Wave Measurements from SeaSondes

CODAR
OCEAN SENSORS

Introduction

HF Radar Wave Monitoring
CODAR Ocean Sensors

CODAR’s work on HF Radar wave monitoring began decades ago

1971 ~ Wave monitoring capability of HF radar discovered.

2005 ~ Empirical model-fitting approach developed, still used today

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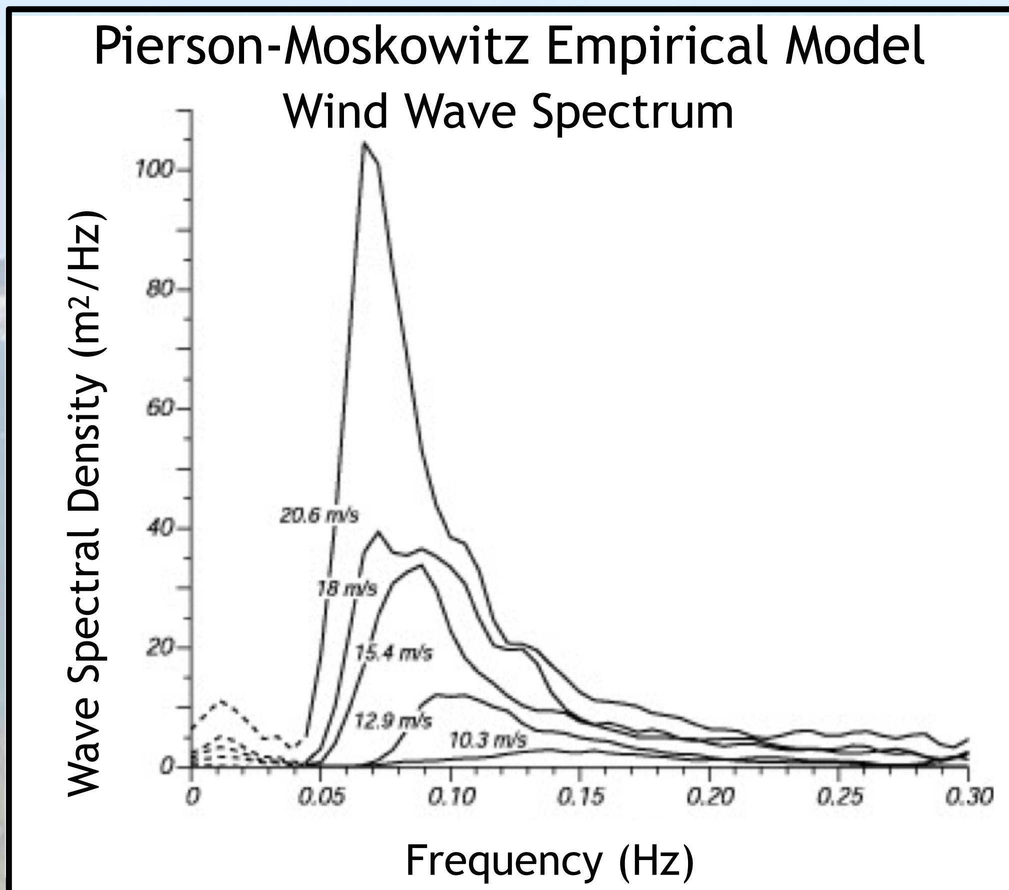

S = wind wave spectrum
k = wavenumber

$$S(k,\phi) = \frac{A_{ww}\, e^{-0.74(k_c/k)^2}}{k^4}$$

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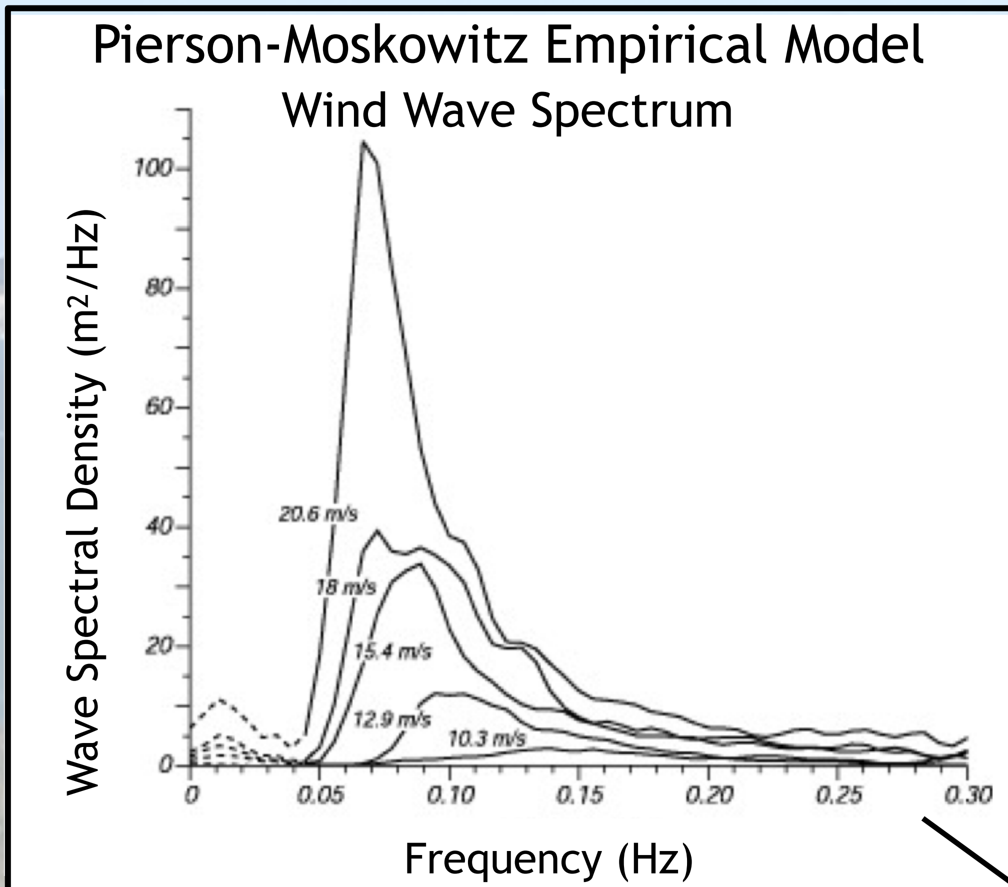

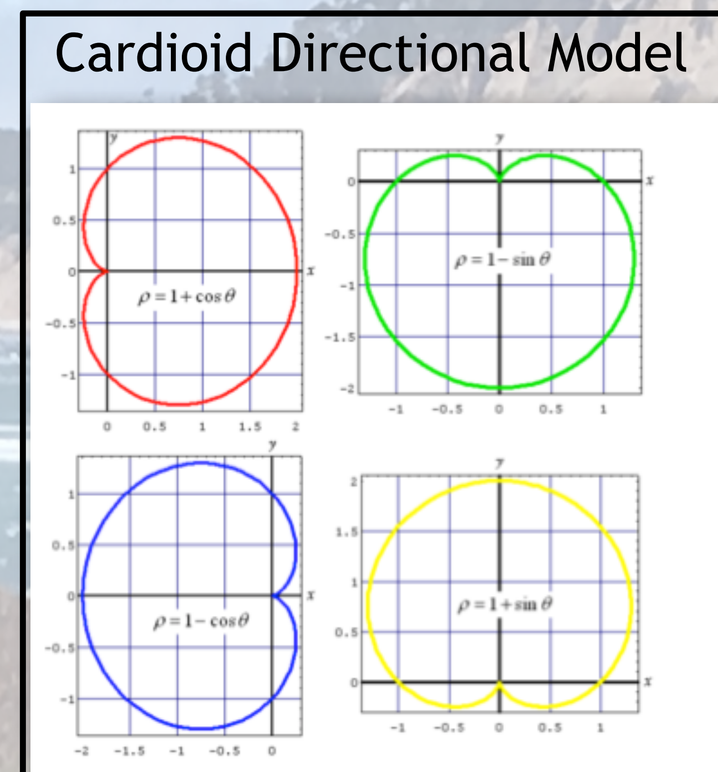

S = wind wave spectrum
k = wavenumber
Φ_{ww} = dominant wave direction

$$S(k,\phi) = \frac{A_{ww}\, e^{-0.74(k_c/k)^2}}{k^4} \cos^4\left(\frac{\phi - \phi_{ww}}{2}\right)$$

