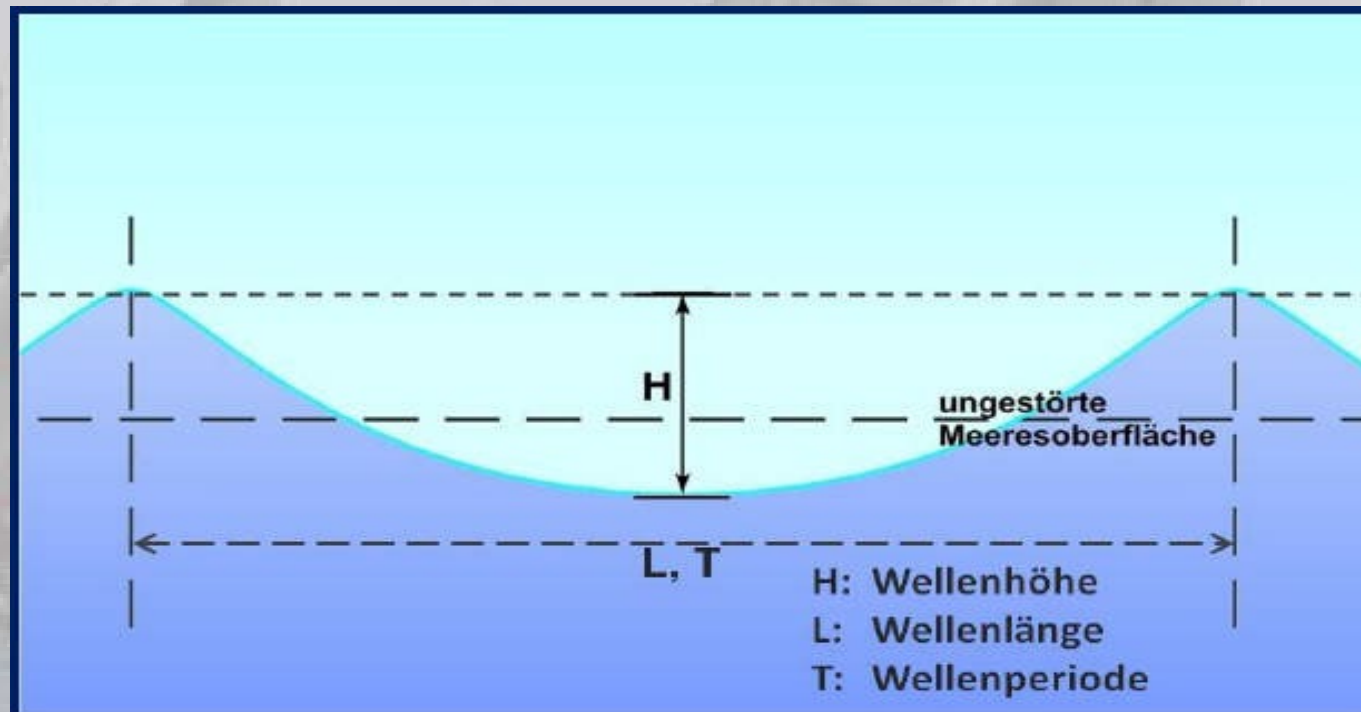
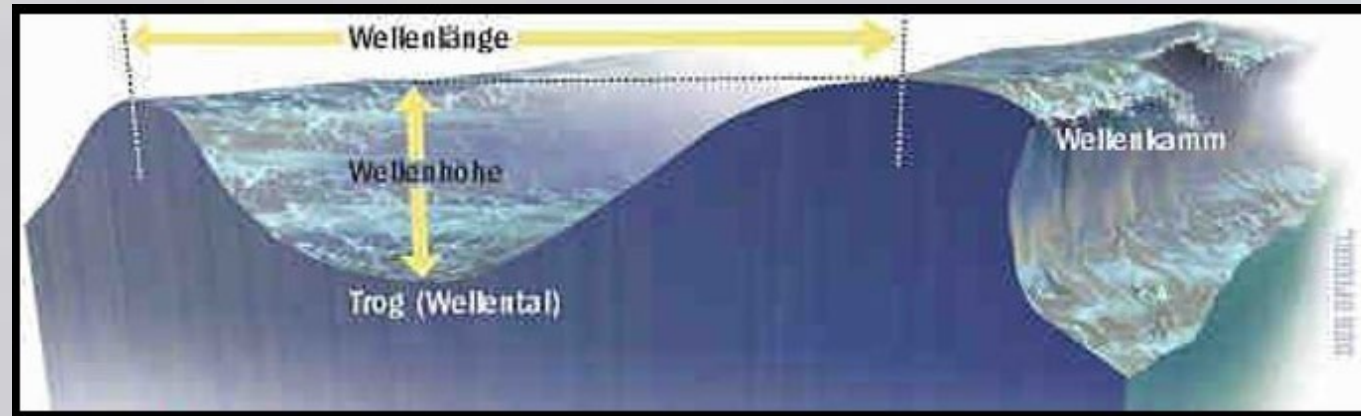
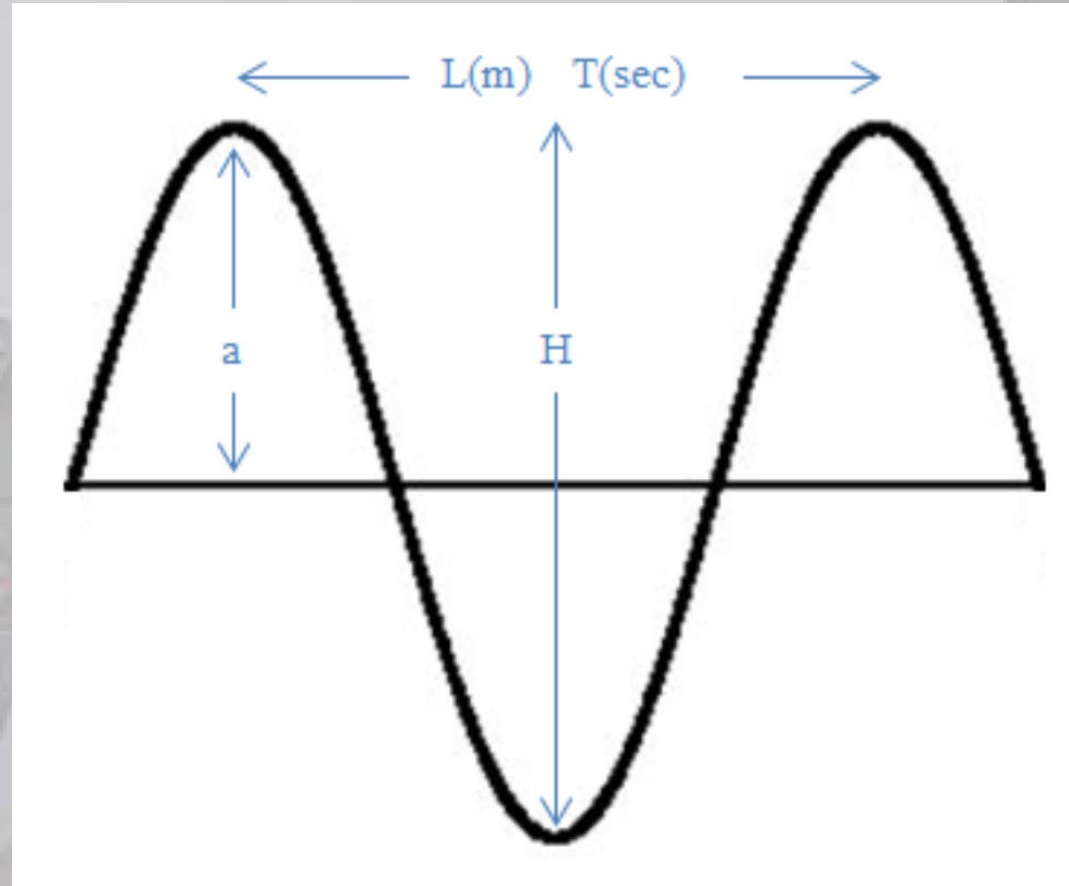


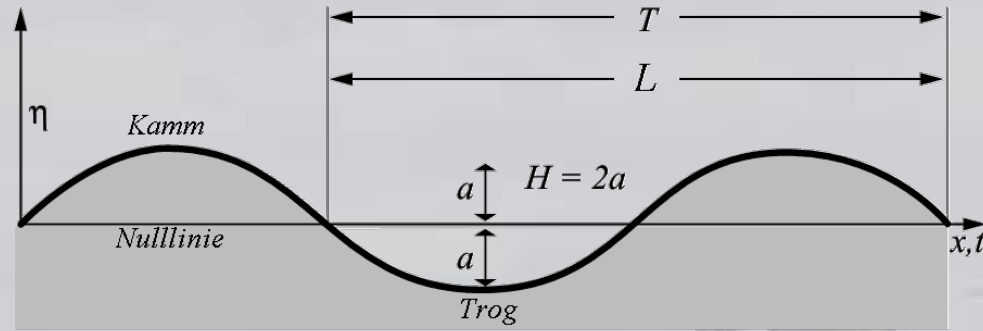
SEA / SWELL PARAMETERS (WAVE HEIGHT, -LENGTH, -PERIOD)



SEA / SWELL PARAMETERS (WAVE HEIGHT, -LENGTH, -PERIOD)



SEA / SWELL PARAMETERS (WAVE HEIGHT, -LENGTH, -PERIOD)



wavelength: distance between two succeeding wave crests

wave height: difference between wave crest and wave trough (double the amplitude)

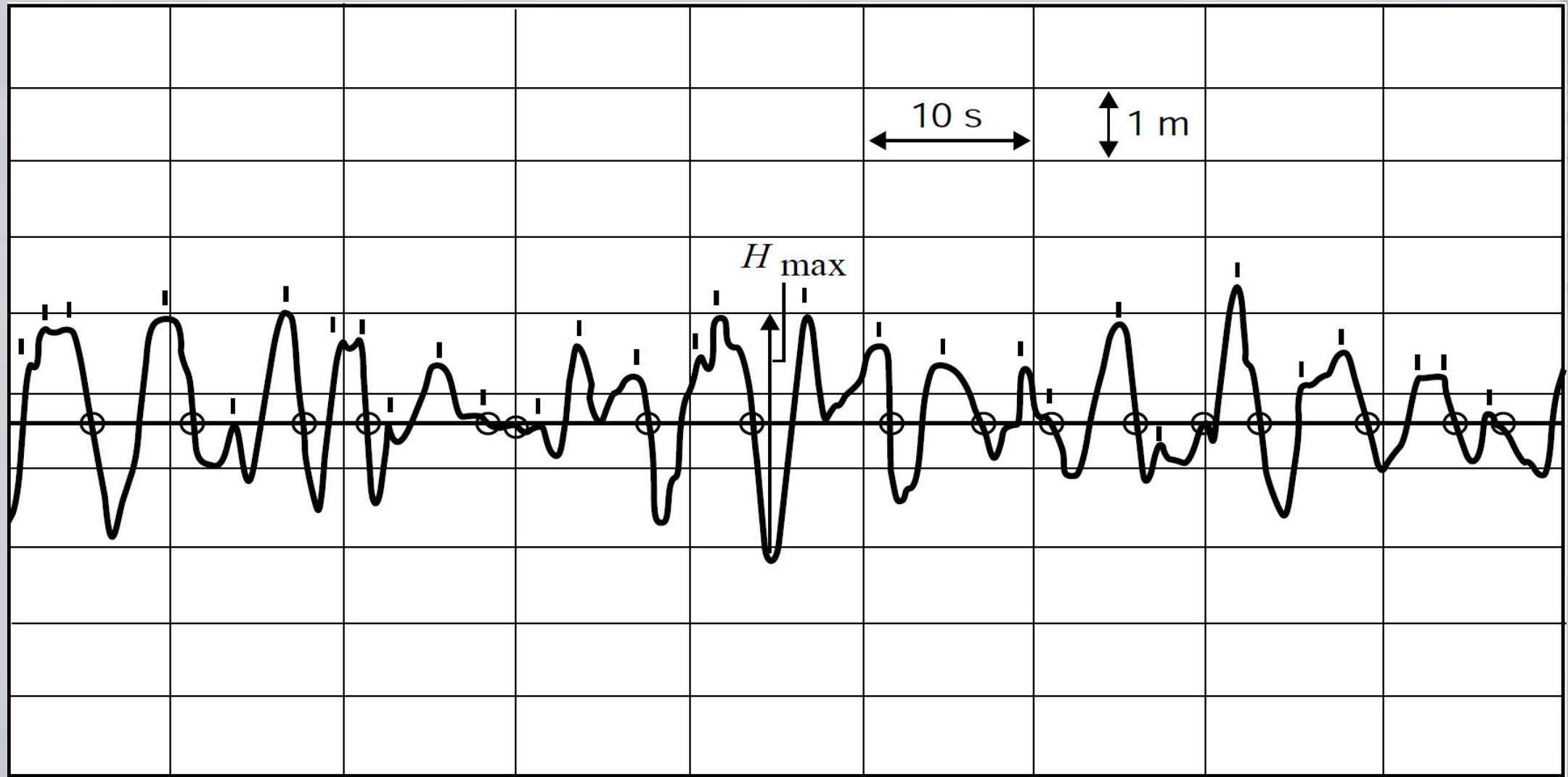
wave period: time between two succeeding wave crests

wave steepness: waveheight-to-wavelength ratio **$S = H / L$** .

