SOME BASIC WAVE THEORY

Wave properties

Waves occur basically because a disturbance affects an area (which may range in size from a molecule to an air/water parcel to an air mass), in which each disturbed area's action affects a nearby area, which affects the next, etc., while each area itself doesn't move far at all. In this manner, the energy from the original action travels a long way through the matter. The area remains fixed by some restoring force. Because the size of the disturbed area can vary tremendously, and because many different types of restoring forces exist, the number of different wave types is almost infinite!

In the atmosphere, the following wave types exist: 1) sound (acoustic) waves; 2) (shallow-water) external gravity waves; 3) (deep-water) external gravity waves; 4) buoyancy waves (also called internal gravity waves); 5) inertia waves; 6) Rossby waves; and 7) Kelvin (edge) waves. It is possible to have some combinations. For example, there are also inertia-gravity waves, and Rossby-gravity waves (also called Yanai waves). Not all combinations are possible though.

Waves propagate with a certain *phase speed.* However, all classes actually contain a spectrum of waves with different wavelengths and amplitudes. For certain classes, all waves move at the same phase speed regardless of wavelength, and are called *non-dispersive waves.* Examples are sound waves (fortunately) and shallow water gravity waves. These waves preserve their shape as they propagate

But for most classes, the phase speed varies with the wavelength, and these classes are called *dispersive waves.* For example, deep-water gravity waves with longer wavelengths move faster than the shorter waves. The next time you see a speedboat, notice the waves as they come ashore. The first to arrive have the longest wavelengths, then increasingly shorter waves arrive. Dispersive waves do not preserve their shape as they propagate. Since different waves move at different speeds, typically the disturbance (and therefore the energy) spreads out with time. Furthermore, the individual wave components will cancel or reinforce each other as they propogate at their particular phase speed, producing a constantly changing trough and ridge system with changing amplitudes. Therefore, dispersive waves produce complicated patterns.

Brief description of waves

A detailed description of each wave is reserved for the dynamics and synoptic classes. They will just be summarized here. When the disturbed area moves in the same direction as the disturbance, it is called a *longitudinal* wave (like a compressed slinky). When the disturbed area moves perpendicular to the disturbance, it is called a *transverse* wave (like shaking one end of a rope attached at the other end). Most atmospheric waves are transverse.

[1.] Sound (acoustic) waves — propagate longitudinally as air molecules "bump" into each other. Restoring force is adiabatic compression and expansion.

[2.] External gravity waves — Propagate transversely along a density discontinuity (like the ocean-air interface, or two liquids of different densities in the same container). When the wavelength is much greater than the depth of the liquid, it is a shallow-water wave. When the wavelength is much less than the depth of the liquid, it is a deep-water wave. The restoring force is, obviously, gravity. If the two fluids individual wind fields strongly shear the interface, *Kelvin Helmholtz* instability occurs.

[3.] Buoyancy waves — Propagate in a continuously stratified fluid, such as the atmosphere. It is characterized by vertical displacements of stable air. Restoring force is negative buoyancy (stability).

[4.] Inertia waves — Characterized by horizontal displacements of air. The restoring force is the Coriolis force, which is at right angles to the horizontal displacement.

[5.] Rossby waves — Synoptic-scale troughs and ridges. The restoring force is the meridional variation of the Coriolis parameter.

[6.] Kelvin (edge) waves — Actually another type of gravity wave, but it's existence requires a boundary, such as the equator, the land-sea interface, or steep topography.

Rossby waves

Rossby wave propagation can be best understood by considering a wave (with one trough and ridge) along some latitude reference. Also recall that $\beta = \partial f / \partial y > 0$, meaning that $f = 2\Omega \sin \phi$ is larger to the north than the south. Therefore, the southwest wind west of the ridge, as well as the southwest wind east of the trough, will advect smaller values of earth vorticity to those regions. Likewise, the northwest wind east (west) of the ridge (trough) will advect larger values of earth vorticity to those regions. The result is that the ridge and trough will tend to move west in the absence of strong westerly winds, a process called *retrograding*. Therefore, the phase speeds of Rossby waves is to the west. (However, in the mid-latitudes troughs and ridges tend to move east because the strong westerly winds overcome the β-effect).

Rossby waves are dispersive. The longer waves tend to move to the west faster than short waves. In fact, even in the mid-latitudes, long troughs and ridges tend to retrograde even when the mid-latitude westerly winds are fast! For more detail, Holton on page 216-220 does a good job describing Rossby waves.