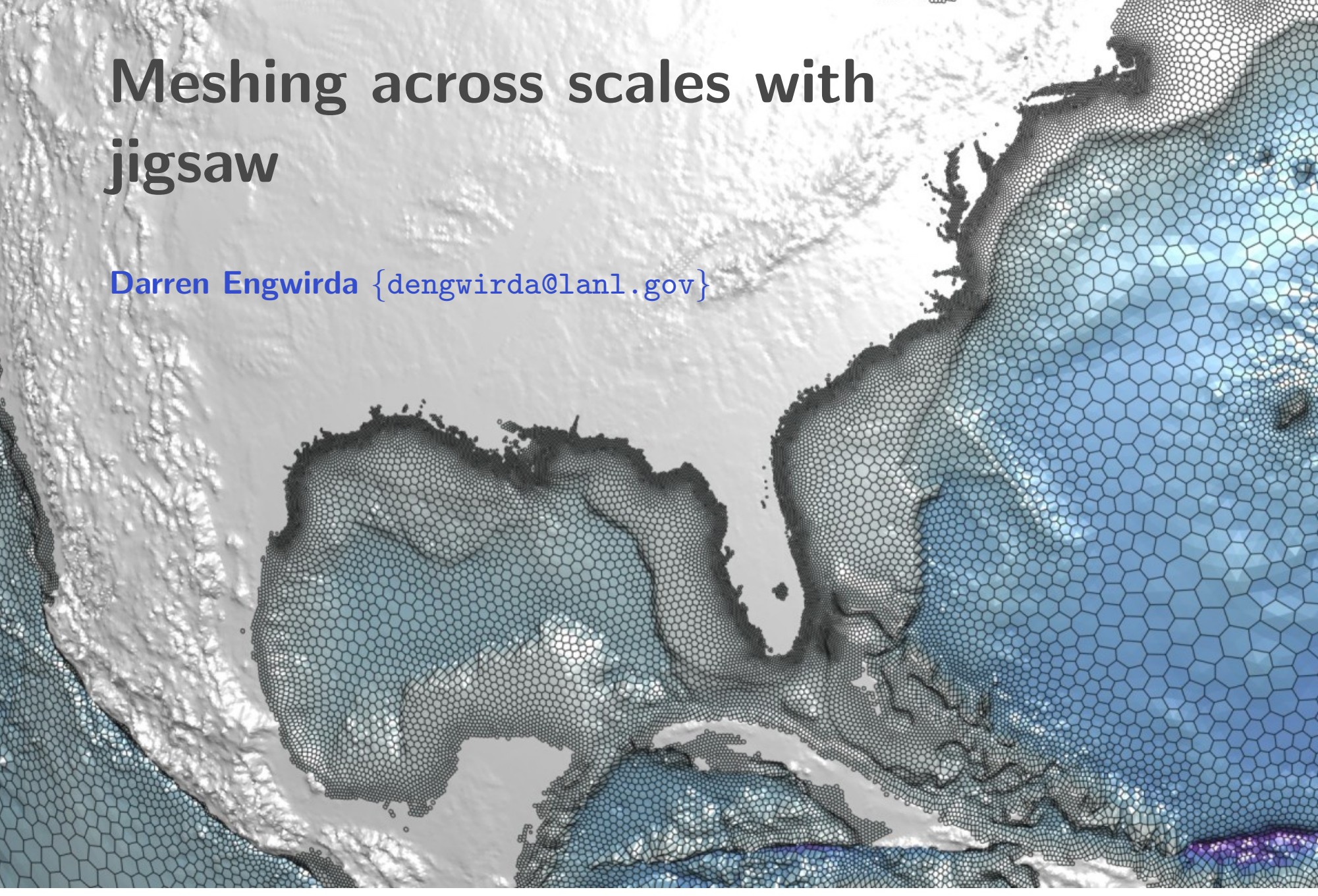
Meshing across scales with jigsaw

Darren Engwirda {dengwirda@lanl.gov}



Los Alamos NATIONAL LABORATORY

DOE / NOAA — March, 2022

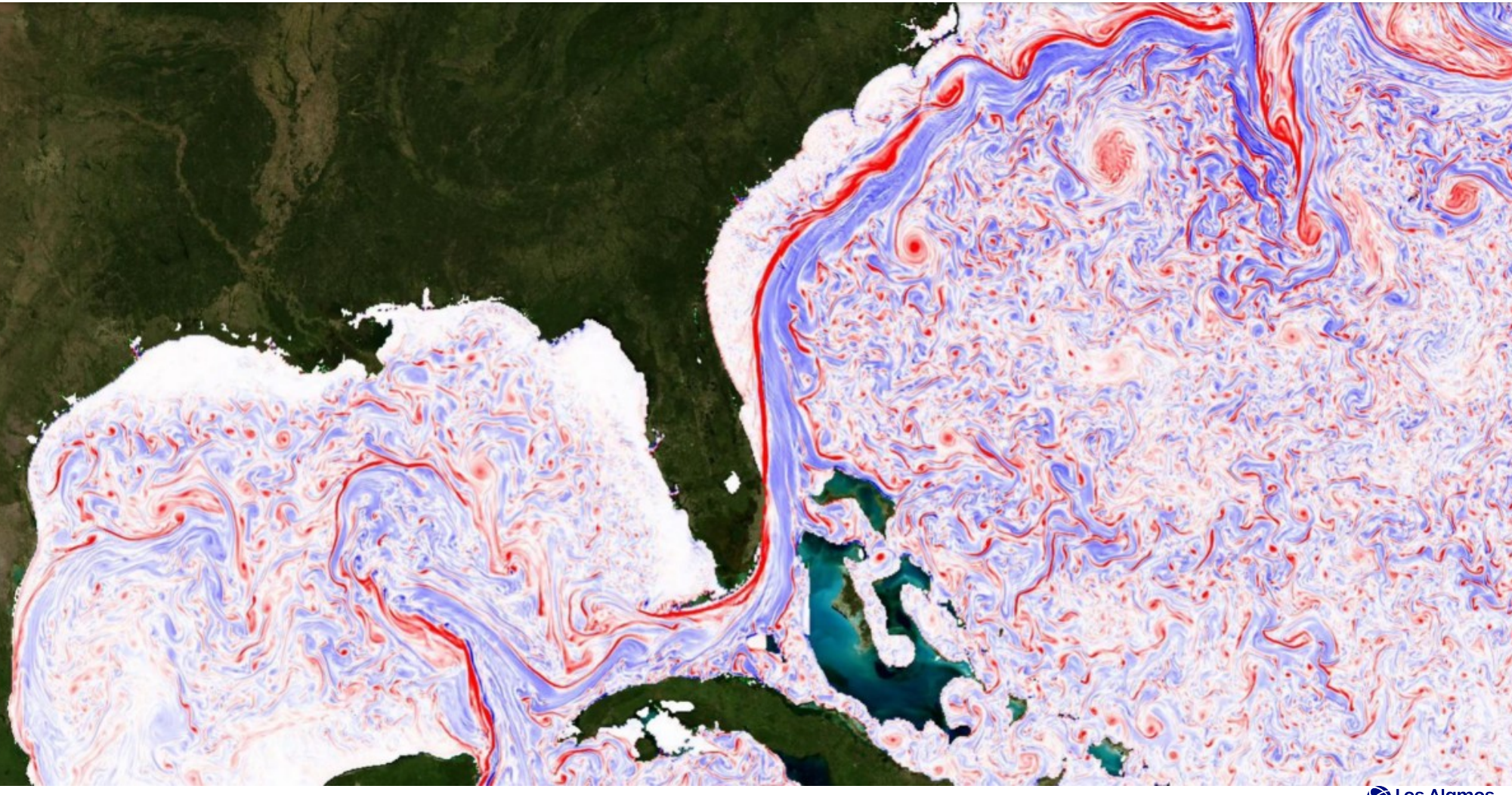
What is 'ocean modelling' target?

