Measurements of upper-ocean turbulence and air-sea interaction during VOCALS REx, part II

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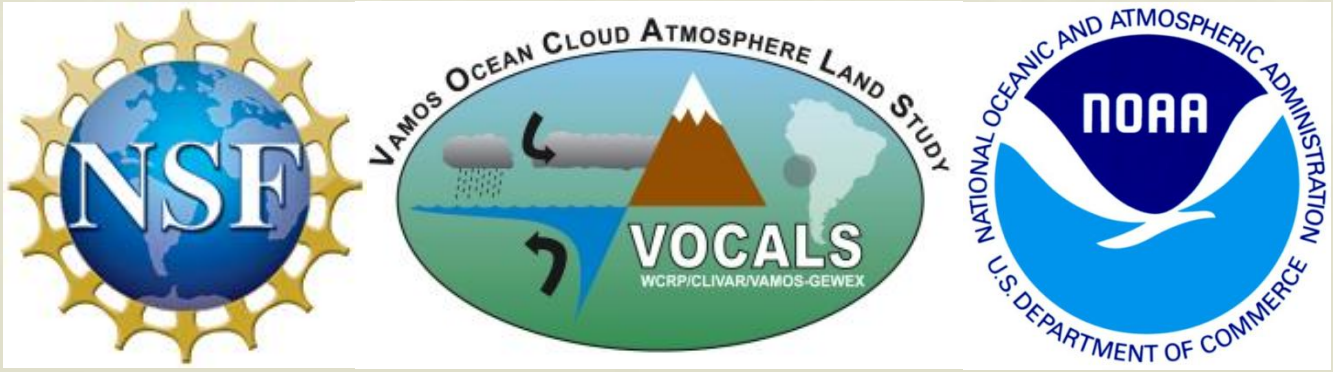


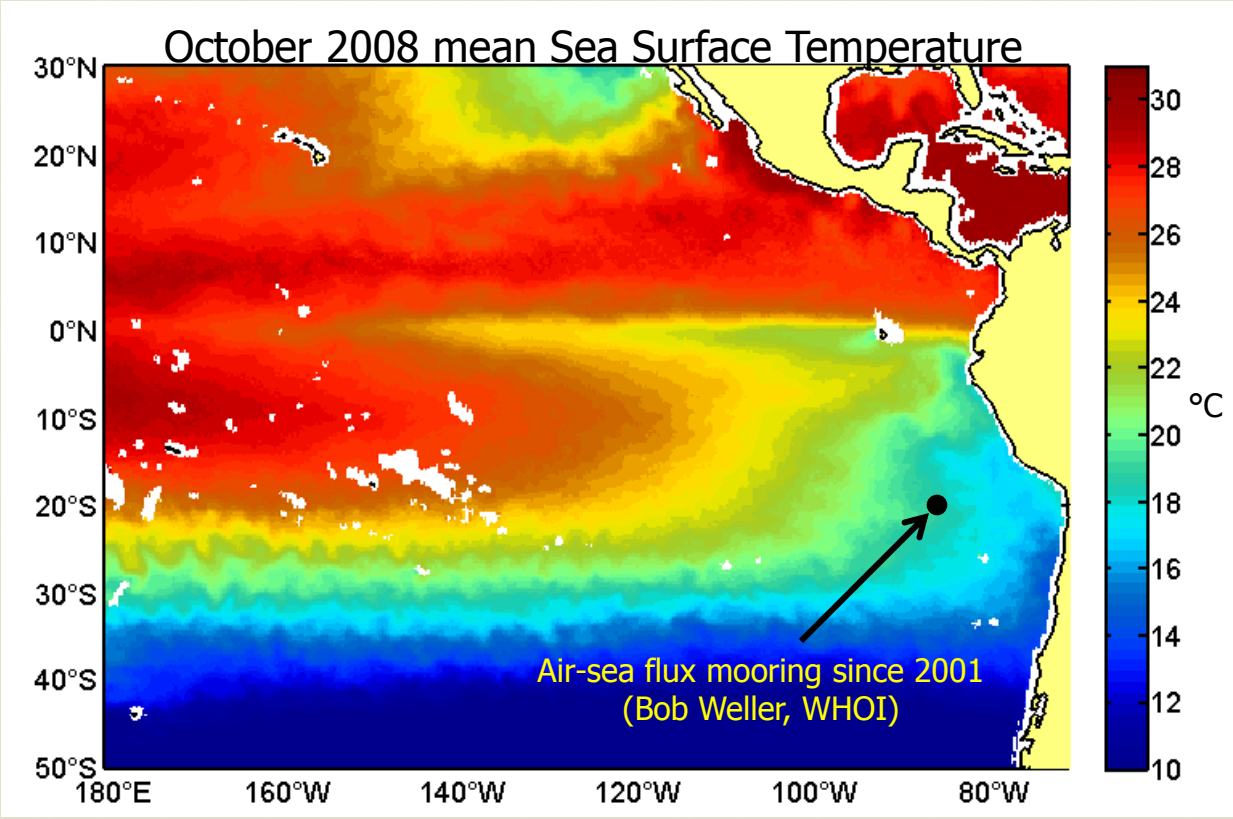
2011 VOCALS meeting, Miami

Selected VOCALS-REx hypotheses (Wood et al., 2006)

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

→Eddy transport in the surface layer appears to be weak (Chelton and Gaube, personal comm.; Zheng et al., 2010).

→Model results suggest a flux of cold water in the low-salinity layer near 200-m depth (Toniazzo et al., 2009; Zheng et al., 2010).



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→The entrainment of cool fresh intermediate water from below the surface layer during mixing associated with energetic mixed-layer near-inertial oscillations is an important process to maintain heat and salt balance of the ocean surface layer in the SEP.

But, there is another vertical mixing mechanism we should consider (this talk):

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But, there is another vertical mixing mechanism we should consider (this talk):

→Vertical mixing due to double diffusion between the warm, salty surface layer and the cool, fresh intermediate water below may help to cool and freshen the ocean surface layer in the SEP.

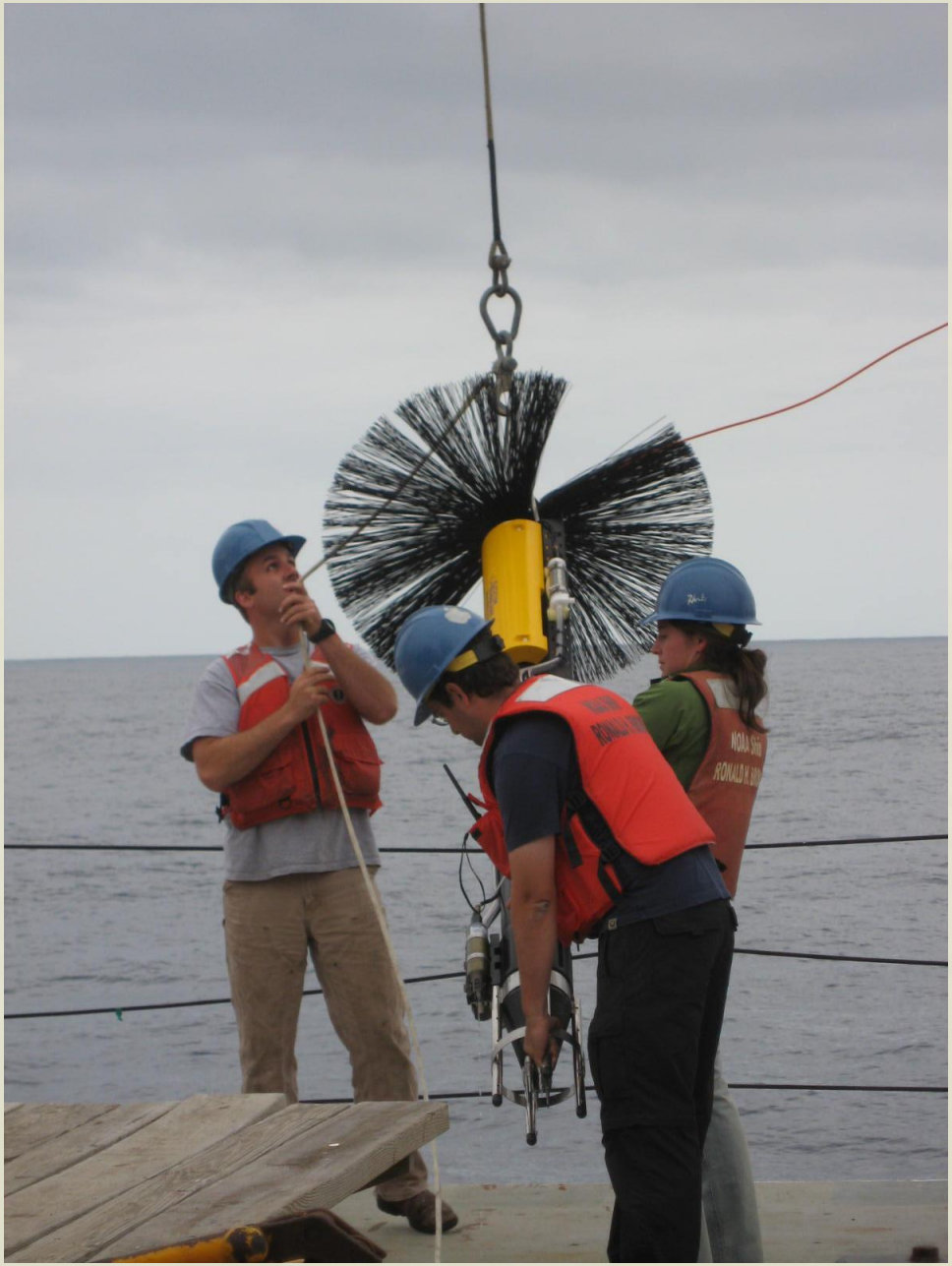
Vertical Microstructure Profiler (VMP) Surveys

→Shipboard surveys carried out in October/November 2008 and January 2010 from the NOAA Ship Ronald H. Brown

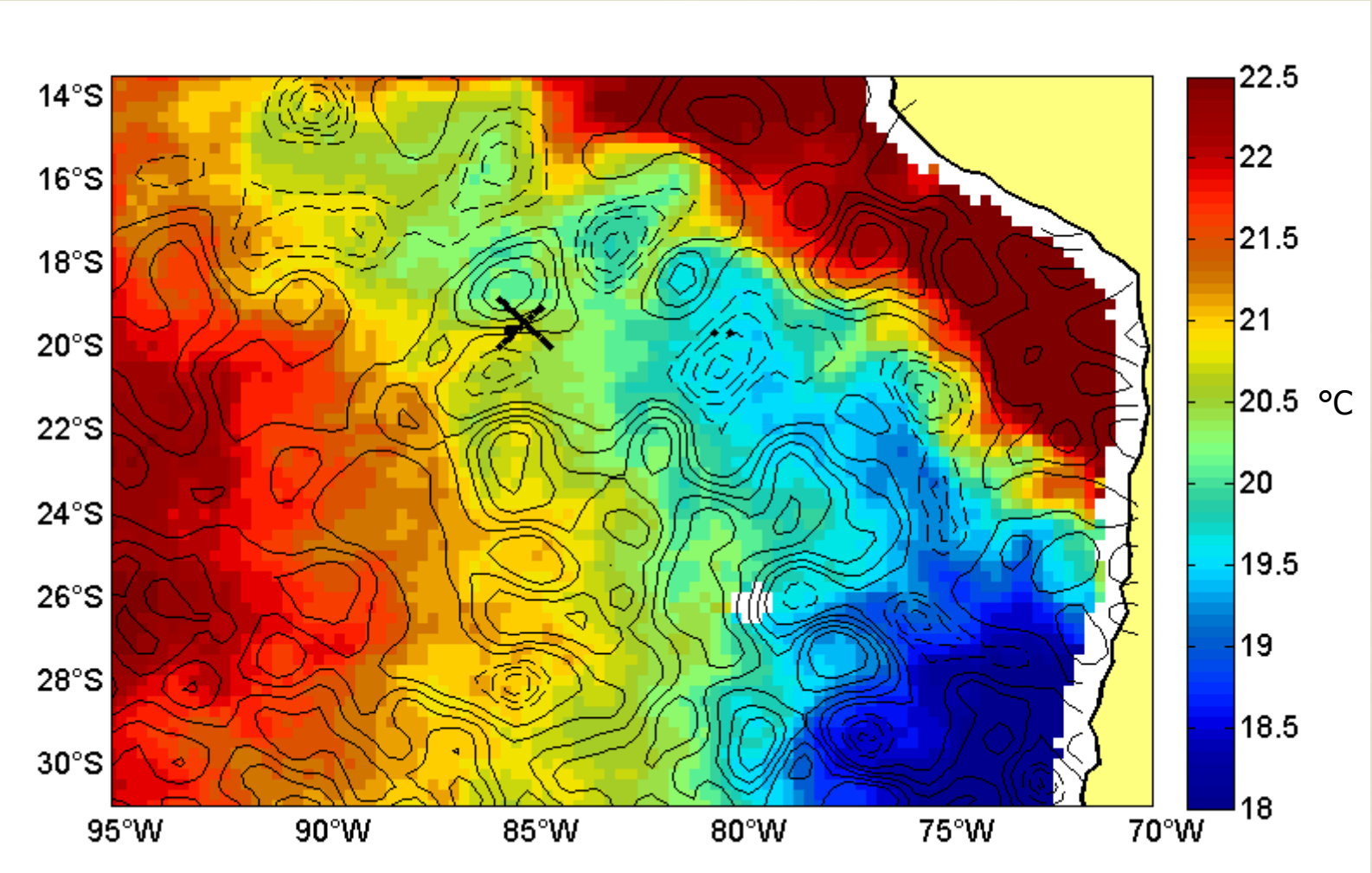
→VMP-2000 model from Rockland Scientific:

- →Seabird CTD (model SBE 3/4/5)
- →2 fast-response micro-temperature probes
- →2 micro-shear probes

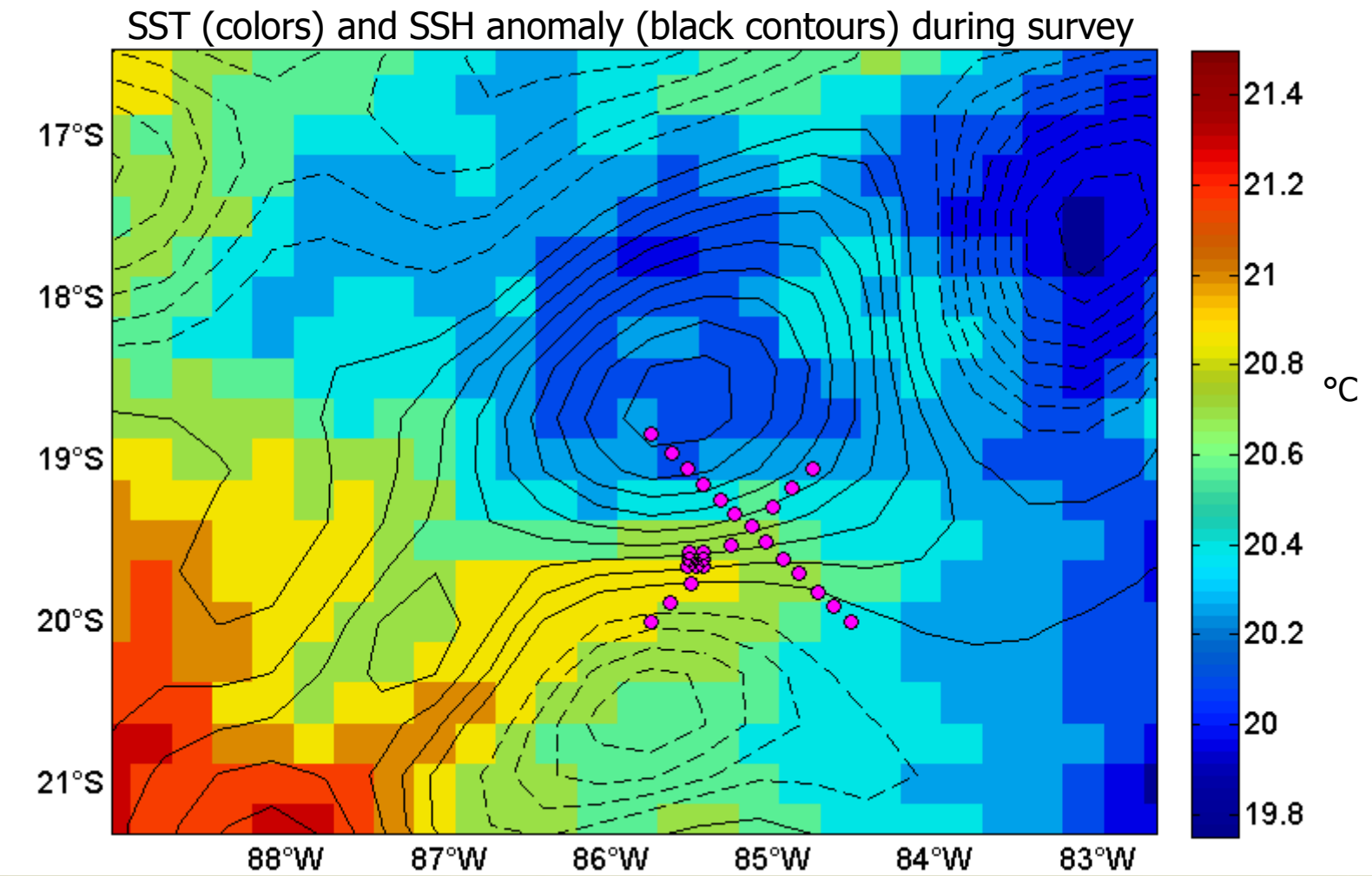
→These centimeter-scale measurements allow estimates of turbulent dissipation and fluxes (or diffusivity).



SST (colors) and sea surface height anomaly (black contours; dashed→<0) during survey, ~21 Jan 2010



SST data: AMSRE satellite microwave, courtesy of Remote Sensing Systems
SSH data: Merged satellite altimetry product, courtesy of AVISO/CNES



SST data: AMSRE satellite microwave, courtesy of Remote Sensing Systems
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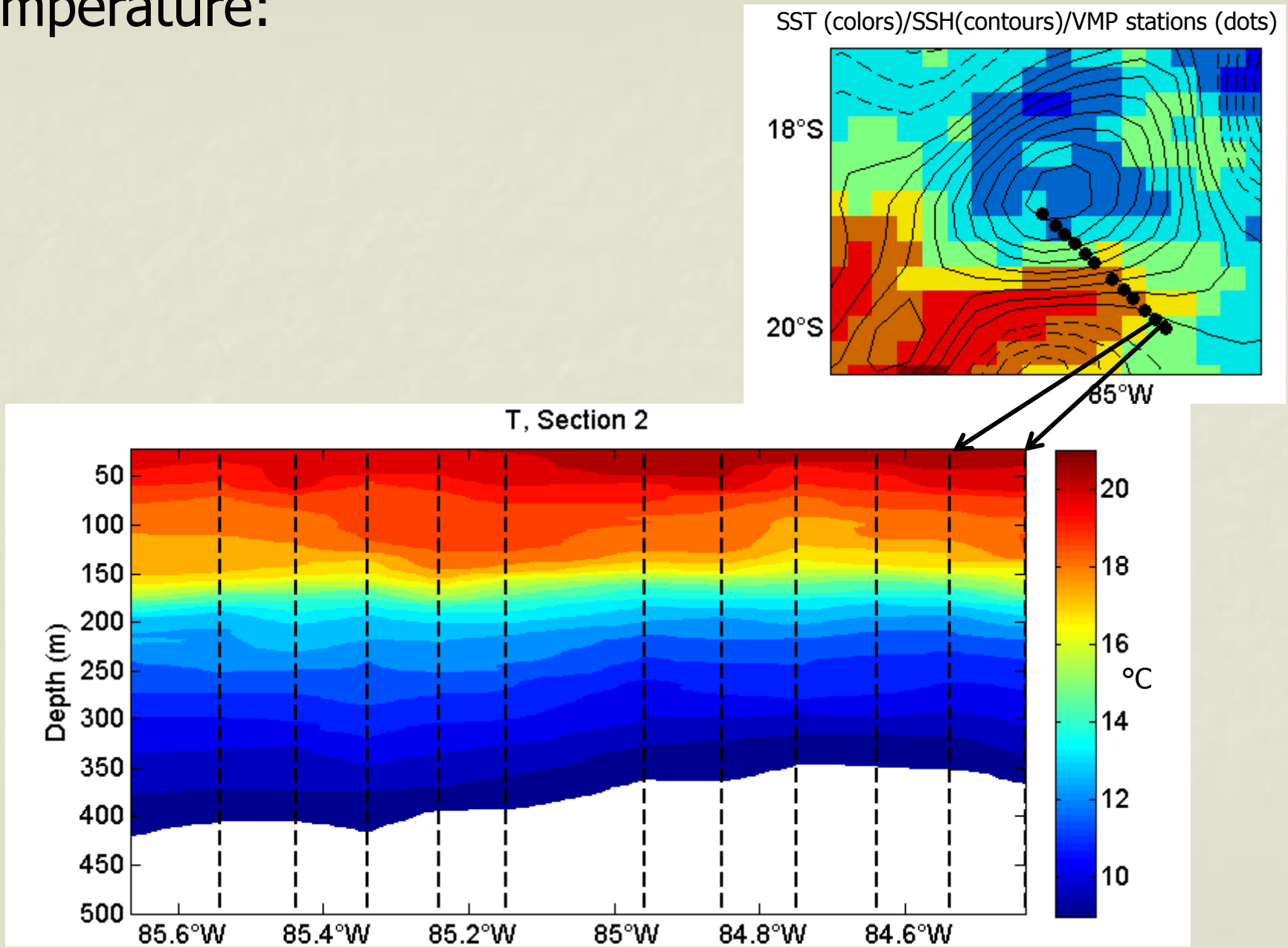
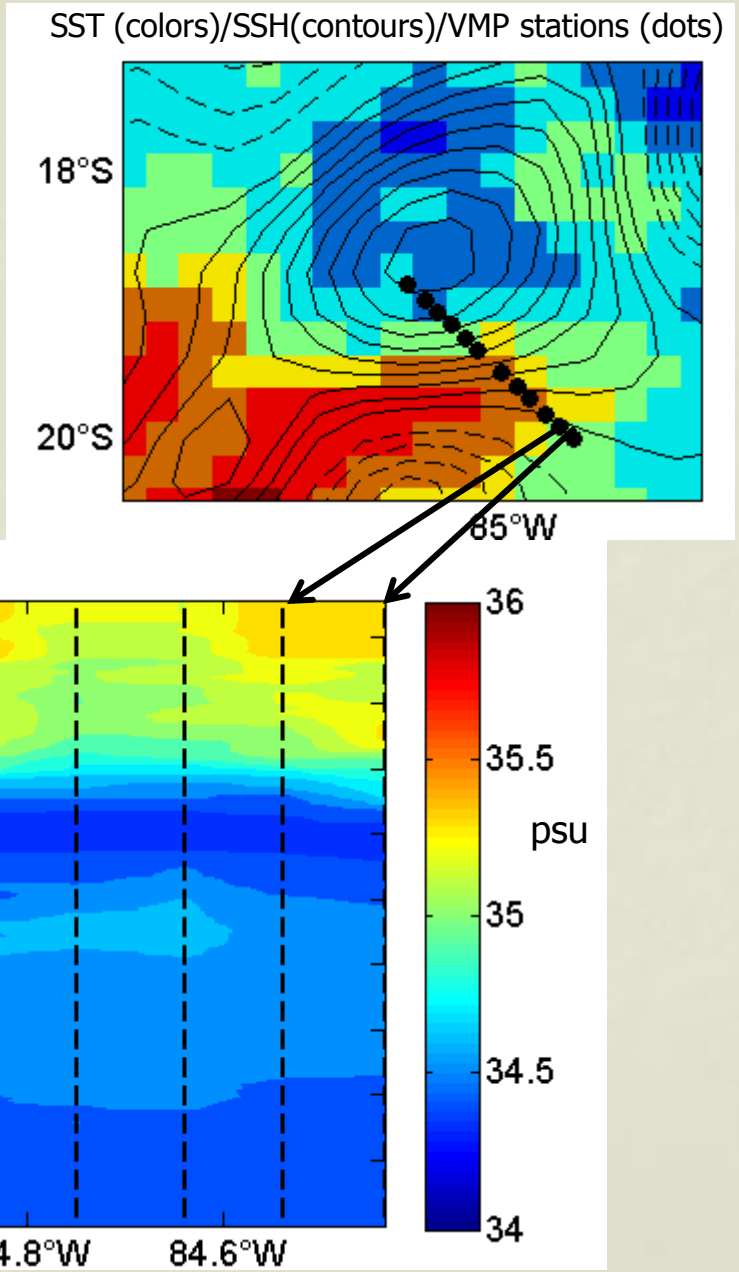
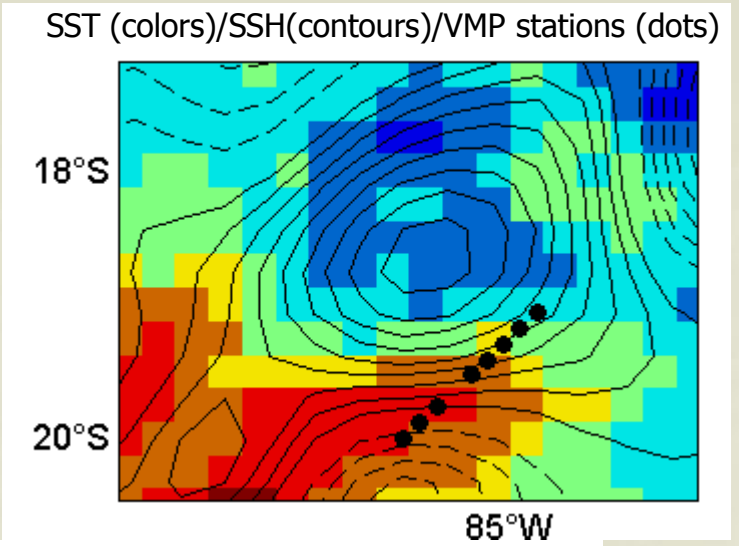
Temperature:

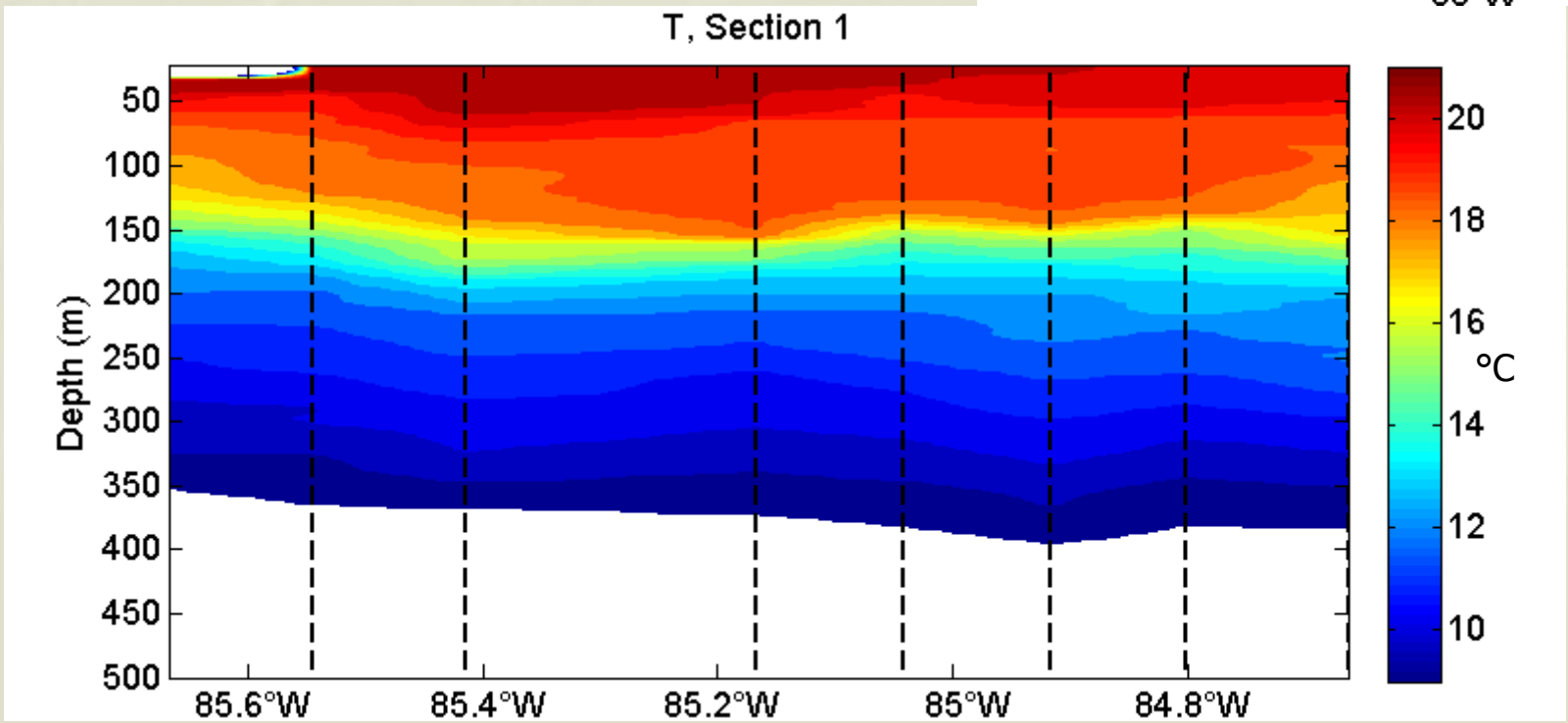


Salinity:

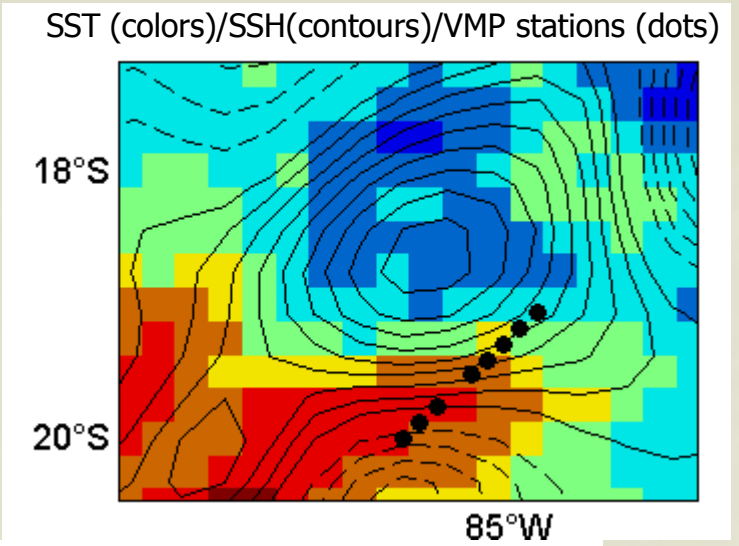

SST (colors)/SSH(contours)/VMP stations (dots)
18°S
20°S
85°W
S, Section 2
Depth (m)
50
100
150
200
250
300
350
400
450
500
85.6°W
85.4°W
85.2°W
85°W
84.8°W
84.6°W
36
35.5
35
34.5
34
psu

Temperature:





Salinity:


SST (colors)/SSH(contours)/VMP stations (dots)
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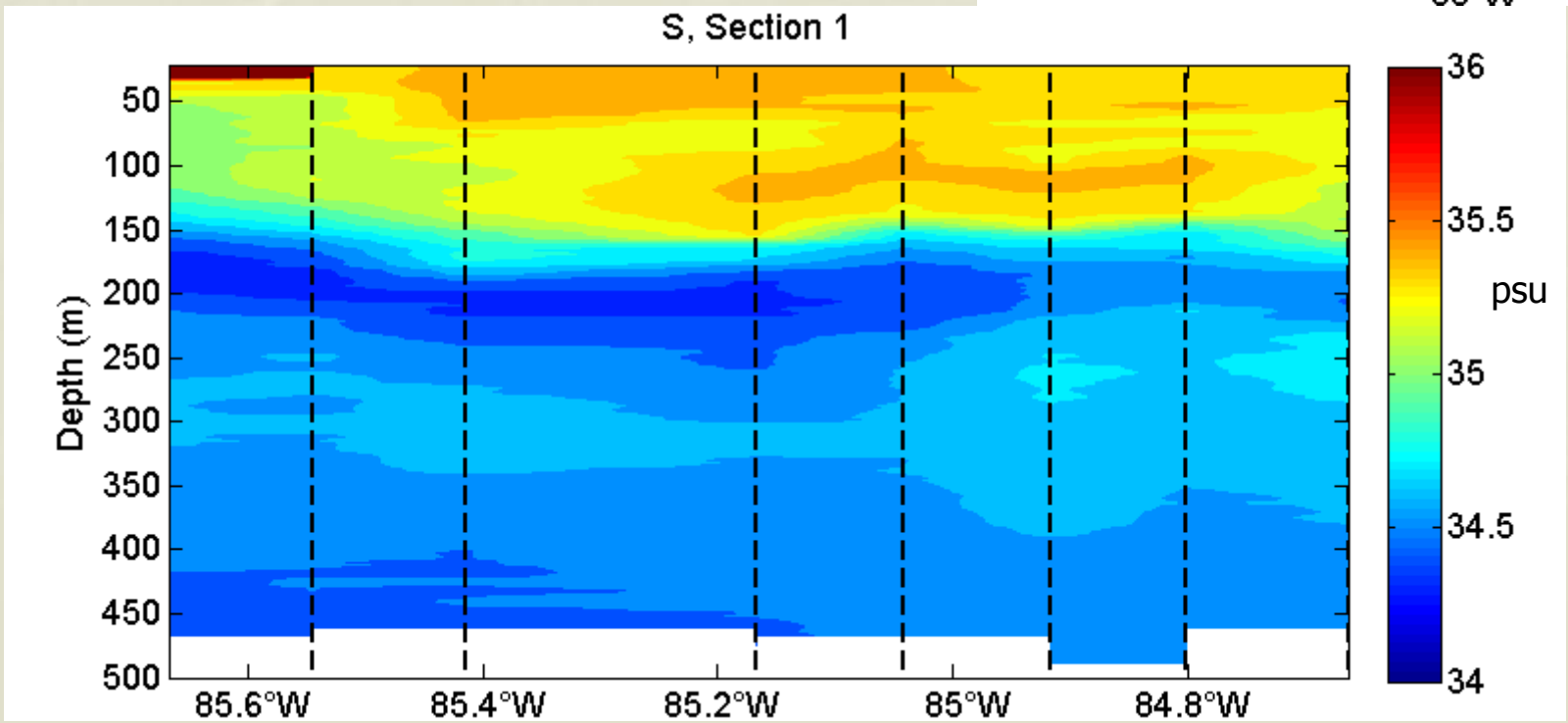
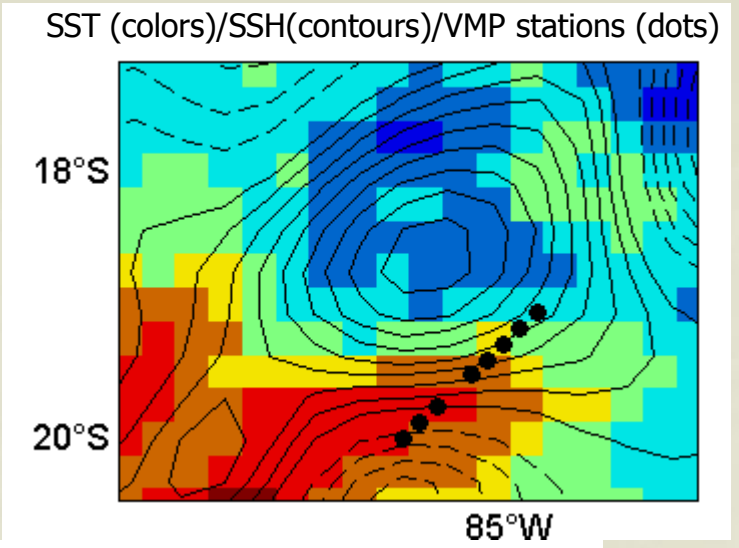
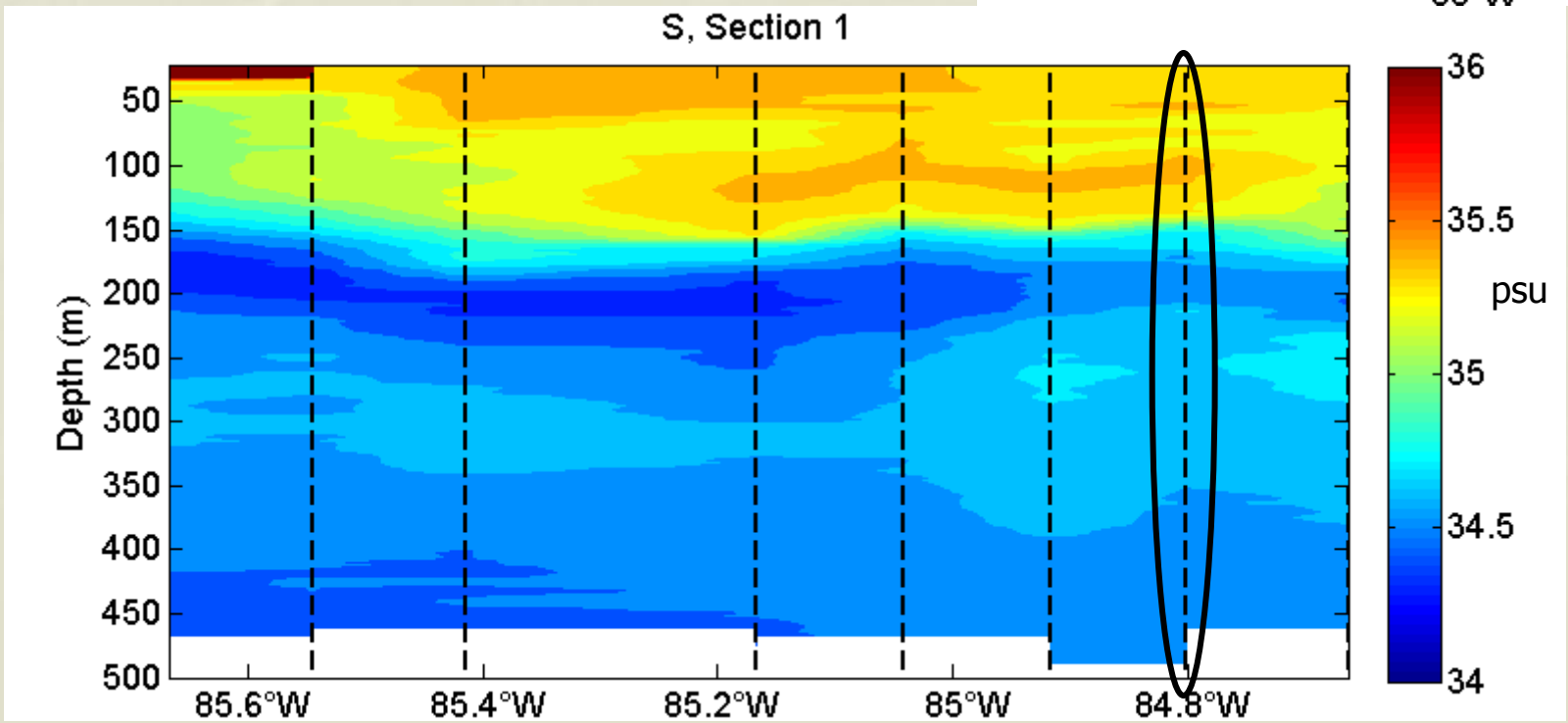
20°S
85°W


