4A.3 HURRICANE FORCE EXTRATROPICAL CYCLONES

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1. INTRODUCTION

The NOAA Ocean Prediction Center (OPC) is responsible for issuing wind warnings for the western North Atlantic and central and eastern North Pacific Oceans. Wind warnings are based on existing and anticipated wind speeds and are used by mariners for storm avoidance and to aid in making safe passage. Wind warning categories are: GALE (17.2 to 24.4 ms^{-1}), STORM (24.5 to 32.6 ms^{-1}), and HURRICANE FORCE (32.7 ms^{-1} or higher). Prior to the launch of the NASA QuikSCAT satellite (Atlas et al, 2001), marine forecasters typically made assumptions on the wind speed distribution within an extratropical cyclone based solely on the coarse network of ship and buoy observations, the satellite representation, and numerical model analyses and short-term forecasts. Using QuikSCAT derived ocean vector winds, forecasters at the OPC routinely observe the near surface wind field within extratropical cyclones.

QuikSCAT's large 1800 km wide swath and frequency allows forecasters to see snapshots of the wind field of entire storm systems two times per day. QuikSCAT has a large retrievable wind speed range from near 0 ms^{-1} to Hurricane Force conditions (in excess of 32.6 ms^{-1}) (Von Ahn et al., 2004). It is no surprise that scatterometer derived winds from QuikSCAT are heavily used by OPC forecasters.

QuikSCAT winds have given OPC forecasters, for the first time, the ability to consistently differentiate between common Storm Force and extreme Hurricane Force cyclones. This paper investigates Hurricane Force (HF) cyclone activity over four winter seasons (October through April) over the North Atlantic and North Pacific for the years 2001 through 2005. The methodology is described in section 2, results are given in section 3, a discussion follows in section 4.

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2. METHODOLOGY

Four times per day OPC forecasters produce surface pressure and frontal analyses for both the North Pacific and North Atlantic Oceans. These analyses are distributed to ships at sea by a variety of communication methods. As part of the analysis process, OPC forecasters label each low-pressure system with the appropriate wind warning category. Forecasters use conventional observations and remotely sensed winds such as QuikSCAT to determine the wind warning category. For the purposes of this study an HF cyclone was defined as any cyclone that reached HF intensity for a minimum of one synoptic period (6 hours) during its lifecycle. The location, central pressure, and warning category for the life cycle of each HF cyclone was catalogued for the period October through May 2001 to 2005. The domain of interest was the North Pacific and North Atlantic Oceans from 30°N to 67°N. A variety of statistics regarding the frequency and behavior of HF cyclones were derived from the catalog and will be discussed in section 3.

3. RESULTS

For the first three years of the study, between 15 and 23 HF cyclones were observed over each ocean basin as shown in Table 1.

	Atlantic	**Pacific**
2001-2002	22	15
2002-2003	23	22
2003-2004	15	22
2004-2005	37	33

Table 1. The number of HF cyclones observed in each ocean basin from October through May for the years listed.

During the most recent season the number of observed HF cyclones increased to 37 in the Atlantic and 33 in the Pacific. It is assumed that this increase was due to the OPC forecasters relying on the higher resolution 12.5 km QuikSCAT winds rather than the standard 25 km winds. There is less horizontal averaging between wind vector cells with the 12.5 km QuikSCAT thus a higher frequency of observed HF conditions. To put these numbers in perspective, during the very active 2001 and 2004 Atlantic hurricane seasons, nine Atlantic tropical cyclones reached hurricane strength.

The monthly frequency of occurrence of HF cyclones for each ocean basin is plotted in Figure 1. HF cyclones were observed to be most frequent from October through March. Although several late season cyclones produced HF conditions this past May in the North Pacific. Only one North Atlantic HF cyclone was observed in the month of April and none in May. Maximum activity was found to occur over the North Pacific in December and in January over the North Atlantic for each of the four years of study.

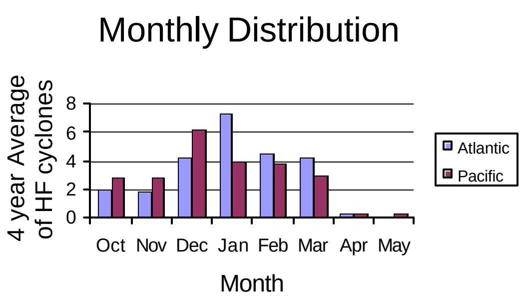

Figure 1. Bar graph showing the monthly average frequency of HF cyclones for each ocean basin.

