Short evaluation of GusT progress to end of 2016

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ABSTRACT

This document is short and not intended to be polished. If you simply look at the pictures, you will get the main science/engineering points. But please read the action items. The purpose of this document is to:

- report progress to date based on a series of at-sea tests in 2016
- provide rough plan for May 2017 tests on Oregon shelf
- request assistance from the group to identify exact platforms/locations for GusT in Pt Sal experiment in 2017
- make recommendations for Tmoor buoyancy element depths and anchor weights for Pt Sal experiment

1. Objectives of this program

At this writing (20 December 2016), we have about 20 working, low noise GusTs and a plan to complete 80 units, including testing and calibration, by late spring 2017. We have deployment strategies for bottom landers, moorings, towed miniBat and profiler. We are pretty sure we can derive meaningful, quantitative estimates of flow speeds, temperature and turbulence quantities in water depths of at least 25 m under strong wave forcing conditions. To date, we are not so sure about depths < 25 m.

2. Field tests to date

Field testing has included:

1. mounting 2 units on pivoting bases in OSU’s Hinsdale Wave Tank in June 2016 (with help from Prof. Pedro Lomonaco, Civil Engineering). This helped us to get a first assessment of both GusT signals and of the pivoting response in a surface wave field. It pointed out the phase lag between changes in wave direction and how well our pivot turned sensors into the instantaneous flow direction.

2. Monterey Bay tests, July 2016. John Colosi (with help from Paul Jessen and Marla Stone, NPS and Kerry Latham, OSU) deployed 2 GusTs and 1 χpod on a mooring in 20 m water depth. A short report was issued and is temporarily available here (http://mixing.coas.oregonstate.edu/temp/InnerShelf/). This led to further improvements in our analog electronics as well as our use of our tilt-compensated compass chip that provides orientation information.

3. mounting 2 units in shallow water off Scripp’s pier. This was done thanks to Falk Fedderson and group. One unit failed to record data. We have yet to fully assess the data from the 2nd unit.

4. tests on bottom lander, T mooring and towed body (miniBat) over Oregon shelf in September 2016.
These tests provided considerable guidance to processing the fast temperature and pitot-static tube data from GusT in challenging situations. An expanded discussion of results and challenges is the focus of this report.

5. Further tests in Monterey Bay, October 2016. This was an add-on to a class exercise developed by Jamie MacMahan (NPS). Three moorings were deployed in 10, 15, 20 m water depth. Buoyancy elements 1 m below the surface were weighted by 200# anchors. They all walked during strong wave forcing, at low tide. Jamie may have more to say about this, esp. if I have a detail incorrect. The lesson from this was that we will have to ensure both sufficient depth of subsurface elements and sufficient anchor weights. During a period of stronger forcing off Oregon, moorings with subsurface buoyancy at 3 m depth and 670# anchor also walked.

6. As of early December, 2016, one unit is at APL/UW with Jim Thomson’s group ready for testing on a Swift drifter in Lake Washington.

3. Summary of OR shelf tests - 23-26 September 2016

Test experiments out of Newport on R/V Oceanus were done to evaluate mounting strategies on a bottom lander (sea spiders), relatively taut mooring (120# subsurface buoyancy with 670# anchor weight), a towed vehicle (miniBat) and a profiler.

![Fig. 2. Photo of Sea Spider bottom lander outfitted with 1200 kHz ADCP (courtesy MacKinnon/Waterhouse, SIO), high resolution Pressure Pod (on the left bracket) and a pivoting GusT. The GusT is mounted on a U-joint that is weighted below to ensure the UP axis orientation aligns with gravity. Note the GoPro video camera and flashlight in front of the ADCP head. The videos were helpful in defining the pivoting phase lag relative to surface wave orbitals (photo courtesy Kerry Latham).](image-url)

![Fig. 3. Comparison of speeds and velocities derived from GusT and ADCP on sea spider 1 m above the seafloor (as in figure 2) in 30 m water depth. 10 minute averages. a,b) flow directions. c) time series of u, v velocities. d,e) direct comparison of speeds as 2D and 1D histograms](image-url)

The sea spider was instrumented with 1200 kHz ADCP, high-resolution pressure sensor and GusT (figure 2). It was deployed along with slack ground line to bottom clump weight with extension to surface flag/reflector/flasher used for recovery. ADCP and GusT were both mounted with weighted U-joints, or gimbals, to maintain vertical orientation.

