Model for Prediction Across Scales—MPAS

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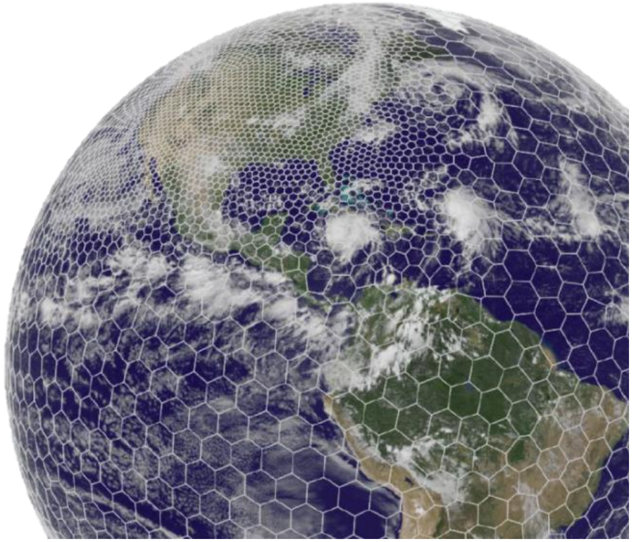
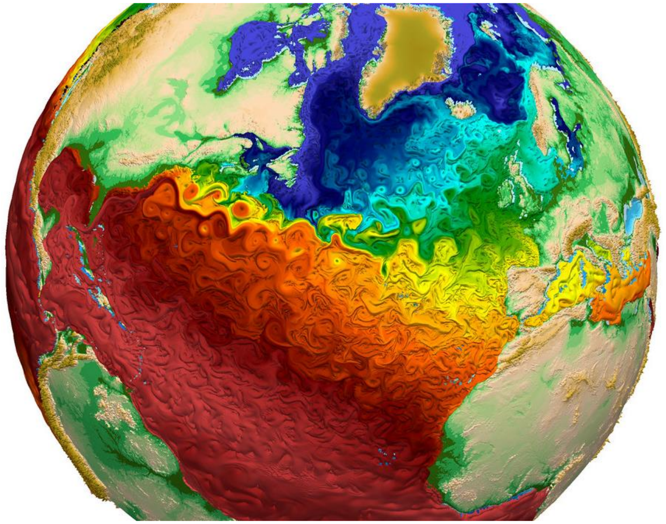
MPAS Model for Prediction Across Scales

MPAS = 4 models (or *cores*)

