WESTERN REGION TECHNICAL ATTACHMENT
NO. 99-13
JULY 20, 1999

THE EFFECTS OF VERTICAL MOTION AND MICROPHYSICAL PROCESSES ON PRECIPITATION TYPE DURING A WESTERN NEVADA SNOW STORM

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Introduction

Prediction of rain versus snow has traditionally relied upon thickness or mean layer temperature forecast techniques. Some adjustments to these techniques involve wet bulb effects in the drier sub-cloud layer. During the morning hours, an unusual weather situation developed during a warm advection pattern over western Nevada on 2 February 1998 when rain changed to snow in the afternoon at the Reno airport. This rain to snow transition was a complete surprise to forecasters in Reno who had expected warm advection and daytime heating to make a transition from rain to snow very unlikely later in the day. The forecasters had relied on the traditional critical thickness and temperature techniques which had projected snow levels to rise 610 m (2000 ft) or more above the valley floor by afternoon. Wet bulb cooling effects were expected to be minimal due to the saturated sub-cloud environment. Closer examination of local soundings revealed that microphysical processes were a significant contributing factor for the snow event. This paper will examine the effects of vertical motion and microphysical processes which resulted in a much lower snow level than predicted.

February 2, 1998 Event

The morning of 2 February 1998 began with light rain falling at the Reno-Tahoe International Airport (1342 m MSL; 4404 ft MSL) which transitioned to snow around 2200 UTC before turning back to rain at 0100 UTC 3 February (Fig. 1). Two to three inches of snow fell in the area surrounding the airport at higher elevations (1450-1500 m MSL) though no measurable snow was reported at the airport.

Examination of the 2 February 1200 UTC (Fig. 2) and 3 February 0000 UTC Reno (REV) soundings (Fig. 3) revealed significant clues as to why this transition from rain to snow happened despite a warming airmass. Strong vertical motion associated with a developing surface low (Fig. 4) and upper-level jet maximum led to saturation of the previously dry mid layers of the atmosphere. Microphysical processes were apparently occurring in the saturated mid layers where temperatures between -10 and -20°C favored the maximization of ice crystal and snow production by deposition, riming and aggregation. Further diabatic cooling caused by melting snow below the freezing level led to cooler surface temperatures and a weaker melt layer (Fig. 5). In this case, the melt level rose through the afternoon due to the warm advection, and the temperature lapse rate became close to isothermal which resulted in the weaker melt layer and transition to snow (see for example the discussion regarding melt layers in the CD-ROM). The strength or weakness of a melt layer is determined by the thermal energy available for melting below the freezing level. This melting energy can be represented graphically by the area between the environmental lapse or actual sounding and the 0°C isotherm below the freezing level (Fig. 6). The depth of the inversion therefore does not always relate to the strength of the melt layer. All of the above factors contributed to the production of large wet snow flakes which survived a weakened melt layer and accumulated at the surface.

Microphysical Processes

A number of important microphysical processes occur when supercooled water droplets coexists with ice crystals in a range of temperatures from 0 to -20°C. The number of active ice crystal nuclei per liter does not become significant until temperatures of -15°C or colder are reached (Fig. 7). Ice crystal growth by deposition occurs primarily between -10 to -20°C and reaches a maximum rate near -15°C (Fig. 8). Growth by aggregation occurs and is maximized when ice crystals of different shapes and terminal velocities collide in layers with temperatures between 0 and -10°C. Riming and rime splintering occurs when ice crystals fall through supercooled drops which collect and freeze on contact in similar temperature ranges. Rime splintering which multiplies ice crystals as supercooled water droplets freeze and shatter upon contact with falling ice crystals reaches a maximum around -5°C. Larger cloud drops will freeze at a warmer temperature since they are more likely to contain particles or freezing nuclei (Fig. 9). Strong vertical motion will produce larger drops due to coalescence which in turn will freeze at warmer temperatures and enhance rime splintering and aggregation in the 0 to -10 °C layer. Figure 10 shows the correlation between drop diameter and freezing temperature, i.e., growth mechanisms. In this snow event, the vertical motion produced the larger drops which froze at a warmer temperature and resulted in larger snowflakes. These larger snowflakes survived a deeper melt layer and weakened this melt layer by the absorption of latent heat from melting snow. In this case, it is difficult to say which of the specific microphysical processes contributed most to the production of snow.

Summary-Lessons Learned

The effects of vertical motion and microphysical processes on snow levels can be a major factor and should not be underestimated. Once the forecaster has made a “first guess” estimate of snow levels based on the traditional methods of thickness, mean layer temperature and wet bulb zero, it is then important to reevaluate this projection based on forecast vertical motion and vertical distribution or moisture and temperature. Forecast soundings and time-height sections (Fig. 11) can be most helpful in assessing these parameters. If strong vertical motion is forecast and saturation is expected within the -10 to -20 °C layer, then lowering snow levels based on a modified sounding would be your best course of action.

References

An Introduction to Winter Precipitation Forecasting CD-ROM. National Weather Service Training Center, Kansas City, MO.

