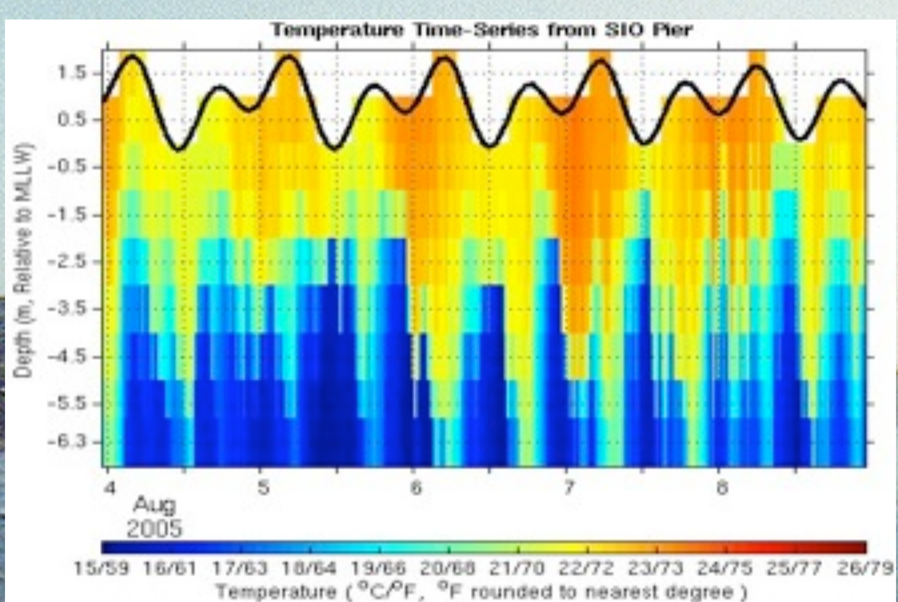
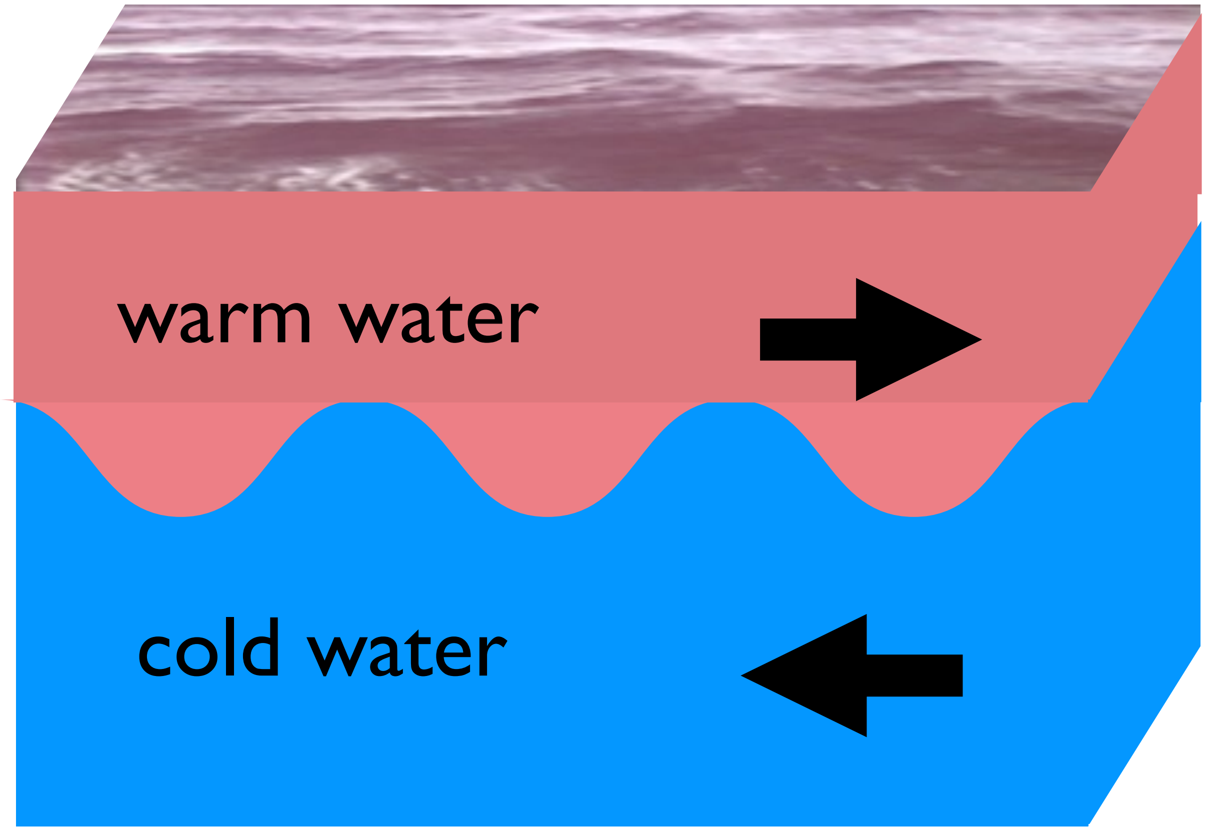
# Erratic internal waves at SIO Pier

data and wavelet analysis courtesy of E. Terrill, SIO



# Surface Waves

# Internal Waves




- Slow

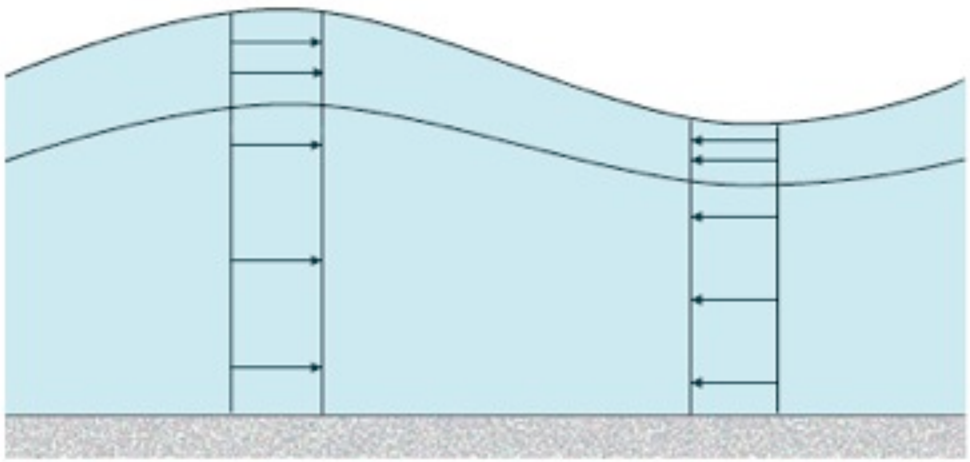
  $f \leq \omega \leq N$

  ~1day ~hours

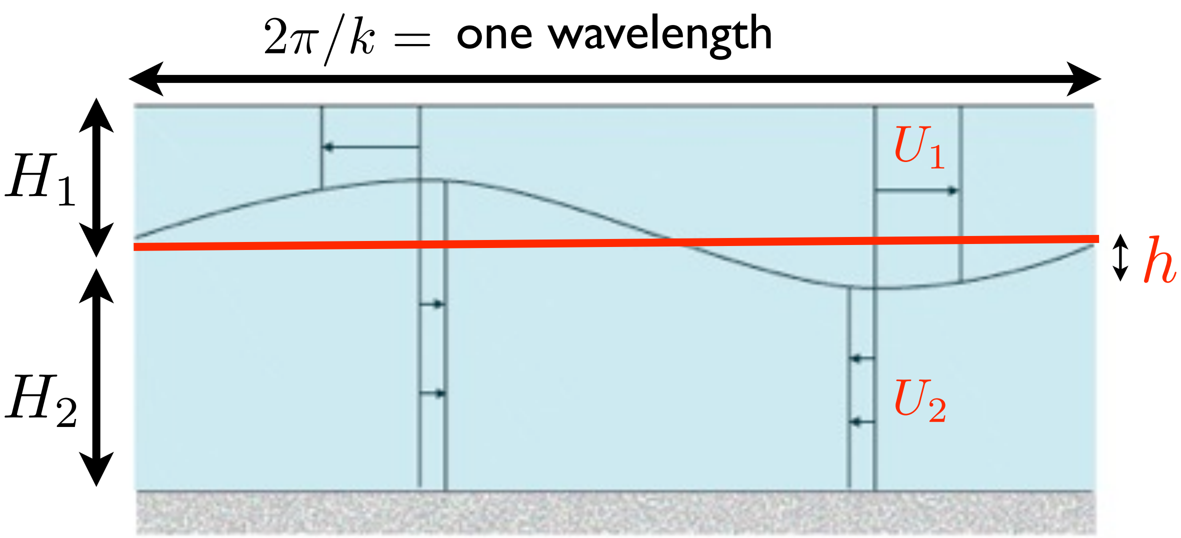
- Big

  tens of meters

# Simple interfacial internal wave



Barotropic Wave




Baroclinic Wave

$$\mathbf{h = -h_0 \cos(kx - \omega t)}$$

$$\mathbf{U_1 = \frac{\omega h_0}{H_1 k} \cos(kx - \omega t)}$$

$$\mathbf{U_2 = -\frac{\omega h_0}{H_2 k} \cos(kx - \omega t)}$$

after Gill,
*Atmosphere-Ocean Dynamics*

# Internal wave equations

Linearize equations of motion

$$\frac{\partial u}{\partial \mathrm{t}} = -\vec{u}\cdot\nabla u + fv - \frac{1}{\rho}\frac{\partial p}{\partial \mathrm{x}} + \nu\nabla^2 u$$

$$\frac{\partial v}{\partial \mathrm{t}} = -\vec{u}\cdot\nabla v - fu - \frac{1}{\rho}\frac{\partial p}{\partial \mathrm{y}} + \nu\nabla^2 v$$

$$\frac{\partial w}{\partial \mathrm{t}} = -\vec{u}\cdot\nabla w - \frac{1}{\rho}\frac{\partial p}{\partial \mathrm{z}} + \nu\nabla^2 w - g$$

$$\frac{\partial \rho}{\partial \mathrm{t}} = -\vec{u}\cdot\nabla \rho + \kappa\nabla^2 \rho$$

