FIP Severity
Technical Document

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Technology Transfer Technical Review Board

1. Introduction

This report describes the new Forecast Icing Product (FIP) Severity algorithm (FIP Severity) developed at NCAR by members of the In-Flight Icing Product Development Team (PDT). A separate verification report concerning this product will be provided by the Quality Assessment PDT.

a) A FIP Primer

FIP was originally designed to identify potential locations of icing and supercooled large drops (SLD). A detailed description of the methods used in these calculations can be found in McDonough et al. (2003, 2004). A brief review will be presented here.

FIP is run using output from 2, 3, 6, 9, and 12-hour forecasts from the Rapid Update Cycle (RUC) model (Benjamin et al., 2004). The horizontal spacing of the grid is 20 km and it contains 50 vertical levels. FIP output covers the same domain as the RUC and is interpolated to flight levels from 1000 to 30,000 feet MSL at 1000-foot levels.

FIP's icing and SLD potential algorithms use RUC forecasts of temperature, relative humidity, vertical velocity, supercooled liquid water content (SLWC), and QPF as inputs. These are first used to identify cloud layers, denote areas of precipitation, and classify the precipitation type. From there, a variety of meteorological situations that represent unique "icing scenarios" are identified using a decision tree. The meaning of each RUC field is assessed using fuzzy logic membership functions. The resulting interest maps are then combined in specific ways, depending on the icing scenario, to calculate the likelihood of icing and SLD conditions.

b) FIP Severity Concept

A new icing severity field has been developed for FIP, providing a much-needed assessment of the icing severity expected at each location in the RUC grid. FIP Severity is closely related to CIP Severity (Politovich et al., 2006). The concepts developed for that algorithm are applied in the same way in the FIP. The basic premise is that different fields can give different information about expected icing severity depending on the icing scenario. Seven meteorological scenarios are identified, each having a specific set of predictors associated with it. An initial icing severity is calculated by combining these predictors in an equation that takes into account the output of the membership function for that field and its weight or importance. Once the initial severity has been calculated, a series of damping factors may be applied depending on the expected presence of an SLWC depletion mechanism (glaciation and/or precipitation). The result is a final

assessment of the expected severity, to which thresholds are applied to translate the field into categories of icing severity that are familiar to pilots: None, Trace, Light, Moderate, or Heavy.

While CIP uses a variety of model fields and actual observations to diagnose icing severity, FIP relies solely on model data output to forecast the expected icing severity. Model surrogates are used whenever possible to mimic the observations. For example, CIP uses infrared temperatures from satellite observations to estimate the cloud top temperature (CTT) and matches that to a column of temperatures from the RUC model to find the cloud top height. FIP uses a combination of relative humidity, condensate, equivalent potential temperature (θ_e), and vertical velocity from the model to find the expected location of cloud top and its corresponding CTT. Sometimes creating surrogates from model output is difficult, if not impossible. Pilot reports (PIREPs) of icing location and intensity provide valuable information used by CIP Severity. These reports are the only actual in-situ observations of icing severity and have proven to be quite useful when the PIREP is nearby in space and time and it is used in combination with other fields to diagnose the icing severity at a given location. The model does not produce any fields that can effectively replicate these direct observations. Thus, a PIREP-like assessment of icing severity is not used as an input to FIP and is not included in the severity equations.

2. FIP Upgrades

The icing severity algorithm is one part of the FIP. As noted earlier, other algorithms inside FIP find the cloud top height, identify the precipitation type, and calculate the icing and SLD potentials. This section will describe the details of FIP Severity and upgrades made to other parts of the FIP for this release.

a) Severity

After the icing and SLD potential calculations are completed the severity algorithm is run. Severity is only calculated at grid points where the icing potential is greater than 0.01, otherwise it is set to "None".

If icing is forecast the first task of the severity algorithm is to figure out which meteorological scenario is present. Each of the seven scenarios is dependent upon the FIP precipitation type identification scheme, which produces forecasts of snow, rain, drizzle, freezing drizzle, freezing rain, and ice pellets by examining the thermodynamic structure of a model column that is producing precipitation (see Section 2b). The precipitation type scheme is discussed in greater detail in McDonough et al. (2003, 2004). These letters will be used to refer to the scenarios in other parts of the document.

A Non-precipitating cloud – No precipitation is identified by the algorithm.
B Snow – The only precipitation type forecast is snow.
C Rain – Rain is forecast as the precipitation type.
D Warm Precipitation – Either drizzle or freezing drizzle is forecast.
E Cold Non Snow/Rain – Any precipitation type besides rain or snow is forecast and the cloud top temperature is less than -12 °C. Also, there is not a classical warm nose (melting layer between two subfreezing layers) present.

F Classical Precipitation *Above* the Warm Nose – Freezing rain, ice pellets, or rain are forecast and a warm nose is present above the subfreezing surface layer. The level in question is above this structure.

G Classical Precipitation *Below* the Warm Nose – Freezing rain, ice pellets, or rain are forecast and a warm nose is present above the subfreezing surface layer. The level in question is below this structure.

Once the scenario has been identified the algorithm calculates interest maps for all of the parameters used for that particular situation. Interest maps are used to give meaning to the value of the parameters so they can be combined with other parameters easily. The value is mapped to a 0 – 1 scale with 0 meaning no interest and 1 meaning maximum interest. For example, the more SLW that is forecast for a grid point the higher the interest that FIP Severity has in that field, which can lead to a forecast of a higher severity level. See Section 3 for a description of all of the fields and their interest maps used in FIP Severity.

The general form of the initial severity equation is shown below.

$$SEV_{init} = \frac{w_1 * i_1 + \ldots + w_n * i_n}{w_1 + \ldots + w_n}$$

where w is the weight, and i is the interest for each field for a total of n fields. The weight for each parameter is assigned based on the relative influence of that parameter in the determination of severity for a given scenario. The weights are based on experience using the parameter to forecast icing conditions and comparisons of parameter values with PIREPs to judge how well they discriminate severity. Table 1 shows the weights associated with each field for all of the scenarios. CIP Severity also uses confidence factors to establish how much the data can be trusted (Politovich et al. 2006). In this version of FIP Severity these are not used because all model fields are treated with the same confidence at this point.

Table 1. Weights assigned to each parameter for all scenarios for the initial severity calculation. Scenario letters are defined previously (**A** = Non-precipitating cloud, etc.).

scenario	vv	moisture	dq	icepot	sldpot	twp_precip	twp_wp	dz_np	dz_sn	dz_ra	dz_wp	dz_fzra	t_bwn	pcond	ctt_bwn	snvv
A	4	4	3	3				3.5								
B	3.5	4		3		3			3.5							
C	3.5	4		2		3				3.5						
D	3	3.5	2		4		3				3					
E	3.5	4		2		3				3.5						
F	3.5	4		2		3										
G		3.5		2								3	3	4	3	2.5

As in CIP, the initial calculation of icing severity is based on the concept of SLW production, with less attention to SLW depletion. In FIP Severity there are three factors used to govern the depletion of SLW. These are the temperature, cloud top temperature, and precipitation intensity. The values for each of these factors are mapped to a $0 - 1$ scale, just like the severity interest maps, and then used to damp the severity by some fraction of the initial value. Further explanation of these factors along with their associated mapping and damping functions can be found in Section 3.

After damping, the final icing severity (SEV_{final}) is a number between 0 and 1, with higher values indicating higher forecast severity. These values are then categorized by applying thresholds to provide a meaningful severity forecast of Trace, Light, Moderate, or Heavy. The thresholds were derived by comparing severity forecasts to PIREPs over a 3-month period where a large variety of icing situations occurred and all of the icing scenarios were well represented. The following categorical thresholds were chosen.

No icing :	$SEV_{final} < 0.01$
Trace icing :	$0.01 \leq SEV_{final} \leq 0.25$
Light icing :	$0.25 < SEV_{final} \leq 0.425$
Moderate icing :	$0.425 < SEV_{final} \leq 0.75$
Heavy icing :	$SEV_{final} > 0.75$

b) Precipitation Identification

The method for identifying areas of precipitation was upgraded in this version of FIP. The accurate identification of precipitation location is important in FIP Severity because of the scenario approach. In the past FIP identified these areas by using the RUC's total quantitative precipitation forecast (QPF) field. The total QPF (Fig. 1a) is the sum of the convective and non-convective (large scale) QPF fields and represents an accumulation of precipitation over a forecast period. If at least 0.2 mm of precipitation accumulated over the model forecast period (usually three hours in the RUC) then FIP indicated precipitation at that grid point and a precipitation type was identified. All of the other fields in the model and output from FIP itself represent instantaneous values that are valid at the FIP valid time. It was determined that it is inconsistent to use an accumulated field in conjunction with the instantaneous fields.

To rectify this, a new field was developed to replace the large scale QPF field. There are five model condensate species in the RUC: cloud water, rain water, cloud ice, snow, and graupel. Three of them (rain, snow, and graupel) are large enough to fall and reach the surface. These are grouped into one category that is defined as precipitable condensate. To get a forecast of where large-scale precipitation is falling at the FIP valid time, the maximum precipitable condensate in the lowest three model levels is determined. If this value is greater than 0.01 g kg^{-1} then precipitation is determined to be reaching the surface.

