Waves

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Waves

- Sound Waves
- Light Waves
- Surface Waves
- Radio Waves
- Tidal Waves
- Instrument Strings

<u>How are they Generated?: Initial disturbance</u>

Finger pluck, nuclear reaction, pressure change, friction between tectonic plates.

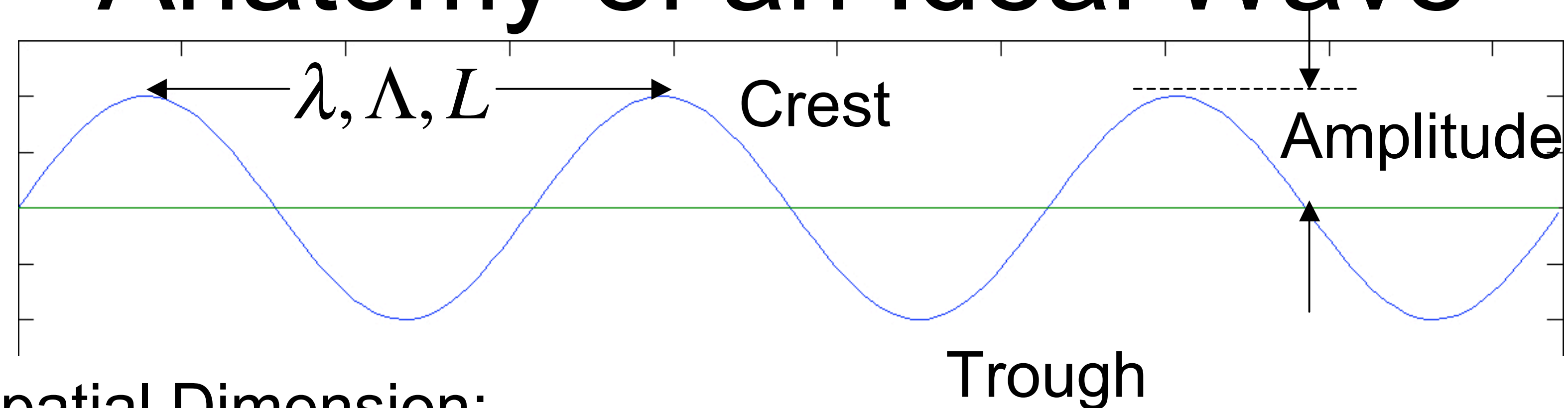
<u>How fast do they travel?: A Finite Speed!</u>

Depends on the medium (tension, density, depth)

(Careful! Some can travel in a vacuum)

Can depend on properties of the wave (amplitude, length)

Anatomy of an Ideal Wave



Spatial Dimension:

λ, Λ, L (Wavelength) [m]

$k = \dfrac{2\pi}{\Lambda}$ (Wavenumber) [1/m]

Temporal Dimension:

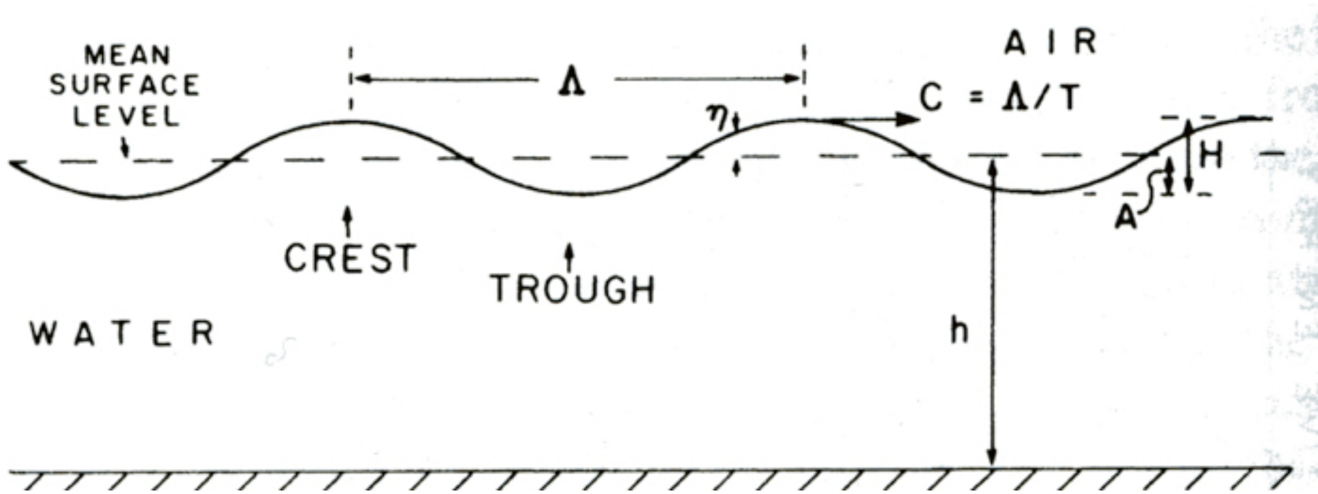
T (Period - time between successive crests measured by fixed observer) [s]

$\omega = \dfrac{2\pi}{T}$ (Angular Velocity) [1/s] (strictly [rad/s])

Celerity: c = L/T

Amplitude can be described equation: $a(x,t) = A\cos(kx - \omega t)$

Ocean Surface Gravity Waves



Restoring Force: Gravity

Initial Perturbation: Astronomical Forcing, Wind, Seismic, etc.

Two Key Ratios control wave dynamics:

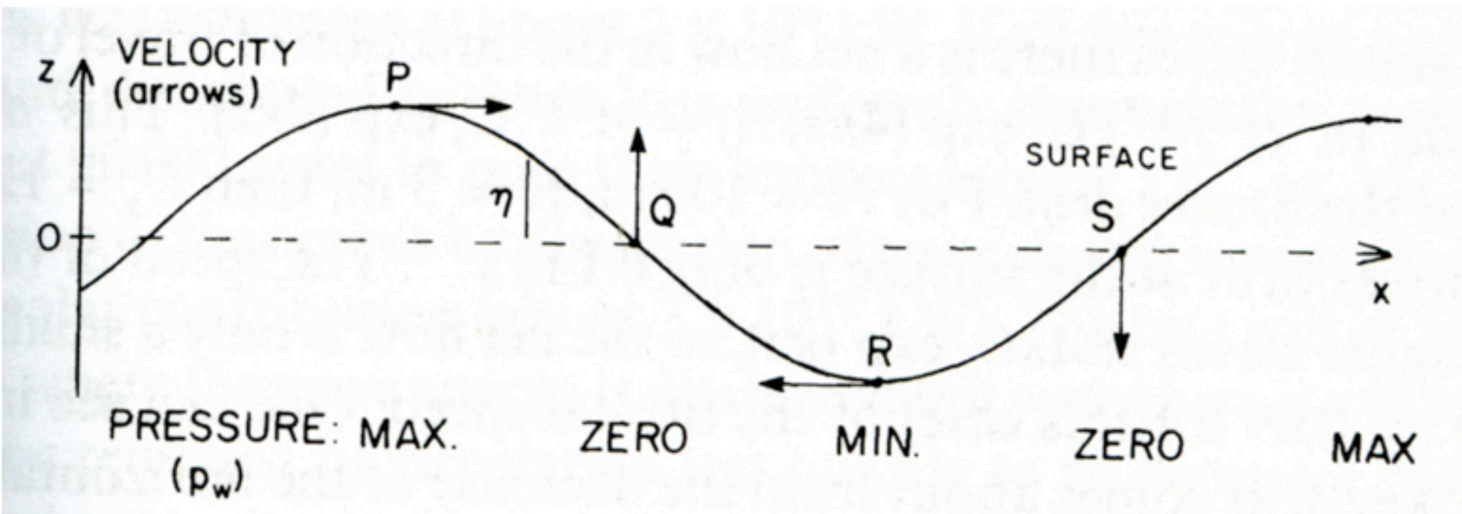
1.) h/L   The ratio of depth to wavelength
2.) H/L   The ratio of amplitude to wavelength

Small Amplitude Waves

We assume H/L << 1 - This “small amplitude approximation” leads to simplified analytical solutions for height and velocity:

Example:
Stokes Wave with H>>L:

$$\eta(x,t) = A\cos(kx - \omega t)$$
$$u(x,t) = A\omega e^{kz}\cos(kx - \omega t)$$
$$w(x,t) = A\omega e^{kz}\sin(kx - \omega t)$$



Particles follows orbital paths but undergo no net motion
Orbits decrease with depth
At about 1/2 L, cannot feel presence of wave above
In reality some net motion (Stokes Drift)

Long vs. Short Waves

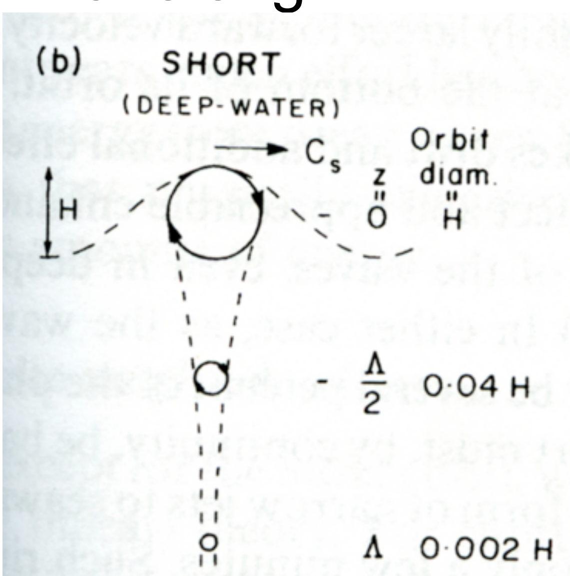
We maintain our small amplitude approximation and look at the limits of h/L

L << h (“short or deep wave”)

Wave cannot feel bottom

Orbits are circular

Dispersive: speed dependent on wavelength

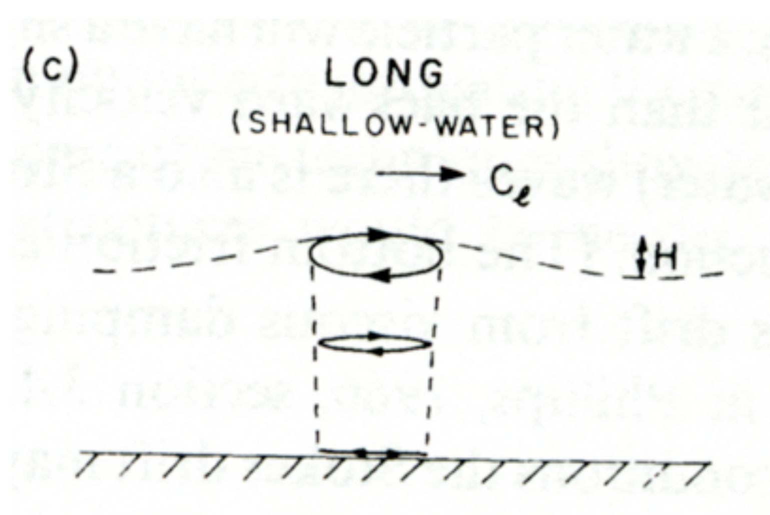


L > h (“long or shallow wave”)

Wave interacts with bottom (can suspend sediment)

Non-dispersive

Orbits are elliptical (flat)



Dispersion, Celerity, and Energy

$\omega^2 = gk\tanh(kh)$ General dispersion relationship for surface gravity waves

$\omega^2 = gk$ Deep water wave limit (h >> L)

$\omega^2 = gk^2 h$ Shallow water wave limit (h < L)

$c = \frac{\omega}{k} = \sqrt{\frac{g}{k}}$ Deep water celerity: depends on properties of the wave (wavelength)!