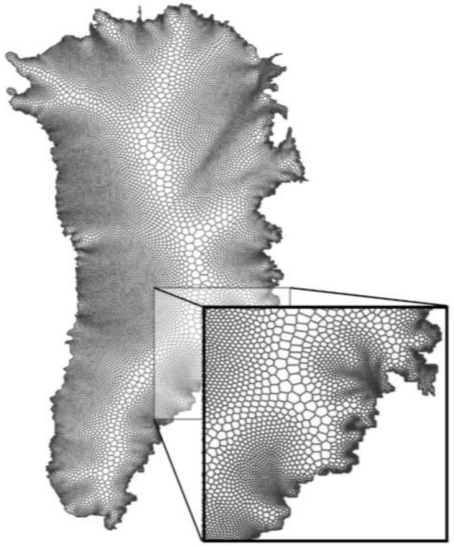
Atmosphere



Ocean



Land ice



Seaice

These are all stand-alone models—there's no coupler in MPAS

MPAS
Model for Prediction Across Scales

MPAS is a collaborative effort

Atmosphere

NCAR | MESOSCALE & MICROSCALE METEOROLOGY

Ocean

Land ice

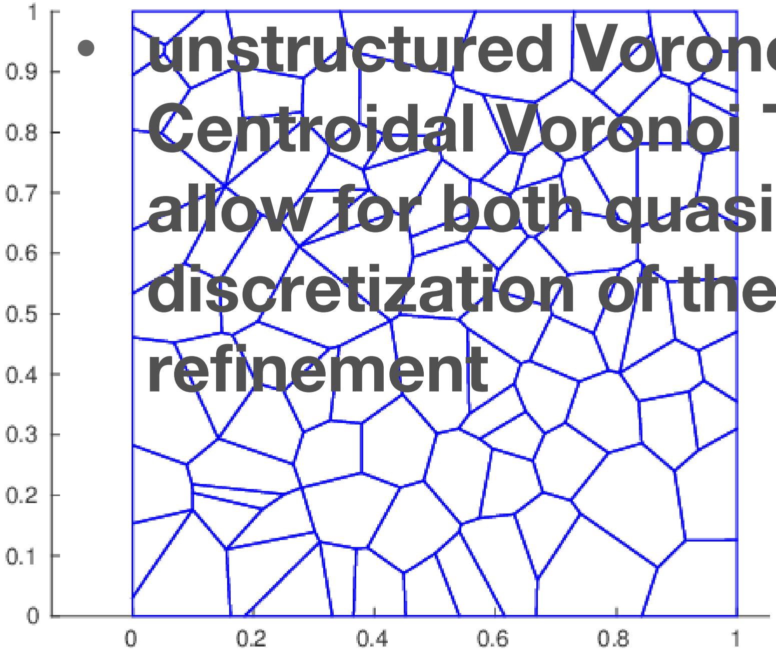
Seaice

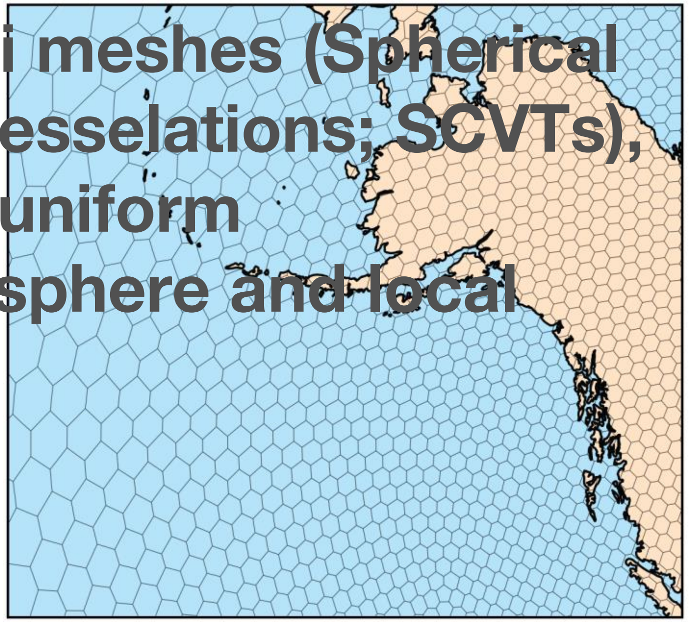
Los Alamos
NATIONAL LABORATORY
EST. 1943

What do all MPAS cores have in common?

- unstructured Voronoi meshes (or *tesselations*) and C-grid discretization

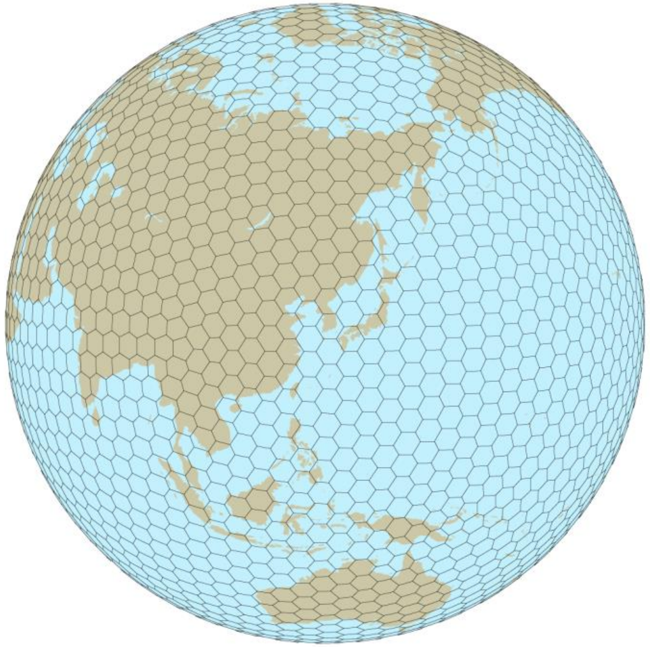
- unstructured Voronoi meshes (Spherical Centroidal Voronoi Tesselations; SCVTs), allow for both quasi-uniform discretization of the sphere and local refinement