This method cannot replace the convective QPF field because convection is parameterized in the RUC and is not well represented by the microphysics. So, there is no model condensate in most areas of convective QPF. In areas where the convective

QPF field is greater than zero the QPF is converted to a condensate value and added to the maximum precipitable condensate. Future versions of FIP will attempt to add a better forecast of convective activity to further improve on the precipitation area identification.
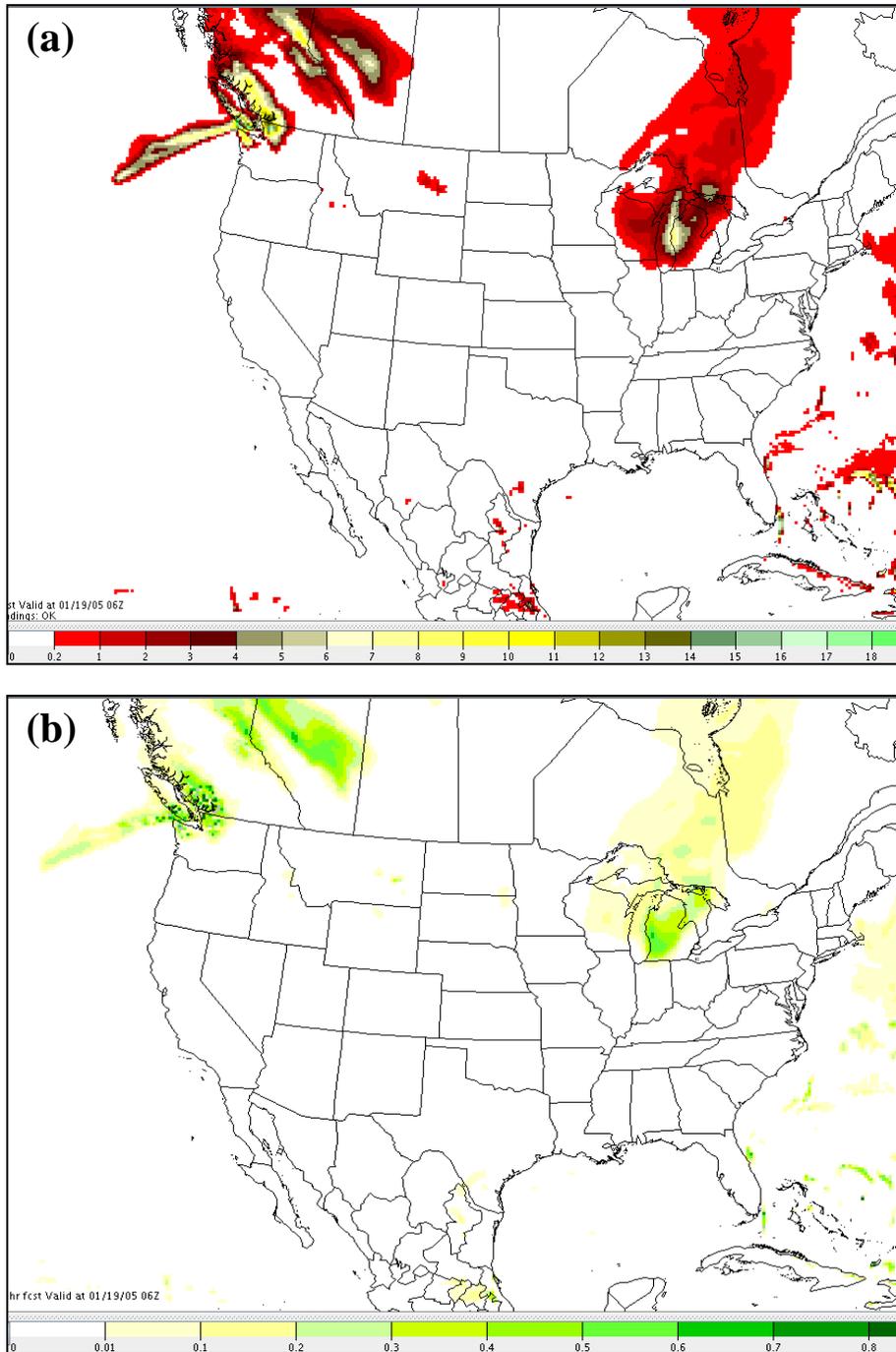

Figure 1. Three-hour forecast valid 0600 UTC on 19 January 2005 of (a) total QPF (mm / 3 hr) and (b) maximum precipitable condensate (g kg^{-1}).

Figure 1b shows an example of the maximum precipitable condensate field. In most areas with widespread QPF the fields overlap quite a bit, with slightly less coverage by the precipitable condensate field (e.g. around Chicago and central British Columbia). There are also places where the new field adds area, likely due to a new area of precipitation that had not yet accumulated enough in the model (e.g. off the Atlantic Coast).

c) Cloud Top Height

The original FIP cloud top height algorithm examined the model column from the top down, until relative humidity of at least 70% was found. The cloud top height (CTZ) was set to the next level up. The cloud top temperature for that grid point became the model temperature at that level. This was a conservative scheme that resulted in cloud tops that were usually higher than observed. One result was a high probability of detection, but also a high forecast volume, which decreased the algorithm efficiency. Another result was the forecast of colder cloud top temperatures, which tended to decrease the icing potential.

The new algorithm uses a variety of model predictors to forecast a more accurate cloud top height, decreasing the forecast icing volume while maintaining a high probability of detection. The predictors use the model relative humidity (RH), and vertical gradients of RH (Drh), total condensate (DTotC), equivalent potential temperature ($D\theta_e$), and vertical velocity (Dvv), where $D = \partial(\ )/\partial z$. The CTZ algorithm expects cloud top to be found at the top of the highest moist layer in the column, where the air is drying above, θ_e shows a rapid warming with height (capping inversion), and the vertical motion is decreasing.

Once the vertical gradients have been calculated the algorithm again examines the data from the top of the column down. If the model RH at the level of interest and the level below is at least 75% then interest maps are computed for the vertical gradients at that level. Figure 2 shows vertical profiles of the fields of interest, the vertical derivatives, and the interest map values for one particular case. After the map values have been calculated they are combined to calculate CTZ_{map} using the following equation.

$$CTZ_{map} = (0.5 * Drh_{map}) + (0.2 * D\theta_{e\ map}) + (0.2 * DTotC_{map}) + (0.1 * Dvv_{map})$$

The weights for each of the input maps were determined by examining how well each forecast the actual cloud tops reported by pilots. Finally, the forecast cloud top is identified by working down the column until the first level is reached where CTZ_{map} is greater than 0.2. The corresponding temperature at that level becomes the cloud top temperature.

Figure 2 shows vertical profiles of the CTZ variables and their vertical derivatives for a case. Sharp transitions can be seen at many levels, but the strongest appear to be between 1700 and 2000 m. This is the level above which the RH and total condensate decrease rapidly. Cloud top is expected when there is a transition from a moist to a dry layer. Also, the θe profile is showing strong warming through this layer and the VV is transitioning from upward to downward motion. They especially stand out in the map

values for the vertical derivatives (Fig. 2, bottom row). These map values were then used to calculate CTZ_{map}, which first exceeded 0.2 at a level of 1900 m (Fig. 3a). Examination of the model sounding (Fig. 3b) shows this to be reasonable. An actual cloud top of 2100 m was reported by a pilot for this grid point.
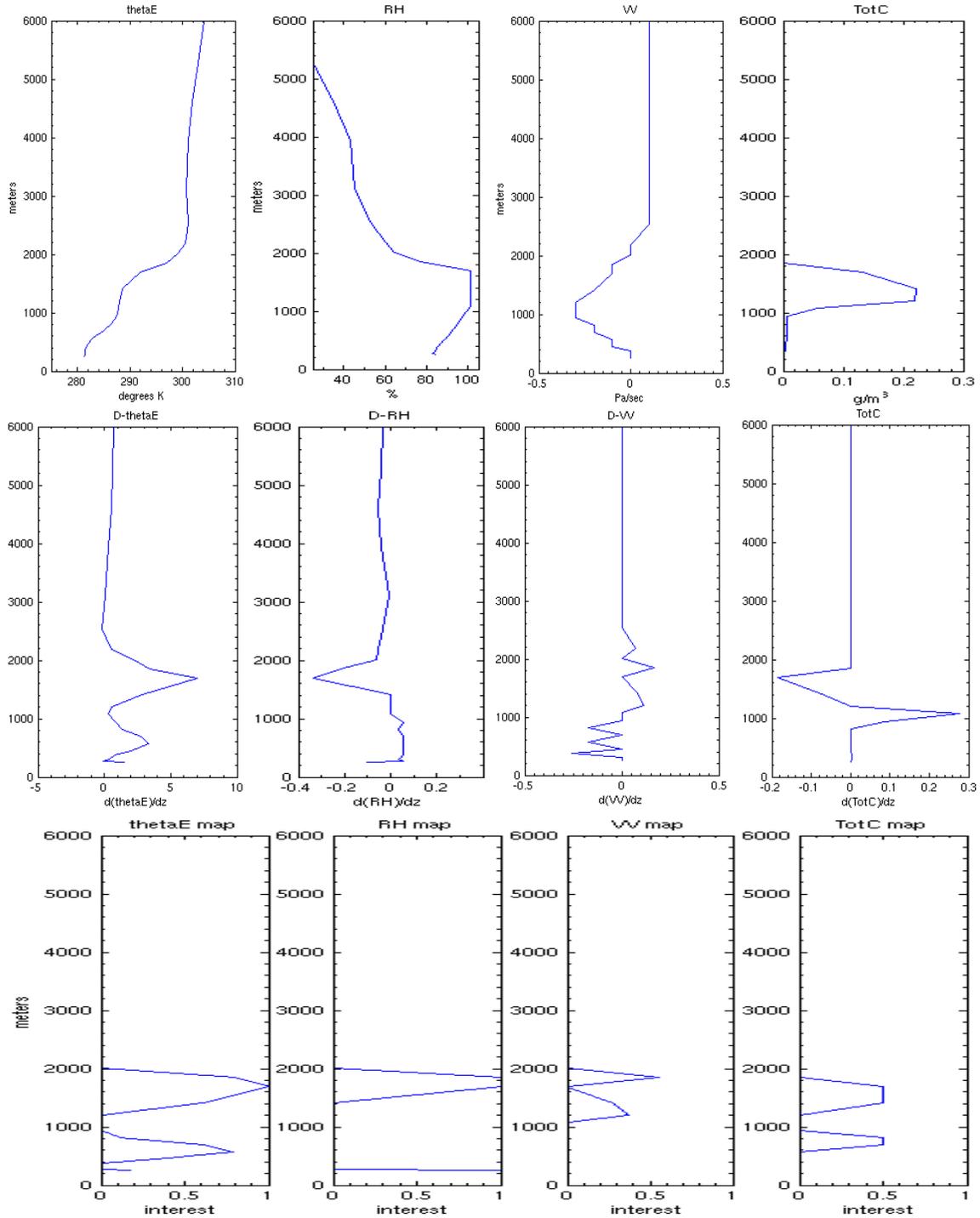

Figure 2. Vertical profiles of the RUC model RH, θe, VV, and total condensate, their vertical derivatives (when RH ≥ 75%), and the resulting map values at a model grid point. Negative values of VV represent upward motion.
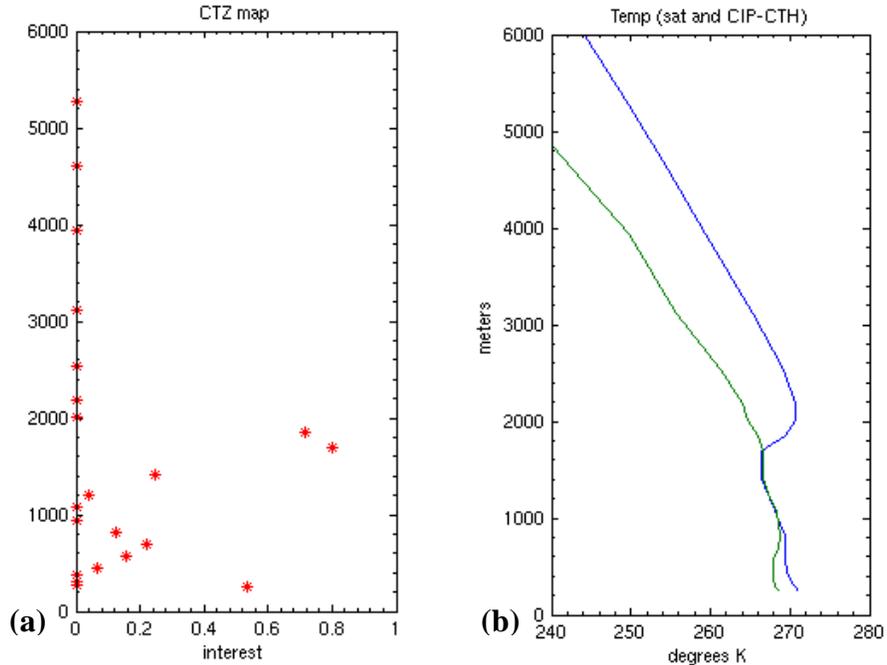
Figure 3. (a) CTZ_{map} for the column detailed in Figure 2. (b) The profile of temperature (blue) and dewpoint (green) for the same model grid point.

