WHOI-2015-04

Woods Hole Oceanographic Institution

UCTD and EM/APEX Measurements in Support of the April 2015 AirSWOT Campaign: Cruise and Data Report

by

J. Thomas Farrar, Benjamin Hodges, Sebastien Bigorre, Nan Galbraith,
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December 2, 2015

Technical Report

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Approved for Distribution:

Albert J. Plueddemann, Chair

Department of Physical Oceanography

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Background:

AirSWOT is an aircraft mounted instrument for measuring and imaging sea surface height (SSH), and it is similar to the SWOT (Surface Water Ocean Topography) instrument that will be deployed on a satellite in 2020. A field campaign was conducted in April 2015 to examine the performance of AirSWOT and to better understand how the measurement is affected by surface waves and currents. Supporting measurements were collected from the R/V *Shana Rae*, the R/V *Fulmar*, and a second aircraft (a Partenavia P68 operated by Aspen Helicopter, Oxnard,CA for UCSD/SIO).

From 17-20 April 2015, the R/V *Shana Rae*, a 50-foot research vessel, was used for collection of Underway CTD (or UCTD) measurements and for deployment and recovery of three EM/APEX floats in a study area off the central California coast. The UCTD measurements are being used to estimate the sea surface height signal associated with variations in ocean density structure. The EM/APEX floats provide time series of the same, as well as vertical profiles of ocean velocity. The purpose of this report is to document the shipboard operations on the R/V *Shana Rae* and the resulting UCTD and EM/APEX data sets.

Synopsis of operations:

The *Shana Rae* sailed from Santa Cruz Small Craft Harbor at 1500 Z on April 17, 2015, deployed 3 EM-APEX profiling floats in the AirSWOT study area, carried out hydrographic sampling with the UCTD, recovered the floats, and returned to port, arriving at 1700 Z on April 20. A UCTD section was collected along the satellite tracks sampled by the SARAL/AltiKa altimeter on April 17, and sampling was conducted in a 40kmx40km region in a "feature survey" for a two day period. 158 UCTD casts were completed (Figure 1).

The timing of the campaign was affected by weather and by the fact that the area of operation falls in US Navy aviation warning areas (W-283 and W-285), where there were restrictions on aircraft operations related to military exercises. The "whiskey areas" are closed during the day (loosely, business hours) on weekdays. The significant wave heights were about 3 m when operations aboard the R/V *Shana Rae* started on 17 April and decreased until the 20th when operations ceased. Seas were forecast to exceed 5 m after the 20th, which was the major factor in the setting the dates of operation on the *Shana Rae*.

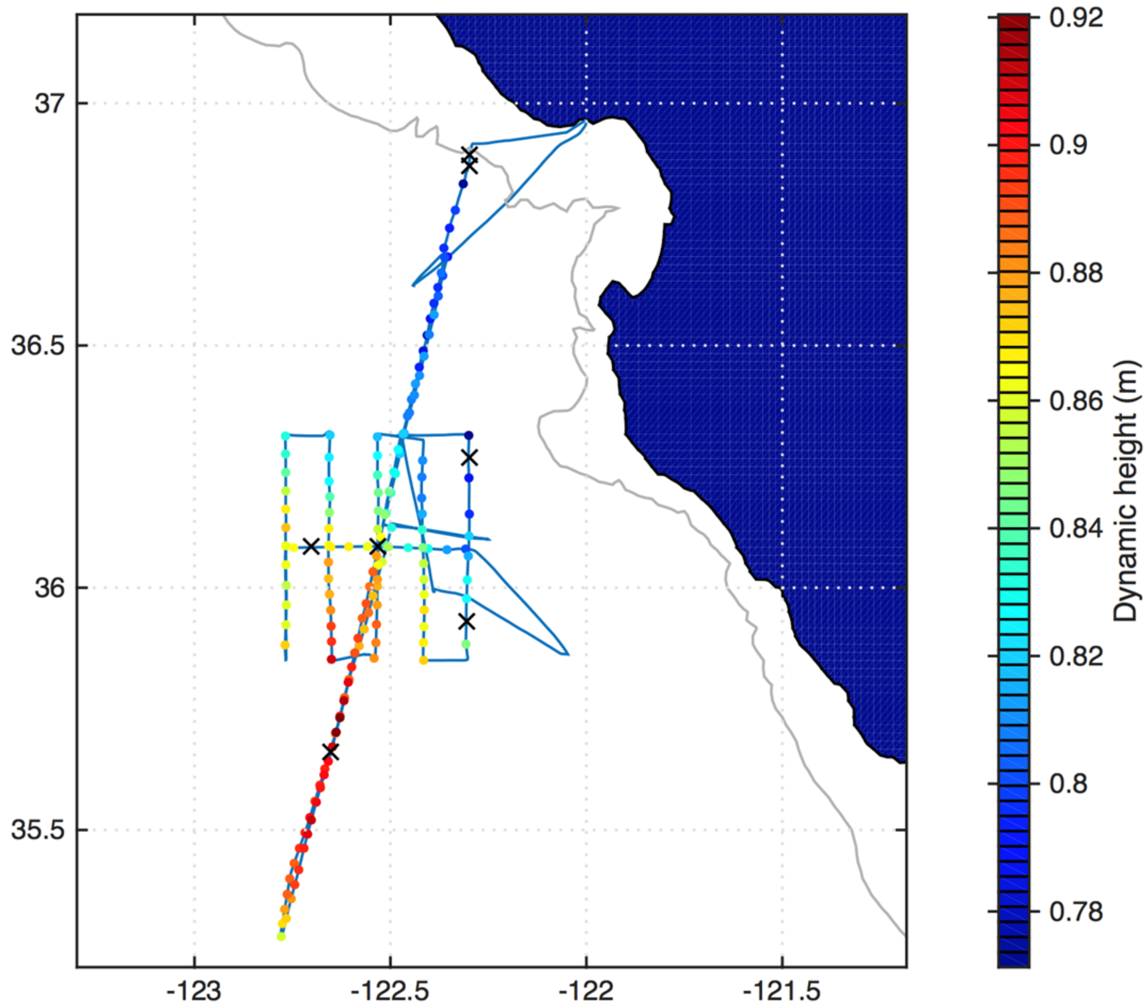

Figure 1: *Shana Rae* cruise track (blue line). Dots mark the locations of UCTD casts deeper than 480 dbar, and are colored by the dynamic height relative to that depth. Black X's mark the locations of shallower UCTD casts. The gray contour is the 500-m isobath.

Principle Investigators

UCTD:	Tom Farrar	*jfarrar@whoi.edu*
EM-APEX:	James Girton	*girton@apl.washington.edu*

Personnel on board

Captain:	Jim Christmann	*jaxmann@shanarae.com*
Mate:	Gene Sofen	
Science:	Ben Hodges	*bhodges@whoi.edu*
Science:	Ben Pietro	*bpietro@whoi.edu*
Science:	Andrew Davies	*adavies@whoi.edu*

Cruise narrative

17 April:

UCTD sampling commenced at 1630 Z at the intersection of the continental shelfbreak (represented in Figure 1 by the 500-m isobath, gray) with the April 17th SARAL/AltiKa satellite groundtrack. The *Shana Rae* proceeded at about 7 knots south-south-westward along the track, collecting ~500-m-deep profiles of temperature and salinity every 15-20 minutes, for an average horizontal spacing of 4-5 km. A brief stop was made upon reaching the crossing point of the April 15th SARAL/AltiKa groundtrack at 1830 Z to deploy EM-APEX float 6665. At 2300 Z, shortly before reaching the crossing point of the April 14th Jason groundtrack, EM-APEX float 6667 was deployed.

18 April:

After the deployment of 6667, UCTD sampling was suspended, and the *Shana Rae* made an eastward jaunt off the track she'd been following to deploy EM-APEX float 6675. The deployment took place at 0030 Z, and the *Shana Rae* returned to the track to resume UCTD sampling. At 1000 Z, at the nominal range of 200 km from Santa Cruz, the *Shana Rae* reversed course and continuing UCTD sampling along the same track, repeating the southern portion of the transect. At 2030 Z, the northern boundary of the 'feature survey' area was reached, and UCTD sampling was suspended briefly during the transit to the northeast corner of the survey box. The *Shana Rae* turned due south at 2100 Z and commenced the UCTD feature survey.

19 April:

The fifth, westernmost meridional transect of the feature survey was completed at 1830 Z. The single zonal transect was carried out from west to east across the middle of the box between 2030 and 2330 Z.

