

Hidrodinámica Estuarina

Basado en el trabajo de:
Arnoldo Valle-Levinson
University of Florida

Data SIO NOAA U.S. Navy NGA GEBCO
Image TECAO
Image USDA Farm Service Agency
Image © 2010 TerraMetrics

29°17'55.62" N 82°33'42.73" W elev: 0 ft

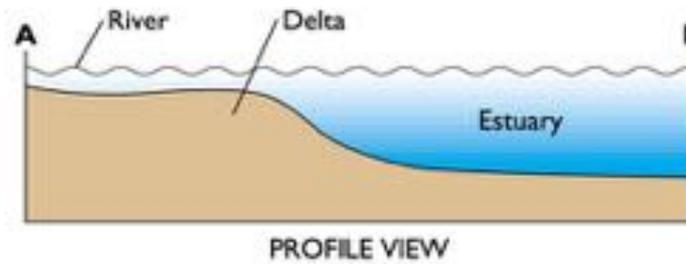
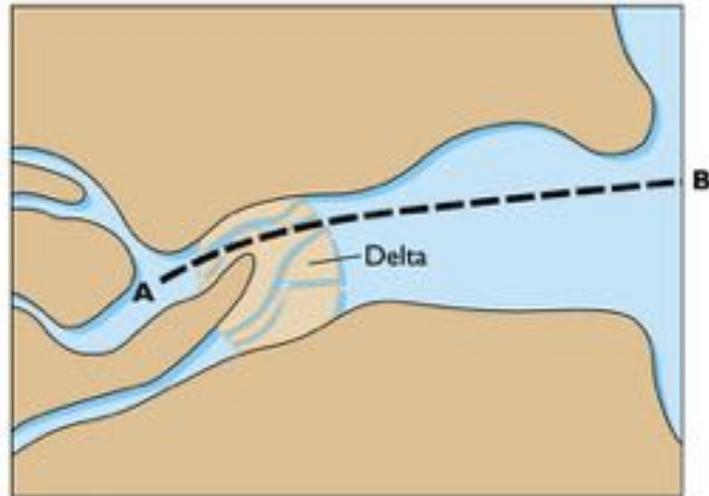
Que es un estuario?

Estuarios

Lagunas costeras

- Cuerpo de agua semicerrado
- Comunicación abierta al oceano
- La salinidad disminuye hacia el interior debido a la presencia de descarga rios

Tipos de estuario

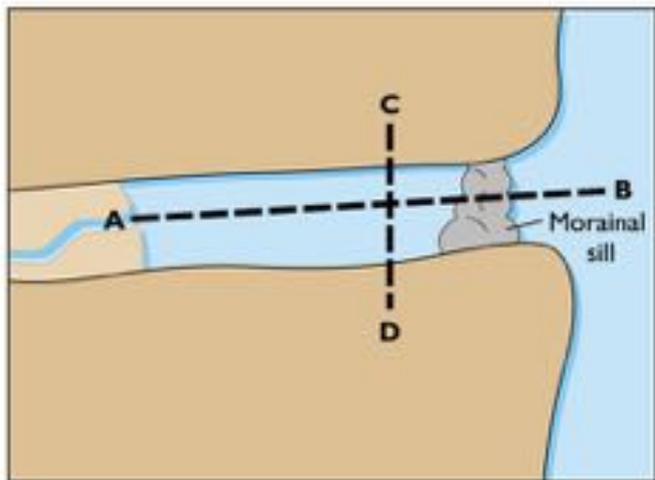


(a) DROWNED RIVER VALLEY (Pinet, 2003)

Deltaico

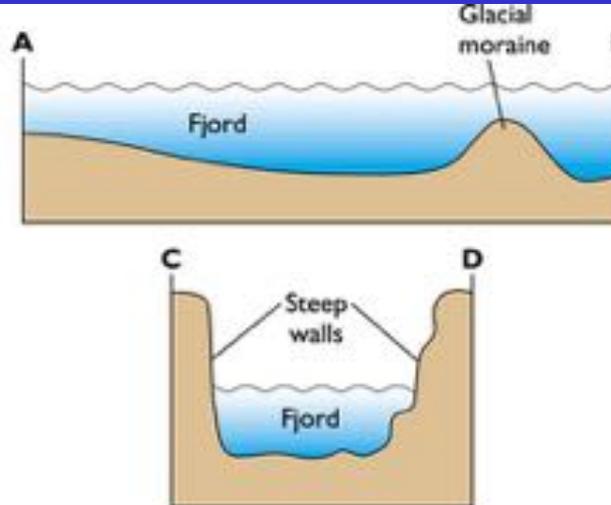


Tipos de estuario

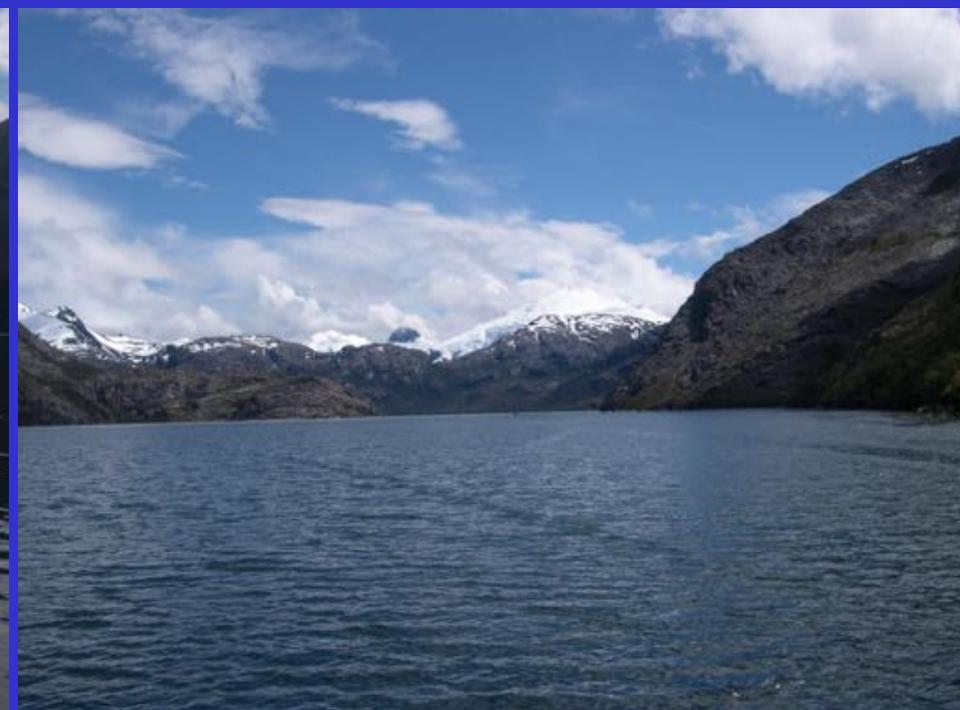


(b) FJORD

(Pinet, 2003)

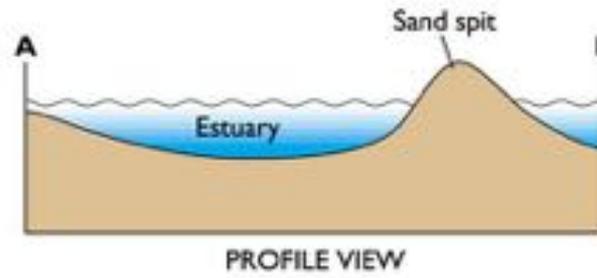
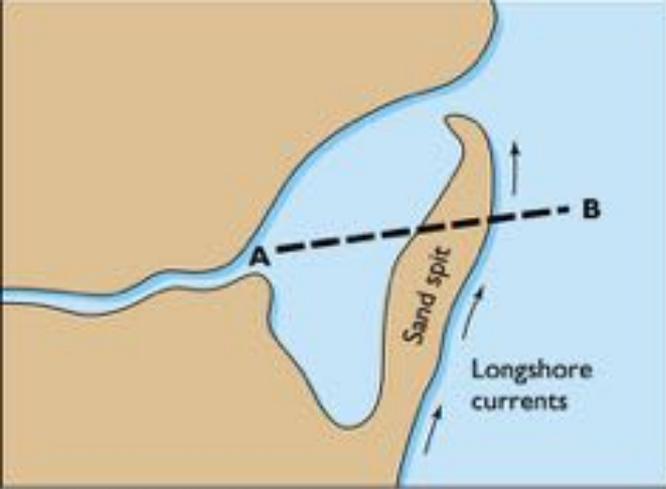


PROFILE VIEWS



Termohalino (Glaciar)

Tipos de estuario

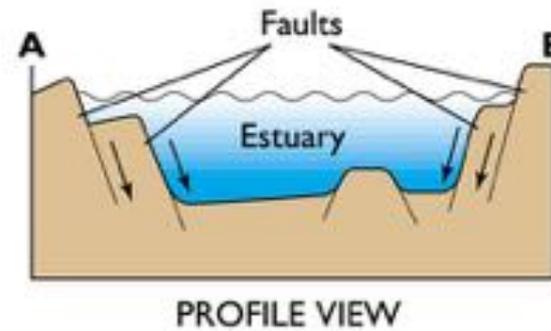
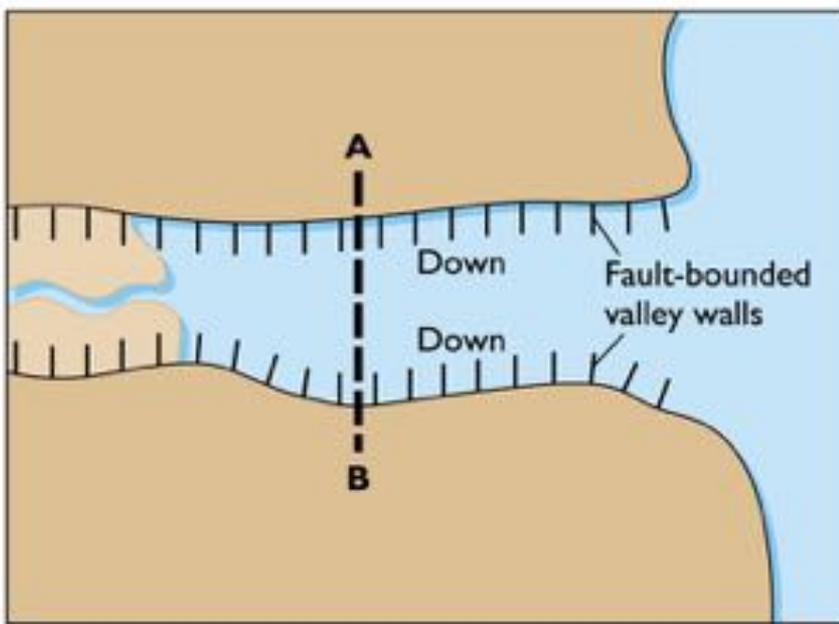


(c) BAR-BUILT ESTUARY

(Pinet, 2003)



Barras de arena



(d) TECTONIC ESTUARY (Pinet, 2003)

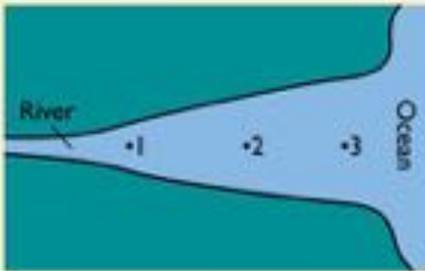
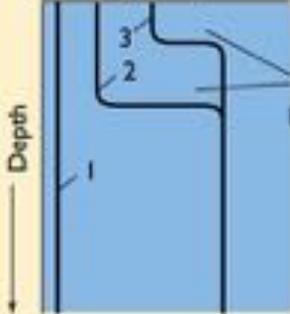
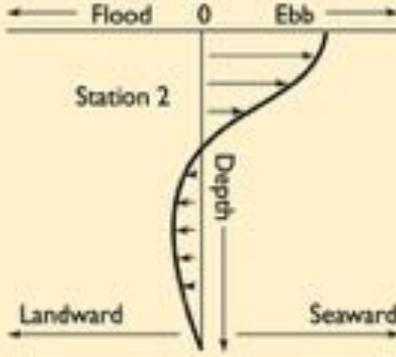
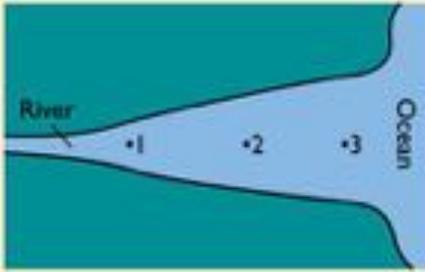
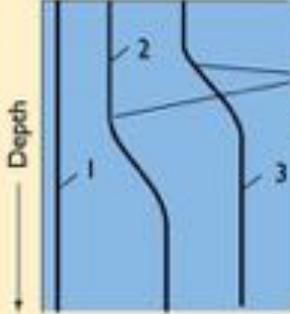
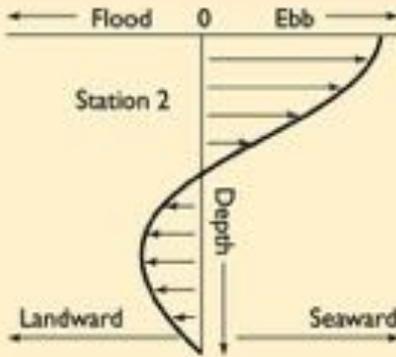
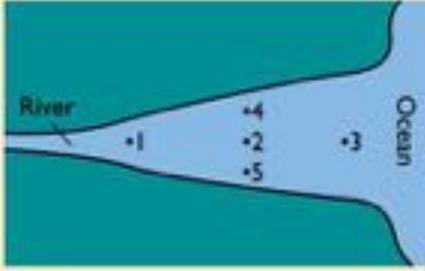
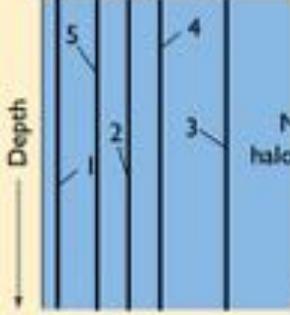
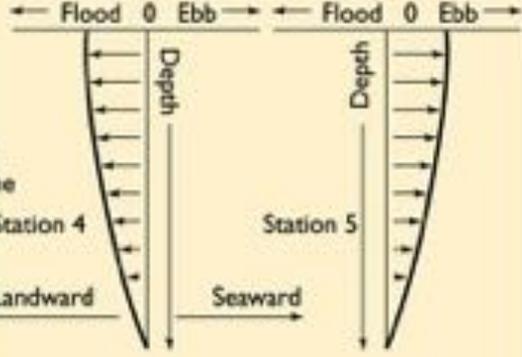


Origen Tectónico

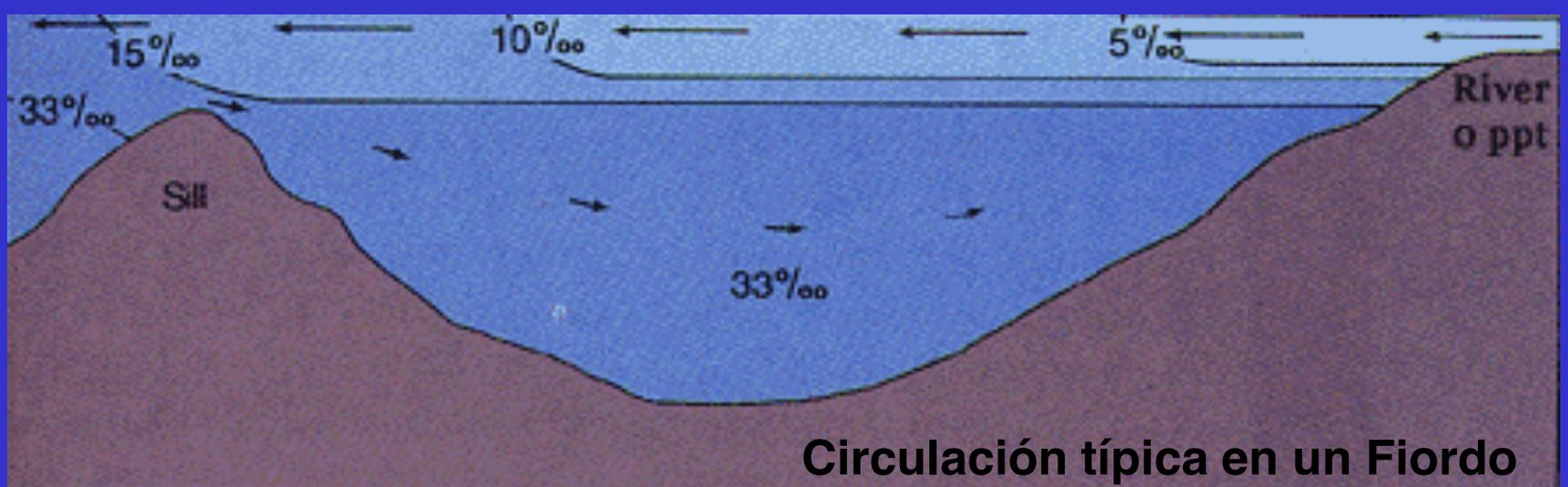
Bahia de San Francisco

Tipos de estuarios de acuerdo a su estratificación (Pinet, 2003)

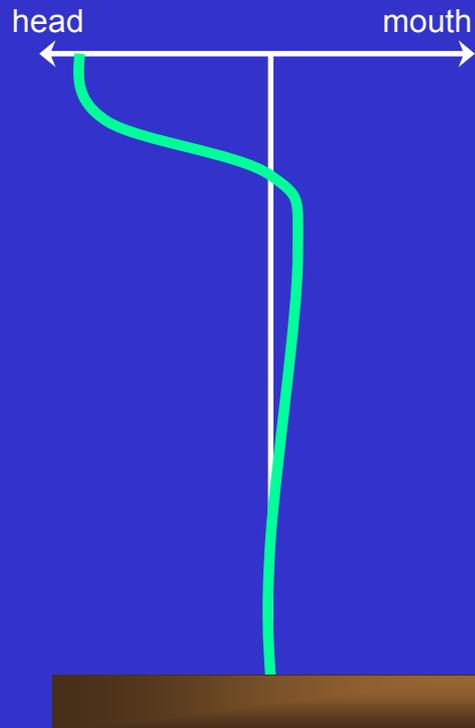
Competencia entre el forzamiento de las mareas y la fuerza de boyancia

FACTORS AFFECTING ESTUARIES	TYPE	SALINITY PROFILES	NET CIRCULATION
<p>High Minimum Weak Strong</p> <p>High Minimum Weak Strong</p>	<p>Hydrographic stations</p>  <p>(a) SALT-WEDGE ESTUARY</p>	<p>Salinity (‰)</p>  <p>Sharp halocline</p>	 <p>Flood 0 Ebb</p> <p>Station 2</p> <p>Depth</p> <p>Landward Seaward</p>
<p>River discharge Tidal mixing Tidal currents Water stratification</p> <p>Low Maximum Strong Weak</p>	 <p>(b) PARTIALLY MIXED ESTUARY</p>	<p>Salinity (‰)</p>  <p>Weak halocline</p>	 <p>Flood 0 Ebb</p> <p>Station 2</p> <p>Depth</p> <p>Landward Seaward</p>
<p>Low Maximum Strong Weak</p>	 <p>(c) WELL-MIXED ESTUARY</p>	<p>Salinity (‰)</p>  <p>No halocline</p>	 <p>Flood 0 Ebb</p> <p>Station 4</p> <p>Station 5</p> <p>Depth</p> <p>Landward Seaward</p>

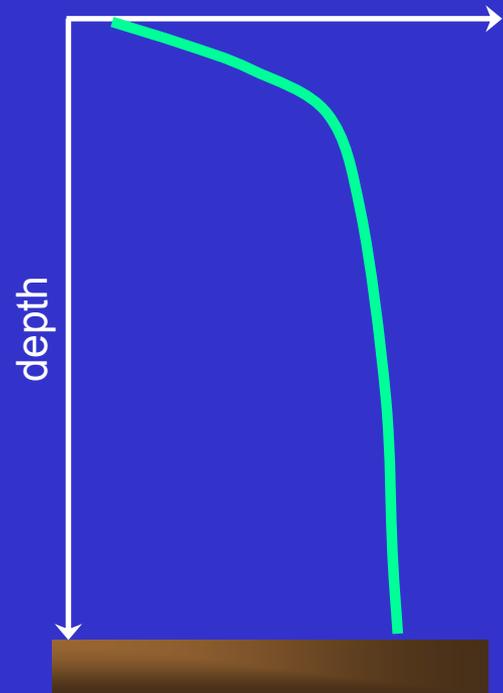




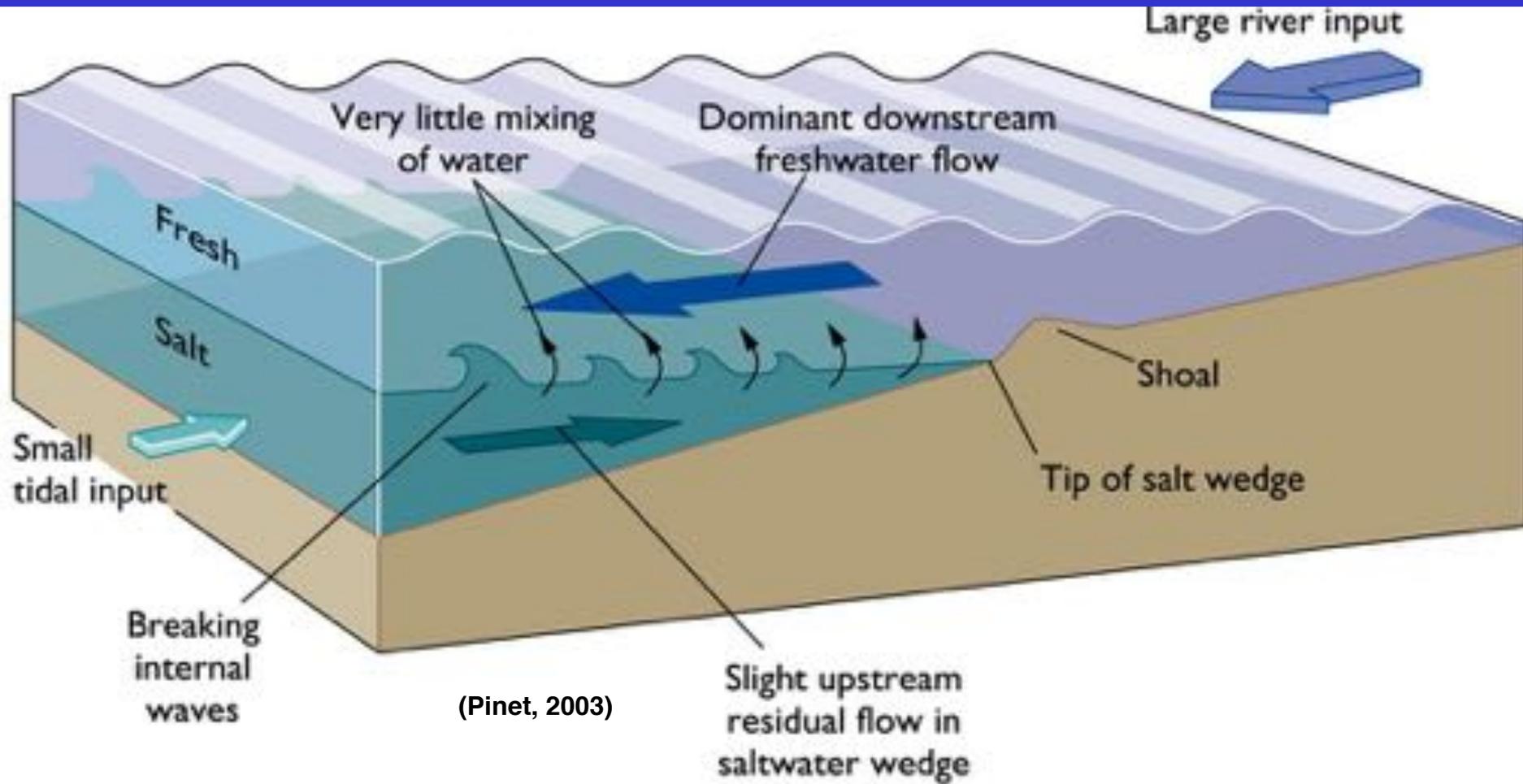
Circulación típica en un Fiordo



Perfil típico de velocidad neta



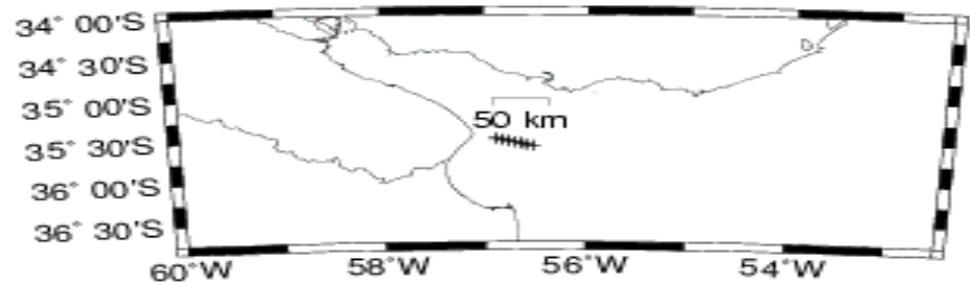
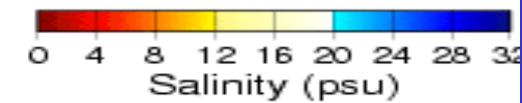
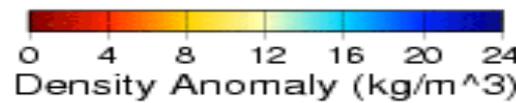
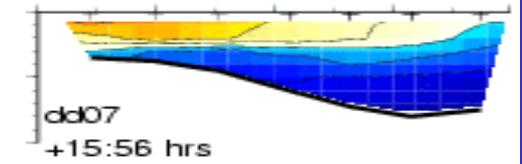
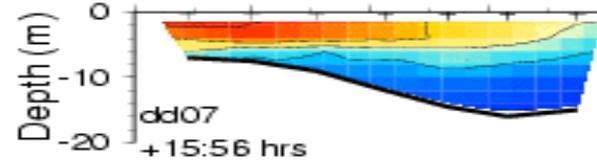
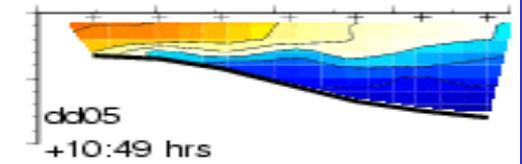
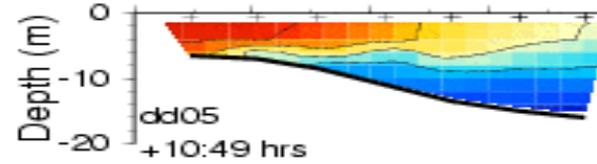
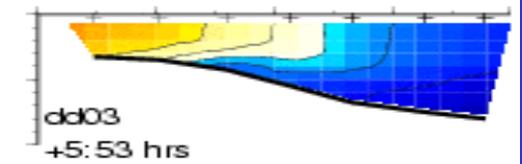
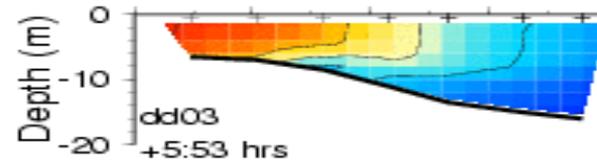
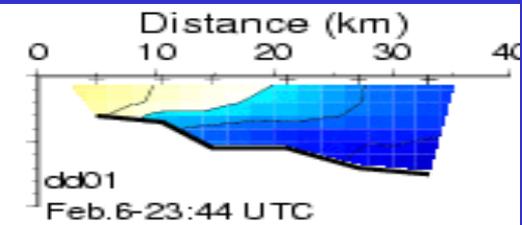
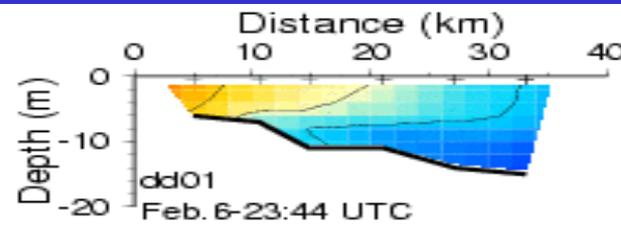
Perfil típico de Salinidad (densidad)

