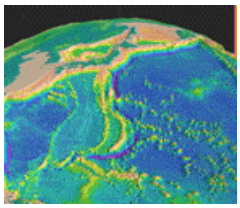
Physics of Surfing Waves - part 2

David T. Sandwell
(http://topex.ucsd.edu/ps)



- Physics of waves
- Characteristics of waves
- Generation of waves by storms
- Wave speed - shallow vs. deep ocean
- Sets - dispersion
- Refraction of waves - Why is Black's so good?

Exercises: April 15

(each problem is covered in class)

1. Derive the expression for the period of a harmonic oscillator with mass *m* and spring constant *k*.

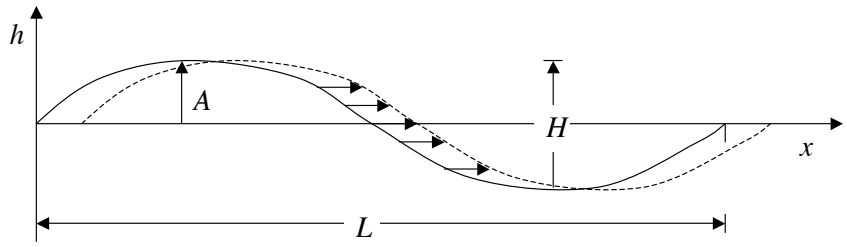
2. Derive the expression for the speed of a deep water wave in terms of the wave period *T*.

3. What are *sinh, cosh,* and *tanh* in terms of the exponential function? What is *tanh*(10^{-6})? What is *tanh*(10)?

4. One more problem. Consider two waves of equal height but different period (T_1=12.5 s and T_2=13 s. What is the time between sets? Here is a hint: add two cosine functions h(t) = cos(ω_1*t) + cos(ω_2*t) where $\omega_1 = 2*\pi / T_1$,use the trigonometric formula for the sum of two cosines, then interpret or plot the results.

wave characteristics

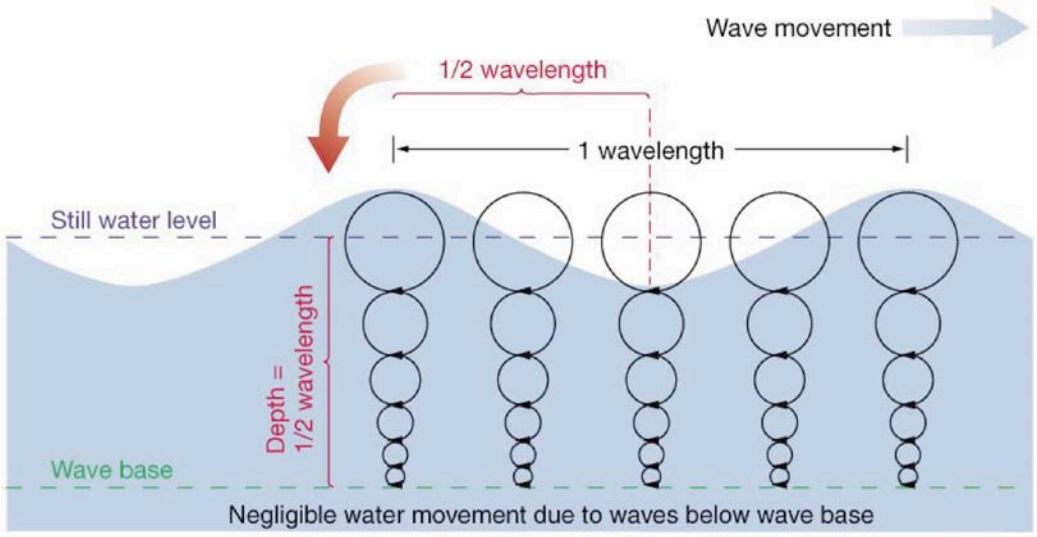
- generated by storms at sea
- far from the storm they are sinusoidal



$$h(x,t) = A\sin\left(\frac{2\pi x}{L} - \frac{2\pi t}{T}\right)$$

L - wavelength
A - amplitude
H - height
T - period (5 - 18 s)

