Plan for the next two days

- Day 1
  - Introduction to SCHISM (Joseph)
  - Mesh generation for compound flooding study (Joseph &Wei)
  - Building SCHISM, pre-processing (ACE tools etc); post-processing, visualization (Joseph)
  - Model setup for 2D compound flooding (Fei)
  - Tutorial: 2D compound flooding setup

- Day 2
  - SCHISM physics (Joseph)
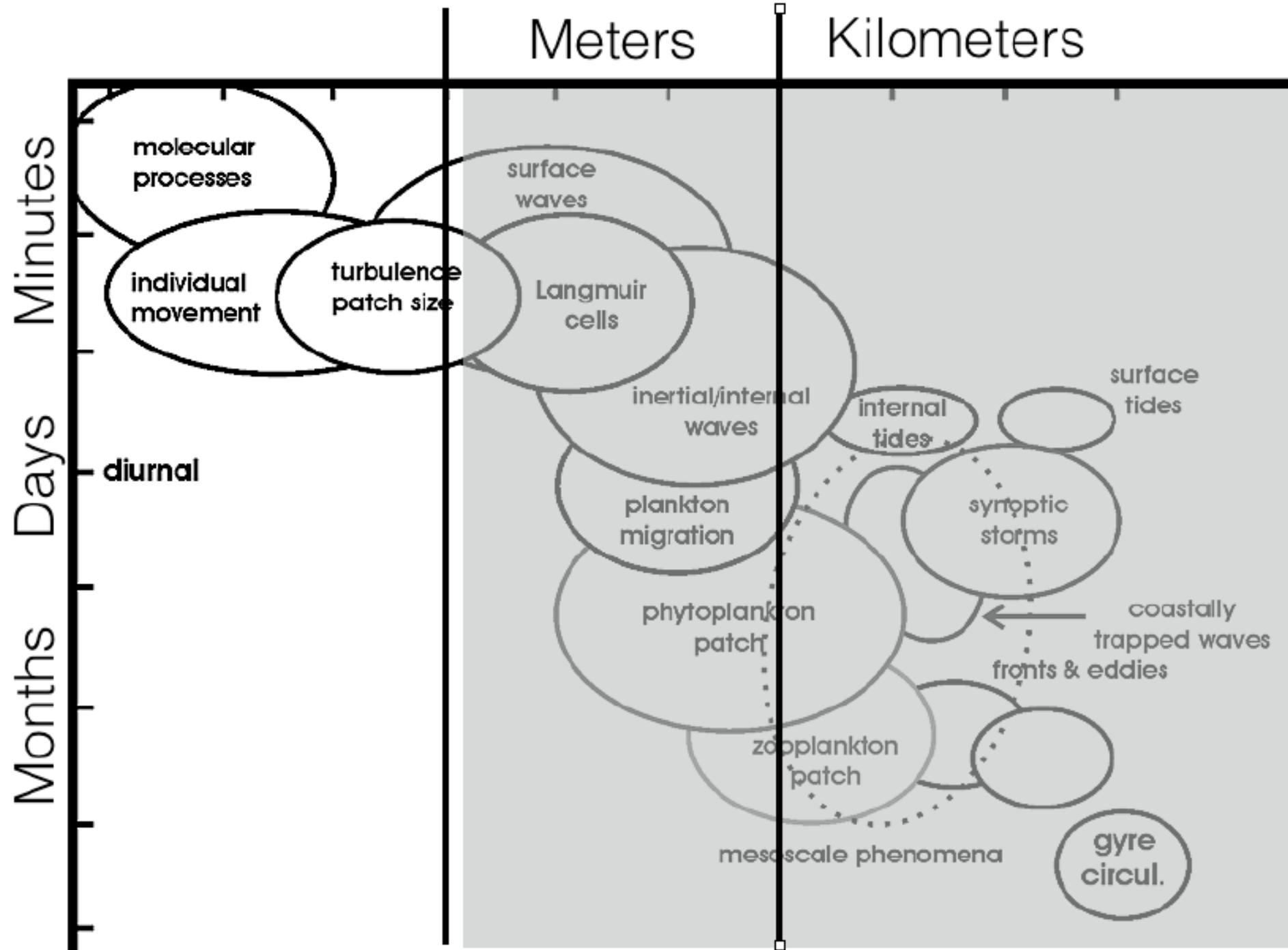 - SCHISM numerics (Joseph)
  - SCHISM I/O (Joseph)

Introduction to Seamless Modeling from Creek to Ocean with SCHISM: Uncompromised Go small & Go big
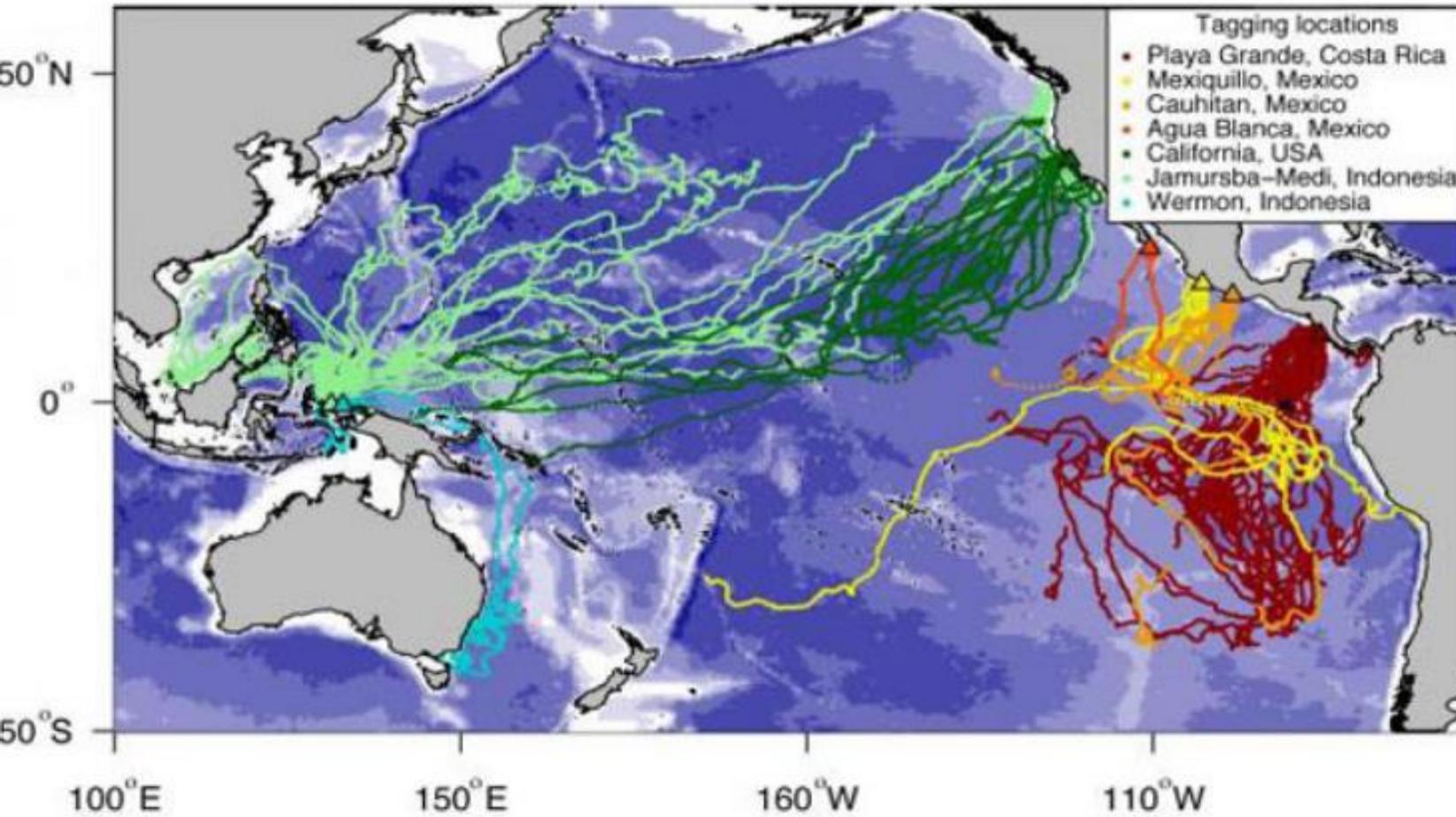
Joseph Zhang

Virginia Institute of Marine Science

Challenges in Geophysical Fluid Dynamics: multi-scale

Most GFD processes are multi-scale in nature

The messy tales of fish

- Fish migration respects no border/boundary
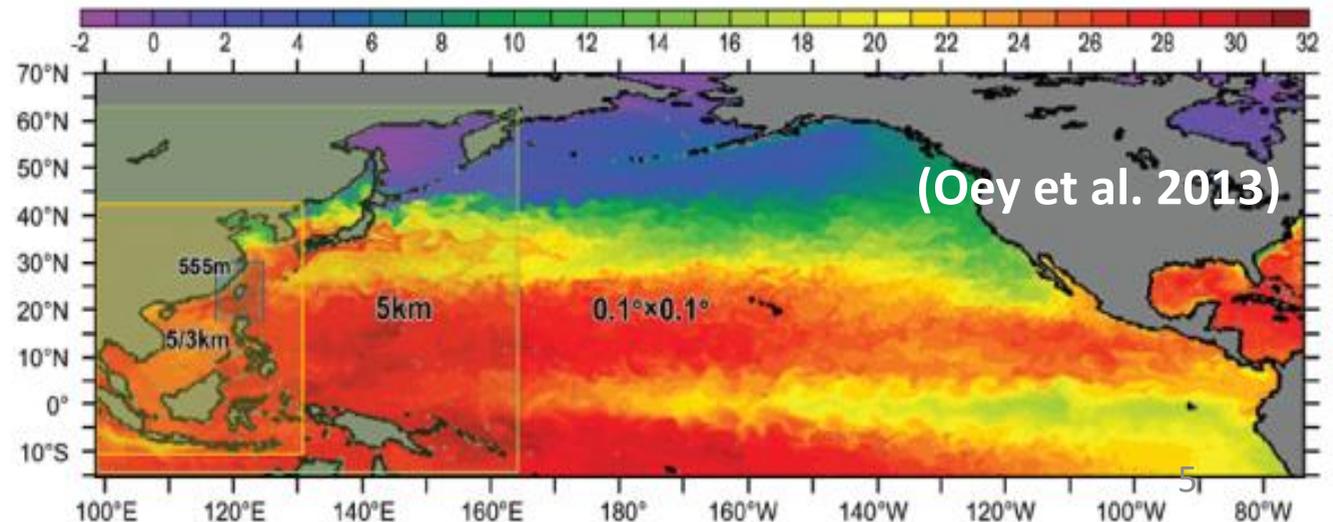- Best to be modeled using a large domain that encompasses the entire pathway

The great disappearing act of UG models

UG models: "complex geometry, simple flow"

SG models: "simple geometry, complex flow"

Can we build a *baroclinic* unstructured-grid model from river to ocean?

Baroclinic circulation is still mostly done using SG models with grid nesting

(Oey et al. 2013)

Progress in the large-scale UG modeling...

- MPAS
  - on Spherical Centroidal Voronoi Tessellations (SCVT), Arakawa-C grid (orthogonal), global
  - FV formulation (vector invariant)
  - Mostly free of spurious numerical 'modes'
  - Ocean, seaice, landice, atmosphere...
- FESOM2
  - on hybrid triangle-quads
  - FV formulation
- ICON
  - on orthogonal triangles
  - FV formulation
- Significant challenges remain from deep ocean into shallow waters
  - Part of these challenges are due to physics (e.g., scale differences =>different parameterizations)
  - Scale-aware parameterization is an active research area
  - However, underlying numerics are lacking even if we restrict ourselves to hydrostatic regime
  - The 3 global models are developing their own coastal components
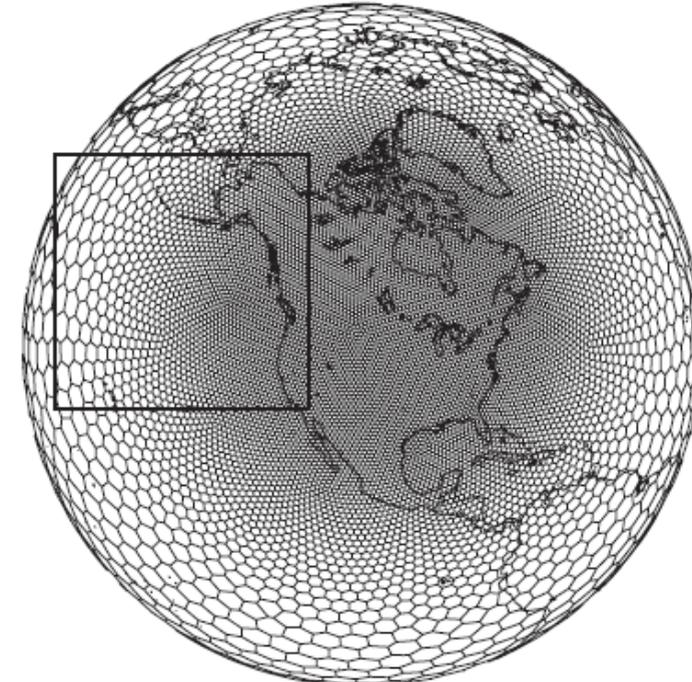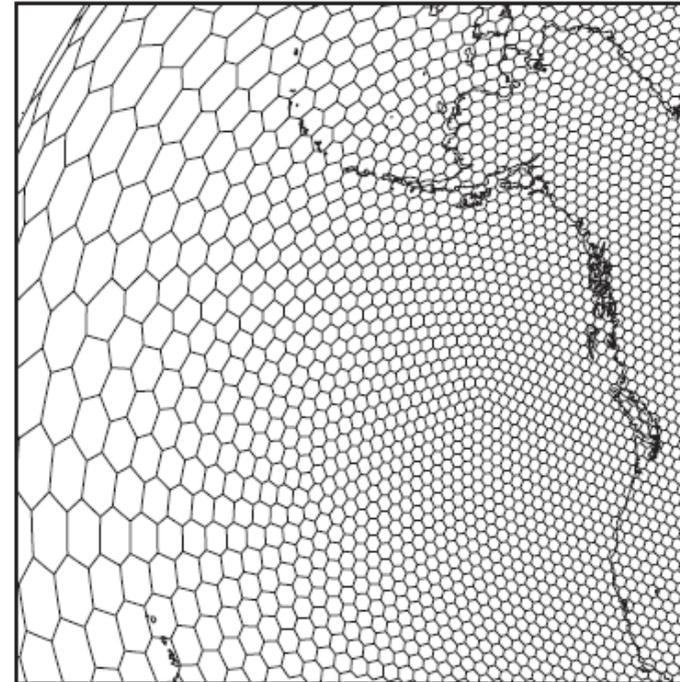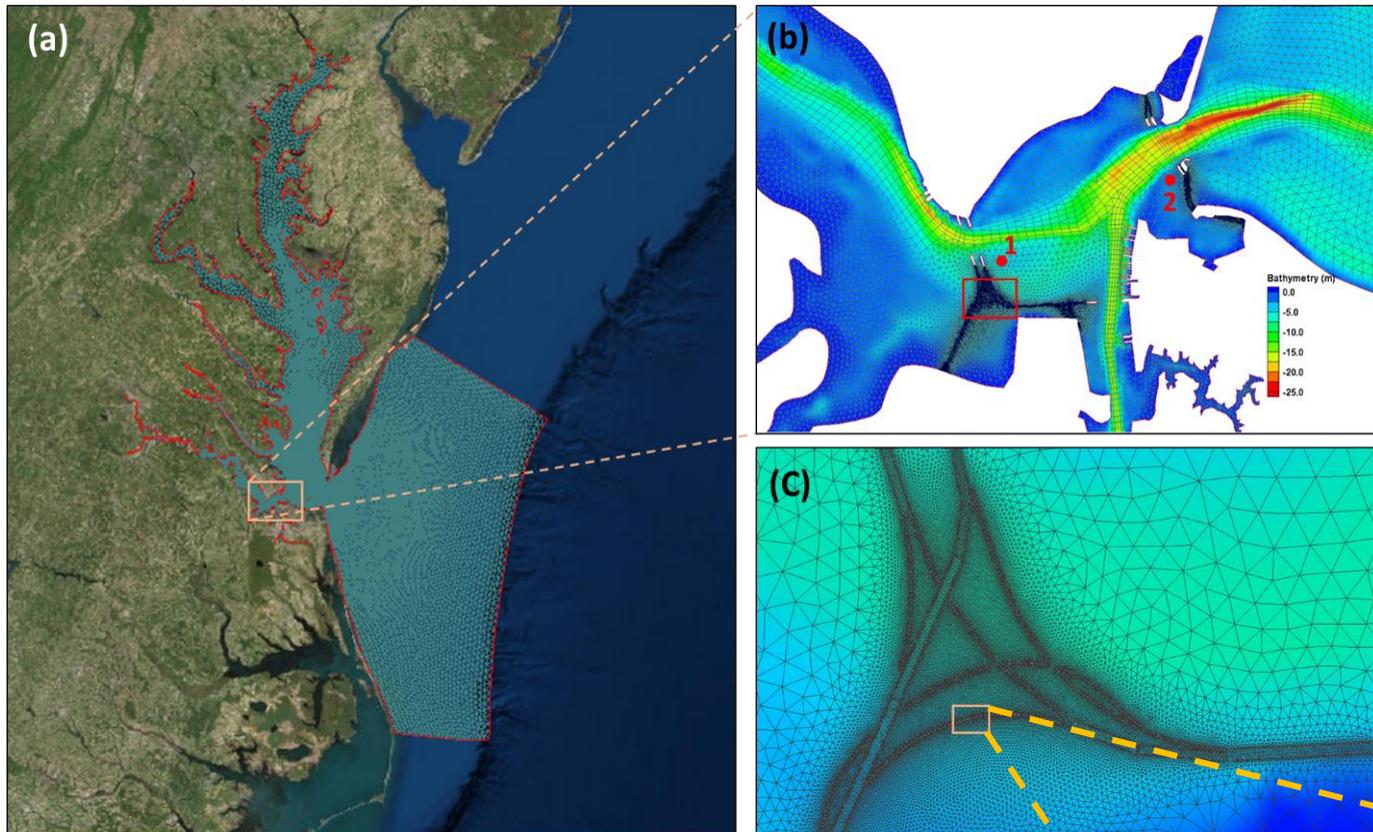

Skamarock et al. (2012)

Seamless cross-scale modeling with SCHISM


San Francisco Bay & Delta

...we started the adventure from the coastal/estuarine side and then waded into eddying regime

