INTRODUCTION TO OCEAN MODELING

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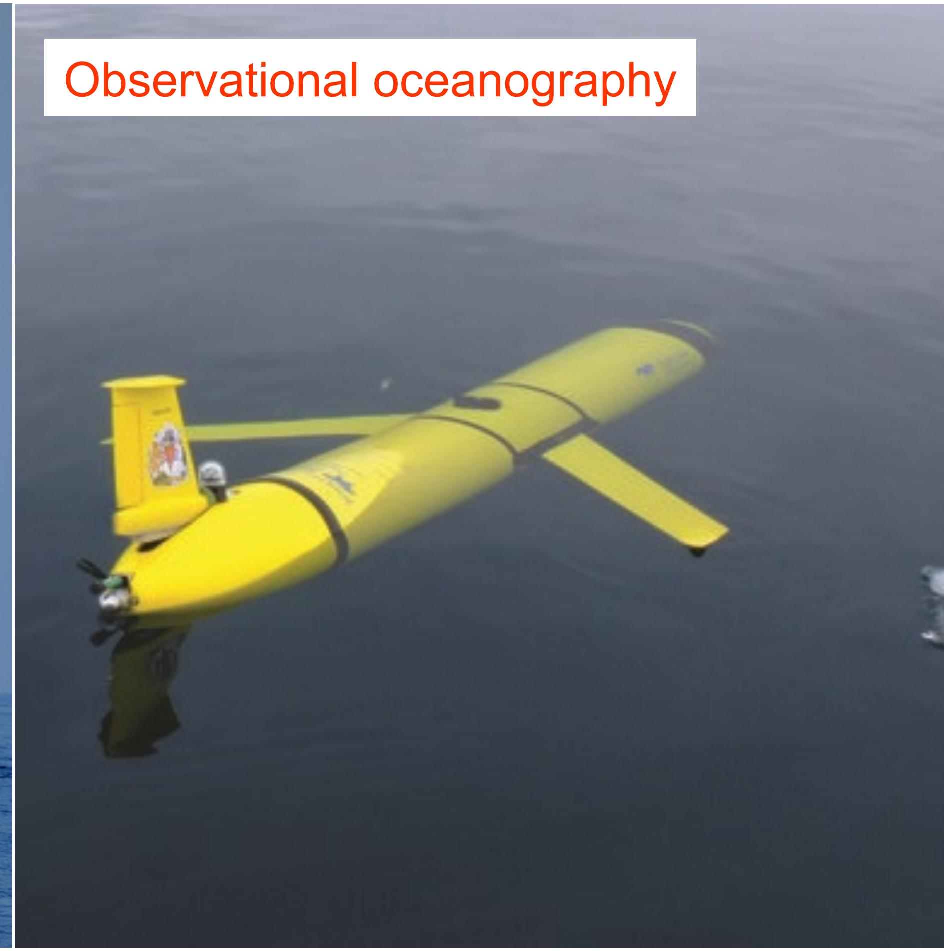
OUTLINE

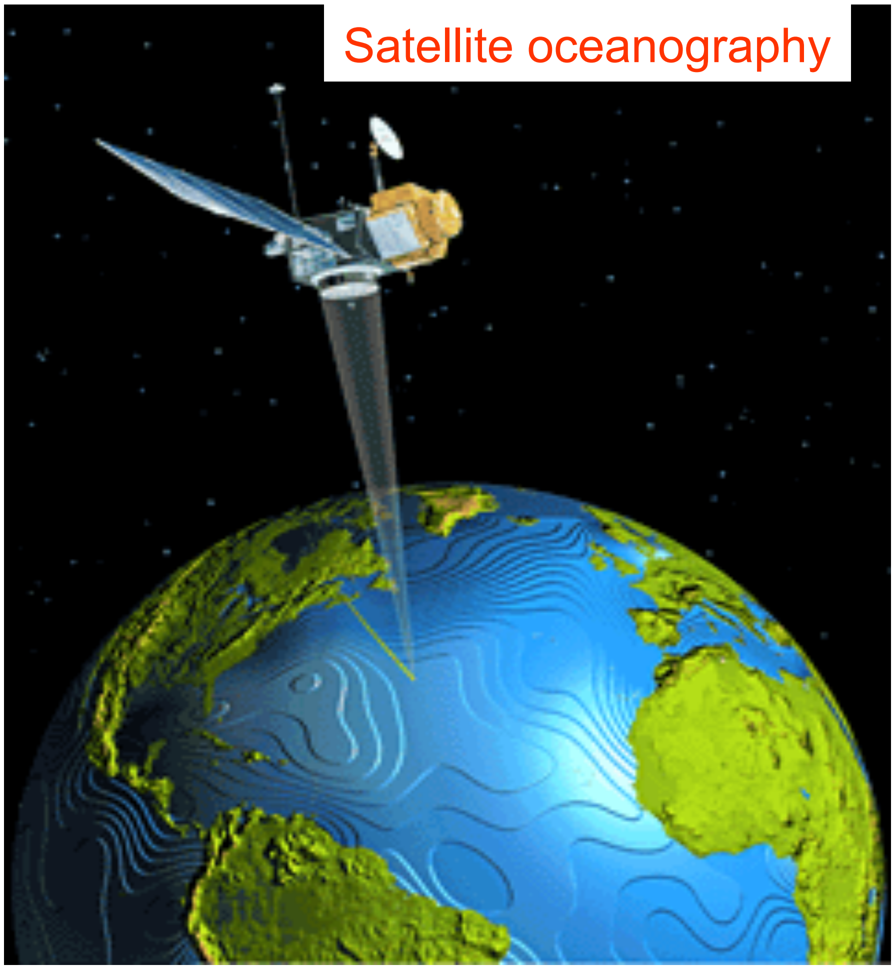
- INTRODUCTION
- MOTIVATION
- EQUATIONS OF MOTION
- EXAMPLES
- CHALLENGES

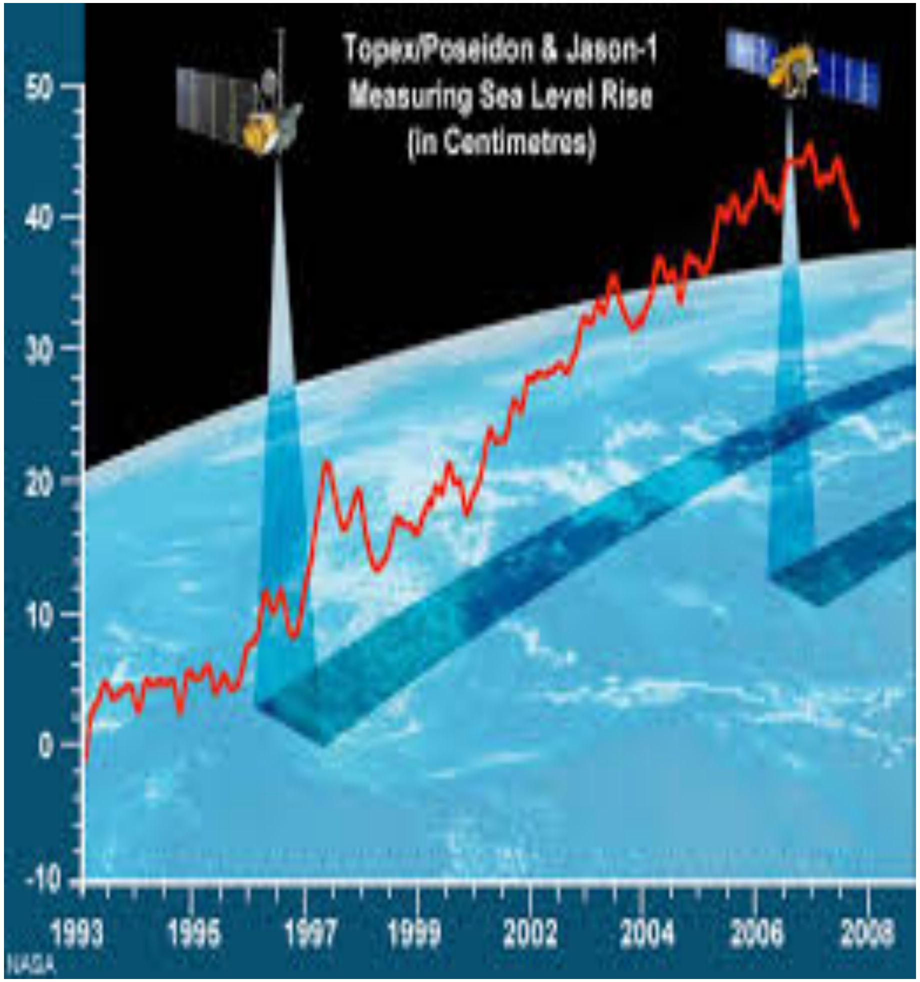
Introduction: Approaches to oceanic studies



Emily/Stephan et al.

Introduction: Approaches to oceanic studies



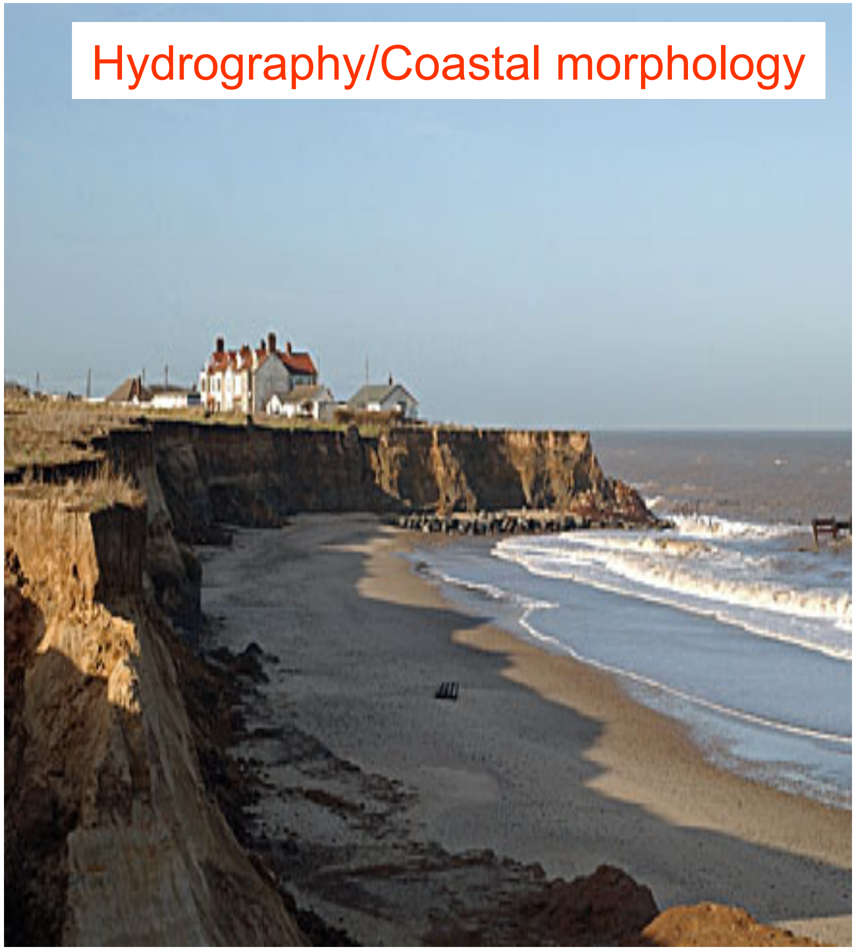


Ebenezer et al.

Introduction: Approaches to oceanic studies

Chemical oceanography

Hydrography/Coastal morphology

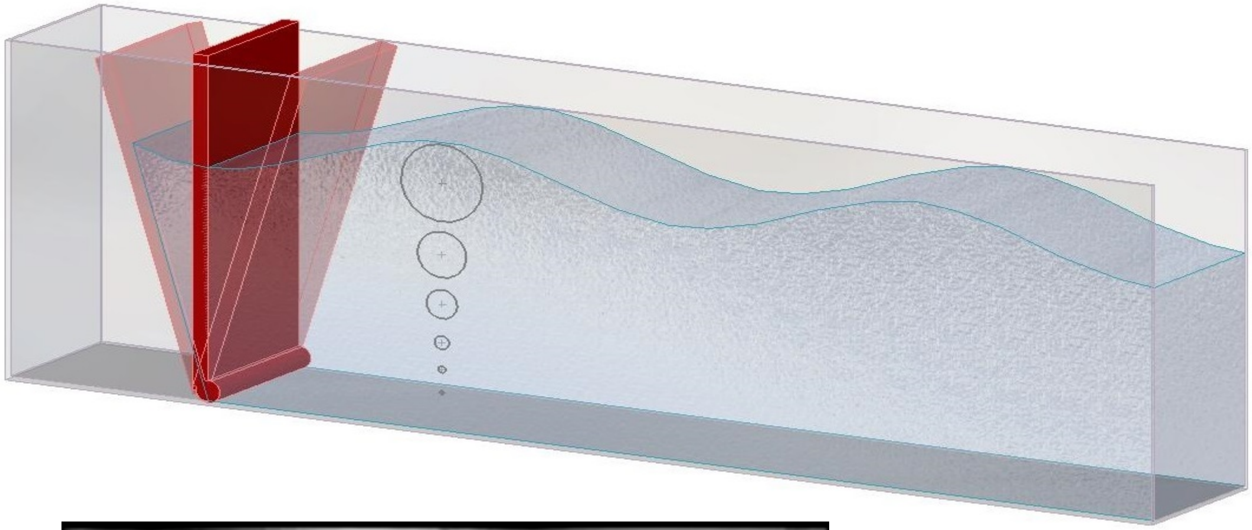


Winn et al.

