A discussion on the processes that maintain a cool ocean surface under the stratus decks of the southeastern Pacific

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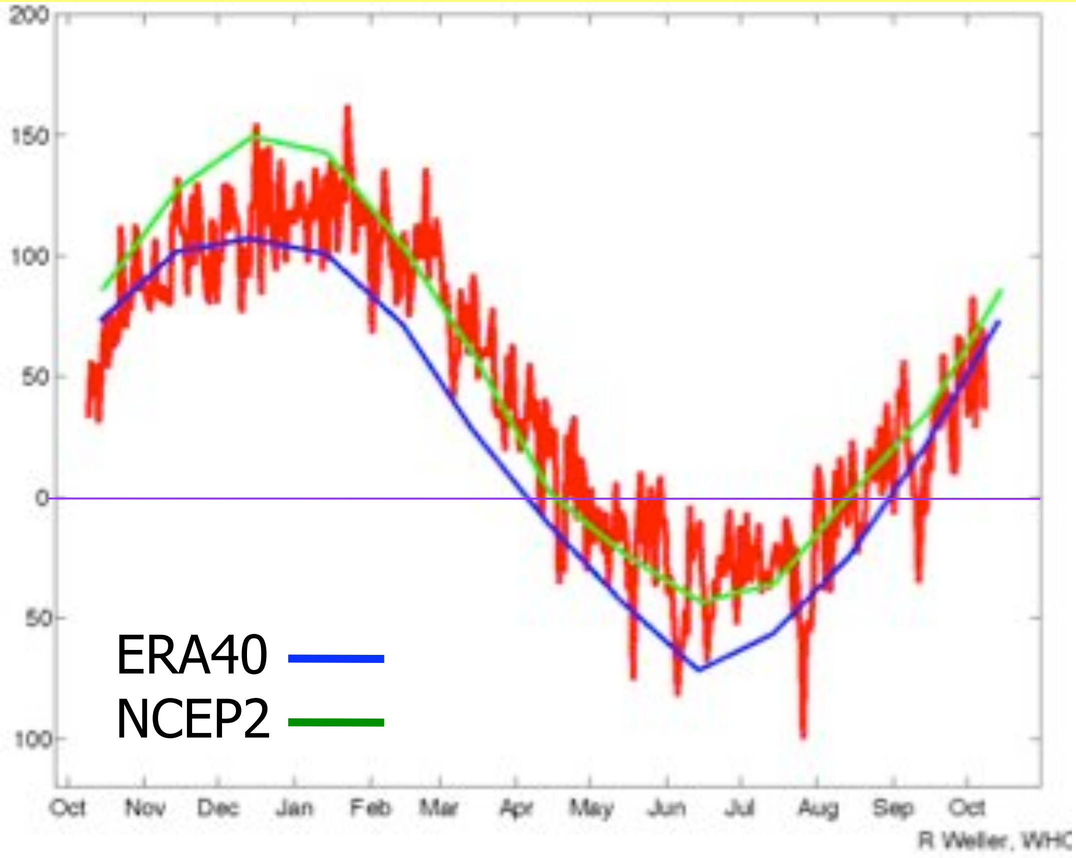
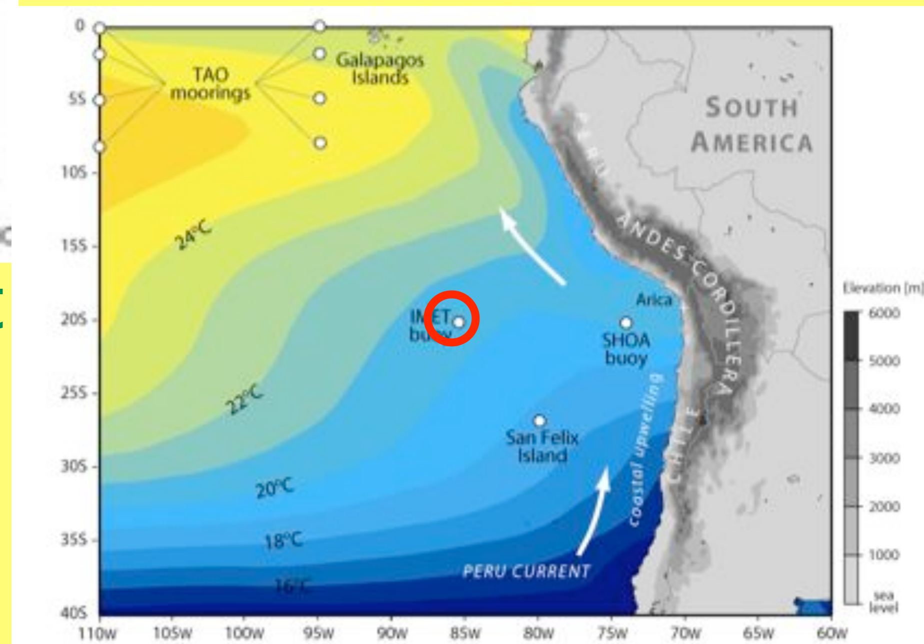
Neat Heat Flux at IMET Buoy Site