Seamless cross-scale modeling with SCHISM

- Bridge crossings on James River, Chesapeake Bay
- Bridge pilings of 1-2m in diameter
- ~1840 pilings located in the middle of salt intrusion path
- We are now capable of traversing scales of 6 orders of contrast (1m to 1000km), all in 3D glory
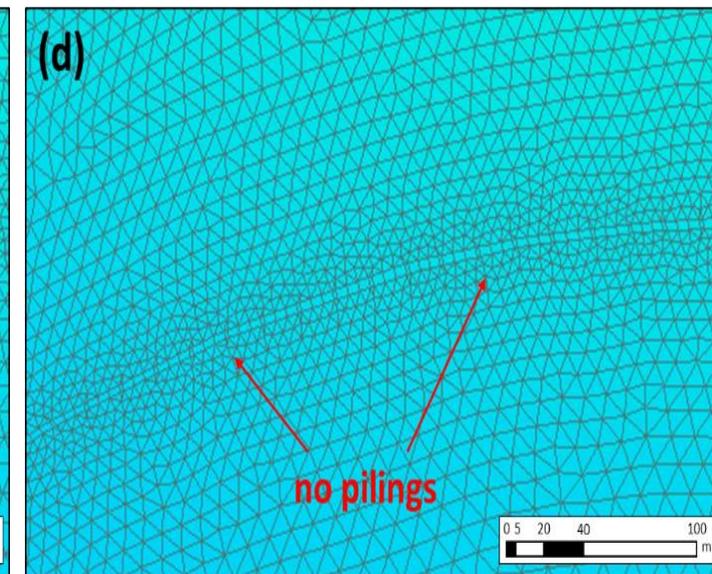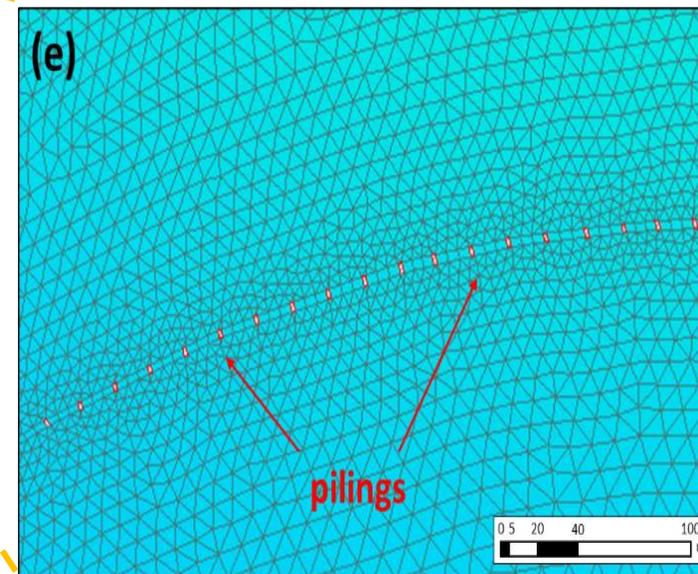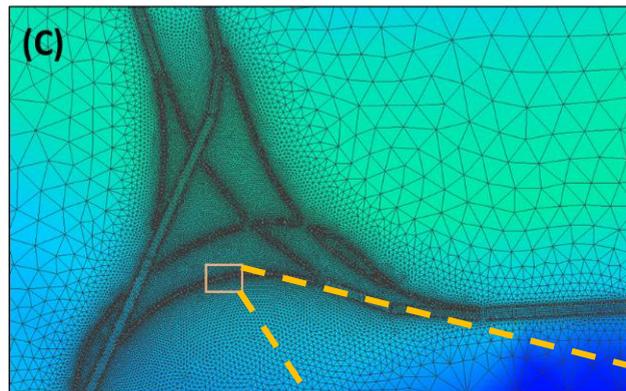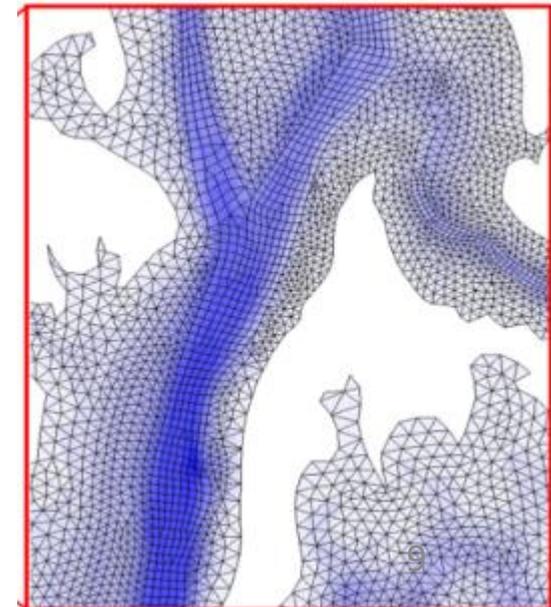
Liu et al. (2018)

SCHISM: <u>S</u>emi-implicit <u>C</u>ross-scale <u>H</u>ydroscience <u>I</u>ntegrated <u>S</u>ystem <u>M</u>odel

- A derivative product of SELFE v3.1, distributed with open-source Apache v2 license
  - Substantial differences now exist between the two models
  - Free github access for general public
- Galerkin finite-element and finite-volume approach: ***generic*** unstructured triangular grids
  - ELCIRC (Zhang et al. 2005), UnTRIM (Casulli 1990; 2010), SUNTANS (Fringer 2006): finite-difference/volume approach →orthogonal grid
  - Hydrostatic assumption
- **Semi-implicit** time stepping: no mode splitting → large time step and no splitting errors
- **Eulerian-Lagrangian** method (ELM) for momentum advection → more efficiency & robustness
- Major differences from SELFE v3.1
  - Apache license
  - Mixed grids (tri-quads)
  - **LSC²** vertical grid (Zhang et al. 2015)
  - Implicit TVD transport (**TVD²**) & WENO³
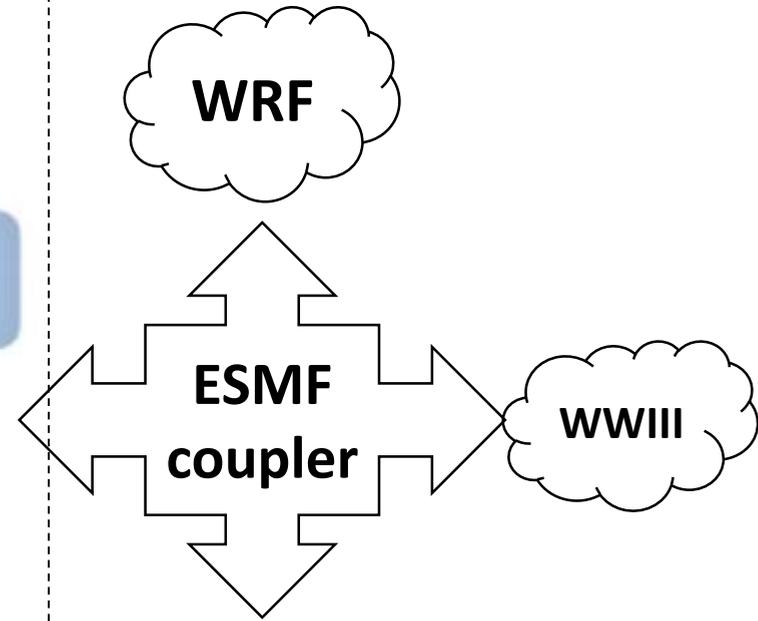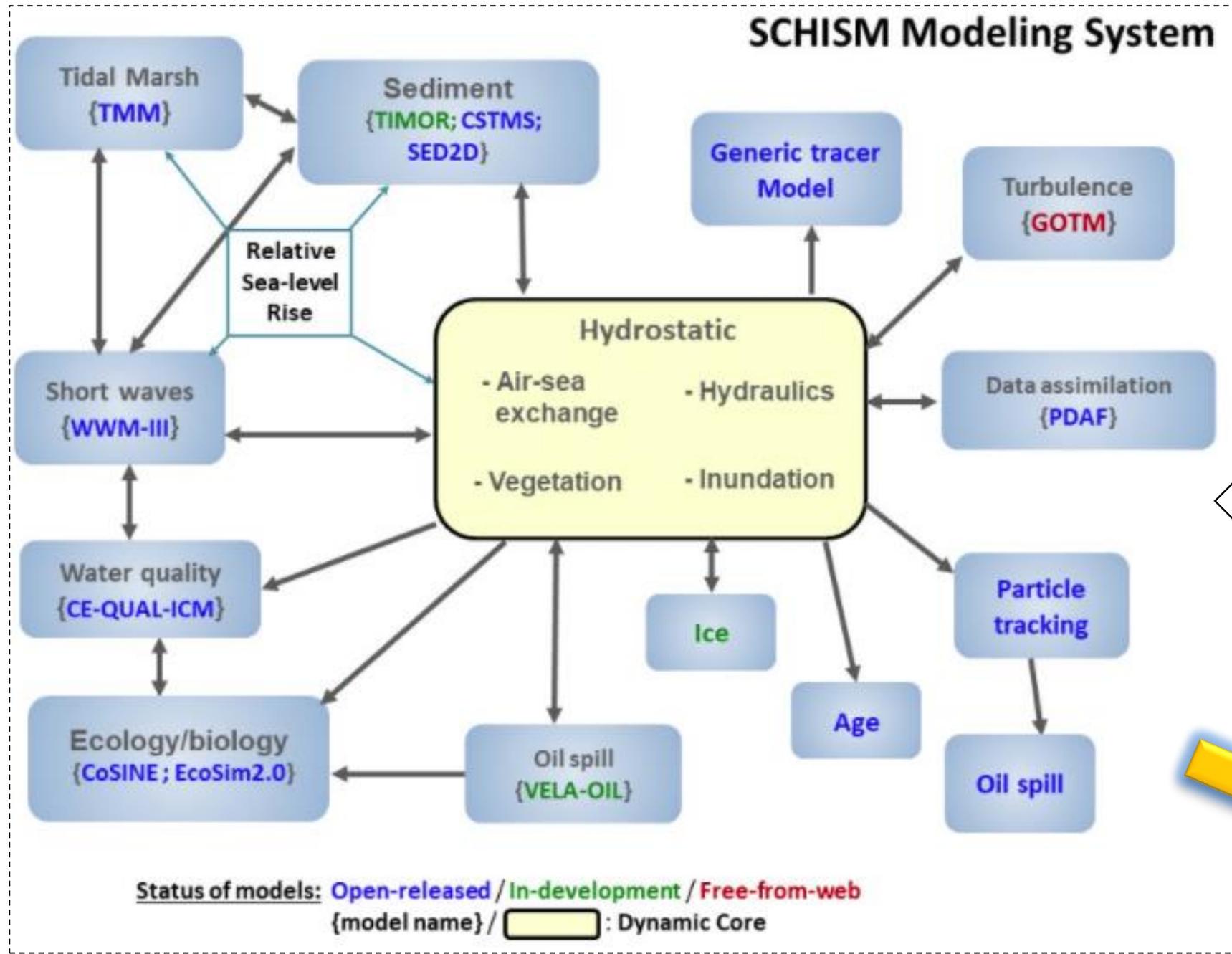 - Higher-order ELM with ELAD
  - Bi-harmonic viscosity

SELFE

SCHISM

Eddying regime (Zhang et al. 2016)

**visit schism.wiki**

SCHISM Modeling System

c/o Karinna Nunez

SCHISM features

- Major differentiators
  - No bathymetry smoothing or manipulation necessary: faithful representation of bathymetry is key in nearshore regime (Ye et al. 2018, OM)
  - Implicit FE solvers → superior stability → very tolerant of bad-quality meshes (in non-eddying regime)
  - Accurate yet efficient: implicit + low inherent numerical dissipation
  - Flexible gridding system: polymorphism
  - Uncompromised seamless cross-scale capability: need for grid nesting is minimized
- Well-benchmarked; certified inundation scheme for wetting and drying (NTHMP)
- Fully parallelized with domain decomposition (MPI+openMP) with good strong scaling (via PETSc)
- Operationally tested and proven by multiple agencies
- Open source, with wider community support

In short, SCHISM is a very different type of beast, which may require some *unlearning* from new users!

Respect the bathymetry

↯ **Faithful representation of bathymetry is arguably the most fundamental aspect for models, especially in nearshore**

↯ **Two types of bathymetric errors**

  ↯ **Type I: Finite grid resolution; bathymetry survey errors (improving rapidly); smoothing of DEM for unresolved sub-grid scales - not a convergence issue**

  ↯ **Type II: Smoothing or other manipulations (e.g. as in terrain-following coordinate models) - a divergence error as refining grid generally makes it worse because steeper slopes begin to appear at finer scales!**

↯ **SCHISM's representation of the bathymetry is piece-wise linear**

↯ **Very skew elements are allowed in non-eddying regime; implicit scheme guarantees stability**

  ↯ **Facilitates feature-tracking in mesh generation**

↯ **There is no need for bathymetry smoothing to stabilize SCHISM in any scale**

  ↯ **Put another way, SCHISM's advantages shine only when accurate DEMs are available**

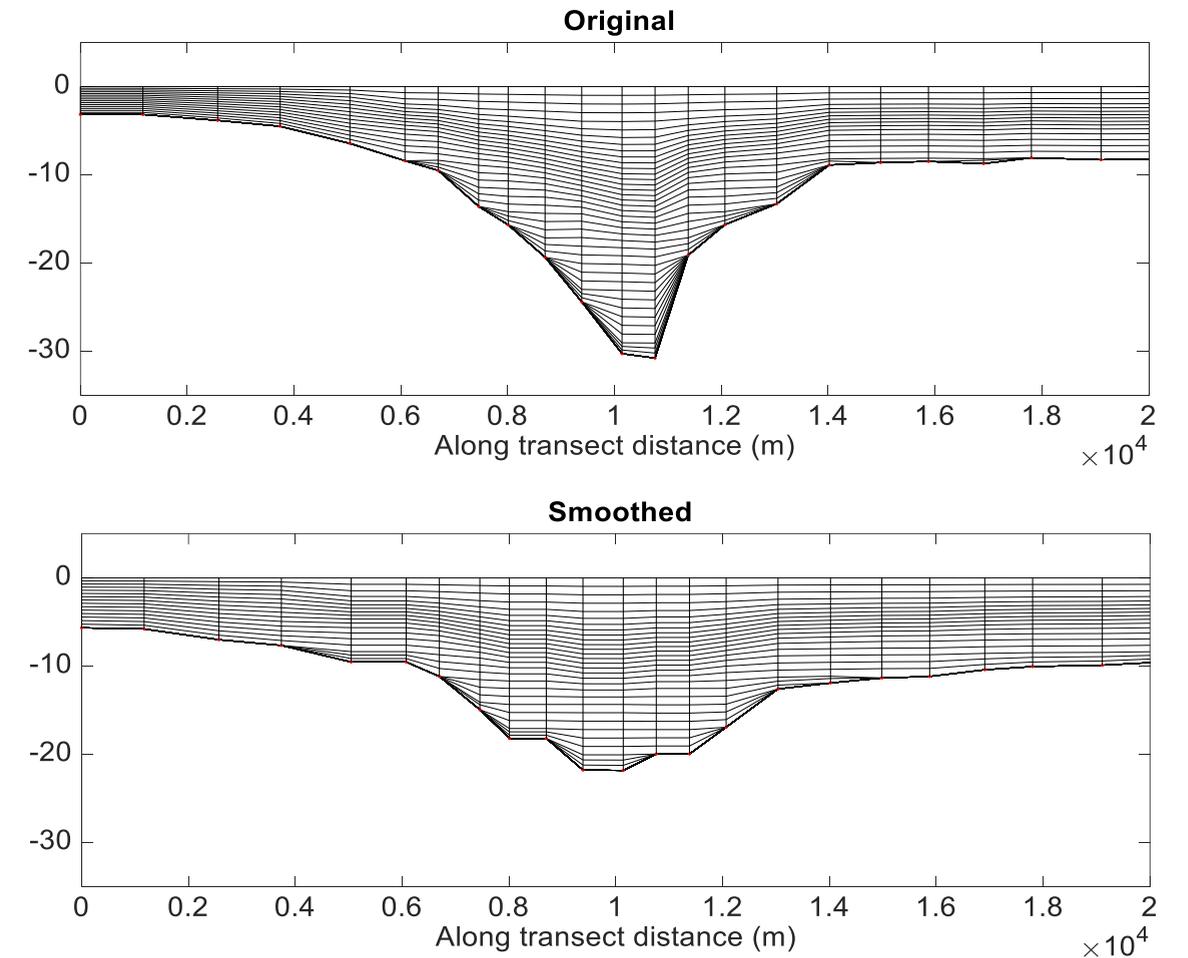 ↯ **Parameterization needs some attention**

(a)

