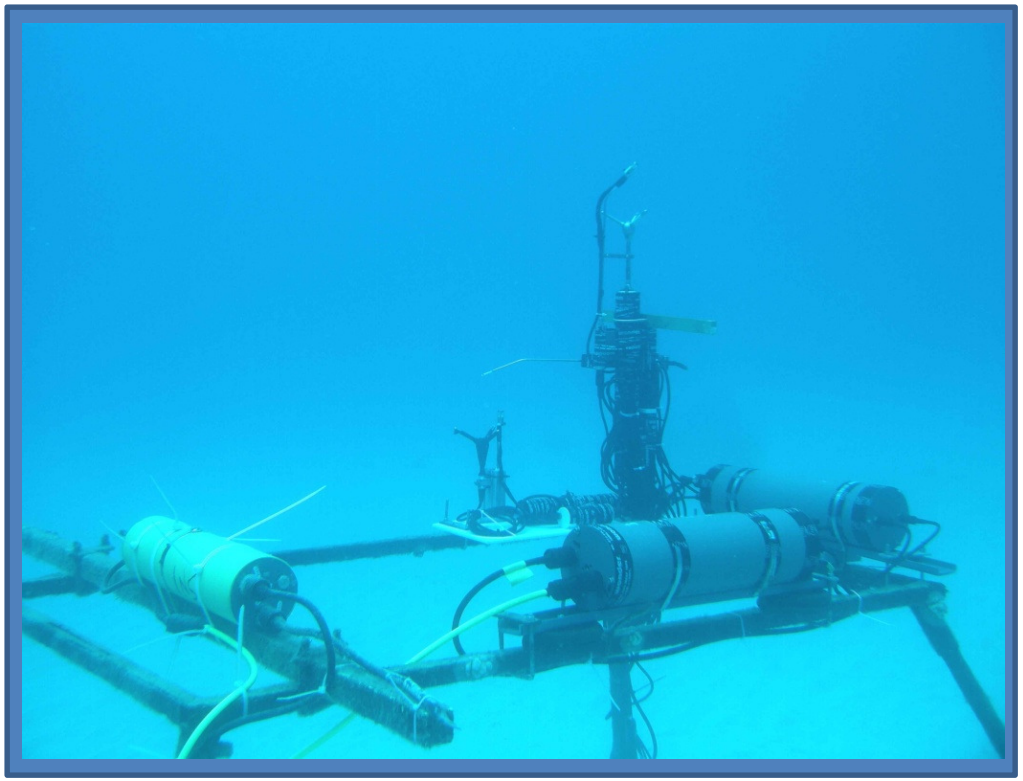
# Exploring wave bias removal methods for turbulence over rough topography



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Nortek USA Student Equipment Grant - 2009

***Nortek Users Conf. 2010***

***5/18/10***

NortekUSA

# Background/Motivation

- Hydrodynamics of turbulence in wave dominated flows
  - Extended Reynolds decomposition

$$u = \bar{u} + u' + \tilde{u}$$

Mean Turbulent Wave

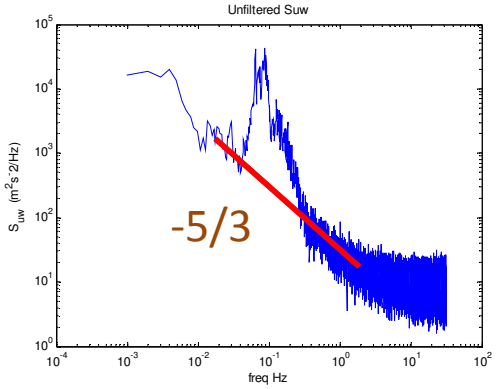
  - Turbulent Kinetic Energy Balance ( P ~ $\varepsilon$ )

$$\frac{Dk}{Dt} + \frac{\partial}{\partial x_i}\left[\frac{1}{2}\overline{u_i u_j u_j} + \frac{1}{\rho}\overline{u_i p} - 2\nu\overline{u_j s_{ij}}\right] = \underbrace{-\overline{u_i u_j}\frac{\partial \bar{U}_j}{\partial x_j}}_{P} \underbrace{- 2\nu\overline{s_{ij} s_{ij}}}_{\varepsilon}$$

  - Fluxes and net transport (i.e. Temperature, Salinity, Chl, or any scalar)

