Developing regional ocean modeling capabilities with MOM6 for use in UFS

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Some of the other contributors…

- Andrew Ross (GFDL)
- Matt Harrison (GFDL)
- Raphael Dussin (GFDL)
- Kate Hedstrom (UAF)
- Rob Cermak (UAF)
- Dujuan Kang (Rutgers)
- James Simkins (Rutgers)

Background

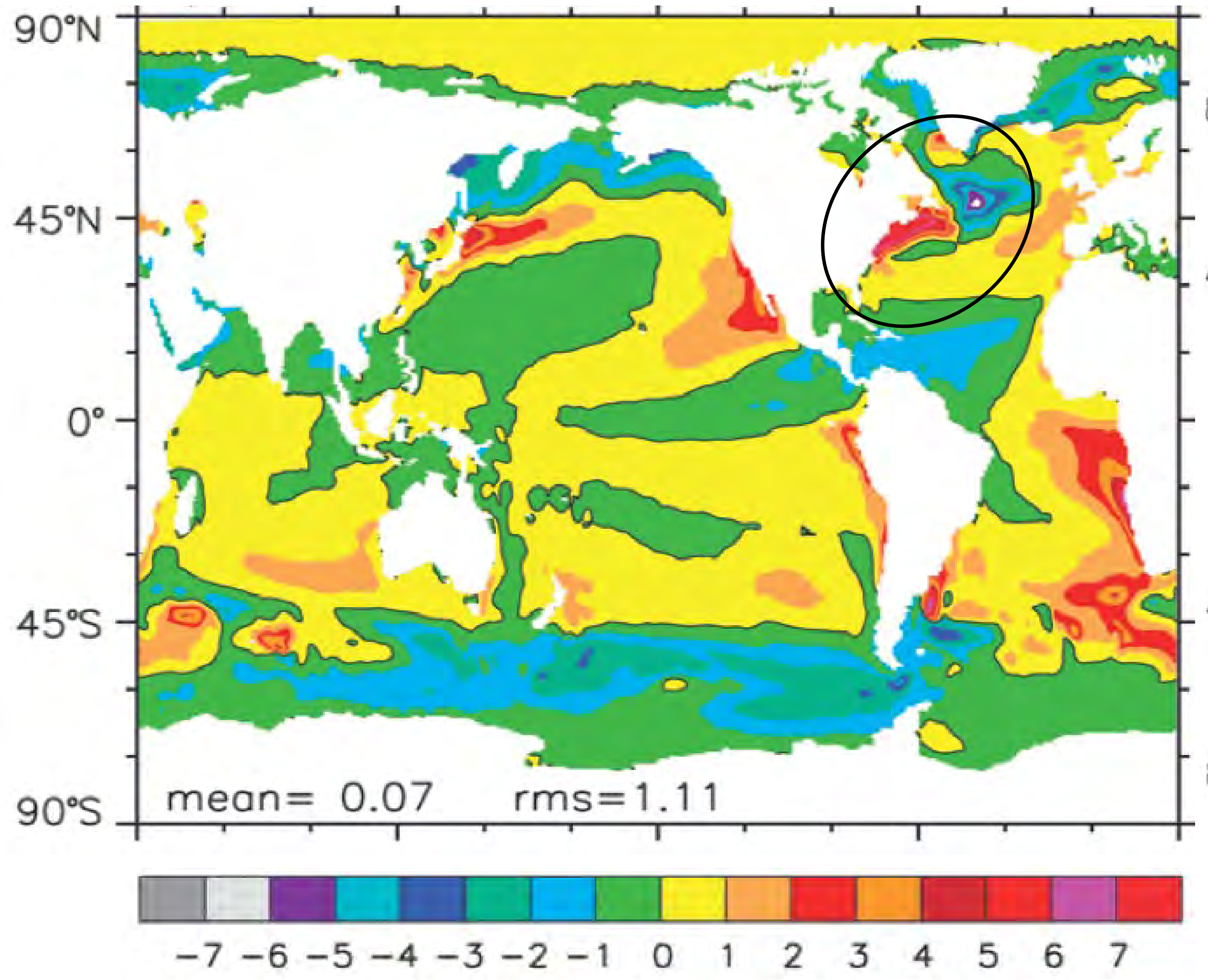
- Motivation:
  - Coastal regions susceptible to extreme weather events
  - 40% of US population lives in coastal regions
  - Significant economic contribution from coastal regions (industry, fisheries, tourism)
  - Provide accurate forecasts is paramount for the safety of the population and economic vitality of coastal regions
  - Global ocean models struggle in coastal regions

- Challenge:
  - Wide range of scales in the dynamics and environments (From sub-tropics to Arctic)

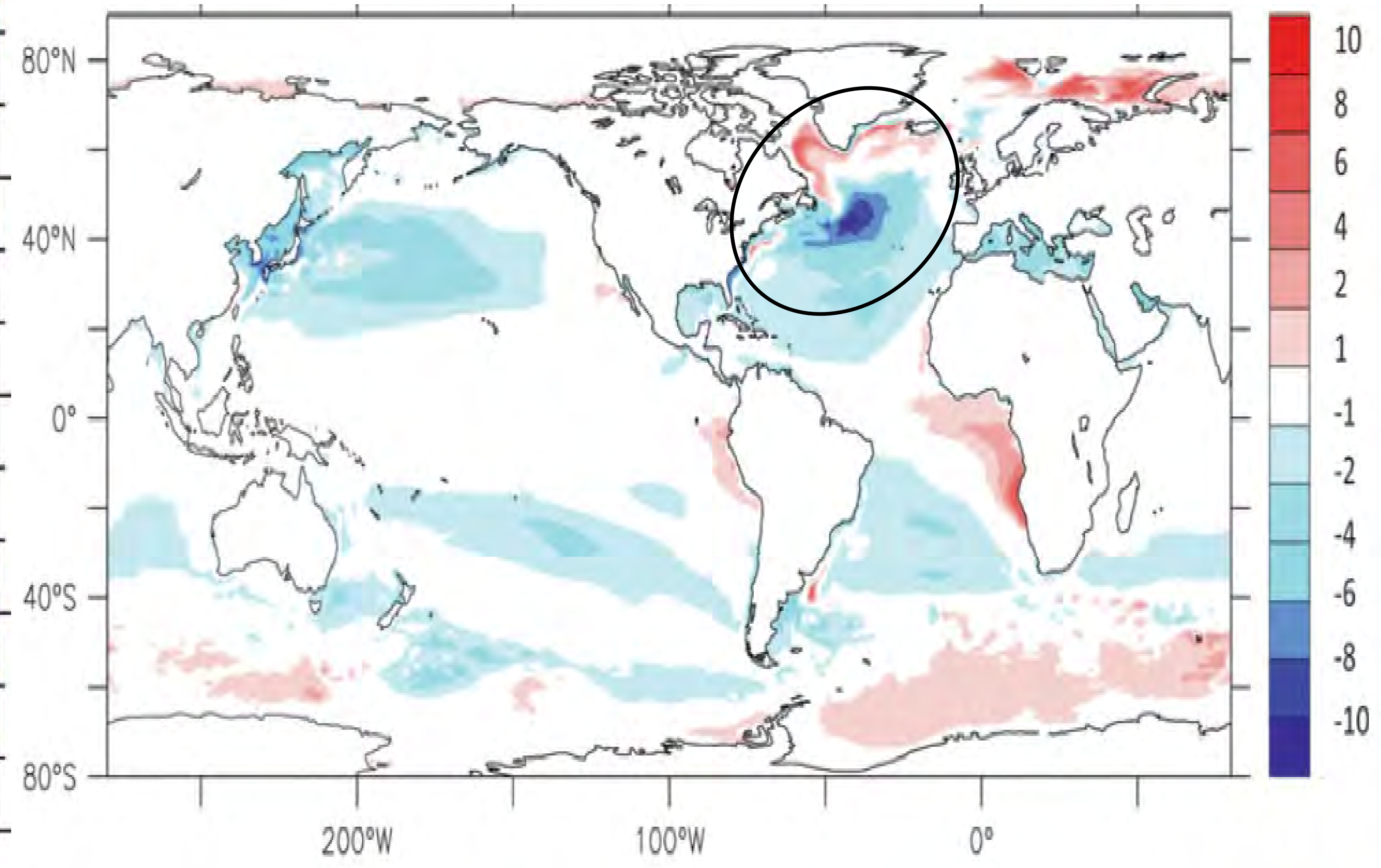
- Approach:
  - Develop a framework for investigating regional weather and climate dynamics via the use of multi-scale models

Climate Model Biases

- **SST Biases: Models - Observations**

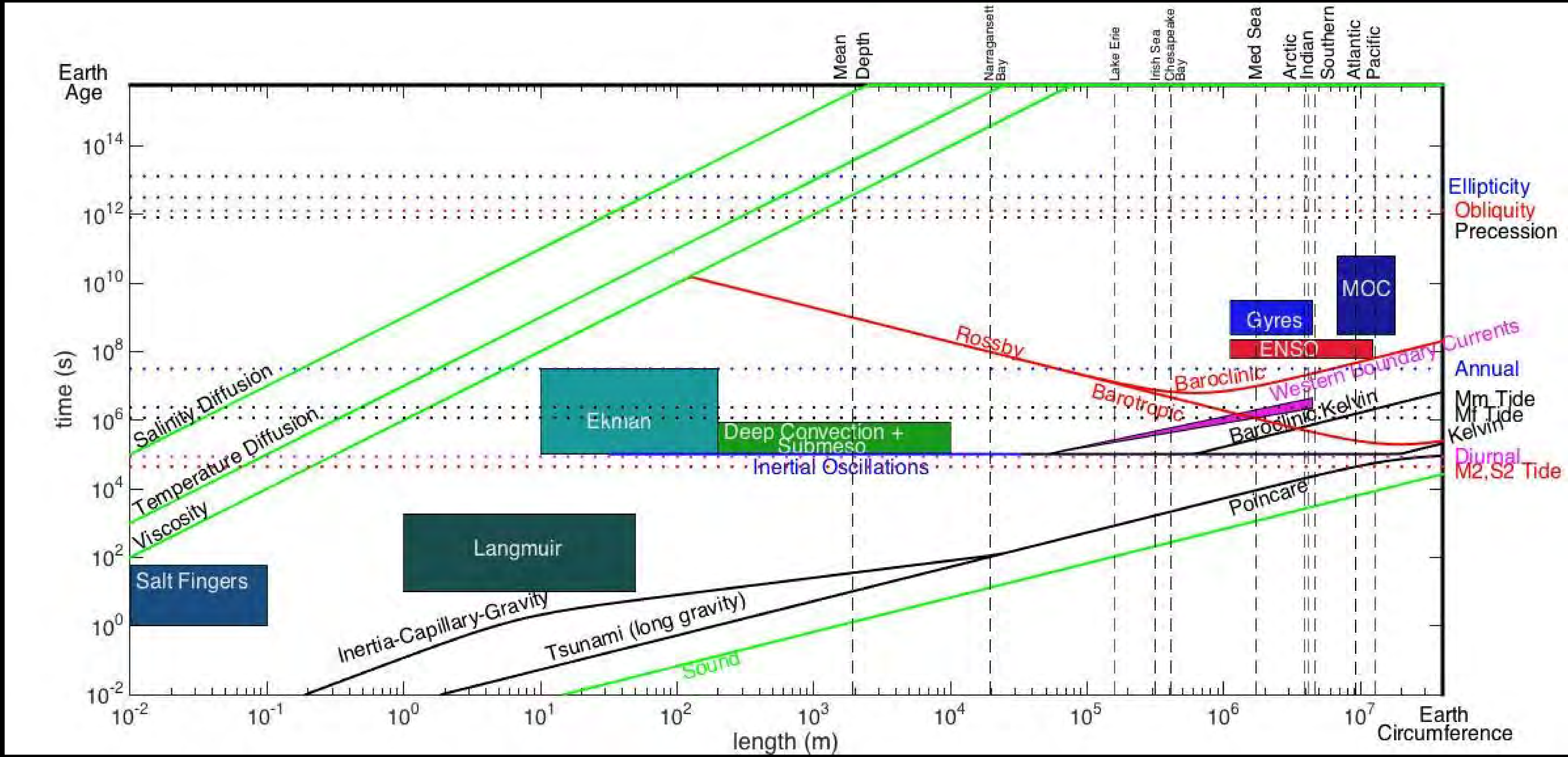


NCAR CCSM4 Model
(Gent et al., 2011)



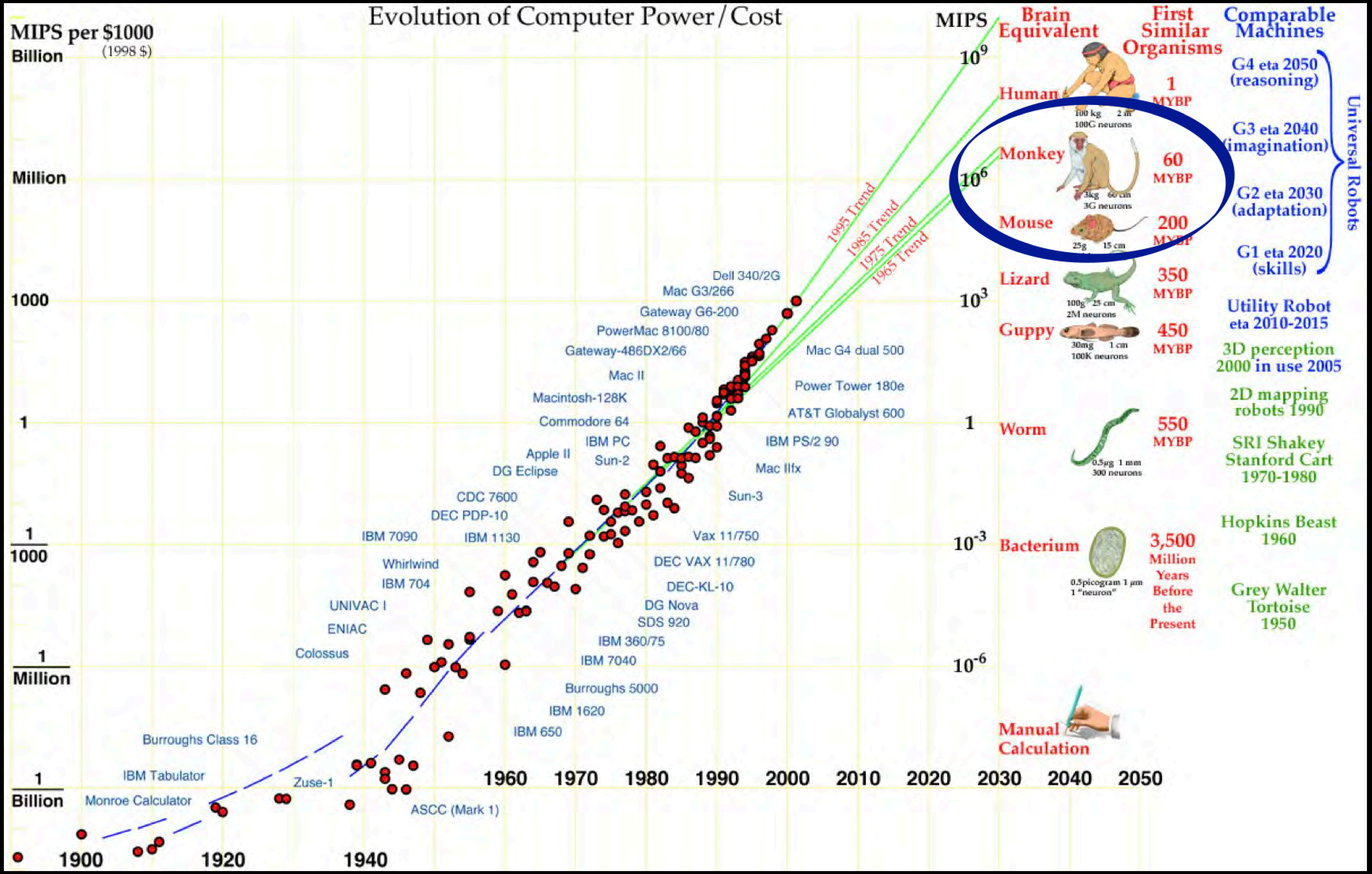
GFDL CM2.5 Model
(Delworth et al., 2012)

Space-time scales for some oceanic processes



Haidvogel, Curchitser, Daniflov and Fox-Kemper (2018)

Evolution of computational power



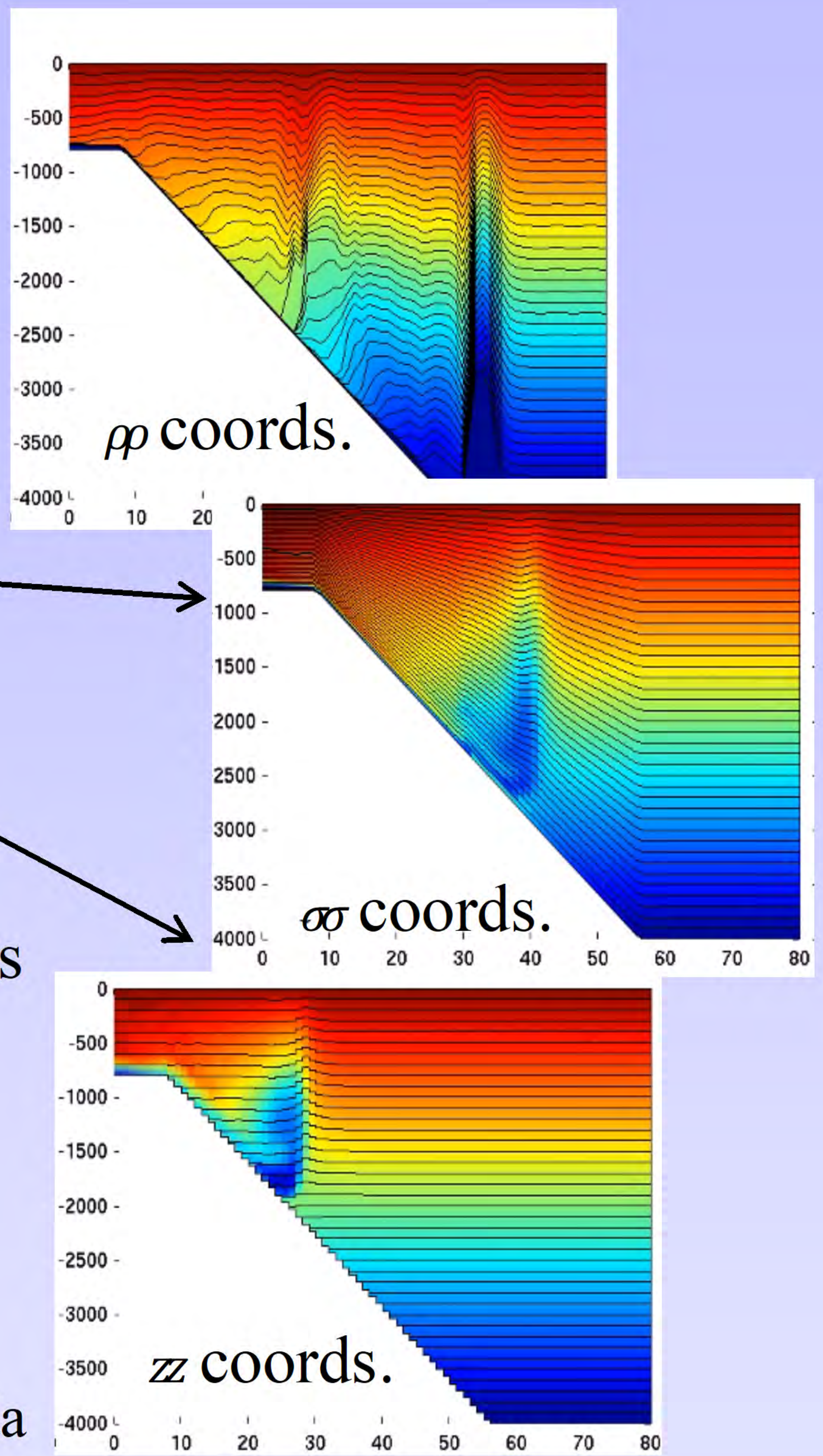
USF-HFIP goals

- HFIP: Reduce errors in forecast for TC track, intensity and other quantities
- HFIP working group advocates improved model resolution as the necessary and fundamental advancement needed to improve forecasting (e.g., Gall et al., 2012)
- NCEP/EMC has adopted GFDL-MOM6 as the next generation ocean model as part of HAFS
- Our goal is to address the HFIP requirements for improved representation of storm parameters by developing and implementing regional, high-resolution, ocean modeling capacity with MOM6

What is the MOM6 ocean model?

