

São Paulo School of Advanced Sciences on Ocean Interdisciplinary Research and Governance

Understanding and Modeling Ocean Basins

Prof. Dr. Edmo Campos

University of São Paulo, Brazil

&

American University of Sharjah, United Arab Emirates



Outline

- The importance of understanding the Ocean
- A brief introduction to Physical Oceanography
- Modeling Ocean Basins
- The Ocean and the Climate
- The role of the South Atlantic



**SPSAS – Oceans
2018**



Why should we better understand the Ocean?

Earth ...



... the planet Ocean

Most of Earth's surface is covered with water



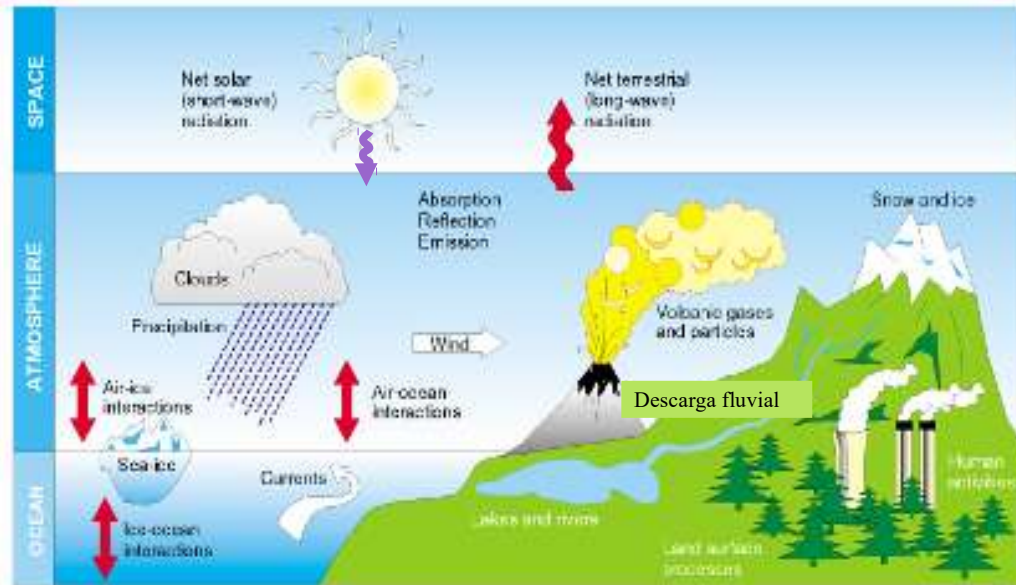
Water is a substance with the highest specific heat in nature

This unique property of water allows life on Earth and makes the ocean the “memory” of the climate system.

With the exception of the sun, the ocean is the most important agent in the control of climate variability

The ocean stores 1000 times more heat than the atmosphere and 50 times more carbon.

The Climate System



courtesy N. Noreiks, L. Bengtsson, MPI

AV/Global0101

The Ocean is a key component of the Climate System

The interactions among the different components result in the mechanism that controls Earth's climate.

Due to its global coverage and the water's high heat capacity, the ocean acts as a "buffer" for the climate variability

The Ocean regulates Earth's climate system



85% of all water precipitated over the planet come from the ocean

The storage, transport and redistribution of heat by the ocean constitute the main mechanism for regulating the climate

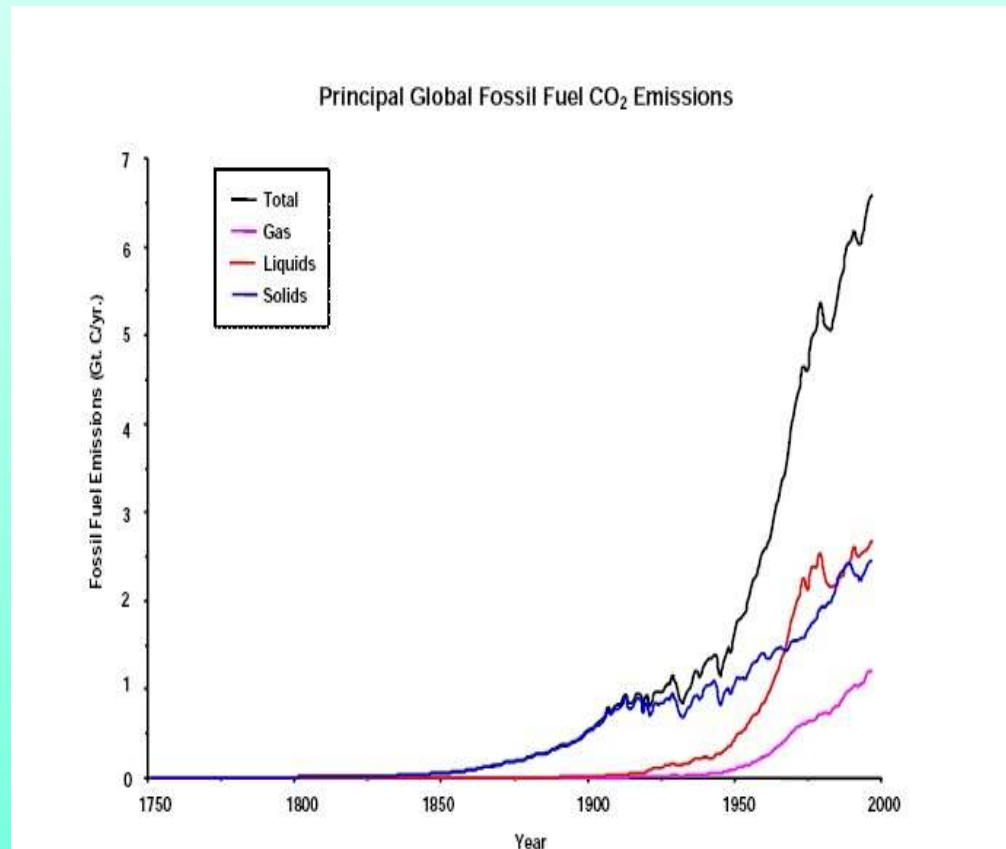
The key for abrupt climate change is in the Ocean's abyssal circulation

But the ocean is also affected by changes in the climate system !

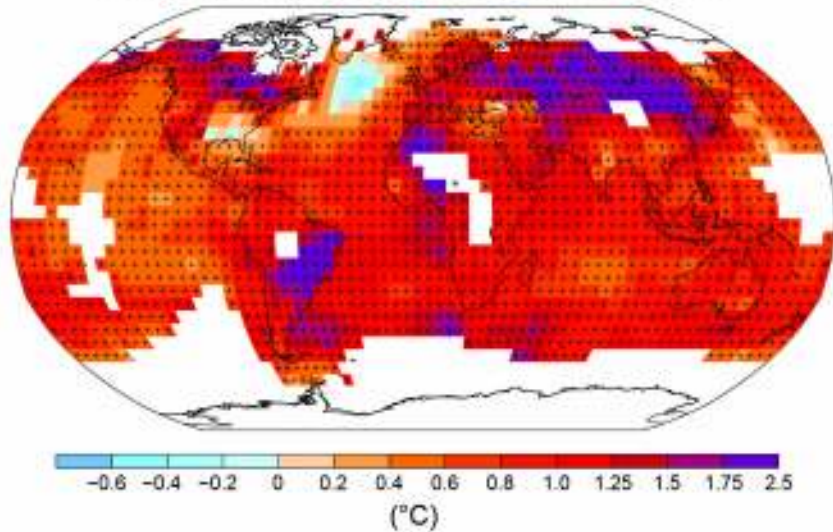
According to IPCC's assessments, the climate is changing

There are people who believe that Earth has an infinite capacity to absorb an unlimited quantity of residues from human activity.

Studies show, however, that this is not true. Earth's health is in serious conditions due to the human lack of care.

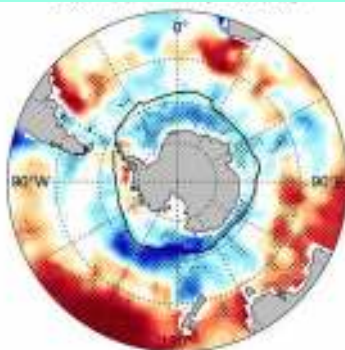


Observed change in surface temperature 1901–2012

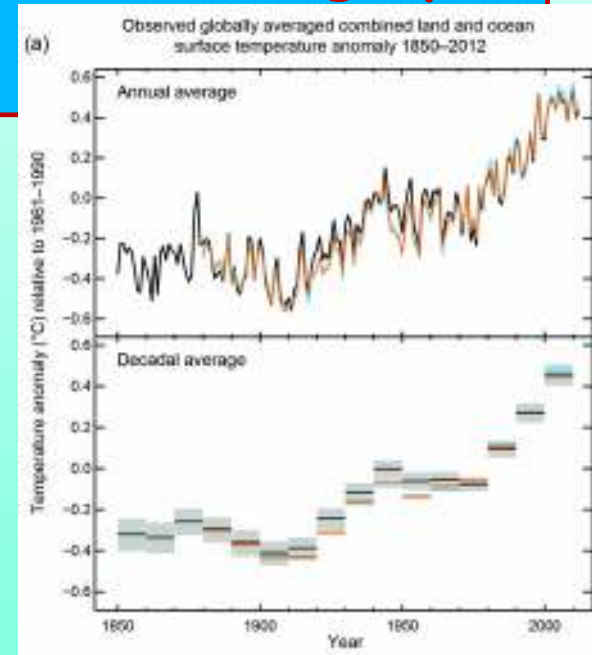


1901–2012
IPCC AR5 WGI (2013)

1979–2013
Purich et al. (Nat. Comm., 2016)



Earth's surface
is warming up!



... and So What?
Why bother?

70%

OF OUR PLANET
IS COVERED
WITH WATERMORE
THAN
HALFOF THE WORLD'S
POPULATION LIVES
WITHIN 50 MILES OF
THE COAST

1 IN 7 PEOPLE

DEPEND ON THE OCEAN
FOR PROTEIN

Warming will destabilize ocean heat transfers



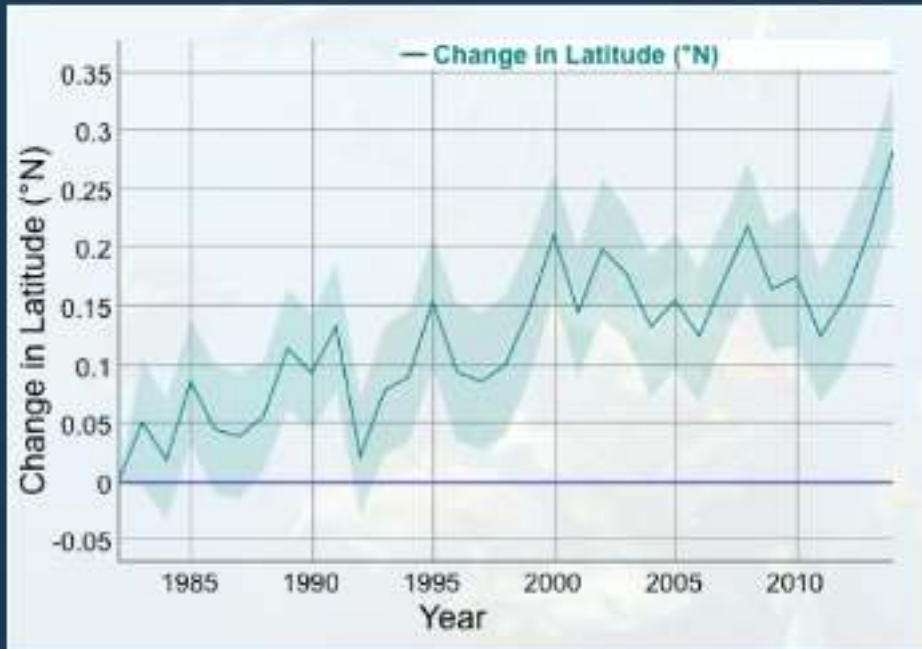
Any changes in habitat temperatures significantly influence:

- Fish metabolism
- Growth rate
- Productivity & reproduction
- Migratory patterns
- Susceptibility to diseases and toxins

Predators and prey will move to different areas,
causing **disruption of food chains**

Warmer water temperatures
exacerbate the variability of
seafood catches; **some fail**
while others flourish.

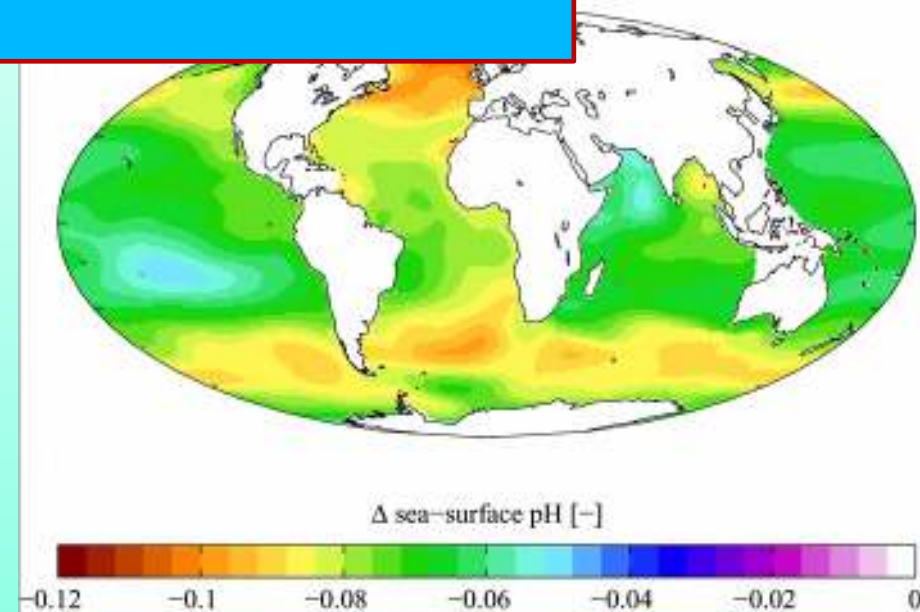
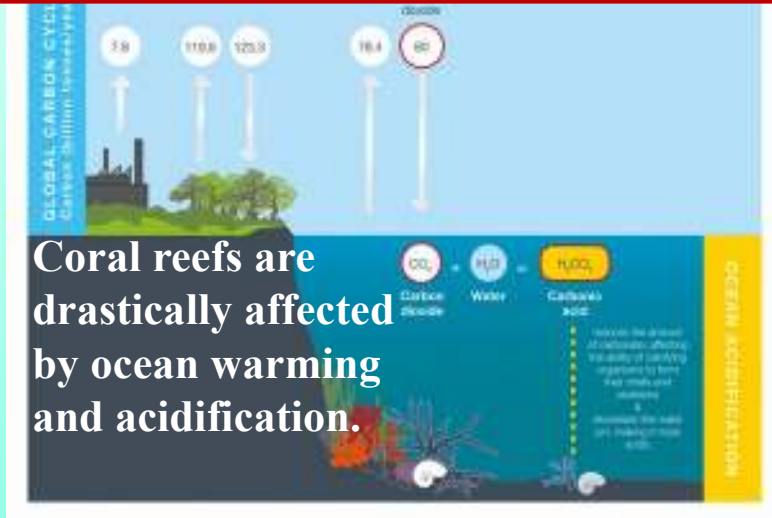
Fish are shifting north



- High numbers of **larval fish** are moving north
- Researchers observed **45** larval fish species and **40** adult fish species, comparing distributions between two decades: **1977-1987**, and **1999-2008**
- **40%** of the larval species and **50%** of the adult species altered distributions



Ocean waters are becoming more acid



Shells dissolve in acid conditions



Alteration in the ocean's surface pH due to the increase of anthropogenic CO_2 , between 1700 and 1990

Impacts to Ports

- More flooding
- More ship and wharf collisions
- Decreased clearance under bridges
- Dislodged containers
- Damaged buildings during storms

A Brief Introduction to Physical Oceanography

General Aspects of the Ocean and Atmospheric Circulation

**What forces drive the the motions of
the Atmosphere and the Oceans?**

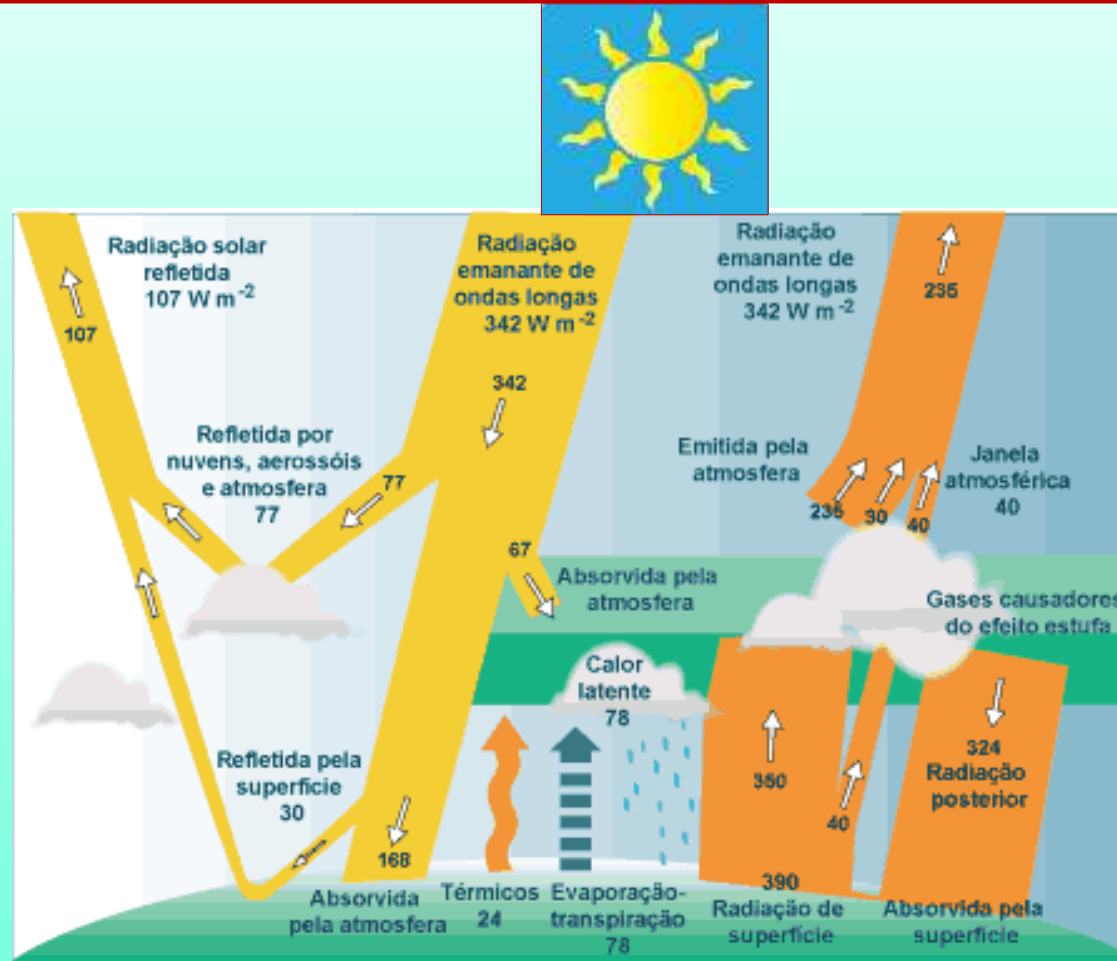
Aeolus



Poseidon

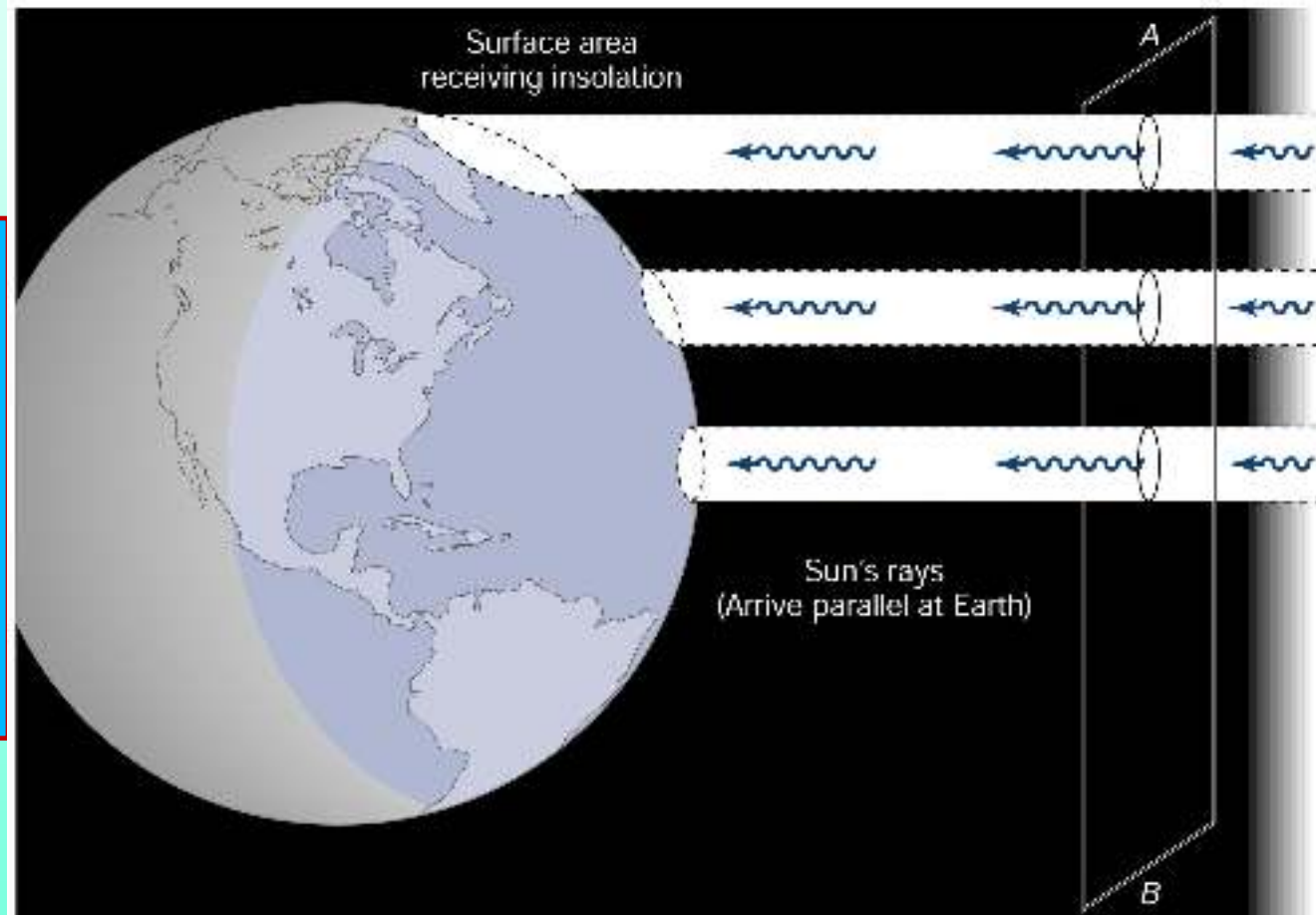


*The Sun is
the primary
energy
source*



Due to its sphericity, insolation at earth's surface is different at different latitudes.

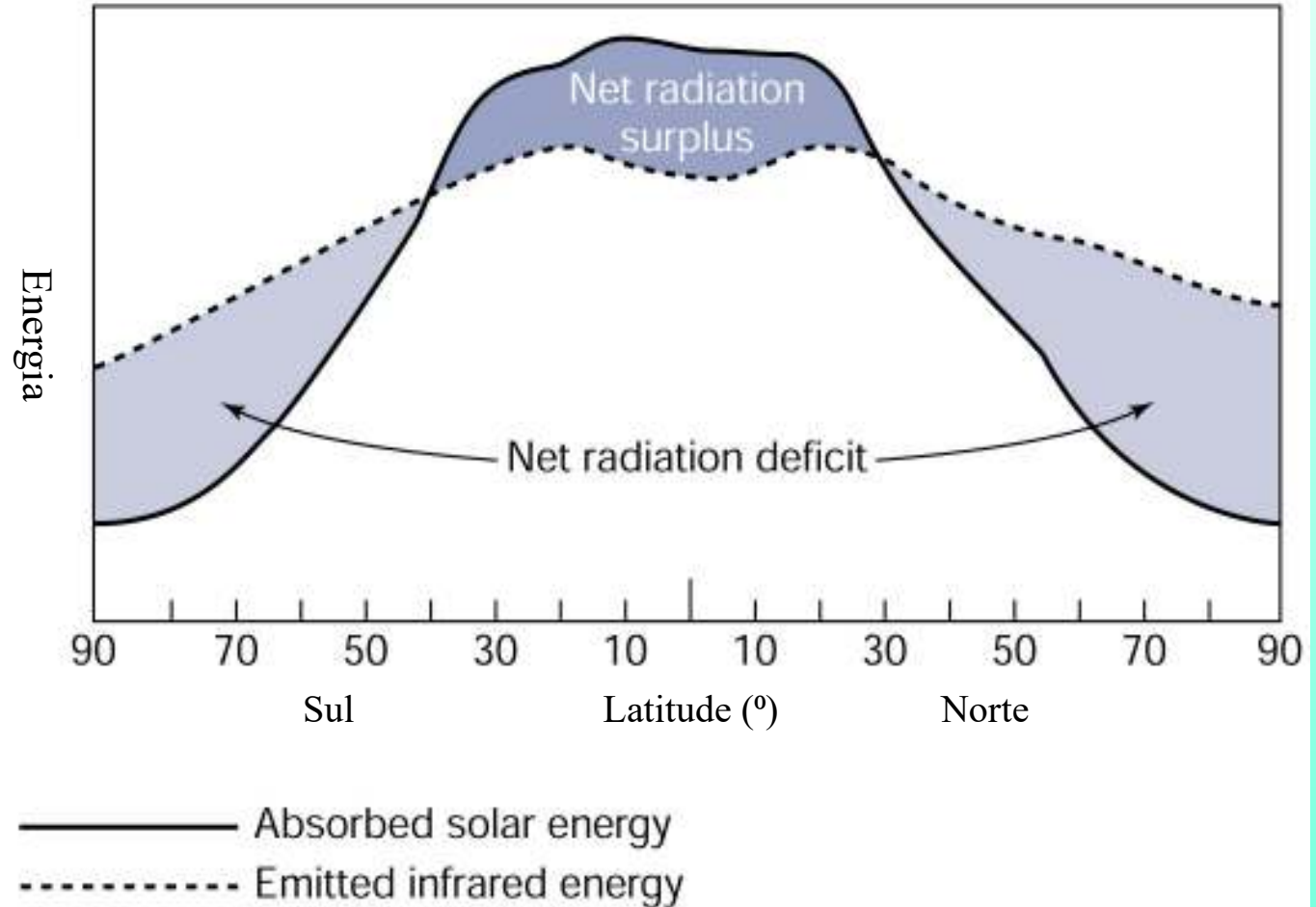
(Try to explain this in a flat earth).



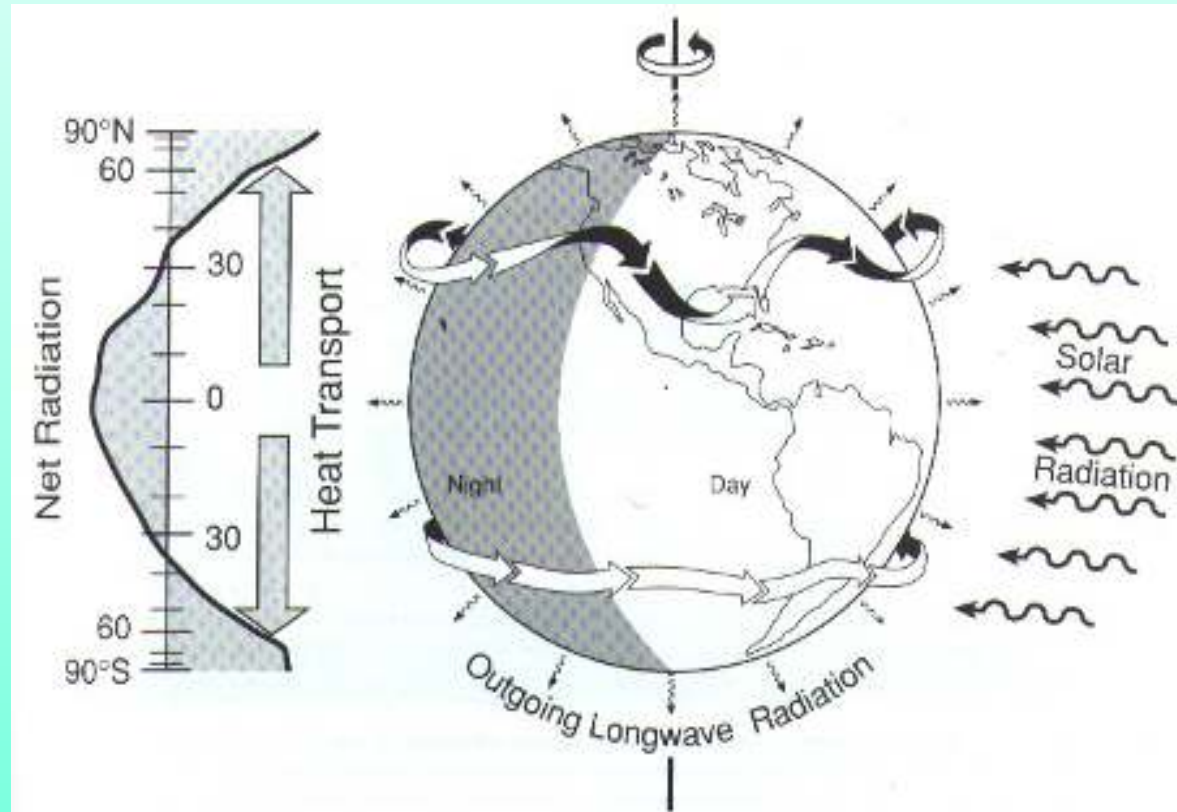
Due to the higher insolation, tropical regions are warmer and higher latitudes are colder ...

... and due to the net gain of heat, these regions should be continuously warming. ...

... and the higher latitudes should be cooling!



The ocean and atmospheric circulations transfer the heat surplus from lower to higher latitudes, maintaining the equilibrium.

