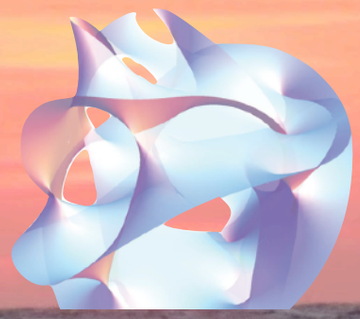
October 4, 2021

A Journey from String Theory to Physical Oceanography



Alex Kinsella

Woods Hole Oceanographic Institution

Self-Introduction

1. Grew up in Novato, CA

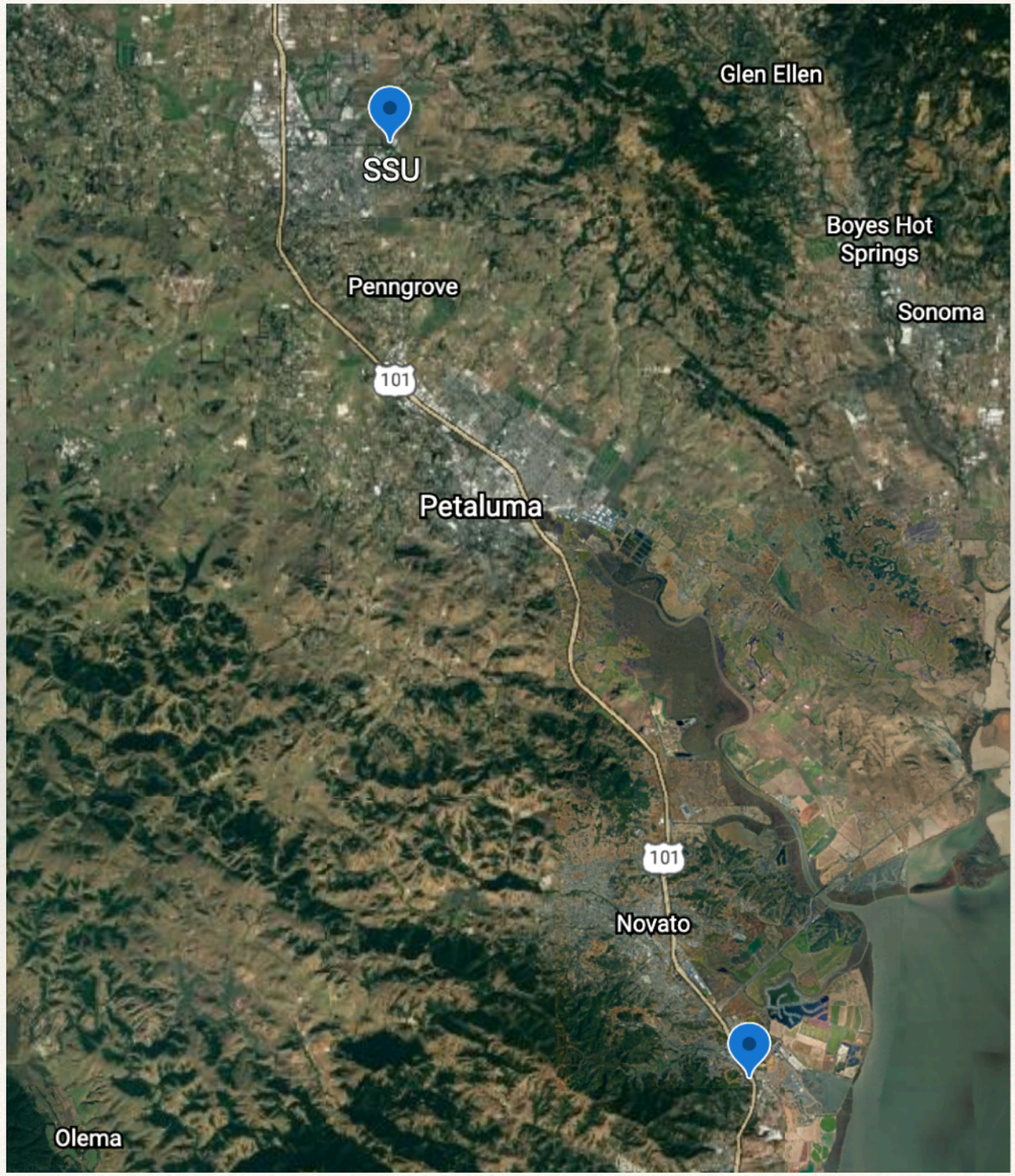


Image from Google Earth

Self-Introduction

2. PhD in physics in Santa Barbara

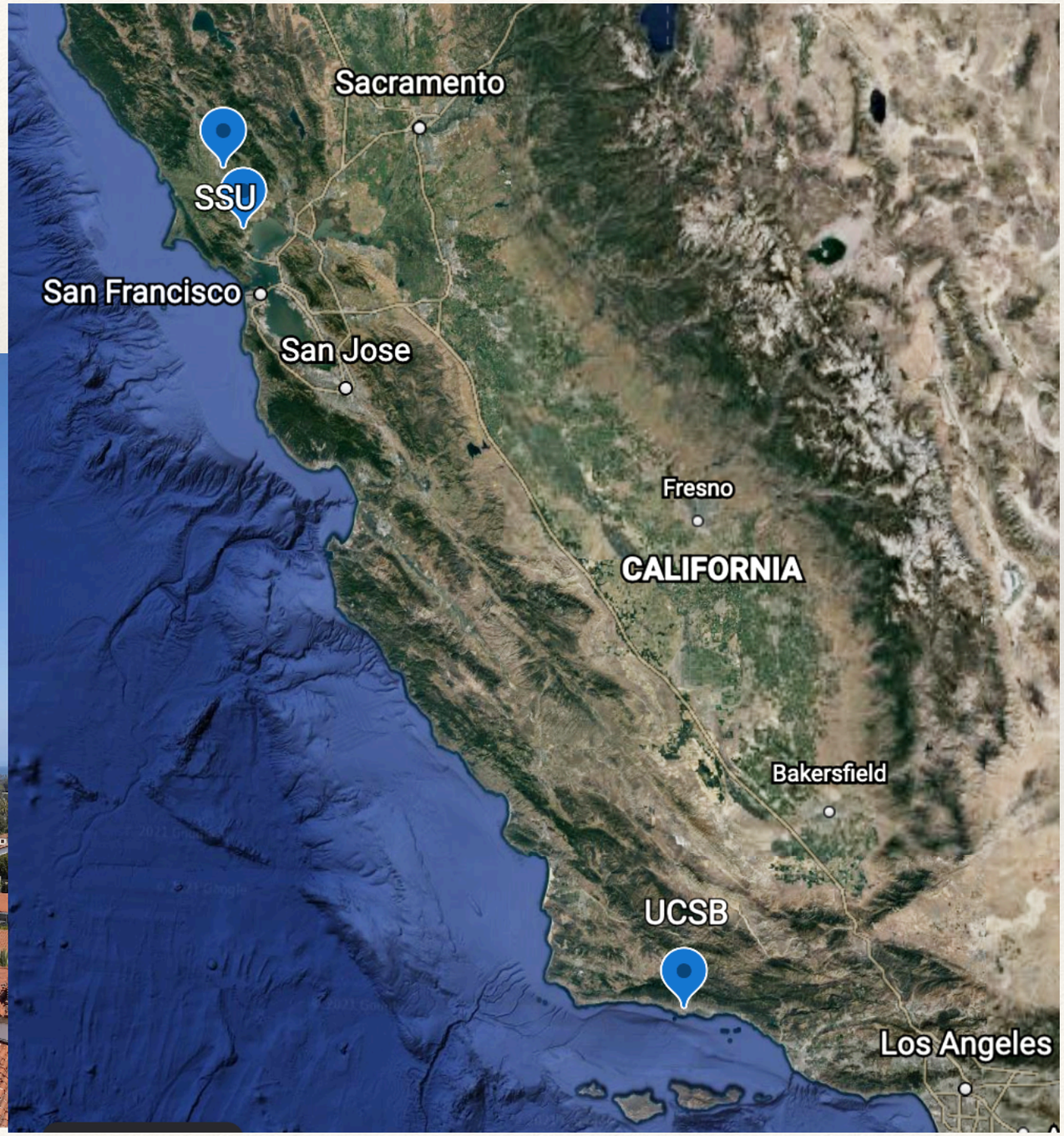


Image from Google Earth

Self-Introduction

3: Postdoc in physical oceanography in Woods Hole, Cape Cod, MA

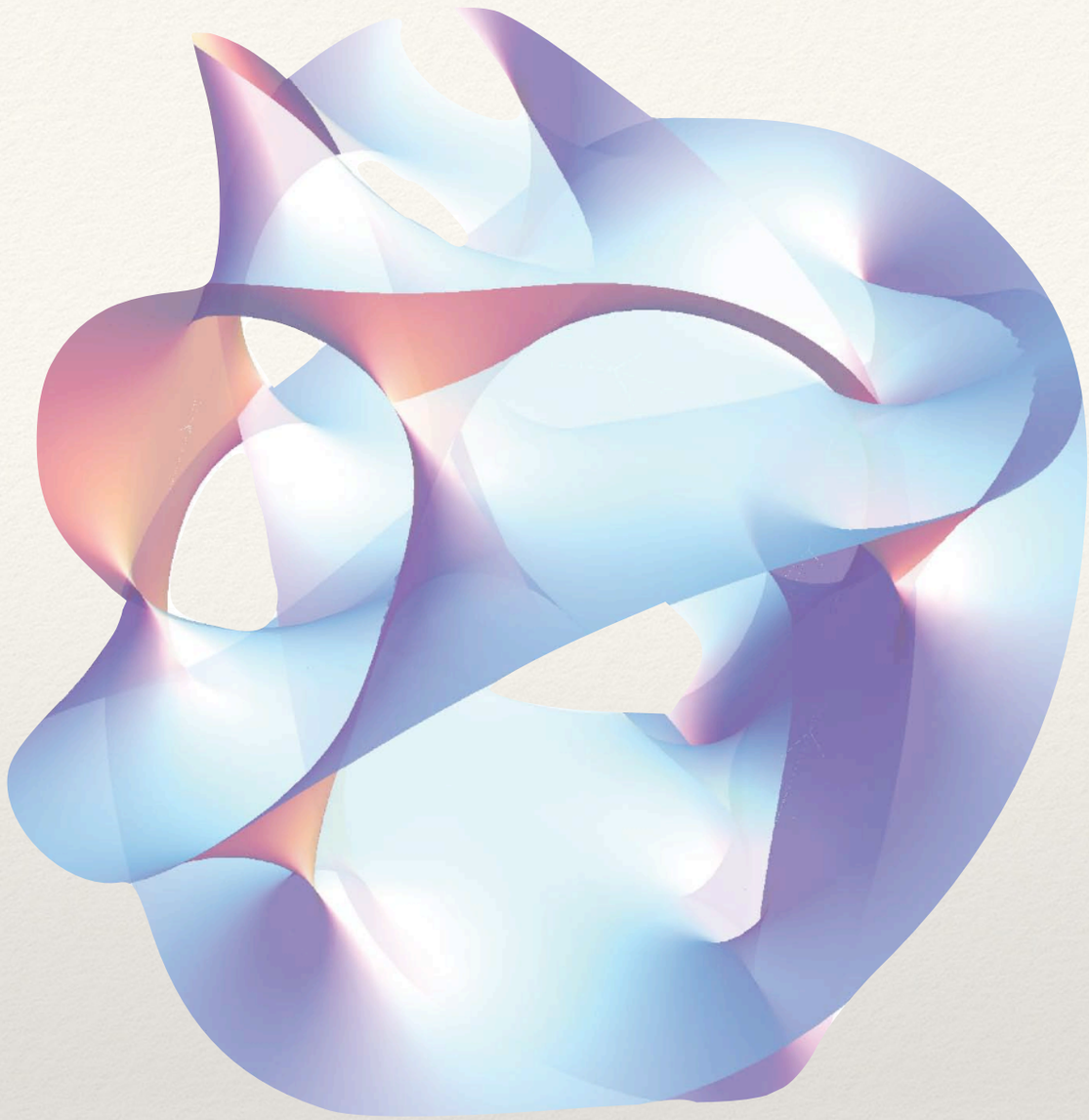
Image from Google Earth

Plan

1) String Theory: Geometry and Dualities

2) Physical Oceanography: The Indian Monsoon

3) A Common Thread: Finding the “Right Concepts”

