P2.11 HURRICANE FORCE EXTRATROPICAL CYCLONES AS OBSERVED BY THE QUIKSCAT SCATTEROMETER

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1. INTRODUCTION

The primary responsibility of The Ocean Prediction Center (OPC) of the National Centers for Environmental Prediction (NCEP) is the issuance of marine wind warnings and forecasts for maritime users in order to foster the protection of life and property, safety at sea, and the enhancement of economic opportunity. The warnings discussed in this study refer to the short-term marine wind warnings that are placed as labels on the North Atlantic and North Pacific Surface Analyses produced by OPC four times per day. The warnings are based on wind speed as listed in Table 1.

Warning	Wind speed criteria
Gale	17.5 to 24.2 m s^{-1}
Storm	24.7 to 32.4 m s^{-1}
Hurricane Force	32.9 m s^{-1} or greater

Table 1. Marine wind warning categories and associated wind speeds.

Until recently, the primary sources of surface wind observations over the oceans have been ship reports through the Volunteer Observing Ship (VOS) program, data buoys and the Special Sensor Microwave Imager (SSM/I). Since ships tend to avoid areas of inclement weather and the current network of data buoys is nowhere near optimal density there has been quite a substantial data void over the open ocean. To fill this void, many attempts have been made to measure surface wind speed and direction using remote sensing instruments flown onboard satellites. While SSM/I derived surface winds provide increased spatial coverage they are of limited value. In precipitation or significant water cloud, the algorithm is unable to report a wind speed. The accuracy of ±2 m s^{-1} for the wind speed data can only be guaranteed in the 2-25 m s^{-1} range. Wind speeds above this value are not reliable (Atlas et al., 1996). Therefore, SSM/I cannot distinguish between gale and storm force winds (Atlas et al, 2001). Since Storm warnings are issued for winds from 24.7 – 32.4 m s^{-1} and Hurricane Force warnings are issued for wind speed greater than 32.9 m s^{-1} the SSM/I wind observations are of limited value to OPC forecasters.

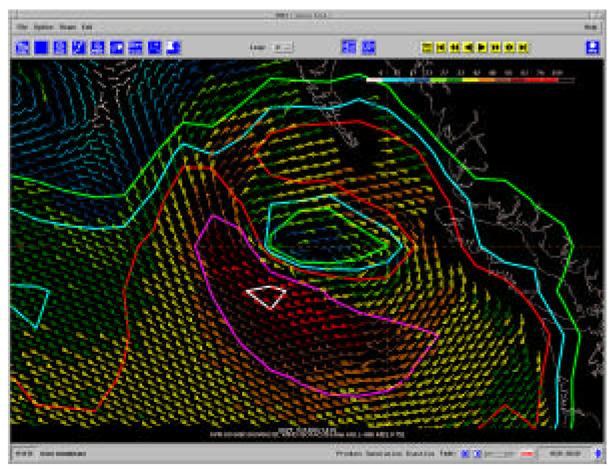

Figure 1. Hurricane Force extratropical cyclone from 8 Oct 2003. The red wind barbs denote Hurricane Force winds. Contours are 40 m isotachs from the NCEP GFS model.

Scatterometer derived winds from the QuikSCAT satellite were incorporated into the National Oceanic and Atmospheric Administration's (NOAA) operational global weather analysis and forecast systems model (GFS) in July 2001. Since October 2001 OPC forecasters have had near real time access to this data right at their operational computer workstations. Although QuikSCAT can measure wind speeds up to 30

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m s^{-1} (near hurricance force) with an accuracy of ±2 m s^{-1} (Shirtliffe, 1999), OPC forecasters routinely observe QuikSCAT winds in excess of 32.9 m s^{-1} as shown in Figure 1.

Hurricane Force extratropical cyclones are an enormous threat to safety at sea. Dangerous winds and waves associated with these extreme cyclones can cover vast ocean areas. A ship encountering a storm of this magnitude is subject to extremely hazardous conditions and can result in loss of life, loss of the vessel or cargo loss. Because of the lack of surface observations over the oceans, forecasters have not been able to identify these storms with consistency. Studies traditionally have related storm intensity to sea level pressure and sea level pressure change such as Sanders & Gyakum (1980). Uccellini et al. (1999) defined significant ocean cyclones as those with a central pressure of 980 hPa or less. In this paper storm intensity will be defined by the near surface wind speed.