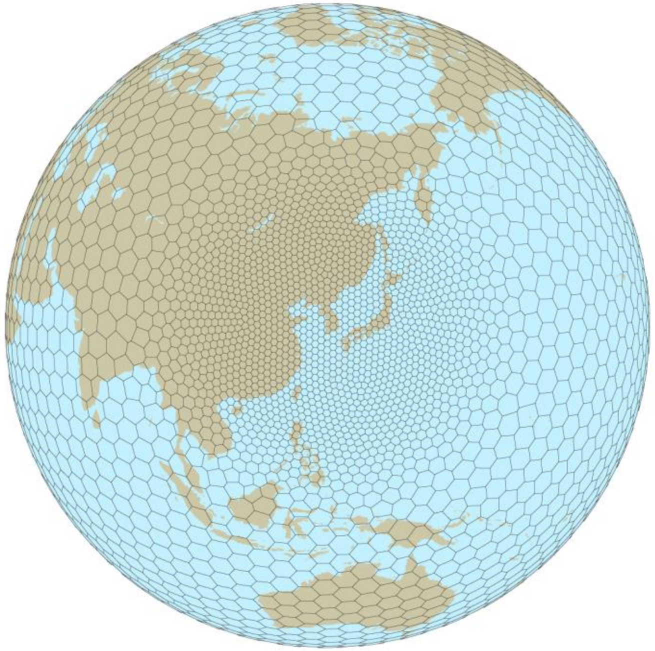


A “Voronoi tessellation” in nature

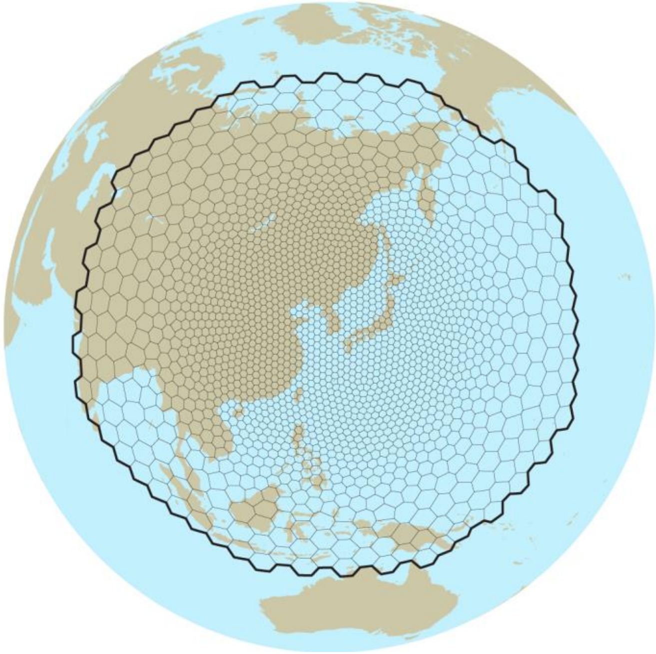
MPAS-A mesh types



Global uniform mesh

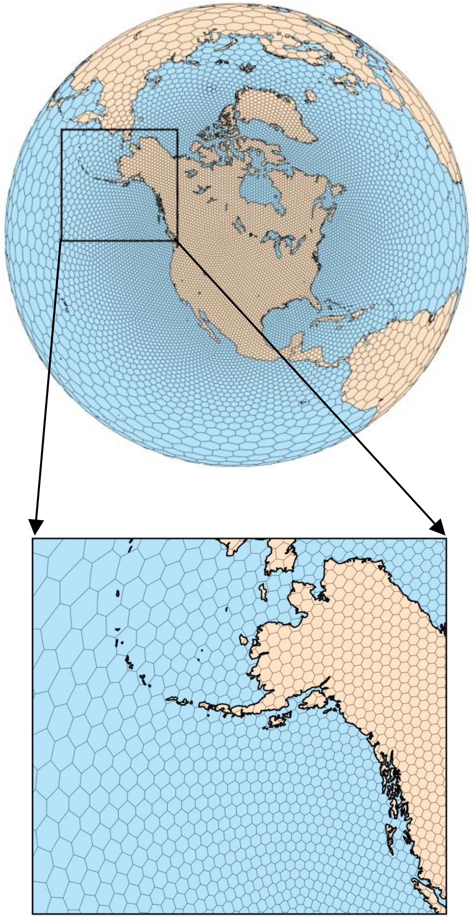


Global variable resolution mesh



Regional mesh (variable/uniform resolution)

MPAS-A: C-grid spherical centroidal Voronoi meshes