Community ocean model rooted in climate modeling
- Structured C-grid, Finite Volume Core
- Global climate modeling focus; Processes oriented origins
- Hydrostatic Primitive Equations
- Conservative, including wetting & drying (ice shelves)

Arbitrary Lagrangian Eulerian Method (ALE)
- General vertical coordinates
- No vertical CFL limit on timesteps/resolution
- Reduces numerical diapycnal mixing for some coordinates
- Efficiencies for biogeochemistry & passive tracers



Comprehensive set of physical process parameterizations
- Required for climate model projections into unobserved states
- Moving toward energetics-based formulations of params.

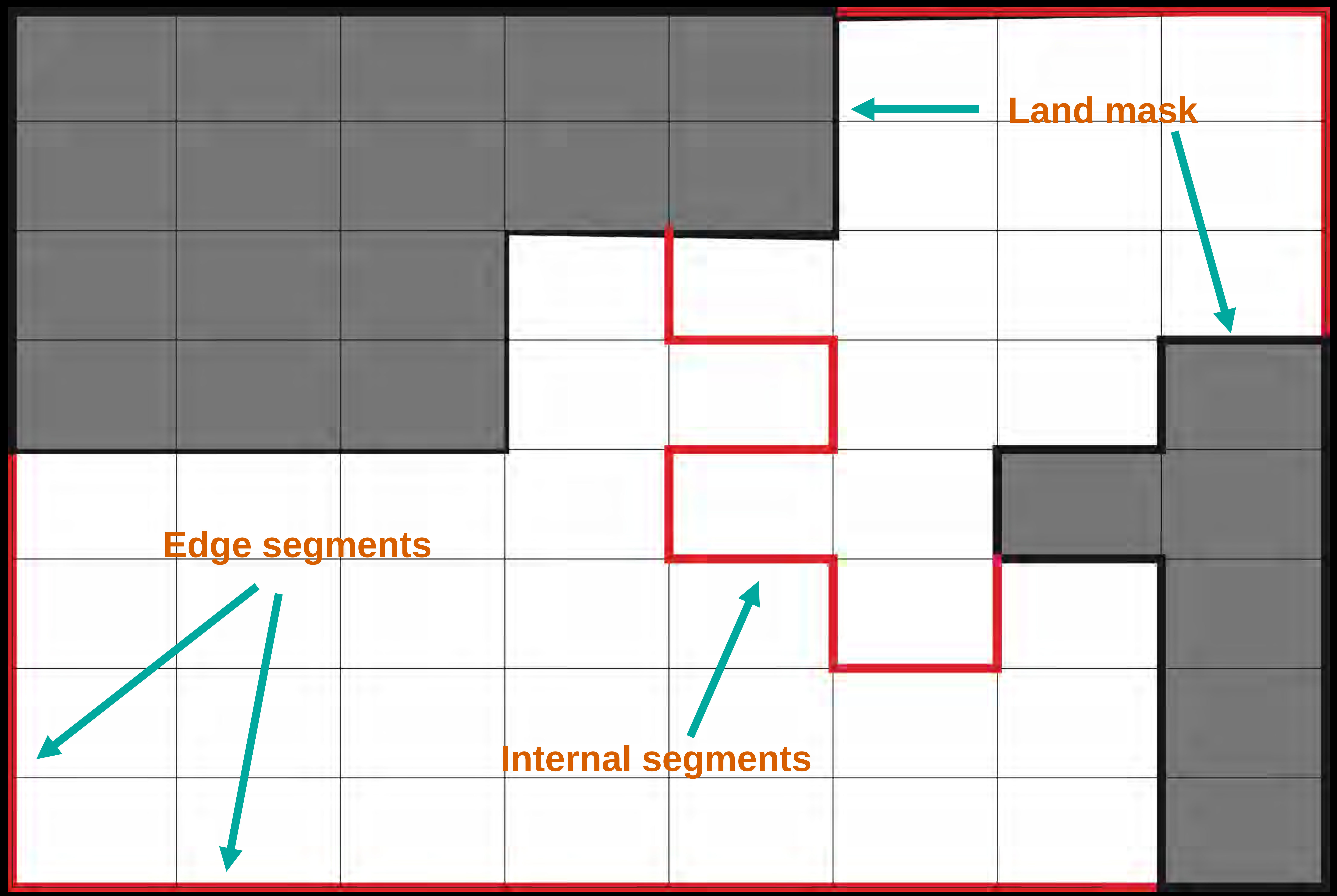
Many capabilities resulted from extensive collaborations
- 4 NSF/NOAA sponsored Climate Process Teams
- CVMix shared NCAR/GFDL/LANL vertical mixing code
- CLIVAR CORE/OMIP ocean-climate model comparisons
- Neutral mixing params. from Dr. A. Shao of U. Victoria, Canada

Embedding SIS2 sea-ice & GFDL icebergs in MOM6

Free Community Open Development with deliberate ocean model software design
- Design drew upon experience from MOM4/5, MITgcm, HIM, GOLD, Poseidon, …

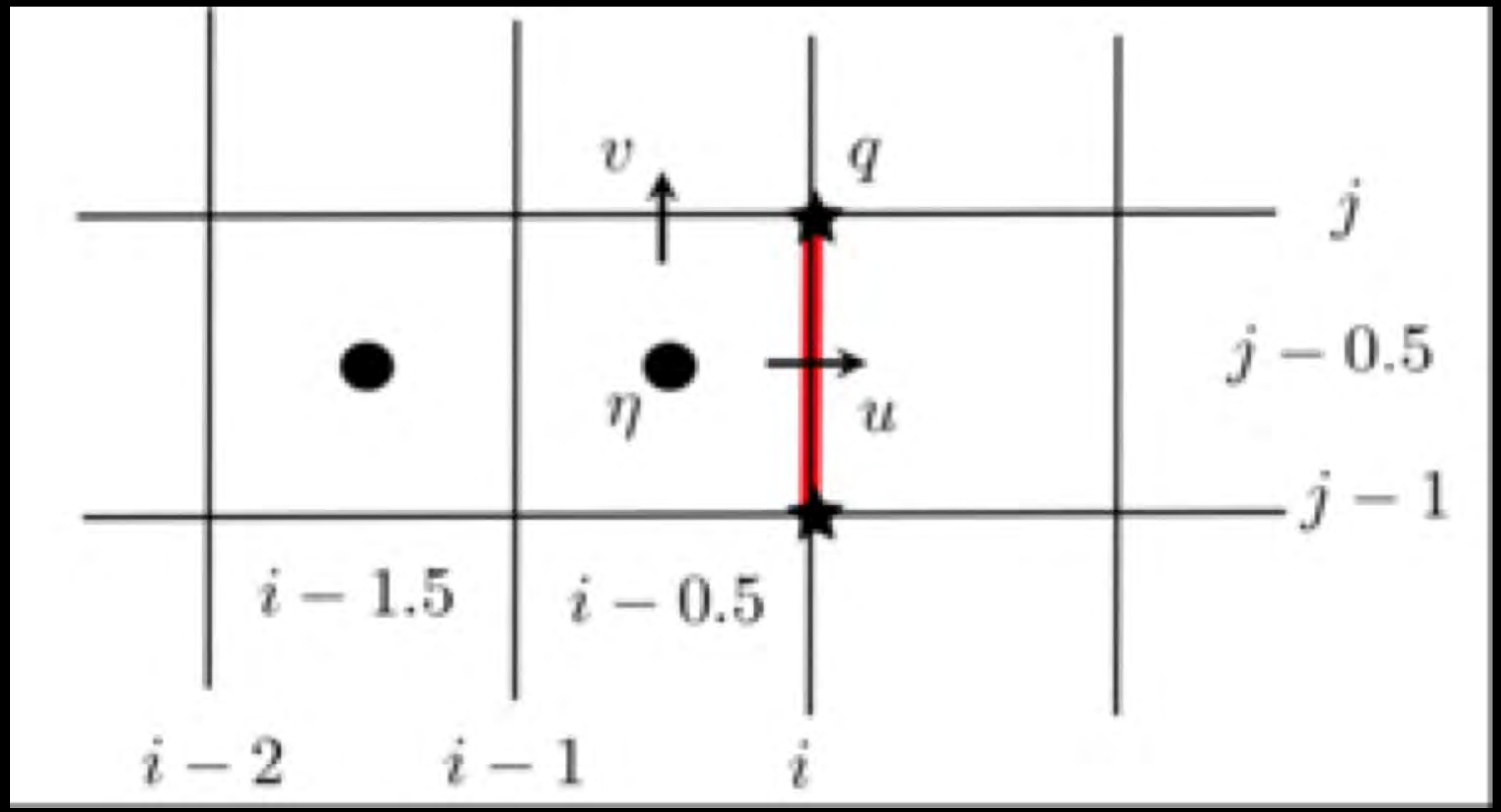
Slide from presentation by Bob Hallberg

How to build a regional model? Open Boundary Conditions!
Design philosophy: Put "OBCs" anywhere



Boundary conditions on the Arakawa C-grid

- Free surface
- Normal velocity
- Tangential velocity
- Tracers
- Layer thickness…would be nice but messy?



OBC Types currently in MOM6

For the normal velocity:

- SIMPLE (aka clamped), needs user code
- GRADIENT (zero gradient)
- FLATHER - barotropic mode
- ORLANSKI - radiation for baroclinic mode
- OBLIQUE - another radiation
- NUDGED - modifier to radiation

For the tangential velocity:

- Strain/Vorticity (Lateral viscosity/Coriolis):
  - Free slip (zero gradient)
  - Specified dv/dx or du/dy from file or radiation condition
  - Computed using velocities from file or radiation condition
  - Zero

Boundary conditions: Barotropic mode

- Flather (needs boundary information for both $U_{barotropic}$ and free surface **η**

$$\bar{u} = \bar{u}_{ext} + \sqrt{\frac{g}{H}}(\eta - \eta_{ext})$$

Boundary conditions: Baroclinic

- Baroclinic Mode:
  - Orlanski or oblique radiation (Raymond & Kuo): Compute local normal phase speed (also used for tangential velocity if needed)

$$\frac{\partial\phi}{\partial t} = -\left(\phi_\xi \frac{\partial\phi}{\partial\xi} + \phi_\eta \frac{\partial\phi}{\partial\eta}\right)$$

where $\phi_{\xi,\eta}$ are the phase speeds

  - On inflow, either zero gradient nudged to external value (Marchesiello)

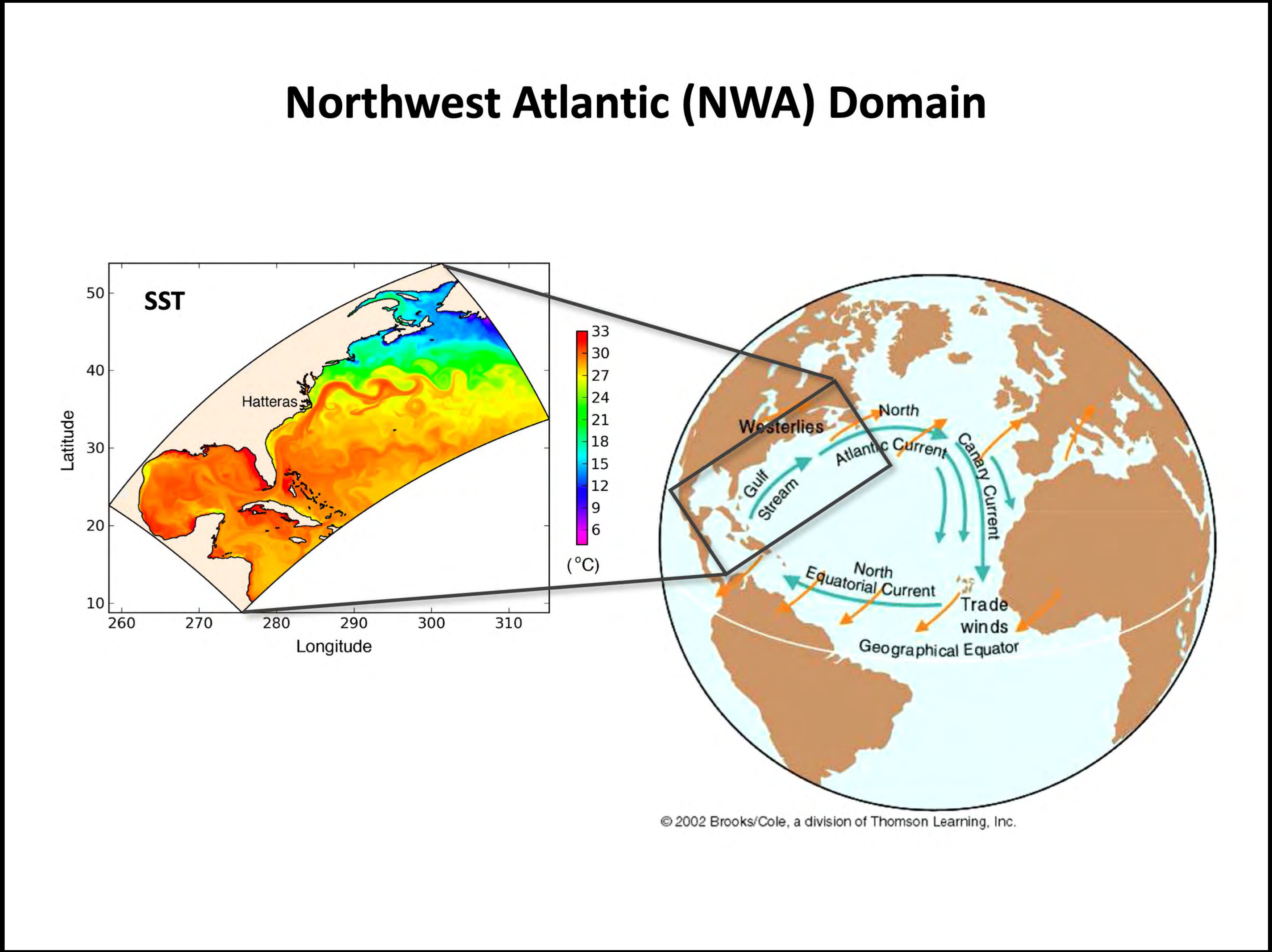
More boundary conditions

- Tracers
  - A reservoir has memory of fluid that has left the domain out of each boundary
  - Can also mix in external values of tracers on inflow
  - Mixing lengths set relative contributions of each tracer
- Layer thickness (used in continuity and Coriolis computations)
  - Set to no-gradient
  - With ALE, may be difficult to implement other options

Boundary conditions:
Explicit tidal boundary forcing

- User provides tidal amplitude and phase data along the boundary for elevation and barotropic u and v velocities [for example, derived from TPXO tide model dataset].
- MOM6 calculates tidally varying elevation and velocity from amplitude and phase, which is then superimposed on the boundary data for non-tidal elevation and velocity.
- Includes option to modulate tides by the 18.6 year nodal cycle.
- Can be used alone or in addition to the tidal potential forcing, including self-attraction and loading, already available in MOM6.

