The Submesoscale MIxed-Layer Eddies Experiment

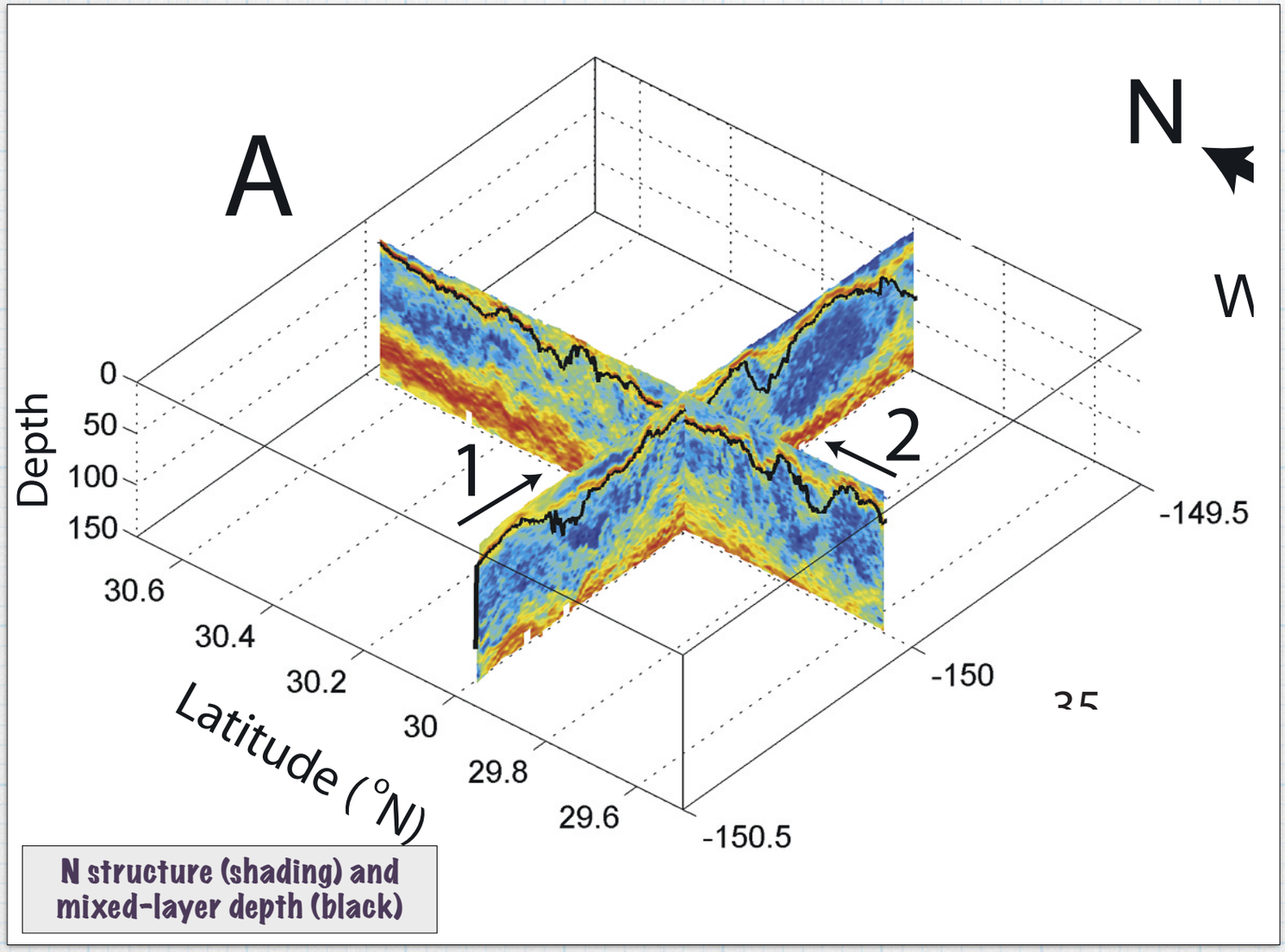
James Girton and John Mickett
Applied Physics Laboratory, University of Washington

Eric Kunze
NorthWest Research Associates

Tom Farrar
Woods Hole Oceanographic Institution

Sponsored by NSF-OCE Physical Oceanography

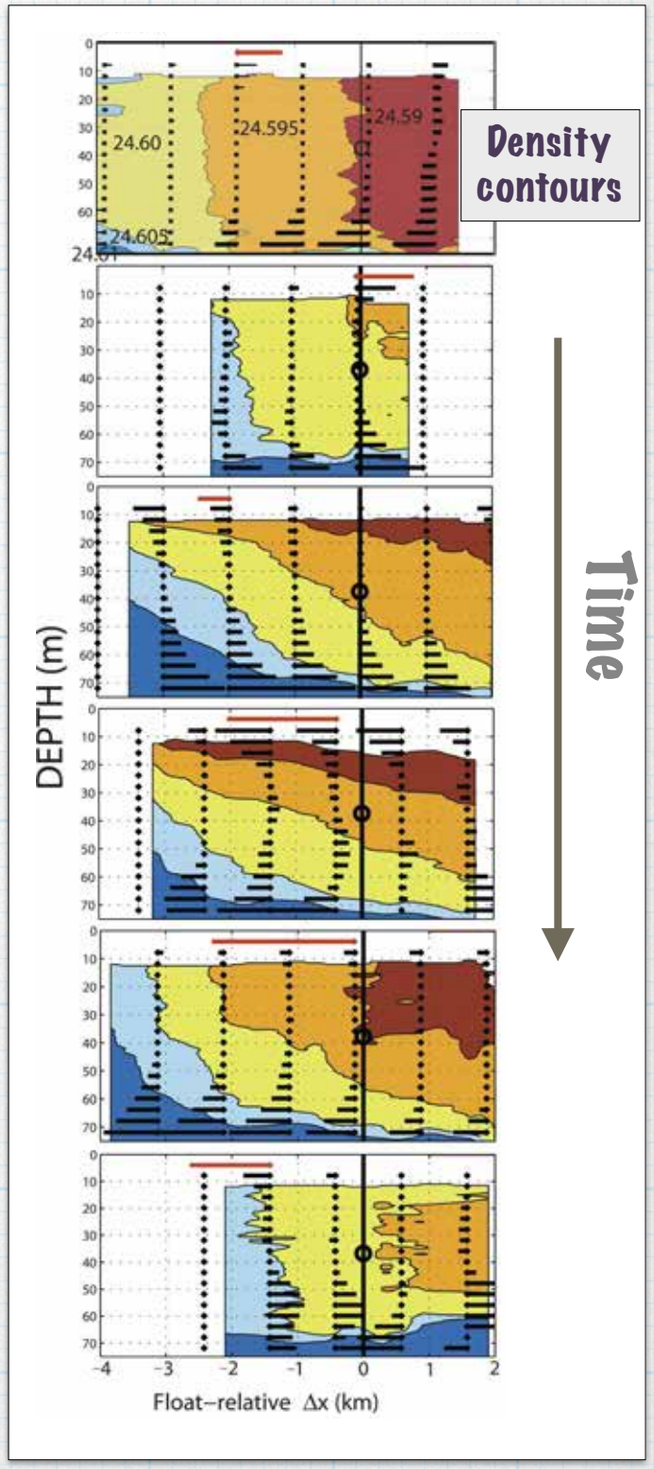
Prior Work: Mixed-layer Structure and Restratification in the North Pacific Subtropical Front



N structure (shading) and mixed-layer depth (black)

Hosegood, Gregg, and Alford, GRL 2006

Observed reversible inertial restratification/slumping—but not for long enough to see net change



Hosegood, Gregg, and Alford, JPO 2008

A New Experiment: SMILE
(Submesoscale MIxed-Layer Eddies)