The new cloud top algorithm produces generally lower CTZs and warmer CTTs in FIP, and also shows better agreement with cloud top height observed by PIREPs. Figure 4 shows a comparison of CTT estimated using the old and new methods. The areal coverage of the clouds is slightly reduced and the CTTs are significantly warmer in the new scheme. A comparison of the probabilities of detection, volume coverage, and volume efficiency is shown in Table 2. The new method has a slightly lower PODy and higher PODn, while the percent of volume covered decreased by ~9%. This has resulted in a more efficient algorithm, which was the goal of introducing the new scheme.
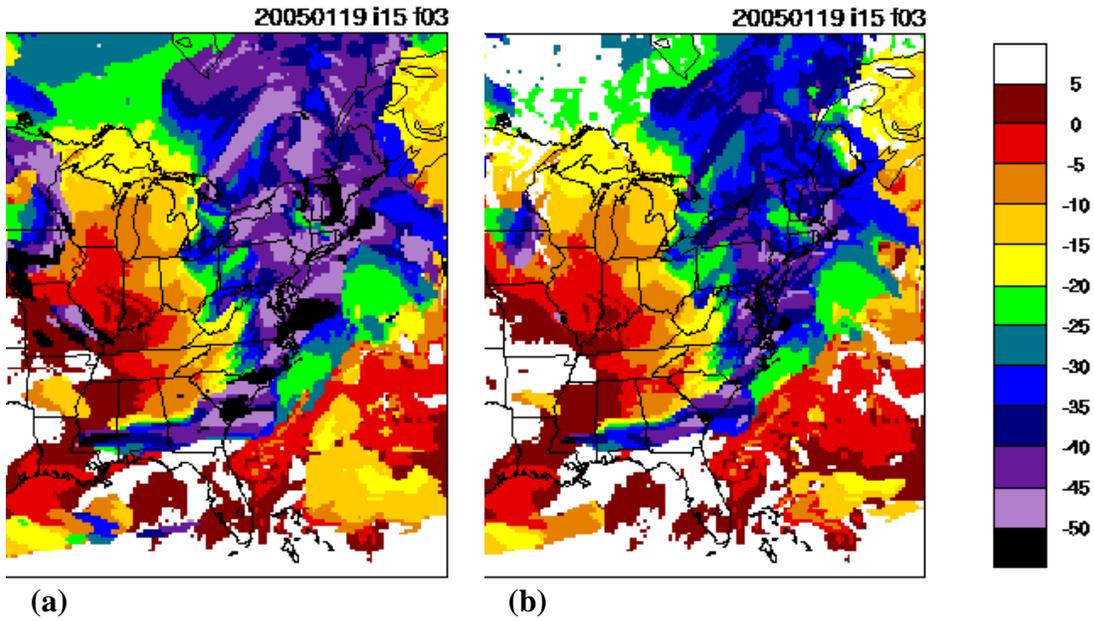
Figure 4. Three-hour forecast of cloud top temperature (°C) valid 1800 UTC on 19 January 2005 for the (a) old and (b) new schemes.

Table 2. Probabilities of detection for yes and no PIREPs and percent of volume covered by icing for the old and new CTZ methods. The PODy and PODn values were calculated for a threshold of 0.02. The formula for Volume Efficiency is [(100 * PODy) / (% Volume)].

	Old CTZ Method (RH $\geq$ 70%)	New CTZ Method (CTZ$_{map}$)
PODy	0.79	0.76
PODn	0.61	0.63
% of Volume Covered	8.2	7.3
Volume Efficiency	9.6	10.4

3. Severity and Damping Interest Maps

This section describes the membership functions used to compute the interest maps that are used in the initial severity calculation and in the damping portion of FIP Severity. The initial severity maps are maximized where an increase in supercooled liquid is to be expected, while the damping maps are highest where more ice crystals are expected to deplete the SLWC. See Sections 2a and 2b for a description of interest maps and how they are used in FIP Severity.

<u>Vertical Velocity and Snow Layer Vertical Velocity Map</u>

if $VV \leq -0.5$
   $vv_{map} = 1.0$
else if $-0.5 < VV < 0.0$
   $vv_{map} = VV / -0.5$
else if $VV \geq 0.0$
   $vv_{map} = 0.0$
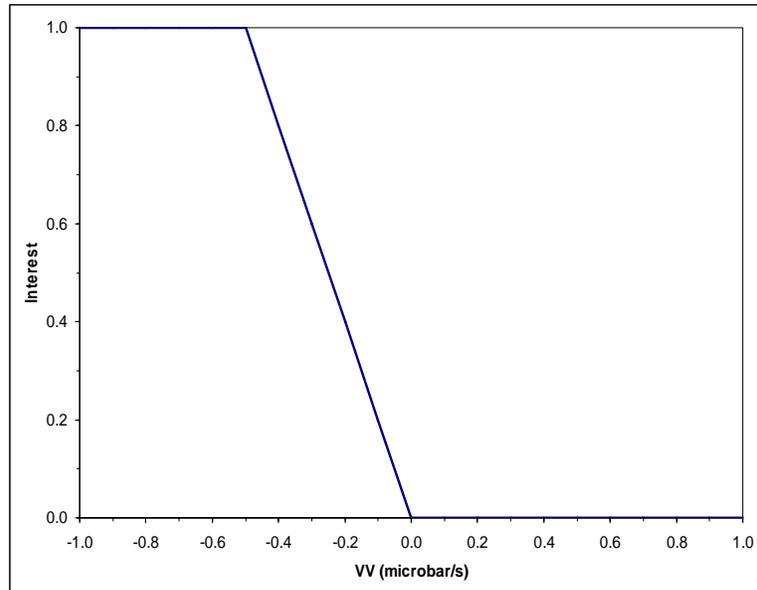
The vertical velocity map is used in every scenario. Upward motion causes cooling, which increases an air parcel's relative humidity and may lead to condensation. Stronger lift is able to produce more condensate and may be able to suspend larger drops. This map is applied to the grid point vertical velocity value in all scenarios except below the warm nose. In this one it is called the snow layer vv_{map} ($snvv_{map}$) and is applied to the average vertical velocity field for grid points that are in cloud and have temperatures between -13 and -16 °C. This temperature range is optimal for the formation of dendritic crystals. More large crystals forming above the warm nose may result in increased amounts of supercooled liquid below it.
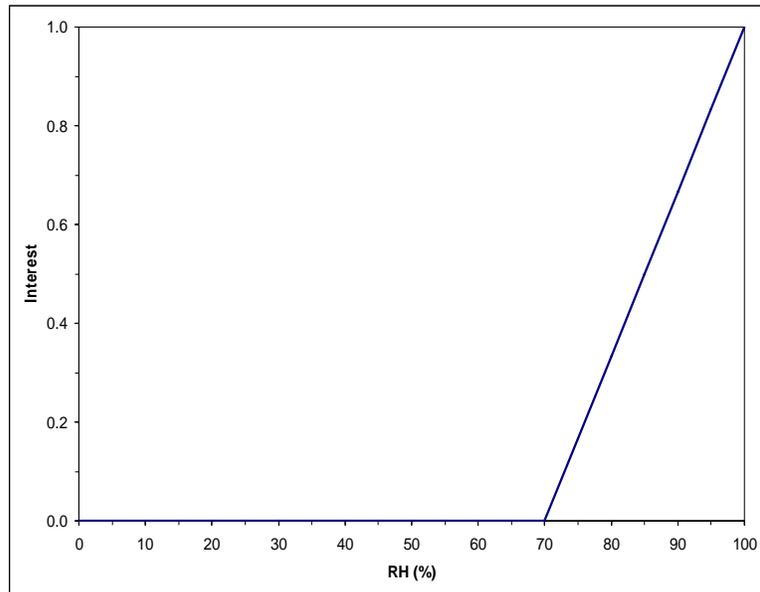
<u>Moisture Map</u>

Relative Humidity
if RH ≤ 70
  rh_{map} = 0.0
else if RH ≥ 100
  rh_{map} = 1.0
else if 70 < RH < 100
  rh_{map} = (RH − 70) / 30

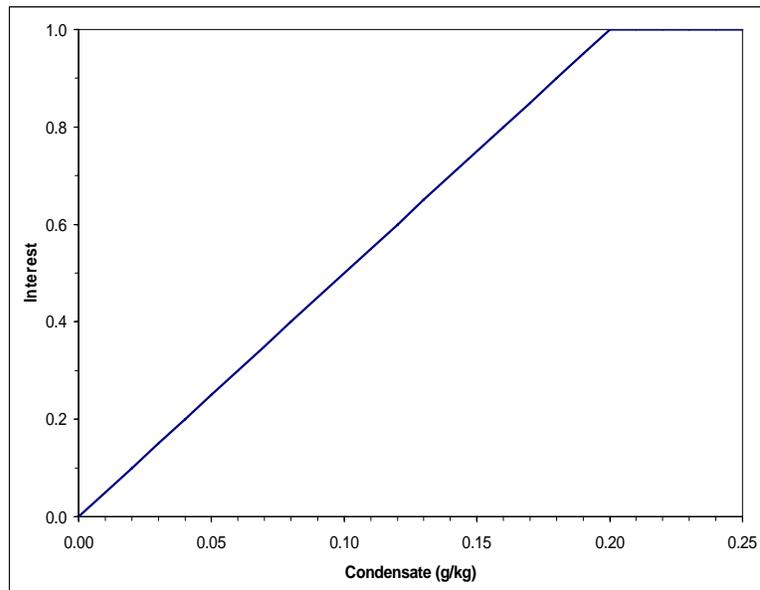*Liquid or Ice Condensate*
if cond < 0.004
  $cond_{map}$ = 0.0
else if cond > 0.2
  $cond_{map}$ = 1.0
else if 0.004 ≤ cond ≤ 0.2
  $cond_{map}$ = 5 * cond