The steepness of a wave is the ratio of its height to the length. From theoretical reasons the steepness cannot exceed values of $1/7$, typical values are $1/10$, in open seas $1/50$ to $1/100$.

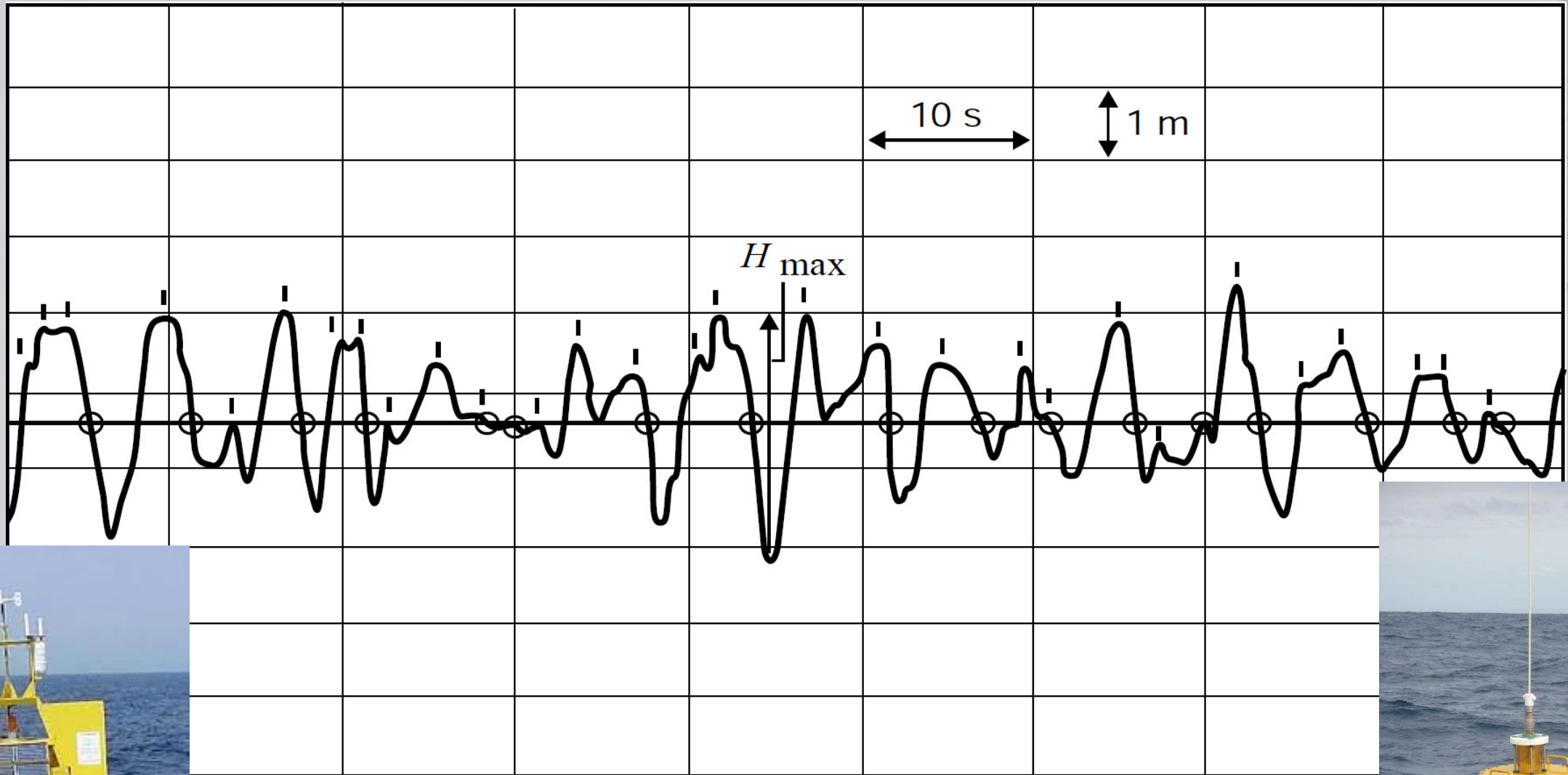
phase velocity: wavelength - to - wave period - ratio **$c = L / T$**

TIME-SERIES OF SEA AND SWELL

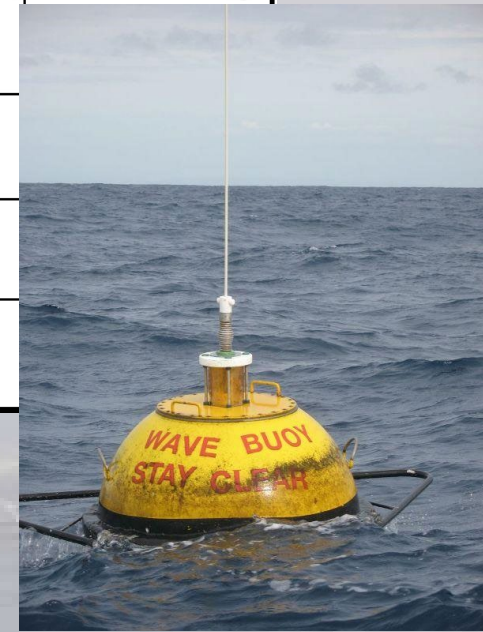


Typical time-series of a wave-rider bouy

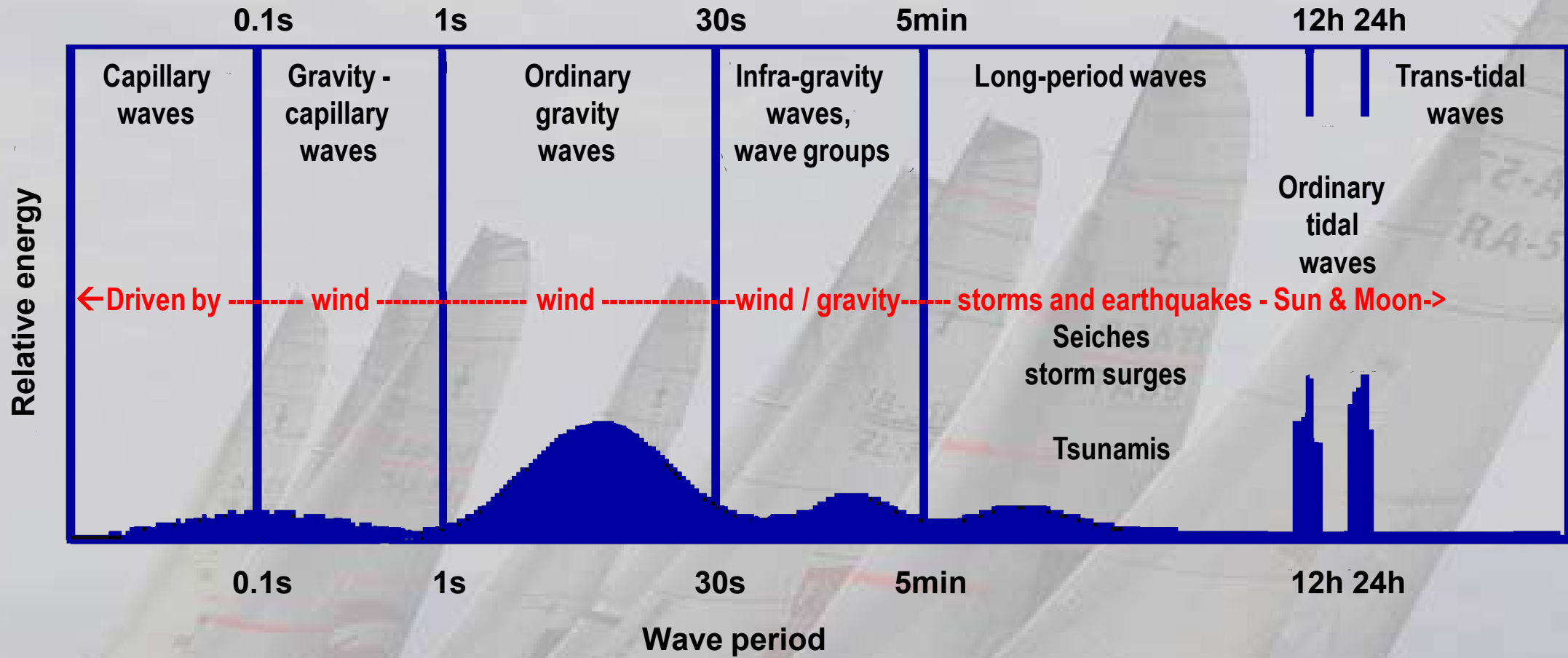
TIME-SERIES OF SEA AND SWELL



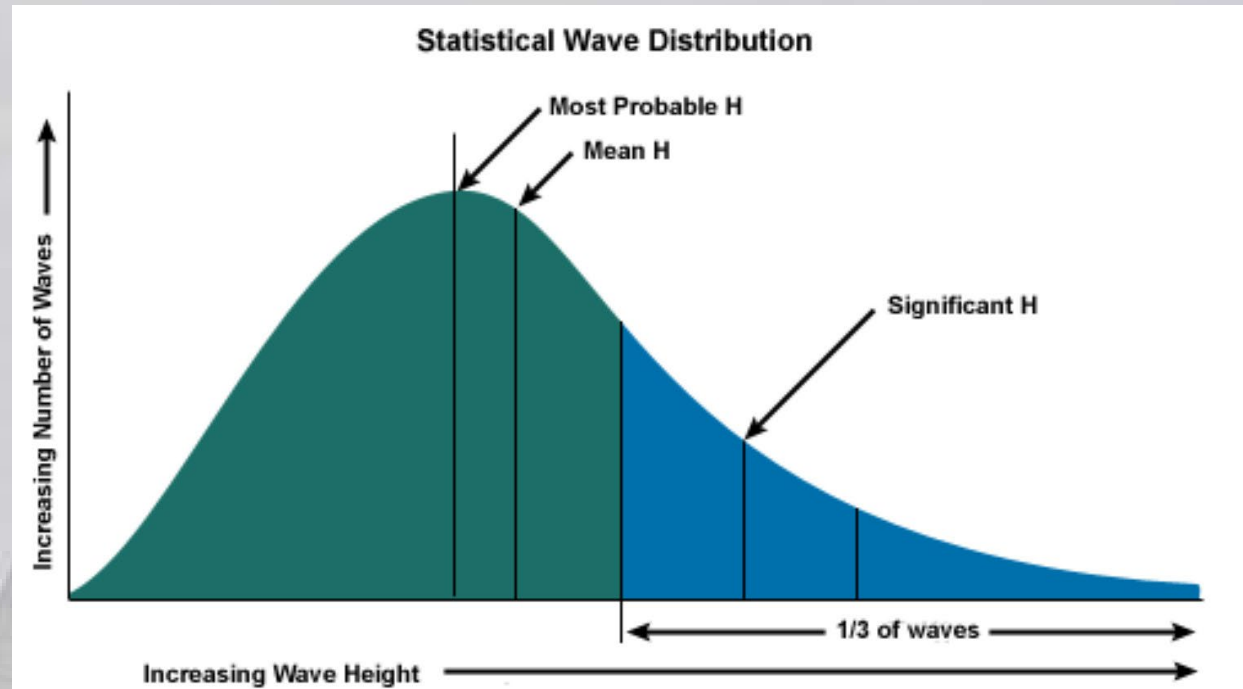
Typical time-series of a wave-rider buoy



WAVE SPECTRUM: HOW MUCH ENERGY IS IN WHICH WAVES ?



