Marine Forecasting at TAFB

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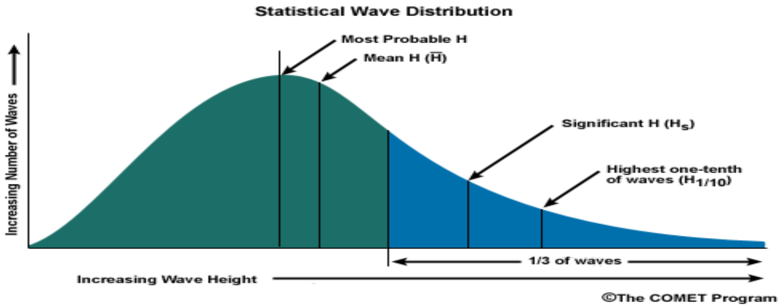
Waves 101

Concepts and basic equations

Have an overall understanding of the wave forecasting challenge

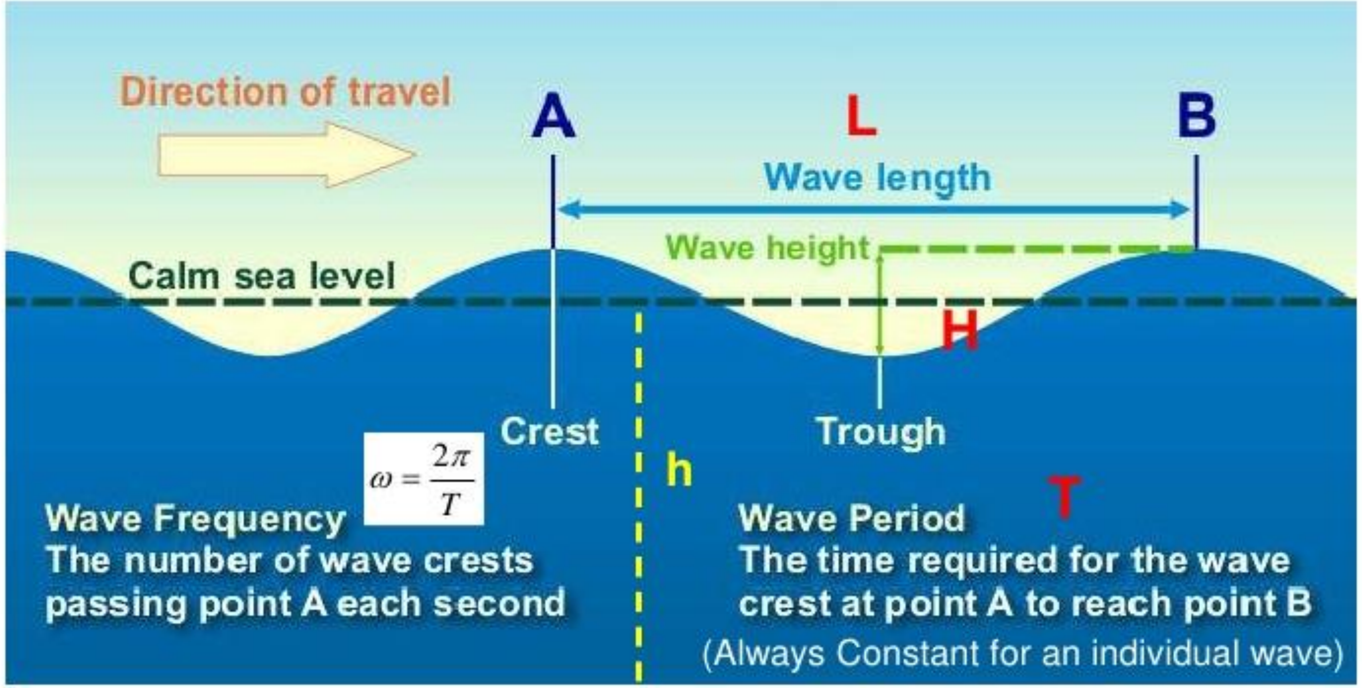
- Wave growth
- Wave spectra
- Swell propagation
- Swell decay
- Deep water waves
- Shallow water waves



Wave Concepts

- Waves form by the stress induced on the ocean surface by physical wind contact with water
- Begin with capillary waves with gradual growth dependent on conditions
- Wave decay process begins immediately as waves exit wind generation area…a.k.a. "fetch" area

Anatomy of a Wave



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

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

Wave Growth

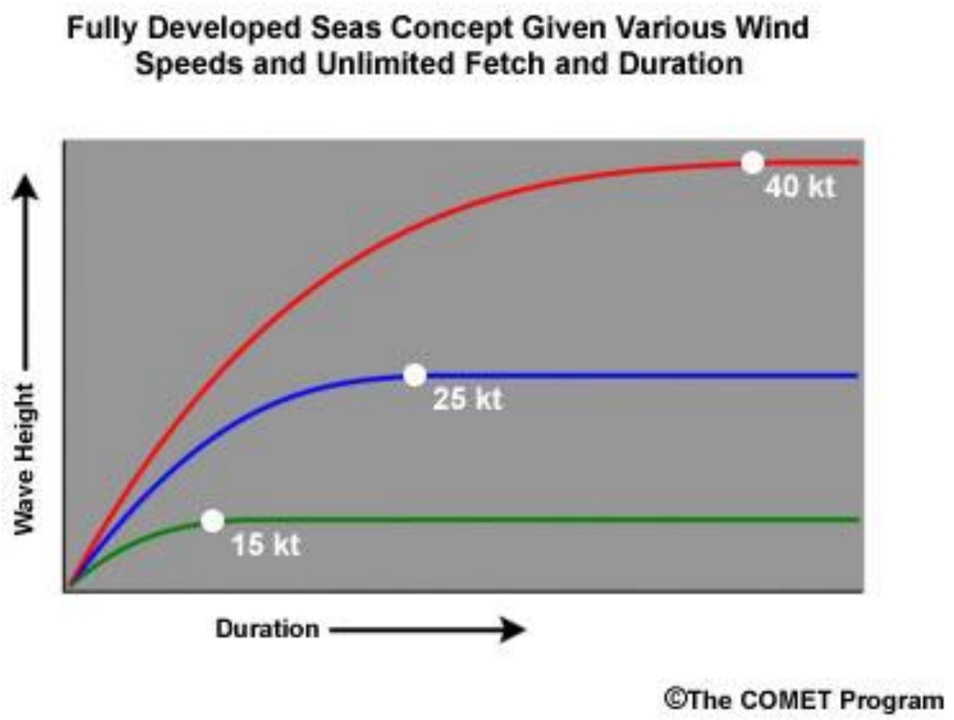
There are three basic components to wave growth:

- **Wind speed**
- **Fetch length**
- **Duration**

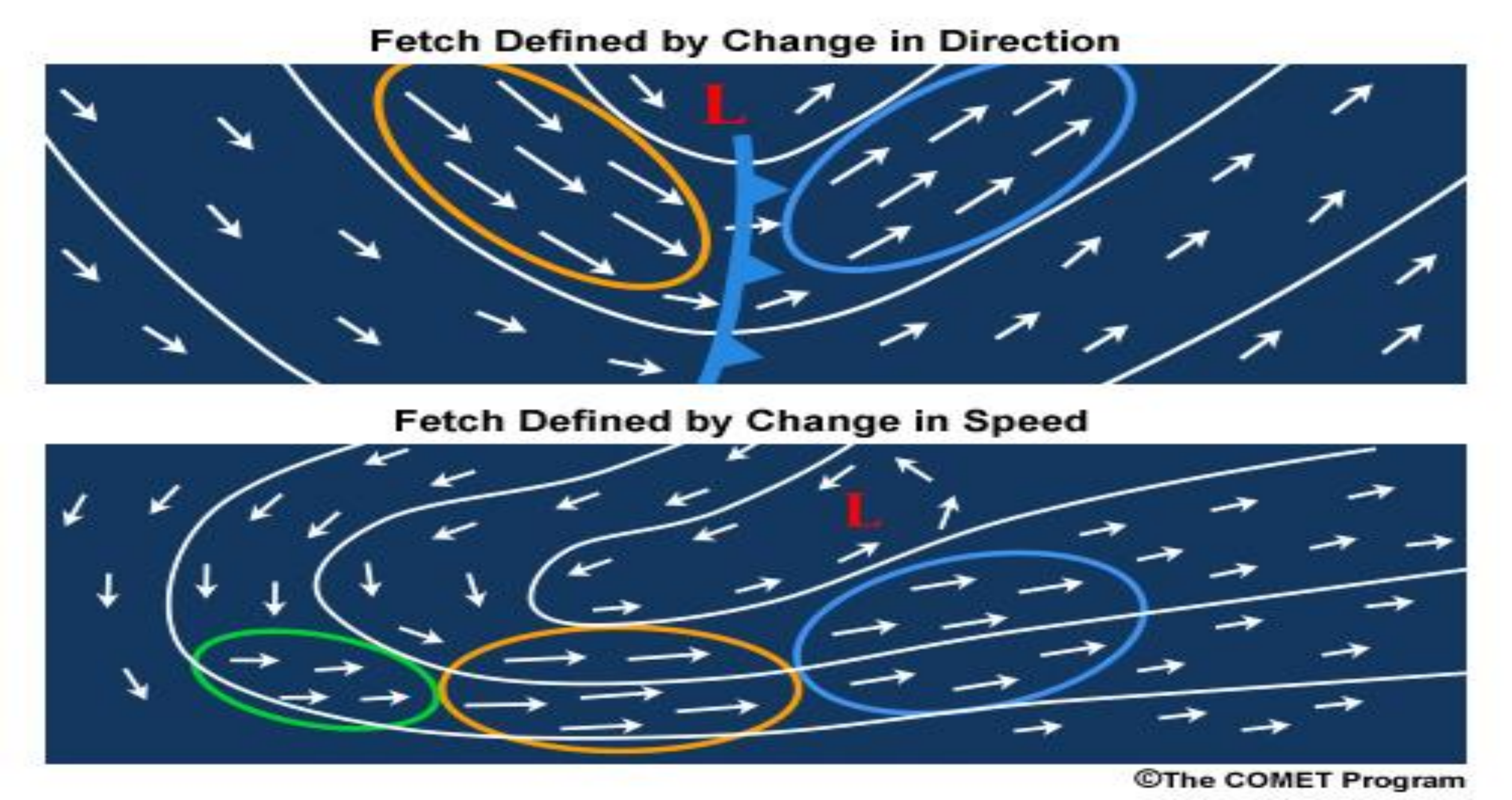
Wave growth is limited by either **fetch length** or **duration**

Fully Developed Sea

- When wave growth has reached a maximum height for a given wind speed, fetch and duration of wind.
- A sea for which the input of energy to the waves from the local wind is in balance with the transfer of energy among the different wave components, and with the dissipation of energy by wave breaking - AMS.

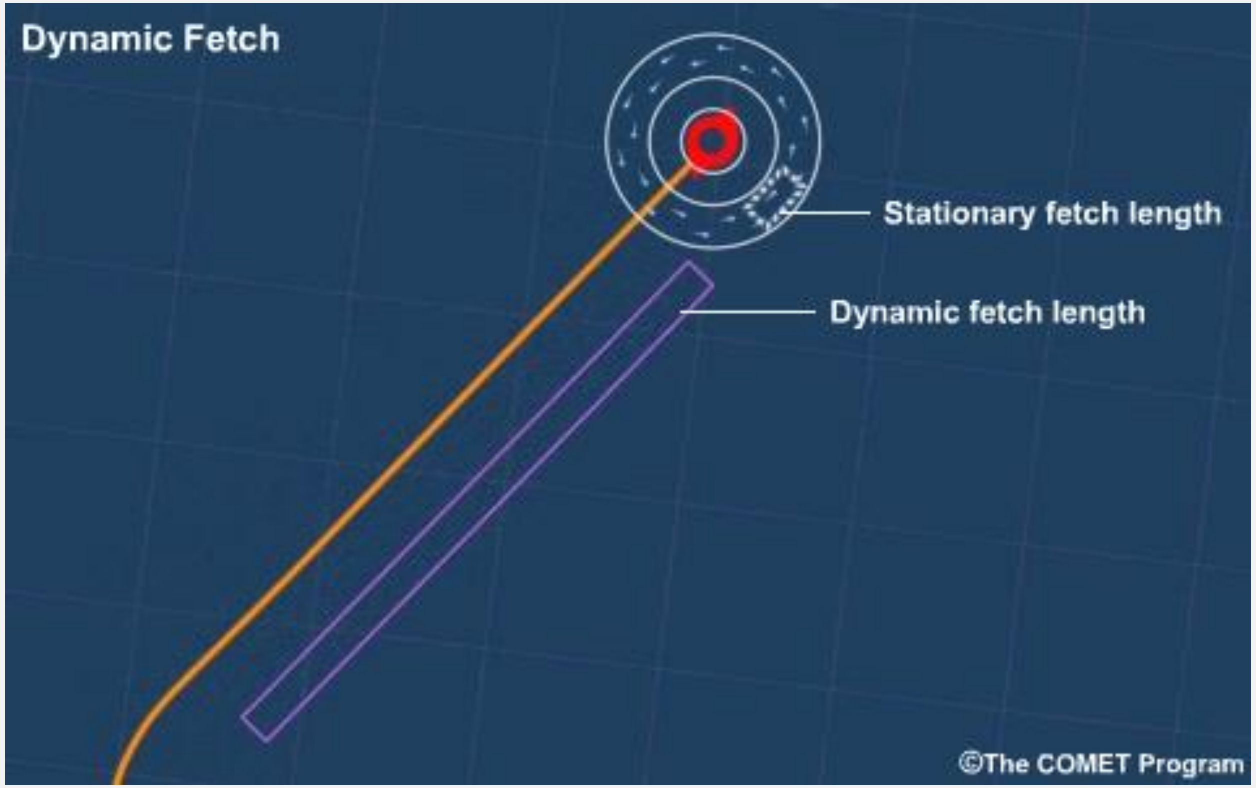


Fetches

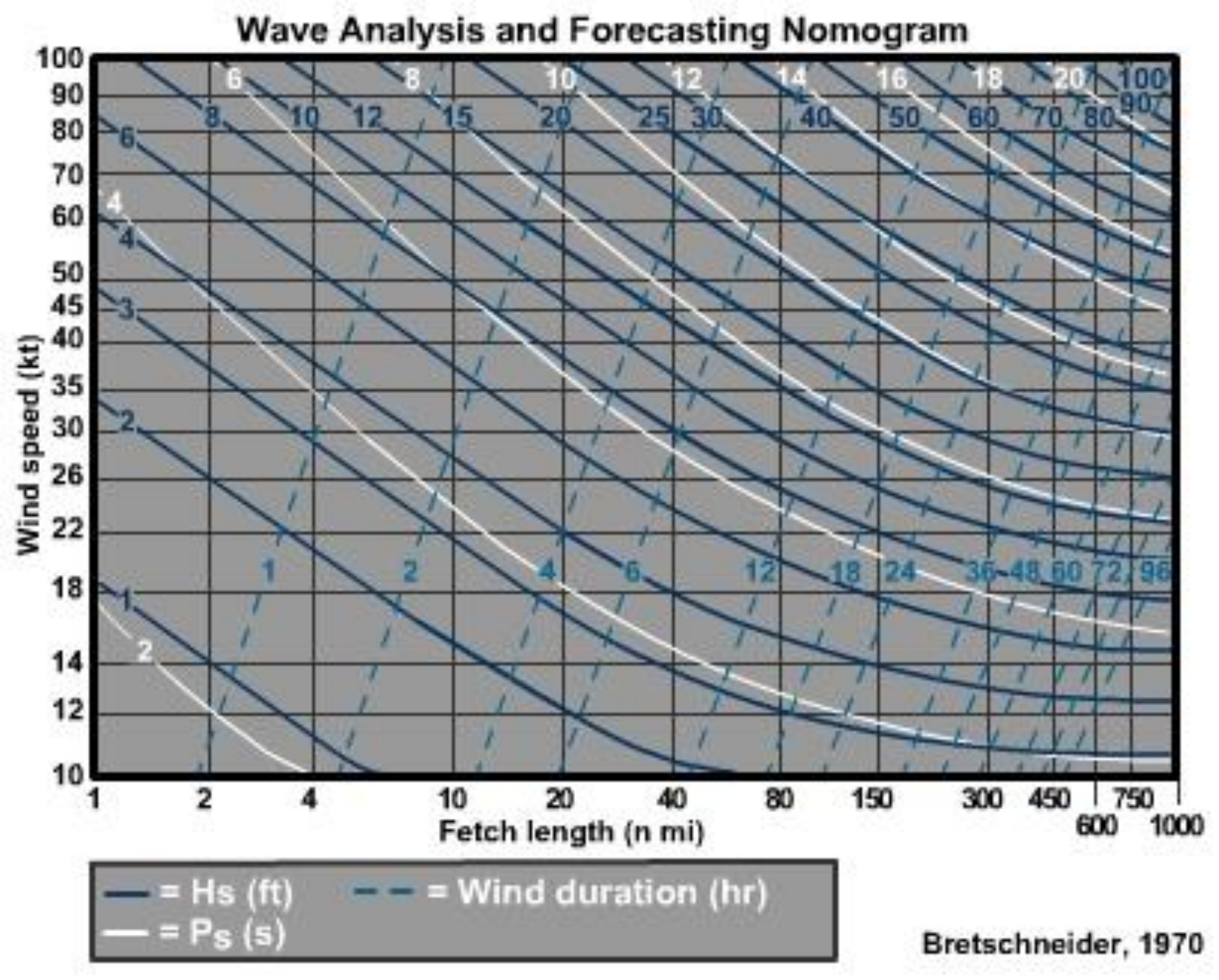


Fetch Defined by Change in Direction
L
Fetch Defined by Change in Speed
L
©The COMET Program

Dynamic Fetch



Wave Growth Nomogram



Calculate Wave H and T

- What can we determine for wave characteristics from the following scenario?
  - 40 kt wind blows for 24 hours across a 150 nm fetch area?
  - Using the wave nomogram – start on left vertical axis at 40 kt
  - Move forward in time to the right until you reach either 24 hours or 150 nm of fetch
  - What is limiting factor? Fetch length or time?
  - Nomogram yields 18.7 ft @ 9.6 sec

