# INTRODUCTION TO OCEAN MODELING


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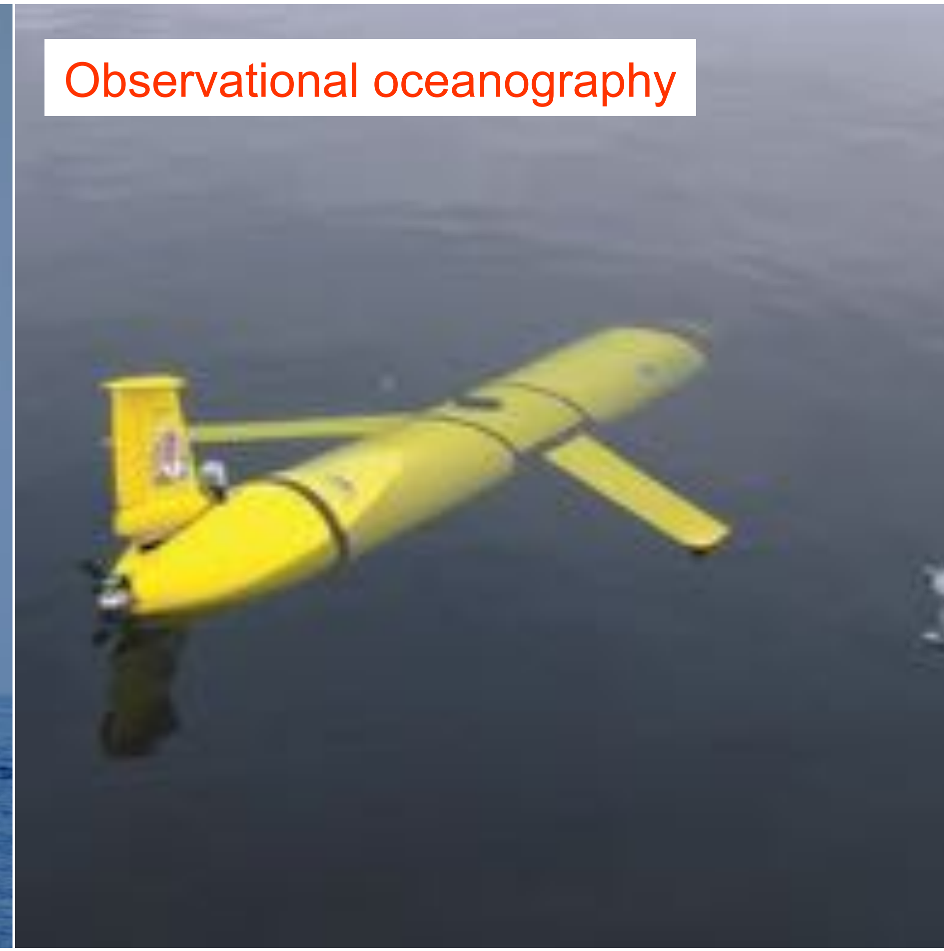
***COESSING-2019***

# OUTLINE

- INTRODUCTION: Approaches to ocean studies
- MOTIVATION: Why model the ocean?
- THE MODELING PROCESS
- SIMPLE EXAMPLES
- CHALLENGES

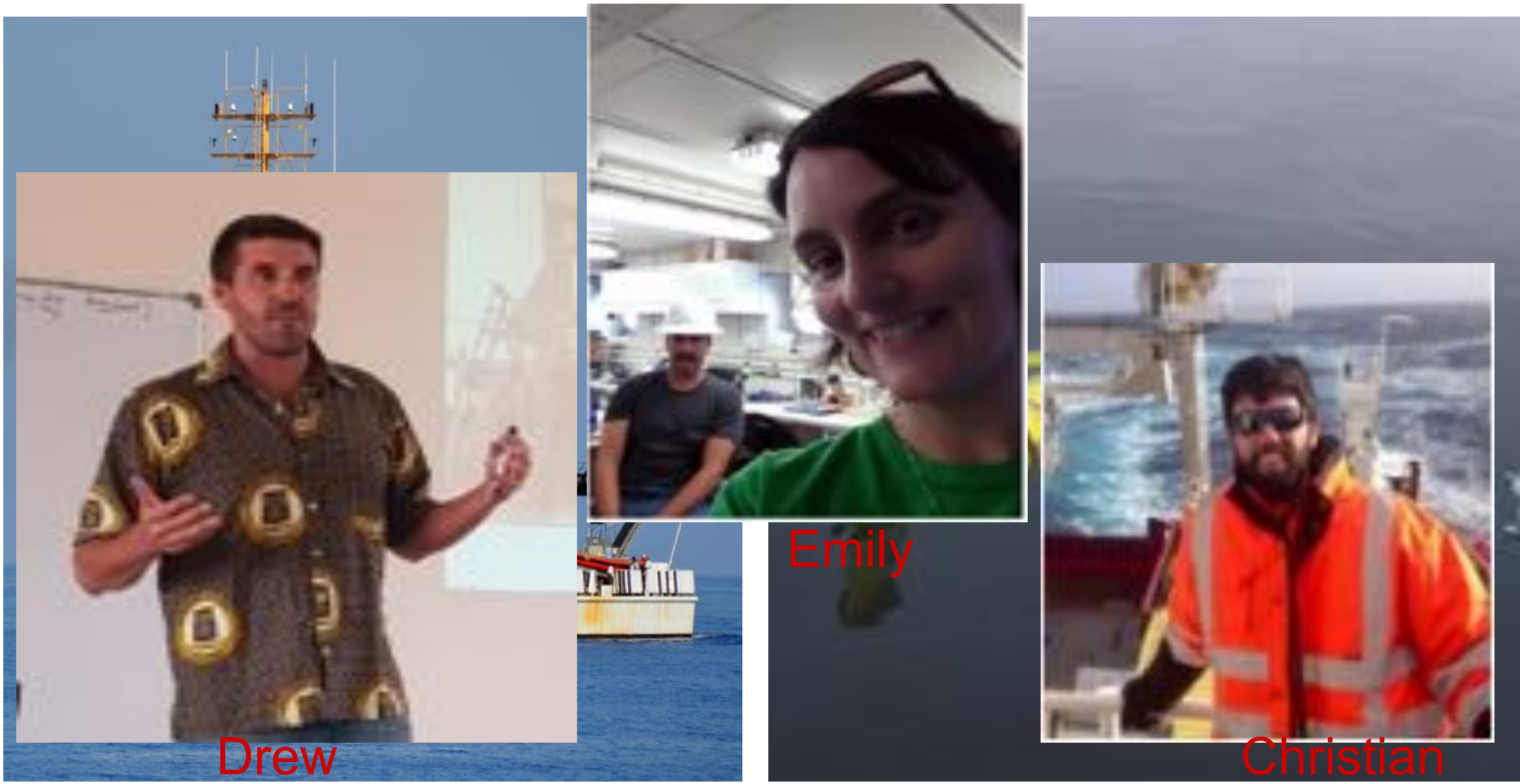
# Introduction: Approaches to oceanic studies


**Drew, Emily, Stephan, Christian**

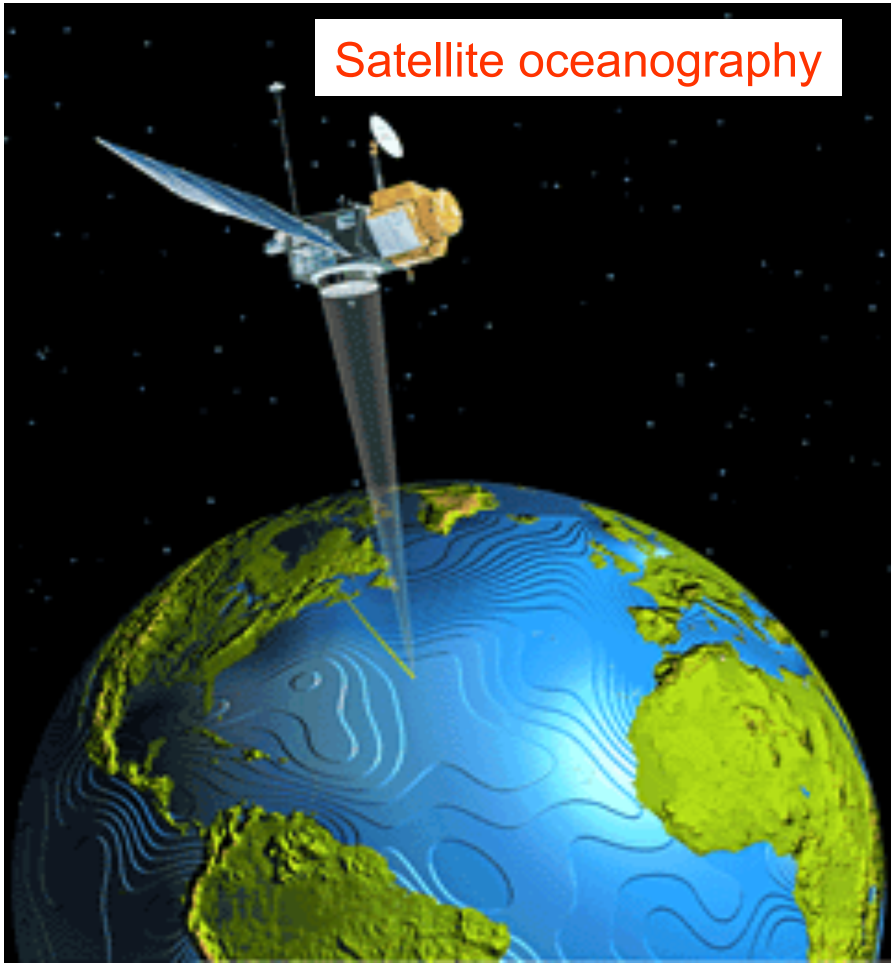
# Introduction: Approaches to oceanic studies

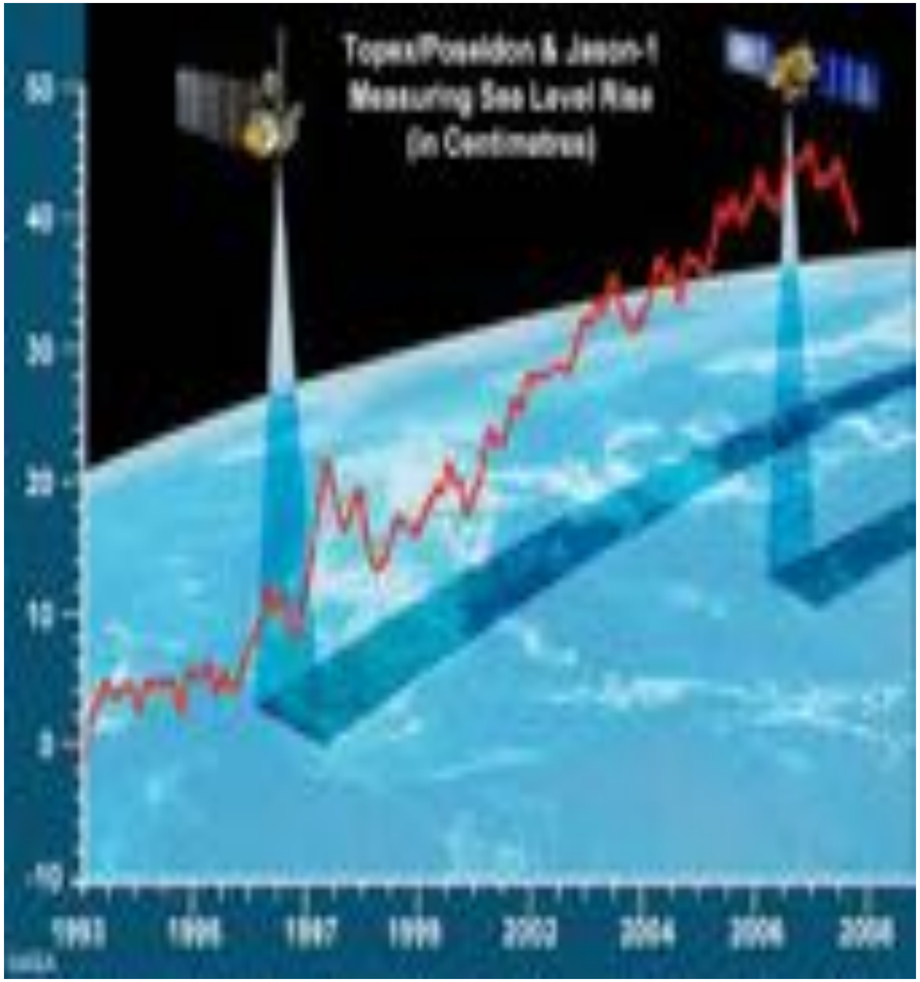
Observational oceanography




**Drew, Emily, Stephan, Christian**

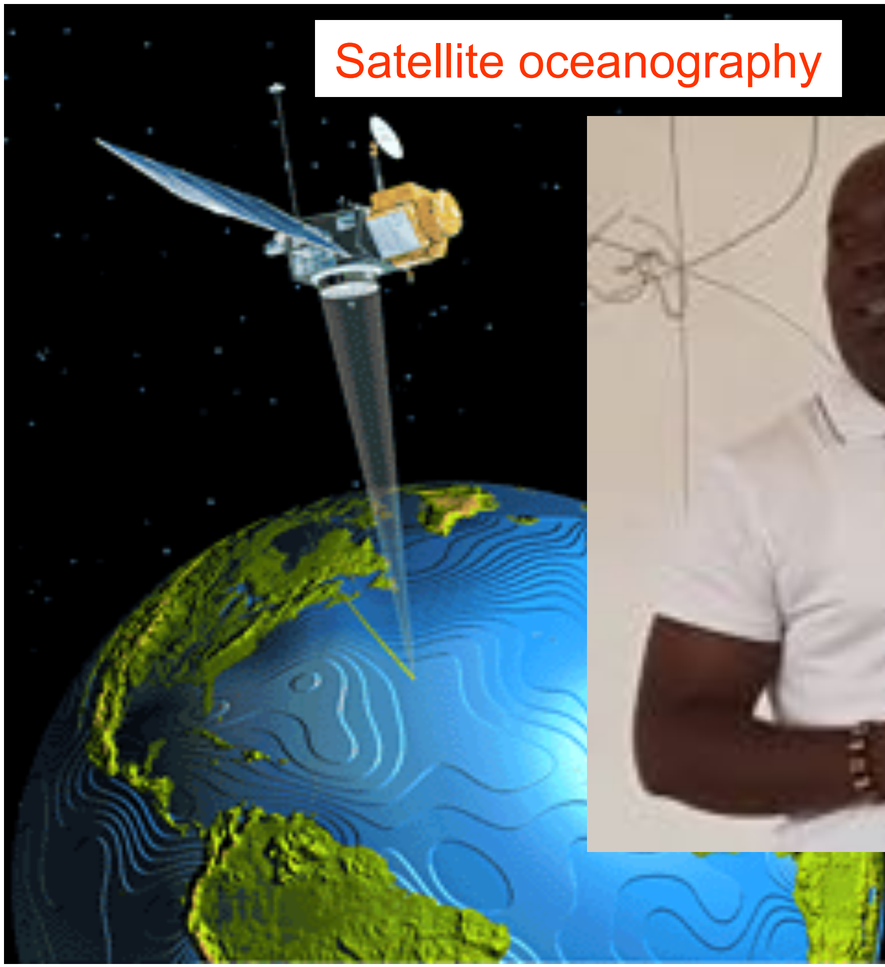
# Introduction: Approaches to oceanic studies

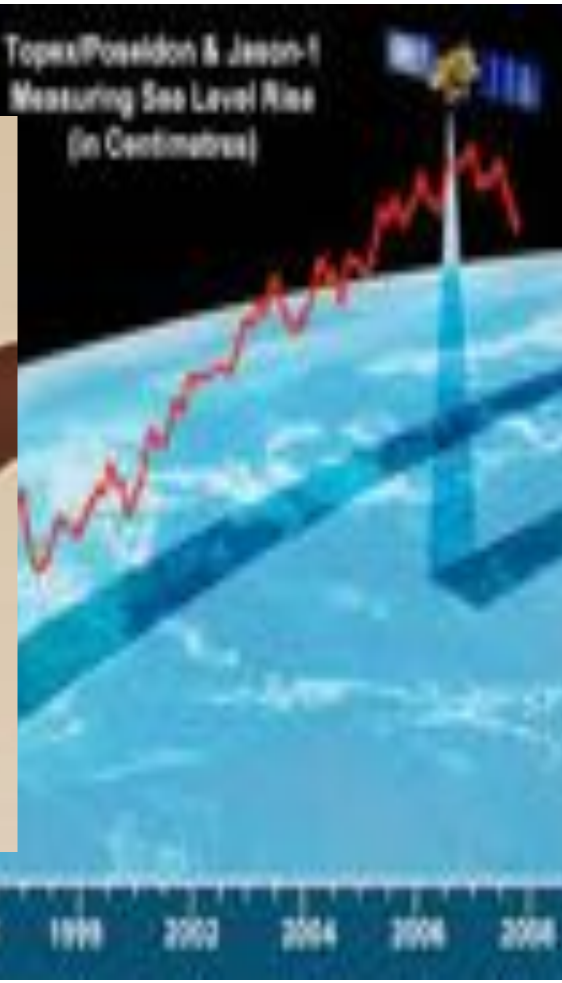



**Ebenezer, Christian, et. al.**

# Introduction: Approaches to oceanic studies

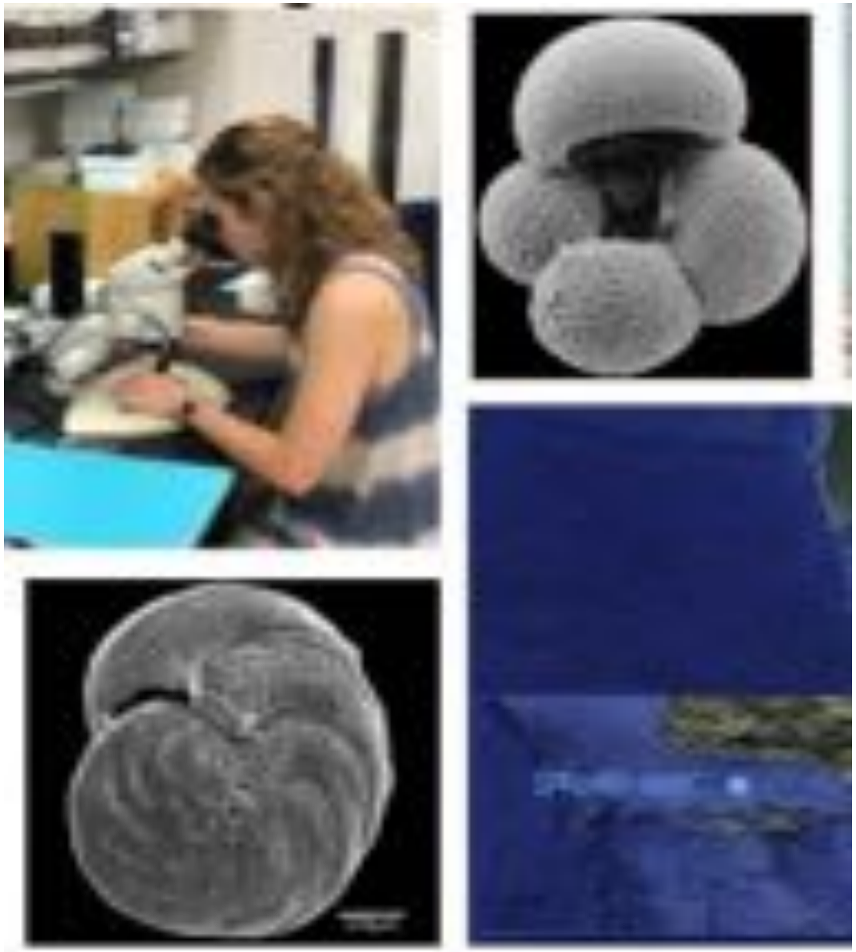



Ebenezer, Christian, et. al.

