Regional Ocean Modeling System ROMS Research Community

Terrain-Following TOMS Ocean Modeling System

The Regional Ocean Modeling System: Strategies for Coastal Modeling

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Acknowledgements

- Andrew M. Moore, UCSC
- Alexander F. Shchepetkin, UCLA
- John C. Warner, USGS
- Kate Hedstrom, ARSC
- David Robertson, Rutgers

RUTGERS MARINE & COASTAL SCIENCES

NOPP National Oceanographic Partnership Program
Promoting Partnerships for the Future of Oceanography

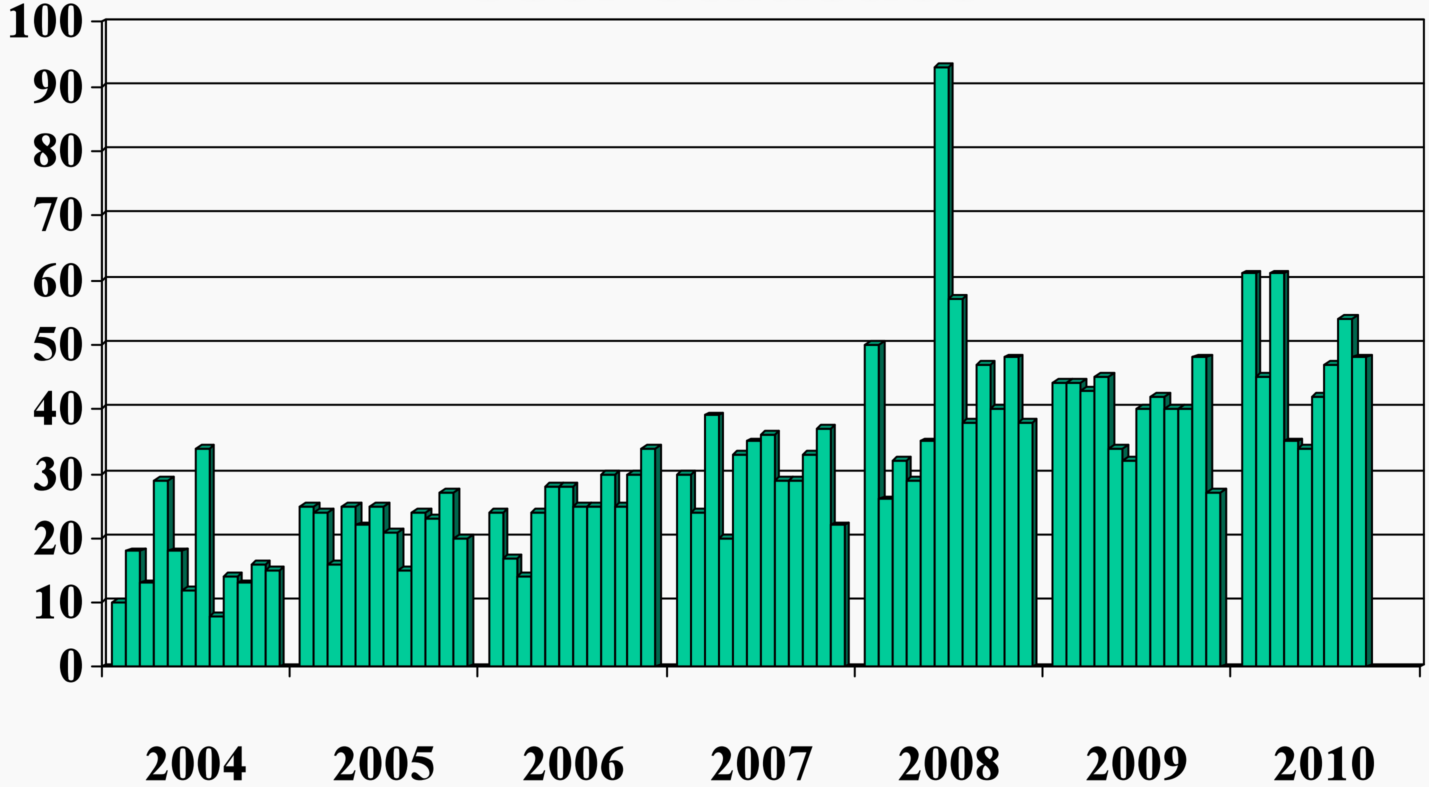
CSTMS Community Sediment Transport Modeling System

ONR Revolutionary Research . . . Relevant Results

NSF

USGS science for a changing world

User Statistics



2004 new users: 204
2005 new users: 267
2006 new users: 288
2007 new users: 367
2008 new users: 533
2009 new users: 475
2010 new users: 443

User Statistics

Oct. '10	Mar. '10	Country	Users
1	1	United States	624
2	2	China	307
3	3	India	106
4	4	Spain	92
5	5	South Korea	89
6	8	France	85
7	6	Australia	82
	6	Japan	82
	9	Brazil	82
10	10	Italy	67

Oct. '10	Mar. '10	Country	Users
11	11	United Kingdom	49
12	12	Norway	45
13	12	Canada	44
14	14	Mexico	42
15	14	Germany	40
16	16	Taiwan	38
17	16	Portugal	36
18	18	Chile	32
19	21	Indonesia	22
20	19	Russia	20

Published Statistics

Journal	#
Journal of Physical Oceanography	54
Ocean Modelling	37
Journal of Geophysical Research	32
Continental Shelf Research	19
Deep Sea Research Part II: Topical Studies in Oceanography	15
Dynamics of Atmospheres and Oceans	13
Journal of Marine Systems	9
Geophysical Research Letters	8
Journal of Atmospheric and Oceanic Technology	7
Journal of Climate	6
Estuarine, Coastal and Shelf Science	4
Computers & Geosciences	3
Ocean Dynamics	3
Global Biogeochemical Cycles	2
Monthly Weather Review	2
Progress in Oceanopgraphy	2

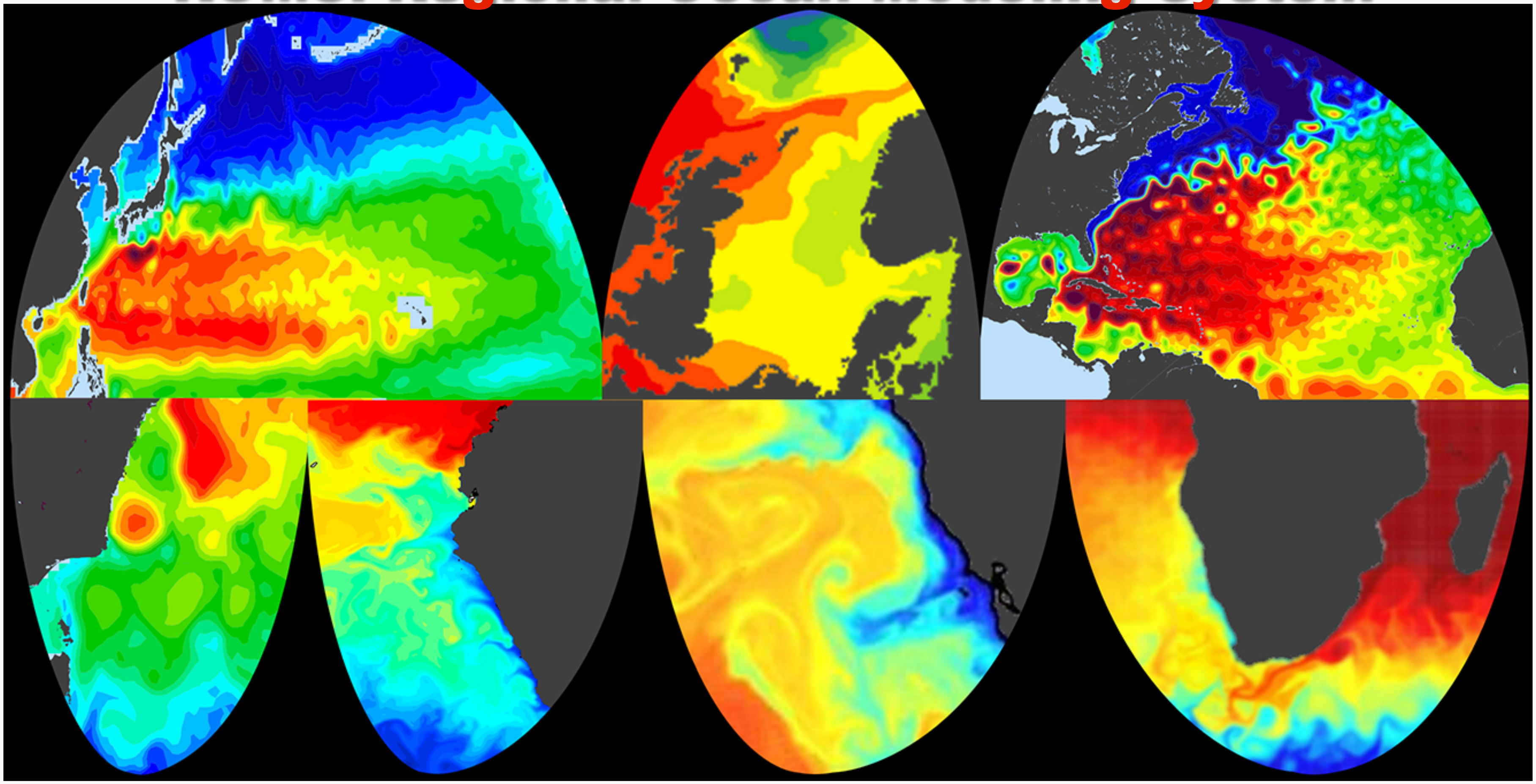
There are 22 other journals containing a single ROMS article for a total of 238 articles.

Long-Term Goals

- **To design, develop, and test an expert ocean modeling system for high-resolution scientific and operational applications over a wide range of spatial (estuaries to basin) and temporal (days to seasons, years to decades) scales.**

- **To provide the ocean modeling community with analysis and prediction tools that are available in meteorology and Numerical Weather Prediction (NWP)**

ROMS: Regional Ocean Modeling System

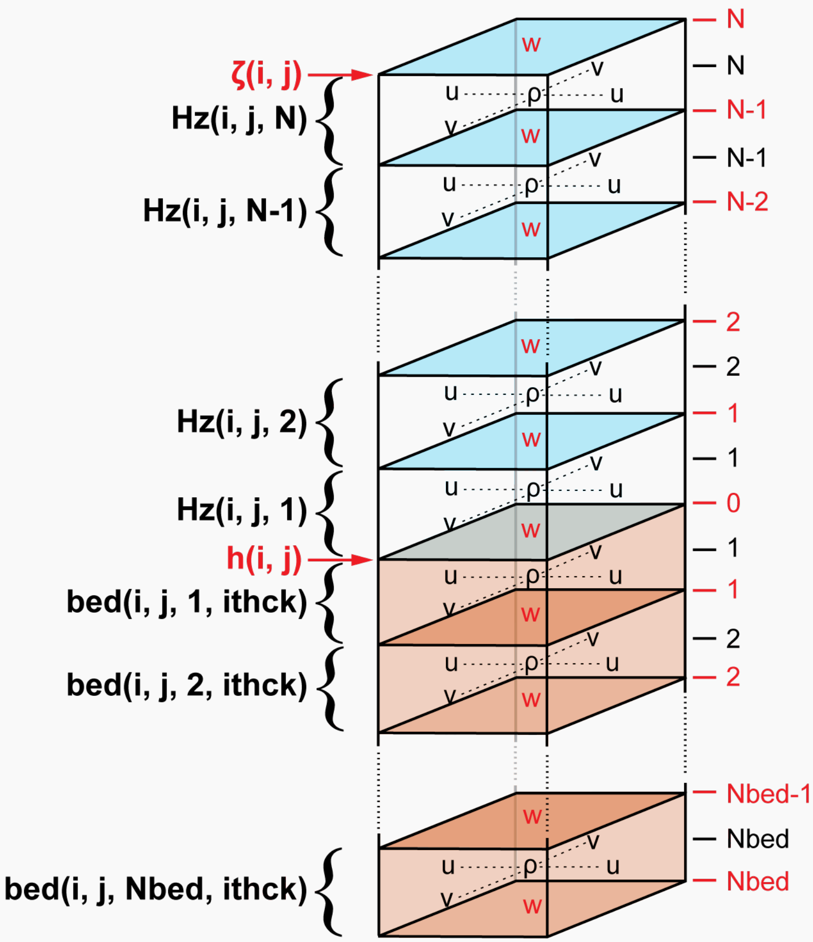


- Free-surface, Hydrostatic Primitive Equation Model
- Generalized Terrain-Following Vertical Coordinates
- Boundary-fitted Orthogonal Curvilinear Coordinates on an Arakawa C-grid: Cartesian, Spherical, and Polar
- Multiple Grid and Model Coupling (MCT, ESMF)
- High-order Numerical Schemes
- Shared- and Distributed-memory (OpenMP, MPI)
- F90/F95, C-preprocessing, NetCDF I/O
- Tangent Linear, Representer, and Adjoint Models
- Adjoint-based Algorithms for 4D-Var data assimilation, Ensemble Prediction, Adaptive Sampling, Sensitivity Analysis, and Generalized Stability Theory Analysis
- Tides, Ecosystem, Sediment, Sea Ice Models
- Various Vertical Mixing Schemes and Bottom Boundary Layer Parameterizations
- Web-Based Documentation and Distribution: www.myroms.org, www.myroms.org/wiki

Sediment-Transport Model

$$\frac{\partial}{\partial t}\left(\frac{H_z T}{mn}\right) + \frac{\partial}{\partial \xi}\left(\frac{H_z u T}{n}\right) + \frac{\partial}{\partial \eta}\left(\frac{H_z v T}{m}\right) + \frac{\partial}{\partial s}\left(\frac{H_z \Omega T}{mn}\right) = \frac{H_z D_T}{mn} + \frac{\partial}{\partial s}\left(\frac{K_T}{mnH_z}\frac{\partial T}{\partial s}\right) + \frac{H_z S_T}{mn}$$

Tendency | Horizontal & Vertical Advection | Horizontal & Vertical Diffusion | Source



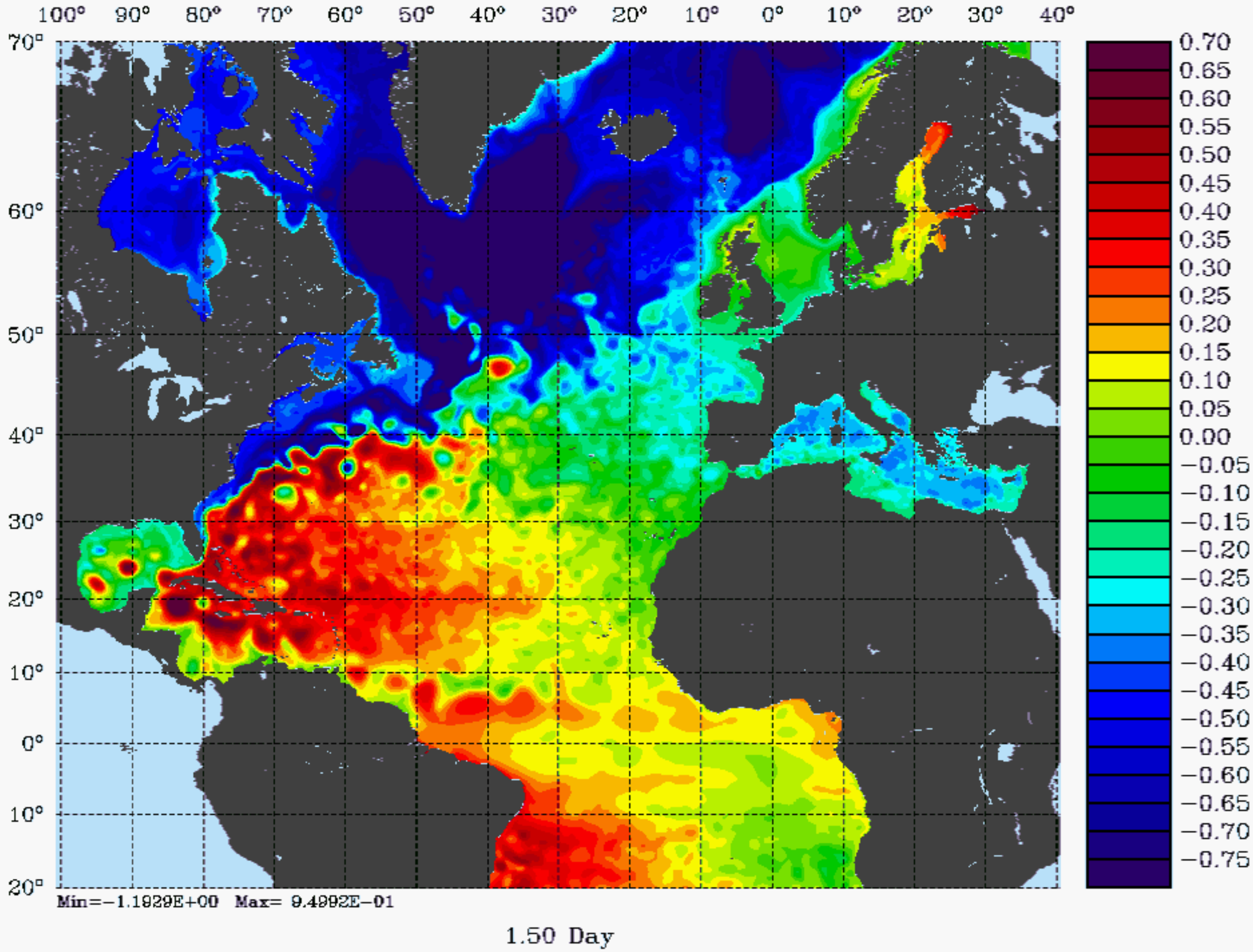
- **Unlimited number of user-defined of cohesive and non-cohesive sediment tracers: $T(\xi, \eta, s, t, itrc)$**
- **Each sediment tracer has fixed grain size, density, setting velocity, and critical shear stress for erosion**
- **Exchange between seabed and water column via erosion and deposition**
- **User-defined number (Nbed) of bed layers**
- **Each bed layer is described in terms of thickness, sediment-class distribution, porosity, and age**
- **Bed layers account for armoring**
- **Array structure design:**

  bed(i,j,k,1:MBEDP), bottom(i,j,1:MBOTP)

  bed_frac(i,j,k,itrc), bed_mass(i,j,k,t,itrc)

