Introduction to Ocean Physics

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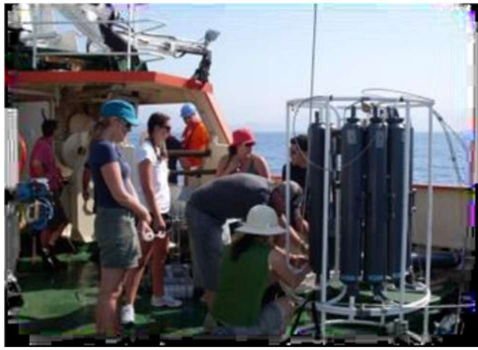

13 to 25th August, 2018
Sao Paulo, Brazil

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

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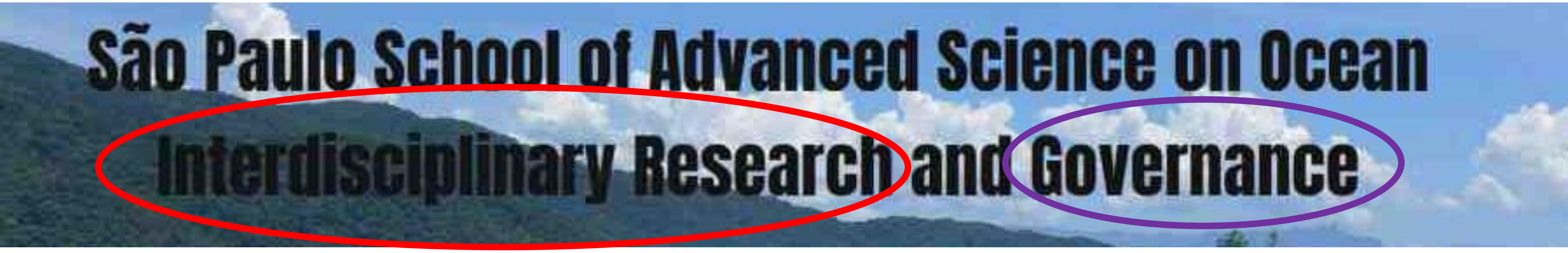
SHORT PROGRAM (To see the detailed program click on each day or scroll down)

Day 1 - Monday AUGUST 13	Day 2 - Tuesday AUGUST 14	Day 3 - We… AUGUS…	Day 5 - Friday AUGUST 17	Day 6 - Saturday AUGUST 18
08h30 // Registration	09h30 // Class 2	09h30 // Clas…	09h30 // Class 8	09h30 // Class 10
09h00 // Opening Section	15h00 // Class 3	15h00 // Class…	15h00 // Class 9	15h00 // Exercise Interdisciplinary
11h35 // Panel 1	18h30 // Poster 1	18h30 // Tutor…	18h30 // Tutoring 2	18h30 // Poster 3
15h00 // Class 1				
18h30 // Book Launching				
Setting the context: theoretical and historical background	**Setting the context: theoretical and historical background**	**Setting the co… theoretical an… background**	**Sharing the advances in oceans sciences: processes and connections**	**Sharing the advances in oceans sciences: processes and connections**

SO LET'S

What are we here for?



…Efficient Governability cannot be achieved without a proper understanding of the Earth system and a good communication between the disciplines that interplay..

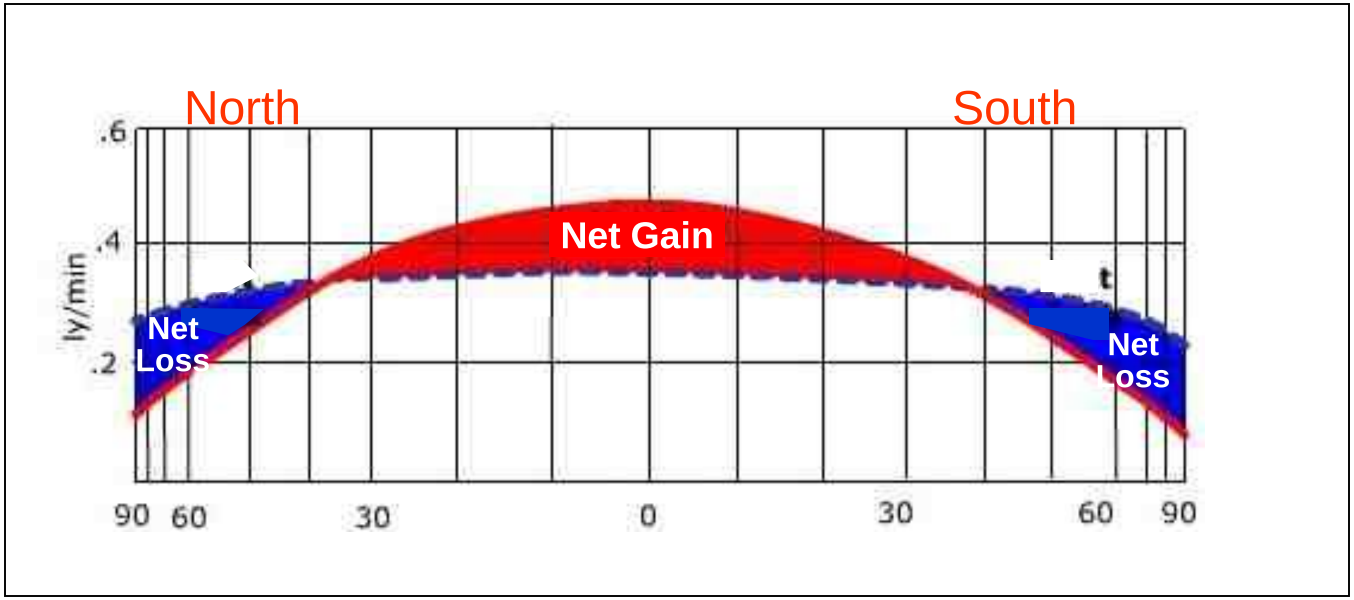
The Earth System includes human society,
Our social and economic systems are embedded within the Earth System.

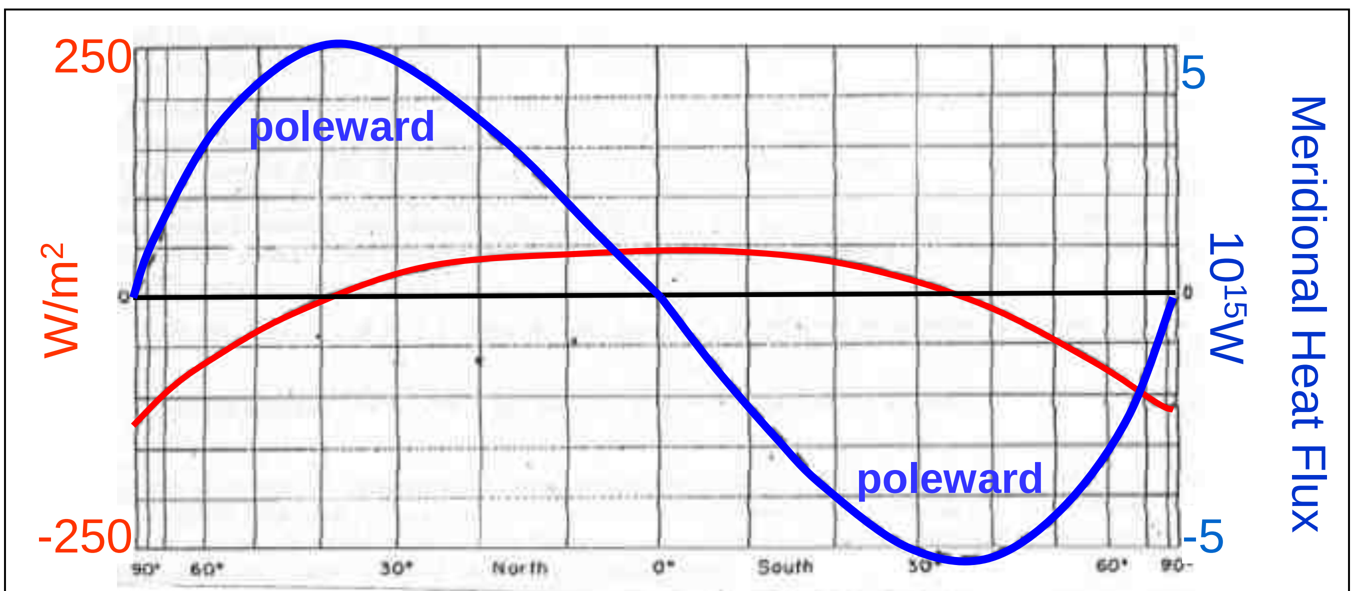
Why SHOULD WE care about ocean physics?

Beware, this list is biased and incomplete

- Together with the atmosphere the ocean redistributes heat on Earth

Heat unbalanced





Mean heat flux 60W/m2.

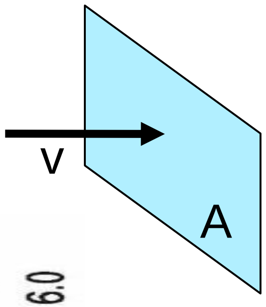
Locally the radiation budget is unbalanced

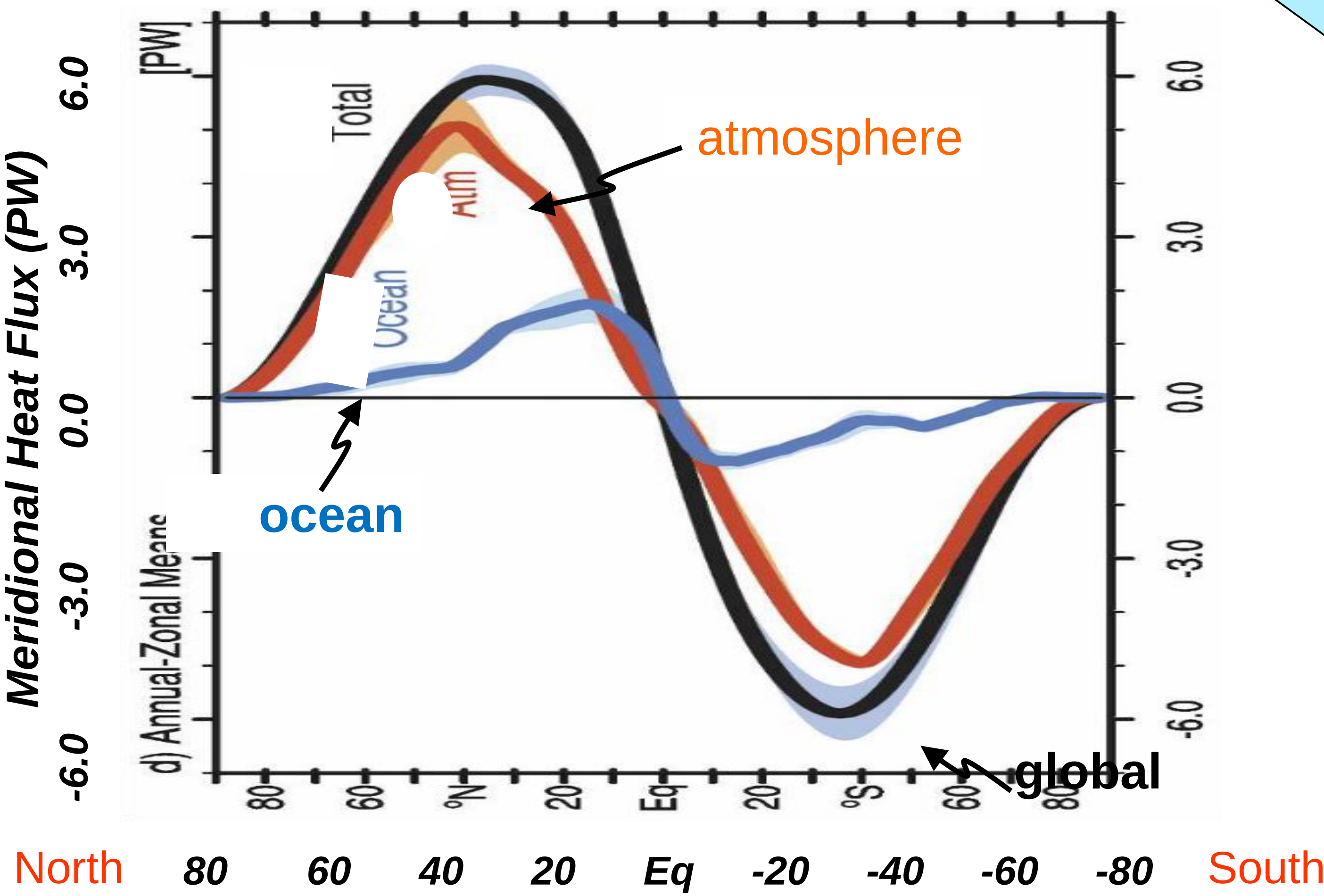
To achieve a radiative balance a meridional heat flux is required

Redistribution of heat on Earth

Poleward Transports

$$Q_m = \rho_0 C_p \mathbf{T}\,\mathbf{v}\,A$$





Fasullo & Trenberth, *J. Climate*, 2008

Most of the required meridional fluxes are accounted for by the **fluid parts of the system**

Why care about ocean physics?

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- Water's high heat capacity, climate modulation at long time scales

Earth radiation balance and ocean heat content

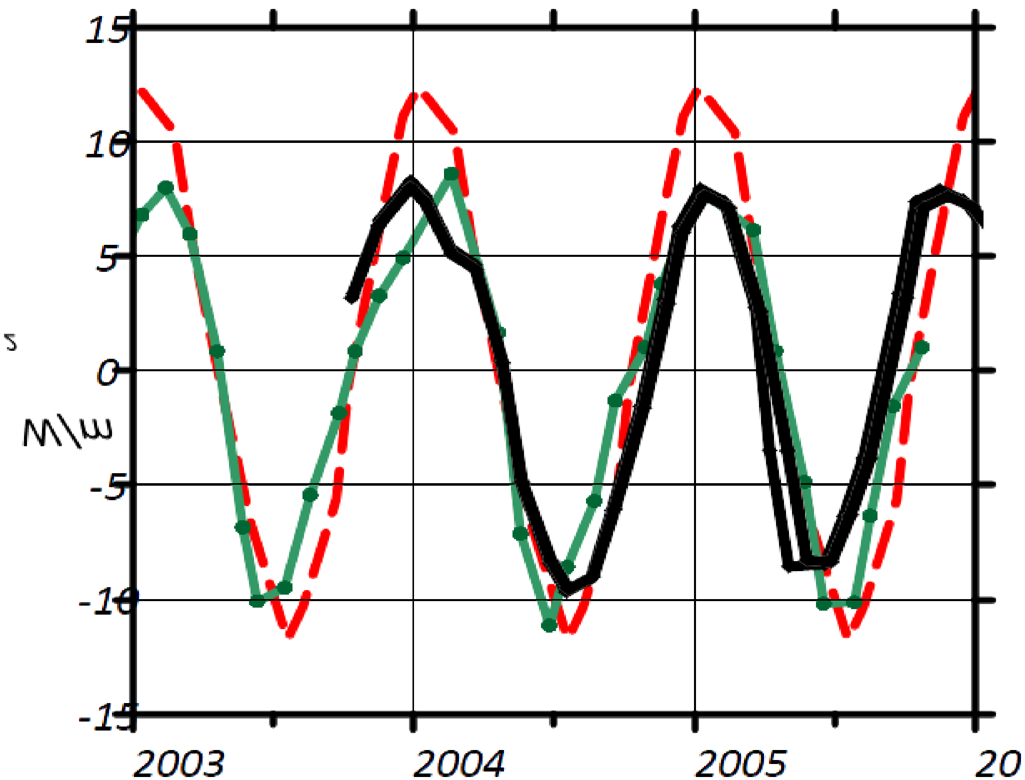
Annual Solar eccentricity effect in radiance

CERES: Clouds and the Earth’s Radiant Energy System

changes in the radiation **flux** at TOA, satellite data

Argo upper ocean (2000 m) autonomous profiling floats

changes in heat content of the global ocean



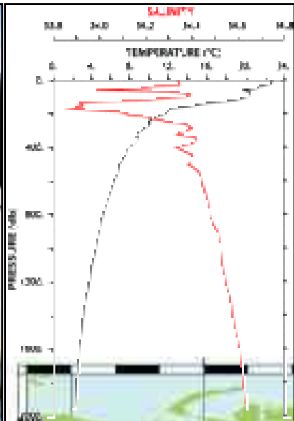
The changes in heat content at the end of the record are not fully understood

relatively fast ocean response due to eccentricity

$$\int_o F_{\mathrm{TOA}}(t)\,dA_o + \int_i F_{\mathrm{geo}}(t)\,dA_i = \frac{d}{dt}\int_o E_O(t)\,dV_O = \frac{dH_O}{dt}$$

Douglass & Knox, *Phys. Lett. A*, 2009

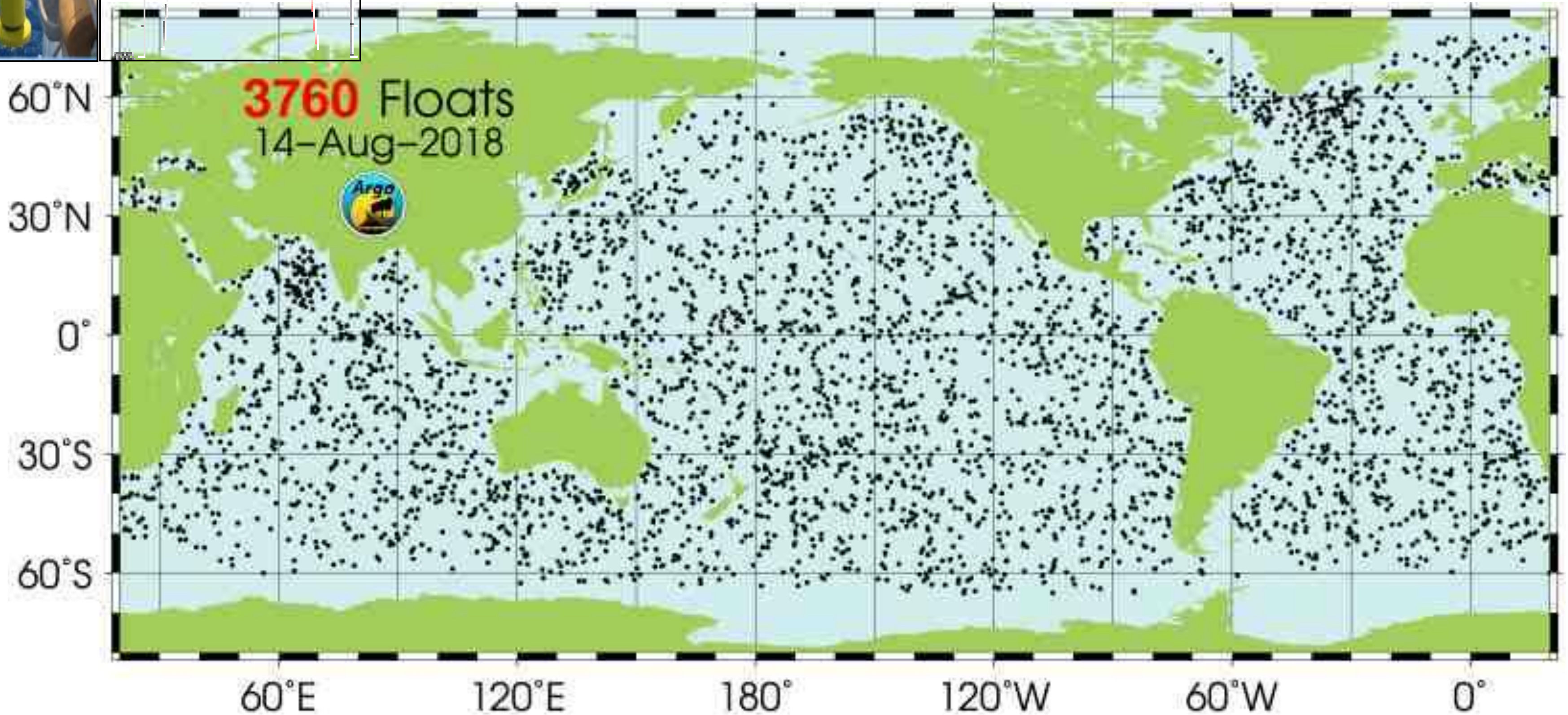
Argo network



Each dot indicates the location of the latest profile collected by the floats

	Global total
Argo float profiles since 2000:	**1,920,476**
Water sample casts since 1772:	3,218,944
High-resolution (CTD) casts since 1961:	1,047,658
High-resolution Pinniped casts:	1,814,217(*)

