P6.1 TWO PERSPECTIVES ON A COLORADO ICING EVENT: GRIDS AND CIP

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1. INTRODUCTION

Two unique approaches to the diagnosis of icing conditions have been developed under the FAA's Aviation Weather Research Program: NOAA-ETL's Ground-based Remote Icing Detection System (GRIDS; Schneider et al. 2002) and NCAR's Current Icing Potential algorithm (CIP; Bernstein et al. 2004). Each integrates different sources of icing-related data to indicate the presence of supercooled water drops, both at small and large sizes. The GRIDS and CIP methods each have their strengths and weaknesses which lead to good and poor icing diagnoses for different icing events. As part of the 2004 Winter Icing and Storms Program (WISP04), GRIDS operated out of its base at Erie CO, while an experimental, 20-km version of CIP was running in real-time at NCAR.

On 10 March 2004, an icing event impacted northeastern Colorado and was documented by a University of North Dakota aircraft. Both GRIDS and CIP diagnosed the presence of icing and provided unique perspectives on the event. In this paper, those diagnoses will be described and compared to the aircraft observations. Ways in which the two systems complement one another will be discussed.

2. DATASETS

2.1 GRIDS

GRIDS integrates microwave radiometer data with Ka-band radar profiles to remotely measure the altitudes of the clouds and identify their phase. This information is then combined with a temperature profile from the Rapid Update Cycle (RUC) model 1-hr forecast to determine if the liquid clouds pose an icing threat and if they contain supercooled large drops (SLD).

In its current configuration, the GRIDS icing algorithm uses liquid water paths derived from a two-channel microwave radiometer to determine if, and how much, liquid is present in the atmospheric column. It then uses the radar reflectivity and depolarization ratio to resolve the cloud vertical profile and to indicate the presence, or lack, of cloud ice or SLD layers. RUC model temperature profiles are used to gauge whether or not the liquid is supercooled.

GRIDS measurements are nominally averaged to provide one-minute resolution data (higher temporal resolutions are possible). The spatial resolution of GRIDS is on the order of several tens of meters.

2.2 CIP

CIP uses GOES satellite data and surface observations to find clouds and identify their bases, tops and cloud top temperatures. It combines this information with a mosaic of NEXRAD radar reflectivity, surface observations of precipitation, observations of lightning from the national lightning detection network, recent pilot reports, and 3-hr RUC model forecasts of temperature, relative humidity, vertical velocity and supercooled-liquid water to estimate the potential for icing and SLD conditions across the contiguous United States and southern Canada.

During WISP04, an operational, 40-km resolution version of CIP ran at the Aviation Weather Center (AWC) and an experimental, 20-km version ran at NCAR. The 20-km version contains many important upgrades and is slated for implementation at the AWC in spring 2005. Output from the 20-km version will be discussed here.

2.3 University of North Dakota Citation

The University of North Dakota's Cessna 550 "Citation" research aircraft was flown out of the Broomfield-Jefferson County Airport (KBJC) to document the microphysical characteristics of clouds and precipitation over the WISP04 domain. The Citation carries an array of probes to record state parameters and cloud physics fields. For this study, the probes of interest are as follows: a CSIRO liquid water content probe (gm^{-3}; King et al. 1978), a Forward Scattering Spectrometer Probe (FSSP; size range 2-47 microns, concentrations in cm^{-3}), and an OAP 2DC probe. The 2DC probe provides images of cloud- and small precipitation-sized particles that the aircraft encounters, including ice crystals and both small and large drops.

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3. 10-11 MARCH 2004 ICING EVENT

Two cold fronts moved southward across the WISP domain on 10 March, as cold advection moved into the area on northwesterly flow at 700mb. The fronts were associated with strong northerly and northwesterly surface winds that developed between a 1040mb high pressure area centered near Vancouver and a 982mb low centered near Winnipeg at 1200 UTC (Fig. 1; only the initial front was analyzed by NCEP). The first front moved southward out of Wyoming and reached KBJC at ~1300 UTC. Winds shifted from westerly to easterly, ushering in slightly cooler temperatures and broken mid-level clouds. Little or no supercooled water was present in these clouds, as evidenced in the intermittent, low integrated water contents measured by the GRIDS radiometer through ~2000 UTC (Fig. 2).

