AIR-SEA INTERACTION MEASUREMENTS FOR BUBBLE RELATED PROCESSES DURING THE RED EXPERIMENT

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MEASUREMENT PROGRAM

R/P FLIP:

- ***directional surface gravity wave spectra***
- ***bubble populations created by breaking waves***
- ***upper ocean currents***
- ***upper ocean temperature, salinity, dissolved gas levels***
- ***optical properties of the upper ocean***
- ***hyperspectral radiances (incoming and outgoing)***

LIGHT AIRCRAFT (use Seneca with T. Clarke's group):

- ***white cap kinematics and distributions***
- ***surface wave measurements using laser altimeter***

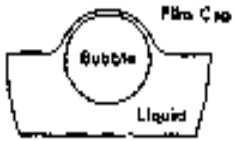
SMALL CRAFT OPERATIONS - WAILOA(coordinate with over-flights)

- ***Meteorological package***
- ***CTD casts***
- ***ocean turbulence package***
- ***surface waves and current measurements***
- ***hyperspectral radiometers***

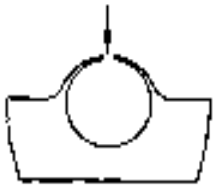
SHORE STATION

- ***Sonic Anemometer at Malekahana (T.Clarke's van)***

Bubble at Liquid Surface

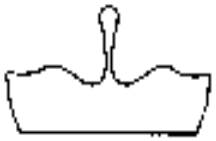


Hole Formation



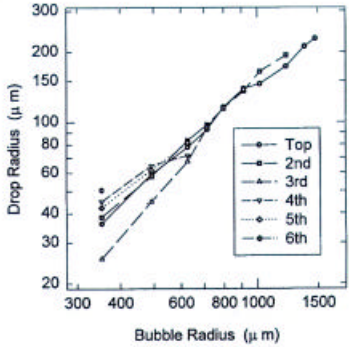
Rapidly Receding Film

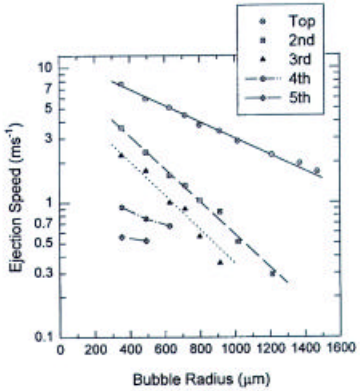
Rising Liquid Jet

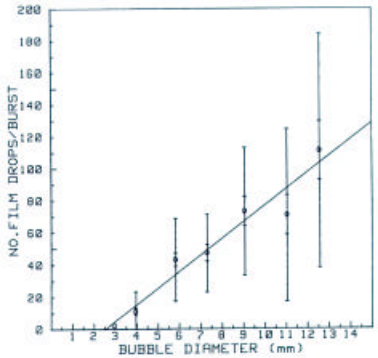


A component of aerosol generation is the process of oceanic bubbles bursting at the sea surface and ejecting small droplets. To leading order, the aerosol source term may scale with the fraction of the ocean's surface which is actively degassing bubbles. This will be proportional to the white cap coverage.

THE DROPLETS PRODUCED BY INDIVIDUAL BUBBLES







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The hydrodynamic mechanism of bubble rupture at the air-liquid interface

from Spiel 1999,

Wu 1994

INSTRUMENTATION DEPLOYED FROM R/P FLIP RED 2001

Surface meteorological package:

- barometric pressure
- air temperature
- relative humidity

Hull mounted temperature sensors

1 m

1.6 m

2.6 m

7 m

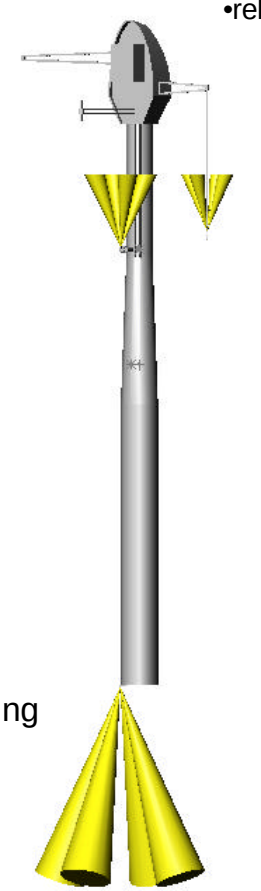
11.4 m

18.5 m

30 m

49 m

80 m



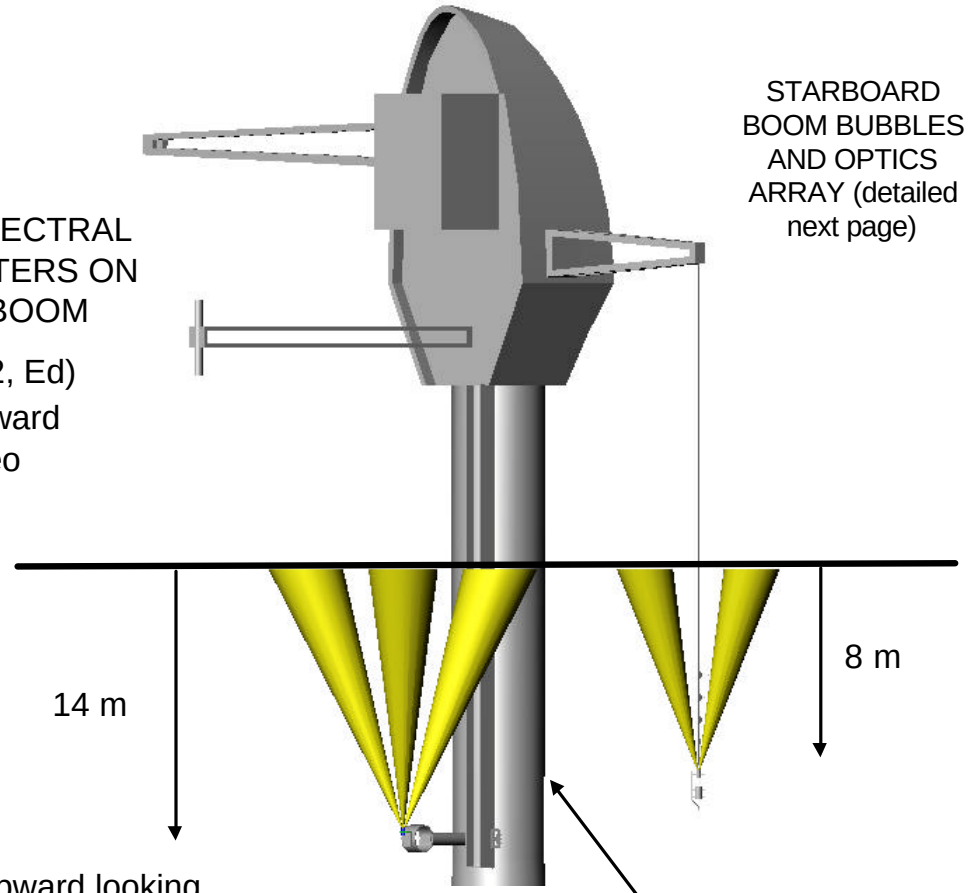
Downward looking 300kHz ADCP

HYPERSPECTRAL RADIOMETERS ON FACE BOOM

(Lw x 2, Ed)

Downward video

STARBOARD BOOM BUBBLES AND OPTICS ARRAY (detailed next page)



600kHz upward looking Doppler Sonar for directional waves, currents, and bubbles

7 m

CTD + total gas saturation level measurement

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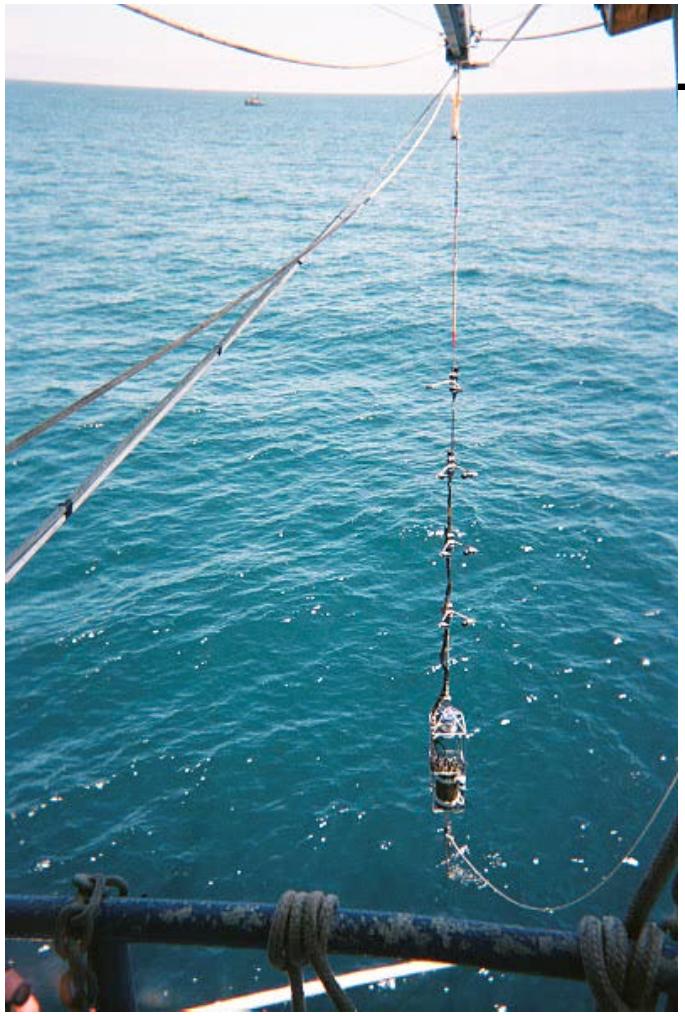
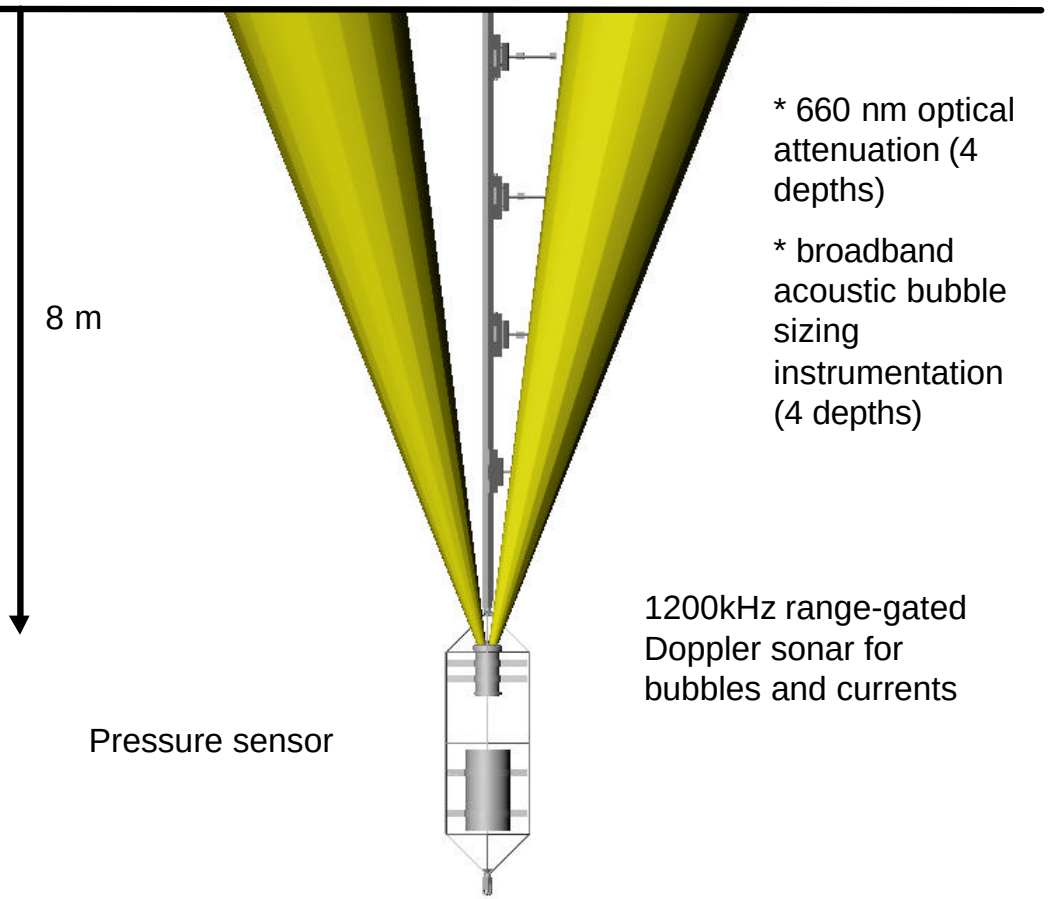
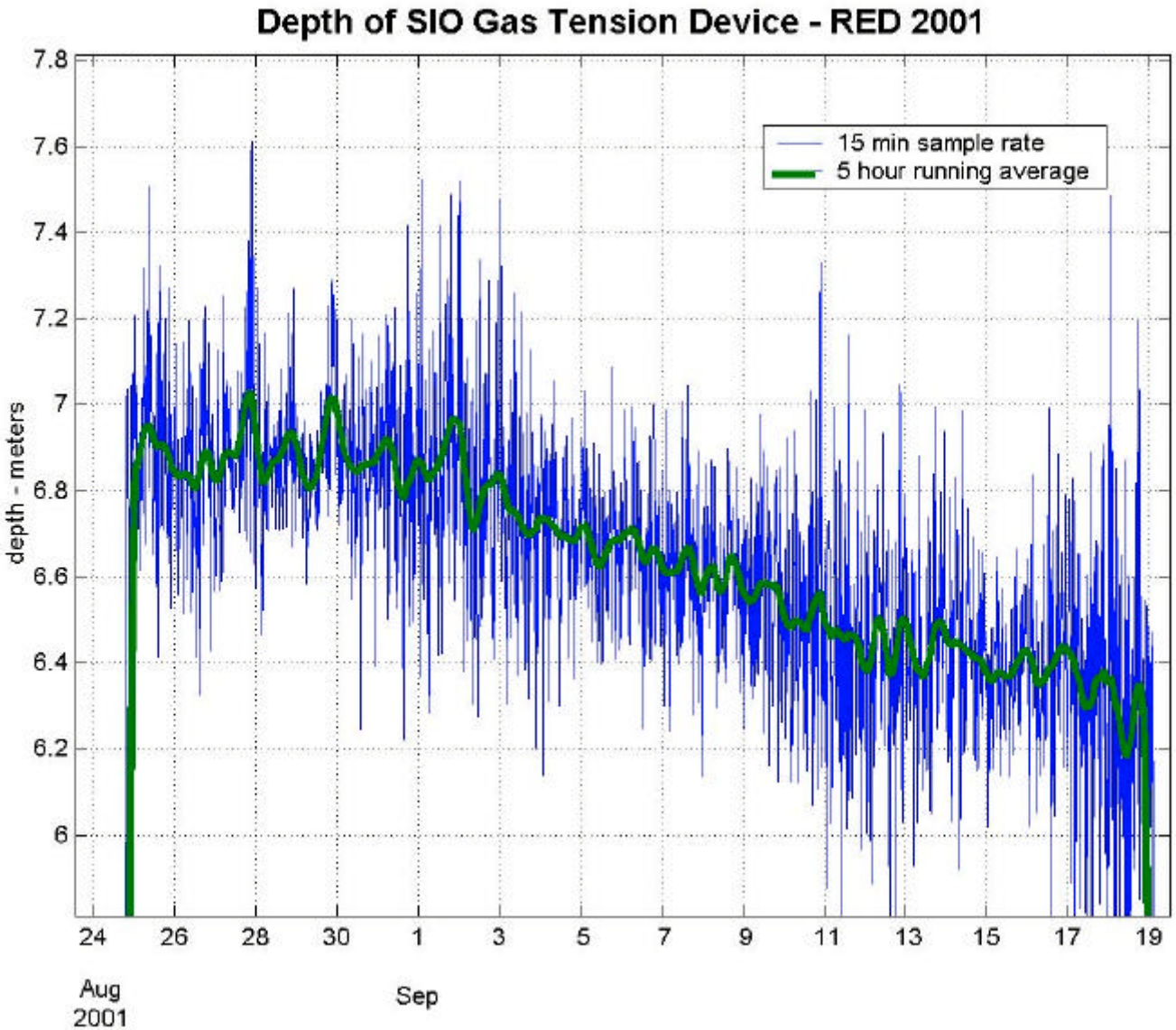
INSTRUMENTATION TO BE DEPLOYED FROM R/P FLIP AUG 20 - SEPT 18, 2001