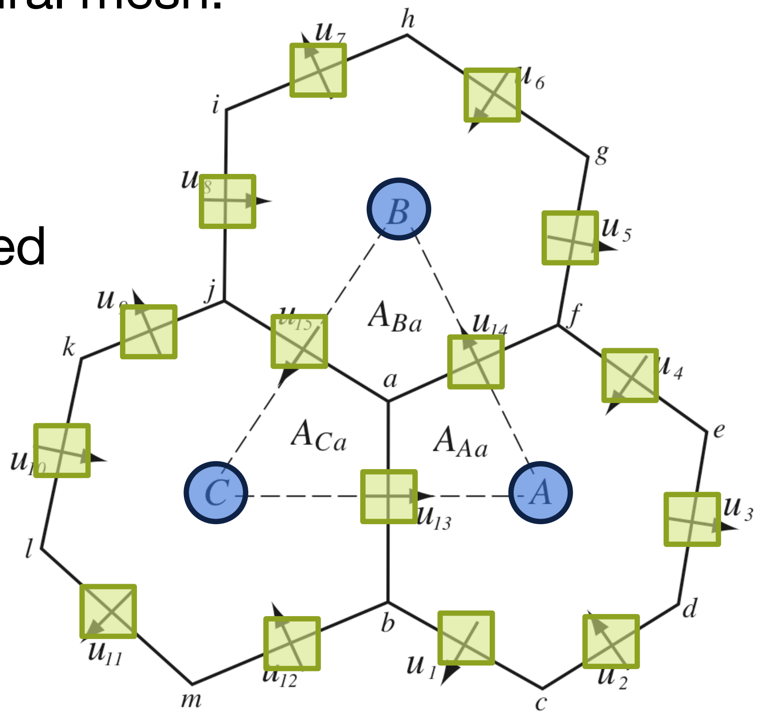


Unstructured spherical centroidal Voronoi meshes

- Mostly *hexagons*, some pentagons and 7-sided cells.
- Uniform resolution – traditional icosahedral mesh.
- Cell centers are at cell center-of-mass.
- Lines connecting cell centers intersect cell edges at right angles.
- Lines connecting cell centers are bisected by cell edge.