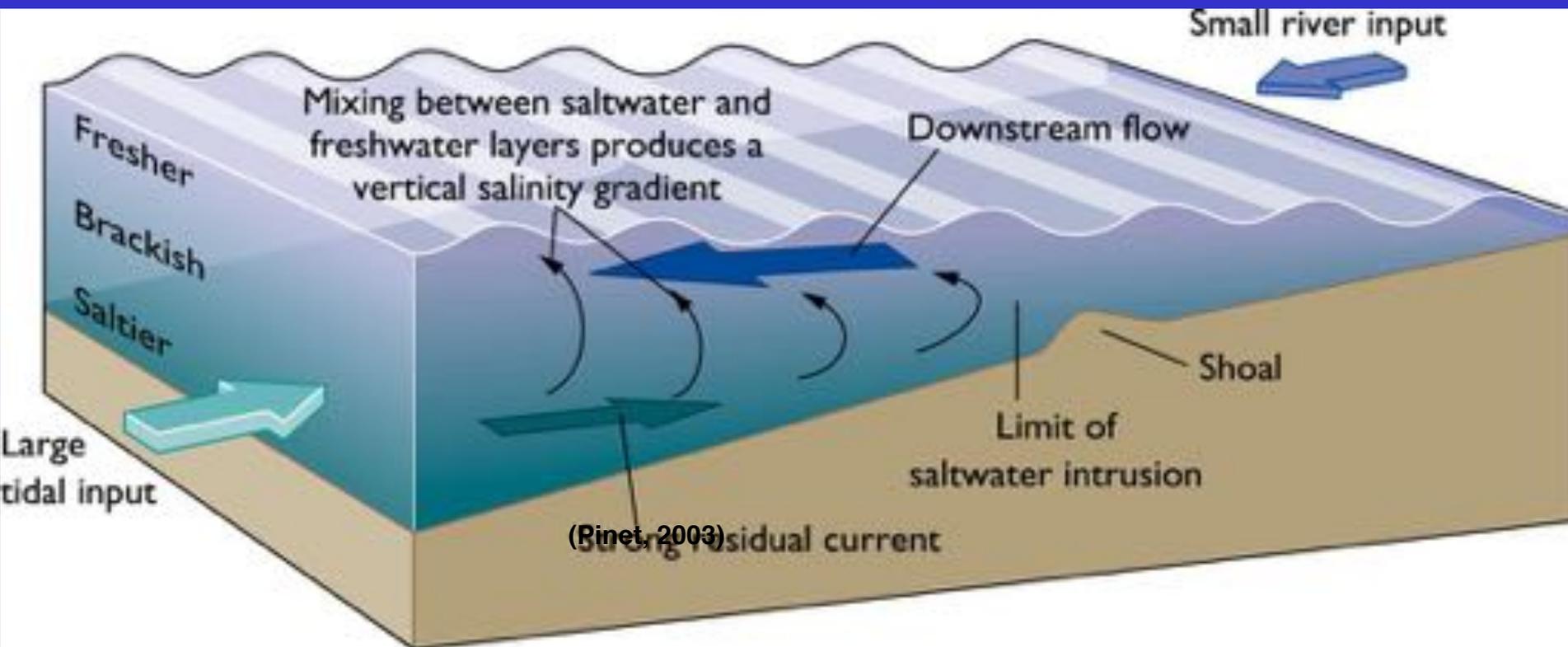


(a) SALT-WEDGE ESTUARY

Estuarios de Cuña de Sal

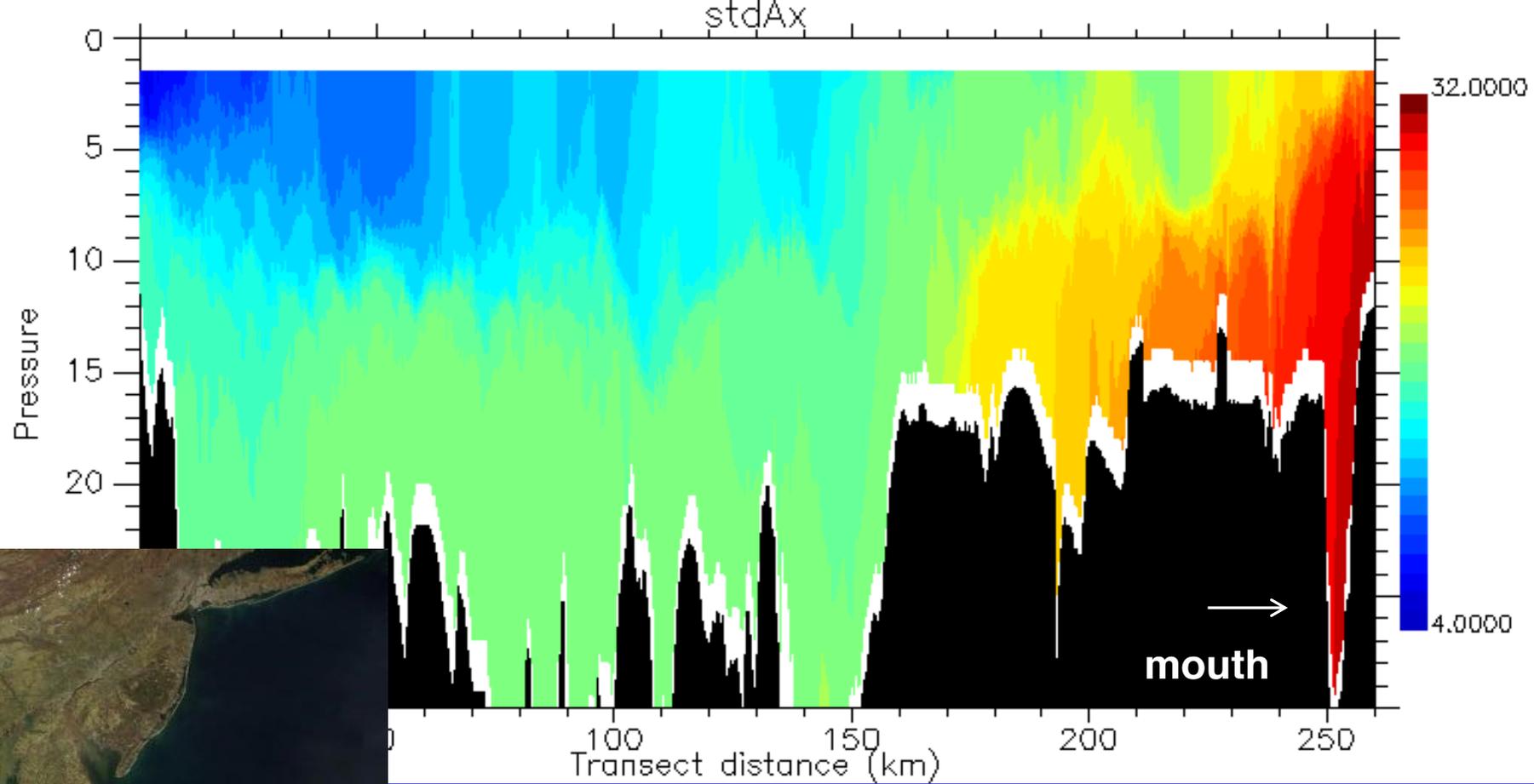
Estuario Rio de la Plata Argentina





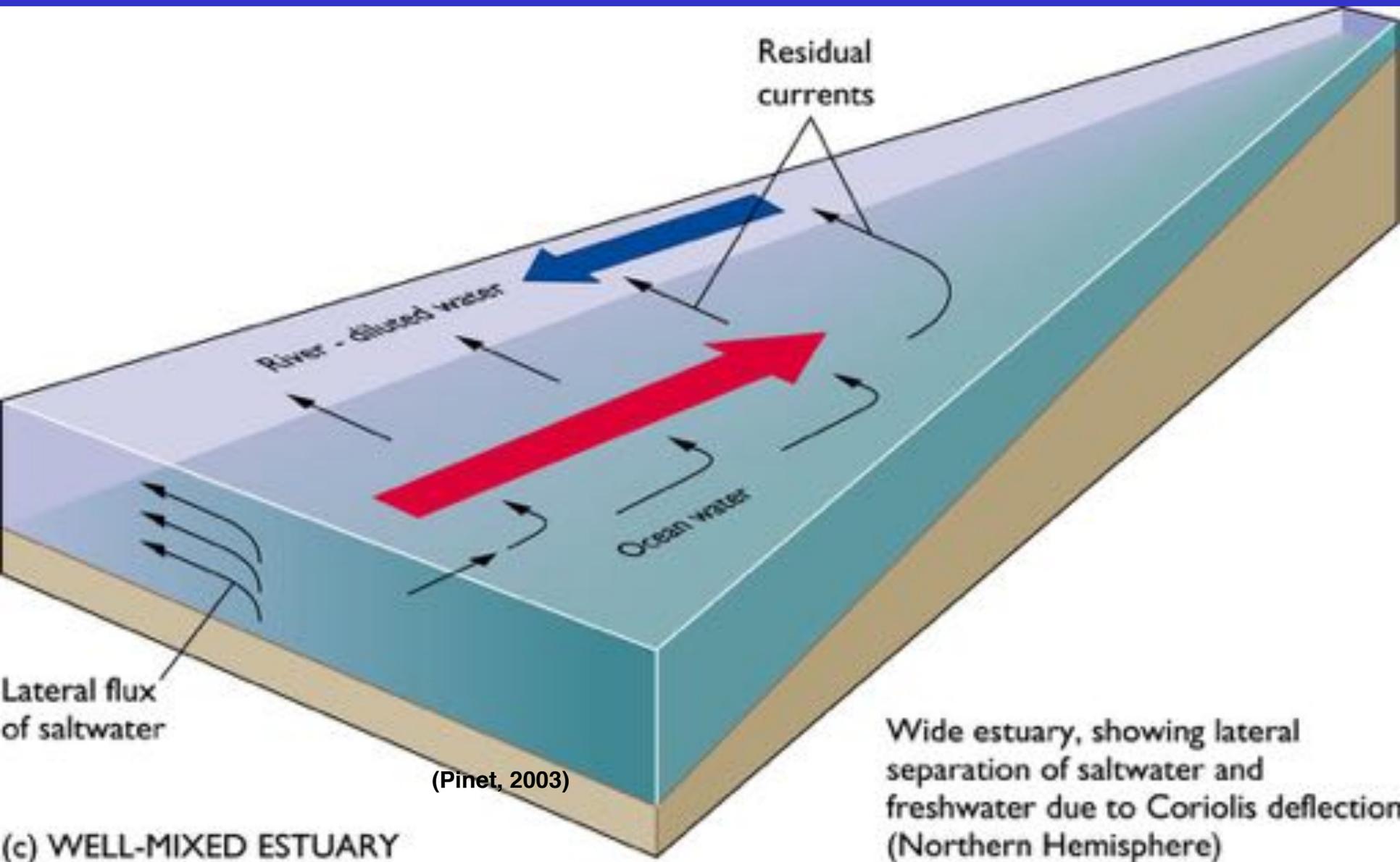
(b) PARTIALLY MIXED ESTUARY

Estuarios parcialmente mezclados

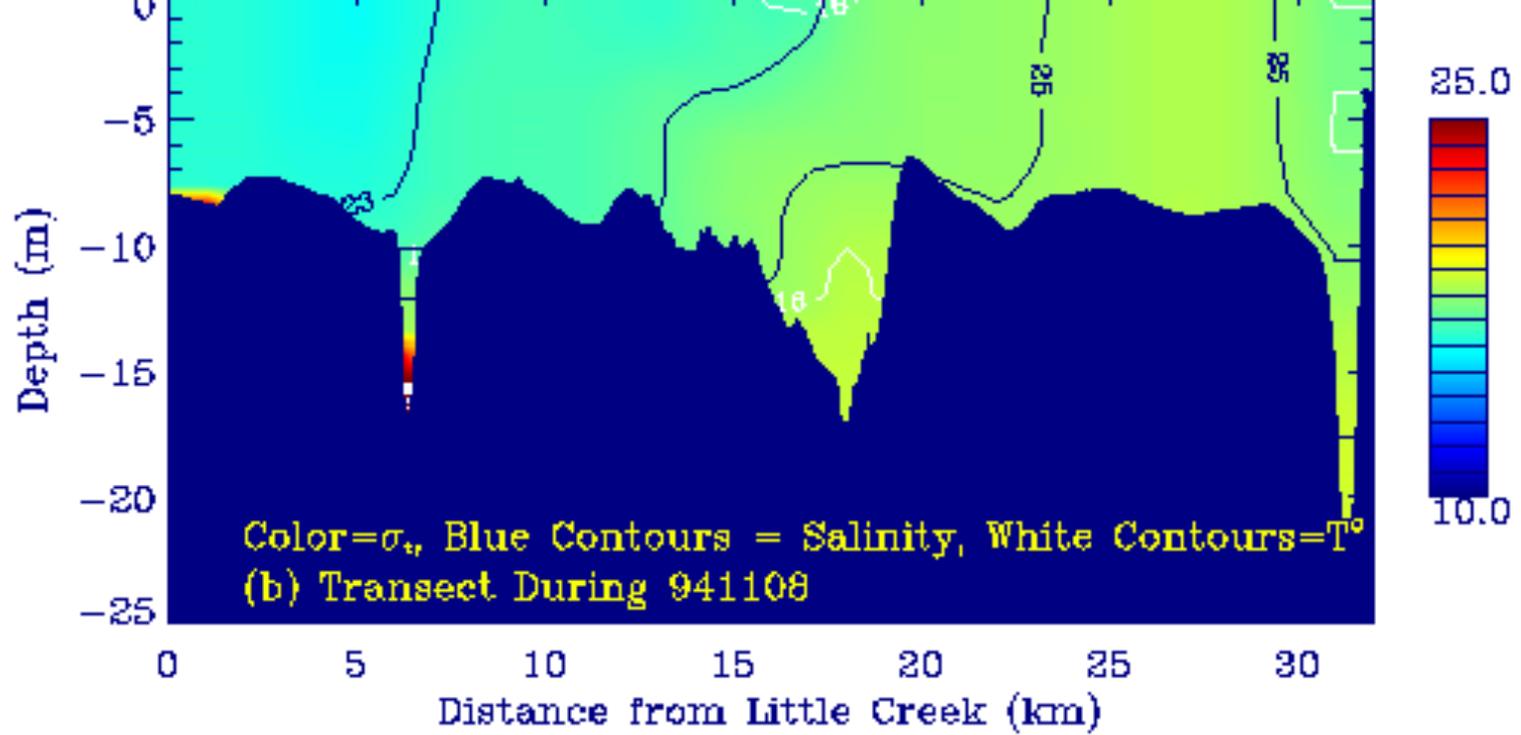


Distribuciones de Sal
Bahia de Chesapeake

Verano de 1999

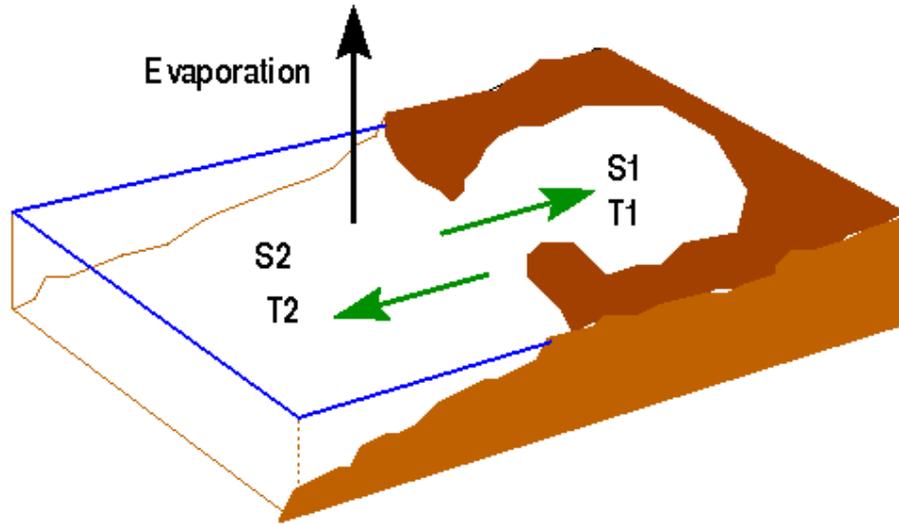


Estuarios bien mezclados



Ejemplo de un estuario bien mezclado

Tipos de estuarios de acuerdo al balance de agua

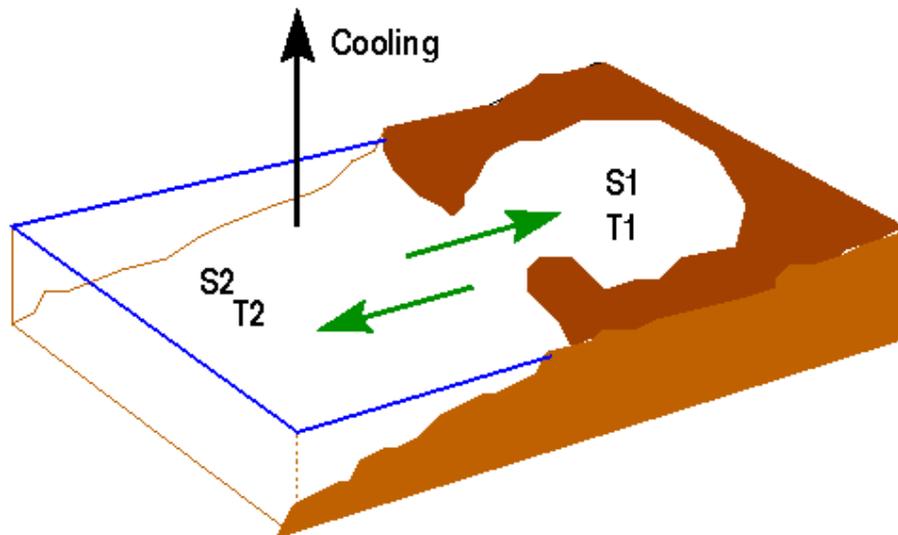


SUMMER

$S1 > S2$; $T1 > T2$

Inverse Estuary

Perdida de masa neta

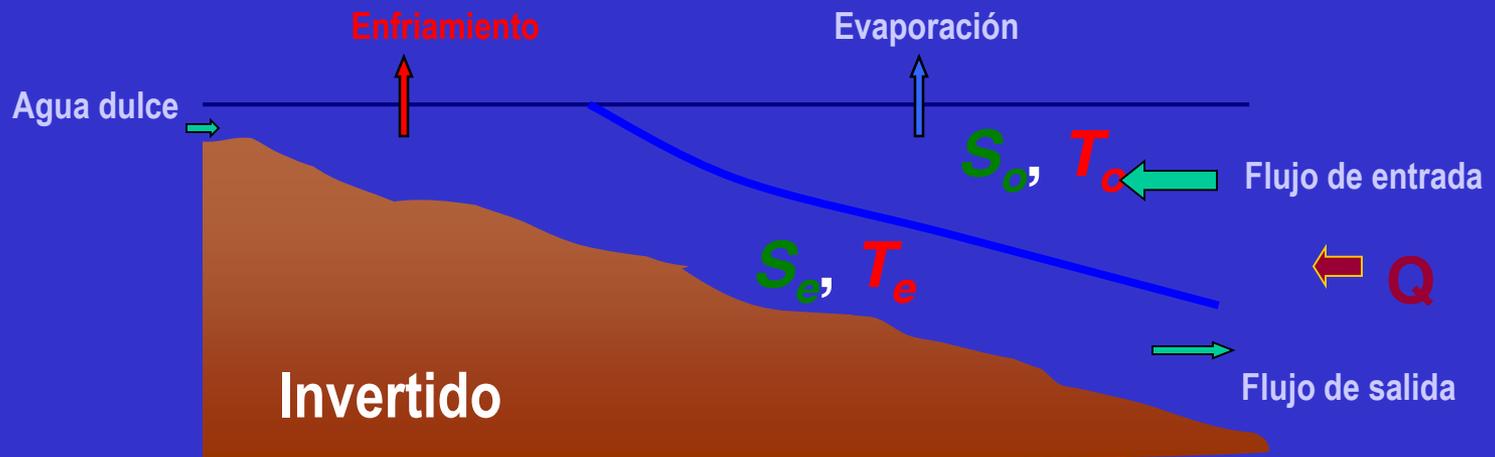
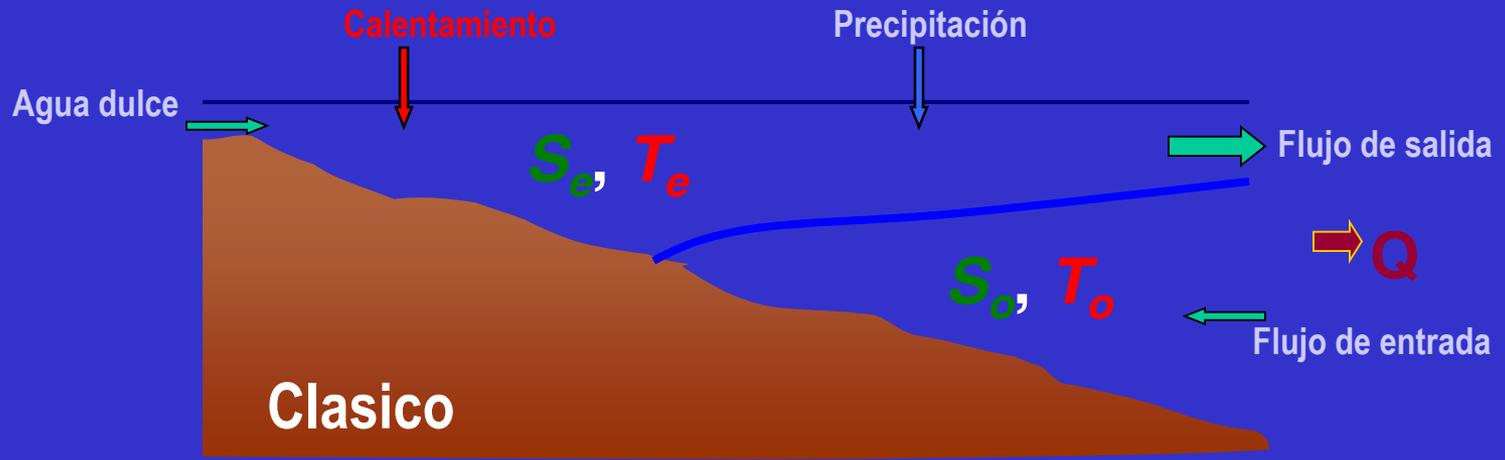


