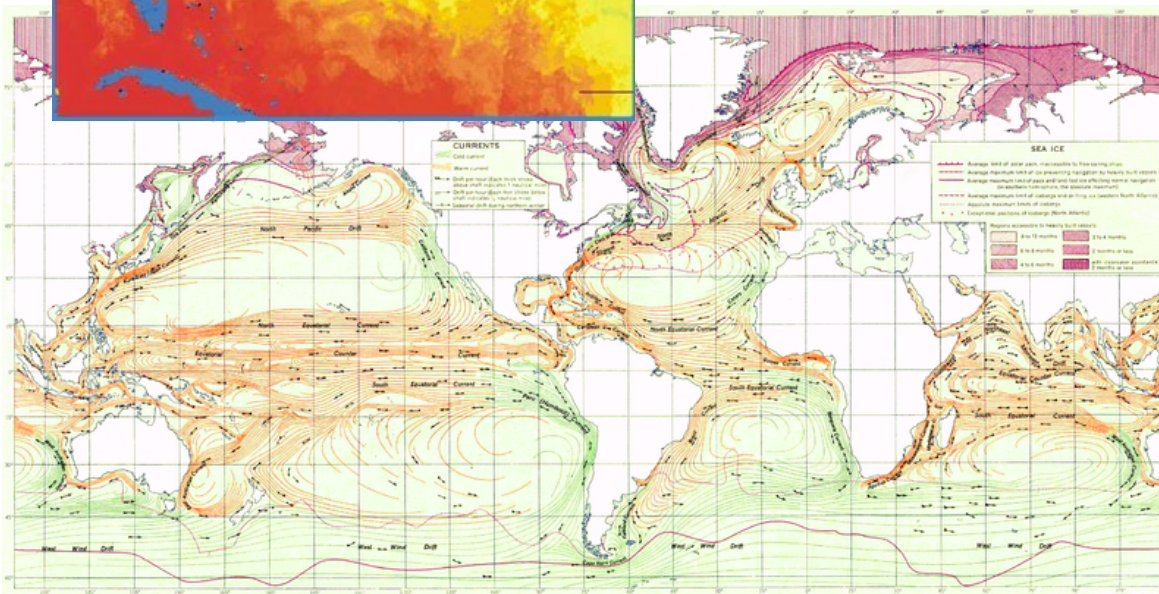
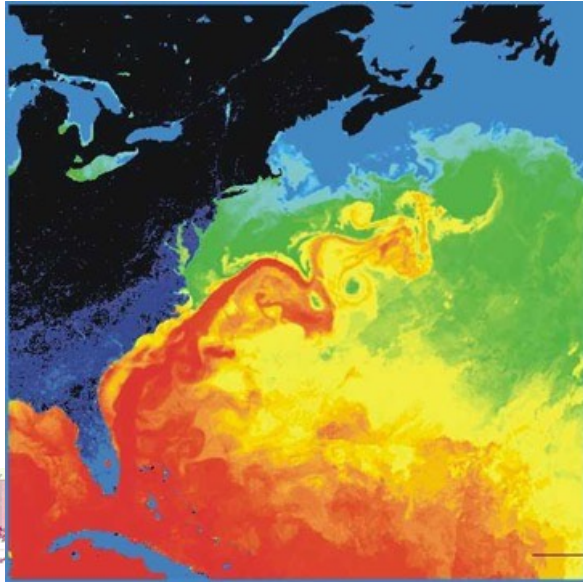




3. Η κυκλοφορία στον παγκόσμιο ωκεανό

3. The restless world ocean (observing the oceanic circulation)



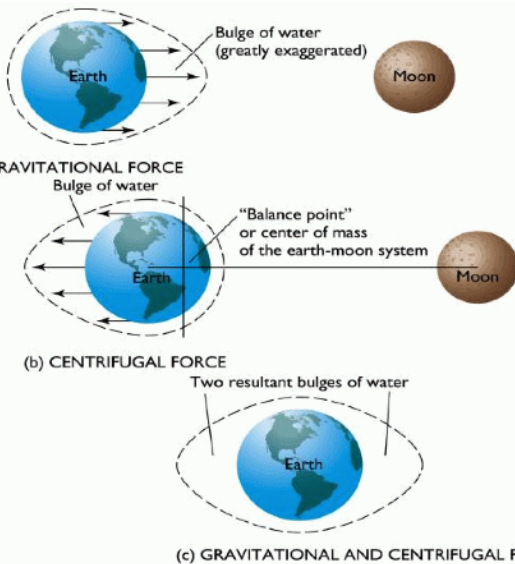
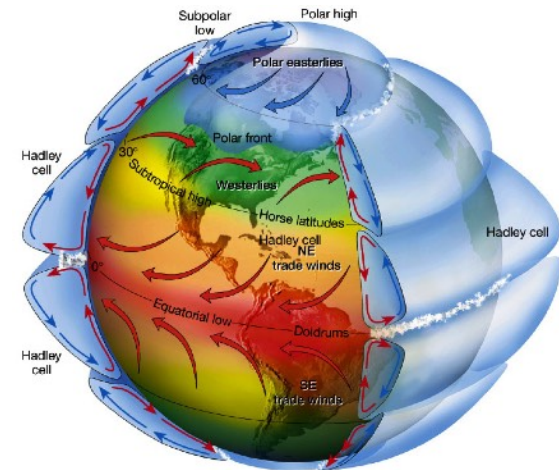
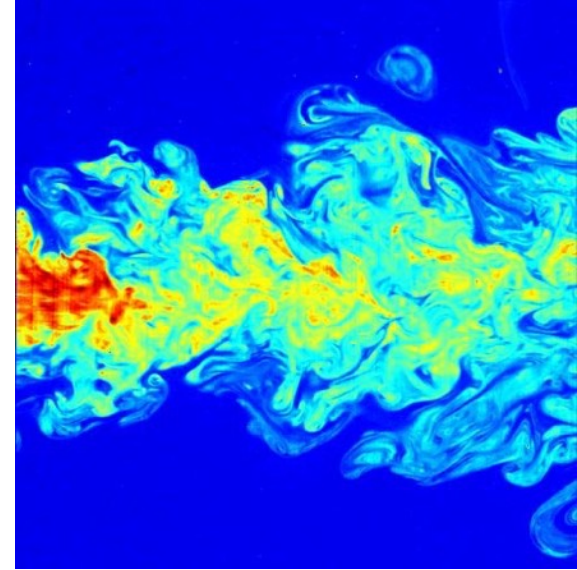
- a. Εξωτερικές επιδράσεις - Forcing mechanisms and the oceanic response
- b. Η δομή της επιφανειακής κυκλοφορίας - Circulation pattern of the oceans

Forcing Mechanisms

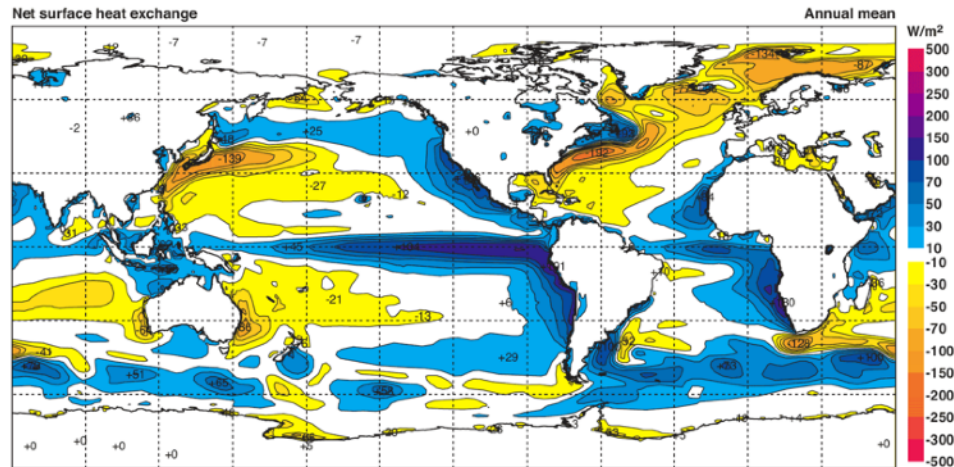
- Winds and Friction
- Heat Transfer
- Evaporation
- Precipitation
- River runoff
- Glacier formation/melting
- Astronomical forcing
- Ocean bottom changes

Ocean Response

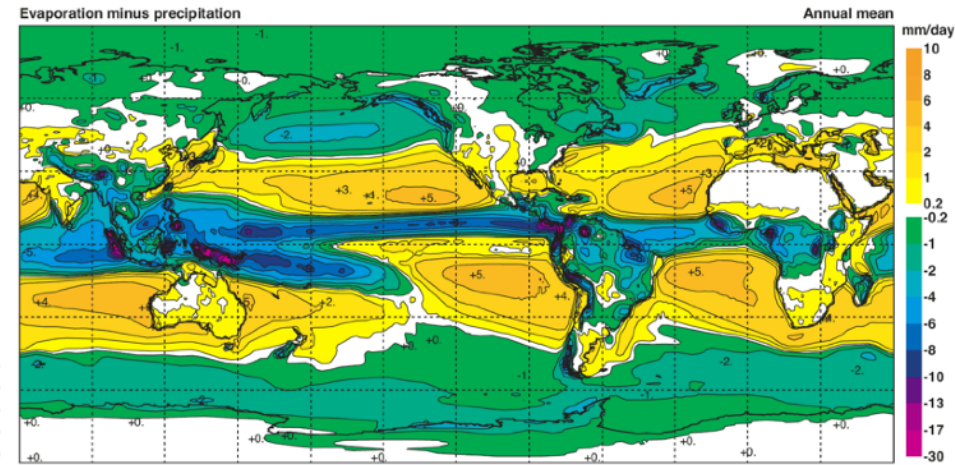
- a. Ocean Currents
- b. Wind waves
- c. Large scale waves
- d. Tides
- e. Internal waves
- f. Upwelling/downwelling
- g. Tsunamis
- h. Turbulence and mixing
- i.



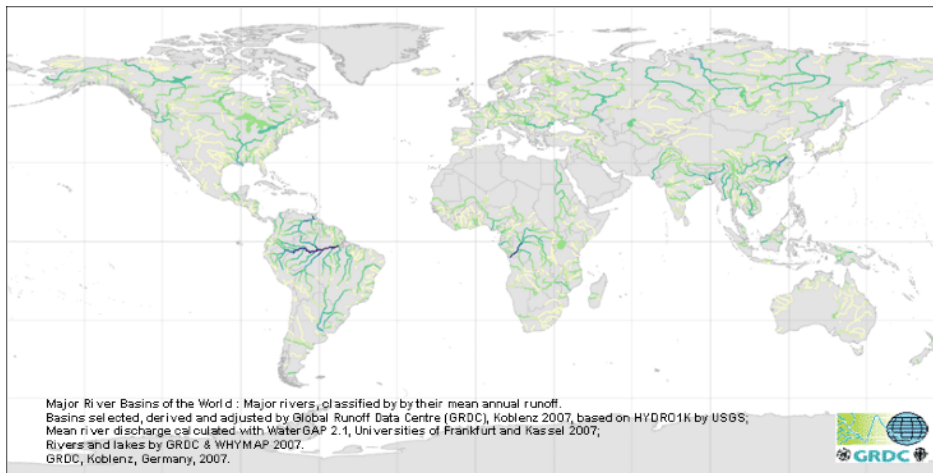
Global sea surface heat flux (Q_{NET})



Global sea surface evaporation-precipitation ($E-P$)



Global River Runoff (R)



Buoyancy

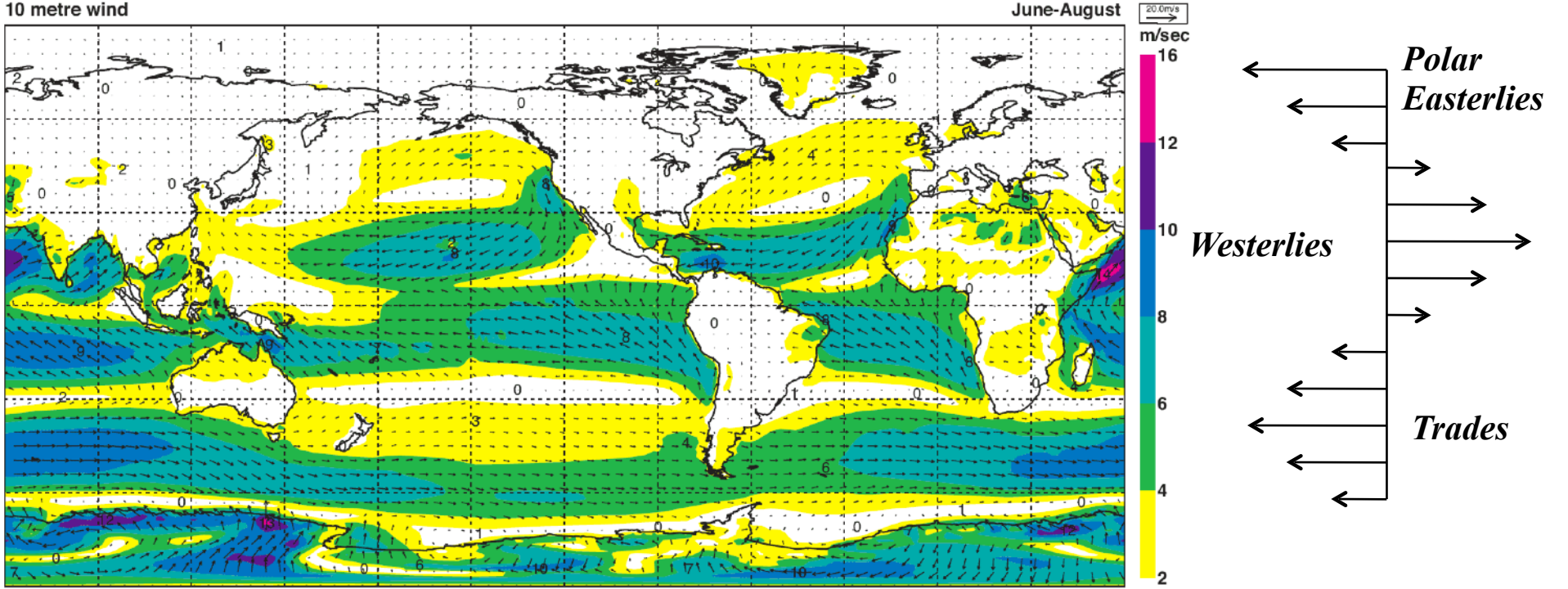
$$b' = -g \frac{\rho'}{\rho}$$

and Buoyancy Flux due to heat and freshwater flux

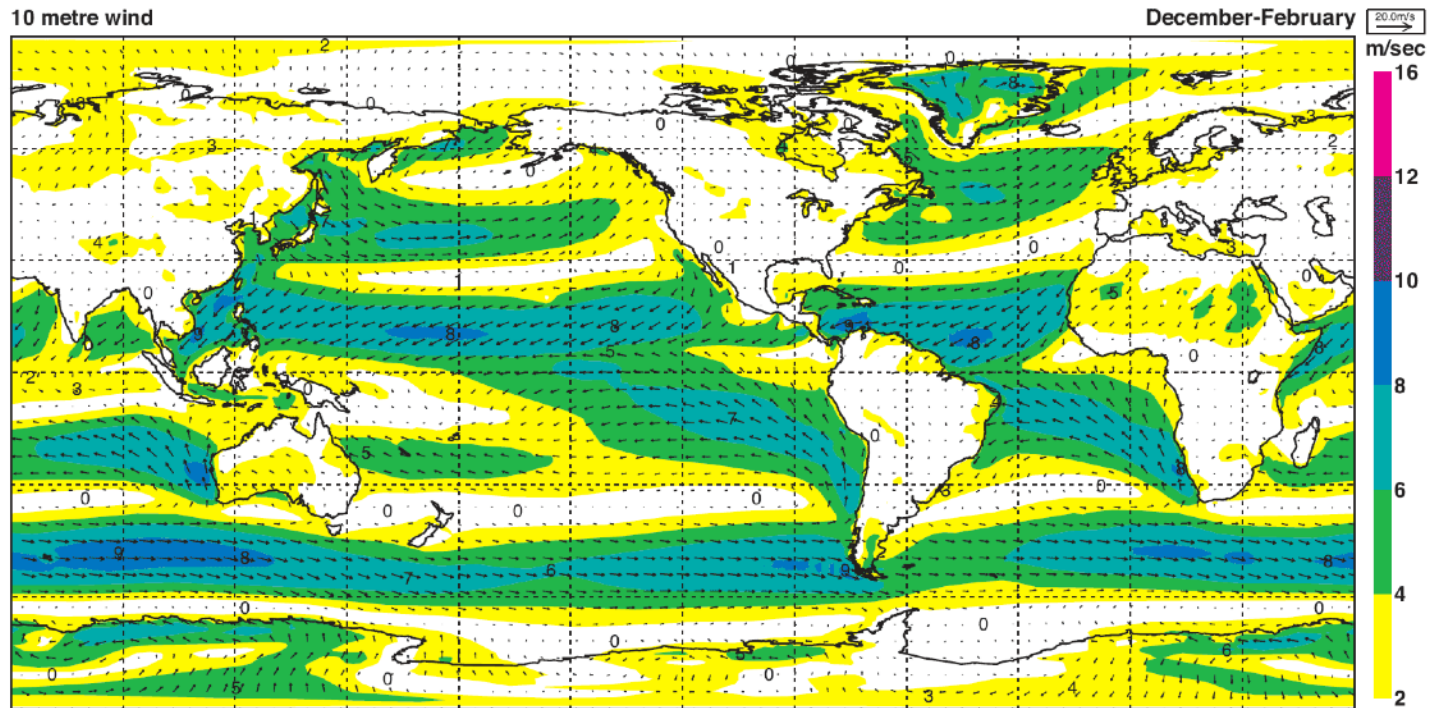
$$B = -g\alpha Q_{TOT} / \rho_w c_p + g\beta S \left(\frac{Q_L}{L_v} - \text{Pr} \right)$$

$$\alpha = -\frac{1}{\rho} \left(\frac{\partial \rho}{\partial T} \right)_{P,S}$$

