Gravity Wave Event

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Disturbance at the ship

In the early morning of February second, an intense squall line passed over the Research Vessel Pt Sur during an otherwise period of relative calm. Prior to the event, visibility as indicated in the quick observation data sheet was logged at 20 km for the previous ten hours and no change in weather conditions was noted for the same time period. The squall line occurred approximately two hours before weather conditions began to worsen associated with a passing cold front. So what caused this brief period of intense rain?

Observations

Ships Underway Data Acquisition System (UDAS) measurements indicated a gradual lowering of pressure from 0900Z to 1000Z followed by a leveling off to 1015 mbars, then a drop of 4 mbars between 1110Z and 1140Z to a low of 1011 mbars. After the low, the pressure increases, overshooting the pre-event value before coming to rest at the original pressure level. There was a noted increase in wind speed as determined by UDAS associated with the period of pressure drop, and a noted shift in wind direction from the west during the period of climbing pressure. Figure 1 illustrates the three hour period surrounding the event

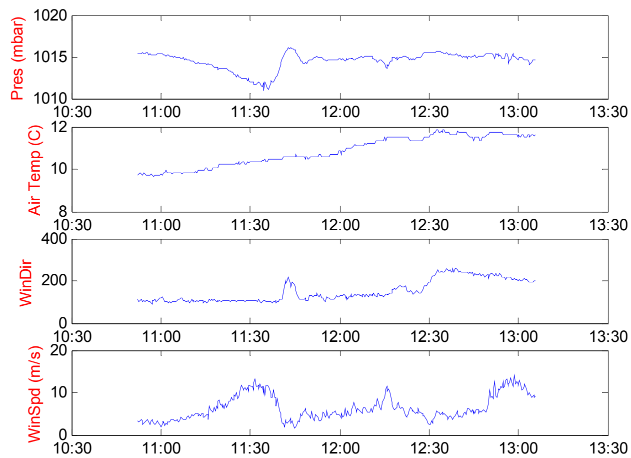

Figure 1. **UDAS data indicating gravity wave passing through area around 1130Z.**

while slide number three of the accompanied power point presentation also includes a longer period surrounding the event.

Similar such events have been noted in the literature for many years, (Tepper 1950, Matsumoto and Akiyama 1969). They are gravity wave events and are known as Mesoscale Wave Disturbances (MWD). The MWD studied thus far have been mainly from the data rich geographical regions of the Midwest and the Eastern US. After some investigation, the gravity wave event occurring over the Pt Sur may be the first to be studied originating from off the California coast.

The MWD passing over the Pt Sur was also observed by two at-sea Monterey Bay Aquarium Research Institute (MBARI) buoys designated M1 and M2, as well as several land sites. The surface meteorological data from the Point Sur Naval

Station site and the MBARI M1 mooring are shown in Figure 2. Surface observations from additional sites can be seen in the accompanied power point presentation. The Point Sur Naval Station indicated a drop in pressure between 1100Z and 1230Z and is assumed to be associated with the gravity wave event. At the same time the irradiance dropped from a

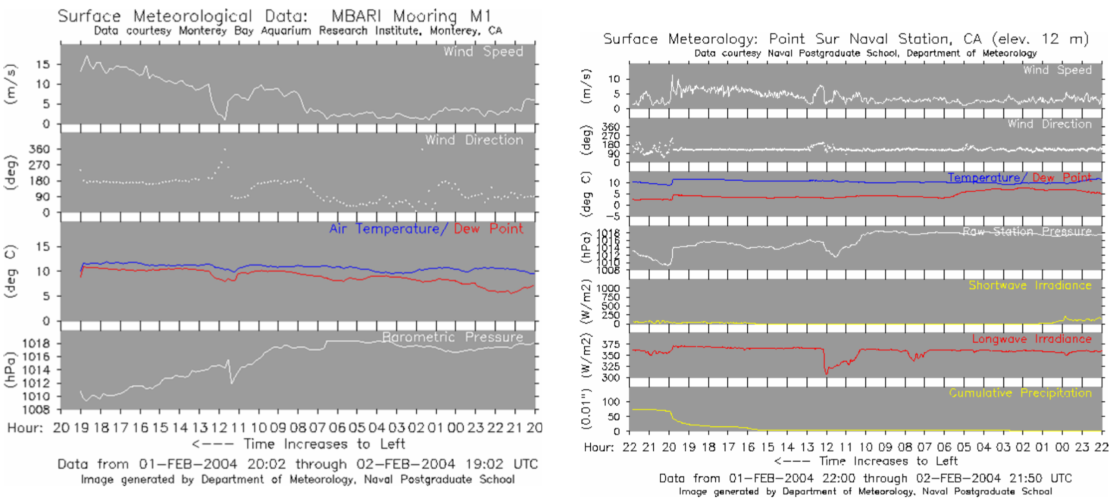

Figure 2. Surface observations from the MBARI M1 mooring and the Pt Sur Naval Station showing a gravity wave signature at about 1130Z.