$$\nabla\cdot\vec{u} = 0$$

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$$\nabla\cdot\vec{u} = 0$$

Try a solution of the form

$$u(x,y,z,t) = \hat{u}e^{-i[kx+ly+mz-\omega t]}$$

Get polarization and dispersion relationships

$$\omega^2 = \frac{(k^2+l^2)*N^2+m^2*f^2}{k^2+l^2+m^2}$$

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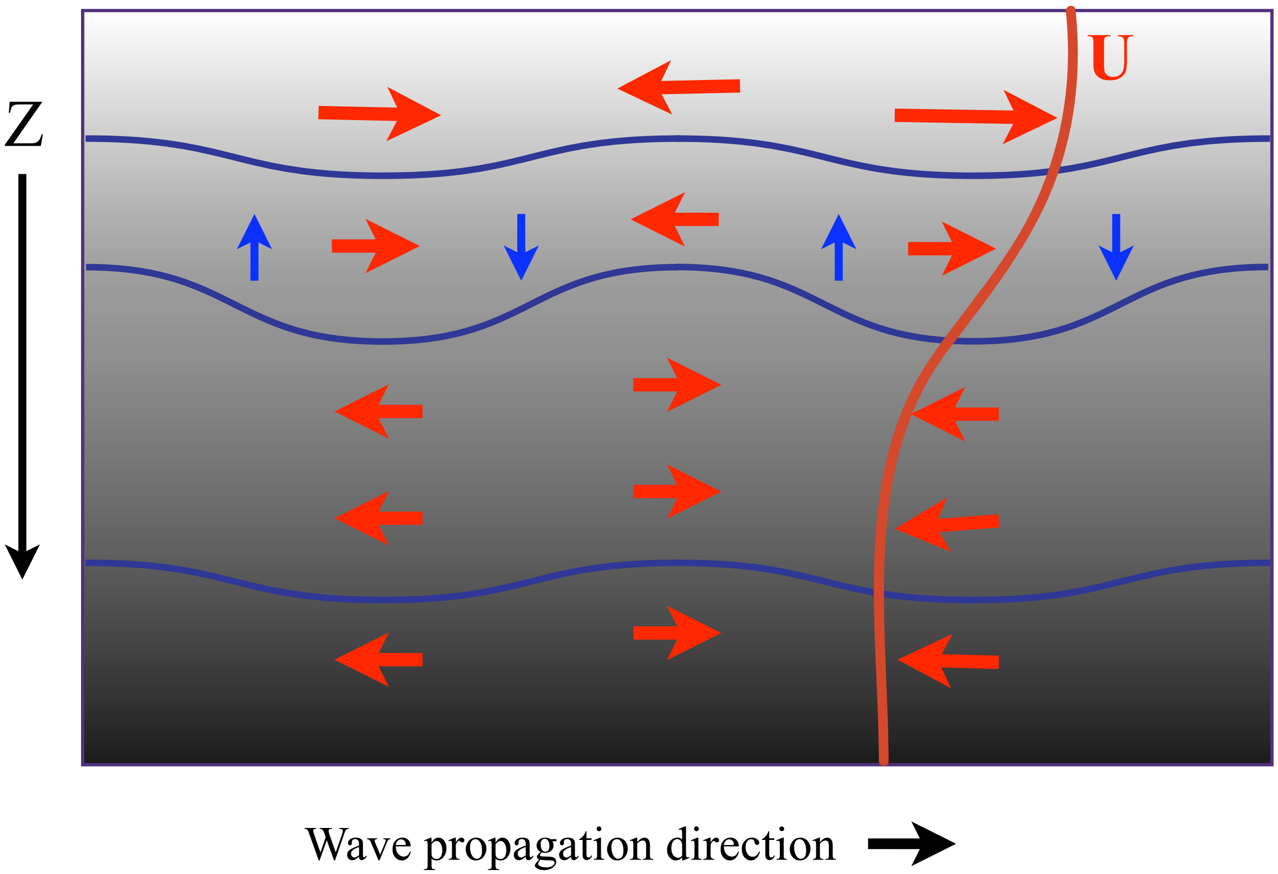
(Glenn Flierl)

# Continuous stratification




Mode-1 wave
(approx two-layer)

$$\mathbf{U = \Psi(z)\cos(kx - \omega t)}$$

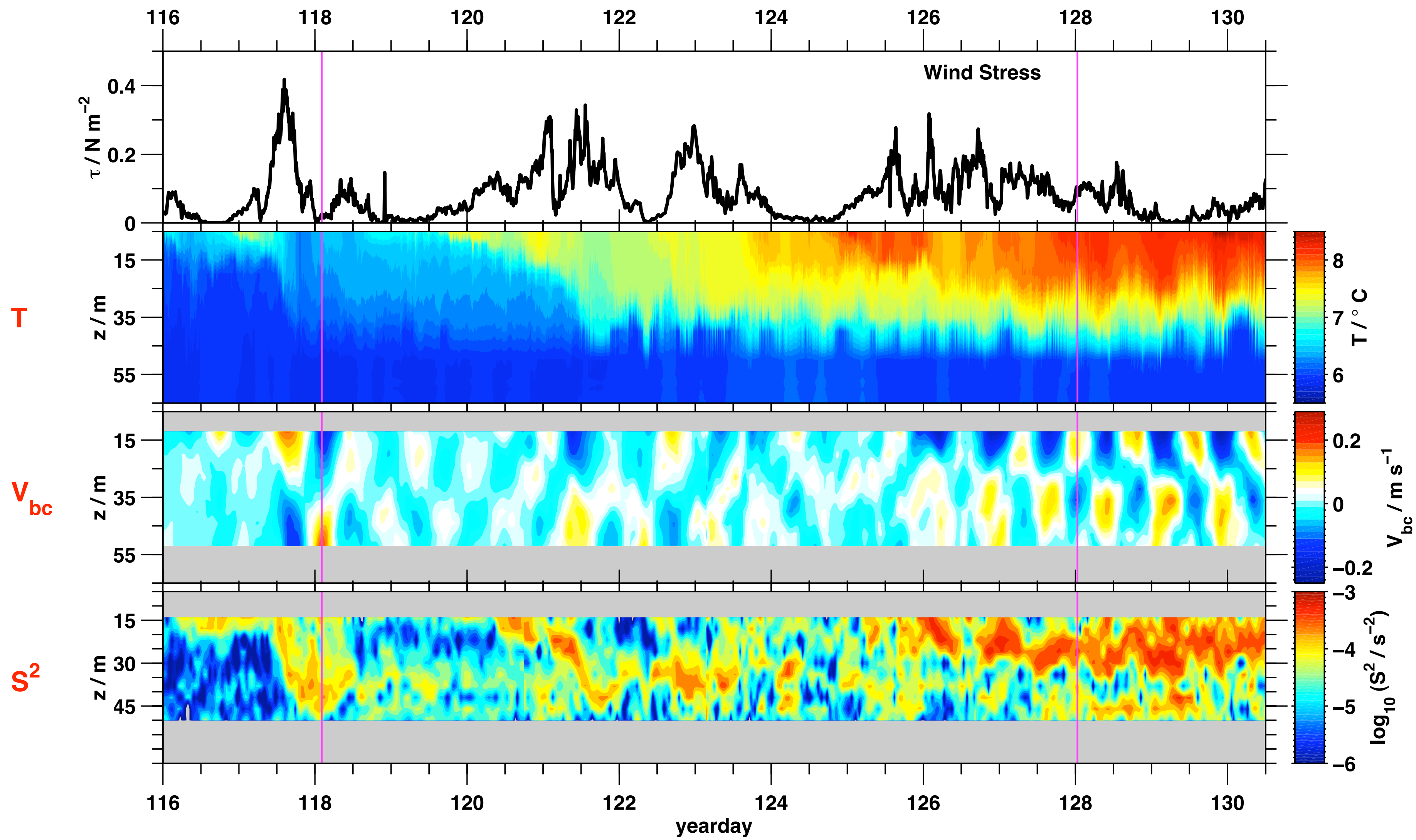
Allowable frequency range

$$\mathbf{f \leq \omega \leq N}$$

days to minutes

# What generates internal waves?

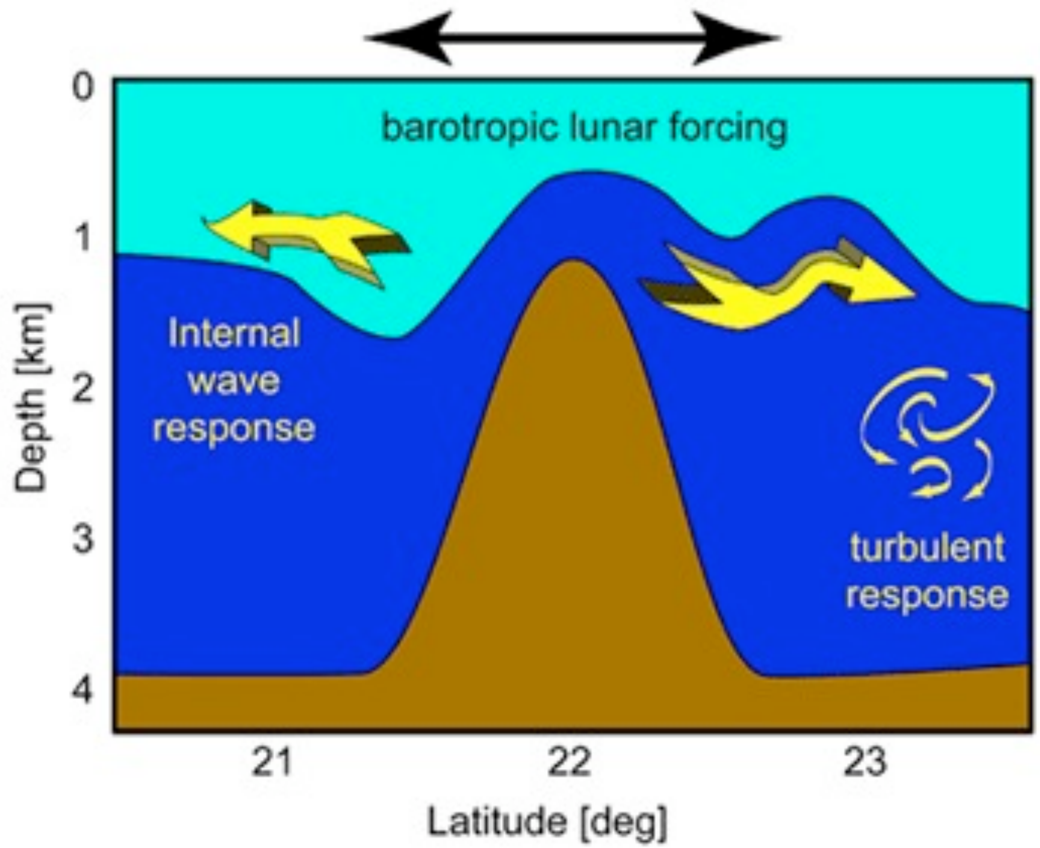
1) Wind makes near-inertial internal waves




(MacKinnon and Gregg, JPO, Dec 05)

# What generates internal waves?

2) Barotropic tide sloshing over topography

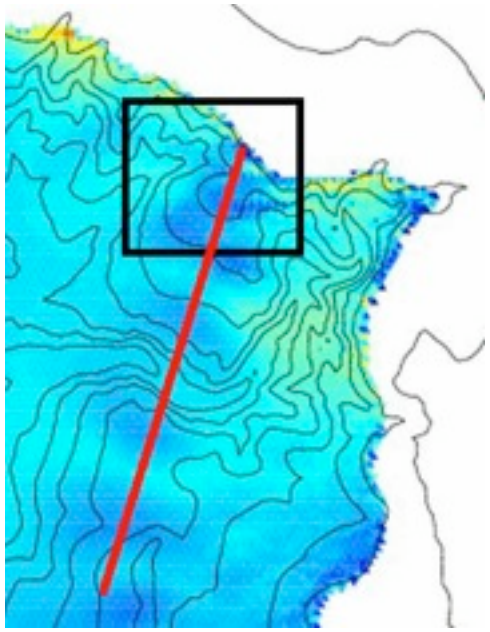



(J. Nash)

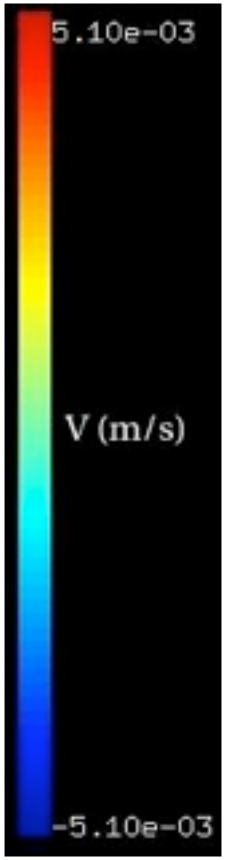
**Internal Tide:** An internal wave with a tidal frequency, usually once in 12.4 hours = M2

Often generated at the continental shelf break, with waves propagating both on and off shore.