Location: (20S, 85W)   Data: Oct 2000 - Sep 2006



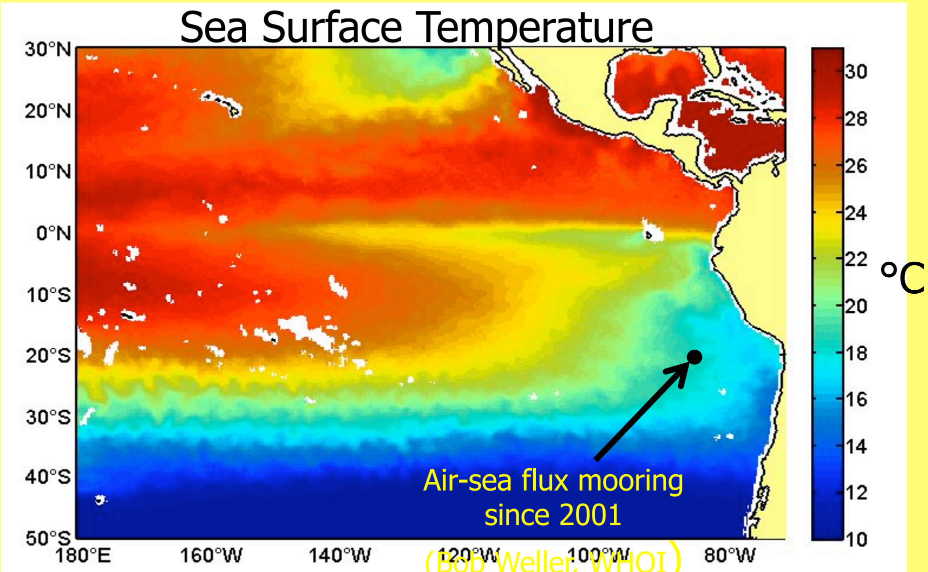
Oct Jan Apr Jul Oct

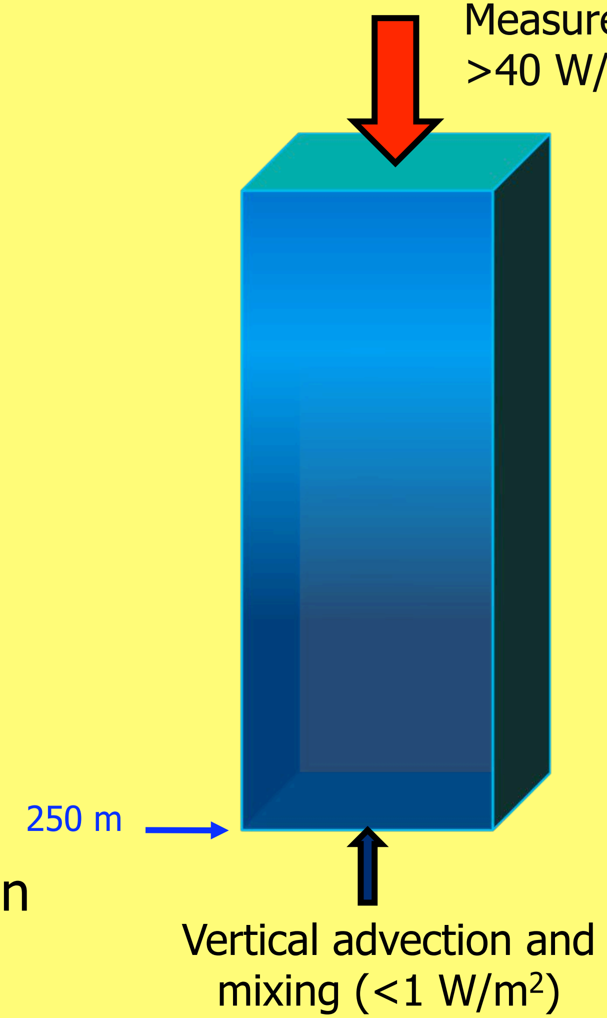
Annual-mean net heat flux **into** ocean > 40 W m^{-2} at 1500 km offshore under persistent low cloud!



How is this net warming at the surface balanced by ocean heat transports?

Annual-mean heat budget



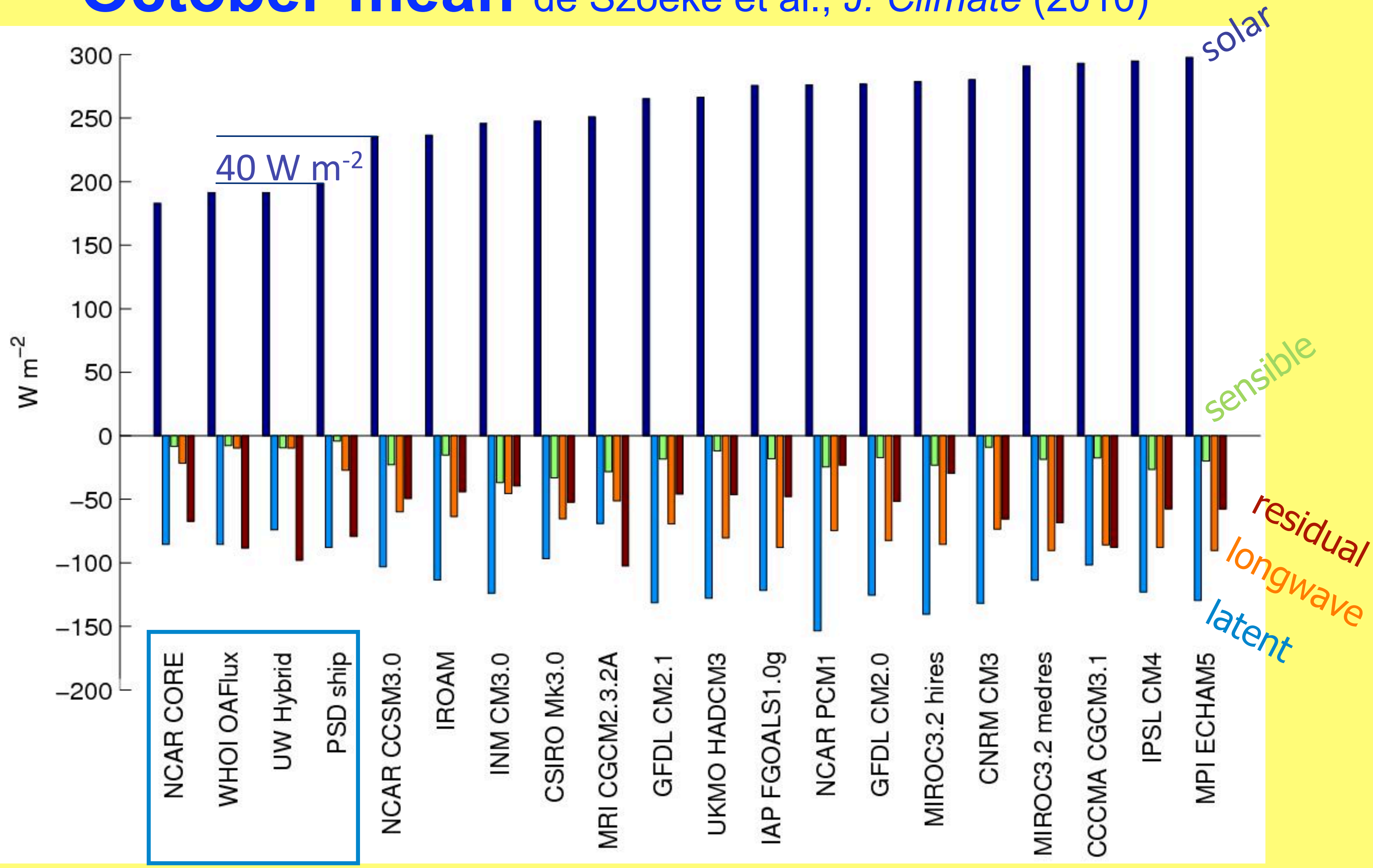


There must be a source of cool water to balance the mean surface heating.