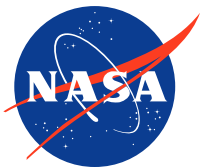
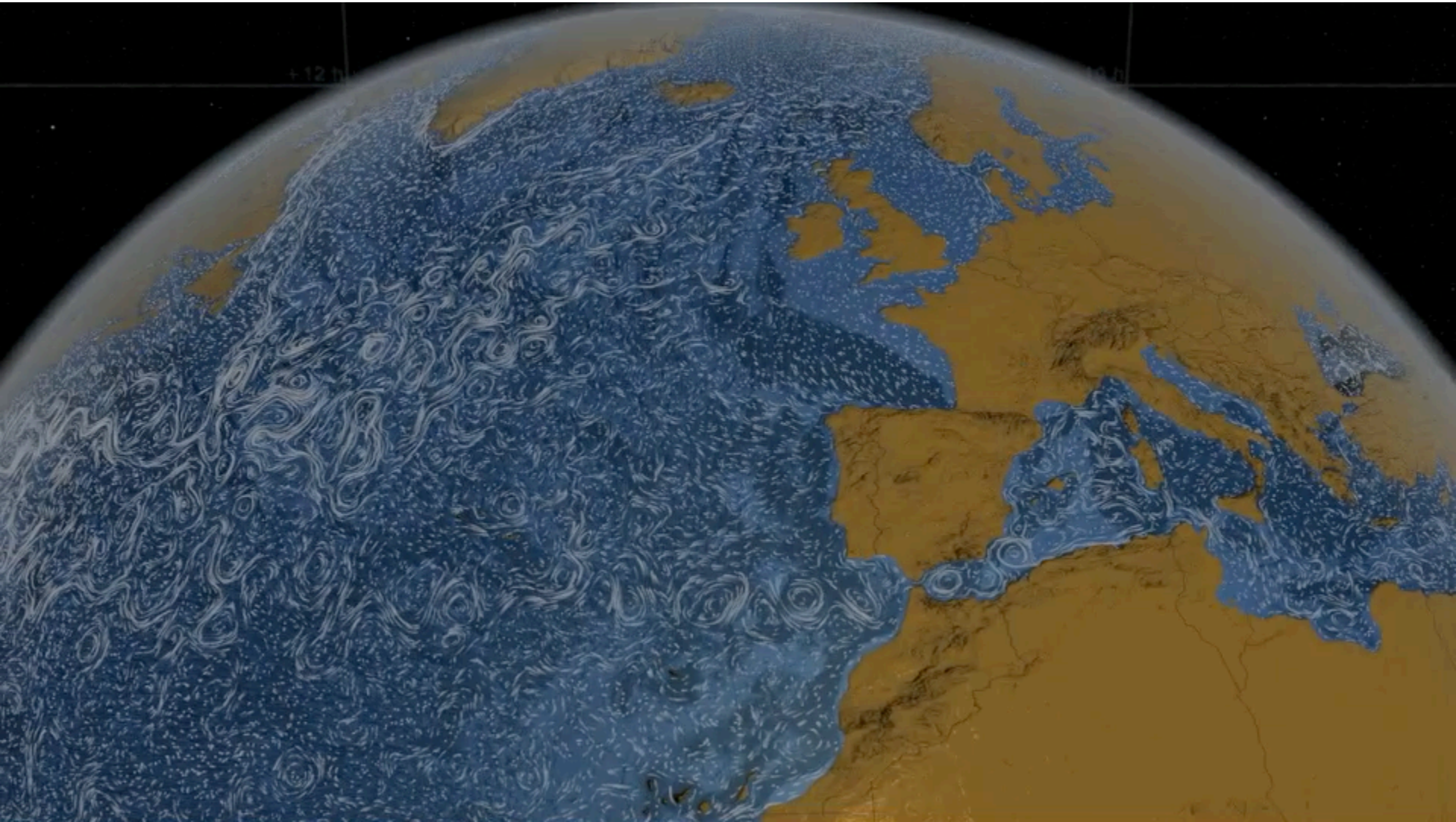
$$\beta = \frac{1}{\rho} \left(\frac{\partial \rho}{\partial S} \right)_{P,T}$$



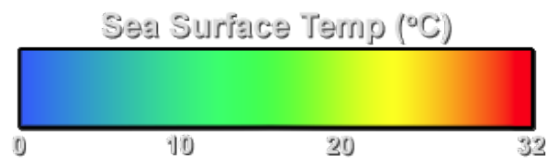
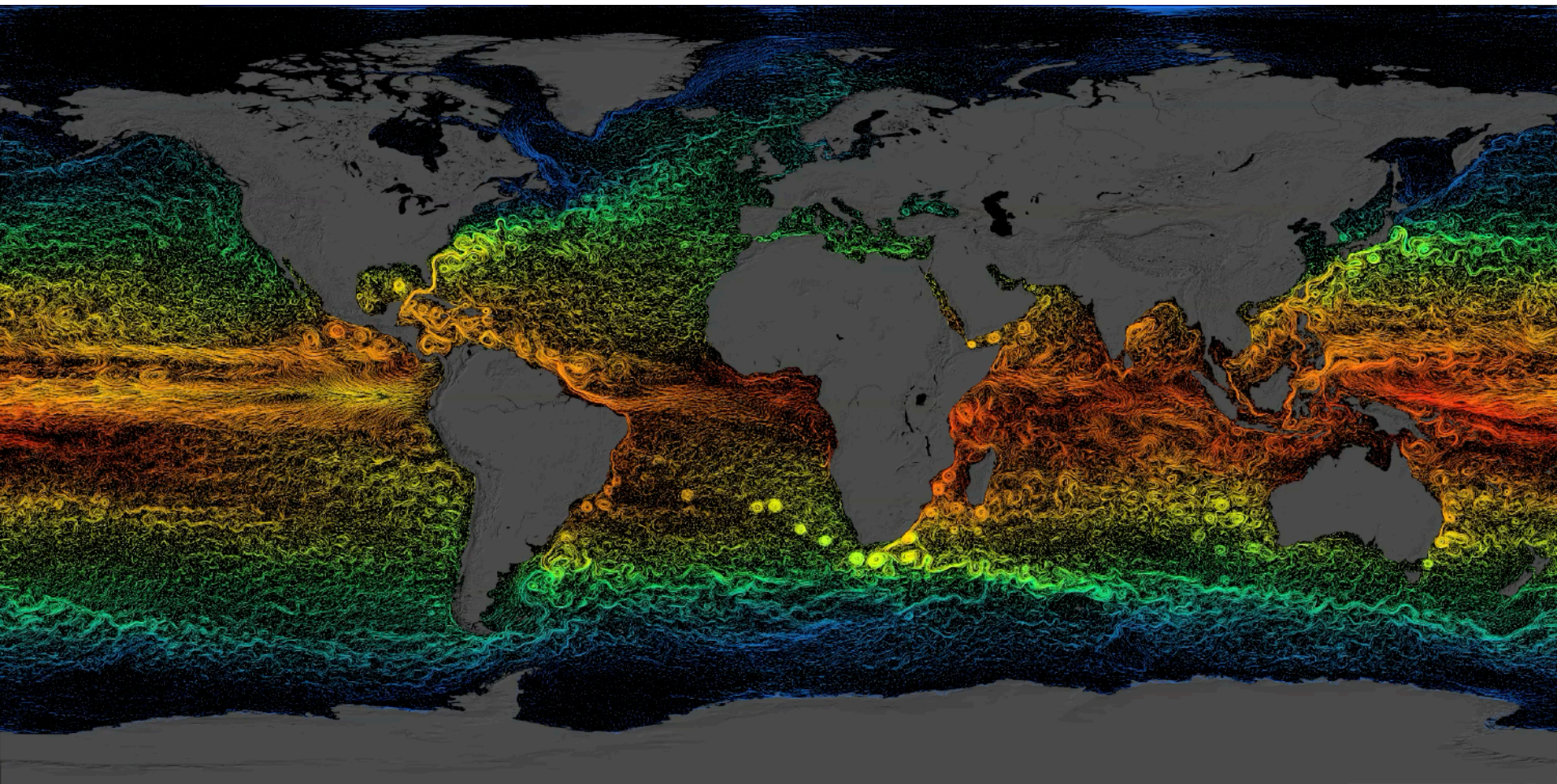
WIND FORCING



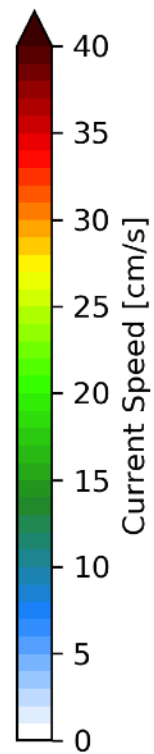
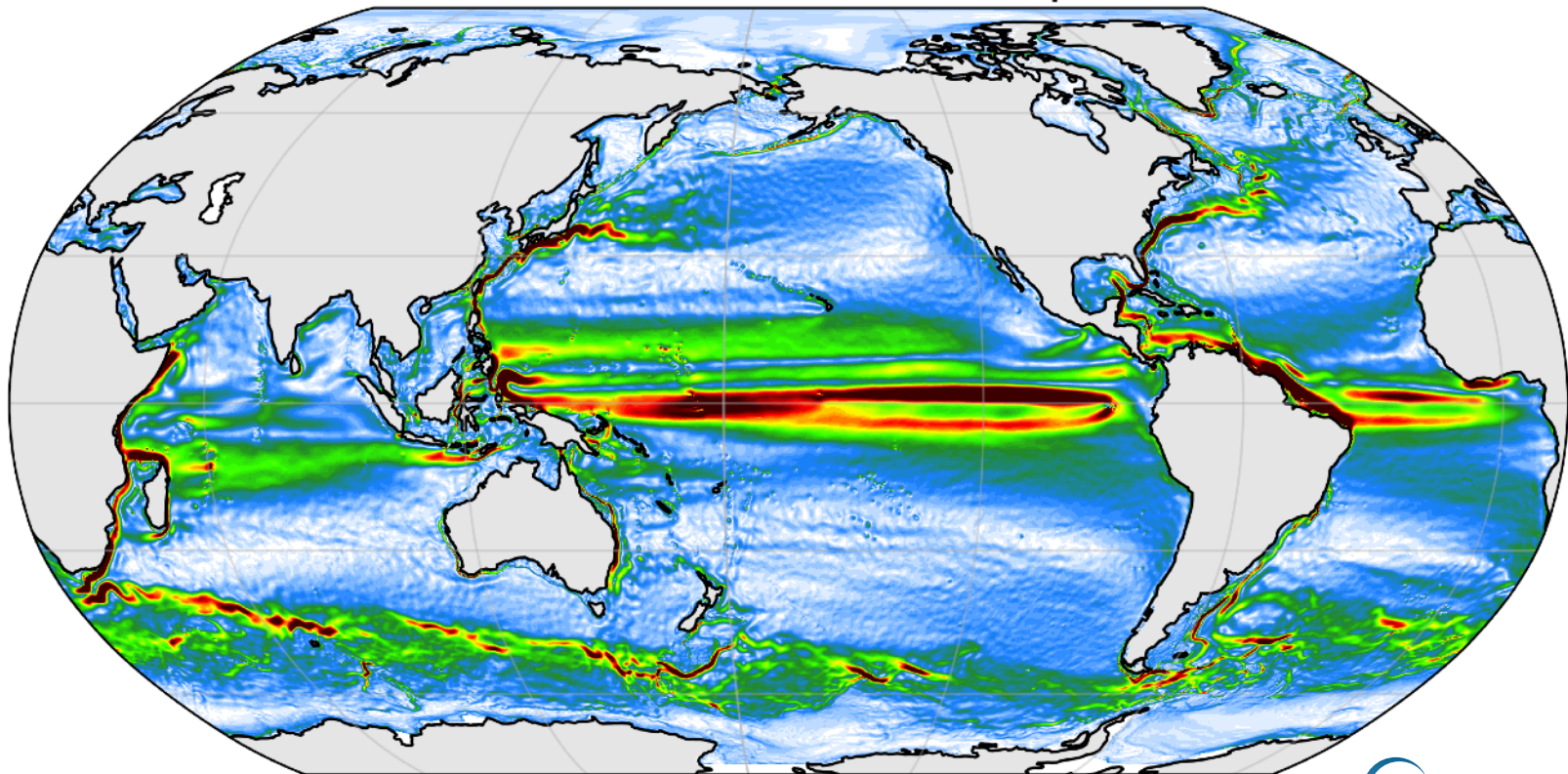
Ocean Currents