# Internal-tide generation in Monterey Bay



courtesy of
Oliver Fringer



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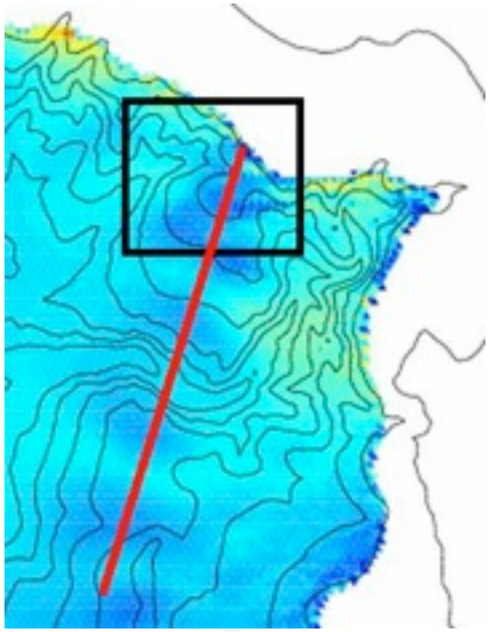

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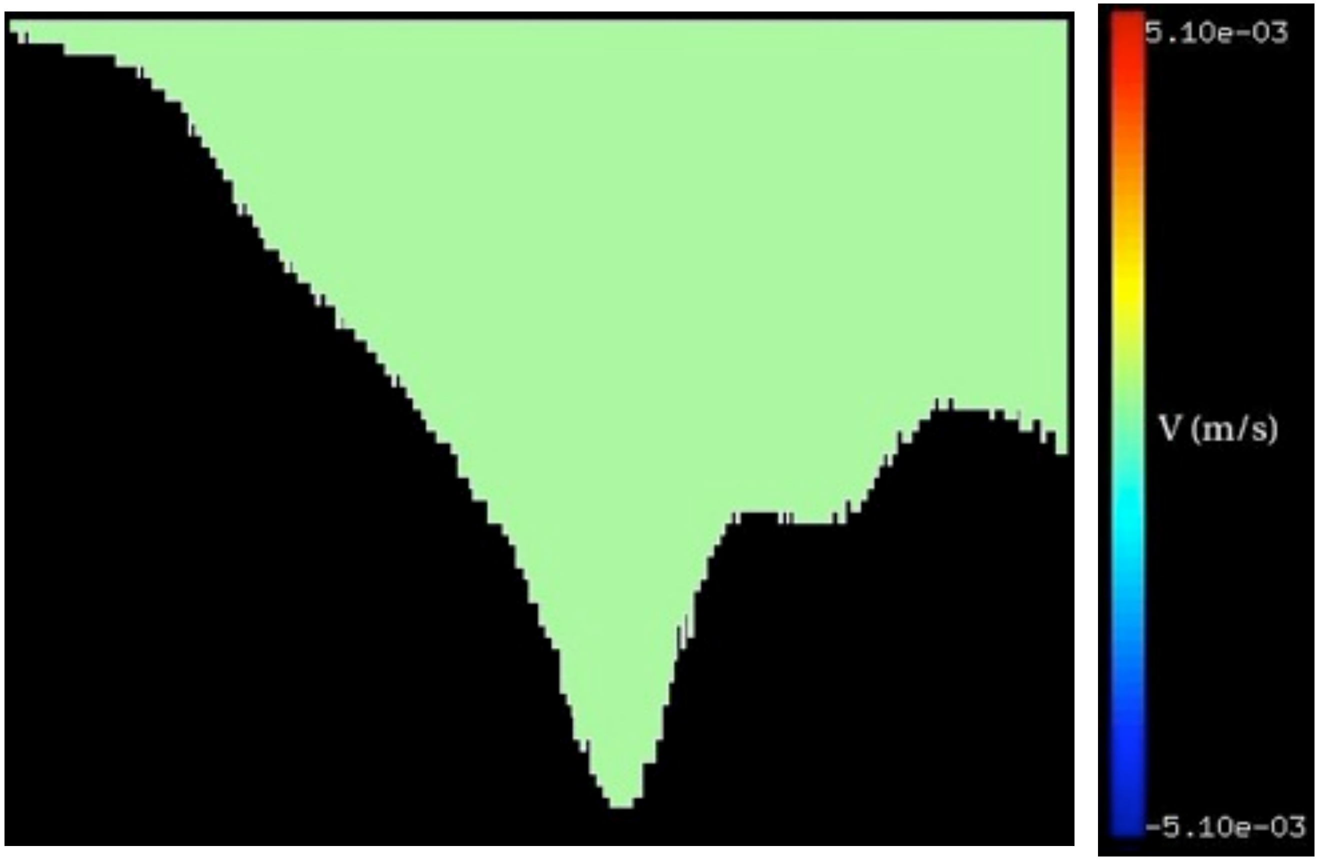
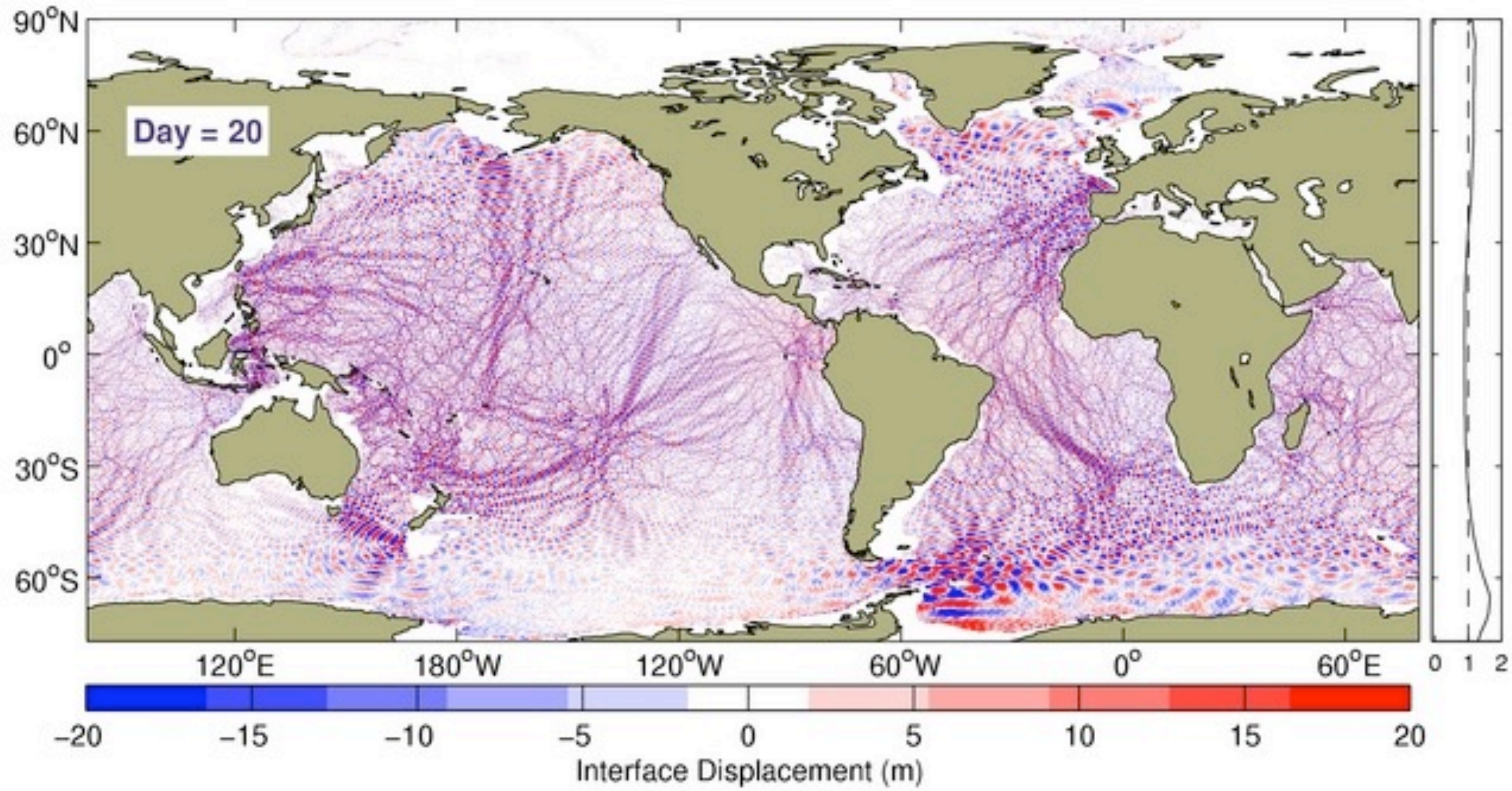


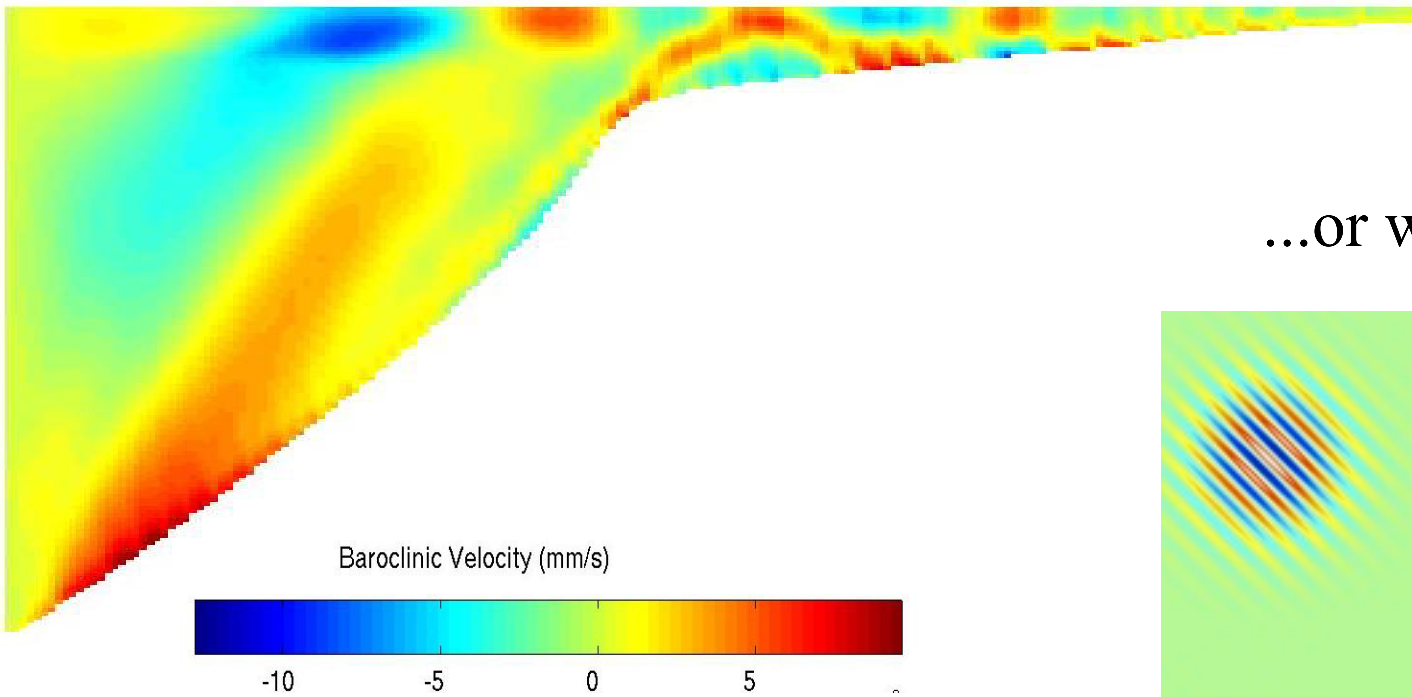
# Global pattern of internal tides




Simmons et al 2004

# Complicating factors: higher-mode waves

Waves propagate in beams...

