

Oceanografia Física

parte 2: Circulação oceânica

PPG em Oceanografia Física, Química e Geológica
2014

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1^a Aula

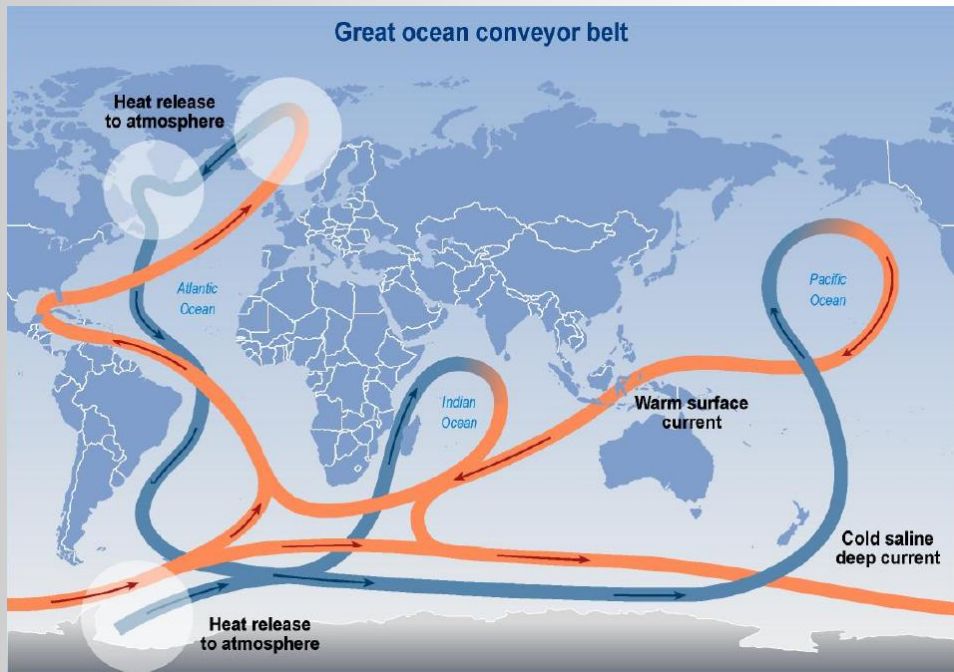
Tópicos a serem abordados

- As escalas envolvidas;
- A Radiação eletromagnética, cinturões de pressão atmosférica;
- As principais forçantes da circulação oceânica;
- Circulação termohalina e *Conveyor Belt*.
- Circulação do Oceano Atlântico

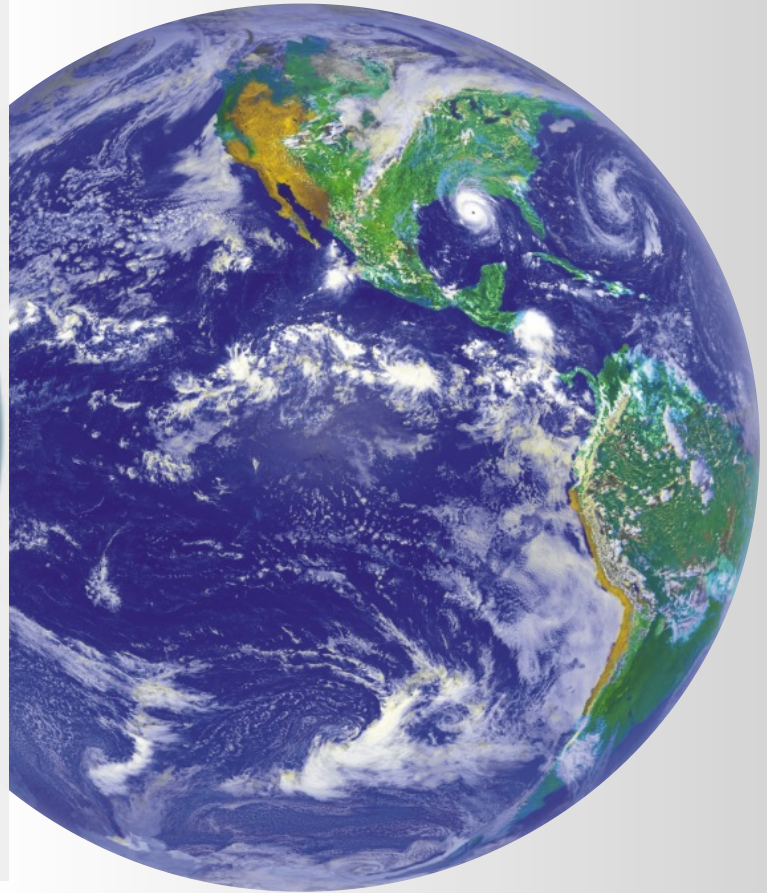
Introdução

- Os primeiros três metros dos oceanos armazenam a mesma quantidade de calor que toda a atmosfera. Este calor é liberado e reabsorvido regularmente em um ciclo do oceano para atmosfera e vice-versa. Conseqüentemente, é fundamental o conhecimento da circulação oceânica para o para que o regime climático dos nosso planeta (e suas mudanças) possa ser compreendido em escalas temporais da ordem de décadas. Em escalas menores, padrões atípicos na taxa e tamanho desta interação oceano-atmosfera pode causar eventos meteorológicos extremos (furacões, enchentes, secas, etc).

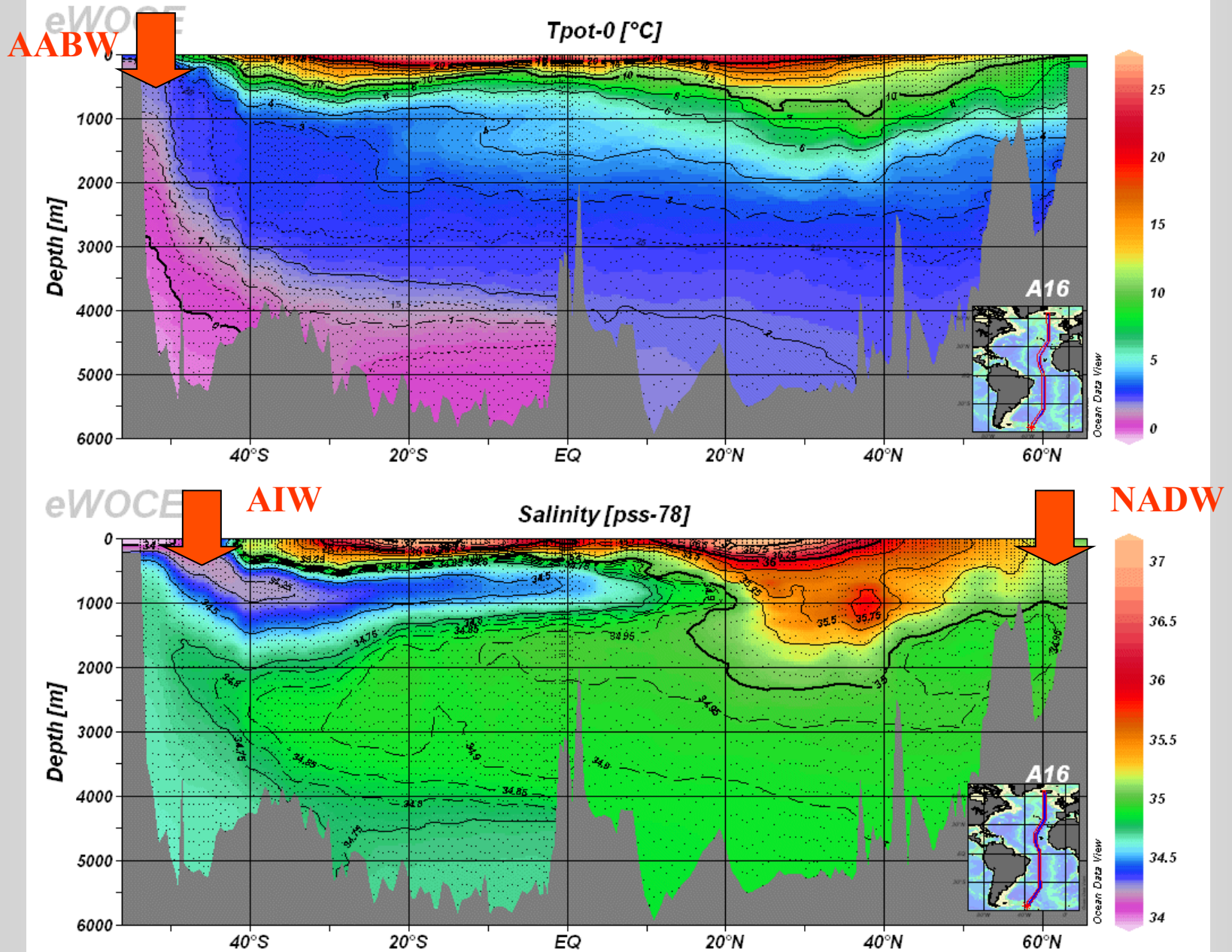
Great ocean conveyor belt



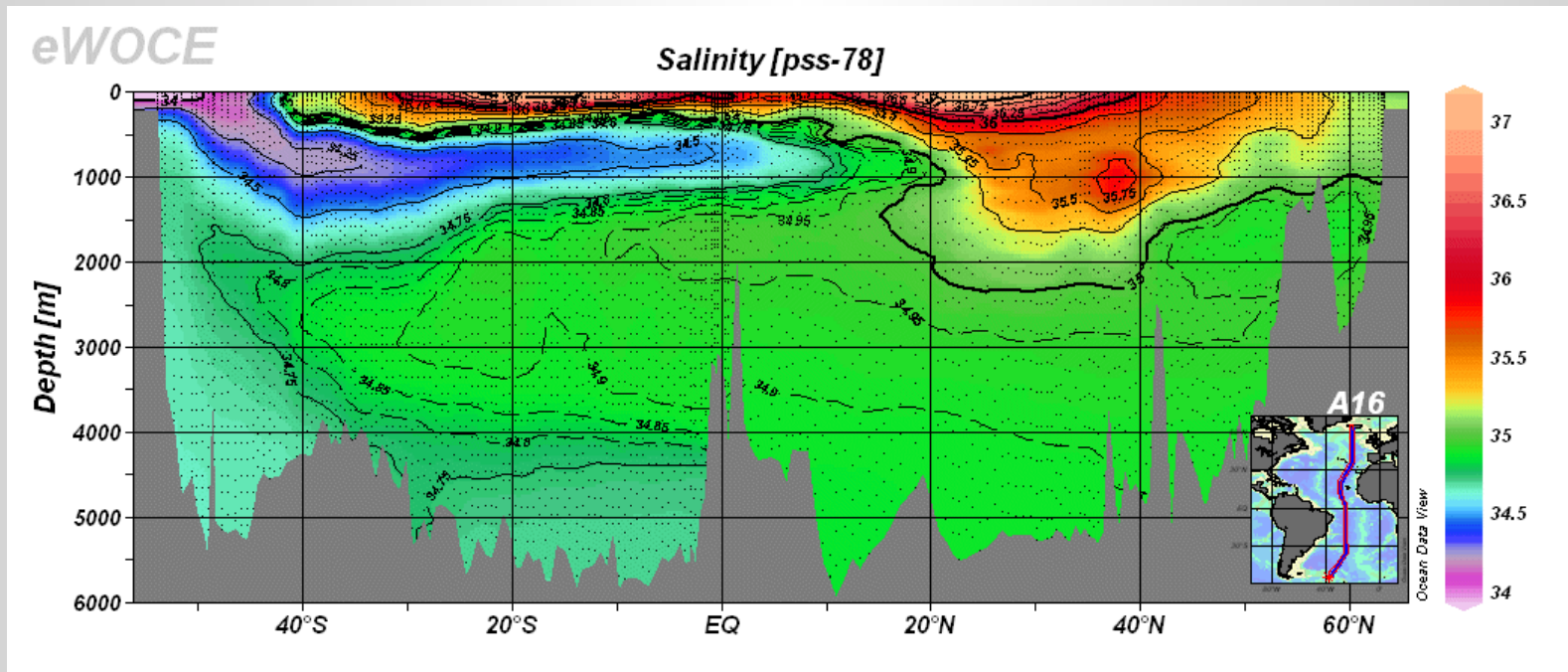
Escalas: “A Terra é uma bola de futebol molhada”. D. Olbers



Atlantic WOCE A16 Section – Theta e Salinidade



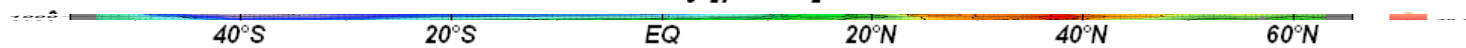
← 15.000 km →



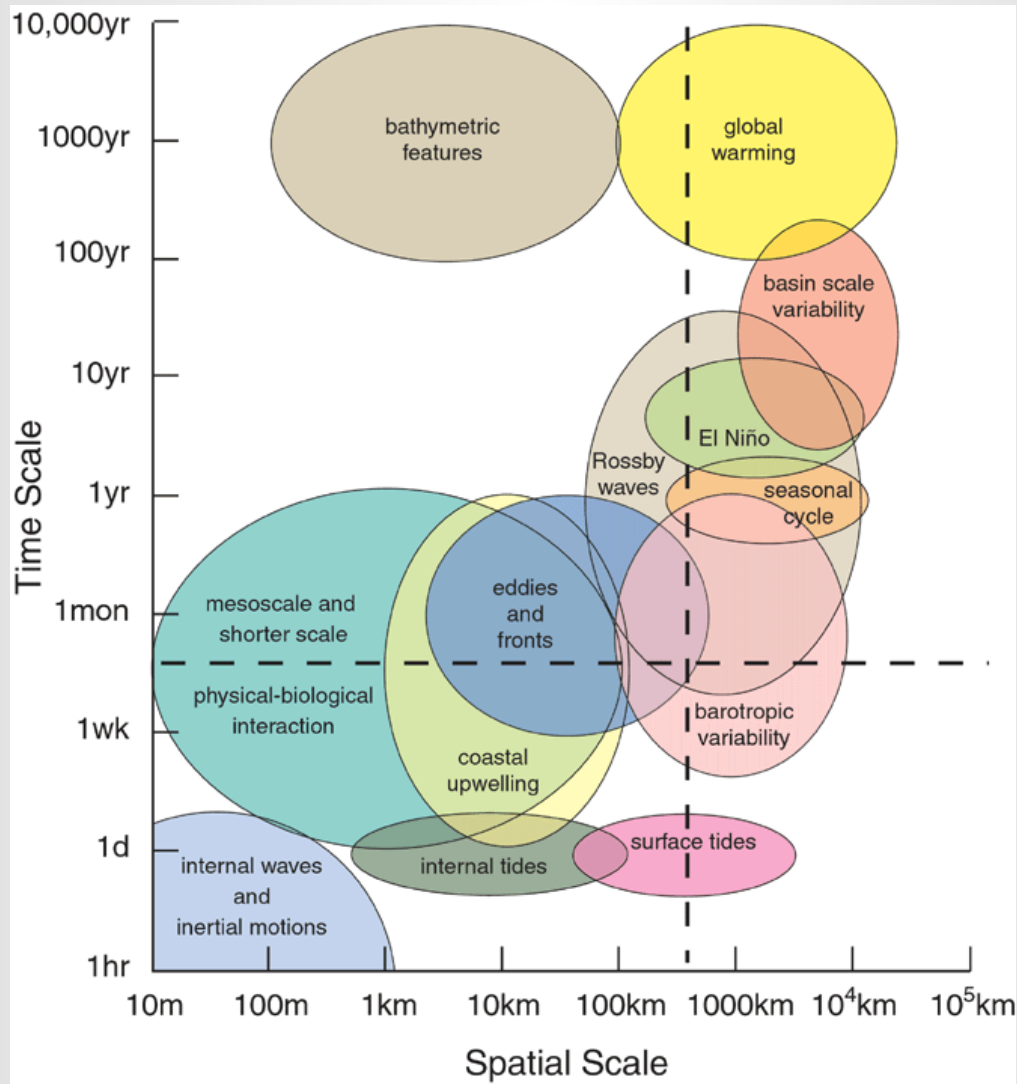


eWOCE

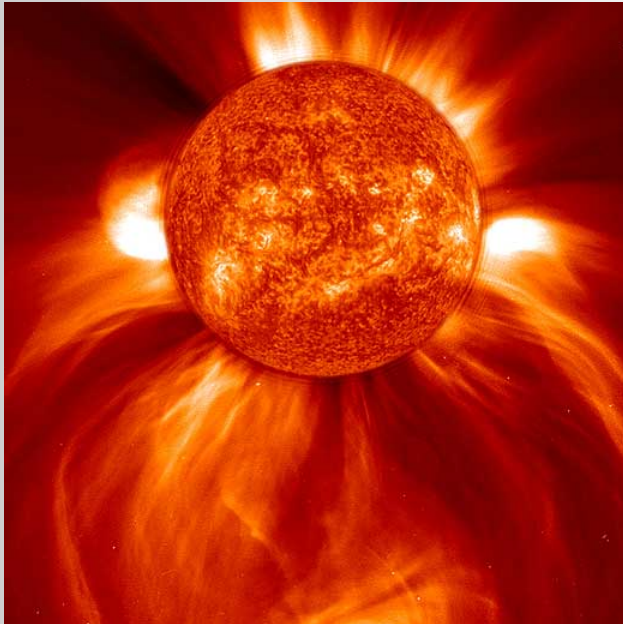
Salinity [pss-78]



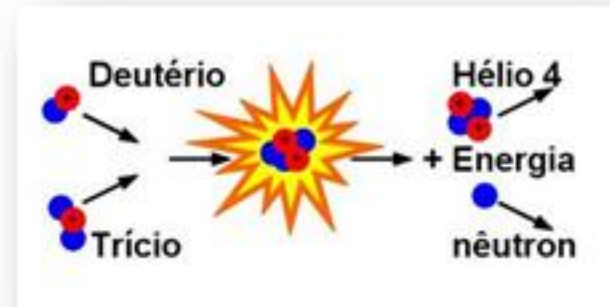
Escalas x Movimentos Oceânicos



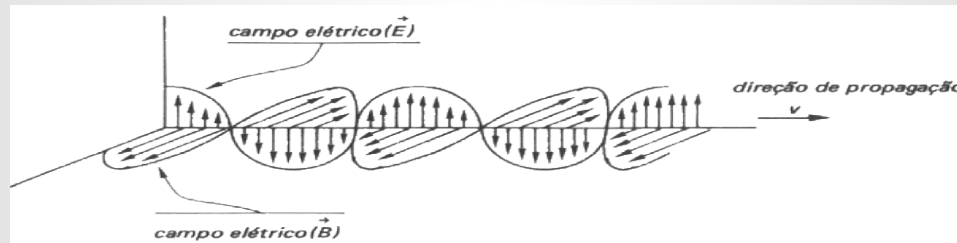
A origem



Fusão Solar

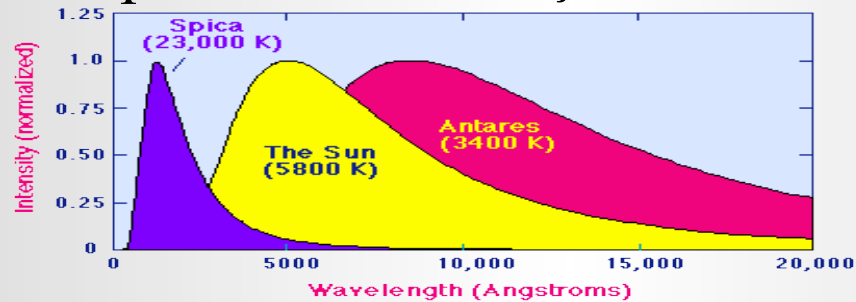


Os gases de hidrogênio (deutério e o trítio, isótopos do hidrogênio) se chocam e formam o hélio e uma partícula atômica chamada de nêutron. Como há uma pequena perda de massa no meio do processo, ela se torna uma quantidade de energia enorme e juntando com a alta temperatura do sol no núcleo, que é aproximadamente $15,7 \times 10^6$ K (Kelvin), ela continua o processo de fusão dos gases de hidrogênio formando o hélio até acabar a sua matéria-prima (este processo levará cerca de 7 bilhões de ano).

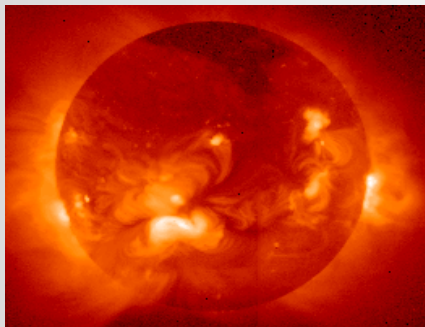


Note que o campo elétrico é perpendicular à direção de propagação e o campo magnético também, o que comprova que a onda eletromagnética é uma onda ***transversal***.

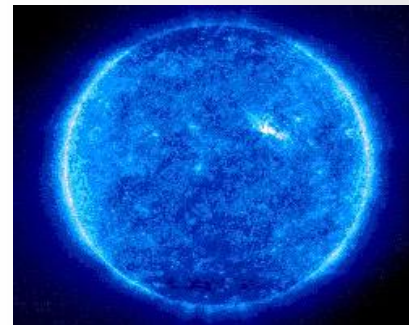
Espectros de Radiação E.M.



Espectro Visível: 4000 a 7000 Å ou 400 a 750 μm .