WINTER

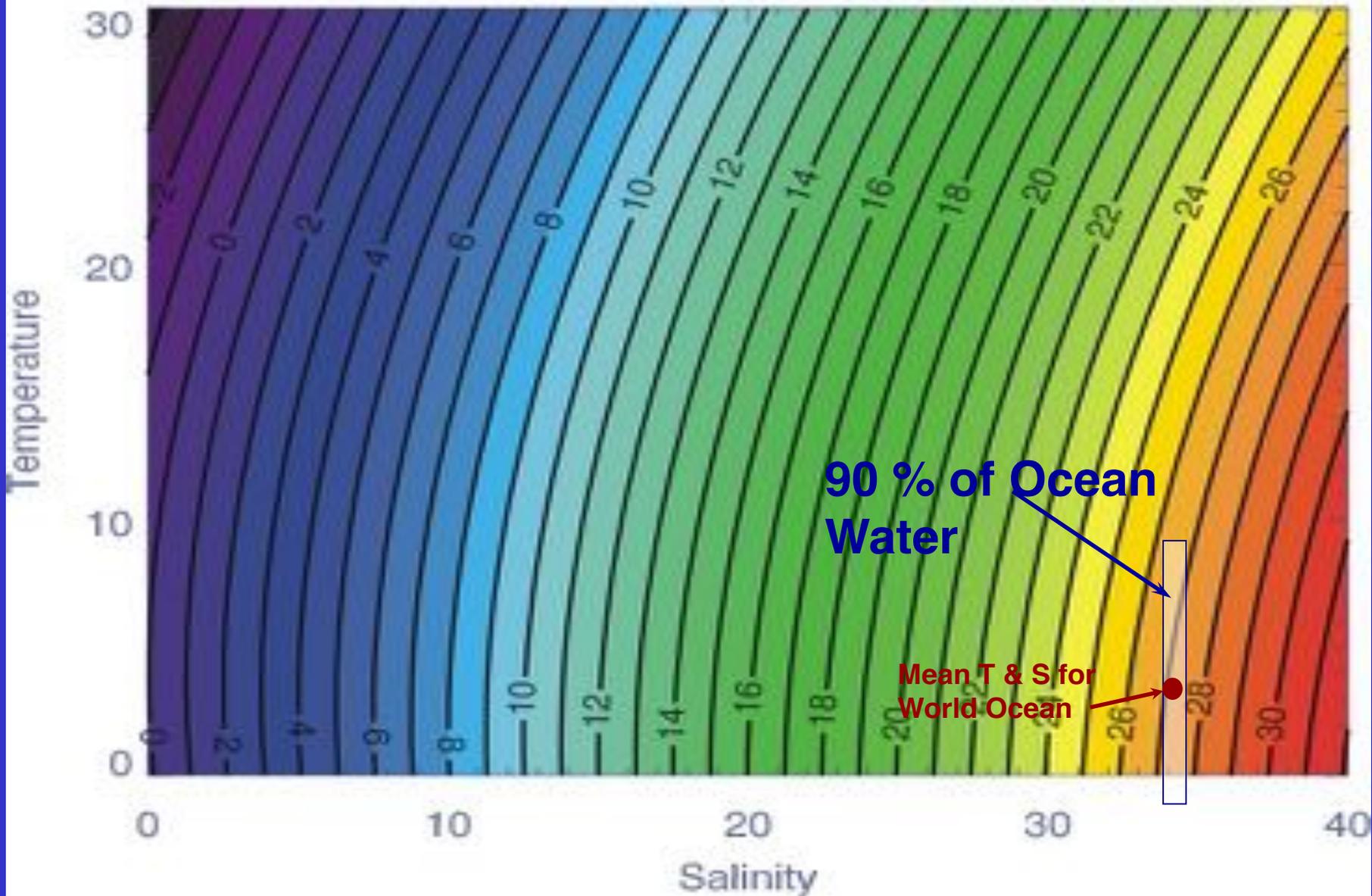
$S1 \sim S2$; $T1 < T2$

Inverse Estuary

No hay perdida de masa



Contours of Density Anomaly as function of T and S

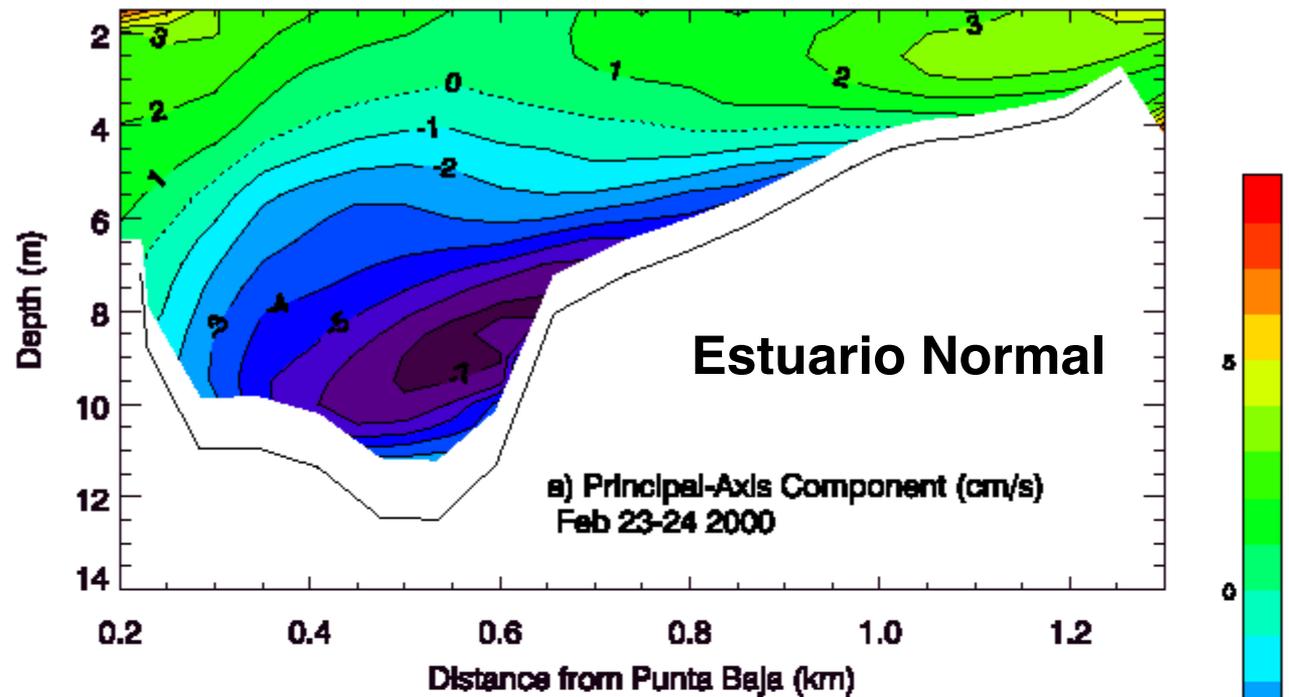
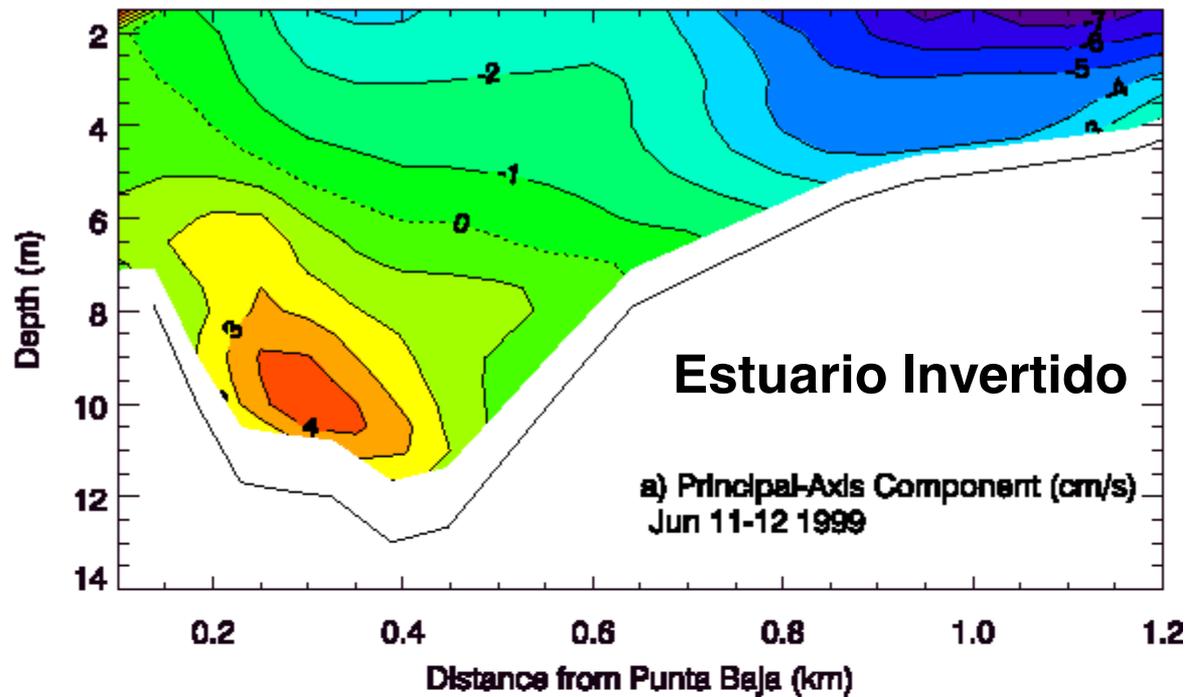
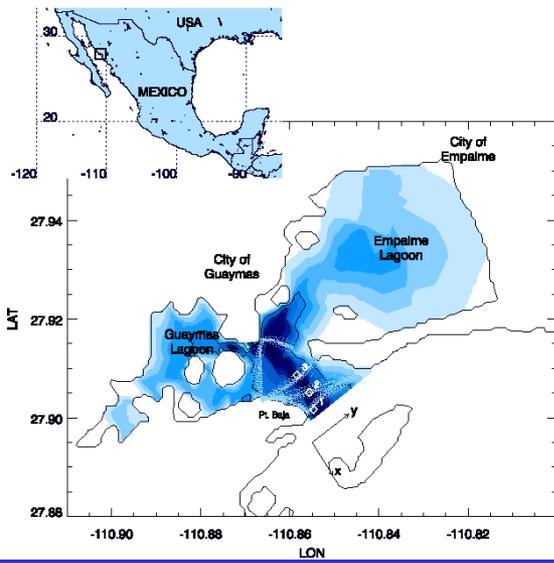


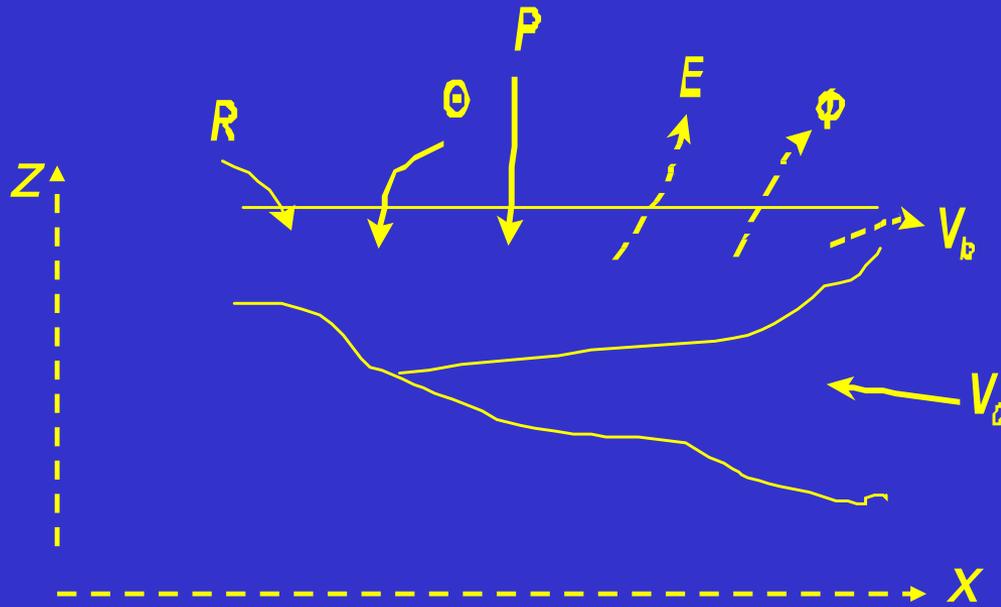
Gran influencia de la salinidad en la densidad

Al interior de un lago

Rojo = Agua sale

Azul = Agua entra





Forma General de la ecuación de continuidad:

$$\mathbf{R + P + V_0 + \theta = E + V_b + \phi}$$

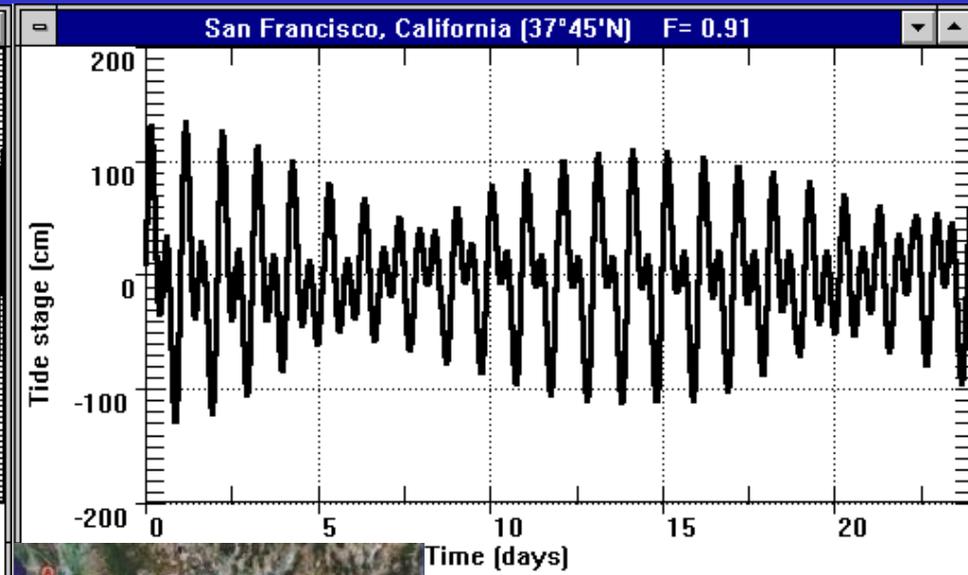
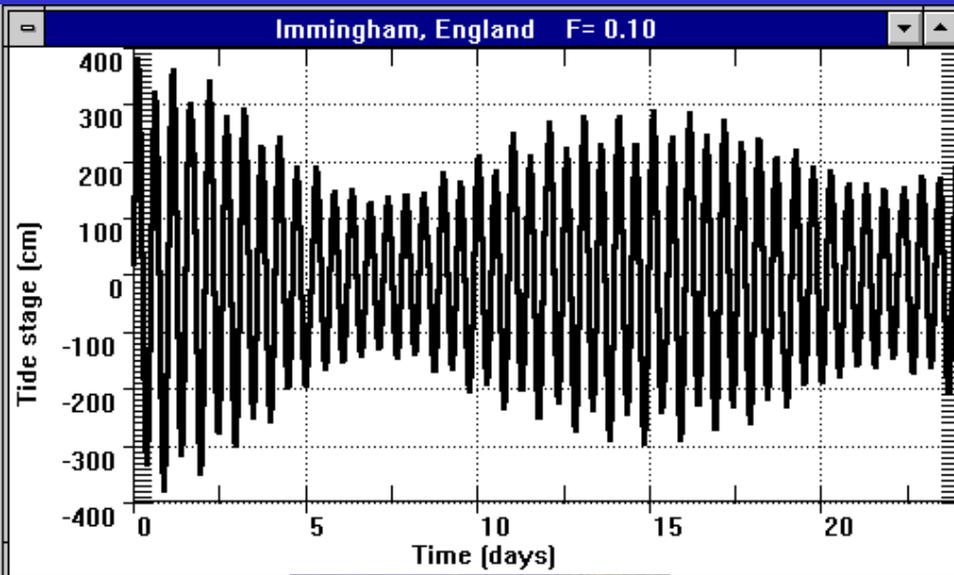
El factor $F = [K_1 + O_1] / [M_2 + S_2]$ es usualmente utilizado para caracterizar la marea.

$0.25 < F < 1.25$ marea mixta, principalmente semidiurna

$1.25 < F < 3.00$ marea mixta, principalmente diurna

$F > 3$ marea diurna

$F < 0.25$ marea semidiurna

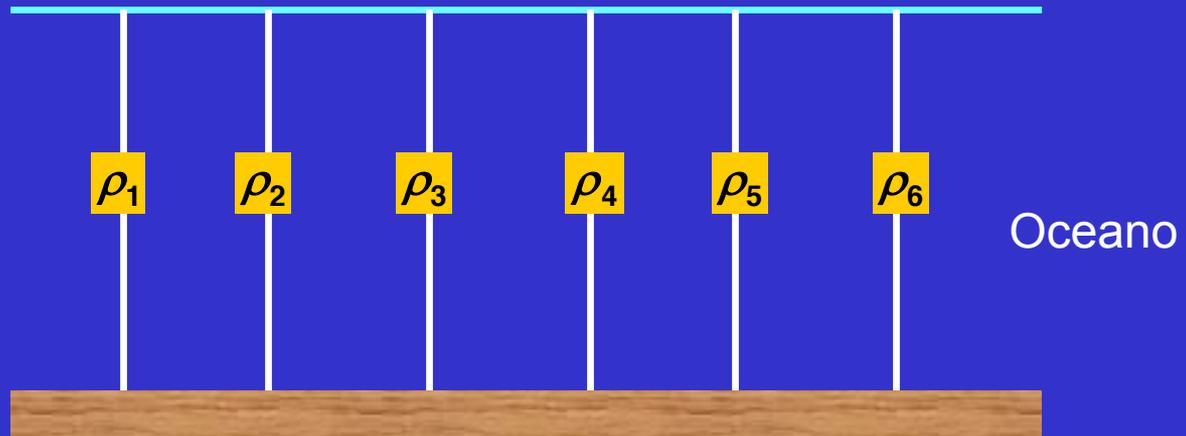


Esfuerzo marea

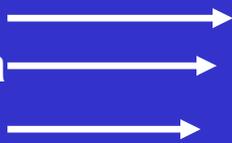
Antes de Reflujo

$$\rho_1 < \rho_2 < \rho_3 < \dots < \rho_6$$

Rio



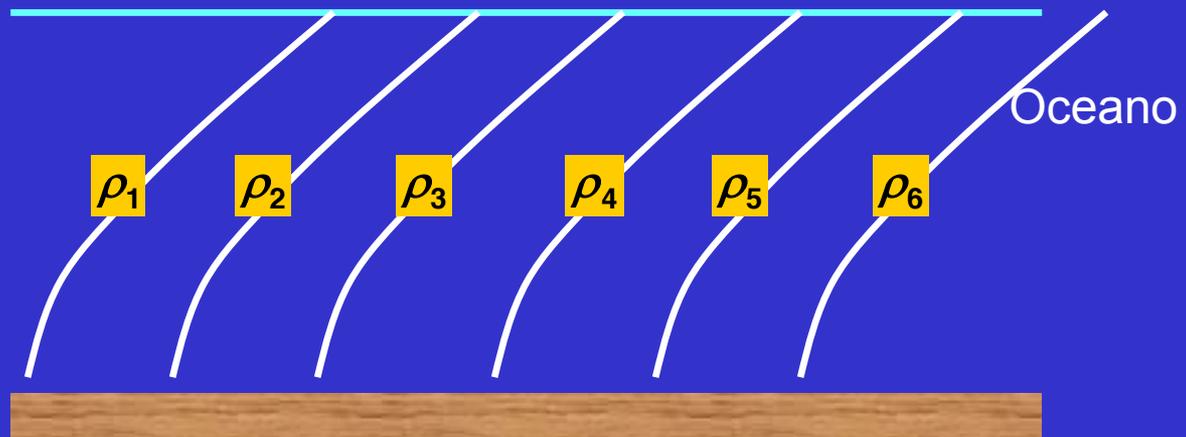
Flujo marea



Reflujo

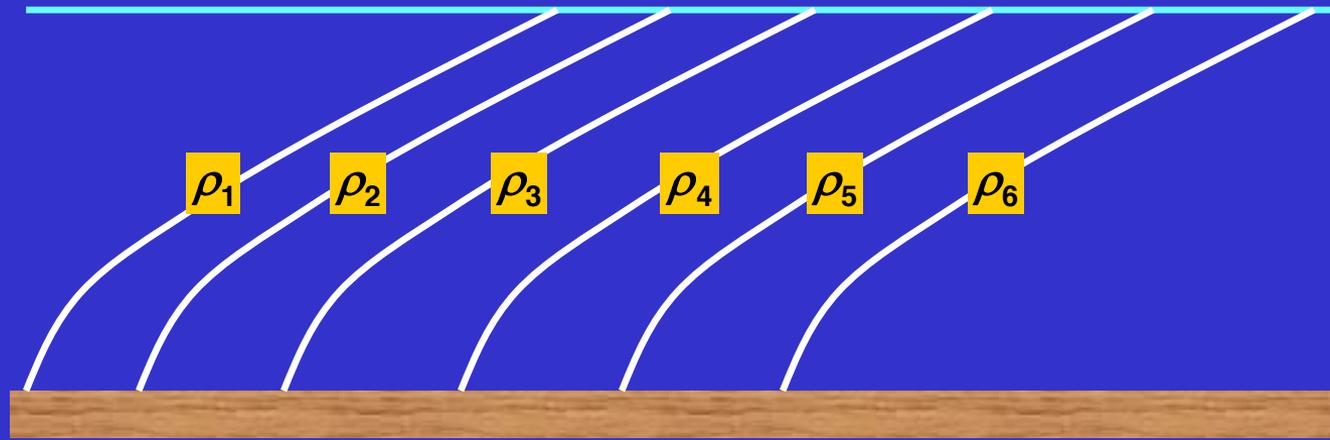


$$\rho_1 < \rho_2 < \rho_3 < \dots < \rho_6$$



Final del refluj

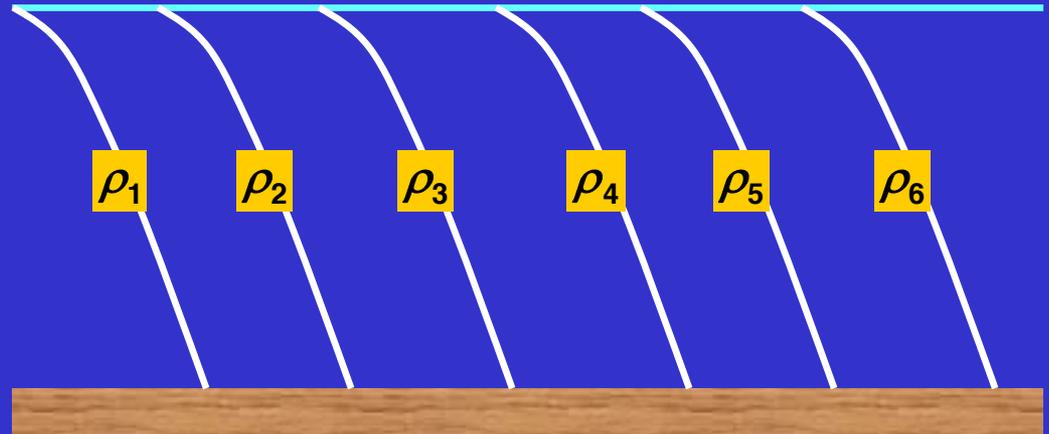
$$\rho_1 < \rho_2 < \rho_3 < \dots < \rho_6$$