$$c = \frac{L}{T}$$ phase velocity



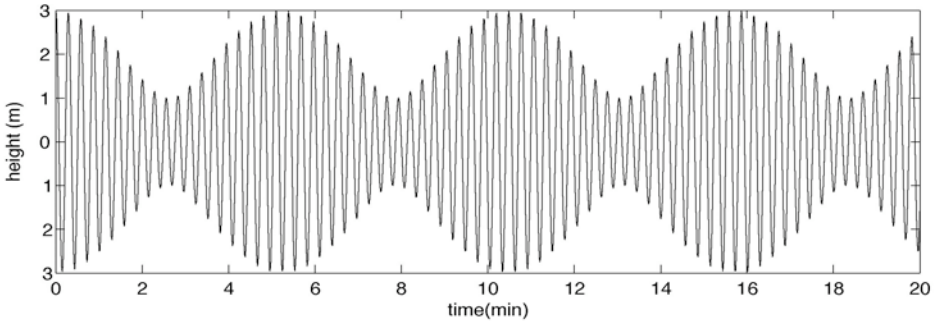
Airy solution

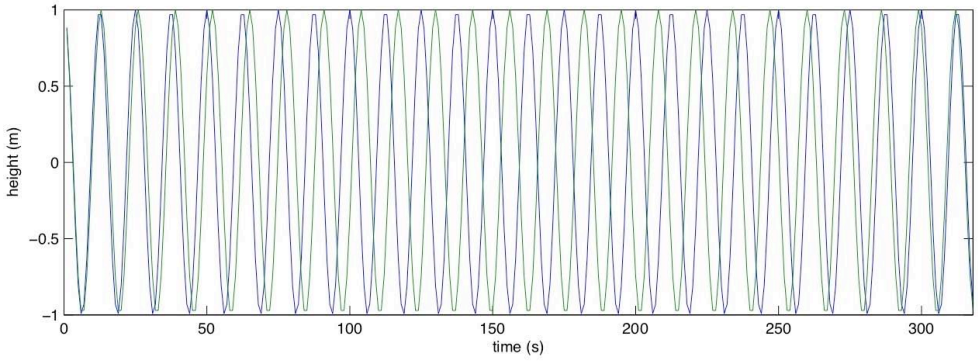
$$c(d) = \left[\frac{gL}{2\pi} \tanh\left(\frac{2\pi d}{L} \right) \right]^{1/2}$$

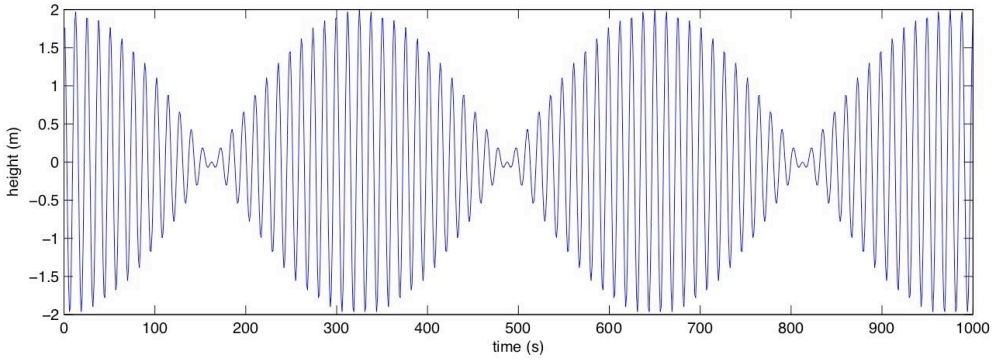
L - wavelength
g - acc. gravity
d - ocean depth

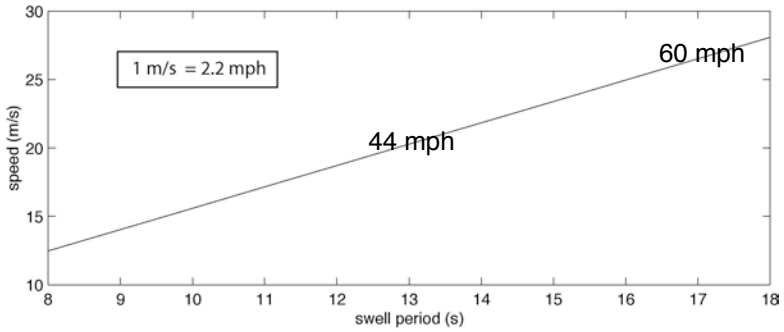
deep water waves	shallow water waves
$d >> L/2$	$d << L/2$
$c_d = \sqrt{\frac{gL}{2\pi}}$	$c_s = \sqrt{gd}$

What causes “sets”?

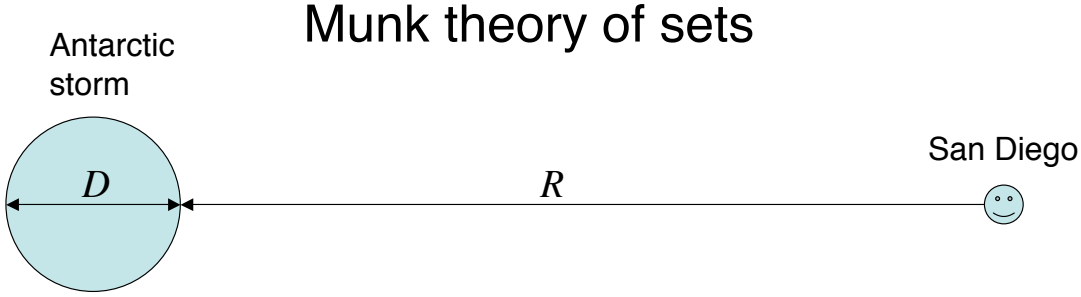



height (m)
time (s)
1
0.5
0
−0.5
−1
0
50
100
150
200
250
300


height (m)
time (s)
2
1.5
1
0.5
0
−0.5
−1
−1.5
−2
0
100
200
300
400
500
600
700
800
900
1000



Munk theory of sets



Waves arrive in San Diego at the same time t_1.