SIGNIFICANT (CHARAKTERISTIC) WAVE HEIGHT H_s



Mean of third of highest wave H_s

Sea / swell spectrum: 14 % of waves are higher than H_s

1 % > $1.5 * H_s$ 0.3 % > $2 * H_s$

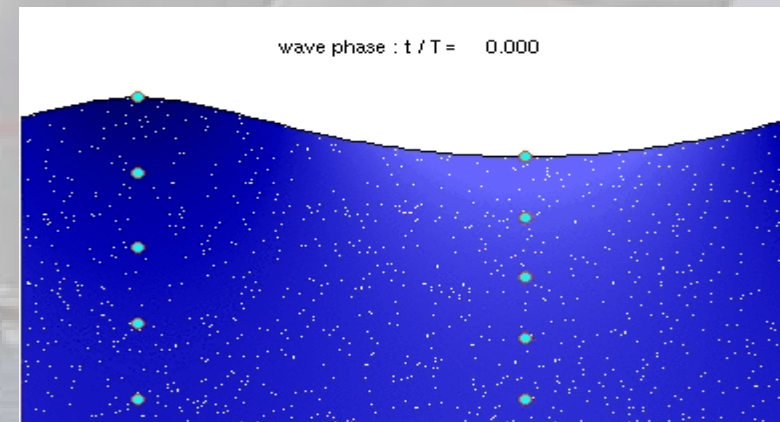
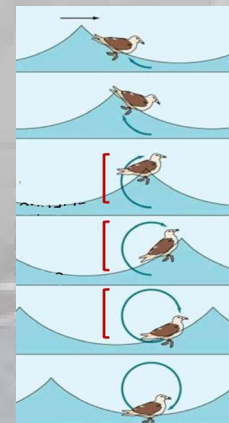
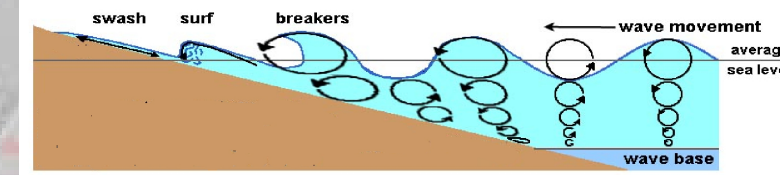
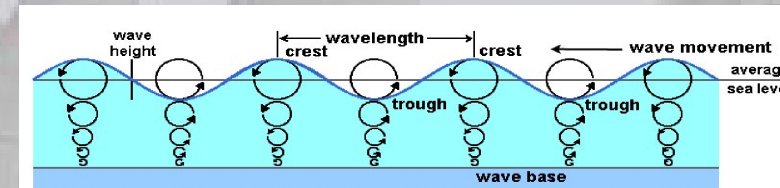
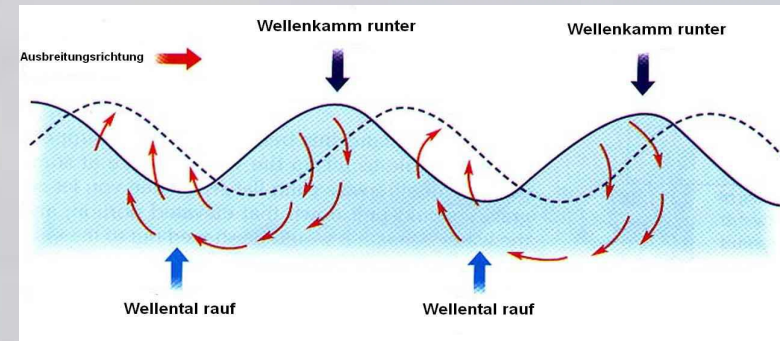
Example: height of sea $H_s = 3$ m, period $T = 6$ sec:

every 100. wave > 4.5 m, every 300. wave > 6 m

CHARAKTERISTICS OF WAVE MOTION

Water particles perform an orbital movement at an almost fix position

- Water particles remain at a fix position. there is no mass transport of water in direction of wave propagation
- Wave propagation ... the longer the wave ... the faster the longer the period ... the faster
- Wave trough up - slightly ahead wave crest down - slightly back
- Circle diameter approx. wave height
- Depth of decay approx. Wave lenght / 2



CHARACTERISTICS OF WAVE MOTION

Wave propagation velocity

Deep water

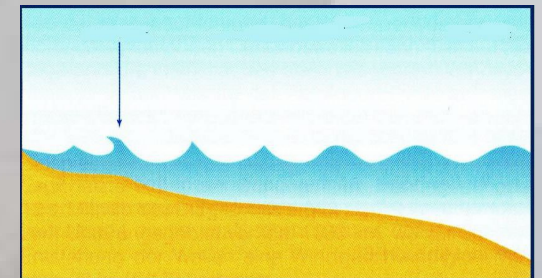
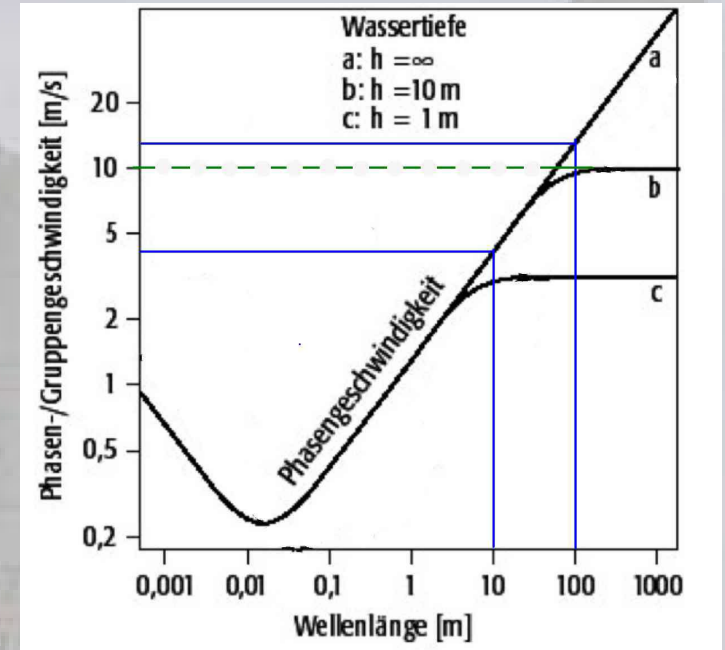
- The longer the wavelength ... the faster
- The longer the wave period ... the faster

Decreasing water depth

- Wave height ... increases
- Wavelength ... increases
- Period ... constant

Approaching shore with breaking of waves

- Phase velocity decreasing
- Wave propagation velocity $\sqrt{g * h}$
- Following waves are overrunning preceding
- Forming of surf and breaking waves



Sea (directly wind driven waves)

- Waves driven by current wind conditions
- Crests with wide variety of waveforms
- Non-linear growth with windspeed
- Is a function of windspeed, fetch, duration, depth and current

Swell (waves generated by wind at another place in the past)

- Waves generated by wind in the past at another place
- Rounded wave forms, prevailing long wavelengths
- Propagation of long waves is faster than of short waves
- May indicate from which direction to expect heavy seas

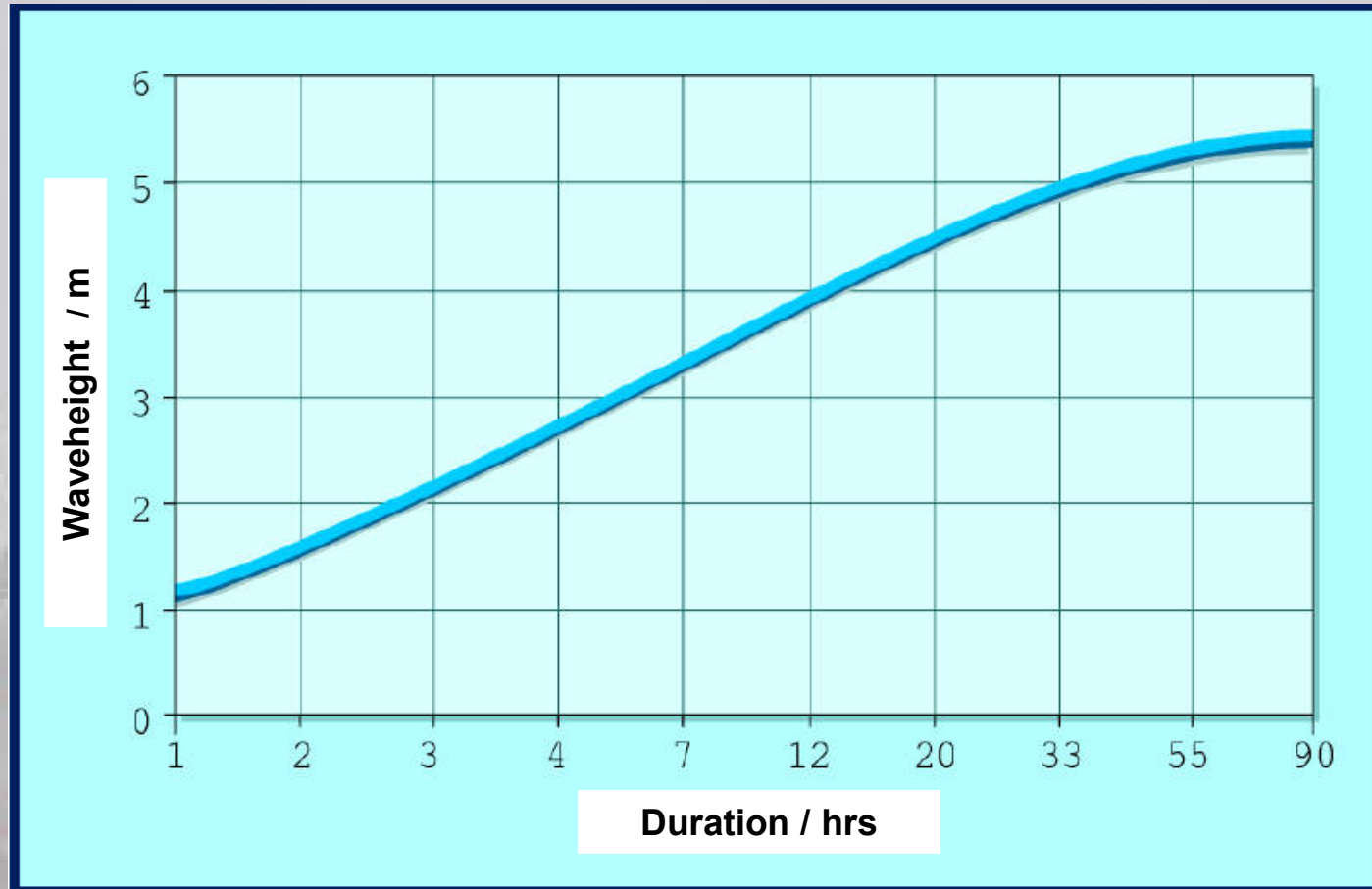
Cross sea

- Superposition of swell waves from different directions with sea driven by current wind conditions. Very chippy (Fastnet-Race)