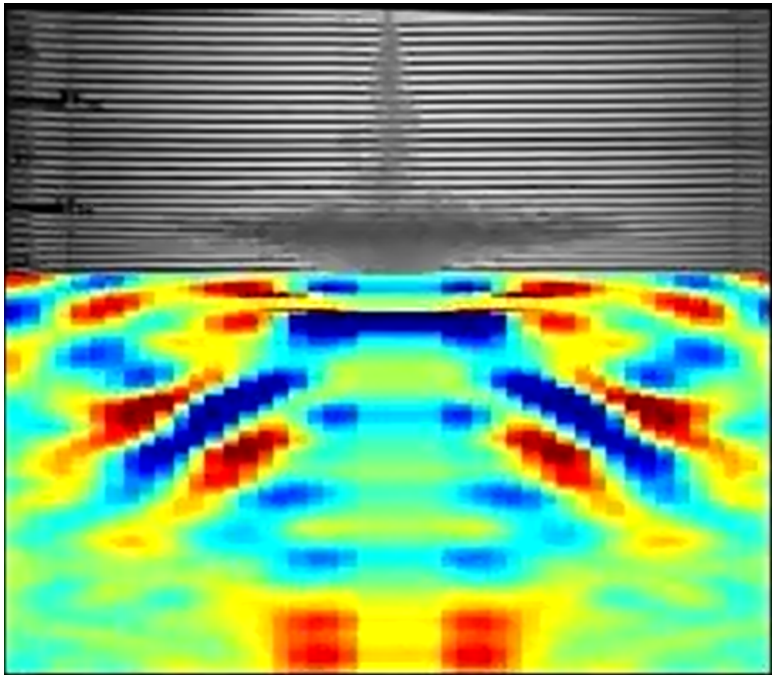
Stephan/Kwasi/Edem et al.


Angela et al.

Introduction: Approaches to oceanic studies

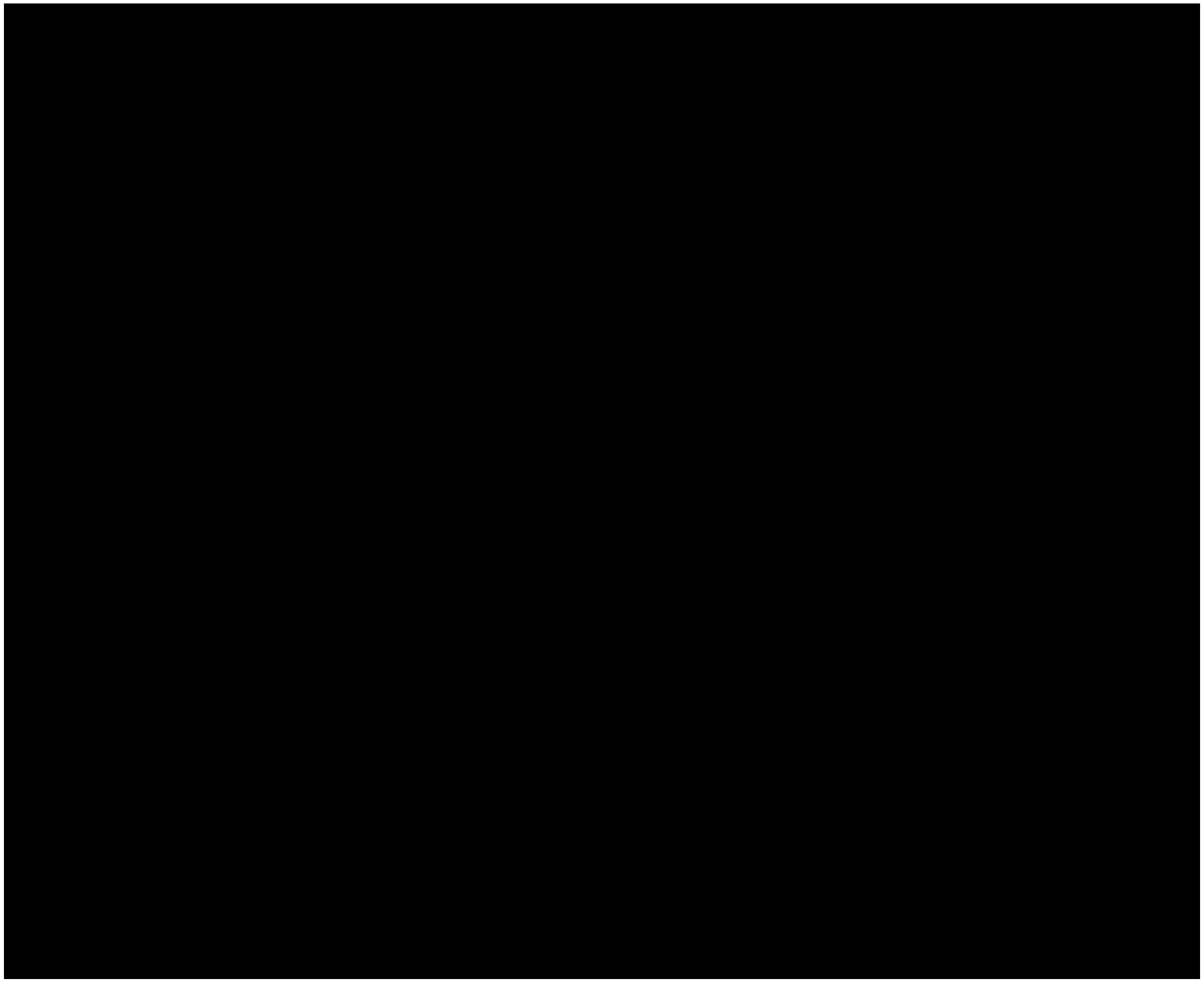


Laboratory tank Experiments- Emily/Stephan



Ansong & Sutherland, 2010, JFM, vol 648

Introduction: Approaches to oceanic studies



Ansong & Sutherland (2010), JFM, vol 648

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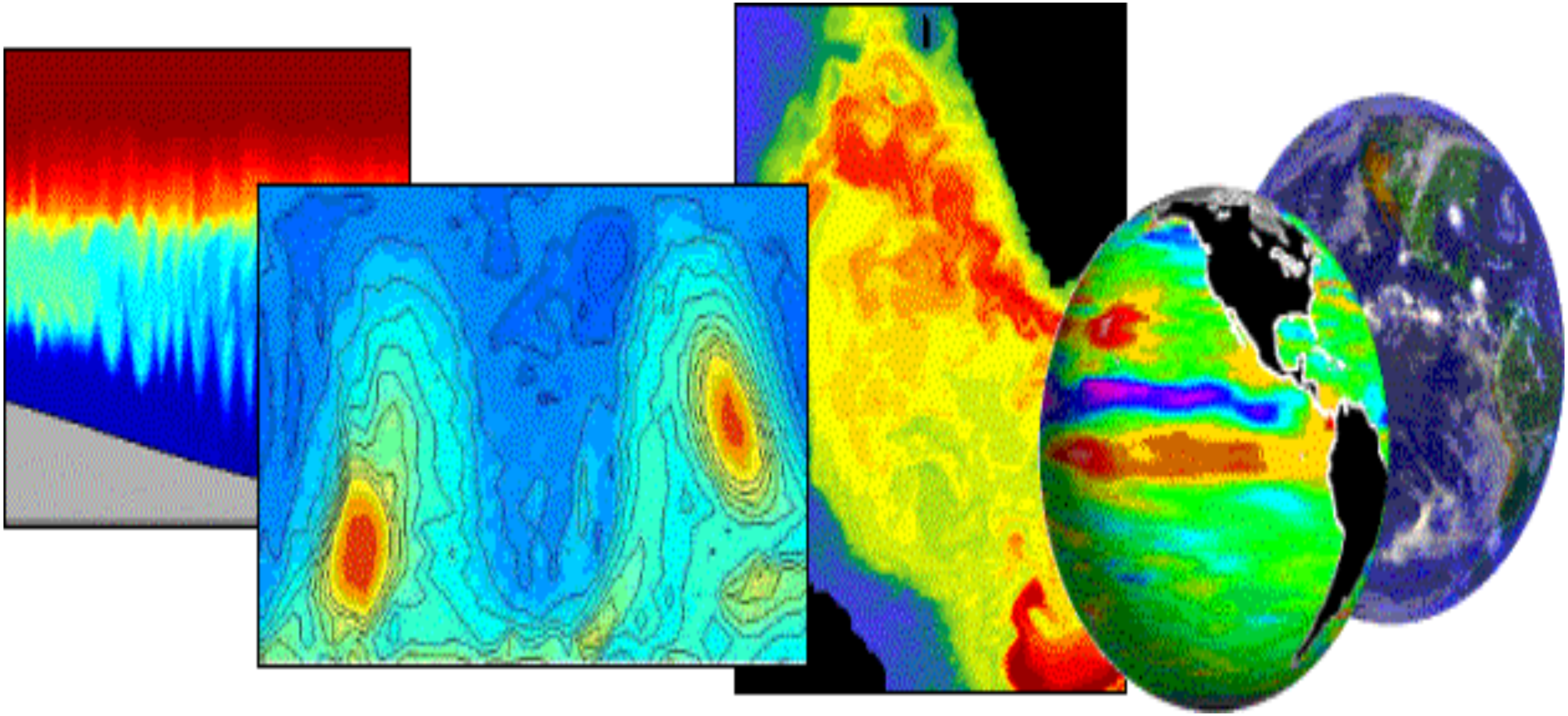


Ocean modeling

Riccardo/Brian/Dimitris/Joseph

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

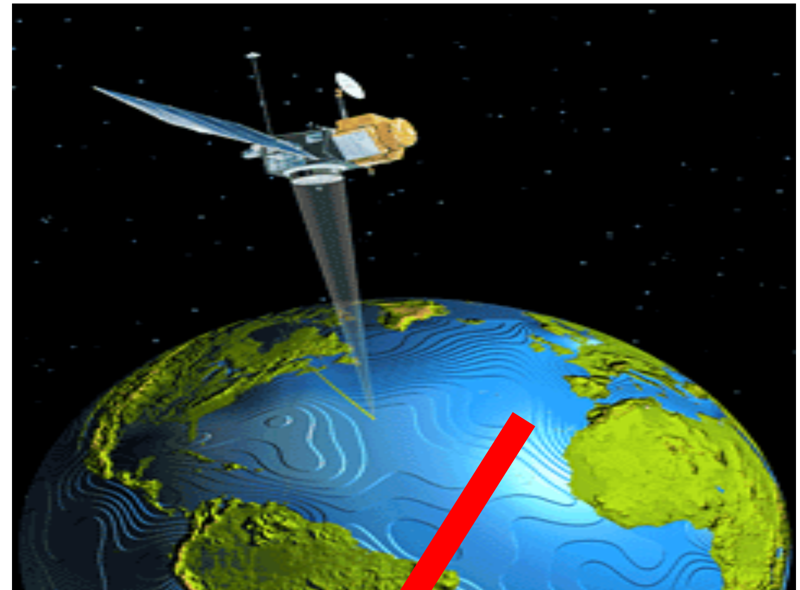
b) Exchange of energy between the ocean and external sources (radiation, precipitation, evaporation, river-runoff, wind, etc)

c) 3D mixing and dissipation processes

QUESTION

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

Motivation: Why model the ocean?