STARBOARD BOOM BUBBLES AND OPTICS ARRAY





INDICATES FLIP's ELEVATION FROM MSL CHANGING OVER THE COURSE OF THE EXPERIMENT.



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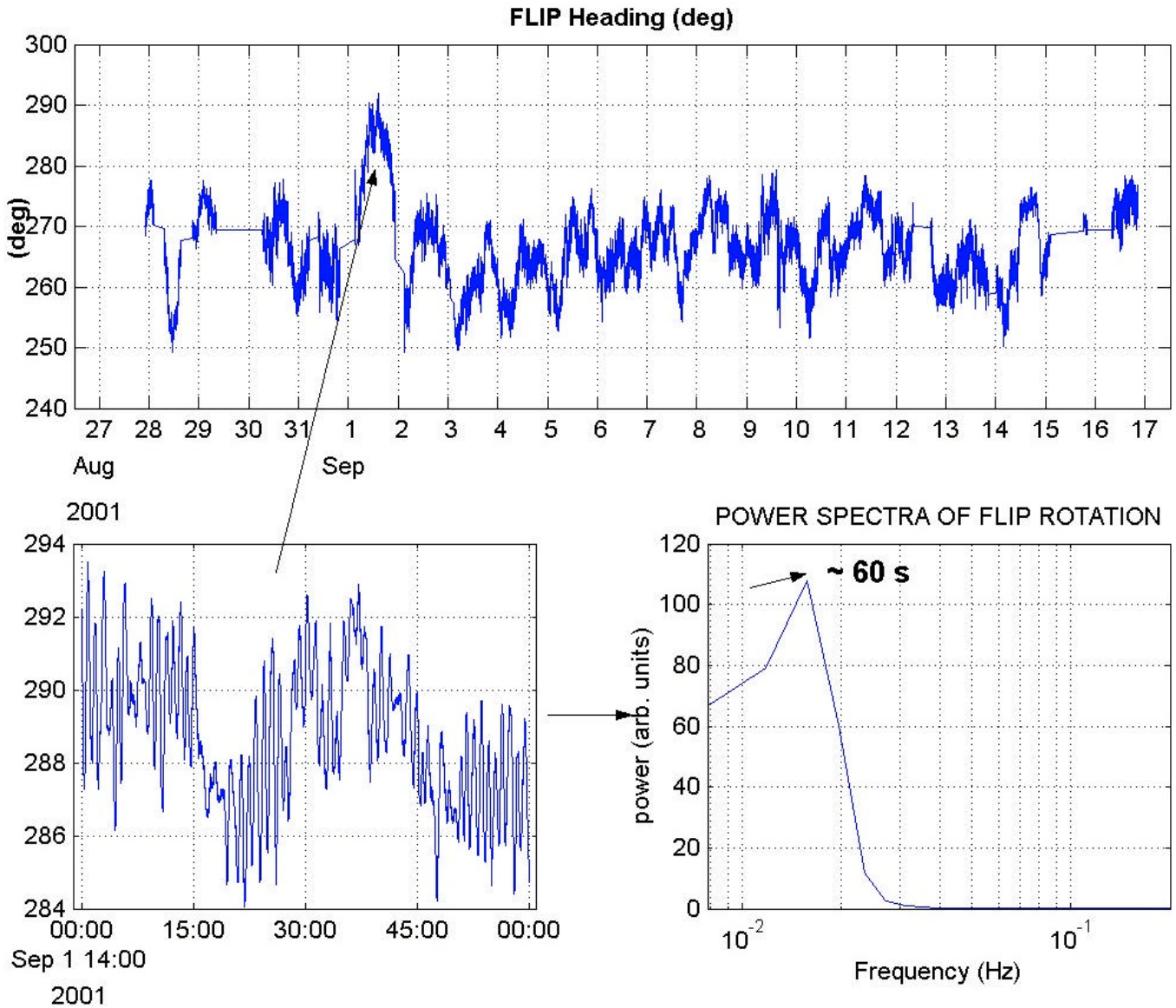
AZIMUTHAL MOTION OF FLIP, TRI-MOOR, 370m water depth



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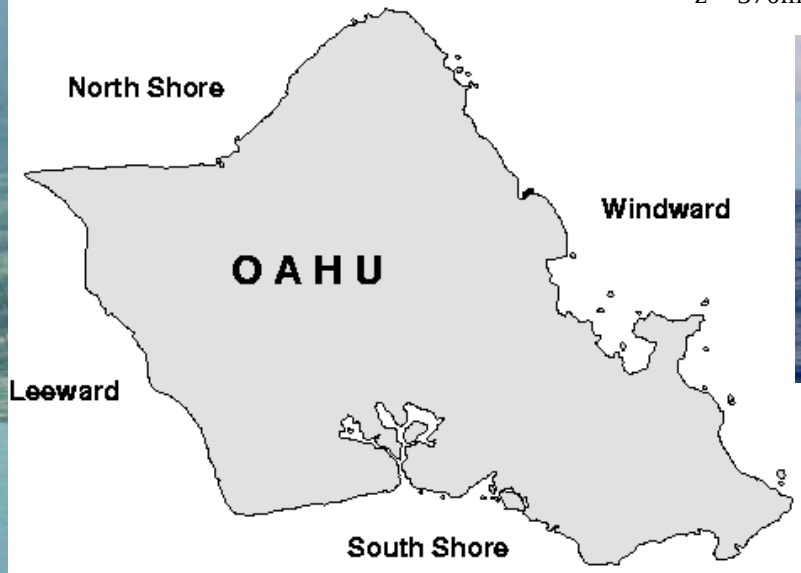
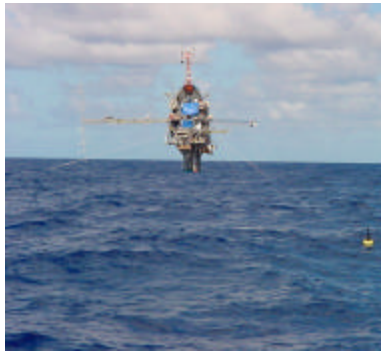
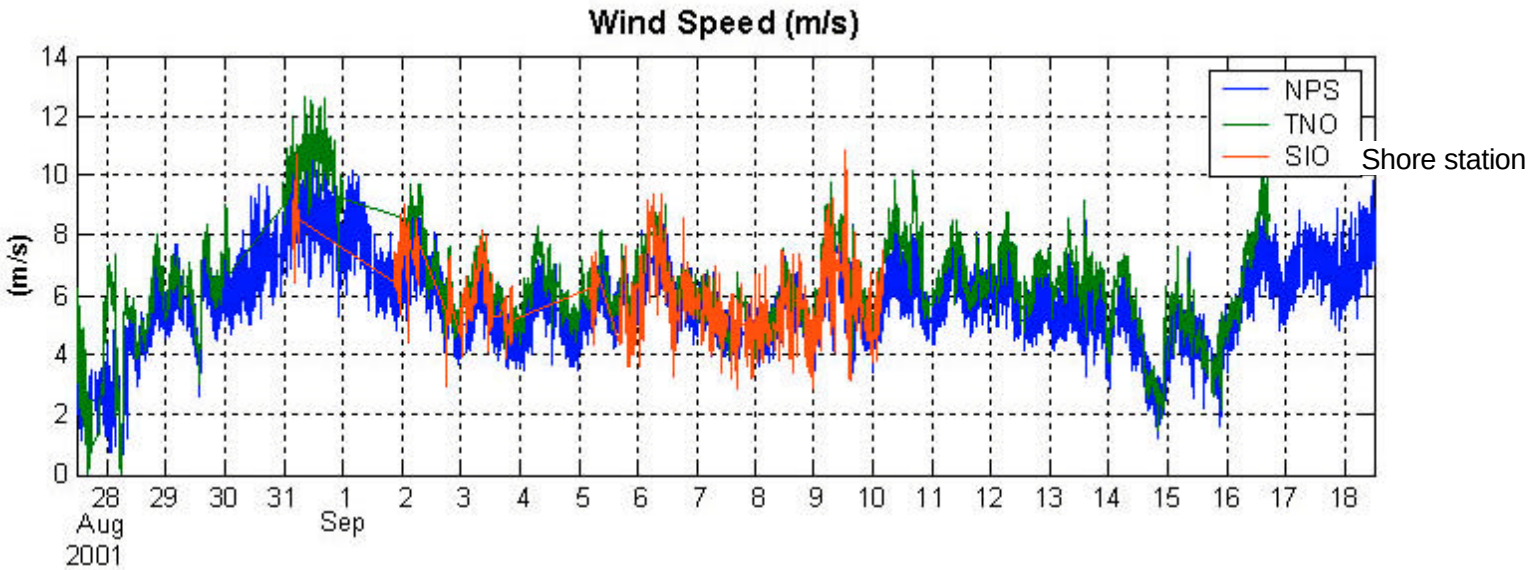
WIND DATA