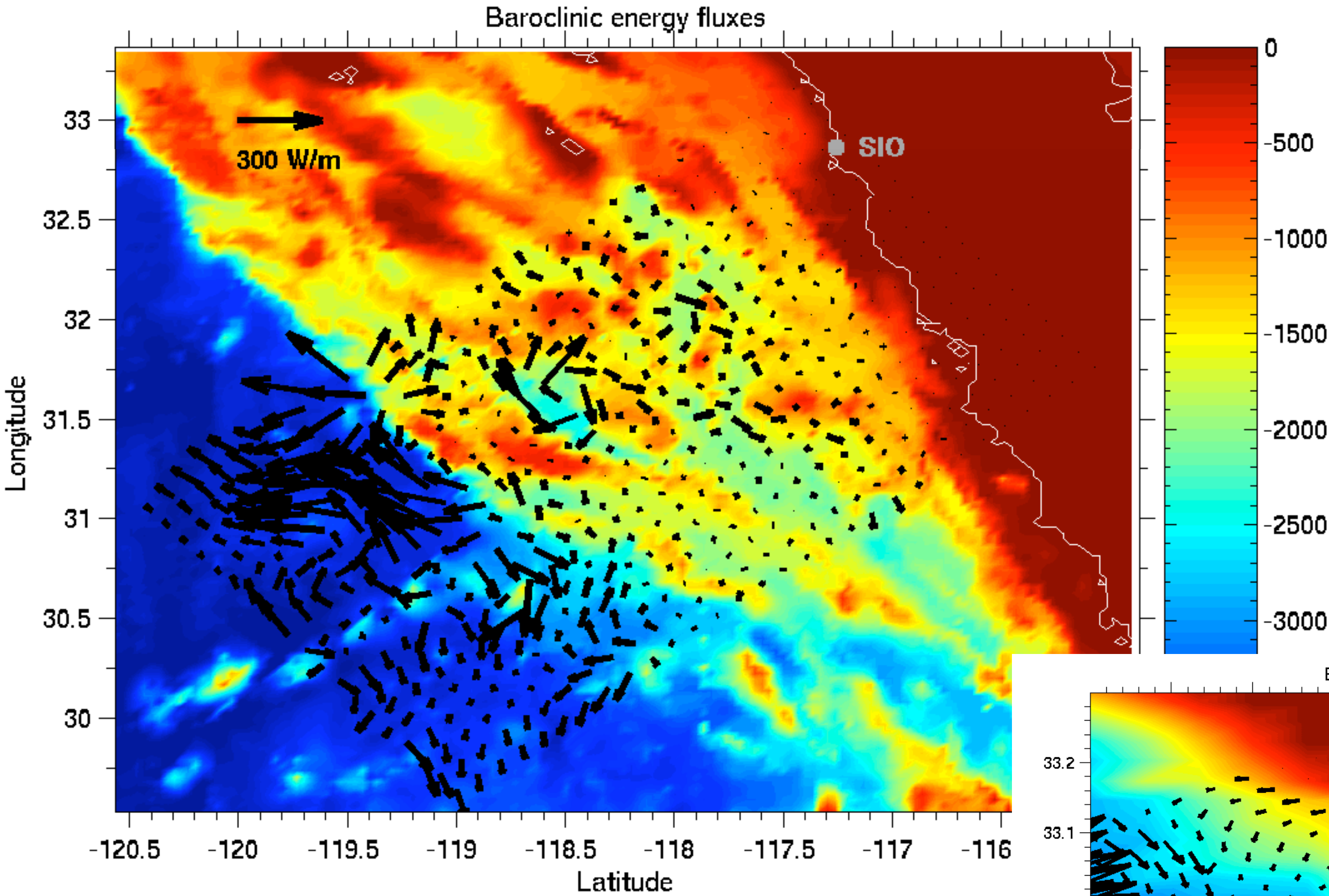


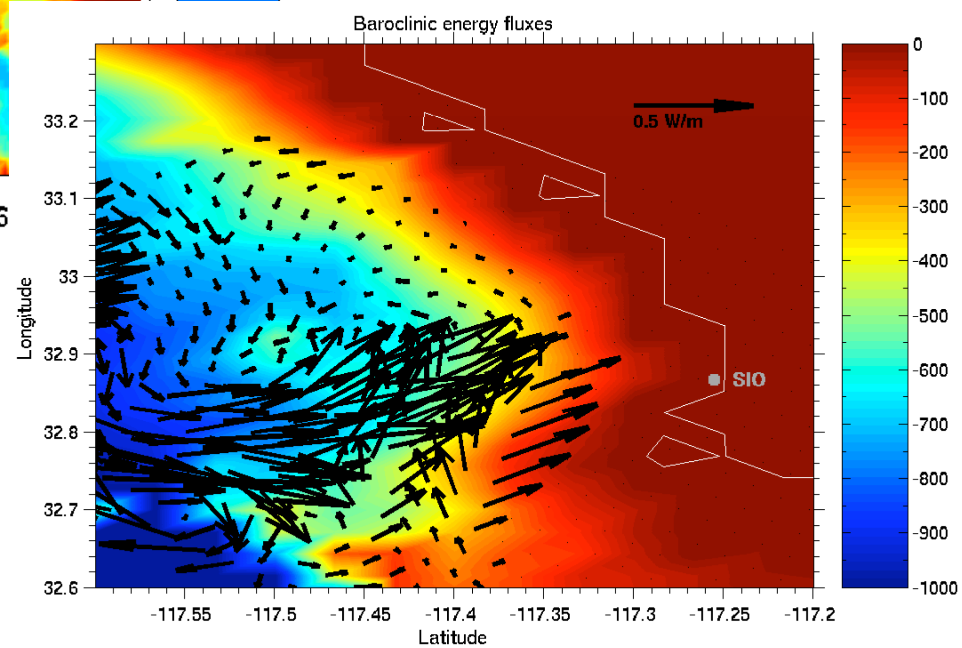

(Oliver Fringer)

...or wave packets

(Glenn Flierl)

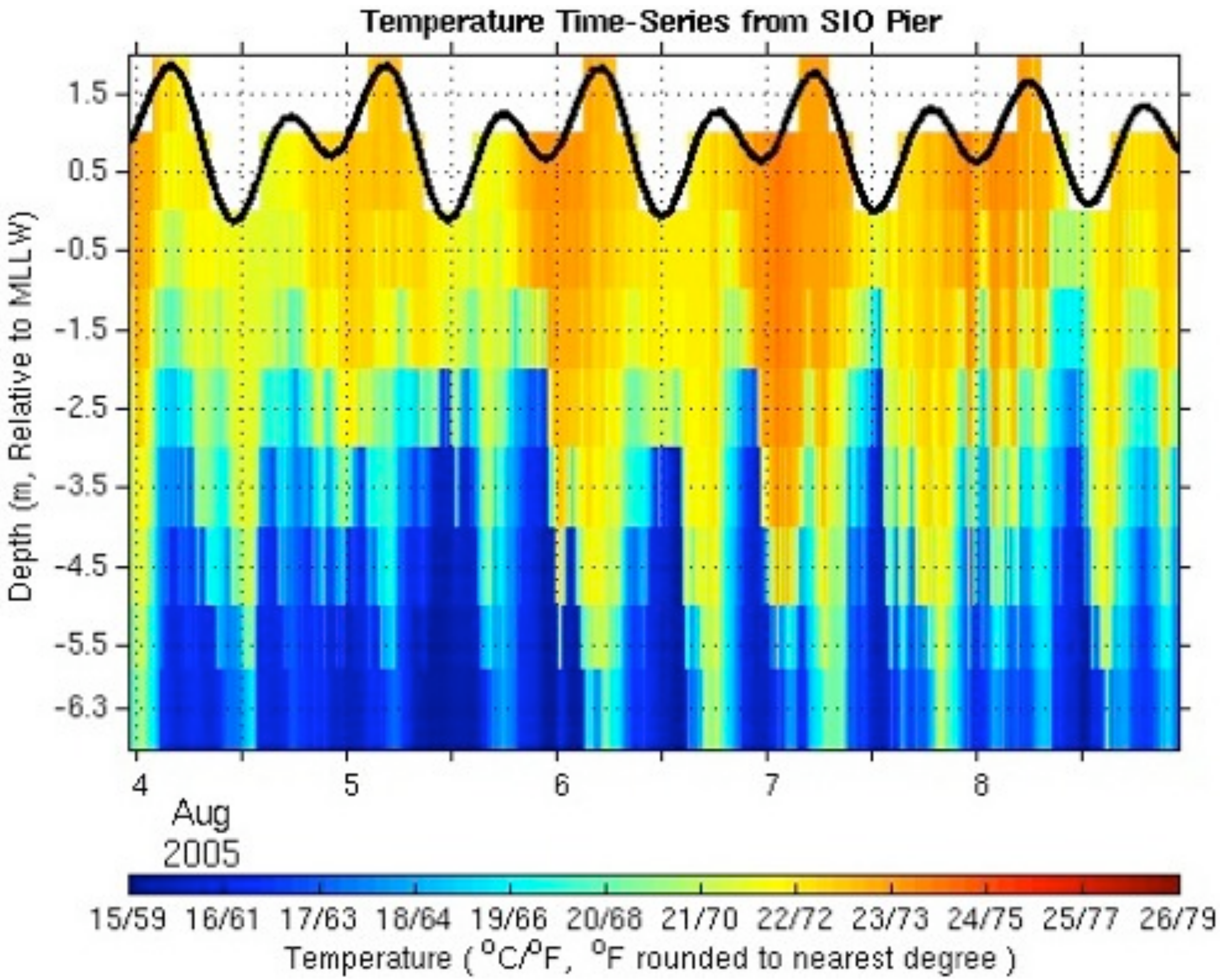
# Complicating factors: complex topography