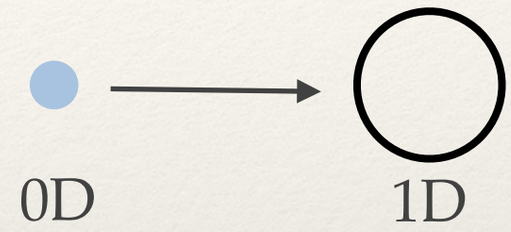


1) String Theory: Geometry and Dualities

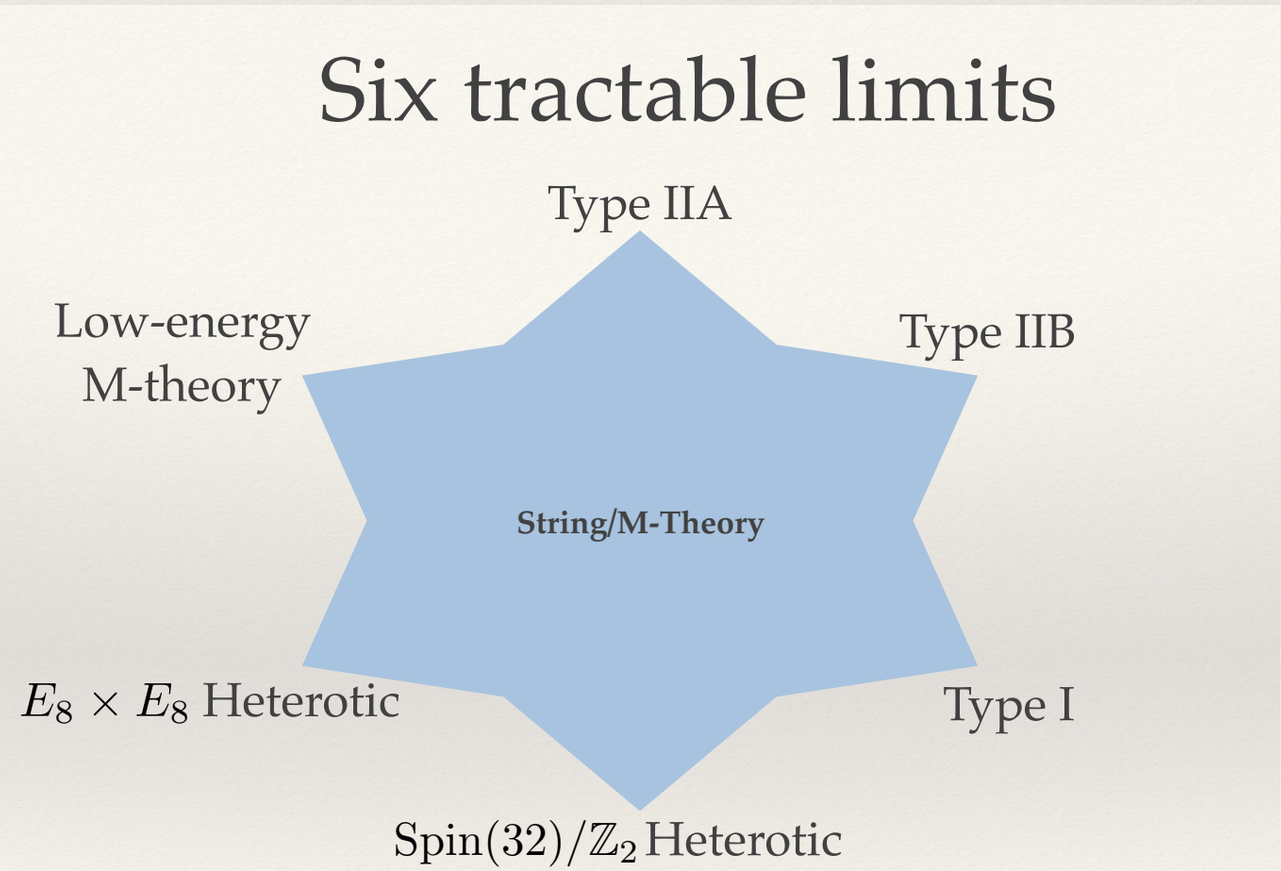
In collaboration with David Morrison (UC Santa Barbara), Bobby Acharya (ICTP & Kings College), and Eirik Eik Svanes (University of Stavanger)

What Is String Theory?

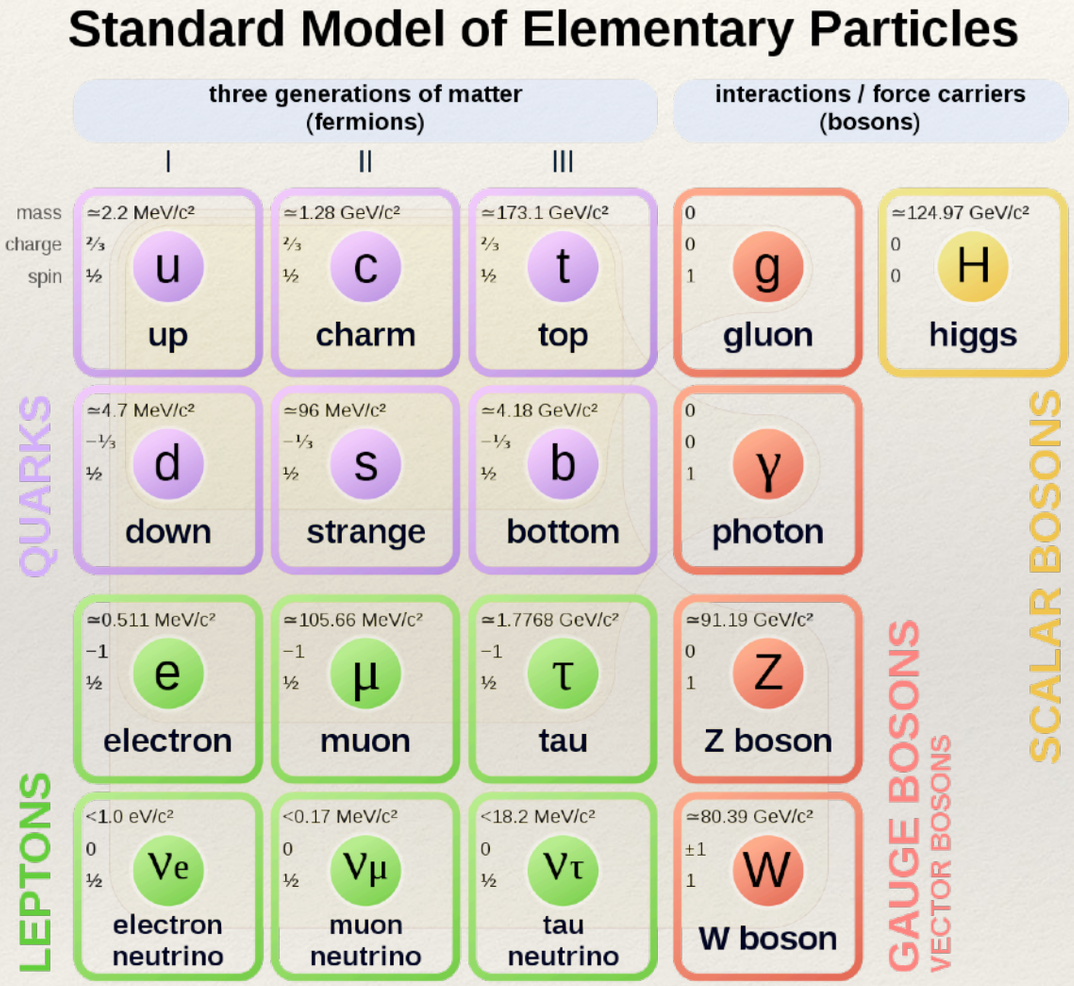
- Idea: Instead of 0D point-particles, take fundamental object to be an infinitesimal 1D string



- Consequences:
  - 10 or 11 spacetime dimensions
  - Supersymmetry
  - Not only 1D objects — all from 0D to 9D

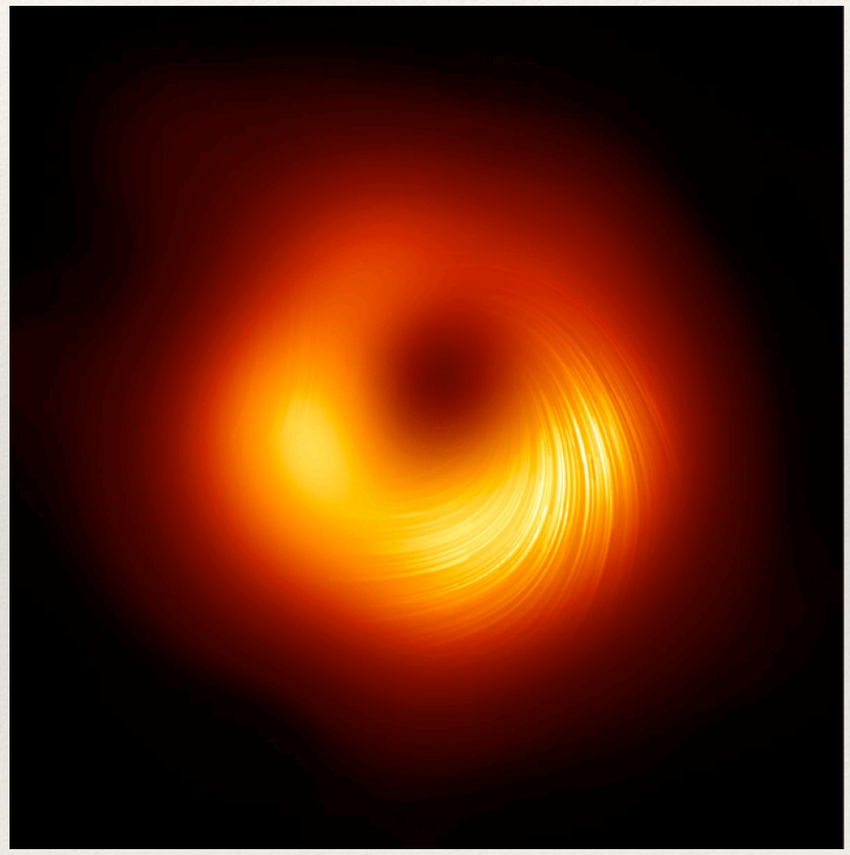


Why String Theory?



+

“Graviton”



M87 from the Event Horizon Telescope

The big challenge: Find a solution with these particles and *only* these particles: “string phenomenology”

Compactification

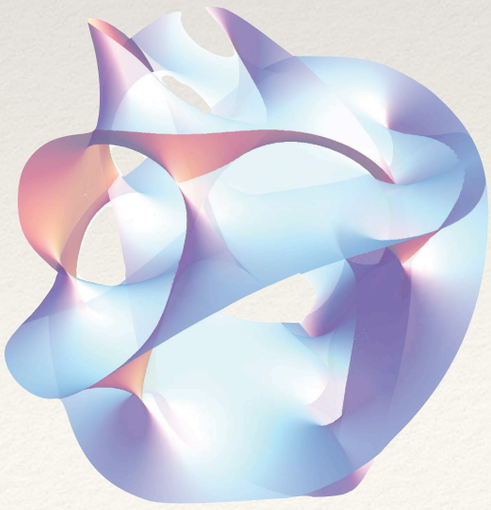
- Insight(?): What if the extra dimensions are small and curled up?