MOM6 Implementation in the Northwest Atlantic



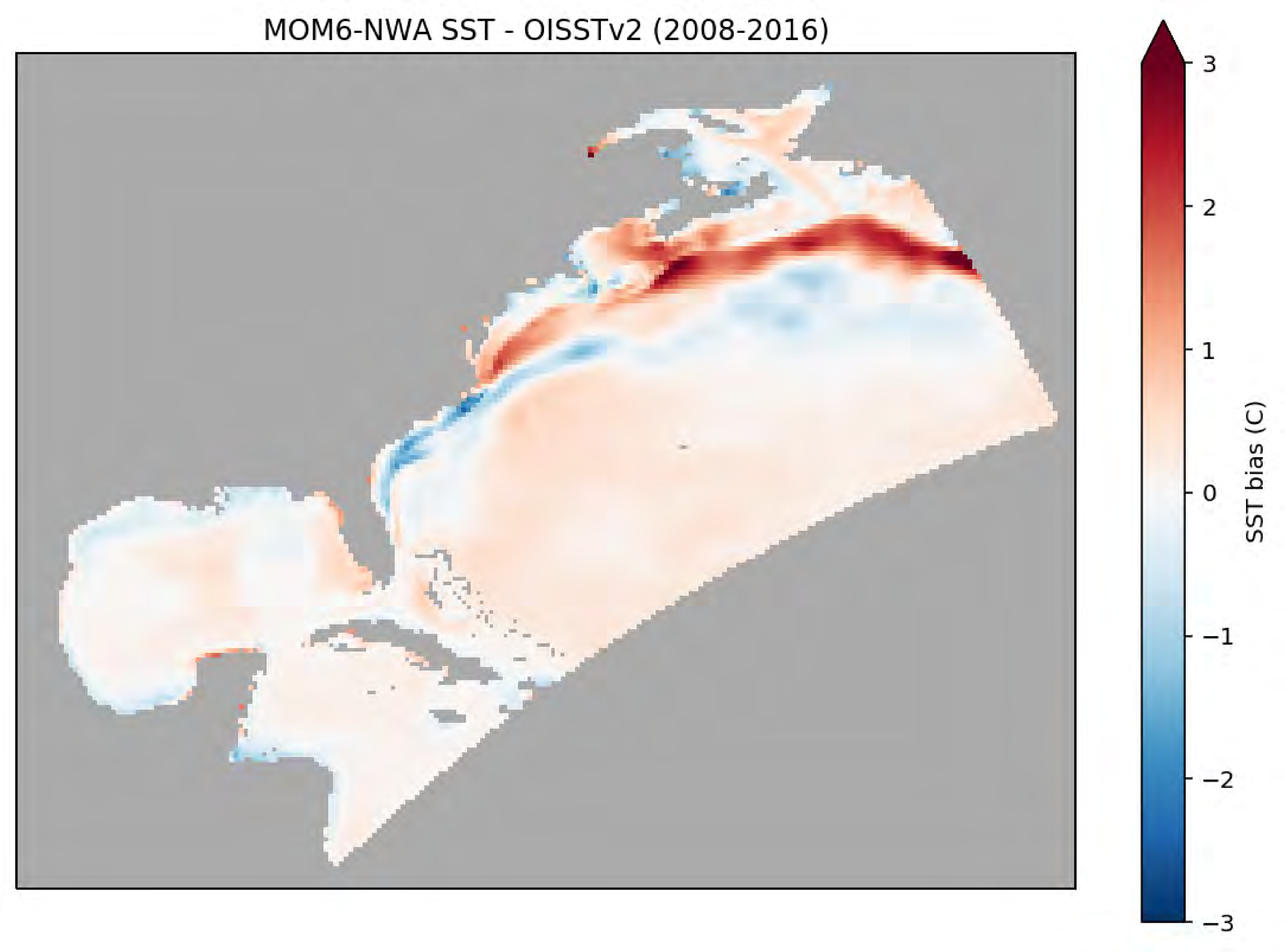
MOM6 Implementations: NW Atlantic

MOM6-NWA Setup

- **Regional MOM6 simulation of Northwest Atlantic (NWA)**
  - **Grid** (converted from ROMS grid of Kang & Curchitser, 2013)
    - **Horizontal**: ~7 km resolution, 720 x 360 grid points
    - **Vertical**:
      - Geopotential (z*) NK=75 & NK=50
      - Hybrid Hycom1 (z* & ρ) NK=75
  - **Forcing**
    - **Ocean BC & IC**: SODA3
    - **Atmospheric forcing**: JRA55-do
    - **Runoff**: Dai & Trenberth river discharge
  - **Computation** (1 simulation year)

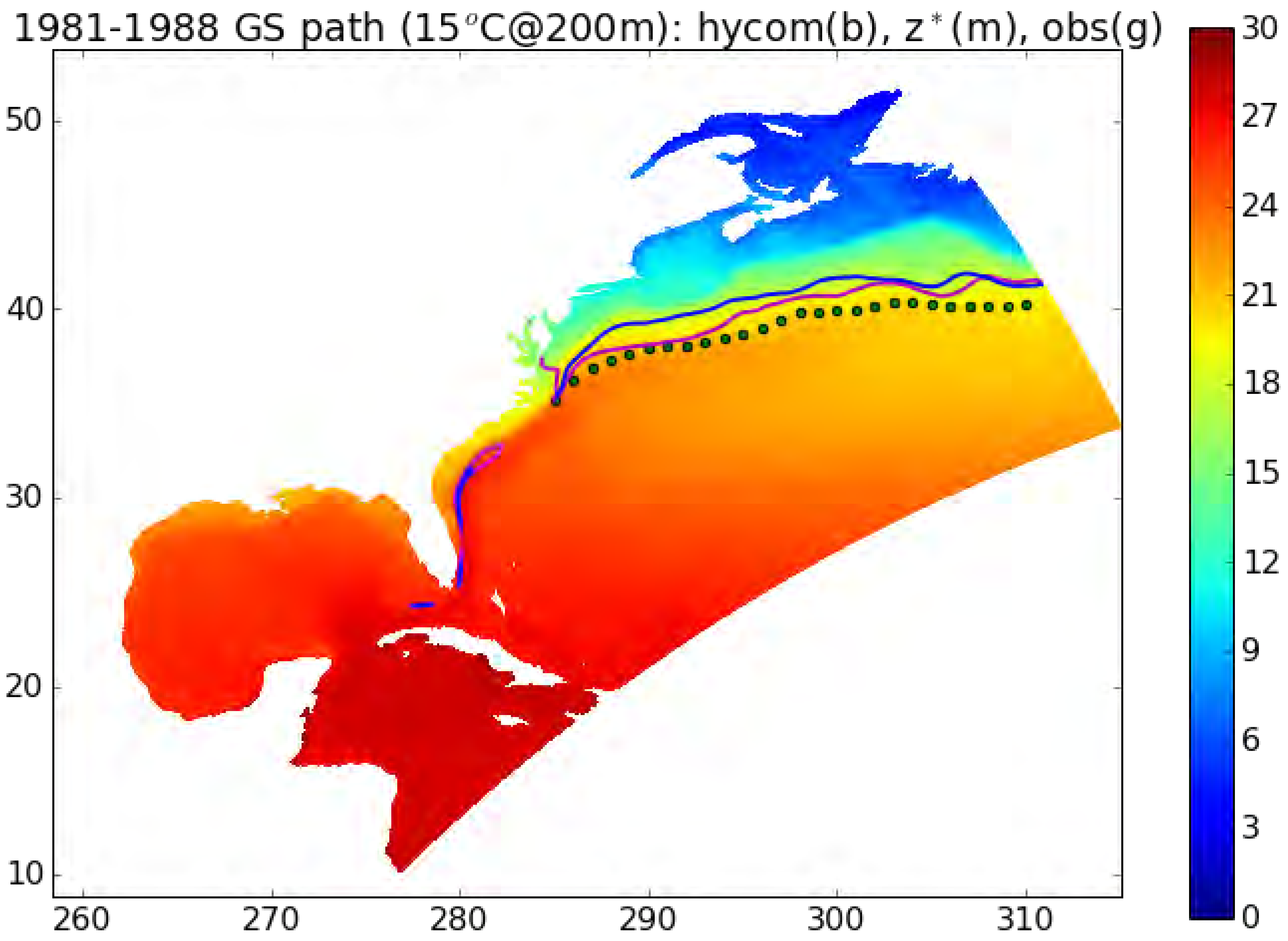
z* (NK=50)	z* (NK=75)	hycom1 (NK=75)
15x160 = 2400 CPU hrs	19x240 = 4560 CPU hrs	21x240 = 5040 CUP hrs

Model evaluation: SST



Gulf Stream Mean Path

15º C @ 200m



hycom1 z* observation

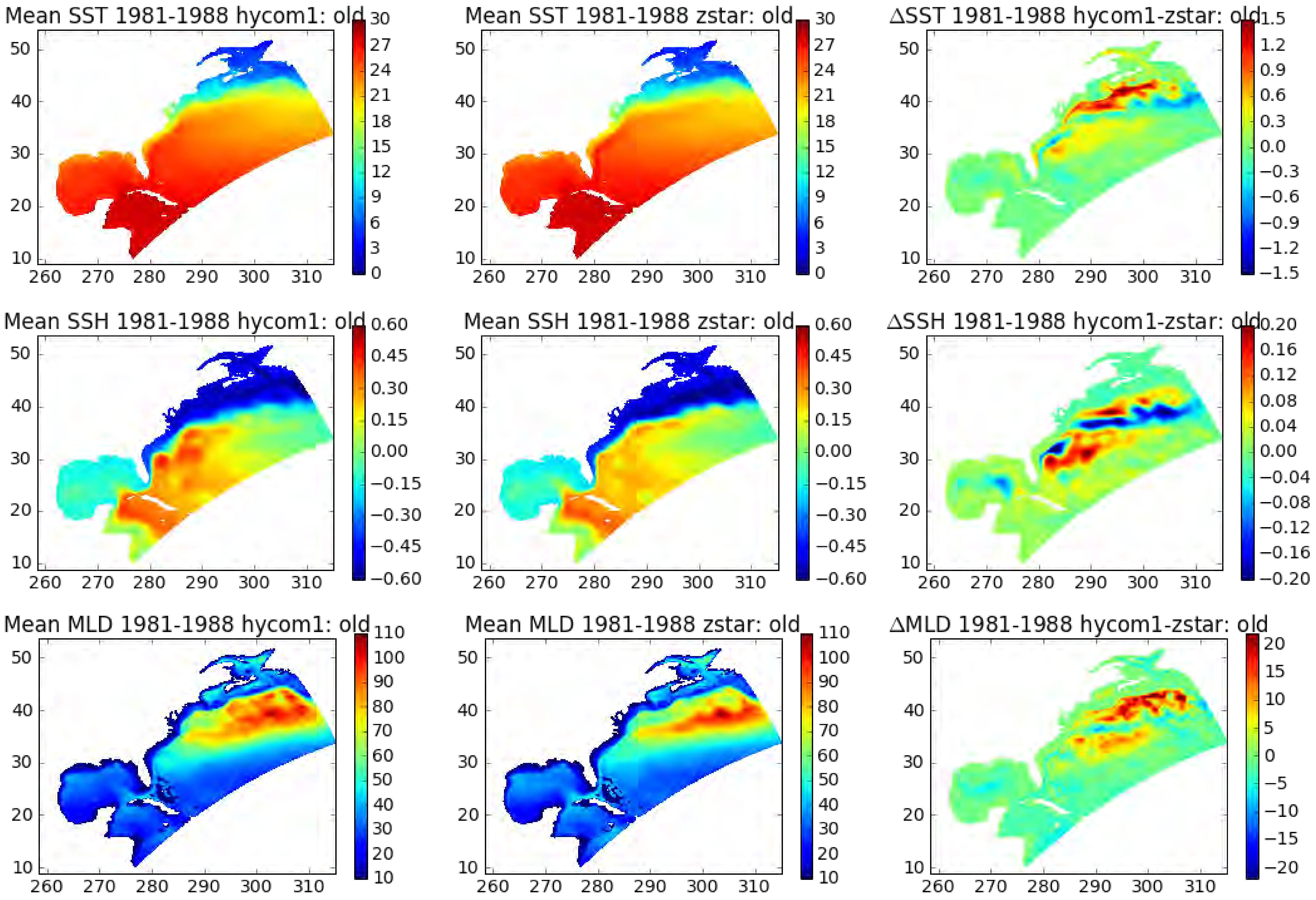
Mean Features: z* vs. hycom1

hycom1 | **z*** | **hycom1 - z***

SST

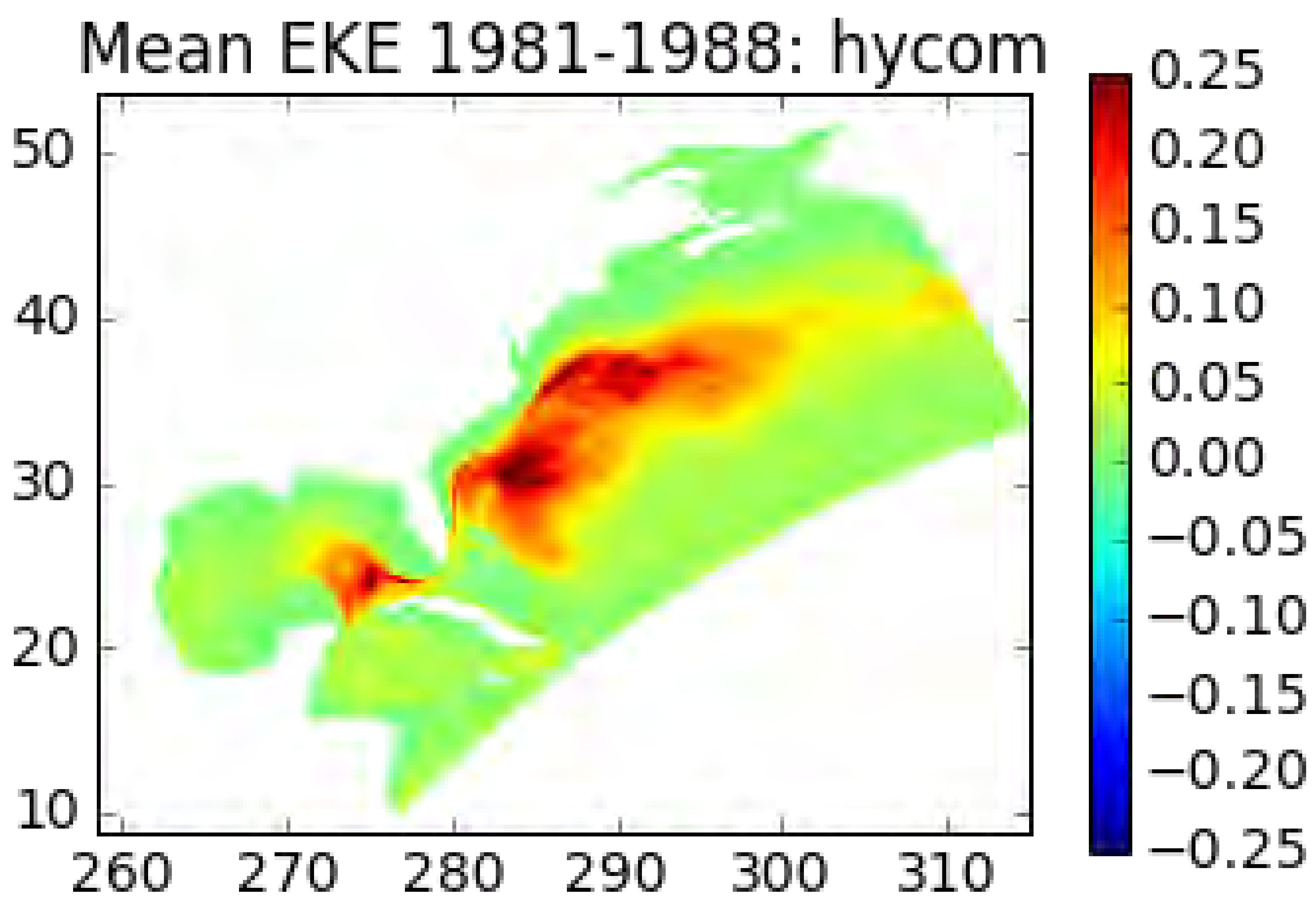
SSH

MLD

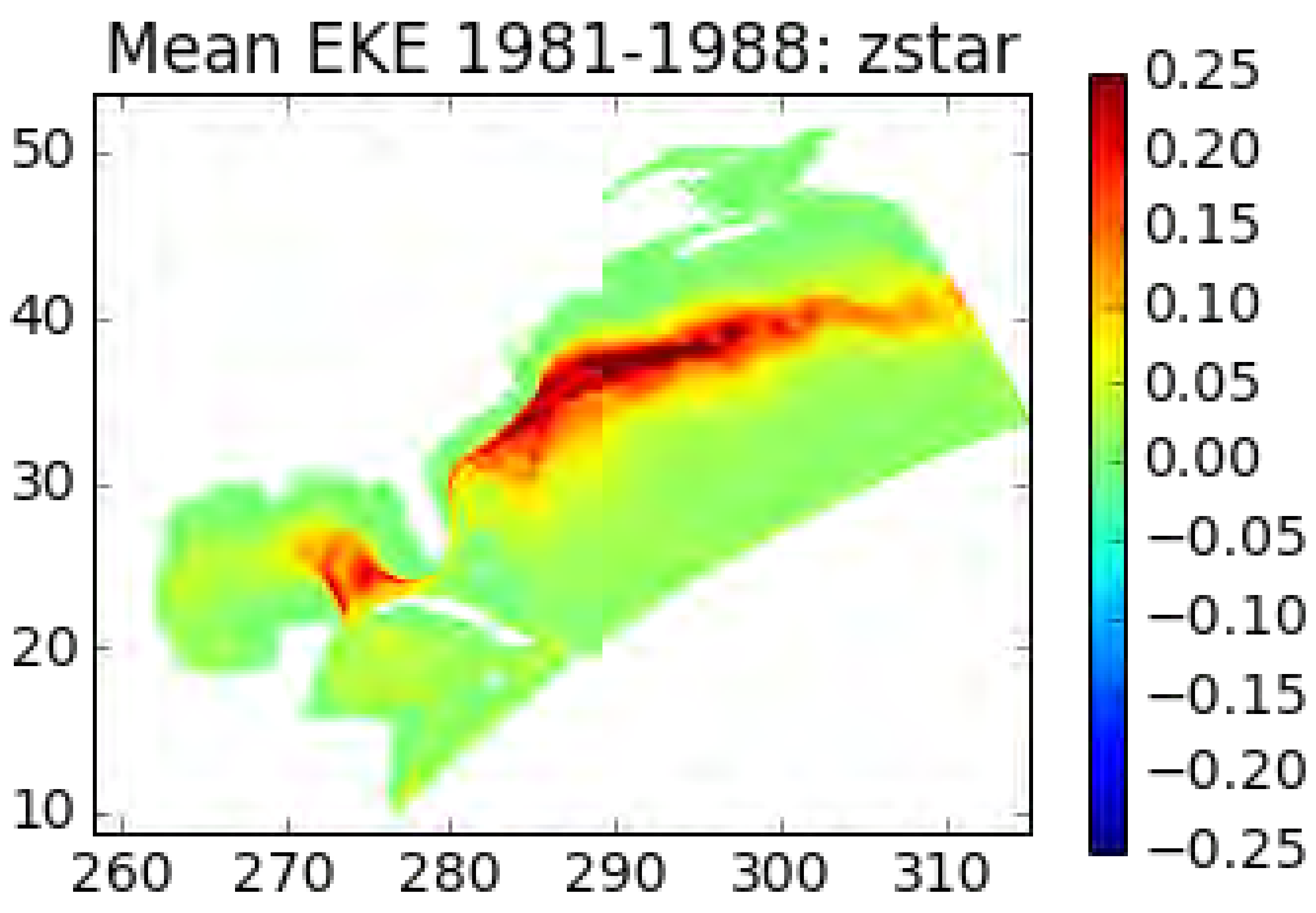


Eddy Kinetic Energy (EKE)