3

2

1

Three sites across the
North Pacific
Subtropical Front
in March 2017

100 km
100 mi

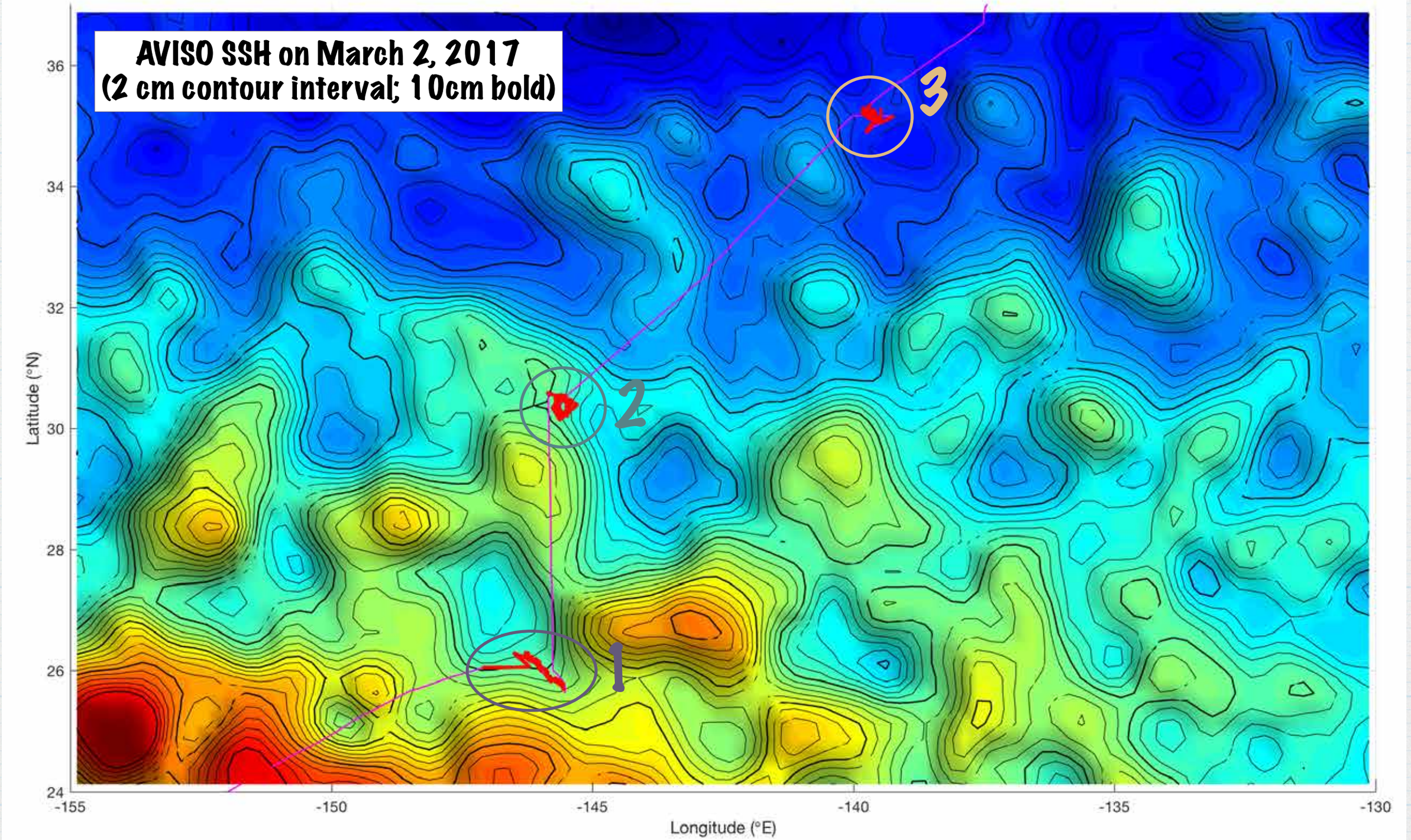
150°00'00"W

145°00'00"W

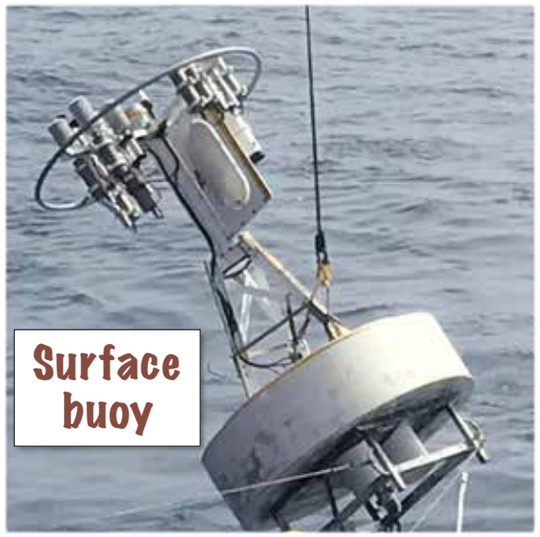
140°00'00"W

Cruise: SKQ201703S
lon: -125.071468567
lat: 44.282364217
heading: 57.99
cog: 62.51
sog: 11.5 knt
Mon, 03 Apr 2017 22:01:59 GMT

- 20170401_12z 30 hrs (20170402 18:00z)
- 20170401_12z 36 hrs (20170403 00:00z)
- 20170401_12z 42 hrs (20170403 06:00z)
- 20170401_12z 48 hrs (20170403 12:00z)
- RTOFS (NCEP Ocean Model)
- SST MUR
  - 20170307 SST MUR
  - 20170308 SST MUR
  - 20170309 SST MUR
  - 20170310 SST MUR
  - 20170311 SST MUR
  - 20170312 SST MUR
  - 20170313 SST MUR


AVISO SSH on March 2, 2017
(2 cm contour interval; 10cm bold)
1
2
3
36
34
32
30
28
26
24
-155
-150
-145
-140
-135
-130
Latitude (°N)
Longitude (°E)

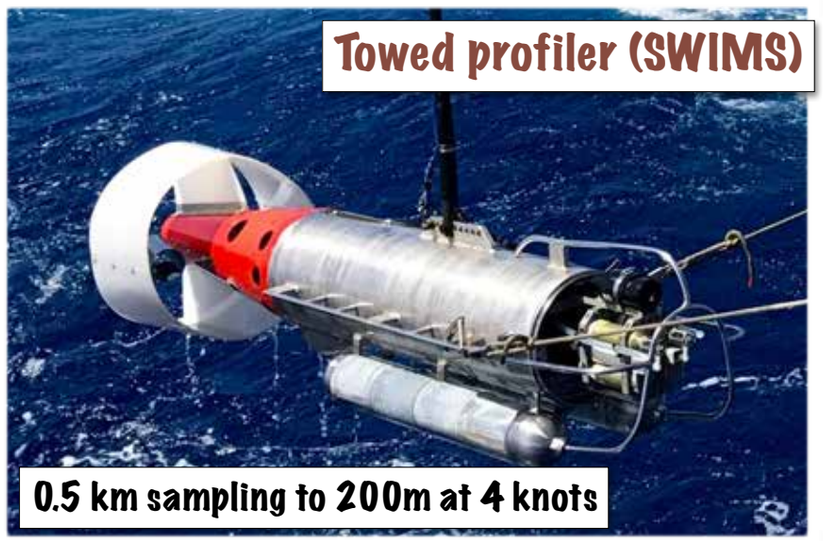
Observational Tools



drifting, drogued at ~50m

Velocity+CTD
+Microstructure profiling float (EM-APEX)