- FLIP: 21°42.6’, 157°50.4’
  z = 370m







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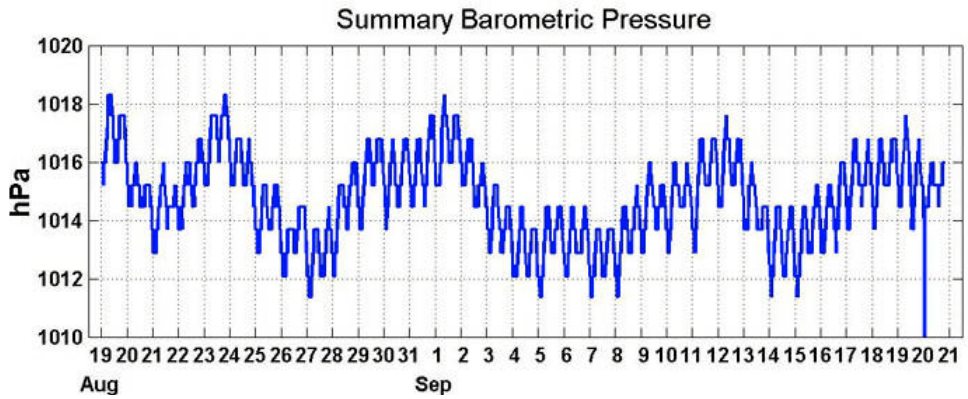
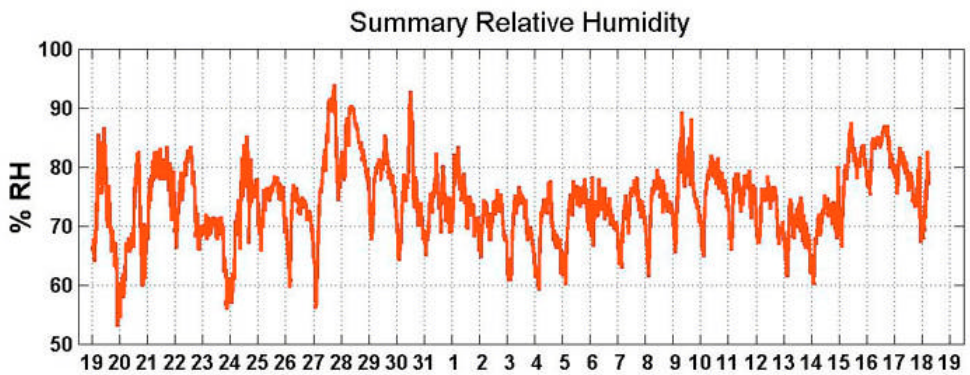
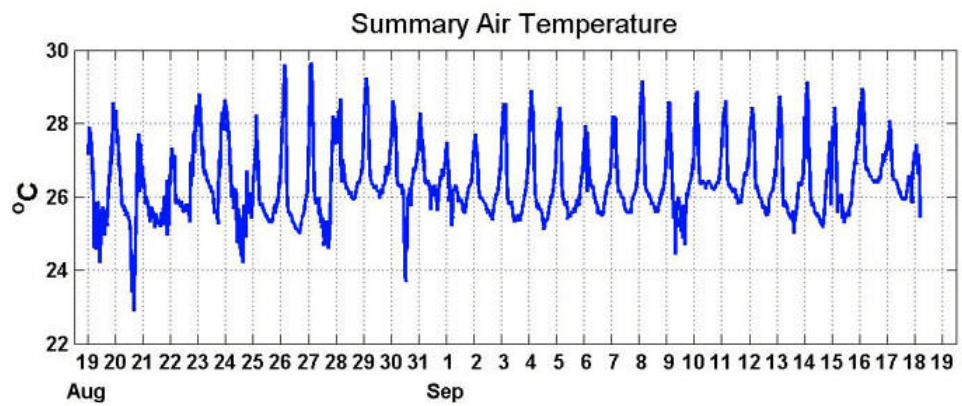
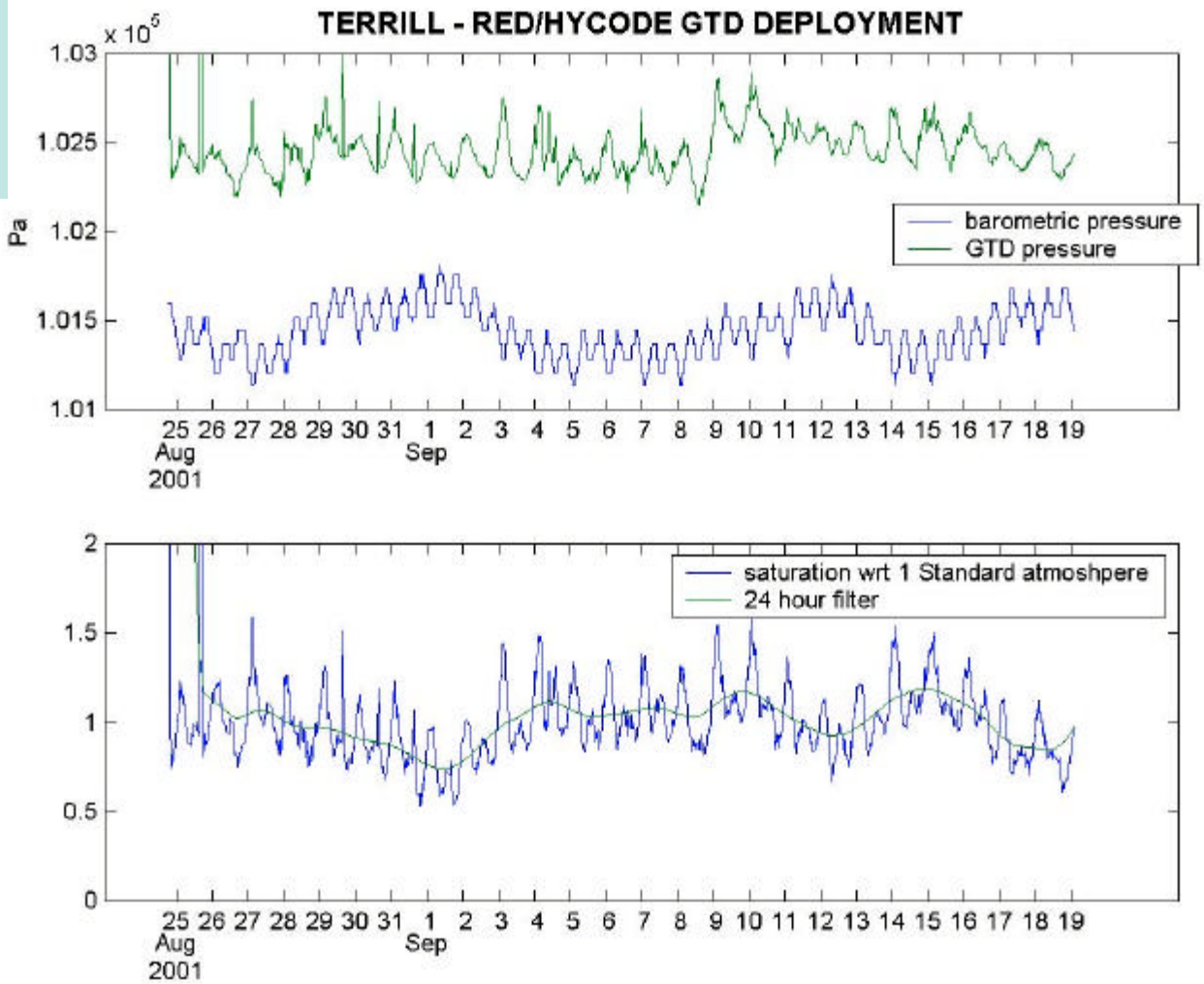
BASIC MET DATA







GAS TENSION DEVICE - MEASURES TOTAL GAS SATURATION LEVEL



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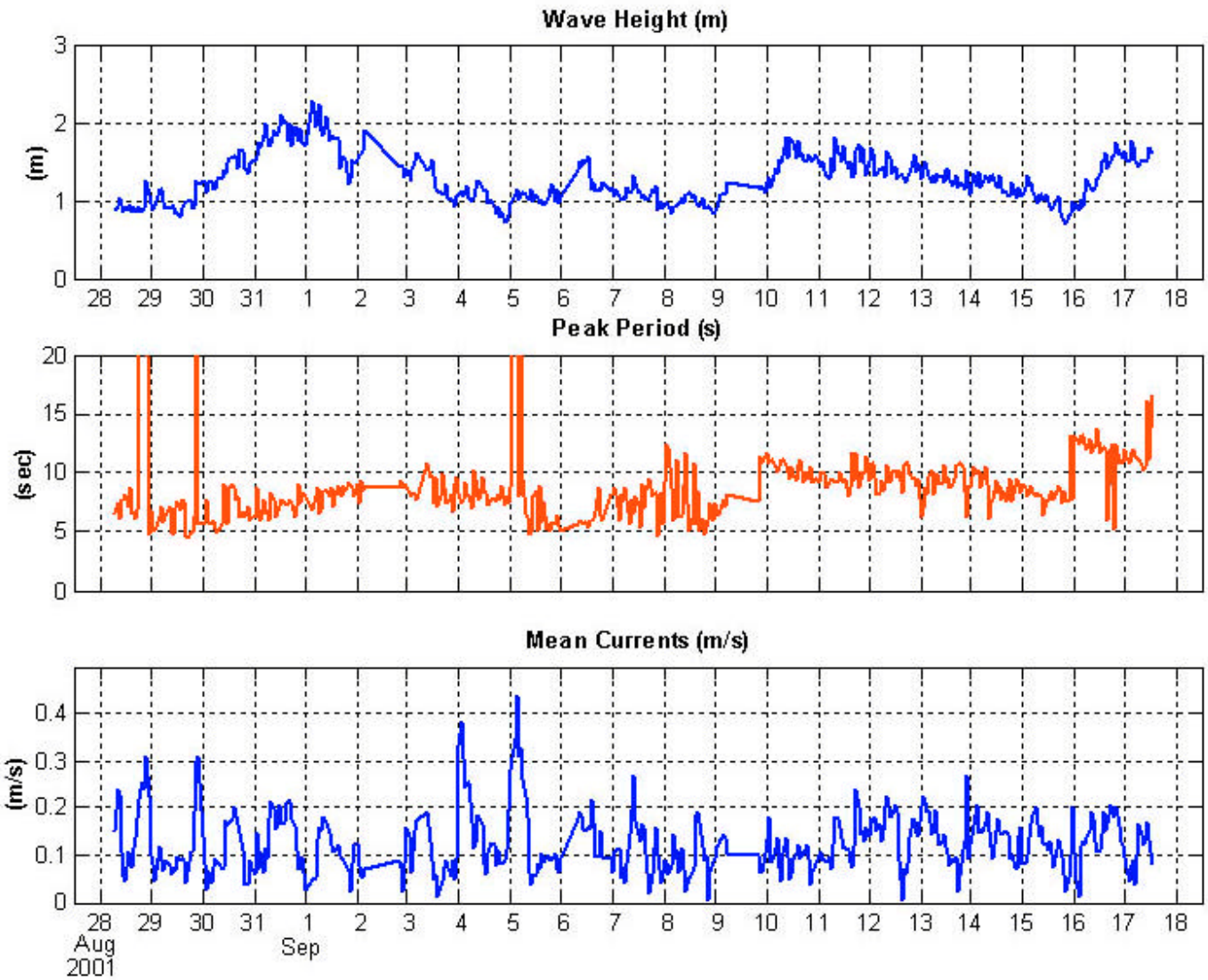
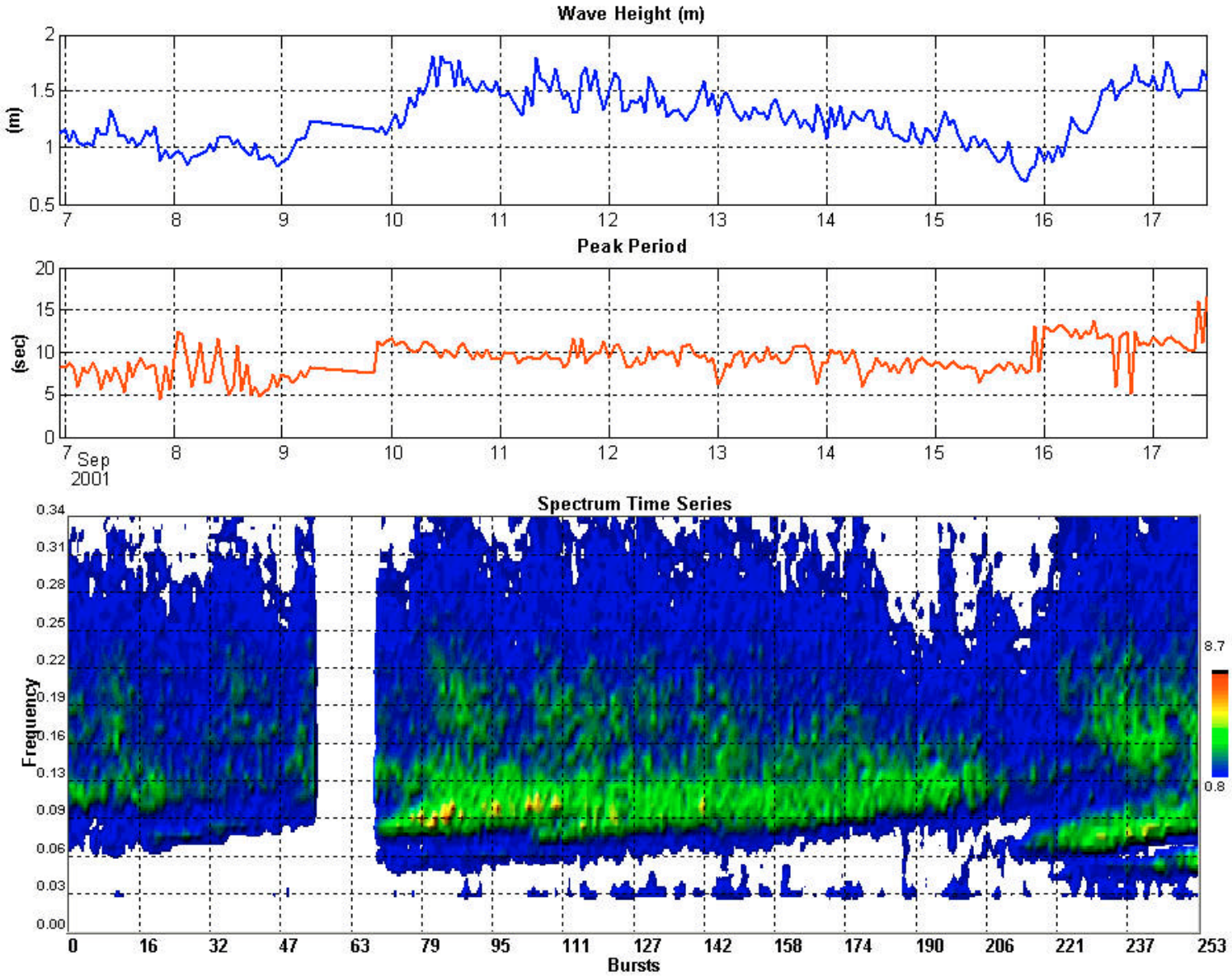

Wave Height (m)
(m)
3
2
1
0
28 29 30 31 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Peak Period (s)
(sec)
20
15
10
5
0
Mean Currents (m/s)
(m/s)
0.4
0.3
0.2
0.1
0
28 29 30 31 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Aug
2001
Sep



