OCEAN MODELING

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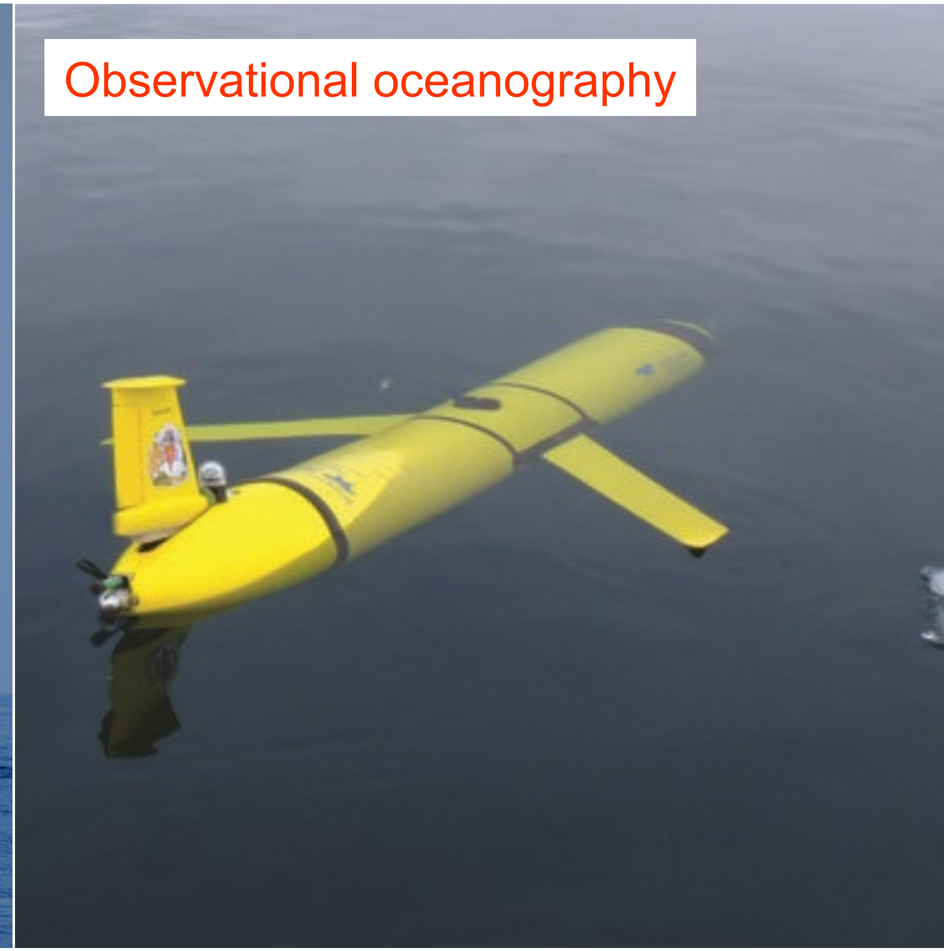
OUTLINE

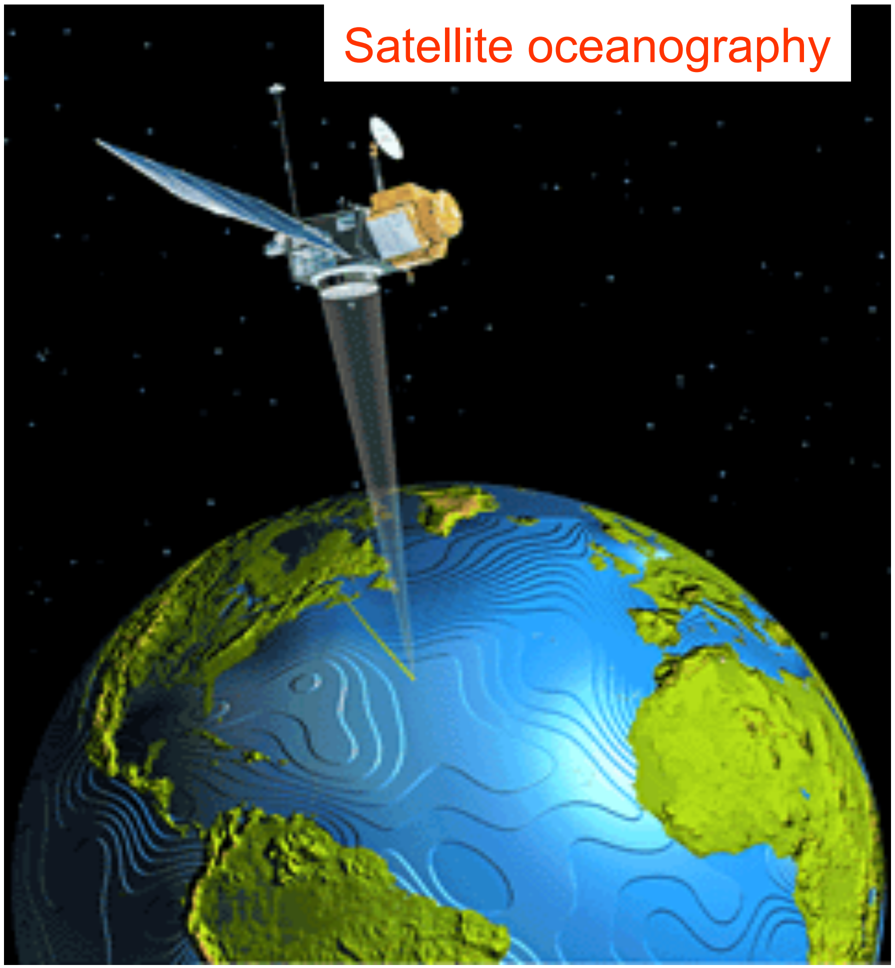
- INTRODUCTION
- MOTIVATION
- EQUATIONS OF MOTION
- INTRODUCTION TO ROMS (Regional Ocean Modeling System)
- EXAMPLES

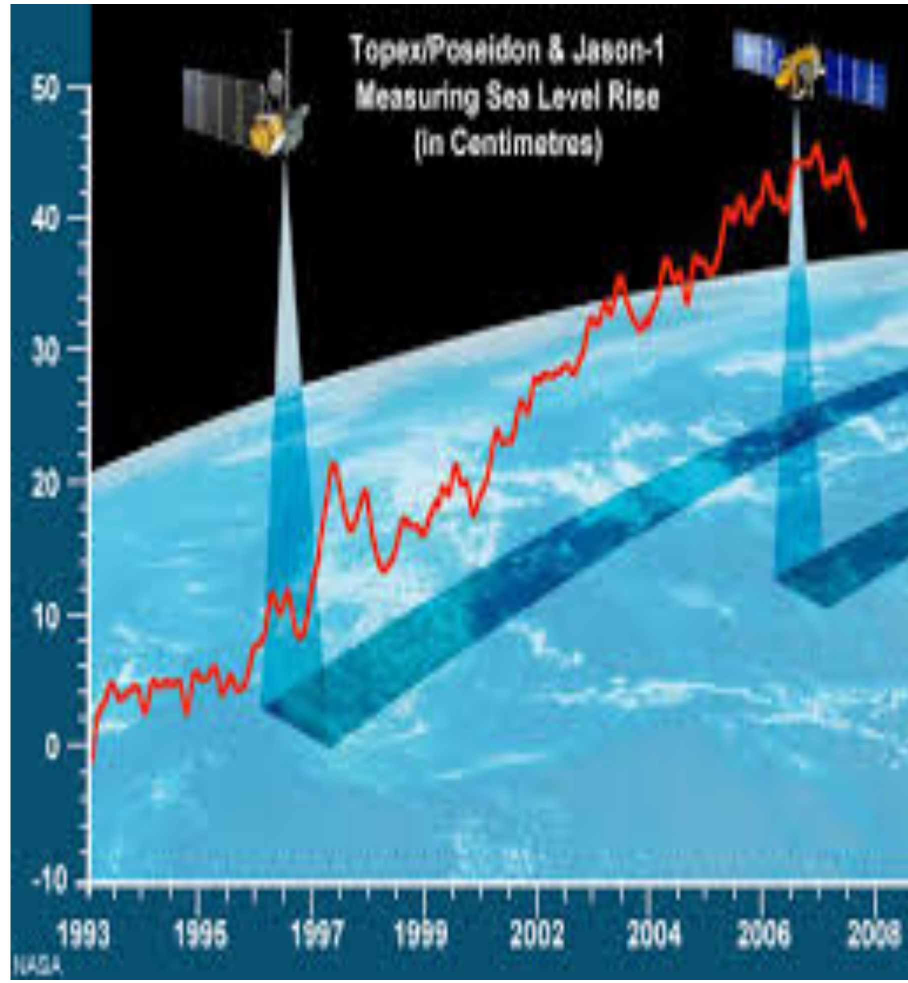
Introduction: Approaches to oceanic studies



Emily & Drew - lectures

Introduction: Approaches to oceanic studies

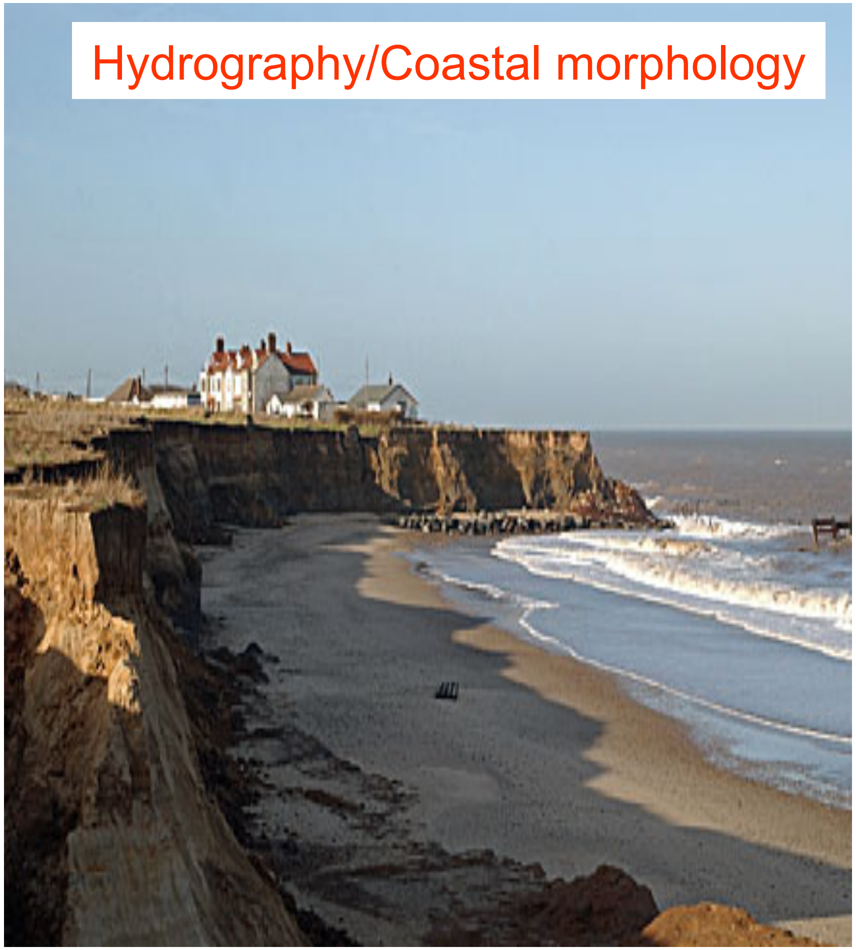




Ebenezer- lectures

Introduction: Approaches to oceanic studies

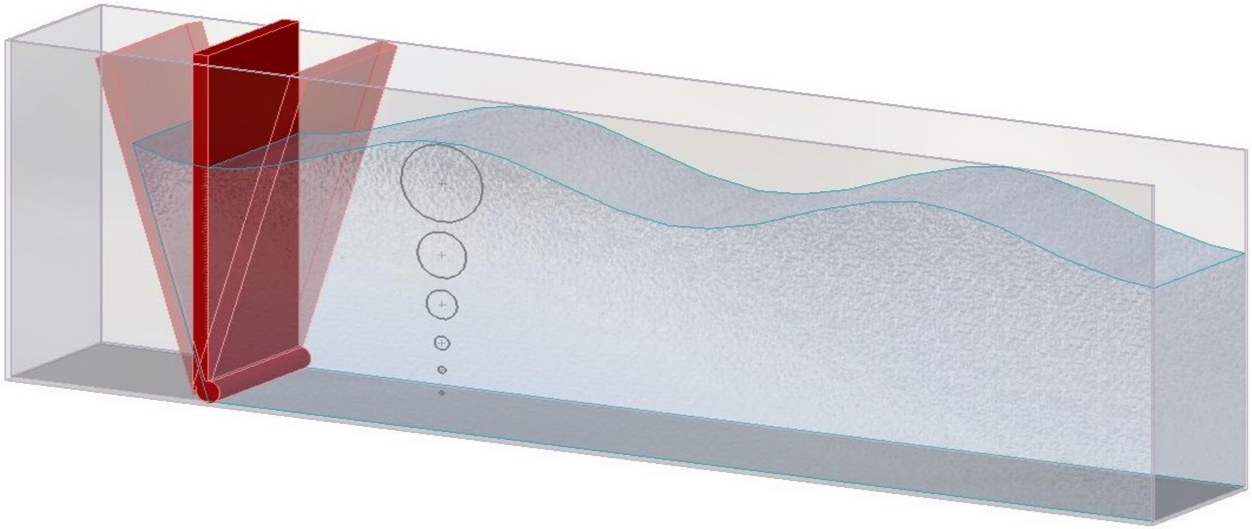
Chemical oceanography



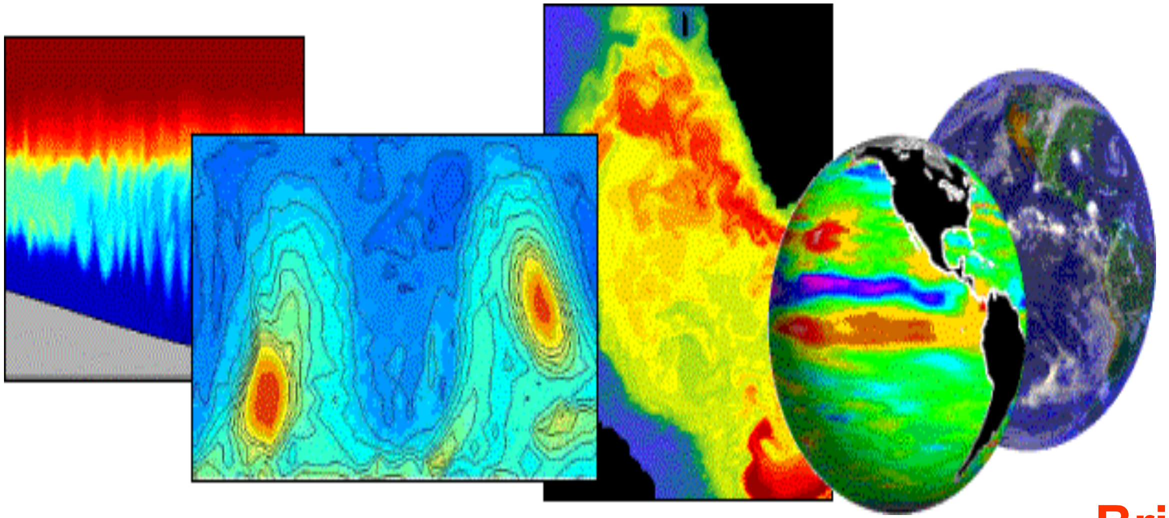
Liz- lectures

Stephan - lectures

Introduction: Approaches to oceanic studies



Laboratory tank Experiments



Ocean modeling

Brian/Dimitris/Joseph - lectures

What is an ocean model?

