Lecture 24 Part II
Swell and Wave Forecasting

Swell and Wave Forecasting

- Motivation
- Terminology
- Wave Formation
- Wave Decay
- Wave Refraction
- Shoaling
- Rouge Waves
Motivation

- In Hawaii, surf is the number one weather-related killer. More lives are lost to surf-related accidents every year in Hawaii than another weather event.
- Between 1993 to 1997, 238 ocean drownings occurred and 473 people were hospitalized for ocean-related spine injuries, with 77 directly caused by breaking waves.

Going for an Unintended Swim?

Lulls: Between sets, lulls in the waves can draw inexperienced people to their deaths.
Motivation

Surf is the number one weather-related killer in Hawaii.

Motivation - Marine Safety

Surf's up!
Heavy surf on the Columbia River bar tests a Coast Guard vessel approaching the mouth of the Columbia River.
Sharks Cove Oahu

Giant Waves

Peggotty Beach, Massachusetts
February 9, 1978
Categories of Waves at Sea

<table>
<thead>
<tr>
<th>Wave Type</th>
<th>Restoring Force</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capillary waves</td>
<td>Surface Tension</td>
</tr>
<tr>
<td>Wavelets</td>
<td>Surface Tension &amp; Gravity</td>
</tr>
<tr>
<td>Chop</td>
<td>Gravity</td>
</tr>
<tr>
<td>Swell</td>
<td>Gravity</td>
</tr>
<tr>
<td>Tides</td>
<td>Gravity and Earth’s rotation</td>
</tr>
</tbody>
</table>

Ocean Waves

Terminology

- **Wavelength** - $L$ - the horizontal distance from crest to crest.
- **Wave height** - the vertical distance from crest to trough.
- **Wave period** - the time between one crest and the next crest.
- **Wave frequency** - the number of crests passing by a certain point in a certain amount of time.
- **Wave speed** - the rate of movement of the wave form. $C = \frac{L}{T}$
Wave Spectra

Wave spectra as a function of wave period

Open Ocean – Deep Water Waves

- Orbits largest at sea sfc.
- Decrease with depth
- At L/2 orbit is 1/23rd at surface
  - When depth > L/2
    - essentially no movement
    - bottom is not felt
    - deep water wave
- Depth of L/2 = Wave Base
Factors Affecting Wind Wave Development
The following factors control the size of wind waves:
1. Wind strength
2. Wind duration
3. Fetch - the uninterrupted distance over which wind blows without changing direction.
4. Air-sea temperature difference
5. Ocean depth

Development of Sea State

- If Wind is Steady - Waves continue to grow with time until limited by either Wind Speed or Fetch
- This is called a: Fully Developed Sea (NOT Duration Limited)
- Significant Wave Height - Average height of the highest third of the waves
- Sea State includes a wide range of periods, wavelengths, and multiple directions due to:
  - Original sea state plus
  - New waves generated in fetch area
Swell and Wave Lifecycle

Three things happen to large waves when they leave the storm region.

1. **Dissipation**: Wave amplitude gradually dies out as the waves travel away from their source. Opposing wind enroute can accelerate the dissipation.
2. **Dispersion**: Swell disperse over the open ocean: longer wavelength swell move faster than shorter wavelength swell.
3. **Angular spreading**: Shorter wavelengths have more angular spreading.

Wave Decay

[Graph showing wave height, distance of travel, and period of swell]
Deep Water Waves and Dispersion

Depth > L/2, where L is wavelength
Longer waves move faster

Wave speed = C
C = (gL/2π)^{1/2}

Dispersion of waves of differing wavelength leads to swell that run ahead of storm.

Graph of the relationship between wave speed and wavelength.

Deep Water Waves: Dispersion & Swell

In deep water, waves of different wavelengths travel at different speeds. Waves with the longest wavelengths move the fastest and leave an area of wave formation sooner. Because of their different speeds, waves separate out from one another into groups with similar wavelength. This process is called dispersion. Dispersion causes groups of waves with the same wavelength to travel together, causing a very regular, undulating ocean surface called swell.
Group Velocity

- Individual waves within a set of waves move faster than the group of waves moves.
- The group velocity is 1/2 the individual wave velocity.
  - Waves in the front loose energy in lifting an “undisturbed” ocean surface.
  - Waves in the back benefit from the energy of waves ahead.
  - Therefore, the leading wave dissipates and the trailing wave grows, resulting in the slower group velocity.

Angular Spreading

Angular spreading is proportional to swell energy. Swell from broad fetches experience less angular spreading. Steep waves dissipate more quickly through angular spreading.
Swell and Wave Lifecycle
Two things happen to large waves when they near shore.

1. Refraction: As waves move into shallower water, they slow down and thus turn toward the shore.
2. Shoaling: As waves move into shallow water they slow and become steeper as they increasingly feel the bottom, until finally the top of the wave pitches forward and the wave breaks.