C-grid staggering

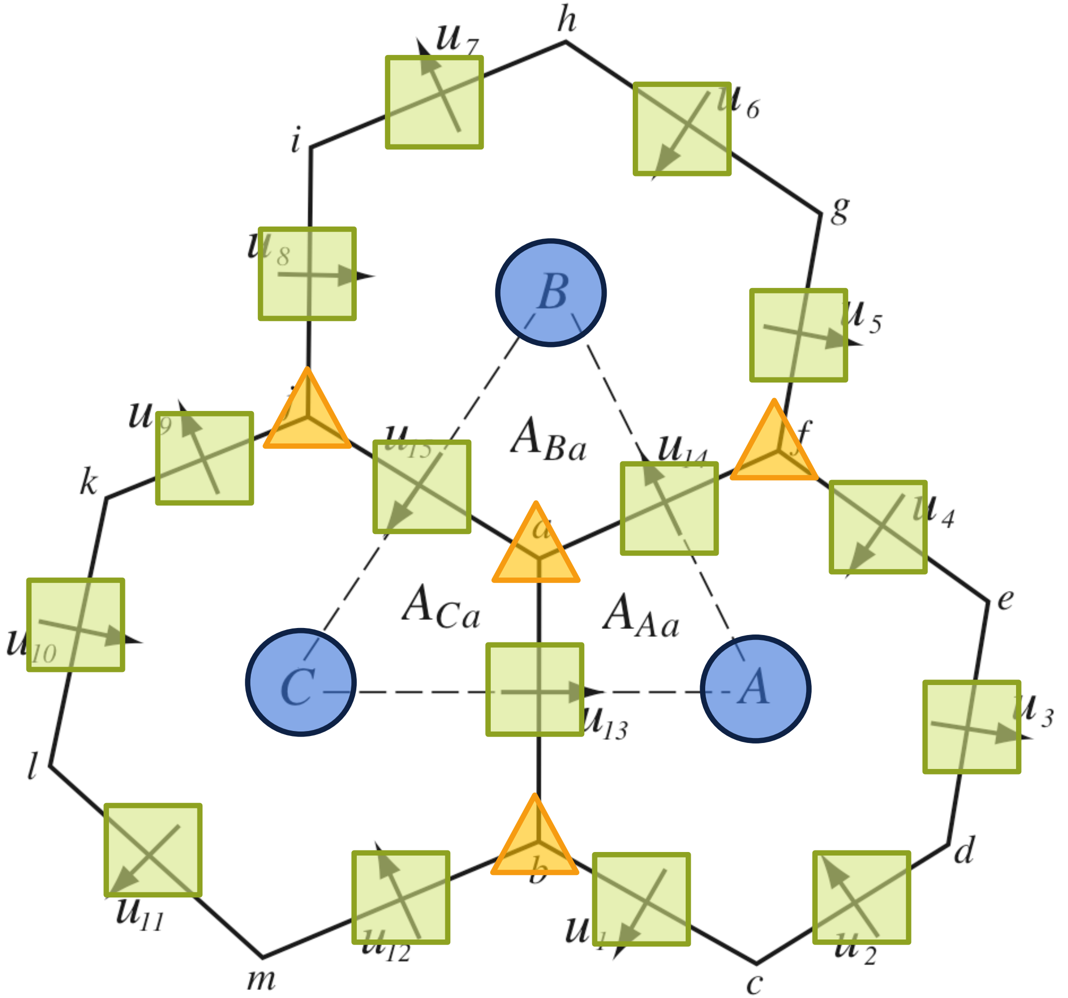
- Mass/temperature: cell centers
- Wind: solve for normal velocities on cell edges



MPAS-A: C-grid spherical centroidal Voronoi meshes

When stored in netCDF files (“grid.nc”), MPAS meshes have at least these dimensions:

```
dimensions:
        nCells = 40962 ;
        nEdges = 122880 ;
        nVertices = 81920 ;  maxEdges = 10 ;
        maxEdges2 = 20 ;
        TWO = 2 ;
        vertexDegree = 3 ;
```