3d circulation? 2d storm-surge + tides?

Short-term forecast? Long-term climate sensitivity?

Which model numerical formulation?

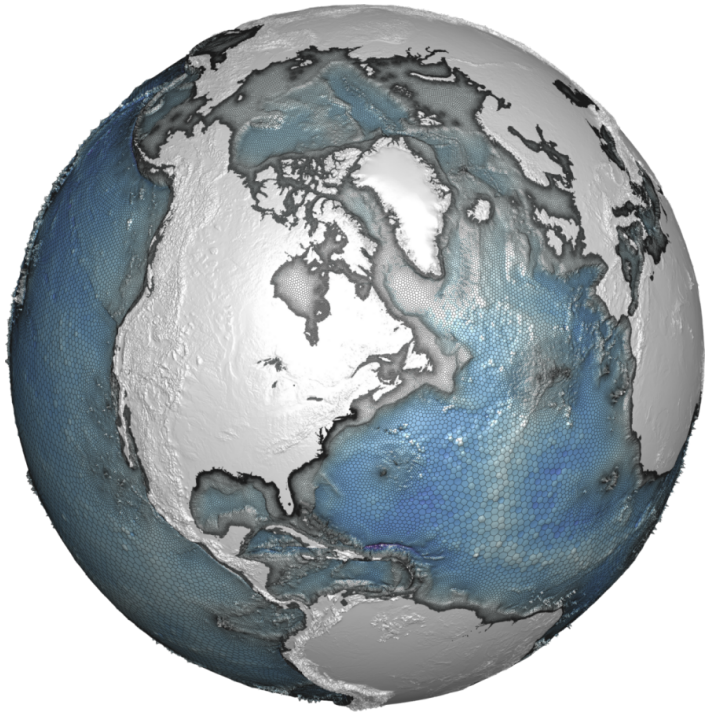
All answers strongly effect 'optimal' approach to mesh generation...