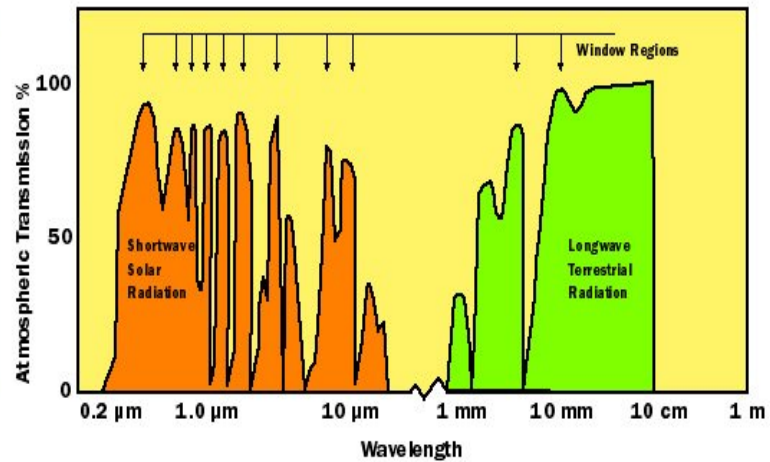
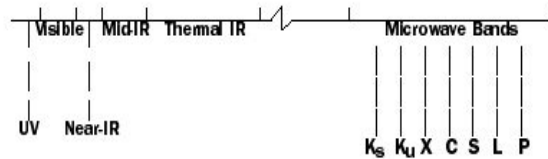
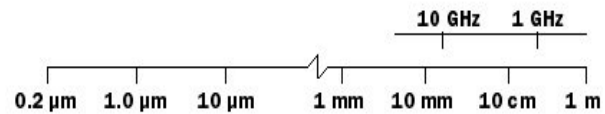
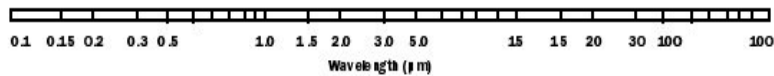
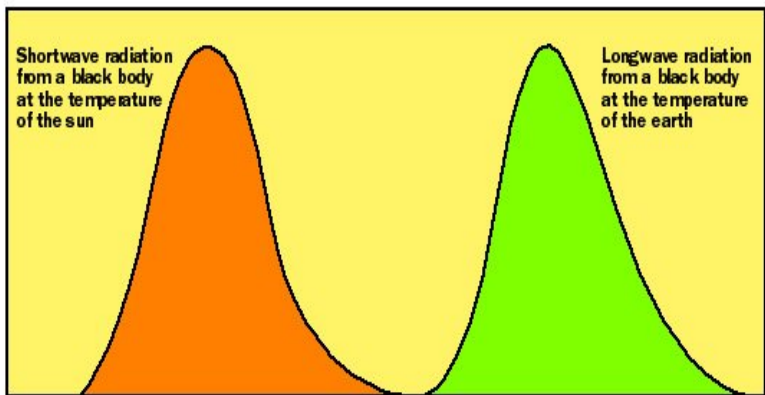


Sol (λ =raios-X)

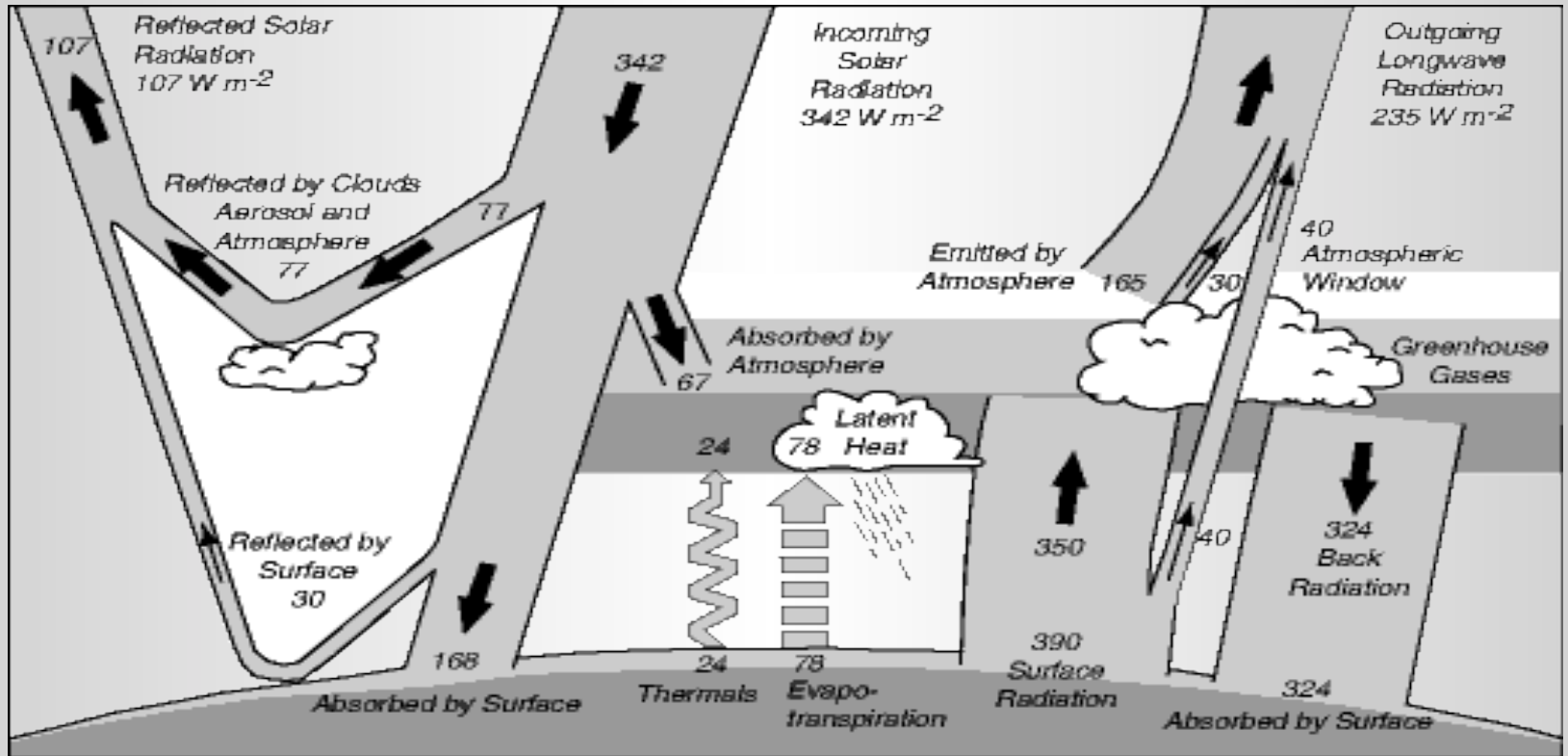


Sol (λ =UV)

λE_λ (normalised)



Balanço de Calor



The mean annual radiation and heatbalance of the earth. From Houghton et al. (1996: 58), which used data from Kiehl and Trenberth (1996).

Forças que atuam nos oceanos

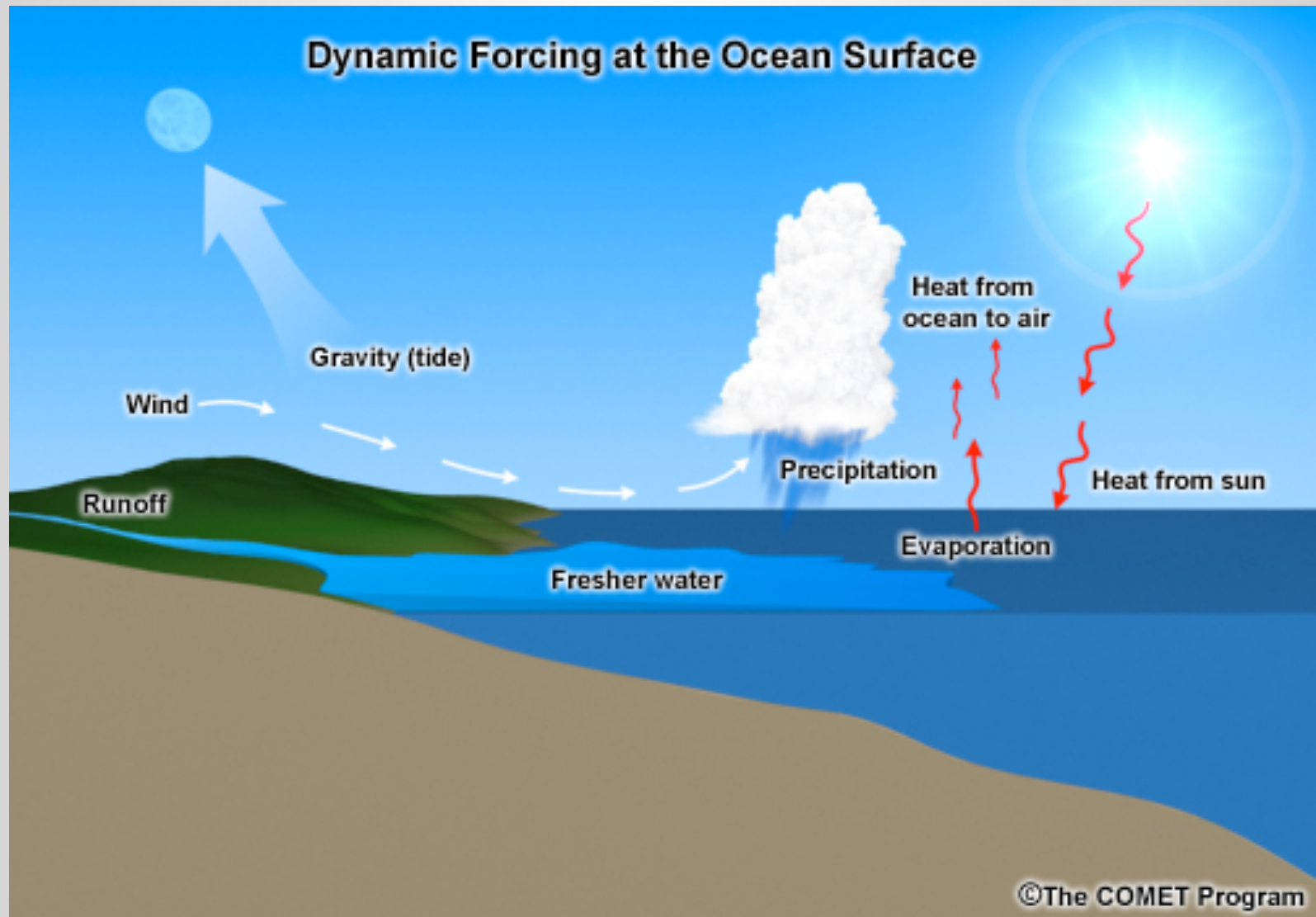
– PRIMÁRIAS

- Cisalhamento do Vento (wind stress)
- Gradiente de Pressão / Densidade
- Gravidade

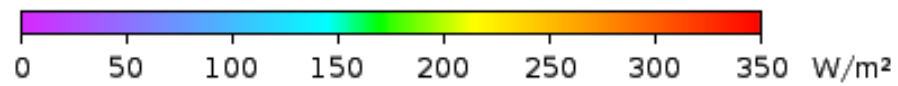
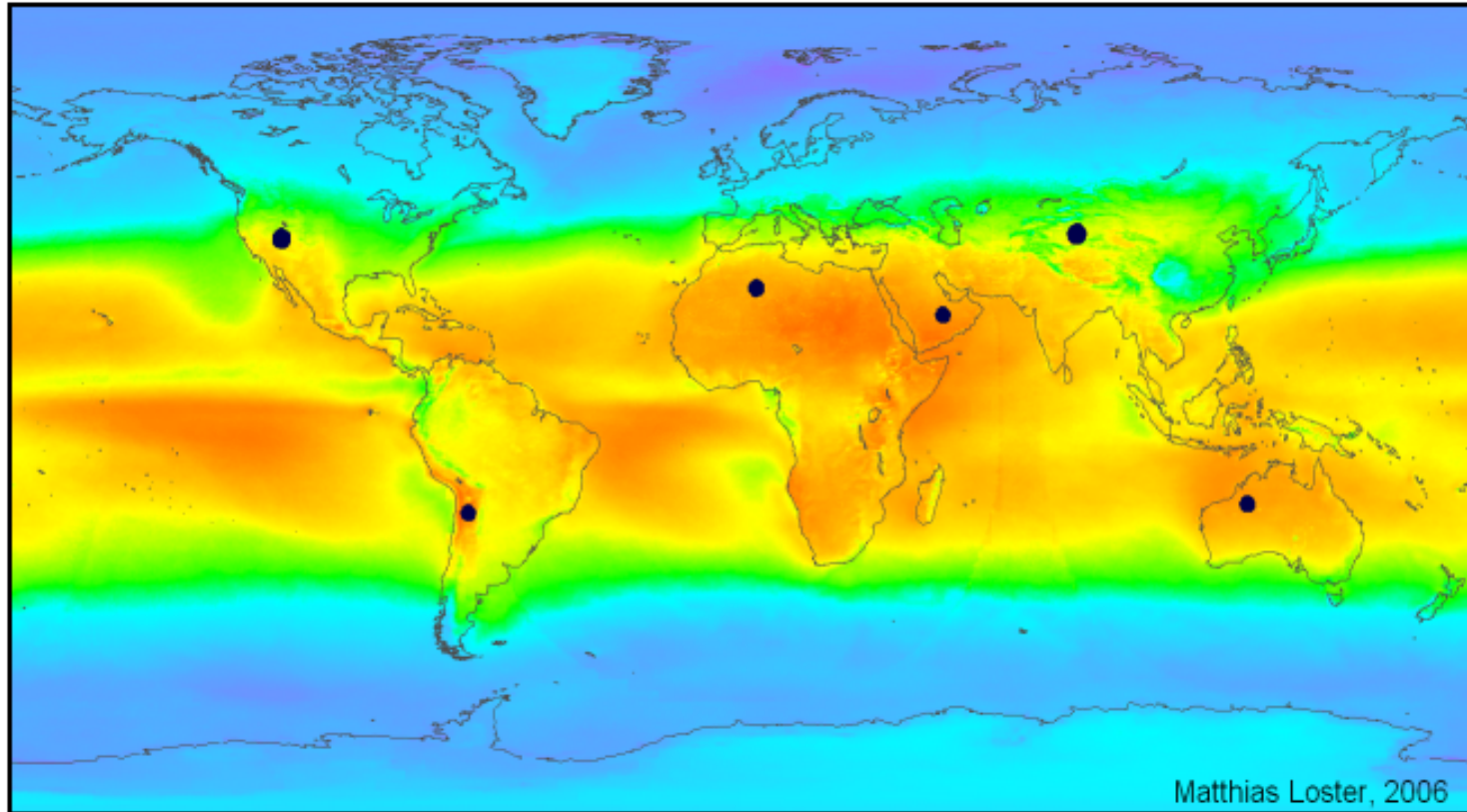
– SECUNDÁRIAS

- Coriolis
- Atrito / Fricção

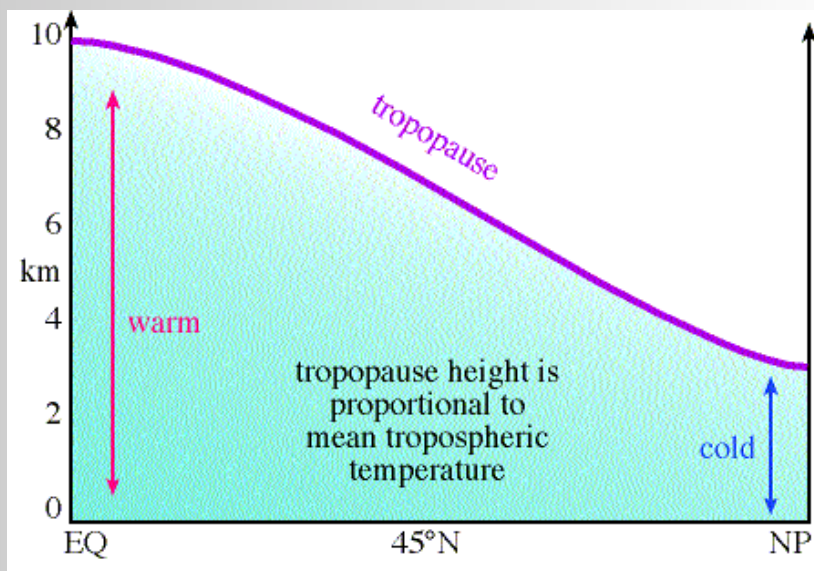
Dynamic Forcing at the Ocean Surface



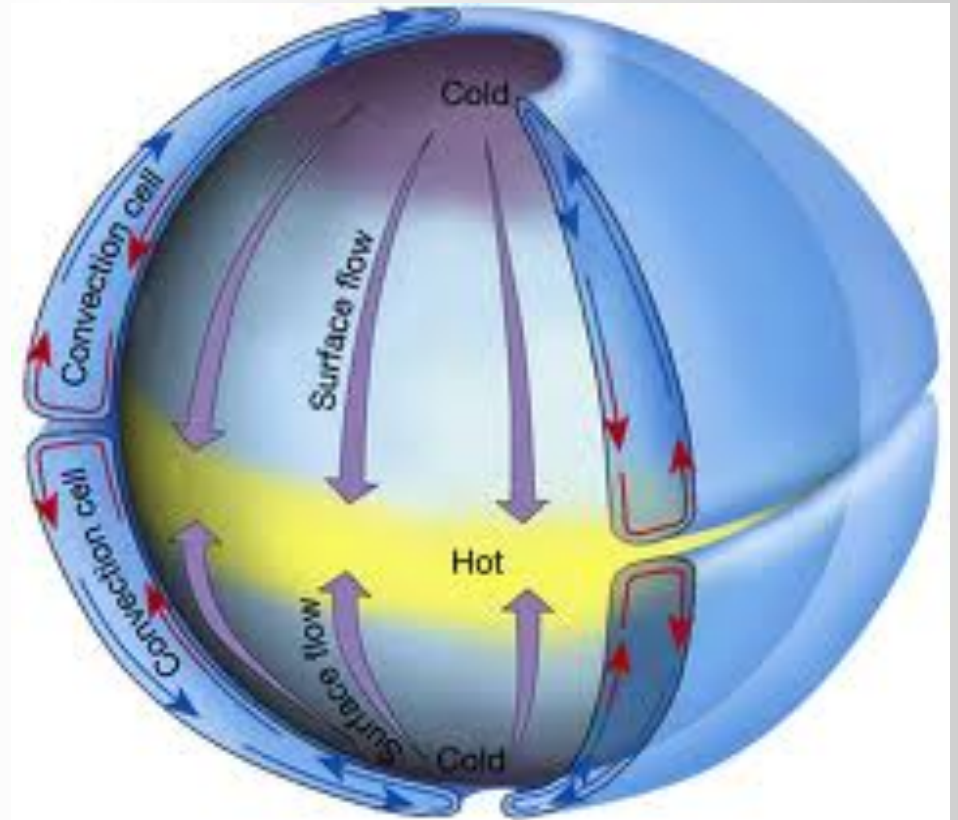
Insolação média (1991 -1993)



$\Sigma \bullet = 18 \text{ TWe}$

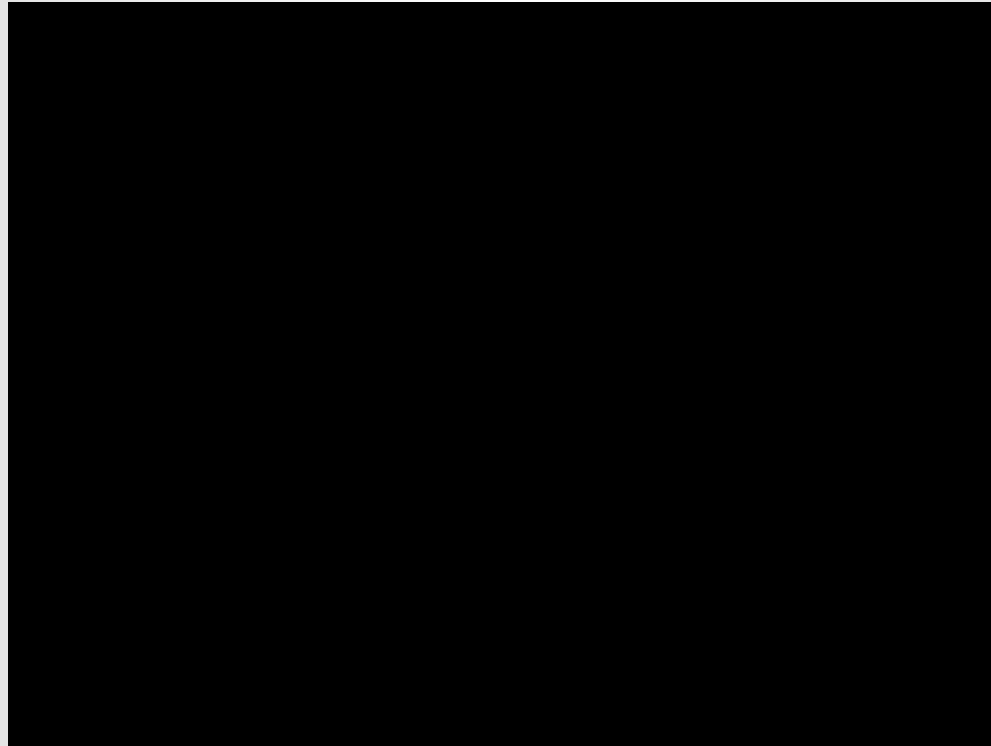


Altura da troposfera

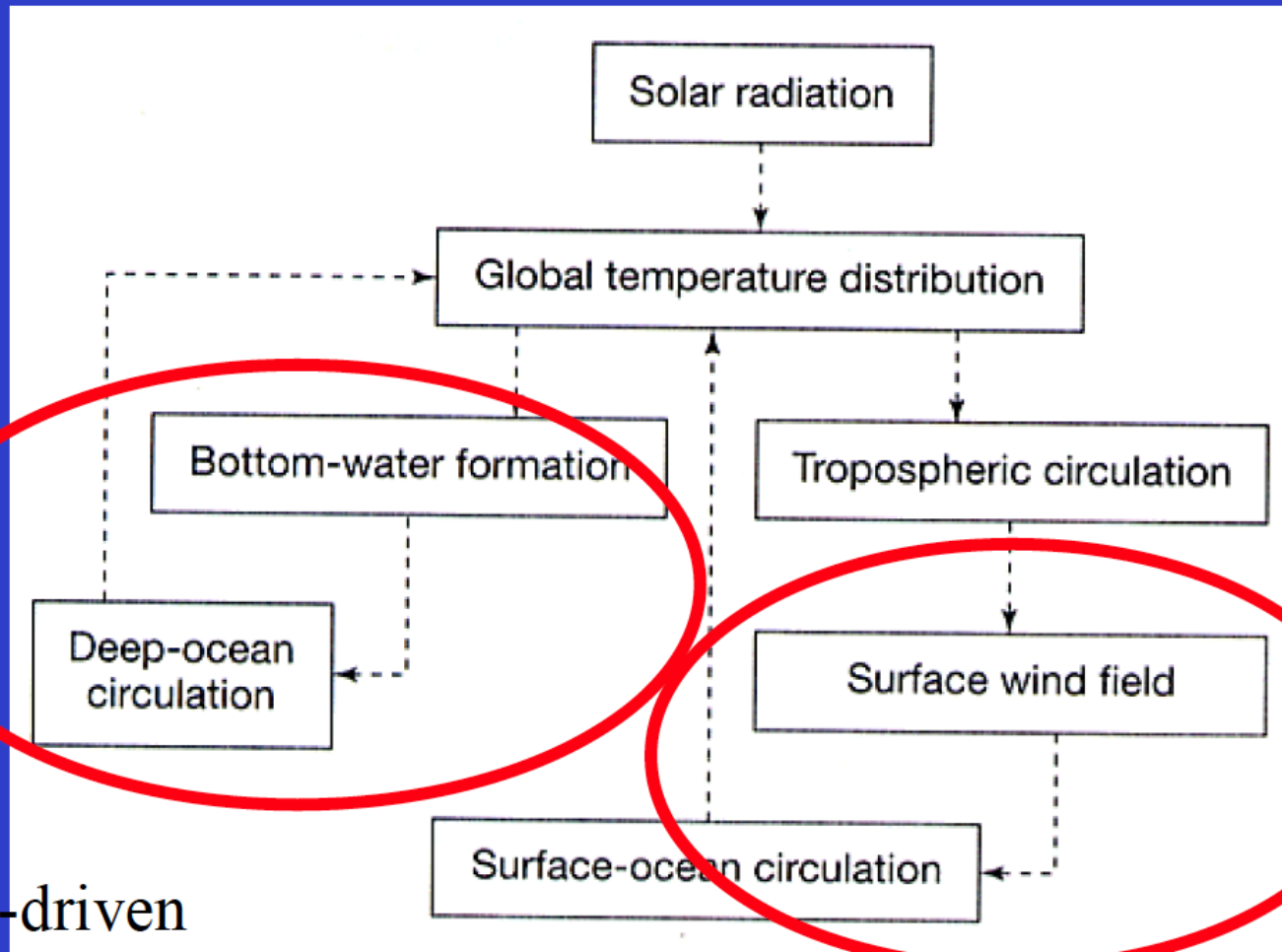


Circulação atmosférica (sem rotação)