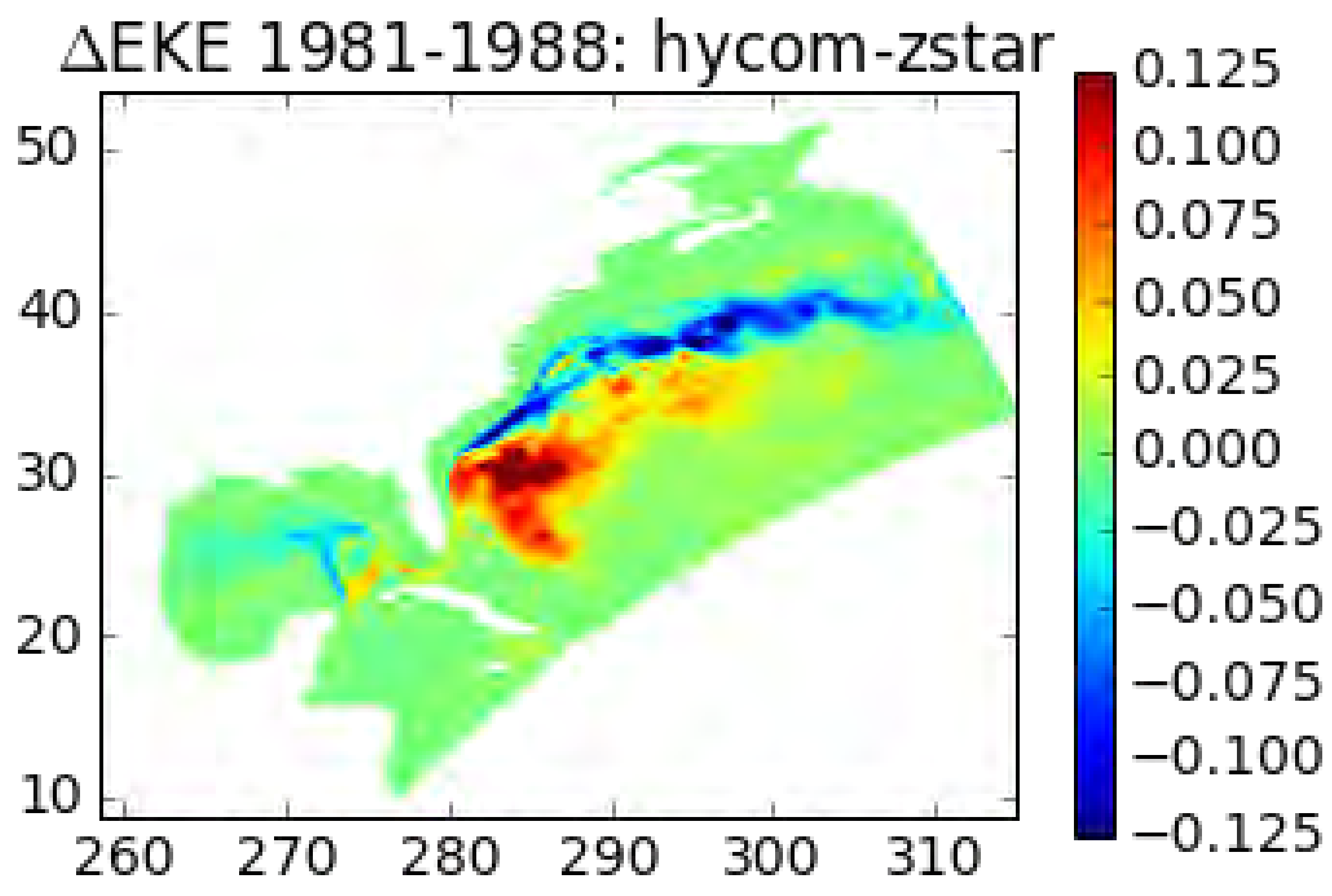
hycom1



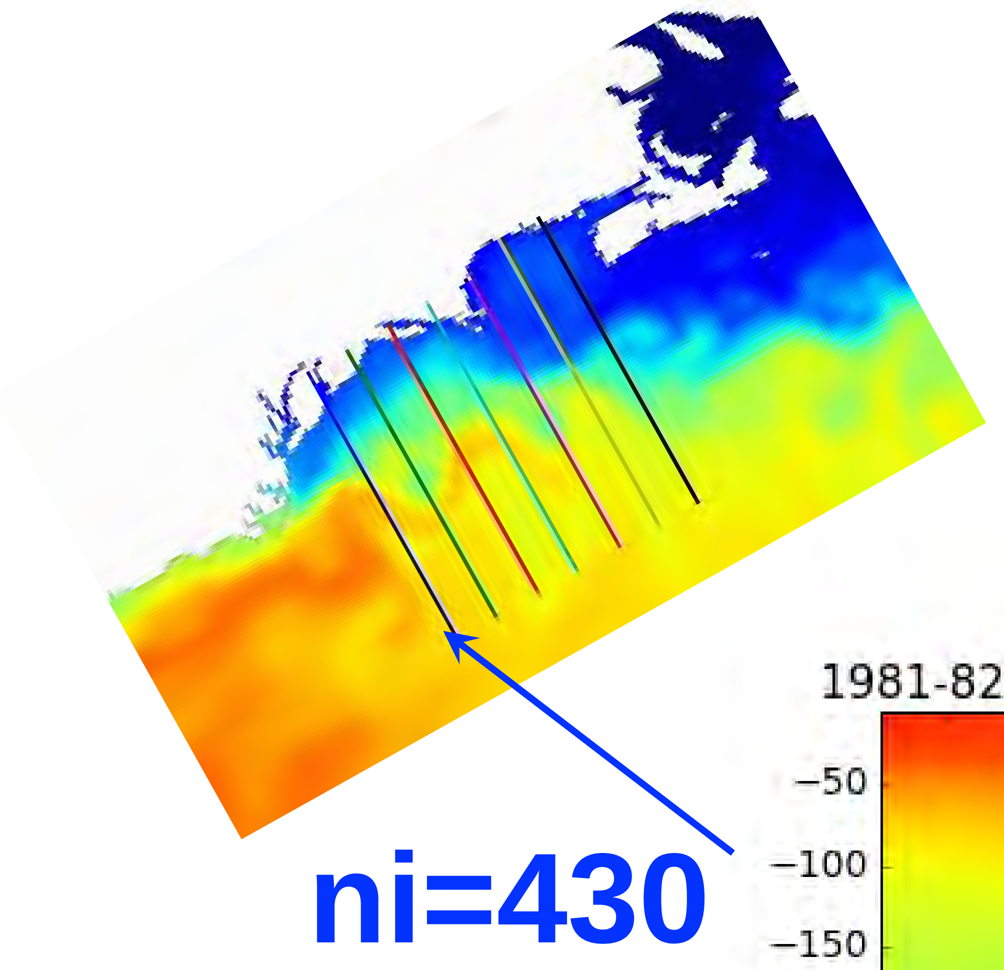
z*

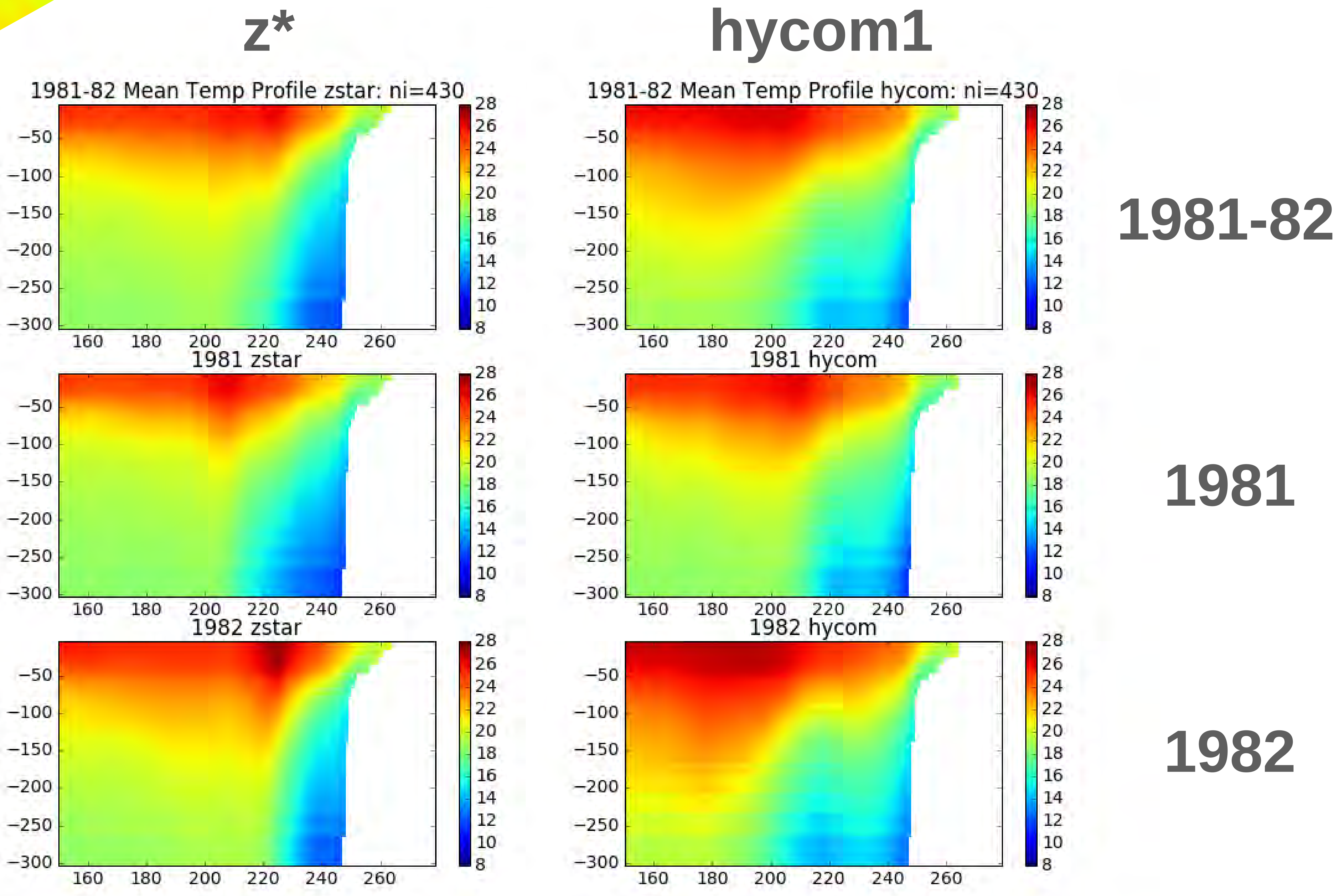


hycom1 - z*

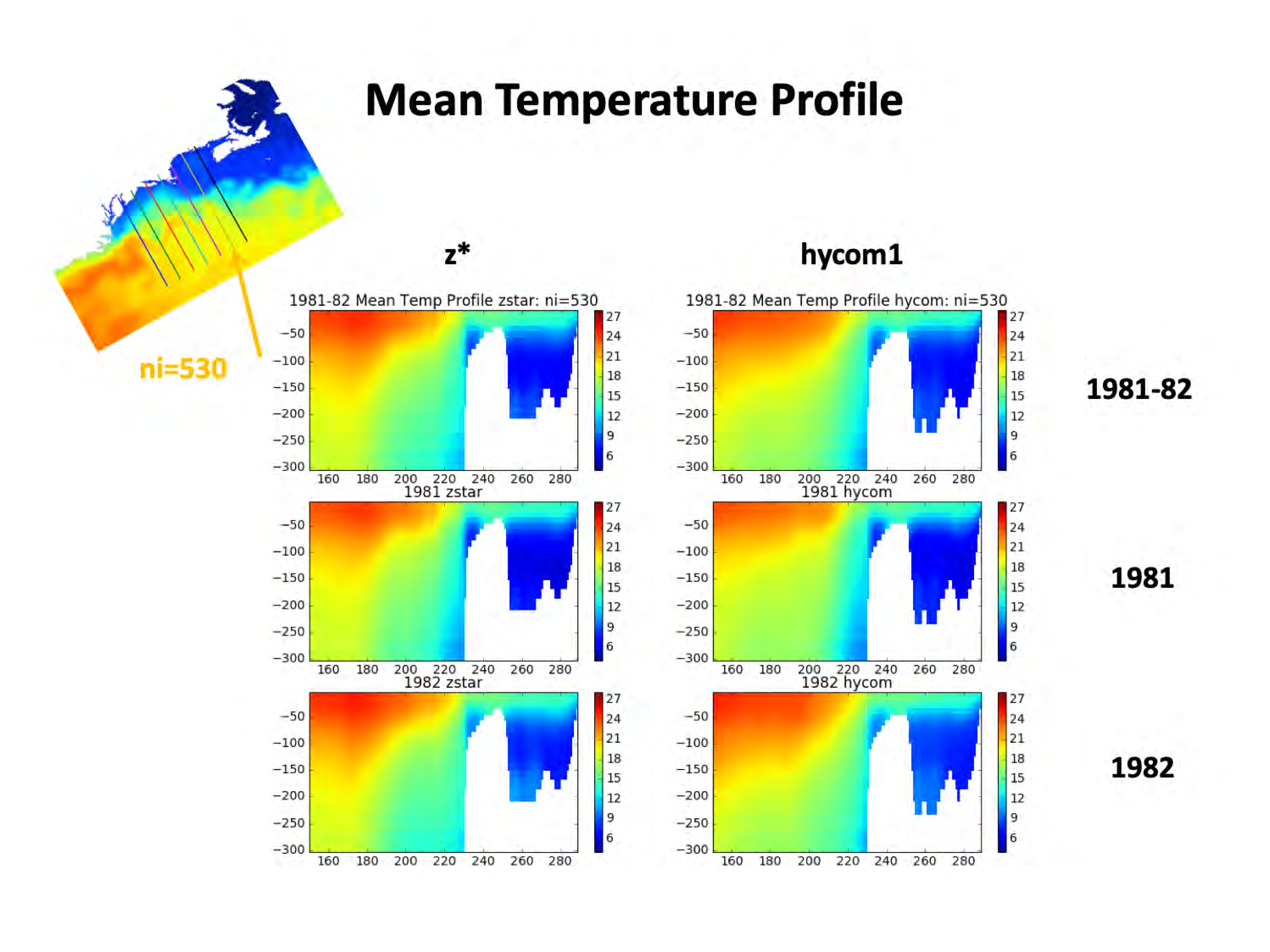


Mean Temperature Profile





MOM6 Implementations:
NW Atlantic temperature transects



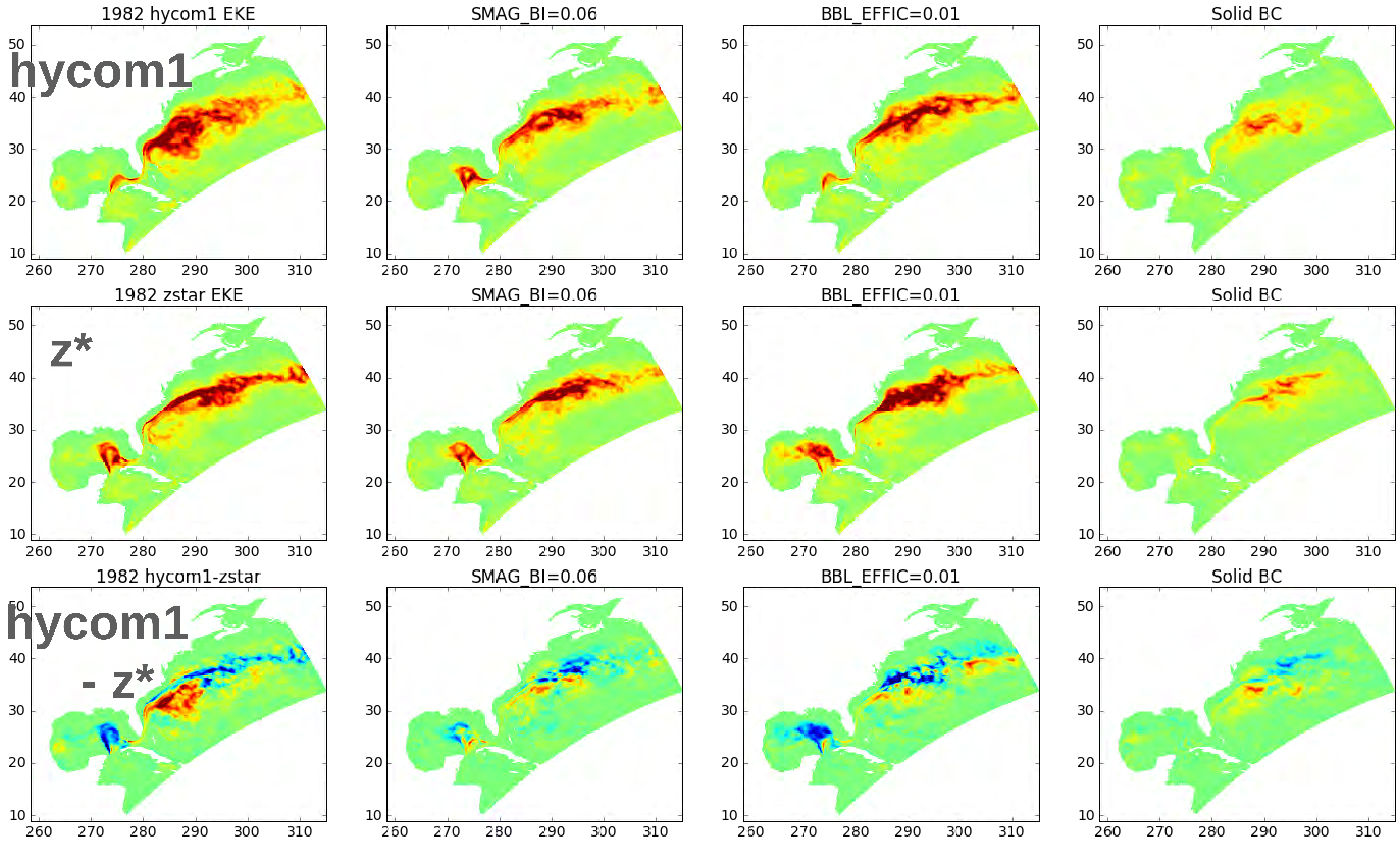
Different MOM6-NWA Settings

- **Different parameters in MOM_input**

	Control	SMAG	BBL	Solid
SMAG_BI	0.015	**0.06**	0.015	0.015
BBL_EFFIC	0.2	0.2	**0.01**	0.2
CORIOLIS_SCHEME	SADOURNY75_ENSTRO	SADOURNY75_ENSTRO	**SADOURNY75_ENERGY CORIOLIS_EN_DIS = True**	SADOURNY75_ENSTRO
BC (East, South)	open	open	open	**wall**