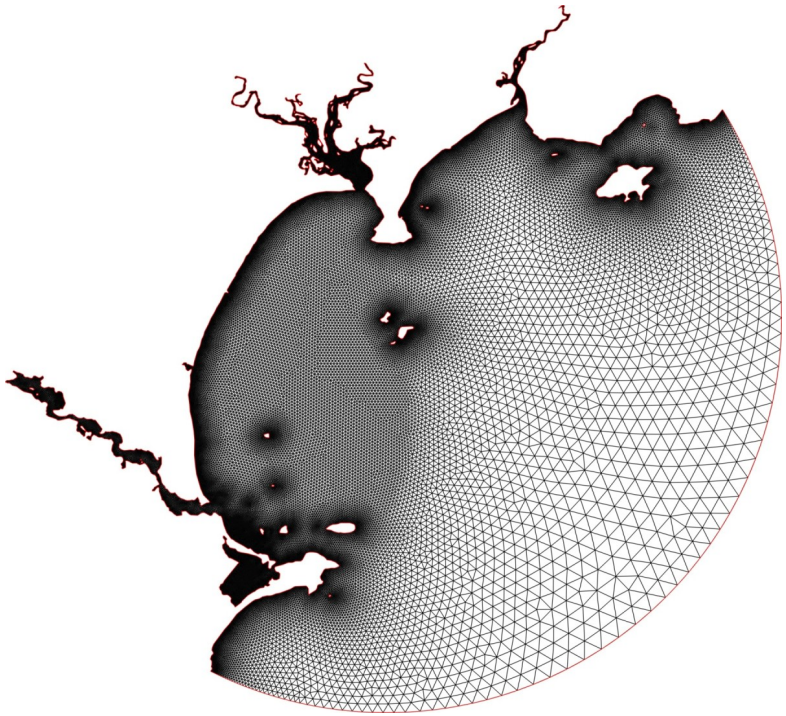
‘Unified’ meshes for Earth System Models

Support a wide range of Earth System Models through generation of multi-scale regional and global unstructured meshes.

`Global meshes`



`Regional meshes [2d proj.]`



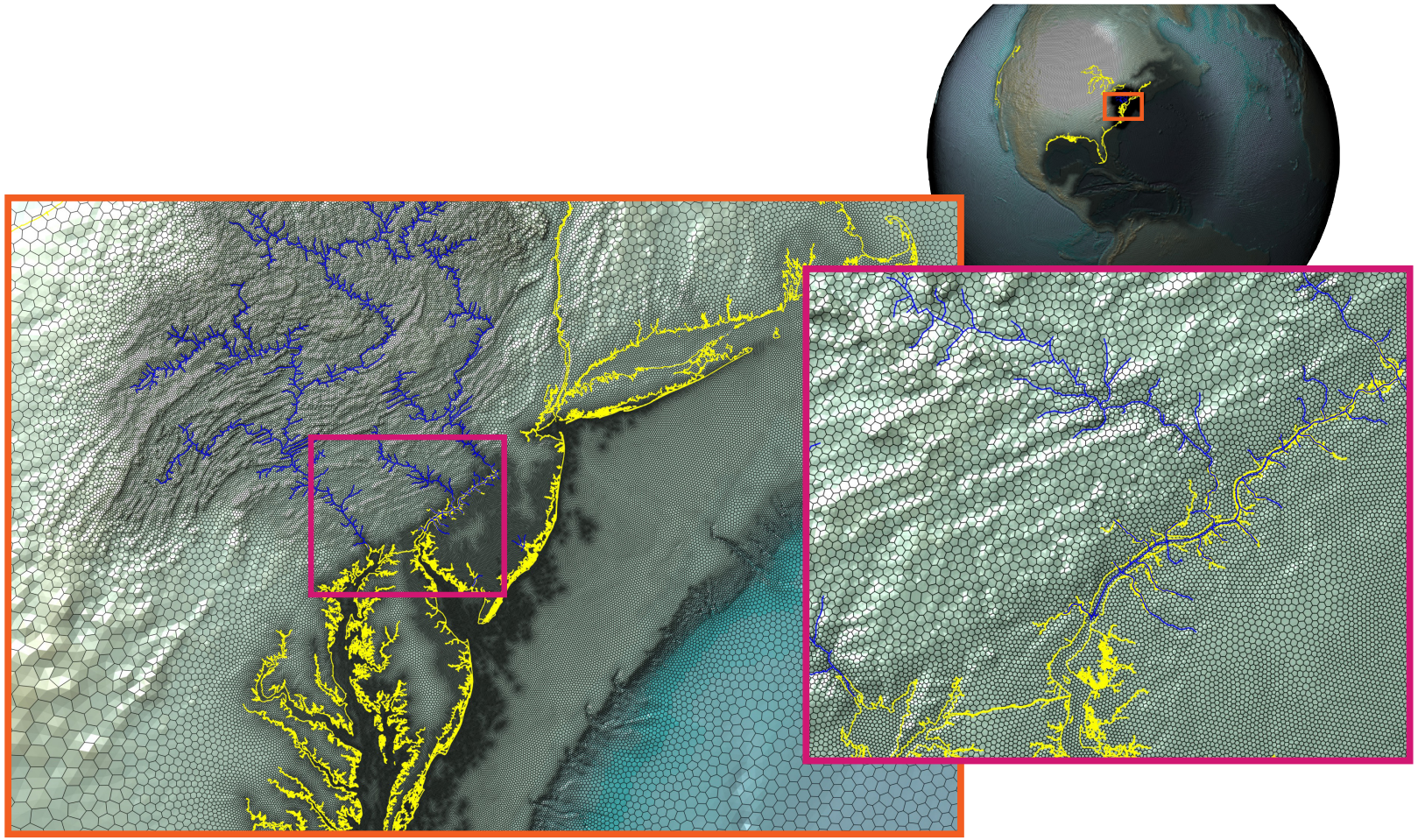
Target variable resolution meshes consisting of **polygonal cells** (Voronoi tessellations) and **triangle cells** (Delaunay meshes).