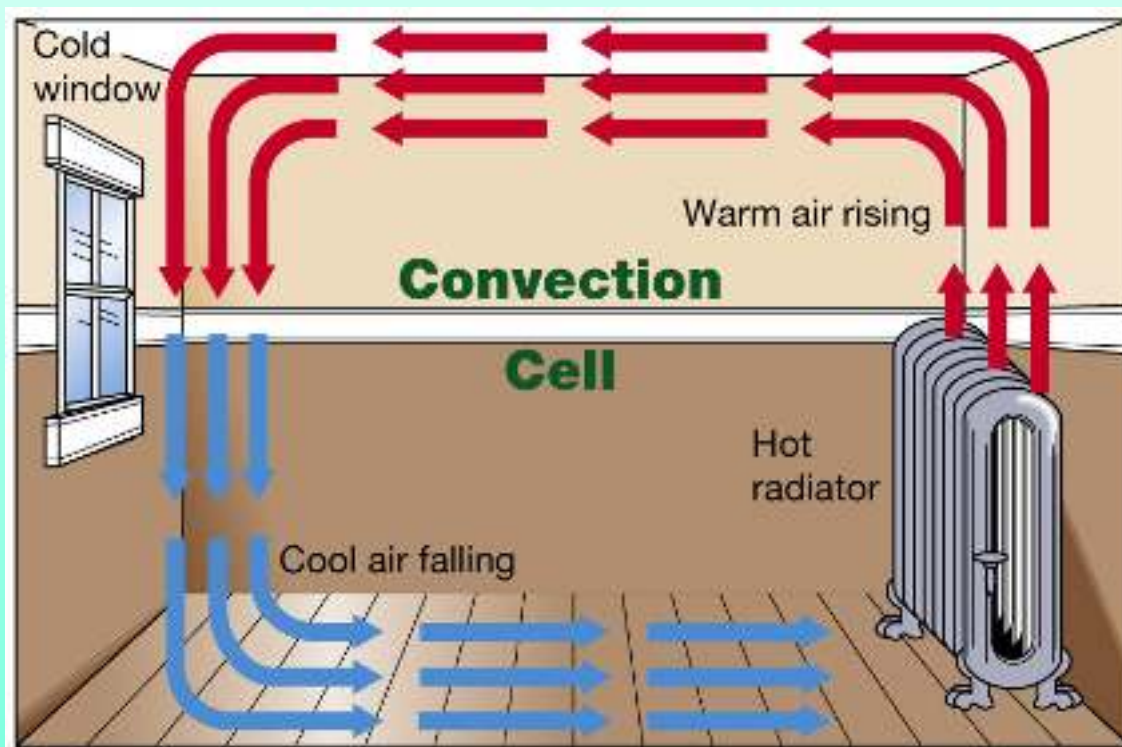


The Atmospheric Circulation

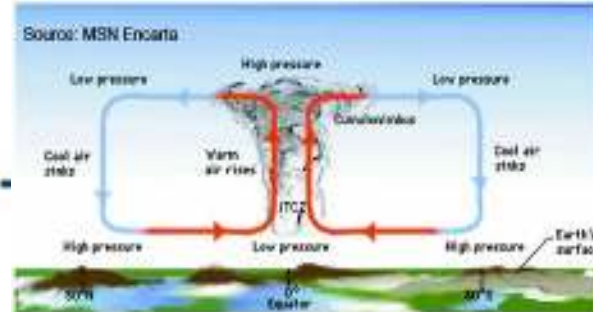
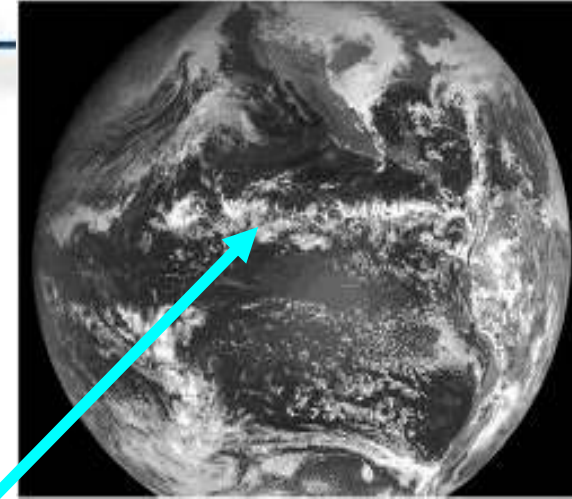
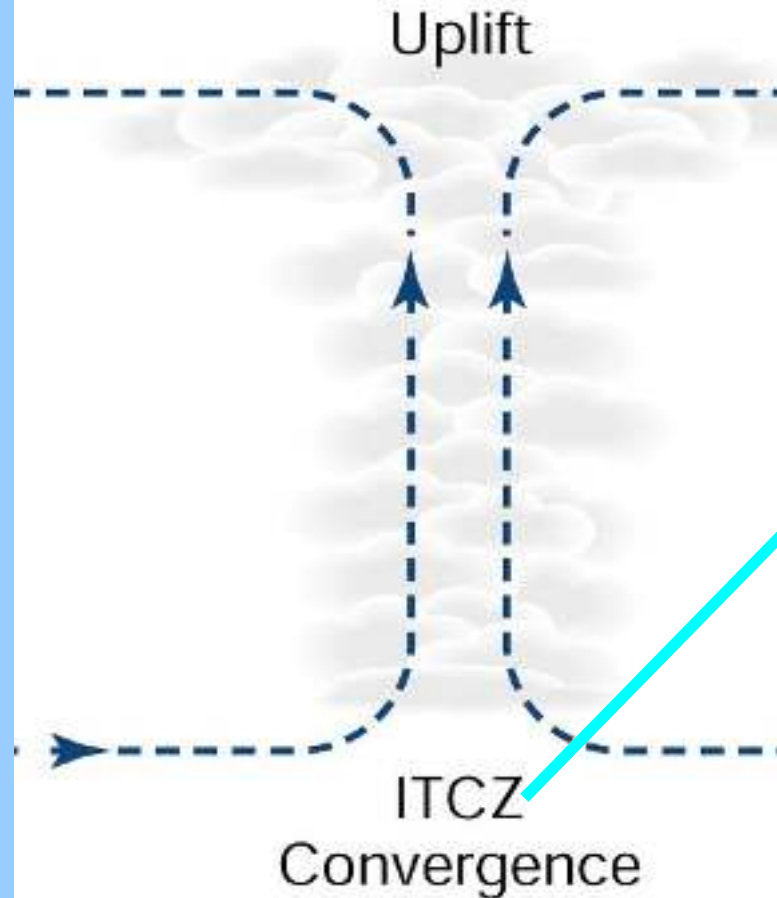


Convection Cell

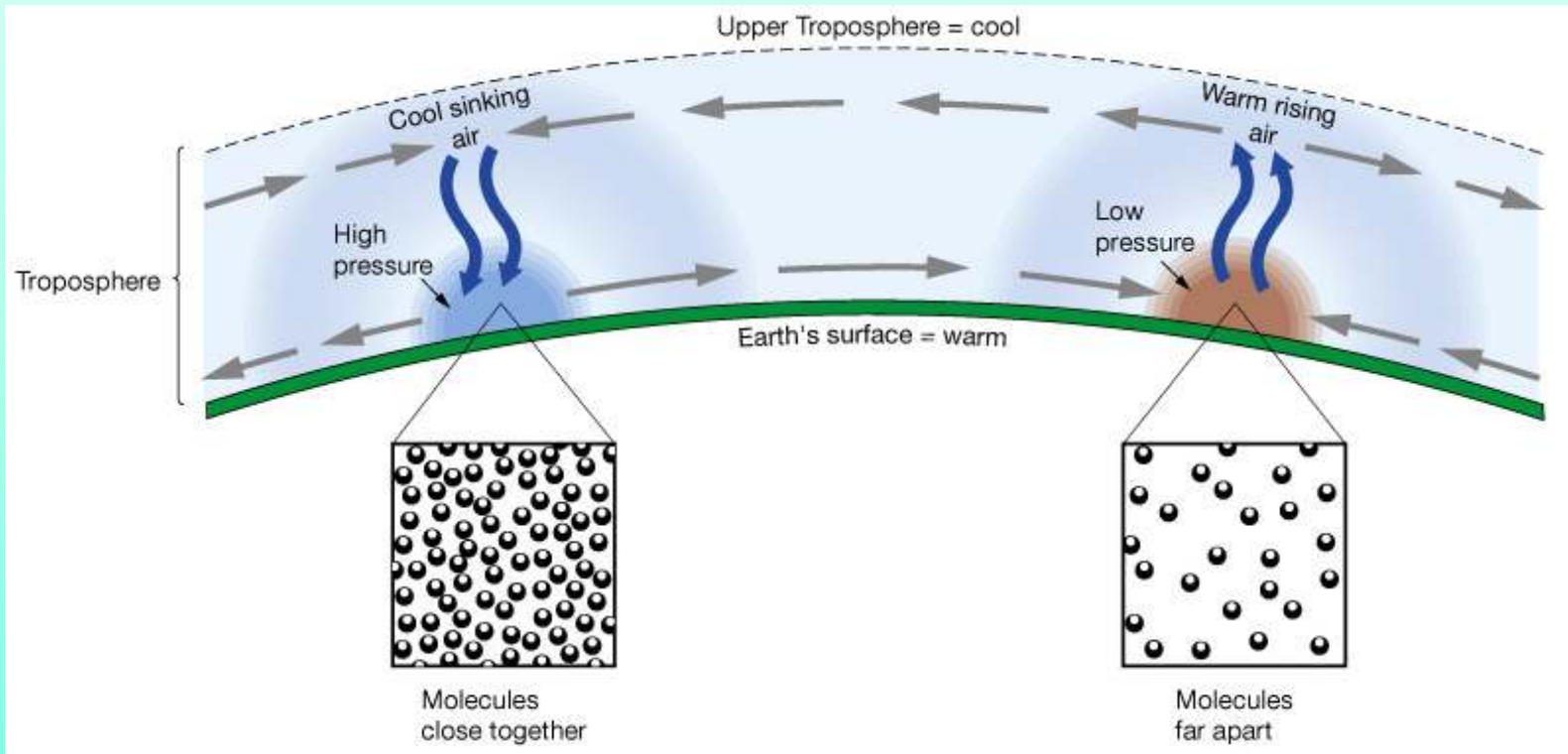
- Hot air, with lower density, goes up.
- Cold air, lighter, goes down.
- The result is a vertical motion cell



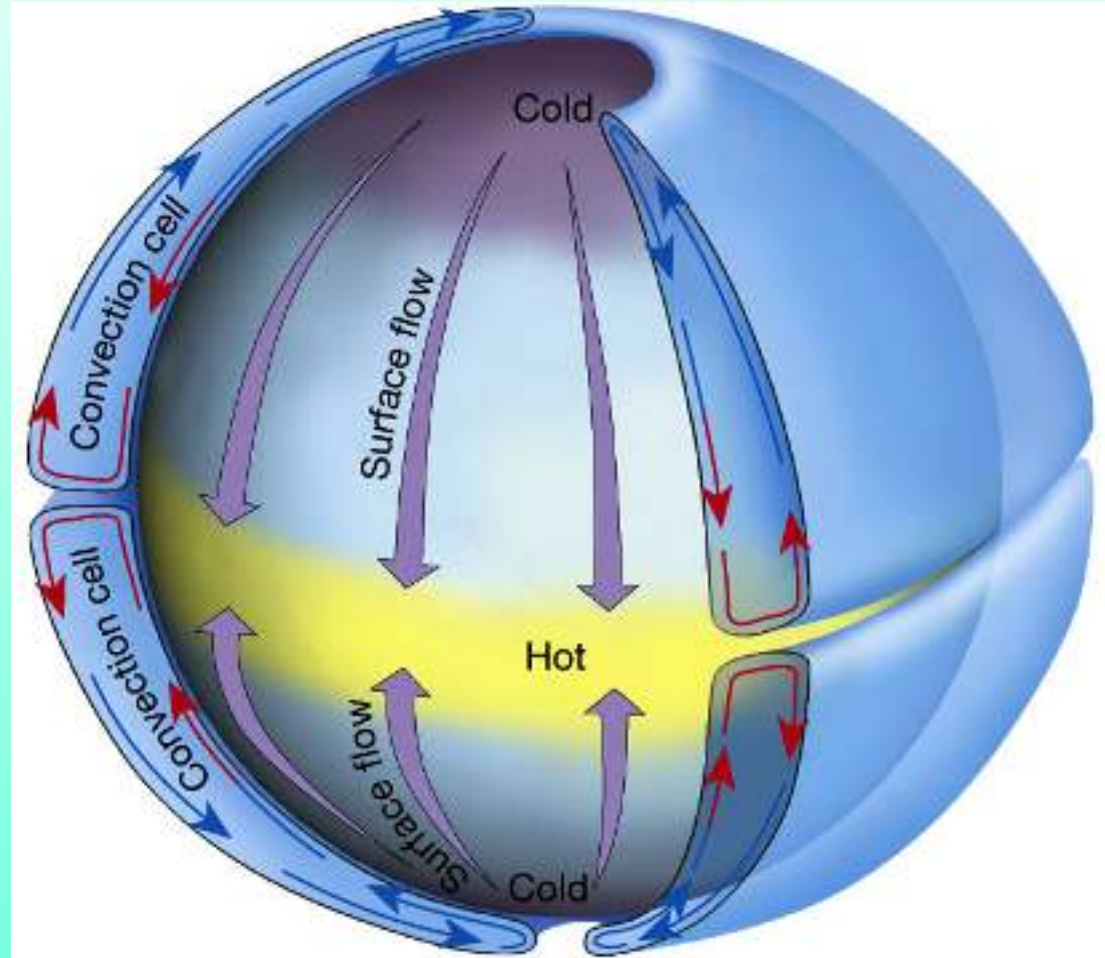
In the equatorial regions, hot air rises, forming a cloudy band, the Intertropical Convergence Zone (ITCZ)

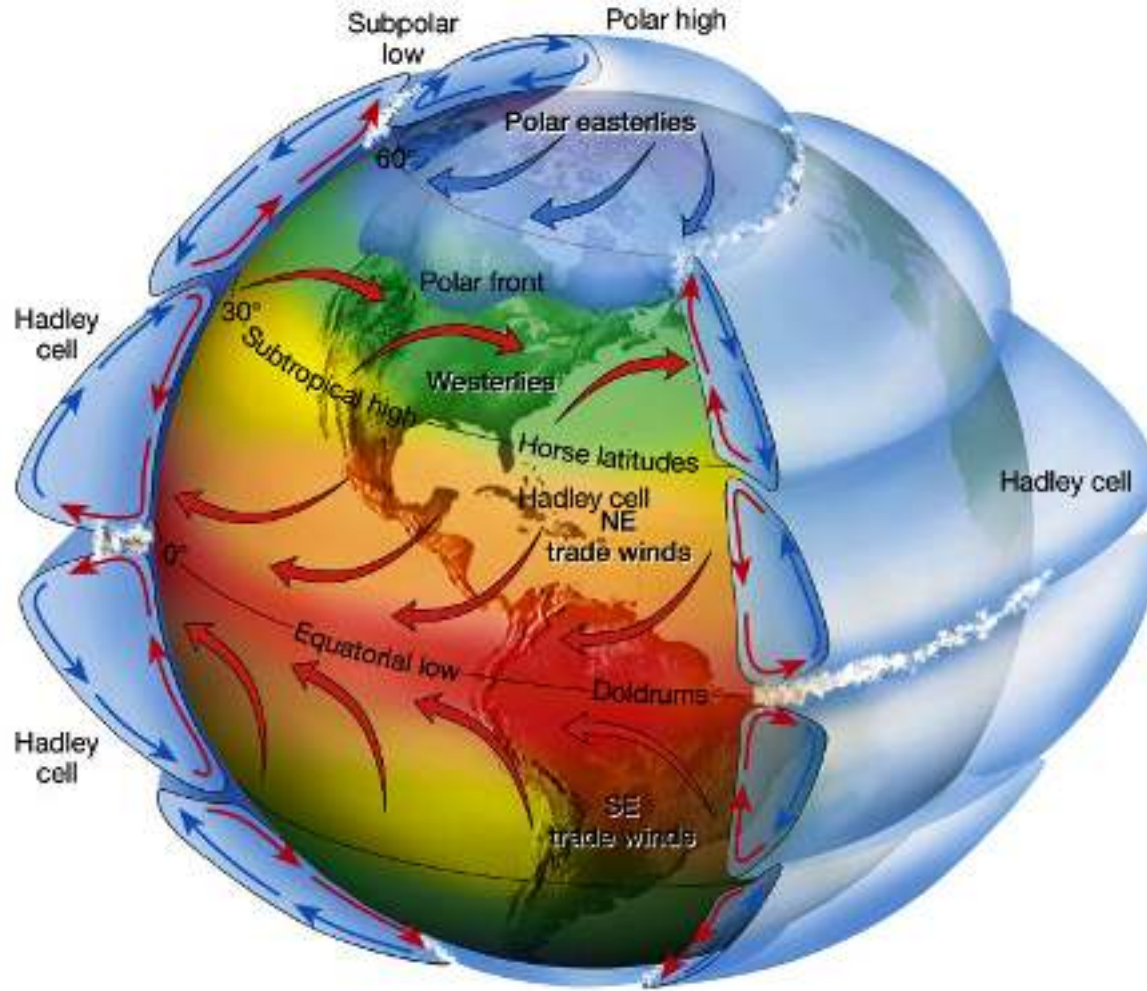


High and Low Pressure Zones



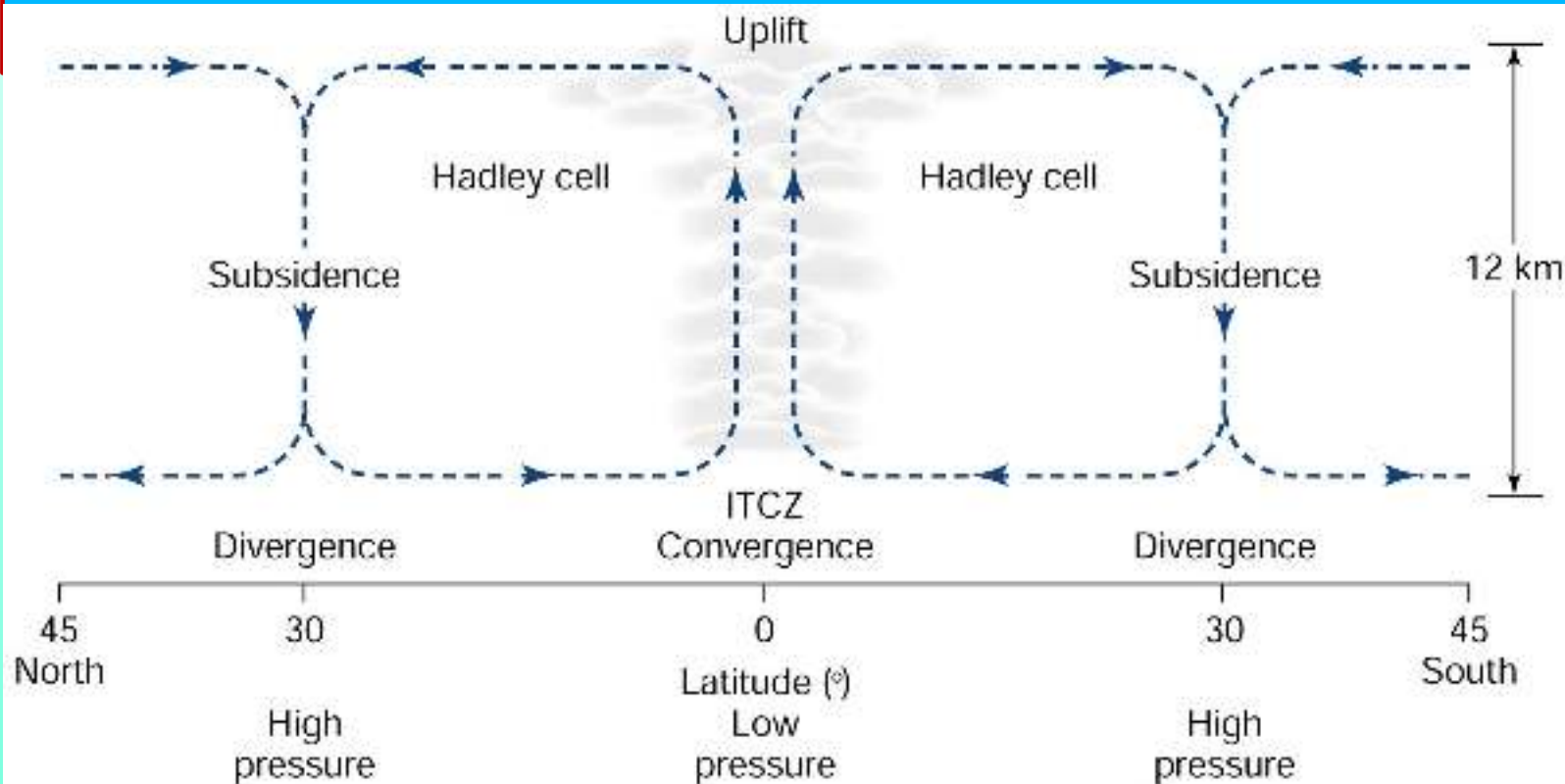
Atmospheric Convection Cell in a non-rotating spherical planet

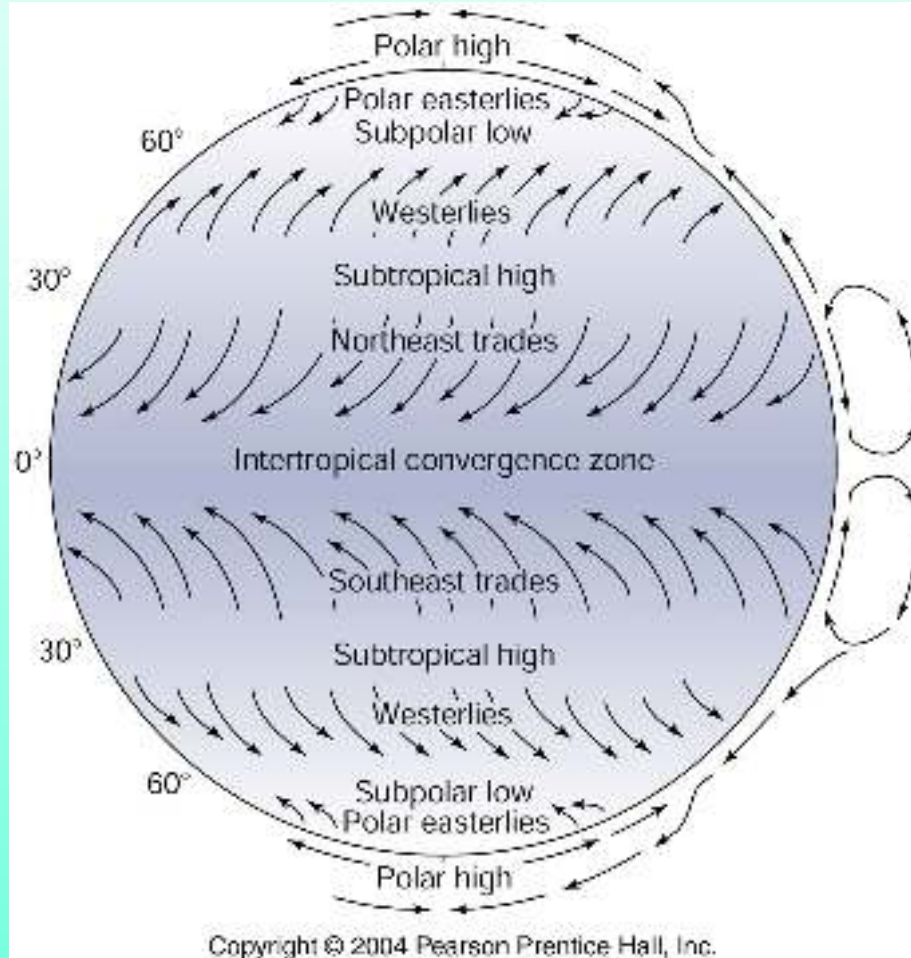




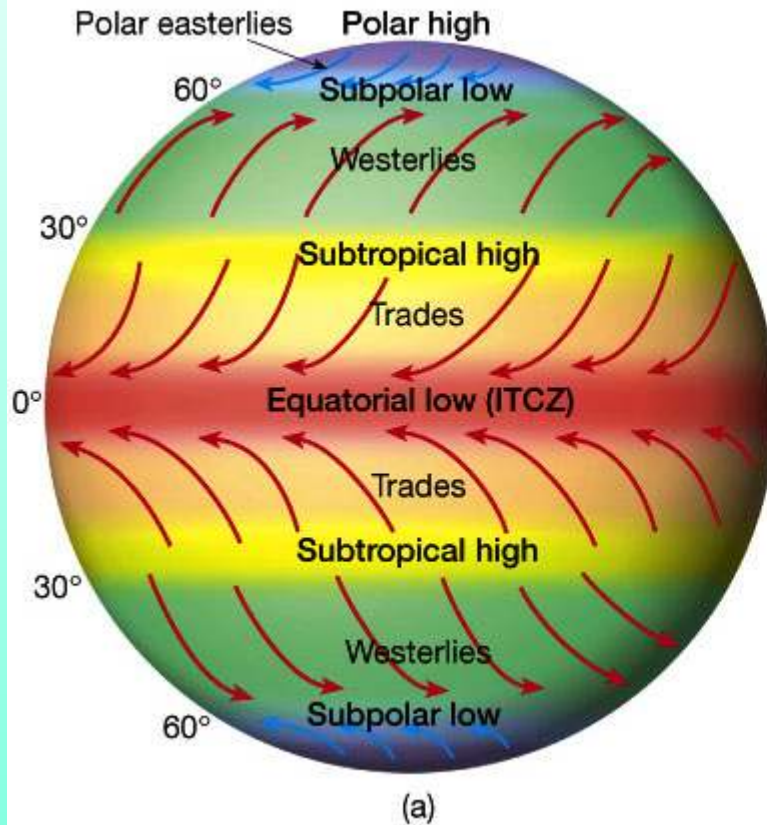
Considering
rotation and
Earth's continents.

→ *Air flows toward regions with lower pressure*

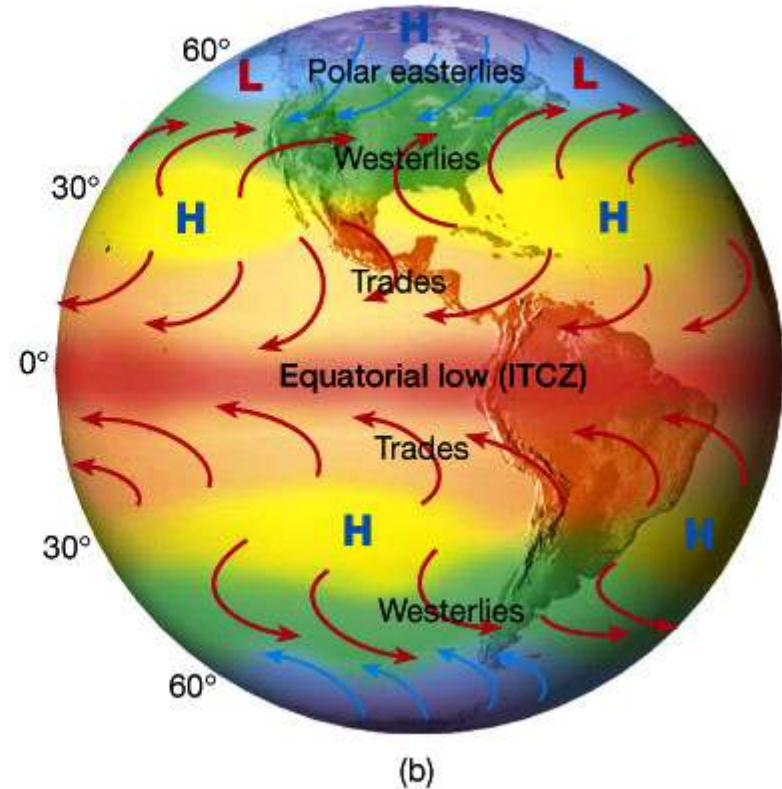




→ *Convective
Cells drive the
atmospheric winds*



Surface winds in the absence of continents.



... With continents

Ocean Circulation

● Surface Currents:

Wind-driven, pper 400 meters of the water column (~10%)

● Abyssal Circulation:

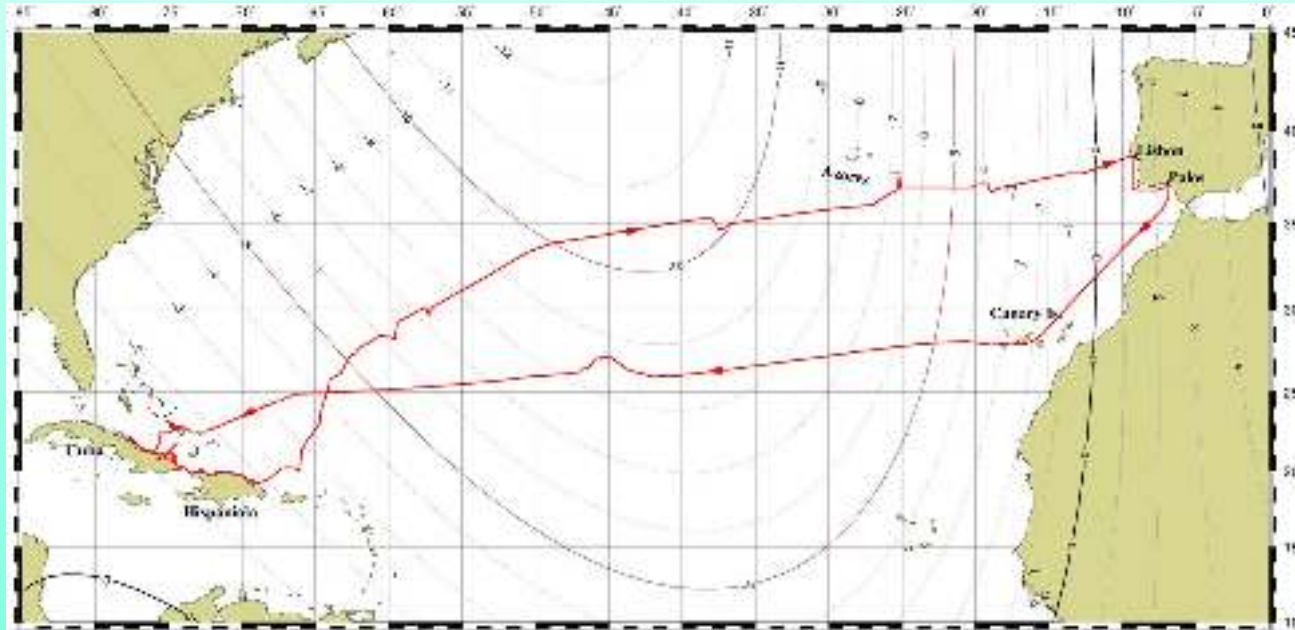
Driven by thermohaline gradients (~90%)

Surface currents have been known (and used) by sailors for several centuries

Viking expeditions to Greenland and North America.



Christopher Columbu's
shiptrack in his first
expedition to the
Americas.



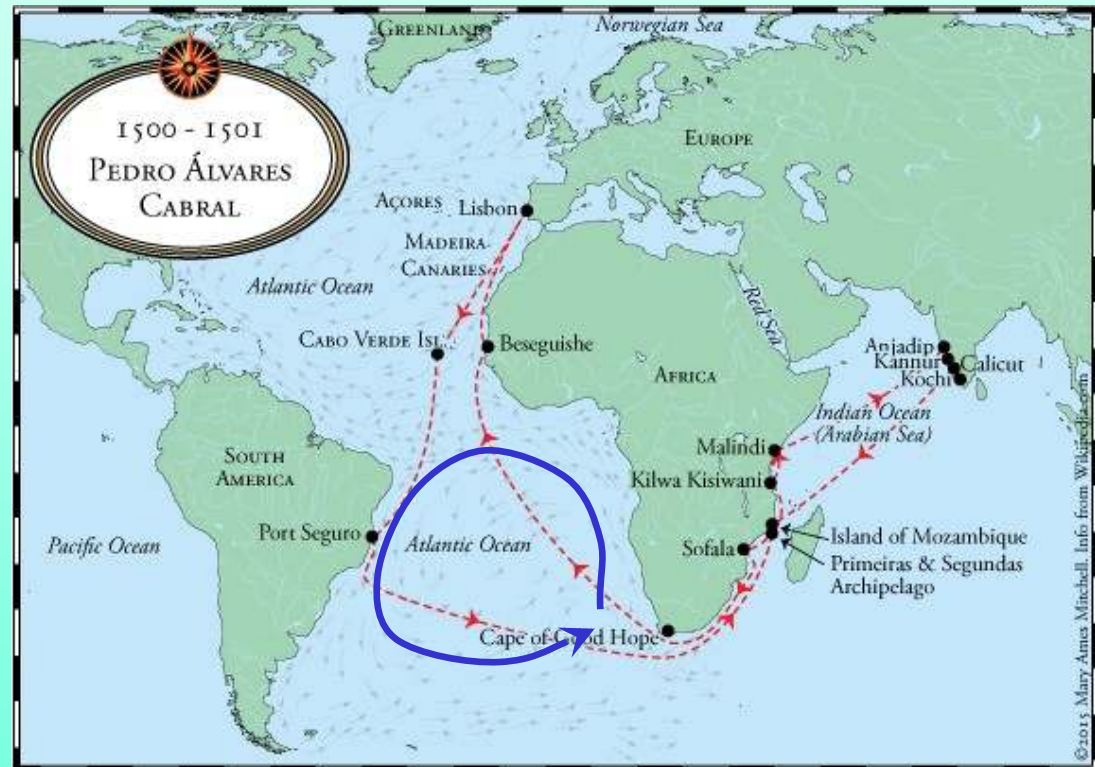
The Gulf Stream, Segundo Benjamin Franklin*

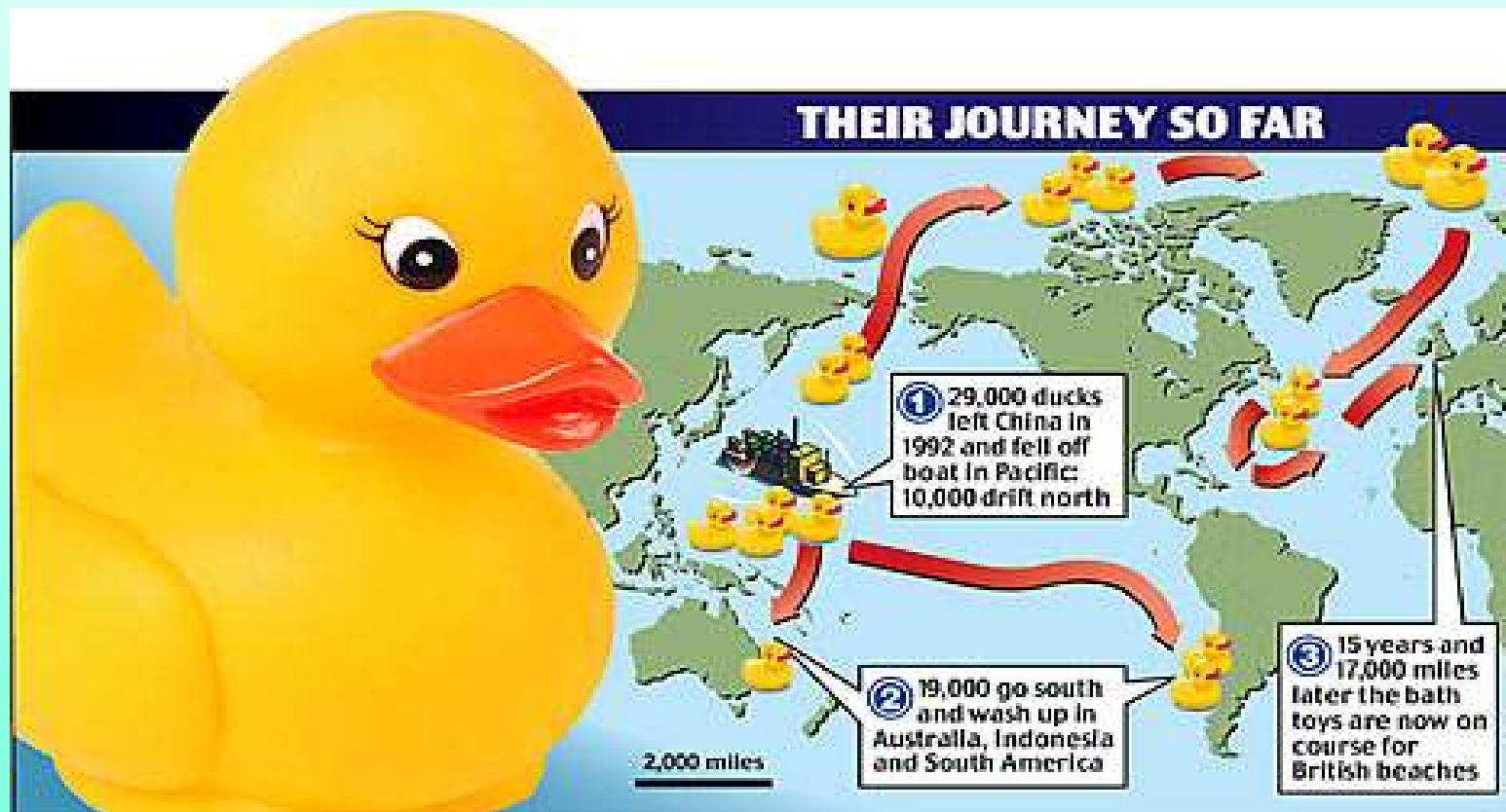


* Benjamin
Franklin
(1706-1790)



Pedro Cabral's Discovery Voyage to Brazil





Disclaimer

If you are a flat-earther (a member or believer of the Flat Earth Society), it's better to stop here. The theory adopted in the sequence only works in a rotating, spherical planet.