Authors' Note

Additional graphics with a slide show presentation is available on the NWSFO Reno world wide web site at http://www.wrh.noaa.gov/reno/study/

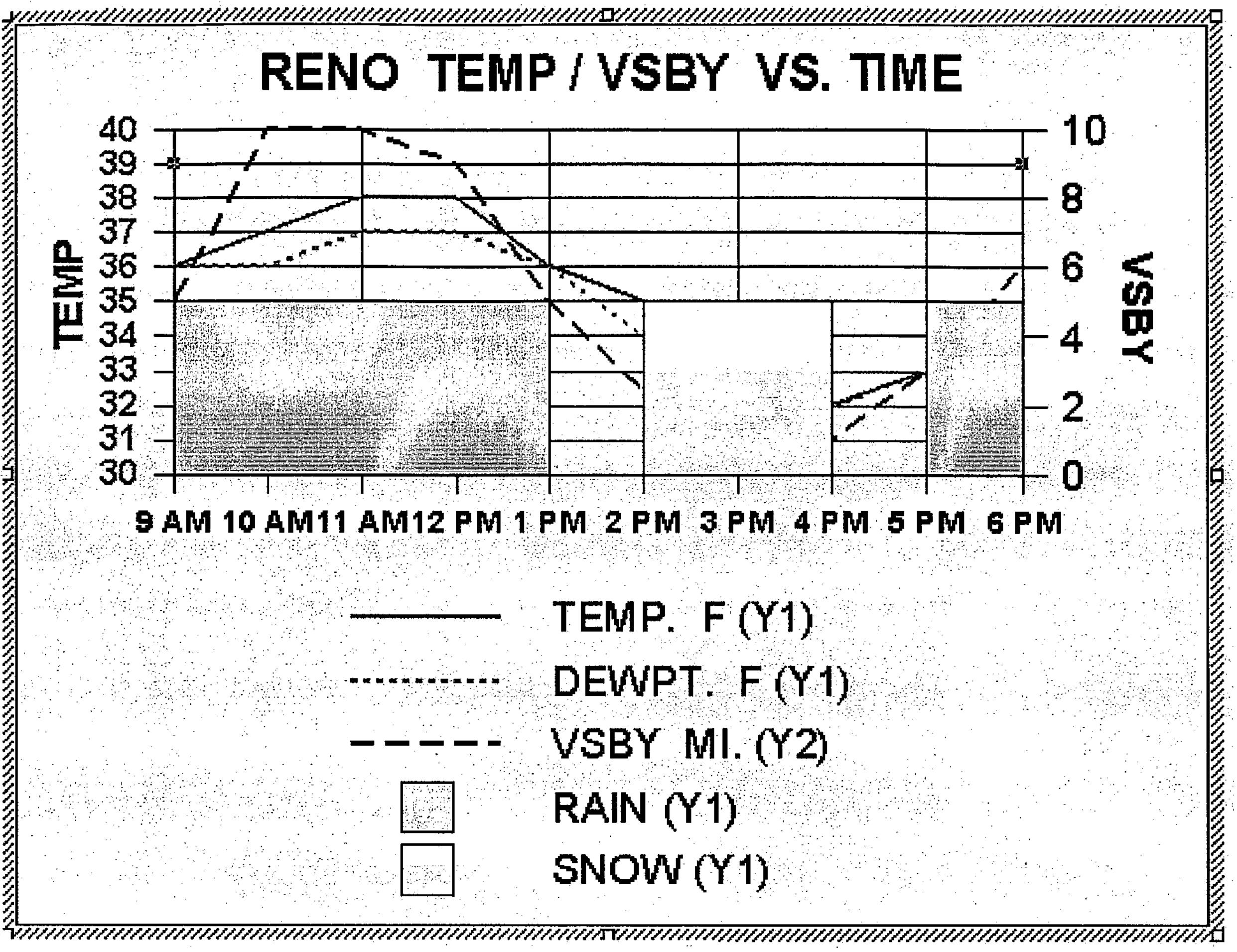
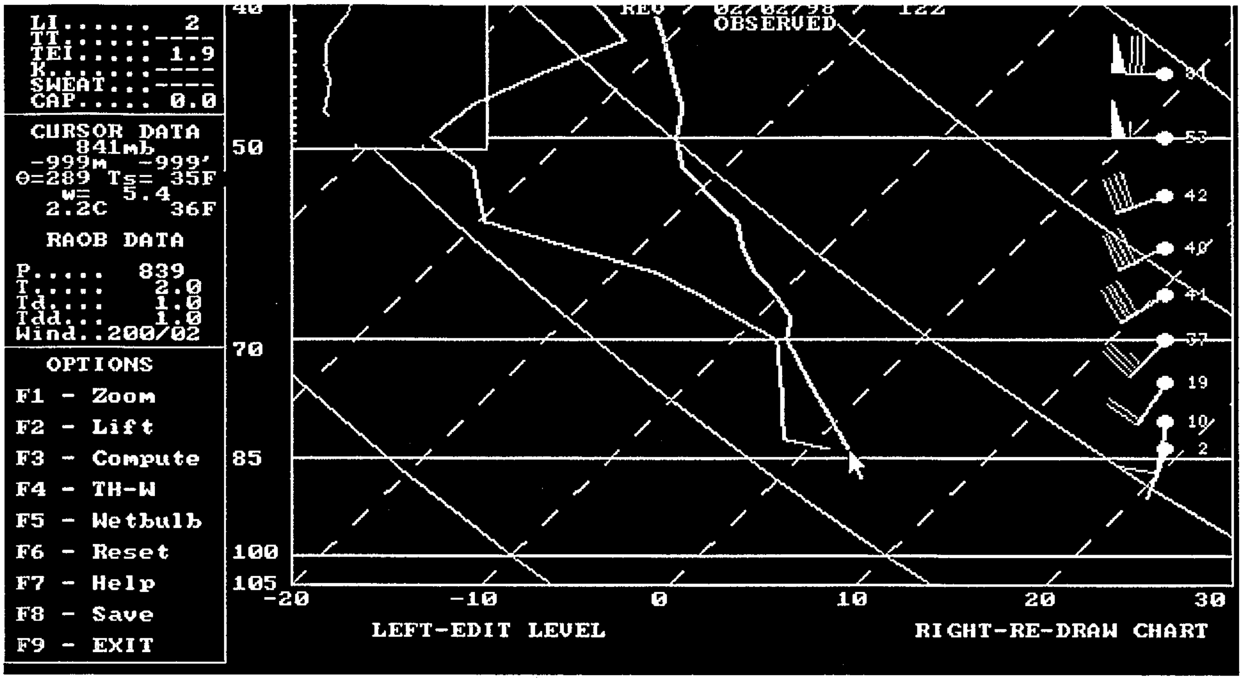


Figure 1. Reno, Nevada ASOS temperature (°F) and visibility (mi) as a function of time (Local PST). Rain turned to snow at 2 PM PST then back to rain 5 PM .