(b)
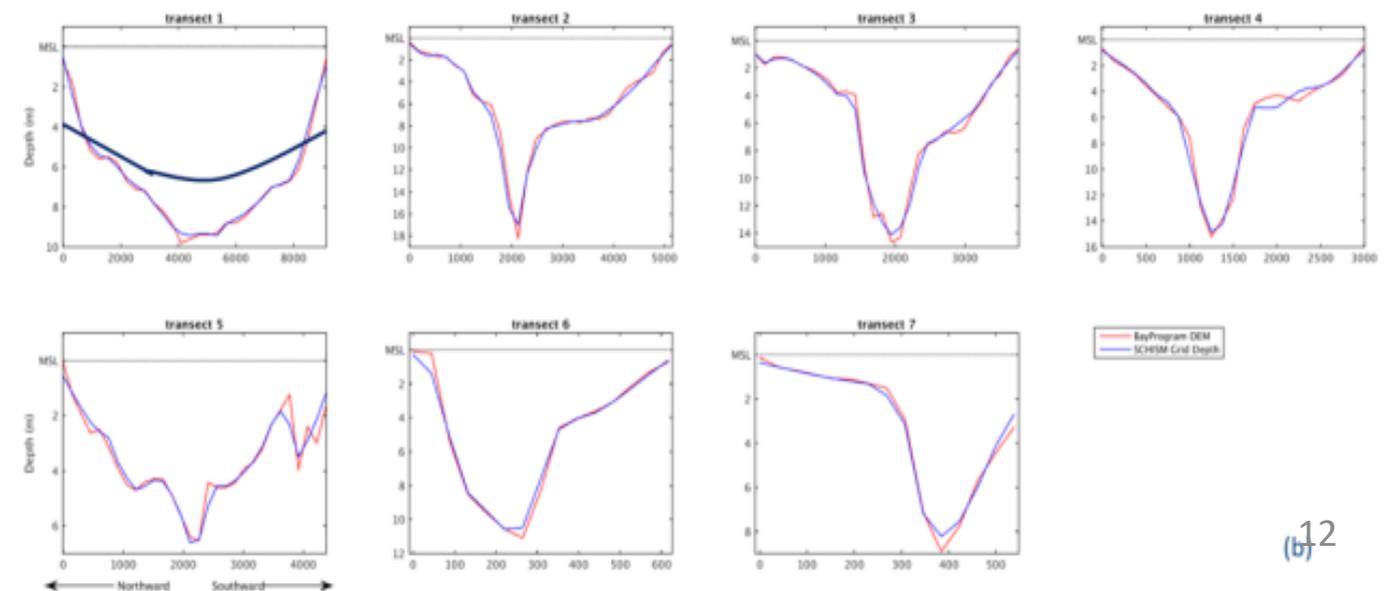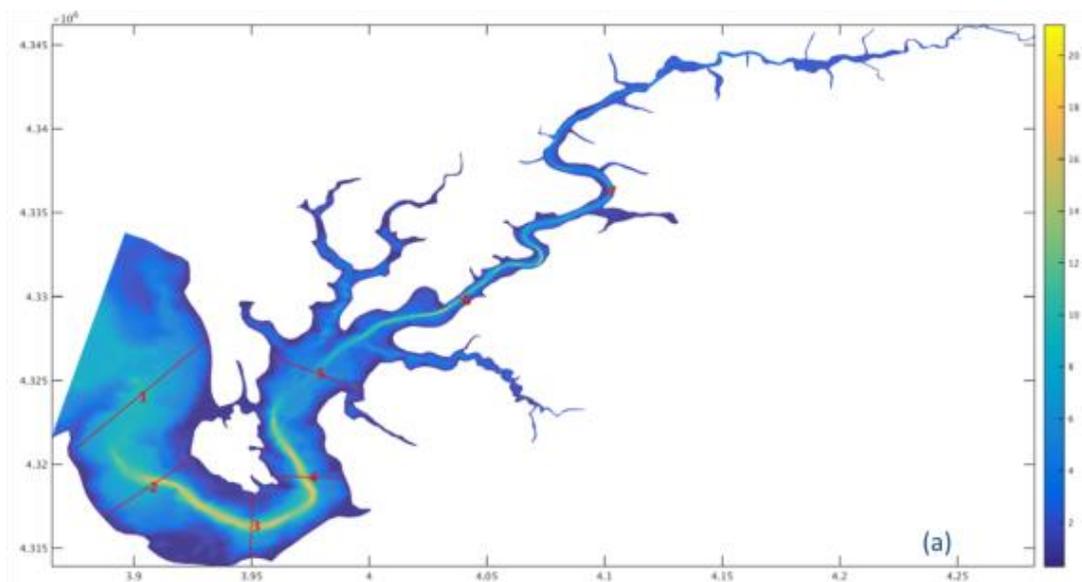
Detrimental effects of bathymetry smoothing

Smoothing in a critical region where the center channel constricts and bends, with multi-channel configurations
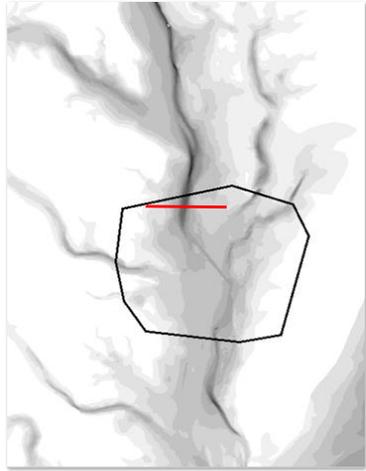

Potomac R.

Rappahannock R.

York R.
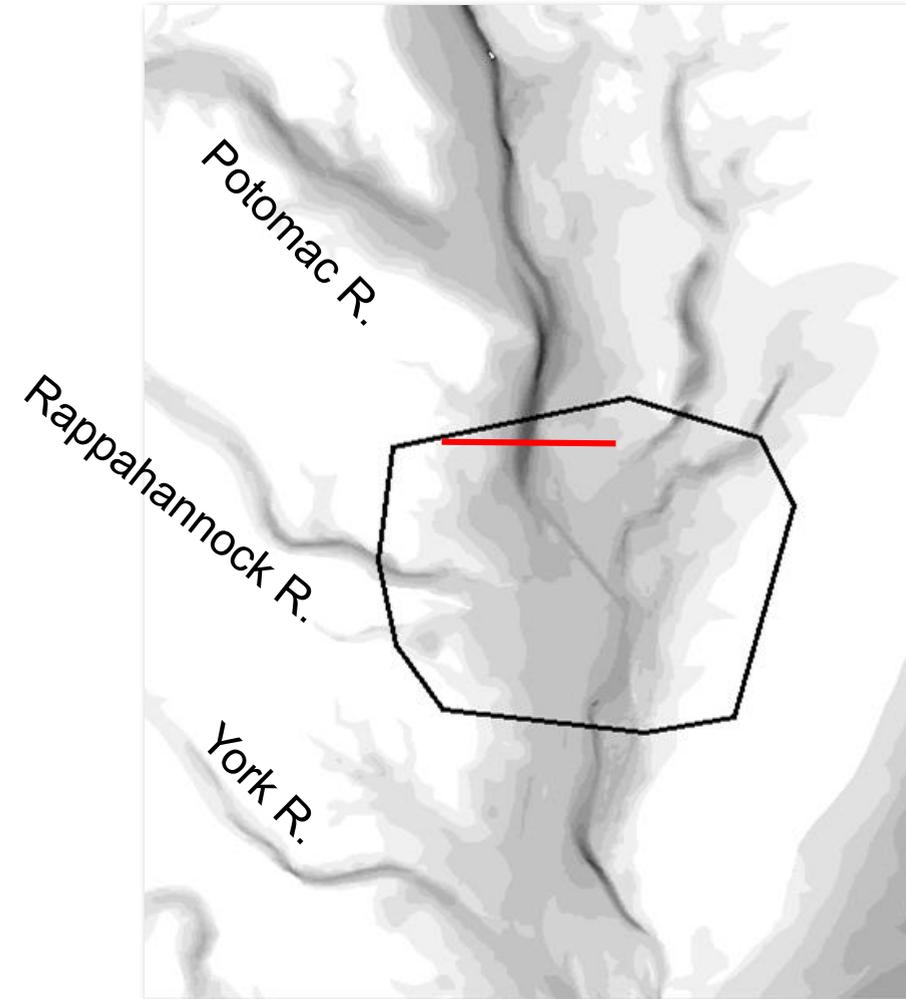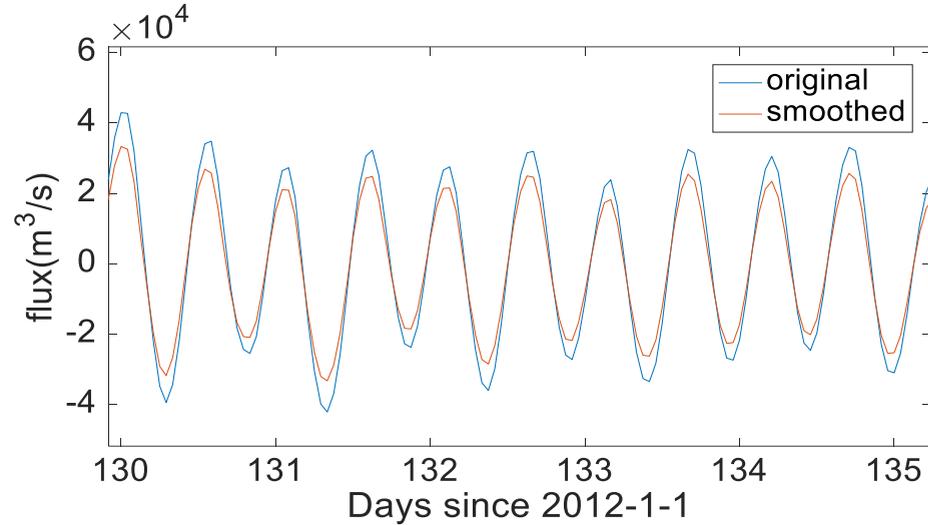
Cross-channel transect with deep center channel

Volume is conserved during smoothing

Ye et al. (2018)

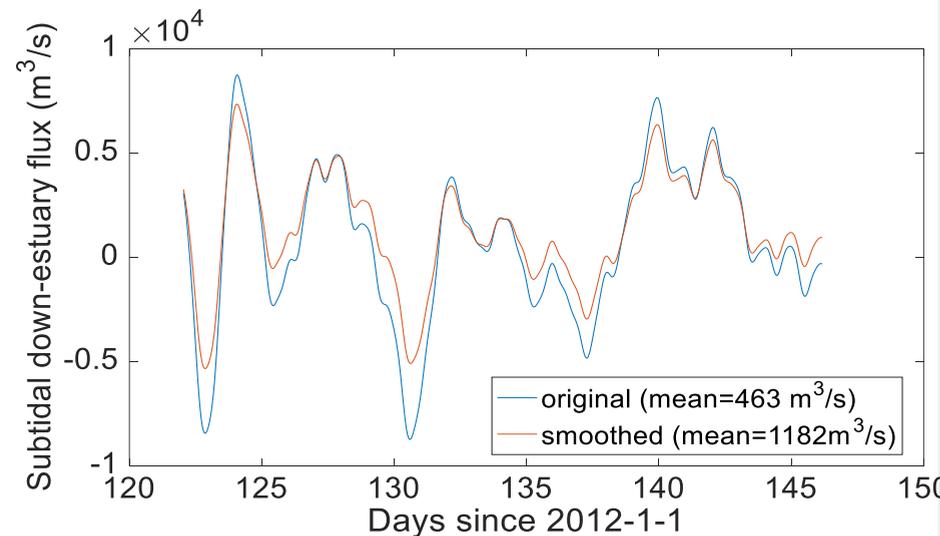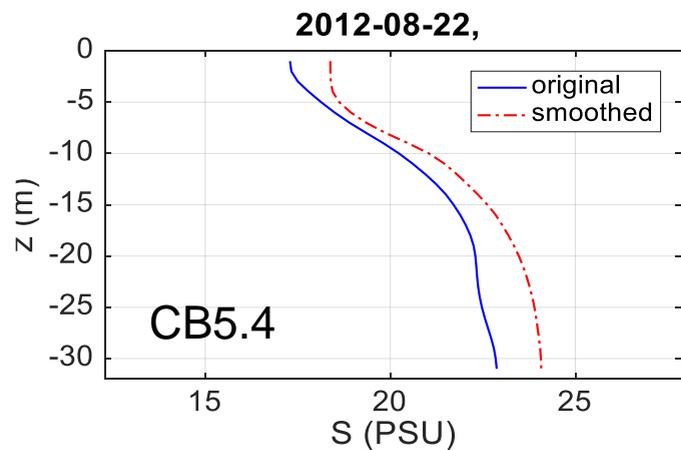# Bathymetry smoothing effectively masks true numerical dissipation!

Focusing on the cross transect on the west part of the main stem, the smoothing effects include:

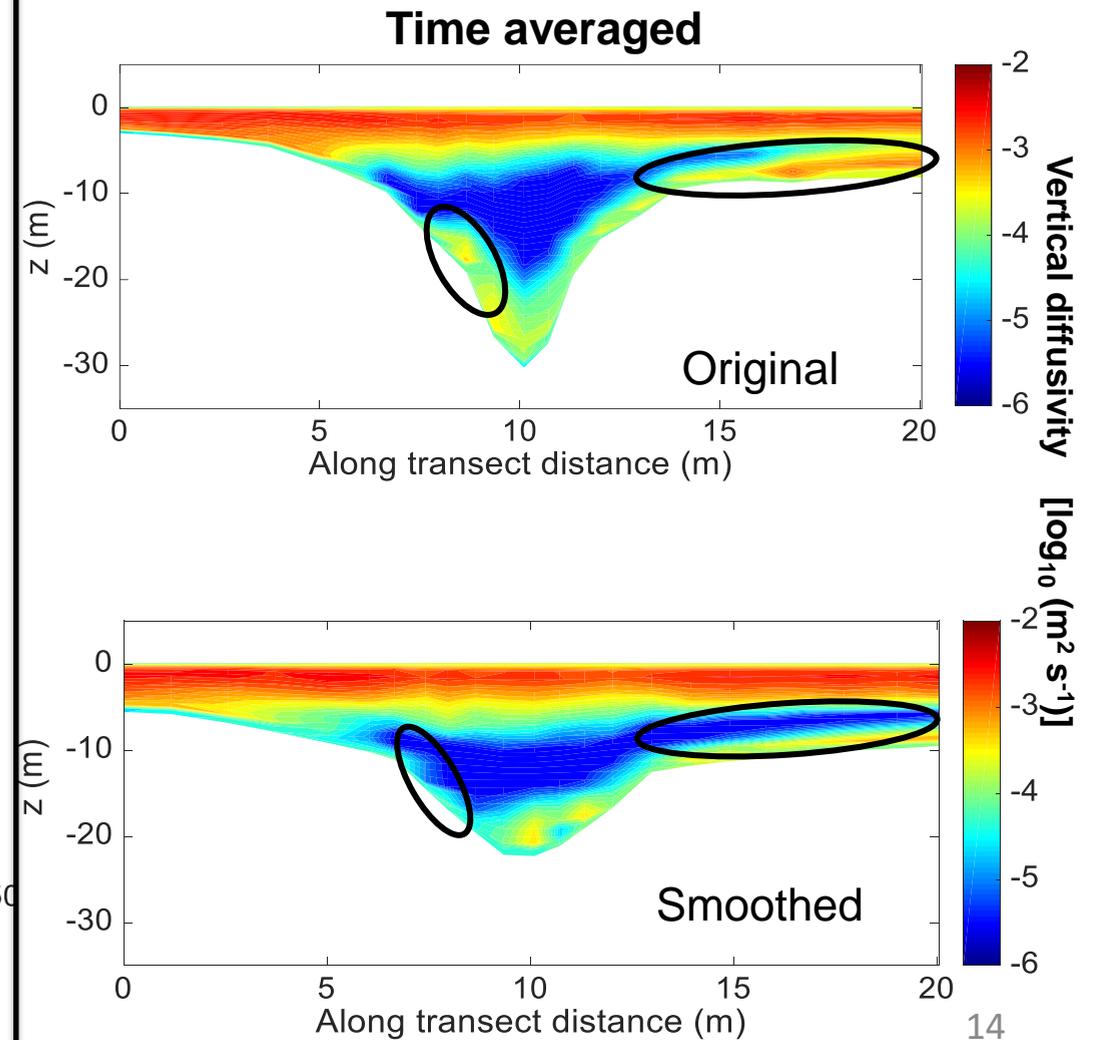Smaller amplitude of tidal volume flux: smoothed = 79% original
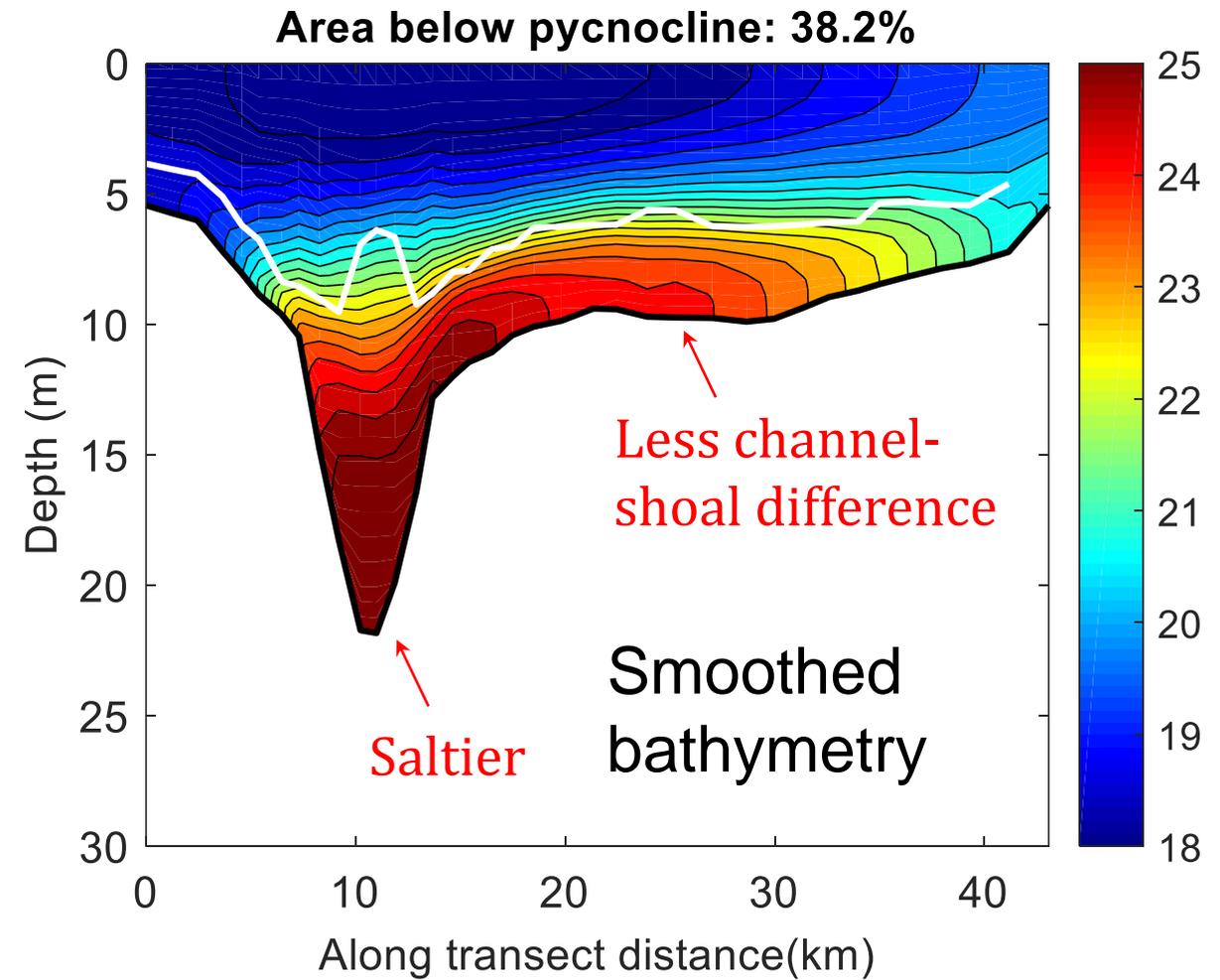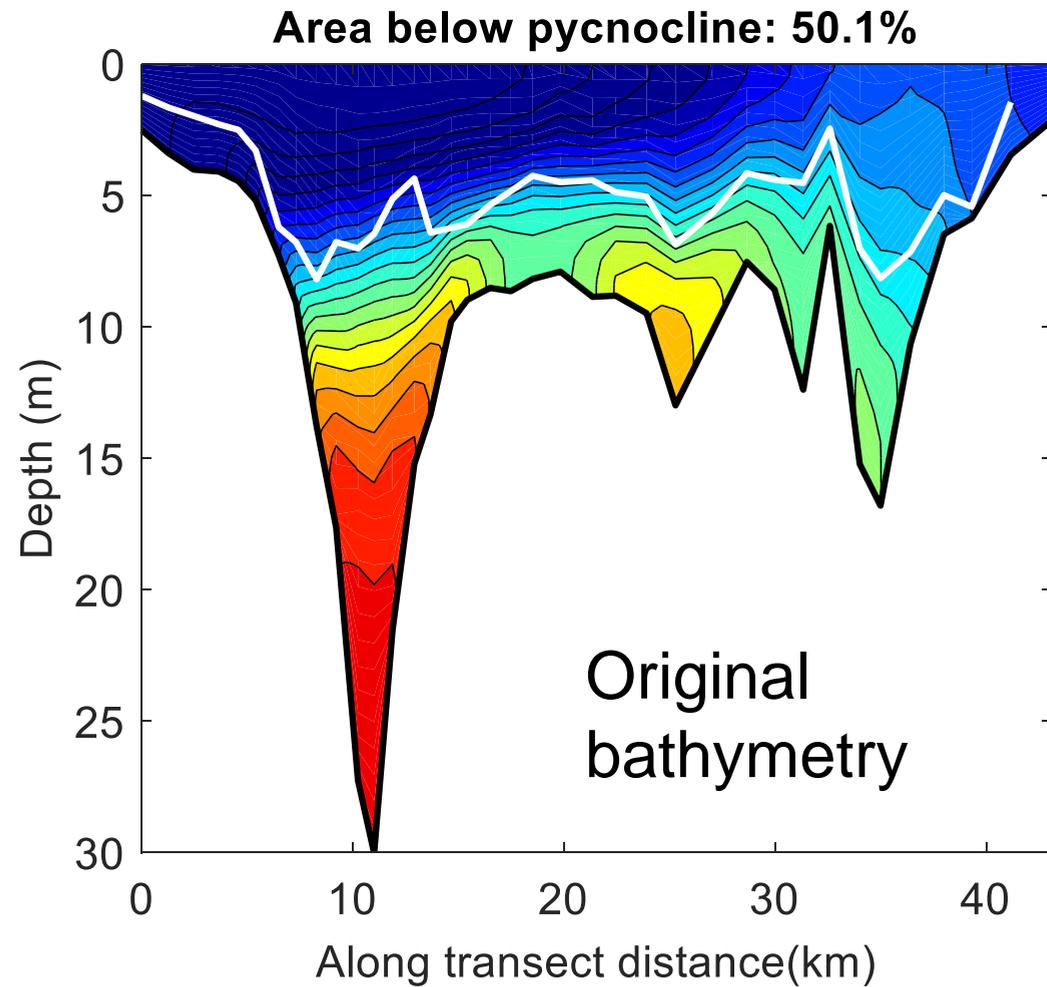

