6.2 A COMPARISON OF WRF-RR AND RUC FORECASTS OF AIRCRAFT ICING CONDITIONS

Cory A. Wolff and Frank McDonough

National Center for Atmospheric Research, Boulder, CO

1. INTRODUCTION

The Current and Forecast Icing Products (CIP and FIP, respectively) have used output from the Rapid Update Cycle (RUC) model to create icing diagnoses and forecasts since their inception. The Rapid Refresh version of the Weather Research and Forecast (WRF-RR; hereafter RR) model will replace the RUC in 2010. Because model output is the only data source in FIP and plays a large role in CIP it is vital to compare and contrast how the models handle icing situations so that the algorithms can be adjusted accordingly.

An upgraded microphysics package has been added to the RR that explicitly predicts five hydrometeor species (rain, snow, graupel, cloud ice, and cloud water) along with number concentrations of rain and cloud ice (Thompson et al. 2008). This double moment scheme should improve the model's hydrometeor forecasts, and its representation of icing conditions is important to the CIP and FIP development team. In this paper we will compare the RR and RUC forecasts of fields used for forecasting of in-flight icing conditions. Model output will be matched with positive and negative pilot reports (PIREPs) of icing to determine what, if any, algorithm changes may need to be implemented.

2. PIREP COMPARISONS

Researchers at NCAR began collecting experimental RR forecasts in real-time in November 2008, and this effort continues, resulting in over a year of data to compare with the RUC. During this time the model has undergone a variety of changes as it is not scheduled to be in final form until later in 2010. A complete list of the changes made to the RR can be found at http://rapidrefresh.noaa.gov/. Because performing reruns with the latest RR version is impossible the authors were forced to use the real-time runs of the model for comparison with the RUC during the periods of interest. This study will focus on two time periods: winter to early spring (January – April 2009) and fall (October – December 2009), with a major focus on comparing the microphysical fields between those times. As will be shown, the upgrades made to the model did not significantly impact those fields between the two periods.

PIREPs from within the RUC domain, which is a subset of the RR domain, were collected during the periods of study. Each one was parsed into one thousand foot levels so that a PIREP that reports icing from five to ten thousand feet would become six PIREPs, one at each flight level inclusive. This resulted in over 43,000 points from the first time frame and nearly 41,000 from the second. Data from the nearest grid point and level to the PIREP were extracted from each model.

a) Temperature

Figure 1 shows the distribution of temperatures from both models for positive icing PIREPs during Jan – Apr 2009. Both models have very similar values for all temperature bins, including the majority of PIREPs at temperatures between -5 and -12 °C. The RUC has slightly more positive PIREPs at above freezing temperatures and below -40 °C. The temperature map for the algorithms is not likely to require any adjusting for the RR version.

* *Corresponding author address:* Cory A. Wolff, NCAR/RAL, P.O. Box 3000, Boulder, CO 80307; e-mail: cwolff@ucar.edu

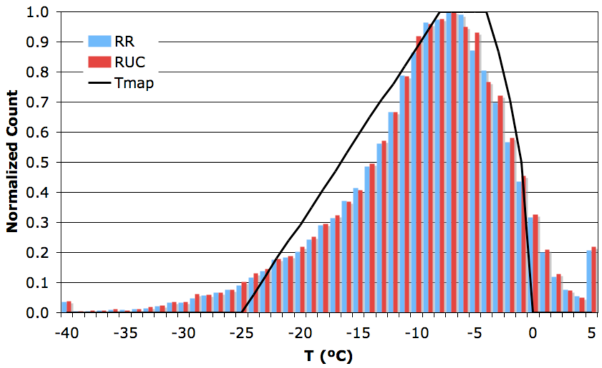

Figure 1. Temperature distribution for positive PIREPs for Jan – Apr 2009 from the RUC (red) and RR (blue). The counts have been normalized by the maximum value. The black line represents the current CIP and FIP temperature interest map.

