Ambient Noise

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Special Issue Archival Papers

ARCHIVAL PAPERS

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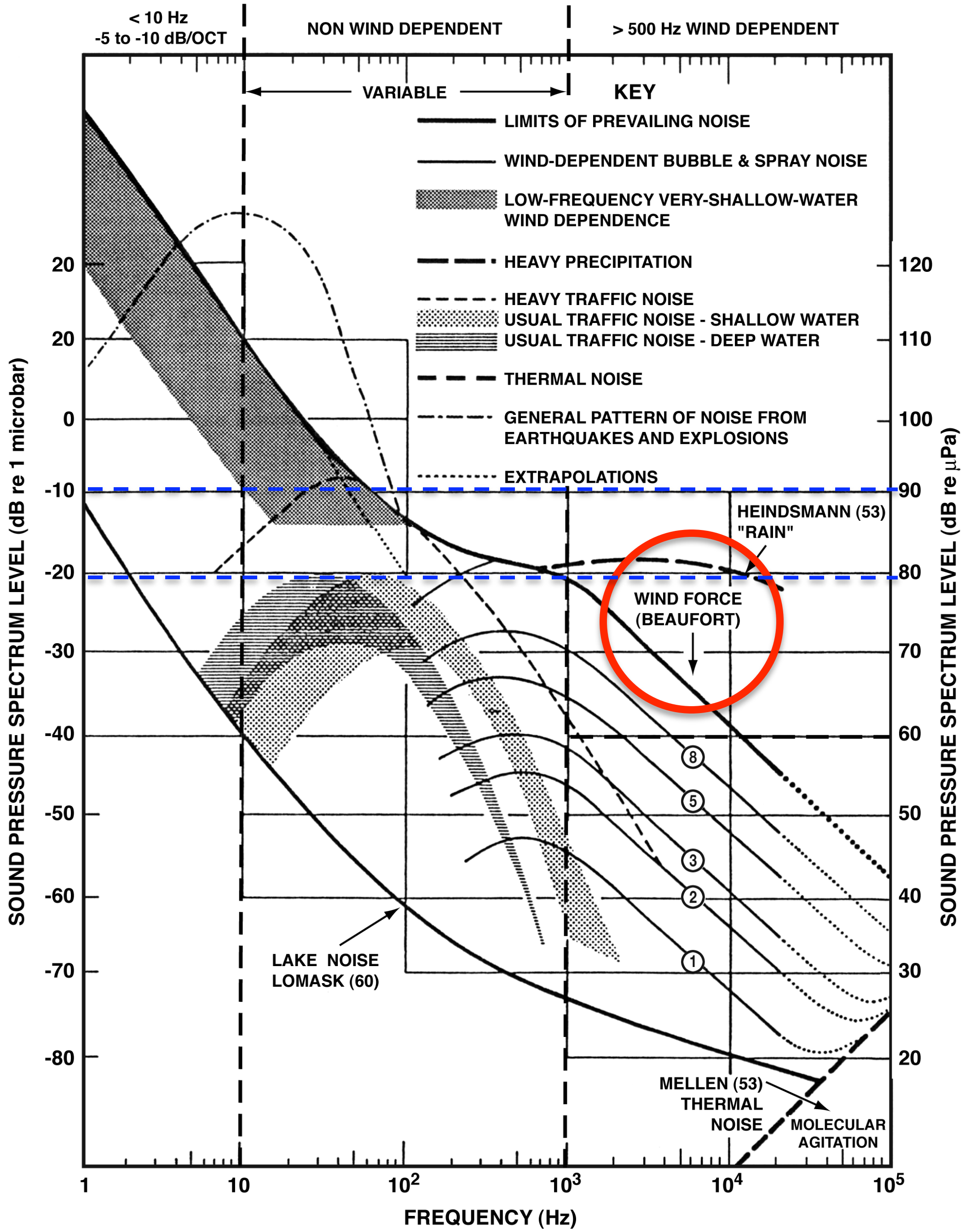
Wenz '62



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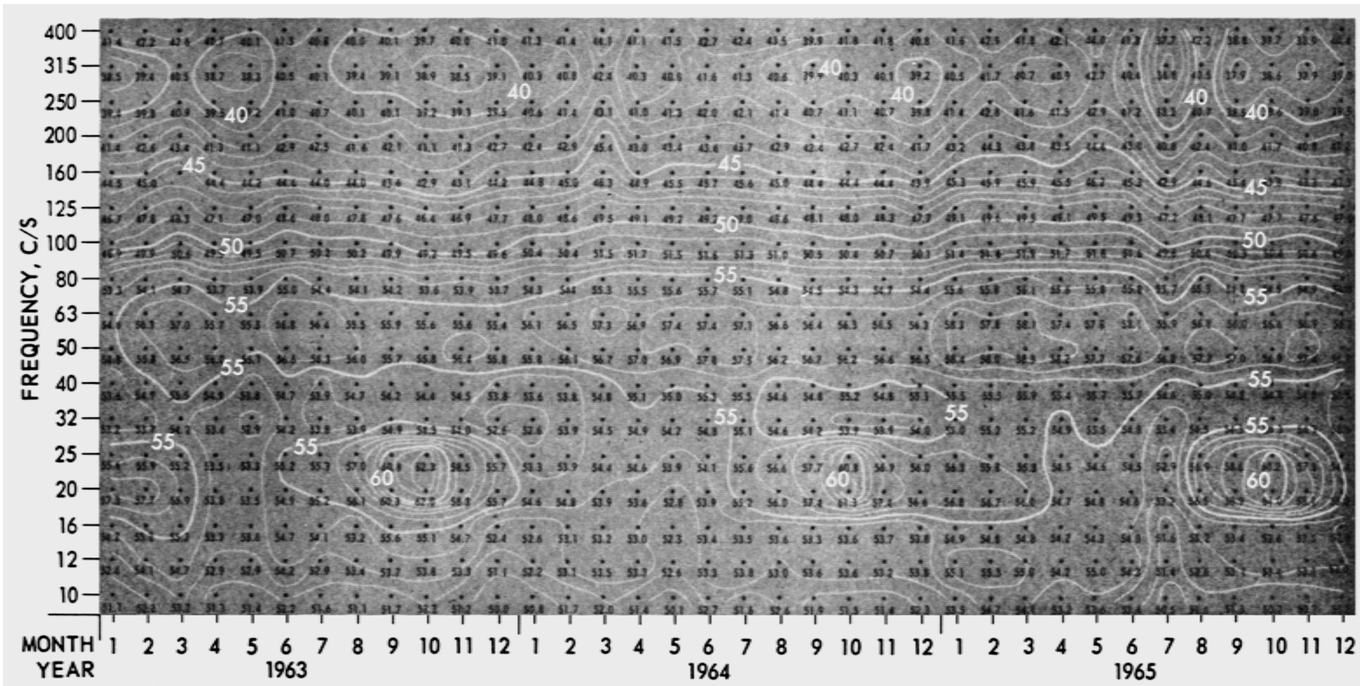
20

Wenz Long Term Observations- Historical Interest



The Beaufort Scale- Wind Speed and Appearance

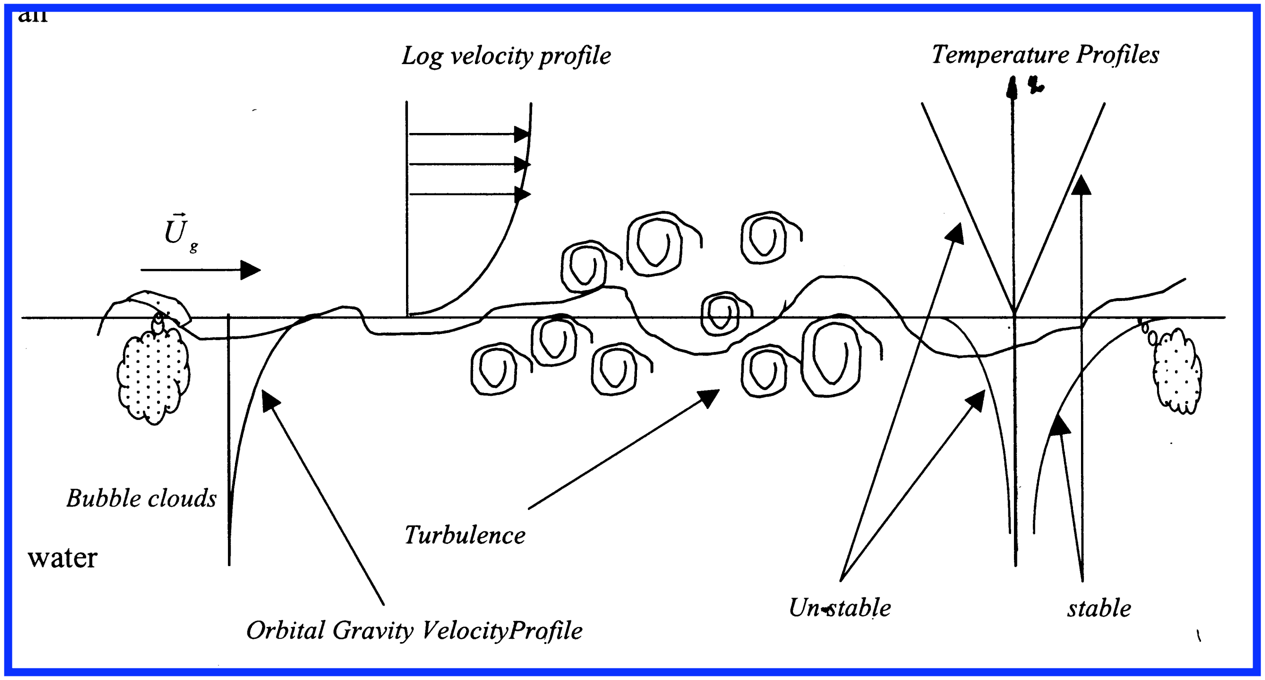
Table I : The Beaufort Scale

Beaufort number	Wind Speed: knots	Wind Speed: mph	Wind Speed: meters per second	Wind Speed: km per hour	Nautical term	U.S. Weather Bureau term	Hydrographic Office: Term and height of waves, in feet	Hydrographic Office: Code	International: Term and height of waves, in feet	International: Code	Estimating wind speed: Effects observed at sea	Estimating wind speed: Effects observed on land
0	under 1	under 1	0.0–0.2	under 1	Calm	Light	Calm, 0	0	Calm, glassy, 0	0	Sea like mirror.	Calm; smoke rises vertically.
1	1–3	1–3	0.3–1.5	1–5	Light air		Smooth, less than 1	1			Ripples with appearance of scales; no foam crests.	Smoke drift indicates wind direction; vanes do not move.
2	4–6	4–7	1.6–3.3	6–11	Light breeze		Slight, 1–3	2	Rippled, 0–1	1	Small wavelets; crests of glassy appearance, not breaking.	Wind felt on face; leaves rustle; vanes begin to move.
3	7–10	8–12	3.4–5.4	12–19	Gentle breeze*	Gentle	Moderate, 3–5	3	Smooth, 1–2	2	Large wavelets; crests begin to break; scattered whitecaps.	Leaves, small twigs in constant motion; light flags extended.
4	11–16	13–18	5.5–7.9	20–28	Moderate breeze	Moderate	Rough, 5–8	4	Slight, 2–4	3	Small waves, becoming longer; numerous whitecaps.	Dust, leaves, and loose paper raised up; small branches move
5	17–21	19–24	8.0–10.7	29–38	Fresh breeze	Fresh			Moderate, 4–8	4	Moderate waves, taking longer form; many whitecaps; some spray.	Small trees in leaf begin to sway.
6	22–27	25–31	10.8–13.8	39–49	Strong breeze	Strong			Rough, 8–13	5	Larger waves forming; whitecaps everywhere; more spray.	Larger branches of trees in motion; whistling heard in wires.
7	28–33	32–38	13.9–17.1	50–61	Moderate gale		Very rough, 8–12	5	Very rough, 13–20	6	Sea heaps up; white foam from breaking waves begins to be blown in streaks.	Whole trees in motion; resistance felt in walking against wind.
8	34–40	39–46	17.2–20.7	62–74	Fresh gale	Gale					Moderately high waves of greater length; edges of crests begin to break into spindrift; foam is blown in well-marked streaks.	Twigs and small branches broken off trees; progress generally impeded.
9	41–47	47–54	20.8–24.4	75–88	Strong gale		High, 12–20	6			High waves; sea begins to roll; dense streaks of foam; spray may reduce visibility.	Slight structural damage occurs; slate blown from roofs.
10	48–55	55–63	24.5–28.4	89–102	Whole gale	Whole gale	Very high, 20–40	7	High, 20–30	7	Very high waves with overhanging crests; sea takes white appearance as foam is blown in very dense streaks; rolling is heavy and visibility reduced.	Seldom experienced on land; trees broken or uprooted; considerable structural damage occurs.
11	56–63	64–72	28.5–32.6	103–117	Storm		Mountainous, 40 and higher	8	Very high, 30–45	8	Exceptionally high waves; sea covered with white foam patches; visibility still more reduced.	
12	64–71	73–82	32.7–36.9	118–133	Hurricane	Hurricane	Confused	9	Phenomenal, over 45	9	Air filled with foam; sea completely white with driving spray; visibility greatly reduced.	Very rarely experienced on land; usually accompanied by widespread damage.
13	72–80	83–92	37.0–41.4	134–149								
14	81–89	93–103	41.5–46.1	150–166								
15	90–99	104–114	46.2–50.9	167–183								
16	100–108	115–125	51.0–56.0	184–201								
17	109–118	126–136	56.1–61.2	202–220								

* Adapted from N. Bowditch (1958 edition), *American Practical Navigator*, U.S. Navy Hydrographic Office Publication No. 9, p. 1059.

† Since January 1, 1955, weather-map symbols have been based upon wind speed in knots, at five-knot intervals, rather than upon Beaufort number.

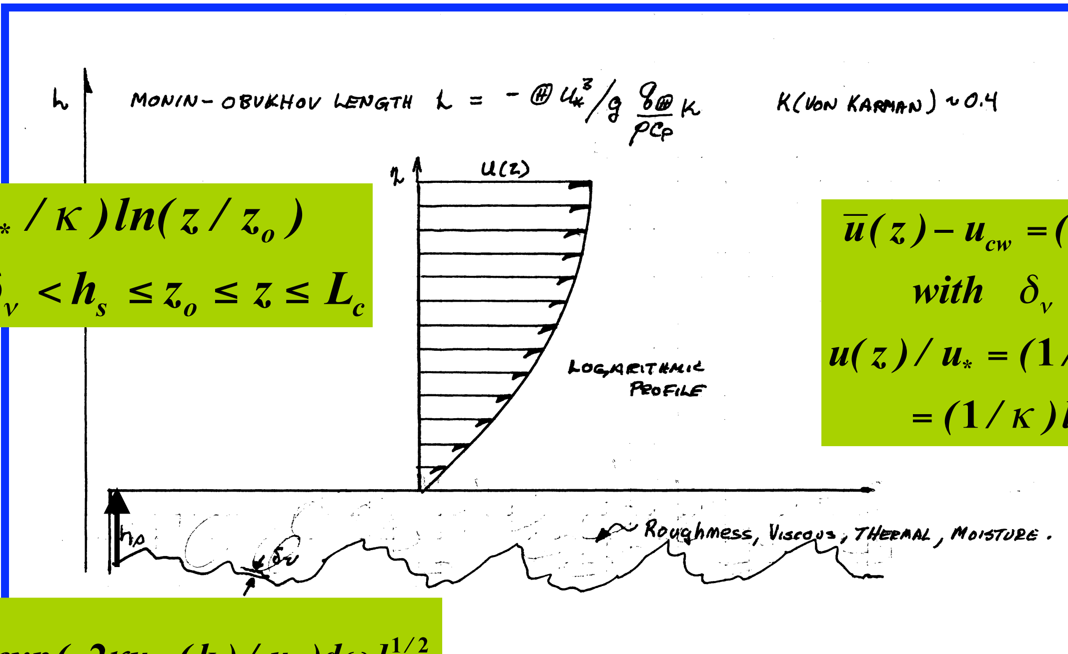
The Air Sea Interaction Zone



A Mass-Momentum-Heat Transfer

Sea Surface Spectrum, Reynolds and Richardson Numbers

The Marine boundary layer for turbulent flow over a rough sea surface



$$\bar{u}(z) = (u_* / \kappa)\, ln(z / z_o)$$
$$with \quad \delta_v < h_s \le z_o \le z \le L_c$$

$$\bar{u}(z) - u_{cw} = (u_* / \kappa)\, ln(z / z_o)$$
$$with \quad \delta_v < h_s \le z_o \le z \le L_c$$
$$u(z) / u_* = (1/\kappa)\, ln(z / z_o) + u_{cw} / u_*$$
$$= (1/\kappa)\, ln(z / h_s \, exp(-\kappa u_{cw} / u_*))$$

$$h_s \simeq [2\int_o^\infty S(k)\, exp(-2\kappa u_{cw}(k) / u_*)\, d\omega]^{1/2}$$

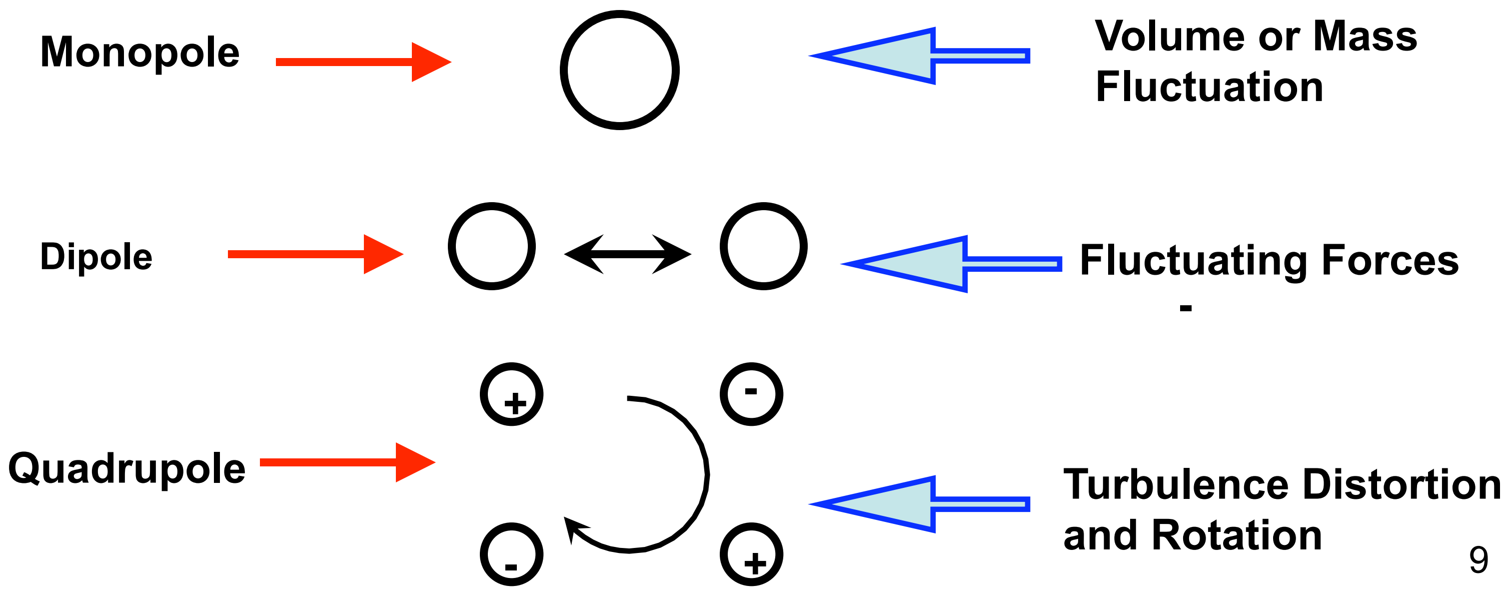
$$C_u[z / h_s, R_i, R_{es}] = [ln(z / z_o) / \kappa]^{-2}$$
$$C_\Theta = C_u[z / h_s, R_i, R_{es}] / [1 + C_u^{1/2}\delta\tilde{\Theta}]$$
$$C_{me} = C_u[z / h_s, R_i, R_{es}] / [1 + C_u^{1/2}\delta\tilde{m}_e]$$
$$C_u \cong C_\Theta \cong C_{me} \qquad z_o \le z \le |L|.$$

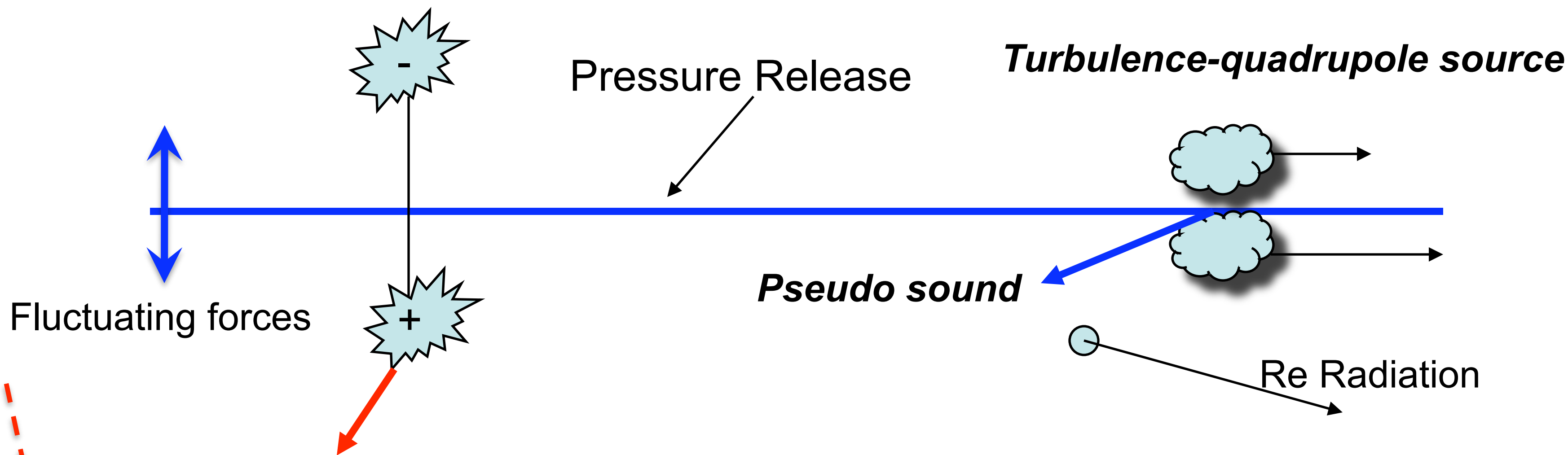
Fundamental Noise Sources

Order o Monopole $\partial^{o} g/\partial x_{oi}^{0}$ with efficiency $\eta_{rad} = (ka)$

Order 1 Dipole $\partial g/\partial x_{oi}$ with efficiency $\eta_{rad} = (ka)^{3}$

Order 2 Quadrupole $\partial^{2} g/\partial x_{oi}\partial x_{oj}$ with efficiency $\eta_{rad} = (ka)^{5}$





Compact Radiators = Monopole+ dipole + quadrupole+…….