Close to 4000 active floats -14 Aug 2018

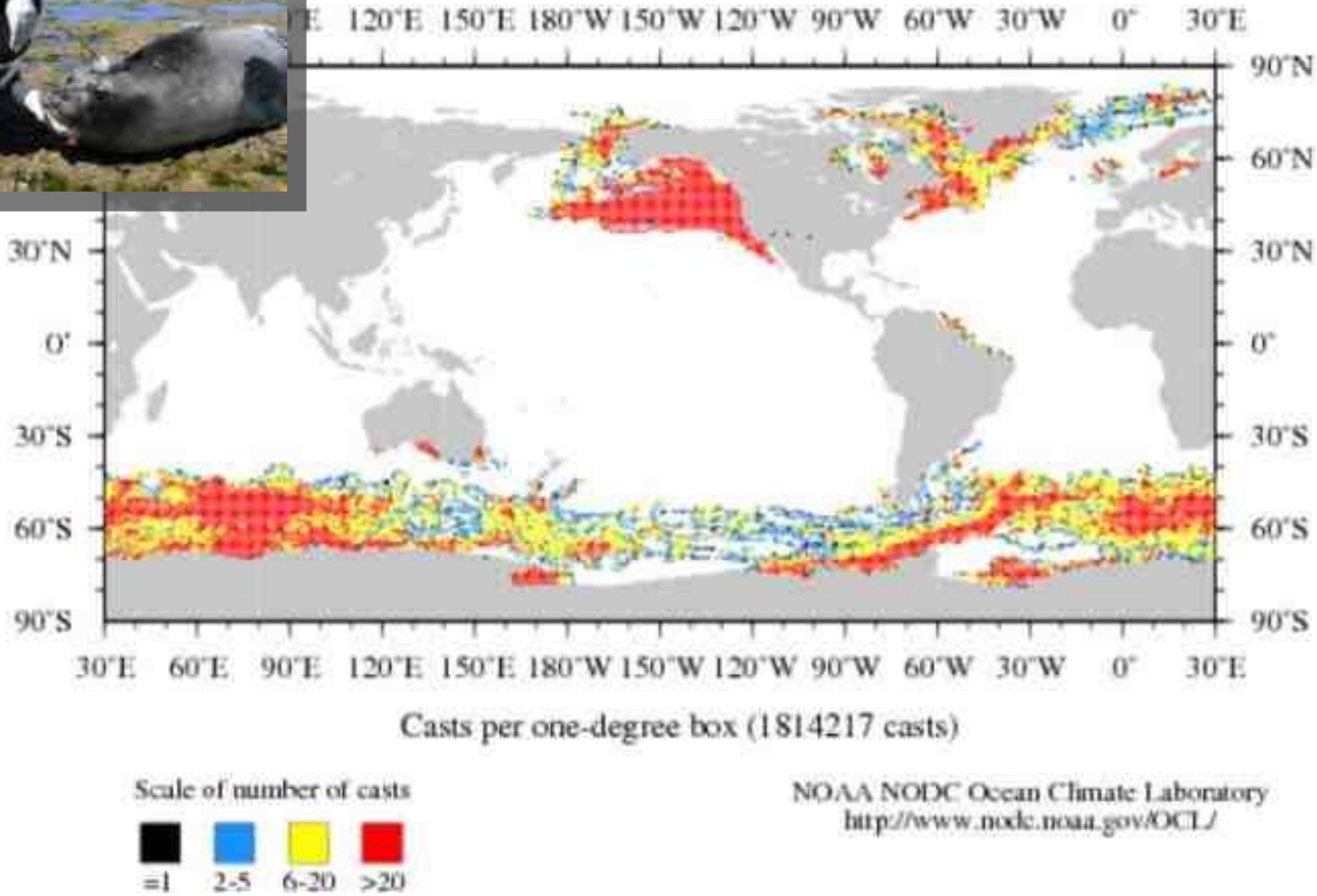


www.argo.ucsd.edu

ADDITIONAL FLOATS ARE NECESSARY

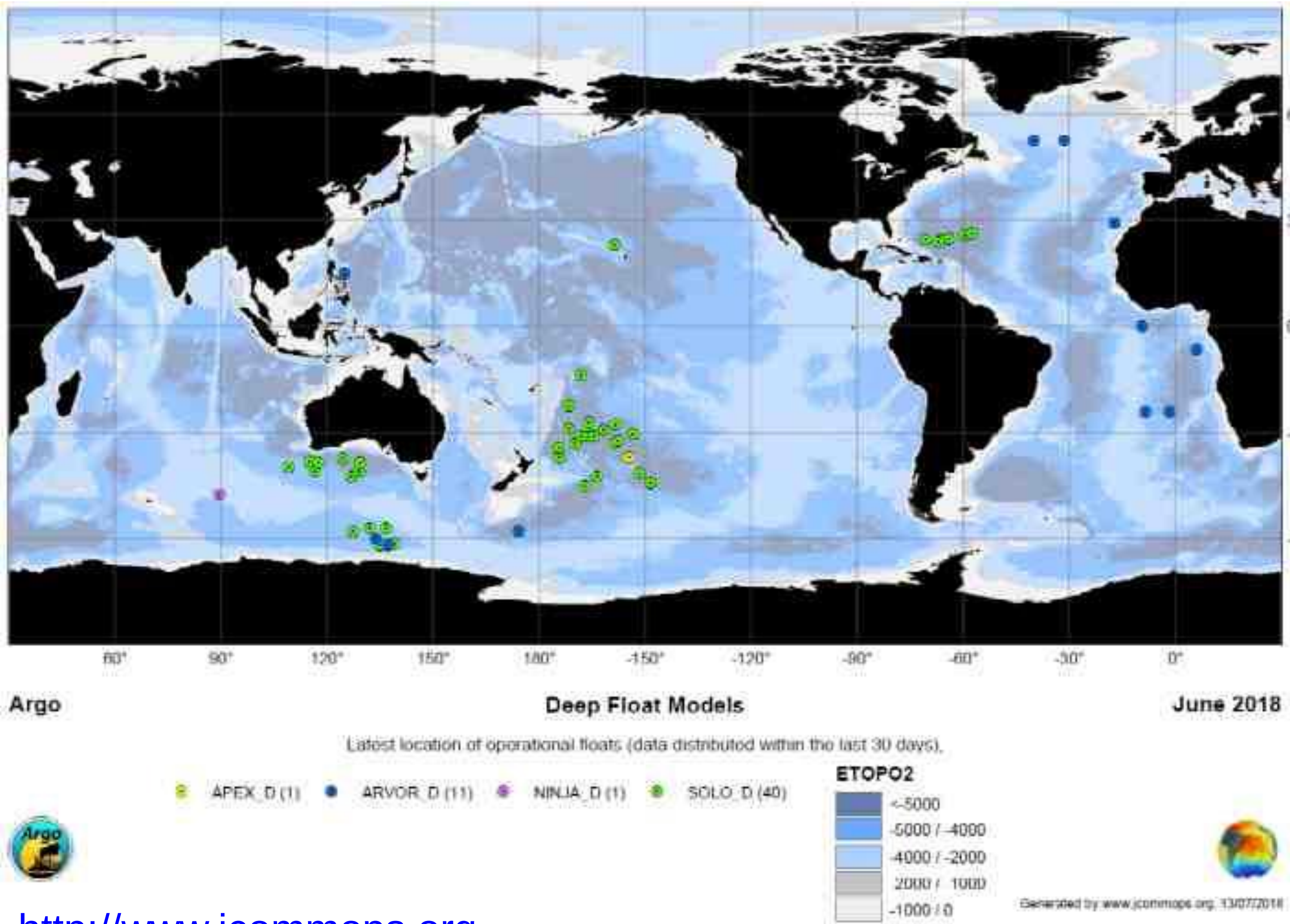
the platforms drift freely at 1000 m

Naturally, data collected by pinnipeds are geographically biased to the regions where the feed



https://www.nodc.noaa.gov/cgi-bin/OC5/SELECT/builder.pl

Deep Argo profiles



http://www.jcommops.org

Why care about ocean physics?

Beware, this list is biased and incomplete

- Together with the atmosphere the ocean redistributes heat on Earth
- Water's high heat capacity, climate modulation at long time scales
- About 50% of the Earth chlorophyll is produced by marine organisms
- Vertical circulation and mixing drive the upward nutrients flux required to support phytoplankton growth

Phytoplankton grows mostly in the surface layer
Light and nutrients are available there.

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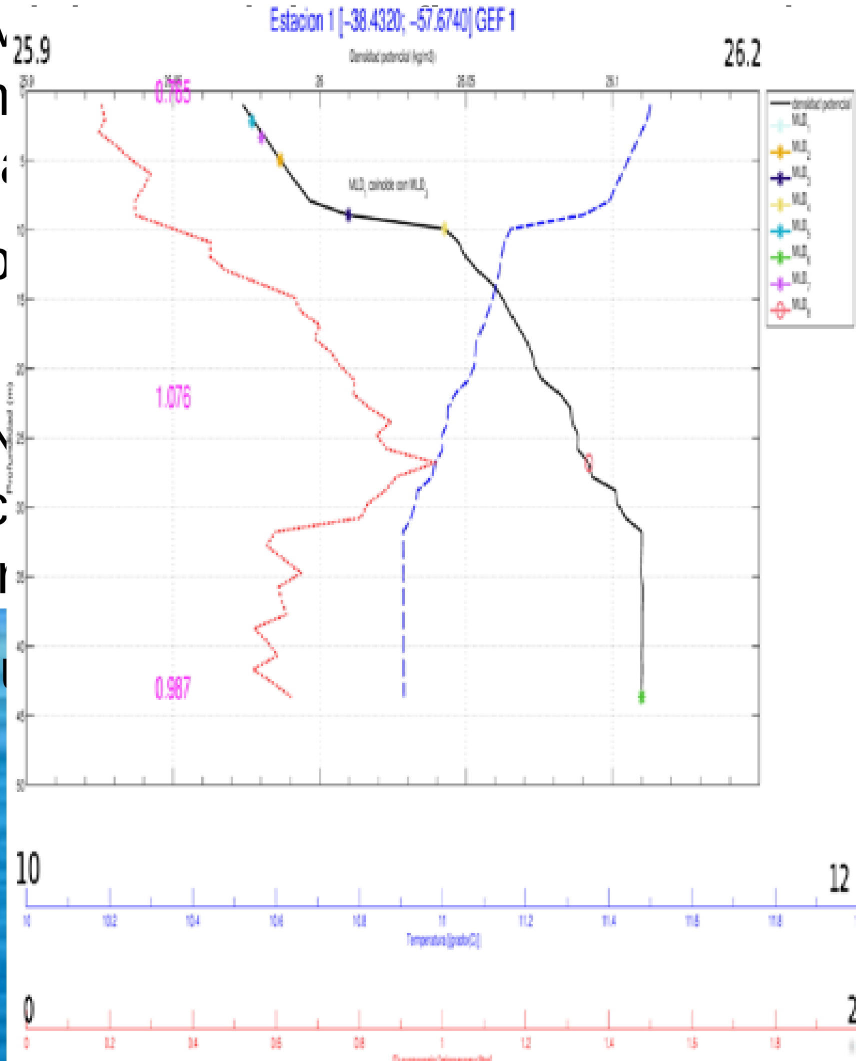
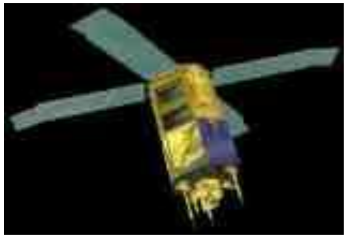
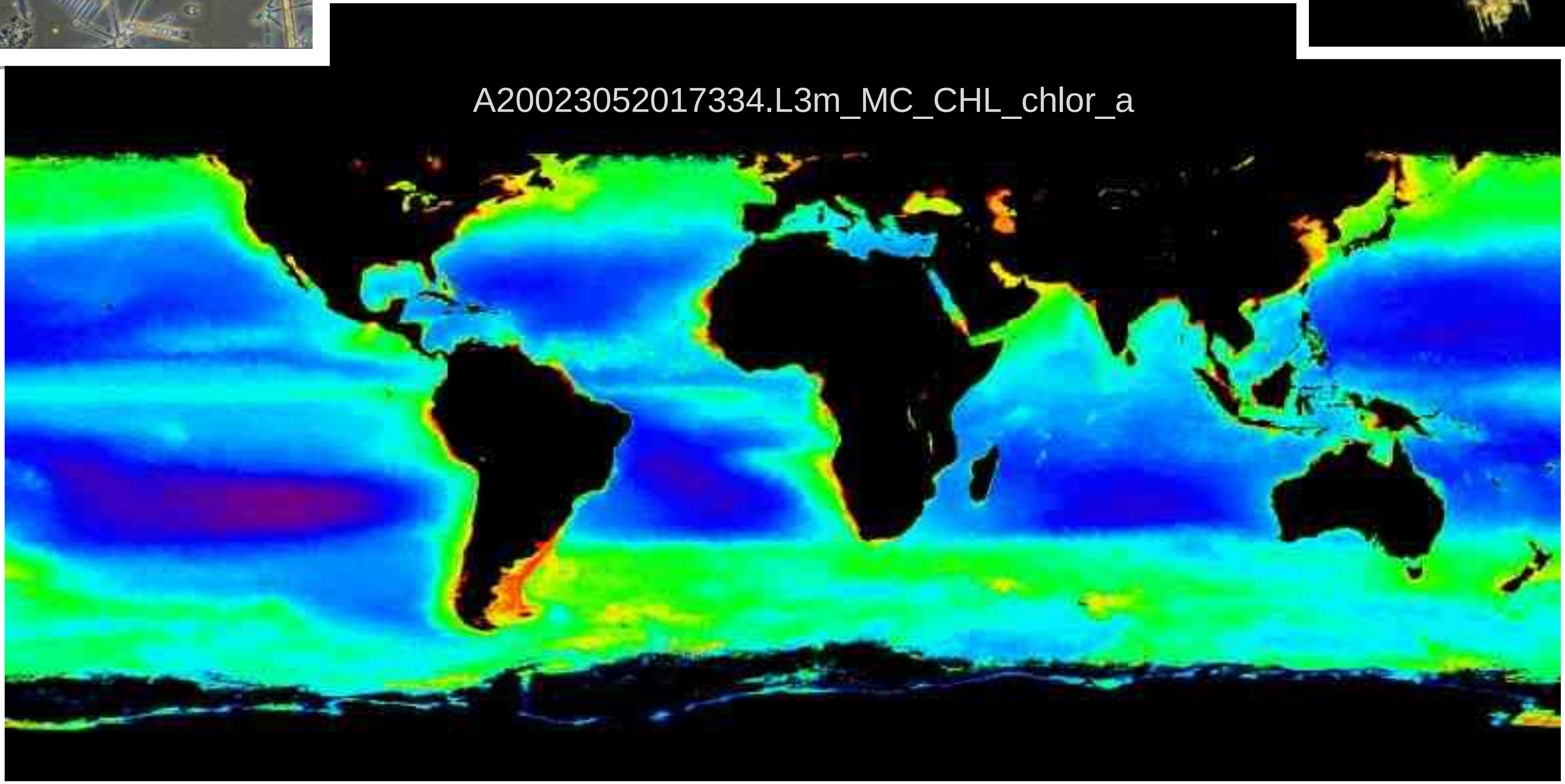
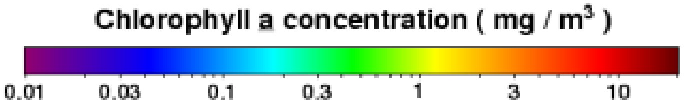


Life in the Ocean

November
Mean surface chlorophyll-a distribution
MODISA 2002-2017







Most of these long-term mean patterns can be explained based on arguments associated with water masses, winds, ocean currents and interaction between currents and bottom topography

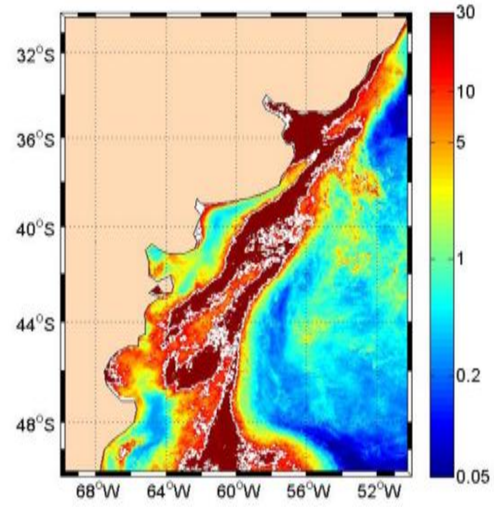
tp://oceancolor.gsfc.nasa.gov/cgi/l3

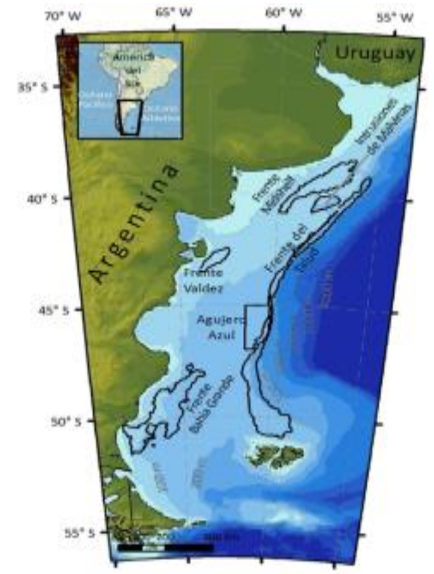
still poorly understood

POLIGONS AND INDICATORS

As a comparison tool among highly productive regions

MODIS AQ 5D 2002-2017
Domain up to 50 S
OM, IM y NM





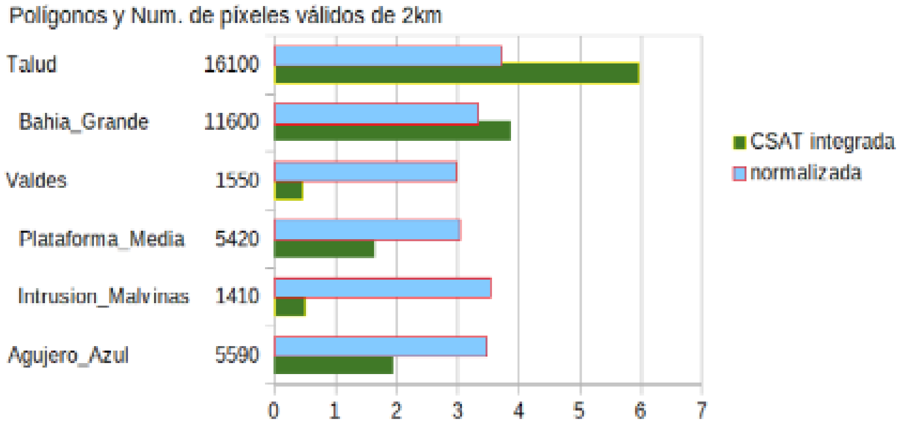
Mean Chlorophyll and Standard Deviation					
Región:	Complete	Autum	Winter	Spring	Summer
Agujero Azul	2,12(0.06)	0,95 (0,05)	0,49 (0,05)	4,24 (0,28)	2,76 (0,15)
intrusión de Malvinas	2,70 (0.20)	2,50 (0,34)	1,40 (0,10)	5,52 (0,37)	2,75 (0,48)
Plataforma Media	1,97 (0.17)	1,15 (0,08)	1,33 (0,22)	4,42 (0,89)	1,27 (0,19)
Valdés	1,74 (0.06)	1,08 (0,10)	1,01 (0,08)	3,61 (0,45)	2,20 (0,30)
Norte de Malvinas	1,96 (0.21)	0,86 (0,27)	0,35 (0,43)	4,57(0,54)	4,47 (0,36)
Octubre Medio	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

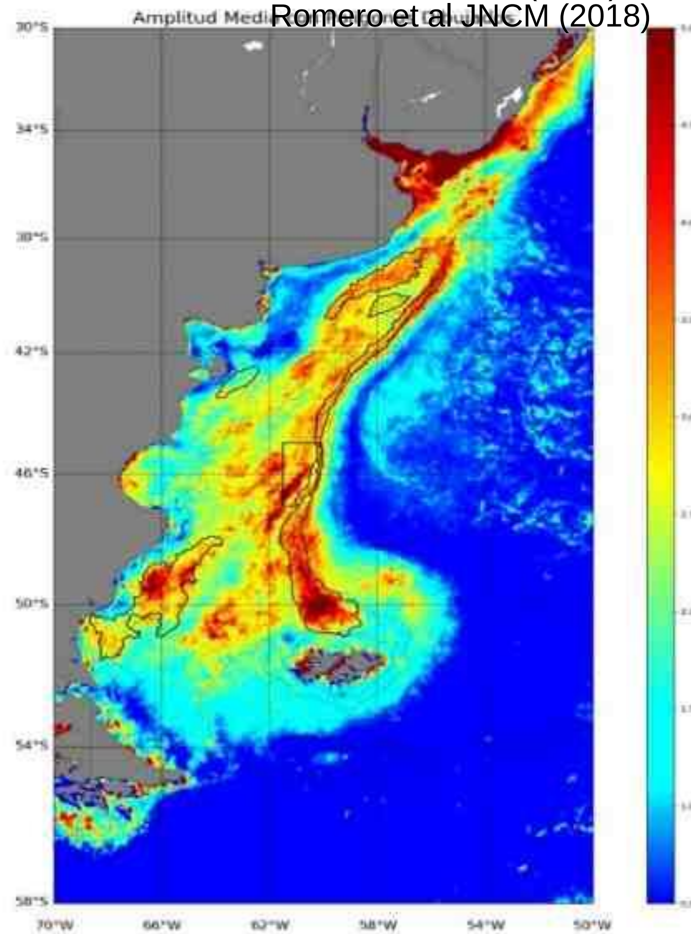
Integrated Chlorophyil and number of valid data					
Región:	Complete	Autum	Winter	Spring	Summer
Agujero Azul	11867 (5587)	1700 (1520)	3 (3)	22921 (5412)	15352 (5587)
intrusión de Malvinas	3766 (1408)	3417 (1408)	2015 (1408)	5504 (1034)	3782 (1408)
Plataforma Media	10847 (5417)	5264 (4433)	7296 (5302)	19950 (4917)	6156 (4460)
Valdés	2723 (1550)	1146 (982)	803 (751)	5546 (1548)	3487 (1550)
Norte de Malvinas	27034 (12844)	1483 (1238)	0 (0)	51015 (11165)	34570 (12830)
Octubre Medio	111320 (53928)	5214 (36423)	34810 (25435)	202740 (50556)	100140 (48983)

Poligons and Indicators as tools of comparison between high productive regions of the Atlantic Patagonian Shelf

Romero et al JNCM (2018)

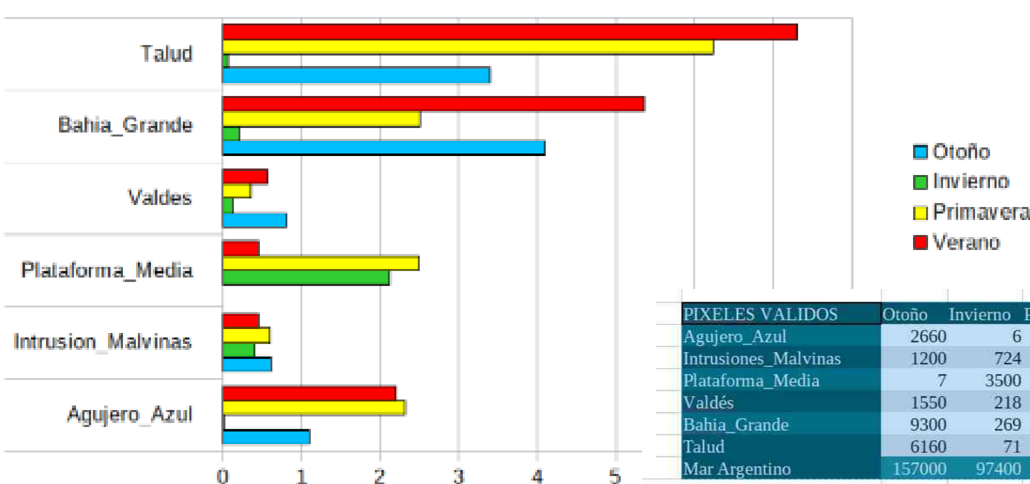
CSAT integrada en % sobre todo
el Mar Argentino (30-58 S, 70-50 O) SeaWifs+ModisAq (1997-2018)



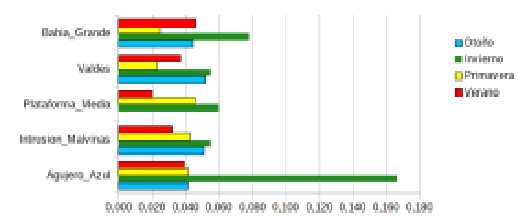


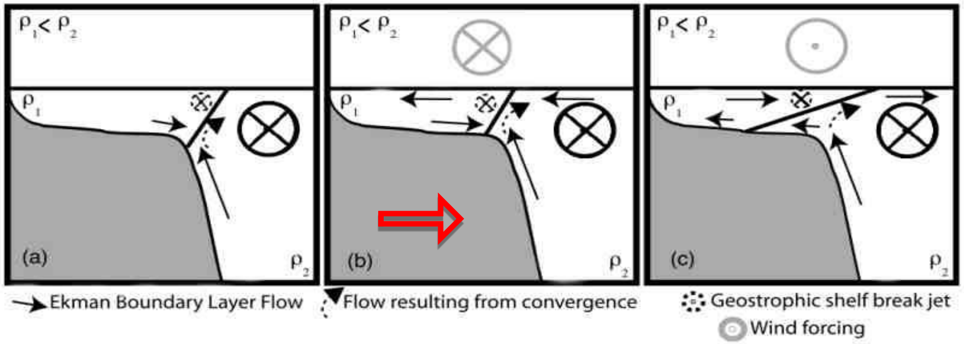
Romero et al JNCM (2018)