The average life cycle for these extreme storms is 5 days. However, HF conditions are relatively short lived lasting on average 24 hours less. The relatively short duration of extreme conditions adds to the difficulty in forecasting the timing of HF events. HF cyclones do tend to be meteorological bombs having maximum deepening rates of one Bergeron or more as defined by Sanders and Gyakum 1980.

Figure 2 shows the distribution of central pressure of the parent low when observed to be producing HF conditions. Both oceans show a maximum occurrence of HF conditions when the parent cyclone has a central pressure of 970 hPa. The spread of the observed central pressures is more limited in the North Pacific than the Atlantic. Although the frequency is minimal, the Atlantic is able to produce both deeper and weaker extreme cyclones than the Pacific. Basically 3 percent of the Atlantic cyclones were observed to be 940 hPa or less whereas no Pacific cyclones were observed that deep. Nine percent of the Atlantic cyclones were observed to be 985 hPa or higher. For the same range of central pressure only two percent of the Pacific cyclones had central pressures so high. The deeper minimal central pressures observed in the Atlantic is most likely due to the higher low-level baroclinicity as compared to the Pacific (Sanders and Gyakum, 1980). The ability for the Atlantic basin to support HF conditions with weaker central pressures is likely due to the topographic effects of Greenland and the generation of boundary jets such as the Greenland tip jet.

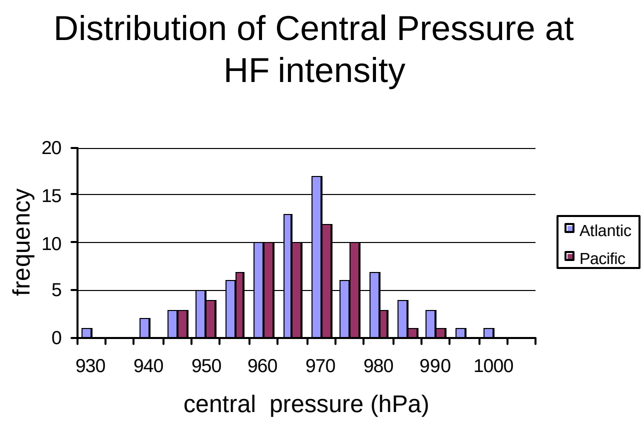

Figure 2. Frequency distribution of central pressure for low pressure systems that had winds of HF intensity. Pacific values are in maroon and Atlantic in blue.

It was found that HF conditions develop on average between 18 to 6 hours prior to the cyclone reaching the minimum central pressure. Therefore HF conditions can be associated with mature cyclones.

The geographic distribution of HF cyclones was also investigated. Figures 3 and 4 show the longitudinal frequency of extratropical cyclones while at HF intensity. The Atlantic shows the highest frequency between 35° and 45°West longitude. Many of these mature cyclones developed in the baroclinic waters of the Gulf Stream region and moved into the open North Atlantic. The North Pacific (Fig. 4) shows a bimodal longitudinal distribution with peak occurrence in the western basin between 155° East and 180°. A secondary maximum can be seen between 145° West and 160° West longitude. The meteorological bomb work by Sanders and Gyakum 1980 and followed by Roebber 1984 showed a secondary maximum of bomb activity over the eastern Pacific. Roebber 1984 surmised that this secondary maximum was associated with enhanced baroclinicity in association with artic outbreaks across the Bering Sea and into the North Pacific.

Composites of maximum wind speed were created to investigate whether HF conditions occur in preferred areas of cyclones (Figure 5). Eleven QuikSCAT passes contributed to the North Atlantic composite (Figure 5a) and 32 QuikSCAT passes for the North Pacific composite (Figure 5b). Only open ocean cyclones were chosen for compositing in order to minimize any orographic influences to the wind field. The one degree latitude and longitude spacing shown is only for a reference of scale. The location of the composite cyclone center was chosen arbitrarily. Red shading shows areas of maximum winds of Hurricane Force. The composites are fairly similar in that hurricane force conditions were most frequently observed over the south semicircle of the low within approximately 600 km of the center. Browning 2004 observed extreme winds in this vicinity of Great Storm of October 1987. It was suggested by Browning 2004 that cyclones producing extreme winds are distinguishable in satellite imagery by a pronounced cloud head with a hooked tip near the tail end of the bent back front. The authors agree that HF cyclones have the pronounced cloud signature of a mature cyclone with a well-wrapped cloud head, extending south of the low center. The areas of HF winds shown in these composites here are larger than that described by Browning but exist in a similar location to the parent low and associated fronts. HF winds were observed in the cold air on the cold side of the bent back front.