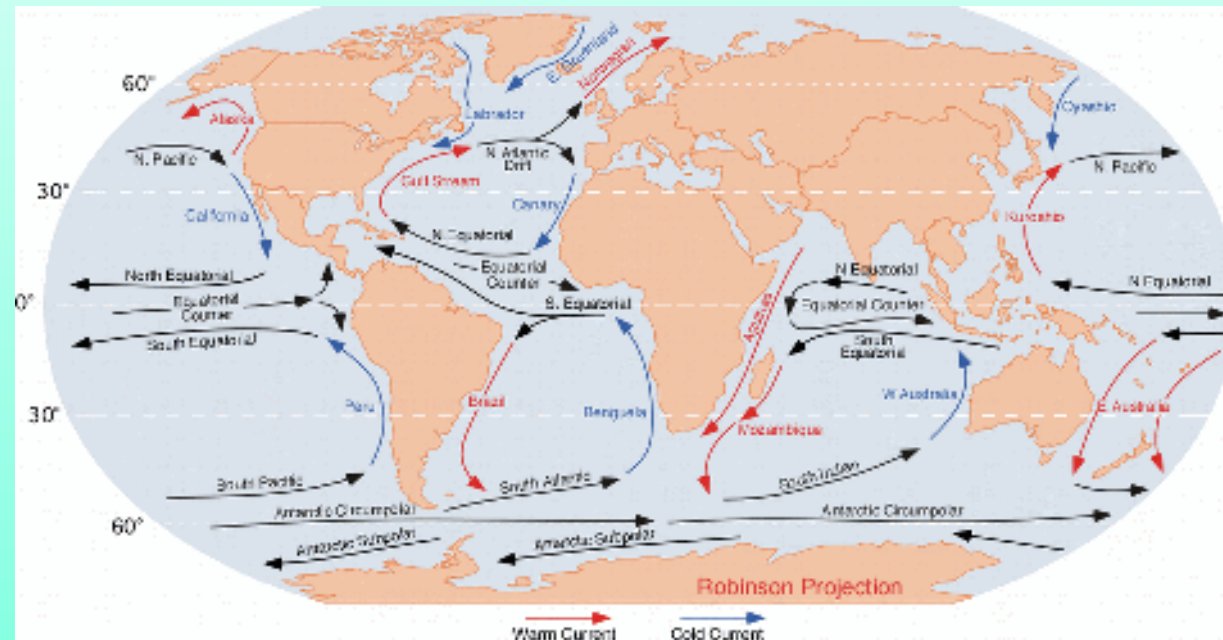
Unfortunately, the FES has no plausible explanation for the observed ocean currents.



Driving Agents

1. Solar Radiation (pressure gradients)
2. Thermohaline gradients
3. Winds
4. Gravity
5. Coriolis (Earth's rotation)
6. Non-linear effects

Ocean Currents



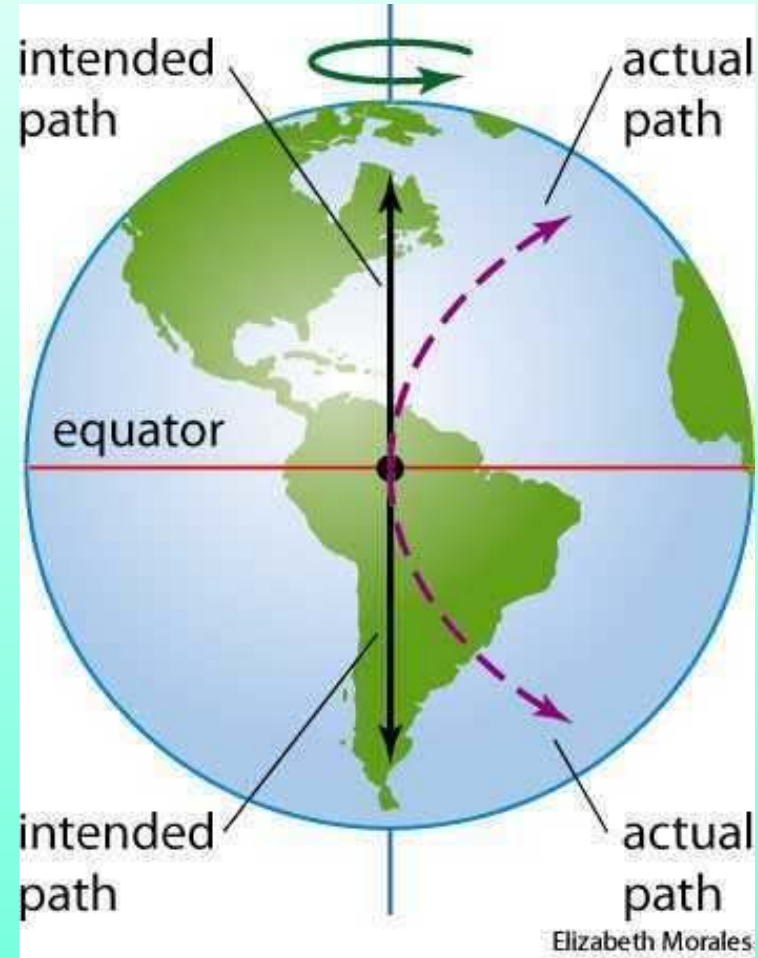
The Coriolis Effect

Is an effect due to Earth's rotation.

In the northern hemisphere, the velocity of a water parcel seems to be deflected to the right.

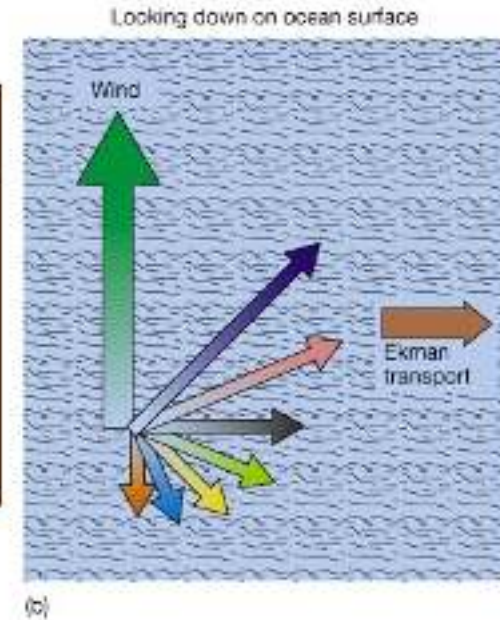
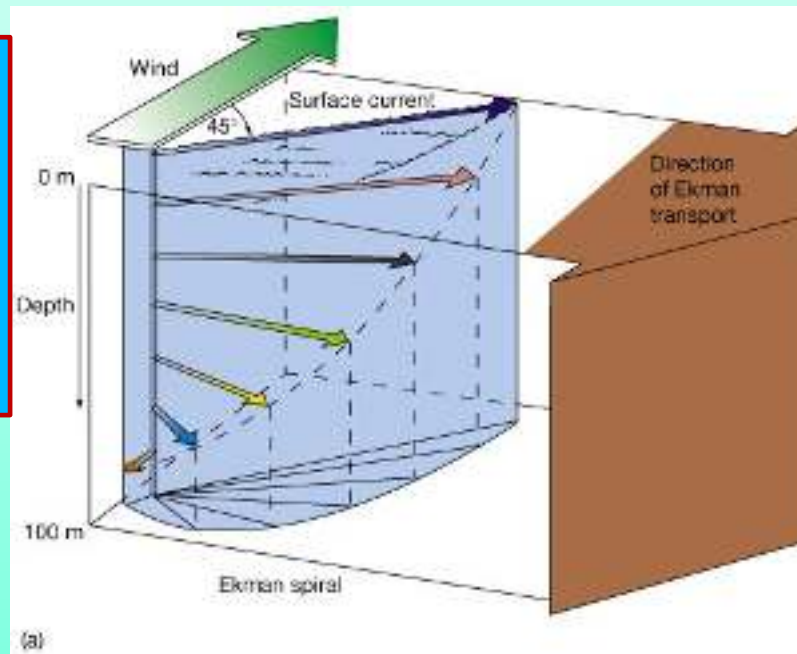
In the southern hemisphere, the velocity is deflected to the left.

In a spherical Earth, the Coriolis Effect varies with latitude (zero at the Equator and maximum intensity at the poles)



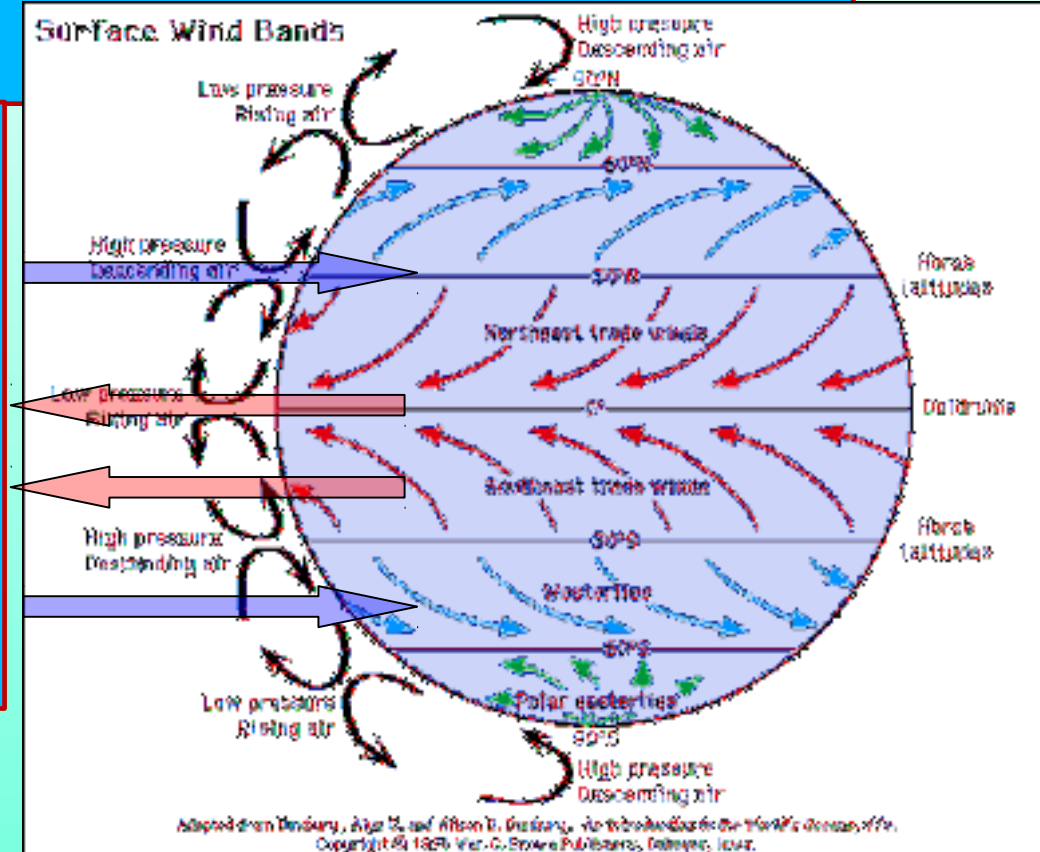
Ekman Spiral

The Ekman Spiral
results from the
Coriolis Effect.



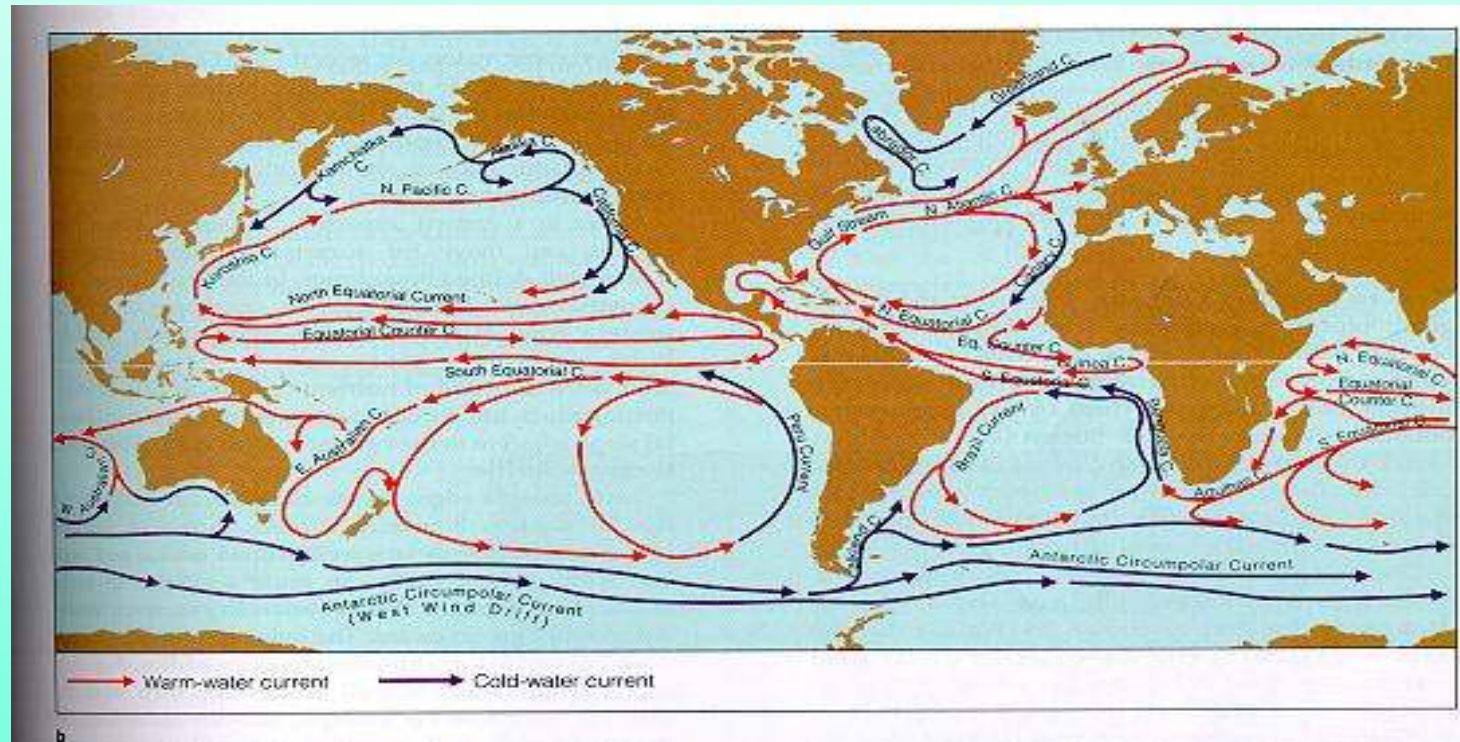
Wind-driven Circulation

In the absence of continents, the wind-driven currents would be predominantly in the zonal direction (E-W)



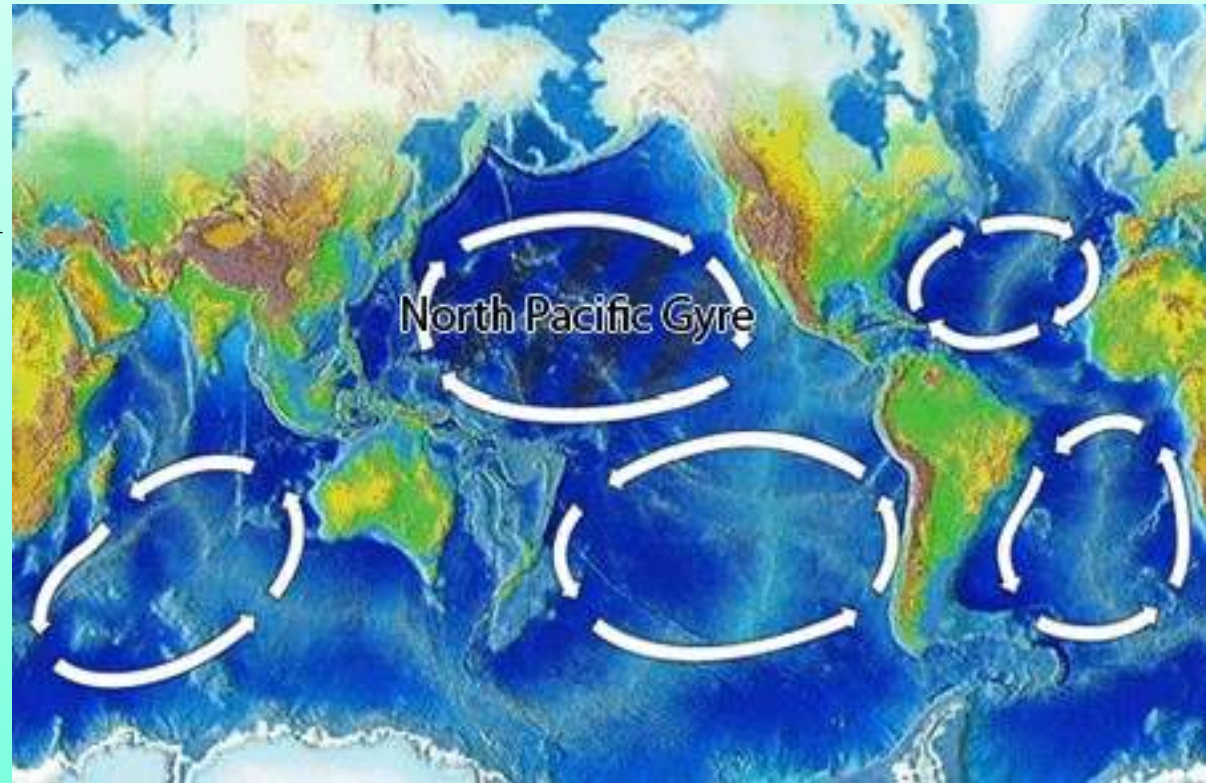
In our planet, with the actual continental distribution, the surface currents form horizontal closed circulation cells named Gyres.

The Oceanic Gyres

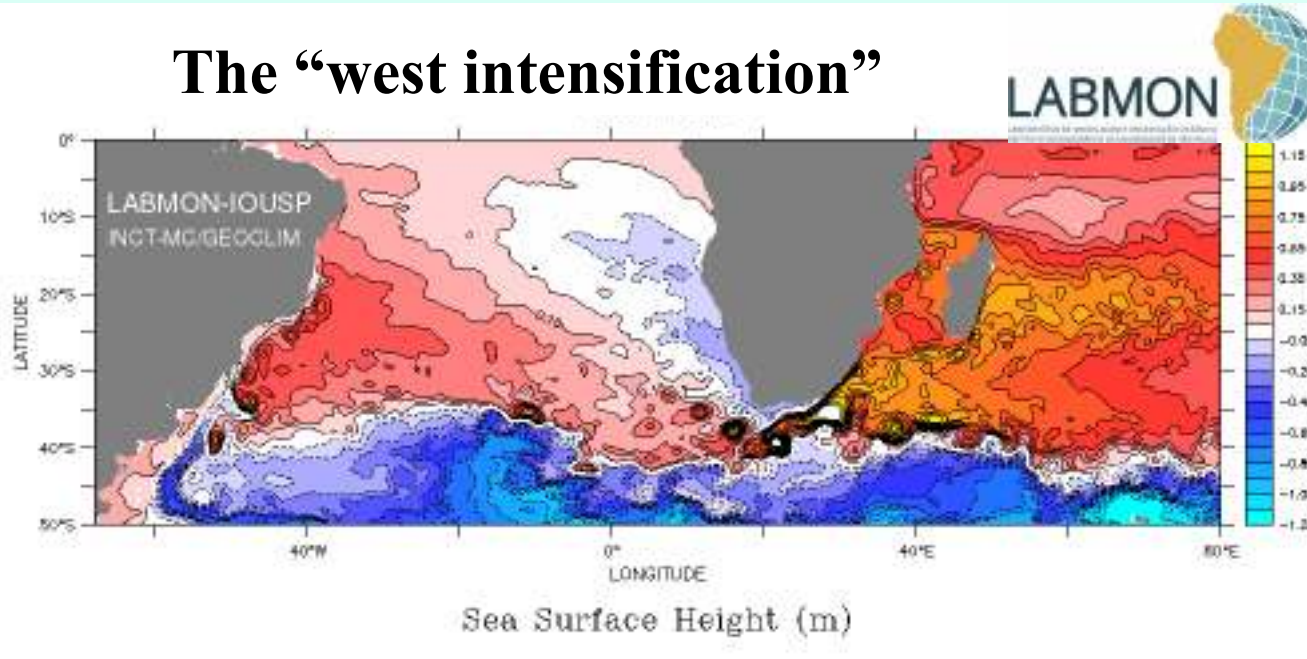


Th Subtropical Gyres

These remarkable circulation pattern in all subtropical basins result from an equilibrium among pressure gradient, wind, effects of sphericity and rotation and the planet's continental distribution.



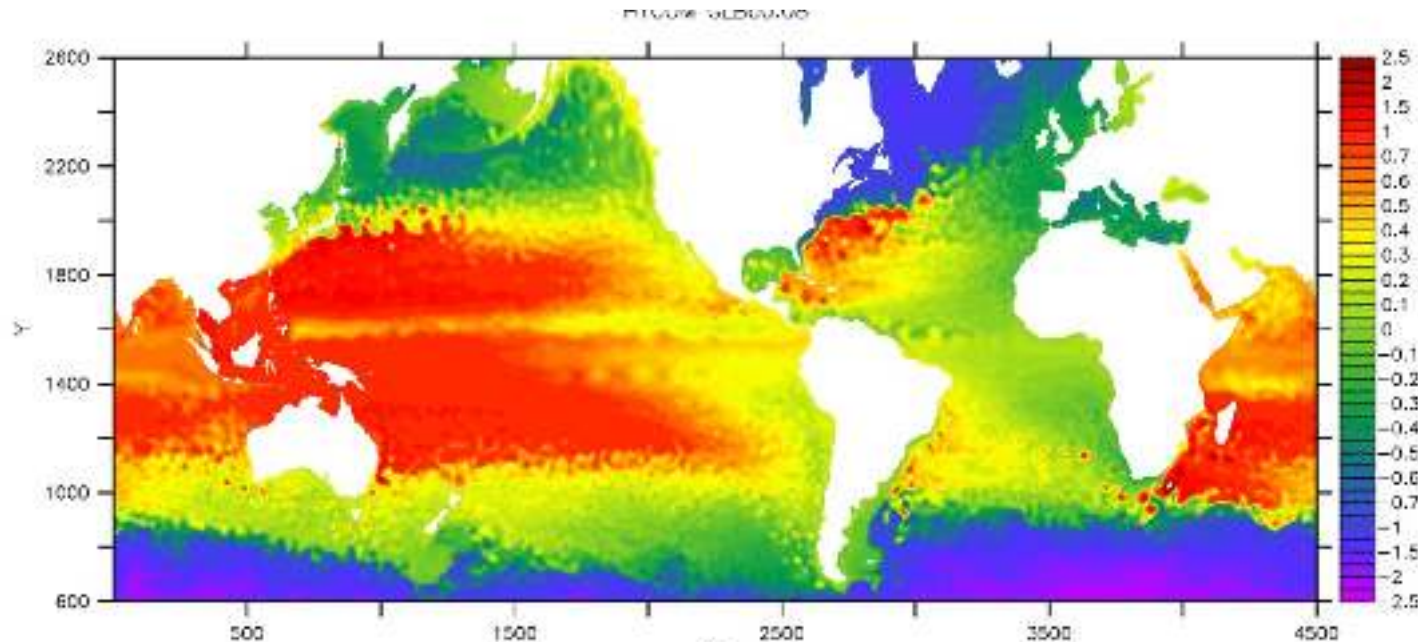
The “west intensification”



The “western intensification” would not exist in either flat or cylindrical planet!

The ocean currents are more energetic along the western boundaries of the basins (eastern continental boundaries). This results from the sphericity and rotation of the planet (the “beta” effect). The rings and vortices seen in this simulation result from non-linear processes.

The ocean currents connects all oceanic basins



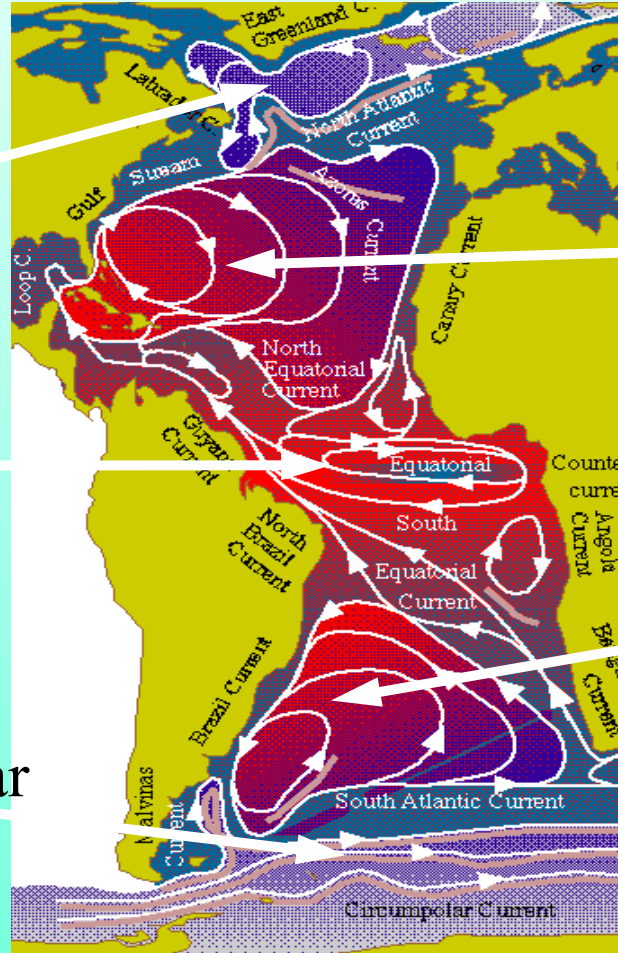
Under the actions of the winds, the oceanic waters circulate along well defined paths, transporting properties throughout the different basins.

The Atlantic Ocean

Sub-polar Gyre
(cyclonic)

Equatorial Gyre
(cyclonic)

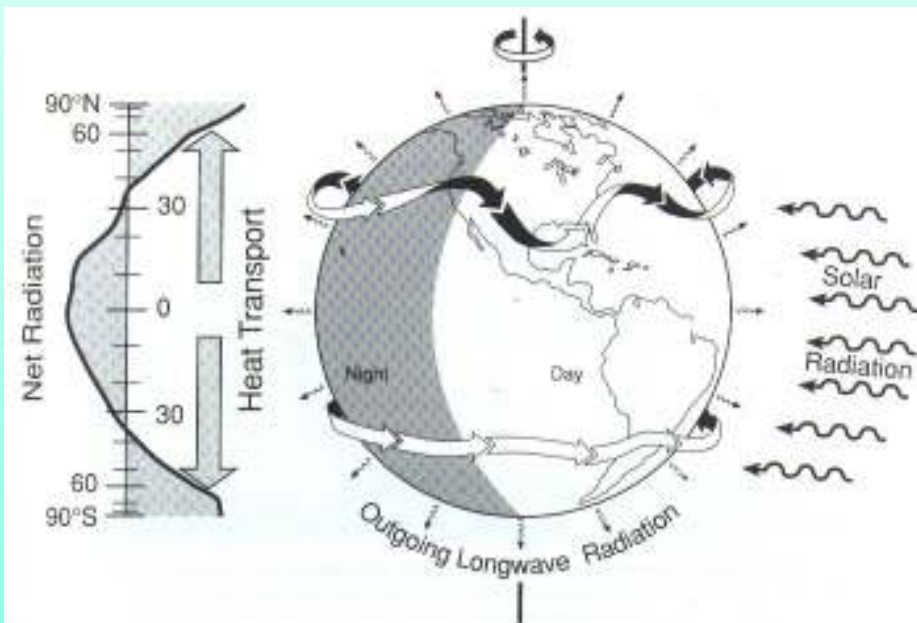
Antarctic Circumpolar
Current



North Atlantic
Subtropical Gyre
(anticyclonic)

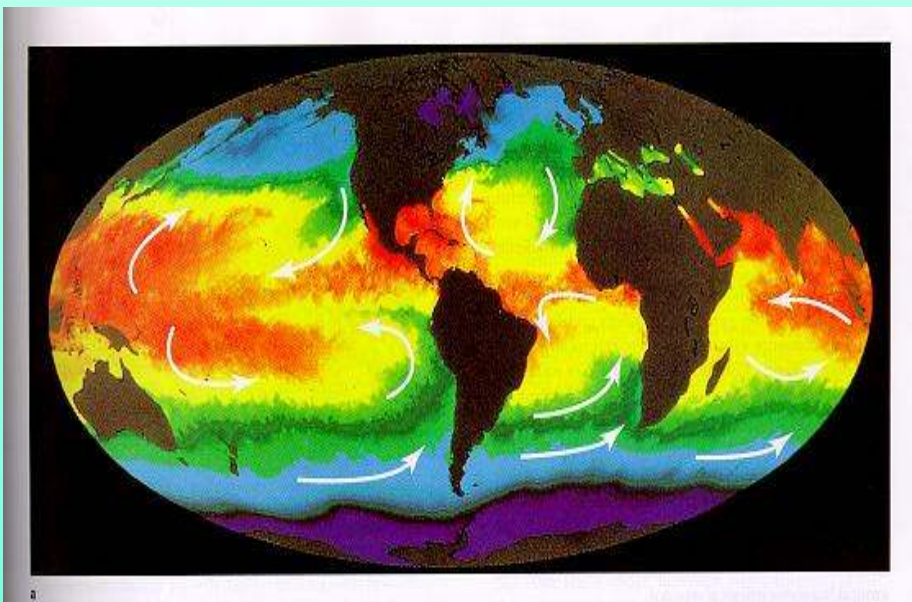
South Atlantic
Subtropical Gyre
(anticyclonic)

Heat Transport by Ocean Currents



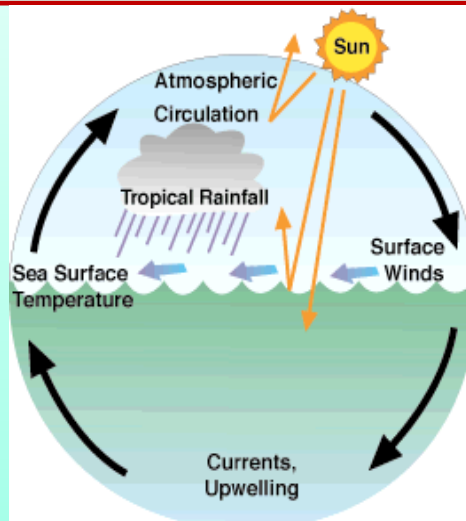
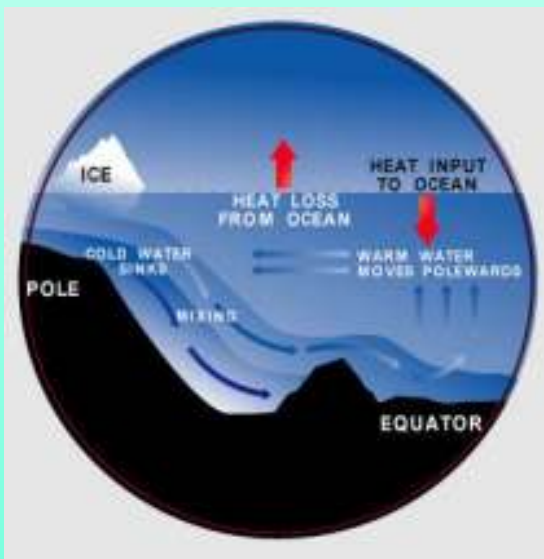
Excess heat from tropical regions are transported poleward by ocean currents

Ocean circulation transport and redistribute heat throughout the basins, contributing for the climate equilibrium

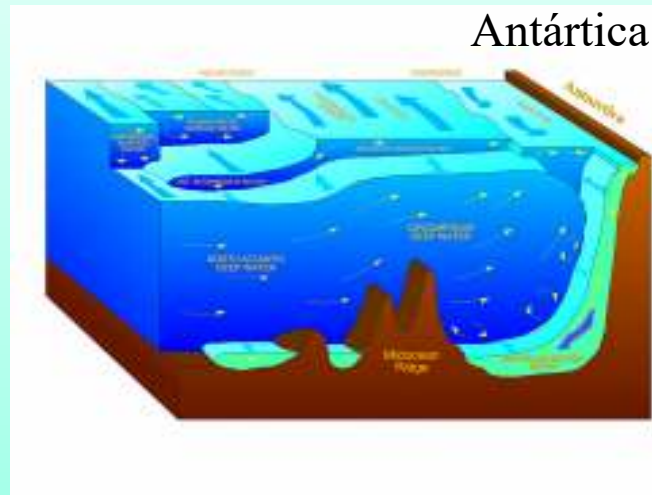


Vertical Motions

The motion of the ocean's water is not restricted to horizontal currents nor to the upper layers of the sea.