Suppose the waves were generated at the same time t_o.

$$t_1 - t_o = 2R/c_1$$

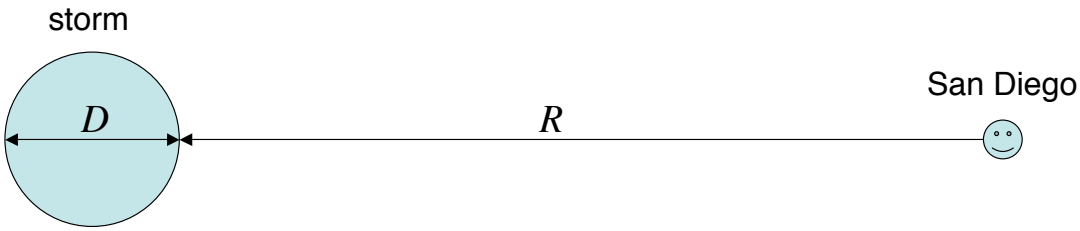
$$t_1 - t_0 = 2(R+D)/c_2$$

$$c_2 = c_1\left(\frac{R+D}{R}\right)$$

$$c = \frac{gT}{2\pi}$$ deep water dispersion

$$T_2 = T_1\left(\frac{R+D}{R}\right)$$

Munk theory of sets



$$h(t) = A\cos\left(\frac{2\pi t}{T_1}\right) + B\cos\left(\frac{2\pi t}{T_2}\right), \qquad \text{suppose} \quad B = A$$

$$h(t) = 2A\cos\left[\pi t\left(\frac{1}{T_1} + \frac{1}{T_2}\right)\right]\cos\left[\pi t\left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right]$$

surf = mean period modulated by beat period

interval between sets

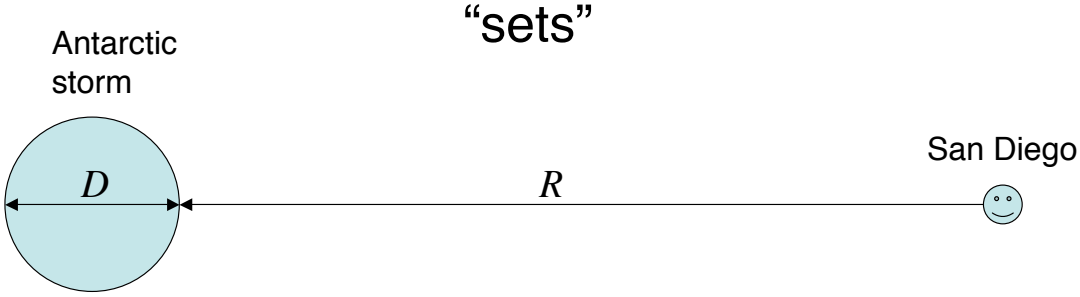
$$T_B = T_1\left(1 - \frac{R}{R+D}\right)^{-1}$$

$R = 7000$ km $\quad D = 400$ km $\quad T_1 = 17s,$

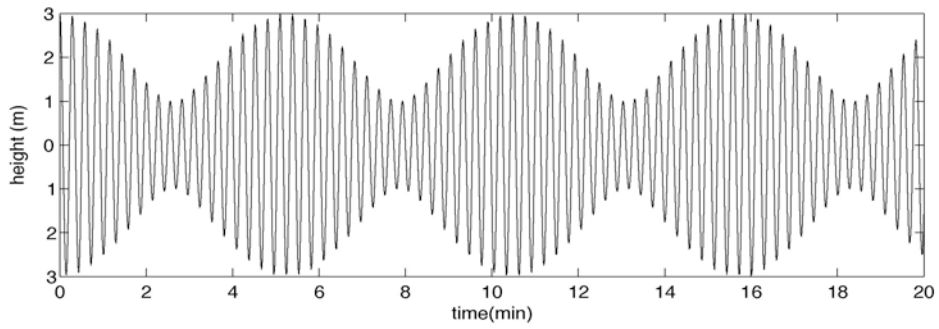
$$T_B = 5.5\,\text{min}$$

A long time to wait between sets!