b) Relative Humidity

The distributions for relative humidity are also very similar (Fig. 2a). Both models have a majority of positive PIREPs at relative humidities greater than 90% and are maximized for the 100% and greater bin. This is a marked improvement for the RUC. The current relative humidity interest maps in the CIP and FIP (black line in Fig. 2) are based on PIREP distributions performed on RUC data in 2003 (Fig. 2b; McDonough et al, 2004). The line matched that distribution quite well. Because earlier versions of the RUC tended to under-predict relative humidity in icing situations, the relative humidity interest maps in CIP and FIP had to compensate. If only locations with high relative humidity (e.g. greater than 80%) were considered to be candidates for icing, then CIP and FIP would have missed a large percentage of all icing situations. It is generally the practice of CIP and FIP developers to make changes in these algorithms based upon improved understanding of the physical processes associated with icing, rather than "chasing" changes in statistical curves. However, the ability of the models to forecast relative humidity in icing situations has improved since the relative humidity map was last set. Thus, an update to it is warranted, possibly including a significant increase in the lower relative humidity bound where icing is allowed to be diagnosed and predicted (e.g. from 30% to perhaps 60%). More emphasis can also be placed on higher relative humidity environments, as developers had intended in earlier versions. Such changes should serve to improve false alarm rates while only minimally decreasing detection rates.

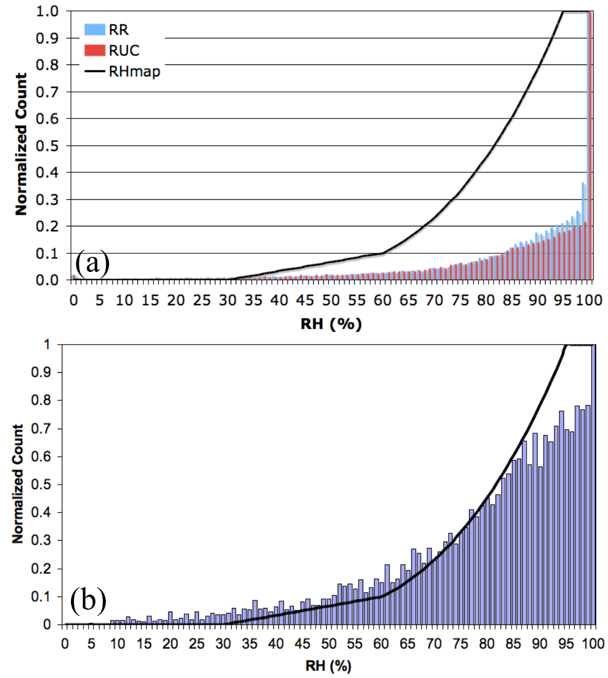

Figure 2. As in Fig. 1 but for relative humidity from (a) the current RUC and RR and (b) a version of the RUC from 2003. The black line represents the current CIP and FIP relative humidity interest map.

c) Vertical Velocity

Most positive PIREPs are expected to occur in areas of upward vertical motion, where rising air cools and condenses. The CIP and FIP interest maps represent this with positive interest in these areas and negative interest in strongly subsiding air. The PIREP distributions for both models (not shown) have the majority of positive icing reports (70%) in rising air. No adjustment to the vertical velocity map appears to be needed at this time.

d) Condensate

The model condensate fields are likely the most difficult icing-relevant fields to predict. They require that the model accurately forecast the presence of saturated conditions, something that they have traditionally struggled to do, especially at coarse resolution. If saturation is reached, then the phase of the condensate must be forecast. In both RUC and RR, phase is dependent partially on both the temperature and vertical velocity. Both models produce five species of condensate: cloud water, rain, cloud ice, graupel, and snow.

In the course of producing the distributions it was discovered that the files containing the RUC forecasts of condensate had a greater precision than the RR forecast files, resulting in more small condensate values (between 0.0001 and 0.01 g m^{-3}) in the RUC than in the RR, where most of the small values were truncated to 0. Because of this, the results presented in this section will treat all condensate values less than 0.01 g m^{-3} as 0 so that a fair comparison is done.

The developers also found out that the graupel field wasn't added to the forecast files until February 2009. That field was ignored for the winter 2009 distributions to keep them consistent for the entire period.