20 April:

Following completion of the survey, UCTD sampling was suspended, and the two southern EM-APEX floats were located and recovered: 6675 at 0130 Z followed by 6667 at 0430 Z. One of 6667's electrodes was found to be loose after recovery, and the hiss of air leaking into the evacuated pressure case could be heard; the likely cause was contact with a boathook during recovery. The *Shana Rae* then returned to the intersection of the northern boundary of the survey box with the April 17th SARAL/AltiKa line to resume the northward UCTD transect along that line. Sampling continued as far as the deployment location of EM-APEX float 6665. The final UCTD cast occurred at 1100 Z. EM-APEX float 6665 was then located and recovered, and the *Shana Rae* returned to port, arriving at 1700 Z.

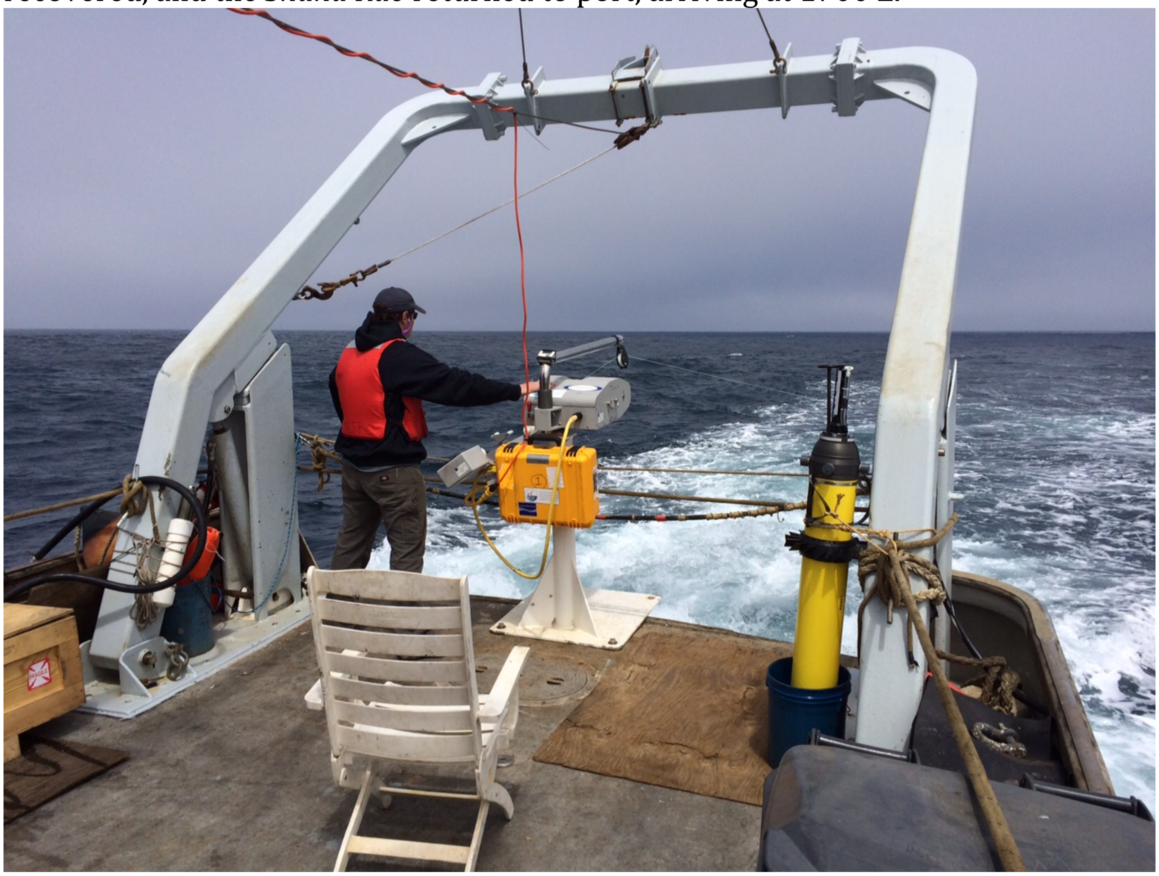

Figure 2: UCTD sampling in progress from the stern of the *Shana Rae* while an EM-APEX float soaks in a bucket in preparation for deployment.

EM-APEX floats

Float S/N	6665	6667	6675
Deploy date	17 April 2015	17 April 2015	18 April 2015
Deploy time (Z)	1839	2256	0037
Deploy latitude	36° 41.14’ N	36° 07.77’ N	36° 06.01’ N
Deploy longitude	122° 21.24’ W	122° 30.88’ W	122° 15.02’ W
Recover date	20 April 2015	20 April 2015	20 April 2015
Recover time* (Z)	1135	0430	0130
Recover latitude*	36° 37.45’ N	35° 59.65’ N	35° 52.01’ N
Recover longitude*	122° 26.43’ W	122° 23.40’ W	122° 03.01’ W

** Recovery times and locations are approximate*

UCTD Data:

The UCTD data are available at the following link:
http://uop.whoi.edu/projects/AirSWOT/AirSWOTdata.html

The Oceanscience UCTD Underway Profiling System (or Underway CTD system, or UCTD) measures seawater conductivity, temperature, and pressure. The UCTD system consists of a battery-powered, internally recording CTD with a tail spool, a tail-spool winder, and a winch (Figure 3). In "free cast" mode, a length of line is wound on the tail spool with the winder, and the probe is dropped over the stern while underway; the probe falls nearly vertically through the water as the tail spool unwinds and the winch, set to free spool, pays out line to compensate for the ship's forward motion. Within each raw data file, there are four columns, corresponding to (1) sample number, (2) conductivity, (3) temperature (°C), and (4) pressure. The probes are designed to fall through the water at approximately 4 m/s, and the target depth for all casts was 500 m (~125 s fall time).

The data record for each cast is stored in an ascii (text) file and contains the pressure, temperature, and conductivity output by the instrument. The file names are based on the date, approximate time, and the probe serial number; for example, file "041815_134006_SN29.asc" was collected on 18 Apr 2015, at approximately 13:40:06 UTC, using probe number 29. The header of each file contains the time the instrument was turned on (i.e., when the magnet was removed), and the scan number stored in the file can be used to precisely determine the time the cast actually started.

The position for each cast was estimated as follows. A Raymarine GPS was mounted on the side rail, and the data were recorded on a PC at 1 Hz. The clocks on the UCTD probes were checked periodically, and they stayed within 2 seconds of the GPS clock. Cast positions were estimated by taking the GPS position at the cast start time. Estimated cast locations should be accurate to O(10 m).