Wave Growth Nomogram

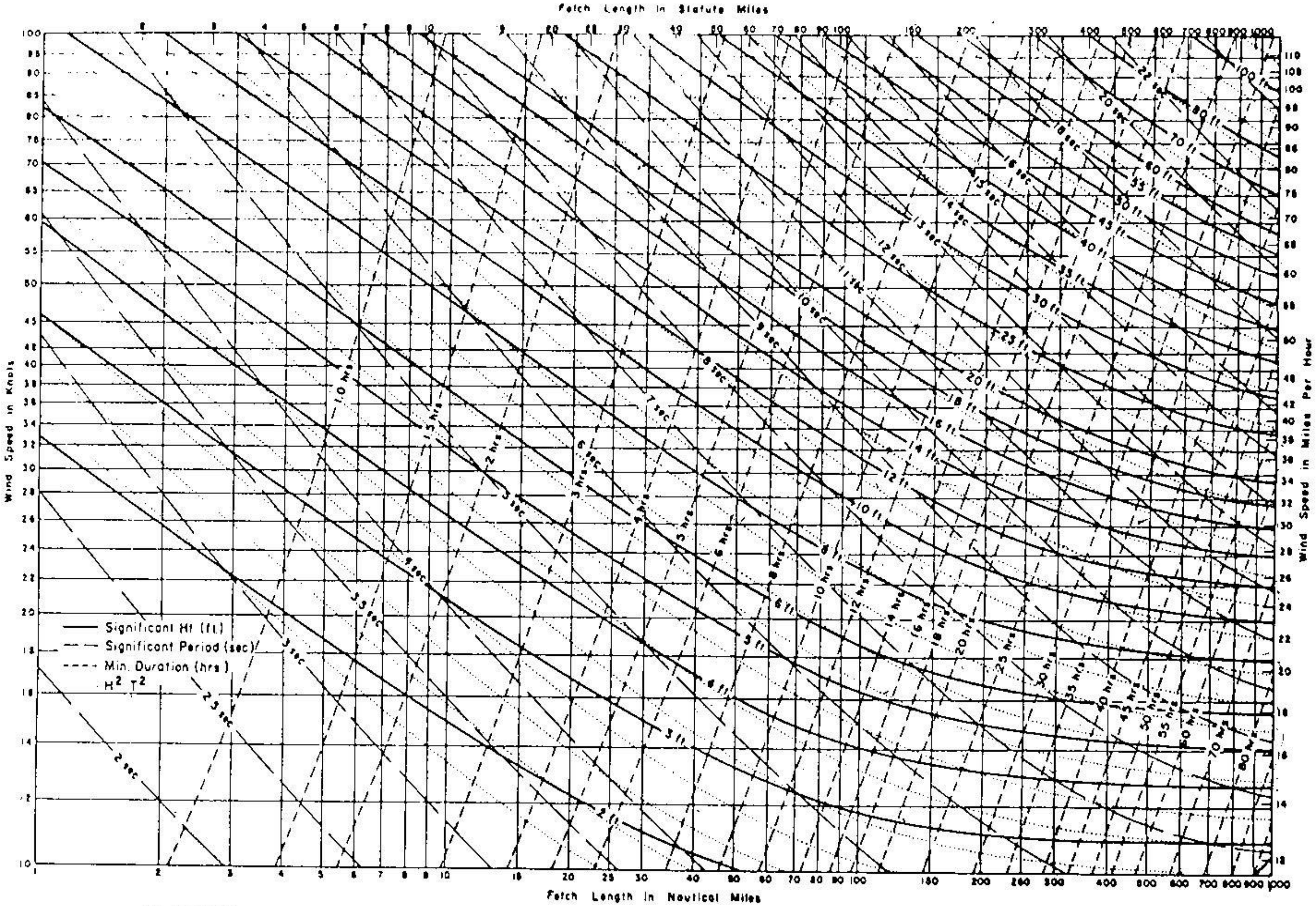


FIGURE 5' DEEP WATER WAVE FORECASTING CURVES AS A FUNCTION OF WIND SPEED, FETCH LENGTH, AND WIND DURATION
(for Fetches 1 to 1,000 miles)

Wave Dimensions

- C=Wave Celerity
- L=Wave Length
- T=Wave Period
- Cg=C/2
- C=L/T
- L=T*C
- T=L/C

Wave Dimensions

- C=L/T
- L=T*C
- T=L/C
- L/2=end of deep H_2O
- **C deep=1.56*T**
- **L= 1.56*T*T**
- (units in meters/sec)

- We only get T from the observations

- Find C and L for a wave period of 10 seconds
- Find shallow water transition depth

Wave Group Velocity (Cg)

- OFTEN THE TERM USED TO INDICATE SPEED OF WAVE PACKET (Cg)
- FOR DEEP WATER Cg=(1.56*T)/2
- FOR SHALLOW WATER Cg=C

- Cd=SQRT(gL/2*Pi)
- Cs=SQRT(gH)

- g=GRAVITY
- L=WAVE LENGTH
- H=WATER DEPTH
- Pi=3.14159

Wave Spectrum Comprises A Combination of Wave Heights & Periods

- “Sea state” is comprised of all wind wave and swell components passing through a point in time. Each wave component has its own individual spectrum of both height (H) and period (T).

Statistical Wave Height Spectrum

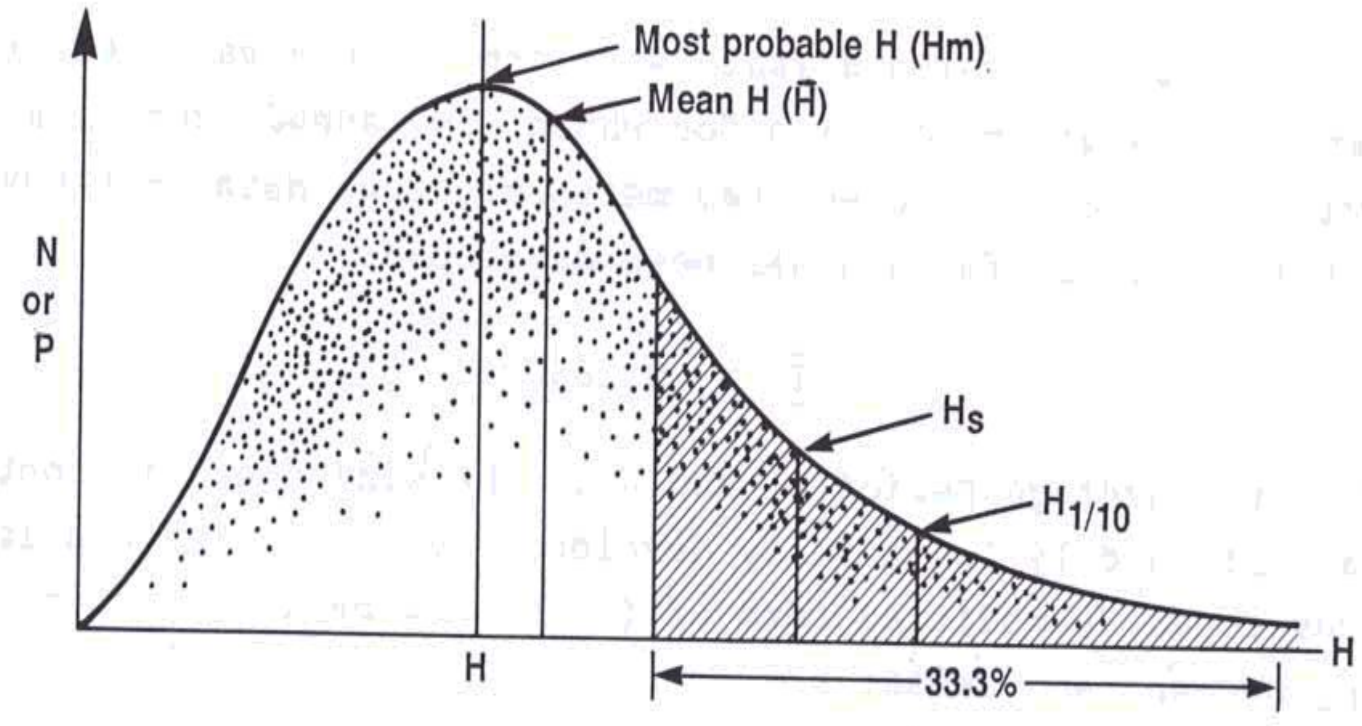
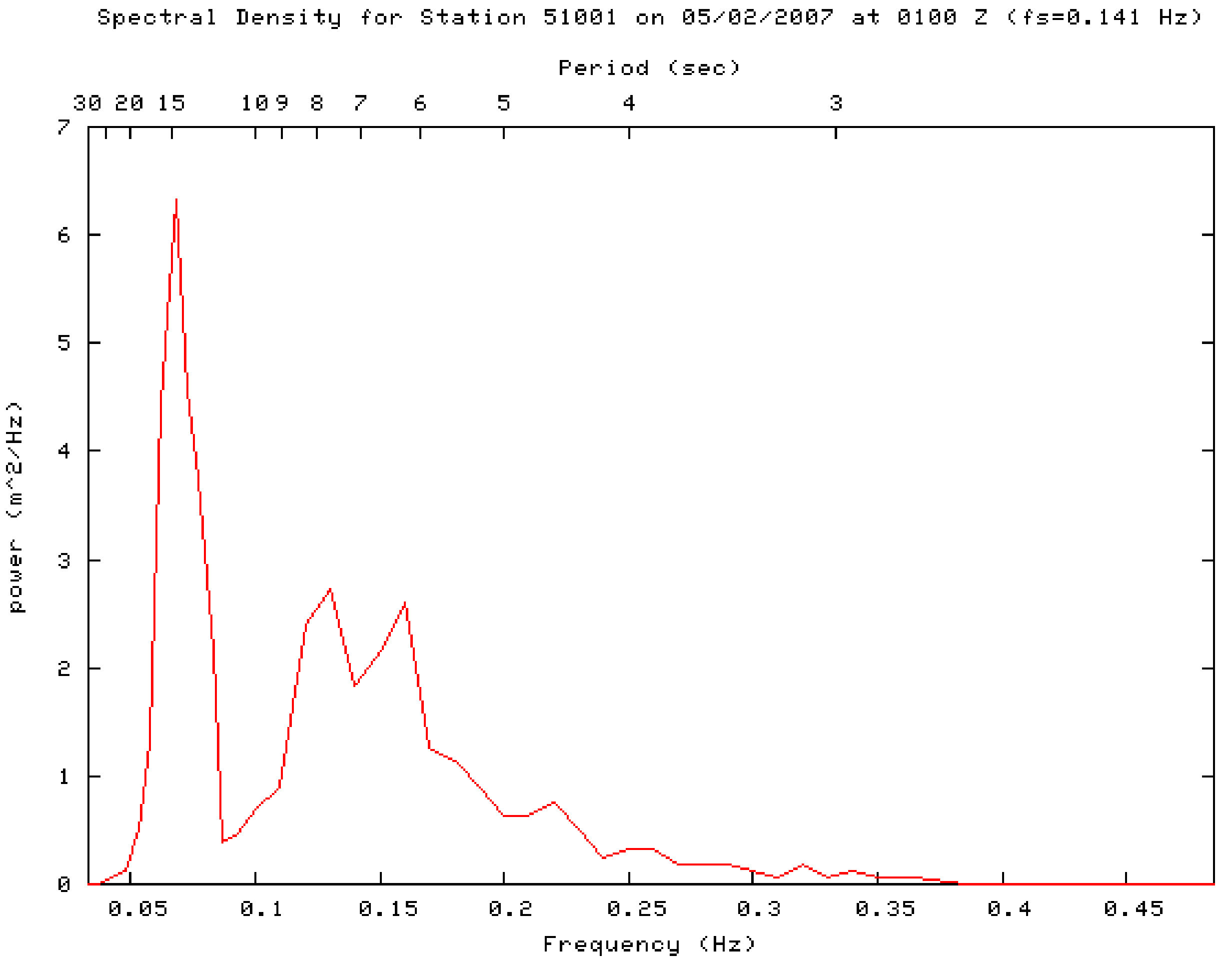


Figure 4.9: The statistical distribution of wave heights showing various parameters (from Bretschneider, 1964)

Wave Height Spectrum

- Measured sea state is typically H1/3 termed Significant Wave Height (**SWH**)
- H1/10 = 1.27*H1/3
- H1/100= 1.67*H1/3
- H max = 2.0*H1/3

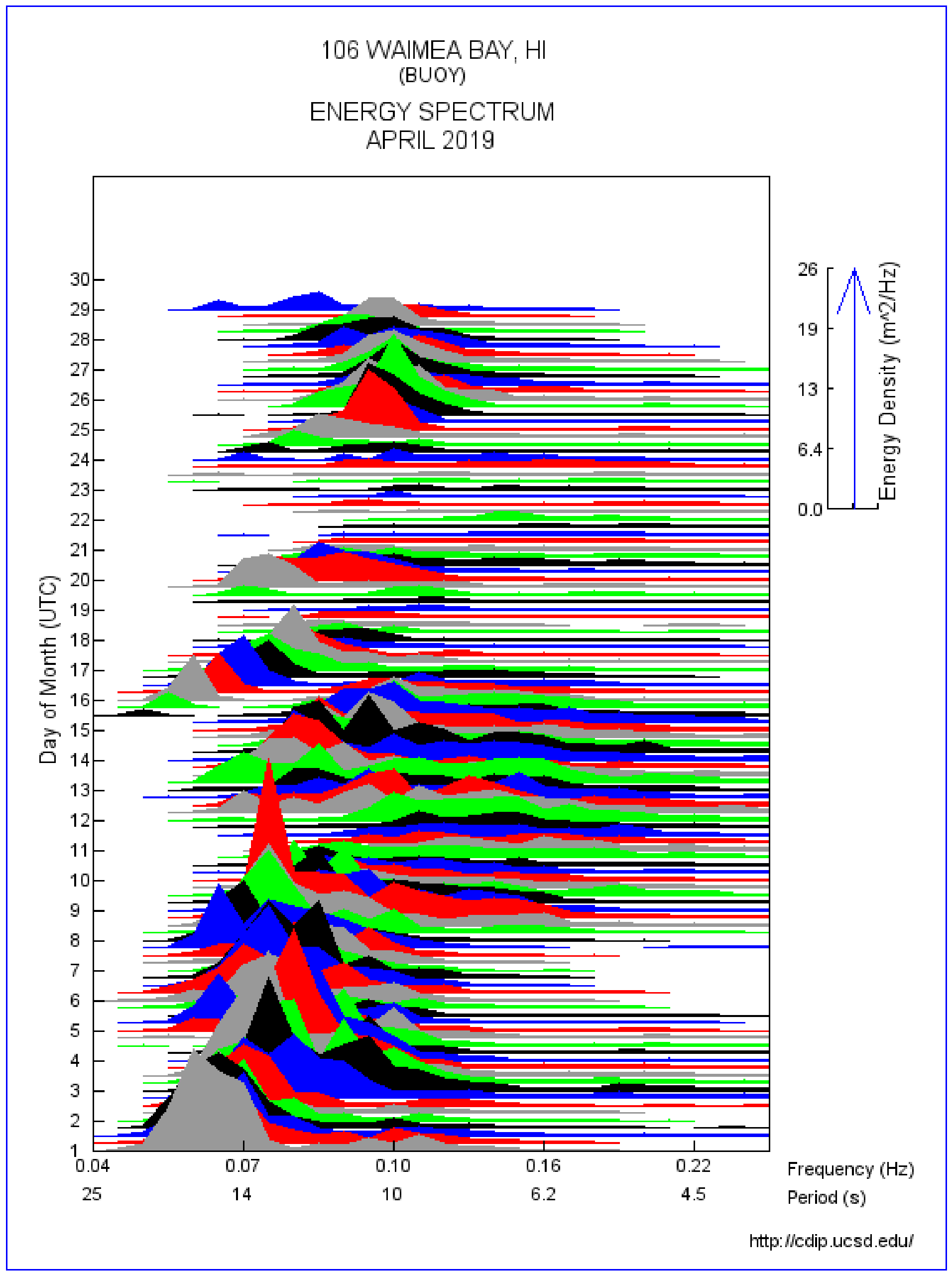
Wave Period Spectrum or Distribution



Wave Period Spectrum or Distribution

Waimea Bay, Hawaii

- From Scripps CDIP site
- Mountain plot
- Cumulative monthly plot of energy spectrum
- Easily see various wave events and peak energy



Combined Seas

- Combined seas (H) represent the sum total height of all wind-wave and any number of swell components.
- Cs=sqrt(ww*ww+ s1*s1+s2*s2+s3*s3
- Max Cs=2.0*Cs

POP QUIZ!

- How fast do 15 sec period waves move?

A. 15 kt
B. 23 m/s
C. 18 m/s

POP QUIZ!

- How fast do 15 sec period waves move?

23.4 m/s

- C deep=1.56*T

POP QUIZ!

- Which wave moves faster, a 20 footer or 12 footer?

A. The 20 footer
B. The 12 footer
C. Same speed
D. Insufficient information

POP QUIZ!

- Which wave moves faster, a 20 footer or 12 footer?

Insufficient information

- C=L/T
- L=T*C
- T=L/C
- C deep=1.56*T

POP QUIZ!

- Which is longer, a football field, or a wave of 3 foot @ 10 seconds?

A. Football field
B. 3 foot, 10 sec wave
C. Equal length

POP QUIZ!

- Which is longer, a football field or a 3 foot, 10 second wave?

- L= 1.56*T*T

3 foot, 10 sec wave

156 m

POP QUIZ!

- What is the combined sea height for a 7’/10 sec wave & 7’/15 sec swell?
- What is MCS?

A. 14 feet
B. 49 feet
C. 25 feet
D. 10 feet

POP QUIZ!