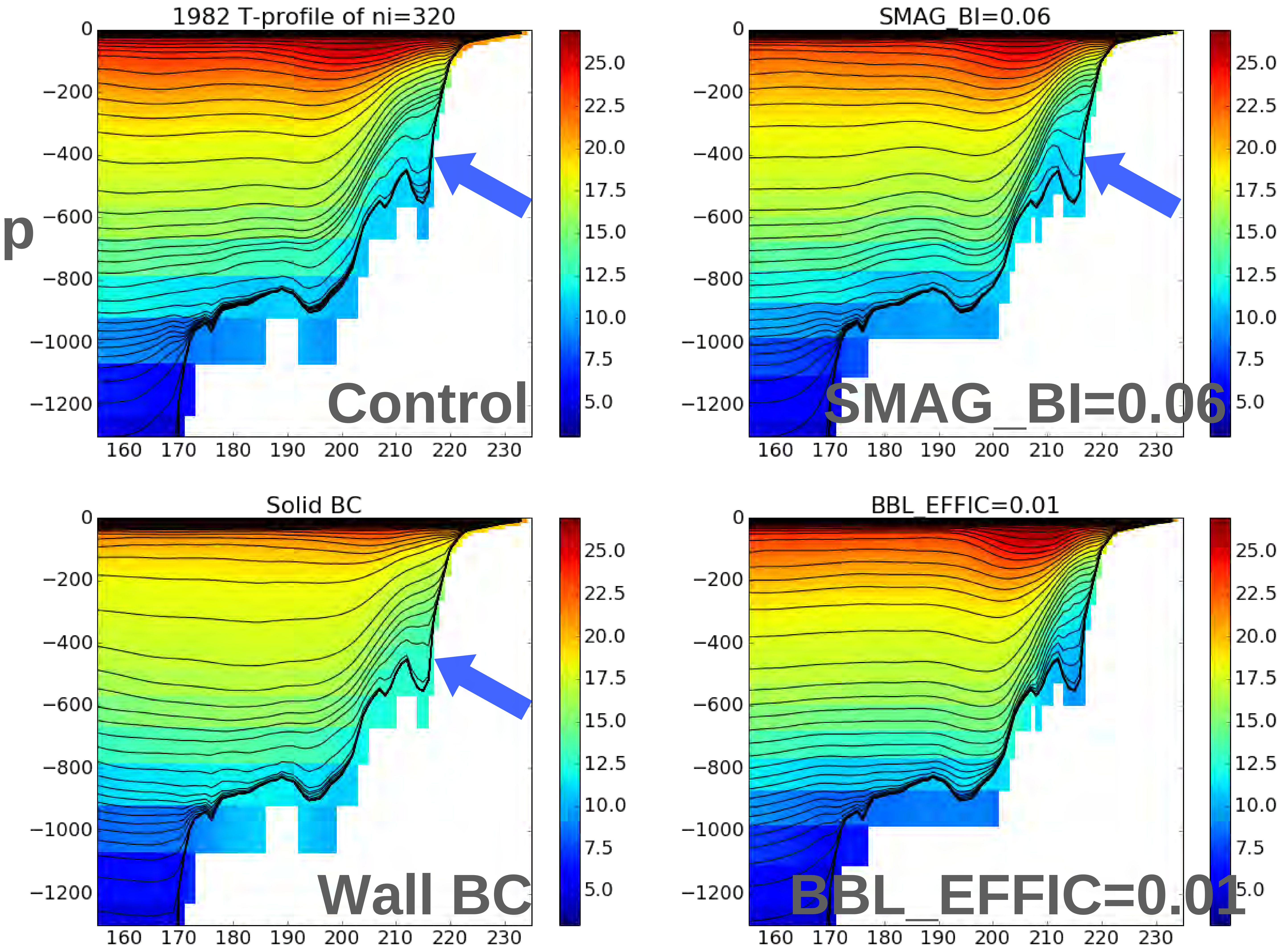
Mean EKE: 1982

Control SMAG_BI=0.06 BBL_EFFIC=0.01 Wall BC

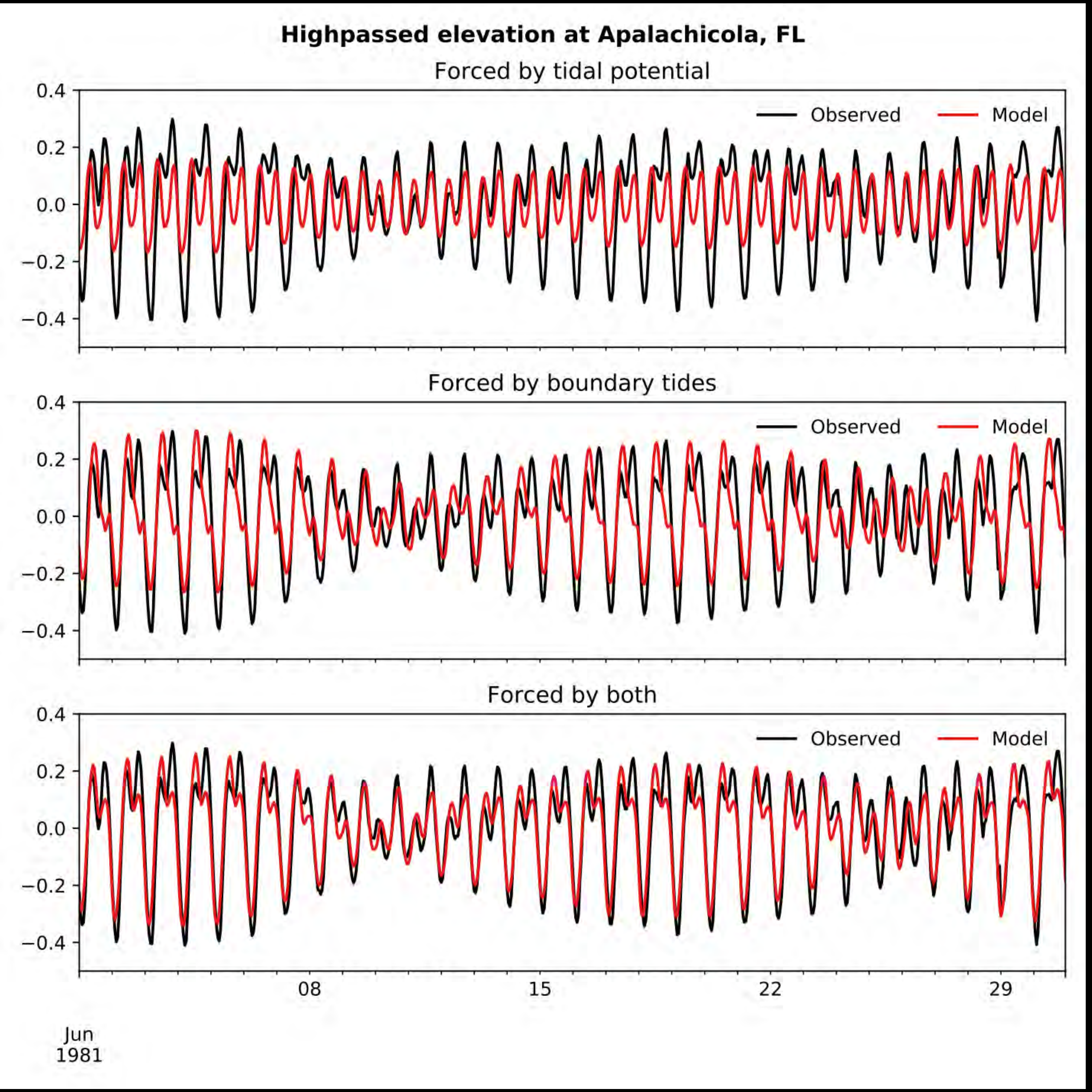


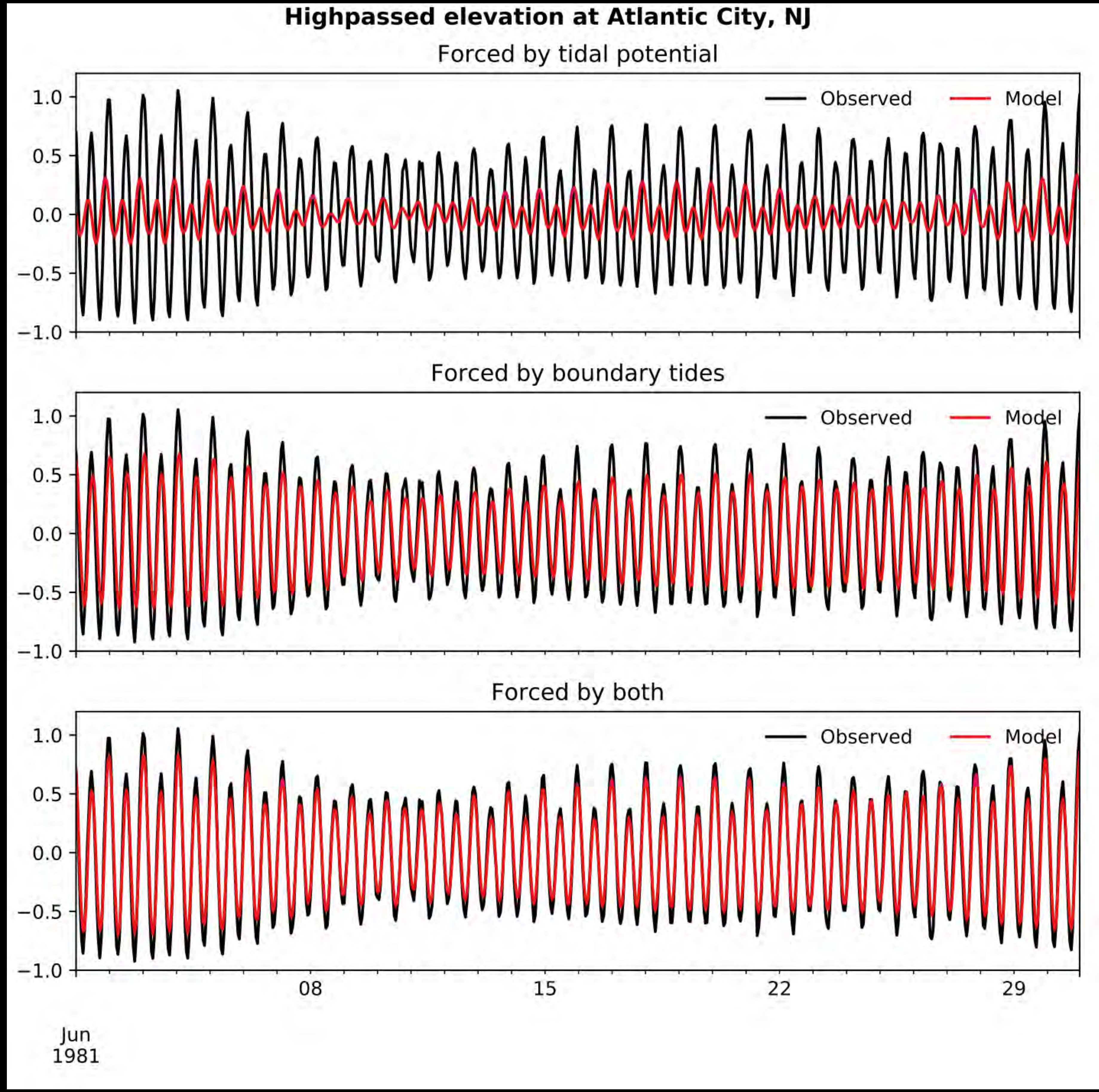
Mean T-profile across Charleston Bump: hycom1