S, Section 1
Depth (m)
50
100
150
200
250
300
350
400
450
500
85.6°W
85.4°W
85.2°W
85°W
84.8°W
36
35.5
35
34.5
34
psu

Salinity:


SST (colors)/SSH(contours)/VMP stations (dots)
18°S
20°S
85°W


S, Section 1
Depth (m)
50
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85.6°W
85.4°W
85.2°W
85°W
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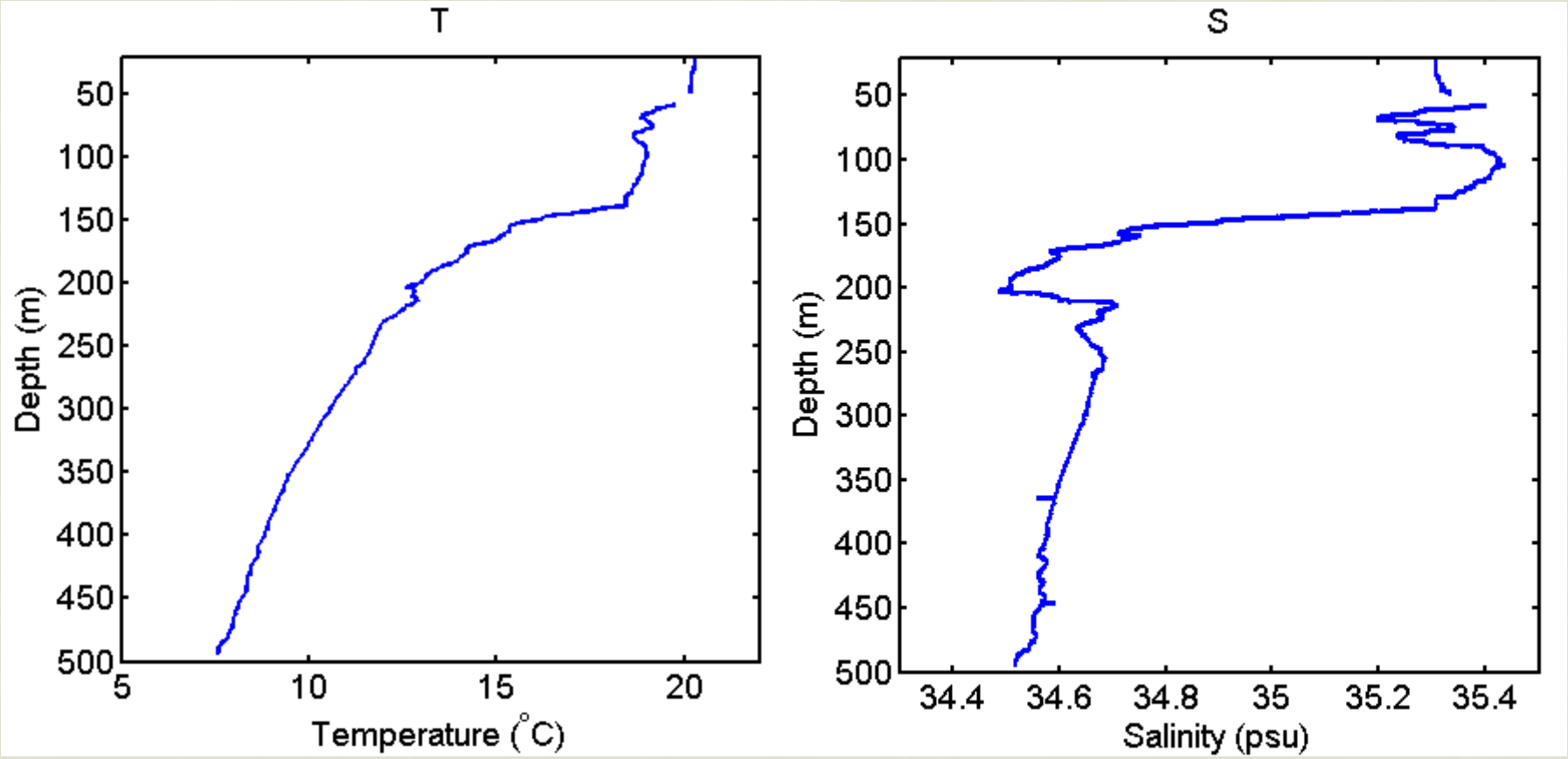
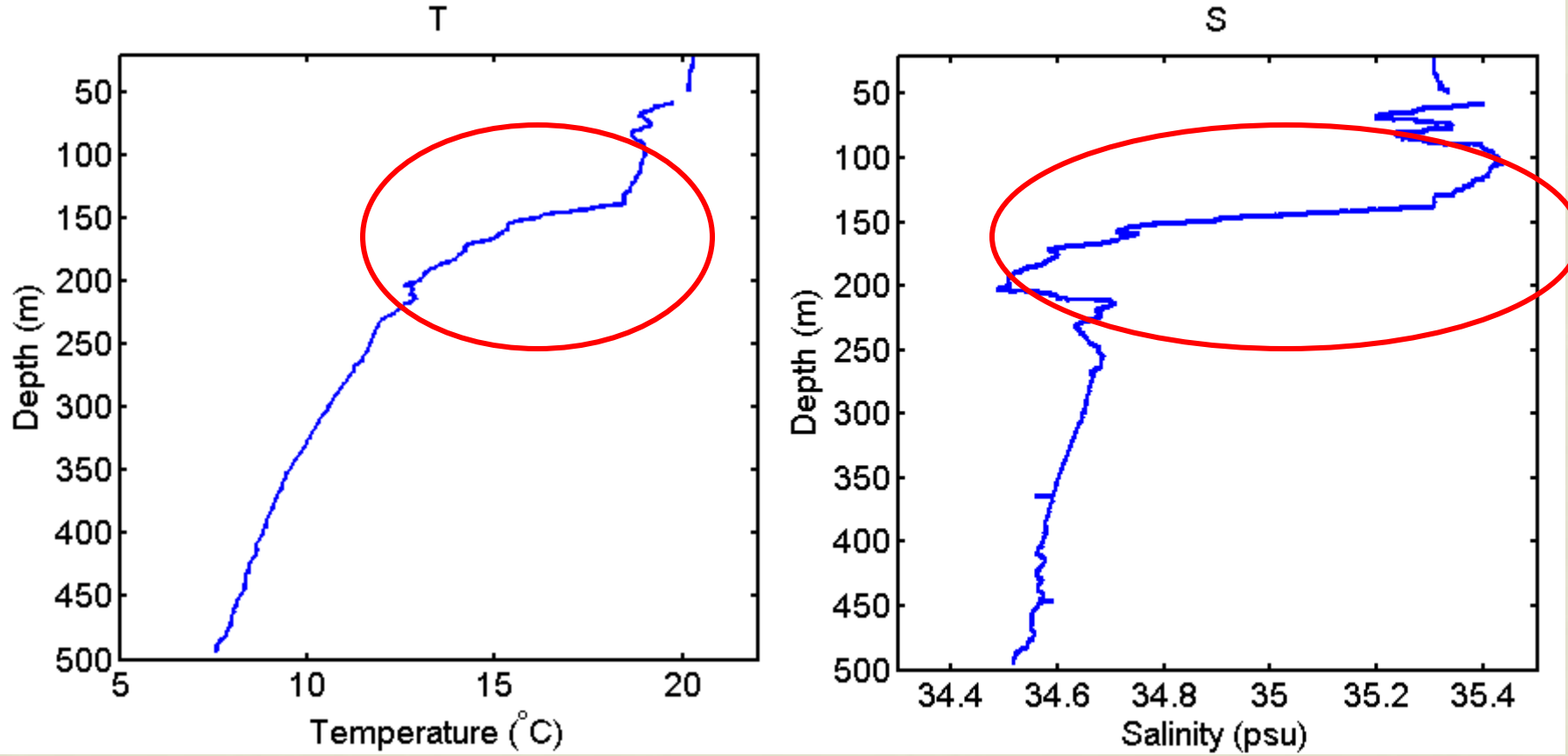
psu

CTD cast from Station 18

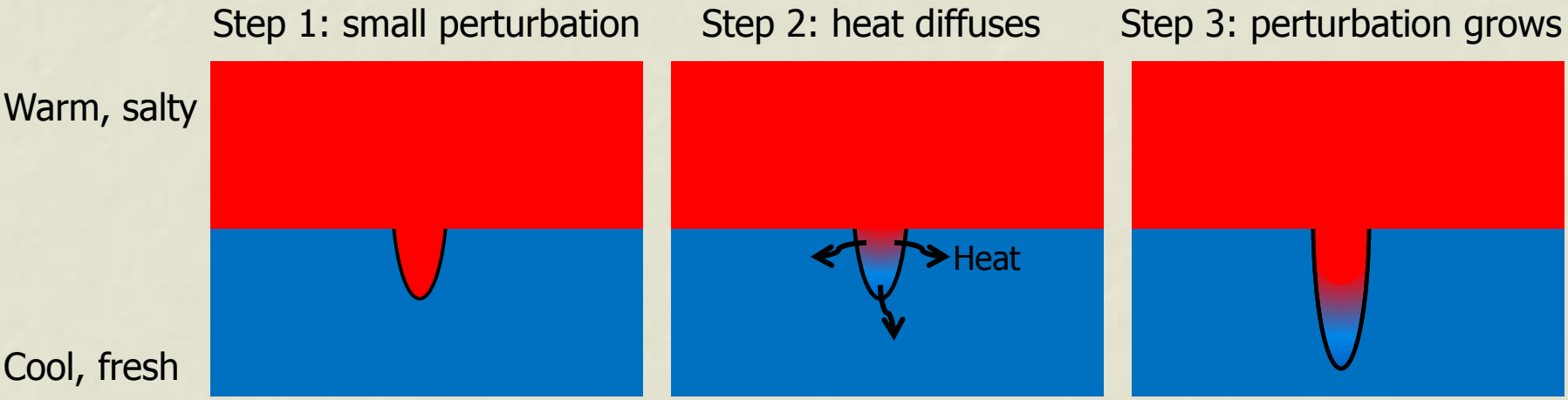


CTD cast from Station 18

→Salinity and temperature decrease with depth over 100-200 m, qualitatively favorable for an instability known as salt fingering



Salt-finger instability concept



Heat diffuses ~100x faster than salt

Essentially retaining its salt, the perturbation becomes denser than its surroundings and sinks more

The density ratio and necessary condition for salt-finger instability

The density ratio measures the relative stratification due to heat and salt:

$$R_\rho = \frac{\alpha T_z}{\beta S_z}$$

$$\left(\frac{\partial \rho}{\partial z} = \alpha T_z - \beta S_z \right)$$

Necessary condition for salt fingering:

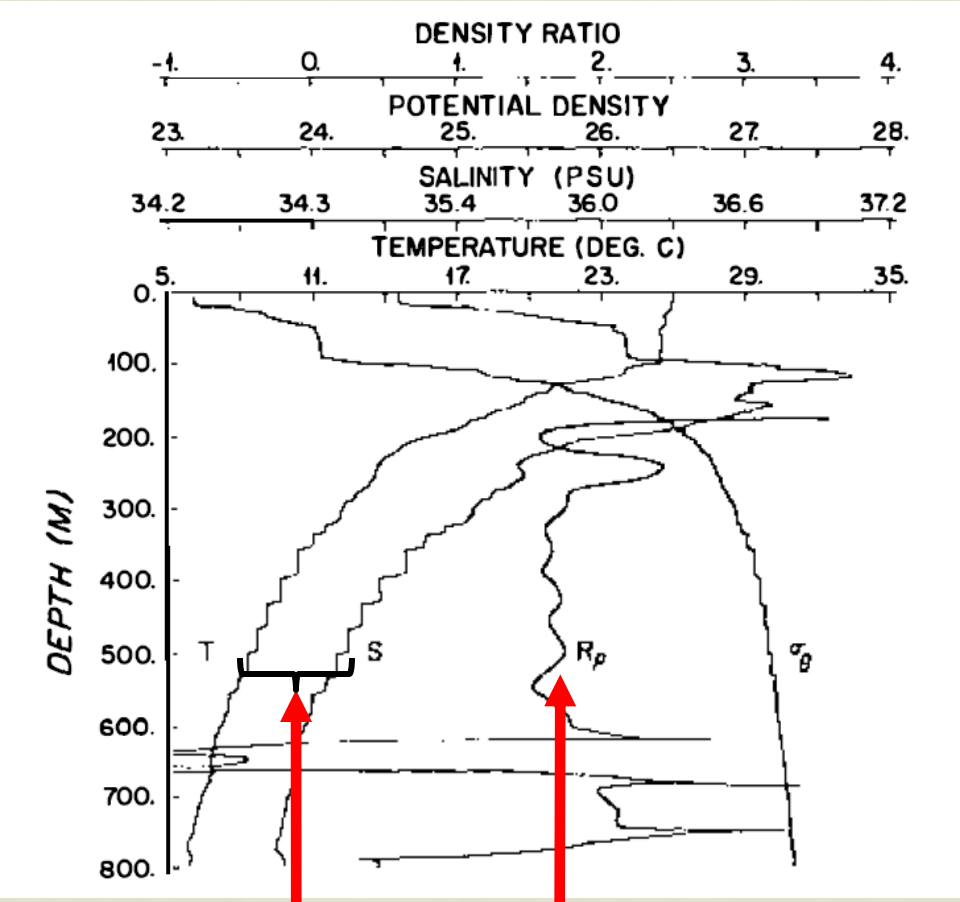
$$1 < R_\rho < 100$$

But, in practice, only instabilities with a growth rate greater than the buoyancy frequency can grow in the presence of internal waves:

$$1 < R_\rho < 2$$

An example of salt fingering

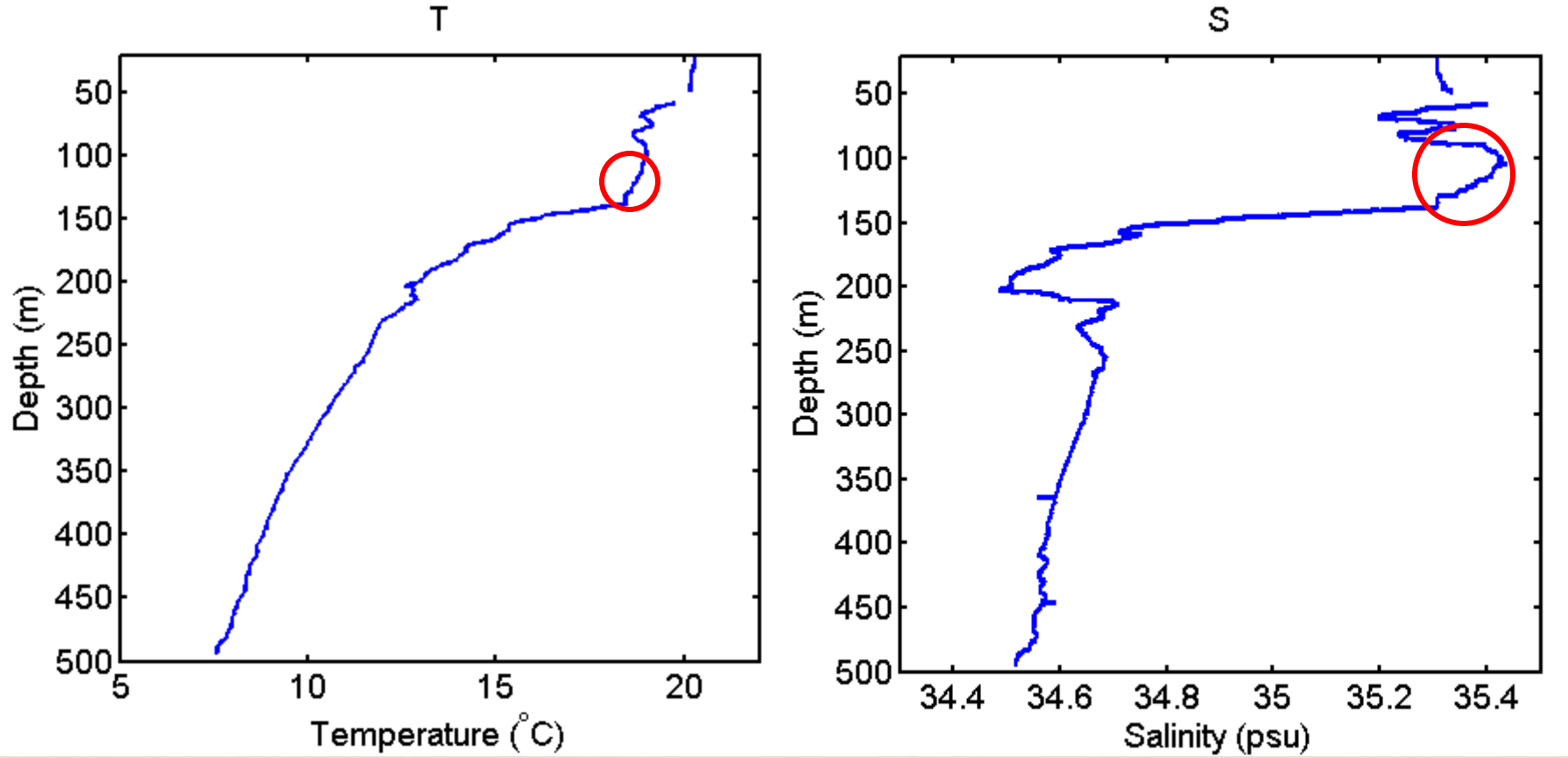
Hydrographic profile in tropical W. Atlantic (Schmitt, 1994)



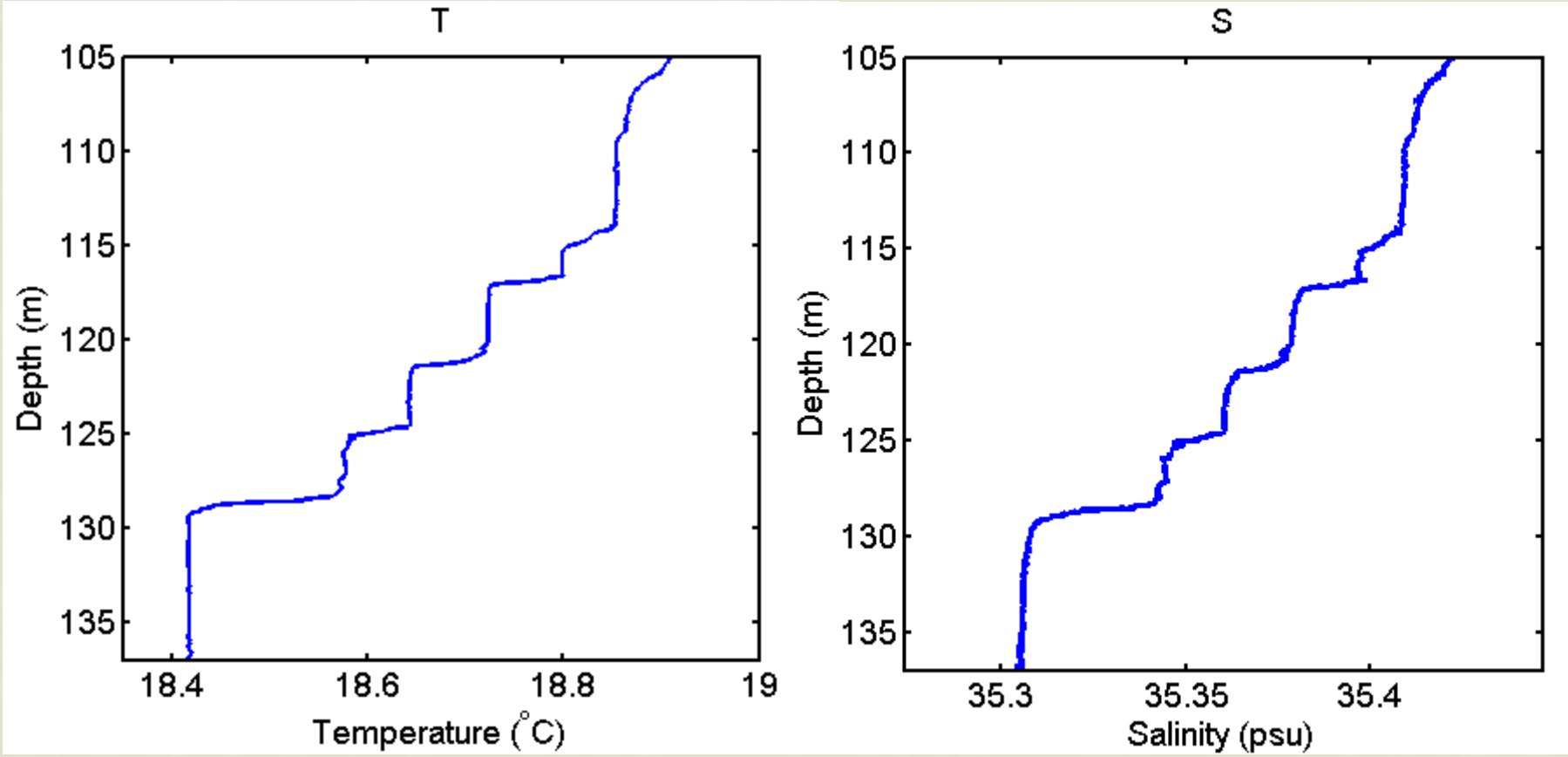
Density ratio ≈ 1.7

Thermohaline 'staircase'