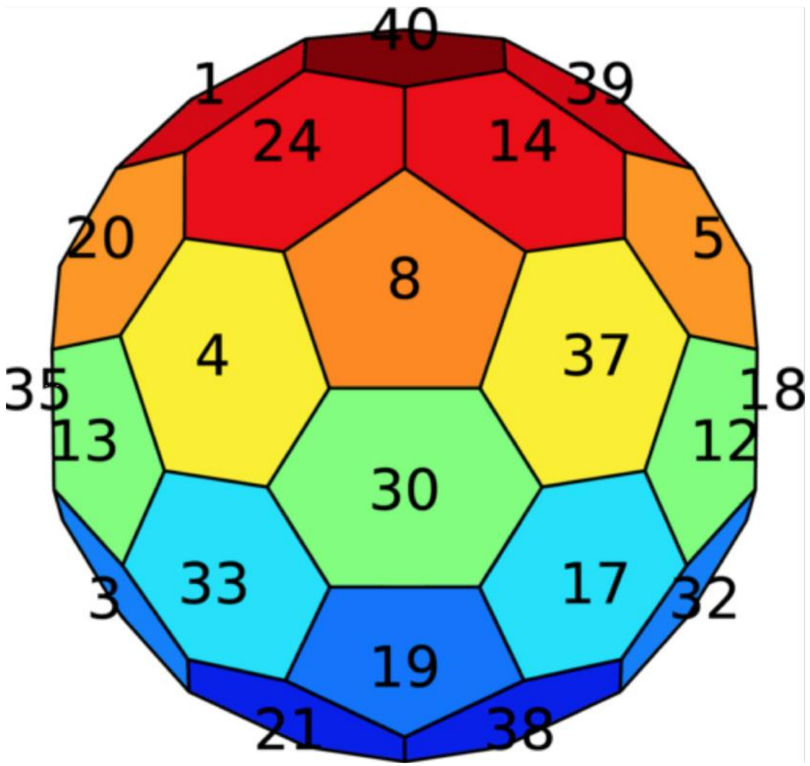


MPAS
Model for Prediction Across Scales

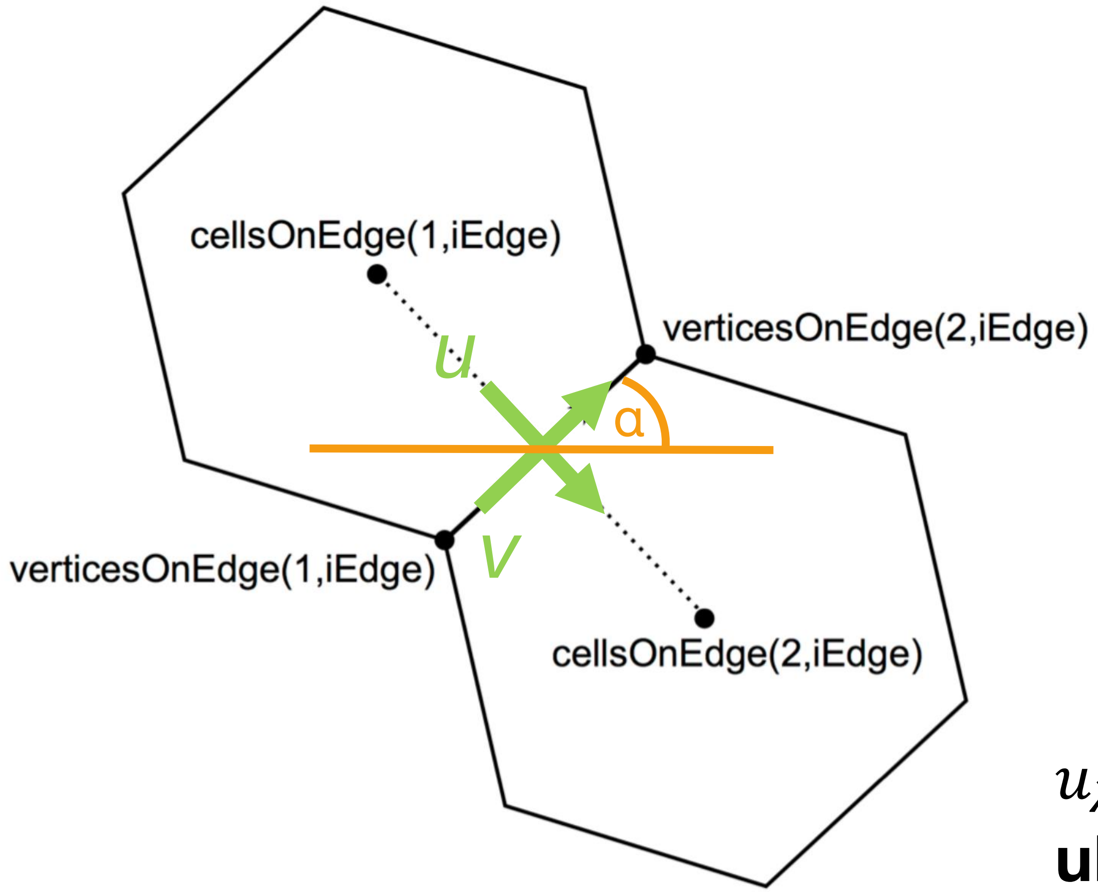
Keeping track of unstructured Voronoi meshes