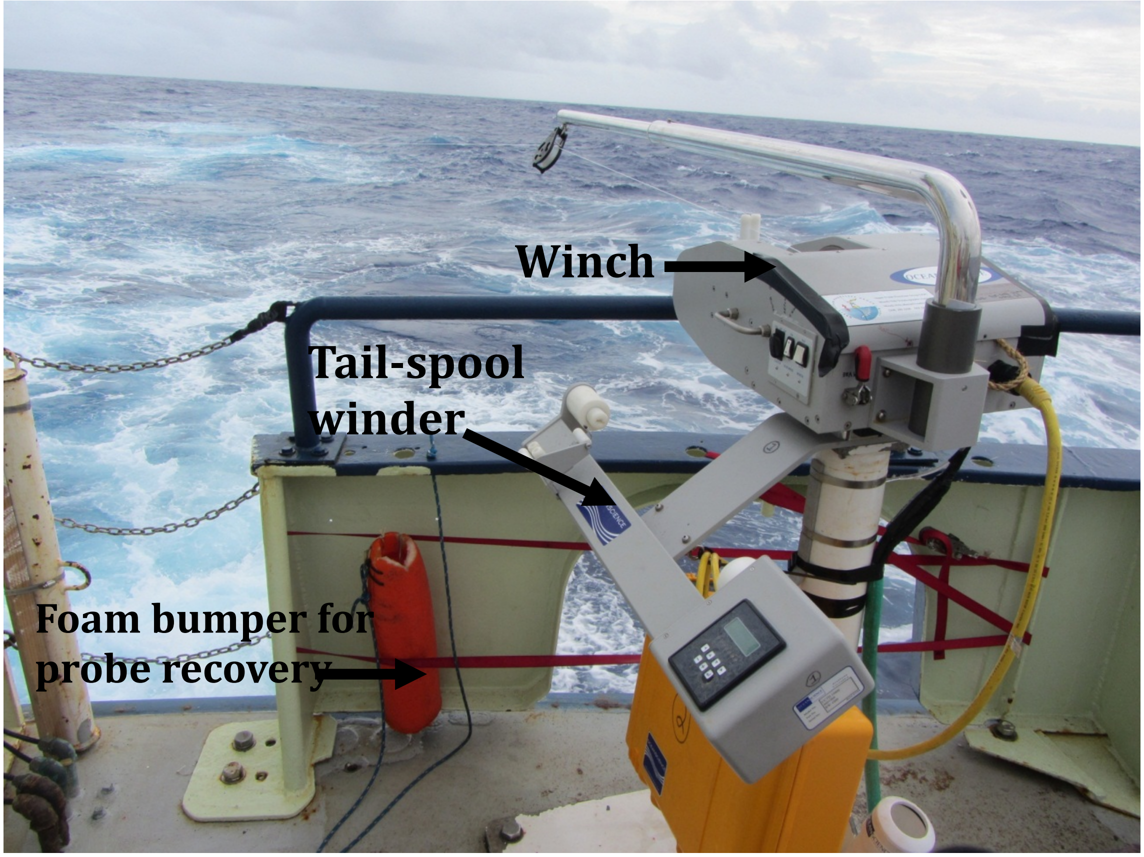

Figure 3: UCTD system during deployment on a research vessel during the NASA SPURS experiment.

The raw data were processed as follows to form a vertically gridded product that was saved in Matlab and netCDF formats. The raw data is 16 hz, or about 4 samples per meter. Conductivity has been lagged by one scan (1/16 second) in an attempt to better align it with the slower temperature measurement for estimation of salinity from temperature and conductivity. This does a reasonably good job of reducing the salinity spiking that results from the mismatch of the temperature/conductivity time responses and is adequate for the anticipated uses of the data. Salinity values outside of 32-36 psu were removed and filled by linear prior to bin averaging. A vertically gridded, 1-decibar (approximately 1-m) data product was formed from the lag-corrected data by bin averaging--after lagging T by one sample relative to C and computing S, all samples between 9.5 dbar and 10.5 dbar (for example) were averaged to form the 10 dbar T and S averages. The average P for the samples included in the bin average will in general not be exactly 10 dbar.

The UCTD casts were taken during a time period of about 2.5 days, with a geographic sampling that used straight sections. These sections are shown in Fig 4. The colors denote the different sections, with the starting point of the section represented with an open square symbol. The legend has sections numbered in chronological order, as they were collected. The two longest sections were about 180 km (section 1, red) and 110 km (section 2, green), while other sections were around 40 to 50 km long. Median distance between casts was 3.7 km. The upper 5 m of UCTD data were not used.

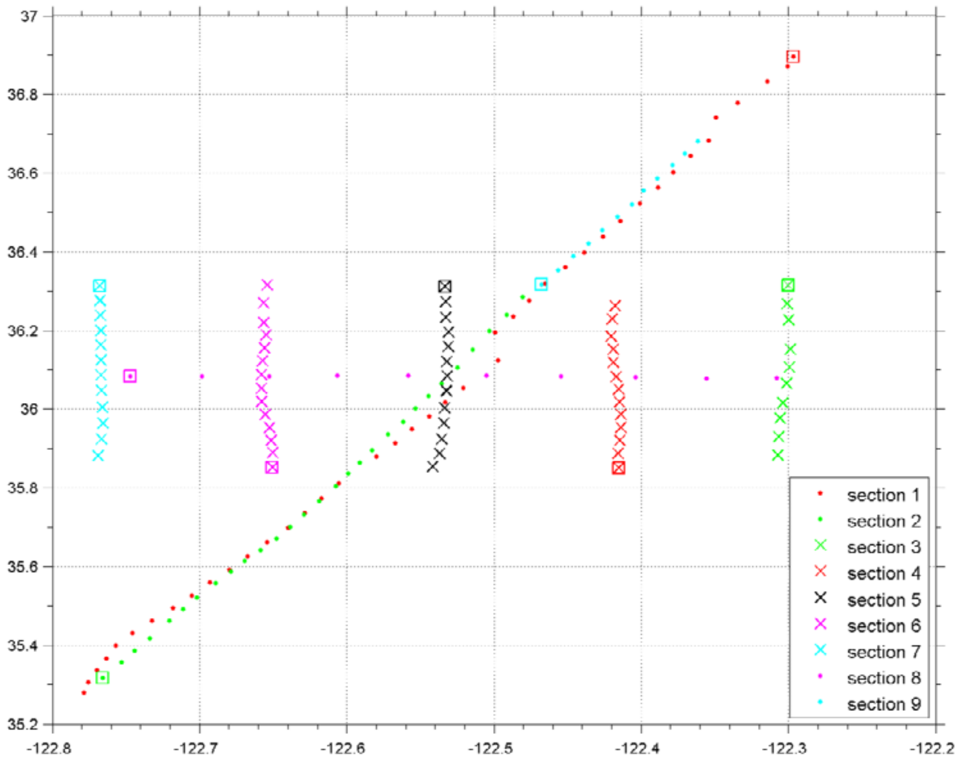

Figure 4: Map with locations of AirSWOT UCTD casts taken in April 2015.

From conductivity, temperature and pressure, density was computed using the Matlab Seawater Toolbox, which implements the 1983 UNESCO algorithms. A 3-dimensional view of the density anomaly is shown in Fig 5. Casts' maximum depth varied between 450 and 550 m.

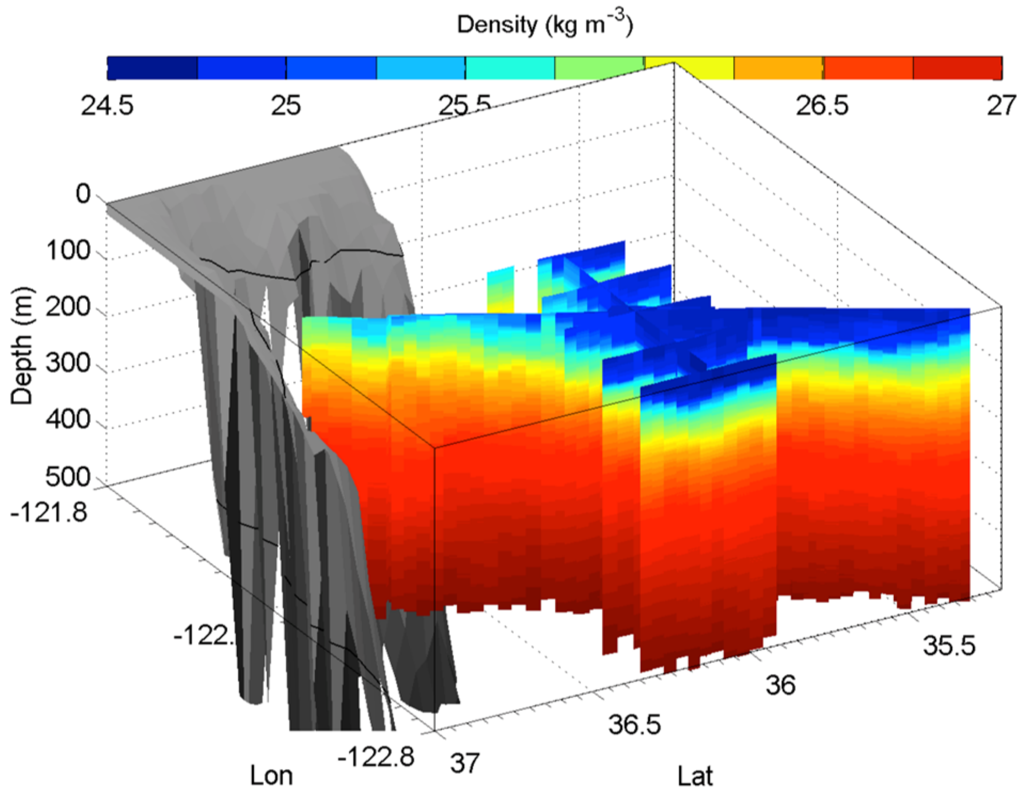

Figure 5: Density anomaly profiles from UCTD casts during AirSWOT campaign in April 2015. Grey shading denotes bathymetry, and the viewing angle is from the northwest.