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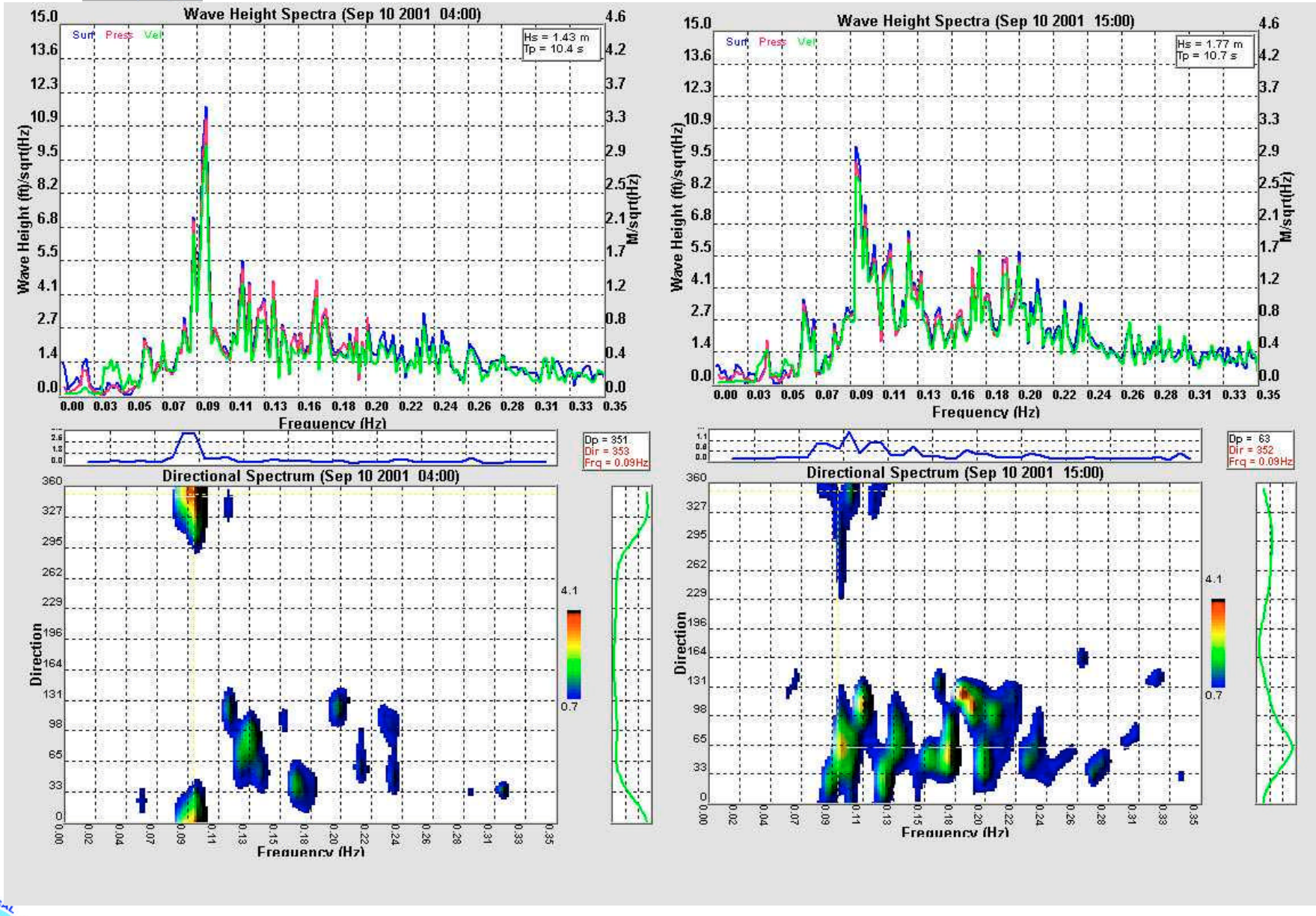
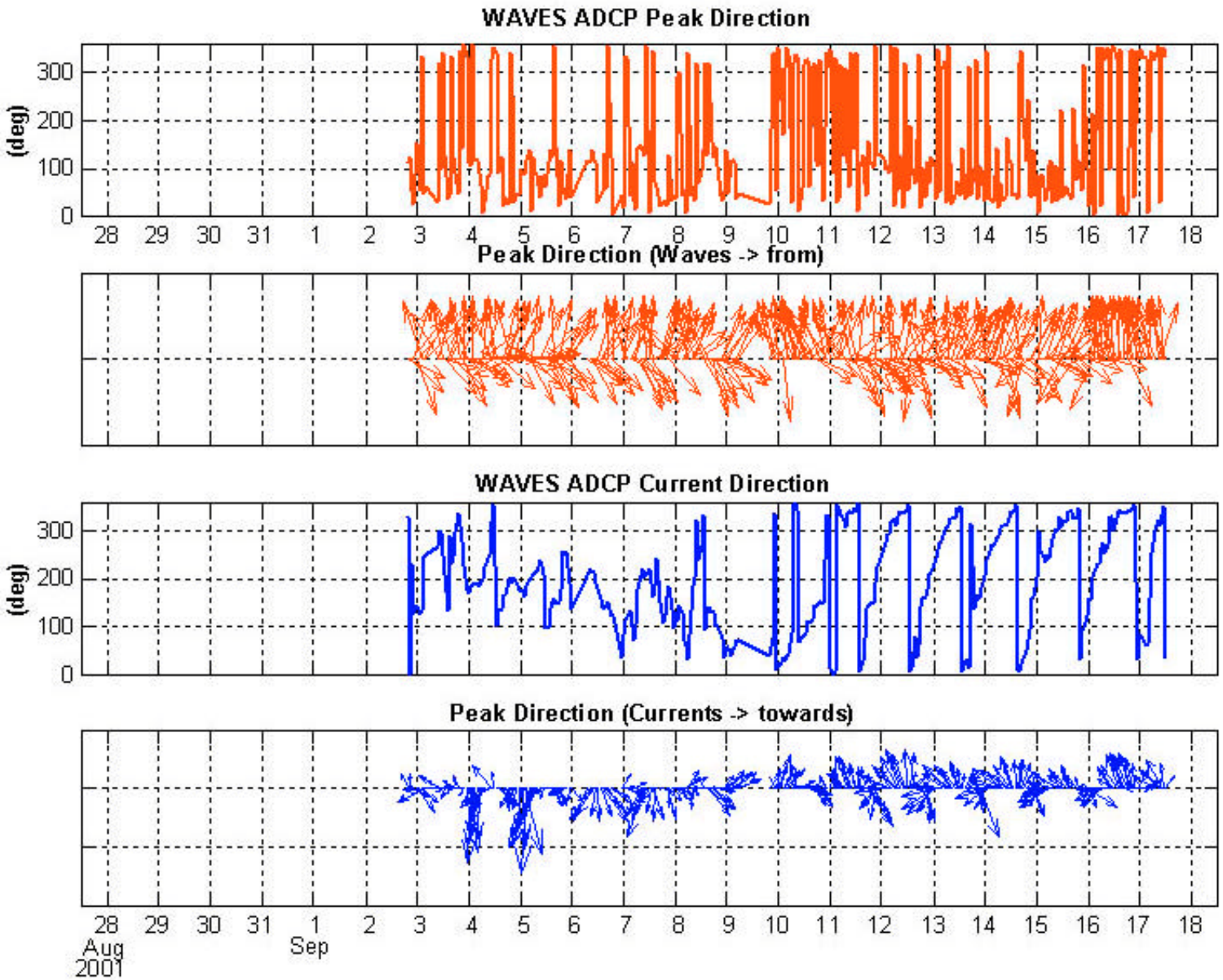

Wave Height Spectra (Sep 10 2001 04:00)
Surf Press Vel
Hs = 1.43 m
Tp = 10.4 s
Wave Height (ft)/sqrt(Hz)
M/sqrt(Hz)
Frequency (Hz)
Dp = 351
Dir = 353
Frq = 0.09Hz
Directional Spectrum (Sep 10 2001 04:00)
Direction
Frequency (Hz)
Wave Height Spectra (Sep 10 2001 15:00)
Surf Press Vel
Hs = 1.77 m
Tp = 10.7 s
Wave Height (ft)/sqrt(Hz)
M/sqrt(Hz)
Frequency (Hz)
Dp = 63
Dir = 352
Frq = 0.09Hz
Directional Spectrum (Sep 10 2001 15:00)
Direction
Frequency (Hz)



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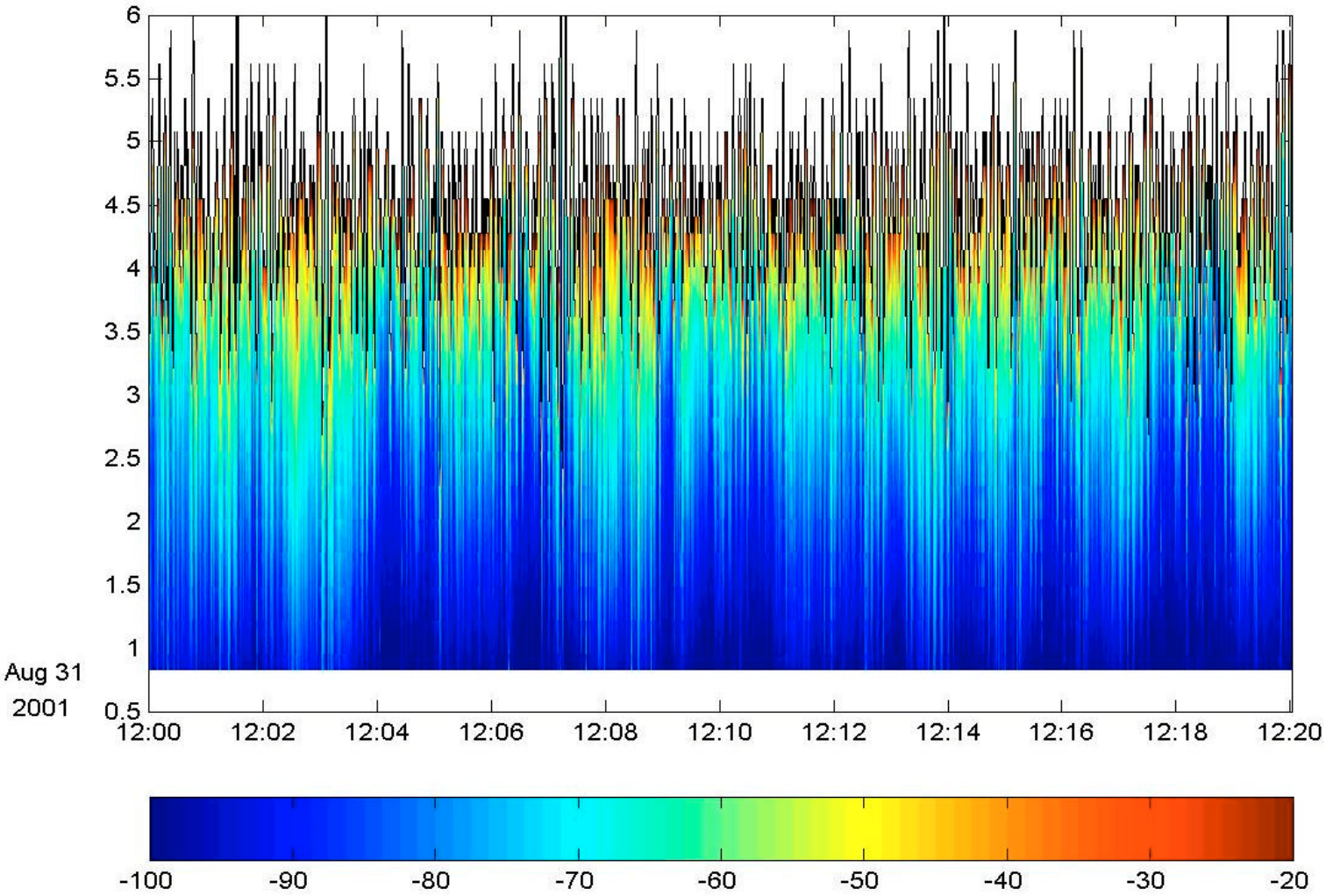
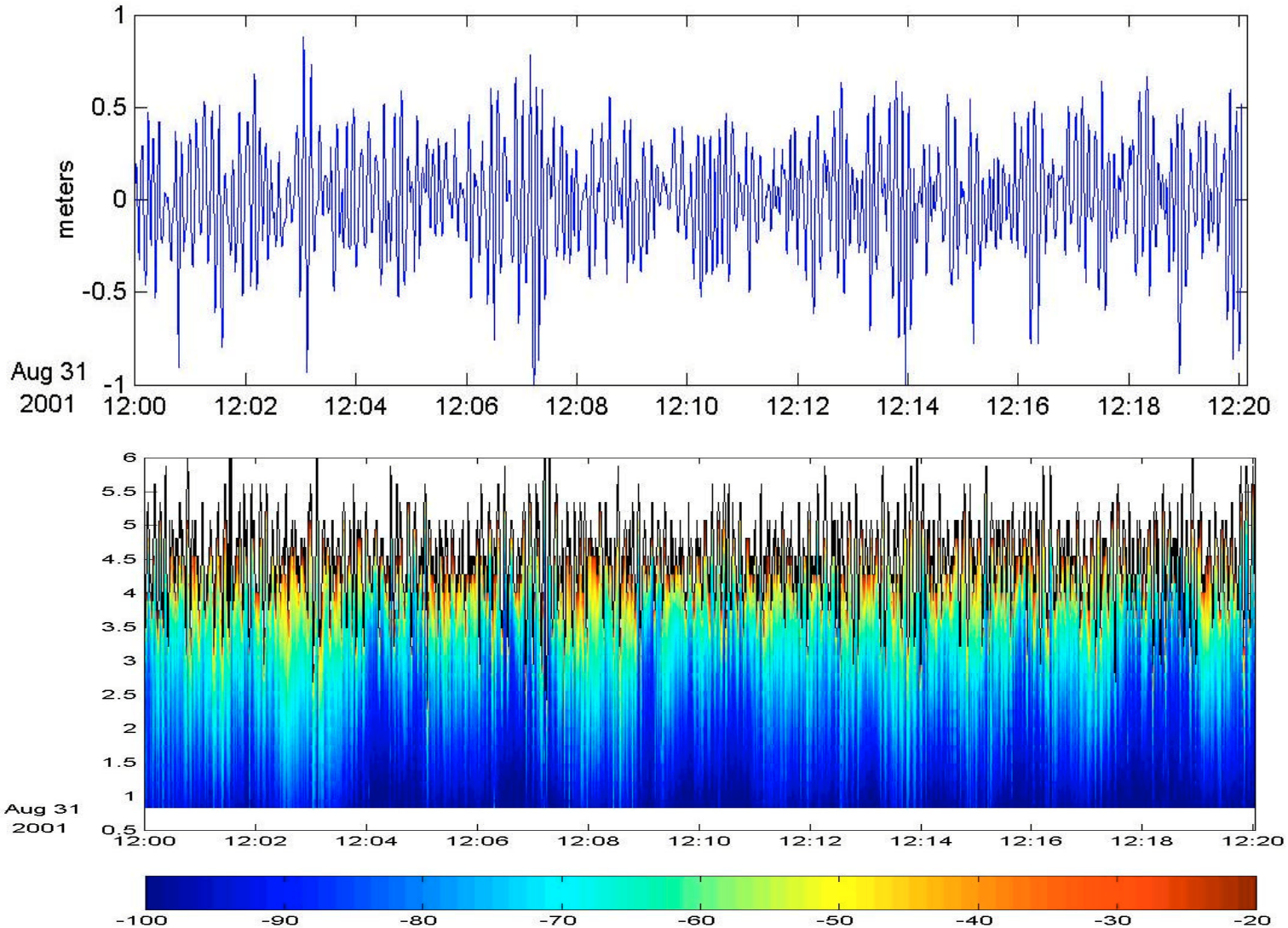
1.2 MHz acoustic scattering strength from bubbles