CSAT integrada en cada polígono, en % sobre todo el Mar Argentino (30-58 S, 70-50 O), sobre las medias del periodo completo estacionales, SeaWifs+ModisAq (1997-2018)



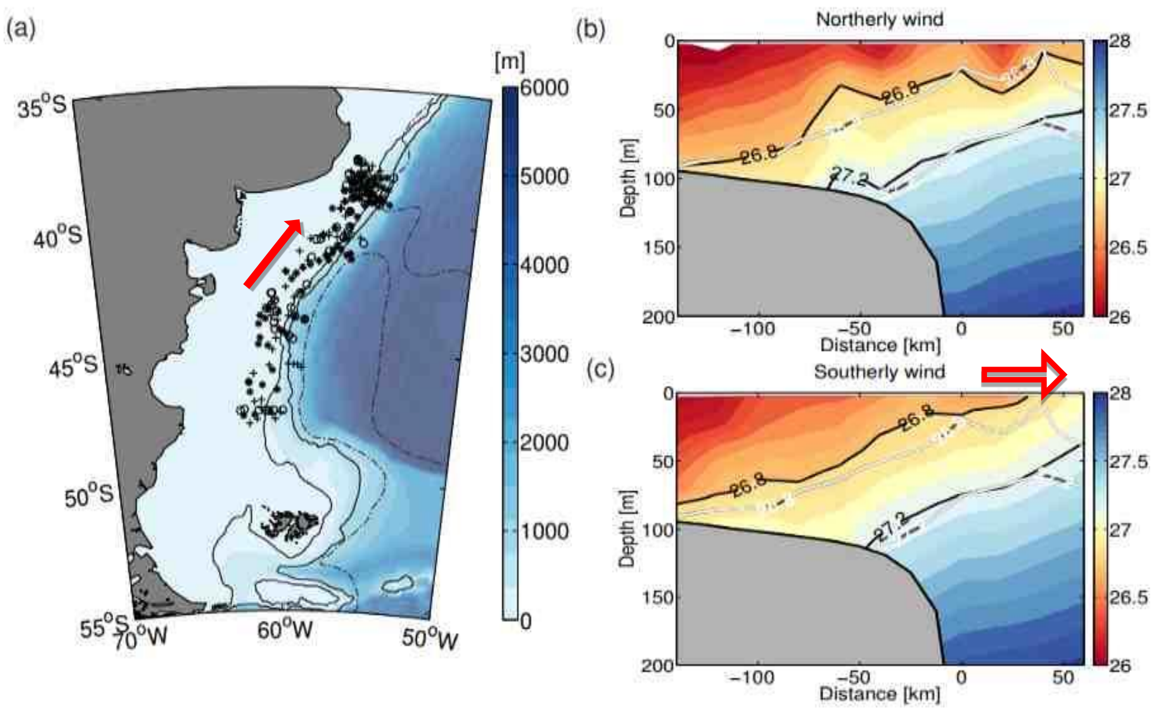
PIXELES VALIDOS	Otoño	Invierno	Primavera	Verano
Agujero_Azul	2660	6	5580	5590
Intrusiones_Malvinas	1200	724	1410	1410
Plataforma_Media	7	3500	5420	2230
Valdés	1550	218	1520	1550
Bahia_Grande	9300	269	10200	11600
Talud	6160	71	16100	16100
Mar Argentino	157000	97400	327000	300000





Adapted for the Southern Hemisphere and modified from **Siedlecki et al. (2011)**

Mechanisms of fertilization Winds parallel to the Shelfbreak



Wind modulation of shelfbreak upwelling Observational monitoring

(Carranza et. al. 2017)

Figure 7. (a) Location of historical hydrographic stations between 38°S and 50°S sampled with northerly (⋆), southerly (+) and no-wind conditions (○), used in mean hydrographic density sections for (b) northerly winds (N=78) and (c) southerly winds (N=94) in winter and spring (JJASON). To segregate profiles, here, we used a threshold of 2 m s^{-1} for the intensity of along-front winds. Cases when the along-front wind component was less than 2 m s^{-1} were considered "calm", although stronger cross-front winds could occur in these cases. Mean density contours for calm conditions (N=67) are overlaid in white.

Why care about ocean physics?

Beware, this list is biased and incomplete

- Together with the atmosphere the ocean redistributes heat on Earth
- Water's high heat capacity, climate modulation at long time scales
- About 50% of the Earth chlorophyll is produced by marine organisms
- Vertical circulation and mixing drive the upward nutrients flux required to support phytoplankton growth
- The ocean can store constituents, such as greenhouse gases during long periods of time

Outline

- Basic properties of seawater:
  Heat capacity, pressure, temperature, salinity and density

- Drivers of the ocean circulation: density and wind
- Rotation
- Wind induced circulation, Ekman and linear theories
- Upwelling: coastal, equatorial, others

- Thermohaline alterations, heat and mass balance
- Overturning circulation

Salinity is the mass of dissolved salts (in grams) per kilogram of seawater.

$$\frac{\textbf{Mass of dissolved salts (g)}}{\textbf{Mass of seawater (Kg)}}$$

Major constituents of seawater S ~ 35

Principal composición del agua de mar
35ppm

Cationes	*g/Kg*	*mEq/Kg*
Sodio	10.752	467.56
Potasio	0.39	9.98
Magnesio	1.295	106.50
Calcio	0.416	20.76
Sr	0.013	0.3
	Total	**605.1**
Aniones		
Cloro	19.345	545.59
Bromo	0.066	0.83
Fluor	0.0013	0.07
Sulfato	2.701	56.23
Bicarbonato	0.145	2.3
	Total	**605.02**

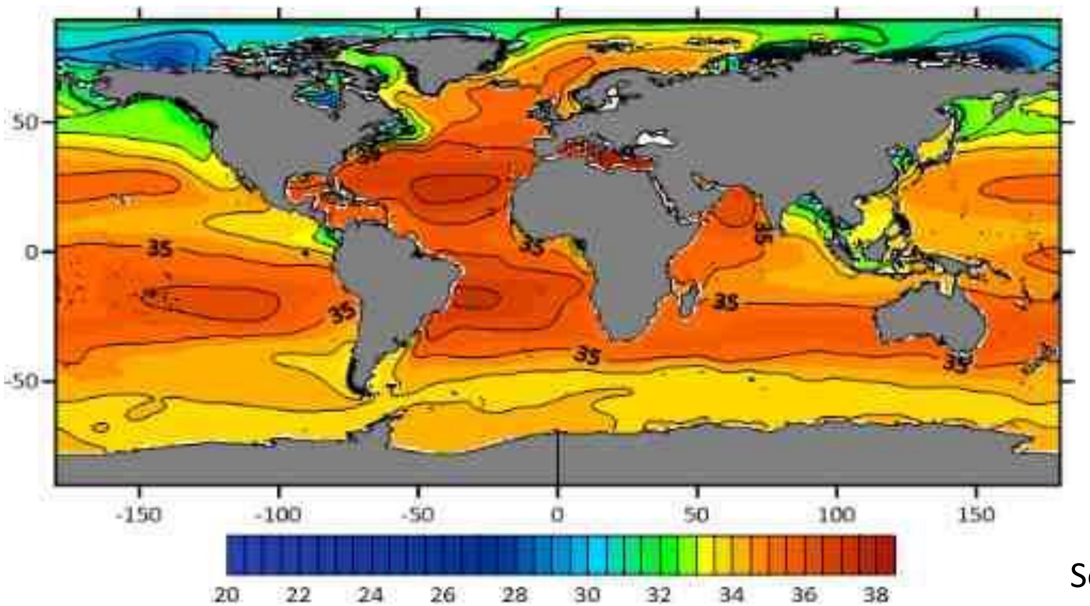
Principales Constituyentes (35 ppm)
por m^3 (aprox. 1026 Kg) de agua de mar

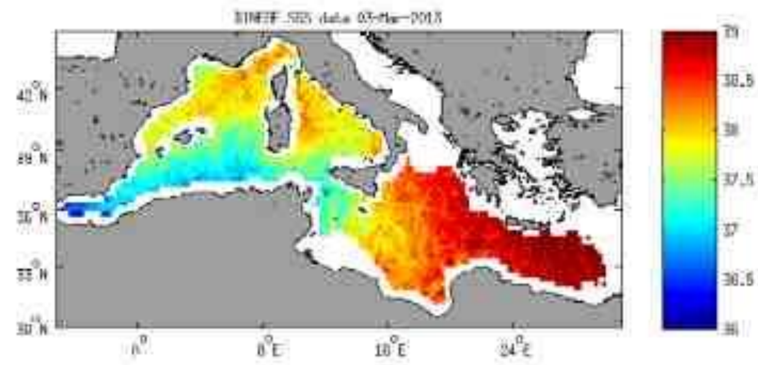
NaCl	28.014 Kg
$MgCl_2$	3.812
$MgSO_4$	1.752
$CaSO_4$	1.283
K_2SO_4	0.816
$CaCO_3$	0.122
Kbr	0.101
$SrSO_4$	0.028
H_2BO_3	0.028
Total	35.956

- Salinity changes the ocean density.
- In short time scales salinity changes due to evaporation, precipitaion and runoff. **Excellent indicator of changes in Earth's water cycle**
- Away from the sea surface salinity is a useful quasi-conservative watermass tracer.
- Changes in salinity produce changes in the electrical conductivity of seawater. Conductivity measurements lead to accurate measurements of ocean salinity

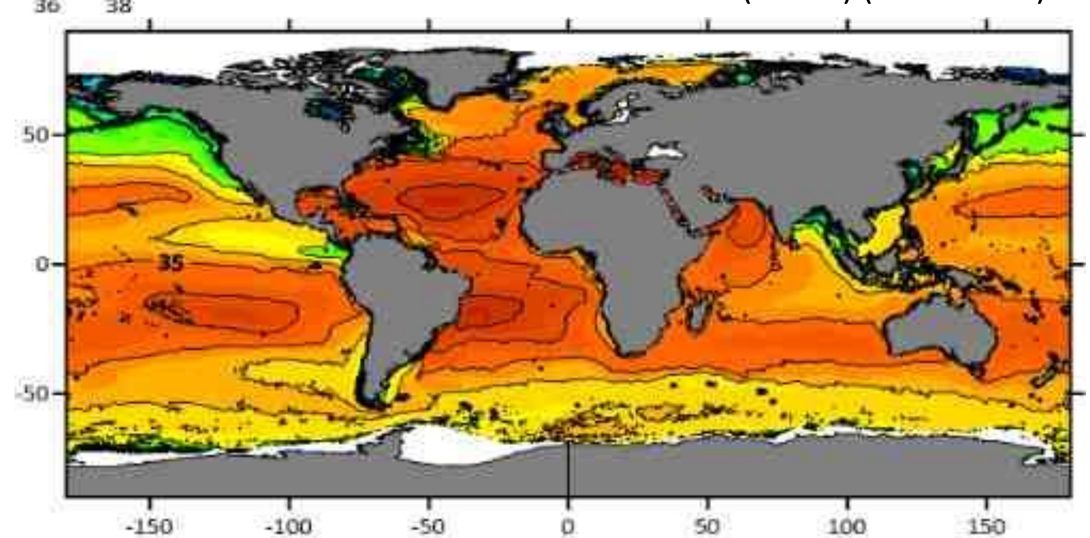
Surface salinity

NODC World Ocean Atlas 2013





Soil Moisture Active Passive (SMAP) (2015-2018)



You can build your own fields here: http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NODC/.WOA09/
and here: https://podaac-tools.jpl.nasa.gov/las/

Density of seawater is a function of its pressure, temperature and salinity $\rho = \rho\,(p, T, S)$

Changes in relative volume are associated with changes in p, T, S through the **compressibility, thermal expansion and haline contraction coefficients**

Compressibility

$$\kappa\, \Delta p = -\Delta V/V$$

$$\kappa = \kappa\,(p, T, S)$$

Thermal expansion

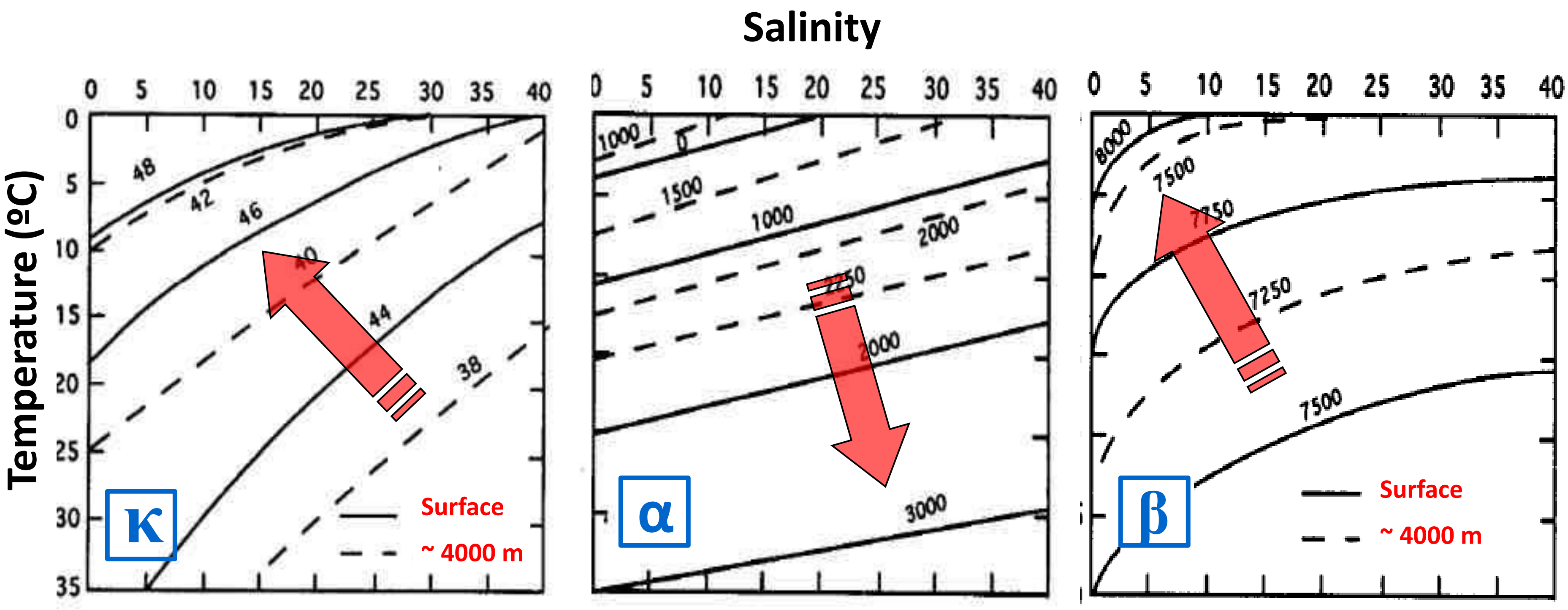
$$\alpha\, \Delta T = \Delta V/V$$

$$\alpha = \alpha\,(p, T, S)$$

Haline contraction

$$\beta\, \Delta S = -\Delta V/V$$

$$\beta = \beta\,(p, T, S)$$

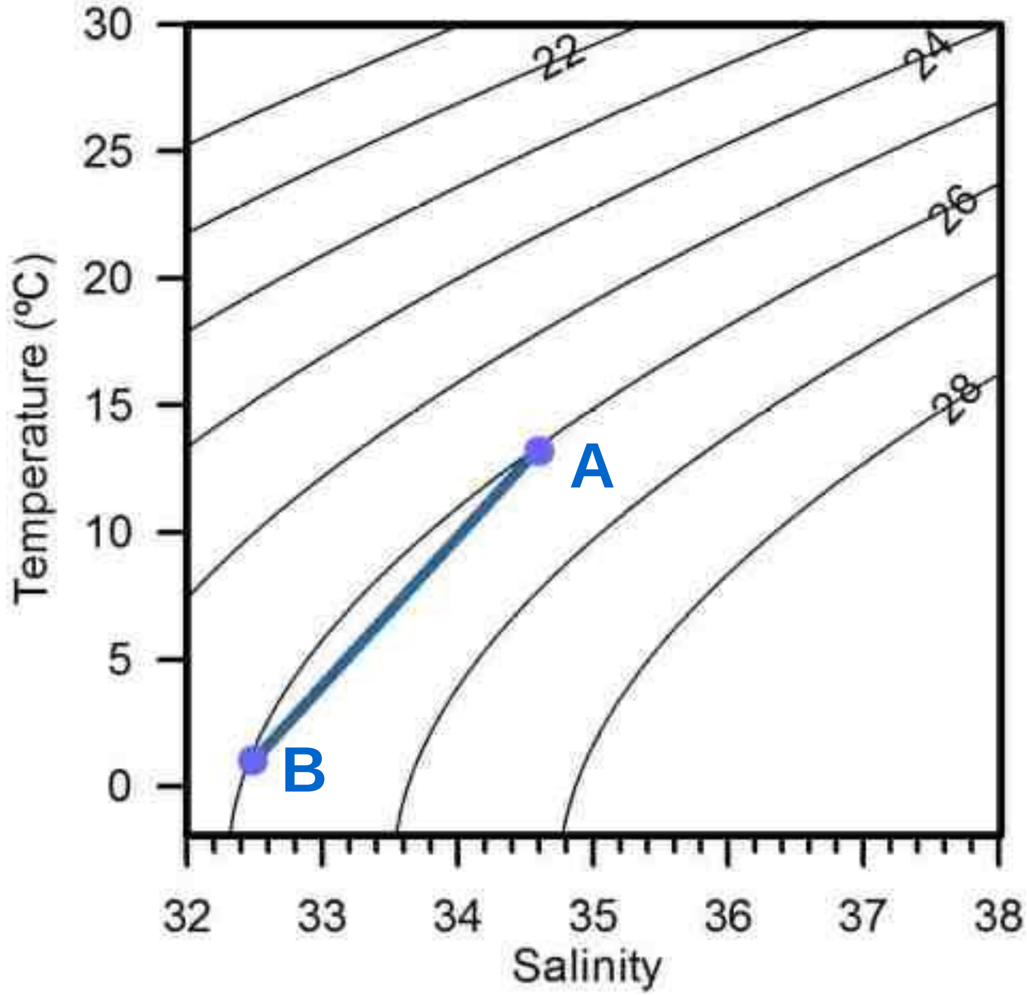


Changes of **compressibility** (**κ**, 10^{-4} kg/m^3/dbar), **thermal expansion** (**α**, 10^{-4} kg/m^3/ºC) and **haline contraction** (**β**, 10^{-4}kg/m^3/psu) as a function of T and S at the sea surface and at 4000 m.

thermal expansion also decreases for low salinity but increases with temperature

The non-linearity of the equation of state of sea water gives rise to several important phenomena:

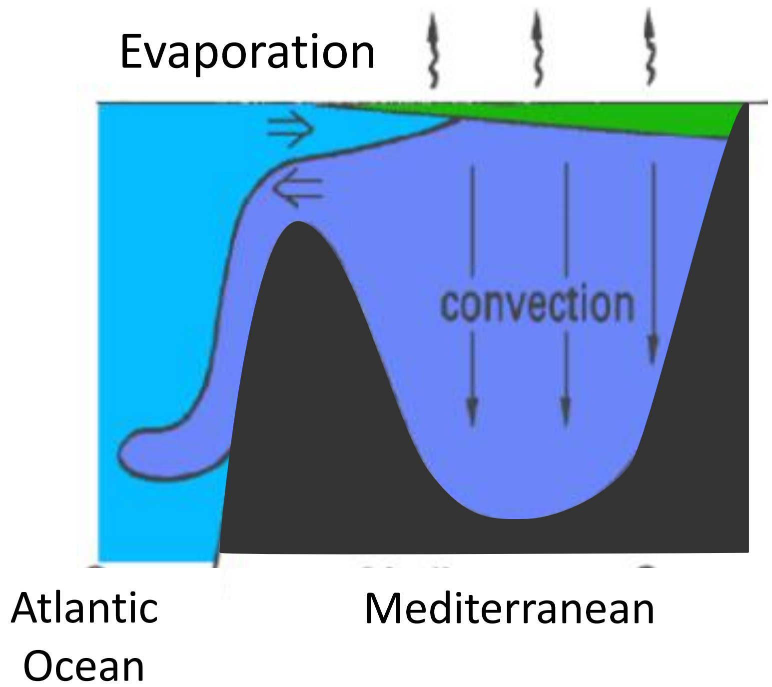
1) At low temperature the effect of salinity changes over density is relatively more important than the temperature changes
2) At low temperature seawater is more compressible than warm water (*thermobaricity*)
3) Mixtures of two waters with different temperature and salinity but the same density is denser than the original waters (*cabbeling*)



Nonlinearity: Cabbeling

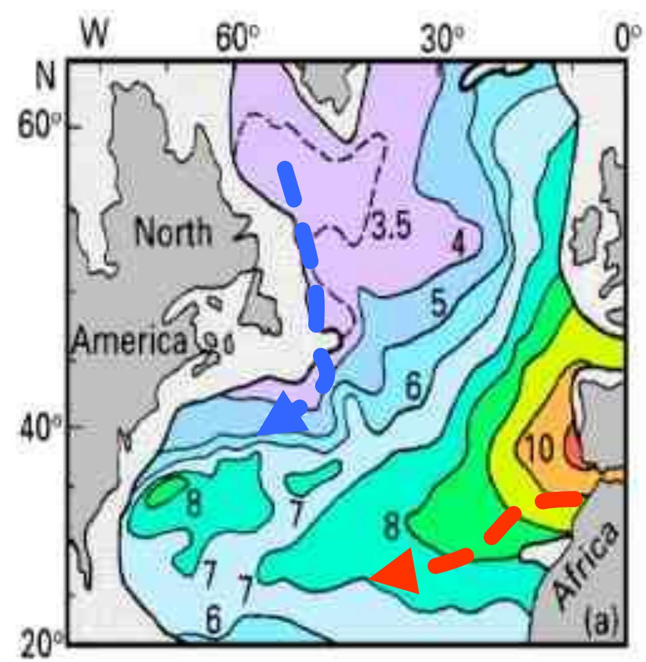
The density σ at the sea surface (0 dbar) plotted as a function of T and S. Note the change in the slope of isopycnals, The gray dots represents two water types of equal density (ρ = 1026 kg/m^3, σ = 26 kg/m^3). The segment is the T-S space of mixtures of A and B, which is denser than the original water masses.