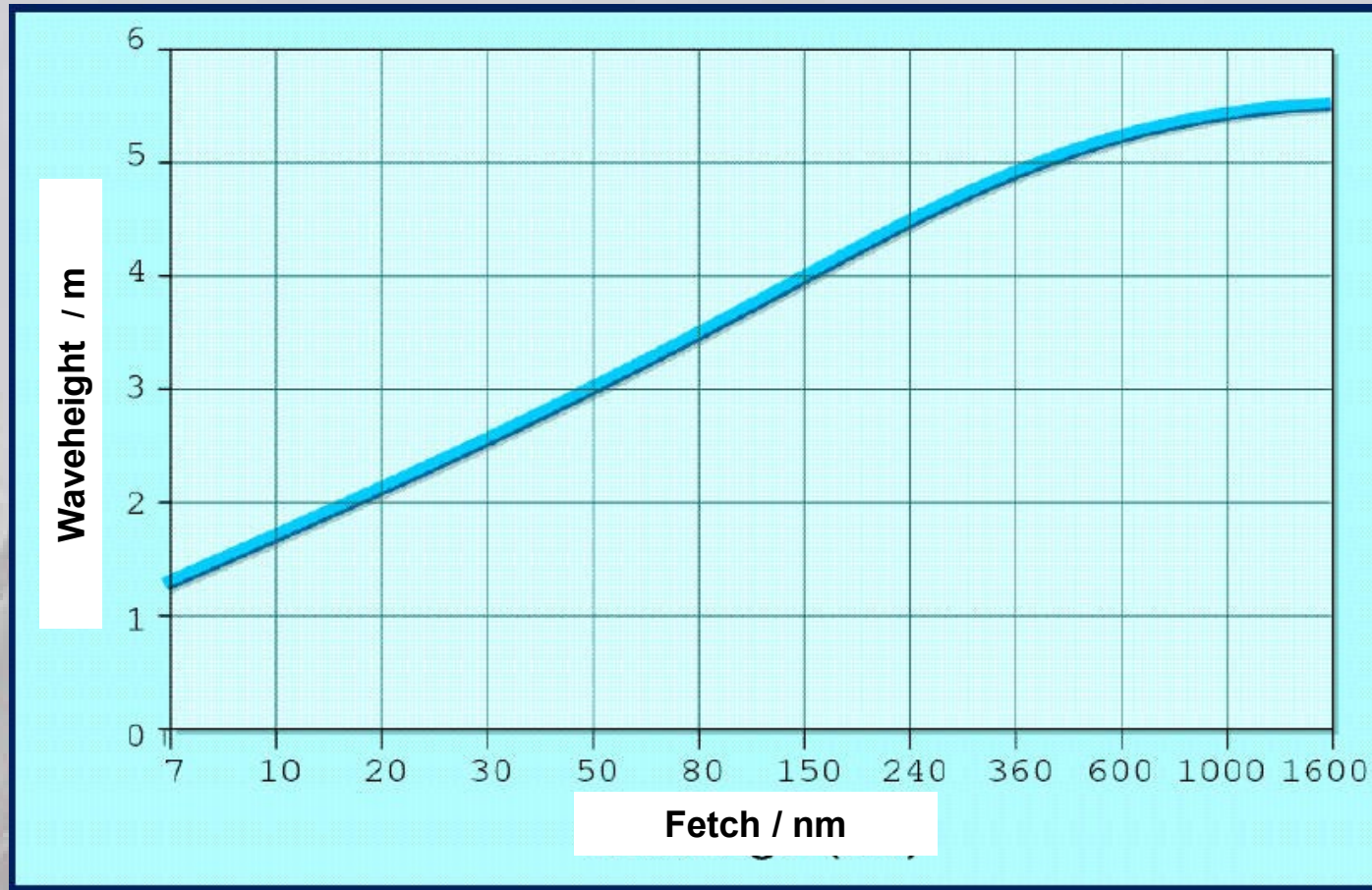
Ground sea

- Forming over shallow water (shoal), steep and high waves

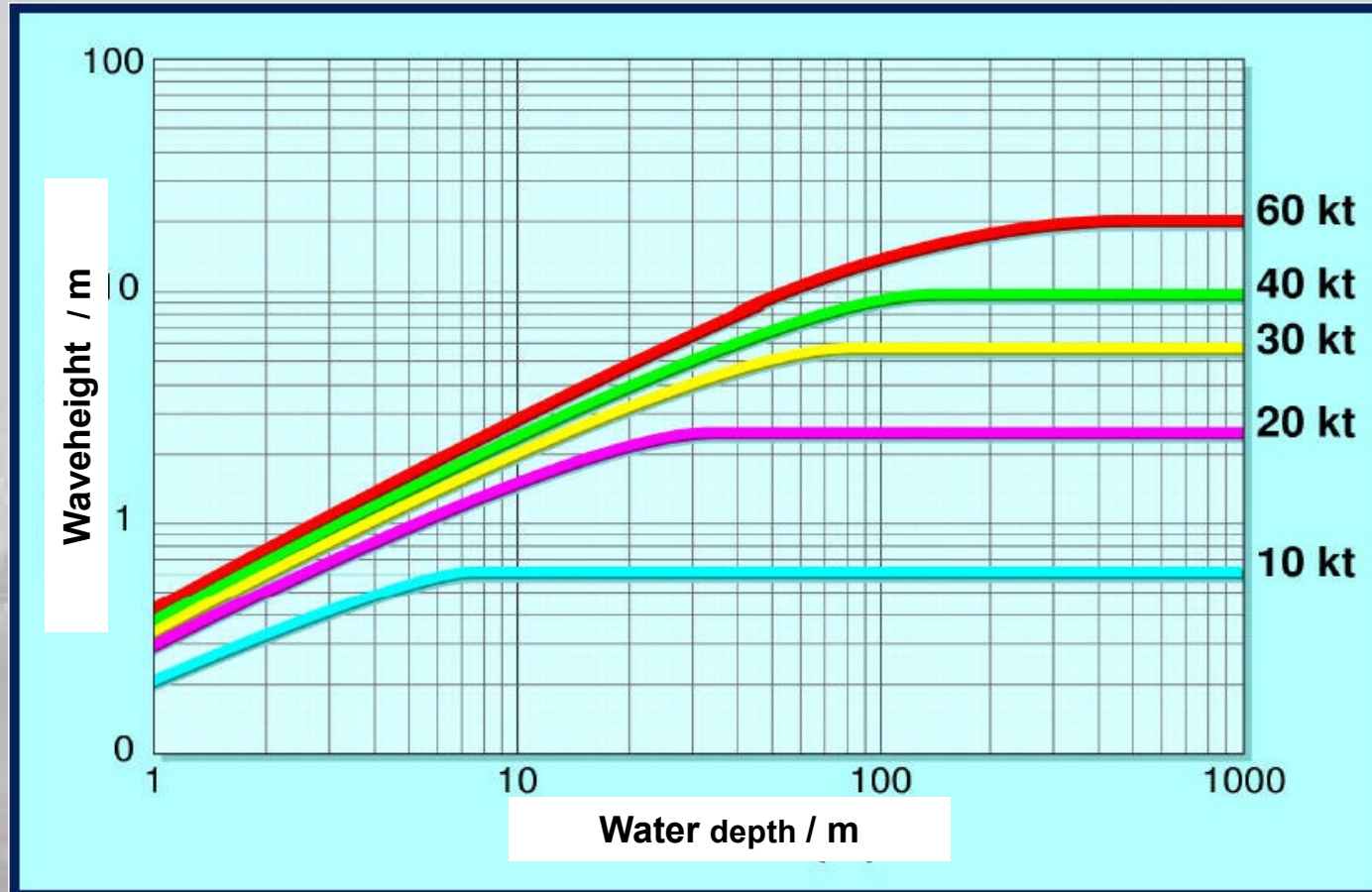
BFT 7: WAVE HEIGHT AS A FUNCTION OF FETCH



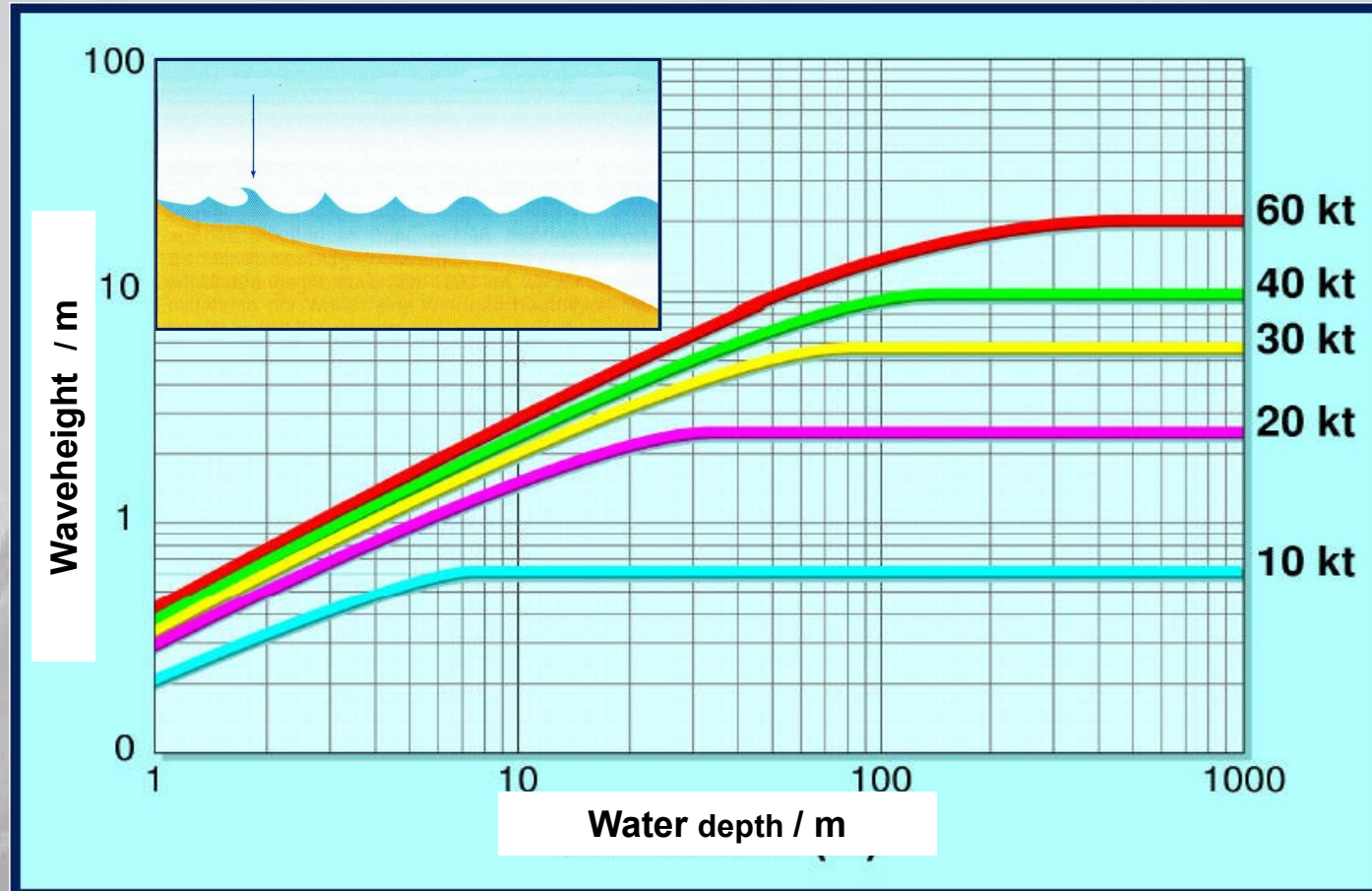
BFT 7: WAVE HEIGHT AS A FUNCTION OF FETCH



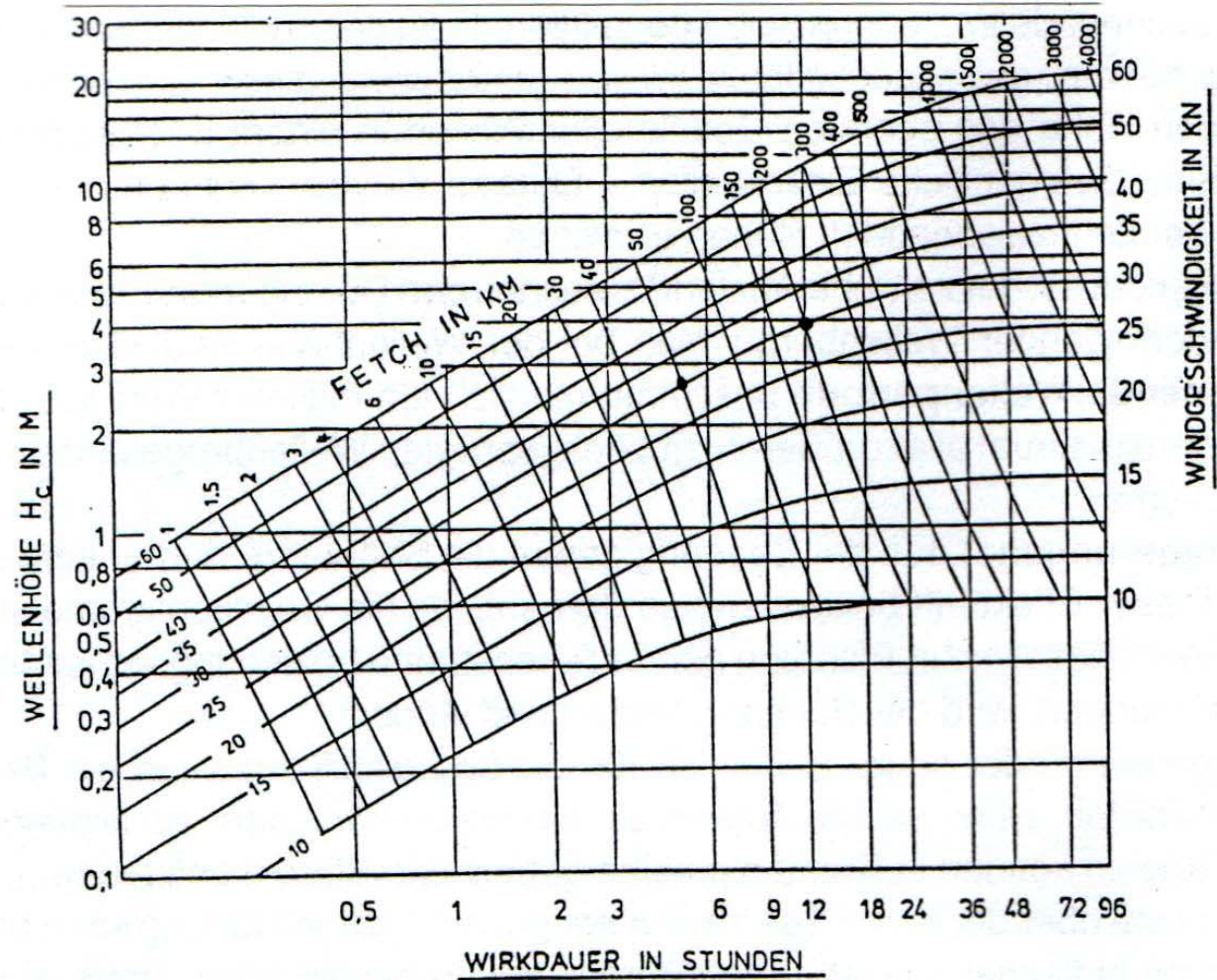
WAVE HEIGHT AS A FUNCTION OF WATER DEPTH