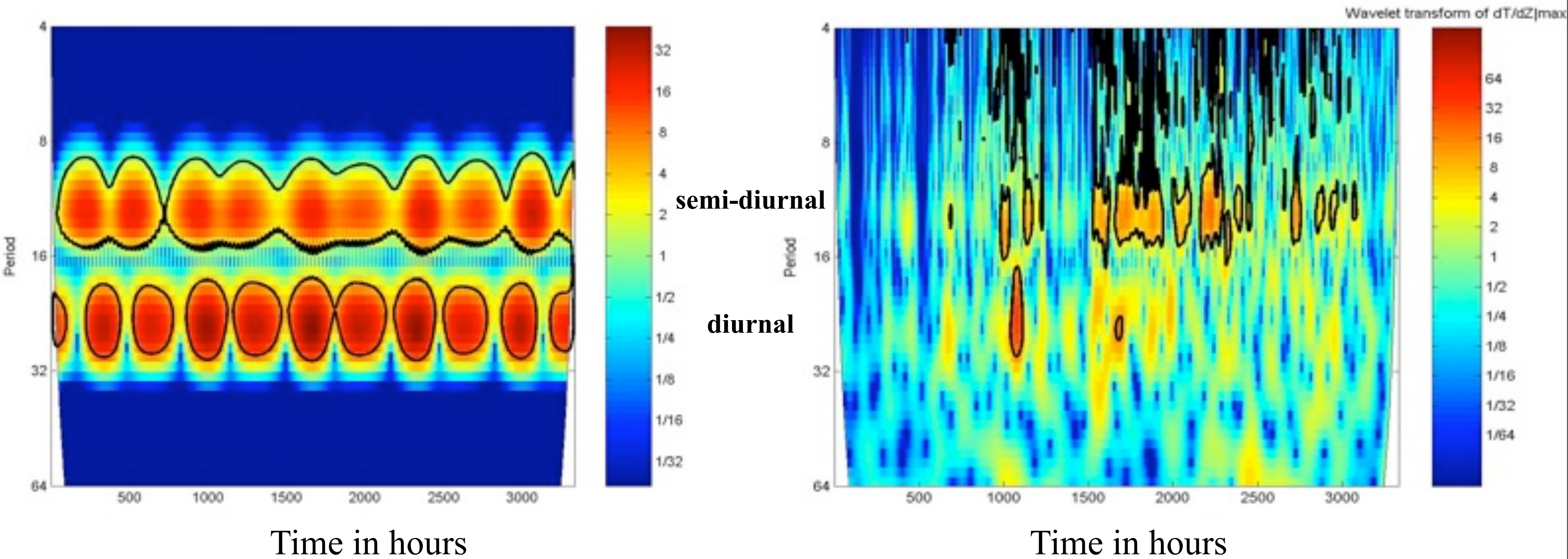
Monday, November 16, 2009

# SIO Pier temperatures



# Strength of surface and internal tide (SIO pier)

Eric Terill




**Barotropic tide:**

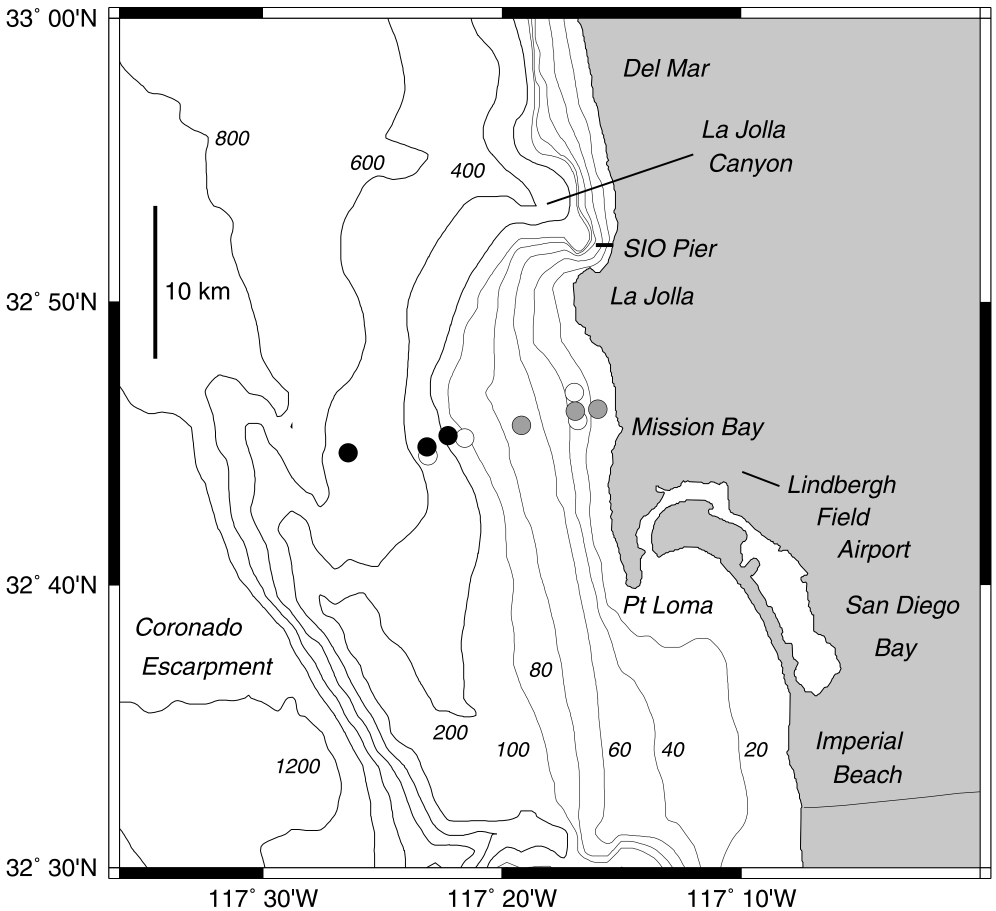
regular beating of semi-diurnal (12 hour) and diurnal (24 hour) signals

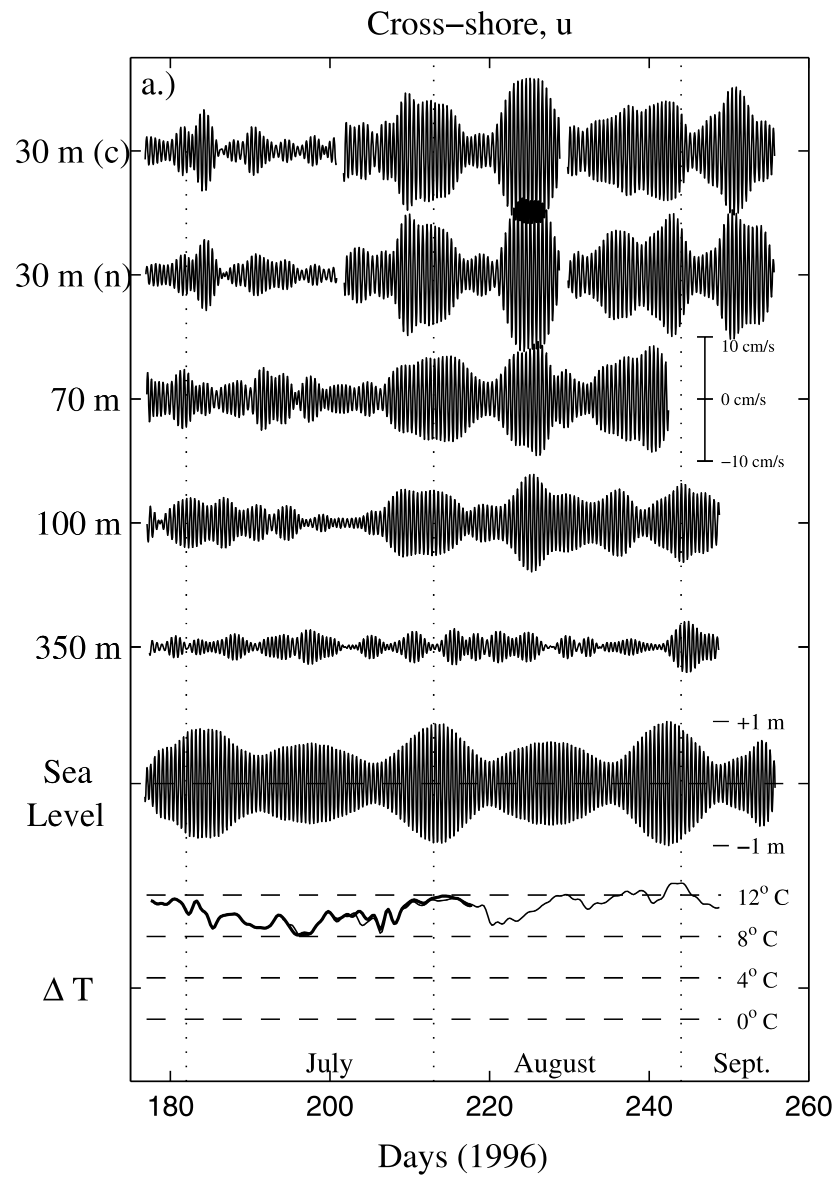
**Internal tide: a mess!**

Changing stratification, mesoscale currents, eddies, ....

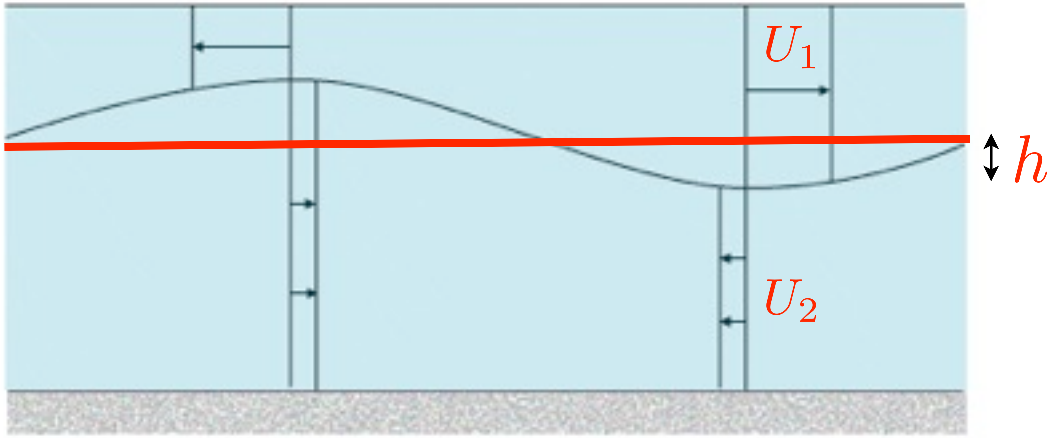
# More local internal tides

Lerczak, Winant and Hendershott, 2003



# Complicating factors: nonlinearity




**Linear waves**

$$\frac{\partial h}{\partial \mathrm{t}} + c_0 \frac{\partial h}{\partial \mathrm{x}} = 0$$

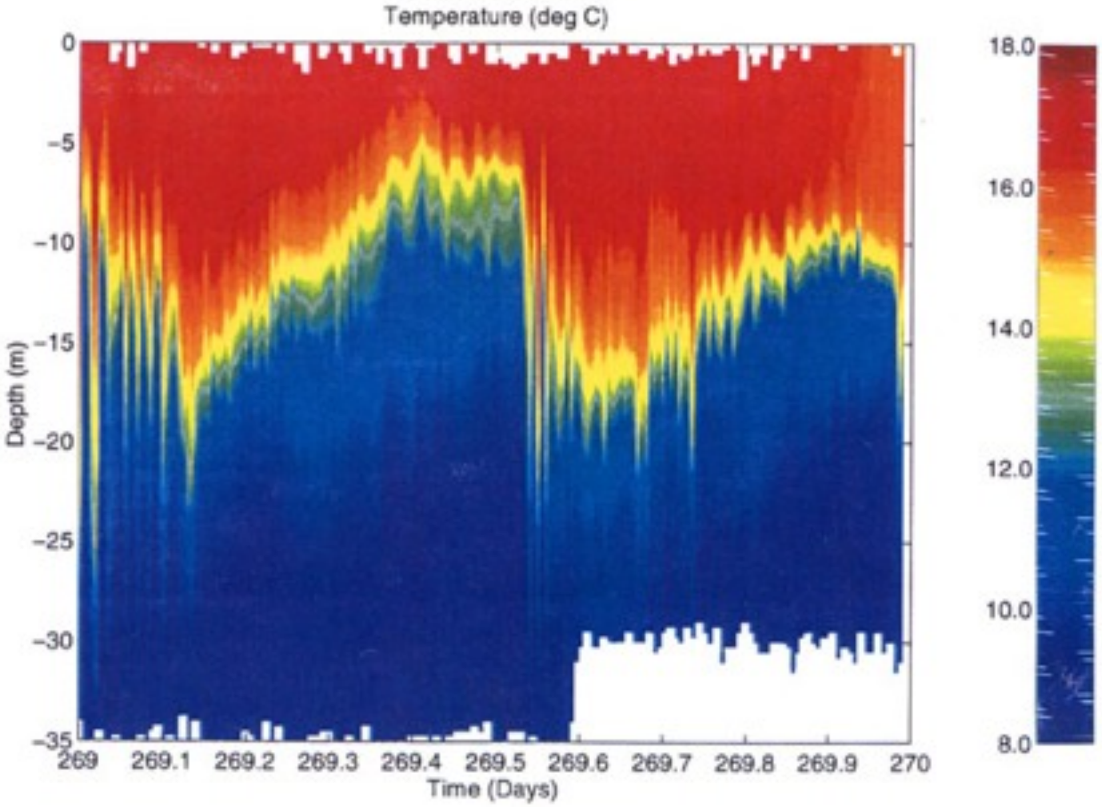
$$h(x,t) = cos(x - c_0 t)$$

**Non-linear waves**

$$\frac{\partial h}{\partial \mathrm{t}} + (c_0 + h) \frac{\partial h}{\partial \mathrm{x}} = 0$$