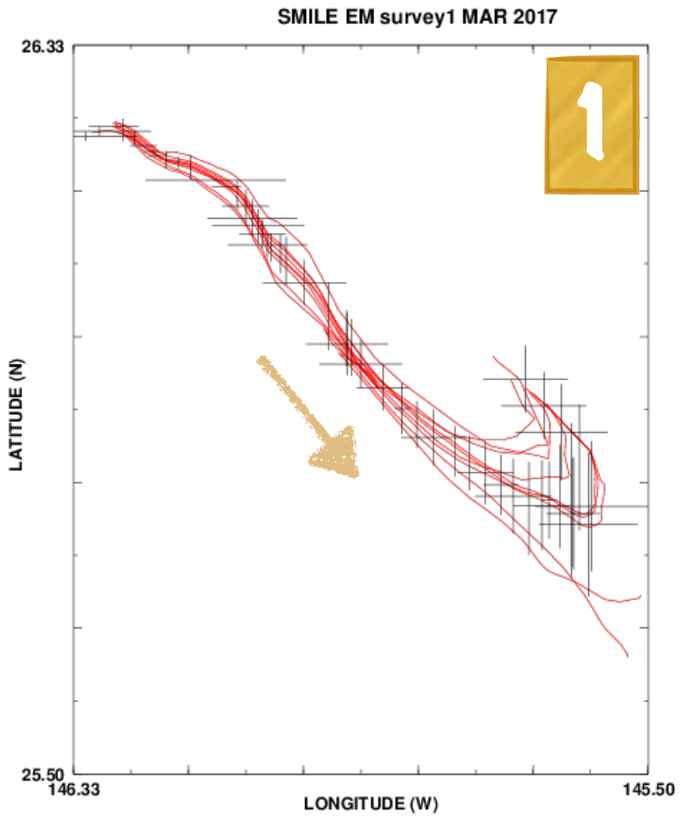
hourly profiles to 150m

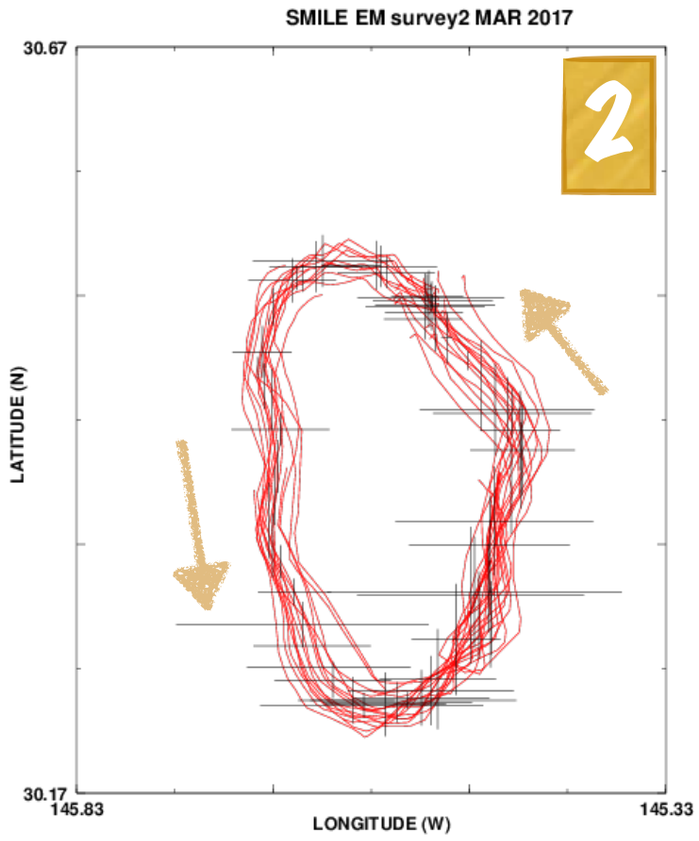


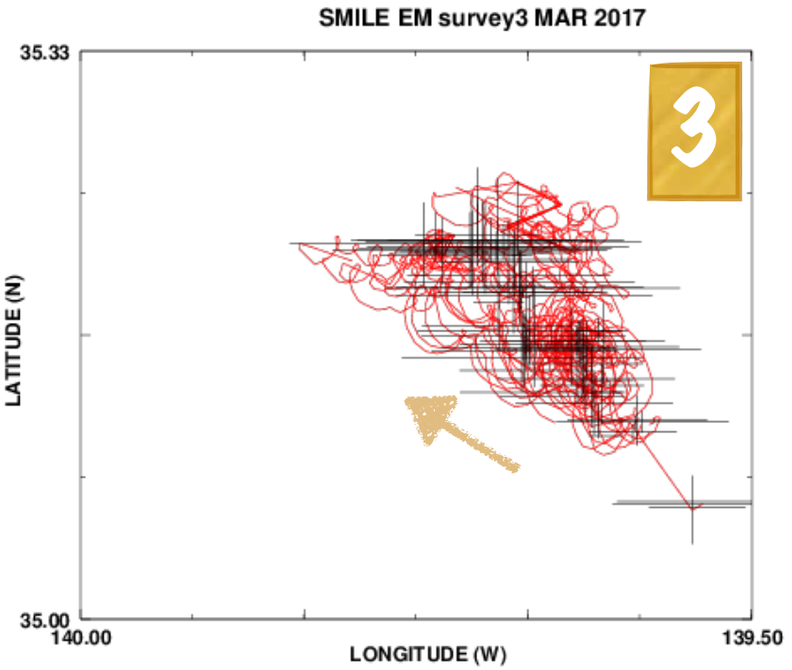
0.5 km sampling to 200m at 4 knots

In fact, an army...

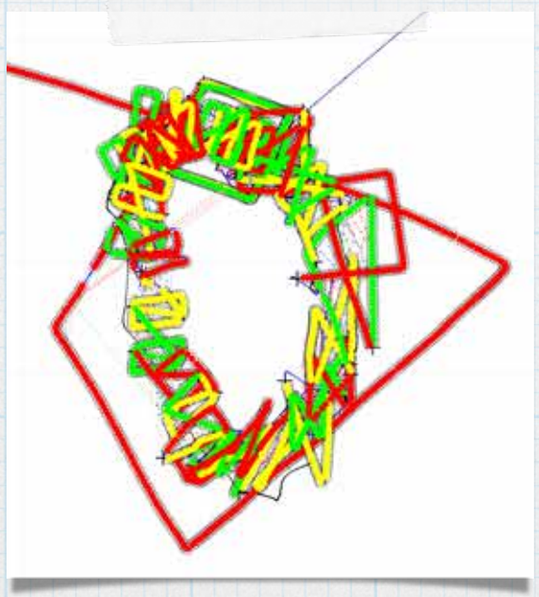
Drifting trajectories (EM-APEX and Surface Buoy)

