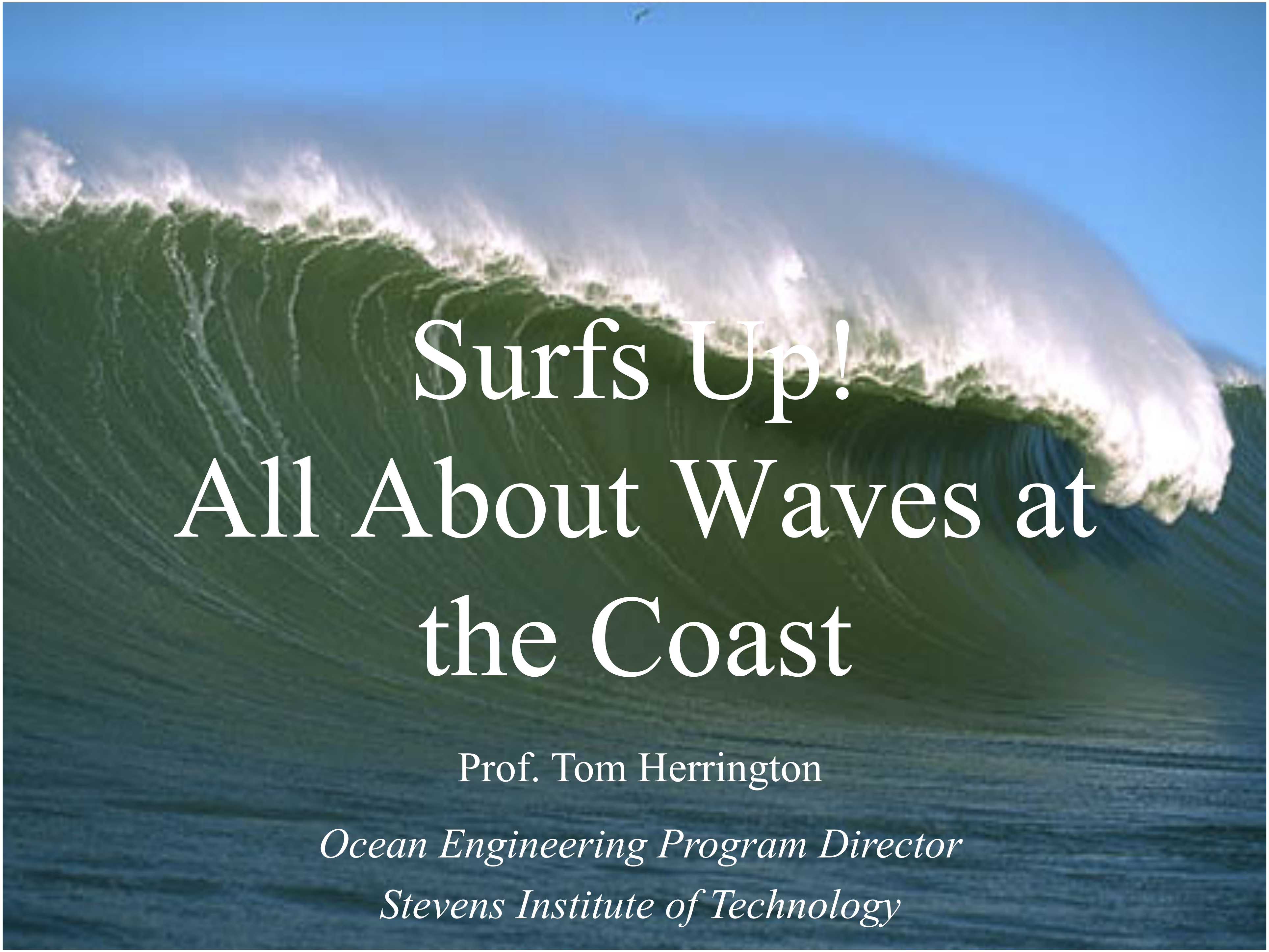
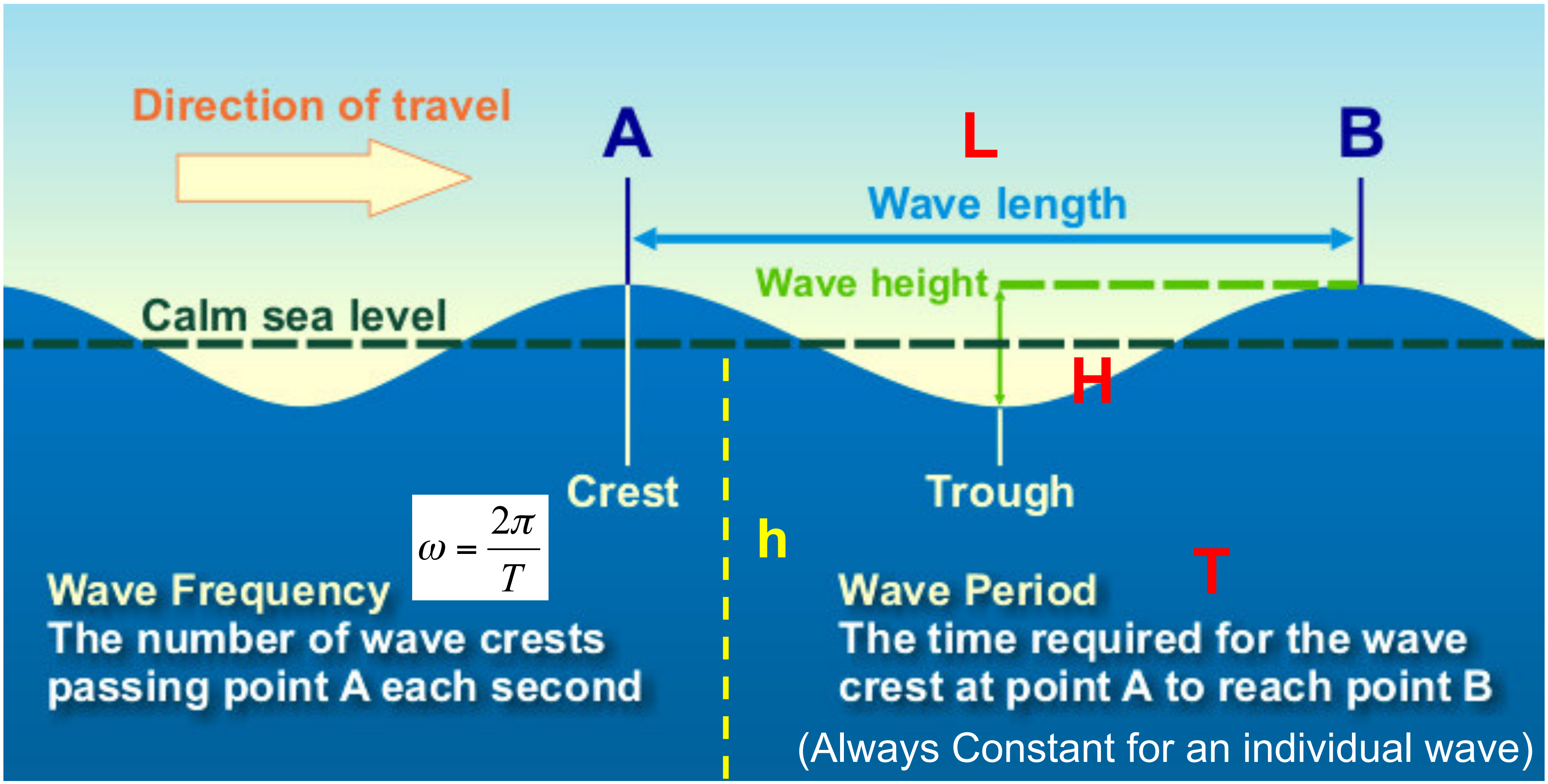

Surfs Up!
All About Waves at the Coast
Prof. Tom Herrington
Ocean Engineering Program Director
Stevens Institute of Technology

Tonight's Lecture

- What happens when waves reach the coast
- Surf zone currents
- Wave & beach interactions
- Shoreline evolution
- Shoreline of the future

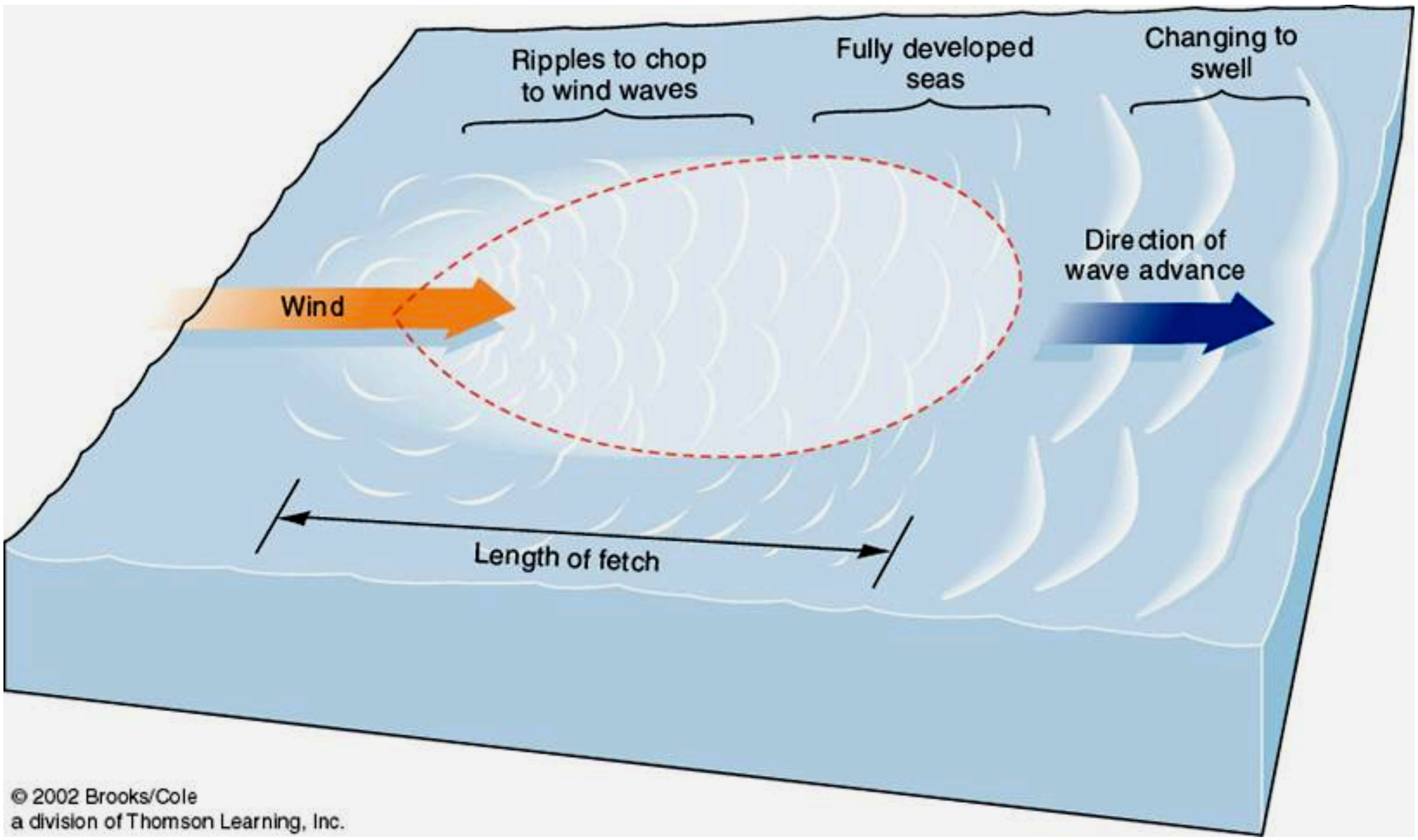
Anatomy of a Wave



Wave Number: $k = \frac{2\pi}{L}$

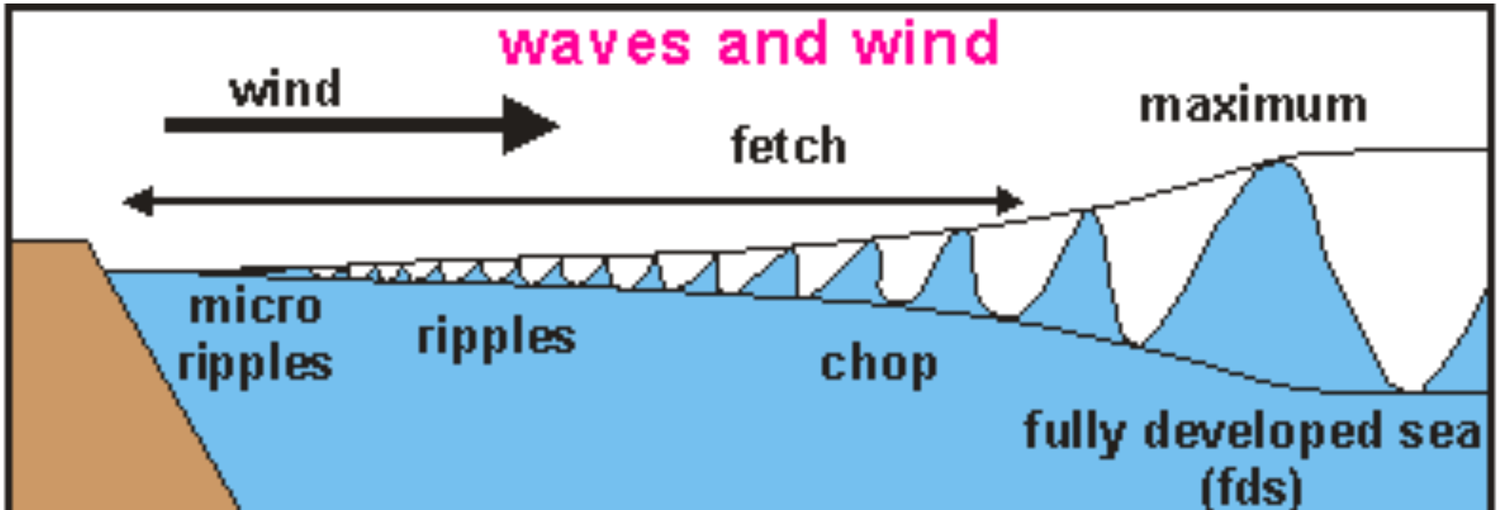
Wave Phase Speed $C = \frac{L}{T}$

Wave Growth



Ripples to chop to wind waves
Fully developed seas
Changing to swell
Wind
Direction of wave advance
Length of fetch
© 2002 Brooks/Cole
a division of Thomson Learning, Inc.

Wave Development Limit



As waves develop, they offer more surface area for the wind to press against (wind stress). Depending on both fetch and time, the size of the waves increases quadratically to a maximum. The energy imparted to the sea increases with the fourth power of the wind speed! As waves develop, they become more rounded and longer and they travel faster. Their maximum size is reached when they travel almost as fast as the wind. A 60 knot storm lasting for 10 hours makes 15 m high waves in open water.

Fully developed seas

Interesting Mathematical Wave Properties

- Wave are dispersive (longer waves move faster) period and length are not independent!

$$\omega^2 = gk\tanh(kh)$$

$$\left(\frac{2\pi}{T}\right)^2 = g\frac{2\pi}{L}\tanh\left(\frac{2\pi h}{L}\right)$$

- In deep water (h>L/2) tanh(kh) ~ 1.0

$$L_o = \frac{gT^2}{2\pi} \qquad C = \frac{L}{T} = \frac{gT}{2\pi}$$

- In shallow water (h<L/20) tanh(kh) ~ kh

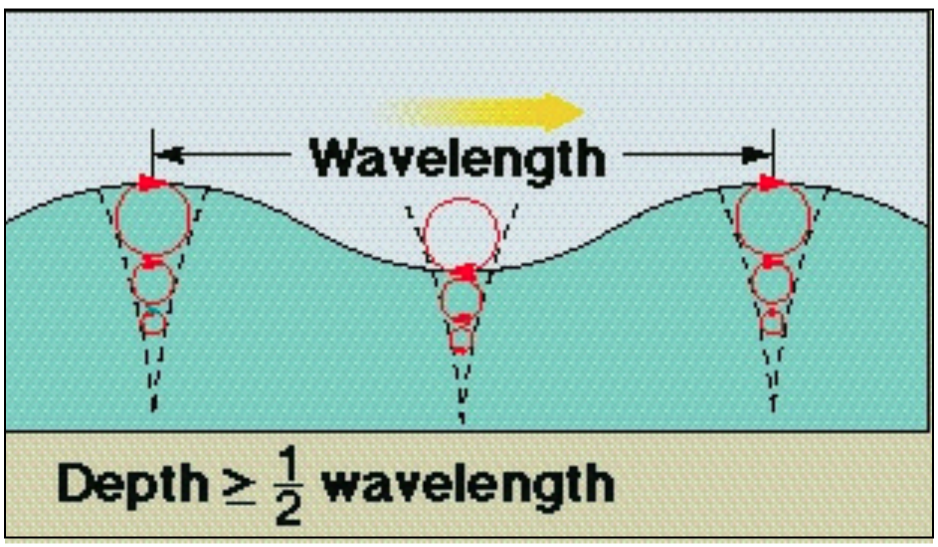
$$L = \left(\sqrt{gh}\right)T \qquad C = \sqrt{gh}$$

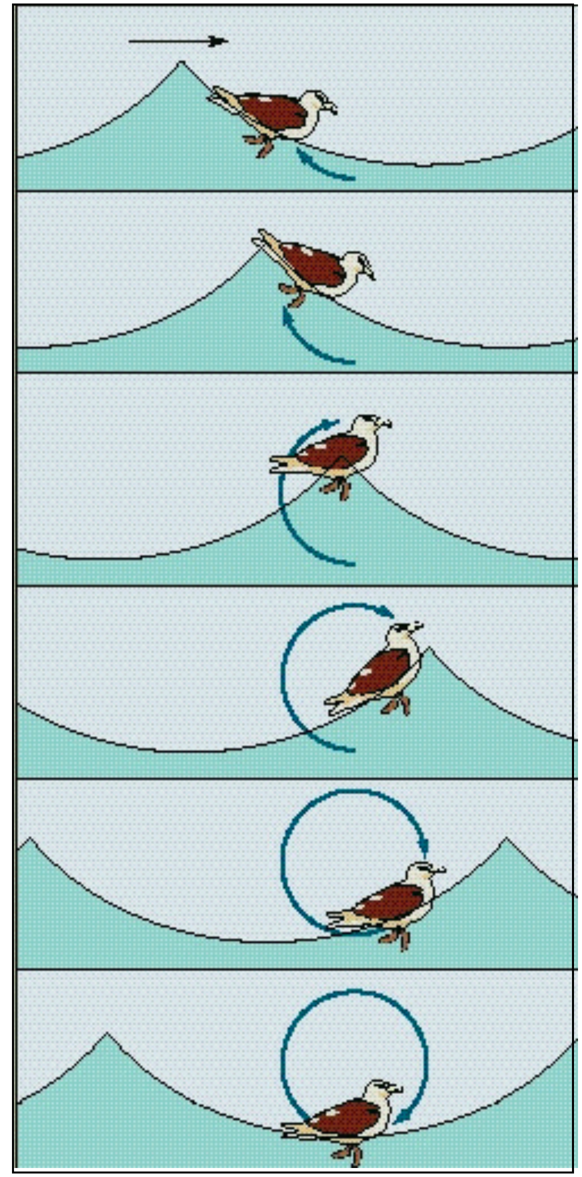
- Between deep and shallow water must use full equation ☹

$$\left(\frac{2\pi}{T}\right)^2 = g\frac{2\pi}{L}\tanh\left(\frac{2\pi h}{L}\right)$$