- Better estimates of Reynolds stresses, $\overline{u'w'}$

$$-\frac{\tau}{\rho} = \overline{\tilde{u}\tilde{w}} + \cancel{\overline{\tilde{u}w'}} + \cancel{\overline{u'\tilde{w}}} + \overline{u'w'}$$




- Improvement on coastal transport models
- Extension to turbulence in stratified environments

# Existing Methods

Several Techniques to choose from:

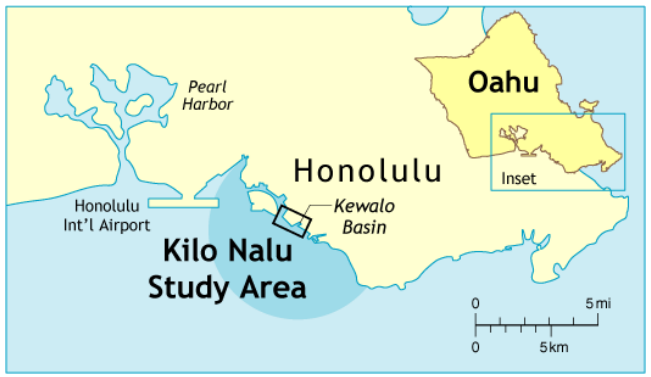
- **Vertical wave correlation** (Trowbridge, 1998; Shaw and Trowbridge, 2001; Fedderson and Williams, 2007
  - Separated velocimeters share correlated wave velocities but uncorrelated turbulence velocities
- **Bottom pressure** (Benilov and Filyushkin, 1970)
  - Correlations between pressure and velocity used to remove wave component
- **AWAC Surface Tracking with directionality**
  - Correlations between surface wave height, direction, and velocity used for bias removal
- **Phase Aided Wave-Turbulence Decomposition** (Bricker and Monismith, 2007)
  - Single velocimeter time series decomposed keeping phase component in Fourier coefficients

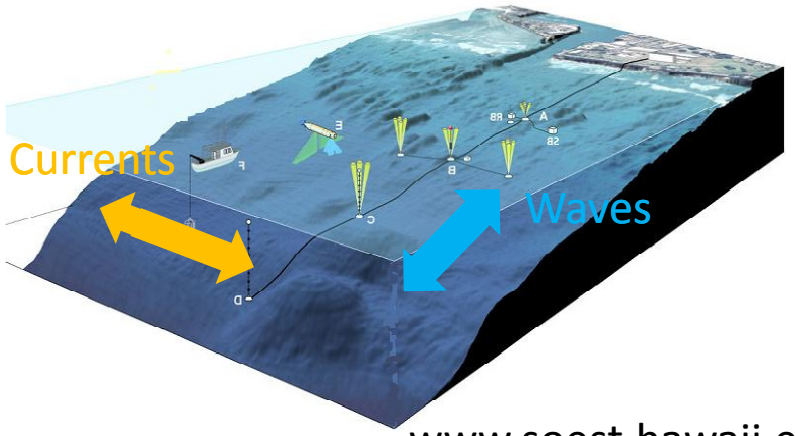
# Field Site Description

- UH Kilo Nalu Observatory, Mamala Bay, HI
  - South Shore of Oahu
  - 12m depth site, data streamed continuously to shore lab

- **August 26th -30th 2009**
  - Wave- Current conditions (August 28th)
    - Wave height: 0.65m (avg)
    - Mean Current: 0.04 m/s (avg)
    - Max Current: 0.19 m/s
    - Peak period: 11.77 s

- **Feb 11th - Mar 12th, 2010**
  - -- Wave- Current conditions (Feb 28th)
    - •Wave height: 0.46m (avg)
    - •Mean Current: 0.07 m/s (avg)
    - •Max Current: 0.18 m/s
    - •Peak period: 9.28 s