Força de Coriolis



Two Circulation Systems



density-driven
circulation

wind-driven
circulation

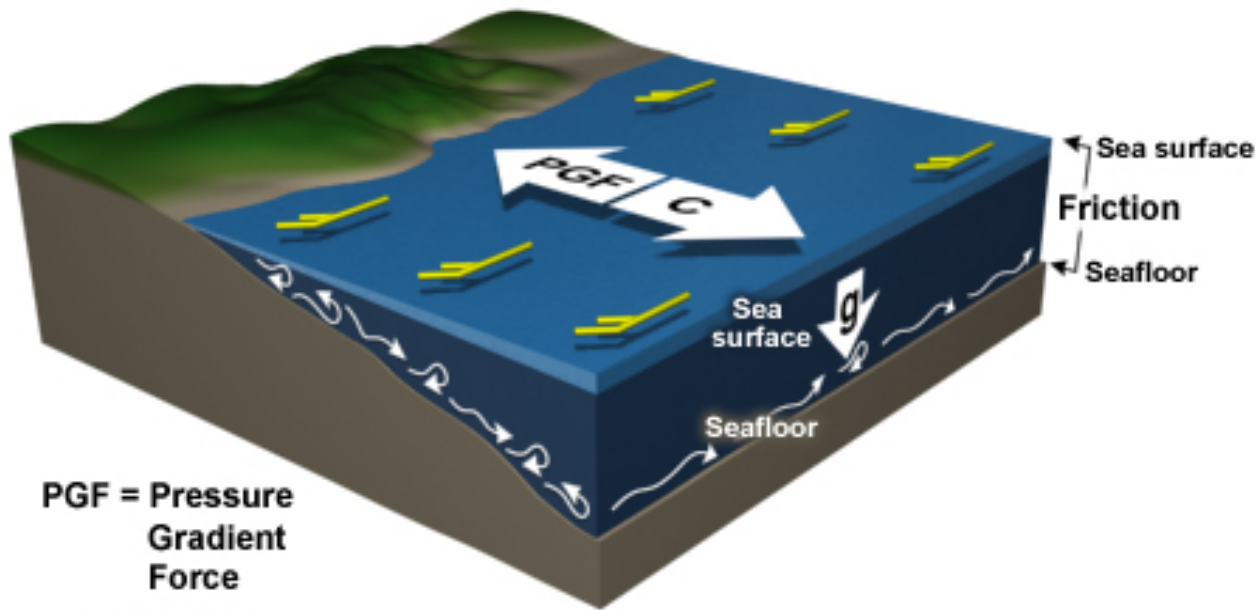
(Figure from *The Earth System*)



2a aula

Forces Acting on a Parcel of Seawater

$$\mathbf{F} = \text{PGF} + \mathbf{C} + \mathbf{g} + \mathbf{Fr}$$



PGF = Pressure
Gradient
Force

g = Gravity

C = Coriolis

Fr = Friction (wind at surface, current at sea floor, between currents)

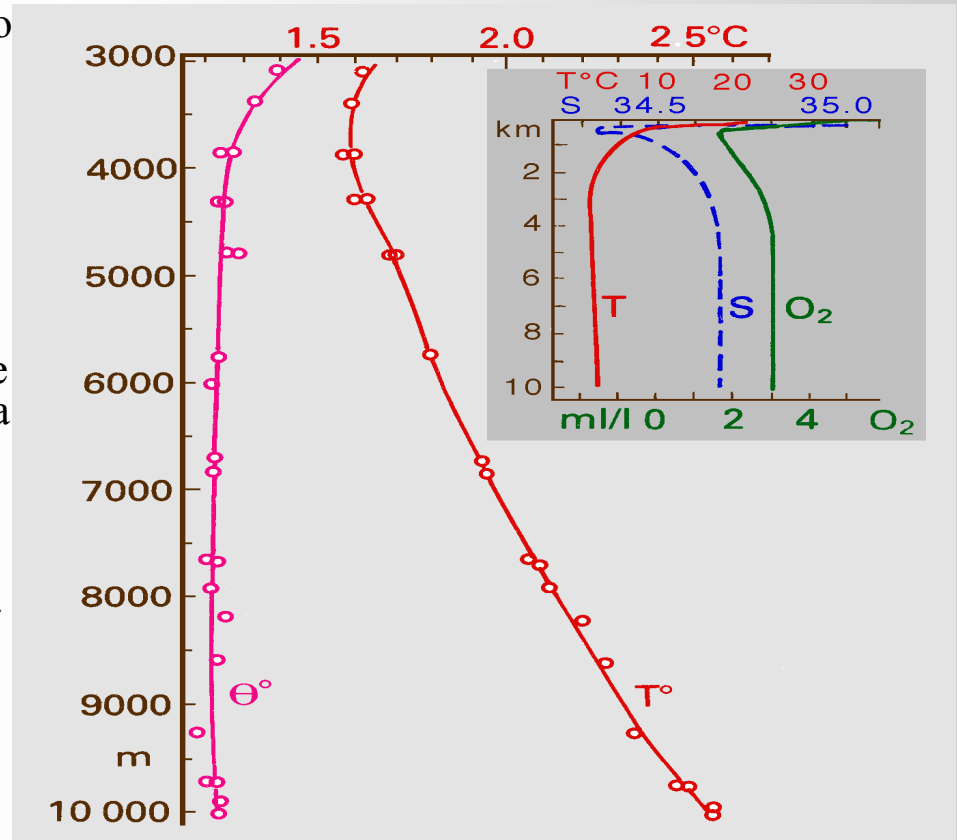
©The COMET Program

$$\frac{D\mathbf{v}}{Dt} = -\frac{1}{\rho} \nabla p - 2\boldsymbol{\Omega} \times \mathbf{v} + \mathbf{g} + \mathbf{F}_r$$

O campo de Pressão nos oceanos

- Grande parte das correntes oceânicas pode ser adequadamente descrita conhecendo-se o campo de pressão (analogia com a atmosfera).
- A pressão em um determinado ponto do oceano é definida como o peso da água acima deste ponto. Este peso, por sua vez, é função da altura da coluna d' água em questão e da sua densidade.
- Como $\rho(S,T,p)$, é possível estimar a distribuição de pressão nos oceanos e, portanto, o regime de correntes a partir de medidas de S,T realizadas, por exemplo, por um CTD.

- $\rho(S,T,p)$ é determinada pela equação de estado da água do mar com precisão de 0.03 kg/m^3 (Millero & Poisson, 1981).
- Como, no entanto, estamos estimando o campo de pressão a partir de ρ e esta por sua vez esta sendo estimada por variáveis que são função da pressão (como T), temos que levar isto em consideração.
- A figura ao lado mostra um perfil profundo de temperatura. Note como a temperatura medida aumenta com a profundidade abaixo dos 3000m. No entanto, a sua 'TEMPERATURA POTENCIAL', i.e., descontando o efeito da enorme pressão nas profundidades abissais continua decrescendo. Assim, para descontar estes efeitos, oceanógrafos usam as quantidades potenciais abaixo dos 1000 dbar (m) de profundidade.



Perfil hidrográfico na fossa das Filipinas (Bruun et al, 1956)

Enquanto encontra-se significativas inversões da densidade in-situ, raramente, no oceano encontra-se inversões da densidade potencial

- O conhecimento do campo de densidade, portanto, é fundamental para o conhecimento do campo de pressão. A relação entre estes dois campos é a equação hidrostática:

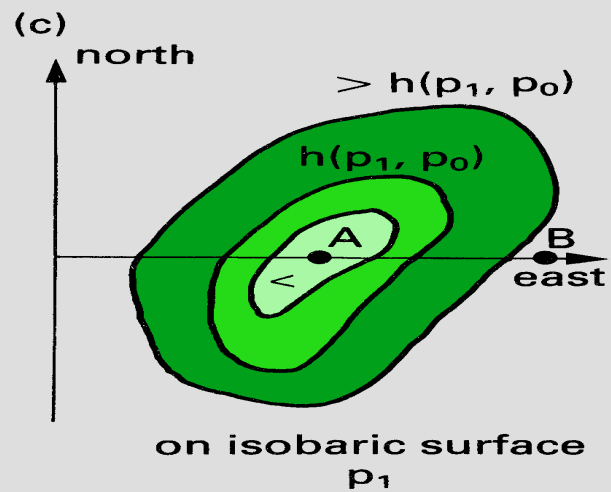
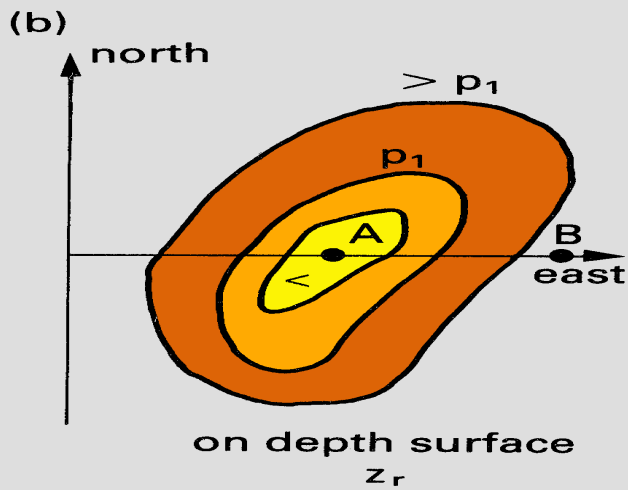
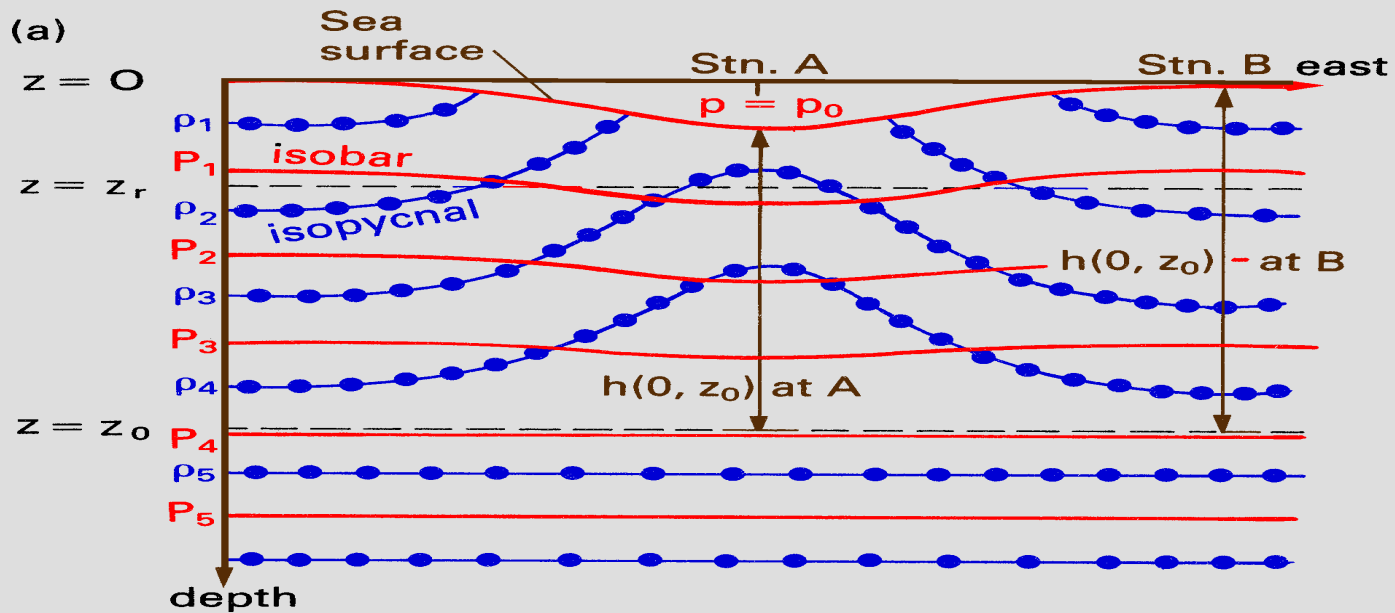
$$\partial p / \partial z = g \rho ,$$

- Para se chegar ao campo de pressão deve-se integrar verticalmente a equação acima:

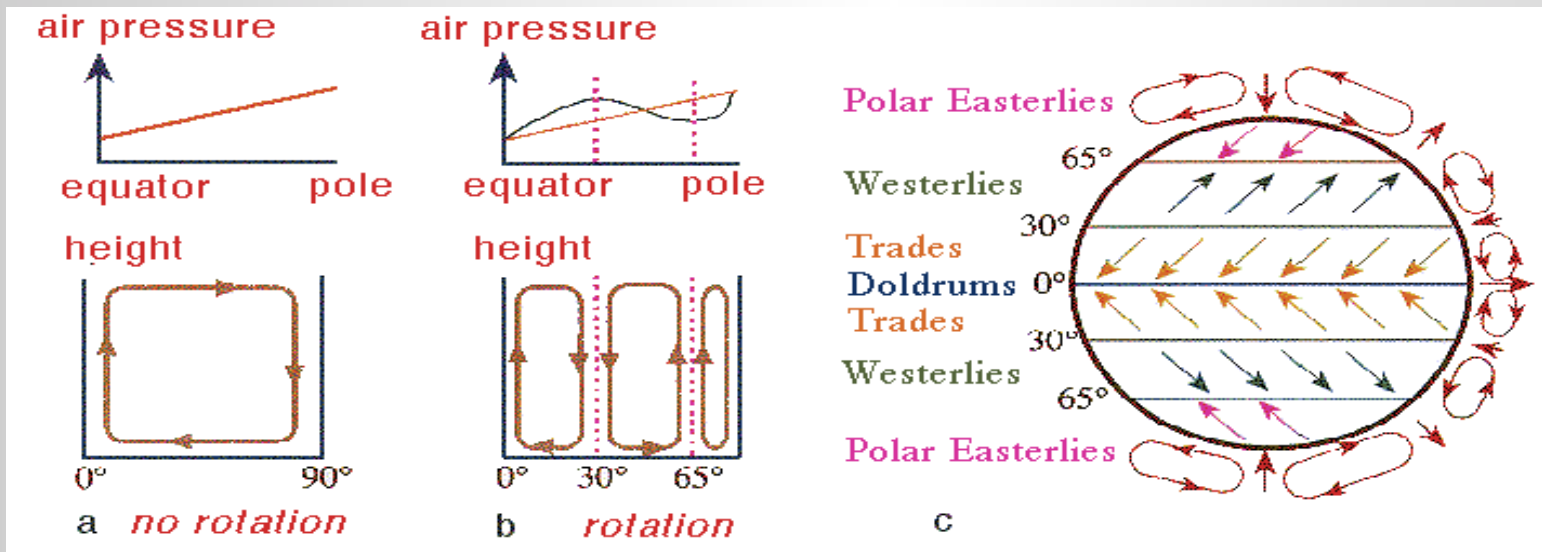
$$h (z_1 , z_2) = \int_{z_1}^{z_2} \delta (T, S, p) \rho_0 dz ,$$

A ‘h’ denominamos : altura estérica. Ou, se escrita em termos de pressão, altura dinâmica (abaixo).

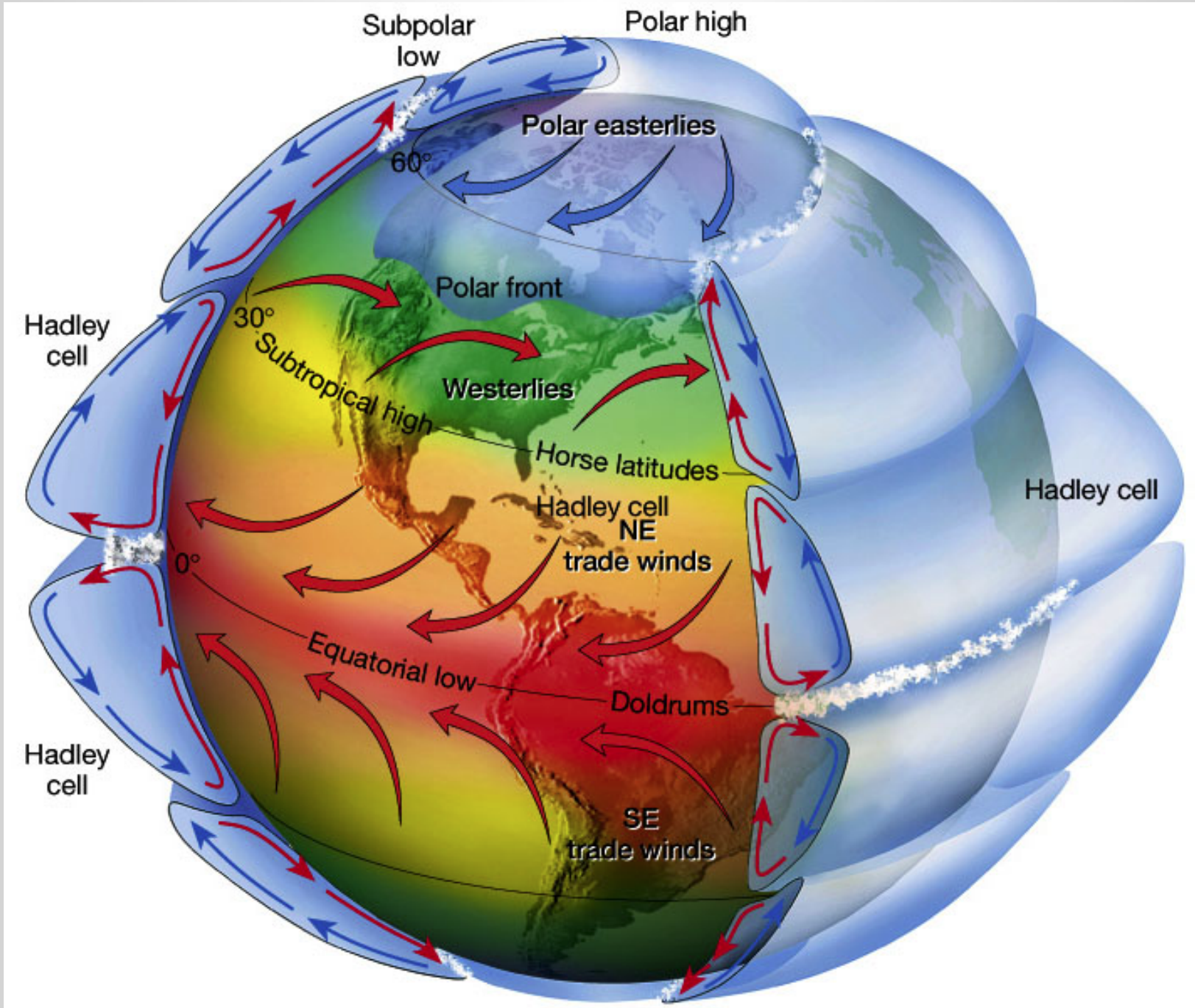
$$D (p_1, p_2) = \int_{p_1}^{p_2} \delta (T, S, p) dp$$



Cisalhamento do Vento



Schematic diagram of the meridional air pressure distribution and associated air movement (a) on a non-rotating earth, (b) on a rotating earth without continents, (c) viewed from above.