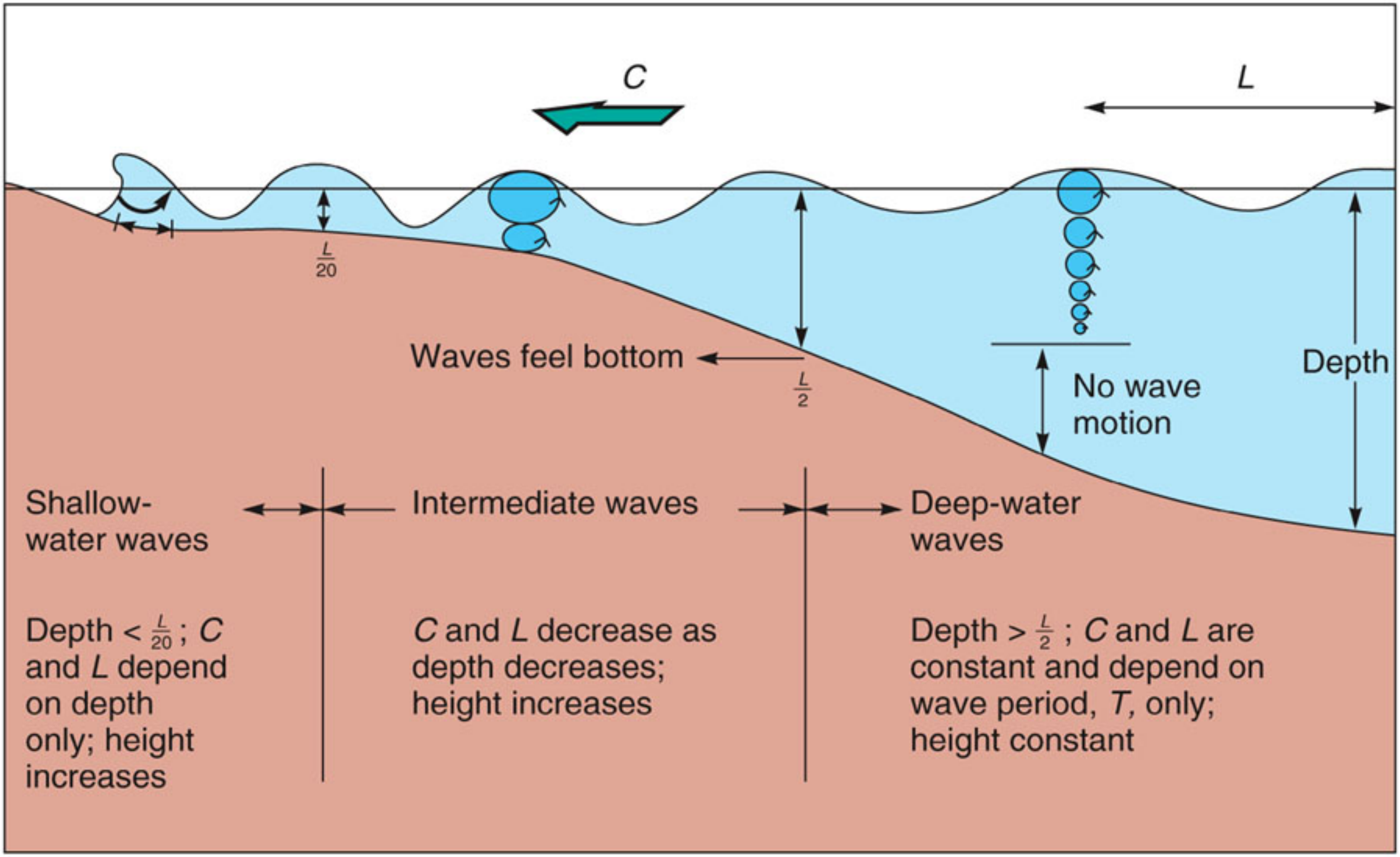
-In Deep-Water -

Waves have *Ideal* Shape and thus Propagate Energy but not Mass



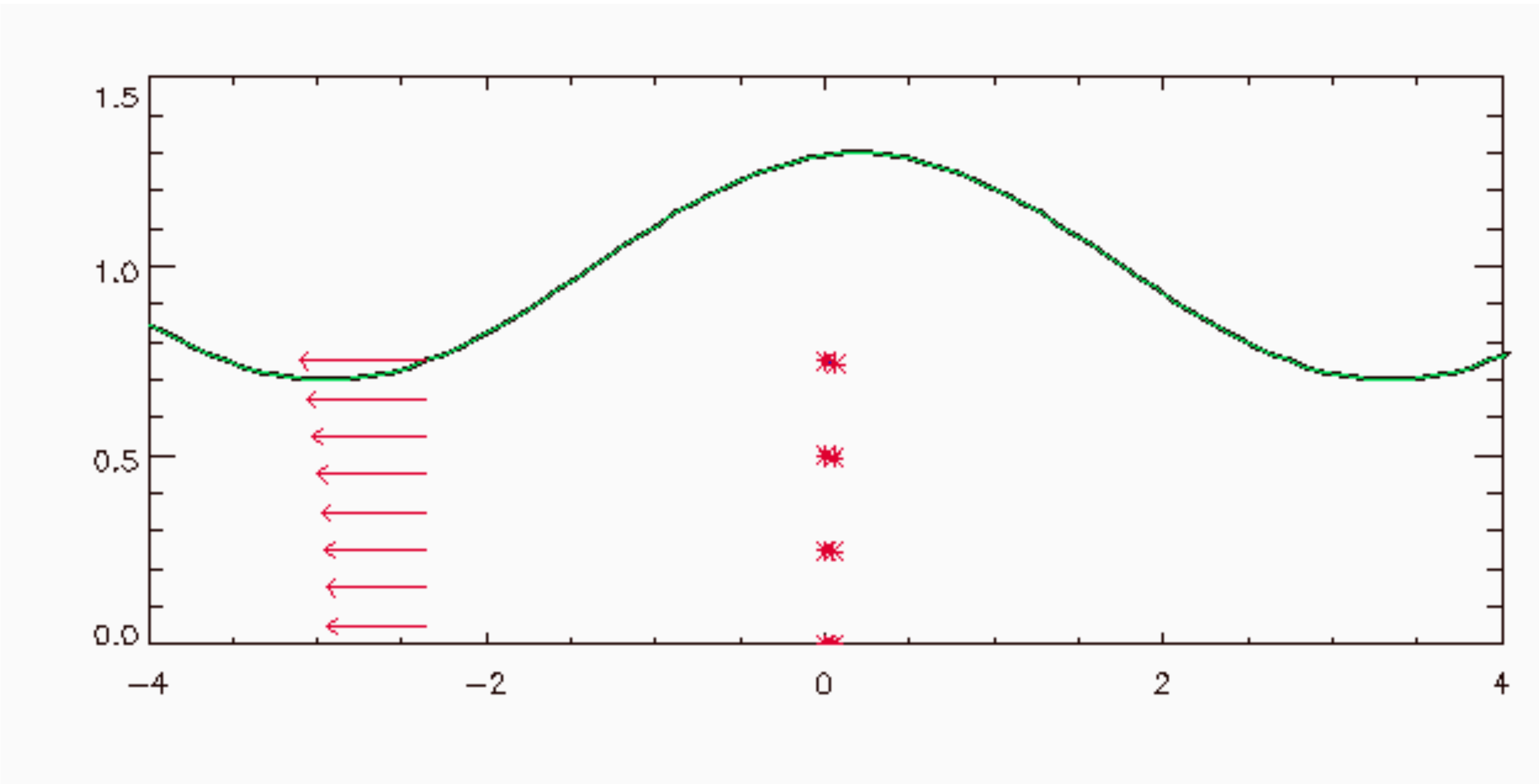


Deep and Shallow-Water Wave Regions

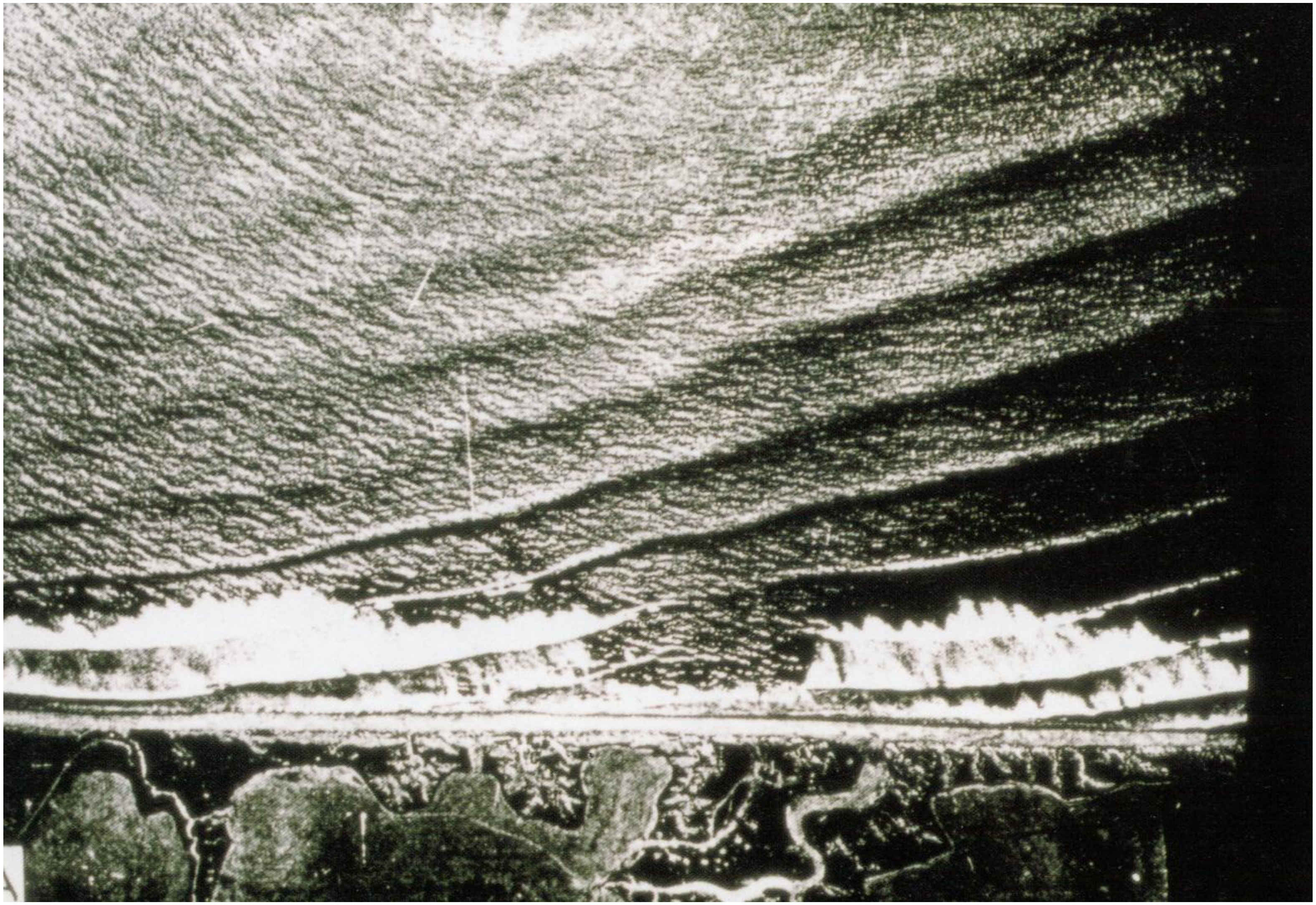


Wave Motion and Particle Motion
Progressive Waves

Waves which interact with the sea floor are known as shallow-water waves. The orbits of the water molecules become elliptical.

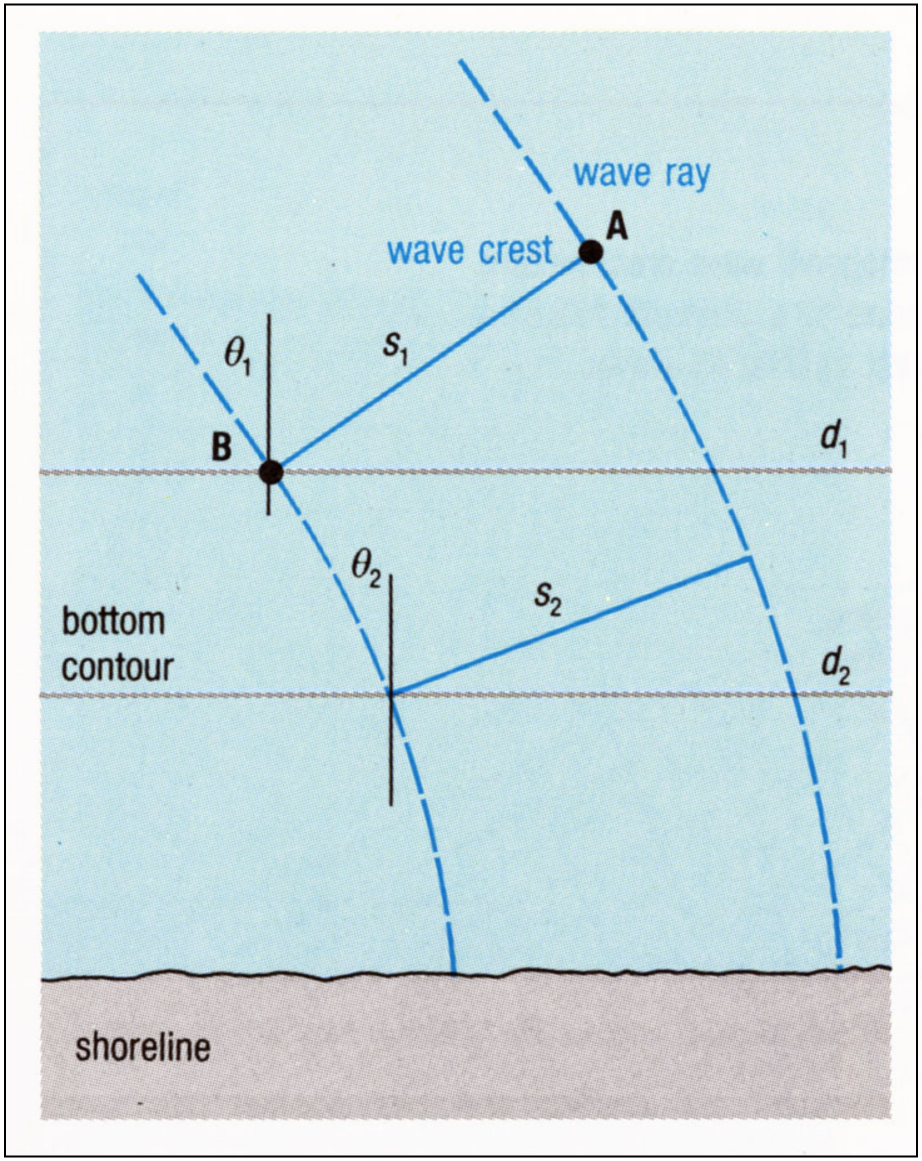


Wave Refraction

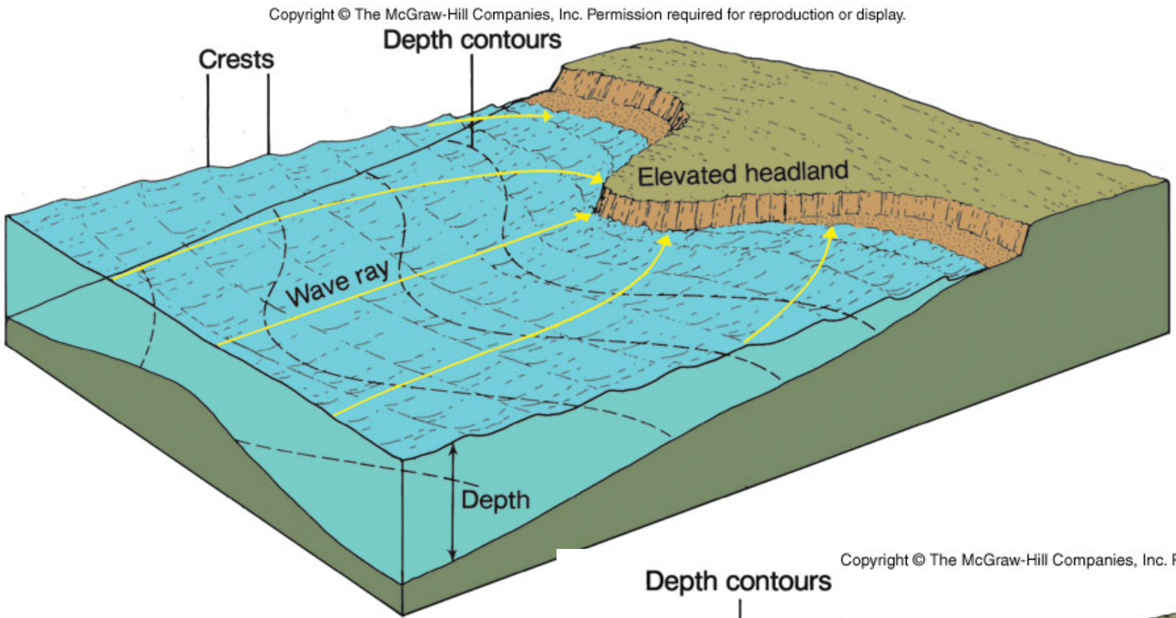


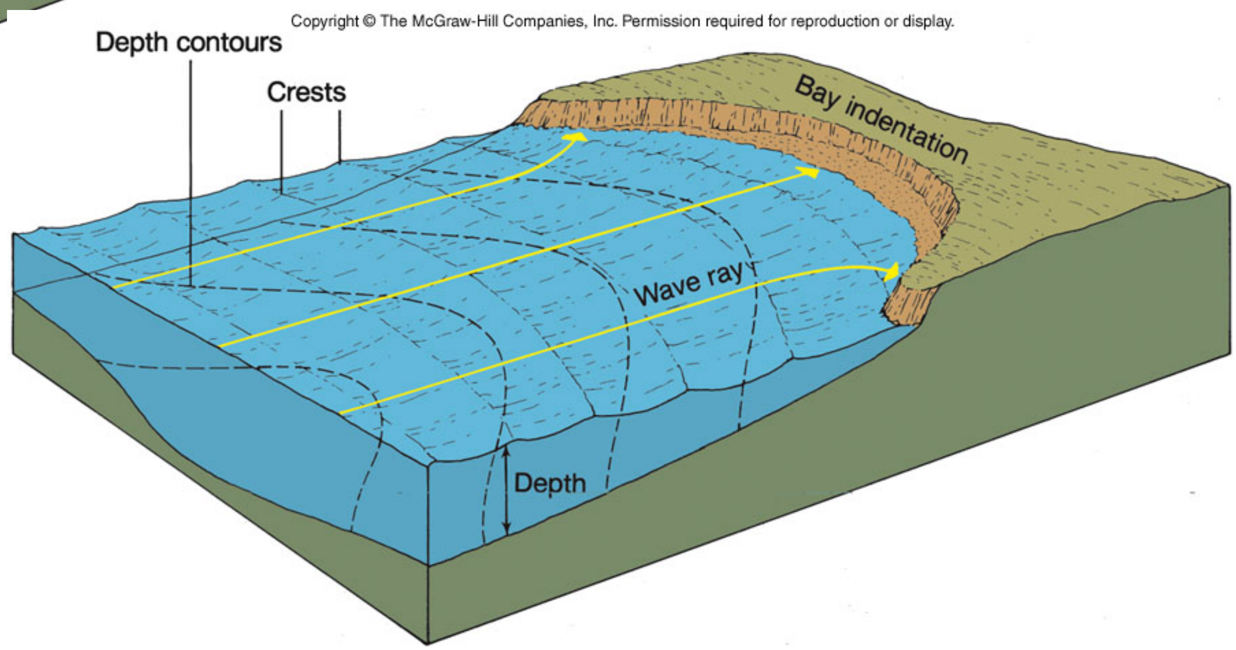
Wave Refraction:

Bending of *Shallow-Water* Wave Fronts Due to Change in Bottom Depth. The Leading Edge of a Wave Front Enters Shallower Water and Slows While the Remaining Front Continues at Higher Speed. The Net Result is a Rotation of Wave Fronts To Become Parallel with Bottom Depth Contours.