$$X^{9,1} = M^{3,1} \times Y^6$$

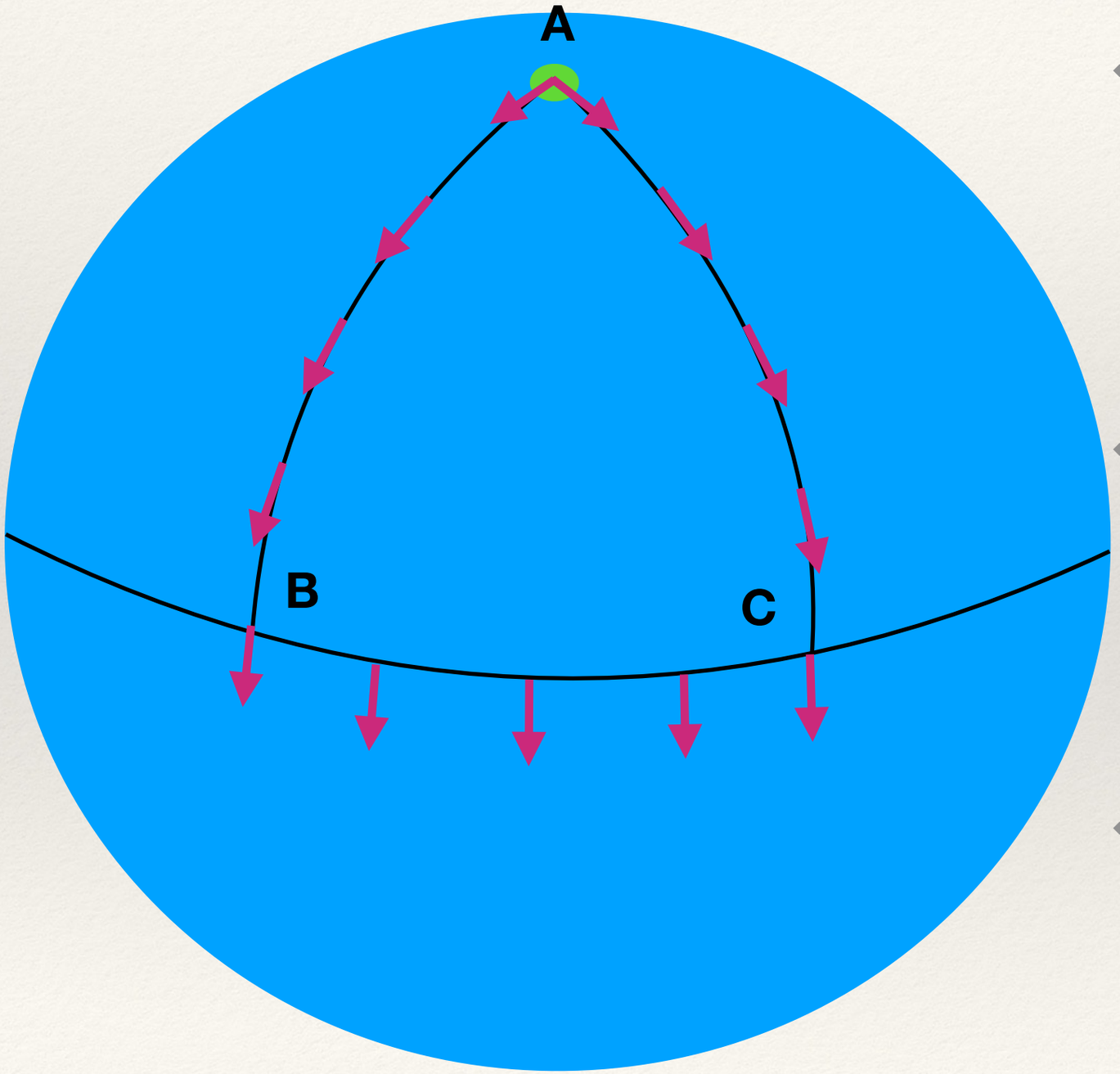
10D spacetime where strings live

4D spacetime that we see

6D "internal" space of *special holonomy*



What Is Holonomy?



- Generic holonomy: all rotations are possible
- Special holonomy: only certain rotations are possible
- Required for string theory by supersymmetry

Spaces of Special Holonomy

- <4 dimensions: Flat space

- 4 dimensions: K3 surface

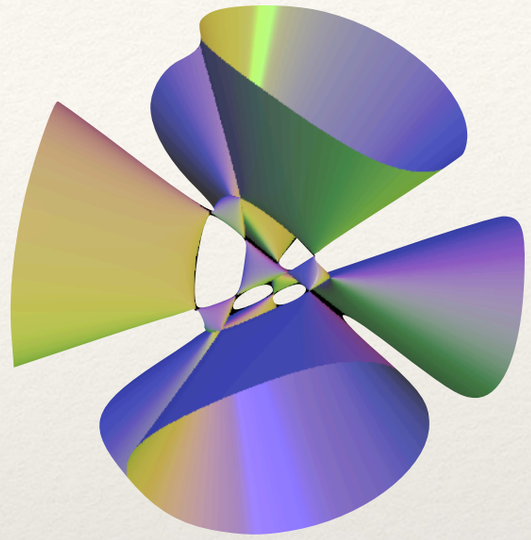
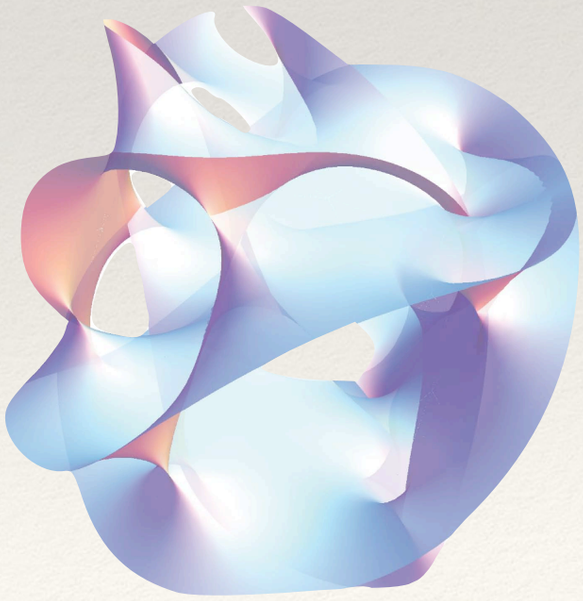


Image from Virtual Math Museum

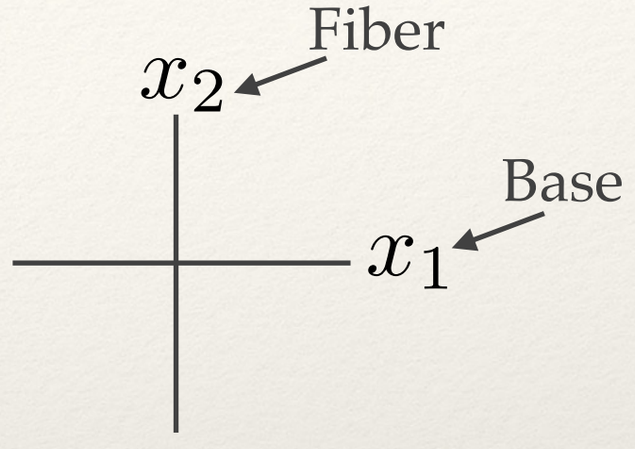
- 6 dimensions: Calabi-Yau threefold

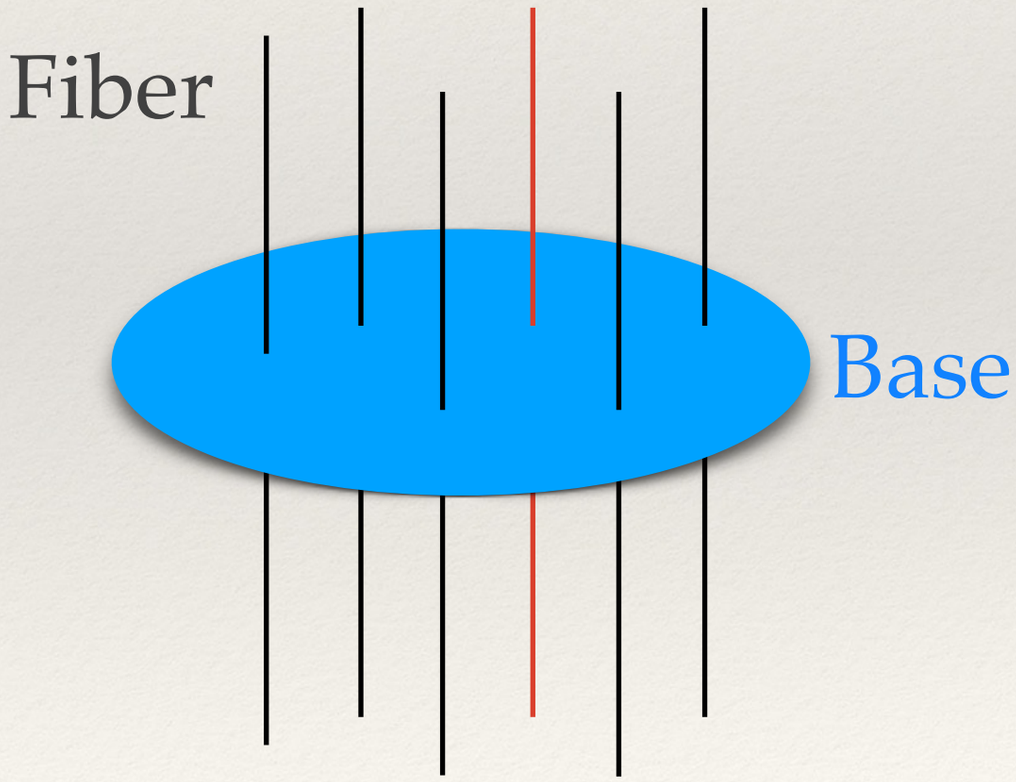


- 7 dimensions: G_2 manifold

Fibrations

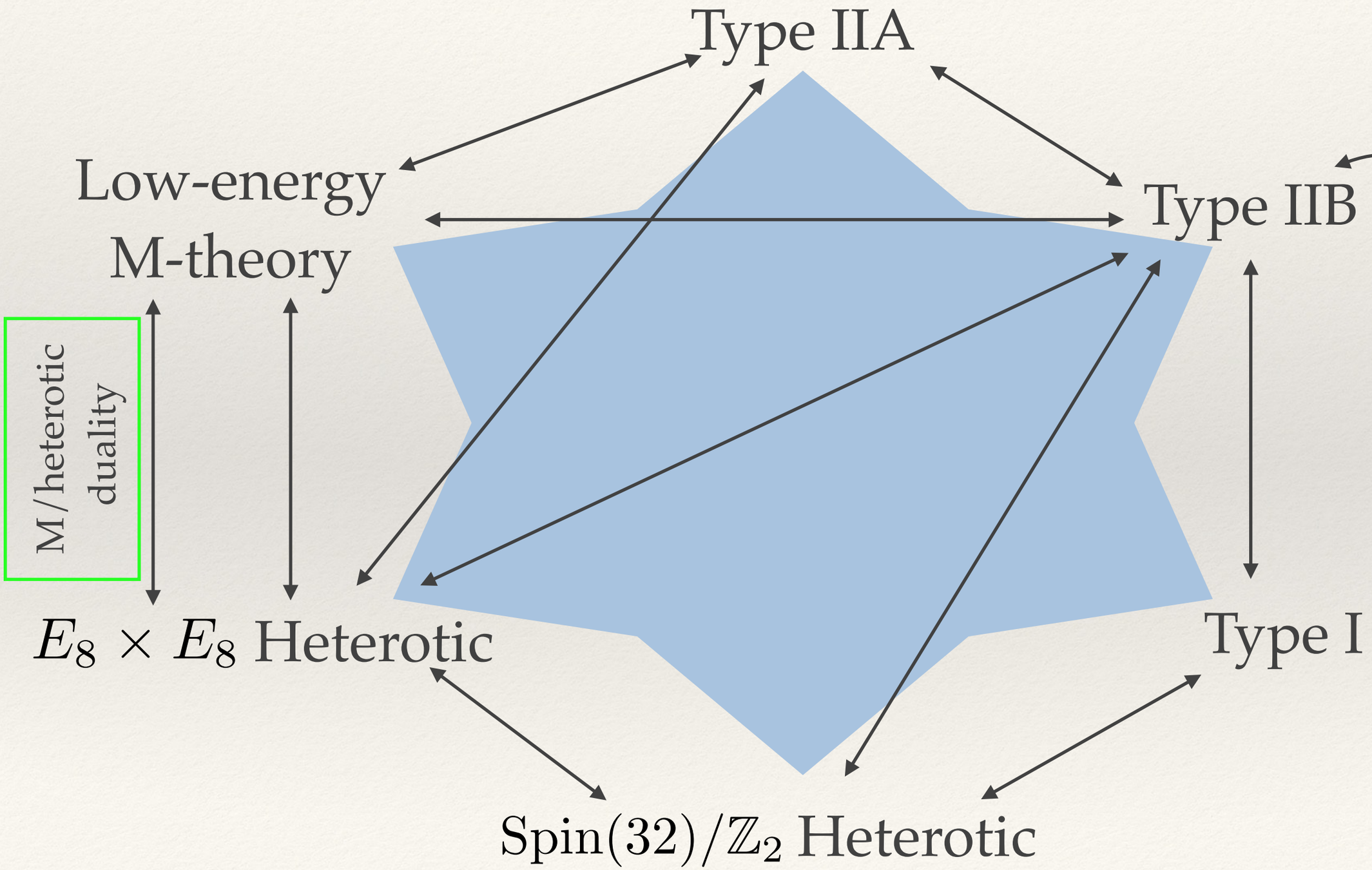
Generalize the product space $X_1 \times X_2$





