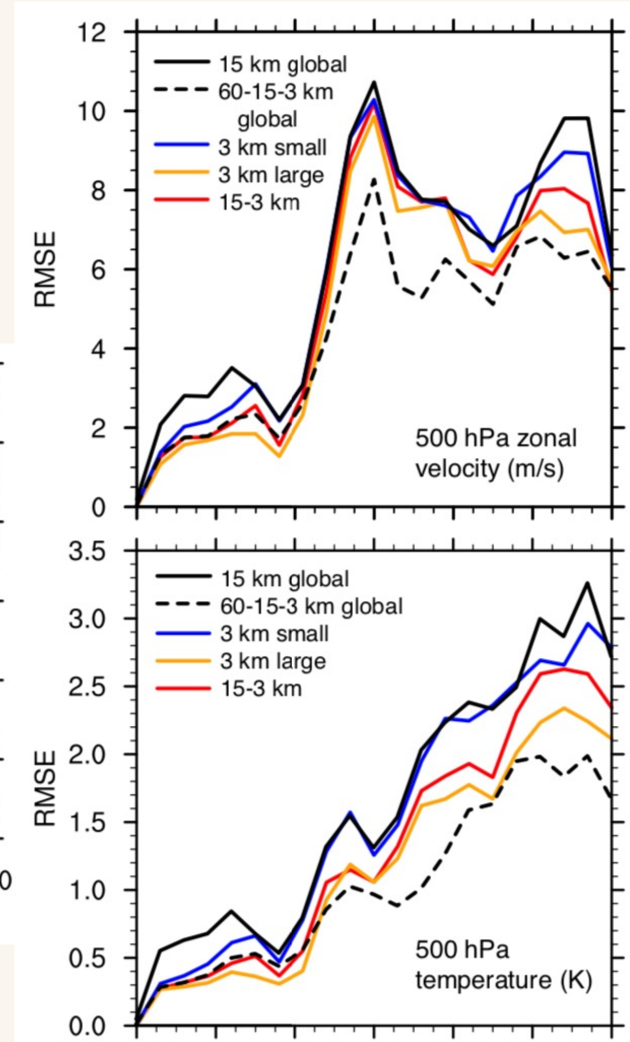
Configuration considerations

Domain size:
Larger is better.
Global is usually the best
(60-15-3 km result)

<u>500 hPa</u>
Zonal velocity
Temperature
height

*Verification over the small 3 km mesh





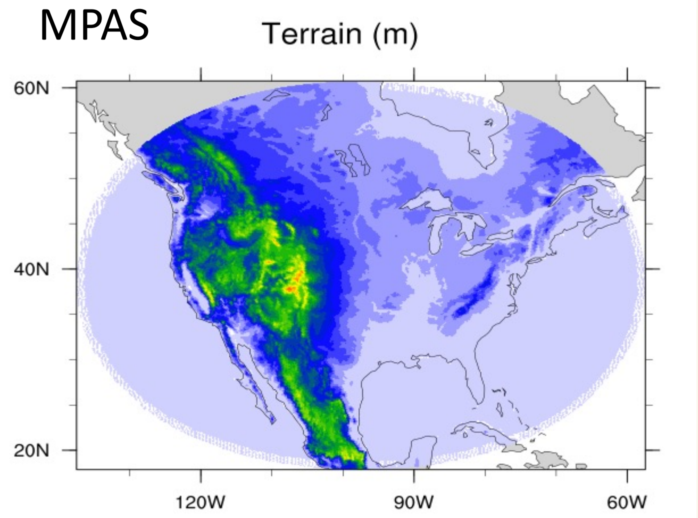
WRF-Regional MPAS Comparison

<u>CONUS regional forecasts test results</u>

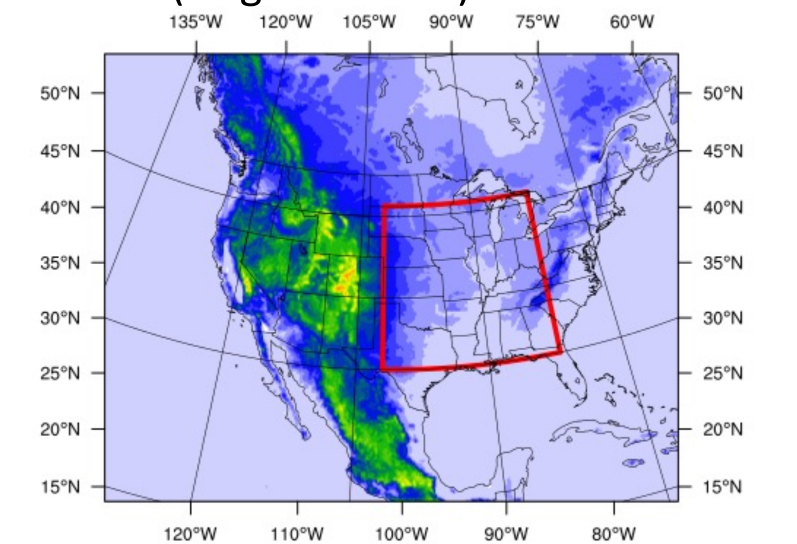
MPAS and WRF domains – 15 km meshes
Identical physics (MPAS mesoscale reference suite)
Two forecast periods, 72 h forecasts every 3 days
Cold starts from GFS analyses.

Winter forecasts (20170201-20170330)
Spring forecasts (20170420-20170613)

Overall view: The forecasts are very similar with only a few small differences.



