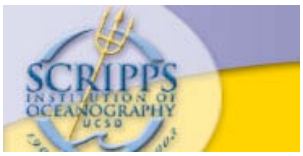
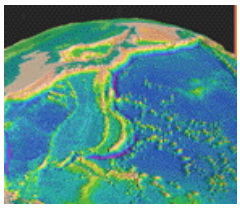


Physics of Surfing Waves

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

Exercises: April 15

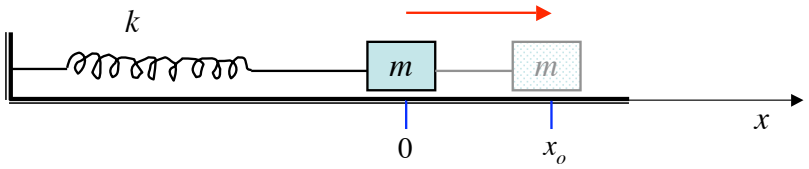
(each problem is covered in class today)

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)?

harmonic oscillator



$$m\frac{d^2x}{dt^2} = -kx$$

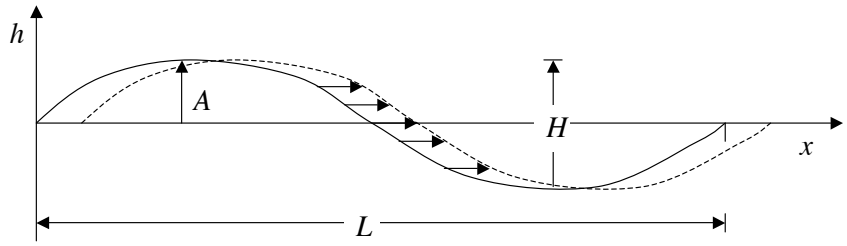
m - mass
k - spring constant

force from acceleration	=	restoring force of spring

guess solution $x(t) = x_o \cos \omega t$

How do we solve for ω?

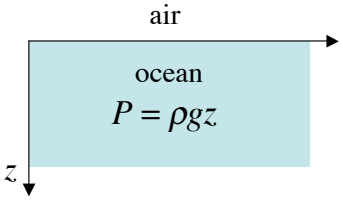
wave characteristics



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

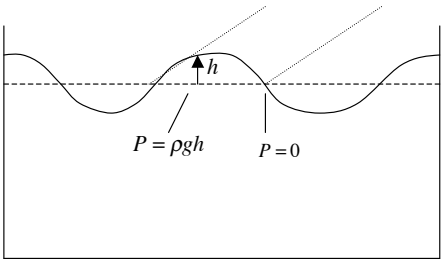
L - wavelength
A - amplitude
H - height
T - period (5 - 18 s)

deep ocean waves



ρ - density (kg m^{-3})
g - acceleration of gravity (9.8 m s^{-2})
z - depth (m)

What are the units of pressure?