Used by: `E3SM (DOE), COMPAS (CSIRO), FESOM (AWI), and others...`

Los Alamos NATIONAL LABORATORY

‘Unified’ meshes for Earth System Models

A new ‘fully-unified’ modelling approach for DOE’s Energy Exascale Earth System Model (E3SM) based on commmon polygonal grid + discretisation strategy:



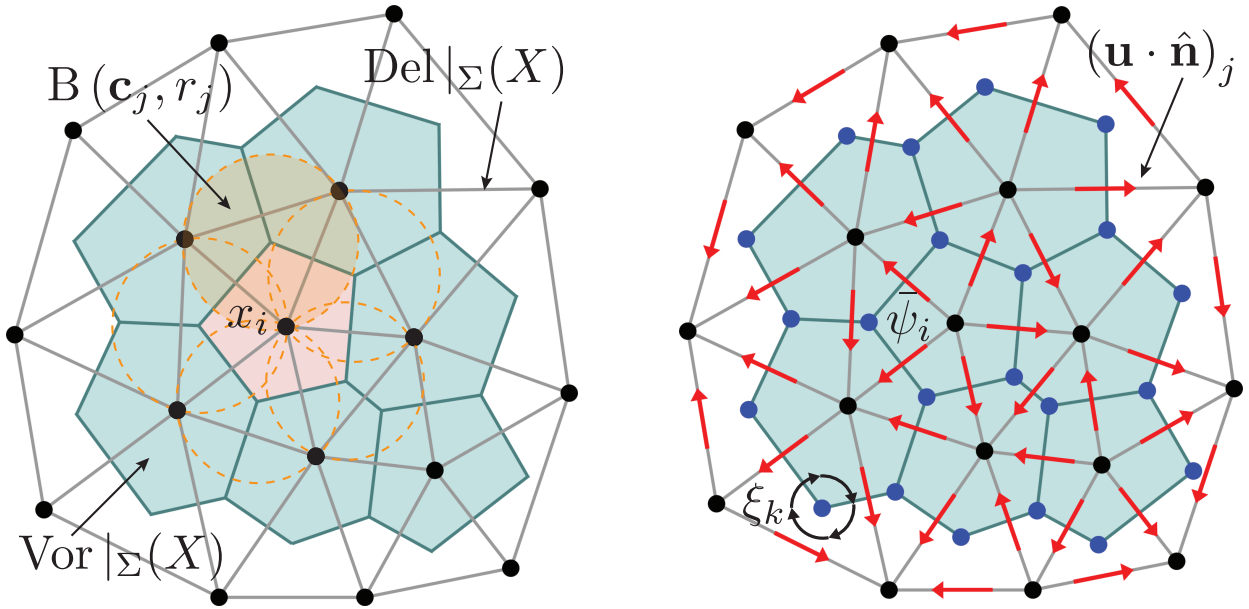
**Embedded mid-Atlantic coastal-zone: ICoM project, Engwirda et al, 2020.

Common physics + coast + stream-aligned meshes for **ocean**, **sea/land-ice**, **land-surface**, **hydrology**, and **sub-surface** flow models in E3SM.