For the unstructured, horizontal dimension there is nothing to be gained from using 2D arrays…

…hence, the horizontal dimension is collapsed into a single array dimension: we then have a simple list of elements (indexed by cell number)



Earth-relative wind velocities



Earth-relative horizontal winds are calculated using *u* and *v* and α (angleEdge):

$$\begin{bmatrix} u_\lambda \\ u_\phi \end{bmatrix} = \begin{bmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{bmatrix} \begin{bmatrix} u \\ v \end{bmatrix}$$

u_λ and u_φ are interpolated to cell centers:
uReconstructZonal, uReconstructMeridional

MPAS
Nonhydrostatic Atmosphere Solver

- Prognostic eqs. for coupled variables
- Generalized height coordinate
- Horizontally vector-invariant eq. set
- Thermodynamic eq. for coupled potential temperature
- Continuity eq. for dry air mass

Time integration scheme:

Split-explicit Runge-Kutta (3rd order) (as in WRF)

Variables:

$$(U,V,\Omega,\Theta,Q_j) = \tilde{\rho}_d \cdot (u,v,\dot{\eta},\theta,q_j)$$

Vertical coordinate:

$$z = \zeta + A(\zeta)\, h_s(x,y,\zeta)$$

Prognostic equations:

$$\frac{\partial \boldsymbol{V}_H}{\partial t} = -\frac{\rho_d}{\rho_m}\left[\nabla_\zeta\left(\frac{p}{\zeta_z}\right) - \frac{\partial \boldsymbol{z}_H p}{\partial \zeta}\right] - \eta\, \boldsymbol{k} \times \boldsymbol{V}_H$$

$$- \boldsymbol{v}_H \nabla_\zeta \cdot \boldsymbol{V} - \frac{\partial \Omega \boldsymbol{v}_H}{\partial \zeta} - \rho_d \nabla_\zeta K - eW\cos\alpha_r - \frac{uW}{r_e} + \boldsymbol{F}_{V_H},$$

$$\frac{\partial W}{\partial t} = -\frac{\rho_d}{\rho_m}\left[\frac{\partial p}{\partial \zeta} + g\tilde{\rho}_m\right] - (\nabla \cdot \boldsymbol{v} W)_\zeta$$

$$+ \frac{uU + vV}{r_e} + e\,(U\cos\alpha_r - V\sin\alpha_r) + F_W,$$

$$\frac{\partial \Theta_m}{\partial t} = -(\nabla \cdot \boldsymbol{V}\,\theta_m)_\zeta + F_{\Theta_m},$$

$$\frac{\partial \tilde{\rho}_d}{\partial t} = -(\nabla \cdot \boldsymbol{V})_\zeta,$$

$$\frac{\partial Q_j}{\partial t} = -(\nabla \cdot \boldsymbol{V}\, q_j)_\zeta + \rho_d S_j + F_{Q_j},$$