Ocean Currents

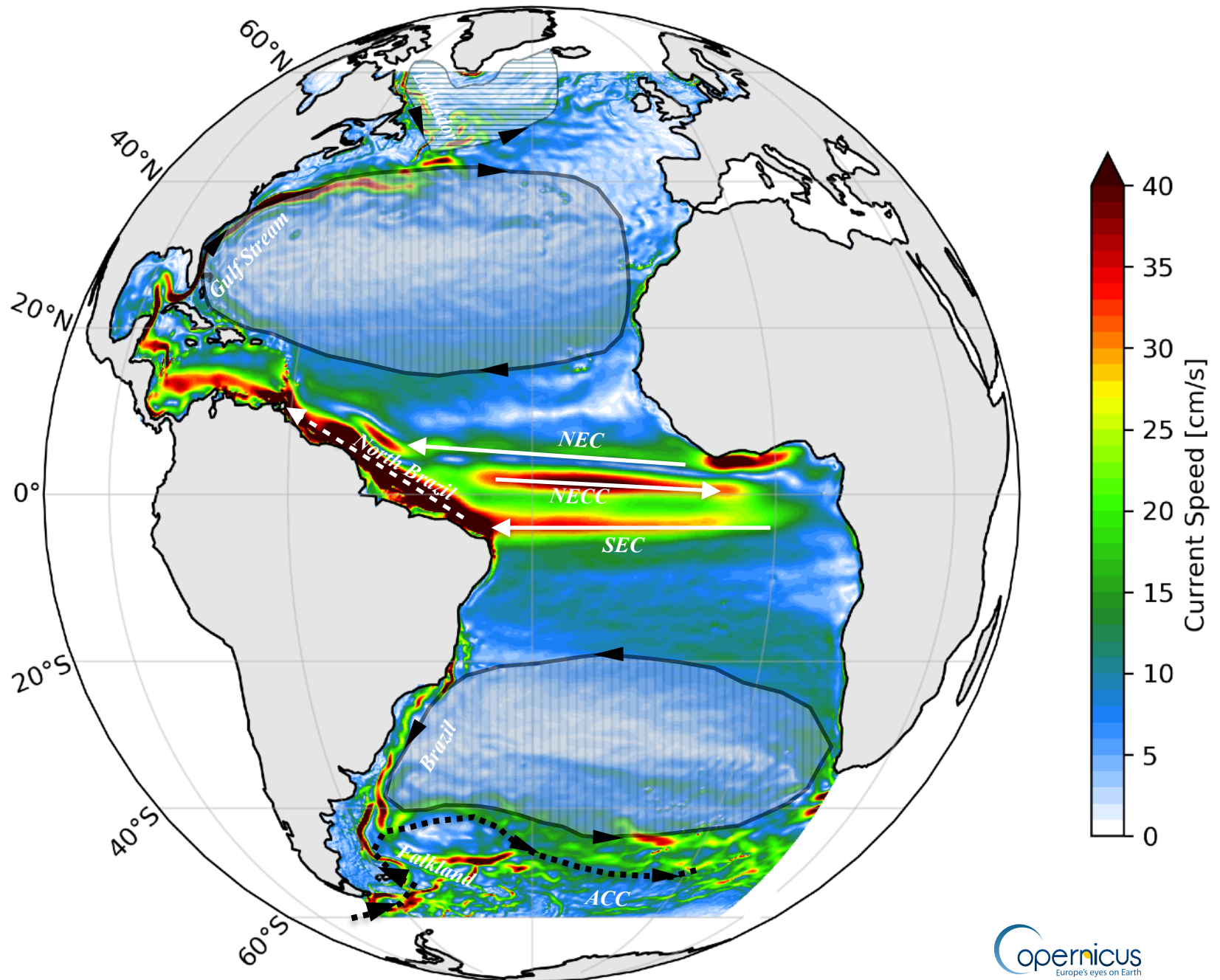


Ocean Surface Current Speed



Atlantic Ocean

OCEAN CIRCULATION

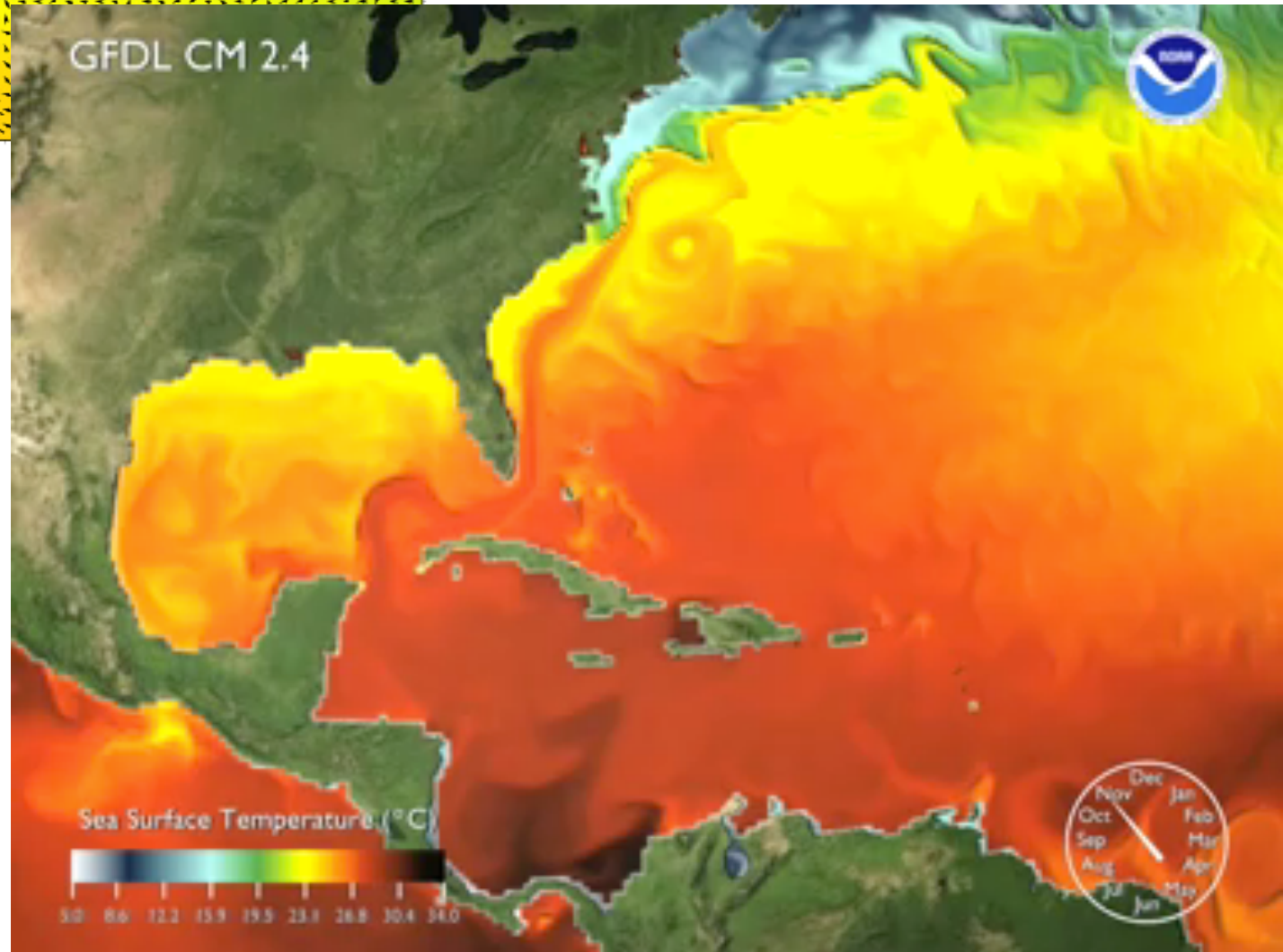
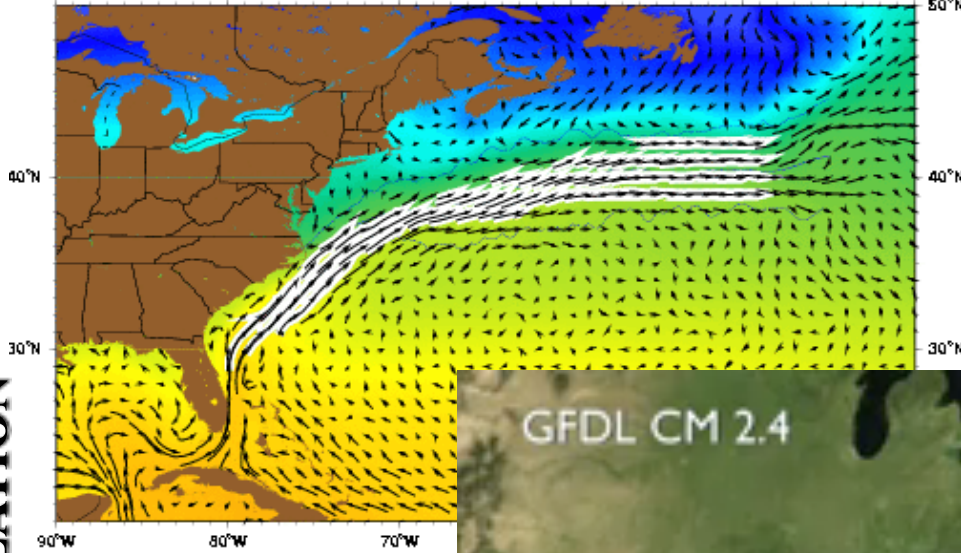


The Gulf Stream System

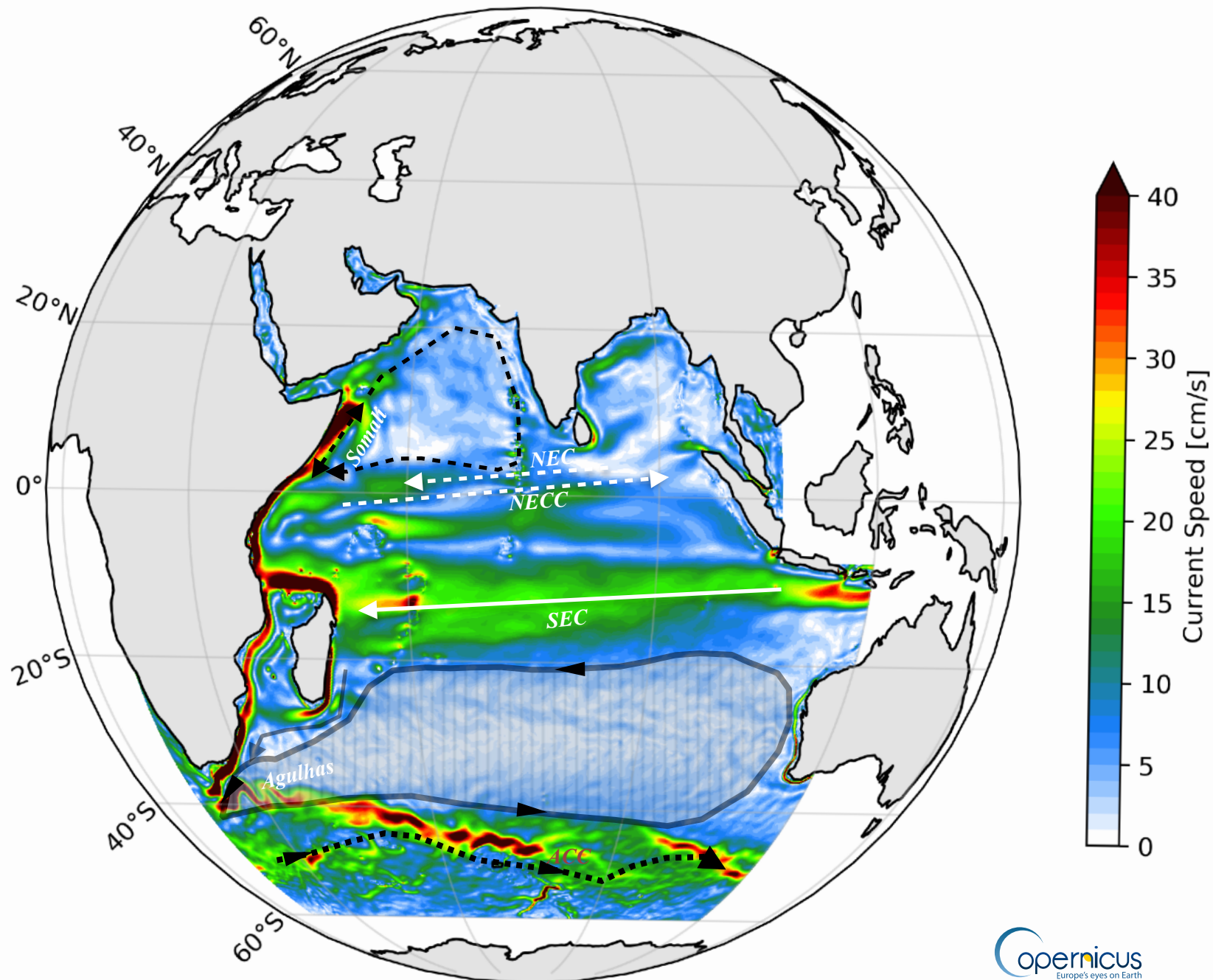
OCEAN CIRCULATION

Looking behind the
“mean” circulation
patterns:

Circulation is
dominated by spatial
and temporal
variability at
various scales



Indian Ocean



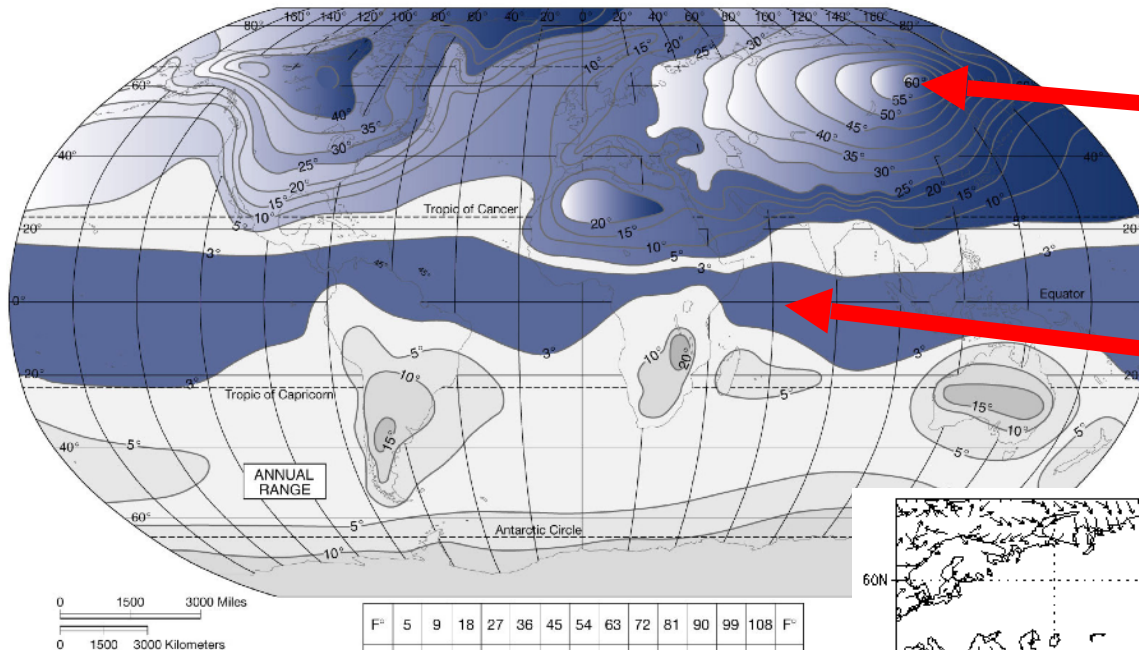
Surface temperature range that results in the monsoon

Sea surface temperature variations are much smaller than land surface temperature variations. (Mainly the seasonal cycle)

Kump et al. (2004)

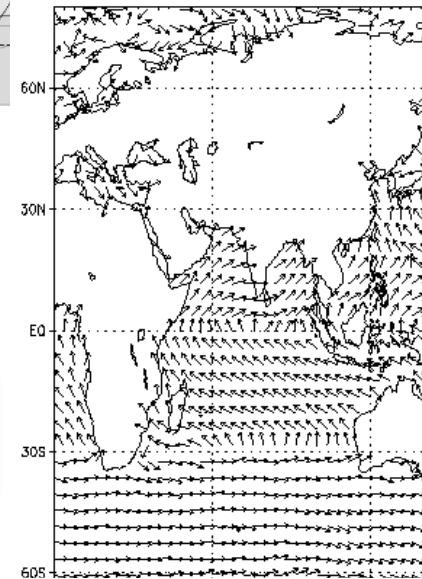
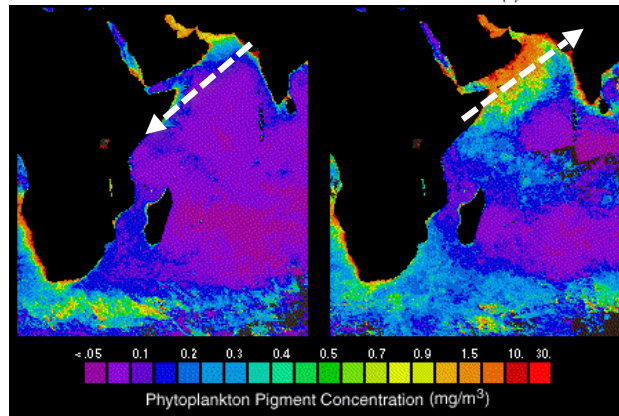
Tibetan plateau:
range of 60°C

Ocean:
range of 3 to 5°C

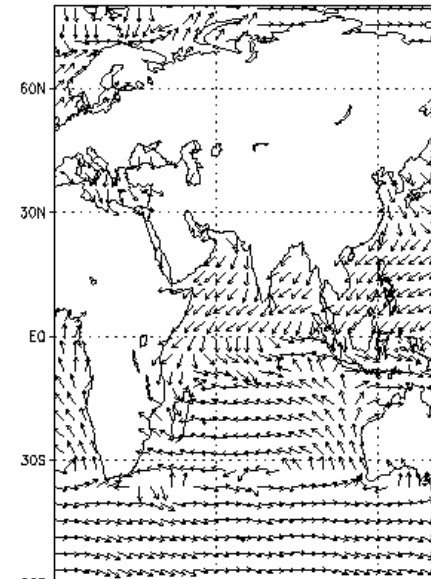


F°	5	9	18	27	36	45	54	63	72	81	90	99	108	F°
C°	3	5	10	15	20	25	30	35	40	45	50	55	60	C°

(c)



Jun-Aug (SW monsoon)



Dec-Feb (NE monsoon)

GFDL CM 2.4

Hi-Res Coupled Model

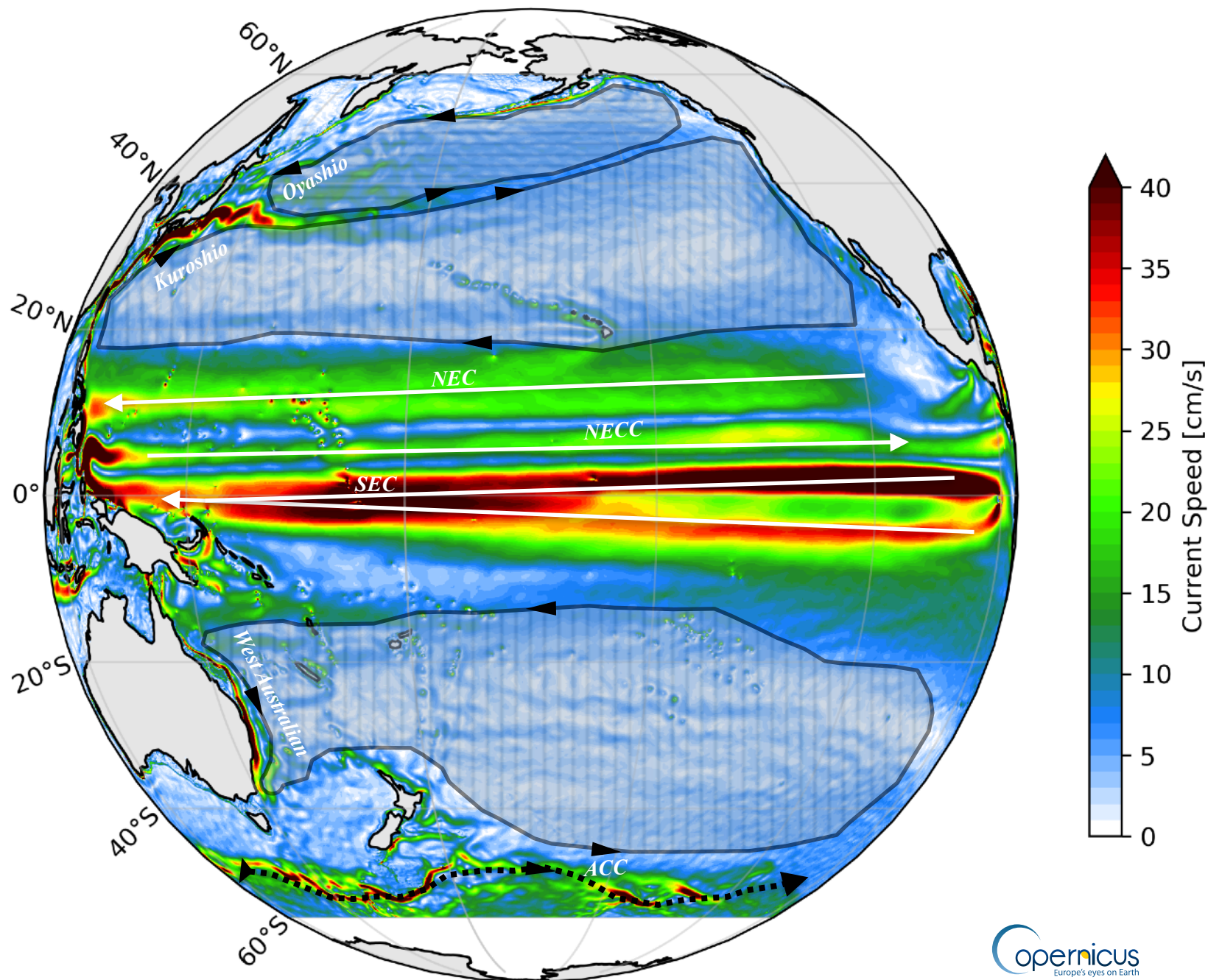


Sea Surface Temperature ($^{\circ}\text{C}$)