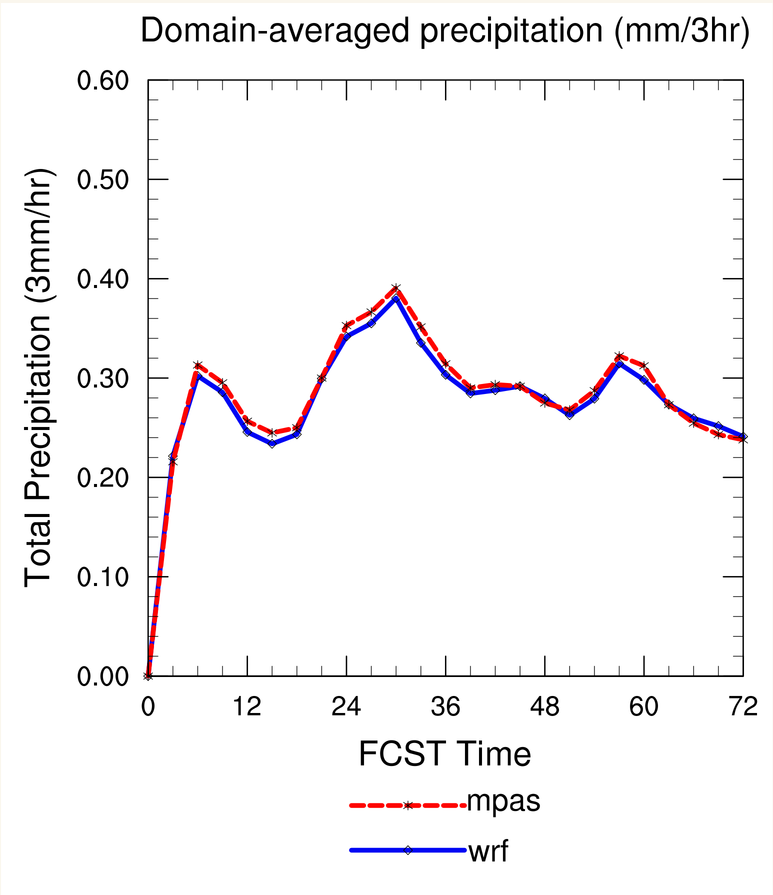
WRF (single domain)



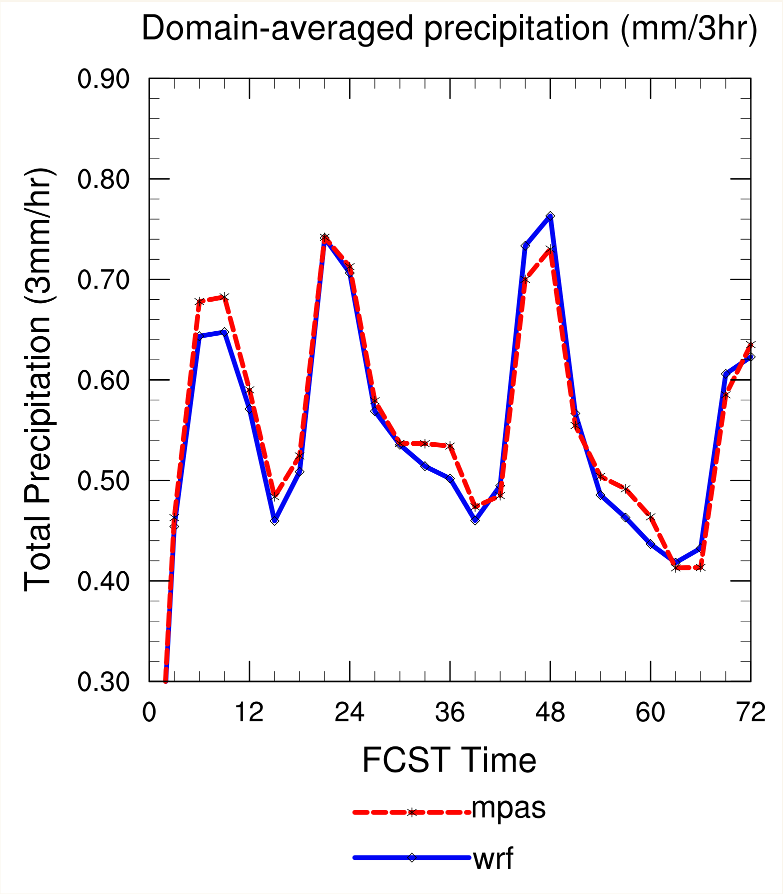
Red rectangle is precip analysis window

WRF-Regional MPAS Comparison

Winter forecasts (20170201-20170330)