"sets"

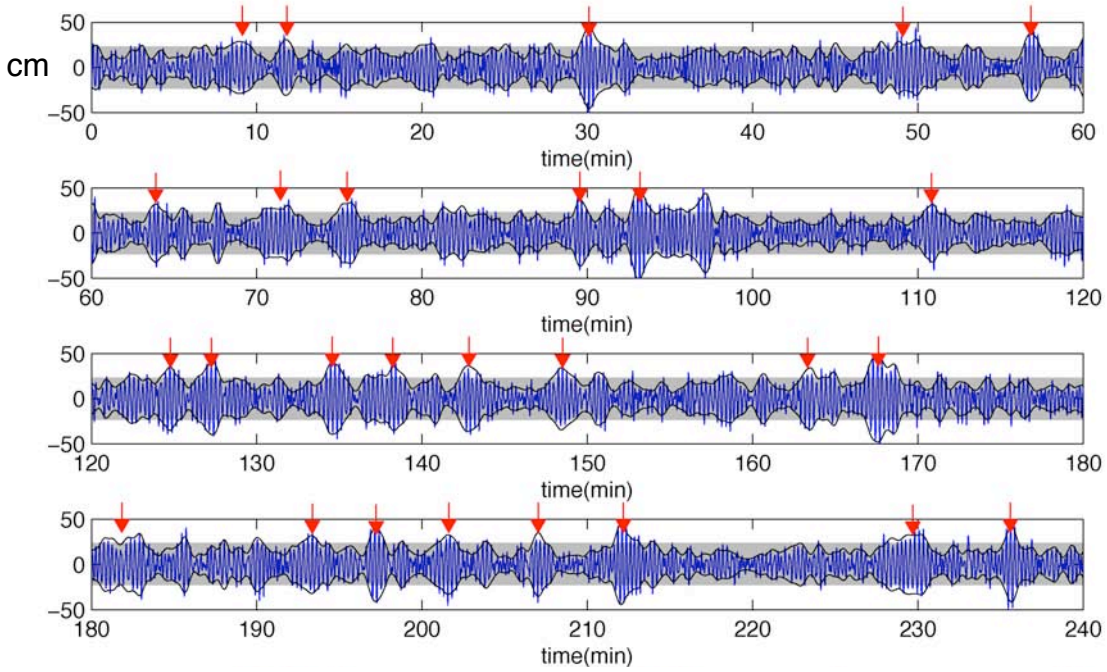


A=3 m, B=1m, sets every 5.5 min



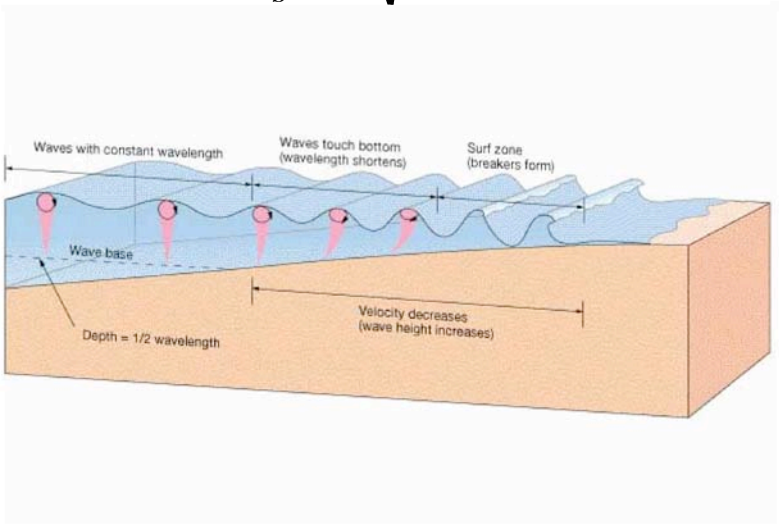
OCEANSIDE OFFSHORE, CA - Station: 04501
Water depth(m): 220.00
August 3, 2007