The Mediterranean case



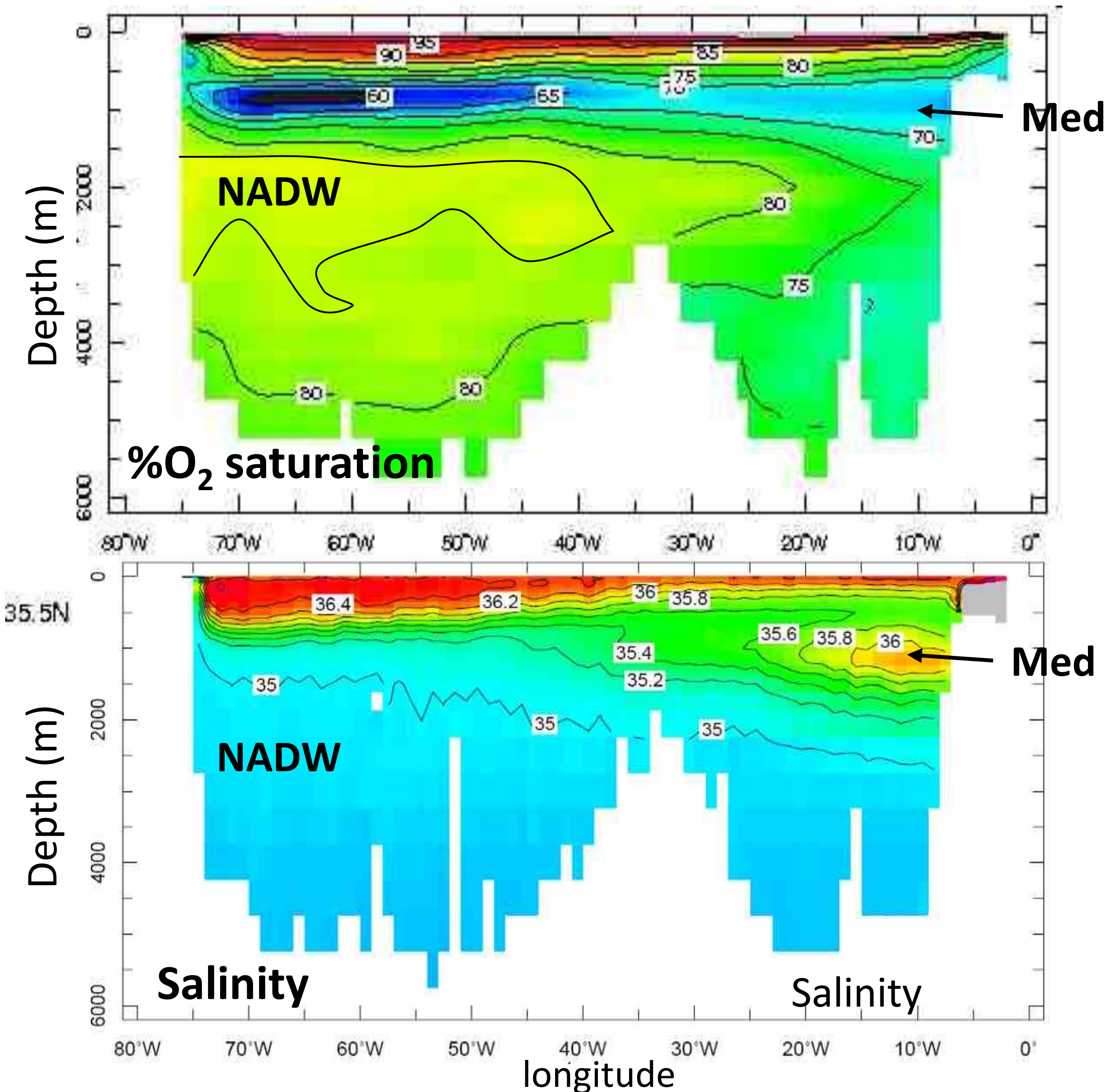
The warm-salty water flowing from the Med into the North Atlantic (red arrow) has density similar to the cold-fresh waters outflowing from the Northern Seas (blue arrow).

T and S distributions at 1000 m in the North Atlantic



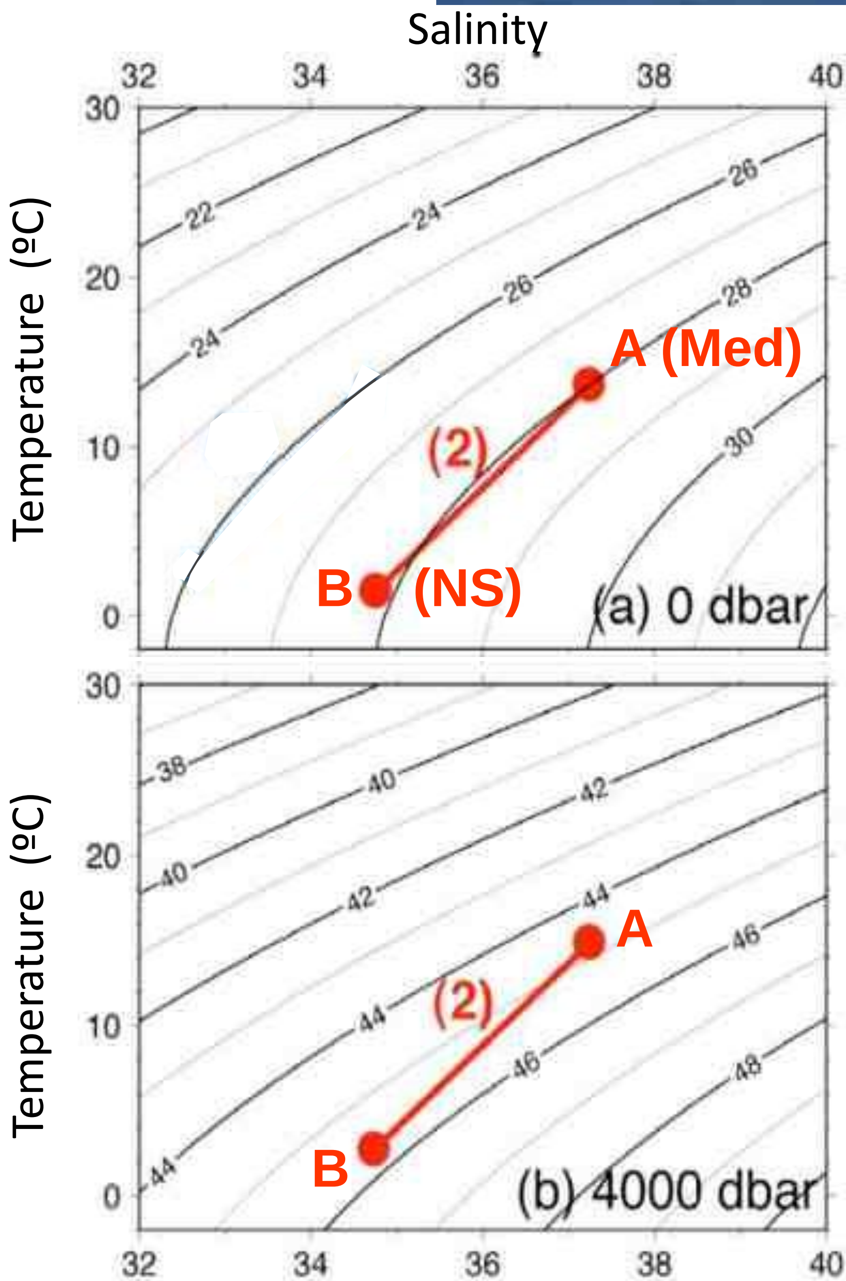
The Mediterranean case

Why do Med waters sink to about 1000 m while the NADW, its Northern Seas counterpart sinks further deep?



%O_2 saturation and salinity section across the N. Atlantic at 35ºN

Temperature vs. Salinity



Nonlinearity

The density σ at the sea surface (0 dbar) (a) and at 4000 dbar (b) as a function of T and S. Note the change in the slope of isopycnals,

Colder and fresher water is more compressible

The red pair (2) in both panels illustrates the comparison of warm-salty water (A) with cold-fresh water (B). If these waters move from the surface (a) to 4000 dbars (b) the warmer water (A), which was denser than B near the surface becomes lighter at 4000 dbars

Adapted from Talley et al., 2011, Descriptive Physical Oceanography, 6th Edition, Academic Press / Elsevier

New Thermodynamics and Equation of State of Seawater

In 2010 several International bodies such as IOC, IAPSO and SCOR **jointly adopted a new standard for the calculation of the thermodynamic properties of seawater**. This new standard, called **TEOS-10**, supersedes the **old** EOS80 standard which has been in place for 30 years, and should henceforth be **the primary means by which the properties of seawater are estimated.**

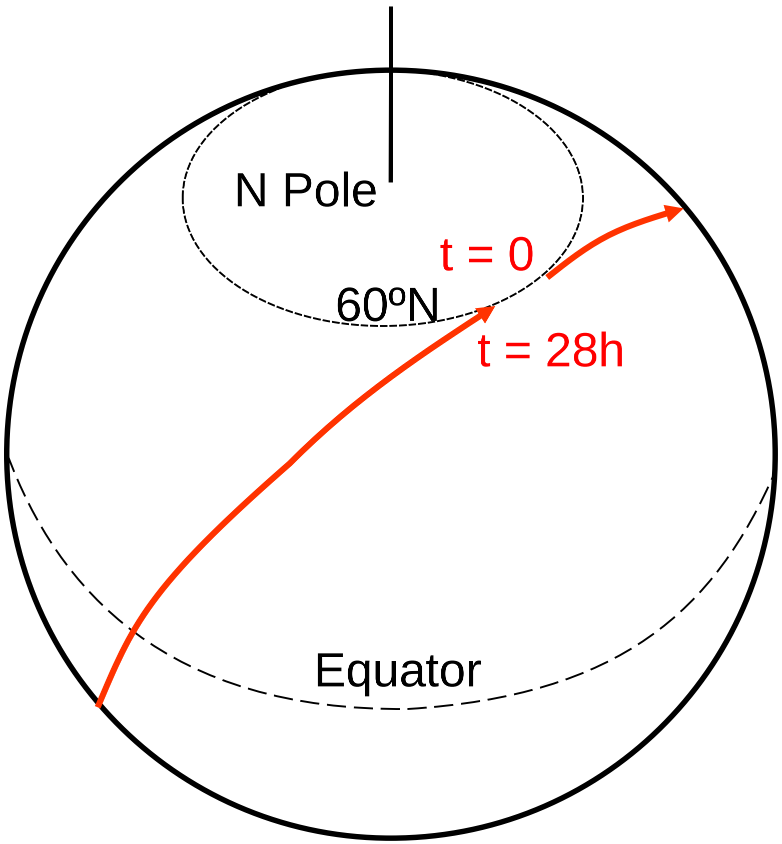
TEOS-10 has constructed a Gibbs function of seawater, from which its **density, sound speed, specific heat capacity, specific enthalpy and specific entropy** can be calculated.

S_P (Practical Salinity)	what we measure with a salinometer, until now was used to determine derived properties, such as density
S_R (Reference Salinity)	mass fraction of solute in Standard Sea Water
S_A (Absolute Salinity)	mass fraction of solute in the sample,

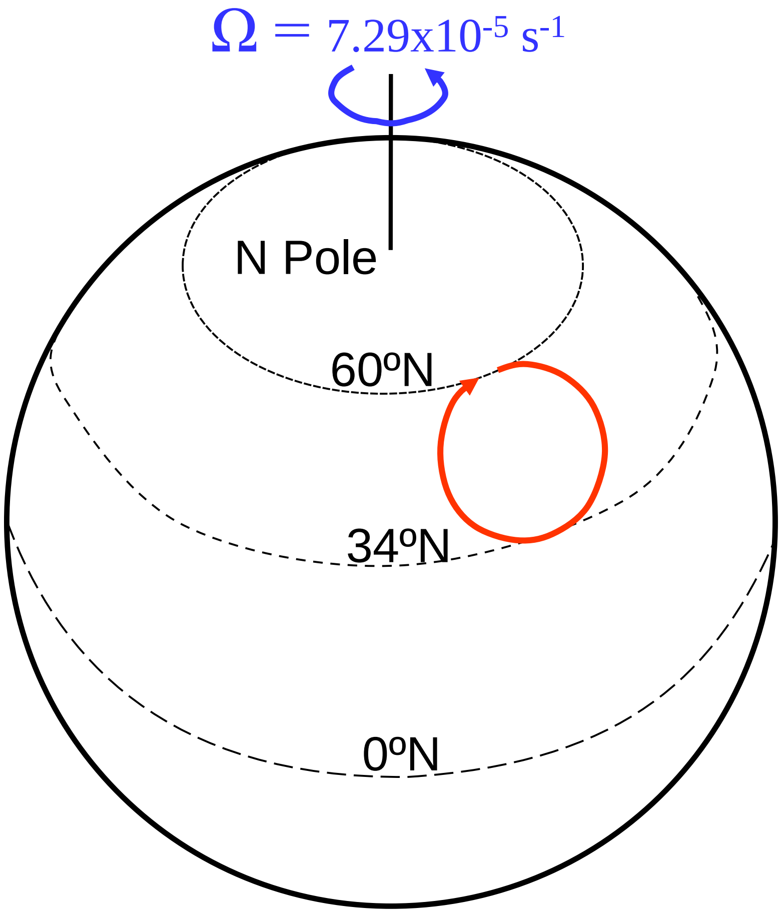
Oceanographers don´t panic **BUT** visit http://www.teos-10.org/ (asap)

Effects of rotation

Coriolis force



Object thrown over sphere at 1389 km/h



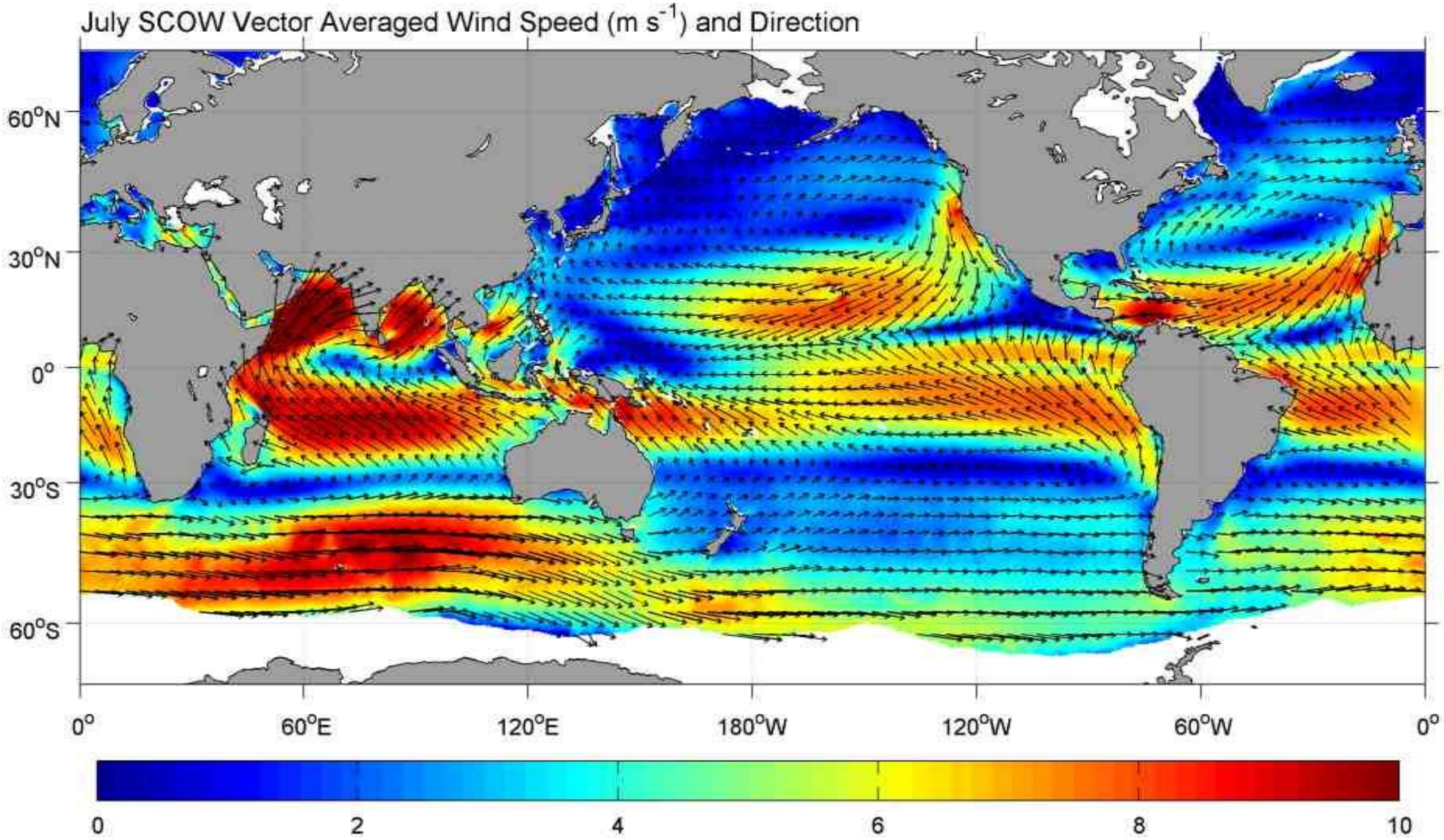
Object thrown over sphere rotating at 1 revolution per day at 1389 km/h (relative velocity = 556 km/h)

Coriolis, 1835, *J. Ec. Polytech.*
Available at http://empslocal.ex.ac.uk/people/staff/gv219/classics.d/index.html
However, also take a look at http://bibliotecadigital.ilce.edu.mx/sites/ciencia/volumen3/ciencia3/128/htm/increhis.htm (in Spanish)

Drains, tornados and other popular myths

(B. Simpson, *Bart vs. Australia*, 1995)

Even Bart can be right, sometimes (though most likely for the wrong reasons).
Before you jump to conclusions check the Rossby Number: the ratio of the inertial to the Coriolis terms in the momentum balance ***Ro = U/L f***. If the Earth rotation plays a role Ro << 1.



Lets now move forward to consider the issue of ocean circulation forcing

trades and **westerlies** as well as regions of increased wind speed

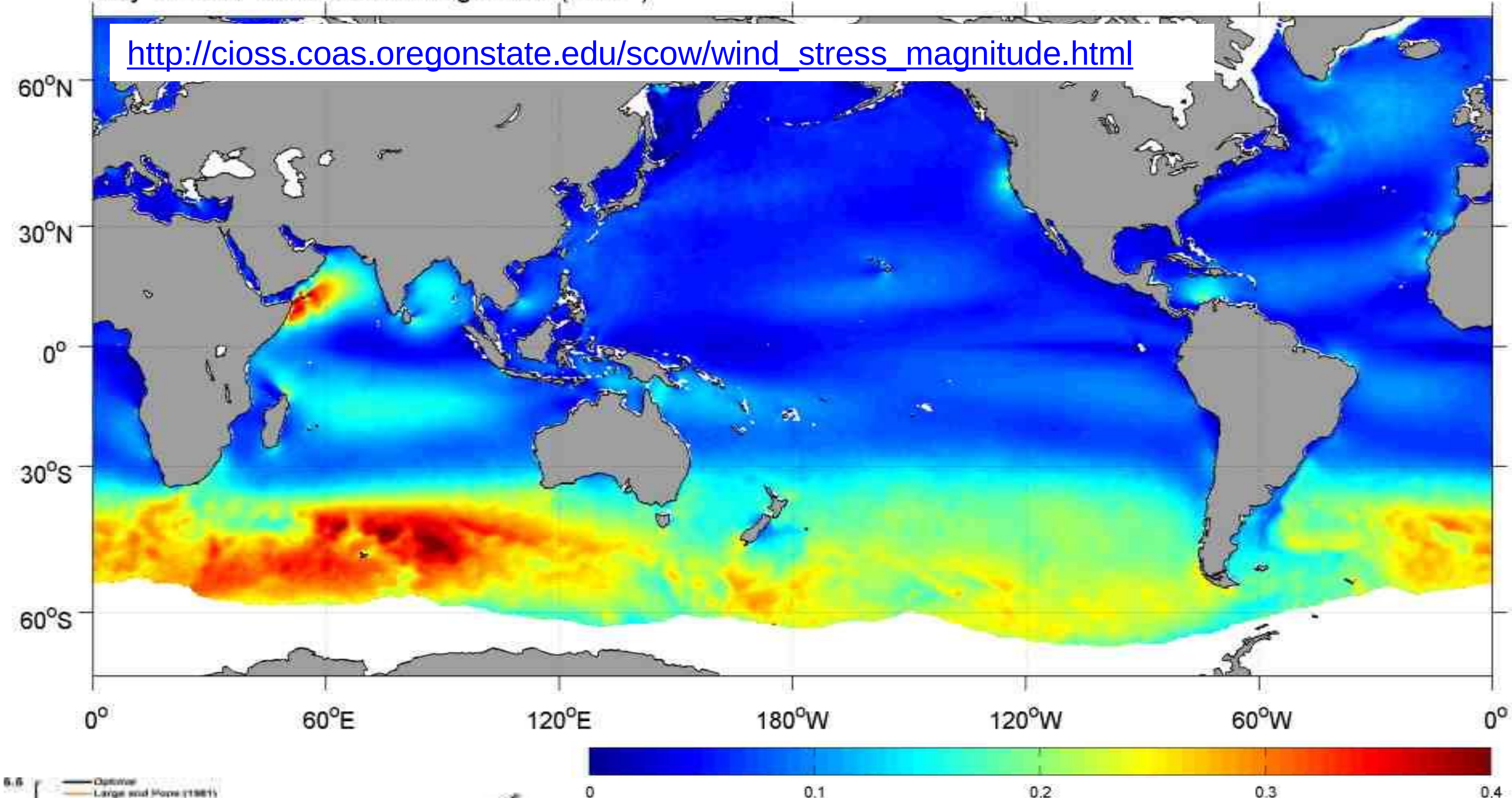
Quicscat scatterometer

Satellite derived wind speed (m s^{-1}) from SCOW climatology – July (Risien and Chelton, *J.Phys.Oceanogr*., 2008).
You can browse maps and download data at http://cioss.coas.oregonstate.edu/scow/index.html

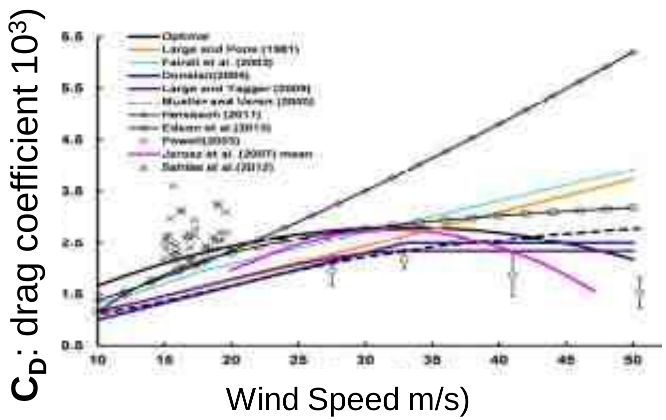
Wind stress

July SCOW Wind Stress Magnitude (N m^{-2})