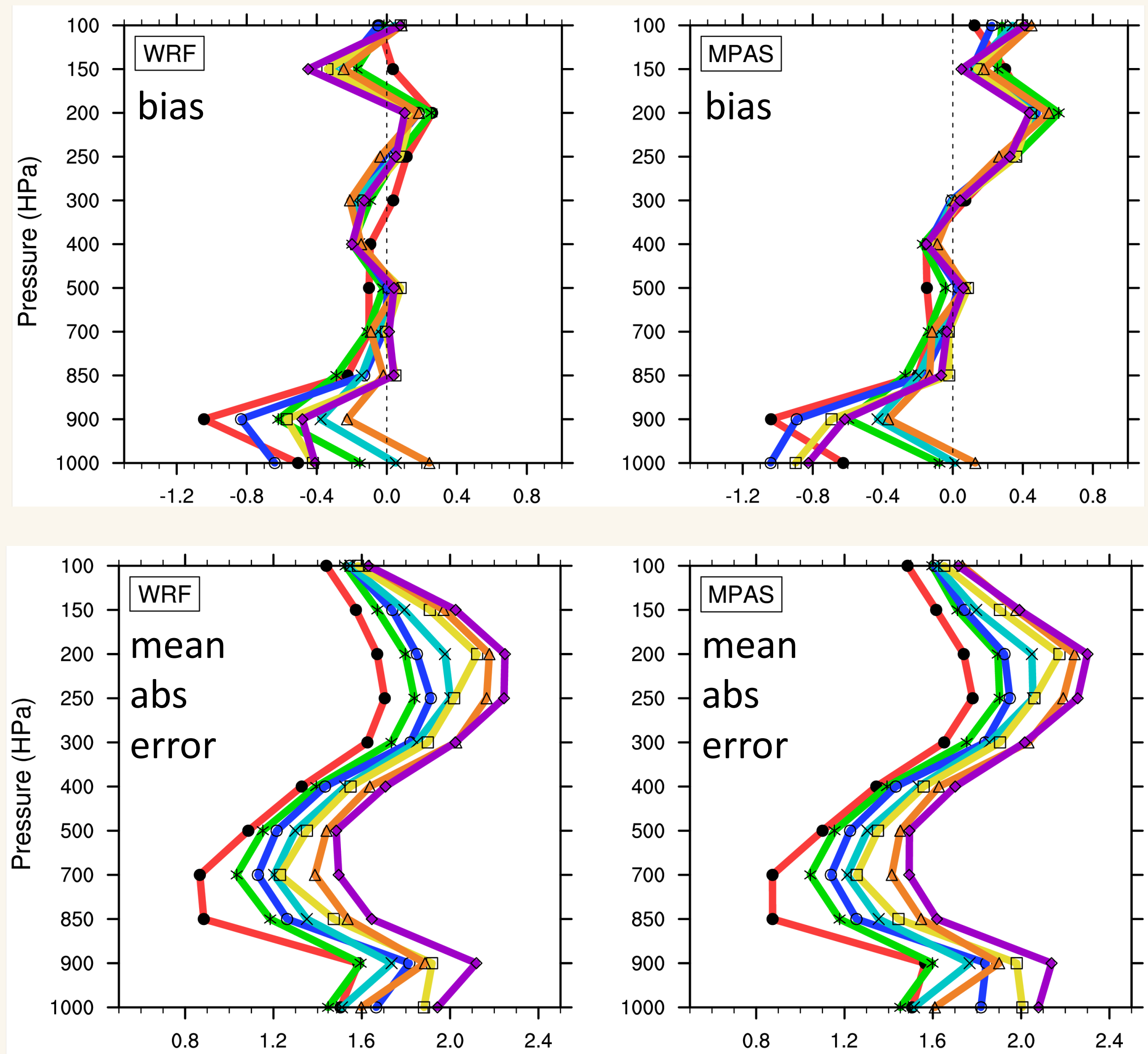


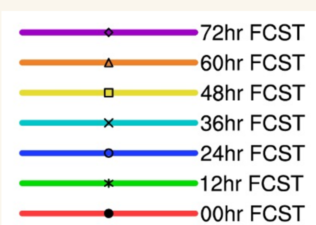
Spring forecasts (20170420-20170613)



WRF-Regional MPAS Comparison

Spring forecasts
(20170420-20170613)