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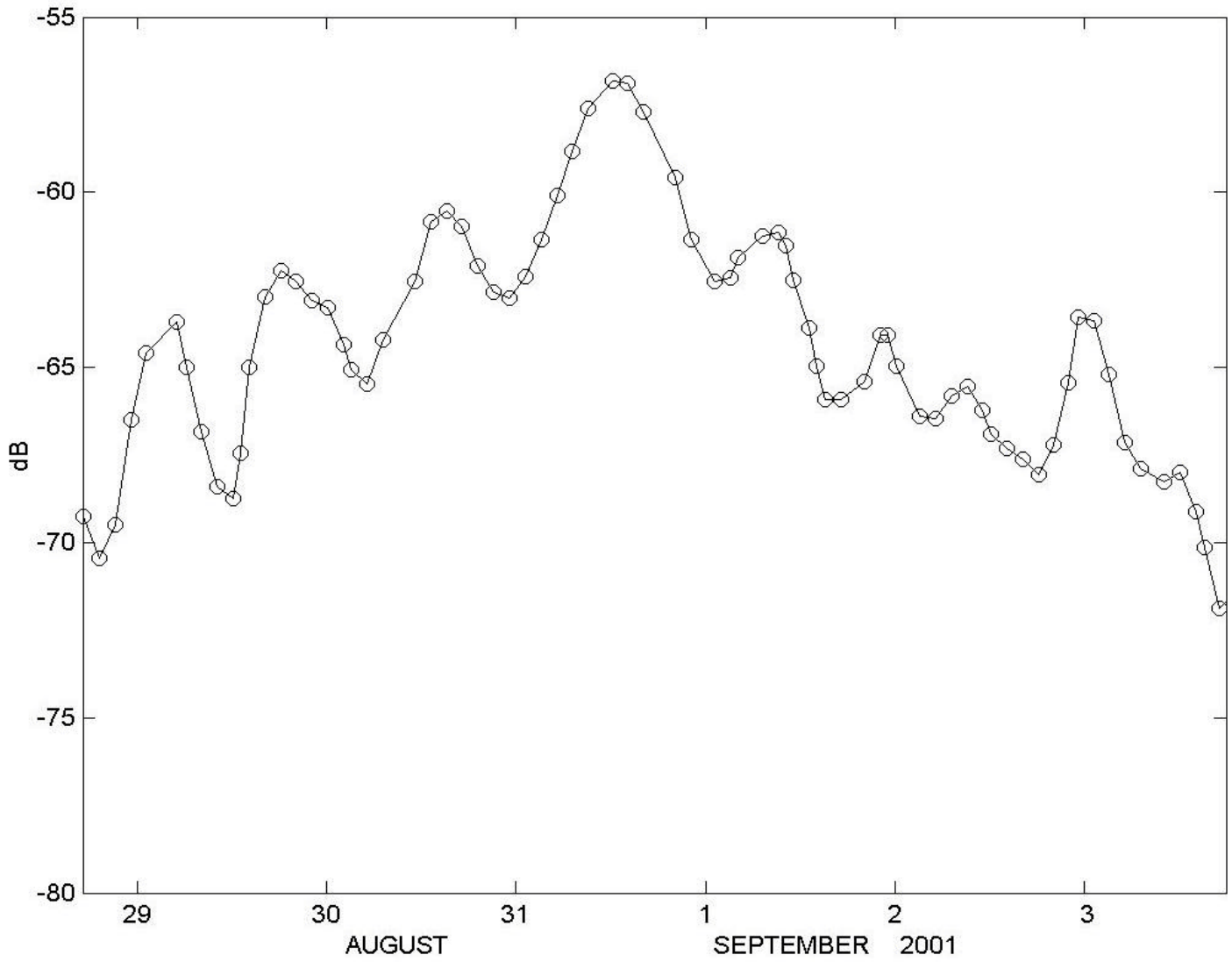

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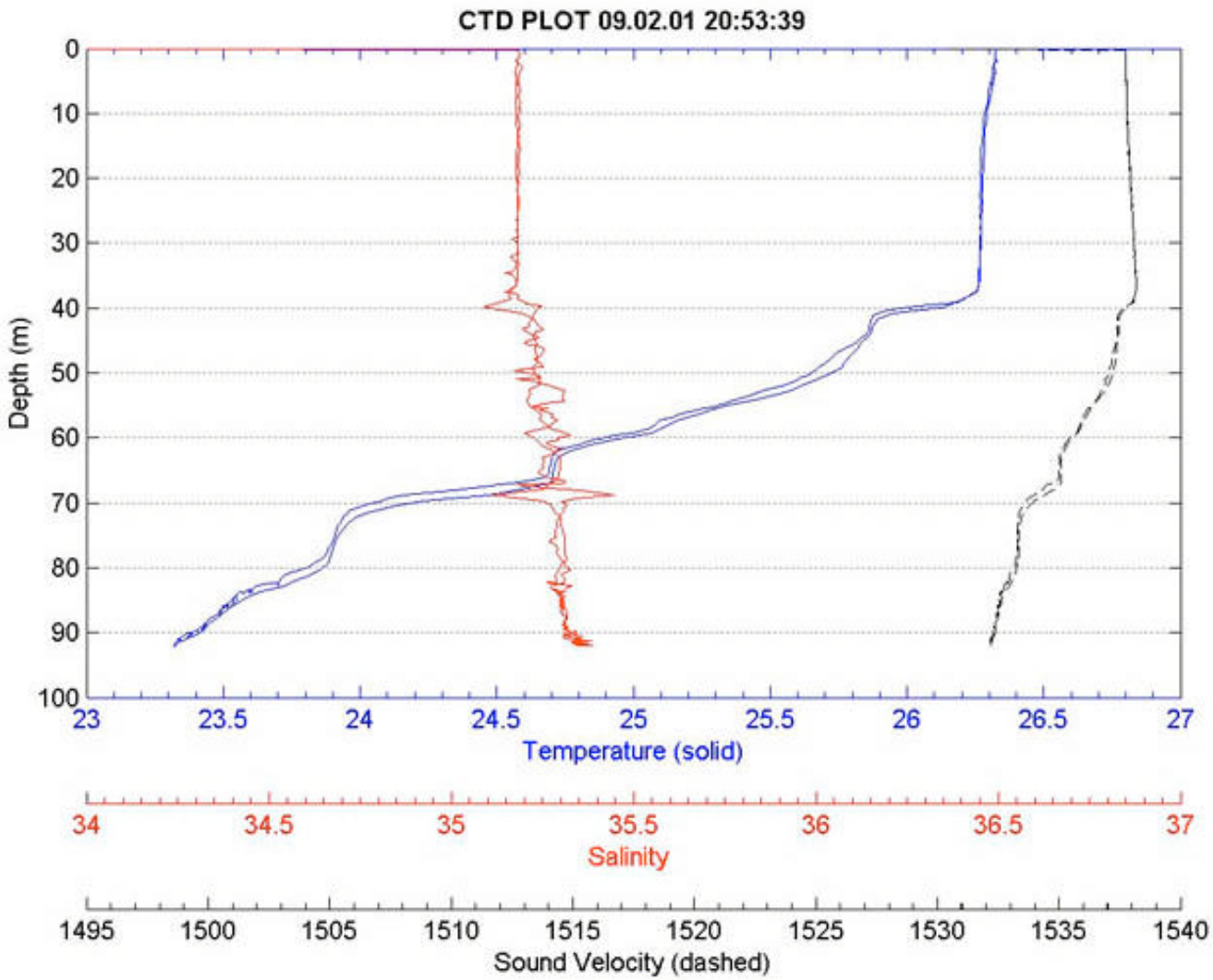
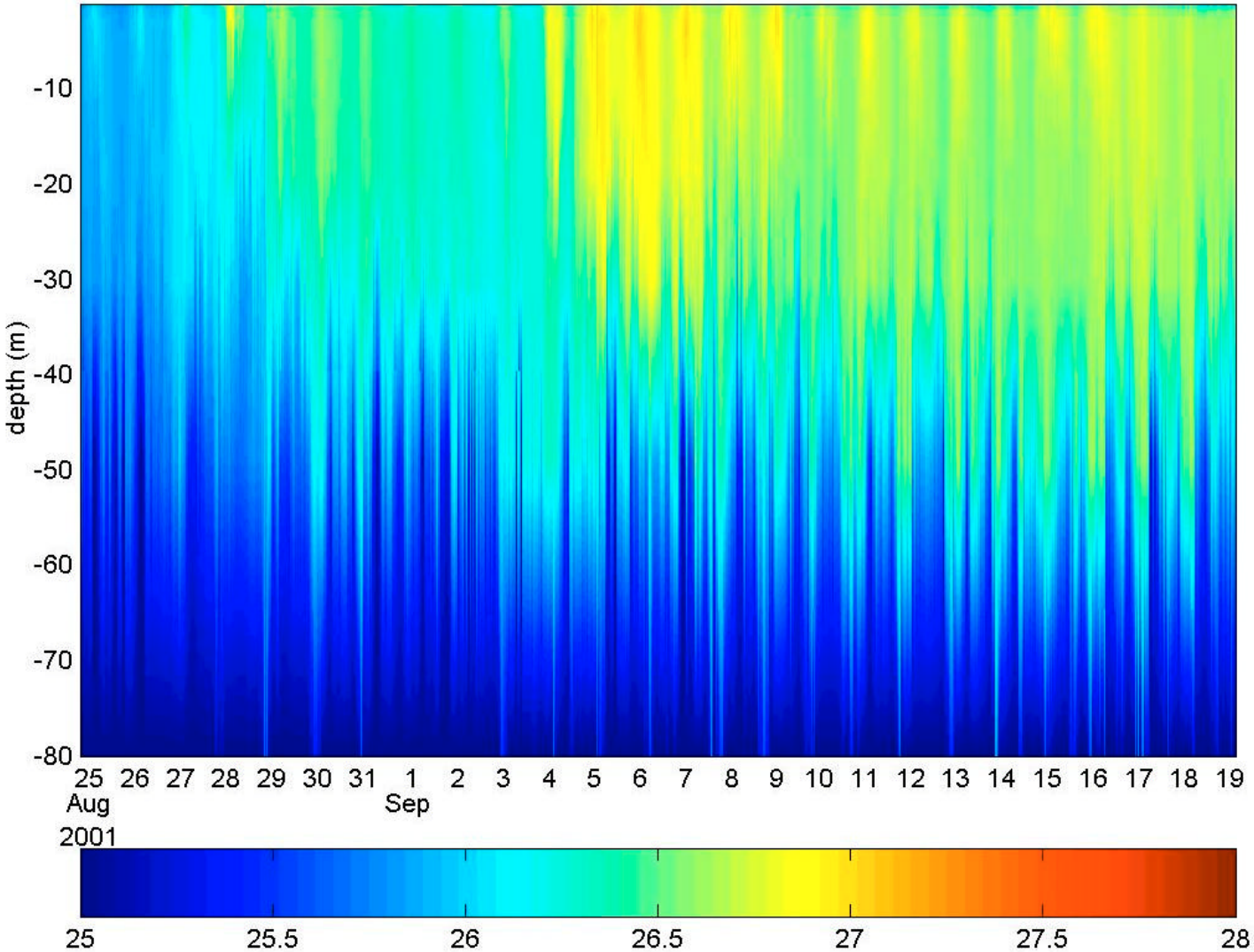
EXAMPLE OF SALINITY/TEMPERATURE STRUCTURE MEASURED DURING RED