Colbo and Weller (2007, *J. Mar. Res.*) argue that the source of cold water is coastal upwelling, and that both mean and transients contribute to the column heat budget.

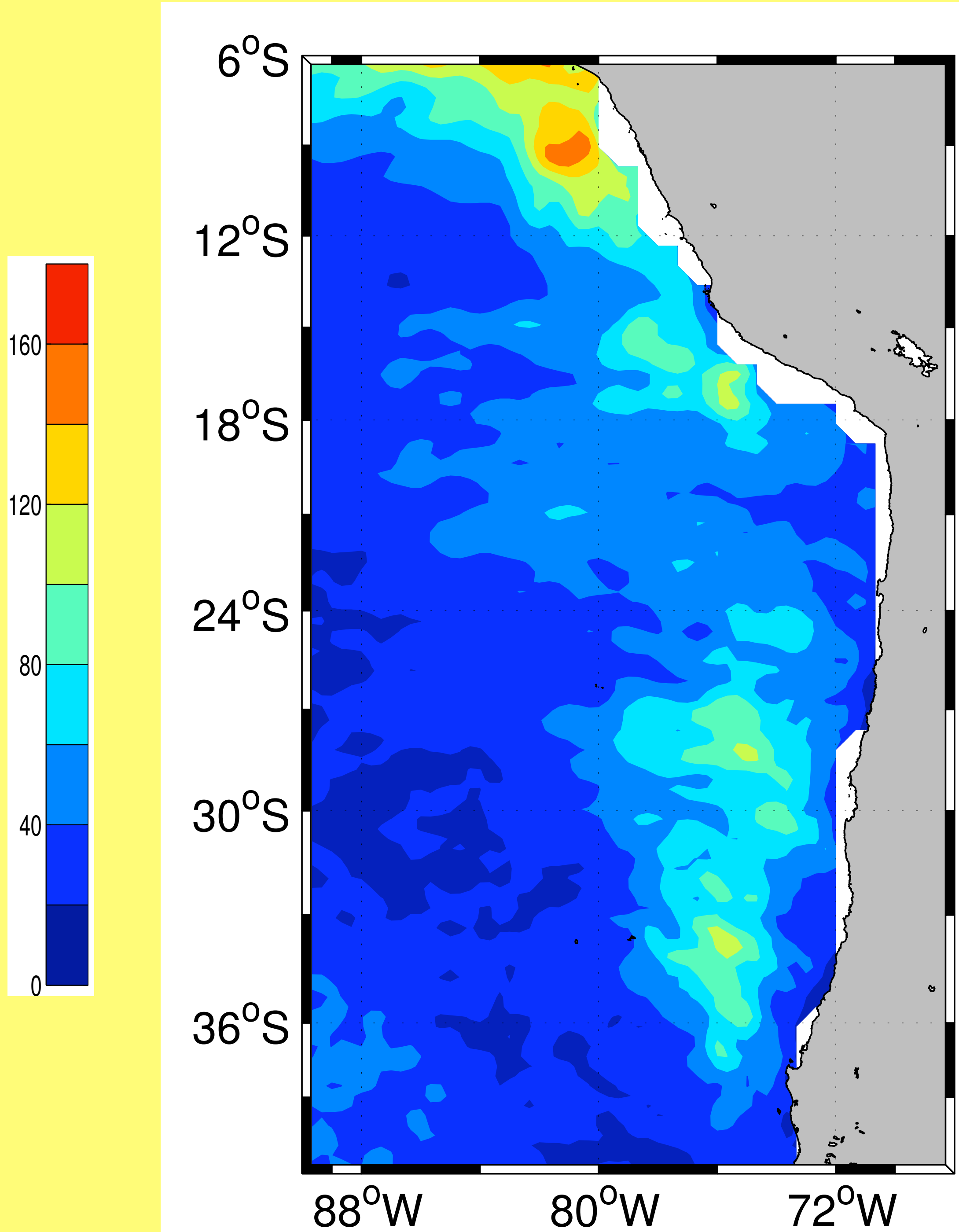
The primary oceanographic goal of **VOCALS (VAMOS Ocean-Cloud-Atmosphere-Land Study)** is to understand why SST is cool in the Southeast Pacific.

CGCMs: Surface heat balances along 20S, 75-85W
October-mean
de Szoeke et al., *J. Climate* (2010)



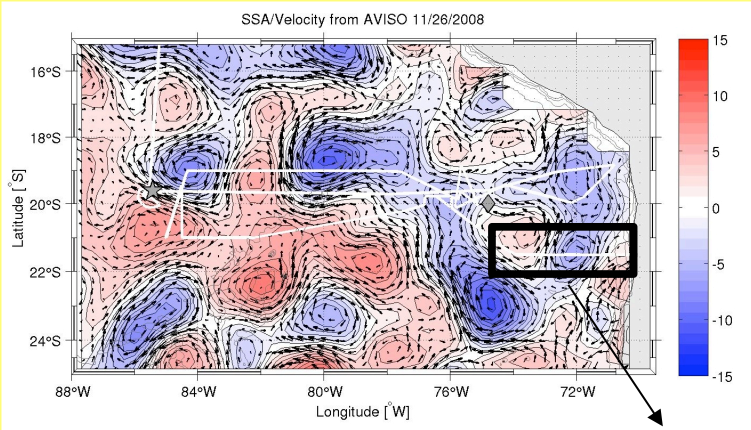
At the ocean surface insolation is too high, evaporation is too high, net heat flux into the ocean is too low, and SSTs are too high.