Average time between sets
8.8 min

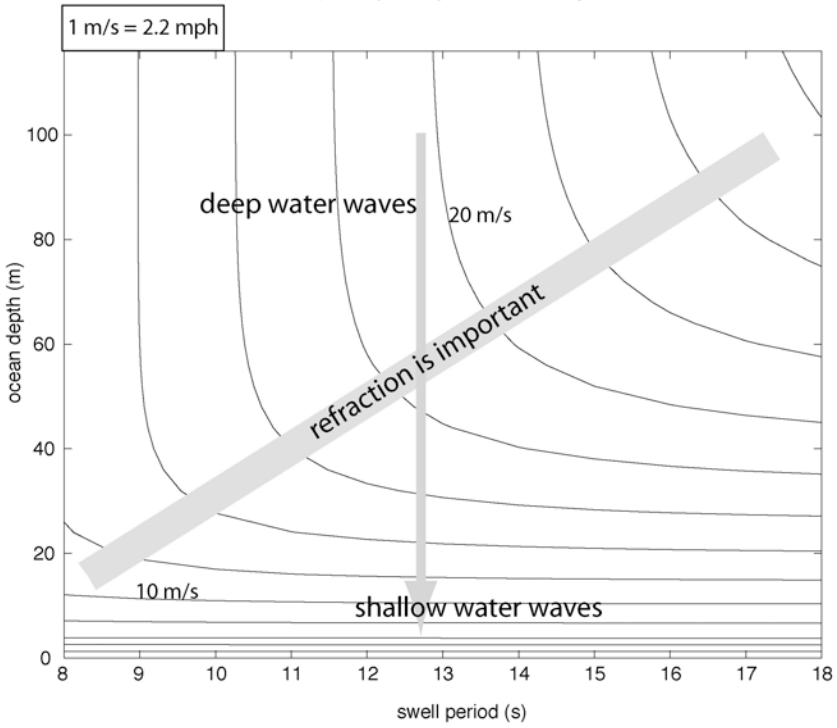


shallow water waves

$$c_s = \sqrt{gd}$$



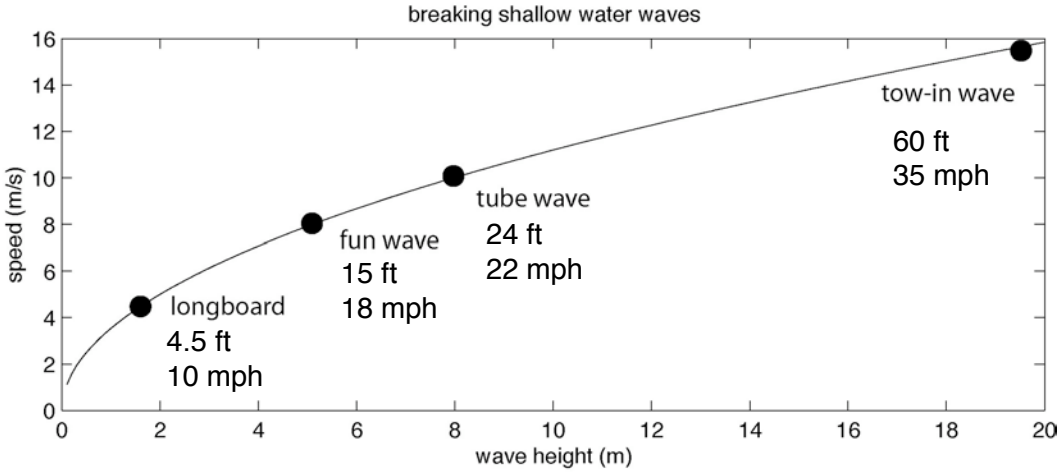
wave refraction



ocean depth and breaker height - **empirical**

$$d_b = 1.28 H_b$$

H_b - height of breaker
d_b - depth where wave breaks



Munk, W. H. and M. A.
Traylor, Refraction of Ocean Waves,
J. Geology, v. LV, No. 1,
1947