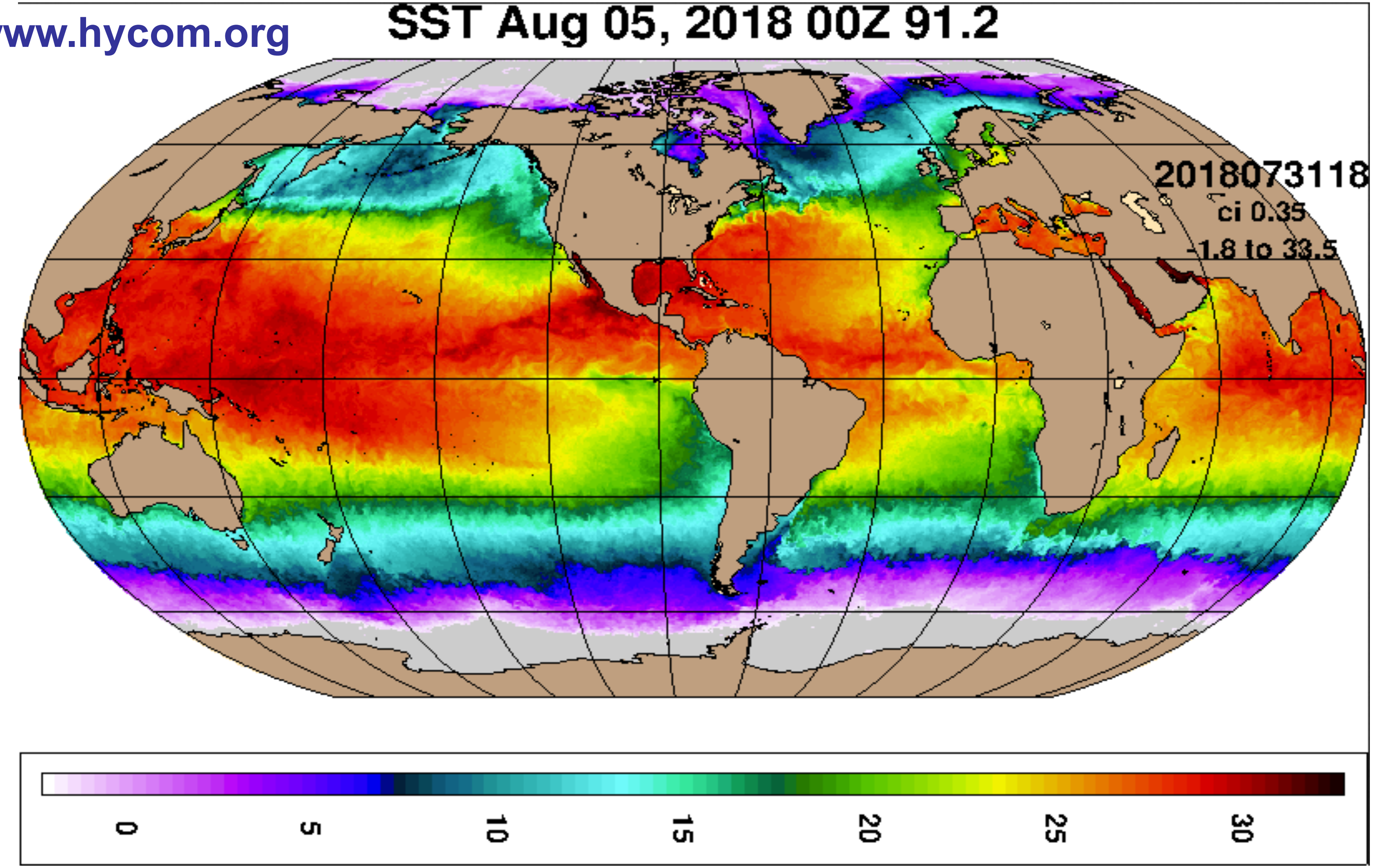


Motivation: Why model the ocean?

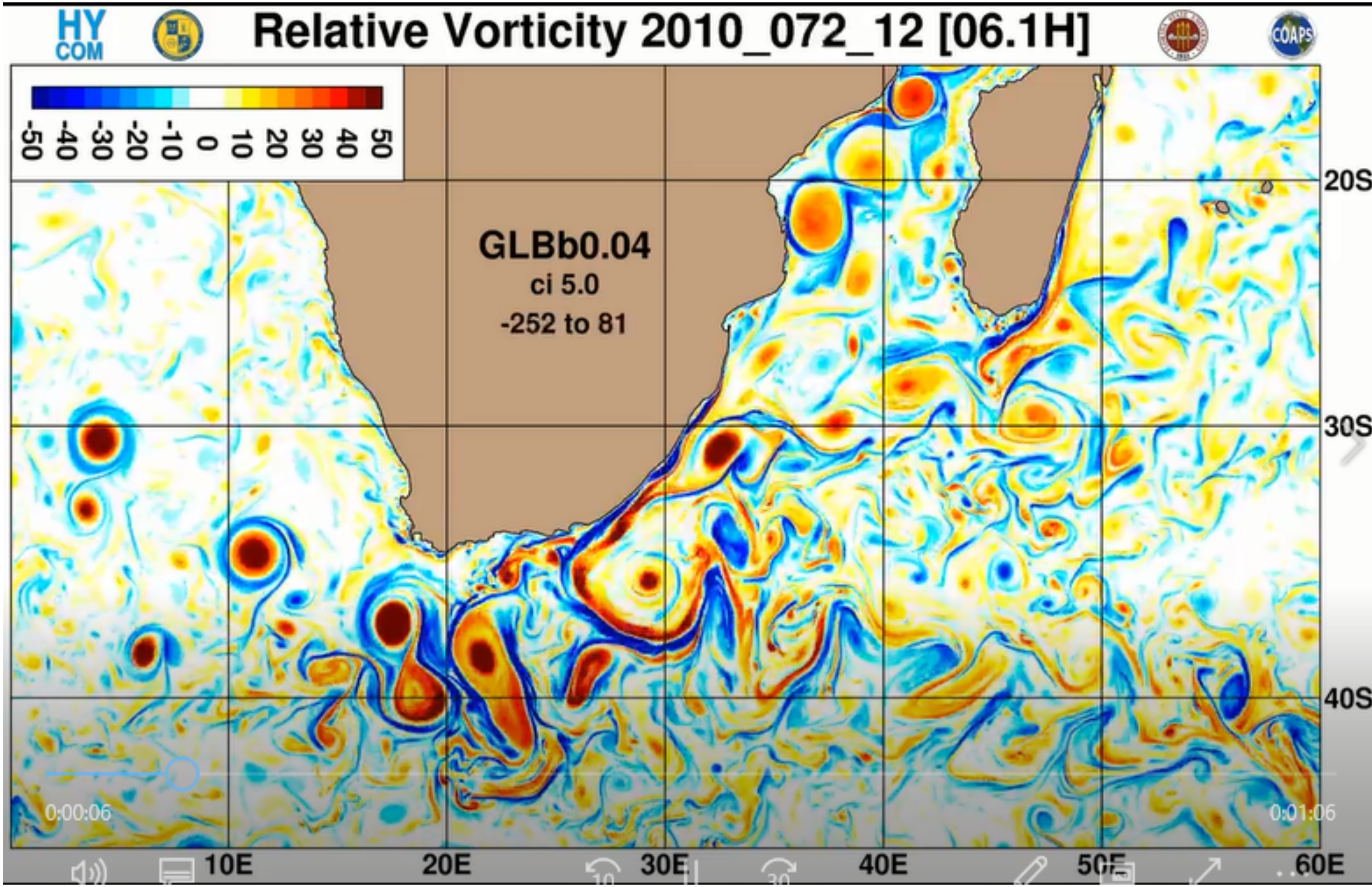
- Comparatively less expensive
- Higher spatial/temporal resolution compared to other methods:
  - Satellites provide only surface data, and
  - In-situ measurement are limited in spatial coverage
- Ability to forecast (e.g. SST, SSH, and positions of major fronts and eddies)

Motivation: Why model the ocean?

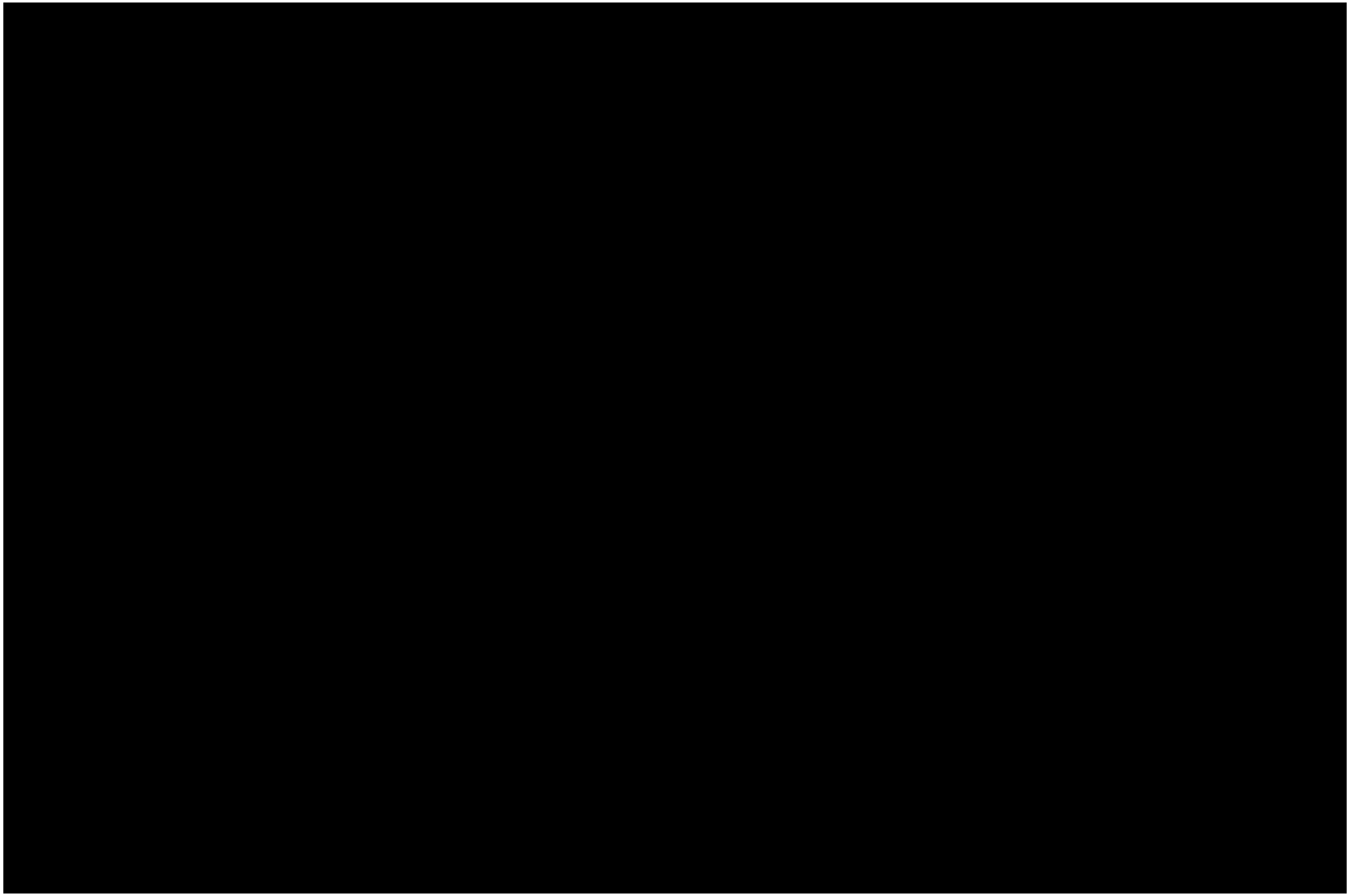
www.hycom.org



Motivation: Why model the ocean?



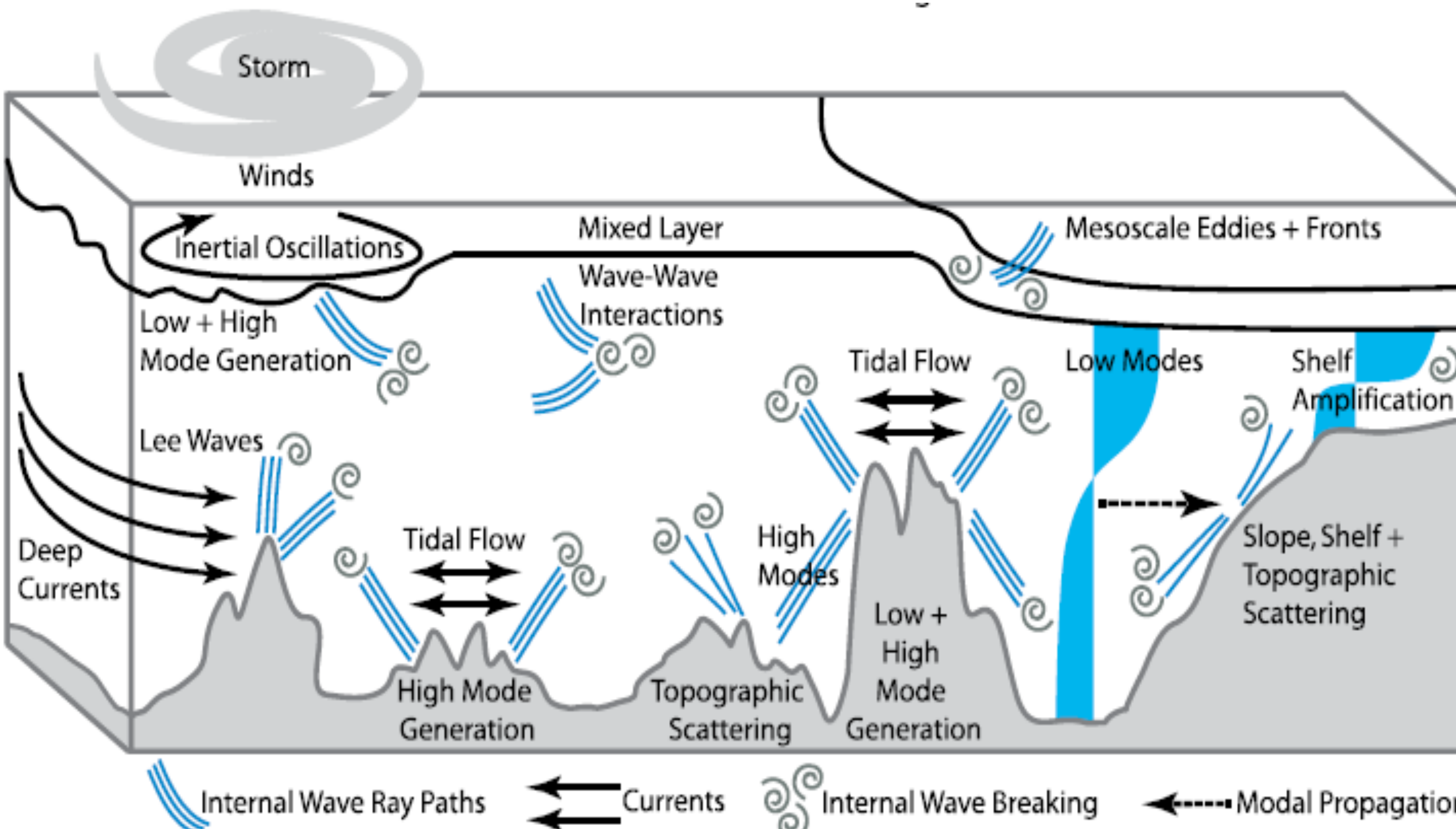
Motivation: Why model the ocean?