Wave Focusing and Spreading



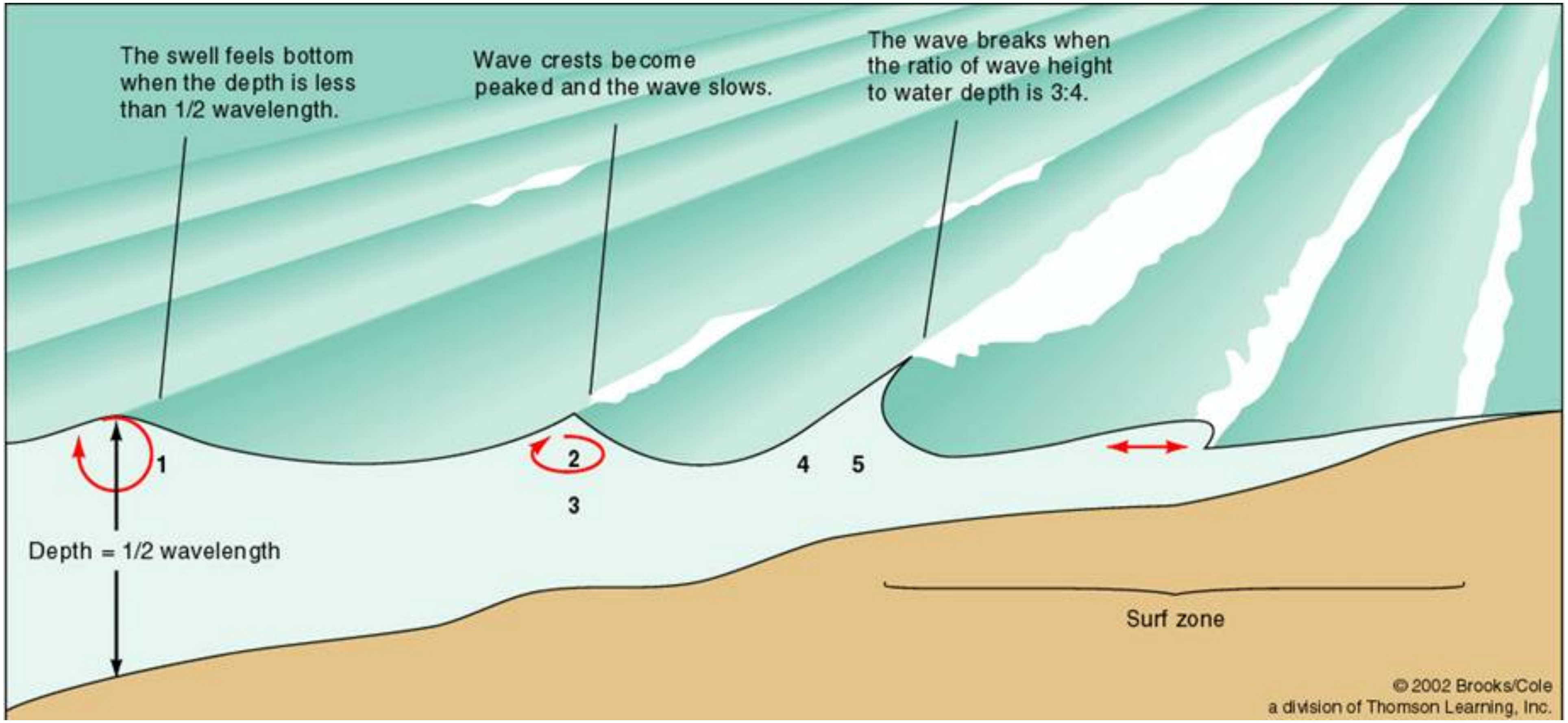


Examples

Headland Focusing

Embayment wave spreading

Wave train breaking



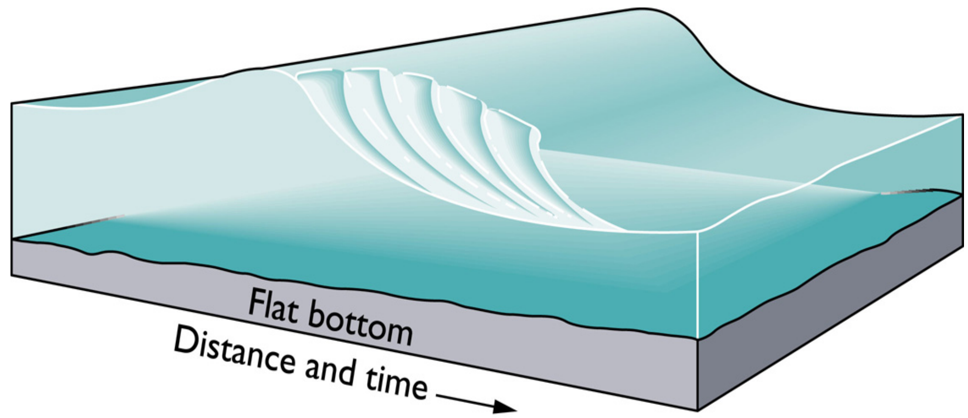
Really amazing rule of thumb

Breaking wave height can be estimated by: $H_b = 0.78h$

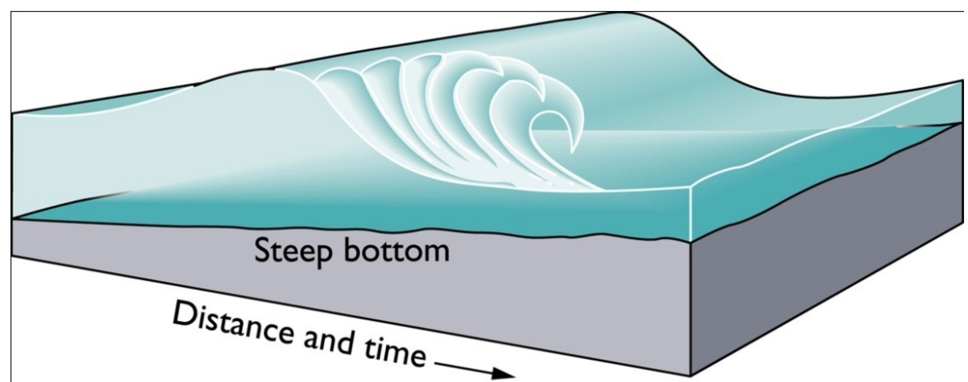
Waves Break by

Plunging and Spilling

- depends on the slope of the bottom



(a) SPILLING BREAKER



(b) PLUNGING BREAKER

Surf Similarity Parameter

- Ratio of slope steepness and local wave steepness

$$\xi = \sqrt{\frac{\tan\alpha}{H_o / L_o}}$$

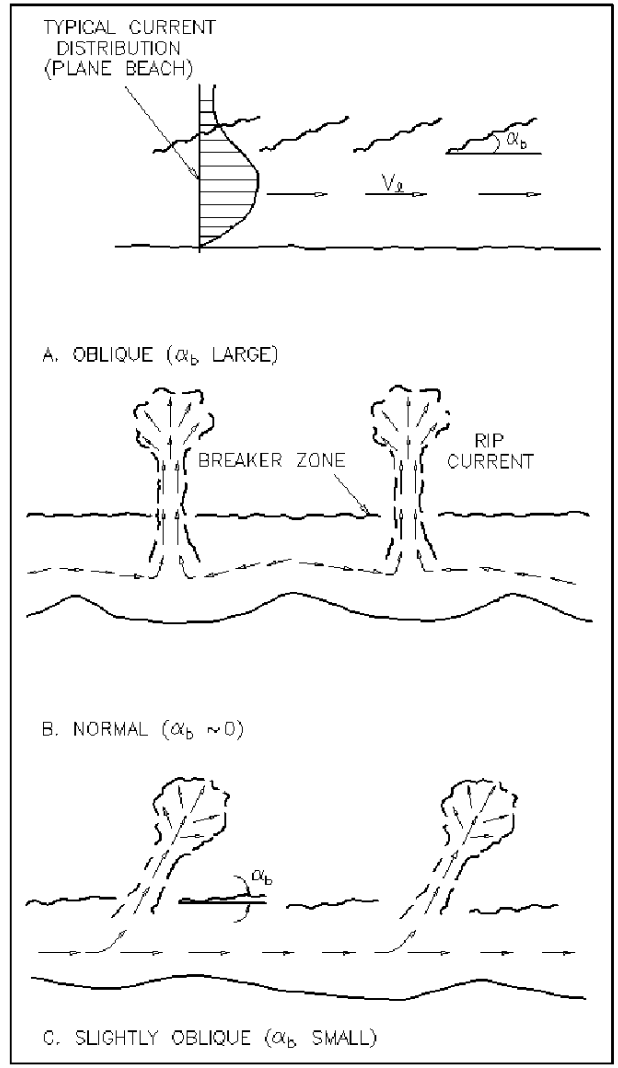
  - ➢ $\xi > 2.0$ – surging/collapsing breaker
  - ➢ $2.0 < \xi < 0.4$ – plunging
  - ➢ $\xi < 0.4$ – spilling

Plunging Breaker at
Avon-by-the-Sea, NJ

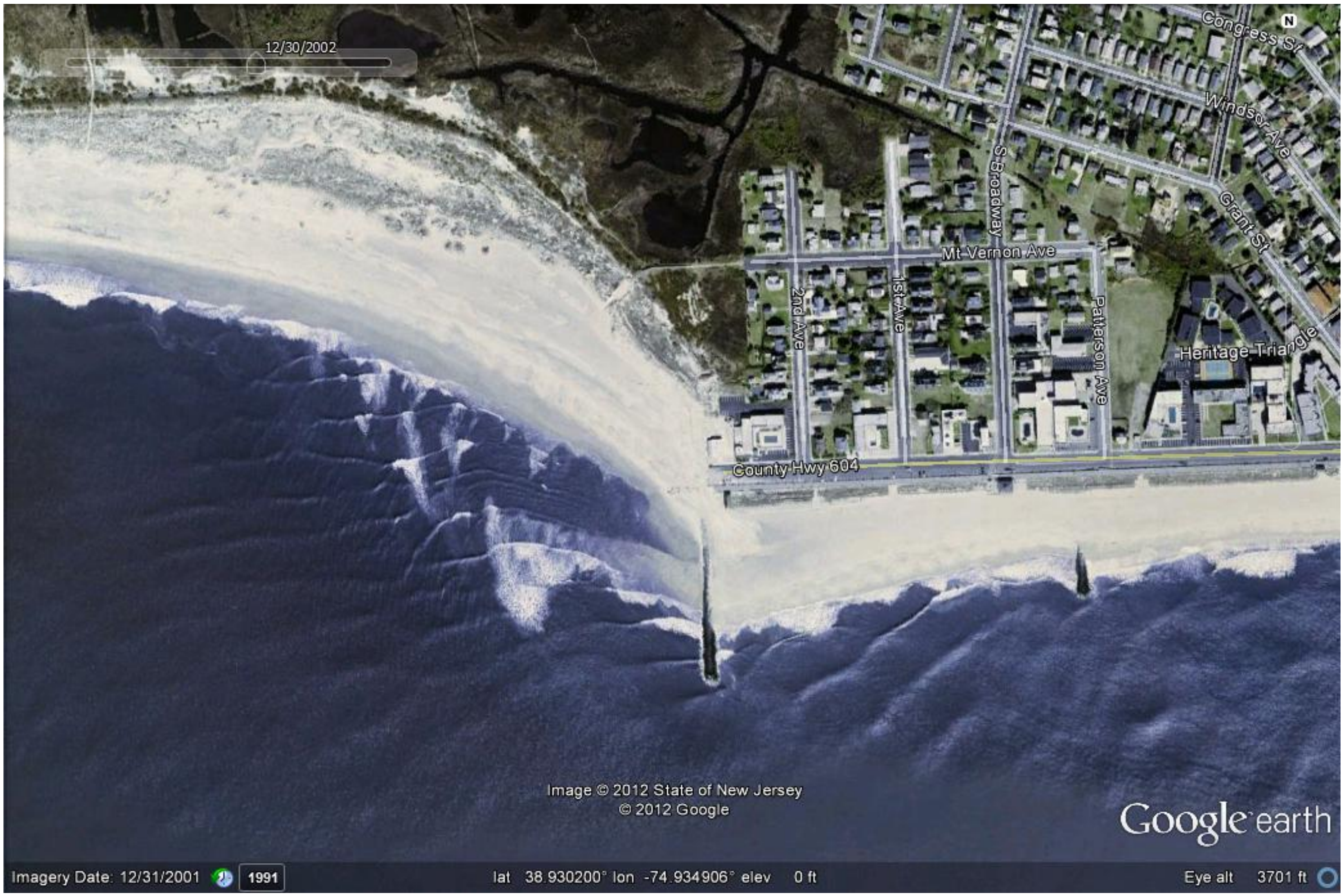
Spilling Breaker at
Ocean City, NJ

Surf Zone Physical Processes

- Currents in the surf zone are generated by the variation in Wave Height across surf zone and the angle at which the waves approach the coast.
- Generates both cross-shore and alongshore currents



Cape May, NJ
oblique wave approach



Flow in the Surf Zone is Very Complex!

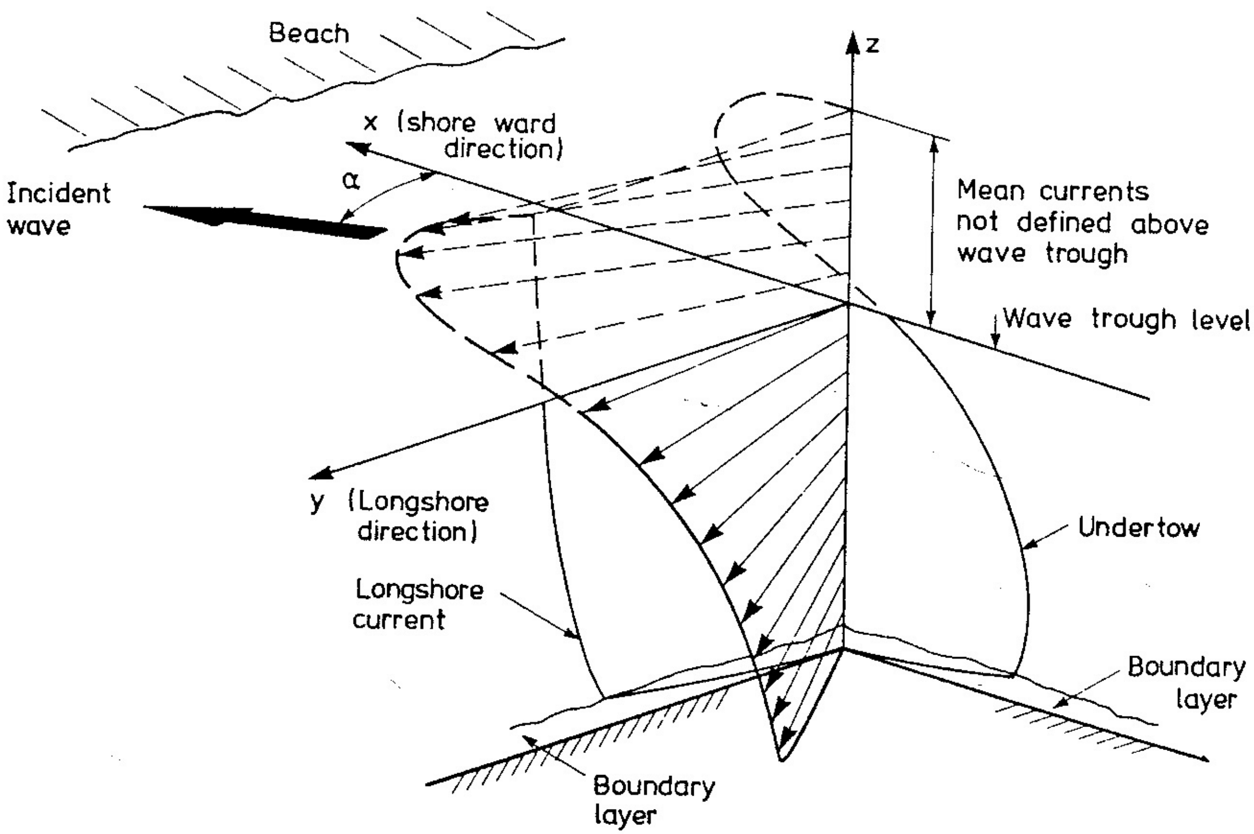


Fig. 1. Three-dimensional resultant mean velocities in the surf zone.

From Svendsen and Lorenz (1989)

Alongshore Current Forcing

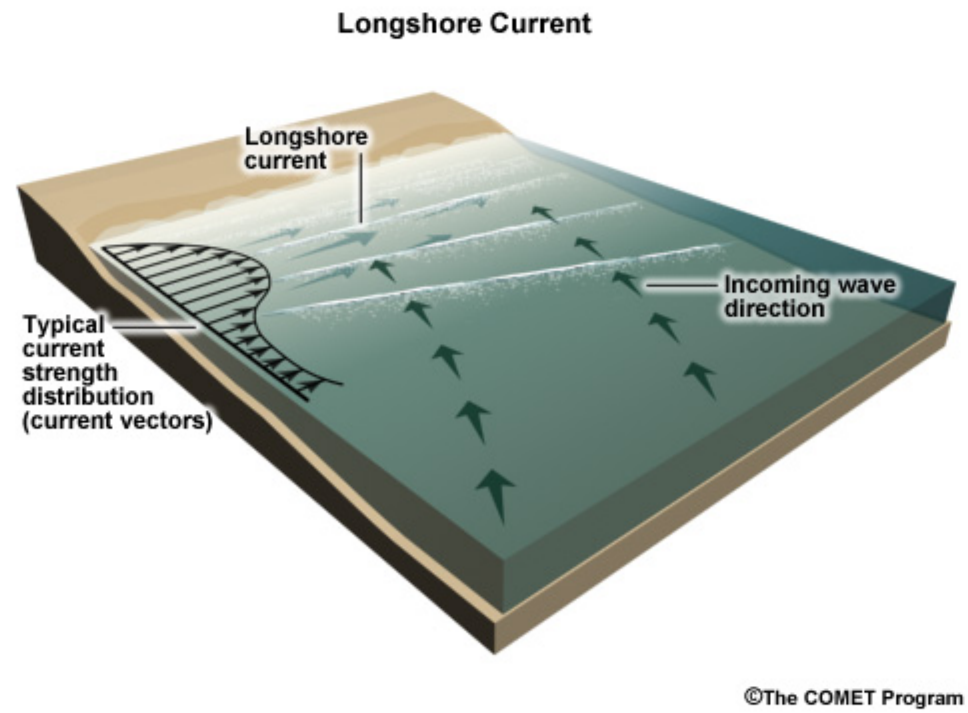
$$V_L = 41.4S\sqrt{gH_b}\sin\alpha_b\cos\alpha_b$$

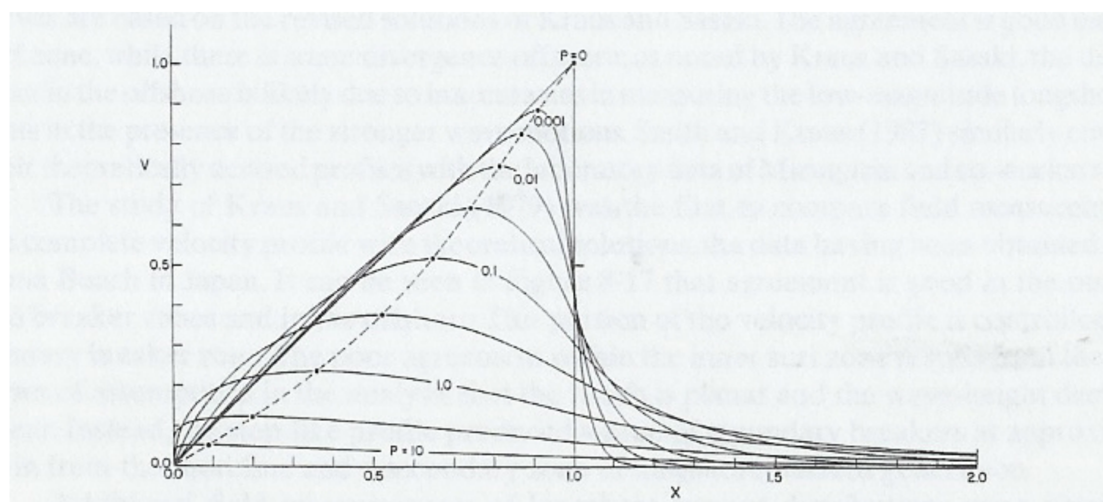
S : beach slope

g : gravity

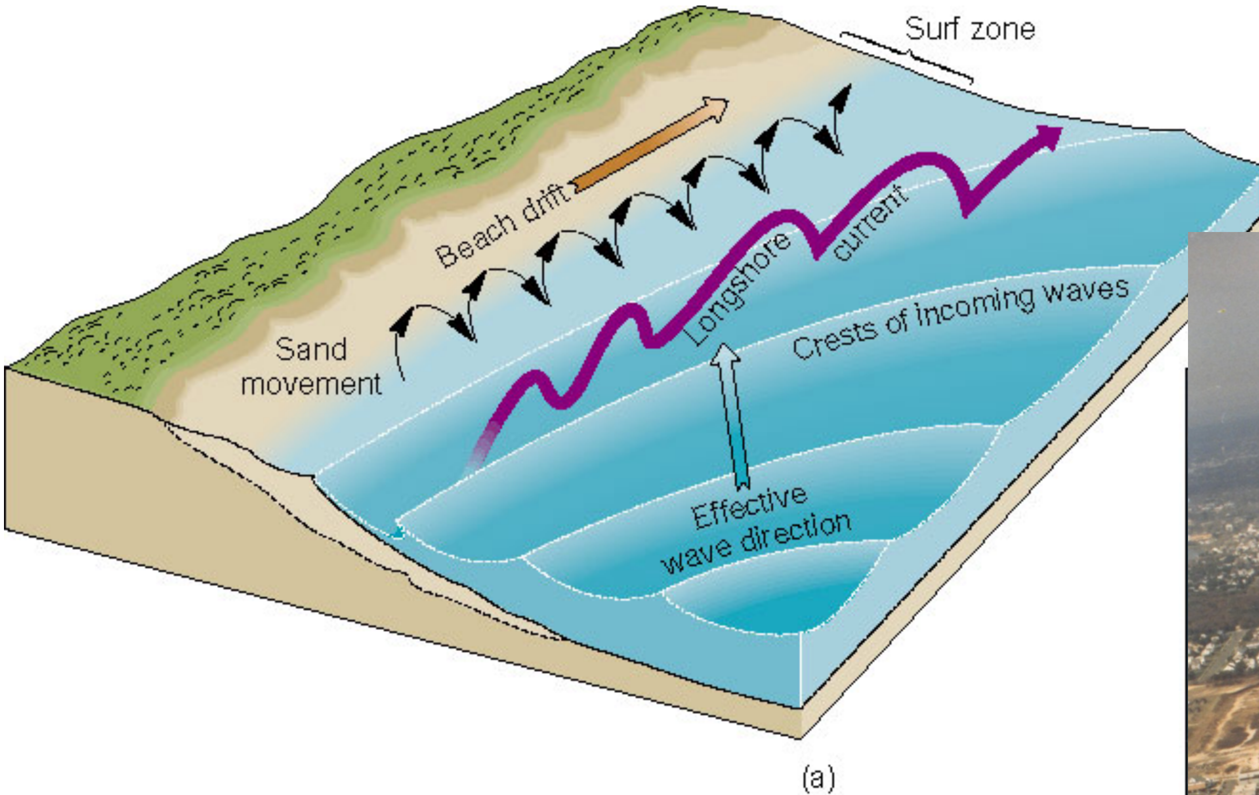
H_b : breaking wave height

α_b : wave angle at breaking





Longuet-Higgens (1970)



