

## Talking points for Mountain waves and orographic enhancement

1. Title
2. Our learning objective is to how make optimal use of GOES-R capabilities in identification of mountain wave clouds, which are may also be referred to as orographic cirrus or lee wave clouds.
3. The mountain wave clouds or orographic cirrus that we'll be discussing are stationary cirrus that develop to the lee of a mountain range. Under the condition that a stable layer exists from the mountain ridge to the upper part of the troposphere and wind direction is nearly constant, a wave is produced by the mountain ridge and is transmitted to upper levels. If sufficient moisture exists at upper levels, these orographic cirrus or mountain wave clouds will develop. These are important to account for in your forecast because they can play a significant role in temperature.
4. As proxy data for GOES-R, we'll be making use of imagery from the Himawari satellite. We'll start off with the familiar visible imagery at 0.64 microns. In western Mongolia we see mountain wave clouds develop since they develop along an east-west oriented mountain range and advect only in the downstream direction. They are stationary in that they are locked in to the terrain. The clouds tend to be relatively thick cirrus which is efficient at preventing insolation and thus playing a significant role in the temperature forecast. A qualitative assessment of cloud thickness can be obtained from the visible imagery but we'll see next that there is significant information in the IR band.
5. Here is the IR imagery from Himawari as seen at 10.4 microns. Choose an enhancement that highlights the clouds such as this one and note that these quasi-stationary clouds appear locked in to the mountain range and advect only in the downstream direction. Since these clouds are relatively thick, they tend to be quite cold at 10.4 microns. Before we move on to the next slide, notice that there are other high level clouds in the vicinity of the mountain wave clouds.
6. At times, there may be a considerable amount of high level clouds advecting through the region, making it more difficult to distinguish mountain wave clouds from these high level clouds that are advecting along. If it's daytime as it is in this case, we can make use of information from the 3.9 micron channel. Mountain wave clouds tend to be composed of relatively smaller ice crystals which are highly reflective. If we take the difference between the 3.9 and 10.4 micron bands, we subtract out the emitted component and are left with the solar reflected component. Notice how the mountain wave clouds stand out from other clouds in the vicinity.
7. Another way of applying the same principle is to make use of the Daytime microphysics RGB product. This RGB is composed of a visible channel, the 3.9 micron channel for the green color and 11.2 microns for the blue color. In this case, highly reflective clouds composed of small ice crystals characterized by mountain wave clouds would have a greater green component than regions with less reflective clouds (in other words, relatively larger ice crystals). Since the RGB makes use of the inverse of the 3.9 micron channel, then the reverse would be true, so that the mountain wave clouds have a lower percentage of green compared to other high level clouds not associated with mountain wave clouds. In other words, the mountain wave clouds would be more purple and comparable high level clouds would be less purple, closer to white.

8. Arguably the best way to look for mountain wave clouds is a 4 panel display, with highest priority on the IR band at 10.4 microns. If it's daytime, use the visible imagery and you may also make use of the 3.9 minus 10.4 micron difference product and/or daytime microphysics RGB particularly if you have a lot of other high level clouds in the vicinity to distinguish from mountain wave clouds.
9. This is a different case looking over the same general area as we've been looking at. However, the key difference here is this is a nighttime event. Remember the 10.4 micron band should still be your most important band for identification of mountain wave clouds and indeed in this case it shows it's value. The mountain wave clouds appear quasi-stationary, locked in to the terrain. Relatively thick (and thus cold) clouds develop along various mountain ranges and advect only in the downstream direction, this provides clear evidence that these are mountain wave clouds.
10. Is there any other useful information from the various bands available on GOES-R? Well, the water vapor bands do provide value as well. In this 4 panel we have the 10.4 micron band, along with the 3 water vapor channels just like you will have with GOES-R. It's important to note that limb effects are substantial here so that brightness temperatures will be colder due to that effect. Nevertheless, one of the signatures you may observe in the water vapor channels are a region of warmer brightness temperatures associated with subsidence on the upstream side of where mountain wave clouds develop. At times, these may be a pre-cursor to mountain wave cloud development. One of the interesting signatures we see here is that subsidence signature shows up well in the lower water vapor band at 7.3 microns, the signature is much more subtle with the mid water vapor band at 7.0 microns and the signature is absent in the upper water vapor band at 6.2 microns in this case. As you develop experience in looking at mountain wave clouds in your CWA, you may notice trends in the subsidence signature with the 3 water vapor bands that could prove useful in forecasting.
11. Time for an interactive exercise. In this panel animation, we're looking at the 10.4 micron IR band, the 3.9 minus 10.4 micron difference product, the lower level water vapor band at 7.3 microns and the mid level water vapor band at 7.0 microns. Is this a daytime or nighttime animation and why?
12. Without having the visible imagery to look at to determine if it's daytime or nighttime, you would make use of the 3.9 micron imagery since it contains a solar reflected component during the daytime. The fact that there is a difference between 3.9 and 10.4 microns alone would be sufficient evidence that this is daytime imagery, however this case is particularly interesting since there are mountain wave clouds that show up about mid way through the loops. Early in the loop, there are larger scale cirrus advecting through, and about halfway through the loop the higher clouds move away, revealing mountain wave clouds since they are developing over a mountain ridge and advecting in the downstream direction. Remember that mountain wave clouds typically contain relatively smaller ice crystals, which tend to be more reflective. This reflective signature shows up in the 3.9 minus 10.4 micron loop once the mountain wave clouds are no longer obscured by other high level clouds moving through. Remember this signature will only show up during daytime hours, which helps answer the question I posed.

13. Summary – last bullet: Finally, water vapor bands are useful in that you may see an upstream subsidence signature, particularly in the lower or mid water vapor channels with weighting function profiles that are not above where the subsidence exists.