ni=320, across Charleston Bump

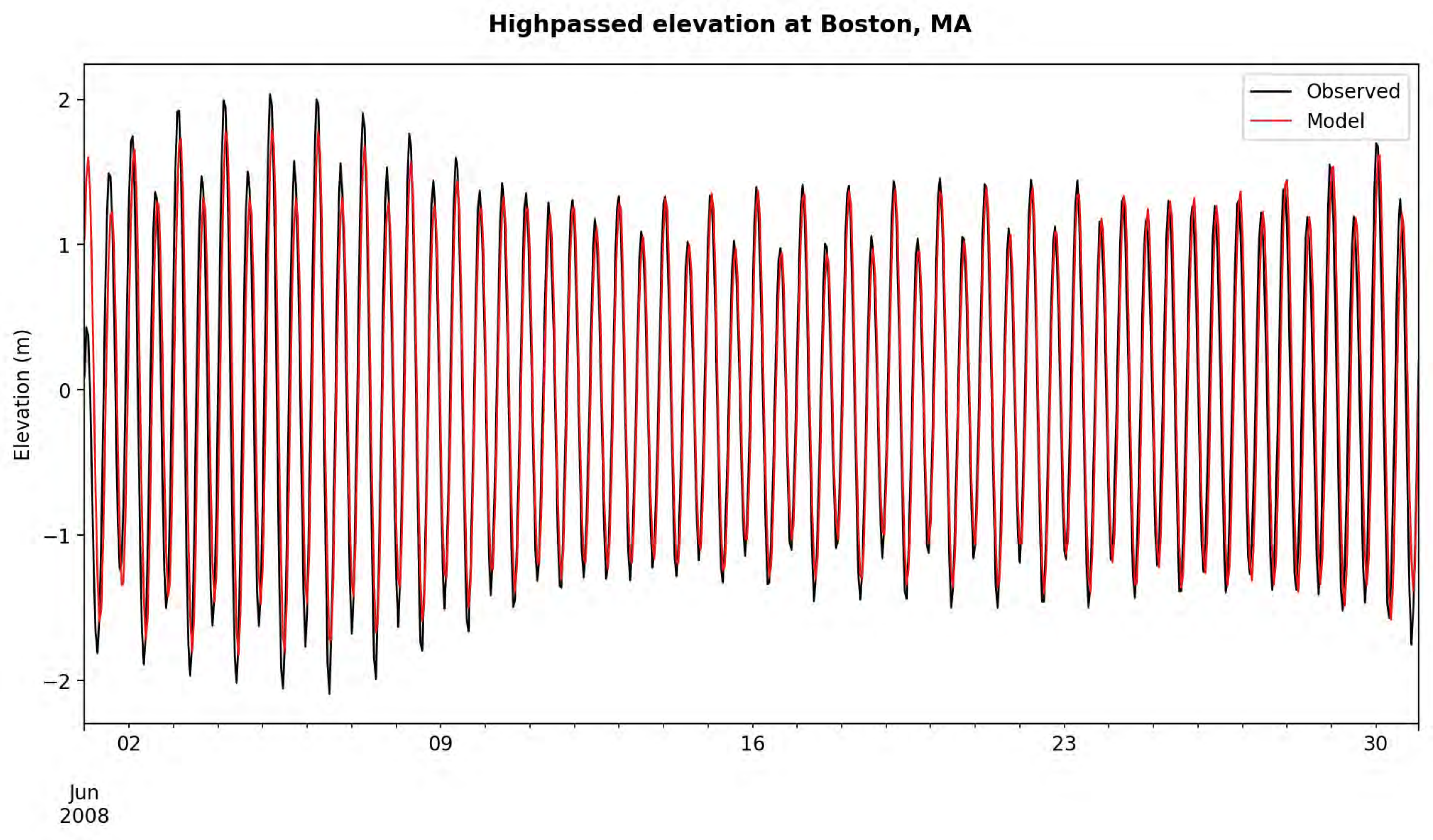


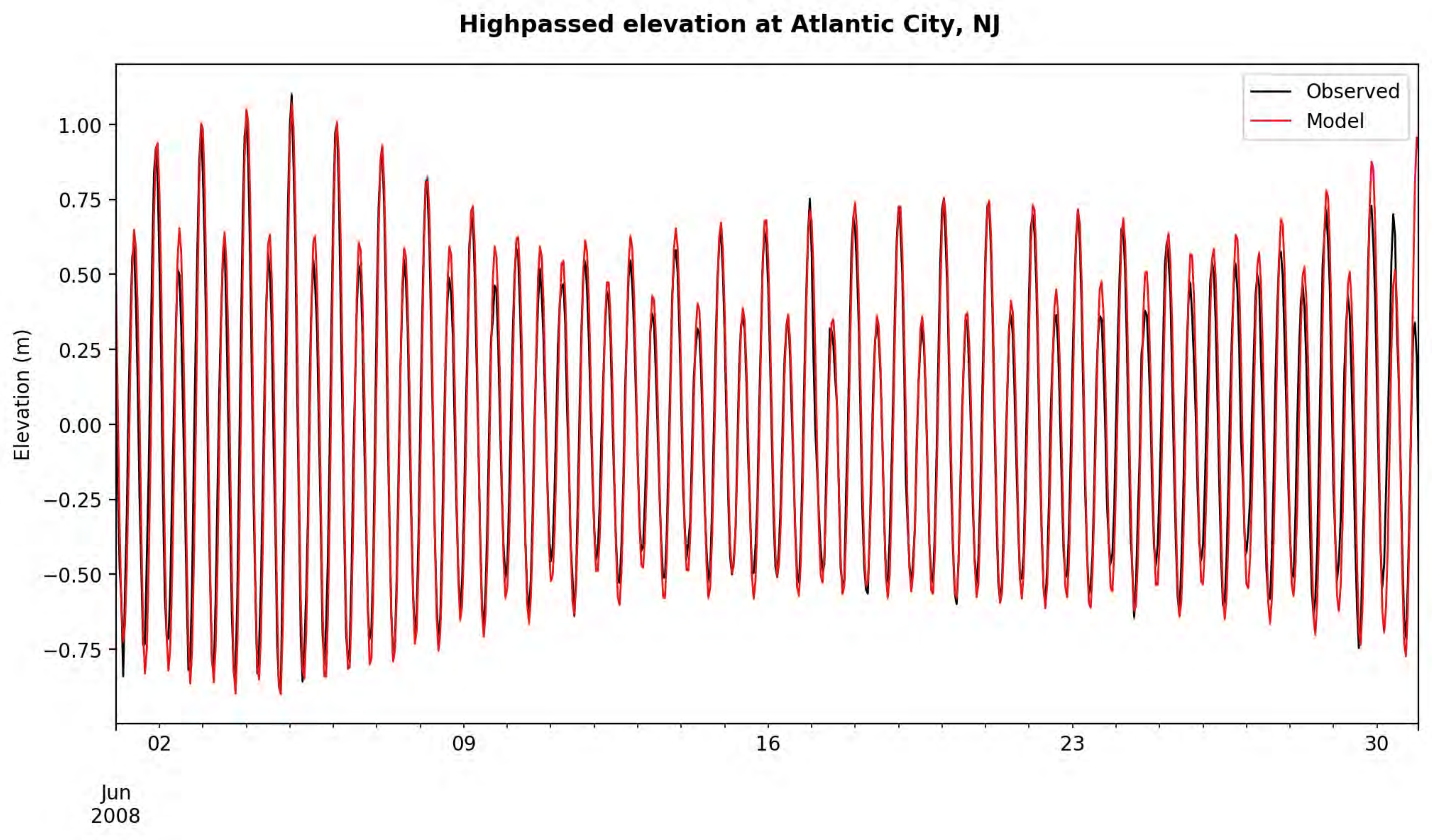
MOM6: Tidal elevations



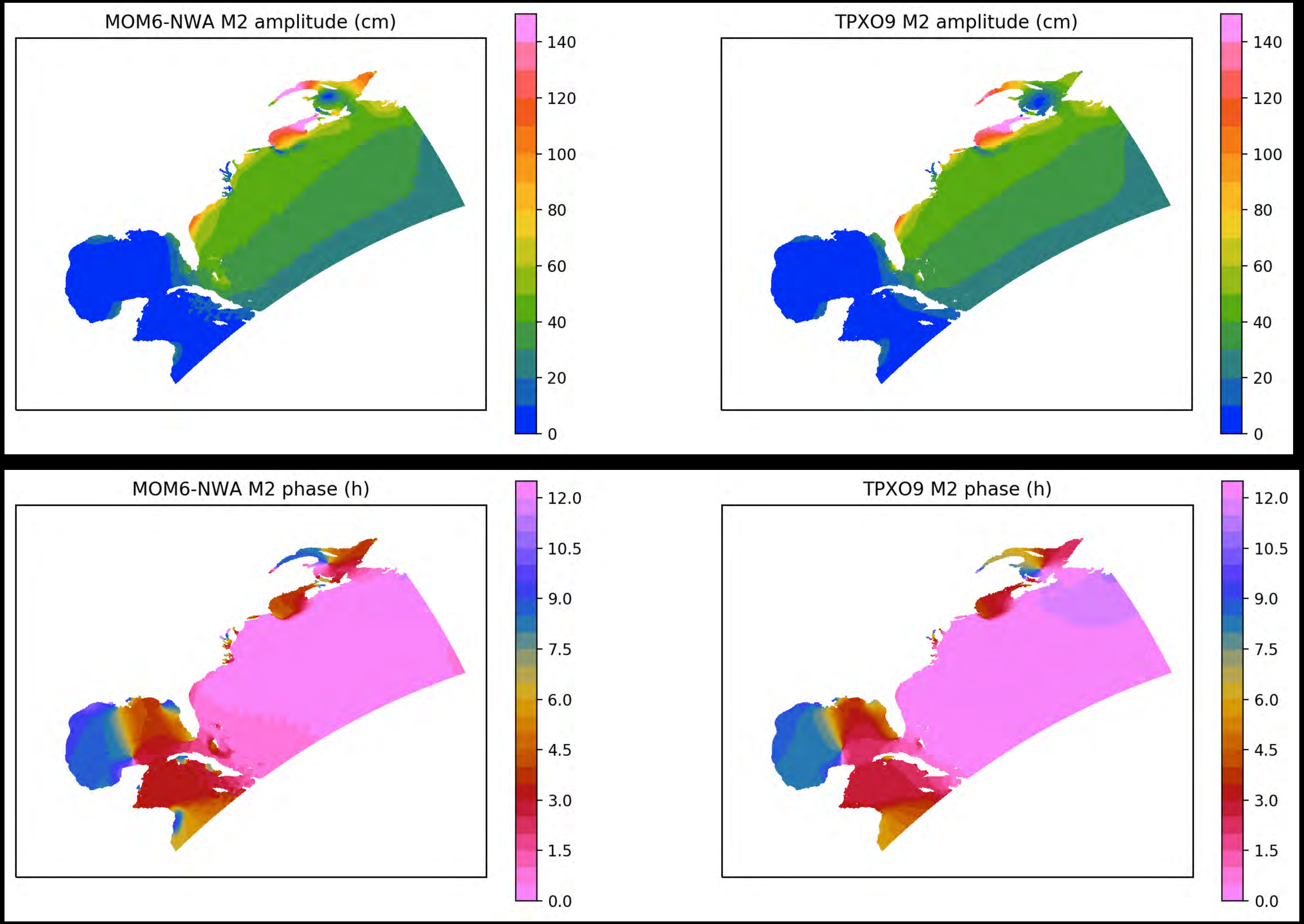


MOM6: Tidal elevations

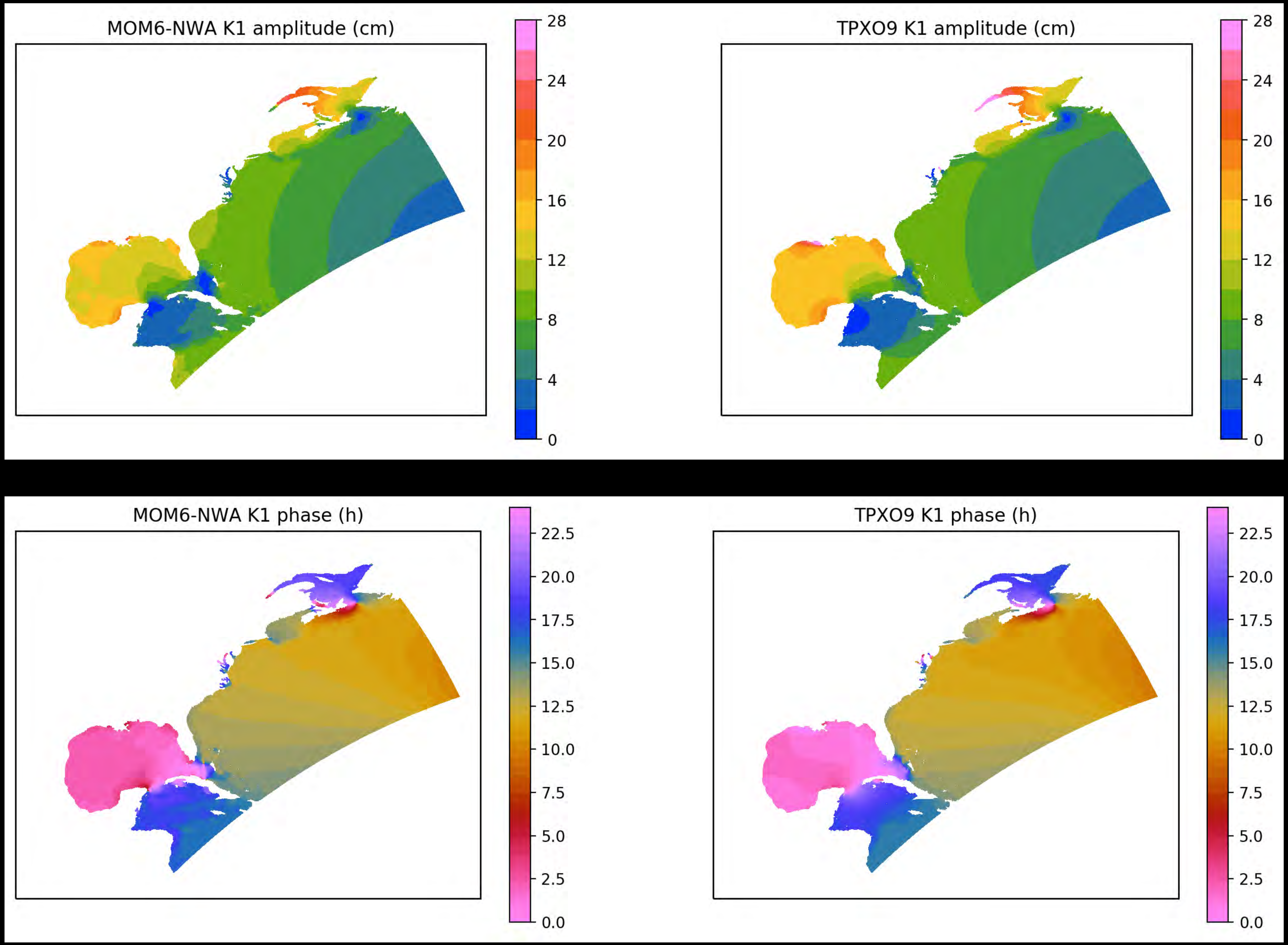




Tides: M2 Amplitude/Phase

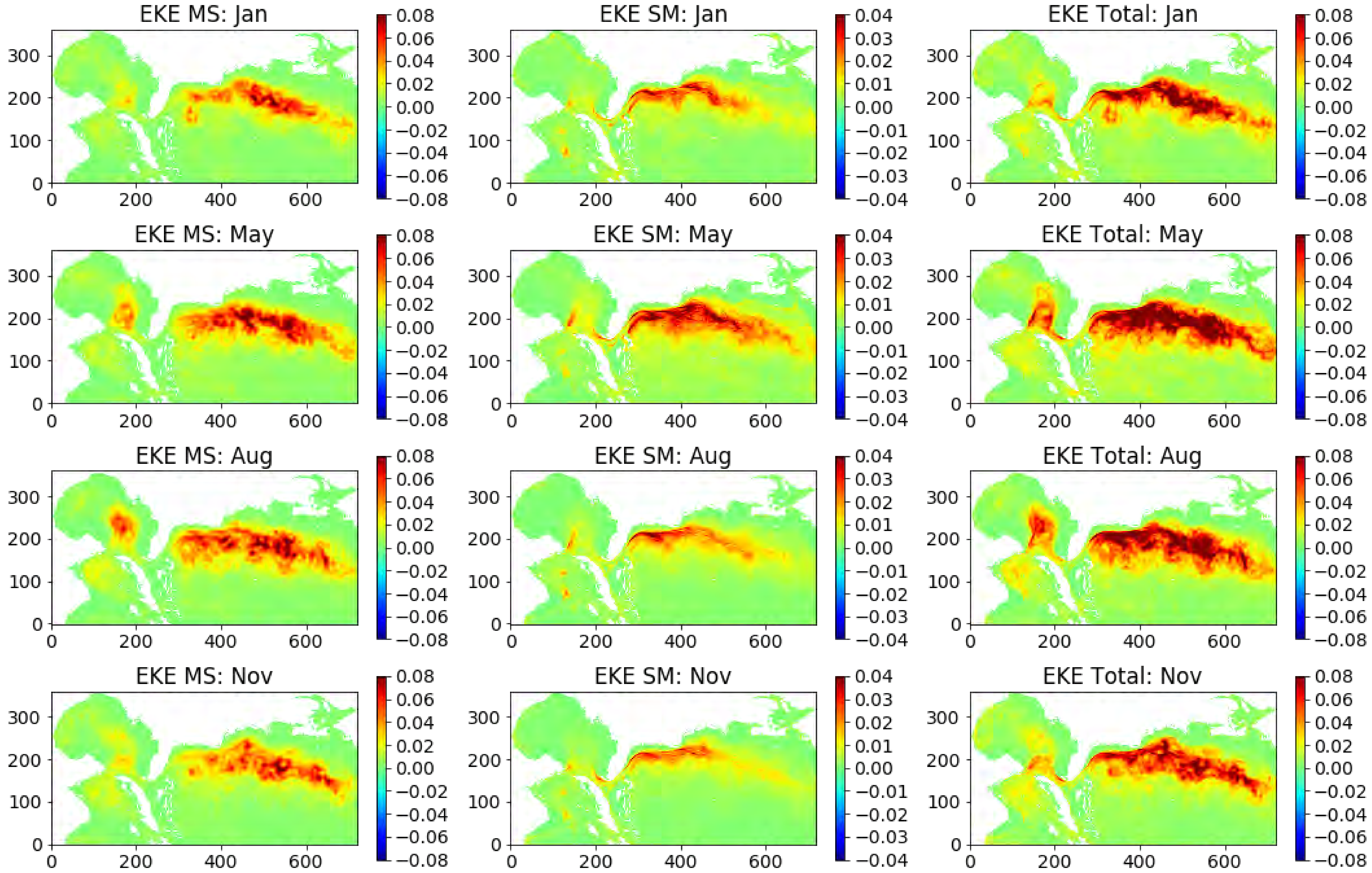


Tides: K1 Amplitude/Phase



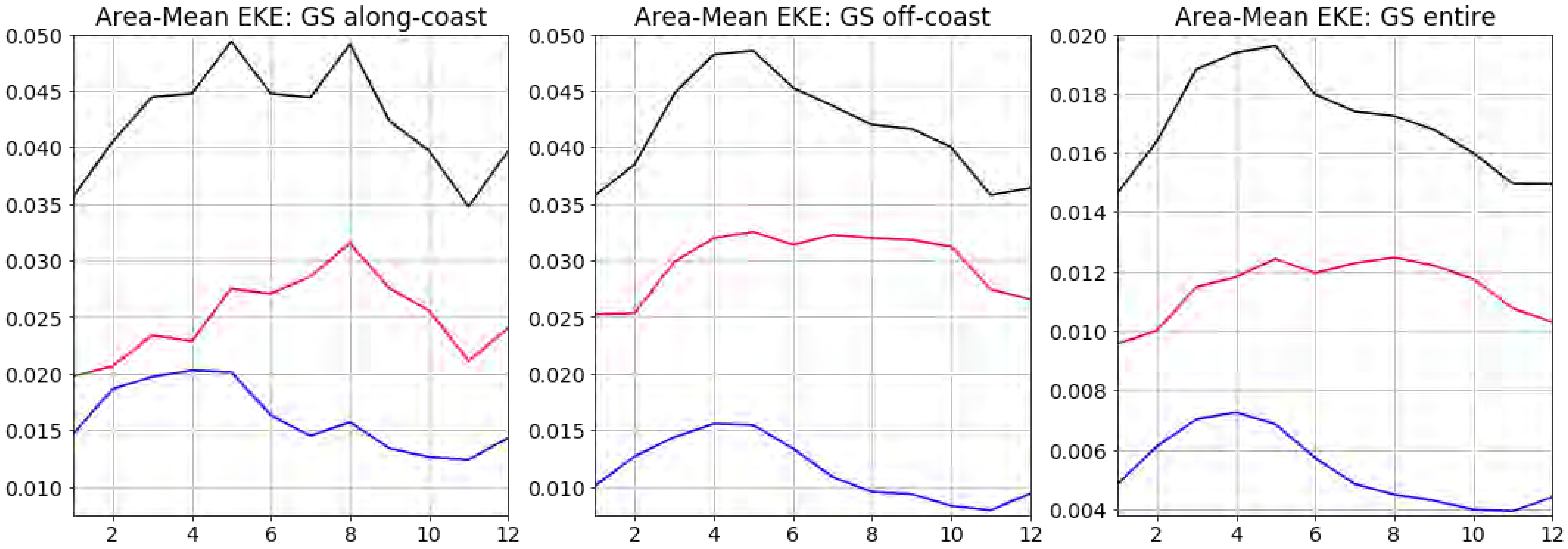
Seasonal EKE using z*-coordinate

Mesoscale Submesoscale Total



Seasonal EKE using z*-coordinate