Longshore Currents

Cross-shore wave generated motion

SURF ZONE WAVE PARAMETERS FROM EXPERIMENTAL DATA

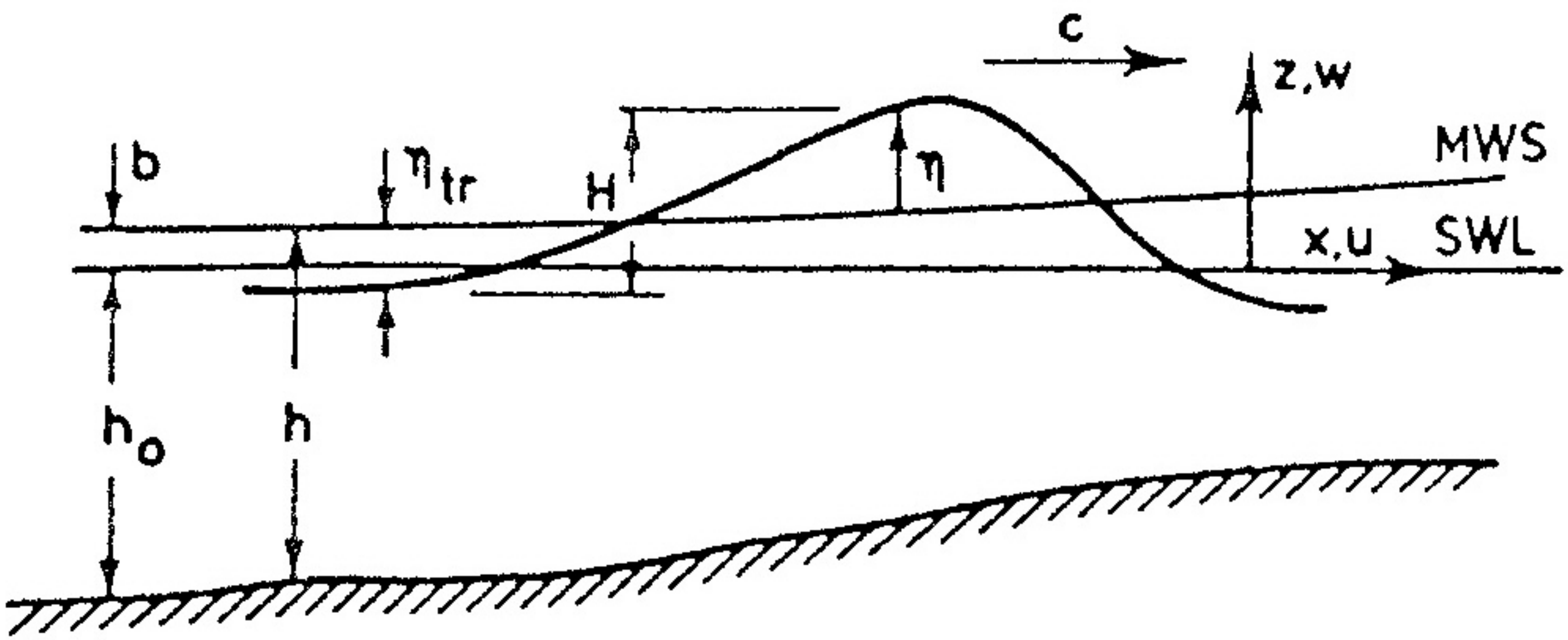


Fig. 2. Definitions.

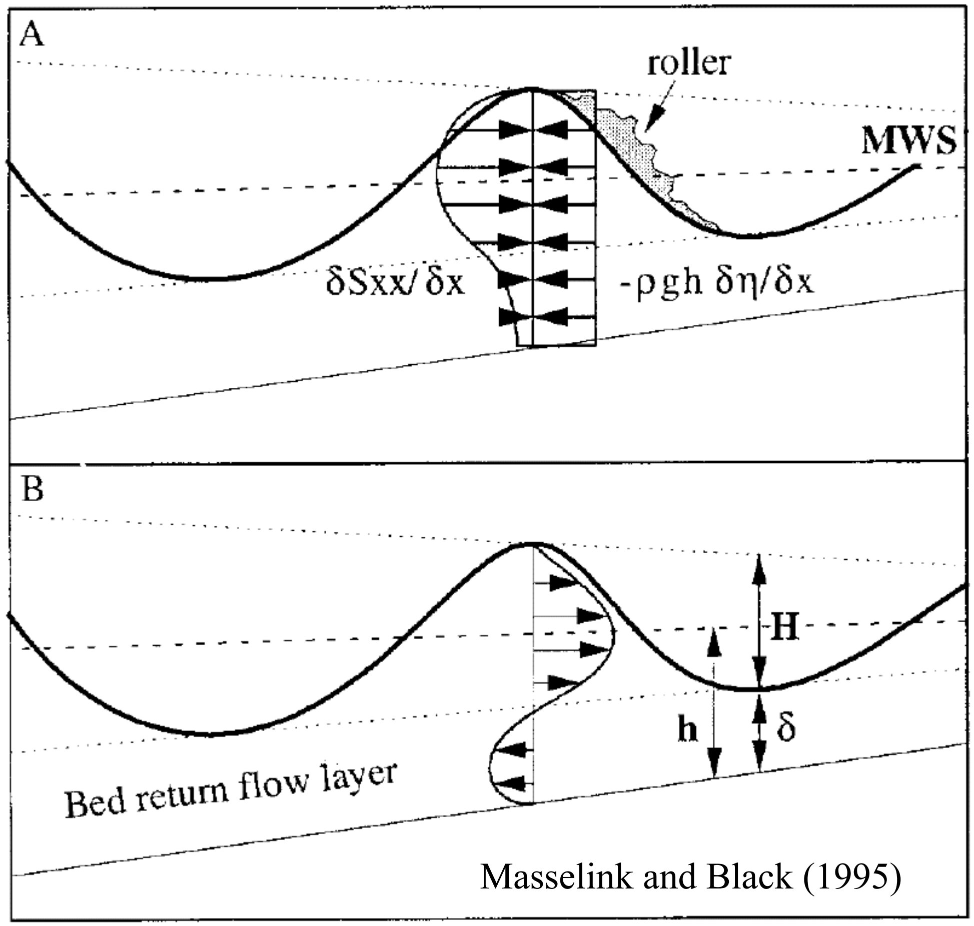
Svendsen, et al. (1987)

Cross-shore Current Forcing

Wave setup balances the gradient in the cross-shore directed radiation stress

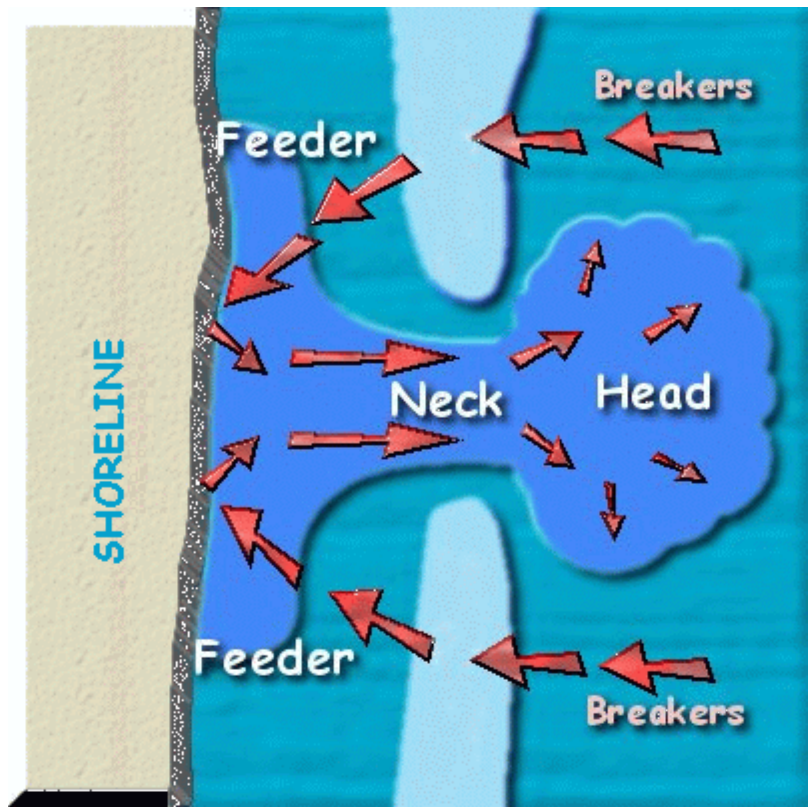
$$R_\alpha = \frac{dS_{xx}}{dx} - \rho g h \frac{d\eta}{dx}$$

$$S_{xx} = \frac{3}{16}\rho g d H^2$$

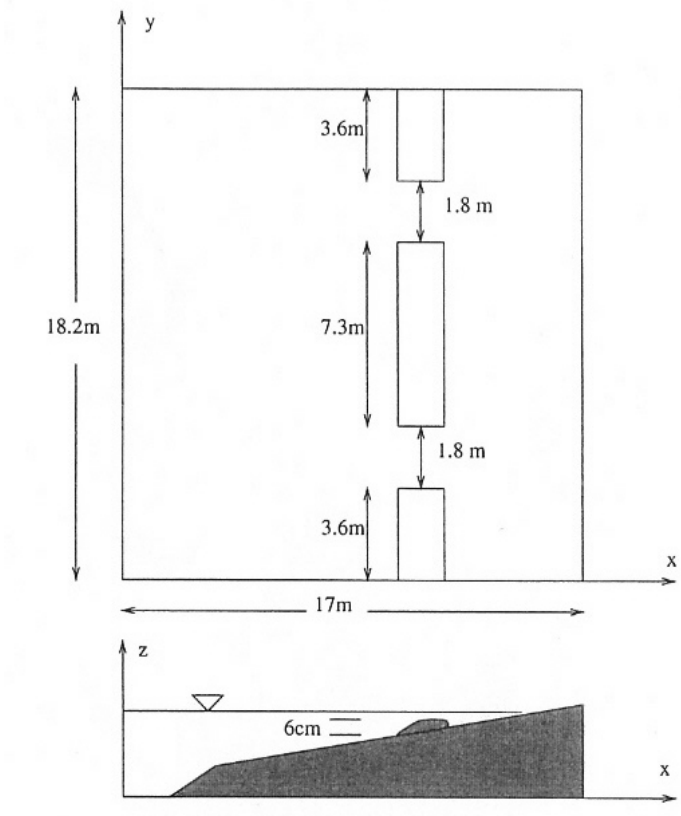


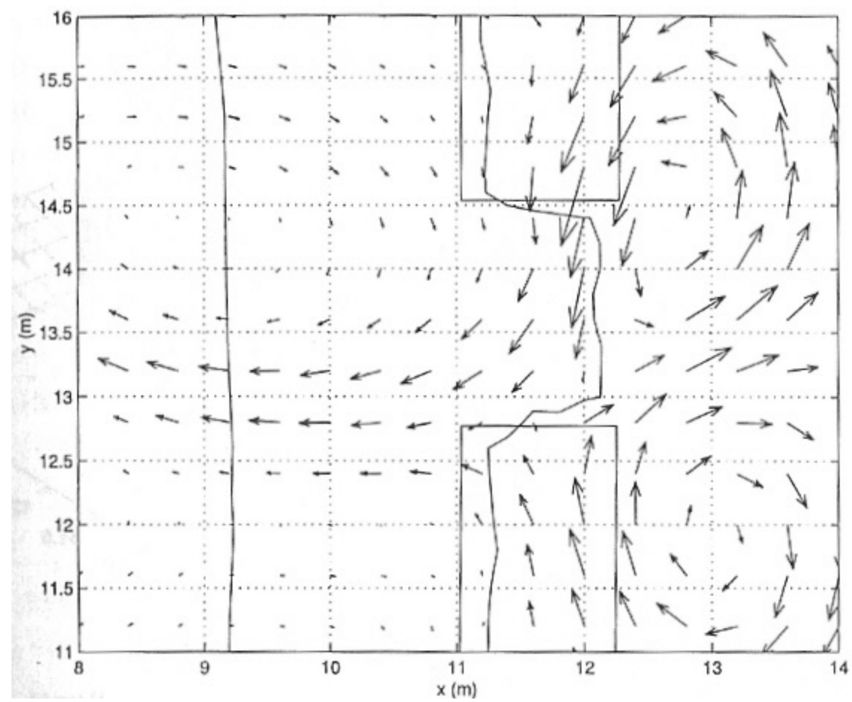
What is a Rip Current?

- Narrow seaward moving current of up to 3 knots
- Related to mass transfer of water trough the breaker zone



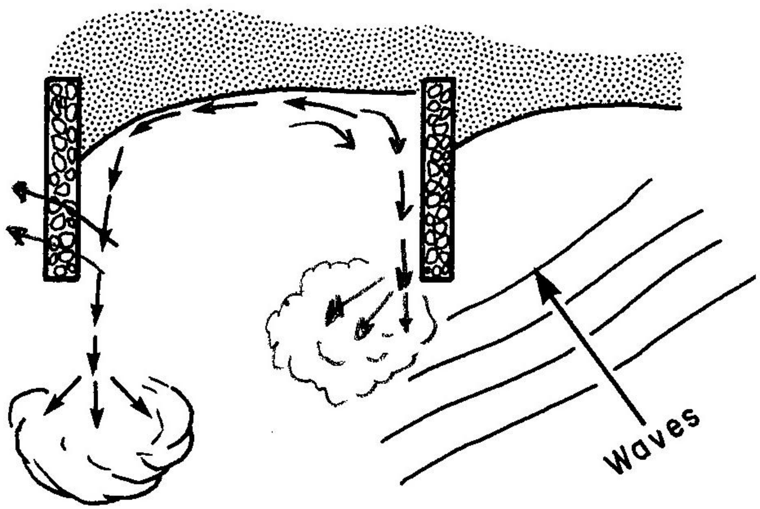
Flow through gaps in the sandbar system





Hass, et al. (2000)

Rip Current Formation between Groins



When do Rip Currents Occur?

…Extremely Large Wave Events…

April 18, 2003
Ocean City, NJ
44009: Hm0=13 ft, Tp =10 sec
Surfer/Lifeguard drowned at this beach

…Tropical Cyclone Swells…

Hurricane Fabian
Sept. 4, 2003
Surf City, LBI
44009: Hm0=5.75 ft, Tp=14 sec

JULY 6, 2003 — THE SUNDAY

1 man drowns, 1 presum

Lifeguards pull hundreds from strong currents

BY DIEGO GRAGLIA AND MARK MUELLER
STAR-LEDGER STAFF

Treacherous rip currents spawned by the remnants of Tropical Storm Bill led to the drowning of one beachgoer yesterday and to the presumed drowning of another on Friday, marring a dazzling holiday weekend at the Jersey Shore.

Be safe

Here are a few tips on how to avoid strong rip currents and what to do if you get caught in one:

Before entering the ocean, ask the lifeguards on duty if there are rip currents present and, if so, where they are strongest. Never swim in an area where a lifeguard is not on duty.

The color of the water can help identify rip currents. A swath of light or sand-colored water sandwiched between darker patches indicates the current is moving very quickly out to sea. A rip current also might look especially foamy or aerated.

If caught in a rip current, try to alert someone nearby or on the beach, but don't panic. Doing so will expend precious energy needed to swim to safety.

If possible, swim parallel to the beach to escape the current. Do not fight the current by swimming straight into it.

Rip currents deliver out … deeper water, freeing you once they run their course. This is where you'll need the energy to tread water until help arrives or to swim back.

THE STAR-LEDGER

Rescue workers continued to search yesterday for a swimmer swept out …

…Low energy Wave Events…

July 5, 2003
44009: Hm0=3 ft, Tp=6 sec
Over 100 rescues along NJ coast

Analysis of Observed Rip Current Events In New Jersey

- Revealed 2 conditions:
  1. Extreme waves (> 8 ft) with periods > 8 sec
  2. Long-period swell of any height
- Rate of wave energy propagation to coast appears to be important

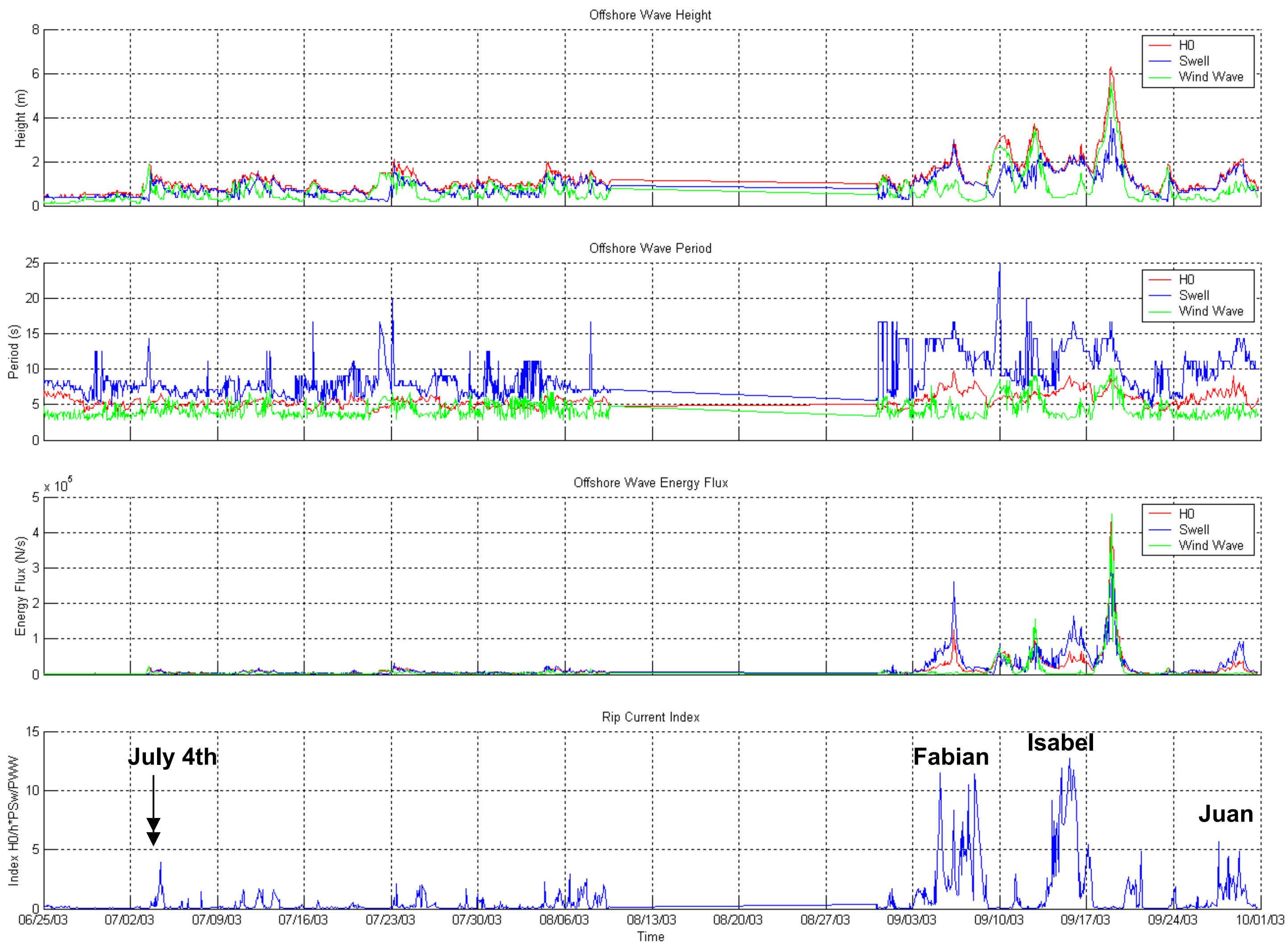
$$P = nEC$$

Rip Current Index

- In order to weight large swell higher than wind waves and smaller swell a Rip Current Index (RI) that is the ratio of swell energy flux to wind wave energy flux multiplied by the ratio of the wave height to water depth appears reasonable.
- Developed from wave buoy data located 20 n.m. off NJ and Stevens Coastal Monitoring Network