www.hycom.org

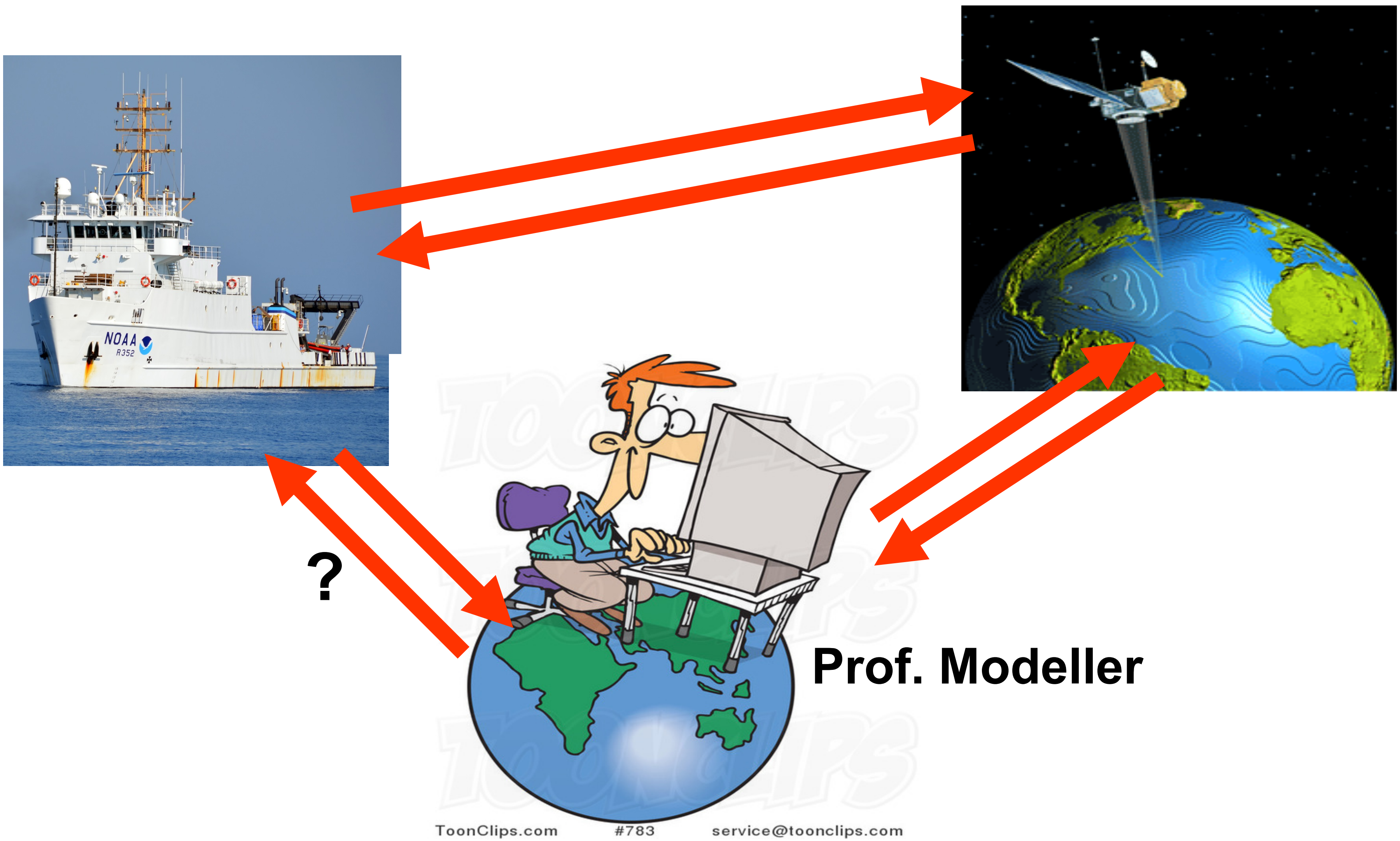
Motivation: Why model the ocean?

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

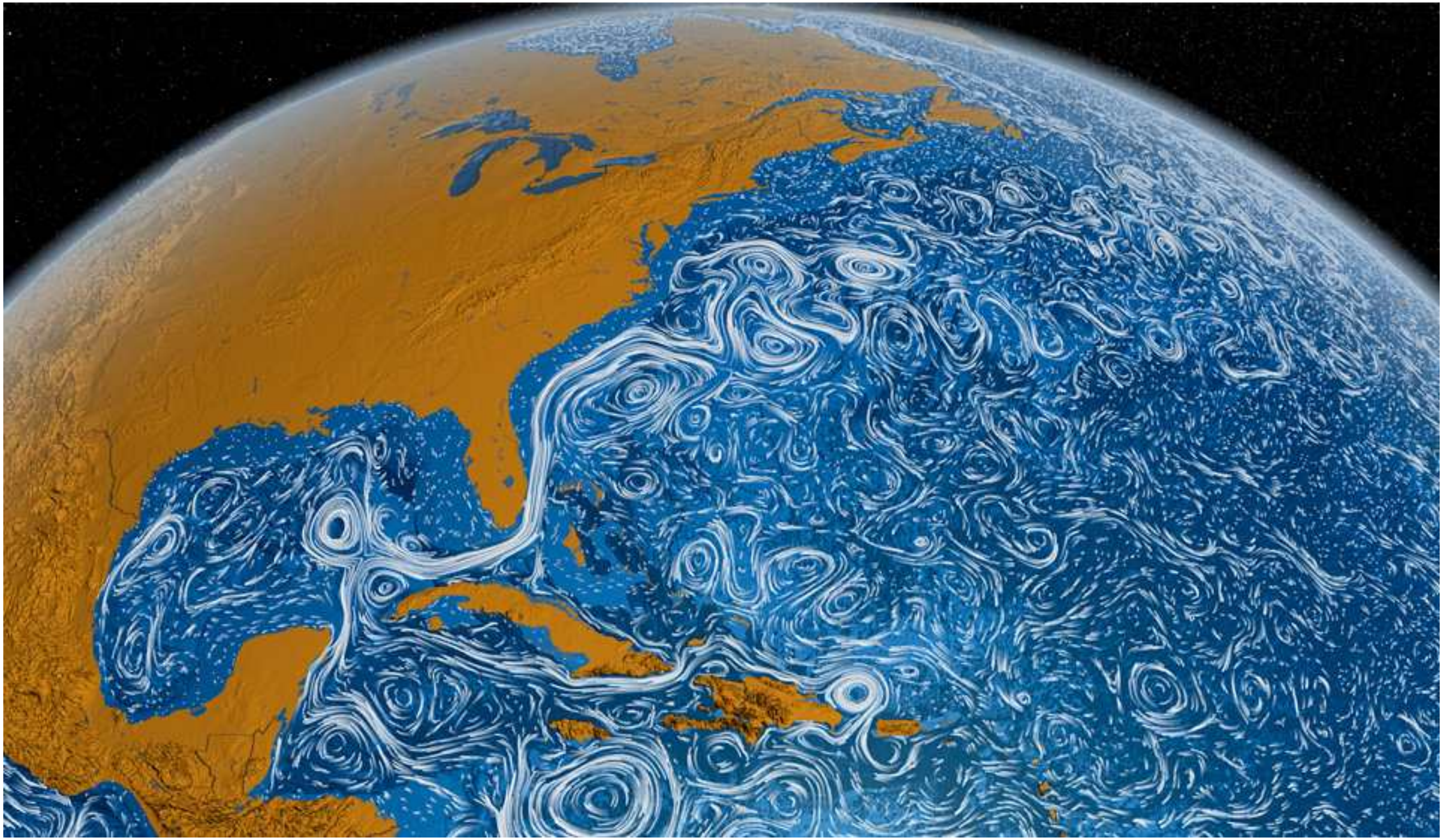


MacKinnon et al, 2017

Motivation: *not a competition*



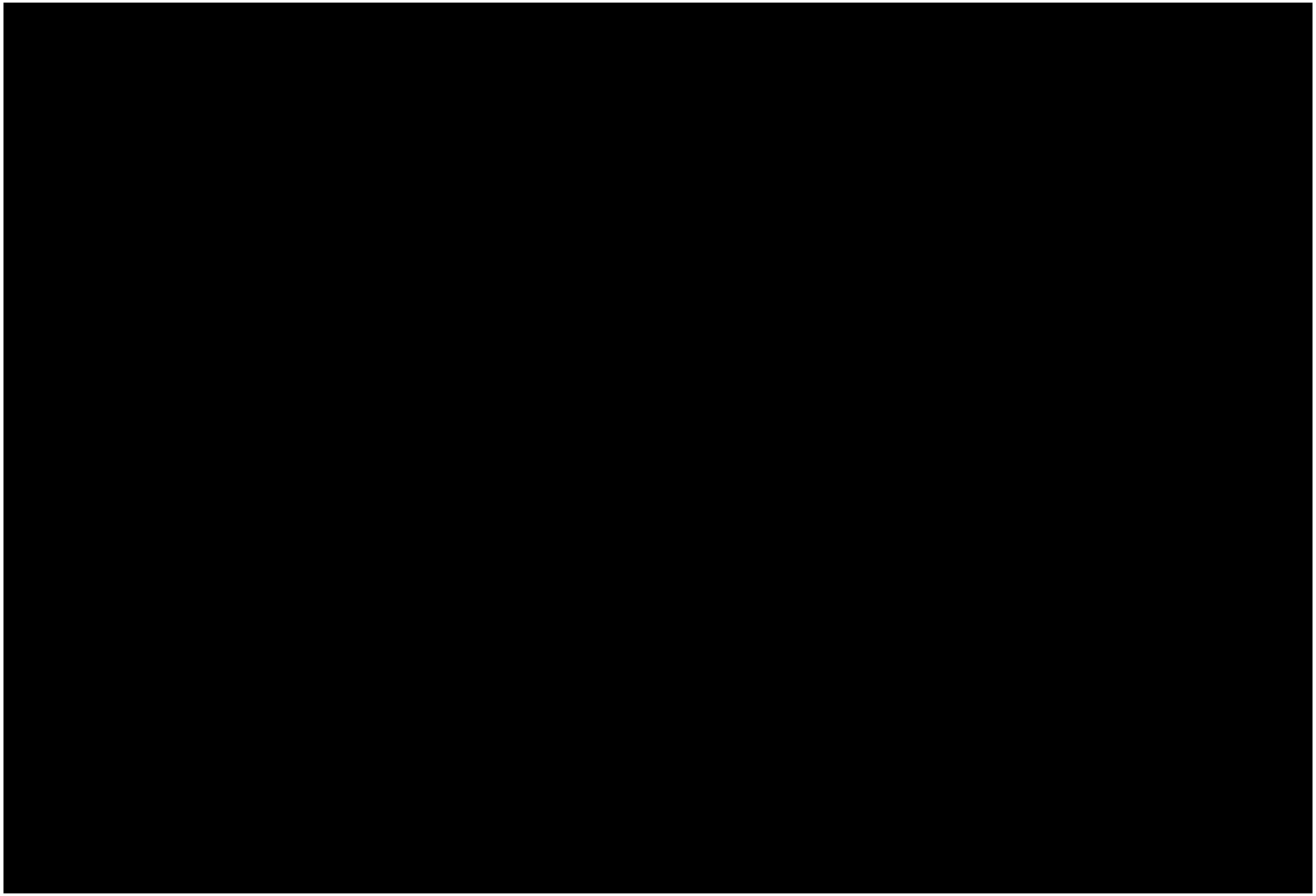
Motivation: global ocean currents



Internal gravity waves

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

Motivation: internal waves



Courtesy: Max-Planck institute of Ocean modeling

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:

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

acceleration (local + advective)

Rotation

Presure gradient

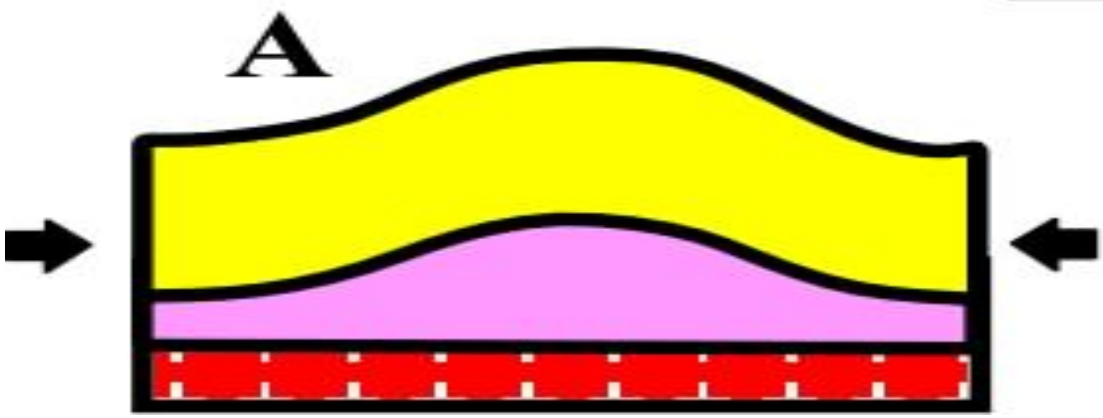
buoyancy

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)

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

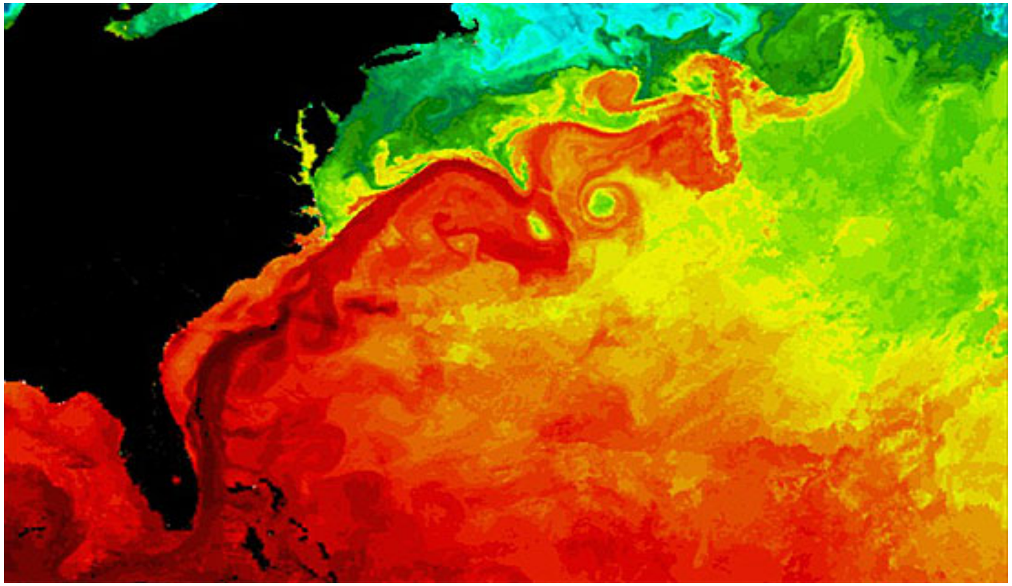


Equation for tracers (Temperature, Salinity, and others),

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.

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

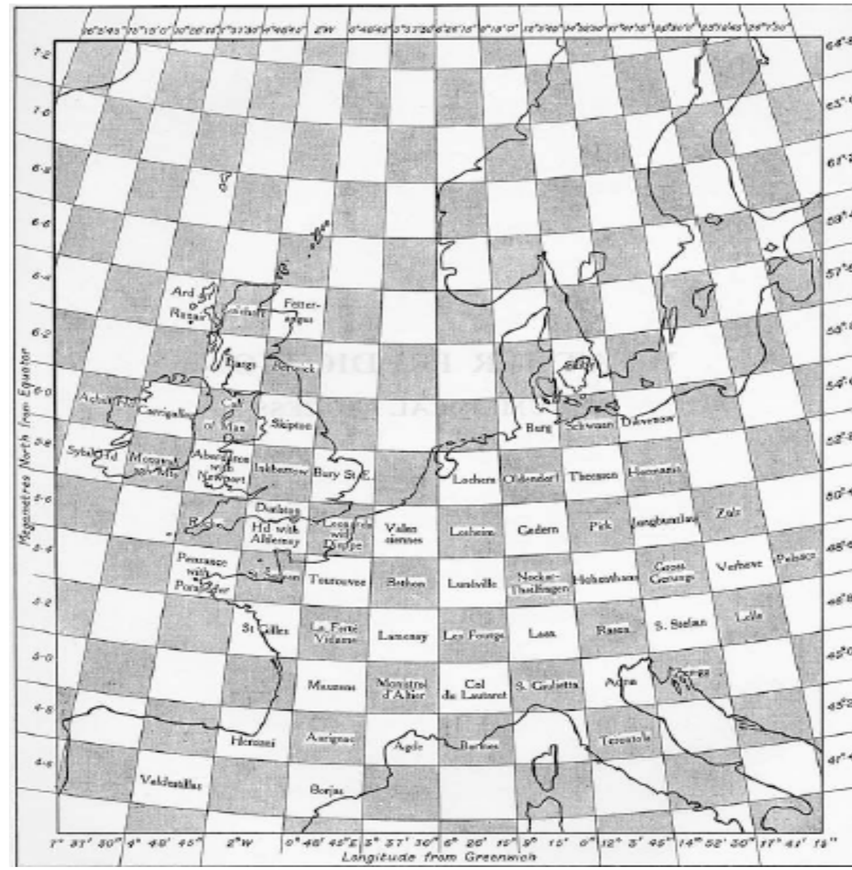
- Continuous equations

↓

algebraic equations

(discrete set of operations)

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

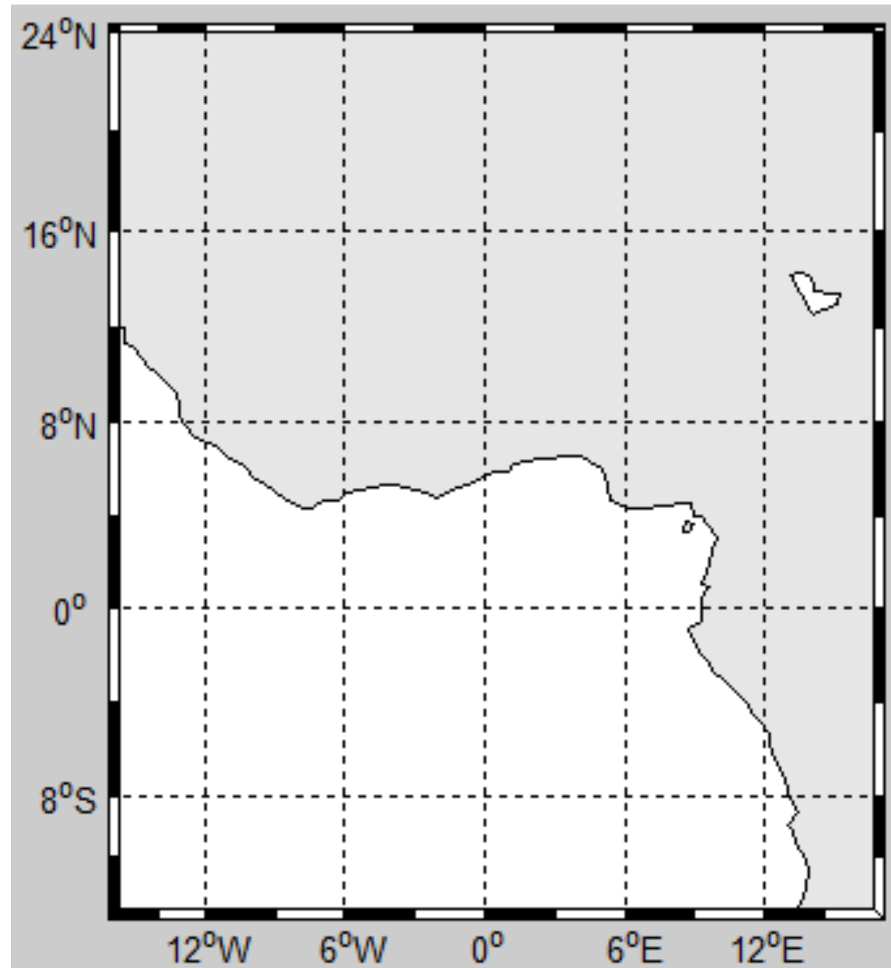


Example early model grid by Lewis Fry Richardson (1928)

