Applying Fog Forecasting Techniques using AWIPS and the Internet

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Abstract

There are a large number of tools that can be utilized to forecast fog. Some of the tools were described in the paper " Radiation Fog: UPS Airlines Conceptual Models and Forecast Methods" (Baker, et al., 2002). Several modules were also developed in the Distance Learning Aviation Course in 2004 which summarized a list of fog forecasting tools (UCAR, 2001). This paper will demonstrate the use of several tools and how effective these tools are in real-time cases utilizing AWIPS and the Internet.

1. Introduction

Forecasting the areal extent of dense fog is very important to Aviation and Highway travelers. The National Transportation Safety Board summarizes a 1995-2000 study stating that 63% of all weather related fatal aircraft accidents were due to low IFR/Fog situations (Pearson, 2002). These conditions can also result in delayed operations and cost the airline industry millions of dollars each year. National Weather Service TAF (Terminal Aerodrome Forecast) verification statistics from 1998-2003 have shown very little if any improvement in the overall POD (Probability of Detection) for VLIFR (Very Low Instrument Flight Rule) conditions. During that 6 year timeframe, the POD was generally less than 0.30 (UCAR, 2004). The National Highway Traffic Safety Administration in 2002 also reported that the average number of highway fatalities per year due to fog is around 600 (Goodwin, 2002). These statistics prove how critical fog forecasts are to many users.

The American Meteorological Society (AMS) Glossary defines fog as water droplets suspended in the atmosphere in the vicinity of the earth' s surface that affects visibility. There are several types of fog. This paper will discuss the two most common types in the Great Plains. The most dominant is the radiation fog. This fog type is produced over a land area when radiational cooling reduces the air temperature to its dewpoint (AMS Glossary). Advection fog, the second most common, is caused by the flow of moist/warm air over a cold surface, and the consequent cooling of that air below its dewpoint (AMS Glossary). The last part of this definition is very subjective in the Great Plains and may fit more of a sea fog situation. This paper will examine some cases that demonstrate where the surface temperatures actually warm when dense fog develops. Forecasting these types of fog is very difficult and requires attention to many parameters and trends. The introduction of the UPS radiation fog forecasting methods in 2002 helped supplement several of these parameters. However, advection fog cases remain poorly documented and need further research in order to predict them more accurately.

This paper will review several tools to forecast radiation and advection fog utilizing AWIPS (Advanced Weather Interactive Processing System) and the Internet. Four case studies will be offered as a demonstration. It is hoped that this study will help the forecaster be more proactive predicting dense fog.

2. Radiation Fog

2.1 Ingredients

Radiation fog formation typically calls for clear skies, ample moisture in the surface layer and lack of turbulence. Low clouds can also build down to form radiation fog which is commonly called the Stratus " Build-Down" Concept (Baker, et al., 2002). Soil conditions play a big role in radiation fog forecasting. One of the most important concepts is the Soil Heat Flux. This is defined as heat flow into or out of the soil (Rosenburg, et al., 1983). S= K dT/dZ. The K term is the thermal conductivity of the soil. Thermal conductivity is defined as the amount of heat that the soil will conduct under a specified temperature gradient (Rosenburg, et al., 1983). Thermal conductivity is very difficult to measure in real-time, because it requires a steady state situation. However, it does play a vital role in the heat flux which is important when forecasting radiation fog. More specifically, low thermal conductivity is desired as to limit heat flow to the surface as much as possible (UCAR, 2001).

There are several factors that affect thermal conductivity. They include the following; porosity, moisture content and organic matter content of the soil (Rosenburg, et al., 1983). Clay and silt loams are very common soils found in the Great Plains. These soils have the ability to hold more moisture than sandy soils, because they become more porous. Therefore, clay and silt loams have a lower thermal conductivity. At similar moisture content, the clay and silt loams also will have lower thermal conductivities than sand (Figure 1) (Rosenburg, et al., 1983).

$$S = K\, dT/dZ \qquad (1)$$

K= term is the thermal conductivity of the soil.

dT/dZ= Change in temperature with respect to height

This means they will usually have lower heat fluxes towards the surface, which is ideal in radiation fog. However, if the soil is dry and compacted this increases the thermal conductivity, because it decreases the volume of the insulating pore spaces (Rosenburg, et al., 1983).