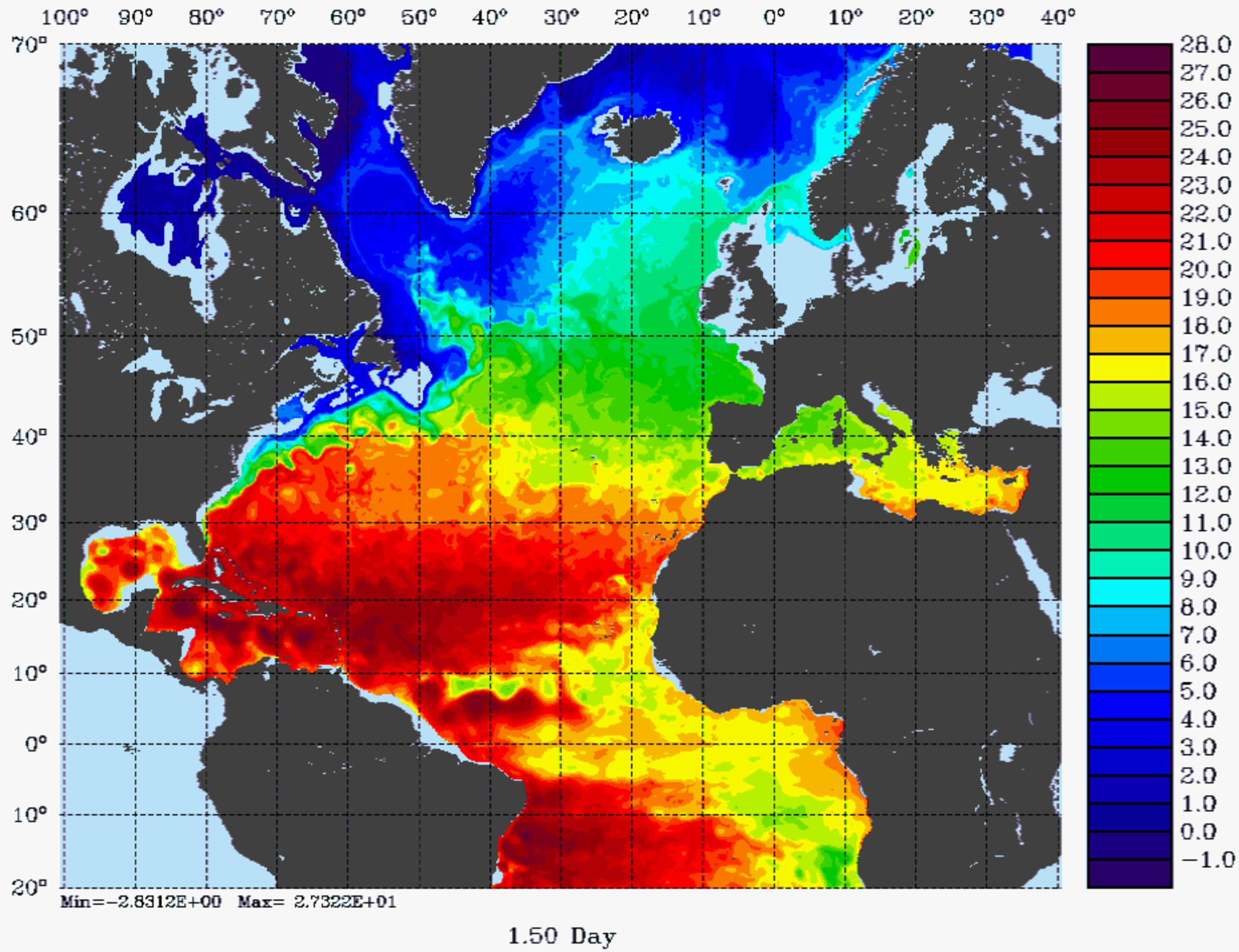
North Atlantic: 1/10 degree

Free-Surface (m)



North Atlantic: 1/10 degree

Temperature at 100 m



Mid-Atlantic Bight (MAB)

- **Basin-scale Hybrid Coordinate Ocean Model (HYCOM)**

  1/12 degree
  operational: June 2002- present
  assimilate satellite observed SSH and SST

- **MAB-GoM Shelf Model (ROMS)**

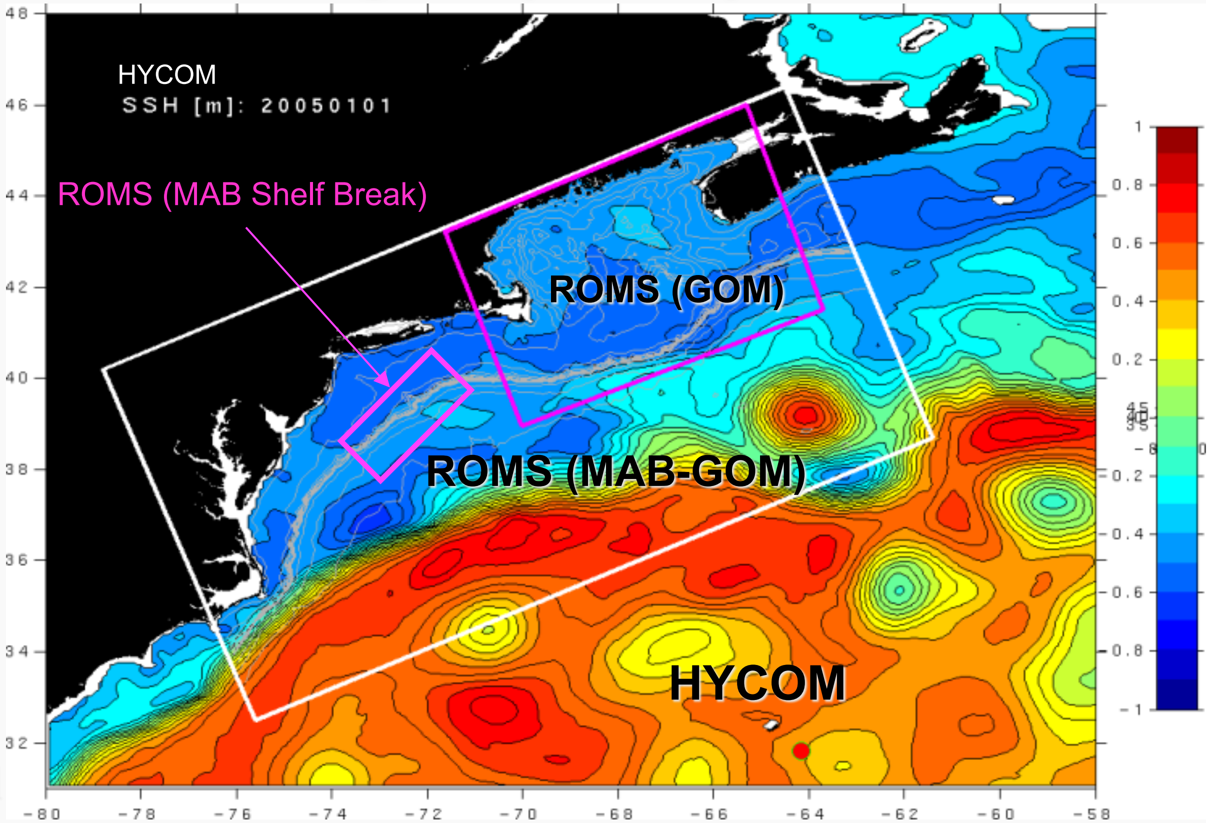
  3-10 km, 36 layers
  nested inside the HYCOM

- **High-Res Regional GoM Model (ROMS)**

  1- km, 36 layers
  nested inside the MAB-GOM ROMS

- **High-Res MAB Regional Shelf Break Model (ROMS)**

  1- km, layers
  Nested inside the MAB-GOM ROMS

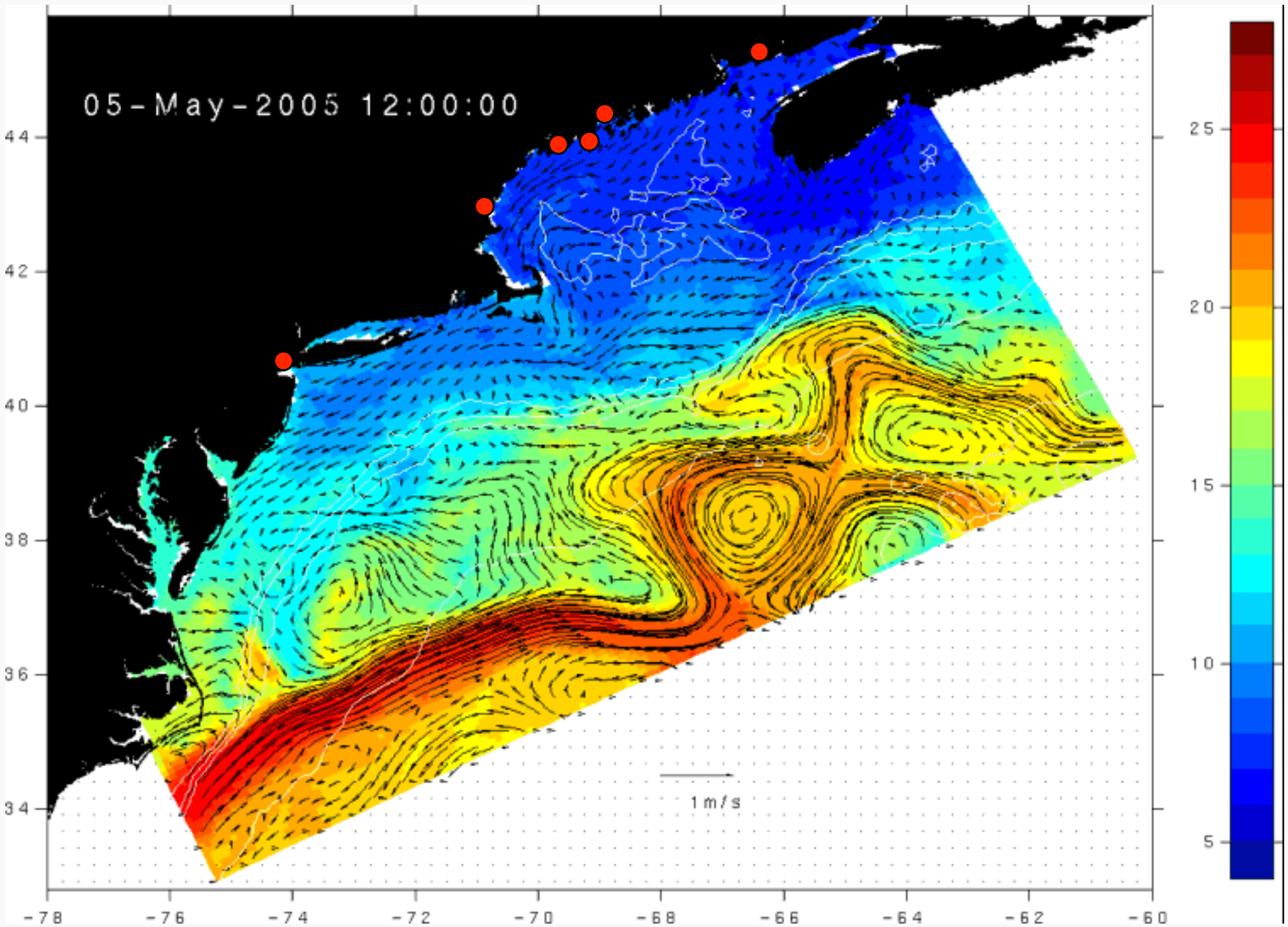


HYCOM T/S fields are used as the coastal models' initial conditions

1-way nesting technique is applied to bring in deep ocean momentum and buoyancy fields (zeta, ubar, vbar, u, v, temp, salt) to the nested coastal Models

From Ruoying He (NCSU)

Daily Modeled SST and Surface Currents
April 15-July 31



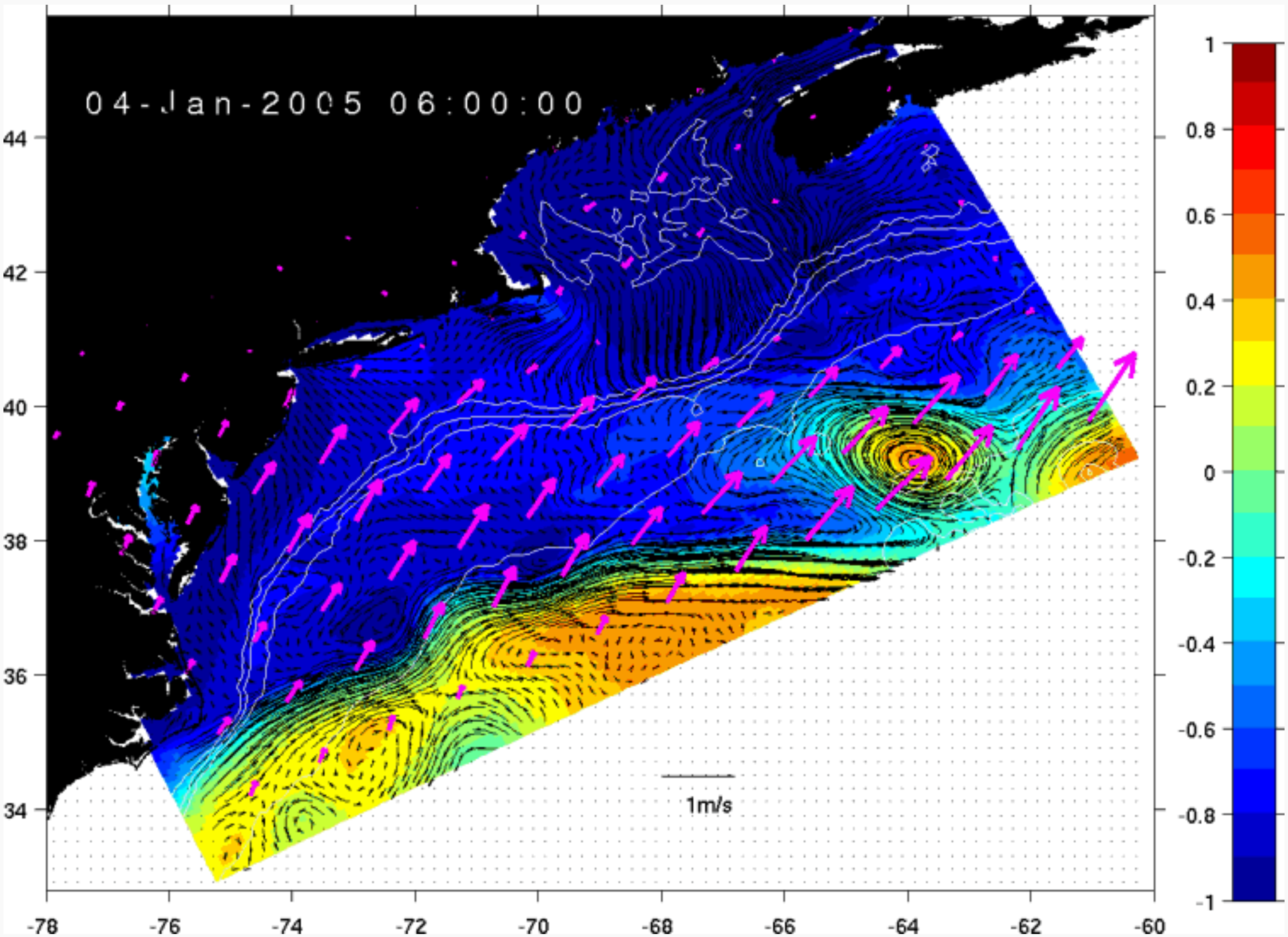
Surface forcing: 6-hr EDAS 10-m winds, surface heat flux calculated from bulk formula

Major Rivers: St. John, Penobscot, Kennebec, Androscoggin, Merrimack, Hudson.

From Ruoying He (NCSU)

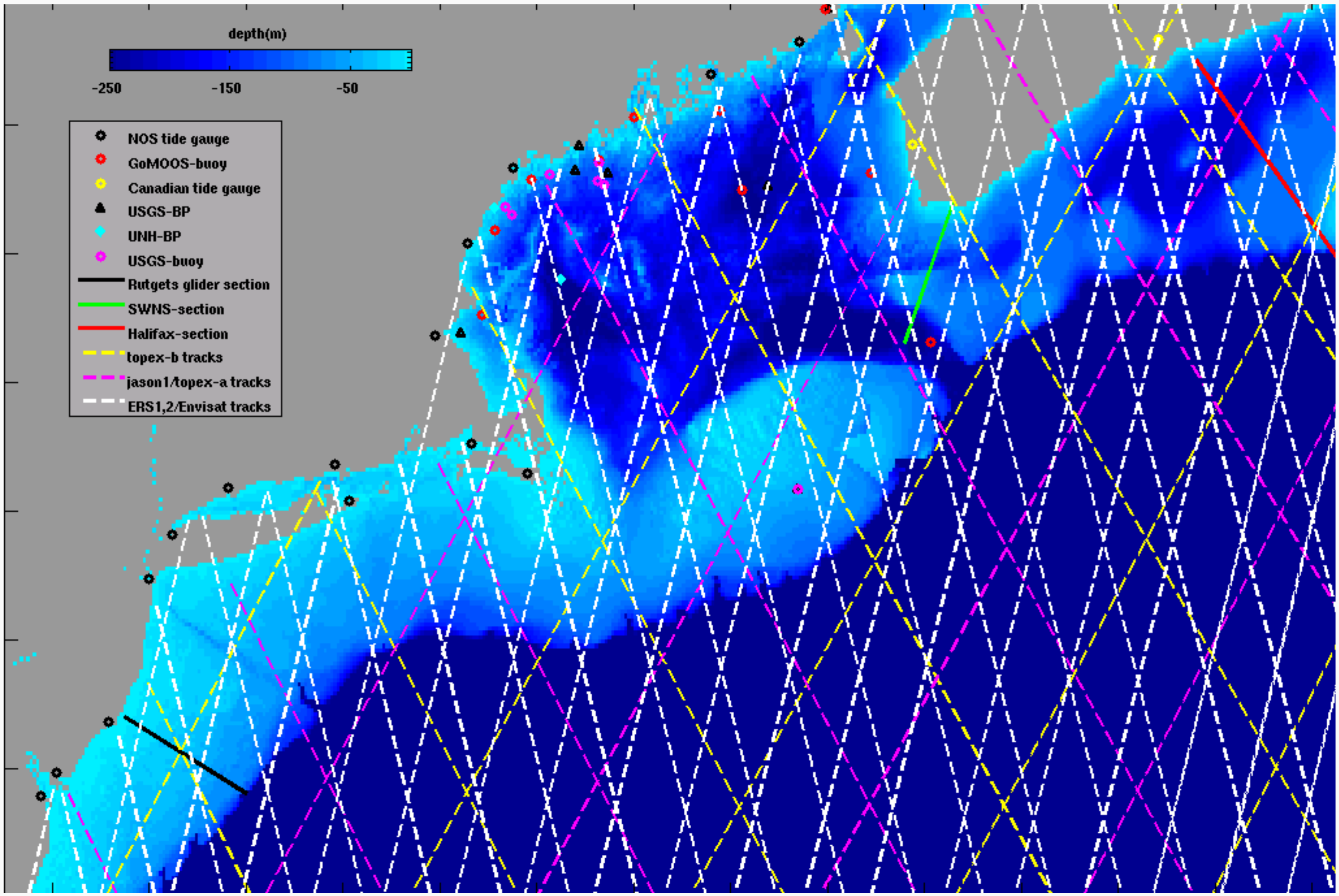
Modeled Sea Surface Height, Surface Current, and Winds

Tidal Forcing (K_1, O_1, Q_1, M_2, S_2, N_2, K_2)



From Ruoying He (NCSU)