Dynamic height was then computed with respect to different depths (200 m, 400m and 500 m) which showed little difference. Dynamic height referenced to 400m is shown in Fig. 6 for all sections, as a function of latitude. Color coding is the same as in the map in Fig. 4. Dates at which sections were started are also indicated in the legend of each panel in Fig. 6. The thermosteric part of the dynamic height is dominant and shown here. Thermosteric dynamic height was computed following Pond and Pickard (1983, p. 10, 66-67):

$$\text{del\_th} = (1000 / (1000 + \sigma_t) \ -0.97266)*1e\text{-}3$$

where σ_t is density anomaly. Integrating del_th from surface (5 m) to 400 m with respect to pressure (in Pascals) yields dynamic height. Dynamic height is expressed in meters by dividing integral by 9.8 m/s^2 (gravity). This is the quantity given in the data files as "Dynamic height (thermosteric)" in units of meters.

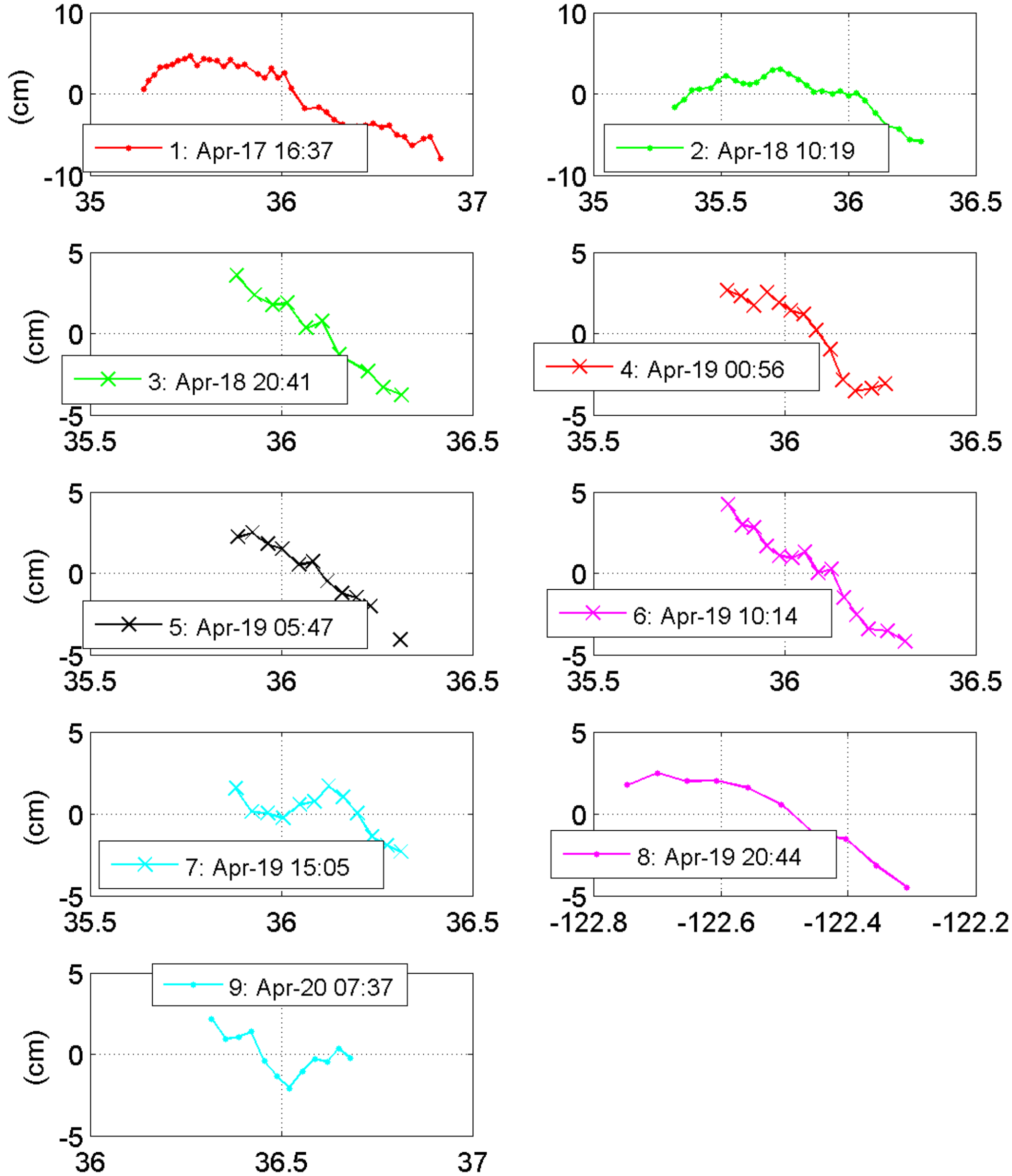

Figure 6: Dynamic height referenced to 400 m for each UCTD section.

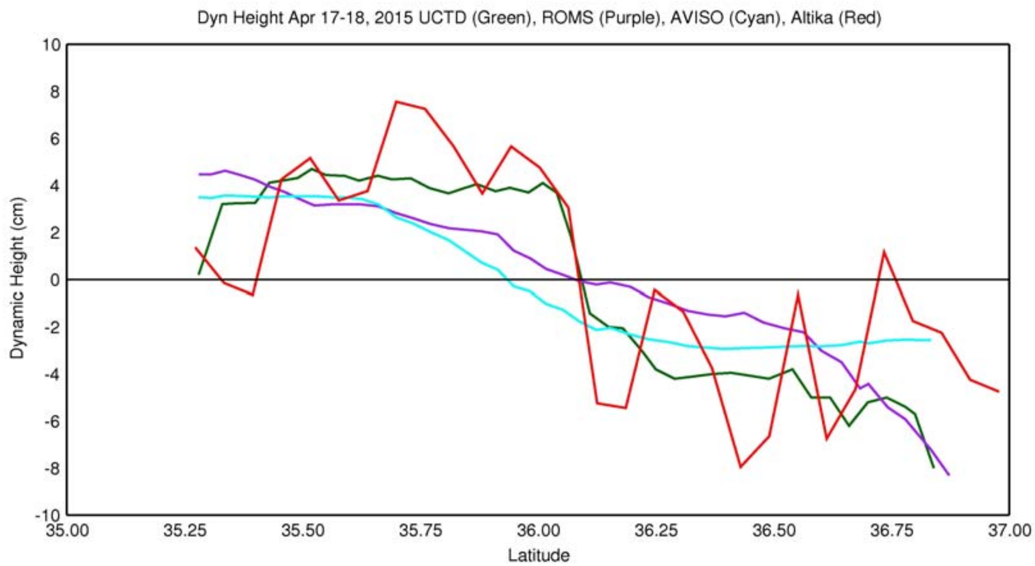

Figure 7: Dynamic height along the 17 April SARAL/AltiKa track (UCTD Section 1). The green line shows the dynamic height relative to 400 m from the UCTD data, which can be compared to the SSH measured by SARAL/AltiKA (red line). Also shown are SSH estimates from the gridded Aviso altimetry product (cyan) and from a run of the ROMS regional ocean model (purple).

Section 1 was the longest continuous section, and ran to the southwest for 180 km along the 17 April SARAL/AltiKa track. Figure 7 shows a comparison of the dynamic height from the UCTD data to the sea surface height (SSH) anomaly data from SARAL/AltiKa and two other SSH products (the gridded Aviso product, Pascual et al., 2006, and from a run of the ROMS regional ocean model, Chao et al., 2009). The SARAL/AltiKa data are the Level 2 NRT data obtained from PODAAC at JPL (doi: 10.5067/AKASA-XOGD1); tides have been removed. Figure 8 shows in detail the hydrography (temperature and salinity) and dynamic height (referenced to 400 m) for section 1.