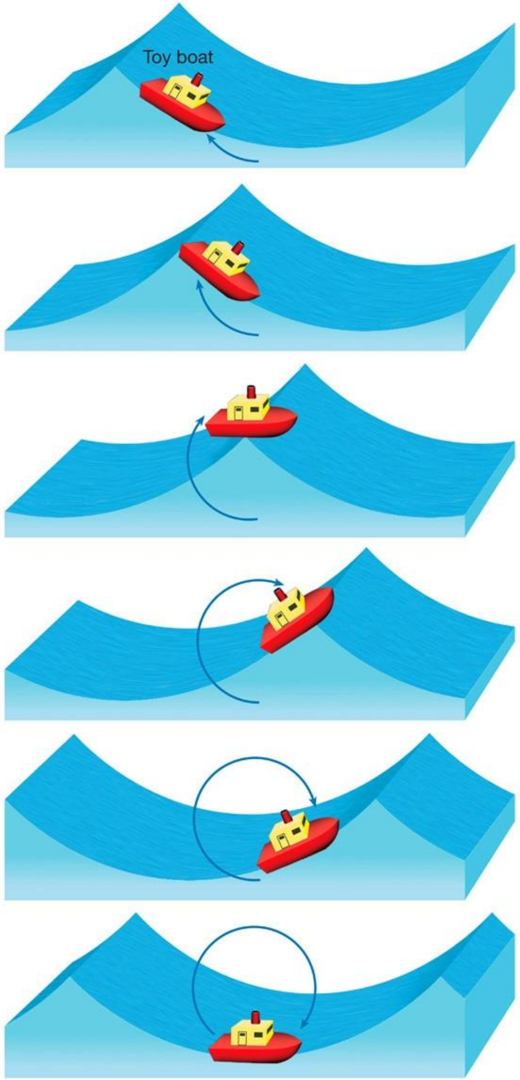
- What is the combined sea height for a 7'/10 sec wave & 7'/15 sec swell?
- Cs=sqrt(ww*ww+ s1*s1+s2*s2+s3*s3…)
- What is MCS?
- Max Cs=2.0*Cs

9.89 or 10 feet

19.8 or 20 feet

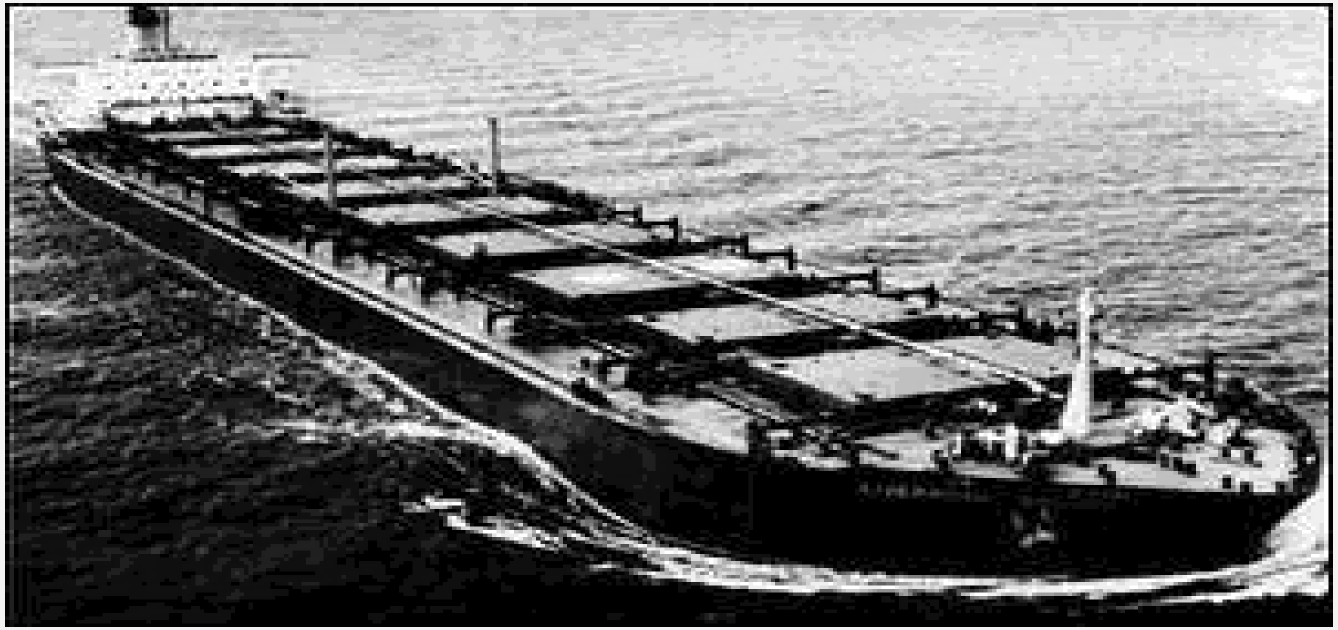
Wave Steepness

- H/L
- Affects vessels differently
- Vessel size and wave height dependent

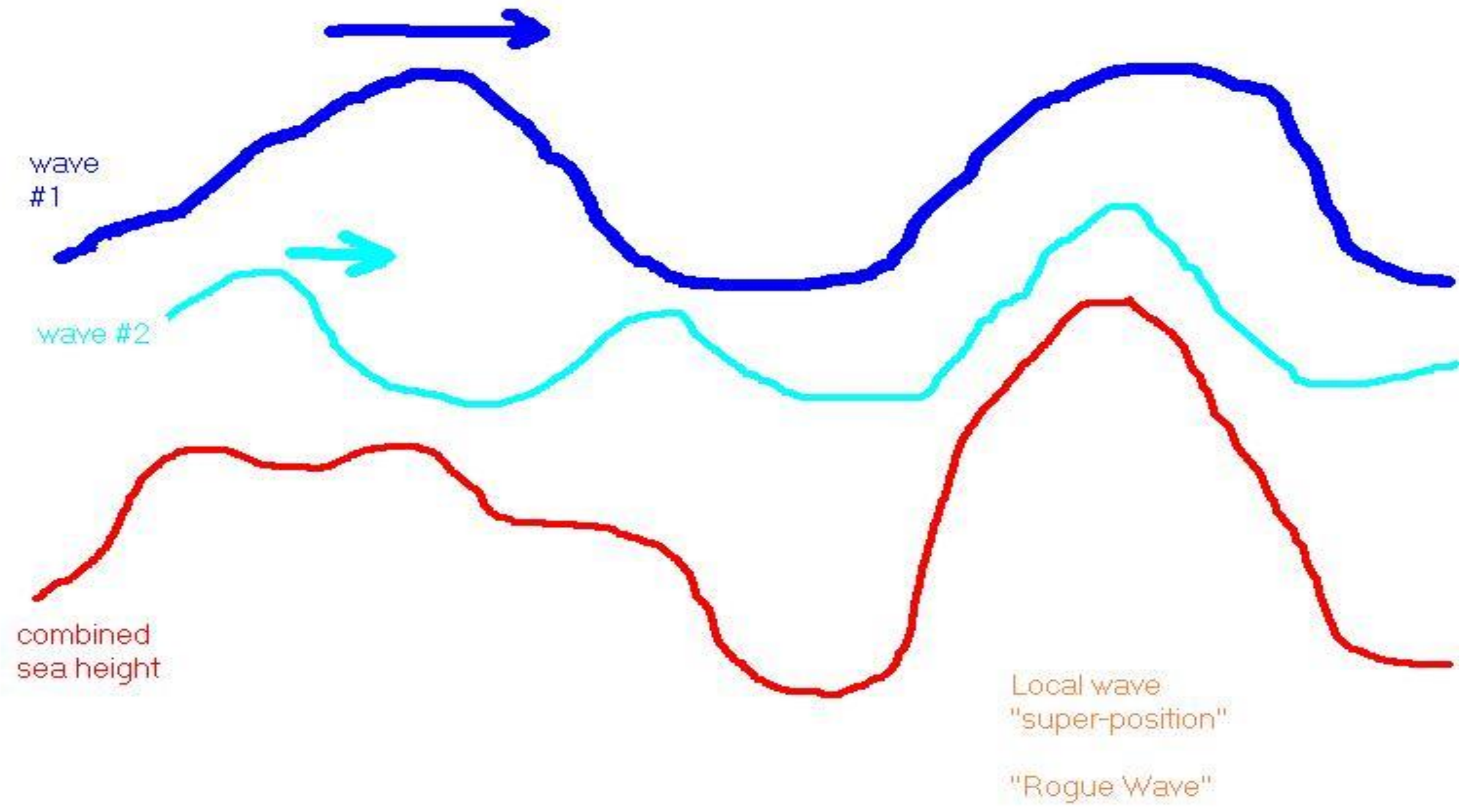


“Rogue” or Extreme Waves

- **'Rogue wave' theory for ship disaster**
- 44 crewmen perished when the bulk carrier MV Derbyshire sank on 9 Sept 1980, south of Japan, in Typhoon Orchid
- Scientists have discovered that a rogue wave pattern helped cause one of the UK's biggest maritime disasters
- **Wave height > 2 * SWH**

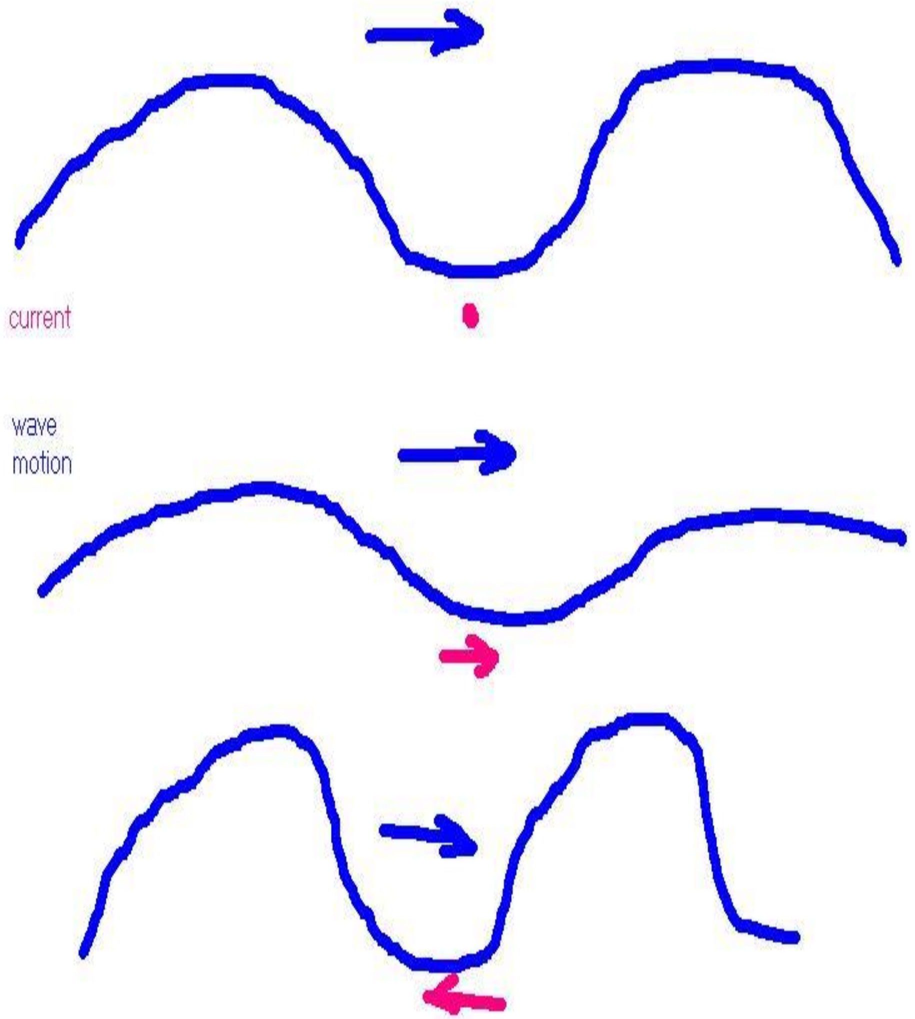


Transient Wave-Wave Superposition

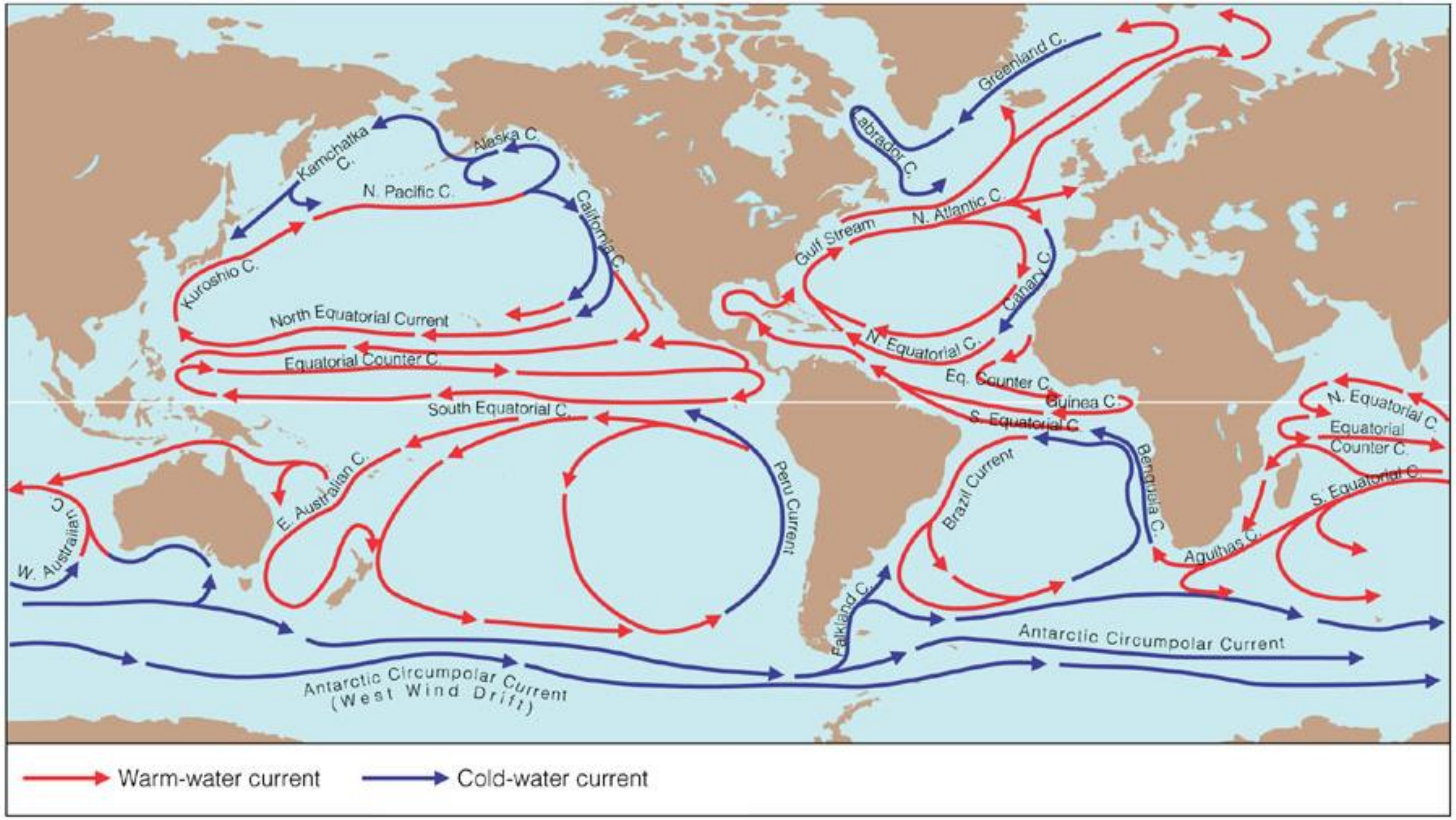


Waves in Significant Currents

- L shortened for waves opposing current
- Largest change for slow waves in fast currents
- Remember C=L/T, where **T is conserved!**
- Wave steepness and height modified!