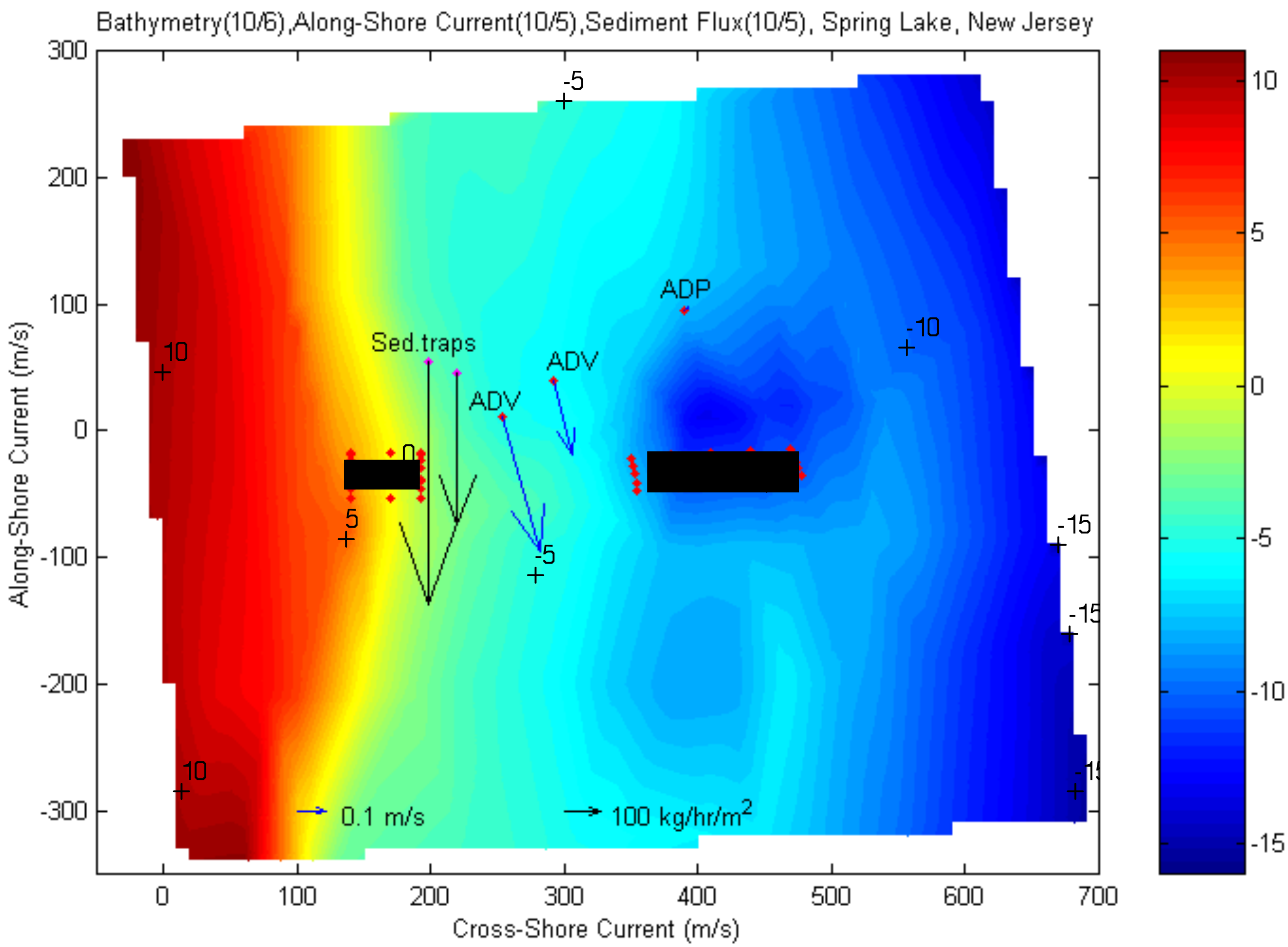
$$RI = 0.1 * \frac{H}{h} * \frac{P_{swell}}{P_{windwave}}$$


Evaluation of Rip Current Index Against known Events in 2003



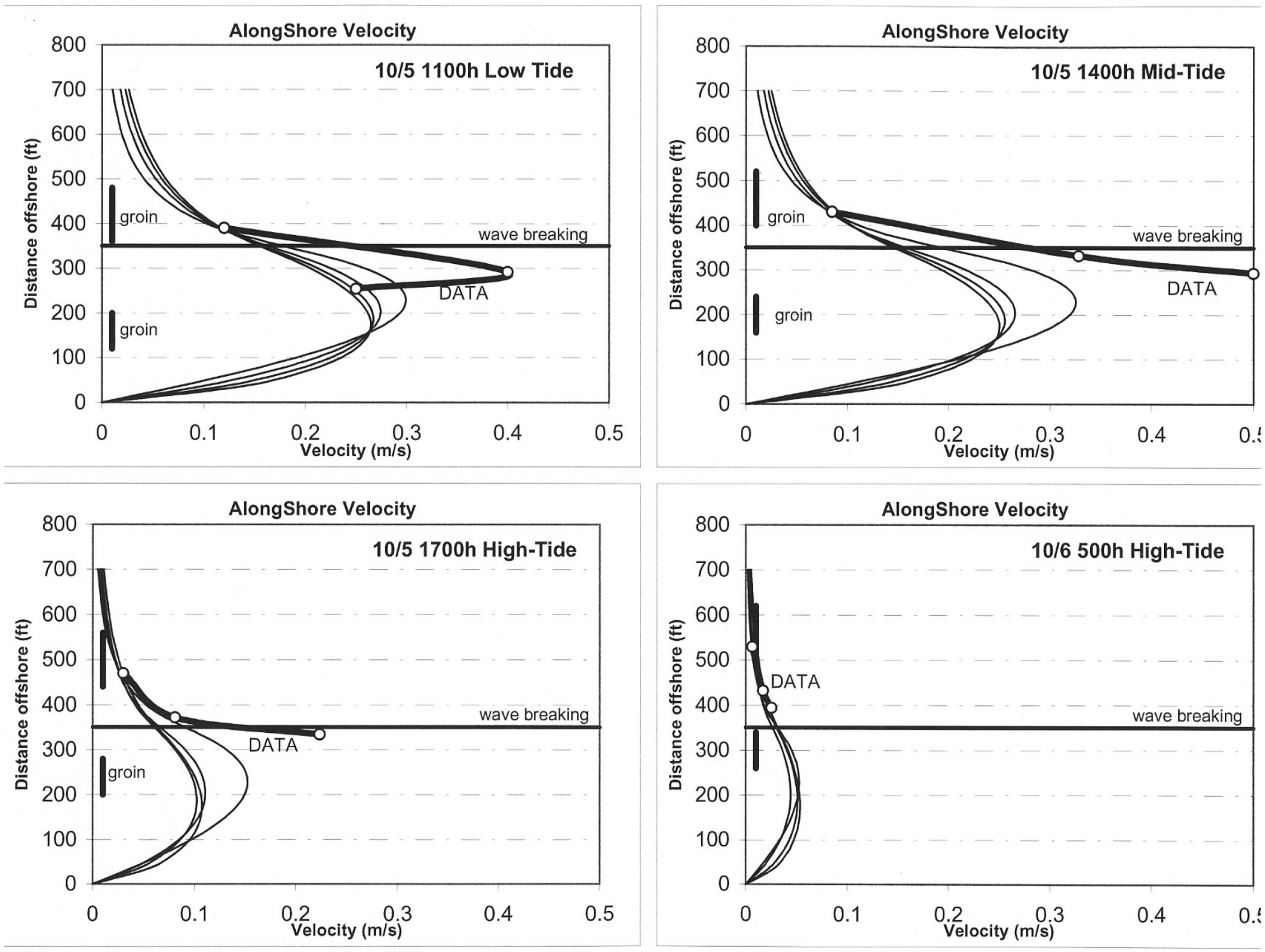
What about Notched Groins?
What are these things?

Current and Sediment Measurements Near Notched Groin



Bathymetry(10/6),Along-Shore Current(10/5),Sediment Flux(10/5), Spring Lake, New Jersey
Along-Shore Current (m/s)
Cross-Shore Current (m/s)
300
200
100
0
-100
-200
-300
0
100
200
300
400
500
600
700
10
5
0
-5
-10
-15
Sed.traps
ADV
ADV
ADP
0.1 m/s
100 kg/hr/m2

Measured Alongshore Current through Notched Groin



Rankin, et al. (2003)

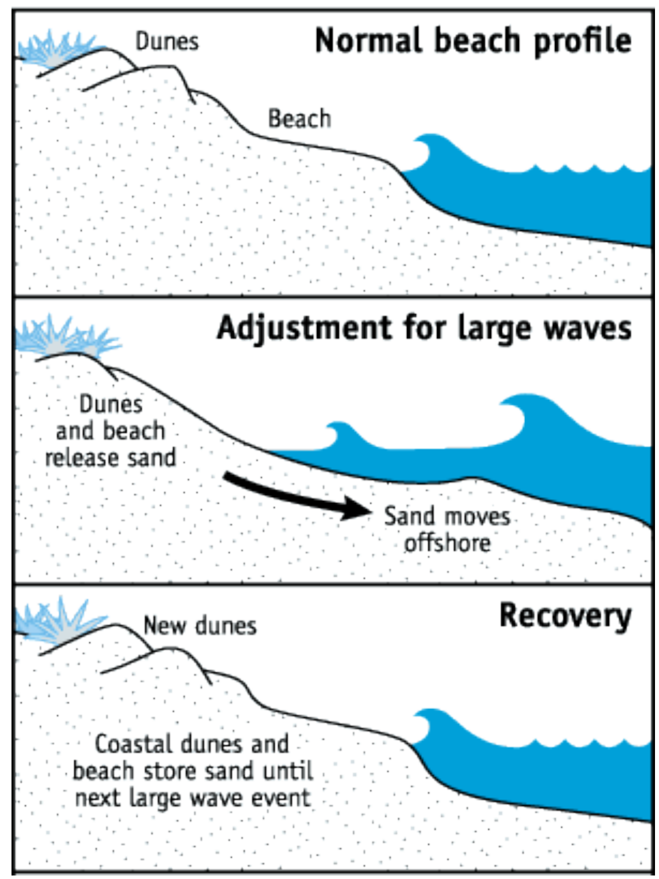
Waves as Agents of Coastal Change

- Shoreline Changes occur on many temporal scales:
  - Seconds (Every wave)
  - Daily (Tides)
  - Seasonally (Changing wave climate)
  - Decadal (Extreme storms)
  - Centuries (Sea level changes)
  - Millennia (Global climate changes)

Seasonal Coastal Changes

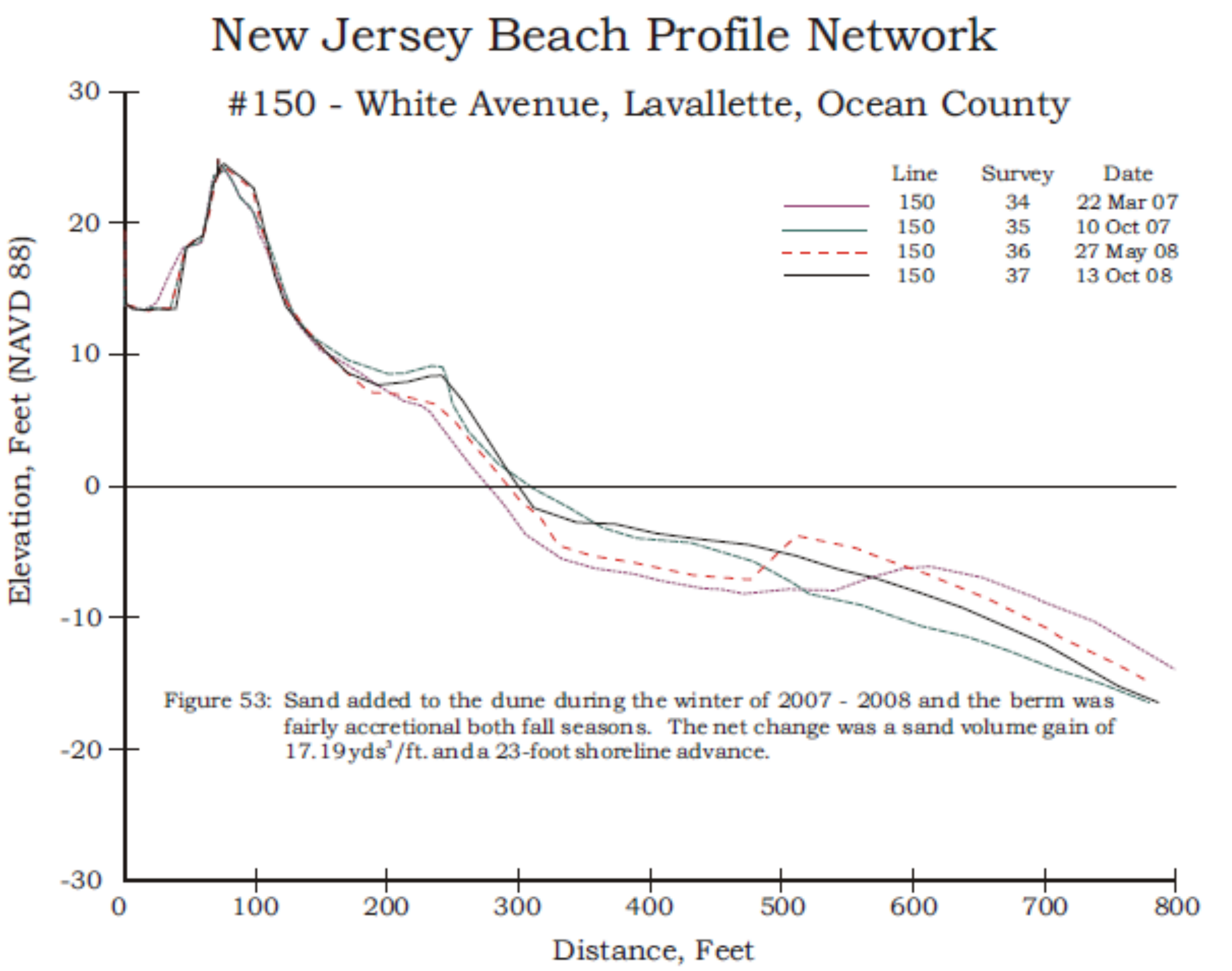
- The cross-shore extent of the beach undergoes erosion and accretion on a seasonal basis
  - In the summer and fall, small waves transport sand up onto the beach
  - In the winter and spring, large storm waves erode sand
  - Transition provides natural protection for the beach.

Seasonal beach profile adjustments



How Do We Know This?

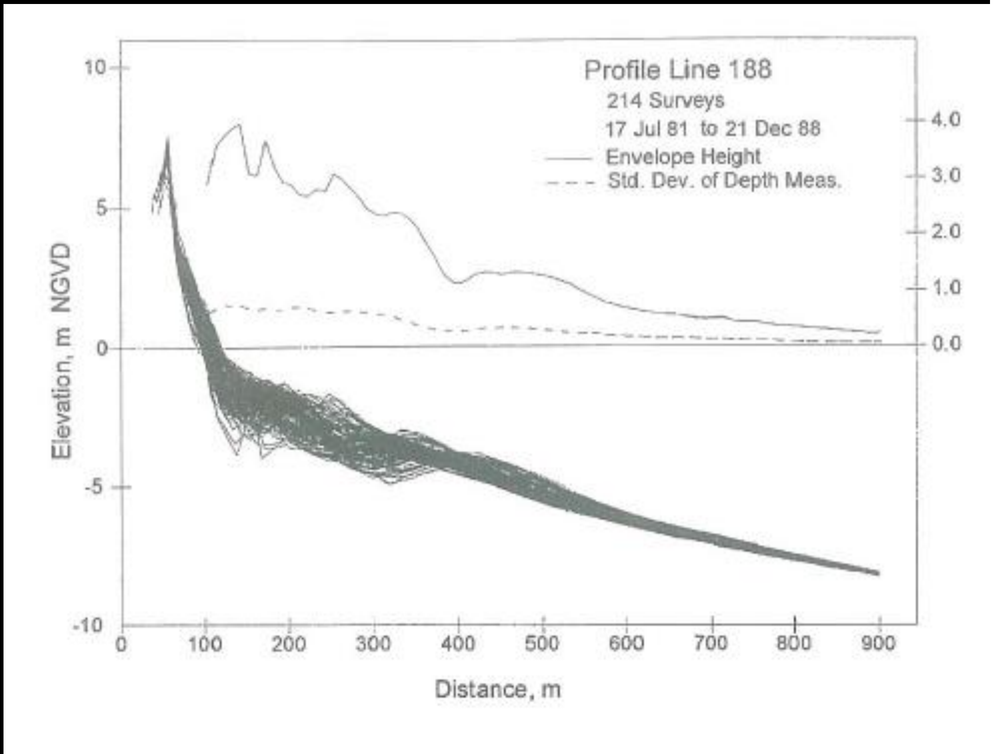
Seasonal Beach Changes



We even know where motion stops…

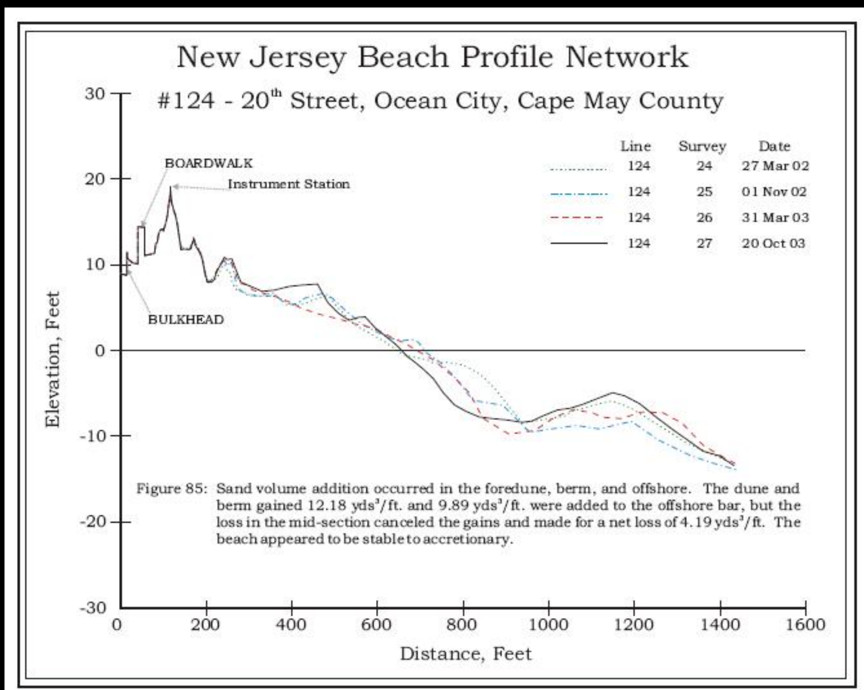
Depth of Closure

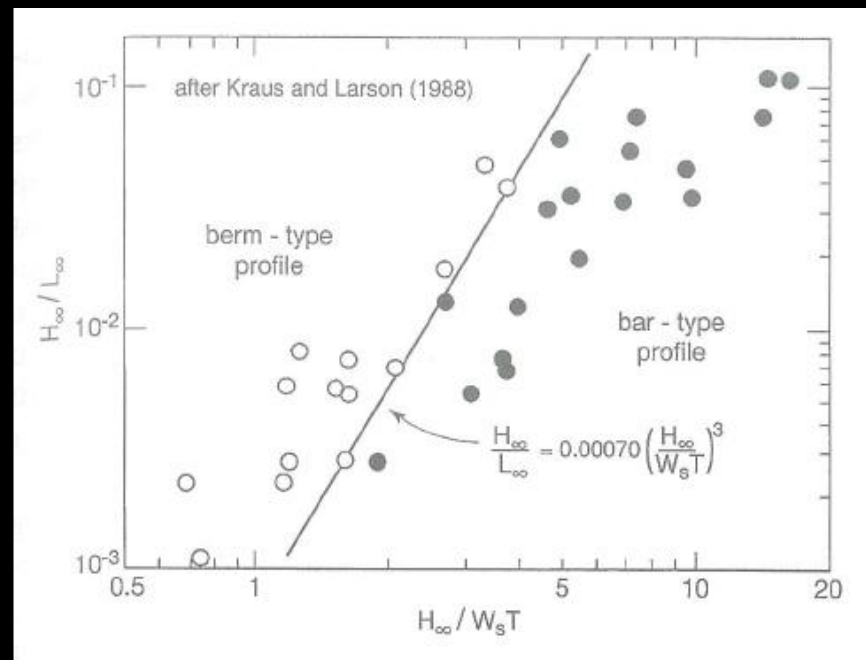
Hallermeier (1981) and Birkemeier (1985)



$$h_c = 1.75H_e - 57.9\left(\frac{H_e^2}{gT_e^2}\right)$$

…and which way the sand is moving!