# Introduction: Approaches to oceanic studies

Chemical oceanography



**Winn, Madelyn, Julia, et al.**

# Introduction: Approaches to oceanic studies

Chemical oceanography

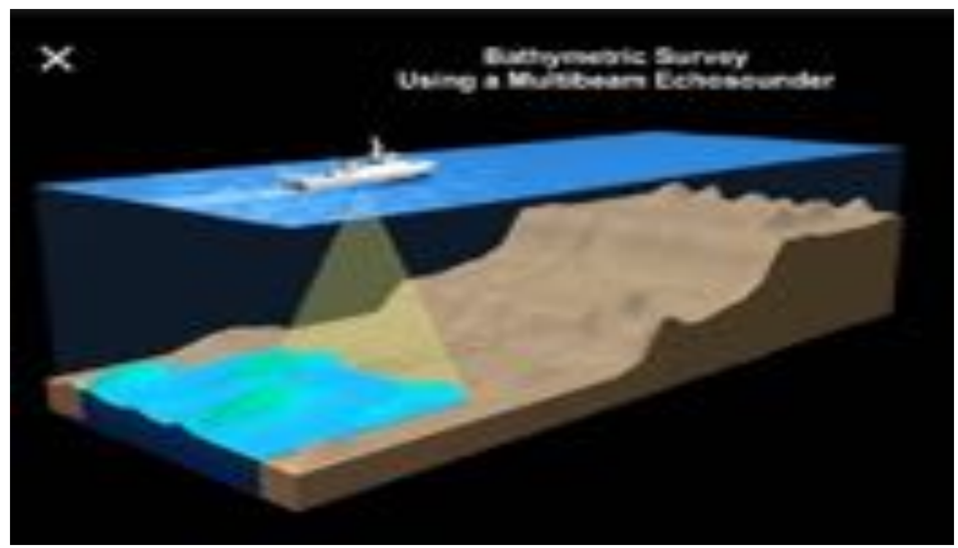
**Julia**

**Winn**

**Madelyn**

# Introduction: Approaches to oceanic studies

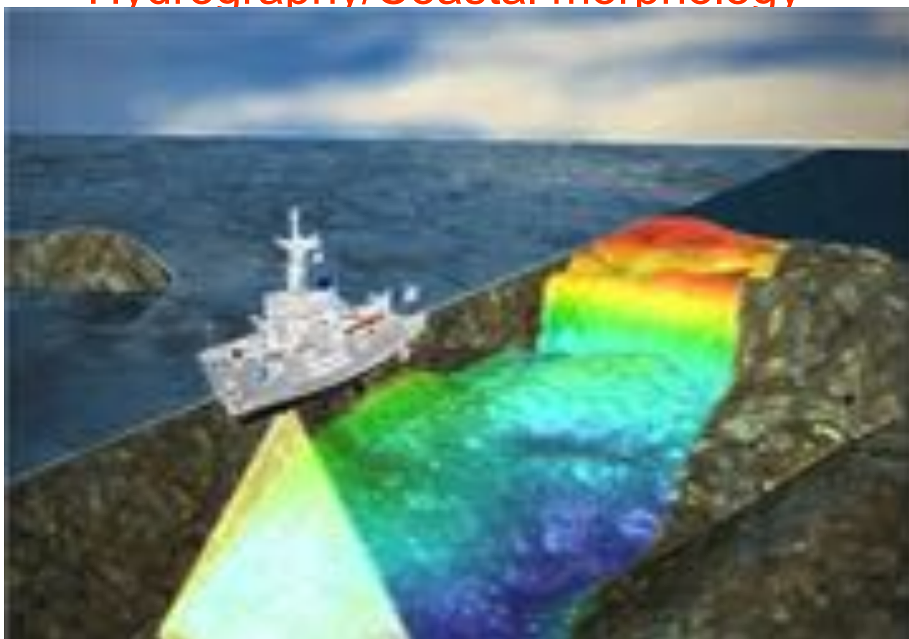
Hydrography/Coastal morphology

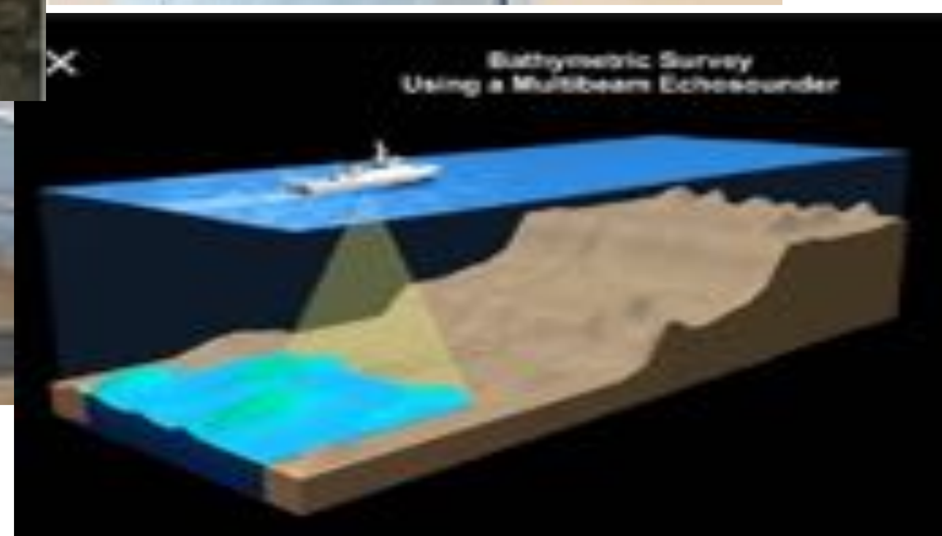



**Stephan/Kwasi**

# Introduction: Approaches to oceanic studies

Hydrography/Coastal morphology





# Introduction: Approaches to oceanic studies


Angela (Talk on Friday)

# Introduction: Approaches to oceanic studies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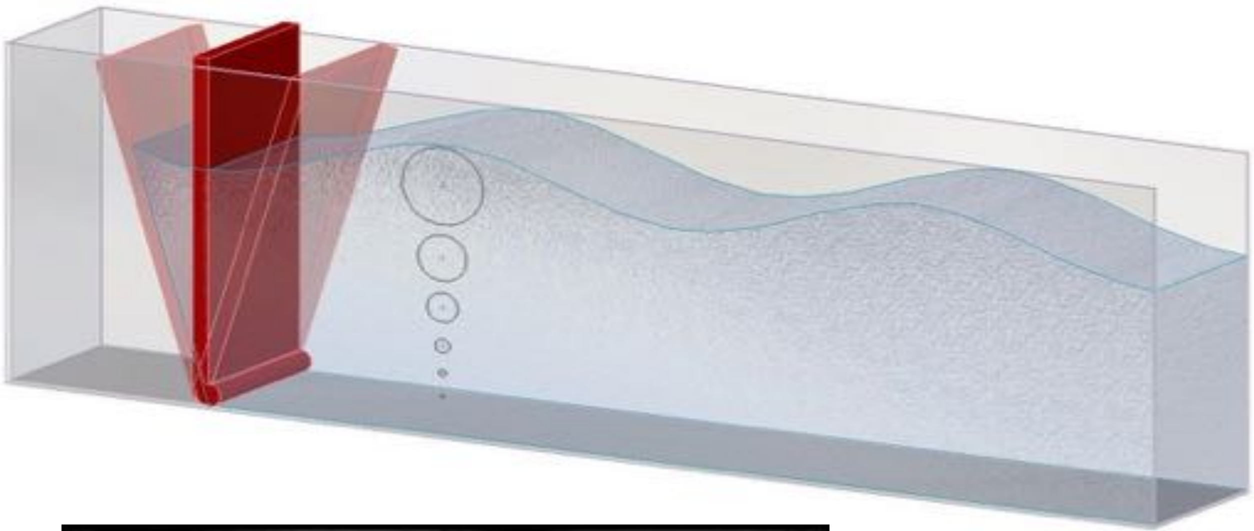
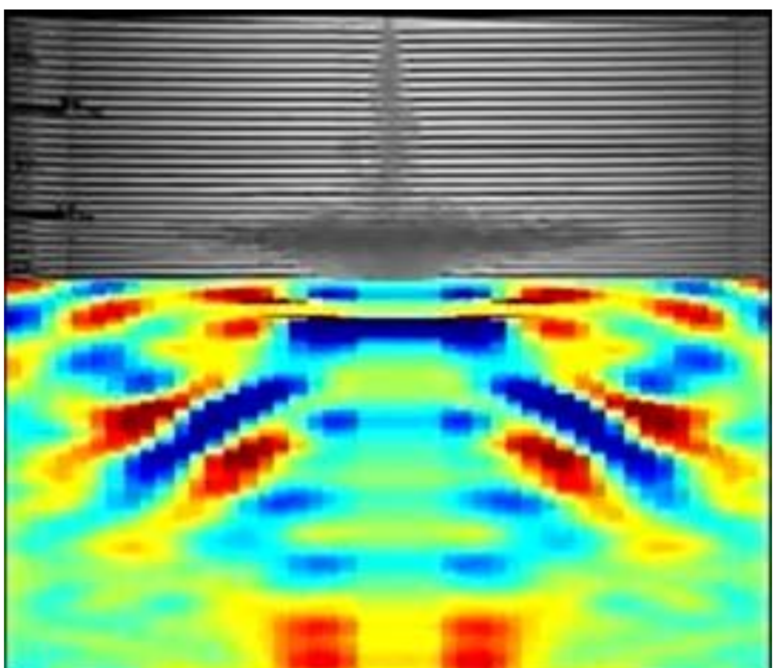


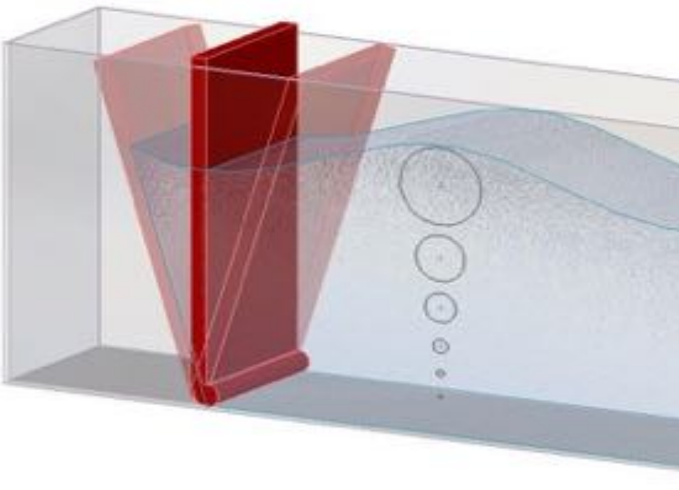
**Laboratory tank Experiments-**

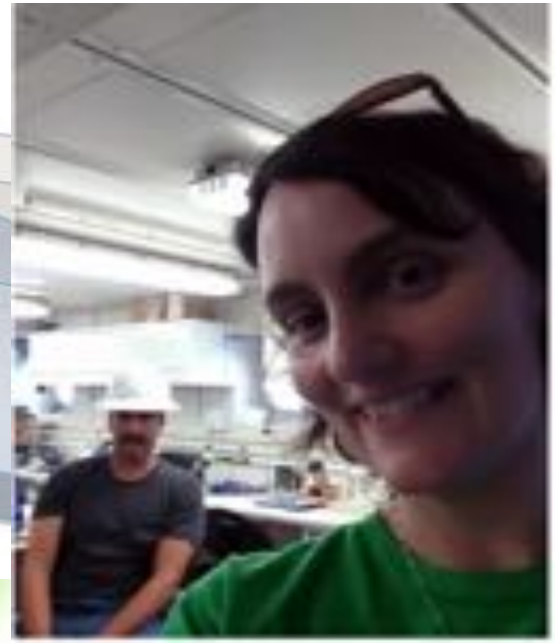


**Ansong & Sutherland, 2010, JFM, vol 648**

# Introduction: Approaches to oceanic studies

**Laboratory tank Experiments- Aline, Emily**



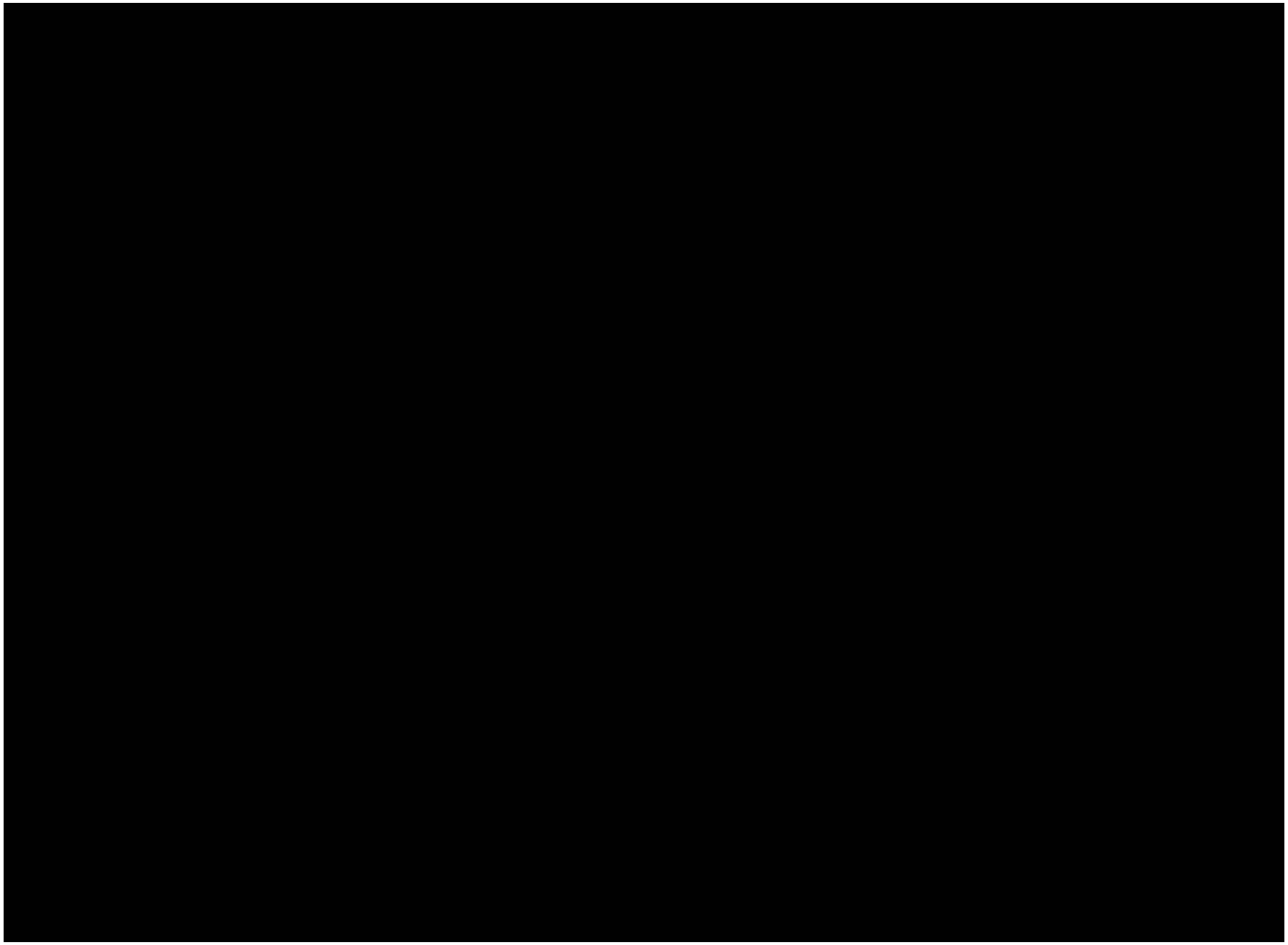


**Emily**

**Aline**

**Maddie**

# Introduction: Approaches to oceanic studies



**Ansong & Sutherland (2010), JFM, vol 648**

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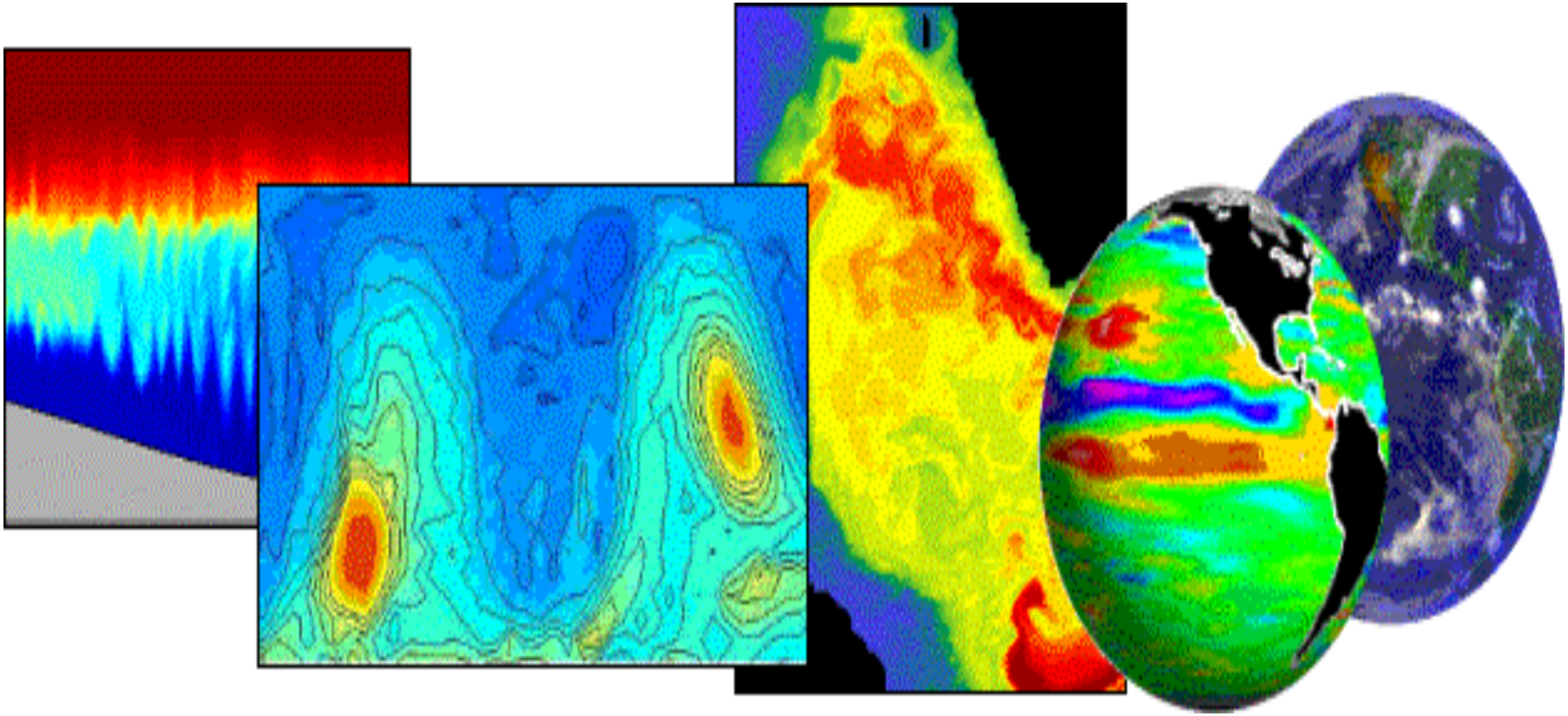