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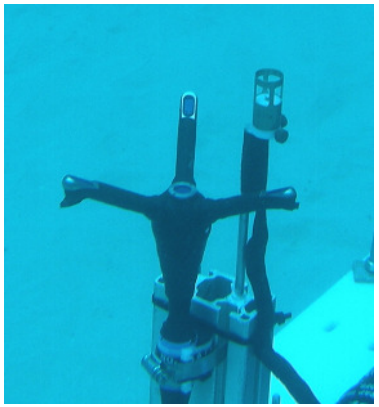
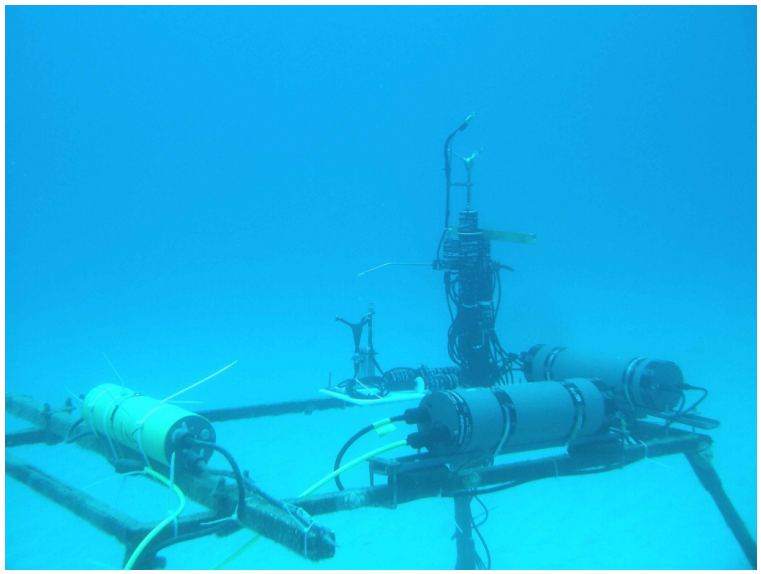
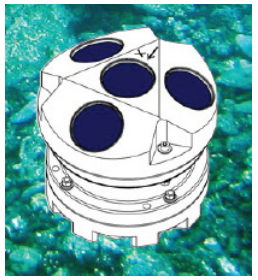
# Experimental Setup

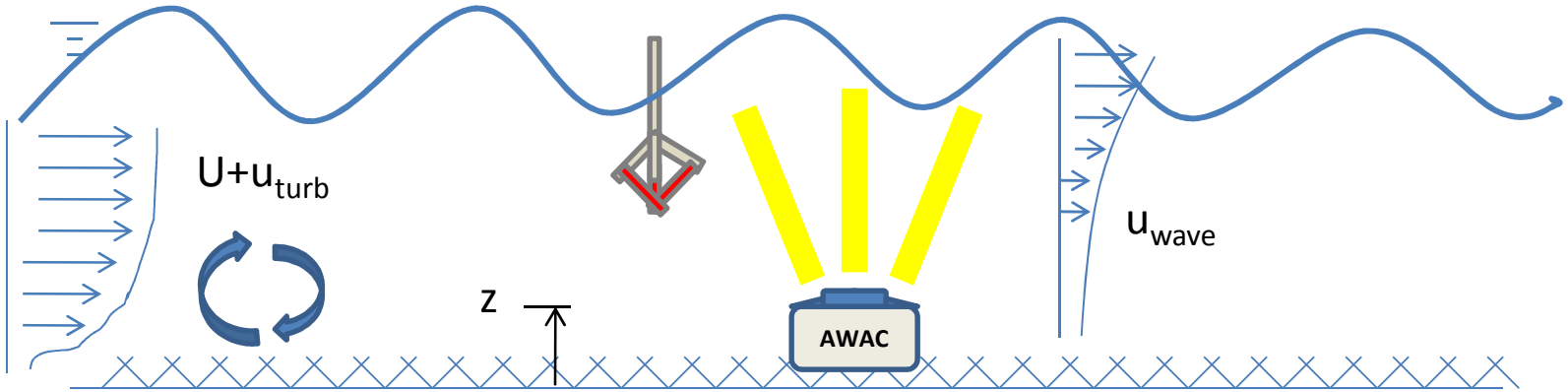
- Two Nortek ADV's deployed vertically staggered [Cabled to Shore]
  - lower (2.15 mab), upper (2.85 mab)
    - spacing/elevation = 0.32 (m/m)
  - Sampling at 64Hz
  - Equipped with PME Fast CT and OSU Chi node (fast T)
- AWAC mounted on bottom plate [Autonomous]
  - 17 min wave sampling bursts every 21 minutes.
  - 4-beam 1 MHz ADCP (Wave Mode)
    - 3 beams sampling current
    - 1 beam directly to surface
    - Pressure sensor
  - Acoustic Surface Tracking (AST) Mode
    - Center beam pings surface displacement (1mm accuracy)
    - Other beams measure near surface "orbital" velocities