Pressure Release Surface

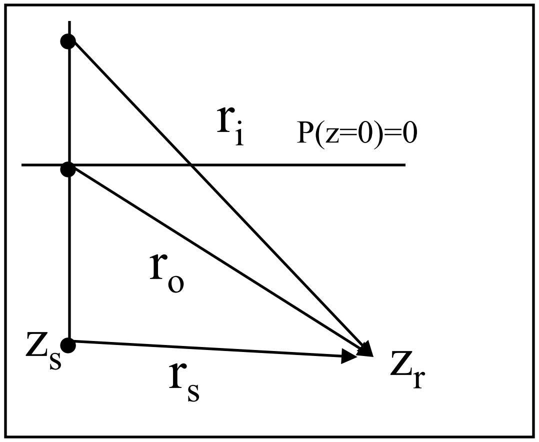
Monopole → ***Dipole***

Dipole → ***Quadrupole (not observed at distance)***

Quadrupoles → ***Octopoles (not observed at distance)***

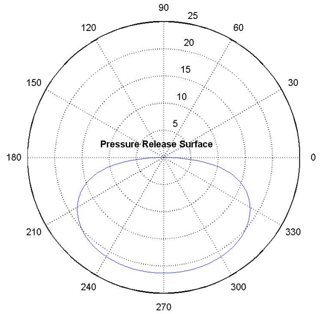
Major Sources are Monopoles (Bubble, Bubble Clouds) below the Pressure release surface or Dipoles sources in the surface(impacts from splash, spray, rain drops).

The pressure release surface with the monopole and it's image.

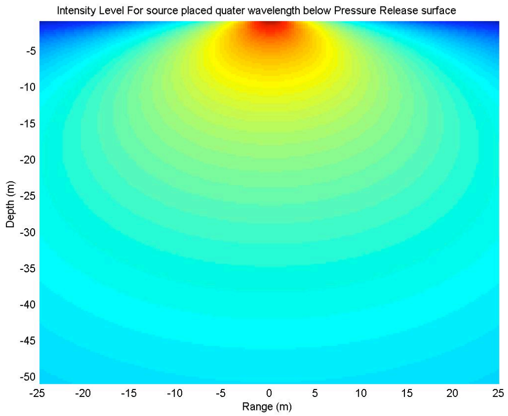


- ***The pressure at r due to the source and image***

$$\sin(\theta) = z_r / r_o \;\; ; \;\; r_o \cong r \cong r_i$$



$$P(r_o)/P_o = \exp(i\vec{k} \cdot \vec{r}_s)/r_s + \mu \exp(i\vec{k} \cdot \vec{r}_i)/r_i$$

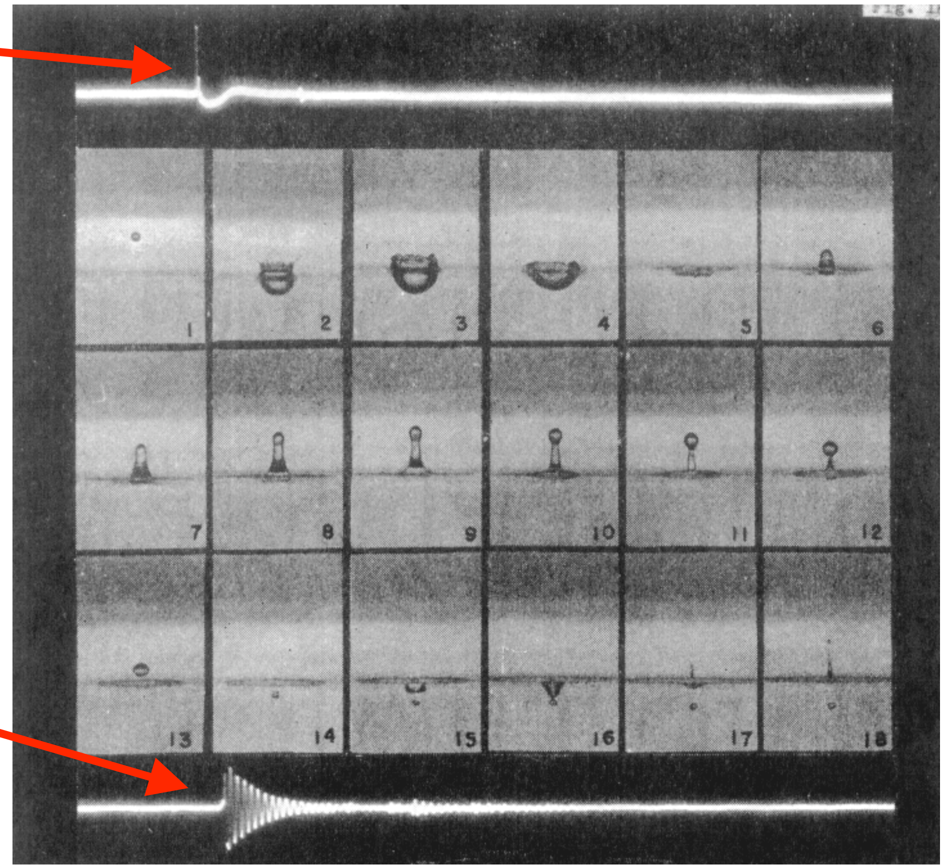


$$\rightarrow \mu = -1; z_s / \lambda < 1/4 \rightarrow \left| P(r_o)/P \right|^2$$

$$= 4\left(2\pi z_s / \lambda\right)^2 \sin(\theta)^2$$

Drop Impact-Dipole

Transient Bubble Oscillation-Monopole



The sequence of events of a liquid drop impinging on a water surface is shown by a series of photographs every 13 ms. Also shown is the corresponding oscilloscope trace of the impact, frames 1-2, The dampened sinusoid due to the bubble, frames 13-14, and the subsurface bubble frames 14-18. The radius of the droplet was 0.24 cm, the mass 56 g, and the droplet speed 350cm/s.

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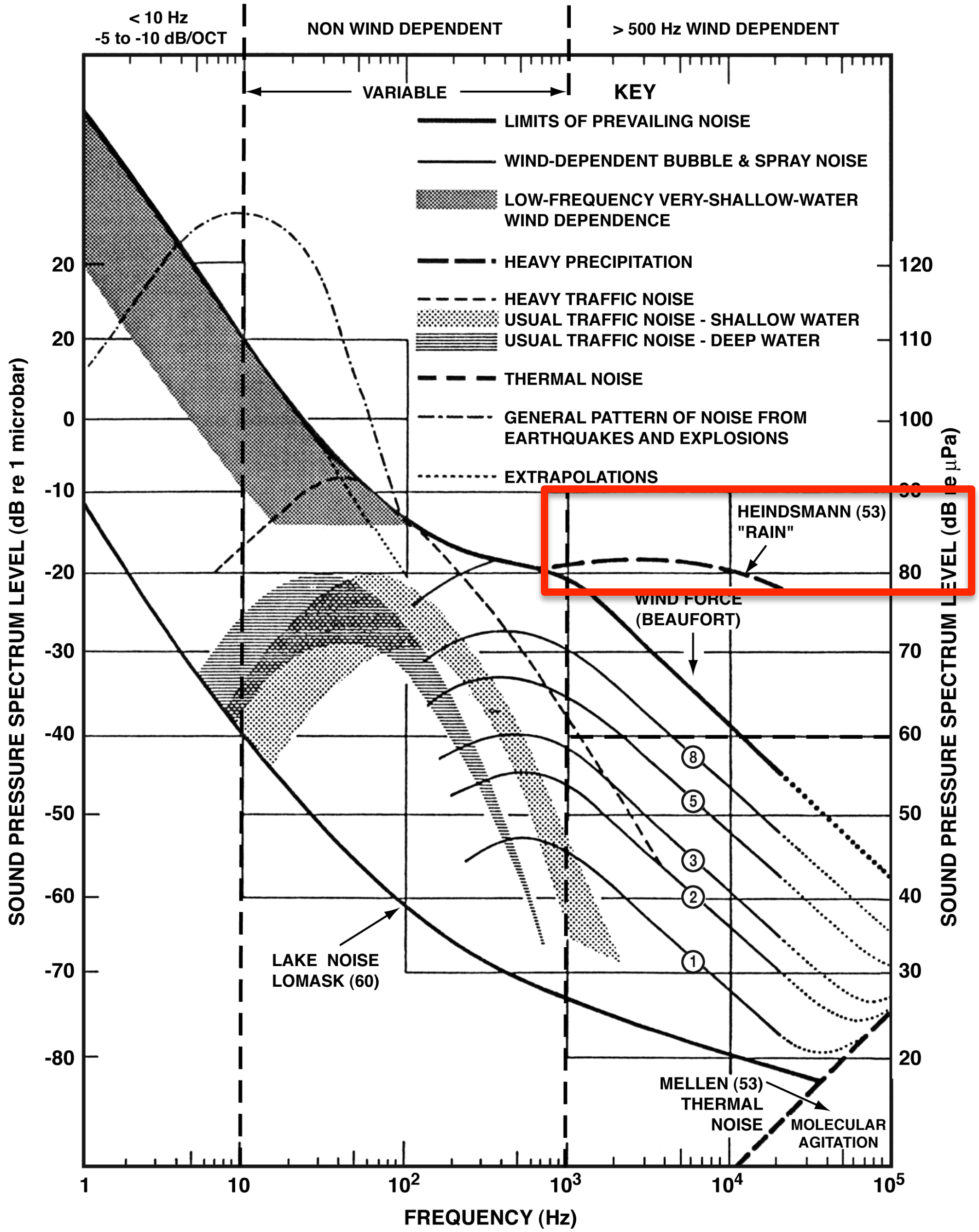

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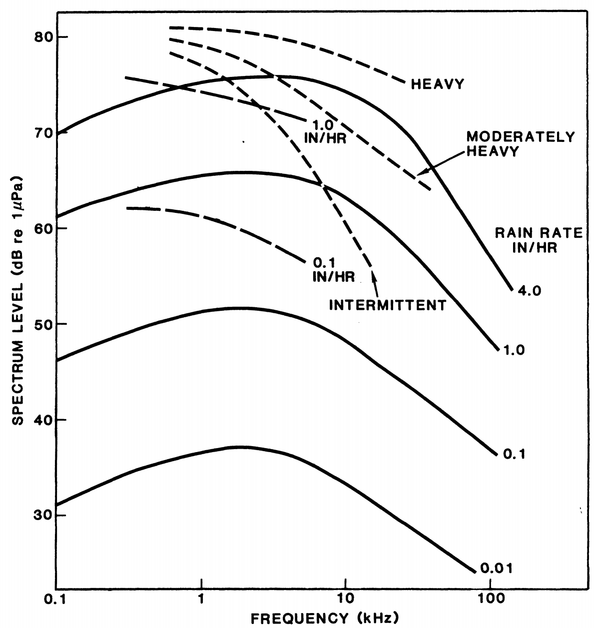
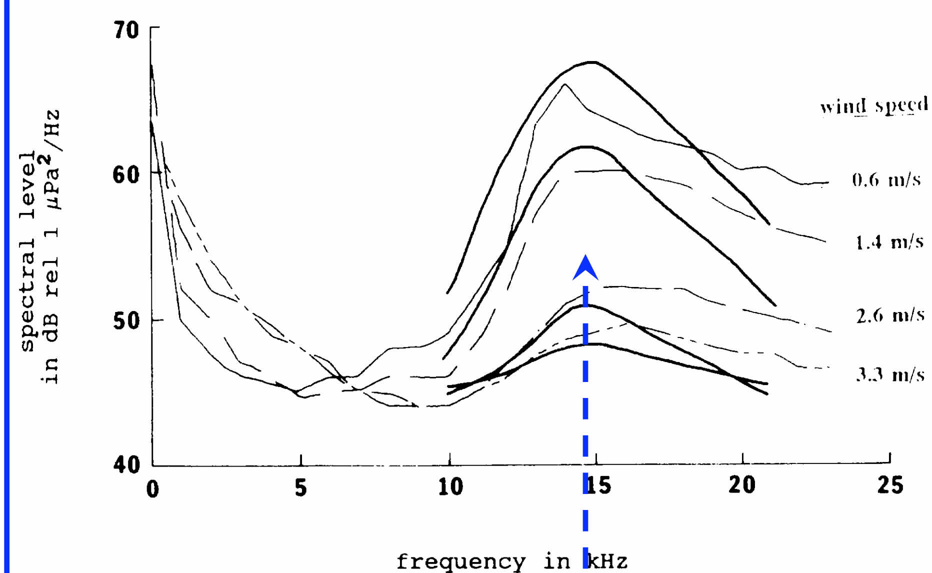
60
50
40
30
20
1
10
10^2
10^3
10^4
10^5
FREQUENCY (Hz)

Impact and Entrained Bubble Oscillation Noise





Rain Noise with Impact and Entrained Bubble Oscillation

Light Rain on a Pond or Lake Entrained Bubble Oscillation

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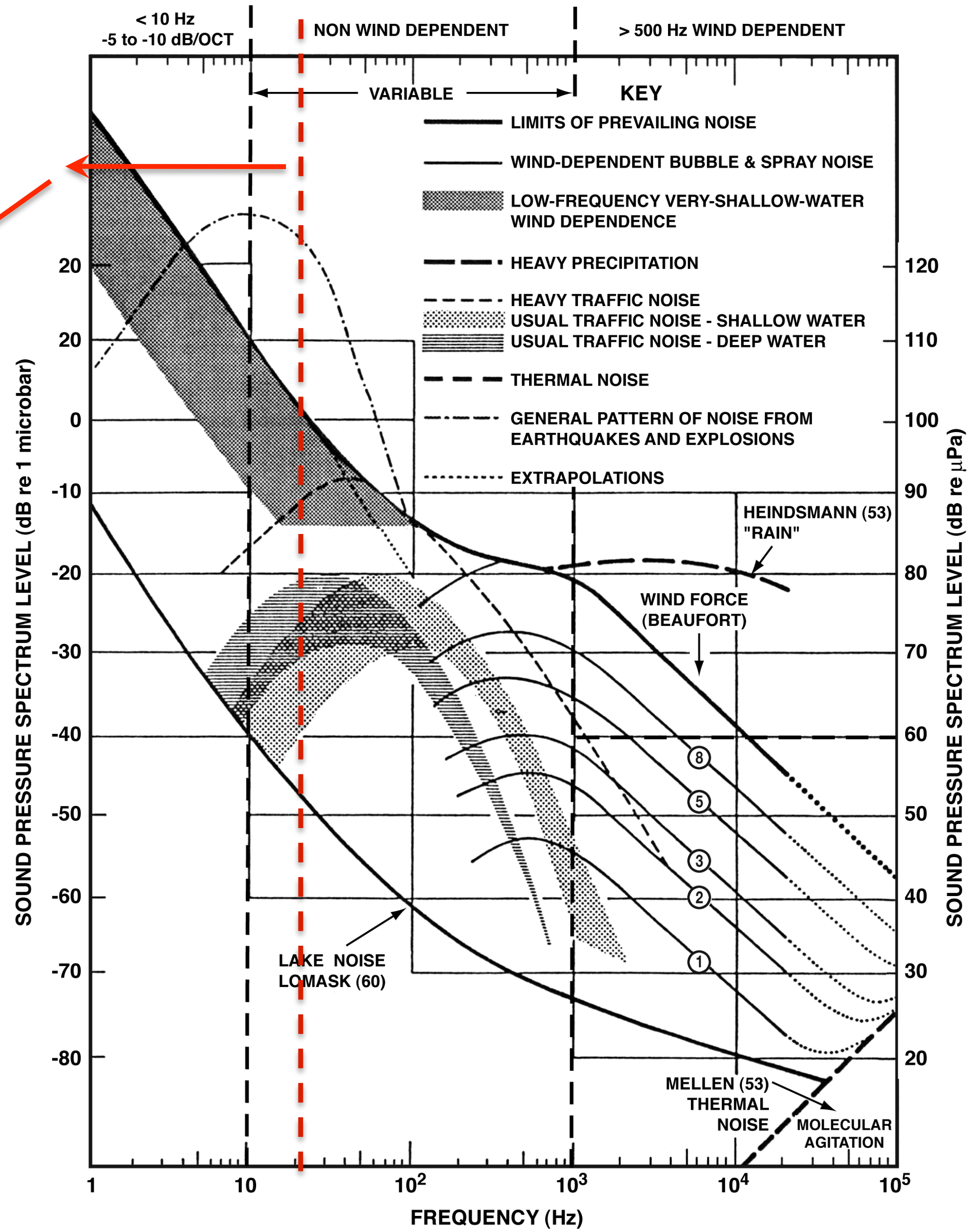
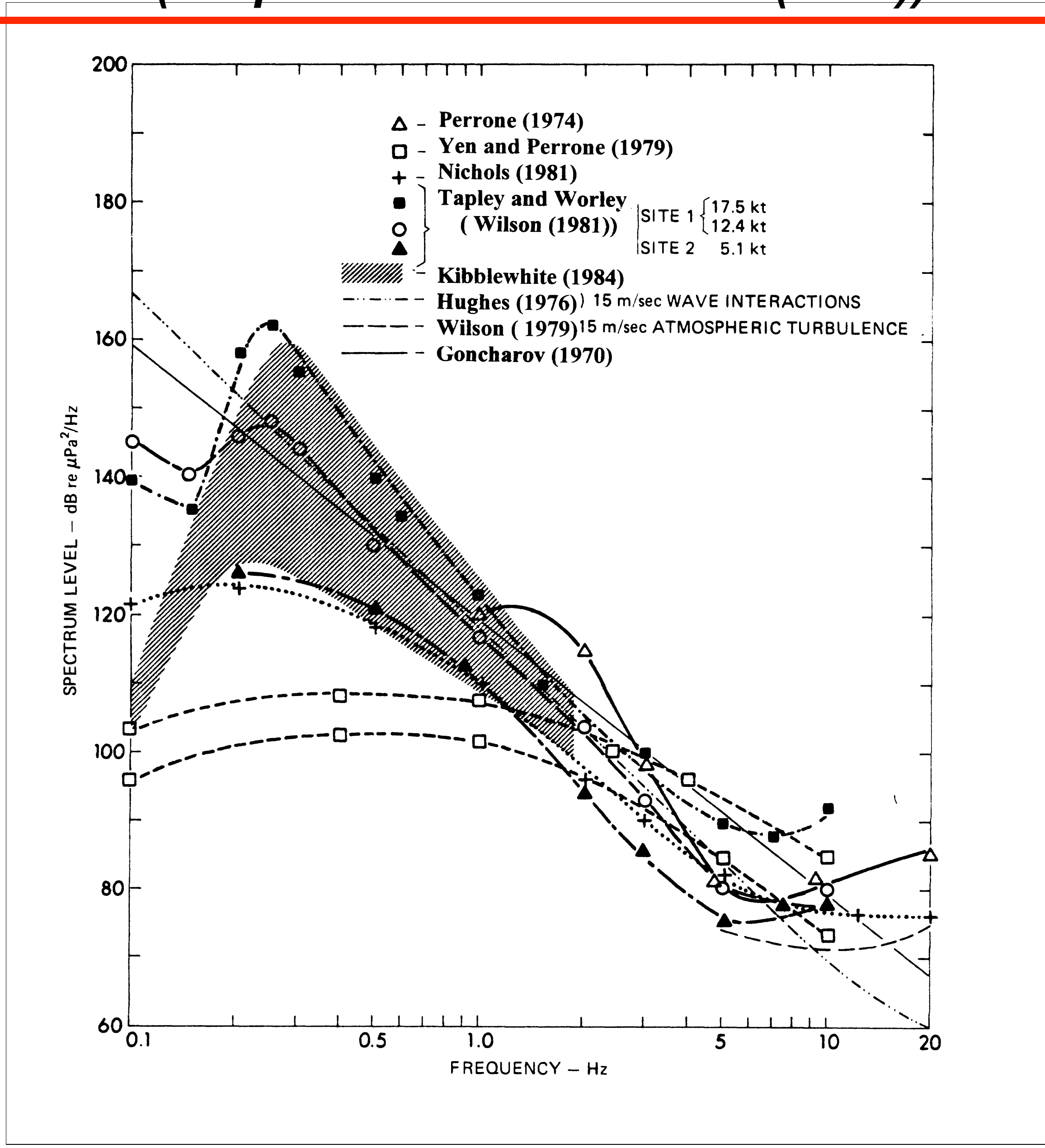
Kibblewhite (1984



Frequency Ranges
0.2-2.0 Hz infrasonic, ULF
2.0-20 Hz infrasonic, VLF
20-200 Hz sonic, LF
200-2 kHz sonic, MF
2-20 kHz sonic, HF
20-200 kHz ultrasonic, VHF
0.2-2 MHz ultrasonic, UHF

A Summary of Infrasonic measurements and theoretical estimates (adapted from Kibblewhite (1984)).