CTD cast from Station 18

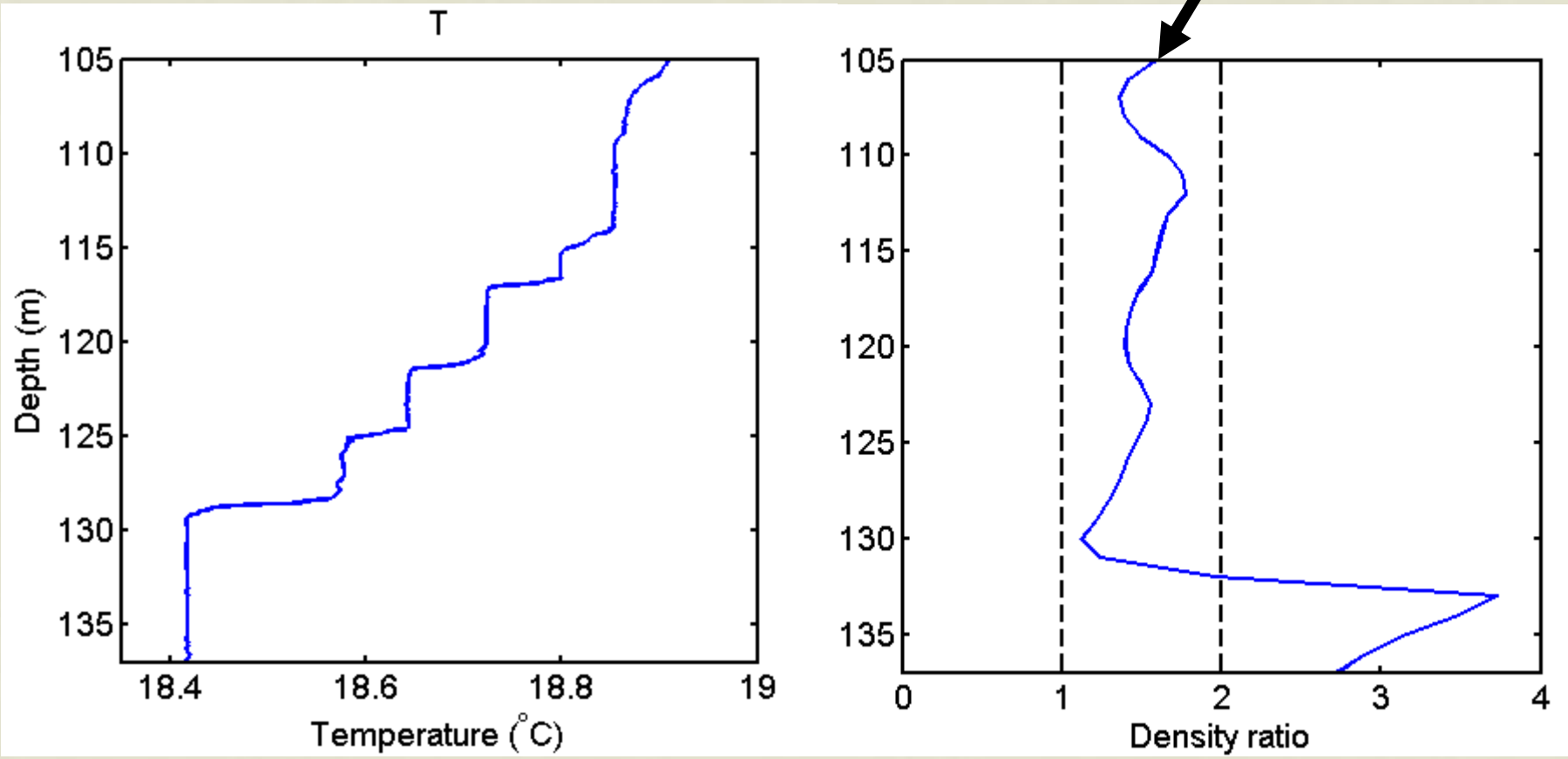


CTD cast from Station 18

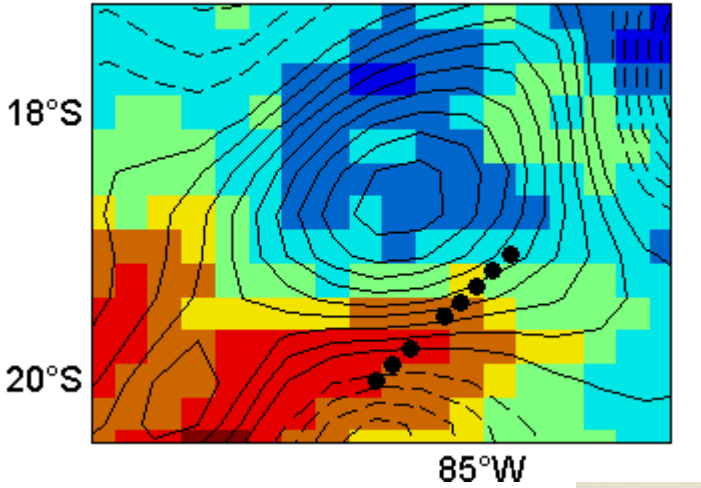


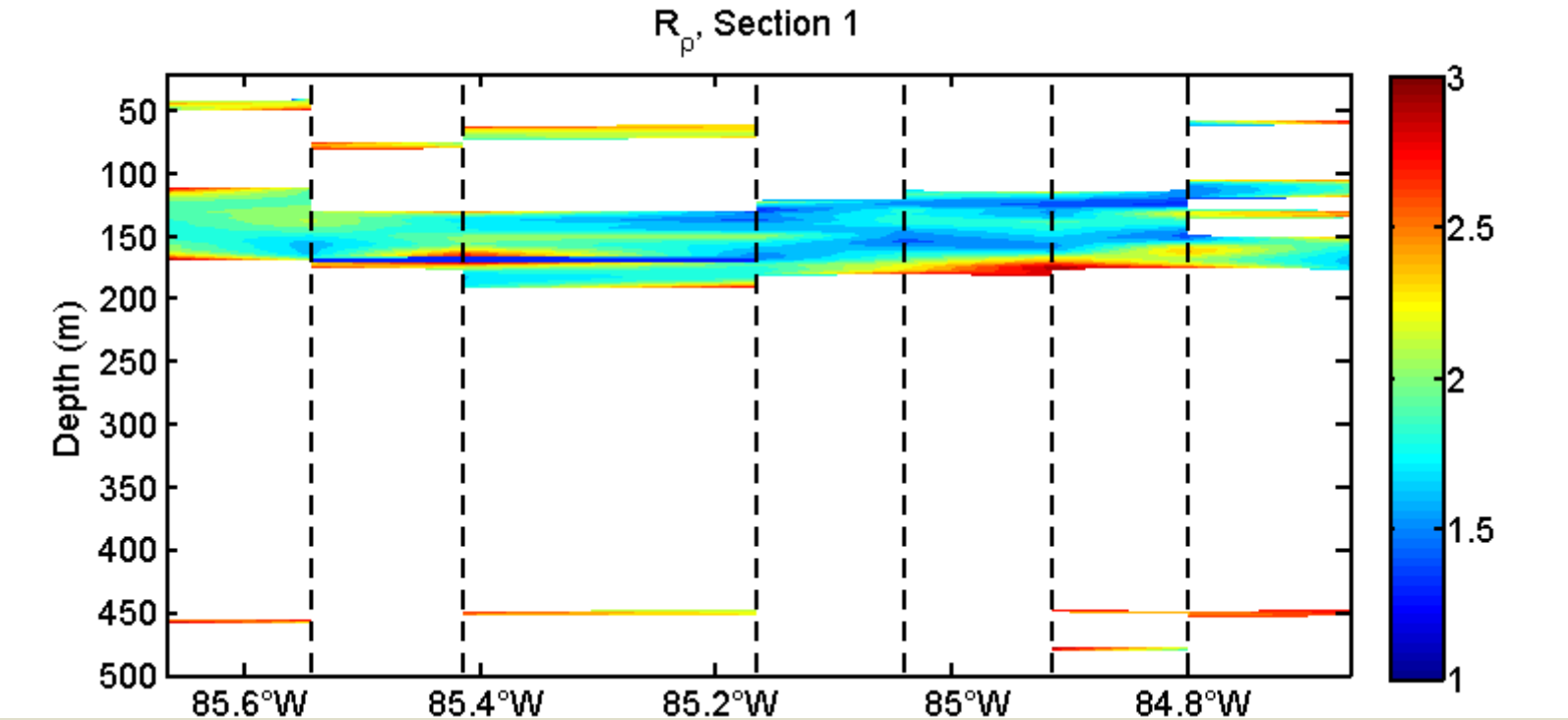
CTD cast from Station 18

Very low density ratio– highly unstable to salt fingering

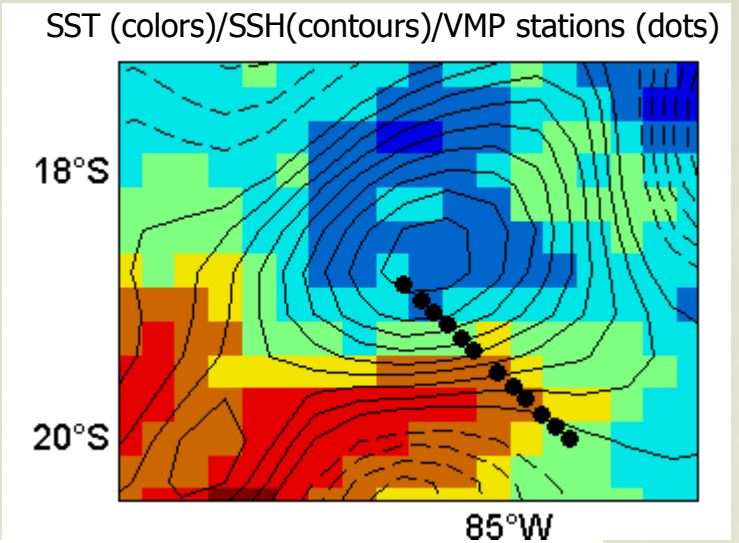


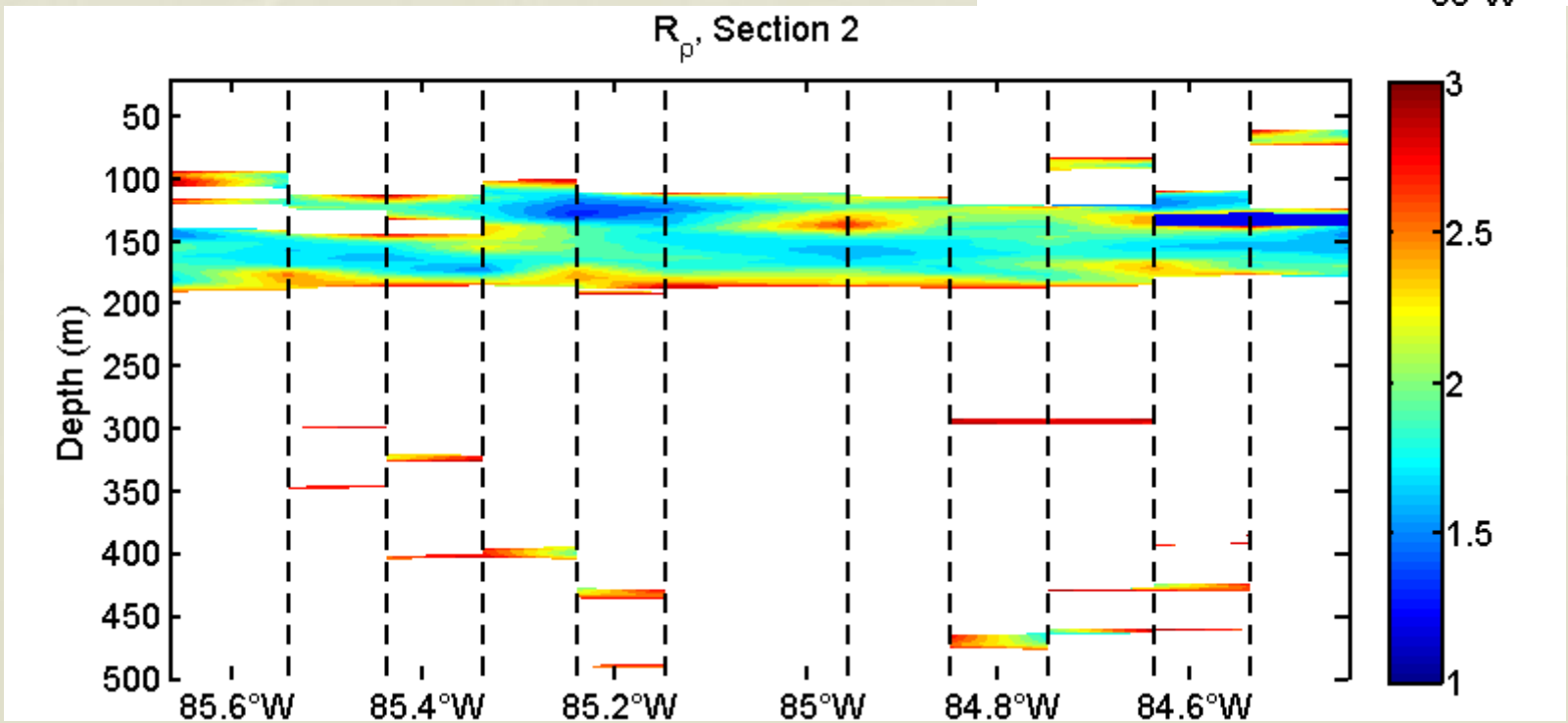
Density ratio:



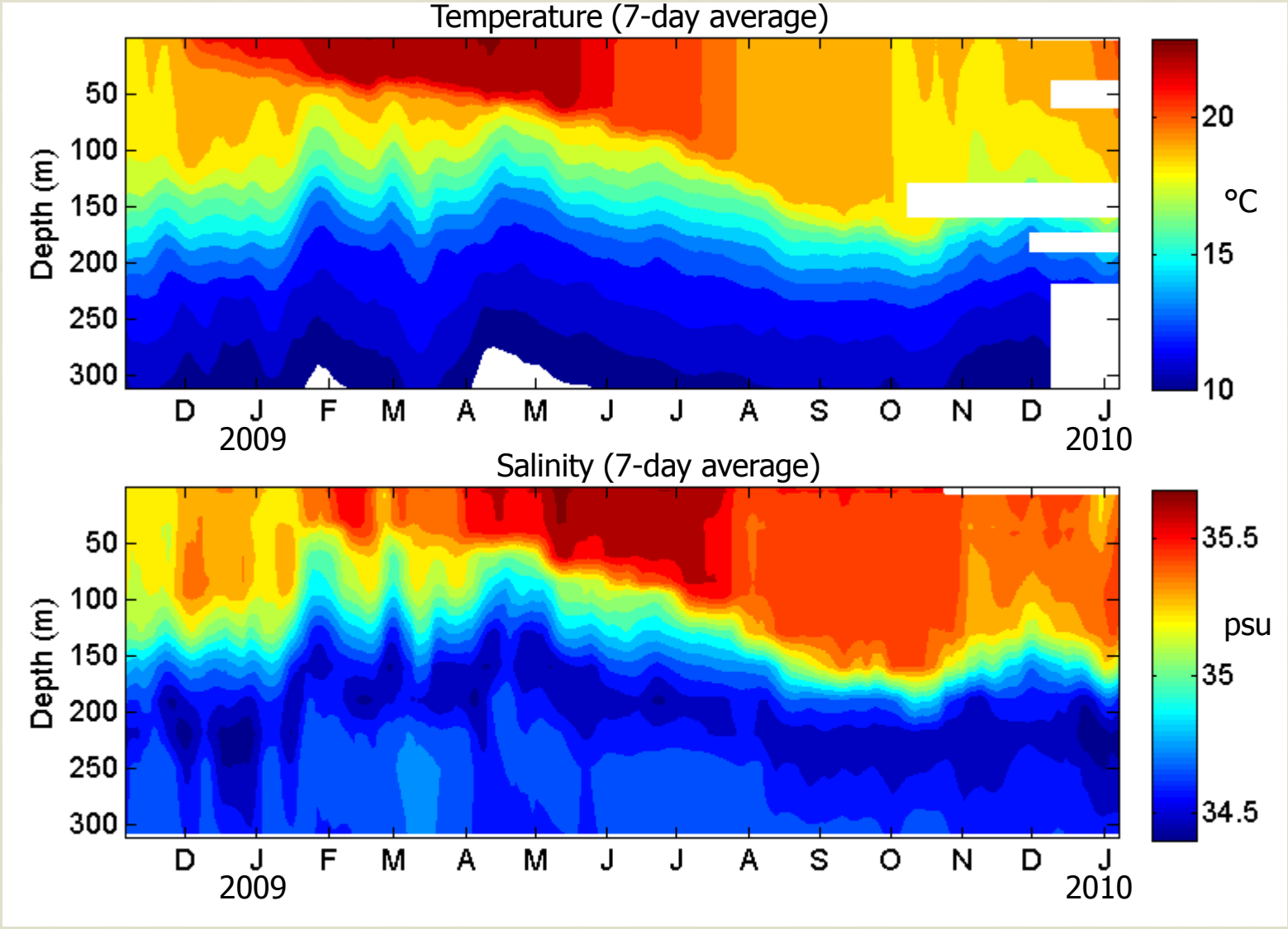


Density ratio:





View through time from mooring at 20°S, 85°W (R. Weller)



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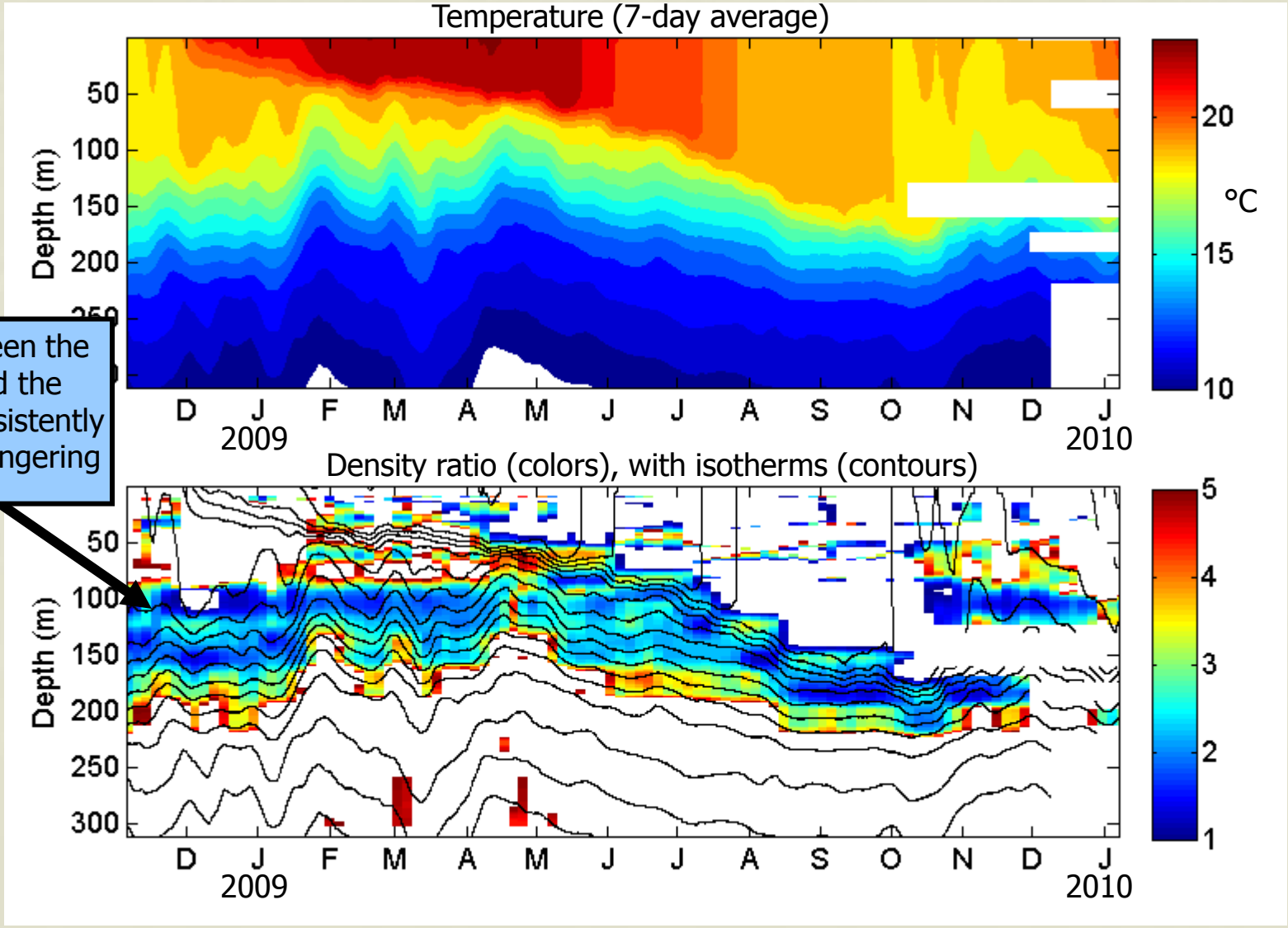

The region between the mixed layer and the thermocline is persistently favorable to salt fingering

Discussion/Conclusion

- Prior work has suggested that salt fingering may be an important mixing process in the broader subtropical southeastern Pacific region (e.g., Tsuchiya and Talley, 1998; Wong and Johnson, 2003; Sato and Suga, 2010).

  →The high evaporation in the subtropics, together with the subsurface salinity-minimum layer, create favorable conditions.

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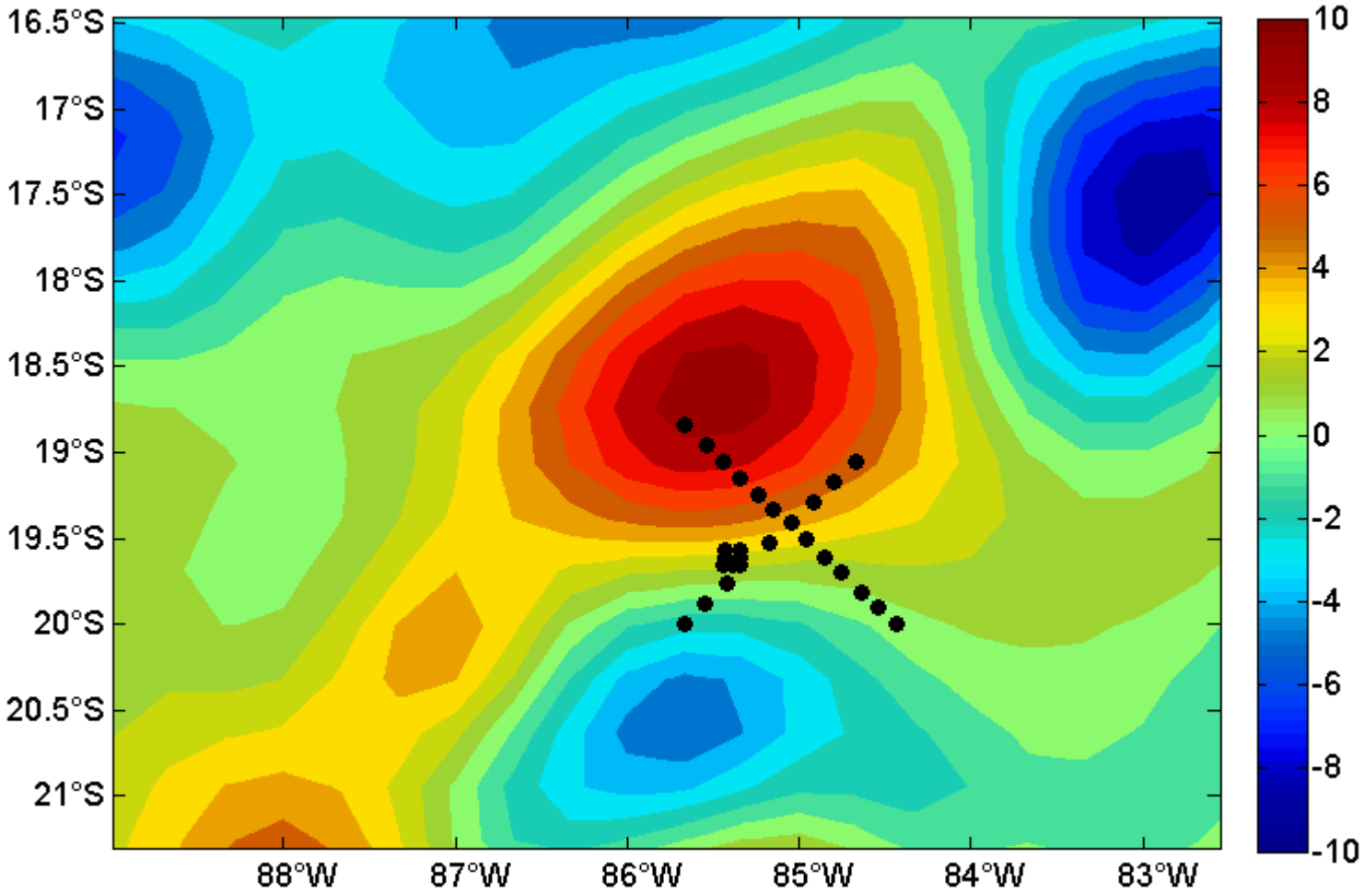
  →The high evaporation in the subtropics, together with the subsurface salinity-minimum layer, create favorable conditions.

- Salt fingering provides an efficient means of cooling and freshening the surface layer, providing a link between the flux of cool water at depth and the cool SST at the surface.

  →Under similar hydrographic conditions (i.e., density ratio), Schmitt et al. (2005) found thermal diffusivities of about 5×10^{-5} m^2/s. If this diffusivity applies here, it would imply a vertical heat flux of O(20 W/m^2) from the upper ocean to the salinity-minimum layer.

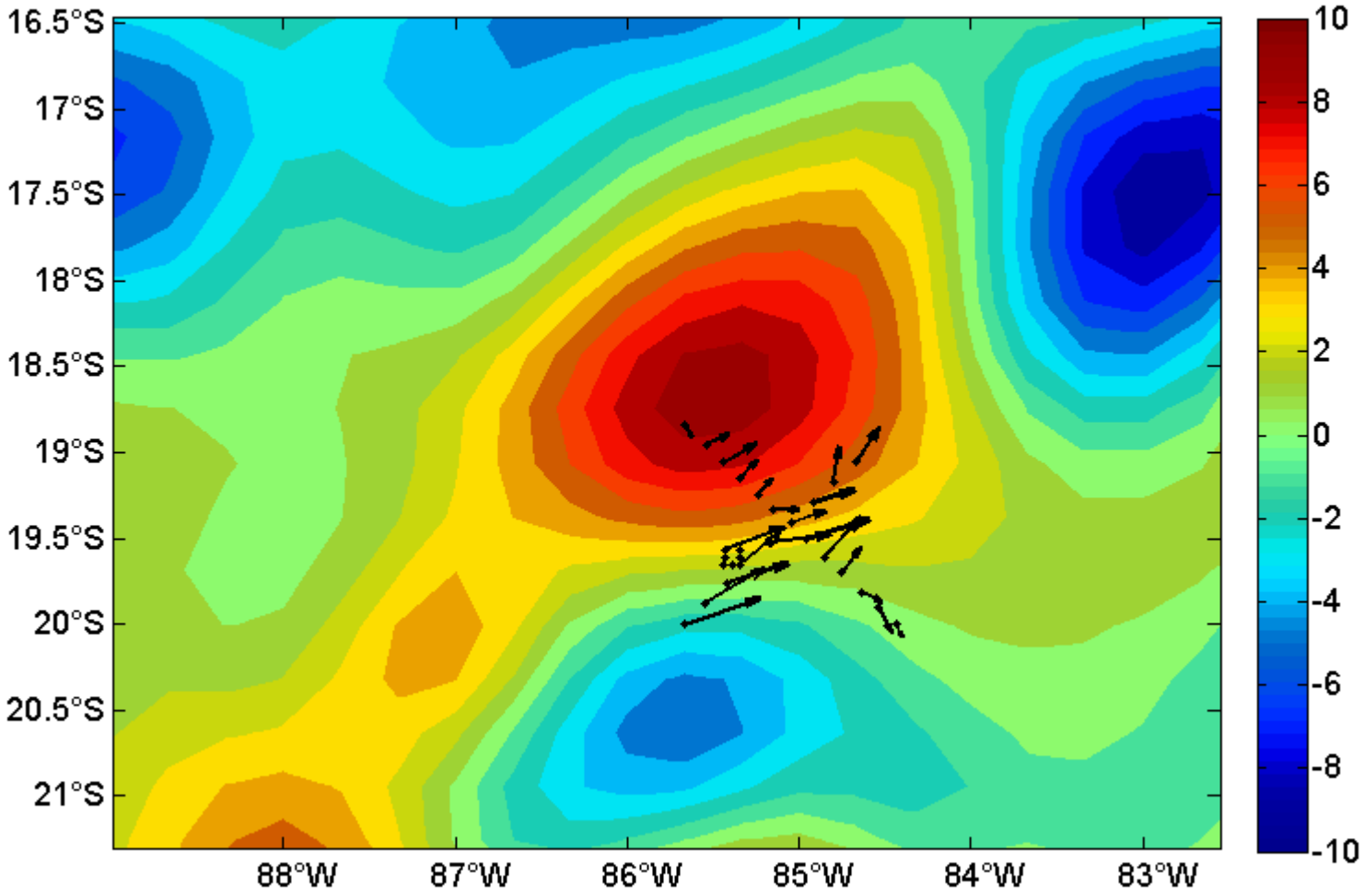
- The microstructure data from VOCALS-Rex should allow us to quantify the vertical heat flux due to salt fingering, using methods similar those of St. Laurent and Schmitt (1999) and Schmitt et al. (2005).