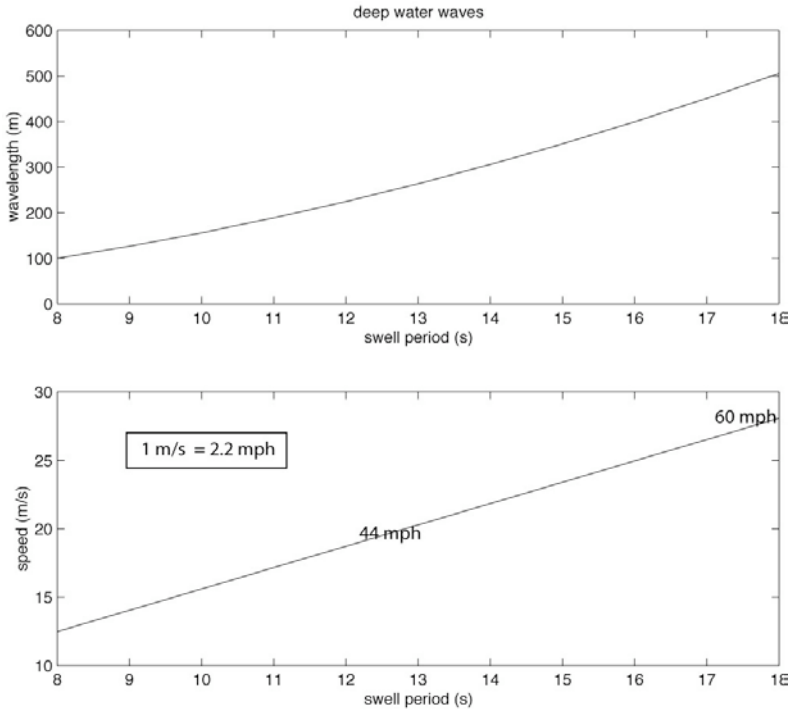
restoring force = $-\rho g h$

acceleration force $= \rho \frac{L}{2\pi} \frac{d^2 h}{dt^2}$

$$\rho \frac{L}{2\pi} \frac{d^2 h}{dt^2} = -\rho g h$$

guess: $h(t) = A\cos\omega t$

What is ω?