constant 365 W/m^2 to 325 W/m^2, indicating that the gravity wave was strong enough to temporarily clear the overlying cloud layer. At the M1 mooring, the gravity wave registered as a drop in pressure followed by a slight jump before returning to the original pressure level. There was a noted shift in the wind direction from the west also observed by the Pt Sur. Similar gravity wave signatures can be seen from the other surface sites presented in the associated power point slides but will not be expounded on here.

Figure 3 shows the ten locations where a definable gravity wave signature can be seen. The time at which the lowest pressure occurred is also indicated. The pressure drop over the land sites was not as sharply defined as those from the at sea readings (either due to frictional effects or the deterioration of the wave) and therefore the time at which the low occurred was more difficult to pin down. Regardless, a general on-shore propagation direction can be observed. Taking the time-distance between the MBARI M1 mooring and the Fort Ord site as being representative of the gravity wave, the phase speed can be approximated to 16 m/s. The frequency can be estimated by the duration the entire event passed the R/V Pt Sur: 25 min. From this the characteristic wavelength can be approximated to 24km.

Figure 3. Locations where sufficient time scale observations were taken.

Evidence can be seen in the northern and central California METAR data that suggest the gravity wave extends over nearly the entire state of California. Figure 4 shows the surface weather observations for the 1100Z timeframe before the gravity wave event. The 1100Z observations indicate that the pressure experiences no significant change in the last hour. The 1200Z observations shown in Figure 5 indicate fluctuation in pressure readings as illustrated by the yellow numbers next to the individual stations. Hourly changes often times did not account for the full pressure changes, indicating that the pressures at the METAR sites dropped, then rose again from some unrecorded pressure low. Typical pressure fluctuations of up to three and four mbars can be seen. Values in the central coast sites often times returned to nearly to the same values from the previous hour.

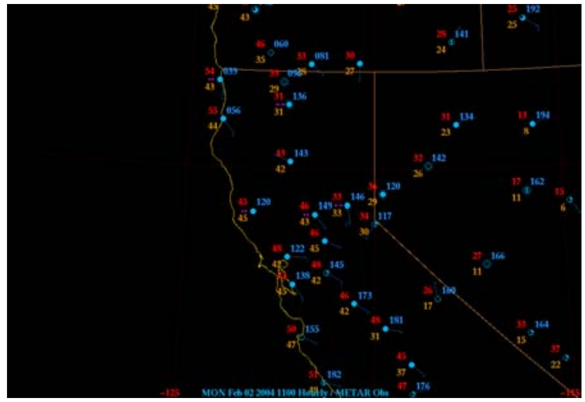

Figure 4. 1100Z METAR data. No significant pressure drop in last hour.

A gravity wave signature can also be seen in the Fort Ord Profiler in both low and high mode,

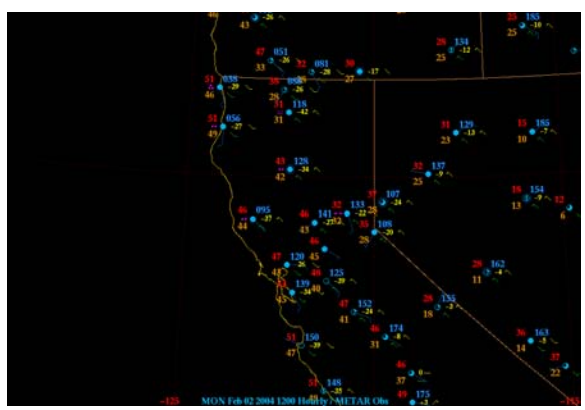

Figure 5. 1200Z METAR data. Significant fluctuation in pressure during last hour.