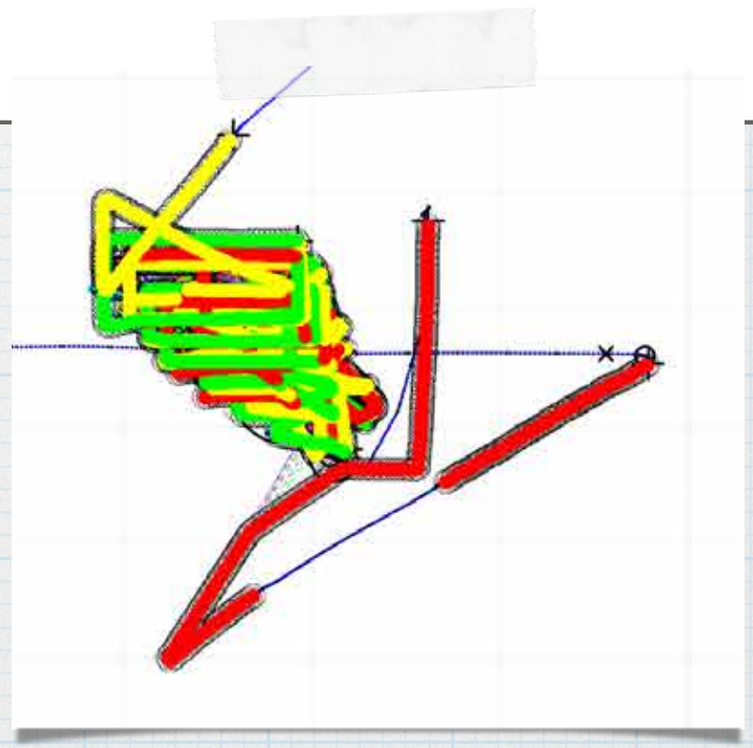






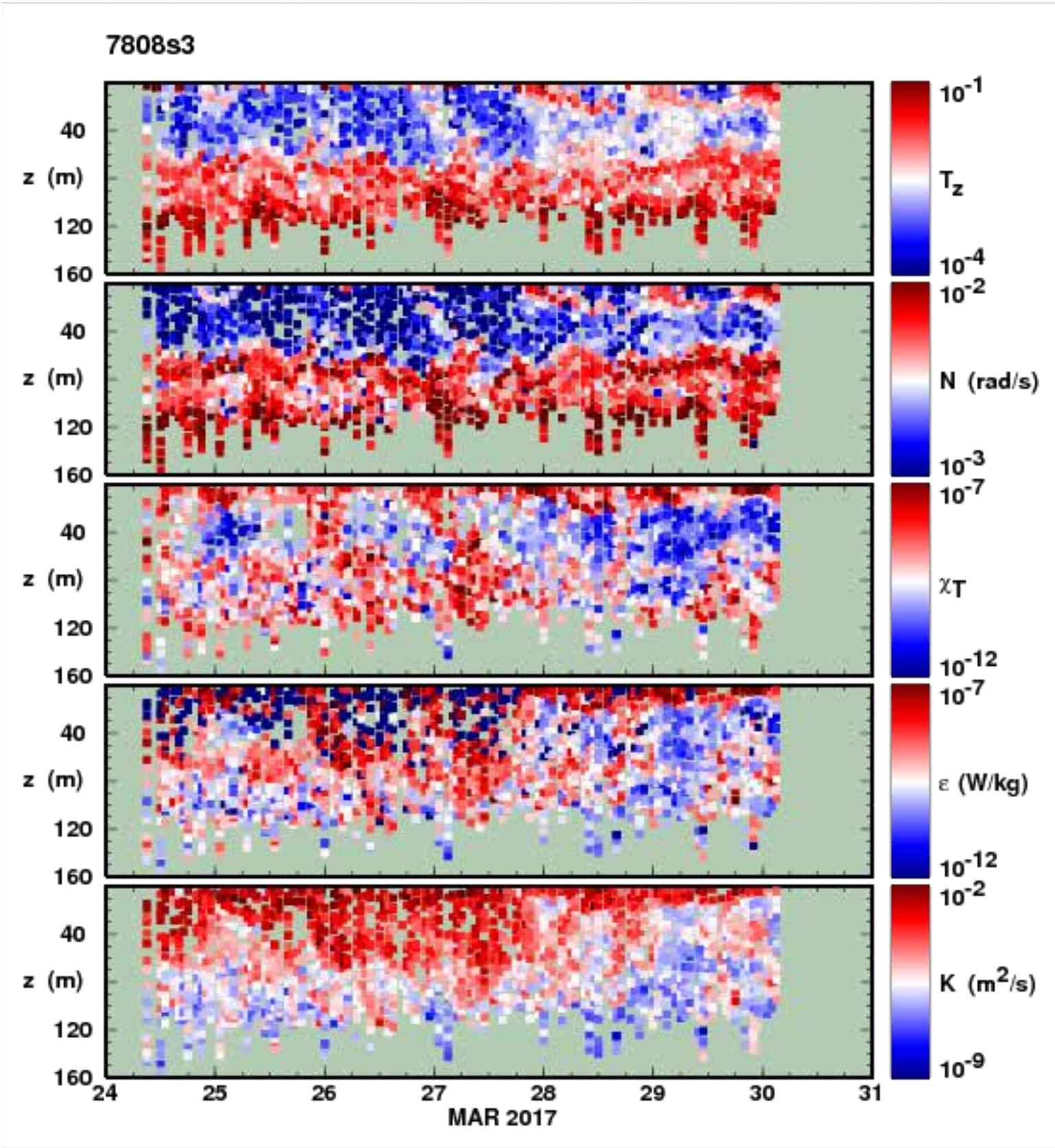
SWIMS Towed Surveys





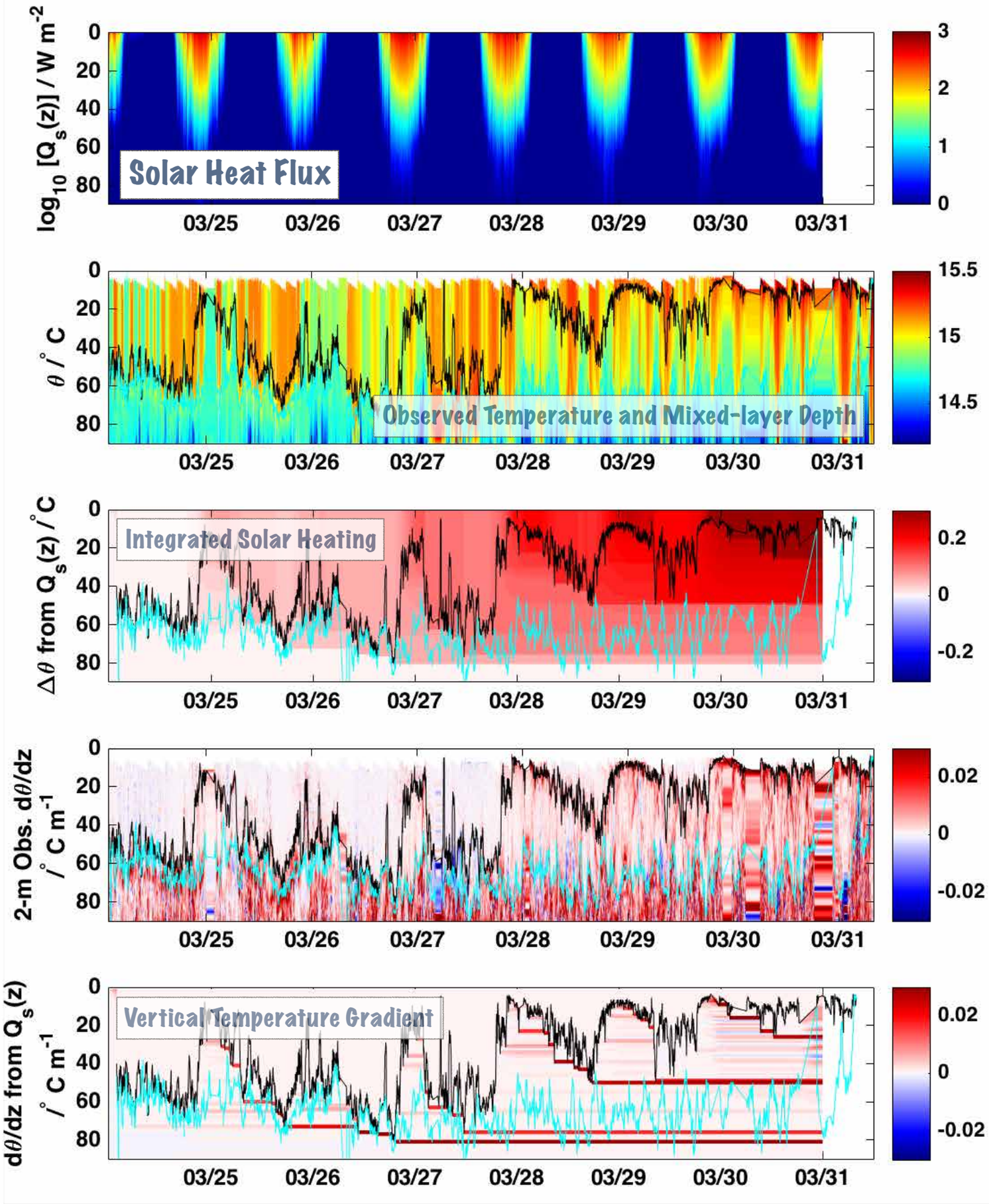
One Story: Site 3 Restratification

- 60m mixed layer
- Restratification over the week-long measurement period
- Little net motion and slow dispersion
- Prominent inertial motions
- Oscillation in Chi (temperature variance dissipation rate) mixing measurement; plus downward propagation in time
- Additional higher-mode internal waves
- Mixing is reduced after restratification

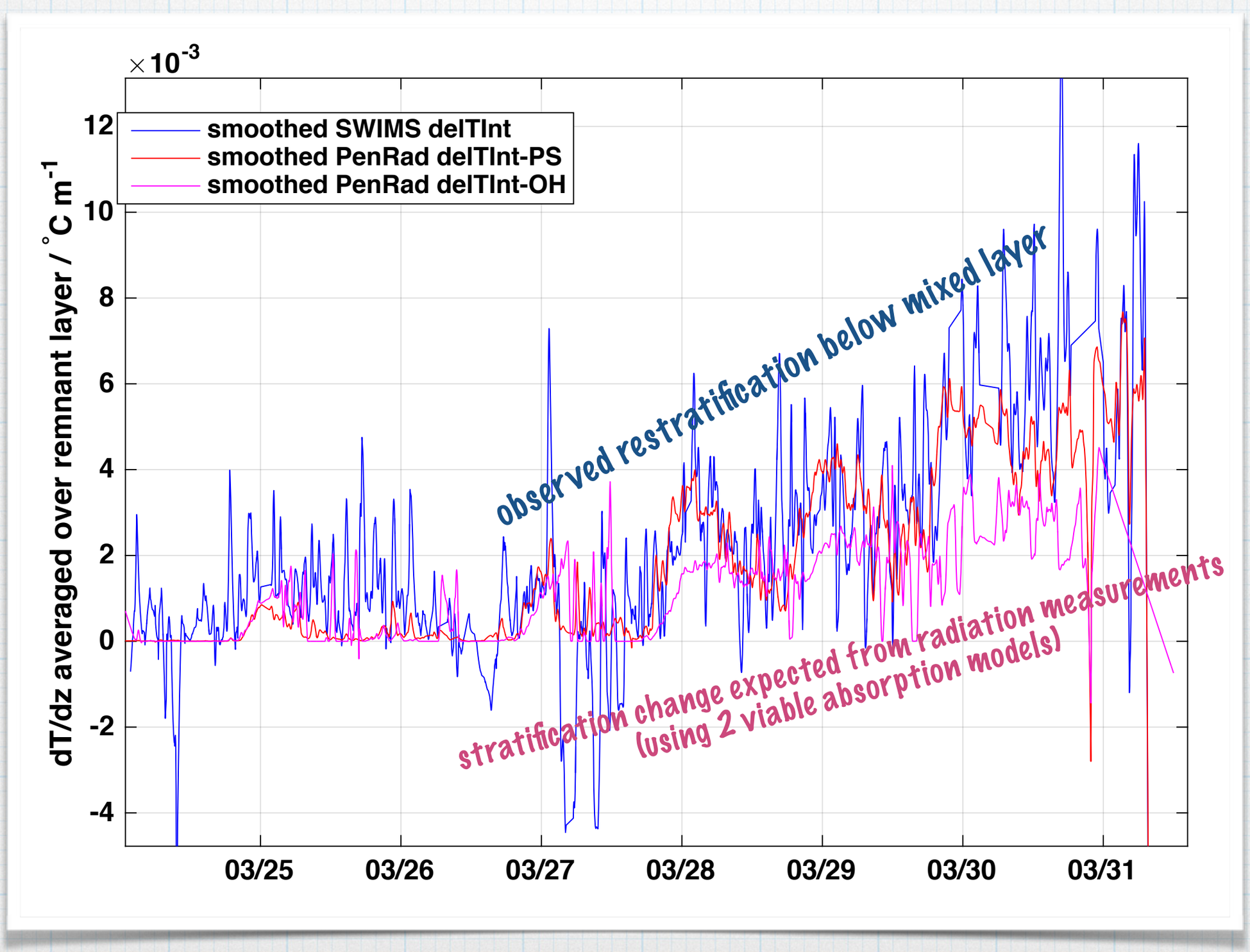


Site 3: Solar Heating

- Radiometer measurements show diurnal heating cycle
- Mixed-layer depth responds to solar heating, but temperature is quite different
- Some of mixed-layer changes are due to vertical advection (internal waves)

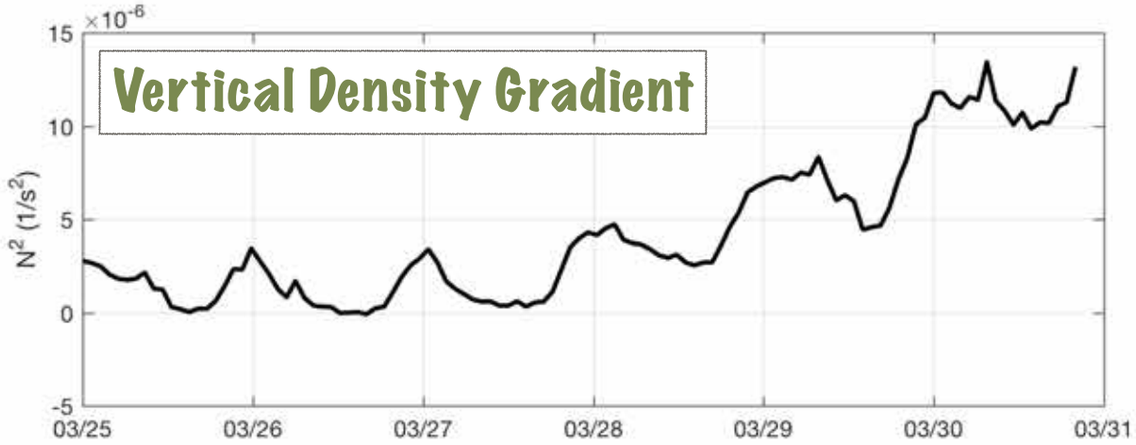


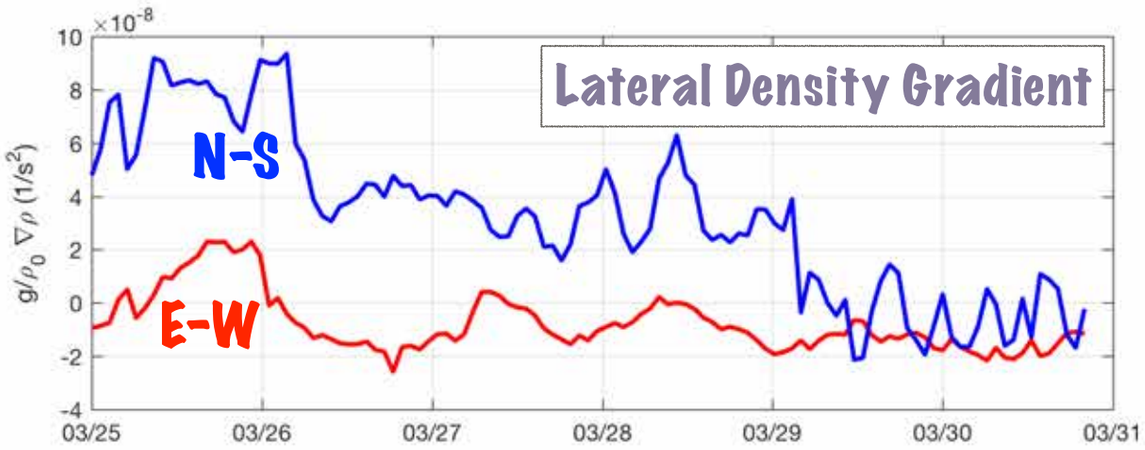
Restratification: Dominated by the Vertical Gradient in Penetrative Radiation (1-D balance)