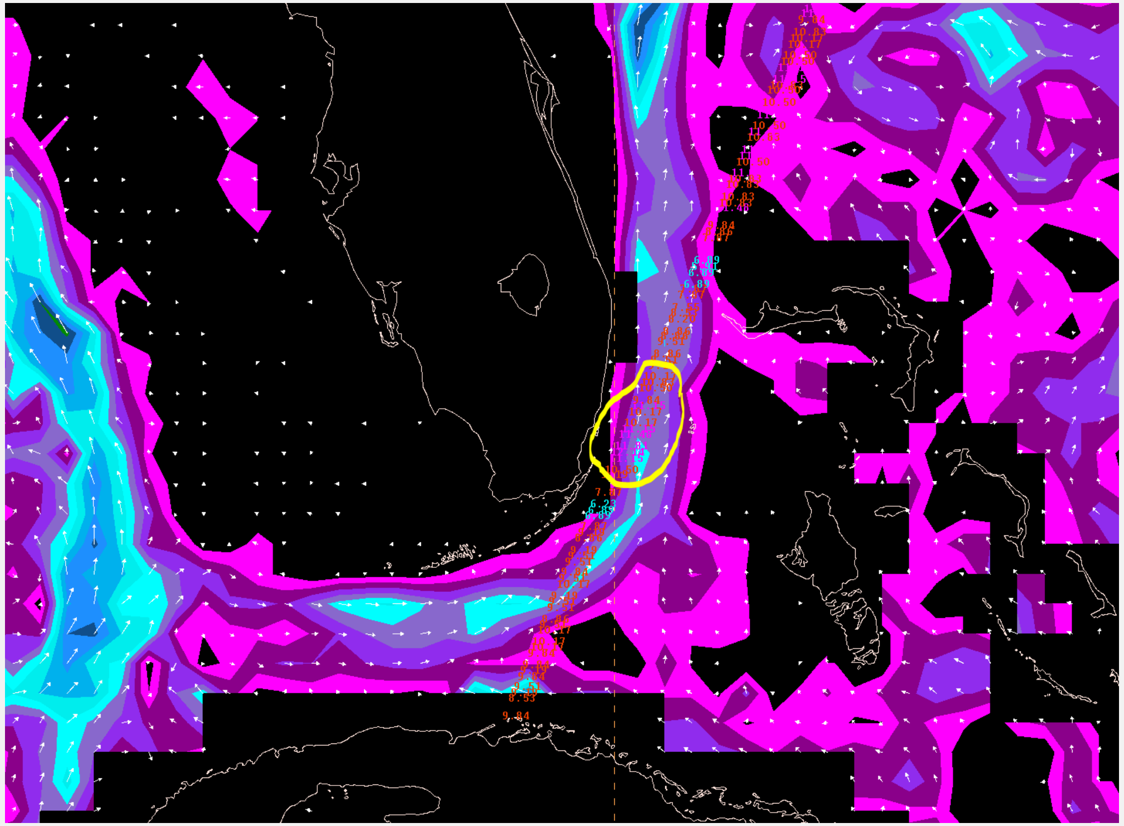


General Positions of Global Oceanic Currents

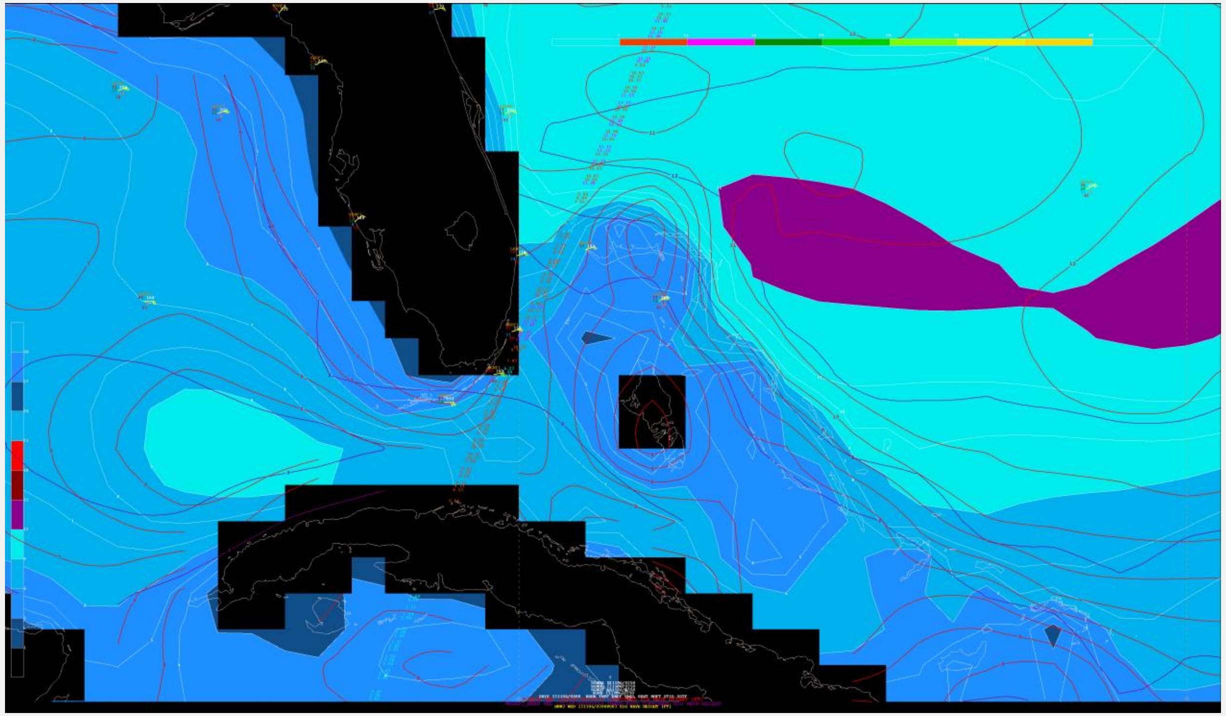


Waves Against Current

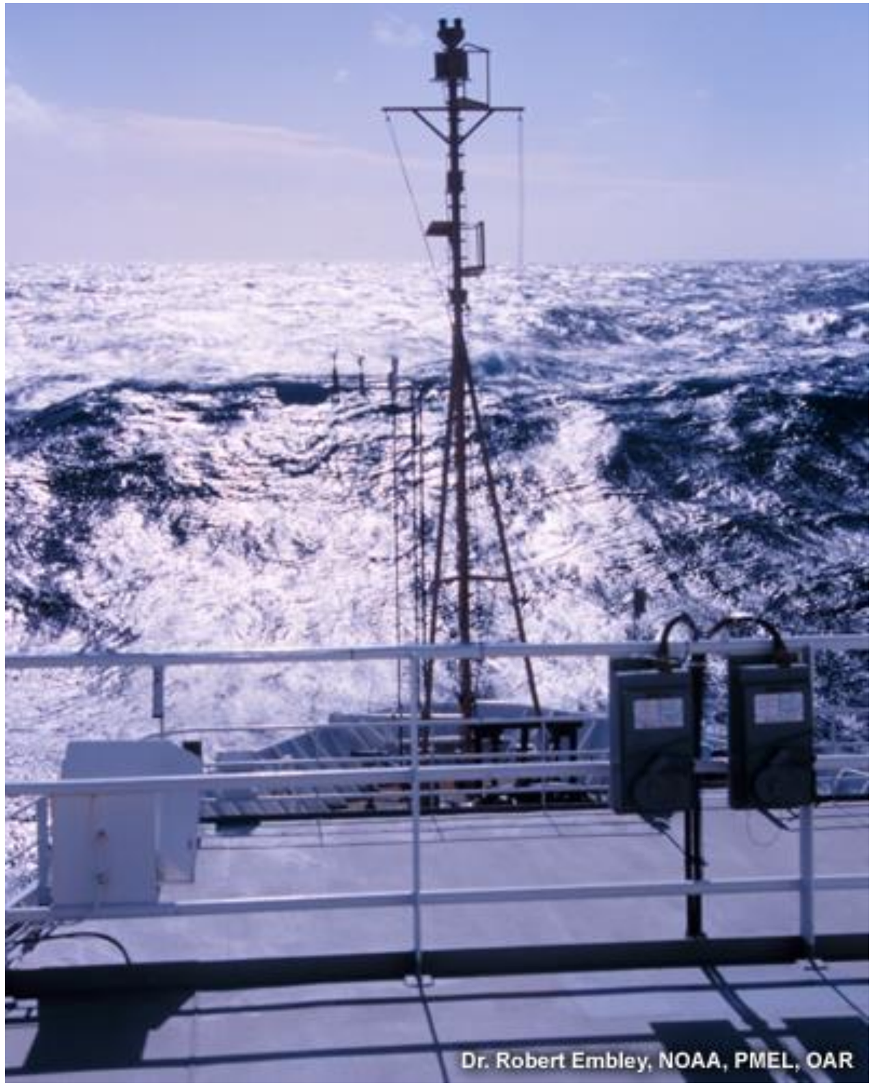
Gulf Stream Forecast with Jason 2 altimeter data



Jason 2 altimeter data vs Wave Models

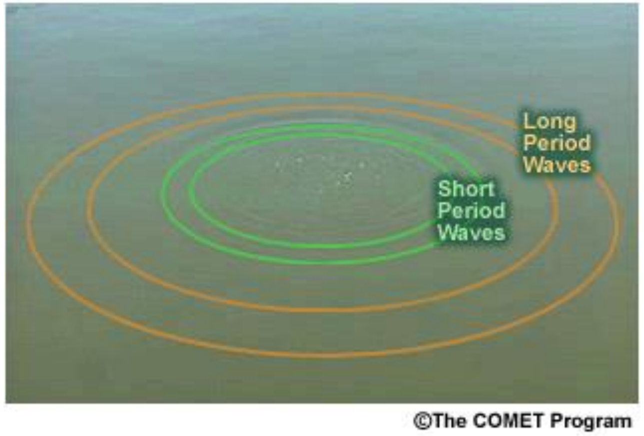


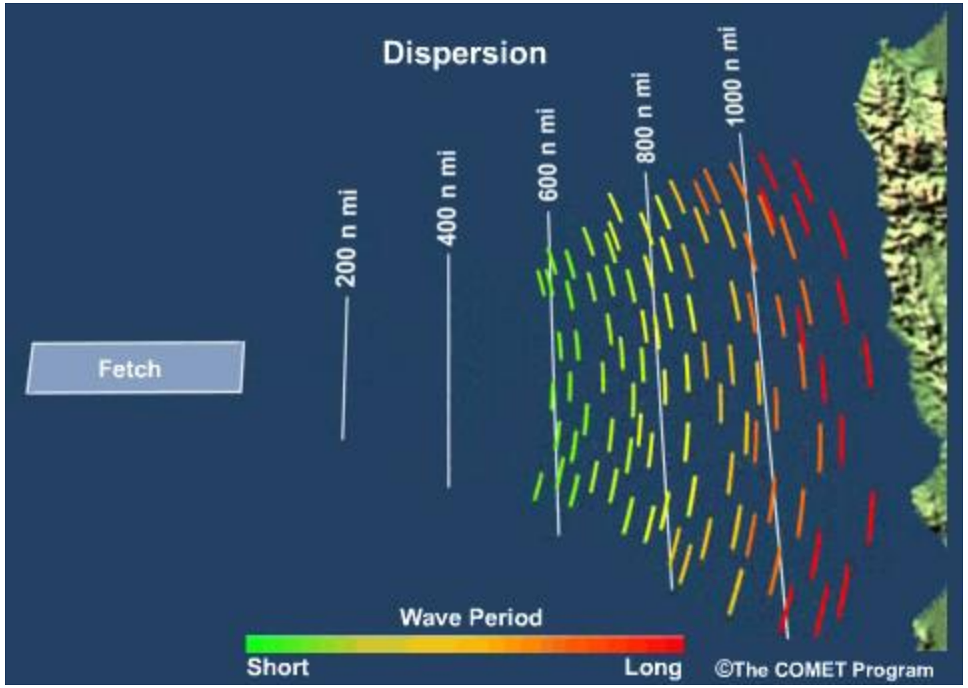
Deep Water Wave Forecasting



Wave Decay

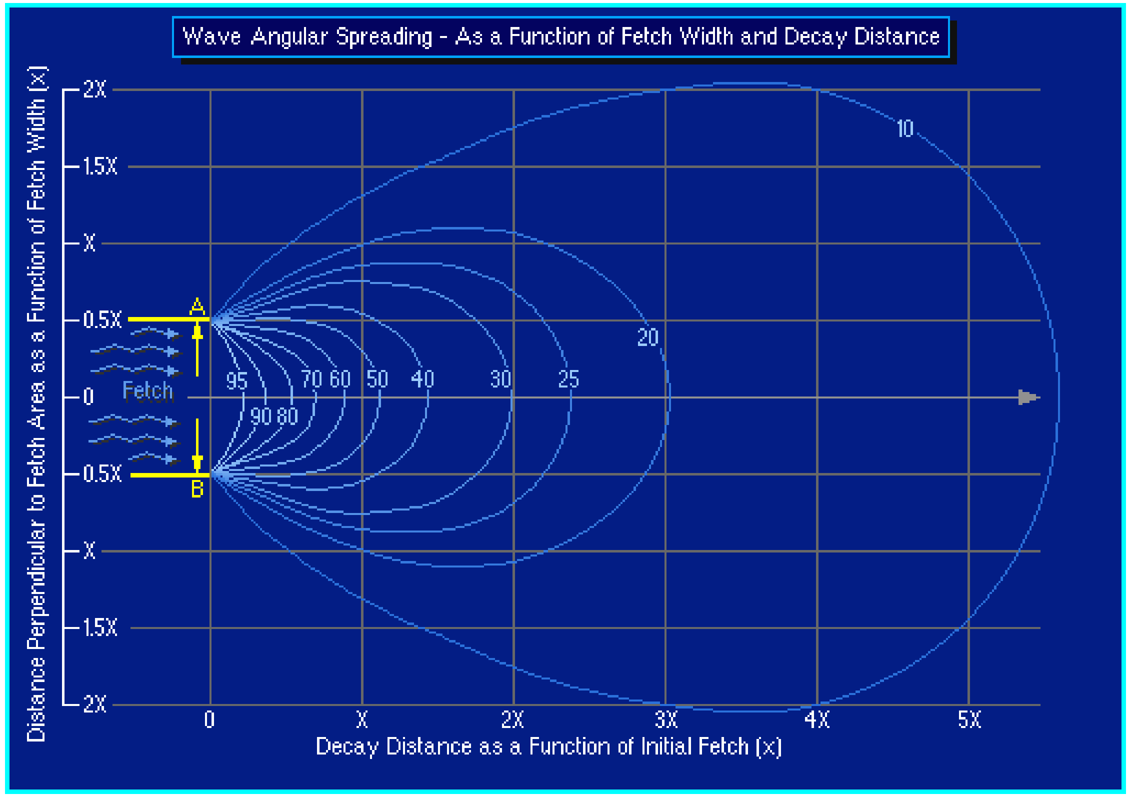
- Wave generation and growth has occurred
- Various wave energy leaves fetch area
- Wave/swell dispersion
- Wave/swell energy dissipation…decay begins immediately
- What happens?



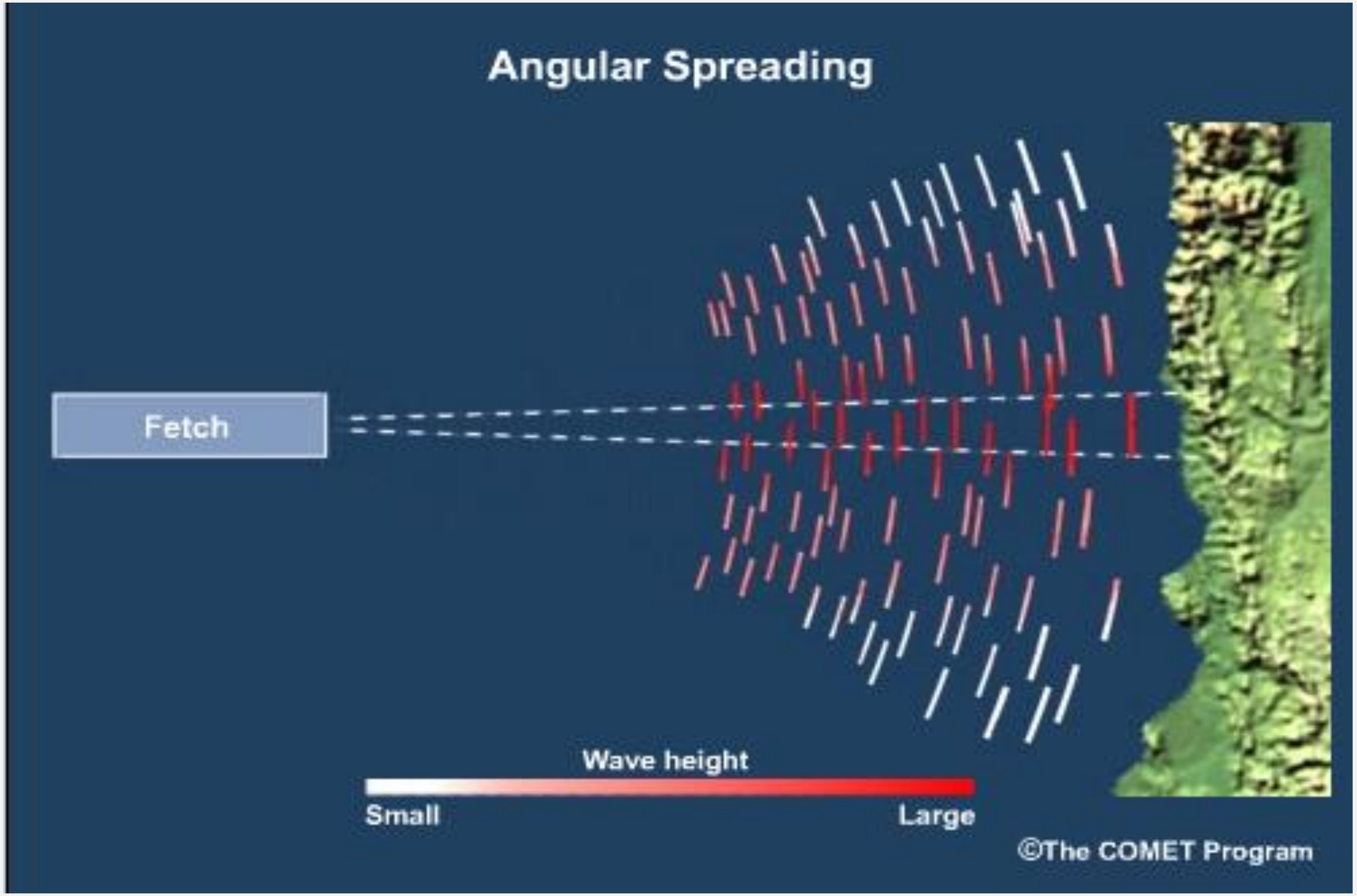


Wave Propagation

- Angular spreading
- Energy can be approximated by **Cos A**
- Energy begins to fall off rapidly when A>60