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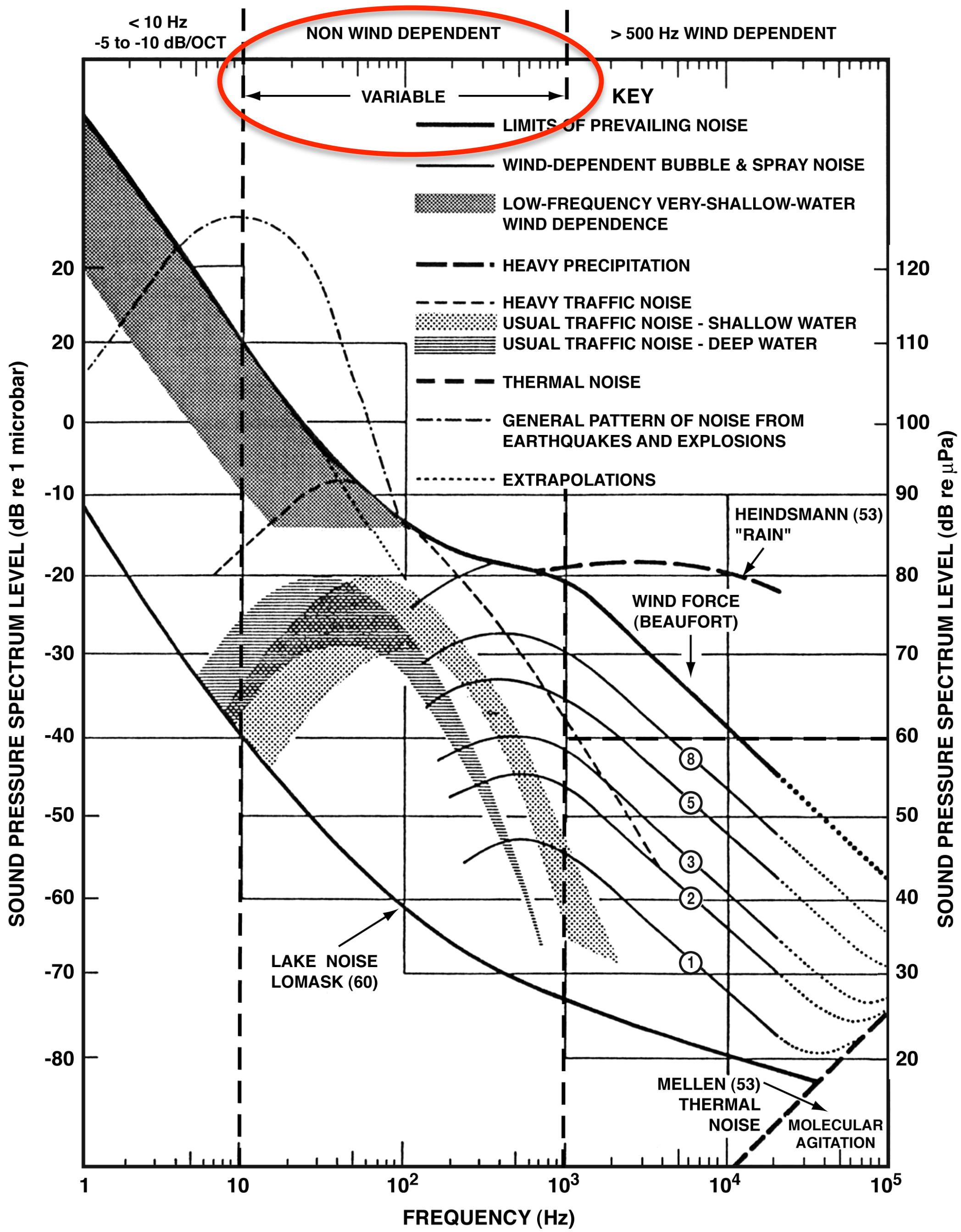

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10^2
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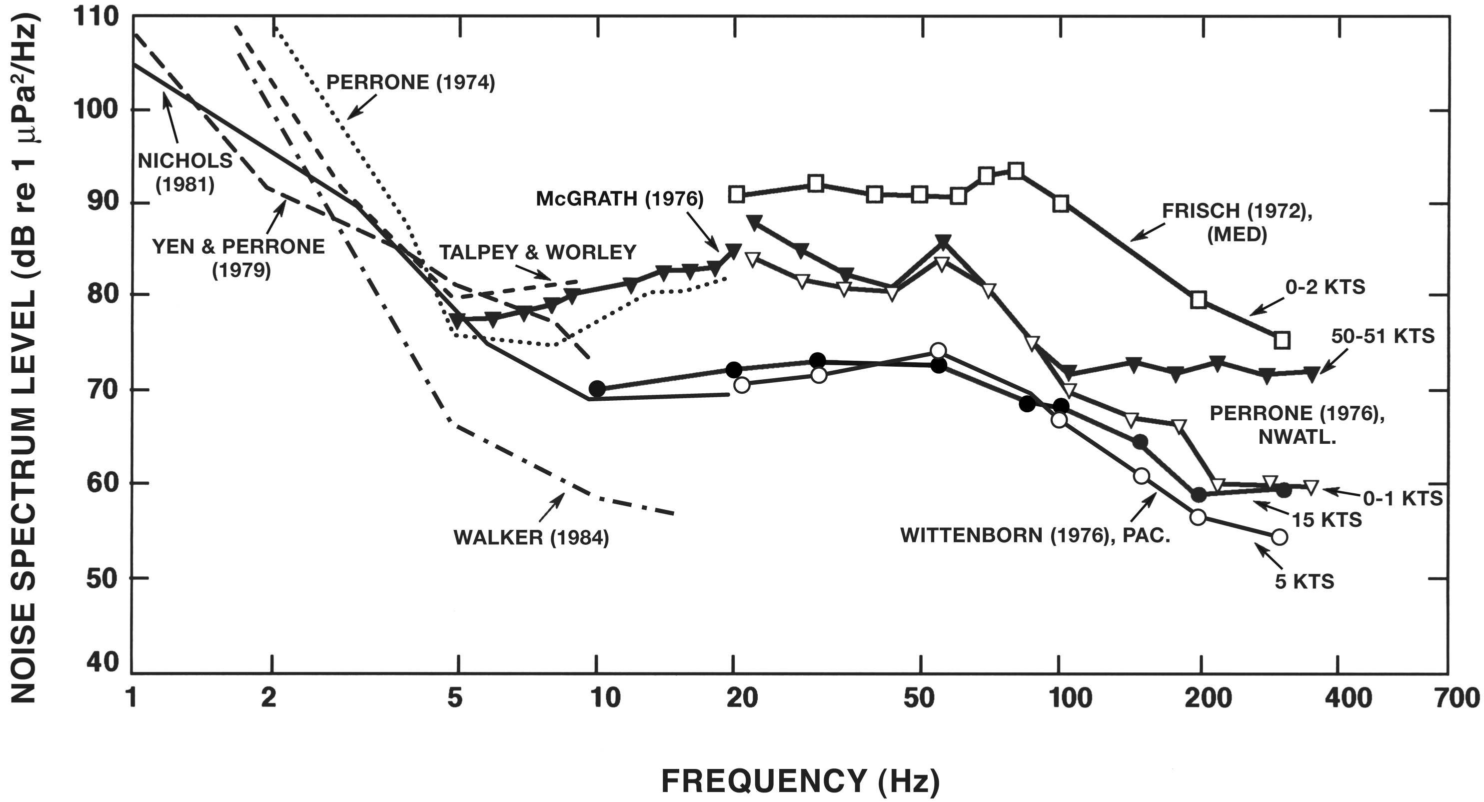
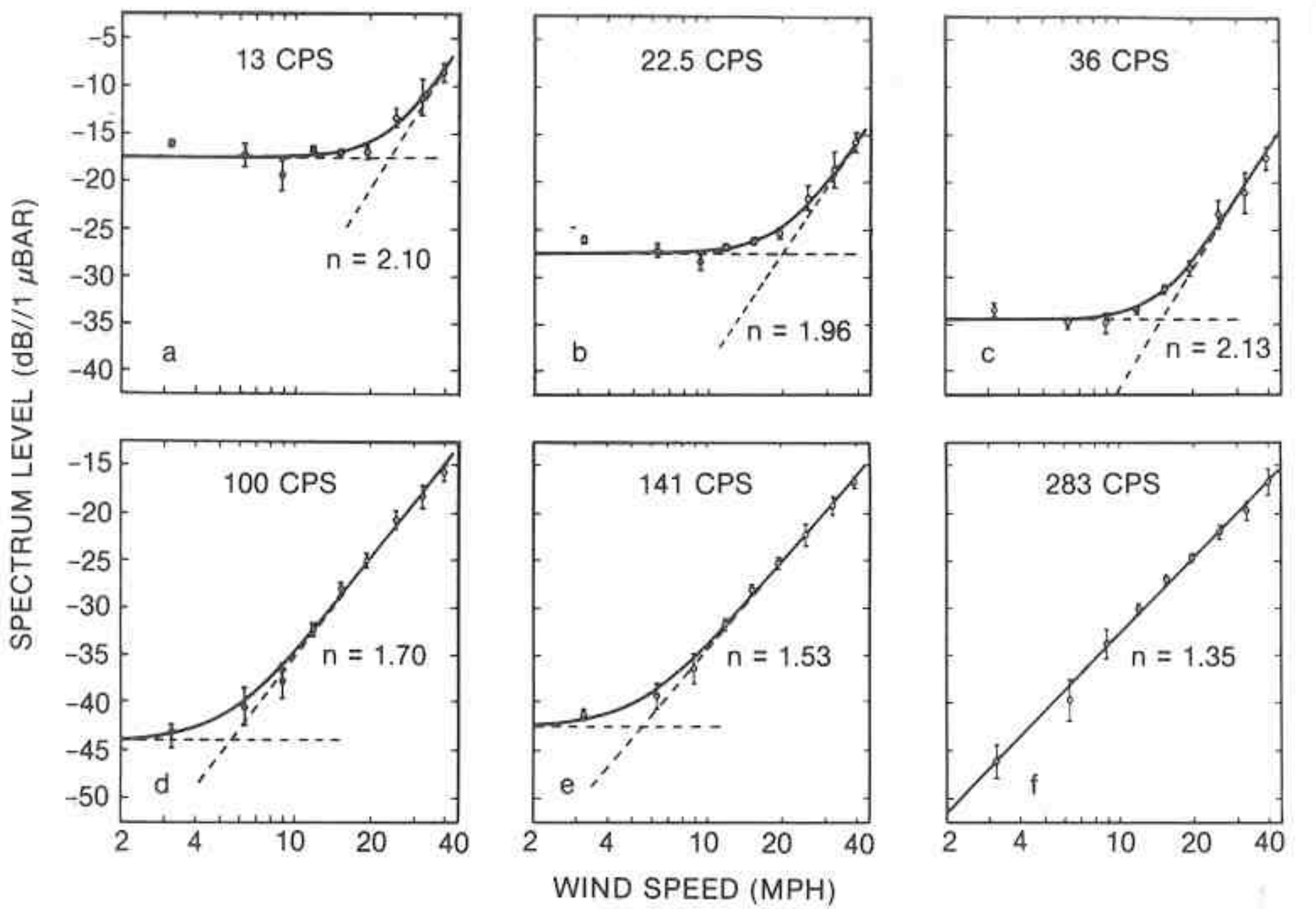
10^4
10^5
FREQUENCY (Hz)

A comparison of Noise Spectrum Levels in the frequency range from 1 Hz to 400 Hz in several ocean basins.

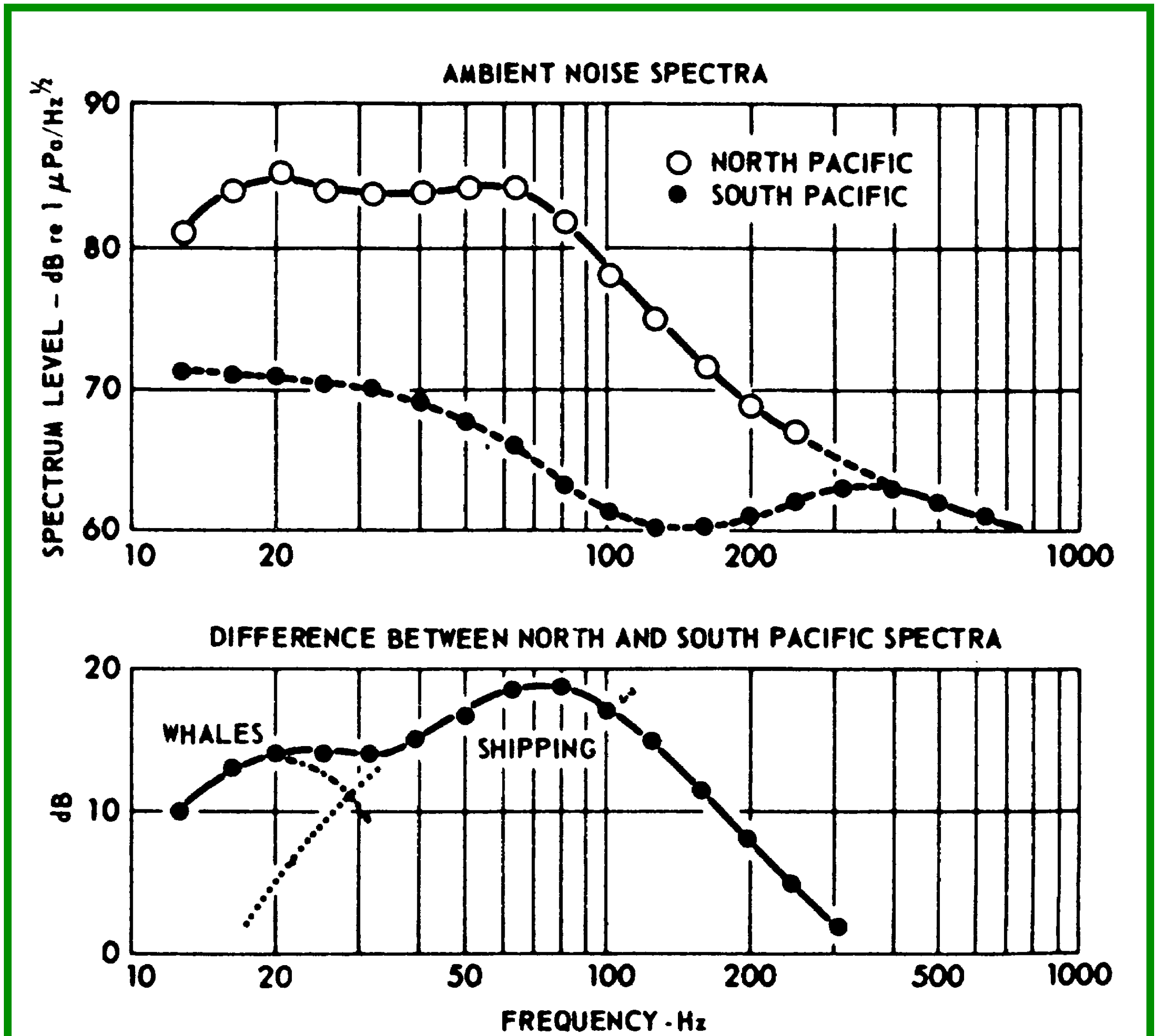


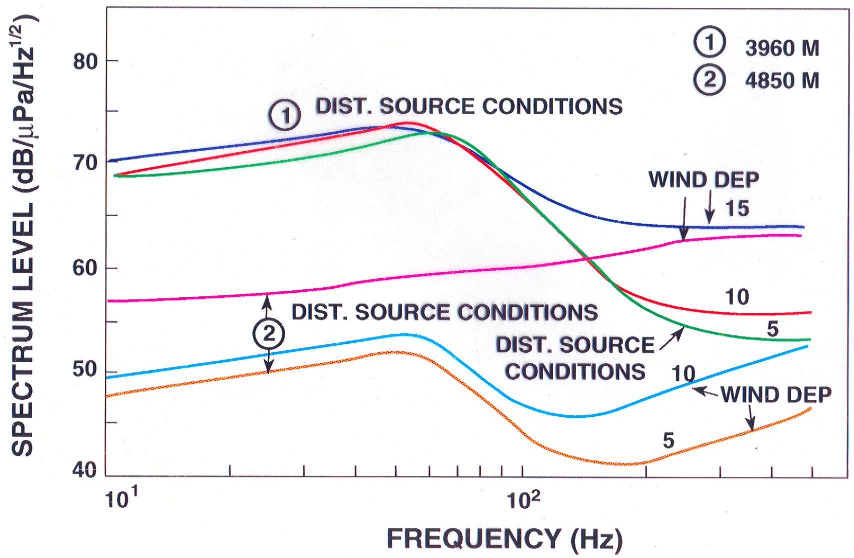
Noise from ships dominates at the lower frequencies!

Frequency dependent WS characteristic is shown for several frequencies. The horizontal lines, no WS dependence, at lower frequencies and low WS show the limiting effect of noise from distant shipping. (Piggott (1964))



The Noise Spectrum Level with and without shipping noise



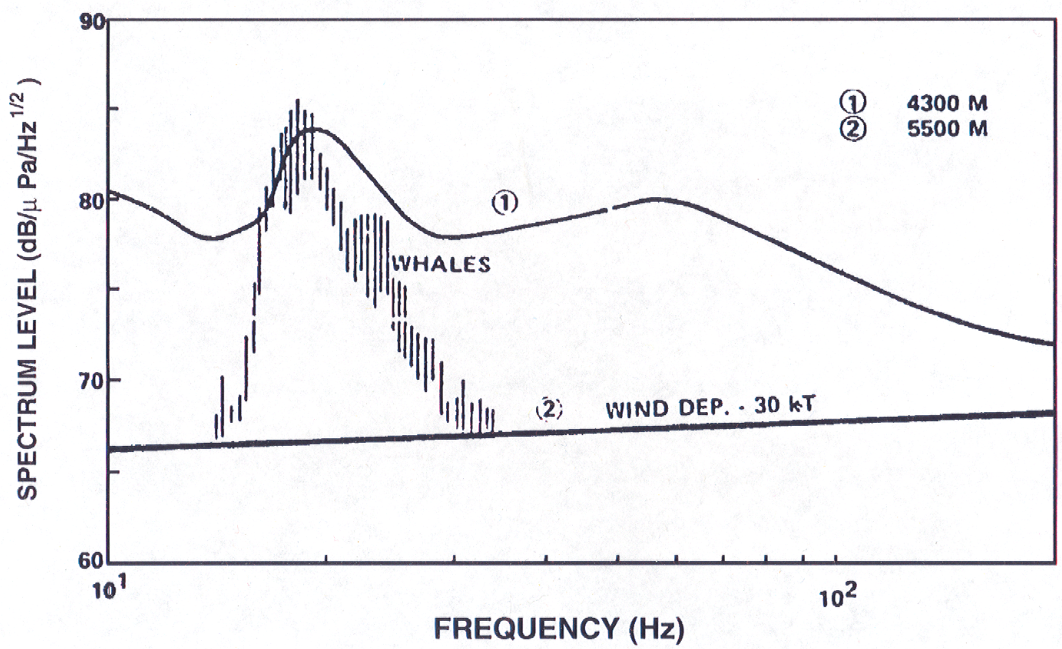


Ambient Noise:

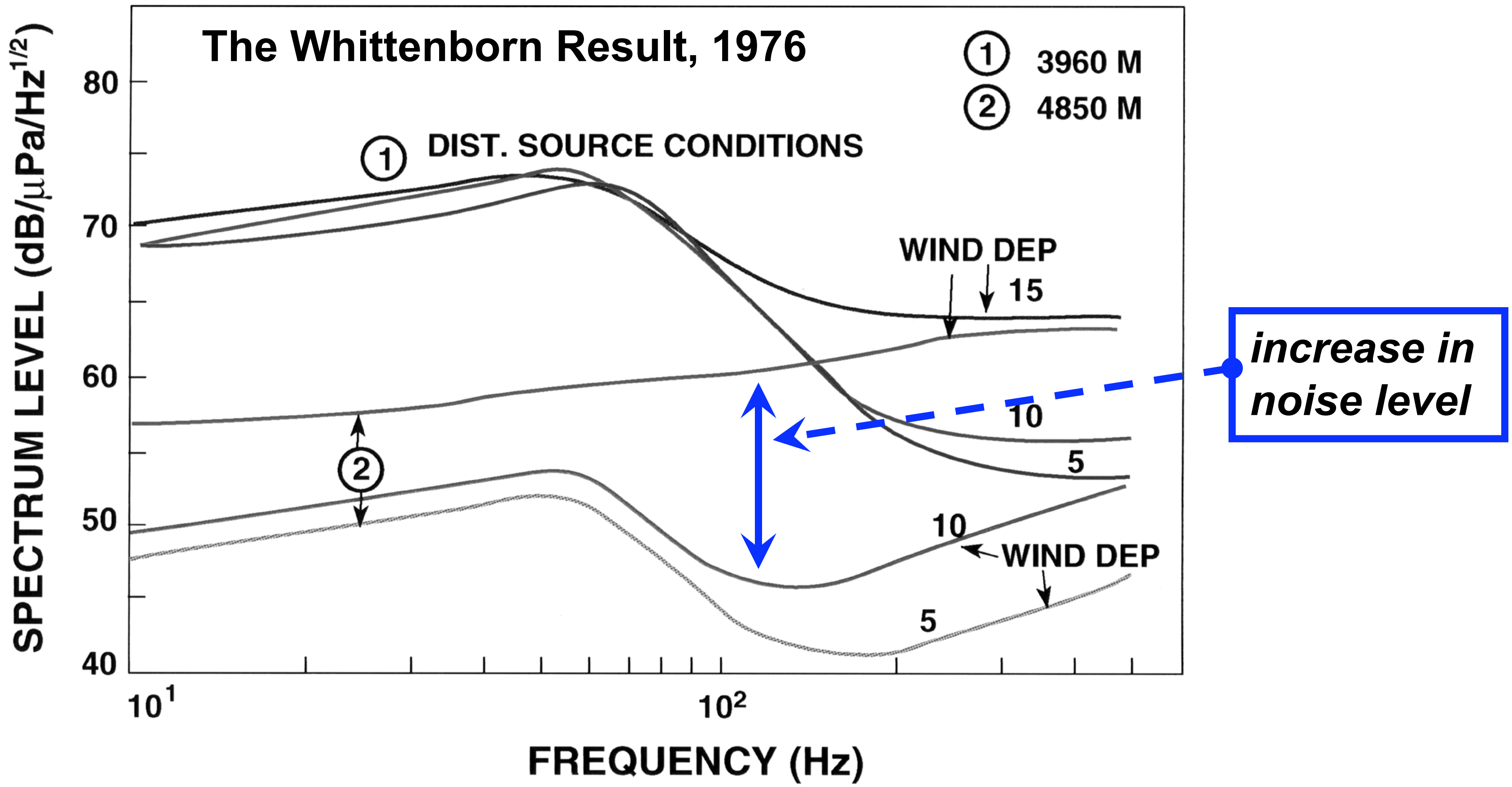
Wind

Shipping

Whales !



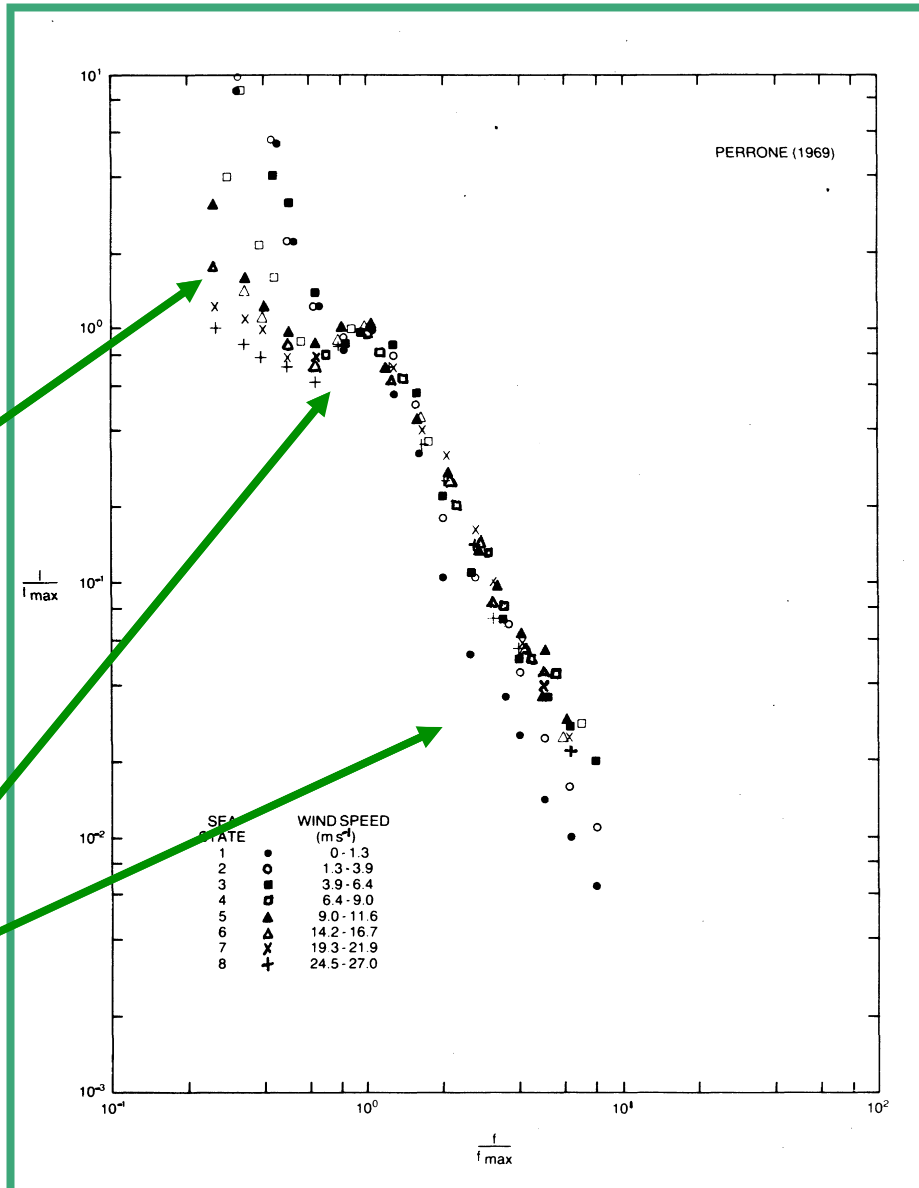
The Noise Spectrum Level from 1 Hz to 500 Hz for a near bottom hydrophone showing the increase in noise level with wave breaking.