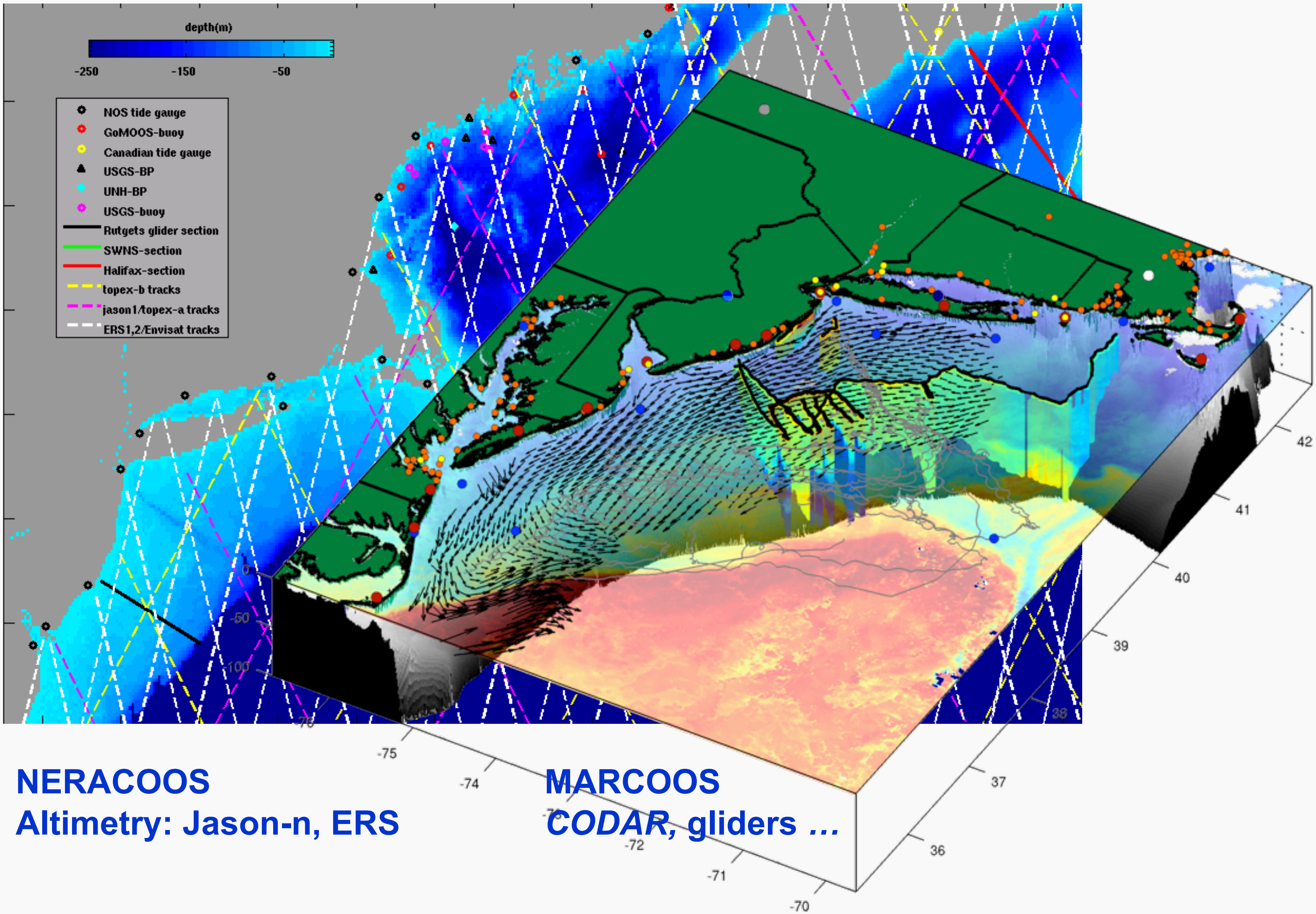
Mid-Atlantic Bight (MAB)



NERACOOS

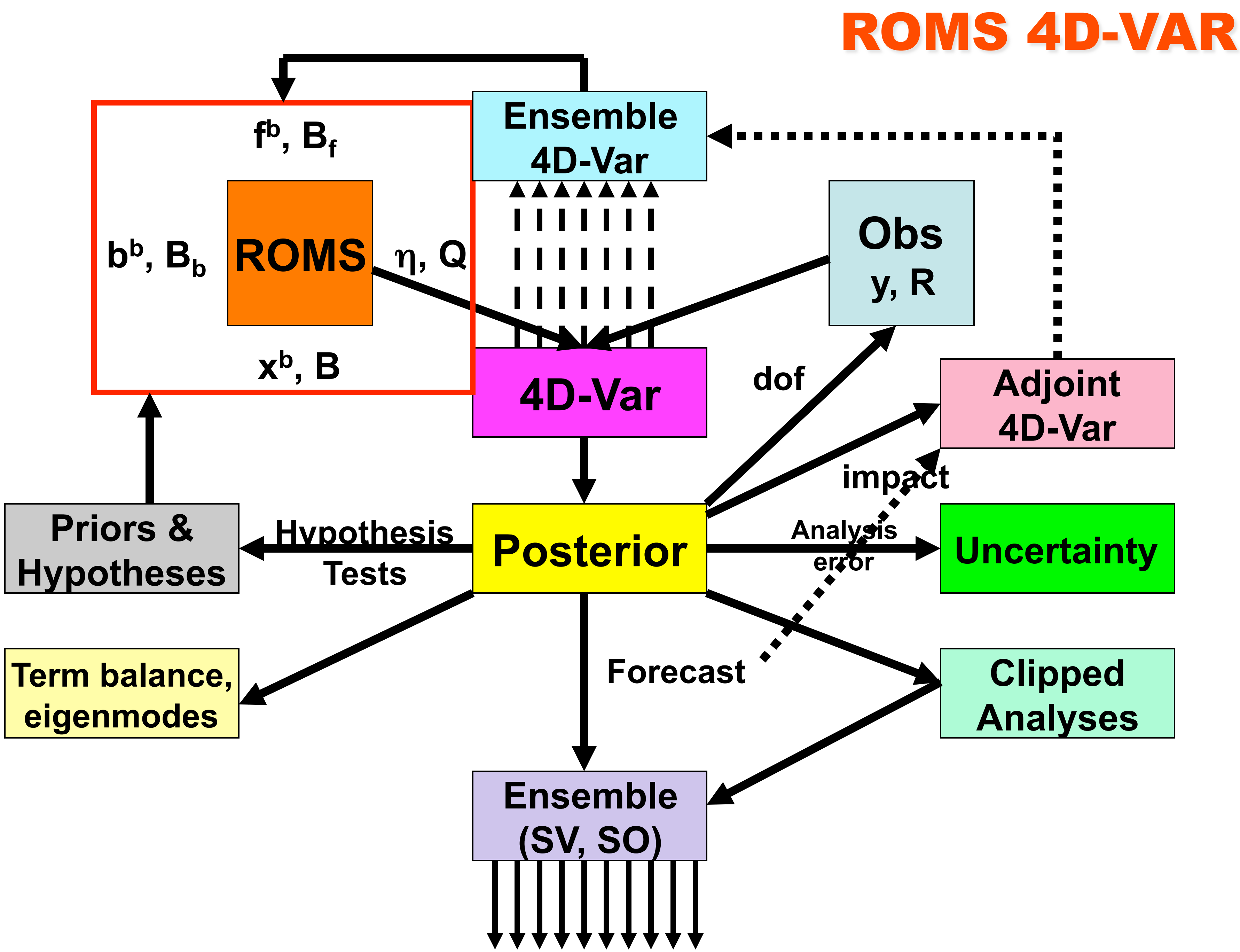
Altimetry: Jason-n, ERS

Mid-Atlantic Bight (MAB)



NERACOOS
Altimetry: Jason-n, ERS

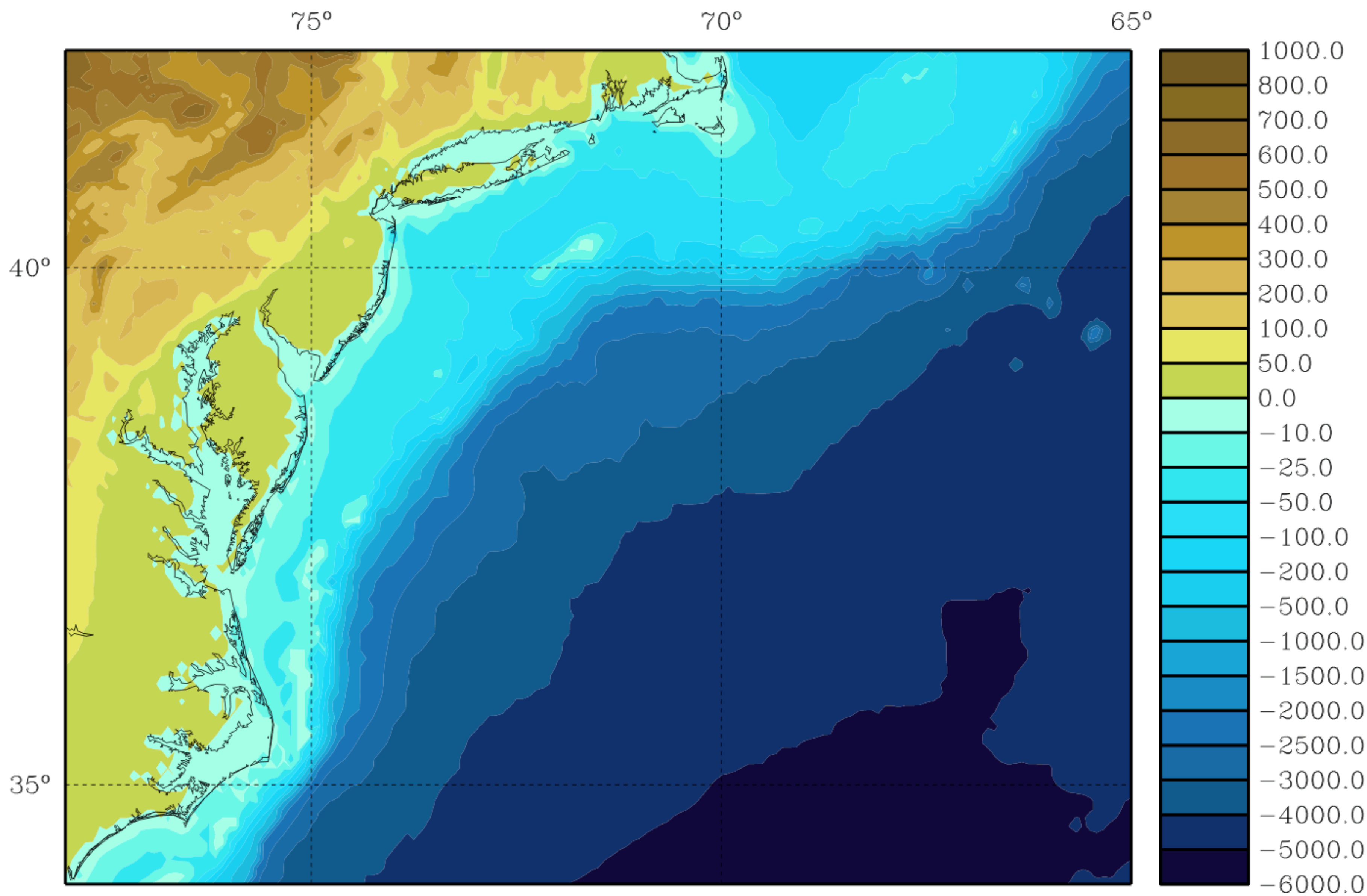
MARCOOS
***CODAR*, gliders …**


ROMS 4D-VAR
Ensemble 4D-Var
f^b, B_f
b^b, B_b
ROMS
η, Q
x^b, B
Obs
y, R
4D-Var
dof
Adjoint 4D-Var
impact
Priors & Hypotheses
Hypothesis Tests
Posterior
Analysis error
Uncertainty
Term balance, eigenmodes
Forecast
Clipped Analyses
Ensemble (SV, SO)

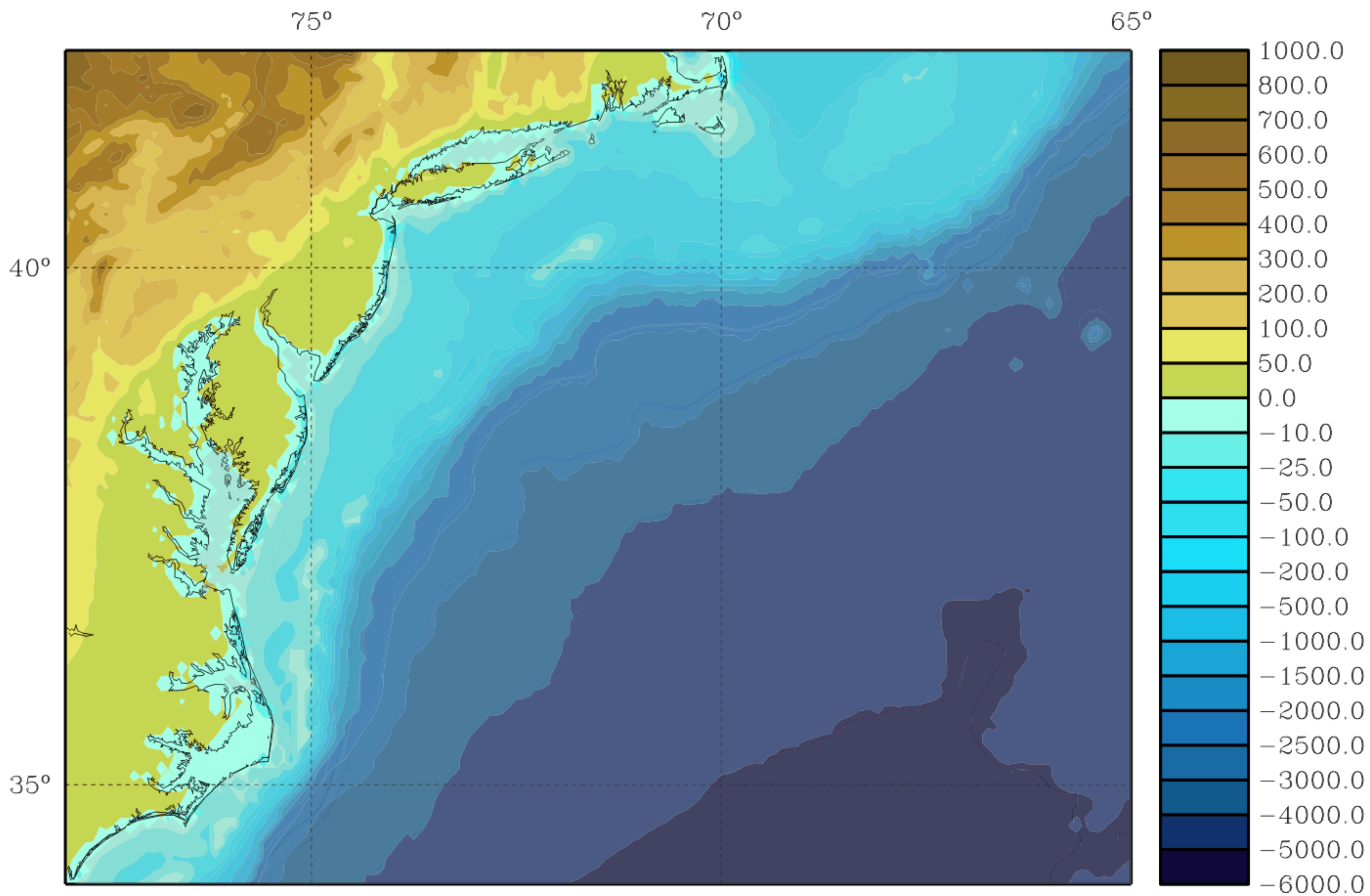
US East Coast Applications

- **NATL** - North Atlantic Basin
- **NENA** - North East North Atlantic
- **CBLAST** – Coupled Boundary Layers Air-Sea Transfer
- **DELAWARE** - Delaware River Estuary
- **SW06** - Shallow Water Acoustics 2006
- **LaTTE** – Lagrangian Transport and Transformation Experiment
- **ESPRESSO** - Experimental System for Predicting Shelf and Slope Optics
- **HUDSON** - Hudson River / NYC Harbor