Kansas Agricultural reports in AWIPS usually report the mean 4 inch soil temperature for the day (Figure 2). However, this alone cannot give a good estimate of what the actual soil temperature is during the times of potential fog. Forecasters need to take into account how the thermal energy and moisture is being distributed in the soil. " In the presence of a temperature gradient, water tends to be distilled from warmer regions to condense in cooler regions. Because of the heat storage and relative constant temperatures of the deeper soil layers, the moisture flow due to temperature gradients is usually downward in summer and upward in winter" (Meteorological Services of Canada, 1978). The same principle also applies to temperature. The heat flows from warmer to colder regions (Rosenburg, et al., 1983).

During the summer, one tends have larger ranges of soil temperature, especially near the surface due to longer days. This is shown in Figure 3. This means that most of the soil heat flux is being directed downward into the soil, even through much of the night (Rosenburg, et al., 1983). During the summer, moisture flux is also being directed downward into the soil which will increase the thermal conductivity, by drying out the soil. Therefore, one will likely not see the radiation fog development during the summer, unless the soil is very moist with good evapotranspiration. Evapotranspiration can play a role in radiation fog development in the Central Plains during the spring and fall during the early morning hours by adding moisture to the boundary layer, but it does not play much of role during the winter since most of the grass and plants are dormant.

This upward movement of moisture flow, during the winter can cause freezing of dry soils and muddiness to occur on thawing soils due to latent heat effects. This muddiness can occur even if no precipitation has occurred. (Meteorological Services of Canada, 1978). This upward movement of moisture can then increase the moisture just above the ground which can lead to subsequent cooling and stronger inversions, especially if there is ideal radiational cooling and decoupling. More specifically, low thermal conductivity is desired as to limit heat flow to the surface as much as possible, which allows for the radiational cooling process to dominate and induce fog formation (UCAR, 2001).

2.2 Forecast Tools

2.2.a UPS Technique

UPS airlines composed some conceptual models and forecast methods to predict radiation fog (Baker, et al., 2002). Several of these techniques are widely being used by NWS forecasters, according to various websites and forecast discussions. One of the conceptual models discussed in Baker, et al., 2002 was how to measure hydrolapse rates in the surface layer. This involved using the crossover temperature which is equal to the minimum dewpoint observed during the warmest daytime hours. Fog is expected when the shelter temperature is expected to cool to a few degrees below the crossover temperature (Baker, et al., 2002). This method is very effective and gives the forecaster a good idea of what the moisture profile is during the day. However, just knowing the vertical moisture profile is not enough when it comes to radiation fog forecasting. Therefore, they supplemented their technique by computing the Modified Richardson # (MRi) to factor in turbulence.

$$MR\# = (T_b - T_{sfc})/U^2 \qquad (2)$$

T_b = boundary layer temperature (°C)

T_{sfc} = shelter temperature forecast (°C)

u= boundary layer wind speed (knots)

Their method utilized FOUS ETA/NGM data which is not readily available for many TAF sites across the plains. However, AWIPS has the capability to compute the MRi utilizing the model data. National Weather Service (NWS) Wichita has the MRi in their volume browser which is computed utilizing the lowest sigma layer of the boundary layer data and the extrapolated 2 m temperatures. The forecaster can then create images of the MRi to display where the best decoupling will take place. The forecaster must use the 2 m temperature data with caution and compare it with real-time observations.

BUFKIT version 4 (Figure 4) capabilities incorporate utilization of the UPS technique which includes diagnosis of the hydrolapse rate, vertical humidity flux, crossover temperature, ground temperature and MRi. BUFKIT is the most flexible of the programs available as the user may alter the expected crossover temperature to explore different outcomes created by the software. This technique works very well, especially in conditions when there is little or no pattern change during the next 12 to 18 hours. Of course, this is all based on model data, so the forecaster will have to take into account all of the raw data which includes surface observations, profilers, RAOBS (Radiosonde Observations, AMDAR (Aircraft Meteorological Data Relay), MDCRS (Meteorological Data Collection and Reporting System), and ACARS (ARINC Communications Addressing and Reporting System).

2.2.b Soil Temperature and Moisture Sources

The Oklahoma Mesonet (Figure 5) is a great real-time source to view the hourly soil temperatures, but more of these sites are needed nationwide to examine soil heat fluxes.