Mean surface geostrophic Eddy Kinetic Energy (cm^2s^{-2}) **estimated from AVISO altimeter data** (2001-2006)



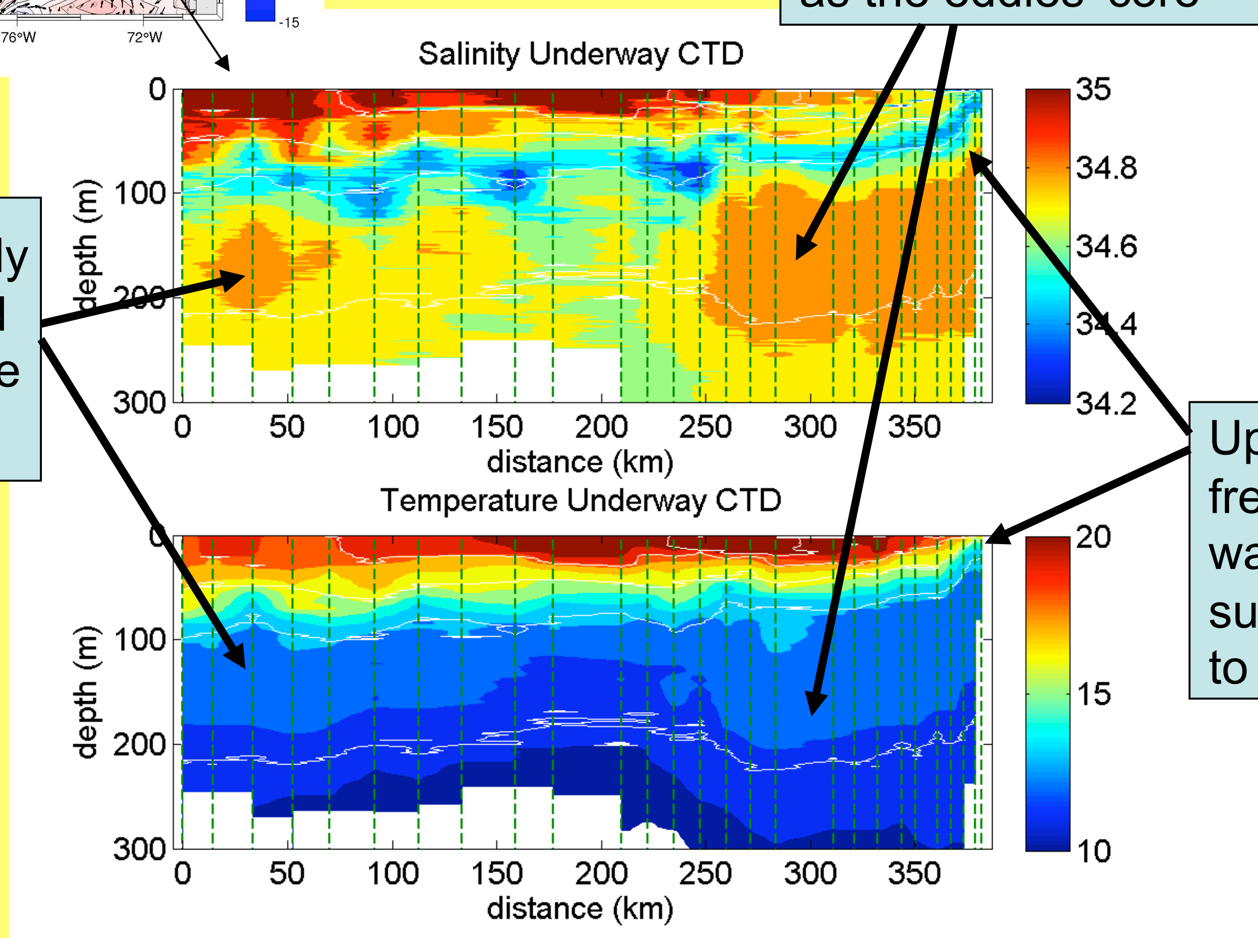
Ocean Eddies in VOCALS-Rex (Oct-Nov 2008)

Ron Brown CTD section up to the coast of Chile - Fiamma Straneo, WHOI



Boundary Undercurrent with same properties as the eddies' core

Anticyclonic eddy with a warm and salty sub-surface core



Upwelling of fresh and cold waters of subpolar origin to the surface

Toniazzo et al (*Clim. Dyn*. 2009):

- In the south-eastern tropical Pacific the global coupled HiGEM ($1/3^o \times 1/3^o$ ocean) simulates significant contributions to the long-term mean heat budget of the water column from heat advection by ocean transients with length scales of 200-450 km, and time scales between 4 month and one year.
- This contribution is highly variable both in space and time, and its magnitude at 20S, 85W is consistent with the estimate by Colbo and Weller (2007). Is such agreement between simulation and estimation merely coincidental?
- At least part of heat advection is due to transients associated with a intrusion of fresh water from higher latitudes along the east-Pacific coast.

Mesoscale Eddies in an Ocean Model

ROMS: 7.5 km x 7.5 km x 32 levels (Colas et al., J. Climate 2010)