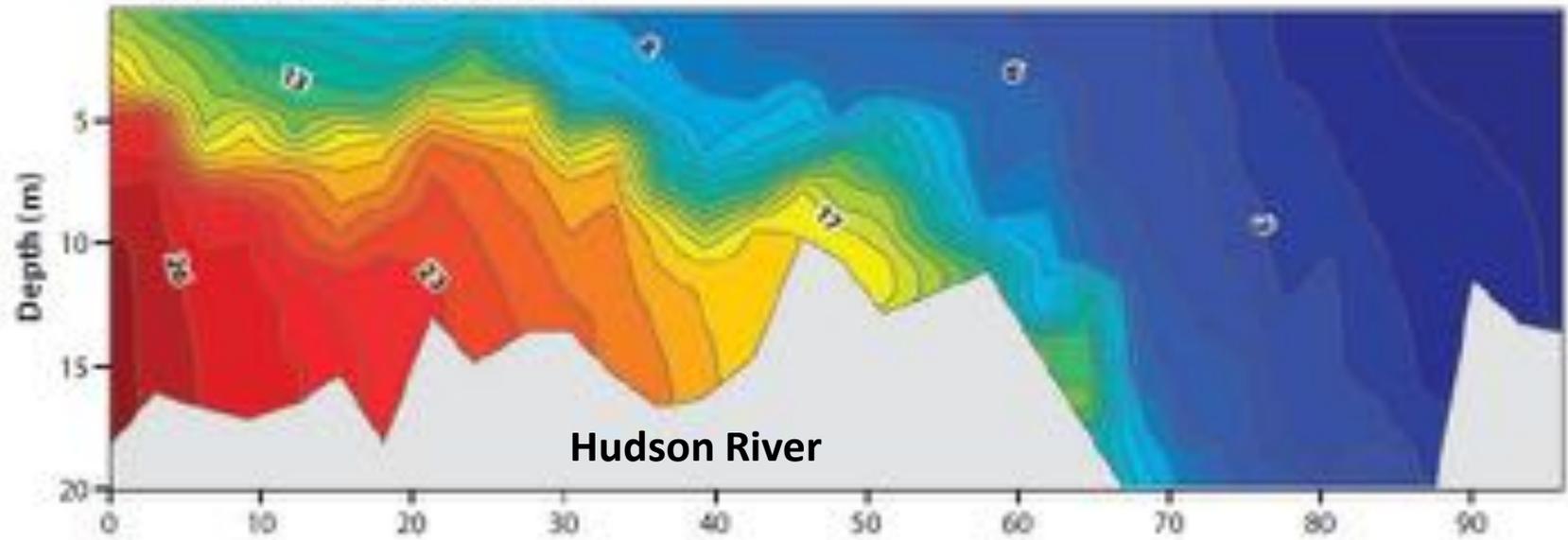
Flujo de marea

Flujo

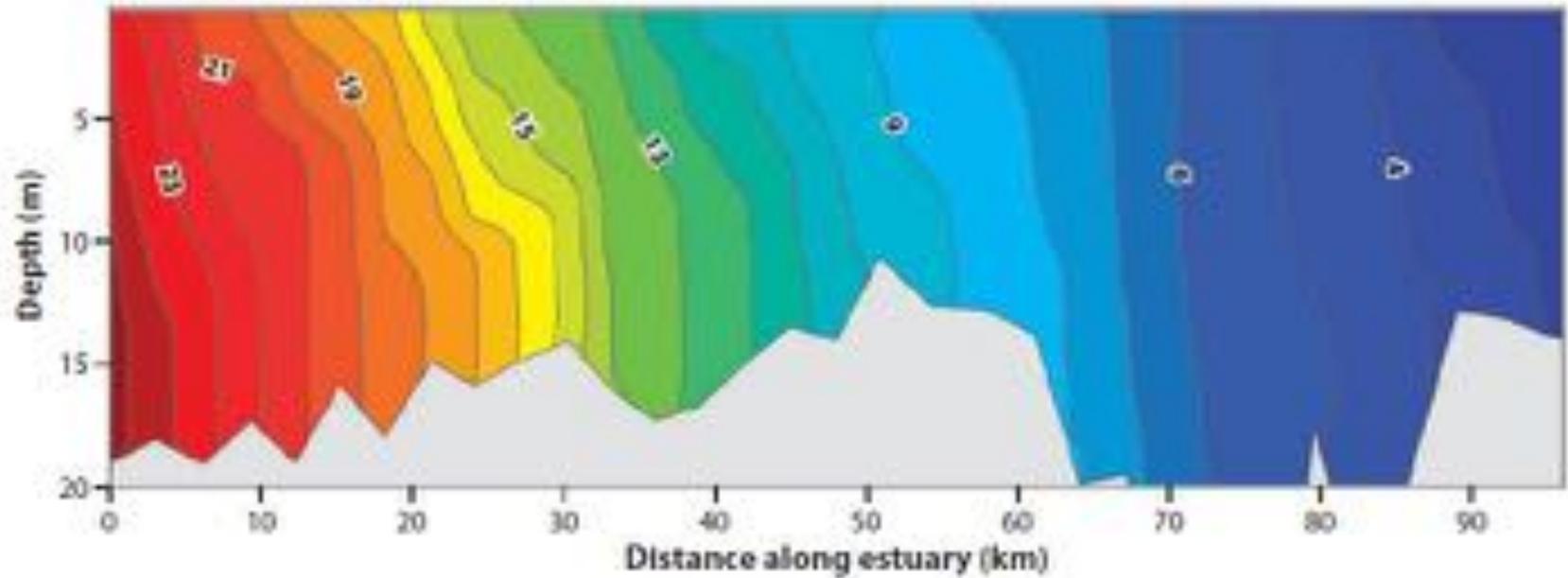
$$\rho_1 < \rho_2 < \rho_3 < \dots < \rho_6$$



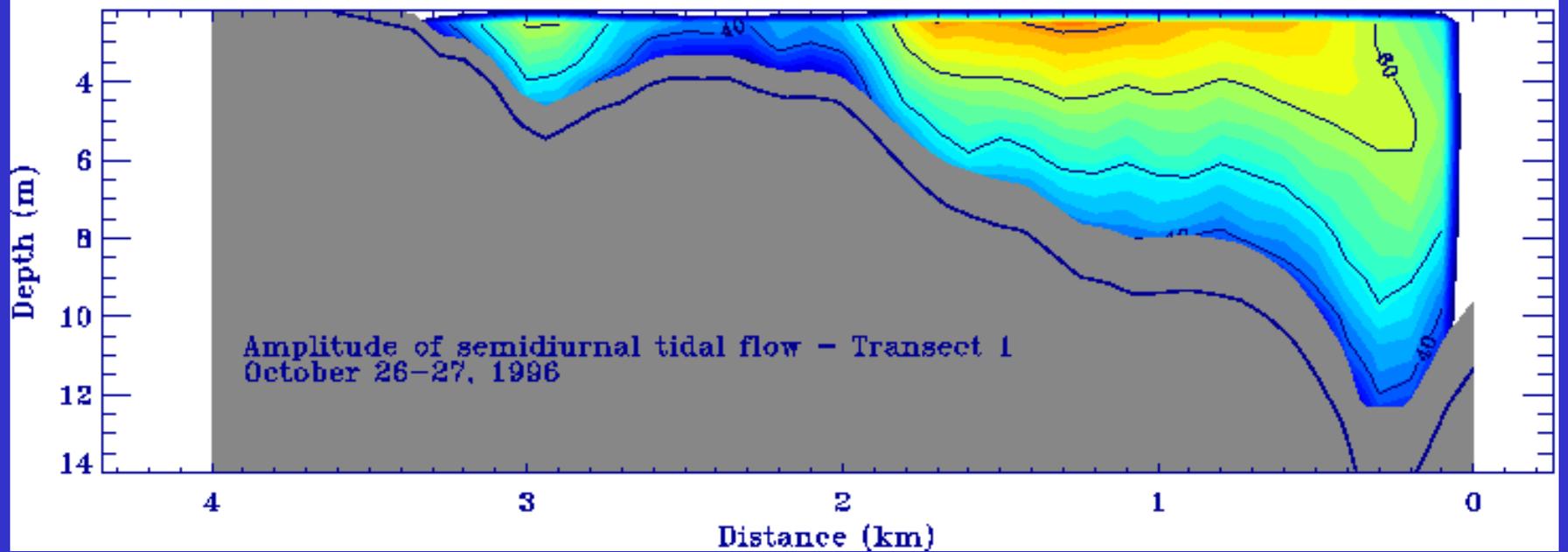
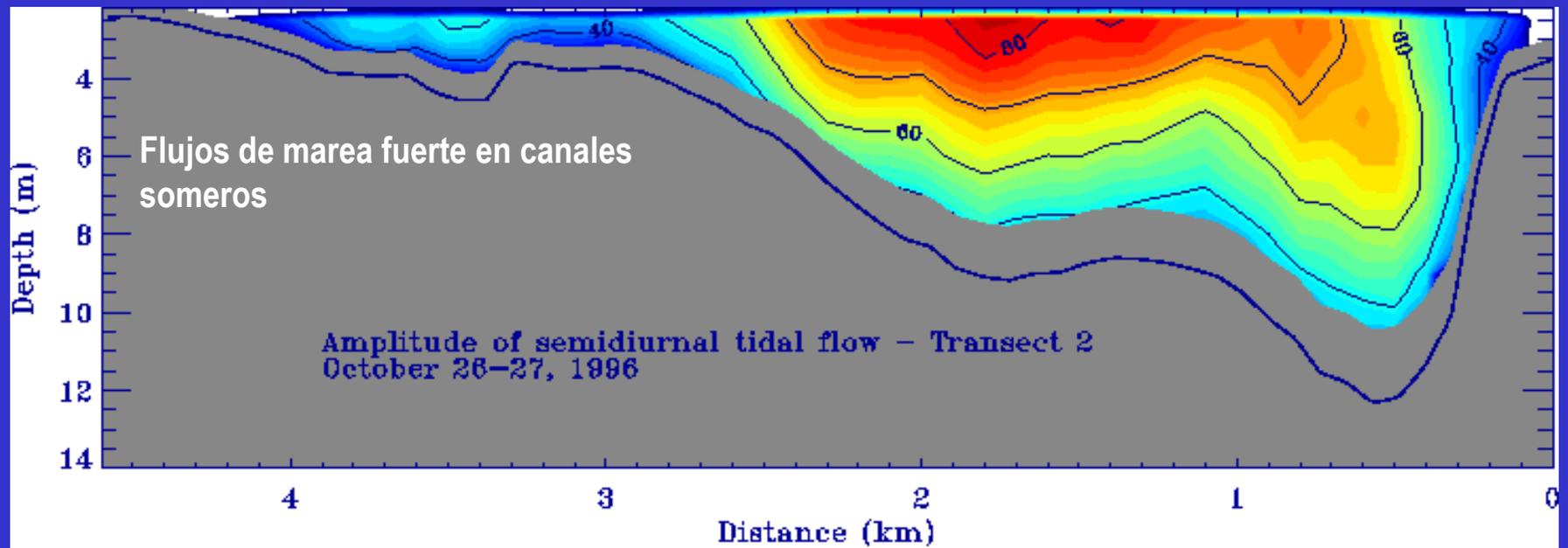
a Neap tide, August 20, 1995



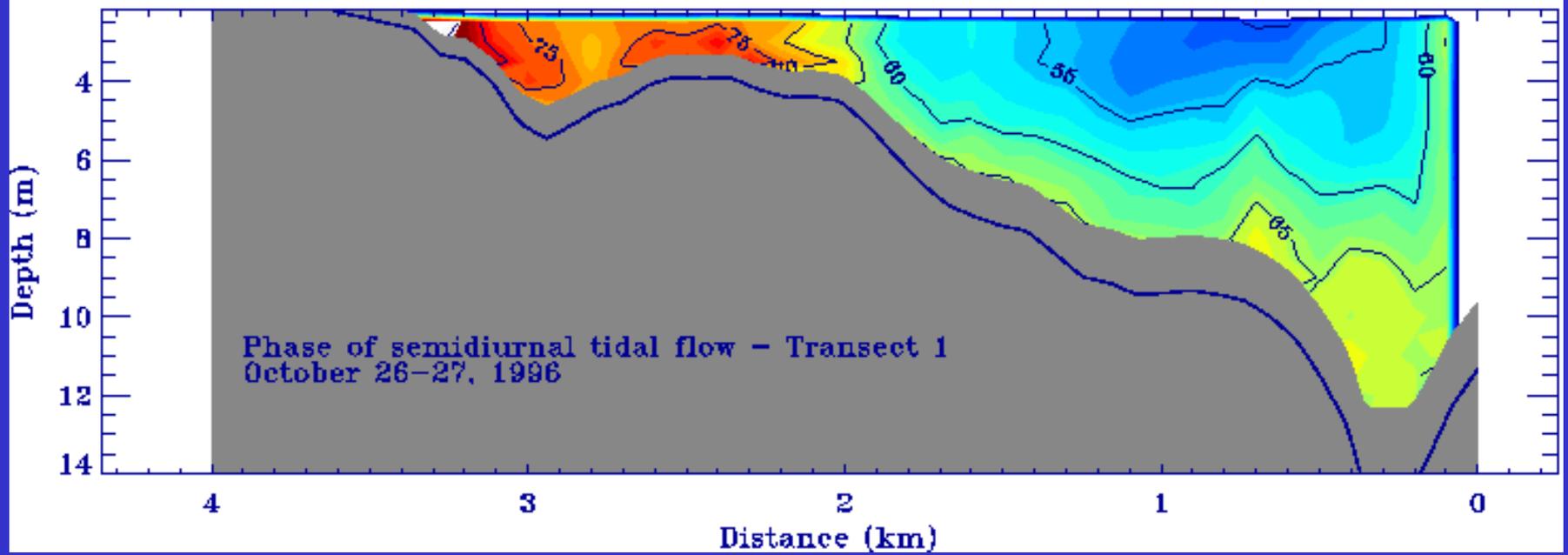
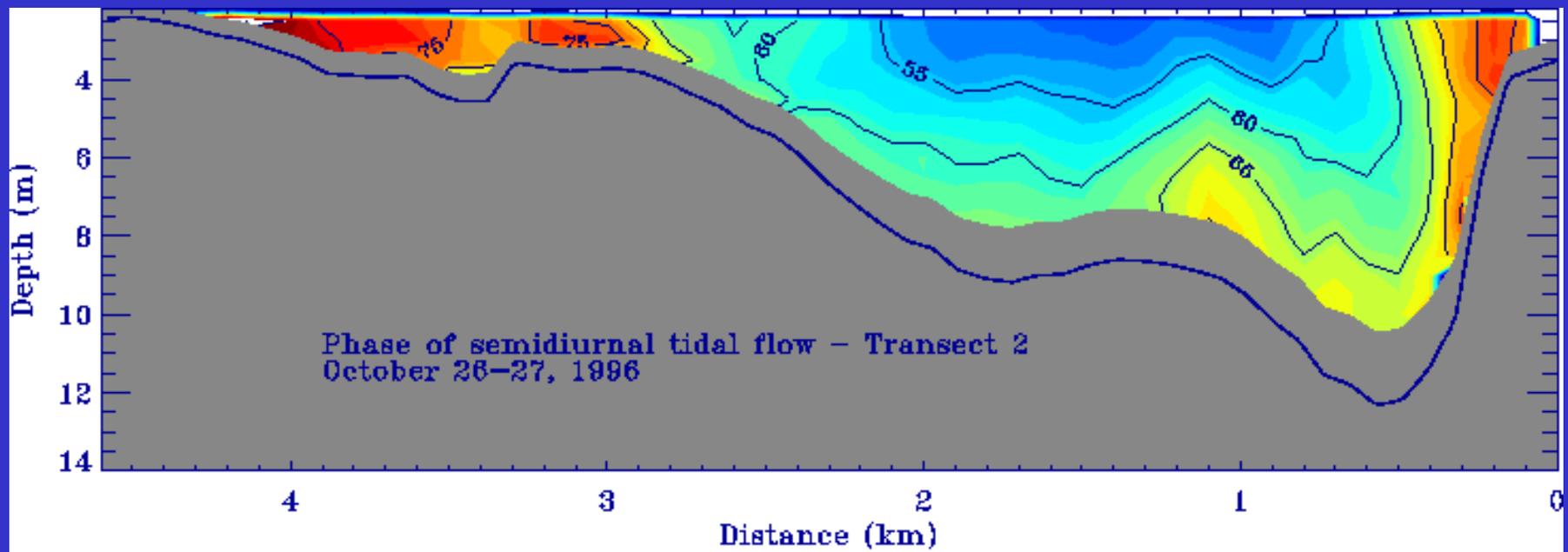
b Spring tide, August 29, 1995





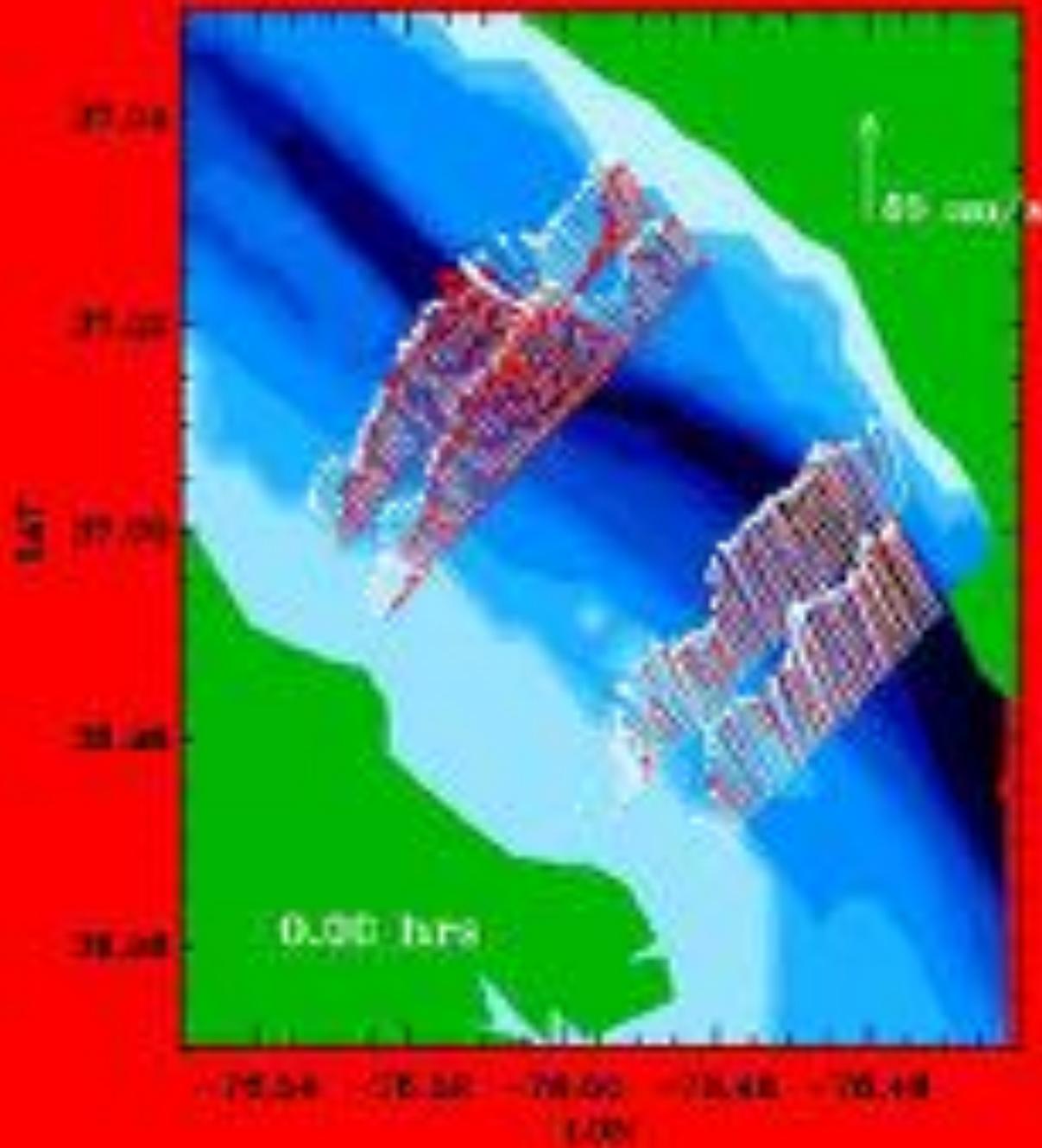


(Mirando hacia el estuario)

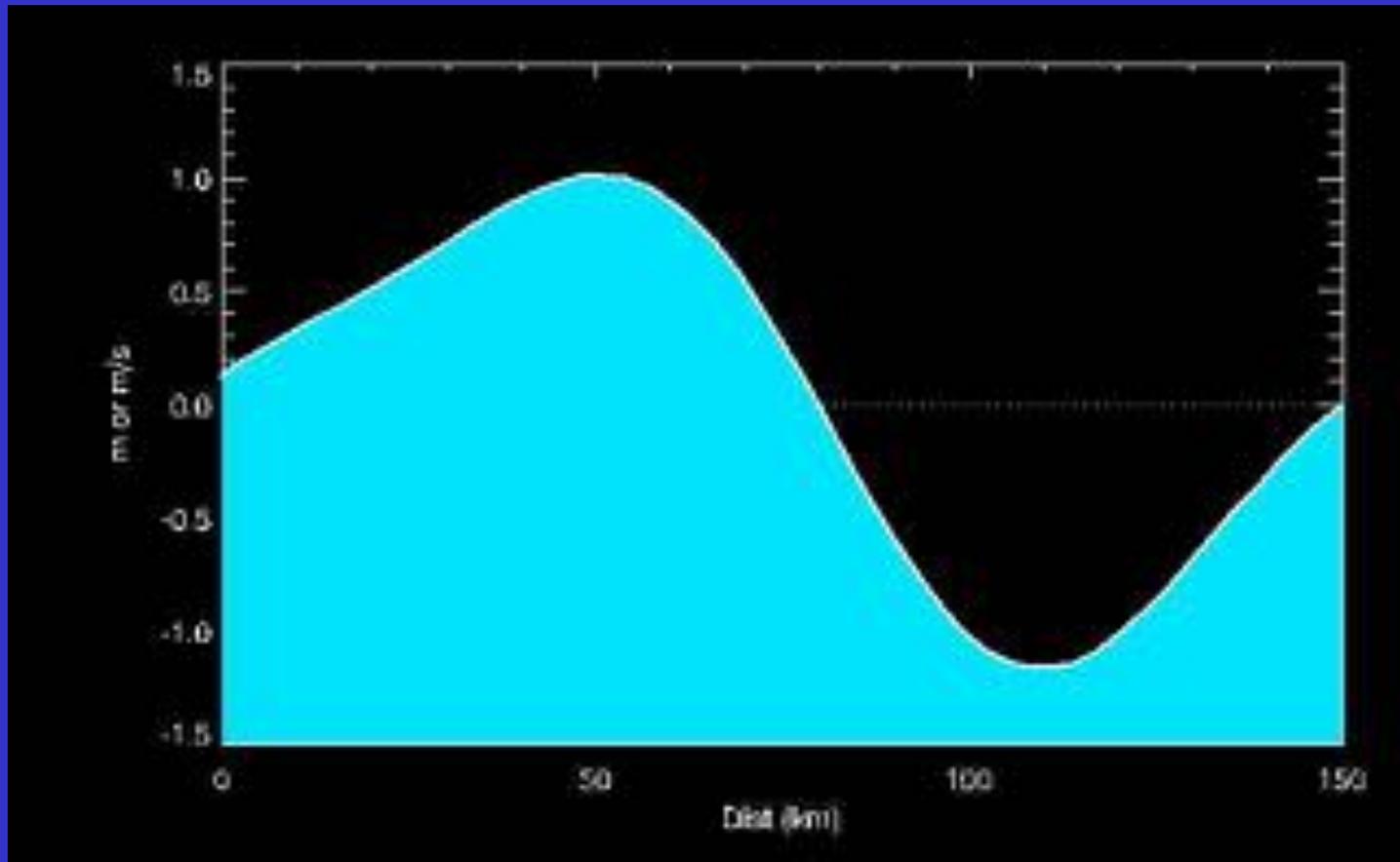


(Mirando hacia el estuario)

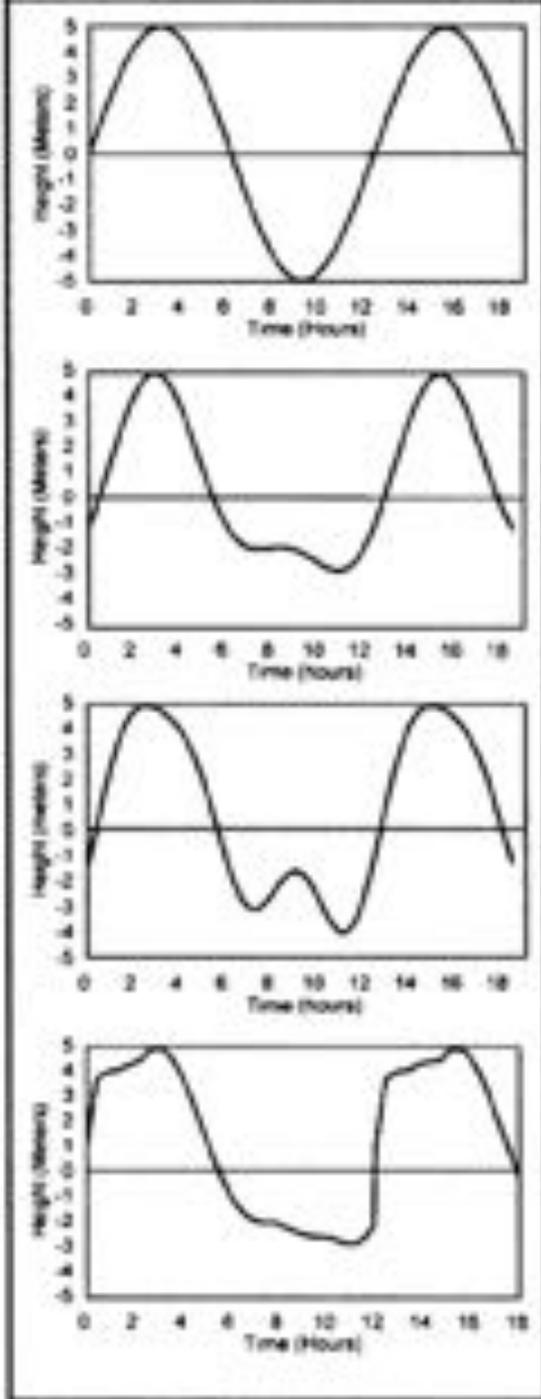
Los flujos de marea son mas fuertes en canales someros