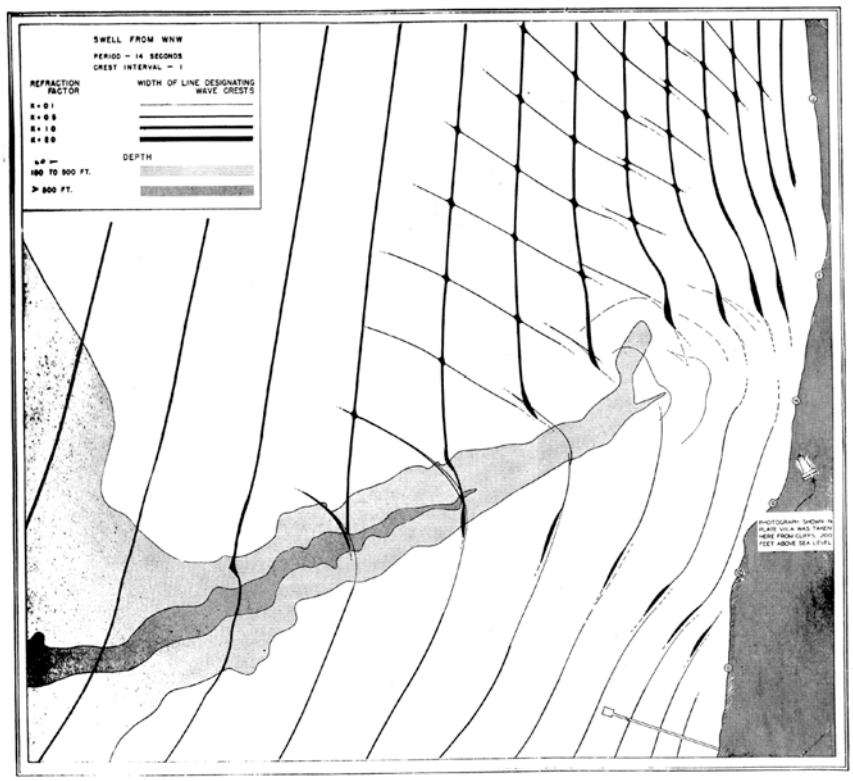
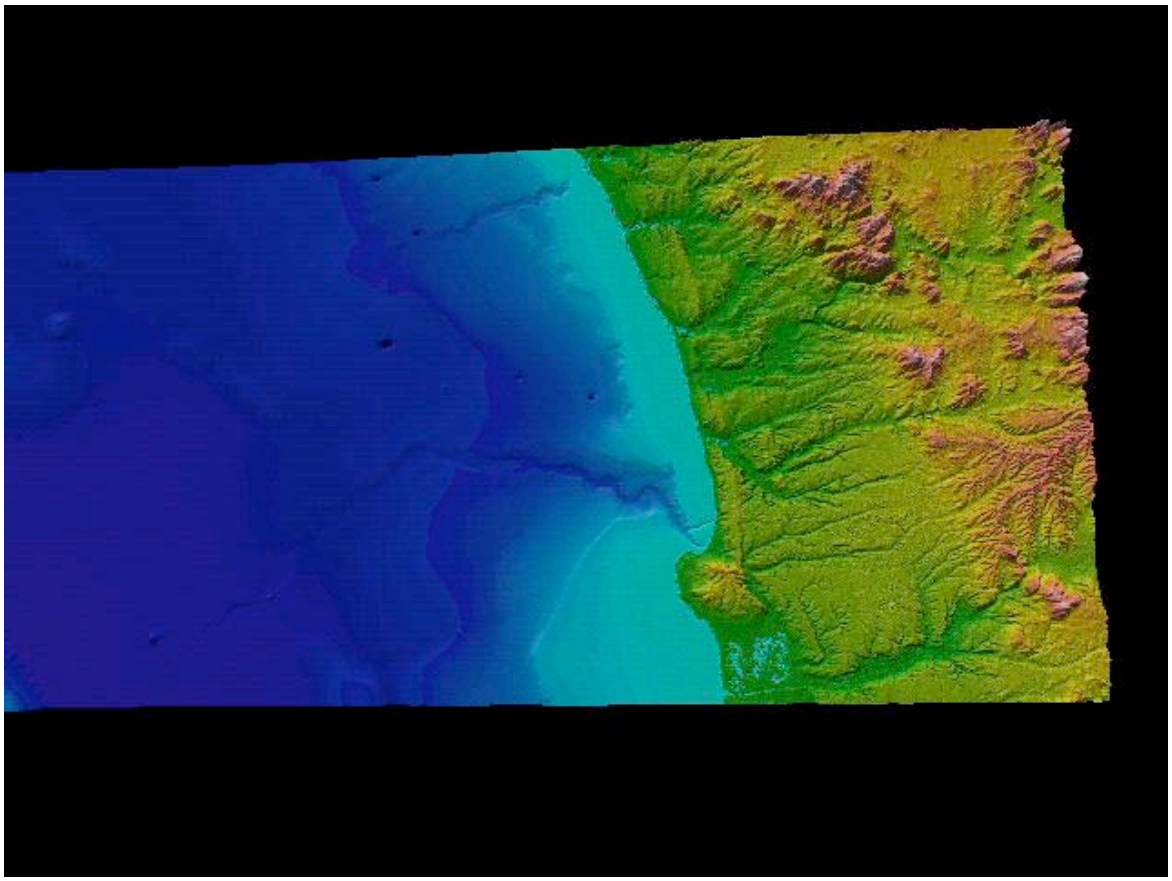
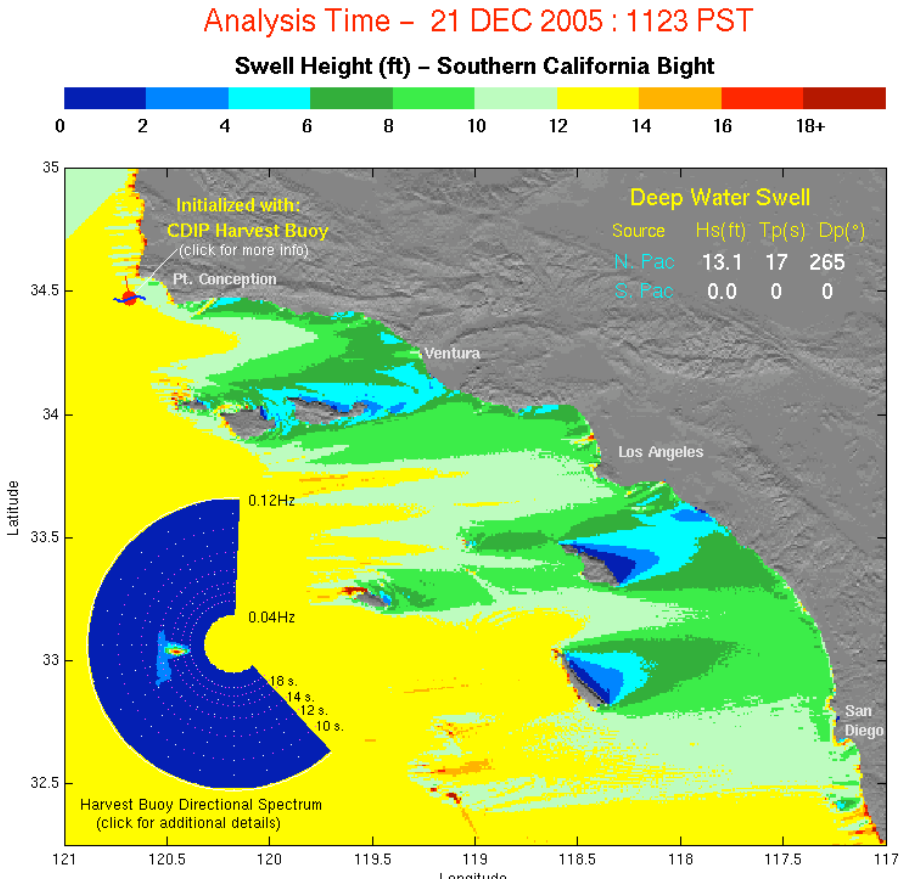