deep water waves
wavelength (m)
swell period (s)
speed (m/s)
1 m/s = 2.2 mph
44 mph
60 mph
swell period (s)

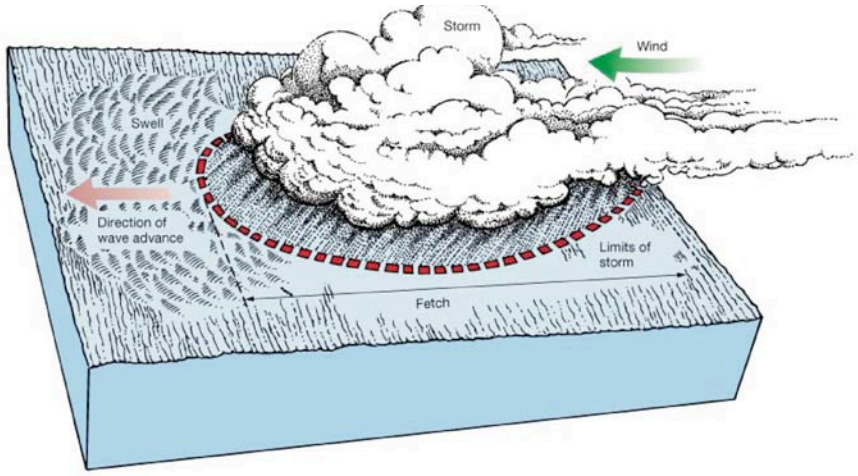
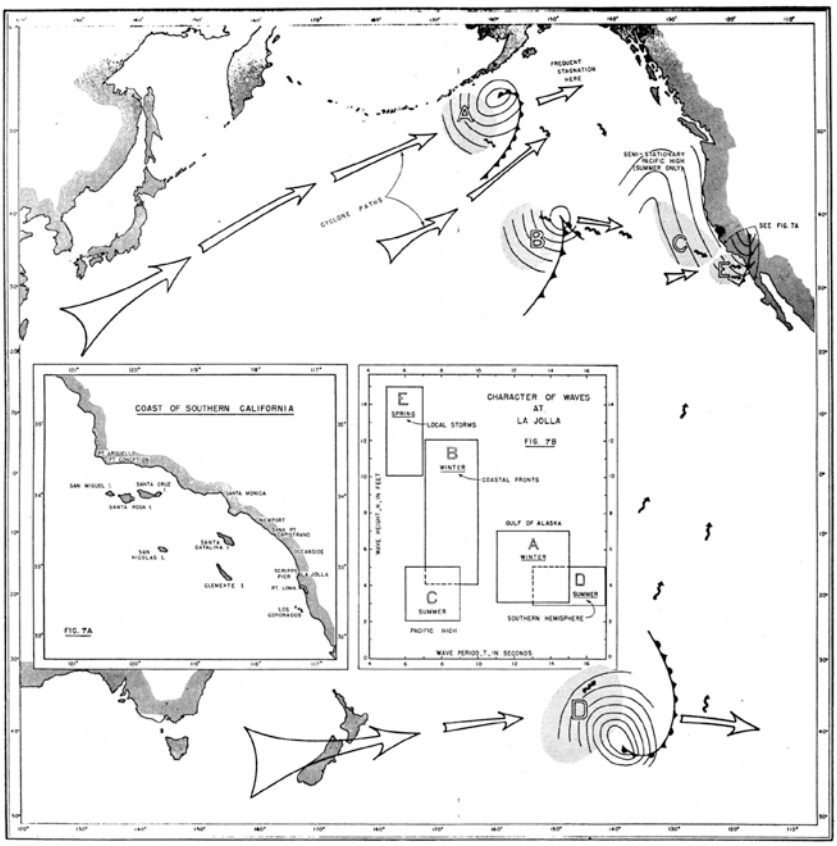
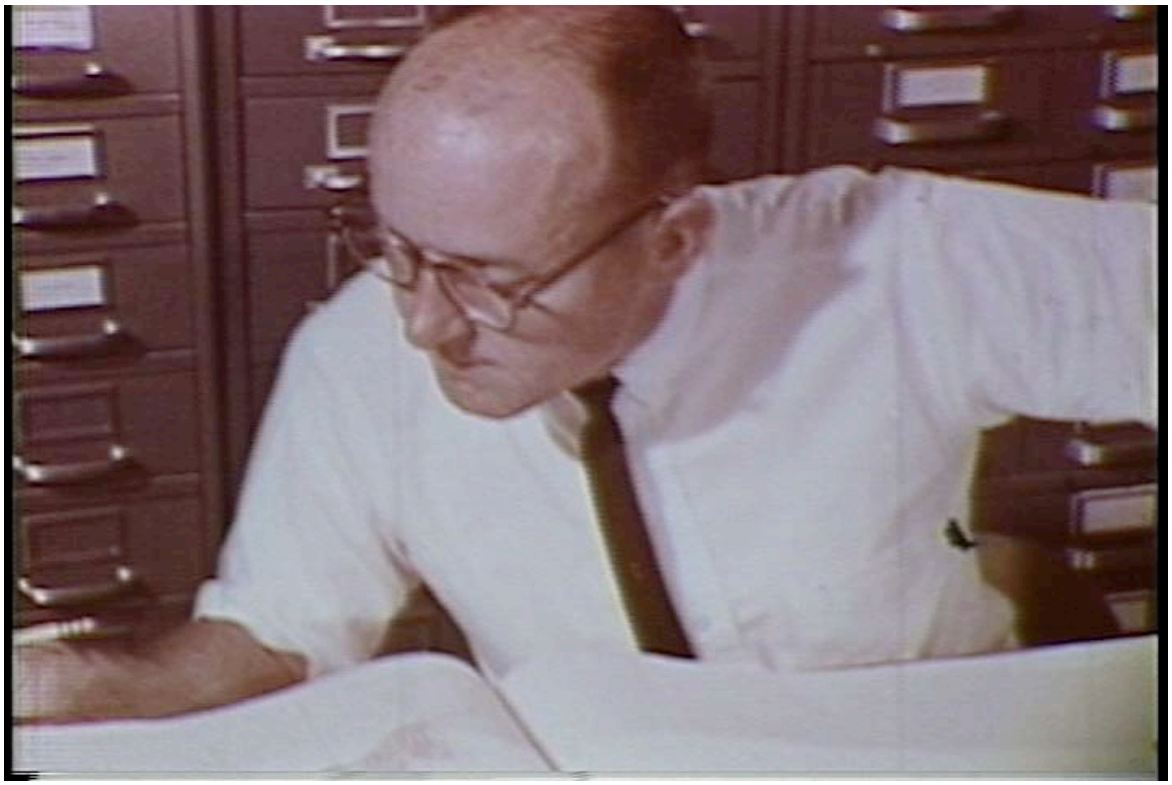