During the fall of 2002 a study was conducted to quantify the effects of QuikSCAT wind data on the issuance of the short-term marine wind warnings. Results showed that considerably more wind warnings were issued when QuikSCAT winds were used in the warning decision process: 30% in the Atlantic and 22% in the Pacific, as shown in Figure 2.

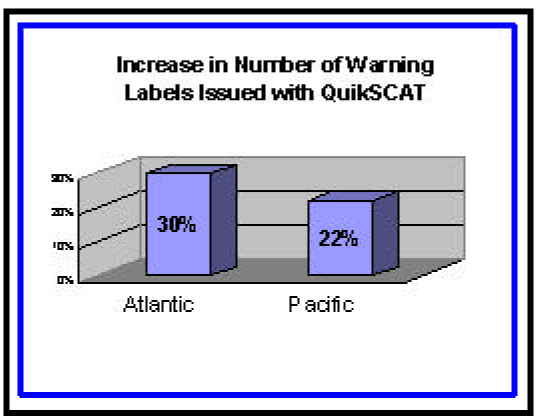

Figure 2. Number of wind warnings issued by OPC increased when QuikSCAT winds were used in the warning and forecast process

In the Atlantic 397 warnings were issued using QuikSCAT winds while only 279 warnings would have been issued if QuikSCAT were not available. In the Pacific 519 warnings were issued with QuikSCAT while only 406 would have been issued without QuikSCAT (see Figure 3).

An analysis of the data according to warning category showed that using QuikSCAT winds had a greater impact with the more significant warnings in both oceans. The number of Hurricane Force warnings issued increased by 38% in the Atlantic and by 42% in the Pacific (Figure 4).

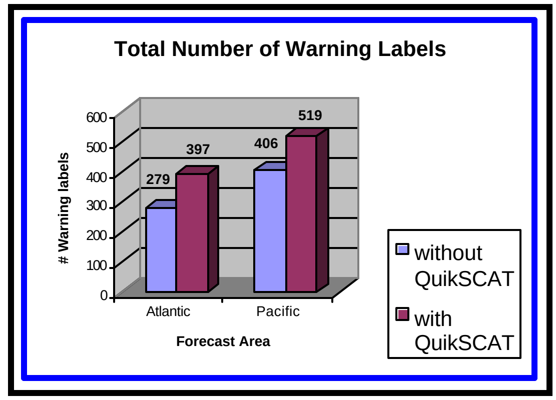

Figure 3. The total number of wind warnings issued increased in both the North Atlantic and North Pacific.

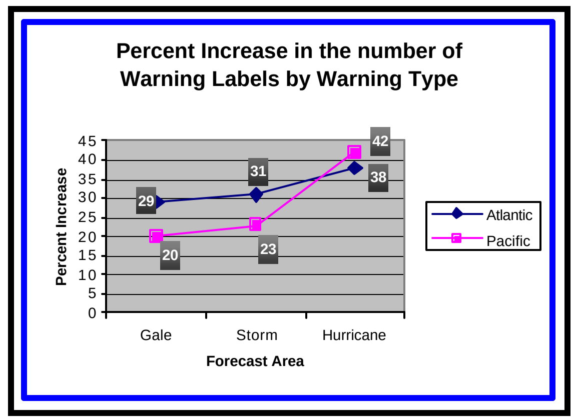

Figure 4. The number of wind warnings issued increased the most with the higher warning categories.

This has led us to believe that prior to QuikSCAT many Hurricane Force extratropical storms were under-analyzed and therefore under warned. Wind warnings may have been a category too low. This could have resulted in loss of life and property. Using QuikSCAT enables forecasters to more accurately identify these storms and thus to keep mariners apprised of their track and intensity.

Upon examining the surface analyses from the two seasons in which QuikSCAT was used in the warning process, we identified eighty-two extratropical cyclones that reached Hurricane Force strength - forty-five in the Atlantic and thirty-seven in the Pacific. Our prime motivation for undertaking this study was to quantify the value of QuikSCAT observations in identifying the development of these Hurricane Force storms. By examining the climatology of these storms for a two-year period we hope to provide forecasters with the tools to more accurately identify the conditions conducive to their development and perhaps better forecasts of such extreme events. We also hope to provide this information to the ocean mariner to help raise their awareness of the frequency and climatology of Hurricane Force extratropical cyclones. The goal is to foster safety at sea.

In this paper we present the results of this two-year study. In section 2 we define the areas of the study and the procedures. Section 3 contains the results and findings. The conclusions are described in section 4.