Density differences resulting from heat exchange with the atmosphere drive vertical motions (convection), exchanging waters between the surface and the deep regions of the ocean.



Antártica



Atlântico Norte

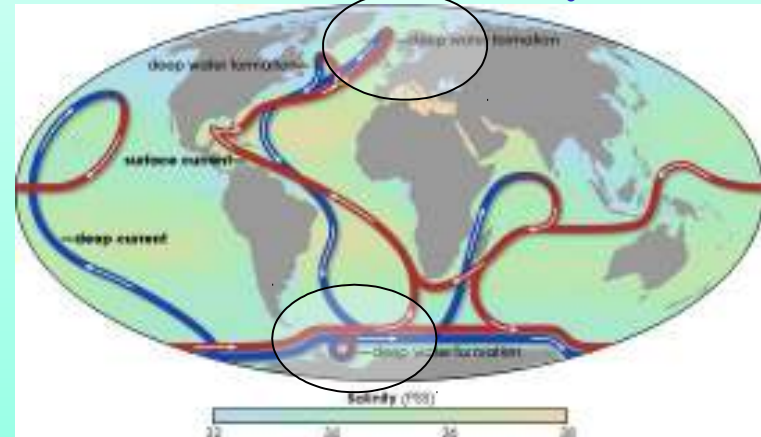
The Global Thermohaline Circulation

Circulation forced by gradients of temperature and salinity

Temperature and salinity differences make the surface water to sink in certain regions and to upwell in others.

This vertical exchange of waters is compensated by horizontal currents, forming a global circulation pattern that redistribute water throughout all oceanic basins and all depths.

The Thermohaline Conveyor-Belt

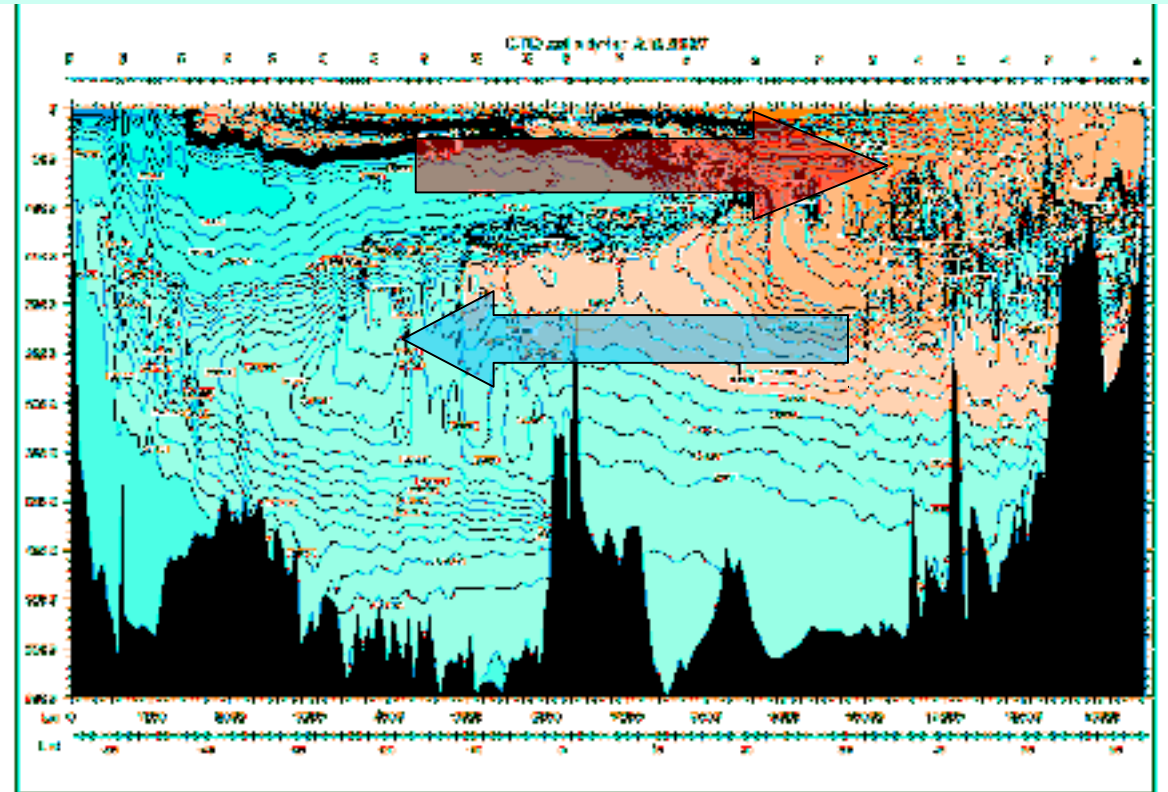


The Atlantic Meridional Overturning Circulation (AMOC)

Warmer surface waters flow from south to North;

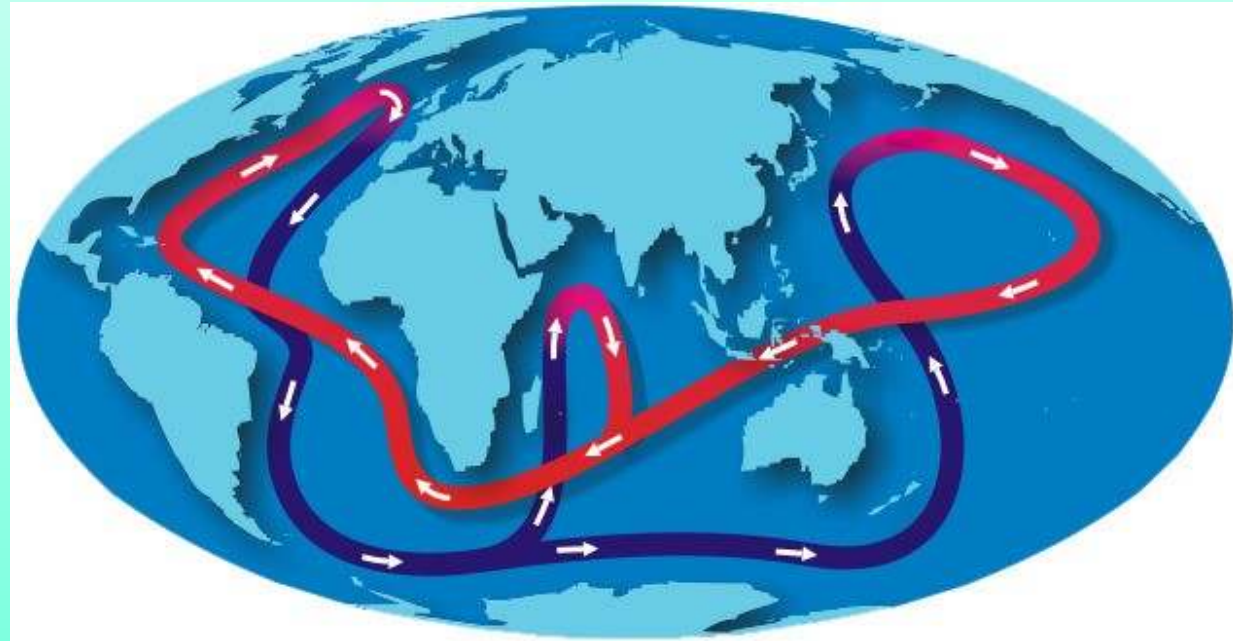
After losing heat to the atmosphere, waters get heavier and sink;

The resulting deeper, colder waters flow back to the southern hemisphere



**The Conveyor Belt's Meridional Overturning Circulation (MOC)
is a crucial mechanism for the maintenance of climate.**

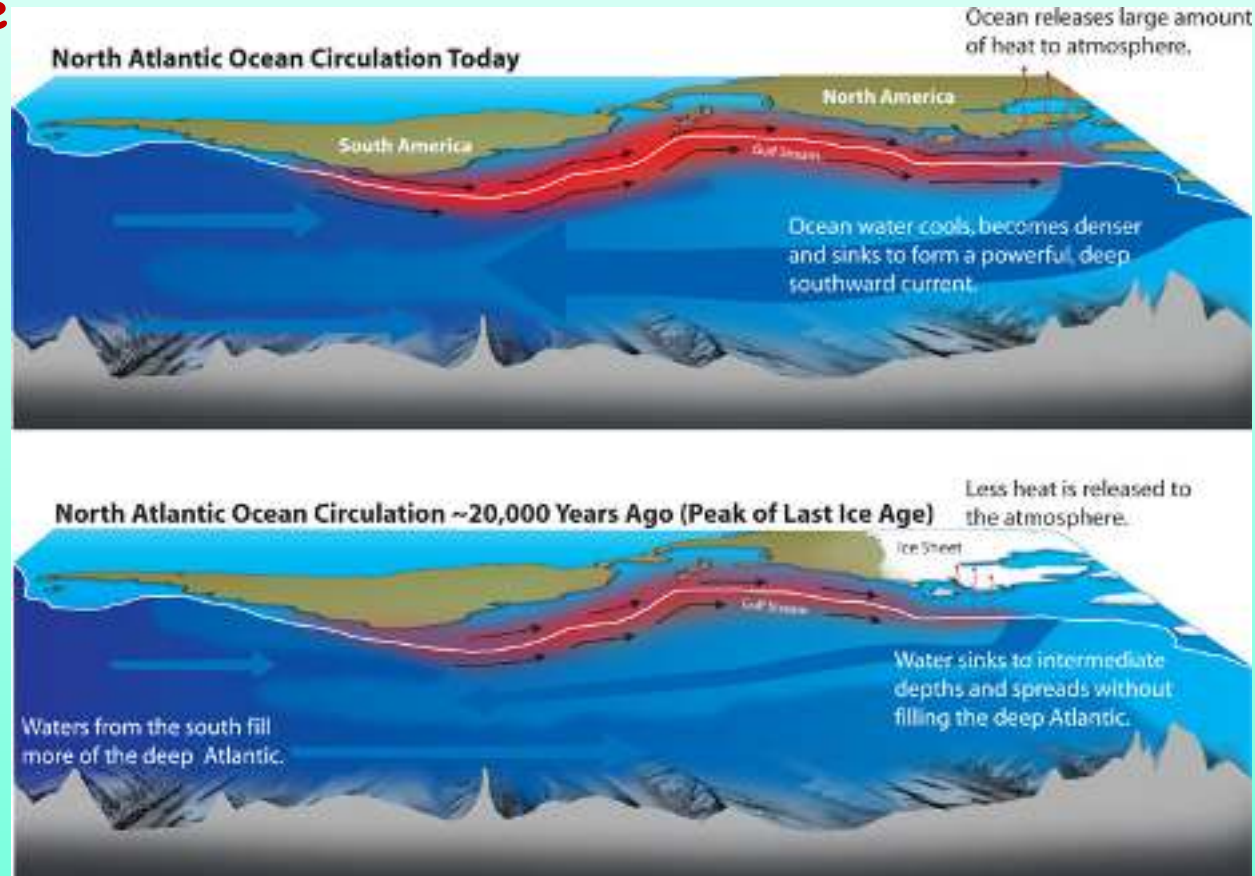
Paleoclimatic studies show a significant correlation between weakening of the MOC and abrupt climate changes.



The MOC and Climate

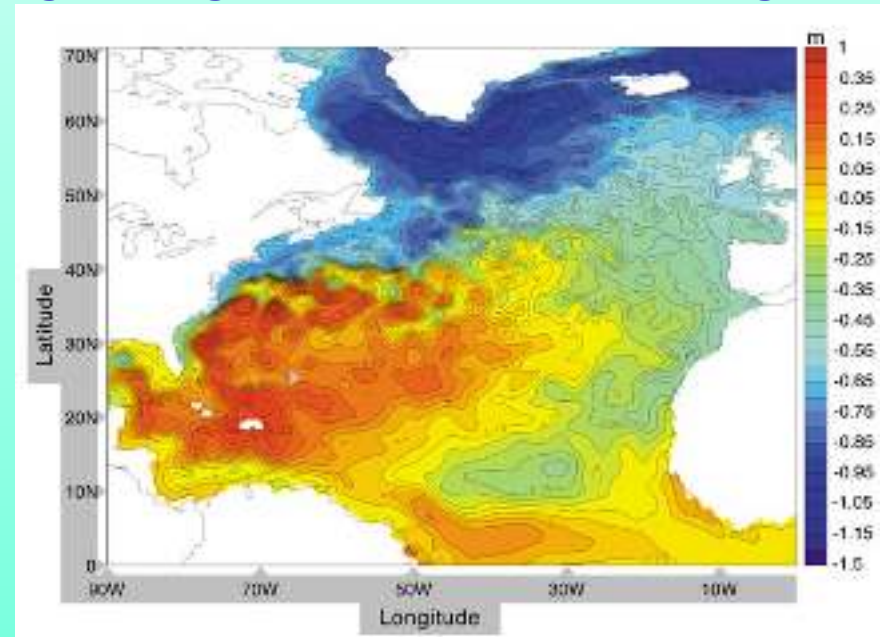
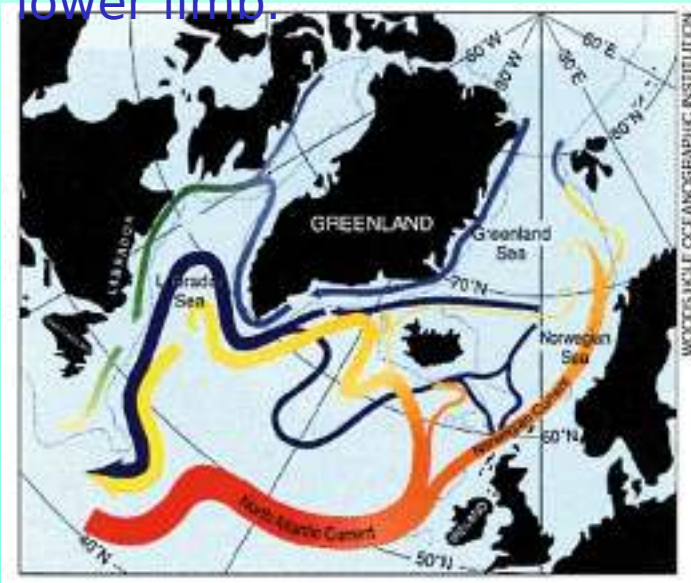
The Atlantic MOC was weakened at the peak of the last Ice Age (~20 thousand years ago)

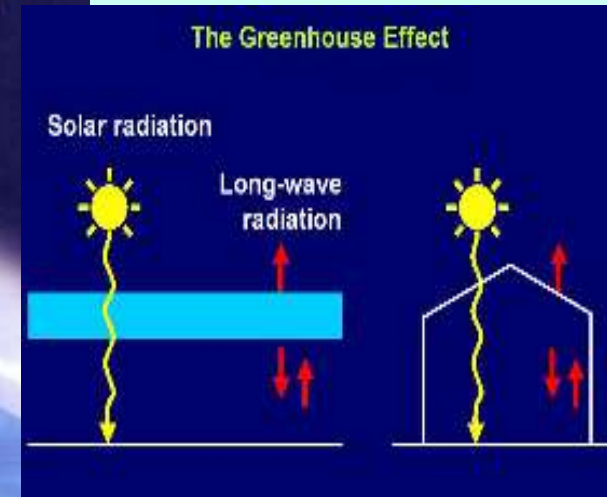
... Can this happen again?



The North Atlantic Heat Pump

In the northern latitudes of the North Atlantic, after releasing heat to the atmosphere, the higher salinity surface waters transported by the MOC get denser and sink, originating the southward flowing lower limb.





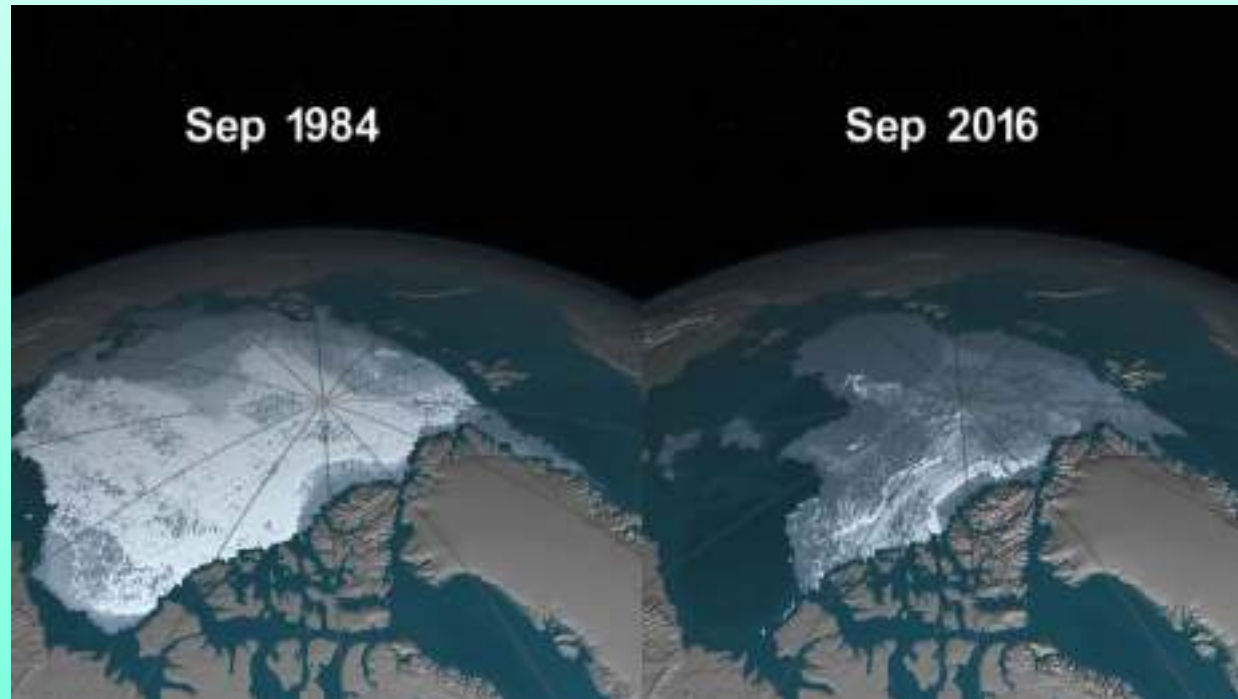
The increasing atmospheric concentration of certain gases, such as carbon dioxide and methane, can lead to the disequilibrium of the radiative balance, **resulting in the increase of the planet's mean temperature.**

The increase of only 1°C in Earth's mean temperature can lead to the melting of a vast amount of ice.

This will result in the injection of an enormous volume of fresh water in the surface layers of the North Atlantic.

... and So What?

The Arctic ice coverage has been decreasing due to the global warming



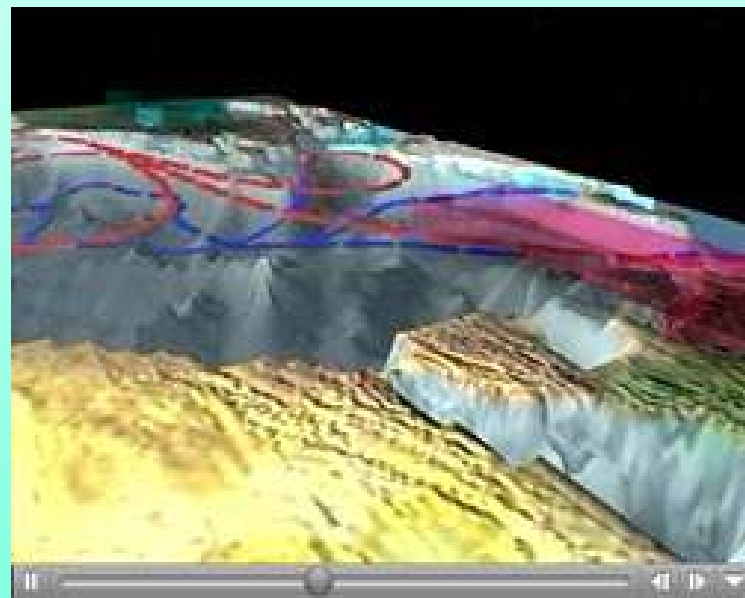
A likely consequence of the Global Warming

Global warming leads to the melting down of the Greenland's and Arctic ice sheets.

With the higher volume of fresher waters in the North Atlantic's surface layers, the more saline waters transported from the south by the MOC will get denser earlier and sink in lower latitudes.

This will result in less heat to warm the westerly winds. Then, the temperature will fall down and a new ice sheet will form.

This might result in a new Ice Age in the North Atlantic.



Modeling the Ocean

The best way to understand the ocean would be a global observing system with sampling points spaced by a few kilometers from each other. This is practically impossible.

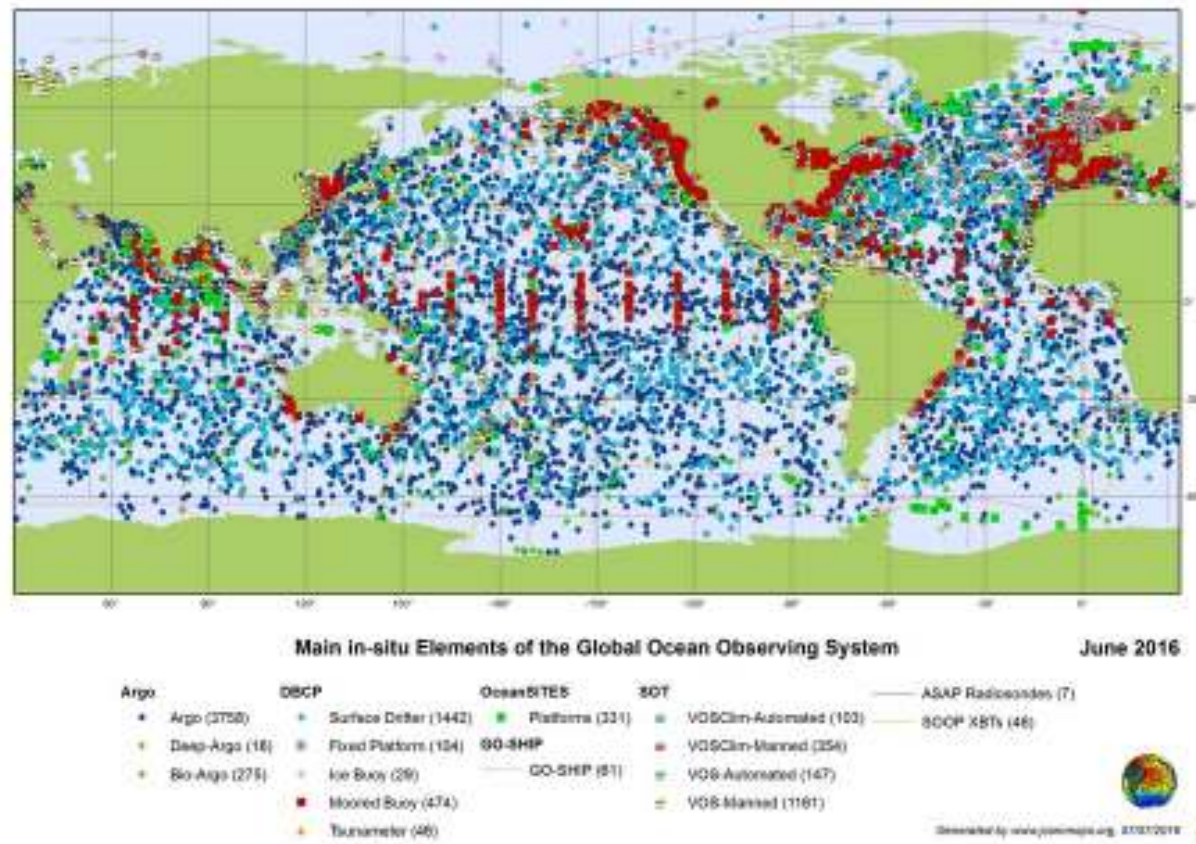
A cheaper alternative is to use computer models, in combination with the fewer observations.



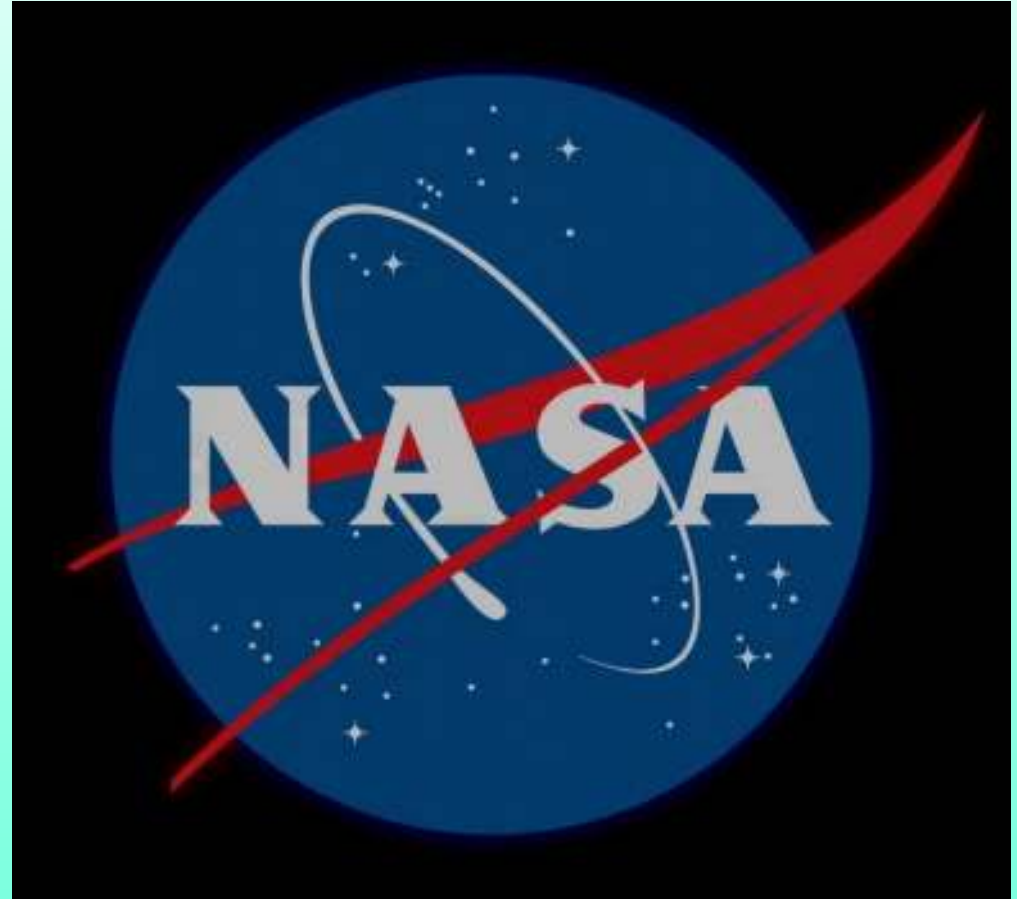
Global Ocean Observing System (GOOS)

An international global system for sustained observations of the ocean.

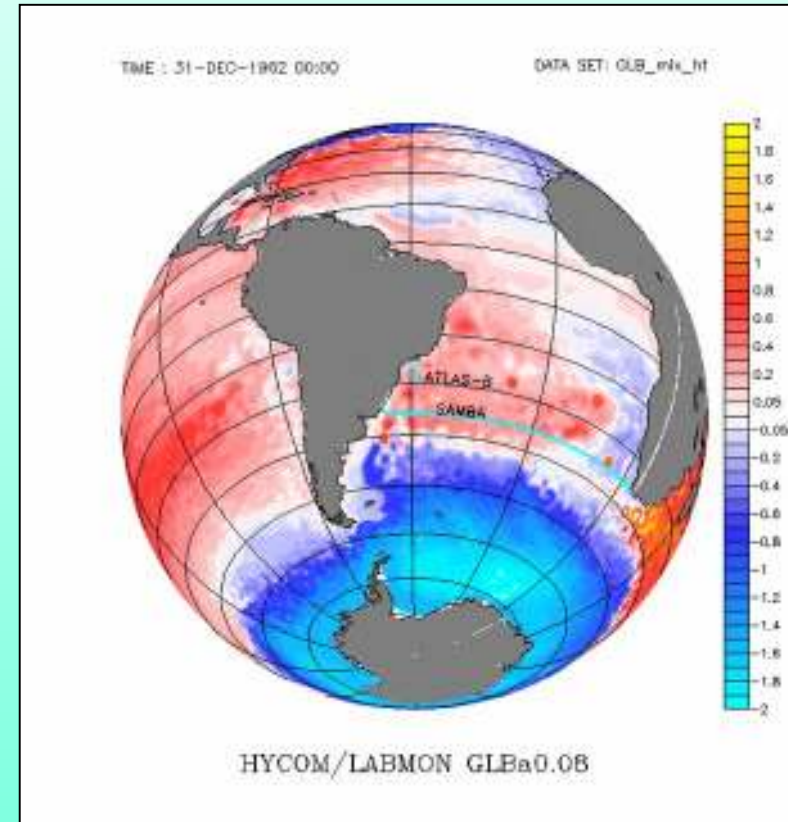
In spite of the apparently dense coverage, the number of observing platforms is far from the minimum necessary.



An example of what its
being done
internationally



An example of what is being
done in Brazil



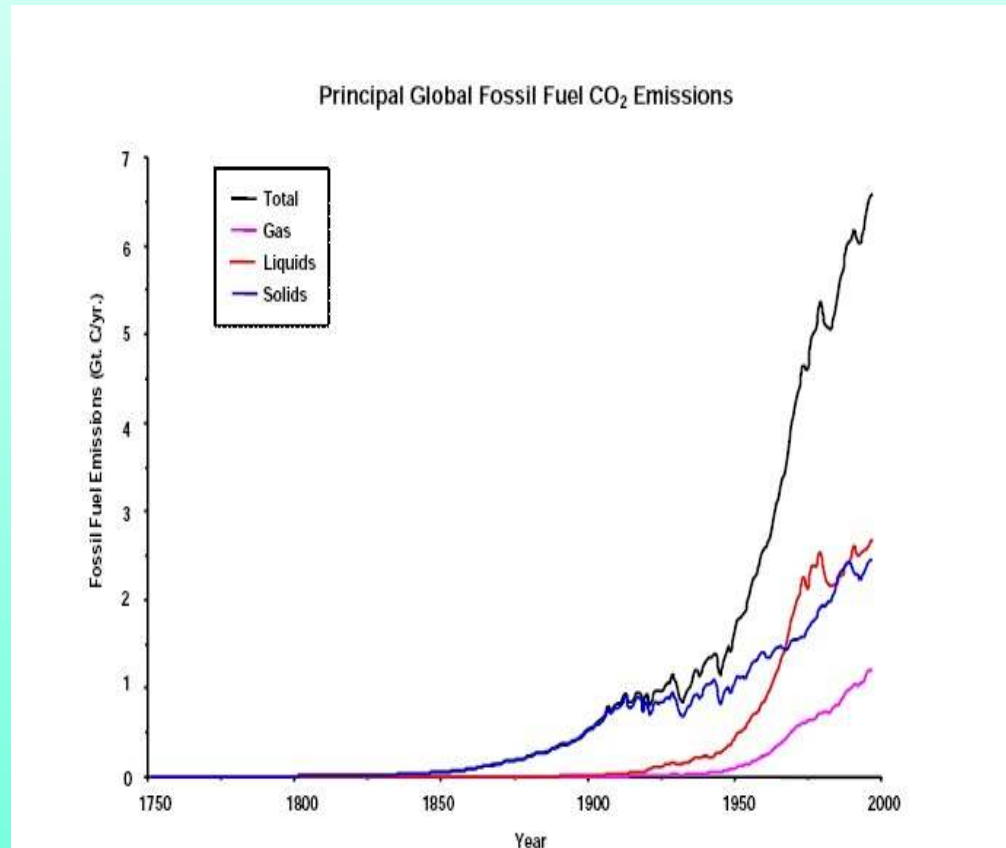
Oceano e Mudanças Climáticas



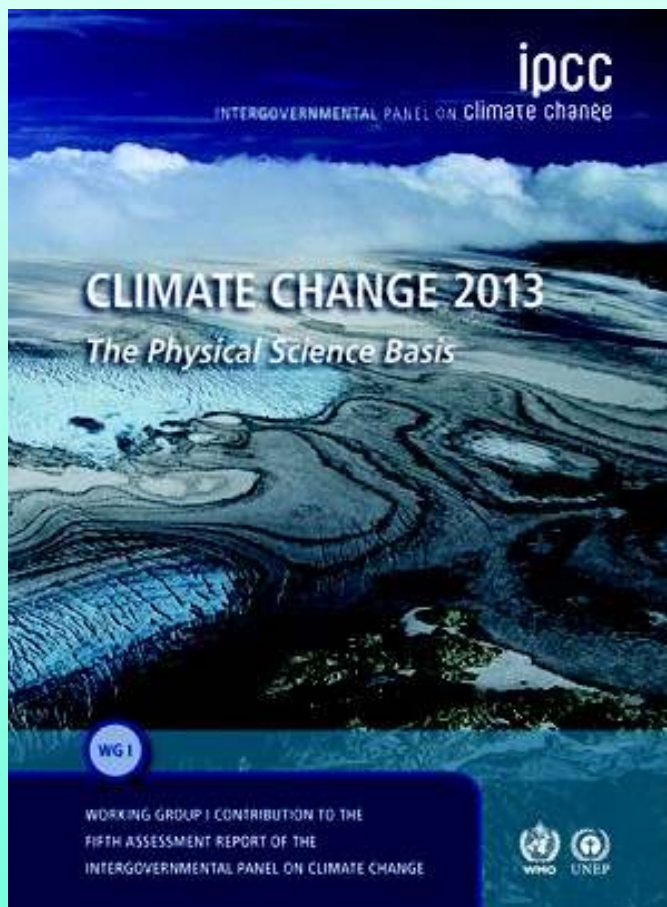
Segundo os levantamentos do IPCC, o clima está mudando.