Los Alamos NATIONAL LABORATORY

jigsaw: meshing for staggered finite-volume schemes

E3SM model components are based on *conservative*, *structure-preserving* numerical methods — an generalisation of GFDL's MOM6 discretisation to unstructured meshes:



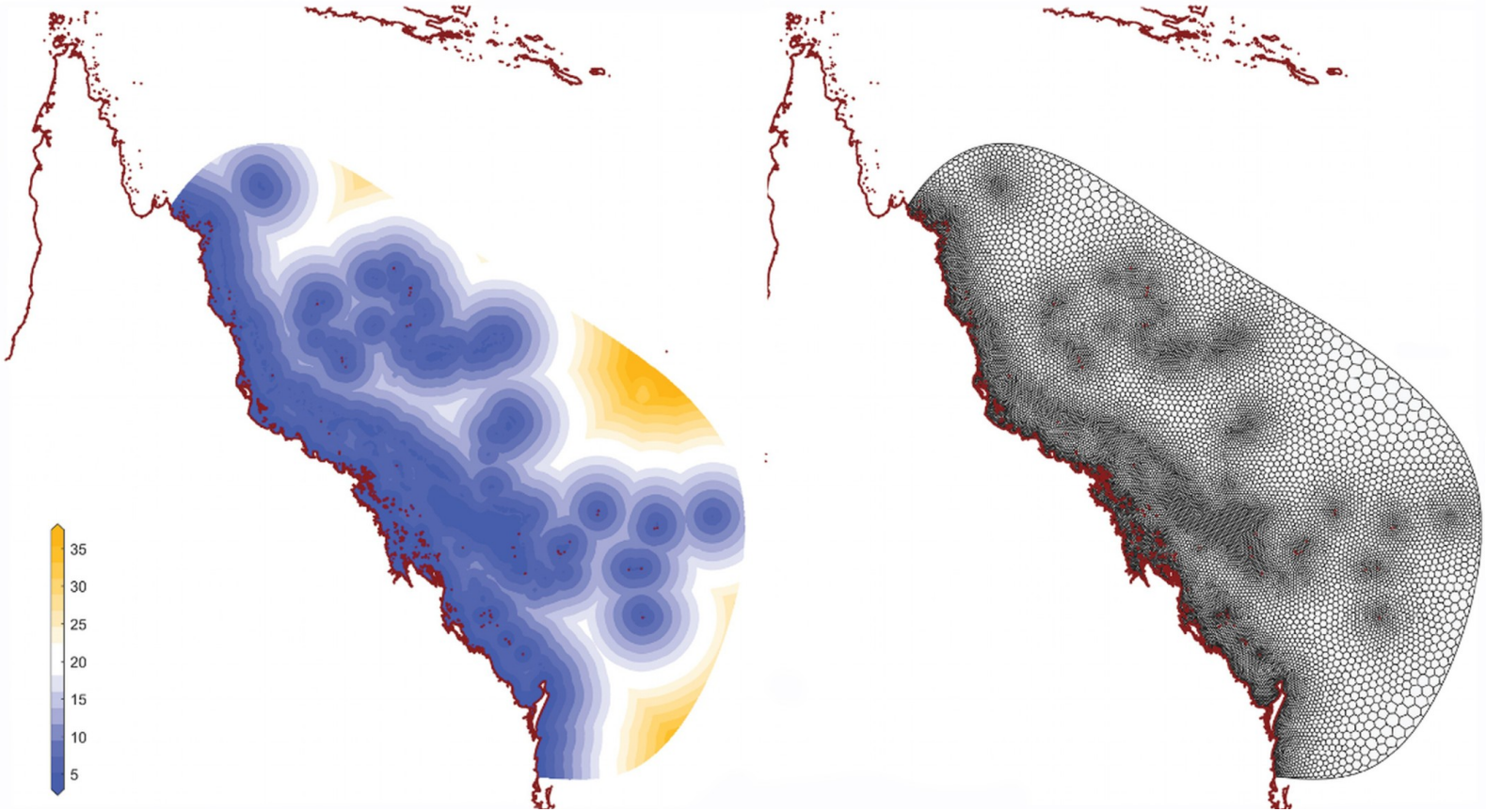
Meshes consist of dual parts: a (Delaunay) **triangulation** and its orthogonal (Voronoi) **polygonal** decomposition.

Numerics consist of dual parts: cell-centred tracers, staggered edge-aligned momentum, and vertex-centred vorticity.

`jigsaw` builds dual meshes with tight theoretical guarantees on mesh quality/shape.

jigsaw: meshing across scales

It is not uncommon (ie. occurs every time!) for the geophysical 'geometry' (coastline, river network, watershed) to be **defined at the 'wrong' resolution**.

