P1.4 GOES SUB-PIXEL ANALYSIS USING AIRS-1.5 REMOTE SENSORS

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1. Introduction

The Areal Vicinity Icing and Snow Advisor (AVISA) is an experimental system for diagnosing and forecasting winter weather hazards for a given location. For now, the primary focus is on Mirabel Airport near Montreal, Canada, where recent Alliance Icing Research Study (AIRS) projects were conducted (Isaac, 2001). Past and present AIRS field programs have involved instrumented research aircraft flights through cloud environments where supercooled liquid water (SLW) and supercooled large drops (SLD) were forecast to exist. At the same time, remote sensing instruments were positioned on the ground in an attempt to observe and predict the macro environment leading to the formation of SLW and SLD.

One approach toward semi-automated warning generation is to achieve a level of ongoing machine cognition of the current atmospheric state. Confidence in numerical models being indicative of atmospheric state depends to a large extent on verification with real observations. Realtime model assessment, however, remains a difficult challenge. The current version of AVISA attempts to infer basic cloud layers aloft using available observations and selected model outputs such as temperature and relative humidity (RH) profiles. In the future, inferred cloud scenarios will be compared with other model output to calculate a measure of confidence in the model. For now, the task is to obtain credible bounds on the extent of icing potential aloft.

As its name implies, AVISA is concerned not only with conditions directly aloft, but also with the nearby vicinity, especially upstream of a given location. Spatial context for cloud cover comes mostly from the GOES satellite, although scanning radar is also important, especially for snow cases. Cloud top height is derived by comparing satellite IR temperatures with Global Environmental Multiscale (GEM) model temperature profiles. This technique is similar to that used by other icing potential schemes such as the Current Icing Potential (CIP) product developed at the National Center for Atmospheric Research (NCAR) (McDonough, 1999) which instead uses the Rapid Update Cycle (RUC) model. GOES measurements also form the basis for a variety of satellite-based icing algorithms (Thompson, 1997).

An important complication for AVISA is that the ground based remote sensors can be considered essentially point based relative to GOES pixel sizes, nominally about 4-km for IR. A key ground based instrument is the vertically pointing X-band radar (VPR) from McGill University whose echo top gives an estimate of cloud top. Since use of GOES observations is a common starting point for cloud icing schemes, we call comparisons with point based instruments such as VPR a sub-pixel analysis. Results from such comparisons could be used to improve local scale icing algorithms.

2. The AIRS-1.5 Field Study

The AIRS-1.5 field study was conducted during the winter of 2002-03 as a practice run for the larger AIRS-2 field study underway during the winter of 2003-04. During AIRS-1.5, a Convair-580 aircraft from the National Research Council in Ottawa was instrumented with various sensors for determining microphysical properties of clouds. The Convair was also equipped with a Ka-band radar measuring reflectivity in upward and downward directions, plus a radio modem for transmitting measurements and location to a ground station at Mirabel.

In addition to the VPR mentioned above, the Mirabel ground site was equipped with a suite of radiometers, precipitation sensors, a ceilometer, a visibility meter, and other instruments. A network connection to the King Radar north of Toronto was maintained during the project so that measurements could be processed and displayed on a web site at five minute intervals. The choice of time resolution was somewhat arbitrary, but it is comparable to the GEM model time step of 7.5 minutes. The Mirabel site was also within range of the McGill S-band scanning radar, although it was partially obscured at low levels by topography.

At the time AIRS-1.5 was conducted, the operational GEM model was run at 24-km resolution, and 1-hour time series data at the grid point nearest to Mirabel were available. RUC model outputs were also available for purposes of comparison.

GOES data were processed with TeraScan software including remapping onto a polar stereographic

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projection. An icing algorithm using a combination of channels was developed for estimating phase at the cloud top. Estimates of cloud top height and cloud base were plotted with radiometer derived liquid water path to form an icing potential time series for Mirabel.

3. February 19, 2003 Morning Case

Shortly after 12Z on February 19, 2003, the Convair-580 left Ottawa in search of icing conditions over Mirabel. The direction of flight from Ottawa to Mirabel happened to be in the direction of cloud movement as observed from GOES imagery. Flying at an altitude of 8800 feet, a thick stratiform cloud layer was photographed below during the 20 minutes it took to fly between airports (Figure 1). Upon arrival at Mirabel, the Convair was put into a series of spiral descents and missed approaches until about 16Z. Moderate to severe icing was encountered, especially within the top portions of the stratiform layer.