2. METHODOLOGY

2.1 Area of Study/Definition of terms

The active storm season for both the North Atlantic and North Pacific oceans occurs during the period from October to April. For this reason we chose Oct 2001 to April 2002 and Oct 2002 to April 2003 as our periods of study. We define the North Atlantic as the Atlantic Ocean North of 30N and the North Pacific as the Pacific Ocean North of 30N. An extratropical cyclone is a non-tropical migratory frontal cyclone of middle and higher latitudes. Tropical cyclones occasionally evolve into extratropical lows losing tropical characteristics and become associated with frontal discontinuity. In this study we are examining extatropical cyclones of Hurricane Force intensity (32.9 m s^{-1} or greater), henceforth referred to as HF cyclones (storms).

2.2 Procedure

We collected all the OPC North Atlantic and North Pacific Surface Analyses for the periods of this study. Forecasters as part of the analysis process label extratropical cyclones on these analyses with an appropriate wind warning (Gale, Storm or Hurricane Force) based on observed or expected maximum near surface wind speed. The charts were examined to identify all extratropical cyclones marked with a Hurricane Force warning label. Each cyclone was assigned a tracking number, e.g. storm ATL011001 where the first three letters represent the ocean (ATL or PAC), the next two digits are the number of the storm, and the last four give the month and year.) The surface analyses were then used to track each storm from its birth to dissipation. For each synoptic time we recorded the central pressure, the latitude and longitude and the wind warning category. Using this data we computed the speed of motion and the 24-hour deepening rate in bergeron as defined by Sanders and Gyakum (1980). Sanders and Gyakum (1980) defined a rapidly intensifying low-pressure system as that with a deepening rate of 1 bergeron or greater in 24 hours. A bergeron is a latitude dependant rate that varies from 24 hPa at 60 degrees north to 12 hPa at 25 degrees north. We also calculated the average speed of motion, the maximum deepening rate and the length of time the storm remained at hurricane strength. For each of the study periods we produced storm tracks.

3. FINDINGS

During the two-year period from 2001-2003 we observed at total of eighty-two HF storms (as shown in Table 2).

Ocean	Time period	# HF Storms
Atlantic	2001-2002	22
Atlantic	2002-2003	23
Pacific	2001-2002	15
Pacific	2002-2003	22

Table 2. Number of HF storms observed from October to April of 2001-2002 and 2002-2003.

Further examination of the data showed that these storms occurred most frequently from October through December in the Pacific and from December through March in the Atlantic with a notable maximum of activity in January (Figure 5).

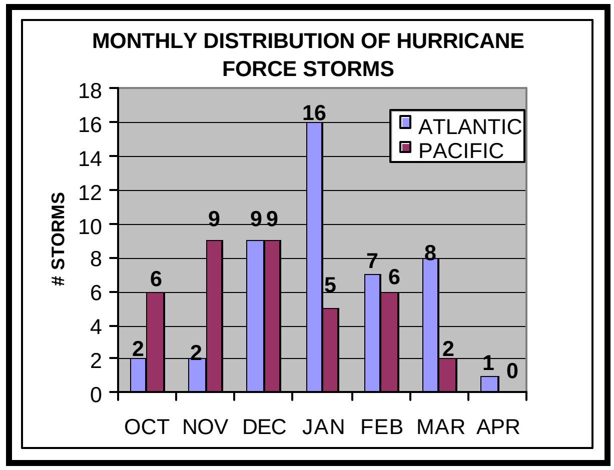

Figure 5. Monthly distribution of HF storms for both winter seasons.

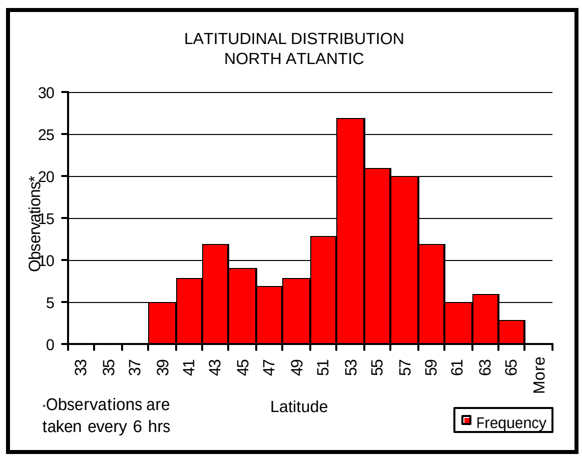

Figure 6. Latitudinal distribution of HF cyclones for the North Atlantic for the two seasons of study.