$moisture_{map}$ = (0.5 * rh_{map}) +
  [(0.6 * $liquid\_cond_{map}$ *
  (1 − (0.5 * rh_{map}))) +
  (0.4 * ice_cond_{map} *
  (1 − (0.5 * rh_{map})))]

     This map is a combination of fields (relative humidity and liquid and ice condensate) that provide forecasts of the amount of moisture expected at a given grid point (Politovich et al. 2006). In real clouds SLW is only present when the relative humidity reaches or exceeds 100%. However, model forecasts of relative humidity are not always accurate, though they do continue to improve. For this reason, FIP Severity is interested in relative humidity values as low as 70%. Also, when clouds are formed by the model, the developers have found that the condensate phase is often incorrect. Thus, there is also interest in both the liquid and ice condensate species. Areas with high RH and larger amounts of SLWC and to a lesser extent, ice condensate, are maximized, while areas where the RH falls below 100% and no condensate is present have a lower interest but are still considered. The moisture map is used in every scenario.

Delta q Map

if dq ≤ 1.0
  dq_{map} = dq
else if dq > 1.0
  dq_{map} = 1.0

DQ

Interest

DQ (g/m³)

1
0.8
0.6
0.4
0.2
0

0   0.2   0.4   0.6   0.8   1
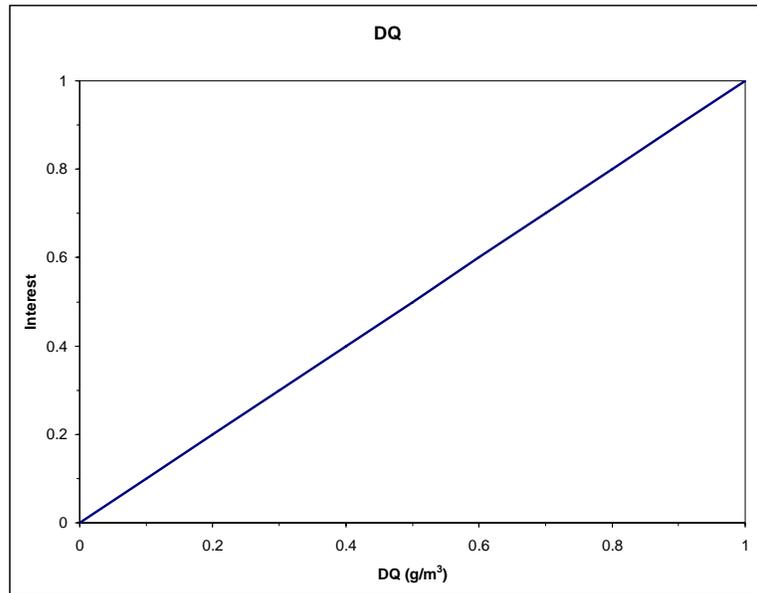
The delta q (dq) field is calculated to provide an estimate of the maximum potential LWC that can be realized between two well mixed levels in a cloud (Politovich et al. 2006). It is most accurate in a moist-adiabatic, non-precipitating cloud because all condensate remains in the cloud. In this case, one can simply calculate dq by subtracting the mixing ratio at the level in question from the mixing ratio at the cloud base. The LWC calculation is then converted into a dq_{map}. The adiabatic assumption will break down if precipitation is falling because it will cause condensate depletion. Also, if the lapse rate is too stable below the level of interest the calculation is not useful and dq_{map} will be minimized since increasing stability will not allow the maximum LWC to be realized. It will be highest in the upper portions of moist-adiabatic clouds. Because of the restrictions on the calculation dq_{map} is only used in the non-precipitating and warm precipitation scenarios. These scenarios have very low depletion rates where the maximum LWC can be realized as long as the lapse rate is close to moist-adiabatic.

Icing and SLD Potentials

The icing potential field was found to have a positive correlation to severity as reported by pilots. It also uses many of the same fields as FIP Severity, with different combinations. For that reason it was added to all scenarios in FIP Severity except warm precipitation. For warm precipitation the SLD potential field is used as an input. It serves as an indicator of the presence of large drops, which can increase the severity of a given icing situation. For a description of how these variables are calculated see Bernstein et al. (2005).

Total Water Path Map

Precipitation
if TWP ≤ 1000
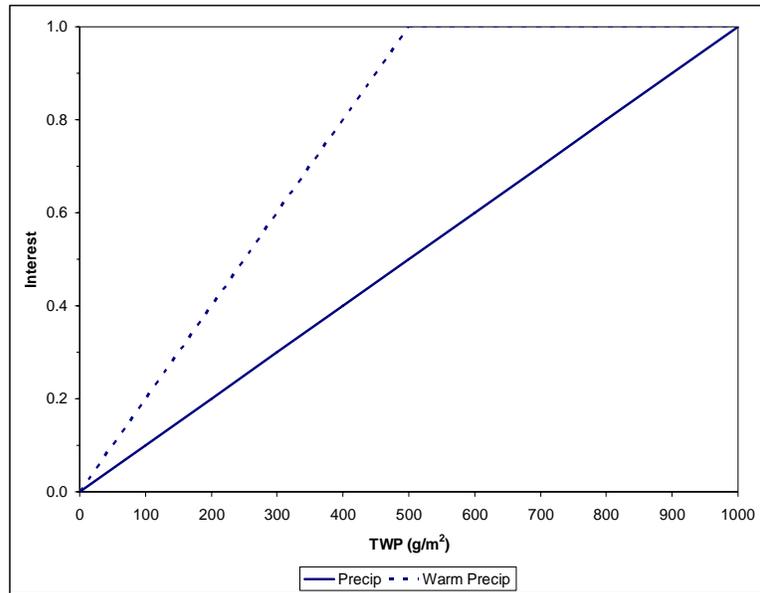   twp_precip = TWP / 1000
else if TWP > 1000
   twp_precip = 1.0

Warm Precipitation
if TWP ≤ 500
   twp_wp = TWP / 500
else if TWP > 500
   twp_wp = 1.0

The total water path is calculated to give an idea of the total amount of frozen and supercooled condensate present in a layer (Politovich et al. 2006). For this field a layer is defined as any consecutive model levels with non-zero condensate. The model often misidentifies SLW as frozen condensate, so the total condensate at temperatures below zero is used. Larger TWP values are often associated with more SLW. There are two different versions of this map. One is used for warm precipitation and has a smaller scale $(0 – 500g\ m^{-2})$ because clouds forming precipitation by the collision-coalescence process often have smaller amounts of total condensate associated with them. Therefore, twp_wp is only used in the warm precipitation scenario. The other version (twp_precip) is used in other precipitating scenarios (snow, rain, cold non-snow/rain, and classical precipitation above the warm nose). These scenarios often have large amounts of condensate in the cloud layer, so the scale is larger $(0 – 1000\ g\ m^{-2})$.

Delta Z Map
No Precip. & Warm Precip.
if DZ ≤ 6000
   dz_np = dz_wp = DZ/6000
else if DZ > 6000
   dz_np = dz_wp = 1.0
Snow
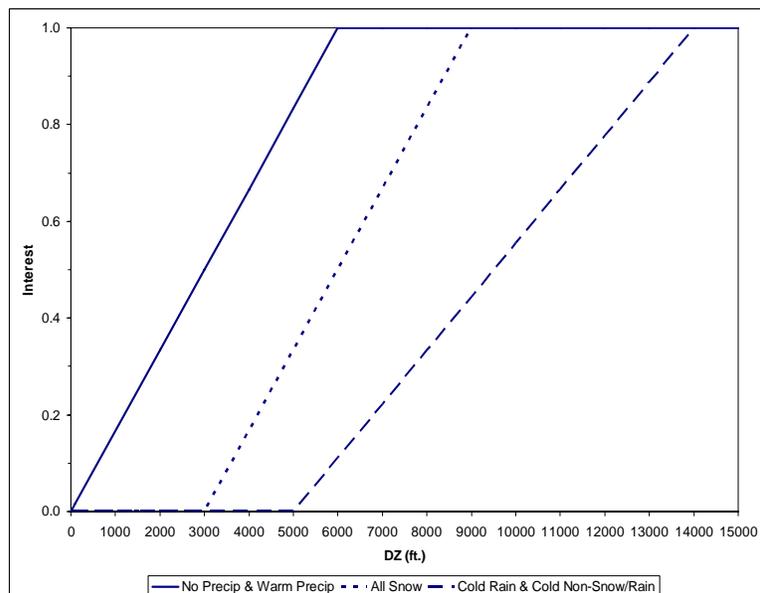if DZ ≤ 9000
   dz_sn = DZ/9000
else if DZ > 9000
   dz_sn = 1.0

Rain & Cold Non-SN/RA
if DZ ≤ 14000
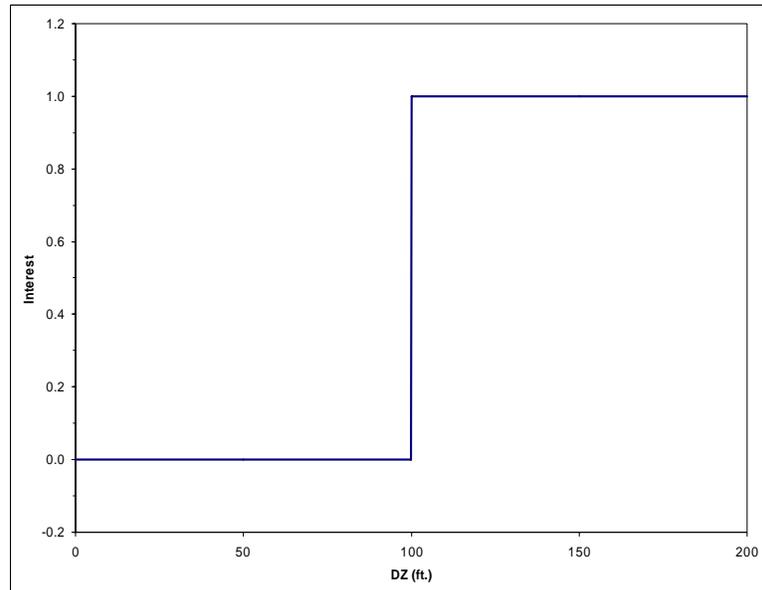   dz_ra = DZ/14000
else if DZ > 14000
   dz_ra = 1.0

Classical   Below   Warm Nose

if DZ < 100
   dz_fzra = 0.0
else if DZ ≥ 100
   dz_fzra = 1.0

The distance of a level from the cloud base can have a large effect on the amount of condensate available at that point. A grid point near to the cloud base will not have the potential for as much SLW as a point near to the cloud top. This is very similar to the dq calculation. However, the dz parameter does not require the stability or moisture parameters be correct. It is simply the distance between cloud base and the level of interest and is used in every scenario except classical precipitation above the warm nose. Each scenario has its own mapping equation for dz. Thicker clouds are required to produce the same interest in precipitating clouds than in non-precipitating clouds. The type of precipitation also plays a role. For example, the rain version requires much more depth to maximize the interest than the snow version. The classical precip below the warm nose version (dz_fzra) only requires a depth of 100 ft to maximize the interest. In this scenario a cloud below the warm nose can contain both supercooled large drops mixed with small drops, which can present an especially dangerous situation to aircraft flying there (Bernstein et al. 1999).