The RUC20 (Rapid Update Cycle 20km Resolution) model is another helpful tool in determining how much soil moisture is present (Figure 6).There are 6 levels in the RUC land-surface model, extending down to 3 m deep, but the field shown is for the top 2 cm of soil only. Therefore, this field responds quickly to recent precipitation or surface drying and may not be indicative of deep soil moisture which may move upwards during the winter. The variable displayed is the soil volumetric moisture content, the ratio of water volume to total volume in the soil. Values of 0.25 or so are relatively high values. (NOAA/Earth System Research Laboratory, RUC development group). Of course, radar and rain gage data must be examined to determine areas of recent rainfall.

Both the soil temperature and soil moisture are important pieces of the puzzle in fog prediction. The lack of this real-time data in operational forecasting can be detrimental and needs to be addressed in future programs.

2.2.c Other Tools

Enhanced GOES IR satellite data can sometimes be used for detection of moist boundary layers and potential fog areas a few hours in advance. There are two reasons for this. One is the moist air mass cools slower than a dry one. The second reason is if both dry and moist air masses were considered equal the moist boundary layer due to radiation from water vapor would be detected at these wavelengths. This may be more visible at higher latitudes. (FMI, 2005). The 11u-3.9u GOES Satellite (fog imagery) can also used to help detect fog formation.

The back edge of stratus decks or clearing-out zones definitely need to watched, because they are especially vulnerable to radiation fog, during the cool season (Baker, et al., 2002). This usually occurs on the eastern edge of the surface ridge axis, where there is a limited amount of isentropic downglide/subsidence just above the boundary layer. Forecasters can view the isentropic data on AWIPS by choosing the theta surface that is closest to the boundary layer without intersecting the surface, or looking at a cross section through the area of interest. Then display the isentropic adiabatic omega variable on the map to see if it falls between – 1 and +1 mb/s which is in the neutral category. If this is the case, it is likely the stratus deck will slow down, stall or even backbuild. Several forecast observations made at NWS Wichita suggest that the models sometimes have a difficult time resolving boundary layer moisture and try to clear skies out too quickly, during these scenarios. Therefore, forecasters must be cautious and examine the isentropic adiabatic omega field before taking the model at face value with the clearing trend. A case demonstrating this will be presented later in this writing.

On the other hand, there are cases, where dew deposition rates were large enough to delay the onset of fog. This often occurs in the midst of strong surface pressure ridges where deposition of dew or frost on elements at the ground surface leads to water vapor depletion in the few lowest meters of the boundary layer. This loss of water vapor can have an impact on the time of the fog onset or even prevent the fog from forming (Tardiff, 2001). Pilie et al. (1975a, b) pointed out that dew deposition can form the near surface dewpoint inversion. This dewpoint inversion is thought to be the mechanism responsible for the initial fog formation aloft and then builds down through fog top cooling, and moisture and heat fluxes. If the deposition rates are too high from strong subsidence (warming) aloft then the result may be patchy fog rather than widespread dense fog, due to the very shallow boundary layer moisture. Forecasters will notice ASOS visibilities tend to be highly variable during patchy fog events.

3.0 Advection Fog

The UPS technique has proven to be quite useful in predicting radiation fog, but it does have its limitations when advection processes are involved. The authors of the UPS paper even state in: " Advection fog situations involving air with dewpoints in excess of 10 deg F higher than the underlying surface temperature can produce fog in well mixed boundary layers; for these extreme situations MRi is irrelevant" (Baker, et al., 2002). This fog type can develop at any time, and last for several hours.

3.1 Ingredients

One of the conditions necessary to produce advection fog is a strong moisture and thermal gradient between the boundary layer and the surface. The MRi is irrelevant in these cases (Baker, et al., 2002), since you are usually involving advection processes in the boundary layer which is not favorable for decoupling. It is difficult to classify the speed of the surface wind, because initially it may appear to be decoupled at the surface until one receives better mixing with the warmer air aloft. Of course, this may not always be the case. Colder ground temperatures and moist soils may help aid in strengthening the inversion even more, so it is important to know the temperature and moisture conditions of the soil.