Singular fiber

String/M Dualities

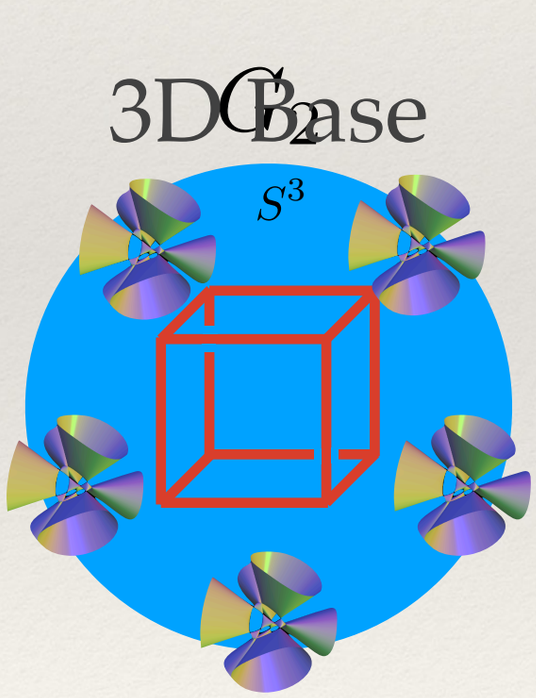


M-Theory/Heterotic Duality

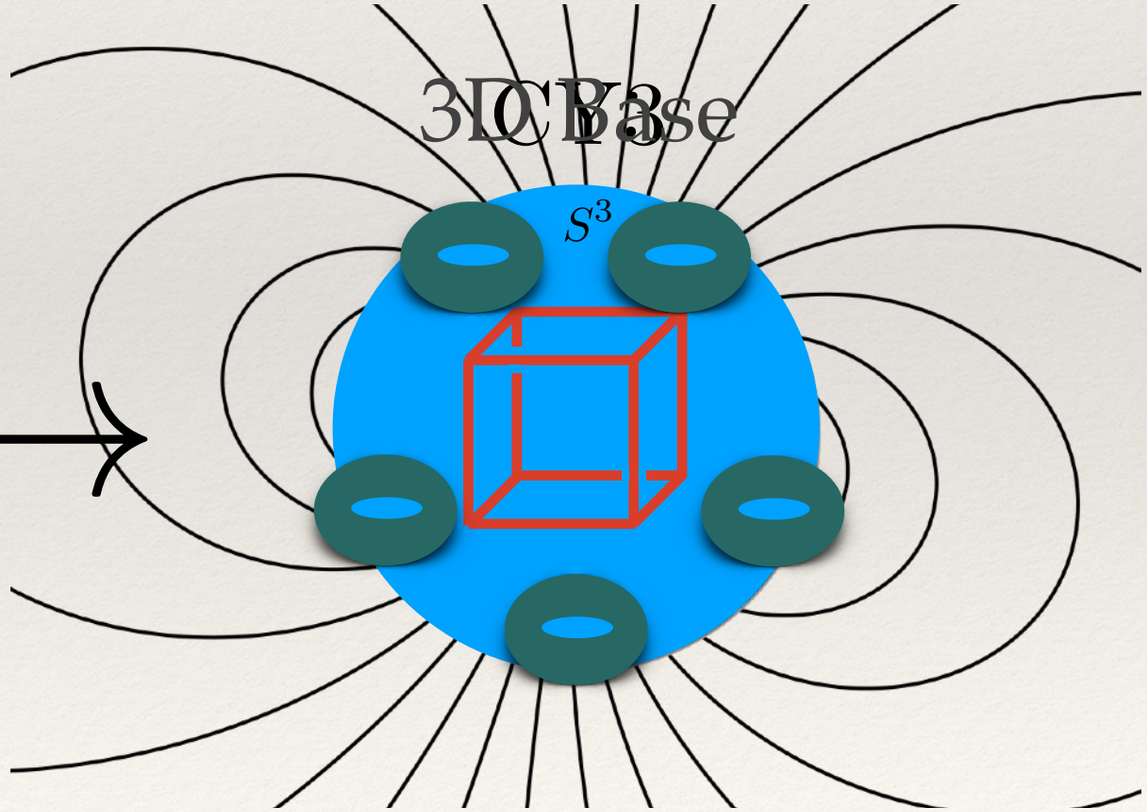
M-Theory on a 7D G_2-space

$\longleftrightarrow$

$E_8 \times E_8$ Heterotic string on a 6D Calabi-Yau space with special fields



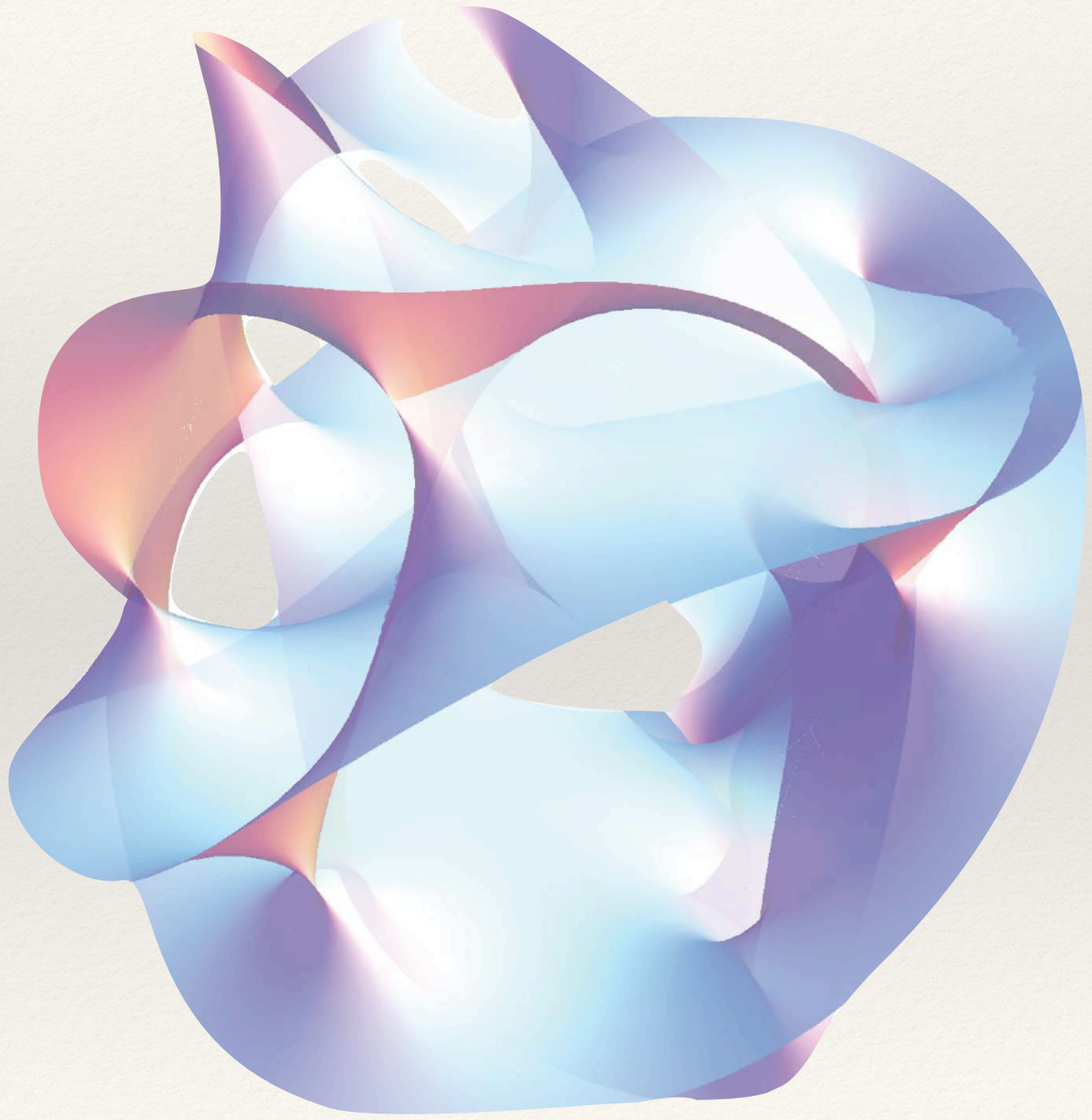
$\longleftrightarrow$



Entirely geometric (7D)