Vento e Correntes Superficiais

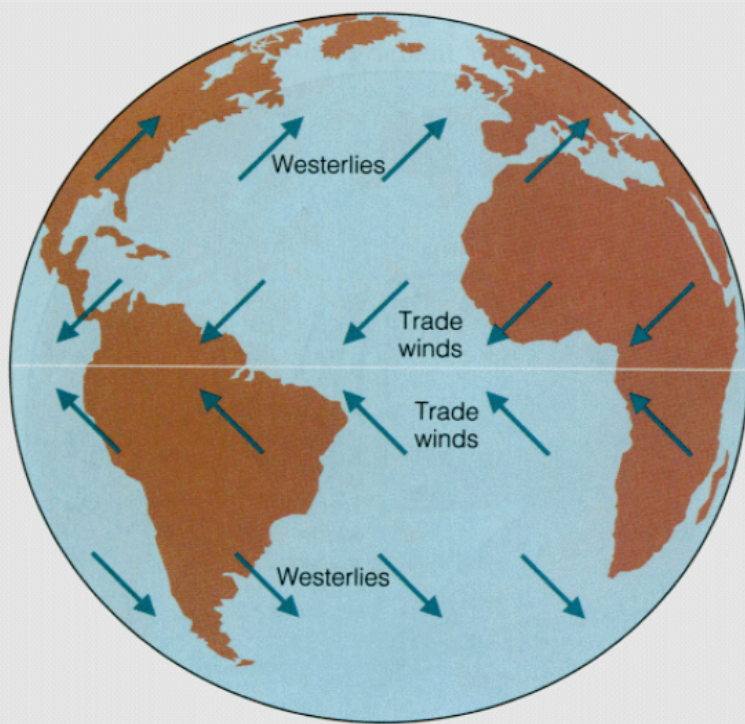


Figure 9.1 Winds, driven by uneven solar heating and Earth's spin, drive the movement of the ocean's surface currents. The prime movers are the powerful westerlies and the persistent trade winds (easterlies).

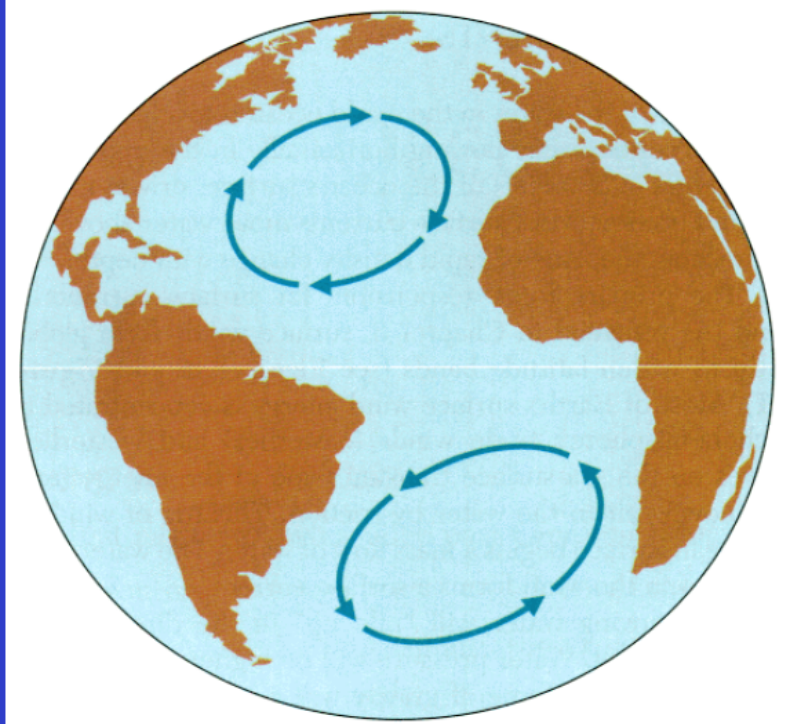
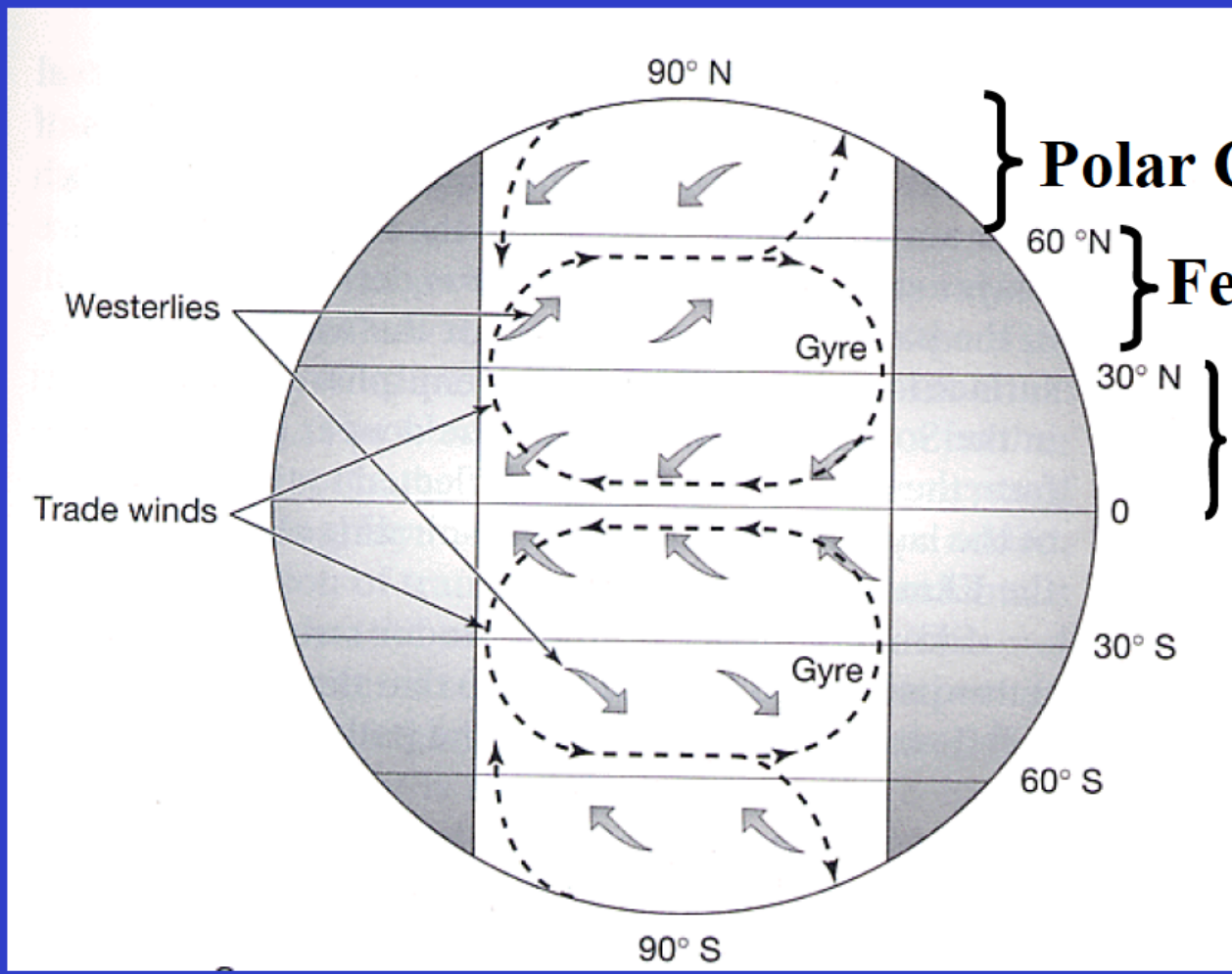


Figure 9.2 A combination of four forces—surface winds, the sun's heat, the Coriolis effect, and gravity—circulates the ocean surface clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere, forming gyres.

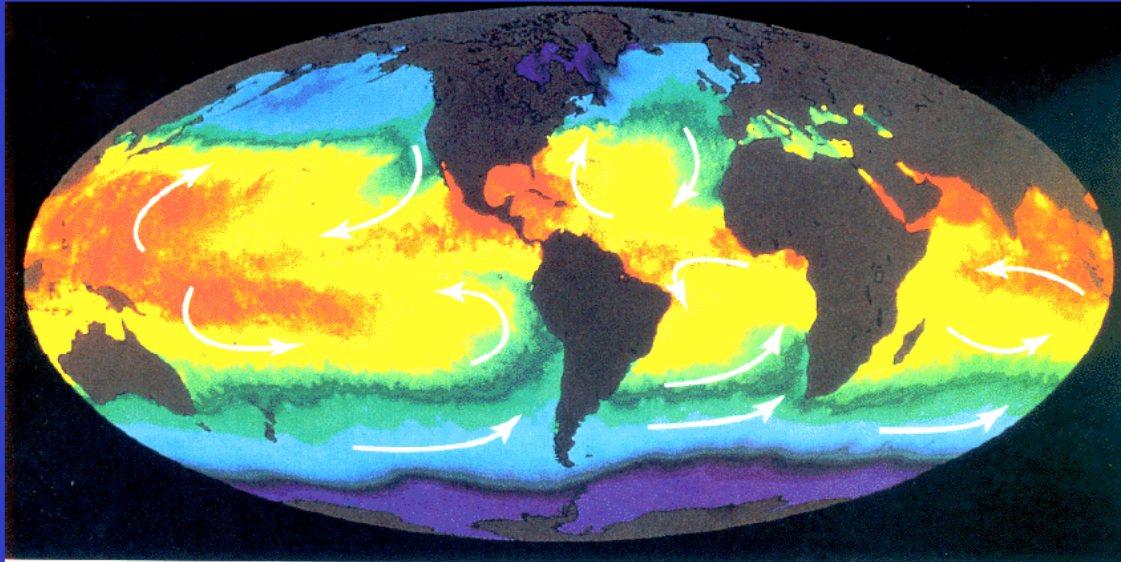


Polar Cell

Ferrel Cell

Hadley Cell

Six Great Current Circuits in the World Ocean



□ 5 of them are geostrophic gyres:

North Pacific Gyre

South Pacific Gyre

North Atlantic Gyre

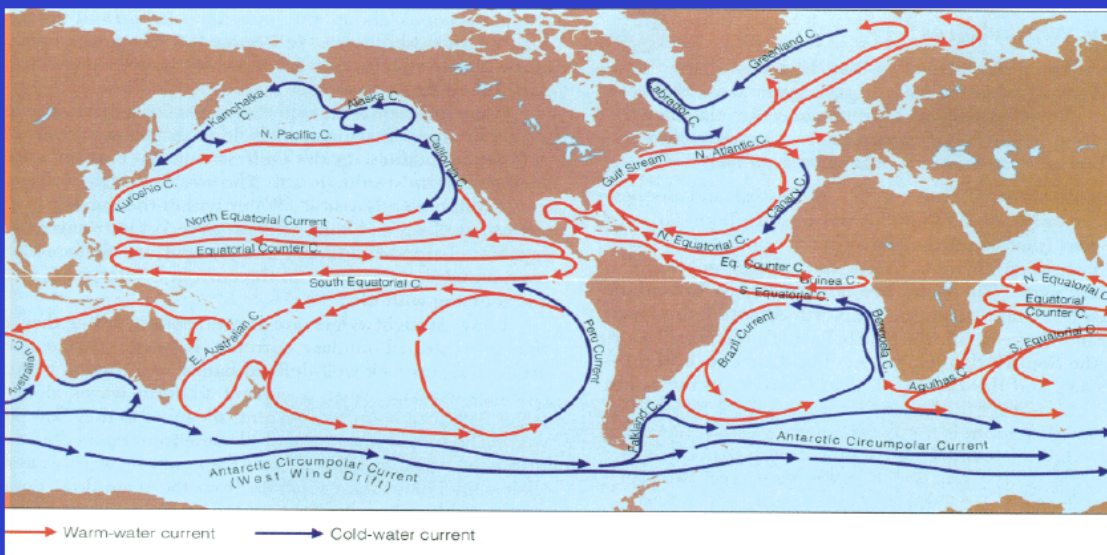
South Atlantic Gyre

Indian Ocean Gyre

□ The 6th and the largest current:

Antarctic Circumpolar Current

(also called West Wind Drift)

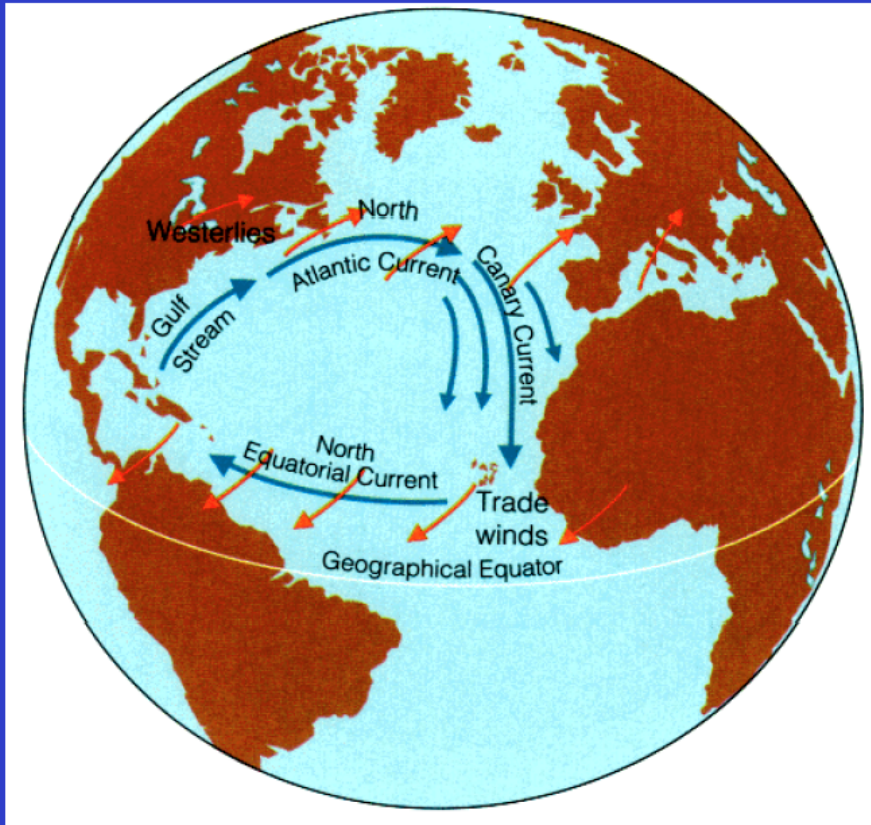


(Figure from *Oceanography* by Tom Garrison)



Characteristics of the Gyres

(Figure from *Oceanography* by Tom Garrison)



Volume transport unit:

1 sv = 1 Sverdrup = 1 million m^3/sec

(the Amazon river has a transport of ~ 0.17 Sv)

- ❑ Currents are in geostrophic balance
- ❑ Each gyre includes 4 current components:
 - two boundary currents: western and eastern
 - two transverse currents: eastward and westward

Western boundary current (jet stream of ocean)

the fast, deep, and narrow current moves warm water polarward (transport ~ 50 Sv or greater)

Eastern boundary current

the slow, shallow, and broad current moves cold water equatorward (transport $\sim 10-15$ Sv)

Trade wind-driven current

the moderately shallow and broad westward current (transport ~ 30 Sv)

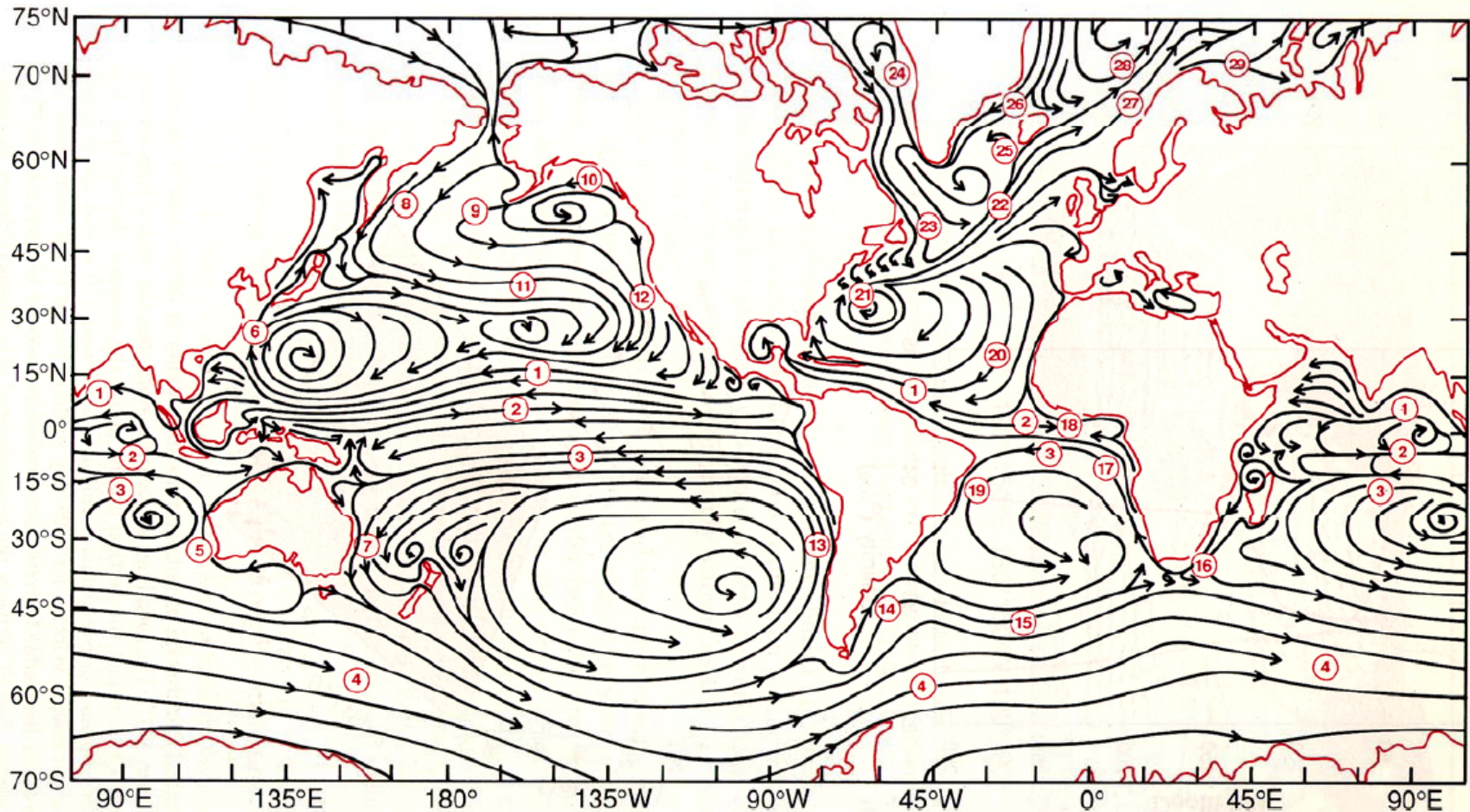
Westerly-driven current

the wider and slower (than the trade wind-driven current) eastward current



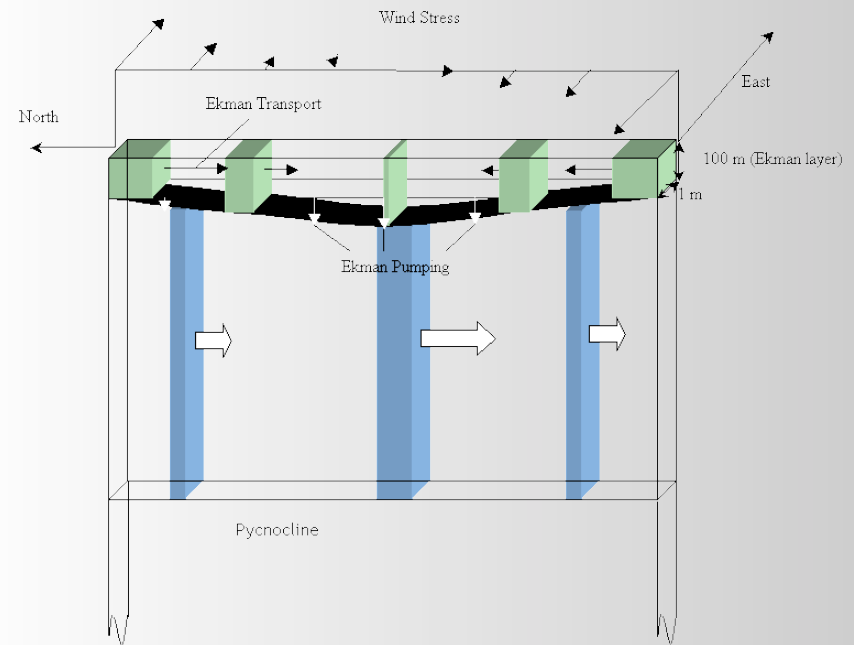
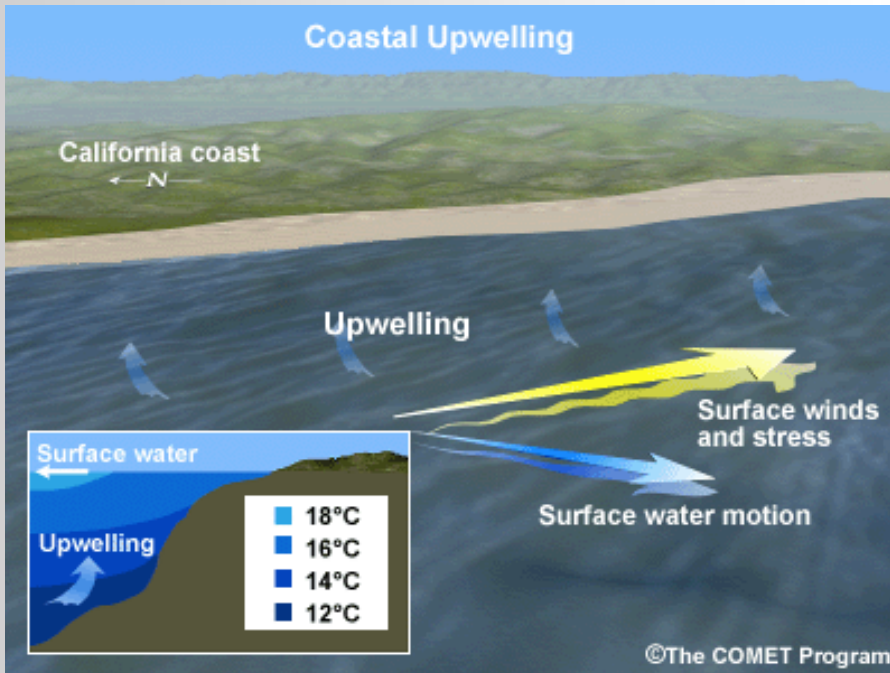
ESS228
Prof. Jin-Yi Yu