The effect of smoothing on turbulent mixing: less mixing overall and less contrast between shoal and channel

More salt, about +1 PSU in the smoothed region, 2-3 PSU upstream

Larger sub-tidal volume flux
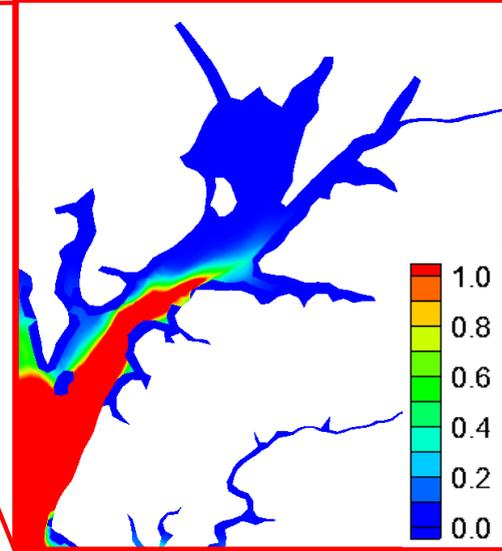
Ye et al. (2018)

Time averaged

14

Cross-sectional salinity distribution

Area below pycnocline: 50.1%

Area below pycnocline: 38.2%

Original bathymetry

Smoothed bathymetry

Less channel-shoal difference

Saltier

Depth (m)

Along transect distance(km)

Stratification

Channelized intrusion

Uniform intrusion
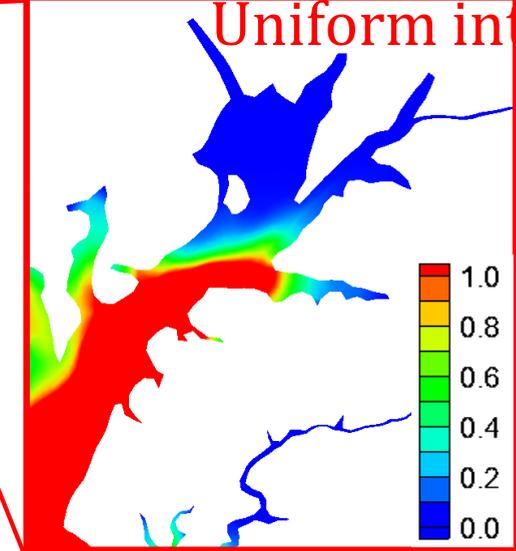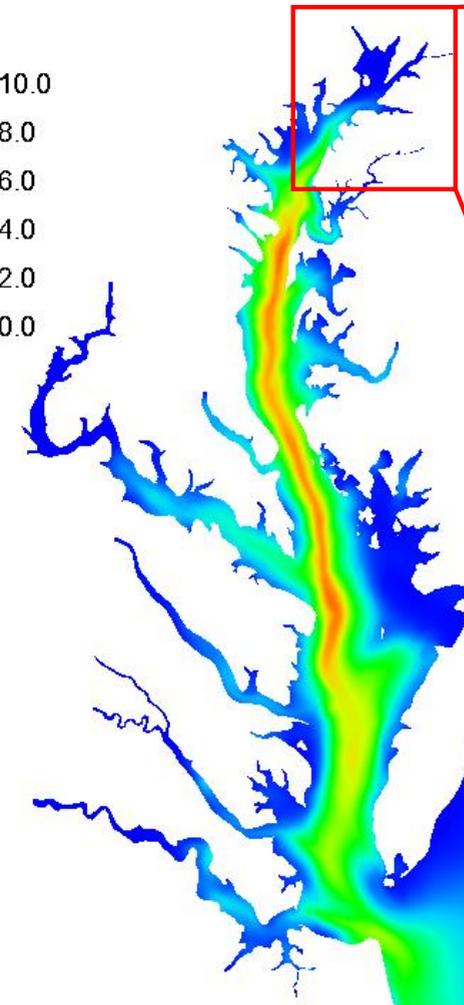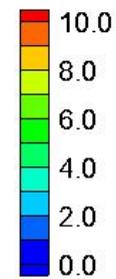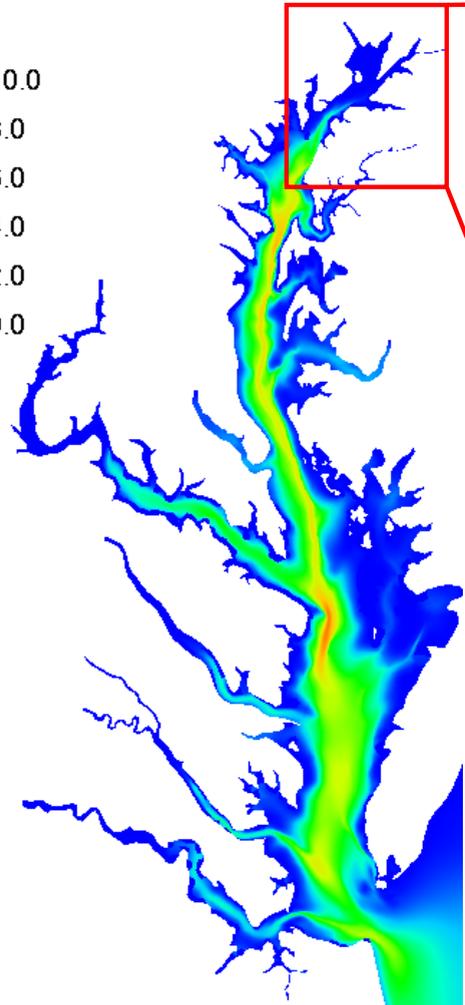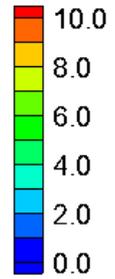
Original Bathymetry

Smoothed Bathymetry

More stratified due to stronger gravitational circulation
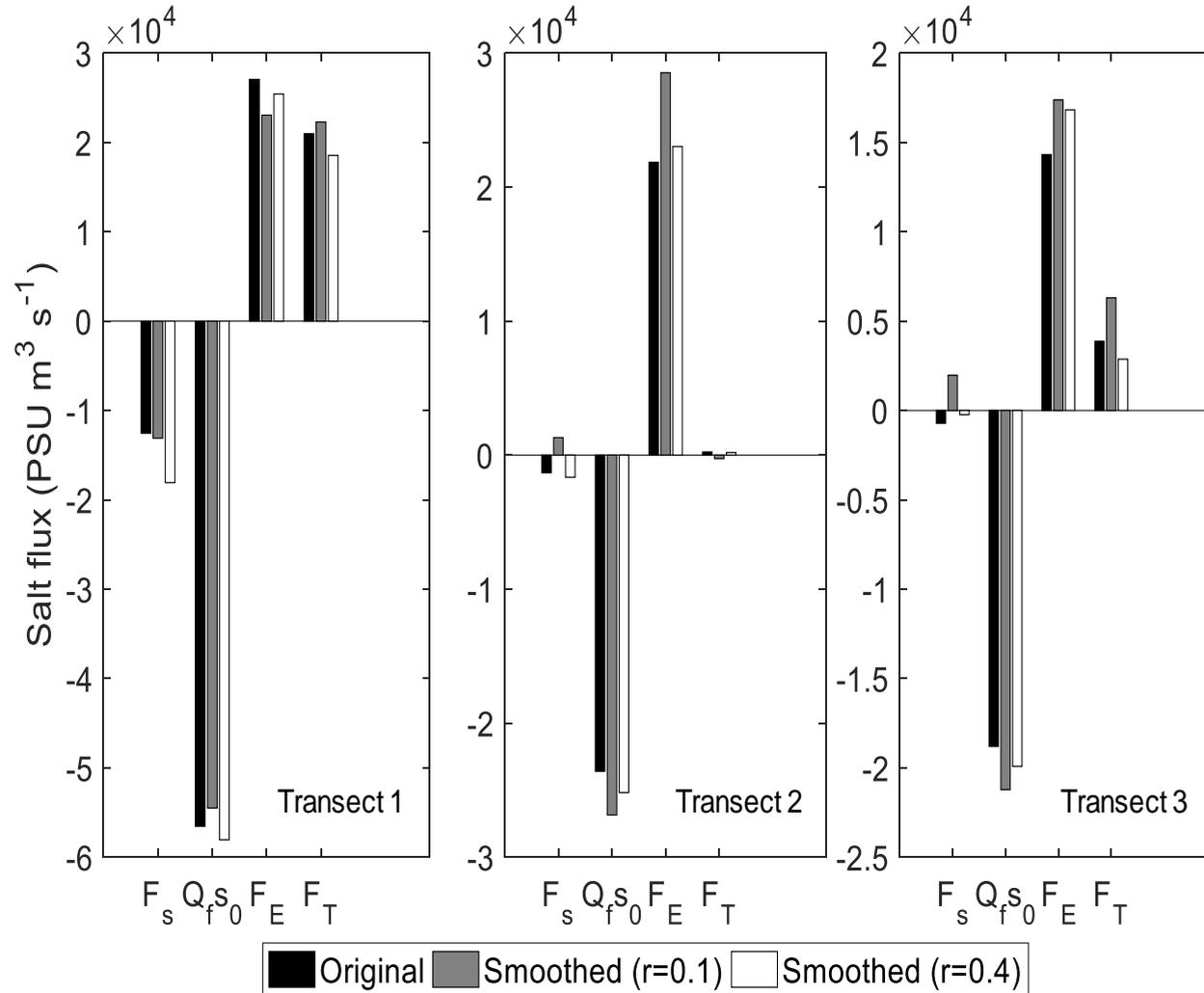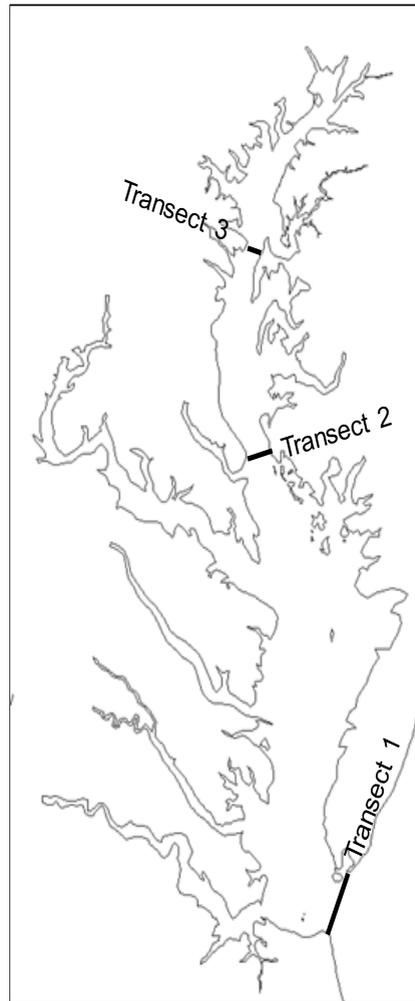
Salt budget

(Lerczak et al., 2006)

$$F_S \approx Q_f s_0 + F_E + F_T$$

F_S: total salt flux;
F_E : estuarine circulation flux;
F_T: tidal oscillatory flux;
$Q_f s_0$: salt flux from river discharge and Stokes transport

Larger salt flux due to estuarine circulation and tidal oscillation, leading to larger total flux

Ye et al. (2018)

Mesh generation in SCHISM: less numerics, more physics

Raster Raster Set
- 4.0
- 2.0
- 0.5
- -1.0
- -4.0
- -6.0
- -8.0
- -10.0

Tidal range

Channel

Shoal

Ship channel

Focus here is on physics....
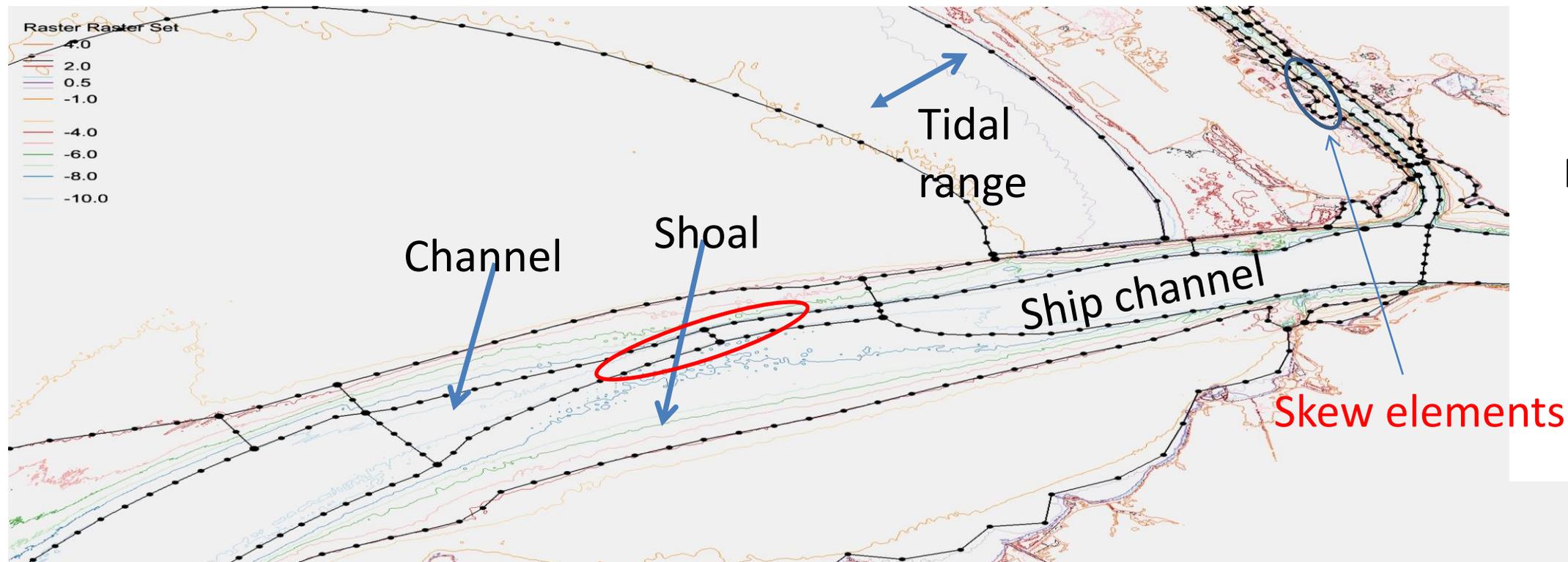
Skew elements