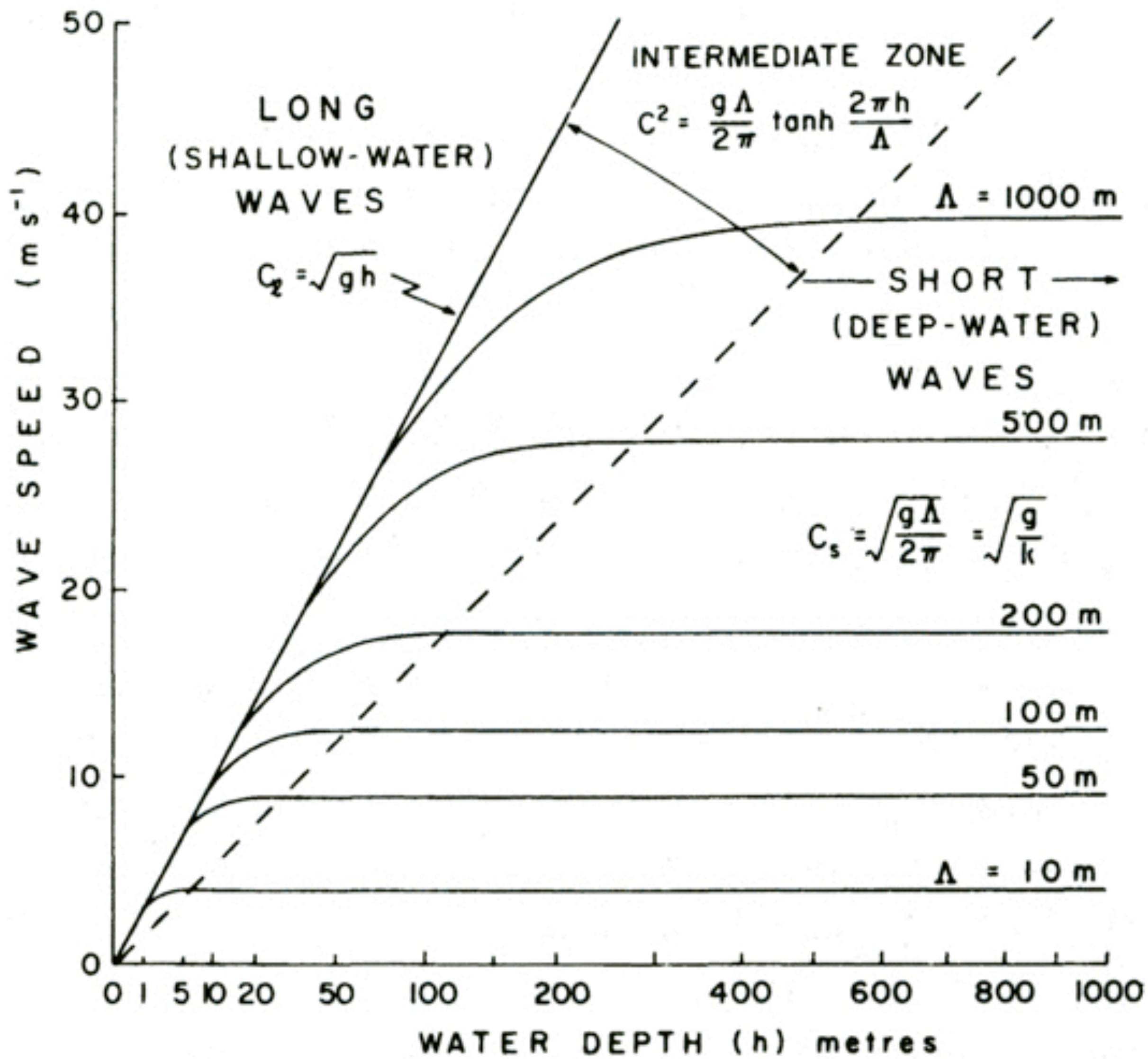
$c = \frac{\omega}{k} = \sqrt{gh}$ Shallow water wave celerity: depends only on the medium (square root of depth)

$c_g = \frac{\partial \omega}{\partial k}$ Group Velocity, This is the speed at which Energy is carried!

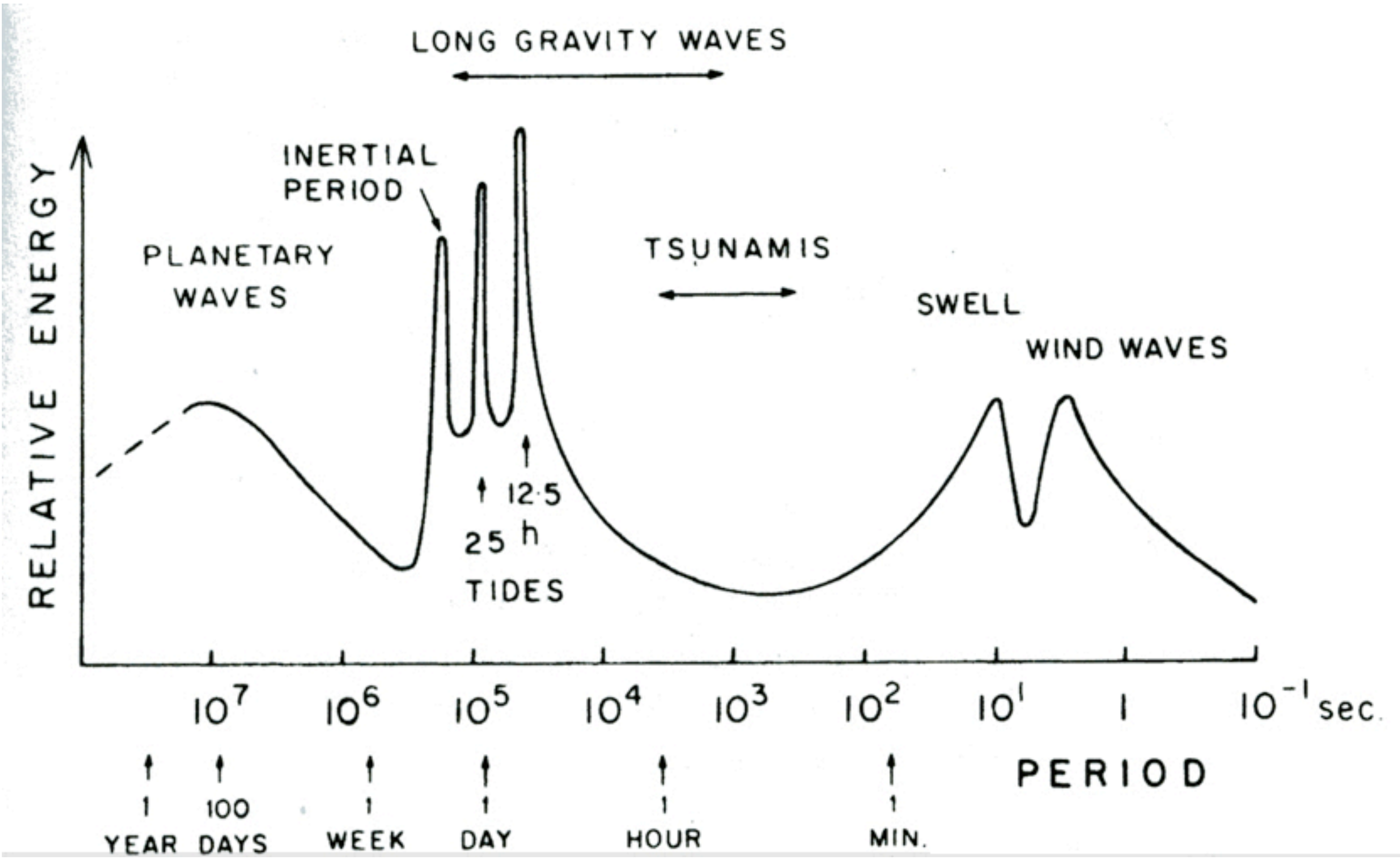
$c_g = \frac{g}{2\omega} = \frac{c}{2}$ Group velocity is 1/2 the wave celerity for deep water waves