Model grid: horizontal

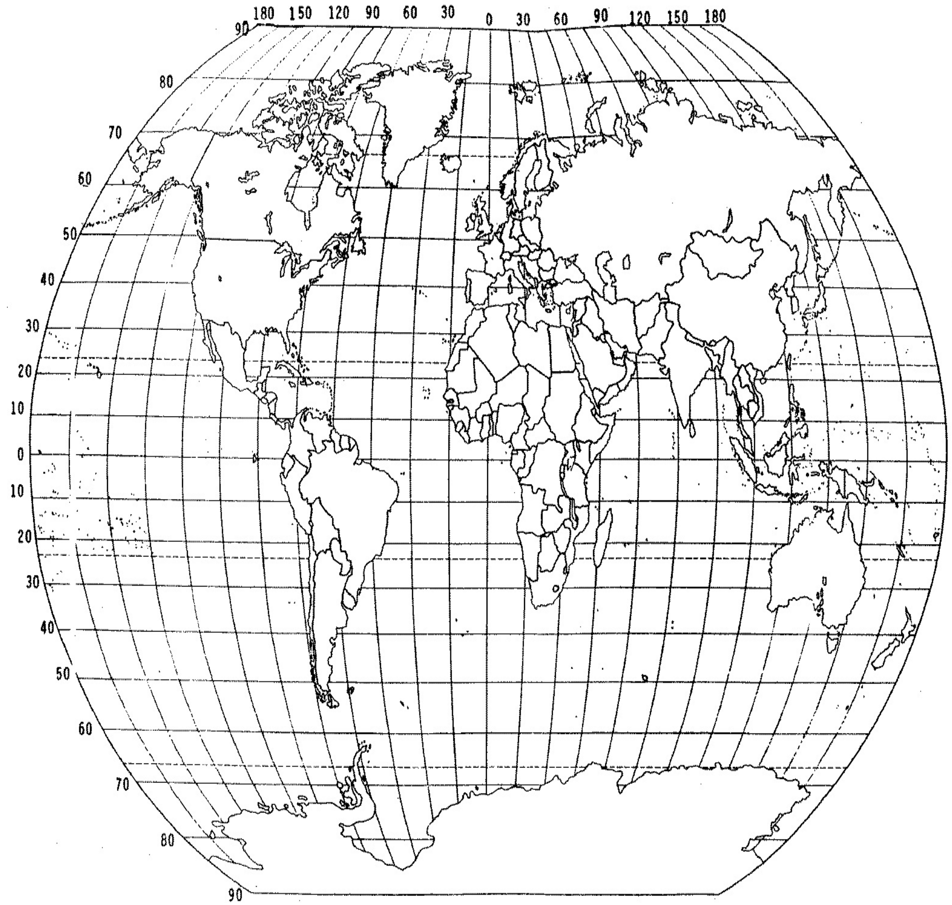
- Regular grids: regularly spaced lines

- possible in a small domain

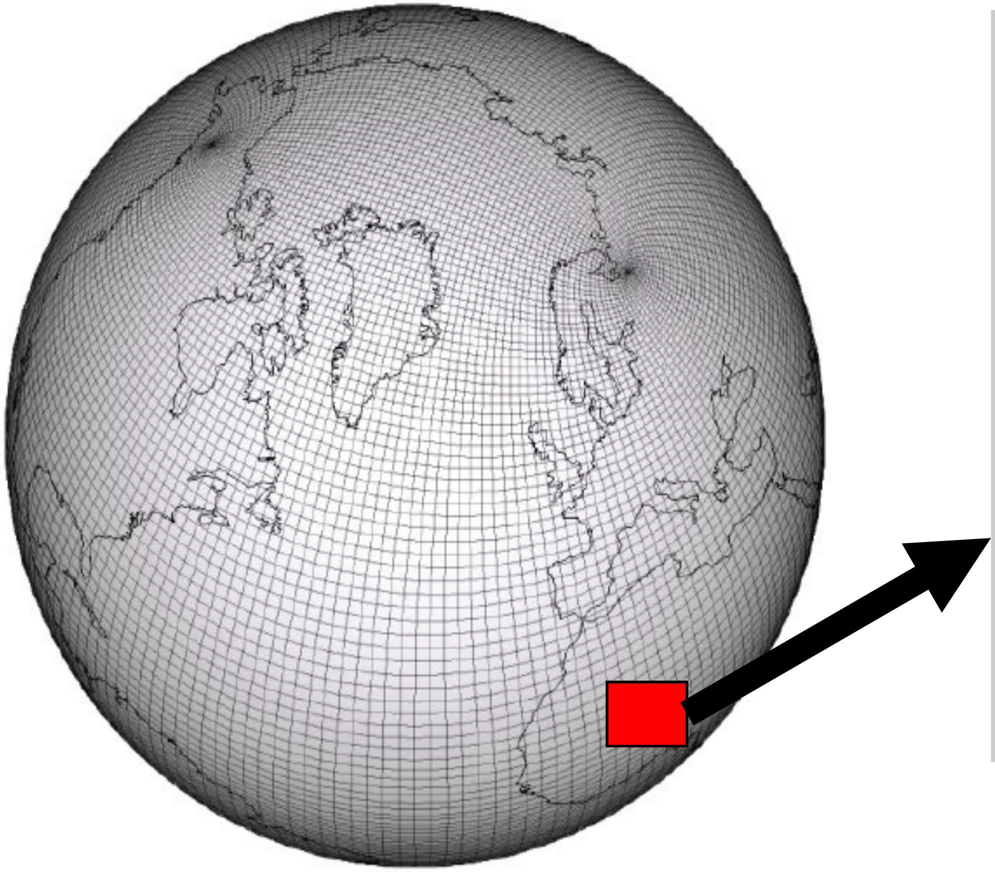


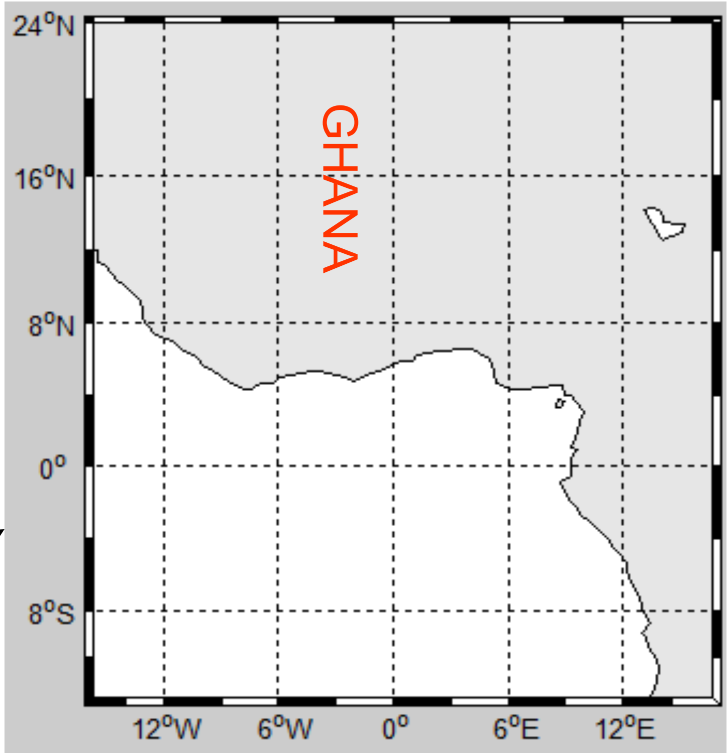
Model grid: horizontal

- 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



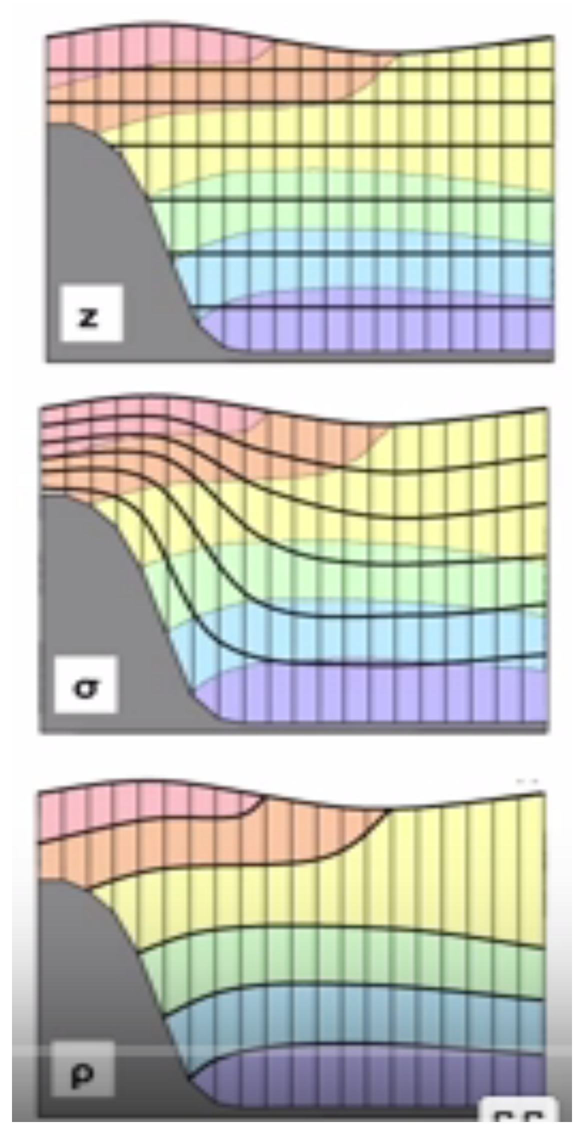


Regional grid

Clever solution: tripolar grid
-circular grid laid over Arctic region with poles on land

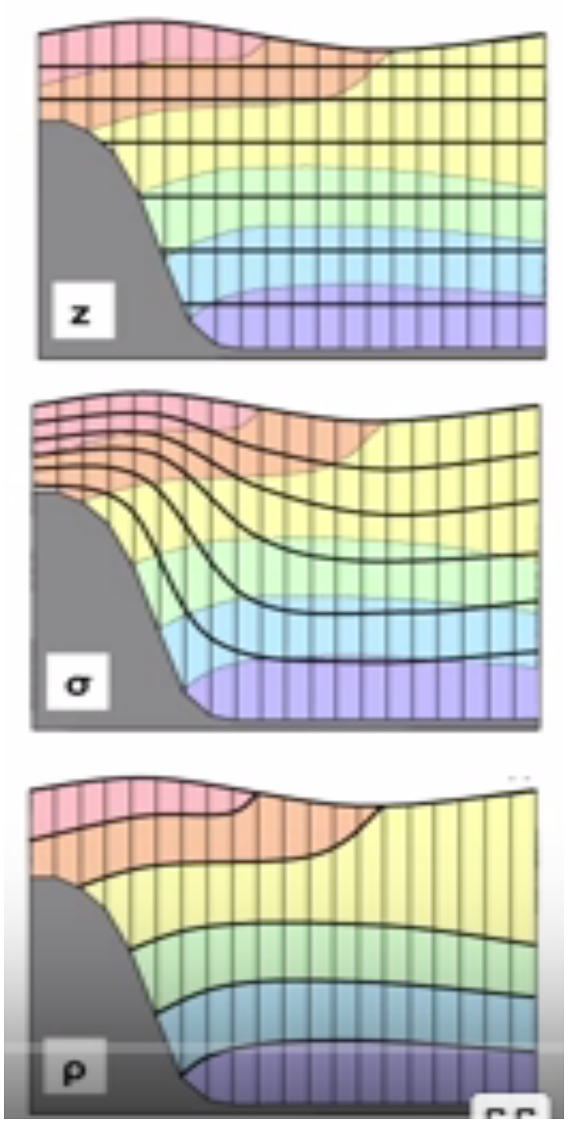
Model grid: vertical

- 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.



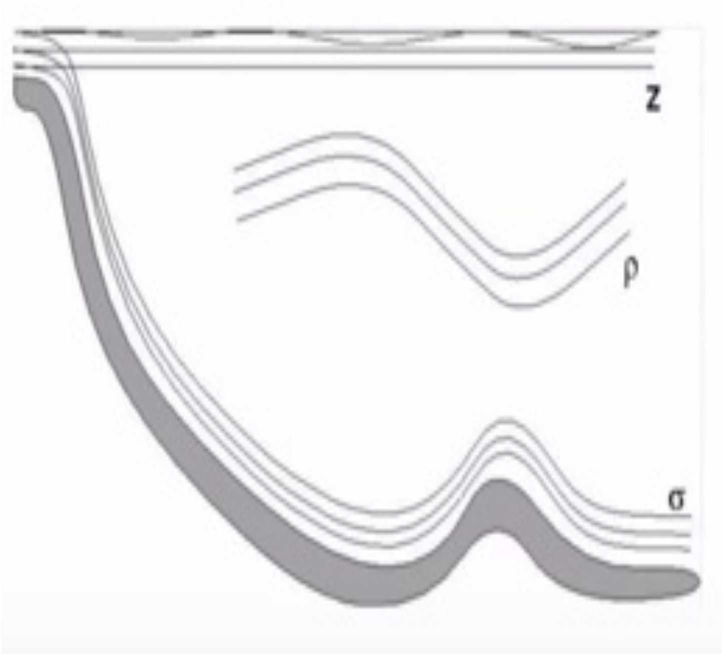
Model grid: vertical

- 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.