Efectos no lineales de la marea



Rectificación marea = Mareas altas y compuestas



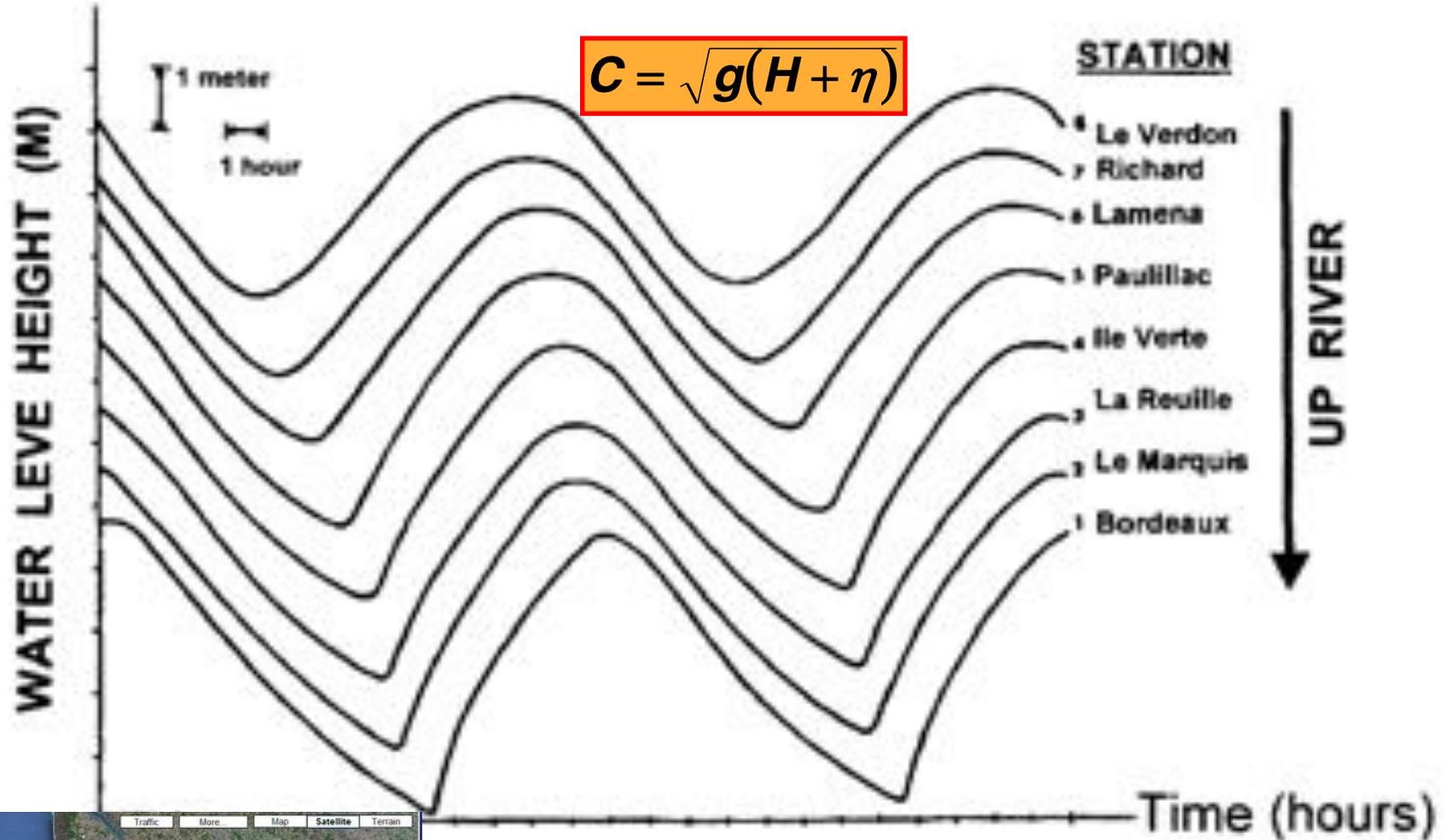
Onda simple (seno, coseno)

Asimetría entre flujo y reflujos

Doble nivel bajo de marea

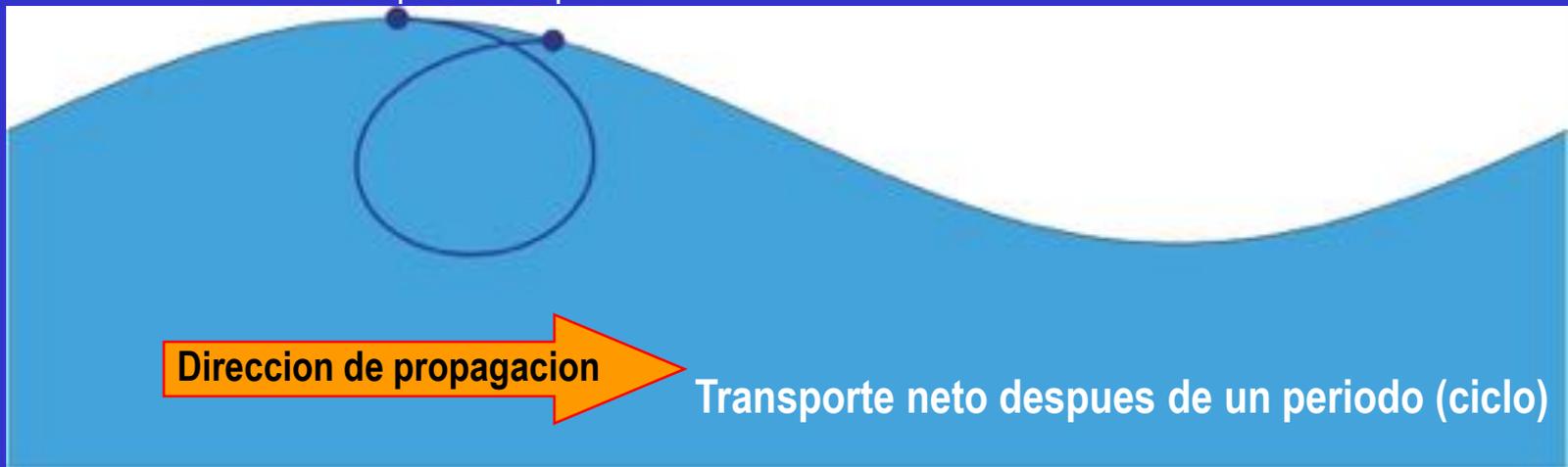
Distorsión extrema: Onda m

Parker (2007)

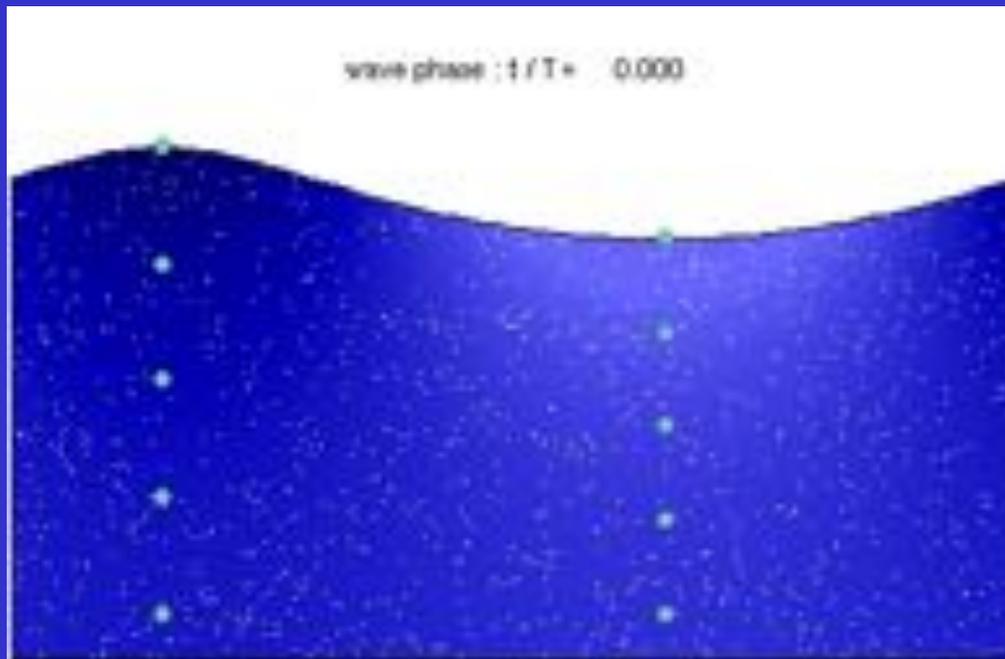


curves from the Gironde River in France showing the effect of refraction. At LeVerdon (just inside the river entrance) the rise to high water is longer than the fall to low water, while at Bordeaux the fall takes 4 times as long as the rise (as worked from George and Simon, 1984.) Parker (2007)

Marea residual en sistemas homogéneos

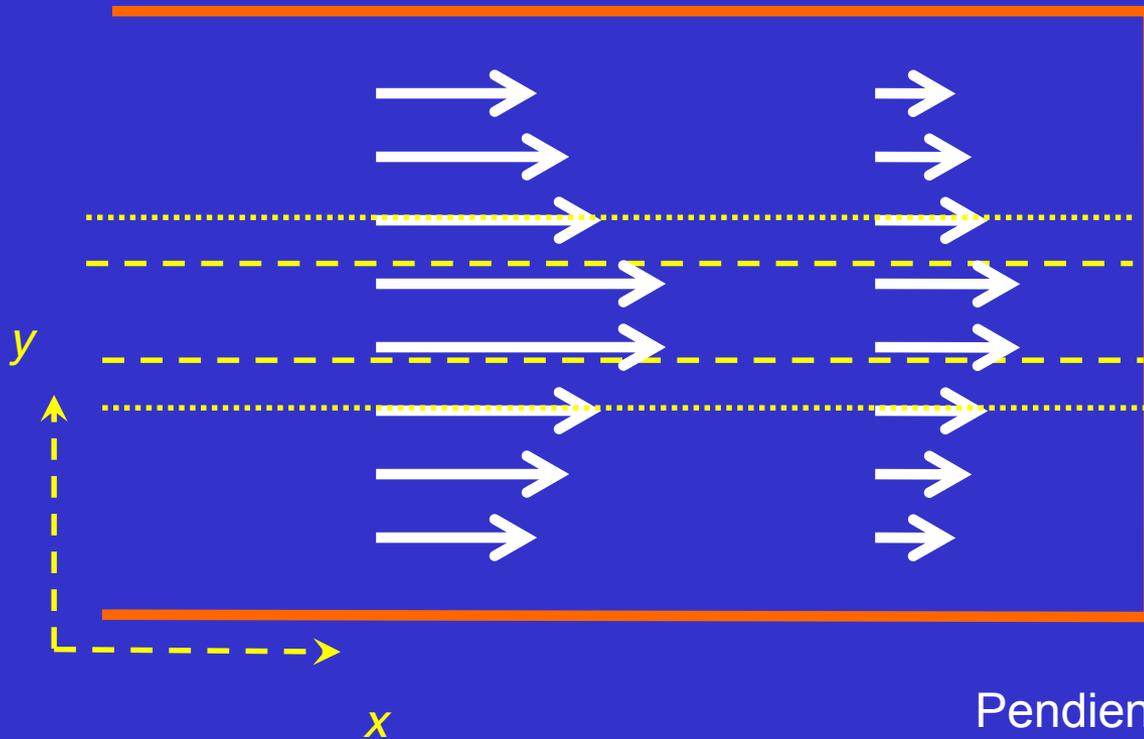


Desplazamiento Neto = Deriva de Stokes (covarianza entre la marea y la corriente)



Animación de GREEN EARTH WORLD POWER (gewp.org)

Gradientes en un flujo de marea (fondo triangular)

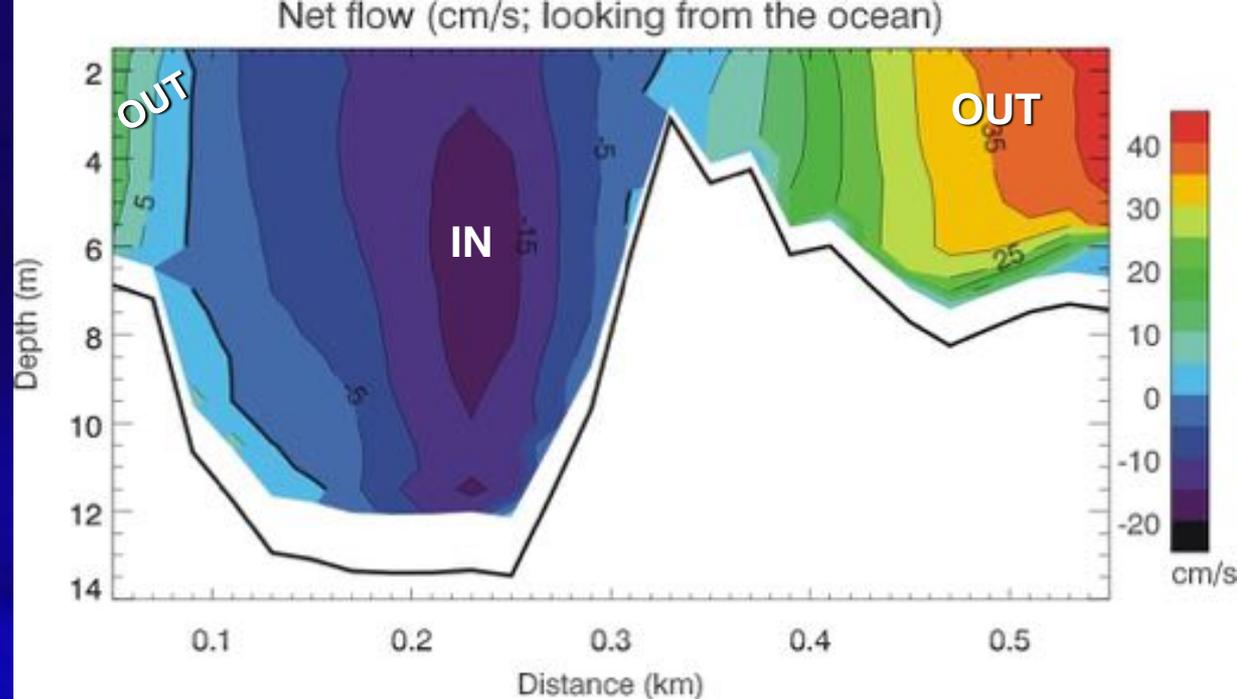


Pendiente residual

$$U_T = U_{Stokes} + U_{gradients} + U_{set-up}$$

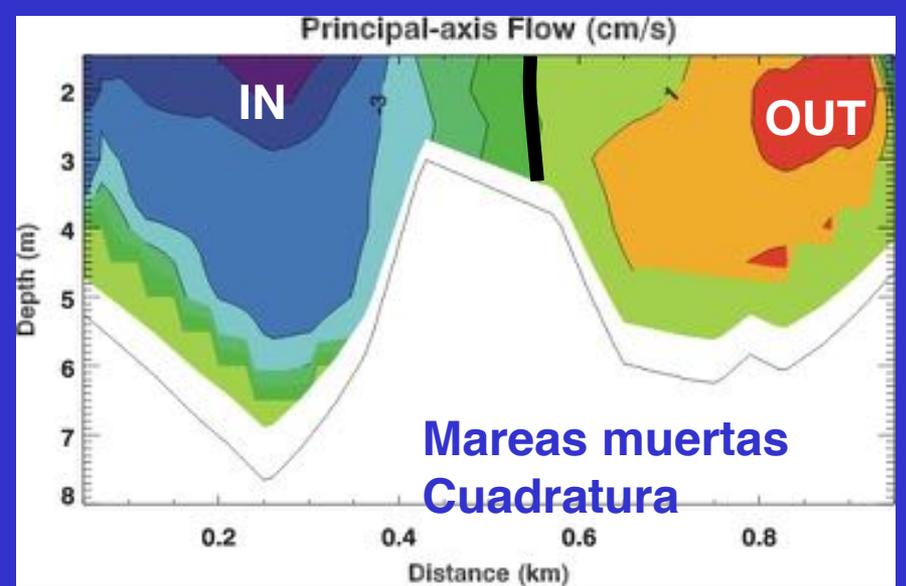
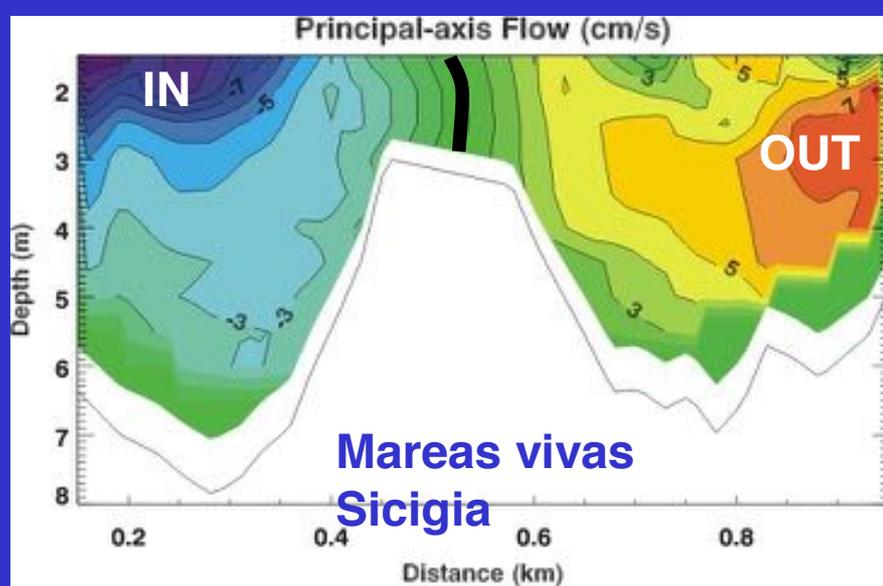
De mareas y corrientes

Ejemplos de marea residual influenciada por la batimetria en un canal corto



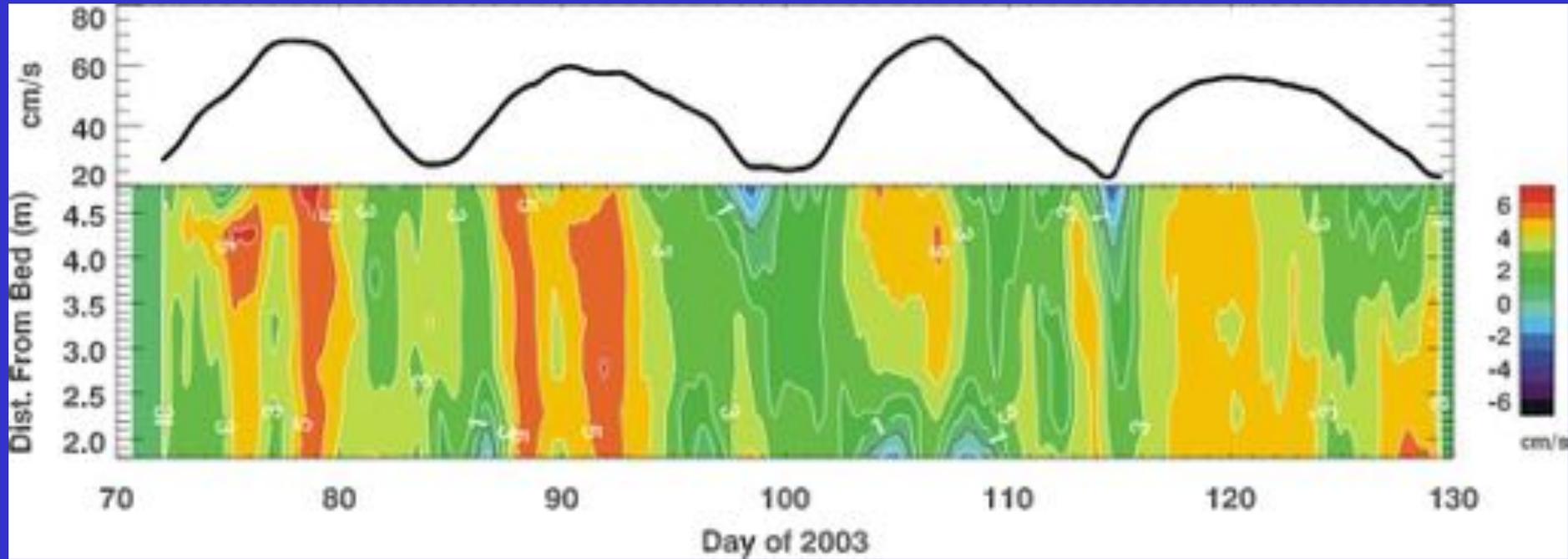
Rojo y amarillos indican regiones de salida de flujo neto mientras azul denota regiones de entrada de flujo