Mid-Atlantic Bight Applications

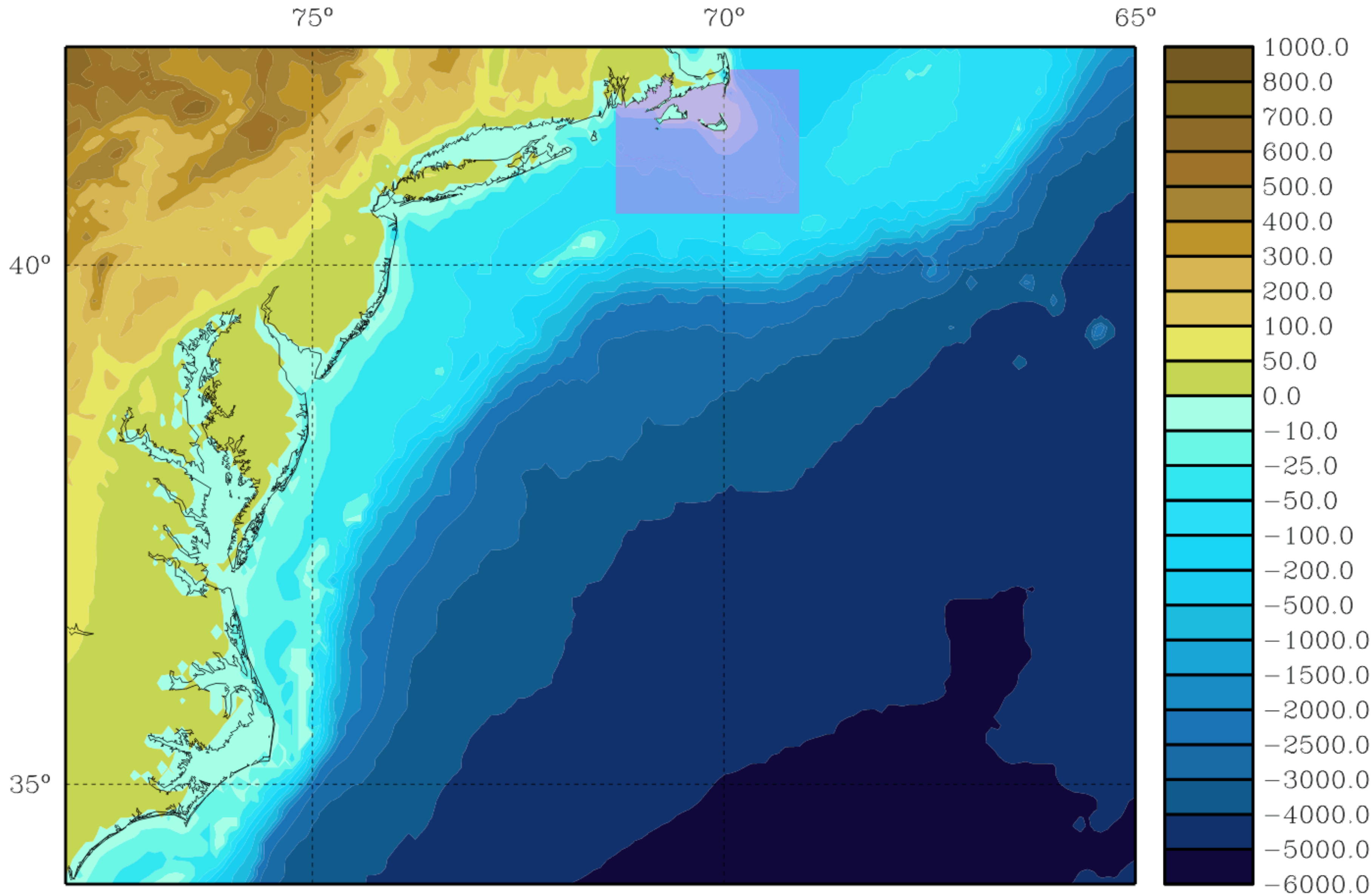


Mid-Atlantic Bight Applications



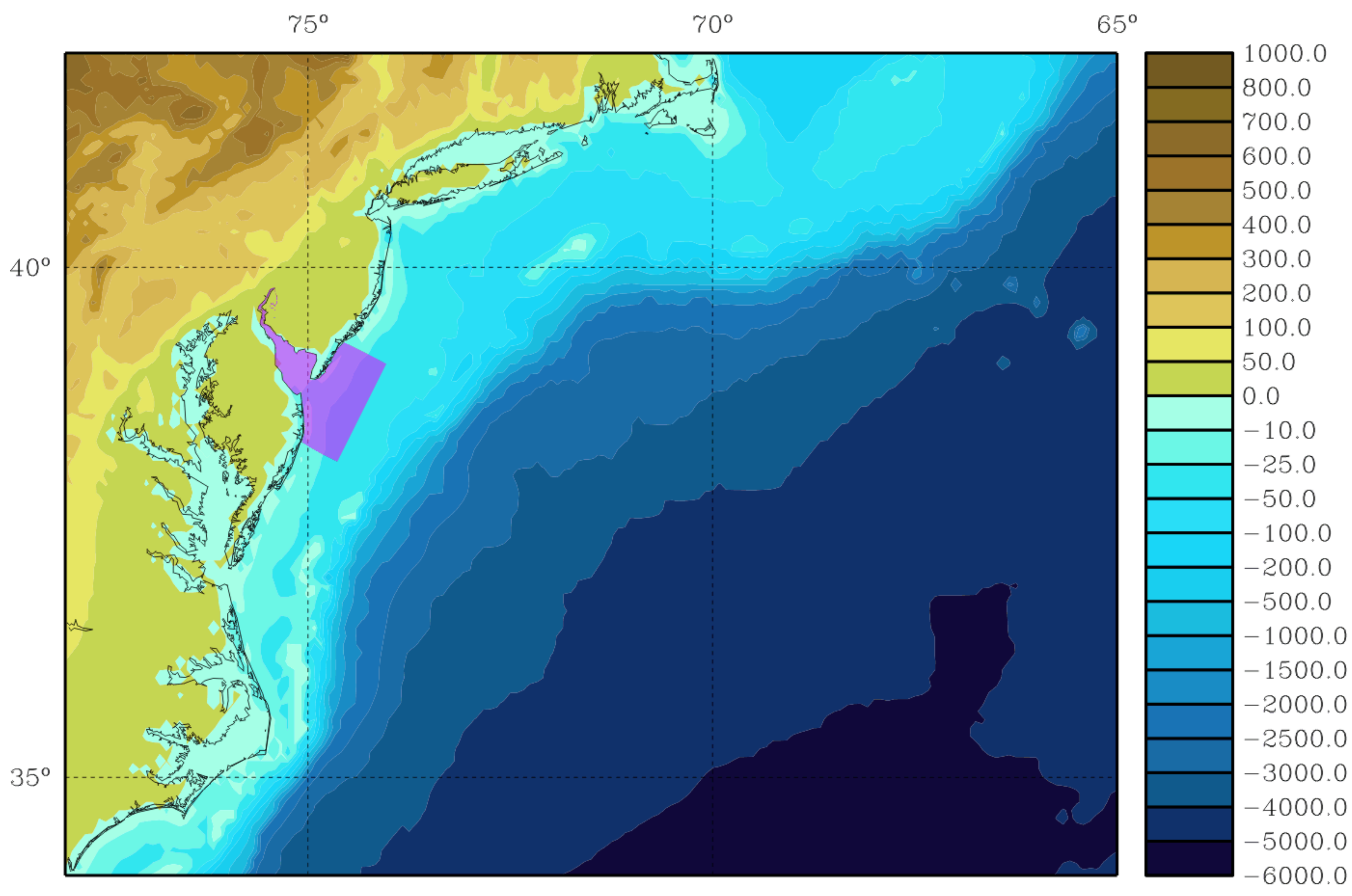
NENA

Mid-Atlantic Bight Applications



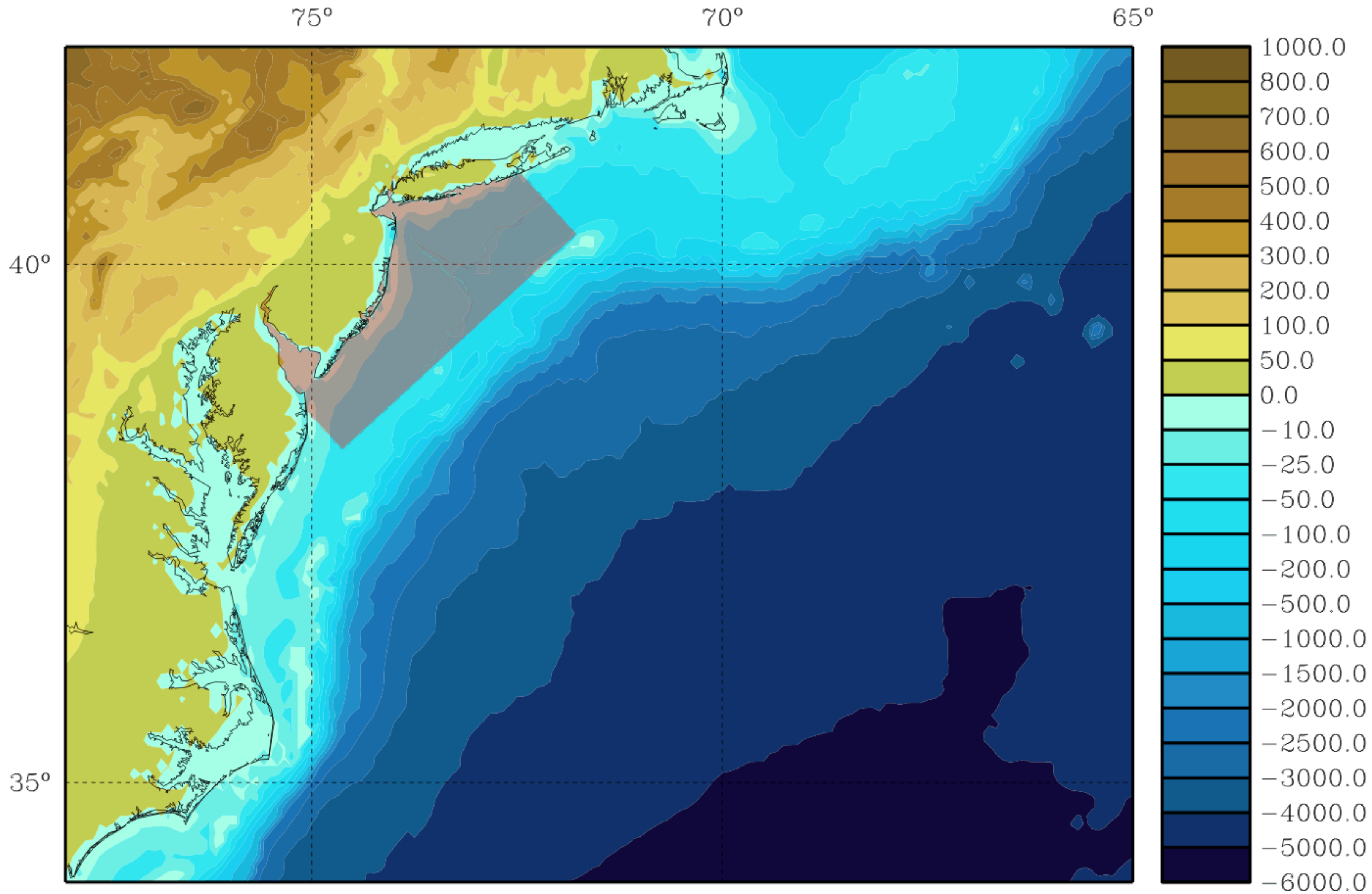
CBLAST

Mid-Atlantic Bight Applications



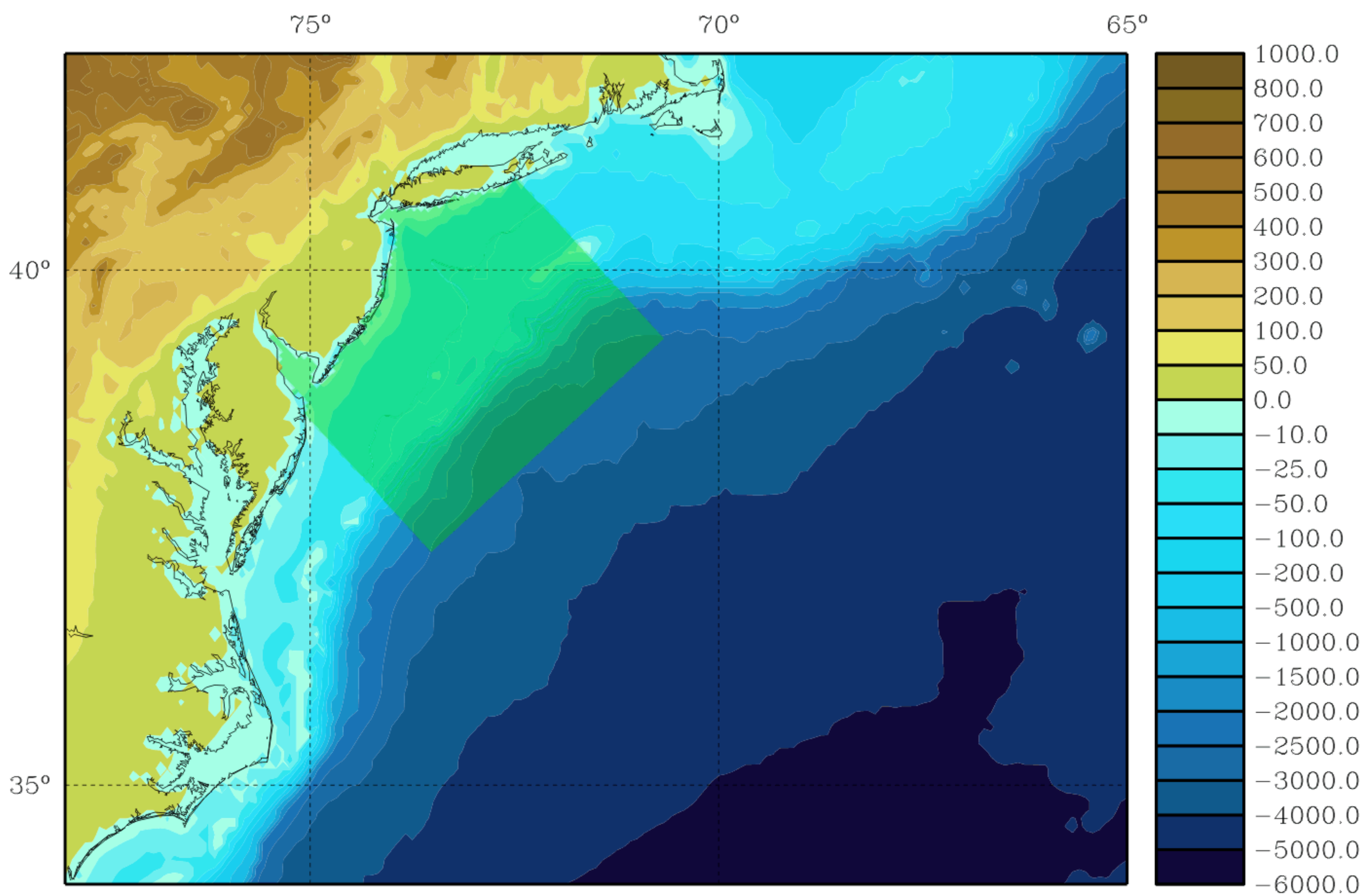
Delaware

Mid-Atlantic Bight Applications



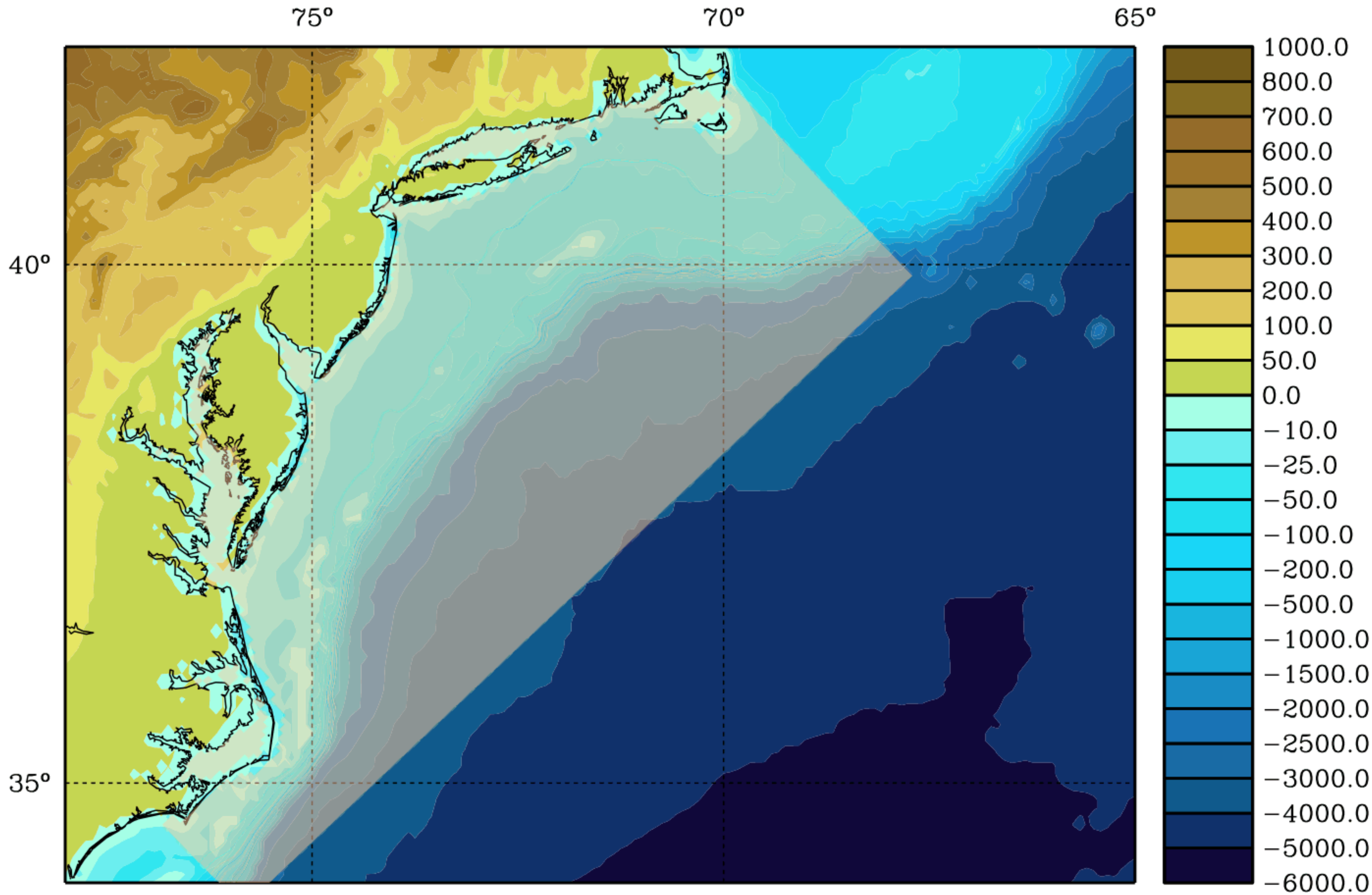
LaTTE

Mid-Atlantic Bight Applications



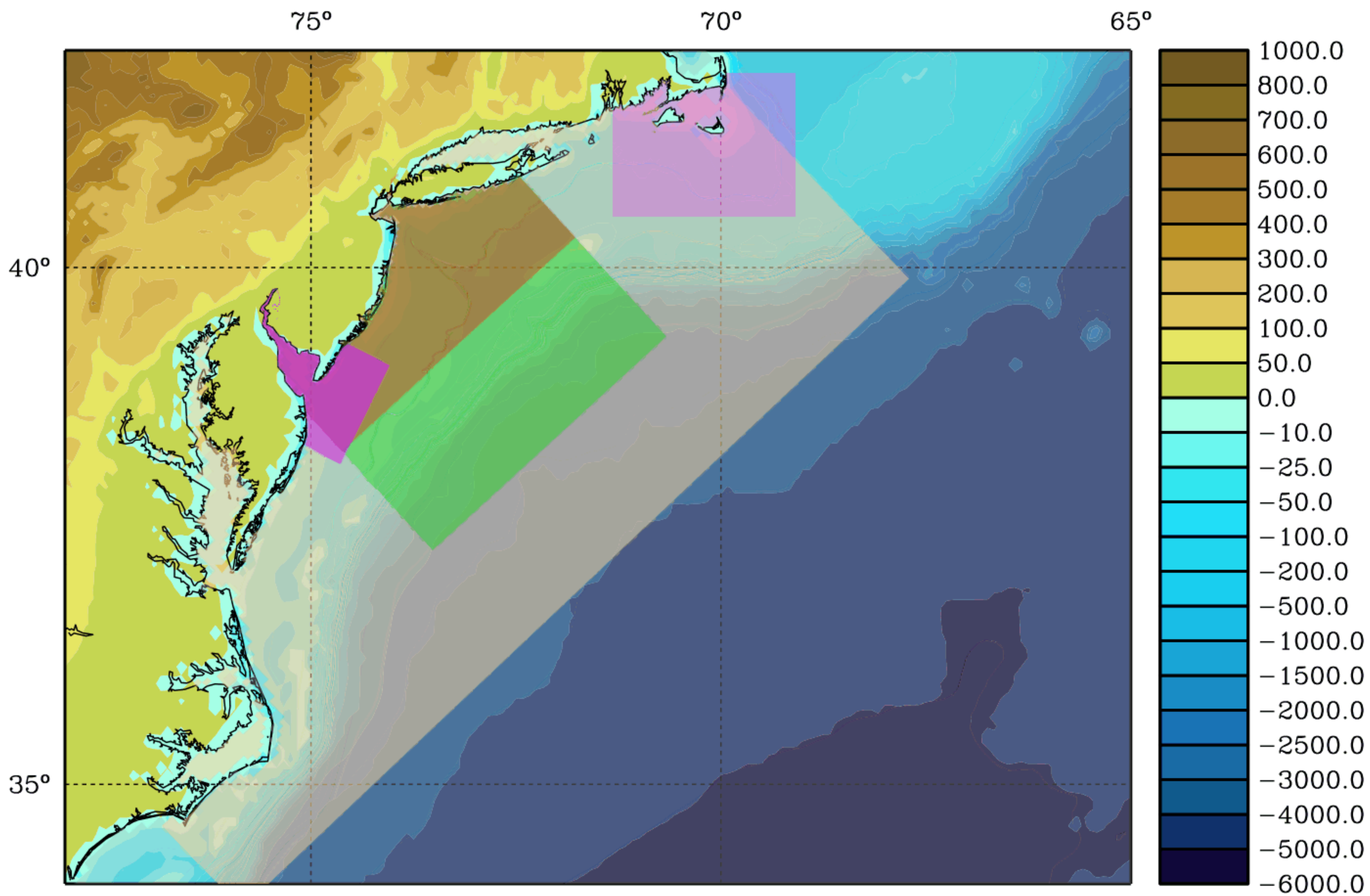
SW06

Mid-Atlantic Bight Applications

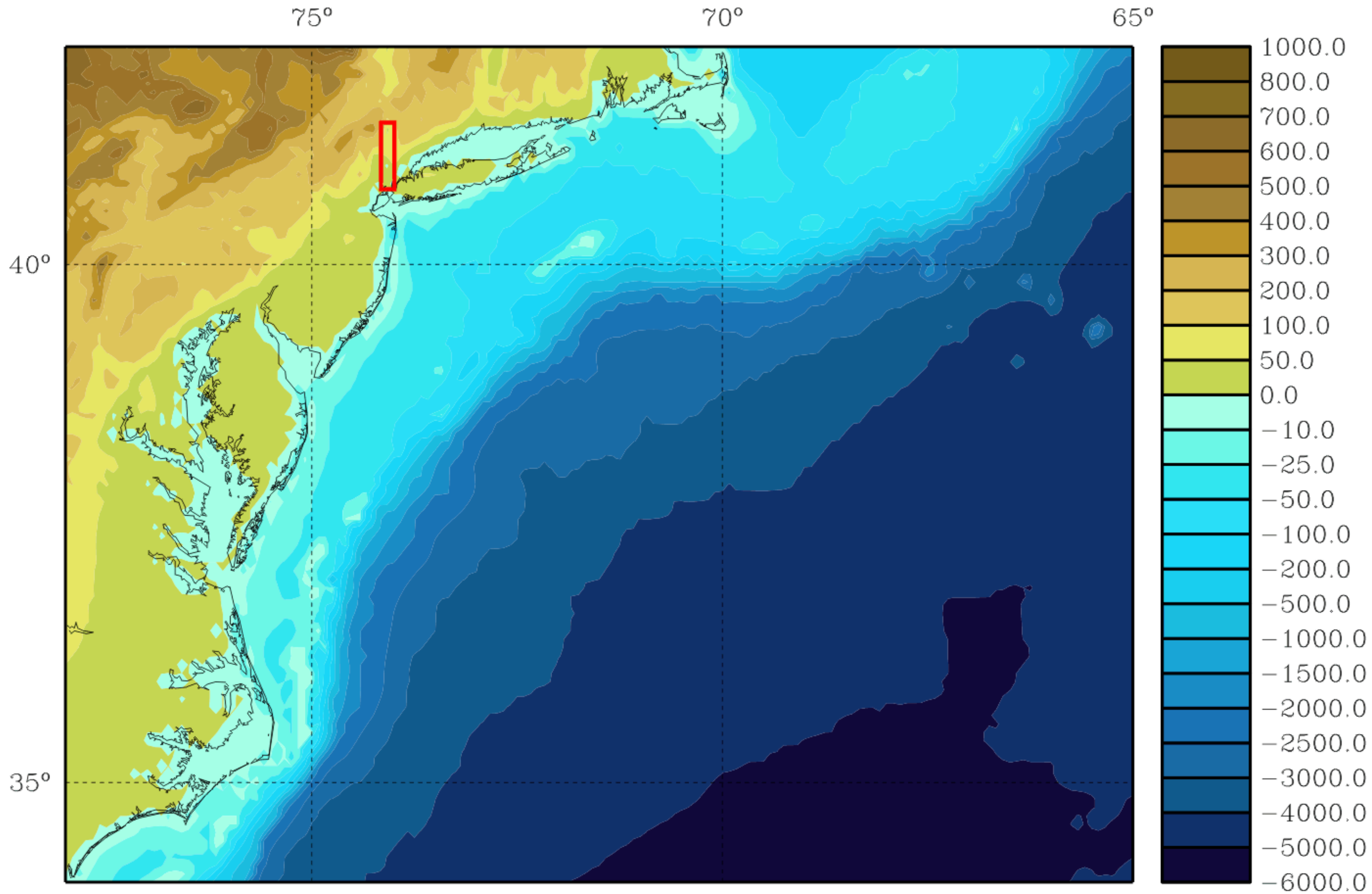


Espresso

