MESO's CAFE
(Computer-Aided Forecasting Exhibition)

Gravity Waves: What's the Attraction?

PART I: What are "Gravity Waves"?

Deep convection produces waves over a broad spectrum of frequencies. Gravity waves are one of many methods the atmosphere uses to transfer momentum (as well as temperature and moisture), and in the process, attempt to establish an energy equilibrium. They are essentially a damped harmonic oscillator, like a spring, but acting in three dimensions instead of one. A better 2-D analogy is a rock tossed into a still pond. The size of the ripples depends on the size of the rock and the depth of the water.

These "ripples" can be caused by flow over a mountain range, a downdraft hitting the ground, or an updraft penetrating the tropopause (i.e., entering the stratosphere). They are *forced by buoyancy* and *damped by gravity* (in fact, Gravity Waves are more correctly called Buoyancy Waves). They propagate most readily in a stably stratified layer... in other words, potential temperature must increase with height in the layer in order for a gravity wave to propagate within that layer. Since the atmosphere has no upper boundary, the waves also travel upward. These waves will not be discussed at length here, but it should be noted that these upward-propagating waves can be reflected into the horizontal (ducting), allowing the amplitude of the horizontal waves to remain greater than it would otherwise.

The basic process responsible for the propagation of gravity waves the atmosphere constantly trying to achieve pressure equilibrium. A parcel of air will travel from an area of high pressure to an area of low pressure due to the "pressure gradient force". Let Point A be a local high and Point B be a local low. Air will travel from Point A to Point B, eventually causing Point A's pressure to drop and Point B's pressure to rise (conservation of mass). In some amount of time, Point A will become a local low and Point B will become a local high. With a little imagination, suppose there are Points C, D, E, etc that also undergo similar pressure fluctuations. So the crests (and troughs) of the waves travel outward in all directions from the source like the ripples of water in a pond.

Some of the fundamental physical characteristics of gravity waves are not well-understood or well-documented, but in general, here are some basic guidelines: they typically have a 1-15 millibar amplitude (vertical displacement), a 50-500 kilometer wavelength, and a period of 1-4 hours. One can then easily calculate the maximum range of wave speeds from this... 12-500 km/h. The gravity waves created by tropopause penetration usually generate the highest amplitude and highest energy waves.

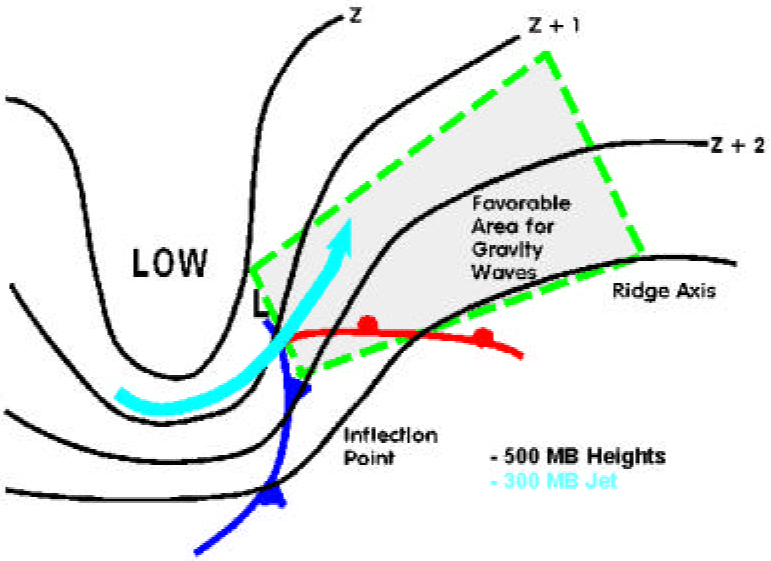
What sort of environment is most favorable for the creation, development, and propagation of gravity waves? As mentioned earlier, the layer must be stably stratified. This is very important;

if the atmospheric layer of interest is unstable, gravity waves do not travel through it as easily. Furthermore, strong wind shear aloft is seemingly beneficial. Both of these ingredients are found near a dryline or a frontal inversion. And since drylines and fronts are quite adept at forcing convection, it makes it very easy for thunderstorms along these boundaries to generate very powerful gravity waves. These atmospheric ripples can sometimes travel across the country for 1500 kilometers or more.