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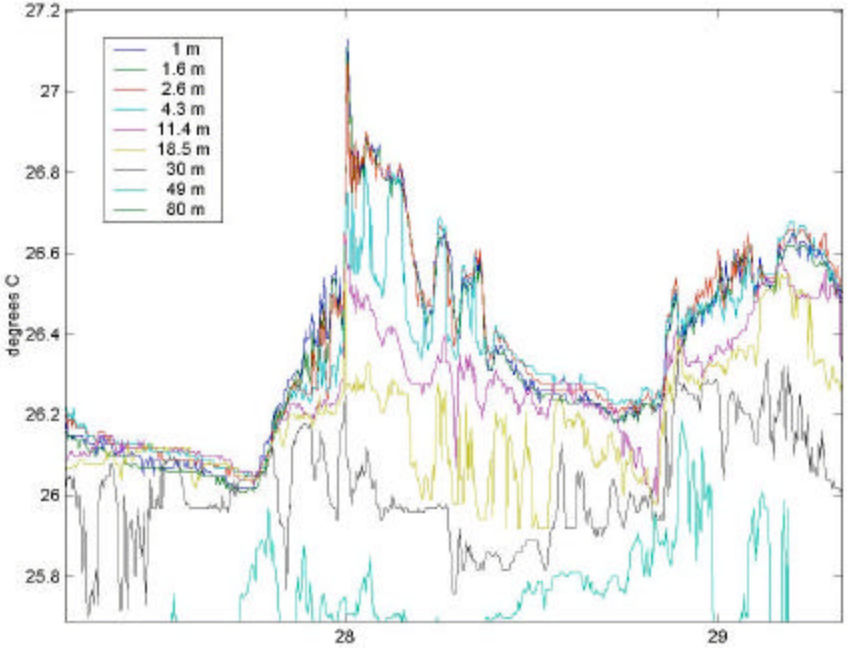
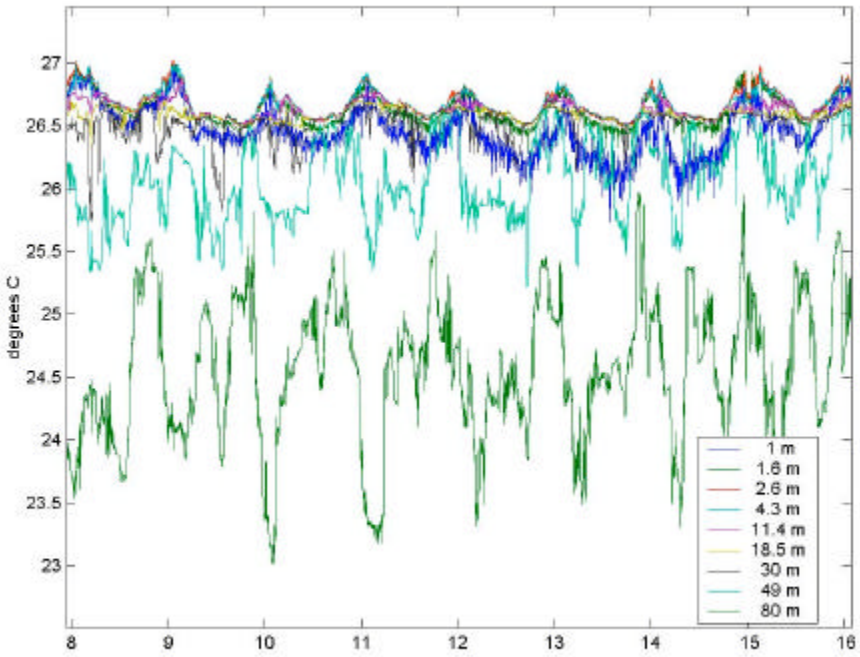
TEMPERATURE VARIABILITY OF UPPER OCEAN



August



September

Wailoa Research Vessel

Meteorological package mounted on roof

- RH
- BP
- AT
- Rain
- Wind Speed / Direction
- GPS

First day of measurements:
8//28/01

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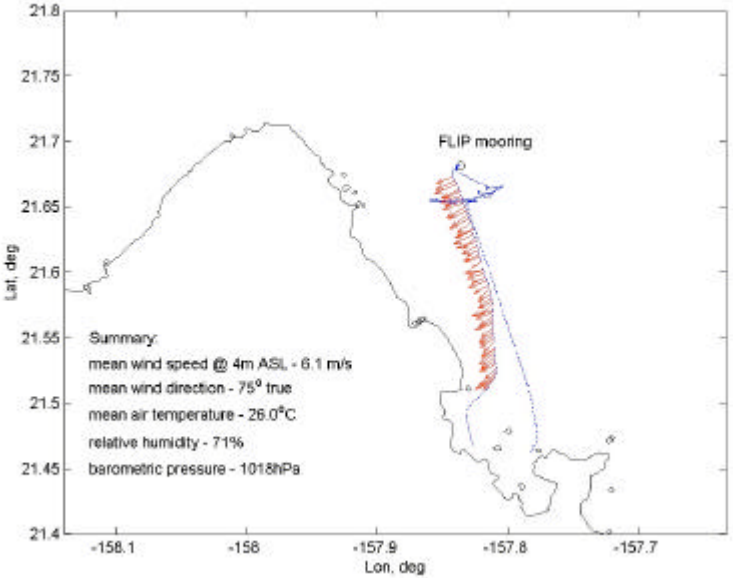
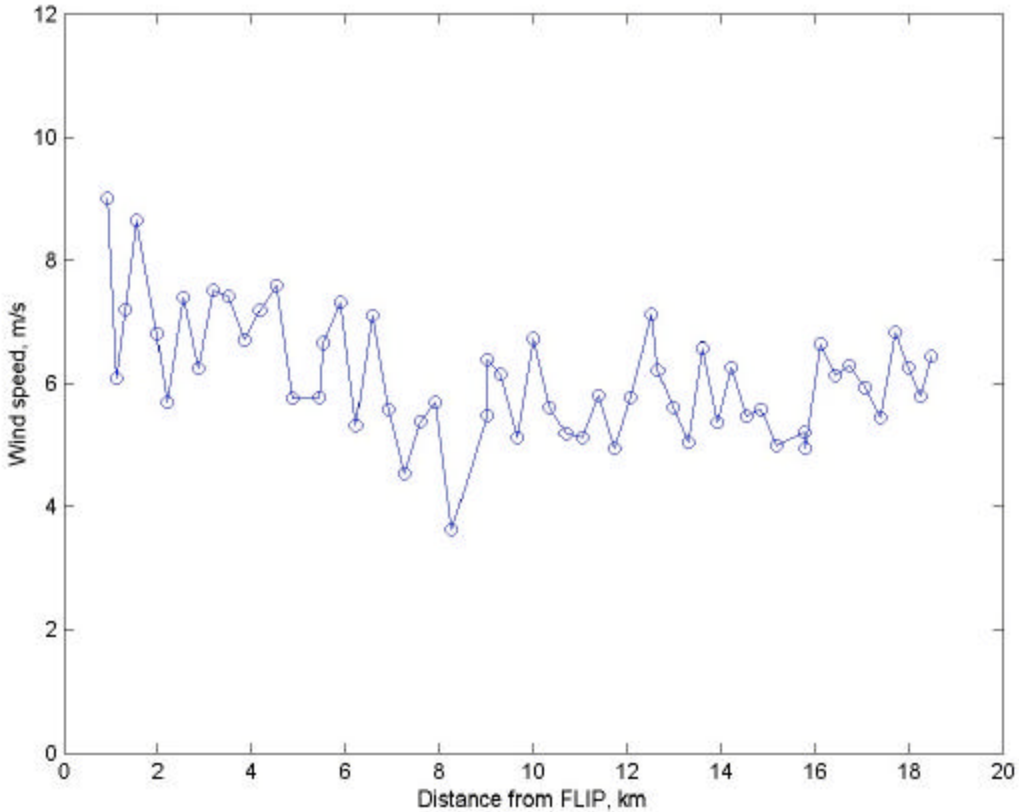
WIND SURVEYS - Example on 8/30/01 morning (local time)





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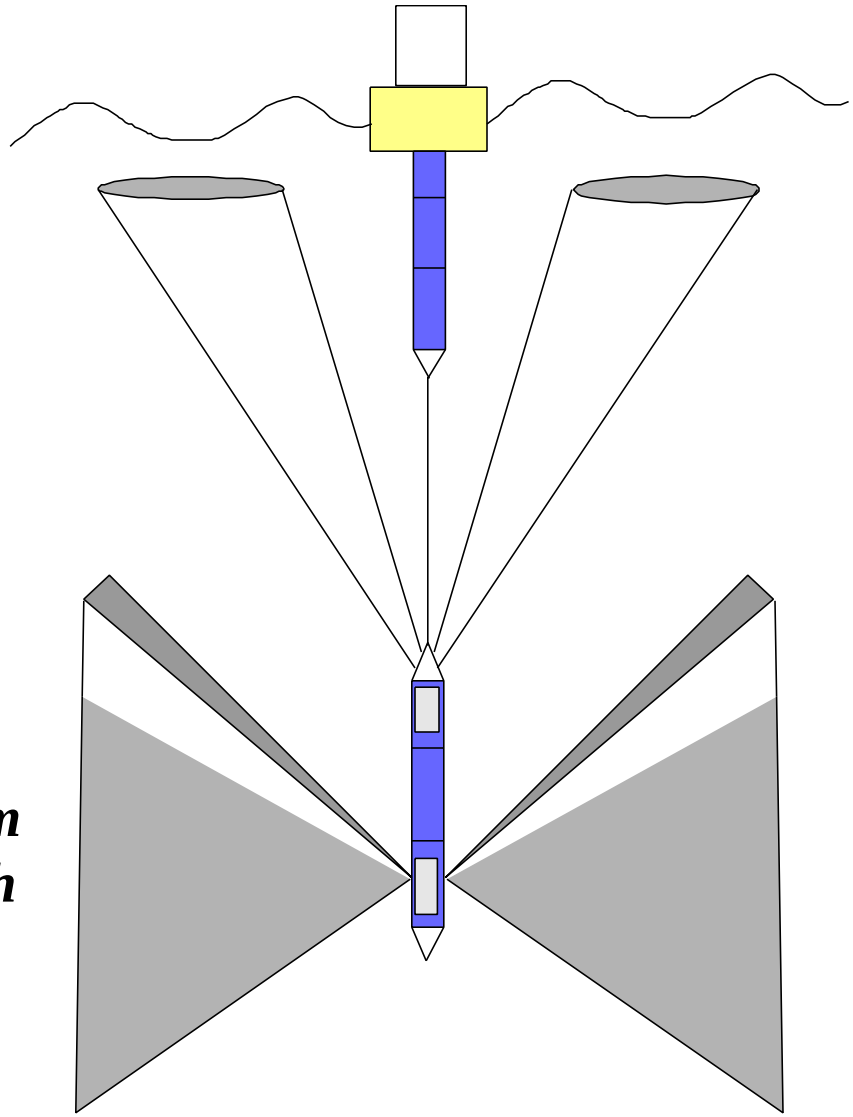
Surface buoy w/ met package

- Pulse coherent Doppler for turbulence and bubbles
- SEACAT
- 550nm optical attenuation and backscatter measurements
- 600kHz upward looking Doppler sonar (4 beams): wave measurements
- Pressure sensor
- 300kHz Doppler fanbeam sonar (4 beams): spatial wave measurements



~10m depth

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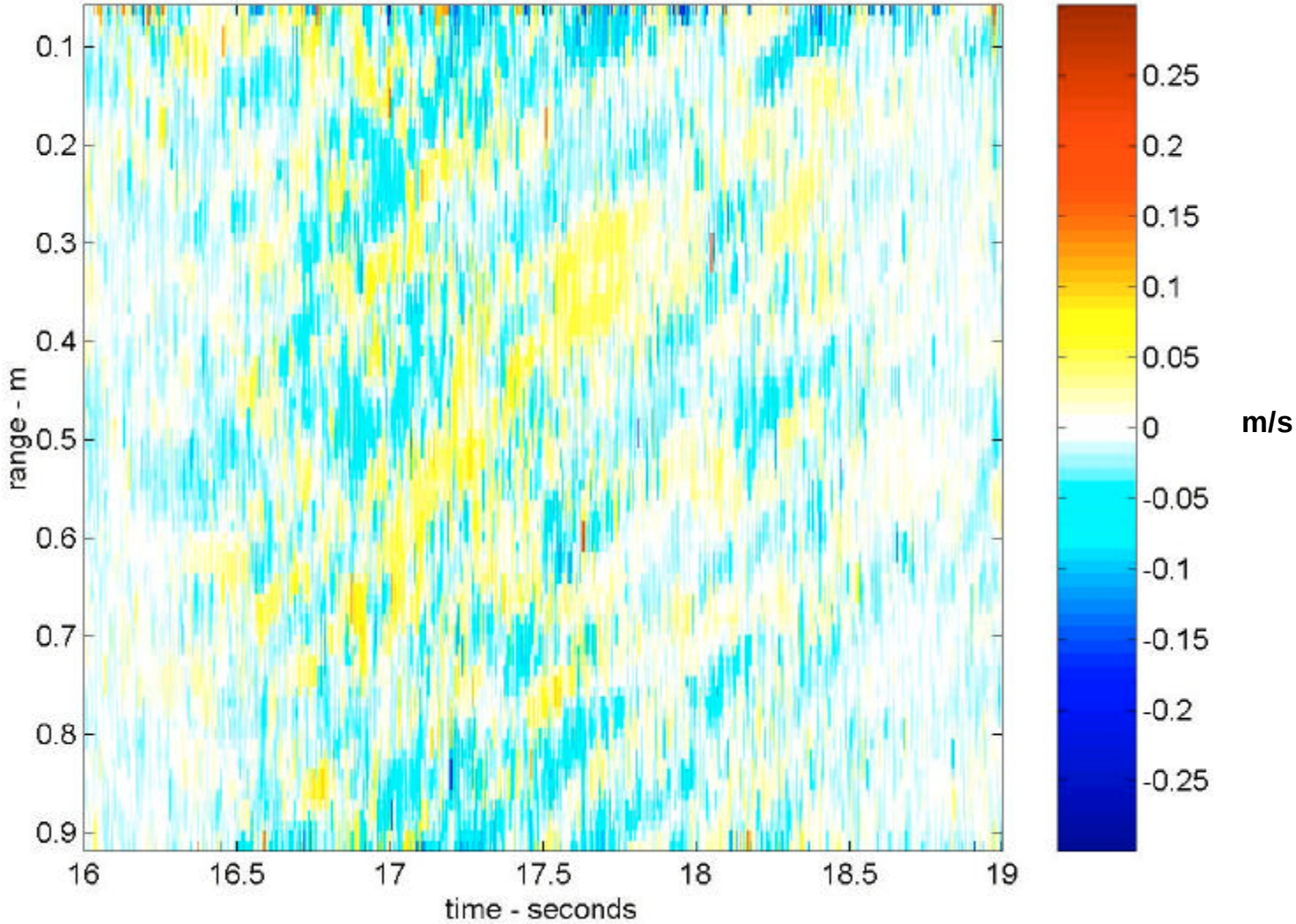
Another example of '*detrended*' velocity perturbations indicative of turbulence.