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K.......----
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θ=289 Ts= 35F
   w=  5.4
 2.2C     36F
 RAOB DATA
P.....   839
T.....   2.0
Td....   1.0
Tdd...   1.0
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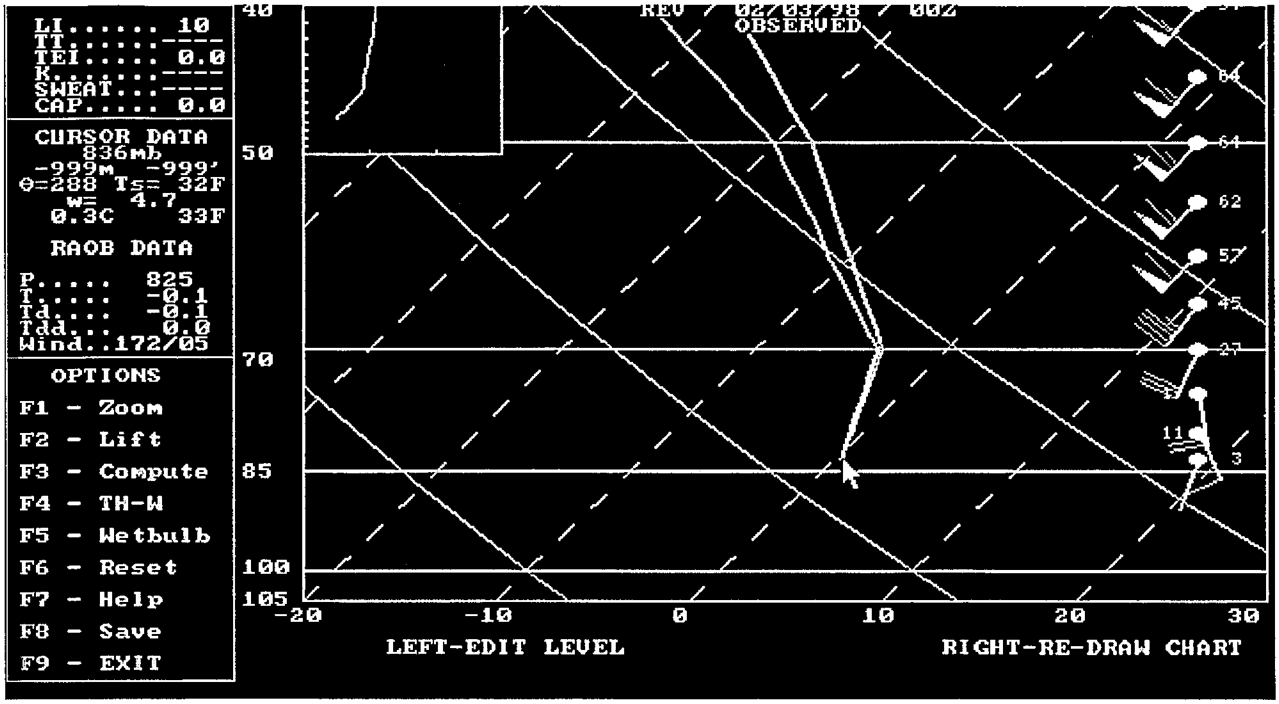
Figure 2. Reno, Nevada upper air sounding for 2 February 1998 at 1200 UTC. Note the relatively shallow moist layer just below 700 hPa with drier air above -7 °C. Light rain was falling in Reno at this time.



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K.......----
SWEAT...----
CAP..... 0.0
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θ=288 Ts= 32F
w= 4.7
0.3C    33F
RAOB DATA
P.....  825
T.....  -0.1
Td....  -0.1
Tdd...   0.0
Wind..172/05
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Figure 3. Reno, Nevada upper air sounding for 3 February 1998 at 0000 UTC. Saturation now occurring throughout the layer between 0° and -20°C. Warm Advection has increased the 700 hPa temperature allowing the temperature profile to become more isothermal in the lower layer. The melt layer is much weaker than at 12 UTC due to melting snow.