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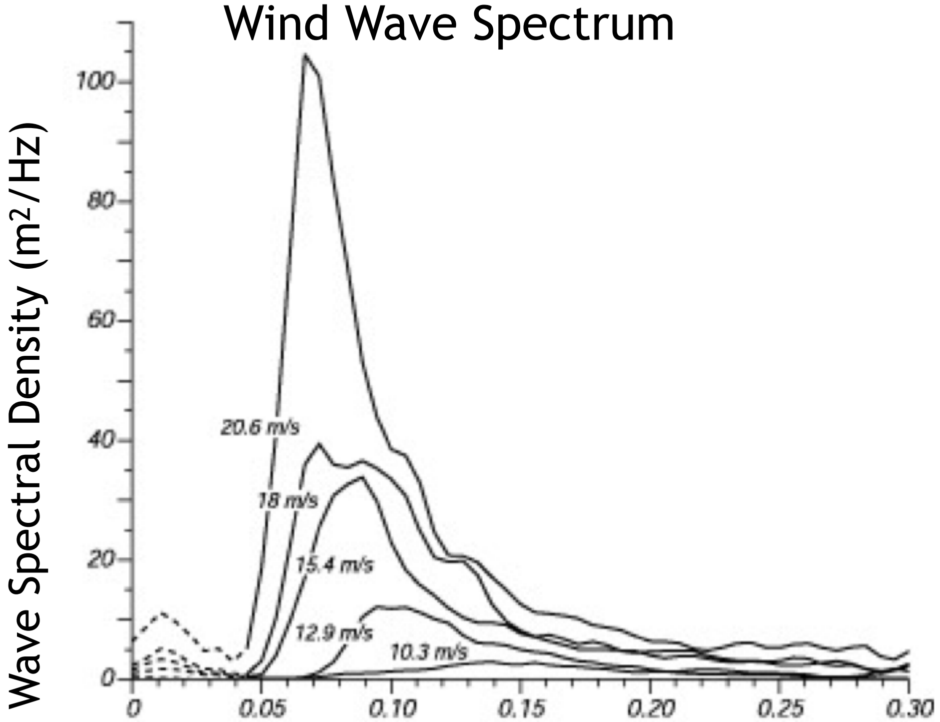
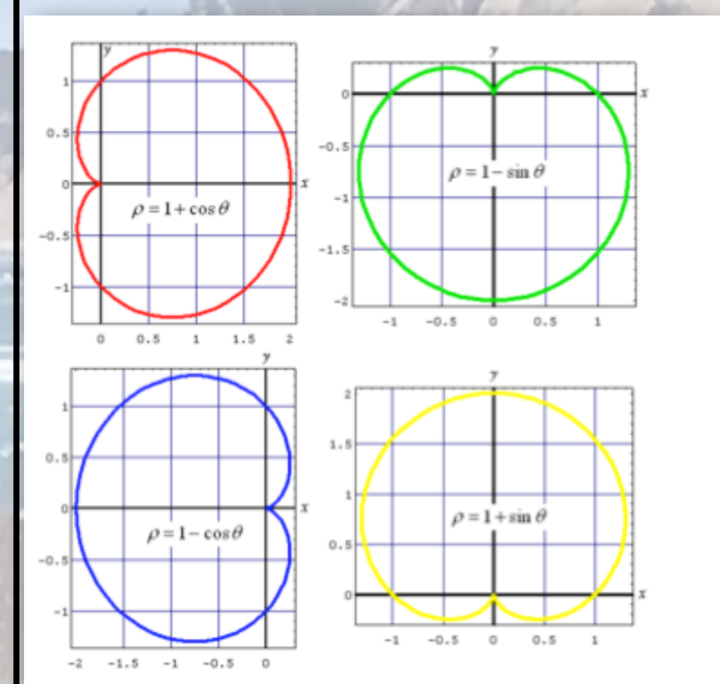


Pierson-Moskowitz Empirical Model
Wind Wave Spectrum



Cardioid Directional Model

P/M model assumes wind waves only, fully developed sea, deep water.

But can also work well in the presence of swell, especially for wave height.

Ocean Waves

Deep water waves

- wind-generated
- wave length $L < 4H$
- surface gravity waves
- wave speed = $(g*L/2\Pi)^{0.5}$

Shallow water waves

- tsunamis, tides, inertial waves, internal waves
- wave length $L > 4H$
- wave speed = $(g*H)^{0.5}$

Ocean Waves

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Ocean Waves

Deep water waves

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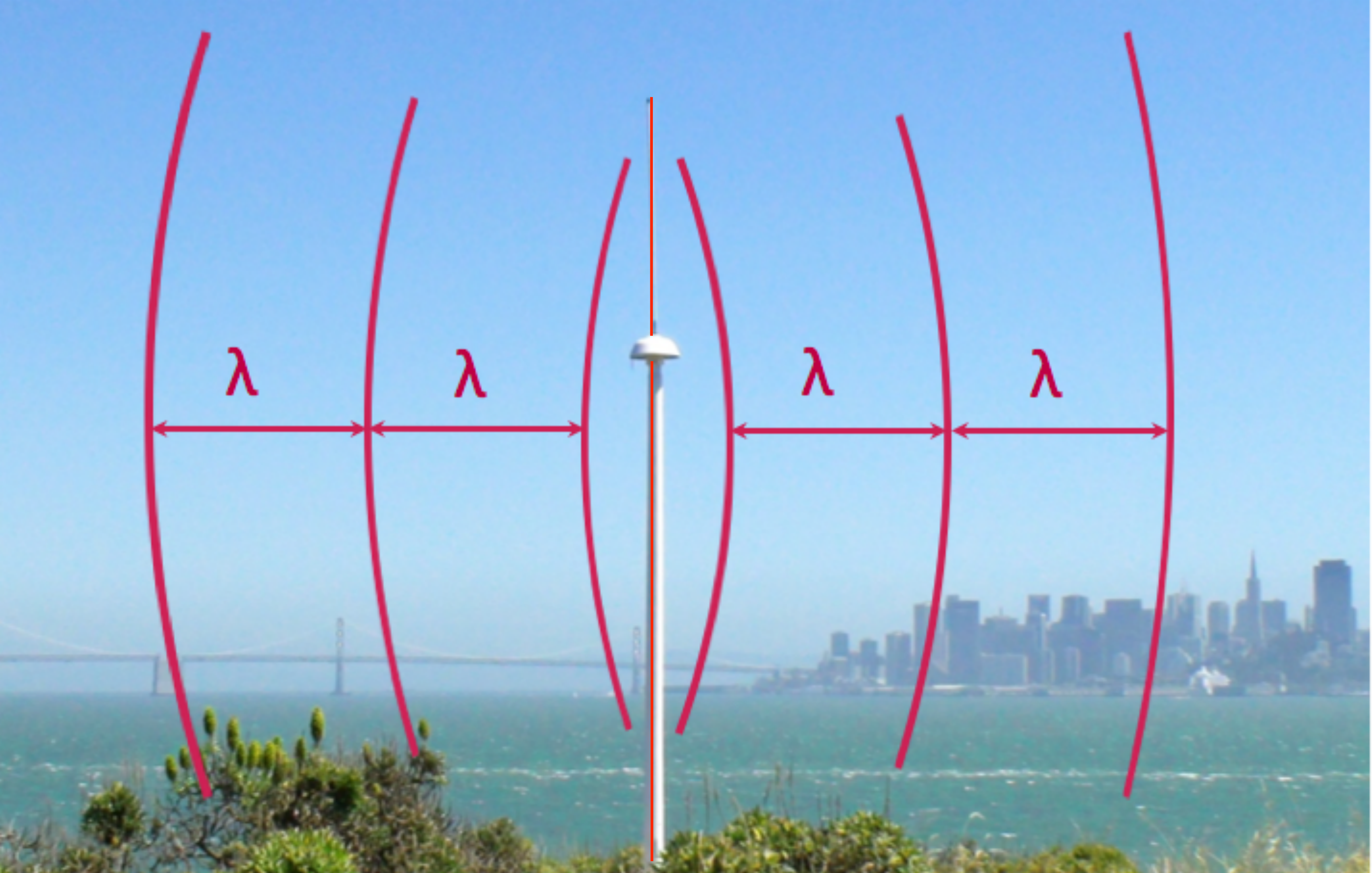
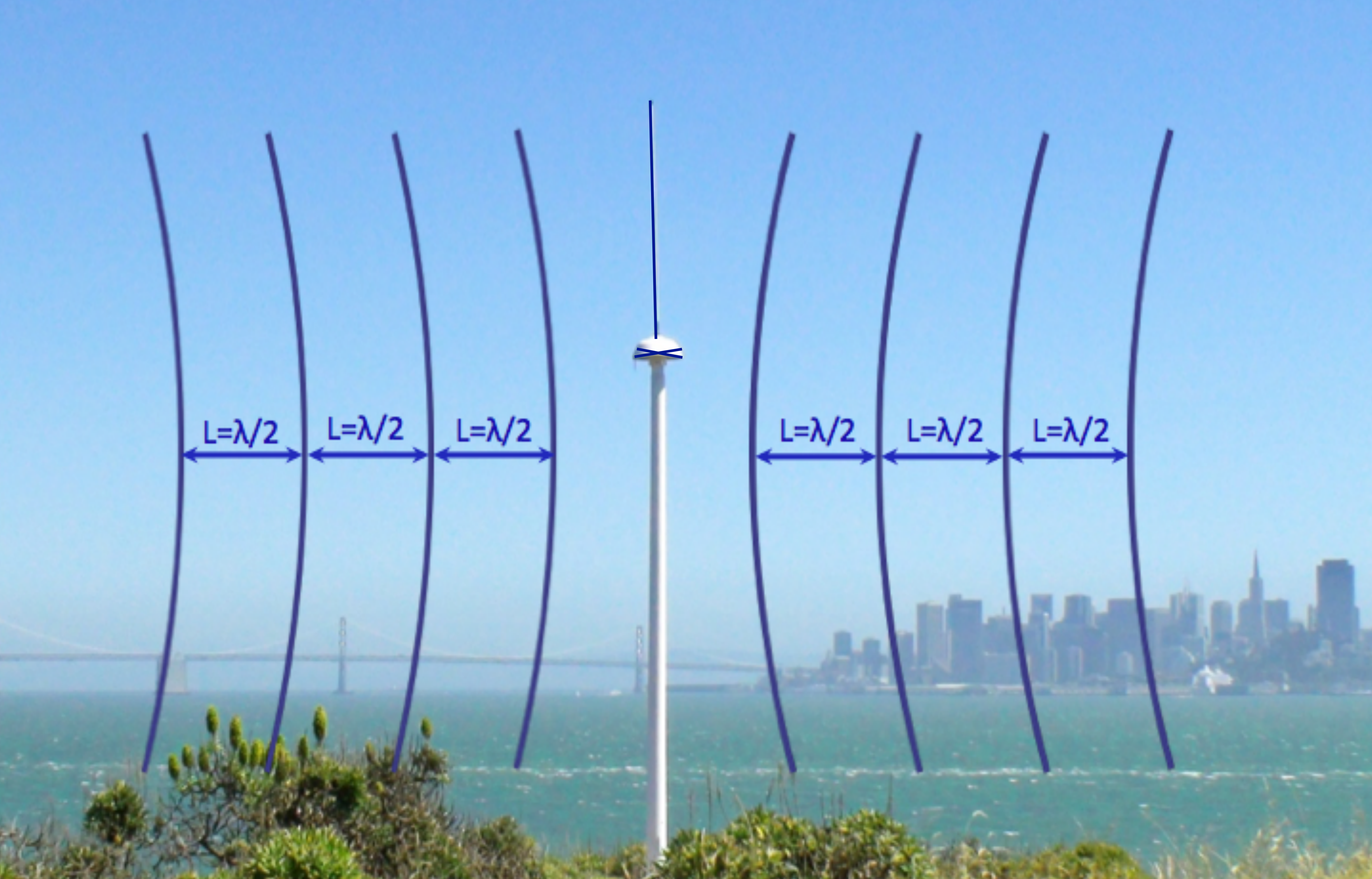
Deep water waves monitored by SeaSondes