PLATE VIII




Analysis Time – 21 DEC 2005 : 1123 PST
Swell Height (ft) – Southern California Bight
0
2
4
6
8
10
12
14
16
18+
Initialized with:
CDIP Harvest Buoy
(click for more info)
Pt. Conception
Deep Water Swell
Source Hs(ft) Tp(s) Dp(°)
N. Pac 13.1 17 265
S. Pac 0.0 0 0
Ventura
Los Angeles
San Diego
0.12Hz
0.04Hz
18 s.
14 s.
12 s.
10 s.
Harvest Buoy Directional Spectrum
(click for additional details)
Latitude
35
34.5
34
33.5
33
32.5
121
120.5
120
119.5
119
118.5
118
117.5
117

Stn 073: 9-Band Energy

Units: metric Timezone: UTC update

Date/Time (UTC)	Hs (m)	Tp (s)	ENERGY (cm^2) - by period band (sec)								
			22+	22-18	18-16	16-14	14-12	12-10	10-8	8-6	6-
12-21-2005 19:45	1.64	9	129	26	121	292	227	176	311	203	199
12-21-2005 18:45	1.49	15	116	21	134	233	215	172	161	167	172
12-21-2005 17:45	1.51	15	87	27	209	240	153	106	209	170	231
12-21-2005 16:45	1.52	17	121	38	287	201	137	98	184	160	219
12-21-2005 15:45	1.46	9	114	37	120	195	155	122	239	176	182
12-21-2005 14:45	1.35	13	89	49	150	116	203	105	112	159	151
12-21-2005 13:45	1.09	9	48	24	66	49	121	94	126	104	108
12-21-2005 12:45	1.05	9	48	22	34	44	93	107	159	82	95
12-21-2005 11:45	1.05	9	41	20	22	37	104	87	143	122	119
12-21-2005 10:45	1.10	9	31	10	9	53	130	132	177	96	117
12-21-2005 09:45	1.12	9	27	8	7	51	121	102	229	107	133
12-21-2005 08:45	1.00	9	26	7	5	33	71	107	160	104	117
12-21-2005 07:45	1.01	9	26	4	5	35	82	104	151	92	137
12-21-2005 06:45	0.94	9	17	2	3	44	53	95	127	104	102
12-21-2005 05:45	0.86	4	13	1	3	21	45	76	107	84	115
12-21-2005 04:45	0.90	4	12	2	4	17	75	98	105	83	112
12-21-2005 03:45	0.85	9	9	1	3	19	60	77	104	75	99
12-21-2005 02:45	0.92	4	11	1	5	12	75	105	108	103	111
12-21-2005 01:45	0.97	9	11	1	6	21	48	122	170	107	108
12-21-2005 00:45	1.03	11	12	2	6	16	73	153	126	136	140
12-20-2005 23:45	1.05	9	14	2	3	16	77	165	168	112	139
12-20-2005 22:45	1.09	9	25	2	4	14	78	158	171	135	152
12-20-2005 21:45	1.12	9	21	3	3	14	134	133	211	122	150
12-20-2005 20:45	1.10	9	24	3	4	12	143	122	189	108	151

Conclusions

- Ocean waves: force of acceleration is balanced by the force of gravity.
- Wind speed >= wave speed. 17-s period waves require wind speed of 27 m/s = 60 mph.
- Wave speed: $d >> L/2$ waves are dispersive; $d << L/2$ speed depends on depth.
- Refraction is important when $d < 5L$.

Lab 1. Wave period

This lab should be performed when the wind speed is low so the swell is apparent. Morning before 10 AM is the best time. This can be done at SIO or the Blacks overlook (UCSD Property).