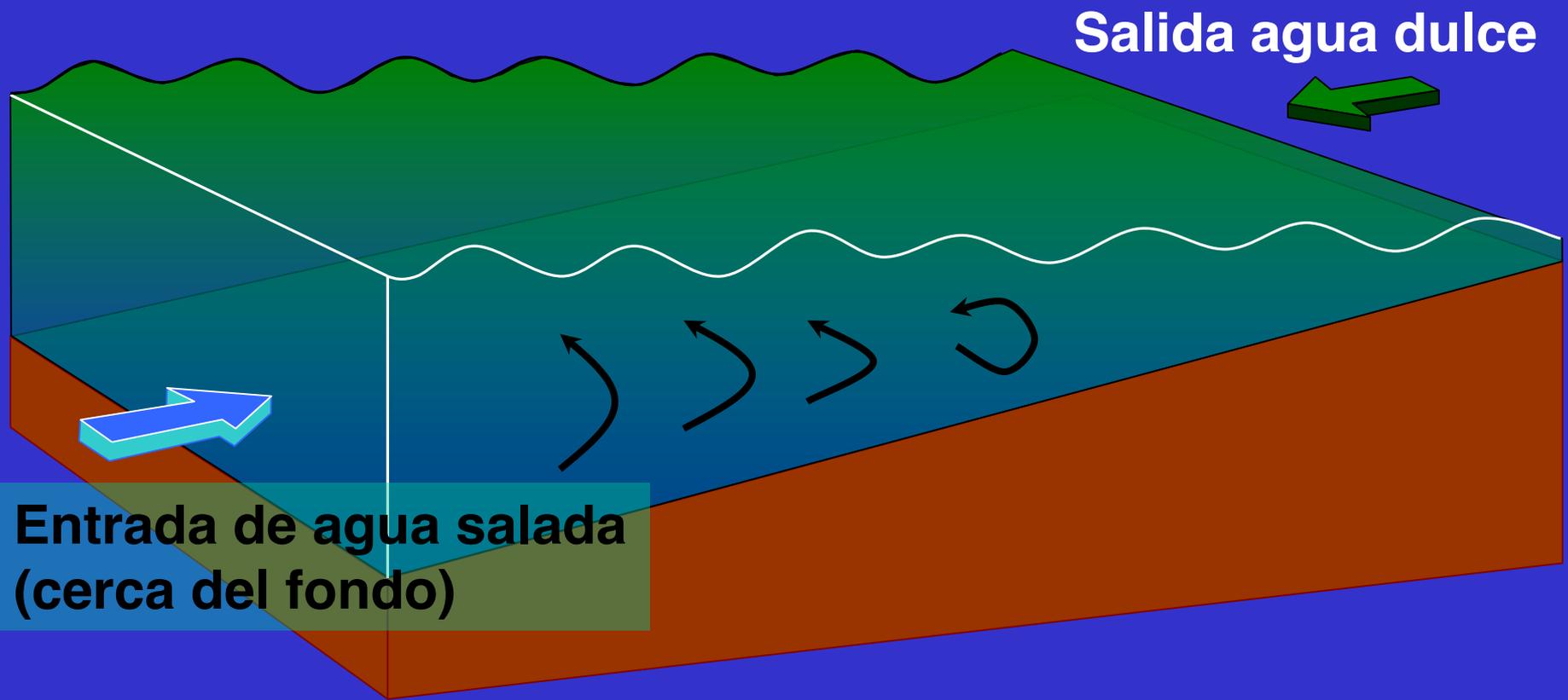




Ensenada de la Paz

Modulación quincenal de residuales de marea en Ensenada de la Paz



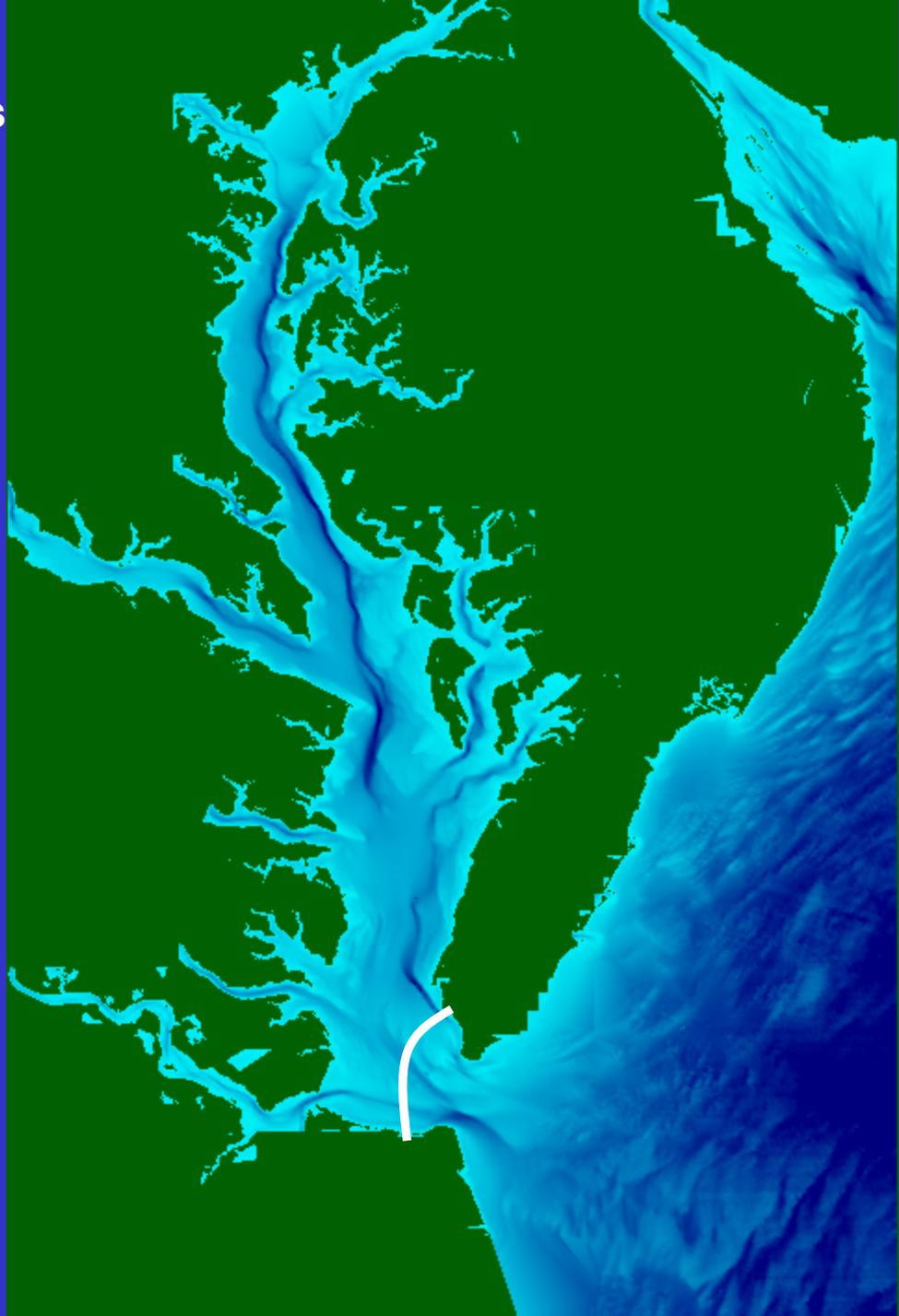


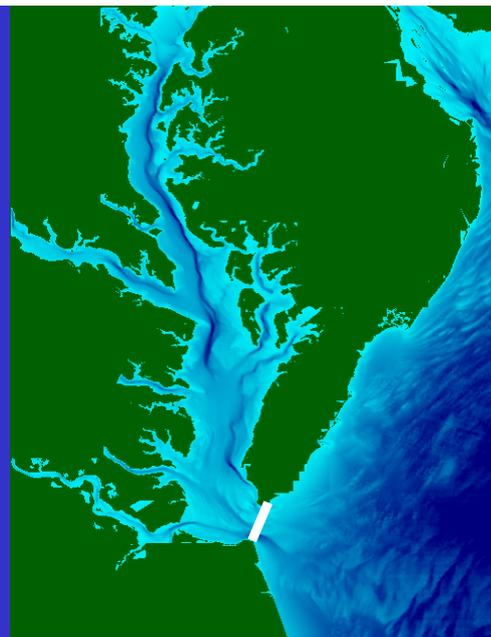
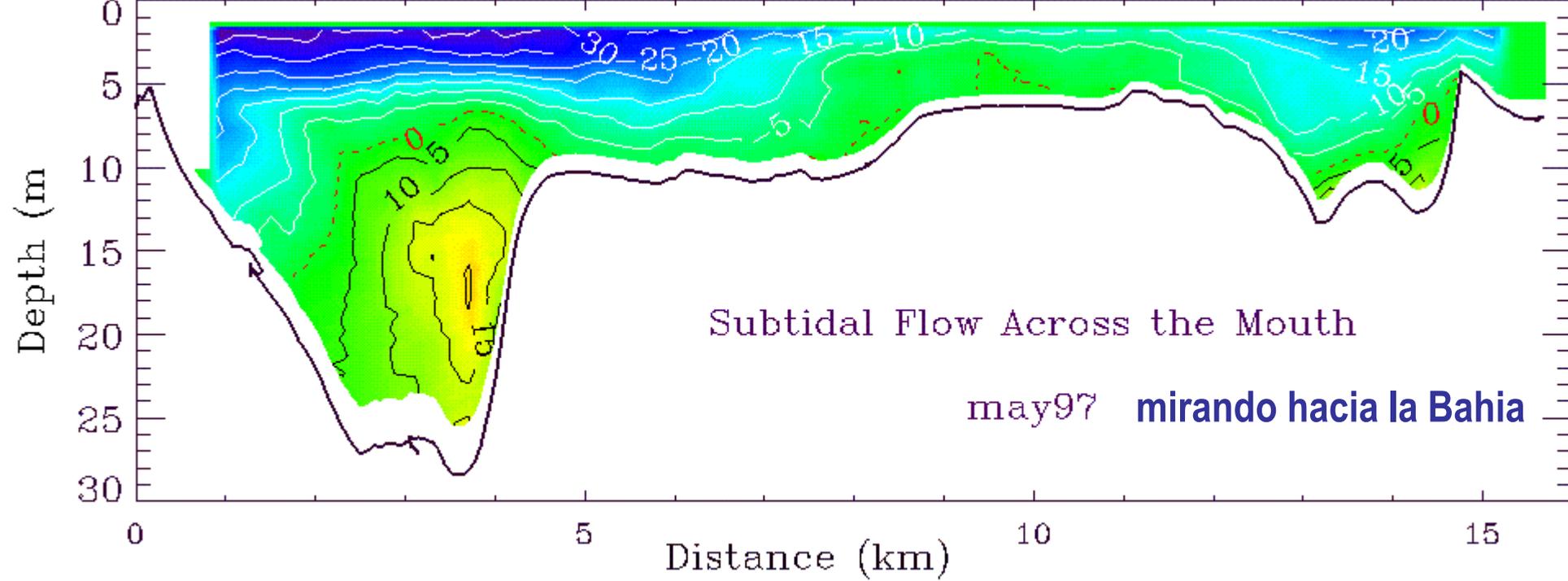
A lo largo del estuario:

**Gradiente de presión balanceado por la fricción
(Pritchard, 1956)**

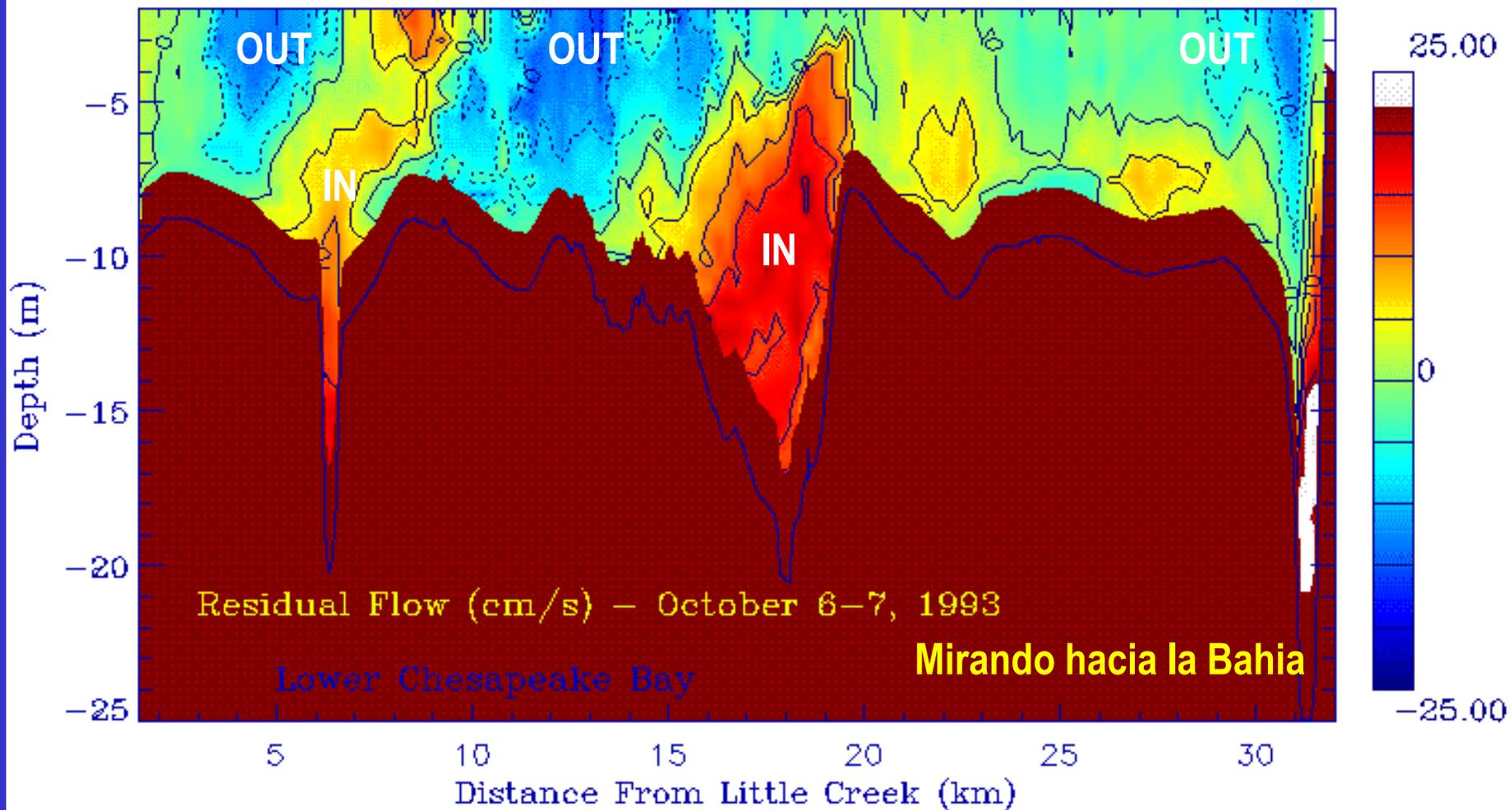
Efecto de los canales en flujos

Inducidos por la densidad



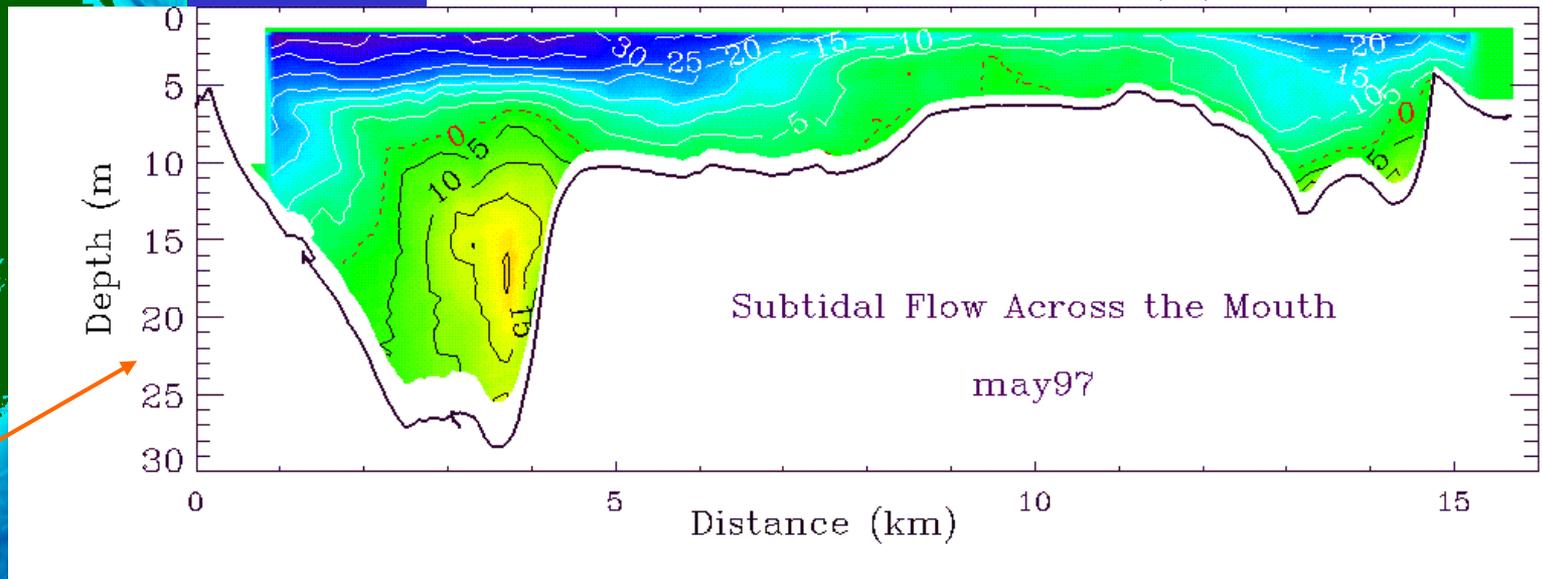
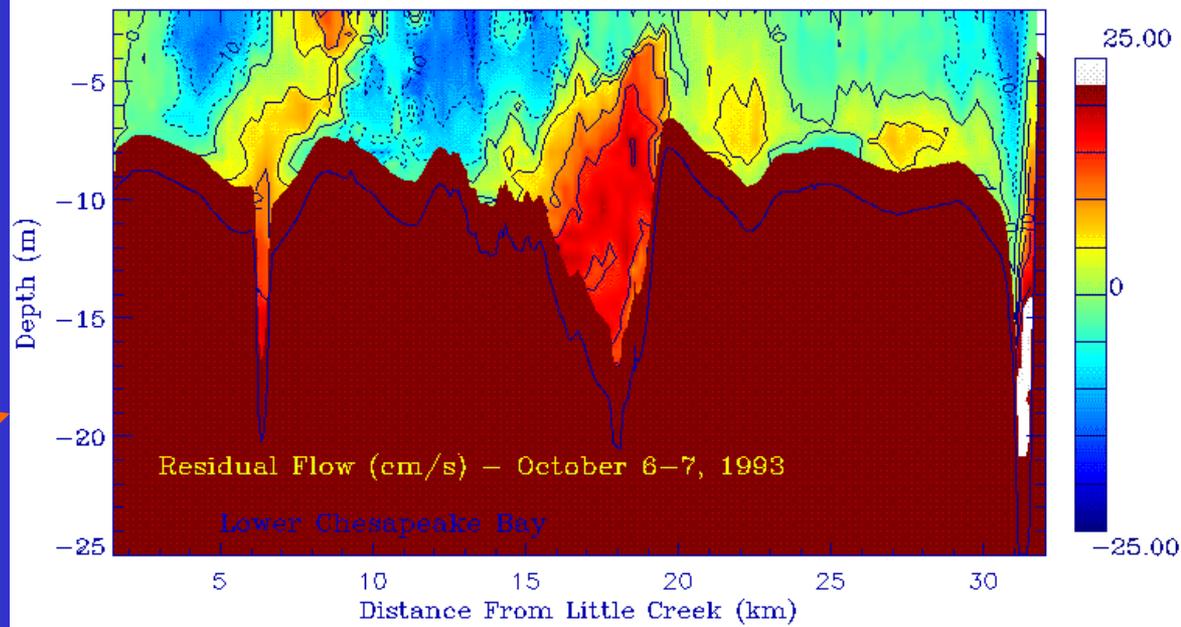
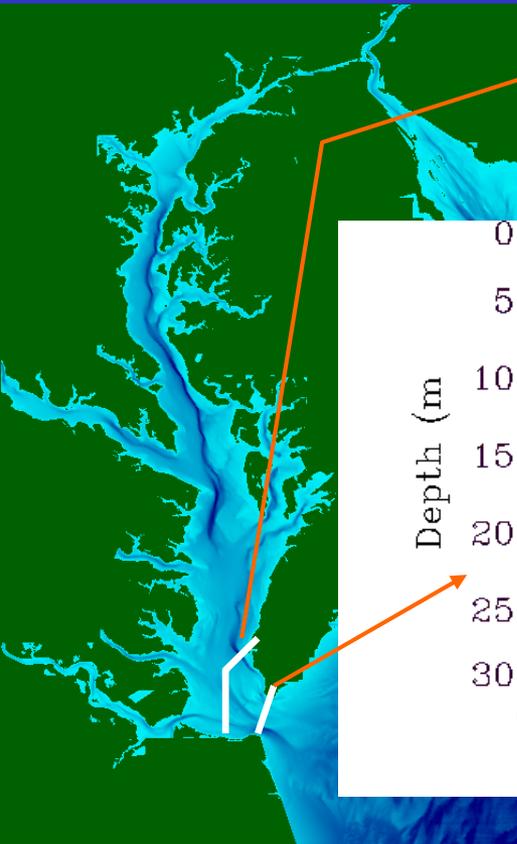


Mirando hacia el mar
 Superficie salida de flujo;
 Fondo entrada



Salida de flujo en lugares someros;
Entrada de flujo en los canales

Bahia de Chesapeake

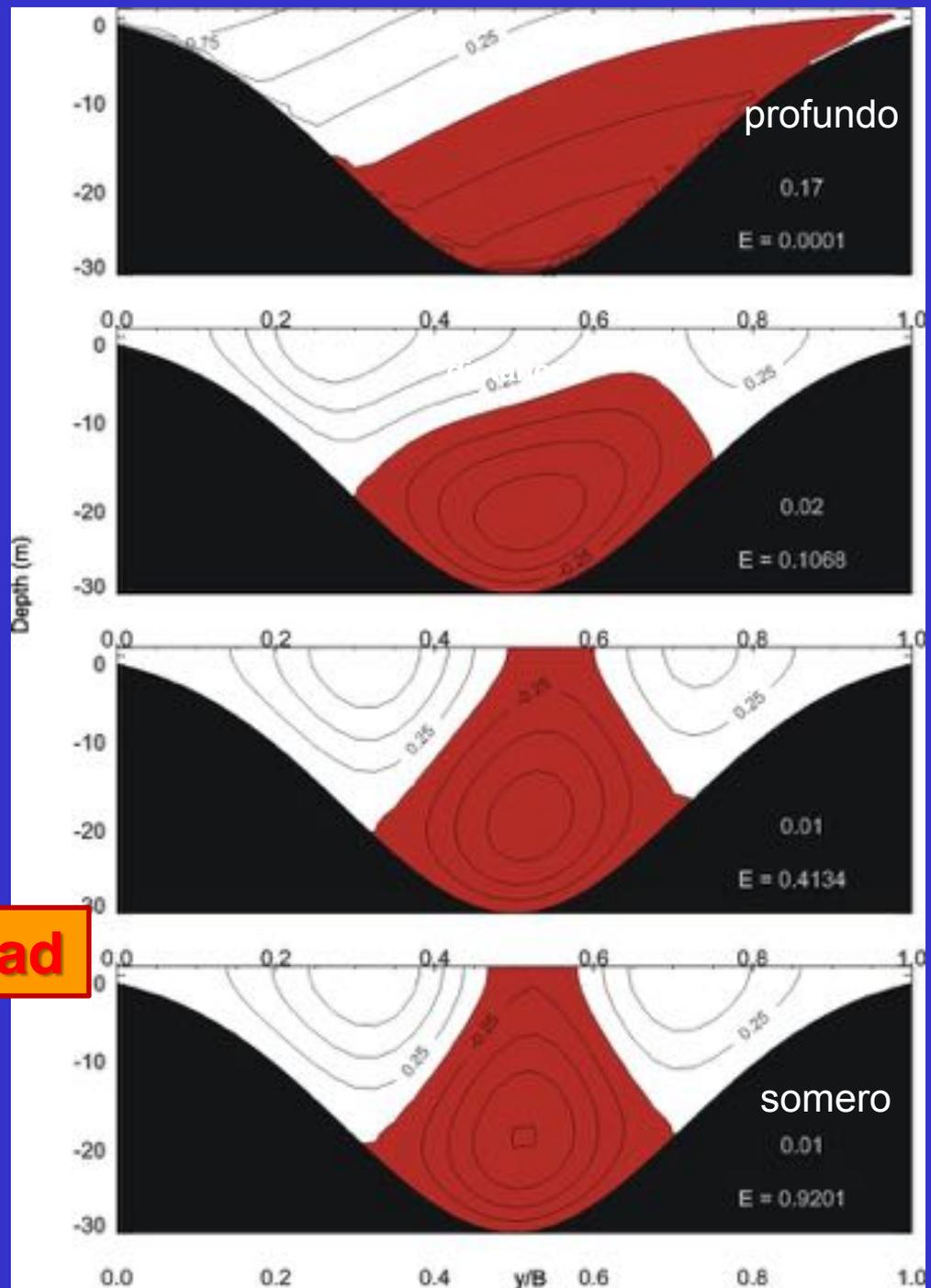


Fricción/Coriolis

$$E = A_z / (f H^2)$$

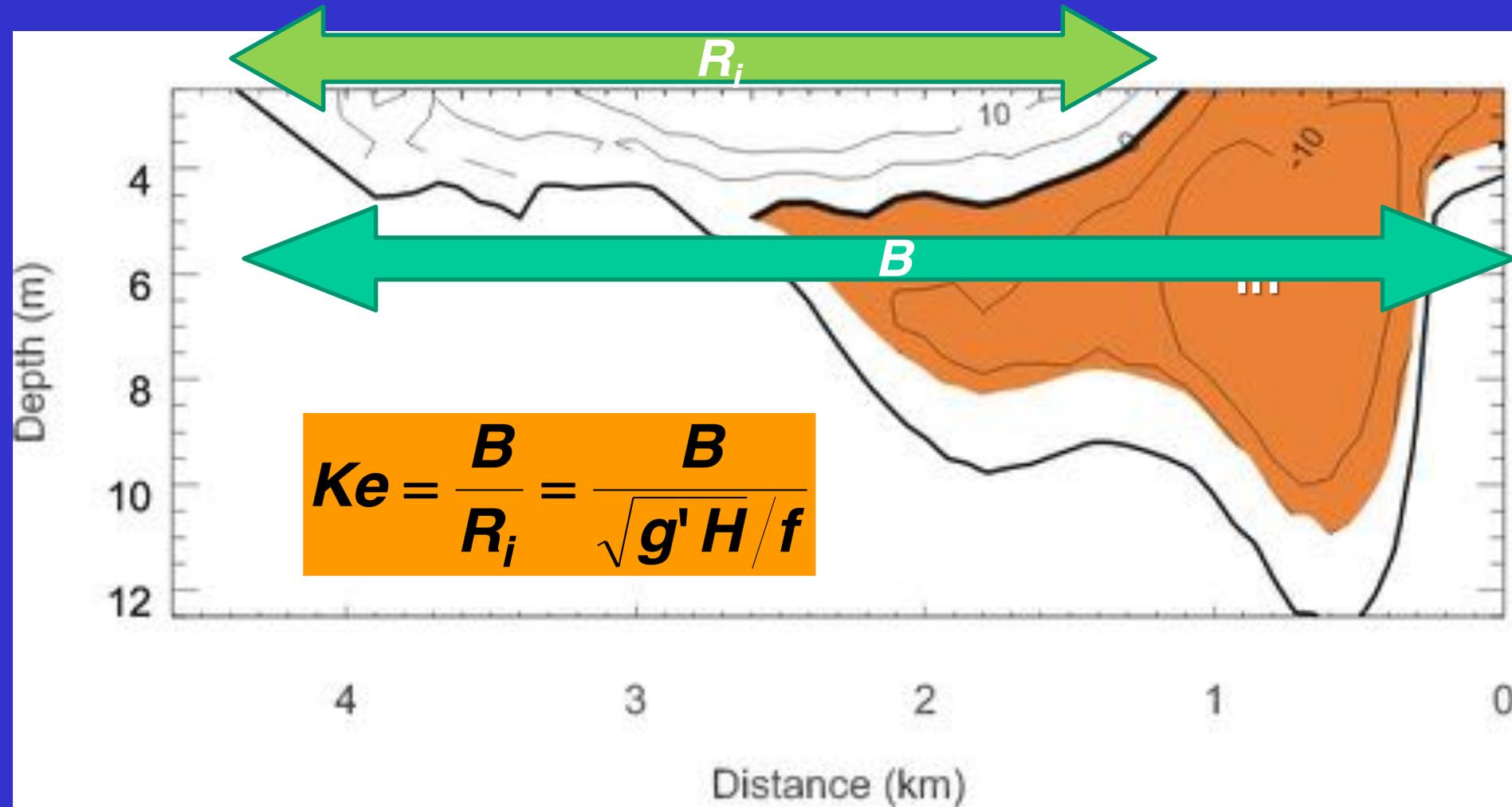
Incrementa fricción

Incrementa Coriolis



Es importante la **Profundidad**

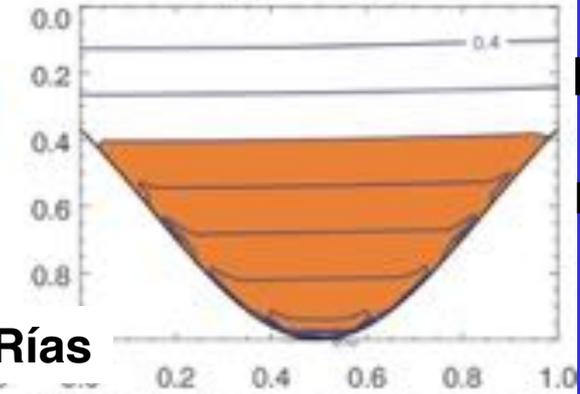
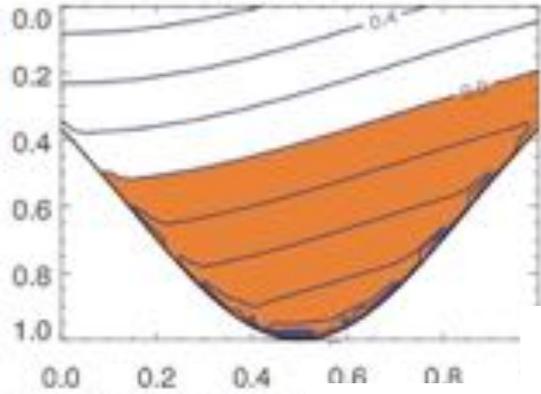
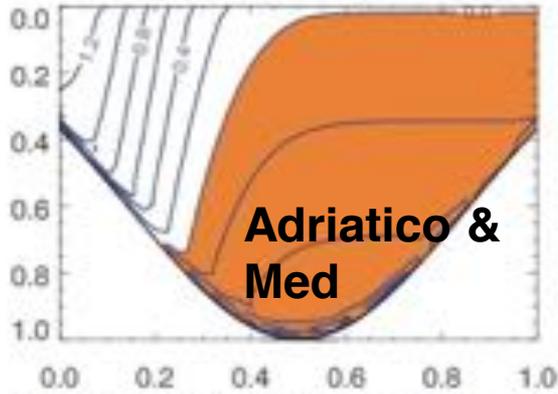
(rojo salida de flujo; blanco entrada de flujo)
(los contornos son normalizados con el
máximo flujo)