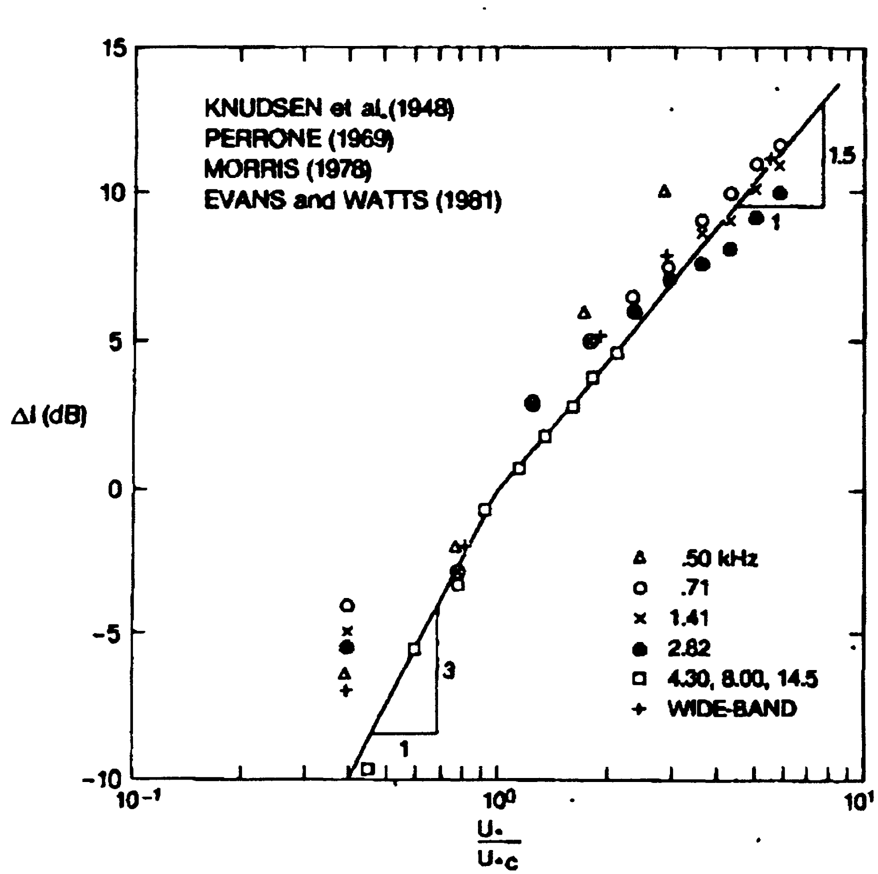


Relative noise intensity versus relative frequency for the results of Perrone (1969) [Kerman (1984)] for a variety of wind speeds.

Note Low Frequency Variability

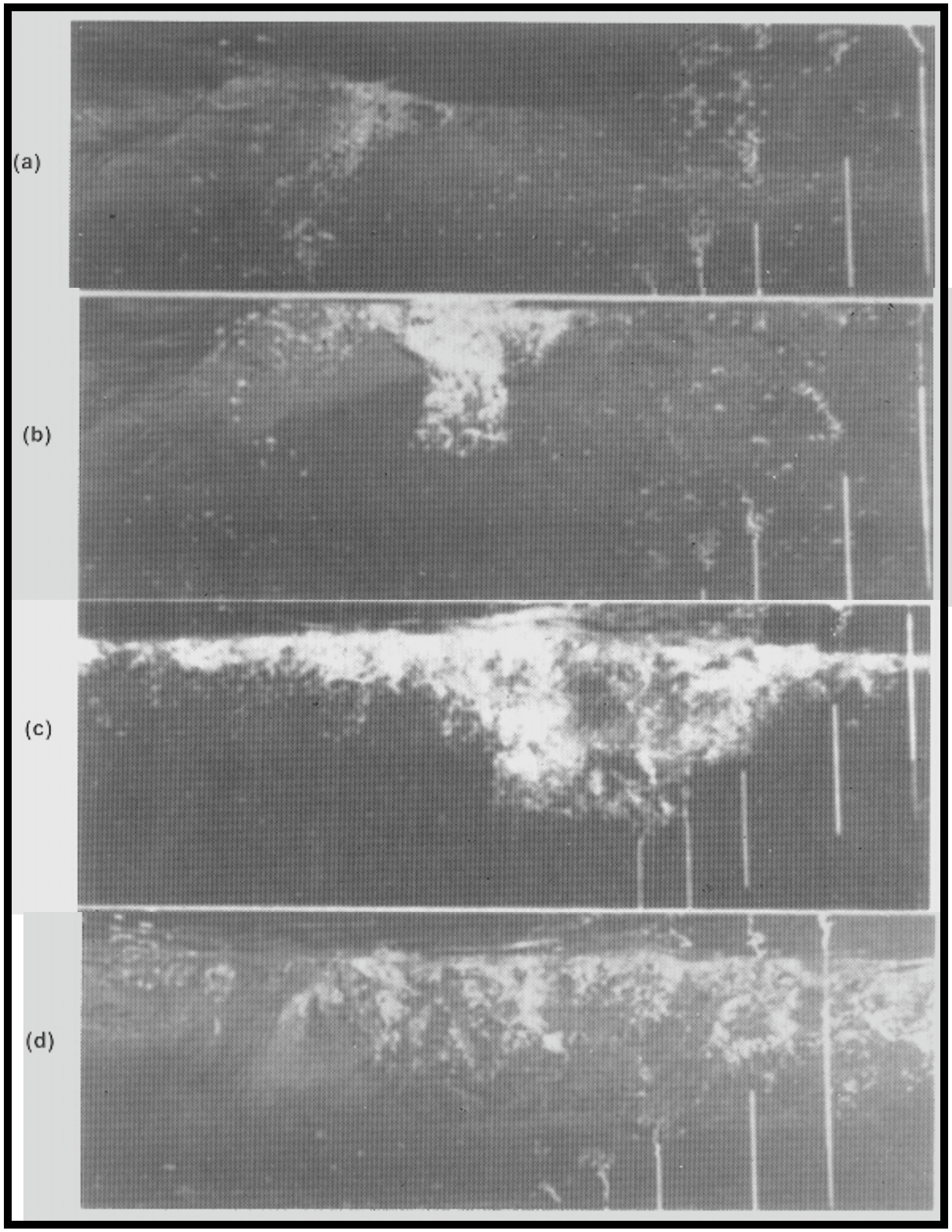
Note Similar Processes





The change in intensity level as a function of normalized friction velocity. Prior to the critical friction velocity there is one wind dependence and for friction velocities greater than critical another. The critical friction velocity is determinative of wave breaking.

Breaking waves produce microbubble clouds



Three-dimensional crescent shaped breakers that resemble deep water oceanic breakers are viewed in 2 second intervals from under the breaking wave. The vertical strings are spaced at 30.5 cm intervals and have 15.3white and black sections. The wave steepness, the initial amplitude ao times the initial wave number ko is 0.33.

Thorp, Nature 1980, Phil. Trans. R.S. 1982

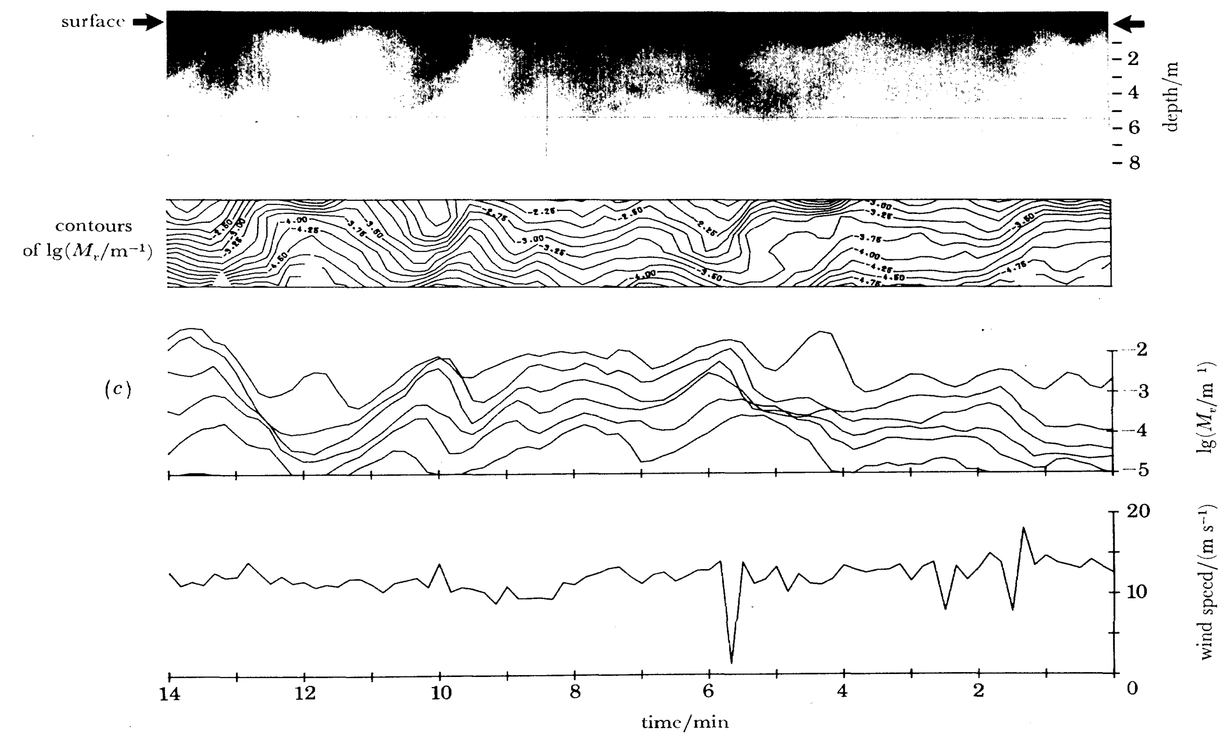


FIGURE 13. Sonagraph, M_v, and wind records from Oban in (a), (c) northeasterly and (b) northwesterly winds: (a) $\Delta\theta = -2.0$ K; (b) $\Delta\theta = -1.8$ K; (c) $\Delta\theta = -3.4$ K. The low value of wind speed at about 5.7 min is due to a fault in the anemometer.

Thorp clearly showed the presence of "bubble Clouds" . But, what were the volume fractions and size distributions near the surface?

THE FUNDAMENTAL QUESTION AND HYPOTHESIS

- **Question:**

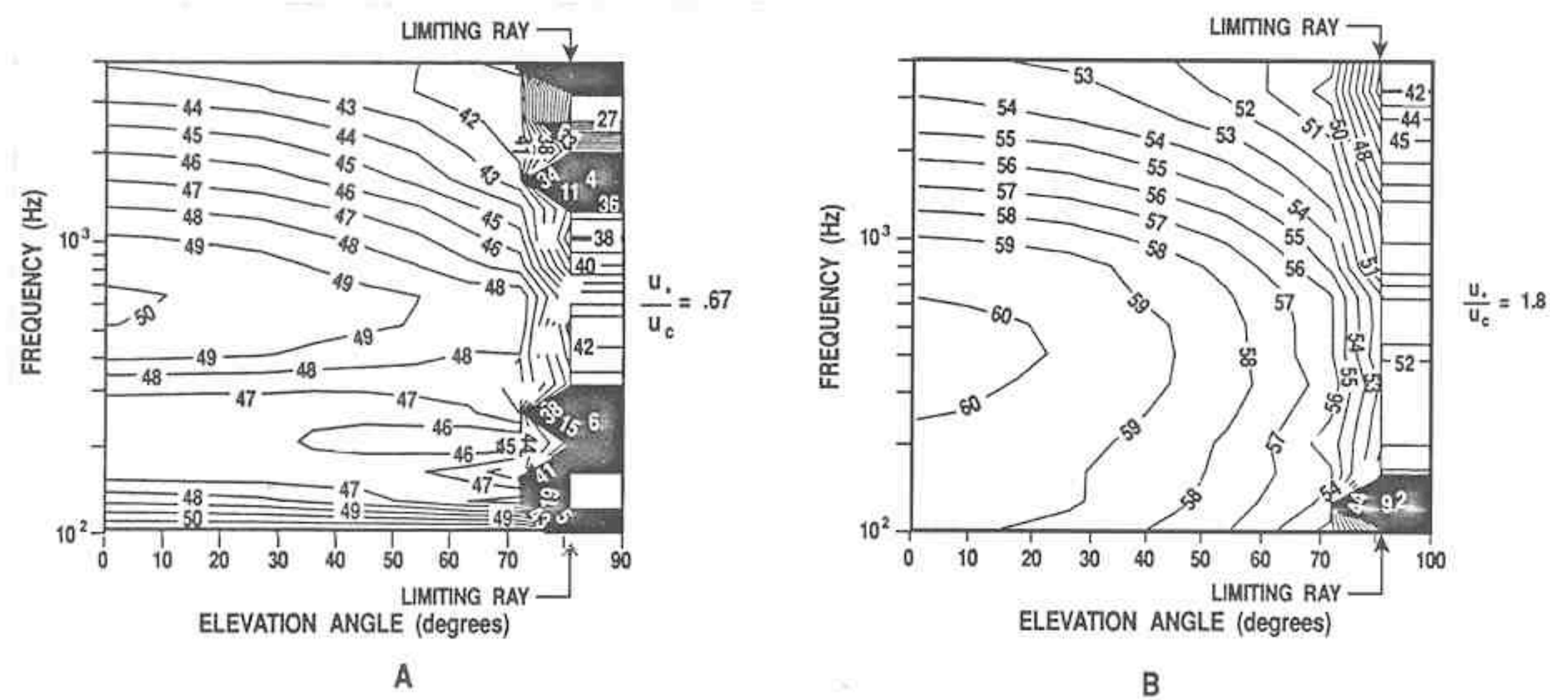
Since micro bubble plumes, clouds and layers are produced when waves break and are convected to depth;

What role, if any, is played by these micro bubble distributions in the production, scattering , and absorption of sound near the sea surface at the low,20Hz, to mid, 2kHz, frequencies?

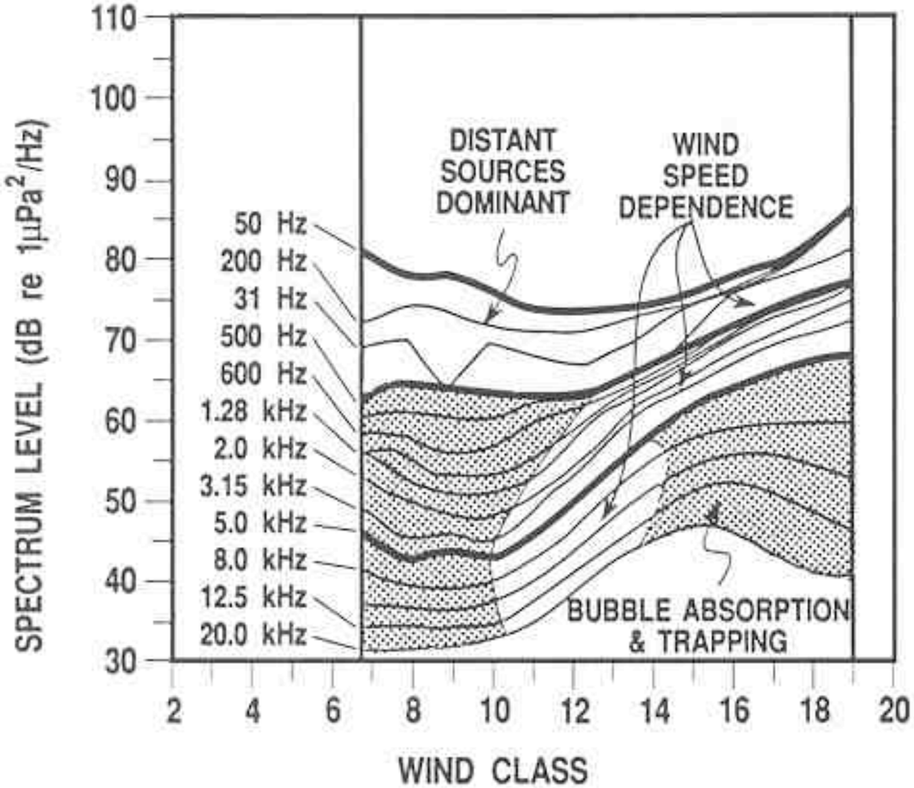
- **Hypothesis:**

If micro bubble plumes with volume fractions of 10^{-4} to 10^{-2} act as collective resonant oscillators, then sound can be produced and scattering can occur with little Doppler shift but ample Doppler spread.

$$N(\theta) = dI/d\Omega = DPWg(\theta')\exp(-2\alpha r)/\cos\theta'(1-\beta\gamma\exp(-4\alpha r)),$$



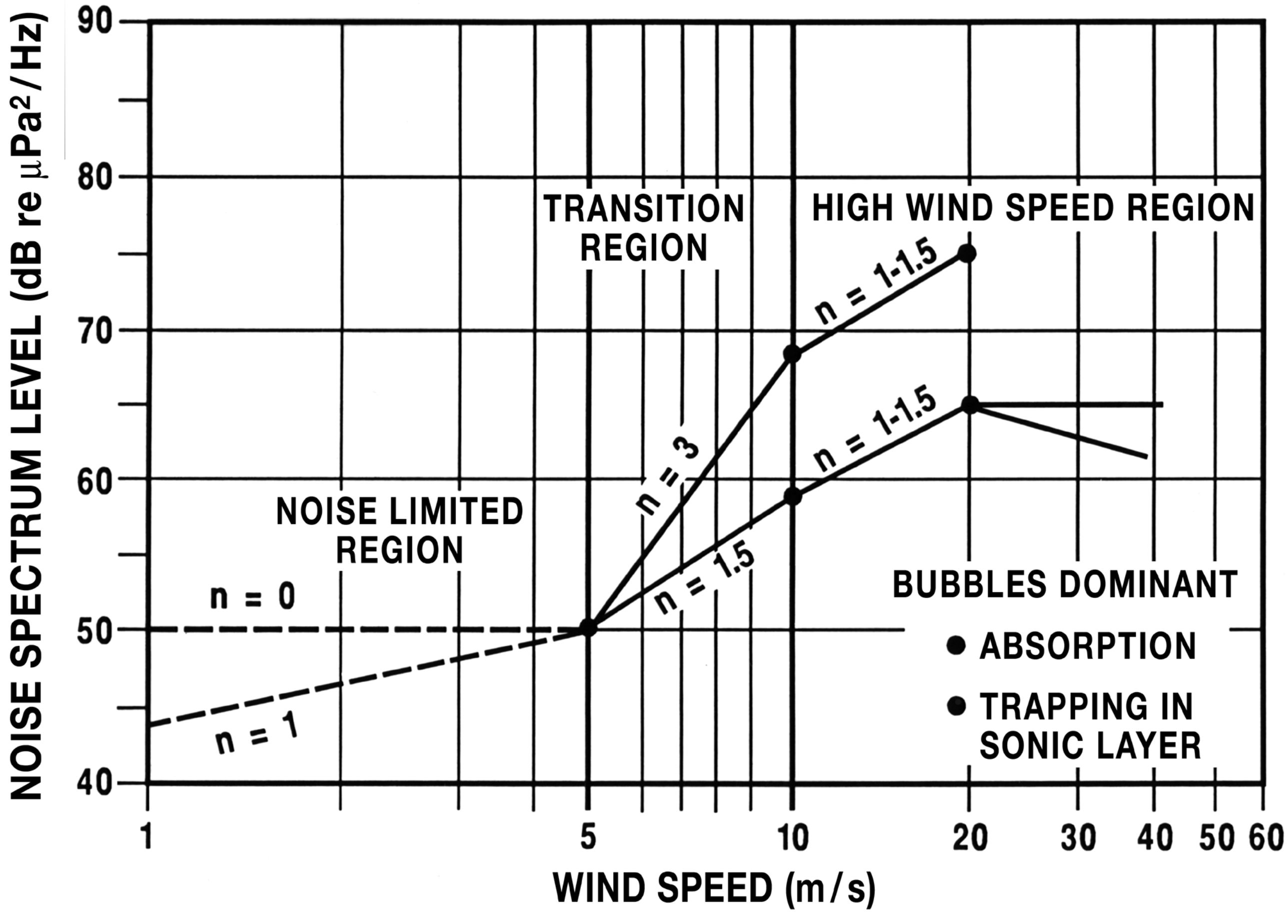
Estimated noise spectrum level vs elevation angle as estimated by Kennedy (1990) for before wave breaking and after wave breaking.



WIND CLASS	WIND SPEED
7	1.6 - 2m/s
8	2 - 2.5m/s
9	2.5 - 3.15
10	3.15 - 4
11	4 - 5
12	5 - 6.25
13	6.25 - 8
14	8 - 10
15	10 - 12.5
16	12.5 - 16
17	16 - 20
18	20 - 25
19	25 - 31.5
20	31.5 - 40

WD = 30m
WSH = 46m

Spectrum level of ambient noise vs wind speed class in the North Sea as measured by Wille (1984). These spectra show the general wind speed dependency of ambient noise.



Wind speed dependency (n(f)) vs wind speed for frequency <20 kHz. Three regions are identified; a noise limited region, a transition region, and a high wind speed region.

The wind stress coefficient ,the estimated friction velocity, u_*, wind speed, and white cap index.