A. Describe the setup of the experiment. Where are you? Where is the surf? How are you measuring the waves?

B. Perform experiment(s). Record the time as the crest of each wave passes a particular pier piling (> 50 waves).

D. Make a histogram of the time interval between wave crests.

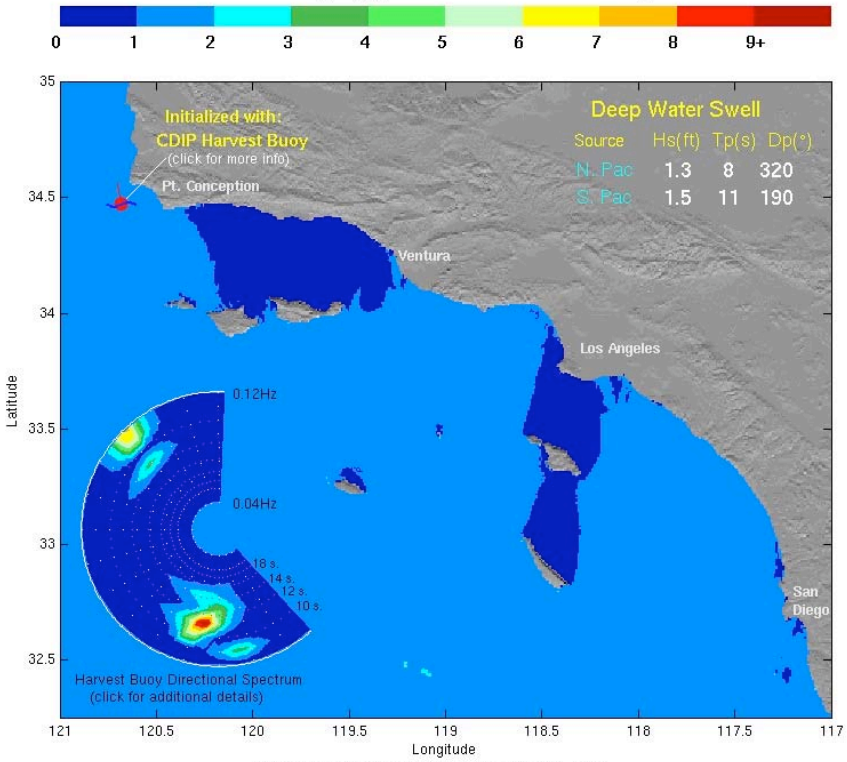
E. Calculate the median and mean period of the swell.

F. How does this compare with the values on the web site (http://cdip.ucsd.edu). (Go to models and then Southern California. Note the site saves the data from earlier that day.) Do the results agree? If they don't agree, what are some possible reasons for the disagreement?

The lab writeup should be neat, clear, and concise.

Analysis Time – 11 OCT 2006 : 1323 PST

Swell Height (ft) – Southern California Bight



Additional Information @ http://cdip.ucsd.edu/

CDIP recent observed 073 pm 10/11/2006 04:08 PM

The Coastal Data Information Program
Integrative Oceanography Division
SCRIPPS Institution of Oceanography
CDBW USACE

Recent | Historic | Documents

Station ID search

news | contact us | home

observed | nowcast models | forecast models

Station 073 - info
SCRIPPS PIER, LA JOLLA CA

Data Tables
- Parameter
- 9-band energy

Daily & Weekly Plots
- Waves - 1 day
- Waves - 1 week
- Wind
- Temperature

Monthly Plots
- Compendium plot
- Mountain plot
- Temperature plot
- Wind/Pressure plot

Latest Data Run
- Spectral plot
- Spectral file

Descriptions/Help
Historic & Metadata

Station: 073

Stn 073: Parameters Units: metric Timezone: UTC update

Date/Time (UTC)	Hs (m)	Tp (s)	Ta (s)	Depth (m)	Wind sp (m/s)	Wind dir (deg)	Air temp (C)
10-11-2006 21:45	0.30	8.26	6.32	6.88	2.0	292.0	20.6
10-11-2006 20:45	0.34	8.83	6.38	7.15	3.1	313.0	20.1
10-11-2006 19:45	0.31	9.48	6.66	7.32	2.5	309.0	20.4
10-11-2006 18:45	0.31	8.83	6.58	7.38	2.2	317.0	19.9
10-11-2006 17:45	0.33	9.14	6.28	7.31	1.5	358.0	20.8
10-11-2006 16:45	0.31	9.48	5.78	7.14	3.1	354.0	18.2
10-11-2006 10:53	0.39	3.88	4.97	6.52	2.2	27.0	16.7
10-11-2006 09:45	0.42	3.32	4.65	6.60	1.7	352.0	17.1
10-11-2006 08:45	0.48	3.88	4.67	6.65	1.6	324.0	17.2
10-11-2006 07:45	0.52	3.82	4.49	6.63	0.8	217.0	17.3
10-11-2006 06:45	0.49	3.82	4.47	6.51	2.6	360.0	17.4
10-11-2006 05:45	0.54	3.37	4.33	6.33	3.2	344.0	17.4
10-11-2006 04:45	0.50	3.51	4.23	6.09	4.8	353.0	17.4
10-11-2006 03:45	0.48	3.08	4.13	5.88	2.7	300.0	17.2
10-11-2006 02:45	0.40	3.32	4.39	5.72	4.2	304.0	17.4
10-11-2006 01:45	0.39	8.53	4.76	5.66	4.4	324.0	17.7
10-11-2006 00:45	0.35	8.83	5.17	5.71	5.1	330.0	18.1
10-10-2006 23:45	0.33	9.14	5.78	5.91	4.4	321.0	19.8

CDIP's major funding contributors are the US Army Corps of Engineers and the California Department of Boating and Waterways.