Table 8–1 Description of a fully developed sea for a given wind speed.

Wind speed in km/h (mi/h)	*Average height in m (ft)*	*Average length in m (ft)*	*Average period in sec*	*Highest 10% of waves in m (ft)*
20 (12)	0.33 (1.0)	10.6 (34.8)	3.2	0.75 (2.5)
30 (19)	0.88 (2.9)	22.2 (72.8)	4.6	2.1 (6.9)
40 (25)	1.8 (5.9)	39.7 (130.2)	6.2	3.9 (12.8)
50 (31)	3.2 (10.5)	61.8 (202.7)	7.7	6.8 (22.3)
60 (37)	5.1 (16.7)	89.2 (292.6)	9.1	10.5 (34.4)
70 (43)	7.4 (24.3)	121.4 (398.2)	10.8	15.3 (50.2)
80 (50)	10.3 (33.8)	158.6 (520.2)	12.4	21.4 (70.2)
90 (56)	13.9 (45.6)	201.6 (661.2)	13.9	28.4 (93.2)

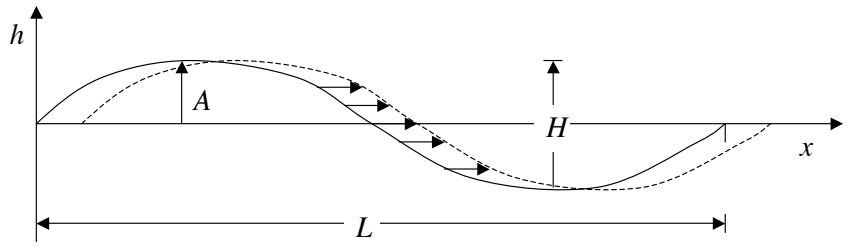
Munk, W. H. and M. A. Traylor,
Refraction of Ocean Waves,
J. Geology, v. LV, No. 1, 1947





wave generation

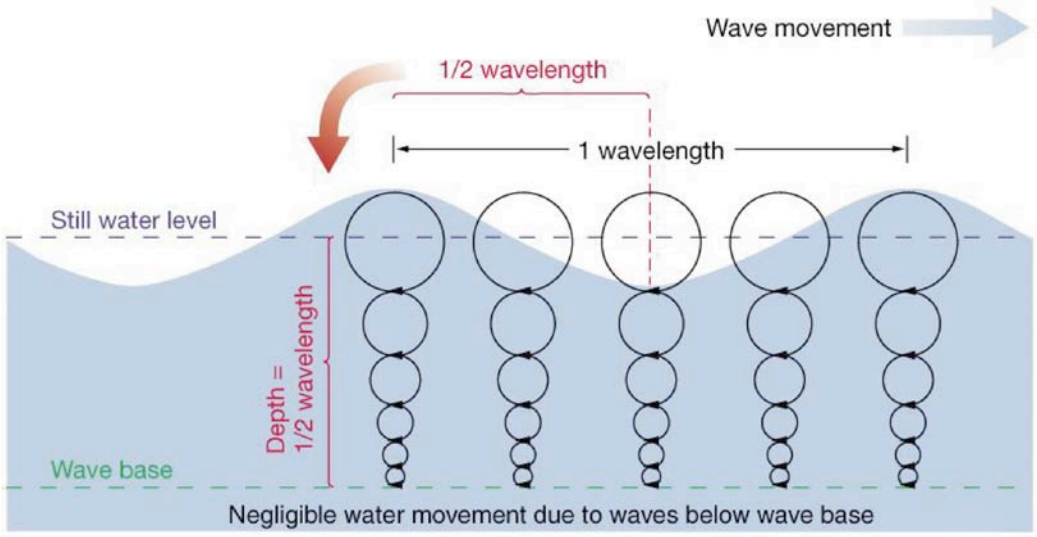
- generated by storms at sea
- far from the storm they are sinusoidal