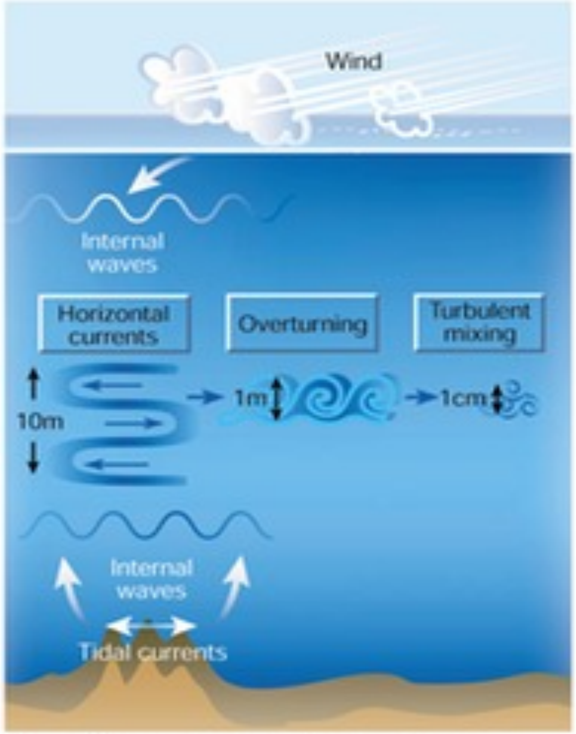
Model grid: vertical

- 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

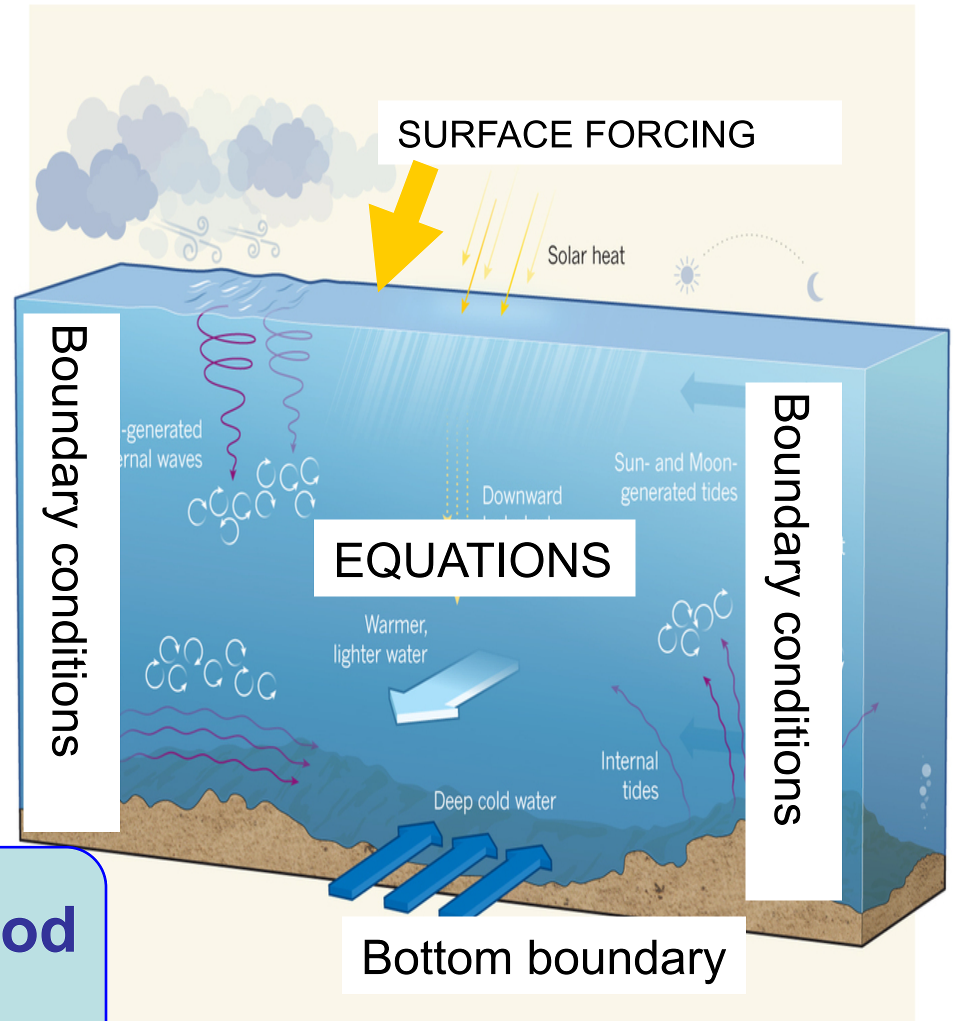
Modeling: summary

- 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

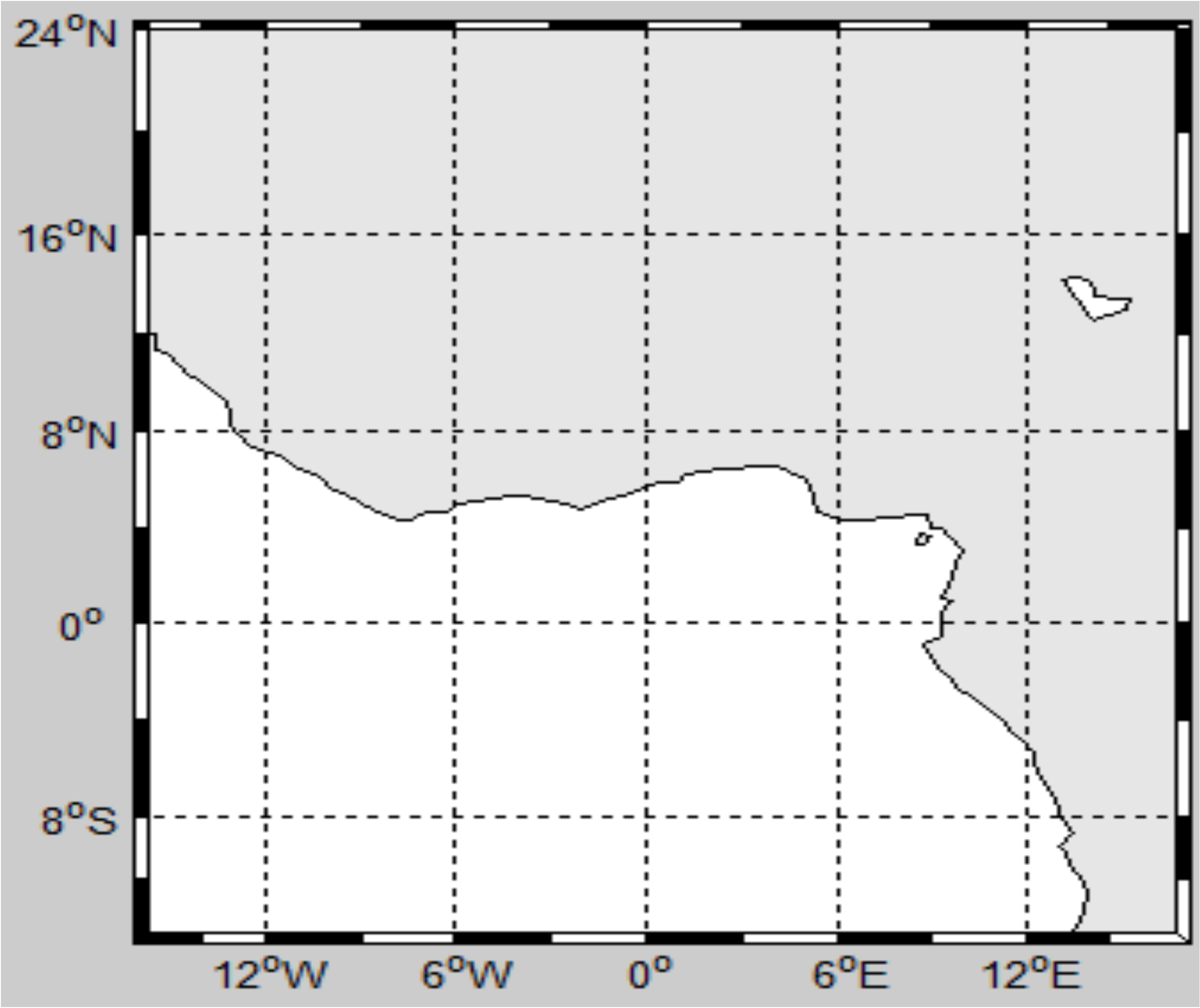
- MOM (The Modular Ocean Model: http://mom-ocean.org/web)
- POM (The Princeton Ocean Model: http://www.ccpo.odu.edu/POMWEB/)
- POP (The Parallel Ocean Program: http://www.cesm.ucar.edu/models/cesm1.0/pop2/)

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)

Examples

Regional Modeling

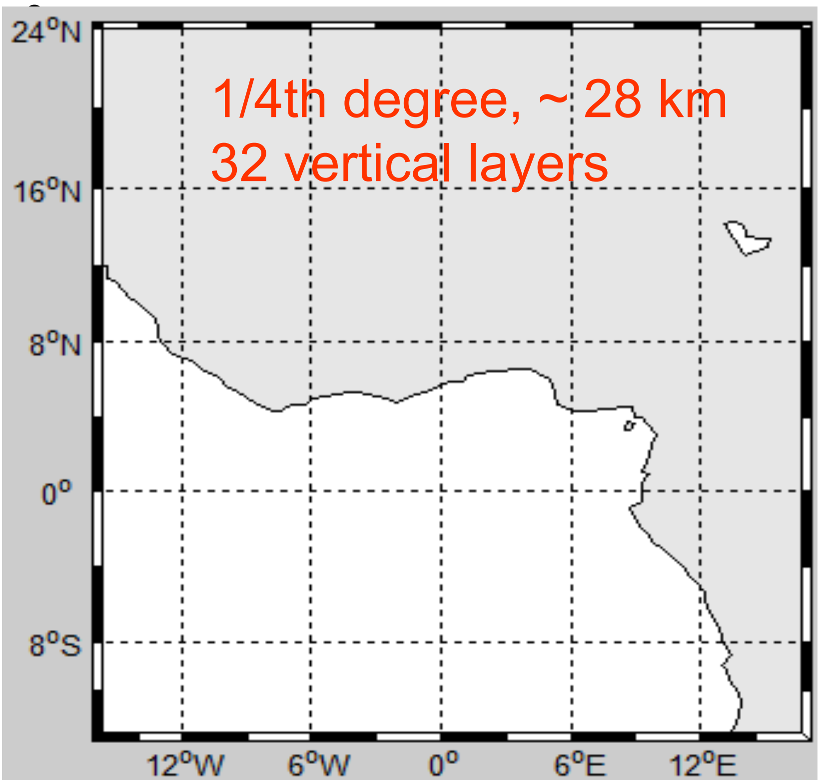


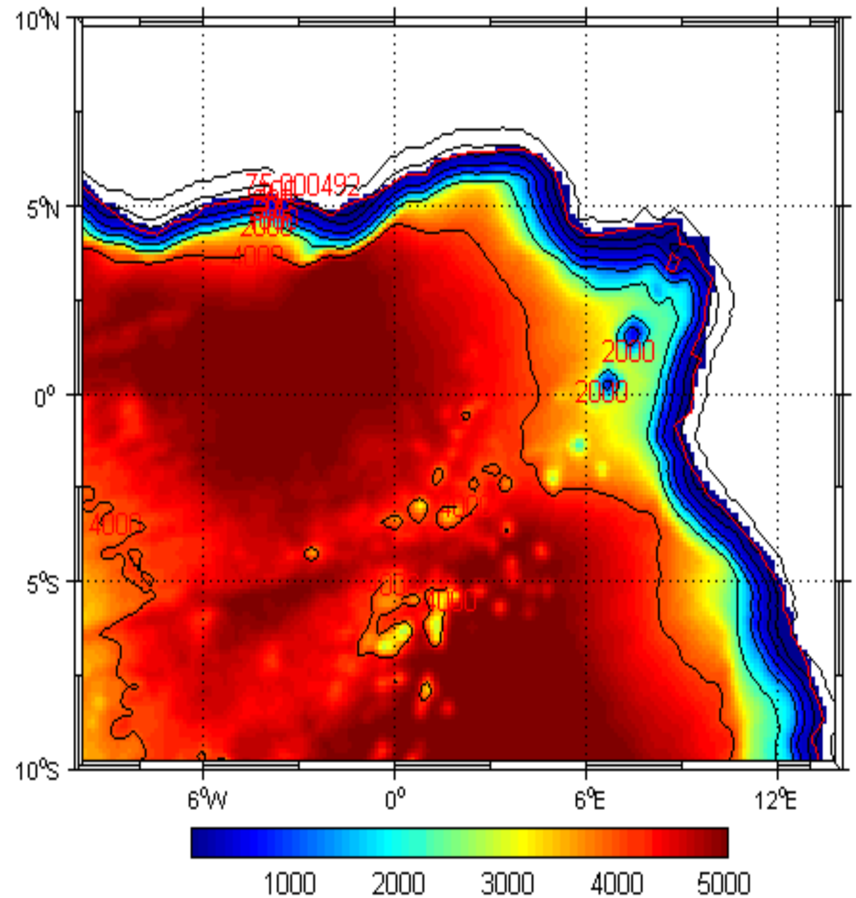
Regional Modeling

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.