# AWAC Bias Removal Method




- Surface displacement and wave velocities linearly related

$$\tilde{u} = \int_{-\infty}^{\infty} L_x(\alpha)\eta_x(t-\alpha)\,d\alpha = L_x(t) * \eta_x(t) \qquad S_{\tilde{x}\tilde{y}} = L_x(f)L_y{}^*(f)S_{\eta_x\eta_y} \qquad S_{\tilde{x}\tilde{y}} - \frac{S_{x\eta_y}(f)S_{y\eta_x}(f)}{S_{\eta_x\eta_y}(f)}$$

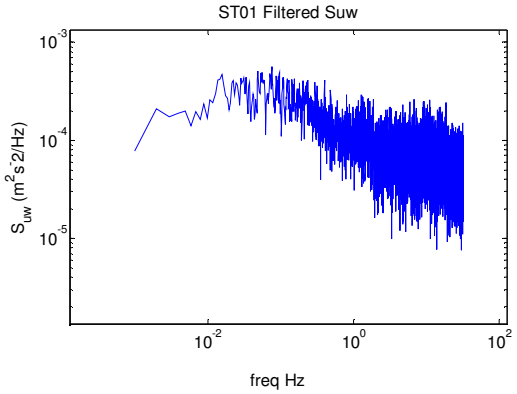
- Directionality is determined by surface wave orbital velocities
- Predicted linear wave velocities are subtracted from velocity spectra in frequency domain

$$S_{x'y'} = S_{xy} - S_{\tilde{x}\tilde{y}}$$

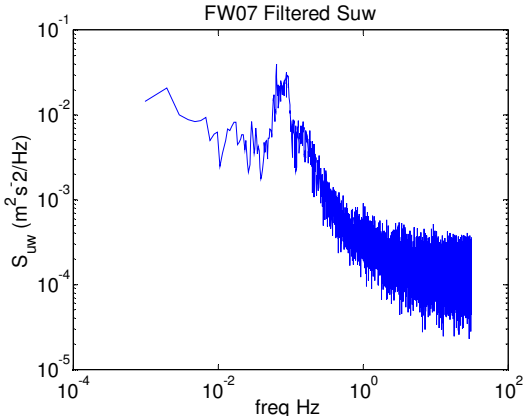
$$\overline{u'w'} = \int_{-\infty}^{\infty} S_{x'y'}(f)df$$