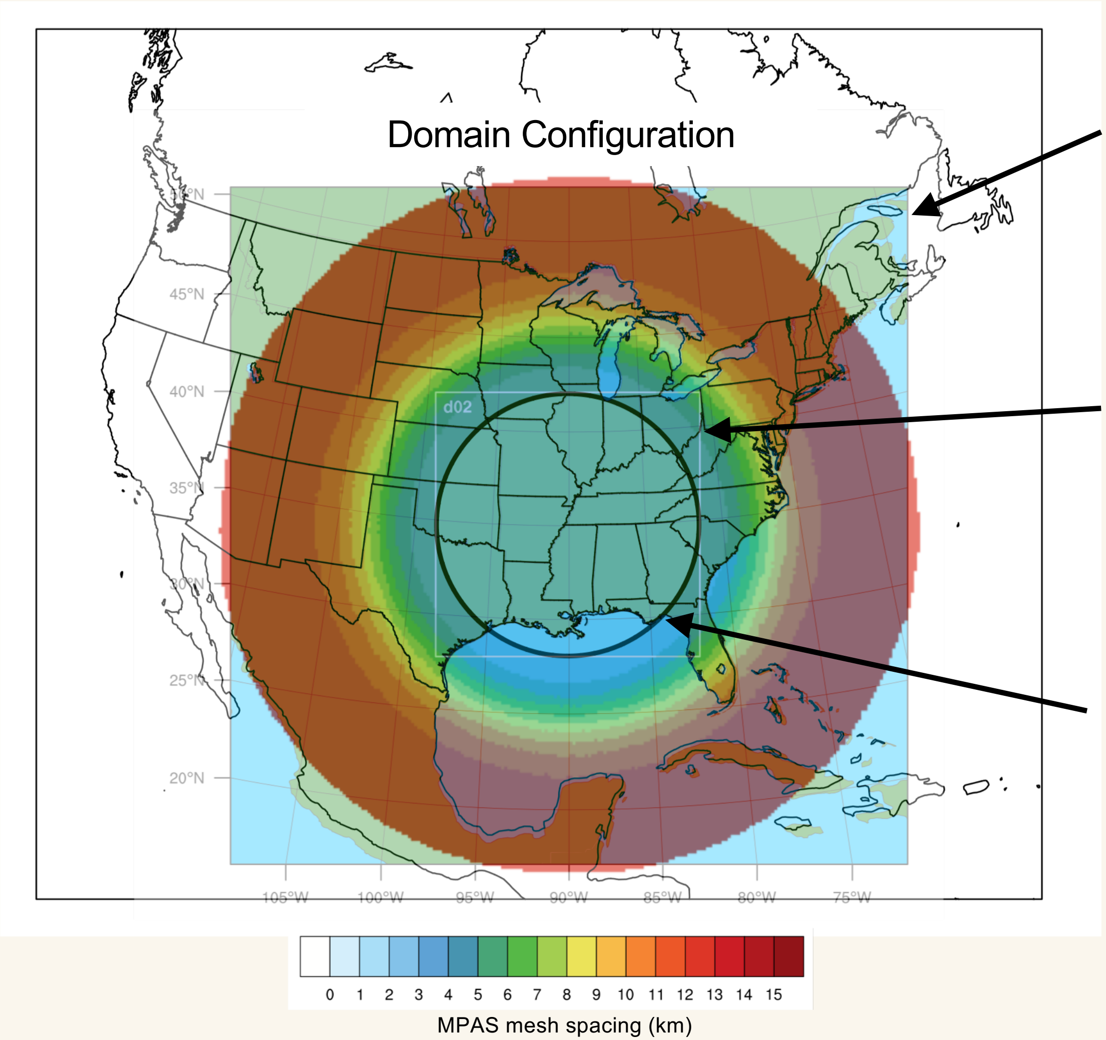
WRF-Regional MPAS Comparison

<u>Comparing WRF nesting to MPAS variable-resolution results</u>

MPAS 15-3 km mesh
and
15-3 km and 9-3 km
2-way nested
WRF configurations

30 May 2017
initialization.

Scale-aware nTiedtke convection scheme is used in these simulations for both WRF and MPAS



WRF 15-km or 9-km domain, and also domain for full 3-km

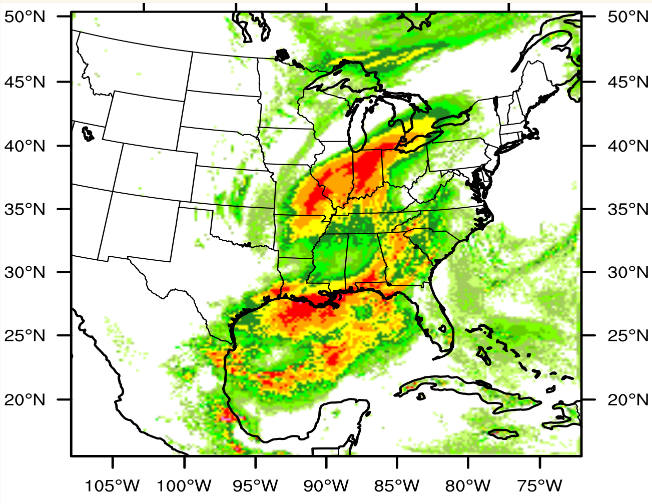
WRF 3-km nest

MPAS 3-km region

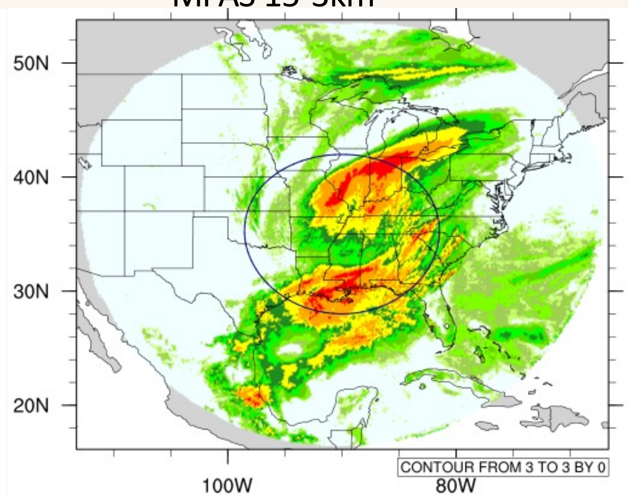
WRF-Regional MPAS Comparison

Total precipitation (24-48hr, mm)