MODIFICATION OF WAVE HEIGHT WITH DECREASING WATER DEPTH

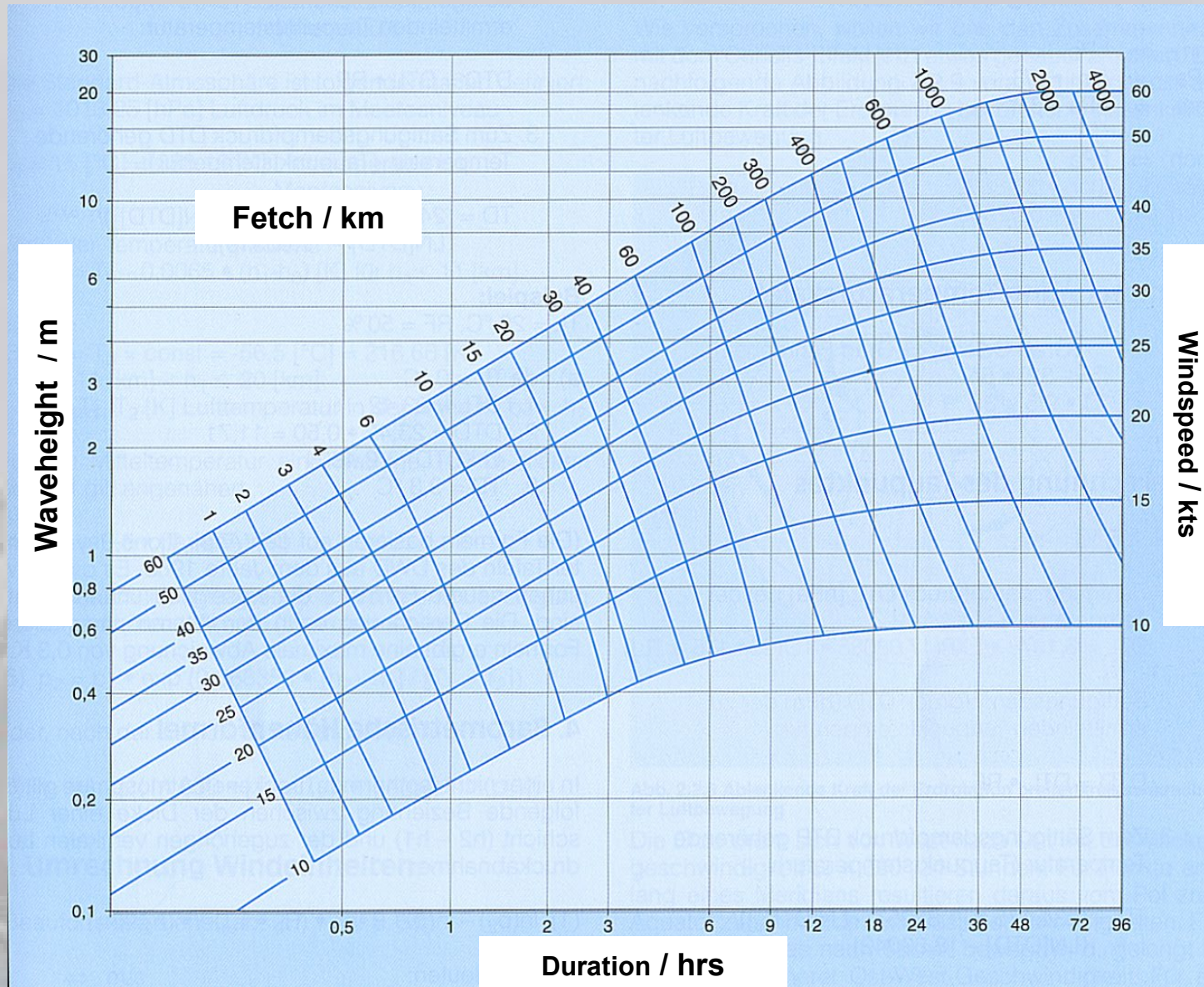


WAVE HEIGHT AS A FUNCTION OF WIND FORCE, FETCH, DURATION



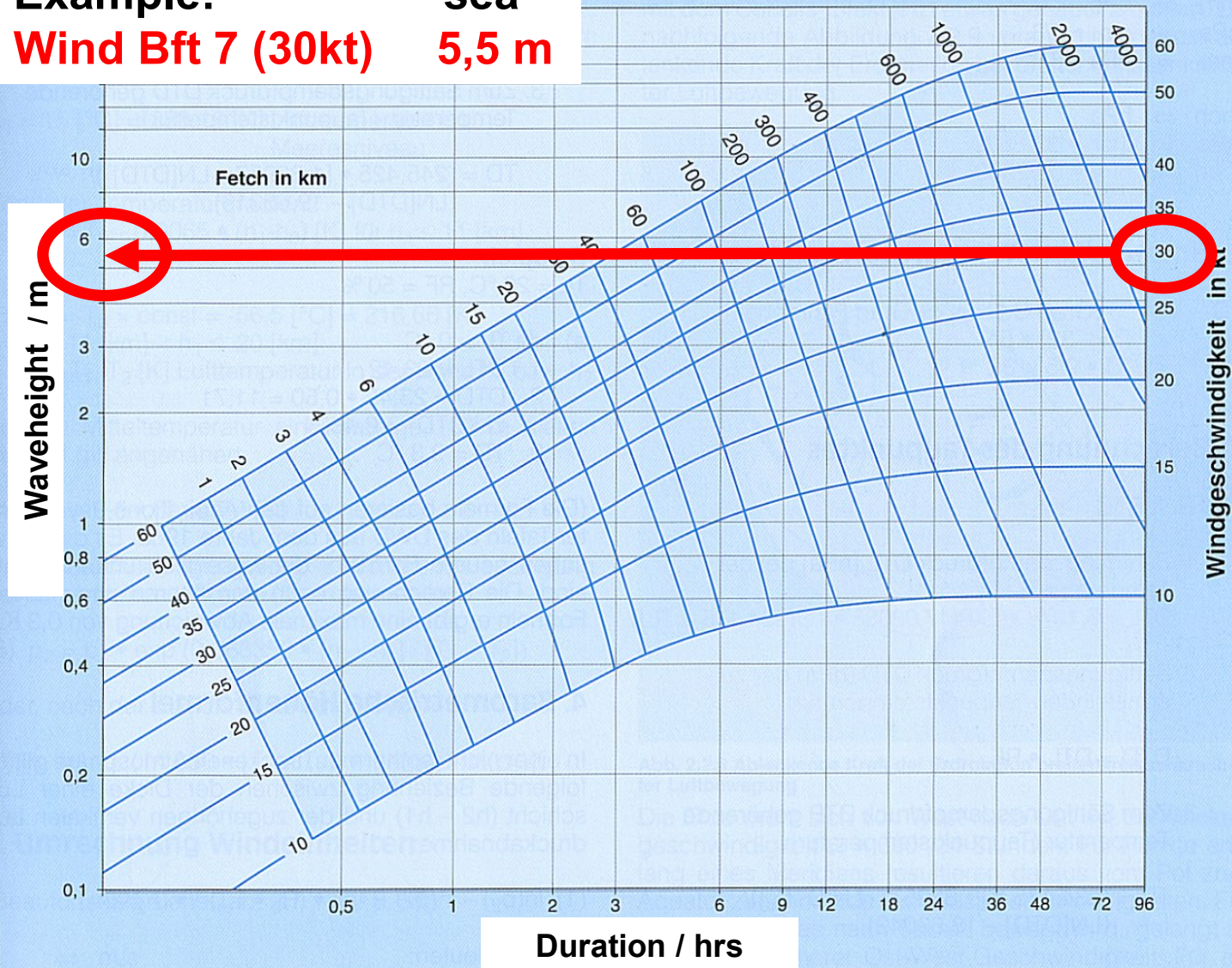
3 Nomogramm zur Bestimmung der kennzeichnenden Wellenhöhe aus Windgeschwindigkeit, Wirkdauer und Wirklänge (Fetch).