3.2 Advection Fog Forecast Tools

In order to predict when this fog will occur, use of real-time data is paramount. This includes examining surface and boundary layer data from observations, profilers, ACARS, RAOBS, and model soundings. On a surface chart, the advection fog will most likely develop along and just north of a warm/stationary front with a tight thermal/moisture gradient. This is also usually east of a developing surface low pressure system. (FMI, 2005) Moisture transport vectors and ThetaE advection in the boundary layer in AWIPS are also good tools to ascertain the degree of moisture advection. Moisture Transport Vectors are defined as: the product of the horizontal velocity vector, V, and the mixing ratio, q. Units are gm-m/kg-s; values typically range from 50-250, depending upon the level and the season.

The NOAA Profiler Network (NPN) also has some data that is not viewable in AWIPS. One of the most interesting pieces of information which can be used for advection fog forecasting is the signal power display. Meteorological features such as moisture advection and cloud layers are often visible in the signal power displays. See Figure 7. Unfortunately, this data is not as useful for fog prediction when the moisture layer is very shallow.

4.0 Case Studies

4.1 December 20-21, 2005 Stratus-Build-Down Radiation Fog Event

In this event, the NAM (North American Mesoscale)/RUC models struggled with clearing out the low level moisture too quickly, which made forecasting this event quite a challenge. Afternoon crossover values ranged from the lower to mid 20s F, but the models were projecting these values to lower during the course of the night mainly across Central and South Central Kansas. This could have led one to believe that strong subsidence from the surface ridge would create dew deposition. Thus, the fog may end up being delayed or patchy. Across Southeast Kansas the models were keeping crossover values about the same which meant the fog could be a problem in this region if they decouple. Figure 8 displays there was some wet snow on the ground. Figure 9 shows the lowest ceilings over Central and South Central Kansas while Southeast Kansas had ceilings mainly in the MVFR category during the afternoon. During the late afternoon and early evening, there was some clearing across the western sections of the forecast area, but the lack of isentropic downglide or rising theta surfaces displayed on the 270k theta surface really slowed down the eastward progression of the clearing line. See Figures 10 and 11.

The NAM/RUC were both showing the clearing line arriving at Wichita by midnight according to the boundary layer RH and soundings. This indeed was not the case, as one can see in Figures 12 and 13.

Around 8 pm, the forecasters made some phone calls to the western fringes of the clearing line. At that time, dense fog was forming in those areas, and the crossover values were being met. The satellite fog imagery displayed this fog layer fairly well as seen in Figures 14 and 15. This was also where the cloud layer was the thinnest which allowed for ideal fog top cooling, downward movement of heat and moisture and good decoupling across this region (Figure 16). As the night wore on, the clearing line made very slow progress to the east. It finally made it to Salina and Hutchinson around 09z, but not before the widespread dense fog developed and persisted for several hours. The dense fog mostly formed where the ceilings started out the lowest in Central Kansas. During the evening, the ceilings were mainly below 500ft and continued to lower until the dense fog settled in. South Central Kansas started out with ceilings around 800ft and then the dense fog developed between 06 and 08z when boundary layer winds started to decouple. Southeast Kansas never did receive dense fog, possibly due to thicker cloud decks which did not allow for good fog top cooling, and lack of decoupling until daybreak. However, the ceilings did lower about a 1,000 ft during the night.

In this case, the UPS technique proved to be useful since there was little if any change in the low level moisture, but if the forecasters would have taken the models into account with regards to low level moisture one would have taken a different approach and lowered the risk for dense fog. To sum it all up, the forecaster needs to be cautious on clearing out trends suggested by the models, especially when there is a lack of isentropic downglide. This can play a crucial role where dense fog could develop, especially if the ceilings are below 1,000ft and there is good decoupling. Sometimes one does not need a cold ground to develop dense fog. Fog top cooling, downward movement of heat and moisture, and decoupling may be enough to cause the stratus build-down effect to take place. This occurred in Springfield Missouri' s forecast area on January 3 rd, 2006 where the dry soil and deposition may have delayed the onset of the fog until 12z.