Há pessoas que acreditam que o planeta tem a capacidade de absorver uma quantidade ilimitada dos resíduos da atividade humana.

Resultados de pesquisas sérias, entretanto, vem mostrando que a Terra está longe de ter essa capacidade infinita de absorção dos nossos dejetos.



O que pode-se dizer com base no que se sabe



3

Observations: Ocean

Coordinating Lead Authors:

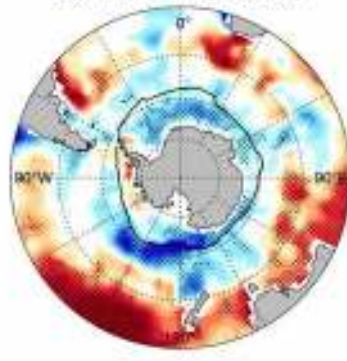
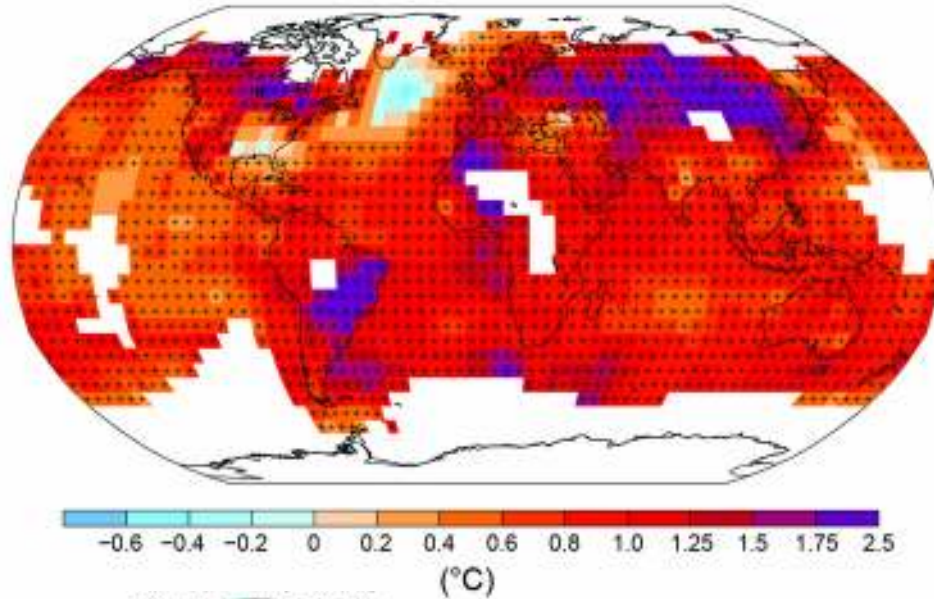
Monika Rhein (Germany), Stephen R. Rintoul (Australia)

Lead Authors:

Shigeru Aoki (Japan), Edmo Campos (Brazil), Don Chambers (USA), Richard A. Feely (USA), Sergey Gulev (Russian Federation), Gregory C. Johnson (USA), Simon A. Josey (UK), Andrey Kostianoy (Russian Federation), Cecilie Mauritzen (Norway), Dean Roemmich (USA), Lynne D. Talley (USA), Fan Wang (China)

Sinais de mudanças no oceano

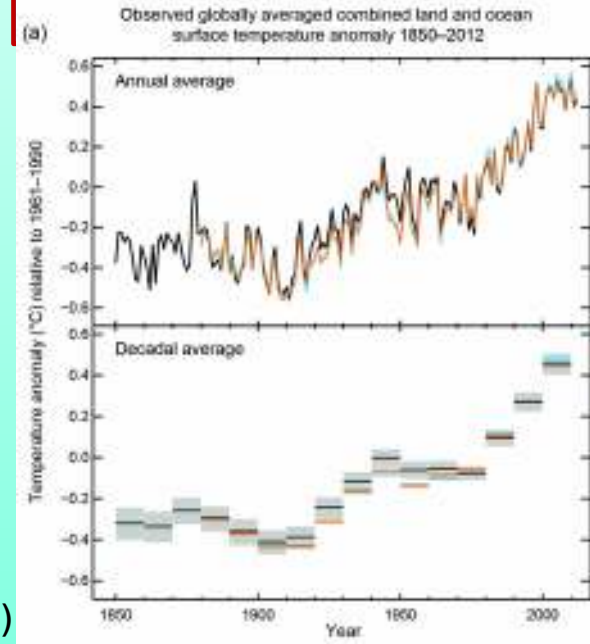
Observed change in surface temperature 1901–2012



1901–2012
IPCC AR5 WGI (2013)

1979–2013
Purich et al. (Nat. Comm., 2016)

Superfície da Terra está
aquecendo

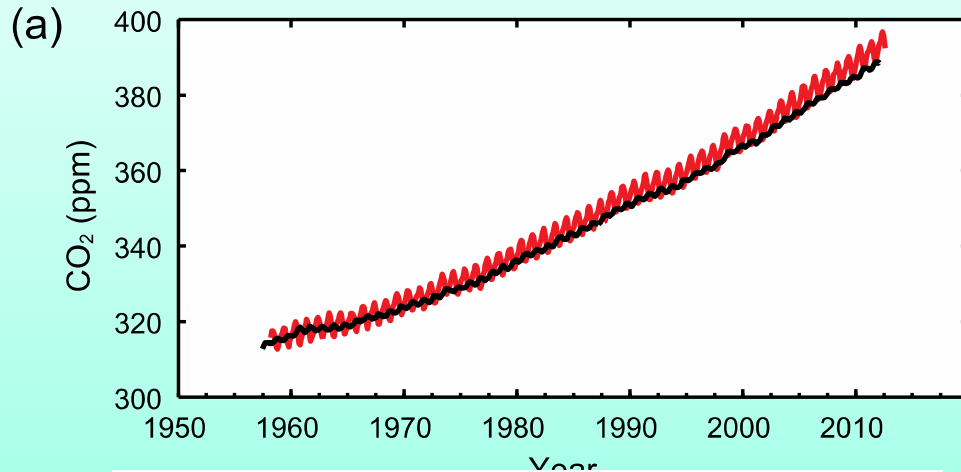


O oceano está absorvendo o excess de CO₂ atmosférico

Oceanográfico

Atmospheric CO₂

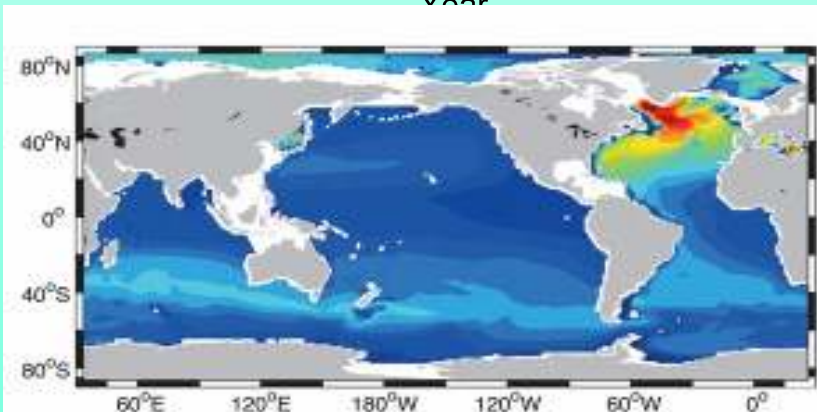
2018



O aquecimento é atribuído principalmente ao aumento do CO₂ atmosférico

(Série de tempo de Mauna Loa)

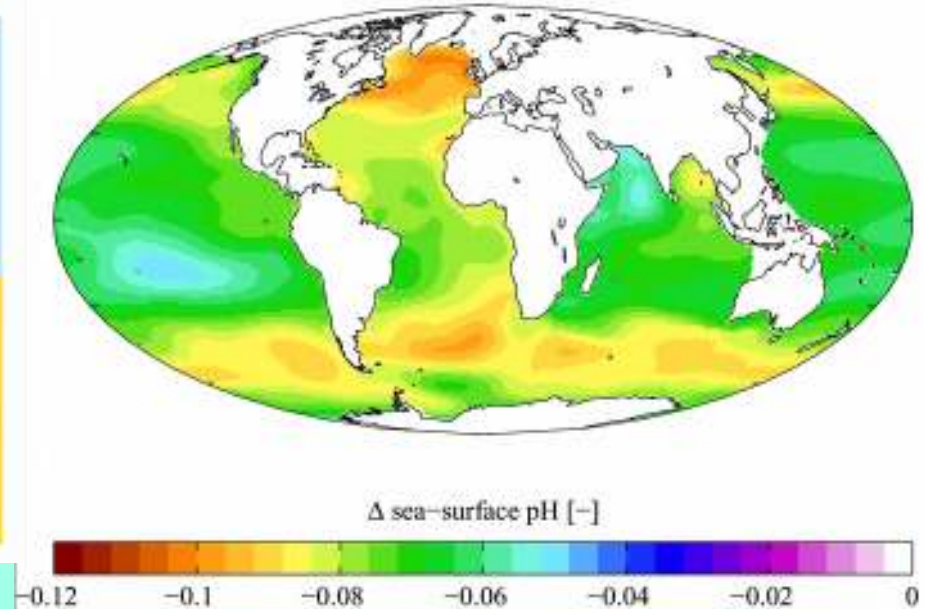
IPCC AR5 WGI (2013)



Anthropogenic CO₂ column inventory
(Khatriwala et al., 2013)

O oceano remove cerca de 1/3 do CO₂ em excesso na atmosfera, causando a acidificação do oceano.

As águas oceânicas estão se tornando mais ácidas

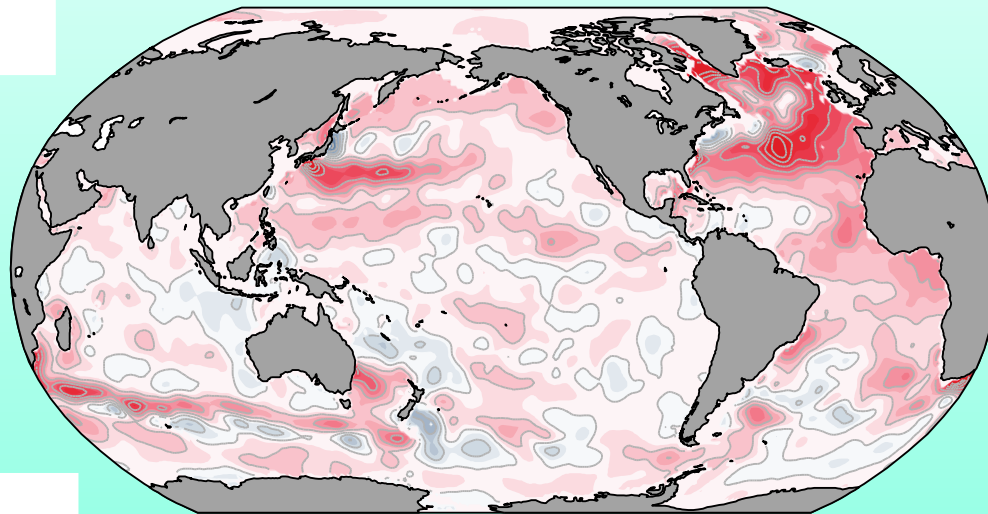


Conchas de moluscos dissolvem em condições ácidas



Alteração do pH na superfície oceânica devido ao aumento de CO₂ antropogênico entre 1700 e 1990

O oceano está se aquecendo



O oceano superior (0-700 m) está se tornando mais quente

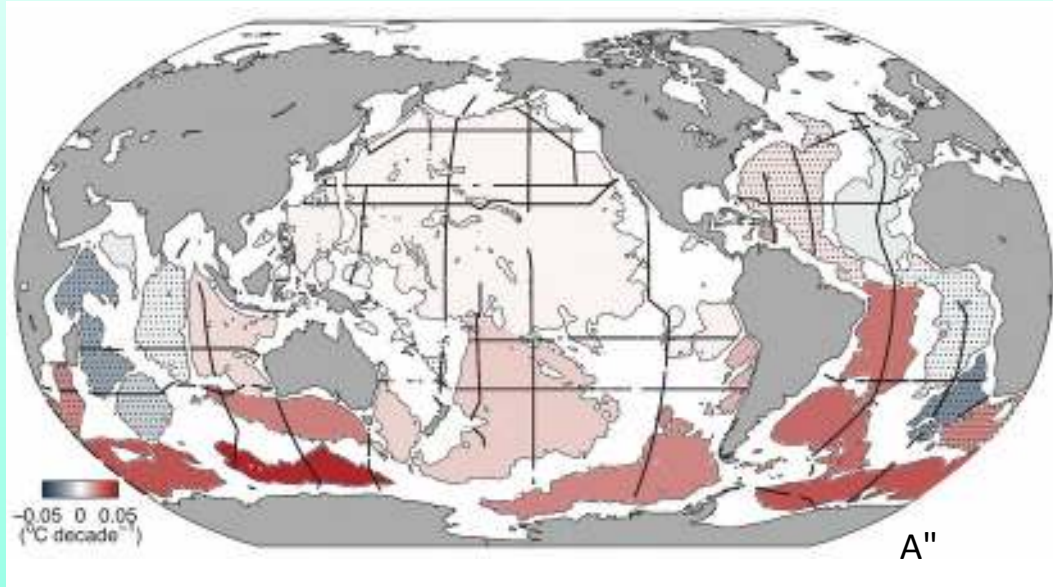
Note que há alguma regiões onde a tendência é negativa. Porém, em média, a temperatura do oceano está aumentando.

IPCC AR5 WGI (2013)

Tendência do conteúdo de calor 1971-2010

Balanco de energia da Terra: : > 90% do aumento total está no oceano.

O calor retirado da atmosfera já está chegando nas regiões abissais!



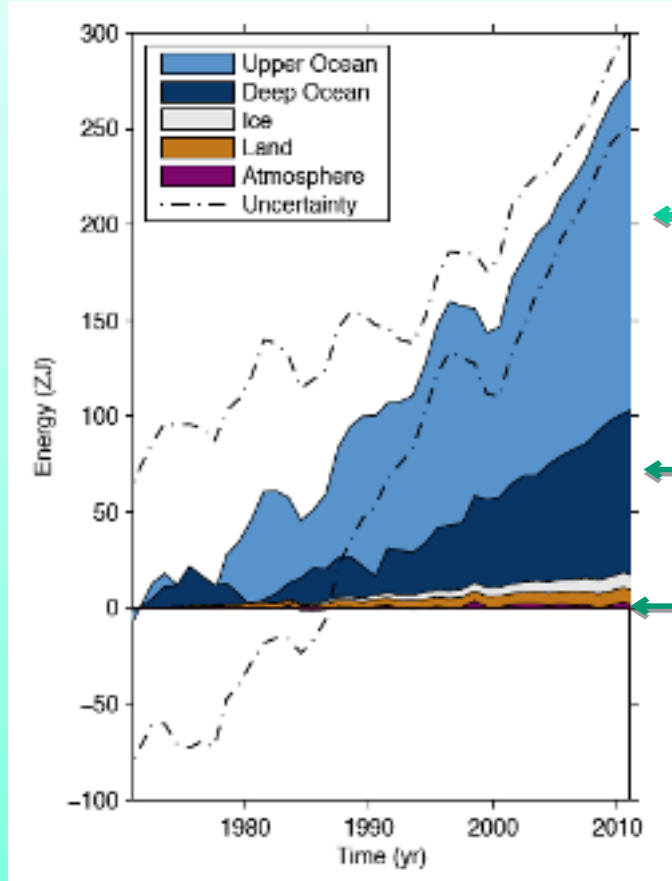
O oceano profundo (> 4000m) está aquecendo, principalmente no hemisfério sul.

IPCC AR5 WGI (2013)

Tendência de temperatura 1992-2005

Balanço de energia da Terra: 19% da mudança total de energia está no oceano profundo (> 2000 m), representando mais do que o dobro do aumento da energia na atmosfera, continentes e gelo, combinados.

Aquecimento Global = Aquecimento do Oceano !!!



Oceano Superior

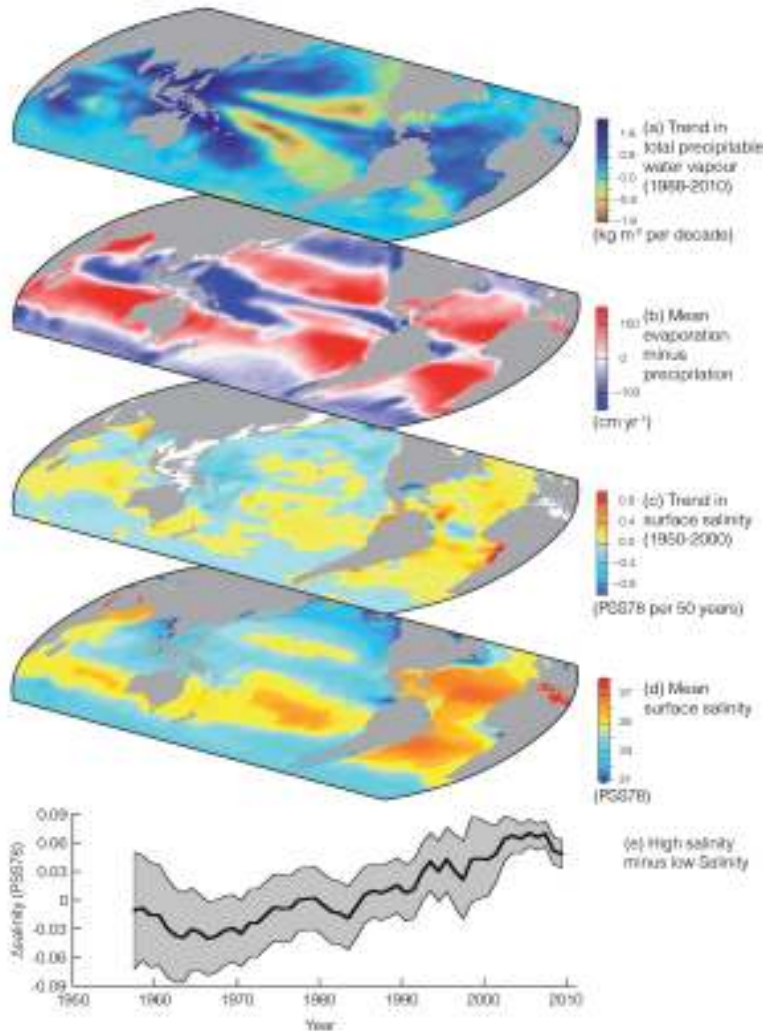
Oceano profundo

Atmosfera+terra+gelo

O excesso de energia resultante do aumento do CO₂ antropogênico está predominantemente no oceano!

IPCC AR5 WGI (2013)

Retroalimentação



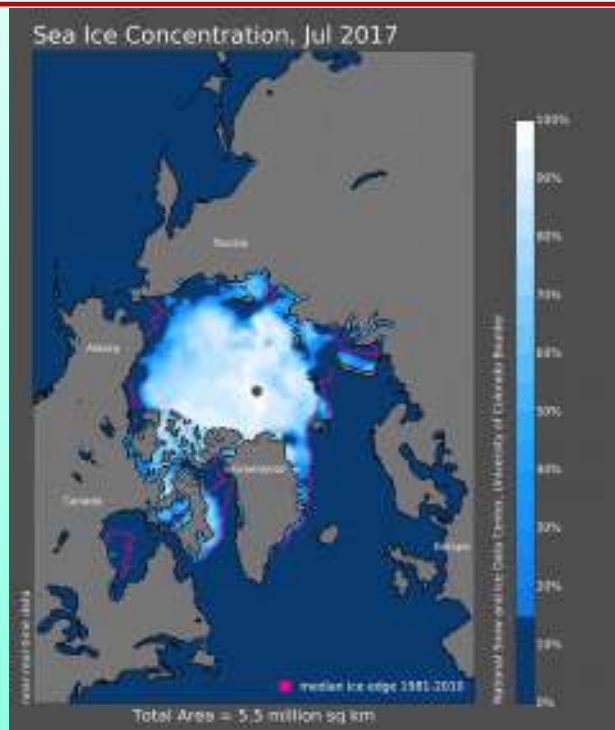
Aquecimento causa mais vapor de água na atmosfera

Isso resulta em evaporação e precipitação mais intensas, causando mudanças na distribuição de salinidade

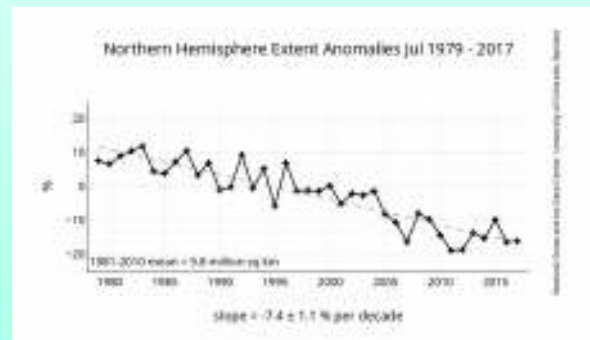
”Salty gets saltier, fresh gets fresher”

IPCC AR5 WGI (2013)

Derretimento da calota polar

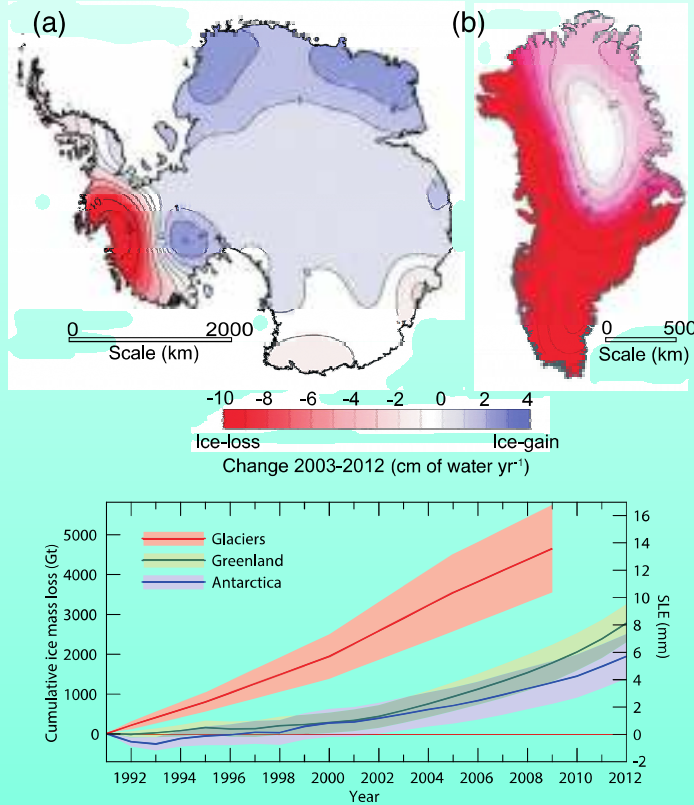


NSIDC satellite data product (2017)

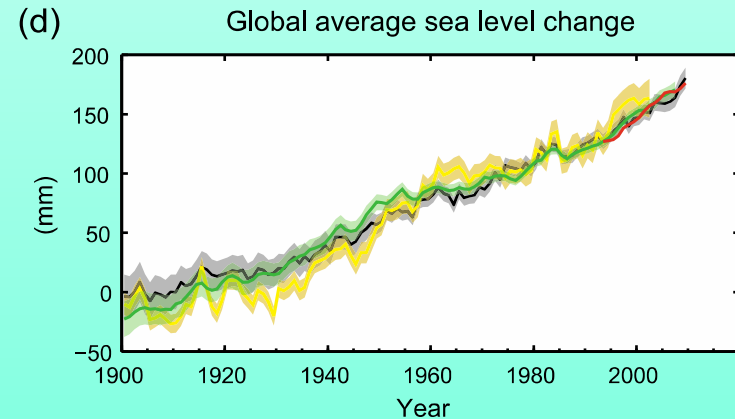


O gelo ártico está derretendo devido ao aquecimento, que é mais intenso na região polar do hemisfério norte.

Retroalimentação



O aquecimento global está derretendo as camadas de gelo, oceânicas e terrestres, contribuindo juntamente com o aquecimento do oceano para o aumento do nível do mar.



Retroalimentação ...



The map above illustrates regional trends in sea level, with arrows representing the direction and magnitude of change. Click on an arrow to access additional information about that station.

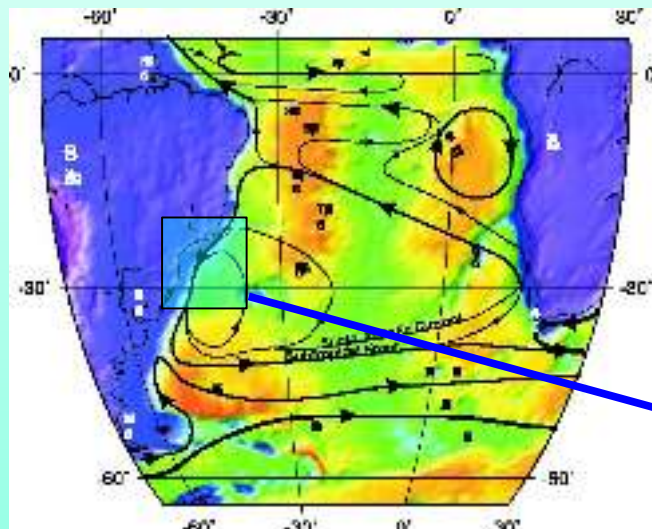
Sea Level Trends mm/yr (feet/century)

15 to 21 (5 to 7)	6 to 9 (2 to 3)	-3 to 0 (-1 to 0)	-12 to -9 (-4 to -3)
12 to 15 (4 to 5)	3 to 6 (1 to 2)	-6 to -3 (-2 to -1)	-15 to -12 (-5 to -4)
9 to 12 (3 to 4)	0 to 3 (0 to 1)	-9 to -6 (-3 to -2)	-18 to -15 (-6 to -5)

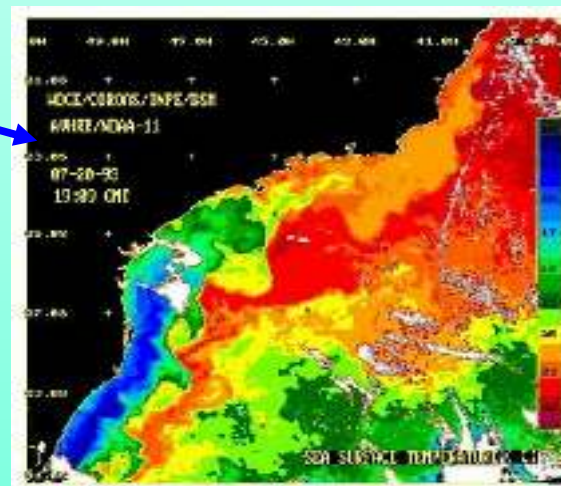
Tendências de aumento do nível médio do mar medidos por marégrafos.

Tides and Currents (NOAA, 2017)
<https://tidesandcurrents.noaa.gov/sltrends/sltrends.html>

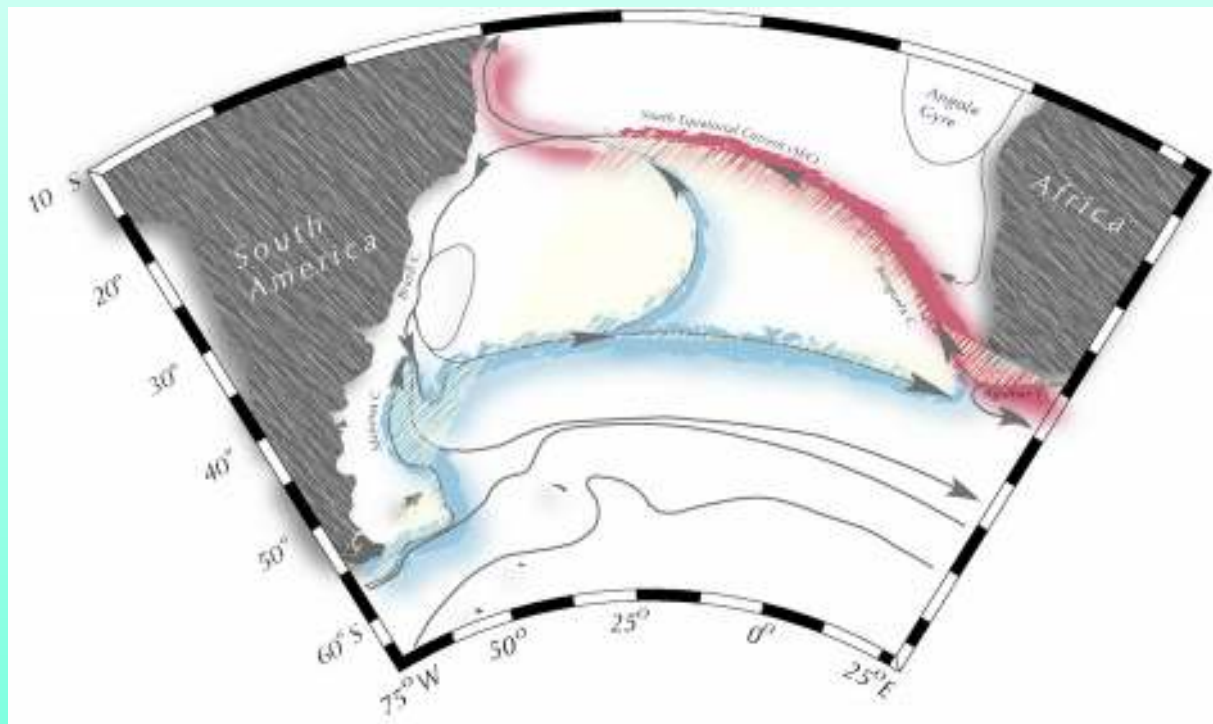
O Atlântico Sul



A Corrente do Brasil

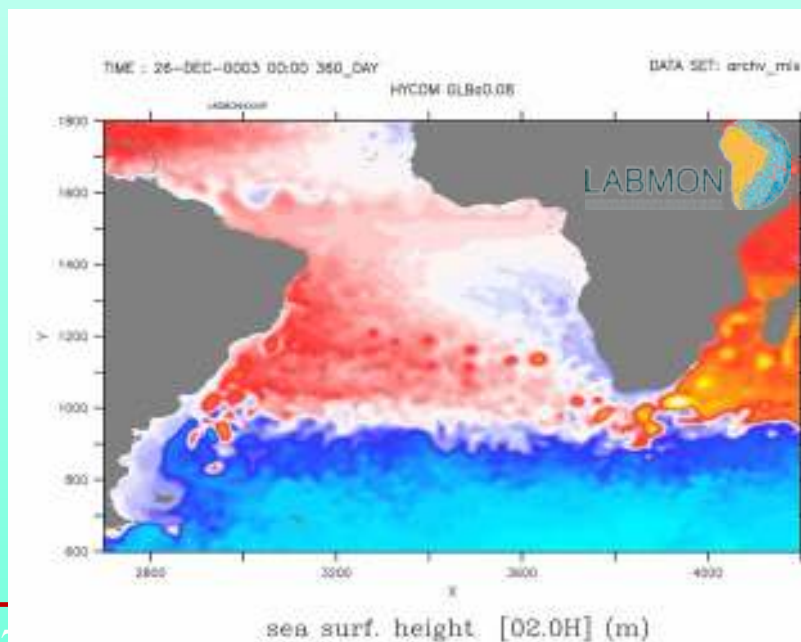


Importância do Atlântico Sul



O Vazamento das Agulhas

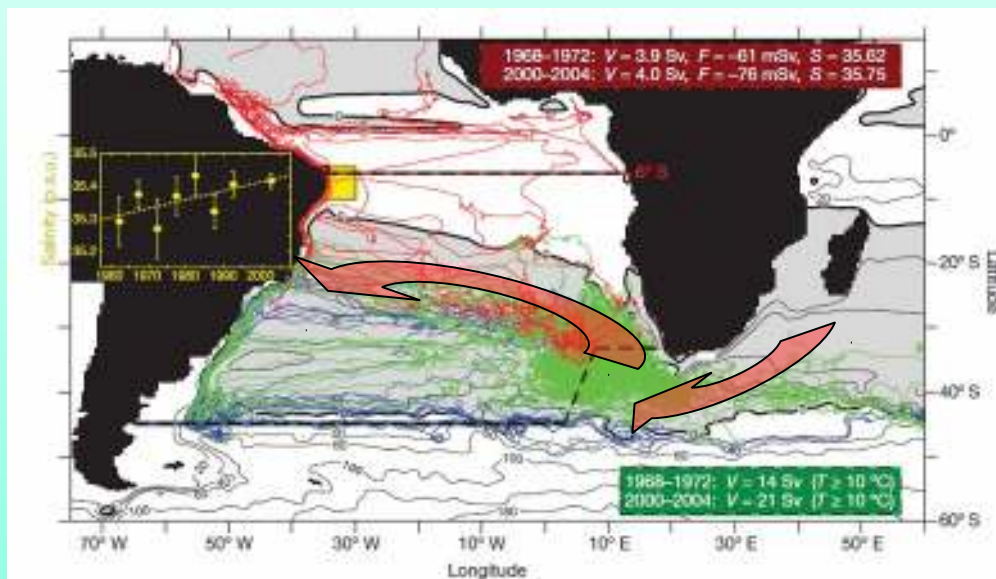
Águas do Índico transferidas para o Atlântico Sul por anéis e filamentos na região de Retroflexão da Corrente das Agulhas.