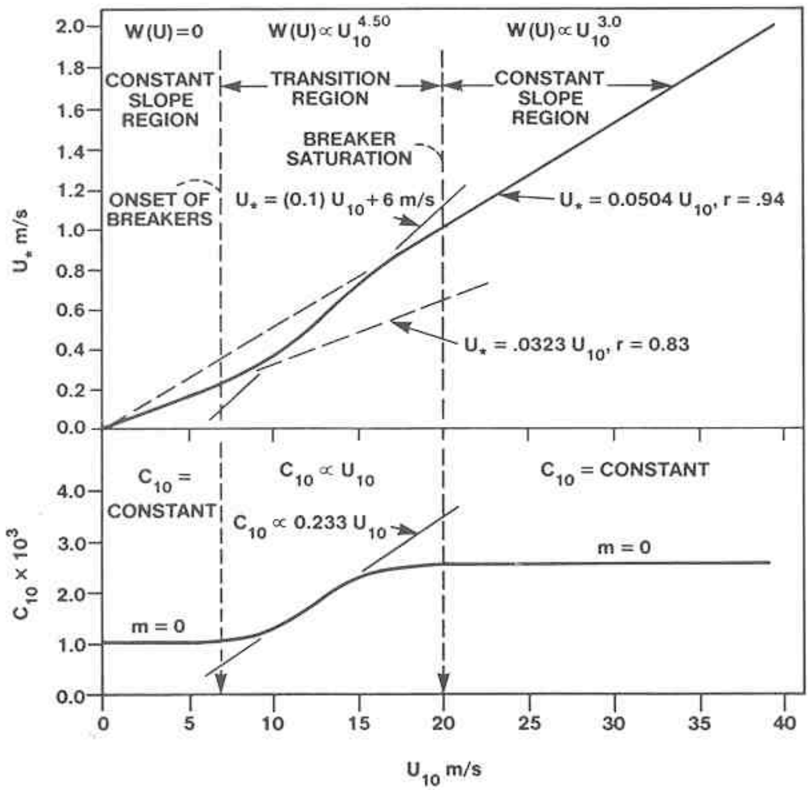
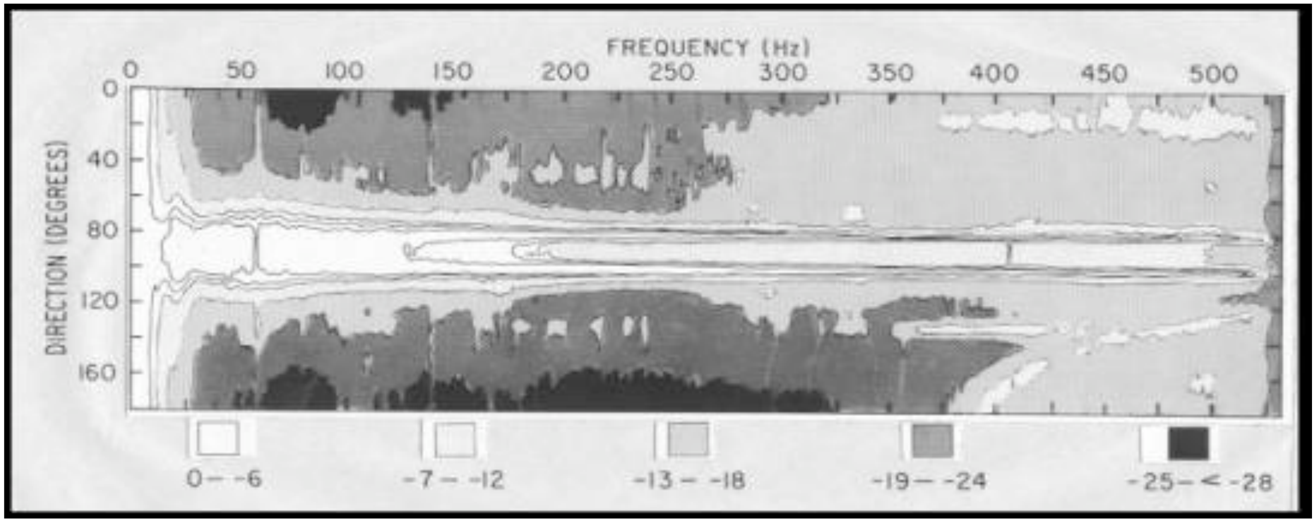
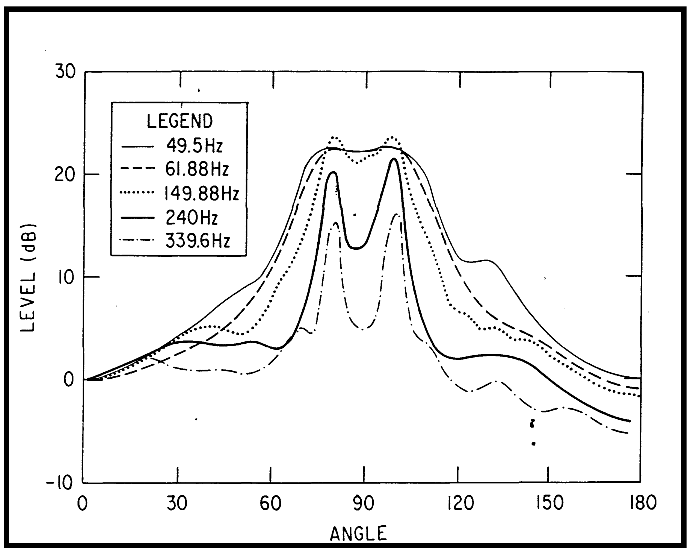


Table III: The White Cap Index

I.	W(u) = 0,	u <4.5 m/s
II.	W(u) = $(4.6x10^{-3})U^3$- $(4.9x10^{-2})U^2$ + $(4.63x10^{-1})U$ -1.5,	4.5 < U < 15 m/s
III.	W(u) = (20.97)(U/15)1.5,	15 m/s < U .

The vertical arrival structure observed on an array in the sound channel as a function of vertical angle and frequency.





Noise level vs. vertical angle (0 deg. is up, low sea state) taken from above at specific frequencies. This figure compares the broad maximum along the horizontal at 49.5, 61.88, and 149.88 Hz with the peaked distributions at 240 and 339 Hz.

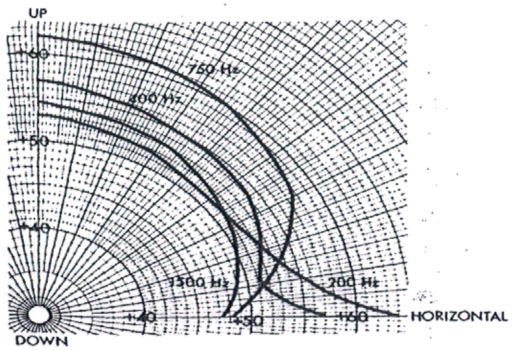


Figure 5-4. Vertical directional patterns in 1/3-octave bands at four frequencies in sea state 3. The scale is spectrum level in dB re 1 μPa per steradian. Reference 121.

Fox, JASA 36, 1964

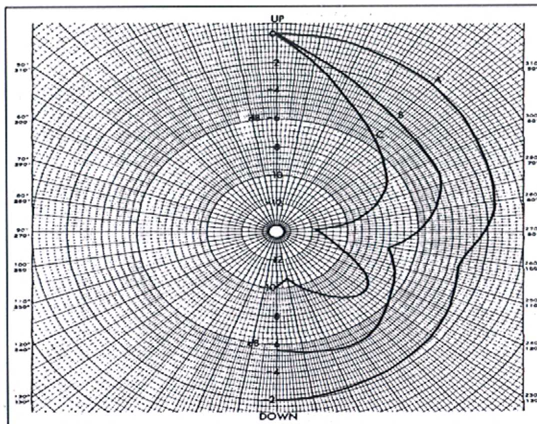


Figure 5-2. Vertical directional patterns at three sea states in the band from 750 to 1500 Hz as obtained by Becken (122) with a 3-dimensional array. A - sea state ½, depth 1000 ft; B - sea state 1½, depth 130 ft; C - sea state 3, depth 560 ft.

5-5

Becken, Scripps,1961

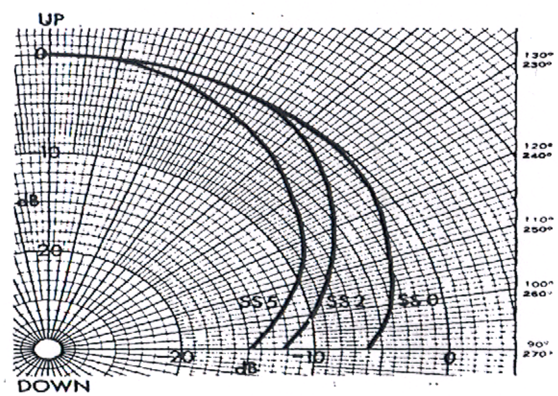
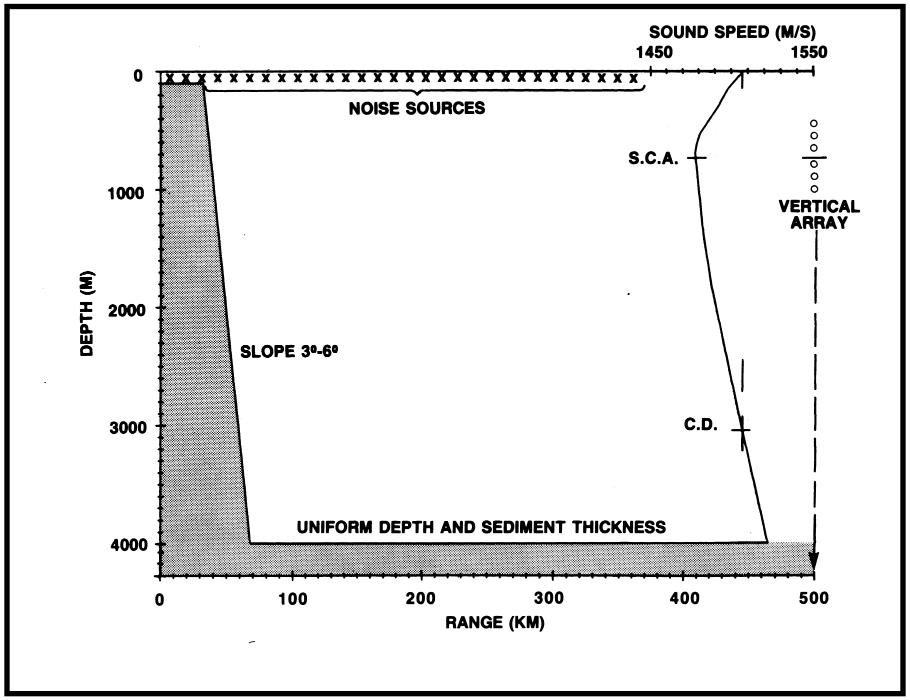
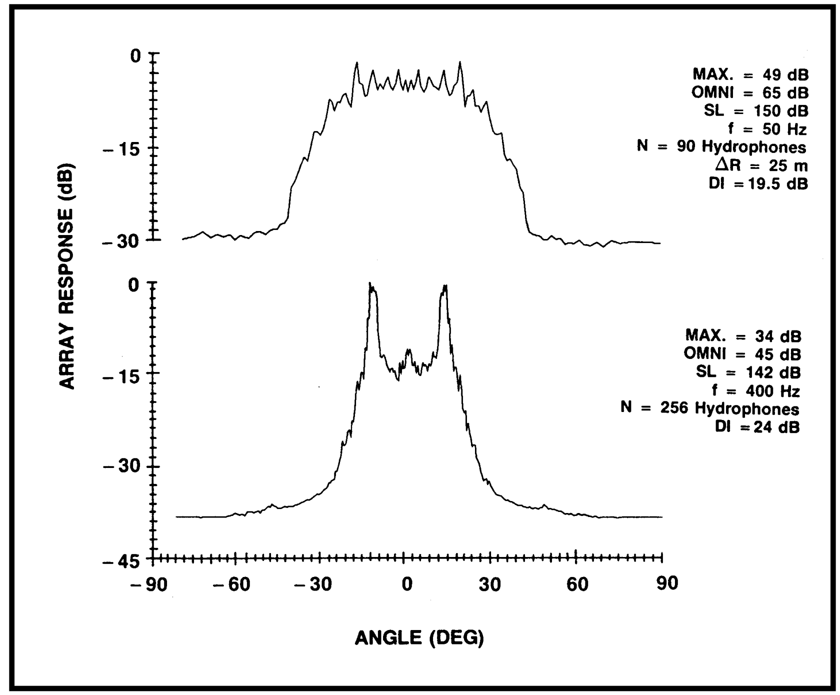


Figure 5-3. Vertical directional patterns as obtained by Forster in a 1/2-octave band centered at 2000 Hz. Reference 129.

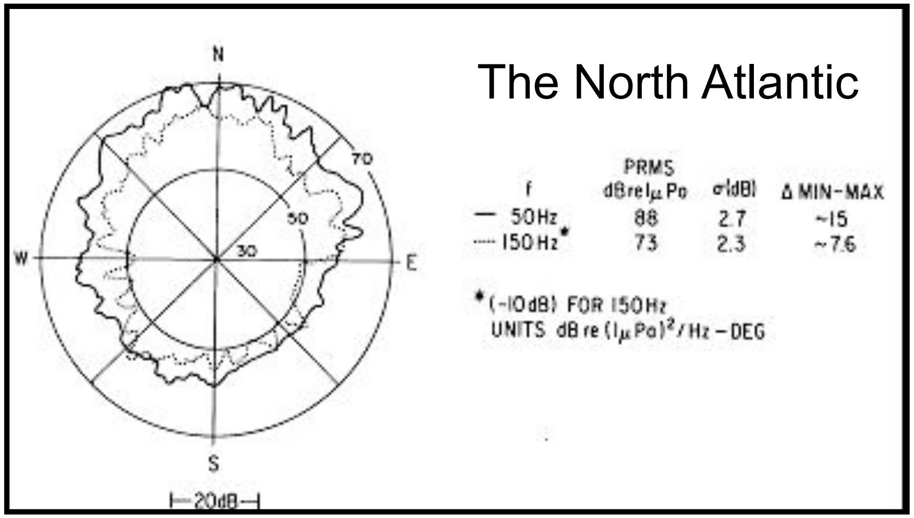
Forster, ASA, 1962

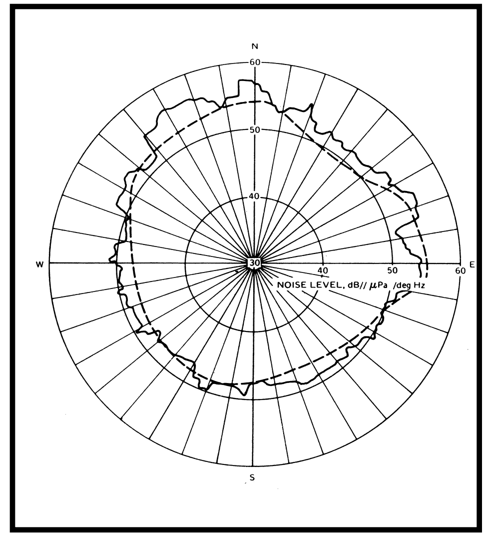


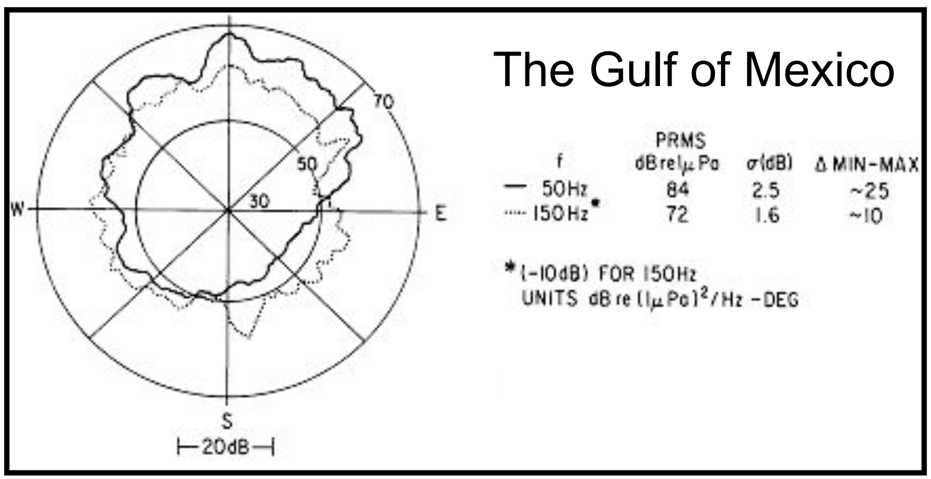


Relative noise levels versus angle (+90 is up) for 50 and 400 Hz. for the geometry and noise source distribution shown above.

Horizontal Noise Directionality

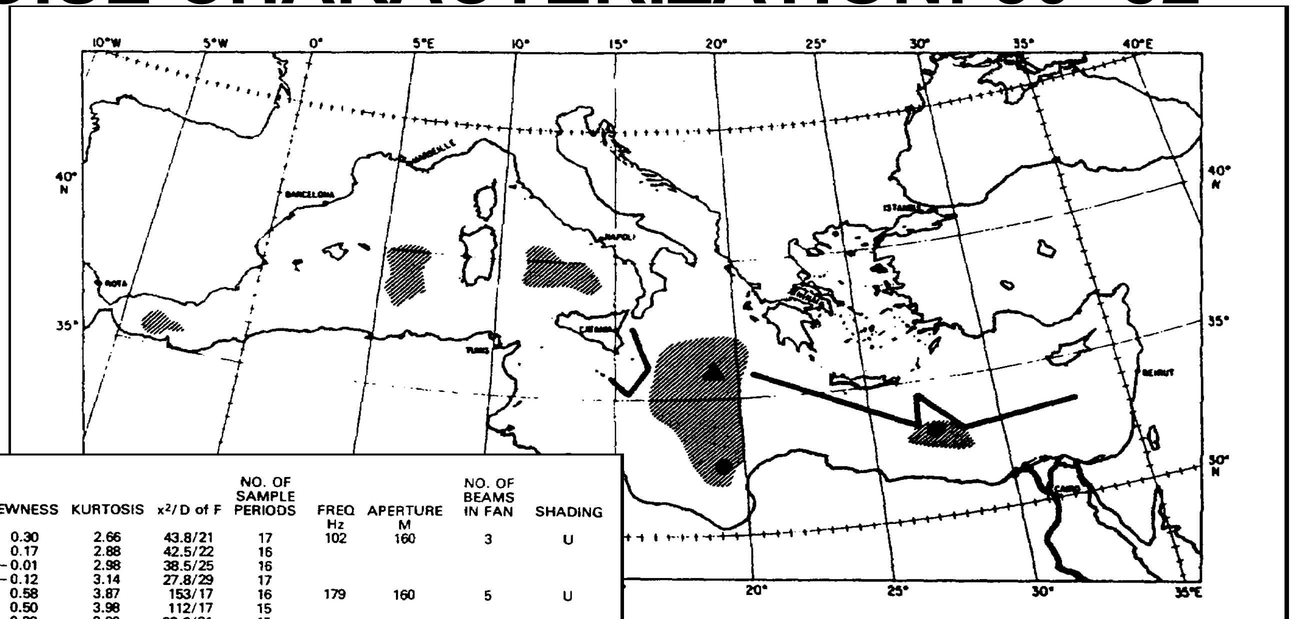




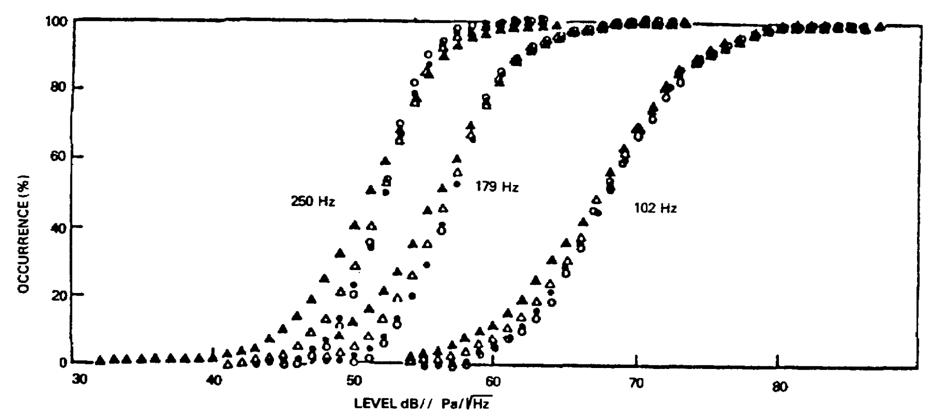


The Northeast Pacific Ocean
(solid curve) compared
to calculations basedon
range dependent bathymetry,
 range dependent sound
velocity profiles and measured
density of ships. [Wagstaff (2005)]

BEAM NOISE CHARACTERIZATION:'80-'82

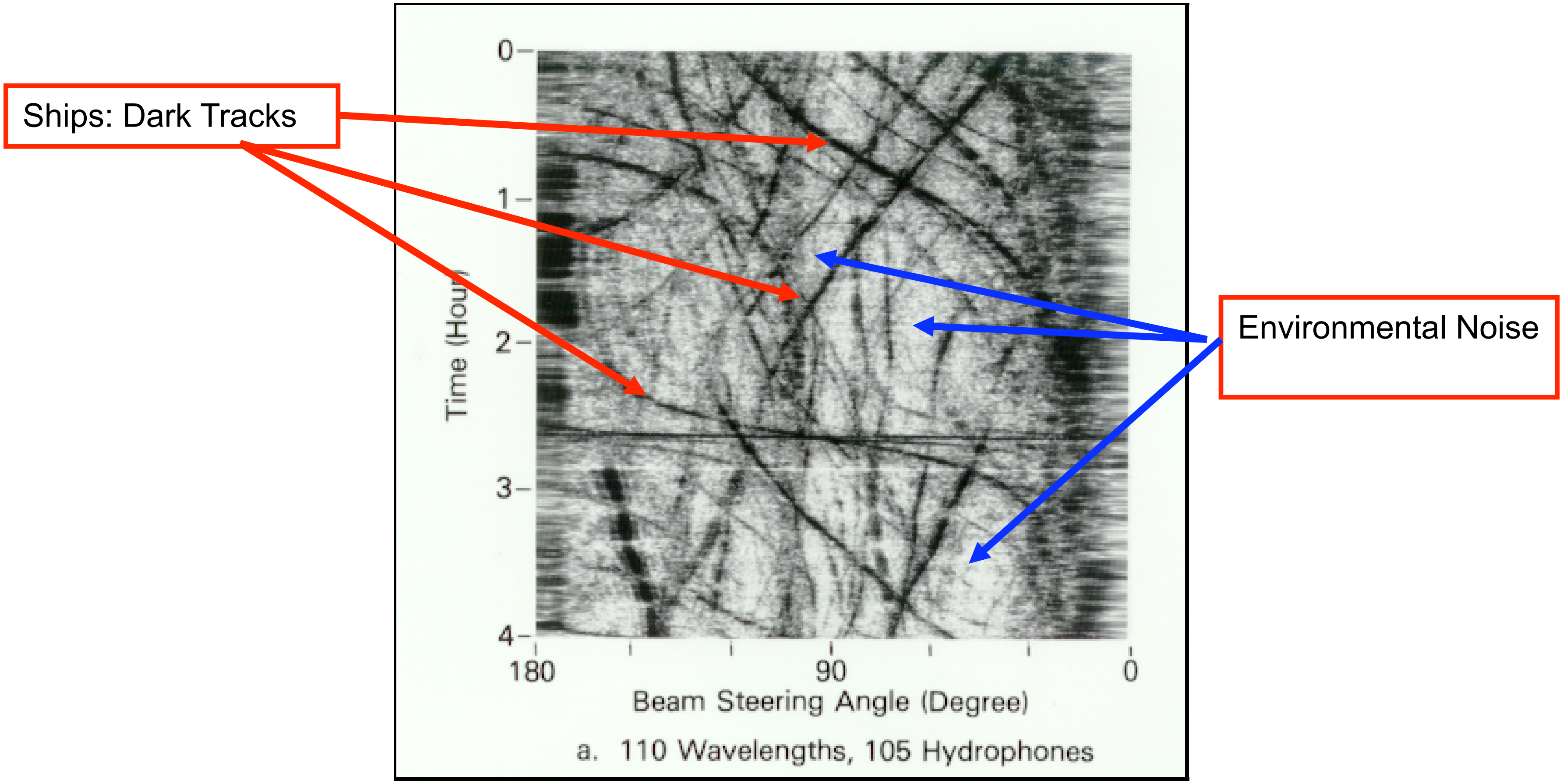


	BANDWIDTH Hz	NO. OF POINTS	MEDIAN dB	MEAN dB	° dB	SKEWNESS	KURTOSIS	x^2/D of F	NO. OF SAMPLE PERIODS	FREQ Hz	APERTURE M	NO. OF BEAMS IN FAN	SHADING
○	1	1203	67.6	68.4	5.0	0.30	2.66	43.8/21	17	102	160	3	U
●	1/4	1149	67.8	68.4	4.9	0.17	2.88	42.5/22	16				
△	1/16	1149	67.5	68.3	5.2	−0.01	2.98	38.5/25	16				
▲	1/32	1203	67.2	67.5	6.0	−0.12	3.14	27.8/29	17				
○	1	1775	56.8	57.4	3.3	0.58	3.87	153/17	16	179	160	5	U
●	1/4	1685	56.7	57.4	3.5	0.50	3.98	112/17	15				
△	1/16	1685	56.4	57.0	4.0	0.33	3.66	93.6/21	15				
▲	1/32	1775	55.8	56.2	4.9	−0.13	3.71	91.6/27	16				
	1	1484	51.8	52.4	2.4	0.22	3.39	26.9/11	13	250	160	5	U
●	1/4	1484	51.9	52.4	2.7	0.06	3.19	19.0/13	13				
△	1/16	1484	51.7	52.1	3.3	−0.12	3.15	29.0/17	13				
▲	1/32	1484	51.0	51.1	4.4	−0.40	3.51	91.1/23	13				