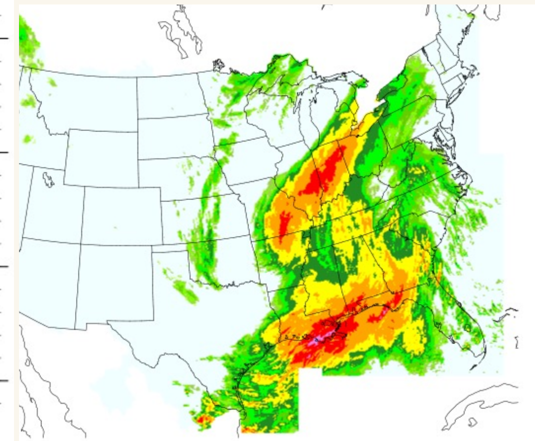
WRF 3km

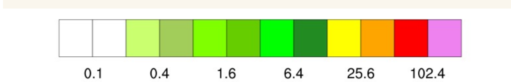


MPAS 15-3km

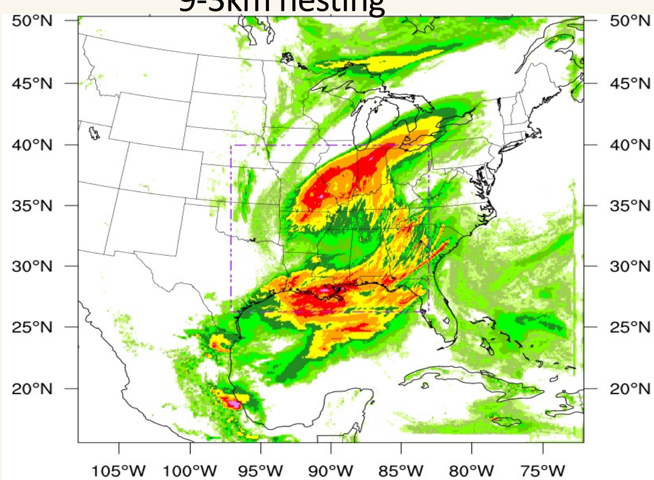


STAGE IV

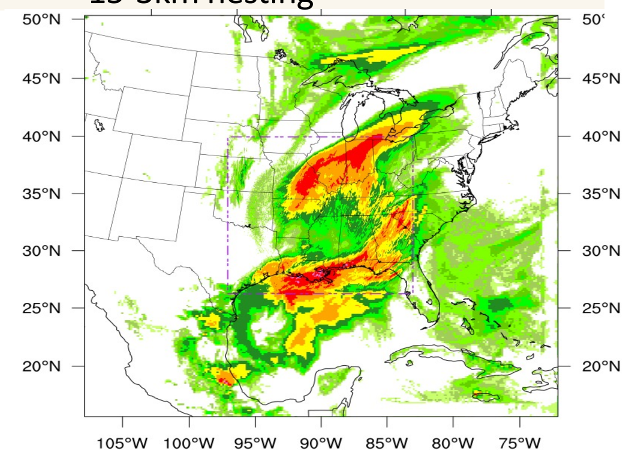




9-3km nesting



15-3km nesting



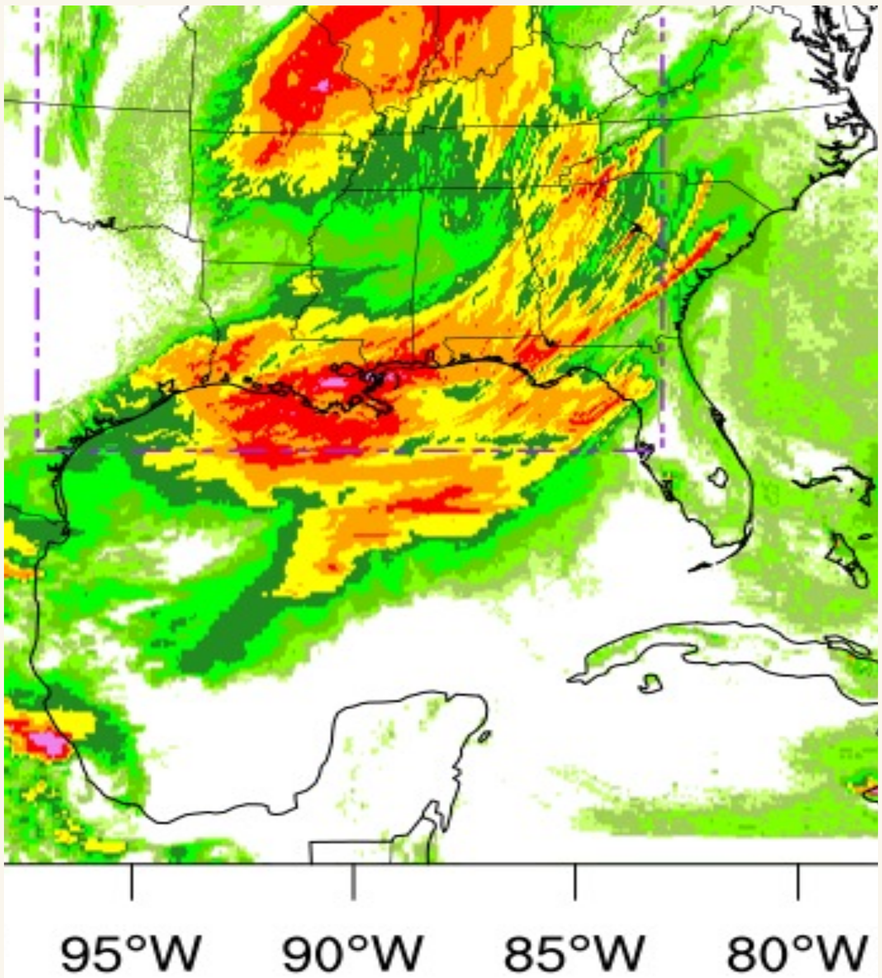
Spatial distribution of total precipitation are similar among the four runs. WRF produces somewhat more precipitation than MPAS.