- wave length L < 2H
- longer than Bragg waves

Reivew of Current Measurements

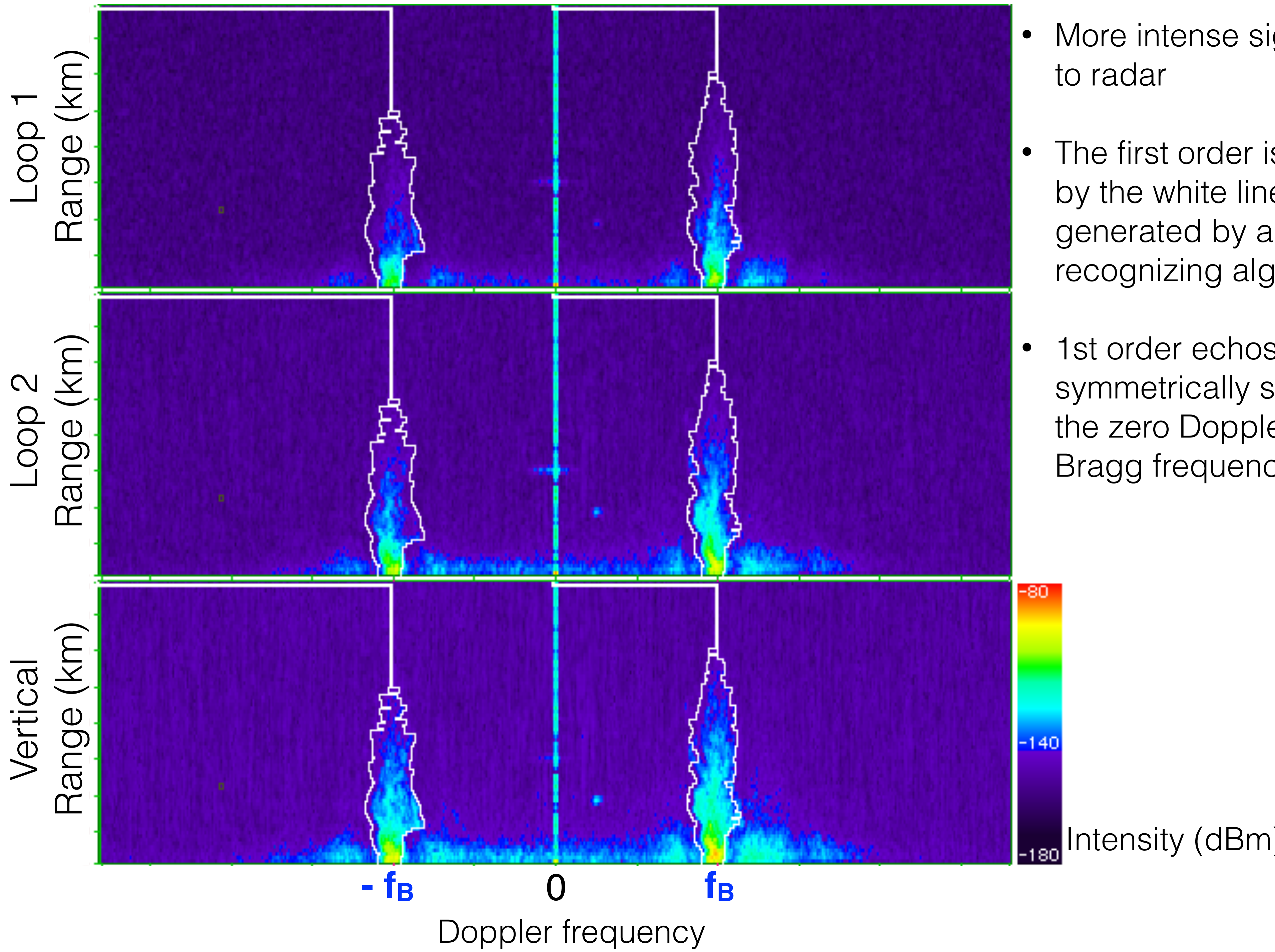


- SeaSonde in transmit mode emitting EM signal of wavelength λ in all directions.



- SeaSonde in receive mode receiving echo from Bragg waves, which have wavelength λ/2.
Bragg waves are choppy wind waves like the ones shown here.