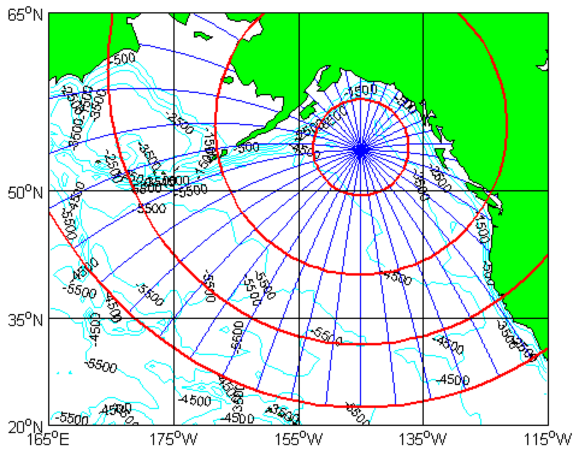
Smith-Reese-Carey-Stuart-

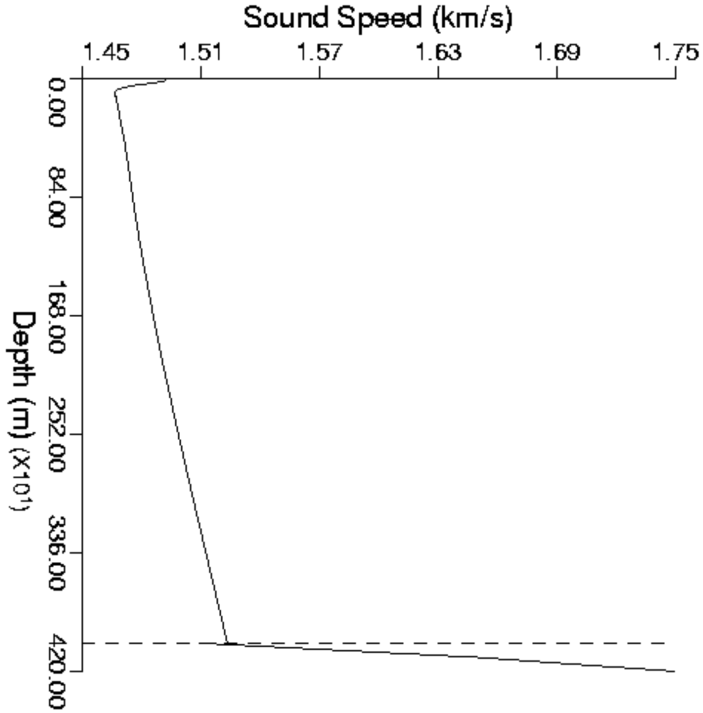
The Dynamic Nature of Shipping Noise

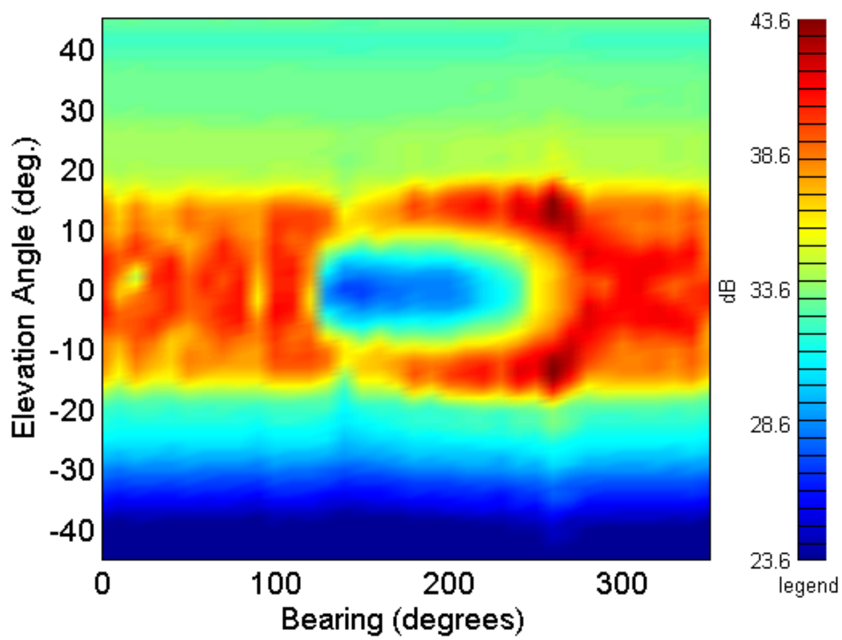


Beam Noise Intensity Levels versus time and steering angle for a frequency of 320Hz, 0.18Hz band, 8 sec. interval for 110 λ array.

Array site at 54º N and 145º W in the Gulf of Alaska

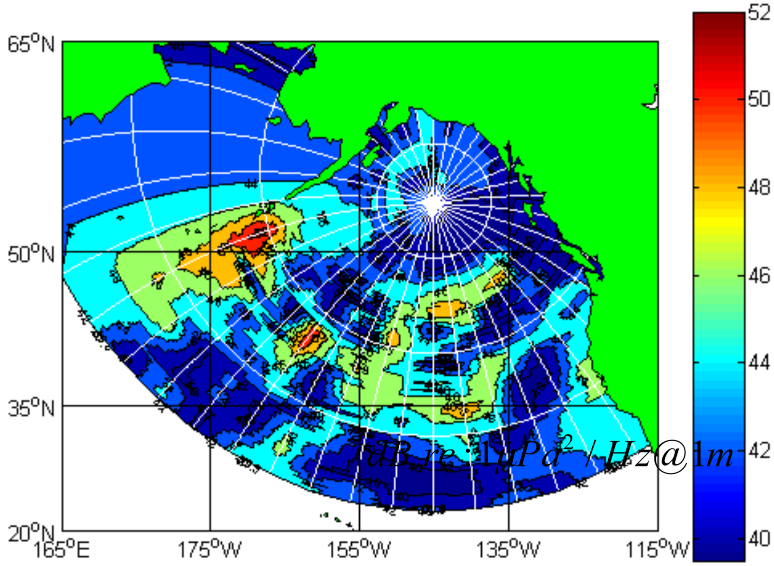


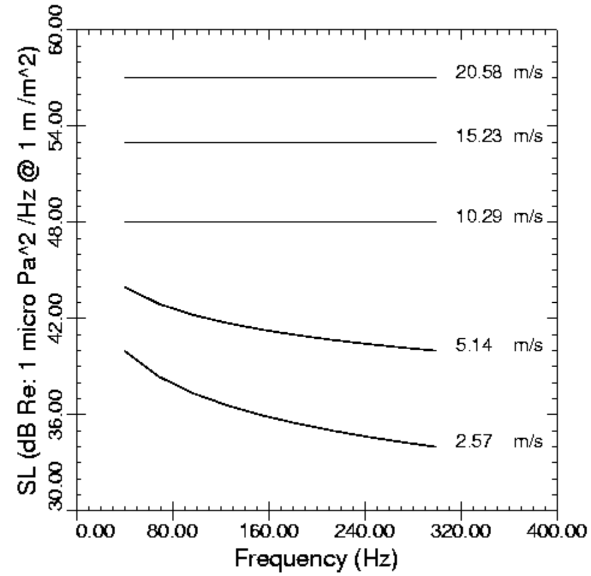


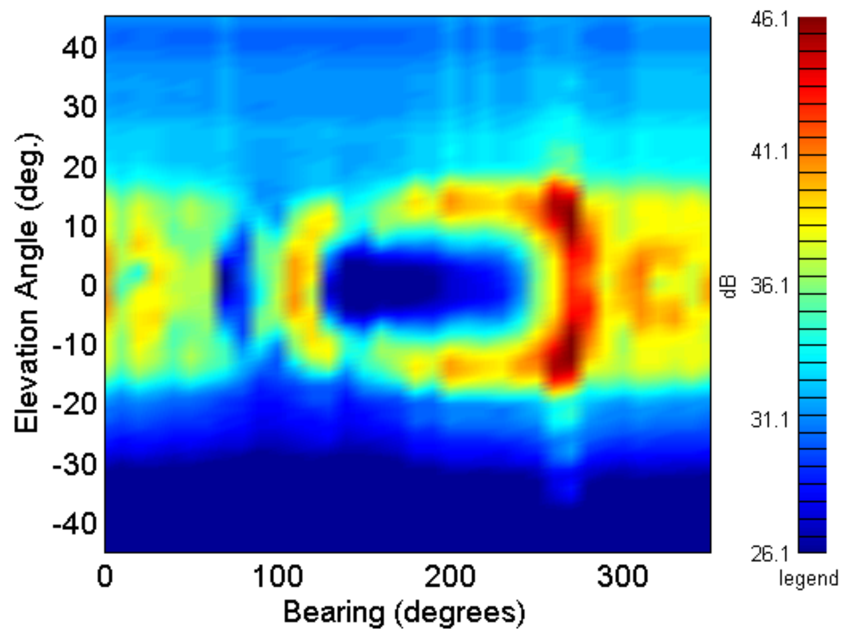


The plane wave noise response versus bearing and elevation angle for the uniform distribution of sources. The azimuthal dependence of the vertical directivity is obtained on a sector-by-sector basis. The down slope conversion of the noise from the sources over the slopes, to the north, fills in the notch at the horizontal. The directivity of the noise arriving from the open ocean, to the south, ispeaked at

Wind noise source levels from satellite measurements

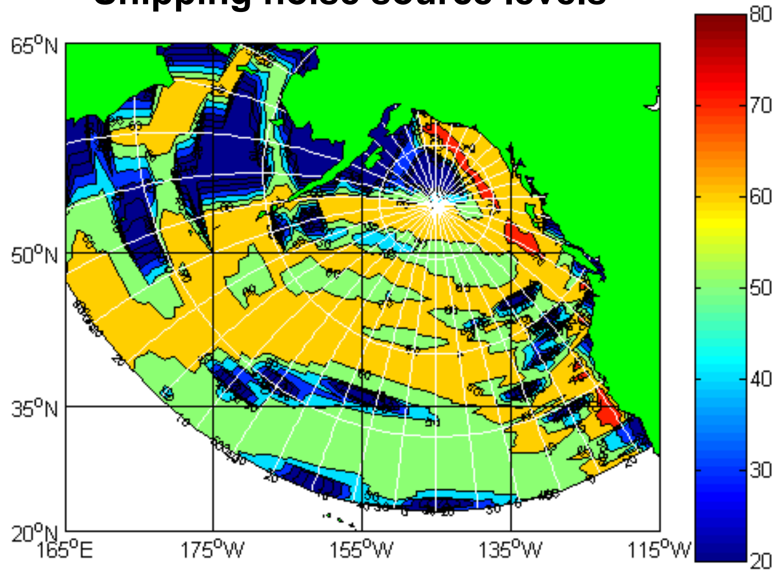






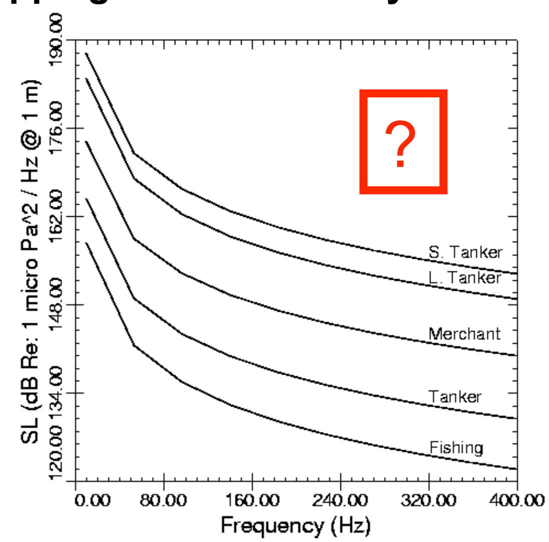
The plane wave noise response versus bearing and elevation angle for the measured distribution of wind noise sources. The peak response is at a bearing of 270°.

Shipping noise source levels

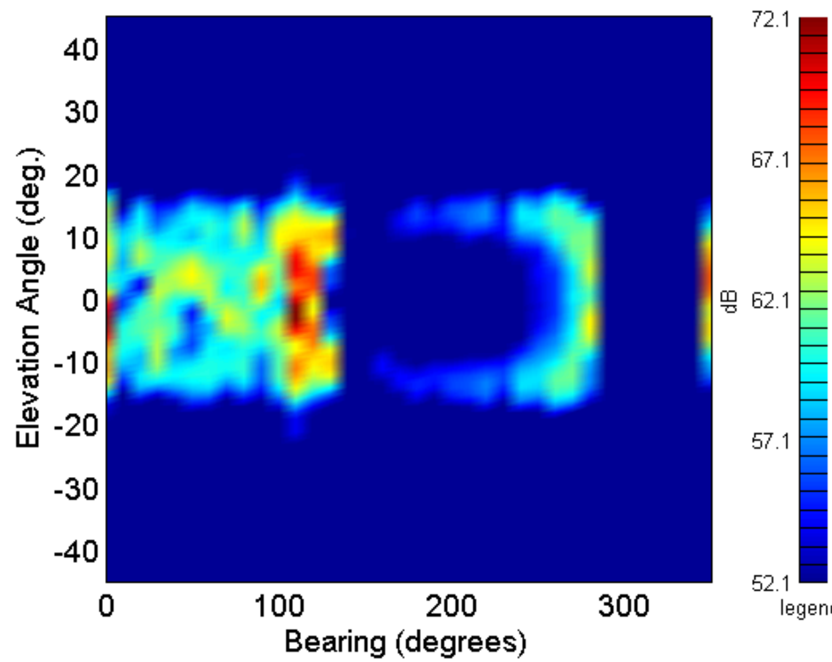


$dB\ re: 1\mu Pa^2 / Hz@1m$

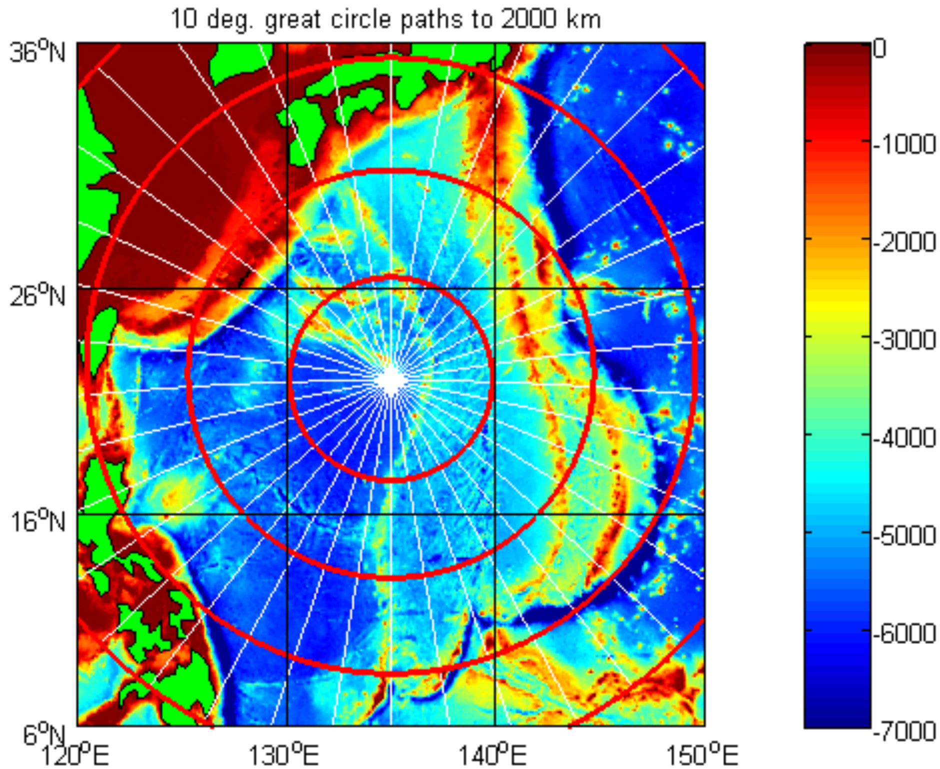
Shipping source intensity level curves



The plane wave noise response Versus bearing and elevation angle for distant shipping.



The Philippine Sea

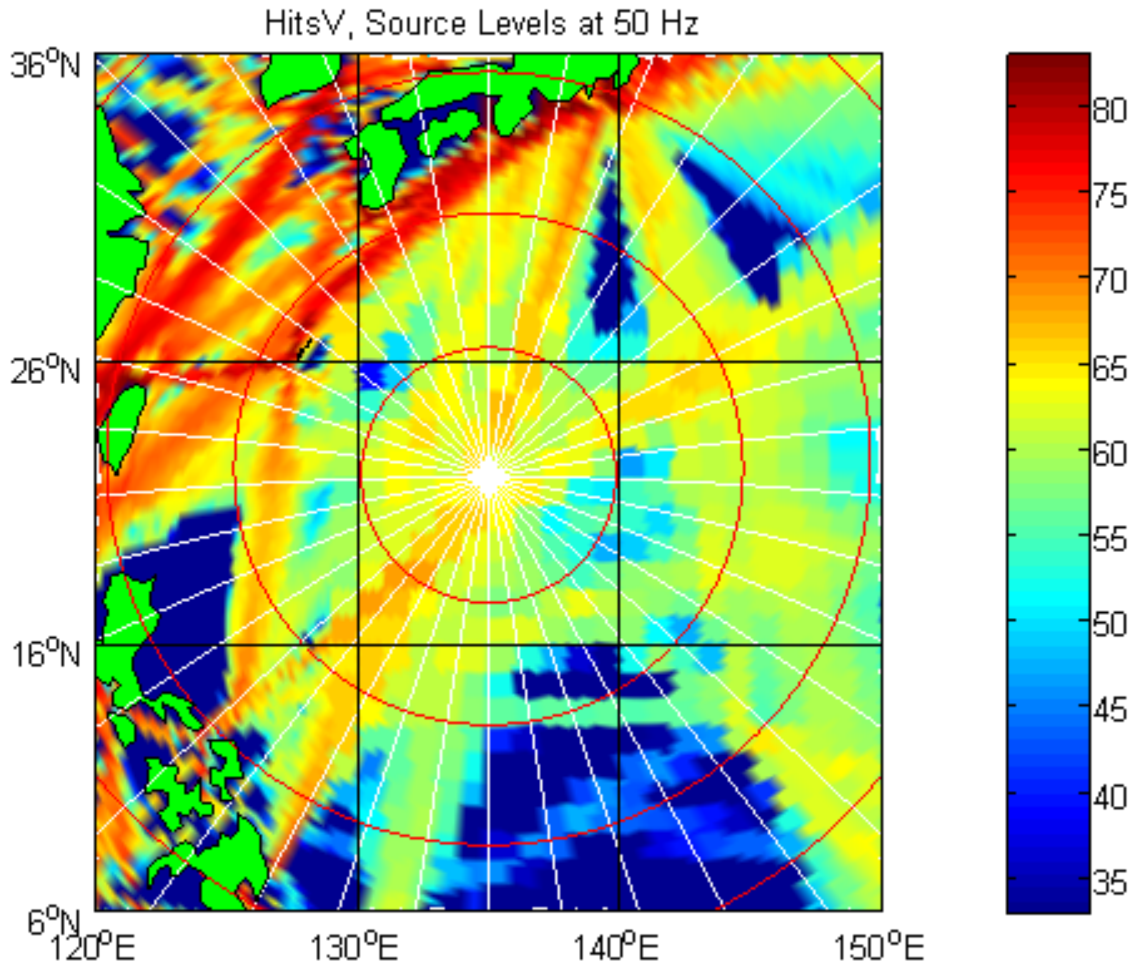


Philippine Sea Shipping Noise (22°N, 135°E)