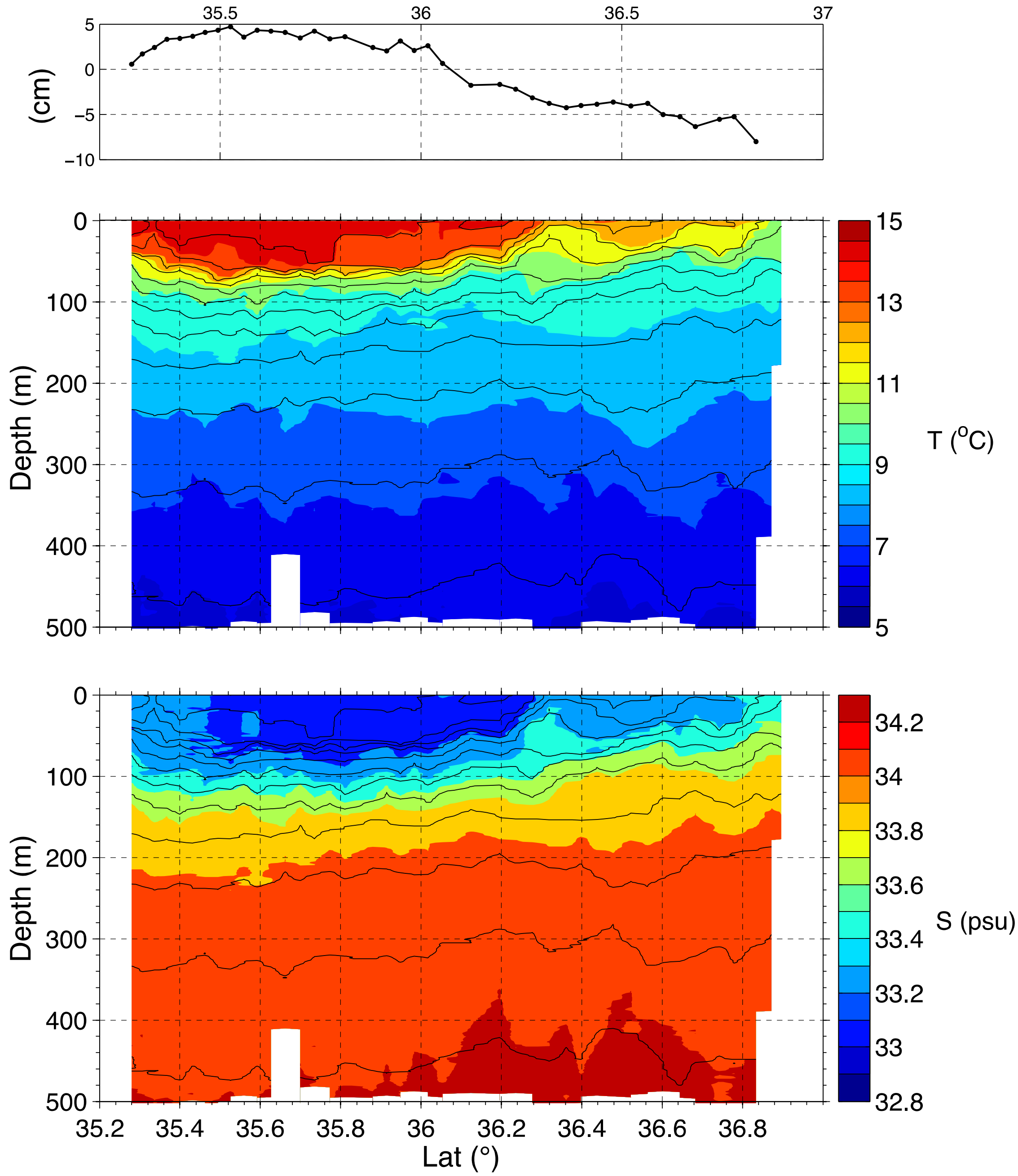

Figure 8: Dynamic height referenced to 400 m (top), temperature (center) and salinity (bottom) for UCTD section 1 (long transect in Fig. 1).

EM-APEX Data:

The EM_APEX data are available at the following link:
http://uop.whoi.edu/projects/AirSWOT/AirSWOTdata.html

The three Teledyne Webb Research (TWR) EM-APEX (ElectroMagnetic Autonomous Profiling Explorer) floats collected timeseries of T, S and horizontal water velocity during the UCTD survey. Figure 9 shows the initial deployment locations (circles) and drifts of the three floats over the 3 day experiment.

The EM-APEX measures horizontal velocity by sensing the electrical currents produced by the motion of the conducting seawater through the vertical component of the geomagnetic field. This method produces a relative velocity profile because the depth-averaged water velocity produces an opposing depth-independent electric field. The profile can be made absolute using the surface GPS positions to estimate the average velocity over the float's profiling range and shifting the profile accordingly. Figure 10 shows the north component (v) measured by the GPS and EM methods at float 6667. In spite of large southward surface velocities and internal wave band variability of 40-50 cm/s, the overall drift of the floats was relatively slow (less than 10 cm/s).

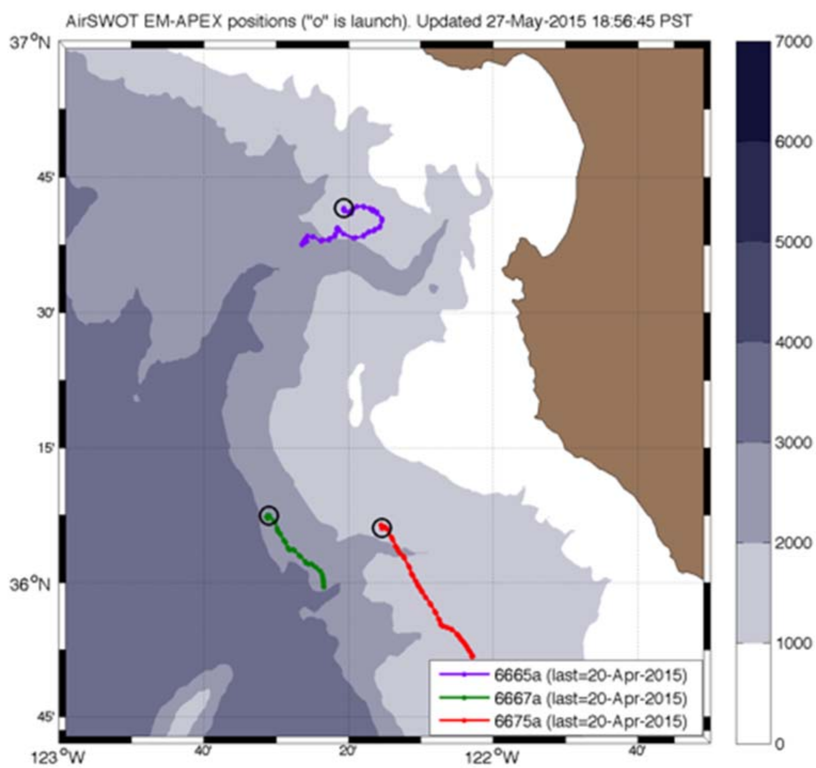

Figure 9: Deployment locations (circles) and drift tracks (lines with dots) for the three EM-APEX deployed in support of the AirSWOT flights of April 17-20, 2015.

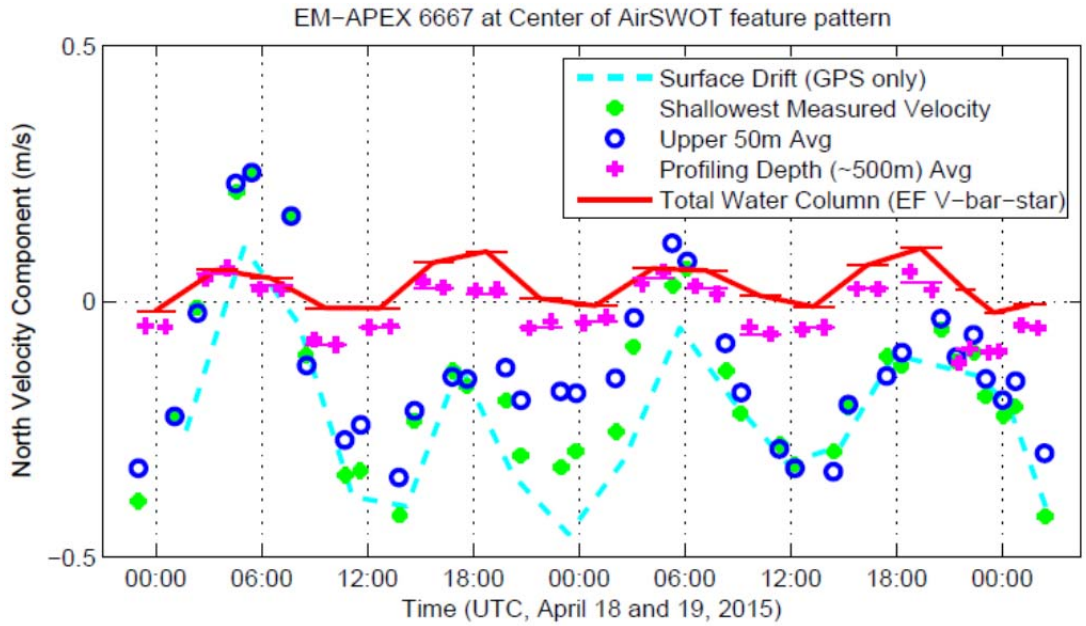

Figure 10: Example of meridional (v) velocity timeseries at EM-APEX 6667. Cyan (drift while at the surface) and magenta (subsurface average between surfacings) timeseries are derived from GPS positions only, while all other timeseries also incorporate the EM velocity profile. Green dots represent the shallowest EM-APEX measurement (~7.5m depth) and blue circles show the upper 50m average. Red horizontal bars are estimates of the full ~3000m water column velocity (including the part below the profiling range) as inferred from the shift applied to the EM velocity to match the GPS. This average is northward, indicating the presence of the California undercurrent.