**Ocean modeling**

**Dimitris/Brian/Christian/Joseph et. al.**

# Introduction: Approaches to oceanic studies

# What is an ocean model?

# 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

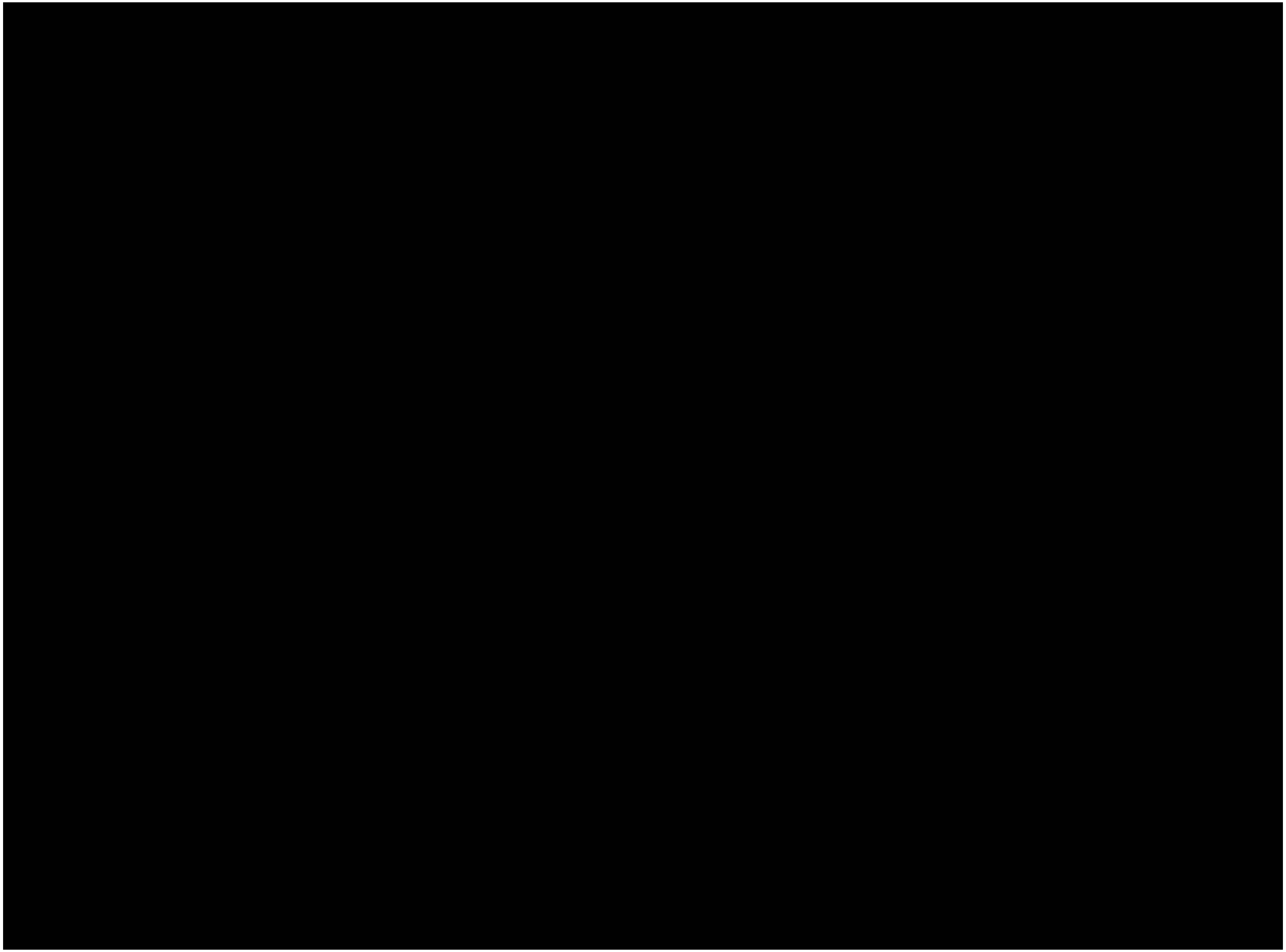
b) Exchange of energy between the ocean and external sources (radiation, precipitation, evaporation, river-runoff, wind, etc)

c) 3D mixing and dissipation processes

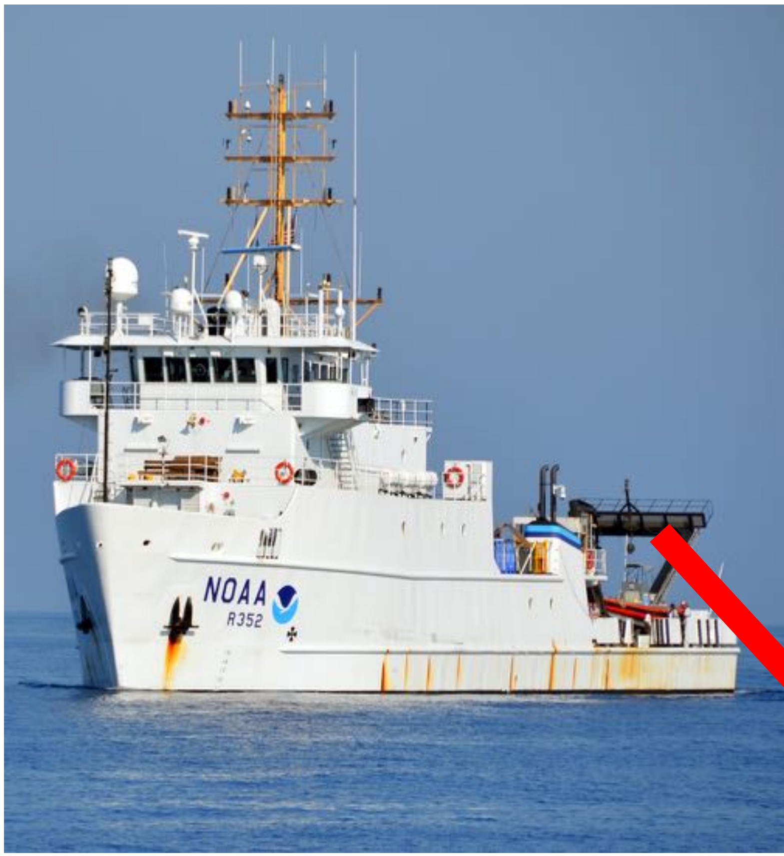
# QUESTION

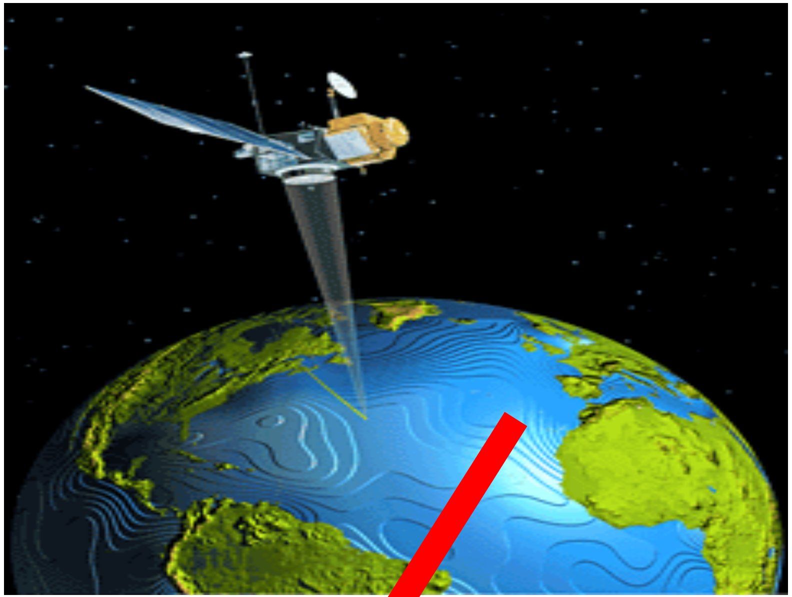
**Why is ocean modeling necessary, when we have alternative means?**

# Motivation: Why model the ocean?



# Motivation: Why model the ocean?



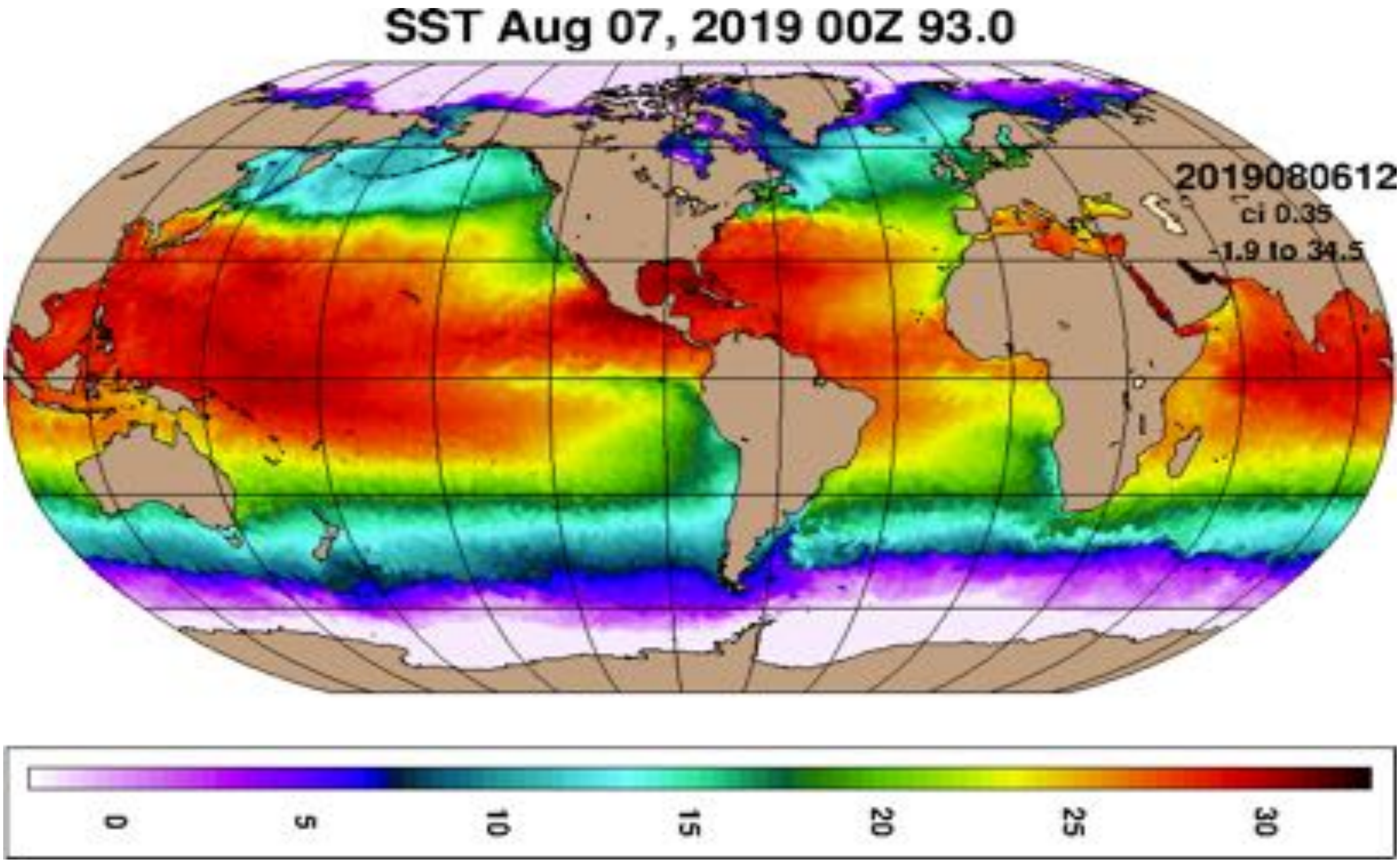



# Motivation: Why model the ocean?

- 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. SST, SSH, and positions of major fronts and eddies)

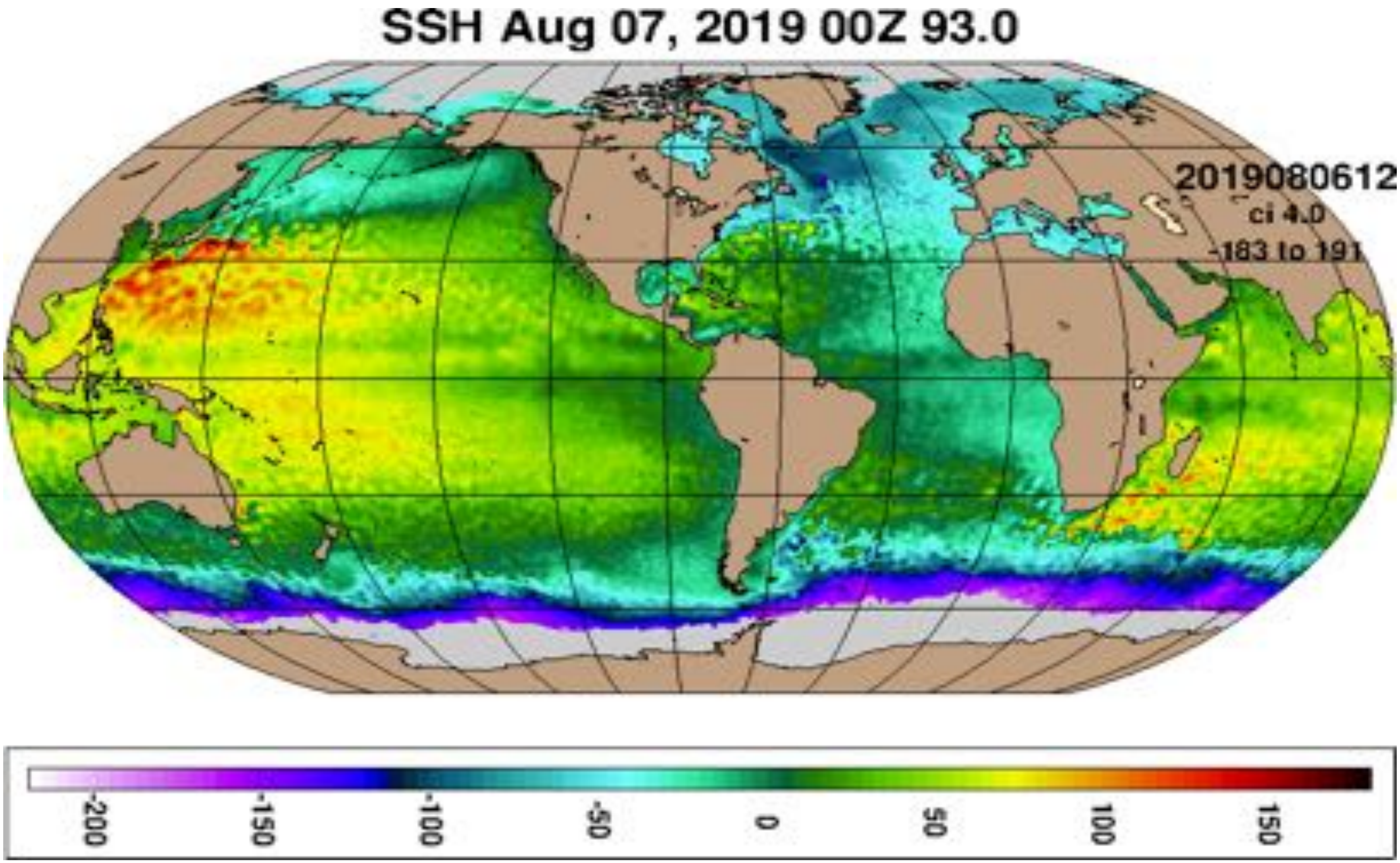
# Motivation: Why model the ocean?