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<u>Below Warm Nose
Temperature Map</u>

if T ≤ 269.15
    t_bwn$_{map}$ = 1.0
else if 269.15 < T < 273.15
    t_bwn$_{map}$ = (273.15-T) / 4
else if T ≥ 273.15
    t_bwn$_{map}$ = 0.0
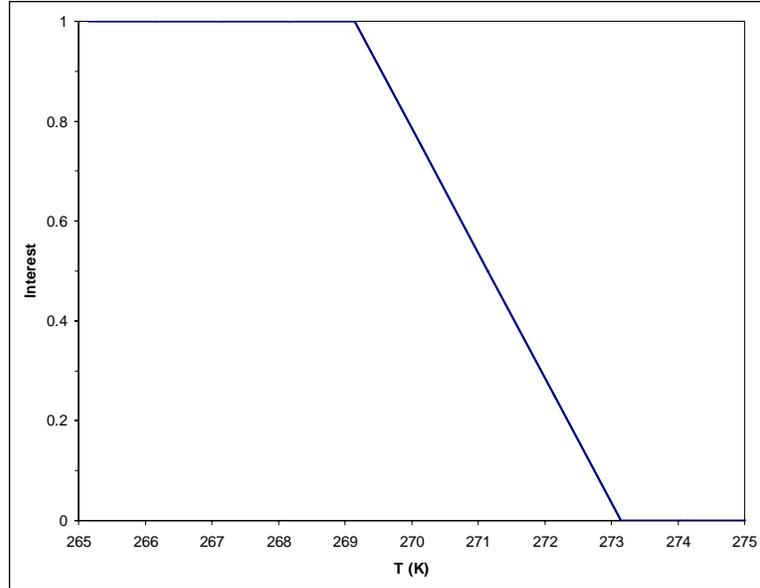
In classical precipitation below the warm nose the temperature is an important indicator of the severity. The colder the temperature the easier supercooled large drops will freeze to an airframe, which can increase the severity of an icing encounter due to a faster accretion rate. This map is maximized at all temperatures colder than -4 °C. It gets lower as the temperatures warm to 0 °C because most aircraft travel too fast to accrete icing at these temperatures due to heating along the leading edge of the wings.

<u>Precipitable Condensate Map</u>

if pcond < 0.05
    pcond$_{map}$ = 0.0
else if 0.05 ≤ pcond ≤ 0.2
    pcond$_{map}$ =
            (pcond − 0.05) / 0.15
else if pcond > 0.2
    pcond$_{map}$ = 1.0
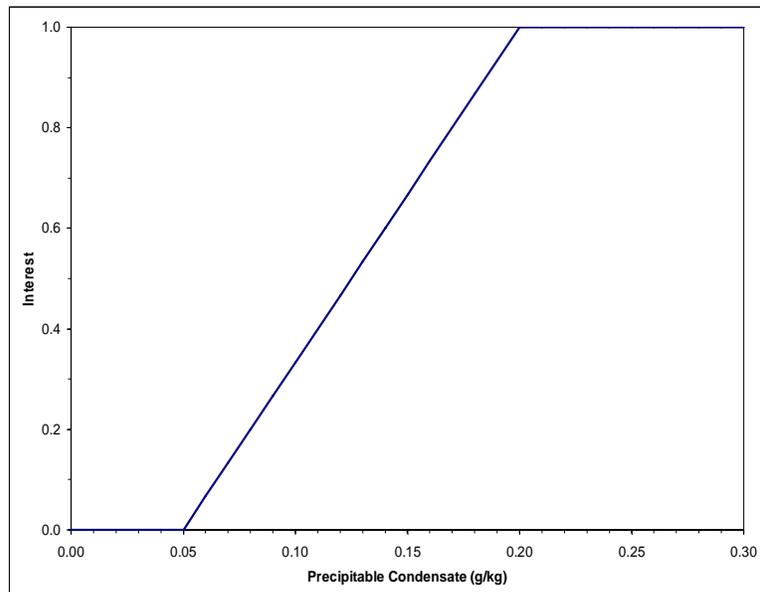
In most cases the presence of precipitation does not increase the icing severity because it represents a depletion of SLW in the cloud. However, in the classical precipitation below the warm nose scenario the amount of precipitation is directly correlated to the amount of SLW present. Therefore, the maximum precipitable

condensate (described in Section 2b) is used to determine the intensity of the precipitation falling. Larger values of this field will map to higher interest.

Below Warm Nose CTT Map

$ctt\_bwn_{map} = 1 - ctt_{map}$
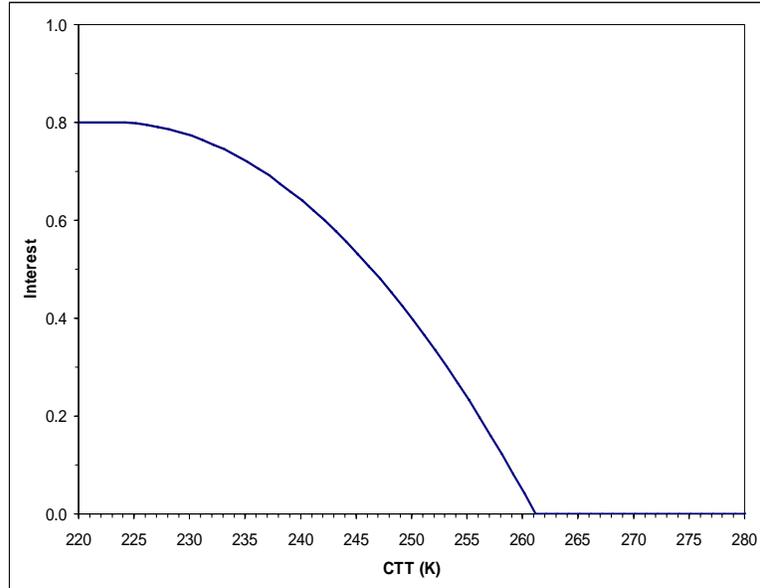
where ctt_{map} is defined by:
if CTT ≥ 261.15
    $ctt_{map} = 1.0$
else if 223.15 <CTT< 261.15
    $ctt_{map} = 0.2 + 0.8 *$
        $((CTT-223.15)/38)^2$
else if CTT ≤ 223.15
    $ctt_{map} = 0.2$

This interest map is used only below the warm nose in the classical precipitation scenario. The interest is high for low cloud top temperatures because the colder the cloud top the more efficient the ice formation process. This leads to an increase in condensate melting in the warm nose and refreezing below it.

Temperature Damping Map

$tdamp_{map} = 1 - t_{map}$

where t_{map} is defined by:
if T ≤ 248.15
    $t_{map} = 0.0$
else if 248.15 < T < 261.15
    $t_{map} = ((T - 248.15)/13)^{1/2}$
else if 261.15 ≤ T ≤ 268.15
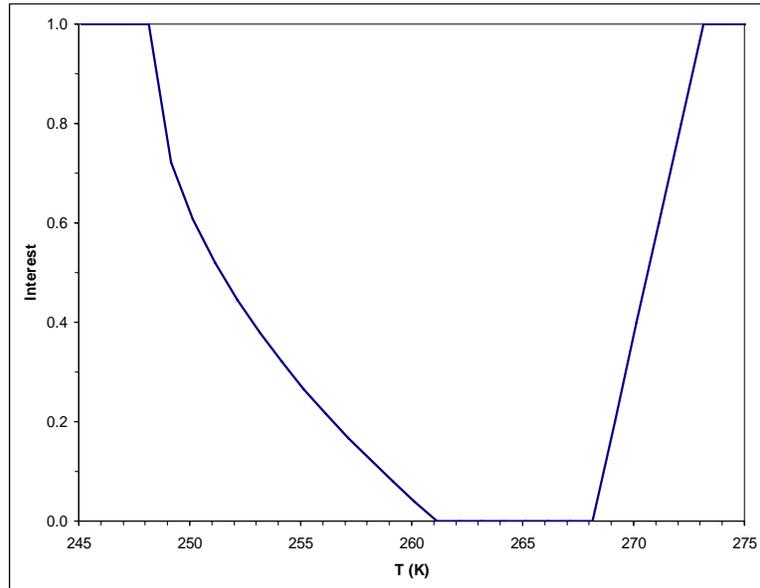 $t_{map} = 1.0$
else if 268.15 < T < 273.15
    $t_{map} = (273.15 - T) / 5$
else if T ≥ 273.15
    $t_{map} = 0.0$

The colder the temperature at a grid point the more likely that ice crystals will begin to activate and deplete the SLWC in a cloud. The temperature damping map is applied to all scenarios except classical precipitation below the warm nose since

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temperature is used as a boosting factor there. This factor can decrease the severity by up to 0.5 of its initial value. It is calculated using the following equation.