WRF-Regional MPAS Comparison

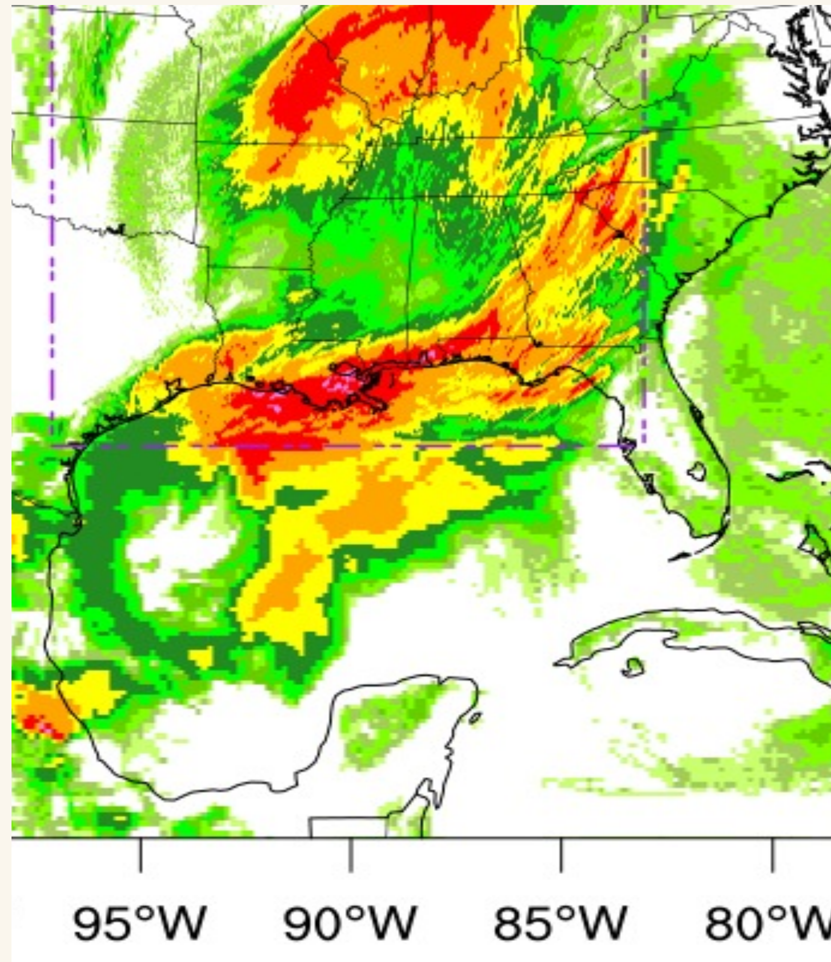
MPAS
Model for Prediction Across Scales

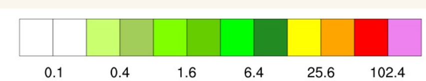
Total precipitation (24-48hr, mm)