Channel representation
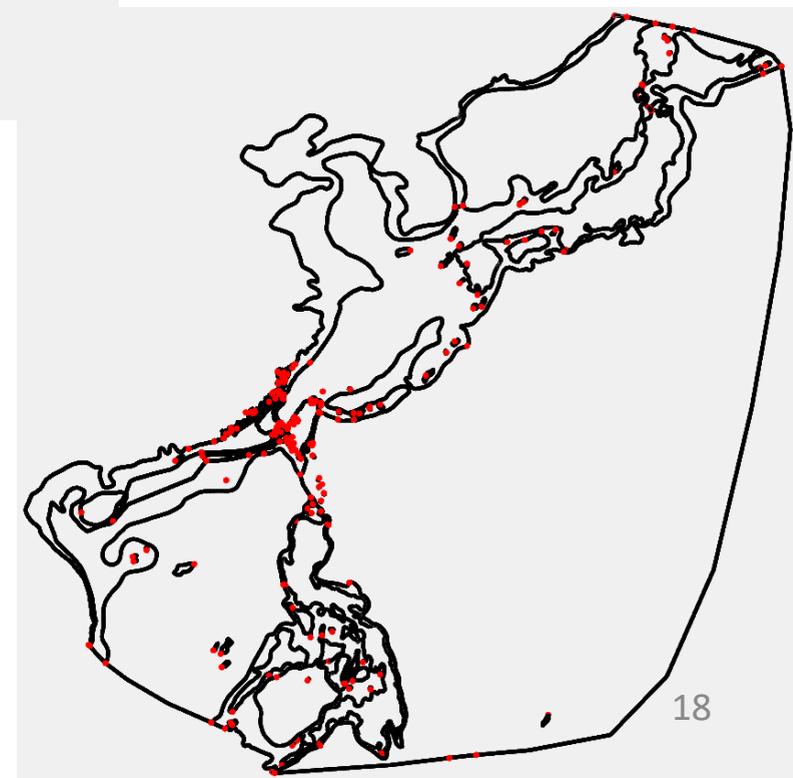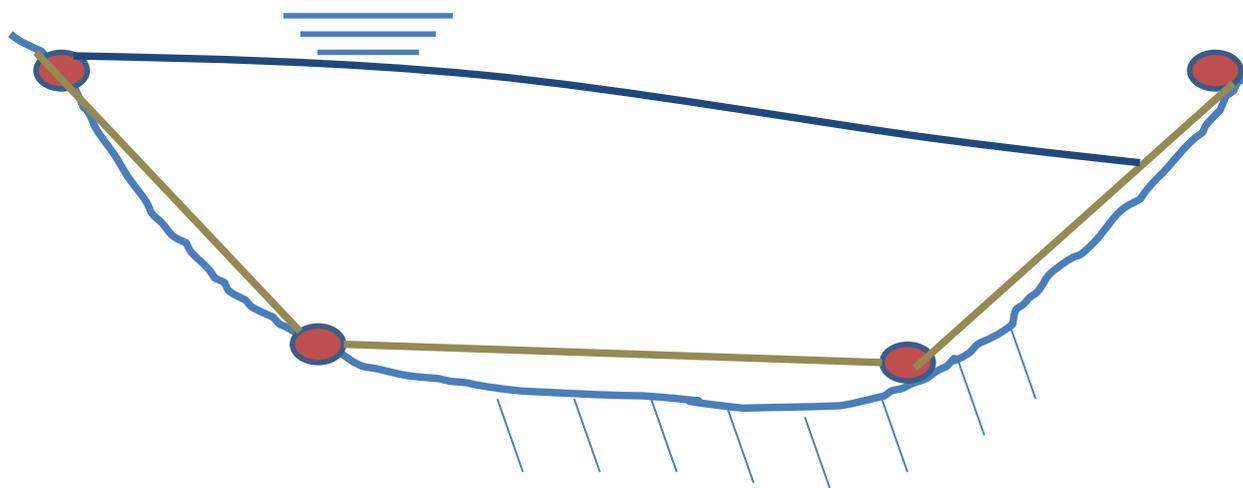
How skew can you go??

- Model is stable on very skew elements! This turned out to be instrumental for compound flooding studies (watershed)
- This allows us to take full advantage of UGs

Inspiration from CFD …

Highly anisotropic meshes for airfoil simulations

Extreme case #1: skew elements are a boon in nearshore applications
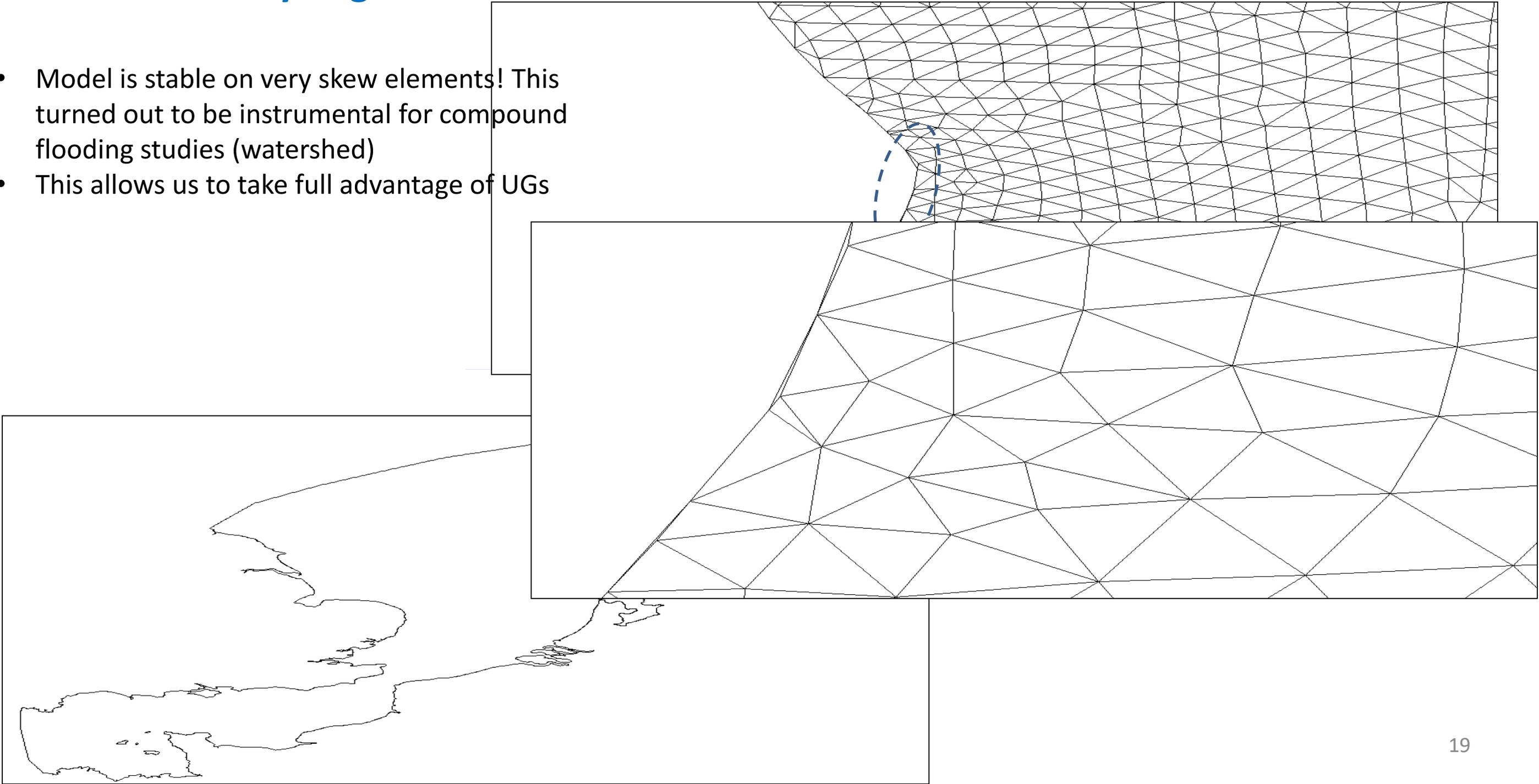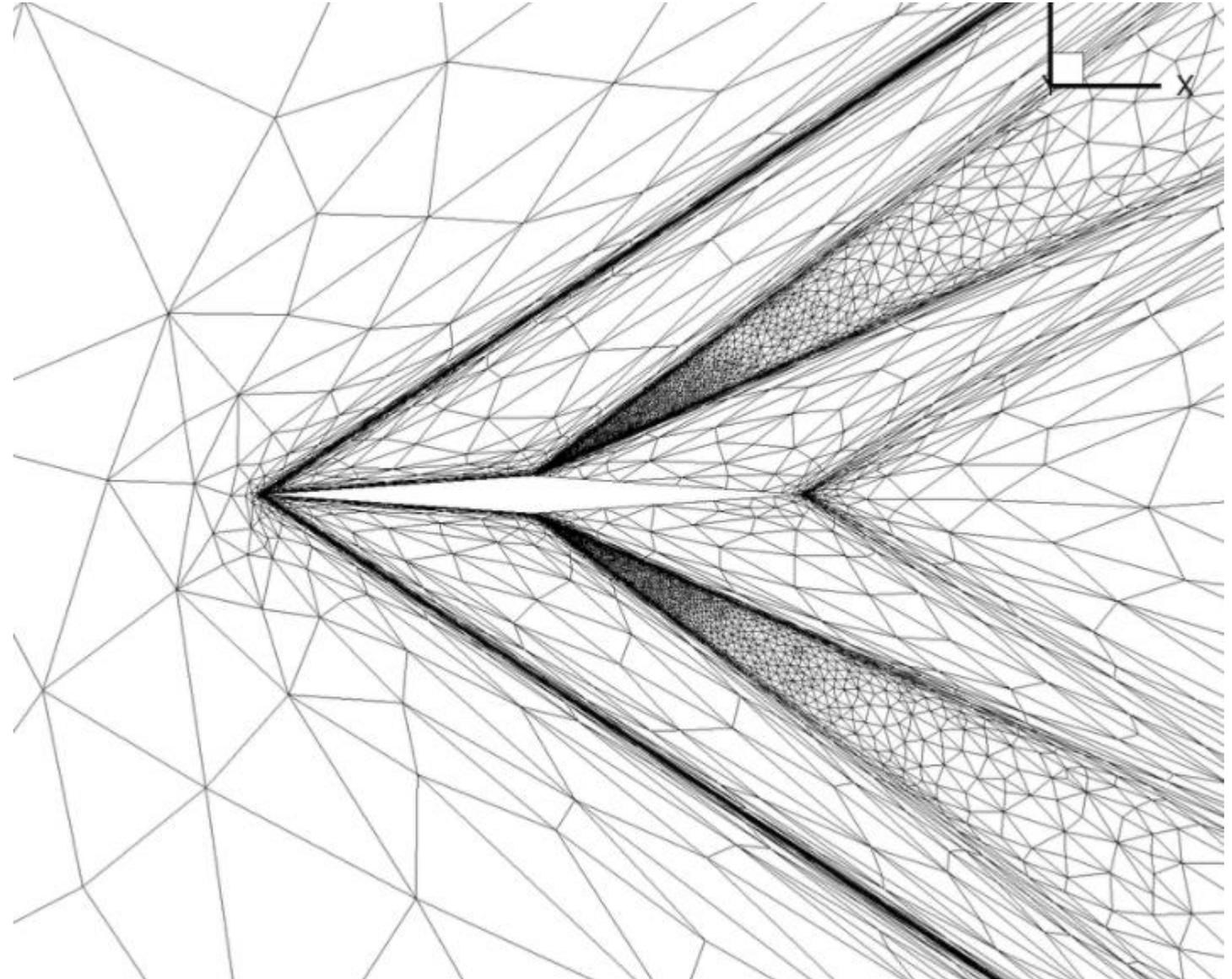

Nunez et al. (2020)
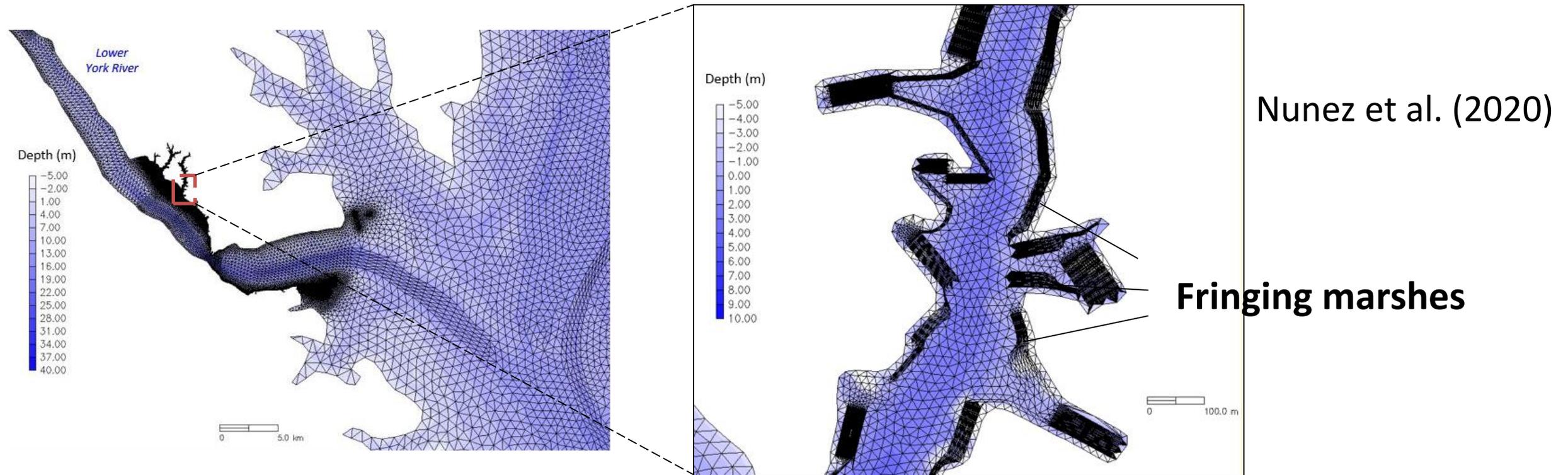
Fringing marshes

Smooth-transitioning grid would be 10x larger!

- In the non-eddying regime, skew elements can save a lot of computational cost!
- Fringing marshes need fine resolution (**1m** cross, **15m** along)
- The implicit FE formulation in SCHISM makes it very tolerant of 'bad' meshes
- Fully coupled SCHISM-SED-WWM-Marsh model runs stably on this type of meshes
- Marsh migration in 30 years, with 4mm/yr sea-level rise
- Flow/wave impedance by marsh vegetation is incorporated in the implicit solver