Profile Transitions between eroded (“bar”) profile and accreted (”berm”) profile on a seasonal basis

$$critical\ \frac{H_\infty}{L_\infty} = 0.00070\left(\frac{H_\infty}{w_s T}\right)^3$$

Kraus and Larson (1988)

Episodic Change: Driven by 3 Components

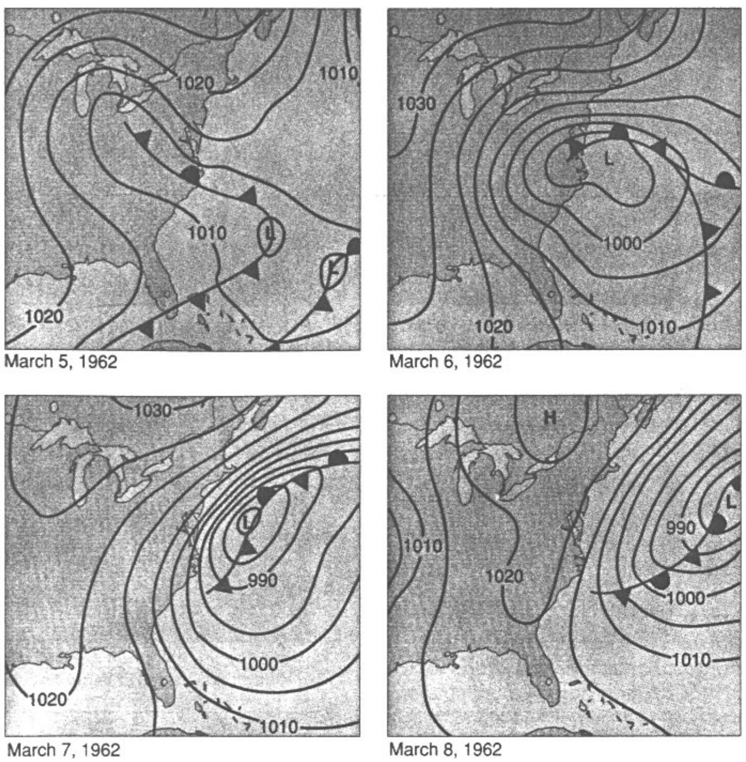
1. **Extreme astronomical tides**
2. **Storm surge**

   generated by intense storms or prolonged onshore winds can generate significant departures from predicted water elevations and wave attack high up on beach berm.

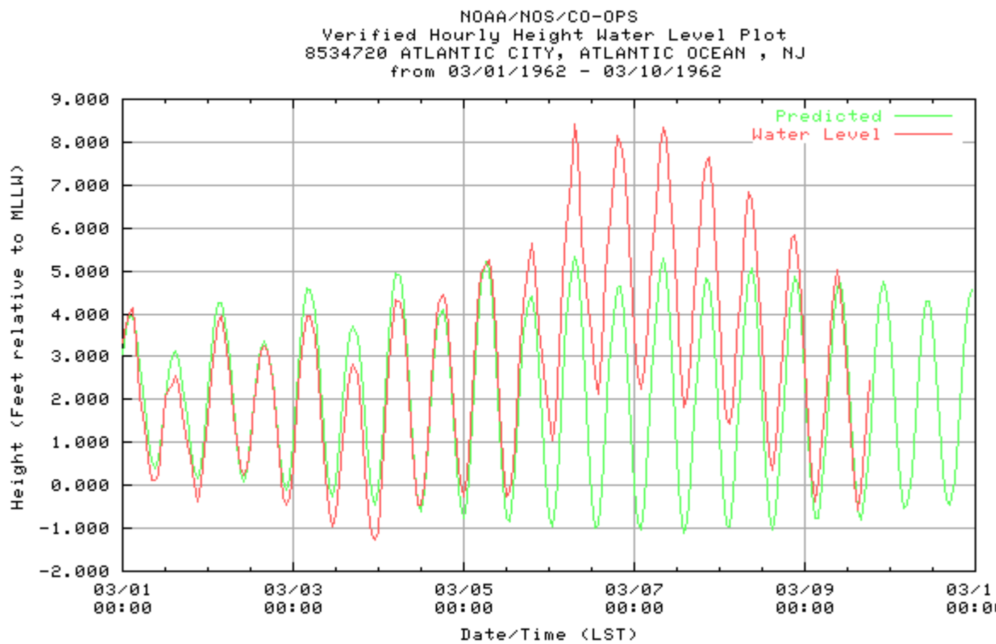
3. **Large waves**

   generate mass transport of water toward coast, increasing flood levels and extent of wave attack.

Prolonged storm surge at Atlantic City during March 1962 Nor'easter



Storm Evolution March 5 – 8, 1962



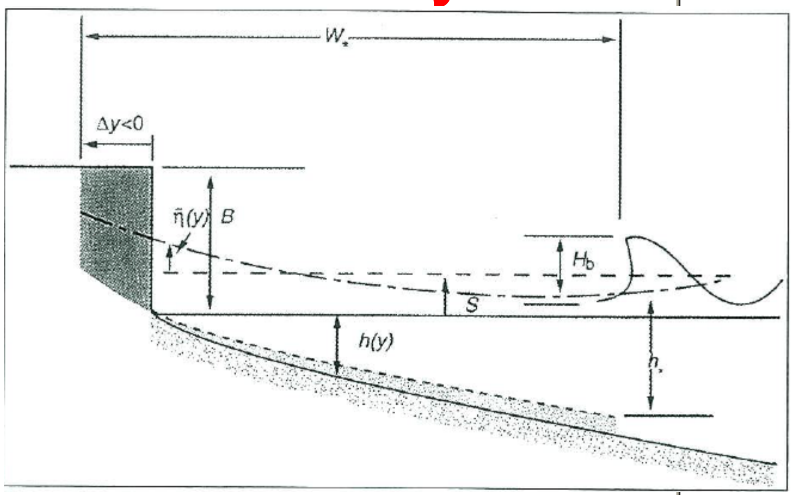
Water Level recorded at Atlantic City Steel Pier

Large-scale Damage

Ocean City, NJ.   Note the transport of water across the island by waves

How can we predict potential storm damage?

Not Easily!



$$PEI(t_j)=W_*(t_j)[(0.068H_b(t_j)+S(t_j))/(B+1.28\,H_b(t_j))] \quad (2)$$

$$SEI = (\sum)\, PEI\,(t_j)$$

A comparison of methods used to calculate northeaster damage potential

By

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ABSTRACT

A common approach to determining the potential damage of a coastal storm has been to focus on flooding impacts and the use stage-frequency analysis as the primary means of determining storm severity. Such an approach, however, appears to have failed in quantifying the coastal erosion and flood impacts generated by the November 12-16, 2009 northeaster. Three indices that have been proposed in the literature as a means to quantify the damage potential of northeasters have been evaluated through a comparison of six significant such storms. Each index was found to accurately rank the severity of observed storm erosion/damage. Through an assessment of the individual variables of each index, storm duration was found to be highly correlated with damage potential followed by maximum significant wave height and water level.

ADDITIONAL KEYWORDS: Beach erosion, extratropical storm, recurrence, stage-frequency, storm surge, waves, coastal damage.

Results

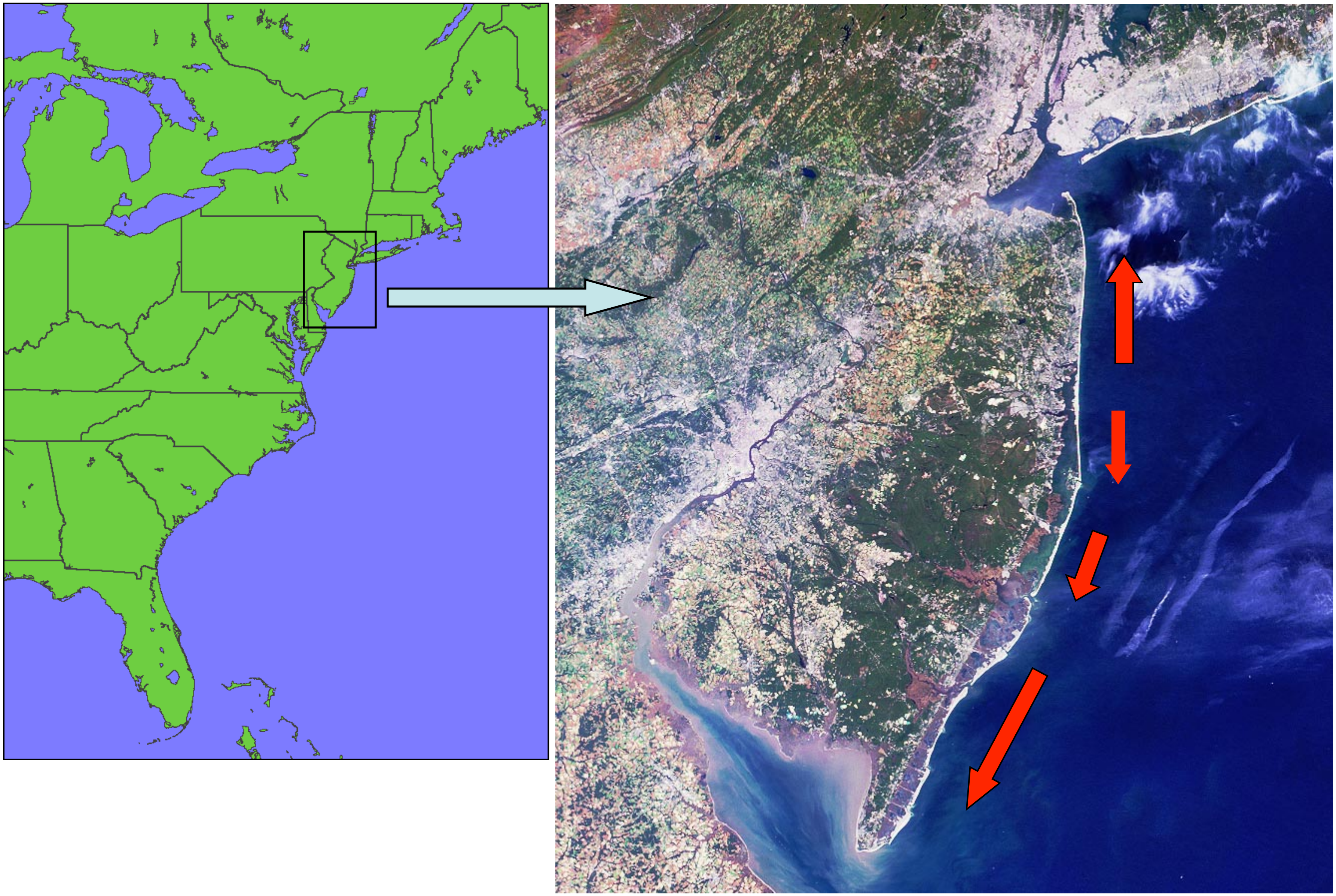
Not so conclusive

- Longer storm duration more important than wave height and surge unless…
- If duration is about equal wave heights dominate

Table 5: PEI and SEI recurrence intervals.

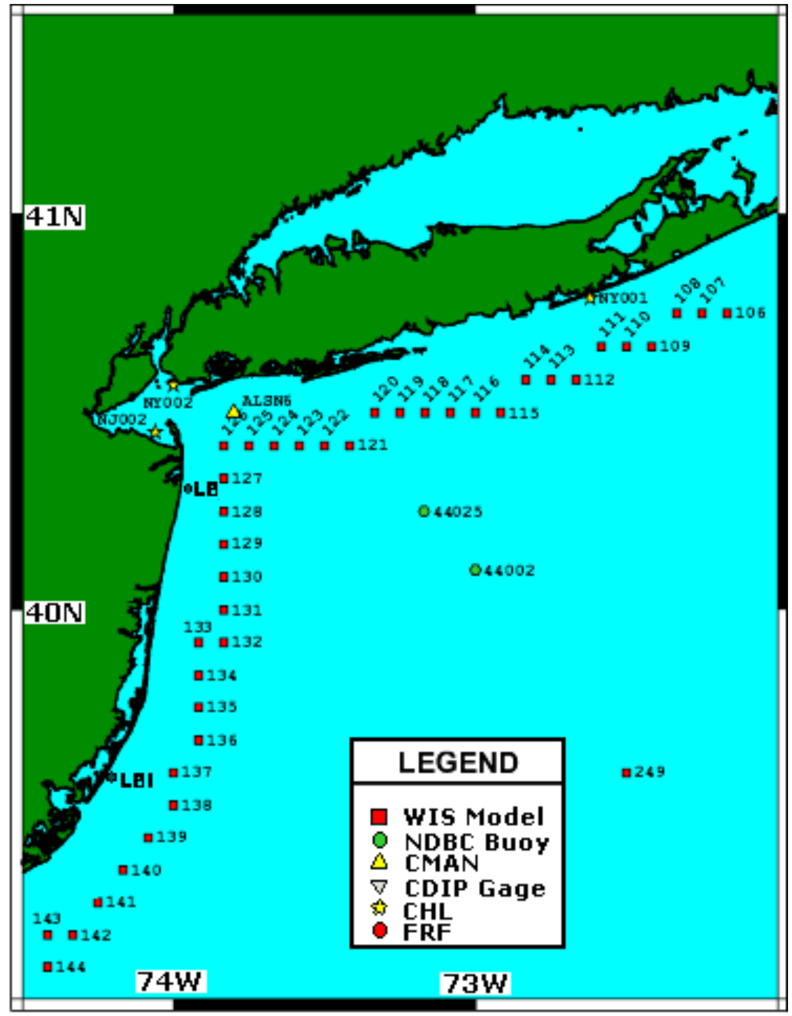
Rank	Date	Max H_0 (m)	Peak WL (m, MLLW)	Duration (hr)	SEI (m)	SEI Recurrence (yr)
1	December 1992	9.3	2.80	124	5143	46.1
2	November 2009	6.1	2.30	104	4381	20.4
3	October 1991	4.7	2.65	117	3481	8.0
4	February 1998	5.7	2.37	55	2190	2.4
5	March 1994	7.4	2.53	44	1868	1.9
6	January 1992	6.3	2.43	46	1404	1.4

Wave Climate Long Term Coastal Change

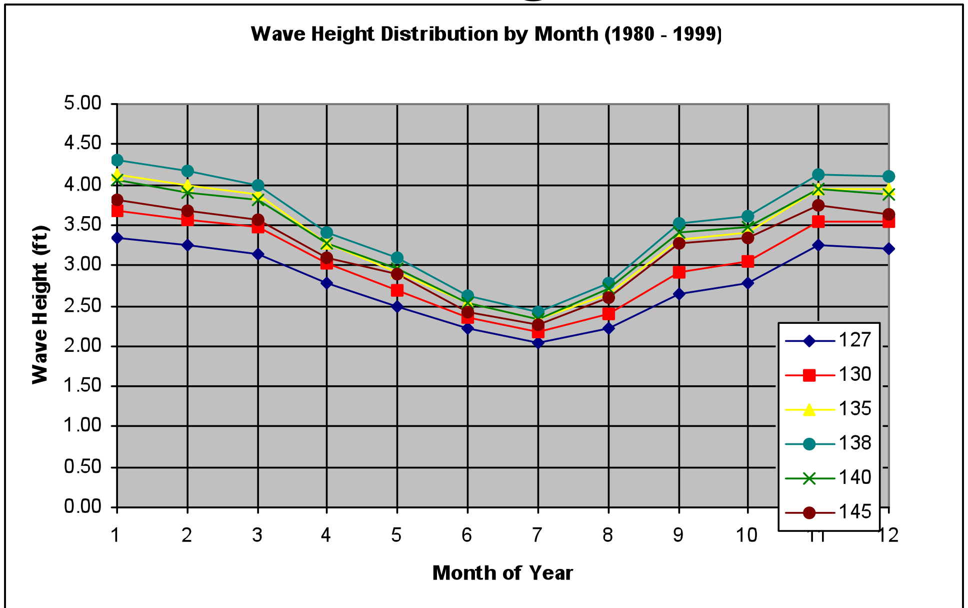


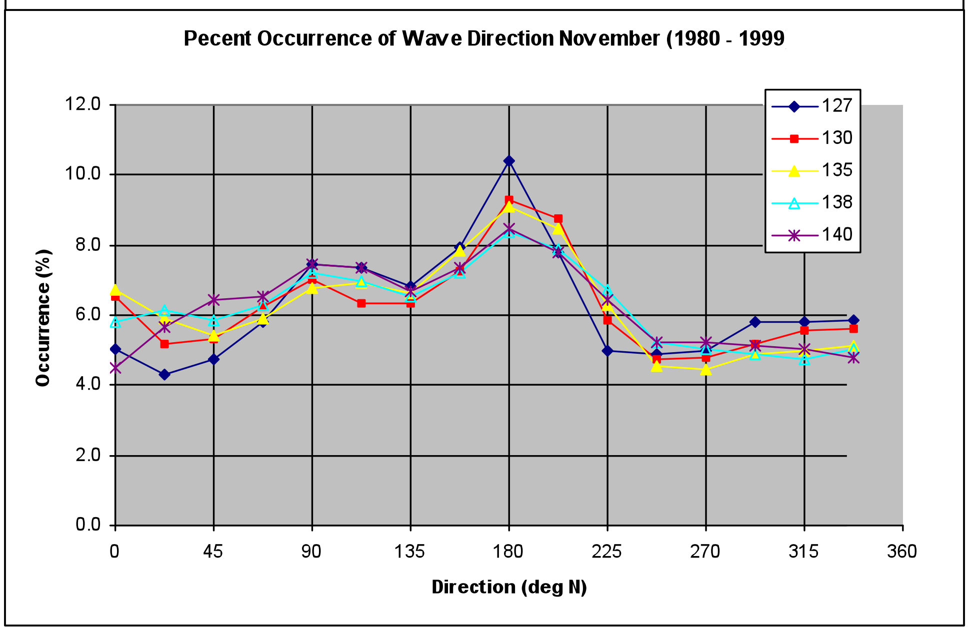
How do we know this?

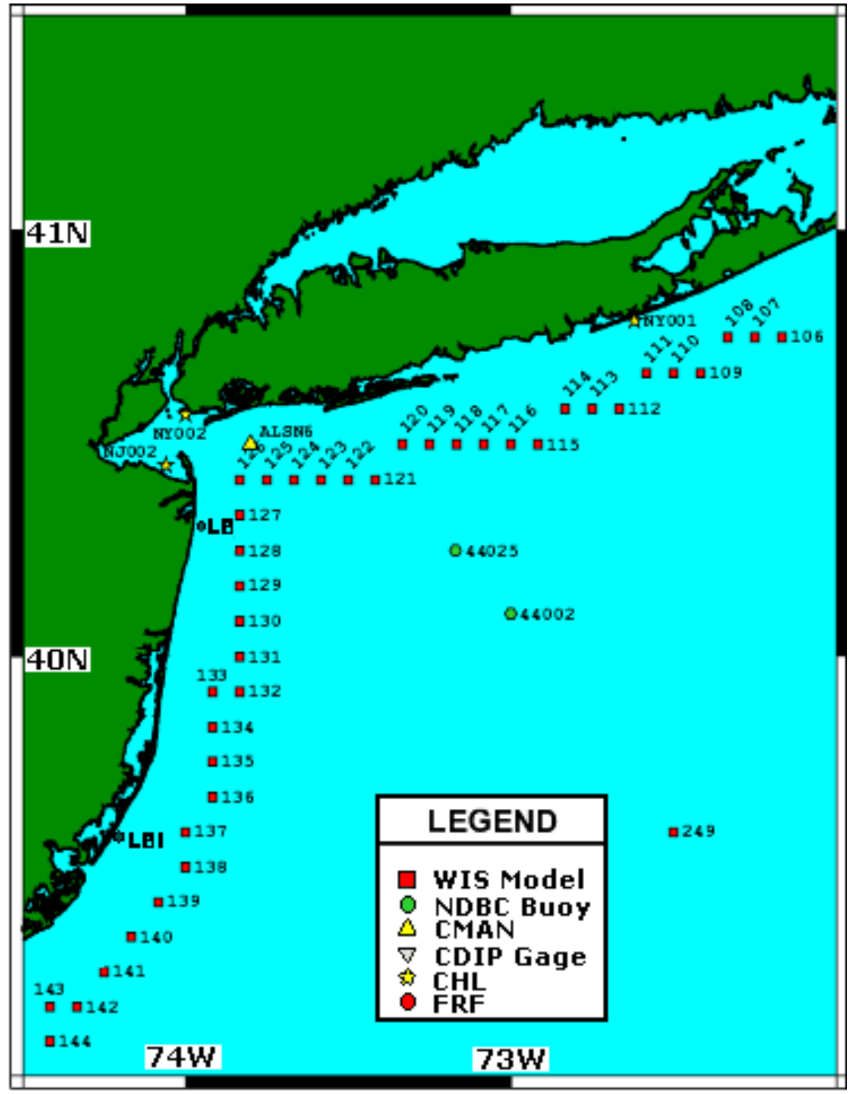
- Wave Hindcasts based on historic weather data
- Offshore Buoy Data
- Neashore Wave Data



