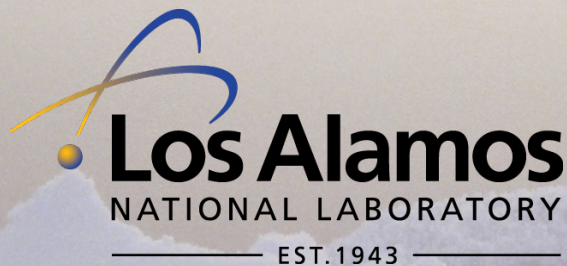


MPAS-CICE initial development

Adrian Turner

Los Alamos National Laboratory

Thanks to Doug Jacobsen, Mark Petersen, Todd Ringler, Elizabeth Hunke (LANL), Michael Duda and Bill Skamarock (NCAR)



U.S. DEPARTMENT OF
ENERGY

Office of Science

Project Goals

- COSIM is creating a ocean model that uses an unstructured grid – the DOE/NCAR MPAS framework



- Traditionally sea ice models have used same grid as underlying ocean model
- CESM coupler requires this
- Need sea ice model that uses same grid as MPAS-O!
- Aim of project is essentially to port CICE to work on the MPAS-O grid

MPAS

Model for Prediction Across Scales

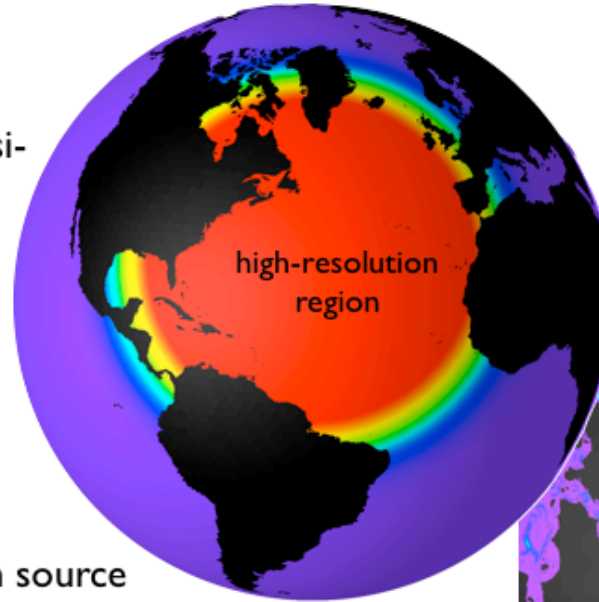
Building a Global, Multi-Scale Ocean Model

MPAS-Ocean supports both quasi-uniform and variable resolution meshing of the sphere.

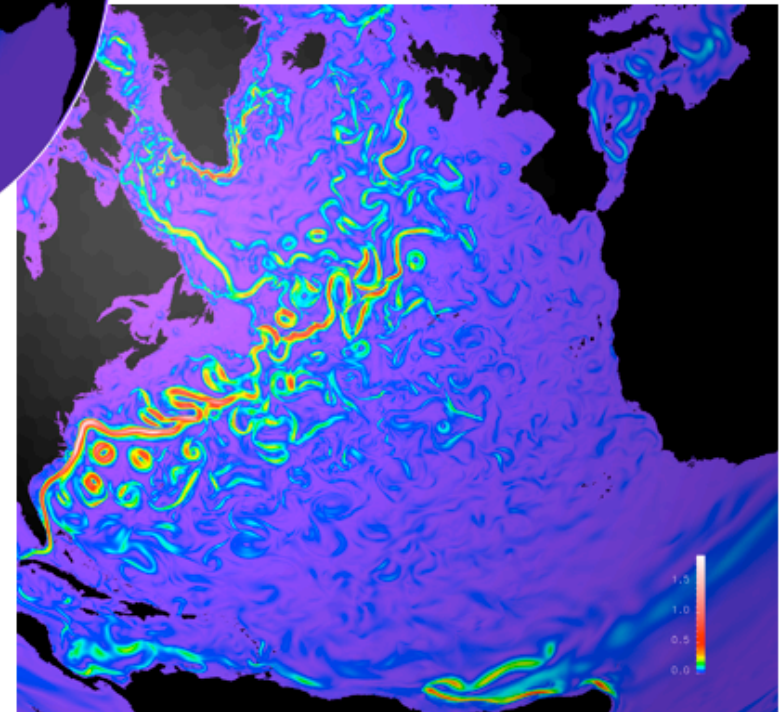
MPAS-O uses a generalized vertical coordinate that supports z-level, z-star, z-tilde, hybrid definitions.

MPAS-O will be released as open source software on Github in June 2013.

We hope to build partnerships within the international modeling community for the ongoing development and scientific application of MPAS-O.

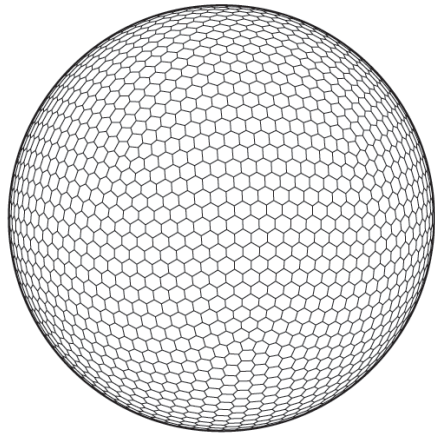


Below: Snapshot of kinetic energy from a global ocean simulation with 7.5 km resolution in the North Atlantic. The rest of the global ocean is resolved with a 40 km mesh.