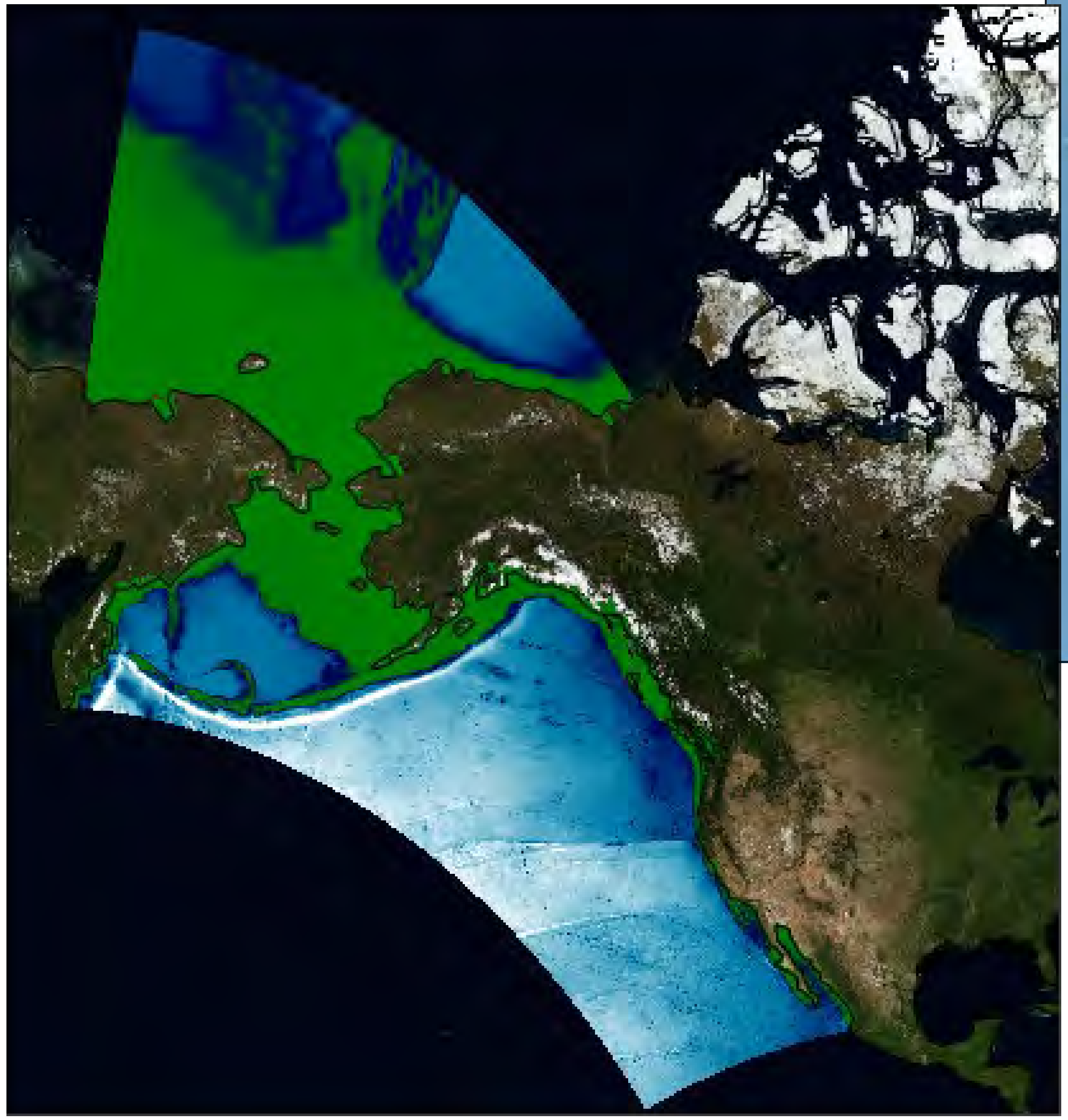
GS along-coast | GS off-coast | Whole domain

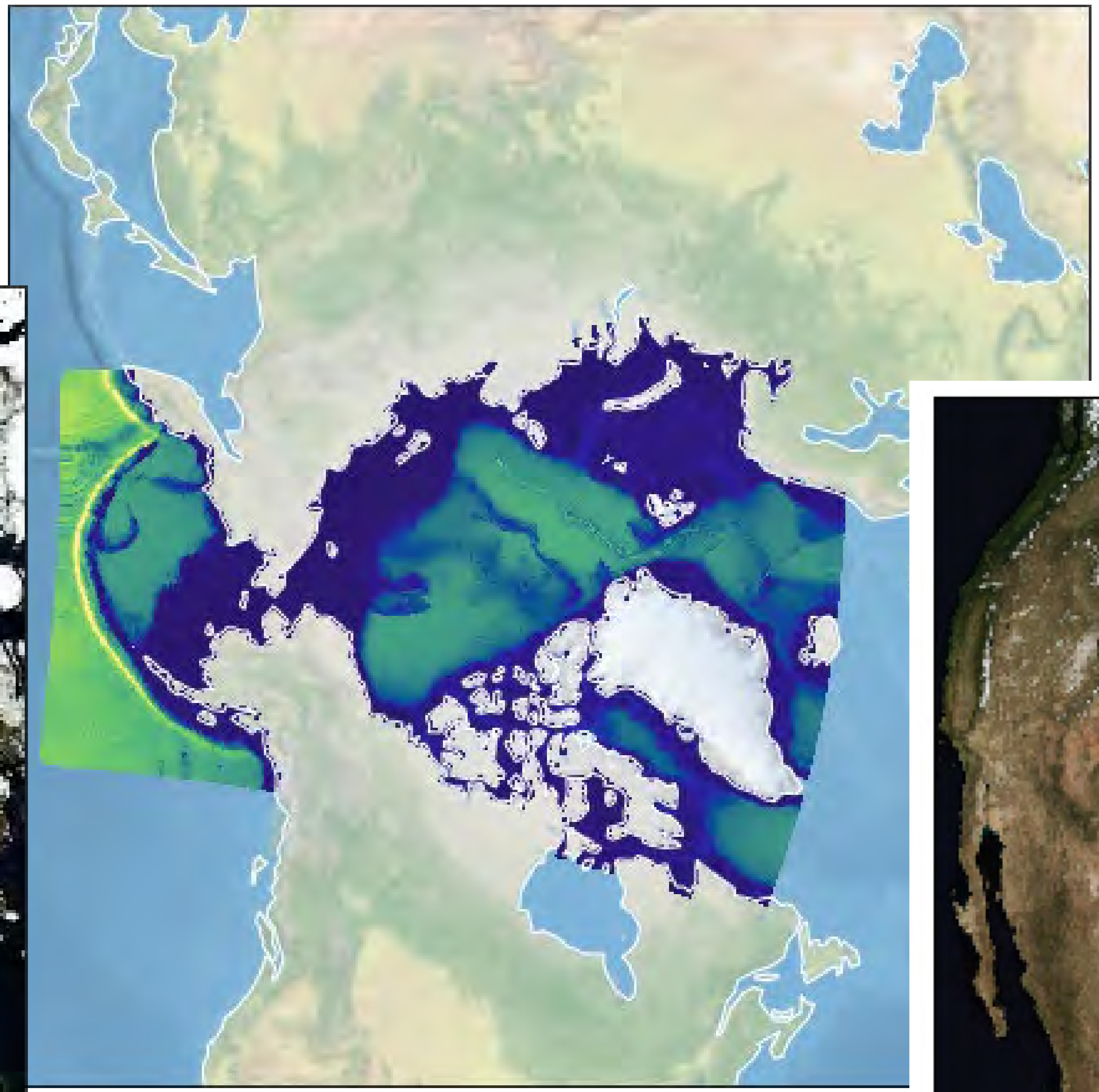


Mesoscale **Submesoscale** **Total**

Other regions in development

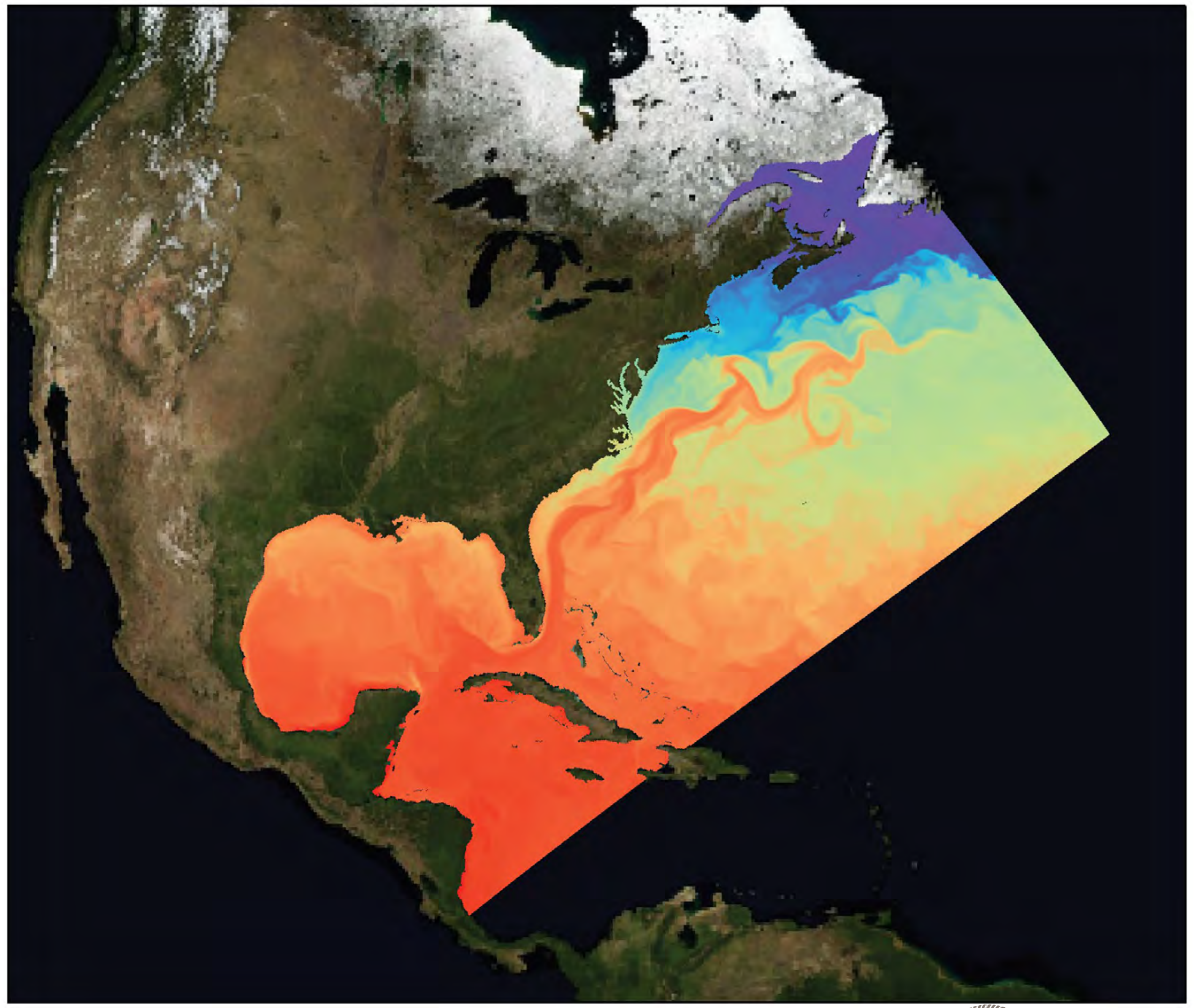
MOM6-NEP





MOM6-Arctic

MOM6-NWA



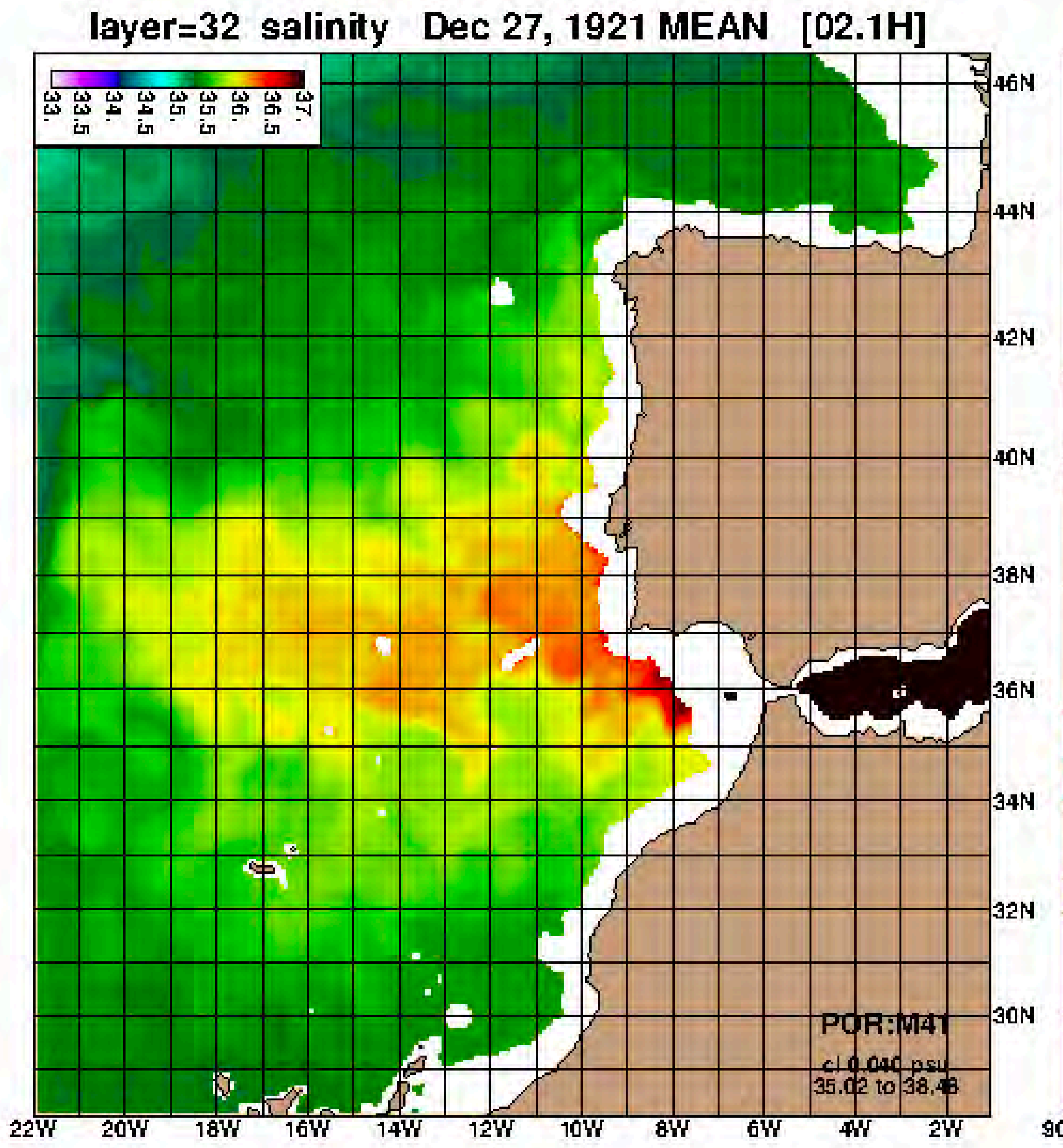
NOAA PRINCETON UNIVERSITY RUTGERS UNIVERSITY OF ALASKA FAIRBANKS

(Near) Future directions

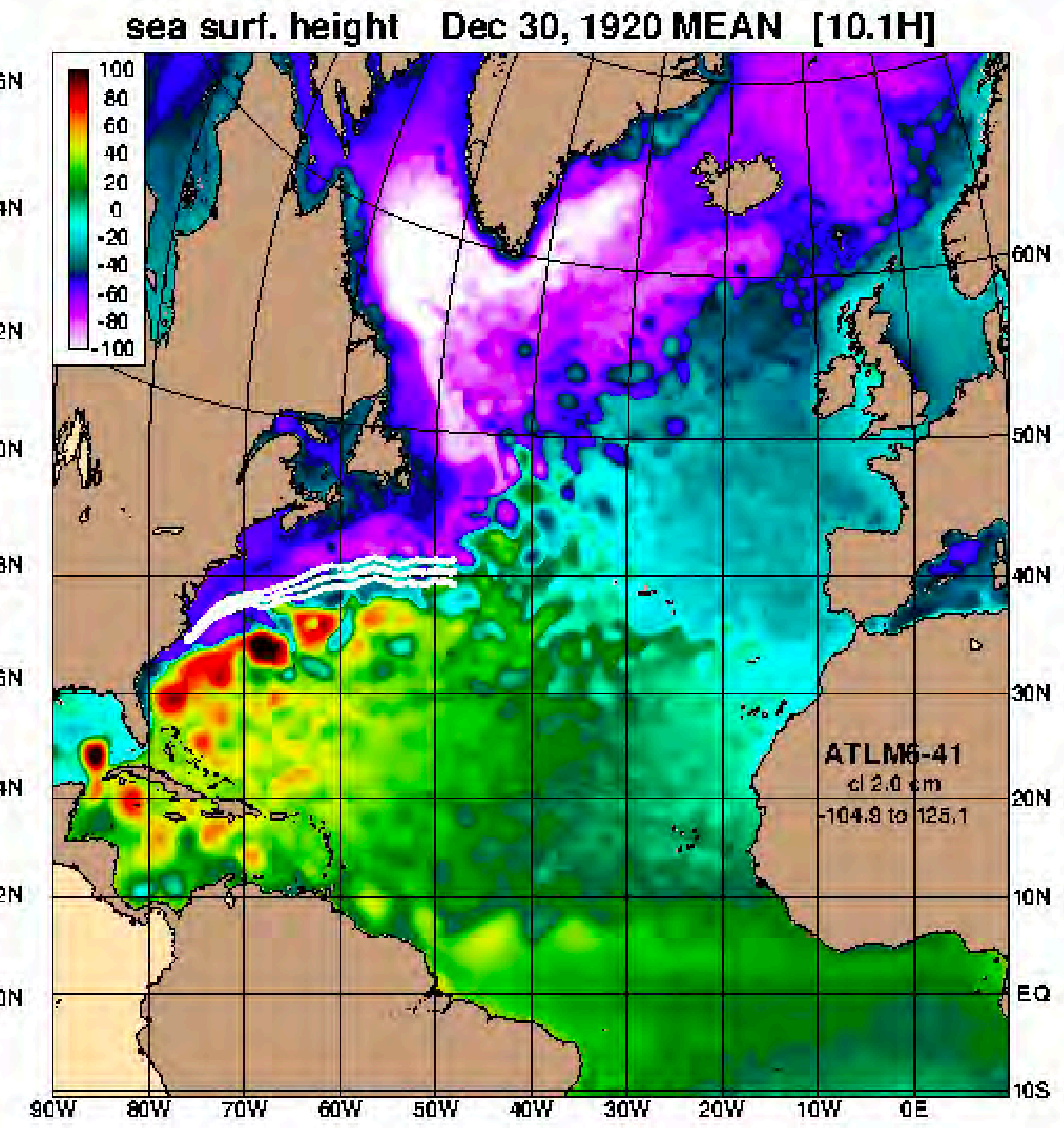
REGIONAL MOM6 DOMAINS SUBSETTING 1/12° GLOBAL (I)