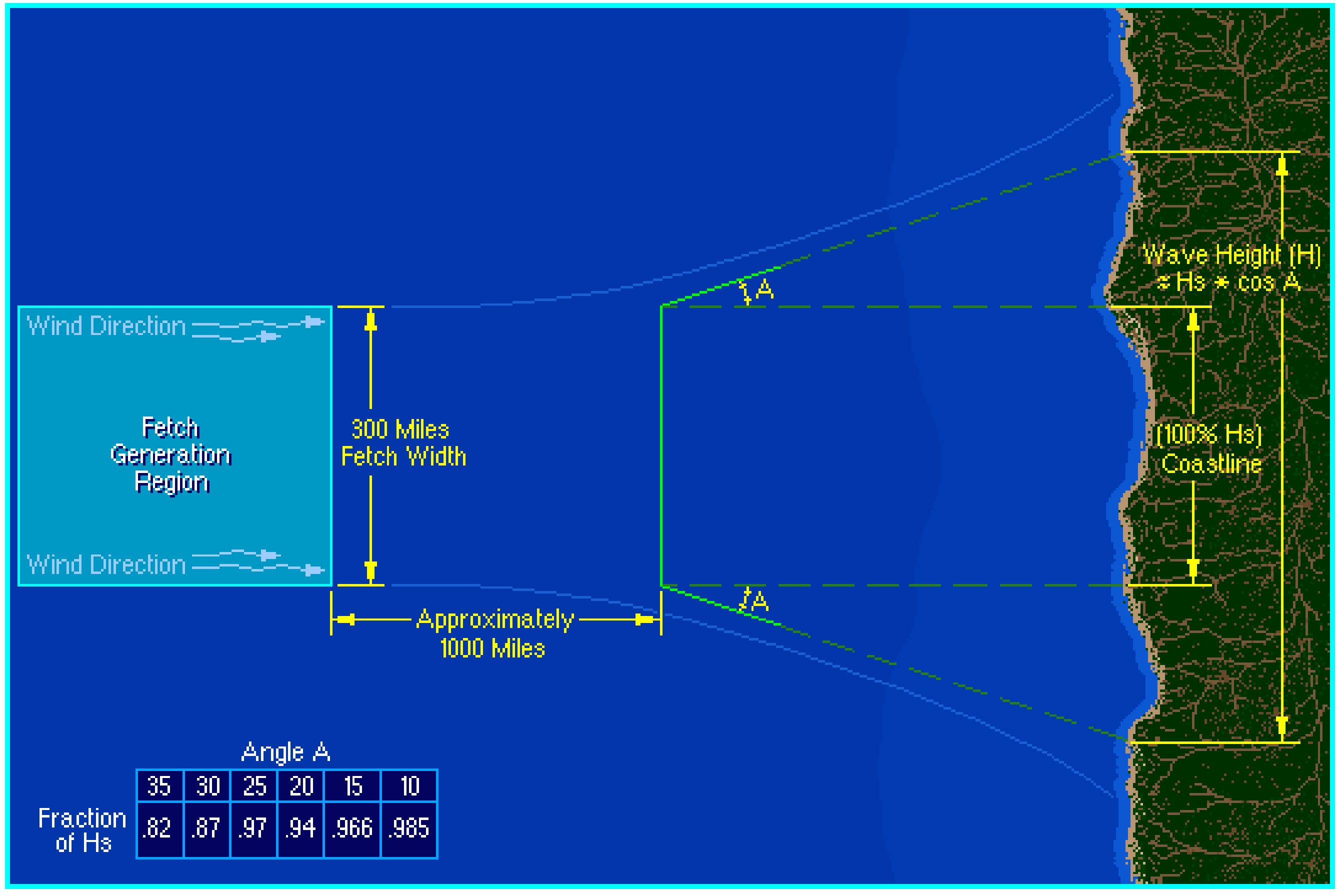


Angular Spreading



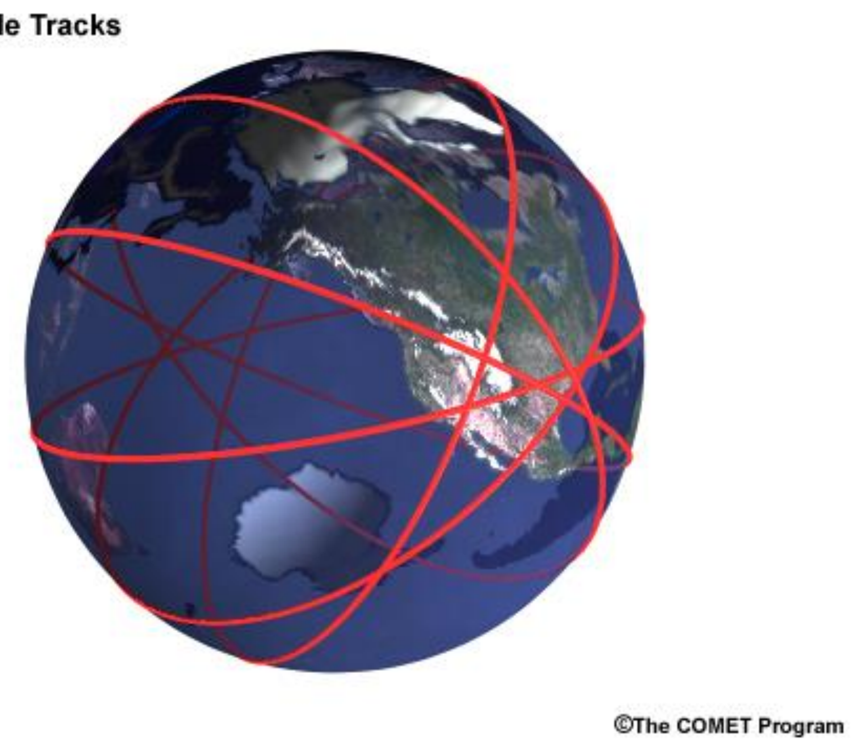
Wave Propagation

- Angular spreading calculations

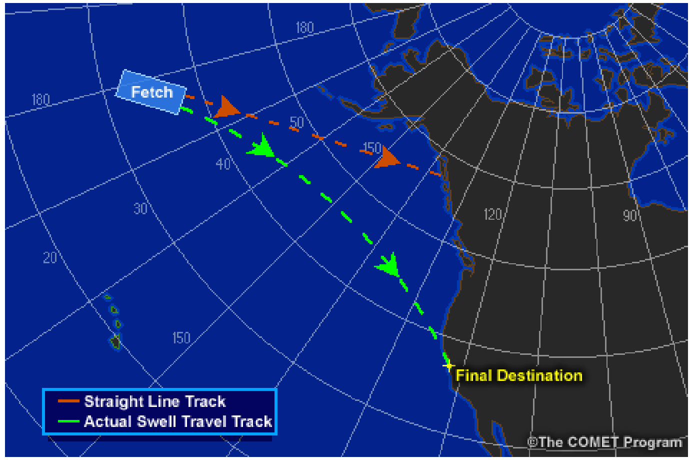


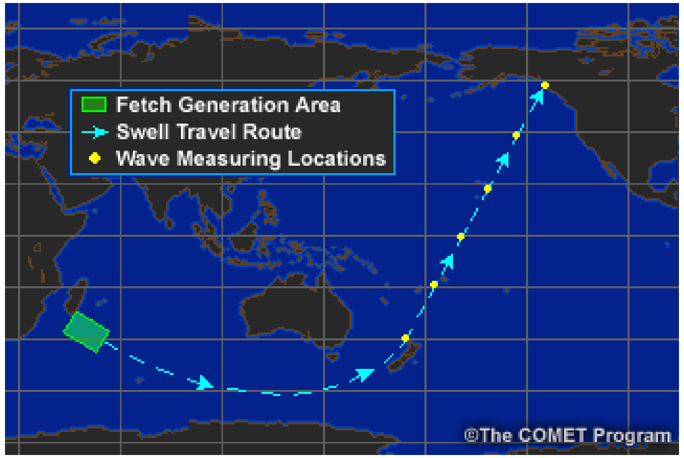
Wave Propagation

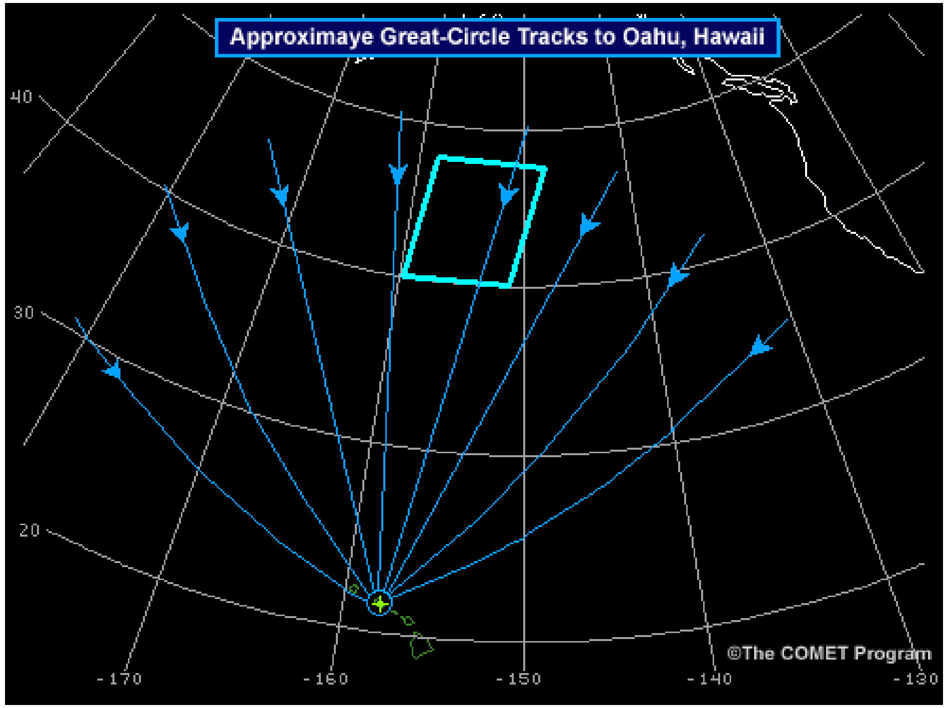
- Gravity Waves on a sphere (Earth's oceans) follow Great Circle Paths (GCP) or Tracks



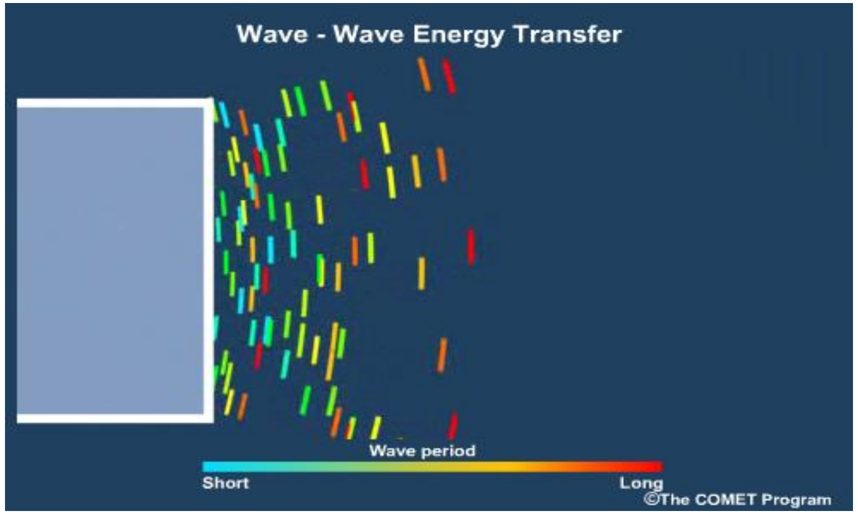
GCP Examples

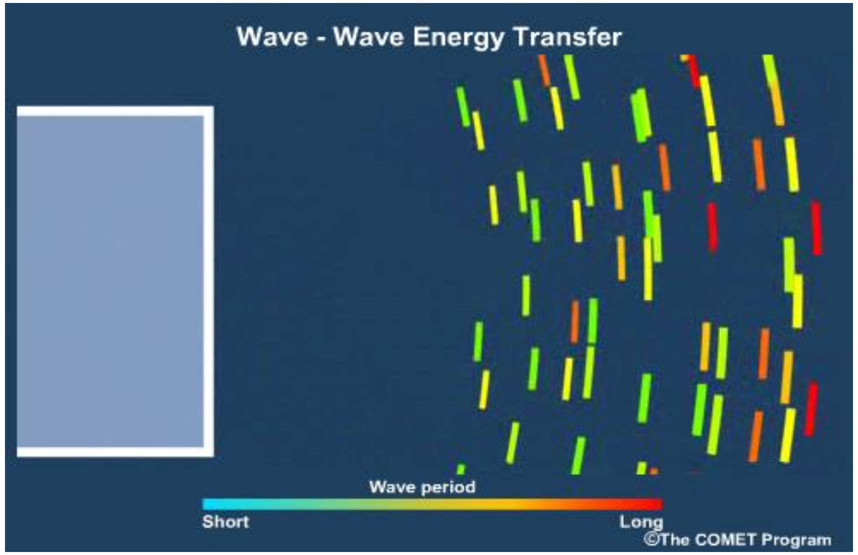






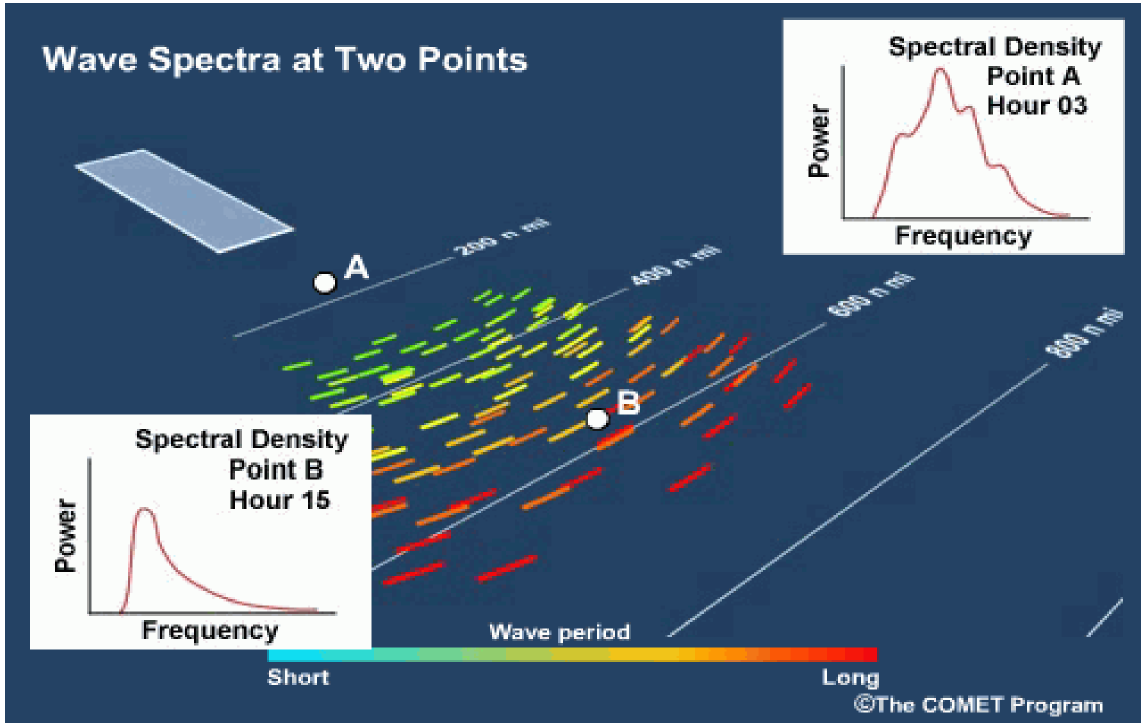
Wave Decay Process





- What happens to H and P during this decay process?
- Lateral spreading
- Horizontal separation
- H diminishes
- P increases
- Wave to wave energy transfer – non linear

Spectral Density Change

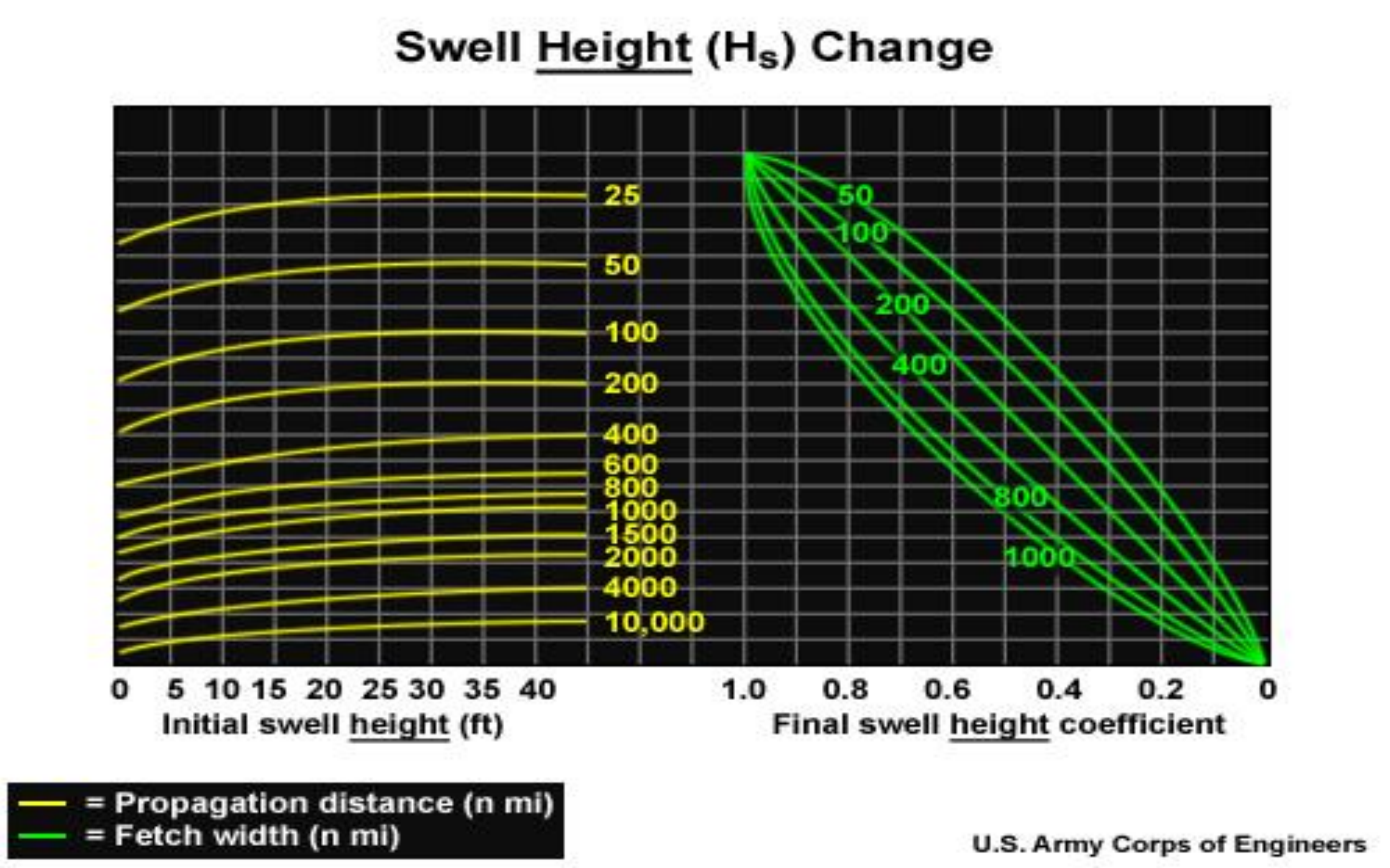


- Separation occurs
- Longest period waves outrun swell packet and are called “forerunners”