WAVE HEIGHT AS A FUNCTION OF WIND FORCE, FETCH, DURATION



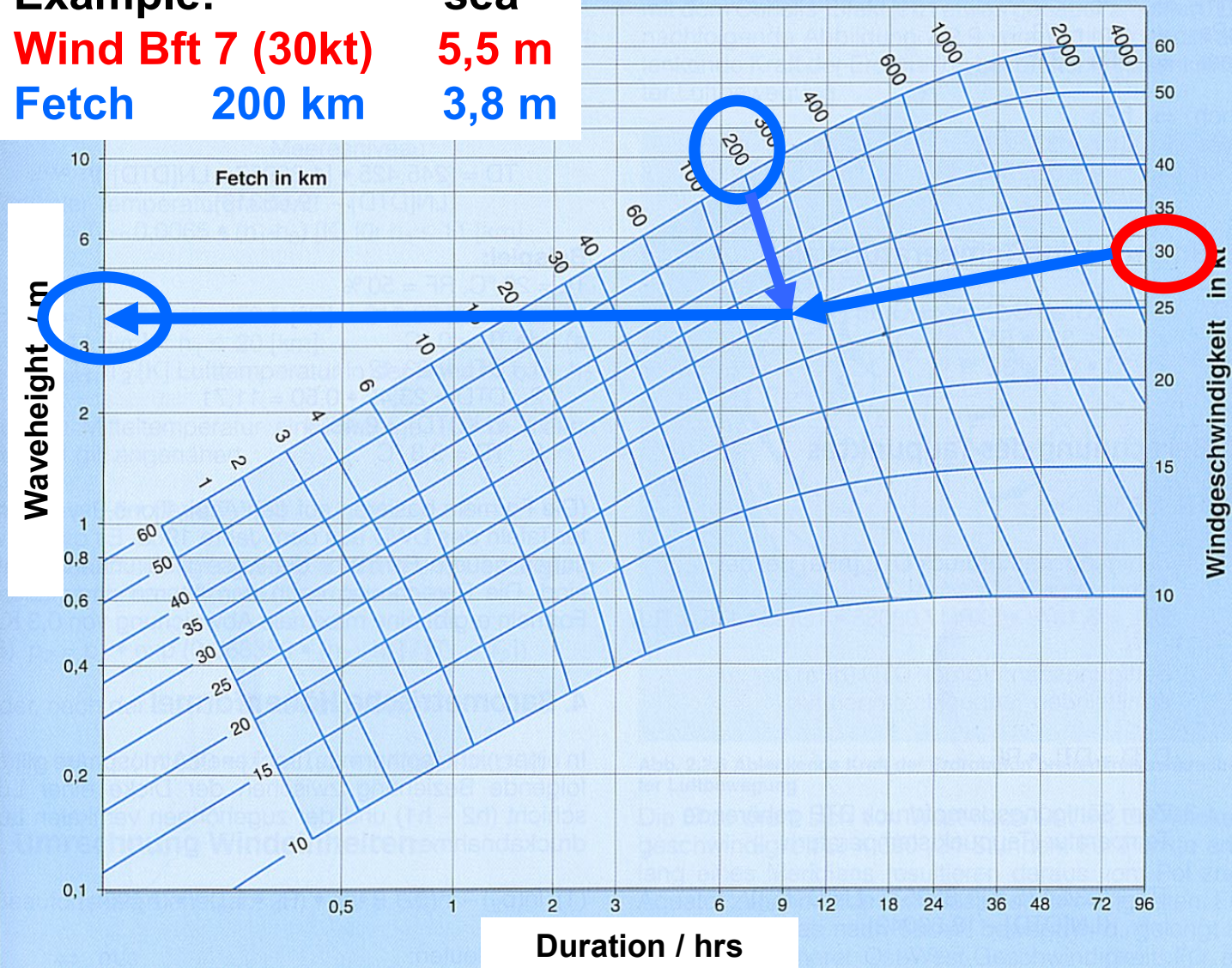
WAVE HEIGHT AS A FUNCTION OF WIND FORCE, FETCH, DURATION

Example: sea
Wind Bft 7 (30kt) 5,5 m



WAVE HEIGHT AS A FUNCTION OF WIND FORCE, FETCH, DURATION

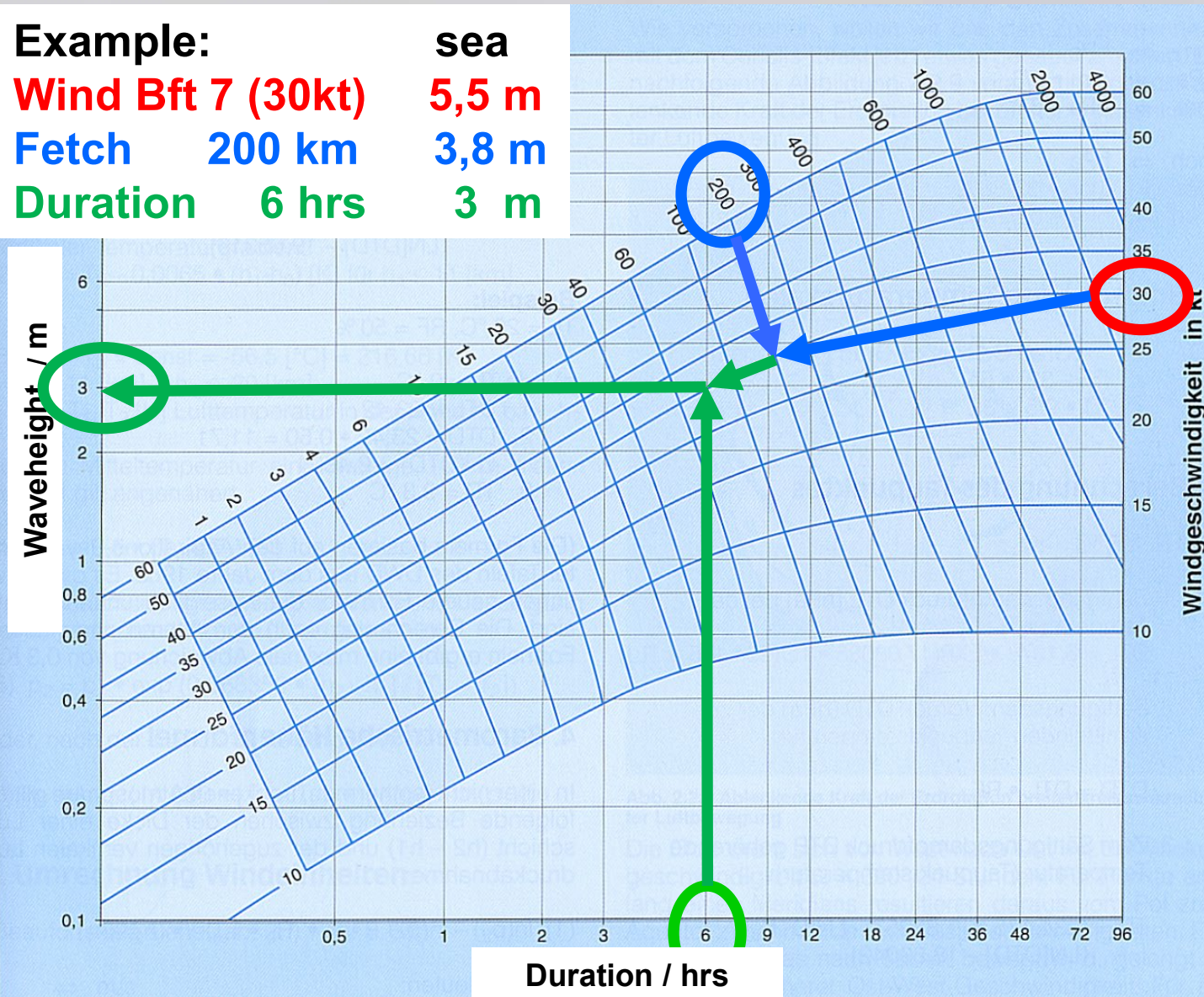
Example:
Wind Bft 7 (30kt)
Fetch 200 km
sea 5,5 m
3,8 m



WAVE HEIGHT AS A FUNCTION OF WIND FORCE, FETCH, DURATION

Example:
Wind Bft 7 (30kt)
Fetch 200 km
Duration 6 hrs

sea
5,5 m
3,8 m
3 m



DISTANCE OF SWELL GENERATING WIND FIELD

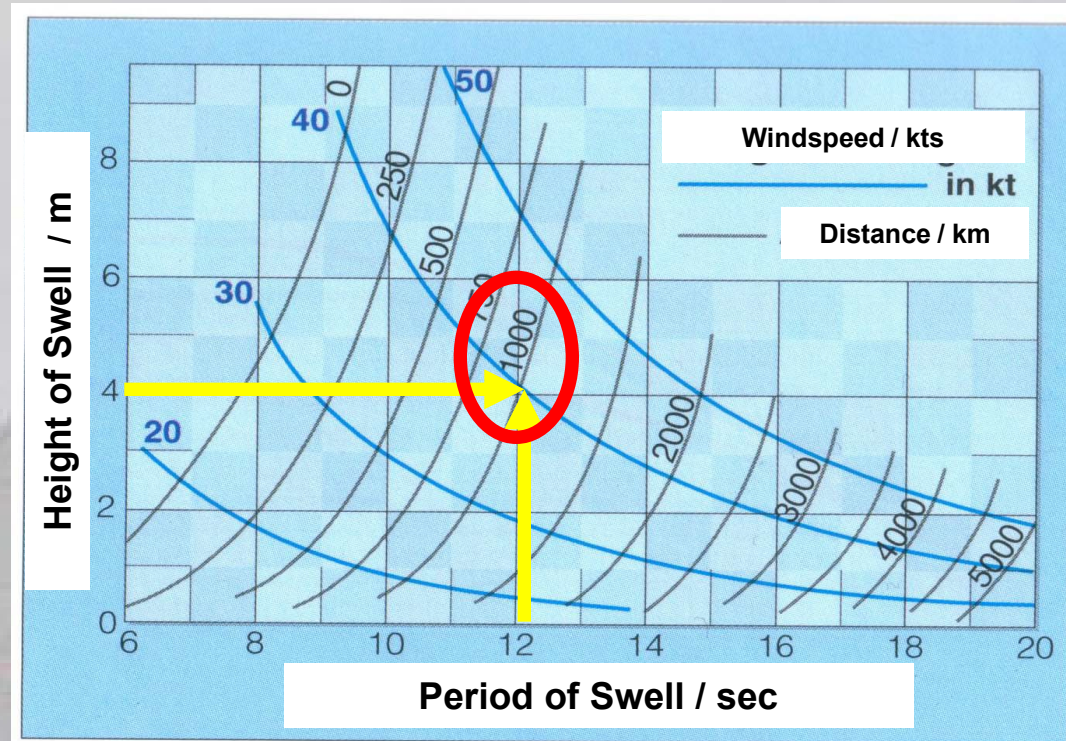
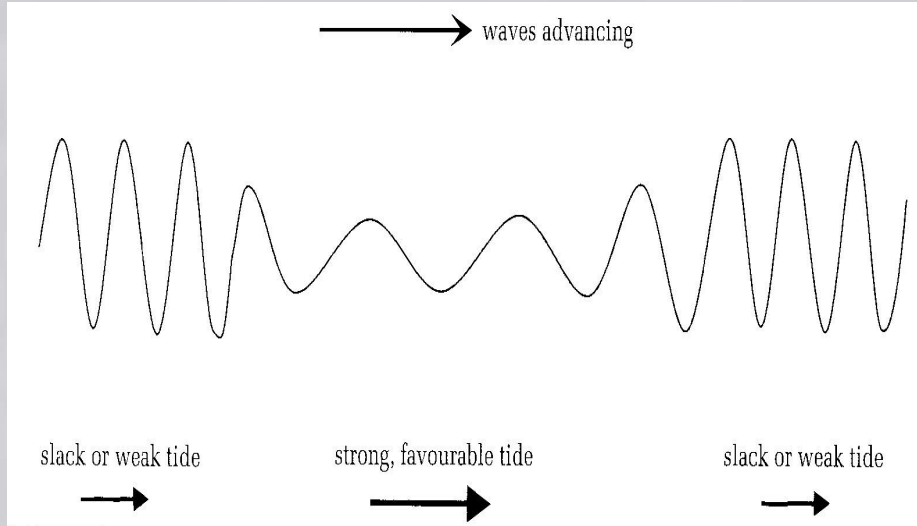
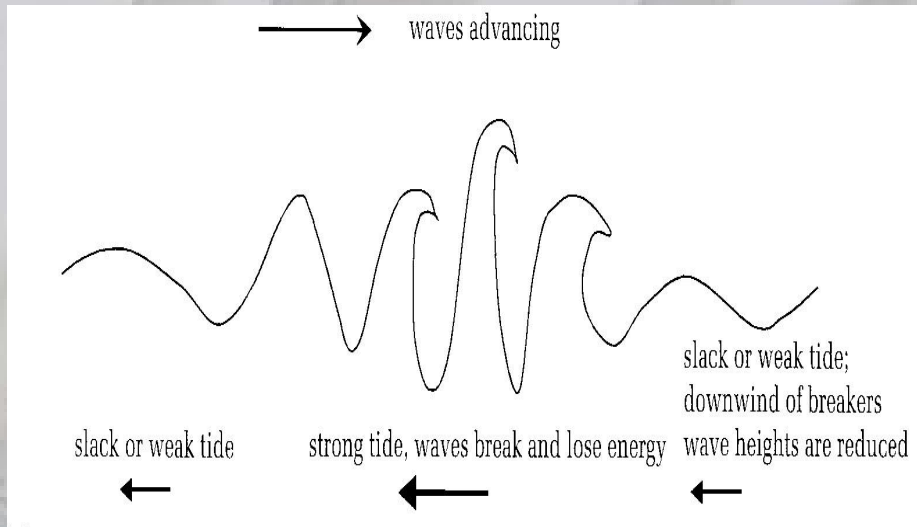


Abb. 21.8 Diagramm zur Abschätzung der Entfernung und der Stärke eines Windfeldes aus der einlaufenden Dünung

MODIFICATION OF SEA ROUGHNESS BY CURRENT



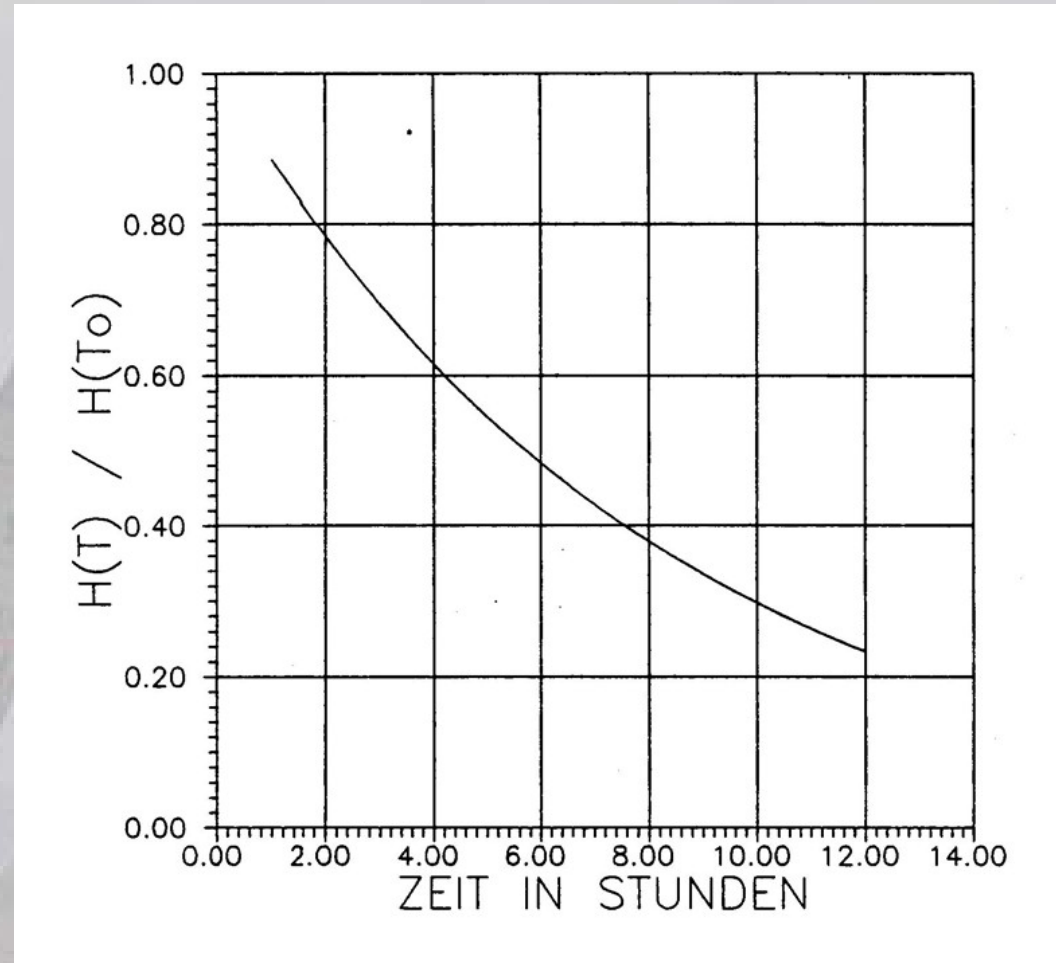
- Current in same direction as propagation of sea ... wavelength of sea increases (sea less rough)