www.hycom.org

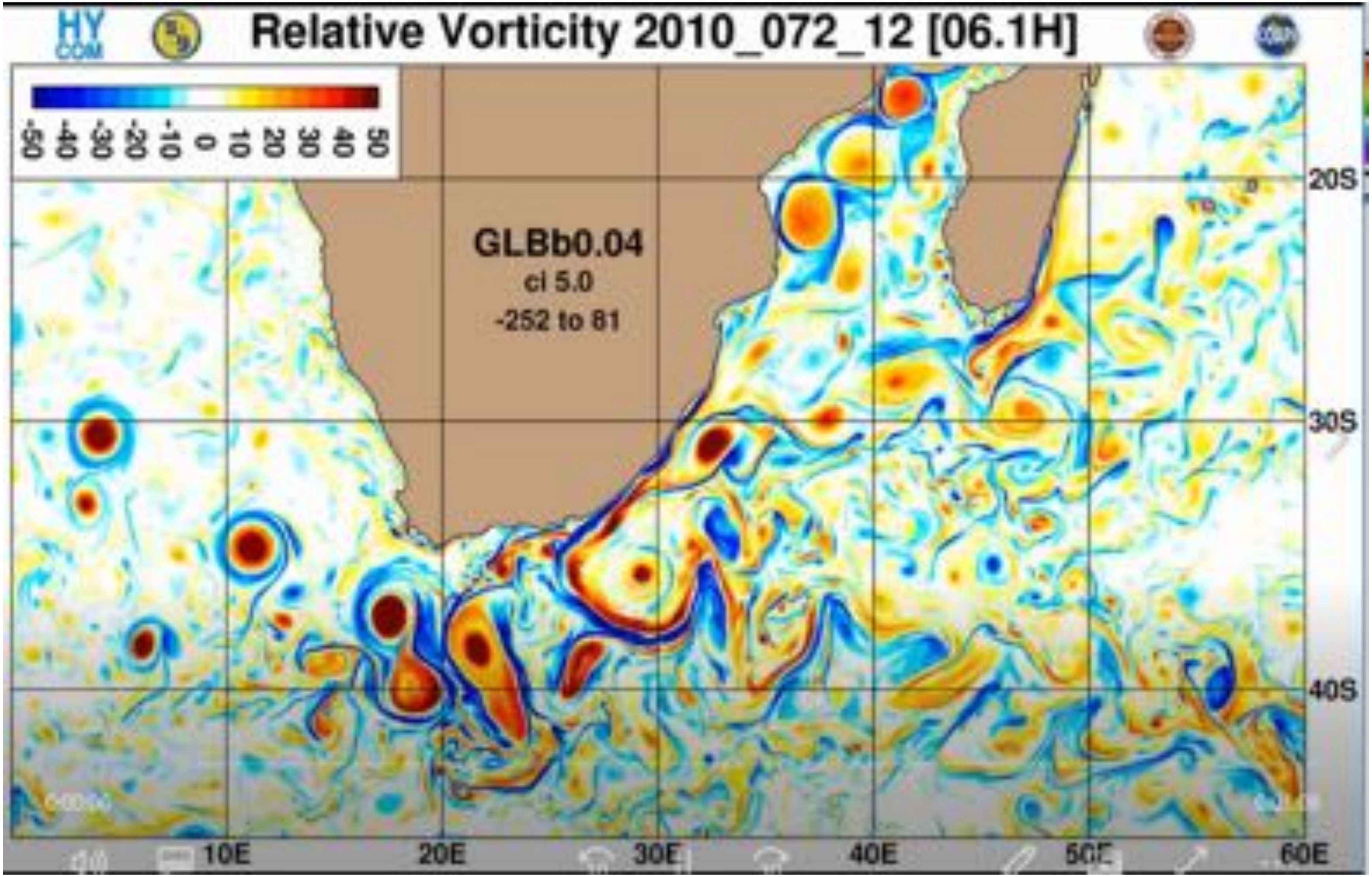


# Motivation: Why model the ocean?

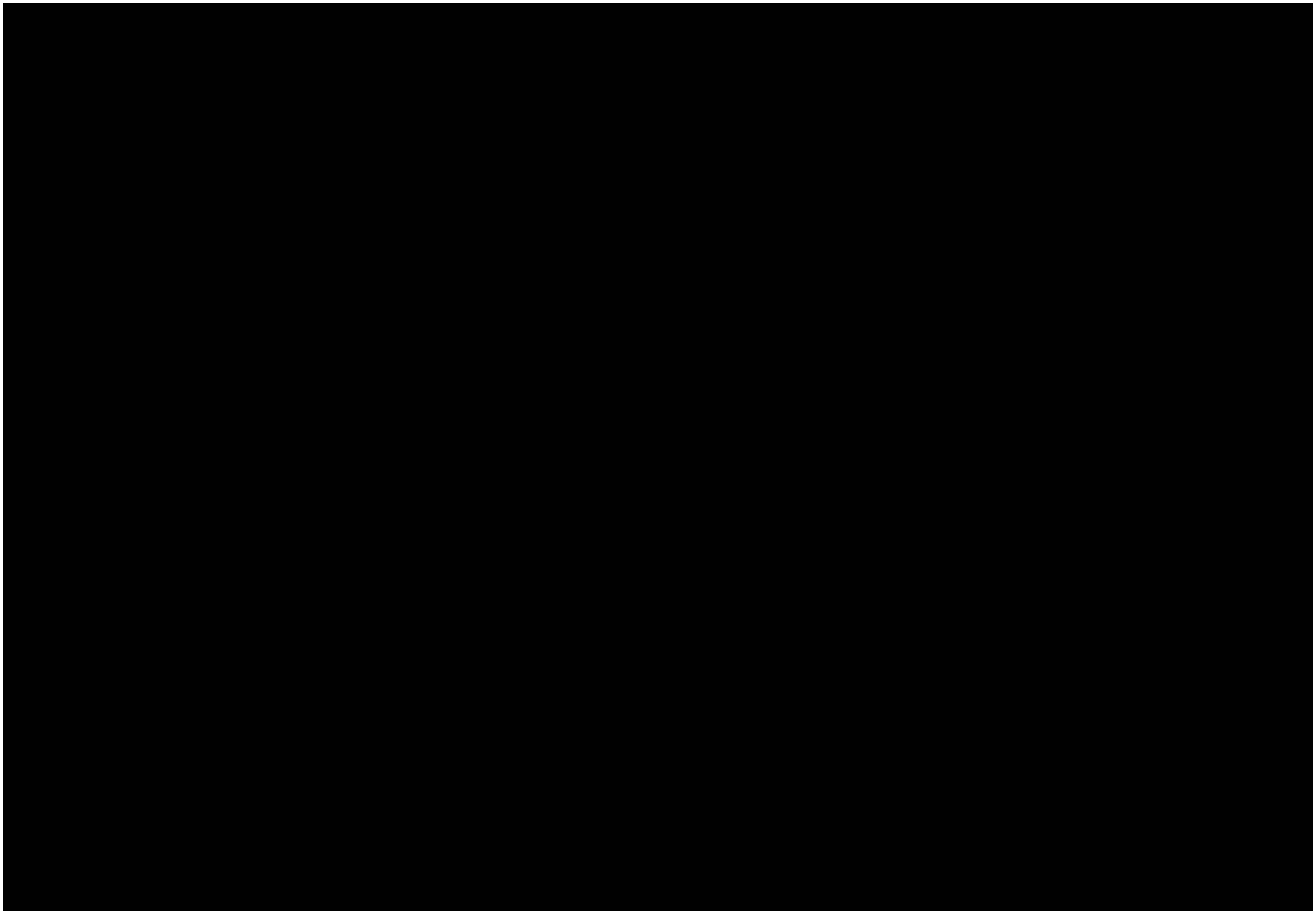
www.hycom.org



# Motivation: Why model the ocean?



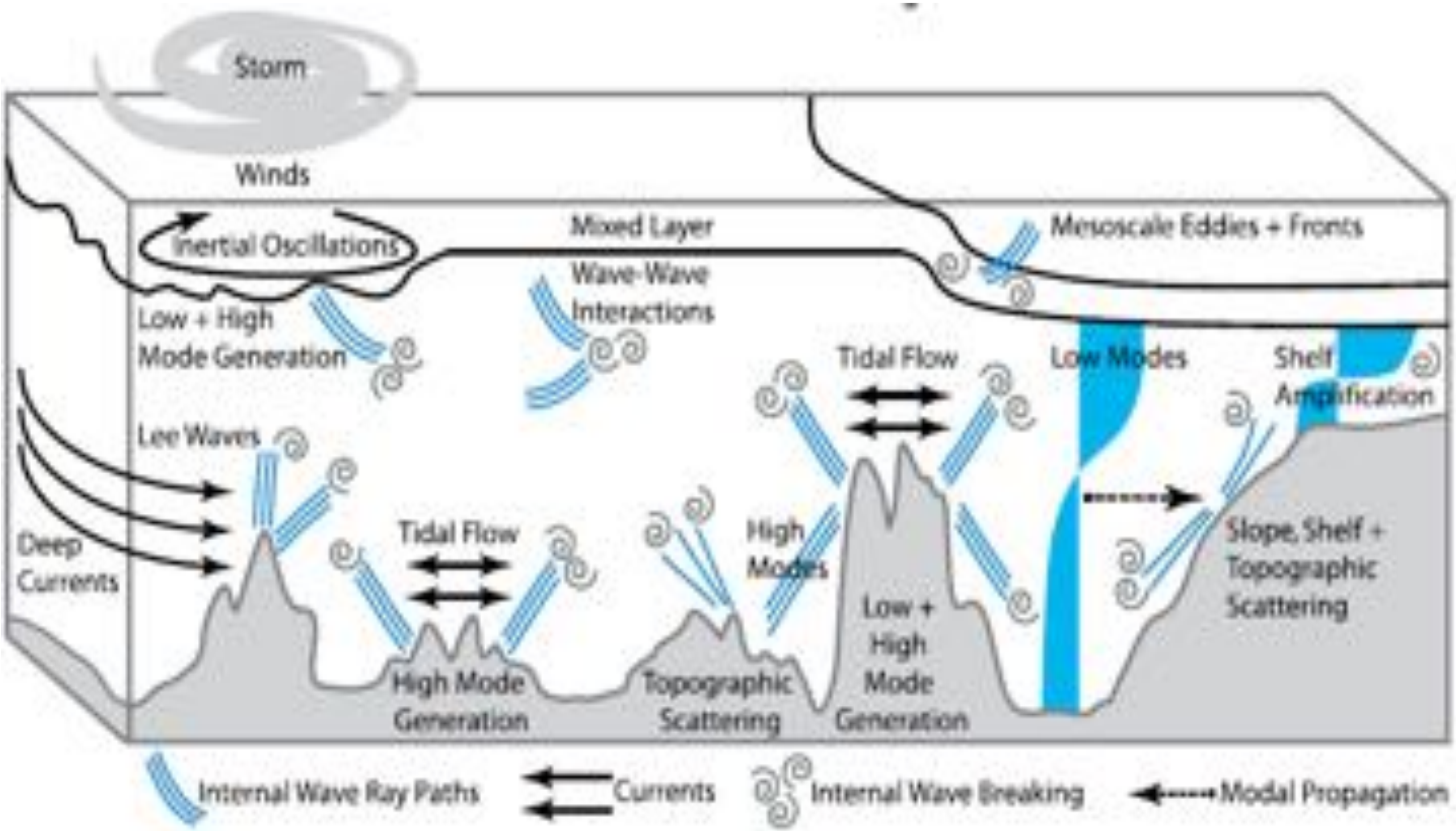
# Motivation: Why model the ocean?



**www.hycom.org**

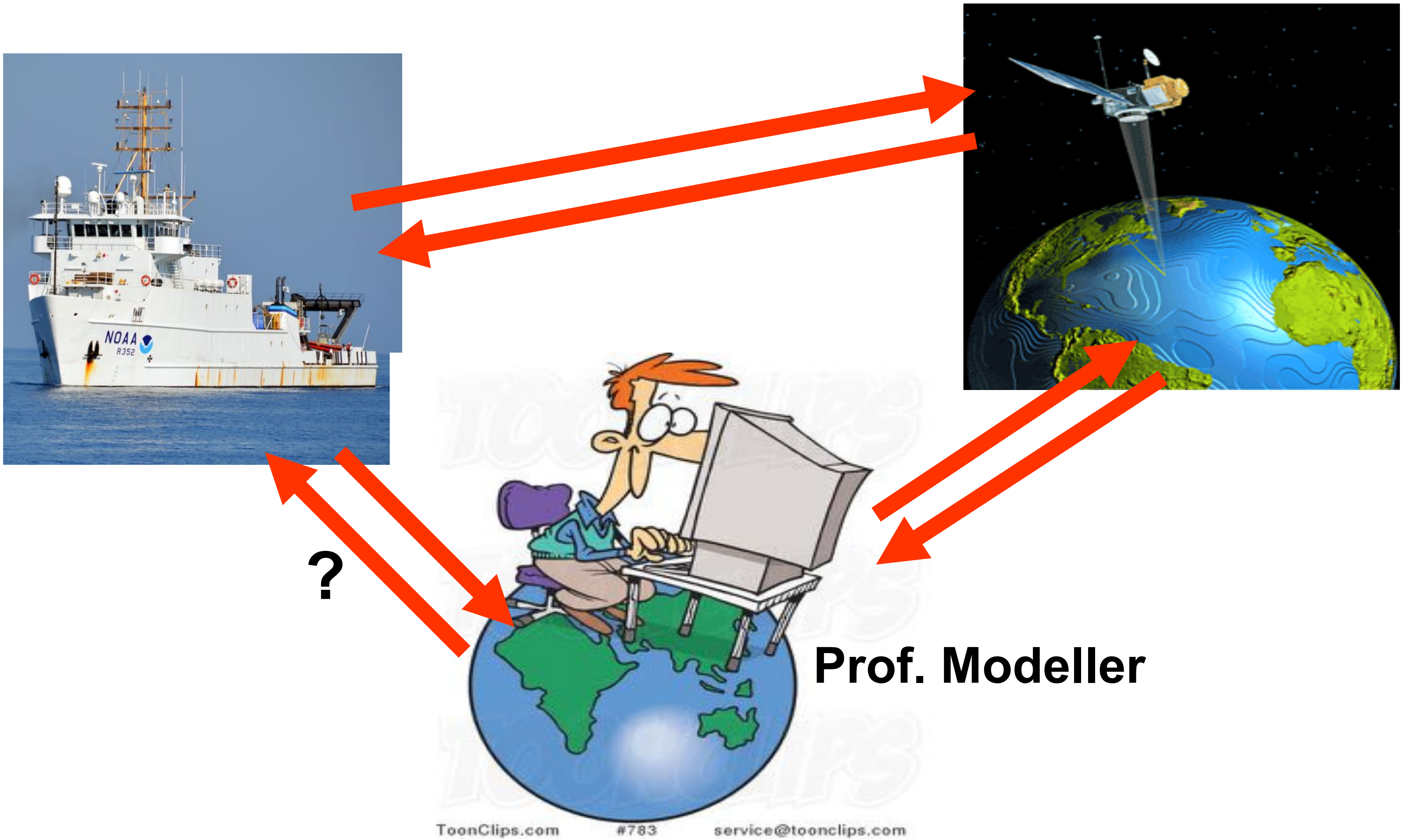
# Motivation: Why model the ocean?

Understanding the 3D dynamics of the ocean on a GLOBAL scale.