A basic comparison of speeds and velocities from the co-mounted Gust pitot-static tube (Moum 2015) and ADCP is shown in figure 3. The measurement volumes, depths and physics are fundamentally different. Without going into details here, the agreement is pretty good. Further evaluations are ongoing.

When background currents are > surface wave orbital speeds, the horizontal angle of attack of the pivoting GusT is modulated within a quadrant. The worst case scenario occurs when background currents are 0, and GusT pivots 180°. The GusT pivot cannot perfectly respond on surface wave orbital time scales when background currents are weak or 0. Fortunately the velocity estimate from the
pitot-static tube has cosine response (± 15°). To deal with this problem in extracting spectral estimates, we identify 2 s periods when GusT points into the instantaneous flow (figure 4), compute mean speed and spectrum over that period from which inertial subrange fitting yields our estimate of $\varepsilon$. Time series of $\varepsilon$ indicate values within the range seen in bottom boundary layers elsewhere during the propagation of internal solibore-like features (Moum et al. 2007; Perlin et al. 2005b).

b. GusT on mooring - with help from Jim Lerczak, Amy Waterhouse and Paul Chua

We deployed the mooring (figure 6) about 500 m away from the sea spider and in deeper water (spider at 30 m, mooring at 36 m). The mooring included GusT and χ-pod units and was deployed off Beverly Beach, OR in September 2016. The mooring locations and sensor deployments are shown in figure 6. Time series from the mooring are shown in figure 7. The mooring was deployed with a 1200 kHz ADCP on lander (which was deployed 500 m away in 30 m water depth). Speeds measured at GusT, χ-pod depths and compared to lander ADCP 500 m away and averaged over the range of pitot-static tube depths. c) time series of $\varepsilon$. 

![Graph of Sample Spectrum](image1.png)

FIG. 4. Sample spectrum from pitot-static tube sampled at 100 Hz on GusT mounted on sea spider. Over a 2 s period during which the pitot-static tube points directly into the instantaneous flow (± 15°), the mean speed is computed (a) and a wavenumber spectrum is estimated from the equivalent frequency spectrum. Scaling of the turbulence in the inertial subrange (red line in b) yield $\varepsilon$. The black line in b indicates the level of the $k^{-5/3}$ slope that best matches the measured spectrum.

![Graph of Time Series](image2.png)

FIG. 5. Time series at the sea spider 1 m above seafloor in 30 m water depth. a) temperature. b) velocities. c) turbulence kinetic energy dissipation rate, $\varepsilon$.

![Graph of Time Series from Mooring](image3.png)

FIG. 7. Time series from the mooring shown in figure 6. a) image plot of $T$ derived from the full set of $T$ sensors on the mooring. Locations of GusTs and χ-pods are denoted by the colored lines. b) Line plots of $T$ from GusTs and χ-pod. c) image plot of onshore velocity from 1200 kHz ADCP on lander (which was deployed 500 m away in 30 m water depth). d) Speeds measured at GusT, χ-pod depths and compared to lander ADCP 500 m away and averaged over the range of pitot-static tube depths. e) time series of $\varepsilon$. 

![Diagram of Mooring](image4.png)

FIG. 6. Mooring deployed in 36 m water depth off Beverly Beach, OR in September 2016. GusT and χ-pod units are denoted by the blue font (drawing courtesy of Amy Waterhouse).
mooring at 36 m). We combined the velocity record from the lander and the temperature/speed/ε records from the mooring imperfectly by shifting in time so that bore arrivals roughly match (figures 7, 8). Comparisons of speeds are rough (because measurements are not co-located) but indicate features agree. ε estimates are in line with expectations.

The dominant signature in this record is the arrival of 2 bores, separated roughly by an M2 tidal period. These show the classic signature of undular bores and suggest that nonlinear internal waves (solitary waves) have escaped from the bores and propagate ahead.

c. GusT on miniBat - with help from Jack Barth and Marnie Jo Zirbel

Twin GusTs were mounted on the towed miniBat (figure 9). The body was towed at speeds of 4-5 kts oriented roughly N and S in reversing paths along the coast on 24 September 2016, at the end of a windy day. Over a 3 1/2
h period, more than 50 tow-yos were executed over the 30 m deep water column. A comparison of speeds estimated from the two units is shown in figure 10. These 2 independent speed measurements agree. We take this as a verification of both our calibration techniques and of our analysis method to compute speed.