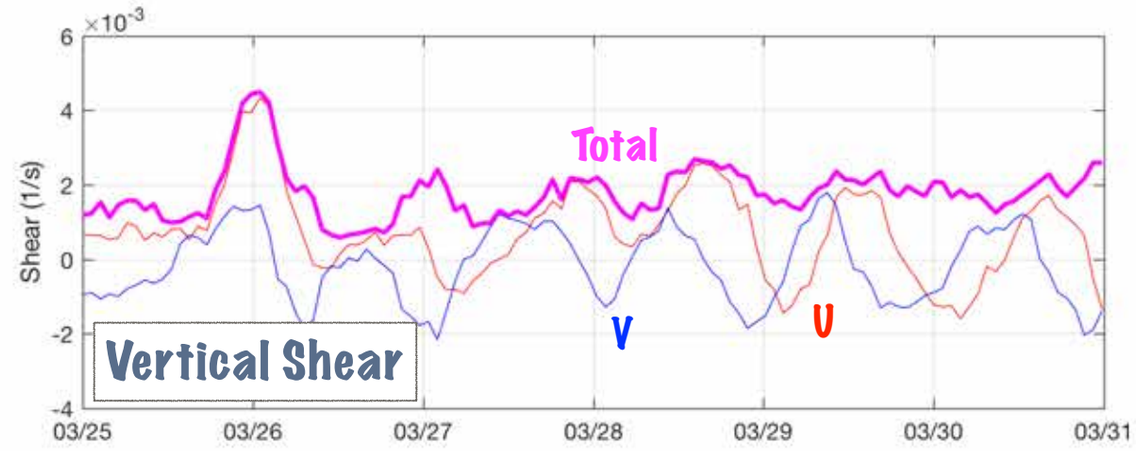


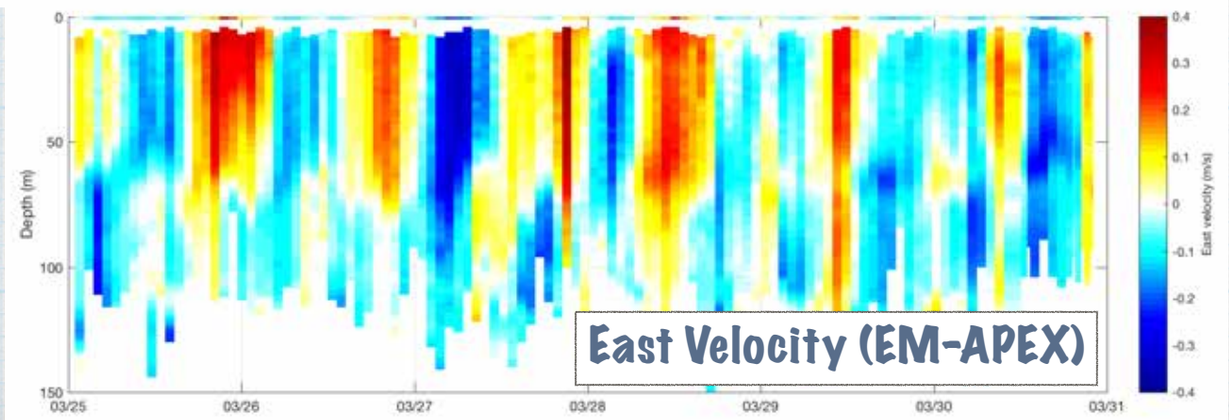
All Present: Solar and Wind-driven Variability, Diurnal and Inertial Cycles, and Low Frequency Changes