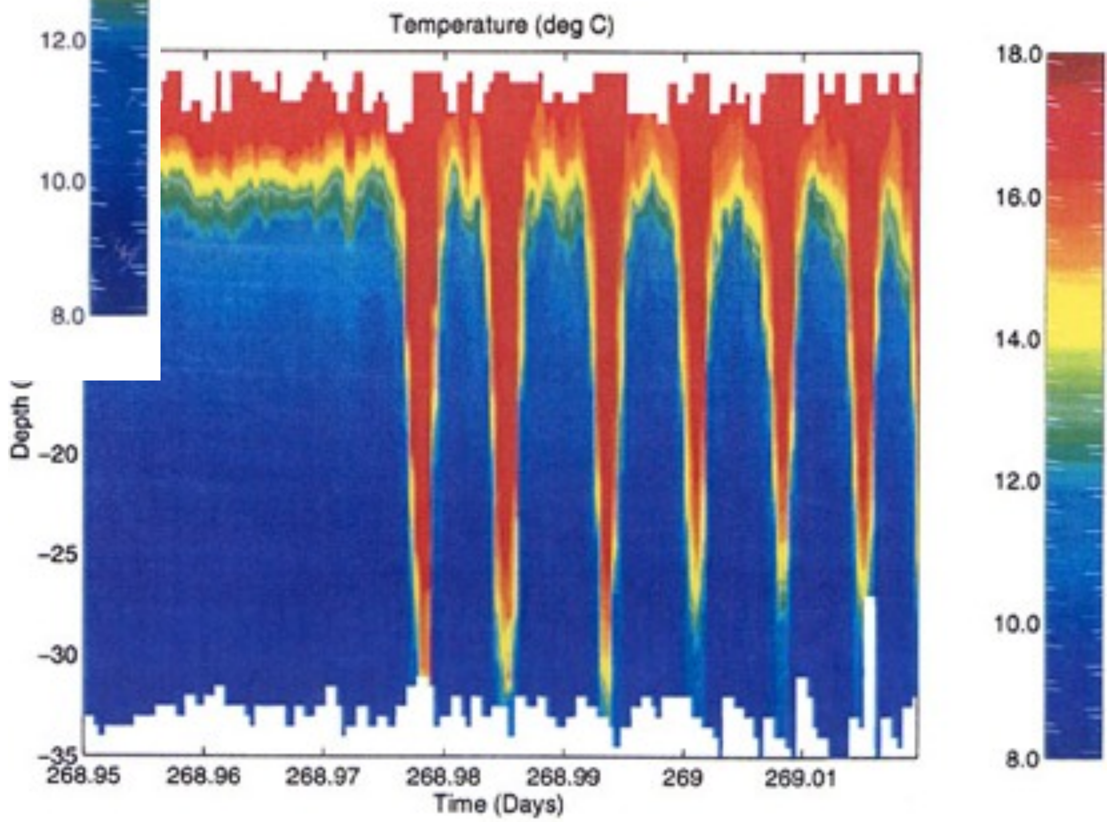
When wave amplitude gets ‘large’ (shallow water), crest of wave moves faster, so wave starts to steepen. This can take several forms...

# Solitons: internal waves of unusual size




|← 24 hours →|

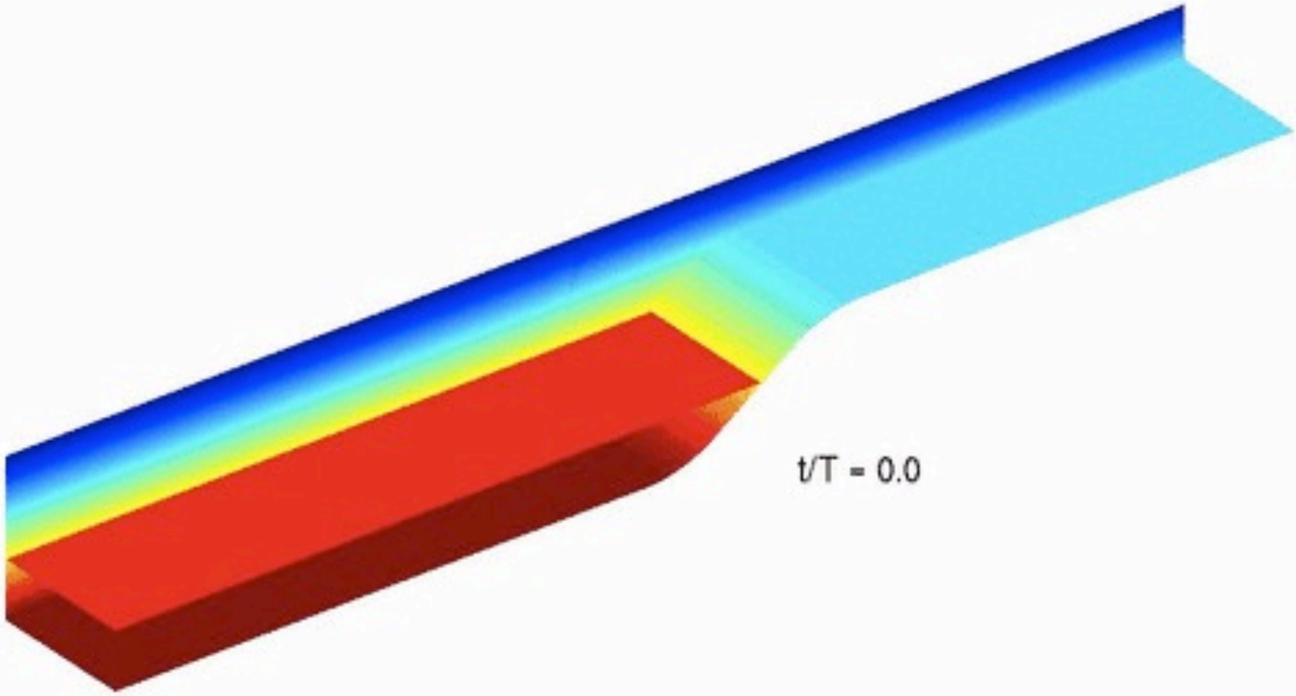
nonlinear steepening
balanced by dispersion




|← 100 minutes →|

Stanton and Ostrovsky
GRL 24(14) 1998

# Nonlinear internal tides:  bores




courtesy of  S. K. Venayagamoorthy
and O. Fringer, Stanford

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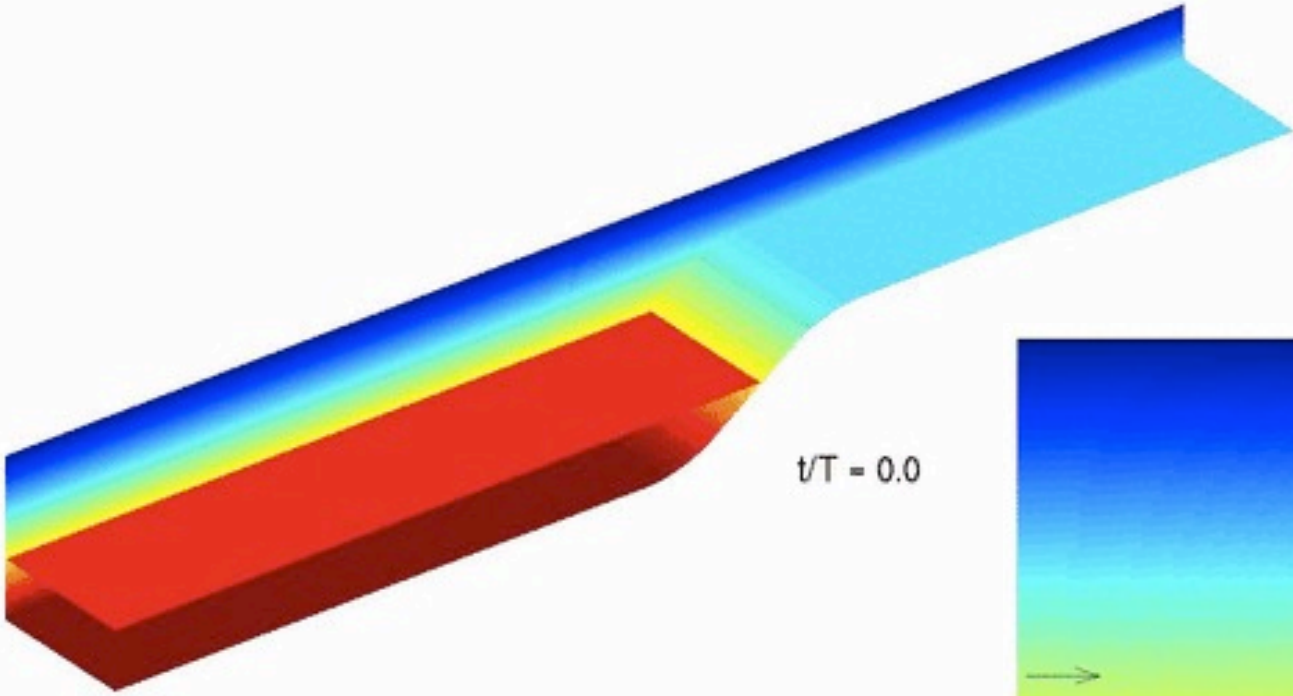
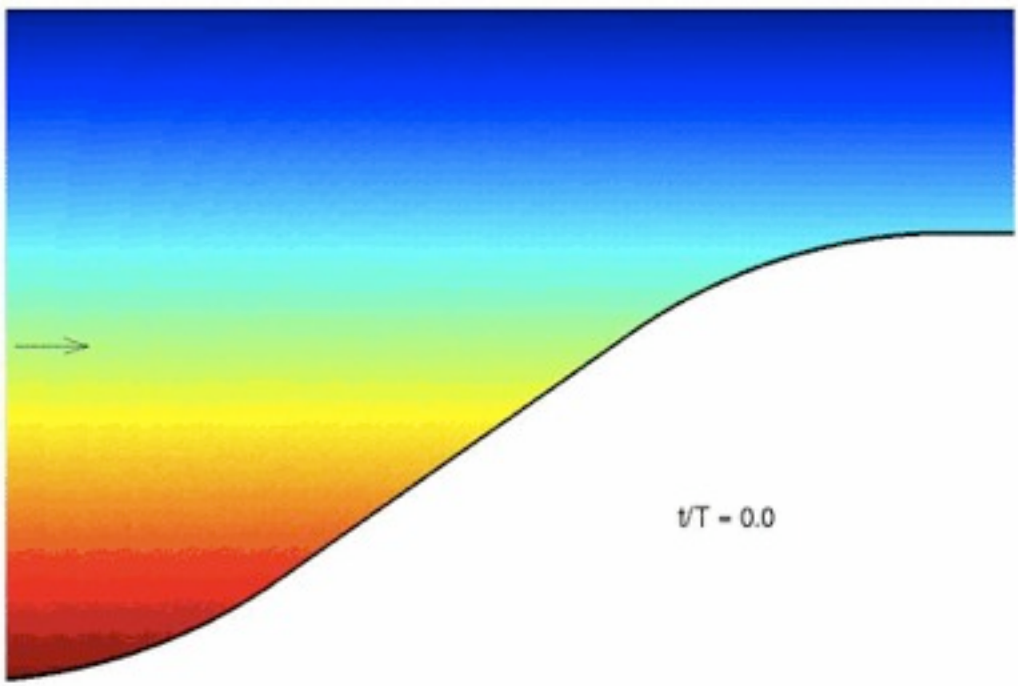