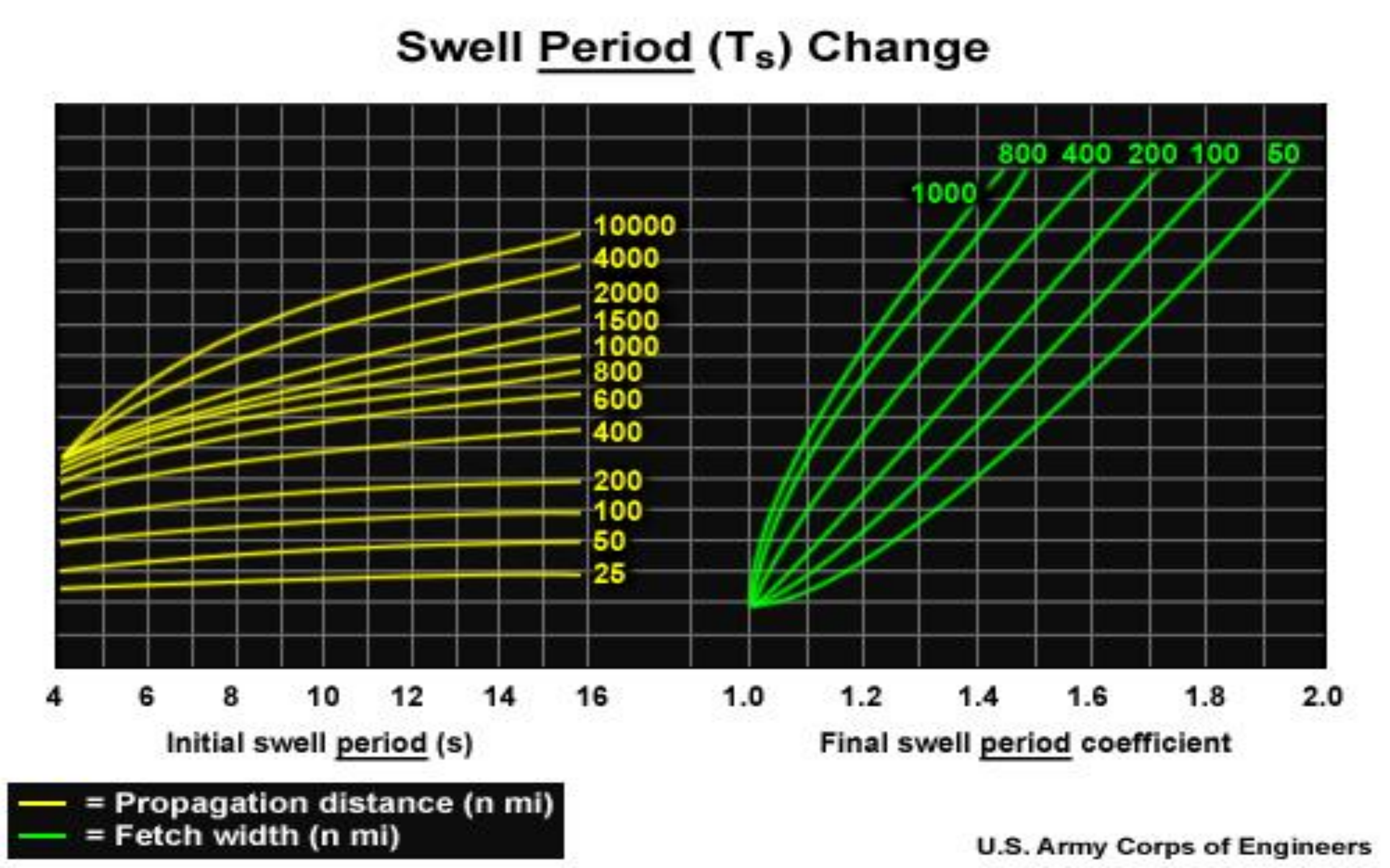
Calculating Wave Decay and Arrival Time

- A storm system is 1000 nm from your coastline
- SWH = 10 meters
- Tp= 11 sec
- Fetch width = 300 nm
- Upon arrival at coastline, what is?
    - SWH
    - Tp
    - Travel time