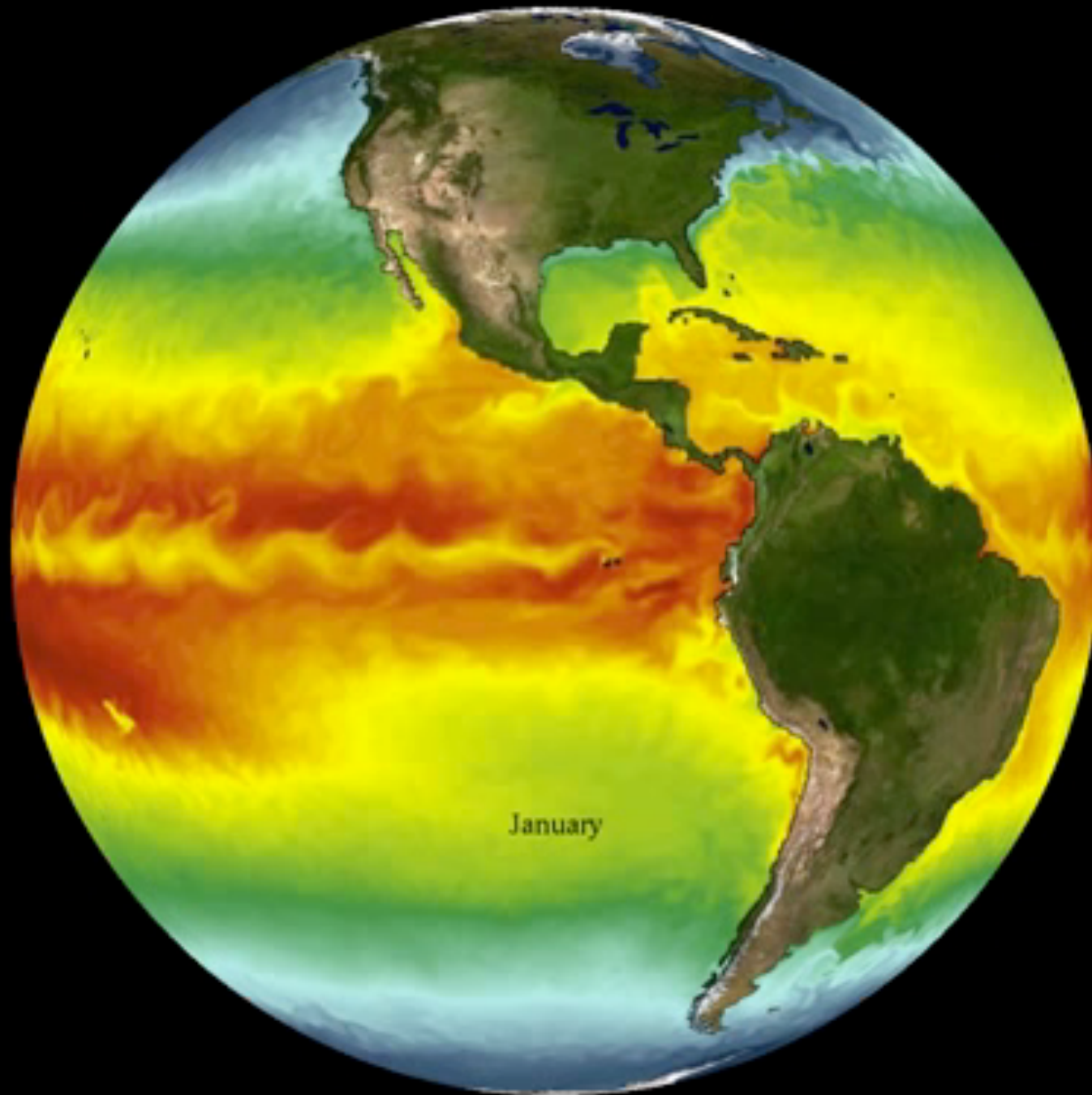


OCEAN CIRCULATION

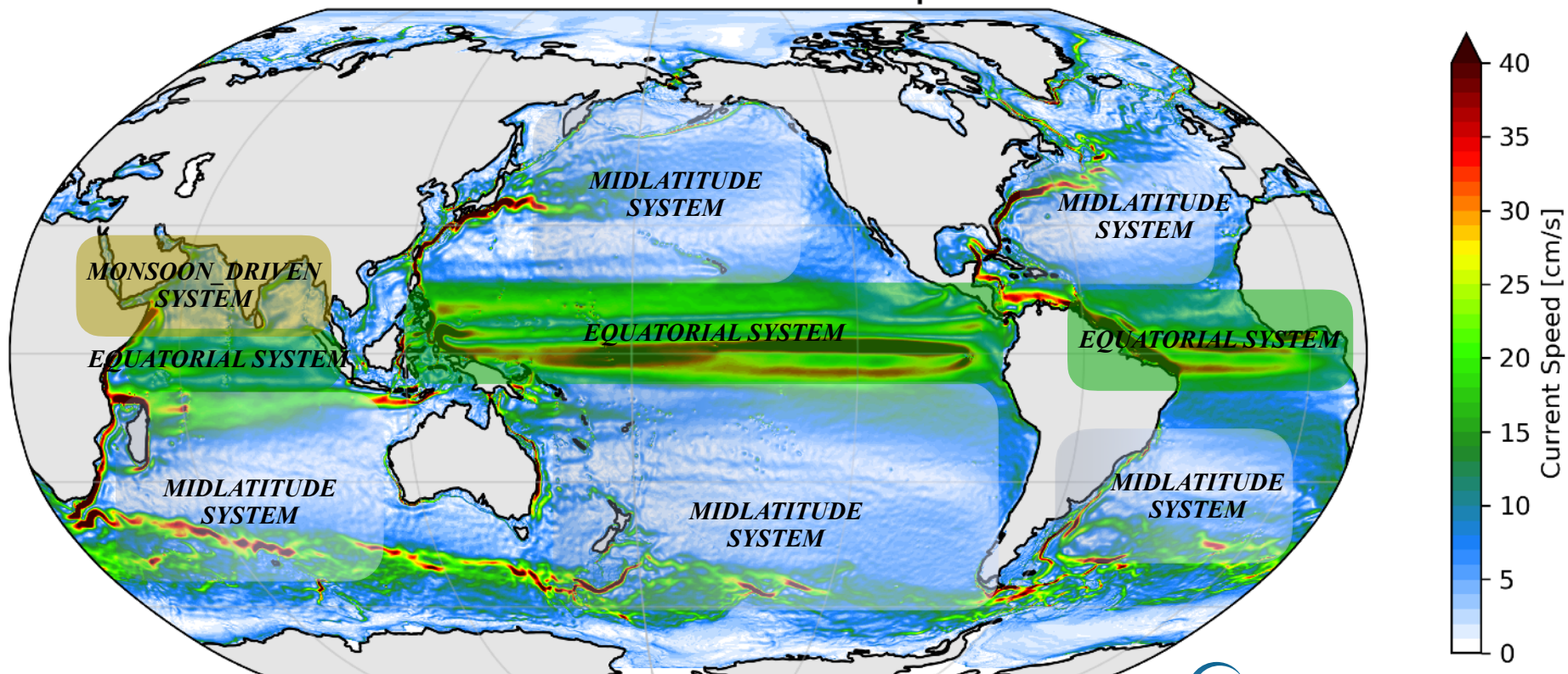
Pacific Ocean



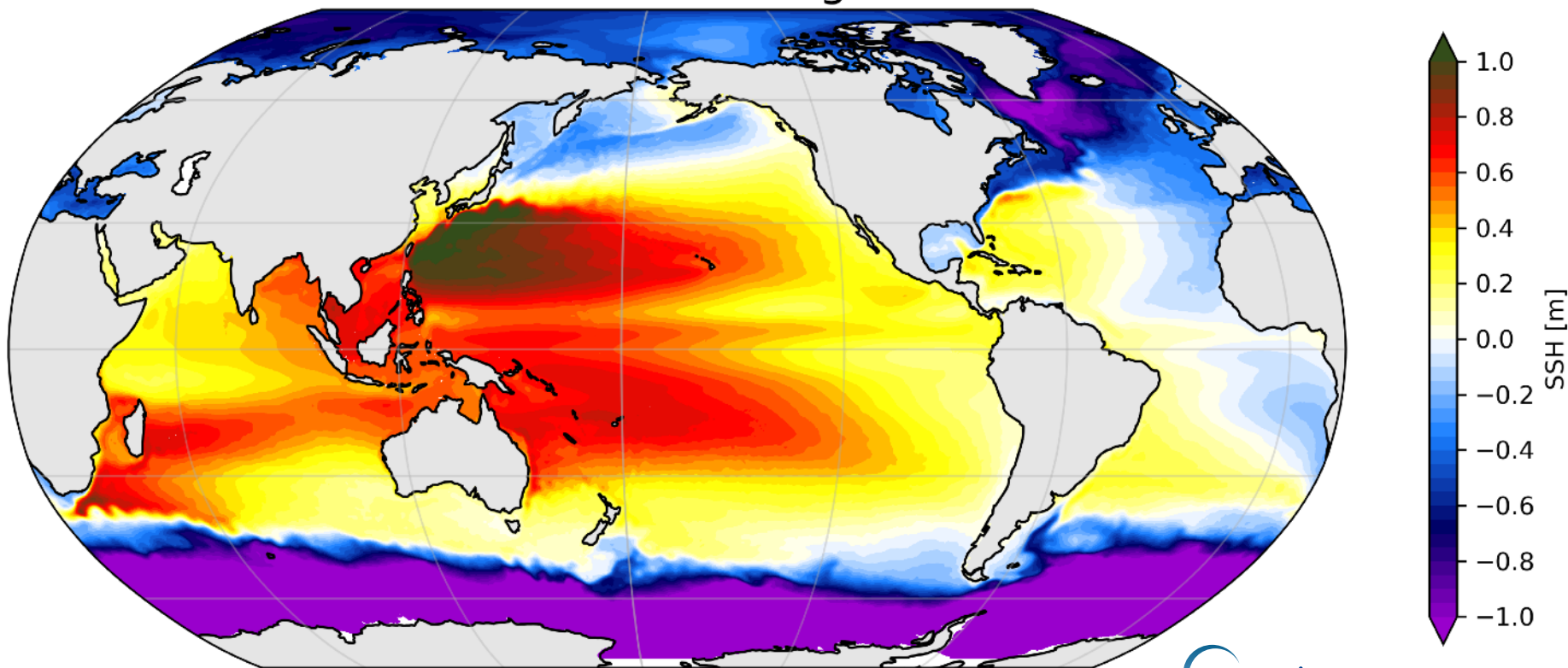
The Pacific Equatorial System



Ocean Surface Current Speed

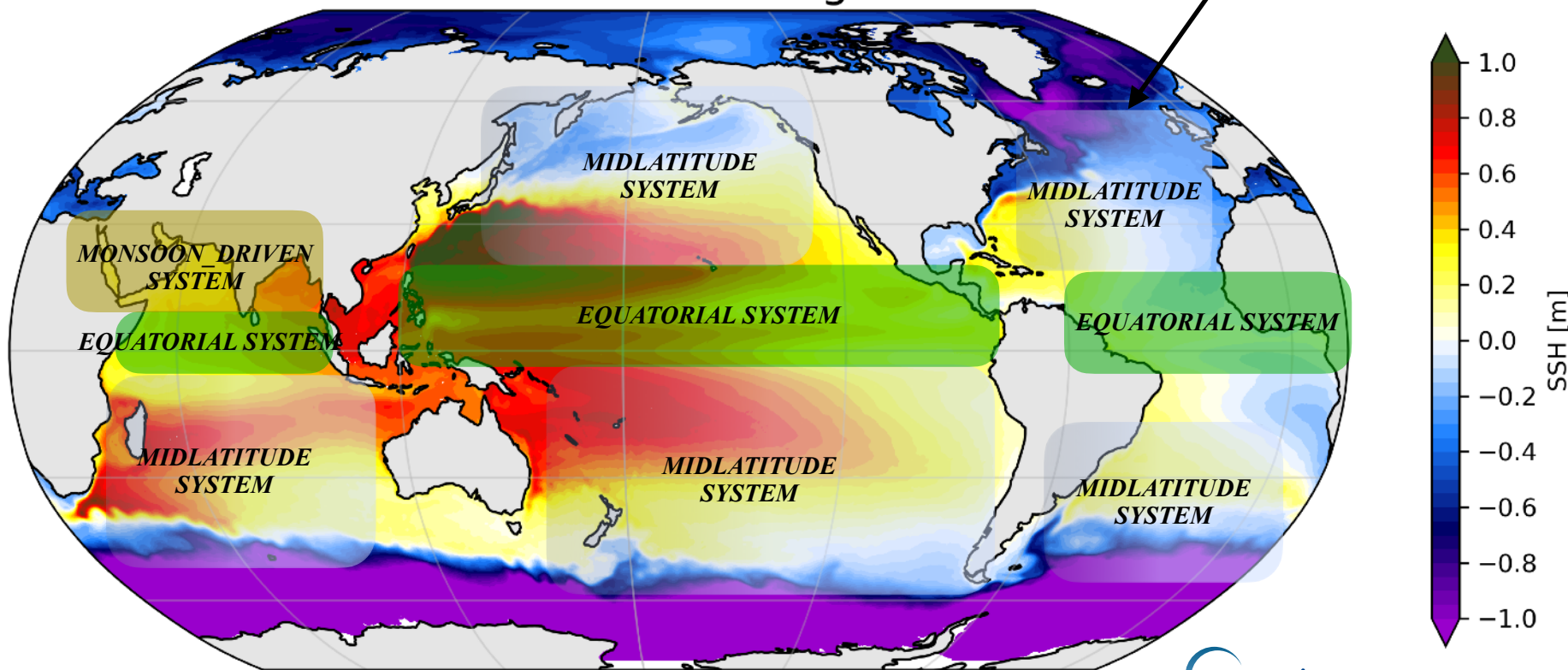


Sea Surface Height

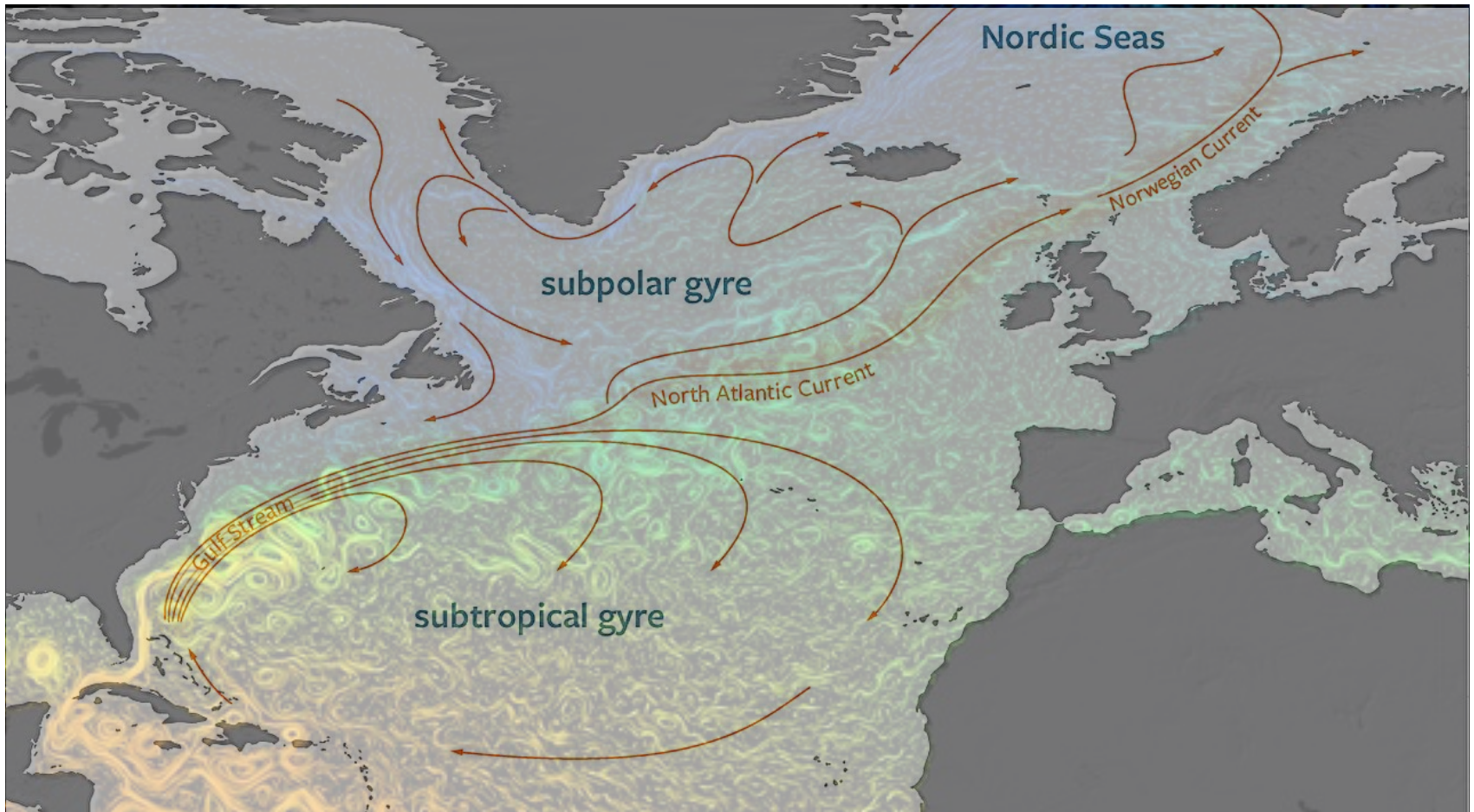


Η κύρια περιοχή μελέτης

Sea Surface Height



Η περιοχή μελέτης



Πως εξηγείται η δομή της κυκλοφορίας (με τα ίδια χαρακτηριστικά στους τρεις ωκεανούς); Αυτά θα μελετηθούν στα κεφάλαια της Δυναμικής Φυσικής Ωκεανογραφίας.