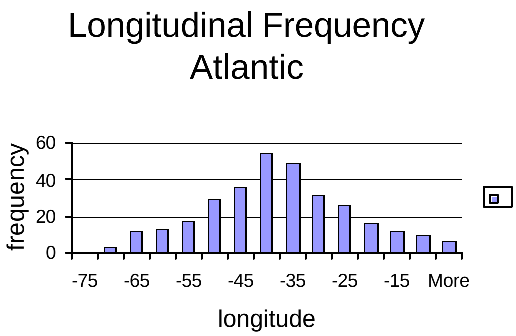

Figure 3. Longitudinal distribution of HF low pressure systems for the North Atlantic.

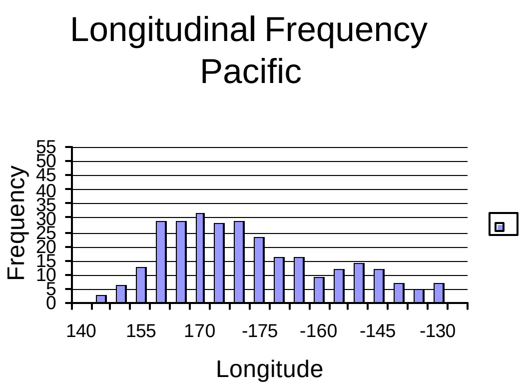

Figure 4. Same as Fig. 3. except for the North Pacific.

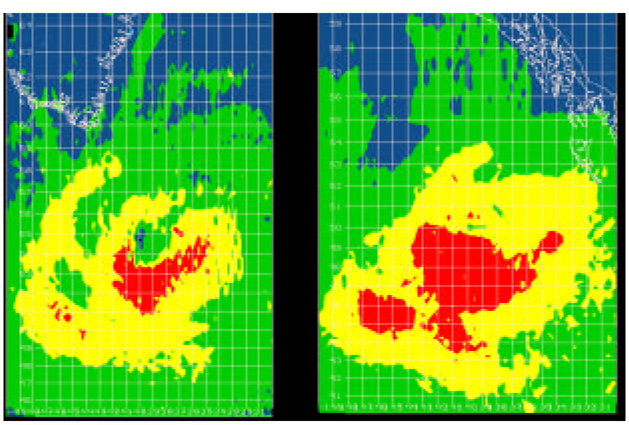

Figure 5. QuikSCAT derived composites of maximum winds for 11 Atlantic HF cyclones (left panel, a) and 32 Pacific cyclones (right panel, b). The composite cyclone center is in the middle of each panel. Red areas show winds of Hurricane Force, yellow Storm Force and green Gale Force. .

3. FORECAST SKILL

The Ocean Prediction Center issues graphical 48 and 96-hour forecasts of sea-level pressure, fronts, cyclone intensity, and wind warning category. The percent correct of day 2 and day 4 warning categories are shown in Figure 6.

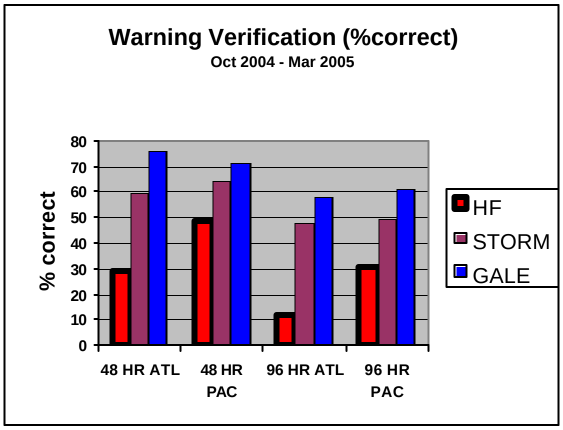

Figure 6. Bar graph showing the wind warning verification (percent correct) for OPC 48 and 96 hour graphical forecasts. Warning verification for HF conditions are in red, Storm in purple, and Gale in blue.