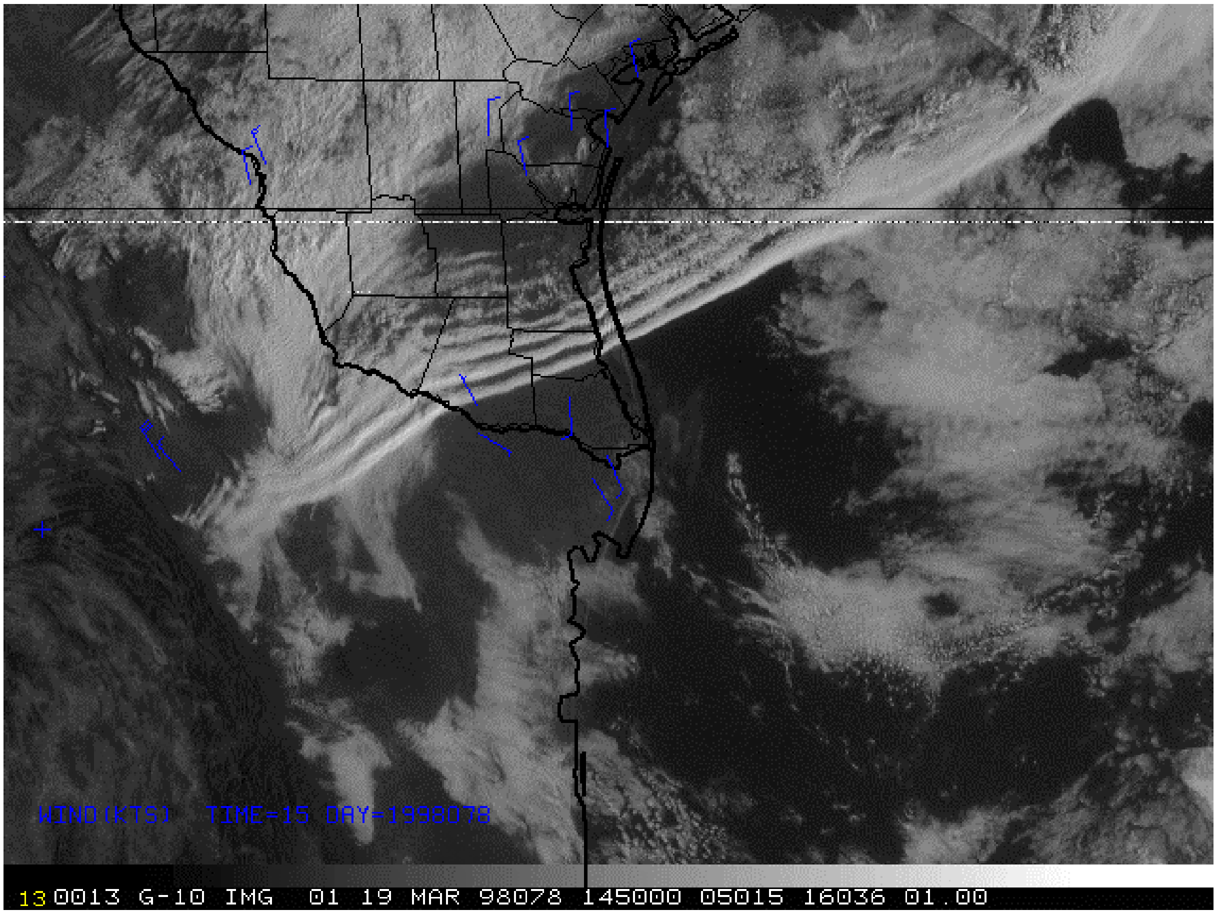
One final point... how do gravity waves interact with convection? Recall the amplitude of these waves can be 15mb (sometimes more). Well, this can be enough to force parcels to rise <fall> above <below> their LCL or LFC; i.e., they are simply displaced upward <downward> from their previous position. So basically, powerful high-amplitude gravity waves *can* force <hinder> condensation and convection. They are also responsible for dangerous clear-air turbulence. In fact, if the amplitude isn't large enough *or* if the air is too dry, condensation will *not* be induced, and the result will be completely oscillatory and invisible turbulence. The clear-cloudy ripple effect has been observed on several occasions using visible satellite imagery. In the case of the May 27, 1997 Jarrell, TX tornado outbreak, the supercells were largely enhanced by gravity waves released several hours earlier by a storm system hundreds of kilometers away.