courtesy of  S. K. Venayagamoorthy
and O. Fringer, Stanford

# Why you should care

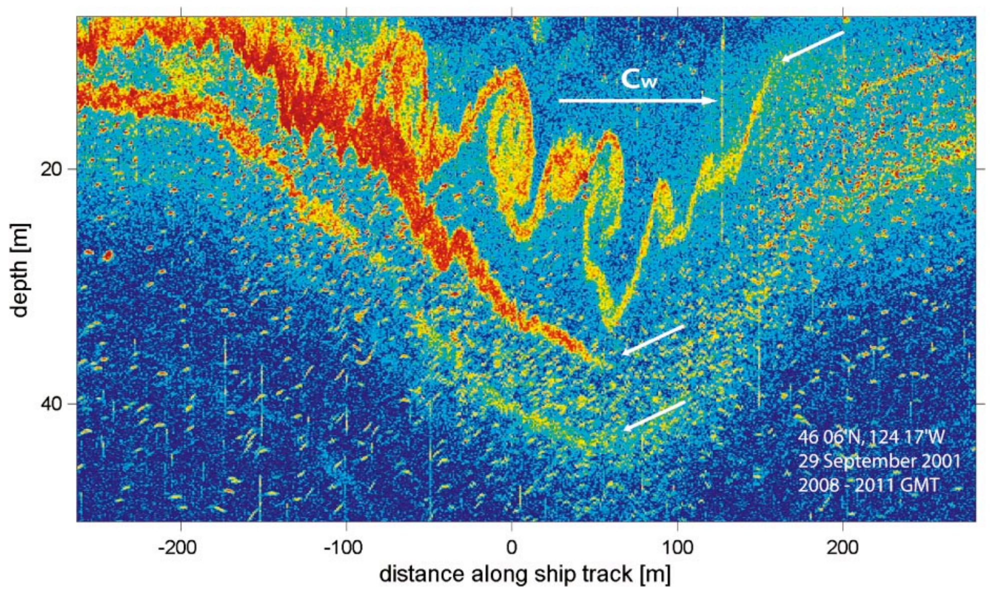
- Internal-wave fluctuations often dominate any signal you measure. Up/down CTD casts. Moorings.

- Internal-wave shear produces turbulence and mixing. Most mixing at interface / thermocline, can bring nutrients up into the euphotic zone. (next week)

- May create net on or offshore transport of mass / nutrients / larvae / ???

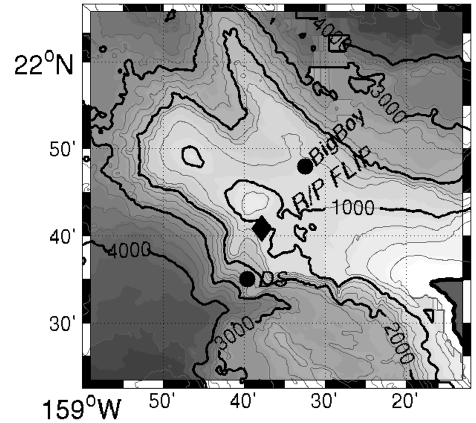
# Consequences of Internal Waves

Wave breaking mixes the ocean (next week).



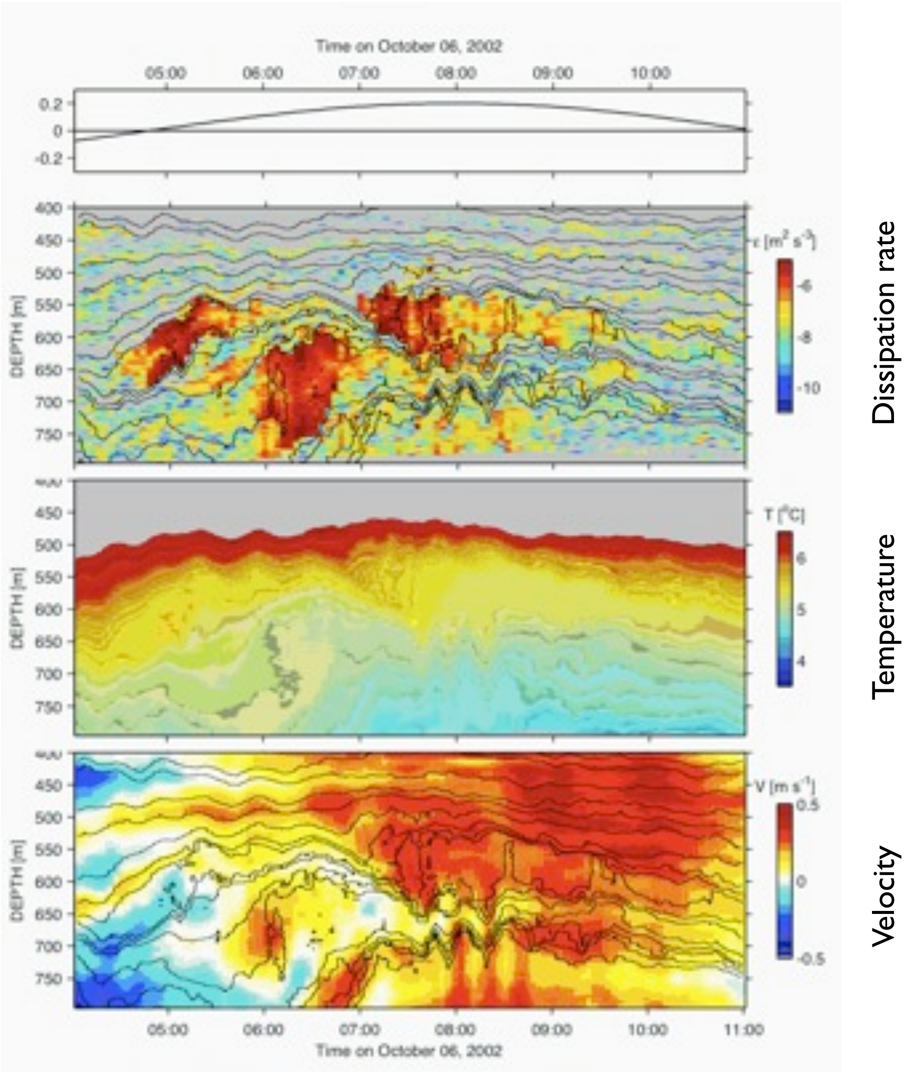

Moum et al 03

# Hawaiian Ocean Mixing Experiment (HOME)




Huge overturns as internal tide sloshes up and down a steep slope

Klymak et al 07
Levine and Boyd 06
Aucan et al 05




Klymak et al 07

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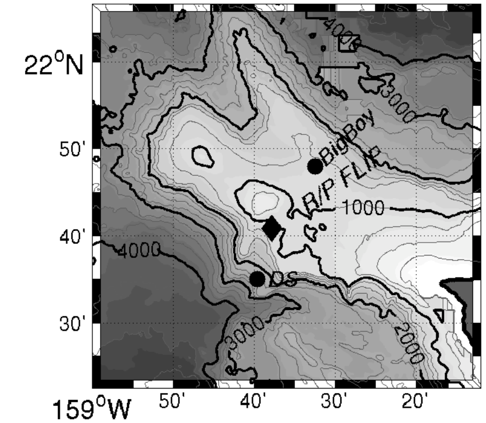


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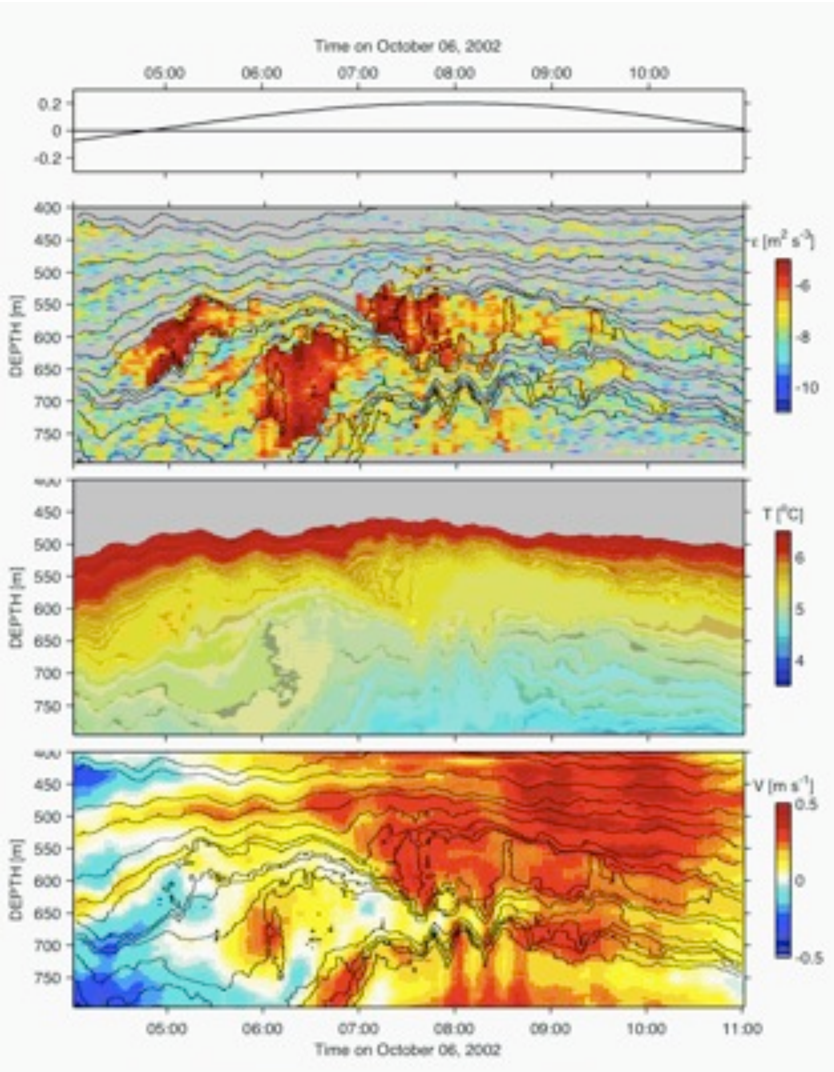


Dissipation rate

Temperature

Velocity

Klymak et al 07

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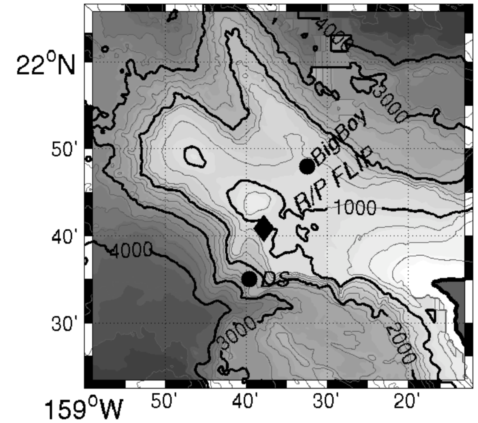