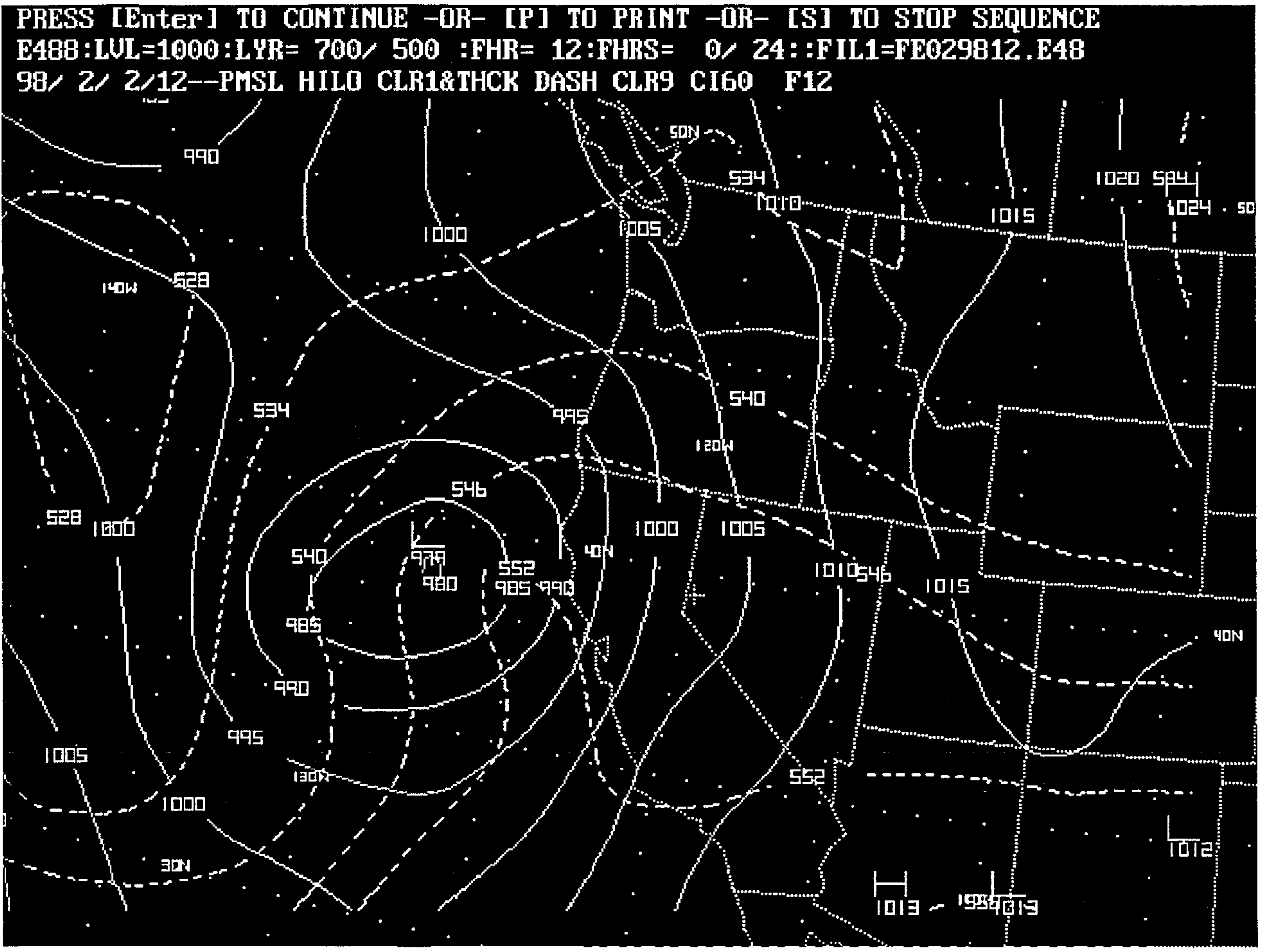

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Figure 4. 12-h forecast surface analysis from the 2 February 1998 1200 UTC Nested Grid Model valid at 0000 UTC 3 February 1998. Surface pressure (solid; hPa) and thickness (dashed; dm) are displayed. Reno is located in the warm sector of this extratropical cyclone with warm advection occurring. The critical thickness for snow in Reno is typically 542 decameters.

