Wave Motion and Wave Actions:
Part 4  Generation of waves by the Wind

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There are four main theories of growth of waves under the action of wind. Some are more effective in the early stages of wave growth and others once the sea has developed.
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4.1 Initiation of small ripples - Phillips resonance theory

A local high static-pressure zone (or equivalently a vertical jet of air impinging on the water surface) will produce a local depression or wave. If the high pressure zone is moved at the natural speed of travel of this wave, the wave will grow. Such zones will exist in a turbulent wind. Since the wave propagates radially outwards it is only necessary that the speeds match in one direction which need not be the wind direction.
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4.1 Initiation of small ripples - Miles shear stress theory

If we travel with the wave celerity, $c$, we see the following pattern of relative motion:

As the wave is moving, this pattern occurs higher up the face of the wave and acts to drive it forward.

Energy transfer falls off as the wave speed increases therefore:
- larger waves grow more slowly
- there exists a maximum wave length for a given wind speed.
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4.2 Pressure-wave form interaction

Also known as Jeffries’ sheltering or drag or flow separation theory. Low pressure in the separation zone exerts drag on the wave profile causing acceleration.

Secondarily, shear on the wave crest accelerates particles at the peak of orbital motion.

The longer wave lengths are favoured by the separation mechanisms that dominate once the sea surface becomes rough. Hence short waves dominate initially but longer waves ultimately take over.
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4.3 Wave-wave interactions - Transfer of momentum by breaking waves

Breaking of short waves contributes energy to longer waves by various mechanisms of which the dominant one is that the wave exposed to the greatest wind and possessing the greatest curvature will break first. This wave will be a small wave at the crest of a longer wave. It will transfer the momentum of its crest to the upper water layers, in phase with the movement of the longer wave.

Banner and Phillips have shown that the short waves shorten on the upward slope of the longer wave and thus steepen. The short waves tend to break near crest on the upward slope of the long waves.
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4.3 Wave-wave interactions – Non-linear interactions

Nonlinear interactions between the different constituents of the wave energy spectrum do not change the energy present in the wave train but transfer energy from one wave length (wave number, frequency) to another.

Energy may be transferred to short waves from the wind and then transferred to a much longer wavelength.

Energy transfer will occur to all waves travelling with wind velocity.

A significant part of the energy in a fully arisen sea is transferred by these processes, which are included in third generation wave generation models.
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4.4 Development of the wave spectrum

Phillips pressure mechanism dominates the earliest stage of wave growth while the Miles shear stress mechanism is important from early stages to well developed seas.

Once gravity waves are established, wave-wave interactions become of major importance.

The numbers refer to the locations in the figure.
1. Short period components appear.
2. Total energy increases but short period components decrease.
3. Total energy decreases. Short period components decrease more rapidly than long period.
4. Short period components decrease more rapidly than long period and wave crests become aligned, waves are now "swell".
5. Off the axis of the fetch there is less long period energy. Energy intensity and hence height decrease away from the fetch because of loss of energy and radial spreading (crest length $\sim x$, hence $E \sim 1/x$).
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Because the waves are dispersive and storm duration is finite, the waves at any point will vary in time and may differ from the above steady state:

(a) For a distant storm the long waves will reach the shore first, the short ones will be severely attenuated and will not have much effect.

(b) For a moderately distant storm of some days' duration the long waves will arrive first then shorter waves will start arriving superimposed on the long waves. Finally only diminishing shorter waves will arrive.

(c) In the fetch the waves will grow until a fully arisen sea state exists for that wind speed and fetch.

The spectrum observed depends on the wind speed, the fetch length, the wind duration, the distance from the fetch, the time of observation relative to the onset of the wind. Relationships between $H$, $T$, $V_{wind}$, duration and fetch are known.
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References