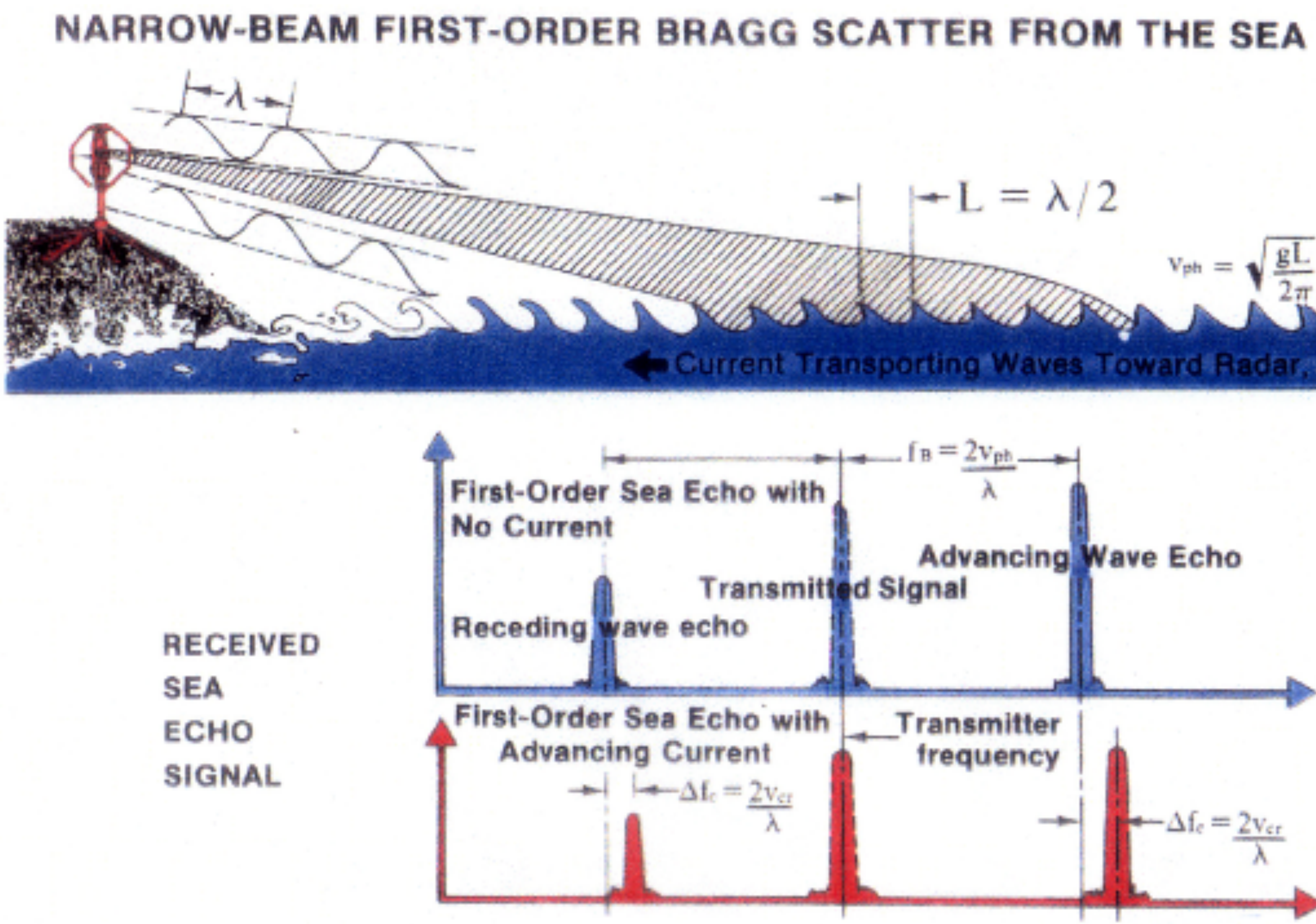
HFR Energy Spectrum



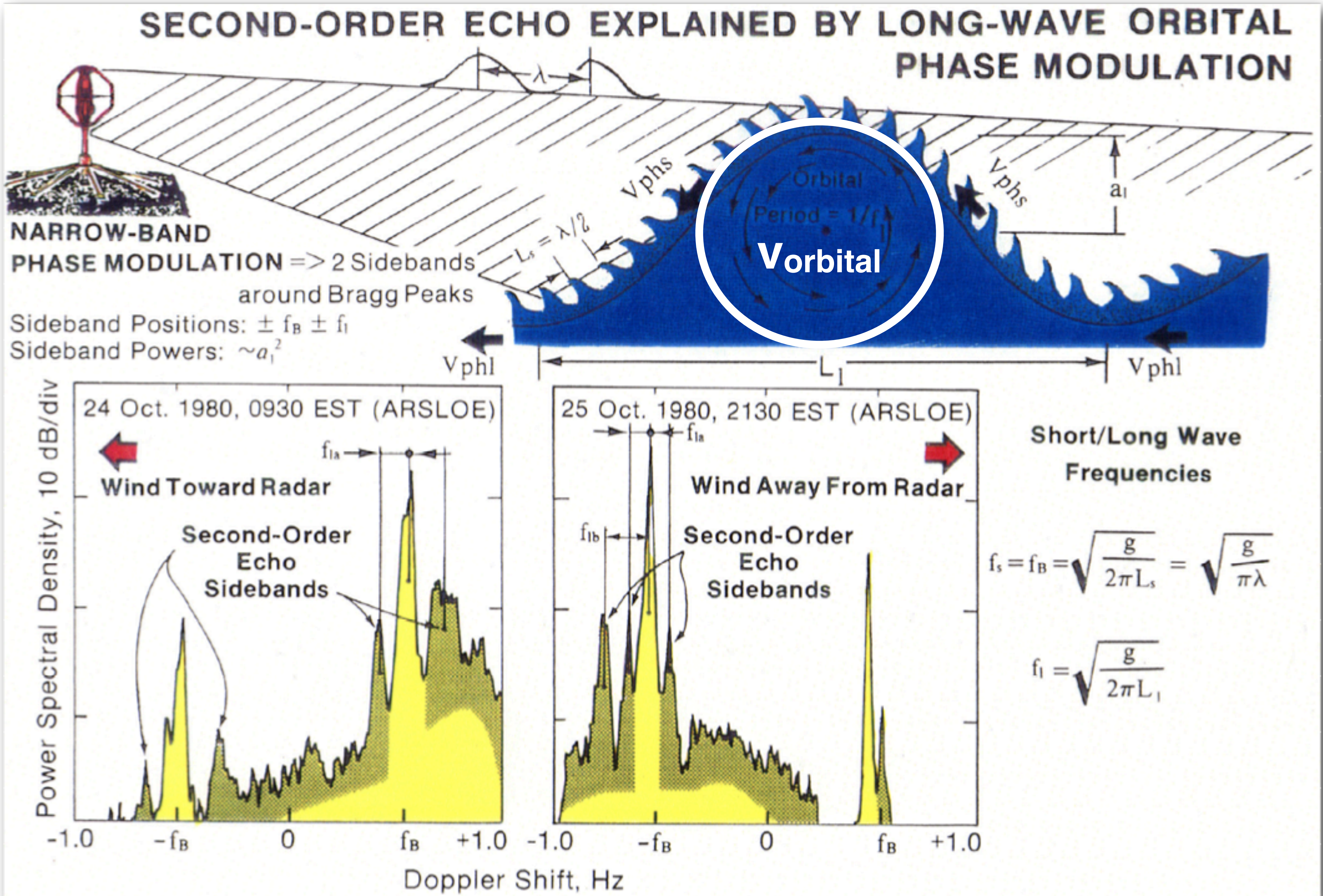
- More intense signal closer to radar
- The first order is delineated by the white lines, these are generated by a pattern recognizing algorithm.
- 1st order echos are symmetrically spaced about the zero Doppler at the Bragg frequency, f_B

Wave Measurements

To Explain 2nd Order, Start with 1st-Order Bragg Scatter from Short Waves

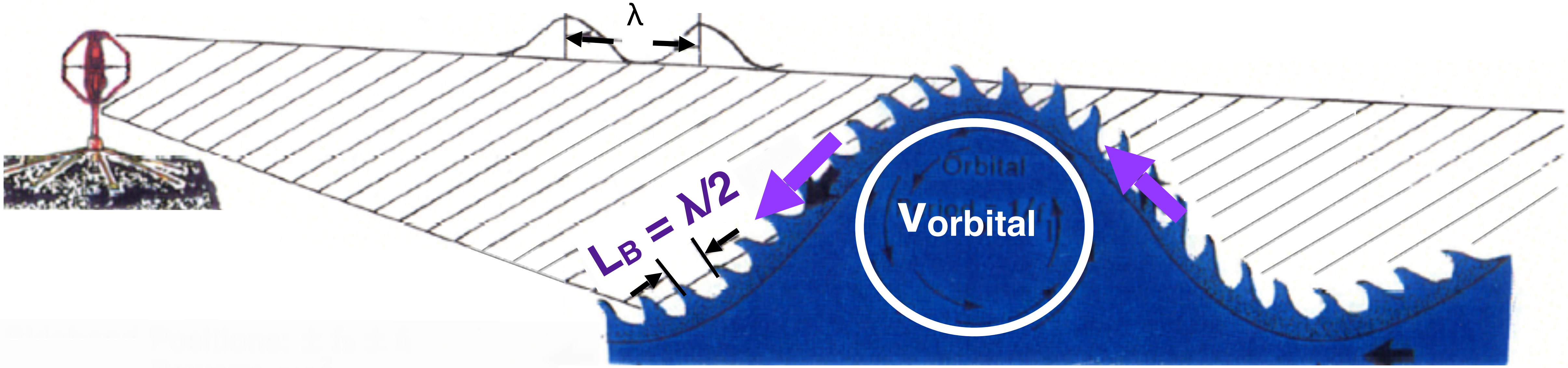


Bragg Waves with Underlying Wave



The interaction of the wave's orbital velocity with Bragg wave motion creates a spectral sideband that comprises the 2nd order.

Bragg Waves with Underlying Wave



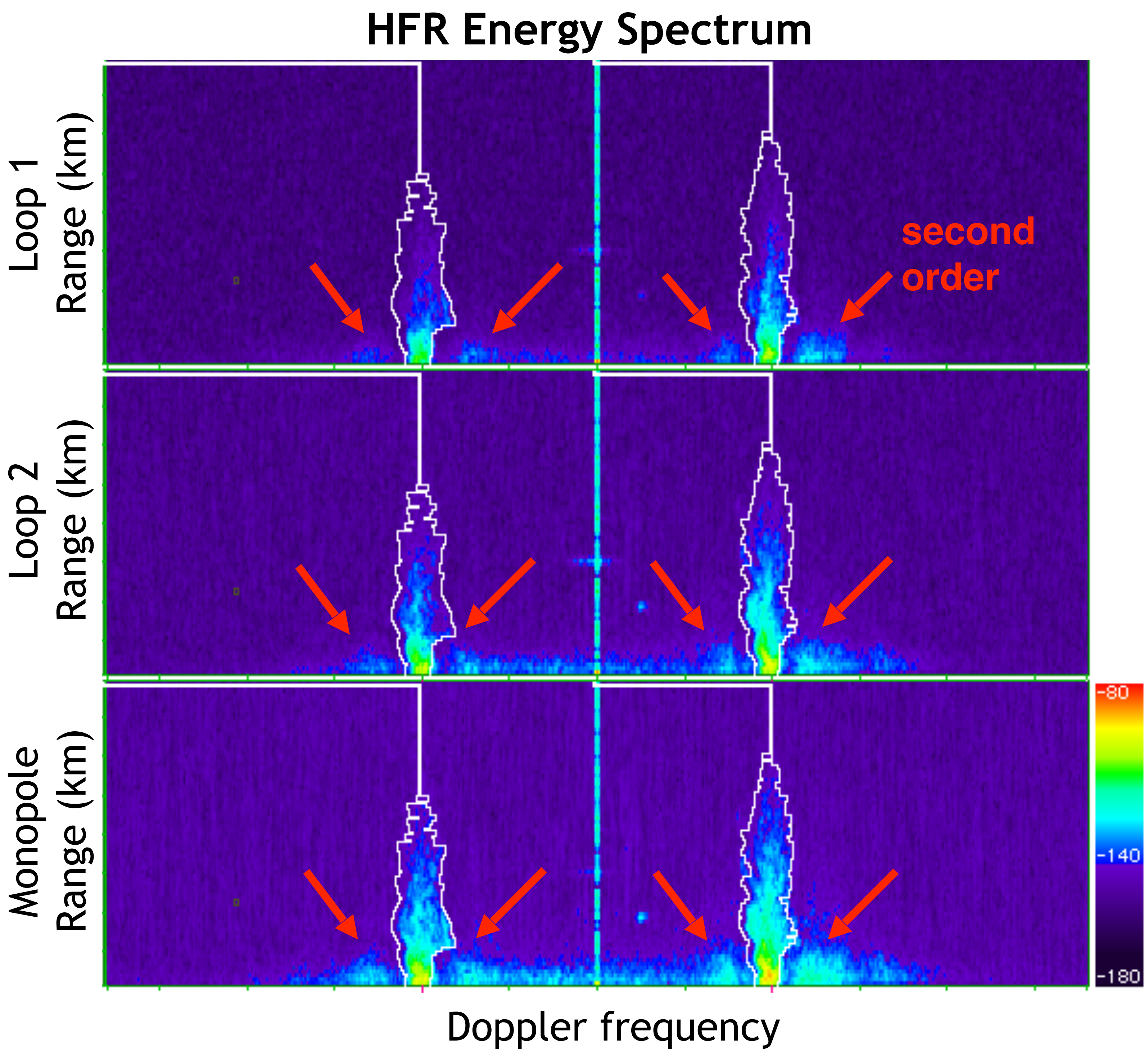
Underlying deep water wave

The interaction of the wave's orbital velocity with Bragg wave motion creates a spectral sideband that comprises the 2nd order.

What Are Second Order Peaks?