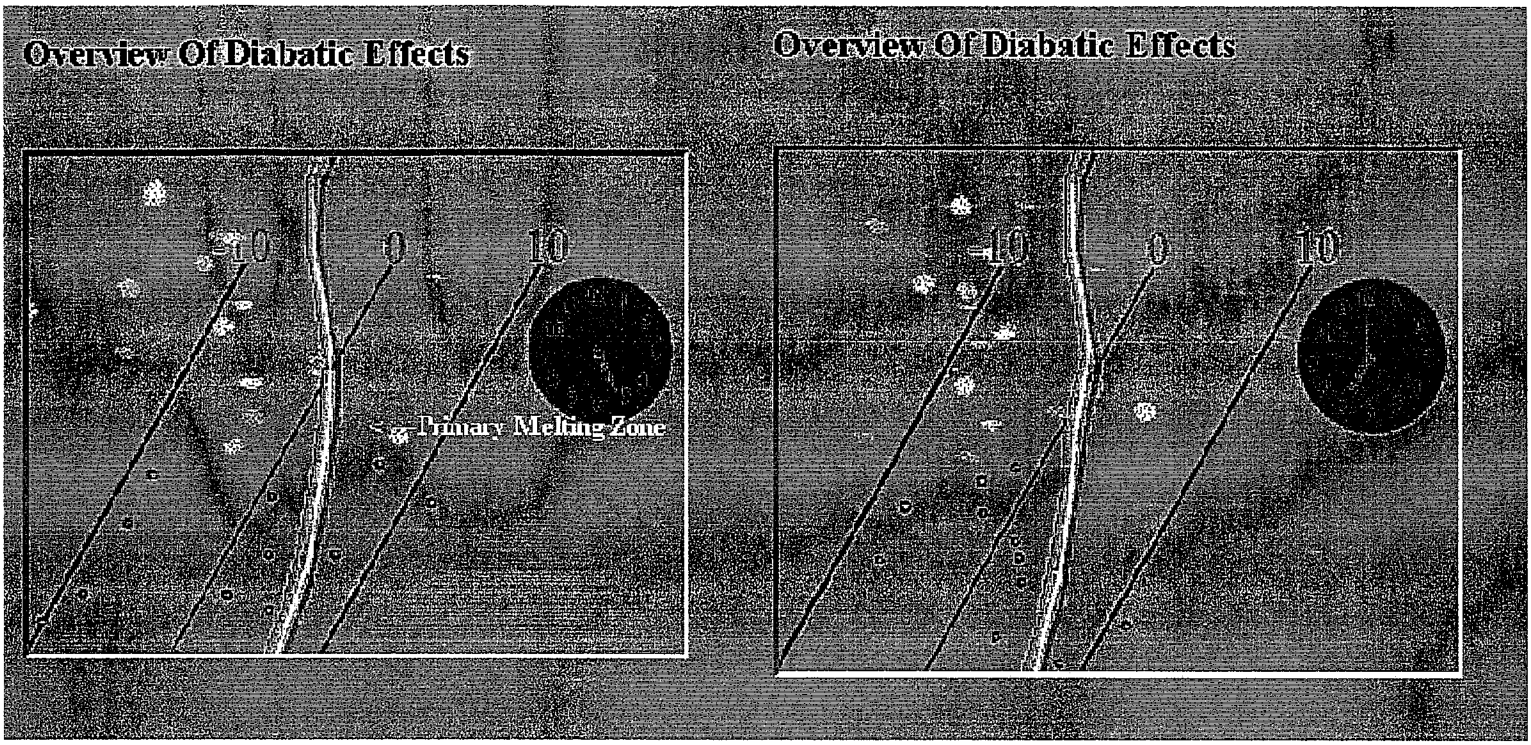


Figure 5. Time sequence of a low level sounding showing slow modification of melt layer by latent heat of melting snow. Note how the melt layer becomes weaker (less melting energy) and not shallower as it approaches the 0°C isotherm.

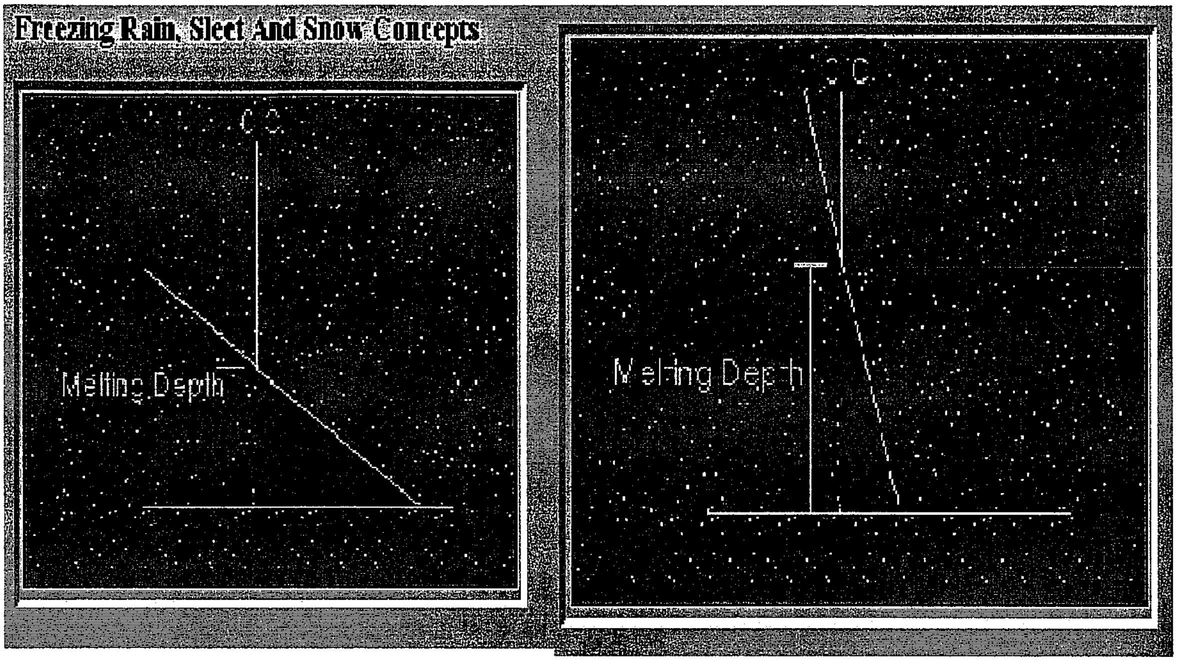
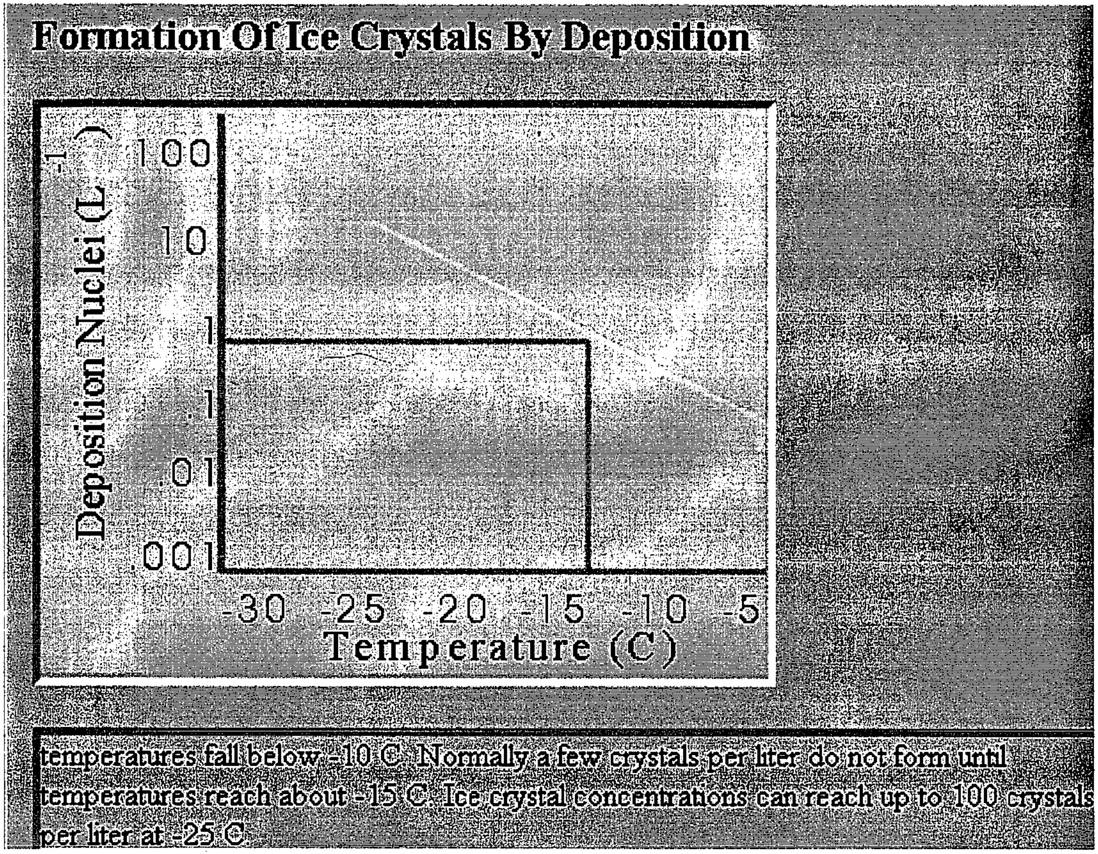
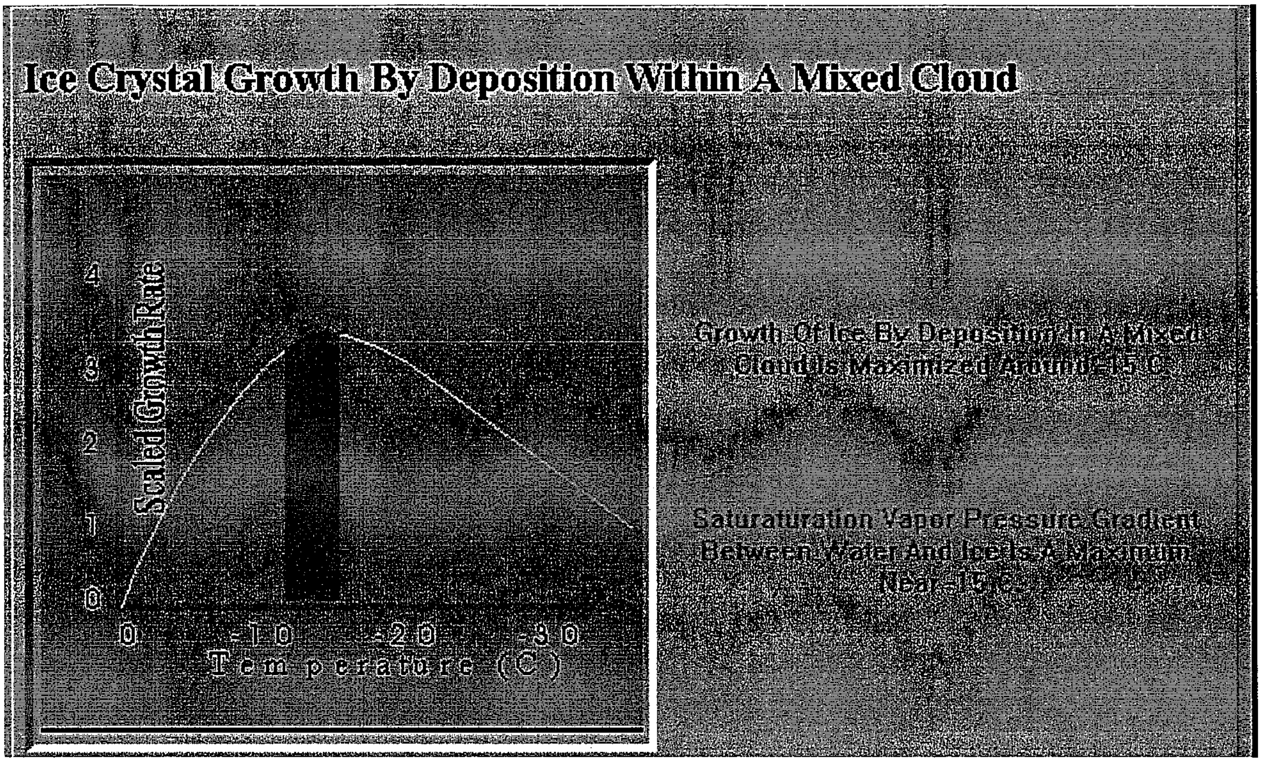