MacKinnon et al, 2017

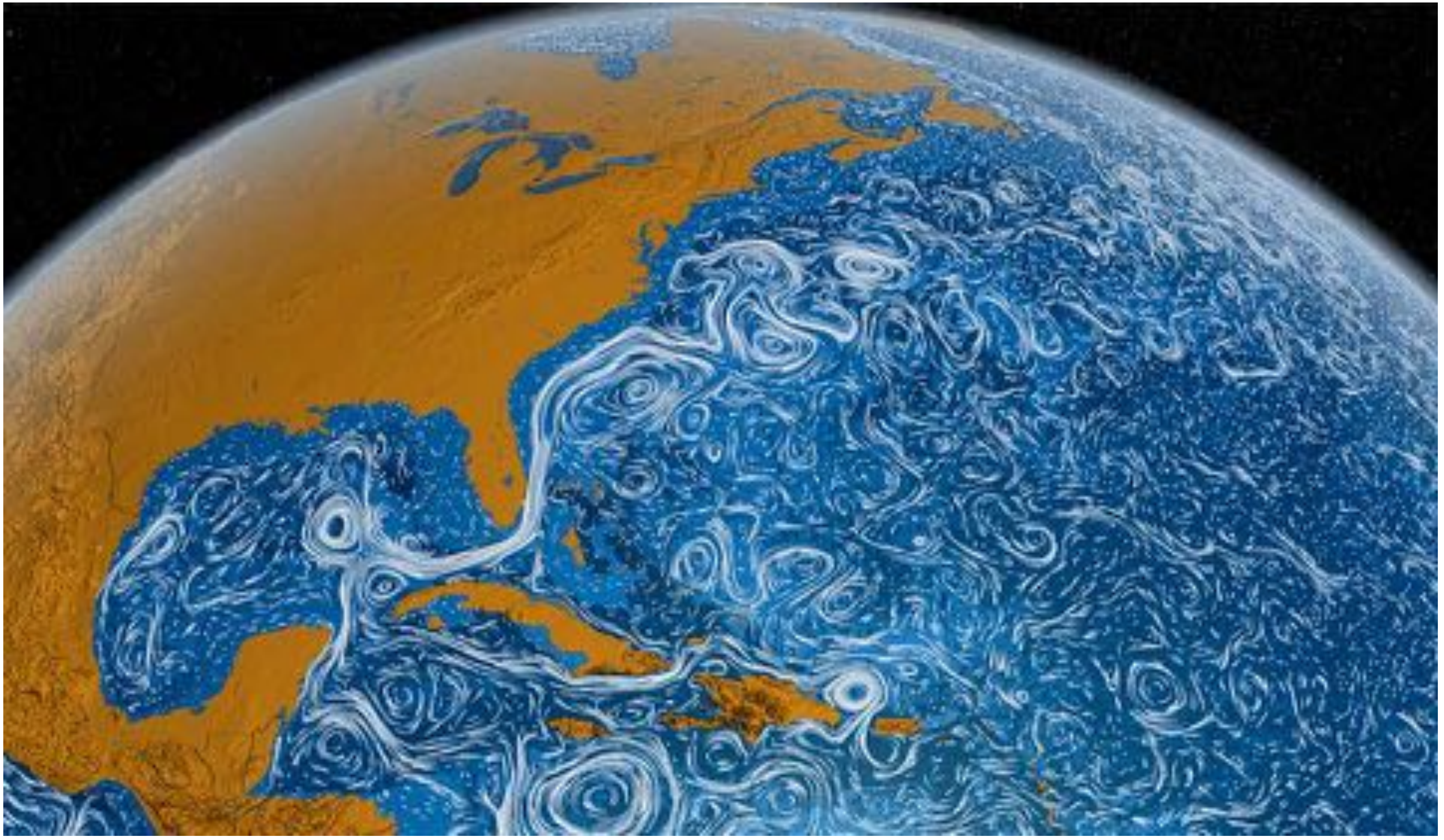
# **Motivation:** *not a competition*



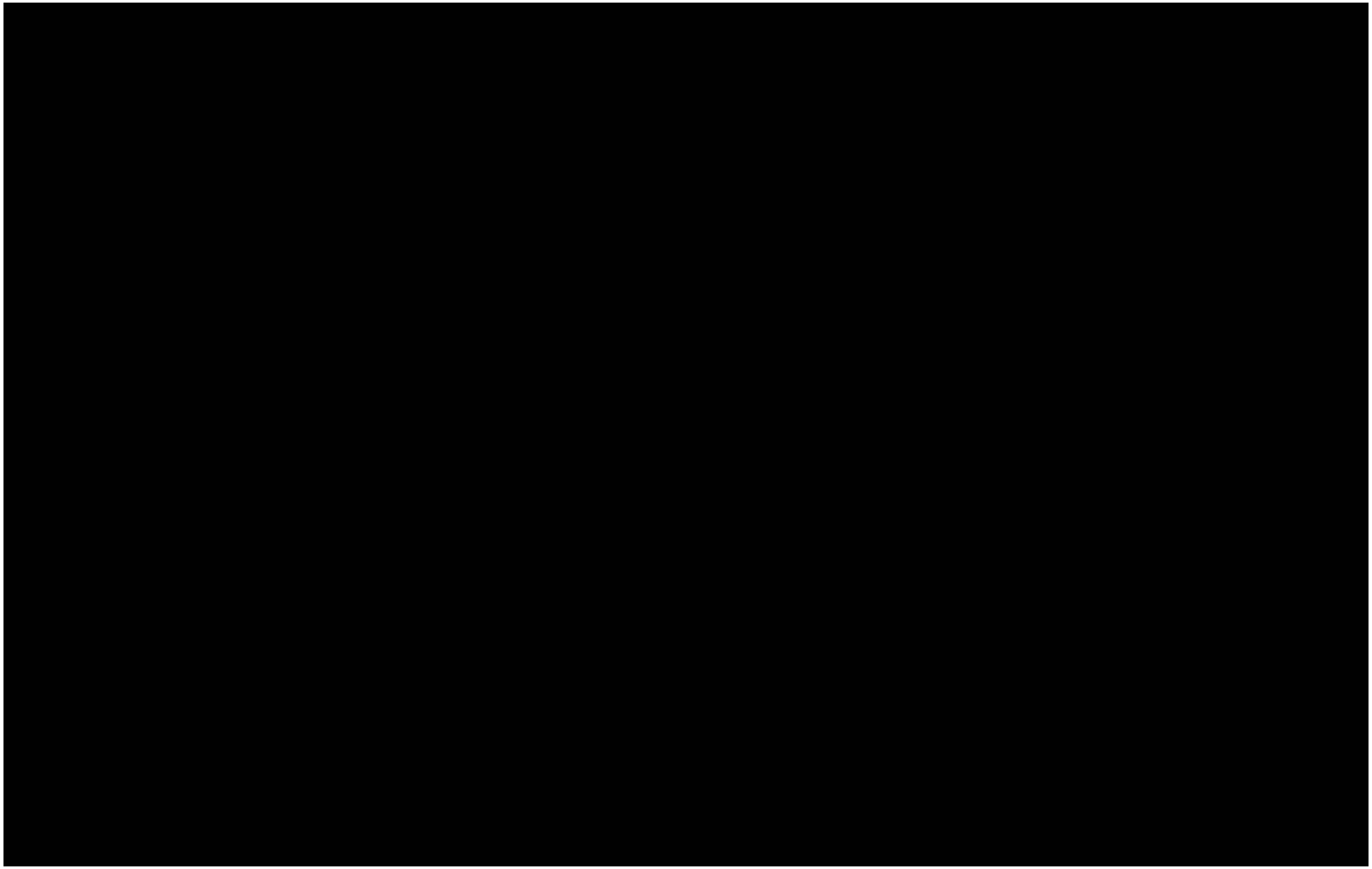
# **Motivation:** *Team Work!*

# **Motivation:** *Team Work!*

# Motivation: global ocean currents

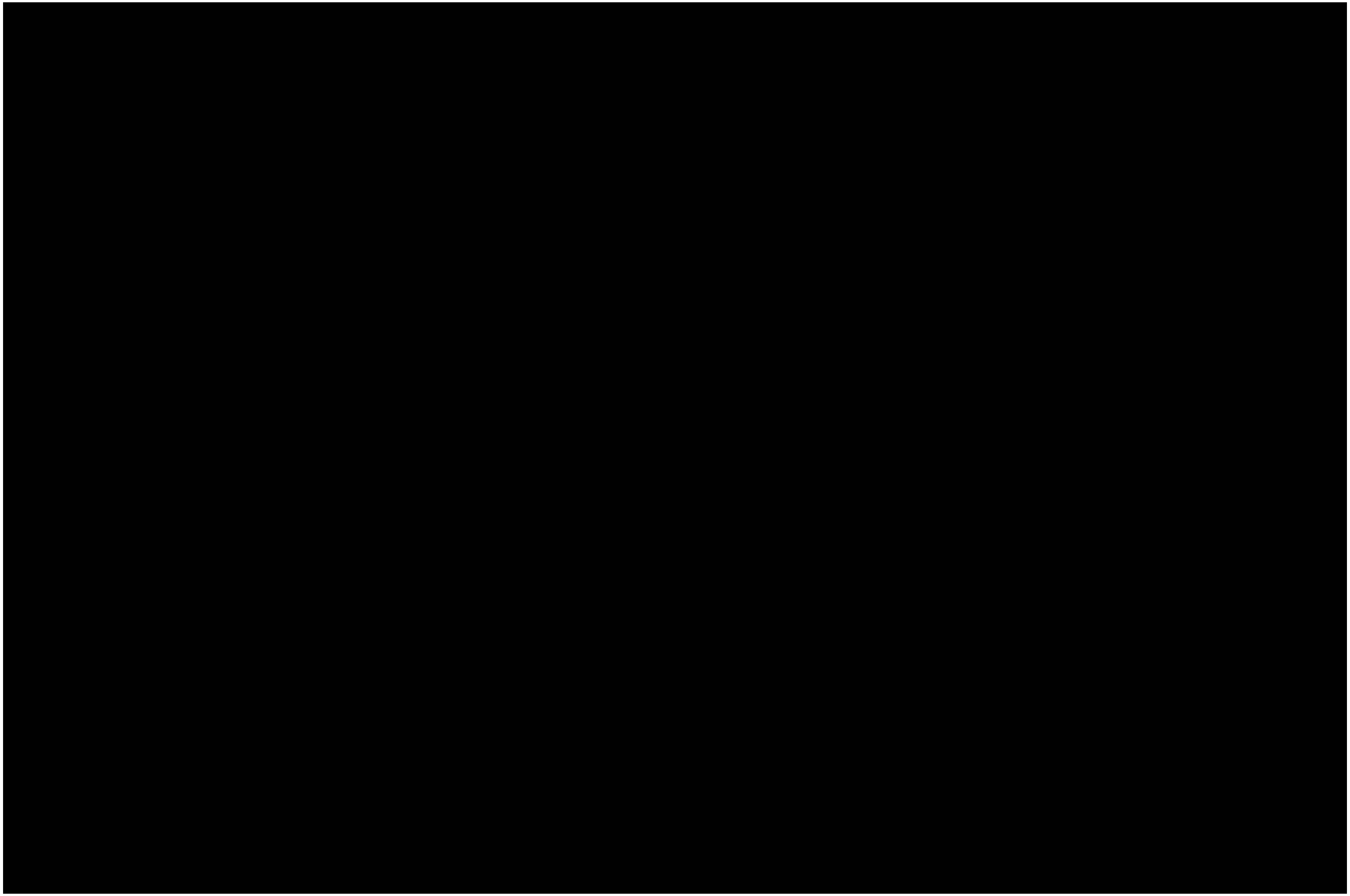


# Internal gravity waves



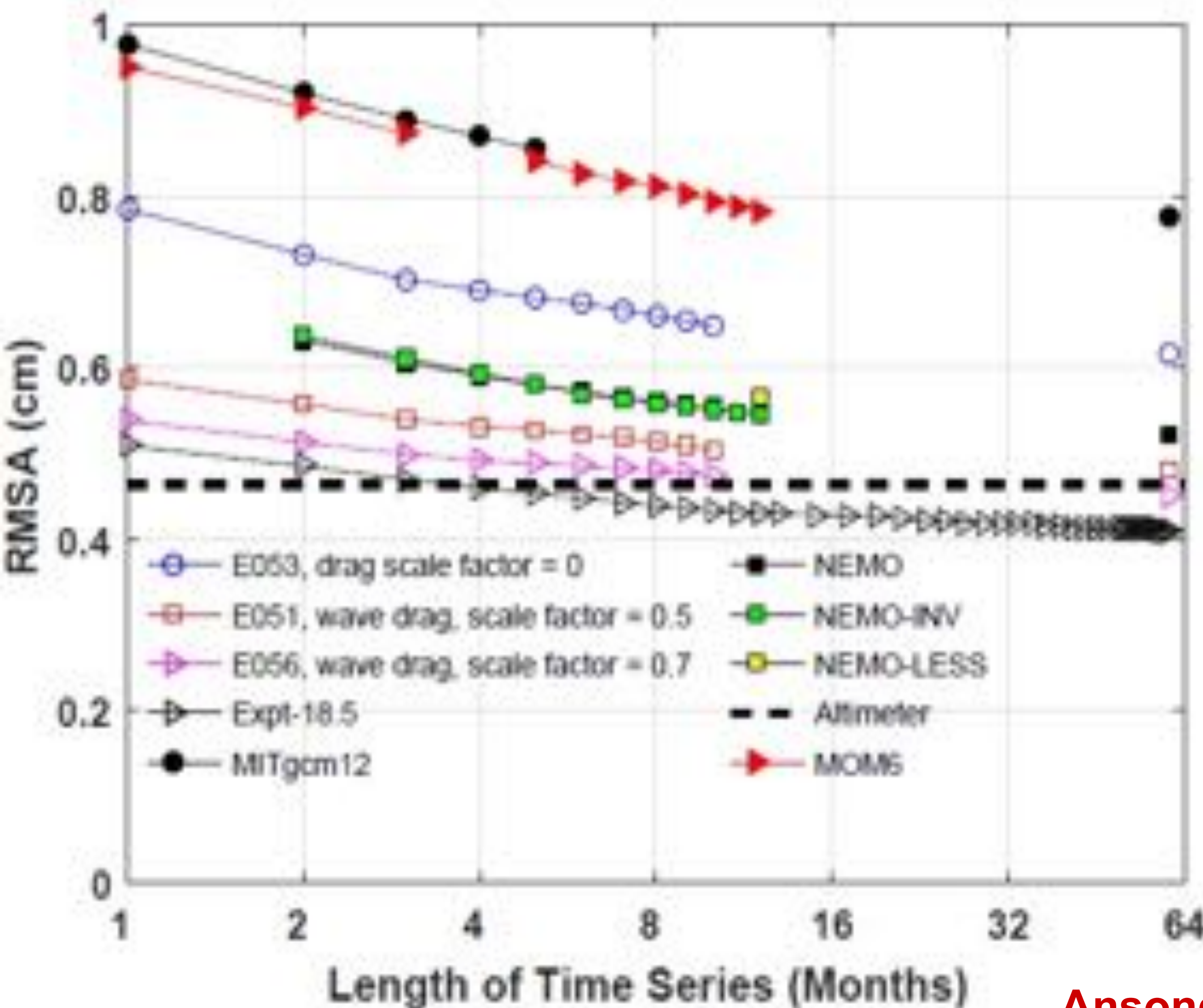
**Generation of Internal gravity waves by sinusoidal hills (Prof. Bruce Sutherland)**

# Motivation: internal waves



Courtesy: Max-Planck institute of Ocean modeling

# Motivation: internal waves




**QUESTION?**
How accurate are the Internal tides in global models compared to observations (altimeter-derived Internal tides)?

Building upon previous Paper…
**Ansong et. al. (2015)**

**Ansong et. al., 2019, in prep**

# 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
- Know some Python, Matlab, etc

# Equations of motion

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

acceleration (local + advective)

Presure gradient

buoyancy

Others (frictional, Tides, Winds, etc)

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

# Equations of motion:

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

acceleration (local + advective)

Rotation

Presure gradient

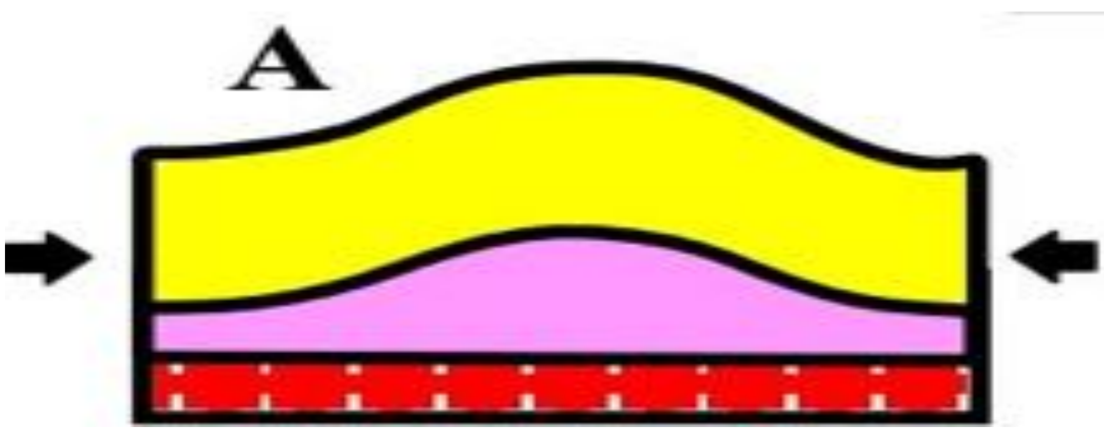
buoyancy

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)

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

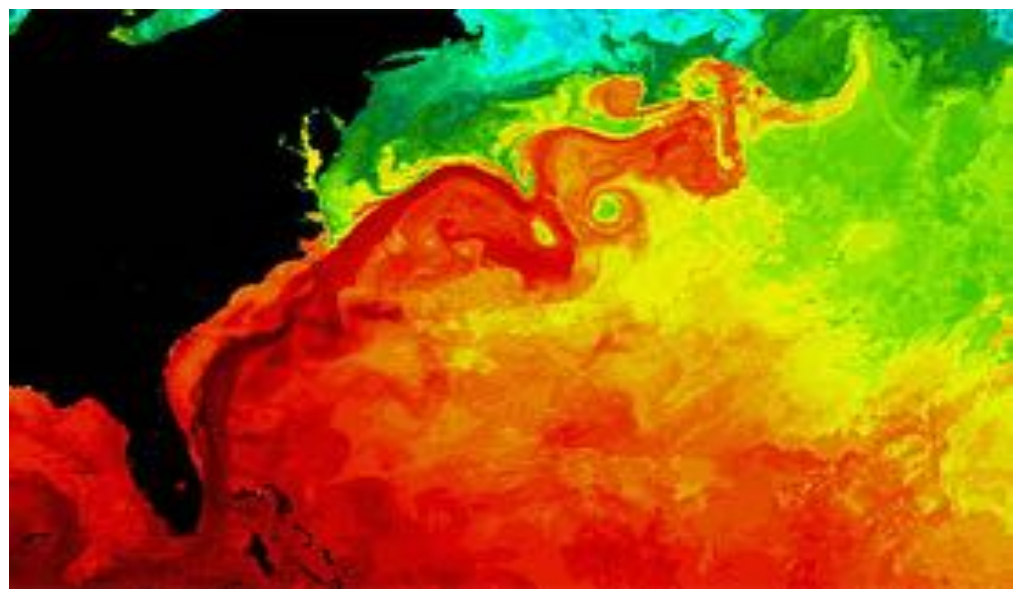


## Equation for tracers (Temperature, Salinity, and others),

Advection-diffusion equation:

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

$$T^c = Tracers$$

# 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.

# Equations of motions

7 equations in 7 unknowns:

- {u,v,w} – 3 velocity components
- T – Temperature
- S – Salinity
- Density
- P – Pressure

# Now that I understand the equations, what next?

A. Discretize equations

B. Consider the horizontal grid

C. Consider the vertical grid

D. Boundary conditions

# Discretize equations

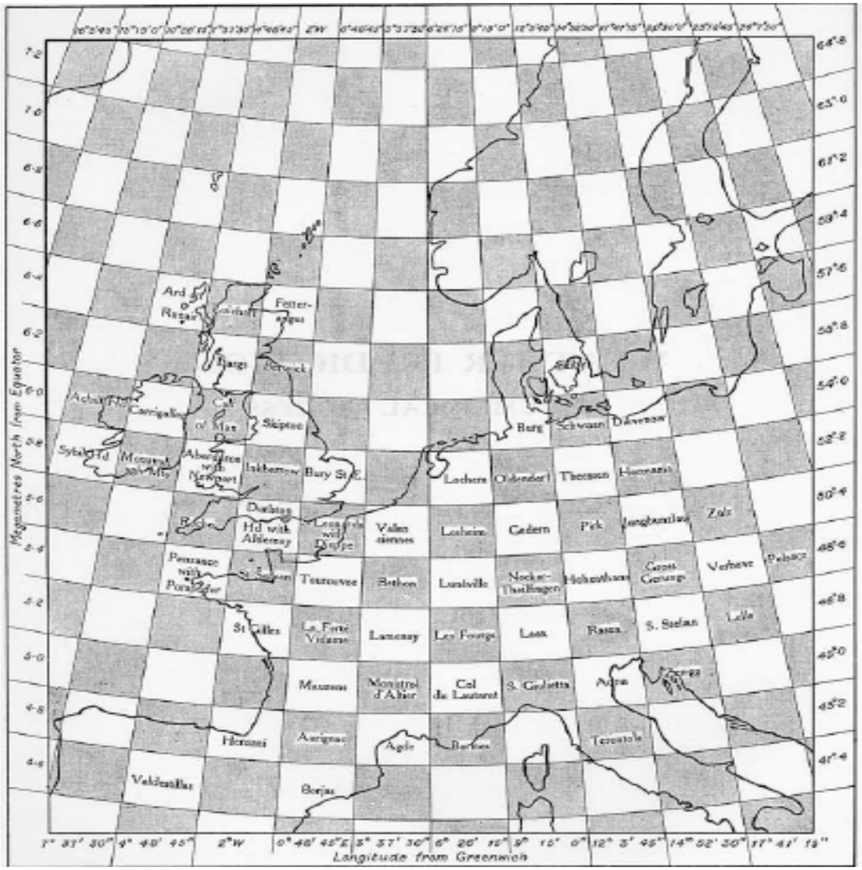
- Continuous equations

↓

algebraic equations

(discrete set of operations)