Mistura de águas oriundas do Índico com águas sub-antárticas circulam pelo Atlântico.

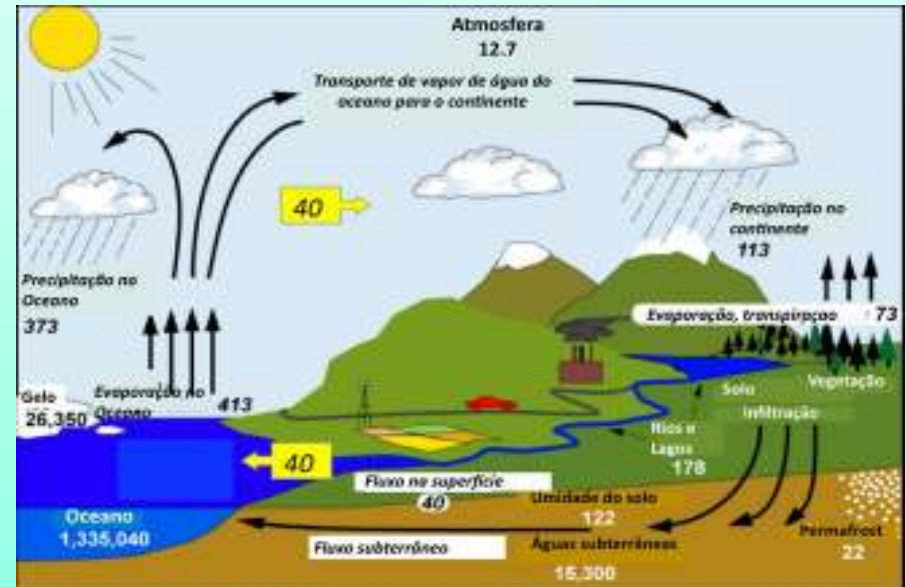
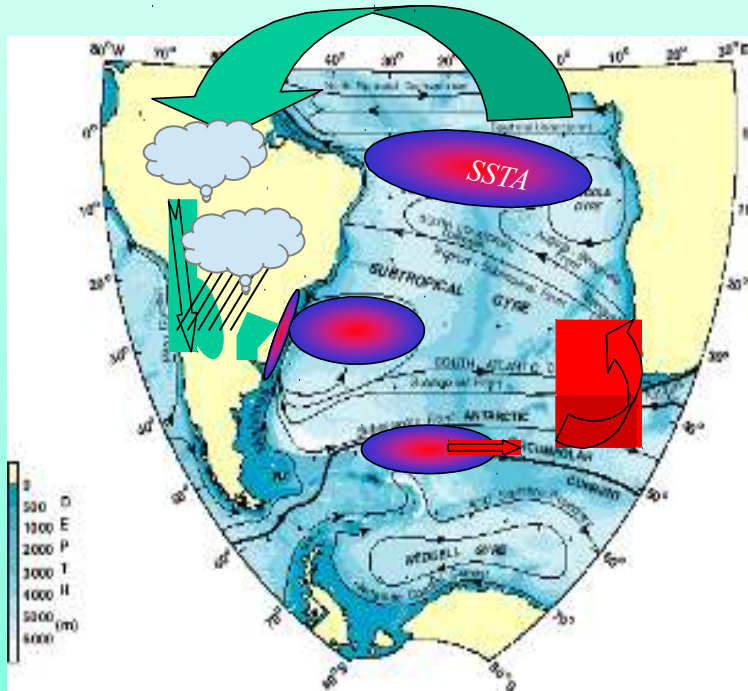
Alteração na composição dessas águas implicam em alterações significativas no clima regional.

Mudanças Climáticas estão alterando o Atlântico Sul



Biastoch, A., C.W. Böning, F.U. Schwarzcopf and J.R.E. Lutjeharms (***Nature* 462, 495-498, Nov/2009**) mostram que a importação de águas do Oceano Índico para o Atlântico Sul vem aumentando nas últimas décadas. Uma das consequências é o aquecimento e salinização do Atlântico Sudoeste, ao largo do litoral brasileiro.

Impactos sobre o ciclo Hidrológico



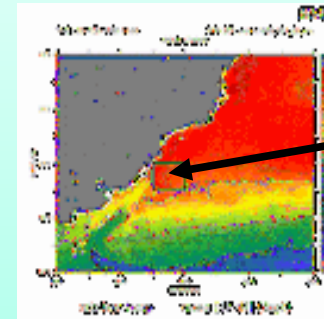
Alterações nas propriedades das massas de água no Atlântico Sul podem ter reflexos significativos no regime de monções da América do Sul e, consequentemente, no ciclo hidrológico.

Impactos regionais

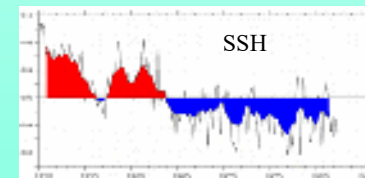
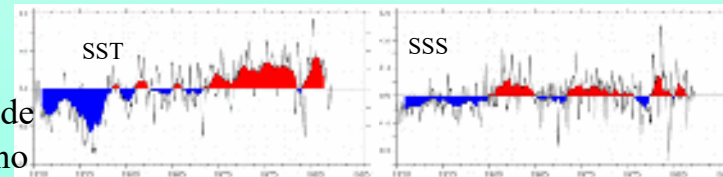
Aumento na ocorrência de eventos extremos ?

Resultados sugerem variabilidades no Atlântico Sudoeste.

REMO poderia fornecer importantes informações do ponto de vista de prevenção de calamidades como o ocorrido recentemente no Sudeste do Brasil.



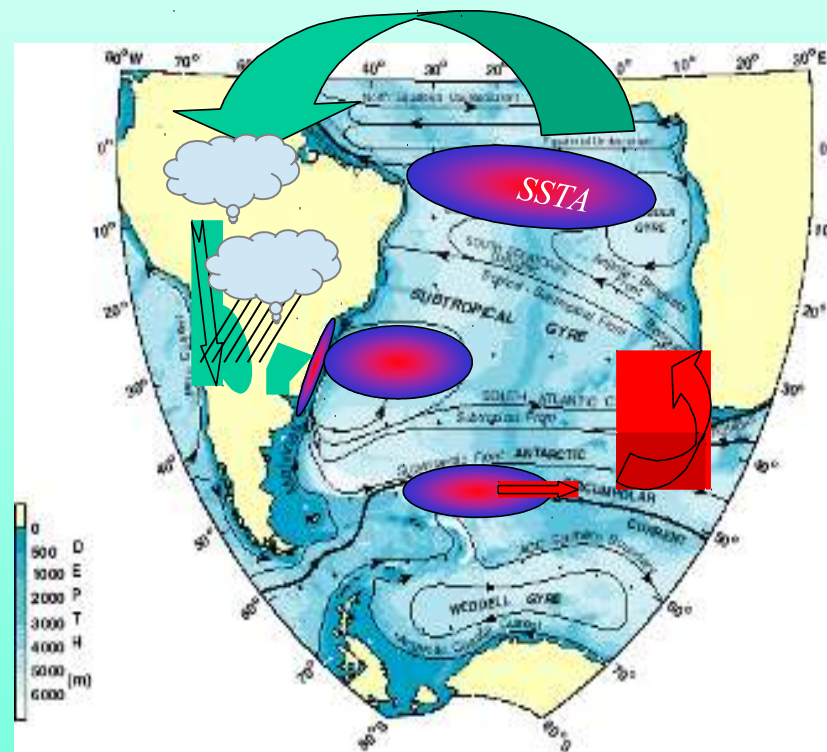
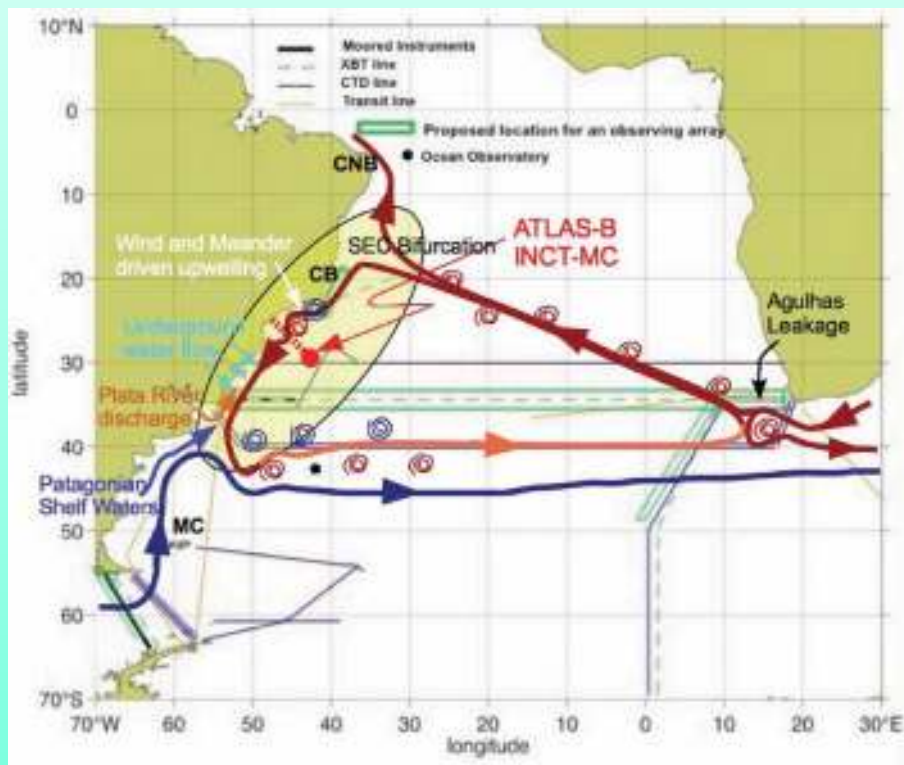
Catarina



Veja, 14/04/2010

Projetos financiados pela FAPESP, investigam impactos dessas mudanças oceânicas no clima regional.

Mudanças na circulação do Atlântico Sul podem ter resultados catastróficos tanto nas regiões litorâneas quanto em todo o território brasileiro.



**São Paulo School of Advanced Sciences on
Ocean Interdisciplinary Research and Governance**

Understanding and Modeling Ocean Basins

Prof. Dr. Edmo Campos

**University of São Paulo, Brazil
&
American University of Sharjah, United Arab Emirates**



Outline

- The importance of understanding the Ocean
- A brief introduction to Physical Oceanography
- Modeling Ocean Basins
- The Ocean and the Climate
- The role of the South Atlantic



**SPSAS – Oceans
2018**



**Why should we better
understand the Ocean?**

Earth ...



... the planet Ocean

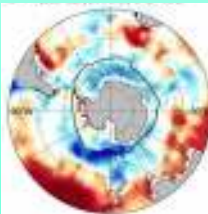
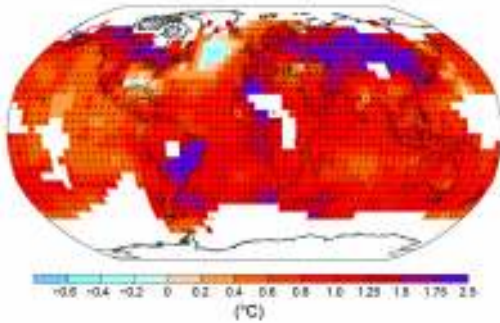








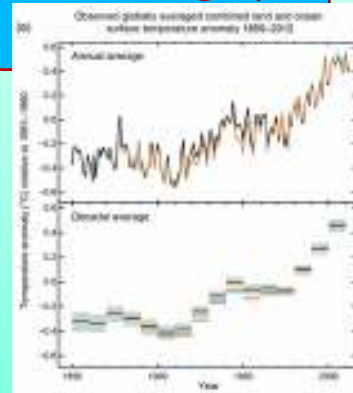
Observed change in surface temperature 1901–2012



1901–2012
IPCC AR5 WGI (2013)

1979–2013
Purich et al. (Nat. Comm., 2016)

**Earth's surface
is warming up!**



... and So What?
Why bother?



SPSAS – Oceans
2018



70%

OF OUR PLANET
IS COVERED
WITH WATER



MORE
THAN
HALF

OF THE WORLD'S
POPULATION LIVES
WITHIN 50 MILES OF
THE COAST

1 IN 7 PEOPLE



DEPEND ON THE OCEAN
FOR PROTEIN

Warming will destabilize ocean heat transfers



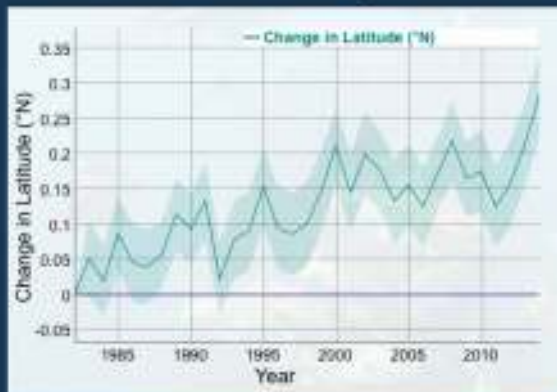
Any changes in habitat temperatures significantly influence:

- Fish metabolism
- Growth rate
- Productivity & reproduction
- Migratory patterns
- Susceptibility to diseases and toxins

Predators and prey will move to different areas,
causing **disruption of food chains**

Warmer water temperatures
exacerbate the variability of
seafood catches; **some fail**
while others flourish.

Fish are shifting north



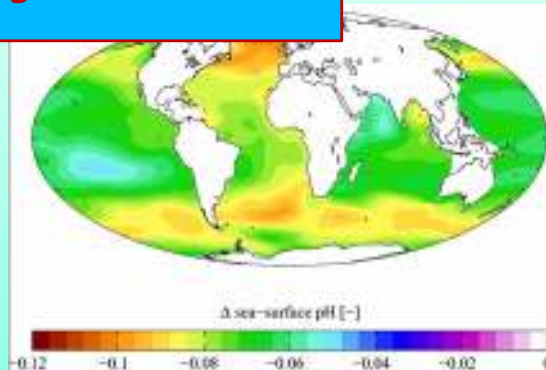
- High numbers of **larval fish** are moving north
- Researchers observed **45** larval fish species and **40** adult fish species, comparing distributions between two decades: **1977-1987**, and **1999-2008**
- **40%** of the larval species and **50%** of the adult species altered distributions

Pinsky, M. L., E. Worm, M. J. Fogarty, J. L. Squire, and S. A. Levin. 2013. Marine taxa track local climate velocities. *Science* 340: 1299-1302 doi: 10.1126/science.1239352

Ocean waters are becoming more acid

Coral reefs are drastically affected by ocean warming and acidification.

Shells dissolve in acid conditions



Alteration in the ocean's surface pH due the increase of antropogenic CO₂, between 1700 and 1990

Impacts to Ports

- More flooding
- More ship and wharf collisions
- Decreased clearance under bridges
- Dislodged containers
- Damaged buildings during storms



**SPSAS – Oceans
2018**



A Brief Introduction to Physical Oceanography

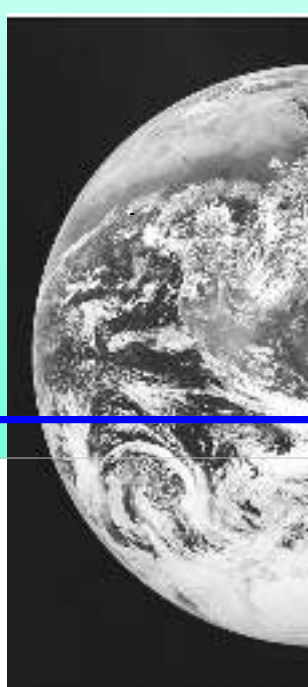


**What forces drive the the motions of
the Atmosphere and the Oceans?**

Aeolus

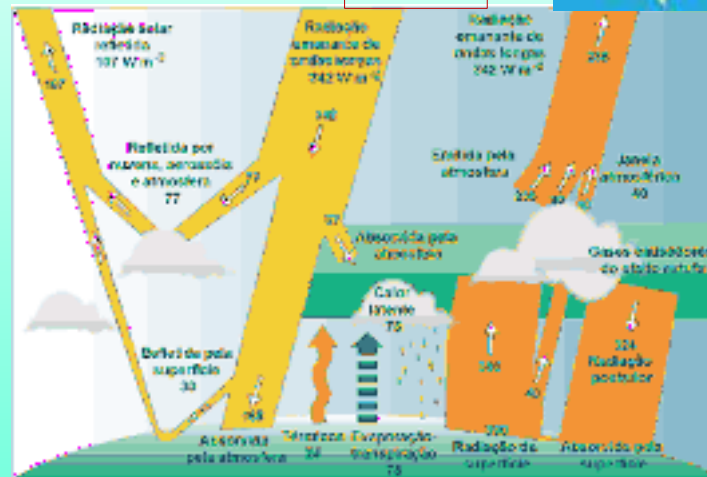


Poseidon



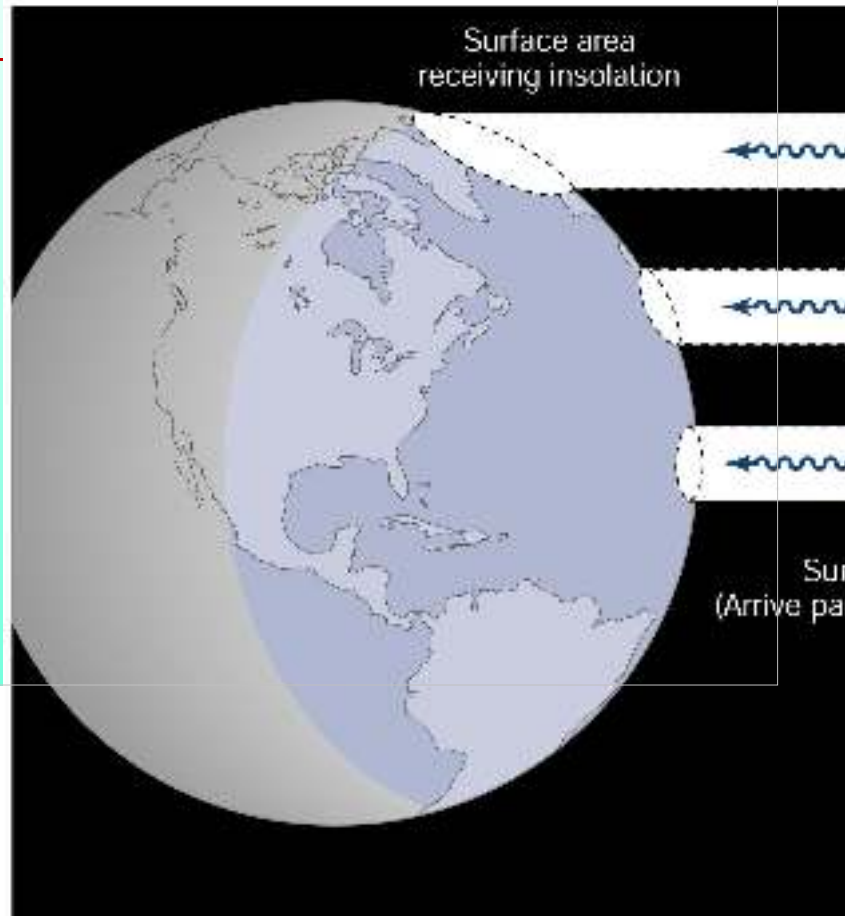


*The Sun is
the primary
energy
source*



Due to it's sphericity, insolation at earth's surface is different at different latitudes.

(Try to explain this in a flat earth).

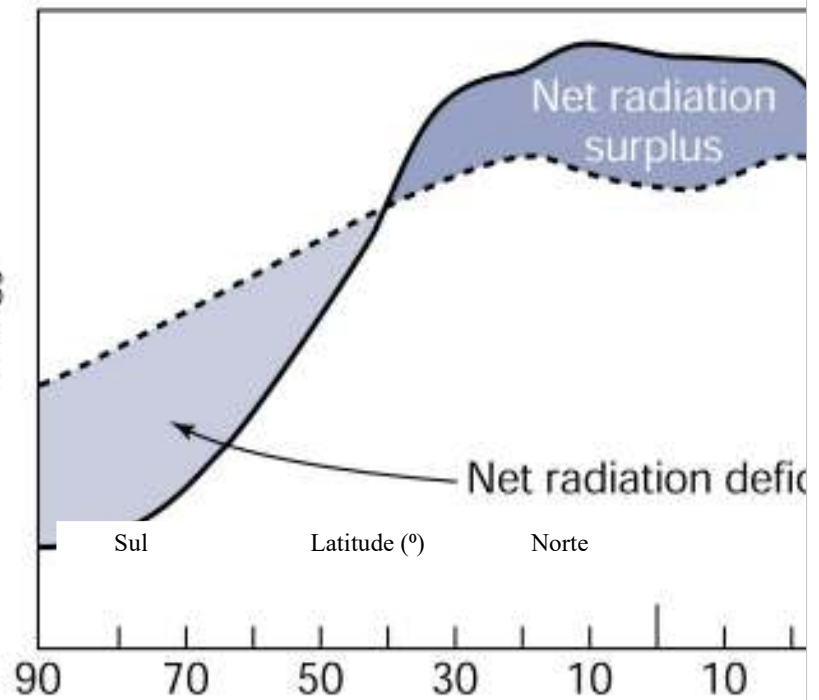


Due to the higher insolation, tropical regions are warmer and higher latitudes are colder ...

... and due to the net gain of heat, these regions should be continuously warming. ...

... and the higher latitudes should be cooling!

Energy



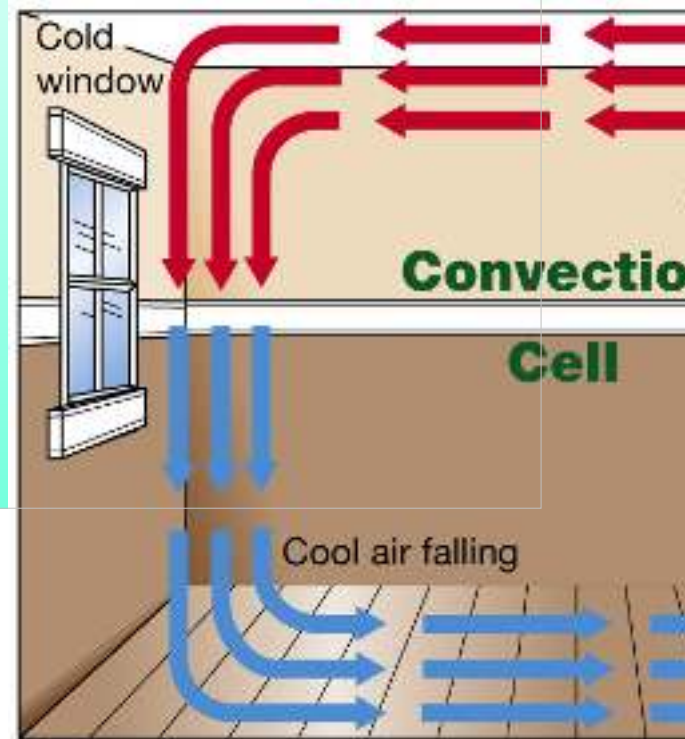
The Atmospheric Circulation



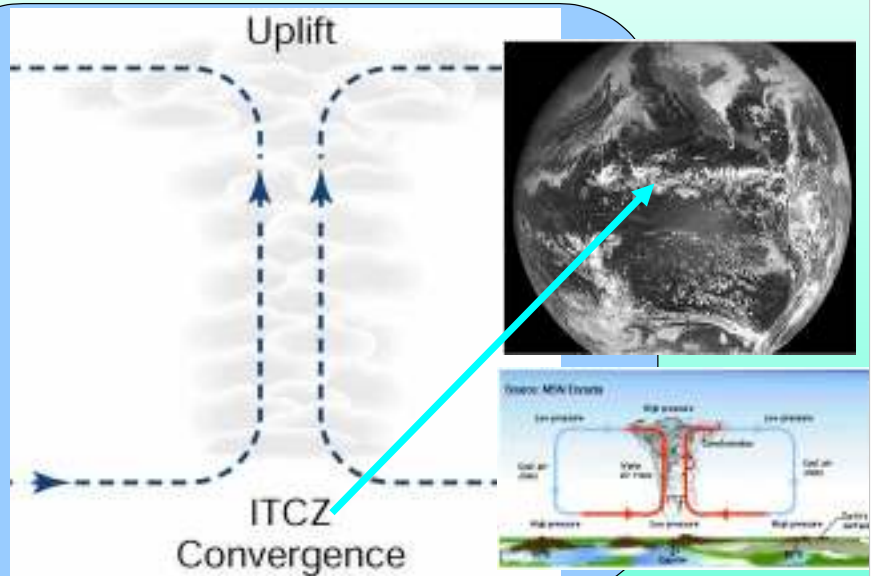
Aeolus

Convection Cell

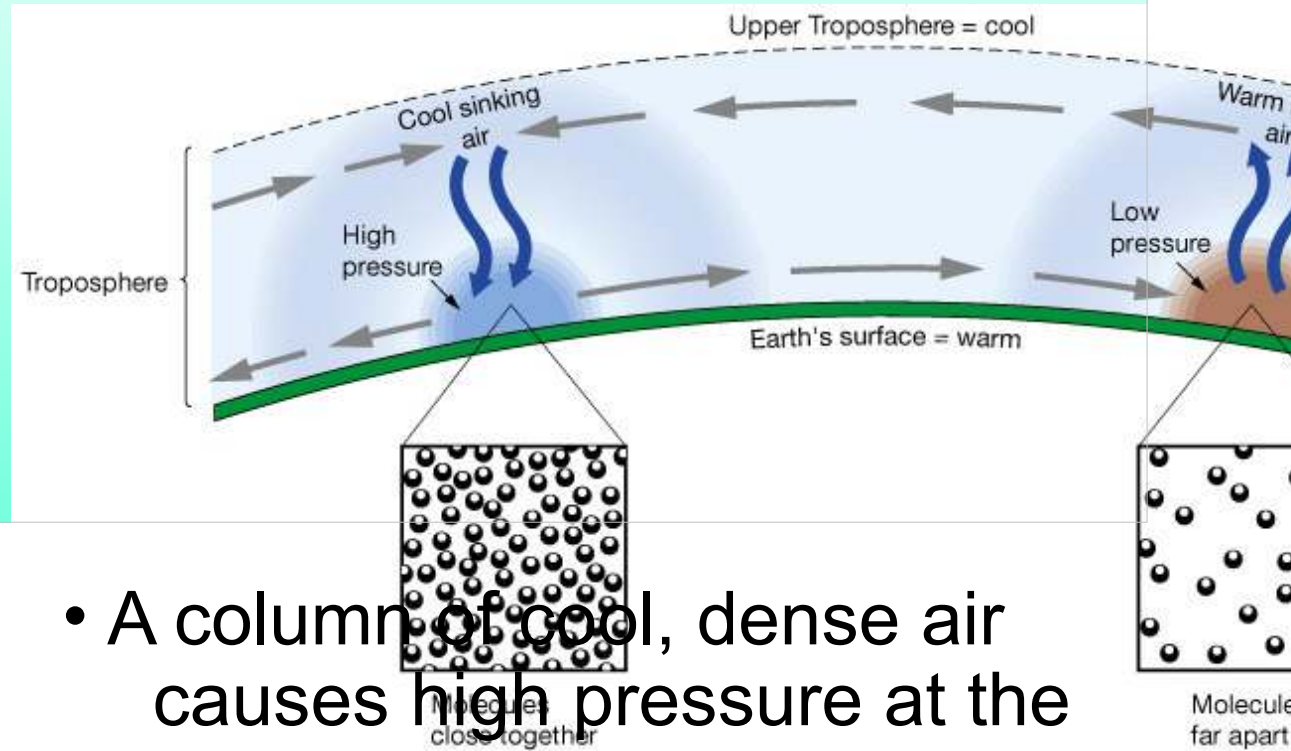
- Hot air, with lower density, goes up.
- Cold air, lighter, goes down.
- The result is a vertical motion cell



In the equatorial regions, hot air rises, forming a cloudy band, the Intertropical Convergence Zone (ITCZ)

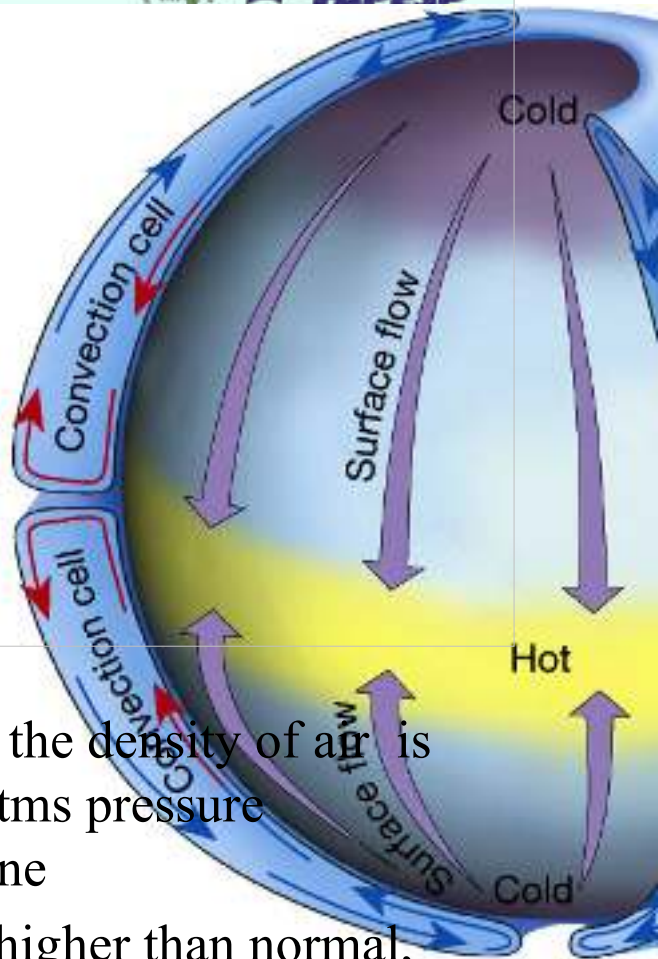


High and Low Pressure Zones



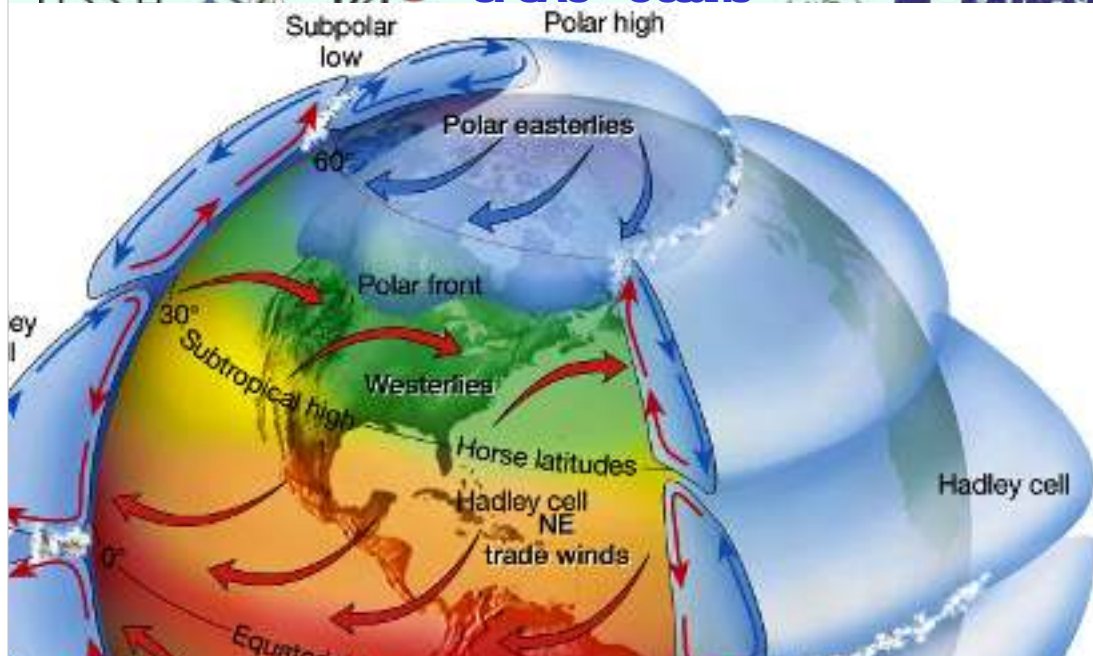
- A column of cool, dense air causes high pressure at the surface, which will lead to sinking air
- A column of warm, less dense air causes low pressure at the surface, which will lead to rising air