$$t\_damp\_factor = 0.5 * SEV_{init} * tdamp_{map}$$

Cloud Top Temperature
Damping Map

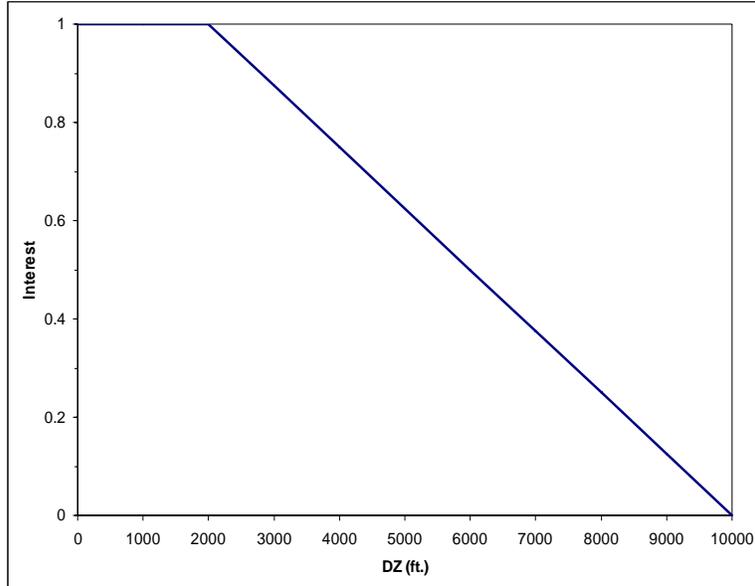*Delta Z Cloud Top Map*
if $DZ \leq 2000$
    $dz\_ctz_{map} = 1.0$
else if $2000 < DZ < 5000$
    $dz\_ctz_{map} = (10000 - DZ) /$
            8000
else if $DZ \geq 10000$
    $dz\_ctz_{map} = 0.0$

A cloud with a cold top is likely to be producing ice crystals. These ice crystals will grow at the expense of any liquid drops and if they grow large enough to fall through the cloud they can deplete the supercooled liquid water as they fall. The CTT damping map (cttdamp$_{map}$) is the same as the below warm nose CTT map shown previously. This factor is only applied at altitudes near cloud top, since the confidence that the cloud is continuous from cloud top down is greatest near cloud top and decreases with distance downward. Thus, a membership function for the distance between the level in question and the cloud top is calculated (dz_ctz$_{map}$). The most this factor can dampen severity is by 0.2 of the initial value. That is if the grid point is very close to a cold cloud top. Again, this is applied to every scenario except classical precipitation below the warm nose. The equation for the CTT damping factor is given below.

$$ctt\_damp\_factor = 0.2 * SEV_{init} * cttdamp_{map} * dz\_ctz_{map}.$$

<u>Precipitable Condensate</u>
<u>Damping Map</u>
Warm Precip & Cold Non-SN/RA
if pcond ≤ 0.05
  $pcdamp_{map}$ = 0.0
else if 0.05 < pcond < 0.15
  $pcdamp_{map}$ = 0.5 *
          ((cond – 0.05) / 0.1)
else if pcond ≥ 0.15
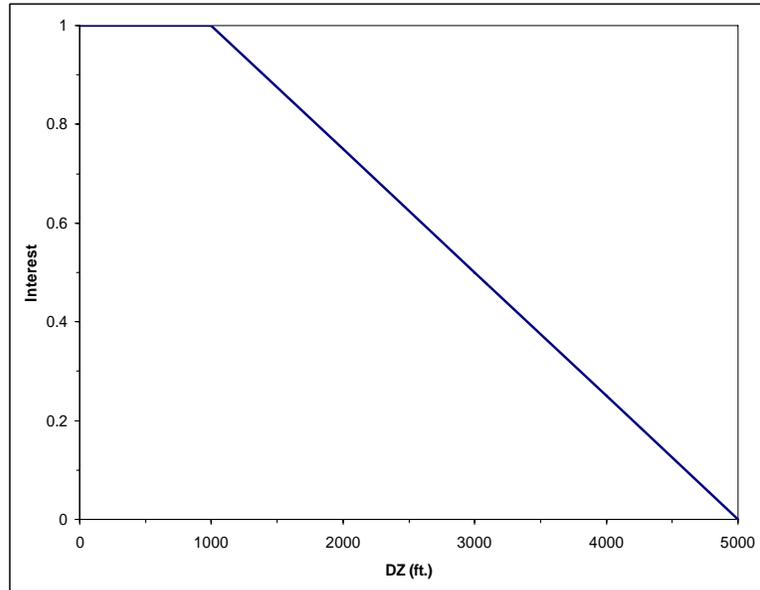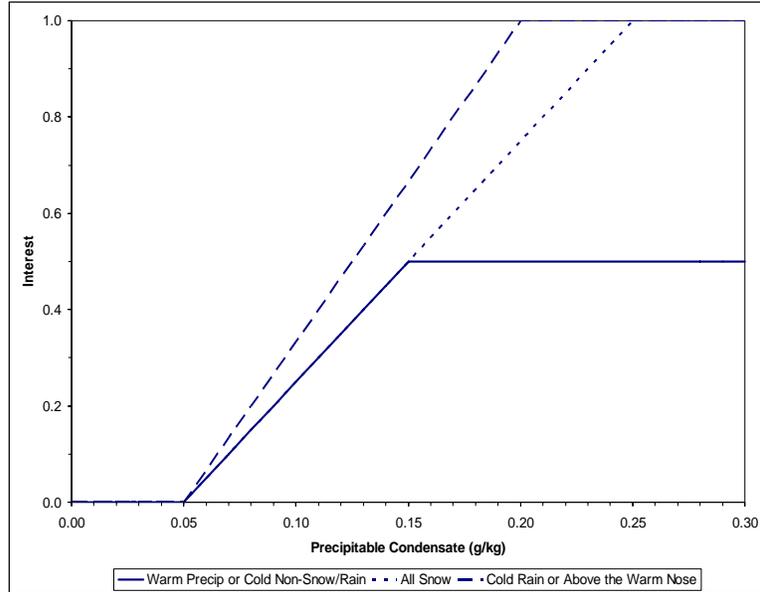 $pcdamp_{map}$ = 0.5

Snow
if pcond ≤ 0.05
  $pcdamp_{map}$ = 0.0
else if 0.05 < pcond < 0.25
  $pcdamp_{map}$ = (pcond-0.05) /
          0.2
else if pcond ≥ 0.25
  $pcdamp_{map}$ = 1.0

Rain & Above Warm Nose
if pcond ≤ 0.05
  $pcdamp_{map}$ = 0.0
else if 0.05 < pcond < 0.2
  $pcdamp_{map}$ = (pcond-0.05) /
          0.15
else if pcond ≥ 0.2
  $pcdamp_{map}$ = 1.0

Delta Z Cloud Base Map
if DZ ≤ 1000
  dz_cbz_{map} = 1.0
else if 1000 < DZ < 5000
  dz_cbz_{map} = (5000 – DZ) /
              4000
else if DZ ≥ 5000
  dz_cbz_{map} = 0.0

Precipitation falling from a cloud will usually reduce or deplete supercooled liquid water. In FIP Severity the amount of reduction depends both on the amount of precipitable condensate and the precipitation type. This damping factor is used in all scenarios except the non-precipitating cloud (because there is no precipitable condensate present) and classical precipitation below the warm nose (because precipitable condensate is used as a boosting factor). For the warm precipitation and cold non-snow/rain scenarios the maximum damping is 0.5 even if the model is producing copious

amounts of condensate because these scenarios tend to precipitate lightly in the actual environment. All other scenarios have a maximum damping of 1. Like the CTT damping factor a distance interest map (dz_cbz$_{map}$) is also calculated, but for cloud base instead of cloud top. It is only applied near the cloud base for the same reason as before. This factor is allowed to dampen severity by a maximum of up to 0.15 of the initial value, which happens when the grid point is close to the base of a heavily-precipitating cloud. The general form of the equation used to calculate the precipitable condensate damping factor is shown below.

$$\text{pcond\_damp\_factor} = 0.15 * SEV_{init} * pcdamp_{map} * dz\_cbz_{map}$$

Once the three damping factors have been calculated, they are simply subtracted from SEV$_{init}$ to get SEV$_{final}$. It is impossible for the damping factors to entirely remove the possibility of icing from a grid point. The factors are set up so that even if all three are maximized, SEV$_{init}$ will be reduced by a maximum of 85% of its original value.

4. Case Study

On 15 February 2005 a cold front was draped across the lower Great Lakes region. To the north of this front was an area of clouds producing icing, evident from several icing PIREPs. Some of these PIREPs (Fig. 5) will be used to illustrate how FIP Severity operates. PIREPs M and L were at 10,000 ft MSL so the conditions are examined at 700 mb, the nearest model level. M was a report of moderate icing, while L was for light icing. Both were in a non-precipitating cloud (**A**) according to FIP Severity. For this scenario the initial severity was calculated in the following way.