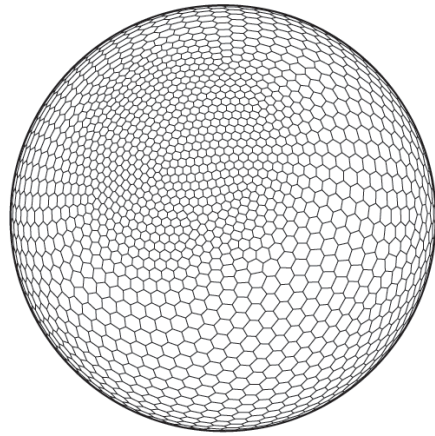


Courtesy Todd Ringler (LANL)

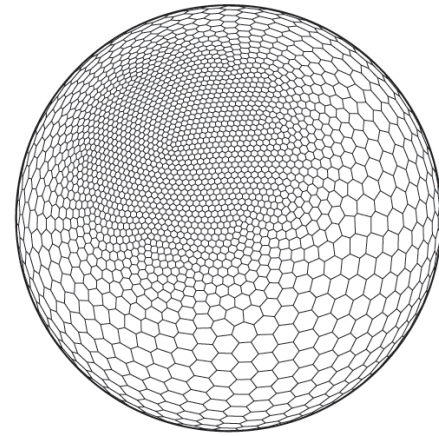
MPAS grid allows variable resolution



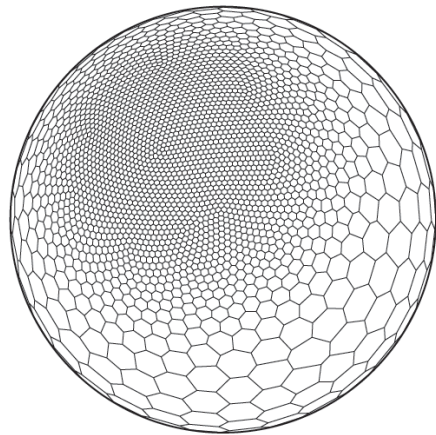
x1



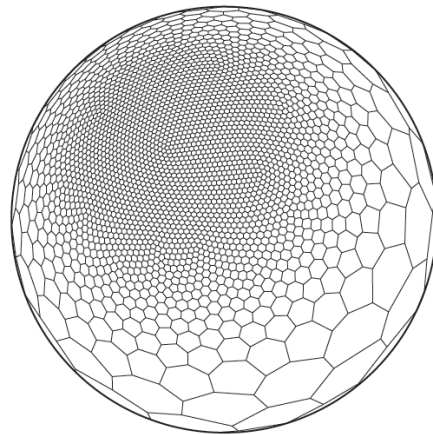
x2



x4



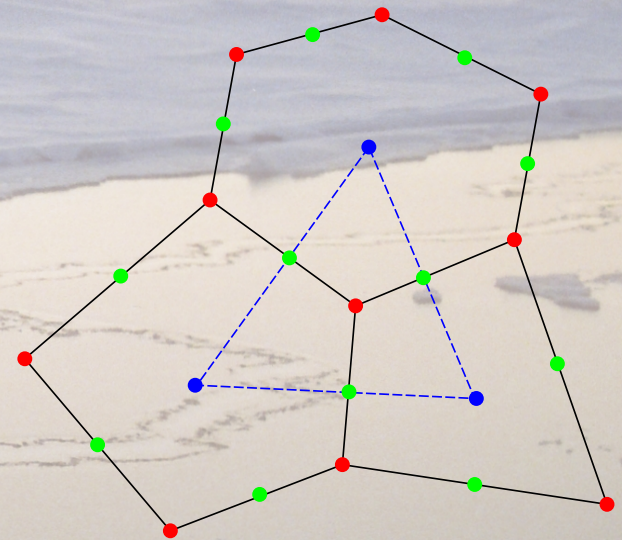
x8



x16

MPAS Grid

- Spherical Centroidal Voronoi Tessellation (SCVT)
- Voronoi Tessellation
 - Cell is formed from points closest to the generator points (cell centers)
 - Dual grid is Delaunay Triangulation
- Centroidal
 - Cell center is at the ‘centre of mass’ of the cell (achieved through iteration during generation)
- Supports quadrilateral grids



- Primary grid: SCVT
- - - Secondary grid: Triangles
- Cell centers
- Vertices
- Edges

Anatomy of CICE

- Framework
 - IO
 - Coupling
 - Block/processor communication
- Physics
 - Column physics (shortwave, thermodynamics, mechanical redistribution,...)
 - Velocity solver
 - Advection

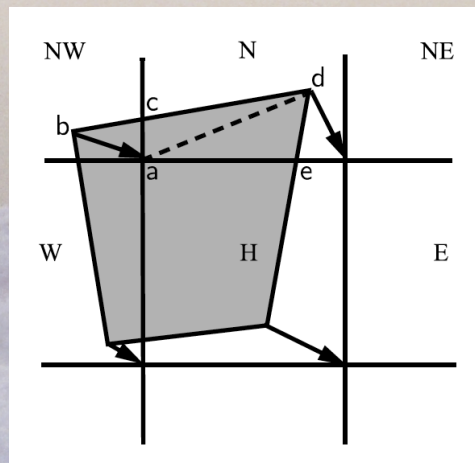
Column physics

- Separate column physics from other parts of the code in CICE (e.g. IO)
- Package into “Column Physics Package” library
- Will be called from MPAS-CICE as a separate library