SST

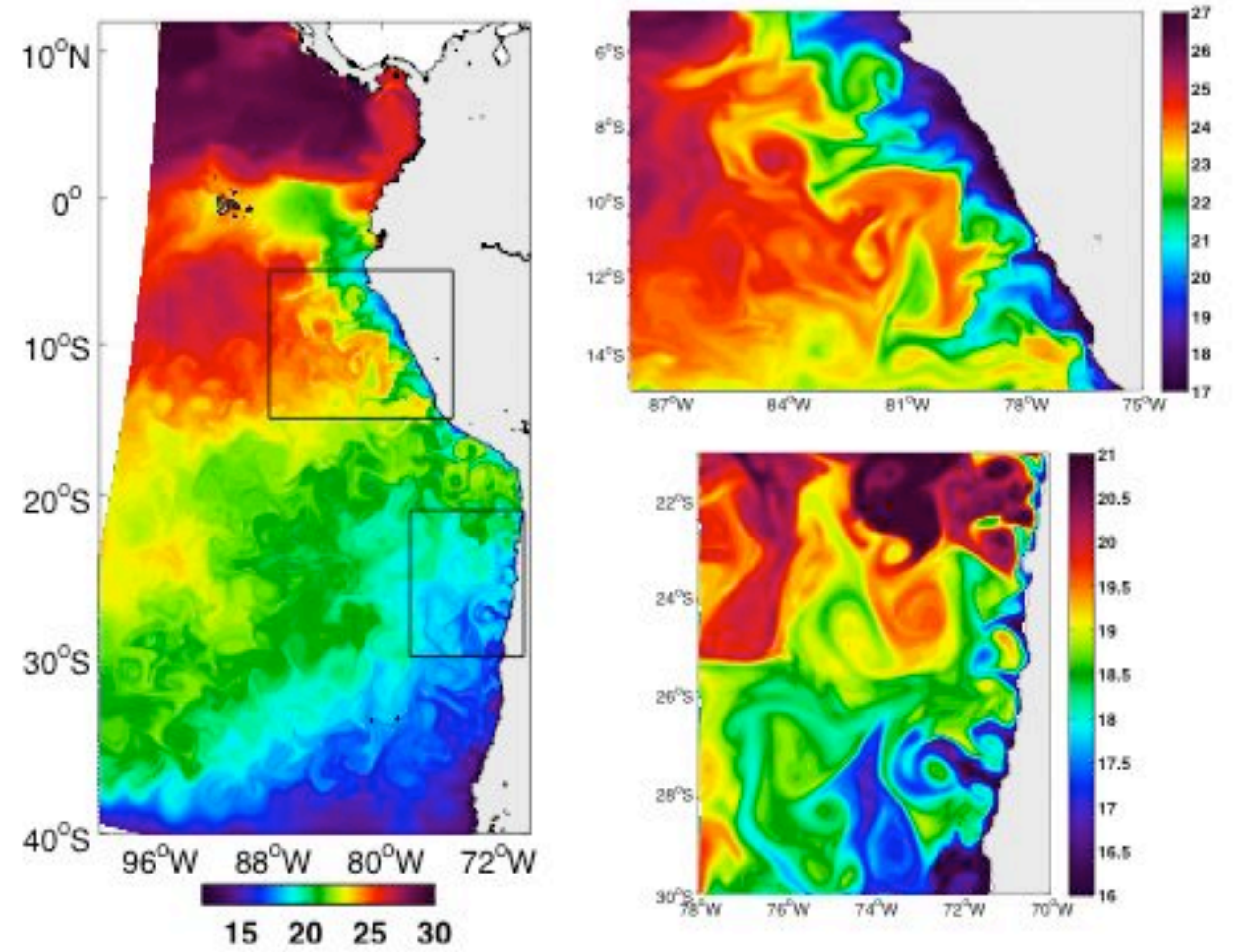


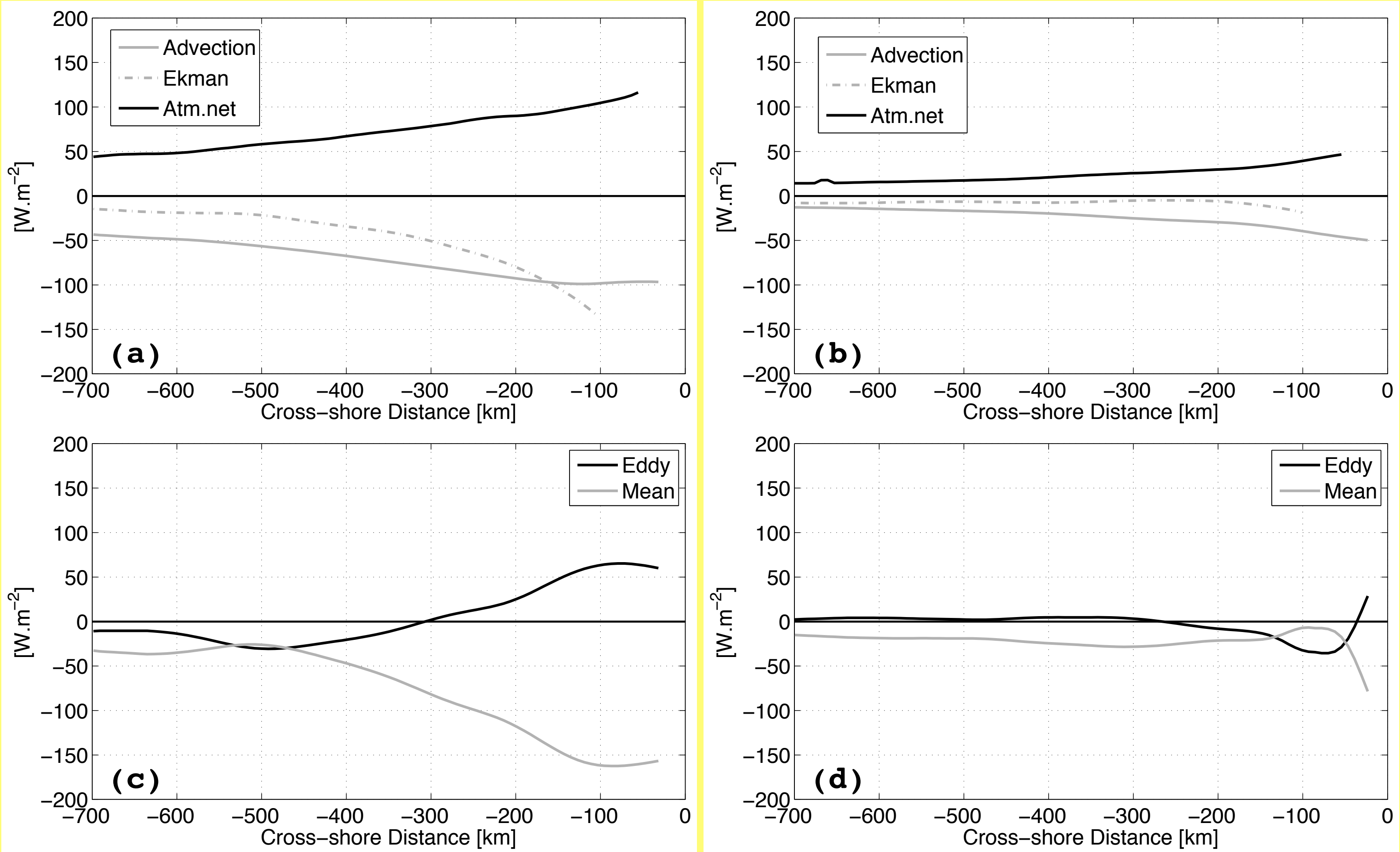
FIG. 1. Snapshot of simulated surface temperature [°C] in the Fall over the entire model domain (left), with zooms (right) into the subdomains indicated by black boxes in the left panel. Color scales are different for the three subplots.