Global Surface Currents

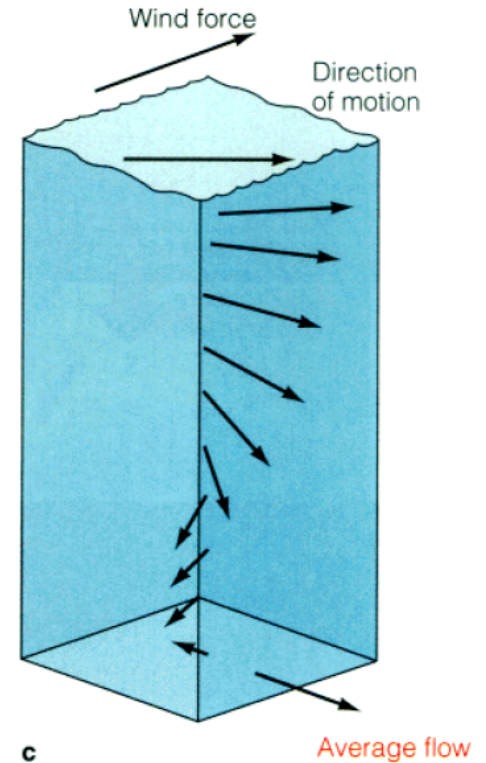
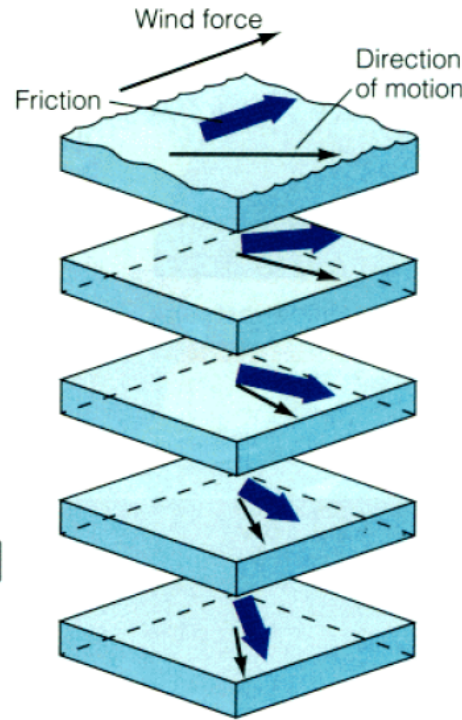
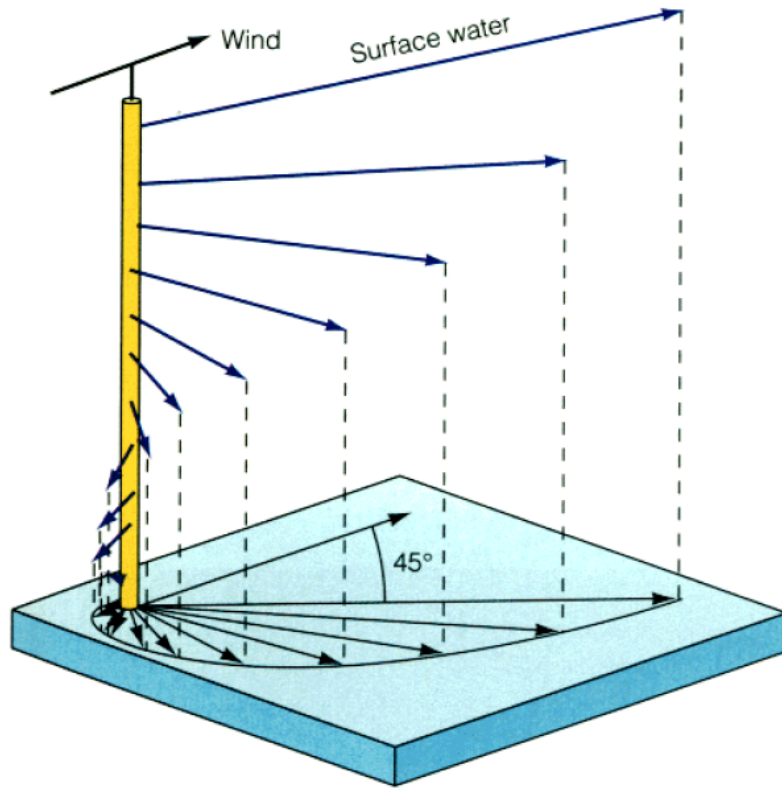


- | | | | | | |
|-----------------------------|---------------------------|---------------------------|---------------------|---------------------------|---------------------------|
| 1 North Equatorial Current | 6 Kuroshio Current | 11 North Pacific Current | 16 Agulhas Current | 21 Gulf Stream | 26 East Greenland Current |
| 2 Equatorial Countercurrent | 7 East Australian Current | 12 California Current | 17 Benguela Current | 22 North Atlantic Current | 27 Norway Current |
| 3 South Equatorial Current | 8 Oyashio Current | 13 Peru Current | 18 Guinea Current | 23 Labrador Current | 28 Spitsbergen Current |
| 4 West Wind Drift | 9 Aleutian Current | 14 Falkland Current | 19 Brazil Current | 24 West Greenland Current | 29 North Cape Current |
| 5 West Australian Current | 10 Alaska Current | 15 South Atlantic Current | 20 Canary Current | 25 Irminger Current | |

A ação local do vento: Ekman



(frictional force + Coriolis Force)

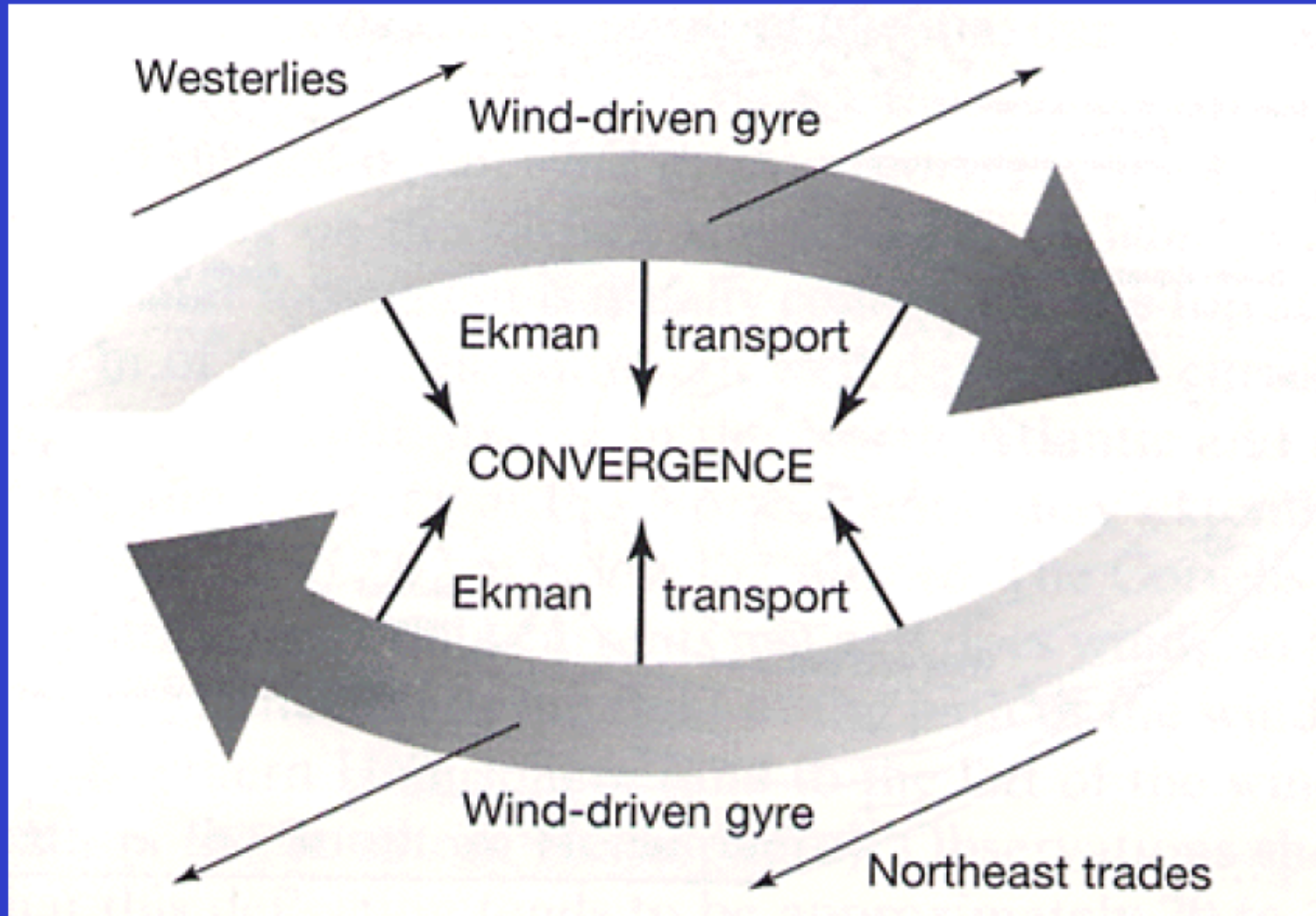


a

b

c

Ekman Transport



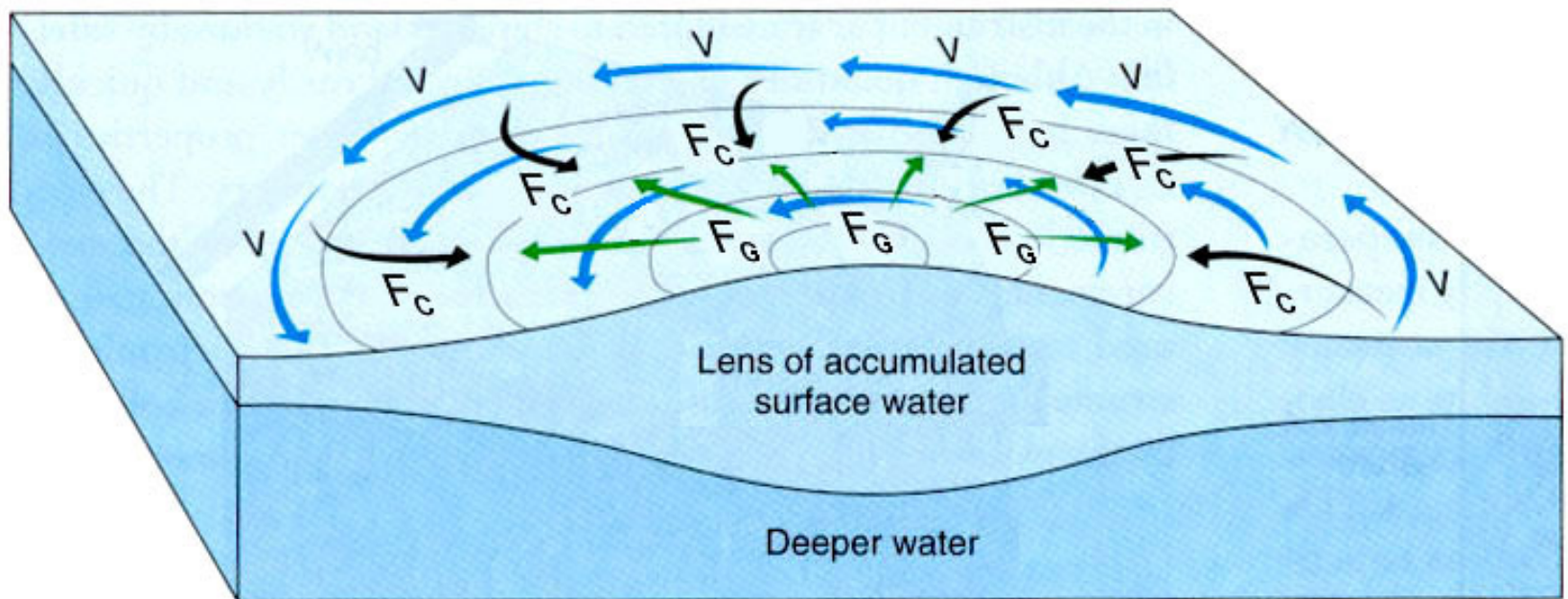
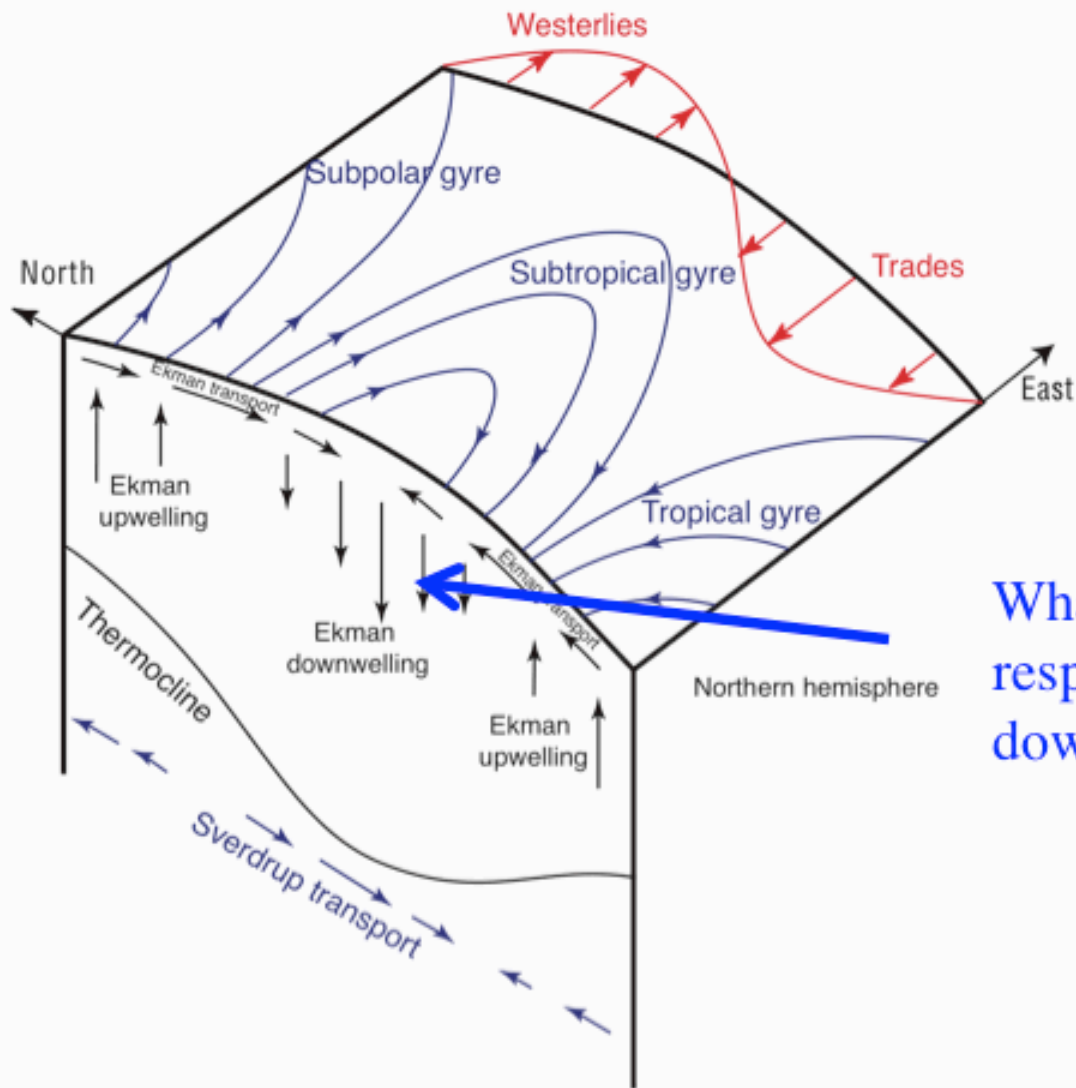


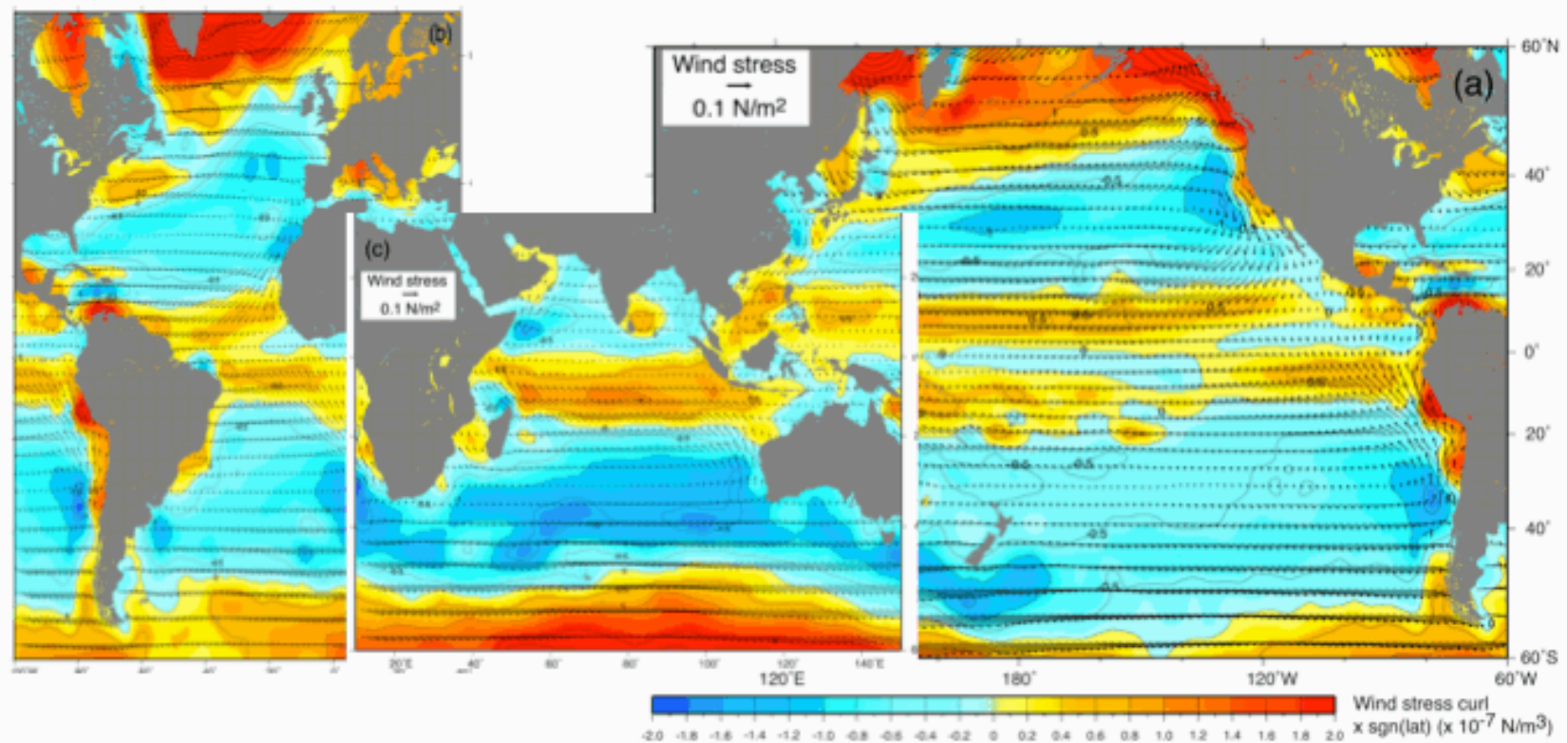
Fig.5 Currents flow (V) around a gyre when the inward Ekman transport due to the Coriolis effect (F_c) is balanced by F_g , the outward force due to gravity.

Sverdrup balance driven by Ekman transport convergence and divergence



What is the interior ocean response to this Ekman downwelling?