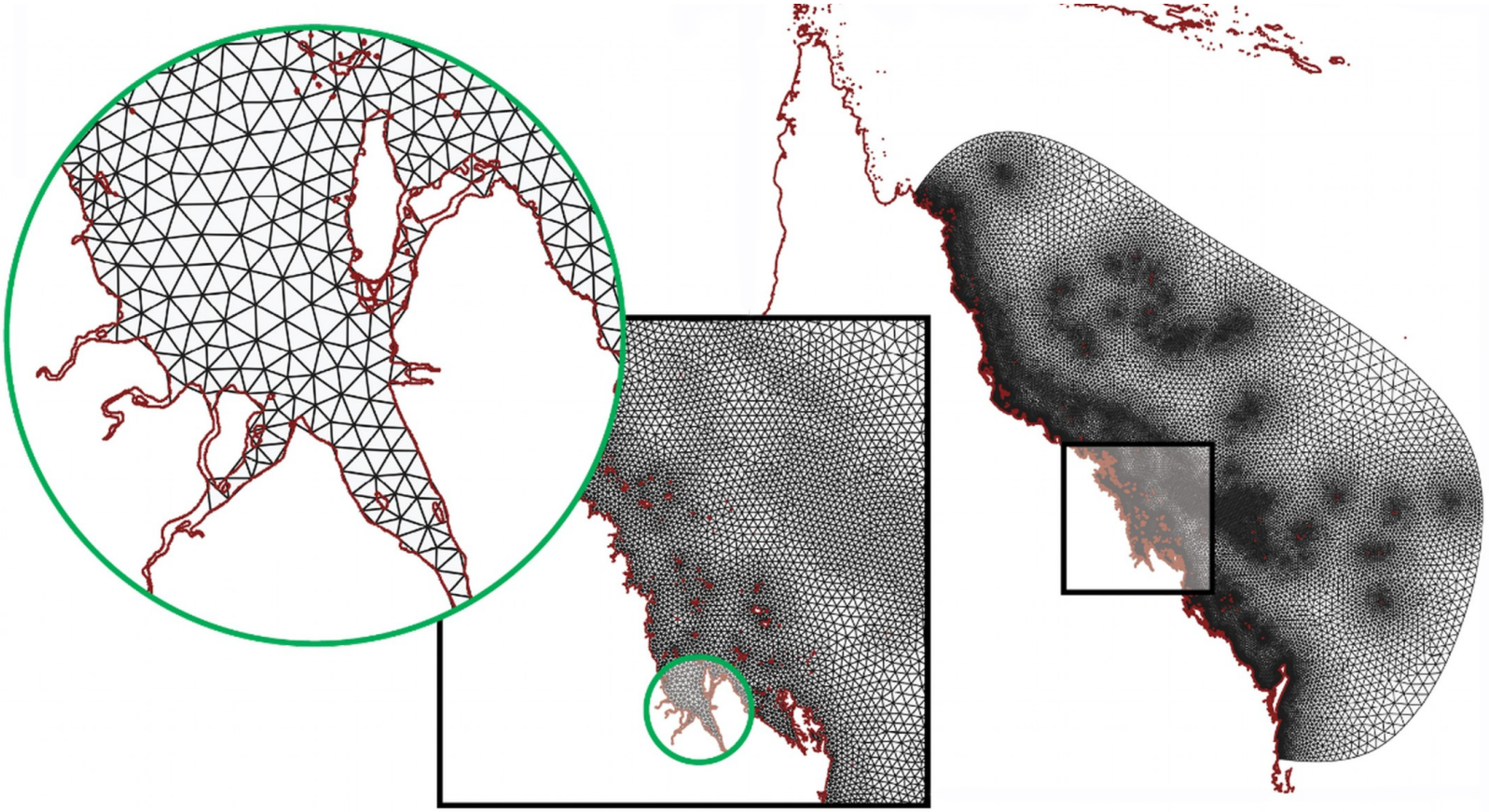


**A coastal unstructured model using Voronoi meshes and C-grid staggering, Engwirda et al, 2020.

Mesh spacing function $\bar{h}(\mathbf{x})$ composed to capture **'scientist-scale'** physics: **wavelengths**, **eddy radii**, **watershed drainage patterns**, etc.

jigsaw: meshing across scales

Build **scale-selective** triangulation as a 'restricted filtration' of the input geometry, sampled at **scientifically relevant length-scales**.