The high latitudes

2010

Sep

Oct

Nov

Dec

Jan

Feb

Mar

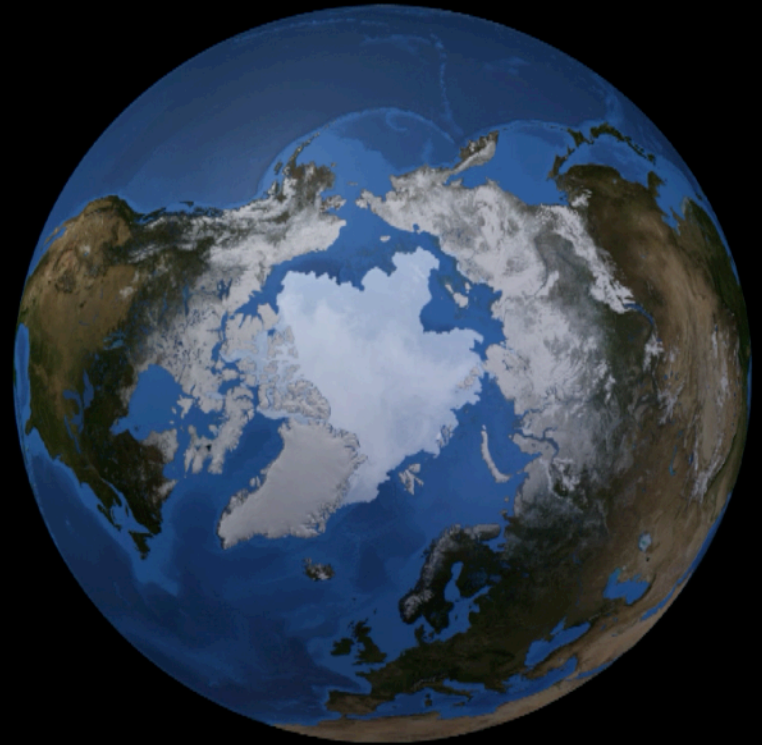
Apr

May

Jun

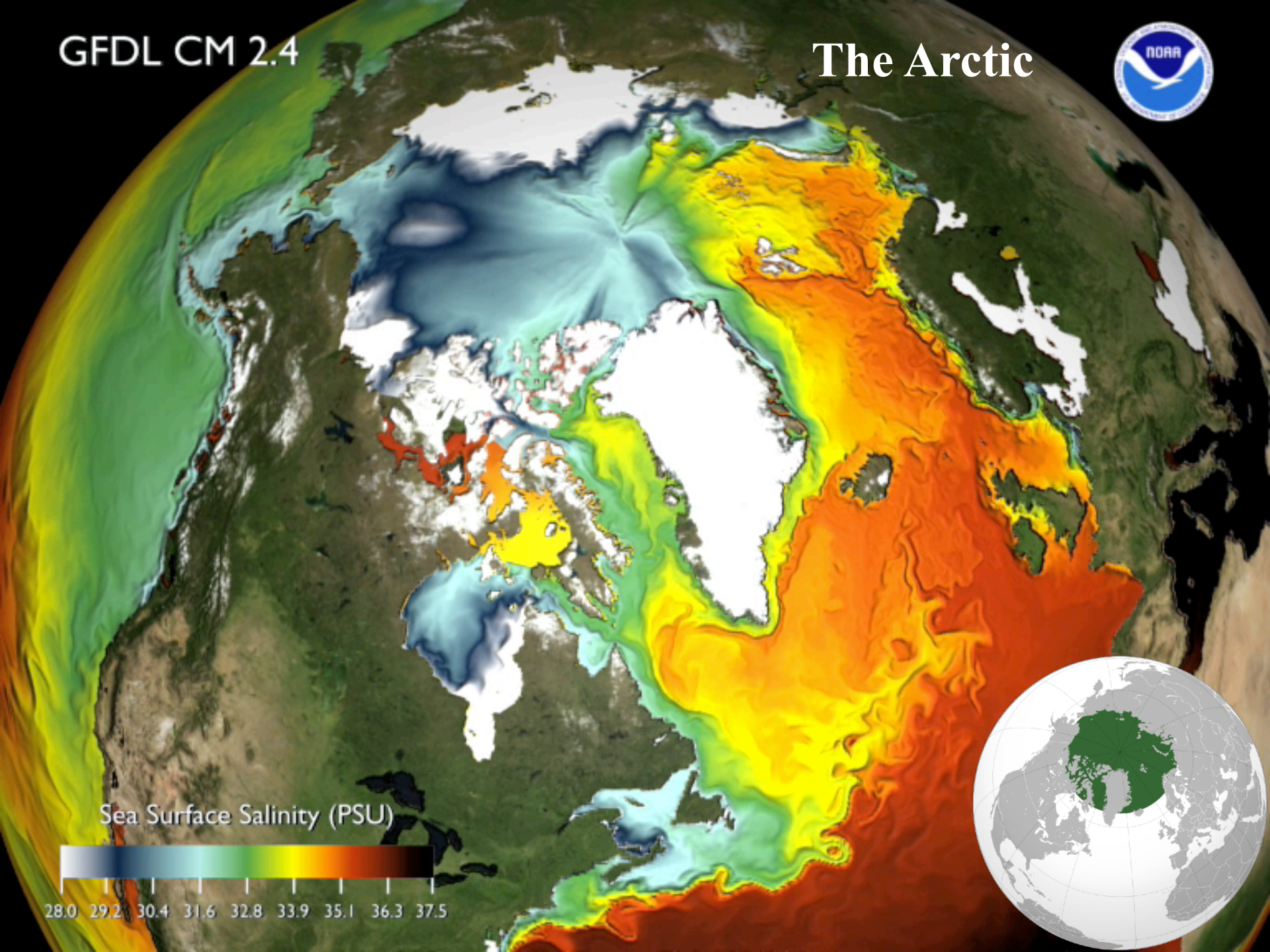
Jul

Aug



GFDL CM 2.4

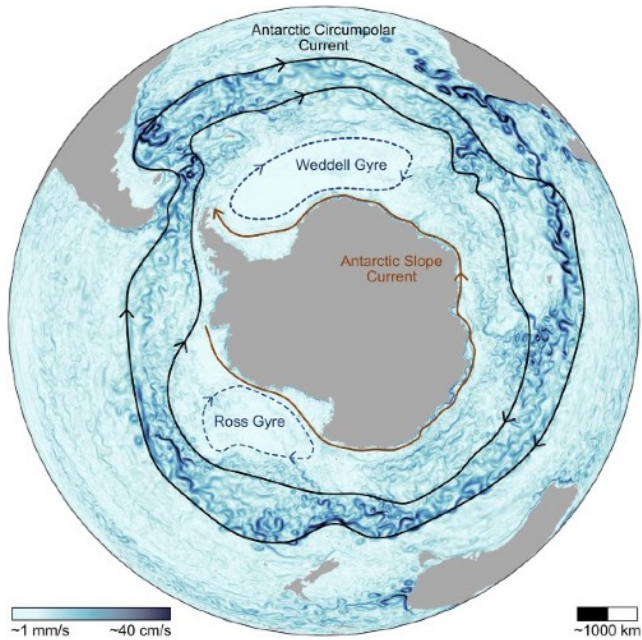
The Arctic



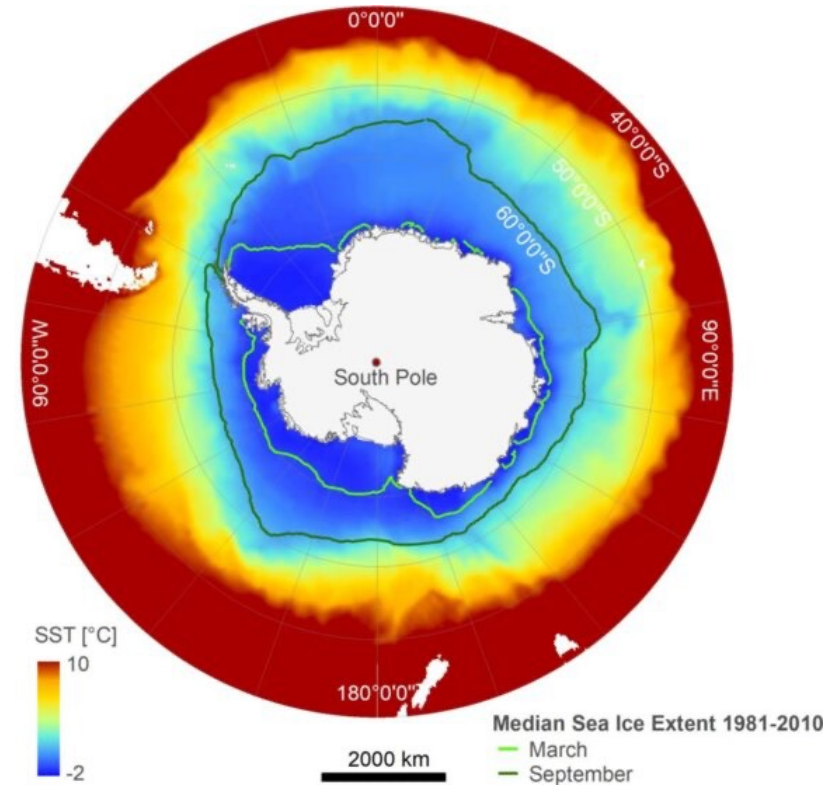
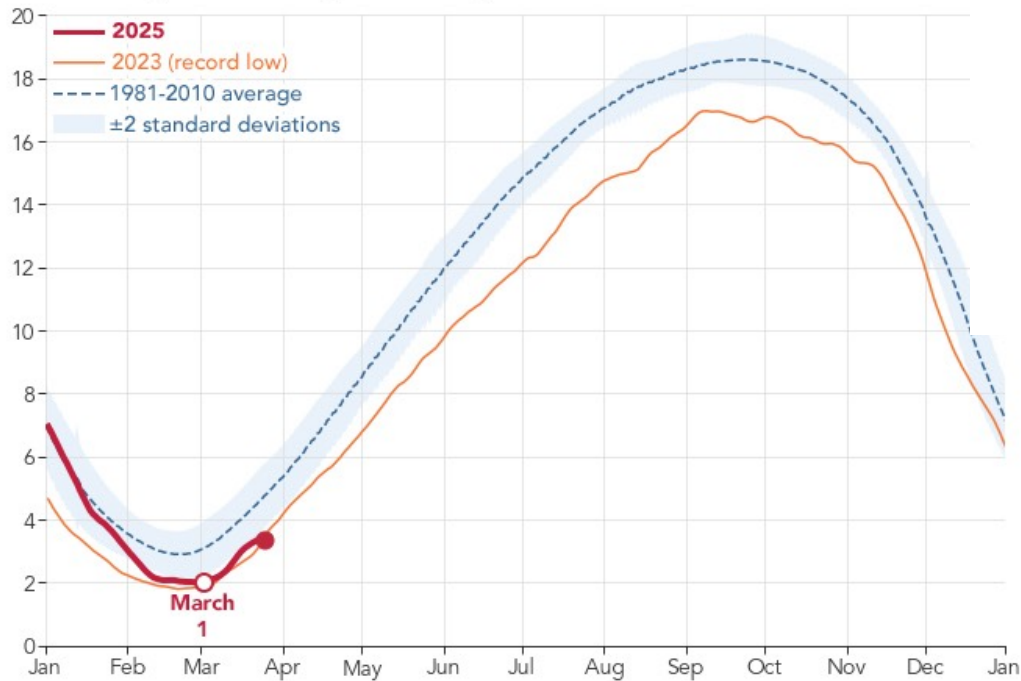
Sea Surface Salinity (PSU)