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Wavenumber Spectra

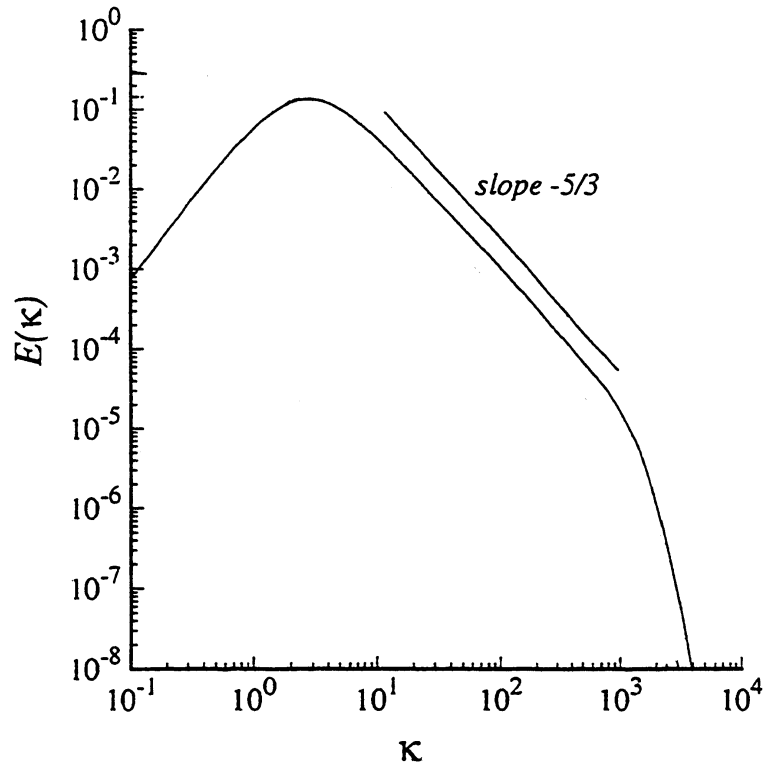
$$©(k) = \frac{18}{55}\left(\frac{8^2}{9®_H}\right)^{2=3} k^{\,i\,5=3}$$

Assumptions

- Kolmogorov Energy Cascade
- Dissipation and Production minimal in equilibrium subrange
- Inertial forces dominate
- Isotropy permits measurement in any direction

$$^2 = 2^o \overline{s_{ij} s_{ij}}$$

$$= 15^o \overline{\left(\frac{@u_1}{@x_1}\right)^2}$$



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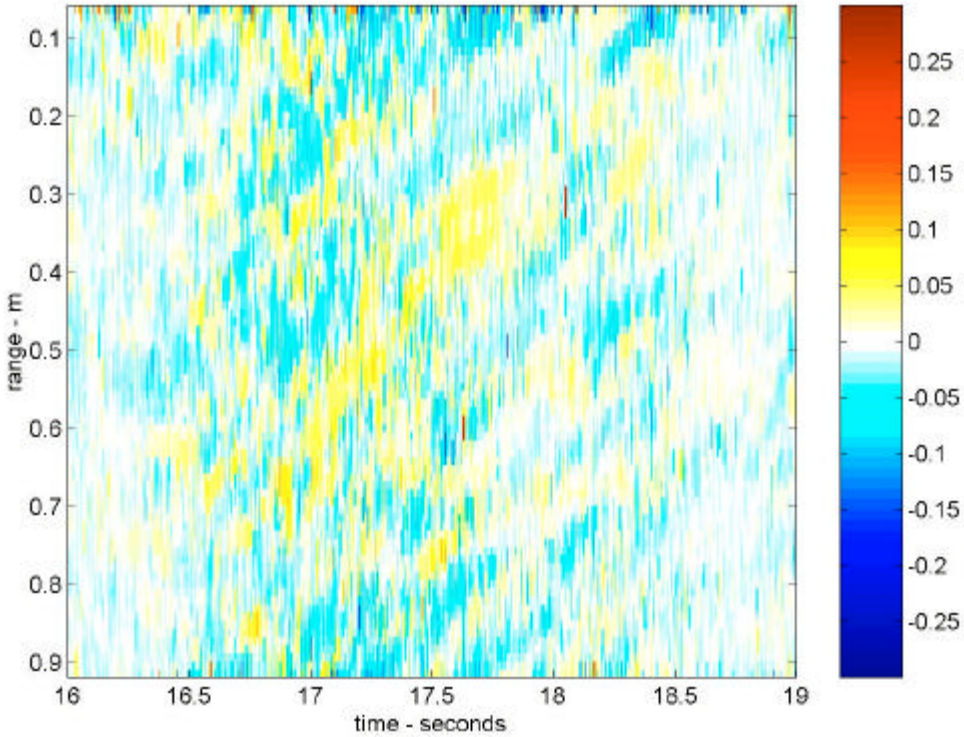
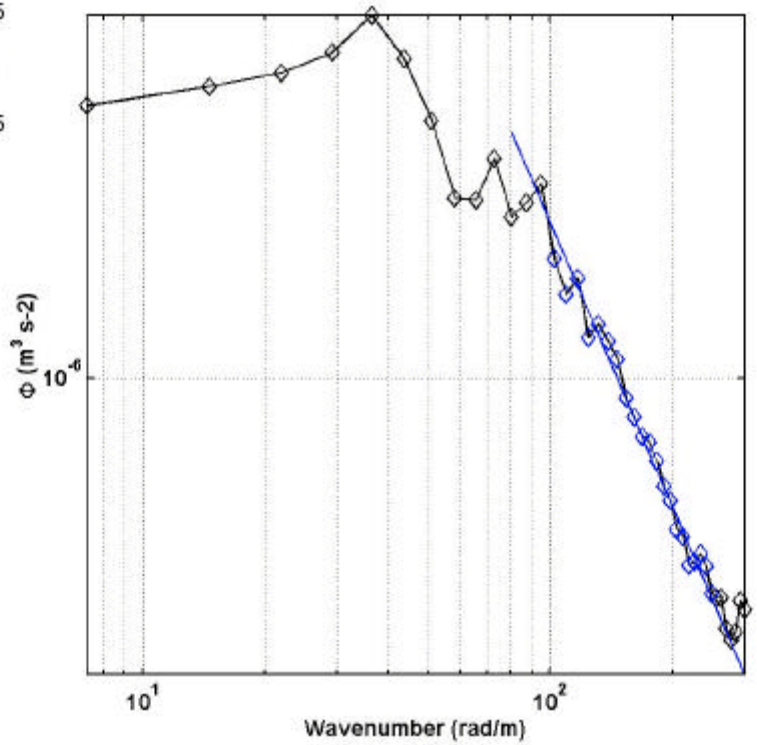
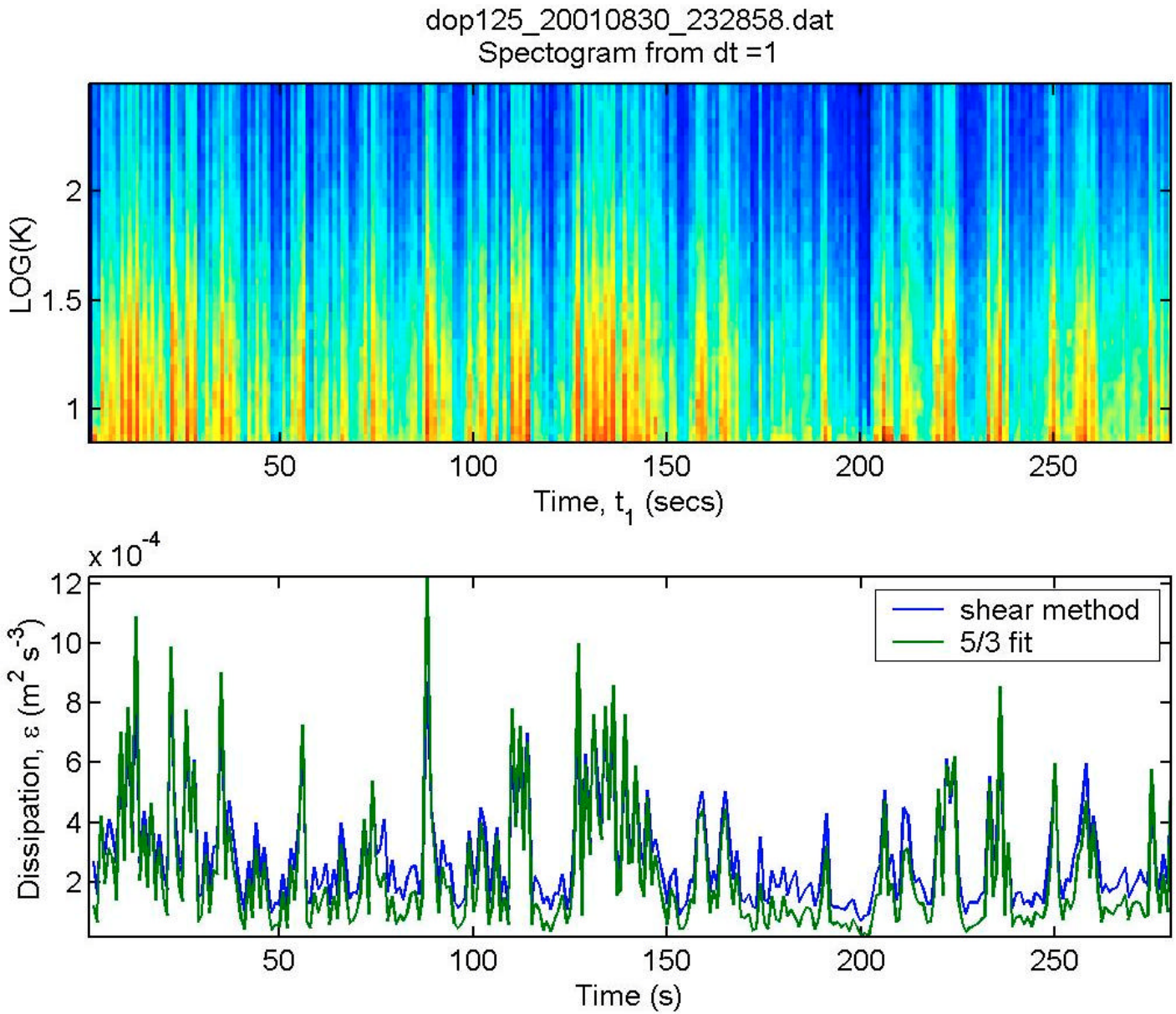
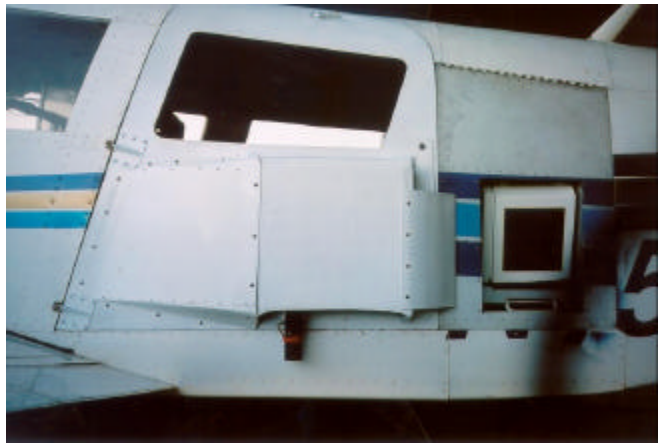

range - m
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
16
16.5
17
17.5
18
18.5
19
time - seconds
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25


Φ (m³ s-2)
10⁻⁶
10¹
10²
Wavenumber (rad/m)

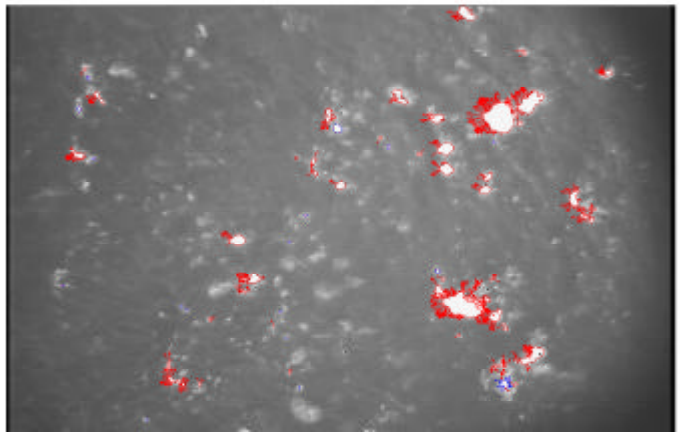

dop125_20010830_232858.dat
Spectogram from dt =1
LOG(K)
2
1.5
1
50
100
150
200
250
Time, t1 (secs)
x 10-4
12
10
8
6
4
2
Dissipation, ε (m2 s-3)
shear method
5/3 fit
50
100
150
200
250
Time (s)

white cap kinematics and distributions

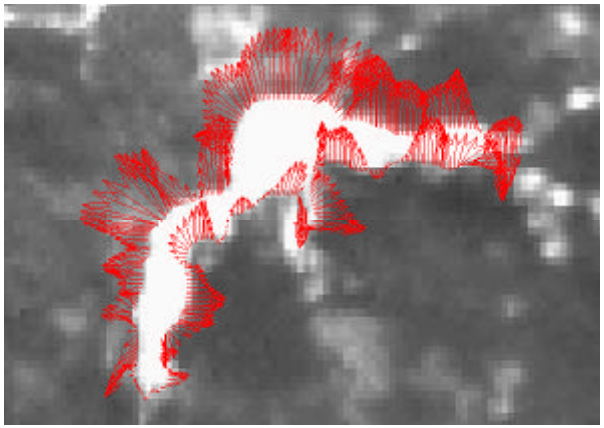


Measurements of the air-sea interface are conducted with a motion compensated, imaging system and a bore-sighted laser altimeter.