- Secondary Doppler spectral peaks caused by the orbital velocity due to long waves passing by.
- Characteristics:
  - Peaks are 1 - 4 orders of magnitude weaker than 1st order Bragg peaks used for currents
  - May occur on one or both sides of 1st order peak
  - May be present in one or both +/- Doppler
  - In strong currents, may be smeared together with 1st order -- not separable

Wave Info In Doppler Spectrum

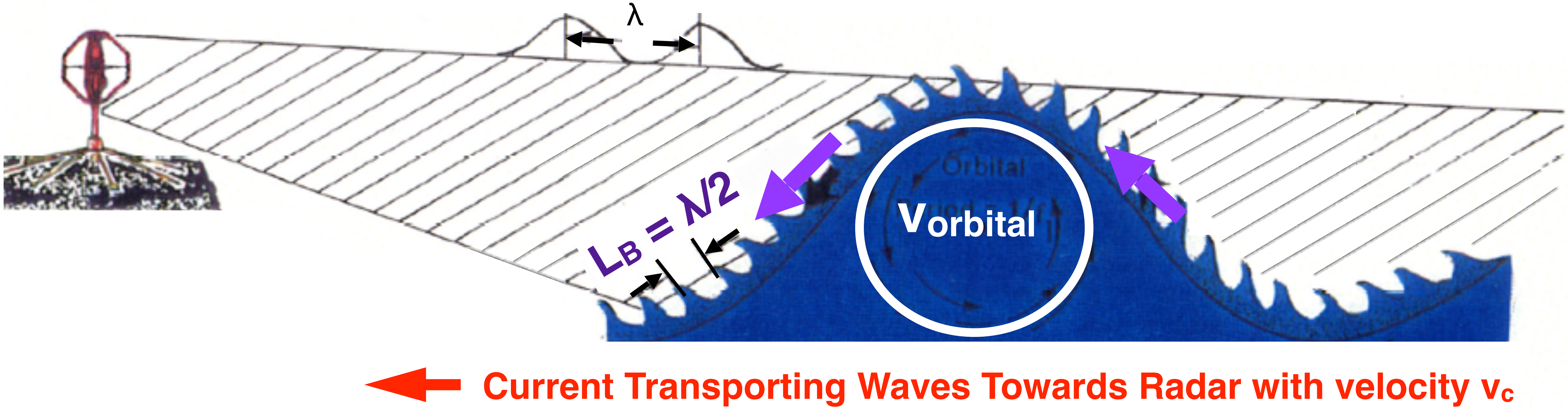


- The second order signal is weaker than the first order signal.
- The second order signal has reduced range coverage.
- Extracting waves from the second order signal is dependent on environmental conditions:
  noise & interference, currents, wave height, depth.
- The first order signal is used to generate wind direction.
- One SeaSonde is needed to monitor waves.

Wave Extraction Process

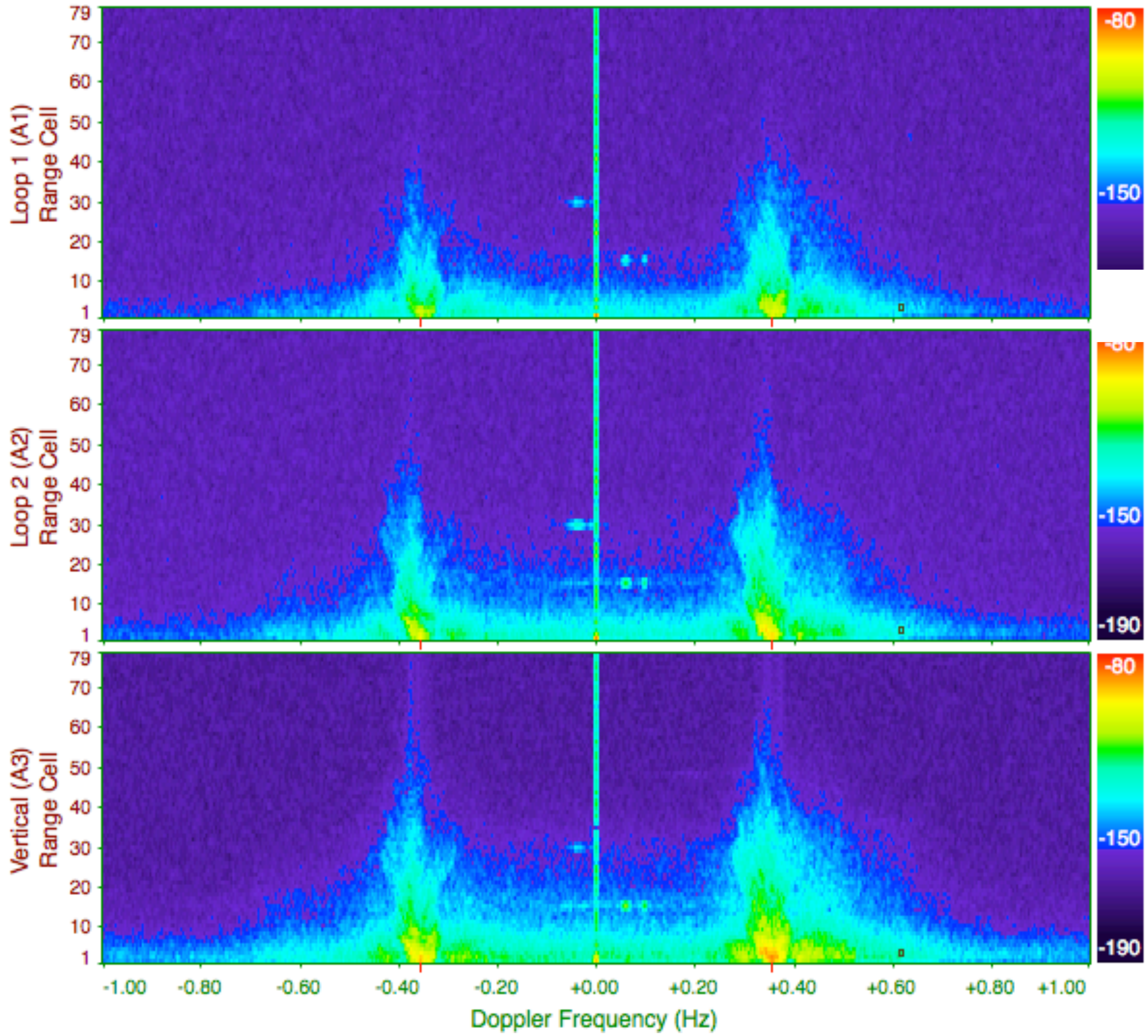
- Separate 1st order from 2nd order regions
  - Four 2nd-order peaks possible, but rarely available (best of all)
  - CODAR algorithm will operate with just one 2nd-order peak - don’t need multiple peaks
- Use 1st order to get wind direction and also to normalize 2nd order echo
- Fit P/M model to normalized 2nd order to determine wave height, period, direction

Bragg Waves with Underlying Wave & Current



- An underlying current spreads the 1st & 2nd orders
- If fast enough, the current will smear the 1st and 2nd orders together, making wave extraction a challenge.