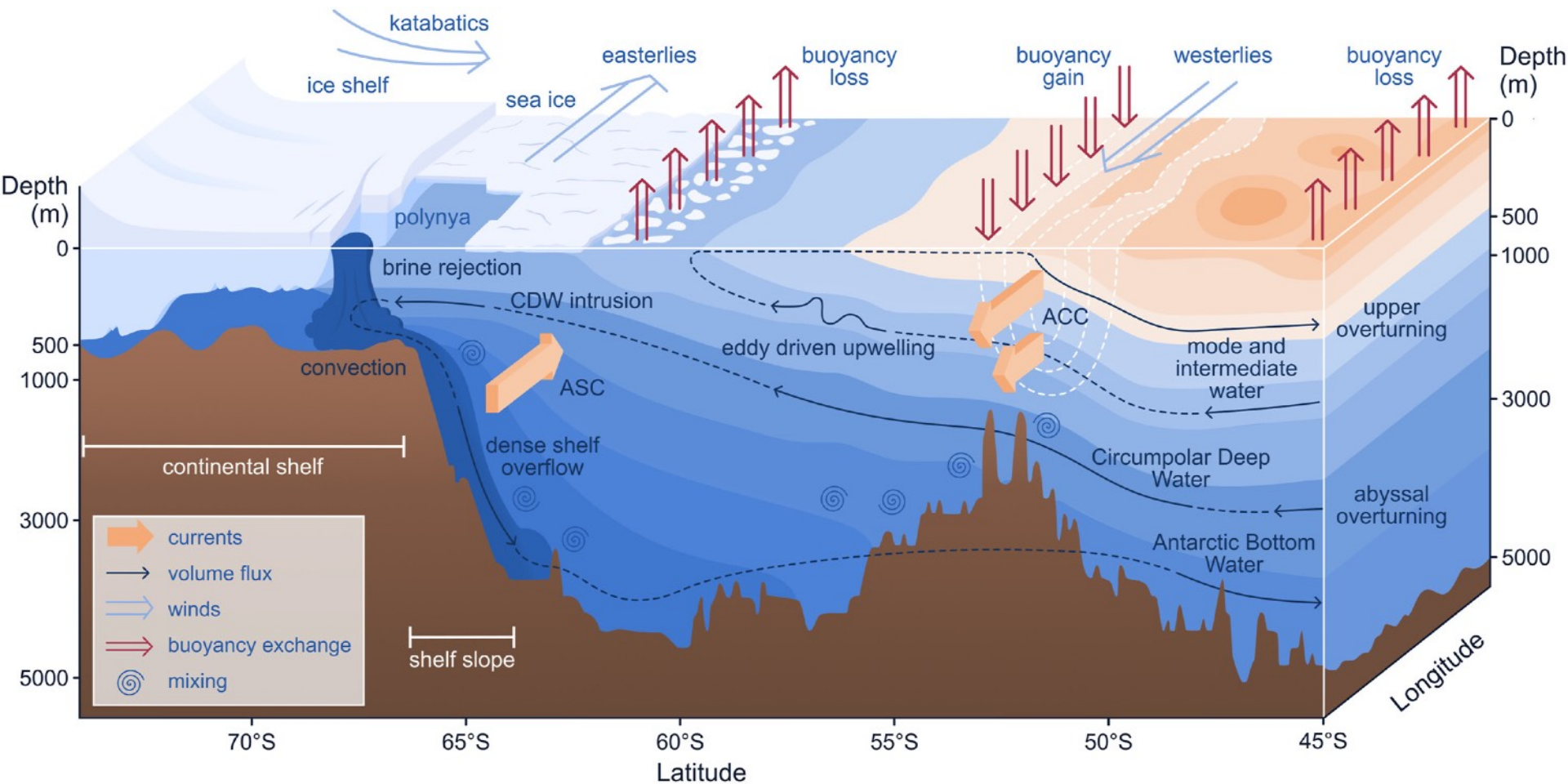
The Antarctic



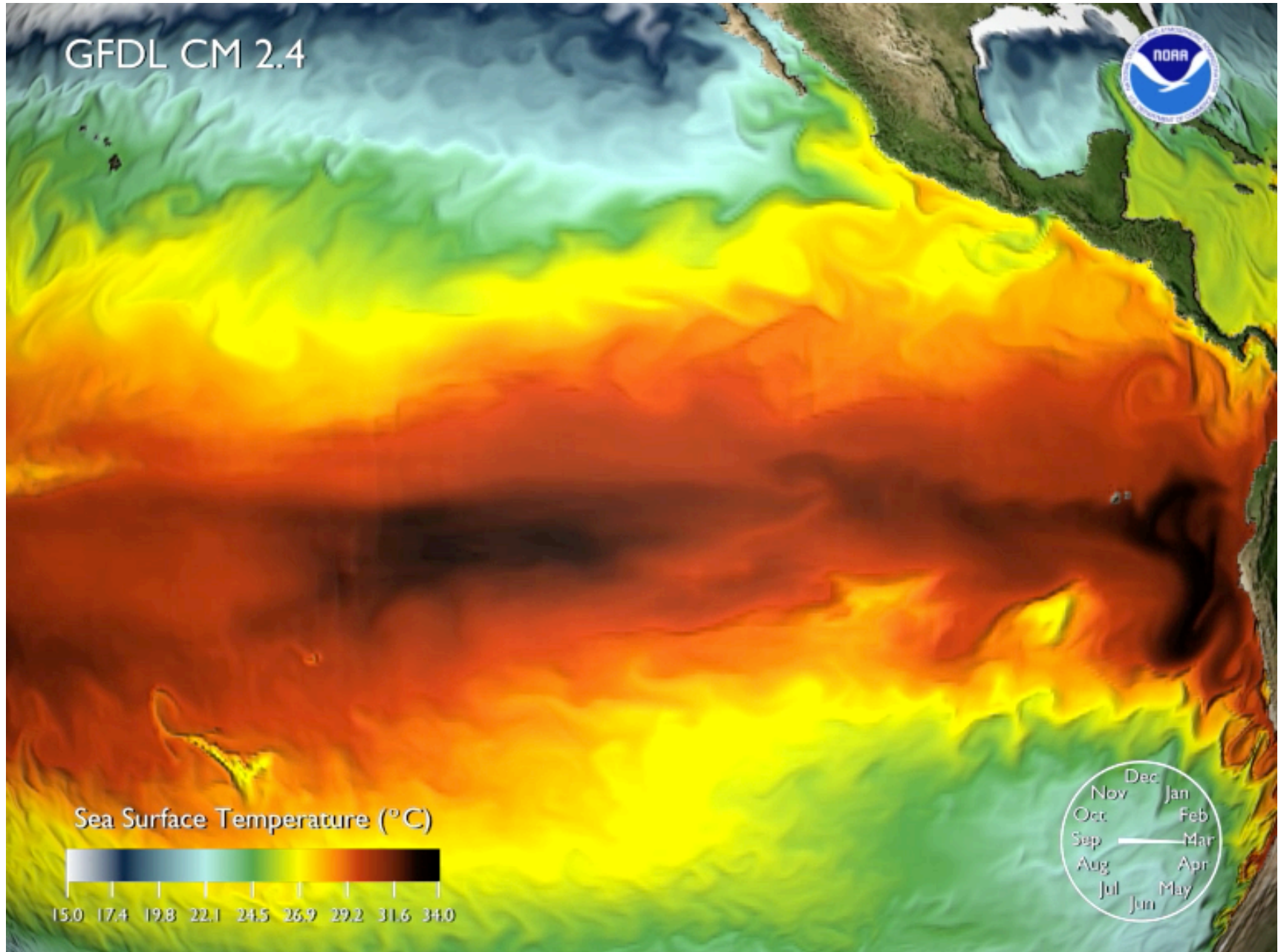
Antarctic Daily Sea Ice Extent (millions of km²)



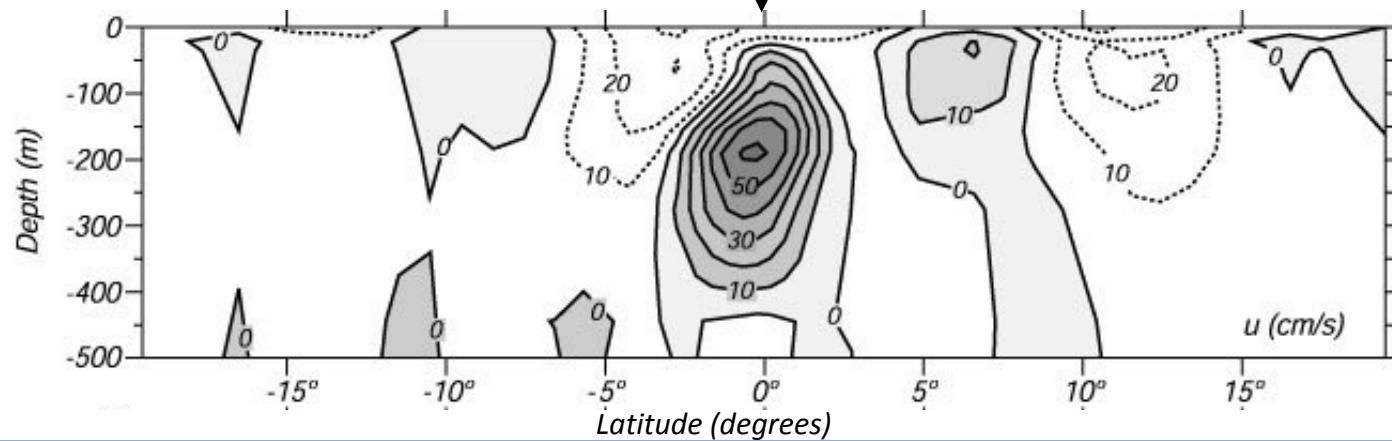
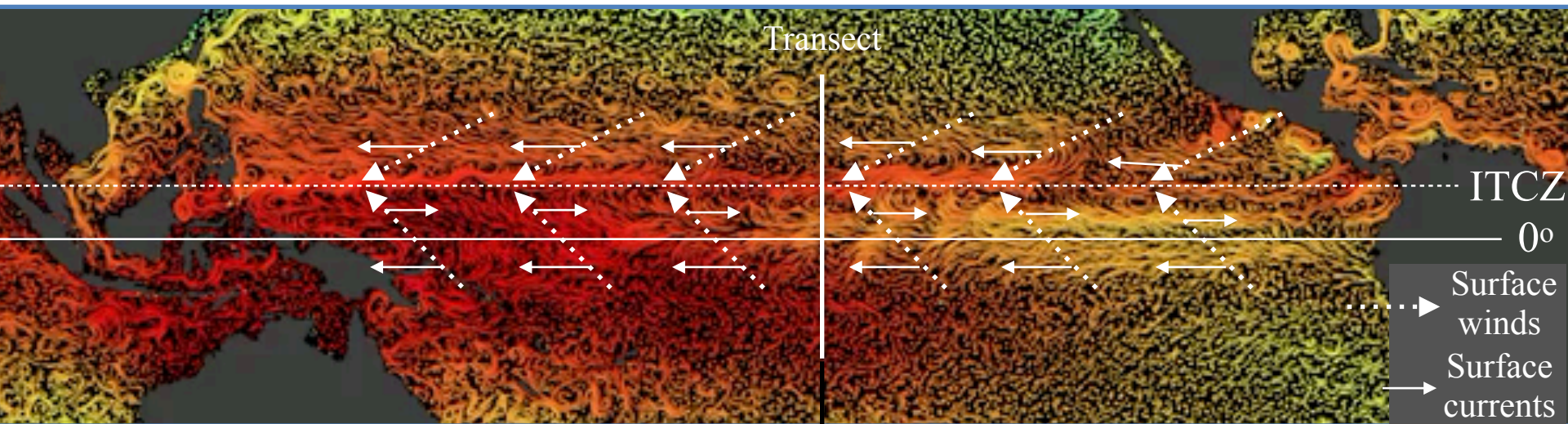
The Antarctic



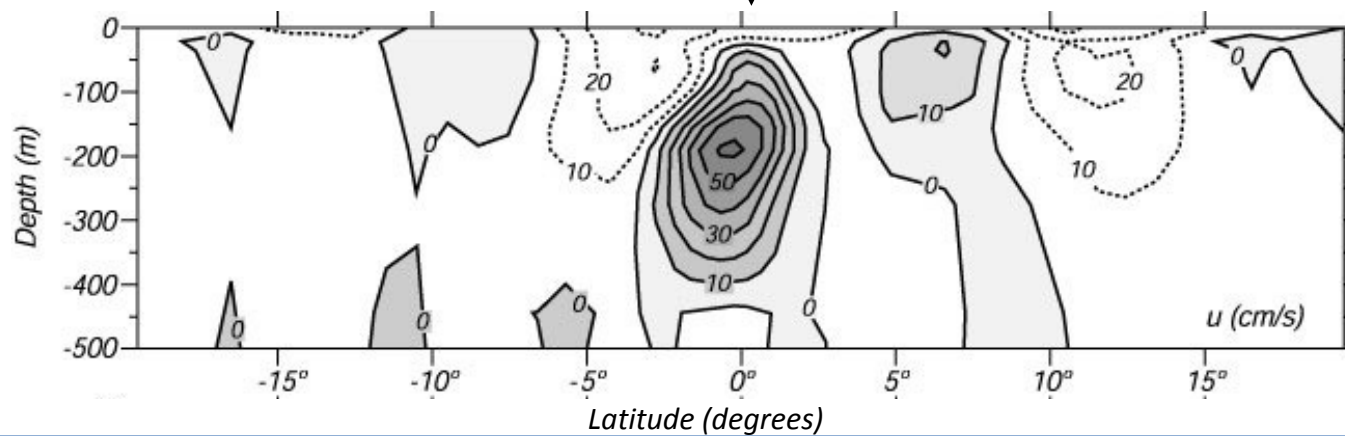
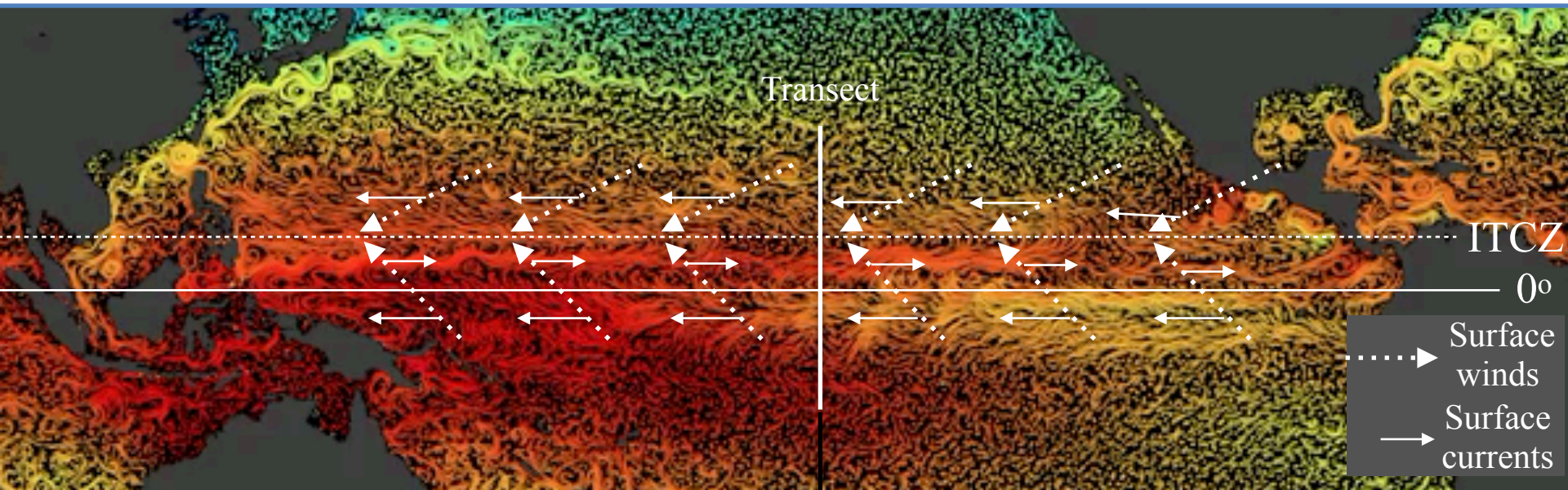
The low latitudes