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

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

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



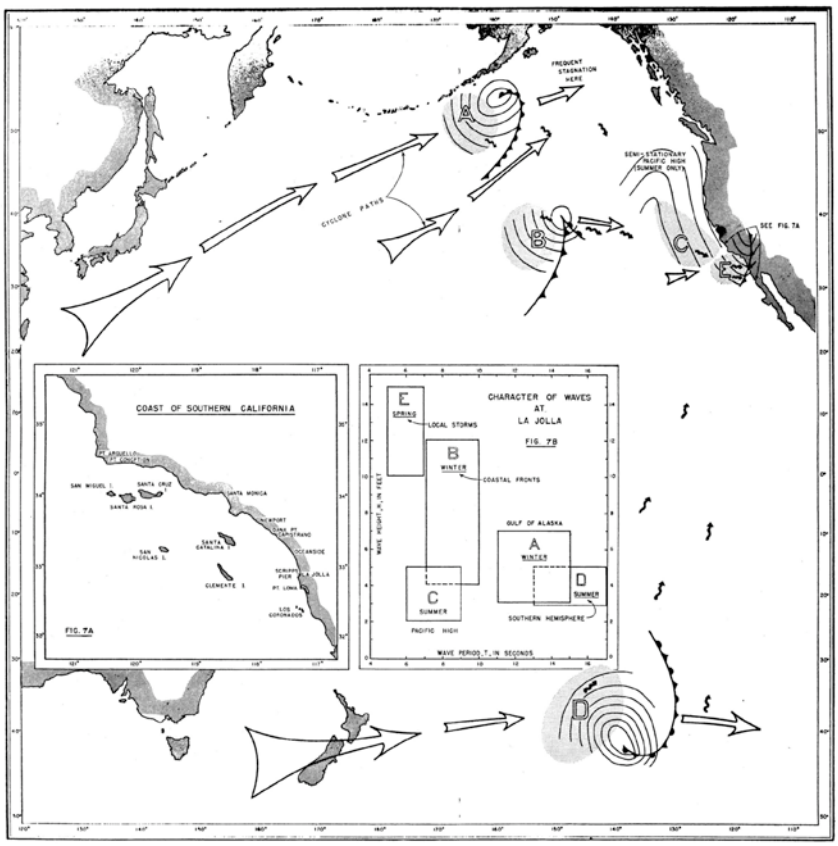
Airy solution

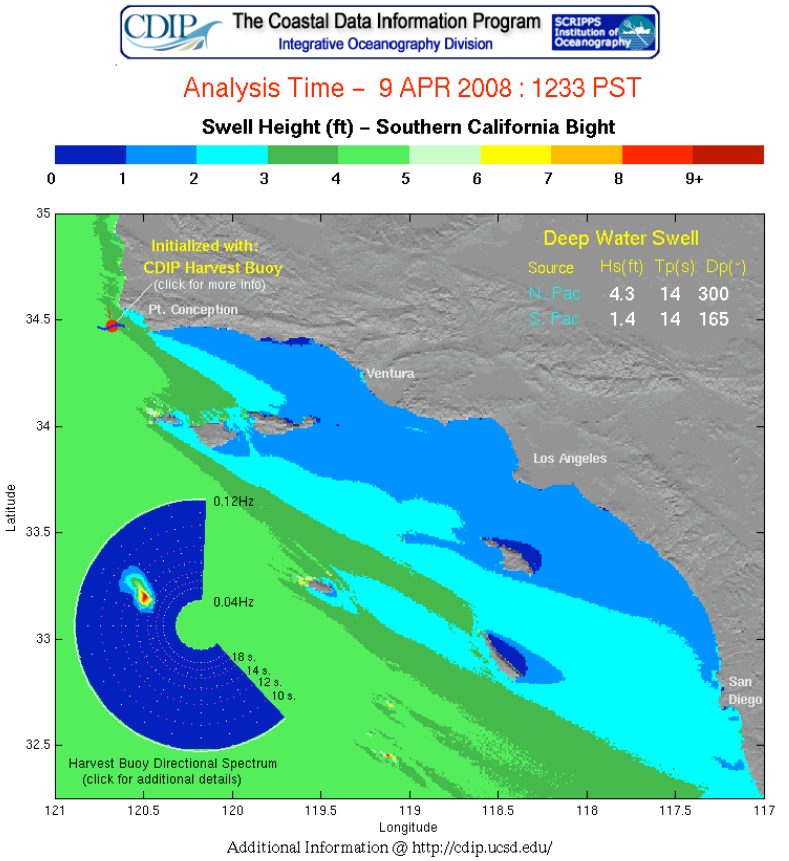
$$c(d) = \left[\frac{gL}{2\pi}\tanh\left(\frac{2\pi d}{L}\right)\right]^{1/2}$$