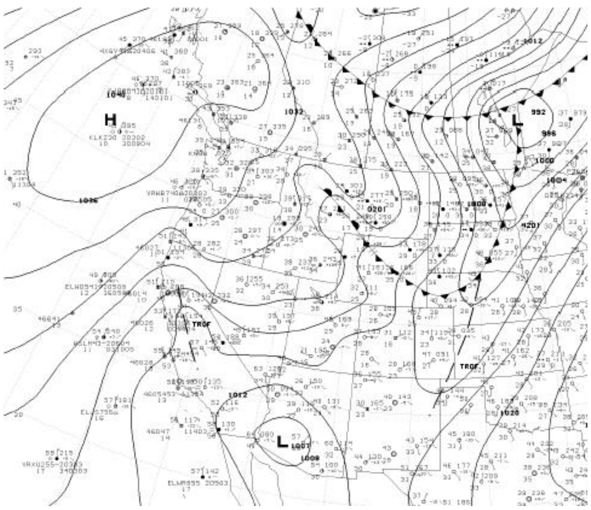

Fig. 1. Surface analysis for 12 UTC on 10 Mar 2004.

A secondary cold front moved southward across the domain in the late afternoon, impacting KBJC by 2100 UTC. Following frontal passage, winds shifted to northerly, temperatures dropped rapidly toward freezing and low stratus clouds moved into the WISP04 domain. These clouds contained significant amounts of supercooled liquid water, which impacted the area between 2100 and 0400 UTC (Fig. 2), and resulted in numerous reports of light and moderate icing. Water contents dropped to near zero by 0400, but skies did not clear at Denver (KDEN) and nearby Greeley (KGXY) until ~0800 UTC on 11 March.

The UND Citation took off from KBJC at ~2230 UTC, not long after the passage of the secondary cold front. The aircraft immediately encountered icing clouds with liquid water contents (LWC) up to 0.45 gm^{-3} during climb out (Fig. 3a). Cloud base and top were found near 2.4 and 3.5 km (all heights MSL), respectively, and the cloud was dominated by liquid water. LWC gradually increased from cloud base to 3.1 km, and then varied dramatically between 0.25 and 0.55 gm^{-3} in the upper 0.4 km of the cloud. Both the CSIRO and FSSP measured LWC values showed the strong deviations and tracked each other well. The cloud top temperature was -7.7^{o}C, which was ideal for icing conditions. There was a 0.7^{o}C capping inversion at cloud top over a 130m depth. Cloud base temperature was -2.5^{o}C.

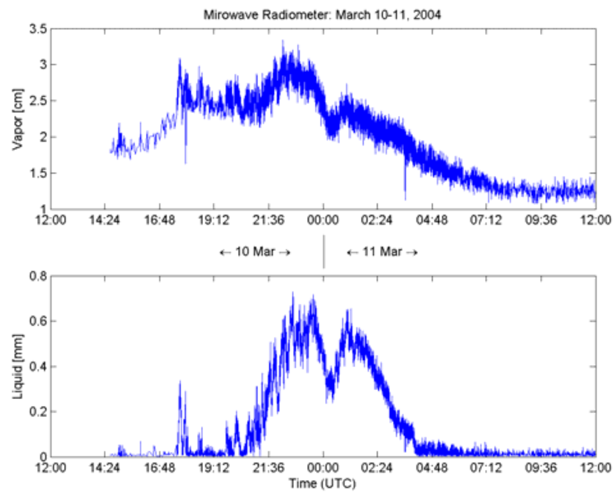

Fig. 2. Integrated vapor and liquid values measured by the GRIDS radiometer for the period 1200 UTC, 10 March through 1200 UTC, 11 March.