All three EM-APEX made continuous round-trip profiles to 500m about every 3 hours for at least a day before transitioning to shorter profiles with more rapid repeat sampling (Figure 11). For the final day, the profiling ranges of two of the floats (6665 and 6667) were controlled by shore-side software using a dynamic algorithm that attempted to minimize drift from the float's initial position (taking into account the ROMS model current forecasts). The experiment ended before the effectiveness of this particular algorithm could really be established, but the method is a promising one for future field experiments.

Dynamic height timeseries have been computed relative to 500m (as described above) for all three EM-APEX, and are shown in Figure 12. Floats 6665 and 6667, launched at about 36.7 and 36.1°N along the Altika track sampled by the UCTD (Fig.7), saw a similar ~7 cm dynamic height difference between the two sites. Time-varying signals on top of this were as large as 3 cm peak-to-peak due to internal tides and other internal waves. Comparison with a satellite altimeter analysis of internal tides (Zhongxiang Zhao, personal communication) shows that the survey box location is at a maximum in an interference pattern between north- and south-bound internal tide waves. The M2 internal tide amplitude at this site is approximately 1.5 cm peak-to-peak, and the instantaneous range may be enhanced by time variability in the form of other constituents (spring-neap cycle) and modulation by seasonal and mesoscale variability (incoherent internal tide).

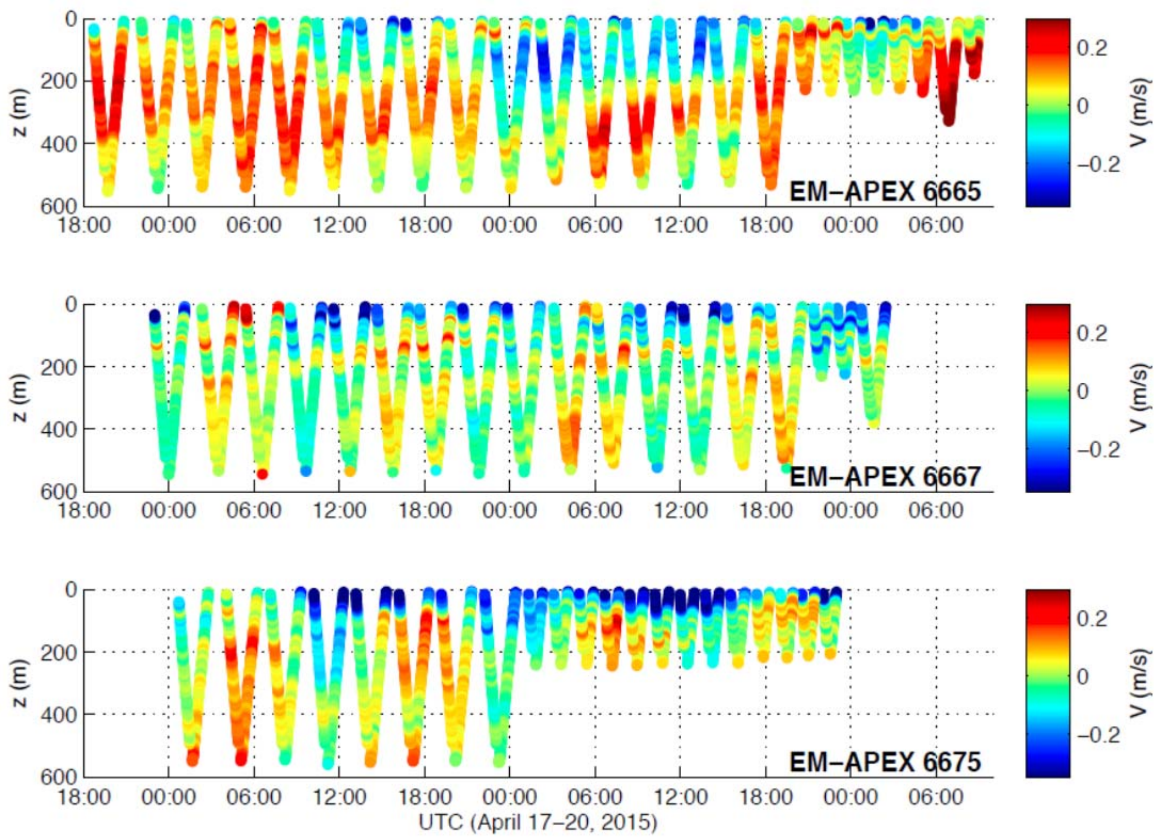

Figure 11: Meridional velocity time-depth series from all 3 EM-APEX.

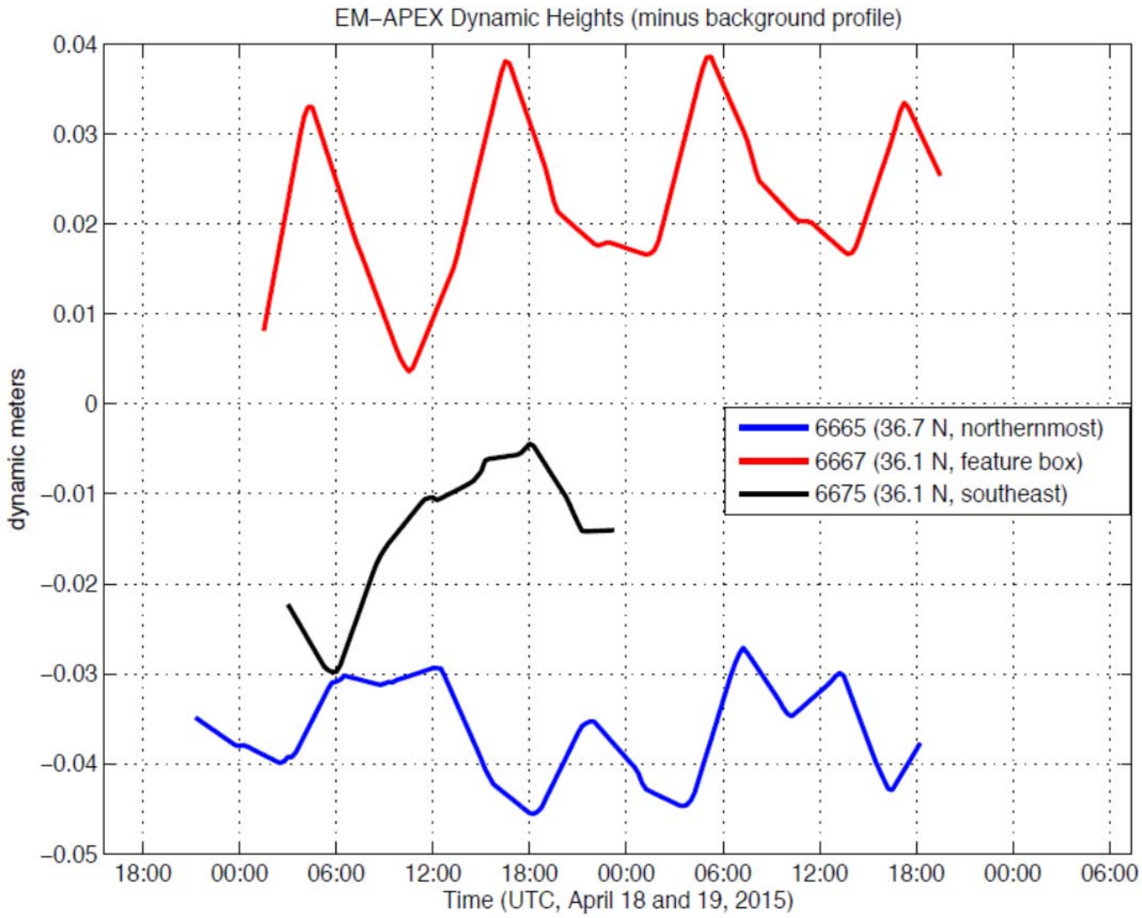

Figure 12: Dynamic height (surface relative to 500m) timeseries from all 3 EM-APEX.