(only the high mode shown here). The resolution of the time scale does not fully describe the event, but some information can be ascertained. As can be seen in Figure 6, between the 1100Z and 1200Z

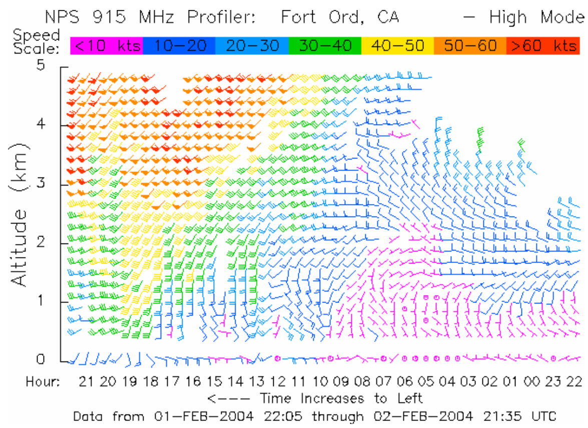

Figure 6. Profiler data showing vertical amplitude of gravity wave.

reading, a wind shift occurs up through the first kilometer of the atmosphere, which gives an indication of the vertical extent of the gravity wave.

The ceilometer collocated at the Fort Ord profiler site indicates a similar atmospheric behavior as seen at the Pt Sur Naval Station. Prior to the gravity wave event, a cloud cover level of about 1000m is observed. Between

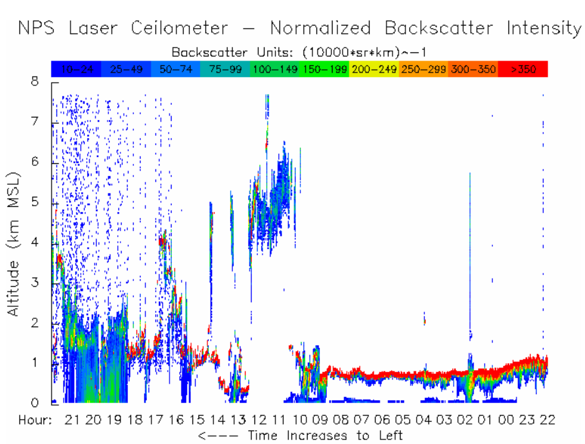

Figure 7. Ceilometer data taken during gravity wave event. Low level clearing occurring at 1100Z.

1100Z and 1230Z there is a clearing event, likely due to the passage of the gravity wave, as seen in Figure 7.

The 1200Z GOES-10 IR gives a good visual picture of the passage of the gravity wave. As the gravity wave passes, the down draft created would tend to cause a clearing in the atmosphere. This clearing was seen on the ceilometer and the irradiance pattern at Pt Sur Naval Station. This clearing can also be seen in the satellite IR photo as the clearing band passing over the central coast, ahead of the cold front. The clearing can be seen to extend up into southern Oregon.

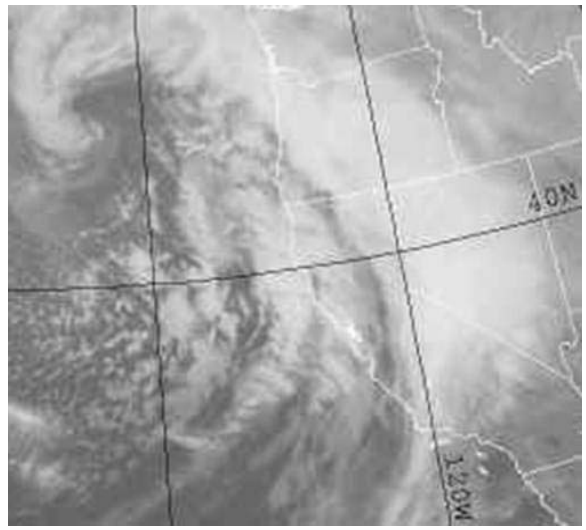

Figure 8. GOES-10 IR 1200Z satellite photo. Band of clearing shown extending through California up in to Oregon.

Comparison Study

As noted above, MWD have been studied in the literature for some time, but they are still not fully understood. Chief among our lack of understanding is a definable mechanism to describe the genesis of a gravity wave. Multiple mechanisms have been offered. The primary mechanisms are believed to include geostrophic adjustment, shearing instability, frontogenesis and frontal collapse, and convection (Jewett *et. al.* 2004). Gravity waves are also known to have very different behaviors from one another. But there are some common characteristics between the event that occurred over the R/V Pt Sur on the morning of February second and the MWD found in the literature.