Vertically Integrated Heat Divergence (ROMS)

Peru (7-13S) | Chile (25-35S)

Total

Mean and Eddy



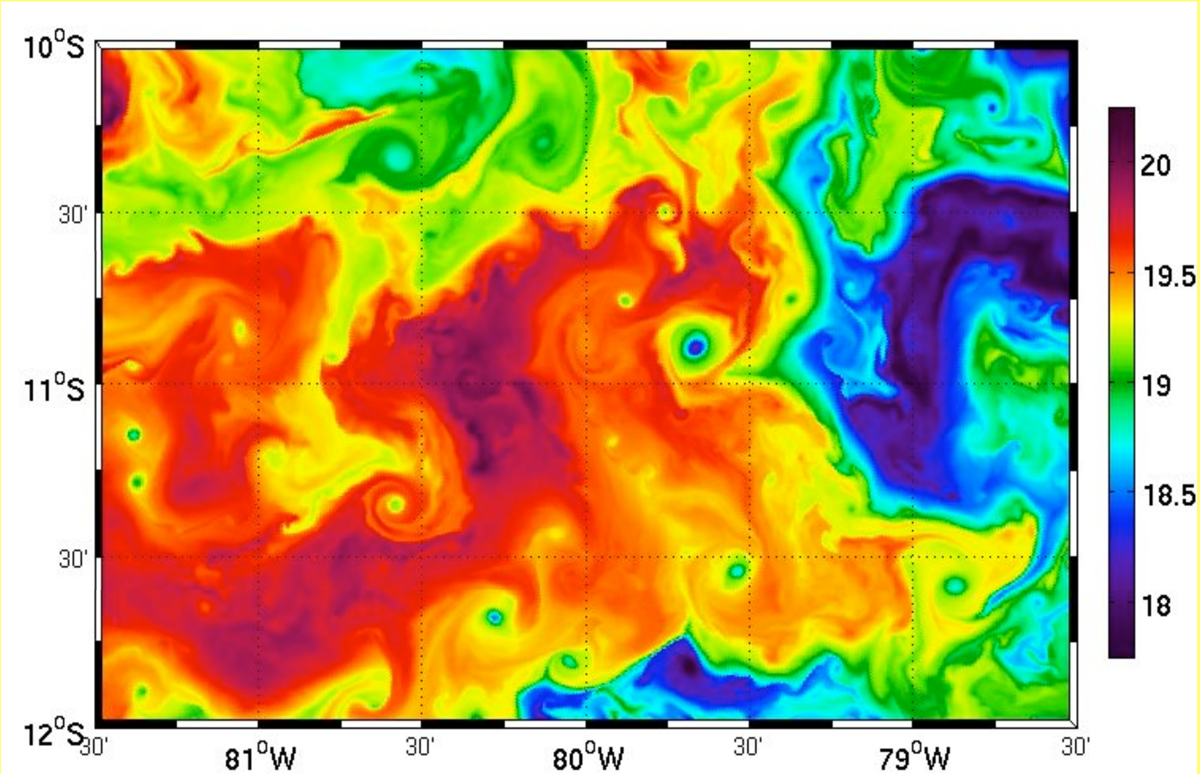
Cross-shore distance (-700km, 0km)

Colas et al. *J. Climate* (2010)

Highlights Colas et al. *J. Climate* (2010), sub-judice.

- In the Perú-Chile current system, the coastal upwelling circulation is the principal source of near-surface cold water that is then advected further offshore while generating mesoscale eddies.
- The mean offshore Ekman transport of upwelled cold water is too small to maintain the cold SSTs by about a factor of two. Thus, the contribution by geostrophic mean and eddy heat advection is necessary to sustain the oceanic cooling.
- Cyclonic vortices tend to dominate the surface field, whereas anticyclonic vortices dominate the subsurface. The Undercurrent sheds coherent subsurface anticyclones with warm and salty cores.
- Oceanic advection has severe sampling estimation errors locally.