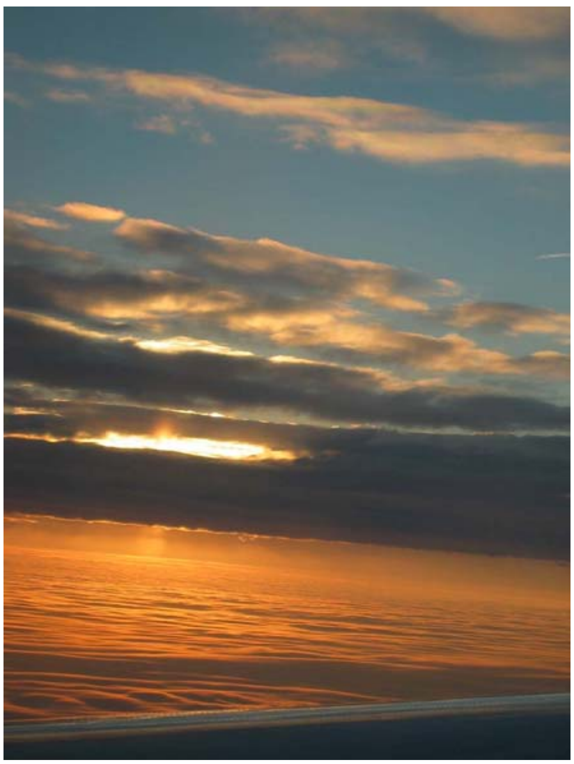

Figure 1. Cloud layers and sunrise enroute from Ottawa to Mirabel near 12Z on February 19, 2003. The stratiform cloud deck below is topped at roughly 4000 feet, and the layer above about 12000 feet.

Figure 2 shows a 12 hour VPR reflectivity time series plot overlaid with GOES/GEM derived cloud top heights. Cloud base measured via ceilometer is also shown. Differences in cloud base are not discussed here, but general conditions of haze and light snow near the surface resulted in ambiguous determination of actual cloud base.

Agreement between VPR and GOES at cloud top was quite good until about 10Z. After that, there was a period of about 3 hours where GOES cloud top hovered above the VPR echo top. Between 12:30Z and 13:15Z the Convair was already at Mirabel, spending most of its time in the upper portions of the stratiform layer, but climbing back out at the end of the segment. Reflectivity plots from the Ka-band radar aboard the Convair (not shown) indicate that the stratiform layer was topped just above 4000 ft, thus confirming that the VPR echo top was representative of reality. Also, the Nevzorov probe onboard the Convair indicated a sharp drop to zero in liquid water content measured at the same altitude during ascent out of these clouds.

Given that the VPR provided a better estimate of the stratiform cloud top during the flight segment above, the corresponding question is why GOES/GEM failed. Figure 1 reveals a higher layer of broken cloud that the VPR apparently did not see. The VPR is typically tuned to resolve larger precipitation sized particles. It is assumed that the broken layer in Figure 1 continued all the way to Mirabel and beyond.

Unfortunately, the broken cloud layer is substantial enough to contaminate the GOES IR pixels. GOES cannot resolve these clouds, but temperatures are reduced sufficiently to result in a higher altitude on the GEM temperature profile. The GOES/GEM cloud top of roughly 8000 feet cannot be correct because the aircraft flew at or above that altitude and the broken clouds were observed to be above it. The actual top is probably around 12000 feet as again revealed by the Ka-band radar onboard the Convair (not shown). This information is useful in hindsight, but is not available for building a realtime diagnostic tool.

Knowledge that GOES/GEM and VPR disagree can be used as a clue that multiple cloud layers exist. In this case, the upper cloud layer is probably incidental to pilots, however, in the context of realtime diagnosis, the possibility of small particle liquid clouds above the VPR echo top vs. multiple cloud layers still needs to be examined. Since no other upper air observations exist, we are forced to use model data, namely relative humidity (RH), to infer an answer. At 12Z, GEM indicates RH dropping from 100% at 4000 feet to about 45% near 7000 feet (Figure 3). This information supports eliminating the possibility of cloud above 4000 feet. On a secondary note, GEM provides little evidence for a cloud layer near 12,000 feet, but at least a slight increase in RH is indicated. Using all inputs, namely GOES, VPR, and GEM, the existence of this layer could be inferred in realtime with some degree of confidence.

GOES icing algorithms rely heavily on temperature, so knowledge that the important lower layer is actually warmer than the IR-observed mixture of layers could be useful in determining cloud top phase, at least for the local scale in the vicinity of an airport.