Ekman upwelling/downwelling map



Blue regions: Ekman pumping \rightarrow equatorward Sverdrup transport

Yellow-red regions: Ekman suction \rightarrow poleward Sverdrup transport

Os principais termos da equação do movimento são, na forma vetorial, os seguintes:

$$\frac{D\mathbf{v}}{Dt} = -\frac{1}{\rho} \nabla p - 2\boldsymbol{\Omega} \times \mathbf{v} + \mathbf{g} + \mathbf{F}_r$$

Cujas componentes ficam resumidas em:

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} = -\frac{1}{\rho} \frac{\partial p}{\partial x} + 2\Omega v \sin \phi + F_x$$

$$\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z} = -\frac{1}{\rho} \frac{\partial p}{\partial y} + 2\Omega u \sin \phi + F_y$$

$$\frac{\partial w}{\partial t} + u \frac{\partial w}{\partial x} + v \frac{\partial w}{\partial y} + w \frac{\partial w}{\partial z} = -\frac{1}{\rho} \frac{\partial p}{\partial z} + 2\Omega u \sin \phi - g + F_z$$

AS ESCALAS DE INTERESSE:

$$L \ 10^6 \text{m}$$

$$f \ 10^{-4} \text{s}^{-1}$$

$$U \ 10^{-1} \text{m/s}$$

$$g \ 10 \ \text{m/s}^2$$

$$H \ 10^3 \text{m}$$

$$r \ 10^3 \text{kg/m}^3$$

$$\frac{W}{H} = \frac{U}{L}; \quad W = \frac{UH}{L} = \frac{10^{-1}10^3}{10^6} \text{m/s} = 10^{-4} \text{m/s}$$

$$P = rhz = 10^3 10^1 10^3 = 10^7 \text{Pa}$$

$$T = L/U = 10^7 \ \text{s}$$

$$\frac{\partial w}{\partial t} + u \frac{\partial w}{\partial x} + v \frac{\partial w}{\partial y} + w \frac{\partial w}{\partial z} = -\frac{1}{\rho} \frac{\partial p}{\partial z} + 2\Omega u \cos \varphi - g$$

$$\frac{W}{T} + \frac{UW}{L} + \frac{VW}{L} + \frac{W^2}{L} = \frac{P}{\rho H} + fU - g$$

$$10^{-11} + 10^{-11} + 10^{-11} + 10^{-14} = 10 + 10^{-5} - 10$$

Assim, o único balanço importante é entre os termos de **P** e **g**, o balanço hidrostático.

$$\frac{\partial p}{\partial z} = -\rho g \quad \text{Correct to } 1:10^6.$$

O mesmo exemplo na equação horizontal do momento ficaria:

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} = -\frac{1}{\rho} \frac{\partial P}{\partial x} + fv$$

$$10^{-8} + 10^{-8} + 10^{-8} + 10^{-8} = 10^{-5} + 10^{-5}$$

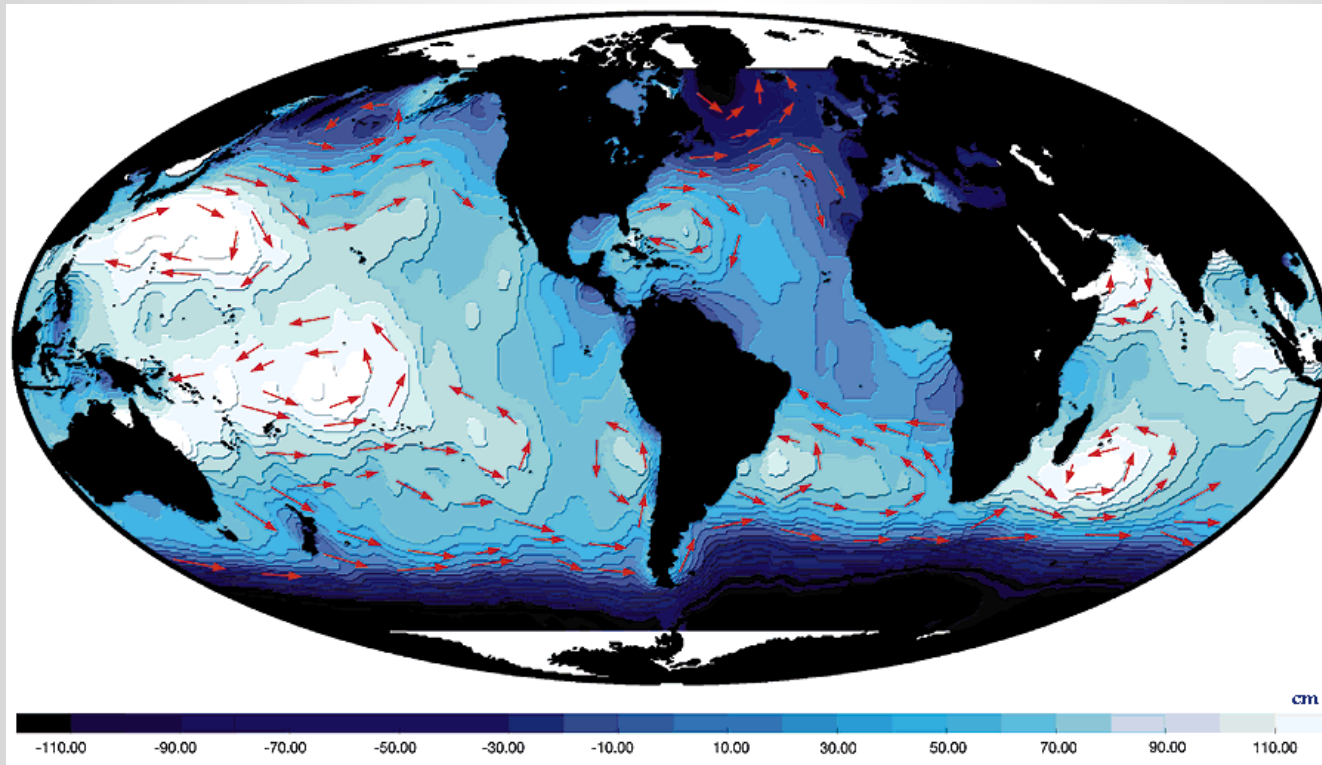
Assim, o balanço entre o termo de Coriolis e o do Gradiente de Pressão é o mais importante; este balanço é denominado **BALANÇO GEOSTRÓFICO**. As equações denominadas de equações geostróficas são:

$$\frac{1}{\rho} \frac{\partial p}{\partial x} = fv, \quad \frac{1}{\rho} \frac{\partial p}{\partial y} = -fu, \quad \frac{1}{\rho} \frac{\partial p}{\partial z} = -g$$

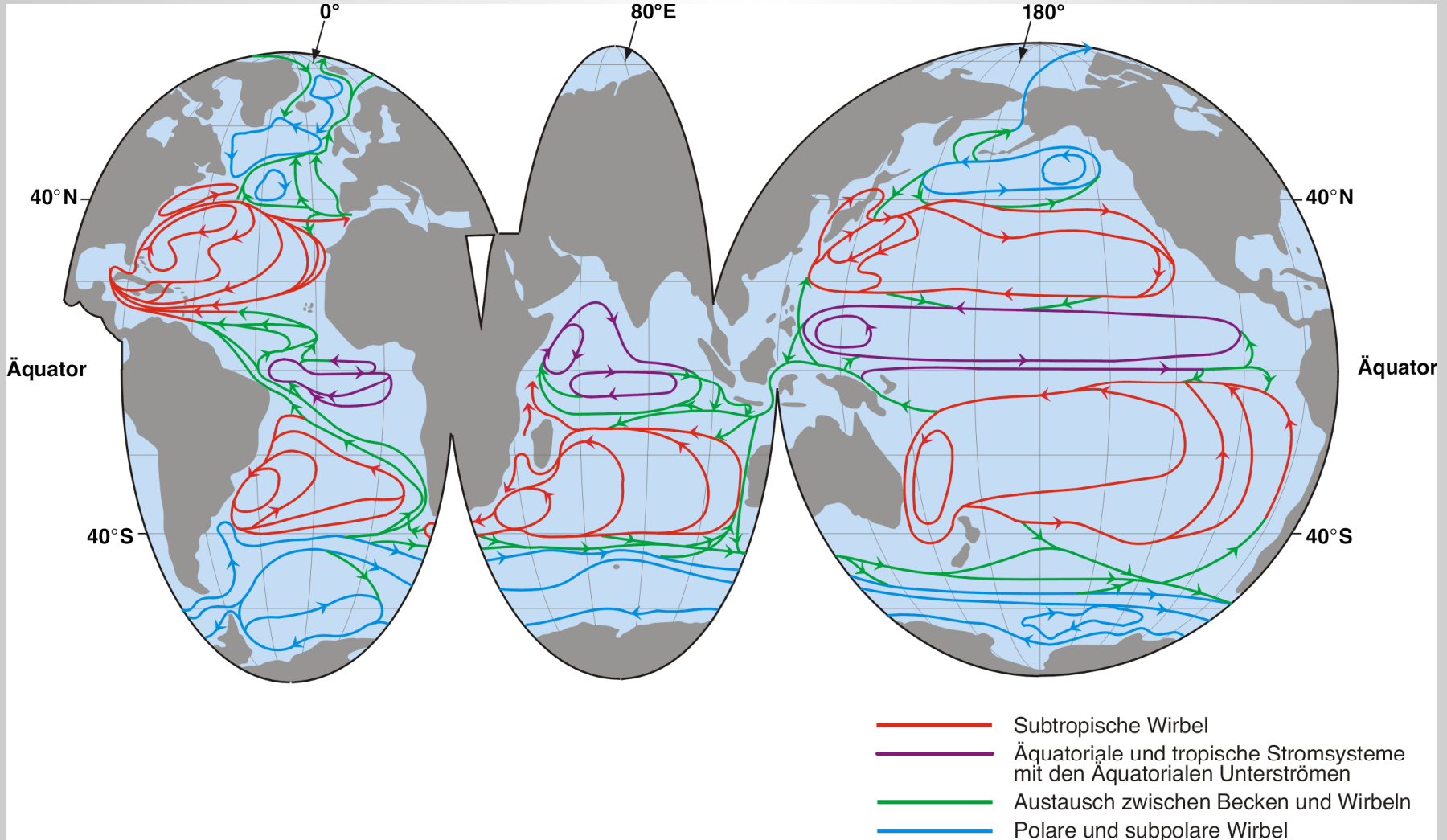
Este BALANÇO domina os fluxos nos oceanos com escalas maiores que 50 Km e alguns dias !!!

CIRCULAÇÃO DE LARGA ESCALA:

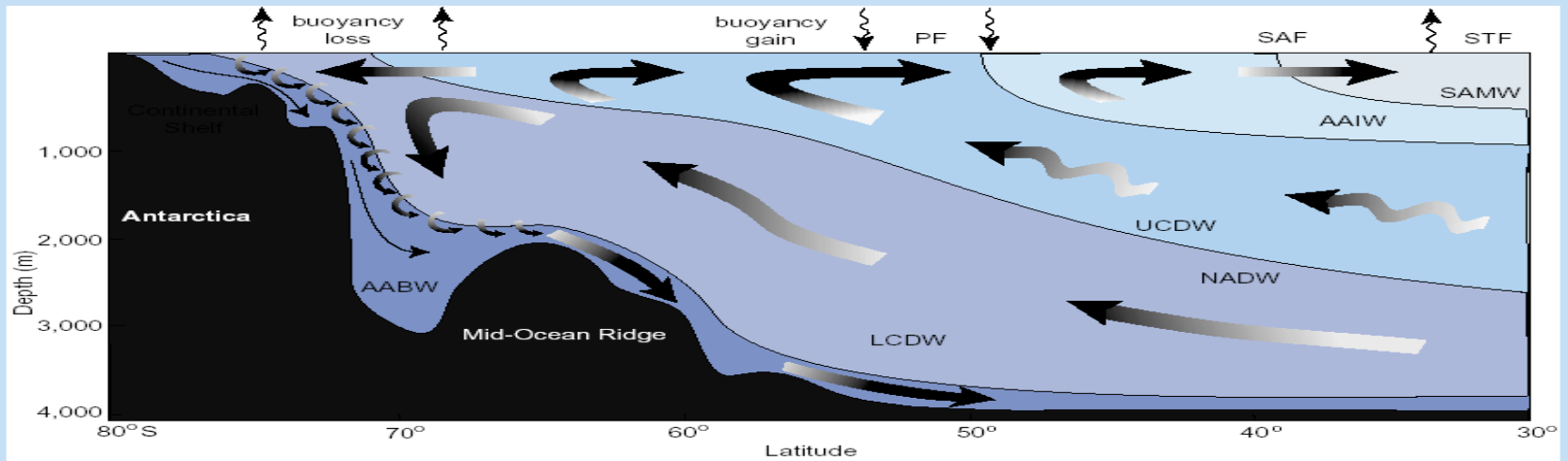
- Dominada pelos Giros Anticiclônicos



Circulação Superficial



Elements of the overturning circulation in the Southern Ocean

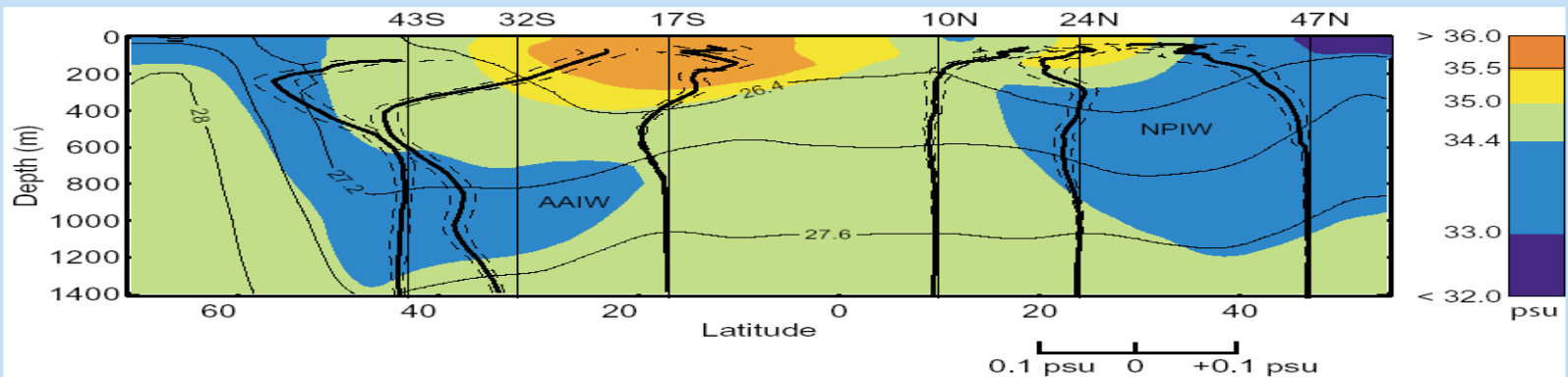


Schematic diagram of the overturning circulation in the Southern Ocean (Speer et al., 2000, *J. Phys. Oceanogr.*, 30, 3212-3222).

AV/D5/0103



Freshening of intermediate waters in the Southern Ocean

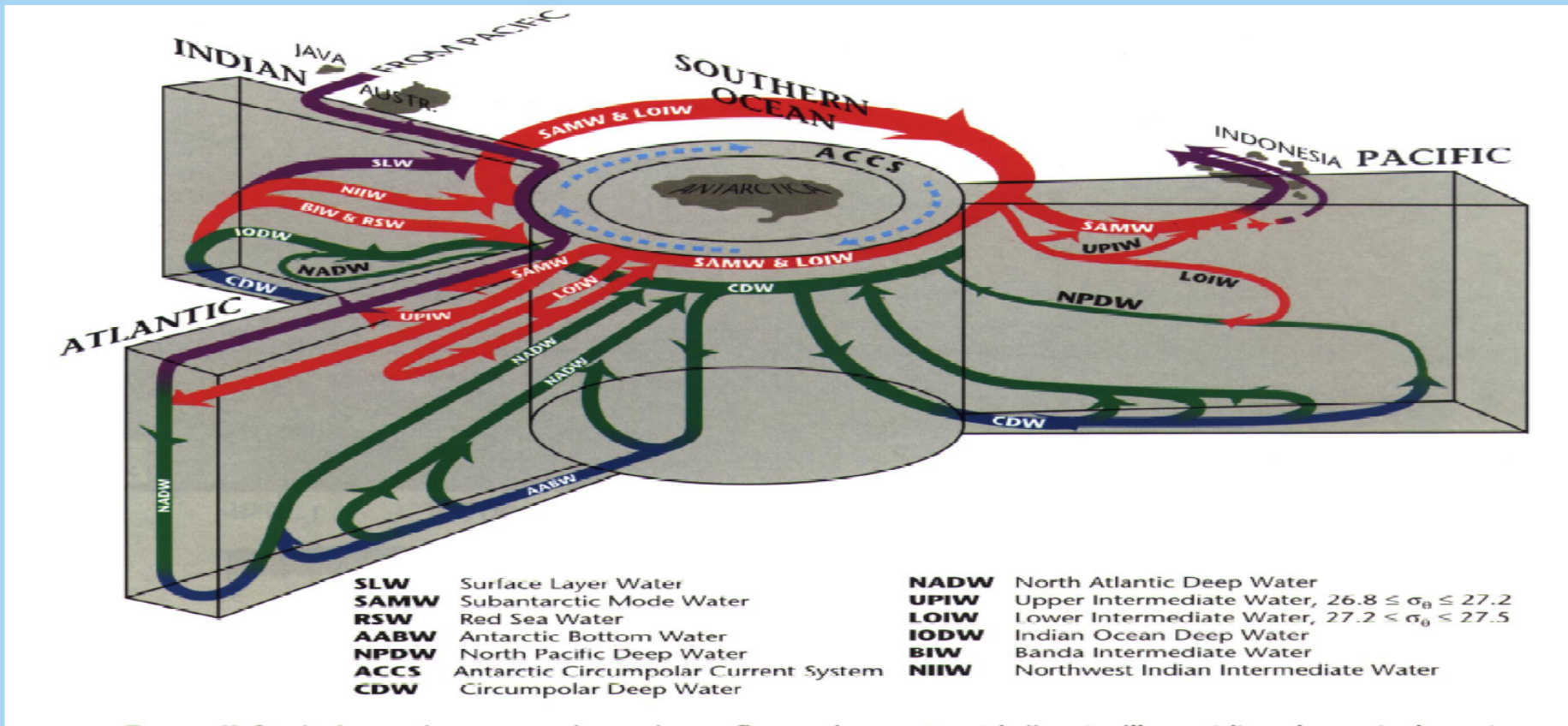


The sparse observations suggest the signature of high latitude freshening may already be detected in the Subantarctic Mode Water (SAMW) and Antarctic Intermediate Water (AAIW) exported from the Southern Ocean to lower latitudes. SAMW and AAIW are renewed on decadal time-scales; ventilate the lower thermocline in the Southern Hemisphere; and sequester heat and anthropogenic CO₂. Determining the sensitivity of the Southern Ocean stratification, overturning circulation, and water mass formation to changes in air-sea exchange is a key task for CLIVAR. (Wong et al., 1999, *Nature*, 400, 440-443)

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Key Role of the Southern Ocean

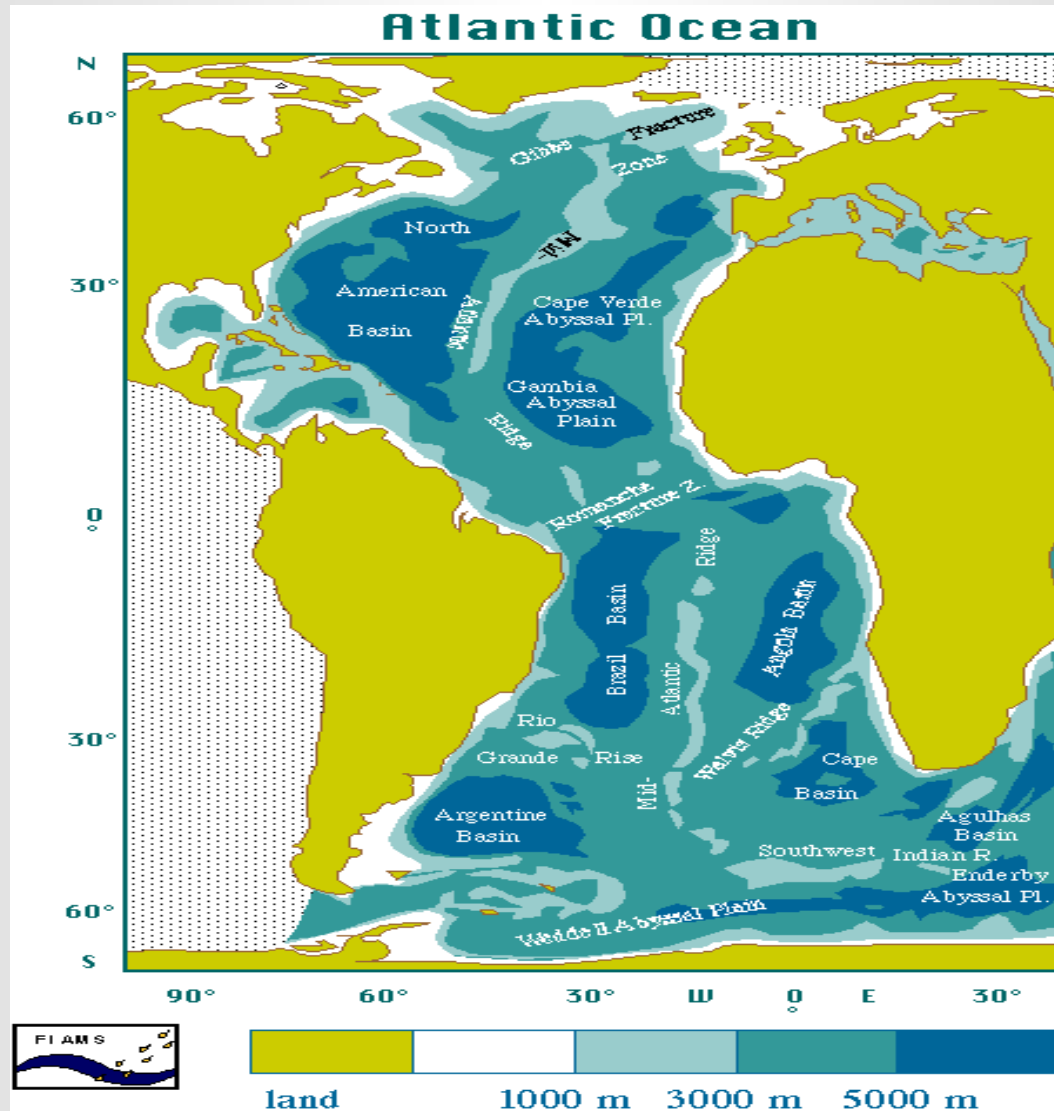


3-D global overturning diagram, from Schmitz (1996)

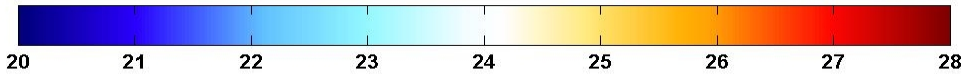
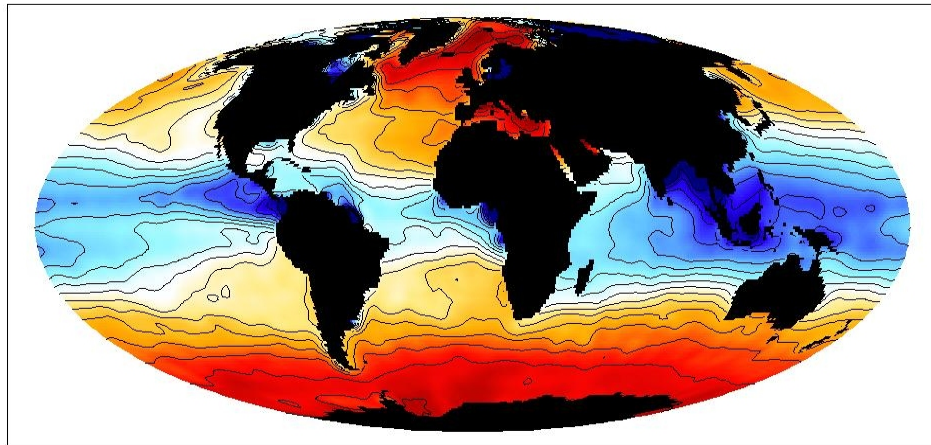
The figure illustrates two of the key roles the Southern Ocean plays in the climate system:

- Water mass transformations in the SO “close” the overturning circulations by converting deep water which upwells at high latitude into lighter intermediate waters and denser bottom waters.
- The Antarctic Circumpolar Current connects the ocean basins, allowing a global overturning circulation to exist, and allowing anomalies to propagate between basins and influence the climate “downstream”.