Refraction Bends Wave Rays so they:
Diverge in Bays (lower energy)
Converge on Headlands (higher energy)
Refracting Waves

Shallow - Water Waves

When depth $< L/2$, wave motions extend to the bottom, causing the waves to slow and their height to increase. These changes are called *shoaling* and the waves at this time are called *shallow water waves*. 
**Shallow - Water Waves**

- For shallow water waves, wave speed is a function of the depth of the water ($D$).
- $C = (gD)^{1/2}$
- Paths of water particles become long and flat
- Crests overtake troughs
- Waves break

**Wave Refraction and Shoaling**

- Waves “Feel the Bottom” at depth < $1/2$ wavelength – causes refraction
- Wave speed and length decrease with depth
- But period and energy remain same
- Thus, wave height increases
- Waves break when the ratio of height/wavelength $\geq 1/7$
Bottom Topography Controls Wave Breaking

(a) SPILLING BREAKER
(b) PLUNGING BREAKER
(c) SURGING BREAKER

Rip Currents

Water returns seaward in narrow jets called rip currents.

If you are caught in one, how can you escape?

Swim parallel to shore to areas where the surf can wash you in!
Rip Currents

Water streams seaward in narrow jets called rip currents.

Water moves toward shore where the waves are breaking.

Tools for Surf Forecasting

- Life Guard Reports, CAMS
- Ocean Buoy Data
- Ship Reports
- Numerical Wave Prediction Models
Lifeguard Observations: Wave Height

Hawaii surf scale is roughly equal to 50% of the wave face. Photo shows 10’ wave Hawaii scale.

Waves are Scale Invariant

Breaking waves are scale invariant; its difficult to tell how large they are without a surfer for scale.
Climatology of North Shore Surf

Climatology of South Shore Surf
Conditions Can Change Rapidly

8 AM Tuesday 20 February, 2001

6 PM Tuesday 20 February, 2001

NWS Watches and Warnings for Hawaii

NWS HIGH SURF ADVISORY AND WARNING CRITERIA

<table>
<thead>
<tr>
<th>Location</th>
<th>Advisory*</th>
<th>Warning*</th>
</tr>
</thead>
<tbody>
<tr>
<td>North-Facing Shores</td>
<td>15 Feet</td>
<td>25 Feet</td>
</tr>
<tr>
<td>West-Facing Shores/Big Island</td>
<td>8 Feet</td>
<td>12 Feet</td>
</tr>
<tr>
<td>West-Facing Shores/Remaining Islands</td>
<td>12 Feet</td>
<td>20 Feet</td>
</tr>
<tr>
<td>South-Facing Shores</td>
<td>8 Feet</td>
<td>15 Feet</td>
</tr>
<tr>
<td>East-Facing Shores</td>
<td>8 Feet</td>
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*Heights of wave face at time of peak cresting.
Location of Federal Buoys

Hawaii Buoy Observations

Buoy locations and island shadowing.
UH/SOEST Coastal Buoys

Wave Watch III

Output from global numerical Wave prediction model
UH Local Wave Modeling

Regional to local wave models that predict refraction and shoaling for the Hawaiian Is.

Swell and Wave Forecasting

Additional tips for wave forecasting:
1. Wave Sets: Swell travel with a group velocity that is \(\sim 1/2\) the speed of individual waves. When a wave group arrives at the shore it is referred to as a set.
2. Lulls: Between sets, lulls in the waves can draw inexperienced people to their deaths.
3. Travel Time: Rule of thumb to estimate of travel time for large swells is 10° latitude per day (10° \(\sim 1110\) km or 665 nautical miles). Thus, it will take \(\sim 3-4\) days from the north Pacific and \(\sim 1\) week from New Zealand for the swell to arrive.
Epic (Giant) Wave Events

December 1969
Epic Event

Surface Analysis
50 Nov 1969, 1800 HST
(31 Hours before high surf)

Max H: 50'
Damage: $1,000,000
Epic Wave Event of December 1969

Software analysis of December 1969

NCAR/NCEP Reanalysis Data for 8 AM 30 November 1969

Animation of SLP Analyses Dec. 1969

A captured fetch occurs when the swell travel at the same speed as the storm, so that high winds remain over the swell region.
Condition Black, Jan. 1998

Animation of SLP Analyses Jan. 1998

Note the captured fetch that again occurred in this case.
Source Regions for Large Swell in Hawaii

Fetches associated with observations of epic surf in Hawaii during past 30 years.

Boxes enclose ≥35 knots pointing toward the islands over a fetch ≥ 600 km.

Hurricane Waves hit Japan

Hurricanes traveling in a straight line produce a captured fetch that focuses wave energy like a lighthouse beam.
Rouge or Freak Waves

- A *Rouge Wave* is a wave of very considerable height (up to 30 meters) that usually appears as a solitary wave ahead of which there is a deep trough.
- It is the unusual steepness of the wave that is its outstanding feature, and which makes it dangerous to shipping.
- Observations suggest that such waves have usually occurred where a strong current flows in the opposite direction to a heavy sea or large swell.
Rouge or Freak Waves

Hurricane Force Trade Winds

Research Vessel Holo Holo sank in the Alenuihaha Channel under high wind conditions, December 1978.
Strong Hawaiian High

Sea-level pressure analysis for 13 December 1978.

Hurricane Force Trade Winds

Hurricane force trade winds recorded by anemometer in Waikaloa, Hawaii, December 1978, produce by an unusually strong surface high north of Hawaii.
Waves Caused by Strong Trade Winds

Large waves at Sandy Beach associated with prolonged strong NE trade winds.

Questions?