Geometry (6D) + fluxes

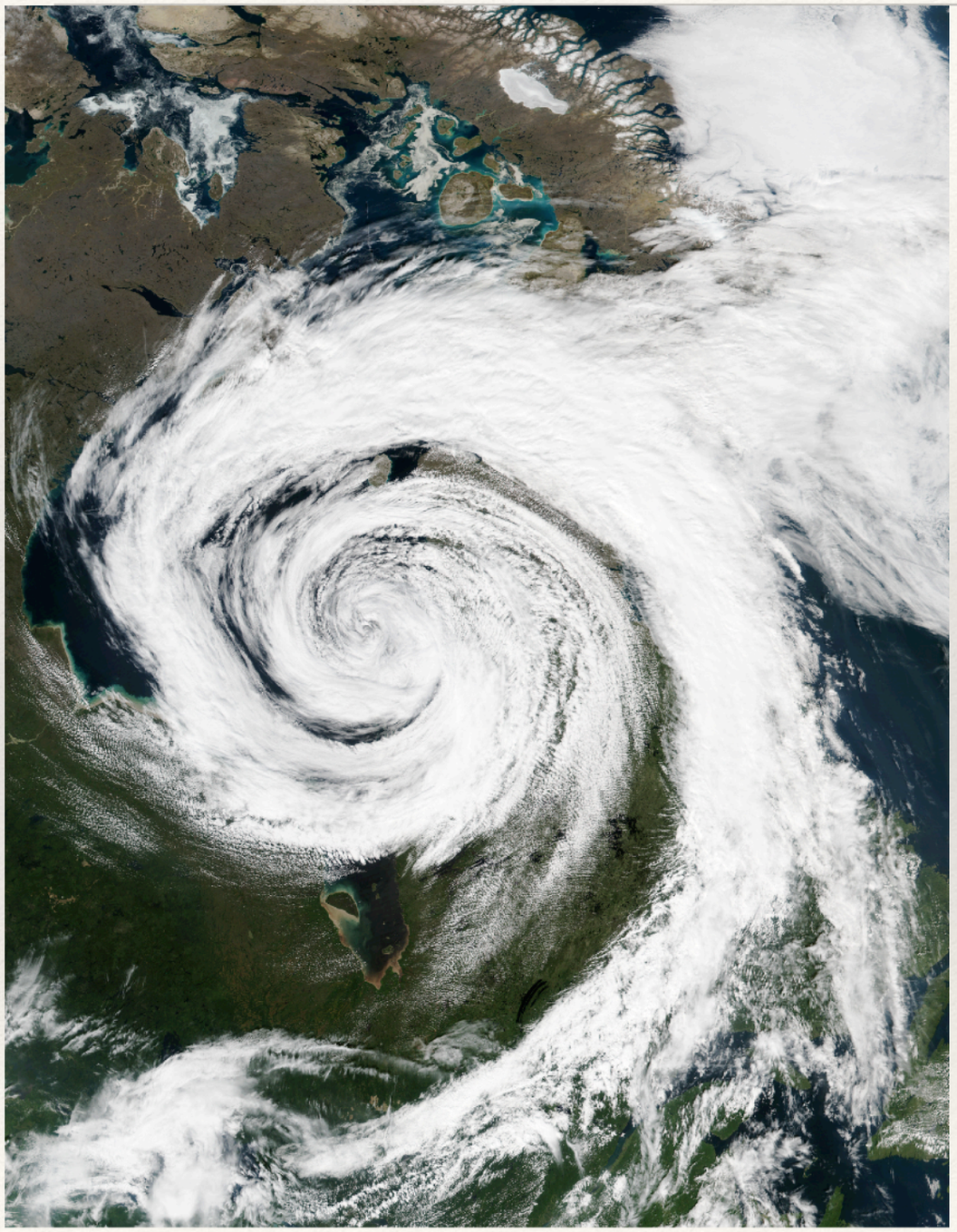
Motivation Redux



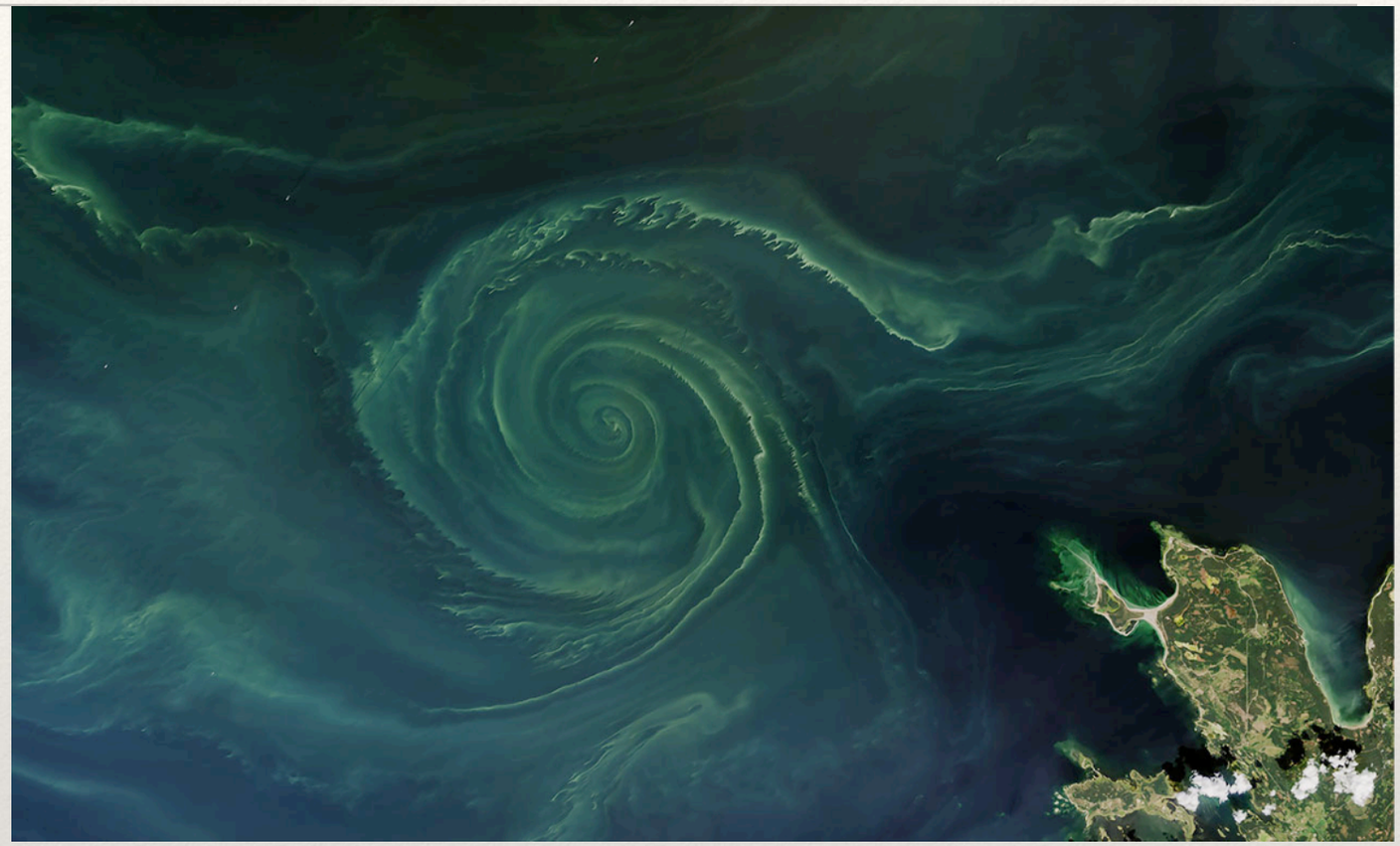
2) Physical Oceanography: The Indian Monsoon

In collaboration with Amala Mahadevan (WHOI)

Oceans and Atmospheres: Geophysical Fluids



Images from NASA Earth Observatory



Mathematically the same! But:

- Atmosphere is 1000x less dense
- Atmosphere is heated from below
- Water can change phase in the atmosphere

Oceans and Atmospheres: Geophysical Fluids

- Rotating: E.g. the "Ekman spiral"

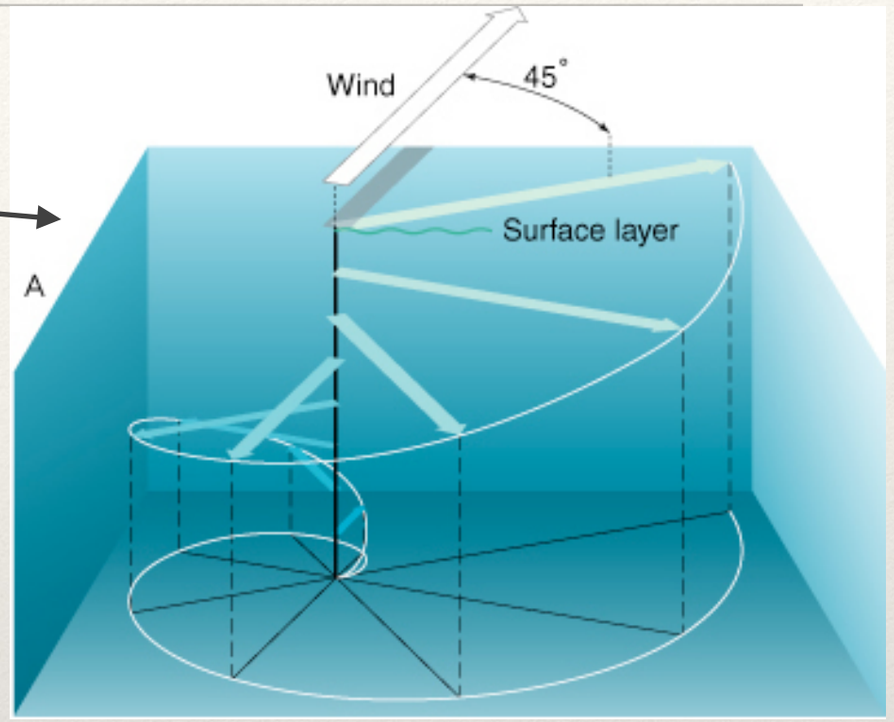


Image from NASA

- Stratified:

- Turbulent:

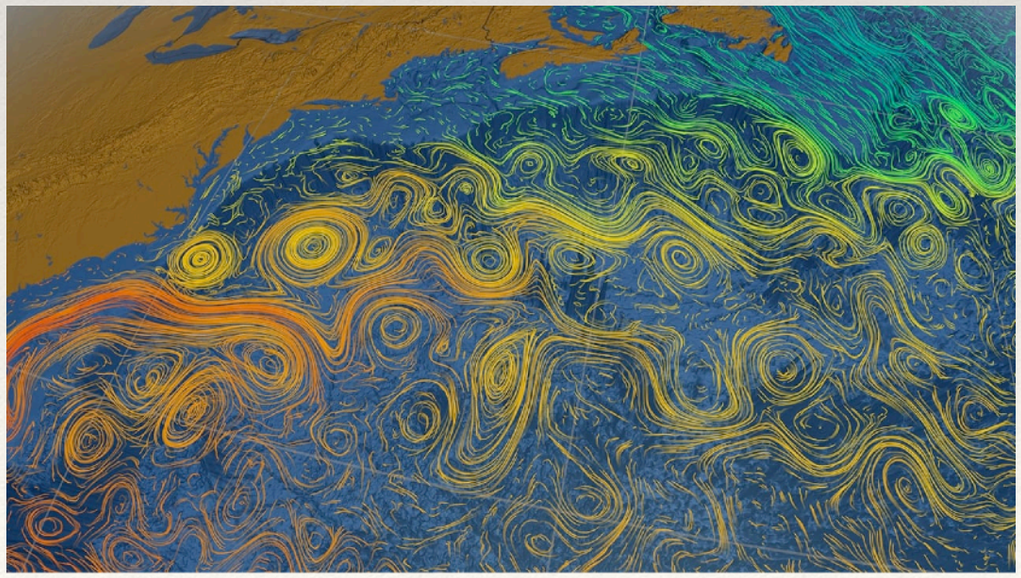


Image from WHOI

"Turbulent energy cascade"

The Global Ocean

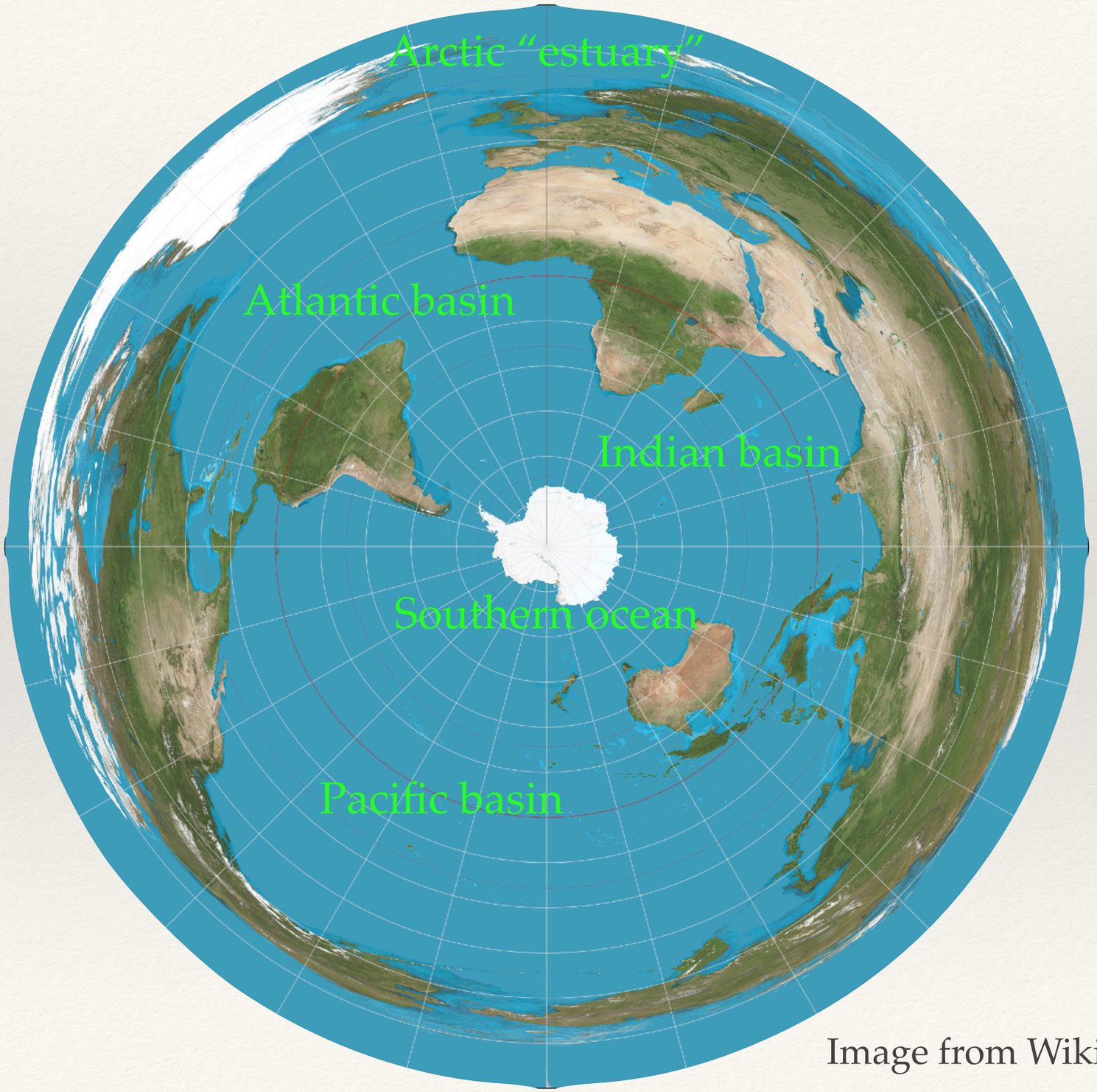
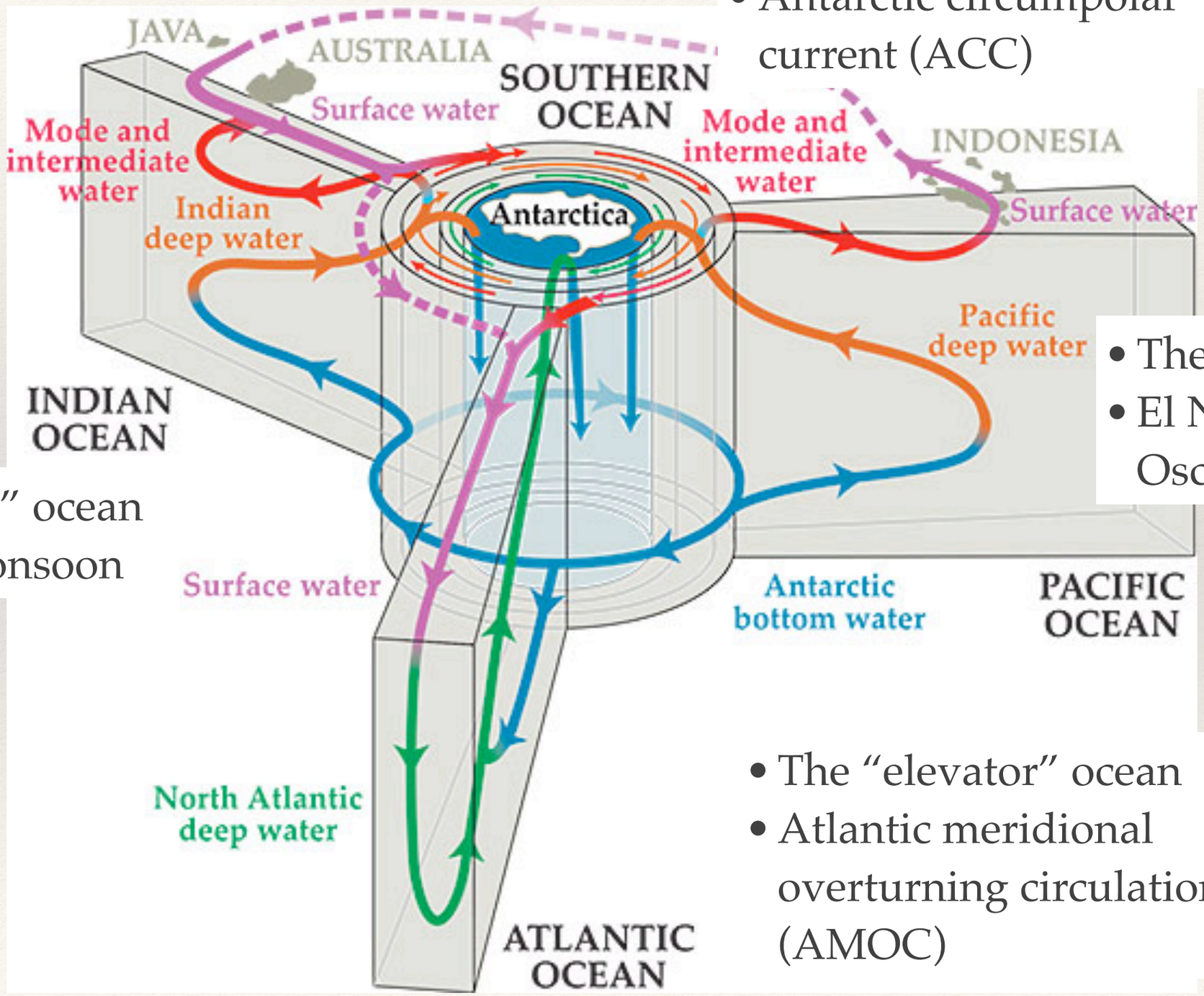