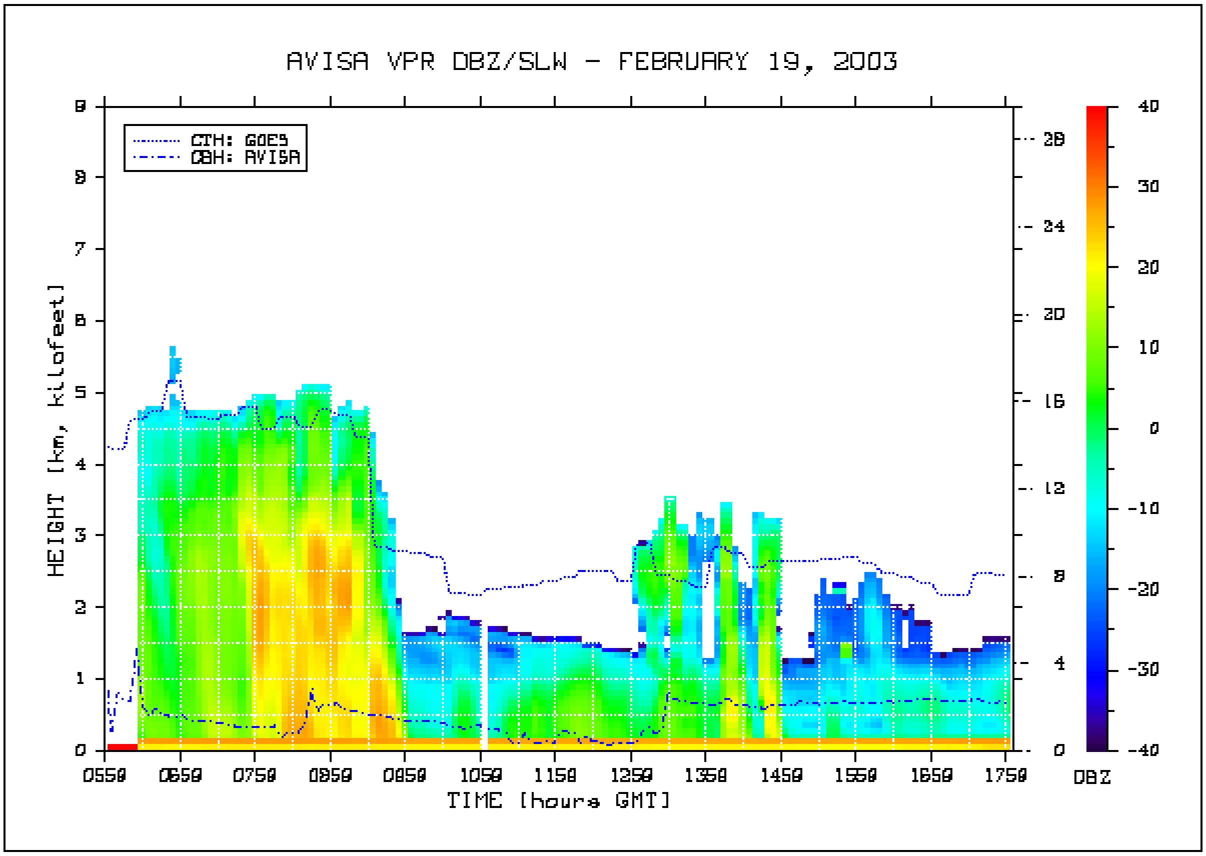

Figure 2. Vertically Pointing X-band Radar reflectivity with GOES/GEM derived cloud top height and ceilometer measured cloud base, located at Mirabel Airport on February 19, 2003, 6-18Z.

Neighboring pixels of similar temperature could be collected using a region growing algorithm to estimate spatial extent (not yet implemented).

Moving on to the period 13-15Z, Figure 2 illustrates a situation where VPR echo top actually exceeds GOES/GEM cloud top by up to 4000 feet. Clearly GOES/GEM is again in error since the intensity of VPR reflectivity is indicative of precipitation sized particles. A possible explanation for this discrepancy is a faulty temperature profile. In post-processing it is evident from ground instruments that a shallow warm front passed through at surface level at 15Z. Therefore the elevated cloud levels during 13-15Z would be consistent with lifting ahead of the front. In the unstable frontal environment, changes to the temperature profile would be expected. Although custom radiosonde launches were not available during AIRS-1.5, changes to small sections of the temperature profile could be confirmed using Convair air temperature measurements. Readings at 6000 to 7000 ft indicated temperatures roughly 4˚C warmer than predicted by GEM. In the future, forecast information about expected fronts might be used to enhance the interpretation of GOES/GEM – VPR differences. For now, further study is needed to determine if the VPR echo top above GOES/GEM phenomenon can be used in a predictive sense.

The fact that the GOES/GEM cloud top remains barely perturbed through the 13-15Z period and beyond suggests that multi-layer clouds could be a factor throughout this period. In other words, the whole episode may be partially obscured from satellite view. Unfortunately, this possibility cannot be confirmed either through VIS-channel imagery, Ka-band radar or inflight photos. The flight track during that entire time was through the thick of the cloud, and substantial icing was encountered. Variations in neighboring IR pixels were investigated and found to be inconsequential. Small isolated cells were observed in the S-band radar imagery (Figure 4), and in principle they should have been large enough and persistent enough to affect IR-imagery, assuming they were not obscured. This phenomenon will be investigated further during AIRS-2 when custom radiosonde launches and a profiling radiometer will be available. It is important for AVISA to recognize the impact of lifting in frontal zones in order to properly assess icing potential.