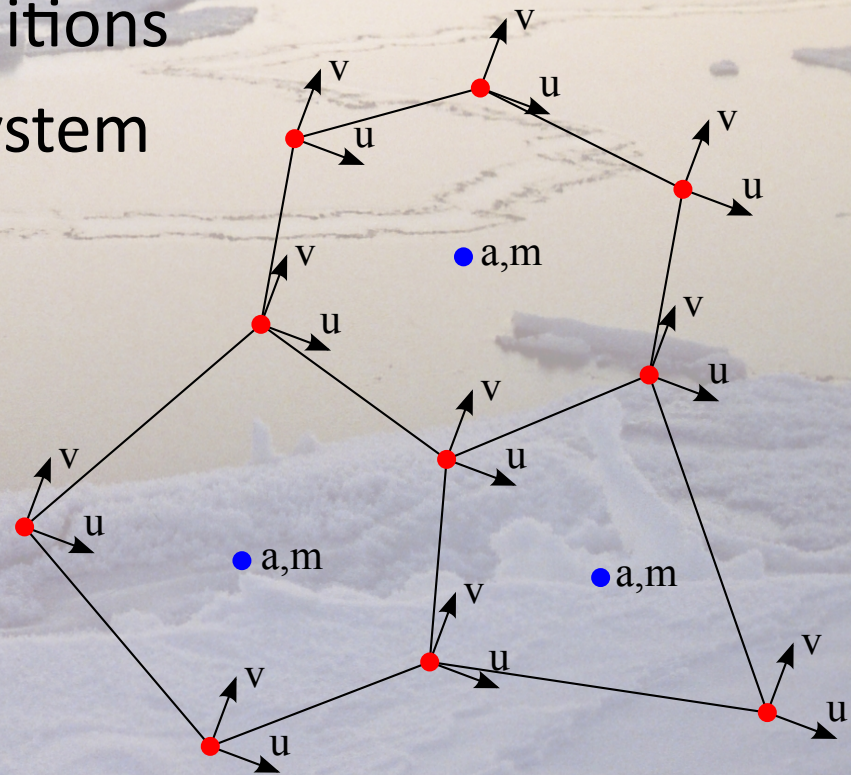
Advection

- Use MPAS-O advection routines
- Initially use FCT routines once its been put in the operators part of the shared framework
- May need MPAS version of incremental remapping



Velocity solver: grid choice

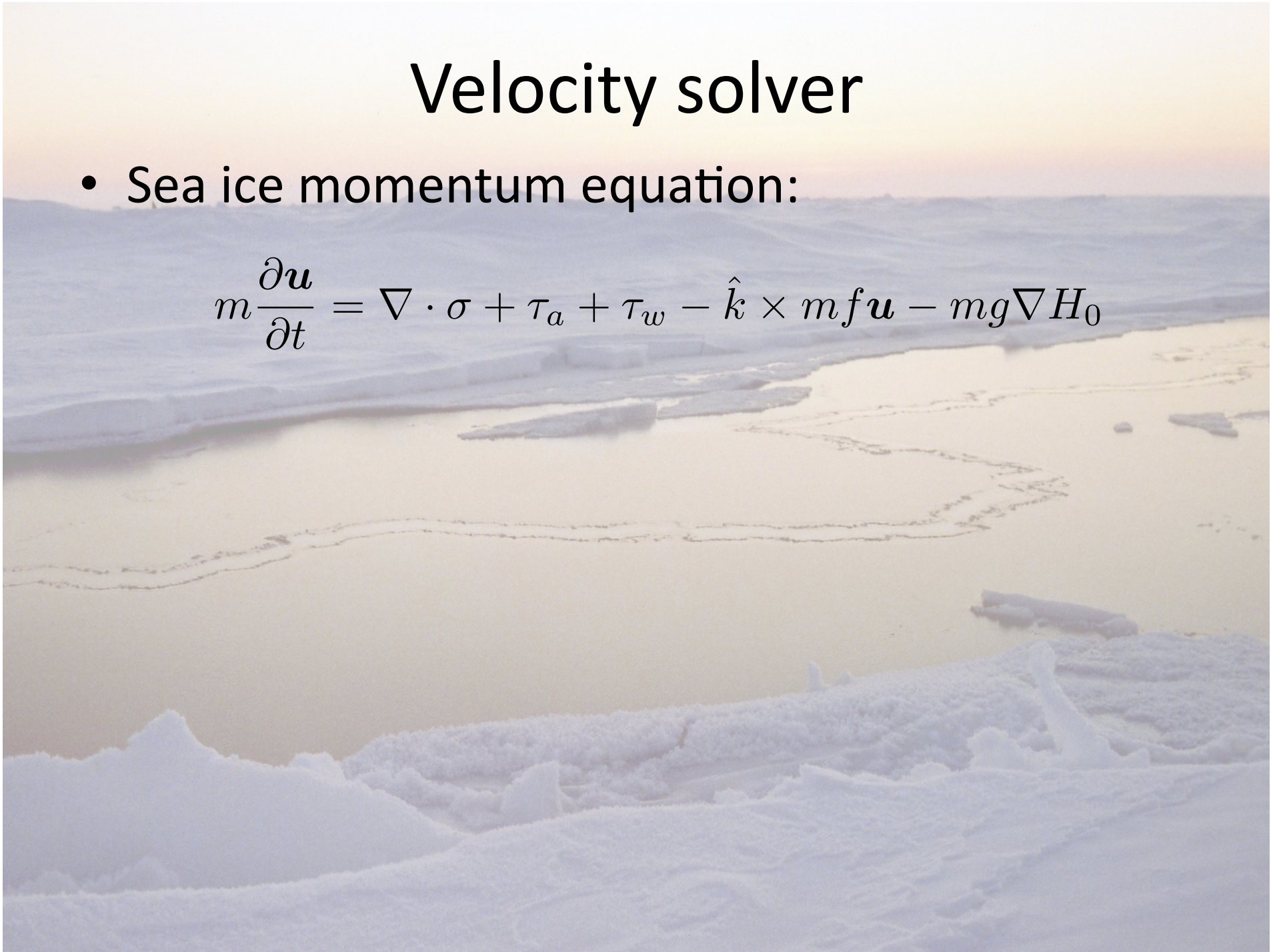
- Use B grid – both U and V velocity co-located at grid vertices
 - On quads becomes original CICE grid
 - Natural boundary conditions
 - Need local Cartesian system