HFR Energy Spectrum with Fast Currents

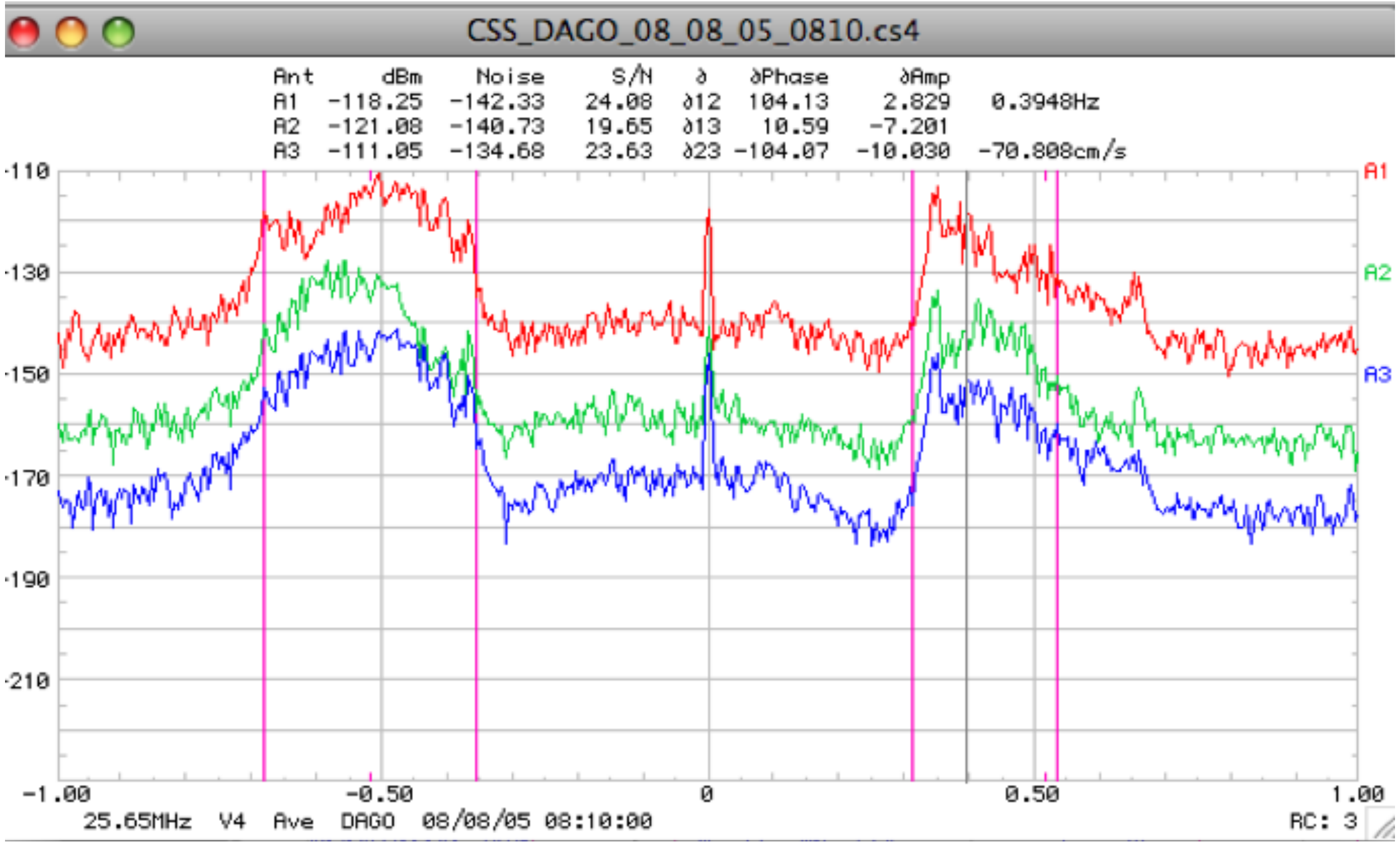


Wave Monitoring Considerations

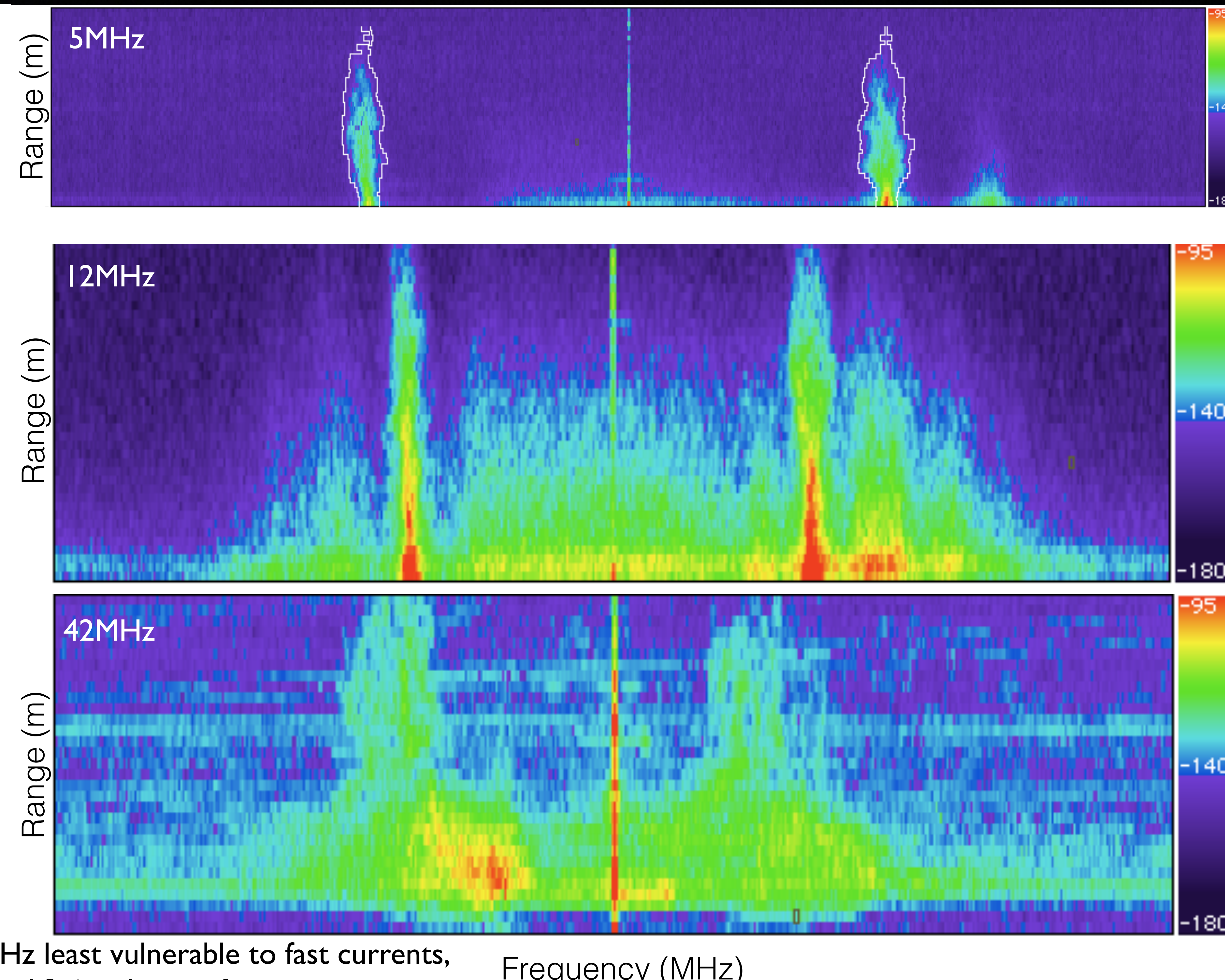
Wave Monitoring Considerations

> **Current Speed: Currents are too strong, 1st and 2nd orders smear together**

Range Cell 3 Spectrum with Fast Currents



2nd Order Visibility



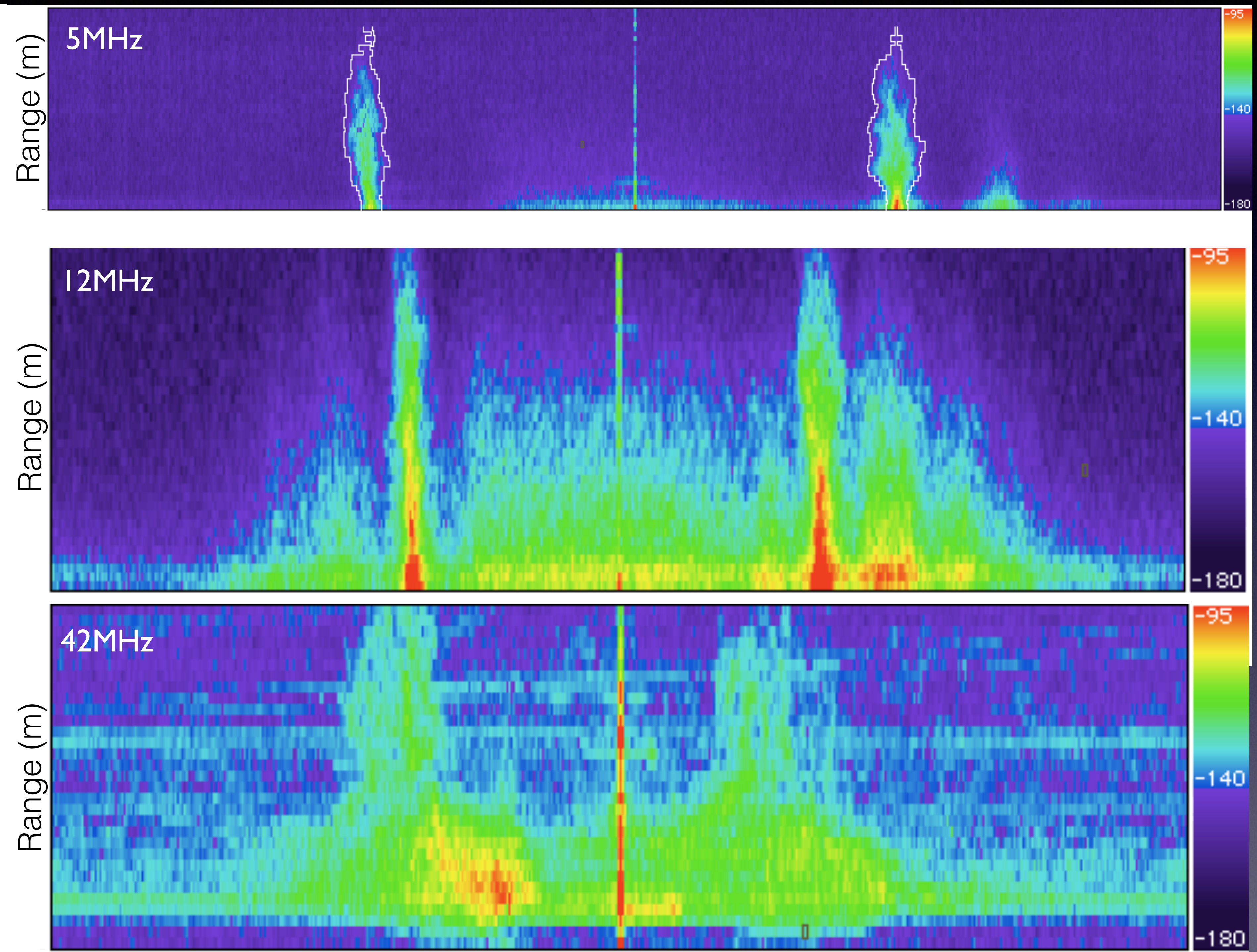
5 MHz least vulnerable to fast currents,
1st and 2nd order are far apart

Wave Monitoring Considerations

- **Current Speed: Currents are too strong, 1st and 2nd orders smear together.**

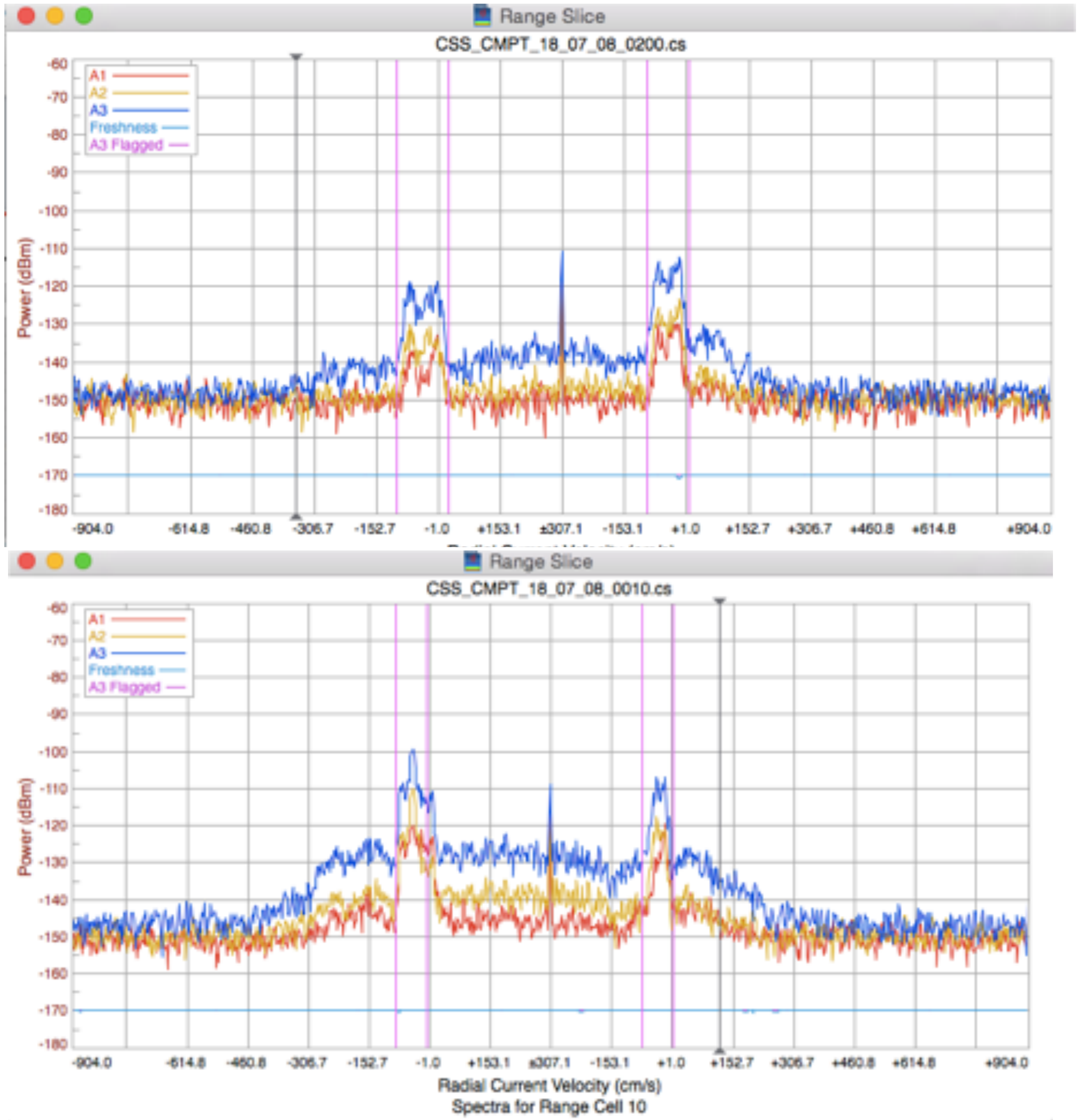
- **2nd Order Visibility: 2nd order peaks may not be visible above noise/interference. Waves are too low and/or noise is too high.**