O Oceano Atlântico

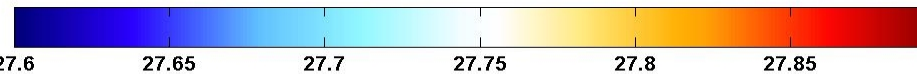
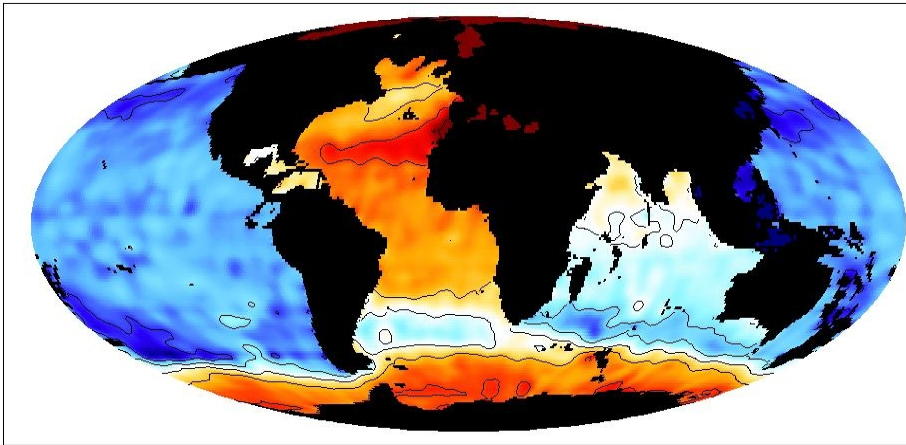


Levitus surface density

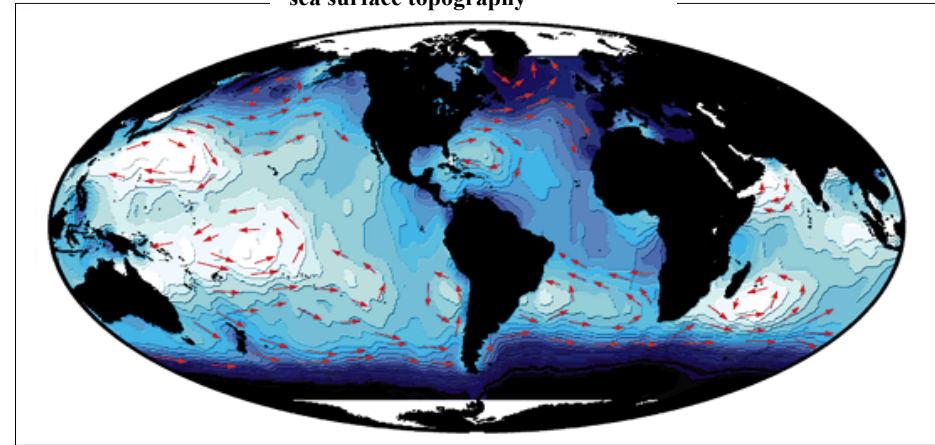


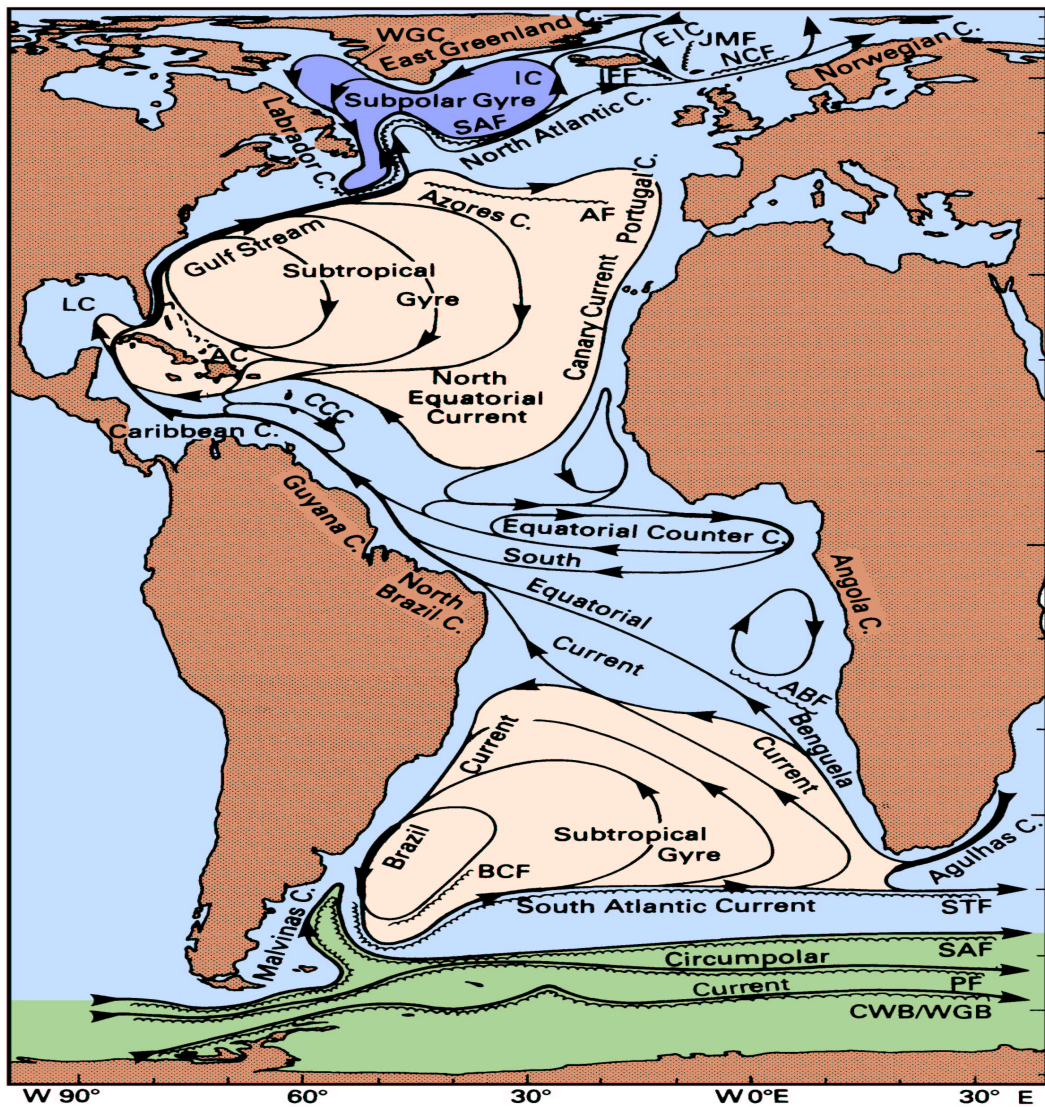
the Atlantic is exceptional !

Levitus density 2000 m



sea surface topography





Correntes de superfície do Oceano Atlântico

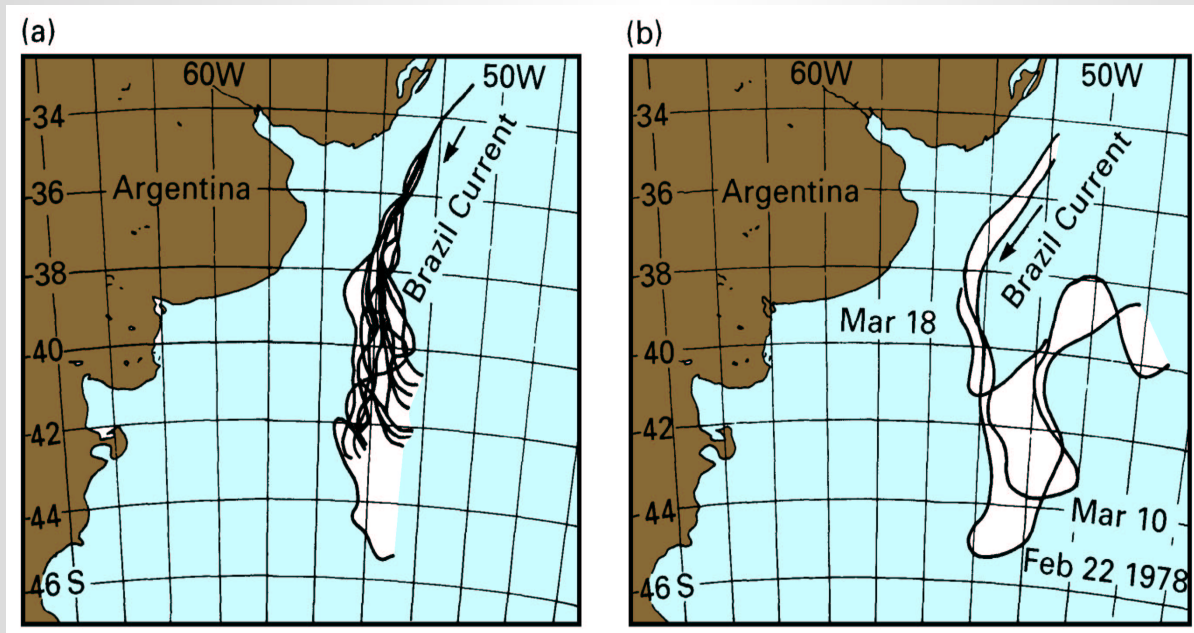
Abreviações usadas para correntes:

- EIC (Leste da Islândia)
- IC (Irminger)
- Oeste da Groelândia (WGC)
- Loop/Giro (LC)
- Antilhas (AC)

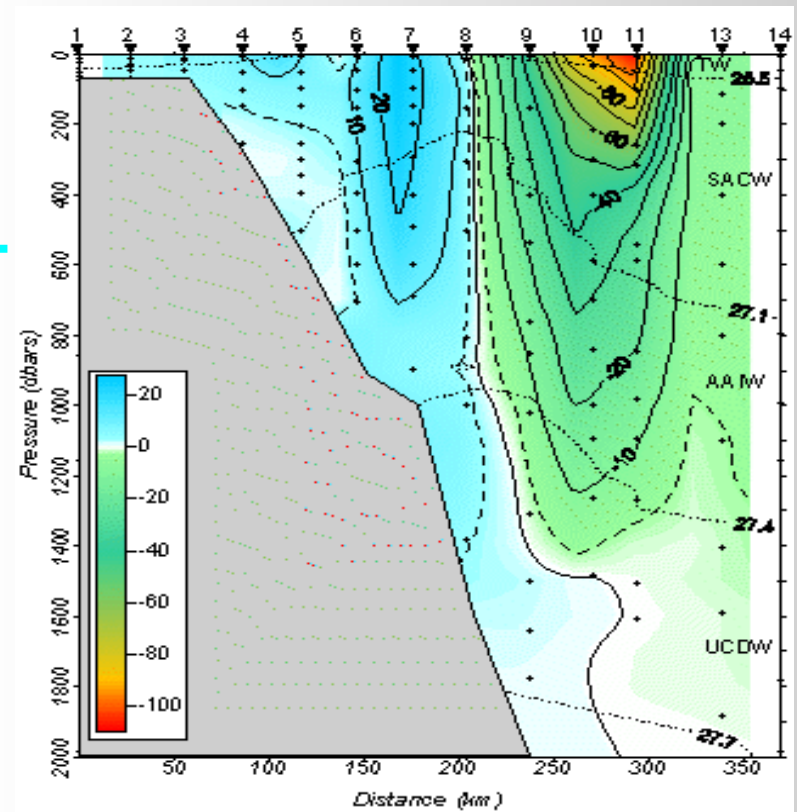
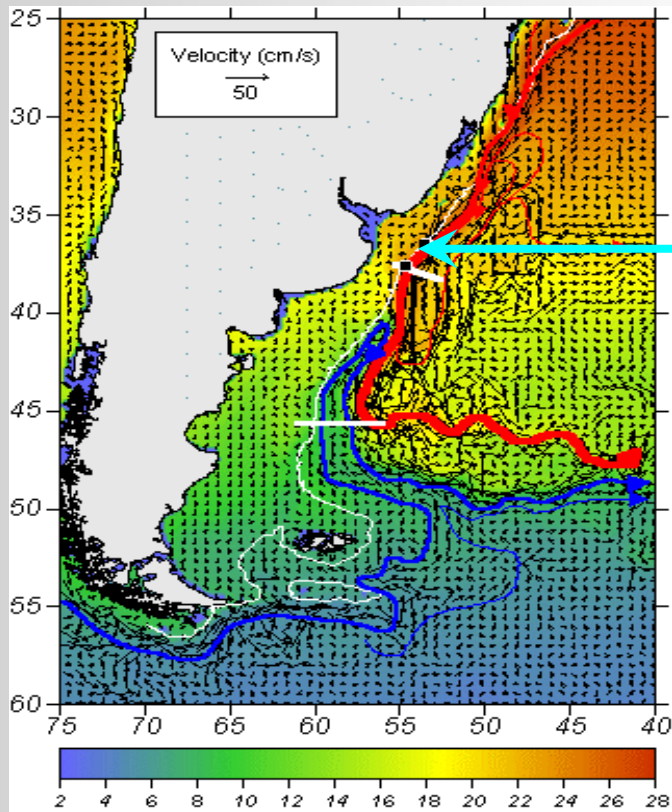
Contra corrente do Caribe (CCC)

Abreviações usadas para frentes:

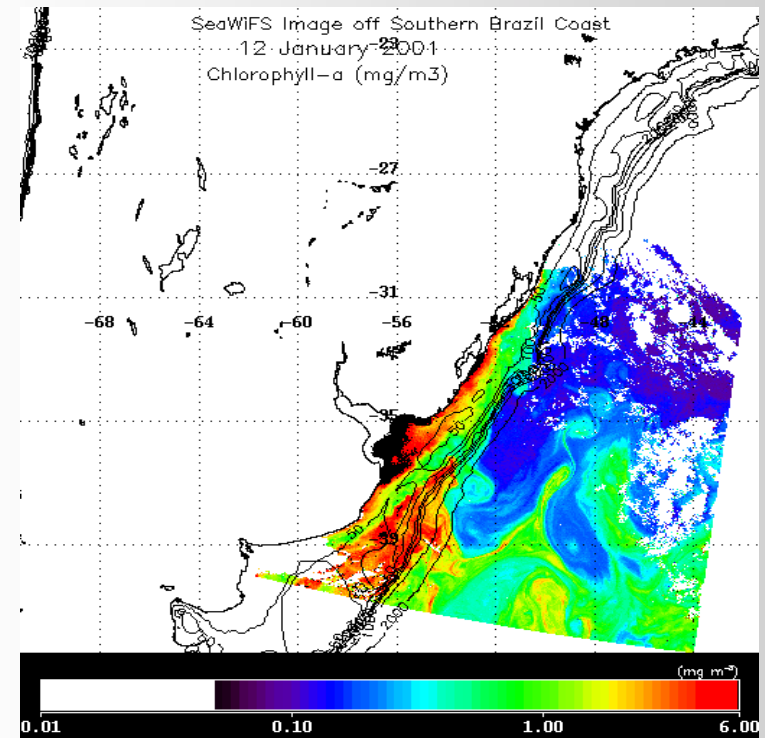
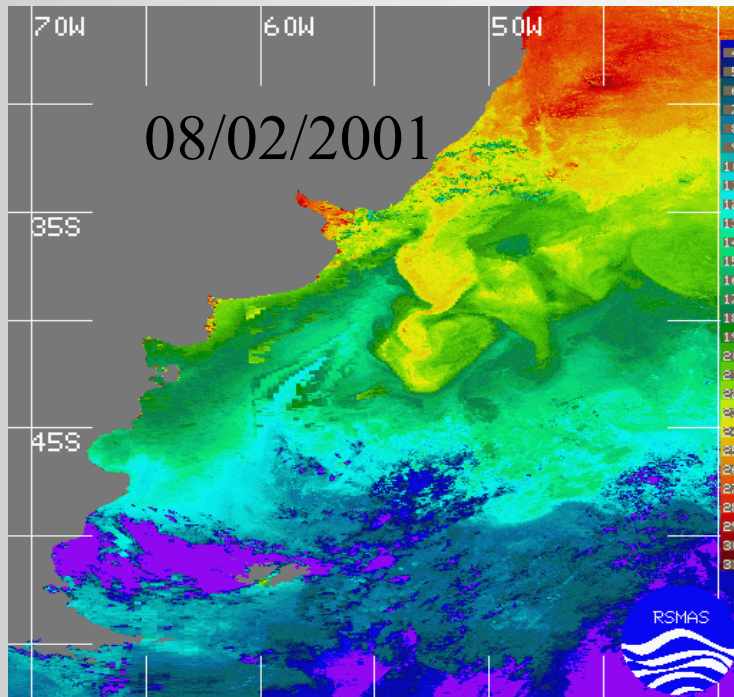
- Frente Jan Mayen (JMF)
- Frente da Corrente da Noruega (NCF)
- Frente da Islândia-Faroe (IFF)
- Frente Subártica (SAF)
- Frente de Açores (AF)
- Frente de Angola-Benguela (ABF)
- Frente da Corrente do Brasil (BCF)
- Frente SubTropical (STF)
- Frente Polar (PF)
- Borda do Giro de Weddell (CWB/WGB)



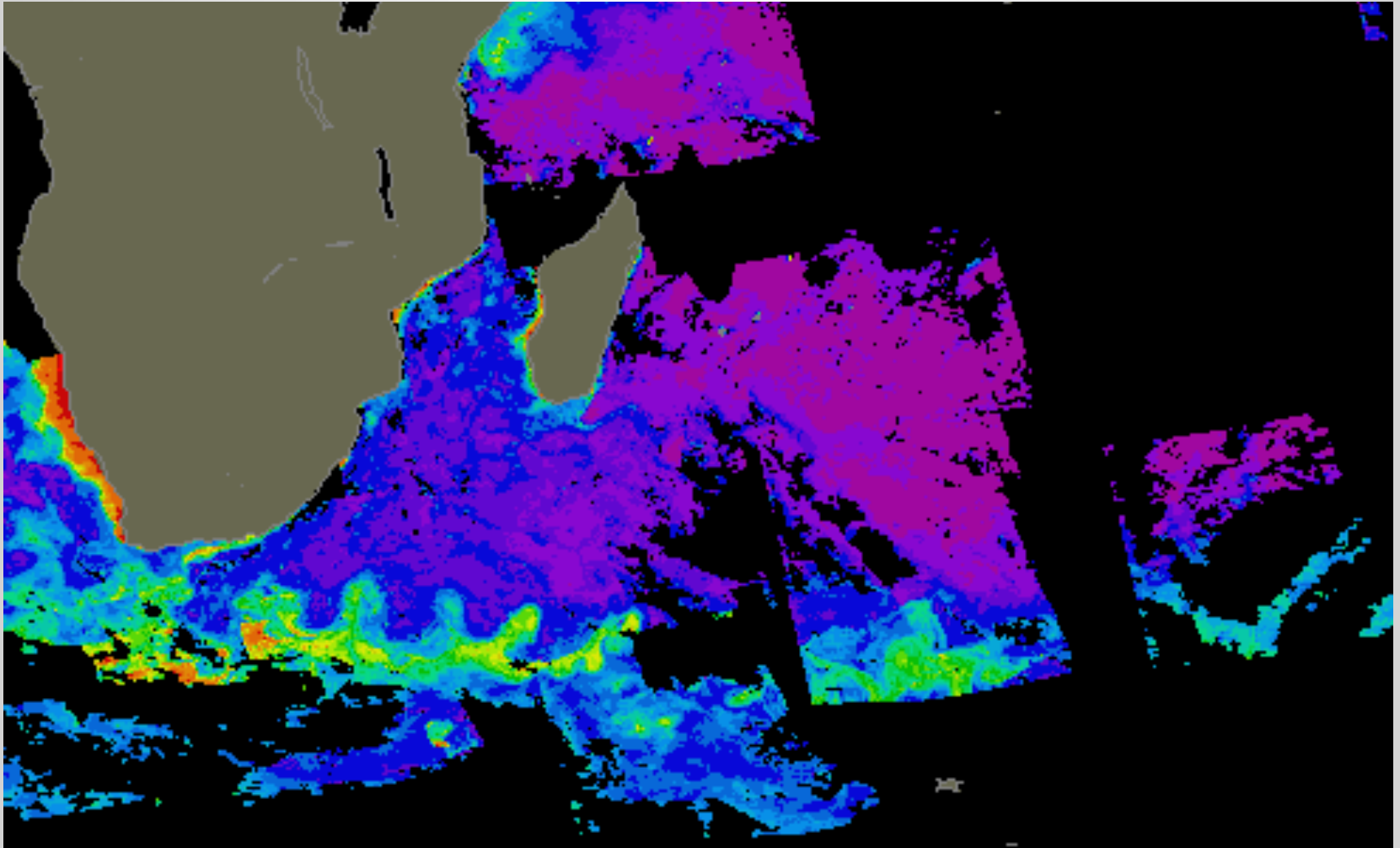
(a) A separação da corrente do Brasil da costa Sul Americana indicada pelas TSM entre Setembro 1975-Abril 1976; (b) A migração da posição de separação da CB entre fevereiro e março de 1978. Durante este último período dois vórtices foram formados (Legeckis e Gordon, 1982).