Velocity solver

- Sea ice momentum equation:

$$m \frac{\partial \mathbf{u}}{\partial t} = \nabla \cdot \boldsymbol{\sigma} + \boldsymbol{\tau}_a + \boldsymbol{\tau}_w - \hat{\mathbf{k}} \times m f \mathbf{u} - m g \nabla H_0$$



Velocity solver

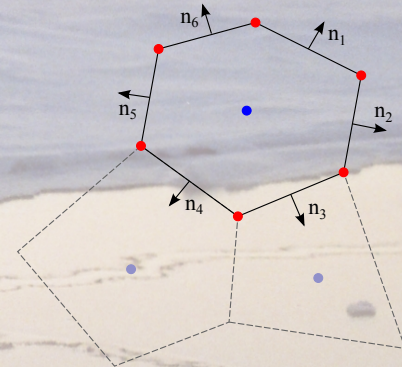
- Sea ice momentum equation:

$$m \frac{\partial \mathbf{u}}{\partial t} = \nabla \cdot \boldsymbol{\sigma} + \tau_a + \tau_w - \hat{k} \times m f \mathbf{u} - m g \nabla H_0$$

- Only divergence of stress tensor depends on horizontal grid
 - Need to calculate the strain rate tensor from the velocity field
 - (Grid independent EVP constitutive relationship converts strain to stress)
 - Then need to calculate divergence of the stress tensor

Divergence of stress operator I

- Two methods: weak and variational
- Weak: line integrals
 - strain rate tensor
 - located at cell centers

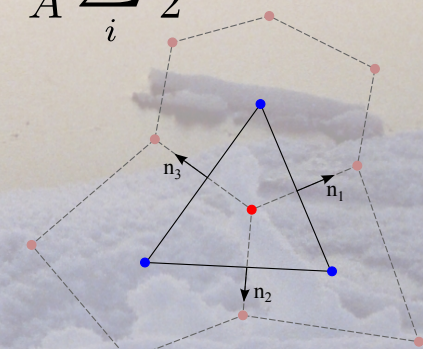


$$\dot{\epsilon} = \nabla_s \mathbf{v} = \lim_{A \rightarrow 0} \frac{1}{A} \oint \frac{1}{2} [\mathbf{n}\mathbf{v} + \mathbf{v}\mathbf{n}] \partial l \xrightarrow{\text{Discretize}} \dot{\epsilon} = \frac{1}{A} \sum_i^{n_e} \frac{1}{2} [\mathbf{n}_i \mathbf{v}_i + \mathbf{v}_i \mathbf{n}_i] l_i$$

- divergence of stress operator

- located at vertices

$$\nabla \cdot \boldsymbol{\sigma} = \lim_{A \rightarrow 0} \frac{1}{A} \oint_C [\boldsymbol{\sigma} \cdot \mathbf{n}] \partial l \xrightarrow{\text{Discretize}} \nabla \cdot \boldsymbol{\sigma} = \frac{1}{A} \sum_i^{n_e} [\boldsymbol{\sigma}_i \cdot \mathbf{n}_i] l_i$$



Variational divergence of stress

- Over whole domain work done by internal stress = equal to dissipation of mechanical energy

$$\int_{\Omega} v \cdot (\nabla \cdot \sigma) dA = - \int_{\Omega} (\sigma_{11} \dot{\epsilon}_{11} + \sigma_{22} \dot{\epsilon}_{22} + 2\sigma_{12} \dot{\epsilon}_{12}) dA$$

- Break domain into cells, with each cell associated with a v point

$$\sum_i \int_i (u F_1 + v F_2) dA = D(u_1, u_2, \dots, u_n, v_1, v_2, \dots, v_n)$$

- Assume velocity and divergence are constant in cell

$$\sum_i (u_i F_{1i} + v_i F_{2i}) A_{ui} = D(u_1, u_2, \dots, u_n, v_1, v_2, \dots, v_n)$$

- Differentiate with respect to u_j

$$F_{1j} = \frac{1}{A_{uj}} \frac{\partial}{\partial u_j} D(u_1, u_2, \dots, u_n, v_1, v_2, \dots, v_n)$$