2nd Order Visibility



42 MHz least vulnerable to noise/ interference, 2nd order is strongest

Range Cell 10 Spectrum with Low Signal, High Noise Floor



Wave Monitoring Considerations

> **Current Speed: Currents are too strong, 1st and 2nd orders smear together.**

> **2nd Order Visibility: 2nd order peaks may not be visible above noise/interference. Waves are too low and/or noise is too high.**

> **$H_{saturation}$: Waves are too high, model used to extract wave height does not apply.**

Typical Upper Limit on Wave Height (Hs):

5 MHz Hs ~ 24 m
13 MHz Hs ~ 8.0 m
25 MHz Hs ~ 4.0 m
42 MHz Hs ~ 2.5

Wave Monitoring Considerations

> Current Speed: Currents are too strong, 1st and 2nd orders bleed together.

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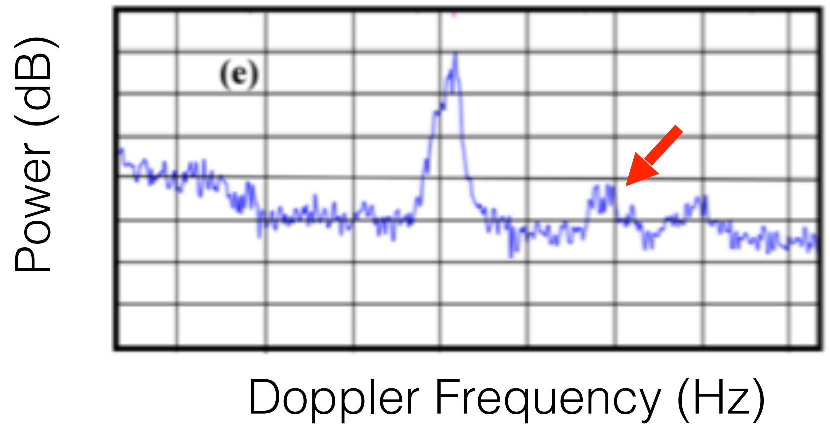
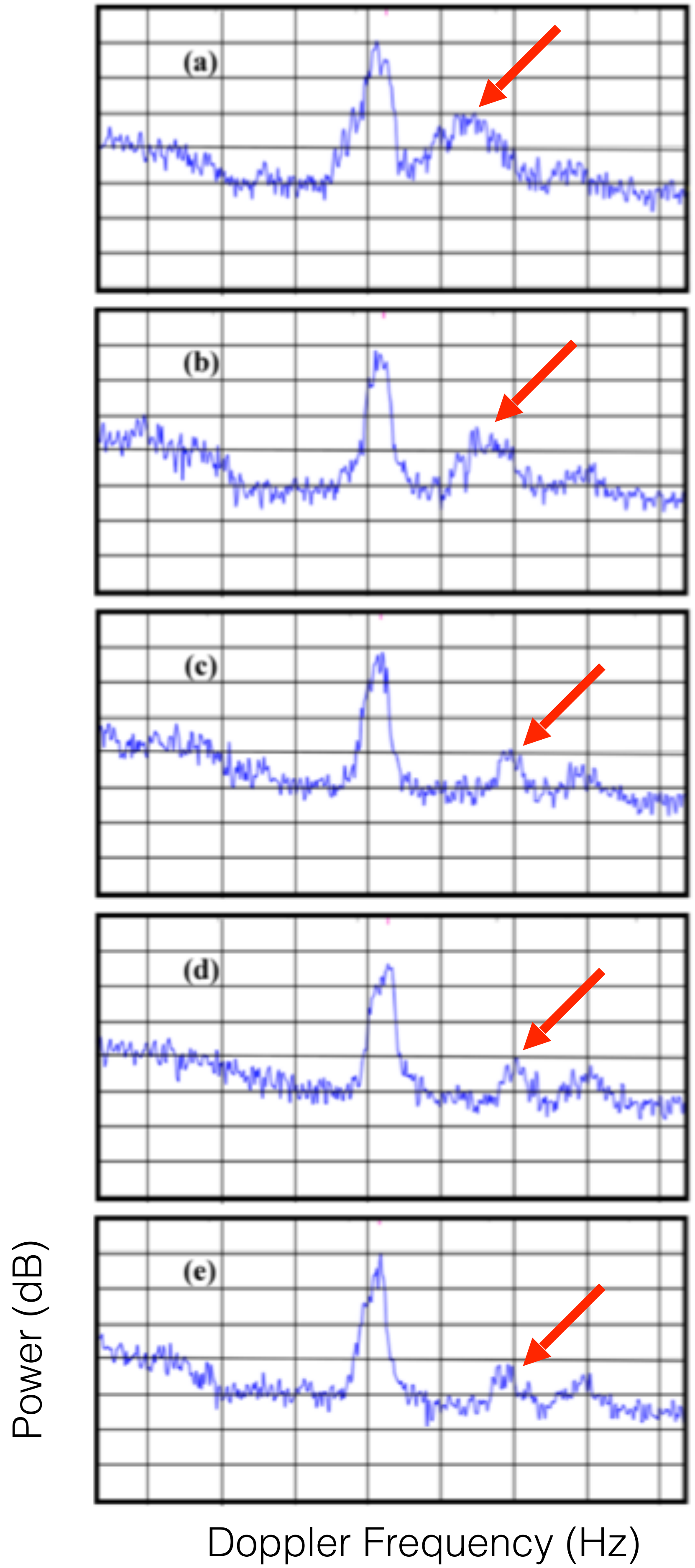
> **Shallow Water Effects: Water is shallow, deep water assumptions are invalid.**

Shallow Water Effects, Long Range Example



far from radar, deep
54 km range
40 < depth (m) < 100

Shallow Water Effects, Long Range Example

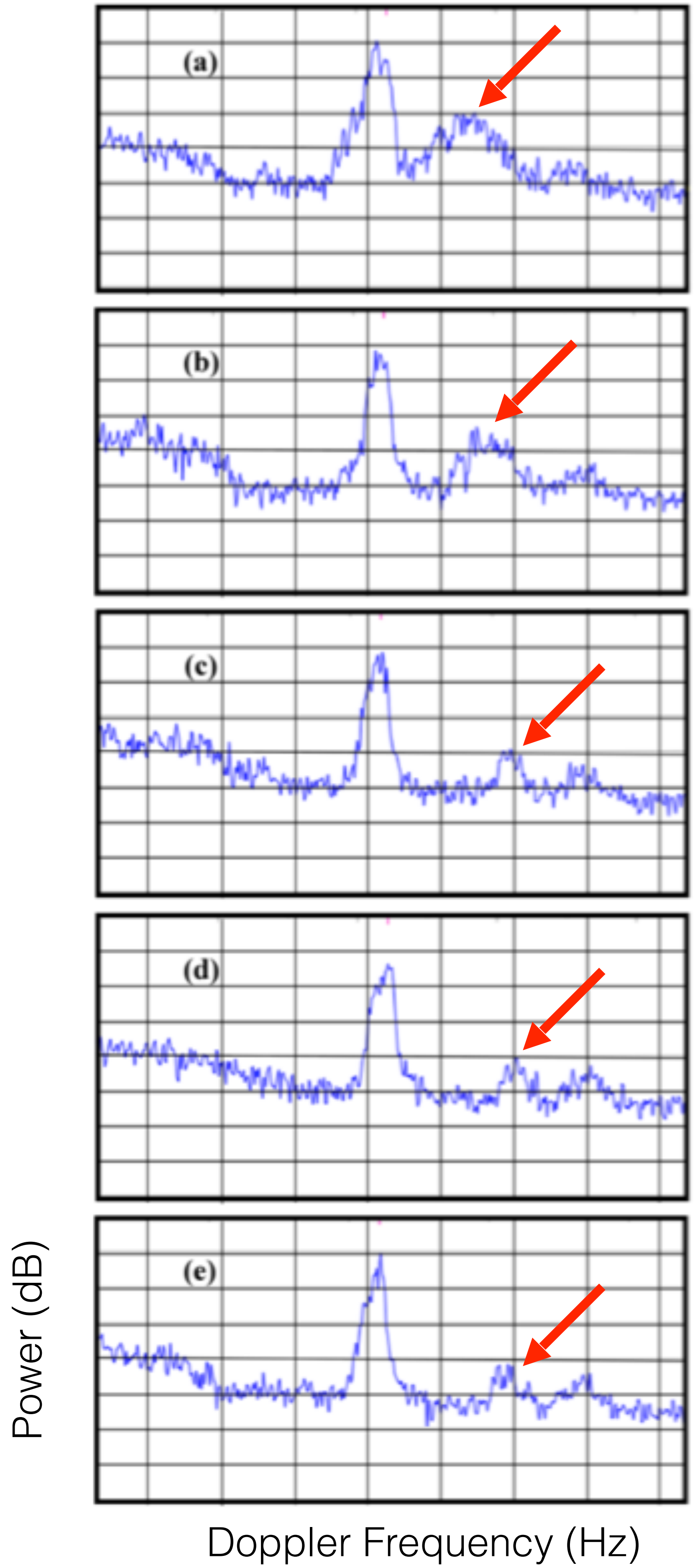


close to radar, shallow
18 km range
5 < depth (m) < 20

Decreasing Depth

far from radar, deep
54 km range
40 < depth (m) < 100

Shallow Water Effects, Long Range Example



close to radar, shallow
18 km range
5 < depth (m) < 20

2nd order peak grows,moves towards 1st order.