Image from Wikimedia user Strebe

Global Ocean Circulation

- The "heart" of the ocean
- Antarctic circumpolar current (ACC)



- The "big" ocean
- El Niño/Southern Oscillation (ENSO)

- The "land" ocean
- Indian monsoon

- The "elevator" ocean
- Atlantic meridional overturning circulation (AMOC)

Figure from Morrison et al. (2015), adapted from Talley (2013)

The Indian Ocean

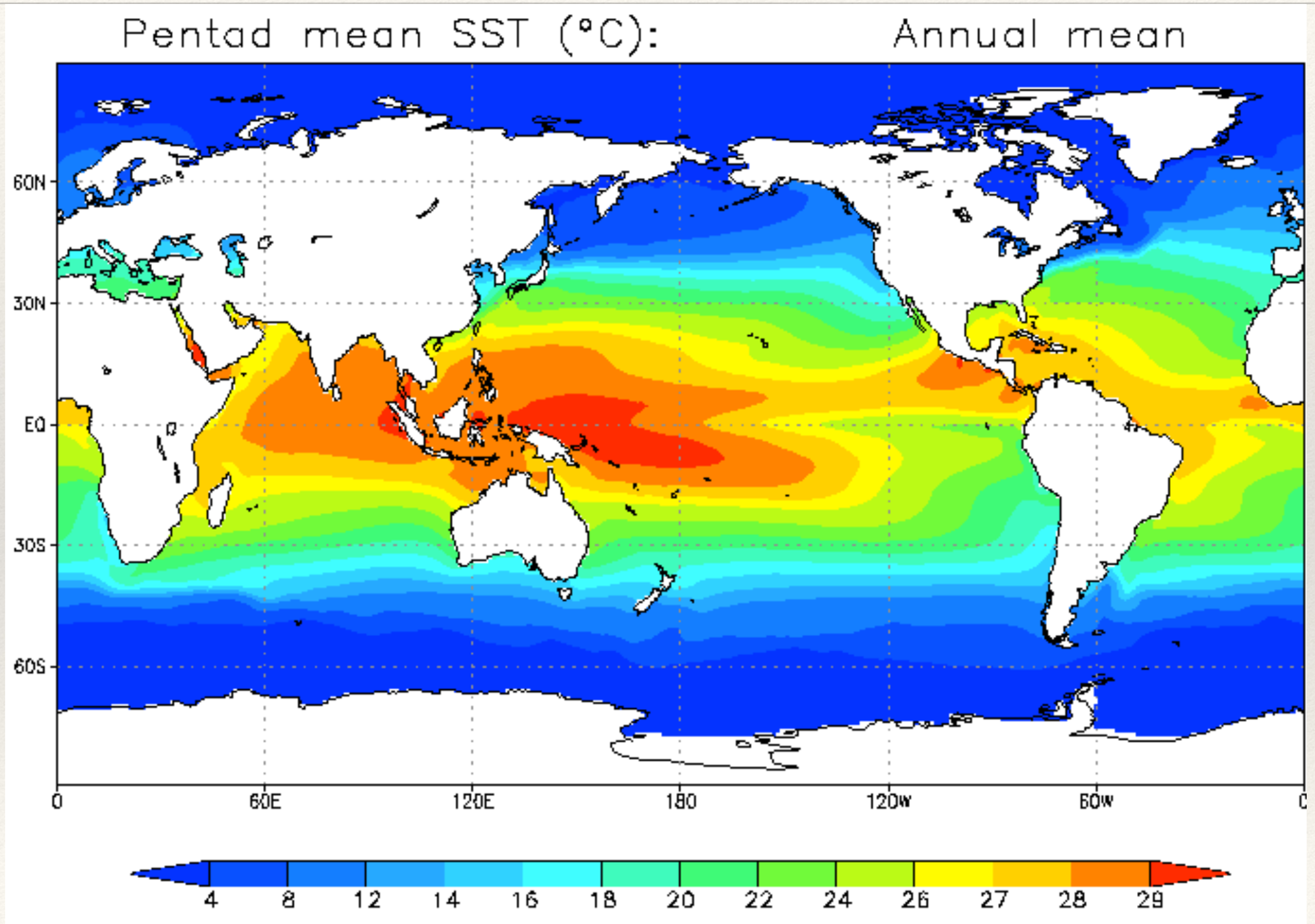
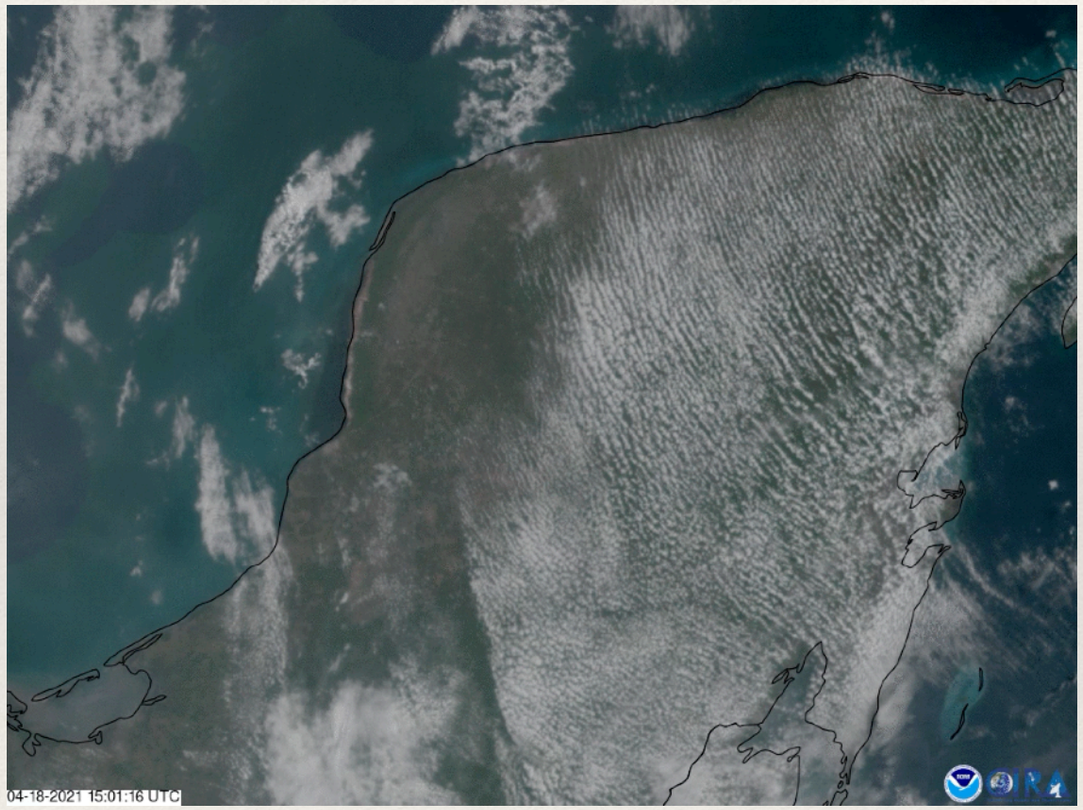


Figure from NOAA Climate Prediction Center

The Indian Ocean

The Indian Monsoon: First Description

- Seasonally-reversing winds create sea/land breezes



A Yucatán sea breeze
(from CIRA Loop of the Day)

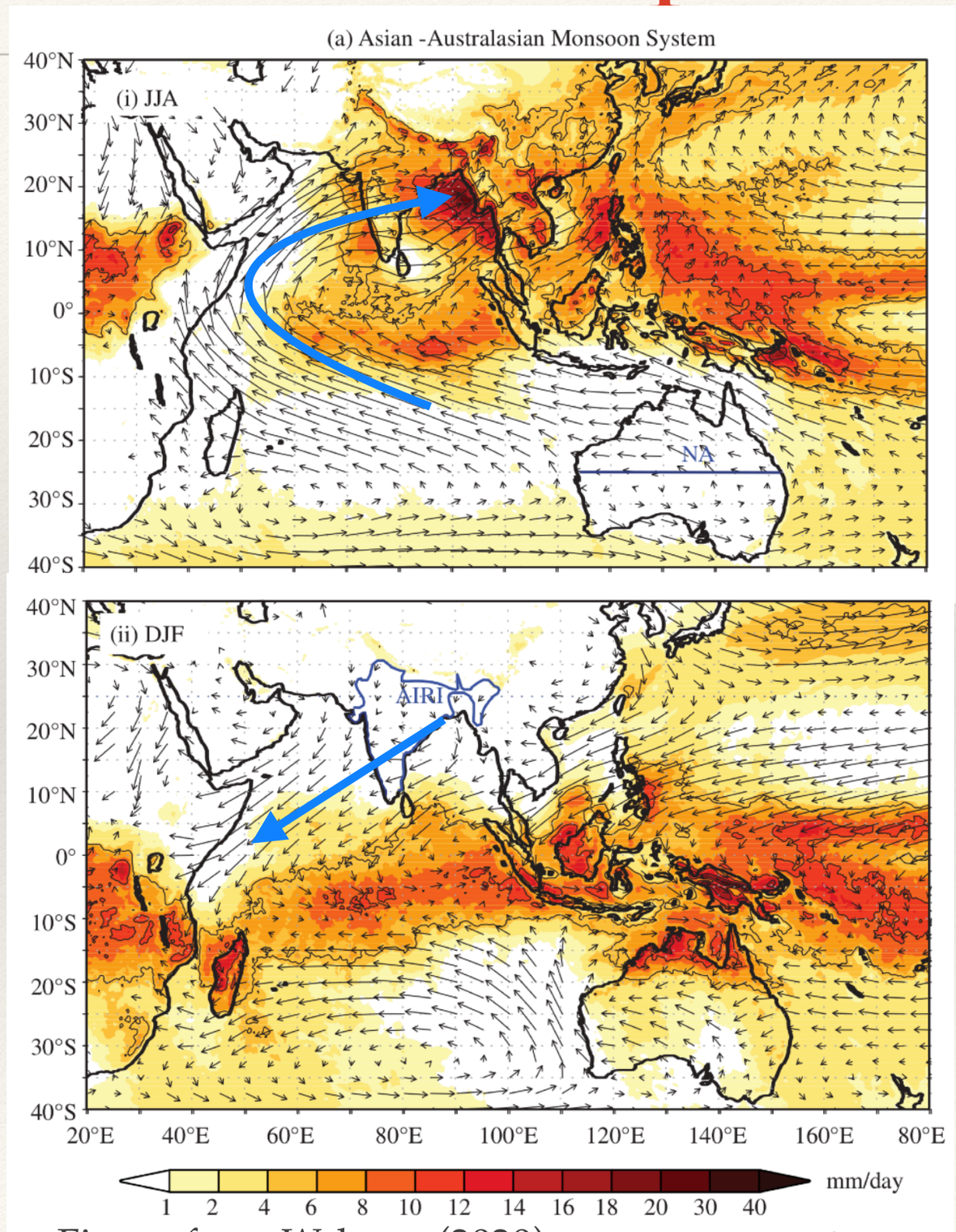


Figure from Webster (2020)