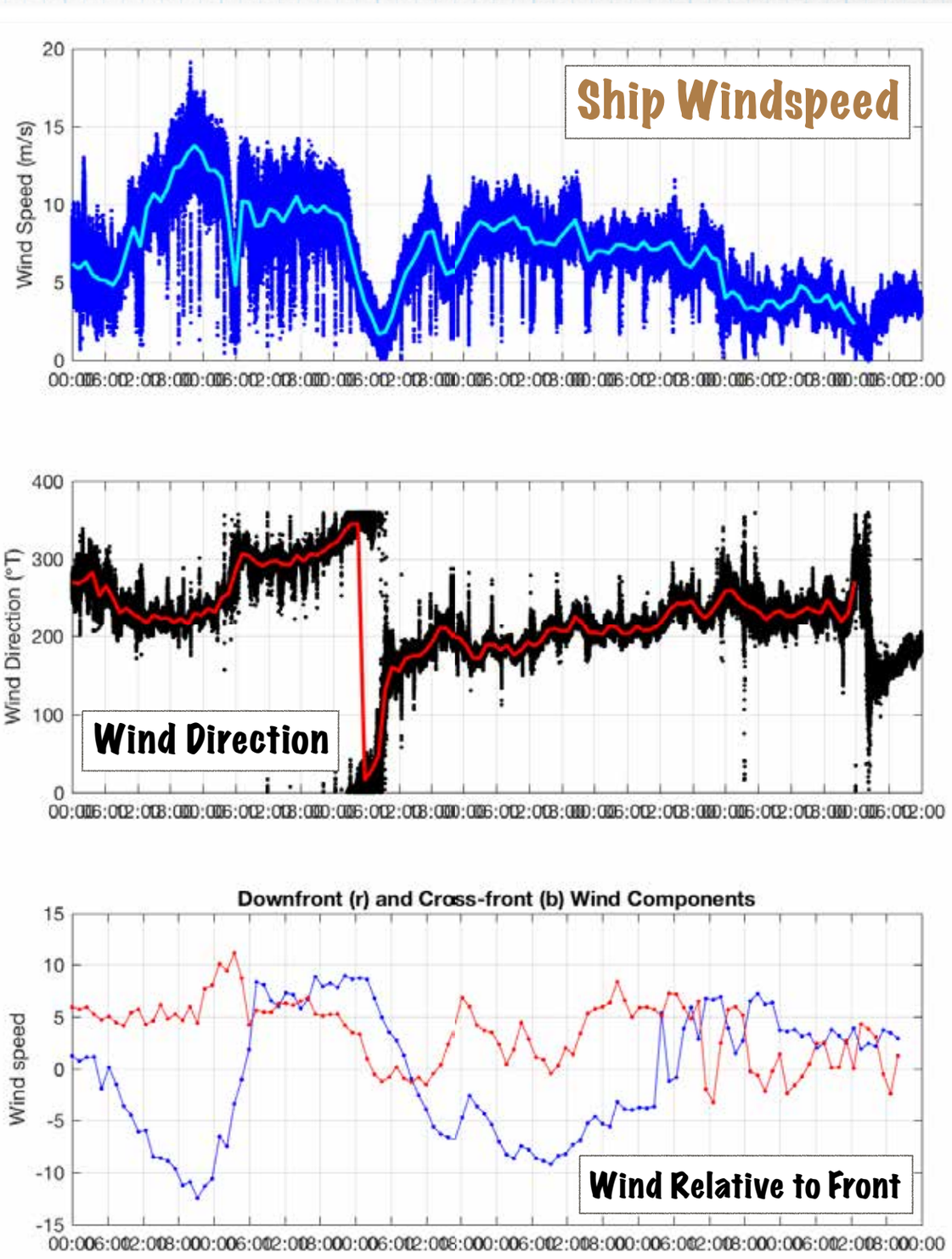
Upper 50m Quantities





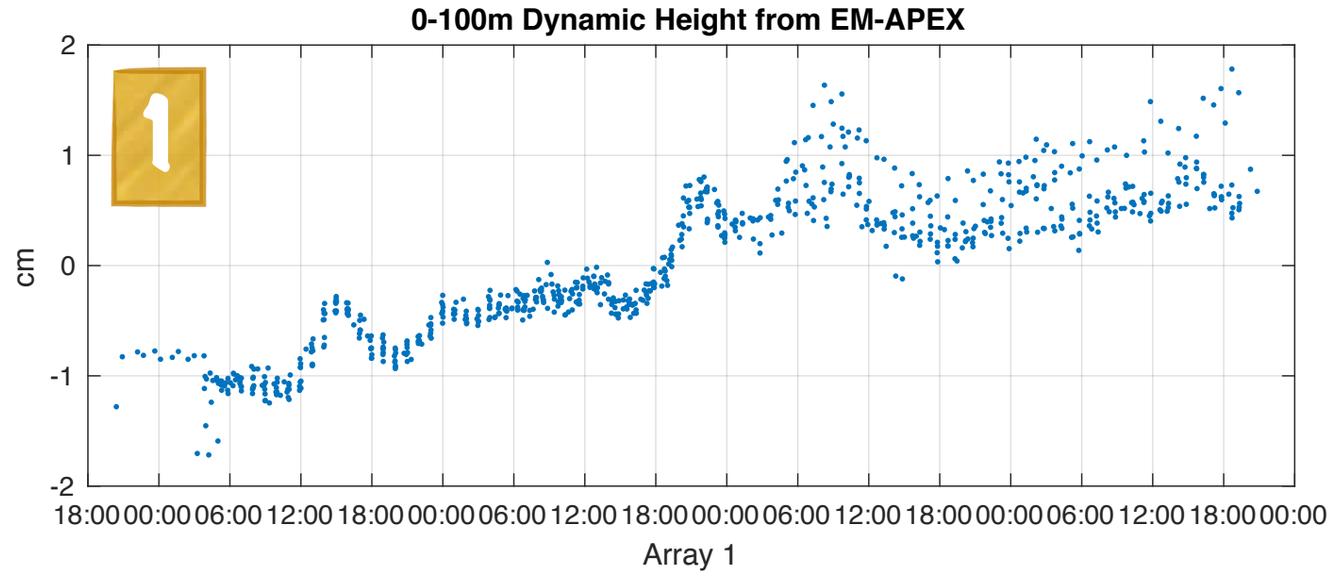


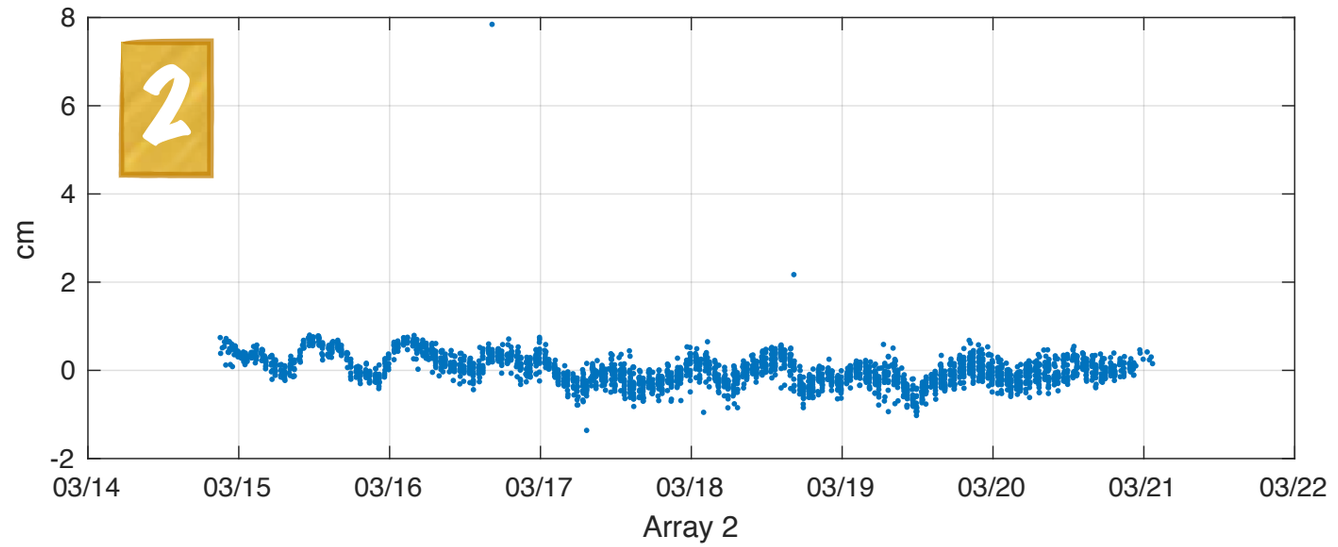


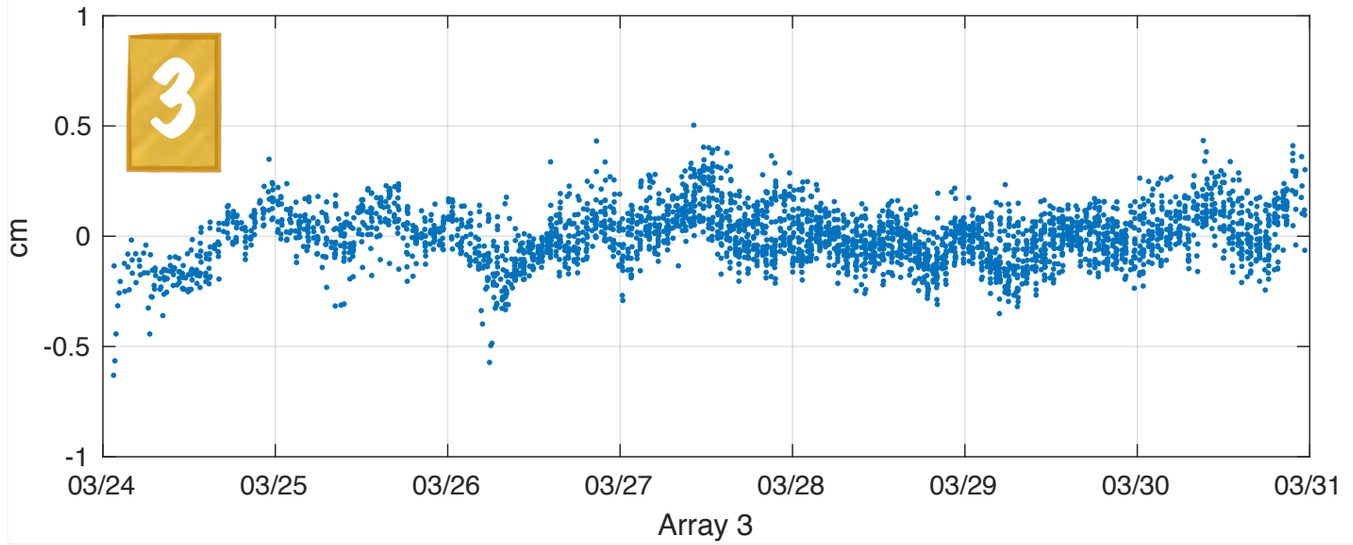


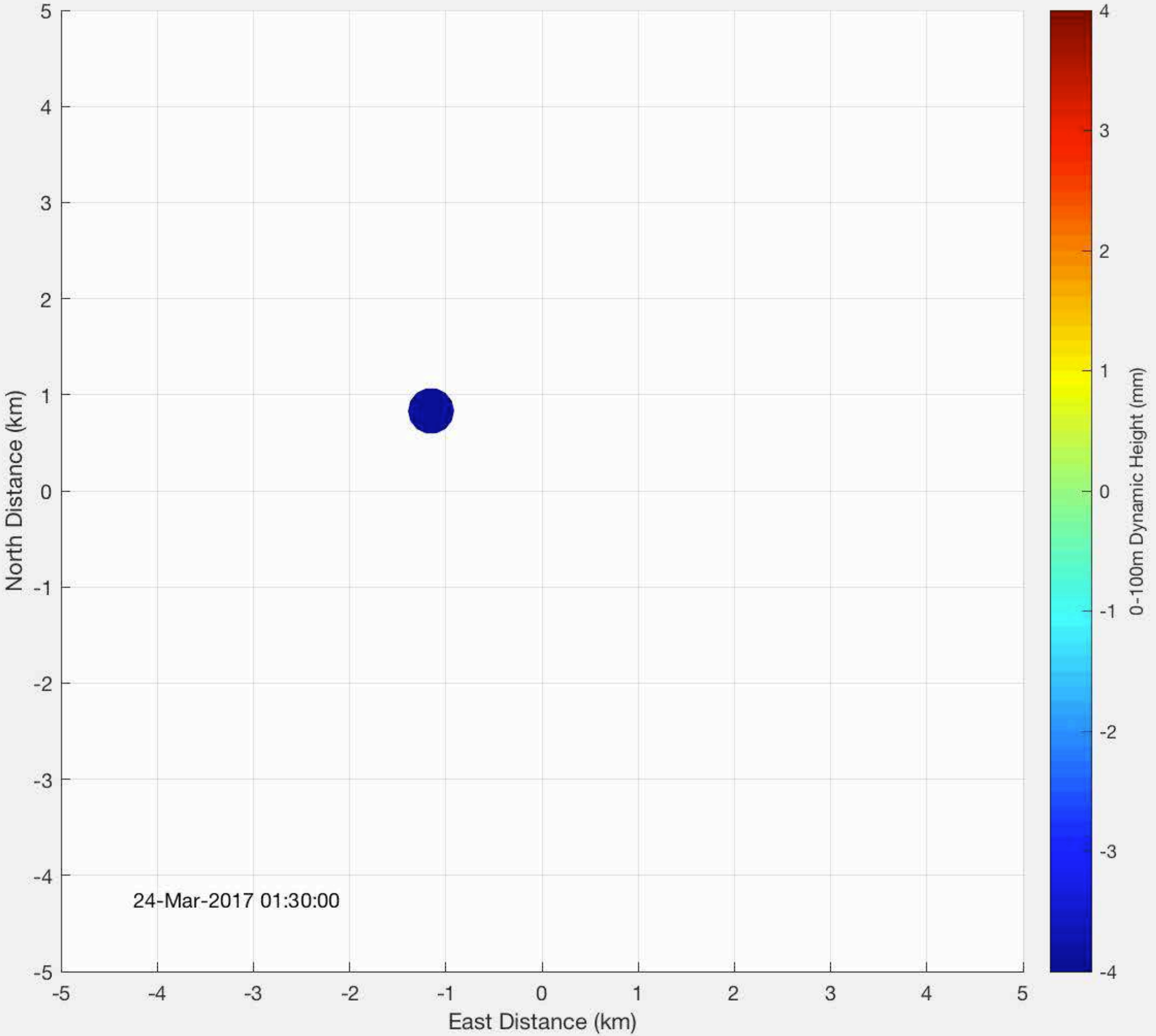
What about SSH on these scales (1-10 km)?