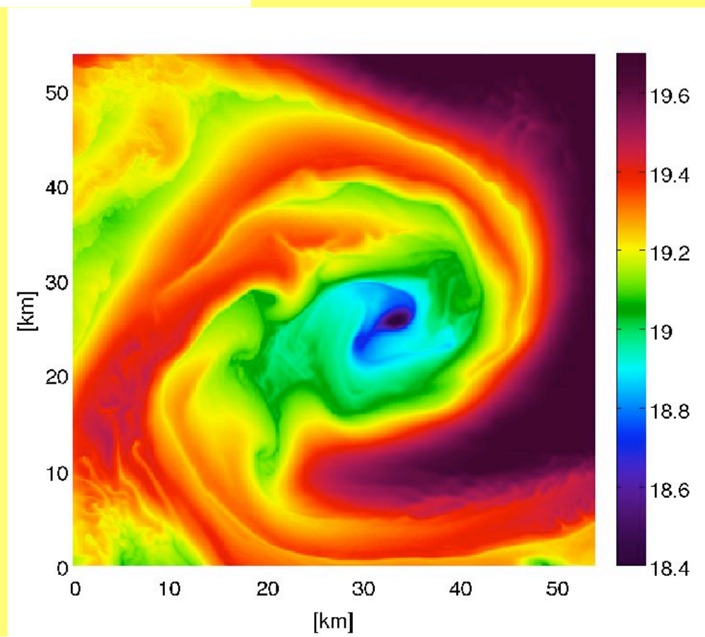
Submesoscale Eddies



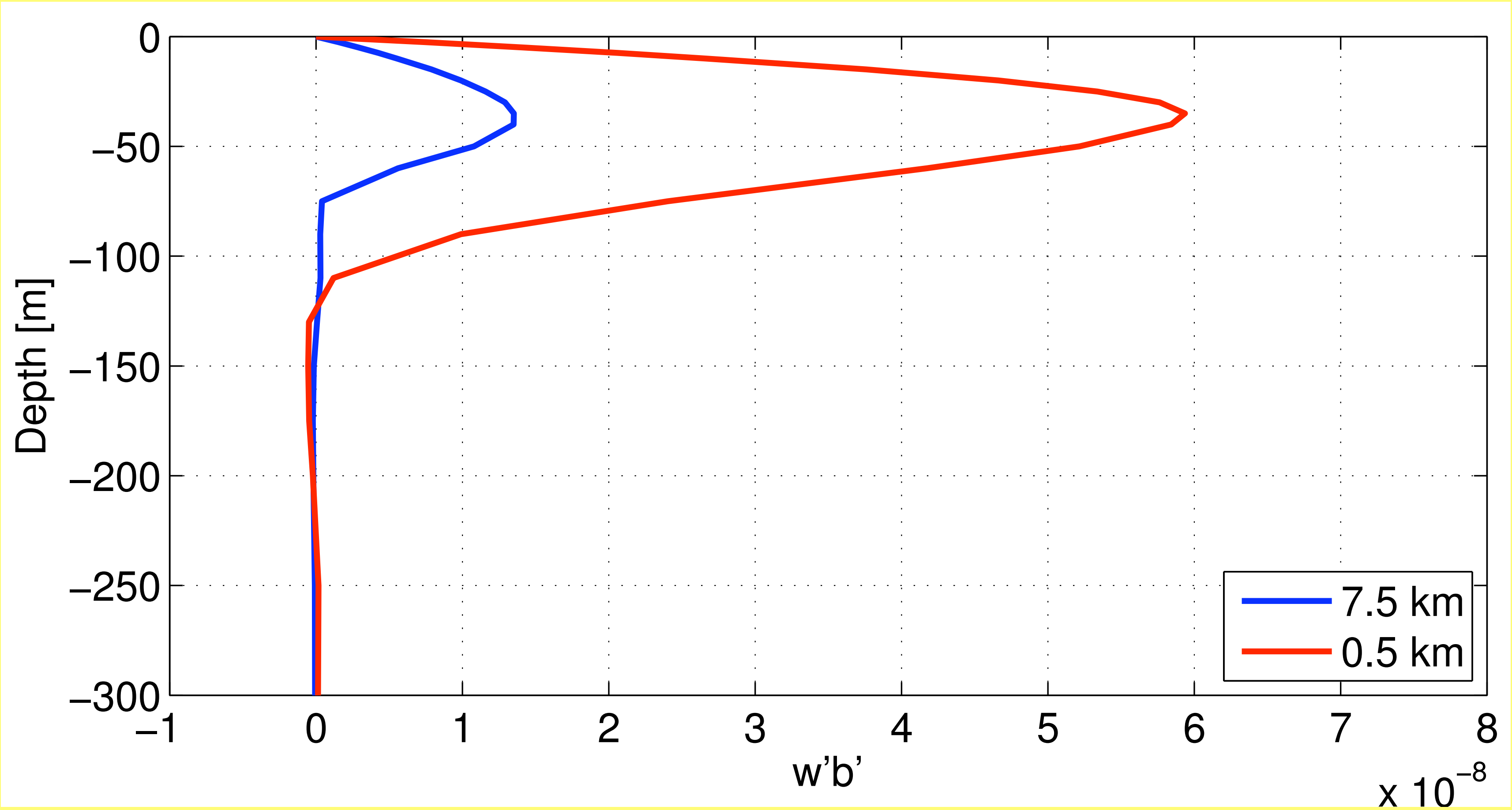
Snapshots of SST [C] at high-resolution numerical simulation (**dx = 500 m**, from a set of embedded domains, dx = 7.5 km and dx = 2 km) of the Peru-Chile coast.

Submesoscale coherent vortices, fronts and filaments are seen between the mesoscale eddies

SST snapshot of one eddy (at resolution **dx = 180 m)**. Note the cold eddy core, and cold filaments (the spiral arms).



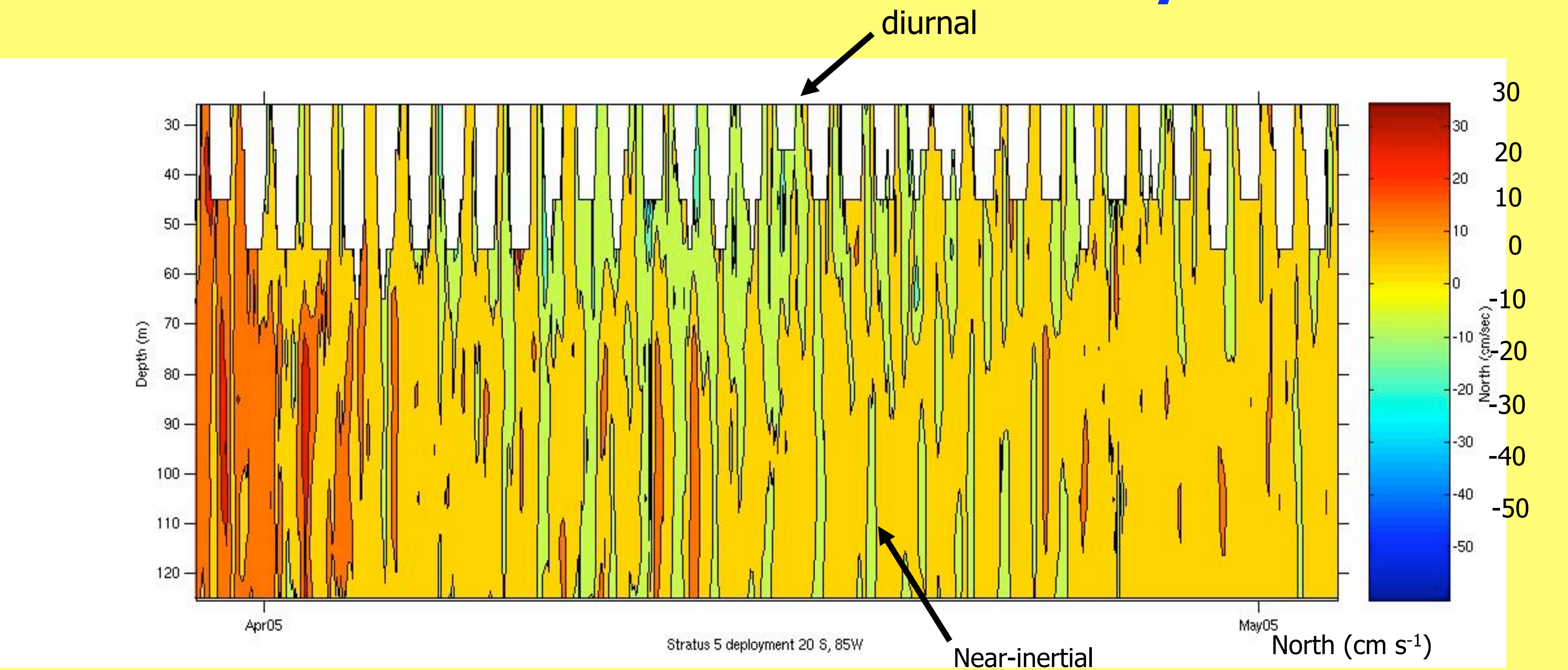
In ROMS, eddies transport heat vertically to the surface layer. This can depend strongly on model resolution.