It is a representation, in the form of equations/computer code, describing physical processes of our understanding of how the ocean works.

-Dr. Stephenie Waterman

What is an ocean model?

Physical processes:

a) Ocean movement/dynamics, including horizontal and vertical advection

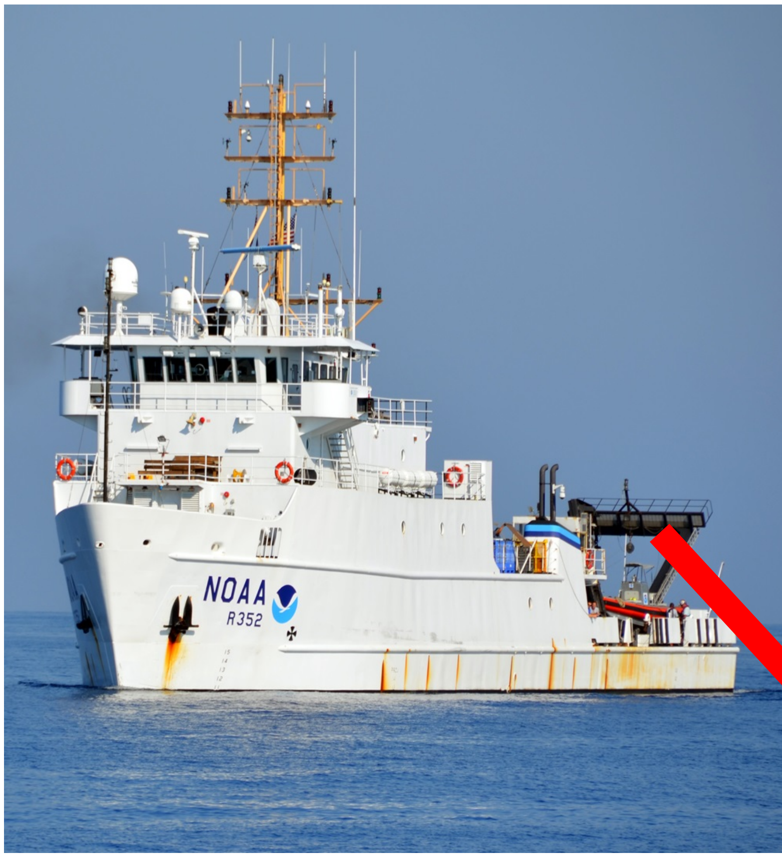
b) Exchange of energy between the ocean and external sources (radiation, precipitation, evaporation, river-runoff, wind, etc)

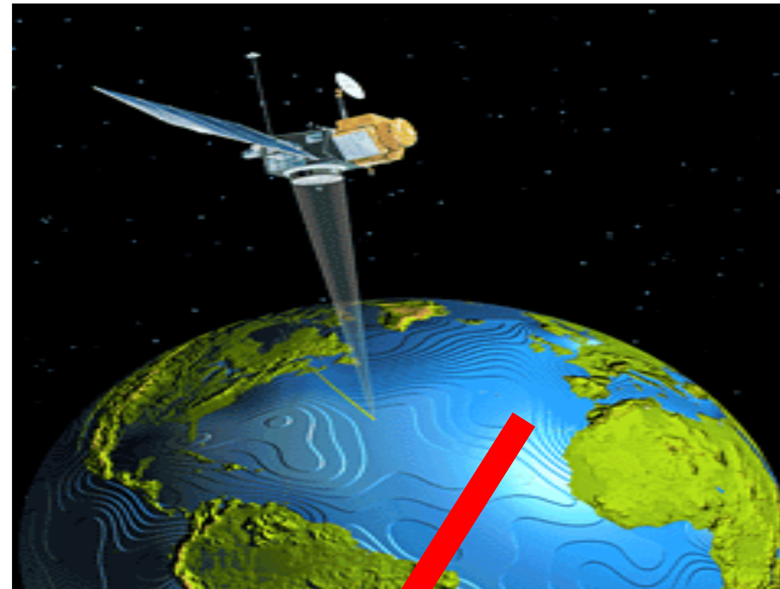
c) 3D mixing and dissipation processes

QUESTION

Why do we need ocean modeling when we have alternative means?

Motivation: Why model the ocean?



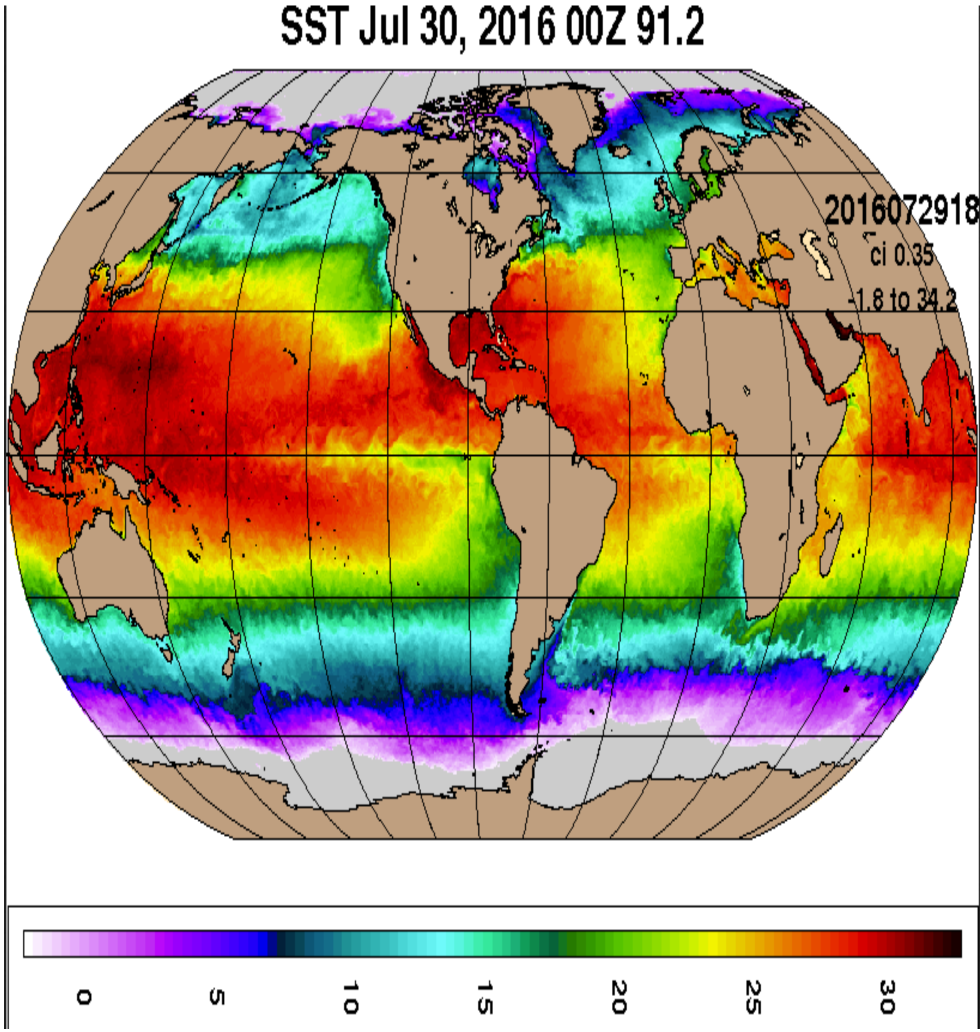


Motivation: Why model the ocean?

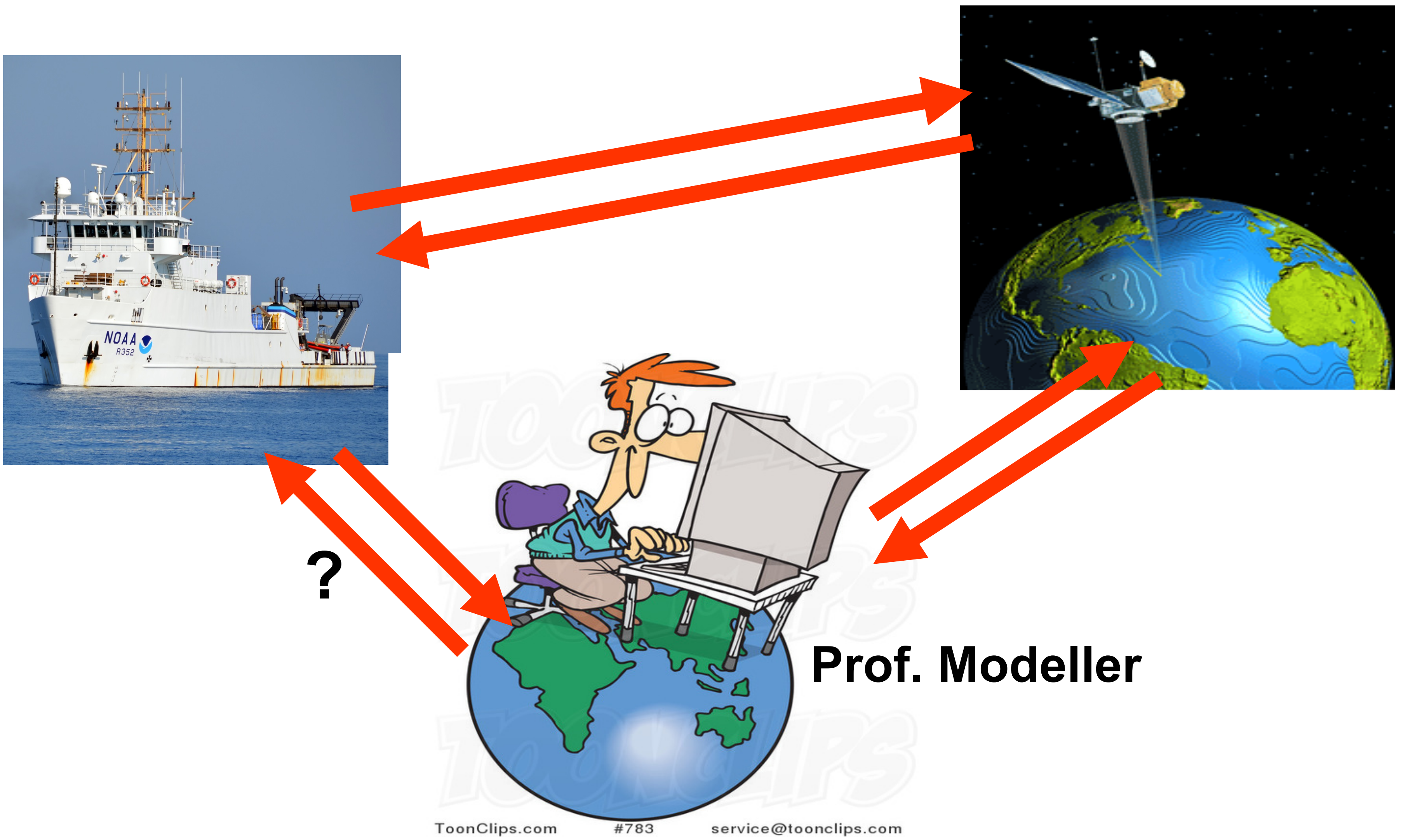
- Comparatively less expensive
- Higher spatial/temporal resolution compared to other methods:
  - Satellites provide only surface data, and
  - In-situ measurement are limited in spatial coverage
- Ability to forecast (e.g. SSH, and positions of major fronts and eddies)

Motivation: Why model the ocean?