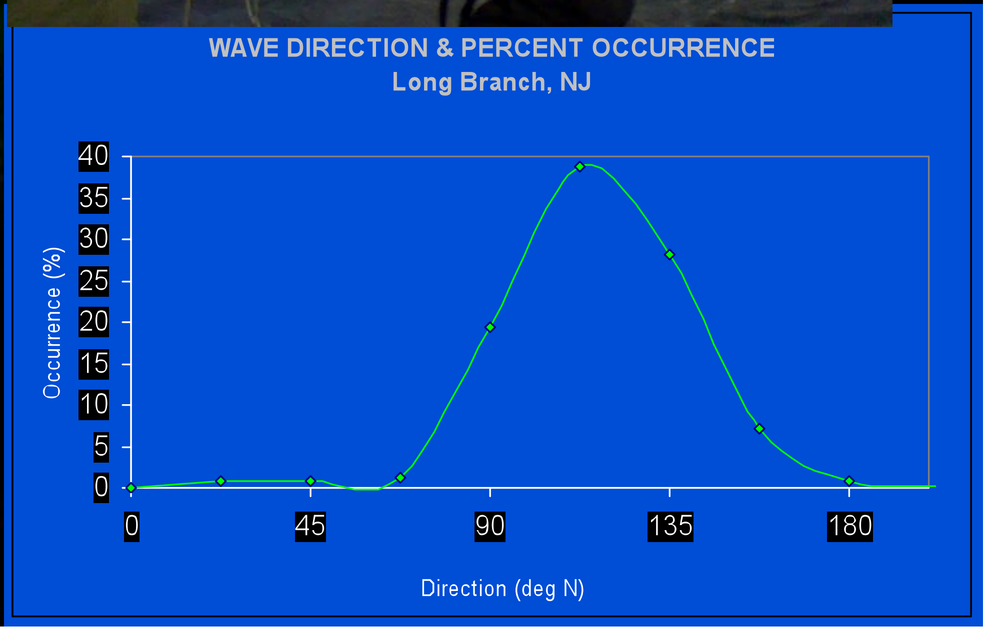
Long Term Wave Climate



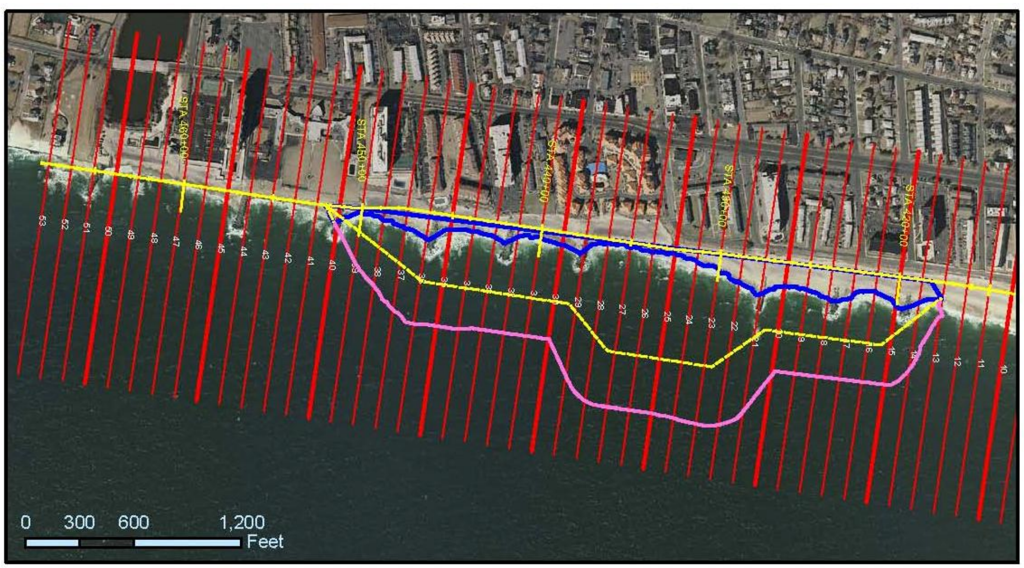




We can use this to our advantage!

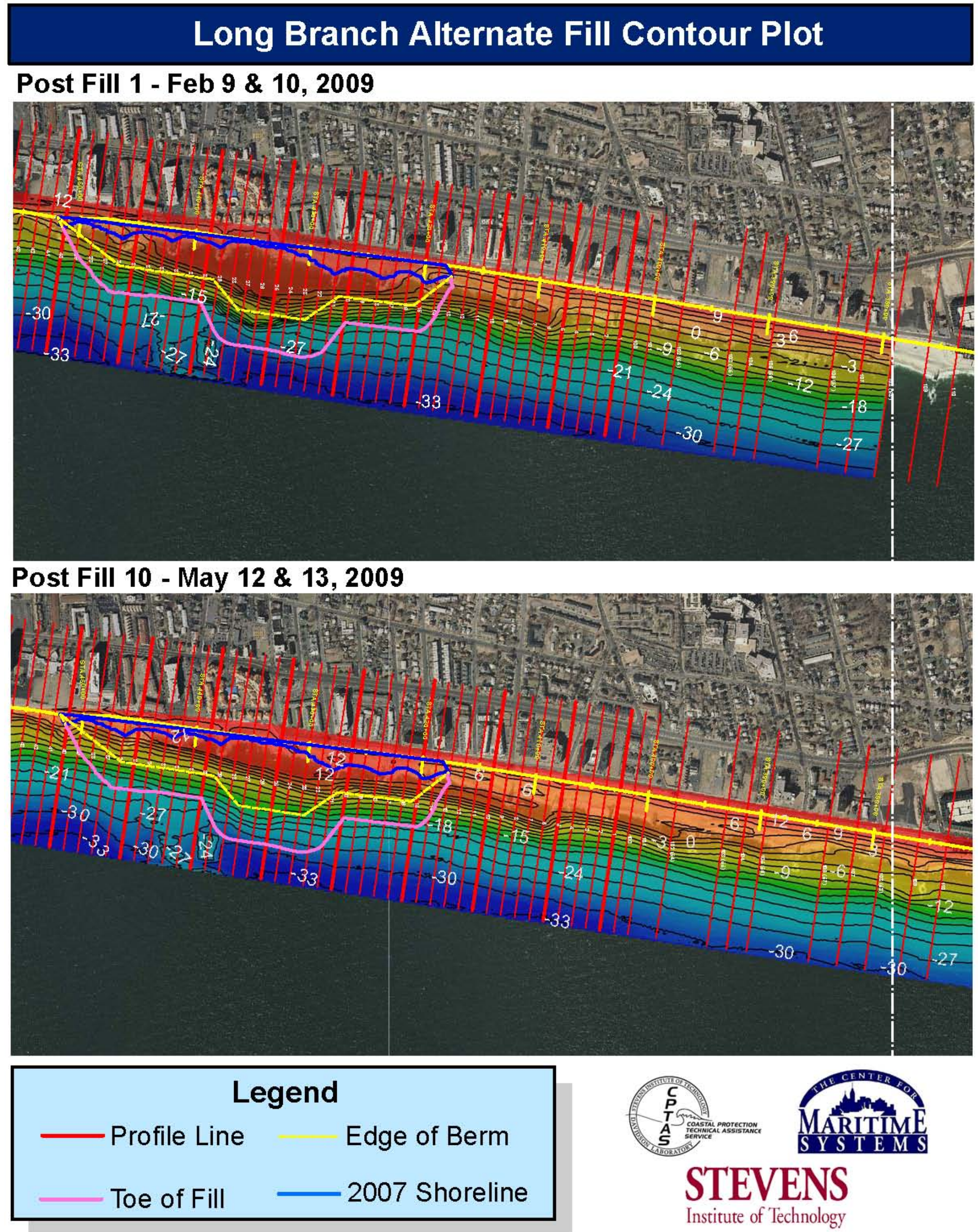


Long Branch Feeder Beach



Shoreline Evolution

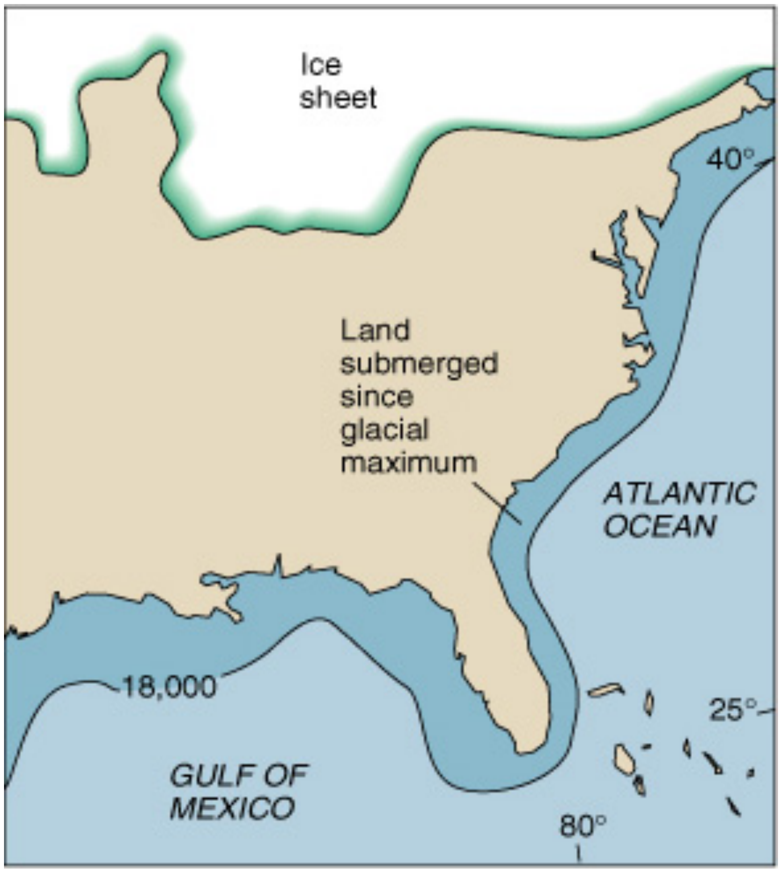
- Elevation Change
  - Offshore contours are becoming parallel to shoreline
  - Deflation of feeder feature
  - 100,000 cu.yds. Per year transport to north



STEVENS Institute of Technology

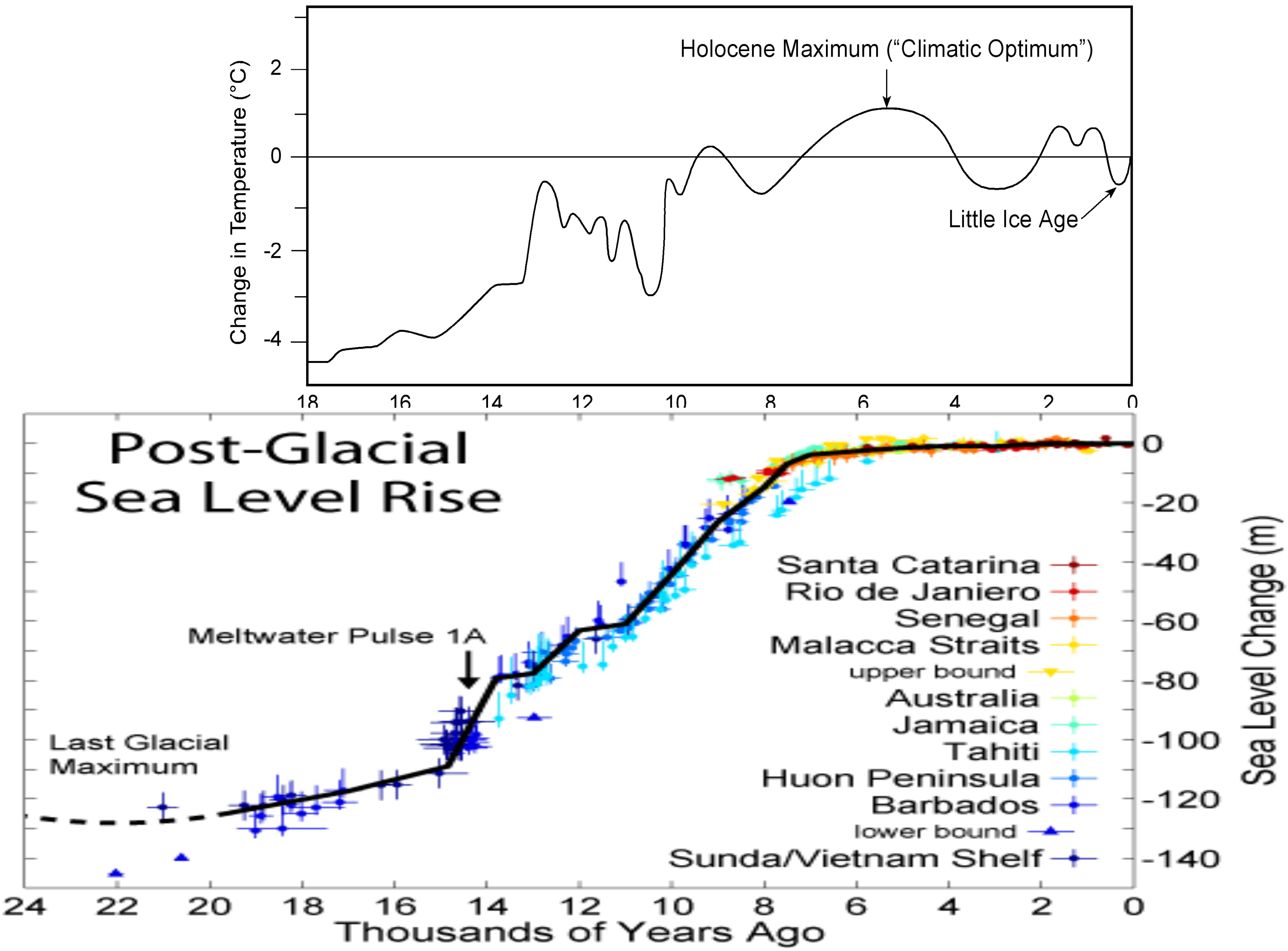
Long Term Change
(Sea-level Rise)

Recent Sea Level Changes



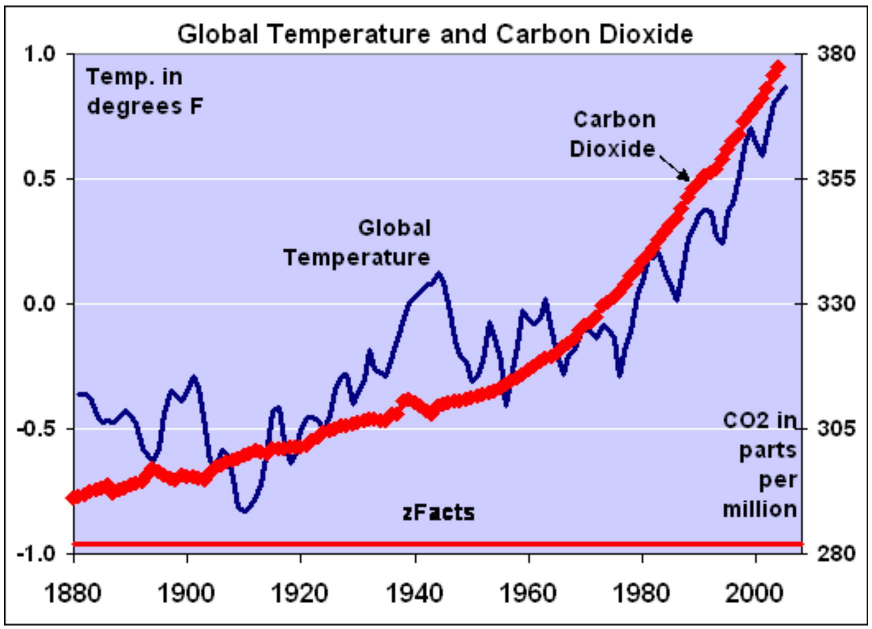
- 18,000 years ago, at the height of the last glaciation, sea level was 130 m lower than today.
- Sea level continues to rise by about 1 foot per century in New York City.
- A rise in sea level of up to a meter is predicted for the coming century.

Global Temp and Sea level changes for past 18,000 years
based on radiometric age dating of corals

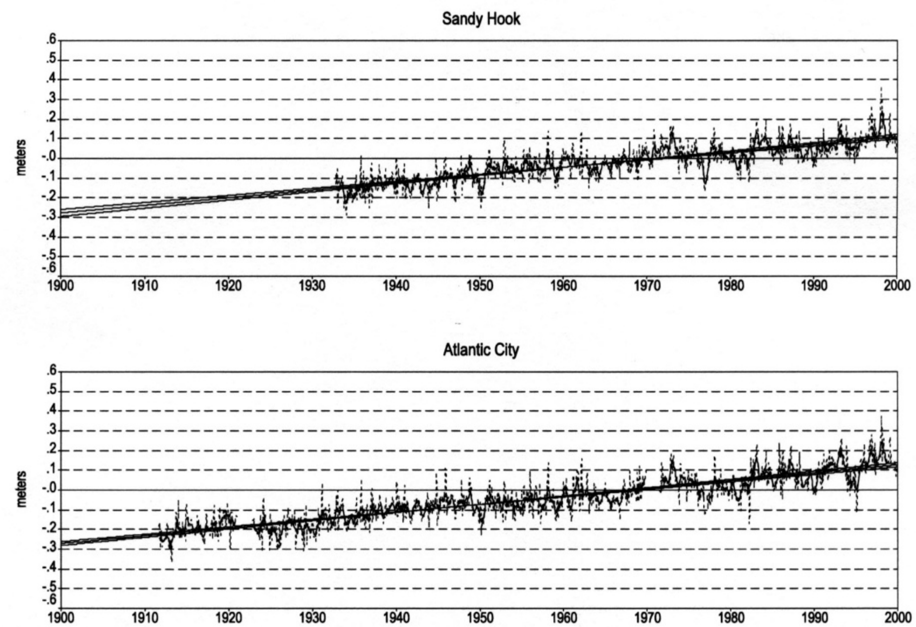


Modern Record Sea level rise about 30 cm/century

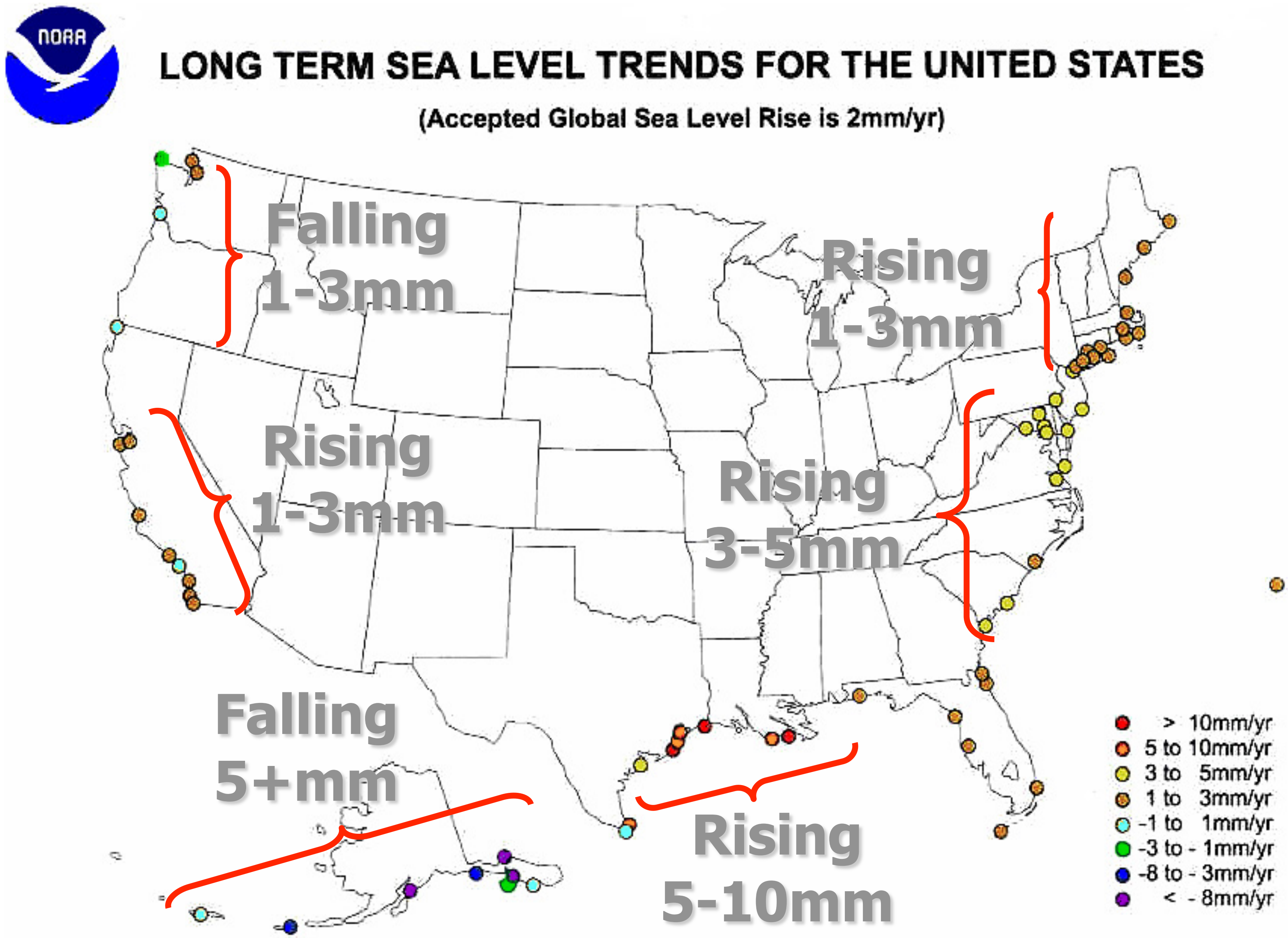
speculation: greenhouse gas>>global warming >>melting ice