$$SEV_{init}(M\&L) = \frac{(4*vv) + (4*moisture) + (3.5*dz\_np) + (3*icepot) + (3*dq)}{(4 + 4 + 3.5 + 3 + 3)}$$
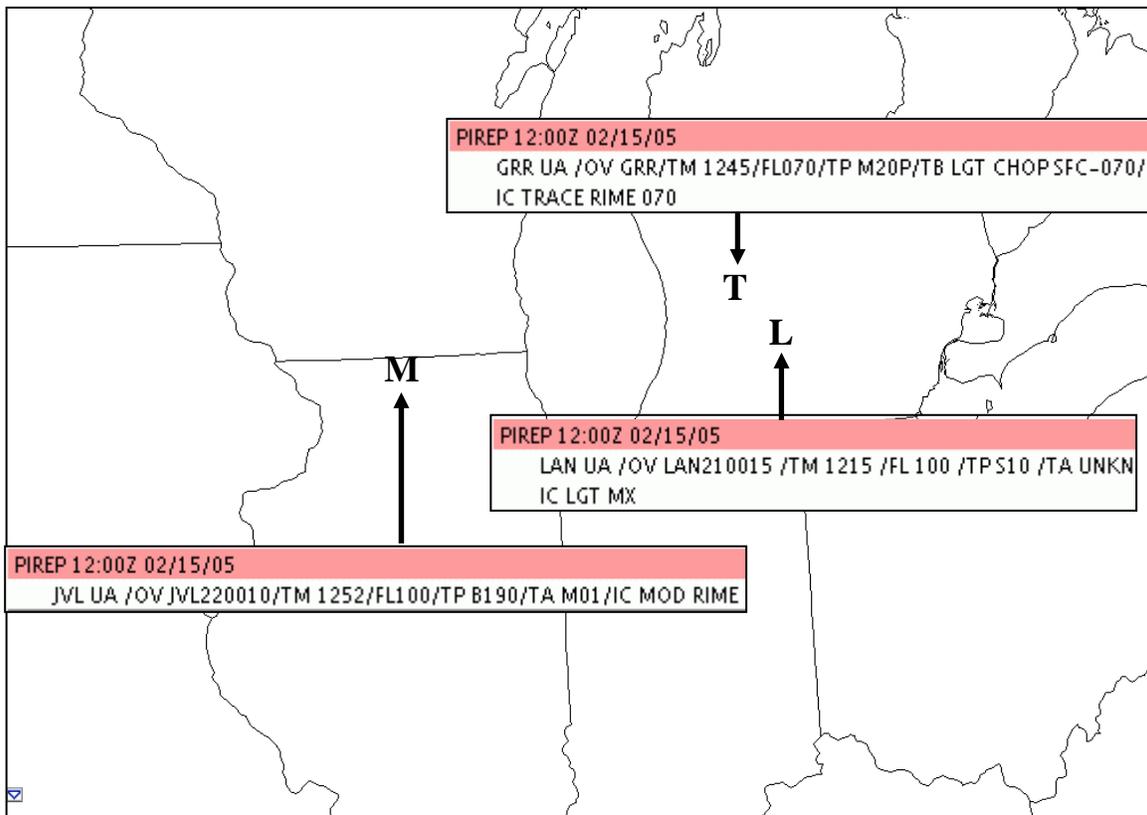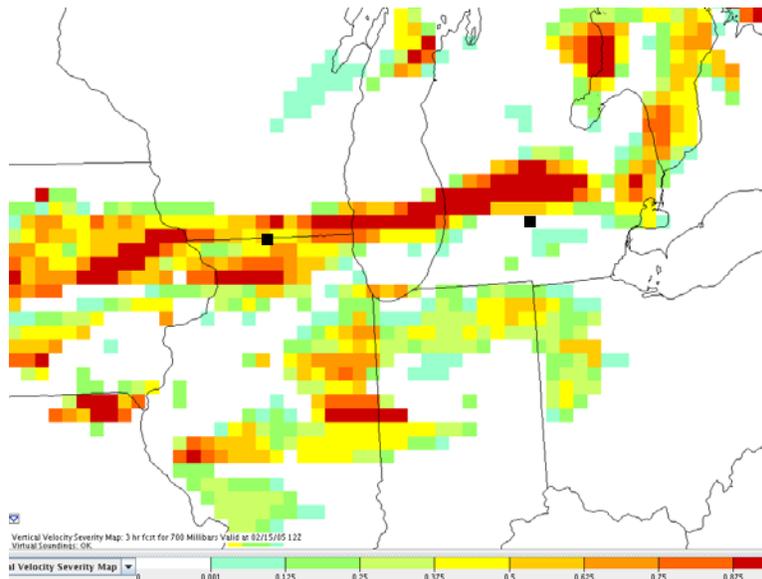

Figure 5. Location of the PIREPs of interest for 1200 UTC on 15 February 2005.

The following images show the interest map values for each of the fields used in the calculations near the altitude of the PIREPs (700 mb). Interest maps were extracted from the 3-h forecast valid at 1200 UTC. The PIREPs are marked with black squares: M is on the Illinois/Wisconsin border and L is in southern Michigan.

Vertical Velocity (vv)

For PIREP M, moderate lift was forecast by the model, resulting in an interest map value (vv_{map}) of 0.6. For PIREP L weak downward motion was forecast, so the value was 0. The weight was 4.0.

Vertical Velocity Severity Map: 3 hr fcst for 700 Millibars Valid at 02/15/05 12Z
Virtual Soundings: OK

Moisture

The model predicted high relative humidity values throughout the region, but no liquid condensate was forecast near either PIREP. A small amount of ice-phase condensate was forecasted near PIREP L. This resulted in $moist_{map}$ values of 0.5 for M and 0.54 for L. This field was also weighted by 4.

Moisture Interest Map: 3 hr fcst for 700 Millibars Valid at 02/15/05 12Z
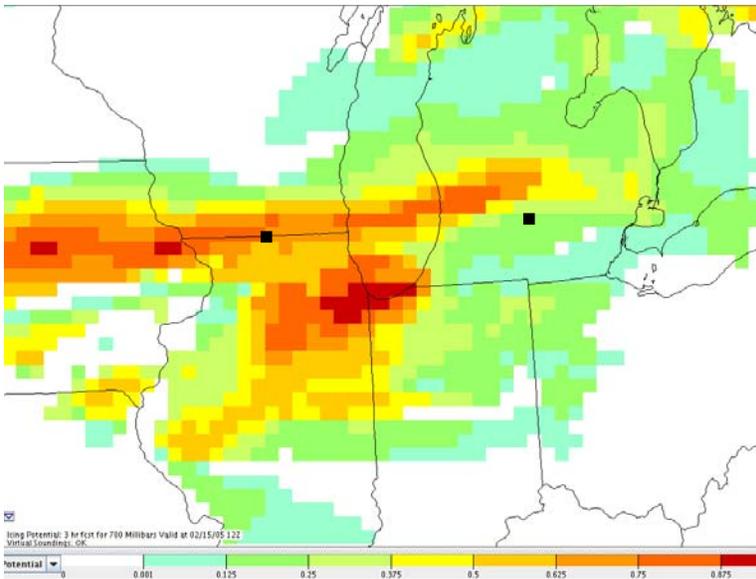Virtual Soundings: OK
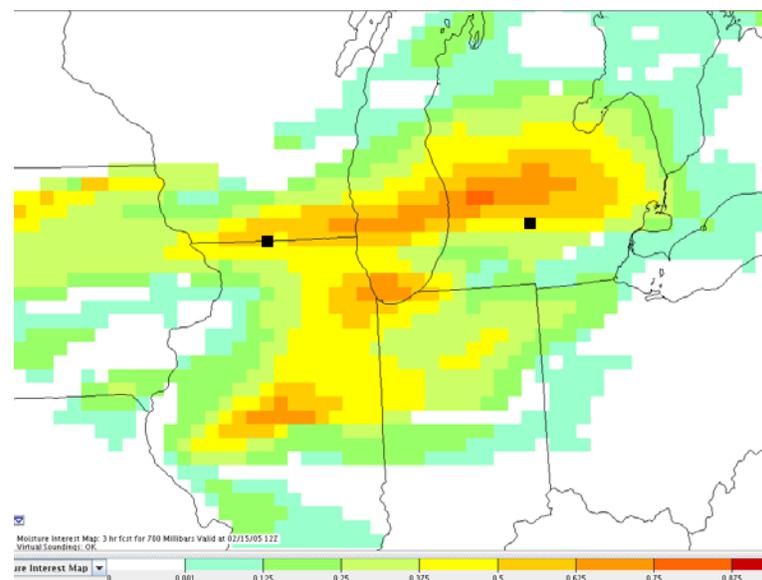
*Delta Z for no precip
(dz_np)*

Both M and L were well above the model cloud base, which resulted in high values for this interest map. M had a map value of 1.0 while L's was 0.8. It was weighted by 3.5.
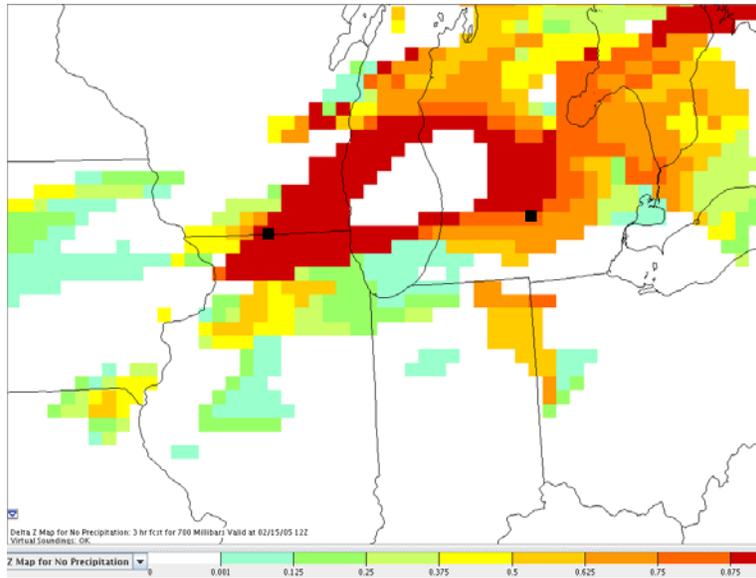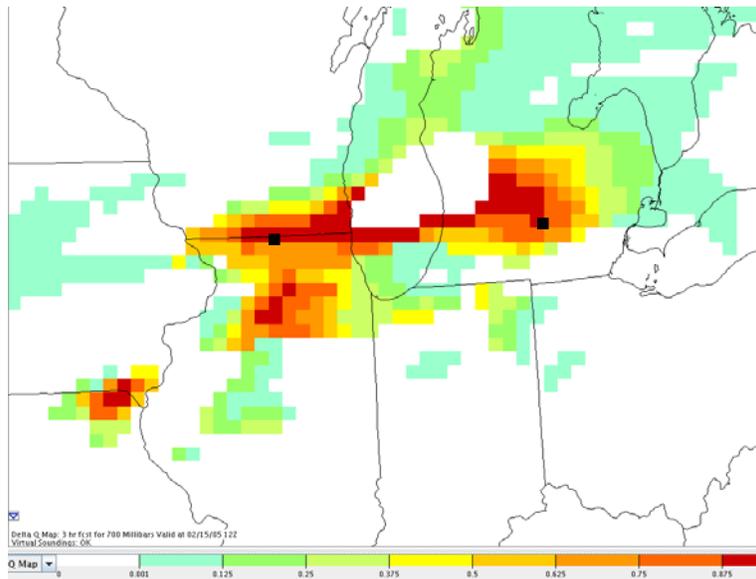

Icing Potential (icepot)

For M the icing potential was 0.66 and for L it was 0.16, with a weight of 3.

Delta Q (dq)

Because M and L were deep into the cloud and there was plenty of moisture available, this field had a high value for each PIREP. For M it was 1.0 and for L it was 0.8. It had a weight of 3.