$c_g = \sqrt{gh} = c$ Group velocity and celerity are the same for shallow water waves.

Wave Speed vs. Depth



Energy Spectrum in the Ocean



- Today We will Focus on < 1 minute Period

Wind -Driven Surface Waves

- When most people think about ocean waves, they are thinking about wind-driven waves These waves are deep water (short) waves except near the beach.
- Primary source of energy: Wind
- Waves can travel very far (entire ocean basins) with little decay.
- Primary dissipation is bottom friction (minimal except nearshore), breaking/whitecapping, and internal friction

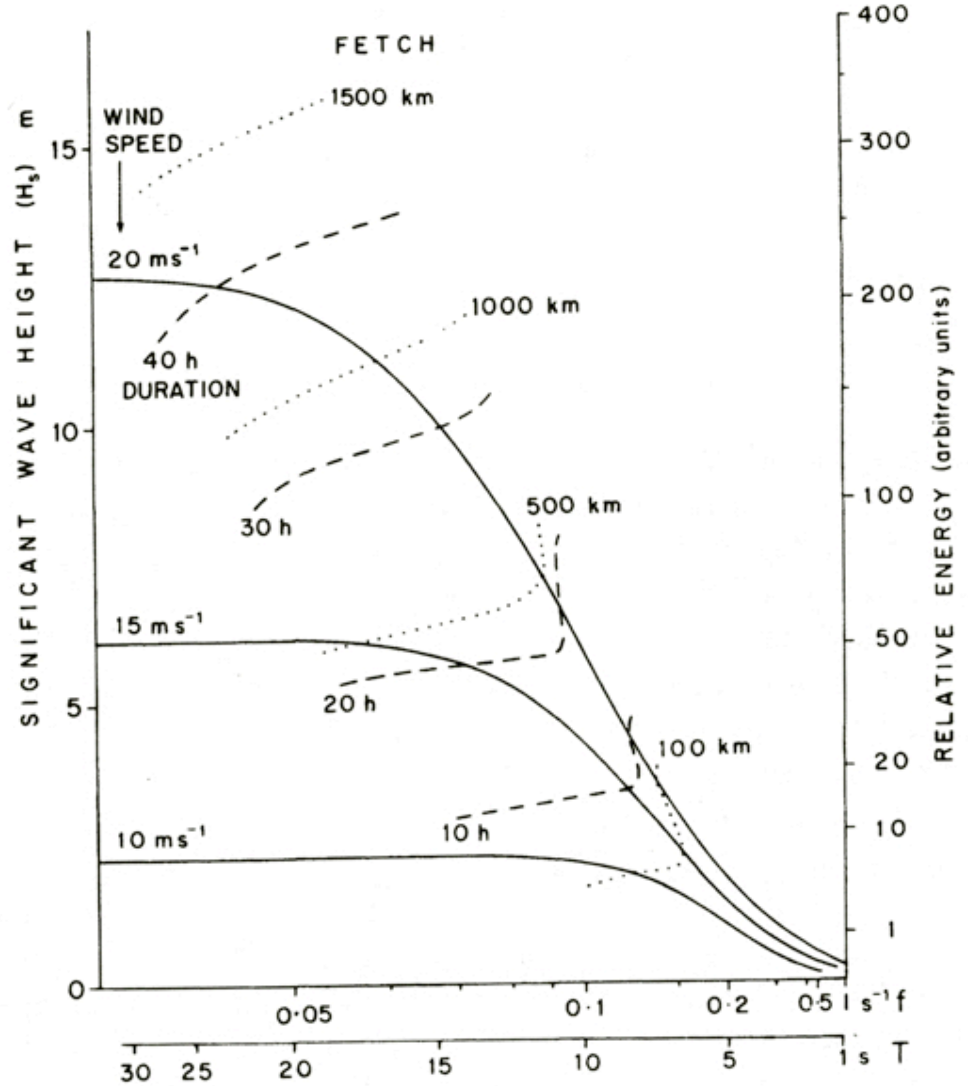
What controls the wave state?

Important Variables:

- Wind Stress
- Time
- Fetch

Note

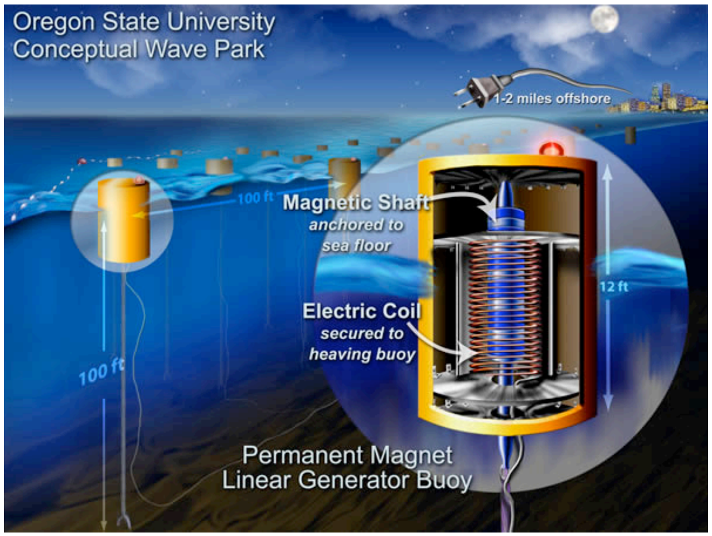
- Amplitude Asymptotes
- Lakes have short waves
- Speed/Stress relationship is very complex



Dispersion - Implications

- Storm - longest waves arrive at the coast first
- Period will change as storm approaches (surfers know this)
- In a group of waves of similar wavelength, the energy will travel at 1/2 the speed of individual waves
- Traveling with the group, waves appear near the back, travel through the group and fall out at the front
- Waves that travel from storms far away are called “swell”, as opposed to “wind-sea” which are waves generated locally.
- Separating these two from measurements can be tricky.