**A coastal unstructured model using Voronoi meshes and C-grid staggering, Engwirda et al, 2020.

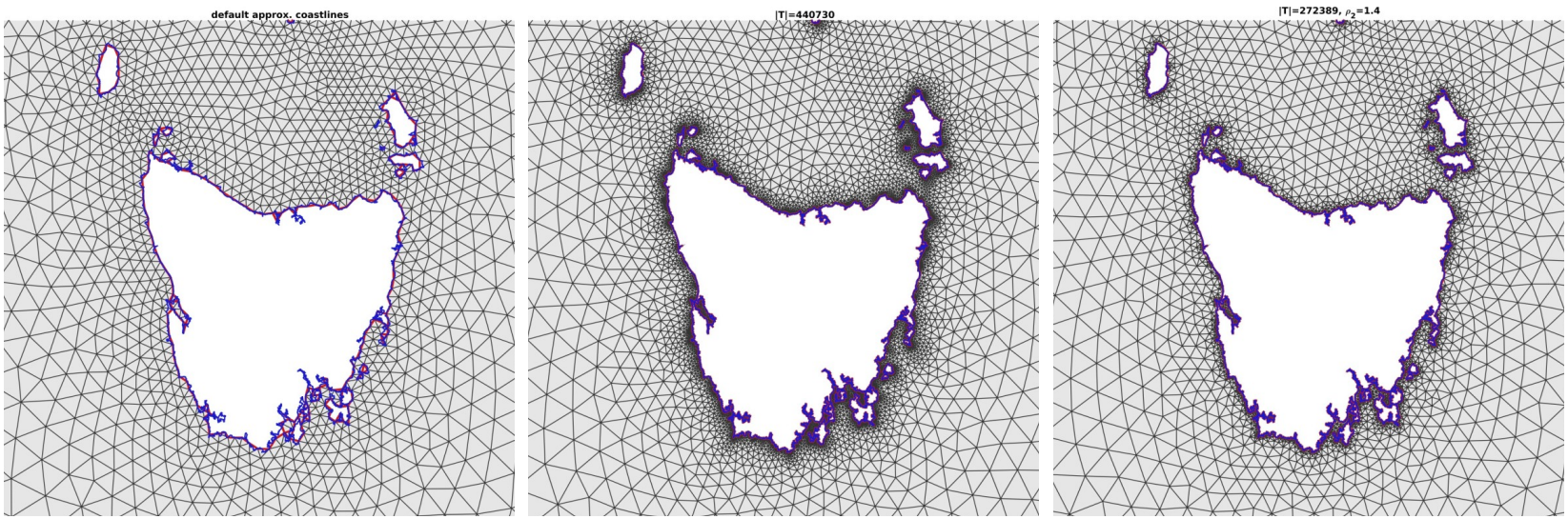
Restricted filtration is a (re)meshing of the domain + boundary, effectively **'filtering-out'** features in the input geometry **smaller than the scales of interest**.

Los Alamos NATIONAL LABORATORY

jigsaw: local-refinement, non-default options, etc...

jigsaw tries to do a good default job out-of-the-box, but there are many different user-config. options (see eg. https://github.com/dengwirda/jigsaw/wiki).

Can generate, for example, **sparse locally-refined meshes at coastlines**:



inexact coast **dense, high-quality** **sparse, relaxed quality**

Various workflows (https://github.com/dengwirda/jigsaw-geo-tutorial):

- 'Initial condition' points + meshes for local refinement.
- 'Internal' boundaries + alignment.
- 'Multi-part' geometries.
- Arbitrary mesh resolution patterns + preparation algorithms.