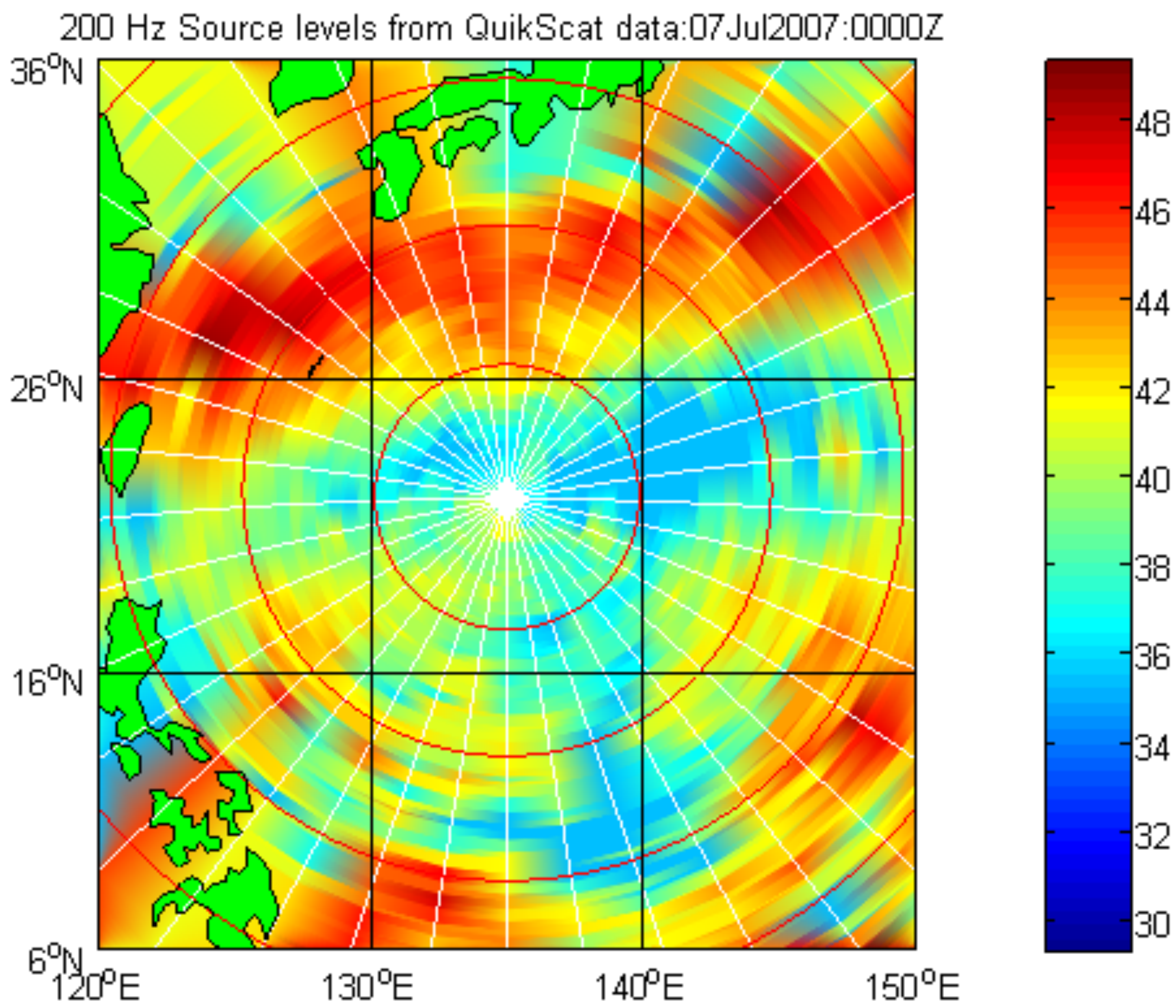
30° and 10° Critical Angle Bottoms

Archival Shipping Density

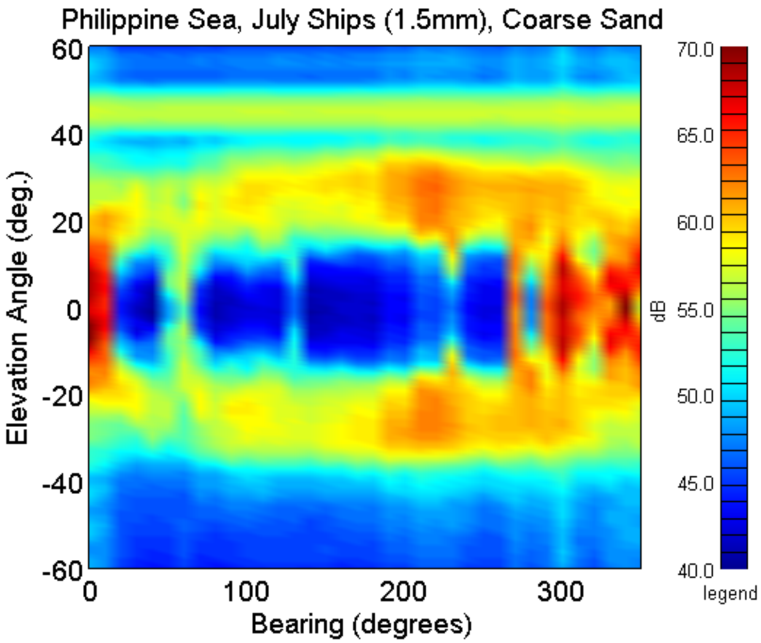
Source Levels at 50 Hz

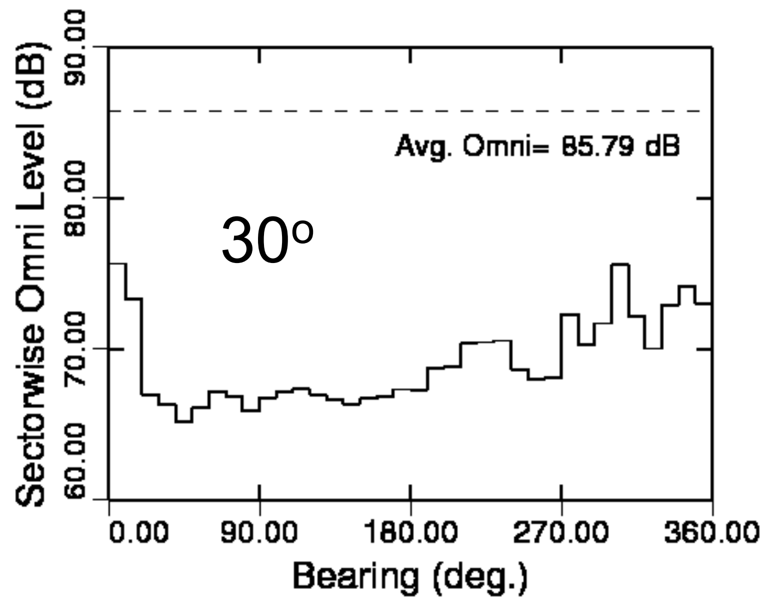


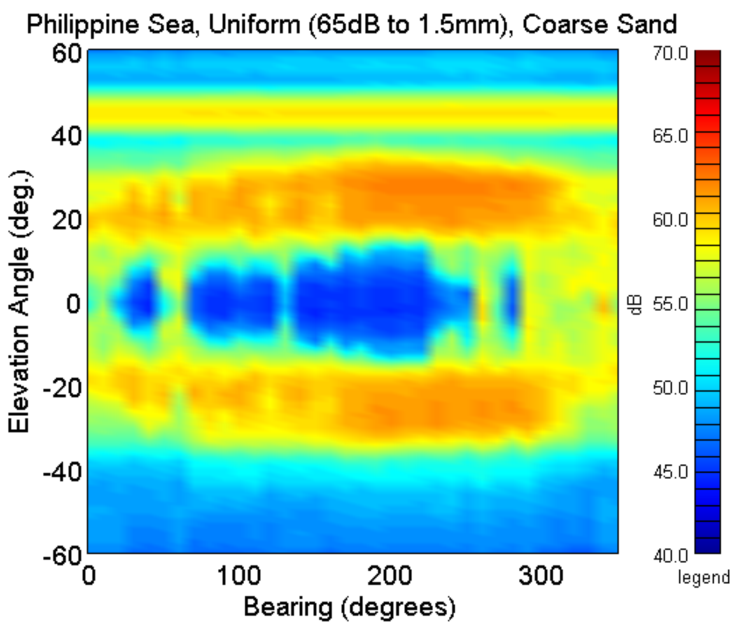
Quick Sat 10m Wind Speed Derived Source Levels

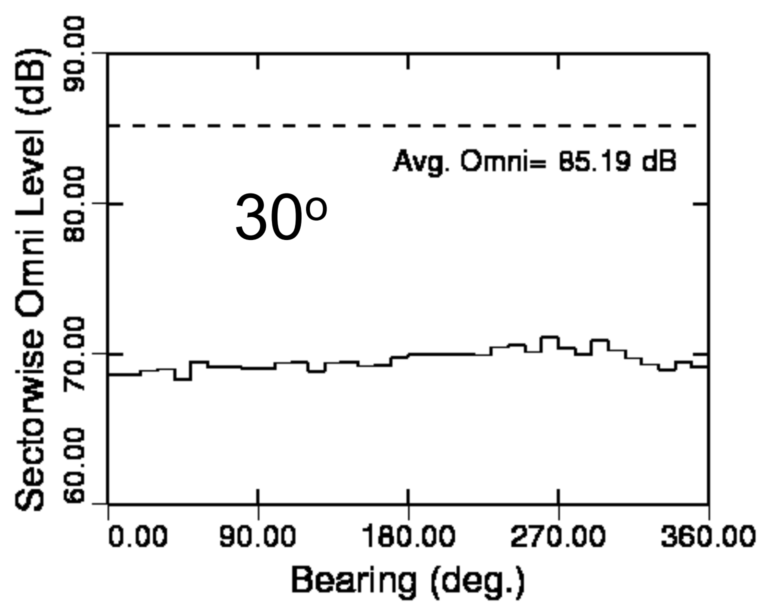


Shipping -Uniform Source Distributions

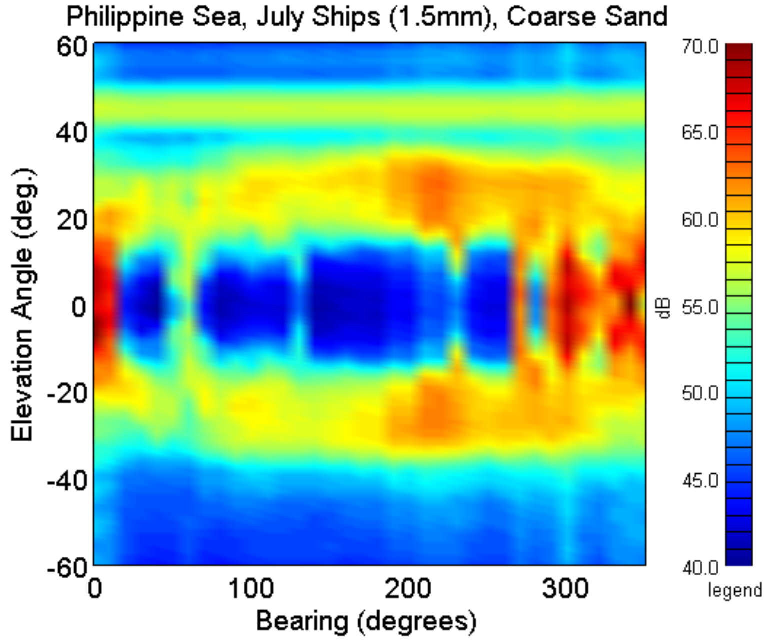


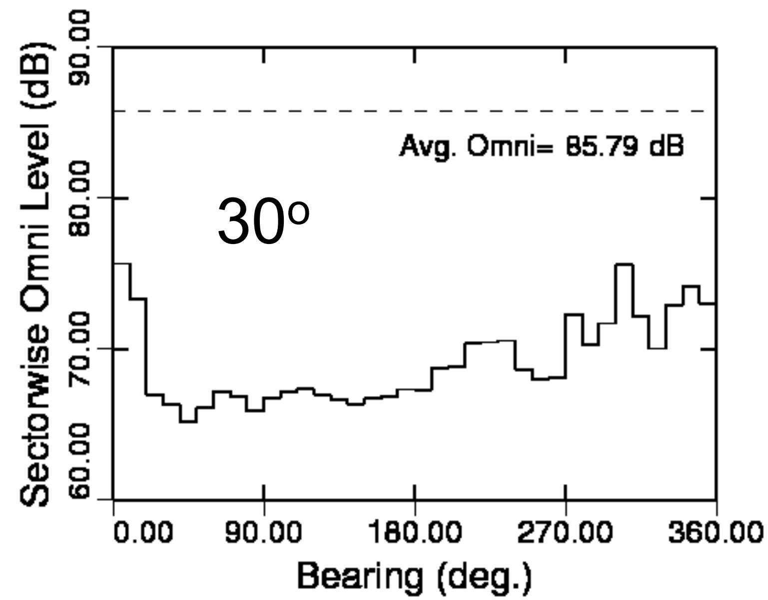


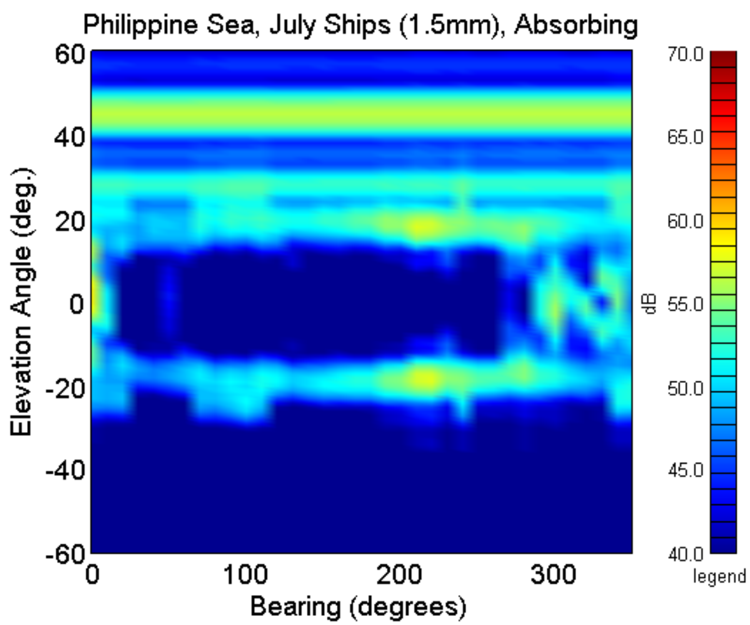


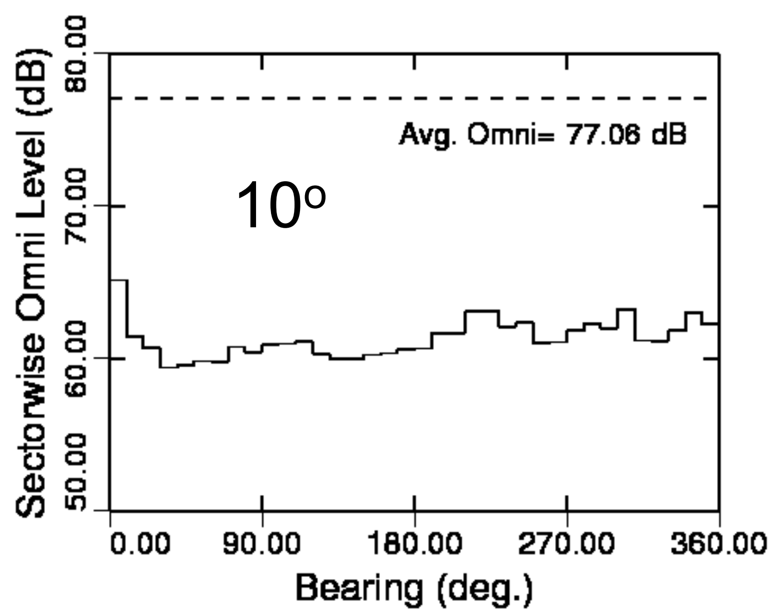


Shipping Source Distribution

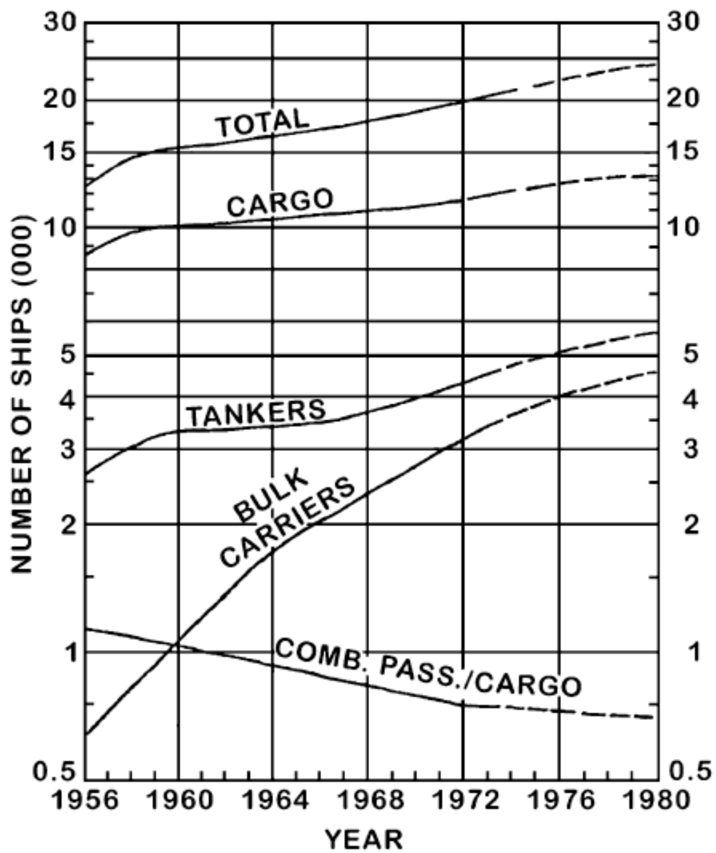


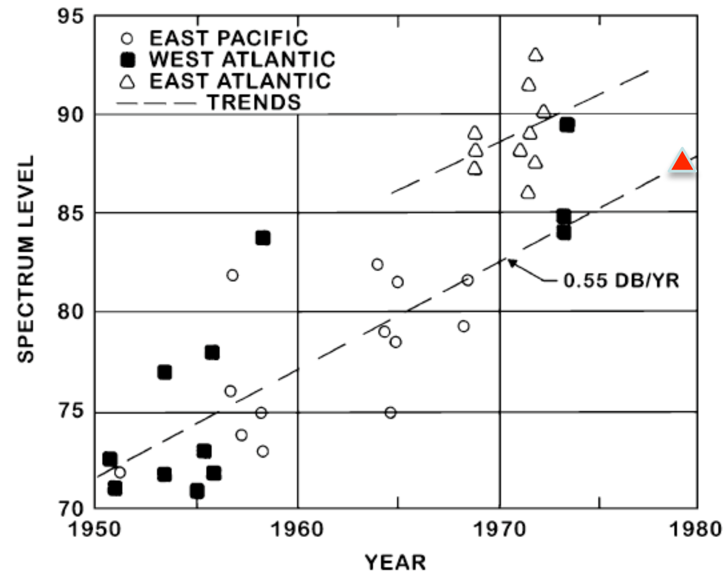




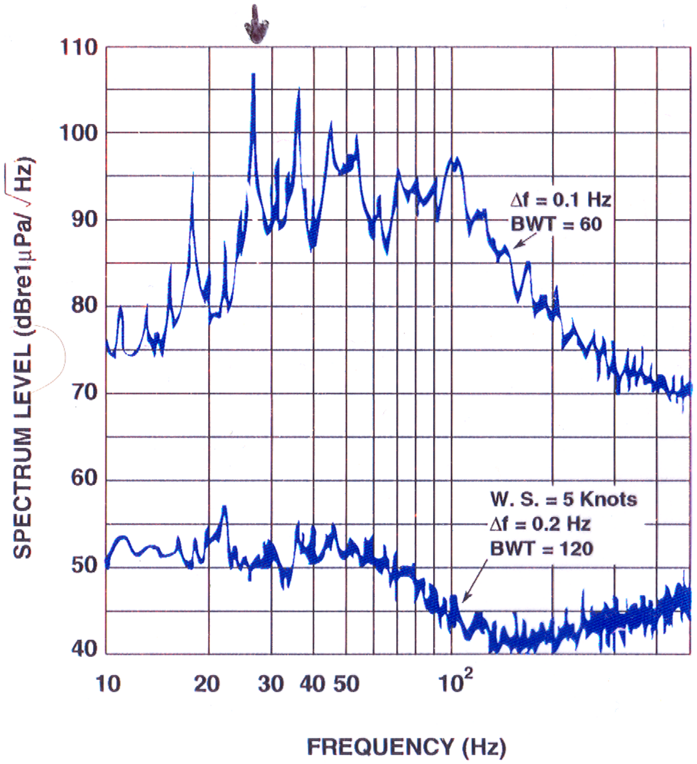


Ross's Result





The Extremes in the Events of the Day in the Life of a Near Bottom Hydrophone



$$SPL = SL - TL = SL - 20\,LOG(R)$$
$$= \; SL - 74 \;\; dB.$$

THE LEVEL AT 26 Hz IS

$$SL = \; 170 \; dB \;\; re \;\; \mu Pa^2 \;\; @ \;\; 1m.$$

<u>NOTE:</u> $I \,/\, \Delta f \;\; \left[W \,/\, m^2 - Hz \right]$

$$I \,/\, \Delta f \propto \; P^2 \,/\, \Delta f \;\; \left[\mu Pa^2 \,/\, Hz \right]$$
$$\propto \left(P^2 \,/\, \Delta f \right) \cdot \left[\mu Pa \,/\, \sqrt{Hz} \right]^2$$

- 12000 TON JAPENESE FREIGHTER PASSING 4,850 METERS OVER THE HYDROPHONE. ALSO SHOWN IS THE AMBIENT NOISE FOR A 5 KNOT WIND SPEED.

Hellespont Alhambra (now TI Asia), a ULCC TI class supertanker, the largest ships in the world

Configuration of ABB LNGC Electrical Propulsion.

Dry Cargo

* Small Handy size, carriers of 20,000 long tons deadweight (DWT)-28,000 DWT

* Handy size, carriers of 28,000-40,000 DWT
  o Seawaymax, the largest size that can traverse the St Lawrence Seaway
* Handymax, carriers of 40,000-50,000 DWT

* Panamax, the largest size that can traverse the Panama Canal (generally: vessels with a width smaller than 32.2 m)

* Capesize, vessels larger than Panamax and Post-Panamax, and must traverse the Cape of Good Hope and Cape Horn to travel between oceans

Container Ship Evolution

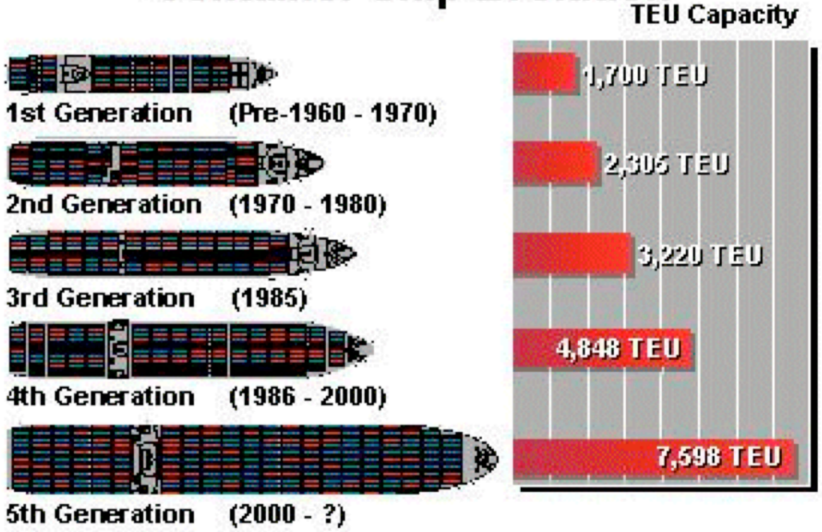


Figure 21

2000 New Build Orders

Expansion of World Post-Panamax Container Fleet

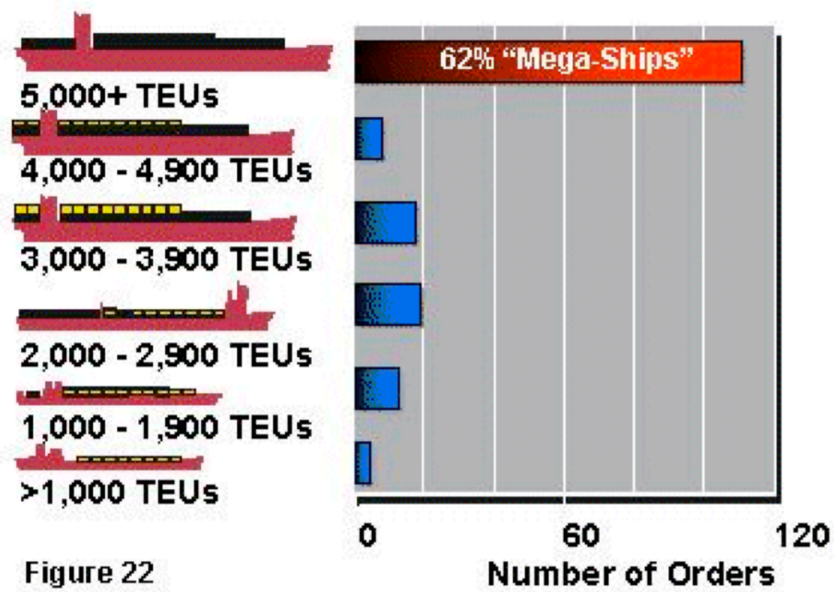
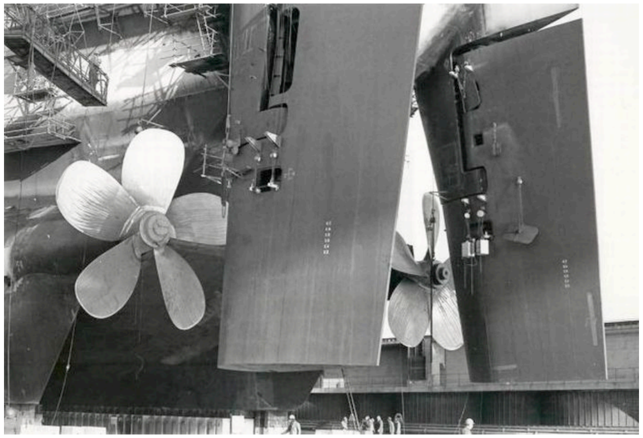
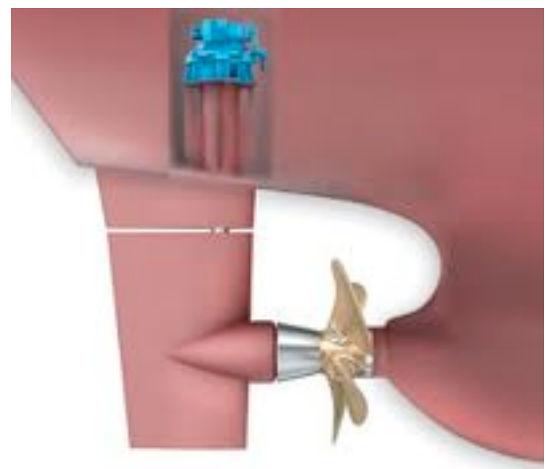


Figure 22

Oil tanker size categories

AFRA Scale[41]		Flexible market scale[4	
Class	**Size in DWT**	**Class**	**Size in DWT**
General Purpose tanker	10,000–24,999	Product tanker	10,000–60,000
Medium Range tanker	25,000–44,999	Panamax	60,000–80,000
LR1 (Large Range 1)	45,000–79,999	Aframax	80,000–120,000
LR2 (Large Range 2)	80,000–159,999	Suezmax	120,000–200,000
VLCC (Very Large Crude Carrier)	160,000–319,999	VLCC	200,000–320,000
ULCC (Ultra Large Crude Carrier)	320,000–549,999	Ultra Large Crude Carrier	320,000–550,000



Wet Cargo

- **Aframax,** oil tankers between 75,000 and 115,000 DWT. This is the largest size defined by the average freight rate assessment (AFRA) scheme.