- Current in opposite direction to propagation of sea ... wavelength of sea decreases (rougher sea)

The above holds for tidal currents as well as for other currents (e.g. Agulhas)

DECAY OF SEA WAVE HEIGHT




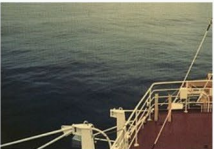



BEAUFORT SCALE : EQUIVALENT WIND SPEEDS

Beaufort-grad	m/s	km/h	m. p. h.	Knoten	Staudruck in kg/m ²
0	0 — 0,2	1	1	1	0
1	0,3— 1,5	1— 5	1— 3	1— 3	0— 0,1
2	1,6— 3,3	6— 11	4— 7	4— 6	0,2— 0,6
3	3,4— 5,4	12— 19	8—12	7—10	0,7— 1,8
4	5,5— 7,9	20— 28	13—18	11—15	1,9— 3,9
5	8,0—10,7	29— 38	19—24	16—21	4,0— 7,2
6	10,8—13,8	39— 49	25—31	22—27	7,3—11,9
7	13,9—17,1	50— 61	32—38	28—33	12,0—18,3
8	17,2—20,7	62— 74	39—46	34—40	18,4—26,8
9	20,8—24,4	75— 88	47—54	41—47	26,9—37,7
10	24,5—28,4	89—102	55—63	48—55	37,4—50,5
11	28,5—32,6	103—117	64—72	56—63	50,6—66,5
12	32,7 und mehr	118 und mehr	73 und mehr	64 und mehr	66,6 und mehr

BEAUFORT SCALE : EQUIVALENT WIND SPEEDS

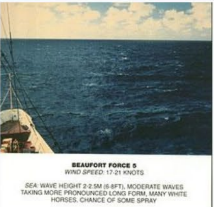
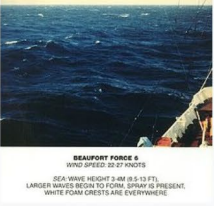

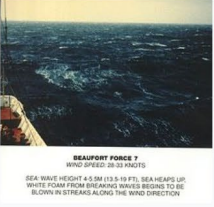

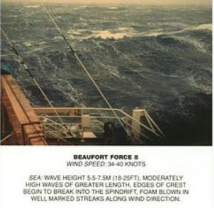

Beaufort-grad	m/s	km/h	m. p. h.	Knoten	Staudruck in kg/m ²
0	0				
1	0,3	1	1	1	0
2	1,6	6	4	4	0,2
3	3,4	12	8	7	0,7
4	5,5	20	13	11	1,9
5	8,0	29	19	16	4,0
6	10,8	39	25	22	7,3
7	13,9	50	32	28	12,0
8	17,2	62	39	34	18,4
9	20,8	75	47	41	26,9
10	24,5	89	55	48	37,4
11	28,5	103	64	56	50,6
12	32,7 und mehr	118 und mehr	73 und mehr	64 und mehr	66,6 und mehr

BEAUFORT SCALE: DESCRIPTION OF WAVES




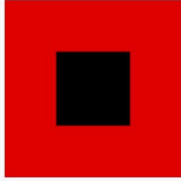
Beaufort number	Description	Wind speed	Wave height	Sea conditions	Land conditions	Sea state photo	Associated warning flag
0	Calm	< 1 km/h	0 m	Sea like a mirror	Smoke rises vertically.		
		< 1 mph					
		< 1 knot	0 ft				
		< 0.3 m/s					
1	Light air	1–5 km/h	0–0.2 m	Ripples with appearance of scales are formed, without foam crests	Direction shown by smoke drift but not by wind vanes.		
		1–3 mph					
		1–3 knots	0–1 ft				
		0.3–1.5 m/s					
2	Light breeze	6–11 km/h	0.2–0.5 m	Small wavelets still short but more pronounced; crests have a glassy appearance but do not break	Wind felt on face; leaves rustle; wind vane moved by wind.		
		4–7 mph					
		4–6 knots	1–2 ft				
		1.6–3.3 m/s					
3	Gentle breeze	12–19 km/h	0.5–1 m	Large wavelets; crests begin to break; foam of glassy appearance; perhaps scattered white horses	Leaves and small twigs in constant motion; light flags extended.		
		8–12 mph					
		7–10 knots	2–3.5 ft				
		3.4–5.5 m/s					
4	Moderate breeze	20–28 km/h	1–2 m	Small waves becoming longer; fairly frequent white horses	Raises dust and loose paper; small branches moved.		
		13–18 mph					
		11–16 knots	3.5–6 ft				
		5.5–7.9 m/s					
Beaufort number	Description	Wind speed	Wave height	Sea conditions	Land conditions	Sea state photo	Associated warning flag




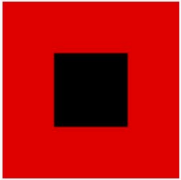

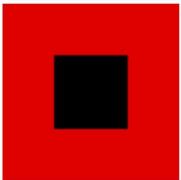
BEAUFORT SCALE: DESCRIPTION OF WAVES

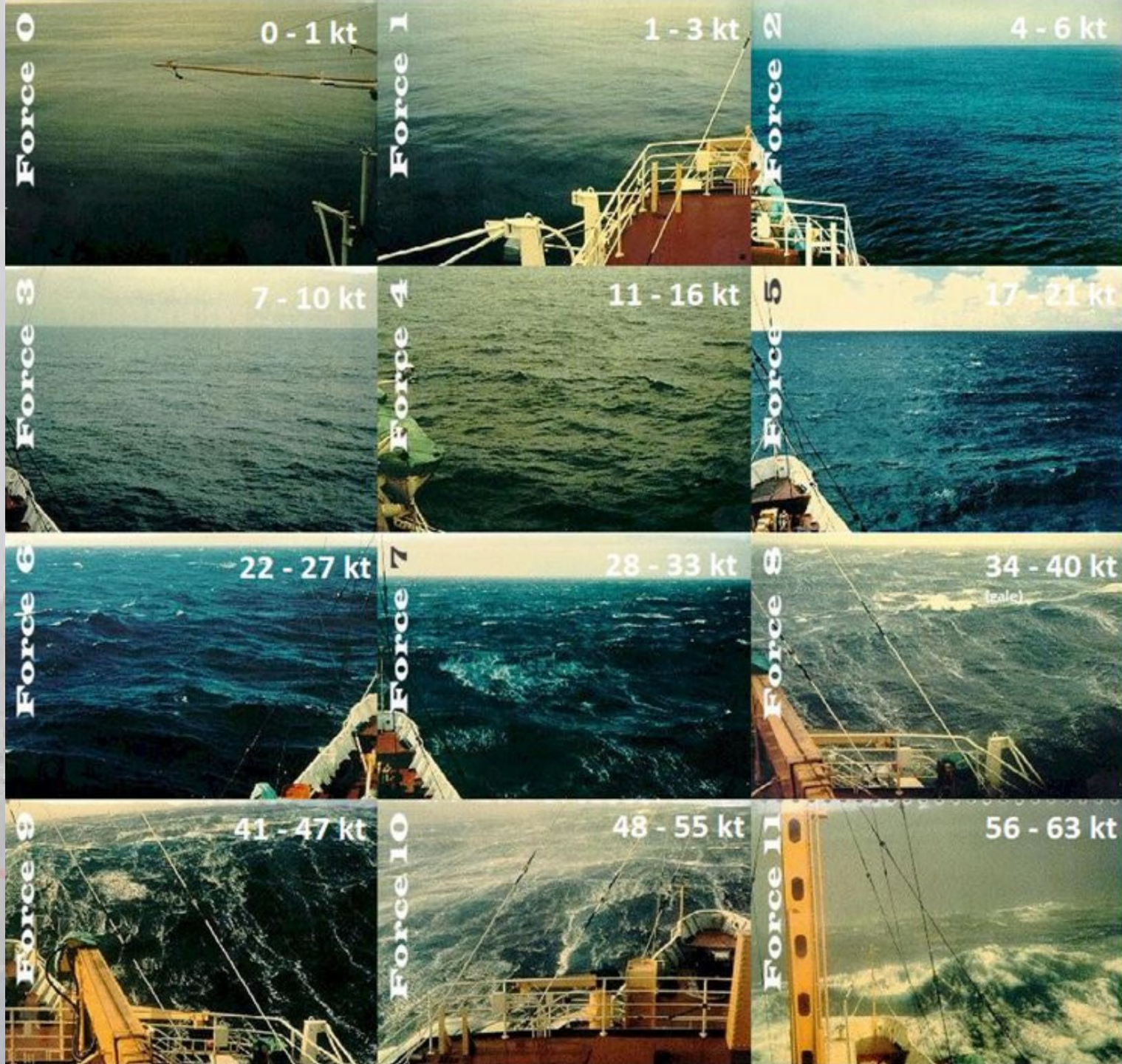
Beaufort number	Description	Wind speed	Wave height	Sea conditions	Land conditions	Sea state photo	Associated warning flag
5	Fresh breeze	29–38 km/h	2–3 m	Moderate waves taking a more pronounced long form; many white horses are formed; chance of some spray	Small trees in leaf begin to sway; crested wavelets form on inland waters.	 <p>BEAUFORT FORCE 5 WIND SPEED: 17-21 KNOTS SEA: WAVE HEIGHT 2-3M (6-9FT), MODERATE WAVES, TAKING MORE PRONOUNCED LONG FORM, MANY WHITE HORSES, CHANCE OF SOME SPRAY</p>	
		19–24 mph					
		17–21 knots	6–9 ft				
		8–10.7 m/s					
6	Strong breeze	39–49 km/h	3–4 m	Large waves begin to form; the white foam crests are more extensive everywhere; probably some spray	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty.	 <p>BEAUFORT FORCE 6 WIND SPEED: 22-27 KNOTS SEA: WAVE HEIGHT 3-4M (9-13 FT), LARGER WAVES BEGIN TO FORM, SPRAY IS PRESENT, WHITE FOAM CRESTS ARE EVERYWHERE</p>	
		25–31 mph					
		22–27 knots	9–13 ft				
		10.8–13.8 m/s					
7	High wind, moderate gale, near gale	50–61 km/h	4–5.5 m	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind; spindrift begins to be seen	Whole trees in motion; inconvenience felt when walking against the wind.	 <p>BEAUFORT FORCE 7 WIND SPEED: 28-33 KNOTS SEA: WAVE HEIGHT 4-5.5M (13-18 FT), SEA HEAPS UP, WHITE FOAM FROM BREAKING WAVES BEGINS TO BE BLOWN IN STREAKS ALONG THE WIND DIRECTION</p>	
		32–38 mph					
		28–33 knots	13–19 ft				
		13.9–17.1 m/s					
8	Gale, fresh gale	62–74 km/h	5.5–7.5 m	Moderately high waves of greater length; edges of crests break into spindrift; foam is blown in well-marked streaks along the direction of the wind	Twigs break off trees; generally impedes progress.	 <p>BEAUFORT FORCE 8 WIND SPEED: 34-40 KNOTS SEA: WAVE HEIGHT 5.5-7.5M (18-25 FT), MODERATELY HIGH WAVES OF GREATER LENGTH, EDGES OF CREST BEGIN TO BREAK INTO THE SPINDRIFT, FOAM BLOWN IN WELL MARKED STREAKS ALONG WIND DIRECTION</p>	
		39–46 mph					
		34–40 knots	18–25 ft				
		17.2–20.7 m/s					
Beaufort number	Description	Wind speed	Wave height	Sea conditions	Land conditions	Sea state photo	Associated warning flag