Figure 6. The melt layer on the right is weaker (less available melting energy) despite being deeper than the inversion on the left.


Formation Of Ice Crystals By Deposition

temperatures fall below -10 C. Normally a few crystals per liter do not form until temperatures reach about -15 C. Ice crystal concentrations can reach up to 100 crystals per liter at -25 C.

Figure 7. Concentration of ice crystals (per liter) as a function of temperature (°C). Depicts the reason why saturation near -15°C is important in ice crystal and snow production.



Ice Crystal Growth By Deposition Within A Mixed Cloud

Growth Of Ice By Deposition In A Mixed Cloud Is Maximized Around -15 C

Saturaturation Vapor Pressure Gradient Between Water And Ice Is A Maximum Near -15 C

Figure 8. Ice crystal growth by deposition as a function of temperature (°C). Another reason why saturation near -15°C is important in ice crystal and snow production.

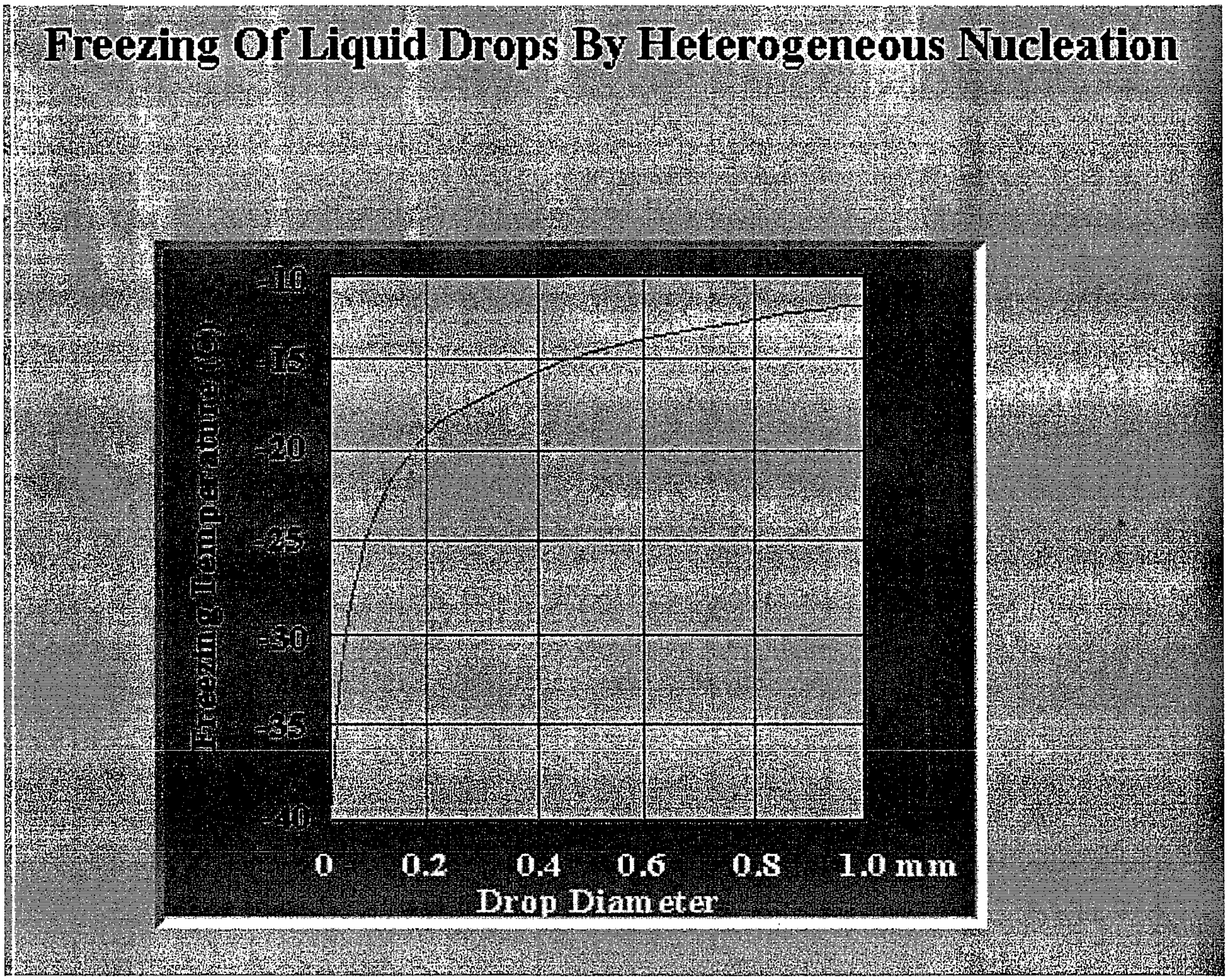
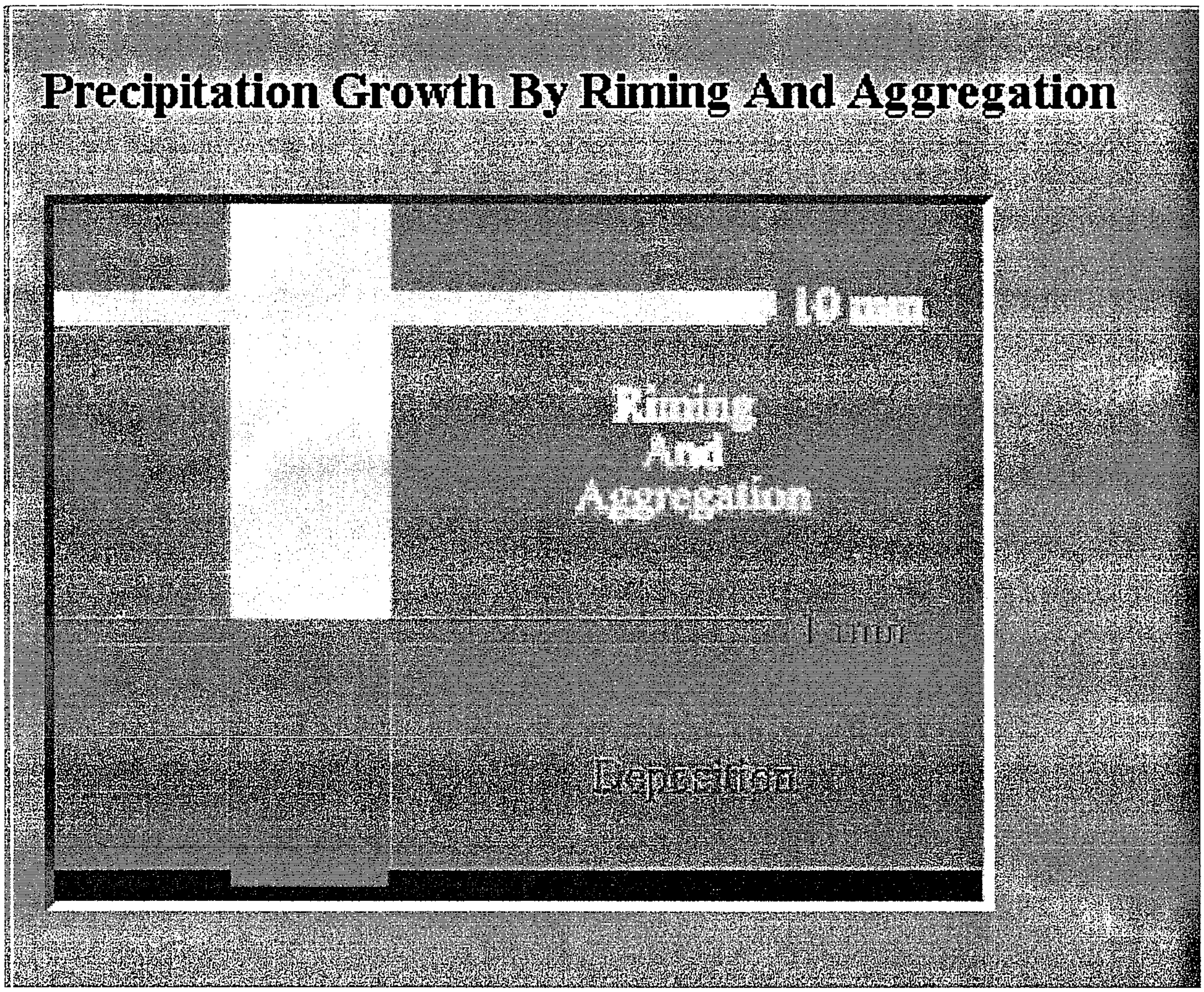