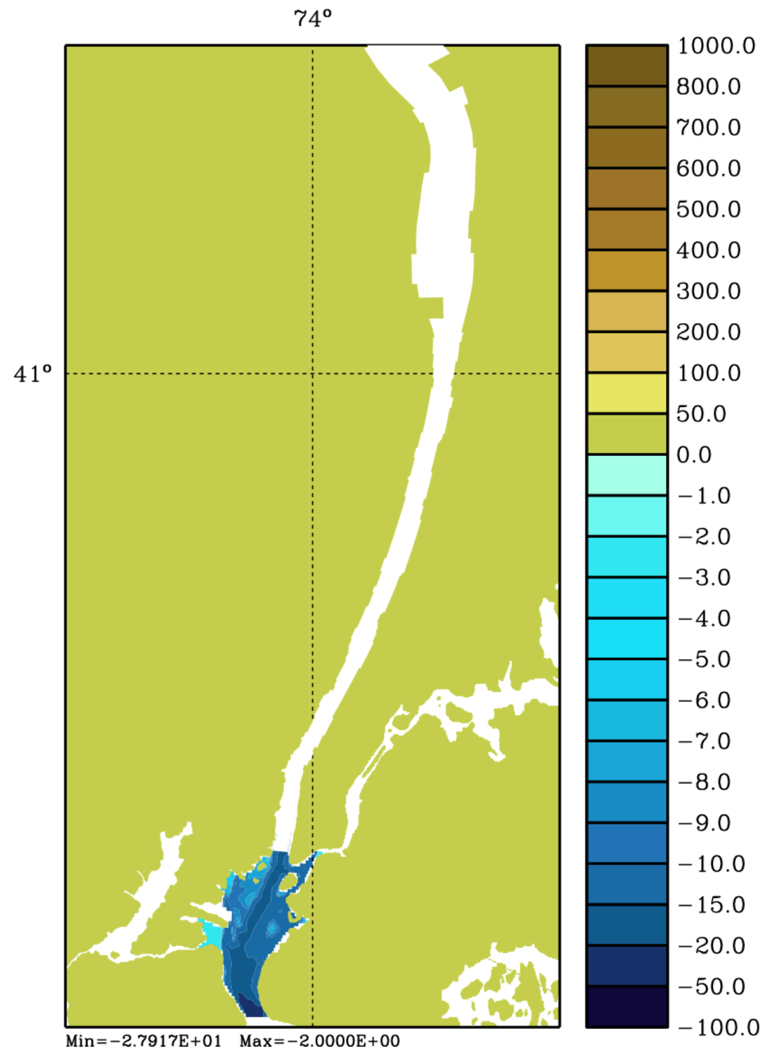
Grid Nesting ?



Hudson River-Harbor Nesting

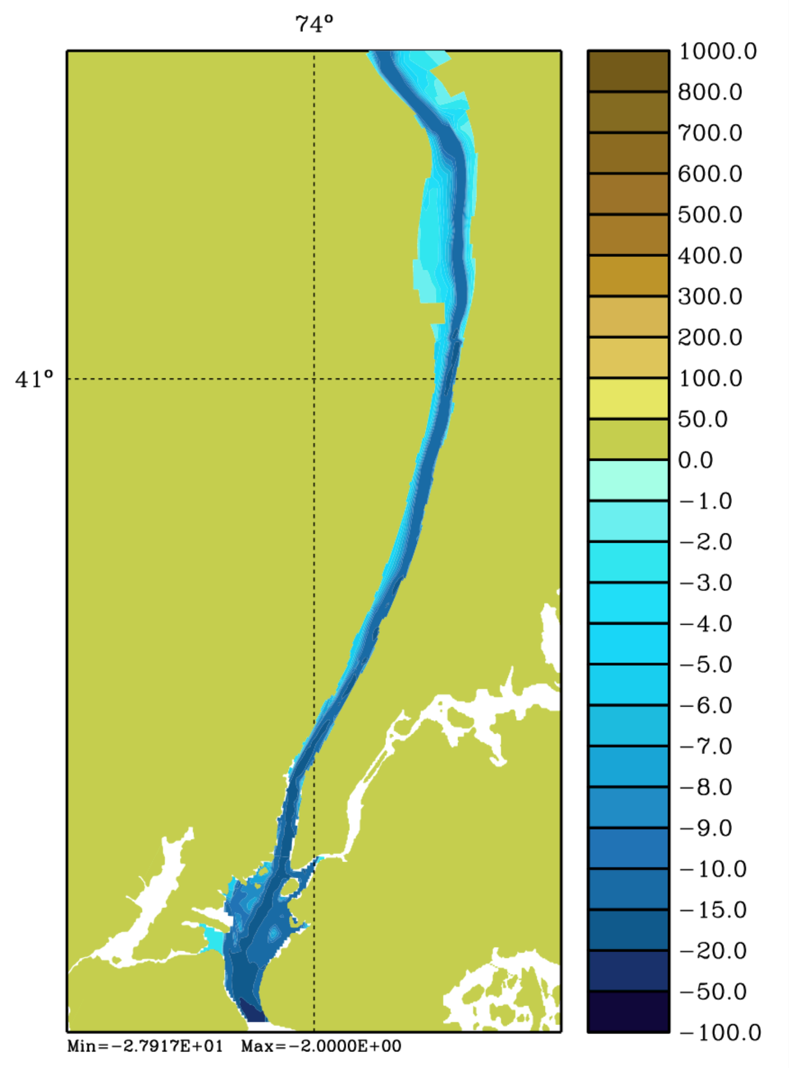


Hudson River-Harbor Nesting



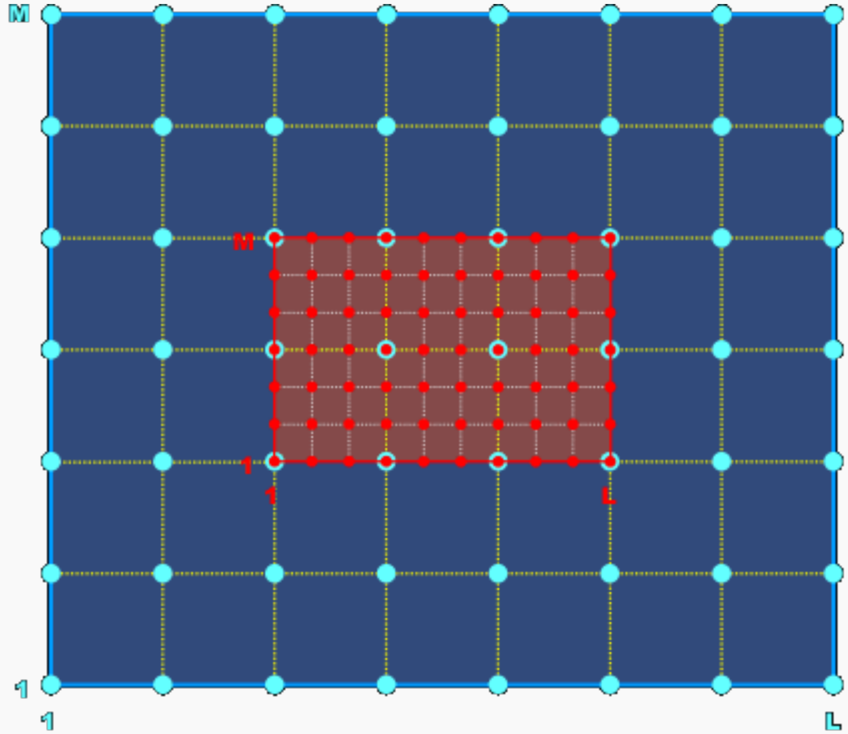
Harbor

Mosaic Grid Nesting

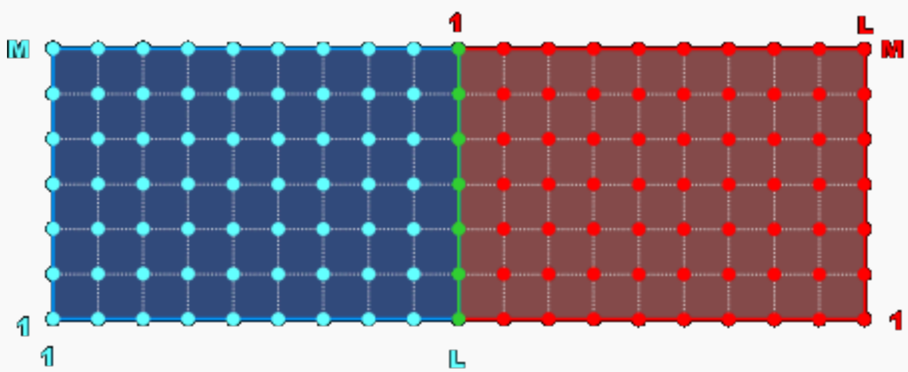


Hudson River/Harbor

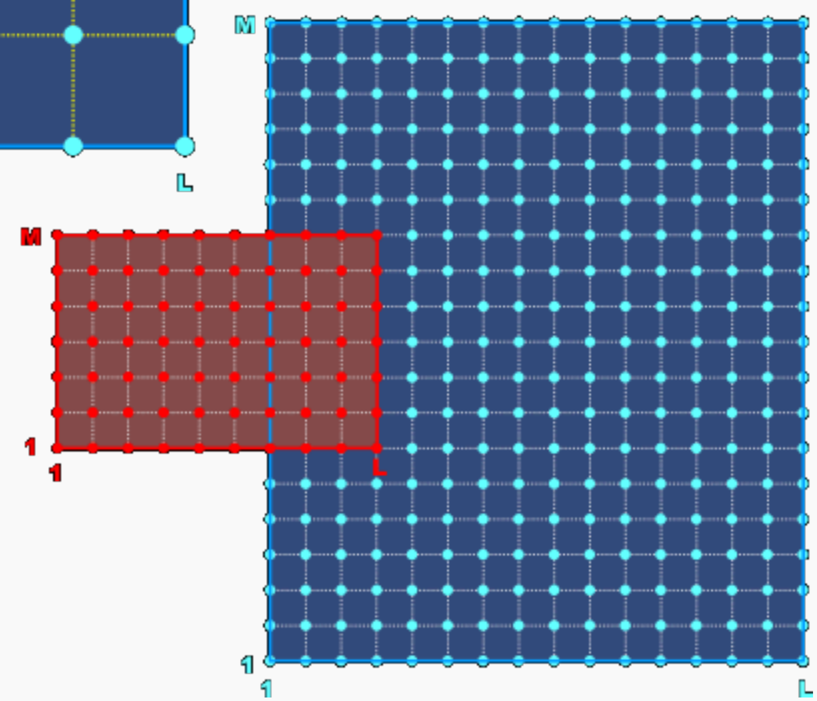
ROMS Nested Grids Types



Refinement



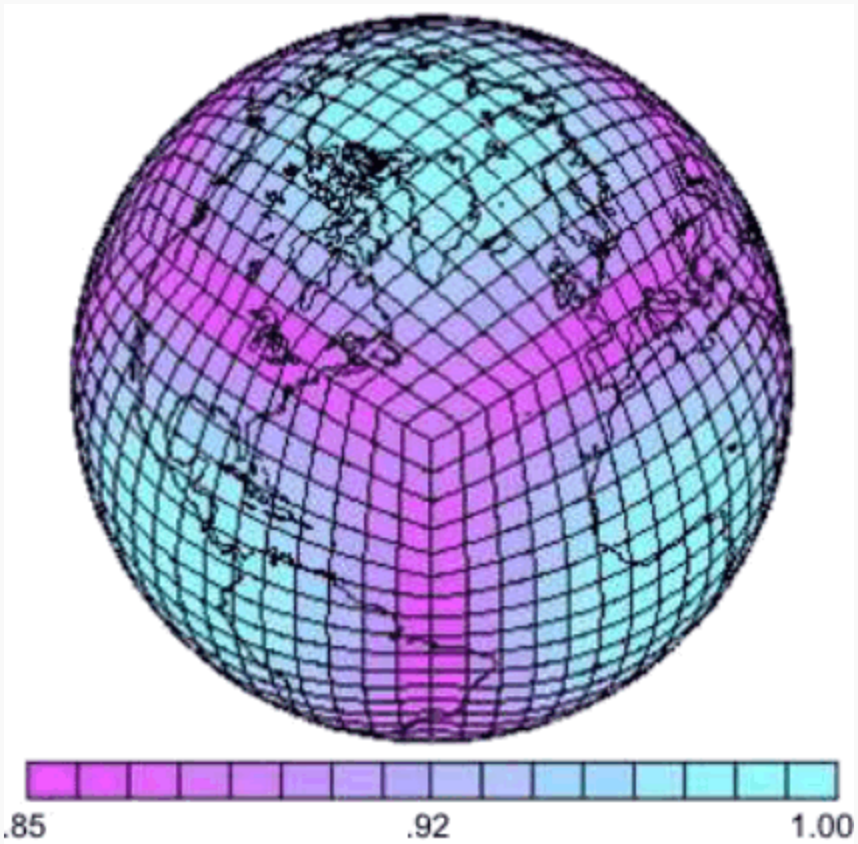
Mosaics



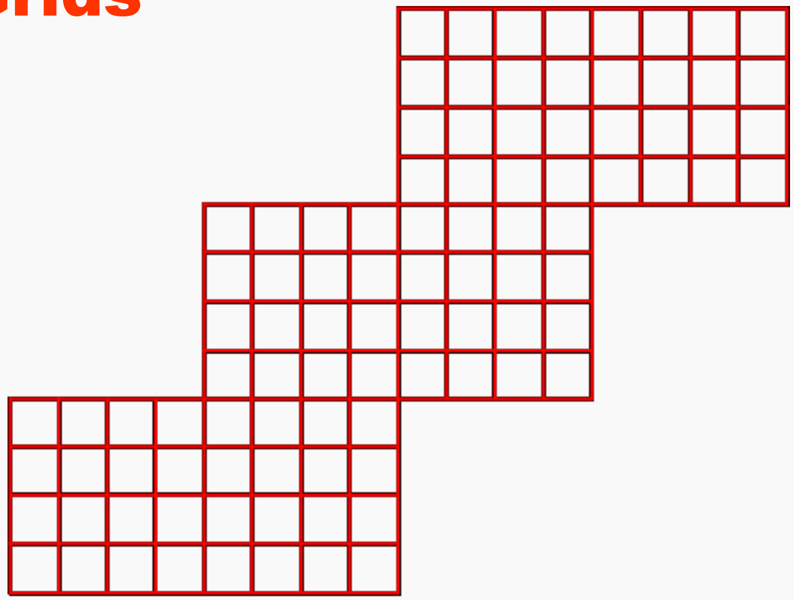
Composite

Mosaics Grids

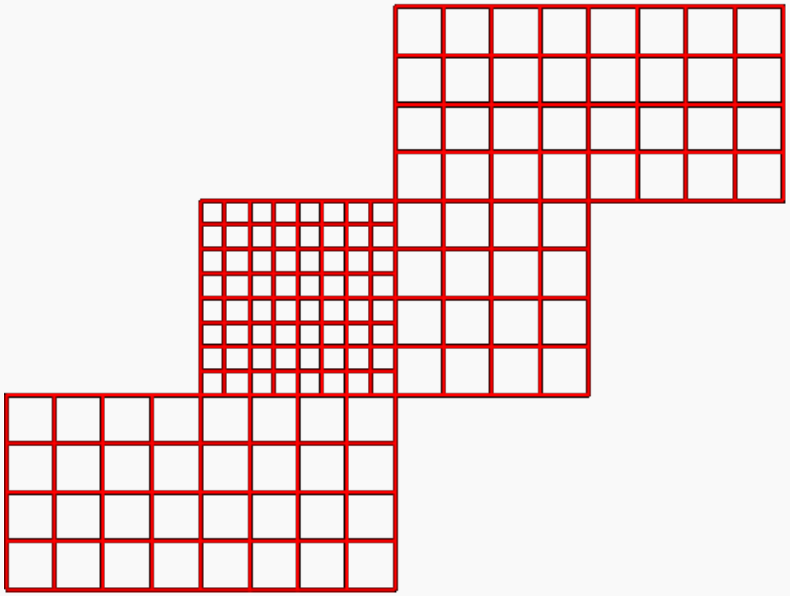
Cubed-Sphere grid



(Rancic and Purser 1996)