9-3km nesting



15-3km nesting

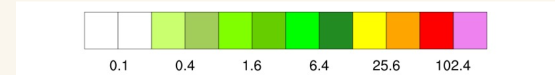


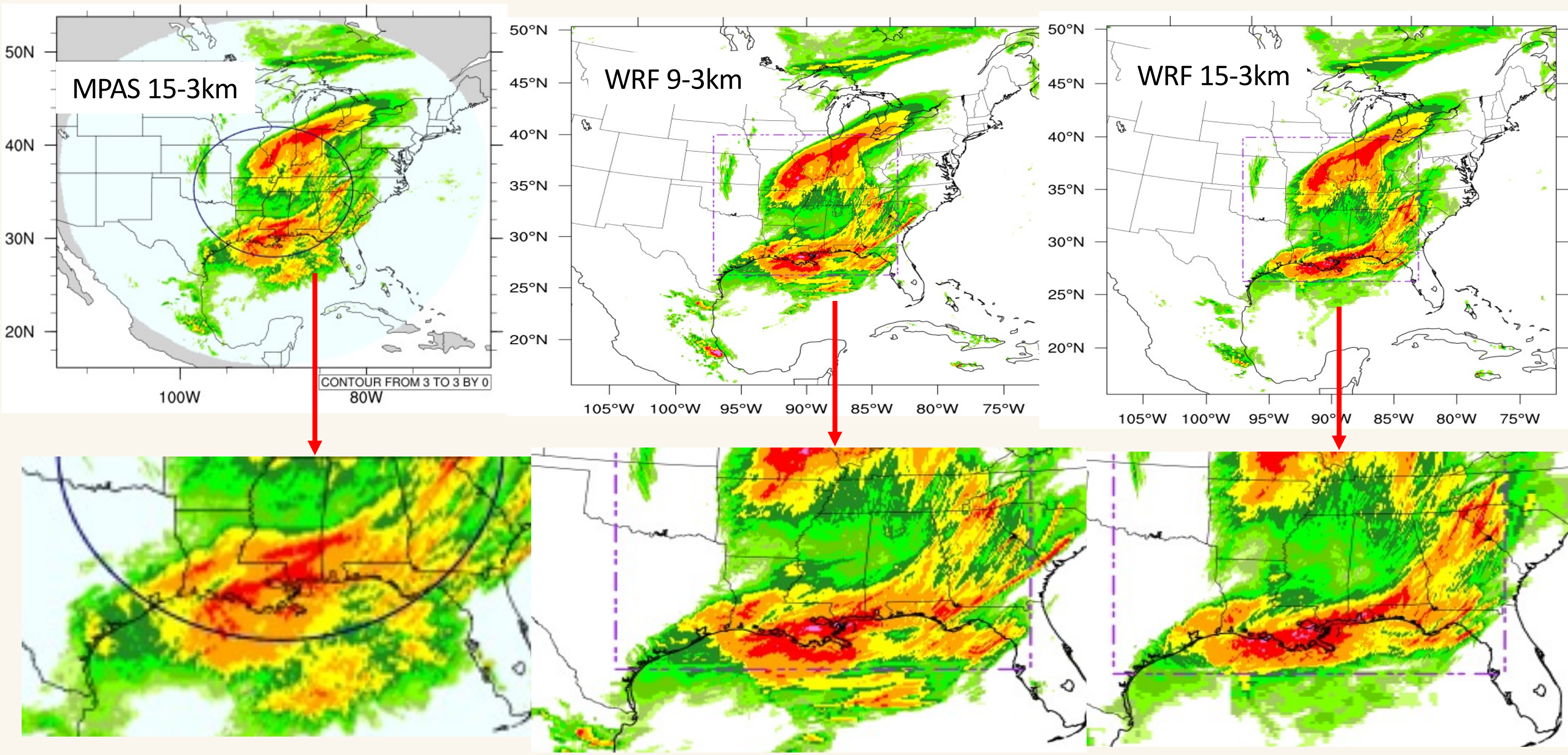


MPAS
Model for Prediction Across Scales

WRF-Regional MPAS Comparison

Resolved (explicit) precipitation (24-48hr, mm)



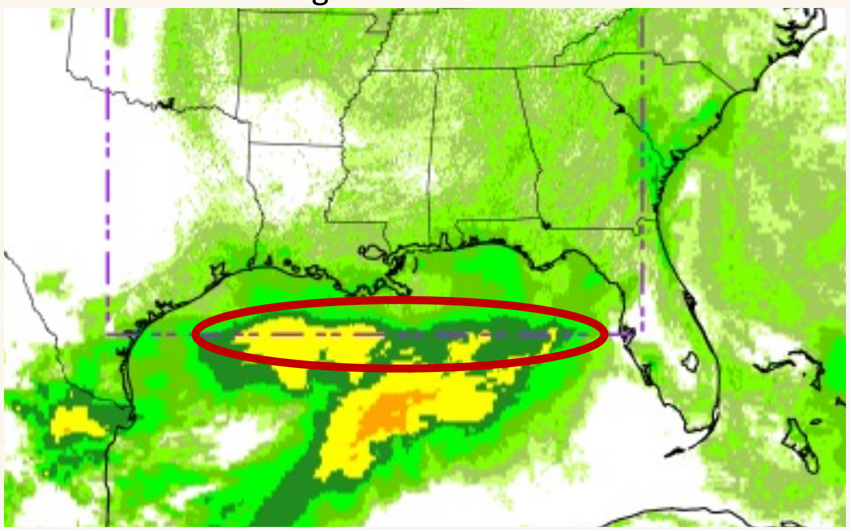


Abrupt transitions in the WRF solutions, although the scale-aware nTiedtke scheme allows for some strong convection on the 9 km WRF grid

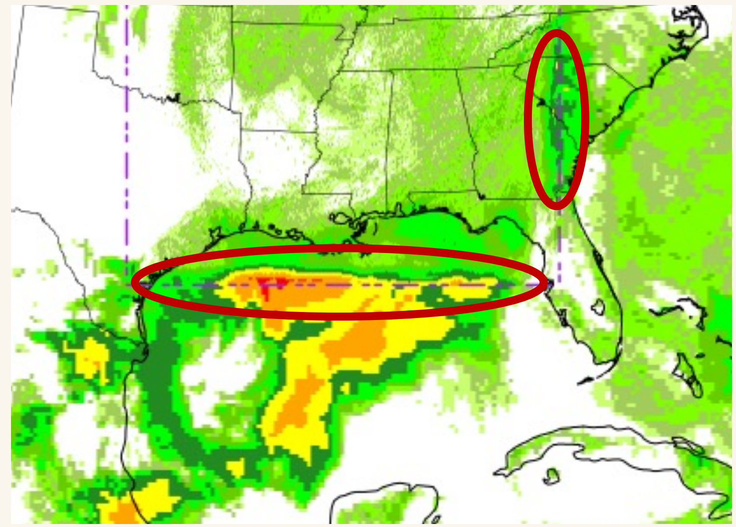
WRF-Regional MPAS Comparison

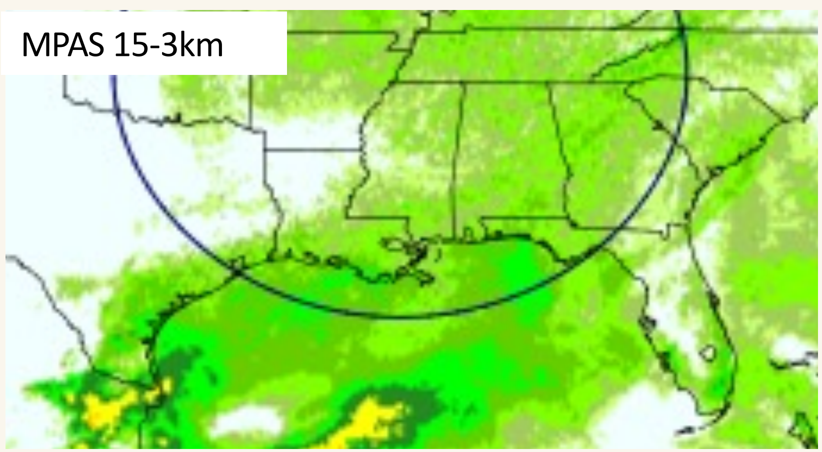
Parameterized precipitation (24-48hr, mm)

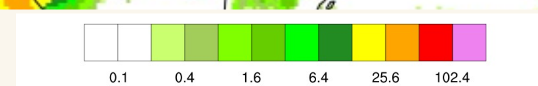
9-3km nesting



15-3km nesting







When convective systems pass through nest boundaries, precipitation transitions abruptly between explicit and parameterized.