Following climb out, the Citation completed a series of northeast-southwest oriented flight legs at stepped altitudes, roughly between KBJC and KGXY (Fig. 3b). LWC varied significantly both with NE-SW location along the constant altitude legs, and with height. Peak LWC values exceeded 0.8 gm^{-3} at altitudes between 2.5 and 3.2 km, mostly toward the northeast end of the flight legs, near KGXY. Cloud and icing tops were found to be as high as 3.6 km along this transect. Note that the highest water contents were consistently found ~0.5km below cloud top in this case. Toward cloud base, icing conditions were found as low as 2.3km MSL. After accreting a good deal of ice, the aircraft landed at KBJC at 0001 UTC. During a brief second flight (not shown), uniform icing conditions with LWC of 0.5 gm^{-3} were found near 3.0km between 0100 and 0200 UTC.

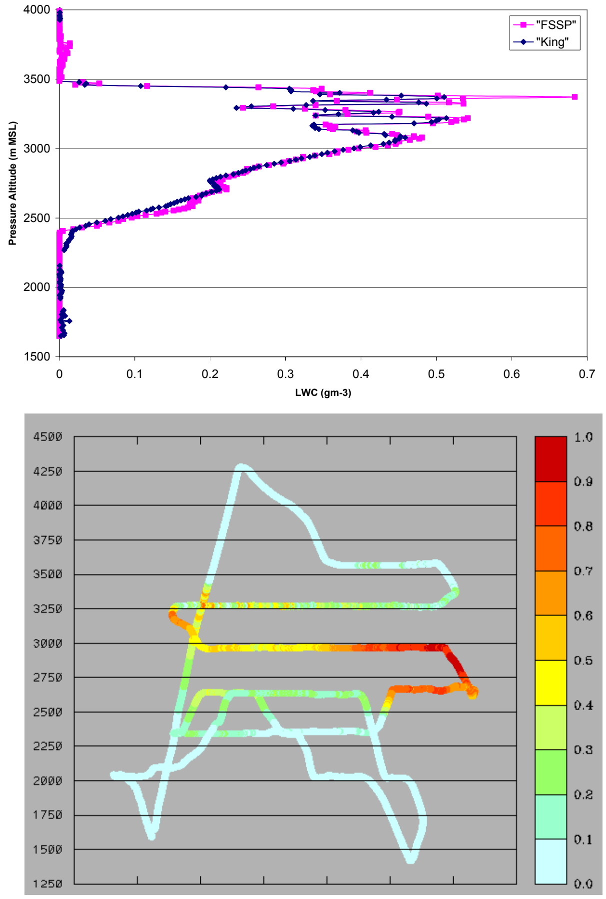

Fig. 3. Liquid water content measured during a) climb out of KBJC at ~2230 UTC and b) in a distance-height cross-section along a line roughly from KBJC (left) to KGXY (right). Altitudes are in m MSL. Magenta and blue lines in part (a) trace water contents measured by the CSIRO/King and FSSP.