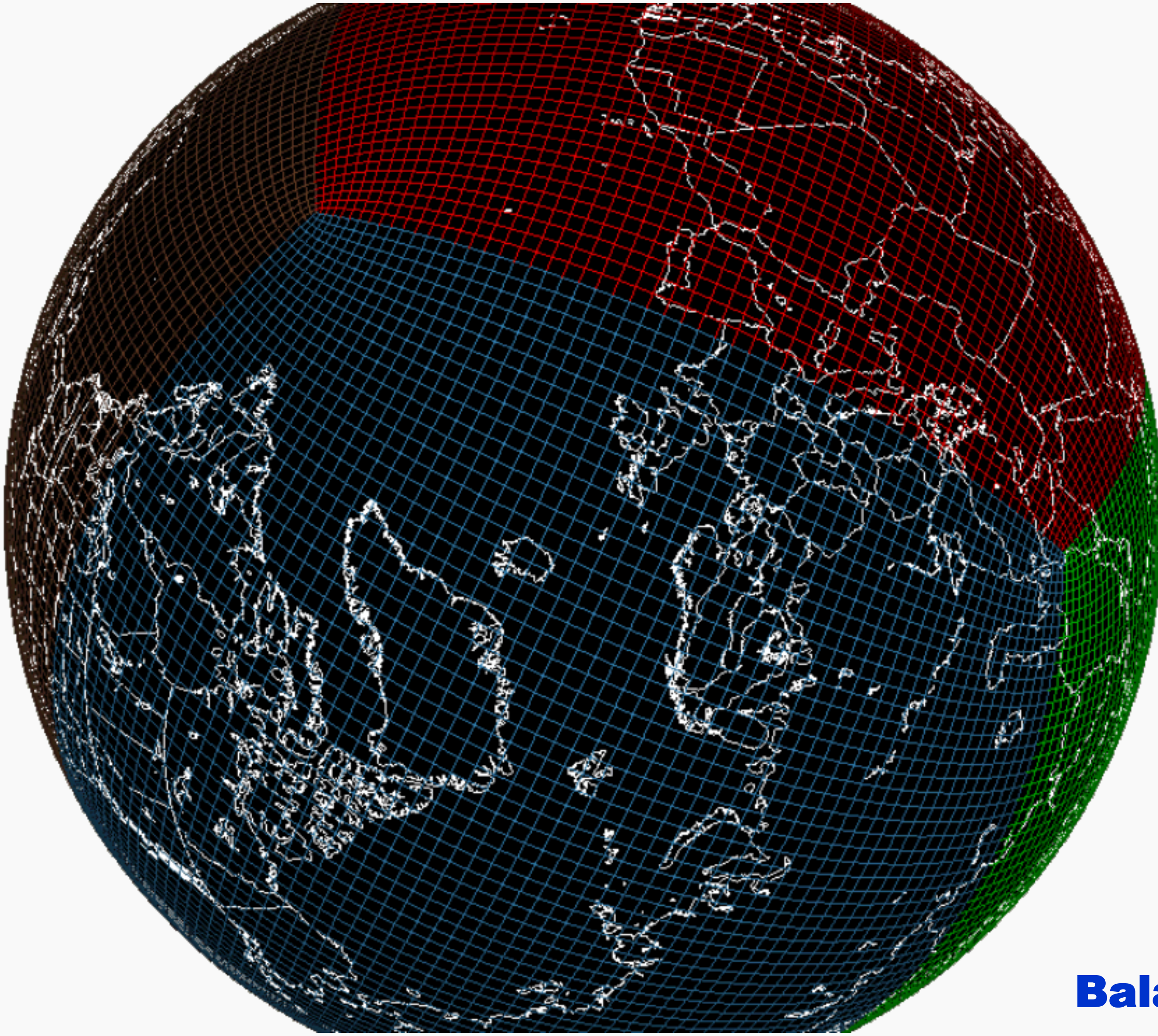


Regular grid mosaic



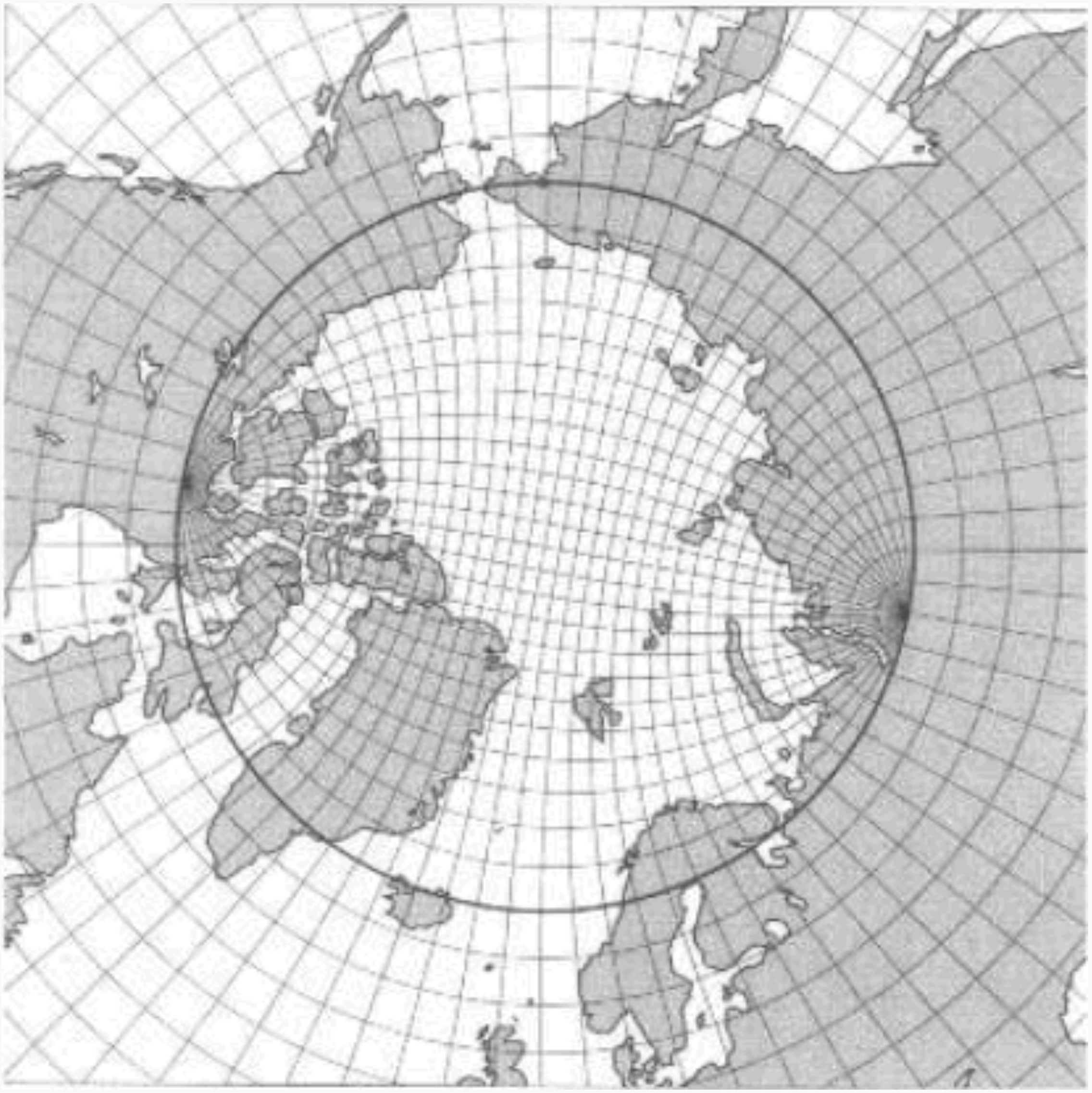
Refined grid mosaic

Mosaics Grids: Cubed-Sphere



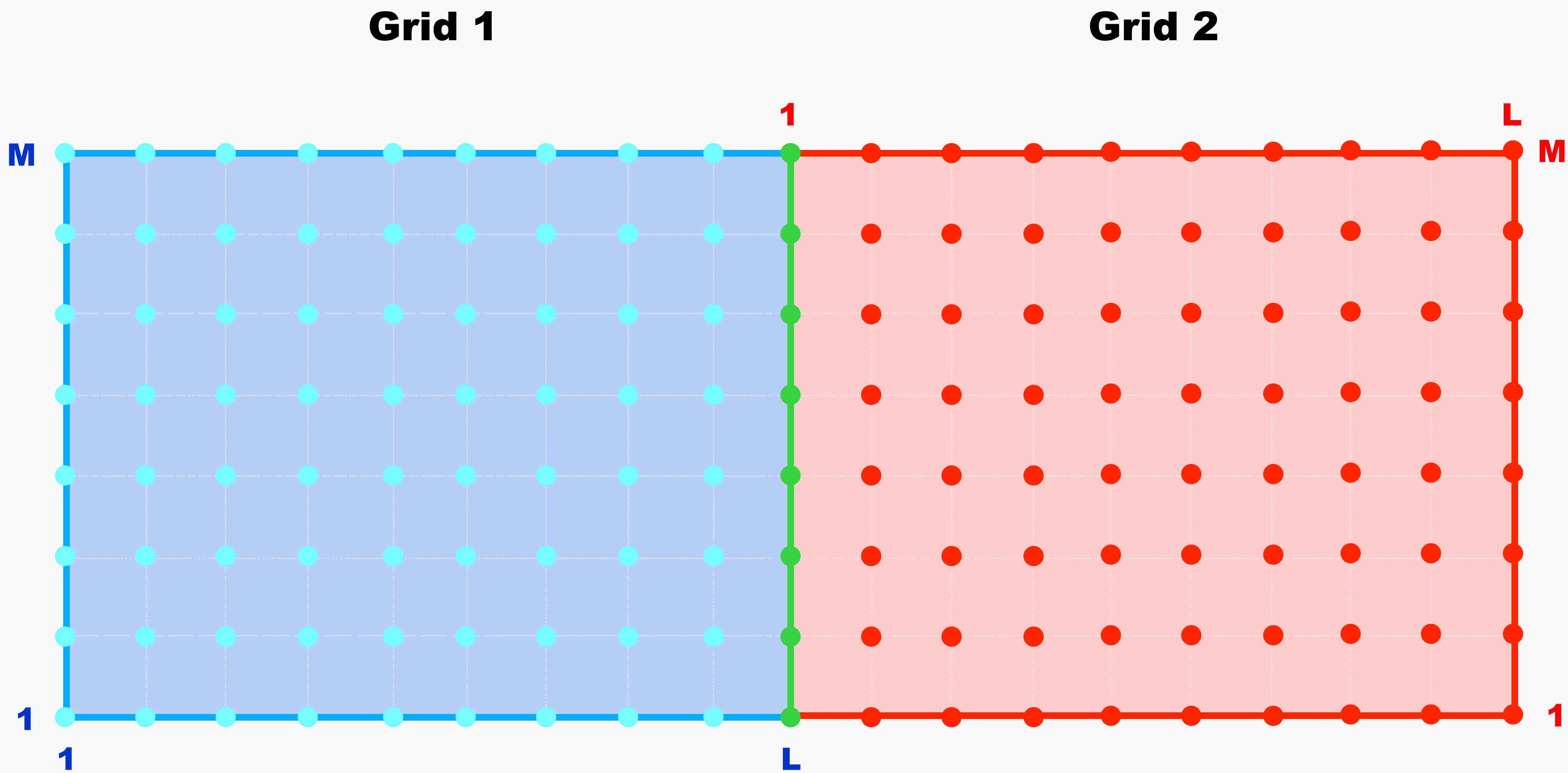
Balaji

Tripolar Grid

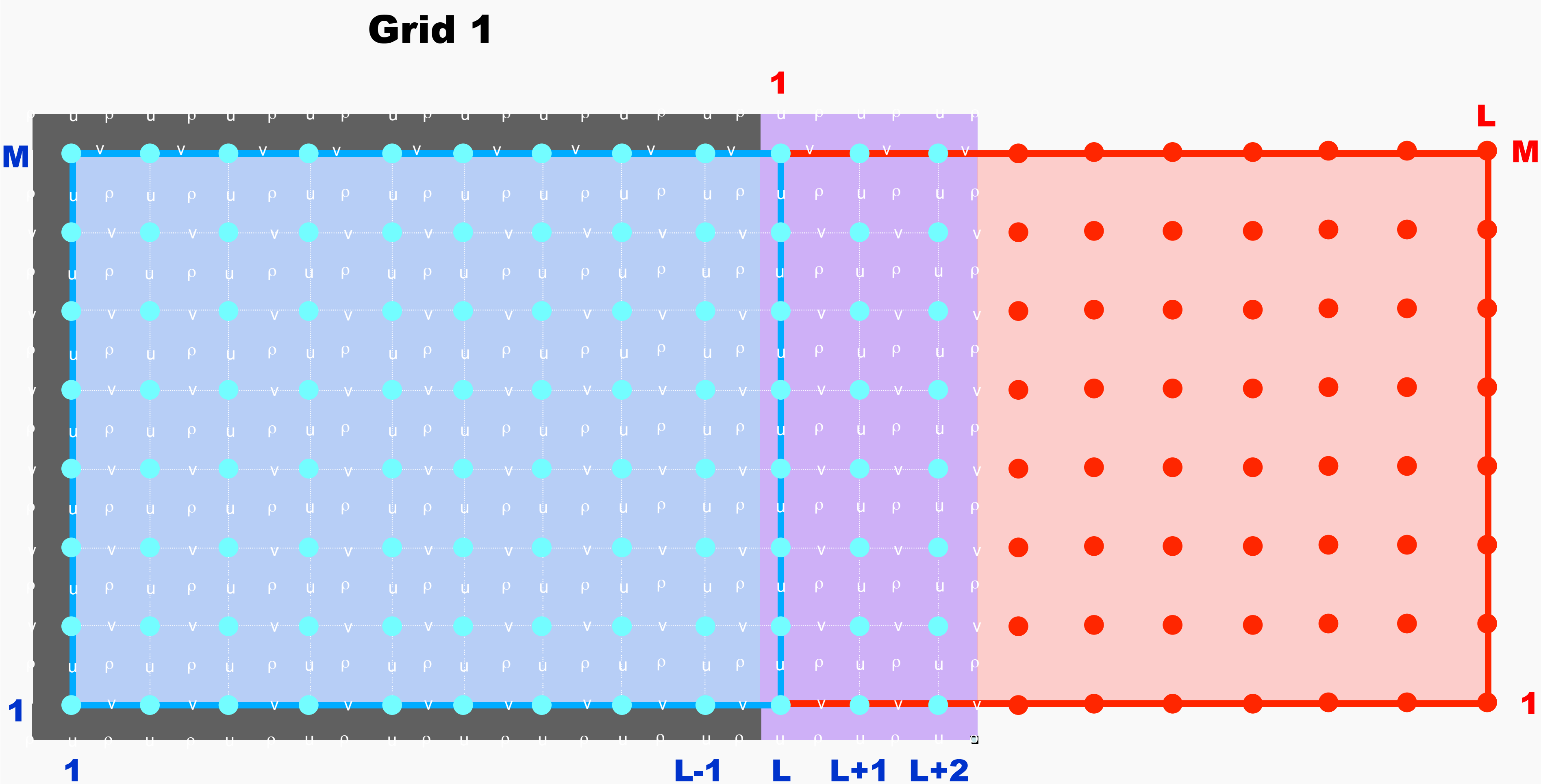


(Murray 1996, Griffies et al 2004)