Gravity waves can occur as a wave packet, such as that associated with, but not exclusive to orographic affects. Gravity waves can also appear as a singular large-amplitude wave of depression. The singular wave is less common and harder to define a genesis mechanism. As shown here, the Pt Sur Gravity wave is the less common, singular wave type.

Another feature associated with MWDs is the importance of a jet streak over the area of the gravity wave. Of the thirteen MWD studied by Uccellini and Koch (1987), all were found to exist exclusively in the exit region of a jet streak and preferentially on the right (anticyclonic) side. In Figure 9, an exit region of a jet can be seen over the California central coast, corresponding to the time period of the gravity wave occurrence. The presence of a jet may be a critical criteria in the development of a gravity wave. One theory for the MWD genesis is that the vertical shearing instability from an

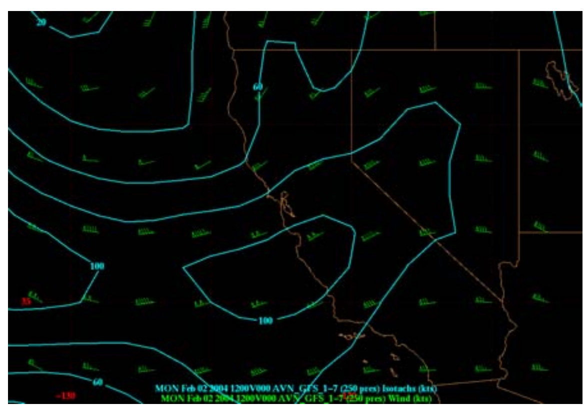

Figure 9. AVN model from February 2 showing jet streak over central coast of California.

overlying jet streak may grow a gravity wave. The presence of a jet streak creates a strong shear environment, with a critical level providing a region for potential energy exchange between the mean flow and the wave (Ramamurthy *et.al* 1993). This theory requires a critical level where the phase speed of the wave matches the ambient wind speed. If the Richardson number (which relates the stability of the layer to the shear stress) where less than .25, the energy from the mean flow could be transferred to the wave energy and a gravity wave can grow. The problem with the instability theory is that, as noted by Uccellini and Koch (1987), not all MWD disturbances have a critical layer. In any event, the jet streak seems to be a key feature of the gravity wave.

Another feature of a gravity wave is the strong association with high precipitation events. Nearly all the MWD studied by Uccellini and Koch (1987) had between 1 and 4 inches of precipitation recorded. As noted before, the Pt Sur noted a squall line passing over the ship at the time of the wind shift. Ramamurthy *et. al.* (1993) indicates that some MWD can persist for 6-15 hours and propagate several hundred kilometers horizontally with little change in amplitude. These waves have been shown to have significant impact on the intensity and distribution of precipitation, the surface winds, and the preexisting cloud cover. All three of these occurrences can be seen in the figures above. Figure 5 shows increased precipitation recorded over the entire state of California, prior to the passage of the cold front. A shift in the winds was noted by the Pt Sur UDAS record as well as the MBARI buoys and the various ground stations. A cloud cover disturbance was noted by the ceilometer at Fort Ord and at the Pt Sur Naval Station.

Out of the thirteen MWD studied by Uccellini and Koch (1987), all had a strong inversion layer below 2 km, usually on the cold side of a warm or stationary front. According to Ramamurthy *et. al.*(1993), the presence of an inversion layer in the lower troposphere is to help generate a duct in which the gravity wave is allowed to propagate. The trapping of a gravity wave within a duct can be maximized when the duct environment is neutrally buoyant (with respect to a saturated air parcel) above the low level inversion. The sounding conducted by the Pt Sur at 1300Z is shown in Figure 10. In this case there is no strong inversion in the lower levels. Assuming the moist adiabatic lapse rate of -6˚C/km (also shown in Figure 10), the environment does appear to be neutrally buoyant throughout the layer, which meets half of Ramamuthy’s criteria. The sounding does show three thin stable layers at 2200m, 2400m, and 4300m.

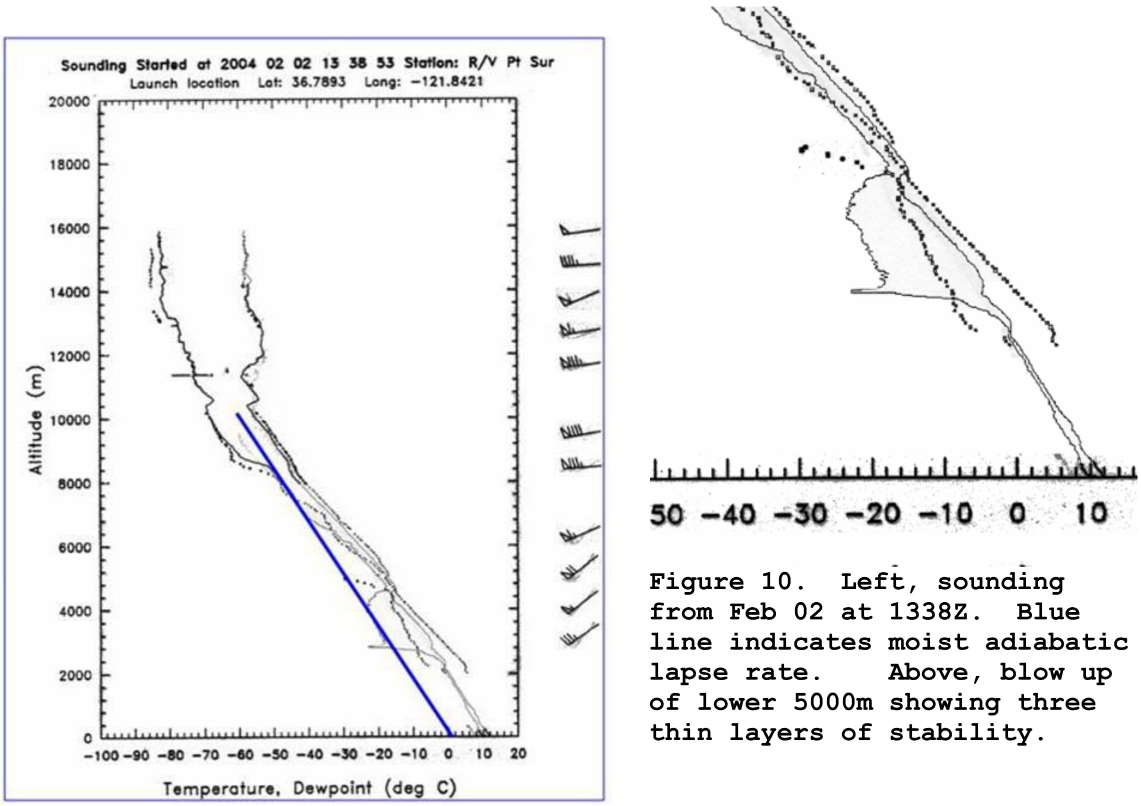

Figure 10. Left, sounding from Feb 02 at 1338Z. Blue line indicates moist adiabatic lapse rate. Above, blow up of lower 5000m showing three thin layers of stability.

The lack of the strong lower boundary inversion layer would imply that a gravity wave would not have the duct necessary for extended propagation distances. The less well defined gravity wave signatures as seen from the various land sites (with the power point presentation) does suggest a degradation of the wave as it travels over land. Another possibility is that the wave is able to maintain its signature within the thin stable layers discussed above.

CONCLUSION

The squall line observed by the R/V Pt Sur showed many characteristics of mesoscale wave disturbances discussed in the literature. The gravity wave induced rain squalls along the central coast and caused an intense wind shift that was strong enough to awaken at least one member of the class. Little study has been performed on west coast gravity waves and further study in this area may provide insight into there genesis and propagation mechanisms.

REFERENCES:

Ramamurthy, M., R. M. Rauber, B. P. Collins, and N. K. Malhotra, 1993: A comparative study of large-amplitude gravity-wave events. *Mon. Wea. Rev.,* **121,** 2951-2974.

Uccellini, L. W., and S.E. Koch, 1987: The synoptic setting and possible energy sources for mesoscale wave disturbances. *Mon. Wea. Rev.,* **115,** 721-729.

Tepper, M., 1950: A proposed mechanism of squall lines: The pressure jump line. *J. Metror.,* **7,** 21-29.

Matsumoto, S., and T. Akiyama, 1969: Some characteristic features of the heavy rainfalls observed over western Japan on 9 July 1967. Part 1: Mesoscale structures and short period pulsation. *J. Meteor. Soc. Japan,* **47,**255-266.

Jewett, B. F., R. M. Rauber, G. M. McFarquhar, and M. K. Ramamurthy, 1992. http://cyclone.atmos.uiuc.edu/~bjewett/Publications/MwConf-Jewett-GravW.pdf