WRF-Regional MPAS Comparison

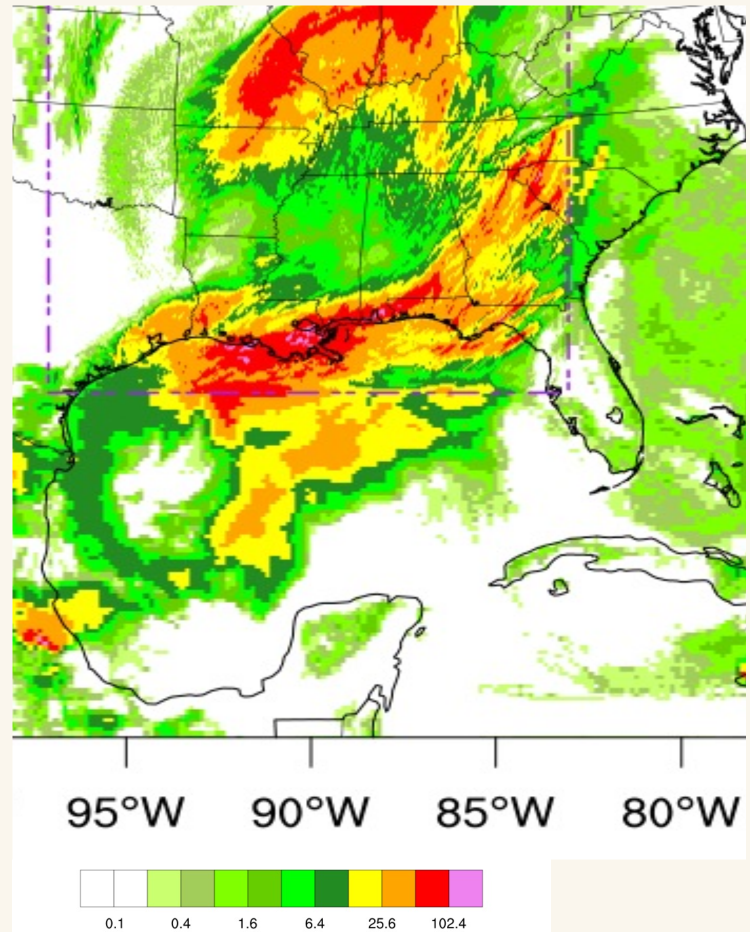
<u>Hydrostatic to non-hydrostatic (convection-permitting) resolution changes:</u>

The abrupt change in resolution in the nested WRF configurations lead to an abrupt changes in the behavior of the parameterized physics and explicitly simulated deep convection that can be problematic.

The smoothly varying MPAS resolution allows scale-aware physics, and the resolved dynamics, to respond more gradually.

total precipitation (24-48hr)

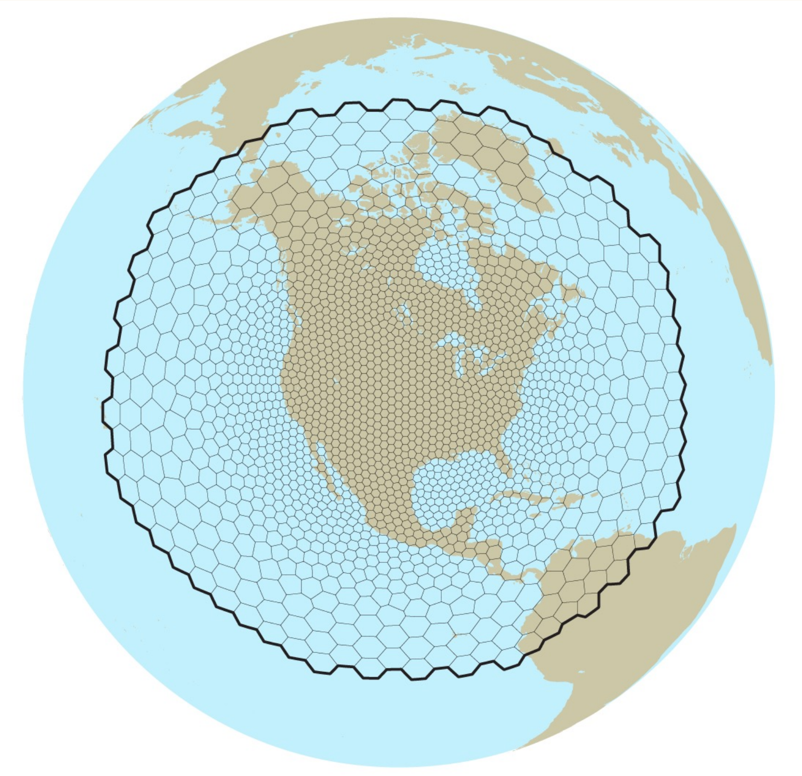
WRF 15-3km nesting



Regional MPAS

Why use MPAS instead of WRF?

- MPAS has clean local refinement capabilities using variable resolution mesh.
- MPAS is a much better global model – no polar filters or pole problems.
- MPAS regional code is a much cleaner implementation of LBCs compared to WRF.
- More extensive capabilities are under development.



More information:

(1) This short course, of course!

(2) Full MPAS tutorial - https://www.mmm.ucar.edu/mpas-tutorial-agenda

(3) Paper describing regional MPAS implementation and tests

W. C. Skamarock, M. G. Duda, S. Ha, and S.-H. Park, 2018: Limited-Area Atmospheric Modeling Using an Unstructured Mesh. Monthly Weather Review, doi:10.1175/MWR-D-18-0155.1