Forecast warning categories were simply compared against warnings listed on OPC surface analyses. This is the third winter season in which the OPC has verified warning categories. Over the previous two winter seasons the OPC showed limited skill predicting HF conditions at both the 48 and 96 hour forecast hours over the North Pacific. Significantly more skill was evident over the North Atlantic. Interestingly, results from this past winter season shown in Figure 6, indicate that the OPC had higher skill in forecasting HF conditions over the North Pacific than North Atlantic. This may be an artifact of the overall predictability for the winter season and requires further investigation. Thirty percent of observed HF conditions over the North Atlantic at 48 hours were forecast. Alarmingly, only 12 percent observed HF conditions were forecast 96 hours in advance. For the Pacific nearly 50 percent of HF events were forecast 48 hours in advance with over 30 percent forecast 96 hours prior to the event. Figure 6 does show increased skill for the weaker wind warning categories.

4. DISCUSSION

One question not addressed so far in this paper is the validity of Hurricane Force QuikSCAT winds. For this study we primarily relied on the forecasters determination as to whether a cyclone reached HF intensity. Forecaster decisions were based on all available observations, including QuikSCAT, satellite representation, and numerical model analyses and short-term forecasts. The validity of extreme winds inferred by QuikSCAT remains a significant science question. Members of the Ocean Vector Winds Science Team recently met at the NASA Jet Propulsion Laboratory to discuss the capabilities of a variety of wind detection instruments. It was determined that the current wind retrieval algorithm for QuikSCAT is likely too low at wind speeds of approximately 30 ms^{-1} and higher in non-raining conditions. If indeed QuikSCAT underestimates winds of 30 ms^{-1} and higher then the findings presented here are conservative. OPC forecasters have gained a familiarity with QuikSCAT capabilities over the past 5 years. From our experience, it does appear that QuikSCAT is able to consistently observe extreme Hurricane Force conditions in extratropical cyclones.

The ability of the 12.5 km resolution QuikSCAT winds to infer higher winds than the standard 25 km winds poses a challenge to operational forecasters. In the first year of availability, the 12.5 km winds observed nearly twice as many HF cyclones as each of the three previous years using only the 25 km resolution winds. There are plans by NASA to process the entire QuikSCAT data set at the higher resolution with an improved algorithm for higher winds. A second look at HF conditions will need to be done when the improved data set becomes available.

The following is a brief summary of what we have learned. HF cyclones are indeed explosive deepening cyclones with nearly all having maximum deepening rates greater than one Bergeron (Sanders and Gyakum 1980). HF cyclones, like meteorological bombs, are a winter phenomena with peak activity in the Pacific in December and January for the North Atlantic. Although we did observe HF conditions in April in one North Atlantic cyclone and two in May in the North Pacific.

HF conditions appear to occur in the mature cyclone with the onset approximately 6 to 18 hours prior to the lowest central pressure. HF conditions do not last long, typically less than 24 hours. This short duration adds to the difficulty in forecast such events. Strong extratropical cyclones have a life span of about 5 days. Hurricane force winds occur at a larger range of central pressure in the North Atlantic as compared to the North Pacific. It appears that the North Atlantic can produce deeper cyclones than the Pacific and is most likely due to the enhanced low-level baroclinicity of the

Gulf Stream region. HF winds were observed in weaker cyclones in the Atlantic and are most likely due to topographic interactions near the Greenland Coast.

Composites of maximum winds for a number of Atlantic and Pacific HF cyclones revealed that HF conditions occur to the south of and within approximately 600 km of the cyclone center. This region is behind the cold front well within the cold air and to the south of the bent back or occluded front. This region in extratropical cyclones has a deep well mixed boundary layer with limited directional vertical wind shear.

The western to central portions of both basins are the preferred areas of frequency. These areas are downstream of the strongly baroclinic waters and boundary layer of the Kuroshio and Gulf Stream regions. The Pacific shows a second area of frequent occurrence east of 160° West longitude.

The forecast verification statistics presented here illustrate how difficult it is to accurately forecast these extreme events at both the day 2 and 4 forecast times. However, it is critical to mariners at sea to have as much advanced warning as possible to avoid hazardous conditions. Rarely were intense HF cyclones not forecast at either 48 or 96 hours forecast periods by OPC forecasters or numerical guidance. Both central pressure and warning errors suggest there is a strong tendency to under forecast these events.

5. ***References***

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