Atmospheric Convection Cell in a non-rotating spherical planet

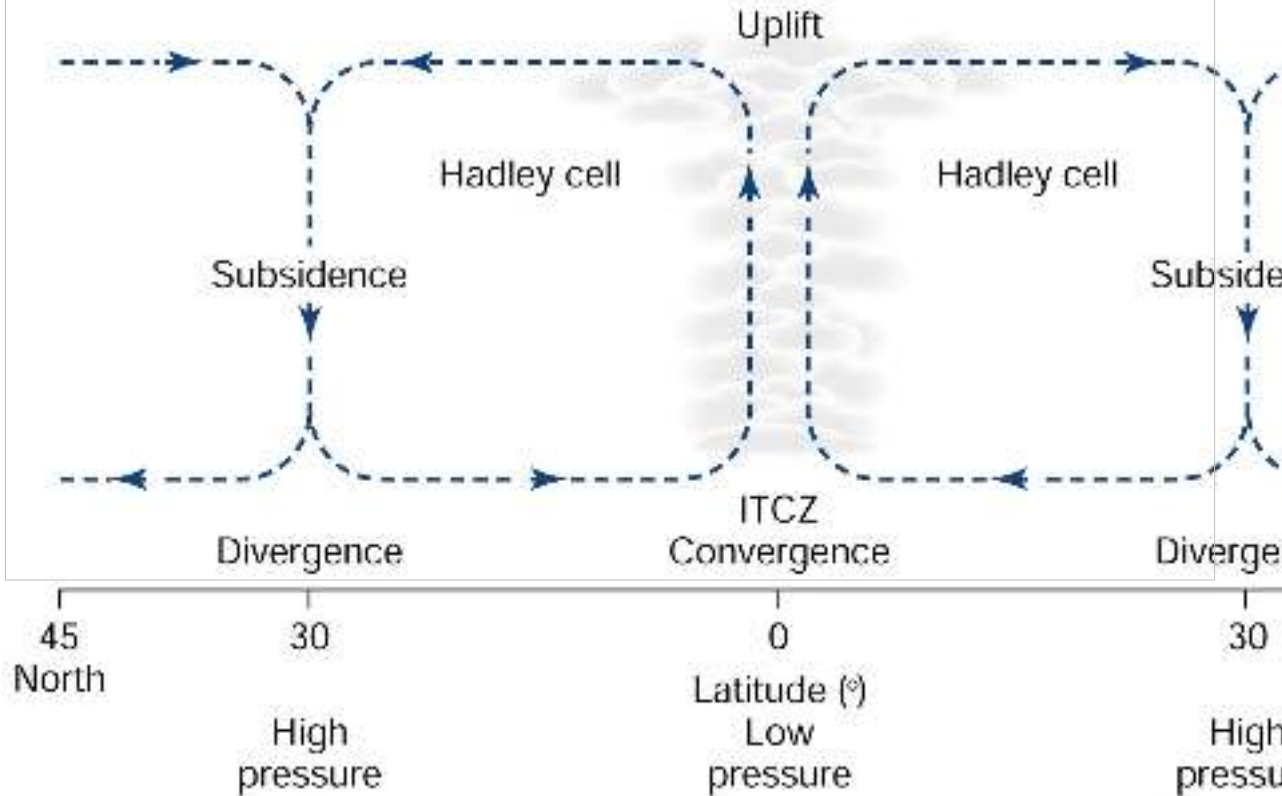


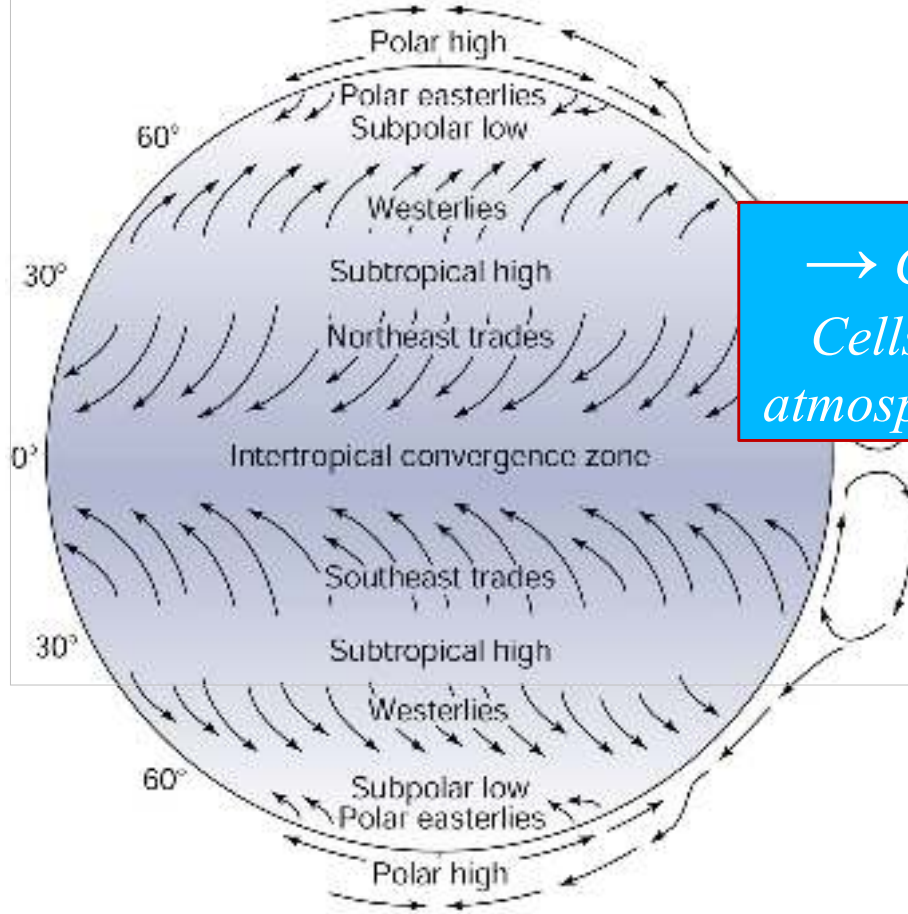
Non rotating model- when the density of air is lower than normal, the atms pressure drops--- low pressure zone

When the density of air is higher than normal, the pressure increases--- high pressure zone

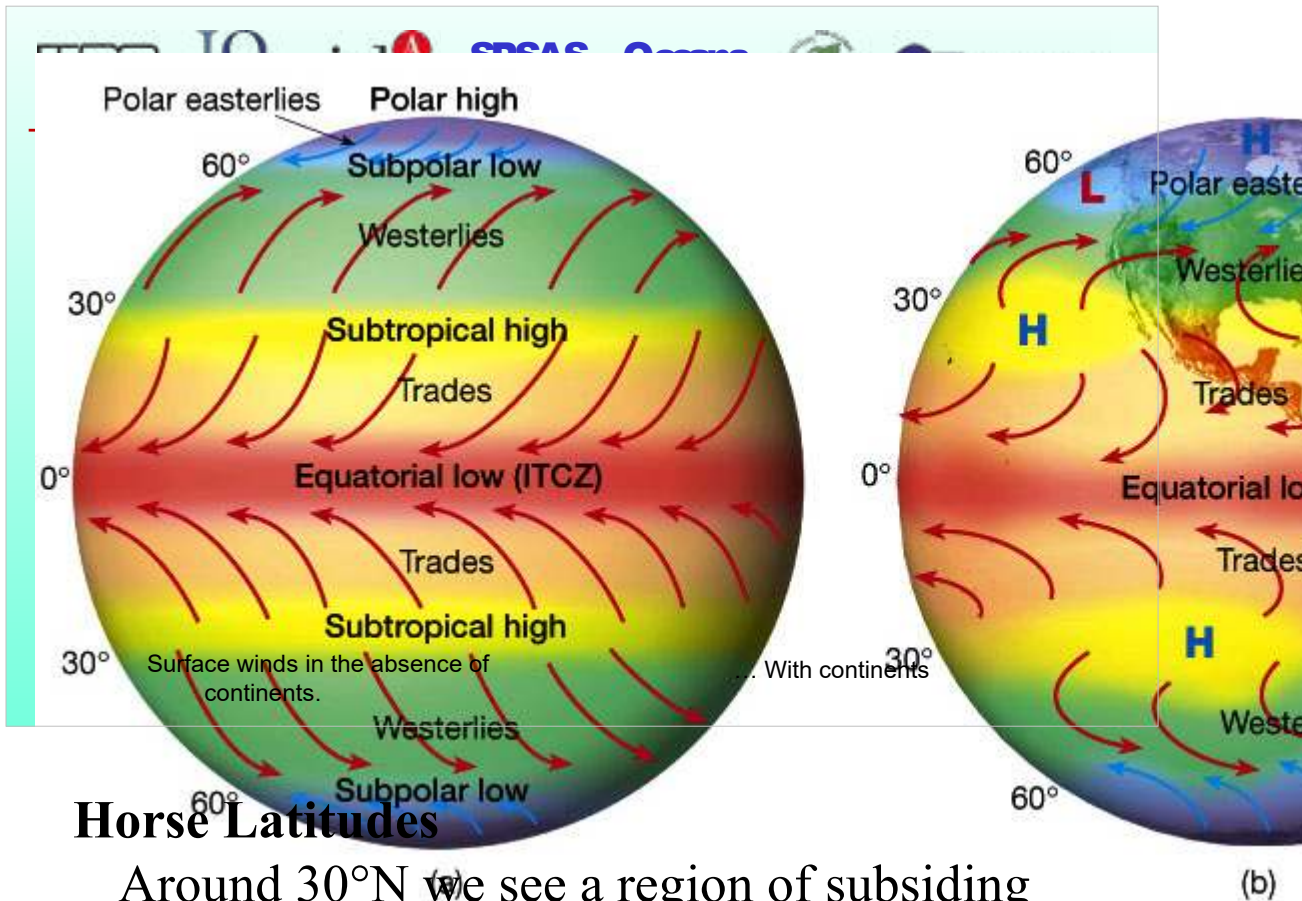


→ Air flows toward regions with lower pressure





→ *Convective Cells drive the atmospheric winds*



Horse Latitudes

Around 30°N we see a region of subsiding (sinking) air. Sinking air is typically dry and free of substantial precipitation.

Many of the major desert regions of the northern hemisphere are found near 30° latitude. E.g., Sahara, Middle East, SW United States.

Doldrums

Located near the equator, the doldrums are where the trade winds meet and where the pressure gradient decreases creating very little winds. That's why sailors find it difficult to cross the equator and why weather systems in the one hemisphere

Ocean Circulation

● Surface Currents:

Wind-driven, pper 400 meters of the water column (~10%)

● Abyssal Circulation:

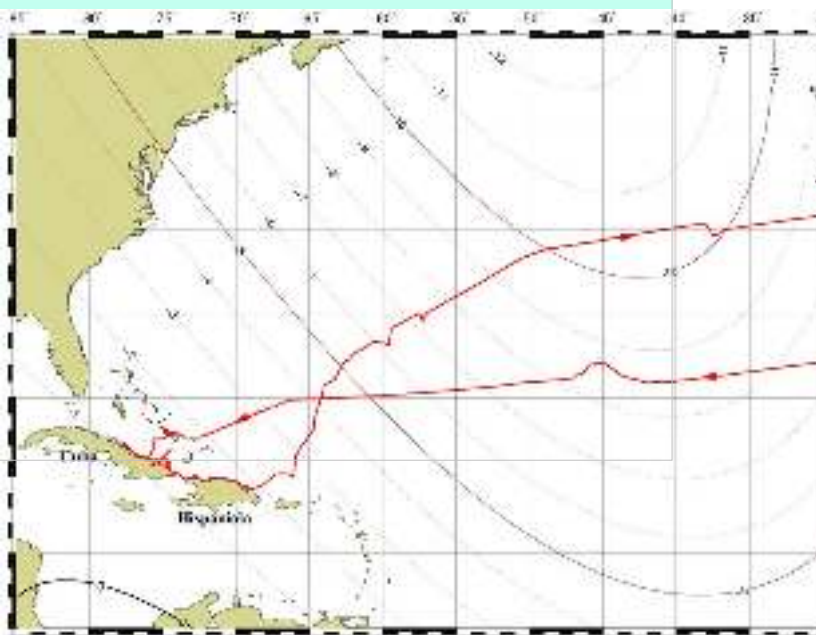
Driven by thermohaline gradients (~90%)

Surface currents have been known (and used) by sailors for several centuries

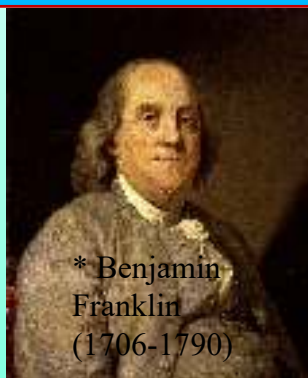
Viking expeditions to Greenland and North America.



Christopher Columbu's
shiptrack in his first
expedition to the
Americas.



The Gulf Stream, Segundo Benjamin Franklin*

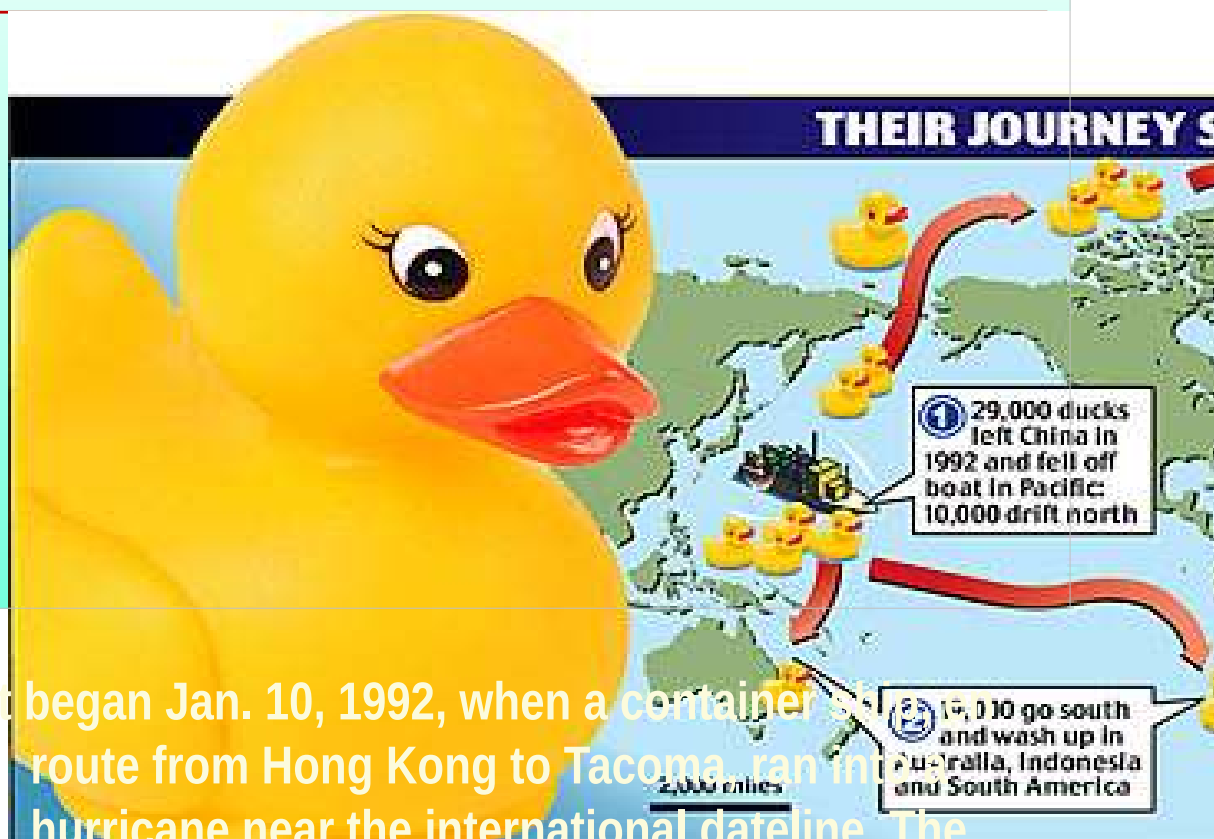


* Benjamin
Franklin
(1706-1790)



Pedro Cabral's
Discovery Voyage to
Brazil





It began Jan. 10, 1992, when a container ship on route from Hong Kong to Tacoma, ran into a hurricane near the international dateline. The

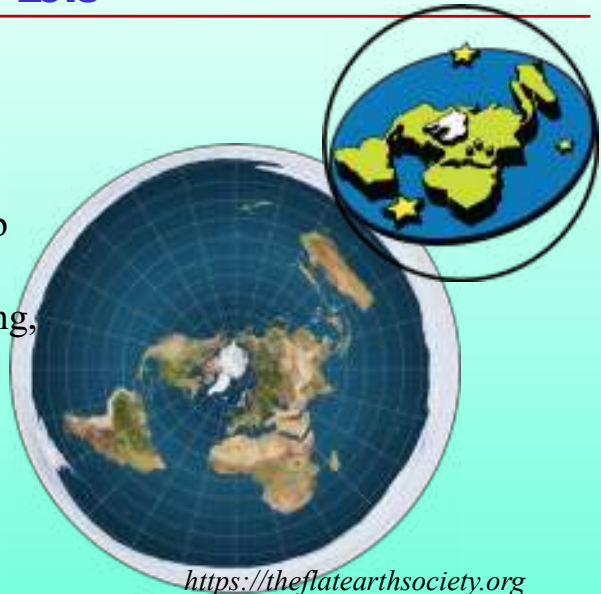
waves were so powerful that they broke some of the steel cables holding the huge containers, releasing 12 of them over the side. One that was lost held 28,800 Friendly Floatee bathtub toys, made in China for The First Years Inc. of Avon, Mass. They were red beavers, green frogs, blue turtles and, of course, yellow ducks.

We might expect that elaborate wrapping around the toys would have dragged them straight to the bottom. But they managed to escape five levels of packing, from the heavy steel containers / friendly toys, around the ship.

Disclaimer

If you are a flat-earther (a member or believer of the Flat Earth Society), it's better to stop here. The theory adopted in the sequence only works in a rotating, spherical planet.

Unfortunately, the FES has no plausible explanation for the observed ocean currents.

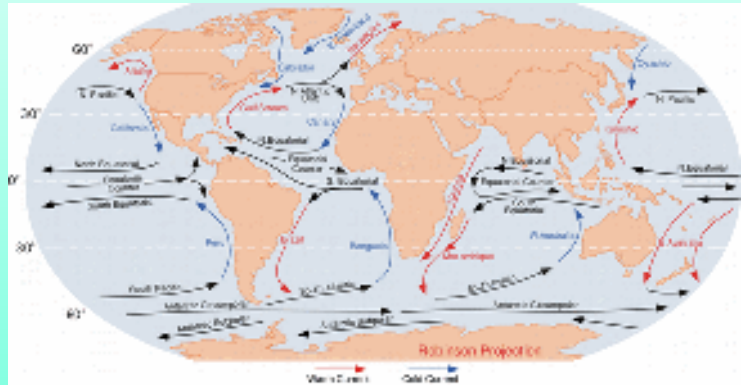


<https://theflatearthsociety.org>

Driving Agents

1. Solar Radiation (pressure gradients)
2. Thermohaline gradients
3. Winds
4. Gravity
5. Coriolis (Earth's rotation)
6. Non-linear effects

Ocean Currents



The Coriolis Effect

Is an effect due to Earth's rotation.

In the northern hemisphere, the velocity of a water parcel seems to be deflected to the right.

In the southern hemisphere, the velocity is deflected to the left.

In a spherical Earth, the Coriolis Effect varies with latitude (zero at the Equator and maximum intensity at the poles)

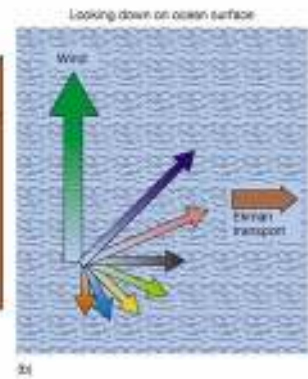
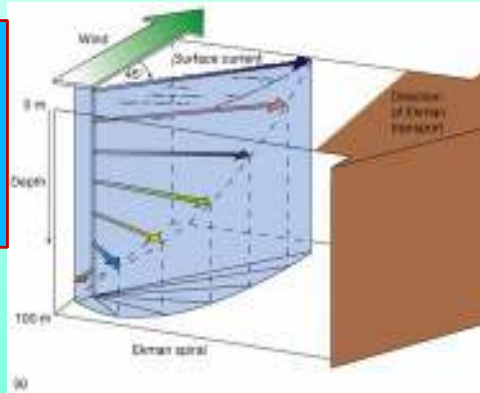
intended
path



intended
path

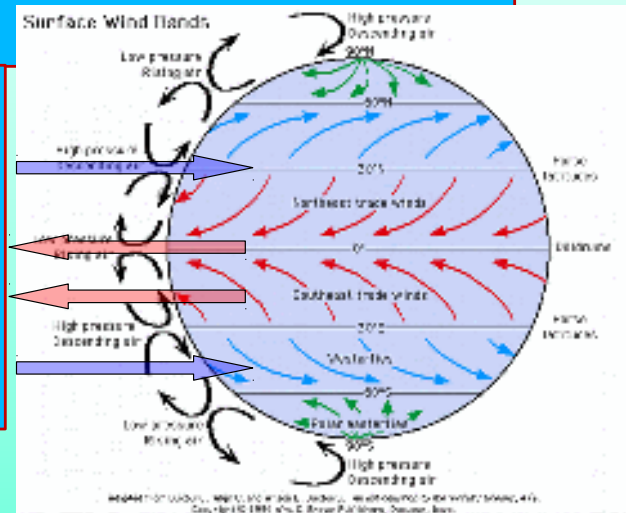
Ekman Spiral

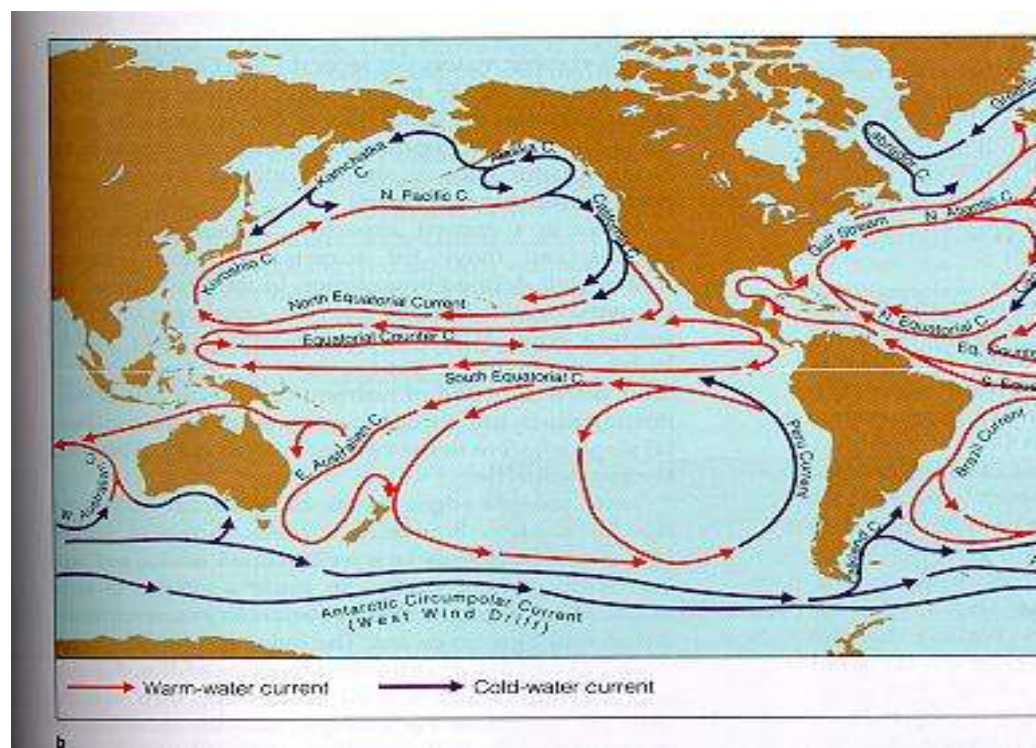
The Ekman Spiral
results from the
Coriolis Effect.



Wind-driven Circulation

In the absence of continents, the wind-driven currents would be predominantly in the zonal direction (E-W)





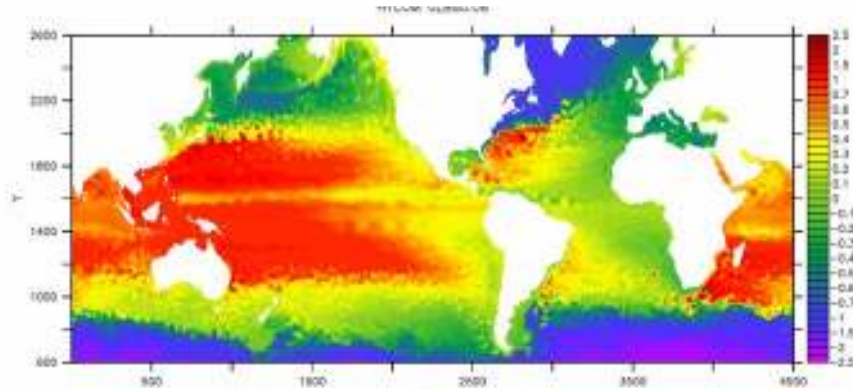
Th Subtropical Gyres

These remarkable circulation pattern in all subtropical basins result from an equilibrium among pressure gradient, wind, effects of sphericity and rotation and the planet's continental distribution.





The ocean currents connects all oceanic basins



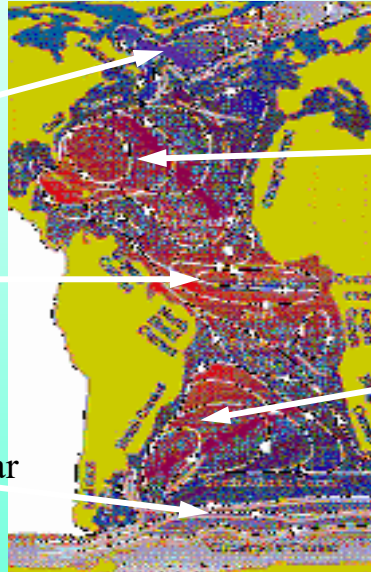
Under the actions of the winds, the oceanic waters circulate along well defined paths, transporting properties throughout the different basins.

The Atlantic Ocean

Sub-polar Gyre
(cyclonic)

Equatorial Gyre
(cyclonic)

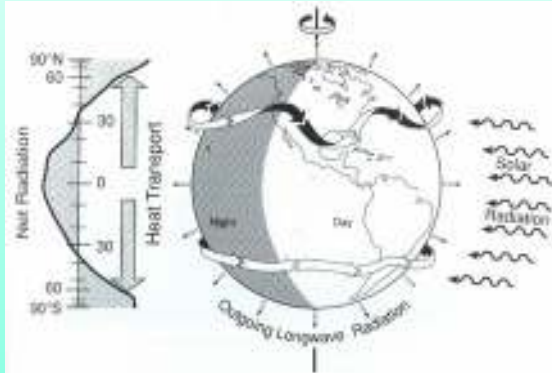
Antarctic Circumpolar
Current



North Atlantic
Subtropical Gyre
(anticyclonic)

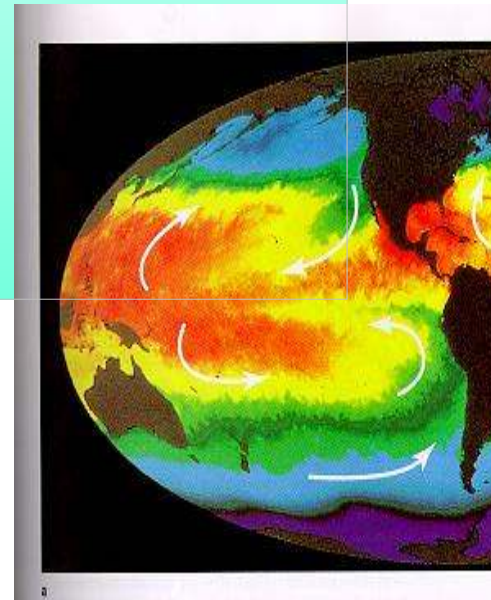
South Atlantic
Subtropical Gyre
(anticyclonic)

Heat Transport by Ocean Currents



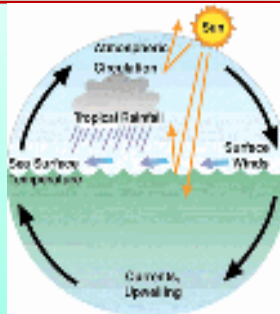
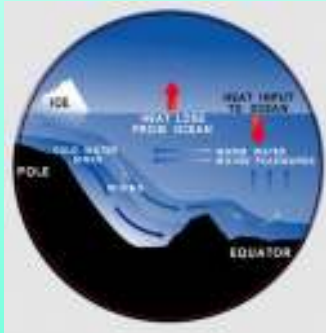
Excess heat from tropical regions is transported poleward by ocean currents

Ocean circulation transports and redistributes heat throughout the basins, contributing to the climate equilibrium

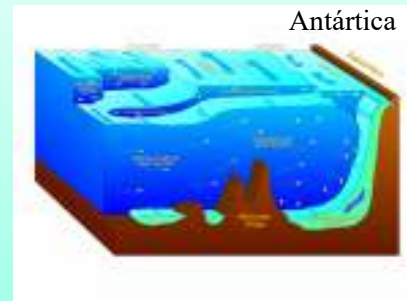


Vertical Motions

The motion of the ocean's water is not restricted to horizontal currents nor to the upper layers of the sea.



Density differences resulting from heat exchange with the atmosphere drive vertical motions (convection), exchanging waters between the surface and the deep regions of the ocean.



Atlântico Norte

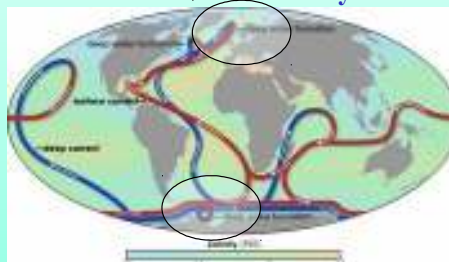
The Global Thermohaline Circulation

Circulation forced by gradients of temperature and salinity

Temperature and salinity differences make the surface water to sink in certain regions and to upwell in others.

This vertical exchange of waters is compensated by horizontal currents, forming a global circulation pattern that redistribute water throughout all oceanic basins and all depths.

The Thermohaline Conveyor-Belt

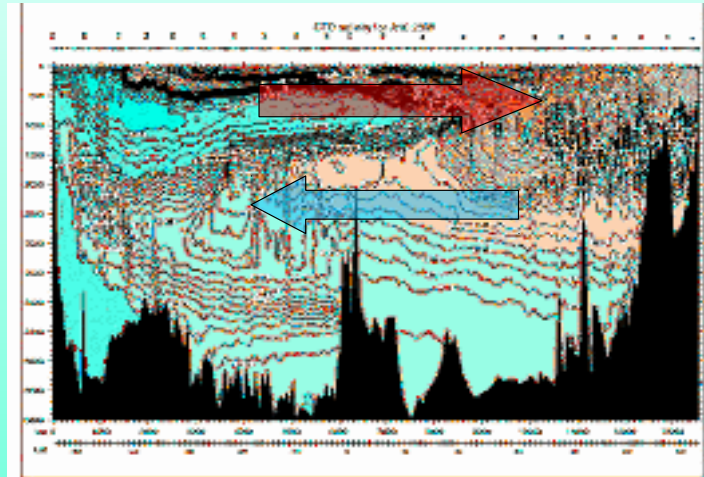


The Atlantic Meridional Overturning Circulation (AMOC)

Warmer surface waters flow from south to North;

After losing heat to the atmosphere, waters get heavier and sink;

The resulting deeper, colder waters flow back to the southern hemisphere



**The Conveyor Belt's Meridional Overturning Circulation (MOC)
is a crucial mechanism for the maintenance of climate.**

Paleoclimatic studies
show a significant
correlation between
weakening of the MOC
and abrupt climate
changes.

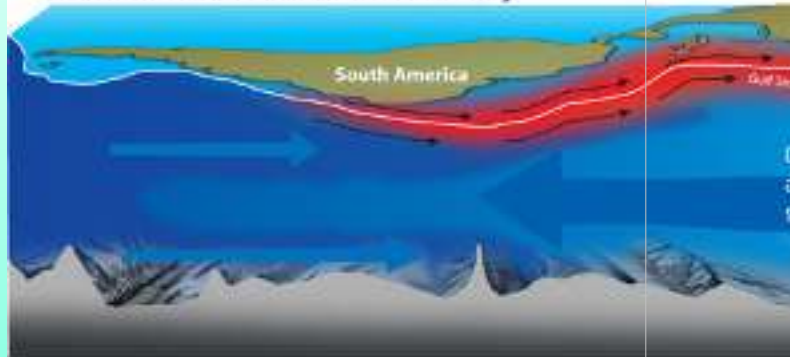


The MOC and Climate

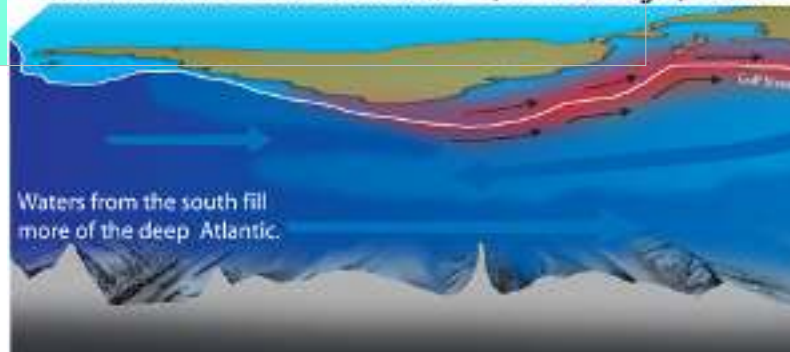
The Atlantic MOC was weakened at the peak of the last Ice Age (~20 thousand years ago)

... Can this happen again?