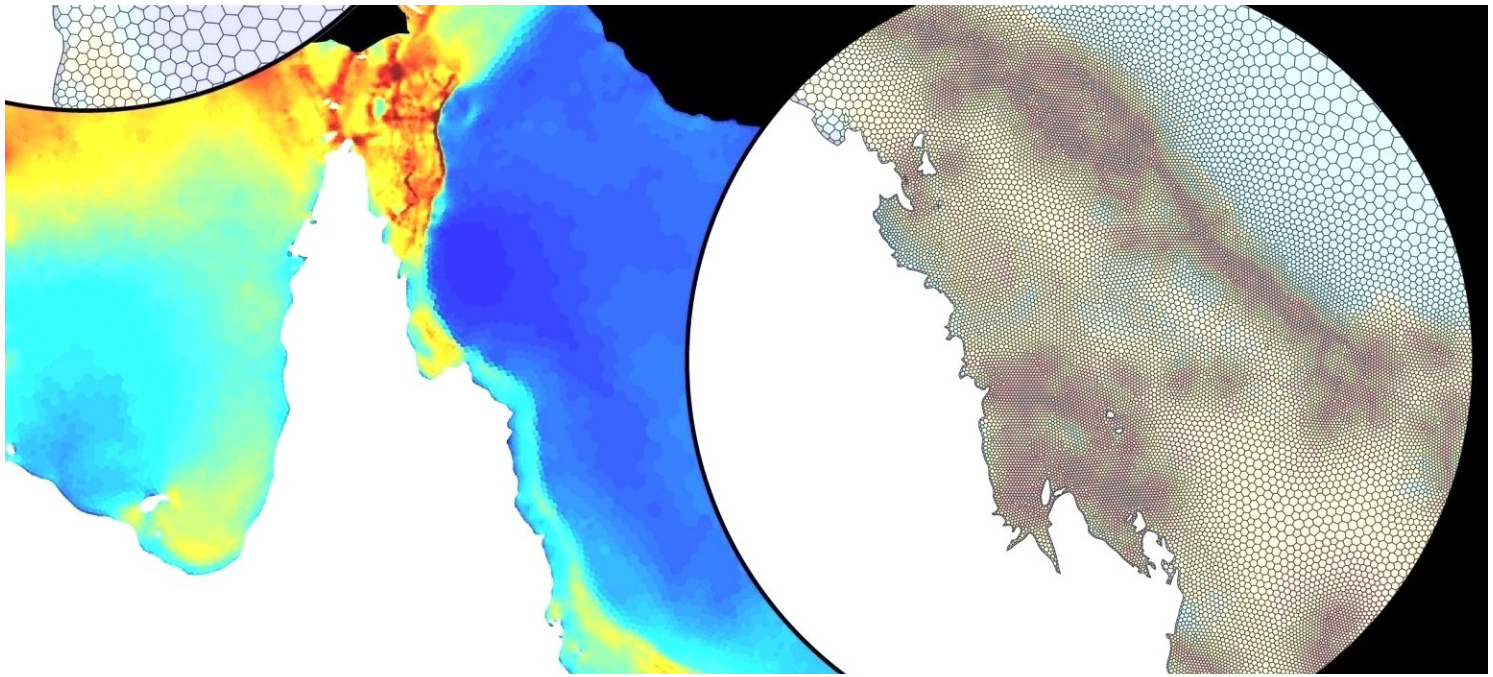
Los Alamos NATIONAL LABORATORY

jigsaw: new feature 'to-do' list...

There are a number of new features under consideration for jigsaw:

- Improved mesh optimisation efficiency, through multi-core optimisation kernels.
- Full support for mixed triangle + quadrilateral meshes.
- Generation + optimisation of anisotropic meshes.

jigsaw is an open-source community meshing engine, with opportunities for collaborative development and enhancement.

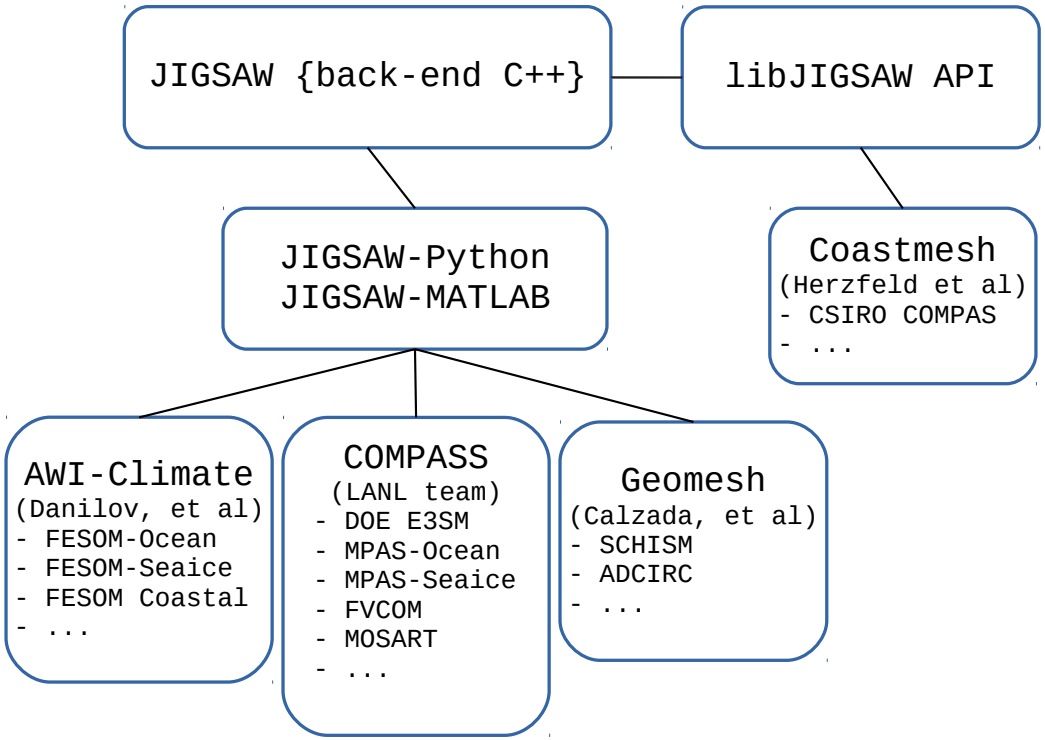


Los Alamos NATIONAL LABORATORY

jigsaw is not mesh2d!

Back in my undergraduate degree, I wrote a simple, heuristics-based meshing scheme: mesh2d.

This MATLAB library is still (surprisingly) popular, though I do not recommend it for real work. **Use jigsaw instead**!



Python and/or MATLAB scripting interface to C++ back-end meshing engine.

jigsaw: simple script-based workflows

At DOE we use Python scripting environments to enable collaborative mesh design → GitHub-based workflow to 'spin-up' E3SM model configurations: