9A.2 Application of the Partial Precipitable Water (PPW) Concept in the Determination of a Potential Ice Accretion Index Aloft

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1. INTRODUCTION

This extended abstract intends to further the concept of the use of PPW in meteorological applications. Previous extended abstracts developed by the author (see references) provided insight into the calculation of PPW by adapting an equation from Roland Stull. This equation when applied to sub-layers in the atmosphere would allow scientists and decision support staff the capability to assess an important meteorology situation not well documented, namely identifying the potential for ice accretion that might exist aloft. For this reason, using the concept of PPW could lead to a new technique for assessing the state of the atmosphere. Also included in the technique is the integration of the new ice accretion remark provided by the Automated Surface Observing System (ASOS), which will become operational within the near future and can contribute to the potential. A user of the technique can quickly assess if significant amounts of precipitable water exist in critical layers potentially impacting an aircraft flying through them. An easy-to-understand computed index is described, thus providing a new means for assisting decision makers who may or may not have much meteorological background.

2. FLIGHT STATES

Figures 1a and b illustrate various states – referred to as *stages* – as an aircraft takes off, ascends, levels off, and descends back to an airfield. For the purposes of this extended abstract the stages are delineated into two phases: an Ascent Phase including the take-off, climb, and leveling-off stages; and a Descent Phase including the starting to descend, approach, final approach, and landing stages. Some may wish to break out the en-route phase separately from the other two, which would be acceptable but adds another dimension to the problem.

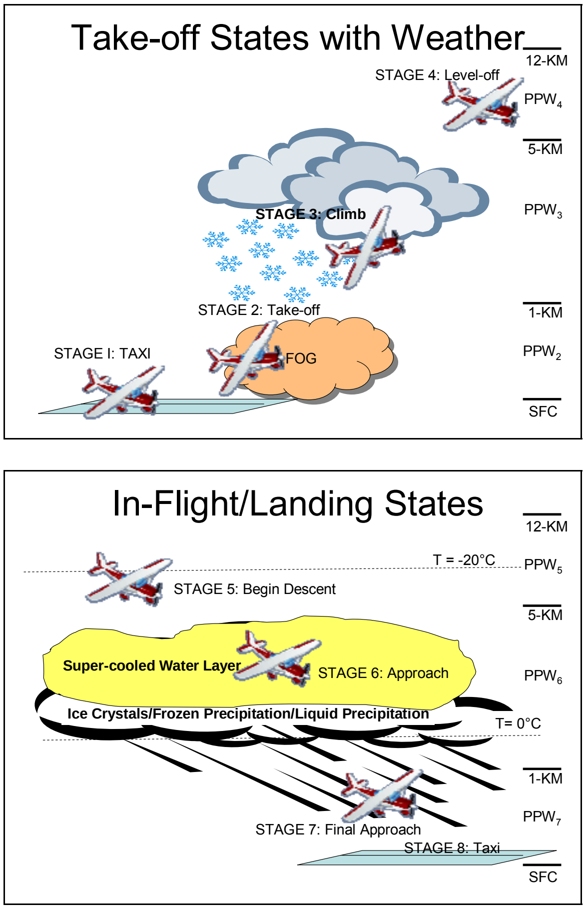

Figure 1a & b. Flight States associated with ascents and descents.

2.1 Super-cooled Water Aloft

An understanding of the concept of super-cooled water is found in the reference below[1] and is reproduced here:

Depending on the product (liquid water droplets or ice crystals), a distinction is made between cloud

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[1] Chapter 6, Humidity, Saturation, and Stability Pages 151–182. Introduction to Atmospheric Science, Fourth Edition, Joseph M. Moran, American Meteorological Society, Boston, MA. 2009

condensation nuclei and ice-forming nuclei. Cloud condensation nuclei (CCN) promote condensation of water vapor at temperatures both above and below the freezing point of water. Within the atmosphere, water vapor can condense into cloud droplets that remain liquid even at temperatures well below 0°C (32°F). ***Droplets at such temperatures are described as super-cooled.*** *Ice-forming nuclei (IN) are much less common than CCNs and promote formation of ice crystals only at temperatures well below freezing.*

Super-cooled water suspended within a cloud has the potential of freezing on contact and accumulating very rapidly on metal surfaces whose temperature is already cold. This can lead to rapid ice accretion impacting an aircraft's operation. The amount, therefore, becomes a function of either the length of time or distance traveled within that layer. Note, other forms of liquid or frozen precipitation may impact the operation as well, but not at the same rate of super-cooled water.

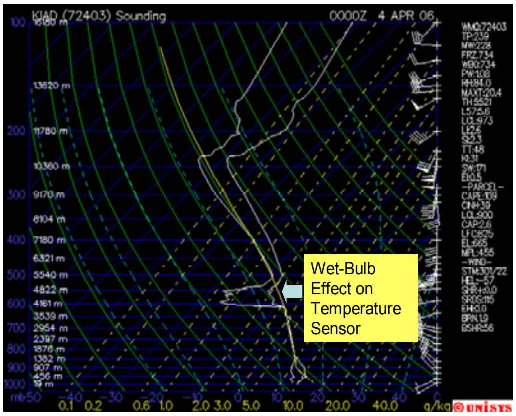

Example of "Wet-Bulb" Effect

Figure 2. Example of "wet-bulb" effect on a radiosonde sounding.

One manifestation of super-cooled water aloft in the atmosphere can be seen in Figure 2 during a radiosonde flight. As the radiosonde ascends the temperature sensor encounters moisture condensing on it and then freezing near the freezing level crossing aloft. As this occurs, latent heat is released as the icing occurs producing an unrepresentative temperature profile -- highly super-adiabatic when no such condition exists -- as a result. This is also known as "a wet-bulb" effect since the temperature sensor would act like a psychrometer on the ground. Note the dew point profile in the sounding also dries out rapidly suggesting the exiting of a very moist layer, i.e., a cloud. As the temperature profile suggests, it takes some time, thereafter, before it can recover fully to its more normal temperature profile. More than likely, this is indicative of a layer of significant super-cooled water suspended within a cloud layer, although the droplet size may be too small to be displayed on radar.

2.2 General Technique

Because one cannot measure through direct means exactly how much ice accretion is occurring in the free atmosphere, one has to infer its quantity through a technique. To accomplish this, various variables are brought together and combined into the *Potential Ice Accretion Index Aloft*. The general technique for formulating the index is as follows:

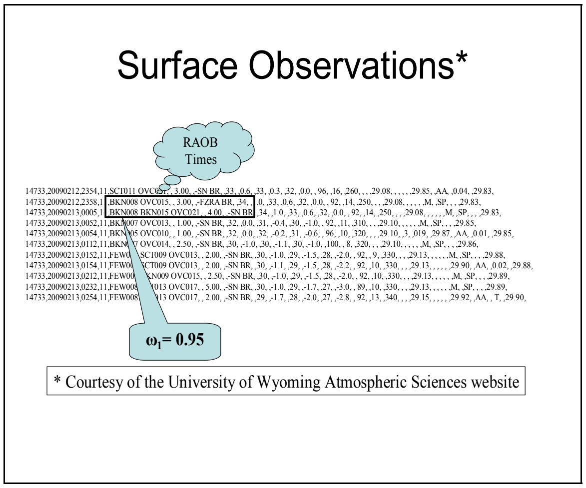
- Determine the presence or absence of ice accretion on the surface (Stages 1 or 8)
- Calculate the potential for ice accretion aloft during Stages 2 through 7) based on PPW
- Ascertain the presence or absence of clouds and weather from the surface observation

The technique brings these factors together and based on the information content determines the potential amount of ice accretion that might exist within each stage while an aircraft is either ascending or descending through various layers of the atmosphere. The index then encompasses relative measures of what the potential is throughout each layer, the entire column, and which layer has the highest potential.

2.3 Identifying Surface and Sounding Features

There are several ways to acquire the actual ice accretion at the surface either manually or through an automated technique. For example the Automated Surface Observing System will be rolling out a new Ice Accretion algorithm in 2010 capable of providing an automated remark on the amount of ice accretion in the METAR observation.

Figure 3 illustrates how the surface data can also be used to ascertain the types of clouds/weather occurring at the time of flight operations for use in determining the index.



Surface Observations*

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14733,20090212,2354,11,SCT011 OVC0[illegible], , 3.00, ,-SN BR, ,33, ,0.6, ,33, ,0.3, ,32, ,0.0, , 96, ,16, ,260, , , ,29.08, , , , , ,29.85, ,AA, ,0.04, ,29.83,
14733,20090212,2358,1[illegible] ,BKN008 OVC015, , 3.00, ,-FZRA BR, ,34, , [illegible].0, ,33, ,0.6, ,32, ,0.0, , 92, ,14, ,250, , , ,29.08, , , , , ,M, ,SP, , , ,29.83,
14733,20090213,0005,1[illegible] ,BKN008 BKN015 OVC021, , 4.00, ,-SN BR ,34, ,1.0, ,33, ,0.6, ,32, ,0.0, , 92, ,14, ,250, , , ,29.08, , , , , ,M, ,SP, , , ,29.83,
14733,20090213,0052,11,BKN007 OVC013, , 1.00, ,-SN BR, ,32, ,0.0, ,31, ,-0.4, ,30, ,-1.0, , 92, ,11, ,310, , , ,29.10, , , , , ,M, ,SP, , , ,29.85,
14733,20090213,0054,11,BKN005 OVC010, , 1.00, ,-SN BR, ,32, ,0.0, ,32, ,-0.2, ,31, ,-0.6, , 96, ,10, ,320, , , ,29.10, ,3, ,019, ,29.87, ,AA, ,0.01, ,29.85,
14733,20090213,0112,11,BKN0[illegible]7 OVC014, , 2.50, ,-SN BR, ,30, ,-1.0, ,30, ,-1.1, ,30, ,-1.0, ,100, , 8, ,320, , , ,29.10, , , , , ,M, ,SP, , , ,29.86,
14733,20090213,0152,11,FEW0[illegible] SCT009 OVC013, , 2.00, ,-SN BR, ,30, ,-1.0, ,29, ,-1.5, ,28, ,-2.0, , 92, , 9, ,330, , , ,29.13, , , , , ,M, ,SP, , , ,29.88,
14733,20090213,0154,11,FEW00[illegible] SCT009 OVC013, , 2.00, ,-SN BR, ,30, ,-1.1, ,29, ,-1.5, ,28, ,-2.2, , 92, ,10, ,330, , , ,29.13, , , , , ,29.90, ,AA, ,0.02, ,29.88,
14733,20090213,0212,11,FEW00[illegible]KN009 OVC015, , 2.50, ,-SN BR, ,30, ,-1.0, ,29, ,-1.5, ,28, ,-2.0, , 92, ,10, ,330, , , ,29.13, , , , , ,M, ,SP, , , ,29.89,
14733,20090213,0232,11,FEW008[illegible]T013 OVC017, , 5.00, ,-SN BR, ,30, ,-1.0, ,29, ,-1.7, ,27, ,-3.0, , 89, ,10, ,330, , , ,29.13, , , , , ,M, ,SP, , , ,29.89,
14733,20090213,0254,11,FEW008[illegible]013 OVC017, , 2.00, ,-SN BR, ,29, ,-1.7, ,28, ,-2.0, ,27, ,-2.8, , 92, ,13, ,340, , , ,29.15, , , , , ,29.92, ,AA, , T, ,29.90,
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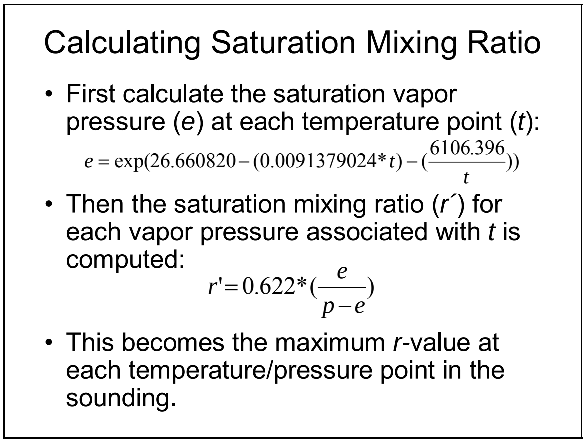
* Courtesy of the University of Wyoming Atmospheric Sciences website

Figure 3. Surface observations associated with a radiosonde sounding.

An analysis of the upper air sounding associated with the ascent or descent phase – usually a radiosonde, but can also be an aircraft, satellite, or even a model output sounding -- is the next step in the process. No matter which technology is used, the moisture data needs to be translated into mixing ratios for application of the technique. There must be two moisture calculations for every point as follows:

- Mixing ratios for each point along the moisture curve for every temperature/pressure up to 12 km.
- Calculation of the saturation mixing ratio along the temperature curve for every temperature/pressure up to 12 km (see Exhibit A). This constitutes the maximum values at each point.



Calculating Saturation Mixing Ratio

- First calculate the saturation vapor pressure (e) at each temperature point (t):

$$e = \exp(26.660820 - (0.0091379024 * t) - (\frac{6106.396}{t}))$$

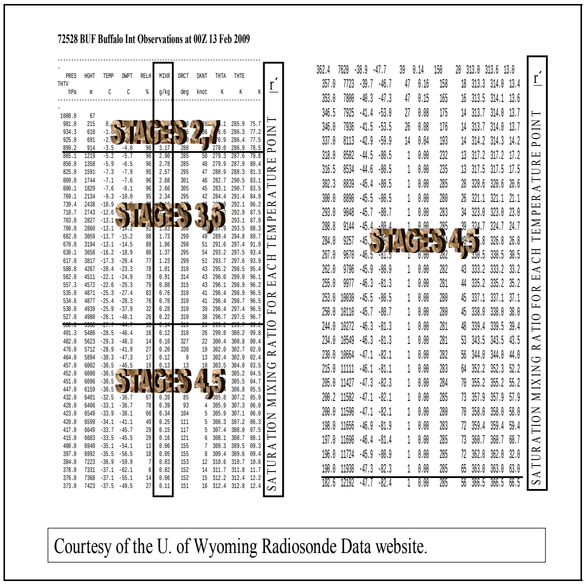
- Then the saturation mixing ratio (r') for each vapor pressure associated with t is computed:

$$r' = 0.622 * (\frac{e}{p - e})$$

- This becomes the maximum r-value at each temperature/pressure point in the sounding.

Exhibit A. Calculation of the saturation mixing ratio for every point.

Once the data are captured as shown in Figure 4 and saturation mixing ratios computed as shown in Exhibit A, the flight data are divided into stages. Note it's understood that aircraft generally fly from one airport to another and so different sets of data for each site will be needed for actual operational use of this technique. Data from the Buffalo flight of February 13, 2009 is shown in Figure 4 although the saturation values are left to the interested reader to compute using Exhibit A.



72528 BUF Buffalo Int Observations at 00Z 13 Feb 2009

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-----------------------------------------------------------------------------
-
   PRES   HGHT   TEMP   DWPT   RELH   MIXR   DRCT   SKNT   THTA   THTE
THTV
    hPa     m      C      C      %    g/kg    deg   knot     K      K      K
-----------------------------------------------------------------------------
-
 1000.0     67
  981.0    215    0.[illegible]                                  285.9  75.7
  934.3    610   -1.[illegible]                                  286.3  77.2
  925.0    691   -2.[illegible]                                  286.4  77.5
  899.2    914   -3.5   -4.0     96   3.17    280  [illegible]  278.0  286.9  78.5
  865.1   1219   -5.2   -5.7     96   2.90    285     50  279.3  287.6  79.8
  850.0   1358   -5.9   -6.5     96   2.78    285     48  279.9  287.9  80.4
  825.0   1591   -7.3   -7.9     95   2.57    295     47  280.9  288.3  81.3
  809.0   1744   -7.1   -7.6     96   2.68    301     46  282.7  290.5  83.1
  800.1   1829   -7.6   -8.1     96   2.60    305     45  283.1  290.7  83.5
  769.1   2134   -9.3  -10.0     95   2.34    295     42  284.4  291.4  84.9
  739.4   2438  -10.9  [illegible]                               292.1  86.2
  710.7   2743  -12.6  [illegible]                               292.9  87.5
  703.0   2827  -13.1  [illegible]                               293.1  87.9
  700.0   2860  -13.1  -14.2     91   1.83    300     48  287.9  293.5  88.3
  682.0   3059  -13.7  -15.2     88   1.73    299     49  289.4  294.8  89.7
  670.0   3194  -13.1  -14.5     89   1.86    298     51  291.6  297.4  91.9
  630.1   3658  -16.2  -18.9     80   1.37    295     54  293.2  297.5  93.4
  617.0   3817  -17.3  -20.4     77   1.23    299     51  293.7  297.6  93.9
  580.8   4267  -20.4  -23.3     78   1.01    310     43  295.2  298.5  95.4
  562.0   4511  -22.1  -24.9     78   0.91    314     43  296.0  299.0  96.1
  557.3   4572  -22.6  -25.3     79   0.88    315     43  296.1  298.9  96.2
  535.0   4871  -25.3  -27.4     83   0.76    310     41  296.4  298.9  96.5
  534.6   4877  -25.4  -28.3     76   0.70    310     41  296.4  298.7  96.5
  530.0   4939  -25.9  -37.9     32   0.28    310     39  296.4  297.4  96.5
  527.0   4980  -26.1  -40.1     26   0.22    310     38  296.7  297.5  96.7
  500.0   5500  -27.7  -44.7     10   0.14    310     20  299.2  299.7  99.2
  491.3   5486  -28.5  -46.4     16   0.12    310     26  299.8  300.2  99.8
  482.0   5623  -29.3  -48.3     14   0.10    327     22  300.4  300.8  00.4
  476.0   5712  -28.9  -41.9     27   0.20    338     19  302.0  302.7  02.0
  464.0   5894  -30.3  -47.3     17   0.12      0     13  302.4  302.9  02.4
  457.0   6002  -30.5  -46.5     19   0.13     13     10  303.5  304.0  03.5
  452.0   6080  -30.5  [illegible]                               305.2  04.5
  451.0   6096  -30.5  [illegible]                               305.5  04.7
  447.0   6159  -30.5  [illegible]                               306.8  05.5
  432.0   6401  -32.5  -36.7     67   0.39     85      4  305.8  307.2  05.9
  428.0   6466  -33.1  -36.7     70   0.39     93      4  305.9  307.3  06.0
  423.0   6549  -33.9  -38.1     66   0.34    104      5  305.9  307.1  06.0
  420.0   6599  -34.1  -41.1     49   0.25    111      5  306.3  307.2  06.3
  417.0   6649  -33.7  -45.7     29   0.15    117      5  307.4  308.0  07.5
  415.0   6683  -33.5  -45.5     29   0.16    121      6  308.1  308.7  08.1
  400.0   6940  -35.1  -54.1     13   0.06    155      7  309.3  309.5  09.3
  397.0   6992  -35.5  -56.5     10   0.05    155      8  309.4  309.6  09.4
  384.0   7223  -36.9  -59.9      7   0.03    153     12  310.6  310.7  10.6
  378.0   7331  -37.1  -62.1      6   0.02    152     14  311.7  311.8  11.7
  376.0   7368  -37.1  -55.1     14   0.06    152     15  312.2  312.4  12.2
  373.0   7423  -37.5  -49.5     27   0.11    151     16  312.4  312.8  12.4
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362.4   7620  -38.9  -47.7     39   0.14    150     20  313.0  313.6  13.0
357.0   7723  -39.7  -46.7     47   0.16    158     18  313.3  314.0  13.4
353.0   7800  -40.3  -47.3     47   0.15    165     16  313.5  314.1  13.6
346.5   7925  -41.4  -53.0     27   0.08    175     14  313.7  314.0  13.7
346.0   7936  -41.5  -53.5     26   0.08    176     14  313.7  314.0  13.7
337.0   8113  -42.9  -59.9     14   0.04    193     14  314.2  314.3  14.2
318.0   8502  -44.5  -80.5      1   0.00    232     13  317.2  317.2  17.2
316.5   8534  -44.6  -80.5      1   0.00    235     13  317.5  317.5  17.5
302.3   8839  -45.4  -80.5      1   0.00    285     28  320.6  320.6  20.6
300.0   8890  -45.5  -80.5      1   0.00    280     26  321.1  321.1  21.1
293.0   9048  -45.7  -80.7      1   0.00    283     34  323.0  323.0  23.0
288.8   9144  -45.4  -80.4      1   0.00    285     39  324.7  324.7  24.7
284.0   9257  -45.[illegible]                                   326.8  26.8
267.0   9670  -46.5  -81.5      1   0.00    282  [illegible]  330.5  330.5  30.5
262.0   9796  -45.9  -80.9      1   0.00    282     43  333.2  333.2  33.2
255.0   9977  -46.3  -81.3      1   0.00    281     44  335.2  335.2  35.2
253.0  10030  -45.5  -80.5      1   0.00    280     45  337.1  337.1  37.1
250.0  10110  -45.7  -80.7      1   0.00    280     45  338.0  338.0  38.0
244.0  10272  -46.3  -81.3      1   0.00    281     48  339.4  339.5  39.4
234.0  10549  -46.3  -81.3      1   0.00    281     53  343.5  343.5  43.5
230.0  10664  -47.1  -82.1      1   0.00    282     56  344.0  344.0  44.0
215.0  11111  -46.1  -81.1      1   0.00    283     64  352.2  352.3  52.2
205.0  11427  -47.3  -82.3      1   0.00    284     70  355.2  355.2  55.2
200.2  11582  -47.1  -82.1      1   0.00    285     73  357.9  357.9  57.9
200.0  11590  -47.1  -82.1      1   0.00    280     70  358.0  358.0  58.0
198.0  11656  -46.9  -81.9      1   0.00    283     72  359.4  359.4  59.4
197.0  11690  -46.4  -81.4      1   0.00    285     73  360.7  360.7  60.7
196.0  11724  -45.9  -80.9      1   0.00    285     72  362.0  362.0  32.0
190.0  11930  -47.3  -82.3      1   0.00    285     65  363.0  363.0  63.0
182.6  12192  -47.7  -82.4      1   0.00    285     56  366.5  366.5  66.5
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Courtesy of the U. of Wyoming Radiosonde Data website.

Figure 4. Actual flight data divided into stages.

2.4 Partial Precipitable Water

Chapter 6 of the cited AMS reference goes on to say:

Precipitable water is another way of describing the amount of water vapor in the atmosphere. Unlike the other humidity measures that represent the amount of water vapor at a specific place (usually near Earth's surface), ***precipitable water*** *is the depth of water that would be produced if all the water vapor in a vertical column of air were condensed into liquid water. The air column is usually taken to extend from Earth's surface to the top of the troposphere, the portion of the atmosphere where most water vapor occurs. A reasonably good measure of precipitable water is obtained from in situ measurements by radiosondes or remotely by Earth-orbiting satellites operating in the sounding mode.*

PPW is, therefore, a subset of this total liquid water integrated over each stage. The PPW is then computed for both the actual moisture profile and the saturated profile as a function of temperature to the 12 kilometer height above ground level using the

Roland Stull equation in Figure 5.[2] The advantage of PPW over mixing ratio or relative humidity is that it represents the amount of liquid water available to form as ice accretion upon contact with a metal surface. Note, it is understood that not all liquid water would be converted to ice due to inflow/outflow dynamics and phase changes; however, the goal here is to assist decision makers with determining regions of potential danger and not to account for all the ice available in the atmosphere.

Computing *Partial Precipitable Water* (PPW)

$$[d'_w = \overline{(r_{layer}}/g \bullet \rho_{liquid})(P_{bottom} - P_{top})]_{\alpha i,j}$$

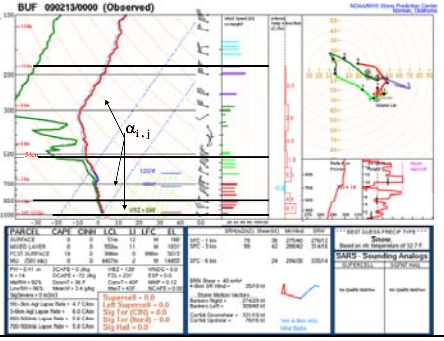

Figure 5. PPW layers used in the development of this index.

Next, determine the amount of PPW for each layer, i.e., stage, denoted as $\alpha_{i,j}$ in Figure 5, where *i* is the ith technology, e.g., radiosonde, aircraft, etc., and *j* is the jth-stage PPW layer, within the sounding.

3. COMPUTING THE INDICES

With all the preliminary steps completed, the next step is generation of the indices consisting of the following main components:

1. Determine the amount of surface ice accretion, clouds, and precipitation type.
2. Calculate the PPWs for each stage of the flight path (Stages 2 through 7, i.e., φ represents ascending stages and ψ for descending ones)
3. Determine the potential ice accretion for each stage of the moisture sounding
4. Determine the maximum ice accretion for each stage of the saturation moisture sounding
5. Determine indices associated with each stage before determining the highest stage, and also the total potential.

Exhibits B1 and B2 provide further details on how each of these components is to be computed.

Equations

Acquire the Surface Ice Accretion (SIA) from either an automated method, e.g., ASOS, or estimate manually, then compute:

SIA = $\omega_{1,8}(IA_{sfc}) / \Delta t_1$ Note, IA may have to be set to .01 in. if liquid/frozen precip is occurring. Values converted to mm when reported in inches.

(where ω is the Stage 1 or 8 weighting factor and Δt is the amount of time on the ground). Note, Δt_1 is generally reported hourly.

Compute the Partial Precipitable Water as follows:

$d_w{'} = \overline{(r_{layer}}/g \bullet \rho_{liquid})_{\varphi,\psi}(P_{bottom} - P_{top})_{\varphi,\psi}{}^{*} = PPW_{\varphi,\psi}$

(where φ are the ascending/leveling-off stage numbers, 2 – 4, and ψ are the descending ones, 5-7)

*Reference: *Meteorology for Scientists and Engineers*, second edition, Roland B. Stull, © 2000, page 171.

Equations

Define the Potential Ice Accretion for each stage as follows:

$PIA_{(\varphi,\psi)} = SIA_{(1,8)}$ or $(\omega(PPW)/\Delta t)_{\varphi,\psi}$ or $(\omega(PPW)/\Delta d)_{\varphi,\psi}$

(where ω is a weighting factor, Δt is the time and Δd is the distance traveled during a particular stage, [φ, ψ]). Note, if the time/distance is not known, let $\Delta t_{\varphi,\psi} = 0.25$ hr and $\Delta d_{\varphi,\psi} = 5$ miles

Define the Maximum Potential Ice Accretion as follows:

$PIA'_{(\varphi,\psi)} = SIA_{(1,8)}$ or $[(\omega(PPW')/\Delta t)_{\varphi,\psi}$ or $(\omega(PPW')/\Delta d)_{\varphi,\psi}]$

(where (PPW′) signifies the maximum PPW that would exist as a function of the temperature/$\overline{r}'$ profile for a particular stage, [φ, ψ])

Compute the Ascent/Descent Stage Index (SI) for each stage, Total Potential (TP), and the Highest Stage Index (HSI) as follows:

$SI = (PIA_{\varphi,\psi}) / (PIA'_{\varphi,\psi})$, $TP = SIA_{(1\ or\ 8)} + \Sigma(PIA_{(\varphi\ or\ \psi)})$ and HSI = highest SI encountered during either the ascent or descent phases.

Exhibits B1 and B2. Equations for calculating the indices.

3.1 Weighting Factors

To ensure the calculations are being applied when the "right conditions" exist, a weighting factor scheme is introduced into the equations above in the form of **ω**. Exhibit C. delineates the expected weighting factors to be applied based on the conditions encountered during each stage of the ascent or descent. For example, if no ice is accreting on the surface, but liquid precipitation is falling with a temperature of 2°C, ω would be 0.50 for Stage 1, meaning some potential exists. If SCT cloud conditions exist for Stage 2 or 7, then ω = 0.0 since logically there isn't sufficient ice to form within this cloud type, although there might be some sub-visible ice suspended in the

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[2] Reference: *Meteorology for Scientists and Engineers*, second edition, Roland B. Stull, © 2000, page 171.

atmosphere under very cold conditions. The weighting factors for Stages 3 through 6 relating to super-cooled water for temperatures between 0°C and -20°C--it might be possible to have this occur at even colder temperatures—is relatively high because of its direct impact on metal surfaces upon contact. Rapid build up then becomes the issue as an aircraft travels in time or distance within that layer.

STAGES	ω	WEIGHT DESCRIPTIONS
1, 8	1.00	if Ice Accretion is acquired directly from surface system or observed manually
	0.95	if freezing/frozen precip or freezing fog is observed
	0.50	if liquid precip below 3°C is observed
	0	if none of the above is present
2, 7	0	if CLR, FEW, SCT is predominately observed through the layer
	0.50	if liquid precip below 2°C is observed & clouds = BKN or OVC
	0.85	if freezing/frozen precip* is observed & clouds = BKN or OVC
	1.00	if freezing fog is observed or super-cooled water possible
3, 6	0	if no BKN or OVC condition exists or aircraft did not reach
	0.55	if liquid precip below 3°C is observed & clouds = BKN or OVC
	0.75	if freezing/frozen precip* is observed & clouds = BKN or OVC
	1.00	if super-cooled water* is possible & clouds = BKN or OVC
4, 5	0	if no BKN or OVC condition exists or aircraft did not reach
	0.75	if super-cooled water * is possible & clouds = BKN or OVC

*Note, super-cooled water or frozen precip is only being evaluated between 0°C and -20°C, although it may be acceptable to calculate its potential to well below -20°C and slightly above 0°C

Exhibit C. Various weights associated with meteorological conditions on the surface and aloft.

Figures 3 and 6 depict examples of different weighting factors assigned to each stage either at the surface and above the Buffalo upper air site based on the presence of clouds, and possibly, super-cooled water. One can also see from the sounding that the maximum and actual PPWs have similar values in Stages 2 or 7 and a maximum weighting factor (ω = 1.00), meaning all the conditions were "right" on this day for significant icing potential within this stage.

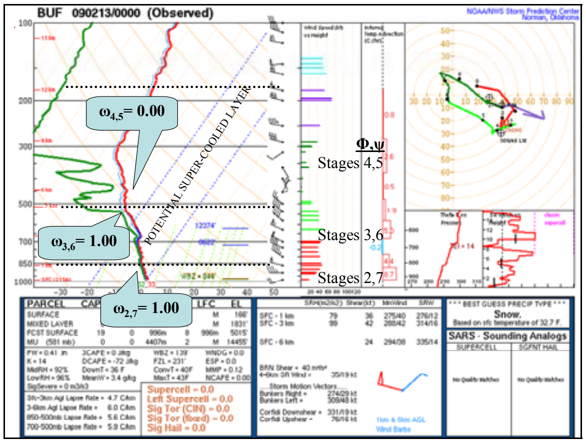

Figure 6. Weighting factors associated with different stages.

3.2 Index Outcomes

There are four potential outcomes from the technique as shown below in Exhibit D.

POTENTIAL ICE ACCREATION INDEX

SI	HSI*	Icing Potential
.99-.90	HIGH	Severe
.89-.65	MEDIUM	Moderate
.64-.40	LOW	Slight
Below .40	NONE	Insignificant

* One overall HSI is applied based on the highest SI encountered either during the ascent, enroute or descent phases.

Exhibit D. Example of SI for each stage and assigning one overall HSI.

The highest ratio of the actual to maximum PPW within all layers (φ, ψ) results in the selection of the *Highest Stage Index* applying to either a flight ascent or descent. So, if an SI of 92 were to be encountered for Stage 3 as the highest value for all ascent stages, the HSI would be rated as HIGH and the icing potential as *SEVERE*. Clearly, *the higher the index the higher the potential*, thus a direct relationship would exist. Note each stage can also have its own individual SI reported and a Total Potential computed for each ascent or descent providing additional insight for decision makers.

4. CONCLUSIONS

The purpose of this paper is to inform the meteorological and aviation communities about the possibility for a *Potential Ice Accretion Index Aloft* centered on the concept of PPW.

This has important attributes for assessing the atmosphere for a potentially dangerous situation:

- PPW is a "conserved" value, meaning it is constant within the layer and can be derived from any in situ/remote sensor measuring water vapor aloft
- Can be used directly in determining the amount of precipitable water available for conversion into ice accretion

- Super-cooled water suspended within cloud structures compound the problem by allowing larger amounts of moisture to accrete onto metal surfaces more so than other types of precipitation
- Could be of great benefit to decision support teams in guiding aircraft to their final destination

Once the method discussed in this paper is further developed and proven, it can be implemented for use by the wider community rather quickly. The technique can be further refined by others who wish to contribute their knowledge and expertise to this concept.

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