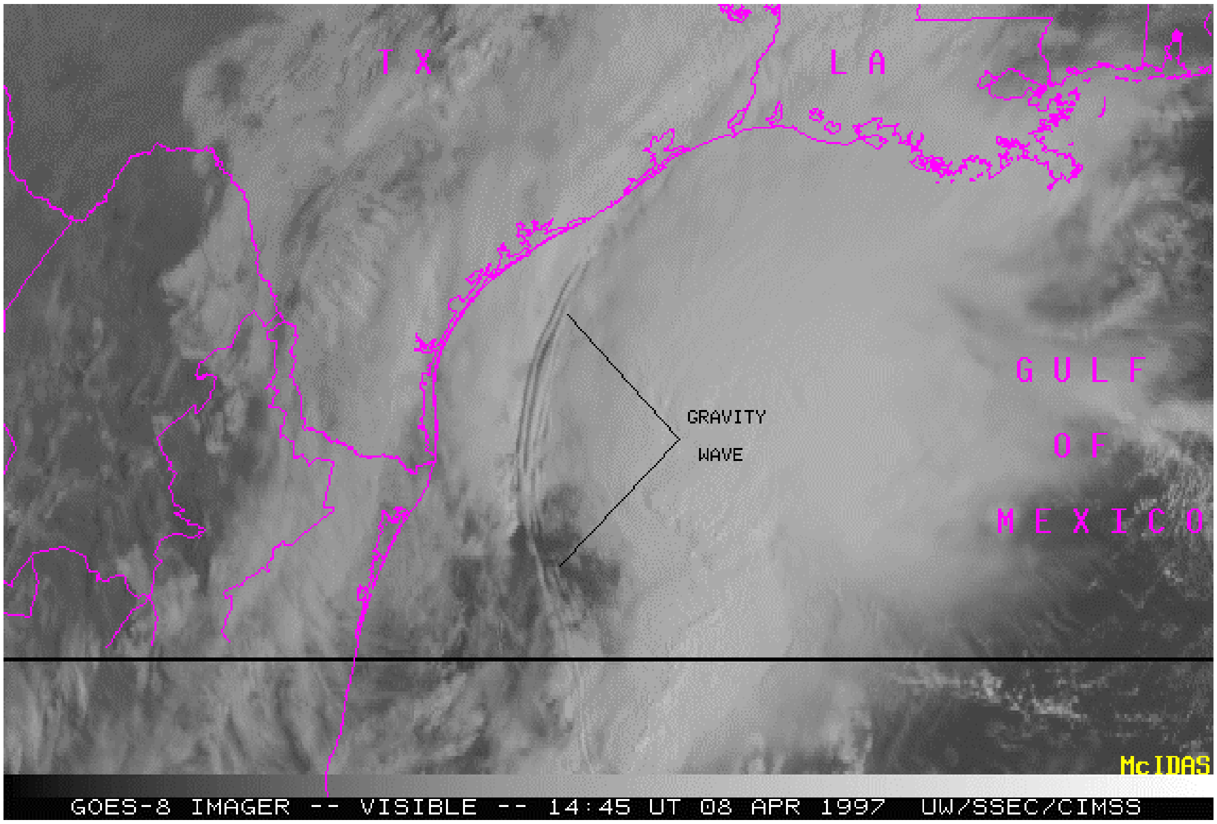
Not only can gravity waves force convection, but convection can create and amplify gravity waves. As mentioned earlier, updrafts and downdrafts colliding with some form of boundary create gravity waves. But the processes in a thunderstorm help to amplify existing gravity waves. Latent heat release provides the waves with energy. The thunderstorm's environment amplifies the crests by means of evaporative cooling (when precipitation encounters dry air, it evaporates and cools the air), while the troughs are amplified by means of compensating subsidence (sinking that warms the air to compensate for cooling caused by evaporation).

Understanding gravity waves can help severe weather forecasters better predict where an outbreak is likely to occur, and how powerful it could potentially become.



Credit for various parts of this section go to:
Steven Koch, Howard Bluestein, James Holton, and Joseph Schaefer.


WIND(KTS) TIME=15 DAY=1998078
13 0013 G-10 IMG 01 19 MAR 98078 145000 05015 16036 01.00


TX
LA
GRAVITY
WAVE
GULF
OF
MEXICO
McIDAS
GOES-8 IMAGER -- VISIBLE -- 14:45 UT 08 APR 1997 UW/SSEC/CIMSS

PART II: Using Knowledge of Gravity Waves in Operational Forecasting

Now that you know what gravity waves are, how does one detect them and use them in forecasting? Two key methods are microbarographs and satellites.

A microbarograph is a sensitive instrument that can record pressure fluctuations with 0.001 millibar precision. Armed with this tool, forecasters can detect minute pressure changes associated with the waves… this is especially useful if there are no visible signs of the waves (i.e., condensation).

Visible satellite imagery has 1-kilometer resolution (from operational geosynchronous satellites such as GOES). This is only useful if the gravity waves are strong enough to force parcels above their LCL or LFC. If there are any clouds induced by the waves, there's a good chance visible satellite imagery will detect them.

The forecaster now knows the extent and amplitude of a series of gravity waves racing across a region. How is this knowledge useful for predicting where and when thunderstorms will break out (or of they will)? If one knows the ambient LFC and the amplitude of the oncoming waves, one can predict whether or not the waves will induce convection and where this is likely to occur. The easiest example to understand is gravity waves approaching a dryline. A dryline is an unstable boundary that typically only needs a little "trigger" to initiate convection (a sharp temperature/dewpoint gradient). That trigger can come in the form of gravity waves. This is precisely what happened in the Jarrell, TX tornado outbreak on May 27, 1997. Gravity wave-induced condensation ripples were traveling SSE across Texas, and by the early afternoon, they encountered a substantial dryline. In less than one hour, towering thunderstorms achieved severe limits and spawned numerous tornadoes that day, including several F5's.

Credit for various parts of this section go to:
Steven Koch and Tobias Kerzenmacher

Brian McNoldy for *MESO, January 2000*

http://www.mcwar.org