Forecasts of cloud water and rain along with below freezing temperatures are used to create the supercooled liquid water (SLW) field in the CIP and FIP. Currently the algorithms have maximum interest in the SLW field for any value above 0.001 g m^{-3}. This is because the RUC does not produce widespread SLW and the amounts are generally much lower than observed when compared to aircraft measurements. The RUC also periodically forecasts the wrong phase; that is, positive icing PIREPs are often found where only cloud ice or snow are forecast to be present. For this reason, the CIP and FIP also use forecasts of the total condensate (TotC), which is the sum of all five microphysical species.

Figure 3 shows the SLW distributions for the RUC and RR from January – April 2009. Notice that the vast majority of positive icing PIREPs occur where no SLW is predicted. However, the RUC appears to outperform the RR in the number of positive PIREPs with non-zero SLW values (see also Table 1). A similar trend is seen for TotC (Fig. 4), though the RR captures more PIREPs with this field and has a higher incidence of larger amounts than the RUC. The RR is certainly producing saturated conditions (and thus, clouds) where positive PIREPs are occurring, but the phase appears to be wrong in many cases.

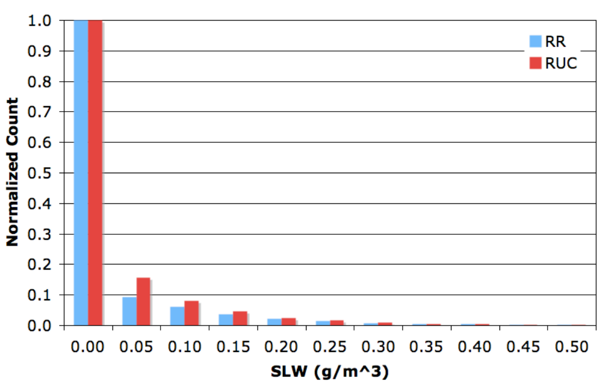

Figure 3. As in Fig. 1 but for SLW.

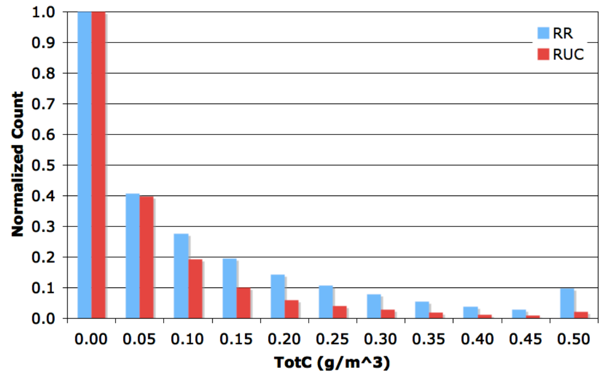

Figure 4. As in Fig. 1 but for TotC.

The SLW and TotC fields were also tested as stand-alone icing predictors in order to gauge their effectiveness at capturing positive and negative icing reports. Simple statistics such as the probability of detection for yes and no reports (PODy and PODn) have been calculated for SLW and TotC in both models and for CIP and FIP and are shown in Table 1.

Table 1 verifies the results shown in Fig. 3 for January - April 2009, when the RUC SLW field outperformed the RR in the detection of positive icing PIREPs (0.26 to 0.20). The RUC was also able to do this without sacrificing PODn, as both had a value of 0.90.

Neither model alone captures nearly as many PIREPs as the CIP and FIP (PODy = 0.90 and 0.79, respectively for Jan – Apr), but the reasons for the poorer performance by the RR are unclear. One theory is that it may be related to resolution differences in the models. The RUC model used for these tests has a horizontal resolution of 20 km because that is the current version used to run the CIP and the FIP. The RR has a horizontal resolution of 13 km; it is not available at 20 km. A RUC grid box has more than twice the area of a RR grid box (400 to 169 km^2) and, therefore, has a larger area over which to potentially produce SLW.

When TotC was used as an icing predictor the RR had a higher PODy than the RUC, but this came at the expense of a lower PODn. It should be noted that all of the PODy values for the model fields would be slightly higher if values less than 0.01 g m^{-3} were used, but due to the precision issues mentioned before this is not possible.