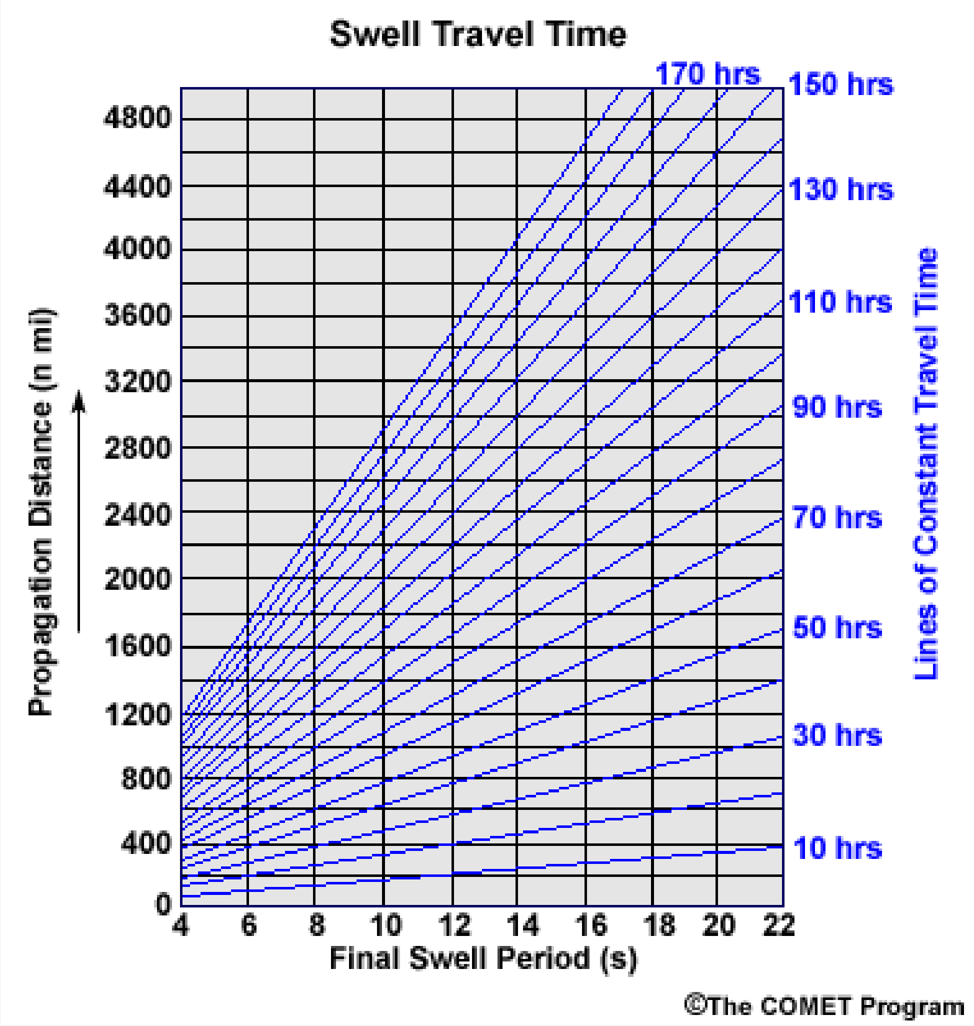
Swell Height Change



Swell Period Change

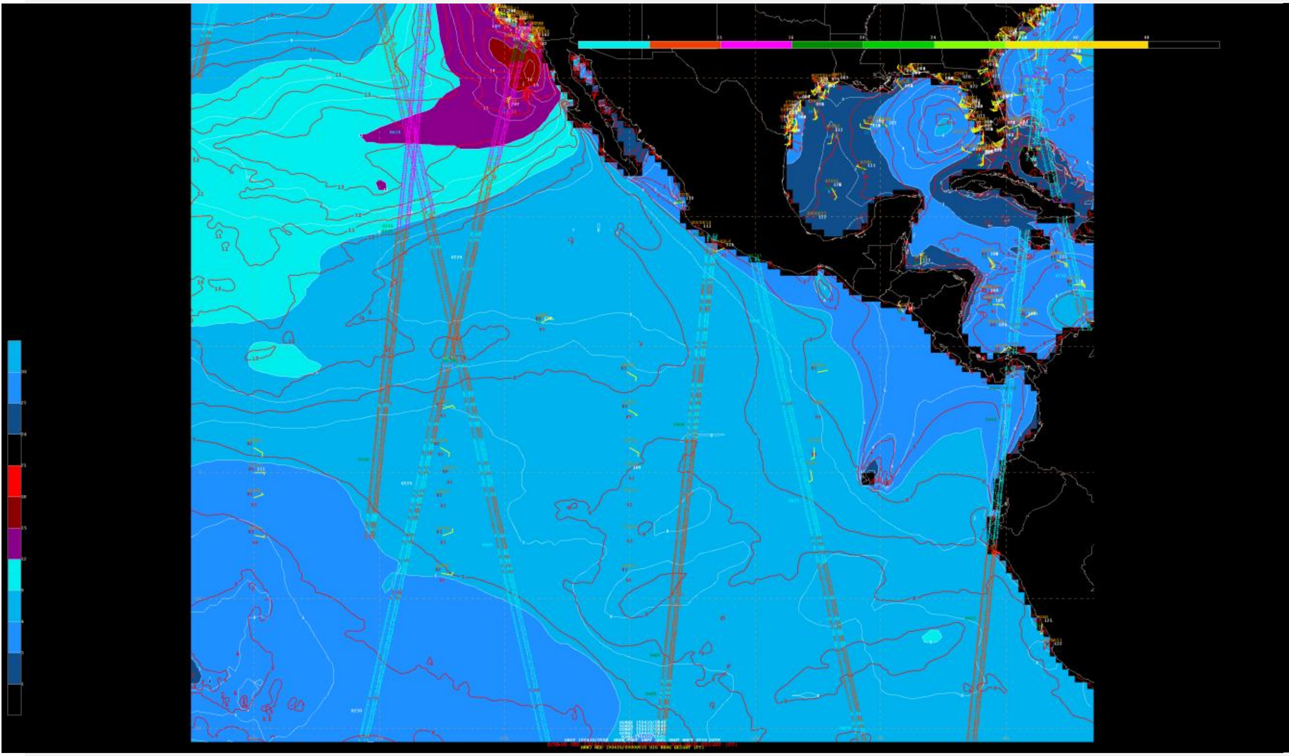


Swell Travel Time

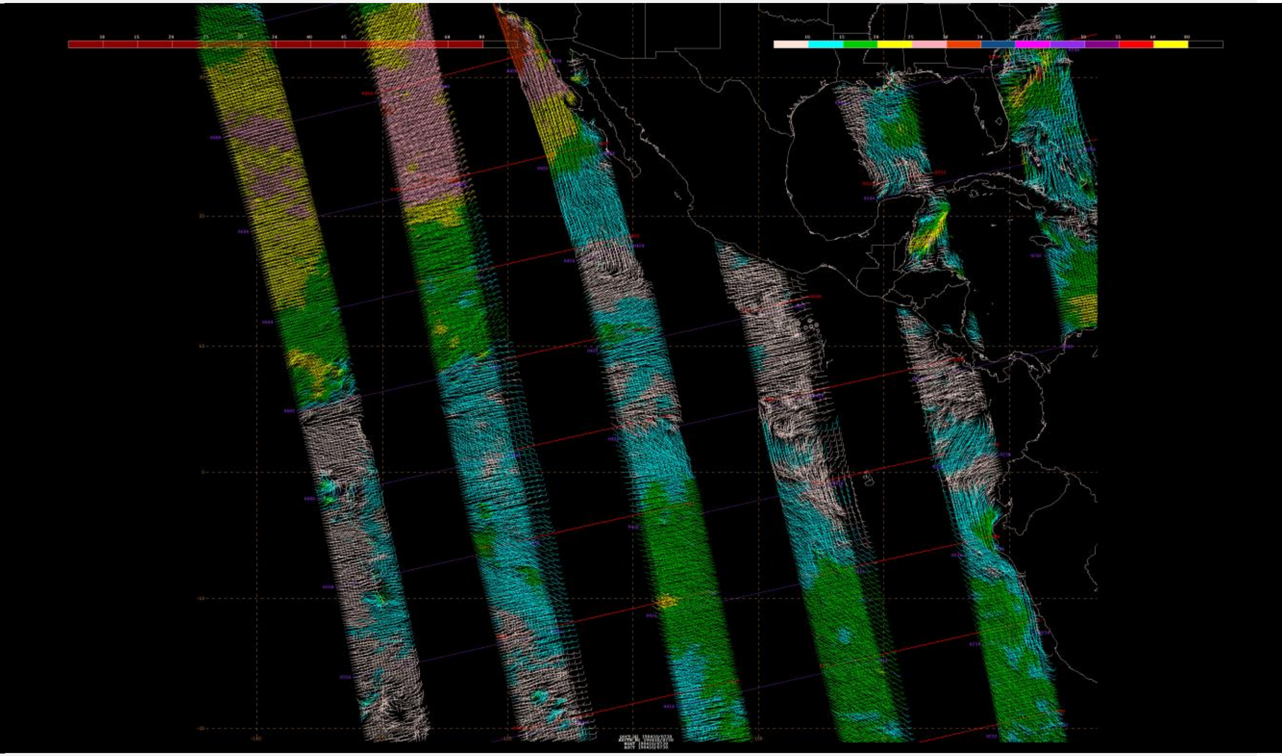


Evaluating Total Sea State

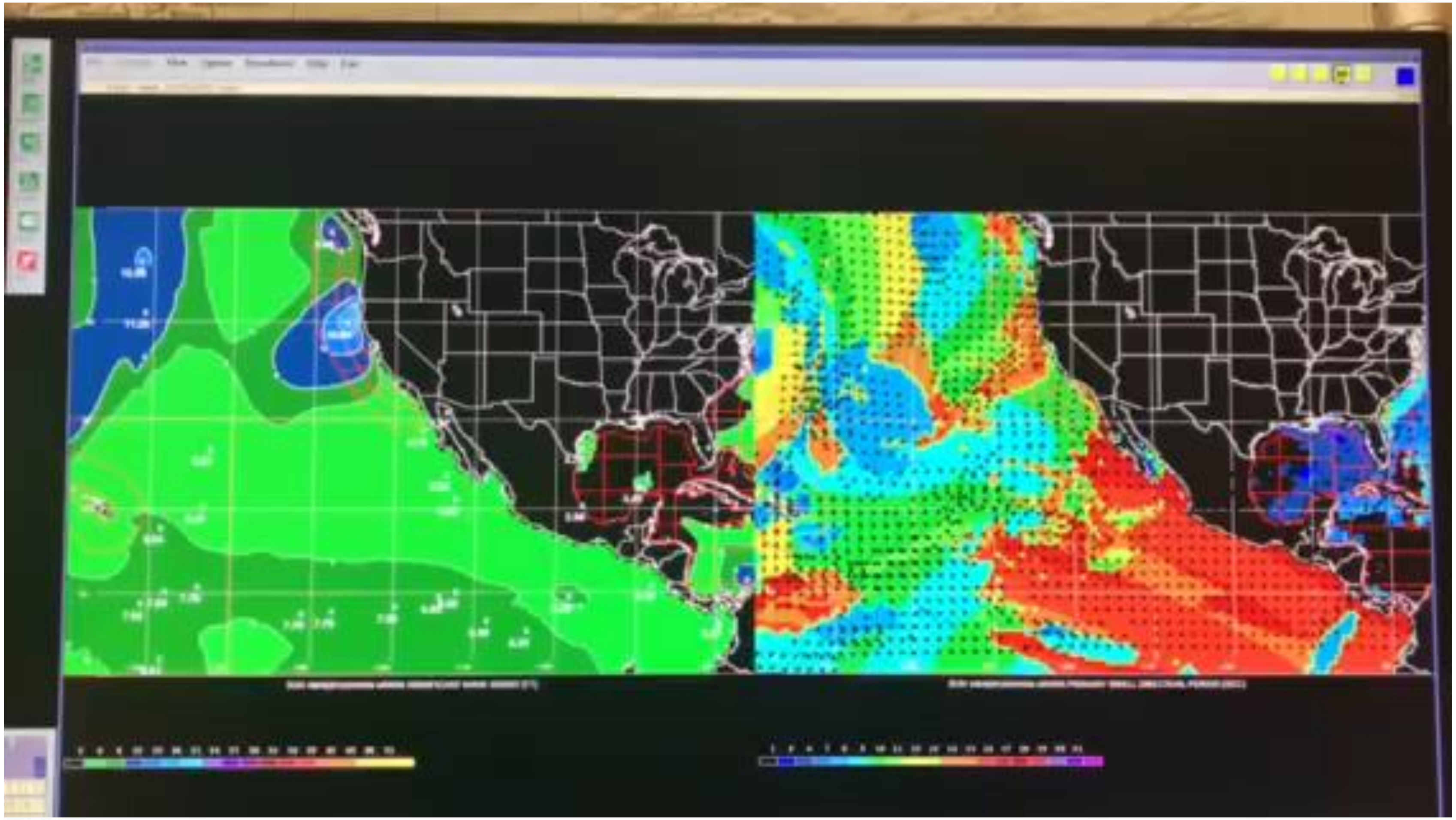
Wave models vs altimeter data



Scatterometer data

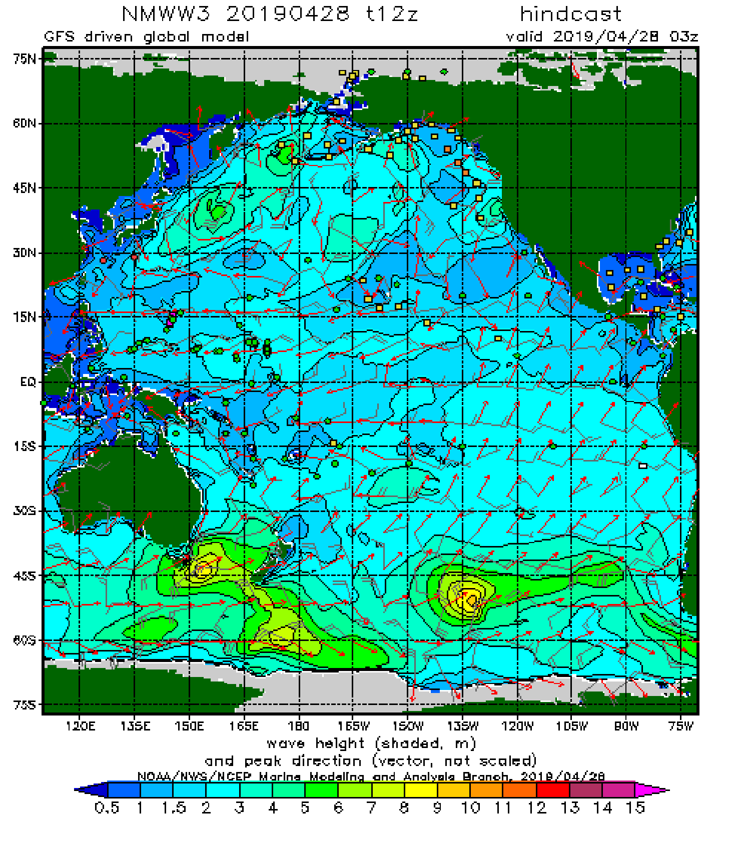


Sea State and Dominant Wave Direction

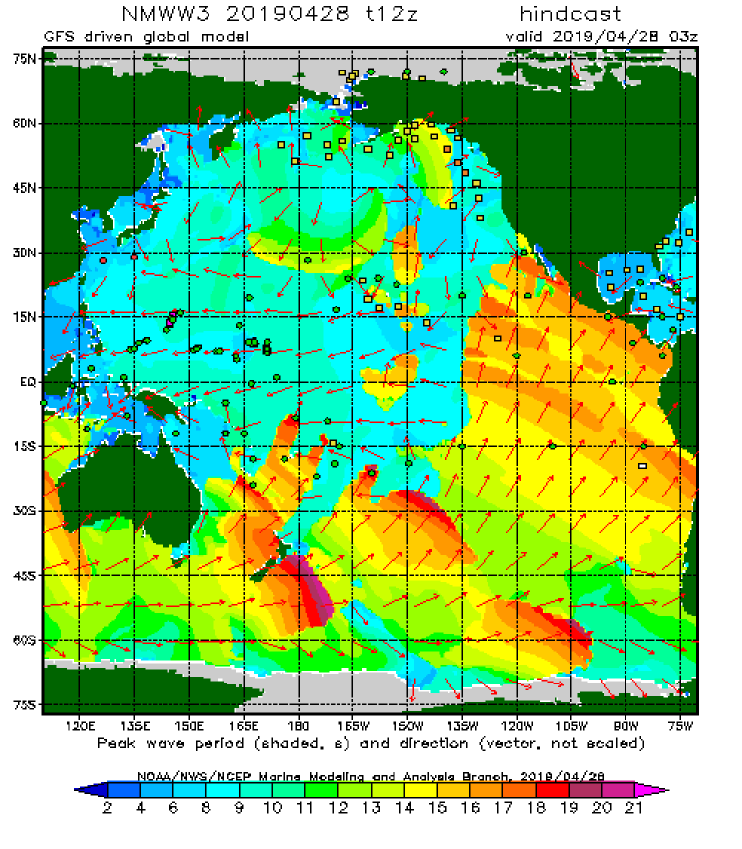


Use of WW3 Model via the NOAA website

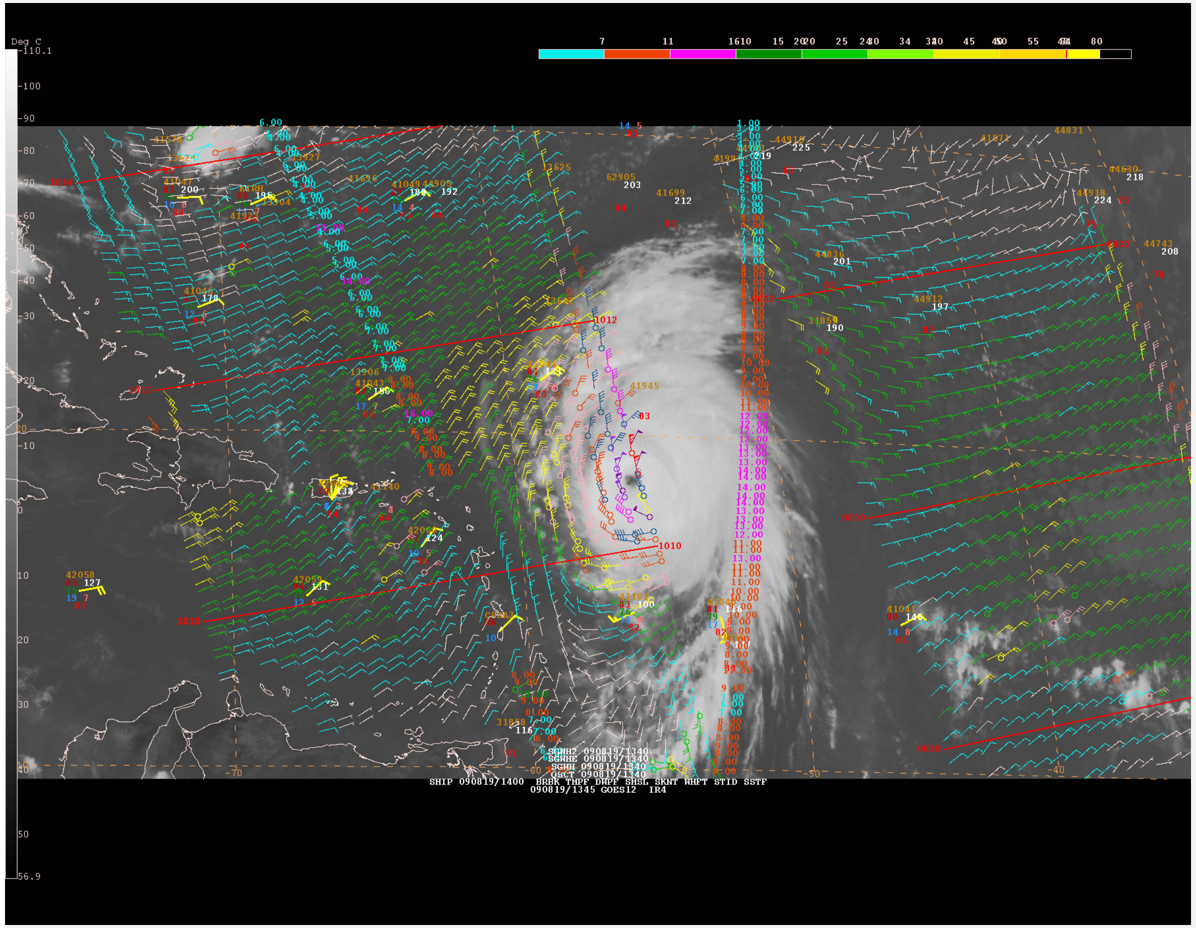
WW3 SWH

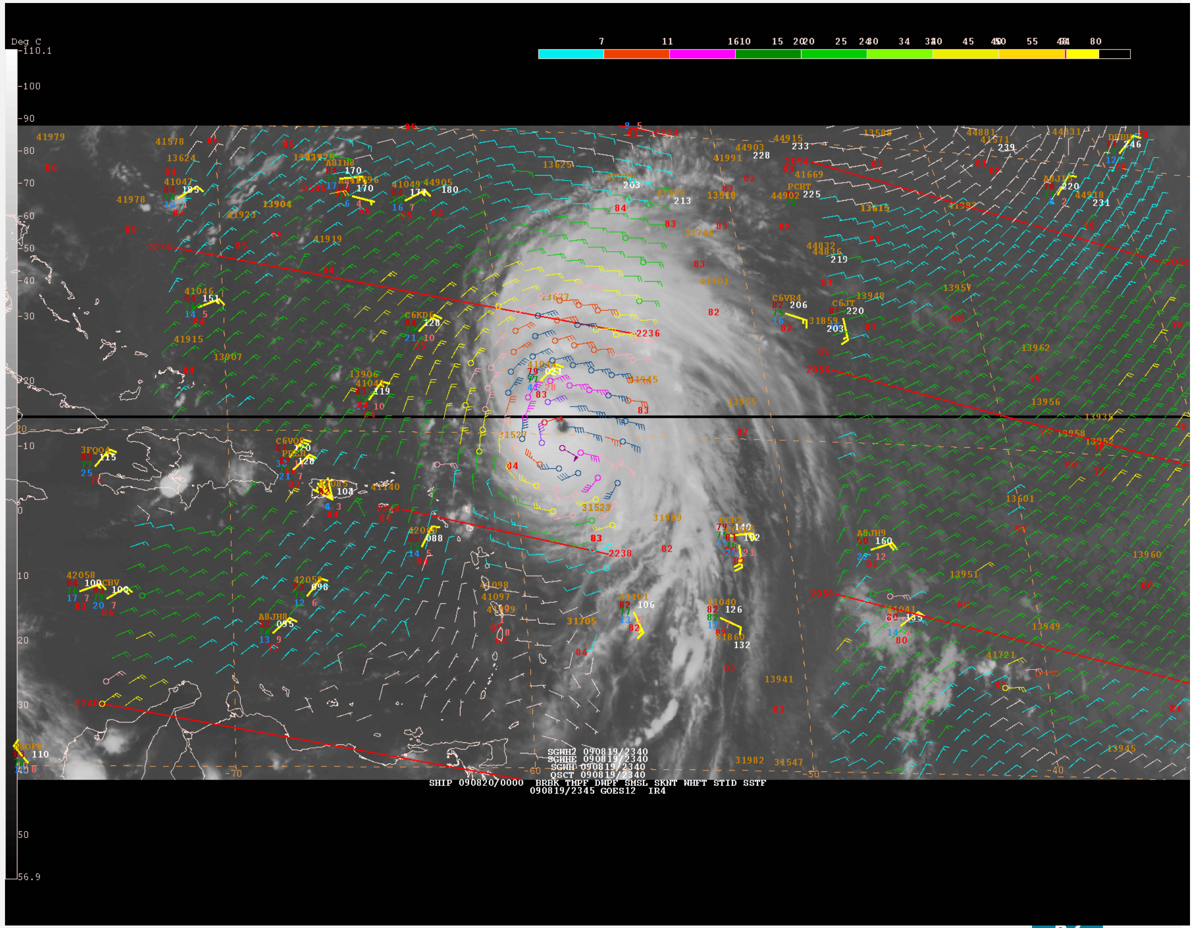


WW3 Tp

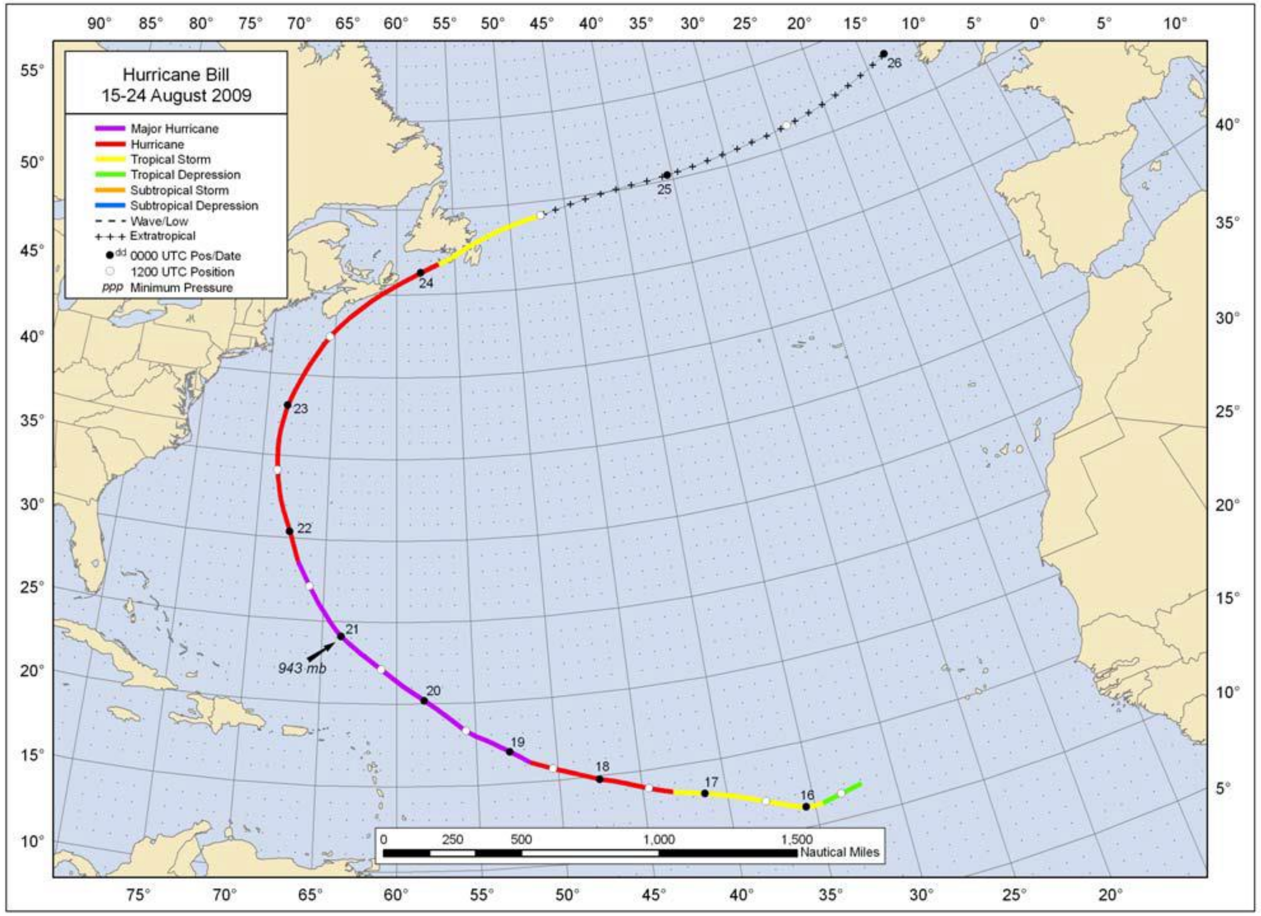


Evaluating Wave Field of TC's

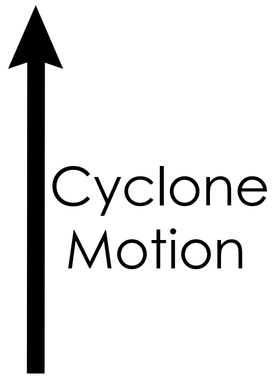




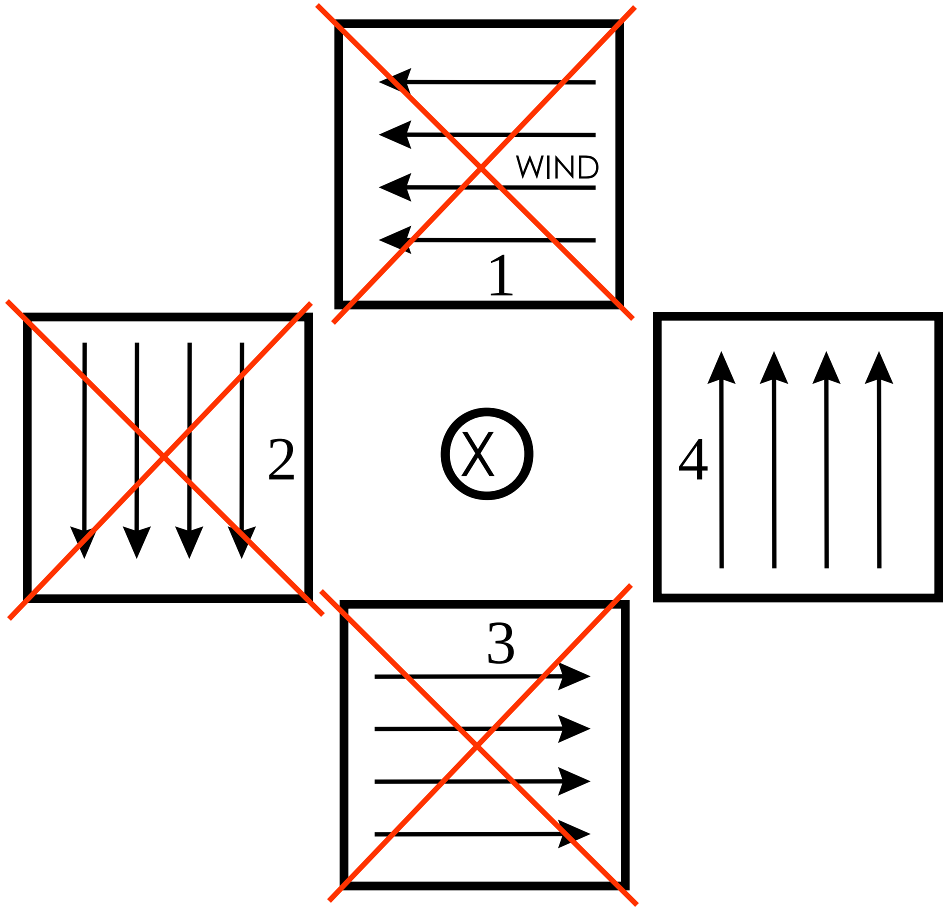
Hurricane Bill 2009



"Fetch Reduction" always occurs in Quadrants 1-2-3 . . . as long as the cyclone is moving



In the 4 fetch areas, which waves will remain in the fetch the longest?