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

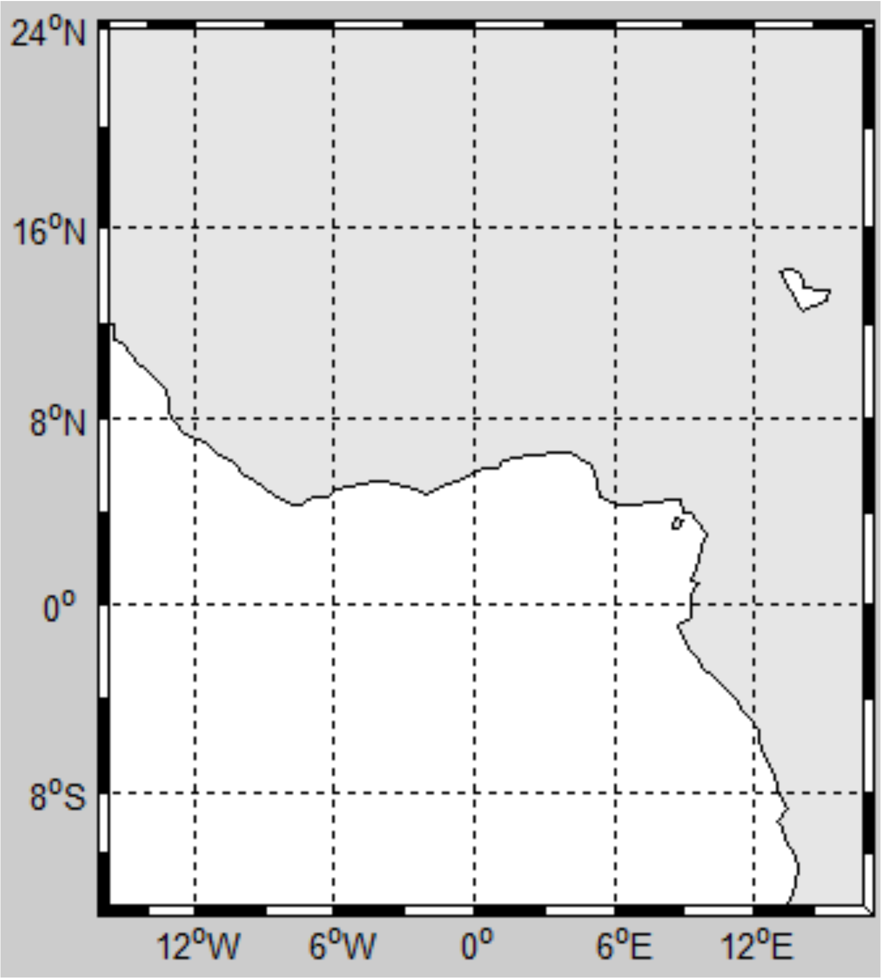



**Example early model grid by Lewis Fry Richardson (1928)**

# Model grid: horizontal

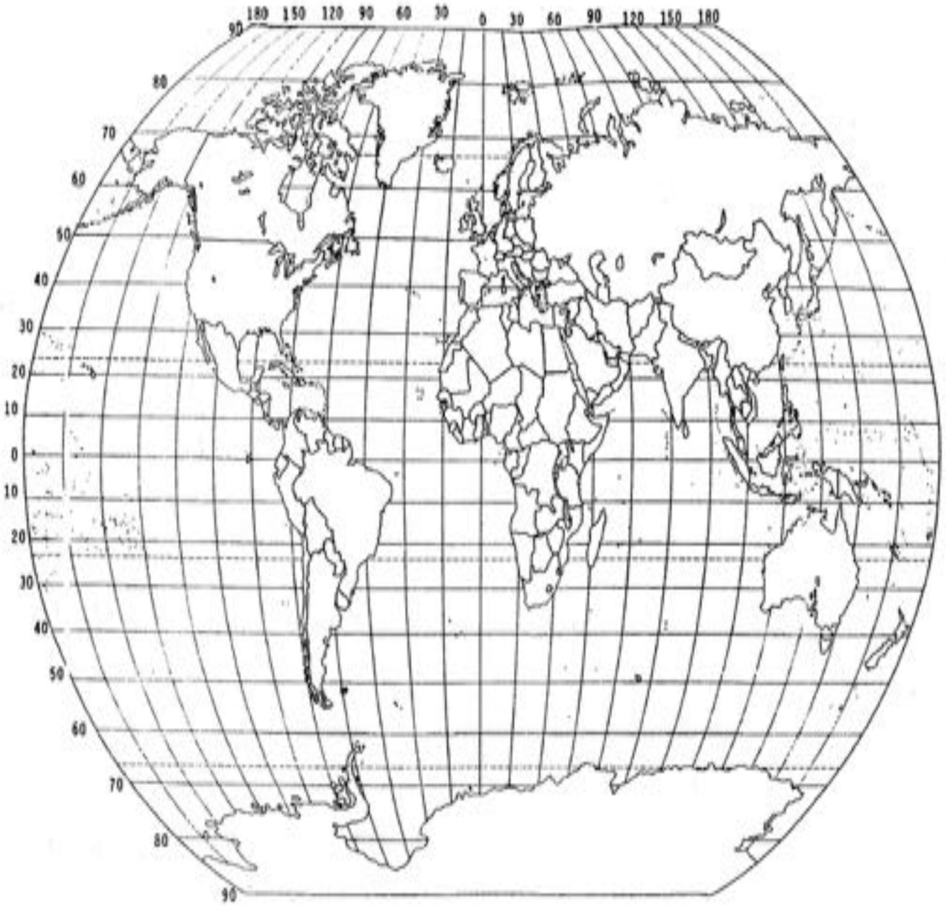
- Regular grids: regularly spaced lines

- possible in a small domain

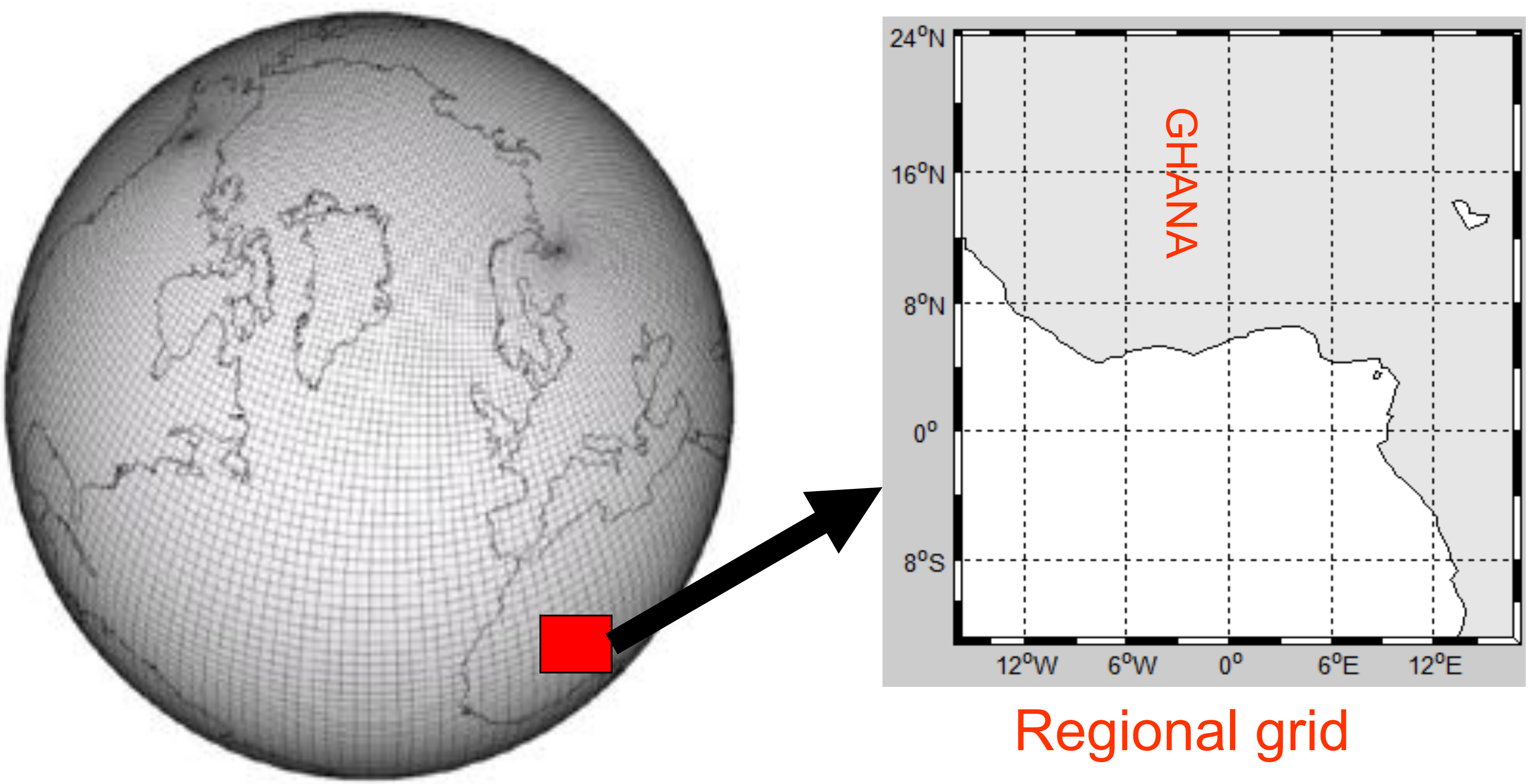


# Model grid: horizontal

- 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



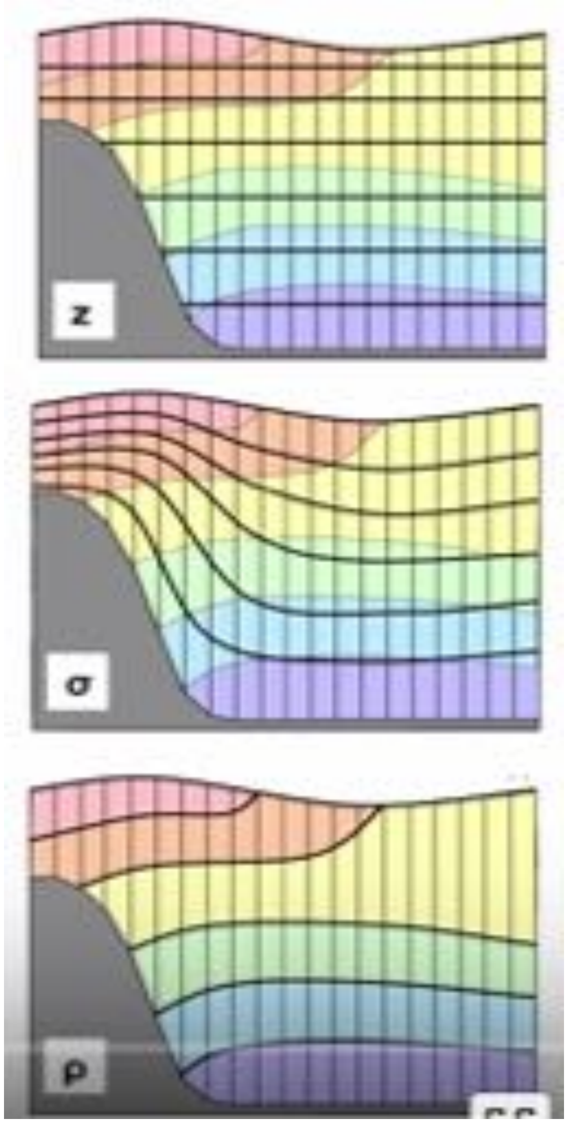

Regional grid

Clever solution: tripolar grid

-circular grid laid over Arctic region with poles on land

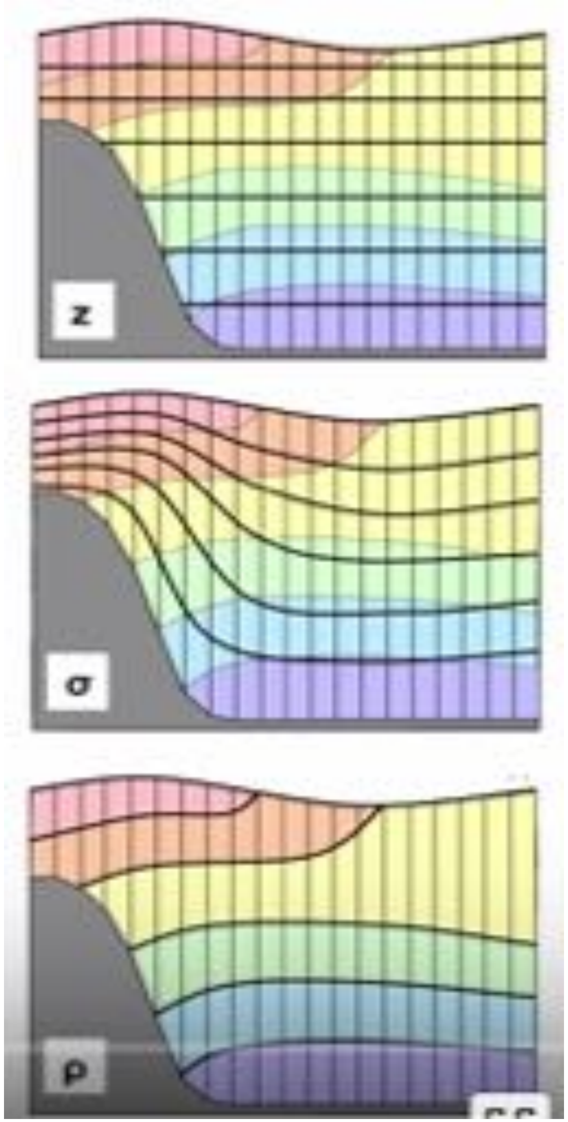
# Model grid: vertical

- 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.



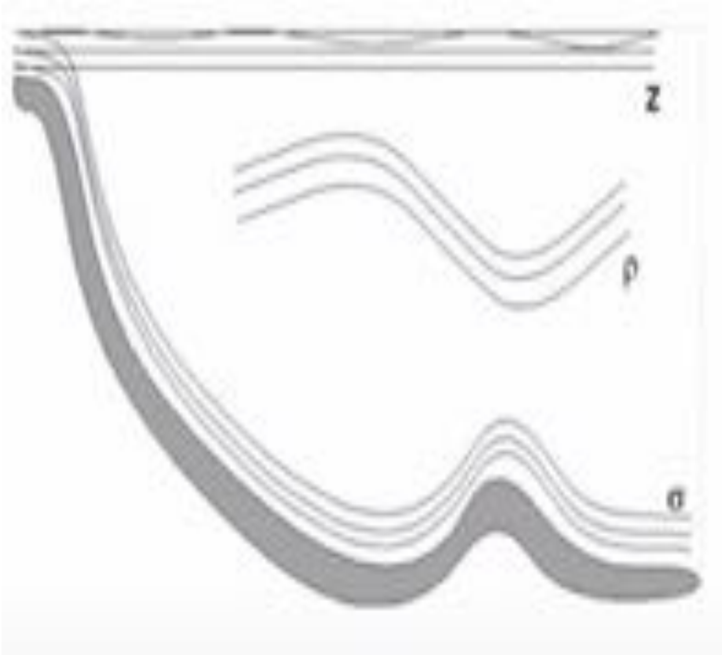
# Model grid: vertical

- 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

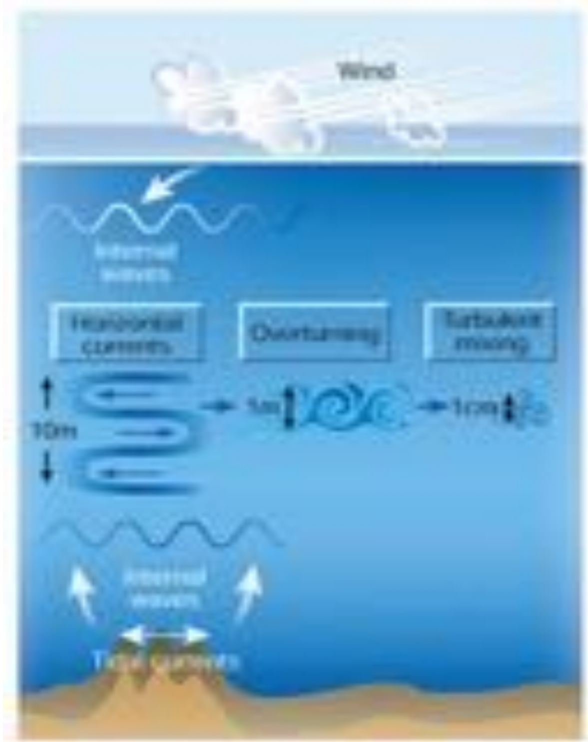
- hybrid-coordinate applies the best suited coordinate system in different regions. Gives improved results but at a high computational cost.