BEAUFORT SCALE: DESCRIPTION OF WAVES

Beaufort number	Description	Wind speed	Wave height	Sea conditions	Land conditions	Sea state photo	Associated warning flag
9	Strong/severe gale	75–88 km/h	7–10 m	High waves; dense streaks of foam along the direction of the wind; sea begins to roll; spray affects visibility	Slight structural damage (chimney pots and slates removed).	 <p><small>BEAUFORT FORCE 9 WIND SPEED: 41-47 KNOTS SEA: WAVE HEIGHT 7-10M (23-32FT). HIGH WAVES, DENSE STREAKS OF FOAM ALONG DIRECTION OF THE WIND. WAVE CRESTS BEGIN TO TOPPLE, TUMBLE, AND ROLL OVER. SPRAY MAY AFFECT VISIBILITY.</small></p>	
		47–54 mph					
		41–47 knots	23–32 ft				
		20.8–24.4 m/s					
10	Storm, ^[7] whole gale	89–102 km/h	9–12.5 m	Very high waves with long overhanging crests; resulting foam in great patches is blown in dense white streaks along the direction of the wind; on the whole the surface of the sea takes on a white appearance; rolling of the sea becomes heavy; visibility affected	Seldom experienced inland; trees uprooted; considerable structural damage.	 <p><small>BEAUFORT FORCE 10 WIND SPEED: 48-55 KNOTS SEA: WAVE HEIGHT 9-12.5M (30-41FT). VERY HIGH WAVES WITH LONG OVERHANGING CRESTS. THE RESULTING FOAM IN GREAT PATCHES IS BLOWN IN DENSE WHITE STREAKS ALONG WIND DIRECTION ON THE WHOLE. SEA SURFACE TAKES A WHITE APPEARANCE. TUMBLING OF THE SEA IS HEAVY AND SHOCK LIKE. VISIBILITY AFFECTED.</small></p>	
		55–63 mph					
		48–55 knots	29–41 ft				
		24.5–28.4 m/s					
Beaufort number	Description	Wind speed	Wave height	Sea conditions	Land conditions	Sea state photo	Associated warning flag

BEAUFORT SCALE: DESCRIPTION OF WAVES

Beaufort number	Description	Wind speed	Wave height	Sea conditions	Land conditions	Sea state photo	Associated warning flag
11	Violent storm	103–117 km/h	11.5–16 m	Exceptionally high waves; small- and medium-sized ships might be for a long time lost to view behind the waves; sea is covered with long white patches of foam; everywhere the edges of the wave crests are blown into foam; visibility affected	Very rarely experienced; accompanied by widespread damage.	 <p>BEAUFORT FORCE 11 WIND SPEED: 50-60 KNOTS</p> <p>SEA: WAVE HEIGHT 11.5-16M (37-52FT), EXCEPTIONALLY HIGH WAVES. SMALL MEDIUM SIZED SHIPS MAY BE LOST TO VIEW BEHIND THE WAVES. SEA COMPLETELY COVERED WITH LONG WHITE PATCHES OF FOAM LINED ALONG WIND DIRECTION. EVERYWHERE THE EDGES OF WAVE CRESTS ARE BLOWN INTO FOAM.</p>	
		64–72 mph					
		56–63 knots	37–52 ft				
		28.5–32.6 m/s					
12	Hurricane force ^[7]	≥ 118 km/h	≥ 14 m	The air is filled with foam and spray; sea is completely white with driving spray; visibility very seriously affected	Devastation.	 <p>BEAUFORT FORCE 12 WIND SPEED: 64 KNOTS</p> <p>SEA: SEA COMPLETELY WHITE WITH DRIVING SPRAY. VISIBILITY VERY SERIOUSLY AFFECTED. THE AIR IS FILLED WITH FOAM AND SPRAY.</p>	
		≥ 73 mph					
		≥ 64 knots	≥ 46 ft				
		≥ 32.7 m/s					
References: Met Office, ^[8] Royal Meteorological Society, ^[9] Encyclopædia Britannica ^[10]							
Beaufort number	Description	Wind speed	Wave height	Sea conditions	Land conditions	Sea state photo	Associated warning flag



High - Very high Rough - Very rough Slight - Moderate Smooth



Bft.0 Glassy sea, like a mirror
0 kt



Bft.1 Ripples with appearance of scales are formed
1 kt



Bft.2 Small wavelets still short but more pronounced
4 kt crests have a glassy appearance but do not break



Bft.3 Large wavelets; crests begin to break;
7 kt foam of glassy appearance; perhaps scattered white horses



Bft.4 Small waves becoming longer, fairly frequent white horses
11 kt



Bft.5 Moderate waves taking a more pronounced long form
16 kt many white horses are formed, chance of some spray



Bft.6 Large waves begin to form, the white foam crests are
22 kt more extensive everywhere, probably some spray



Bft.7 Sea heaps up and white foam from breaking waves
28 kt begins to be blown in streaks along the wind direction



Bft.8 Moderately high waves of greater length; edges of crests
34 kt break into spindrift foam is blown in well-marked streaks
along the direction of the wind



Bft.9 High waves; dense streaks of foam along the wind direction
41 kt sea begins to roll; spray affects visibility



Bft.10 Very high waves with long overhanging crests; resulting foam in great patches
48 kt is blown in dense white streaks along the wind direction; the surface of the sea takes on a white appearance; rolling of the sea becomes heavy; visibility affected



Bft.11 Exceptionally high waves; small- and medium-sized ships might be for a long time
56 kt lost to view behind the waves sea is covered with long white patches of foam
everywhere the edges of the wave crests are blown into foam; visibility affected



Bft.12 The air is filled with foam and spray; sea is completely white with driving spray
64+ kt visibility very seriously affected



BEAUFORT 12 'FREAKWAVE'



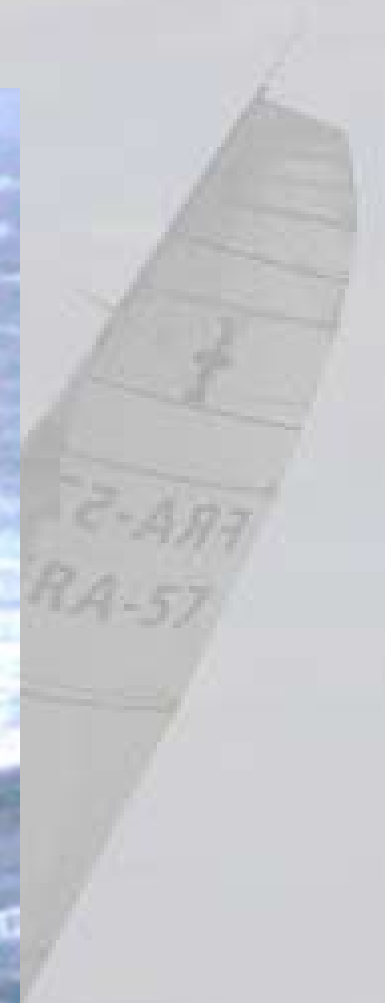
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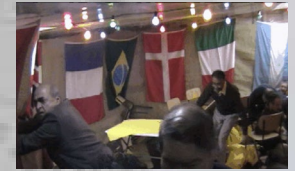
Bft.12 Tanker hit by Freak Wave



Bft. 9 Supply ship in rough sea

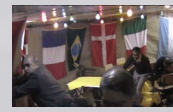


Parametric Rolling



RA-57

Parametric Rolling



1 Jan 2019 Northsea MSC Zoe loss of 270 containers



Nov 1998 Pacific APL China Typhoon Babs damage 100 M\$





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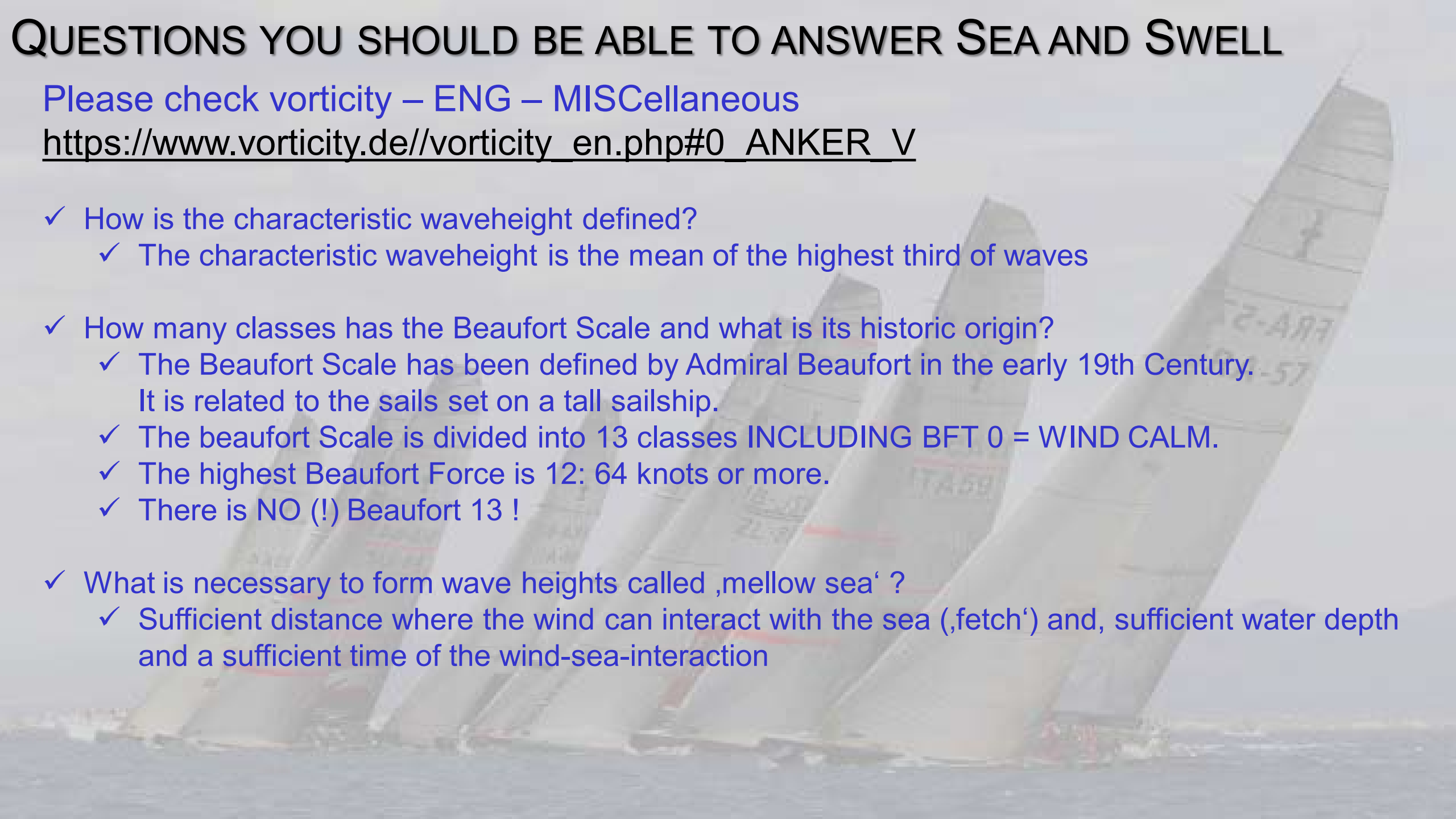
QUESTIONS YOU SHOULD BE ABLE TO ANSWER SEA AND SWELL

Please check vorticity – ENG – MISCellaneous

https://www.vorticity.de//vorticity_en.php#0 ANKER V

- ✓ How is the characteristic waveheight defined?
 - ✓ The characteristic waveheight is the mean of the highest third of waves

 - ✓ How many classes has the Beaufort Scale and what is its historic origin?
 - ✓ The Beaufort Scale has been defined by Admiral Beaufort in the early 19th Century. It is related to the sails set on a tall sailship.
 - ✓ The beaufort Scale is divided into 13 classes INCLUDING BFT 0 = WIND CALM.
 - ✓ The highest Beaufort Force is 12: 64 knots or more.
 - ✓ There is NO (!) Beaufort 13 !

 - ✓ What is necessary to form wave heights called ,mellow sea' ?
 - ✓ Sufficient distance where the wind can interact with the sea (,fetch') and, sufficient water depth and a sufficient time of the wind-sea-interaction
- 

QUESTIONS YOU SHOULD BE ABLE TO ANSWER SEA AND SWELL

- ✓ What is the reason for breaking waves to develop near the beach?
 - ✓ If the waterdepth decreases towards the beach, the wave propagation speed is defined by $\sqrt{g \cdot h}$ The lower the depth, the slower the wave propagation – following waves ,overtake‘ preceding ones thus ,breaking‘ them
- ✓ What is the difference between sea and swell?
 - ✓ Sea describes waves generated by the current wind field,
Swell has been generated by wind in the past by another storm field at another place.
 - ✓ It can have (and typically has) another direction than the current wind.
- ✓ What is a characteristic interaction between sea and swell, which maybe dangerous to sailors?
 - ✓ Cross seas – superposition of waves with different directions