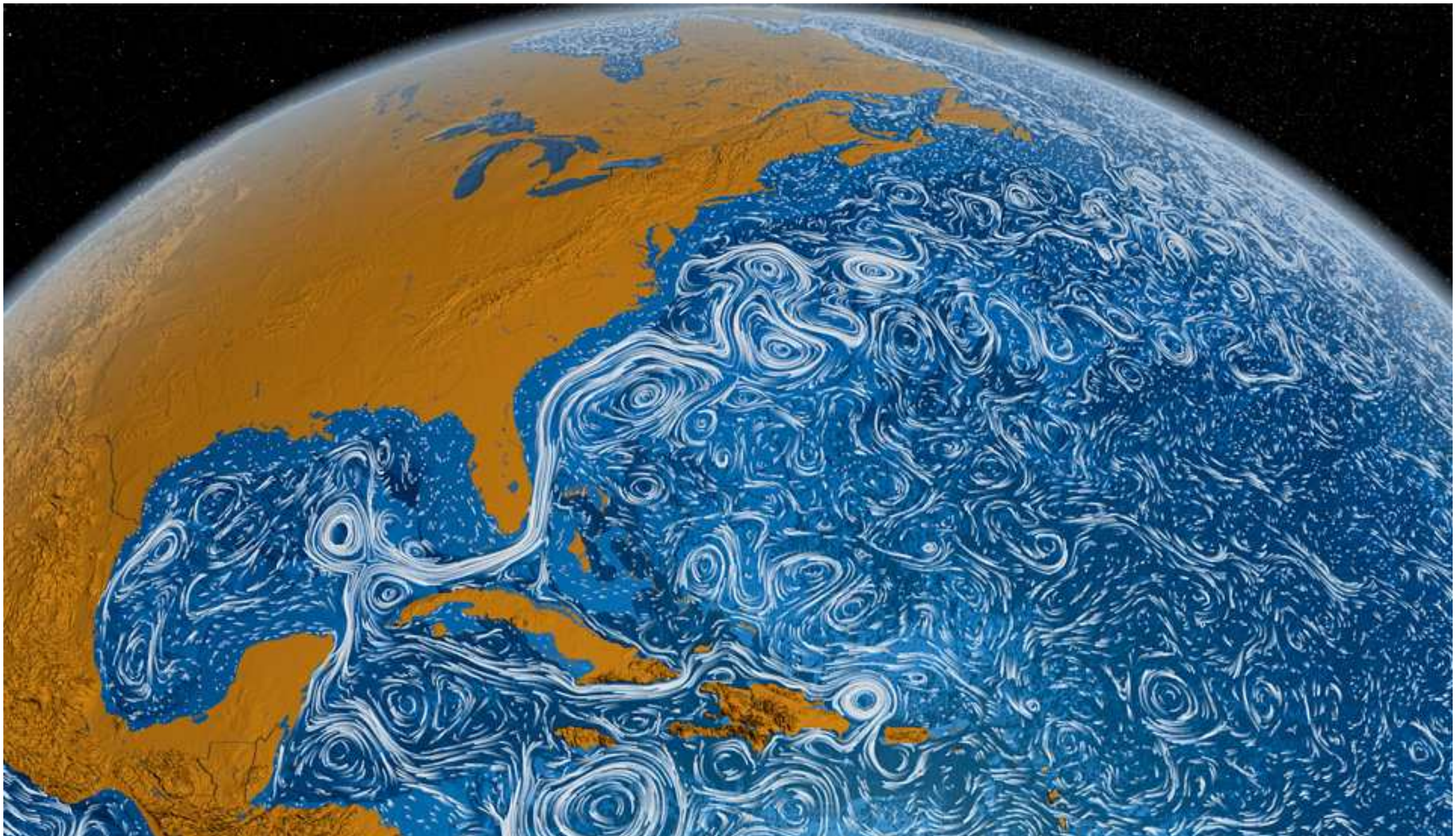
- helps in understanding the 3D dynamics of the ocean on a GLOBAL scale.
  - Dynamics of the ocean include: the general circulation, waves, tides, turbulence, instabilities, convection, mixing, jets, etc.



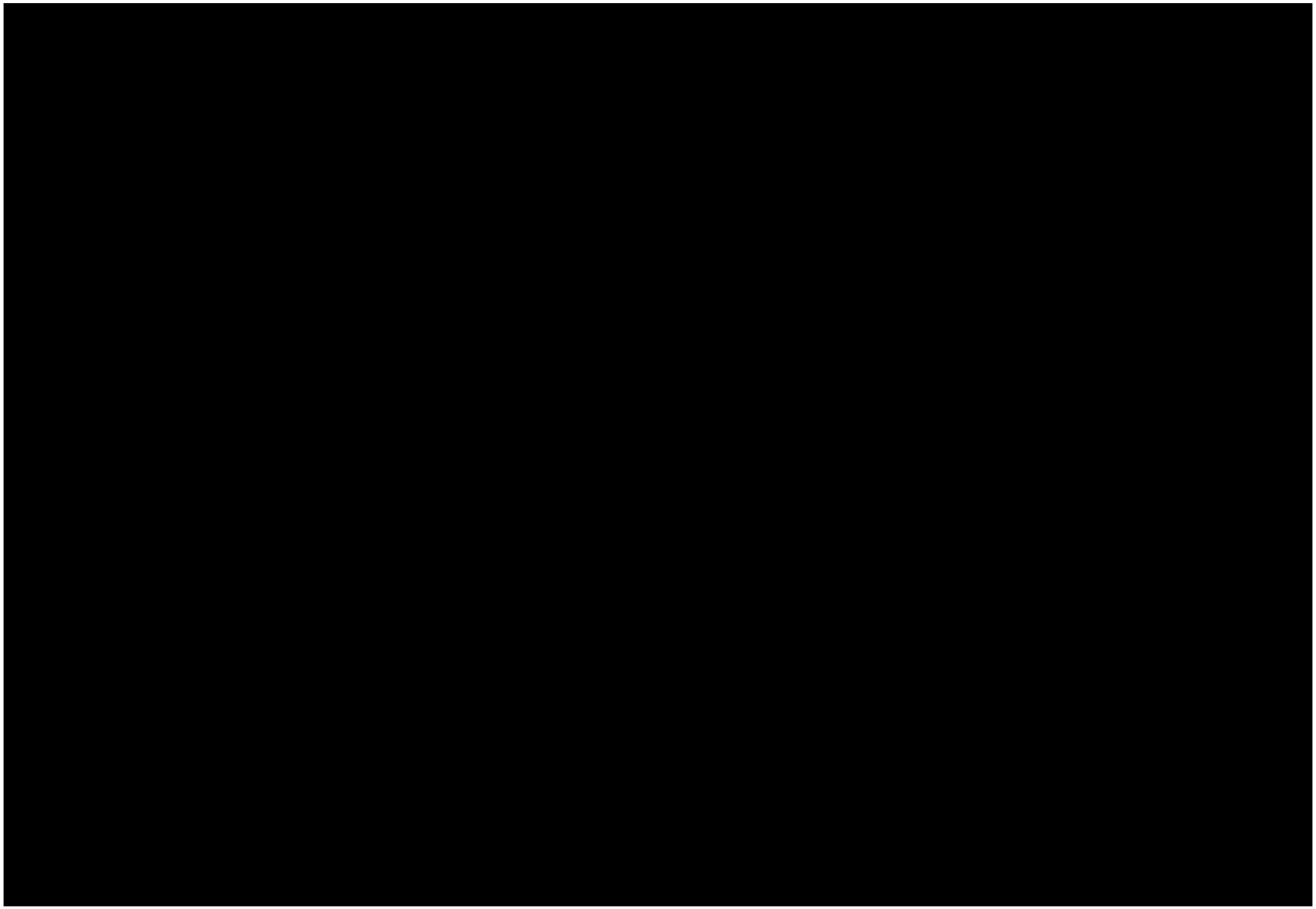
Motivation: *not a competition*



Motivation: global ocean currents



Motivation: internal waves



Courtesy: Max-Planck institute of Ocean modeling

Where/how do I start learning ocean modeling?

Definition: ocean model

It is a representation, in the form of equations/computer code, describing physical processes of our understanding of how the ocean works.

-Dr. Stephenie Waterman

Equations of motion

- Start ocean modeling by understanding the equations of fluid flow (Navier-Stokes equations).
- Learn how to discretize the equations
- Understand some numerical analysis
- Others…

Equations of motion

$$\frac{D\vec{u}}{Dt} + [?] = -\frac{1}{\rho_o}\nabla p + \frac{\rho}{\rho_o}\vec{g} + \vec{F}$$

acceleration (local + advective)

Presure gradient

buoyancy

Others (frictional, Tides, Winds, etc)

where (**u**=[u,v,w]) are velocity components, p is the pressure, ρ the density, and g gravity.

Equations of motion

$$\frac{D\vec{u}}{Dt} + [?] = -\frac{1}{\rho_o}\nabla p + \frac{\rho}{\rho_o}\vec{g} + \vec{F}$$

acceleration (local + advective)

call DREW now!

Presure gradient

buoyancy

Others (frictional, Tides, Winds, etc)

where (**u**=[u,v,w]) are velocity components, p is the pressure, ρ the density, and g gravity.

Momentum equations:

$$\frac{D\vec{u}}{Dt} + 2\vec{\Omega} \times \vec{u} = -\frac{1}{\rho_o}\nabla p + \frac{\rho}{\rho_o}\vec{g} + \vec{F}$$

acceleration (local + advective)

Rotation

Presure gradient

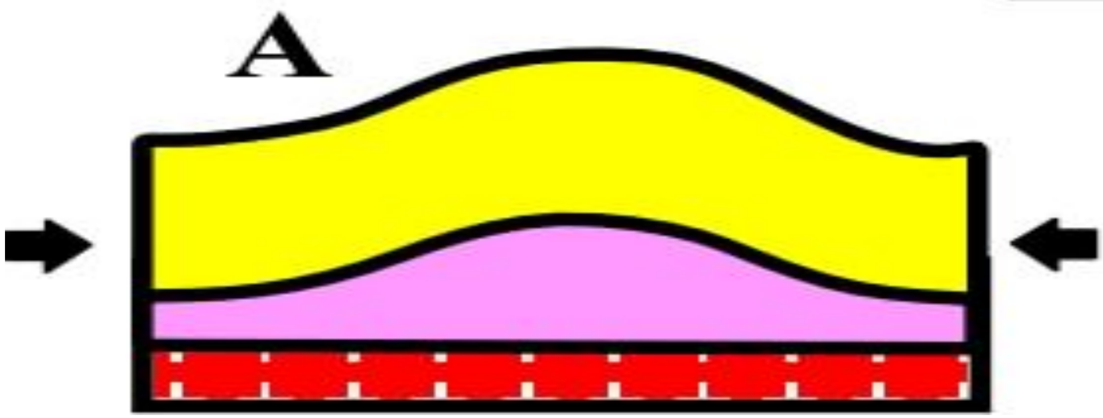
buoyancy

Others (frictional, Tides, Winds, etc)

where (**u**=[u,v,w]) are velocity components, Ω is the earth's rotation rate, p is the pressure, ρ the density, and g gravity.

Continuity equation (Conservation of volume)

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

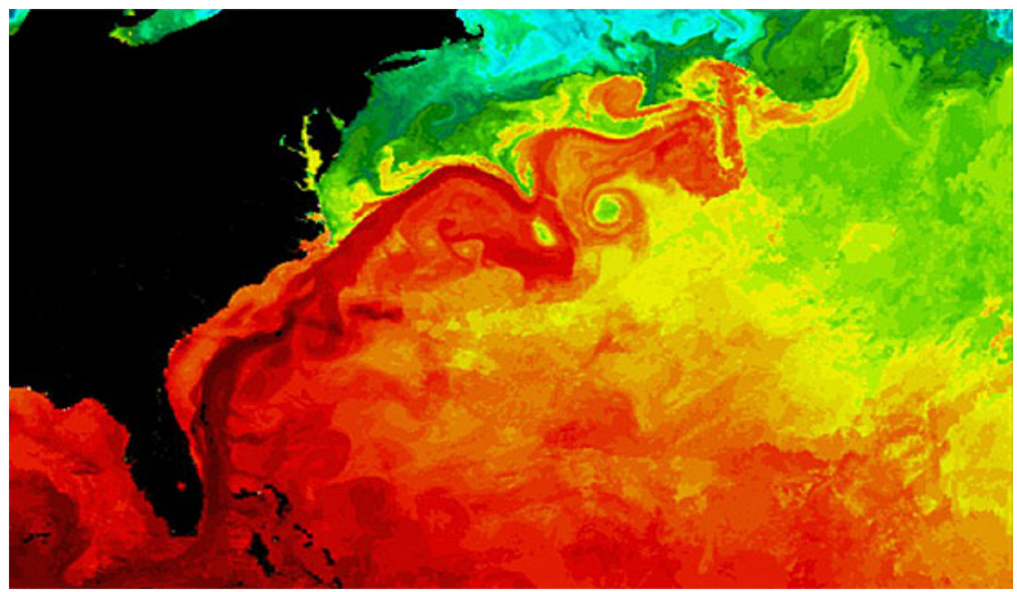


Equation for tracers (Temperature, Salinity, and others),

Advection-diffusion equation:

$$\frac{\partial T^c}{\partial t} + \vec{u} \cdot \nabla T^c = \kappa_{T^c} \nabla^2 T^c$$

$$T^c = Tracers$$



Equation of state (Linear)

$$\rho = \rho_0[1 - \alpha(\mathrm{T} - \mathrm{T}_0) + \beta(\mathrm{S} - \mathrm{S}_0)]$$

$$\rho_0 = 1028\, kg/m^3$$

$$T_0 = 10^o C = 283K$$

$$S_0 = 35\, psu$$

$coefficients\ of\ thermal, \alpha,$

$and\ saline\ contraction, \beta$

Where T is temperature and S is salinity.

Now that I understand the equations, what next?