4.2 January 3, 2006 Radiation Fog Event

The second case took place on January 3, 2006 in Central Missouri. This event was very similar to the case of December 20-21st, but in this case the models did a better job with the low level moisture (Figure 17). The stratus deck came to a halt just east of Springfield (Figure 18), due to lack of isentropic downglide (Figure 19). This stratus deck then began to build to the west shortly after midnight with 700ft ceilings at Springfield (Figure 20). The formation of the stratus deck at this layer could have been a result of a dewpoint inversion formed from the dew deposition process in the lower part of boundary layer (Figure 21). These ceilings continued to lower through daybreak until dense fog formed across the back edge of stratus (Figure 22). This is where the cloud deck was the thinnest which allowed for ideal fog top cooling, downward moving heat and moisture, and decoupling. The only difference between this fog event and the fog event that took place on December 20-21st was that the ground was dry and there could have been more subsidence from the surface ridge. This could have offset the timing of the fog due to the soil temperature flux upward and dew deposition. However, the fog top cooling and good decoupling towards sunrise provided the necessary ingredients to form dense fog over central Missouri between 12 and 16z. Further west, there was more isentropic downglide (Figure 23) and possibly higher deposition rates which could have depleted the boundary layer moisture around 12z.

4.3 December 3, 2001 Advection Fog Event

The 04z surface analysis (Figure 24) on December 3rd, 2001 depicted low pressure over Southeast Colorado. From this low pressure system, a trough extended northeast from the

Oklahoma Panhandle through Wichita and extending northeast. There was a tight moisture gradient along this boundary mainly across South Central Kansas with temperatures in the lower 50s and dewpoints around 50 south of the boundary. North of the boundary, temperatures were generally in the mid 30s, dewpoints in the mid 20s with good radiational cooling in place (Figure 24). The 08z and 13z surface maps (Figures 25 and 26), indicated the low level moisture advecting northward into Northern Kansas. This low level moisture was moving up a gradual slope from Northern Oklahoma to Central Kansas (Figure 27). Water Vapor imagery also indicated a cirrus shield stretching from the Central Rockies to Eastern Kansas. The forecaster on duty expected the cirrus shield to suppress the fog potential, but in retrospect it did not have much affect on it. The fog initiated in Southern Kansas at Wichita between 08z-09z and areas to the north towards 12z. The visibility dropped to one quarter of a mile within 30 minutes across the area (Figure 28). The fog was not a long-lived event with most of the fog dissipating within a couple of hours of its development. The observations also show a 3 degree C temperature climb during this timeframe. The fog that moved into these areas all had one thing in common. The dewpoints that advected in were several degrees higher than the ambient air temperature. The fog also was denser over the areas that had good radiational cooling prior to the advection of higher dewpoints. It appears like the dense fog did not develop over Southeast Kansas due to lack of radiational cooling and higher low level moisture in place.

The BUFKIT data was very useful during this event. The ETA showed the low level moisture advecting into the lowest 25 mb of the sounding after 06z, in Wichita, Hutchinson and Salina. See Figures 29 and 30. The ETA also showed Russell receiving the low level moisture, but after examining the observations the low level moisture never did arrive at that point. See Figures 31 and 32. Soil temperatures were also about 5 deg c cooler than surface temperatures which could have played a role in strengthening the inversion and limiting the heat flux upwards. See Figure 33.

4.4 January 12, 2005 Advection Fog Event

At 06z on January 12, 2005, a surface warm frontal boundary extended from the Oklahoma Panhandle to Northwest Arkansas (Figure 34). This boundary then extended northeast through St. Louis into Central Ohio. Temperatures north of this boundary were primarily in the 20s and 30s with temperatures ranging from the 40s to the 60s south of the boundary (Figure 34). The visibility was around ¼ of a mile in Central Oklahoma near the frontal boundary (Figure 35). By 15z, the frontal boundary had moved north into Wichita and extended through St. Louis to near the Michigan and Northern Indiana border (Figures 36 and 37). The surface visibility and ceilings dropped to the LIFR (Low Instrument Flight Rules) category with the visibility generally one quarter of mile or less, especially along and north of the front (Figures 38 and 39). You will also notice the temperatures and dewpoints showed a dramatic rise when the dense fog started to develop and continued to rise until the inversion mixed out late in the day. There was good moisture transport in the boundary layer (Figure 40). The profilers could have also a benefited in this case. These profilers displayed an increase in signal power in the lowest 1km mainly after 09z which means there was an increase in low level moisture (Figures 41 and 42). In addition, the MRi was greater than 0.01 across the region, which means that the boundary layer was well mixed (Figure 43). The RUC soundings displayed a strong inversion over Northern Indiana and Southeast Kansas(Figures 44 and 45). One interesting thing to note in this case was that the dense fog developed over both snow covered areas and non-snow covered areas (Figure 46). In the non-snow covered areas the ground temperatures were also slightly warmer than the surface temperatures (Figure 47). Therefore, this event was primarily driven by advection.