Can look at Dynamic Height (1/density) variability in the upper 100m



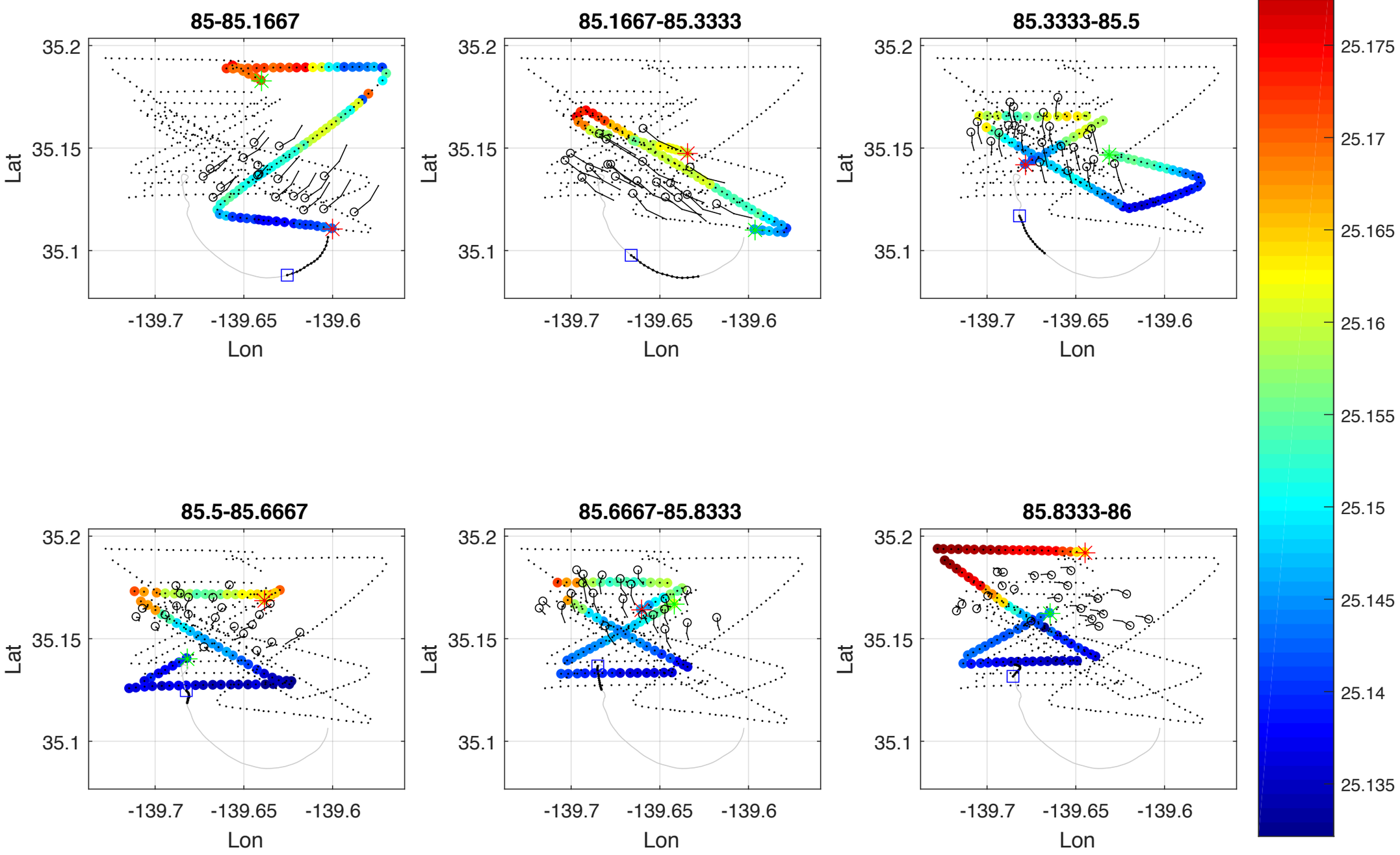





North Distance (km)
East Distance (km)
0-100m Dynamic Height (mm)
24-Mar-2017 01:30:00
5
4
3
2
1
0
-1
-2
-3
-4
-5

Sigma Theta at 15m Depth, YDay 85

(Mar 27, 2017)



Relationship of upper layer to low modes

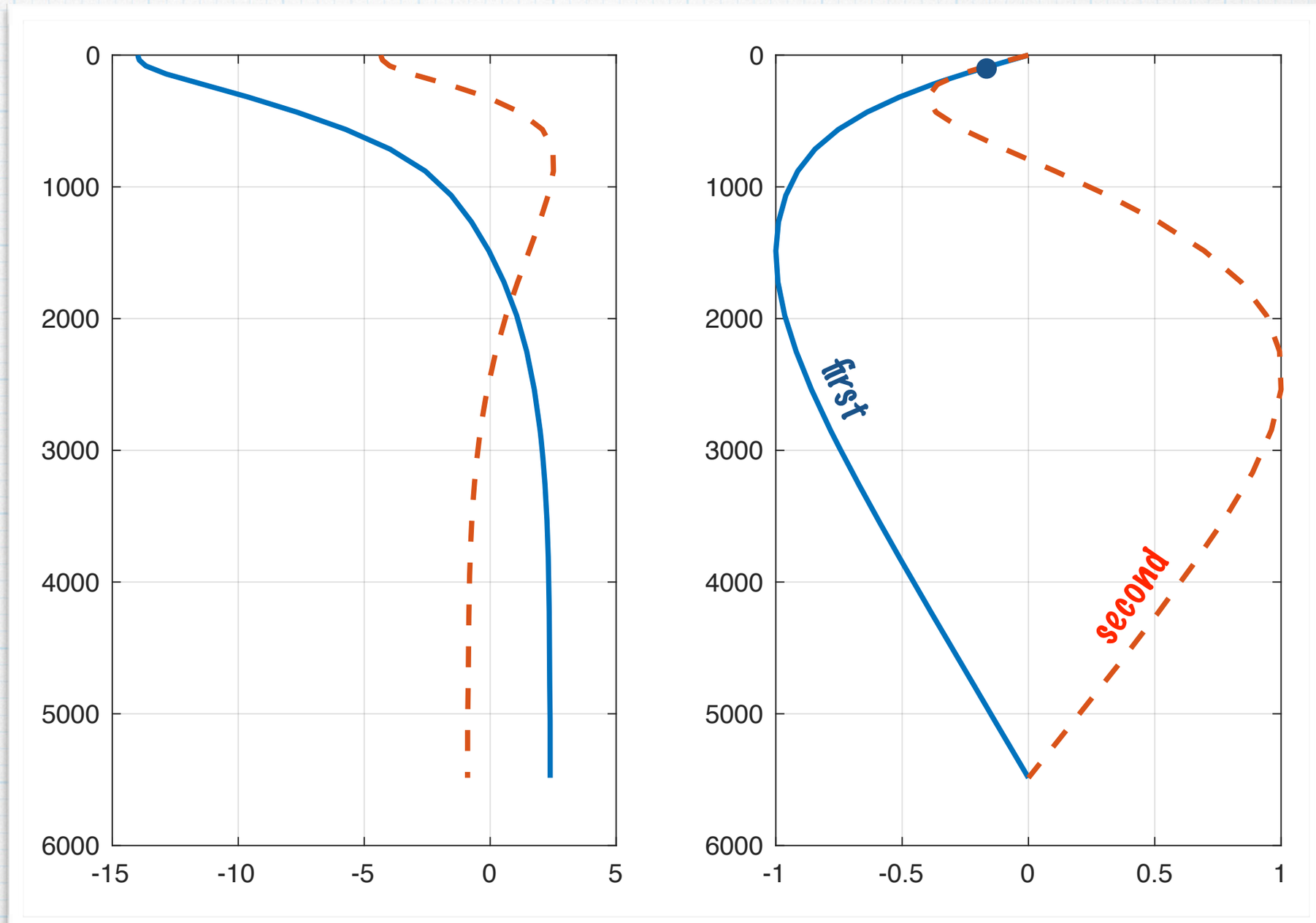
Upper 100m only captures 15-20% of the first-mode displacement and cannot separate modes 1 and 2.

But low mode spatial scales should be larger (>100 km for mode 1).

Sampling a bit deeper would help (e.g., 500m every 3 hours).

Horizontal (velocity or pressure)

Vertical (velocity or isopycnal displacement)



baroclinic mode structure in Northeast Pacific

Conclusions

* An intensive upper-ocean experiment with Lagrangian (up to 23 EM-APEX floats at a time) and shipboard measurements (200m profiles at 500m spacing) was carried out in the North Pacific Subtropical Front in March 2017
* Three sites, with distinct stratification and mesoscale environments
* Mixed layers were unusually shallow and storms were unusually scarce
* Restratification observed at the third site is a combination of solar heating and relaxation of wind mixing.
* Potential signals at other sites include:
  * Small mesoscale eddy structure
  * Subthermocline cross-frontal exchange and filamentation
  * Influence of strain on internal waves

physical oceanography

POSTDOC OPPORTUNITIES

mixed layers | submesoscale | internal waves | turbulence

UNIVERSITY *of* WASHINGTON

Applied Physics Laboratory

1013 NE 40th Street, Seattle, WA 98105–6698

www.apl.uw.edu
www.facebook.com/apluw
www.youtube.com/apluw

Four postdoctoral researcher opportunities to participate in analysis and interpretation of several data sets are available with the Applied Physics Laboratory at the University of Washington in Seattle. At least two years of funding is available for each of these positions.