# 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

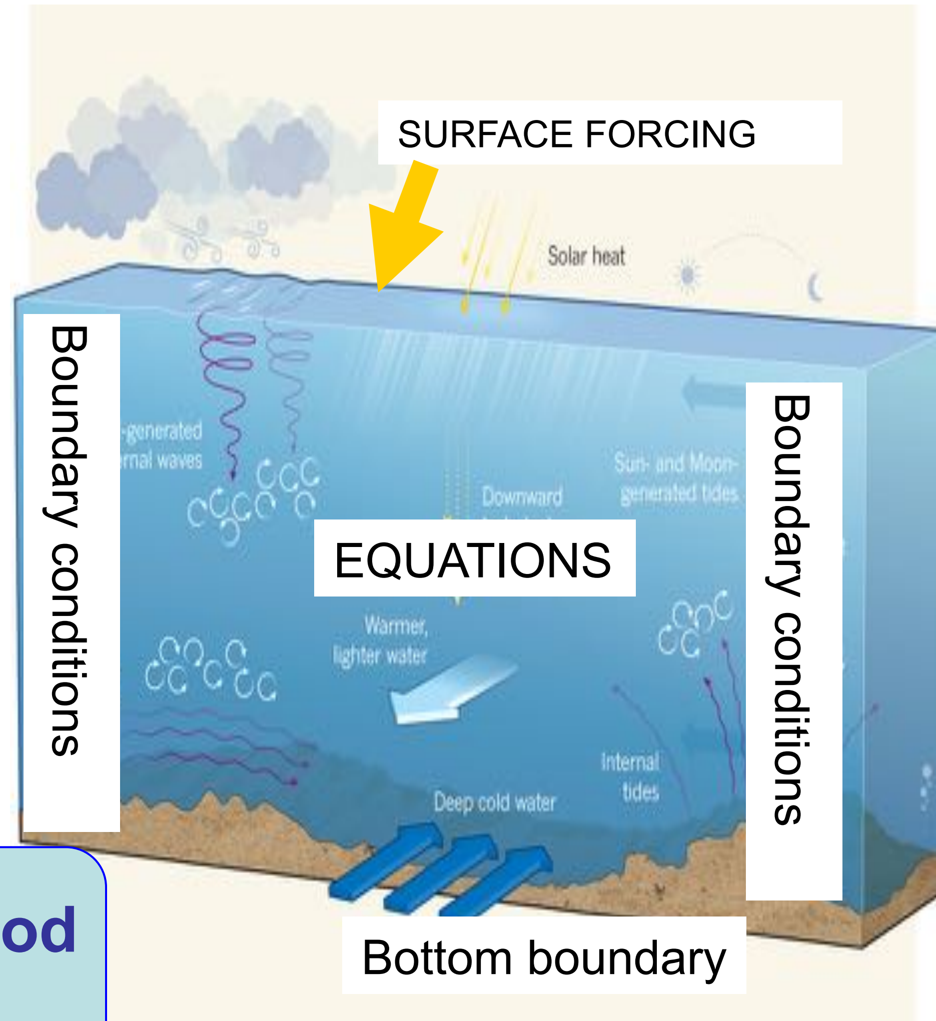
# Modeling: summary

- Complex differential equations
- Set of algebraic equations
- 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/ )

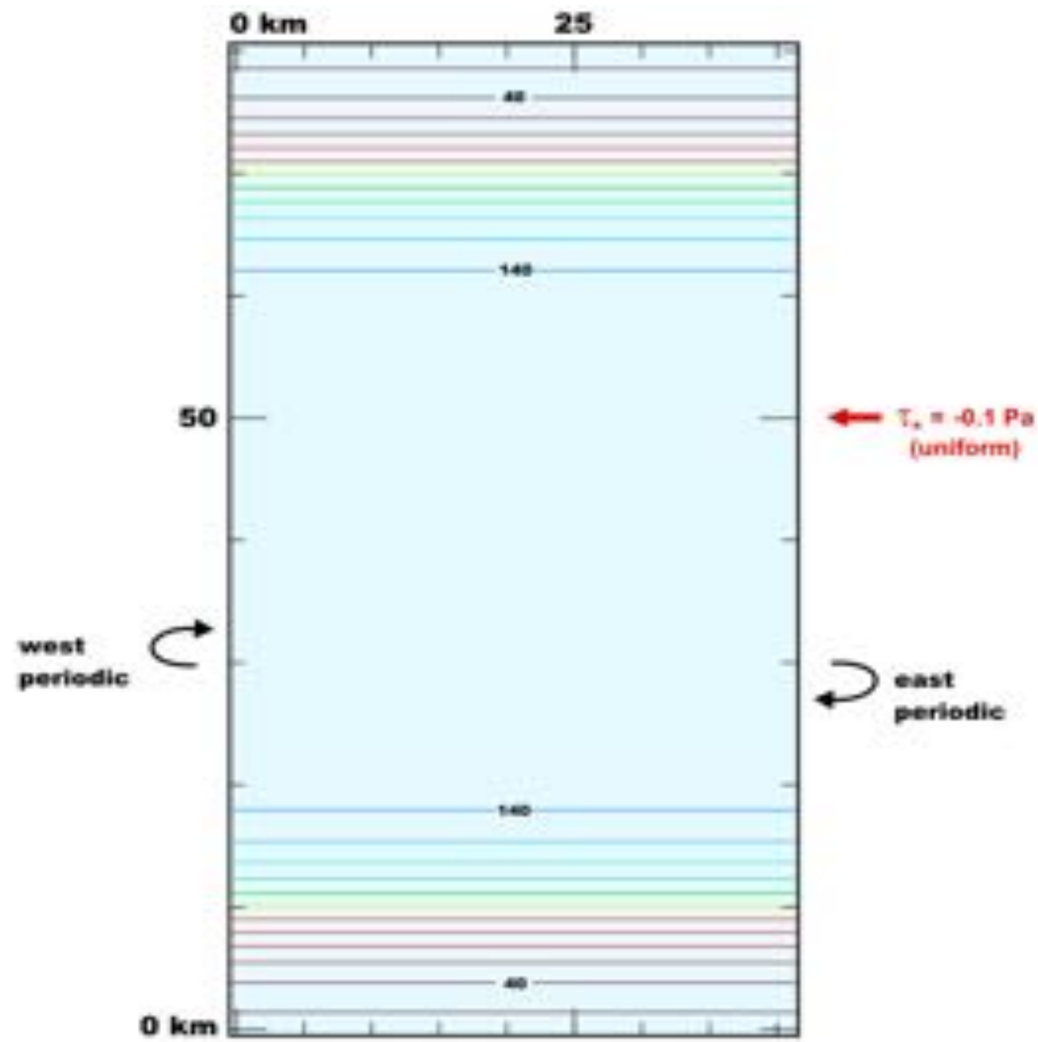
- HYCOM (The Hybrid Coordinate Ocean Model : https://hycom.org/ )

- ROMS (Regional Ocean Modeling System: www.myroms.org )

# Simple Examples

# Test Case 1: Upwelling

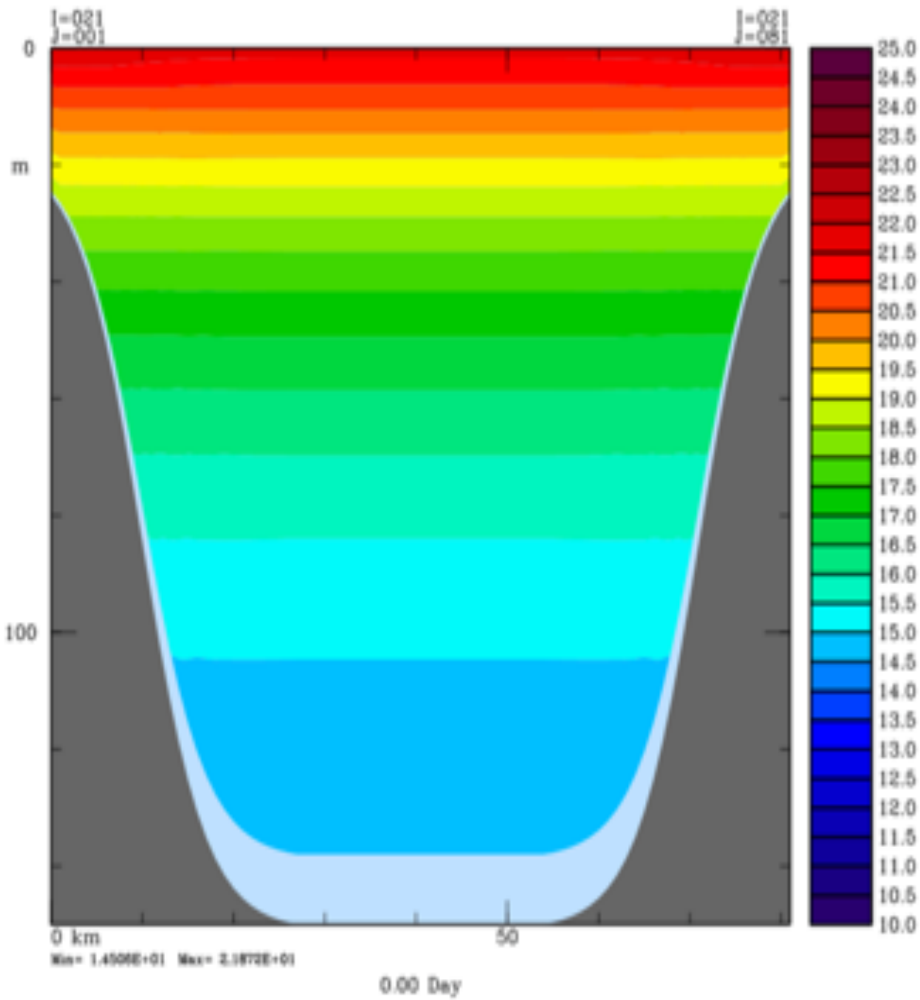
- East-West periodic channel
- Spatially-uniform winds blowing from east to west
- Wind stress = 0.1 Pascals