Result is that wave height can be over estimated.

Look for these effects in spectra if monitoring in 10 to 20 m depths.

far from radar, deep
54 km range
40 < depth (m) < 100

Wave Monitoring Considerations Summary

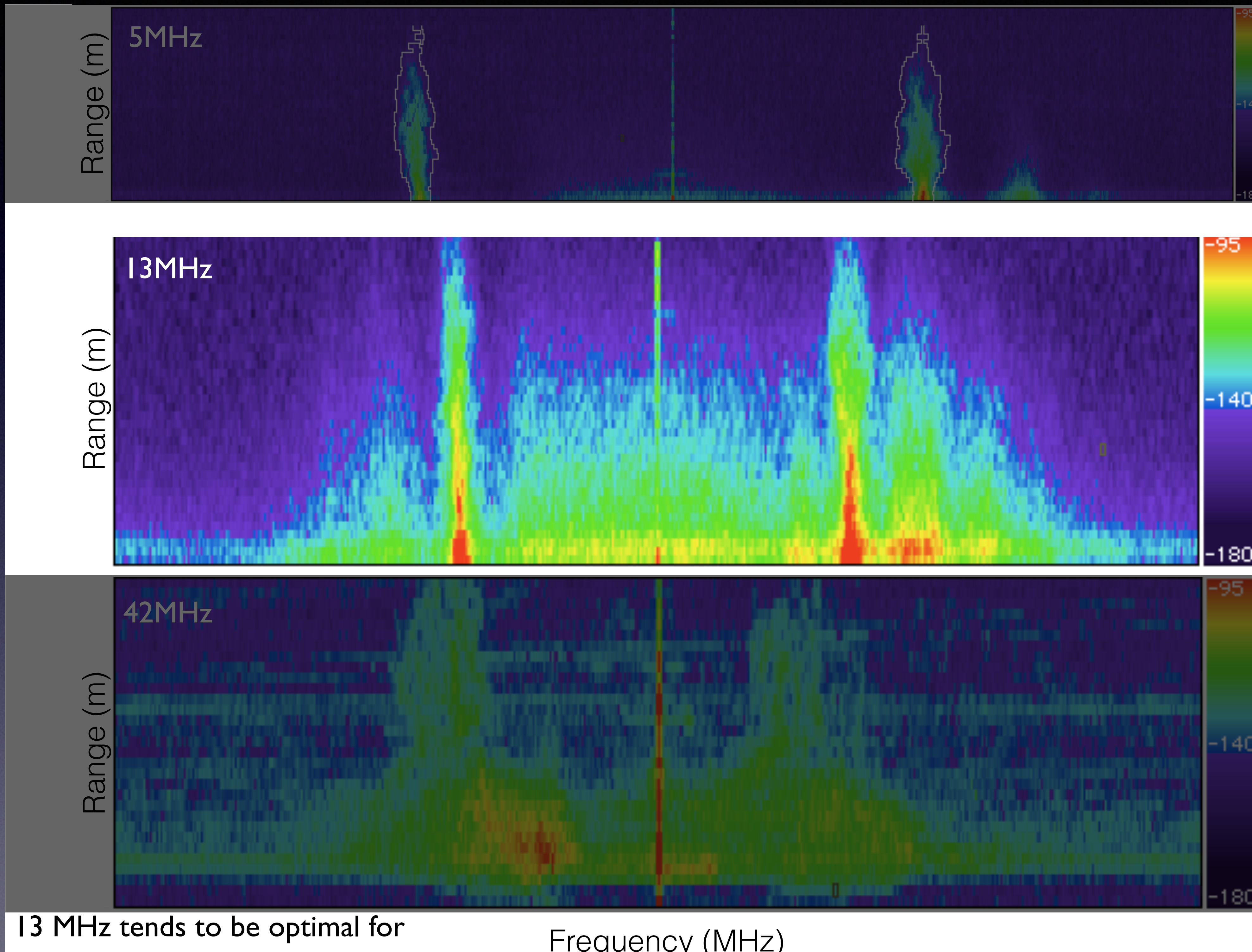
> **Current Speed: Currents are too strong, 1st and 2nd orders bleed together. (low frequency optimal).**

> **2nd Order Visibility: 2nd order peaks may not be visible above noise/interference. Waves are too low and/or noise is too high. (high frequency optimal).**

> **$H_{saturation}$: Waves are too high, model used to extract wave height does not apply. (low frequency optimal).**

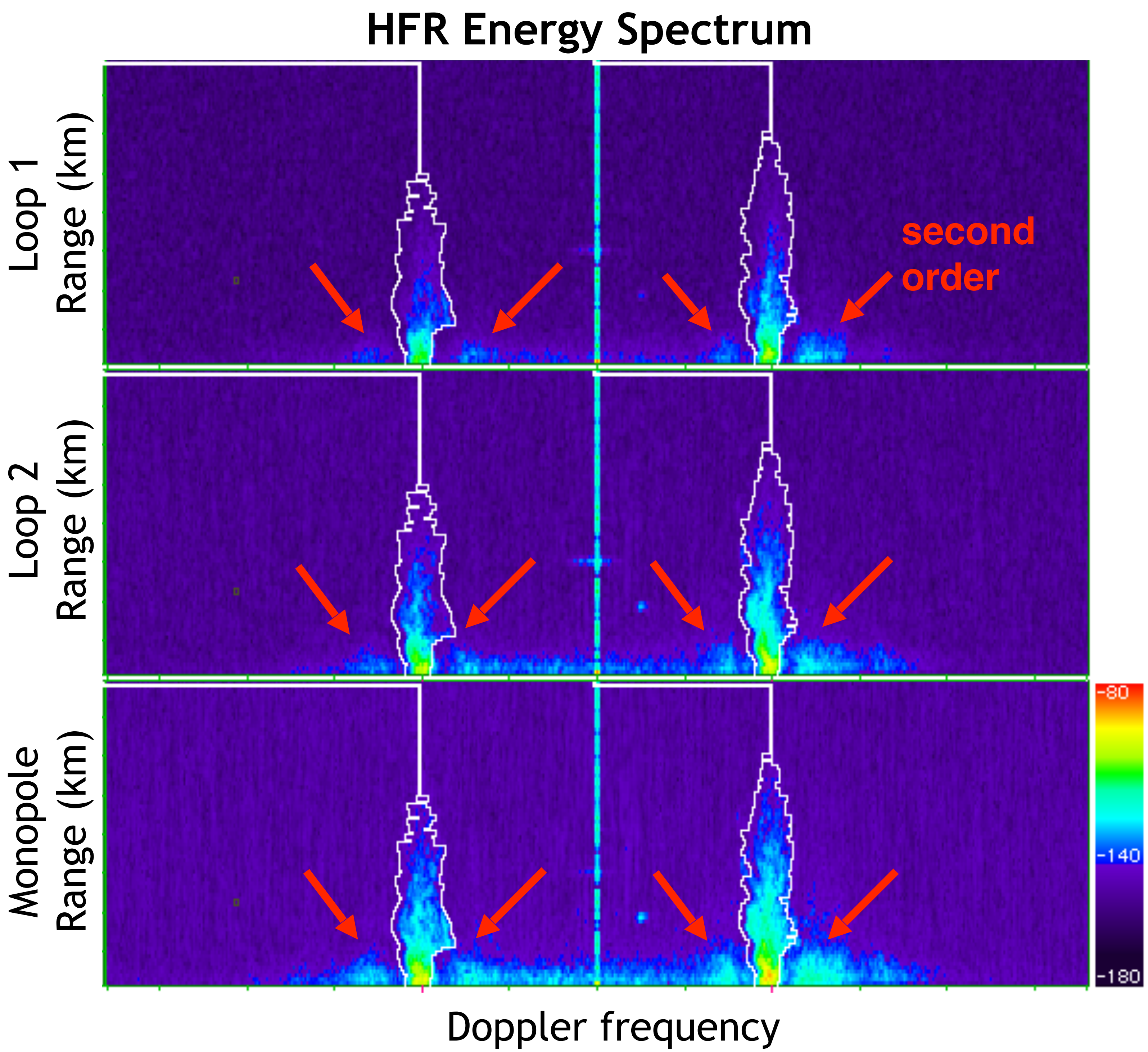
> **Shallow Water Effects: Water is shallow, deep water assumptions are invalid. (high frequency optimal).**

2nd Order Visibility



13 MHz tends to be optimal for monitoring waves.

Recap: Wave Info In Doppler Spectrum



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Recap: Limitations

Not All Radars in All Locations Can Give Useful Wave Data -- Reasons Limiting Data Are:

- No 2nd order echo peaks visible above noise
- Waves too high, inversion model everyone uses for 2nd order does not work
- Currents are too strong
- Water is too shallow where waves are measured
- Sidelobes and severe pattern distortion limits accuracy, if not accounted for

Technical References

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- Lipa, B.J., B. Nyden (2005), Directional wave information from the SeaSonde, IEEE Jour. Ocean. Eng., vol 30, no. 1, pp 221-231.