On interpretation of dynamic height versus SSH

Dynamic height is really just the dynamic pressure difference between some reference depth and the surface (except it is expressed as a height via the hydrostatic pressure relation). This would completely capture the SSH signal due to baroclinic variability if the water were motionless at the reference depth. That is, if there were no motion at the reference depth, the dynamic pressure at the reference depth would be zero and the dynamic pressure difference would be the total dynamic pressure. Dynamic height variance will underestimate SSH variance to the extent it does not capture all of the pressure difference over the water column or if there is some barotropic signal (or surface-only signal, like infragravity waves).

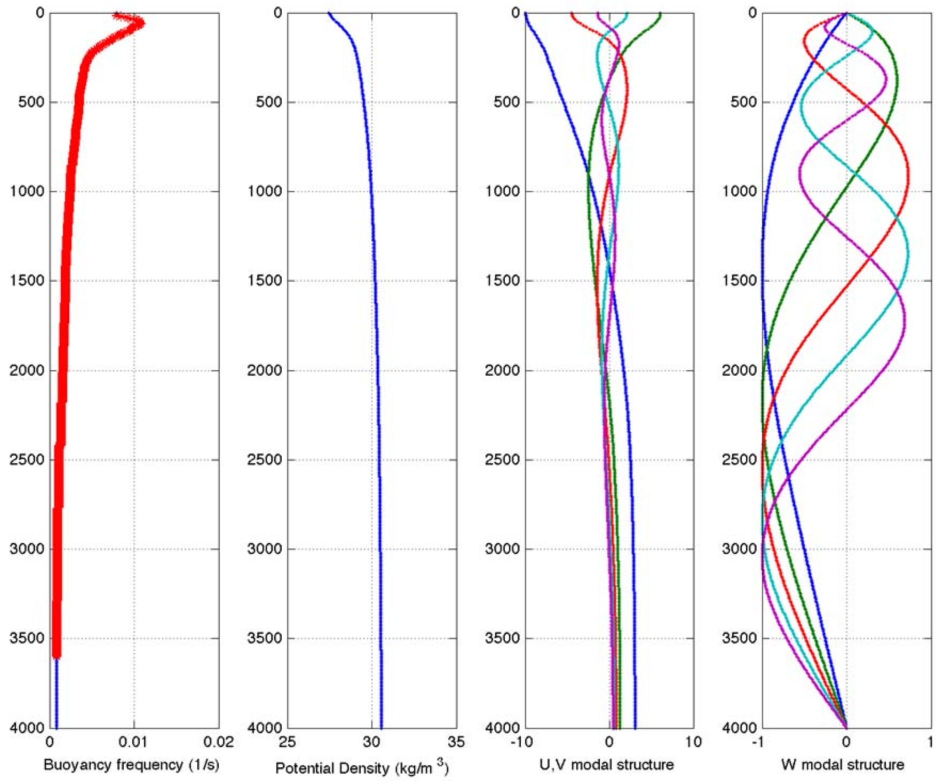

Figure 13: Near-full-ocean-depth hydrographic cast taken near Monterey Bay and the associated vertical mode structure. From left to right: buoyancy frequency (1/s), potential density (kg/m^3), vertical mode structures for pressure and horizontal velocity (dimensionless), and vertical mode structures for vertical velocity (dimensionless). The third panel (vertical mode structures for pressure) can be used to qualitatively assess the extent to which dynamic height captures baroclinic surface pressure variations (and SSH variations); for example, dynamic height relative to 400m will capture a little less than half of the amplitude of the surface pressure signal of the first baroclinic mode (blue line).

The limited-depth profiles (~500m) are not sufficient for the dynamic height to capture all of the pressure signal at the surface. One can get a sense of the extent to which the pressure signal may be underestimated by examining the baroclinic modes computed from (near) full ocean depth hydrographic data in the region. These modal profiles were used in planning the in situ work for AirSWOT and deciding on how deep to make the UCTD and EM/APEX float profiles. The vertical structure of the modal pressure signals is in the third panel of Figure 3. The blue curve is the first baroclinic mode. One can see that, if we took the pressure difference between z=0 m and z=400m, we capture about 40% of the total pressure signal. (The total pressure signal of any mode at the surface would be the surface value.) We capture more of the signal of some of the other modes (fortuitously about 100% of modes 2, 4, and 5). So, loosely speaking, since most of the signal in surface pressure is probably mode 1, one might suppose we are capturing only about half of the total SSH variance due to the baroclinic variability. We could thus expect the dynamic height to underestimate baroclinic SSH signals by a factor on the order of 2 (so a factor of 4 in a spectrum). This concept, relating dynamic height to SSH, is also discussed by Farrar and Durland (2012).

There are probably also contributions from barotropic variability and surface phenomena (such as infragravity waves) in the AltiKa and AirSWOT data that are "invisible" in the hydrographic data.

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Appendix A: UCTD Data Files

There are 159 raw UCTD data files (ascii).

The processed UCTD data (with GPS positions, uniform depth gridding, and derived dynamic height) exist as Matlab data files and as netCDF files. The same variable names and units are used for the netCDF and Matlab data files. The variable names and units, as well as other metadata, are embedded in the netCDF files and are given below for reference.

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available; distributor assumes no responsibility for the manner in 
which the data are used.'
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           platform                       = 'R/V Shana Rae'
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           citation                       = 'UCTD data from the April 
2015 AirSWOT campaign were made available by Dr. J. Tom Farrar of the 
Woods Hole Oceanographic Institution.'
           acknowledgment                 = 'Collection of the UCTD 
data for the April 2015 AirSWOT campaign was funded by NASA under a 
contract from the Jet Propulsion laboratory.'
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           creator_email                  = 'jfarrar at whoi.edu'
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'http://www.whoi.edu/profile/ngalbraith/'
           publisher_email                = 'N. Galbraith'
           contributor_name               = 'Ben Hodges; Sebastien 
Bigorre'
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average; calculate dynamic height'
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sbigorre at whoi.edu'
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http://www.whoi.edu/profile/sbigorre'
           date_created                   = '2015-10-02T16:04:56Z'
           history                        = '17-20 Apr 2015, data
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lagging T by one sample relative to C and computing S using Matlab
seawater toolkit, Ben Hodges. Dynamic height calculated from 1-dbar
data, set to NaN in upper 5dbar, Seb Bigorre'
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           geospatial_vertical_min        = 0.99269
           geospatial_vertical_max        = 543.2766
           geospatial_vertical_units      = 'meters'
           geospatial_vertical_positive   = 'down'
           geospatial_vertical_resolution = 'point'
           time_coverage_start            = '2015-04-17T16:37:28Z'
           time_coverage_end              = '2015-04-20T10:48:10Z'
           time_coverage_duration         = 'P2D'
Dimensions:
           TIME      = 158
           DEPTH     = 548
           LATITUDE  = 158
           LONGITUDE = 158
Variables:
    TIME
           Size:       158x1
           Dimensions: TIME
           Datatype:   double
           Attributes:
                       long_name          = 'time'
                       standard_name      = 'time'
                       units              = 'days since 1950-01-
01T00:00:00Z'
                       calendar           = 'gregorian'
                       valid_min          = 23847.6927
                       valid_max          = 23850.4501
                       QC_indicator       = 8
                       QC_indicator_value = 'Interpolated value'
                       QC_procedure       = 5
                       QC_procedure_value = 'Clock drift corrected'
                       comment            = 'Time at start of cast'
                       axis               = 'T'
    DEPTH
```