Risien & Chelton, *J Phys Oce*, 2008

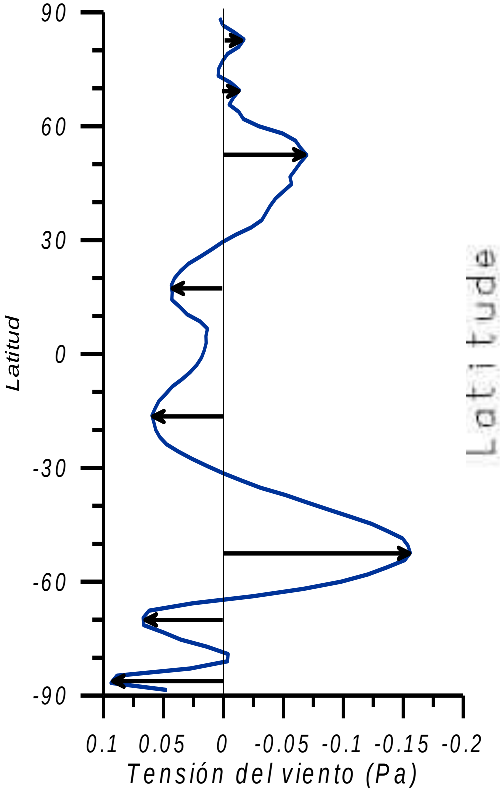


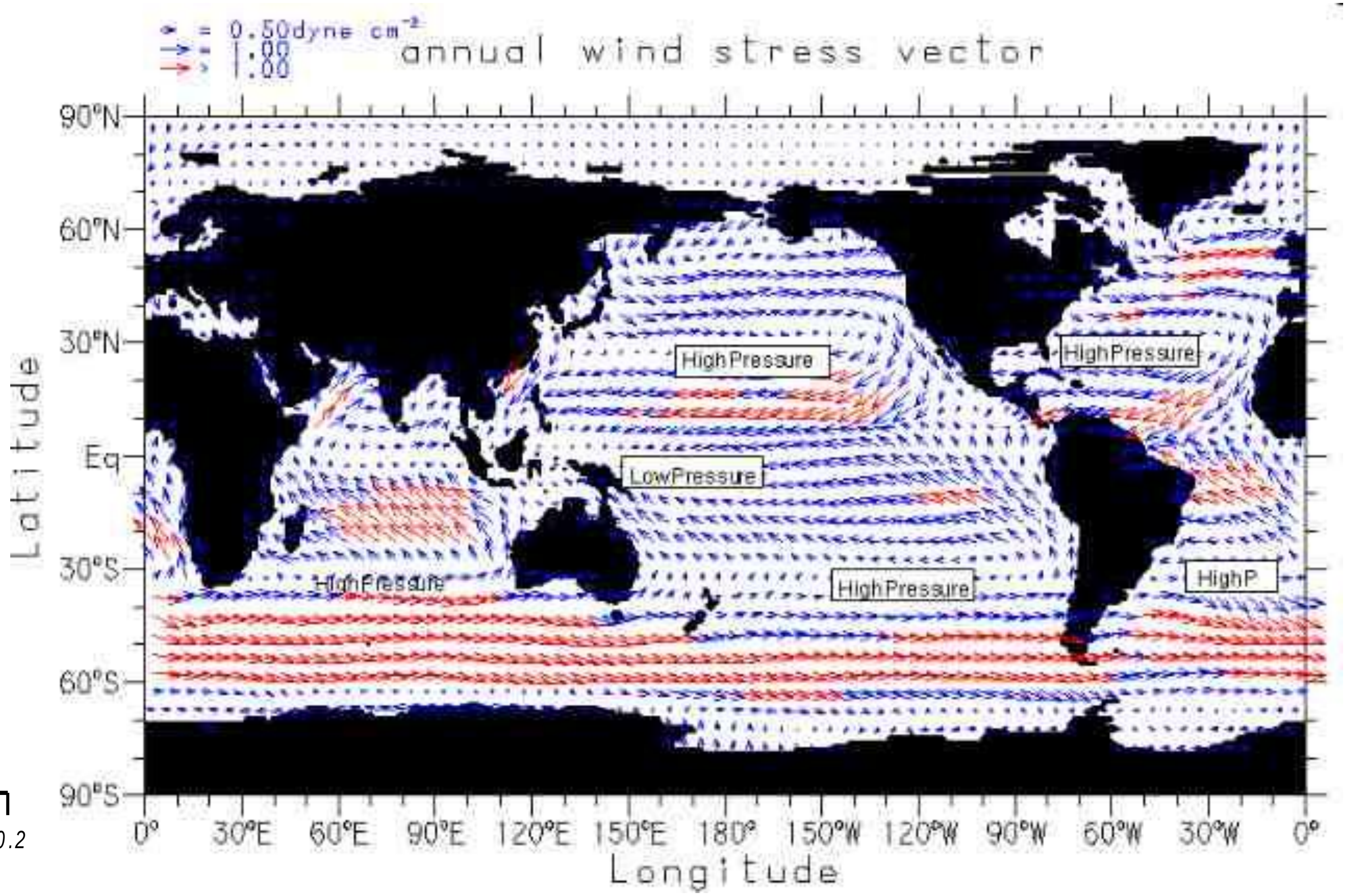
$$\tau = \rho_a C_D U^2_{10}$$



Peng & Li, *Sci Rep*, 2015

Surface wind stress

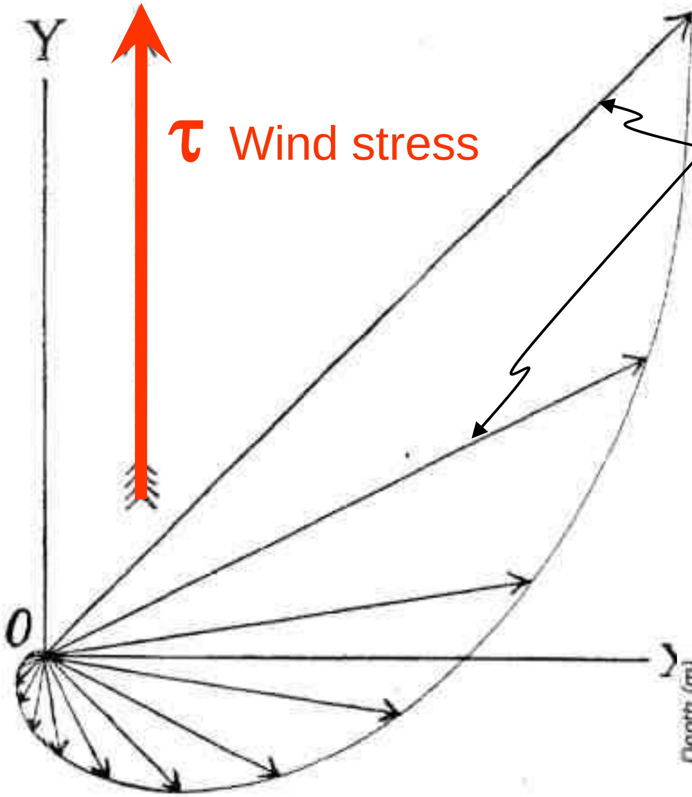




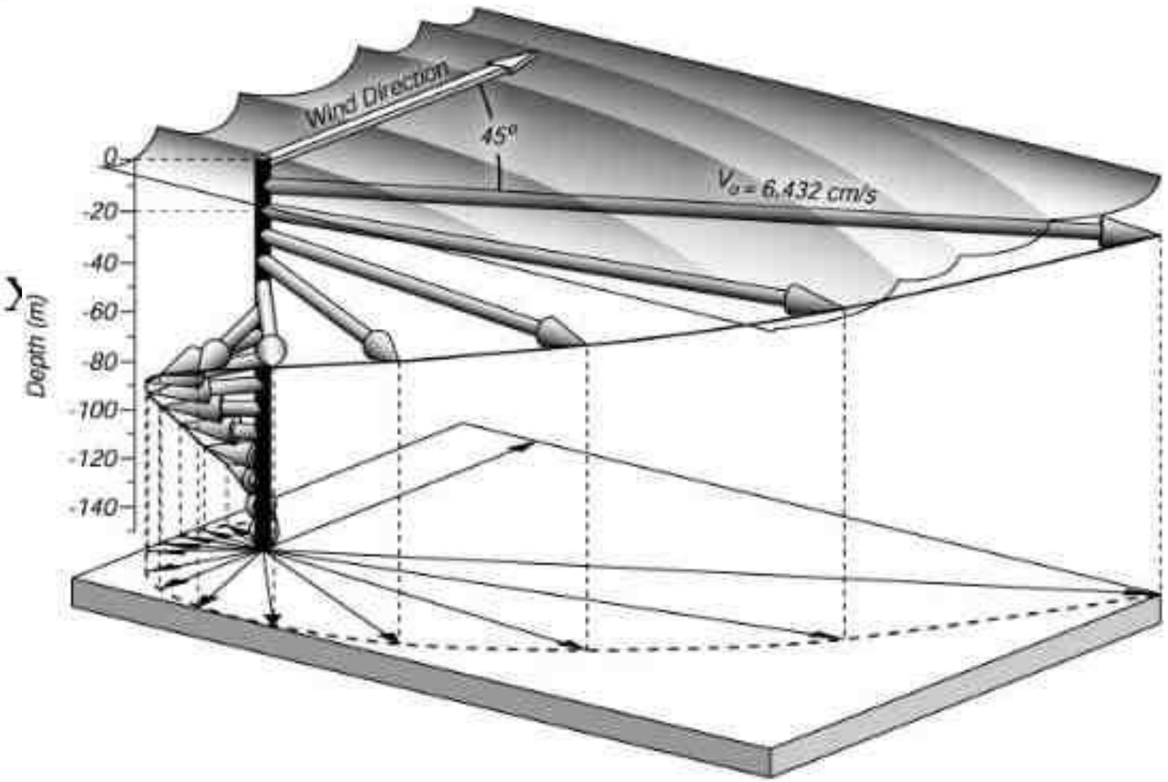
From D. Reed SJSU Oceanography course, reproduced from M. Tomczak

Ekman layers:

The balance between vertical turbulent mixing and the Coriolis force



Current velocity vectors plotted at increasing depths

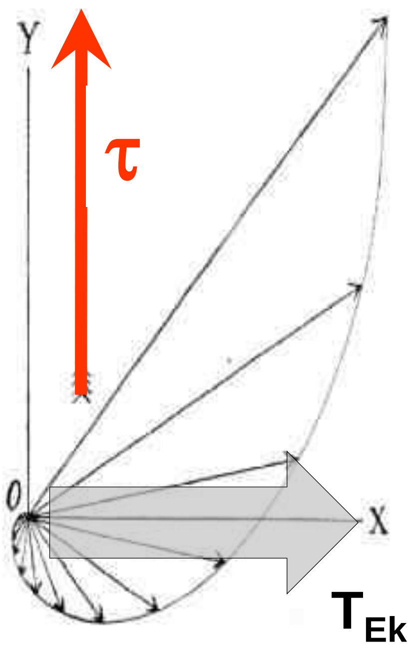


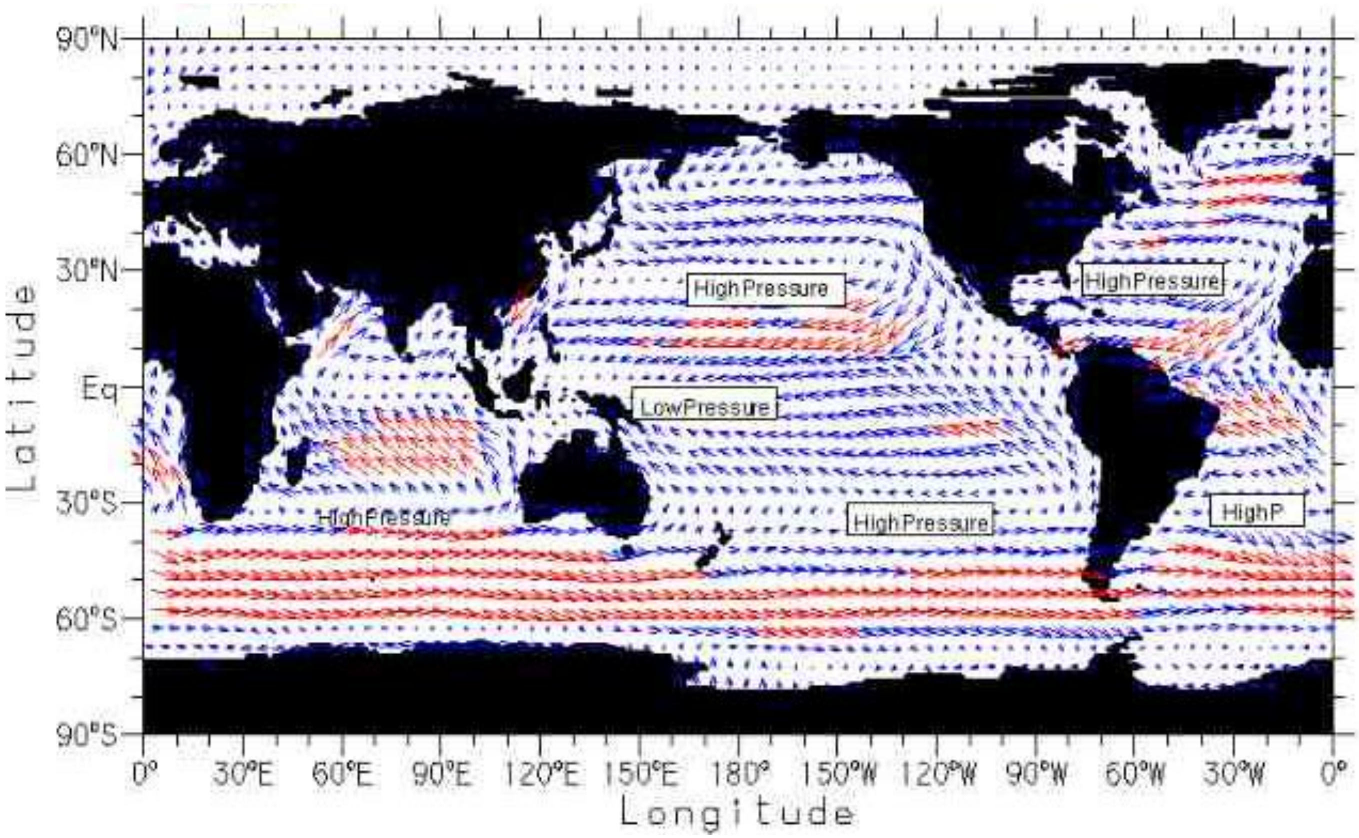
Ekman, *Ark. Mat. Astron. Fys., 2 (11), 1-52,* 1905.
Available at http://www.aos.princeton.edu/WWWPUBLIC/gkv/history/Ekman05.pdf

Ekman transport

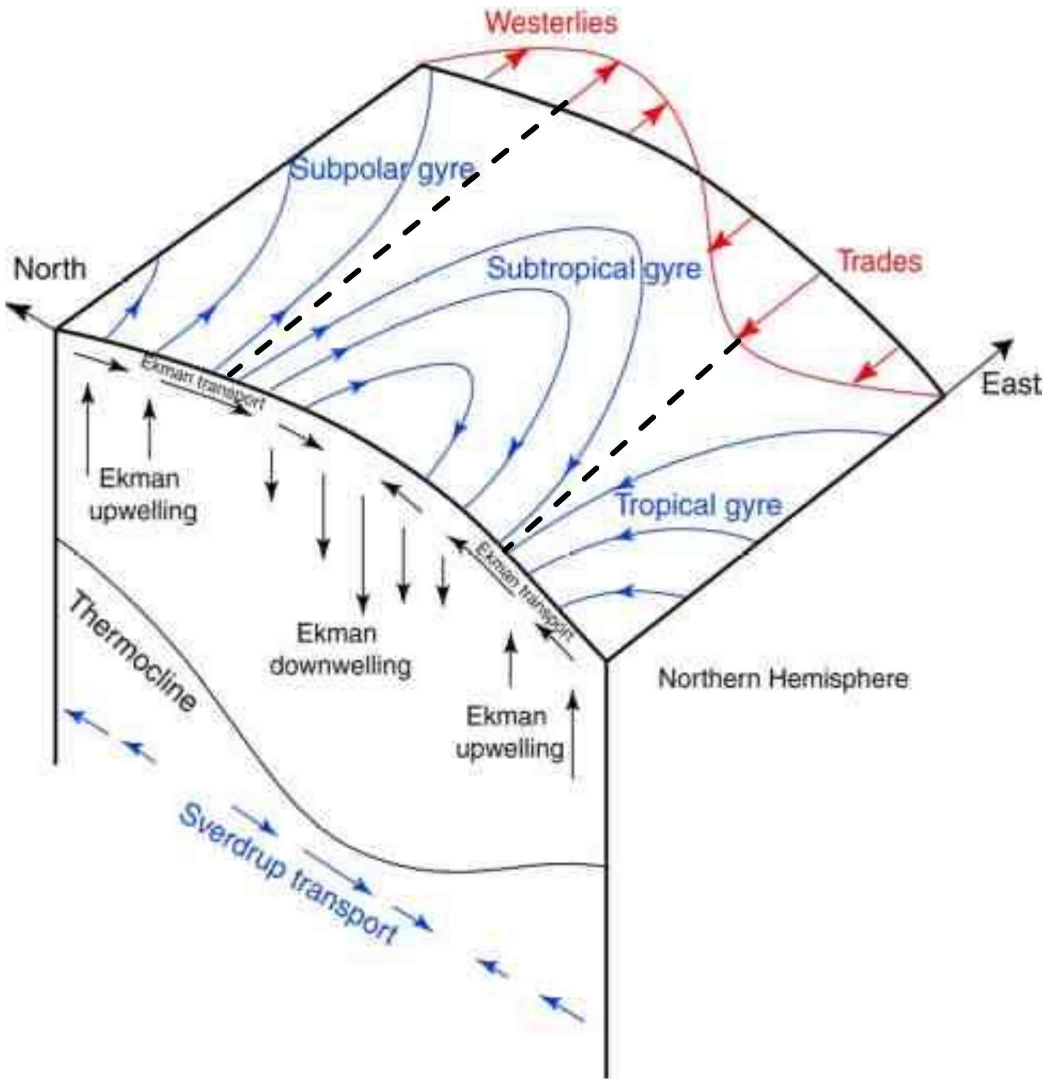
The vertical integral of the velocity vector (the Ekman transport, $\boldsymbol{T_{Ek}}$) is perpendicular to the wind direction.

Opposing wind directions create regions of mass convergence and divergence in the Ekman layer, which are compensated by vertical motions.





A linear wind induced circulation



Sverdrup balance circulation (Northern Hemisphere). Westerly and trade winds force Ekman transport, creating Ekman pumping and suction and hence Sverdrup transport.

$$\beta V = \nabla \times \tau / \rho$$

The meridional transport (V) can be determined from the curl of the wind stress

Adapted from Talley et al., 2011, Descriptive Physical Oceanography, 6th Edition, Academic Press / Elsevier

Realistic winds

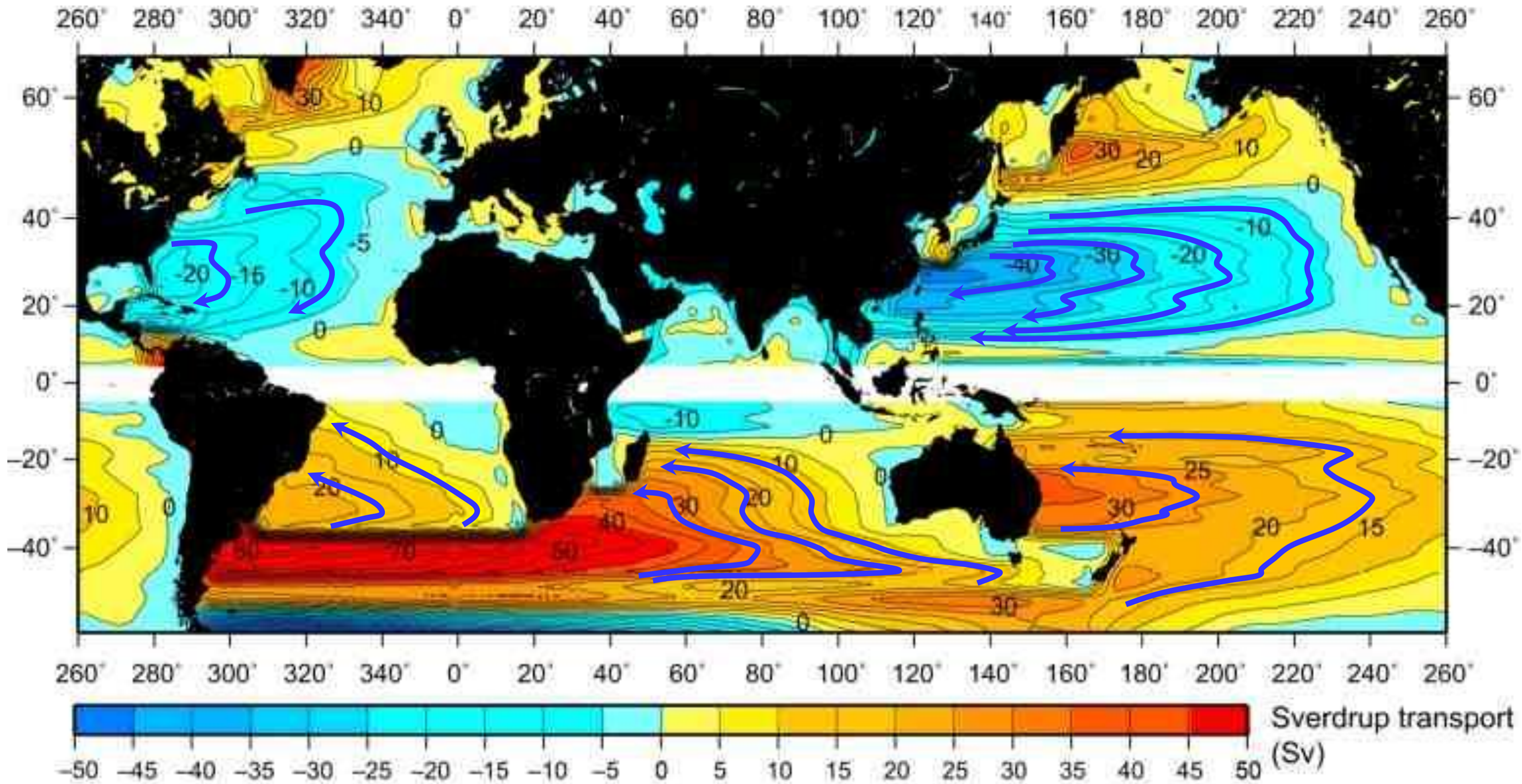


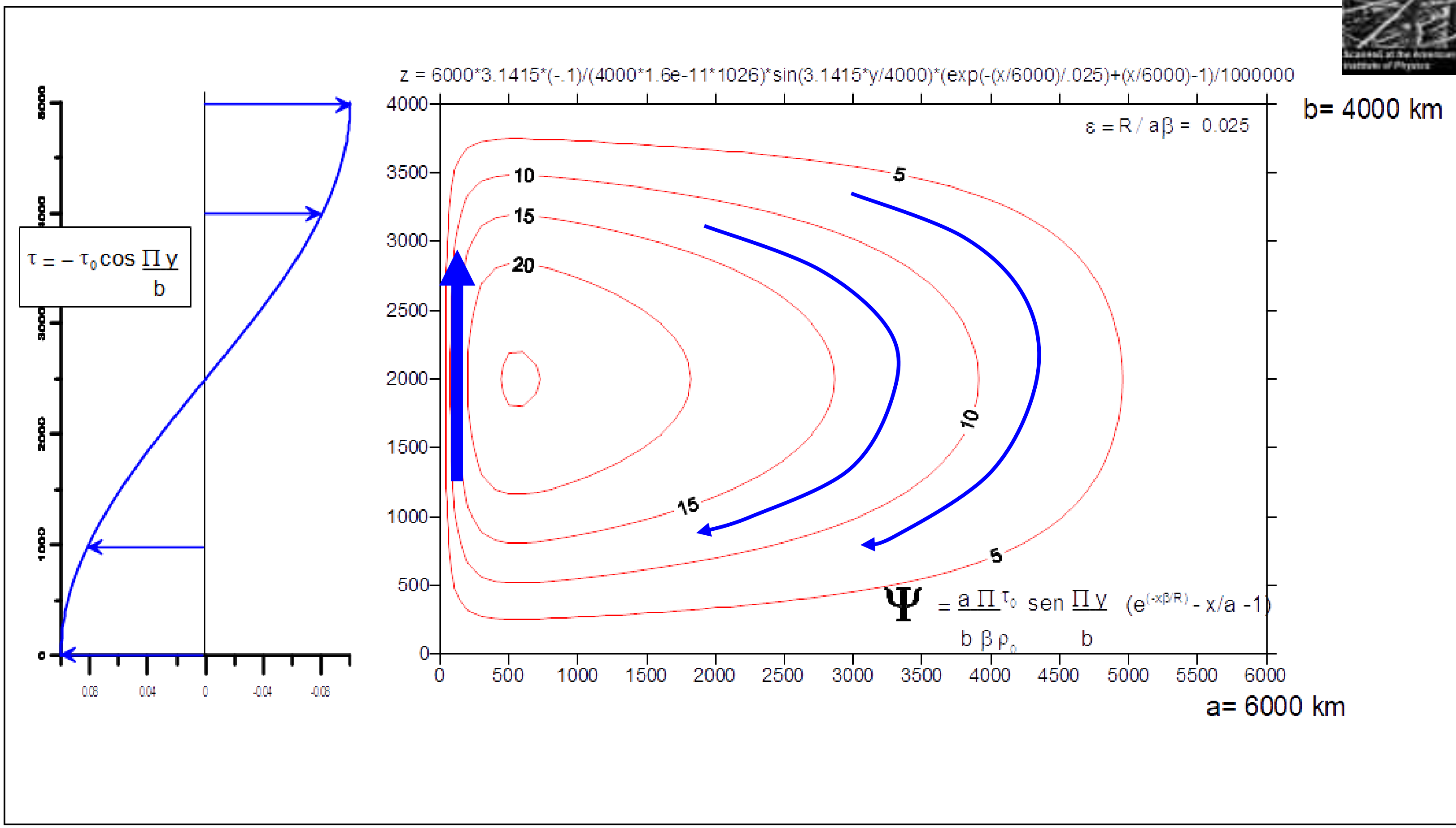
FIGURE 5.17

Sverdrup transport (Sv), where negative (blue) is clockwise and positive (red) is counterclockwise circulation. Wind stress data are from the NCEP reanalysis 1968–1996 (Kalnay et al., 1996).