Wave Power $P = \frac{\rho g^2}{64\pi} H_{m0}^2 T$



Generator Buoys

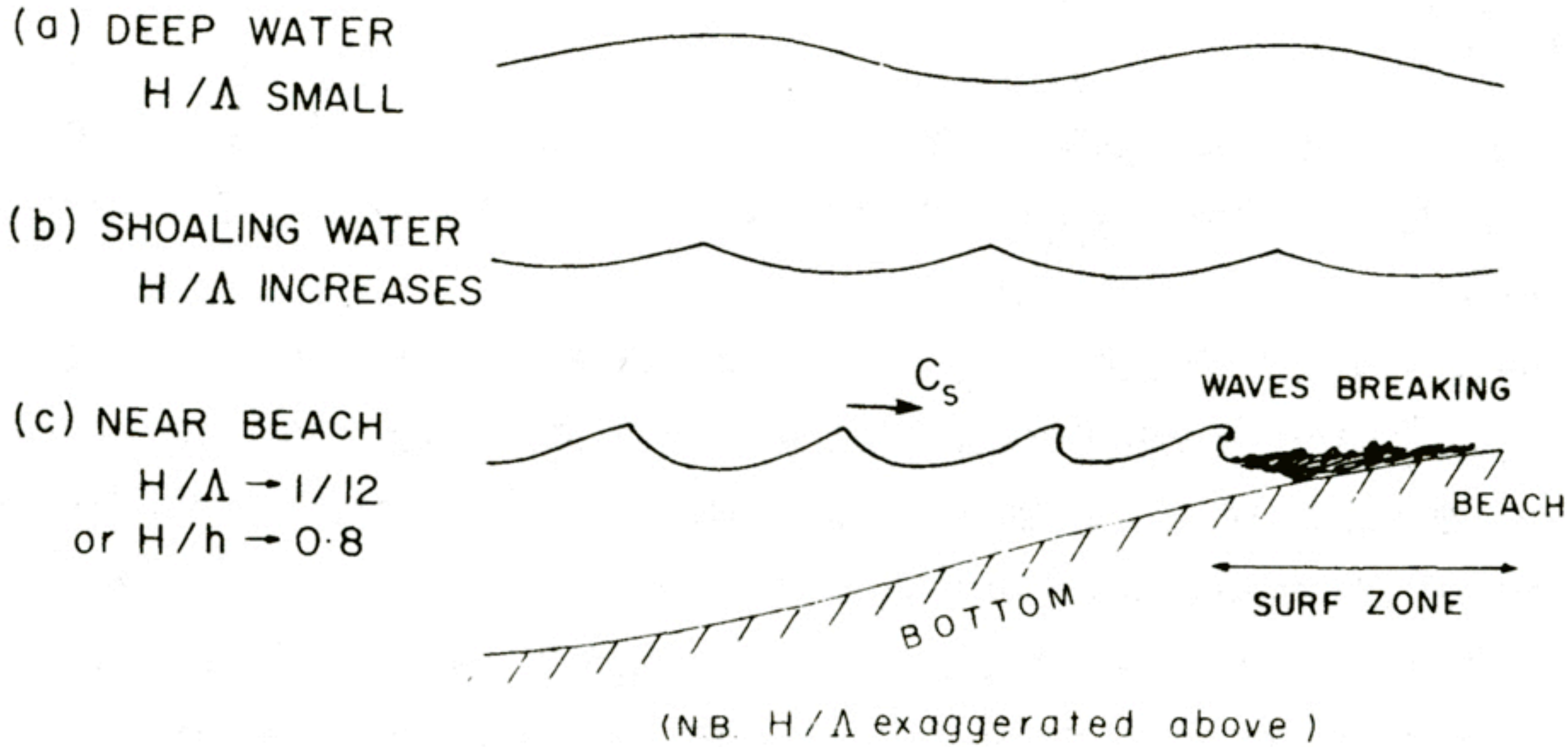
Useful Resource: ~2 TW

2005 World Consumption ~15 TW

Limpet

Pelamis (already operational)

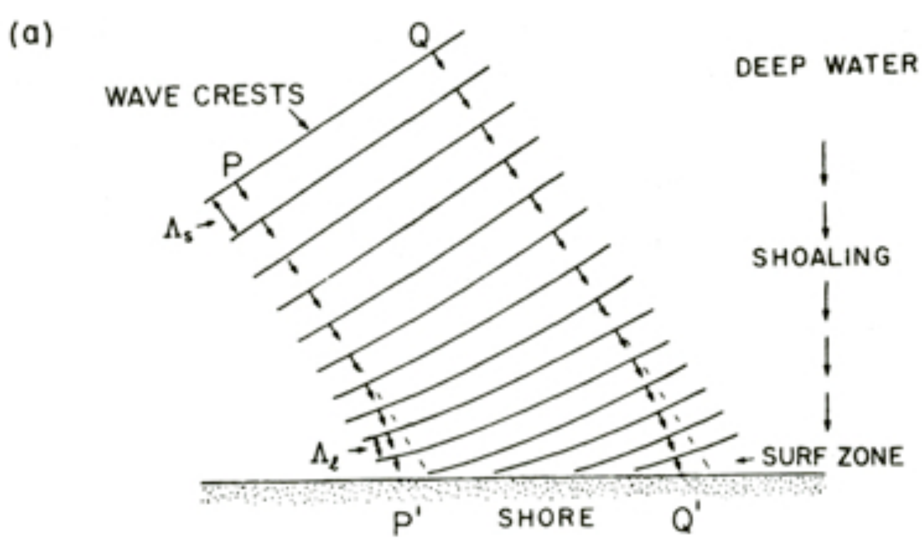
What happens at the Coast?