The Indian Monsoon: Second Description

The monsoon transfers energy aloft from the summer hemisphere to the winter hemisphere

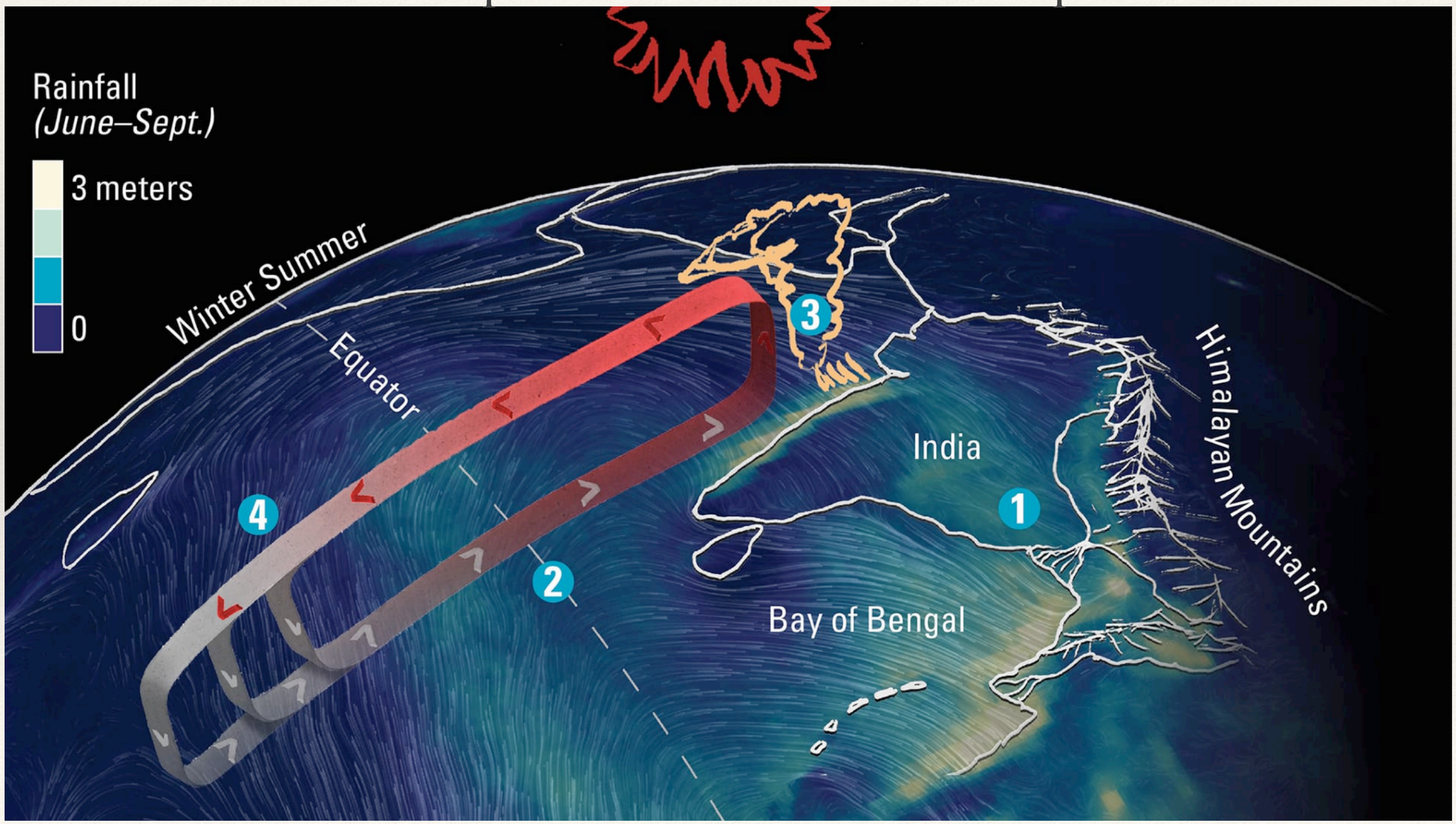


Figure by Gualtiero Spiro Jaeger

Ocean Profiles and the Mixed Layer

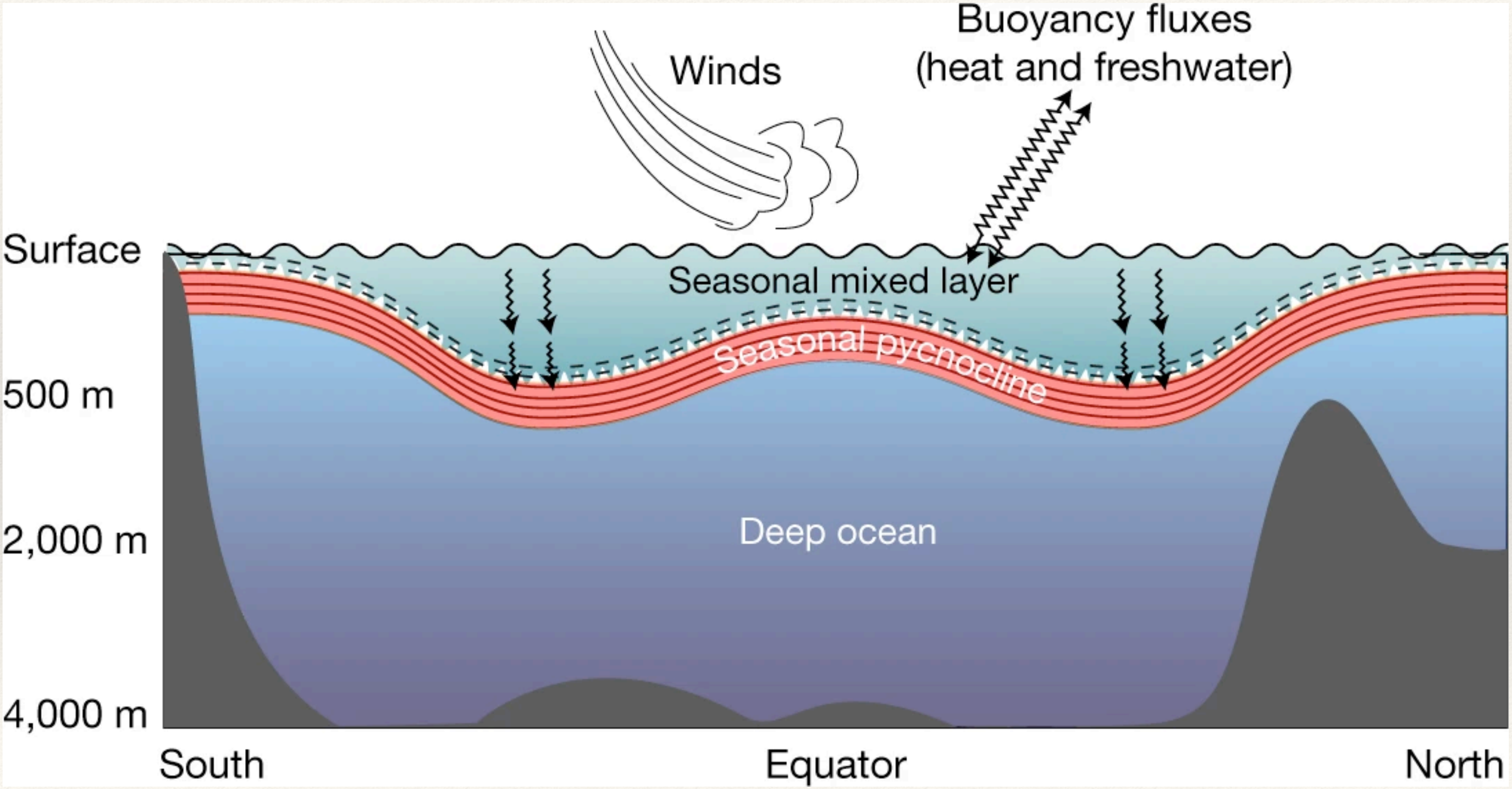
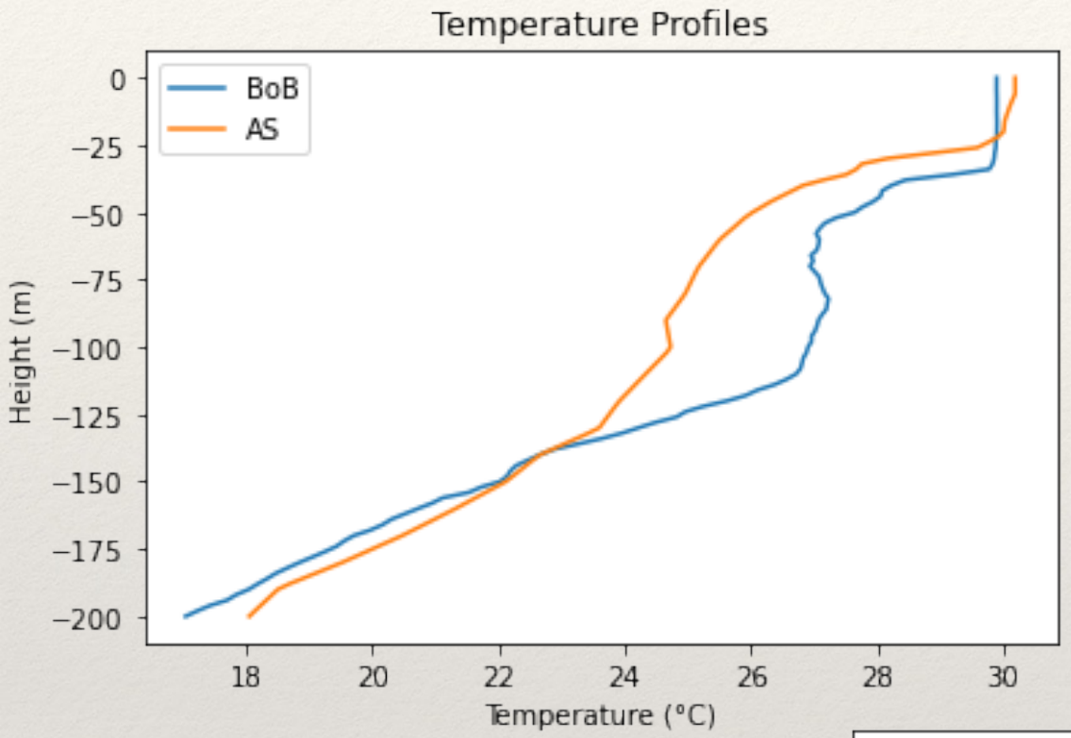
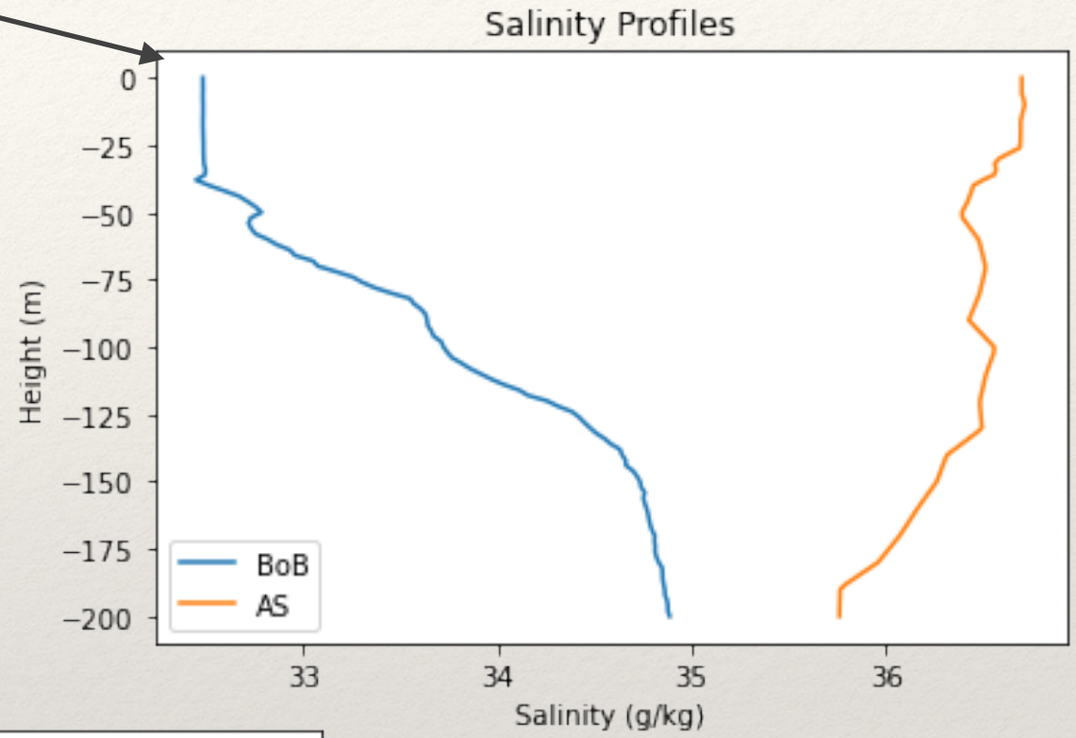