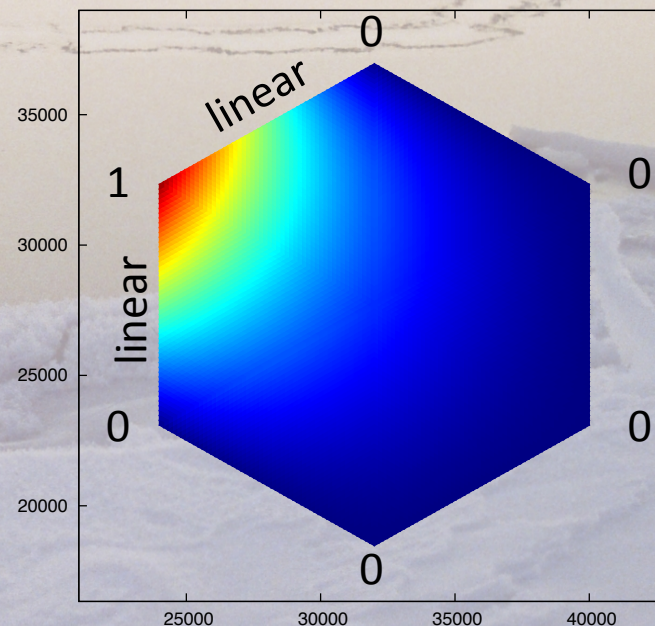
Variational divergence of stress II

- Need to calculate global dissipation as function of discretized velocities – then take derivative
- Use basis functions, ϕ_i , within the cells
- u_i is velocity at vertex i
- ϕ_i is 1 at vertex i and 0 at other vertices
- Use “Wachspress” basis functions to cope with arbitrary polygons

$$\sum_i \phi_i = 1$$

$$u = \sum_i u_i \phi_i$$

$$\frac{\partial u}{\partial x} = \sum_i u_i \frac{\partial \phi_i}{\partial x}$$



Variational divergence of stress III

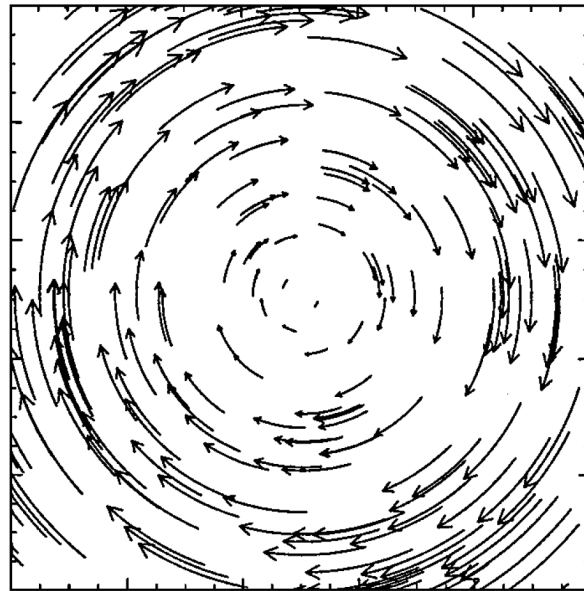
- Work through the math....
- Sum of terms like:

$$(\nabla \cdot \sigma)_j = \frac{1}{2} \sum_i^n \sigma_{1i} \underbrace{\int \phi_i \frac{\partial \phi_j}{\partial x} dx dy}_{S_x(i,j)}$$

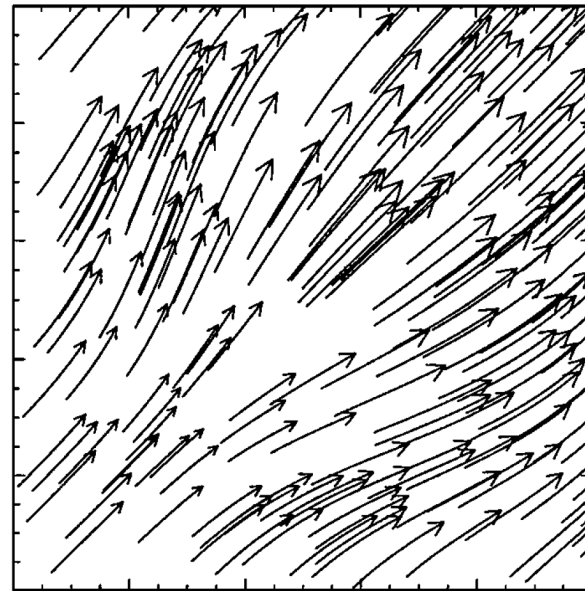
- Calculate S_x at initialization – just geometrical factor of unmoving grid
- Requires quite a bit of storage – looking at PieceWise Linear (PWL) basis as alternative to Wachspress

Planar test case – Square domain

- 80km × 80km – Constant 2m thick ice with area varying linearly in u-direction from 0 to 1
- Circular ocean currents
- Uniform winds with added divergence