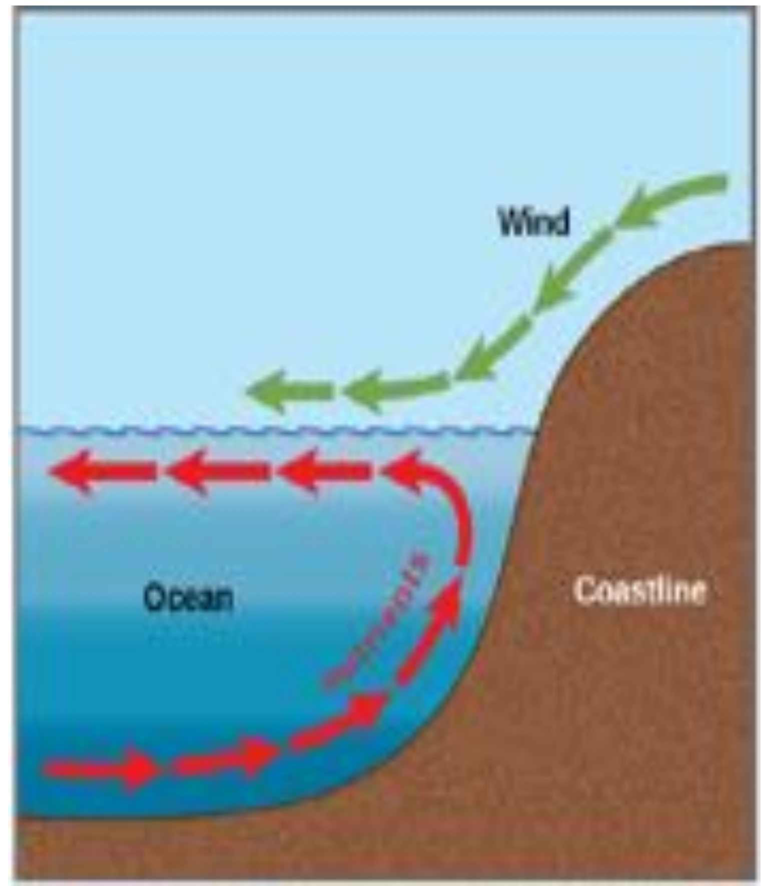

- Contributed by

**Anthony Macks and**
**Jason Middleton**
(Macks, 1993)

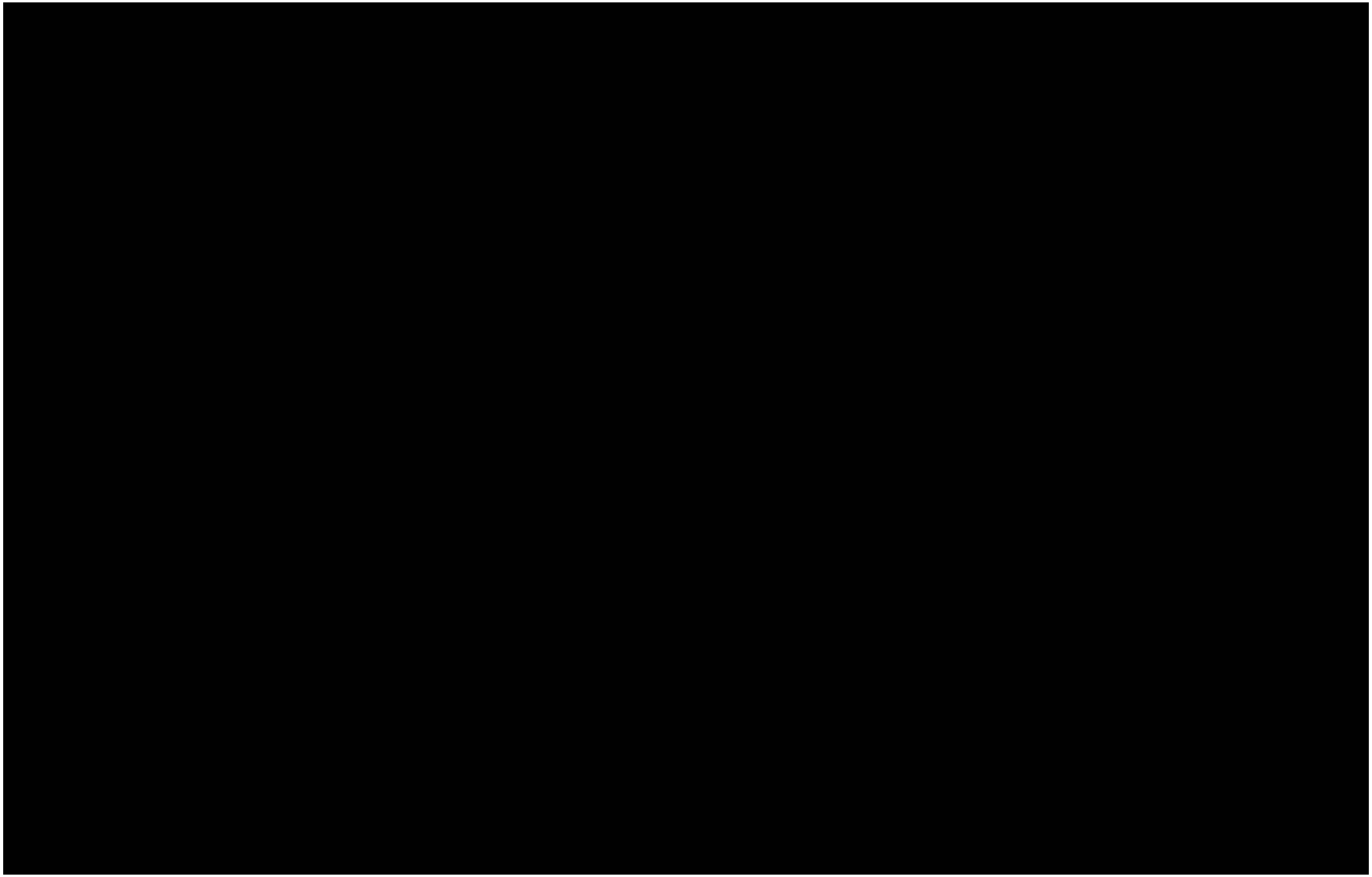
# Upwelling



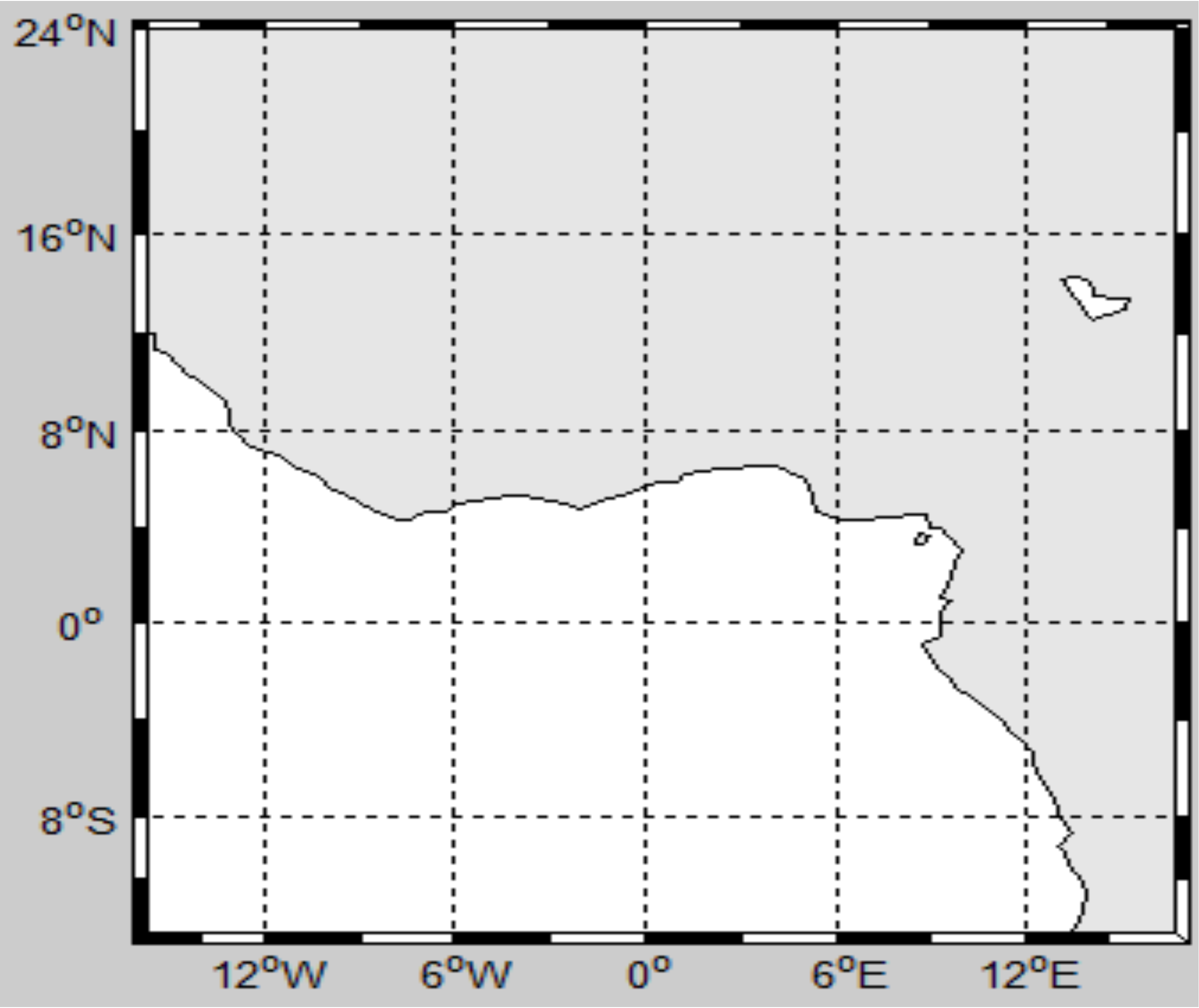

Initial temperature distribution



# Upwelling



# Regional Modeling

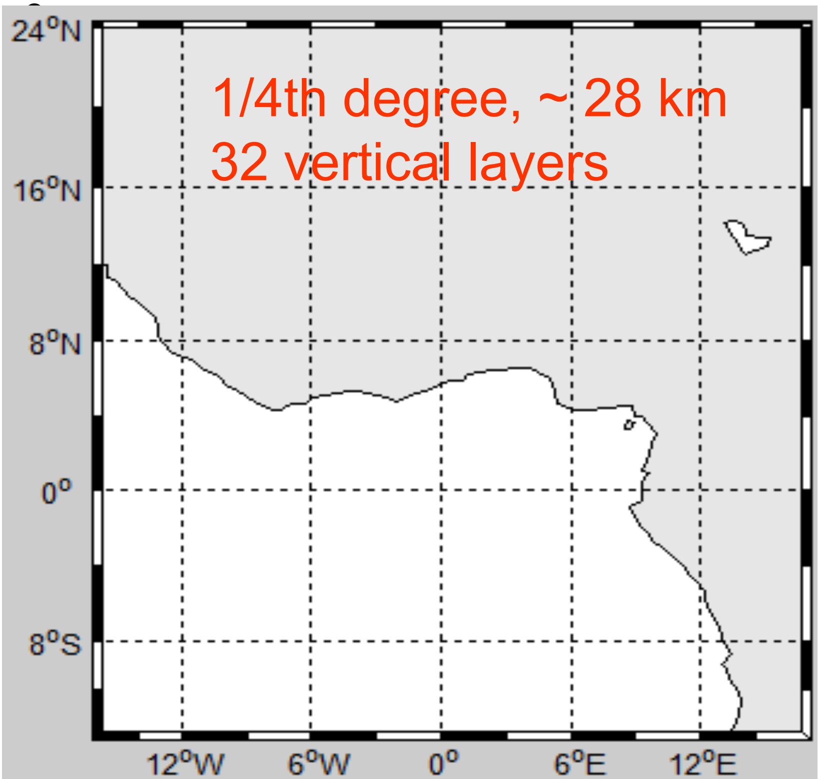


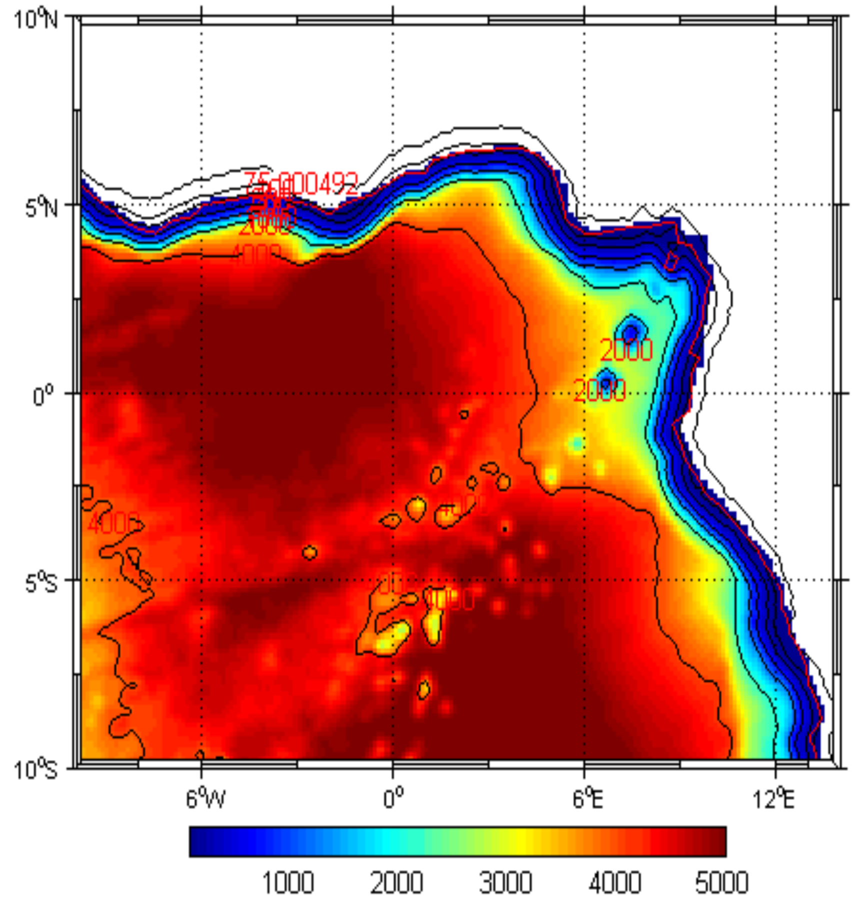
# Regional Modeling

## 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
6. Run the simulation.
7. Plot and analyze results.

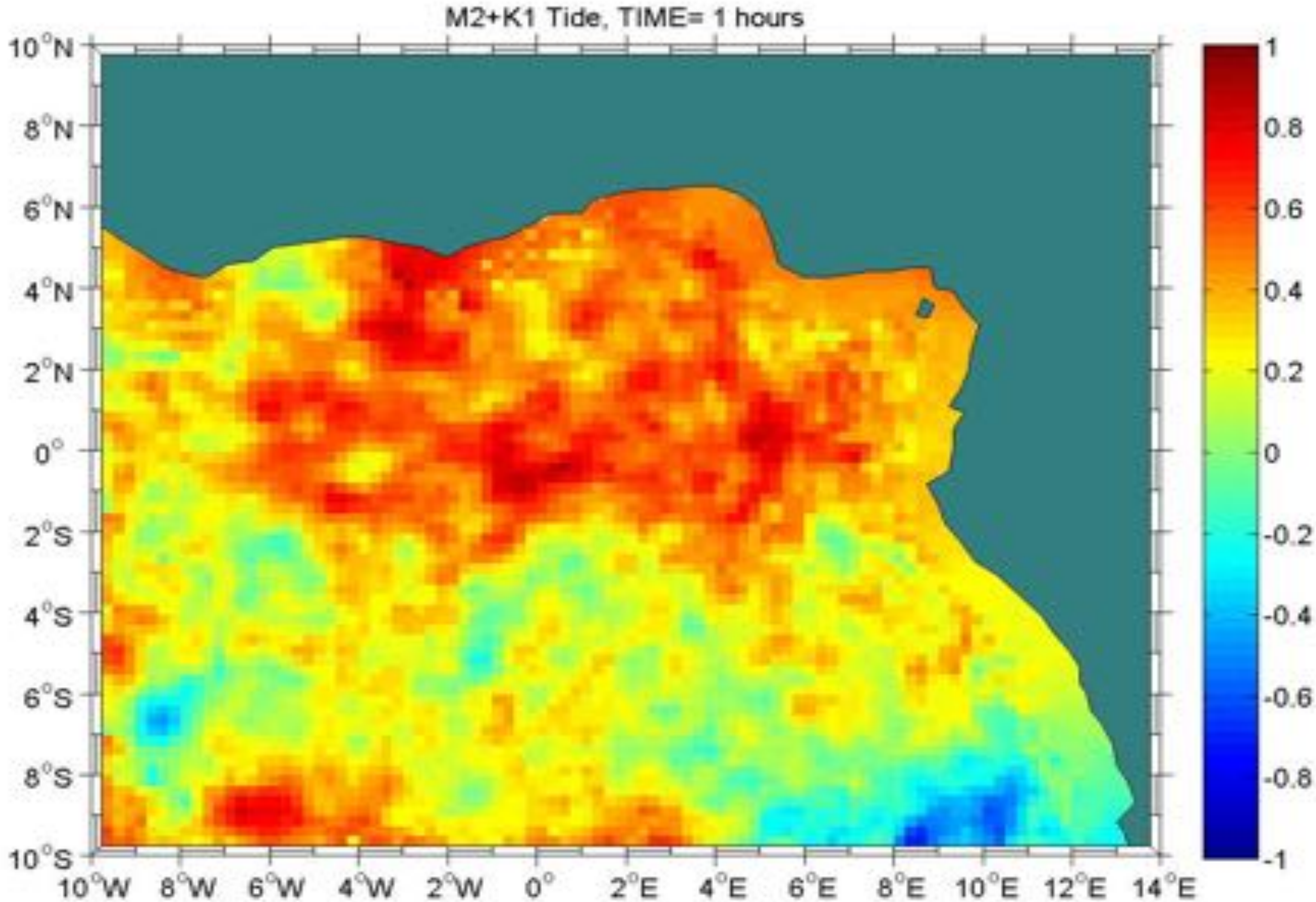
# Regional Modeling



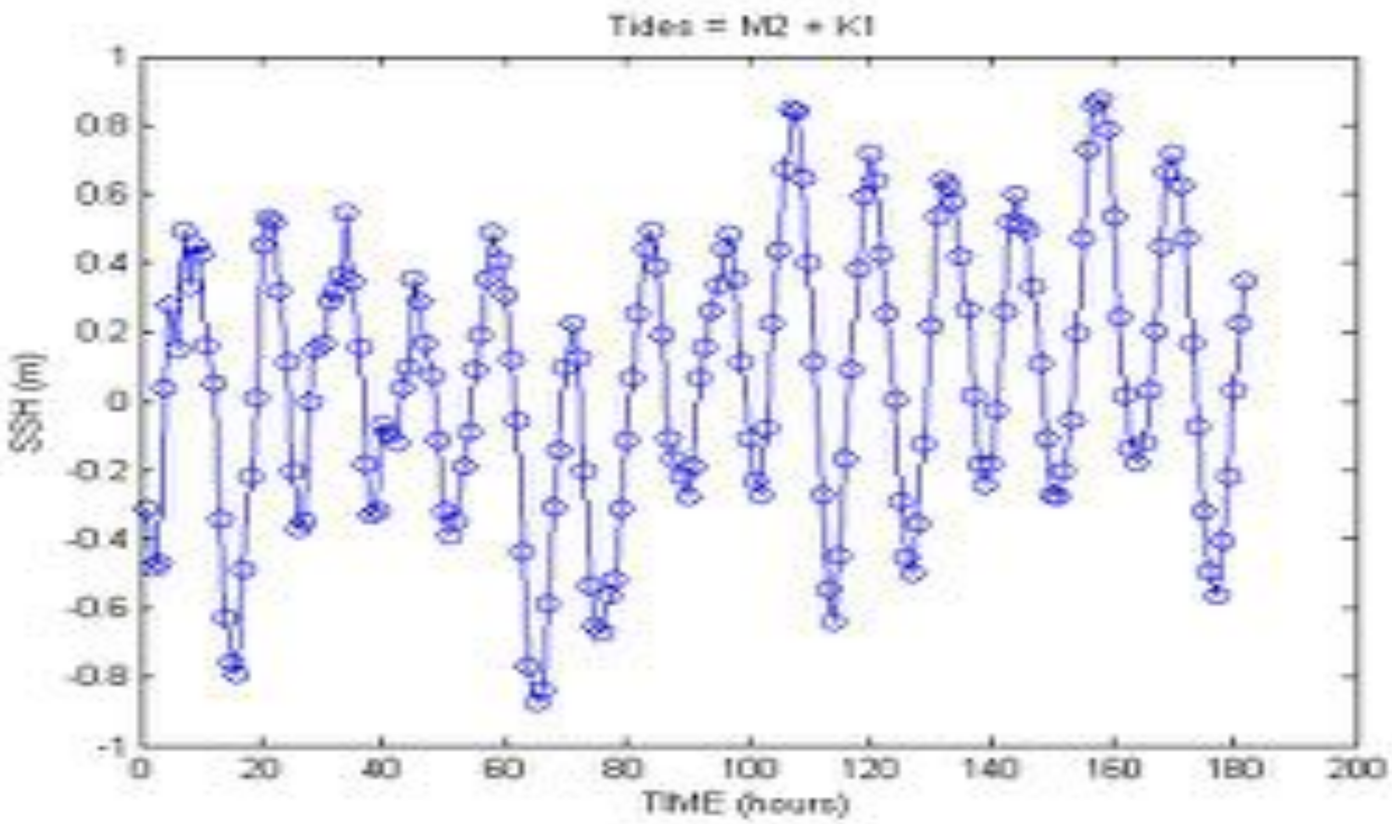




**Etopo5: http://www.ngdc.noaa.gov/mgg/global/etopo5.HTML**

# Results: Tides



# Results: tidal time series



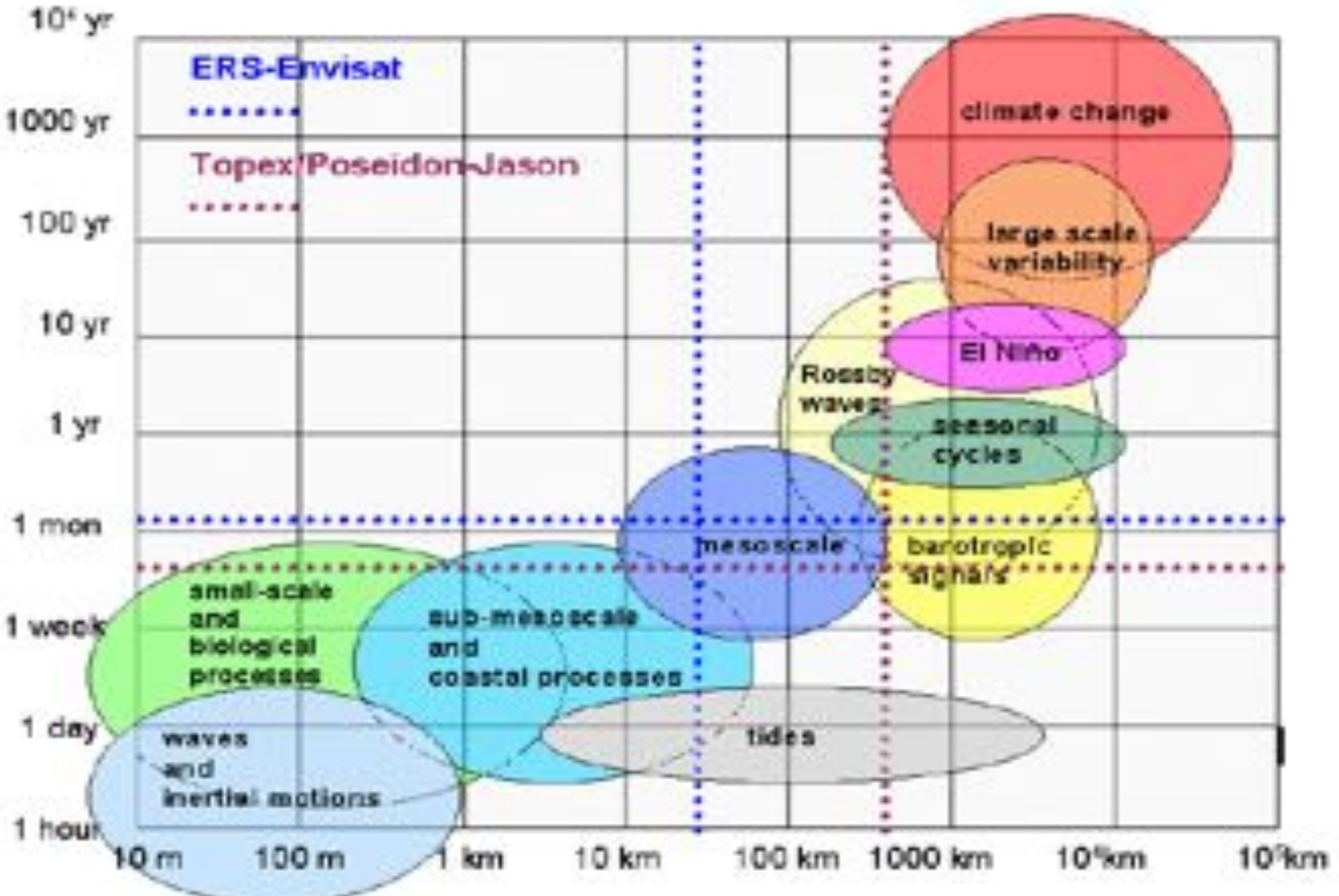

**Challenge: compare to tide-gauge data (Takoradi/Tema)**

# Challenges to ocean modeling

What are some challenges?

# Challenges to ocean modeling

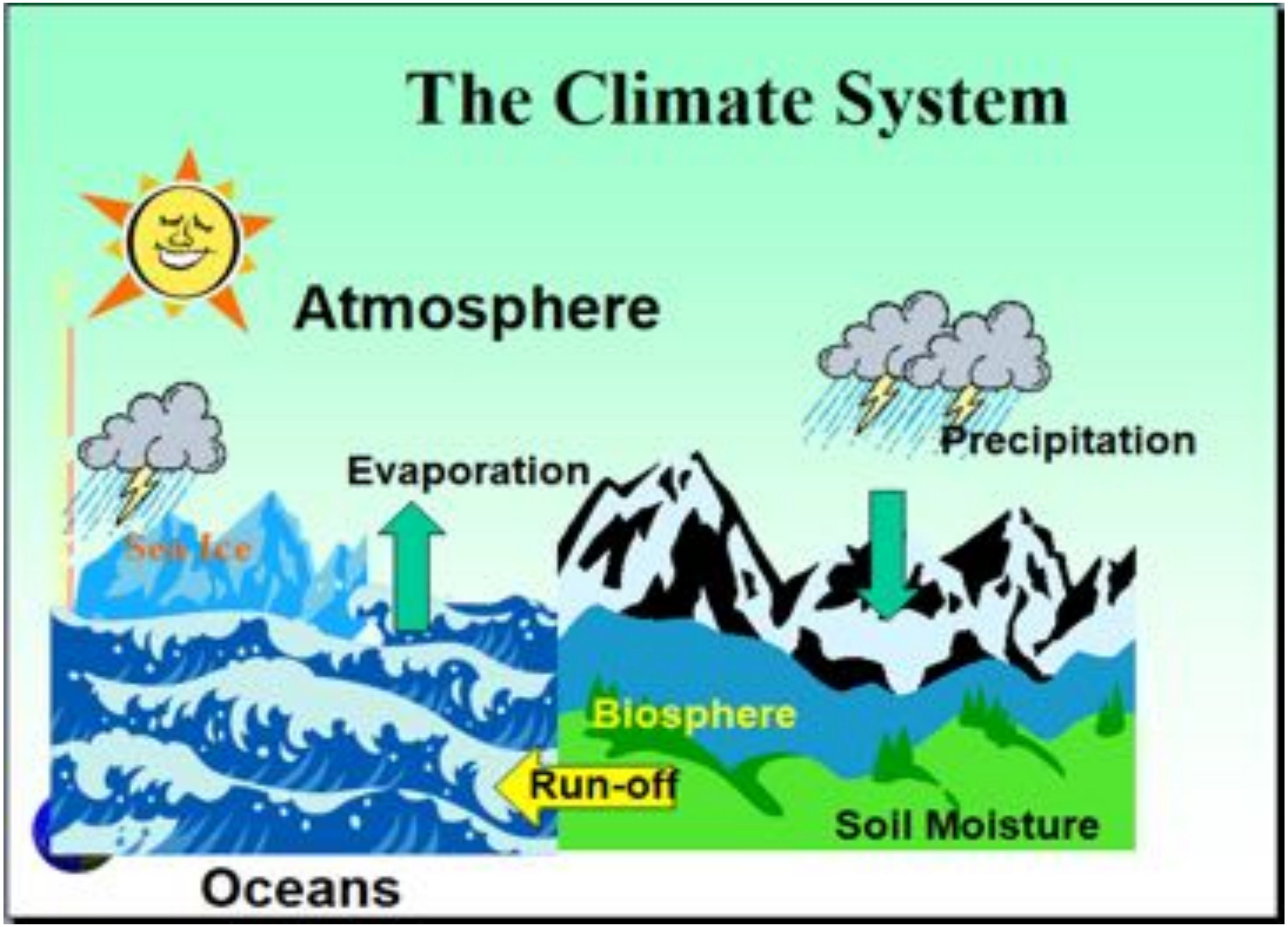
1. Variable spatial/temporal scales



# Challenges to ocean modeling

2. Coupling the Atmosphere to the Ocean

Antonio Navarra



# Challenges to ocean modeling

3. Complex topography and lateral boundaries

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

5. Availability of **computational power**

QUESTIONS?

- For a windows laptop/computer
  - download a VirtualBox
  - Install Ubuntu
- Install MITgcm (www.mitgcm.org)
  - Try some of the examples