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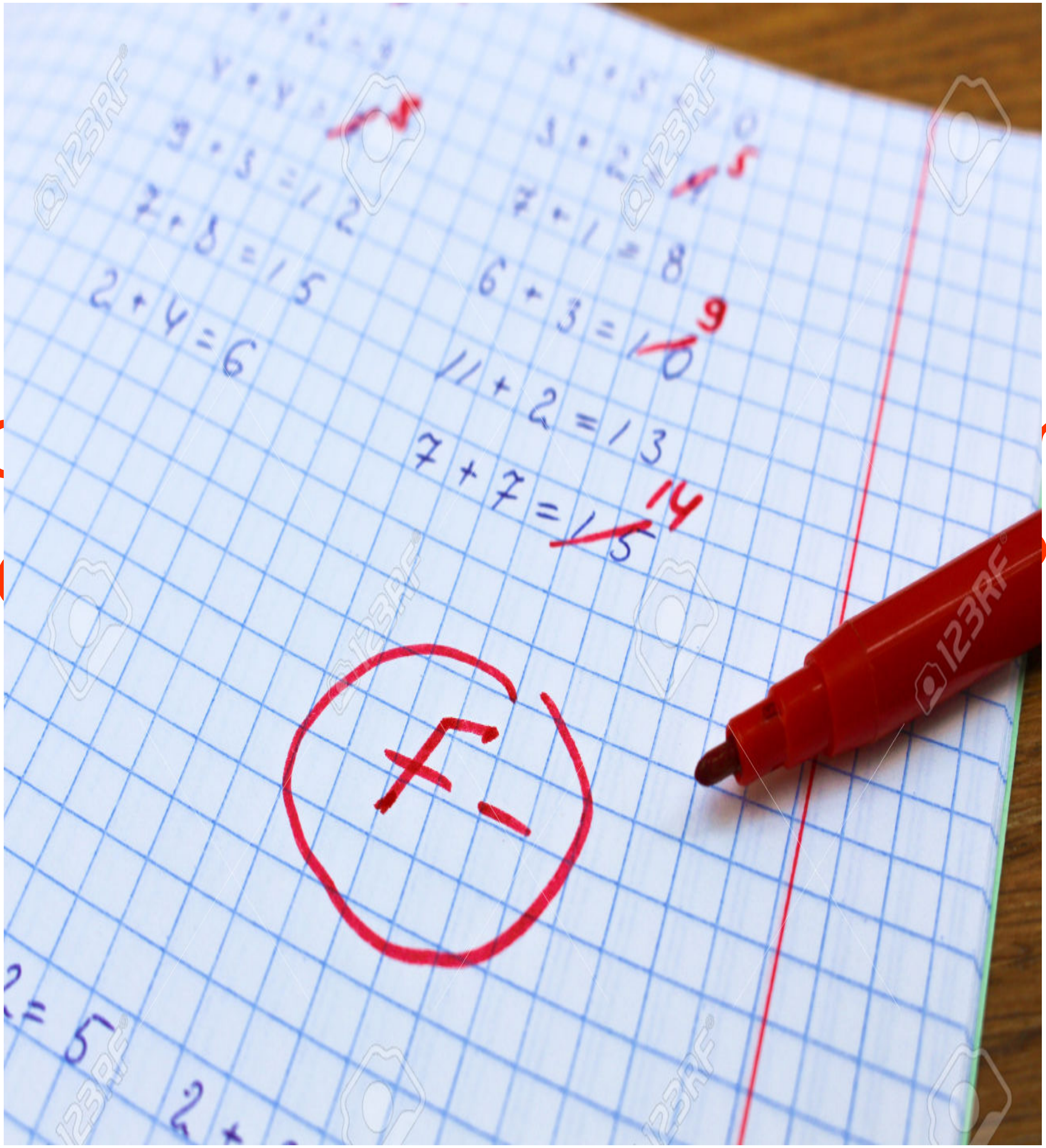

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A. Discretize equations

B. Consider the horizontal grid

C. Consider the vertical grid

D. Boundary conditions

Discretize equations

- Continuous equations

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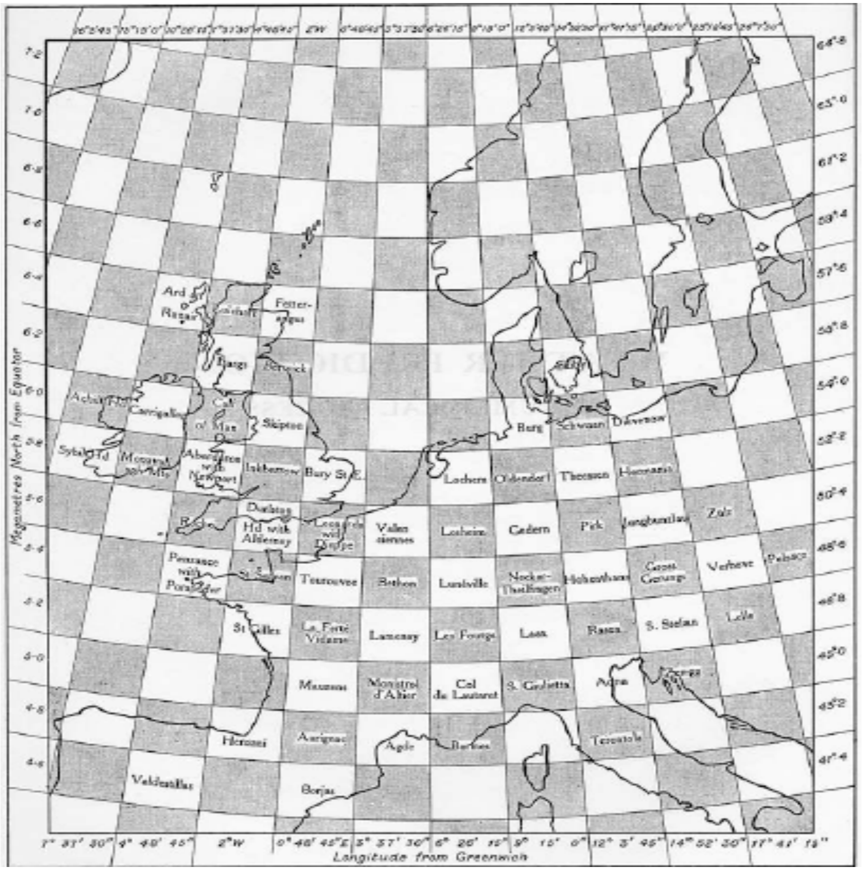
  algebraic equations

(discrete set of operations)

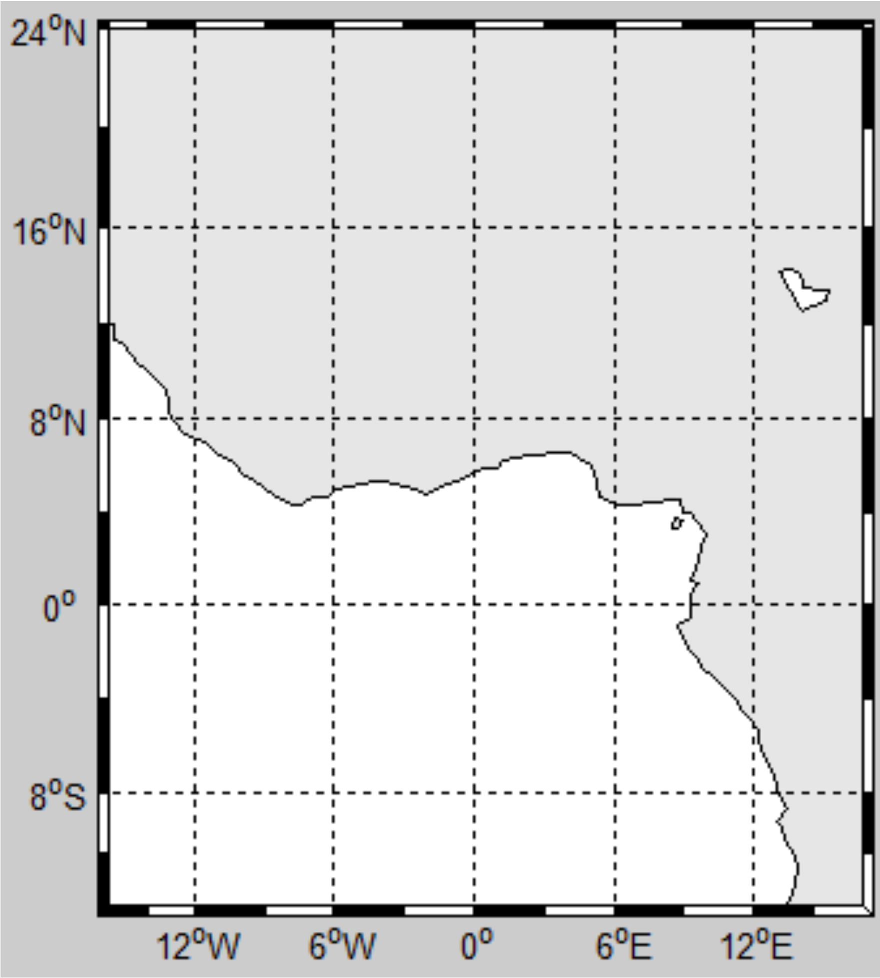
- Discretization methods:
  - Finite difference methods
  - Finite element methods
  - Finite volume methods



Example early model grid by Lewis Fry Richardson (1928)

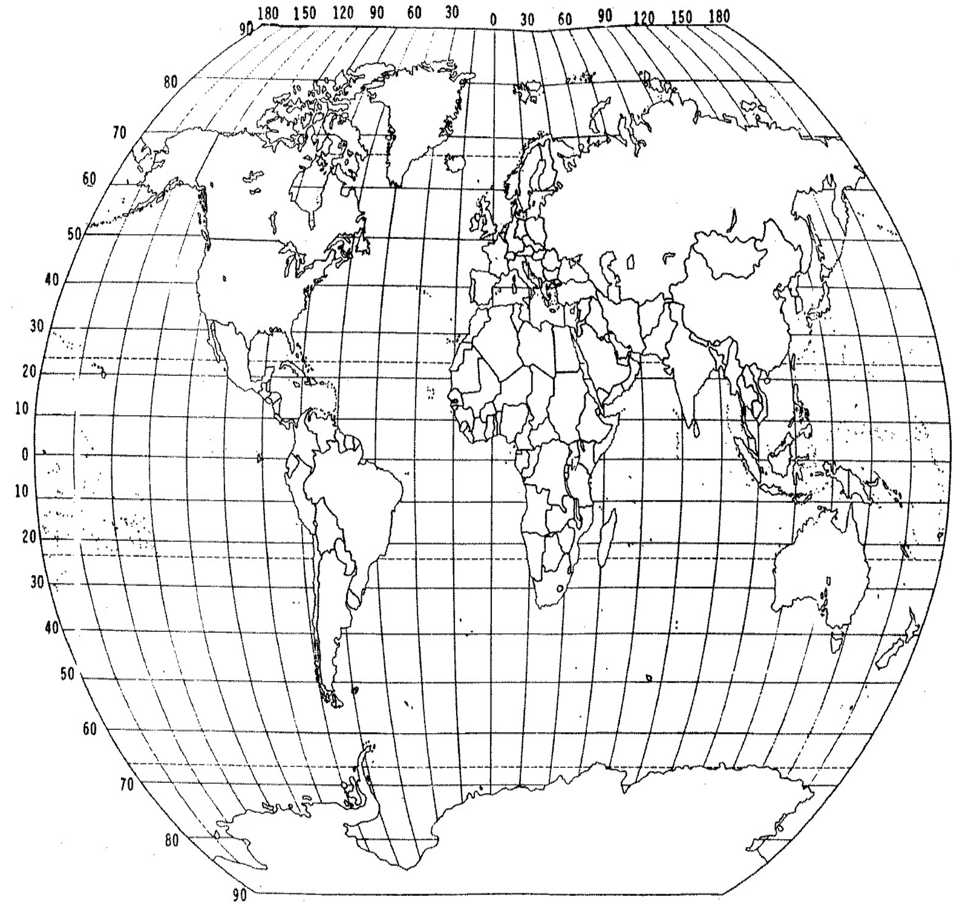
Model grid: horizontal

- Regular grids: regularly spaced lines
- On a spherical earth can't have both uniform grid spacing and straight lines

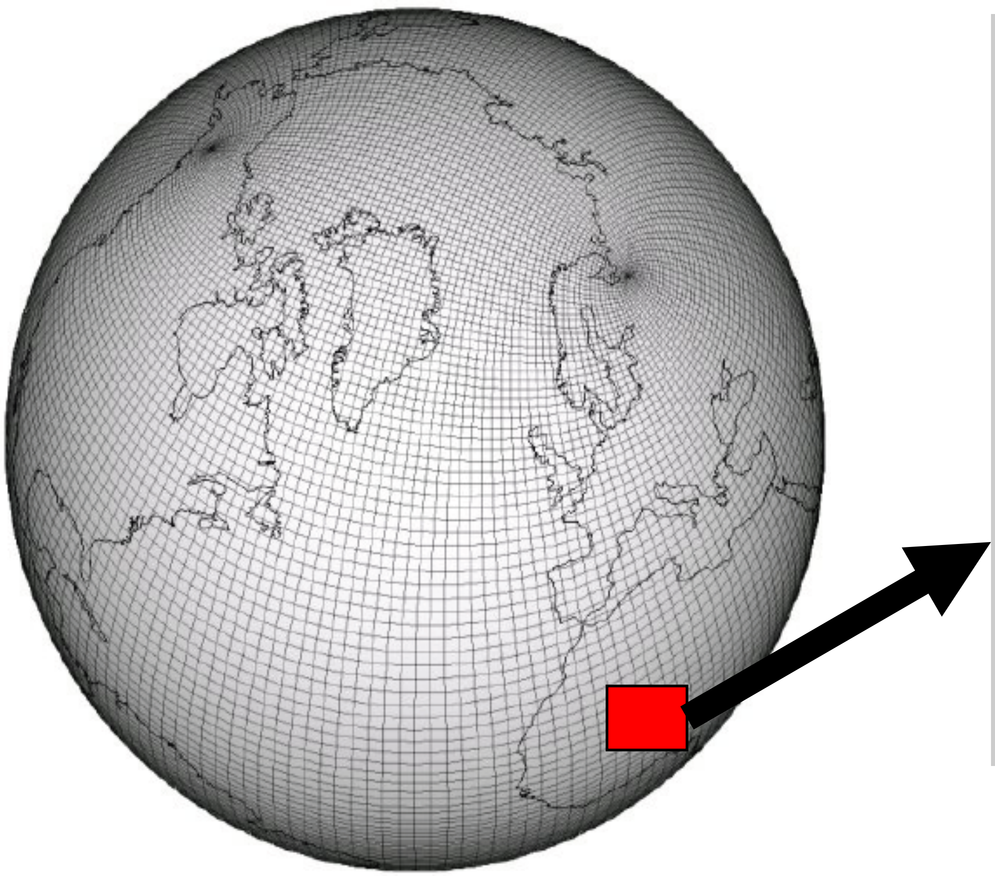


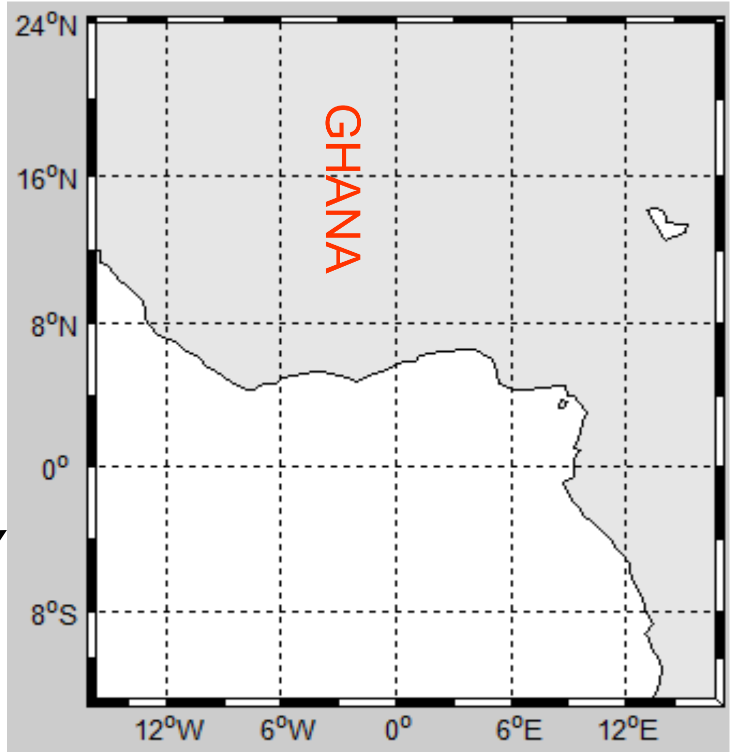
Model grid: horizontal

- Regular grids: regularly spaced lines
- On a spherical earth can't have both uniform grid spacing and straight lines
- Regular lat/lon grids have a problem at the poles where grid lines converge