Diagnostics & definitions

$$\theta_m = \theta\,[1 + (R_v/R_d)q_v]$$

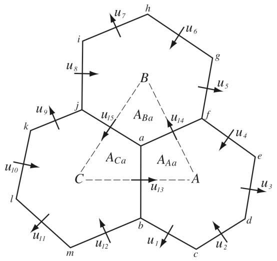
$$p = p_0\left(\frac{R_d \zeta_z \Theta_m}{p_0}\right)^\gamma$$

$$\frac{\rho_m}{\rho_d} = 1 + q_v + q_c + q_r + \ldots$$

MPAS DYAMOND setup

MPAS mesh (3.75 km)

dimensions:
nVertLevels = 75 ;
nCells = 41943042 ;
nEdges = 125829120 ;
nVertices = 83886080 ;
TWO = 2 ;
maxEdges = 6 ;
maxEdges2 = 12 ;
vertexDegree = 3 ;



Parameterizations	
Microphysics	Thompson (6 sp.)
Convection	Scale-aware Tiedtke
PBL	MYNN
Surface layer	MYNN
Land surface	Noah
Gravity wave drag	YSU
Radiation (lw/sw)	RRTMG

Output

- MPAS can only write netCDF files
- For DYAMOND: output is in netCDF 64-bit Data Format (CDF-5) (better I/O performance than netCDF-4)
- MPAS output files can be read with CDO/NCO/other netCDF utilities

MPAS
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Output & Variable Dimensions

diag.2016-09-10_00.00.00.nc

2D diagnostics (high frequency)

```
dimensions:
        Time = UNLIMITED ; // (1 currently)
        nCells = 41943042 ;
        nVertices = 83886080 ;
```

2D fields: vert_int_qi(Time, nCells)
vorticity_850hPa(Time, nVertices)

history.2016-09-10_00.00.00.nc

3D model state variables and
2D diagnostics (low frequency)

```
dimensions:
        Time = UNLIMITED ; // (1 currently)
        nCells = 41943042 ;
        nVertLevelsP1 = 76 ;
        nSoilLevels = 4 ;
```

3D fields: w(Time, nCells, nVertLevelsP1)

Variable Names

Many variables are named intuitively

relhum_200hPa, uzonal_850hPa, mslp, t2m

Checking the netCDF long_name attribute via ncdump -h can also be helpful:

```
float vert_int_qi(Time, nCells) ;
        vert_int_qi:units = "kg m^{-2}" ;
        vert_int_qi:long_name = "Vertically integrated ice    mixing ratio" ;
```

Special Variables: Precipitation

total precipitation (accumulated) = rainc + rainnc

rainc: precip from cumulus parameterization
rainnc: explicit precip from microphysics scheme

Special Variables: Wind

Wind (*u* and *v*), 3D field:

float **uReconstructZonal**(Time, nCells, nVertLevels) ;
uReconstructZonal:long_name = "Zonal component of reconstructed horizontal velocity at cell centers" ;

float **uReconstructMeridional**(Time, nCells, nVertLevels) ;
uReconstructMeridional:long_name = "Meridional component of reconstructed horizontal velocity at cell centers" ;

Special Variables: Wind

Wind (*u* and *v*), , 2D field (interpolated to pressure level):

float **uzonal_500hPa**(Time, nCells) ;
uzonal_500hPa:long_name = "Reconstructed zonal wind at cell centers, vertically interpolated to 500 hPa" ;

float **umeridional_500hPa**(Time, nCells) ;
umeridional_500hPa:long_name = "Reconstructed meridional wind at cell centers, vertically interpolated to 500 hPa" ;

Special Variables: Radiation

Accumulated radiation:

Should be "J m^{-2}"

```
float acswupb(Time, nCells) ;
                acswupb:units = "W m^{-2}" ;
                acswupb:long_name = "accumulated all-sky upward surface
shortwave radiation flux" ;
```

ac	= accumulated	ac	= accumulated
sw	= short-wave	lw	= long-wave
up	= up	dn	= down
b	= bottom	t	= top

Variables not listed on DYAMOND website

lh	= latent heat flux (instantaneous)
hfx	= sensible heat flux (instantaneous)
meanT_500_300	= Mean temperature in the 300 hPa - 500 hPa layer
refl10cm_1km	= diagnosed 10 cm radar reflectivity at 1 km AGL

4-km Global Storm-Resolving Simulation with MPAS