Various moments of the distributions of wave breaking kinematics are related to bubble and aerosol source functions.



Example image of the open ocean in stormy conditions. Red arrows superimposed on the image indicate surface velocity of the boundaries of the white caps.



Large breaking wave with superimposed boundary velocity vectors.

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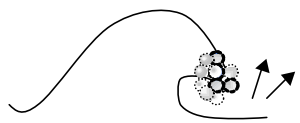
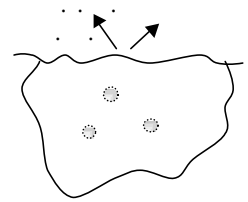
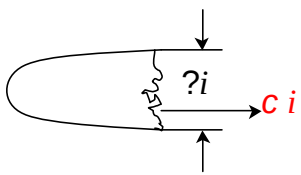
Another mechanism of aerosol generation is the region of the wave which is actively breaking. Quantitative analysis of image sequences allows kinematic measurements of the breaking process. Potential relationships between the kinematics of breaking and aerosol generation are presented below.



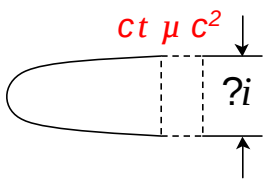
Active breaking source proportional to the length of breaking front



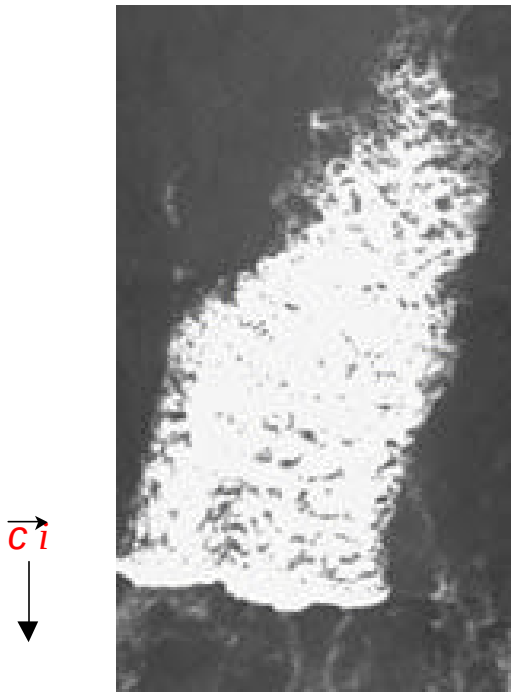
Area of the active breaking region



? (c)dc – average length of breaking fronts in (c,c+dc) per unit area of surface. These statistics can be measured directly through dynamic processing of motion compensated image sequences.

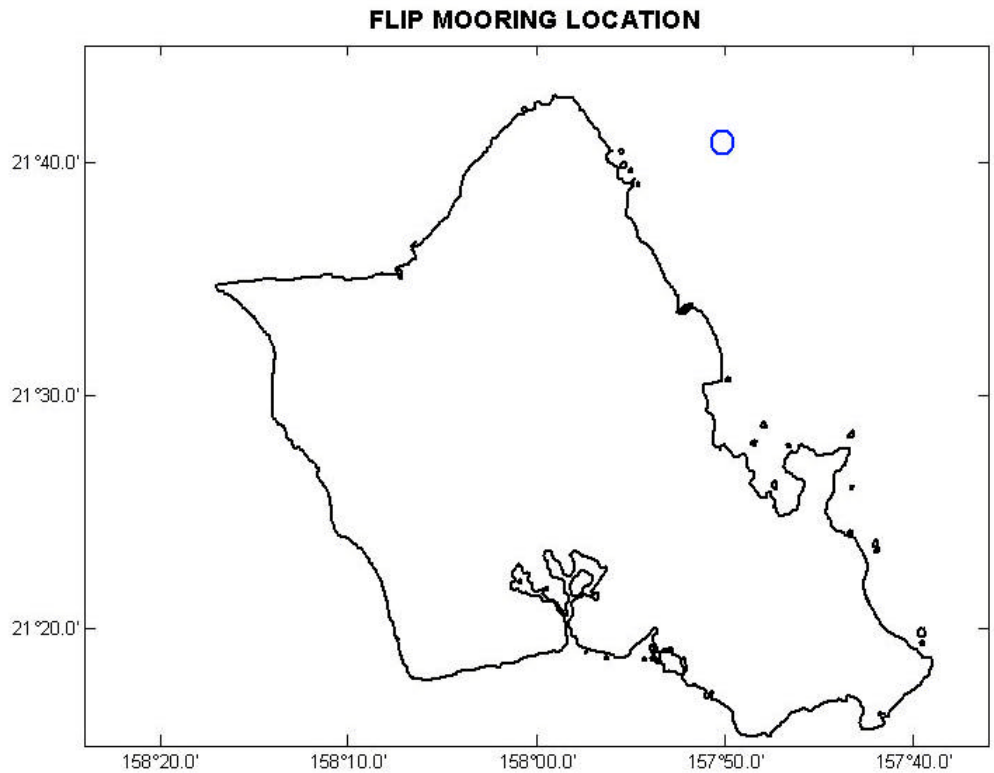


c^2? (c)dc – AREA swept out by breaking waves/unit area/unit time. The second moment of the distribution is proportional to the area coverage of the whitecap which is *actively* breaking.

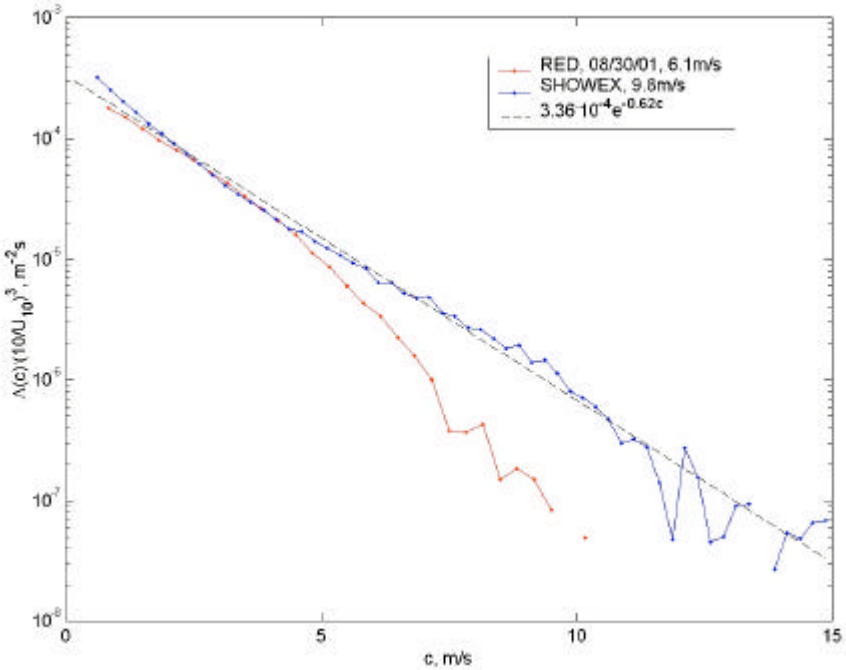


? $_i$ – Length of breaking front

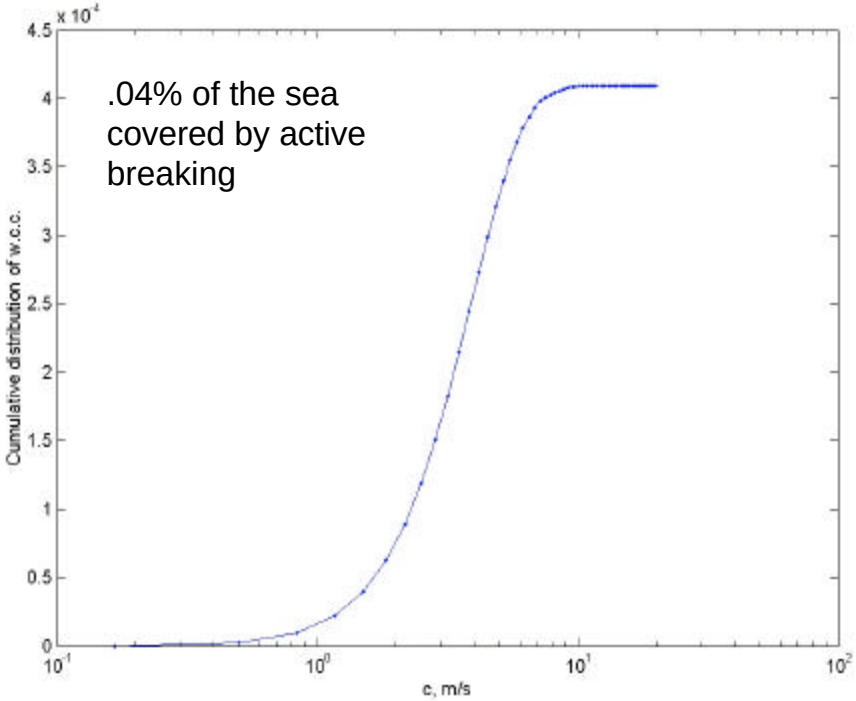
C_i – Velocity of breaking front


FLIP MOORING LOCATION
21°40.0'
21°30.0'
21°20.0'
158°20.0'
158°10.0'
158°00.0'
157°50.0'
157°40.0'

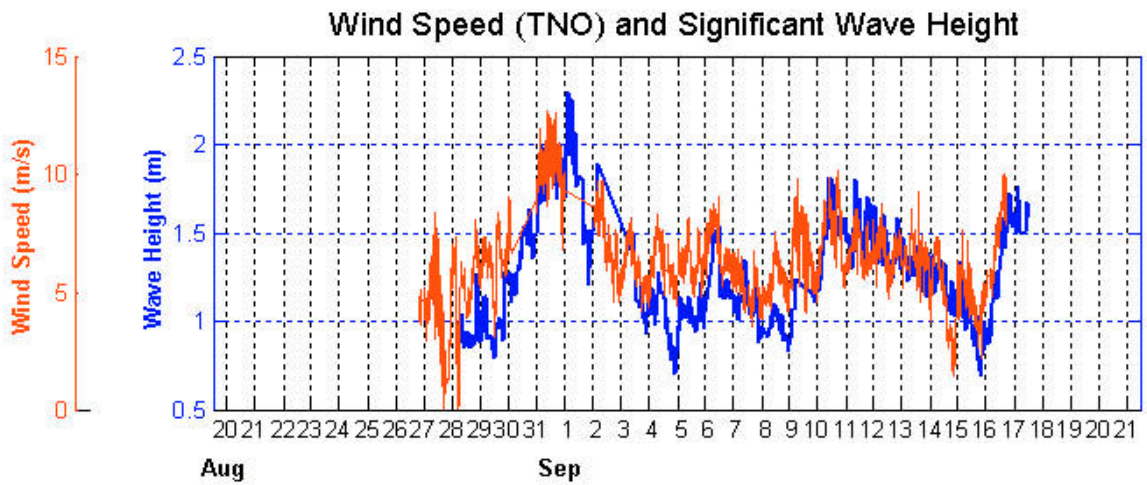
Breaking speed statistics scaled by U^3 (wind measurements used from WAILOA)

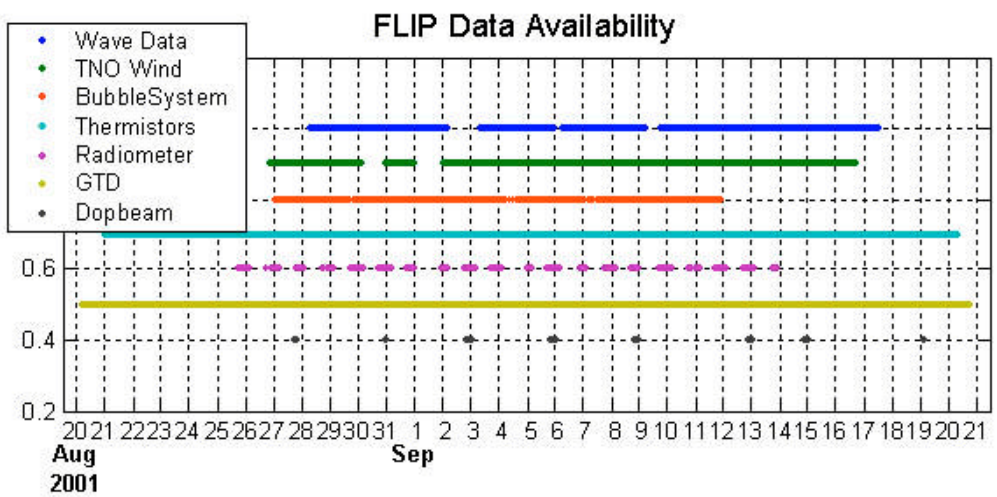


CUMULATIVE DISTRIBUTION OF SECOND MOMENT (WHITE CAP COVERAGE) AS A FUNCTION OF BREAKING SPEED



Terrill & Melville


Wind Speed (TNO) and Significant Wave Height
Wind Speed (m/s)
Wave Height (m)
15
10
5
0
2.5
2
1.5
1
0.5
20 21 22 23 24 25 26 27 28 29 30 31 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Aug
Sep


FLIP Data Availability
Wave Data
TNO Wind
BubbleSystem
Thermistors
Radiometer
GTD
Dopbeam
0.6
0.4
0.2
20 21 22 23 24 25 26 27 28 29 30 31 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Aug
2001
Sep