Adapted from Talley et al., 2011, Descriptive Physical Oceanography, 6th Edition, Academic Press / Elsevier

Stommel solution for a rotating Earth "β plane"

Beta plane takes into account the variation of f with latitude, this affect currents
Earth rotation forces western intensification to balance angular momentum



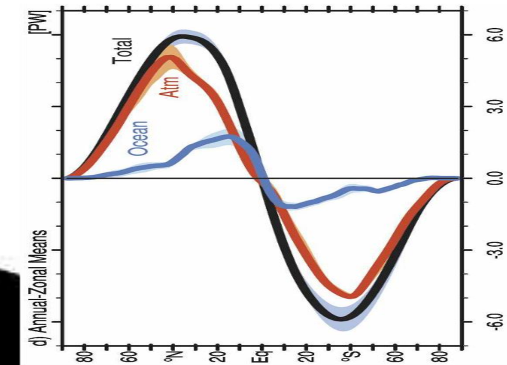
Example Kuroshio vs. California, 5knots vs. 1 knot, transport 6 to 1, zonal scale ¼ to 1

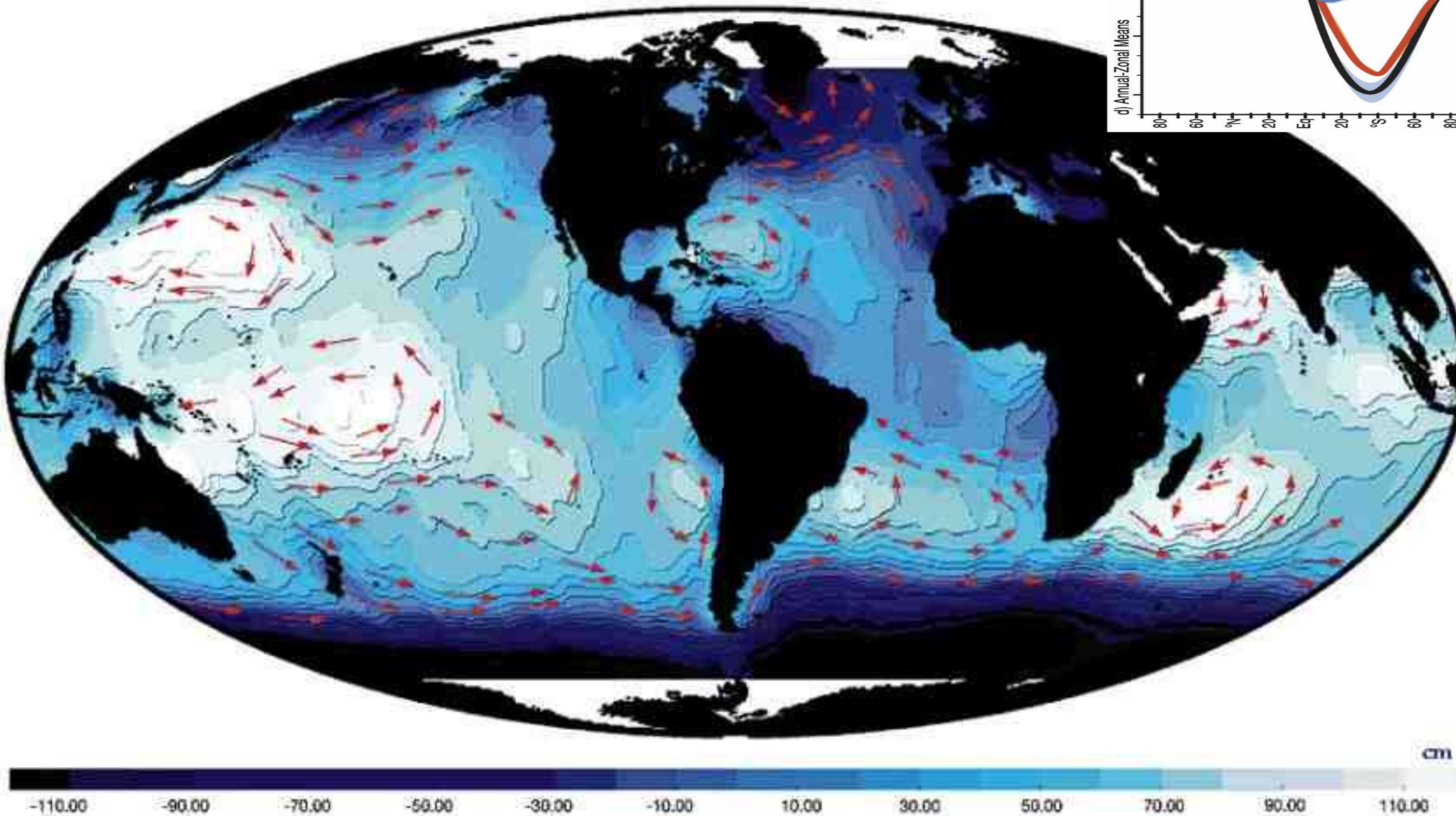
-

LARGE SCALE CIRCULATION DOMINATED BY GREAT ANTICYCLONIC GYRES

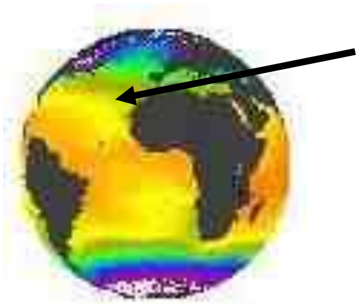
Ocean topography

GYRES. Transfer HEAT from the Equator to the poles





Temperature observations in the deep ocean



HMS Earl of Halifax, 1751

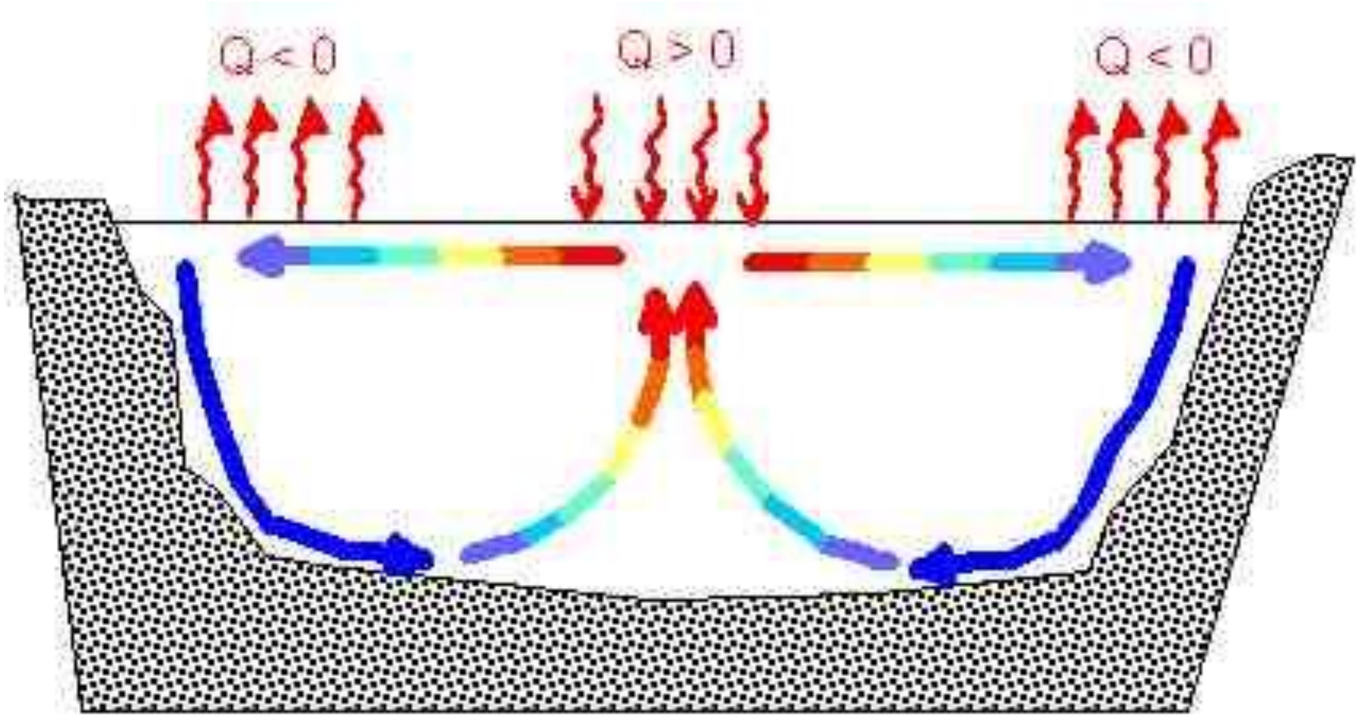
Observations from Captain Ellis:
28.9°C at the surface and 11.7°C at 1630 m depth

"*The experiment, which seem'd at first but mere food for curiosity, became in the interim very useful to us. By its means we supplied our cold bath, and cooled our wines or water at pleasure; which is vastly agreeable to us in this burning climate*"

"*It appears to me to be extremely difficult, if not quite impossible, to account for this degree of cold at the bottom of the sea in the torrid zone, on any other supposition than that of <u>cold currents from the poles</u>*."

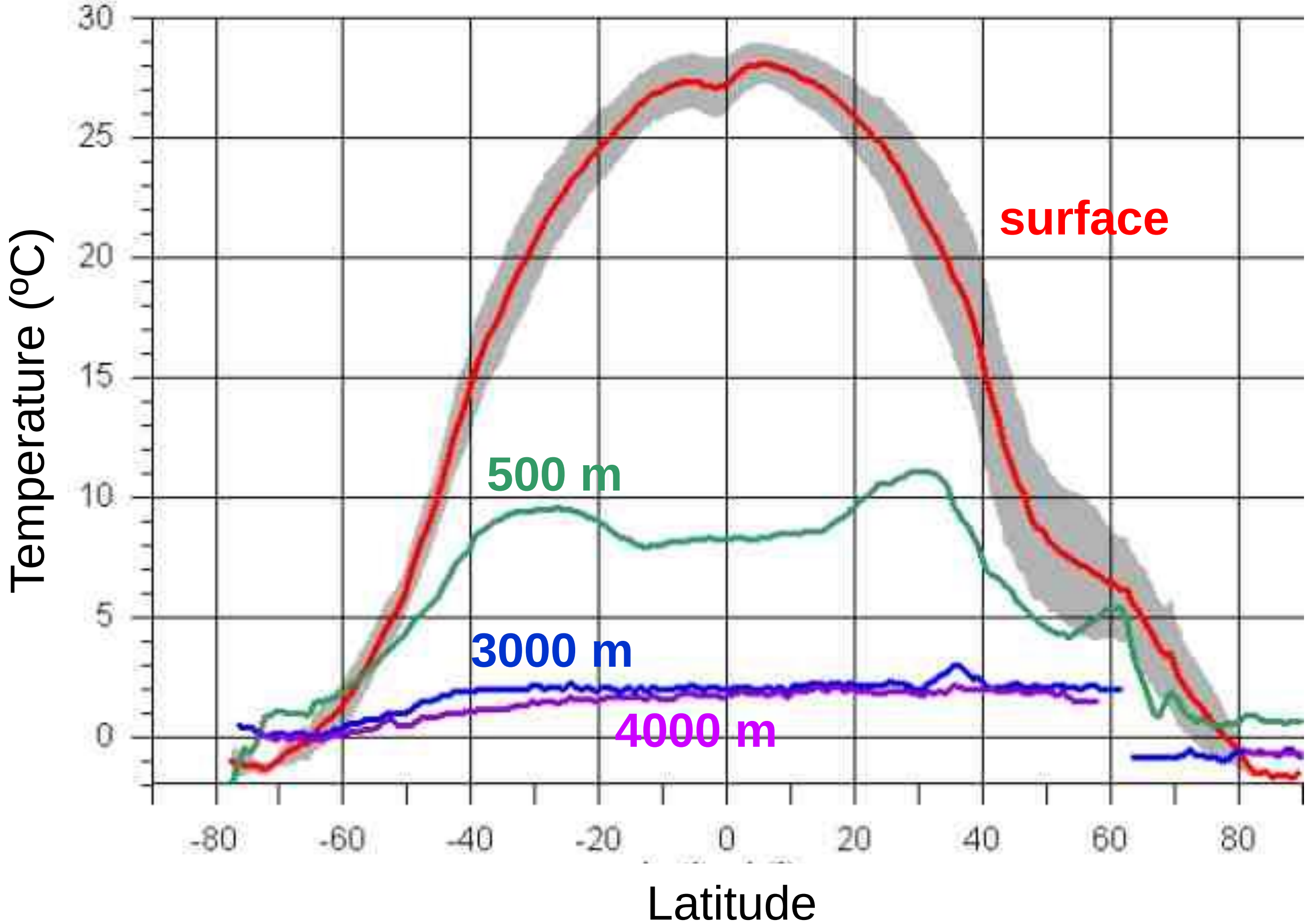
Count Rumford (Benjamin Thompson, 1753-1814), 1800

Efectos del calentamiento y enfriamiento superficial

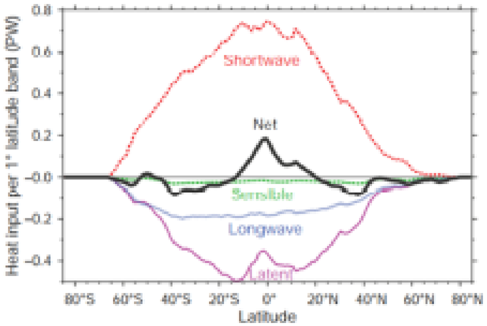


Flujos de calor mar-atmósfera (Modelo de Rumford)

Meridional and vertical temperature structure

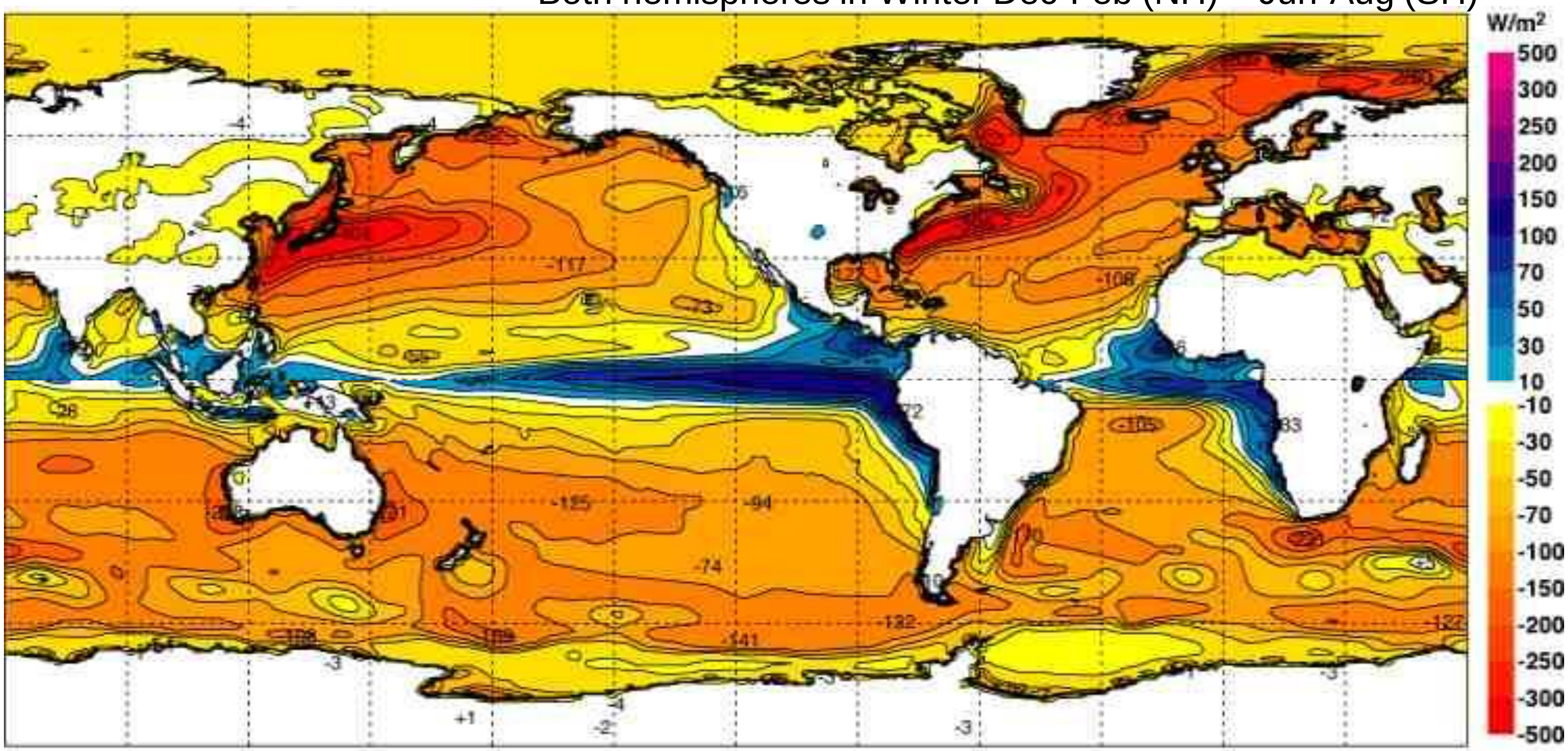


Data from World Ocean Atlas 2009 http://www.nodc.noaa.gov/OC5/WOA09/pr_woa09.html



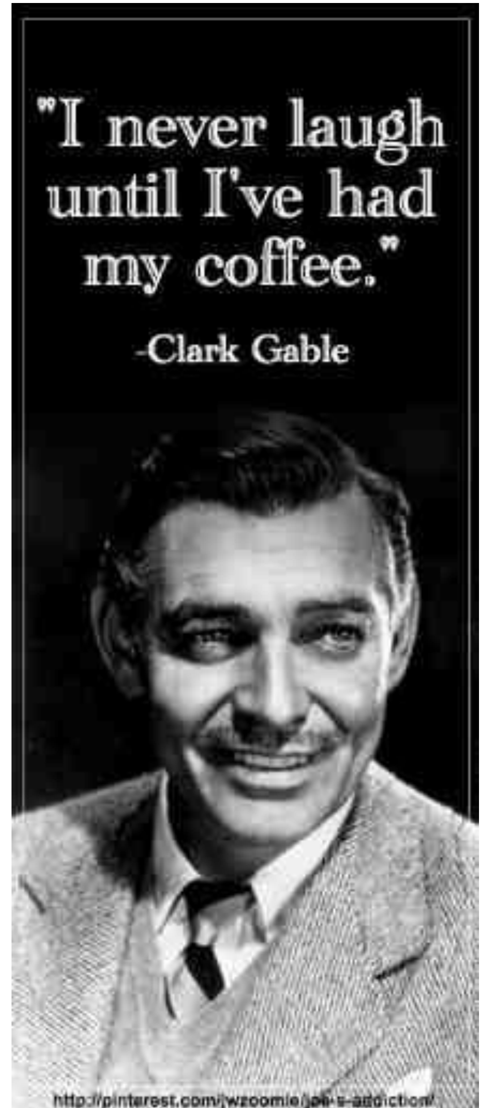
Net winter heat flux through the sea surface (W/m^2)

Both hemispheres in Winter Dec-Feb (NH) – Jun-Aug (SH)



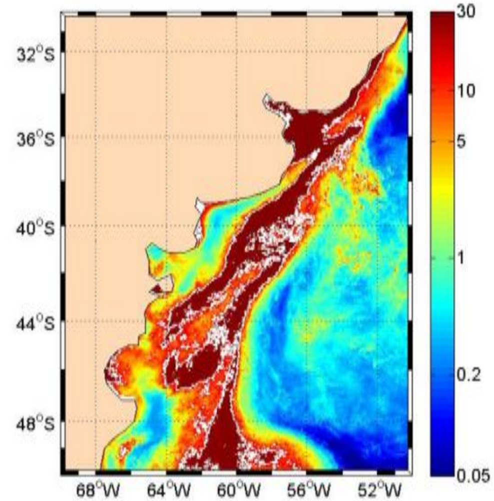
ECMWF : ERA-40 Atlas http://www.ecmwf.int/research/era/ERA-40_Atlas/