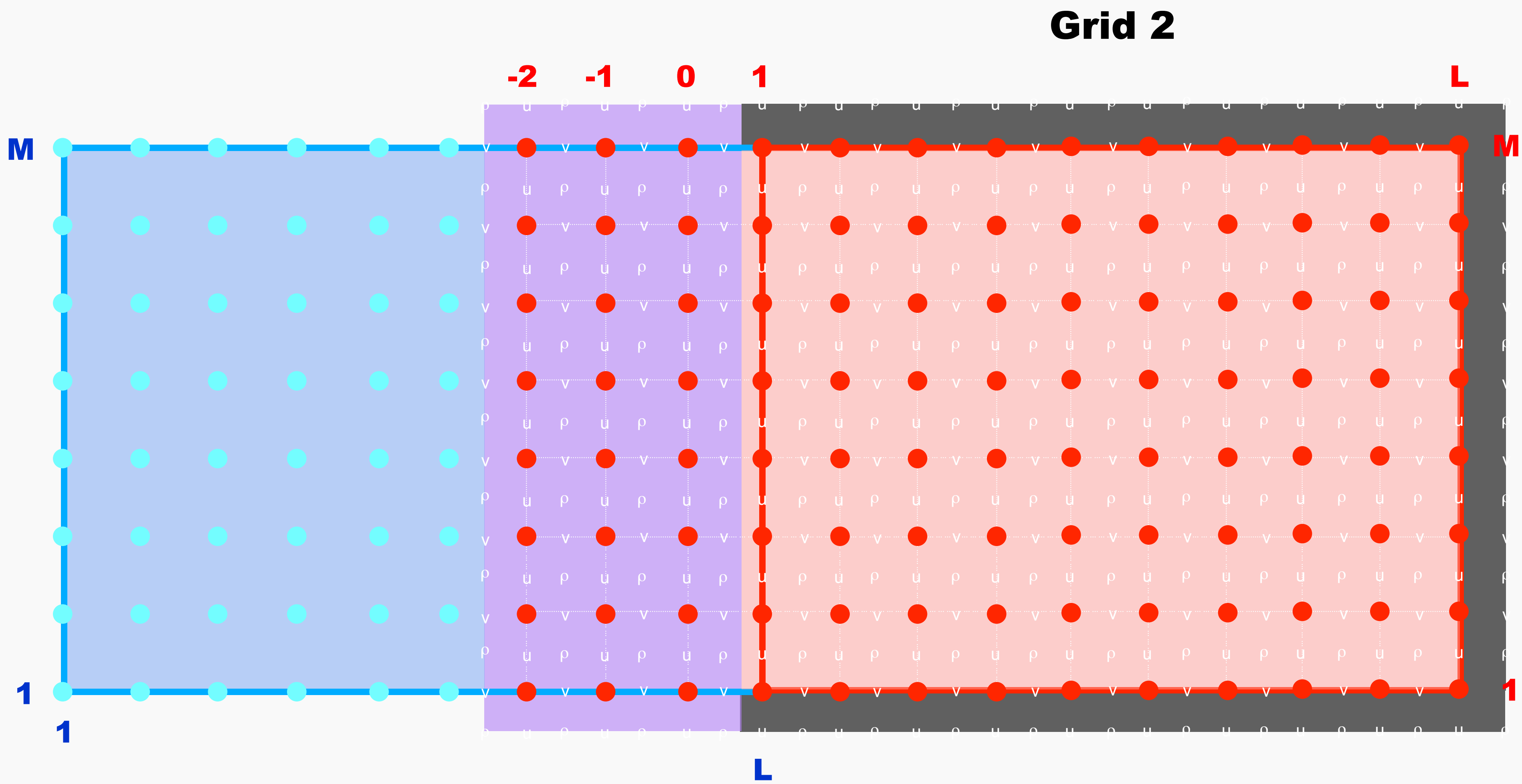
Mosaic Grids: East-West Contact



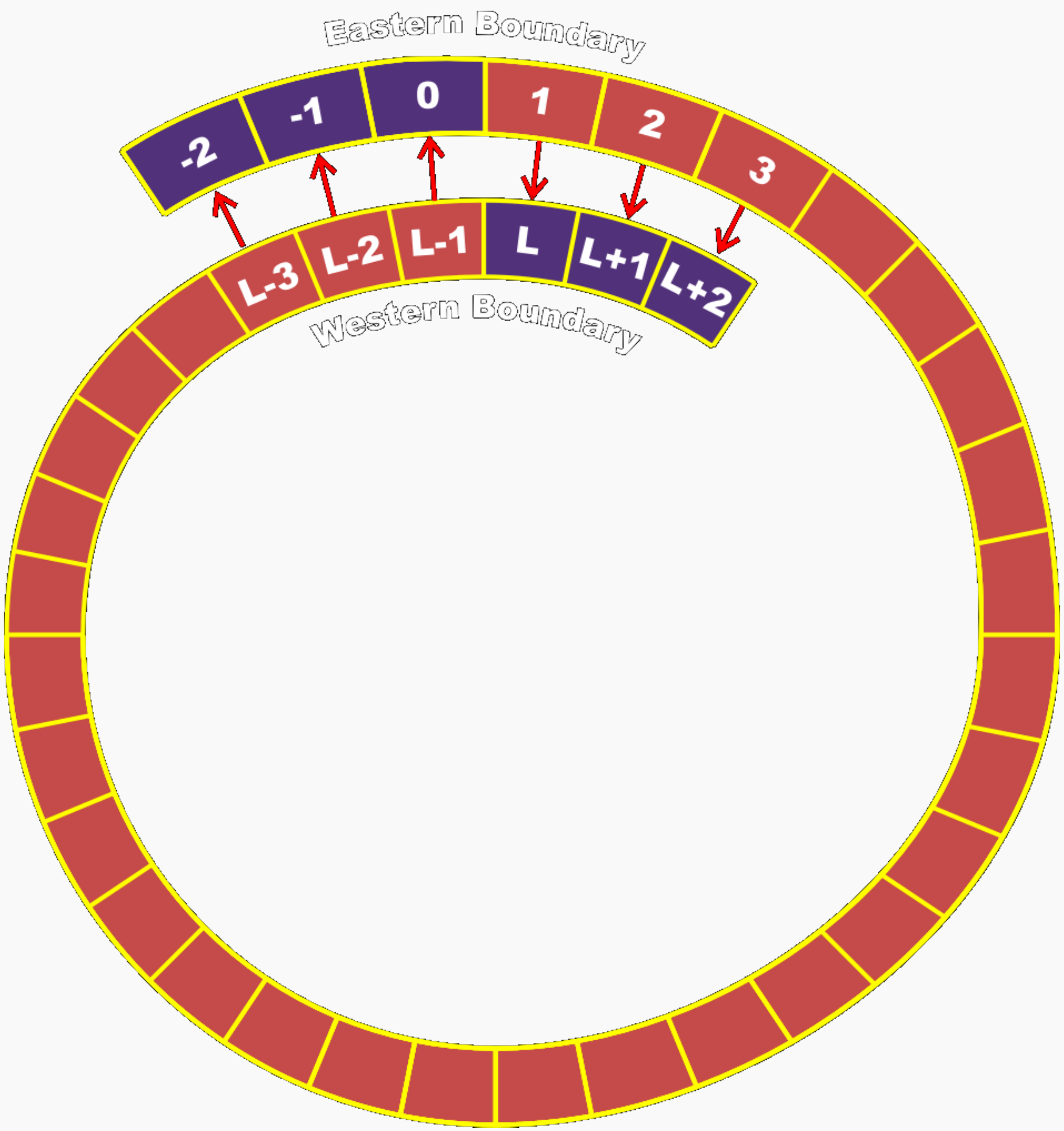
Mosaic Grids: East-West Contact



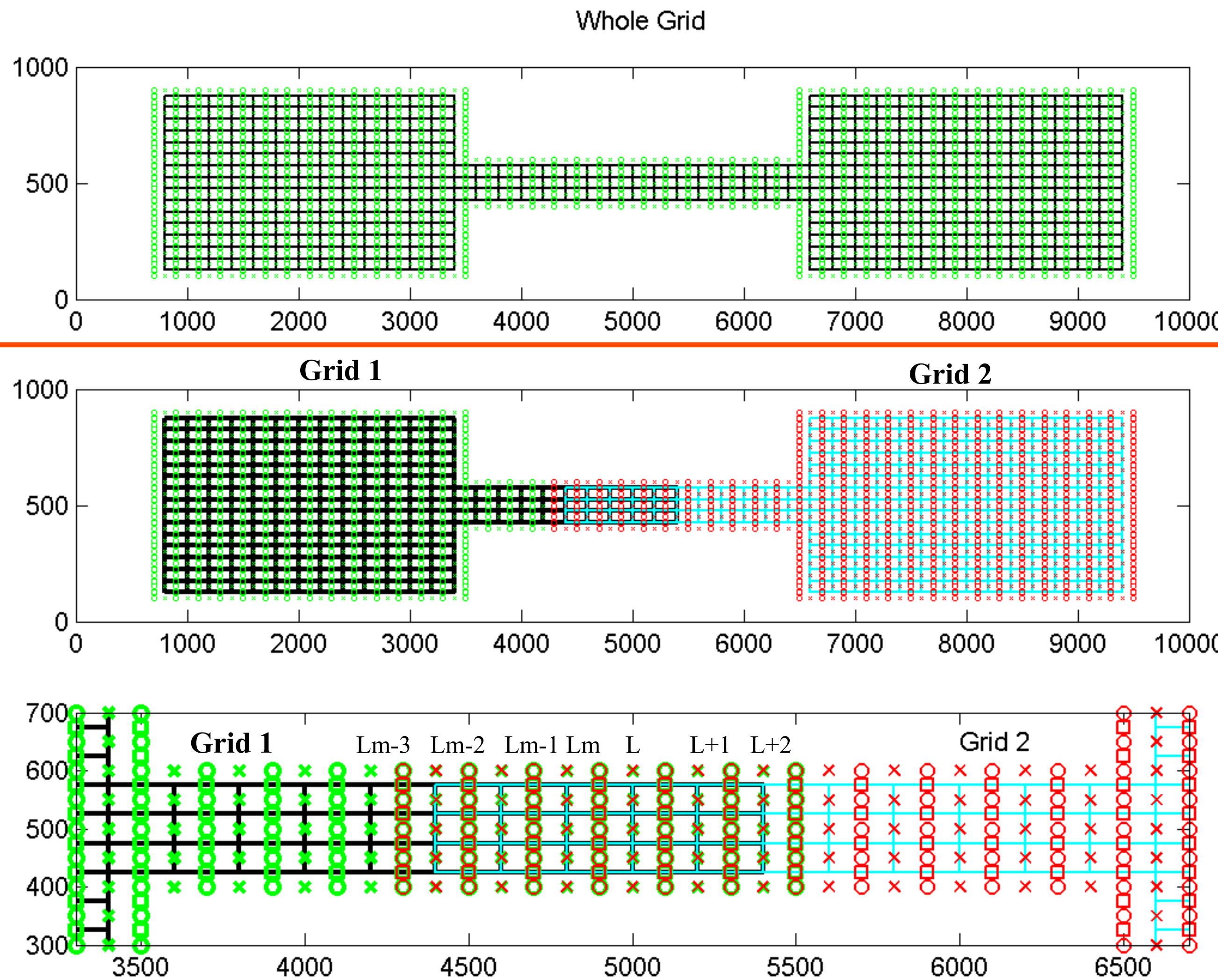
Mosaic Grids: East-West Contact



East-West Periodic Annulus



Dogbone Test: Configuration



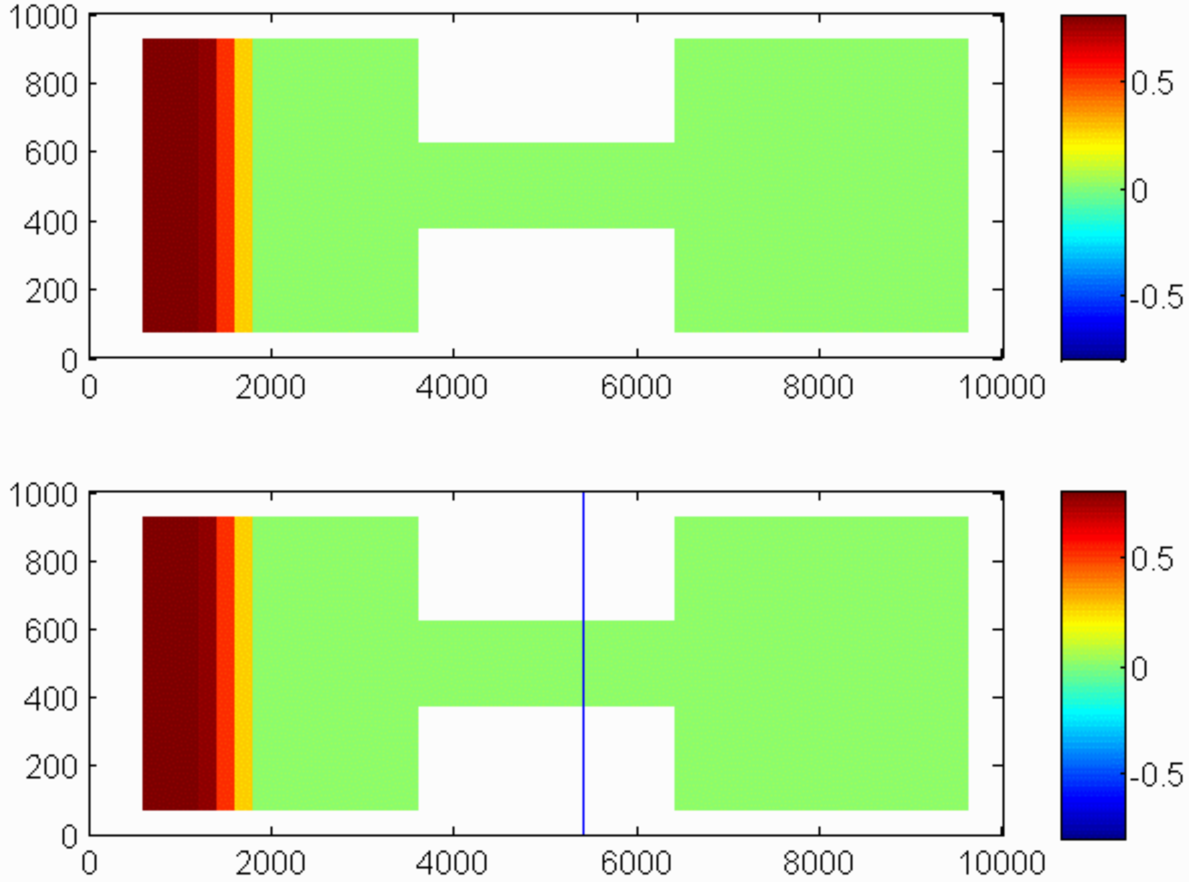
Case 1: Whole Grid

Case 2: Two Separate Grids

Contact Region

Warner, J. C., R. W. Geyer, and H. G. Arango (2010)

Dogbone Test: Results



Case 1: Whole Grid

Case 2: Two Separate Grids

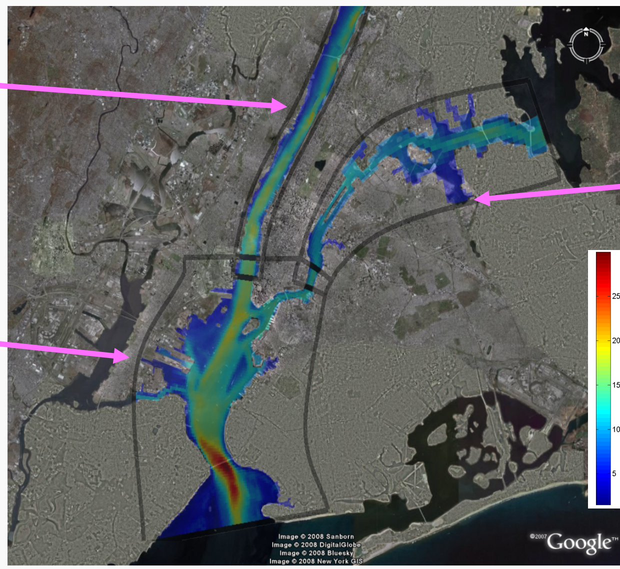
Warner, J. C., R. W. Geyer, and H. G. Arango (2010)