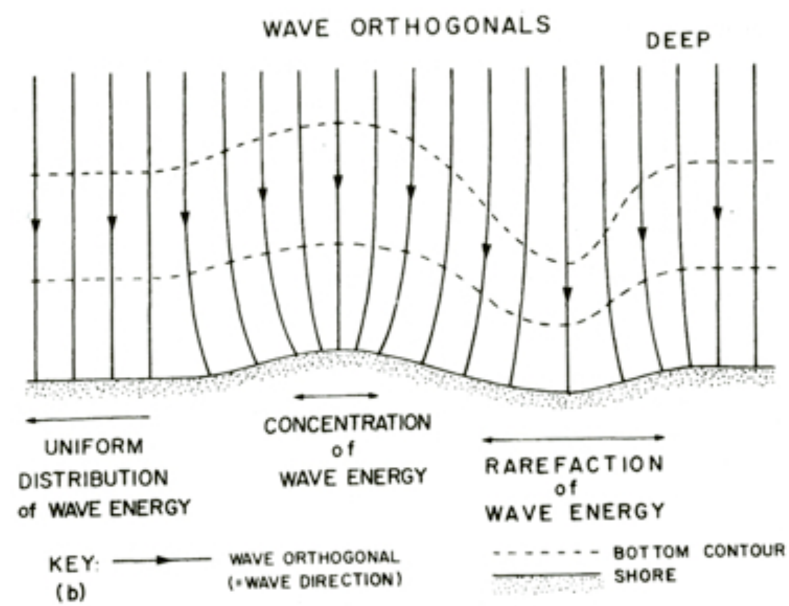


- *Energy flux (rate of wave energy passing a fixed point at a given time) is constant: Wavelength Decreases*
- *Our small amplitude approximation fails: These waves are nonlinear*

Refraction

Waves at oblique angle: Shallow side will slow down, wave will turn towards the beach.

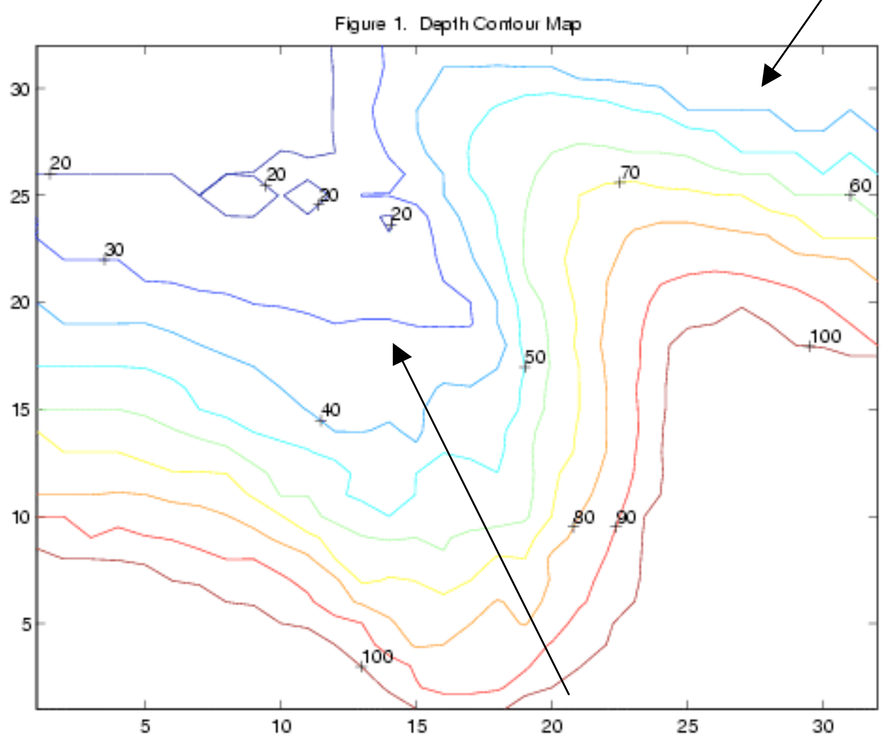




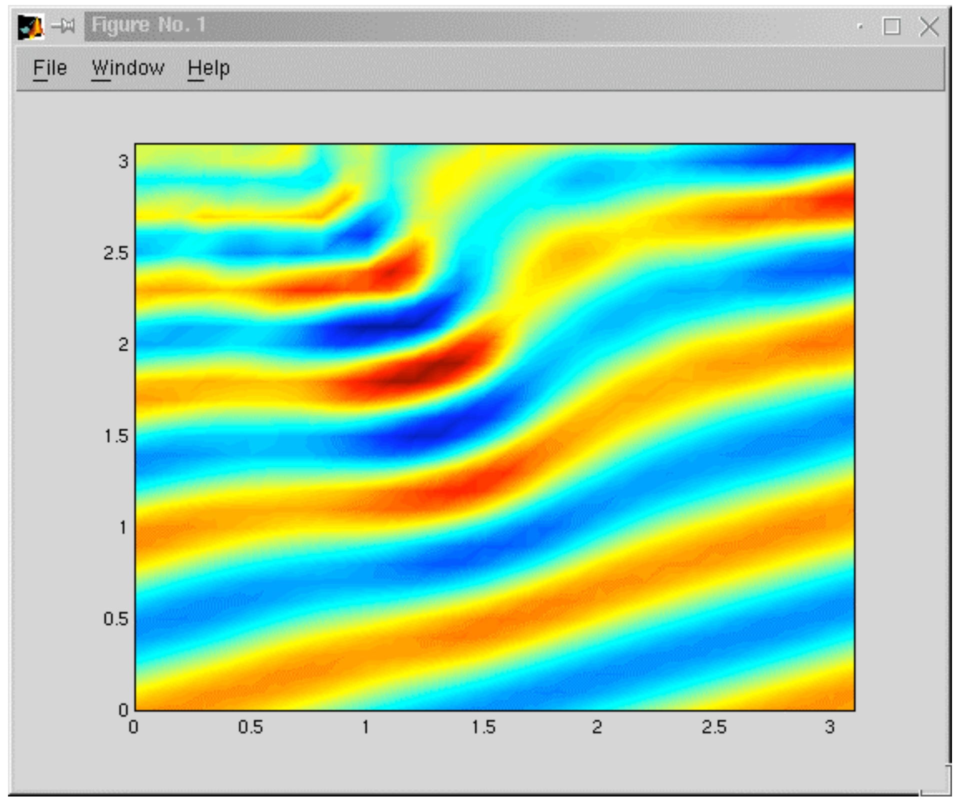
Refraction: Peahi

A steep, lobed bank amplifies the pacific swell (not Wellfleet)