- **Suezmax**, the largest size that can traverse the Suez Canal
- **VLCC (Very Large Crude Carrier)**, supertankers between 150,000 and 320,000 DWT.

  Malaccamax, the largest size that can traverse the Strait of Malacca

- **ULCC (Ultra Large Crude Carrier)**, enormous supertankers between 320,000 and 550,000 DWT

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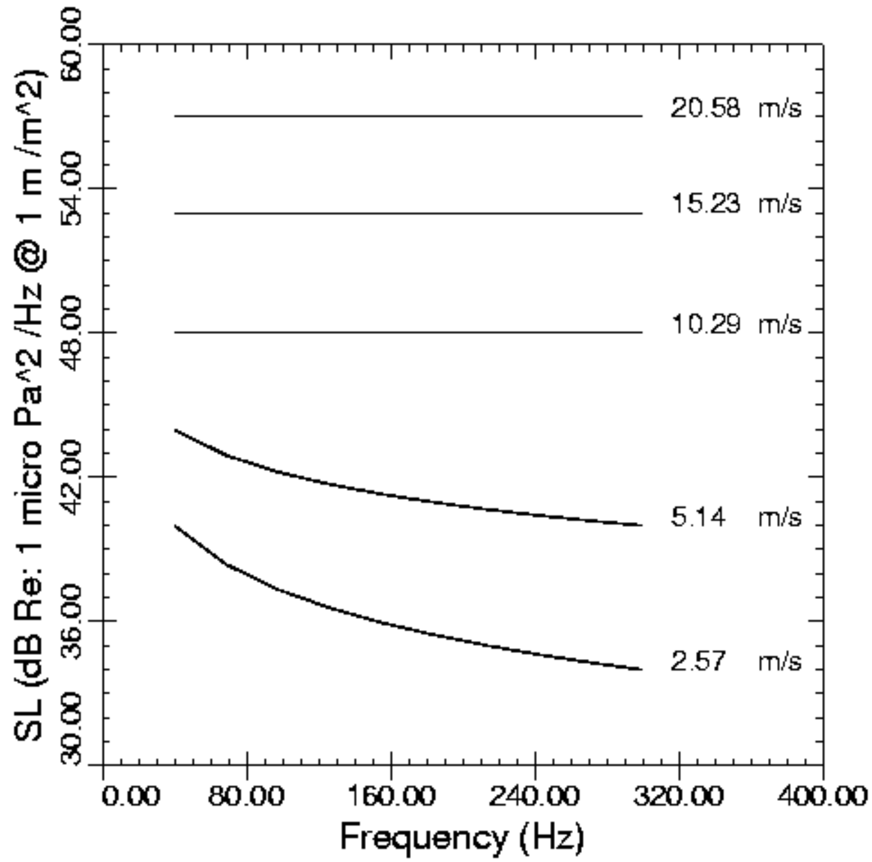
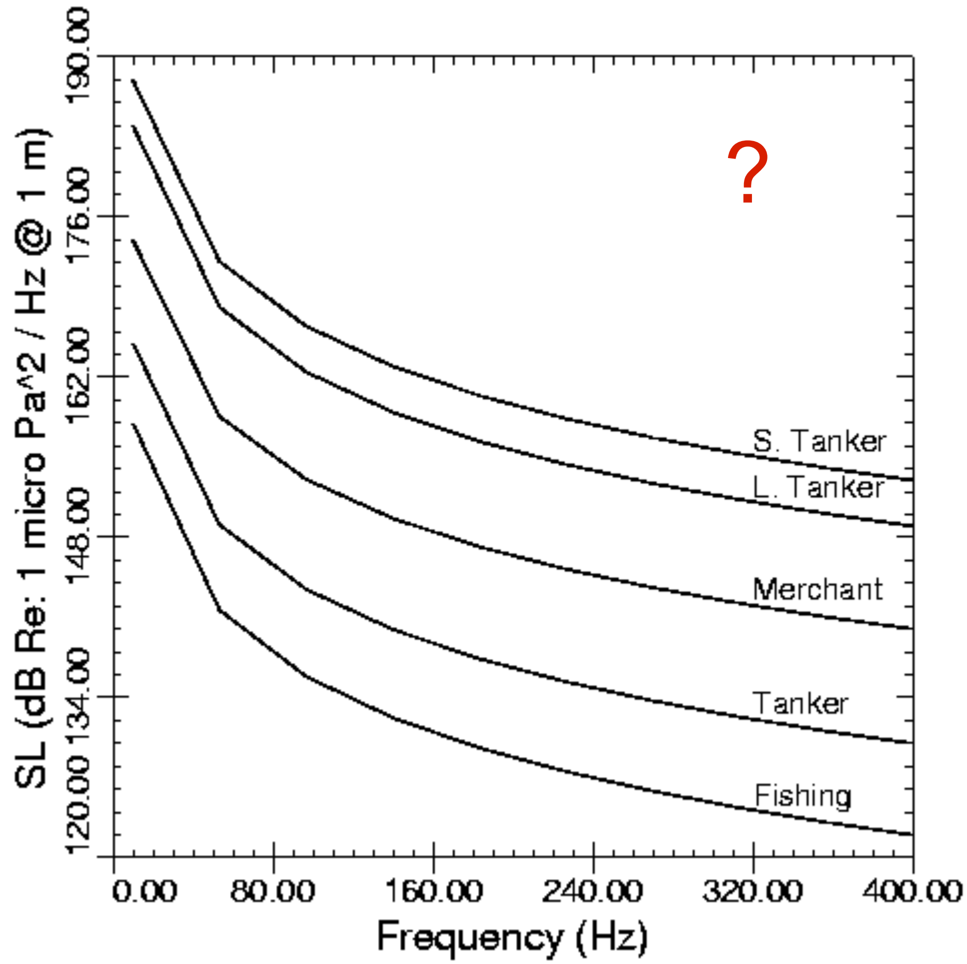


Wind noise source intensity level curves versus frequency and wind speed, due to [Kewley et al., 1990]. The wind speeds in m/s are equivalent to 5, 10, 20, 30 and 40 knots, respectively. The source levels are in units of

$$dB\ re: 1\mu Pa^2 / Hz@1m$$

per square meter of surface area. The source depth is assumed to be one quarter of a wave length.

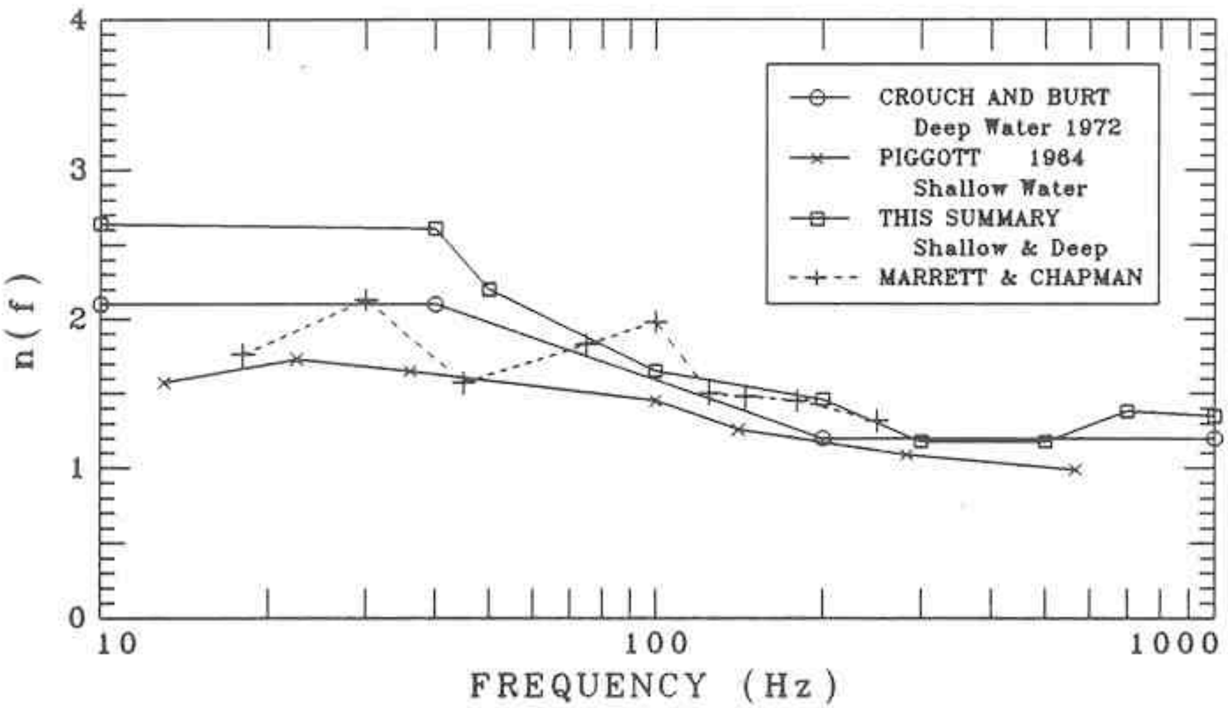


ANDES shipping source intensity level curves versus frequency and ship type, due to [Renner, 1986]. The source levels are in units of

$$dB\ re: 1\mu Pa^2 / Hz@1m$$

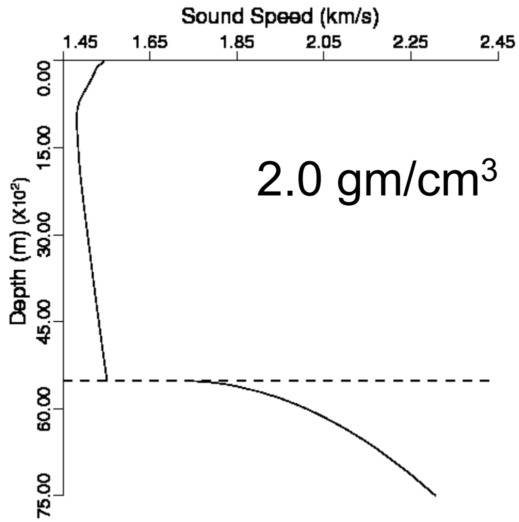
The source depth is assumed to be 6 m.

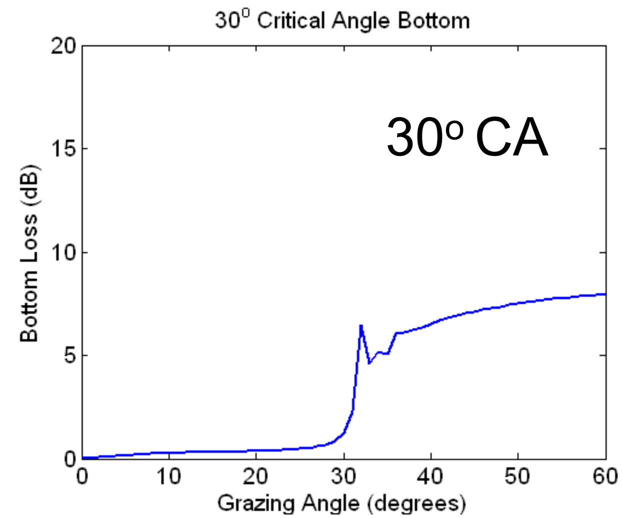
$$\Delta NL(f, f_o U, U_o) = 20n(f) LOG(U / U_o)$$
$$+ 10m(f) \cdot LOG(f / f_o),$$

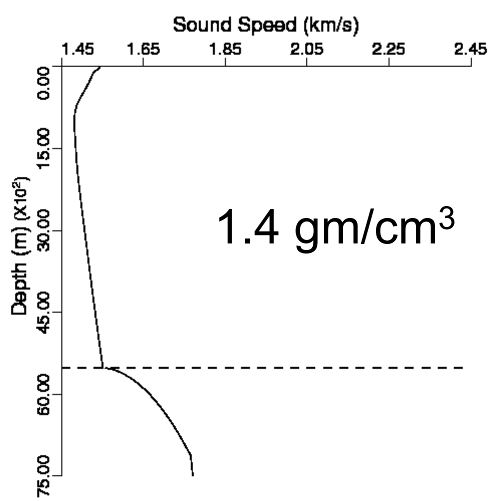


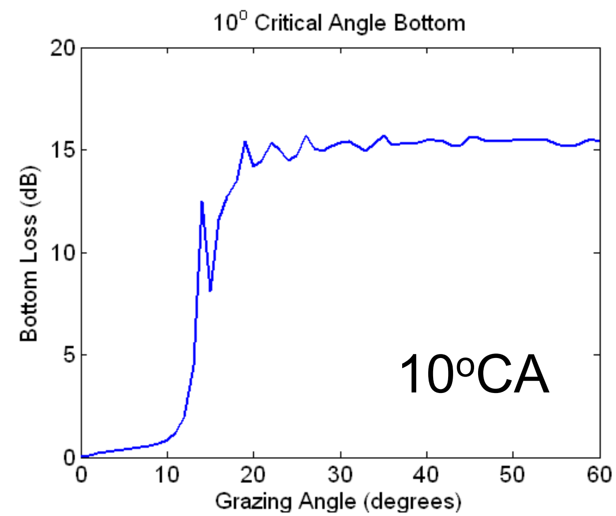
Wind speed dependency factor n(f) vs frequency for wind speeds >13 knots. Shown are the results of Crouch and Burt (1972), Piggott (1964), and Marrett and Chapman (1990) and an average of all data.

Critical Angle Bottom Loss

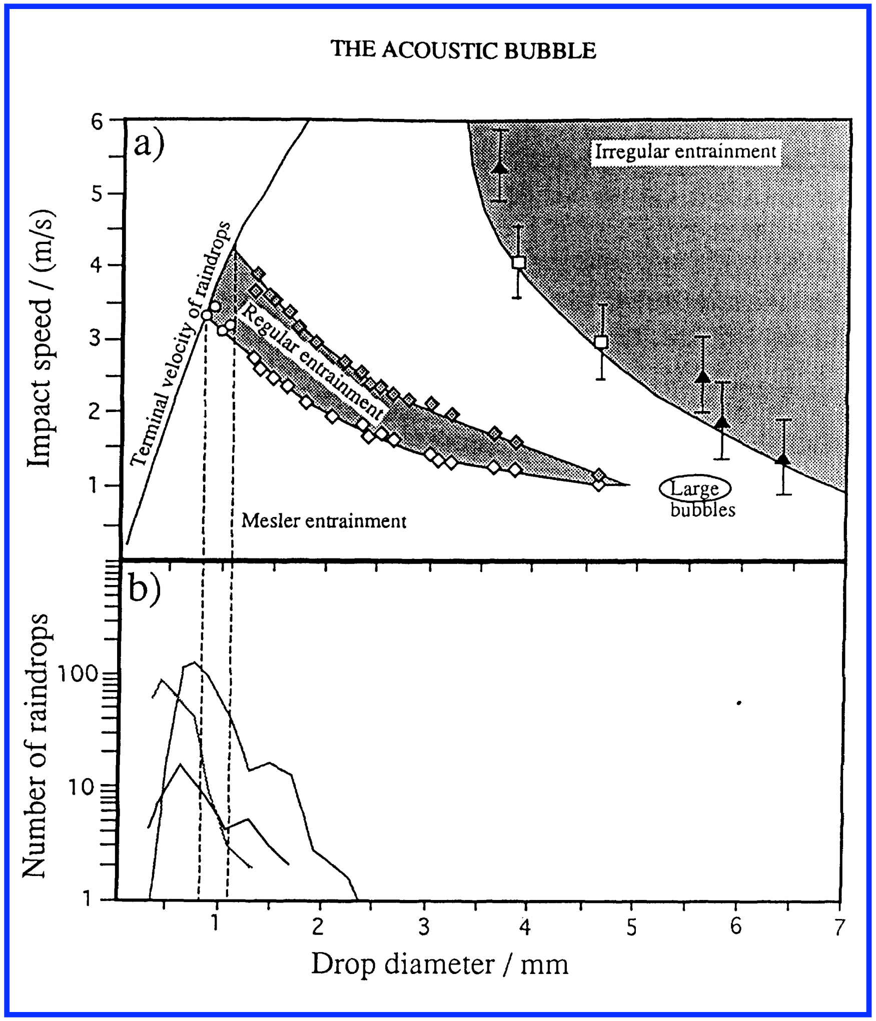




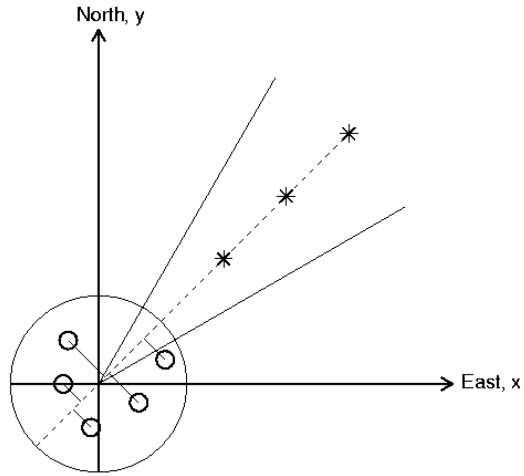


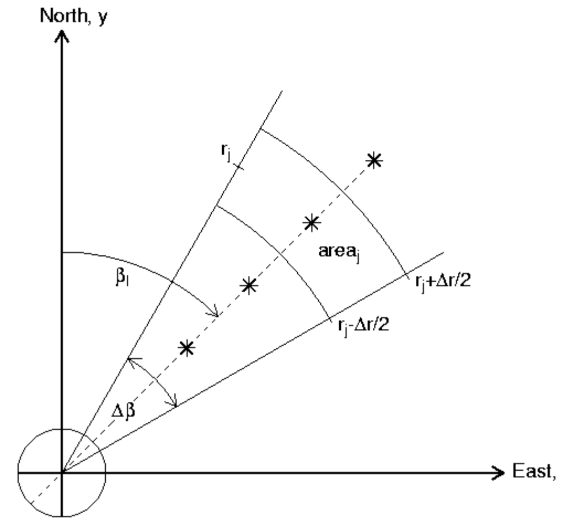


Rain Drop Entrainment

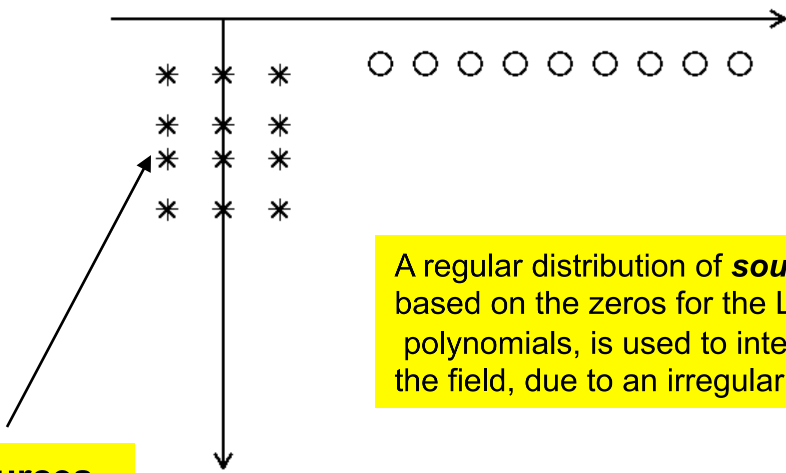


Array Projection onto Vertical Plan



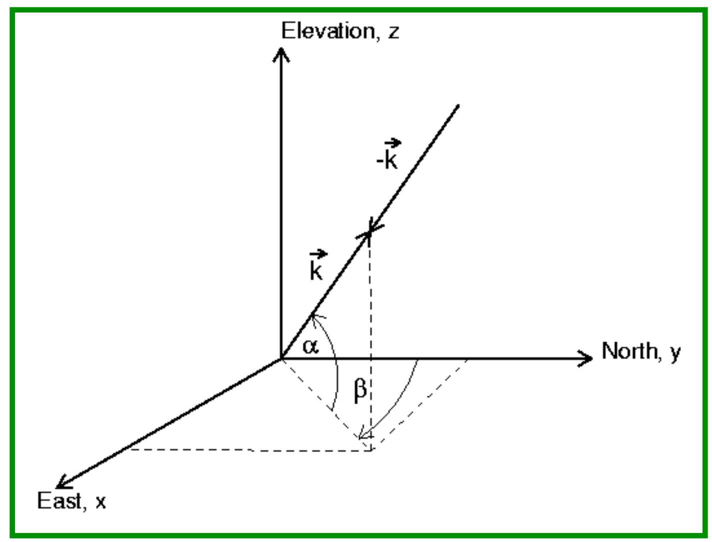


Source level per unit area representation



A regular distribution of ***sources***,
based on the zeros for the Legendre
polynomials, is used to interpolate
the field, due to an irregular set of positions

Sources



Application of Reciprocity in the vertical plane