Figure 9. Freezing temperature as a function of drop diameter. Strong vertical motion leads to larger cloud drops due to coalescence which freeze at warmer temperatures.



Precipitation Growth By Riming And Aggregation

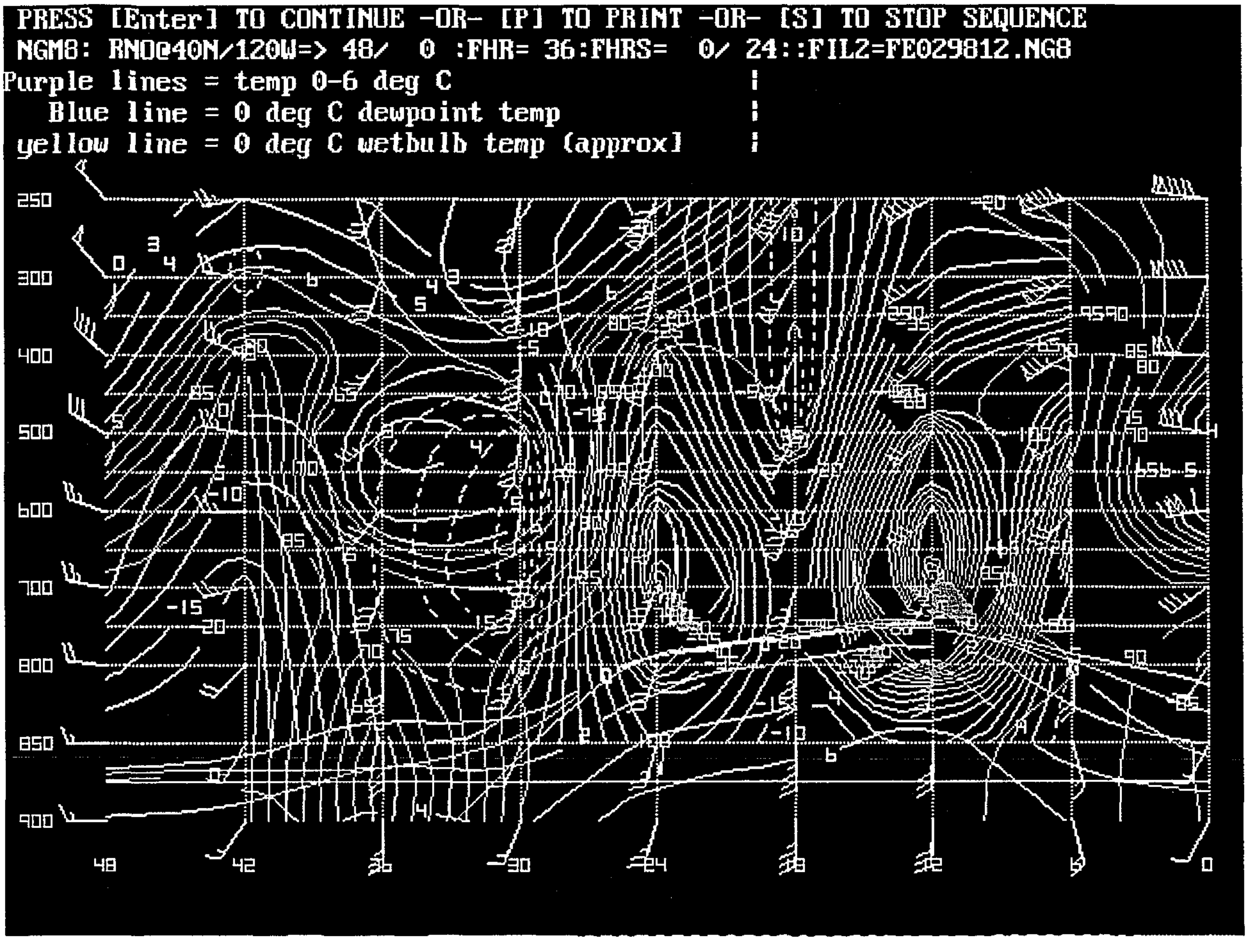
10 mm

Riming
And
Aggregation

1 mm

Deposition

Figure 10. Primary precipitation growth mechanisms by riming, aggregation and deposition as a function of drop diameter. Vertical motion will enhance the riming and aggregation processes with larger drop diameters.



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   Blue line = 0 deg C dewpoint temp      !
 yellow line = 0 deg C wetbulb temp (approx]     !
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Figure 11. Time-height for Reno, Nevada from the 1200 UTC 2 February 1998 Nested Grid Model. Vertical velocity (μbars s^{-1}), relative humidity (%), wind (kt), and zero (°C) temperature line. Note: maximum upward vertical motion is at the 12-h forecast or 0000 UTC 3 February 1998 when snow was occurring at Reno. Saturation has extended through a much deeper layer at 0000 UTC at 12-h compared with 1200 UTC at 0-h on far right.