Computations using REFDIF at U.DEL



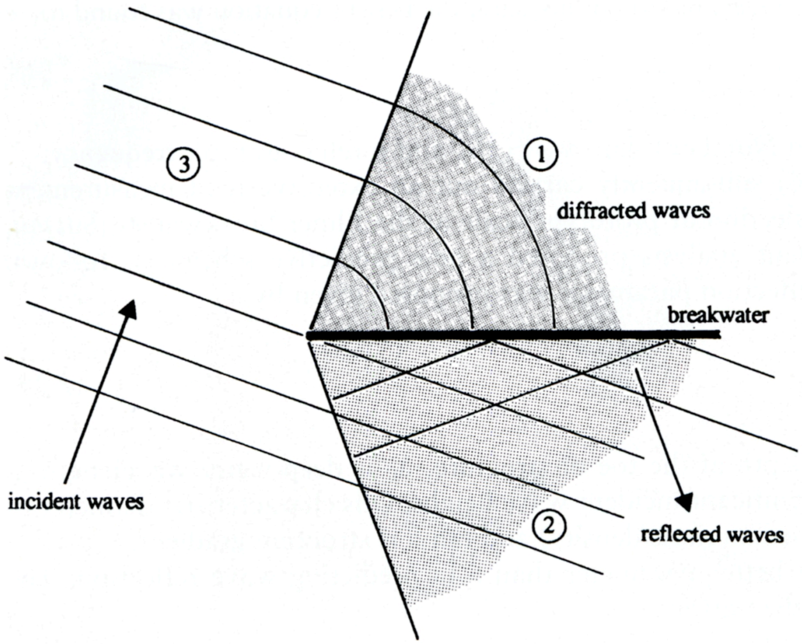
Bathymetry



Wave Height

Diffraction

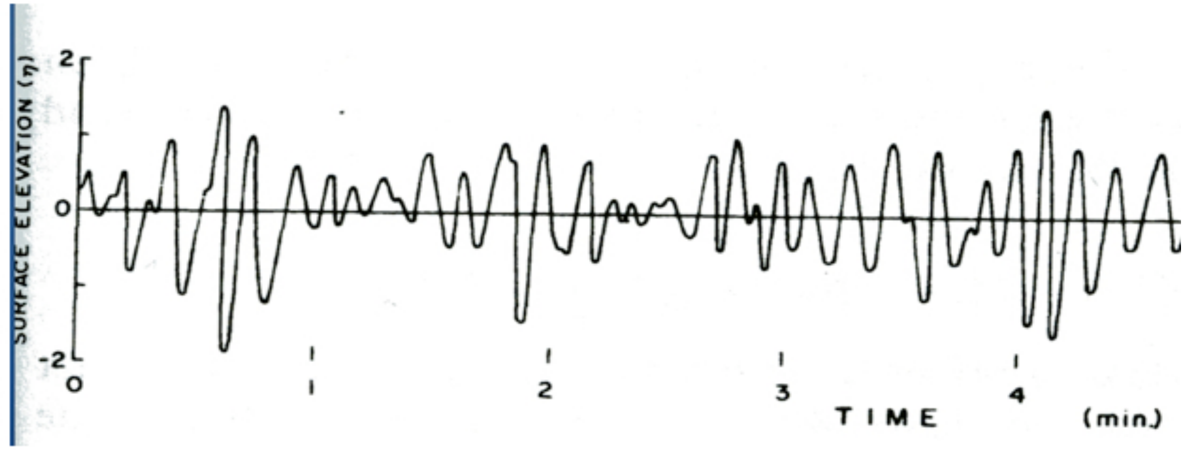
The tendency for waves to bend around obstructions. applicable to sound waves ,light waves, wind driven waves, etc.



Wave-Current Interaction

- Shallow Water: c = $(gh)^{(1/2)}$: relative to the speed of the water.
- What if the current $u > (gh)^{(1/2)}$ and moves in the opposite direction? *Waves can't propagate upstream!, Like walking on a treadmill slower than the belt speed.*
- Waves entering area of opposing current slow down, shorten, and steepen (think: waves at the beach).
- River mouths (e.g. Columbia), and areas of strong tidal flows can generate some nasty conditions.

Reality: Many waves of different wavelengths/heights superimposed



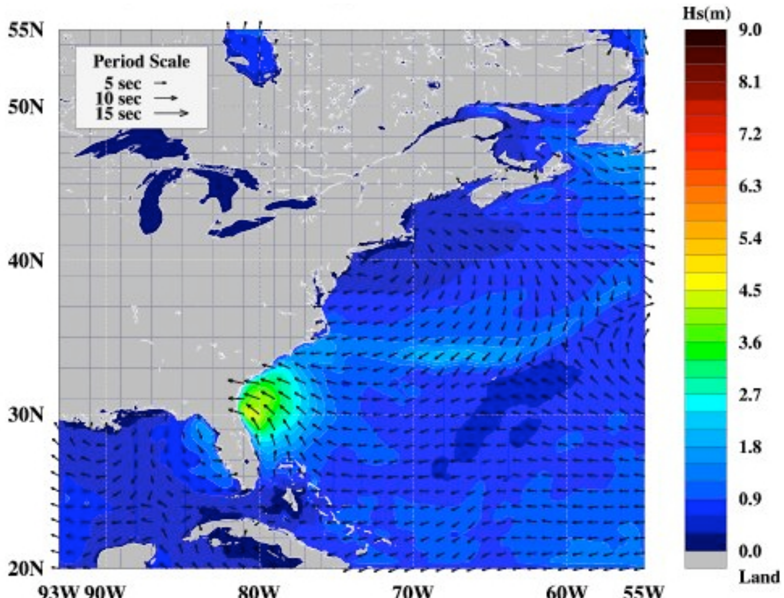
<u>We need to use statistics to describe wave state:</u>