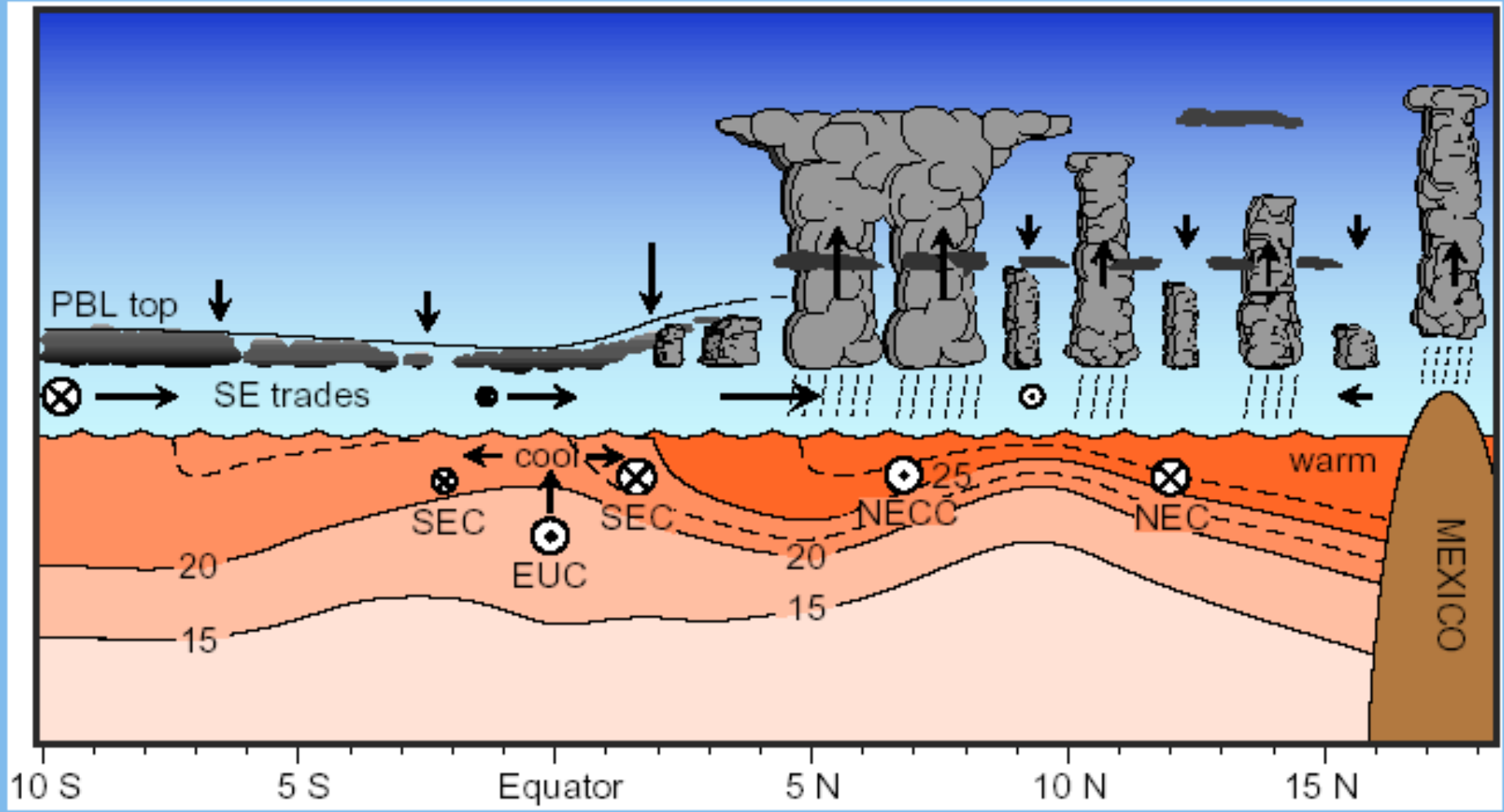
EQUATORIAL CURRENT SYSTEM

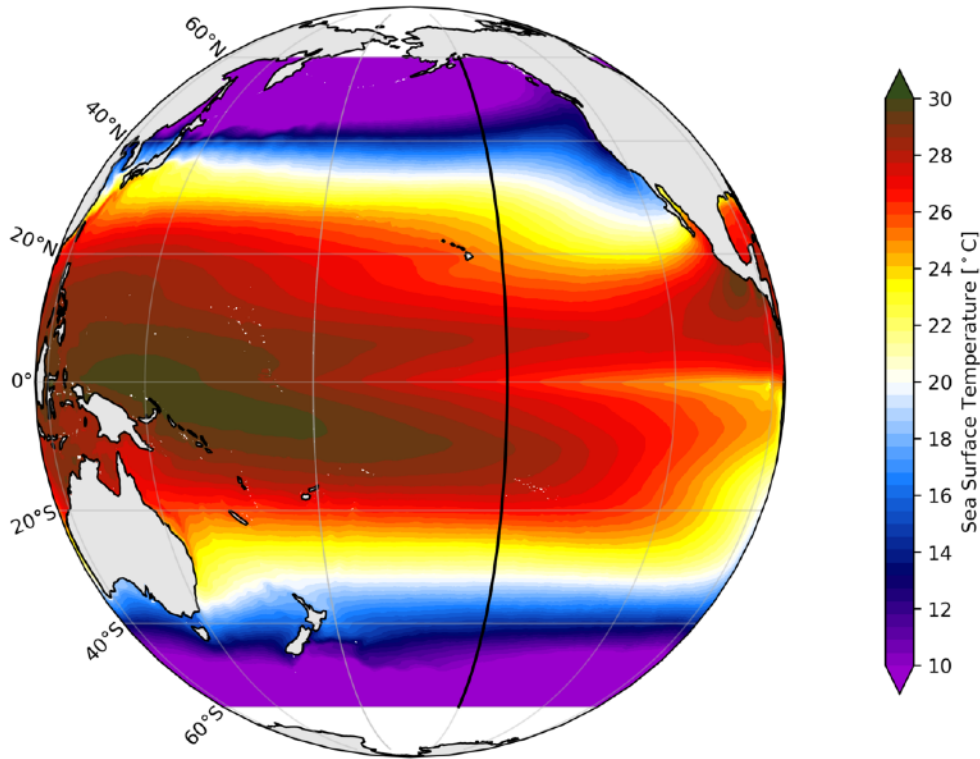


EQUATORIAL CURRENT SYSTEM



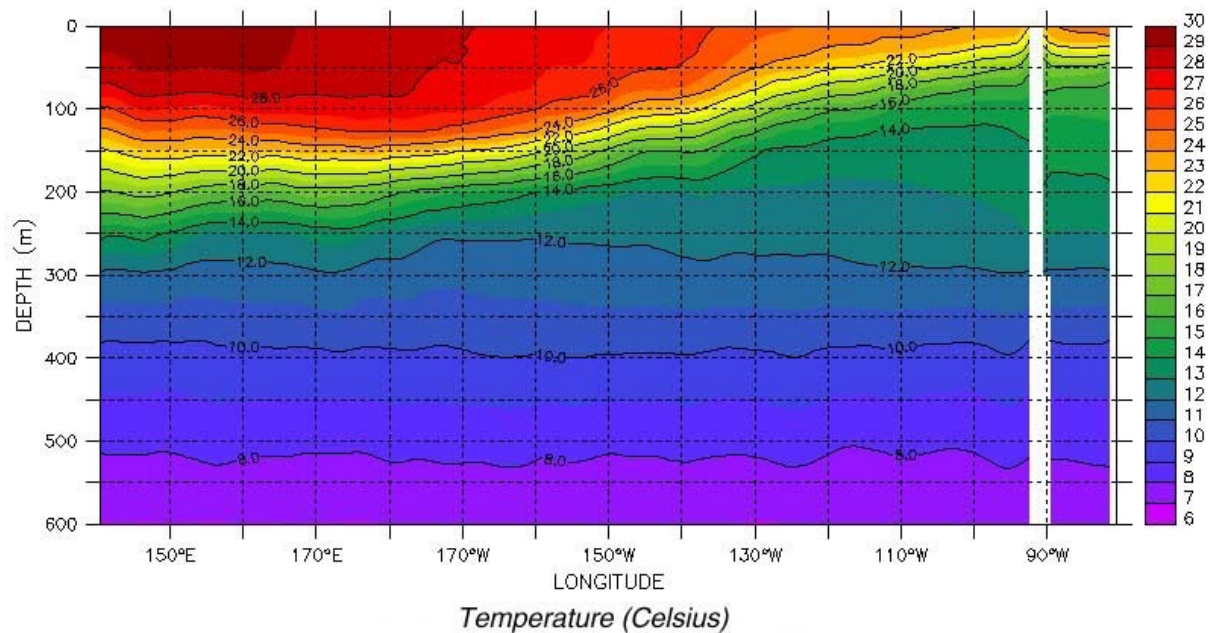
EQUATORIAL CURRENT SYSTEM



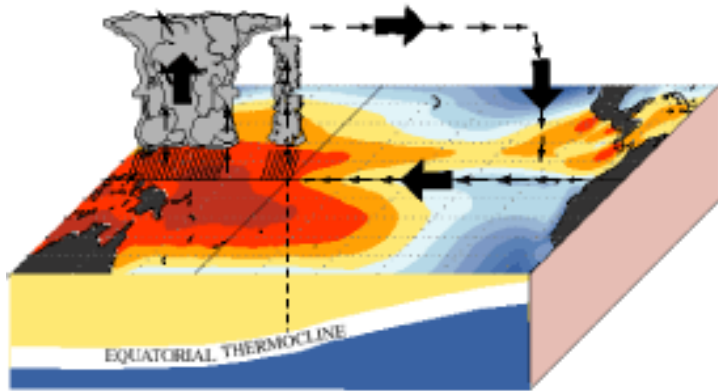


***El Nino, La Nina and
the Southern
Oscillation
ENSO***

**Average temperature
conditions in the
Equatorial Pacific**



December - February Normal Conditions

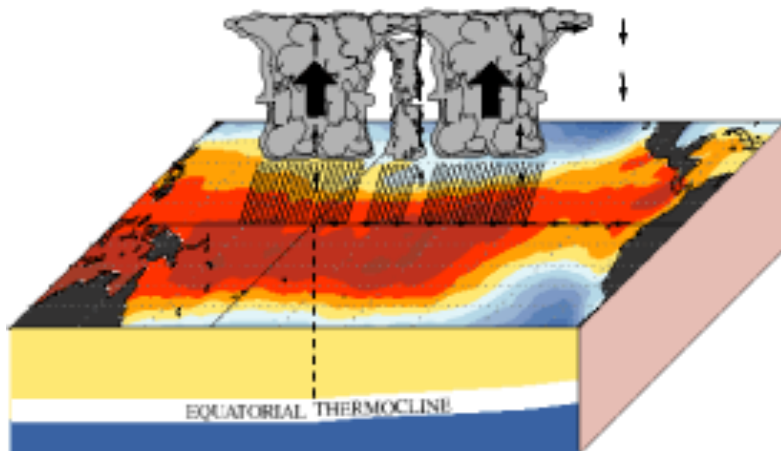


***El Nino, La Nina and
the Southern
Oscillation
ENSO***

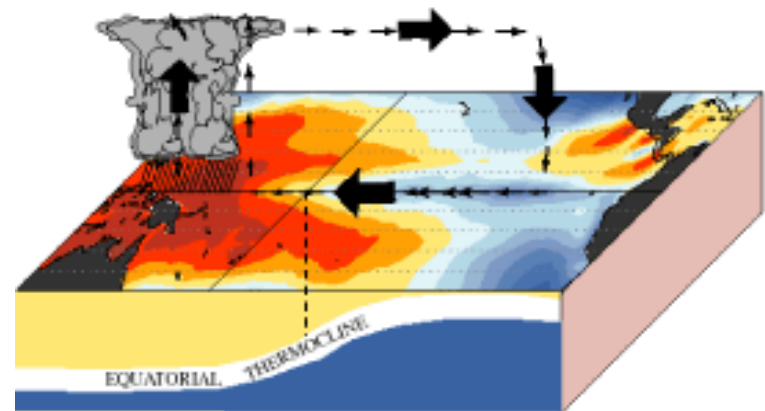
***Positive SST Anomaly
travels eastward***

***Slackening/reversal of
the Trade Winds
Negative SST Anomaly***

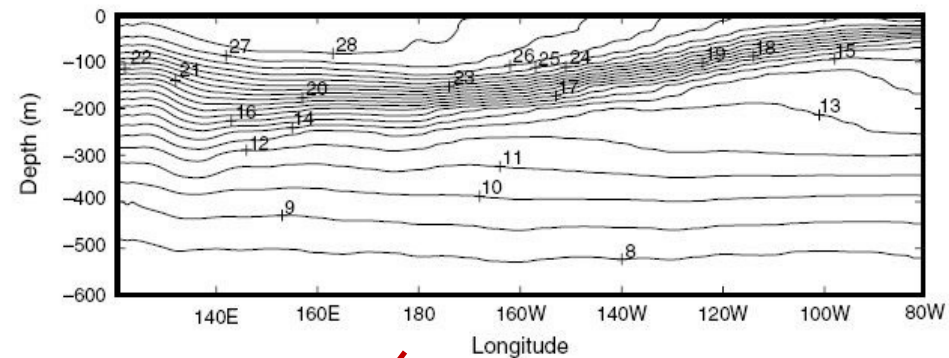
December - February El Niño Conditions



December - February La Niña Conditions

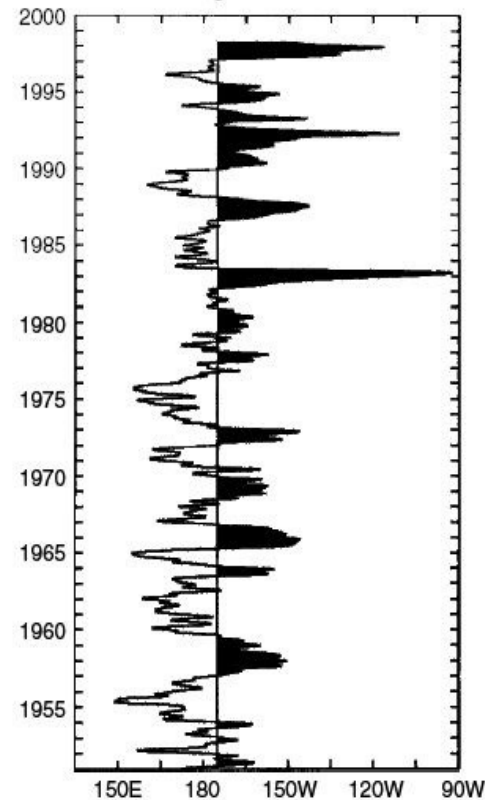


El Nino

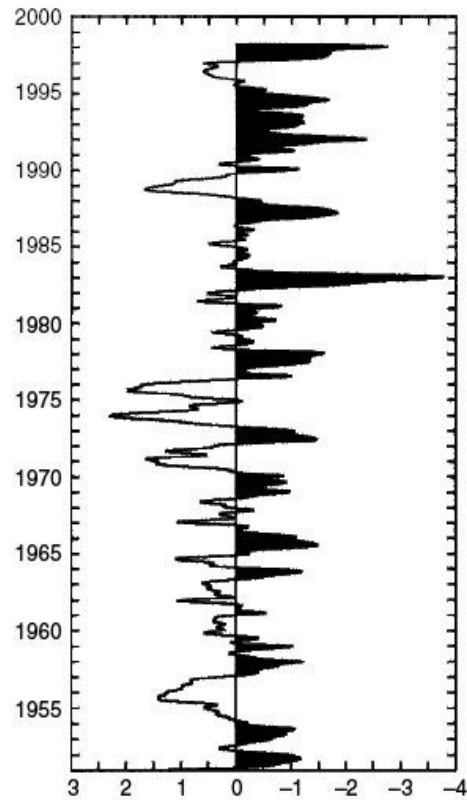


SST anomaly

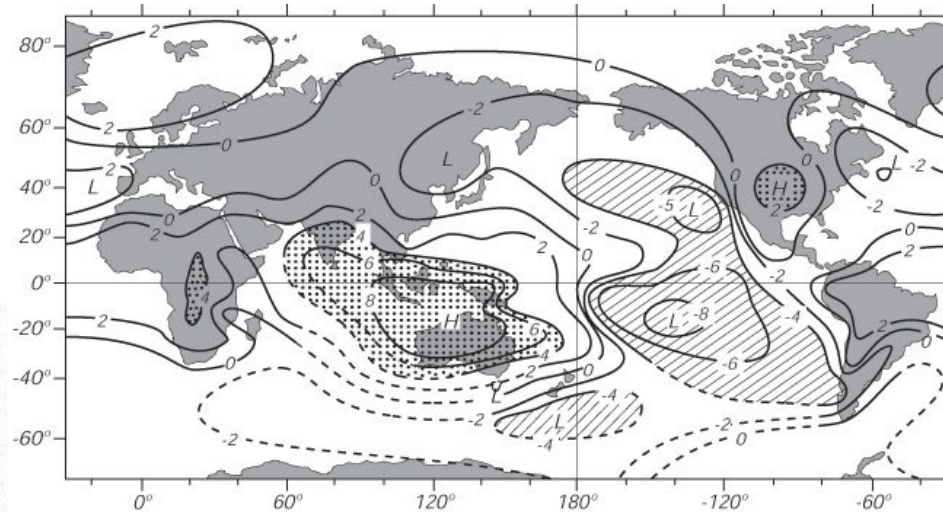
Eastern edge of the 28.5°C SST



Southern oscillation index

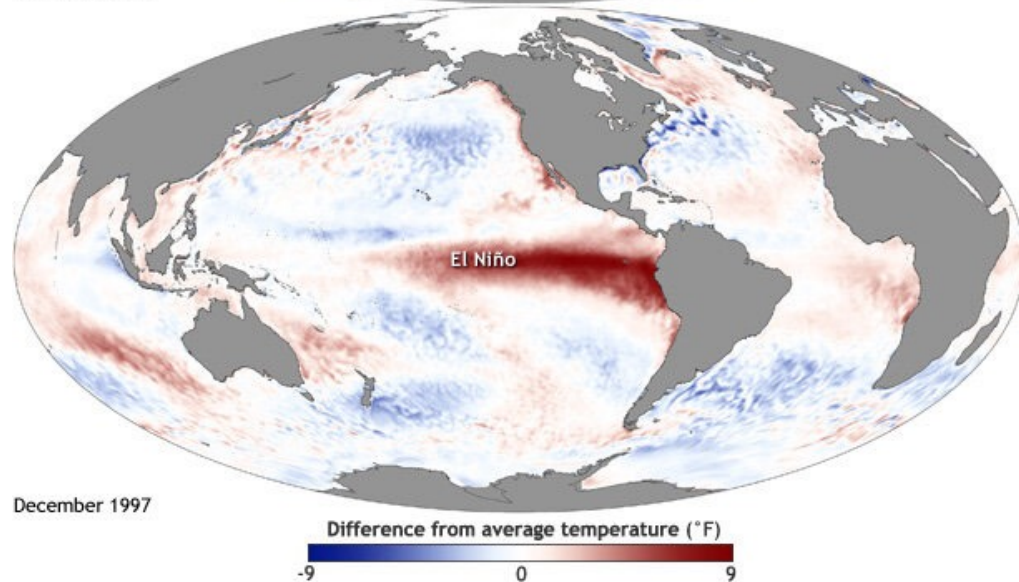
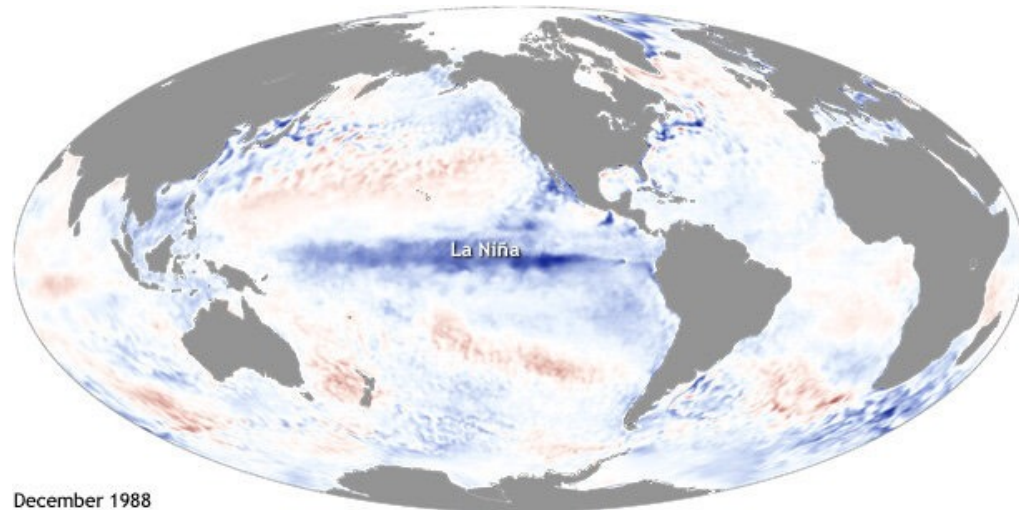
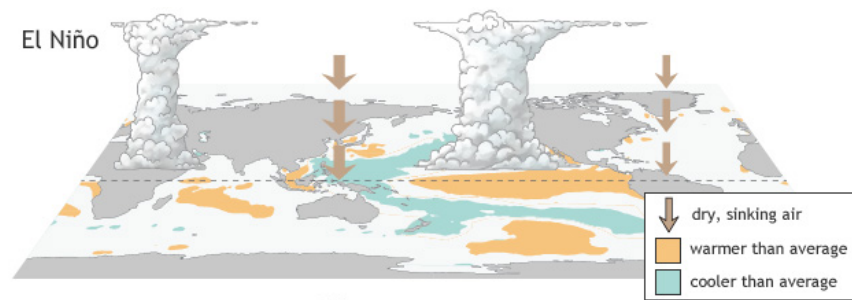
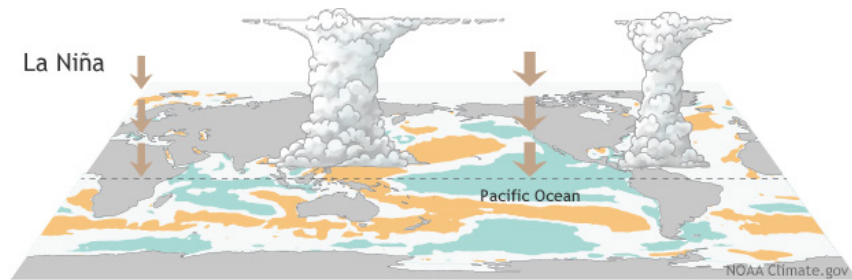