4. February 19, 2003 Afternoon Case

Differences between VPR and GOES/GEM were also considered for 6 hours beyond what is shown in Figure 2. This period brackets a second Convair flight on February 19 that was less successful in locating SLW although models were predicting it. From 19Z onwards a new regime of high cloud at roughly 20,000 feet led to significant disagreement between GOES/GEM and VPR (not shown), similar to the morning case. The existence of this high cloud layer was indicated eventually by trace VPR echoes, but at least 2 hours after the GOES/GEM cloud top rose almost to 16,000 feet. The 19Z GEM relative humidity profile (also not shown) strongly supported the existence of high level clouds, although perhaps even higher than indicated by the VPR. More importantly, GEM also supported the non-existence of mid-level clouds in this regime, eliminating the likelihood of icing at these heights.

5. Conclusions

The February 19 case shows that low level GOES/GEM cloud tops heights can easily be contaminated by multi-layer clouds or instability from fronts. Comparison with VPR reflectivity provides clues for determining when contamination is happening. If concern was only for conditions at a point, the VPR could perhaps be taken by itself to provide bounds on icing potential, but there would still be questions of whether it was seeing all the cloud, i.e. the smaller liquid particles. Also, in order to achieve spatial context, linkage to spatial observations must be made, one common source being GOES satellite measurements. Because of large differences in scale between sensors and related model data, disagreement amongst measurements from different platforms can be expected.

AVISA attempts to combine sensors and model data to resolve different estimates of cloud top height. Better confidence in how cloud layers are determined together with early detection of forming processes such as fronts will lead to better icing potential products and model assessment.

6. References

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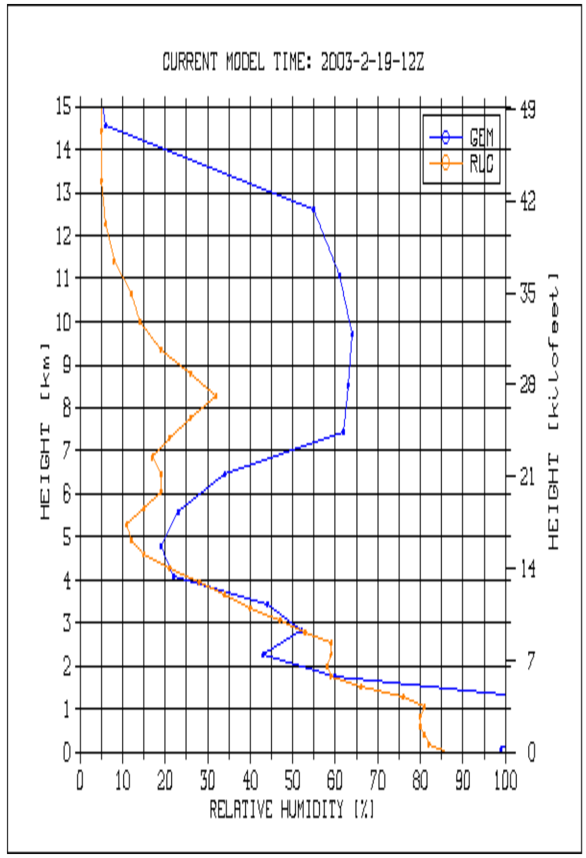

Figure 3. GEM relative humidity (0Z run) in blue together with RUC relative humidity. Drop to near 45% above 4000 feet suggests cloud free area.

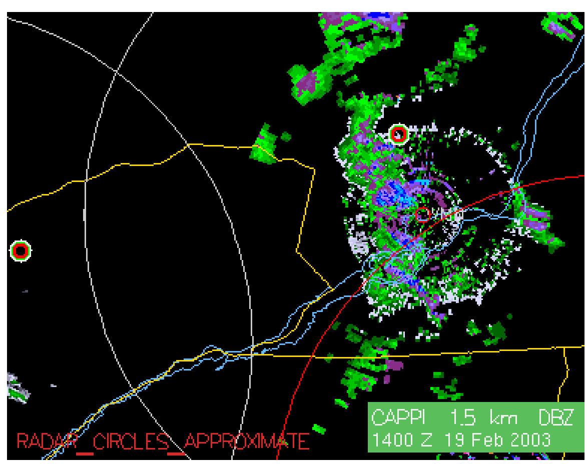

Figure 4. McGill S-band radar reflectivity at 14Z on February 19, 2003. The topmost (northerly) red circle marks the location of Mirabel Airport.