Ocean currents



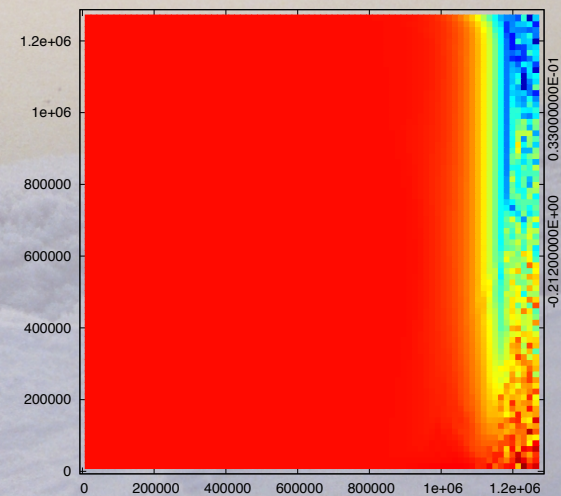
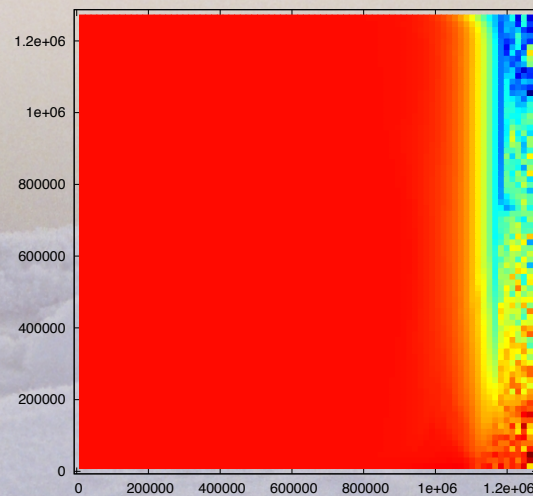
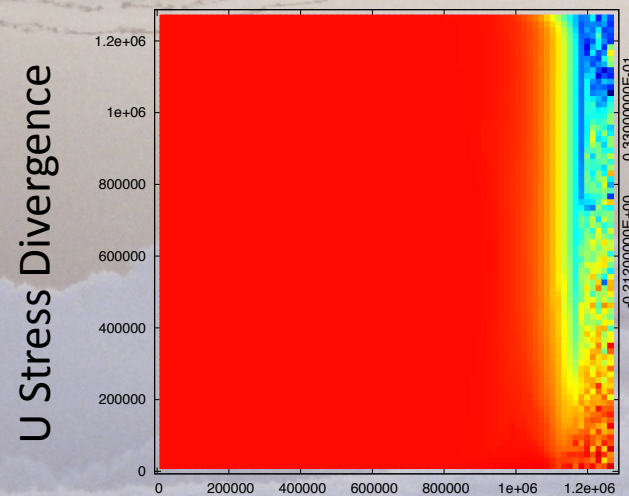
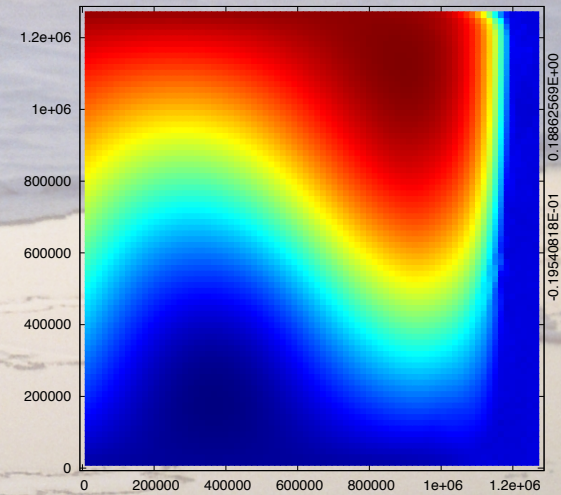
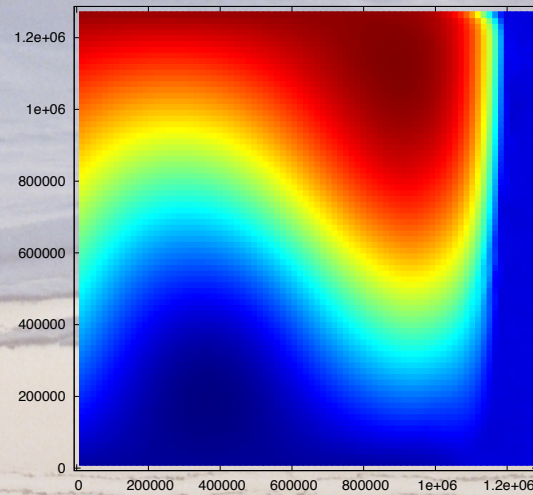
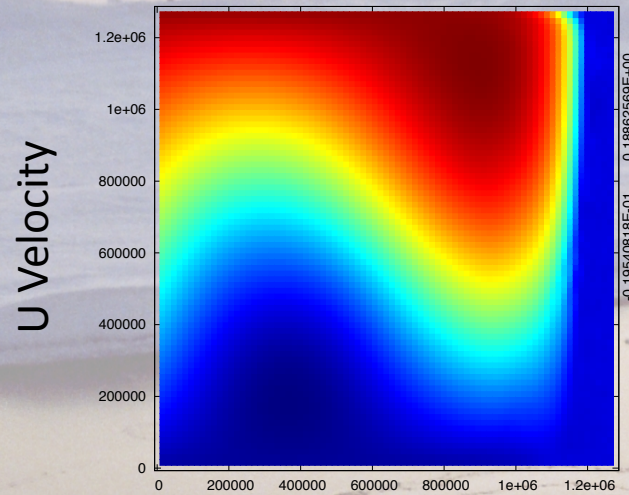
Atmospheric winds