Figure from Sallée et al. (2021)

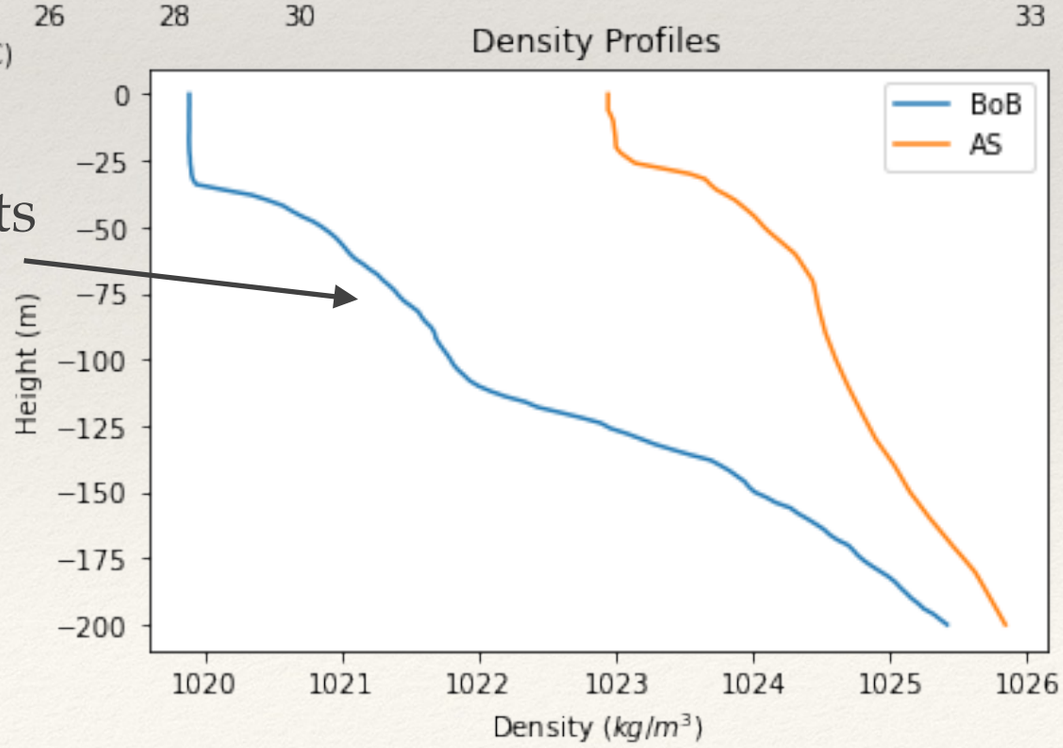
Ocean Profiles and the Mixed Layer

Bay of Bengal is fresh at the surface

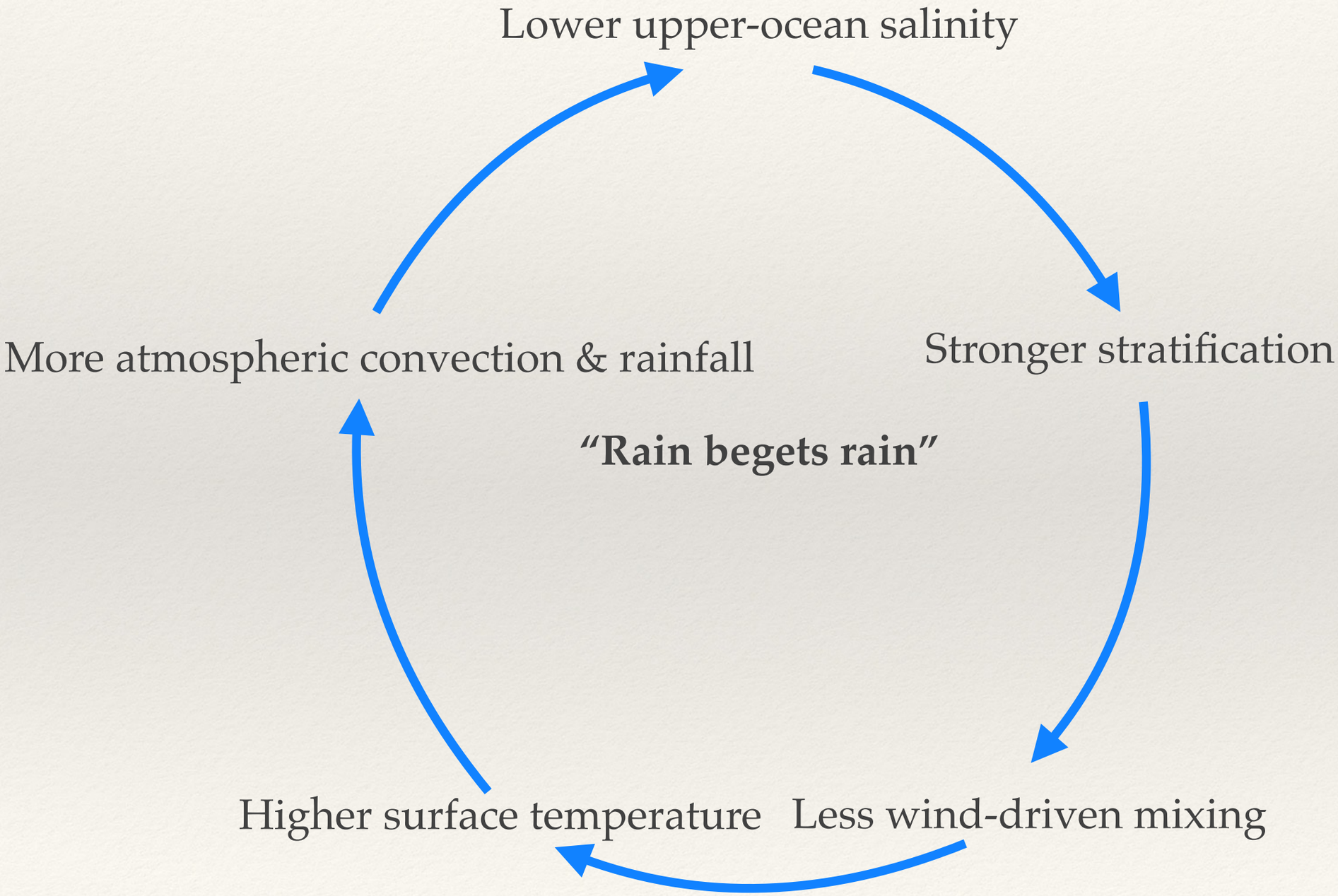




Higher stratification resists mixing by strong winds



Salinity-Rainfall Feedback Hypothesis



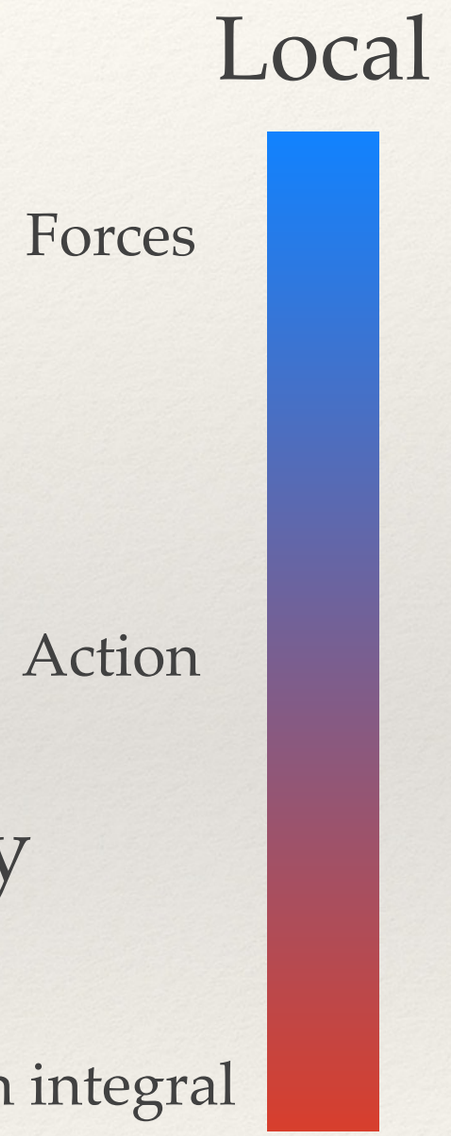
3) A Common Thread: Finding the "Right" Concepts

Example: Mechanics

1) Objects follow Newton's laws of motion

2) Objects follow the path of least action

3) Objects take all possible paths, but we see only the ones of least action



Refining String Theory

1) It's a theory of 1D strings propagating in spacetime

2) It's a theory of the geometry of an internal space that controls our visible particles

3) It's a theory of interacting extended objects of various dimensions whose internal dynamics generate spacetime

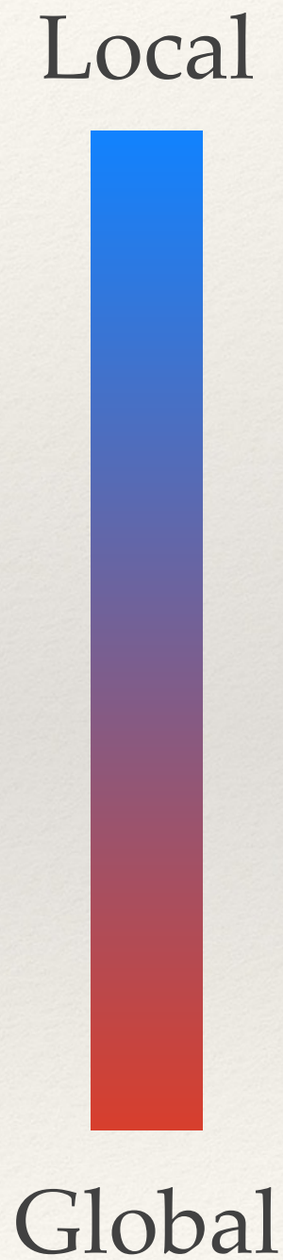
4) ?

Refining the Indian Monsoon

1) It's a giant sea breeze

2) It's an engine that transfers excess heat from the summer to the winter hemisphere in the Indian ocean

3) It's part of a global, annual mode of the coupled ocean/atmosphere system that localizes due to surface boundary conditions



See Geen et al. (2020) for more

Thank you!

alex.kinsella@whoi.edu

Example: Electromagnetism

1) Charged objects exert forces on one another

2) An electromagnetic field permeates the universe and interacts with charged particles, obeying Maxwell's equations

3) The electromagnetic field defines (part of) a derivative on a geometric structure that lives over spacetime