```
            Size:       548x1
            Dimensions: DEPTH
            Datatype:   double
            Attributes:
                        long_name                   = 'measurement depth'
                        standard_name               = 'depth'
                        units                       = 'meters'
                        positive                    = 'down'
                        valid_min                   = 0.99269
                        valid_max                   = 543.2766
                        reference                   = 'mean_sea_level'
                        coordinate_reference_frame =
'urn:ogc:crs:EPSG::5113'
                        axis                        = 'Z'
                        comment                     = 'measurement depth'
    LATITUDE
            Size:       158x1
            Dimensions: LATITUDE
            Datatype:   double
            Attributes:
                        long_name                   = 'Mooring anchor
latitude'
                        standard_name               = 'latitude'
                        units                       = 'degrees_north'
                        valid_min                   = 35.2799
                        valid_max                   = 36.8966
                        reference                   = 'WGS84'
                        coordinate_reference_frame =
'urn:ogc:crs:EPSG::4326'
                        uncertainty                 = 0.01
                        axis                        = 'Y'
                        comment                     = 'position at start
of cast'
    LONGITUDE
            Size:       158x1
            Dimensions: LONGITUDE
            Datatype:   double
            Attributes:
                        long_name                   = 'Mooring anchor
longitude'
                        standard_name               = 'longitude'
                        units                       = 'degrees_east'
                        valid_min                   = -122.7786
                        valid_max                   = -122.2967
                        reference                   = 'WGS84'
                        coordinate_reference_frame =
'urn:ogc:crs:EPSG::4326'
                        uncertainty                 = 0.01
                        axis                        = 'X'
                        comment                     = 'position at start
of cast'
    PRESS
            Size:       548x1
            Dimensions: DEPTH
            Datatype:   double
            Attributes:
                        coordinates   = 'DEPTH LATITUDE LONGITUDE'
```

```
                    long_name     = 'sea water pressure'
                    standard_name = 'sea_water_pressure'
                    units         = 'dbar'
    TEMP
           Size:       548x158
           Dimensions: DEPTH,TIME
           Datatype:   double
           Attributes:
                       long_name       = 'sea water temperature'
                       standard_name   = 'sea_water_temperature'
                       units           = 'degree_C'
                       coordinates     = 'TIME DEPTH LATITUDE
LONGITUDE'
                       reference_scale = 'ITS-90'
                       valid_min       = 5
                       valid_max       = 15
                       C_format        = '%.5g'
    PSAL
           Size:       548x158
           Dimensions: DEPTH,TIME
           Datatype:   double
           Attributes:
                       long_name       = 'sea water practical salinity'
                       standard_name   = 'sea_water_practical_salinity'
                       units           = '1'
                       coordinates     = 'TIME DEPTH LATITUDE
LONGITUDE'
                       reference_scale = 'PSS-78'
                       valid_min       = 32
                       valid_max       = 35
                       comment         = 'In-situ measurement; PSS-78.'
                       C_format        = '%.4g'
    CNDC
           Size:       548x158
           Dimensions: DEPTH,TIME
           Datatype:   double
           Attributes:
                       coordinates   = 'TIME DEPTH LATITUDE LONGITUDE'
                       long_name     = 'sea water conductivity'
                       standard_name =
'sea_water_electrical_conductivity'
                       units         = 'S/m'
    SIGMAt
           Size:       548x158
           Dimensions: DEPTH,TIME
           Datatype:   double
           Attributes:
                       coordinates   = 'TIME DEPTH LATITUDE LONGITUDE'
                       long_name     = 'density'
                       standard_name = 'sea_water_sigma_t'
                       units         = 'kg m-3'
    SIGMA
           Size:       548x158
           Dimensions: DEPTH,TIME
           Datatype:   double
           Attributes:
                       coordinates   = 'TIME DEPTH LATITUDE LONGITUDE'
```

```
                       long_name     = 'potential density relative to 0
dbar'
                       standard_name = 'sea_water_potential_density'
                       units         = 'kg m-3'
    DYNHT
           Size:       548x158
           Dimensions: DEPTH,TIME
           Datatype:   double
           Attributes:
                       coordinates = 'TIME DEPTH LATITUDE LONGITUDE'
                       long_name   = 'dynamic height (thermosteric)'
                       units       = 'm'
    th_a400
           Size:       158x1
           Dimensions: TIME
           Datatype:   double
           Attributes:
                       coordinates = 'TIME LATITUDE LONGITUDE'
                       long_name   = 'dynamic height relative to 400m'
                       units       = 'm'
    trackdist
           Size:       158x1
           Dimensions: TIME
           Datatype:   double
           Attributes:
                       coordinates = 'TIME LATITUDE LONGITUDE'
                       long_name   = 'cumulative distance between
casts'
                       units       = 'km'
    GPAnom
           Size:       548x158
           Dimensions: DEPTH,TIME
           Datatype:   double
           Attributes:
                       coordinates = 'TIME DEPTH LATITUDE LONGITUDE'
                       long_name   = 'geopotential anomaly'
                       units       = 'm'
```

Appendix B: EM/APEX Data Files

EM/APEX data are also provided in NetCDF format.

EM-APEX File Metadata (output of "ncdisp" command in Matlab):

```
>> ncdisp AirSWOT_EMAPEX_ALL_PROFILES.nc
Source:

/Users/girton/Projects/SWOT/AirSWOT/report/AirSWOT_EMAPEX_ALL_PROFILES.
nc
Format:
           netcdf4_classic
Global Attributes:
```

```
           Created by       = 'Byron F. Kilbourne'
           Creation date    = '01-Oct-2015 15:51:21'
           Data description = 'Gridded [2 m] horizontal currents,
Temperature, and Salinity from EM-APEX used in AirSWOT'
Dimensions:
           rows    = 1000
           columns = 126
Variables:
    S
           Size:       1000x126
           Dimensions: rows,columns
           Datatype:   single
           Attributes:
                       description = 'salinity'
                       units       = 'PSU'
    T
           Size:       1000x126
           Dimensions: rows,columns
           Datatype:   single
           Attributes:
                       units       = 'deg C'
                       description = 'in-situ temperature'
    U
           Size:       1000x126
           Dimensions: rows,columns
           Datatype:   single
           Attributes:
                       units       = 'm s^-1'
                       description = 'corrected east velocity'
    V
           Size:       1000x126
           Dimensions: rows,columns
           Datatype:   single
           Attributes:
                       units       = 'm s^-1'
                       description = 'corrected north velocity'
    time
           Size:       1000x126
           Dimensions: rows,columns
           Datatype:   double
           Attributes:
                       units               = 'days'
                       reference date-time = '0000 1 Jan 0'
                       description         = 'matlab serial time'
    UBS
           Size:       126x1
           Dimensions: columns
           Datatype:   single
           Attributes:
                       units       = 'm s^-1'
                       description = 'east component, correction
velocity determined from GPS positions, included in corrected east
velocities'
    VBS
           Size:       126x1
           Dimensions: columns
           Datatype:   single
```

```
            Attributes:
                        units       = 'm s^-1'
                        description = 'north component, correction
velocity determined from GPS positions, included in corrected north
velocities'
    LON
            Size:       126x1
            Dimensions: columns
            Datatype:   single
            Attributes:
                        units       = 'decimal deg'
                        description = 'surface position from GPS'
    LAT
            Size:       126x1
            Dimensions: columns
            Datatype:   single
            Attributes:
                        units       = 'decimal deg'
                        description = 'surface position from GPS'
    FLID
            Size:       126x1
            Dimensions: columns
            Datatype:   int16
            Attributes:
                        data type = 'Float serial number'
    depth
            Size:       1000x1
            Dimensions: rows
            Datatype:   single
            Attributes:
                        units = 'm'
```

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16. Abstract (Limit: 200 words)

AirSWOT is an aircraft mounted instrument for measuring and imaging sea surface height (SSH), and it is similar to the SWOT (Surface Water Ocean Topography) instrument that will be deployed on a satellite in 2020. A field campaign was conducted in April 2015 to examine the performance of AirSWOT and to better understand how the measurement is affected by surface waves and currents. Supporting measurements were collected from the R/V Shana Rae, the R/V Fulmar, and a second aircraft (a Partenavia P68 operated by Aspen Helicopter, Oxnard,CA for UCSD/SIO). >From 17-20 April 2015, the R/V Shana Rae, a 50-foot research vessel, was used for collection of Underway CTD (or UCTD) measurements and for deployment and recovery of three EM/APEX floats in a study area off the central California coast. The UCTD measurements are being used to estimate the sea surface height signal associated with variations in ocean density structure. The EM/APEX floats provide time series of the same, as well as vertical profiles of ocean velocity. The purpose of this report is to document the shipboard operations on the R/V Shana Rae and the resulting UCTD and EM/APEX data sets.

17. Document Analysis a. Descriptors

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Cruise Report

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