SSH anomaly (colors) and VMP stations (black circles), ~21 Jan 2010

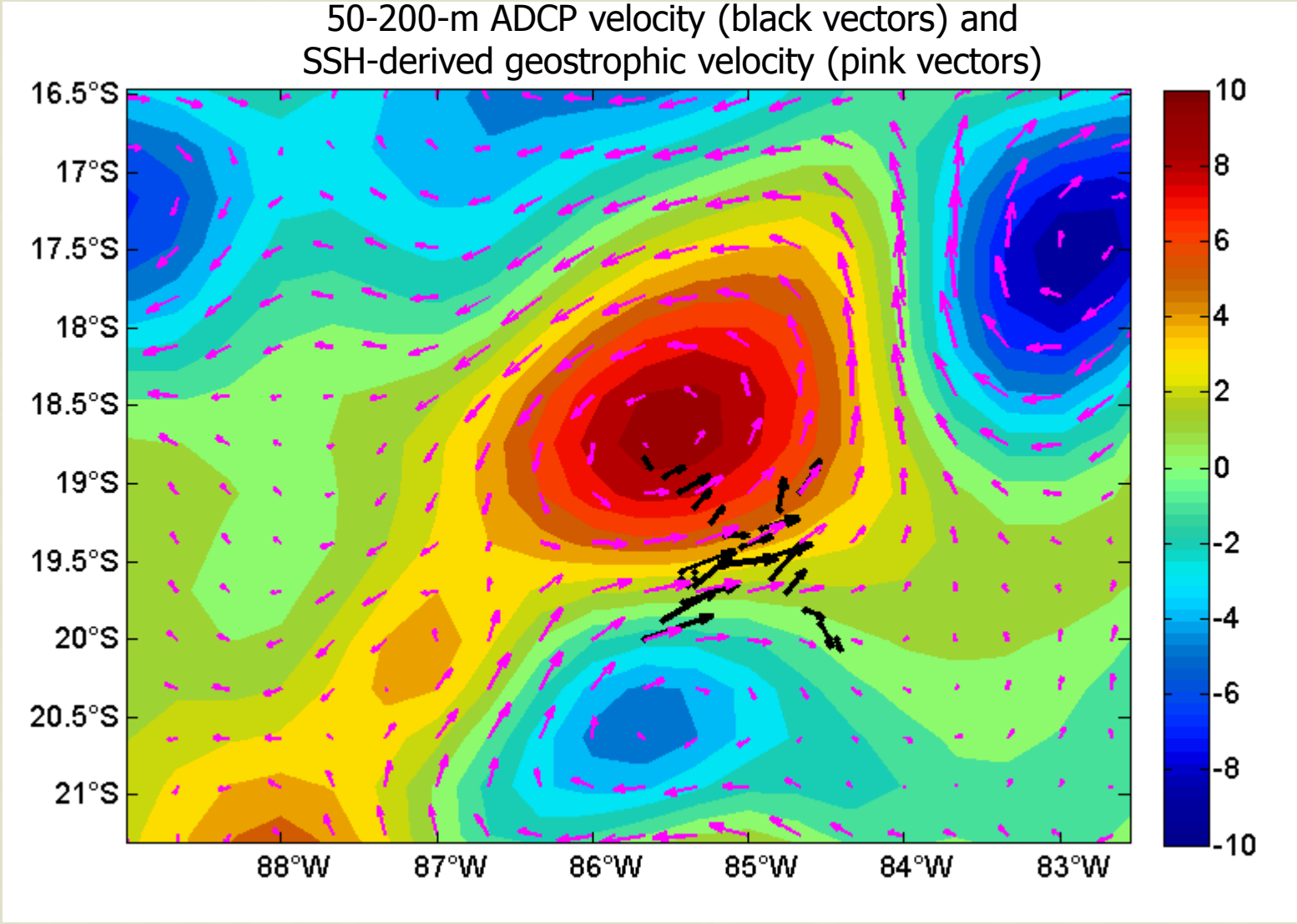


SSH data: Merged satellite altimetry product, courtesy of AVISO/CNES

SSH anomaly (colors) and 50-200-m average ADCP velocity (vectors)

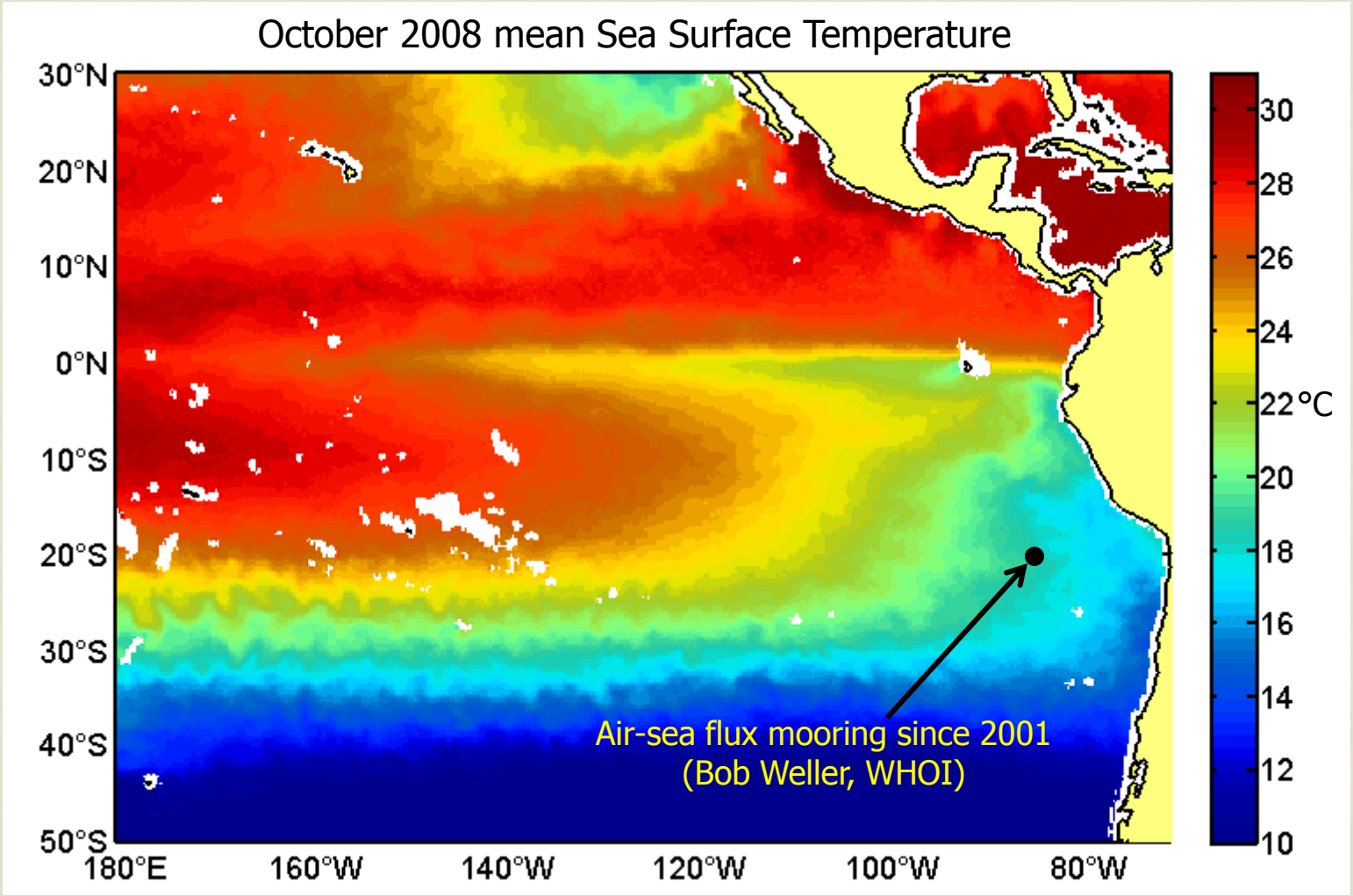


SSH data: Merged satellite altimetry product, courtesy of AVISO/CNES



SSH data: Merged satellite altimetry product, courtesy of AVISO/CNES
SSH geostrophic velocity: From AVISO/CNES– includes estimate of mean SSH (i.e., not anomaly)

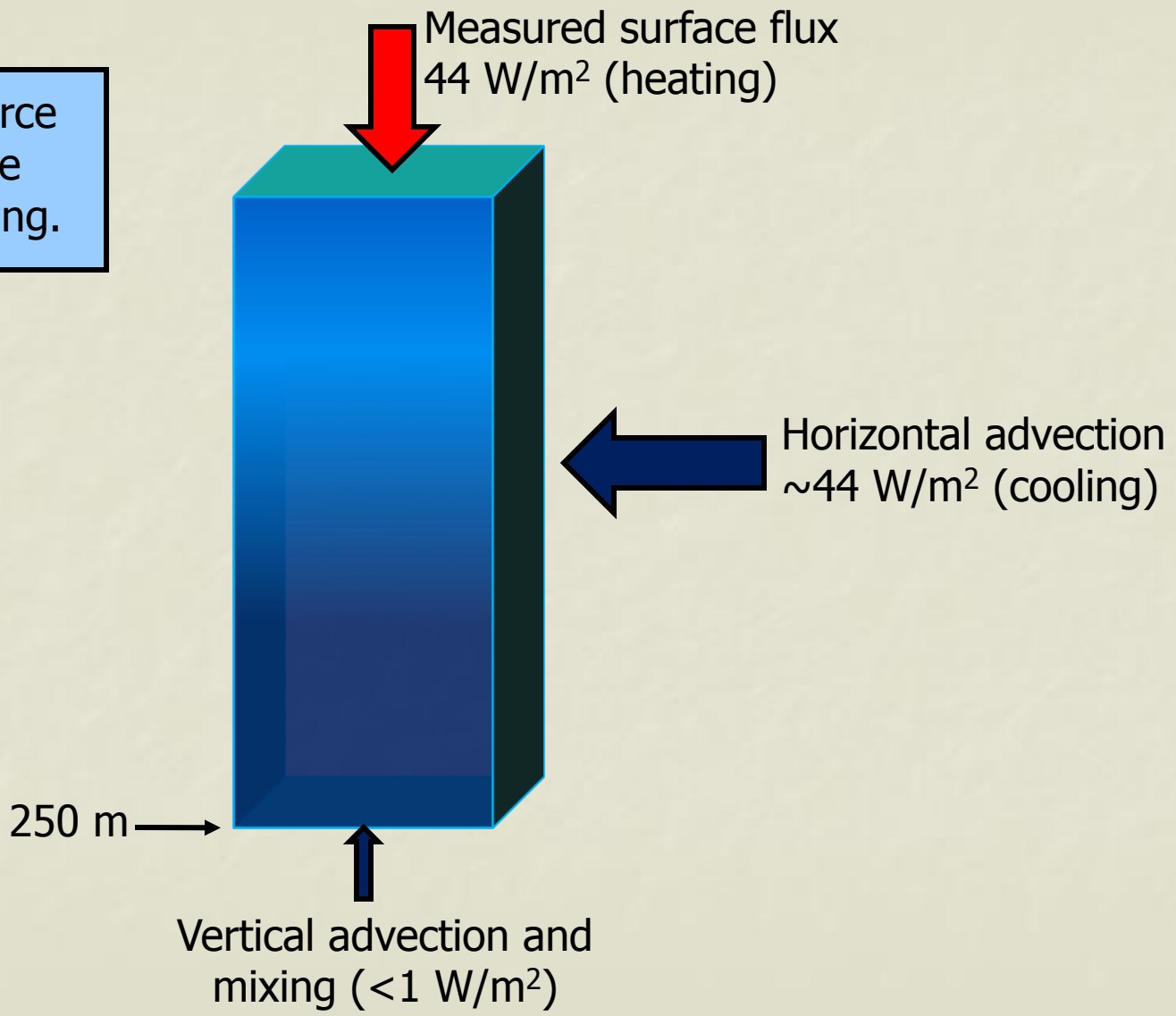
→A primary oceanographic goal in VOCALS REx:
Understanding why SST is cool in the Southeast Pacific



SST data: AMSRE satellite microwave, courtesy of Remote Sensing Systems

Colbo and Weller (2007, *J. Mar. Res.*): Time-mean heat budget

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



Colbo and Weller (2007, *J. Mar. Res.*): Time-mean heat budget

→Their budget was for the upper 250 m, but for SST, the depth of this horizontal flux matters.