5.0 Conclusions

The goal of this paper was to present some operational tools that have proven to be useful in predicting radiation and advection fog. The UPS technique is a very useful tool especially for aviation radiation fog forecasting, but it does have its limitations when your TAF sites are not on the FOUS data list. Therefore, you are more dependent on AWIPS and the model generated boundary layer information. Outside of AWIPS, you can also utilize BUFKIT version 4.

Soil conditions also play a big role in fog forecasting. One of the most important parameters is knowing the heat and moisture fluxes within the soil which affects the thermal conductivity. In radiation fog situations, you need low thermal conductivity values, because you want the least amount of heat flow to be transported to the surface (UCAR, 2001). It is important to know the porosity and organic matter content of the soil in your part of the country because this greatly affects thermal conductivity. (Rosenburg, et al., 1983). Unfortunately, there are very limited resources to view the moisture content of the soil, but there are a couple of things you can use as a guide. The RUC20 utilizes the field for the top 2 cm of soil, but you must utilize the radar precipitation and rain gauge data to help supplement this model.

The back edges of stratus decks or clearing-out zones are especially vulnerable to radiation fog, during the cool season (Baker, et al., 2002). This usually occurs on the eastern edge of the surface ridge axis, when there is a limited amount of isentropic downglide/subsidence just above the boundary layer. December 20-21, 2005 and January 3, 2006 were good cases that utilized the isentropic adiabatic omega fields on AWIPS. The only difference between January 3rd and the fog event that took place on December 20-21st was that the ground was dry and there was possibly more dew deposition effects. In order to predict radiation fog more accurately, we need a complete description of surface characteristics along with a high vertical resolution model to view the small scale gradients in the boundary layer (Tardiff, 2001).

Advection fog is one of the more challenging fog types in operational forecasting. The December 3, 2001 and January 12, 2005 cases both show temperatures increasing as the dense fog develops. There has not been a lot of research on this topic, but there are some tools that forecasters can utilize on AWIPS and the Internet. Forecasting this fog type will require using real-time data, such as surface and boundary layer data from observations, profilers, ACARS, and RAOBS. Boundary layer Moisture Transport Vectors are also a good tool in determining the amount of moisture that will move into the region of interest. Another good tool to use in predicting advection fog is the Signal Power found on the NPN Profiler Website.

he December 3, 2001 case even had some upslope and radiational cooling effects. The good radiational cooling prior to the dense fog combined with the upslope and moisture advection produced a hybrid-type fog event. These types of situations are beyond the scope of this study, and will need further research to gain more understanding of these events.

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Other websites used for research:

AMS Glossary:

http://amsglossary.allenpress.com/glossary/browse?s=h&p=28

Atmospheric Radiation Measurement:

http://www.archive.arm.gov/

National Weather Service, NOAA Profiler Network:

http://www.profiler.noaa.gov/npn/aboutProfilerData.jsp

Oklahoma Mesonet:

http://www.mesonet.ou.edu/public/current.html

BUFKIT Website:

http://www.wbuf.noaa.gov/bufkit/bufkit.html

The Volume Browser provides access to numerical models and other gridded data sources, such as RAOB, BUFR, and Profiler data. Through the Browser interface, you can choose the data source(s), field(s), plane(s), and point(s), and generate a customized list of model graphics or images for display. Forecast Systems Laboratory, " *AWIPS D2D User Manual*" , http://www-md.fsl.noaa.gov/~cheatwoo/AWIPS/OB4-UM/3_1.htm (September 2004)

Equivalent Potential Temperature - The temperature a parcel of air would have if a) it was lifted until it became saturated, b) all water vapor was condensed out, and c) it was returned adiabatically (i.e., without transfer of heat or mass) to a pressure of 1000 millibars.

" The signal power is a measure of the amount of backscattered power received from the atmosphere. High signal power values (greater the 60dB) are typically associated with high moisture content or the presence of particles, while low power values (less than 40dB) usually indicate a dry or stable atmosphere."