Of concern to the CIP/FIP developers were the changes to the microphysical scheme in the RR. A new version of it was installed in the operational version of the RR in late June 2009 (Stan Benjamin, personal communication). Table 1 shows the same statistics calculated for October – December 2009. The microphysics upgrades did not appear to affect the ability of SLW to explicitly predict the presence of it at the location of icing PIREPs, as the fall 2009 POD values remained similar to those from the winter 2009. However, there was an increase in PODy for the RR TotC field (0.59 to 0.64) that was not reflected in the RUC. This came at the expense of a lower PODn. The increase in PODy may be partially attributed to the addition of graupel for the fall comparisons. Distributions such as those shown in Figs. 3 and 4 were also created and did not show any drastic differences in the model output when compared to positive PIREPs.

Dates	Model	Field	PODy	PODn
Jan | Apr	RR	SLW	0.20	0.90
		TotC	0.59	0.61
	RUC	SLW	0.26	0.90
		TotC	0.47	0.76
	CIP	Ice Pot	0.90	0.62
	FIP	Ice Pot	0.79	0.70
Oct | Dec	RR	SLW	0.21	0.87
		TotC	0.64	0.54
	RUC	SLW	0.25	0.86
		TotC	0.47	0.76

Table 1. PODy, PODn, and FAR statistics for the RR and RUC SLW and TotC fields during the periods of Jan – Apr and Oct – Dec 2009. All values were calculated using a threshold of 0.01.

3. DISCUSSION

This study confirmed that the RUC and RR forecasts of basic model fields used to diagnose and forecast aircraft icing do not significantly differ from each other. Temperature, relative humidity, and vertical velocity were all shown to have similar distributions for the two models. The only change to the algorithms that appears to be needed at this point is in the relative humidity map, since both models showed an increased ability to forecast this field when compared with older versions of the RUC. The new map has not been devised yet but will be more aggressive than the current one.

Comparisons of the microphysical fields showed that the RUC captures more positive icing PIREPs with the SLW field but the RR is better when looking at the TotC field. The differences probably aren't great enough to require any changes to the algorithms, but they will need to be kept in mind if the performance suffers when the RR becomes operational.

Future work will involve further examination of the effects of the different model resolutions on the results. Instead of using the nearest grid point the maximum of some number of the nearest grid points may provide a fairer comparison. The goal will be to have a similar amount of surface area covered by both models. Using the nearest four grid point from the RUC (a 2x2 box measuring 40 km on a side) and the nearest nine from the RR (a 3x3 box measuring 39 km on a side) would give similar footprints from which to draw on.

More subtle differences in the model microphysics will also be examined. The distributions shown were for all temperatures and regions. Knowing if one model produces more or less condensate in various temperature ranges (0 – -10 °C, -10 – -20 °C, etc.) or in different regions (Great Lakes vs. Pacific Northwest) will also be useful in future algorithm development.

4. REFERENCES

Bernstein, B.C., F. McDonough, M.K. Politovich, B.G. Brown, T.P. Ratvasky, D.R. Miller, C.A. Wolff, and G. Cunning, 2005: Current icing potential (CIP): Algorithm description and comparison with aircraft observations. *J. Applied Met.*, **44**, 969 – 986.

McDonough, F., B. C. Bernstein, M. K. Politovich, and C. A. Wolff, 2004: The forecast icing potential (FIP) algorithm. *20th International Conf. on Interactive Information Processing Systems (IIPS) for Meteorology, Oceanography, and Hydrology*. 11 – 15 Jan, Seattle, WA.

Thompson, G., P. R. Field, R. M. Rasmussen, and W. D. Hall, 2008: Explicit forecasts of winter precipitation using an improved bulk microphysics scheme. Part II: Implementation of a new snow parameterization. *Mon. Wea. Rev.*, **136**, 5095 – 5115.

Acknowledgments. This research is in response to requirements and funding by the Federal Aviation Administration (FAA). The views expressed here are those of the authors and do not necessarily represent the official policy or position of the FAA.