Applications
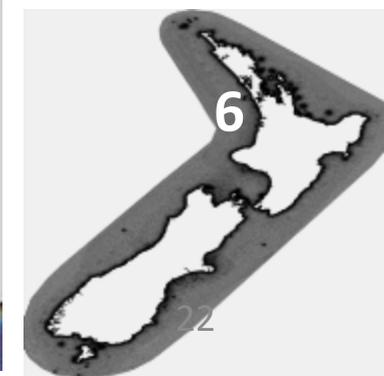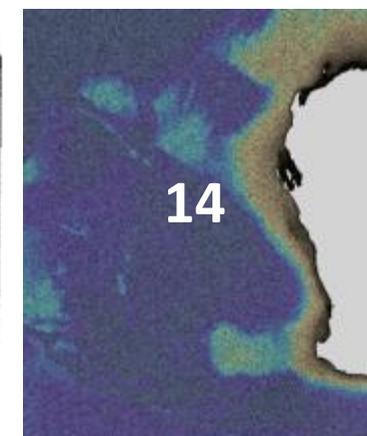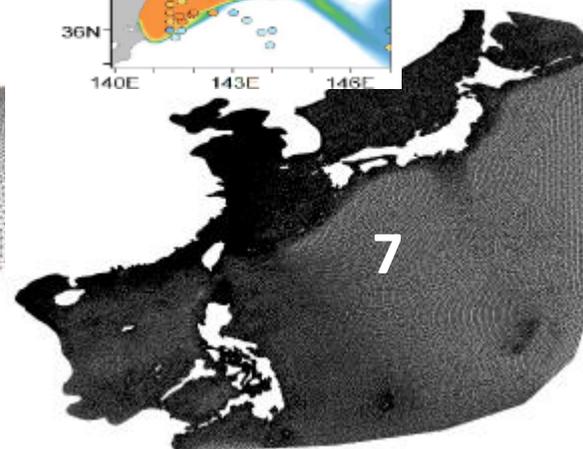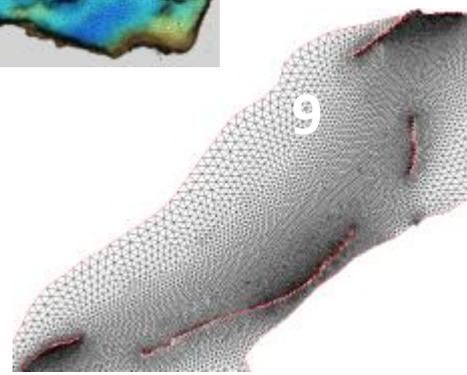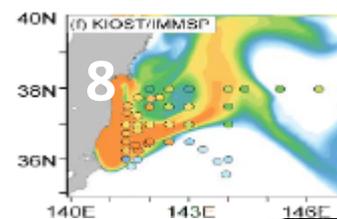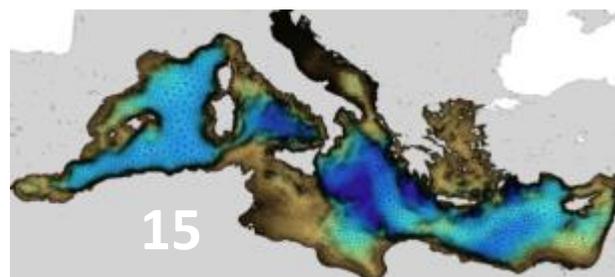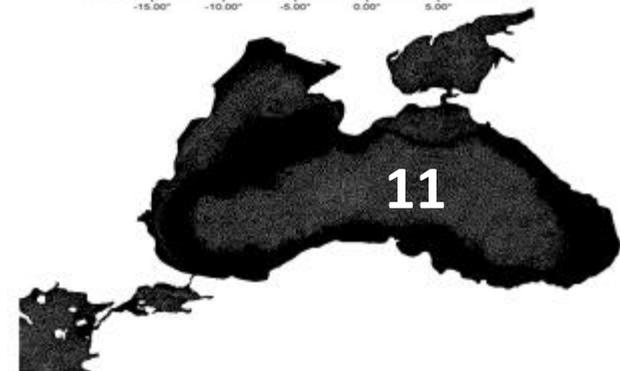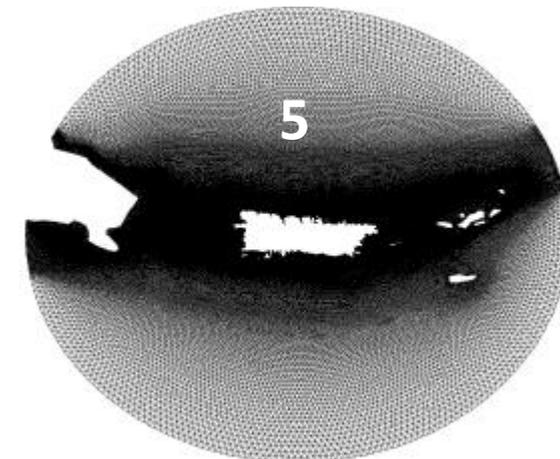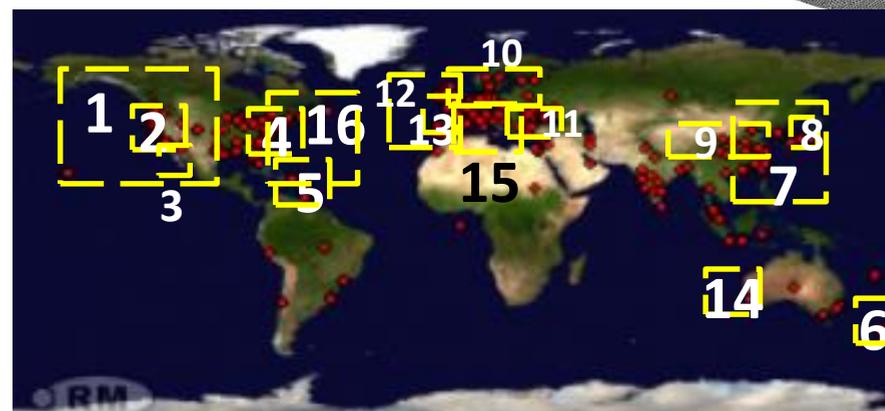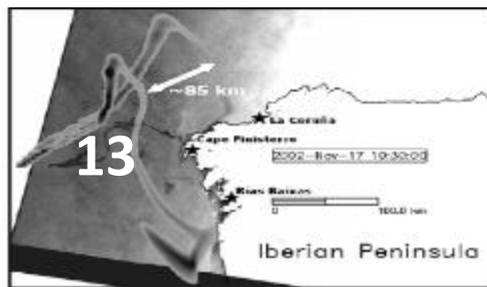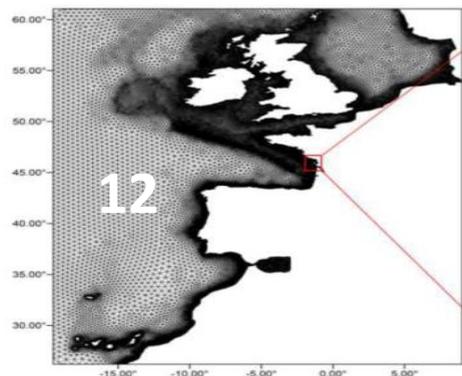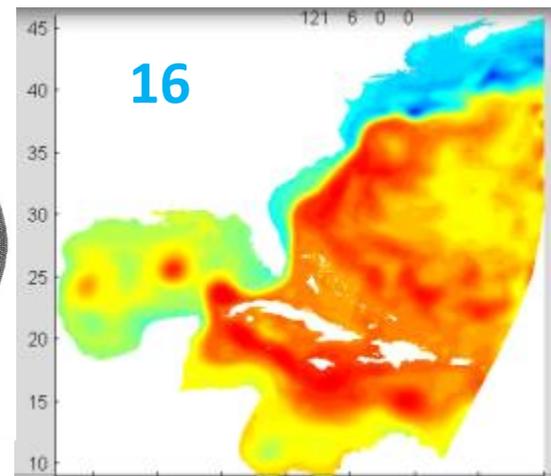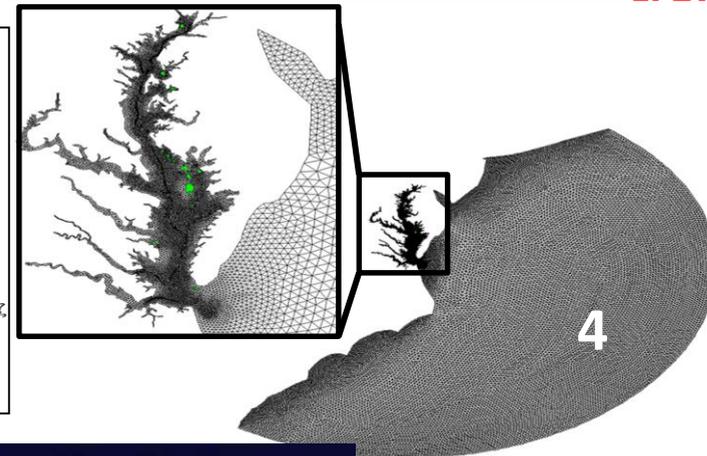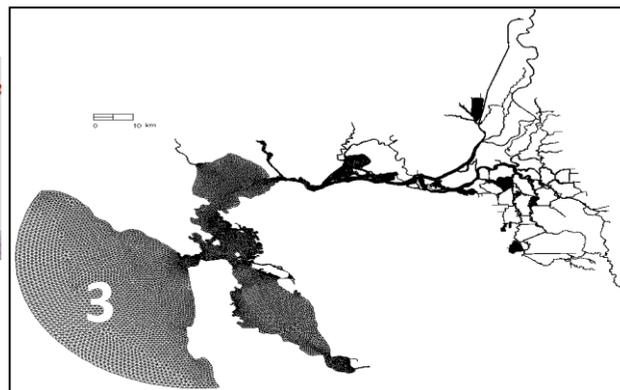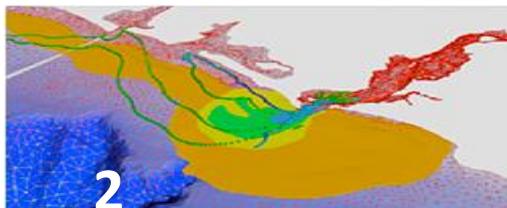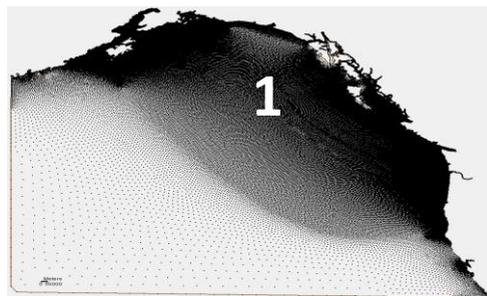
Extend the model to large scale: from estuary to shelf and beyond

- Main motivation is the errors & uncertainties at the ocean boundary often strongly influence the solution interior
- Numerical challenges for cross-scale processes
  - Efficiency: mainly related to higher-order transport solver
  - Performance in eddying regime (baroclinic instability): PGE, spurious numerical modes/mixing….
    - UG models can make some old issues more acute with sharp transition
      - Grid transition in SG models is always smooth
      - Coarser resolution masks issues with steep bathymetry
- Strategy (for eddying and non-eddying regimes)
  - Reduce inherent numerical dissipation by combining the FE (dispersive) and implicit scheme (diffusive)
  - Make the higher-order transport solver implicit (in the vertical), without introducing excessive numerical diffusion
  - Make the grid system flexible (good for shallow depths also!)
  - Rework momentum advection and viscosity schemes to control dissipation

Polymorphism
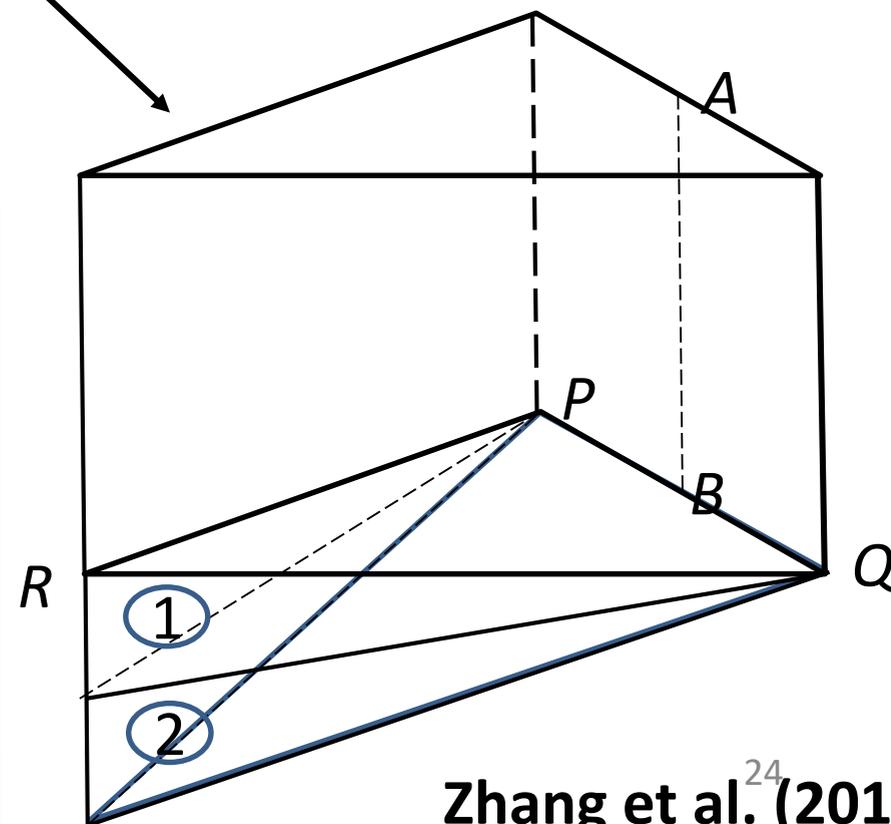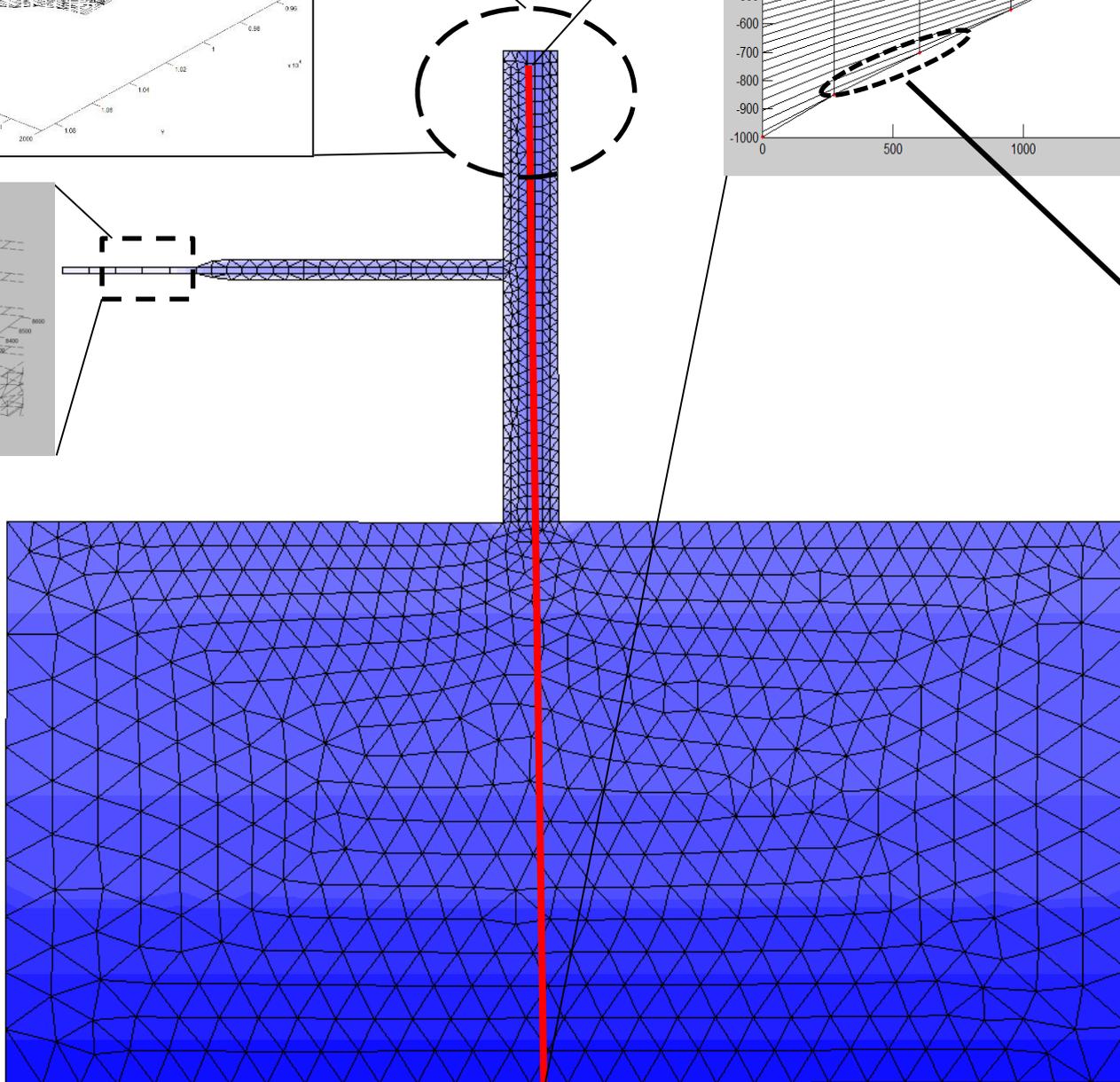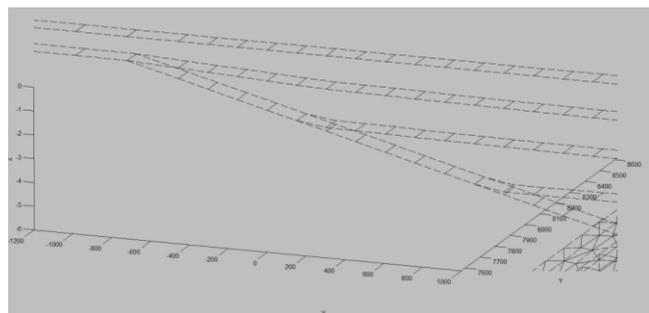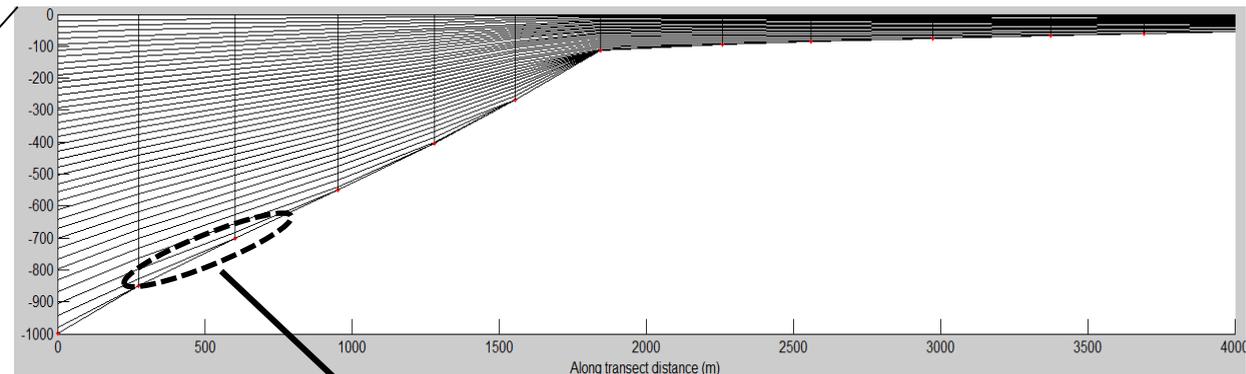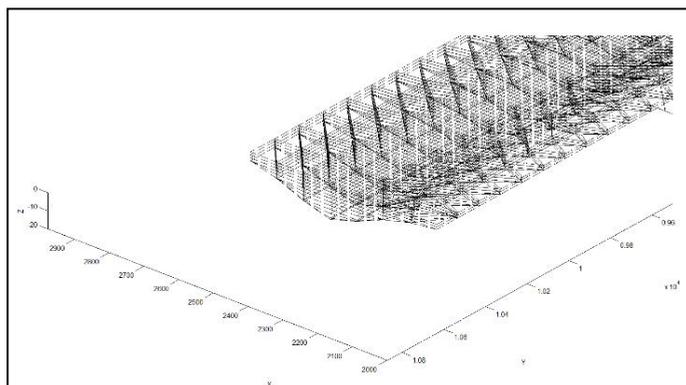
† A single grid seamlessly morphs between 1D/2DV/2DH/3D cells
† Efficiency and flexibility
† Shaved cells for bottom controlled processes
† As a result, the underlying bathymetry can be accurately represented, including steep slopes

One stone, many birds...