Southern Oscillation



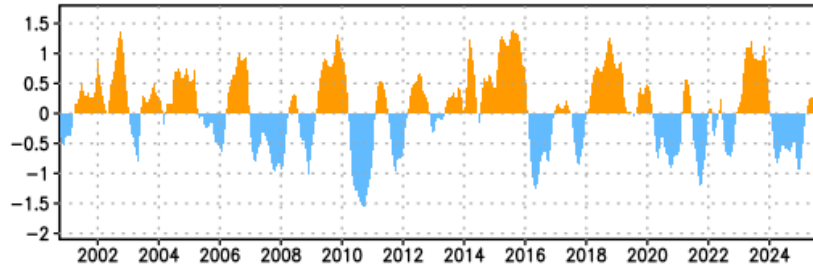
*Pressure difference
between Darwin
(Australia) and Tahiti*

El Niño and the Southern Oscillation ENSO

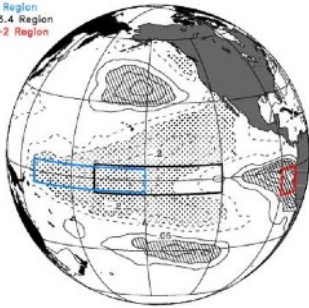


ENSO Nowcast-Forecast

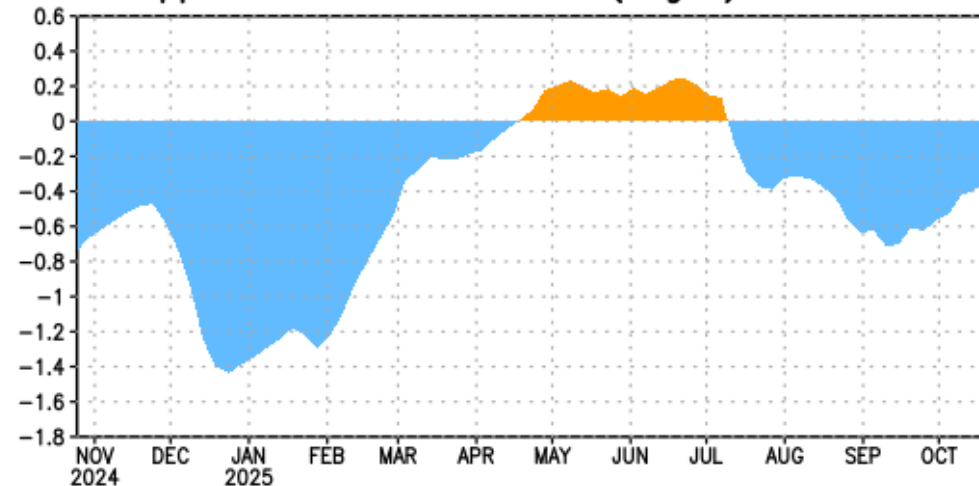
Basin-wide EQ. Upper-Ocean Heat Anoms. (deg C)



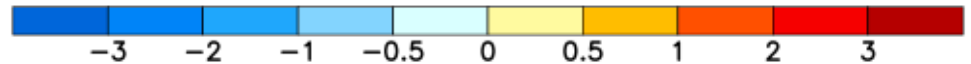
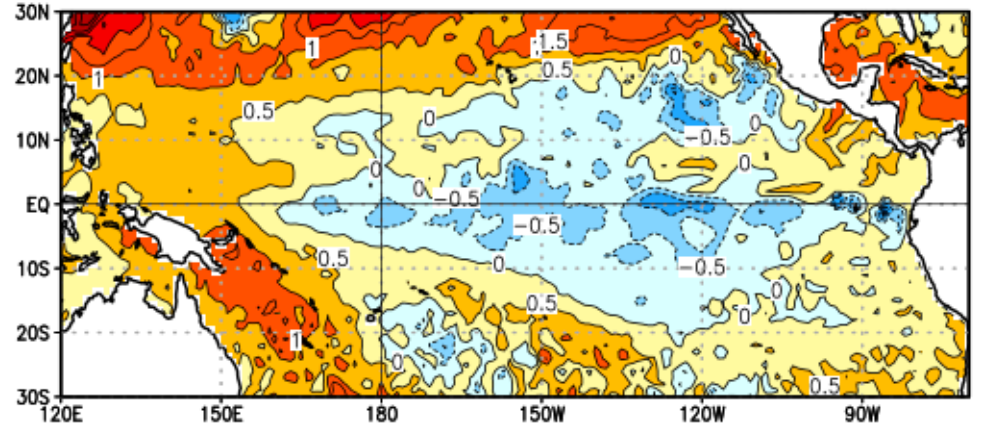
Blue = Niño 4 Region
Black = Niño 3.4 Region
Red = Niño 1+2 Region



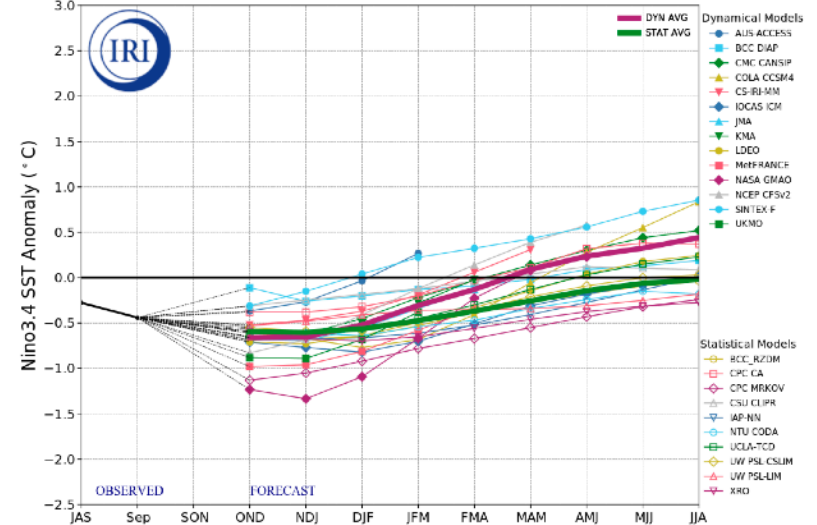
EQ. Upper-Ocean Heat Anoms. (deg C) for 180–100W

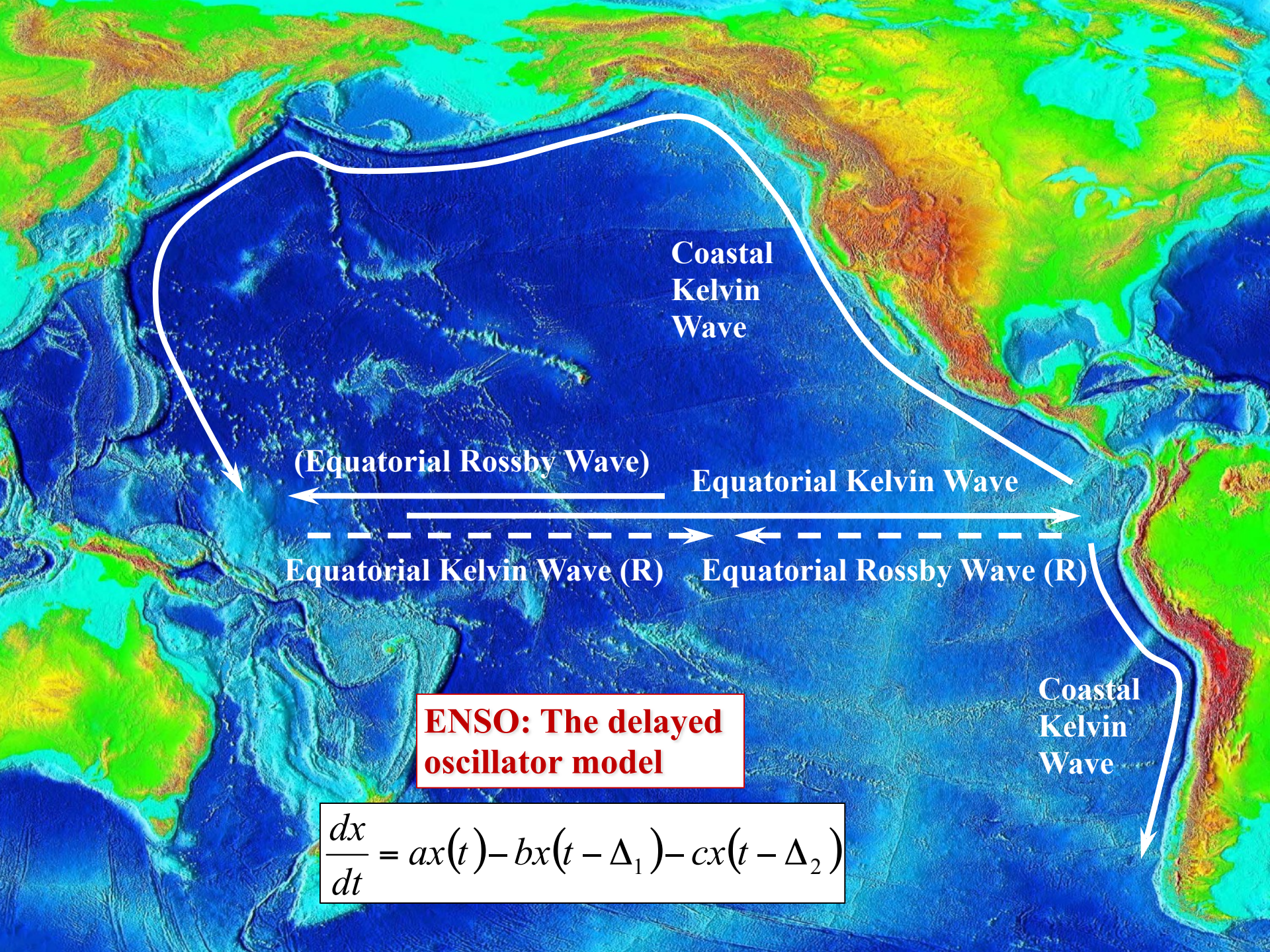


Average SST Anomalies
28 SEP 2025 – 25 OCT 2025



Model Predictions of ENSO from Oct 2025





Coastal
Kelvin
Wave

(Equatorial Rossby Wave)

Equatorial Kelvin Wave

Equatorial Kelvin Wave (R)

Equatorial Rossby Wave (R)

Coastal
Kelvin
Wave

**ENSO: The delayed
oscillator model**

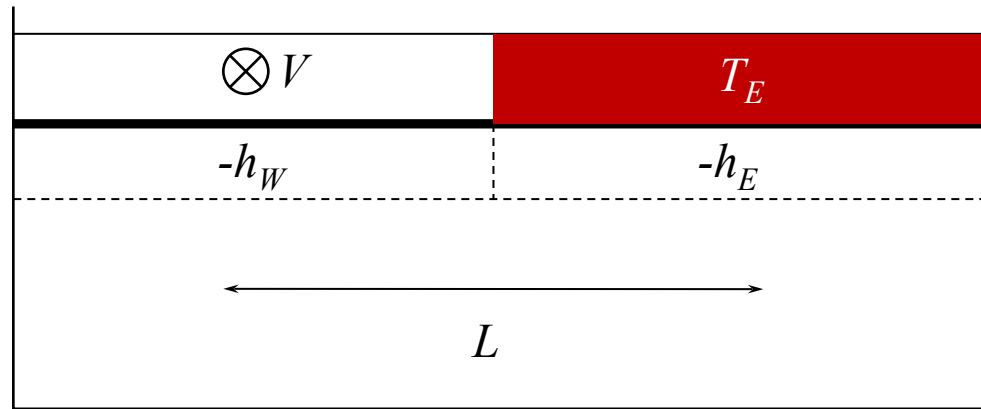
$$\frac{dx}{dt} = ax(t) - bx(t - \Delta_1) - cx(t - \Delta_2)$$

ENSO: The recharge oscillator model

Jin (1997)

West Pacific

H



East Pacific

along the equator (0°N)

• Dynamics

pressure-gradient/wind-stress balance:

$$g' \frac{h_E - h_W}{L} = \frac{\tau}{\rho_0 H}$$

• Conservation of volume

compensating meridional flux:

(from each side of the equatorial zone)

$$\frac{dh_W}{dt} = -D - r h_W$$

Assuming the **atmosphere** adjust immediately to temperature anomaly T_E

$$\tau = \mu T_E$$

• Heat budget

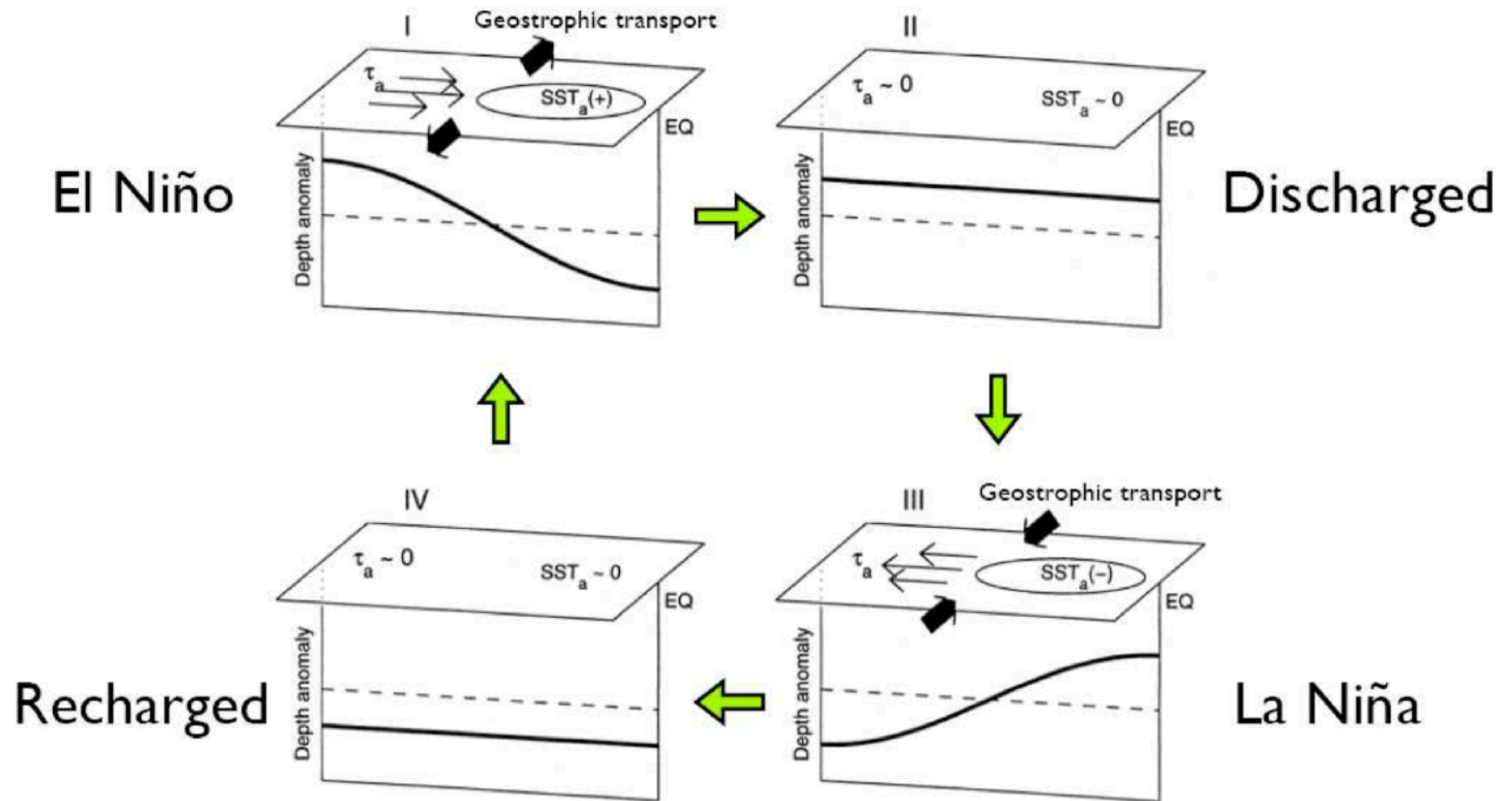
a. Advection of temperature

b. Vertical advection

$$\begin{aligned} \frac{dT_E}{dt} = & - \left(r' + \frac{\bar{w}}{H} \right) T_E + \\ & + \frac{\bar{w} \Delta_v T}{H^2} h_E + \left(\gamma \frac{\Delta_h T}{L} + \alpha \frac{\Delta_v T}{H} \right) \tau \end{aligned}$$

$$\frac{dh_W}{dt} = - \frac{\mu}{\rho \beta_0 R_{eq}^2} T_E - r h_W$$

$$\frac{dT_E}{dt} = \left[\mu \left(\gamma \frac{\Delta_h T}{L} + \alpha \frac{\Delta_v T}{H} + \frac{\bar{w} L \Delta_v T}{H^3 g' \rho_0} \right) - r' - \frac{\bar{w}}{H} \right] T_E + \frac{\bar{w} \Delta_v T}{H^2} h_W$$



Jin (1997)

Simulation of the “recharge-discharge oscillator in Matlab