- Used to inexpensively explore model issues
- Sponge zone at “open” boundaries
  - Relax to monthly climatology in layer space

Strait of Gibralter Overflow

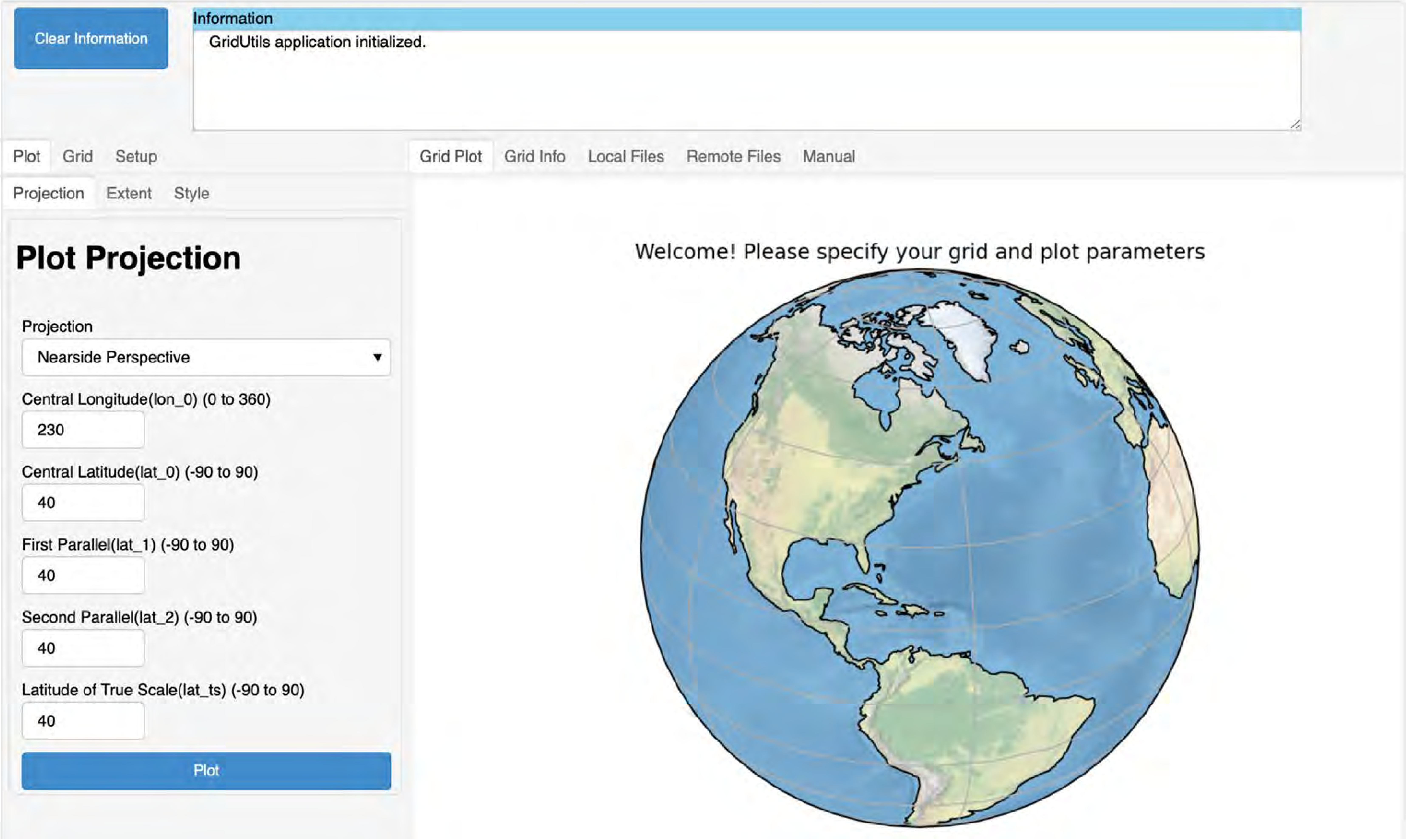


Atlantic North of 28S



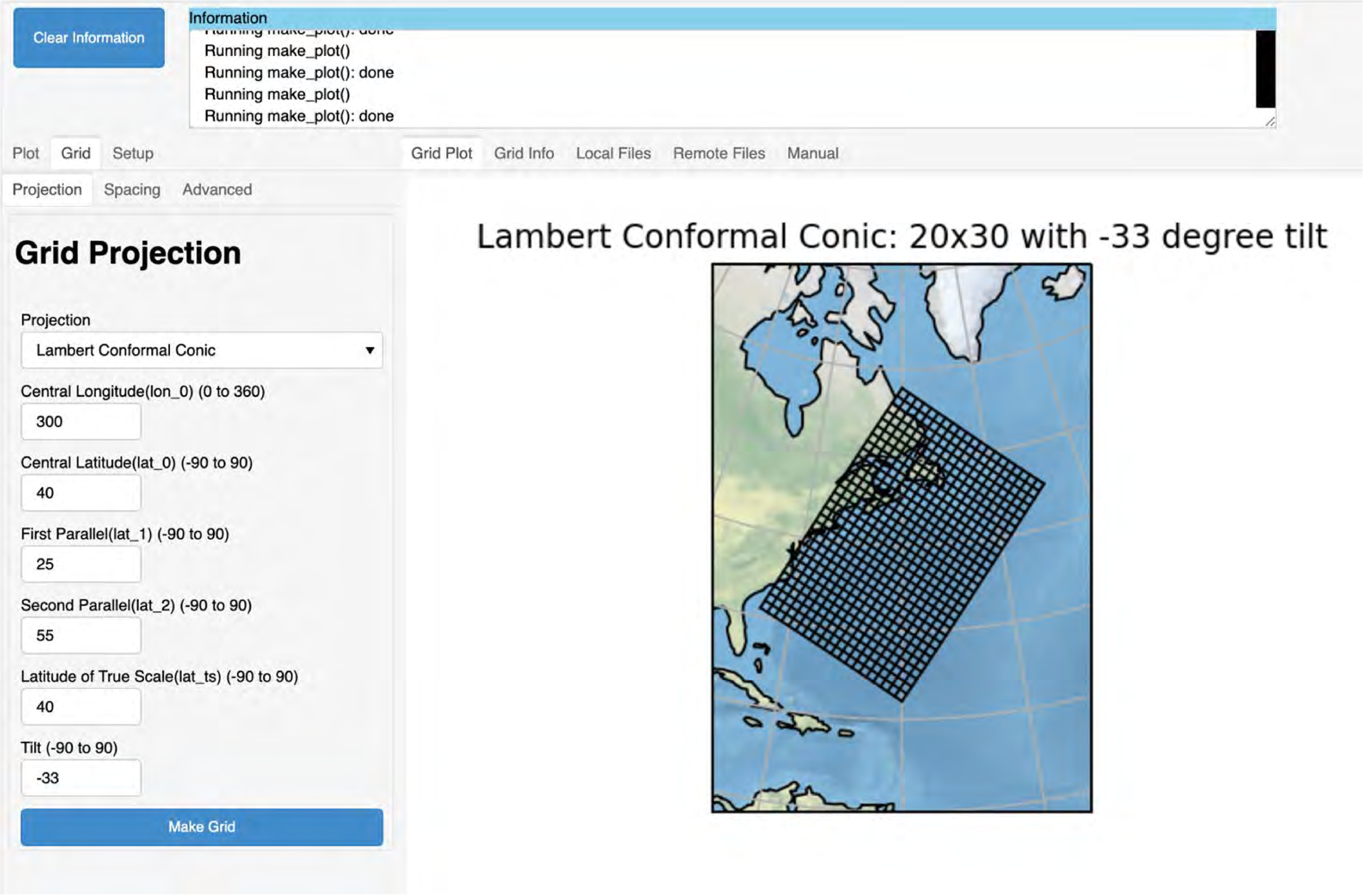
Courtesy of A. Wallcraft and E. Chassignet

Regional Grid Generation Tool *(under construction)*



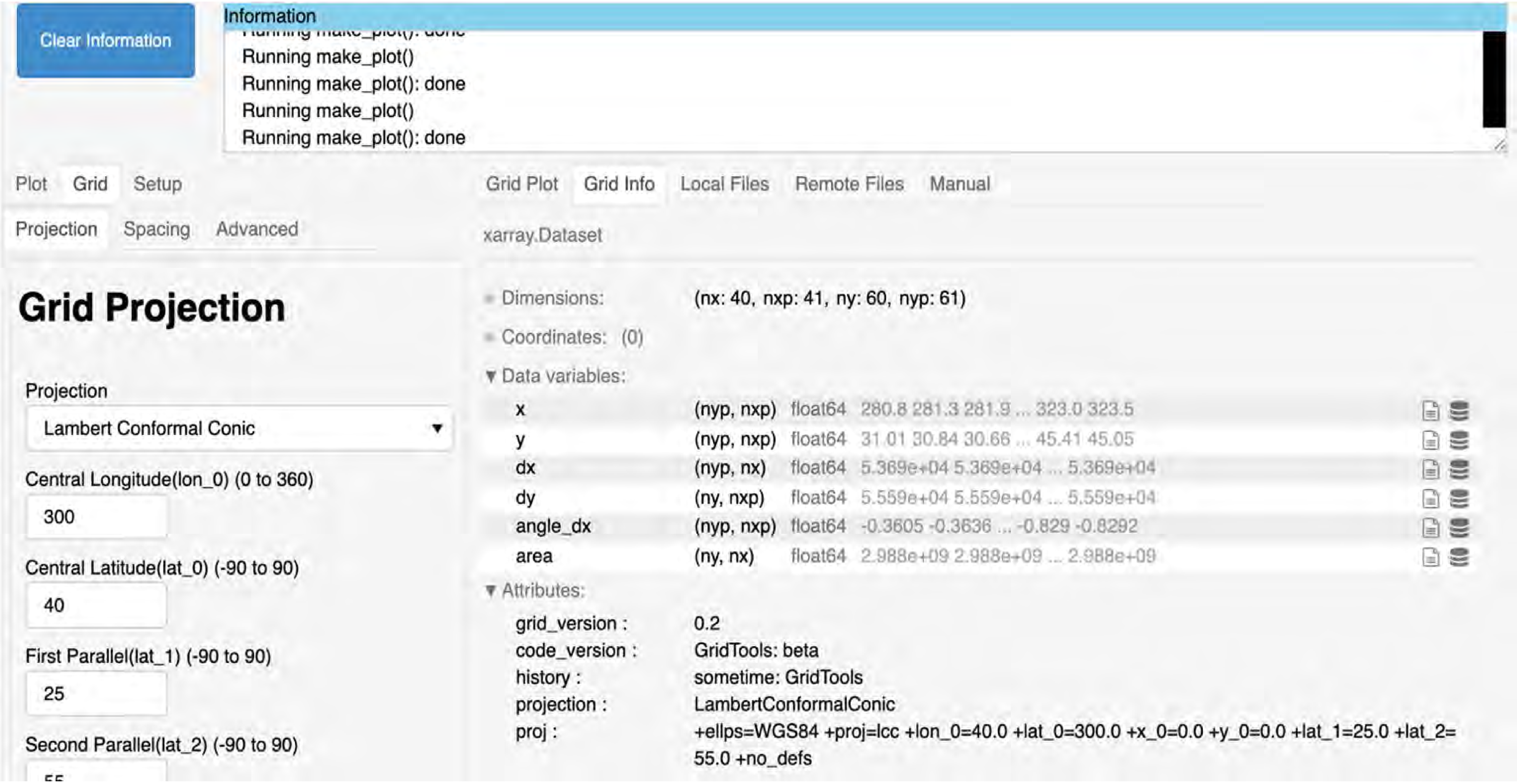
- Interactive Python tool for generating grids
- Allows a user to create a grid, visualize it, and download it as netCDF
- Can be spawned as stand-alone application or run on local machine

Visualize a Grid



- Specify projection parameters, grid spacing, and resolution
- Click ‘Make Grid’ and your grid will appear
- Easily edit parameters and shift grid to your exact specifications

Download Grid as netCDF



- Select the Grid Info tab so see a live view of your grid as an xarray object
- Grid angles, area, etc. are calculated on the fly
- Click ‘Download Grid’ and this will be saved to your machine as a netCDF file

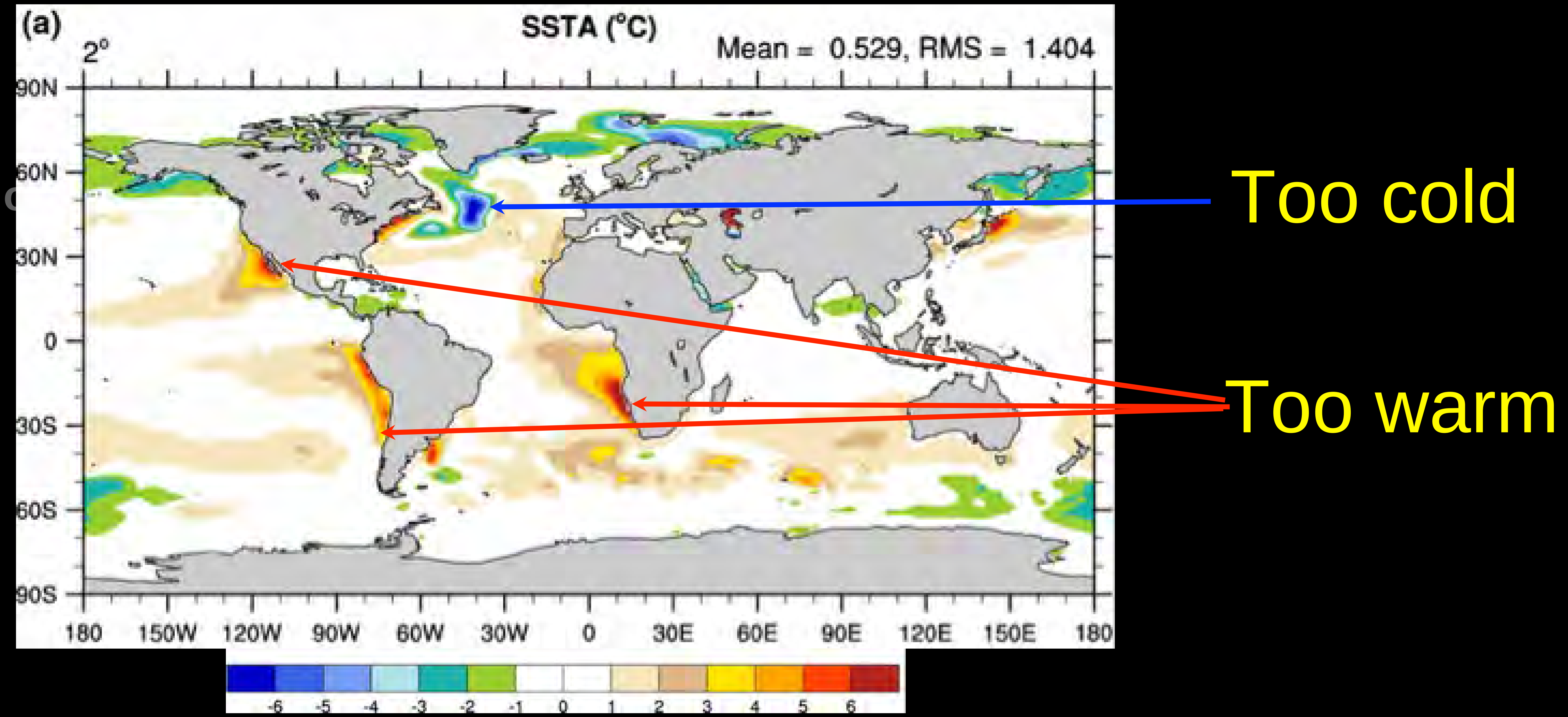
Final remarks

- Regional MOM6 is quickly becoming a reality
  - Most desired features have been coded up:
    - Barotropic/Baroclinic OBCs
    - Sponge layers
    - Tracer boundary conditions (including BGC)
    - Tides
  - Several implementations are being tested (NWA, CCS/NEP, Arctic, Indian Ocean, Eastern Tropical Pacific…)
  - Community is expanding fast (Climate and Fisheries Initiative)
- Ancillary software is being developed (python based)
- New North Atlantic models will be tested starting this summer
- Much remains to be done!

Additional slides

Low-resolution model biases: SST
(Model minus Observations of mean SST)

(CCSM 3.5 - WOA98)



"Models still show significant errors … The ultimate source of most is that many important small-scale processes are not represented explicitly in models …"

Randal et al., 2007.