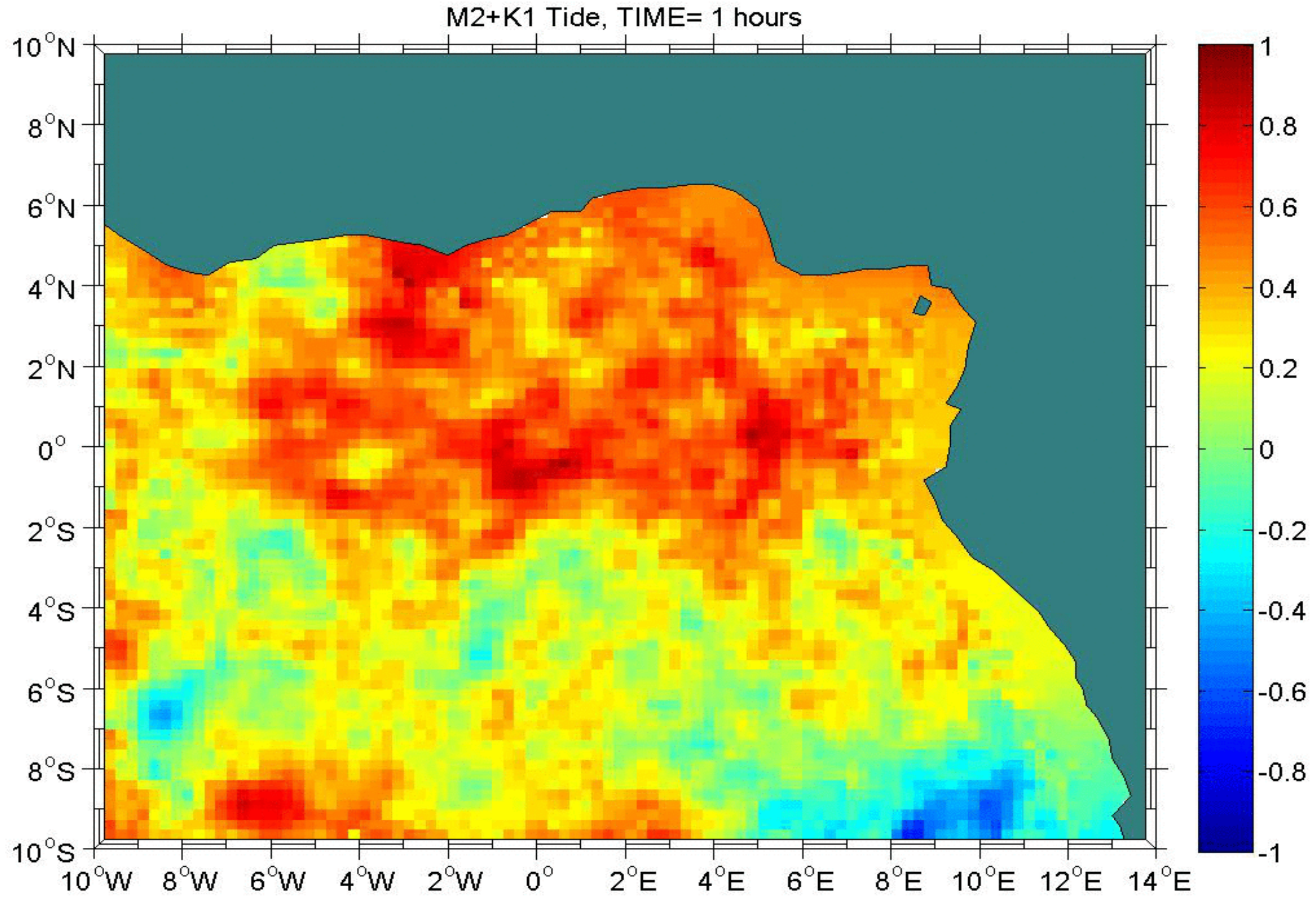
Regional Modeling



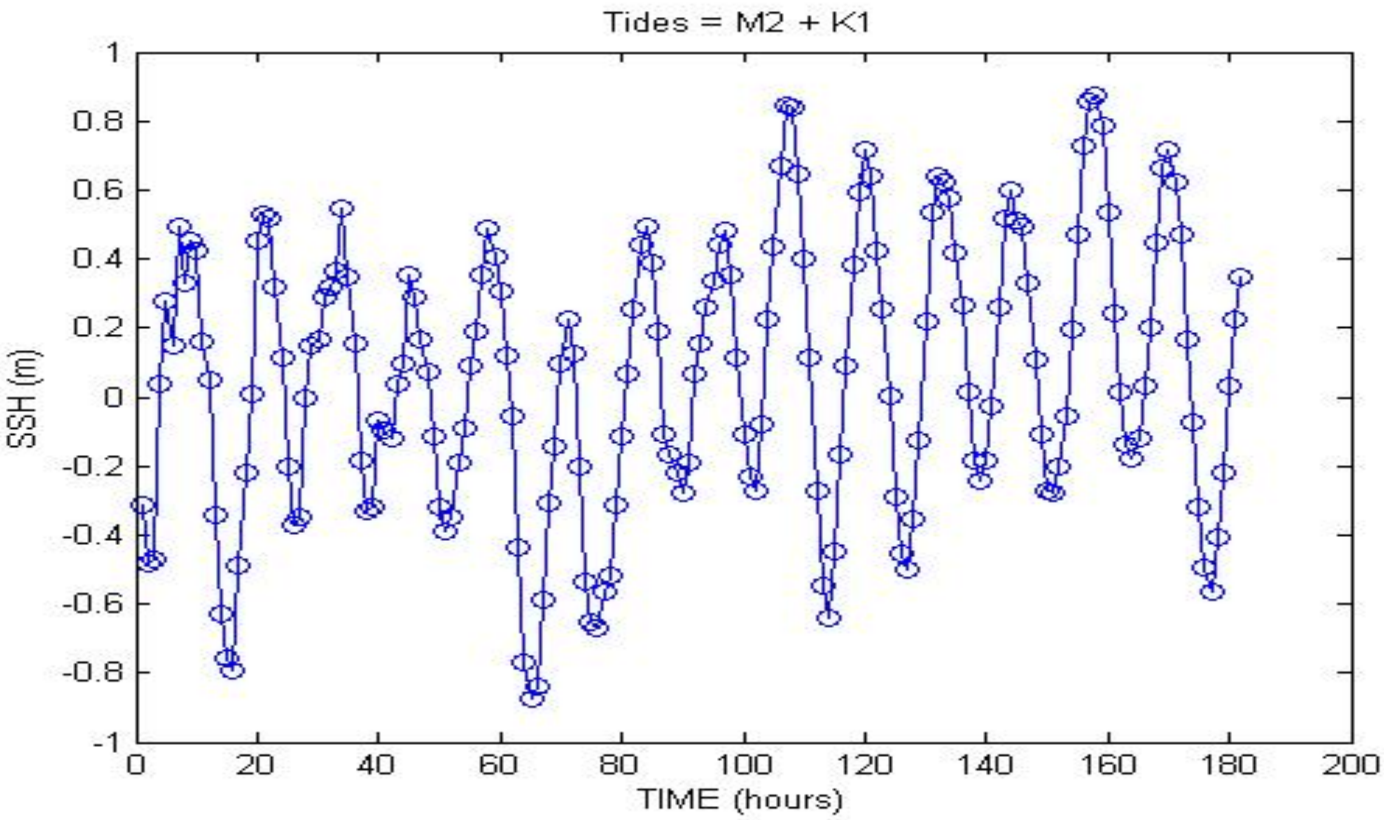


Etopo5: http://www.ngdc.noaa.gov/mgg/global/etopo5.HTML

Results: Tides



Results: tidal time series



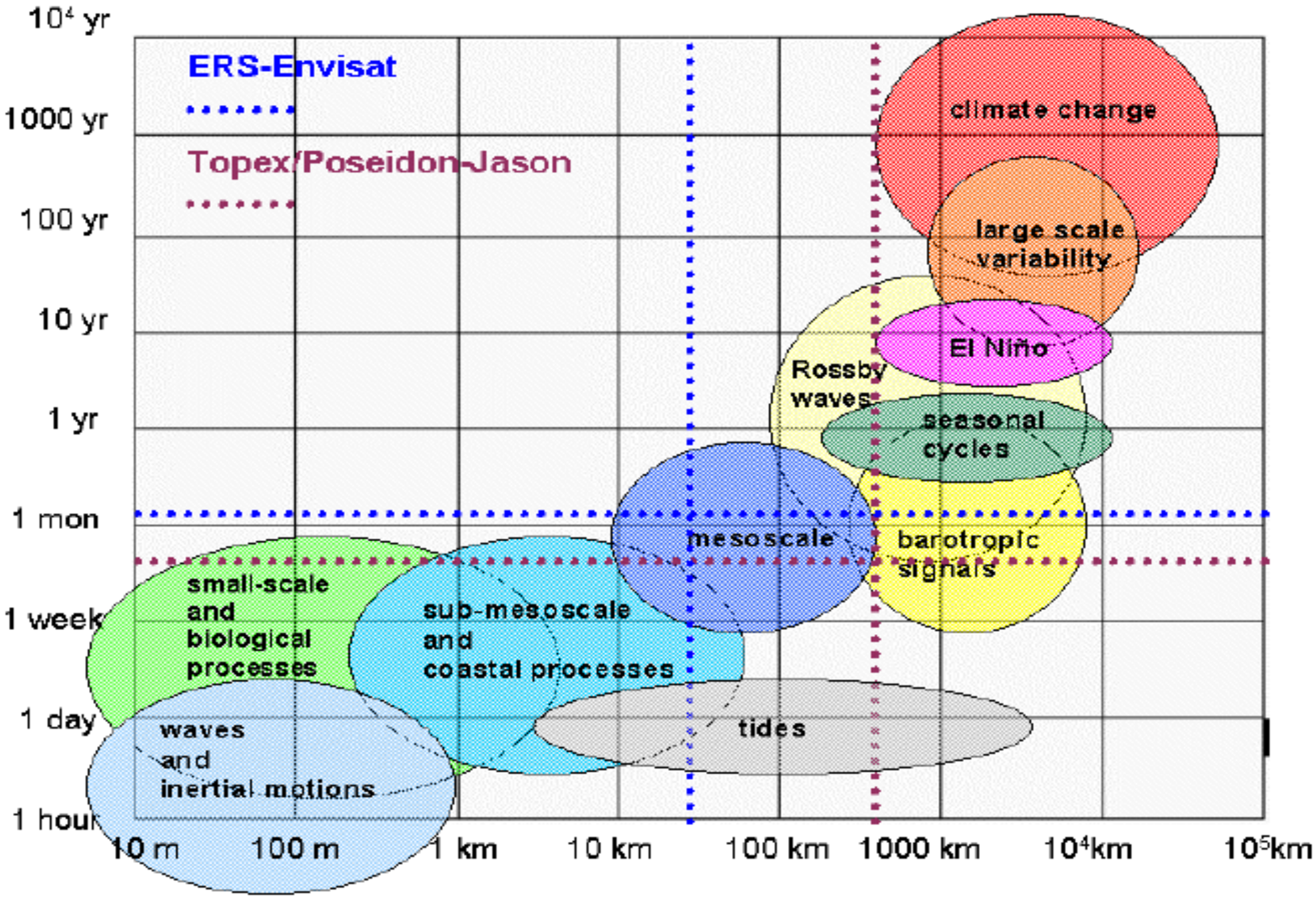
Challenge: compare to tide-gauge data (Takoradi/Tema)

Challenges to ocean modeling

What are some challenges?

Challenges to ocean modeling

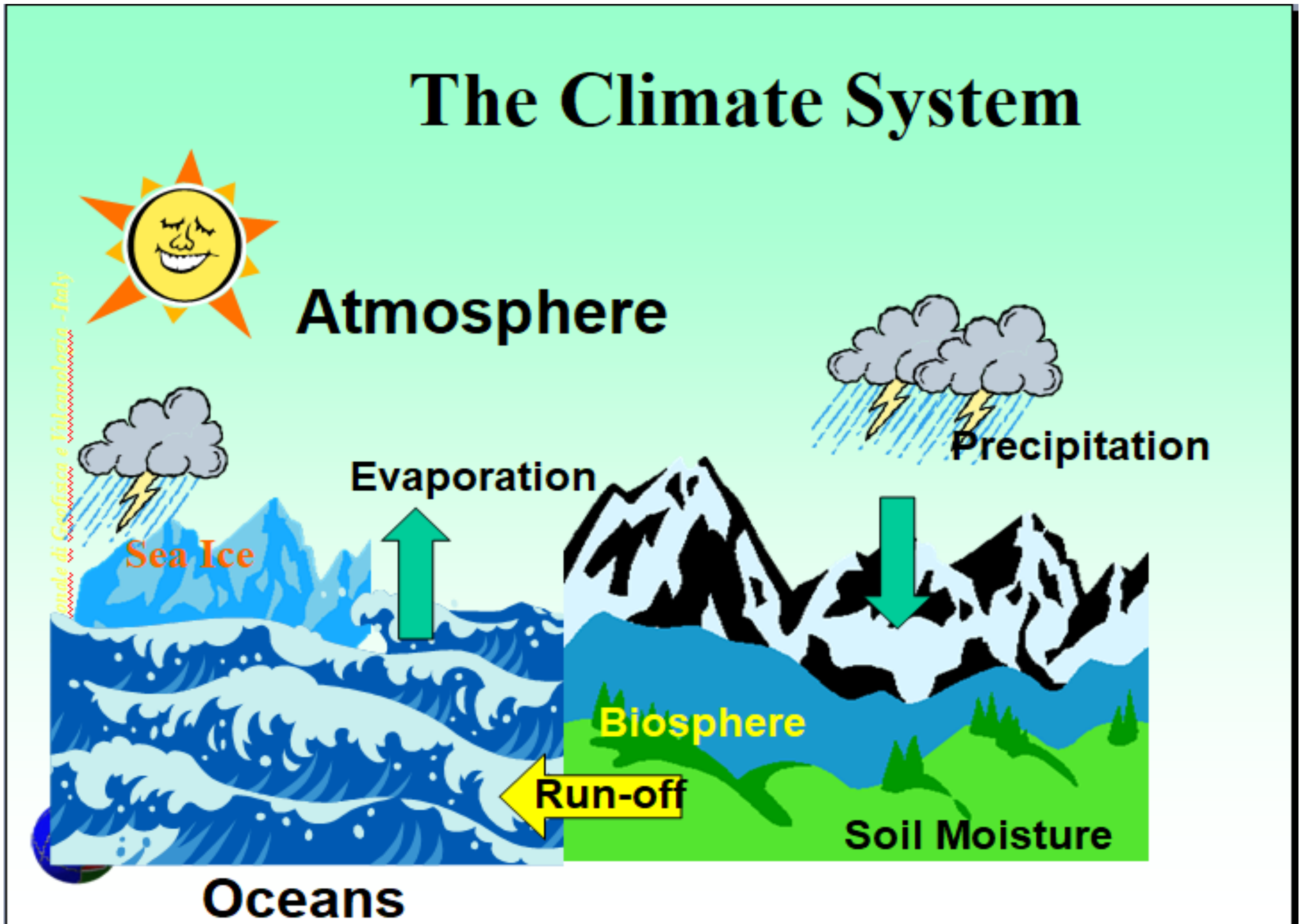
1. Variable spatial/temporal scales



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?