Square test case: results I

CICE

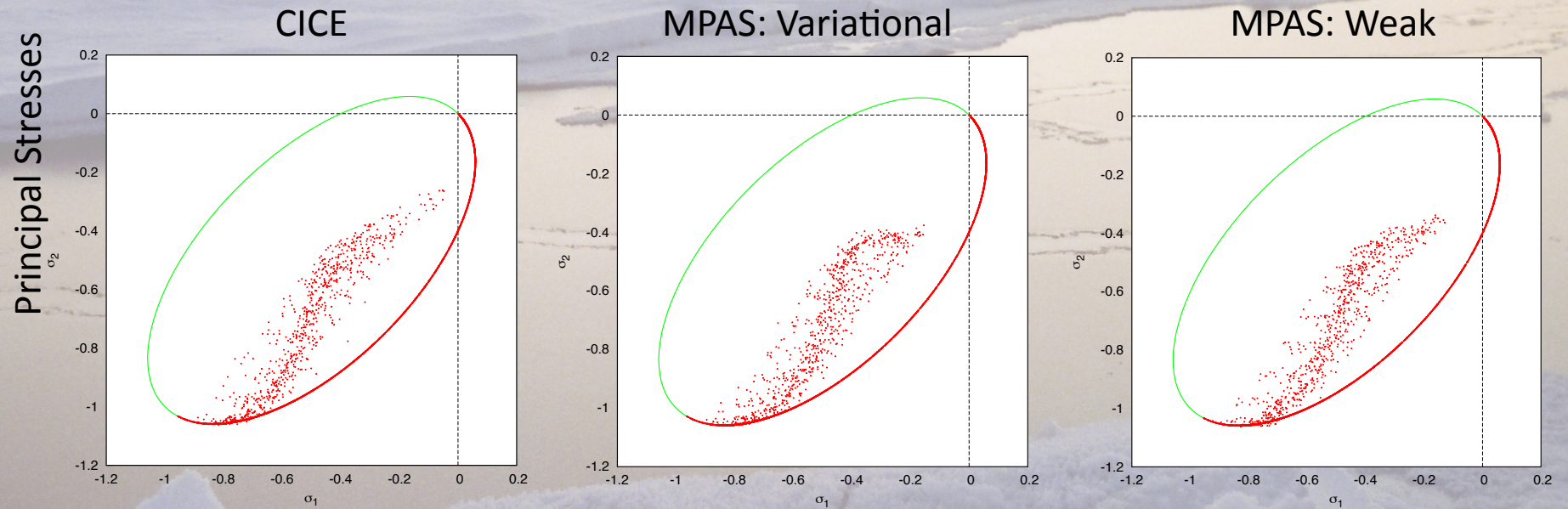
MPAS: Variational

MPAS: Weak



Square test case: results II

- Can also look at the yield curve



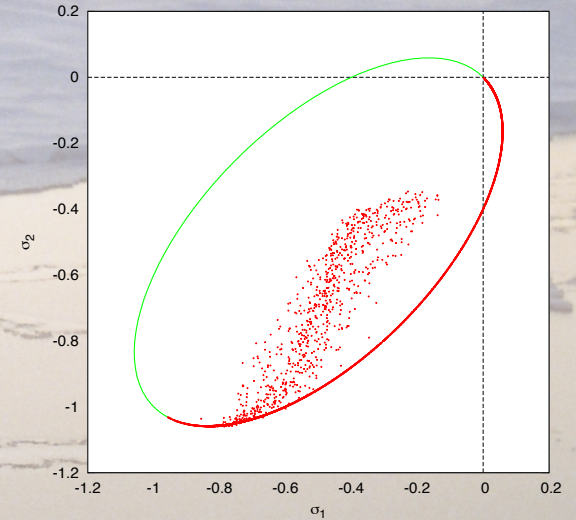
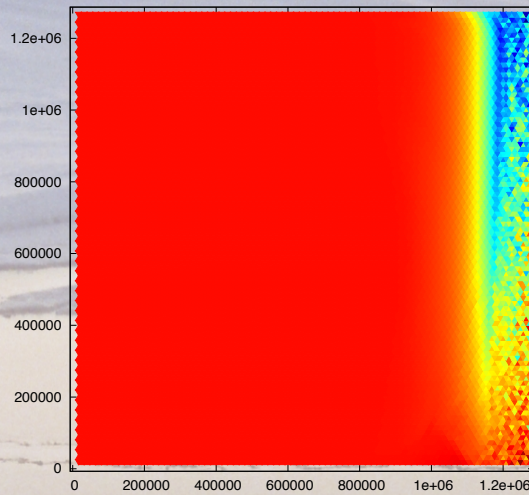
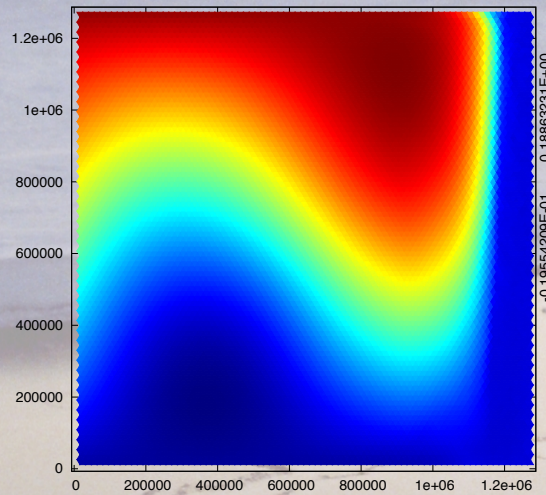
Square test case: results III