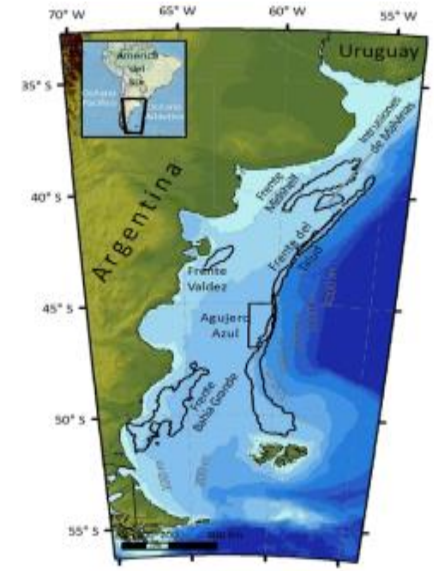

coffee break


"I never laugh until I've had my coffee."
-Clark Gable
http://pinterest.com/jwzoomie/joe-s-addiction/

POLÍGONOS E INDICADORES
como herramientas de comparación
entre zonas altamente productivas

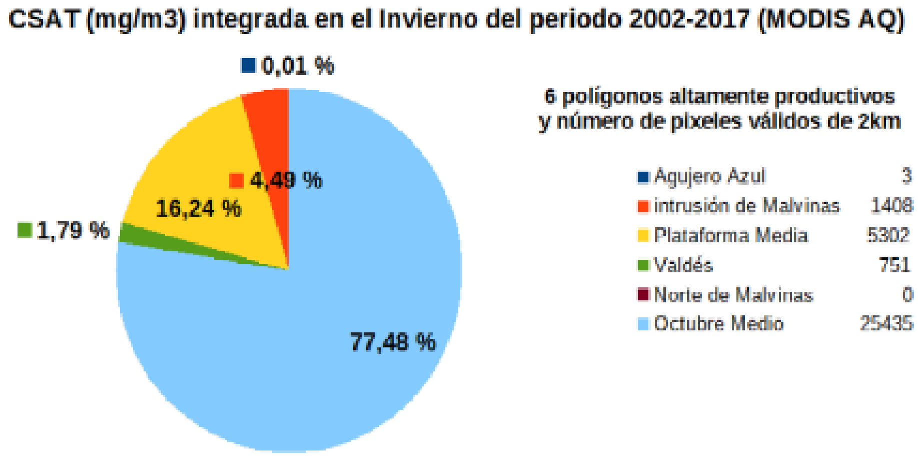
MODIS AQ 5D 2002-2017
Dominio hasta 50 S
Sin FBG y Talud
Con OM, IM y NM

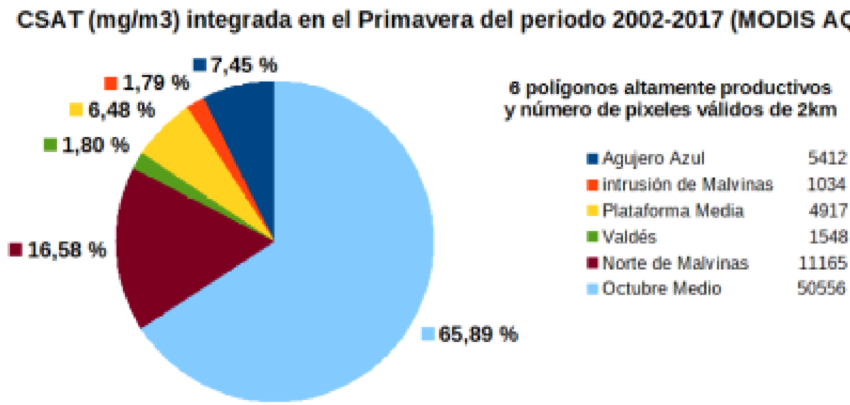


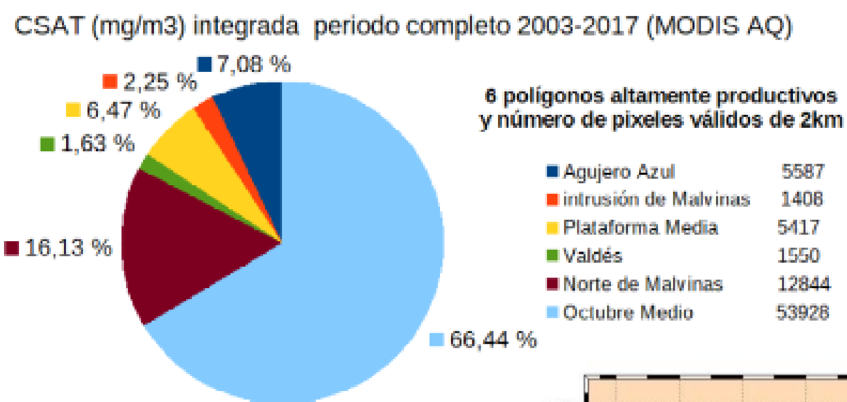


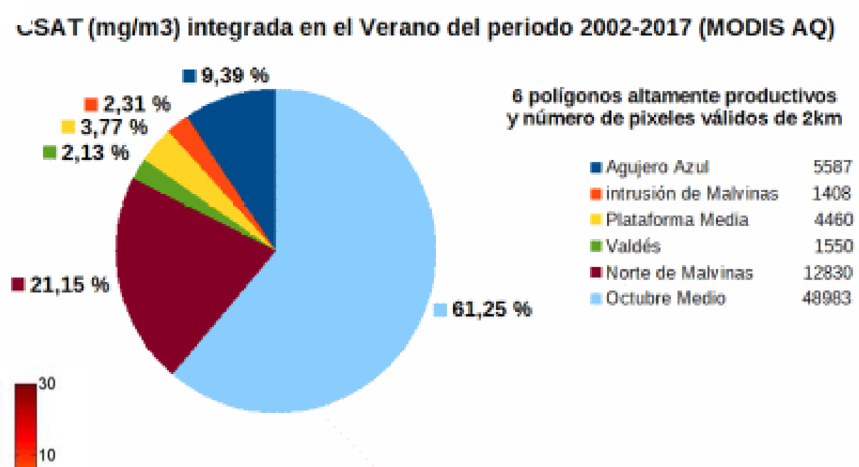
Media de Clorofila y desvío estándar					
Región:	Completo	Otoño	Invierno	Primavera	Verano
Agujero Azul	2,12(0.06)	0,95 (0,05)	0,49 (0,05)	4,24 (0,28)	2,76 (0,15)
intrusión de Malvinas	2,70 (0.20)	2,50 (0,34)	1,40 (0,10)	5,52 (0,37)	2,75 (0,48)
Plataforma Media	1,97 (0.17)	1,15 (0,08)	1,33 (0,22)	4,42 (0,89)	1,27 (0,19)
Valdés	1,74 (0.06)	1,08 (0,10)	1,01 (0,08)	3,61 (0,45)	2,20 (0,30)
Norte de Malvinas	1,96 (0.21)	0,86 (0,27)	0,35 (0,43)	4,57(0,54)	4,47 (0,36)
Octubre Medio	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

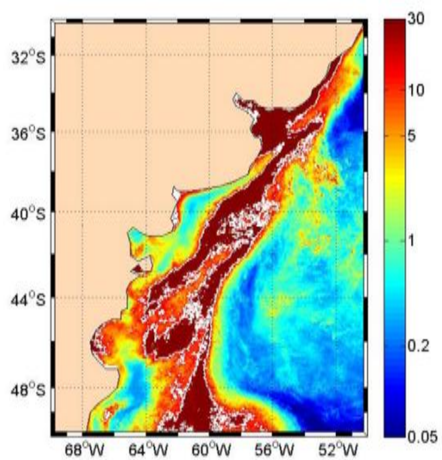
Sumatoria de Clorofila y número de datos válidos					
Región:	Completo	Otoño	Invierno	Primavera	Verano
Agujero Azul	11867 (5587)	1700 (1520)	3 (3)	22921 (5412)	15352 (5587)
intrusión de Malvinas	3766 (1408)	3417 (1408)	2015 (1408)	5504 (1034)	3782 (1408)
Plataforma Media	10847 (5417)	5264 (4433)	7296 (5302)	19950 (4917)	6156 (4460)
Valdés	2723 (1550)	1146 (982)	803 (751)	5546 (1548)	3487 (1550)
Norte de Malvinas	27034 (12844)	1483 (1238)	0 (0)	51015 (11165)	34570 (12830)
Octubre Medio	111320 (53928)	5214 (36423)	34810 (25435)	202740 (50556)	100140 (48983)









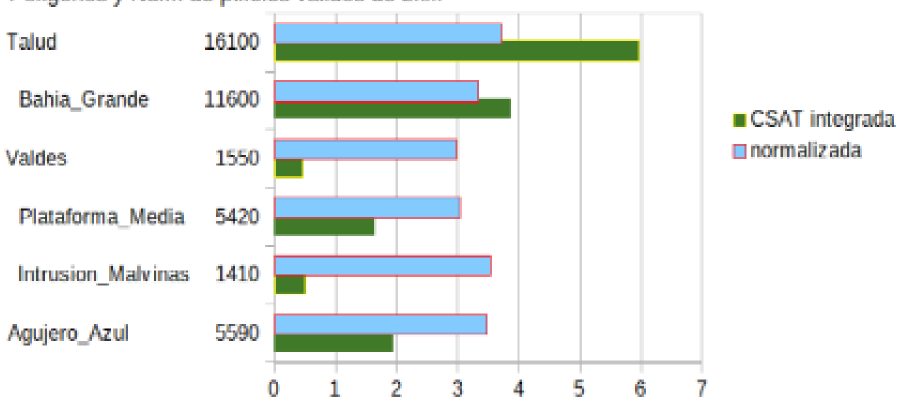


OCTUBRE PROMEDIO 2003-2016
DISTRIBUCIÓN MEDIA DE CLOR
CONTORNO 3,5 mg/m3

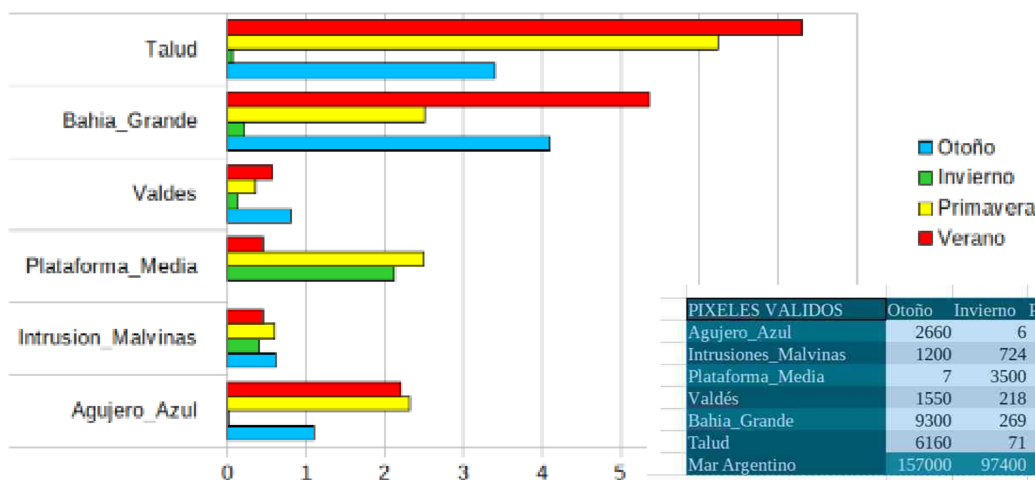
POLÍGONOS E INDICADORES como herramientas de comparación entre zonas altamente productivas.

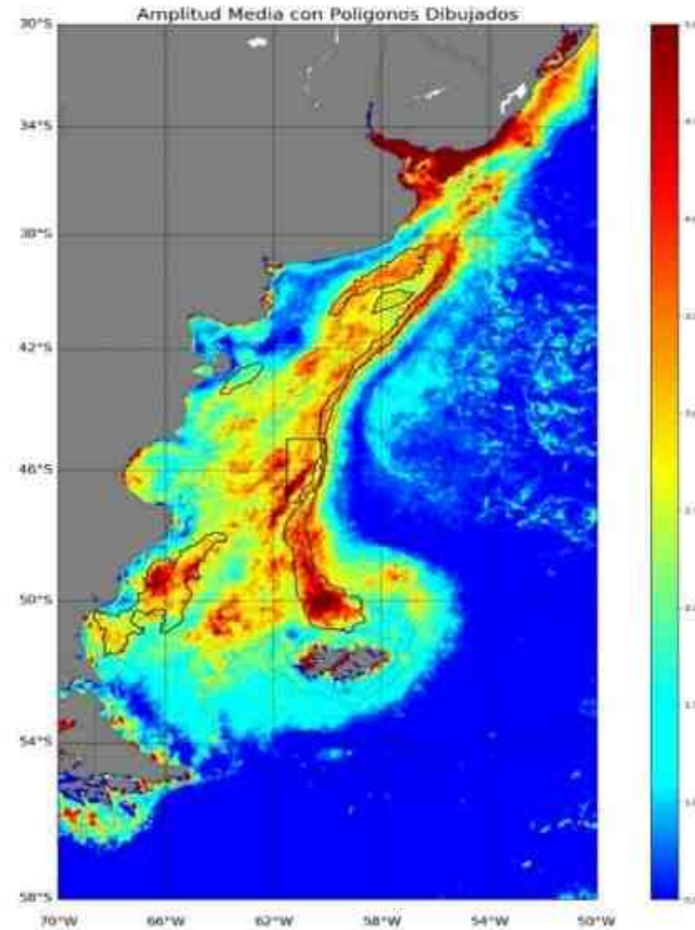
SWF+MODISA mensuales 1997-2018 (M.Marrari et al. 2016). Dominio hasta 58 S, **Sin** OM, NM, **Con** Talud e IM

CSAT integrada en % sobre todo
el Mar Argentino (30-58 S, 70-50 O) SeaWifs+ModisAq (1997-2018)

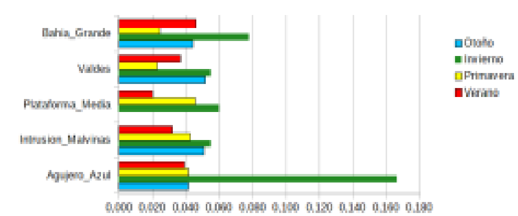


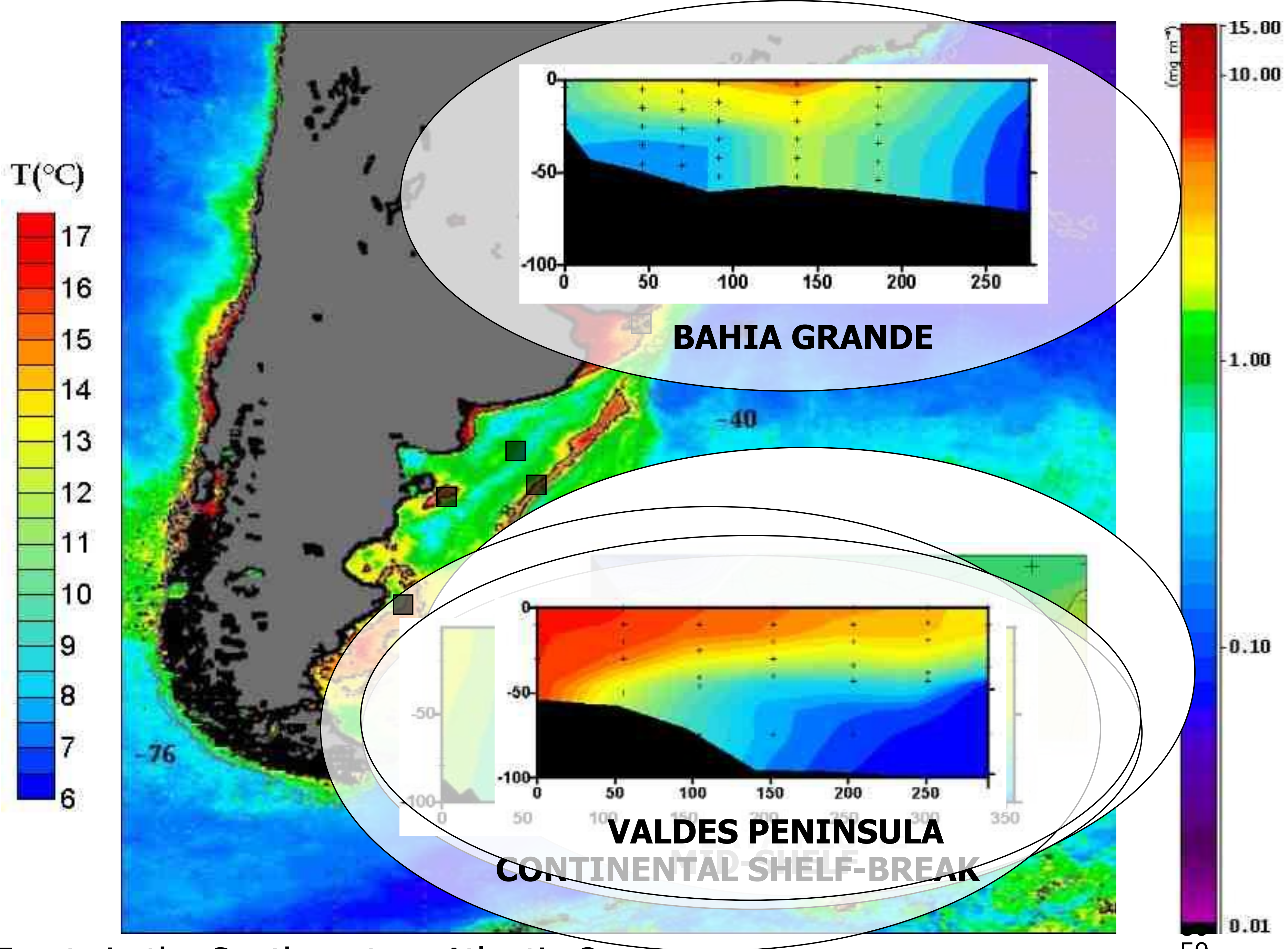
CSAT integrada en cada polígono, en % sobre todo el Mar Argentino (30-58 S, 70-50 O),
sobre las medias del período completo estacionales, SeaWifs+ModisAq (1997-2018)



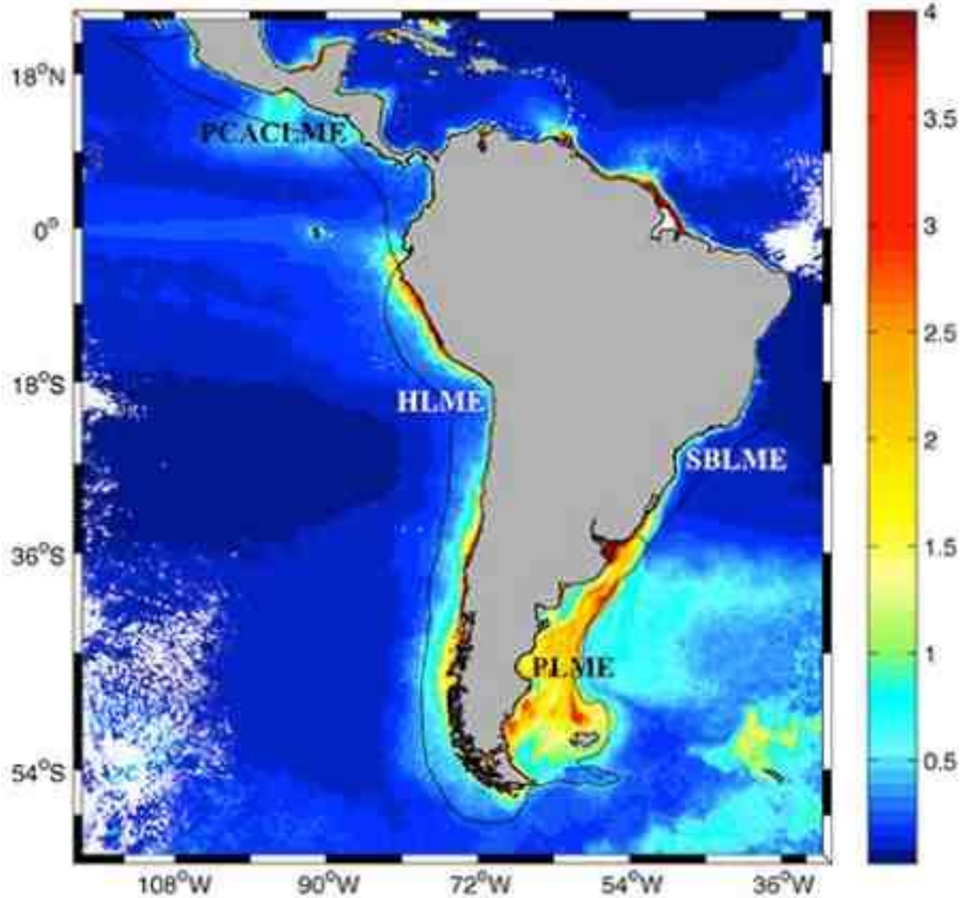


PIXELES VALIDOS	Otoño	Invierno	Primavera	Verano
Agujero_Azul	2660	6	5580	5590
Intrusiones_Malvinas	1200	724	1410	1410
Plataforma_Media	7	3500	5420	2230
Valdés	1550	218	1520	1550
Bahia_Grande	9300	269	10200	11600
Talud	6160	71	16100	16100
Mar Argentino	157000	97400	327000	300000