Model grid: horizontal





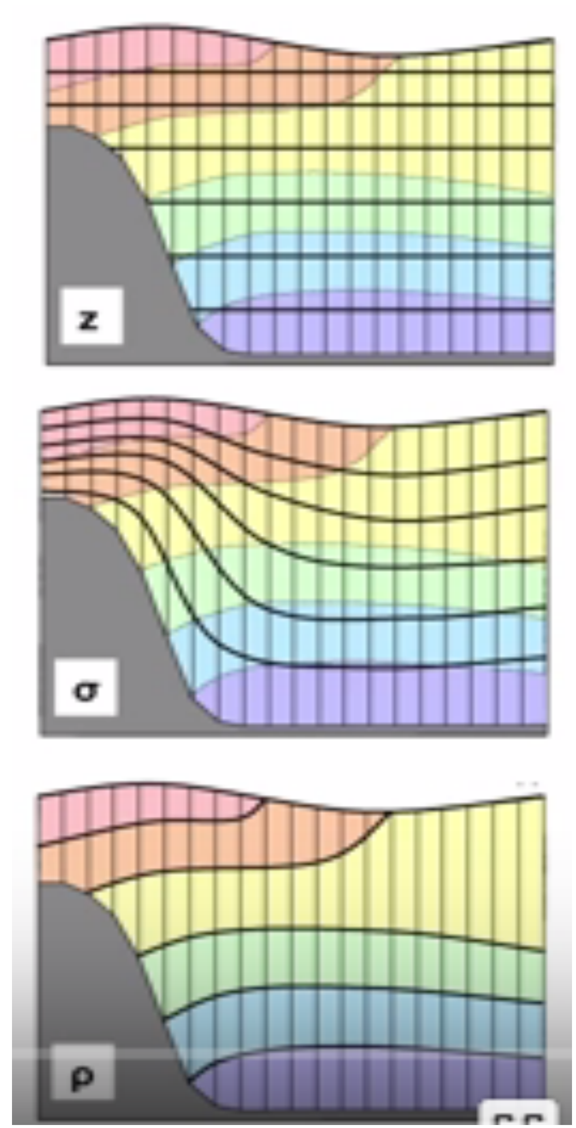
Regional grid

Clever solution: tripolar grid

-circular grid laid over Arctic region with poles on land

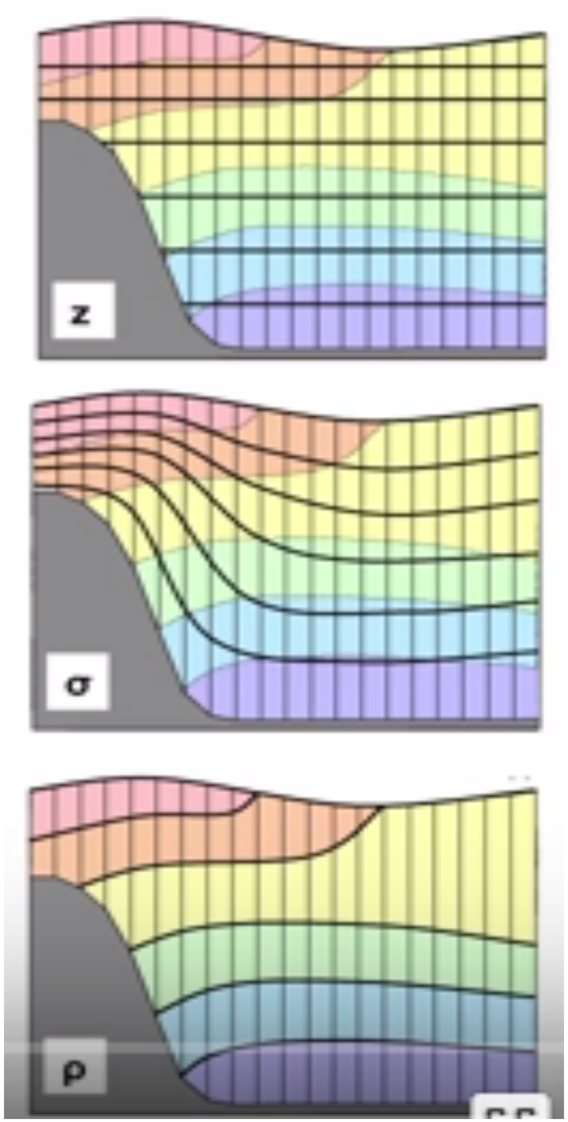
Model grid: vertical

- z-coordinate system based on a series of depth levels. Easy to setup. Difficult to locally increase resolution.
- terrain-following coordinate system. Mimics bathymetry and allows higher resolution near ocean floor.



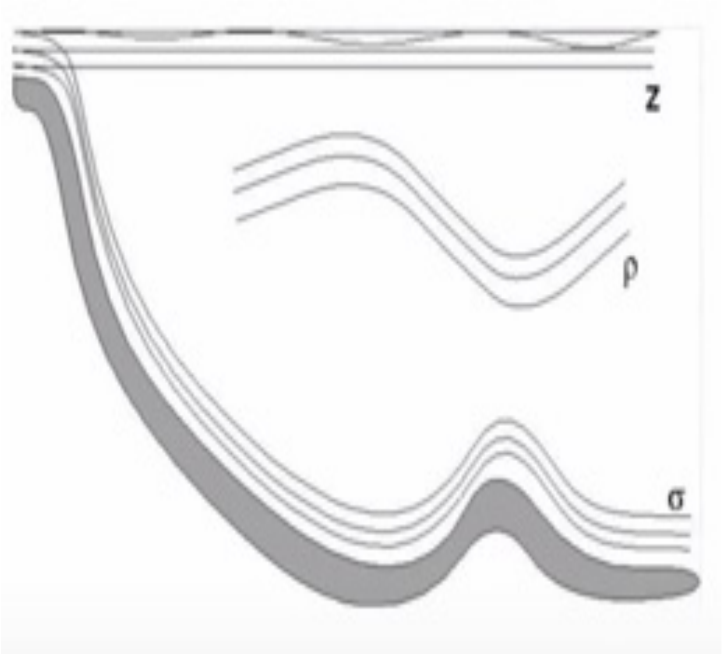
Model grid: vertical

- density (isopycnal)-coordinate system based on density layers. Great in the deep ocean where there's less diapycnal mixing. Poor in regions with high vertical mixing.



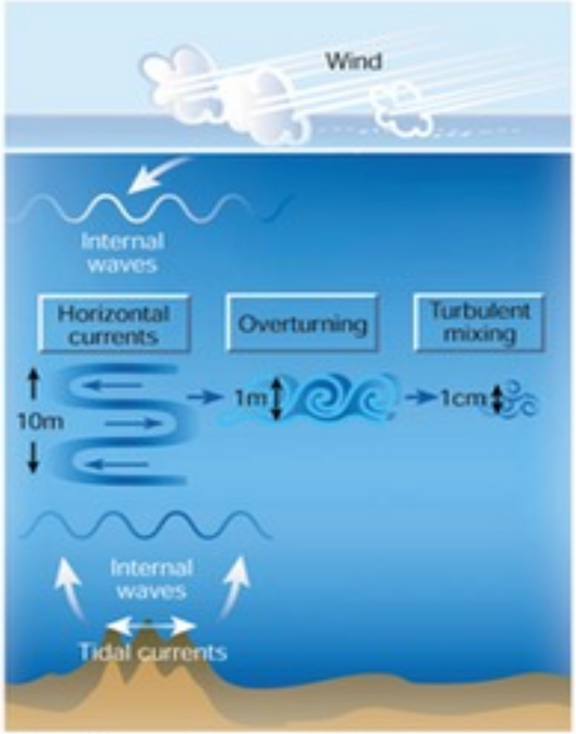
Model grid: vertical

- hybrid-coordinate applies the best suited coordinate system in different regions. Gives improved results but at a high computational cost.



Boundary conditions

- Free surface
  - Flux exchanges at surface: momentum and tracer (winds, solar radiation, rainfall, precipitation, etc).
- Ocean bottom
  - Topography/bathymetry
  - Velocity normal to bottom is zero
  - Lateral boundaries (open/closed)
- Flow normal to solid boundary is zero



Modeling: summary

- Complex differential equations

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- Set of algebraic equations

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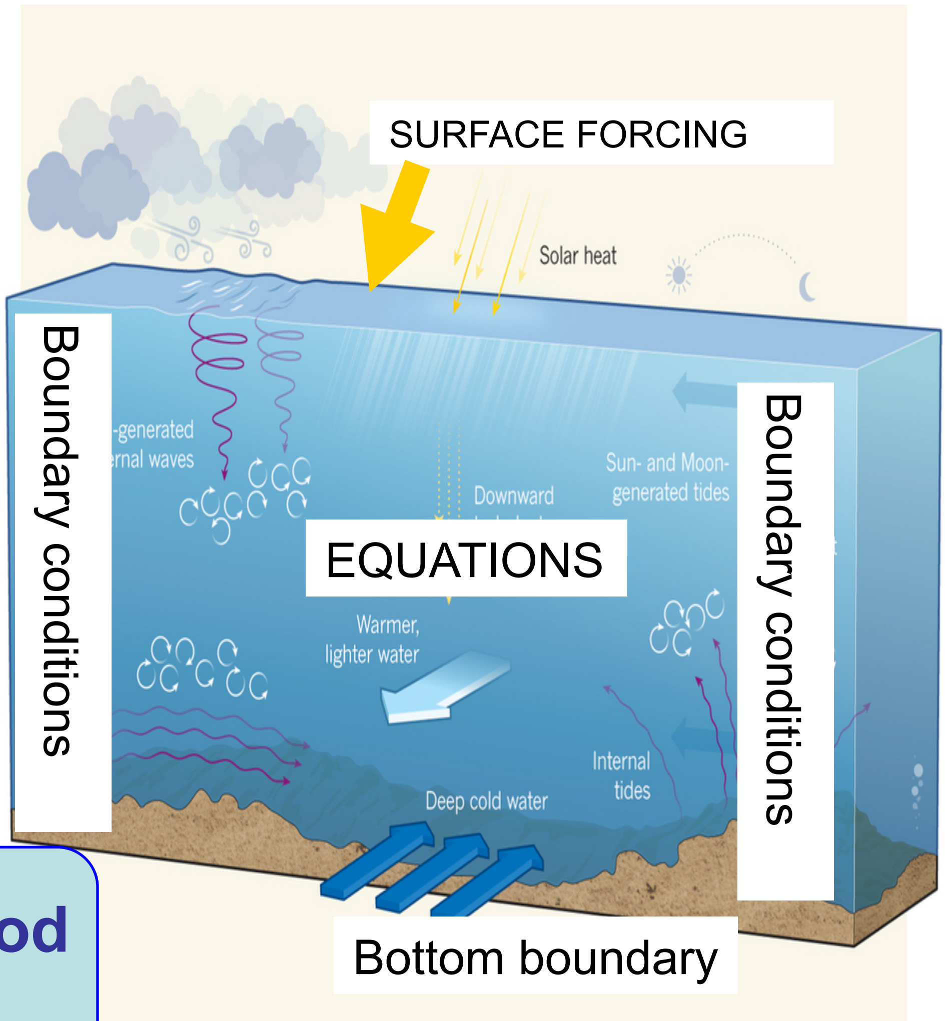
- Step-by-step method of solution

  (model time stepping)

at selected points in space

  (model spatial grid)



It takes years to develop a good ocean model!