Zhang et al. (2015)

Polymorphism in action
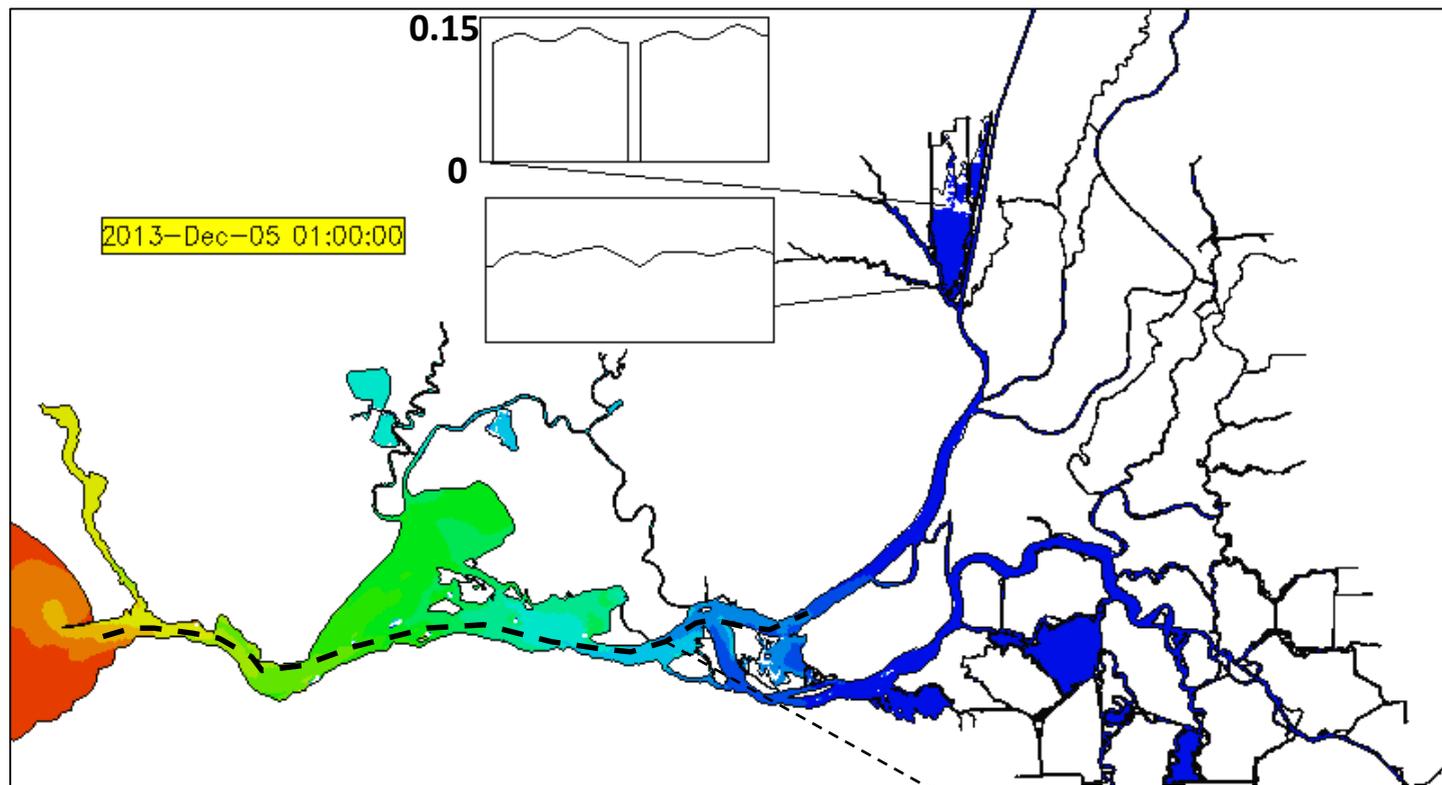
- The stratified Bay is represented by 3D grid
- The shallow Delta region is mostly represented as 2D
- There are only ~**10** layers on average
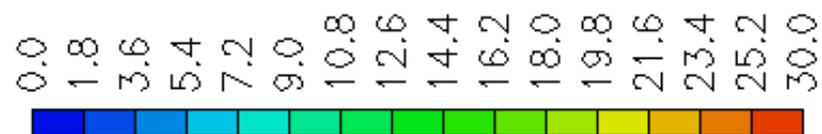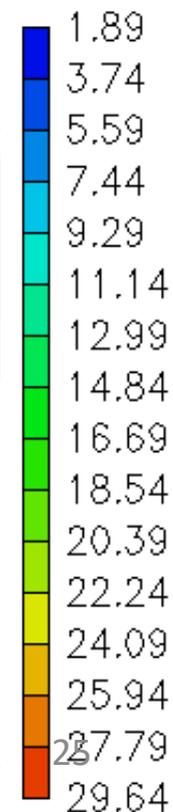
Ateljevich et al. (2014)

Multi-scale application: cascading basins in Azov-Black-Marmama-Aegean Sea
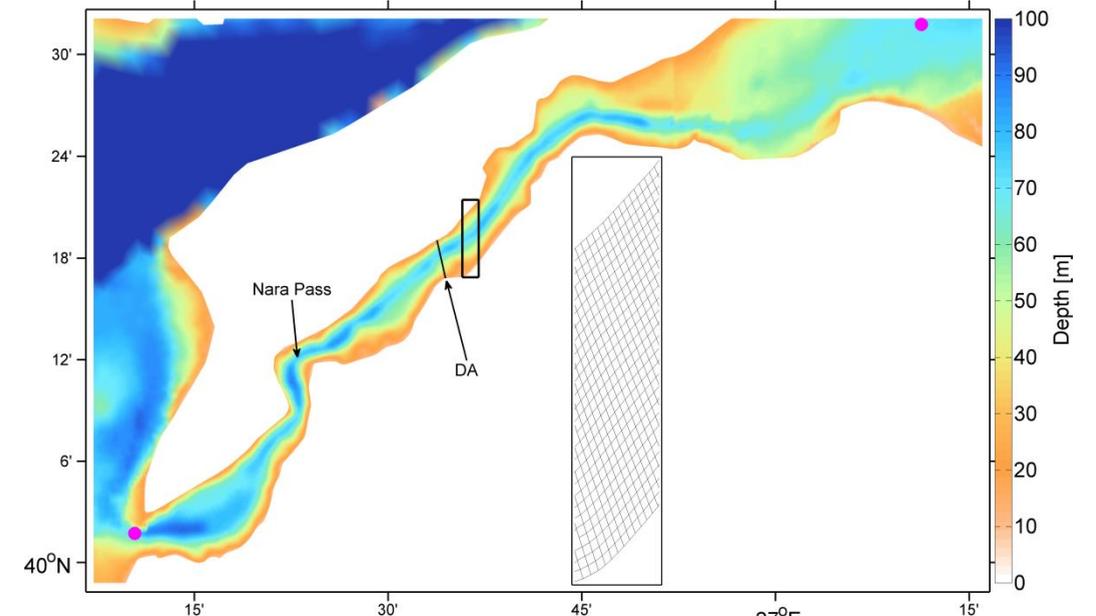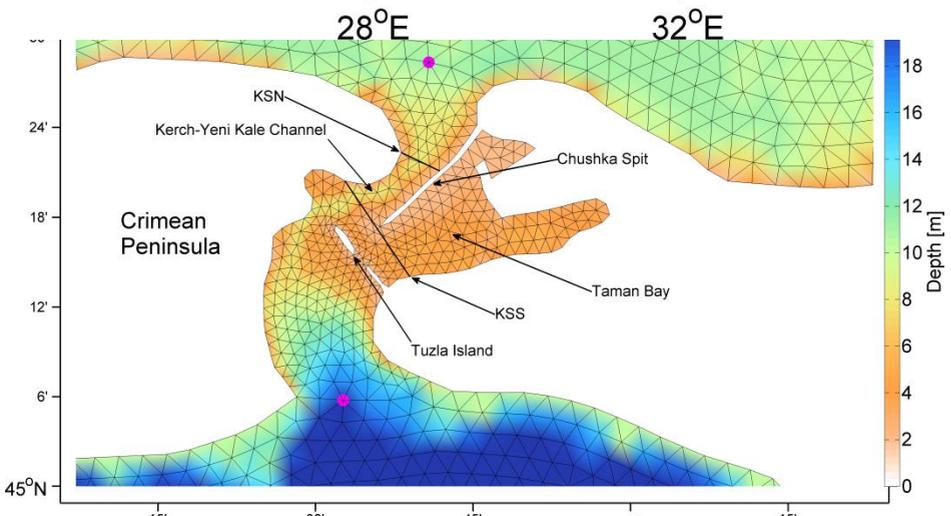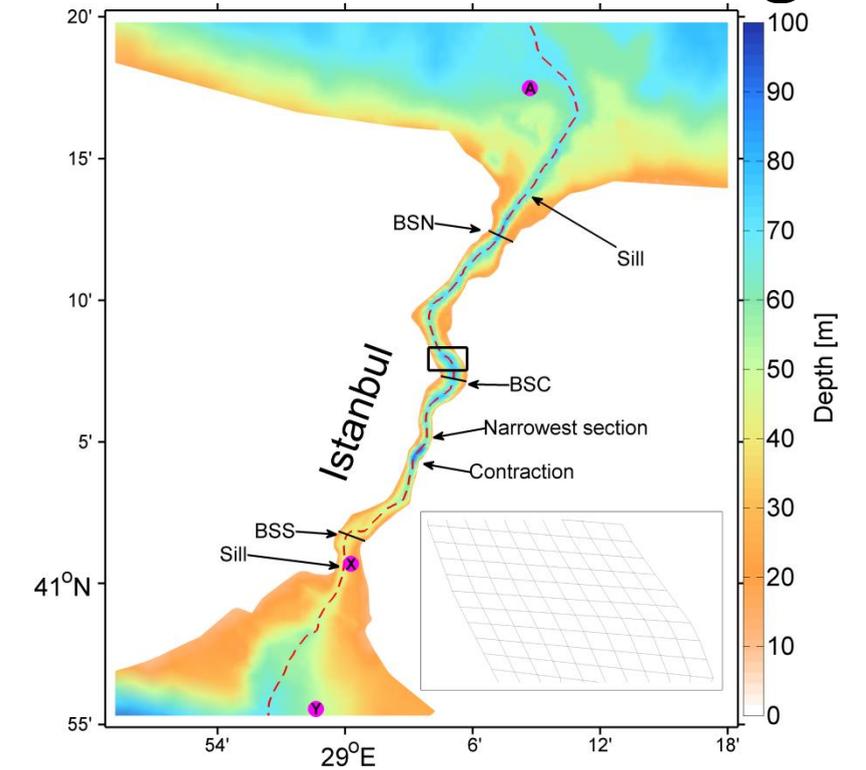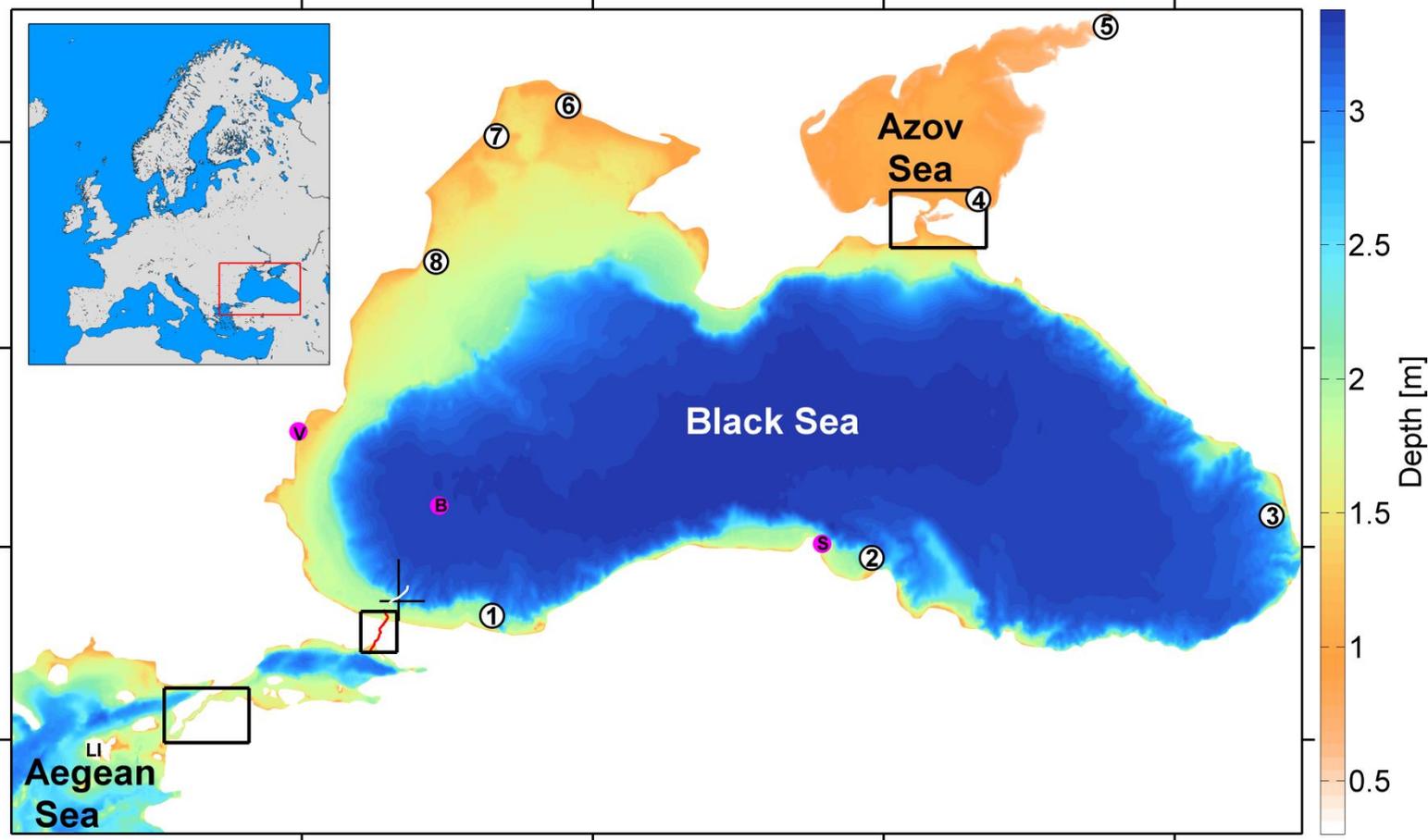
Stanev et al. (2017)

An extreme case…

Marmara Sea ←   Bosphorus Strait   Black Sea →

2008-Oct-05 06:00:00

Bosphorus Strait

(a)

(b) 2008-10-21 00:00:00 ; S

S (PSU)
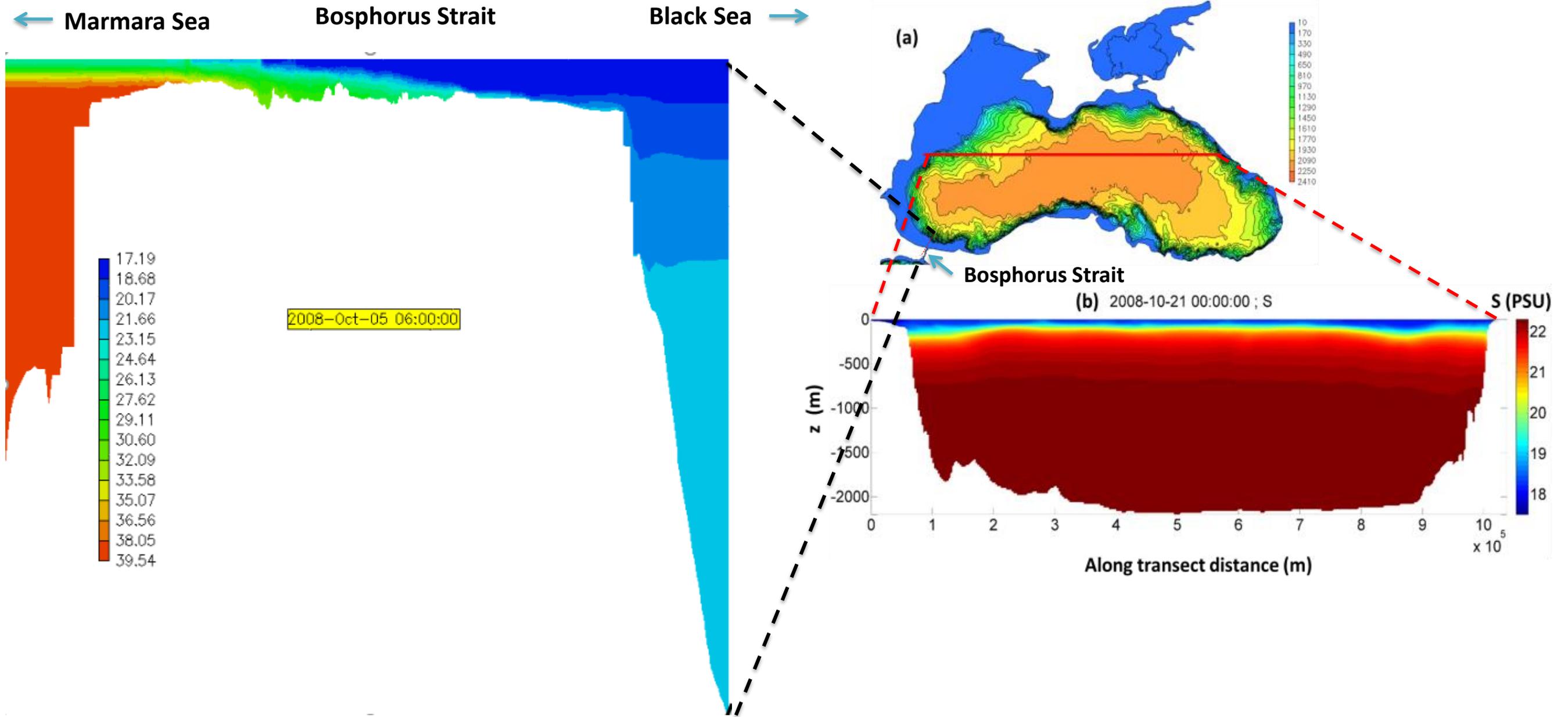
Either Z or terrain-following grid will have issues here…