July-mean vertical buoyancy flux ($10^{-8} m^2 s^{-3}$)

Mc Williams et al. *GRL* (2009); Colas et al. *J. Climate* (2010)

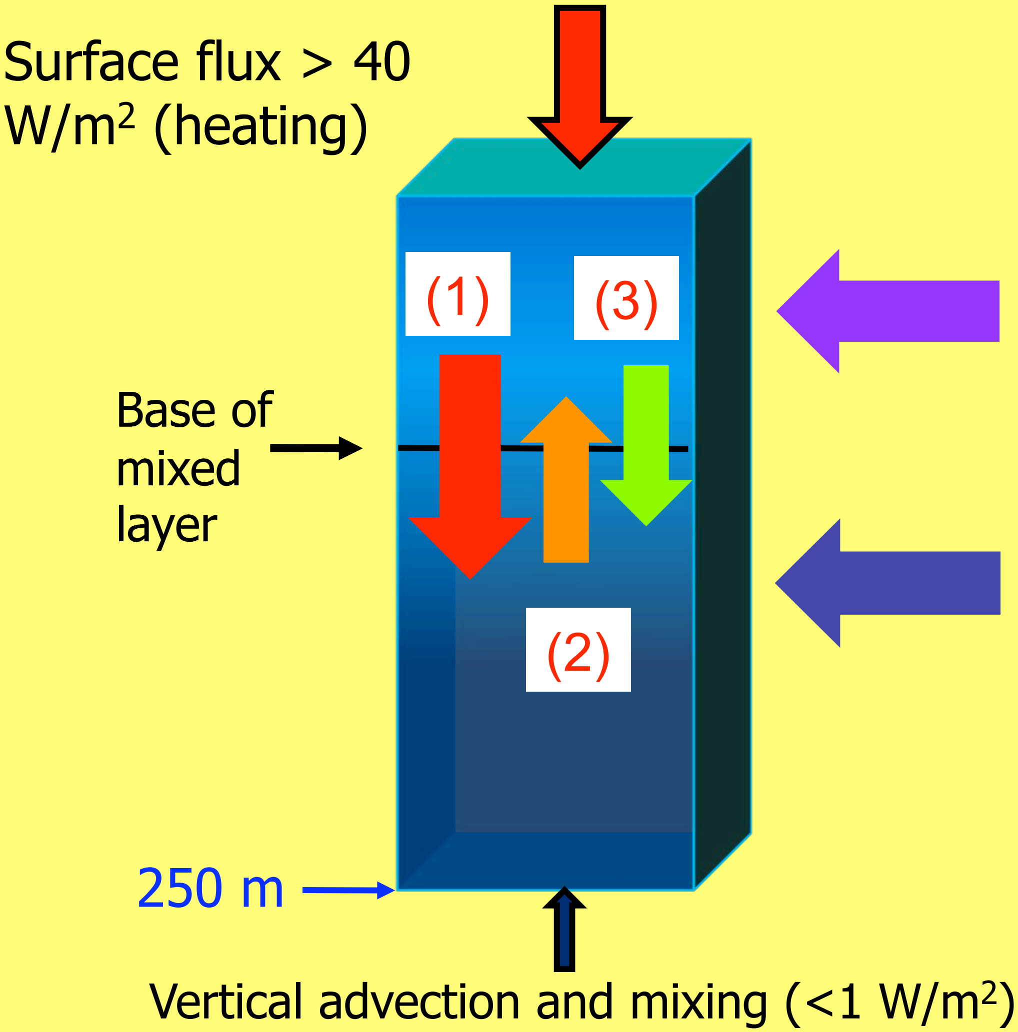
Near-inertial oscillations below the surface can remove heat from the surface Layer



One month of upper ocean velocity (15 to 125 m) data at the Stratus mooring from an acoustic Doppler velocity profiler. At the surface, a diurnal (24 hour) cycle in the depth of the scattering layer modulates Doppler return. Below the surface layer, near-inertial (36 hour) oscillations are evident; these play a role in mixing.

Weller et al. (2008)

Hypothesis on the heat budget of the ocean column



Weak horizontal cooling above the thermocline (~ 0-10 W/m^2 from current meters and satellite SSTs).

Horizontal advection at and below the thermocline (cooling) due to processes that vary with region; it is partly by transient eddies.

(1) Heat transport by turbulence processes
(2) Heat transport by submesoscale eddies
(3) Heat transport by processes such as mixing associated with near-inertial oscillations, with a possible contribution by others such as salt fingering.

Summary

- In the SEP, the ocean underneath the stratocumulus decks is heated by the atmosphere and cooled by advection of cold water upwelled along the South American coast.
- The contribution to heat advection by Ekman transport is too small. The contributions by geostrophic mean and eddy advection are both necessary to sustain the oceanic cooling.
- The current discussion is on the vertical transports of heat within the oceanic column by submesoscale and near-inertial processes.
- How can this be handled by climate models? On the parameterization of what physical processes should we focus?

VOCALS Hypothesis

Oceanic mesoscale eddies play a major role in the transport of heat and fresh water from coastally upwelled water to regions further offshore.

VOCALS research supports the validity of this hypothesis. The research is also providing insight into the structure of oceanic mesoscale eddies in the region. In addition, a physically consistent paradigm has emerged on how CGCMs with low resolutions misinterpret the regional heat budget in the VOCALS region. More analysis of the oceanic microstructures are required for a better understanding of the vertical heat transports in the oceanic column.