Ocean models

- MOM (The Modular Ocean Model: http://mom-ocean.org/web)
- POM (The Princeton Ocean Model: http://www.ccpo.odu.edu/POMWEB/)
- POP (The Parallel Ocean Program: http://www.cesm.ucar.edu/models/cesm1.0/pop2/)

Ocean models

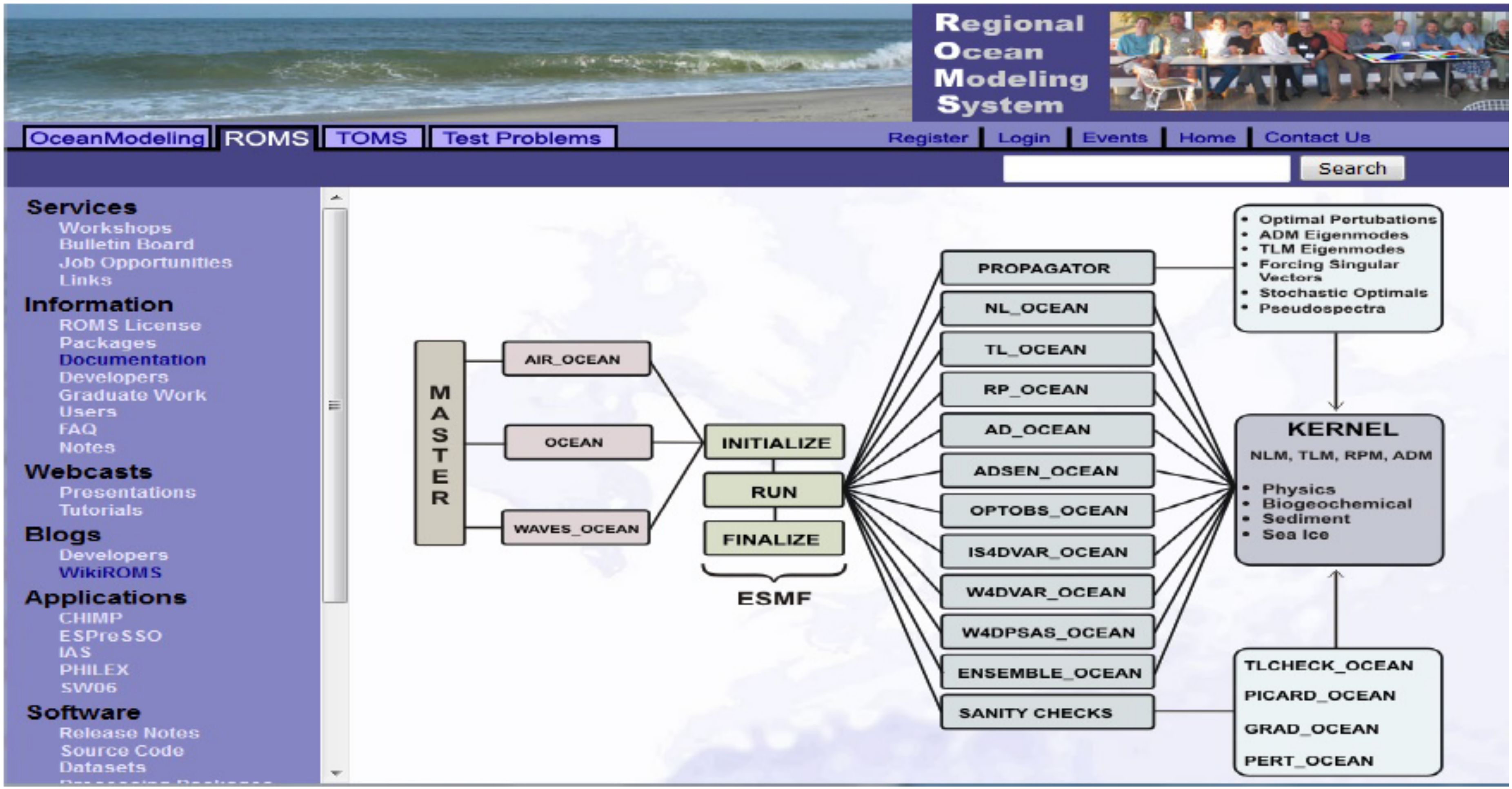
- MITgcm (MIT general circulation model: http://mitgcm.org/)
- HYCOM (The Hybrid Coordinate Ocean Model : https://hycom.org/)
- ROMS (Regional Ocean Modeling System: www.myroms.org)

Introduction to ROMS

- What is ROMS?
  - simple answer: a regional ocean model
  - but there is a lot more to ROMS: active and continuous development of source code
    - Lead by Hernan G. Arango (Rutgers University) and Alexander F. Shchepetkin (UCLA)

Where do I begin?

Go to the website:
http://www.myroms.org



Learning about ROMS

- The ROMS website contains:
  - Access to Source Code
  - Documentation (WikiROMS)
  - Access to Online Help

- Pre-processing Packages
  - Grid generation, Input file creation, etc

Learning about ROMS

- Become a ROMS user:
  - Register, download, install, compile and run the source code yourself
- Become a Collaborator:
  - Collaborate with a ROMS user and use your combined expertise to investigate problems

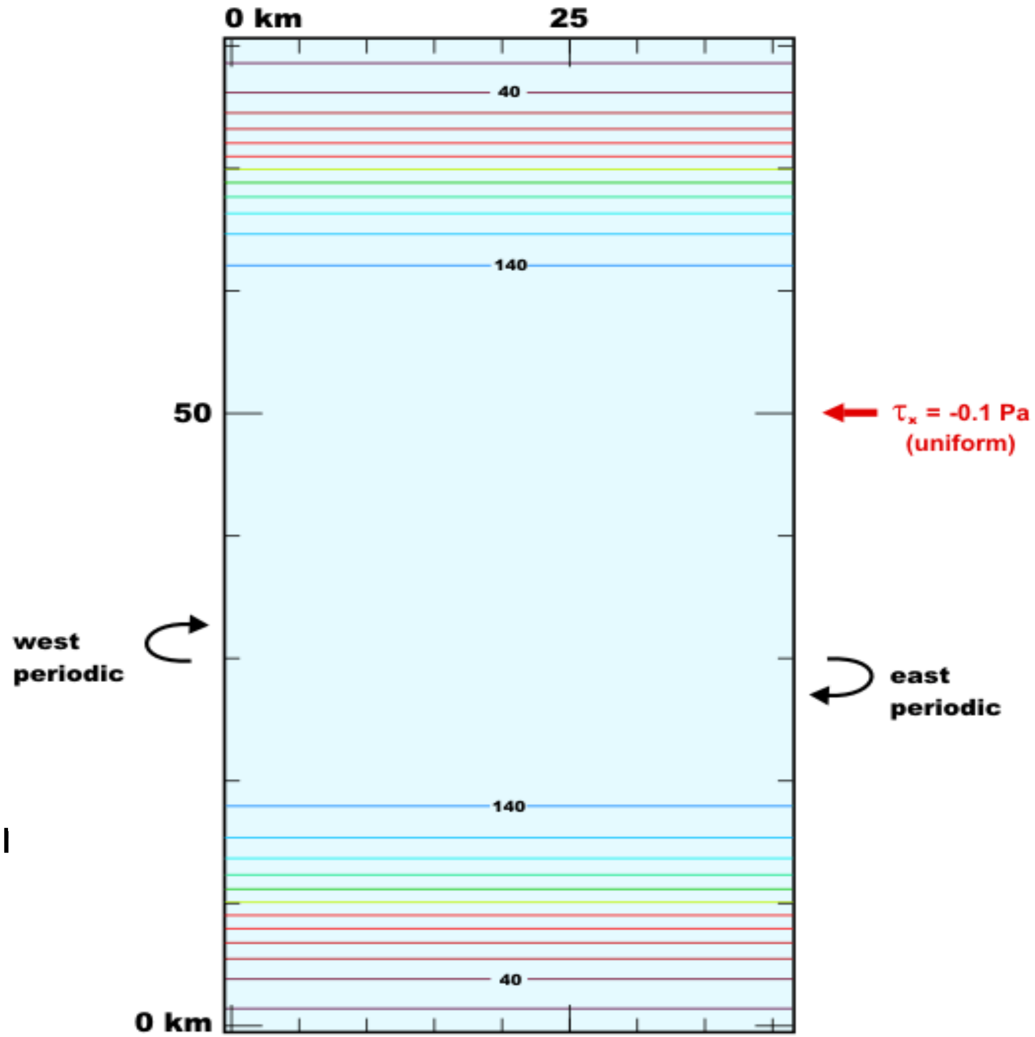
Example: A biologist may understand ecosystems but may not wish to do the numerical modeling themselves but would rather interpret the results from a model simulation.

Examples

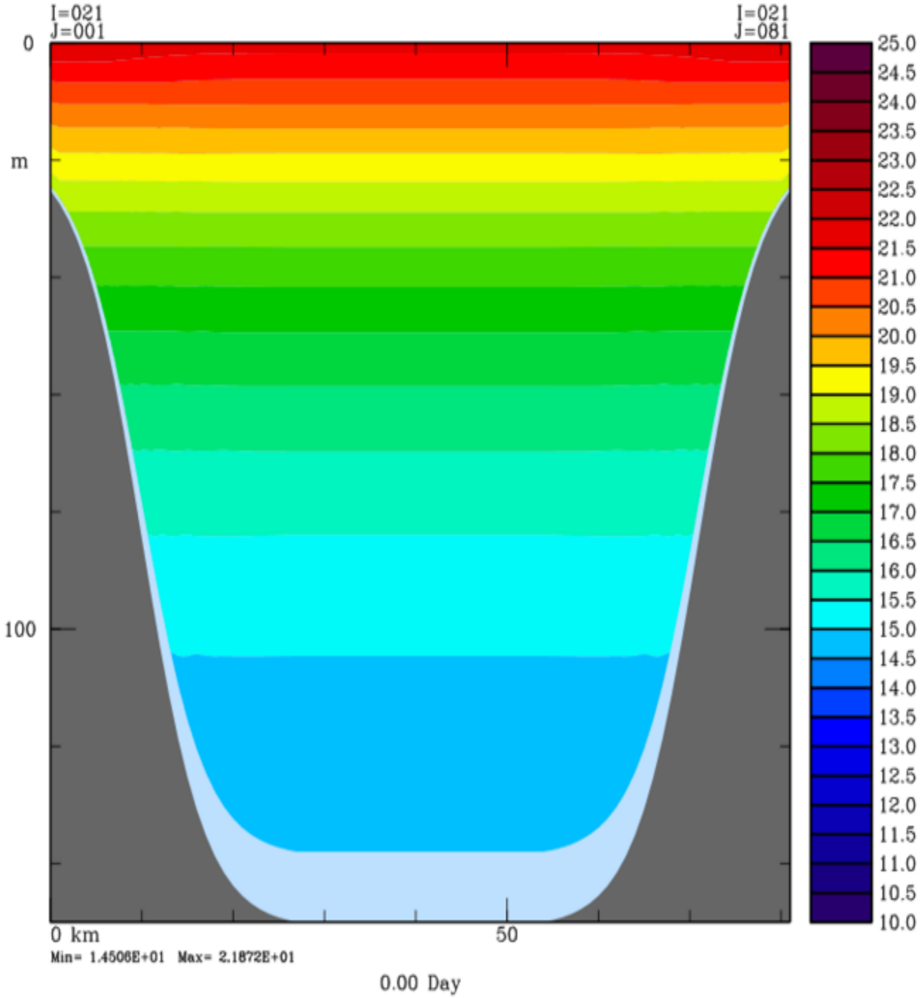
Test Case 1: Upwelling

- East-West periodic channel
- Spatially-uniform winds blowing from east to west
- Wind stress = 0.1 Pascals
- Contributed by

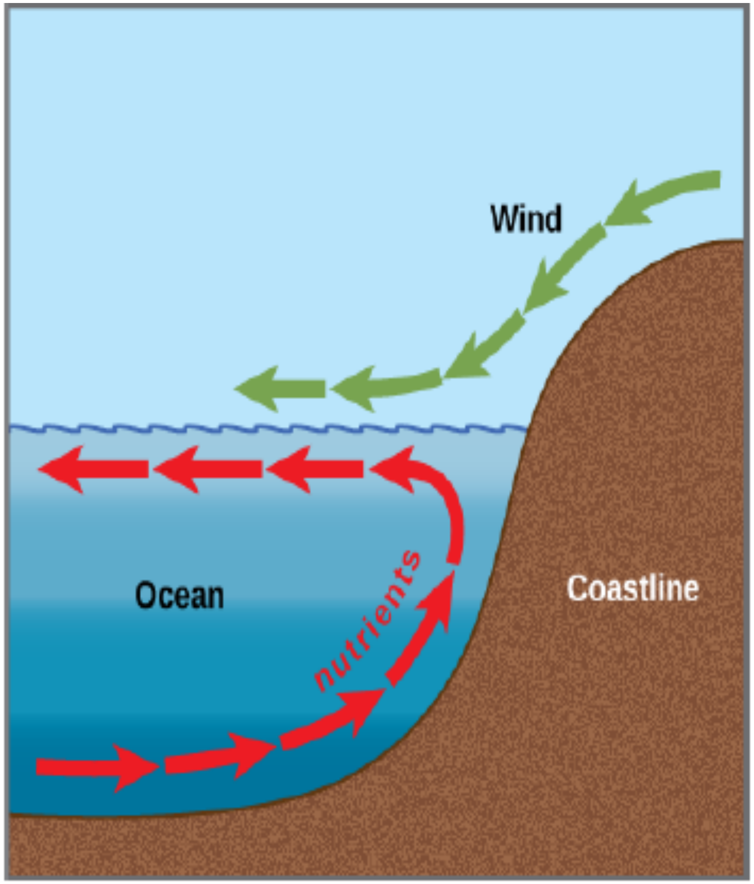
Anthony Macks and Jason Middletoı (Macks, 1993)