Importance of higher-order scheme in eddying regime: Gulf Stream meandering

2nd order TVD
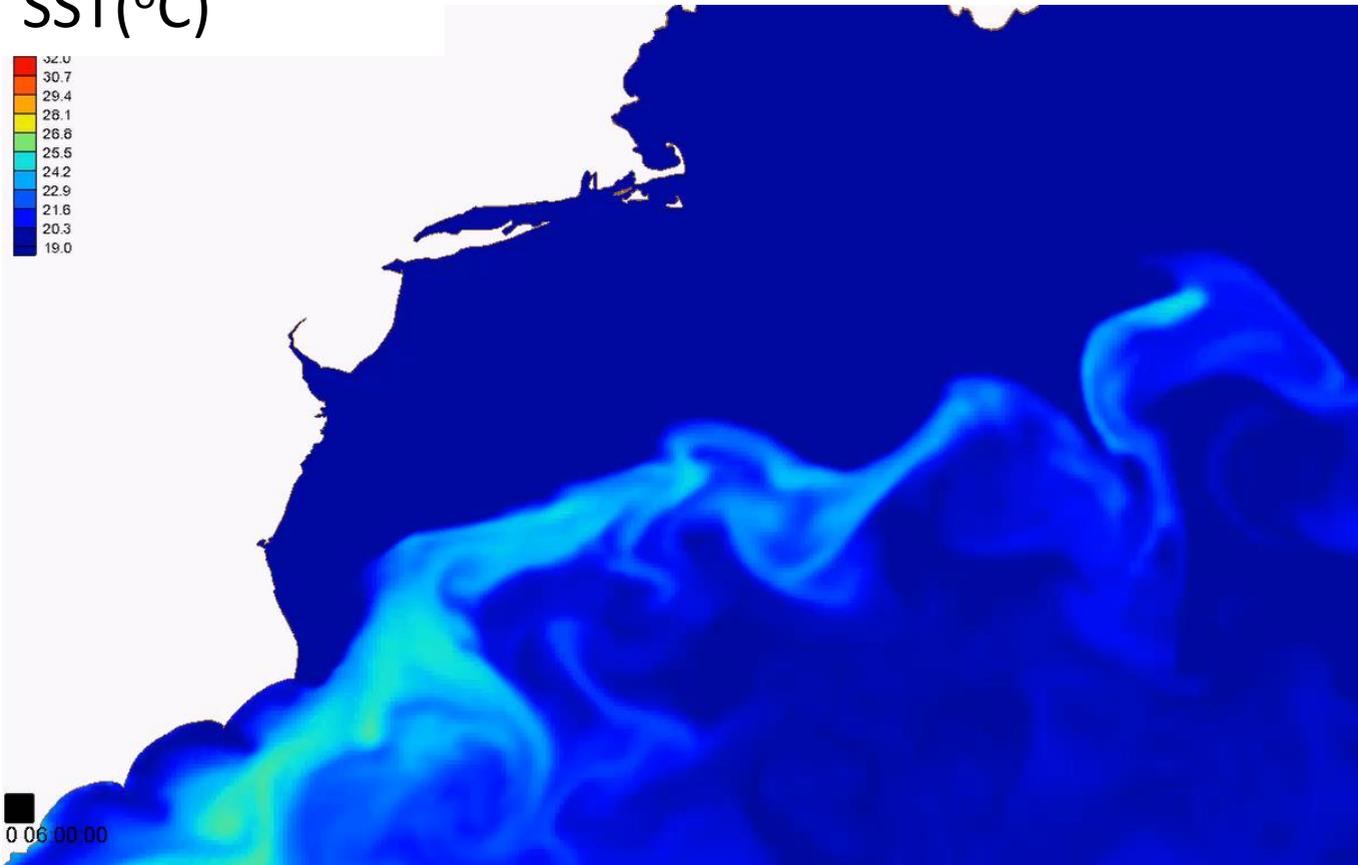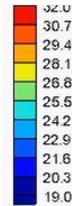
3rd order WENO
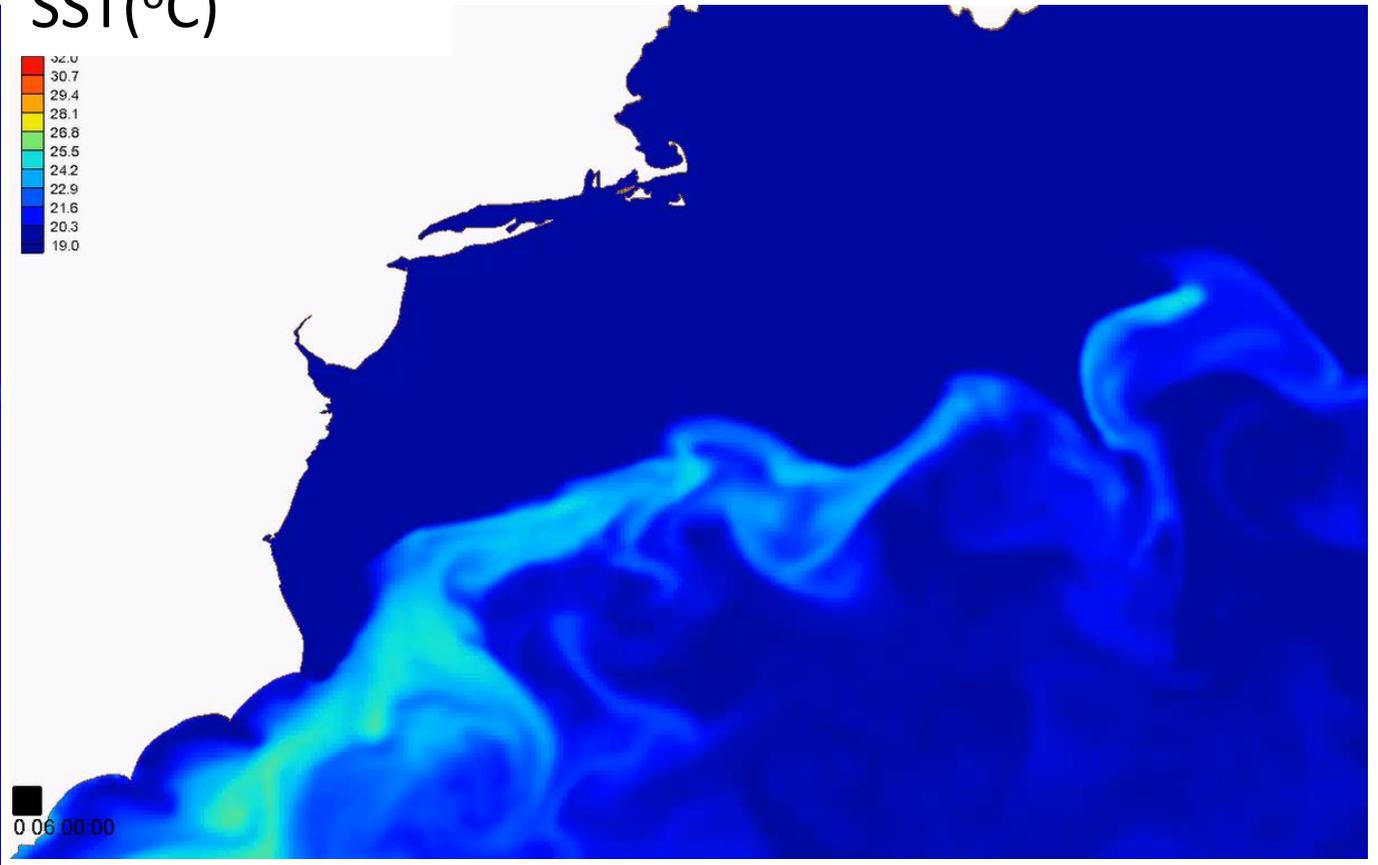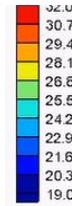
- Grid resolution: 2~7 km; 388K nodes and 766K elements; 27 LSC^2 vertical levels on average
- Time step=150 seconds
- No bathymetry smoothing

(Ye et al. in prep)

SCHISM web

Home | Manual & Download | Publications | Case study | Join SCHISM mailing list | News | Forum | Team SCHISM

SCHISM modeling system is a derivative work from the original SELFE model (v3.1dc as of Dec. 13 , 2014). SCHISM has been implemented by Dr. Joseph Zhang (College of William & Mary) and other developers around the world, and licensed under Apache. SELFE was developed at the Oregon Health Sciences University. However, there are now significant differences between the two models.

SCHISM (Semi-implicit Cross-scale Hydroscience Integrated System Model) is an open-source community-supported modeling system based on unstructured grids, designed for **seamless** simulation of 3D baroclinic circulation across creek-lake-river-estuary-shelf-ocean scales. It uses a highly efficient and accurate semi-implicit finite-element/finite-volume method with Eulerian-Lagrangian algorithm to solve the Navier-Stokes equations (in either hydrostatic and non-hydrostatic form), in order to addresses a wide range of physical and biological processes. The numerical algorithm judiciously mixes higher-order with lower-order methods, to obtain stable and accurate results in an efficient way. Mass conservation is enforced with the finite-volume transport algorithm. It also naturally incorporates wetting and drying of tidal flats.

The SCHISM system has been extensively tested against standard ocean/coastal benchmarks and applied to a number of regional seas/bays/estuaries around the world (see 'Case study') in the context of general circulation, tsunami and storm-surge inundation, water quality, oil spill, sediment transport, coastal ecology, and wave-current interaction. SCHISM now includes many upgrades of the original SELFE code (v3.1dc); the major differences are summarized in Zhang et al. (Seamless cross-scale modeling with SCHISM, Ocean Modelling, 2016; see Publications).

The source code and user manual can be downloaded from this web site. The plot to the right shows a snapshot of various modules inside SCHISM.

Major Characteristics of SCHISM

- Finite element/volume formulation
- Unstructured mixed triangular/quadrangular grid in the horizontal dimension
- Hybrid SZ coordinates or new LSC^2 in the vertical dimension
- Polymorphism: a single grid can mimic 1D/2DV/2DH/3D configurations
- Semi-implicit time stepping (no mode splitting): no CFL stability constraints → numerical efficiency
- Robust matrix solver
- Higher-order Eulerian-Lagrangian treatment of momentum advection (with ELAD filter)
- Natural treatment of wetting and drying suitable for inundation studies
- Mass conservative, monotone, higher-order transport solver: TVD^2; WENO
- **No bathymetry smoothing necessary**
- **Very tolerant of bad-quality meshes in the non-eddying regime**

Modeling system & application areas

- 3D baroclinic cross-scale lake-river-estuary-plume-shelf-ocean circulations
- Tsunami hazards
- Storm surge
- Sediment transport
- Biogeochemistry/ecology/water quality
- Oil spill
- Short wave-current interaction

Citation

SCHISM Modeling System

Related web sites

Bay-Delta SCHISM
3D Hydrodynamics and Transport

Delta Modeling Section | Project home | Search | next | index
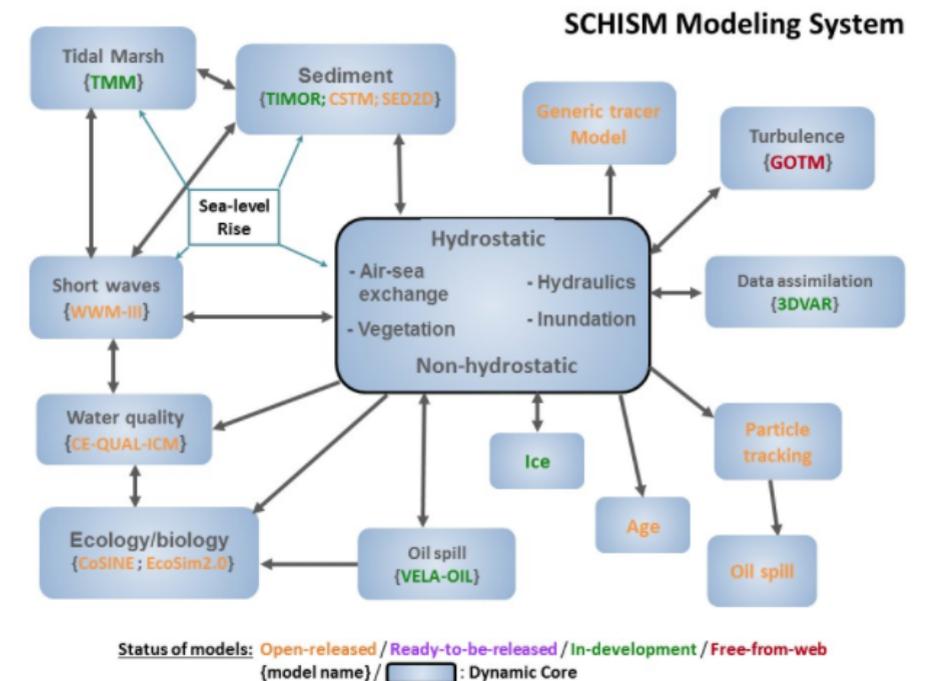
Bay-Delta SCHISM Project

Bay-Delta SCHISM is an application of the 3D open source SCHISM hydrodynamic and water quality suite to the San Francisco Bay Delta estuary. The project is a collaboration between the California Department of Water Resources and the Virginia Institute of Marine Sciences (VIMS).

Contents

- Getting Started
- Calibration and Versioning
- Training
- Support

Independent manual web pages are available for VTools and DWR's Python-based SCHISM Toolset.

Project description

The goal of our project is to develop an open-source, cross-scale multidimensional model suitable to answer flow and water quality questions involving large extents of the Bay-Delta system over periods of several years. Target applications include:

- Habitat creation and conveyance options under BDCP;
- Salinity intrusion changes under drought or sea level rise;
- Velocity changes following the installation of drought barriers;
- Fate of mercury produced in the Liberty Island complex;
- Temperature, flow and food production in the estuary as part of a 3-model full life cycle bioenergetic model of salmon (as participants in the SESAME project).

These applications vary a great deal in scope. Some can be studied with our base model with a few quick adjustments, but the last two require focal regions of intense study, multi-disciplinary biogeochemistry, or more careful validation of a particular transport mechanism. In our collaboration with NOAA and NASA in the SESAME project, the flexibility and openness of SELFE (forebearer of SCHISM) allowed swift incorporation of CoSINE, an alternate nutrient model to the standard EcoSIM 2.0 emphasizing the most important constituents for salmon in the system.

Our immediate goal has been to establish a foundation – to develop a sense of global accuracy, requiring that we resolve (or craftily under-resolve) the main mechanisms of hydrodynamics and in Delta channels. These include gravitational circulation and exchange flow; periodic stratification; axial convergence; tidal trapping; flood-ebb asymmetry of flow paths, shear dispersio

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Bay-Delta SCHISM Project
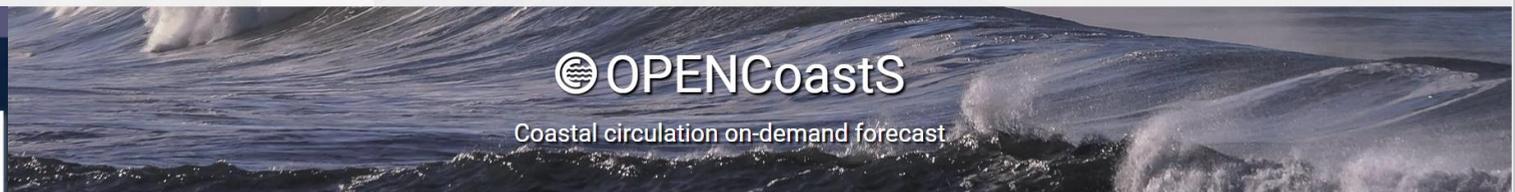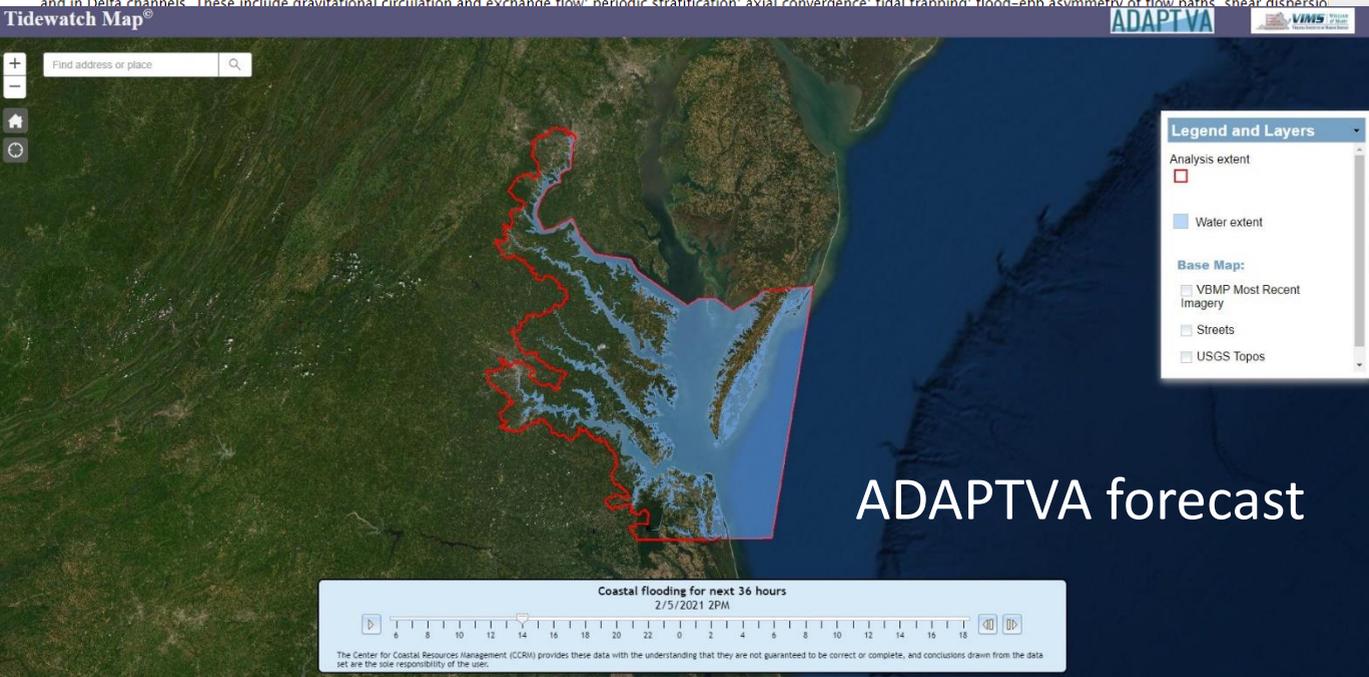- Contents
- Project description
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Getting Started

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Tidewatch Map®

ADAPTVA forecast

Legend and Layers

Analysis extent

Water extent

Base Map:
- VBMP Most Recent Imagery
- Streets
- USGS Topos

Coastal flooding for next 36 hours
2/5/2021 2PM

The Center for Coastal Resources Management (CCRM) provides these data with the understanding that they are not guaranteed to be correct or complete, and conclusions drawn from the data set are the sole responsibility of the user.

OPENCoastS   FEATURES   TARGET   MORE INFO   Manual   FAQ   REGISTER   LOGIN   PT EN

OPENCoastS
Coastal circulation on-demand forecast

Forecast systems are fundamental assets for emergency response and everyday management of coastal regions

The OPENCoastS service assembles on-demand circulation forecast systems for selected coastal areas and keeps them running operationally for a period defined by the user. This service generates daily forecasts of water levels, vertically averaged velocities and wave parameters over the region of interest for 48 hours, based on numerical simulations of all relevant physical processes.
Presently, all forecasts are made with the SCHISM model. Tide gauge data are provided by EMODnet Physics.
The following forcing sources are used:

- Atmospheric forcings:
  - GFS (NOAA)
  - ARPEGE (MétéoFrance)
- Atmospheric forcings:
  - PRISM2017 (LNEC)
  - FES2014 (LEGOS)
  - CMEMS (Copernicus)
- Wave forcings:
  - North Atlantic WW3

Access to the service is free, and a new user only needs to register following the link above. Access to the 3D simulations is granted on request to aoliveira@lnec.pt, due to the large computational resources required.

You can find a sample grid file to test the service here, and the corresponding vertical grid here. The coordinate reference system of this grid is

How far can we push the cross-scale model?

- We have made good progress on seamless cross-scale modelling during the past 20 years
- Seamless cross-scale modeling can be effectively done with *unstructured grids* and *implicit time stepping*
  - Besides accuracy consideration, efficiency, flexibility and robustness are also important factors in this endeavor
  - Balance between lower- and higher-order schemes is a key
  - A seamless platform with 1D/2D/3D capability leads to efficiency
  - SCHISM is well demonstrated for cross-scale applications
- How far can we go?
  - Nearshore: upstream rivers/creeks/watershed
  - Offshore: basin scale
  - 6-7 orders of spatial contracts are now possible (in a single 3D grid)
  - Ultimate goal is to build a model that covers ocean-shelf-estuary-river-creek system without nesting (or at least minimize its use)