A summary of the 3 sets of measurements discussed in sections 3a,b,c is shown in figure 11. These are averages of \( \varepsilon, \chi \) and \( N^2 \) (sort of, since this estimate is solely from GusT \( T, N^2 = g \alpha T_z \)). These combine the vertical profiles from the miniBat GusTs with averaged values over the same time period from 5 depths on the mooring (3 GusTs, top and bottom \( \chi \)pod sensors) as well as the bottom lander. These are not colocated but offer a broad view of the mixing over the shelf in that time period. The upper 10 m was vigorously mixing. The miniBat estimates of \( \varepsilon, \chi \) decreased below 10 m to values that merge with averaged values from the mooring. The bottom boundary layer estimates are considerably larger, as we expect.

d. GusT on profiler

![Fig. 12. Byungho Lim with profiler version of GusT / September 2016 R/V Oceanus](image)

We also mounted a GusT in a mockup of our CHAMELEON turbulence profiler (figure 12). We deployed with a synthetic line on the TSE winch, allowing it to free fall and then recovered with the winch. This works fine in shallow water. At this point, we have not spent much time evaluating these data other than to see that it looks similar to what we expect from CHAMELEON.

4. Spring 2017 tests

We are presently on the schedule of R/V Oceanus for an 8d experiment 30 May - 07 June 2017. This will be our final opportunity to define deployment strategies before Pt Sal. Our plan is to densely instrument a line across the shelf at 45°N from about 150 m to 30 m water depths. This was the location of a series of measurements made in 2001 and 2003 as part of the COAST experiment (see Perlin et al. (2005a) figure 3). Previous measurements were made without such high-density of moored instrumentation and without moored mixing measurements provided by \( \chi \)pods and GusTs, which did not exist at the time.

Based on lessons learned from Monterey Bay and Oregon shelf deployments, the T moorings will have subsurface elements 10 m below low tide level, the idea being to get them below the most intense short wave orbitals excited by storms. Anchors will all be 700# (nominal). Lightweight \( T \) sensors (RBR Solo) will be deployed on slack lines above the subsurface floats to complete the high-density of sampling throughout the water column.

Following deployment, we will execute continuous transects across the line of moorings profiling the water column with CHAMELEON, ship adcp and high-frequency echosounder.

We are actively planning for the spring 2017 experiment now. Part of the plan is to outfit a range of bottom landers with GusT pivot mounts as in figure 2 as part of preparation for the Main Pt. Sal experiment.

5. Summary conclusions

Our tests have resulted in a range of data to evaluate. Using these data, we have developed analysis strategies to obtain speeds (and velocities using internal compass measurements) and turbulence quantities. We have a pretty good idea that this will work on bottom landers and moorings in water depths \( \geq 25 \) m.

6. Pt Sal Experiment

Because of the imperfect phase response of the GusT pivot mount to surface waves in shallow water, we have 2 new designs. As shown in figure 14, the 8 sensing heads do not pivot, eliminating the phase response problem. At the same time, it introduces the complexity of determining the instantaneous direction of the mean flow from multiple ports - this is the direction of maximum differential pressure. This unit will be tested in Spring 2017 and hopefully available for use in the Pt Sal experiment.

A 2nd design, based on a single sphere with 24 sensing ports in 8 coordinate directions, is on hold due to potential personnel changes. It is a more elegant but internally complicated design.

We have yet to identify specific platforms for Pt. Sal deployments.
Fig. 13. Mooring plan for 2017 test experiment over the continental shelf at 45°N off Cascade Head, OR.

Fig. 14. Conceptual design for 8-component GusT.

7. Action items

1. Recommendation for taut T moorings - 10 m subsurface buoyancy element, RR wheel anchor (700#).

2. Identify specific landers/moorings to target GusTs, χ pods. We should stick to depths ≥ 25 m.

3. Identify locations for 6 high-resolution pressure pods to go on fixed landers. These would likely best be used to detect time-dependent pressure differences, $\delta P(t)$

4. Tests ongoing to see if we can make useful measurements on Swift drifters. (Thomson/APL)

5. Develop plan to mount on Calantoni quad-pod.

6. Other?

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References