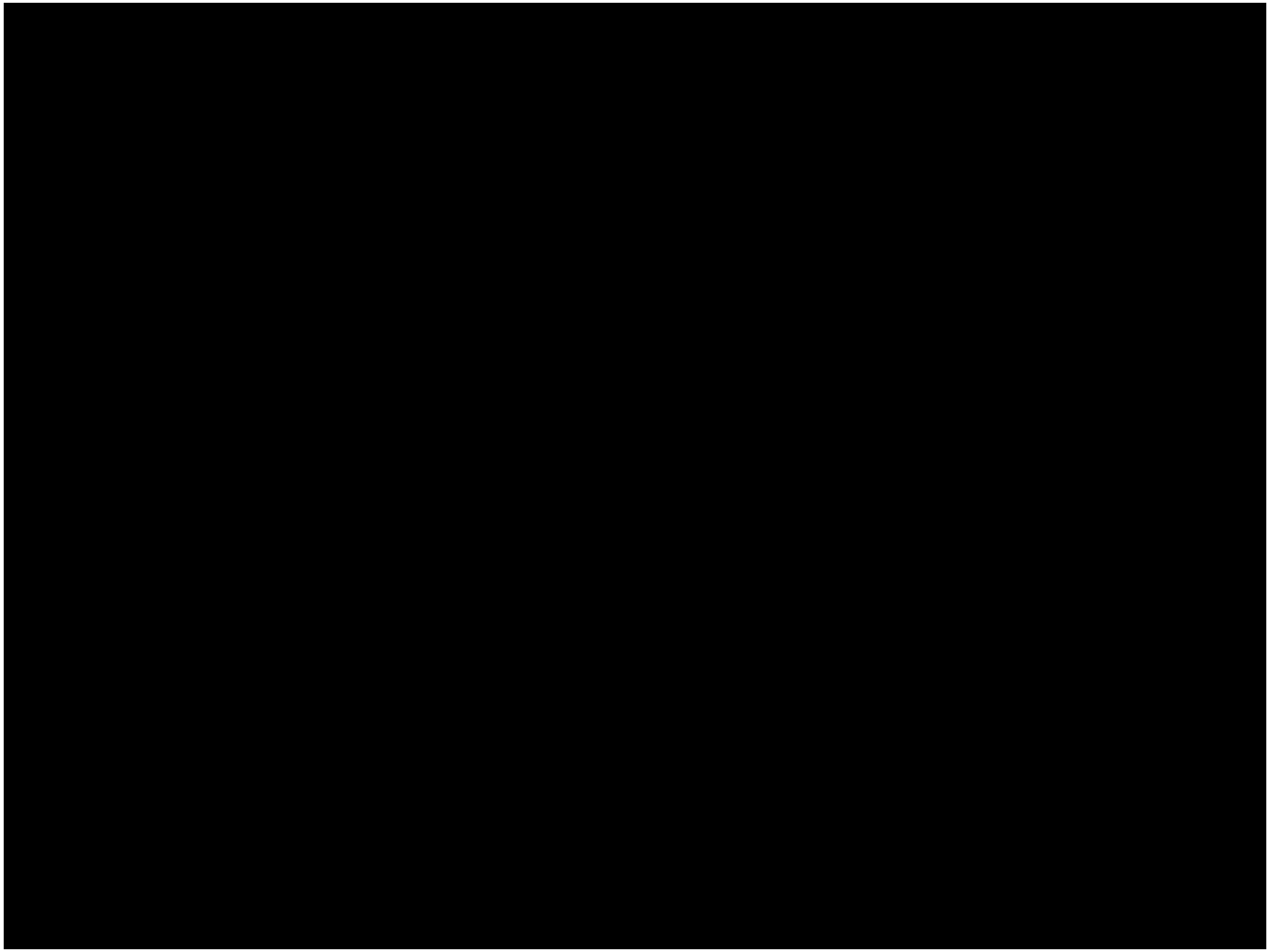
Upwelling



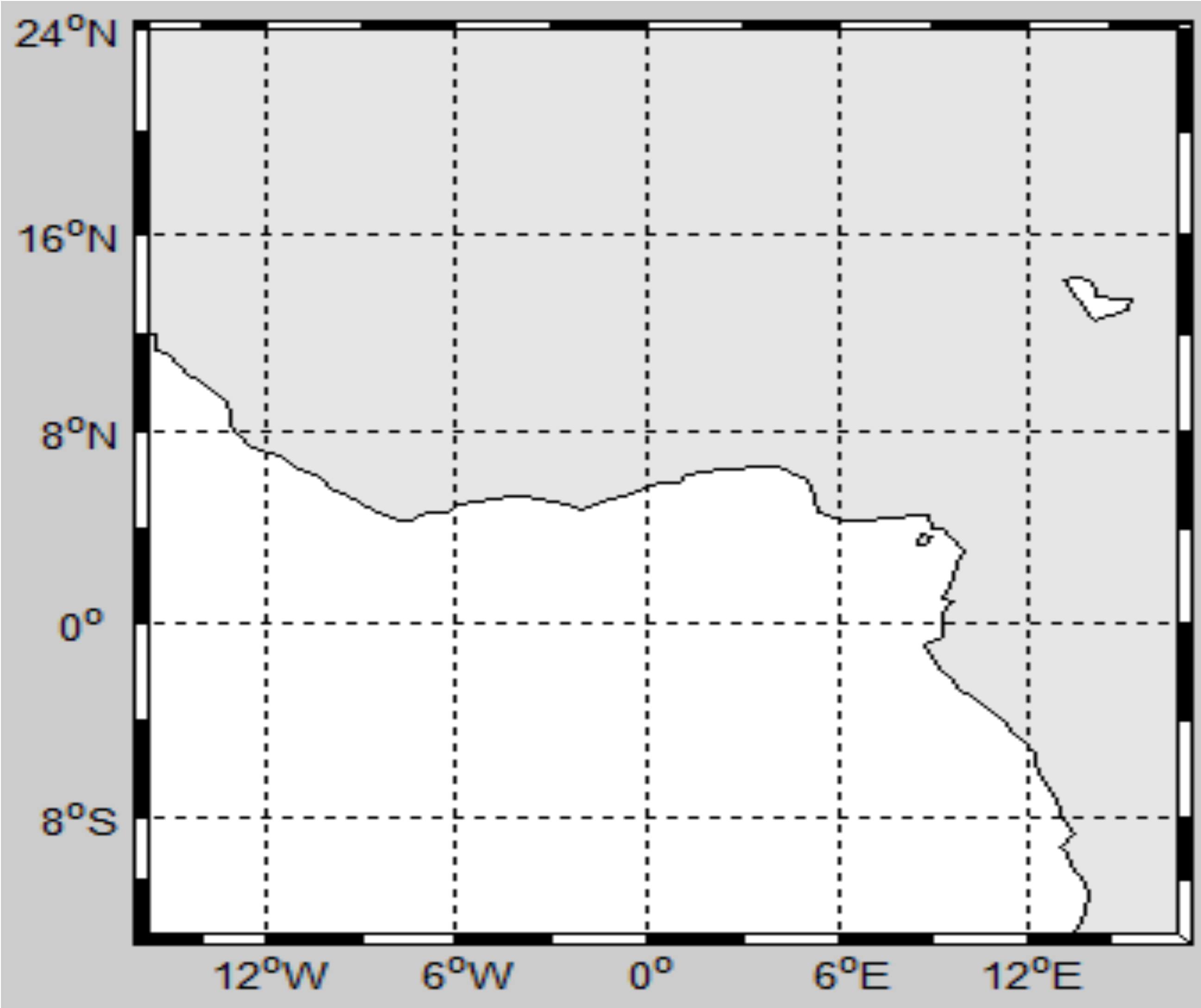
Initial temperature distribution



Upwelling



Case 2: Regional Modeling

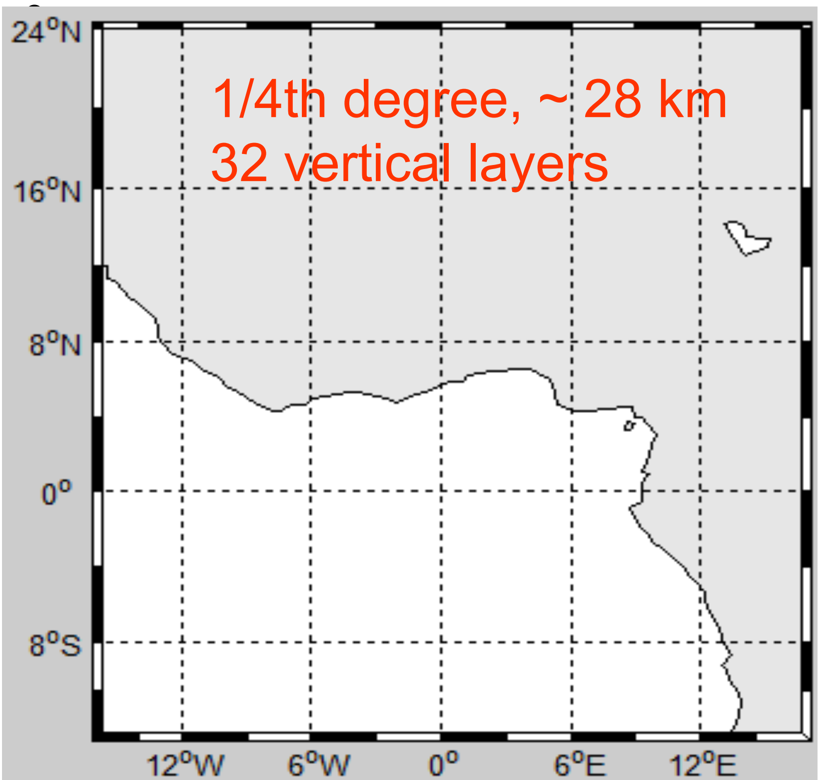


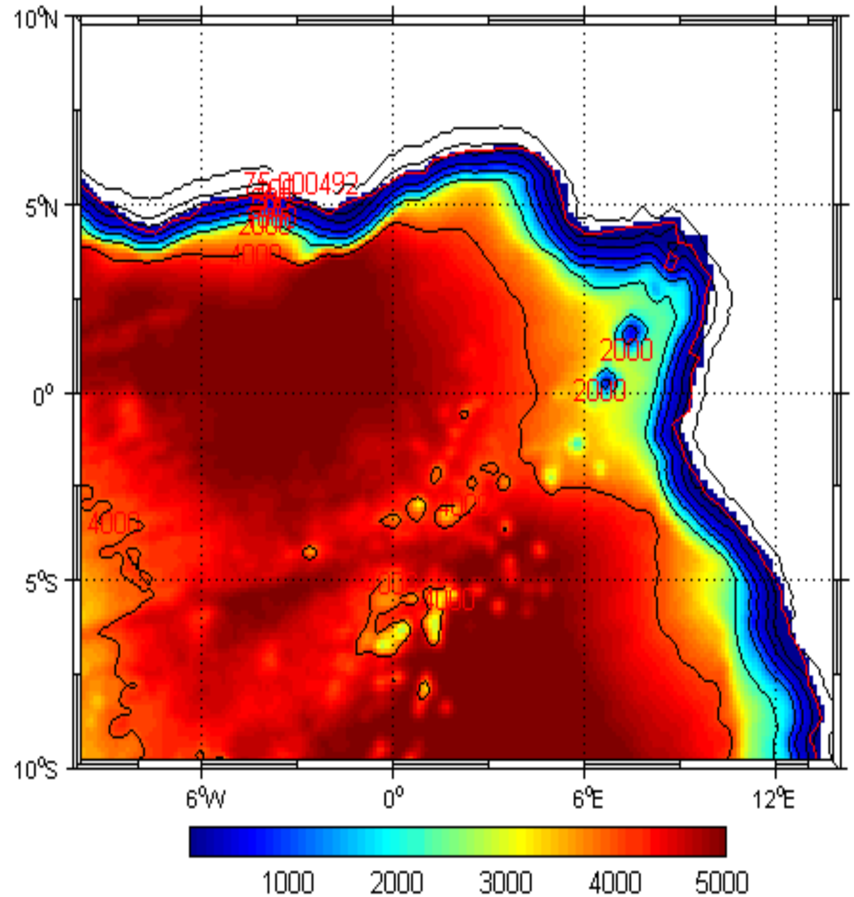
Case 2: Regional Modeling

Operational Guidelines:

1. Choose a domain and resolution.
2. Build a bathymetry.
3. Interpolate atmospheric forcing to the domain.
4. Choose vertical structure
5. Interpolate T/S climatology to the model domain and the chosen vertical structure.
6. Run the simulation.
7. Plot and analyze results.

Case 2: Regional Modeling





Etopo5: http://www.ngdc.noaa.gov/mgg/global/etopo5.HTML

Surface forcing data

- COADS05: Surface fluxes of global monthly climatology at 0.5 degrees resolution (Da Silva et al., 1994).

  http://iridl.ldeo.columbia.edu/SOURCES/.DASILVA/.SMD94/.climatology/index.html?Set-Language=en

Climatological data

- WOA: World Ocean Atlas 2001 global dataset (monthly climatology at 1 degree resolution) -> 3D fields of temperature, salinity,etc.