Delta Q Map: 3 hr fcst for 700 Millibars Valid at 02/15/05 12Z
Virtual Sounding: OK

Q Map

After application of the proper maps and weights the initial icing severity for PIREP M is calculated.

$$\text{SEV}_{\text{init}} (M) = \frac{(4*0.6) + (4*0.5) + (3.5*1.0) + (3*0.66) + (3*1.0)}{(4 + 4 + 3.5 + 3 + 3)}$$

$$= 12.88 / 17.5$$
$$= 0.74$$
$$= \text{Moderate}$$

Likewise, the initial severity for PIREP L can be calculated.

$$\text{SEV}_{\text{init}} (L) = \frac{(4*0.0) + (4*0.54) + (3.5*0.8) + (3*0.16) + (3*0.8)}{(4 + 4 + 3.5 + 3 + 3)}$$

$$= 7.84 / 17.5$$
$$= 0.45$$
$$= \text{Moderate}$$

An initial severity of moderate icing was calculated for both PIREPs. The next step was to calculate and apply the damping maps for both grid points. There was some temperature damping for both PIREPs because the model temperature was slightly above -4 °C at those grid points. M also had some CTT damping since the CTT was forecast to be < -20 °C and the grid point was close to the cloud top. The CTT for L was colder, but the cloud top was higher, so the CTT damping map was not applied to that grid point. There was no precipitable condensate damping for either PIREP because it was a non-precipitating scenario. After damping the final severity for M was found to be 0.72,

which results in a severity of Moderate for that grid point (Fig. 6). For L the final severity was reduced to 0.41, resulting in a severity forecast of Light (Fig. 6).
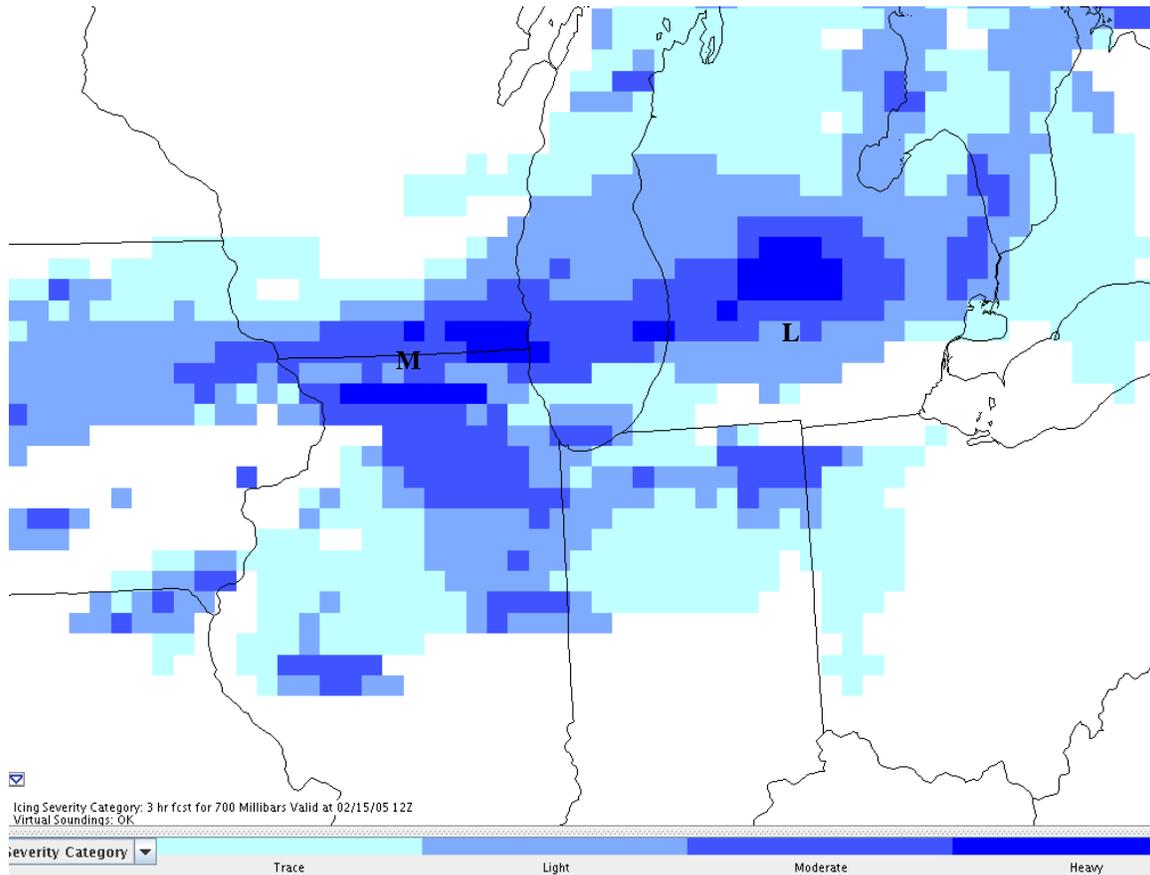

Icing Severity Category: 3 hr fcst for 700 Millibars Valid at 02/15/05 12Z
Virtual Soundings: OK

Severity Category ▼

Trace | Light | Moderate | Heavy

Figure 6. Three-hour forecast of the final icing severity category valid at 1200 UTC on 15 February 2005 at 700 mb. The locations of PIREPs M and L are labeled.

PIREP T (see Fig. 5) was a report of trace icing at 7000 ft MSL and occurred in the rain scenario (**C**). Interest map images for all of the fields will not be shown for this PIREP, but the values were taken from the 800 mb level. The initial icing severity for T is calculated below.

$$SEV_{init}(T) = \frac{(4*moisture) + (3.5*vv) + (3.5*dz\_cr) + (3*twp) + (2*icepot)}{(4 + 3.5 + 3.5 + 3 + 2)}$$

$$= \frac{(4*0.69) + (3.5*0) + (3.5*0.05) + (3*0.62) + (2*0.11)}{(4 + 3.5 + 3.5 + 3 + 2)}$$

$$= 5.01 / 16$$
$$= 0.31$$
$$= Light$$

In this case the damping factors had a larger effect on the final severity. The temperature was higher, at -1 °C, so the temperature damping decreased the initial severity from 0.31 to 0.19. Precipitable condensate damping was also used in this case because rain was forecast and PIREP T was close to the cloud base. However, there was little precipitable condensate forecast so the effect was not very large, only reducing the severity from 0.19 to 0.17. There was no CTT damping for this case because the PIREP was well below cloud top. A final severity value of 0.17 results in a severity forecast of Trace for this grid point (Fig. 7).
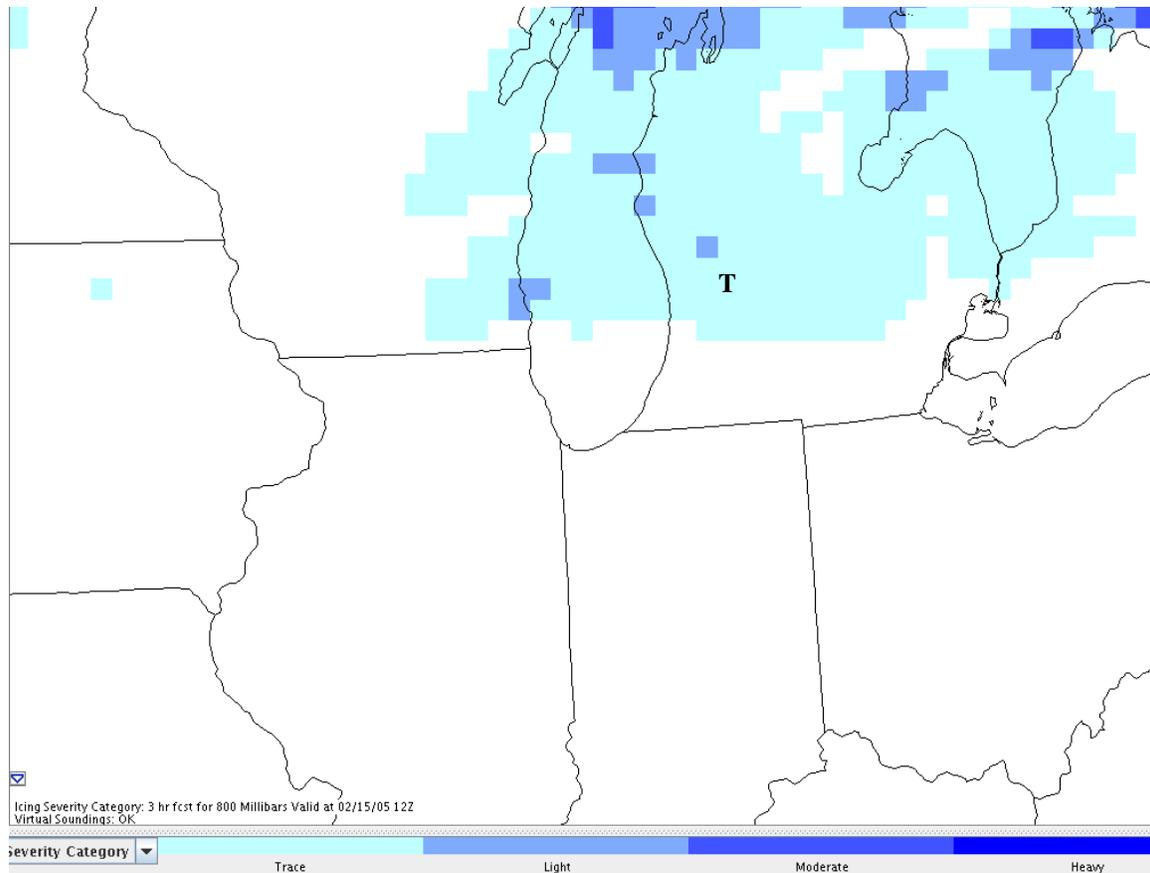

Figure 7. As in Figure 5, but for 800 mb. The location of PIREP T is labeled.

5. Summary

FIP Severity is very similar to CIP Severity except that it uses model surrogates for satellite, surface, and radar observations. Interest maps are extracted from RUC model fields and combined appropriately for various icing scenarios using fuzzy logic to calculate a forecast of the initial icing severity. Damping factors are then applied to reduce the initial severity in areas where depletion of the expected SLWC may occur. The final product is a forecast categorical icing severity (None, Trace, Light, Moderate, or Heavy) at 20-km horizontal resolution every 1000 feet over the CONUS.

This report has documented the premise behind FIP Severity, provided an in-depth look at each of the inputs and their membership functions, and illustrated how the algorithm works using some examples. The developers relied on years of experience in forecasting icing conditions and the application of basic cloud physics principles to create this algorithm, which is meant to serve as a supplementary piece of information in the overall decision making process for flights where in-flight icing is a concern. Upgrades to the precipitation identification and cloud top height schemes, which increased the efficiency of the FIP, were also discussed.

5. References

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