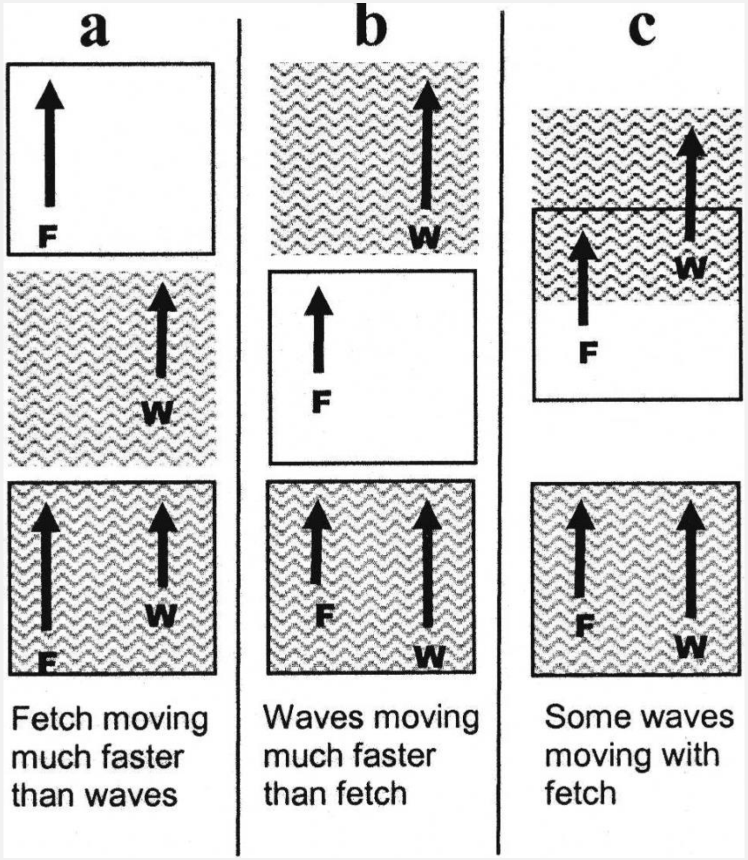


"Fetch Enhancement" may occur in Quadrant 4 . . . depending on the speed of the cyclone

Wave Growth in TC's

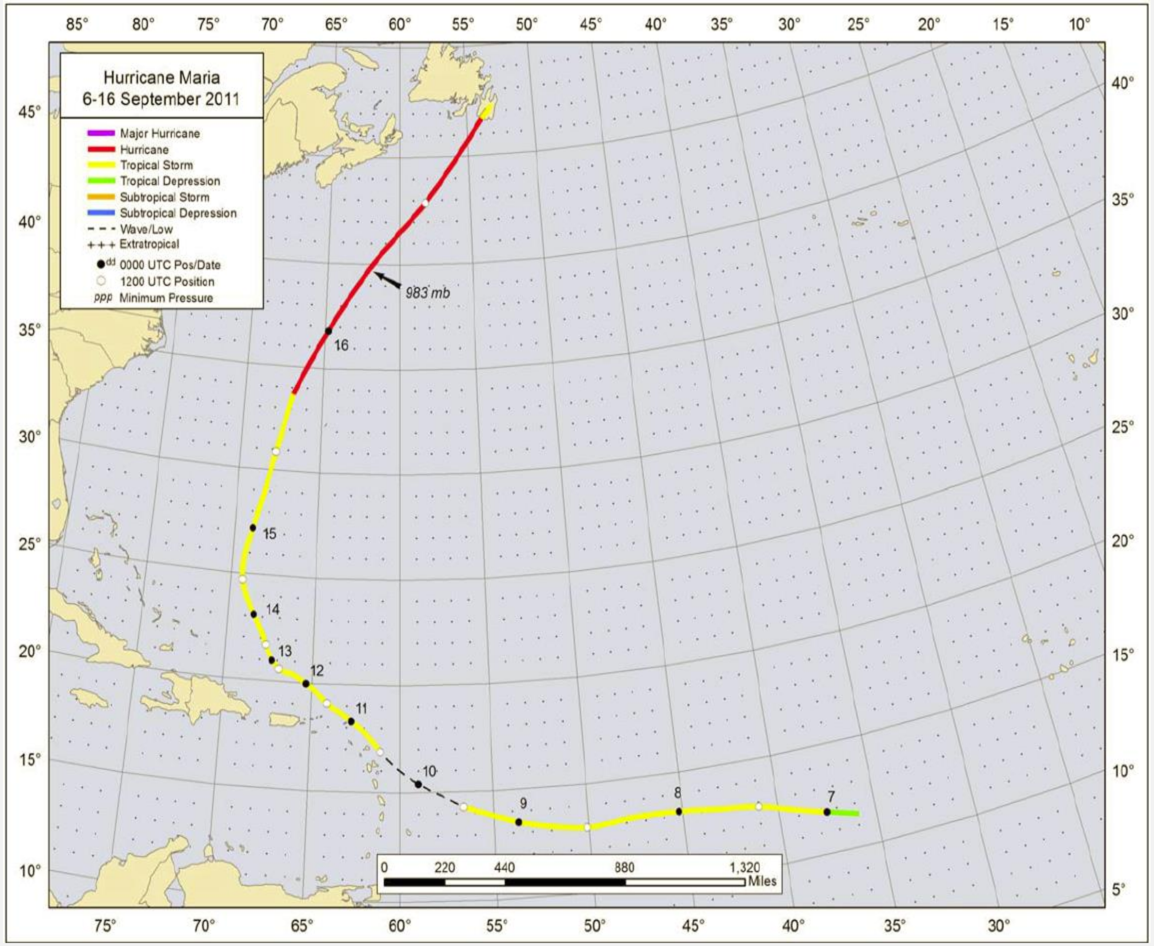
Three possible scenarios for wave growth in right quadrant of TC's

Optimum wave growth will occur when waves are in phase with dynamic fetch

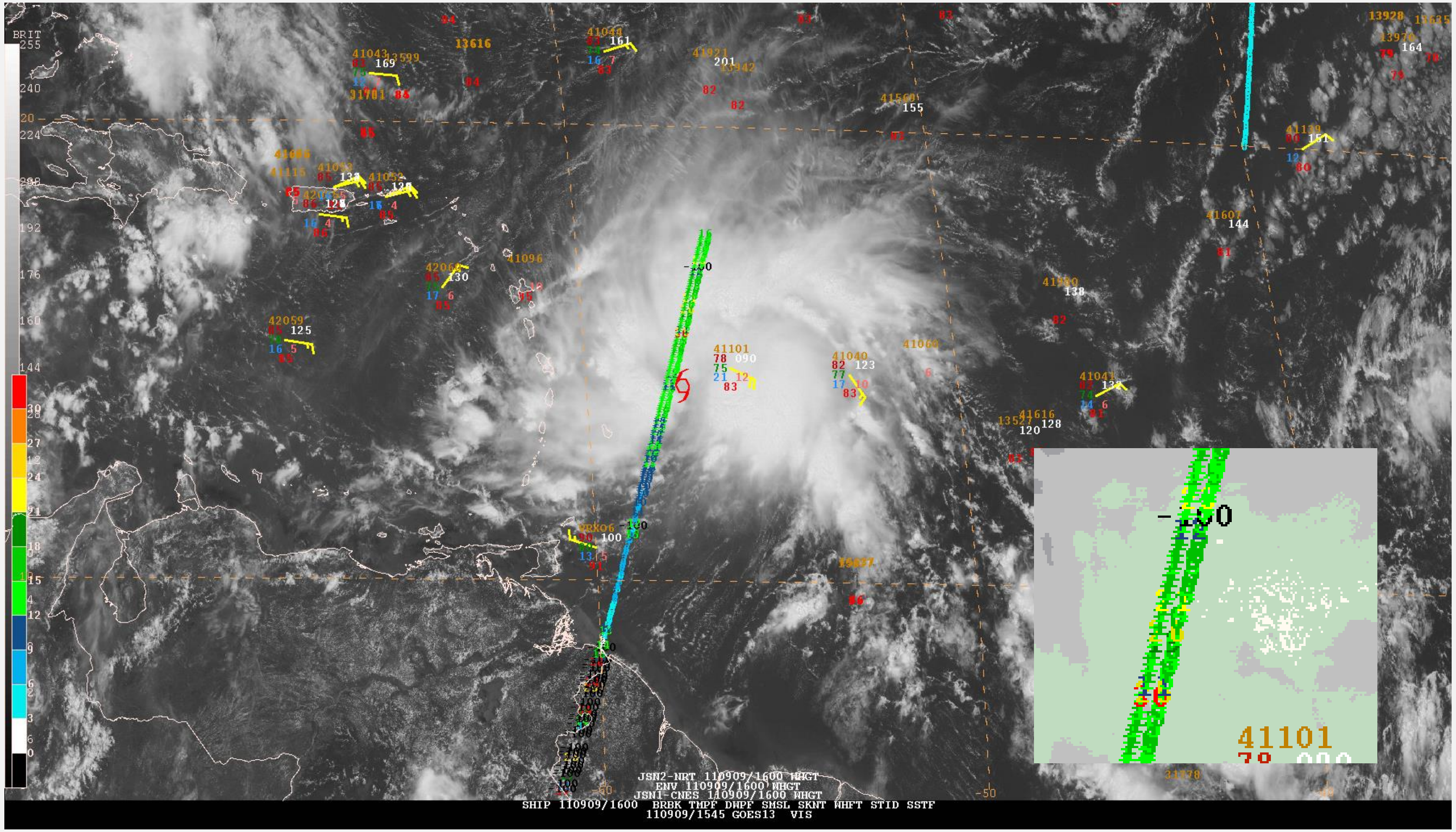


Dynamic Fetch Wave Growth in TCs

TC Maria's Trajectory



Maria Downgraded to Tropical Disturbance 09/1200 UTC



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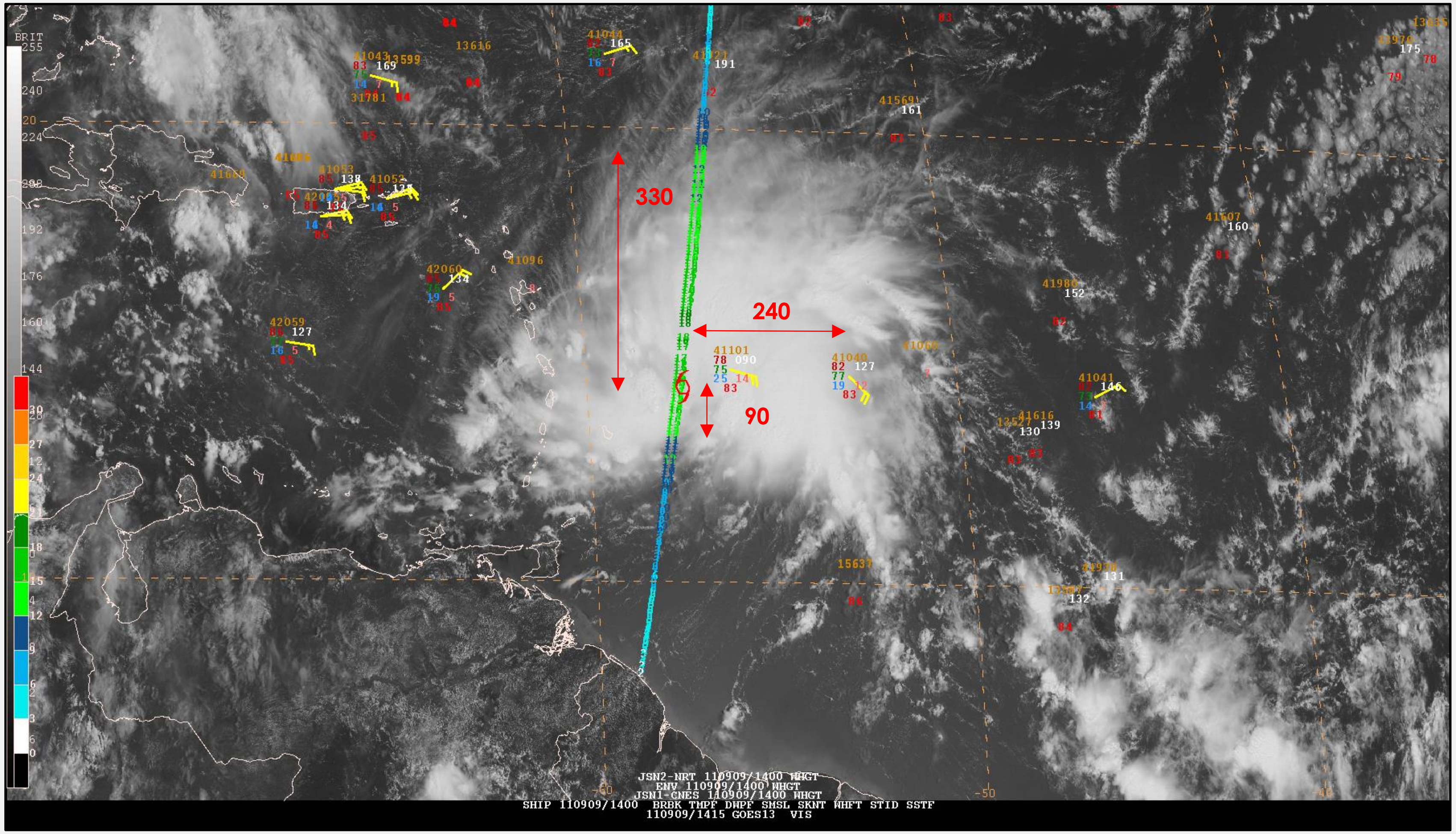
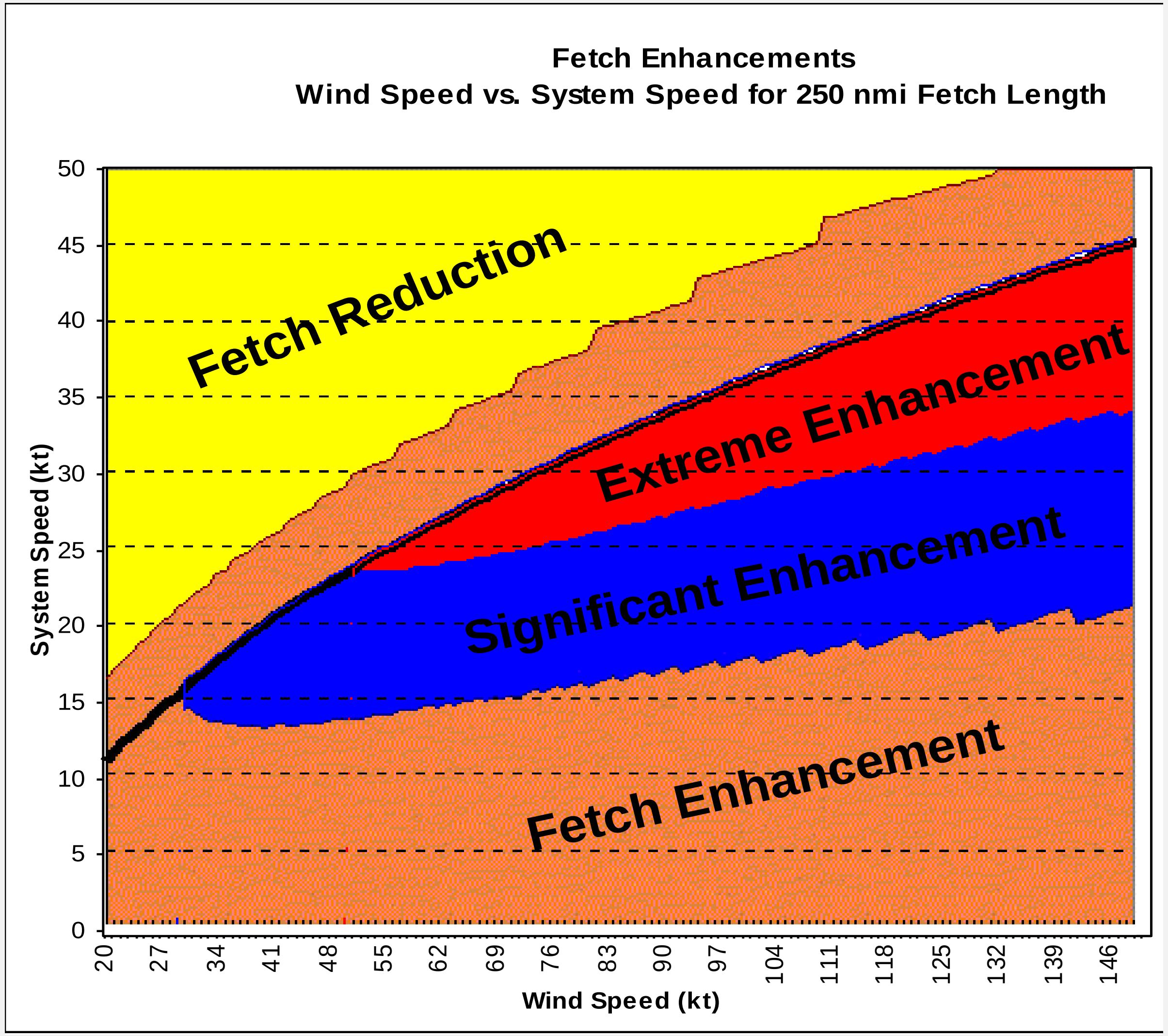


Key Points for Trapped Fetch Waves (TFW) in TC's

- Straight line storm motion with fetch duration of **18** (or more) hours necessary
- Storm motion of **20 kt** and greater yields significant wave growth enhancement
- The smaller the fetch, the greater the enhancement (above a stationary storm scenario)
- Sub-synoptic scale storm systems, like TCs, cyclones and polar lows, have the greatest potential for optimum resonance.
- *Perfect* resonance occurs if TC *acceleration* matches that of the waves …yielding maximized wave growth

CHC Fetch Enhancement Nomogram




Questions?