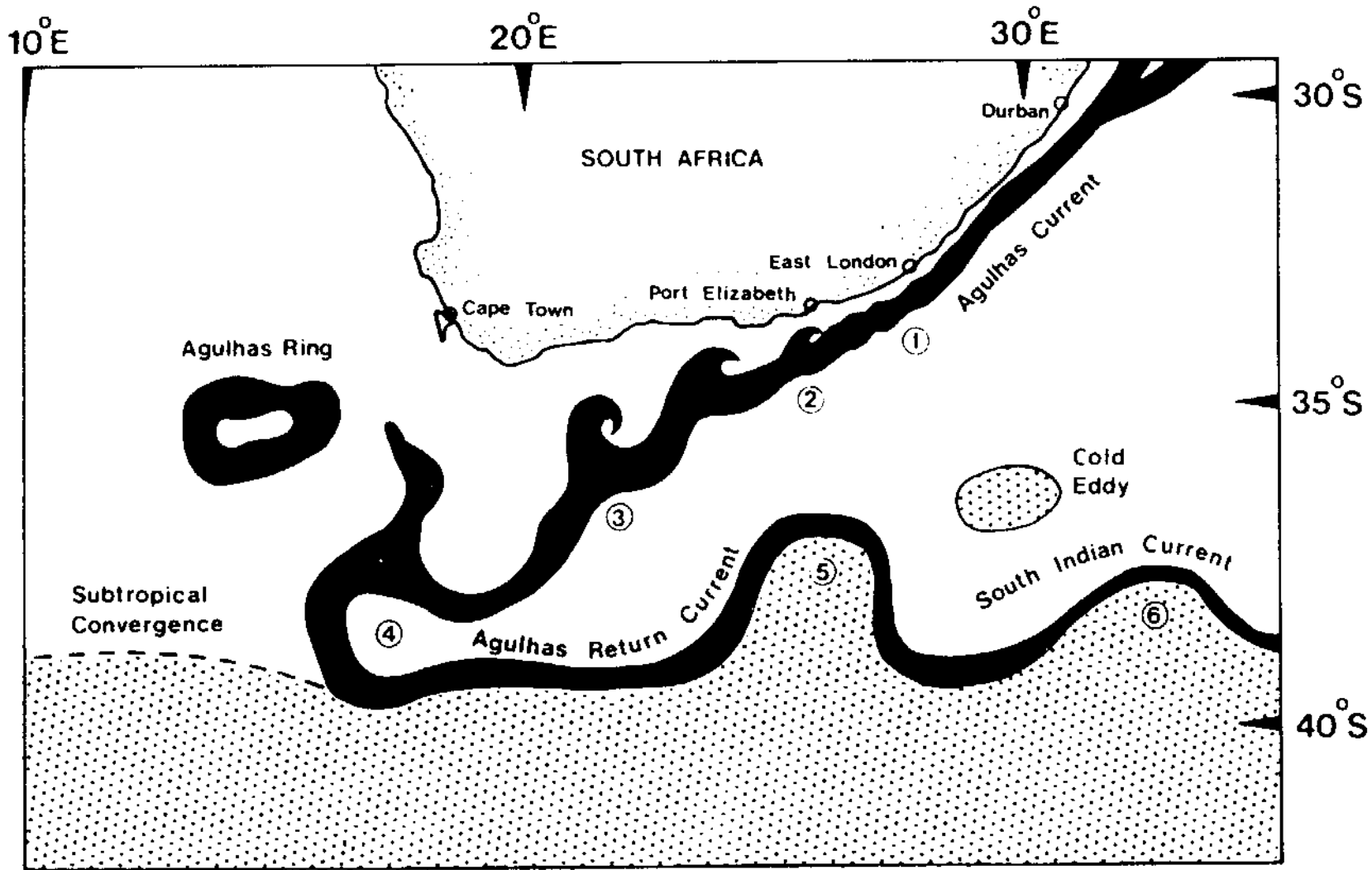
Circulação simulada por modelo numérico na região SW do Atlântico Sul (esquerda) e uma seção hidrográfica mostrando a interface CB/CM (direita).

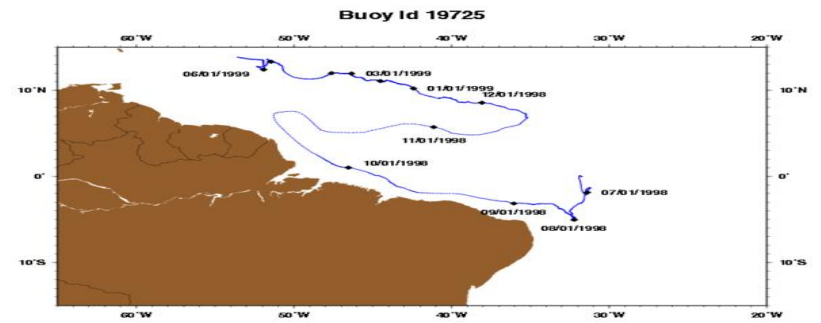
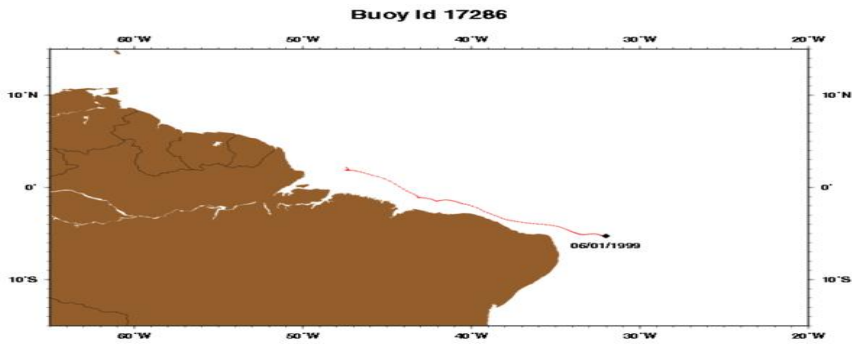


Variabilidade de mesoescala na confluência Brasil/Malvinas observada a partir de dados de TSM (AVHRR/NOAA, a esquerda) e de cor do oceano ([] clorofila-a pelo SeaWIFS, a direita).

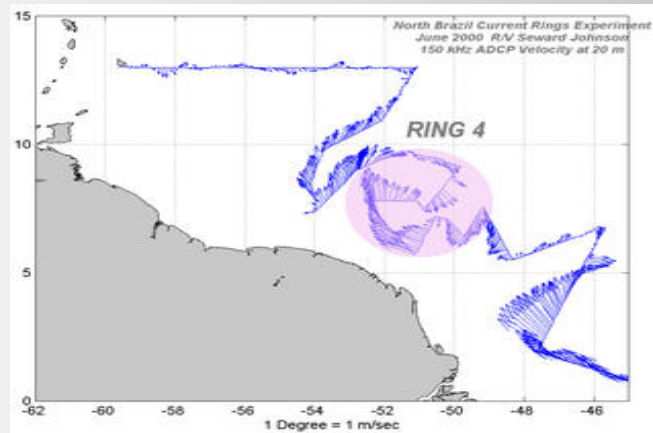
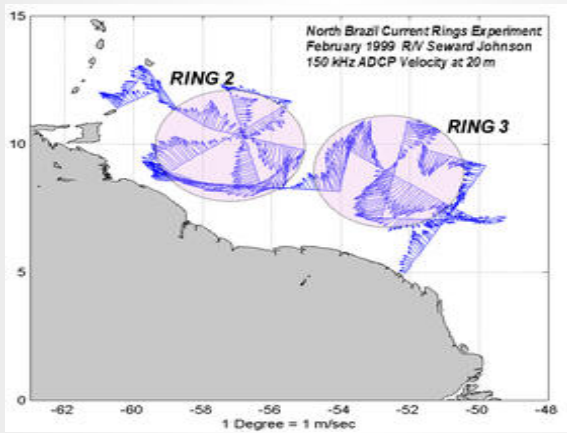
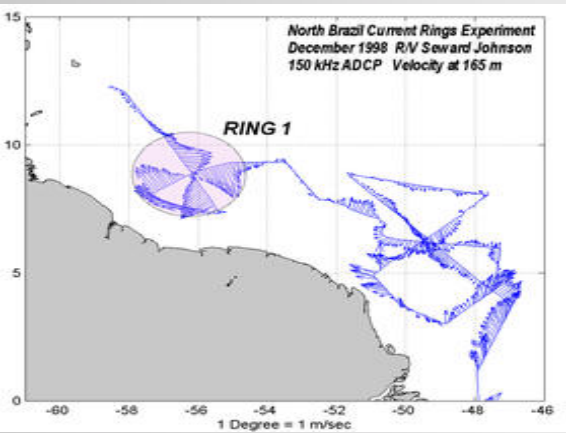


Mosaico de imagens do CZCS (Coastal Zone Colour Scanner) de 1983. Maiores concentrações de clorofila podem ser observados em tons vermelhos. Note a ressurgência na costa da Namíbia/Angola.

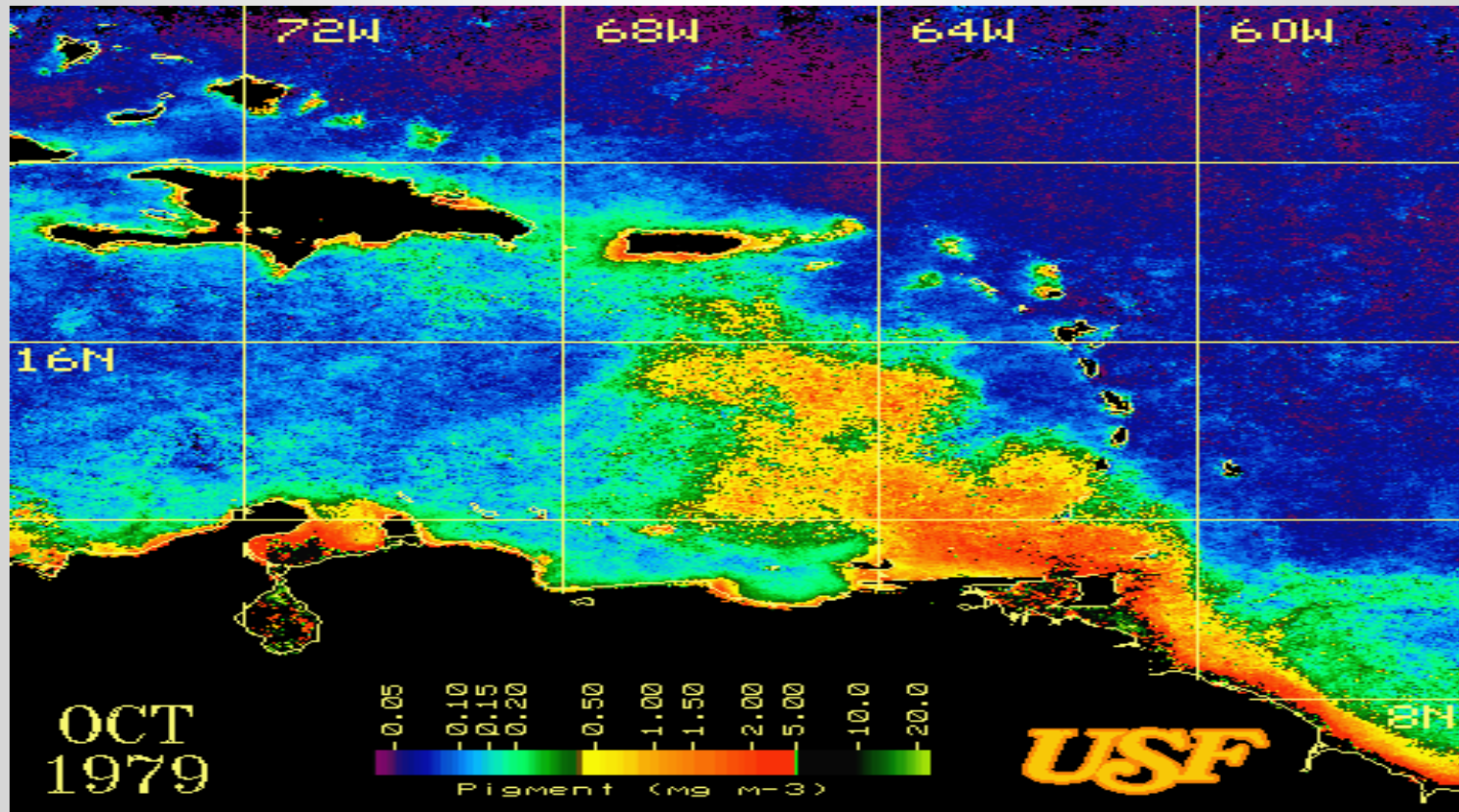




Buoys ID 17286 (red) and 19725 (blue) both move quickly along just offshore of the North Brazil Coast. Buoy 19725 also exhibits the well-known retroflection of the North Brazil Current during October of 1998. It is then advected by the North Equatorial Current into the source region for the Antilles Current.

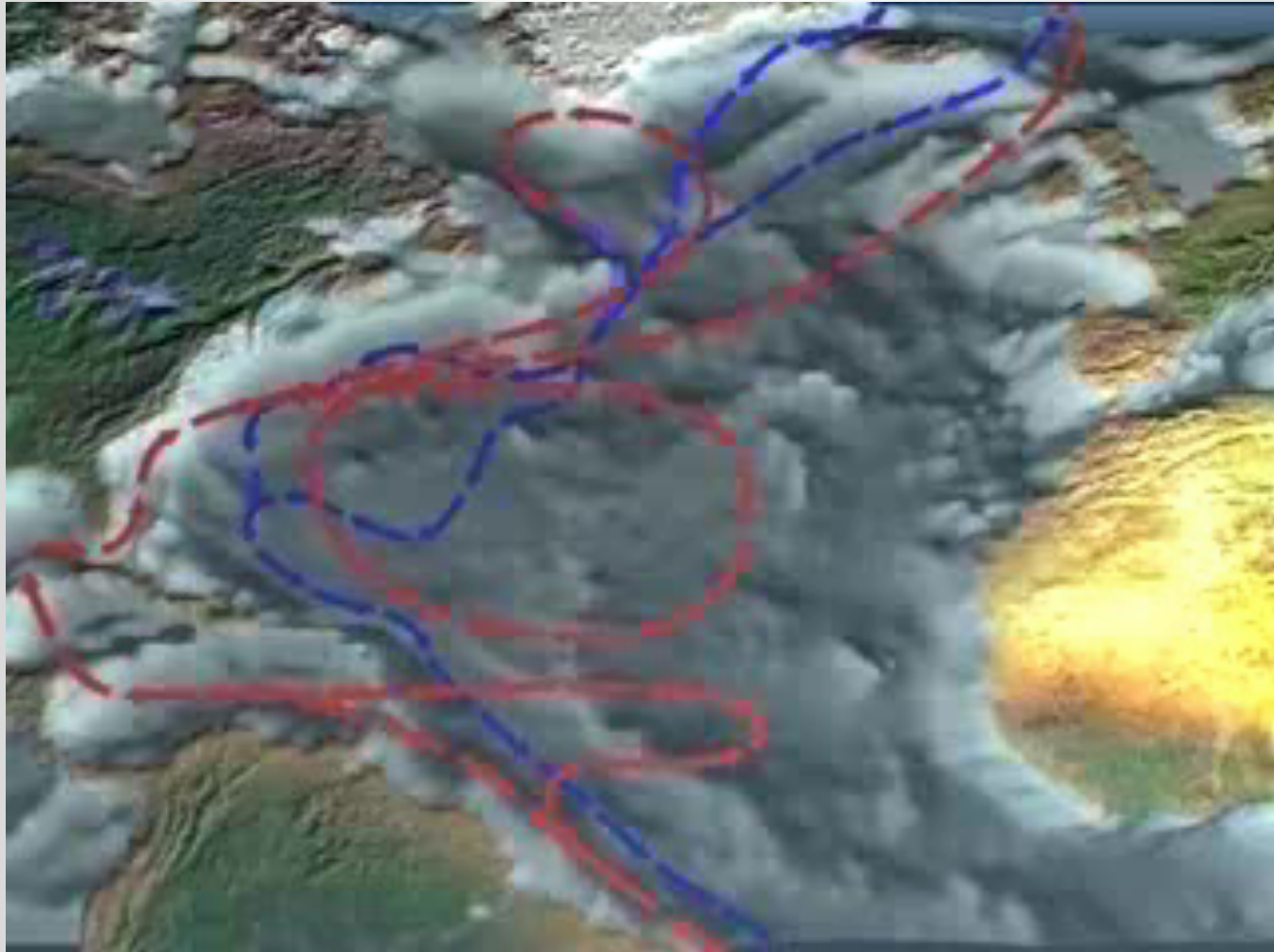


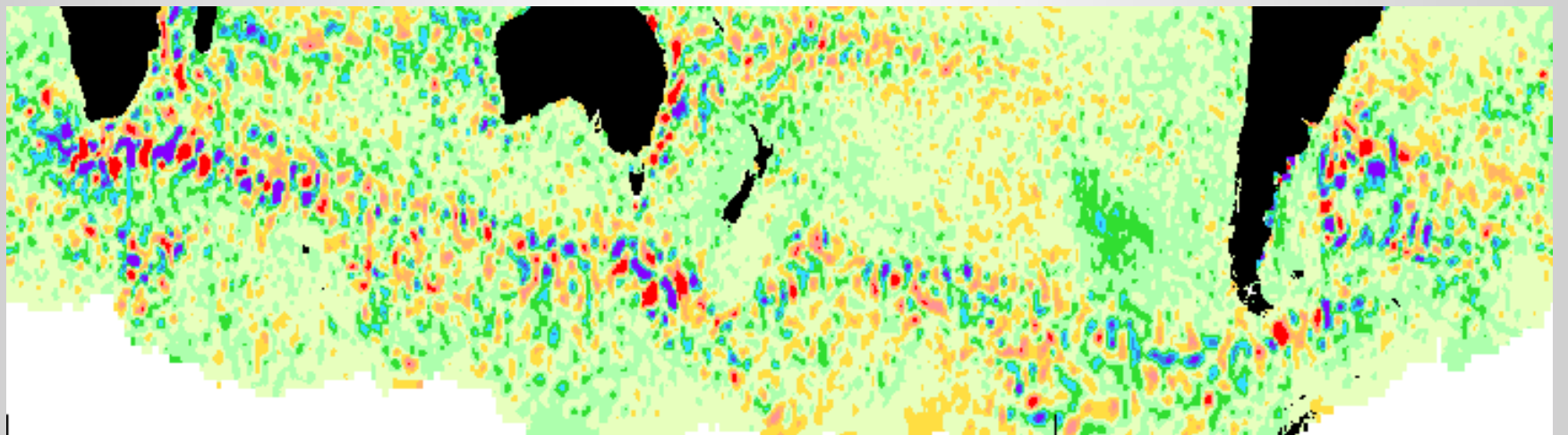
Maps of the SADCPC current vectors obtained for each of the four rings surveyed during three cruises: NBC1: December 1988, NBC2: February 1999, NBC4: June 2000.



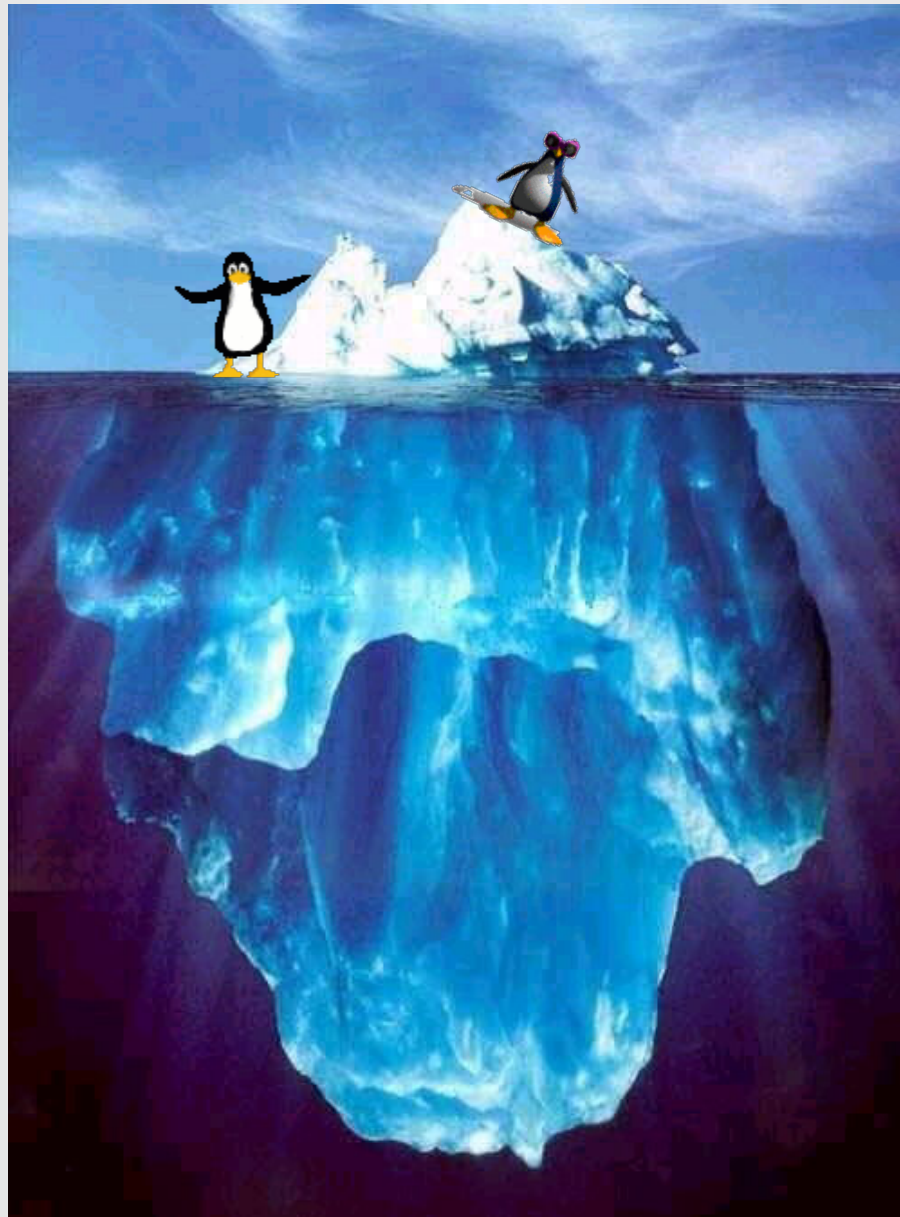
CZCS composite image of the eastern Caribbean Sea for October 1979, showing the spatial extent of the Orinoco River plume of induced high productivity that occurs during the summer rainy season. (Image courtesy of Dr. Frank Muller-Karger, University of South Florida Remote Sensing Laboratory.)







Deu...



...por
agora!