North Atlantic Ocean Circulation Today

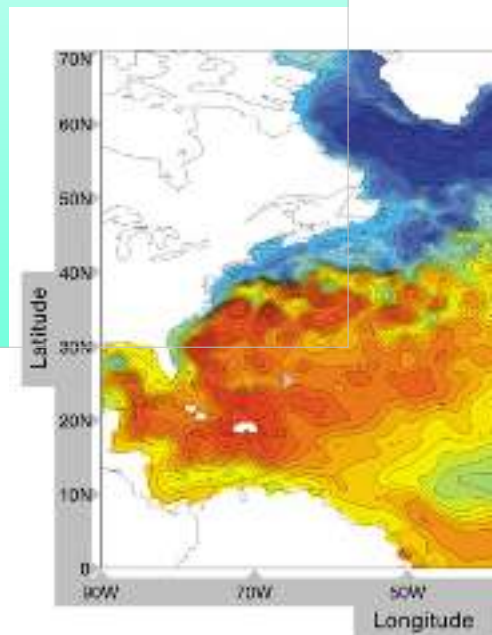
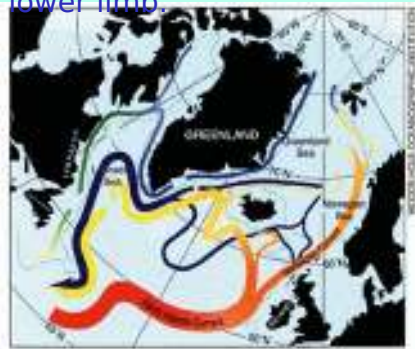


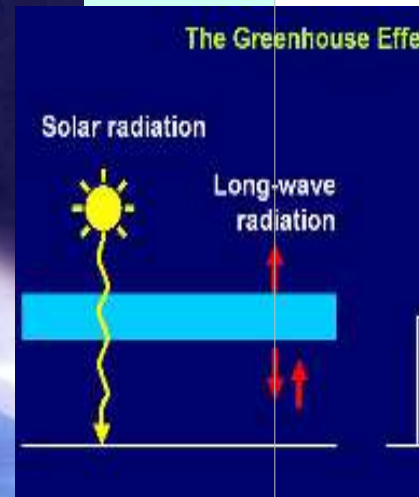
North Atlantic Ocean Circulation ~20,000 Years Ago (Peak of L)



The North Atlantic Heat Pump

In the northern latitudes of the North Atlantic, after releasing heat to the atmosphere, the higher salinity surface waters transported by the MOC get denser and sink, originating the southward flowing lower limb.



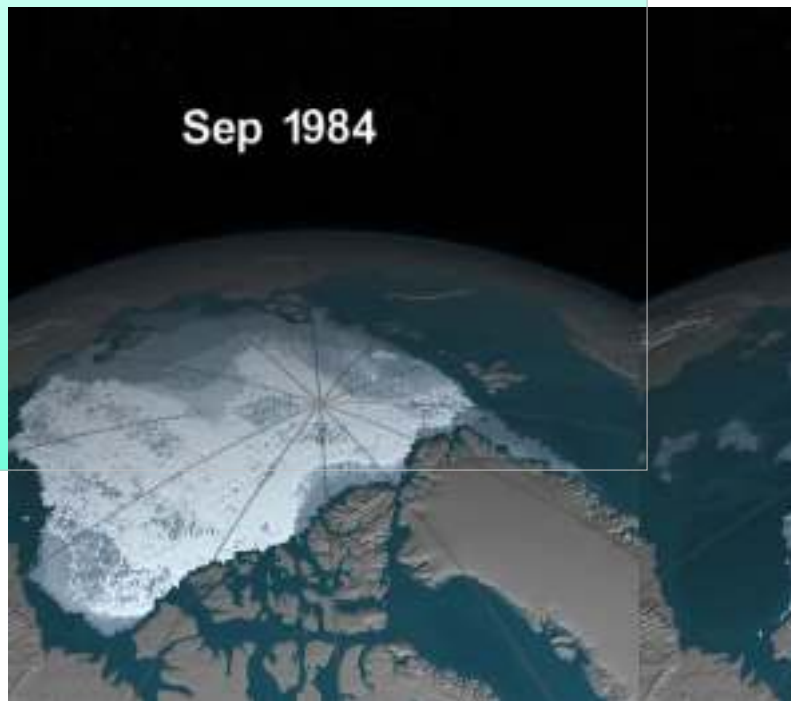


The increase of only 1°C in Earth's mean temperature can lead to the melting of a vast amount of ice.

This will result in the injection of an enormous volume of fresh water in the surface layers of the North Atlantic.

... and So What?

The Arctic ice coverage has been decreasing due to the global warming



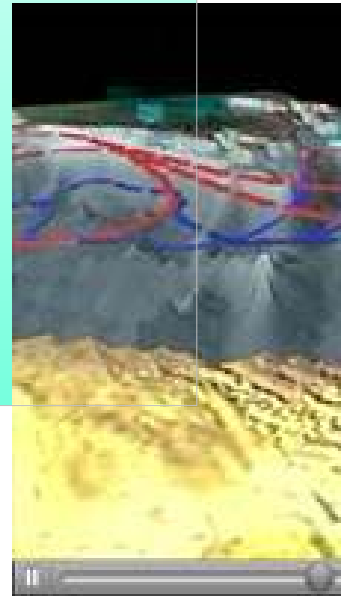
A likely consequence of the Global Warming

Global warming leads to the melting down of the Greenland's and Arctic ice sheets.

With the higher volume of fresher waters in the North Atlantic's surface layers, the more saline waters transported from the south by the MOC will get denser earlier and sink in lower latitudes.

This will result in less heat to warm the westerly winds. Then, the temperature will fall down and a new ice sheet will form.

This might result in a new Ice Age in the North Atlantic.



Modeling the Ocean

The best way to understand the ocean would be a global observing system with sampling points spaced by a few kilometers from each other. This is practically impossible.

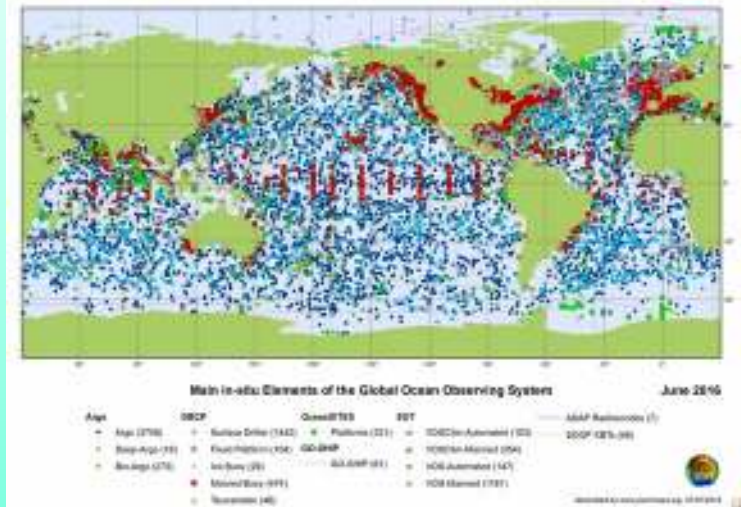
A cheaper alternative is to use computer models, in combination with the fewer observations.



Global Ocean Observing System (GOOS)

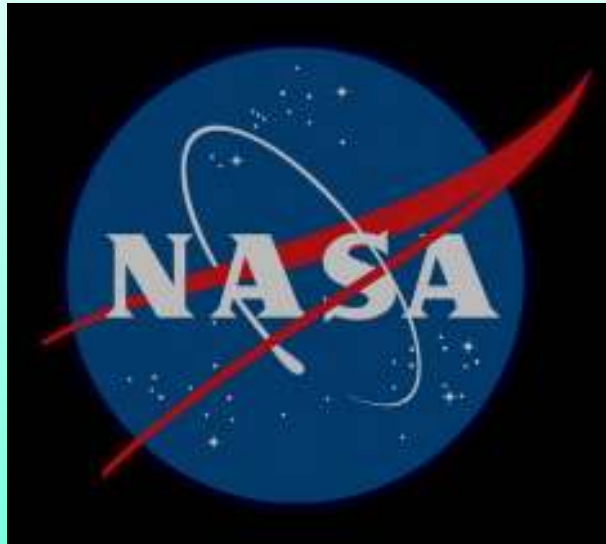
An international global system for sustained observations of the ocean.

In spite of the apparently dense coverage, the number of observing platforms is far from the minimum necessary.

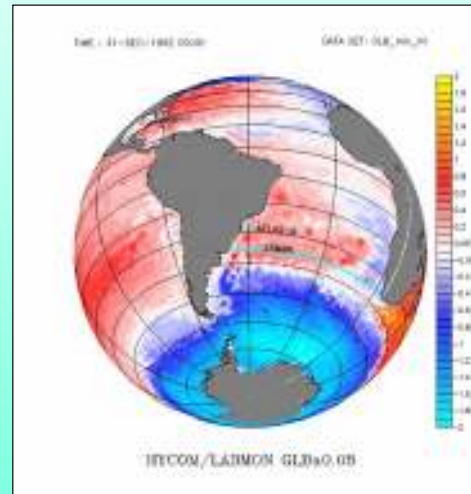


http://www.goos-ocean.org/index.php?option=com_content&view=article&id=24&Itemid=123

An example of what its
being done
internationally



An example of what is being
done in Brazil





**SPSAS – Oceans
2018**



Oceano e Mudanças Climáticas





O que pode-se dizer com base no que se sabe



3

Observations: Ocean

Coordinating Lead Authors:

Monika Klein (Germany), Stephen R. Stieglitz (Australia)

Lead Authors:

Shigero Aoki (Japan), Edmo Campos (Brazil), Don Chambers (USA), Richard A. Feely (USA), Sergey Galin (Russian Federation), Gregory C. Johnson (USA), Simon A. Josey (UK), Andrey Kockany (Russian Federation), Cecilie Mauritzen (Norway), Deke Renfrew (USA), Lynn B. Talley (USA), Xian Zhang (China)

Sinais de mudanças no oceano

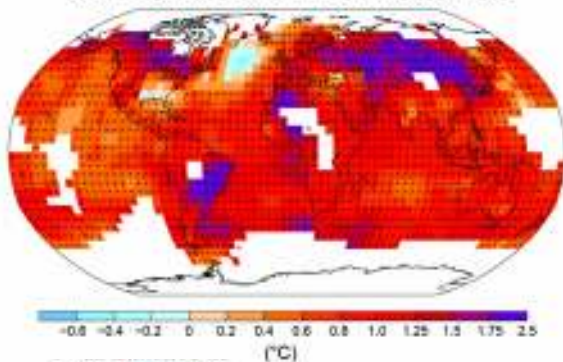


SPSAS – Oceans

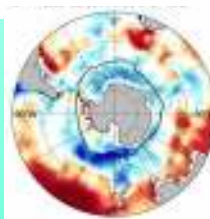


FAPESP

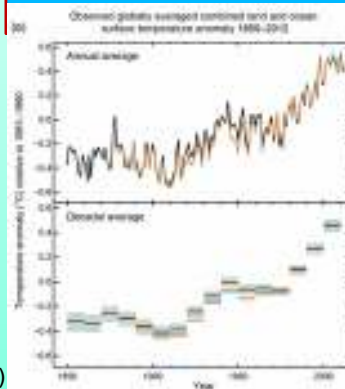
Observed change in surface temperature 1901–2012



1901-2012
IPCC AR5 WGI (2013)
1979-2013
Purich et al. (Nat. Comm., 2016)



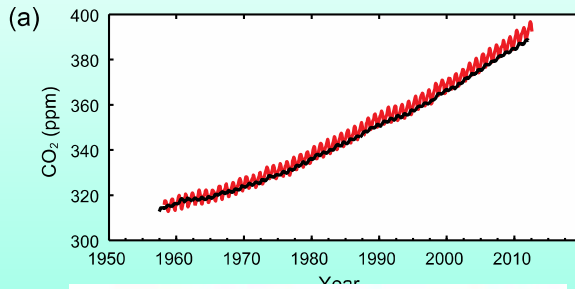
Superfície da Terra está
aquecendo



O oceano está absorvendo o excesso de CO₂ atmosférico



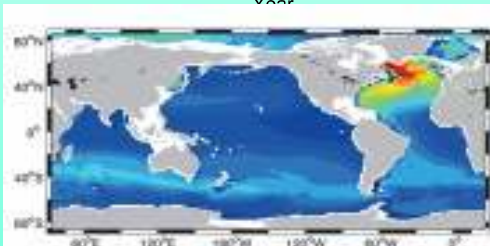
Atmospheric CO₂



O aquecimento é atribuído principalmente ao aumento do CO₂ atmosférico

(Série de tempo de Mauna Loa)

IPCC AR5 WGI (2013)

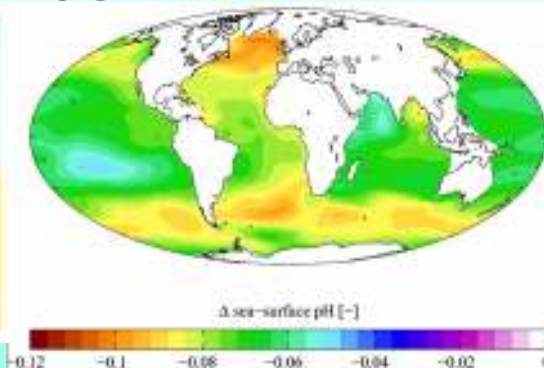


Anthropogenic CO₂ column inventory
(Khatriwala et al., 2013)

O oceano remove cerca de 1/3 do CO₂ em excesso na atmosfera, causando a acidificação do oceano.

As águas oceânicas estão se tornando mais ácidas

Diagrama sobre a acidificação do oceano. No topo, uma escala de pH vai de 8,2 a 8,1, com um círculo vermelho em 8,1. Abaixo, uma paisagem mostra uma fábrica e árvores. No fundo, um recife de corais está sendo afetado. À direita, uma lista de impactos inclui: 'Aumento da mortalidade de organismos calcários', 'Redução da biodiversidade', 'Impactos na cadeia alimentar', 'Impactos na pesca', 'Impactos no turismo', 'Impactos na cultura', 'Impactos na saúde humana'.



Alteração do pH na superfície oceânica devido ao aumento de CO₂ antropogênico entre 1700 e 1990

O oceano está se aquecendo

USP

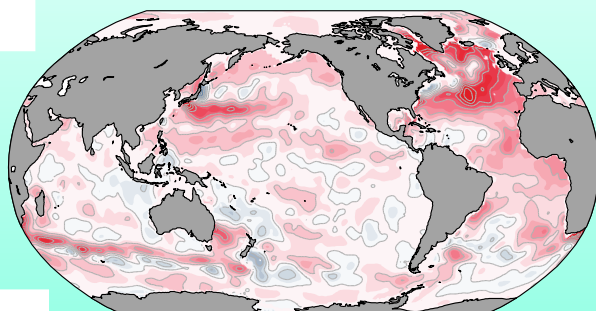
INSTITUTO DE OCEANOGRÁFIA

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O oceano superior
(0-700 m) está se
tornando mais
quente

Note que há alguma
regiões onde a tendência
é negativa. Porém, em
média, a temperatura do
oceano está aumentando.

IPCC AR5 WGI (2013)

Tendência do conteúdo de calor 1971-2010

Balanco de energia da Terra: : > 90% do aumento total está no oceano.

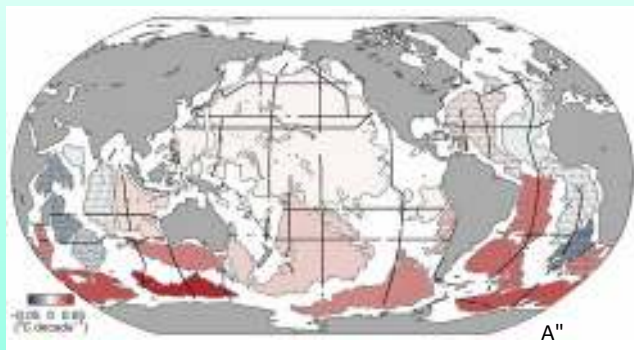
O calor retirado da atmosfera já está chegando nas regiões abissais

USP

SPSAS - Oceans
2018



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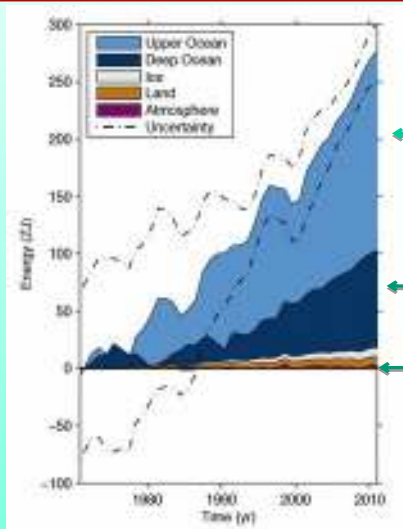


O oceano profundo (> 4000m) está aquecendo, principalmente no hemisfério sul.

IPCC AR5 WGI (2013)

Tendência de temperatura 1992-2005

Balanco de energia da Terra: 19% da mudança total de energia está no oceano profundo (> 2000 m), representando mais do que o dobro do aumento da energia na atmosfera, continentes e gelo, combinados.



Oceano Superior

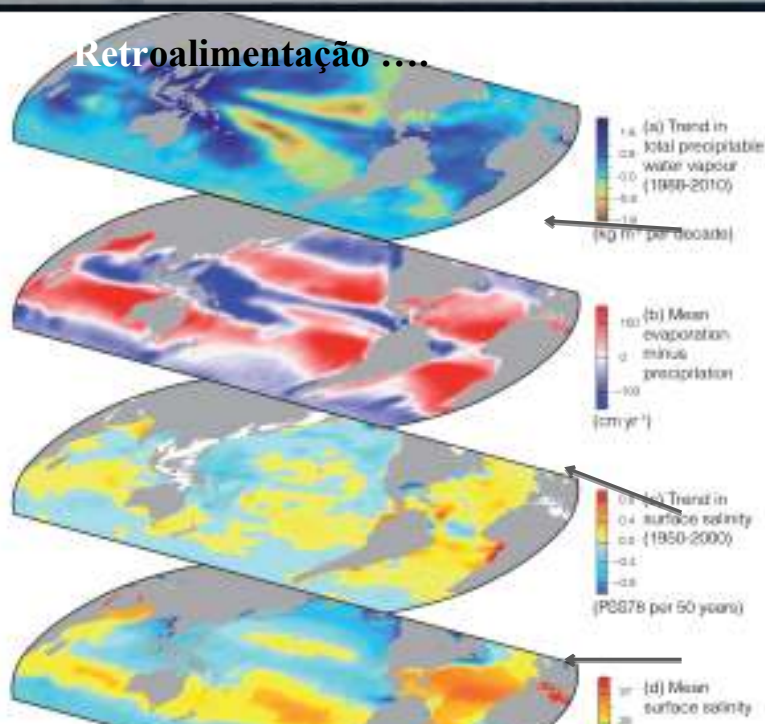
Oceano profundo

Atmosfera+terra+gelo

O excesso de energia resultante do aumento do CO₂ antropogênico está predominantemente no oceano!

IPCC AR5 WGI (2013)

Retroalimentação

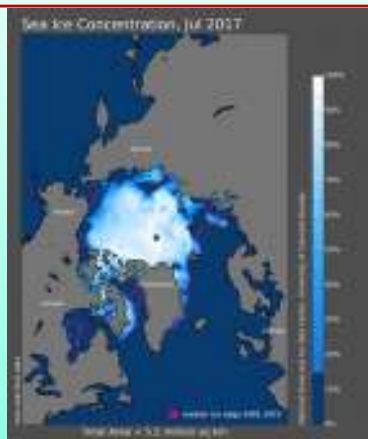


...mento causa mais
de água na atmosfera

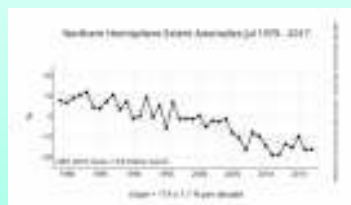
... resulta em evaporação
... ipitação mais
... as, causando
... ças na distribuição
... nidade

... gets saltier, fresh
... resher”

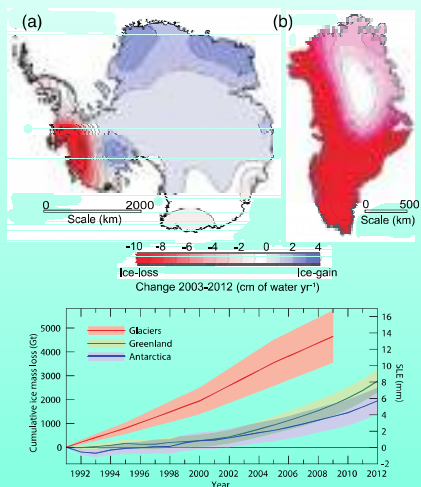
IPCC AR5 WGI (2013)



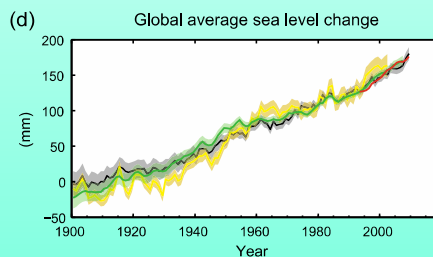
NSIDC satellite data product (2017)



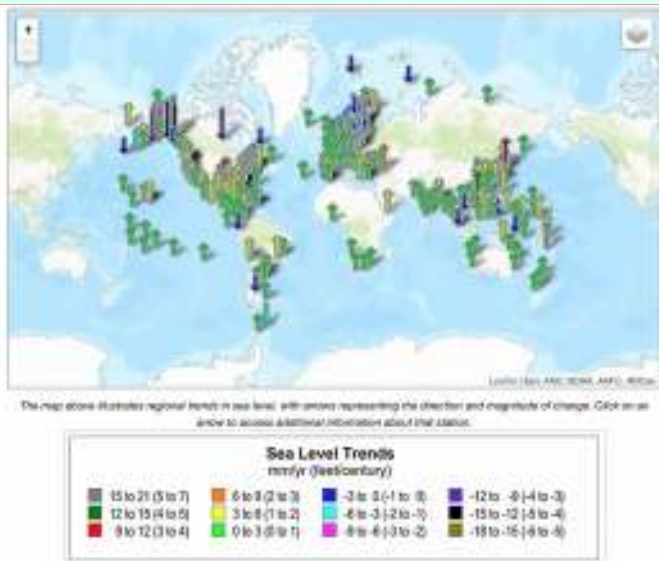
O gelo ártico está derretendo devido ao aquecimento, que é mais intenso na região polar do hemisfério norte.



O aquecimento global está derretendo as camadas de gelo, oceânicas e terrestres, contribuindo juntamente com o aquecimento do oceano para o aumento do nível do mar.



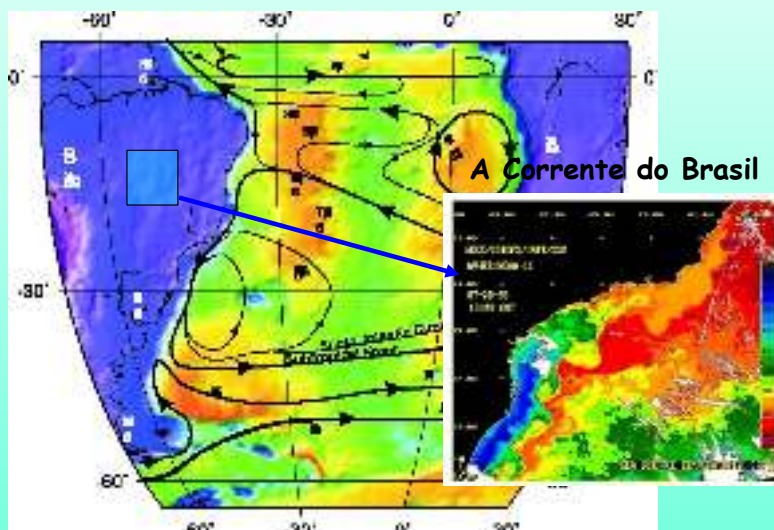
IPCC AR5 WGI (2013)



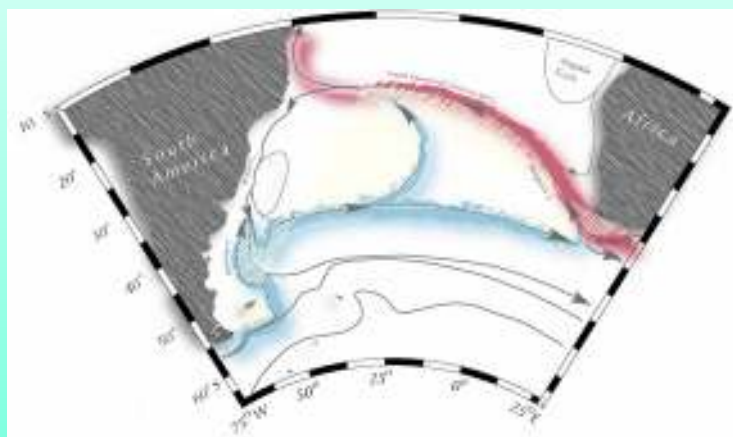
Tendências de aumento do nível médio do mar medidos por marégrafos.

Tides and Currents (NOAA, 2017)
<https://tidesandcurrents.noaa.gov/sltrends/sltrends.html>

O Atlântico Sul

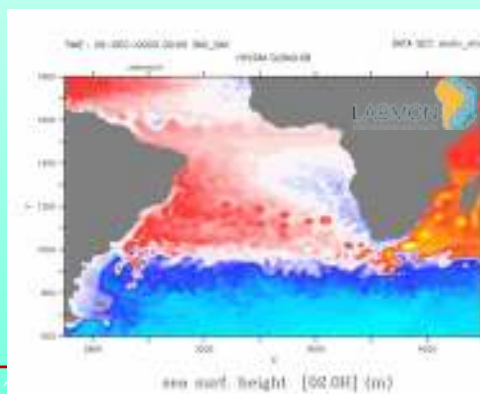


Importância do Atlântico Sul



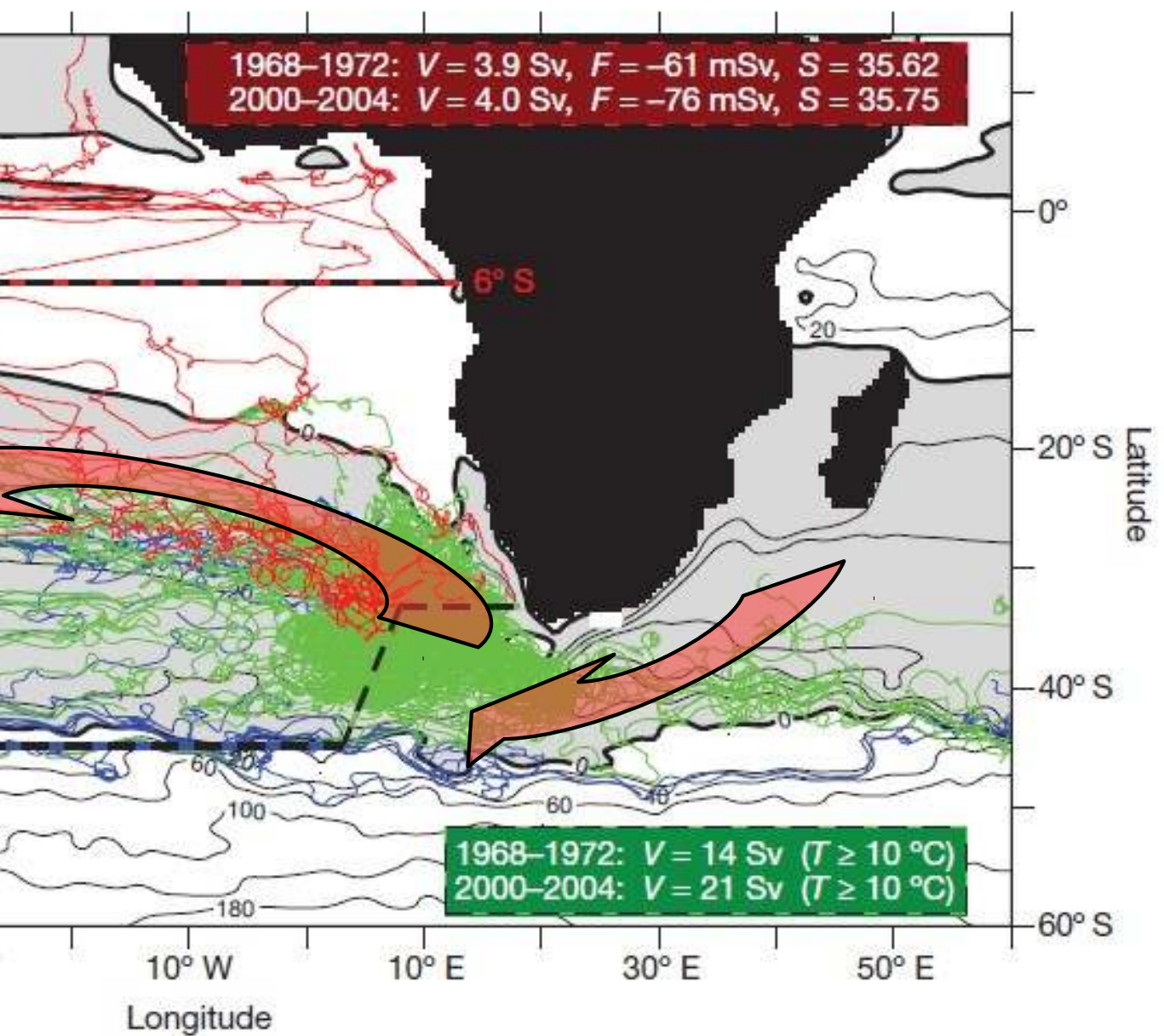
O Vazamento das Agulhas

Águas do Índico transferidas para o Atlântico Sul por anéis e filamentos na região de Retroflexão da Corrente das Agulhas.



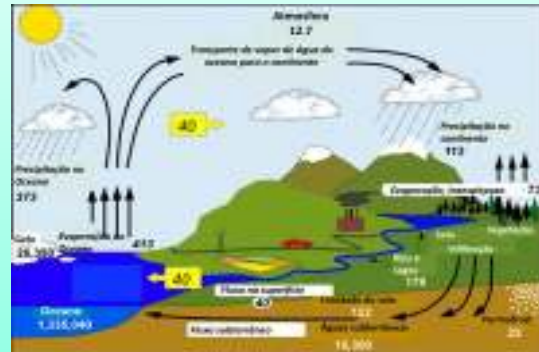
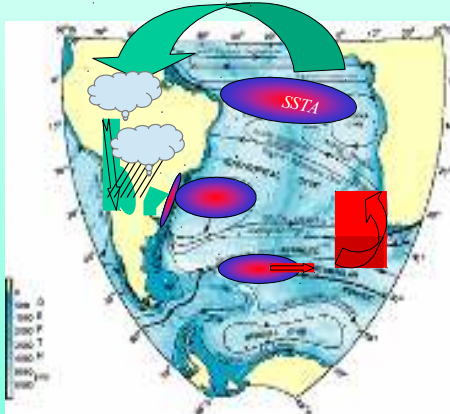
Mistura de águas oriundas do Índico com águas sub-antárticas circulam pelo Atlântico.

Alteração na composição dessas águas implicam em alterações significativas no clima regional.



. Schwarzcopf and J.R.E. Lutjeharms
(2009) mostram que a importação de
no Atlântico Sul vem aumentando nas
consequências é o aquecimento e
este, ao largo do litoral brasileiro.

Impactos sobre o ciclo Hidrológico



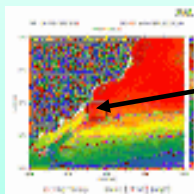
Alterações nas propriedades das massas de água no Atlântico Sul podem ter reflexos significativos no regime de monções da América do Sul e, consequentemente, no ciclo hidrológico.

Impactos regionais

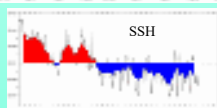
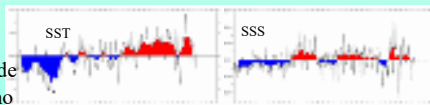
Aumento na ocorrência de eventos extremos ?

Resultados sugerem variabilidades no Atlântico Sudoeste.

REMO poderia fornecer importantes informações do ponto de vista de prevenção de calamidades como o ocorrido recentemente no Sudeste do Brasil.



Catarina



Projetos financiados pela FAPESP, investigam impactos dessas mudanças oceânicas no clima regional.



Mudanças na circulação do Atlântico Sul podem ter resultados catastróficos tanto nas regiões litorâneas quanto em todo o território brasileiro.