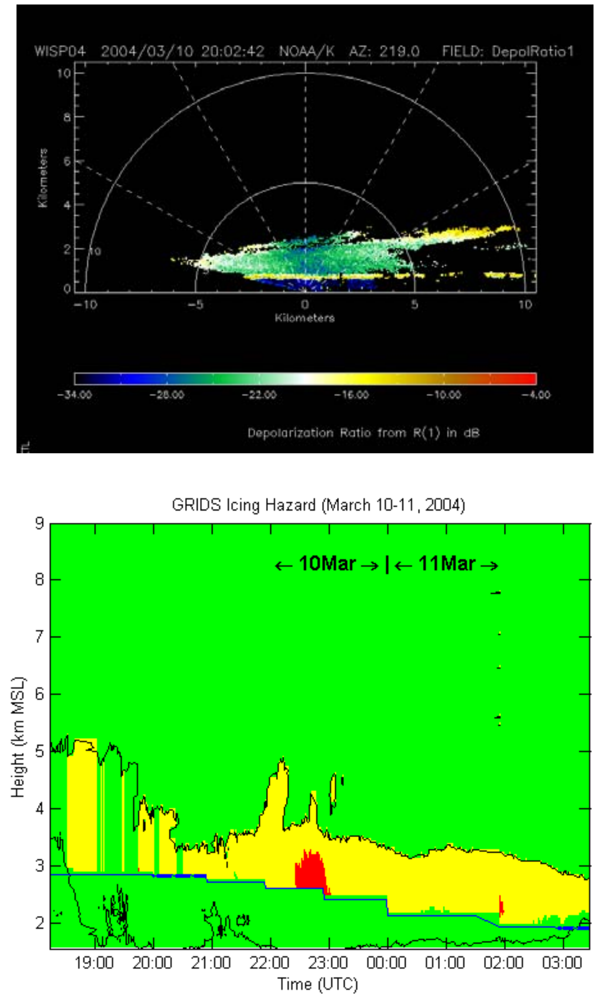

Fig. 4. a) Vertical slice (RHI scan) of the depolarization ratio (DR) at 2002 UTC, parallel to the KBJC (right) to KGXY (left) line. The DR clearly shows the bright band at ~0.5 km (~2 km MSL) and the presence of ice above it (DR > -32 dB). Range is relative to radar which sits at 1.5 km MSL. b) Time-height (MSL) image of the GRIDS icing product (green=safe; yellow=caution; red=serious hazard), with a cloud boundary overlay (black contour) and the zero degree isotherm (blue line) from 1-hr RUC.

4. GRIDS OBSERVATIONS

The NOAA Ka-band radar depiction of the clouds during this case suggested more dynamic clouds for the first half, then weaker more stratiform clouds during the second half. Depolarization ratio (DR) measurements indicated that there was some cloud ice present somewhere in the column throughout the duration of this case.

Prior to 2100 UTC, the Ka-band radar indicated that there were ice clouds between 2 and 5 km MSL (Fig. 4a). By 1915 UTC there was a bright-band which persisted until 2050 UTC, showing the freezing level to be just above 2 km MSL during this period. During this same period the RUC model had the freezing level ~0.8 km higher (Fig. 4b). The GRIDS algorithm most likely missed lower level icing hazards because the RUC model had the freezing level too high.

At present the GRIDS icing algorithm uses three indicators to represent the icing threat: green which means that there is no supercooled liquid present; yellow which indicates that icing conditions are likely; and red which depicts a definitive icing hazard. The mild ambiguity inherent in the yellow condition stems from the difficulty in distinguishing between ice crystals and liquid when both are known to be present in the column. The range resolved DR measurements can accurately indicate the presence of ice, but they do not preclude the simultaneous presence of water, i.e. "mixed phase" conditions. The presence of ice is determined from the range-resolved DR measurements (e.g. Fig. 4b) and liquid (a path integrated quantity whose presence is determined from the radiometer, e.g. Fig. 2)

The GRIDS icing algorithm issued icing cautions (yellow) throughout the duration of the case until the system dissipated. Notably, the algorithm flagged conditions red during and just after the Citation initially took off (~22:30 UTC). During the latter period, the radar echoes were generally weak and the shallow clouds were identified as being mixed phase. Such conditions were documented by the Citation during both flights.

5. CIP DIAGNOSES

CIP diagnosed icing conditions across northeastern Colorado throughout the period of the flights. At approximately the time of the UND Citation climb out (2230 UTC), CIP indicated potential for icing between 2.5 and 4.3 km, with high potentials (0.8-1.0 on a scale of 0.0-1.0) between 2.8 and 3.7 km (see Fig. 5). This range of altitudes very closely matches the icing altitudes observed by the Citation, both during its climb and during the NE-SW flight legs.

Using GOES observations of clouds with -9^{o}C cloud top temperatures (CTT; compared to the -7.7^{o}C value observed by the aircraft) in combination with the RUC profile of temperature, CIP overestimated the cloud top height by ~0.5 km (~1500 ft). The overestimate was caused by a combination of slightly cold satellite-measured CTT, slightly warm RUC forecast temperatures at 4.0 km and CIP's conservative method of cloud top height estimation, which places the cloud top at the first vertical level that is colder than the satellite observed cloud top temperature.

Ceiling observations from KBJC indicated a cloud base of 2.6 km, which CIP brought down to the next lower grid point, vertically, at 2.5 km. Ideal icing temperatures (-3^{o}C to -9^{o}C), satellite-indicated CTT (-9^{o}C), and both high relative humidity (>90%) and weak upward motion from the RUC all contributed to the high icing potentials. Although the cloud top height was overestimated by 0.5 km, low relative humidity values and slight downward motion at altitudes between the actual and the CIP-diagnosed cloud tops resulted in low (0.1-0.4) icing potentials there. Warm RUC temperatures (approaching -1^{o}C) also resulted in low icing potentials (0.35) near cloud base.