# Results: Existing Methods

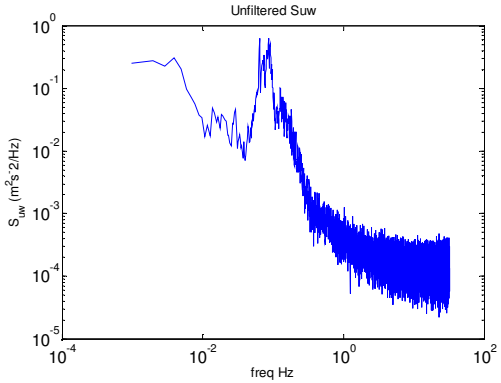
## Shaw Trowbridge, 2001



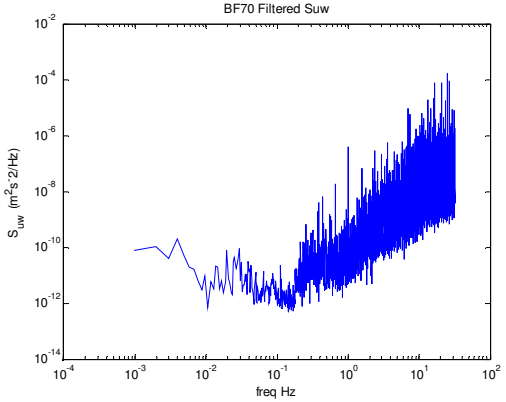

## Fedderson and Williams, 2007



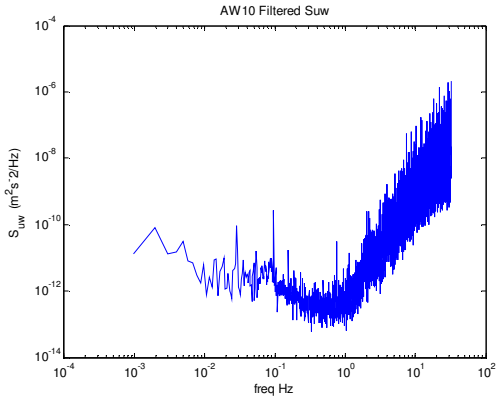

## Unfiltered




## Benilov and Filyushkin , 1970



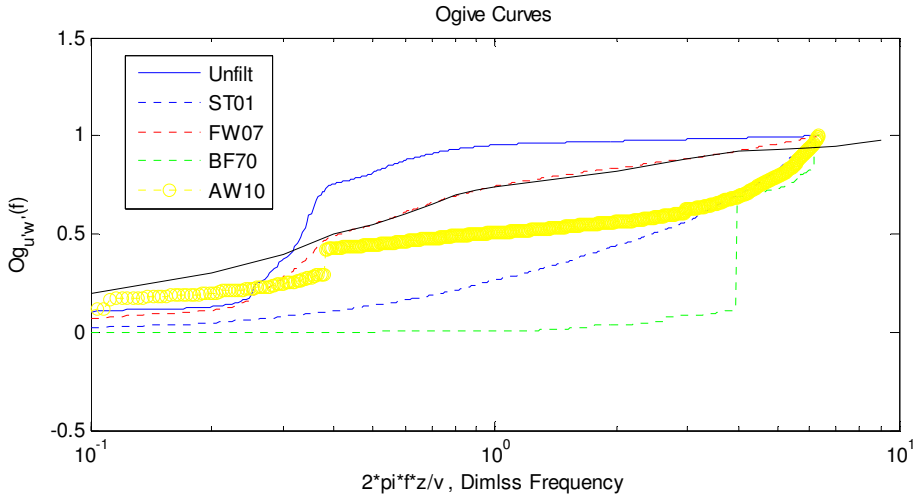

## AWAC, 2010



# Evaluation (Ogive curves)

- Use Ogive Cospectra curves to assess the success of the removal
- Compare to theoretical Kaimal et.al. (1972)

$$Og_{u'w'}(f) = \frac{\int_0^f Co_{u'w'}(\hat{f})d\hat{f}}{\overline{u'w'}}$$



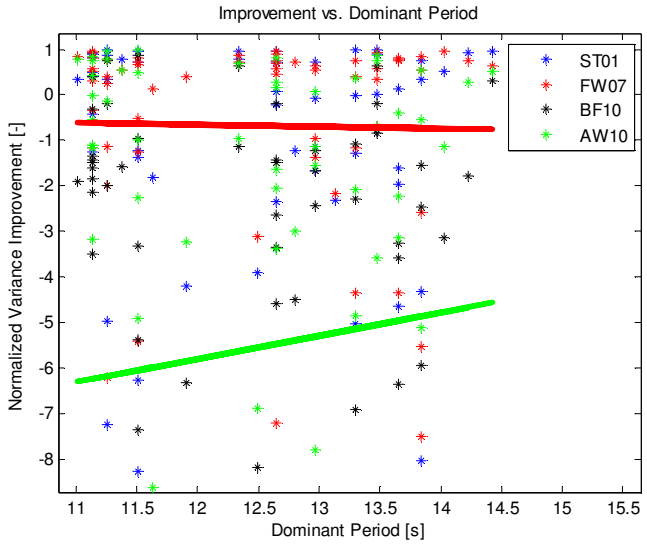

# Comparison

- Clear advantages to using FW07
- Each suited to a different system/experiment
- Environment changes throughout the time series