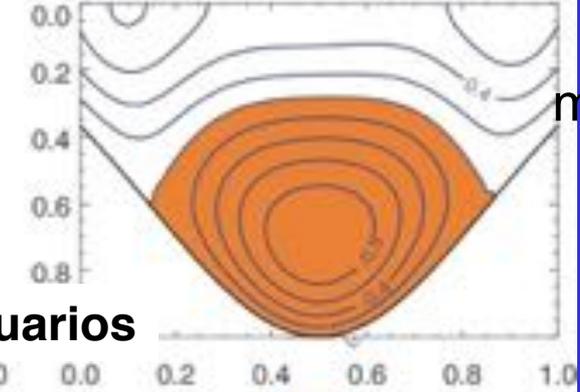
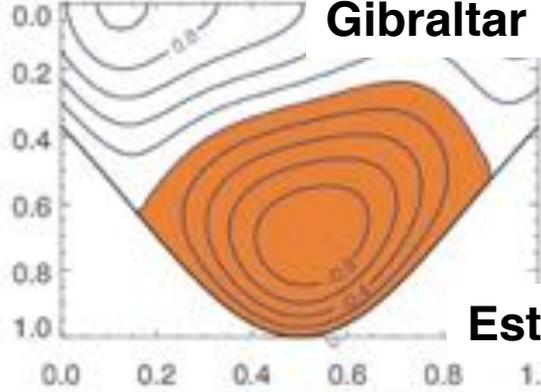
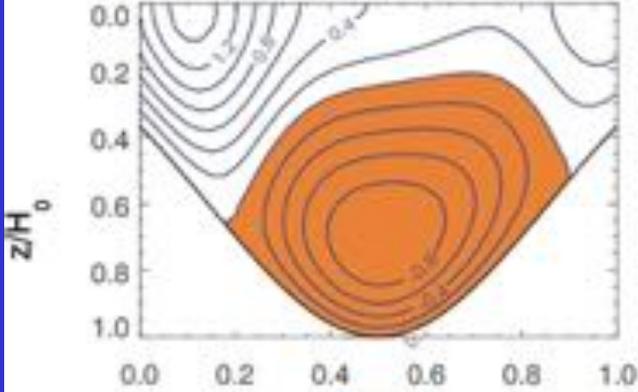
$Ke = 4$ (ancho)

$Ke = 1$

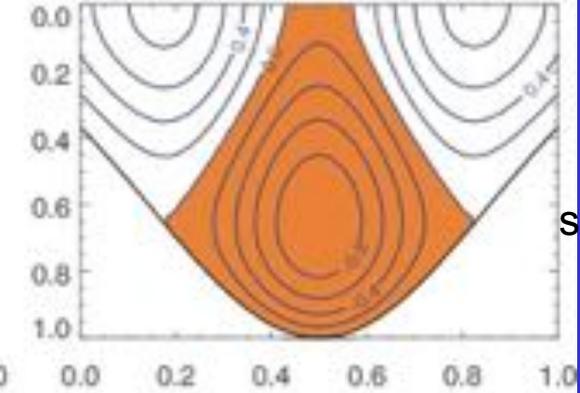
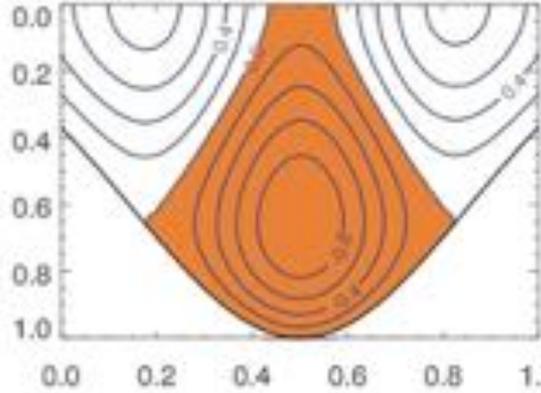
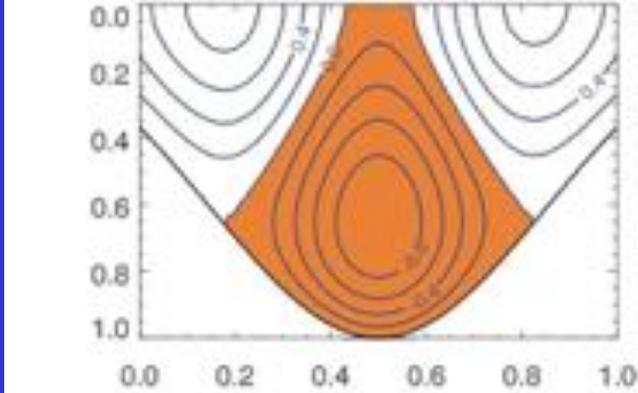
$Ke = 0.25$ (angosto)



Bajo
E
prof



medio
E

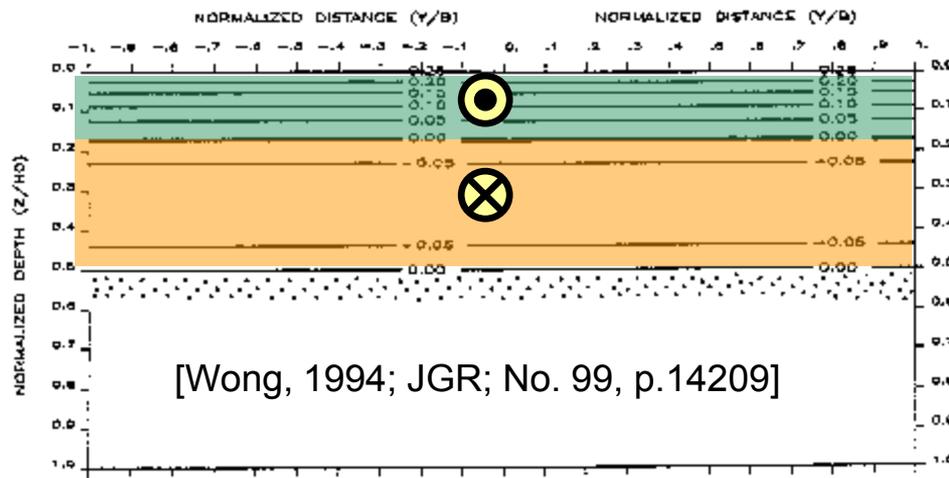


alto
E
somero

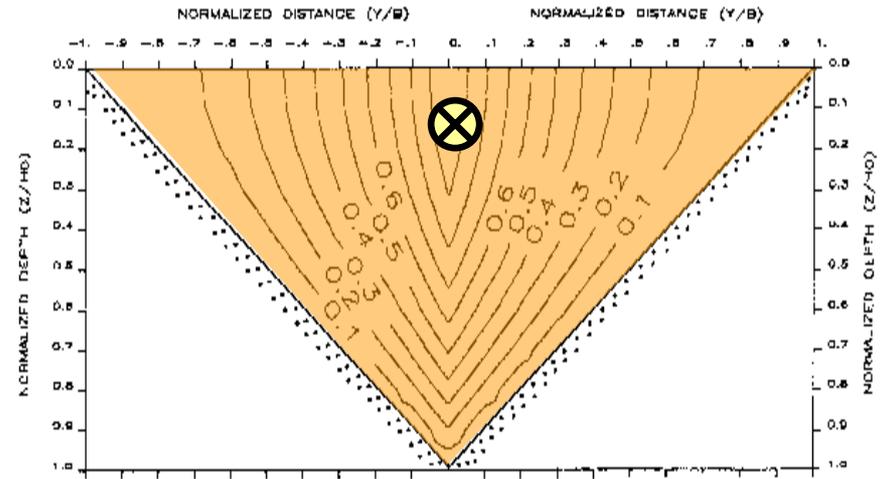
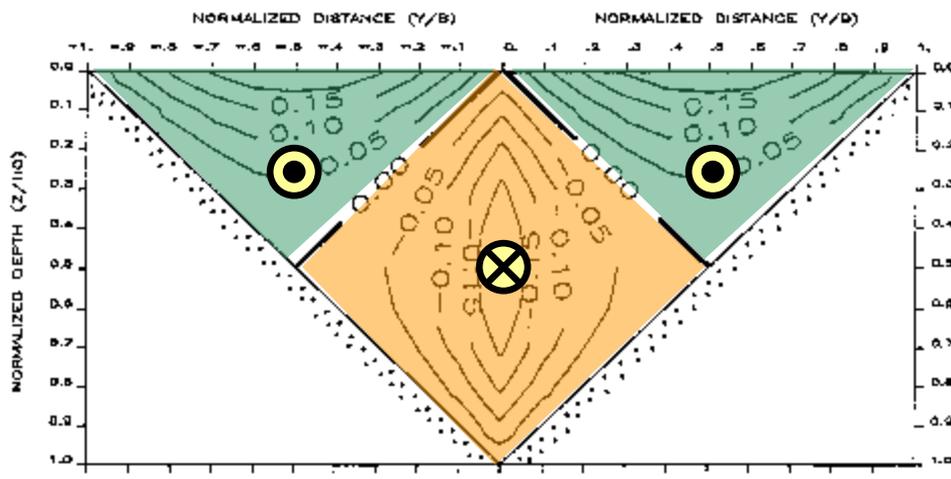
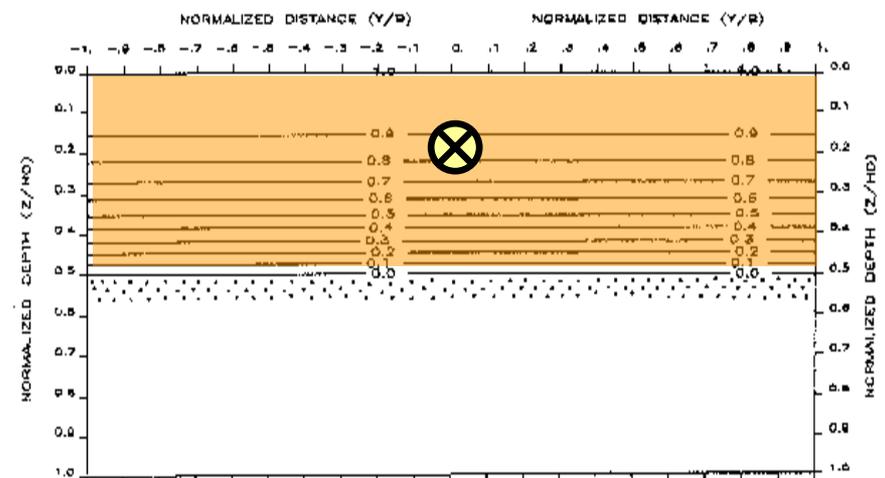
$Ke = B/R$

$E = A_z / (f H^2)$

Flujo inducido por el viento



[Wong, 1994; JGR; No. 99, p.14209]

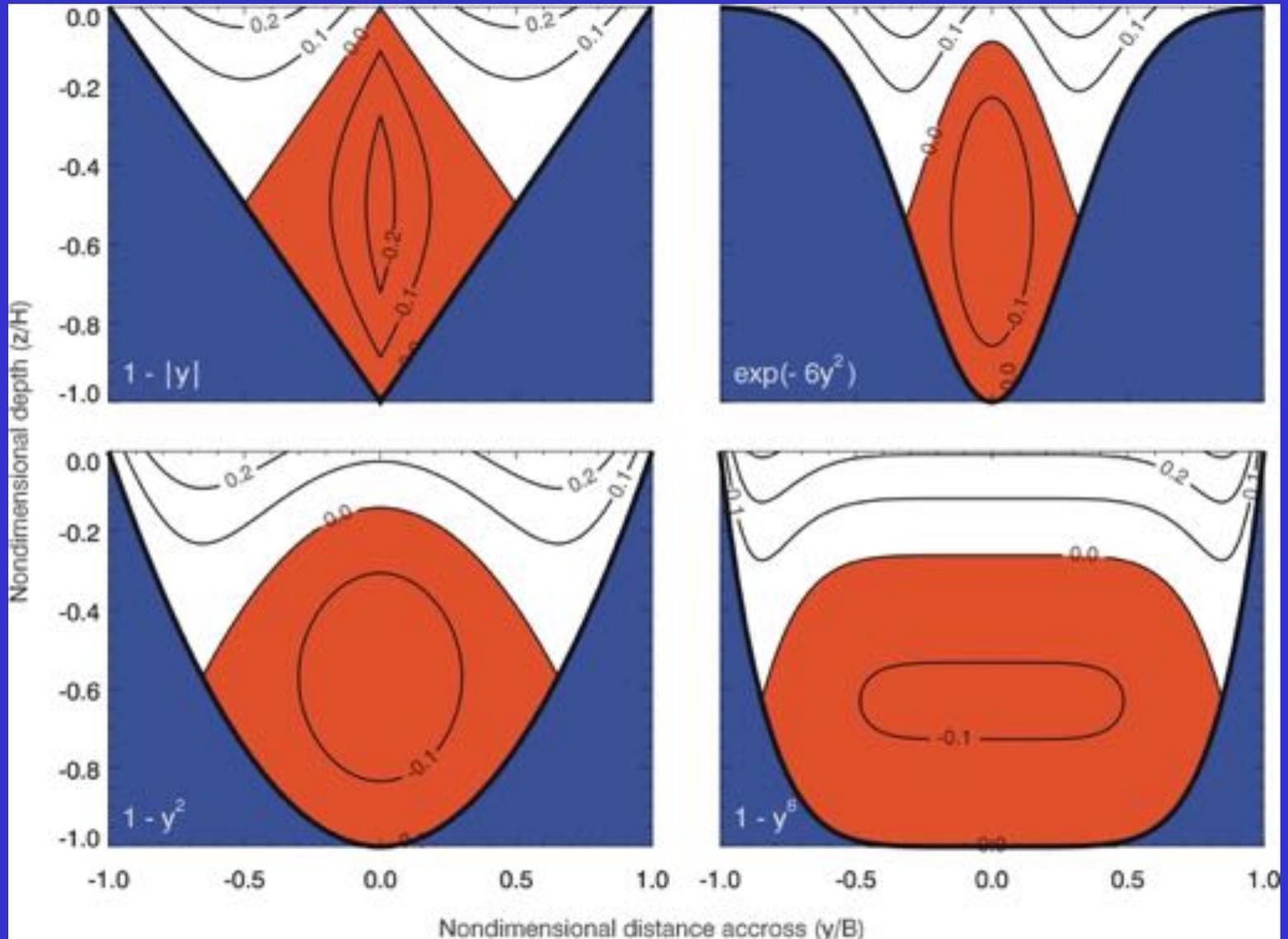


Efectos locales

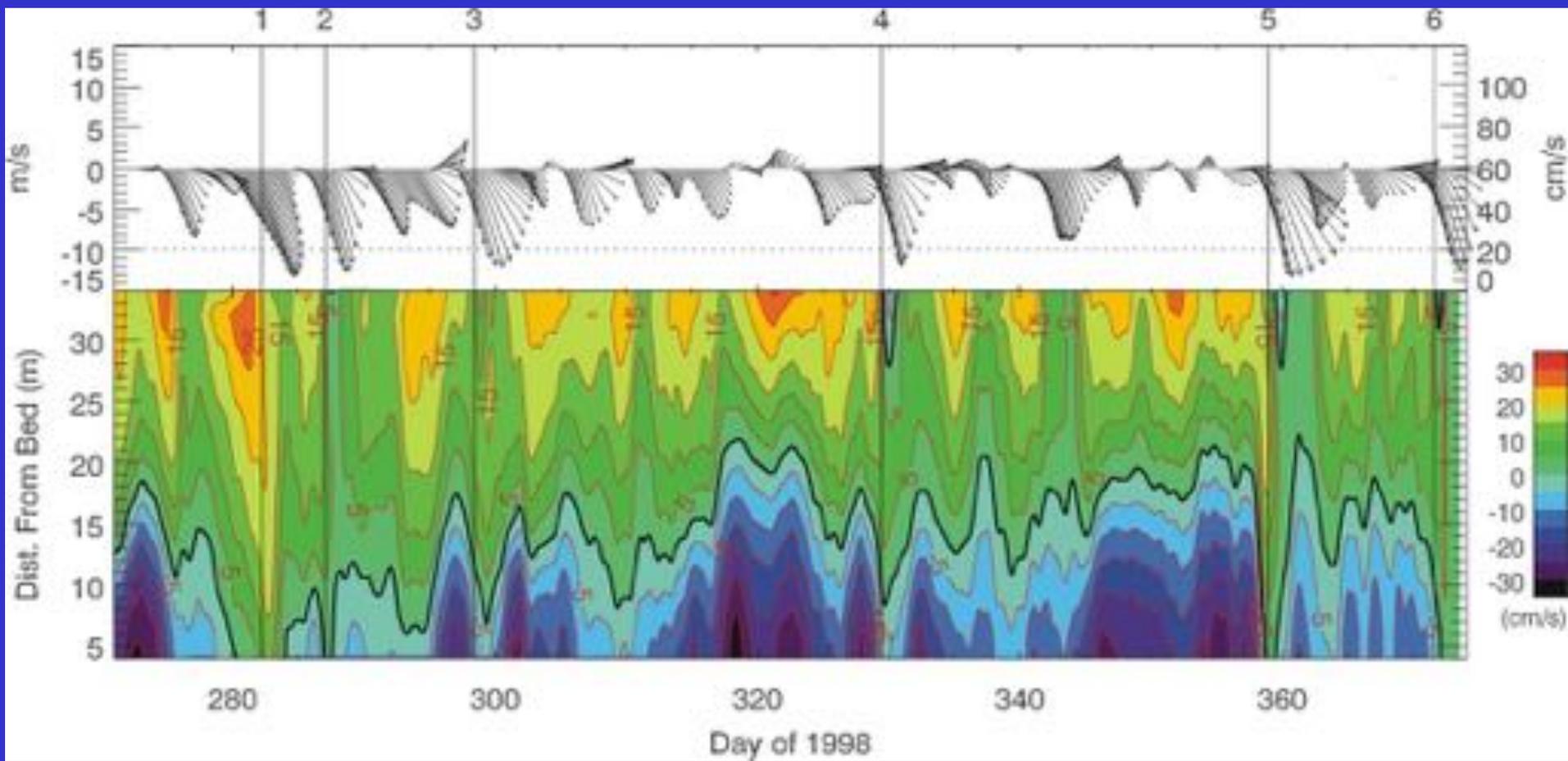
Efectos remotos

A lo largo del estuario: Gradiente de presión + fricción

Winant (2004)

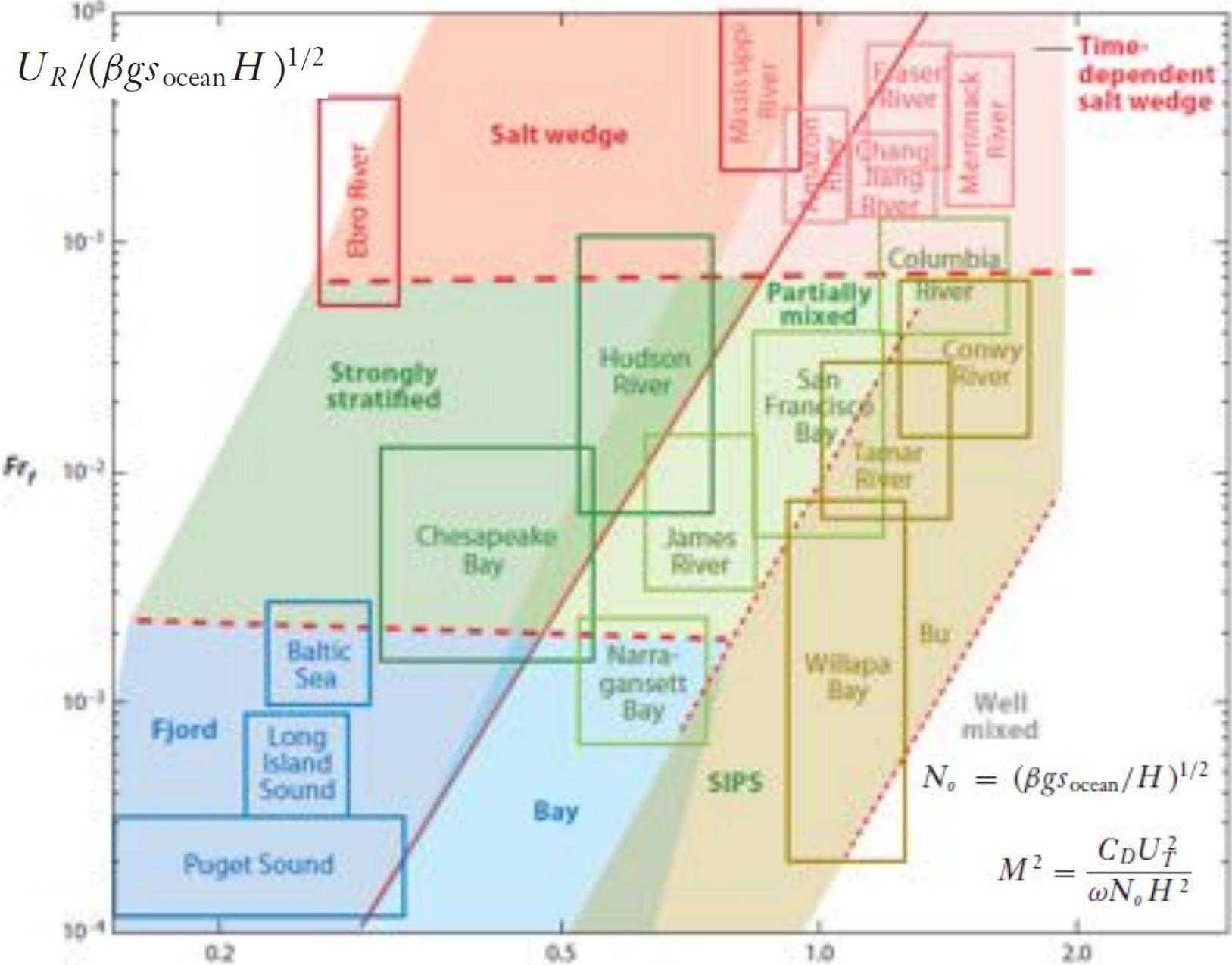


A lo largo del estuario: Gradiente presión + fricción
Transversal estuario: Gradiente presión + fricción



Numero de Froude – Agua dulce

$$Fr_f = U_R / (\beta g s_{\text{ocean}} H)^{1/2}$$



$$N_o = (\beta g s_{\text{ocean}} / H)^{1/2}$$

$$M^2 = \frac{C_D U_T^2}{\omega N_o H^2}$$

Parametro mezcla

Frentes

Que es un frente?

Difícil de definir, fácil de ver

Es el cambio de x en pocos metros?