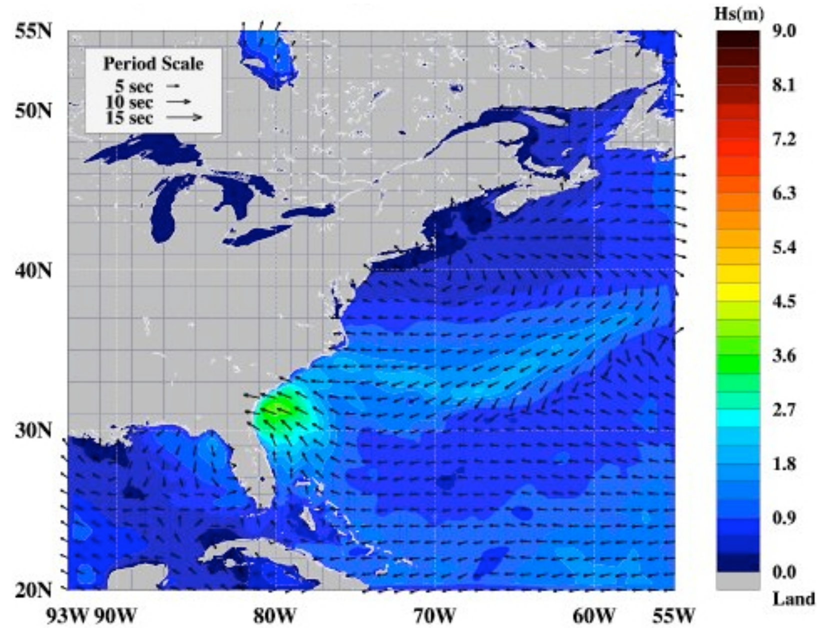
- Period (T_p)- Average period over some time
- Significant Wave Height (H_s) - Average **Height** of the largest 1/3 of the observed waves
- Direction - More difficult to measure, not always available

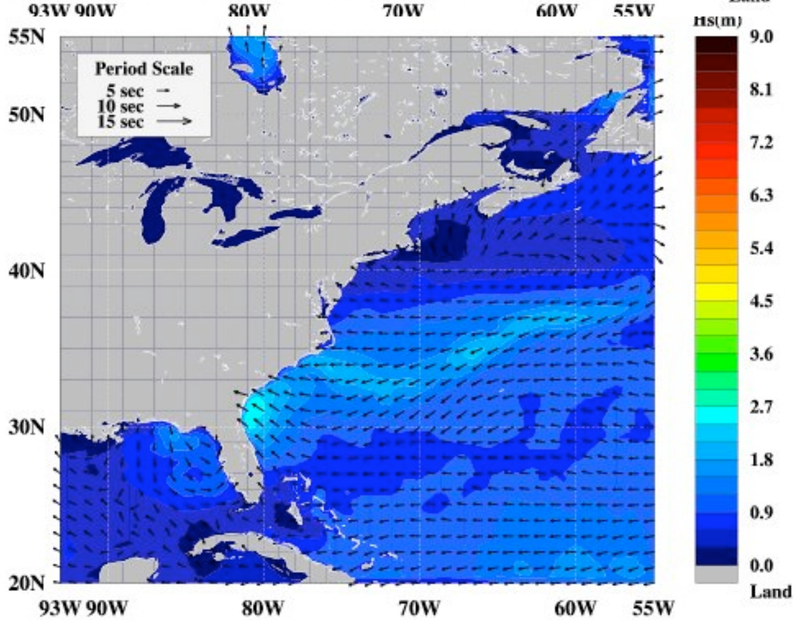
<u>Current Wave Data in the Gulf of Maine:</u>

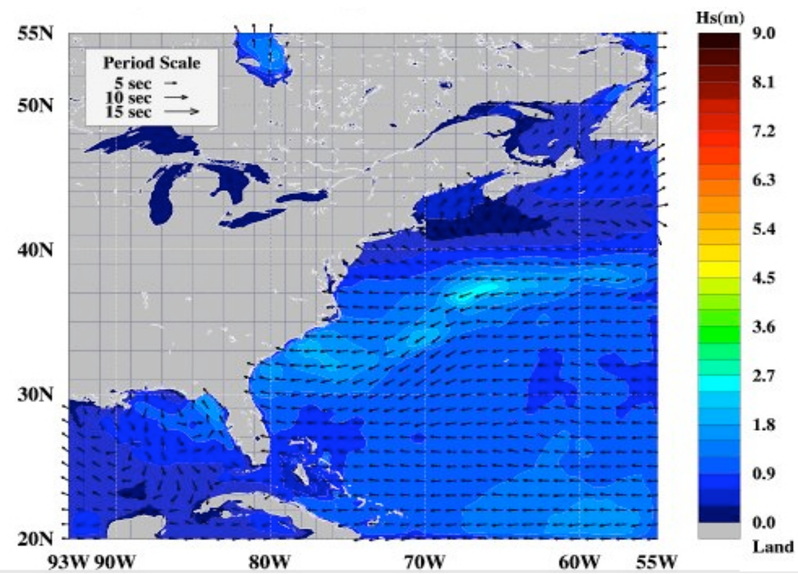
http://www.gomoos.org/data/recent.html - *click on a buoy*

WaveField Evolution: TS Fay Aug21-23









Why do Oceanographers care about surface waves?

- Increase Mixing at the surface
- Increase Air-Sea Gas exchange: particularly breaking waves
- Play a role in Langmuir Circulation (will cover later)
- Can increase the bottom stress and thus the natural disturbance to benthos
- Shallow water, can impart a stress on the fluid (radiation stress) leading to increased storm surge.
- Influence sediment transport and development of coastal features

Homework Question 1

1.) Goto the gomoos page (http://www.gomoos.org/gnd/), and request a graph of the following data: wave height and period and wind speed from Oct 28, 2008 to Nov 3, 2008 from the Nantucket Buoy (44008). Save the graph.
2.) What is the maximum wave height achieved during this period. What is the wave amplitude at that time? What is the wave period at that time?
3.) Assuming a fetch of +1000km and a period of forcing of several days, is the significant height consistent with the wind-speed measured at the buoy?
4.) Would you characterize this as swell, or wind-sea?
5.) At the time of peak height, how quickly are the waves traveling on average?

Homework Question 1, con'td

6.) Based on info about the buoy at the link below, what is local speed of a shallow surface gravity wave. http://www.ndbc.noaa.gov/station_page.php?station=44008 the Nantucket Buoy (44008). Save the graph.

7.) The Power of the wave/unit length can be estimated by the following formula (deep water wave only) Where H is the significant wave height and T is the Period. If the southern shore of Nantucket is 20km long, how much power could theoretically be extracted from an offshore array during the time of maximum significant wave height from the GOMOOS data?

$$P = \frac{\rho g^2}{64\pi} H_{m0}^2 T$$

Homework Question 2

The wave spectra below is typical of a coastal observations station. Explain why there are two prominent peaks in the signal.