U Velocity

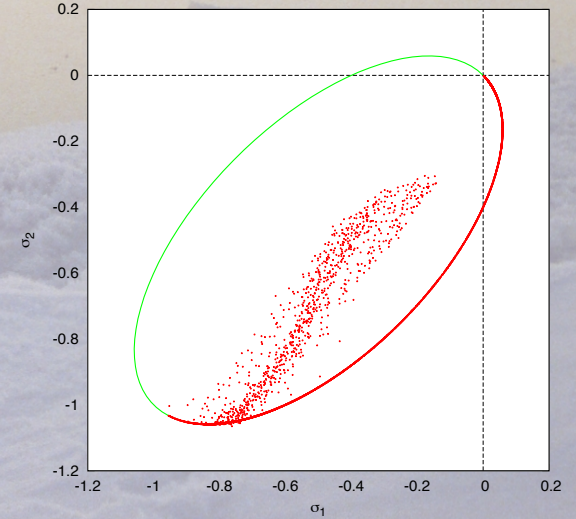
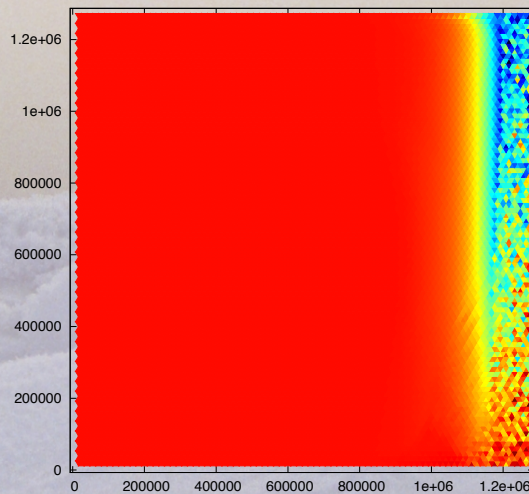
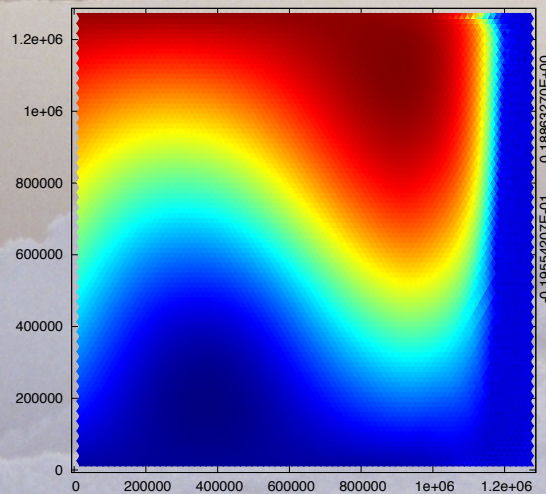
U Stress Divergence

Principal Stresses

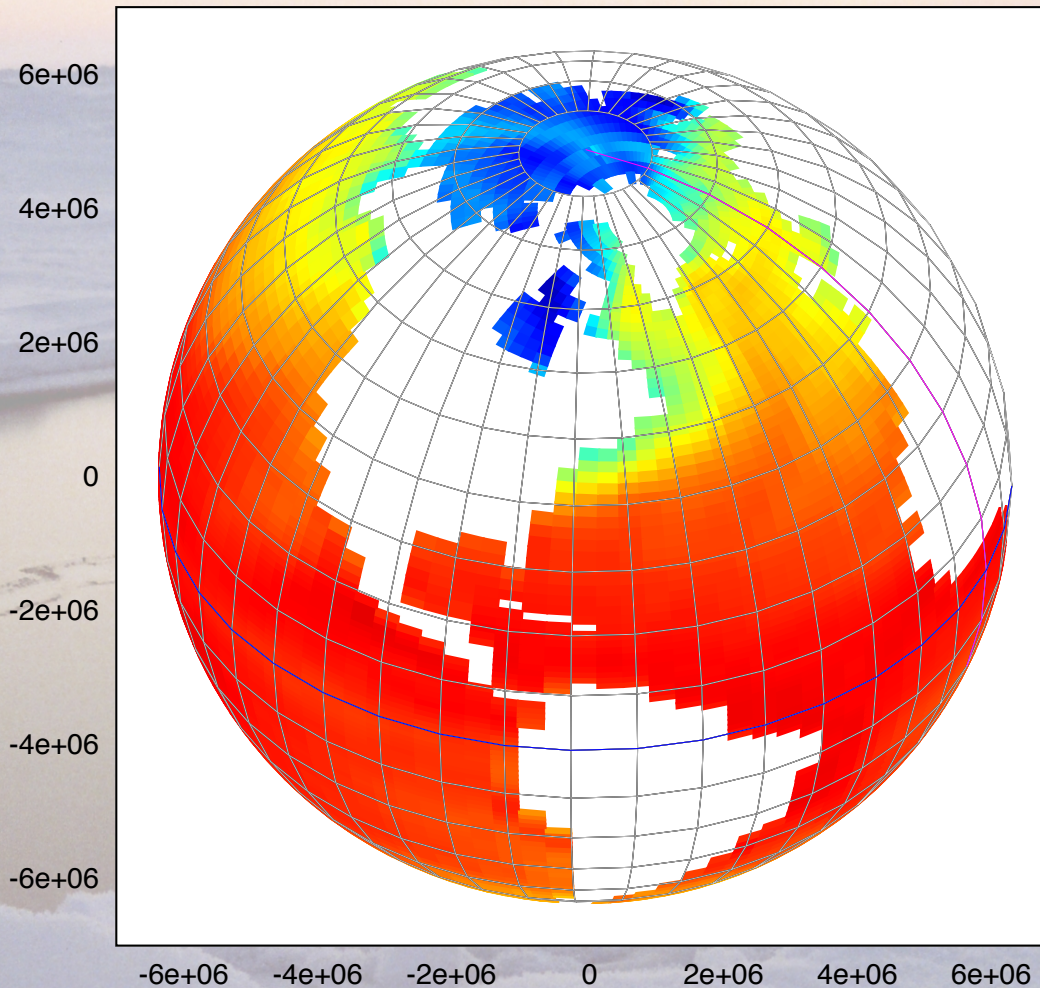
MPAS: Variational



MPAS: Weak



Global tests of velocity solver



Air temperature

Global testing of both the weak and variational formulation of the velocity solver is to begin soon. Forcing routines already implemented.