La palabra “frente” viene de meteorología

Denota sitio de rápido cambio de propiedades

Los frentes son causados por procesos físicos

Solo nos enfocaremos en frentes superficiales

Filamentos son el resultado de tensiones superficiales causadas por la acumulación de materiales en el frente



Frentes de Pluma



Son los mas estudiados

La pluma es liberada durante el refluo de marea

La pluma es formada como una capa delgada de agua de rio sobre el oceano ($\Delta S \sim 10$)



El borde de la pluma Chesapeake en Duck,. NC.
Foto de William Birkemeier, US Army Corps of Engineers (via S. Lentz)

Pluma son generalmente delimitadas por una zona estrecha de altos gradientes de densidad horizontal



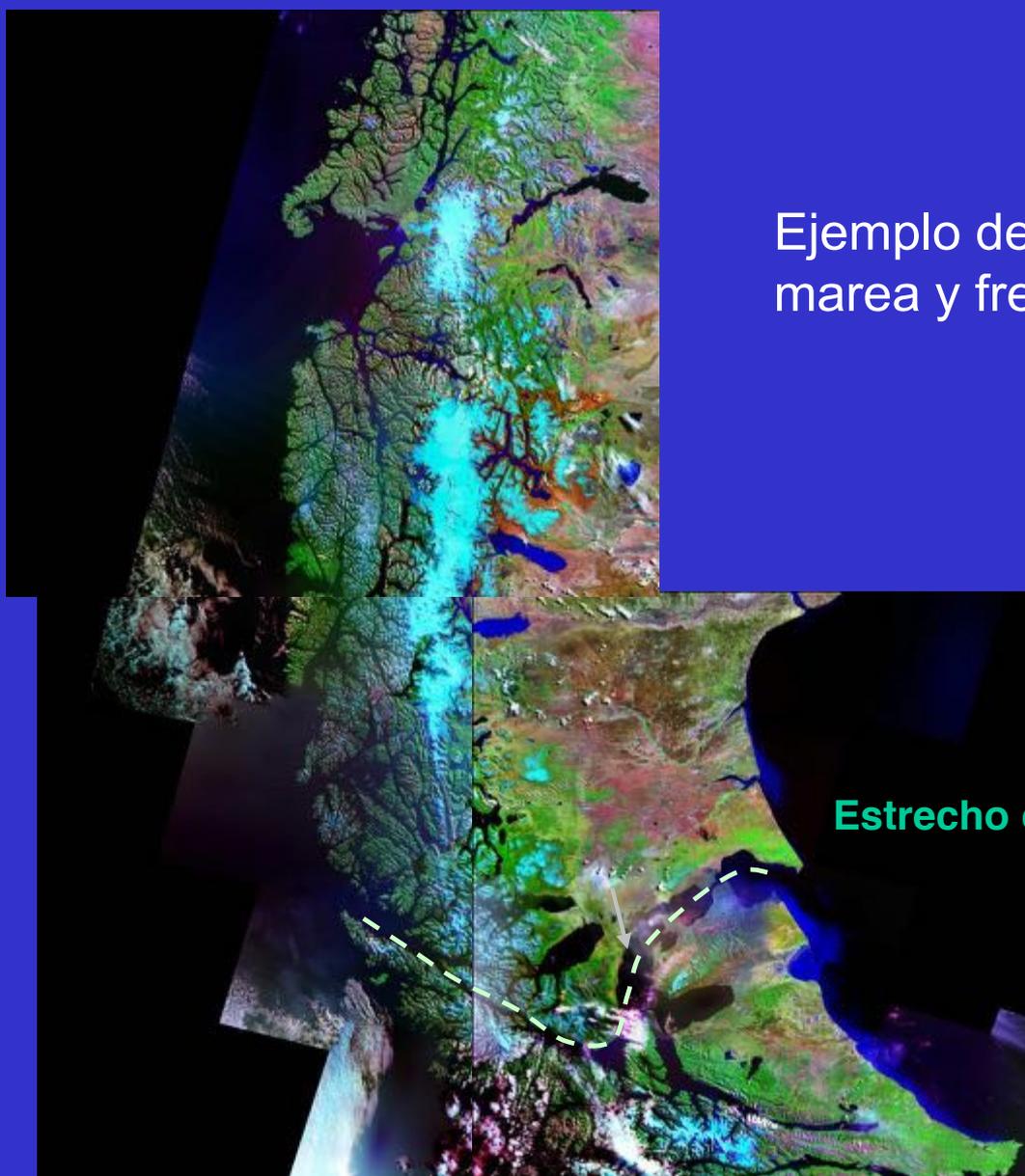
Estos gradientes pueden estar asociados con un cambio marcado en el color o turbidez y tal vez una linea de espuma y detritus

Frentes de instrusion de marea estan relacionados con los frentes de pluma.

Ellos aparecen cuando agua densa se introduce en una cuenca con agua dulce y se hunde hacia abajo como una corriente de gravedad



Ejemplo de una intrusión de marea y frentes de pluma

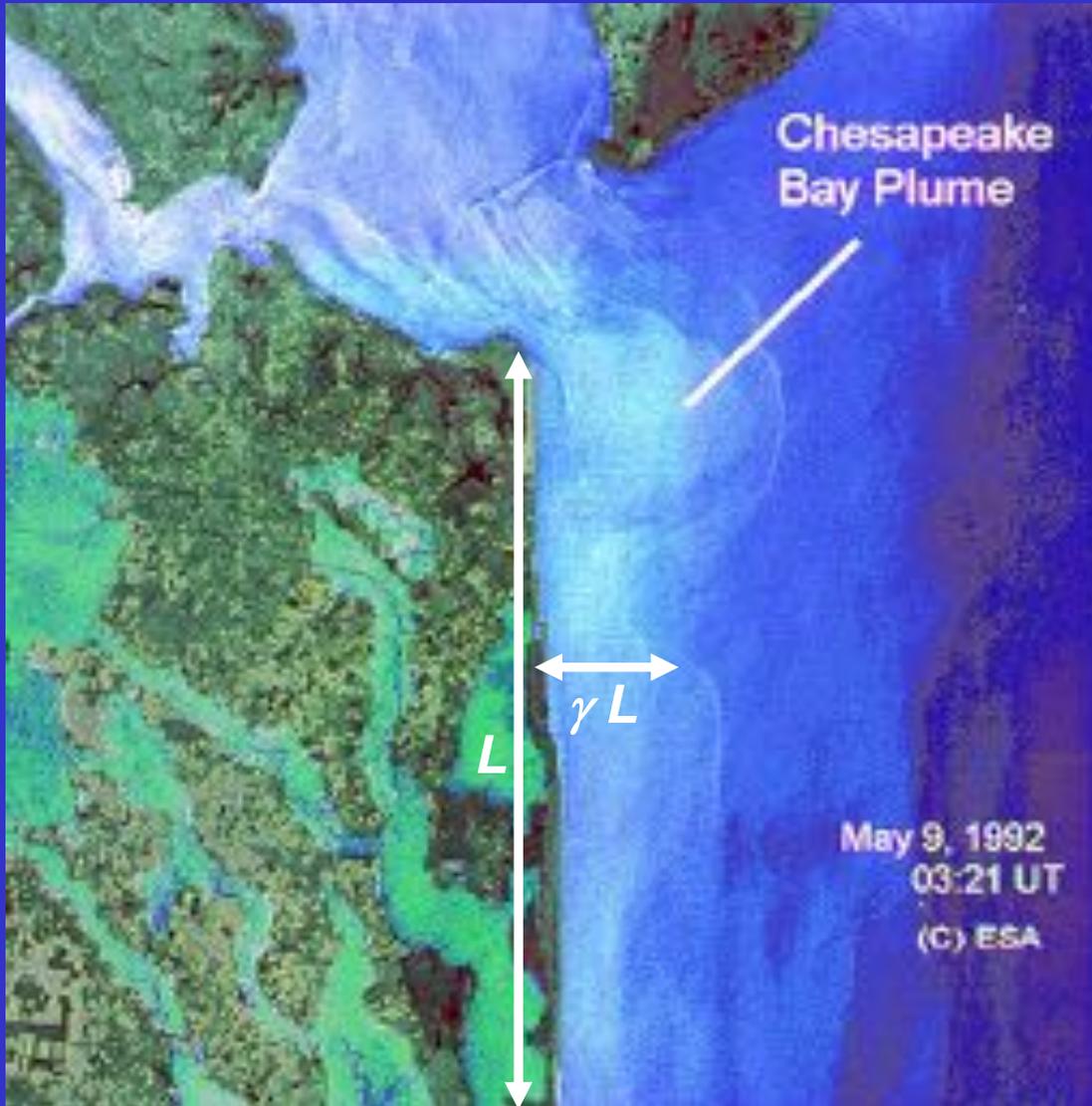


Estrecho de Magellanes



Pluma como un frente de marea saliente

Puede decirse algo de la dinámica de pluma con base en su forma?

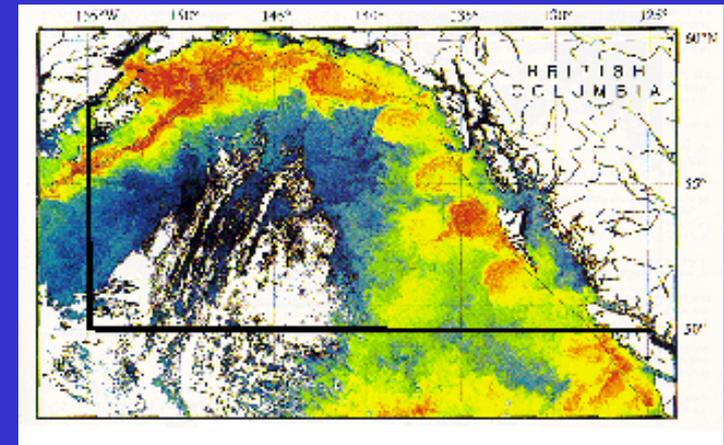


El valor pequeño de γ
descarga lineal

El gran valor de γ
descarga radial

Garvine's (1995) Clasificación plumas

Name	$K = L / Ro_i$	$F = u / C$
Point Beach	0.1	2.0
Mississippi	0.2	1.0
Amazon	0.6	0.6
Niagara	1.0	1.0
Alaska	1.0	0.3
Gaspé	2.0	0.4
Algerian	3.0	0.3
Rhine	3.0	0.1
Delaware	4.0	0.1
SAB	4.0	0.3
Norwegian	4.0	0.1
Scottish	10.0	0.1



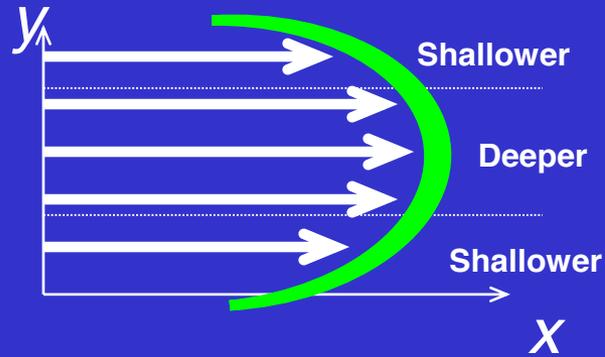
Kelvin No. Froude No.

(Cont. Shelf Res., 1995, 15(13), 1585-1596)

Frentes de corte

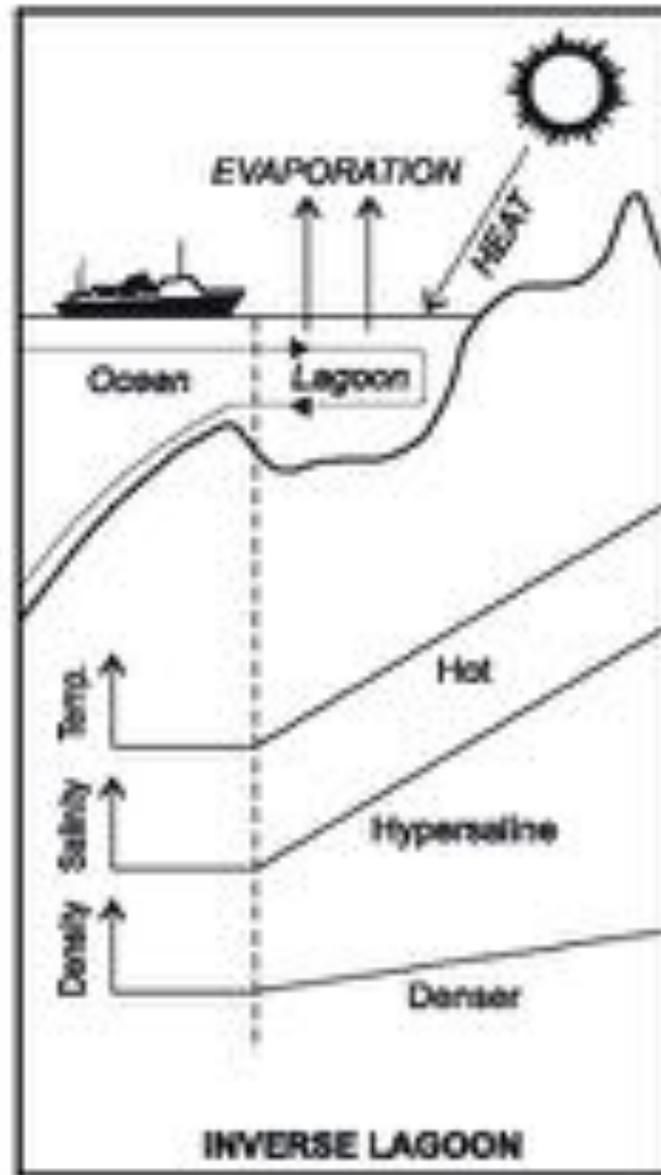
Resulta de la adveccion diferencial de fluido debido a las corrientes de marea

Probablemente la más facil y frecuente clase de frentes de estuarios observados





Hipersalino
pero no
invertido

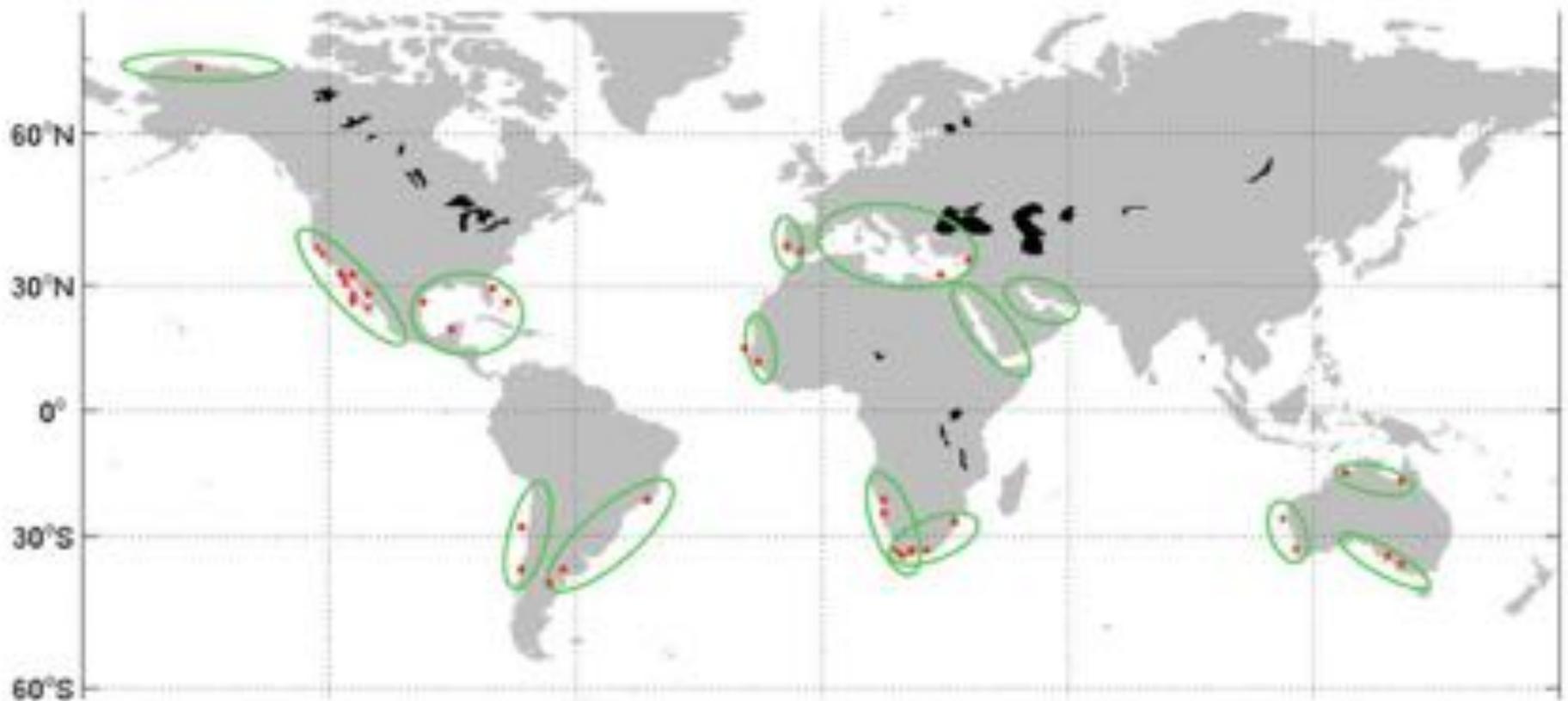


Como y cuando
se reversa el
Sistema?

Depende del
gradiente de
densidad

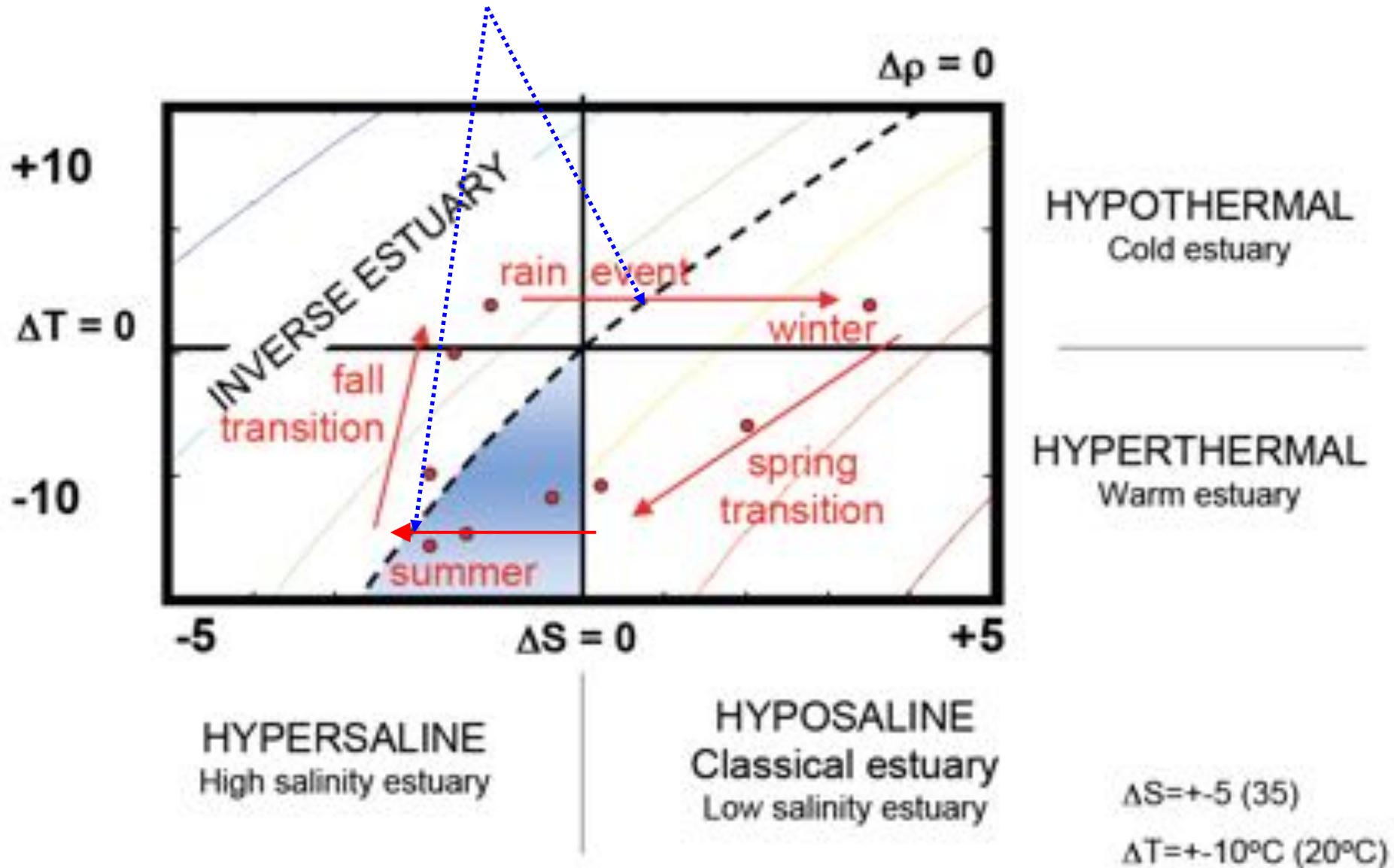
$$\Delta\rho/\rho$$

Global Distribution (at least some of them).



*Larger basins are more persistent - marginal seas and gulfs.
Most are smaller and seasonal - "hypersaline estuaries".*

Transiciones de Stommel

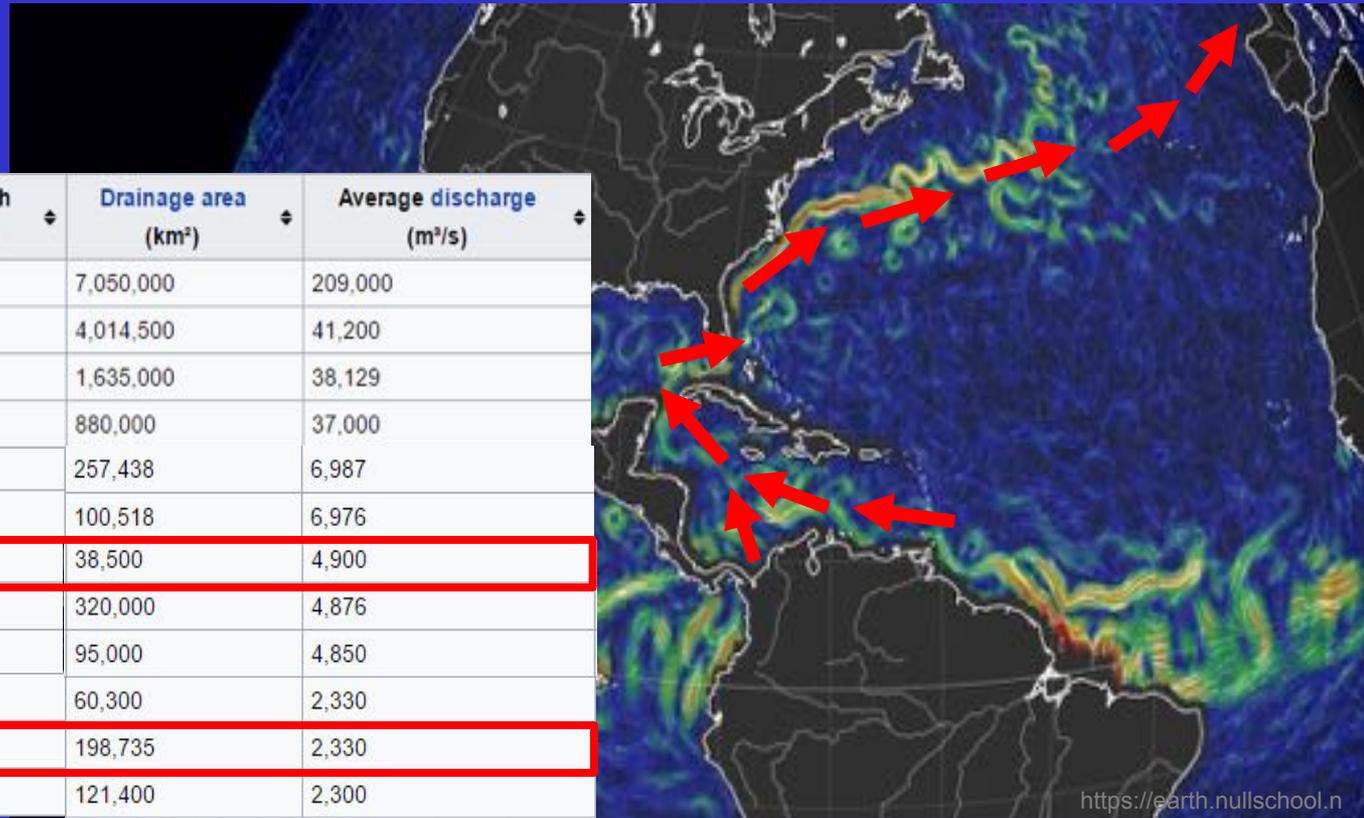




Las costas europeas sobre el Océano Atlántico están influenciadas por las condiciones que se generan en el Mar Caribe (donde también hay territorios europeos) de manera específica en Colombia y en los Golfos de Darién y de Urabá.

Fuente: Wikipedia.org

Continent	River	Length (km)	Drainage area (km ²)	Average discharge (m ³ /s)
S. America	Amazon ^[note 1]	6,992	7,050,000	209,000
Africa	Congo	4,371	4,014,500	41,200
Eurasia	Ganges	2,948	1,635,000	38,129
S. America	Orinoco	2,140	880,000	37,000
S. America	Magdalena	1,540	257,438	6,987
S. America	Napo	1,075	100,518	6,976
S. America	Atrato	750	38,500	4,900
Eurasia	Salween	2,815	320,000	4,876
S. America	Caroní	952	95,000	4,850
S. America	Urubamba	724	60,300	2,330
Eurasia	Rhine	1,233	198,735	2,330
S. America	Apure	1,038	121,400	2,300



<https://earth.nullschool.net>