Fronts in the Southwestern Atlantic Ocean



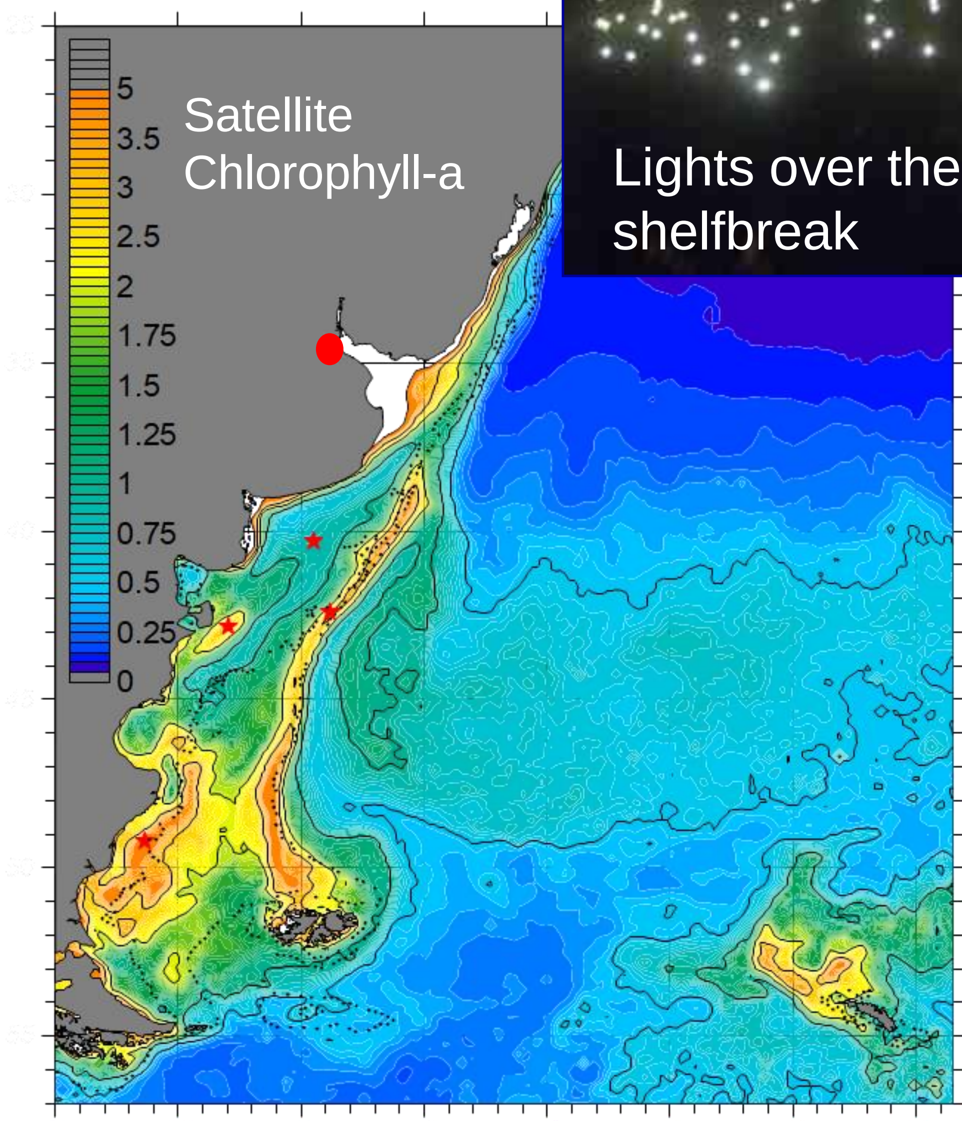
PLME
Presencia de fitoplancton fotosintetizador, triplica la media global

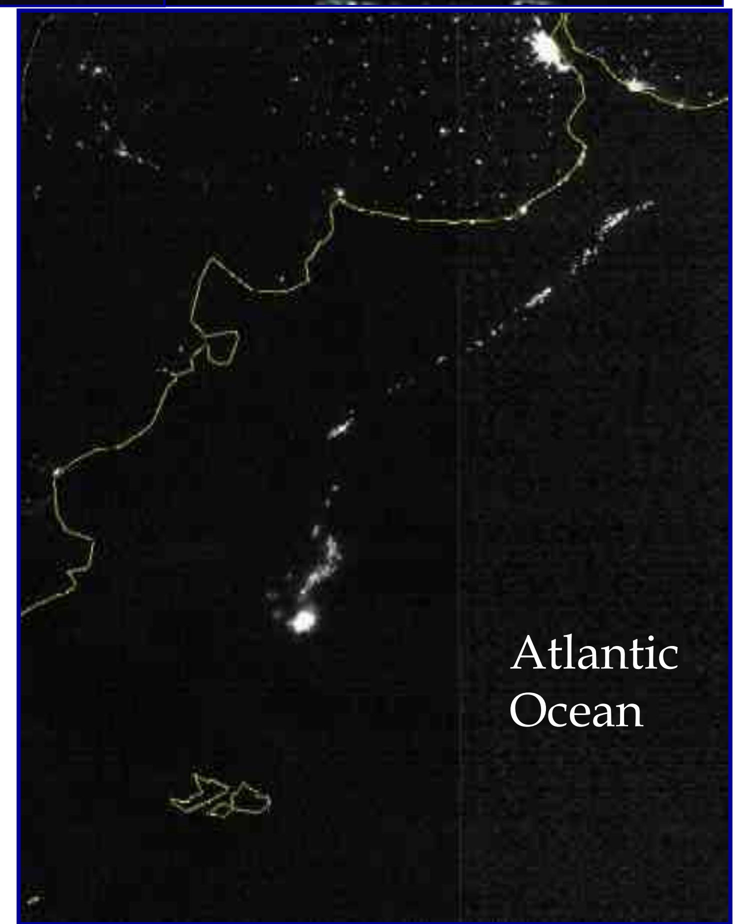
Distribución climatológica de SeaWiFS (1997–2006) concentración de clorofila satelital en primavera austral (Octubre–Diciembre) alrededor de América del Sur y Central. Se indican en el mapa las ubicaciones de los grandes ecosistemas marinos (LMEs) del Sur de Brasil (**SBLME**), Patagonia (**PLME**), Humboldt (**HLME**) y de la costa americana del Pacífico Central (**PCACLME**).

Variabilidad y Tendencias de 20 años en las Concentraciones de Clorofila satelital en los Grandes Ecosistemas Marinos alrededor de América del Sur y Central. PLME tendencia de aumento 78,23%.

Marrari et.al Front. Mar. Sci., (Nov 2017) | https://doi.org/10.3389/fmars.2017.00372

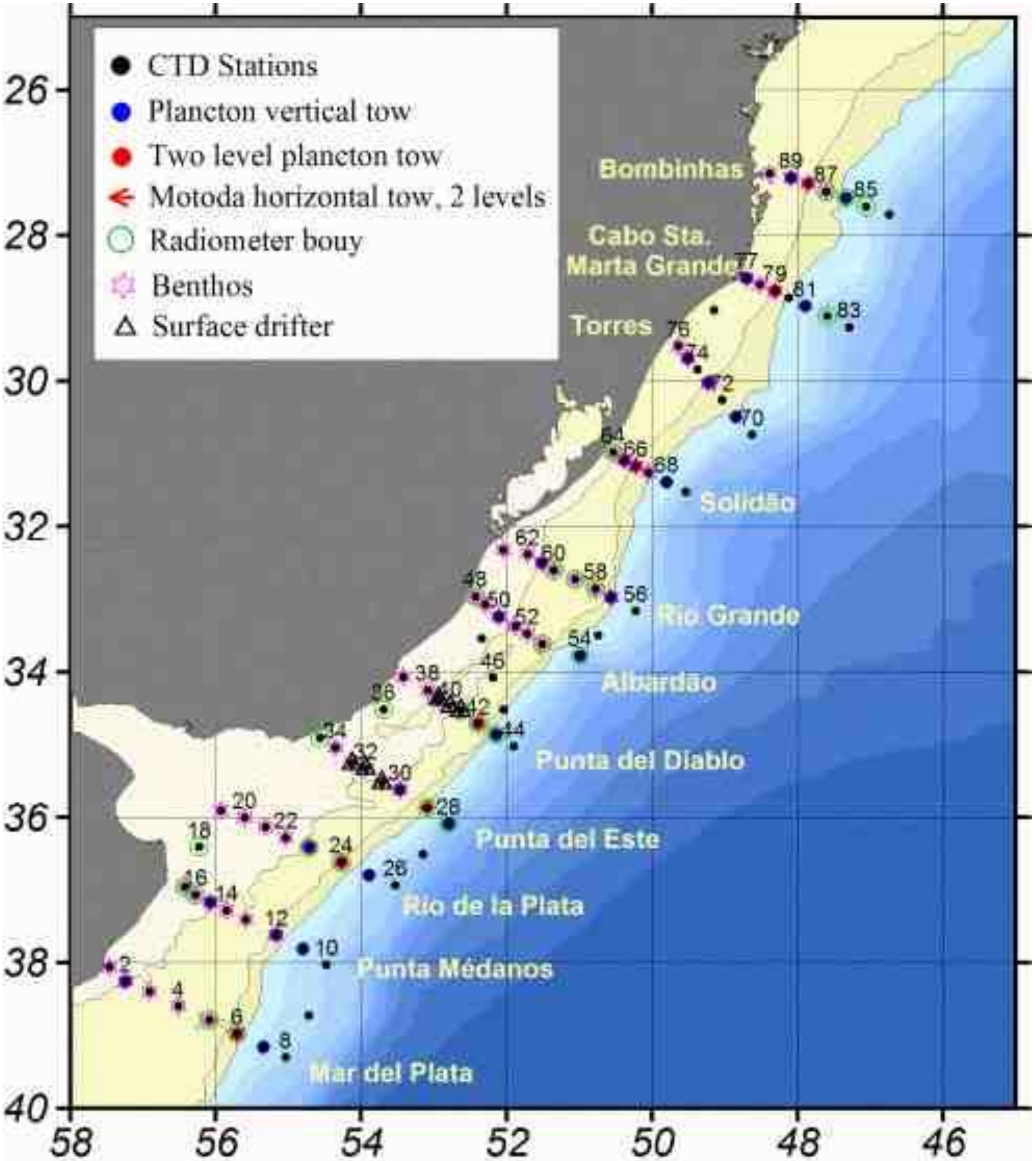
Atlantic Patagonian Shelf





Romero et al., *J. Geophys. Res.*, 2006

In Situ Data


CTD Stations
Plancton vertical tow
Two level plancton tow
Motoda horizontal tow, 2 levels
Radiometer bouy
Benthos
Surface drifter
Bombinhas
Cabo Sta. Marta Grande
Torres
Solidão
Rio Grande
Albardão
Punta del Diablo
Punta del Este
Rio de la Plata
Punta Médanos
Mar del Plata
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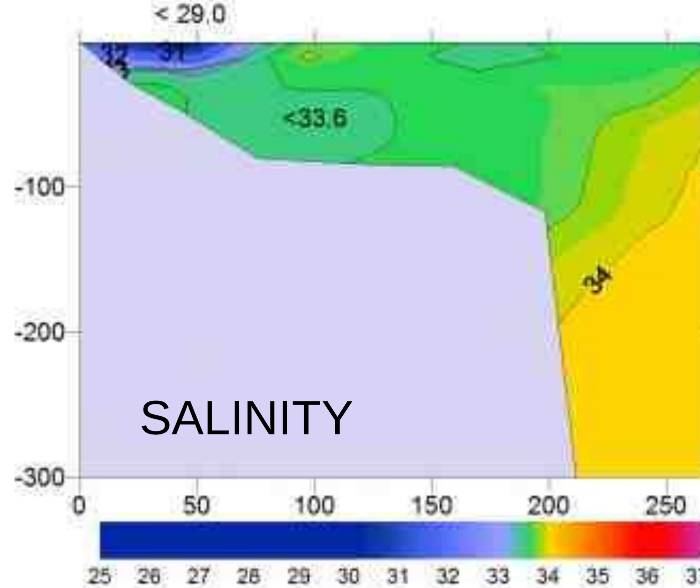
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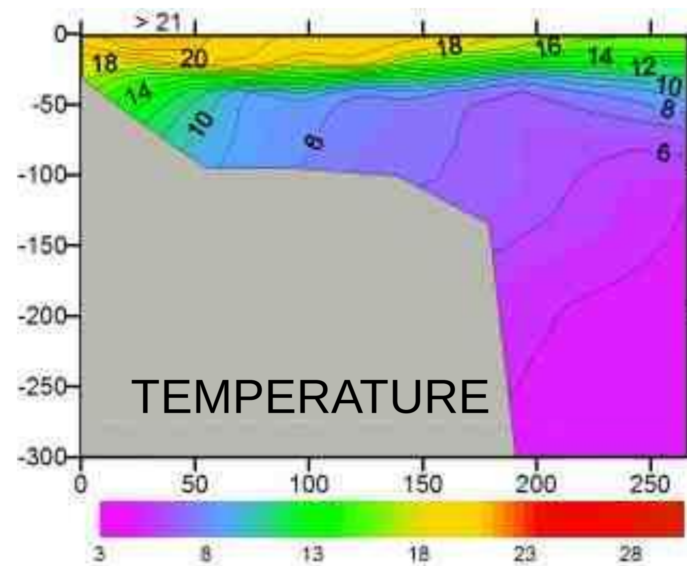
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Modelled Data

Combes y Matano 2014

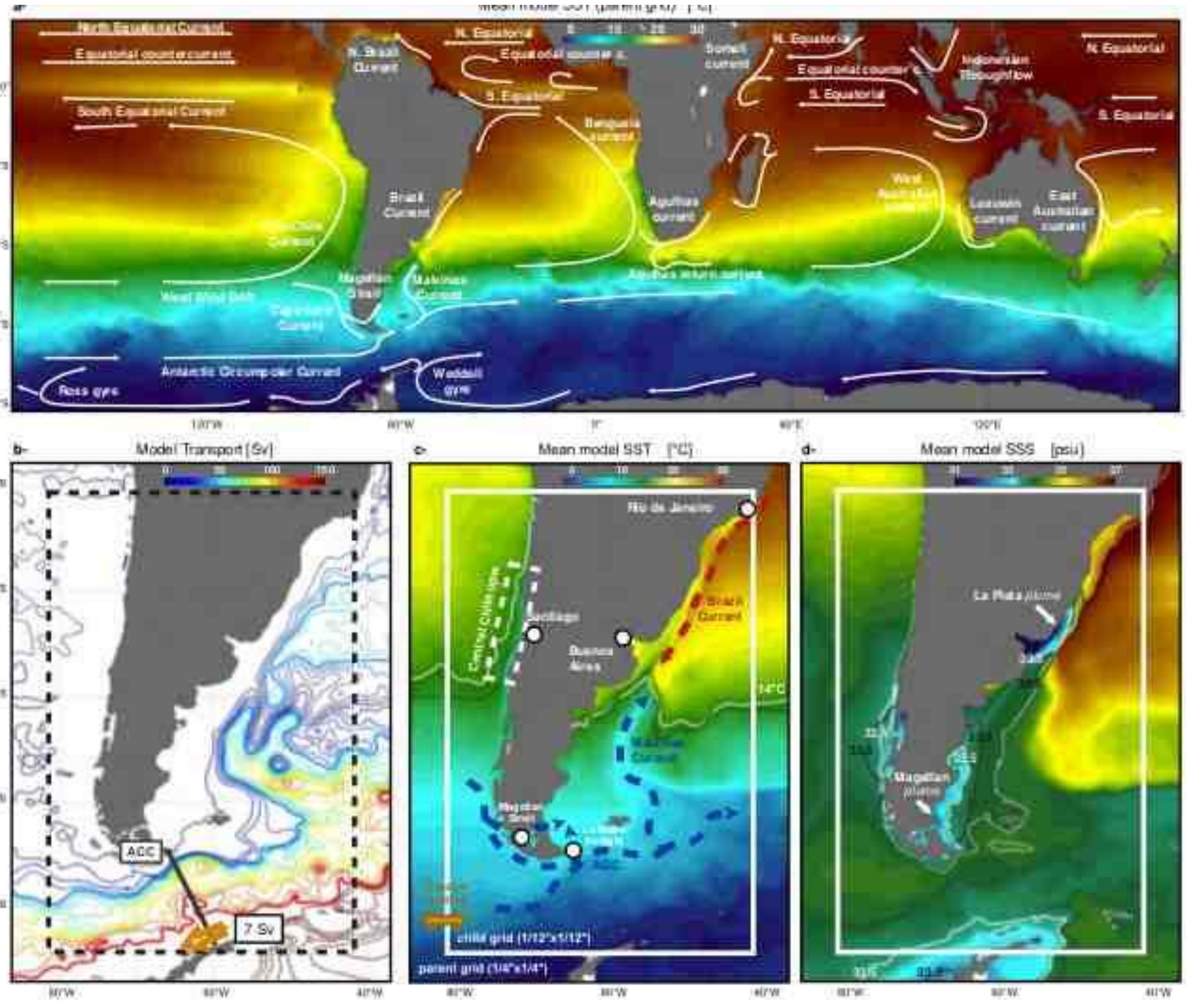
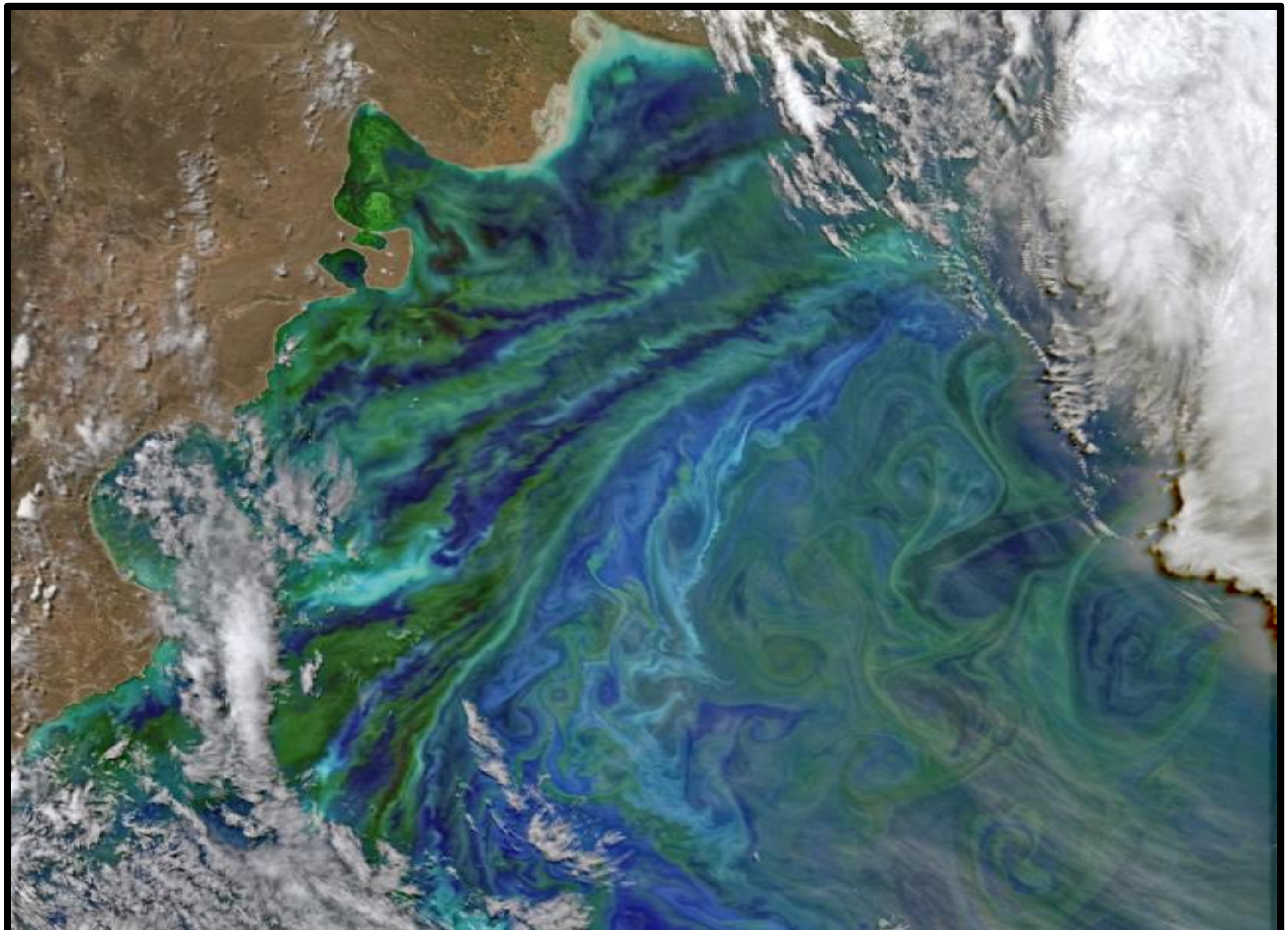


Figure 5. (a–c) Mean model Sea Surface Temperature (SST). The model parent grid encompasses the entire southern hemisphere from Antarctica to 15.2°N (1/4° × 1/4° resolution), th

Satellite Data

50 years of Oceanography from space



Ocean Color. 2 Dic 2014. Credit to NASA/NASA’s Earth Observatory

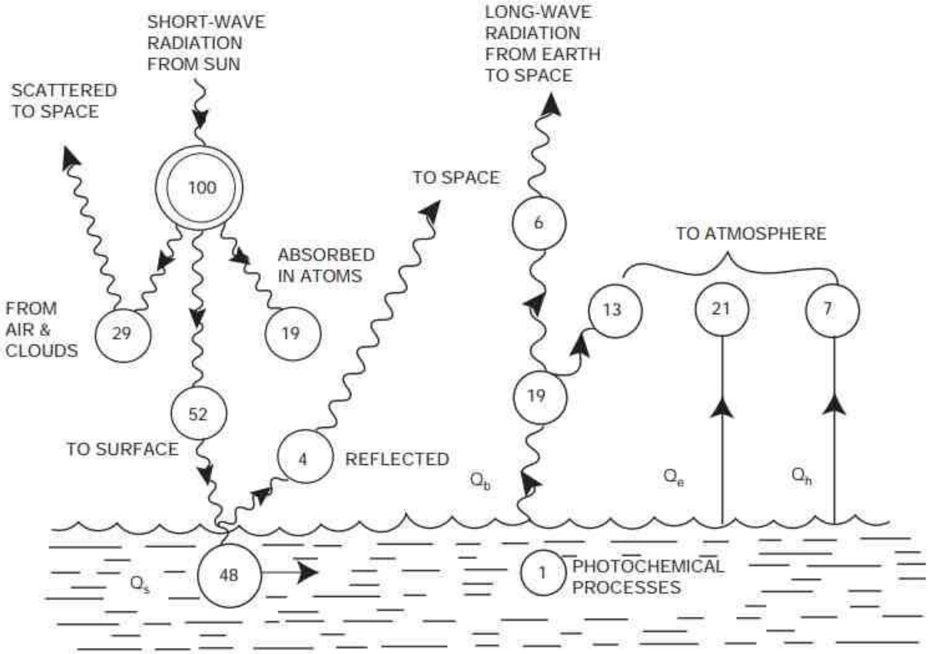


FIGURE 5.5 Distribution of 100 units of incoming shortwave radiation from the sun to Earth's atmosphere and surf[...] long-term world averages.

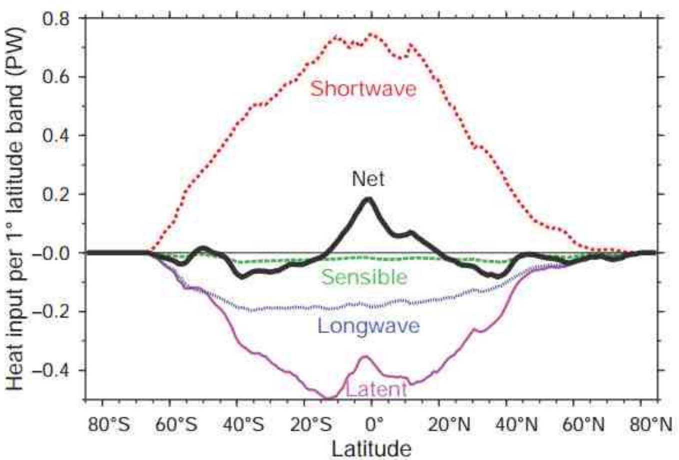


FIGURE 5.13 Heat input through the sea surface (where 1 PW = 10^{15} W) (world ocean) for 1° latitude bands for all components of heat flux. Data are from the NOCS climatology (Grist and Josey, 2003).

Talley, 2011