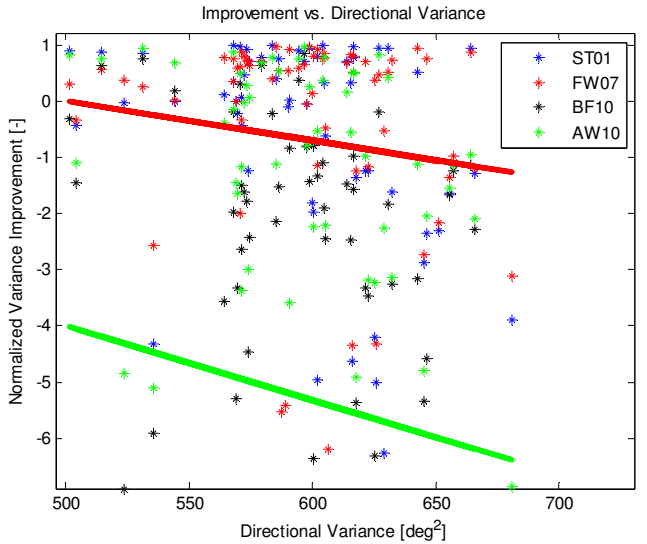
| | Unfilt | ST01 | FW07 | BF70 | AW10 |
|---|---|---|---|---|---|
| *1st* | 22.06% | 32.35% | 33.82% | 0.00% | 8.82% |
| *2nd* | 13.24% | 22.06% | 35.29% | 4.41% | 22.06% |
| *3rd* | 16.18% | 32.35% | 22.06% | 5.88% | 25.00% |
| *4th* | 36.76% | 8.62% | 8.82% | 10.29% | 36.76% |
| *5th* | 10.29% | 5.88% | 0.00% | 79.41% | 5.88% |

# Optimal Conditions for AWAC Removal Method

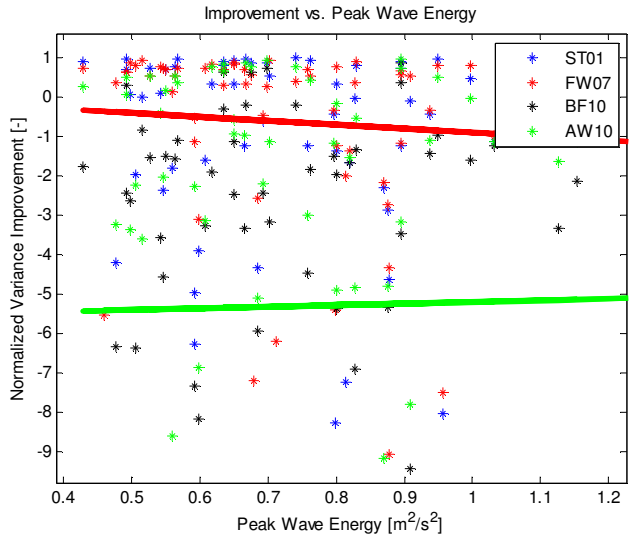
## Improvement vs. Dominant Period



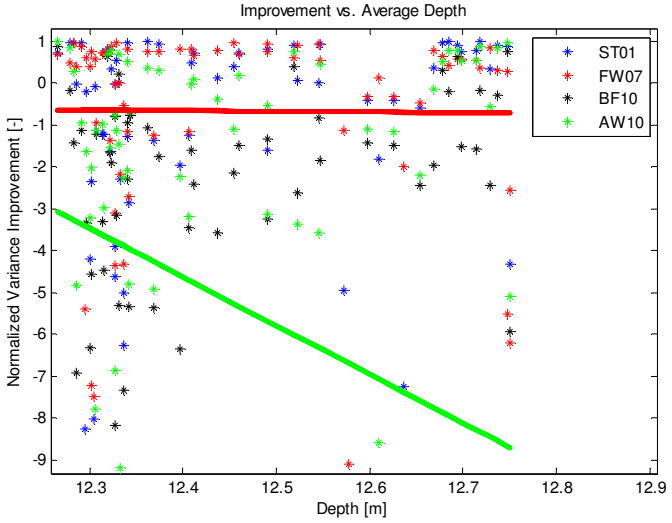

## Improvement vs. Directional Variability




## Improvement vs. Wave Energy




## Improvement vs. Water Depth



## Conclusions

- AWAC removal method distinct improvement over Benilov, 1970
- Best results come from Fedderson and Williams, 2007
- Success of wave removal depends on conditions
- Gain rough understanding of optimal conditions for AWAC removal method

## Future Work

- Run AWAC at different depths or wavelength to depth ratios
- Estimates of Reynolds stress production and dissipation from spectra
- Vertical heat and salinity fluxes
- Shear interactions between top of mixed bottom boundary layer and gradually stratified column
- Dynamics of internal tide cold pulses to Kilo Nalu 20m site

# Acknowledgements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