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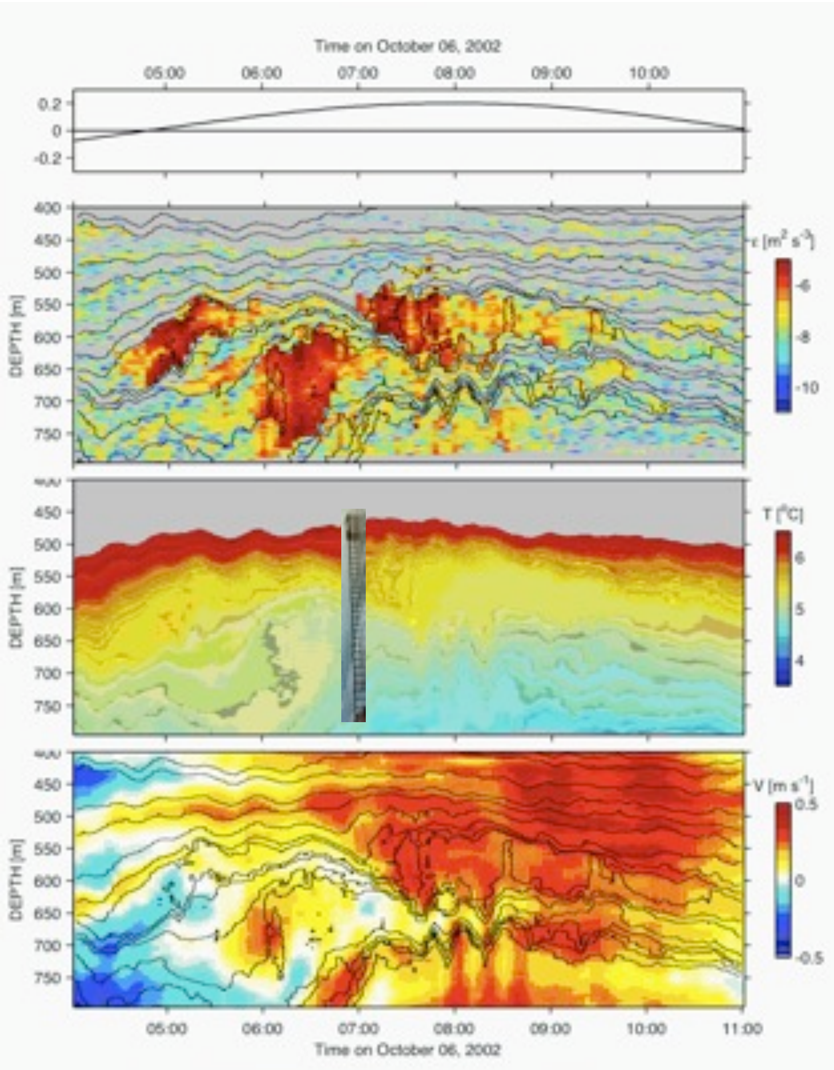


Dissipation rate

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Klymak et al 07

Klymak et al 07

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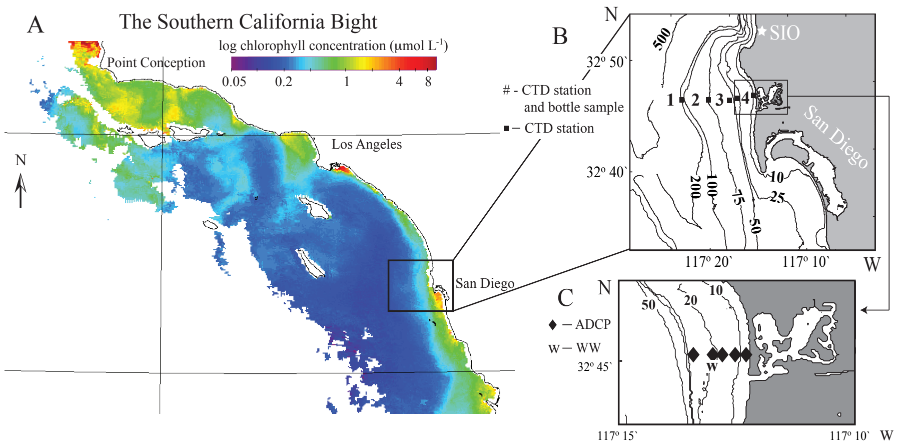
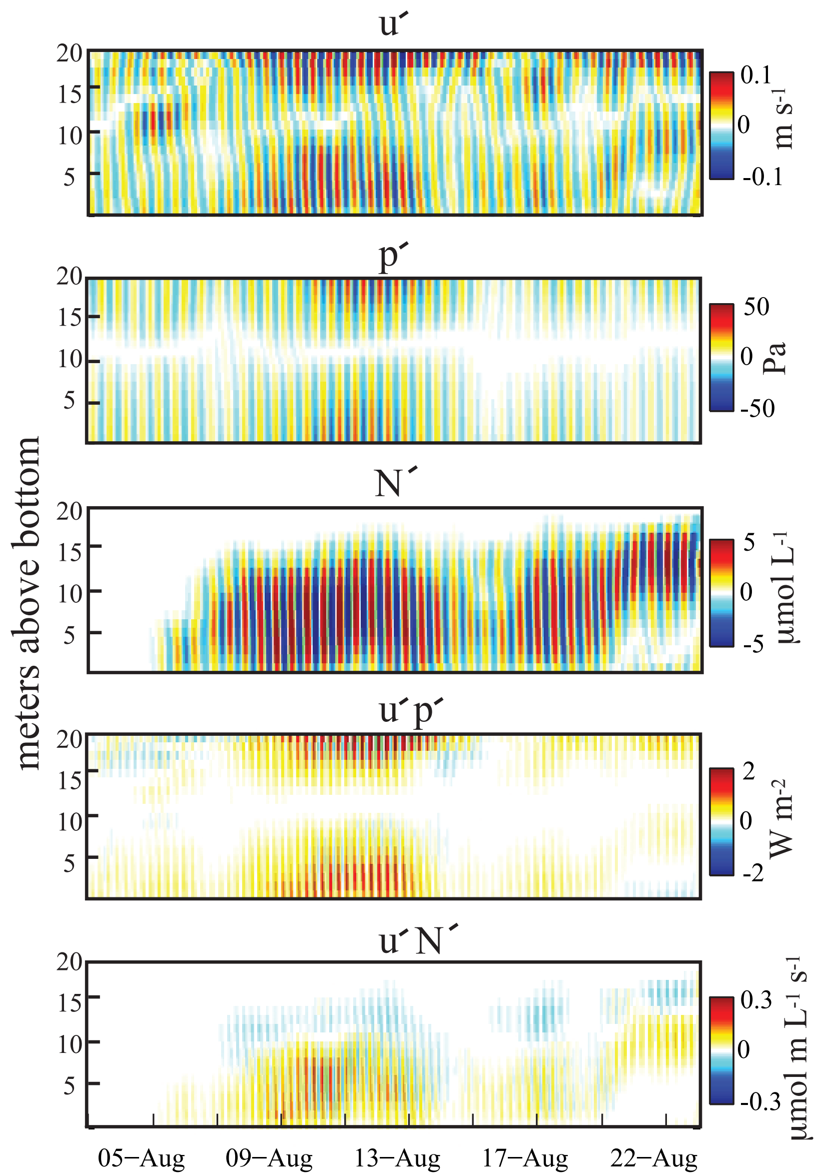
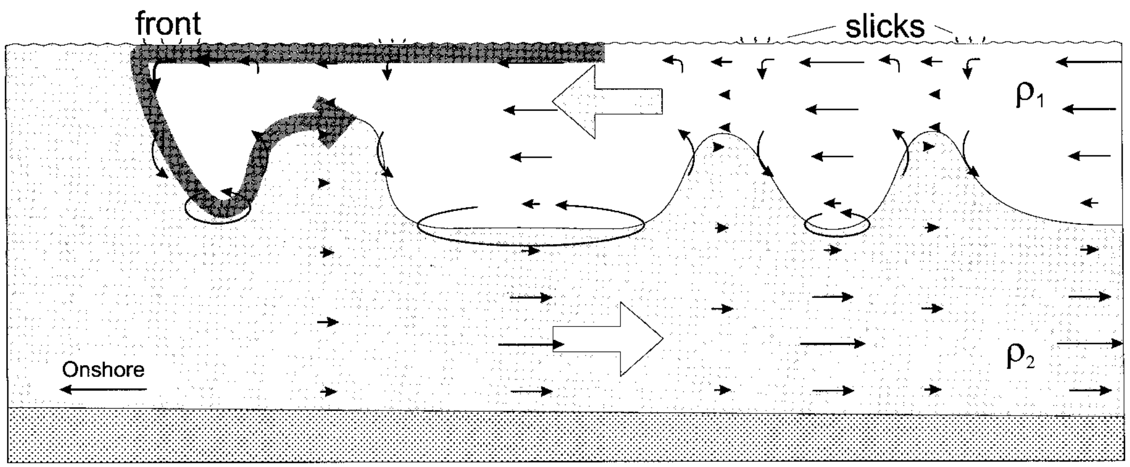
# IW transport larvae/nutrients



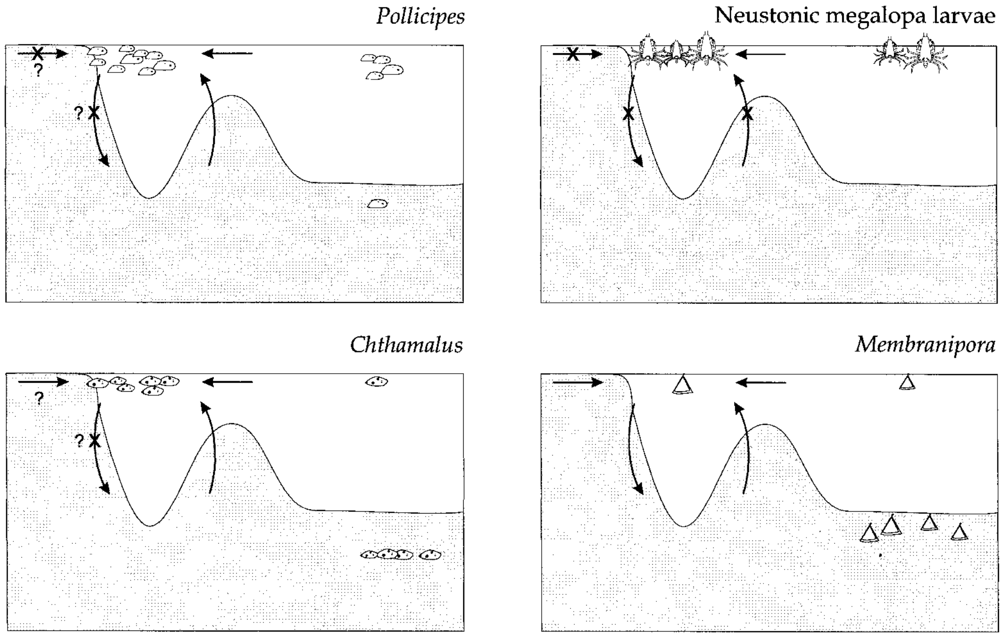

Drew
Lucas, SIO

# Larvae transport onshore




Convergence at the front of a wave train

Only strong upward swimmers can stay in the front




Pineda 99