Horizontal restratification of the surface mixed layer. Data were collected at 3 sites in the North Pacific Subtropical Front during March 2017 using O(1 km) arrays of chi-augmented EM-APEX profiling floats collecting repeated profiles of temperature, salinity, horizontal velocity and temperature microstructure, larger-scale repeated shipboard tow-yo and ADCP surveys and an air–sea flux buoy. Each site was sampled continuously for roughly one week. Results of this project aim to improve modeling of air–sea fluxes in coupled climate models.
Scientists include James Girton (girton@apl.uw.edu) and John Mickett (mickett@uw.edu).

Storm-forced inertial waves and turbulent mixing in forcing regions in the western North Pacific. Measurements were taken with EM-APEX floats during the 2016 and 2017 fall and winter storm seasons. These measurements are aimed at quantifying the dissipation of near-inertial waves at the near-field.
A participating scientist is Ren-Chieh Lien (lien@apl.uw.edu).

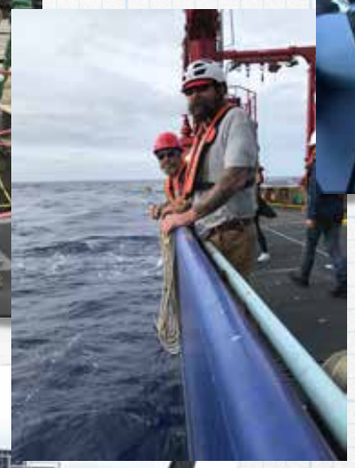
Instabilities, internal waves, mixing and entrainment at the base of the mixed layer near Ocean Station P in the Northeast Pacific. Two neutrally buoyant Lagrangian floats will be placed within the entrainment zone and measure shear and stratification on scales of cm's to many 10's of meters during the fall 2018 entrainment season. Results will be compared with LES model results with the aim of understanding the processes of entrainment. There will be opportunities for seagoing work. *Scientists include Eric D'Asaro (dasaro@apl.uw.edu), Andrey Shcherbina (ashcherbina@apl.uw.edu) and Ramsey Harcourt (harcourt@apl.uw.edu). See https://tinyurl.com/TLpostdoc*

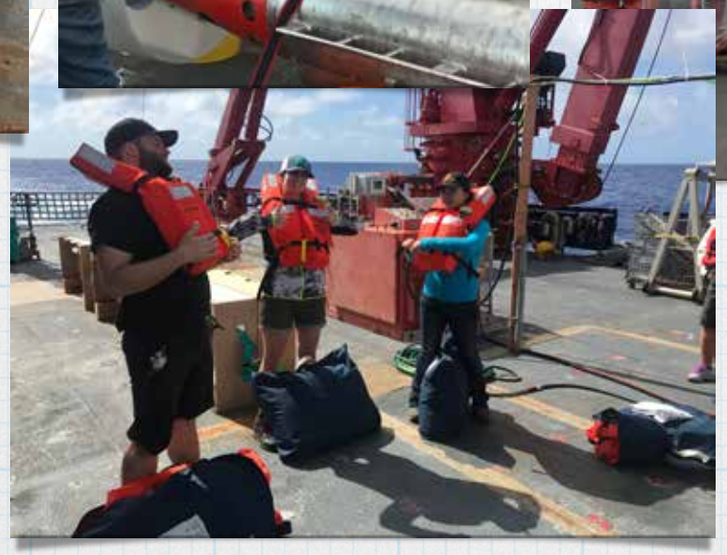
The horizontal wavenumber spectrum of water-mass tracers on isopycnals. Submesoscale shipboard CTD chain and ADCP surveys to determine controlling dynamics will be conducted during July 2018. These measurements will also be used to test a recent spectral model for anisotropic stratified turbulence.
A participating scientist is Ren-Chieh Lien (lien@apl.uw.edu).

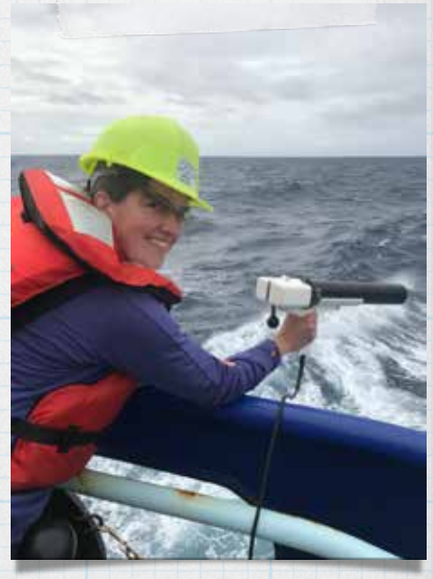
Interested qualified candidates are encouraged to contact any of the relevant scientists with questions, CVs, published and submitted articles, and references.

join us
apply yourself to what
MATTERS

Many Thanks to All Involved:
R/V Sikuliaq
Captain and Crew
Students and
Volunteers
Engineers
Scienti







Motivation: Restratification of a lateral density gradient in the oceanic mixed layer

(Mixed-layer Eddies Parameterization)

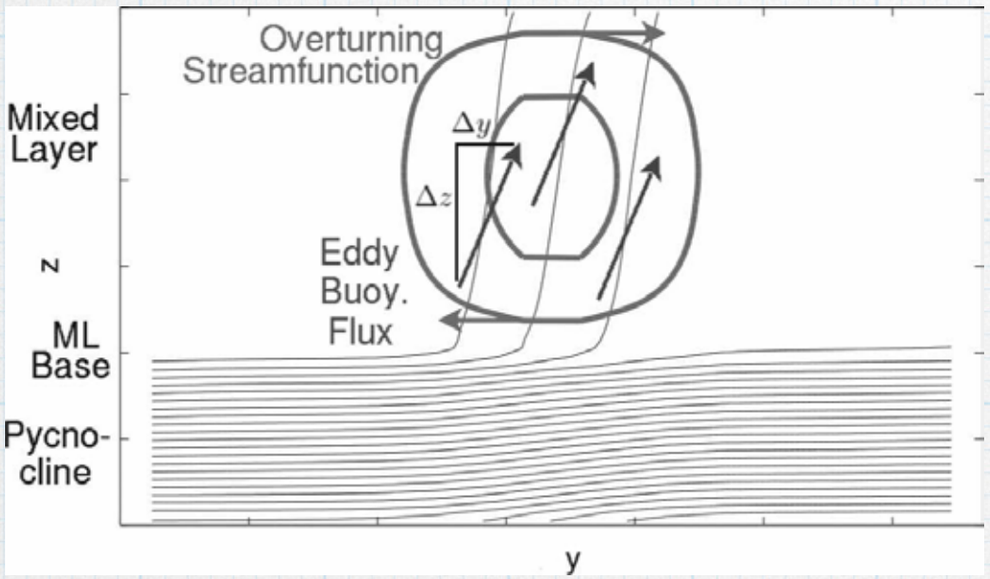
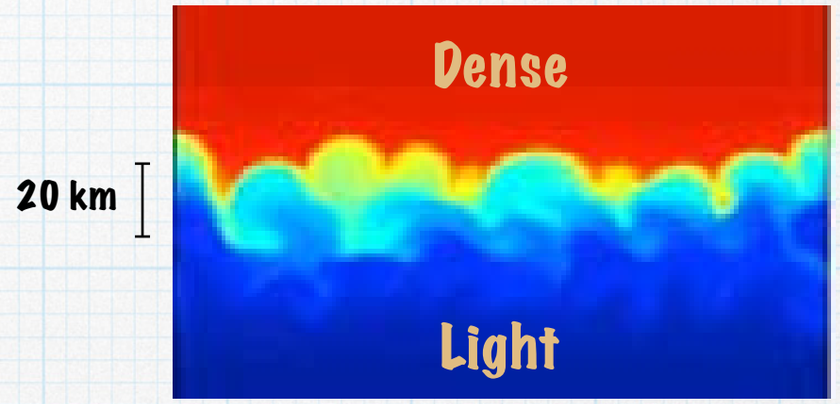


FIG. 8. Schematic of the ML restratification. Thin contours denote along-channel mean isopycnals. Straight arrows denote direction of the eddy buoyancy fluxes, and circular contours/arrows indicate eddy-induced streamfunction contours and direction. The decorrelation lengths of the eddies Δy and Δz are indicated. The reader is reminded that after Rossby adjustment the isopycnals are already flattened to slopes $O[10\ \text{m}\ (\text{km})^{-1}]$ despite their near-vertical appearance in this figure.

Fox-Kemper, Ferrari, and Hallberg, JPO 2008



Mahadevan, Tandon, and Ferrari, JGR 2010

- **Restratification** as an adjustment of lateral density gradients through baroclinic instability
- Parameterized as an overturning streamfunction scaling with the lateral **density gradient** and **mixed-layer depth**
- Aimed at implementation in **climate models** (i.e., long runs at low resolution)

Site 3: Solar Heating

- Radiometer measurements show diurnal heating cycle
- Mixed-layer depth responds to solar heating, but temperature is quite different
- Some of mixed-layer changes are due to vertical advection (internal waves)