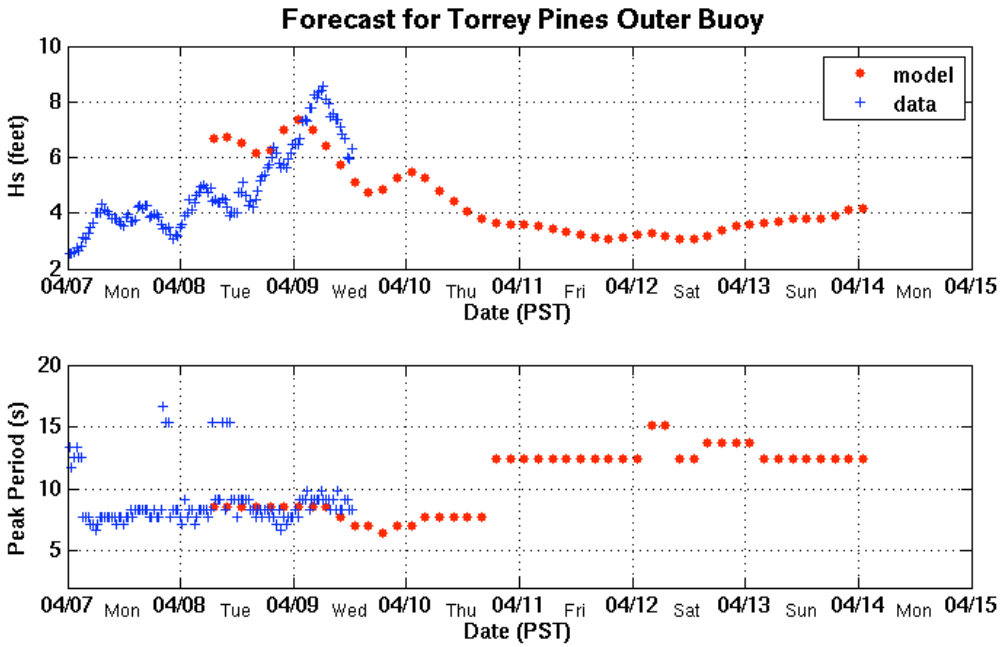
L - wavelength
g - acc. gravity
d - ocean depth