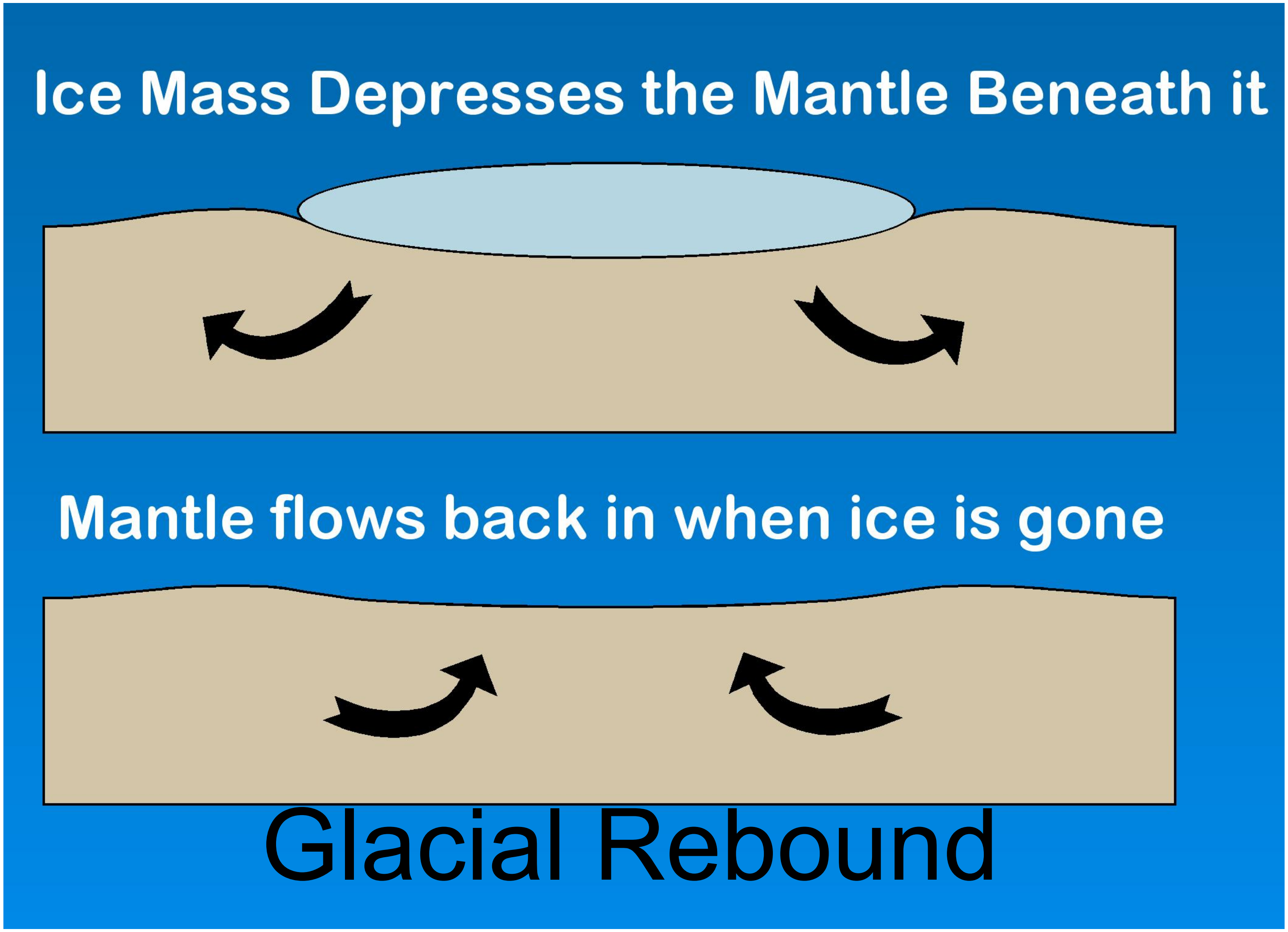
NJ Tide Gauge Records



3.8 mm/yr in New Jersey

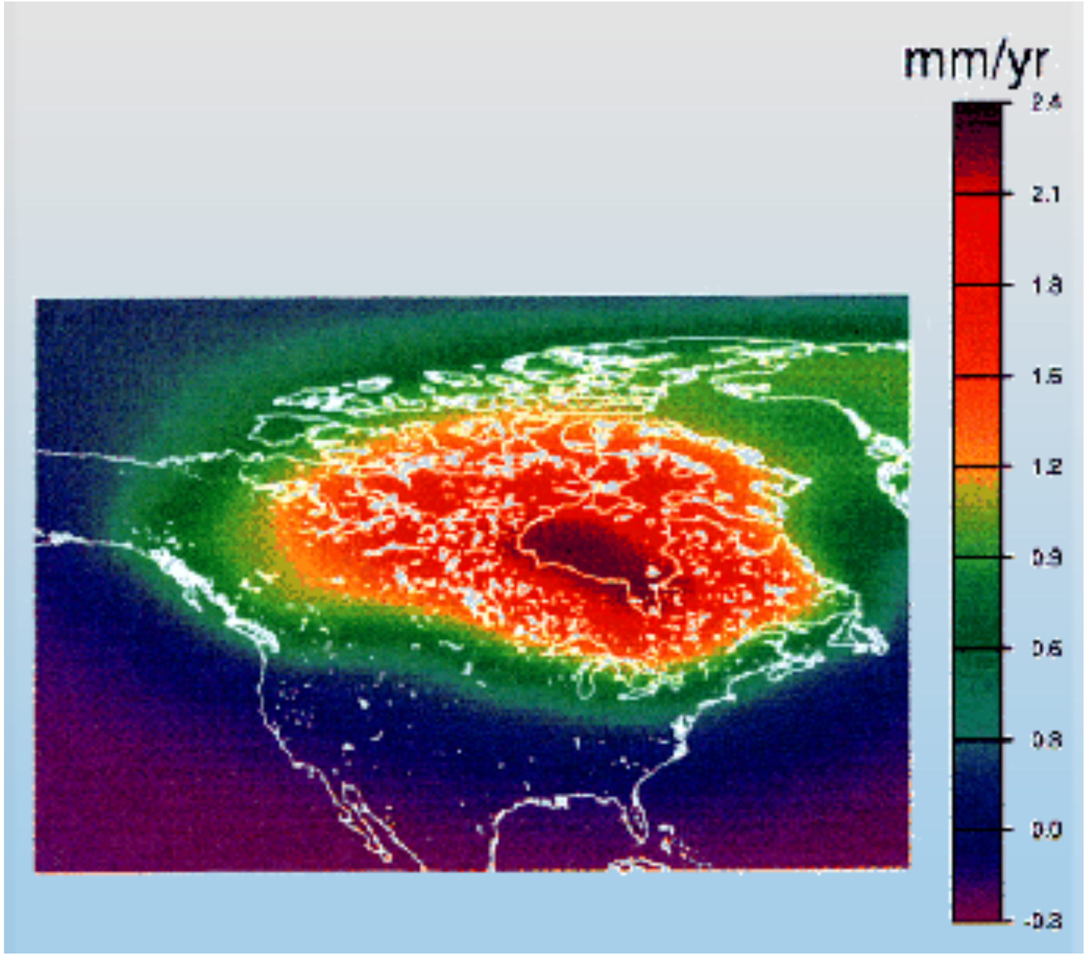

LONG TERM SEA LEVEL TRENDS FOR THE UNITED STATES
(Accepted Global Sea Level Rise is 2mm/yr)
Falling 1-3mm
Rising 1-3mm
Rising 1-3mm
Rising 3-5mm
Falling 5+mm
Rising 5-10mm
> 10mm/yr
5 to 10mm/yr
3 to 5mm/yr
1 to 3mm/yr
-1 to 1mm/yr
-3 to - 1mm/yr
-8 to - 3mm/yr
< - 8mm/yr

Tectonic Factors Affecting Sea Level

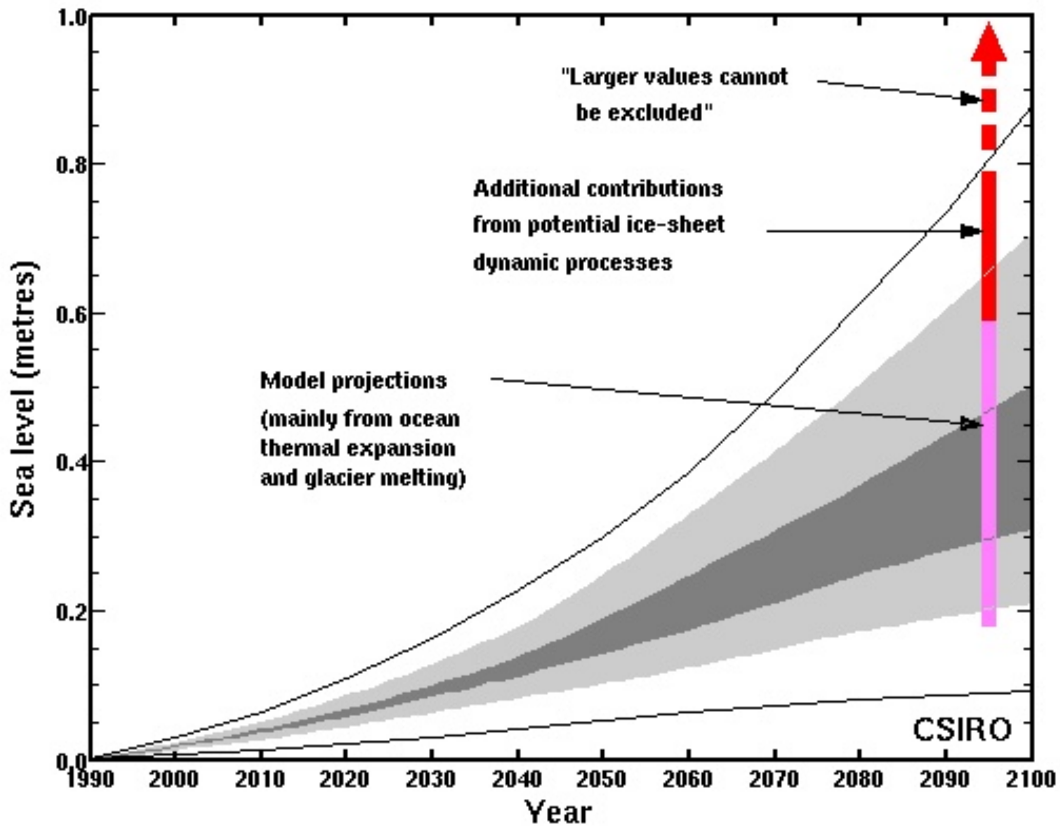


North American Glacial Rebound

Rebound occurs much more slowly than ice melting. Even though the ice has been gone for 10,000 years, North America is still rebounding at 1 to 2 mm/yr.

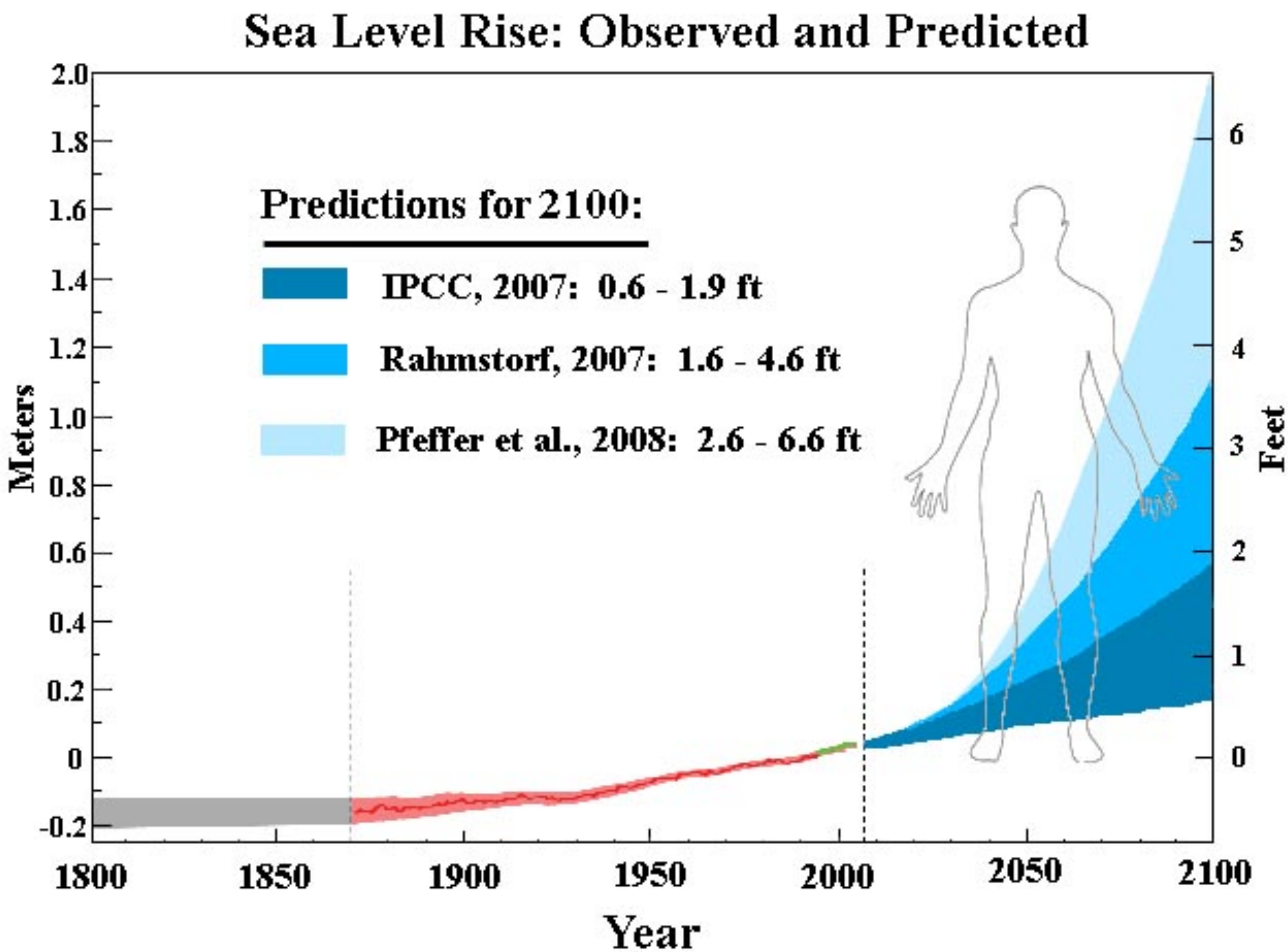


What does the future hold?



Projected sea-level rise for the 21st century. The projected range of global-averaged sea-level rise from the IPCC (2001) assessment report for the period 1990–2100 is shown by the lines and shading (the dark shading is the model average envelope for the range of greenhouse gas scenarios considered, the light shading is the envelope for all models and for the range of scenarios, and the outer lines include an allowance for an additional land-ice uncertainty). The AR4 IPCC projections (90% confidence limits) made in 2007 are shown by the bars plotted at 2095, the magenta bar is the range of model projections and the red bar is the extended range to allow for the potential but poorly quantified additional contribution from a dynamic response of the Greenland and Antarctic Ice Sheets to global warming.

Considerable Uncertainty



What does this mean for the Coast?

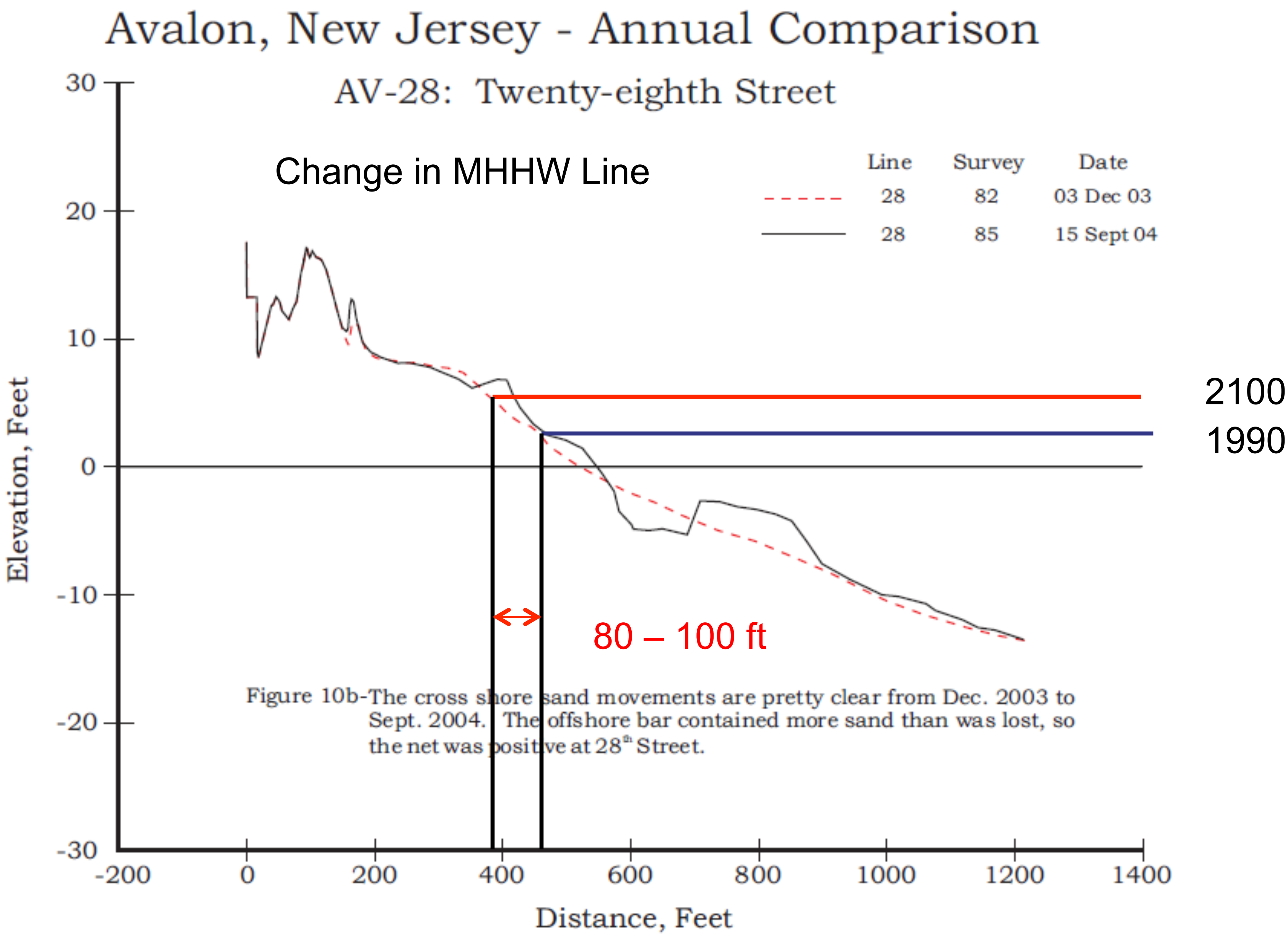
INCREASED FLOOD LEVELS

Adjusted Flood Levels at Atlantic City

Storm	**Meas. Elev.**[1]	**Surge**	**2012**[2]	**2100**[3]
Sept. 1944	8.96 ft	4.17 ft	9.81 ft	11.43 ft
March 1962	8.80 ft	3.43 ft	9.42 ft	11.05 ft
Dec. 1992	9.14 ft	4.28 ft	9.39 ft	11.01 ft
Oct. 1991	8.93 ft	4.48 ft	9.19 ft	10.81 ft

1. Relative to MLLW at Atlantic City
2. Adjusted for historic sea level rise of 3.8 mm/yr
3. Adjusted for IPPC Max Sea Level Rise Projection of 1.9 ft by 2100

What does this mean for the Coast?



Print

Food for Thought ?

May 4, 2012

NSF Press Release 12-088
Analysis of Speed of Greenland Glaciers Gives New Insight for Rising Sea Level

Researchers determine that although glaciers continue to increase in velocity, the rate at which they can dump ice into the ocean is limited

Changes in the speed that ice travels in more than 200 outlet glaciers indicates that Greenland's contribution to rising sea level in the 21st century could be significantly less than the upper limits some scientists thought possible.
The finding comes from a paper funded by the National Science Foundation (NSF) and NASA and published in today's journal *Science*.

Useful Data Sources:

Waves: http://www.ndbc.noaa.gov/
Tides: http://tidesandcurrents.noaa.gov/
Stevens: http://hudson.dl.stevens-tech.edu/maritimeforecast/
Stevens Storm Surge: http://hudson.dl.stevens-tech.edu/SSWS/
NJ Beach Data: http://www.gannet.stockton.edu/crc/index.asp