CIP diagnosed icing all along the flight track, and continued it southwestward into the foothills and northeastward to the Nebraska border (Fig. 5). Icing was consistently depicted during the hours of flight, when icing was encountered aloft and the radiometer showed significant amounts of integrated liquid water (Fig. 2).

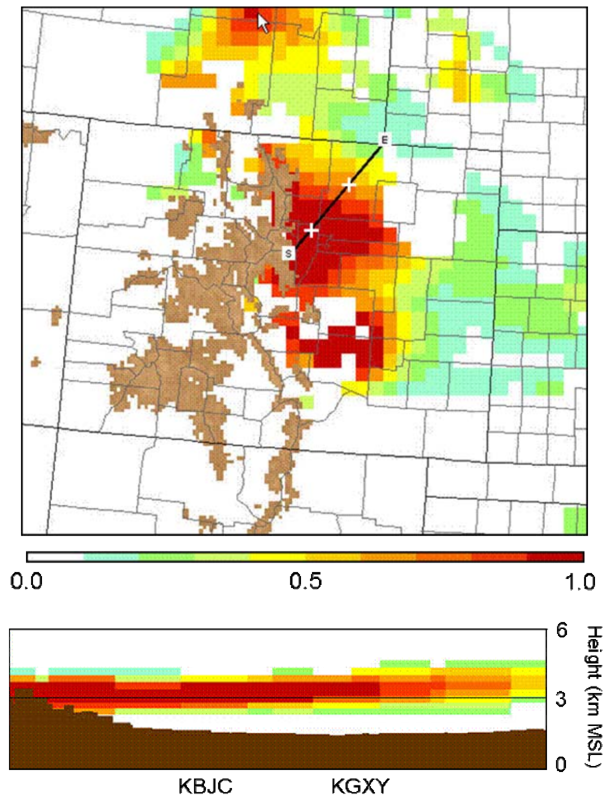

Fig. 5. Horizontal and vertical cross-sections of CIP icing potential for 2300 UTC a) at ~3.0 km (700mb) and b) vertically, along the black line in part (a). White crosses in part (a) indicate the locations of KBJC (lower-left) and KGXY (upper-right). Brown filled areas indicate topography.

6. COMPARISON AND CONCLUSIONS

Both GRIDS and CIP were able to diagnose the icing that occurred on this day. While CIP consistently depicted icing throughout the ~7 hour event, it provided relatively coarse, hourly output with 20 km horizontal and 0.3 km (1000 ft) vertical grid spacing. It also overestimated the upper extent of the icing by ~0.5km. GRIDS demonstrated the ability to diagnose the icing on very fine time (1 min) and space (0.1 km) scales, accurately portraying the regions which contained icing. One area in which the GRIDS technique needs to be improved is in handling mixed-phase conditions, specifically assigning the liquid to the correct portions of the cloud. The algorithm could also incorporate existing information (radar reflectivity and liquid water path from the radiometer) to provide quantitative estimates of the icing severity.

GRIDS and CIP could easily benefit one another. GRIDS can accurately identify the altitudes of clouds and provide estimates of their phase and liquid water content. CIP's satellite and surface observation based cloud scheme can help to fill the gaps in GRIDS' cloud field when radar signals are weak or when heavy precipitation saturates the Ka-band signal, and to extend GRIDS' point-like measurements over a broader region. These two systems may complement each other particularly well in a terminal-scale setting, especially when the new terminal-scale version of CIP, with 5km and 15 min resolution, is running.

It should be noted that he GRIDS design calls for a much more sensitive Ka-band radar (work in progress) than was used during WISP04, which will improve the discrimination of ice regions and extend the range of application of GRIDS. One lesson learned is that from the perspective of remote sensing of in-flight icing conditions, a real-time observation of the temperature of cloud liquid is necessary. The most promising technology at present is enhanced microwave radiometry.

7. REFERENCES

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