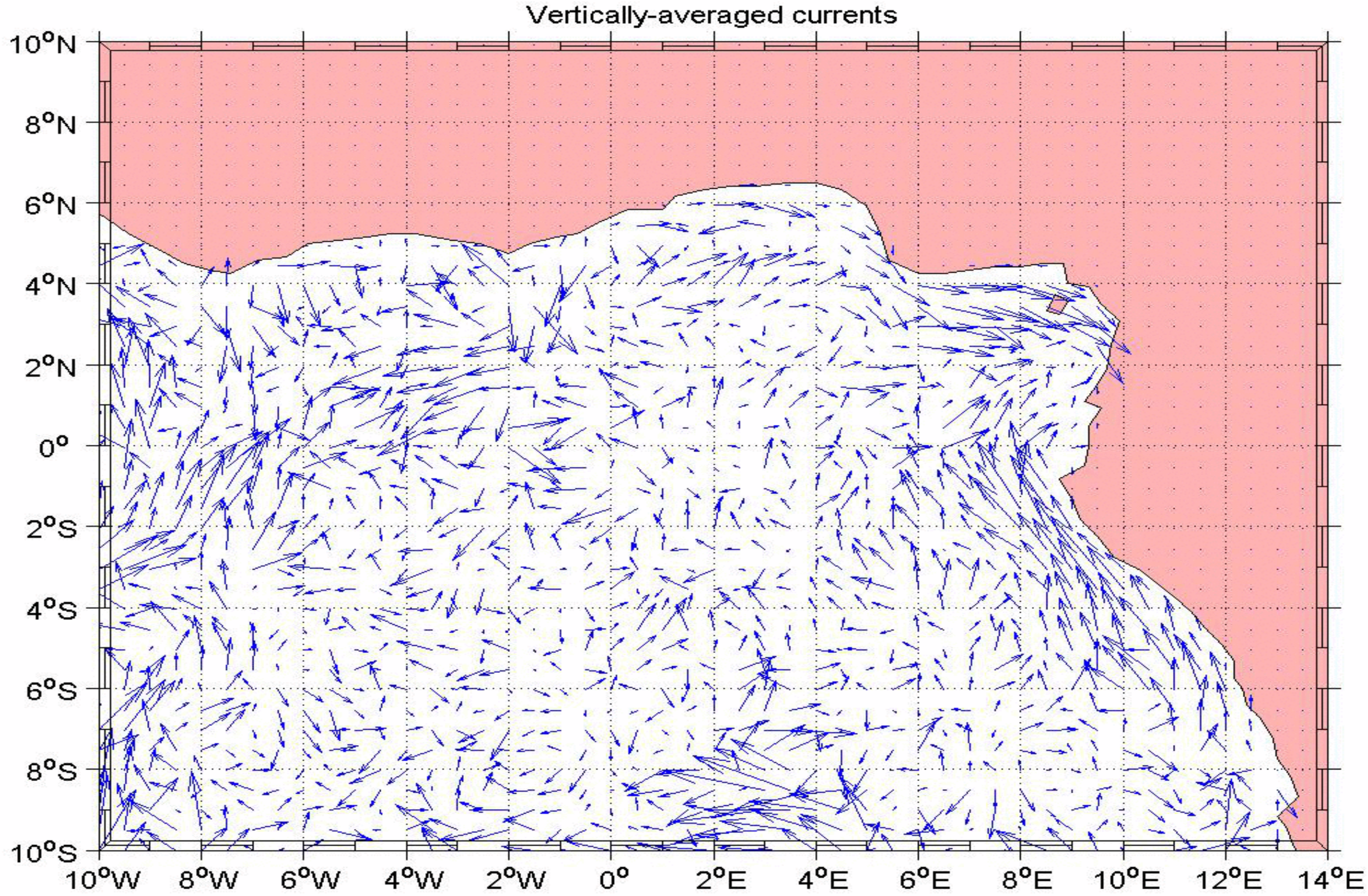
  https://www.nodc.noaa.gov/OC5/WOA01/pr_woa01.html

Tidal forcing data

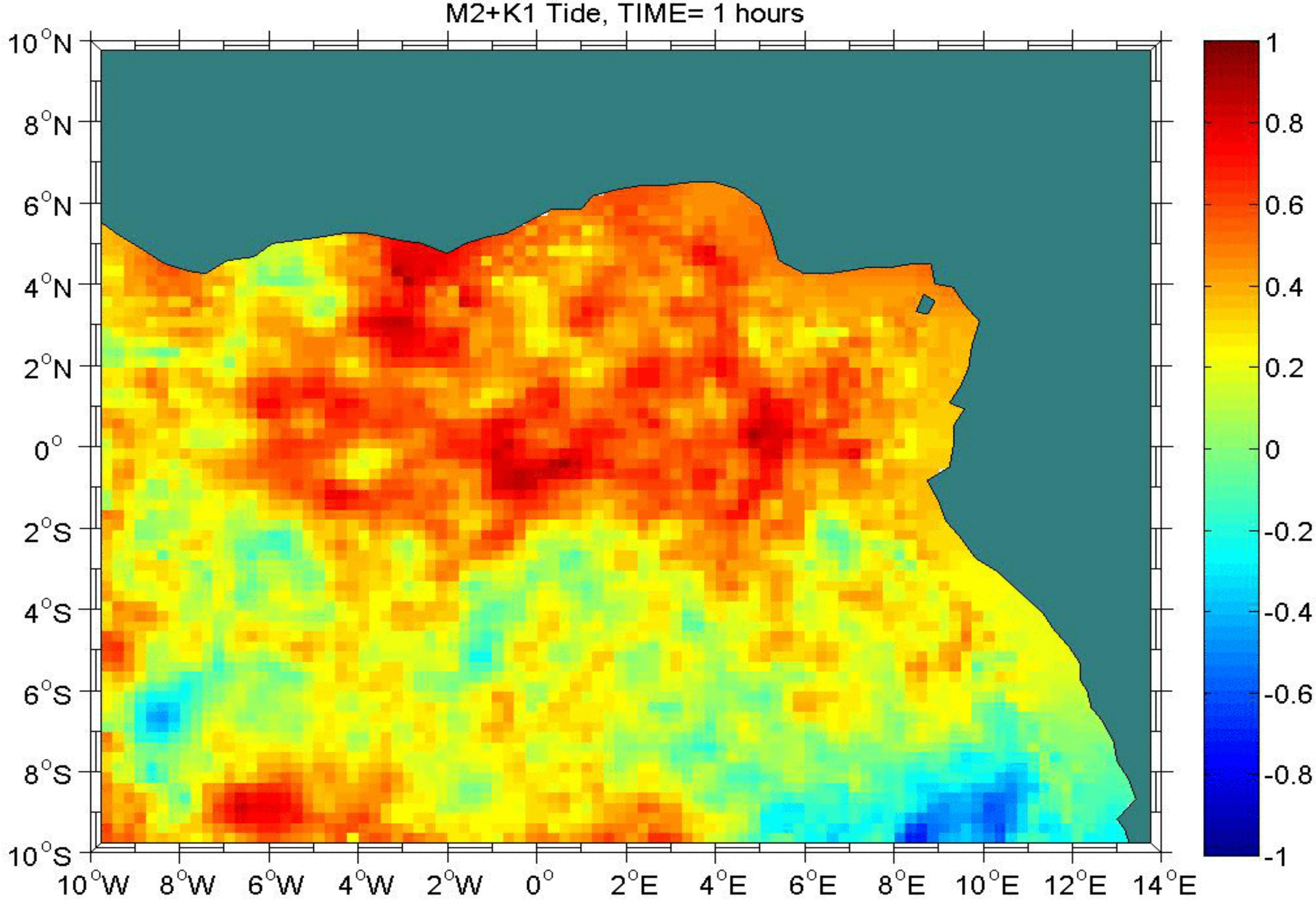
- Tidal data are derived from the Oregon State University global models of ocean tides TPXO6 and TPXO7 (Egbert and Erofeeva, 2002):

  http://www.oce.orst.edu/research/po/research/tide/global.html

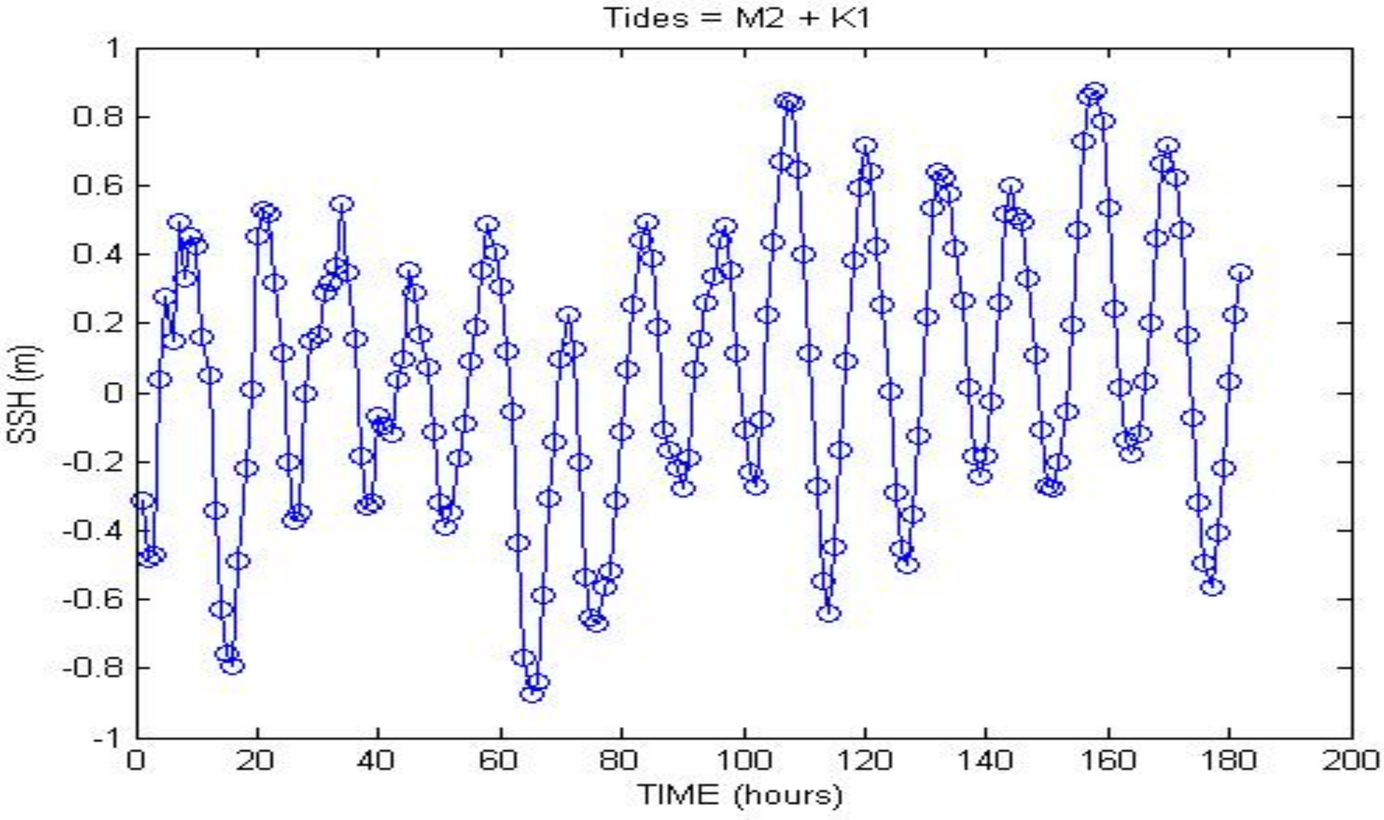
Results: currents



Results: Tides



Results: tidal time series



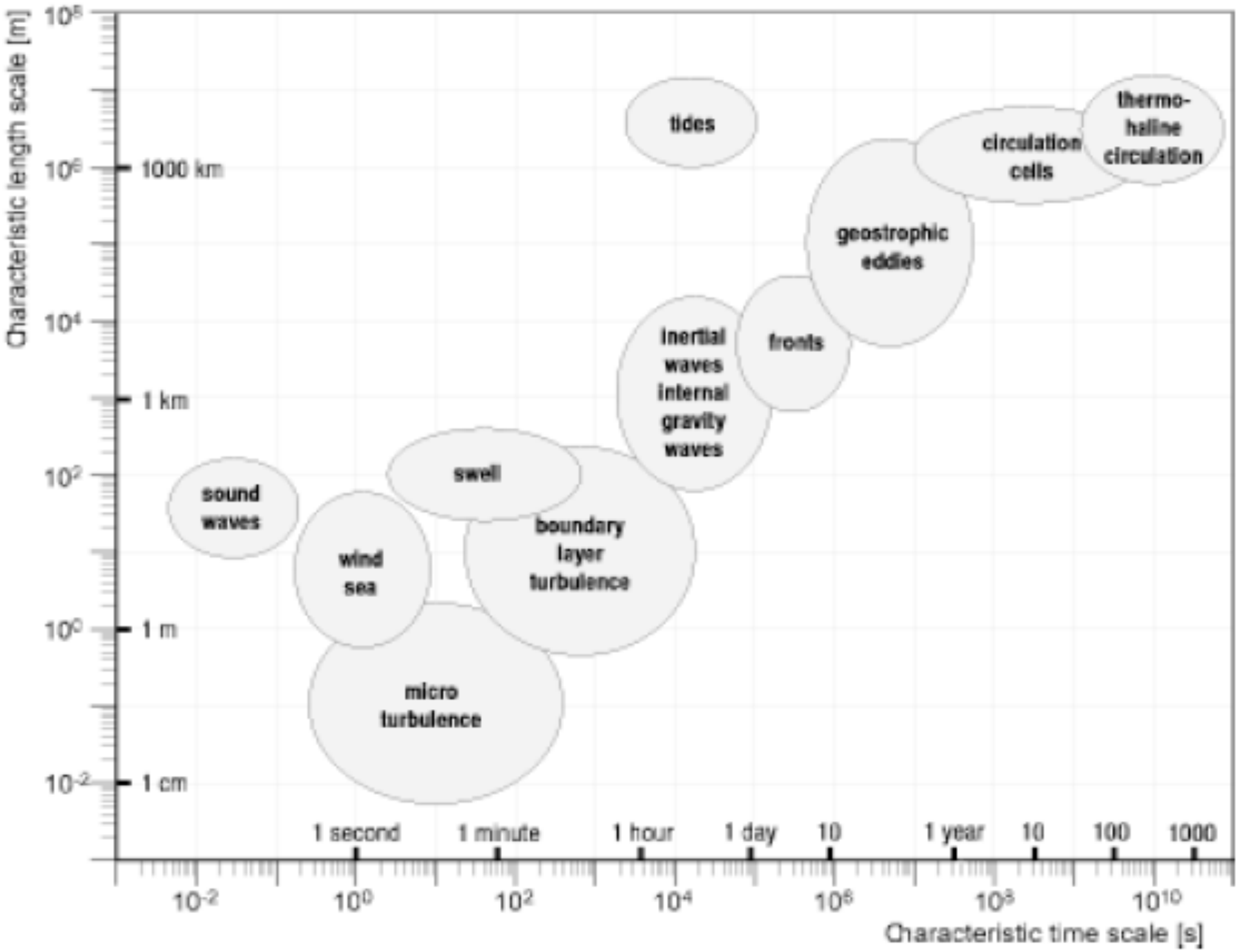
Challenge: compare to tide-gauge data (Takoradi/Tema)

Challenges to ocean modeling

What are some challenges?

Challenges to ocean modeling

1. Variable spatial/temporal scales



Challenges to ocean modeling

2. Complex topography and lateral boundaries

3. Few observational measurements for validation
   - -most available data are confined to upper ocean

4. Availability of computational power