Nesting: Composite Grids

Hudson River Application

Grid 1
Estuary
20 x 248

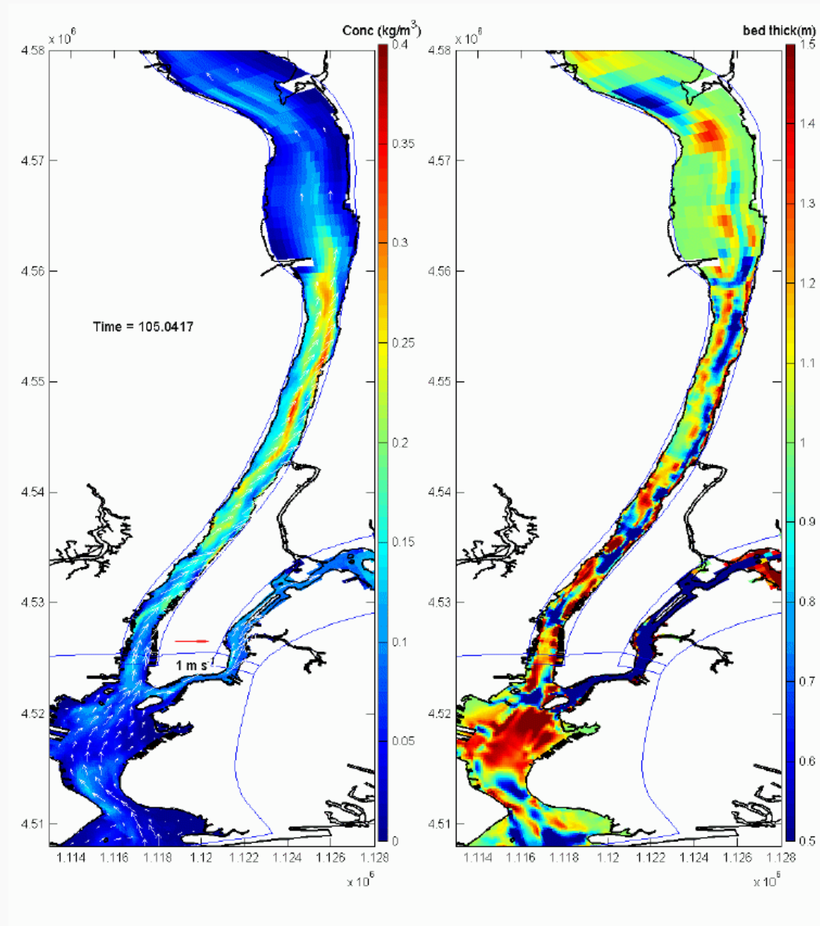
Grid 2
Harbor
111x100



Grid 3
East River
21x66

Bathymetry

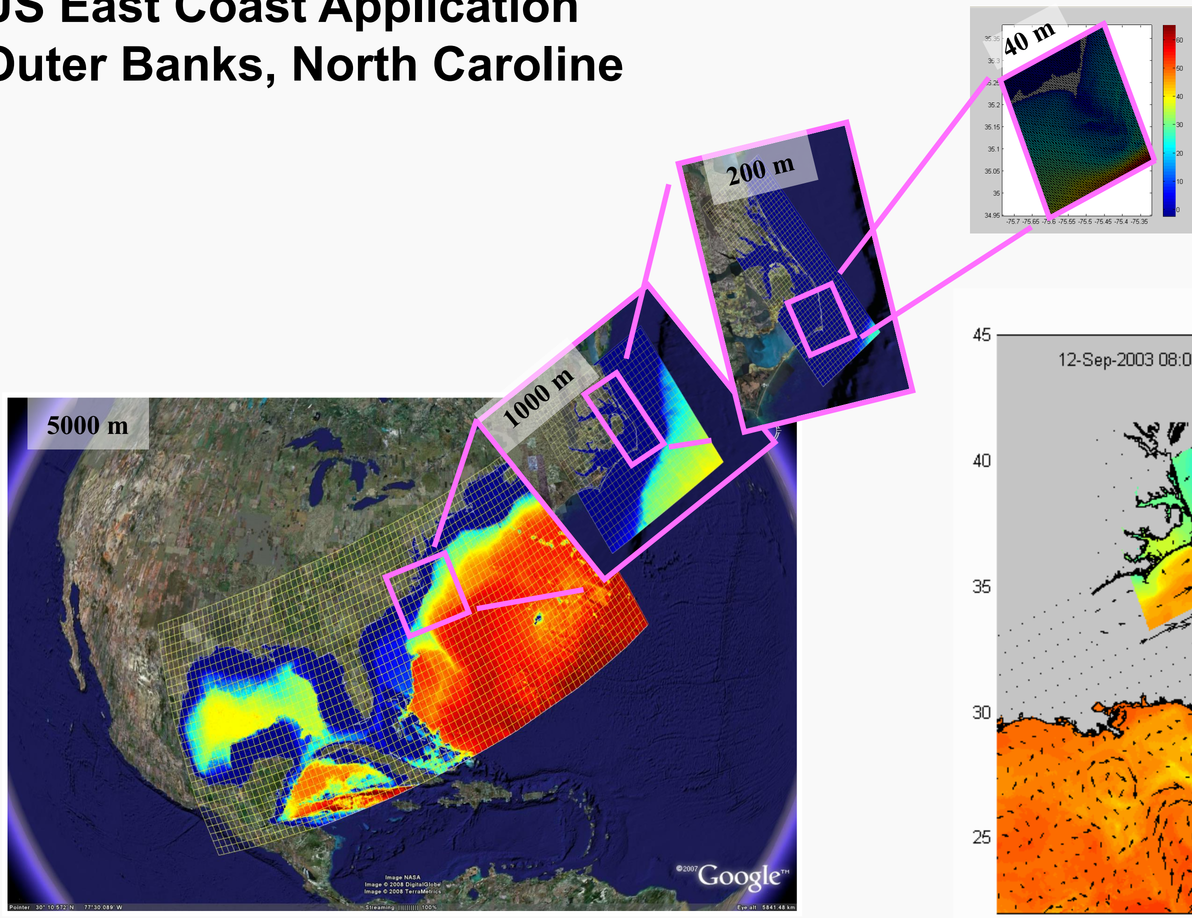
Suspended Sediment

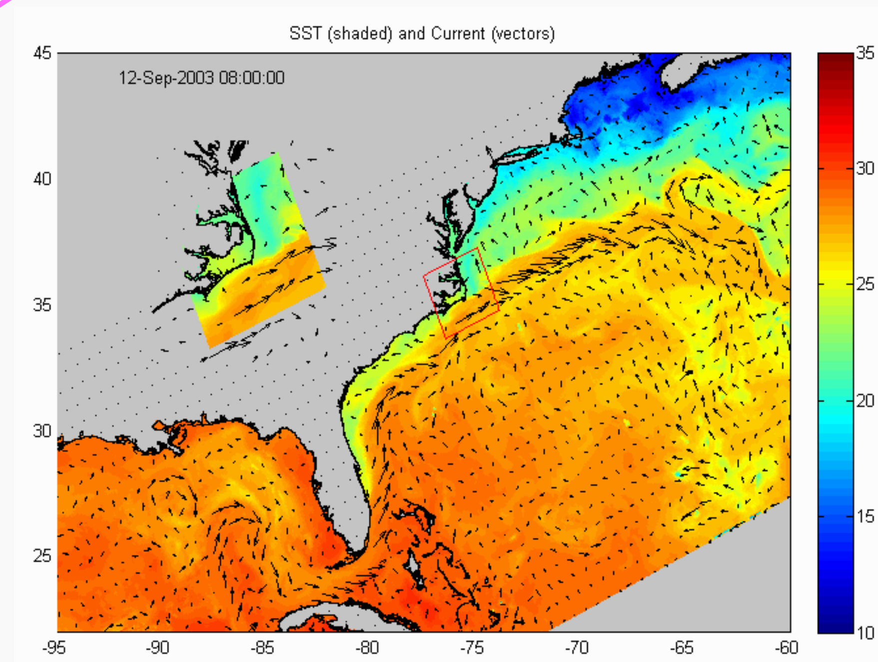


Warner, Geyer, and Arango, 2009: Using a composite grid approach in a complex coastal domain to estimate estuarine residence time (submitted).

Nesting: Grid Refinement

US East Coast Application
Outer Banks, North Caroline



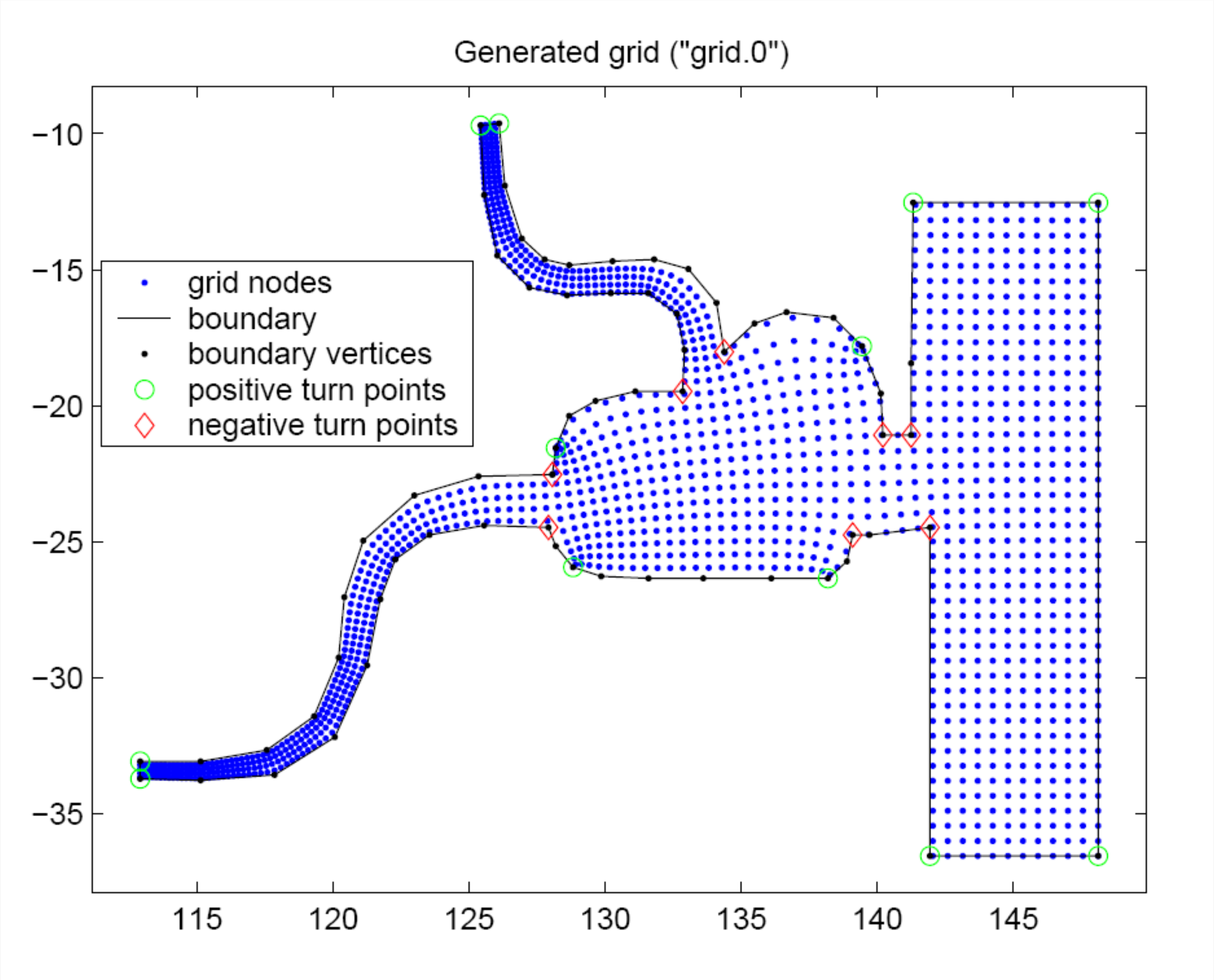


SST and Surface Currents

Grid refinement of the ocean and wave models is required to allow increased resolution in coastal areas.

From John C. Warner

Nesting: Grid Generation



Pavel Sakov's Gridgen

Coupling

- The Sediment-Transport Model needs to be part of the Physical and Numerical Kernel of the Hydro-Dynamical Model
- Decoupling of Physical Phenomena may yield inaccurate and unstable solutions
- On-line vs Off-line Coupling
- Loosely vs Tightly Volumetric Coupling (ESMF vs MCT): Computational efficiency
    - Earth System Modeling Framework: www.earthsystemmodeling.org
    - Model Coupling Toolkit: www.mcs.anl.gov/mct
- Modularity Paradox:
    - Splitting models into their fundamental components is advantageous for exploring new algorithms, adding new processes, and readability
    - Over-isolating algorithms for porting to other modeling systems is dangerous and may cause interferences in the numerical kernel (spatial discretization, time stepping, advection/diffusion schemes, physical parameterizations, stability, parallelization, etc)

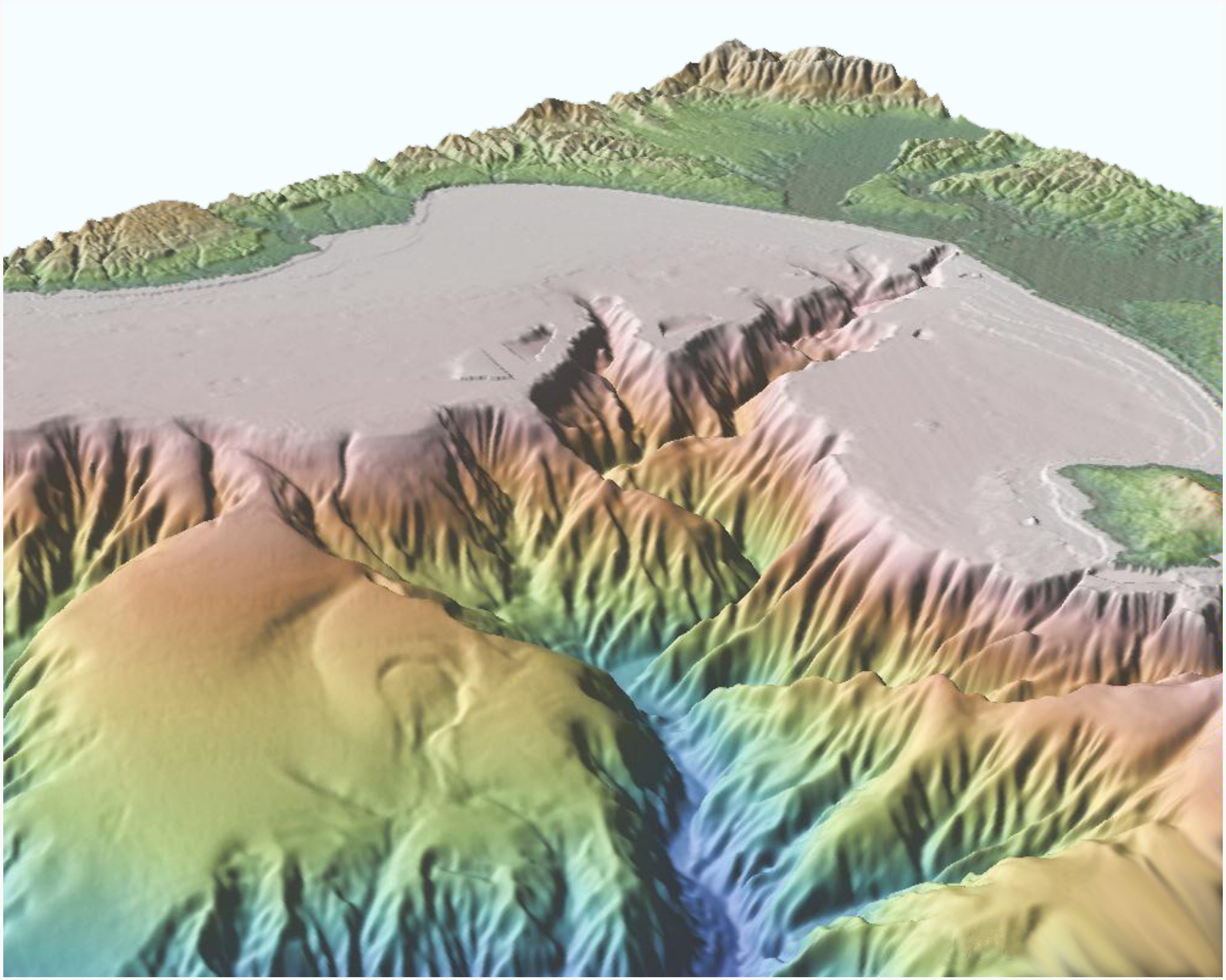
Final Remarks

- ROMS is one of the most advanced and complex ocean numerical frameworks freely distributed to modeling community
- ROMS is a robust open-source model available online www.myroms.org
- ROMS is still evolving and new algorithms are currently been developed
- ROMS has flexible nesting capabilities that will be released in version 4.0 soon.
- ROMS uniquely includes several adjoint-based algorithms for:
    - Variational 4-Dimensional Data assimilation (4D-Var)
    - Adjoint Sensitivity Analyses
    - Ensemble Prediction
    - Observation Impact
    - Observation Sensitivity
    - Adaptive Sampling
    - Generalized Linear Stability Circulation Analyses

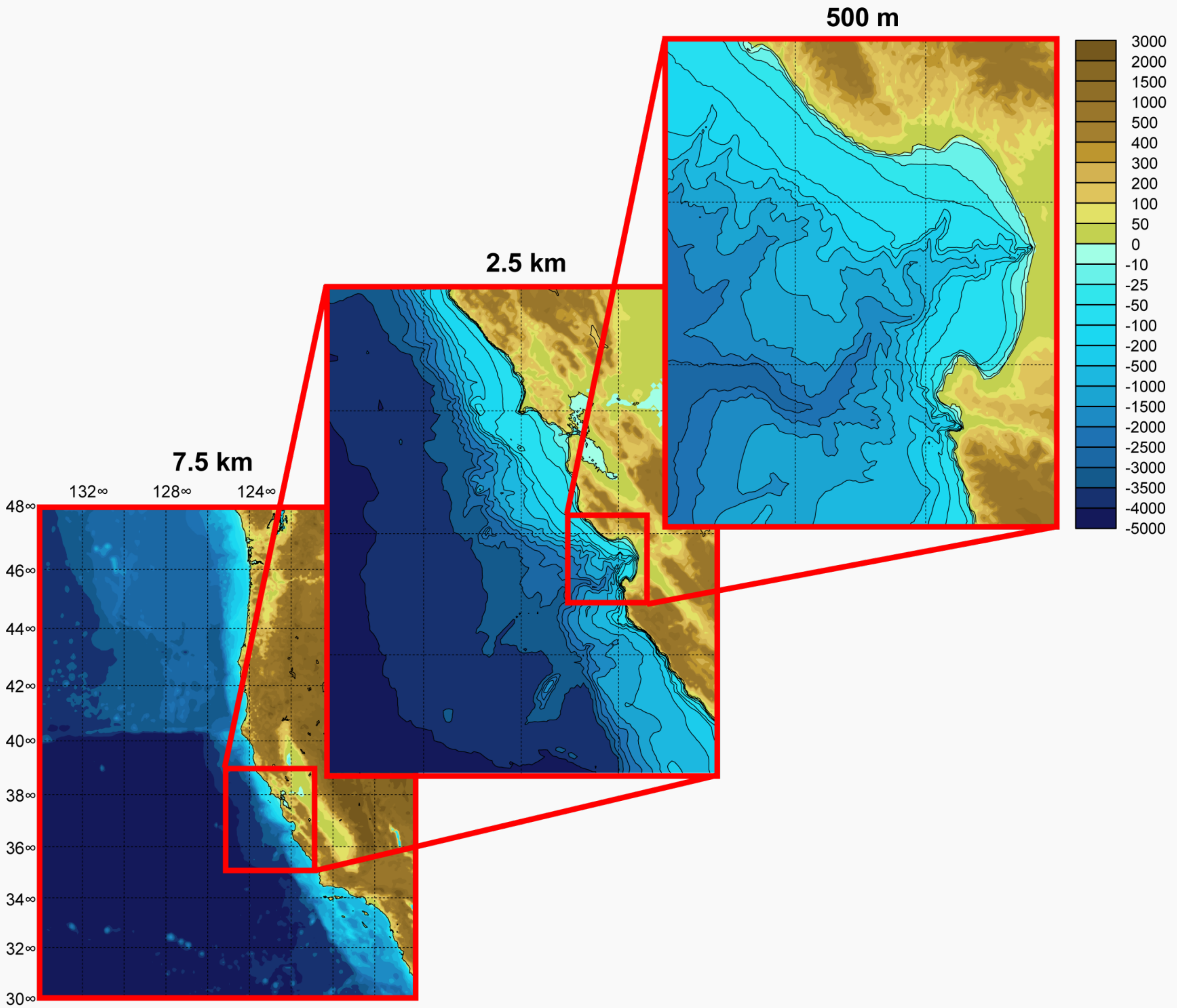
Future Work

- Submitted a NSF proposal to the SI2-SEE Program in collaboration with Eckart Meiburg (UCSB) to study Turbidity Currents in Monterrey Bay Cannon System.
- Combine ROMS with DNS and RANS models to study gravity flows and turbidity currents and associated sediment transport

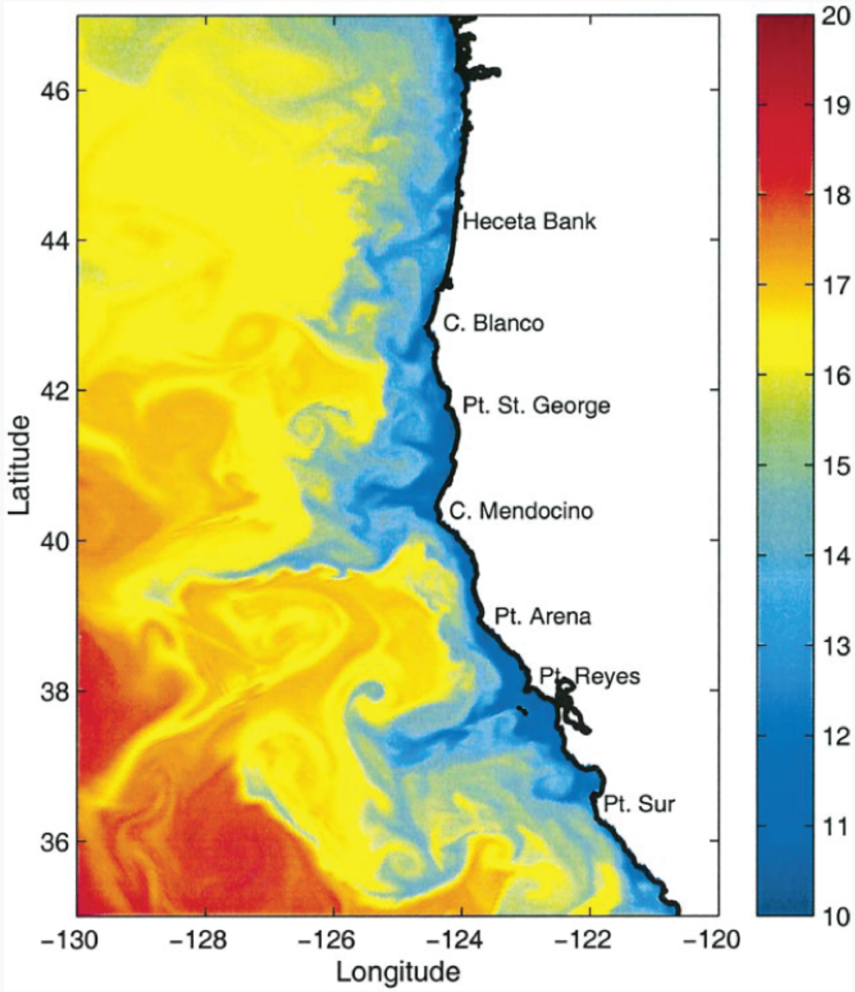
Monterey Canyon



Monterrey Bay Nested Grids



California Current System



From Patrick Marchesiello