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

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

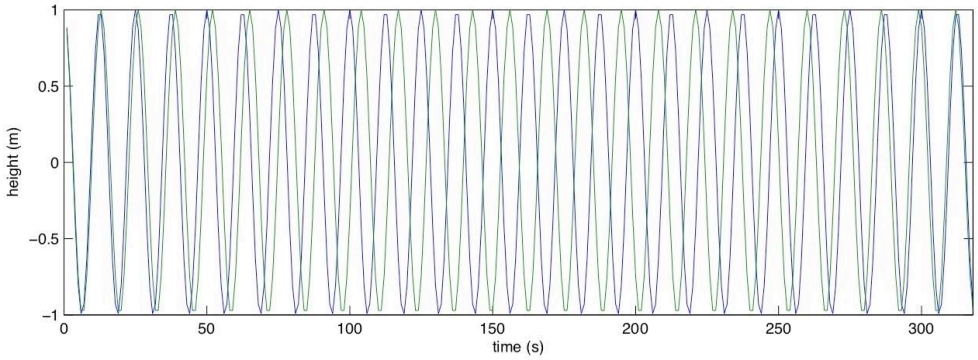


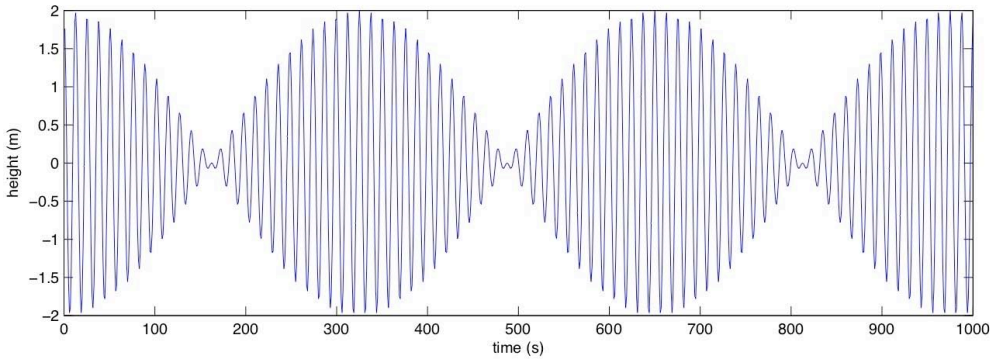




Sets

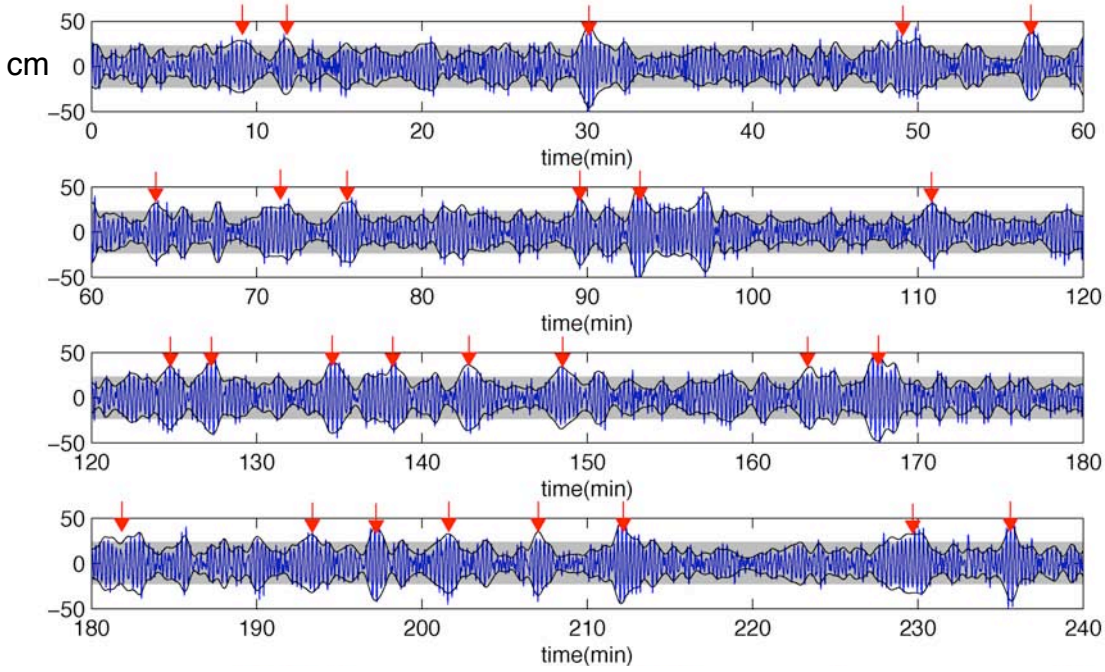
- Are sets real? How is a set defined?
- More analysis of buoy data can provide characteristics of sets.
- Why do waves come in sets?



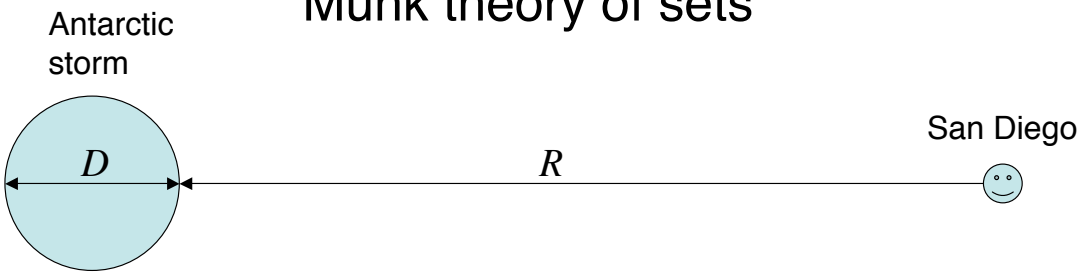


OCEANSIDE OFFSHORE, CA - Station: 04501
Water depth(m): 220.00
August 3, 2007

Average time between sets
8.8 min



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.

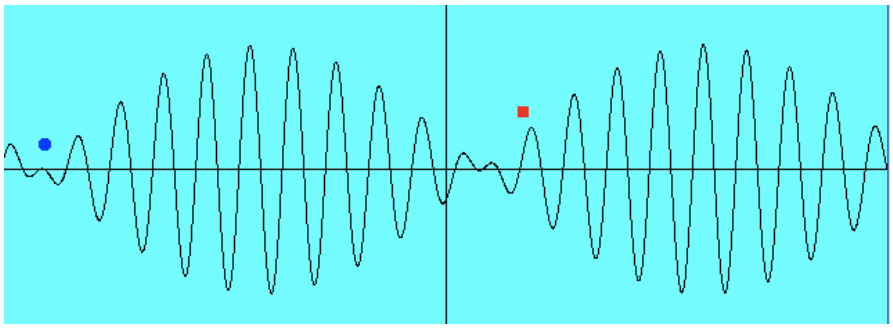
$$t_1 - t_o = 2R/c_1$$

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

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

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

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



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

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

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!

Conclusions - Waves

- 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:
  deep water (d >> L/2), speed depends on period (dispersive)
  shallow water (*d << L/2),* speed depends on depth (refraction)
- Refraction is important when $d < L$ or about 200 m = 650 feet
- Surfers believe sets are real but the data are not clear. Why?