3.4 A Tool To Interpret The National Hurricane Center Wind Probability Forecasts

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1. Introduction

The 45th Weather Squadron (45 WS) is the U.S. Air Force unit that provides weather support to America's space program at Cape Canaveral Air Force Station (CCAFS), NASA Kennedy Space Center (KSC), and Patrick AFB (PAFB). The weather requirements of the space program are very stringent (Harms et al., 1999). In addition, the weather in east central Florida is very complex.

One of the many duties of the 45 WS is tropical cyclone support (Winters et al., 2006), e.g. predicting the onset and ending of various wind speed thresholds from approaching and receding tropical cyclones, respectively. This is important since east central Florida is often threatened by approaching tropical cyclones that usually pass to the south of the area, or are recurving to pass north of the area, or approach from the west after crossing the Florida peninsula, especially late in the hurricane season (Figure-1). These typical paths with many near misses make forecasting the impacts on CCAFS/KSC/PAFB very challenging. This is especially true for the recurving tropical cyclones that approach or recede nearly parallel to the east central coast of Florida—a small change in direction can make a large change in the wind fields that will be experienced.

Another challenging aspect for tropical cyclone support by 45 WS is the long lead-time requirements. For example, the Space Shuttle can ride out winds up to 70 Kt peak at the launch pad. If winds will exceed this threshold, the Space Shuttle must roll back to the Vehicle Assembly Building that is rated to 90 Kt sustained/109 Kt peak. However, the roll back itself has a wind limit of ≥ 40 Kt sustained/60 Kt peak and so the roll back must be completed before that threshold is met. While the actual roll back only takes about 9 hours, the decision process begins 3 days beforehand and discussion of the requirement to roll back can begin as much as 5 days beforehand. Bottom-line: if a Space Shuttle is at the launch pad, the 45 WS needs to inform KSC 3-5 days or more before the onset of ≥ 40 Kt sustained/peak 60 Kt from a tropical cyclone, if the winds will also eventually be ≥ 70 Kt peak.

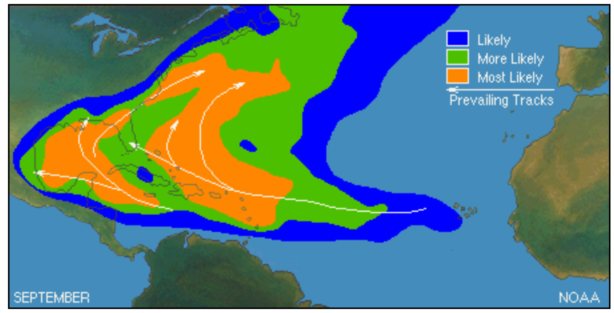

Figure 1. Typical tropical cyclone paths for the Atlantic basin. Tropical cyclones often approach but do not hit east central Florida. This makes forecasting tropical cyclone impacts at CCAFS/KSC challenging. This graphic is for Sep, but is a fairly representative summary for the entire season. Figure from NOAA (2010).

2. Wind Probability Tool From The National Hurricane Center

The relatively new tropical cyclone wind speed probability forecast product from the National Hurricane Center (NHC) (DeMaria et al., 2009) is one of the main tools used by 45 WS in predicting the likelihood and timing of various winds from tropical cyclones. This product provides the probability of winds from a tropical cyclone meeting three speed thresholds (≥ 34, ≥ 50, and ≥ 64 kt) over seven forecast intervals (12, 24, 36, 48, 72, 96, and 120 hours). The interval version of the product indicates the probability that the winds will begin during each forecast interval. The cumulative version indicates the probability of the winds occurring from the issue time of the forecast through the forecast interval. The tropical cyclone wind speed probability forecast product is provided in a graphical format that shows all areas being affected by the tropical cyclone (Figure-2) and in a tabular format for specific points along the coast (Figure-3). The NHC began providing this product for operational use in 2006. The tropical cyclone wind speed probability forecast product performs well (Splitt et al., 2010; DeMaria et al., 2009, Knaff and DeMaria, 2006).

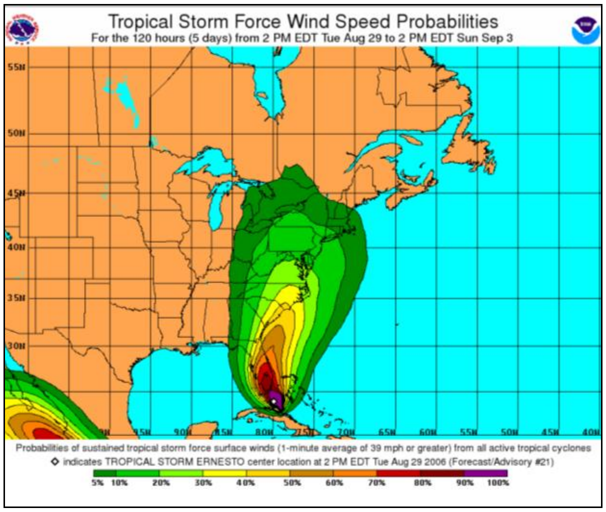

Figure 2. Example of the graphical version of the NHC wind speed probability product. The 120-hr, ≥ 34 kt forecast for Hurricane Ernesto at 1800 UTC, 29 Aug 06, close the the same time as the tabular forecast in Figure-3. NOAA (2010).

The new tropical cyclone wind speed probability forecast product was a significant improvement over the previous strike probability product (now discontinued). The old product gave only the probability of the tropical cyclone center passing within 65 nmi of certain points, rather than the probability of expected wind speeds—a 65 nmi distance can make a big difference in wind speed at a point, depending on the size of the tropical cyclone. The old product also was only text, rather than graphical and text. Finally, the old product was issued for only certain predetermined locations, rather than the continuous area coverage available on the new graphical product. The new tropical cyclone wind speed probability product also has similar advantages over the tropical cyclone path uncertainty product (aka cone of uncertainty). The path of uncertainty model only considers best path of the center of the tropical cyclone and its uncertainty. Not the size of the wind field.

However, as useful as the new tropical cyclone wind speed probability forecast product is, it has a drawback. The operationally important probabilities change for the varying forecast intervals, especially in the interval forecasts (Splitt et al., 2010). This complicates the interpretation of the product. For example, a 12% probability in the 12-hour interval forecast for 64 Kt or greater sustained wind is a low likelihood of occurrence and is likely due to the tropical cyclone passing a

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ZCZC MIAPWSAT5 ALL
TTAA00 KNHC DDHHMM
TROPICAL STORM ERNESTO WIND SPEED PROBABILITIES NUMBER  21
NWS TPC/NATIONAL HURRICANE CENTER MIAMI FL   AL052006
2100 UTC TUE AUG 29 2006

AT 2100Z THE CENTER OF TROPICAL STORM ERNESTO WAS LOCATED NEAR
LATITUDE 24.3 NORTH...LONGITUDE 80.2 WEST WITH MAXIMUM SUSTAINED
WINDS NEAR 40 KTS...45 MPH...75 KM/HR.

CHANCES OF SUSTAINED (1-MINUTE AVERAGE) WIND SPEEDS OF AT LEAST
   ...34 KT (39 MPH... 63 KPH)...
   ...50 KT (58 MPH... 93 KPH)...
   ...64 KT (74 MPH...119 KPH)...
FOR LOCATIONS AND TIME PERIODS DURING THE NEXT 5 DAYS

PROBABILITIES FOR LOCATIONS ARE GIVEN AS IP(CP) WHERE
    IP  IS THE PROBABILITY OF THE EVENT BEGINNING DURING
        AN INDIVIDUAL TIME PERIOD (INDIVIDUAL PROBABILITY)
   (CP) IS THE PROBABILITY OF THE EVENT OCCURRING BETWEEN
        18Z TUE AND THE FORECAST HOUR (CUMULATIVE PROBABILITY)

PROBABILITIES ARE GIVEN IN PERCENT
X INDICATES PROBABILITIES LESS THAN 0.5 PERCENT
LOCATIONS SHOWN WHEN THEIR TOTAL CUMULATED 5-DAY
   PROBABILITY IS AT LEAST 2.5 PERCENT

Z INDICATES COORDINATED UNIVERSAL TIME (GREENWICH)
   ATLANTIC STANDARD TIME (AST)...SUBTRACT 4 HOURS FROM Z TIME
   EASTERN  DAYLIGHT TIME (EDT)...SUBTRACT 4 HOURS FROM Z TIME
   CENTRAL  DAYLIGHT TIME (CDT)...SUBTRACT 5 HOURS FROM Z TIME


  - - - - WIND SPEED PROBABILITIES FOR SELECTED  LOCATIONS - - - -

               FROM    FROM    FROM    FROM    FROM    FROM    FROM
  TIME       18Z TUE 06Z WED 18Z WED 06Z THU 18Z THU 18Z FRI 18Z SAT
PERIODS        TO      TO      TO      TO      TO      TO      TO
             06Z WED 18Z WED 06Z THU 18Z THU 18Z FRI 18Z SAT 18Z SUN

FORECAST HOUR    (12)   (24)    (36)    (48)    (72)    (96)   (120)
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
LOCATION       KT

JACKSONVILLE   34  1   8( 9)  20(29)  10(39)   2(41)   X(41)   1(42)
JACKSONVILLE   50  X   X( X)   5( 5)   3( 8)   1( 9)   X( 9)   1(10)

DAYTONA BEACH  34  6  24(30)  24(54)   4(58)   1(59)   1(60)   X(60)
DAYTONA BEACH  50  X   3( 3)  15(18)   2(20)   X(20)   1(21)   X(21)
DAYTONA BEACH  64  X   X( X)   3( 3)   1( 4)   X( 4)   X( 4)   X( 4)

ORLANDO FL     34 15  33(48)  16(64)   1(65)   1(66)   X(66)   X(66)
ORLANDO FL     50  X  10(10)  10(20)   X(20)   X(20)   1(21)   X(21)
ORLANDO FL     64  X   1( 1)   2( 3)   X( 3)   X( 3)   X( 3)   1( 4)

COCOA BEACH FL 34 21  34(55)  13(68)   2(70)   1(71)   X(71)   X(71)
COCOA BEACH FL 50  X  10(10)  11(21)   1(22)   X(22)   X(22)   X(22)
COCOA BEACH FL 64  X   1( 1)   4( 5)   X( 5)   X( 5)   X( 5)   X( 5)

FT PIERCE FL   34 37  29(66)   6(72)   1(73)   X(73)   X(73)   X(73)
FT PIERCE FL   50  1  13(14)   4(18)   1(19)   X(19)   X(19)   X(19)
FT PIERCE FL   64  X   2( 2)   1( 3)   X( 3)   X( 3)   X( 3)   X( 3)

W PALM BEACH   34 56  19(75)   2(77)   1(78)   X(78)   X(78)   X(78)
W PALM BEACH   50  6  12(18)   1(19)   X(19)   X(19)   X(19)   X(19)

MIAMI FL       34 75   9(84)   1(85)   X(85)   X(85)   X(85)   X(85)
MIAMI FL       50 25   6(31)   X(31)   X(31)   X(31)   X(31)   X(31)
MIAMI FL       64  2   1( 3)   X( 3)   X( 3)   X( 3)   X( 3)   X( 3)
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Figure 3. Example of the tabular version of the NHC wind probability product. Excerpt from the 2100 UTC, 29 Aug 06 forecast for Tropical Storm Ernesto, close to the same time as the graphical product in Figure-2. (NOAA, 2010).

moderate distance from the point of interest. However, that same 12% probability for 64 Kt winds or greater in the 120-hour interval forecast still represents a low likelihood of occurrence, but would be the highest probability ever forecast for the 120-hour forecast of these winds (Figure-4) and is likely due to the tropical cyclone being far from the point of interest at this time but predicted to pass very near it. The NHC also acknowledges this issue in interpreting their product (NOAA, 2010). While the NHC tropical cyclone wind speed probability forecast product performs well, this sliding scale of operationally important probabilities can hinder interpretation of the product by decision makers with little meteorological or statistical expertise or by the public.

3. Interpretation Tool

A tool to help interpret the sliding scale of operationally important probabilities from the NHC tropical cyclone wind speed probability forecast product was developed.

3.1 Development Of The Interpretation Tool

The interpretation tool was developed using the observed distribution of the tropical cyclone wind speed probability forecasts issued by the NHC. The distribution is converted quasi-objectively into Probability Interpretation Categories (PIC). Each PIC represents a plain language likelihood of occurrence that has the same interpretation regardless of the forecast interval and wind speed being predicted, i.e. the sliding scale of the operational importance of the probabilities is taken into account. This should help interpret these wind probability forecasts for non-meteorological or non-statistical decision makers and the public. An example of this tool is shown in Figure-4.

LIKELIHOOD OF OCCURRENCE VS. FORECAST PROBABILITY (%)
>= 64 Kt NHC WIND PROBABILITY INTERVAL FORECASTS
Based on verification of all land threatening tropical cyclones along U.S. East Coast and Gulf of Mexico (2004-2007)

Forecast Interval (Hr)	VERY LOW		LOW		MEDIUM		HIGH		VERY HIGH (highest forecast)	
12	0	1	2	12	13	46	47	92	93	100 (100)
24	0	2	3	16	17	45	46	79	80	100 (85)
36	0	1	2	14	15	33	34	53	54	100 (56)
48	0	0	1	7	8	20	21	35	36	100 (37)
72	0	0	1	3	4	10	11	17	18	100 (18)
96	0	0	0	1	2	6	7	11	12	100 (12)
120	0	0	0	1	2	4	5	6	7	100 (6)

Figure 4. Probability Interpretation Categories (PIC) for the ≥ 64 Kt interval forecasts.

Five PICs were chosen for this tool: 1) very-low, 2) low, 3) moderate, 4) high, and 5) very-high. Initially only three PICs were used (low, moderate, high) to match the standard “stop light” status indicator used by the Air Force where green means good conditions, yellow means marginal, and red means bad. The number of categories was increased to five to match well know studies where most people can mentally handle 5 ± 2 categories at the same time (Zimmer, 1983) and also at the suggestion of the Launch Weather Officers. Black was chosen for the ‘Very High’ category to convey danger. This color is contrary to the common practice in meteorology of increasingly warm colors representing higher threat. Purple would also have been a good choice, following the common color scales in radar displays. However, black was chosen to facilitate interacting with non-meteorological decision makers with little meteorological expertise and the public. White was chosen for the ‘Very Low’ category as the opposite of black.

The categories were initially called risk categories, but it was quickly realized that many people interpreted ‘risk’ to include, the likelihood of the event occurring, the impacts of not taking action, and the costs of mitigation. However, this tool only addresses the likelihood of occurrence. The next term used was ‘likelihood of occurrence’ categories. However, a review of the tool (section-3.2) suggested that the term ‘probability’ should be included, but the authors were concerned that this might lead to confusion with the actual numerical probability forecasts. The term Probability Interpretation Category (PIC) was finally chosen as the best term for the tool. It includes the word ‘probability’, the ‘interpretation’ function is stated, and the fact that the result is a ‘category’, as opposed to a numeric probability, is also included.

Tables were developed to convert the probability forecast into the corresponding PIC for each of the three wind speed thresholds (≥ 34, ≥ 50, and ≥ 64 kt), each of the seven forecast intervals (12, 24, 36, 48, 72, 96, and 120 hours), and for both the interval and cumulative wind probability forecast products. The PICs in the table are color coded for easier use (Table-1).

Table-1

The Probability Interpretation Categories (PICs) for the tool to aid interpreting the National Hurricane Center wind probability forecasts and the color codes used in that interpretation tool.

No.	Probability Interpretation Category (PIC)	Color Code
1	Very Low	White
2	Low	Green
3	Moderate	Yellow
4	High	Red
5	Very High	Black

The probability thresholds for each PIC were calculated from three numbers from the performance evaluation for land-falling tropical cyclones (Splitt et al., 2009). An idealized model for assigning PIC thresholds was used (Figure-5). Most people interpret ‘Low’, ‘Moderate’, and ‘High’ as the lowest, middle, and highest one third of the possible range of values, respectively. Likewise, most people interpret ‘Very Low’ and ‘Very High’ as the lowest and highest tenth of the range of possible values, respectively.

The forecast probability that provided the best division between yes/no forecasts was arbitrarily defined to be the middle of the ‘moderate’ PIC. This was considered reasonable since probabilities below this value become increasing more likely to be ‘no’ forecasts i.e. ‘low’ or ‘very low’ PICs, and probabilities above this value become increasingly more likely to be ‘yes’ forecasts, i.e. ‘high’ or ‘very high’ PICs. Thus the optimal yes/no probability should be in the middle of the ‘moderate’ PIC. The process is best shown graphically as a schematic (Figure-6) and by an actual example (Figure-7).

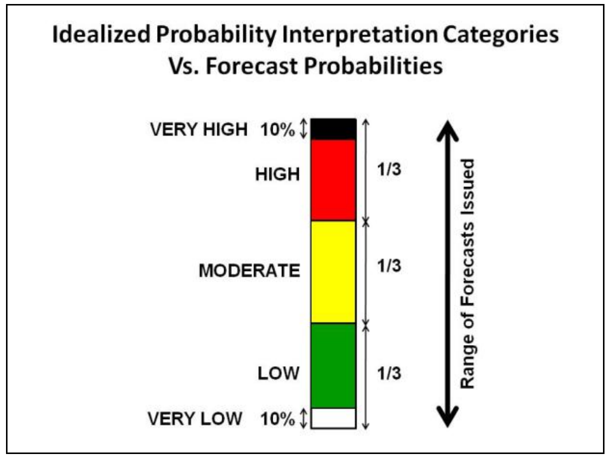

Figure-5. Idealized model to assign Probability Interpretation Categories (PIC). PICs are assigned based on percent ranges of several years of past forecasts. The percent ranges are based on human factors studies.

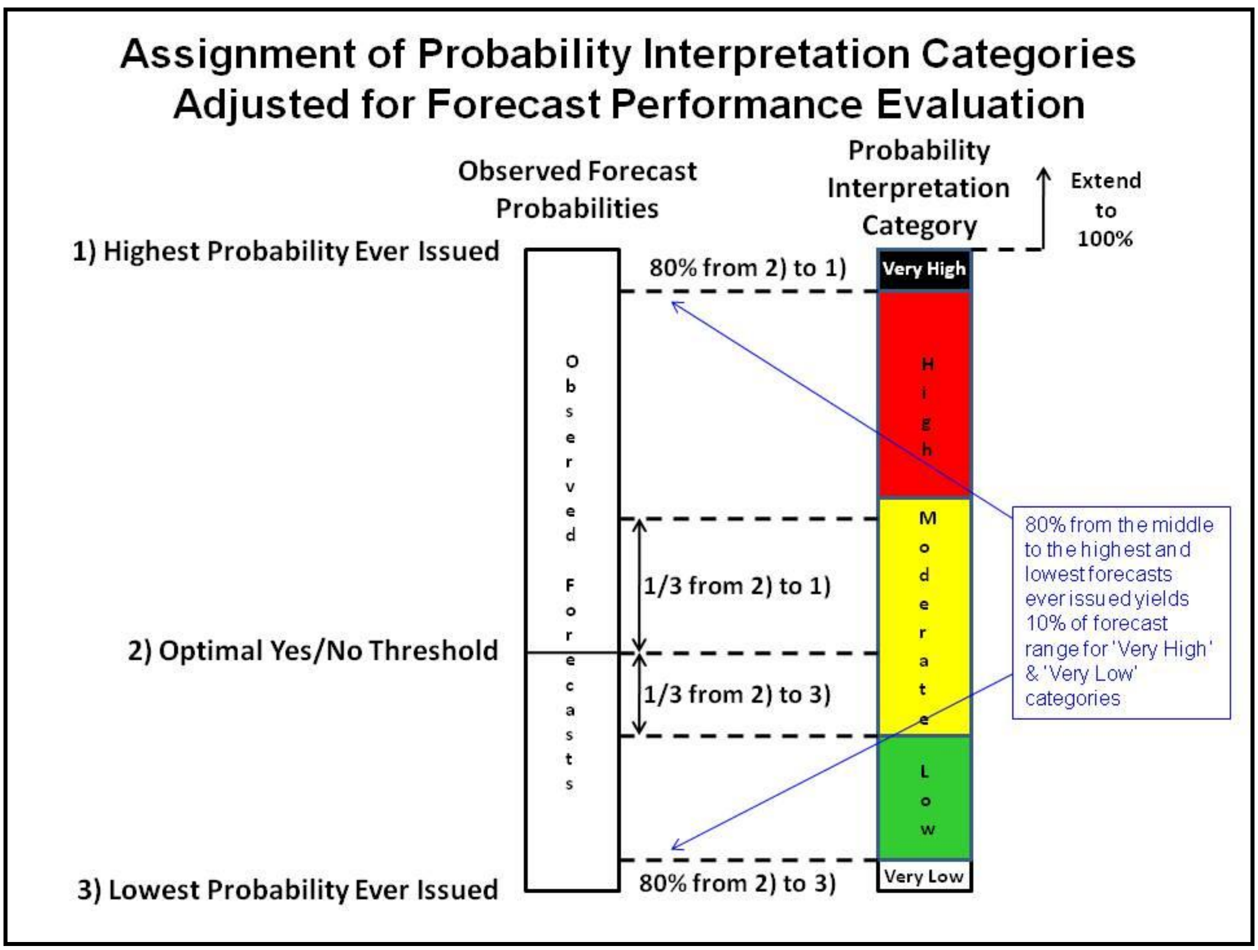

Figure-6. Process for assigning Probability Interpretation Categories using the performance evaluation of the NHC wind probability forecasts.

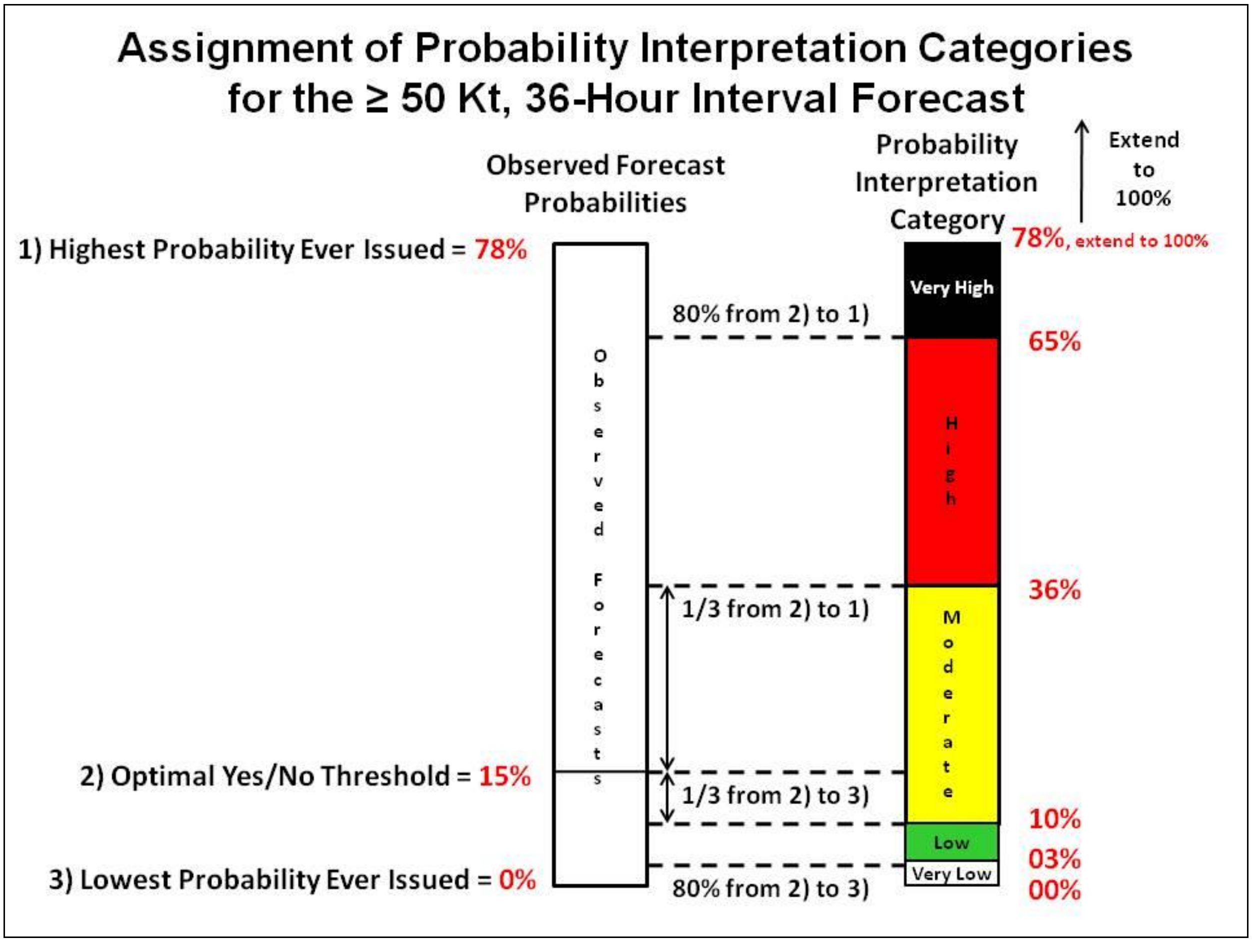

Figure-7. Example of how the Probability Interpretation Categories were assigned for the ≥ 50 Kt interval 36 Hour NHC wind probability forecasts.

PIC was arbitrarily defined to be one third of the way from the best skill probability to the lowest probability ever forecast, which was 0% for all categories. The threshold of the 'very low' PIC was arbitrarily defined to be 80% of the way from the best skill probability to the lowest probability ever forecast. This defines the 'very low' PIC to be the lower 10th percentile of the observed forecast distribution. The threshold of the 'high' PIC was arbitrarily defined to be one third of the way from the best skill probability to the highest probability ever forecast. The threshold of the 'very high' PIC was arbitrarily defined to be 80% of the way from the best skill probability to the highest probability ever forecast to make the 'very high' PIC include the upper 90th percentile of the observed forecast distribution. The 'very high' PIC was then extended to 100% to allow for all possible forecasts.

The 'very low' and 'very high' PIC thresholds were originally defined to be 90% of the way from the best skill probability to the lowest probability forecast and the highest probability ever forecast, i.e. including the lower 5th and upper 95th percentiles of the observed forecast distributions, respectively. However these thresholds were changed based on human factor studies uncovered in the review of the interpretation tool in section-3.2 where most people interpret 'very low' and 'very high' to be the lower and upper 10% of a distribution, respectively. Note that the PICs can be asymmetric, i.e. the range of probabilities in the 'low' and 'high', and 'very low' and 'very high' categories are not necessarily the same. Likewise, the best skill probability is not necessarily in the middle of the 'moderate' PIC.

The probability thresholds were developed for each of the five PICs, for each of the three wind speed thresholds, for each of the seven forecast intervals, for both the interval and the cumulative wind probability products. The tool for the ≥ 35 Kt, ≥ 50 Kt, and ≥ 64 Kt interval forecasts are in Figure-8. The tool for the ≥ 35 Kt, ≥ 50 Kt, and ≥ 64 Kt cumulative forecasts are in Figure-9. These figures include the new thresholds for the 'very low' and 'very high' PICs.

LIKELIHOOD OF OCCURRENCE VS. FORECAST PROBABILITY (%)
>= 34 Kt NHC WIND PROBABILITY INTERVAL FORECASTS
Based on verification of all land threatening tropical cyclones along U.S. East Coast and Gulf of Mexico (2004-2007)

Forecast Interval (Hr)	VERY LOW		LOW		MEDIUM		HIGH		VERY HIGH (highest forecast)	
12	0	6	7	22	23	57	58	87	88	100 (100)
24	0	4	5	16	17	50	51	84	85	100 (99)
36	0	5	6	18	19	50	51	80	81	100 (93)
48	0	4	5	16	17	45	46	73	74	100 (85)
72	0	4	5	16	17	33	34	45	46	100 (50)
96	0	3	4	11	12	25	26	36	37	100 (40)
120	0	1	2	6	7	14	15	19	20	100 (21)

a) Probability interpretation tool for the ≥ 34 Kt interval forecasts.

LIKELIHOOD OF OCCURRENCE VS. FORECAST PROBABILITY (%)
>= 50 Kt NHC WIND PROBABILITY INTERVAL FORECASTS
Based on verification of all land threatening tropical cyclones along U.S. East Coast and Gulf of Mexico (2004-2007)

Forecast Interval (Hr)	VERY LOW		LOW		MEDIUM		HIGH		VERY HIGH (highest forecast)	
12	0	5	6	18	19	53	54	86	87	100 (100)
24	0	4	5	16	17	48	49	80	81	100 (94)
36	0	2	3	9	10	36	37	65	66	100 (78)
48	0	2	3	8	9	29	30	50	51	100 (59)
72	0	2	3	8	9	19	20	26	27	100 (29)
96	0	0	1	4	5	12	13	19	20	100 (22)
120	0	0	1	2	3	7	8	9	10	100 (10)

b) Probability interpretation tool for the ≥ 50 Kt interval forecasts.

LIKELIHOOD OF OCCURRENCE VS. FORECAST PROBABILITY (%)
>= 64 Kt NHC WIND PROBABILITY INTERVAL FORECASTS
Based on verification of all land threatening tropical cyclones along U.S. East Coast and Gulf of Mexico (2004-2007)

Forecast Interval (Hr)	VERY LOW		LOW		MEDIUM		HIGH		VERY HIGH (highest forecast)	
12	0	3	4	12	13	46	47	84	85	100 (100)
24	0	4	5	16	17	45	46	73	74	100 (85)
36	0	3	4	14	15	33	34	49	50	100 (56)
48	0	1	2	7	8	20	21	32	33	100 (37)
72	0	0	1	3	4	10	11	16	17	100 (18)
96	0	0	1	1	2	6	7	10	11	100 (12)
120	0	0	1	1	2	4	5	5	6	100 (6)

c) Probability interpretation tool for the ≥ 64 Kt interval forecasts.

Figure-8. Probability Interpretation Tool for the ≥ 34 Kt, ≥ 50 Kt, and ≥ 64 Kt interval forecasts. These include the new thresholds for the 'very low' and 'very high' PICs.

LIKELIHOOD OF OCCURRENCE VS. FORECAST PROBABILITY (%)
>= 34 Kt NHC WIND PROBABILITY CUMULATIVE FORECASTS
Based on all land threatening tropical cyclones from Brownsville to Galveston, TX & Miami to Jacksonville, FL (2004-2007)

Forecast Interval (Hr)	VERY LOW		LOW		MEDIUM		HIGH		VERY HIGH	
12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
24	0	8	9	30	31	64	65	89	90	100
36	0	9	10	32	33	67	68	90	91	100
48	0	9	10	33	34	67	68	90	91	100
72	0	8	9	29	30	63	64	89	90	100
96	0	8	9	28	29	62	63	89	90	100
120	0	8	9	28	29	62	63	89	90	100

The highest probability forecast = 100% for all forecast intervals.

a) Probability interpretation tool for the ≥ 34 Kt cumulative forecasts.

LIKELIHOOD OF OCCURRENCE VS. FORECAST PROBABILITY (%)
>= 50 Kt NHC WIND PROBABILITY CUMULATIVE FORECASTS
Based on all land threatening tropical cyclones from Brownsville to Galveston, TX & Miami to Jacksonville, FL (2004-2007)

Forecast Interval (Hr)	VERY LOW		LOW		MEDIUM		HIGH		VERY HIGH	
12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
24	0	3	4	13	14	47	48	84	85	100
36	0	4	5	14	15	49	50	85	86	100
48	0	4	5	14	15	49	50	85	86	100
72	0	4	5	16	17	50	51	85	86	100
96	0	3	4	13	14	47	48	84	85	100
120	0	3	4	12	13	46	47	84	85	100

The highest probability forecast = 100% for all forecast intervals.

b) Probability interpretation tool for the ≥ 50 Kt cumulative forecasts.

LIKELIHOOD OF OCCURRENCE VS. FORECAST PROBABILITY (%)
>= 64 Kt NHC WIND PROBABILITY CUMULATIVE FORECASTS
Based on all land threatening tropical cyclones from Brownsville to Galveston, TX & Miami to Jacksonville, FL (2004-2007)

Forecast Interval (Hr)	VERY LOW		LOW		MEDIUM		HIGH		VERY HIGH	
12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
24	0	4	5	16	17	50	51	85	86	100
36	0	3	4	13	14	47	48	84	85	100
48	0	3	4	11	12	45	46	84	85	100
72	0	2	3	8	9	42	43	83	84	100
96	0	2	3	8	9	42	43	83	84	100
120	0	3	4	12	13	46	47	84	85	100

The highest probability forecast = 100% for all forecast intervals.

c) Probability interpretation tool for the ≥ 64 Kt cumulative forecasts.

Figure-9. Probability Interpretation Tool for the ≥ 34 Kt, ≥ 50 Kt, and ≥ 64 Kt cumulative forecasts. These include the new thresholds for the 'very low' and 'very high' PICs.

3.2 Evaluation Of The Interpretation Tool

Use of probability weather forecasts is difficult for decision makers and the general public (Joslyn et al., 2007). Therefore, a review of the interpretation tool was conducted to make it easy to use. This review included a literature review, review of common practices, and case studies of the interpretation tool on past tropical cyclones. The full report of this review is at Szpak (2009).

3.2.1 Literature Review

This literature review focused on three topics related to how users respond to probability forecasts: 1) subjective word interpretation, 2) word to numeric probability conversion, and 3) number of categories.

3.2.1.1 Subjective Word Interpretation

Researchers have noted the importance of using words to help people interpret probabilities (Renooij and Witteman, 1999; Druzdzel, 1996; Mosteller and Youtz, 1990). The public's interpretation of a probability forecast appears to be sensitive to the words used. Words that appear to be similar can have surprisingly different interpretations, e.g. low likelihood and slight chance. The interpretation also varies depending on the climatological frequency of the event being forecast (Pepper and Prytilack, 1974), e.g. a slight chance of rain in Seattle is interpreted differently than a slight chance of rain in the Sahara Desert. Even the same word can be interpreted differently by different people. One study found 16 categories that describe how people interpret hurricane risk information, e.g. job level, gender, type of residence, having been in a previous hurricane evacuation, etc. (Drabek, 2001).

3.2.1.2 Word To Numeric Probability Conversion

Extensive research in the field has been done showing that people consistently equate different words to different probabilities and that the interpretation from varies greatly person to person. A meta-study of 20 studies quantified the way people convert words to probabilities (Mosteller and Youtz, 1990). The nine phrases that best apply to the NHC wind probability forecast tool and the mean probability people associate with those phrases are listed in Table-1. The best terms for the five categories in the interpretation tool were chosen. The thresholds between the categories were selected by interpolating linearly between the mean probabilities associated with each category. The result was Table-2 that serves as a candidate to improve the interpretation tool.

Table-1.
Selected phrases and the mean probability people most often associate with them. The phrases selected are the nine that best apply to the NHC wind probability interpretation tool. From Mosteller and Youtz (1990).

PHRASE	ASSOCATIED PROBABILITY
Very High Probability	91%
Very Likely	85%
High Probability	81%
Likely	69%
Moderate Probability	52%
Low Probability	16%
Unlikely	16%
Very Unlikely	8%
Very Low Probability	6%

Table-2.
Recommended probability ranges for the probability categories that best match the NHC wind probability interpretation tool. Color coding matches the practice in the current interpretation tool. Adapted from Mosteller and Youtz (1990).

PHRASE	RECOMMENDED PROBABILITY RANGE
Very High Probability	86% - 100%
High Probability	66% - 85%
Moderate Probability	34% - 65%
Low Probability	11% - 35%
Very Low Probability	0% -10%

These results are very consistent with what the PIC development process (section-3.1) would have selected for unbiased well behaved forecasts that predict the full range of possible probabilities (0% to 100%). Under those conditions, the PIC process would give ranges of 0-10%, 11-33%, 34-66%, 67-89%, and 90-100% for the 'Very Low', 'Low', 'Moderate', 'High', and 'Very High' categories, respectively. These match the desired results in Table-2 very closely, with the largest difference being only 4%. This helped motivate the change of the PIC thresholds so that the 'Very Low' and 'Very High' PICs covered the 10th and 90th percentiles of the observed forecast range, respectively. The 5th and 95th percentiles had originally been used, respectively, but this review of the tool convinced the authors to change the selection process.

3.2.1.3 Number Of Categories

It is well known that most people can only process 5 ± 2 categories at one time in decision making (Zimmer, 1983). This suggests that forecasts will provide the maximum amount of information without overwhelming the decision makers (Beyth-Marom, 1982). The Deputy State Meteorologist for Florida Division of Emergency management indicated that more than five categories would be useful, but not to exceed seven categories (Godsey, 2009). The Warning Coordination Meteorologist at the National Weather Service Forecast Office Melbourne, FL stated that they found five categories worked much better than three in their 'Impact Graphics' program but was unsure if more would work better (Spratt, 2009). Their number of categories is actually six if you include 'No Threat' as a category. Although it would be easy to increase the number of categories in the interpretation tool, the authors believe it more prudent to use the middle of the range of categories that most people can assimilate in decision making, i.e. 5 explicit categories. The majority of people will have enough categories to be useful. Those capable of handling more information at once will be slightly underserved, but those who can't handle as many categories at the same time would be strongly hindered and the product's utility would be reduced. The current interpretation tool already has five categories. Although the PIC tool includes 0% and 100% within the highest and lowest categorizations, the tool can be interpreted as a gauge of the chance in between these two probabilities. Such an interpretation would, in the mind of the user, imply two more categories (no chance and certain) which would total 7. This reasoning, in addition to the above arguments, supports not to changing the number of categories in the current NHC wind probability interpretation tool.

3.2.1.4 Recommendations From Literature Review

The literature review produced the following recommendations.

- Keep five categories
- The names of the five categories are acceptable, e.g. Very Low, Low, etc.
- Change the name of the product from 'Likelihood Of Occurrence Categories' to 'Probability Interpretation Categories' *{already implemented}*

3.2.2 Common Practices

The probability interpretation procedures of three other organizations were reviewed to compare and contrast with the 45 WS's probability interpretation table. The three other organizations were: 1) the Storm Prediction Center, 2) National Weather Service Forecast Office in Melbourne, FL, and 3) Florida Division of Emergency Management.

3.2.2.1 Storm Prediction Center

The Storm Prediction Center converts probability forecasts to categories to aid interpretation of their Watch and Outlook products for severe weather. They chose to use three categories since they felt this would provide the most distinction for their users. The frequency of occurrence, or reliability, from 5 years of forecasts was analyzed. Conversions of frequency of occurrence to interpretation categories were developed by a small survey and consensus of the forecasters at Storm Prediction Center. The probability thresholds were rounded to the nearest 10% and used to build Table-3. The gaps in the probabilities in this table are by design to account for uncertainty in forecasts and to clearly differentiate between categories. The frequency of occurrence of probabilities for the watches and outlooks for various forecast intervals are then determined using Table-3. Note that the name of the 'low' category is changed to 'slight'. The resulting Day-1, Day-2, and Day-3 probability interpretation tables for the Storm Prediction Center are in Table-4, Table-5, and Table-6, respectively. The Storm Prediction Center also uses a color coding of red/yellow/ green for their high/moderate/low categories, which is identical to the stop-light color coding initially used in the 45WS interpretation tool, and then extended to five categories. Note that these tables suggest the Storm Prediction Center watches and outlooks have the same issue of decreasing probabilities at longer forecast intervals, similar to the NHC wind probability forecasts.

Table-3.
Probability interpretation categories vs. frequency of occurrence used by Storm Prediction Center.

PHRASE	FREQUENCY OF OCCURRENCE
High	0% - 20%
Moderate	30% - 60%
Low	70% - 100%

Table-4.
Day-1 Probability interpretation categories vs. frequency of occurrence used by Storm Prediction Center.

PROB-ABILITY	TORNADO	WIND	HAIL
2%	See Text	See Text	See Text
5%	Slight		
10%			
15%	Moderate	Slight	Slight
30%	High		
45%		Moderate	Moderate
60%		High	High

Table-5.
Day-2 Probability interpretation categories vs. frequency of occurrence used by Storm Prediction Center.

PROB-ABILITY	COMBINED TORNADO, WIND, HAIL
5%	See Text
15%	Slight
30%	
45%	Moderate
60%	High

Table-6.
Day-3 Probability interpretation categories vs. frequency of occurrence used by Storm Prediction Center.

PROB-ABILITY	COMBINED TORNADO, WIND, HAIL
5%	See Text
15%	Slight
30%	
45%	Moderate

3.2.2.2 National Weather Service Forecast Office, Melbourne, Florida

The National Weather Service Forecast Office in Melbourne, FL developed a method to convert the NHC wind probability forecasts to 'threat assessment' and an 'impact graphic' for displaying the threat assessments on a map. Their 'threat assessments' combine the likelihood of occurrence and the potential damage, while the 45 WS tool only deals with likelihood of occurrence. In addition, their approach includes subject input from the expert forecaster while the 45 WS tool is entirely objective. The map display does not apply to 45 WS since the winds from tropical cyclones change very little over the relatively small areas of CCAFS/KSC/PAFB as compared to the county warning area served by National Weather Service Melbourne. While the National Weather Service Melbourne approach forecasts a different parameter, the human factors in their approach can be compared to the 45 WS tool.

They used six levels of threat (Table-7). However, one of those 'threat assessment' levels is 'no threat', so their number of actual threat levels is five, which is the same as used in the 45 WS interpretation tool. Their names for their threat levels match those used by 45 WS except that they use 'extreme' for the highest level of threat, while the 45 WS uses 'very high'. Their term conveys more warning, but the 45 WS term provides symmetry with the 'very low' term in the lowest threat category. It is not clear if either term provides significant advantage over the other; although given the literature, we hypothesize that "extreme" would be interpreted as representing a smaller range of probability. They also used a different color scale that mimics the color code for radar reflectivity; cooler/warmer colors correspond to lower/higher threat. This works well for meteorologists.

Table-7.
The 'threat assessment' categories and associated color code used in the 'Tropical Cyclone Impact Graphics' product developed by the National Weather Service Forecast Office in Melbourne, FL.

NO.	THREAT ASSESSMENT LEVEL
0	No Threat
1	Very Low
2	Low
3	Moderate
4	High
5	Extreme

Although this is a similar approach as that of the Storm Prediction Center, the authors believe the color code used by the 45 WS generally provides better application for non-meteorologists, i.e. the decision makers that are the customers of the tool. Although the NWS forecast office in Melbourne uses gray for their "No Threat" categorization, the authors believe this color - being a shade of black - would be confusing if used in the PIC tool for the 'Very Low' PIC, if the 'Very High' PIC remains black. The choice of gray for 'Very Low' should be considered only if the 'Very High' PIC is changed to purple.

3.2.2.3 Florida Division Of Emergency Management

The Florida Division of Emergency Management uses a daily 'threat bar' to convey the level of threat to their workers and the public for certain weather such as lightning, flooding, damaging winds, and rip tides. This threat bar uses four categories of threat (Table-8) (Fuller, 2010). The assignment of threats does not use numerical probabilities and appears to be entirely subjective. Their threat categories do not have a middle range, unlike the other methods examined in this paper. Also, their 'moderate' category is in the upper half of the distribution, while in the 45 WS tool 'moderate' straddles the middle of the distribution. The authors prefer the 45 WS use of 'moderate' given that a 49% probability represents a significant level of threat, being on the verge being a 'yes' forecast, but would be a 'low' threat in the Florida Division of Emergency Management method. Additionally, as the PIC tool is geared towards non-meteorological decision makers and public understanding, literature shows that values around 50% are generally considered "moderate," while "low" more often translates to a range between 10-35% (Mosteller and Youtz, 1990).

Table-8.

The 'threat' categories and associated color code used for weather threats in the daily 'threat bar' used by the Florida Division of Emergency Management. A 3-category (low, moderate, high) 3-color scale (green, yellow, red) is used for critical sector threats.

NO.	THREAT CATEGORY
0	No Threat
1	Low
2	Moderate
3	High

3.2.2.4 Recommendations From Common Practices

No firm recommendations were found in the practices of other organizations. However, 45 WS should consider if the term 'extreme' for the highest risk category, or if the color gray for the lowest risk category, offers advantages over the 45 WS use of 'very high' and 'white', respectively. The term and color may be slightly better, but the 45 WS terms provides symmetry within its interpretation tool. As mentioned in 3.2.2.2, we are feel these changes would be less constructive for the 45 WS PIC tool, however, further research would allow a more thorough conclusion.

There appears to be no standard method in meteorology for converting probability to the number, term, or color code. This may be an opportunity for the meteorology community to improve its practices in collaboration with the various human factors research disciplines.

3.2.3 Case Studies

The performance of the 45 WS interpretation tool for the NHC wind probability forecast was evaluated on seven real-world land-falling tropical cyclones. Also, two other simple interpretation tools were created to use as baselines against which to compare the 45 WS tool. Note that this evaluation was done on the original version of the PIC tool that used the lower 5th and upper 95th percentiles of the observed forecast distributions for the 'very low' and 'very high' categories, respectively. These thresholds were subsequently adjusted to the 10th and 90th percentiles, as discussed in section-3.2.1.2, so the results of these case studies no longer strictly apply to the new version of the interpolation tool.

3.2.3.1 Case Study Methodology

The reliability of the NHC wind probability product forecasts for 23 tropical cyclones was analyzed to form the basis for two alternative probability interpretation threshold schemes. This process was similar to that done by the Storm Prediction Center discussed in section-3.2.2.1. In this context, reliability is used in the statistical sense, measuring how often the event occurs versus the forecast probability, e.g. when X% is forecast, the frequency of occurrence should be X%. The 23 tropical cyclones used in the reliability analysis are listed in Table-9. One of the alternate interpretation tools used a linear fit through the plot of reliability vs. product probability for the 23 tropical cyclones and determined the corresponding probability thresholds based off of reliability values correlating to the ideal probabilities outlined by Mosteller and Youtz (1990). The other alternate interpretation tool used subjectively assigned interpretation categories based on the reliability analysis. The 45 WS interpretation tool and the two alternative tools were evaluated on seven land-falling tropical cyclones (Table-10). Full details on the case studies are available at Szpak (2009).

Table-9.
The 23 tropical cyclones used to analyze the reliability of the NHC wind probability forecasts and create two alternative interpretation models to compare against the 45 WS interpretation tool.

NAME	YEAR	NAME	YEAR
Alberto	2006	Ernesto	2006
Alex	2004	Frances	2004
Andrea	2007	Franklin	2005
Arlene	2005	Gaston	2004
Barry	2007	Ivan	2004
Bonnie	2004	Jeanne	2004
Charley	2004	Katrina	2005
Chris	2006	Noel	2007
Cindy	2005	Ophelia	2005
Dean	2007	Rita	2005
Dennis	2005	Wilma	2005
Emily	2005		

Table-10.
The seven tropical cyclones used evaluate the 45 WS interpretation tool and the two alternatives.

NAME	YEAR	NAME	YEAR
Charley	2004	Jeanne	2005
Ernesto	2007	Ophelia	2005
Frances	2005	Wilma	2005
Ivan	2005		

3.2.3.2 Case Studies Results

The 45 WS tool performed well overall, but tended to over forecast slightly. For this reason, we say the tool was accurate but less precise. The subjective alternative tool also performed well with an overall performance score comparable to the score of the 45 WS tool. On closer inspection, its performance was not as accurate, but when it erred, it's errors were smaller than the 45 WS tool, deeming it more precise. The linear interpretation tool did not perform as well in accuracy as either the 45 WS tool or the subjective alternative tool. Similar to the subjective alternative tool, however, the linear interpretation tool performed more precisely on events where the 45 WS tool erred.

3.2.3.3 Case Studies Recommendations

The 45 WS performed well on seven land-falling tropical cyclones (Table-10). However, it tended to over-forecast slightly and when it erred, it had large errors. This suggests that retuning the probability to PIC conversions could provide better performance. Since the subjective alternative model preformed almost as well overall but when it erred its error were smaller than the 45 WS tool, blending the two PIC conversion thresholds is one likely approach. Note that the thresholds for the 'very low' and 'very high' PICs were changed after these case studies to be based on the lower and upper 10th percentiles, respectively. This may have reduced this problem already.

3.3 Future Work

3.3.1 Implement Results Of Review

The recommendations of the review of the current interpretation tool should be considered for implementation. Two recommendations have already been incorporated. First, the name of the product was changed to 'Probability Interpretation Category'. Second, the thresholds for the 'very low' and 'very high' PICs were changed to include the lower 10th and upper 90th percentiles of the observed forecast distribution, respectively, as inferred from Mosteller and Youtz (1990) in section-3.2.1.2. The lower 5th and upper 95th percentiles had originally been used.

The current 45 WS tool performed well overall, but tended to over-forecast and when it makes errors, those errors tend to be large. The probability thresholds should be tuned to reduce those large errors. One approach is to blend the current thresholds with those from the subjective alternate tool developed in section-3.2.3.1. Note that the thresholds for the 'very low' and 'very high' categories were changed since this performance evaluation, which may have reduced this problem.

The alternate color-code of gray for the 'very low' and purple for 'very high' categories should be considered. However, since the intended users are non-meteorological decision makers, the 45 WS believes the current color codes of white and black for the 'very low' and 'very high' PICs is appropriate. Note that gray should not be used for the 'very low' category if black is kept for the 'very high' category.

Finally, the review recommended the use of six to seven PICs, rather than the current five categories. However, the 45 WS decide to keep the current number of categories for the reasons discussed in section-3.2.1.3.

3.3.2 Proposed New Interpretation Tool

An entirely new approach to developing an interpretation tool for the NHC wind probability forecast is being considered. The current interpretation tool for the NHC wind probability forecasts is based on several reasonable but arbitrary definitions. In addition, the interpretation tool has its own shortfall in that the same probability is interpreted differently at different forecast intervals. Since the forecasts perform well, all a user should need is the probability forecast and a measure of its certainty, i.e. an interpretation tool should not be needed.

Upon further reflection, the cause of the decreasing operational importance of the probabilities at longer forecast intervals is simply due to the accumulation of forecast errors over time. As the location, intensity, and size of a tropical cyclone becomes more uncertain at larger forecast intervals, the wind field and its associated probabilistic distribution becomes dispersed over ever larger area, resulting in generally lower probabilities. It is analogous to the Gaussian probability density function where distributions with larger variance have lower peak values.

This suggests a better interpretation tool would be based on comparing the probability at a point of interest to the largest probability for the same forecast interval. The simplest approach would use the ratio of the forecast at a point to the maximum probability in that forecast. Consider the example where the shortfall of the NHC wind probability forecasts was introduced at the end of section-2. In a ≥ 64 Kt forecast, the 12-hour forecast is 6% representing a low risk, while that same 6% in the 120-hour forecast represents a high risk. Under the new proposed interpretation tool, the point of interest in the 6% 12-hour forecast would be near the edge of the wind forecast field. The maximum probability in that forecast might be 60%, near the center of the wind field. In this case, the ratio of the forecast at the point of interest to the maximum forecast is 0.10. However, the 6% forecast at 120-hours would be near the centerline of the wind field and the maximum forecast might be 8%. In this case, the ratio of the forecast at the point of interest to the maximum forecast is 0.75, much higher than the first ratio. Therefore, two sets of numbers are required to interpret the wind probability forecast properly. The probability itself gives the absolute likelihood that the event will occur and the ratio indicates the relative likelihood as compared to the wind field as a whole. For example, in the scenario just discussed, the 6% in the 120-Hour forecast is a low probability, but your point of interest is near the centerline and at relatively large risk for this particular forecast.

This two-metric approach has the potential to improve the interpretation of the NHC wind probability forecasts significantly. In the above example, one can envision decision makers using the two numbers in emergency management, i.e. the probability is low at the moment, but we are near the most likely track of the tropical cyclone. Let’s do the easy inexpensive preparations now, like alerting the public to the possibility, to work ahead of the normal plan and start preparing the harder more expensive actions in the case the tropical cyclone stays on the same track. This two metric approach overcomes the shortfall of the current interpretation tool mentioned earlier in this section. This new proposed interpretation tool will be developed and verified as the seniors thesis by one of the authors (Szpak) and should be completed by Spring 2011. This two-metric tool might appear as in Figure-10.

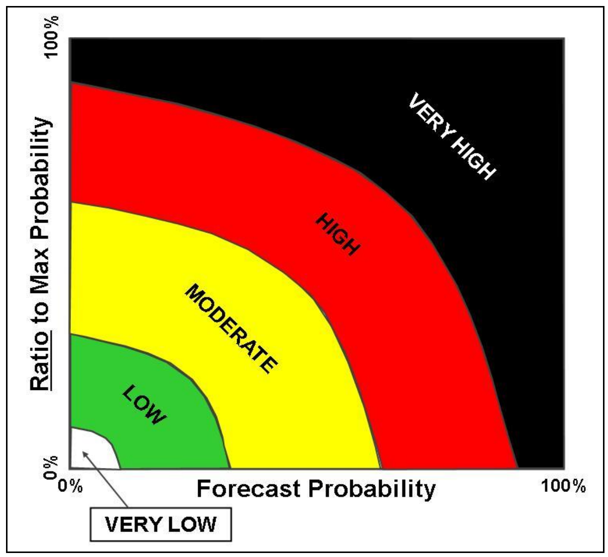

Figure-10. One possible form of the proposed new two-metric interpretation tool for the NHC wind speed probability product.

3.3.3 Customers Reviews

A review of the interpretation tool should be conducted. This would include 45 WS Launch Weather Officers and other operational staff and 45 WS customers responsible for decisions driven by approaching tropical cyclones, e.g. rolling space launch vehicles back from the launch pads, protective actions for the various facilities, and evacuation of CCAFS, KSC, and PAFB. In addition, reviews from experimental use by NHC, NWS Forecast Offices, and emergency managers would also be useful. Anecdotal feedback from the real world use by the 45 WS Launch Weather Officers indicates that the interpretation tool is performing as expected, which suggests it may be appropriate for use by decision makers without meteorological or statistical expertise.

3.3.4 Improved Performance Evaluation Of NHC Wind Probability Forecasts

One of the crucial components of the current interpretation tool is the performance evaluation of the NHC wind probability forecasts. The performance evaluation used was by Splitt et al. (2010). An extended and improved performance evaluation of the NHC wind probability forecasts is in progress at the Florida Institute of Technology and should be finished early in 2011. This new study could help refine the current interpretation tool if the new proposed tool discussed in section-3.3.1 does not prove viable. This new performance evaluation is co-funded by the 45th Weather Squadron and the Kennedy Space Center.

3.3.5 Improved NHC Wind Probability Forecasts

The interpretation tool would likely be improved by improvements in the NHC tropical cyclone forecasts themselves. A study of the error characteristics of the NHC tropical cyclone forecasts and possible ways to improve the NHC forecasts is finishing at the Naval Postgraduate School in early 2011, part of which is already available at Neese (2010). This research is funded by the 45th Operations Group.

4. Summary

The NHC tropical cyclone wind speed probability forecast product performs well. However, there is a difficulty in interpreting the product since the operationally important probabilities decrease considerably with forecast interval. For example, for a $\geq$ 64Kt forecast, a 12% probability in the 12-hour forecast represents a low risk of occurrence with the tropical cyclone missing the point of interest, while that same 12% in the 120-hour forecast still represents a low risk of occurrence but with the distant tropical cyclone predicted to come very near the point of interest. An interpretation tool was developed to convert the NHC tropical cyclone wind speed probability forecasts into plain language Probability Interpretation Categories (PICs) that have a consistent interpretation at all forecast intervals.

This tool was reviewed resulting in the five decisions to improve the tool as listed in Table-11.

The core of this interpretation tool is the observed performance of the NHC wind probability forecasts. A new verification of these forecasts will finish in early 2011 and will be used to refine the tool. In addition, a new approach to the tool will be investigated during the Spring of 2011. Users interested in applying the PIC tables are urged to contact the author for these updates.

Table-11.

Decisions resulting from the review of the probability interpretation tool for the NHC wind probability forecast products.

NO.	DECISION	STATUS
1	Change the name of the product to ‘Probability Interpretation Category’, rather than ‘Likelihood Of Occurrence Category’ or ‘Risk Categories’.	Implemented
2	Change the ‘very low’ and ‘very high’ PICs to use the lower 10th and upper 90th percentiles of the observed forecast distribution.	Implemented
3	Keep the number of PICs at five.	No Action Required
4	Keep the current names of the five PICs (“very low’, ‘low’, ‘moderate’, ‘high’, and ‘very high’).	No Action Required
5	Keep the current color code of the five PICs (white, green, yellow, red, black).	No Action Required

5. Acknowledgements

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