An examination of the latitudinal distribution of the HF storms in the Atlantic showed three distinct preferences centered at 44N, 54N and 64N as shown in Figure 6. This is the distribution for the storms when they were at Hurricane Force intensity. We believe that these three maxima represent Gulf Stream or Cape Hatteras developments, cyclones that lift northeast past

Newfoundland into the open Atlantic, and Greenland lows.

In the Pacific the latitudinal distribution was less definitive than in the Atlantic (Figure 7). We observed one preference at 47N followed by a rapid fall off in distribution north of 53N.

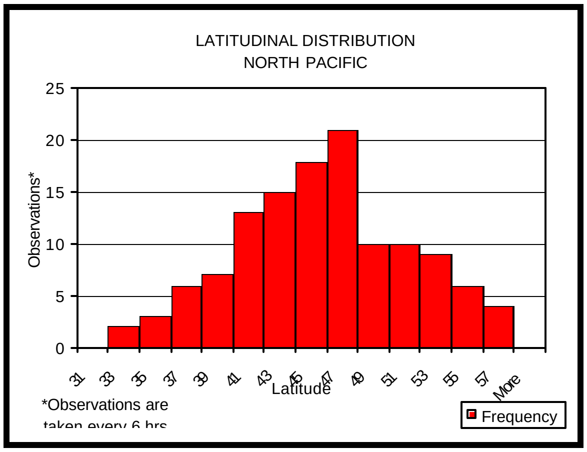

Figure 7. Latitudinal distribution of HF cyclones for the North Pacific**.**

The longitudinal distribution showed three maxima in the Atlantic (Figure 8). These were west of 60W, a broad area centered on 40W, and a third maximum at approximately 20W. The lows that developed west of 60W are believed to be Cape Hatteras lows. The storms from 50W to 35W are a mix of lows near Greenland where orographic forcing may be responsible for the extreme winds and open ocean developments that pass close to Newfoundland. The storms east of 20W appear to be secondary developments downstream.

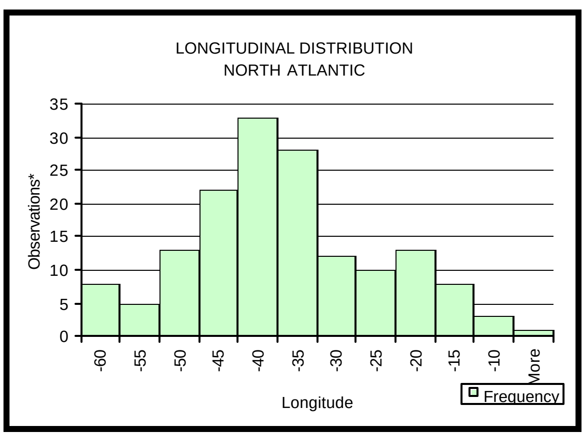

Figure 8. Longitudinal distribution of HF cyclones for the North Atlantic**.**

A clear west Pacific preference is evident in the longitudinal distribution (Figure 9). Two maxima were observed at 165E and 180. A secondary max was observed east of 165W with a minimum number of occurrences at 170W. During the two years of this study, a ridge persisted over the eastern Pacific thus limiting the activity. In fact, during early October 2003 a progressive pattern existed over the North Pacific. During this time period two HF cyclones were observed in the eastern Pacific and made landfall in British Columbia. The first HF cyclone is shown in Figure 1.

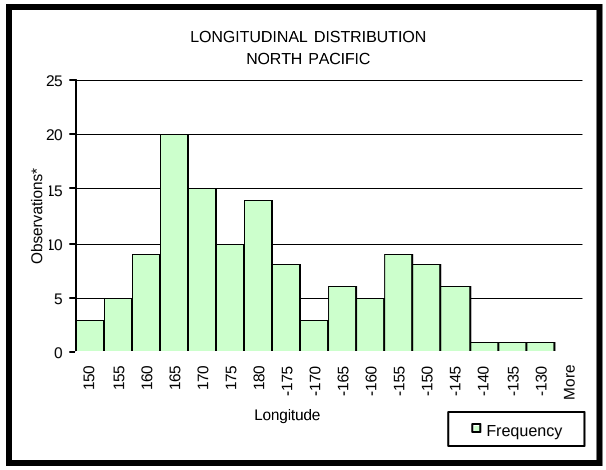

Figure 9. Longitudinal distribution of HF cyclones for the North Pacific

Each storm was examined to determine its longevity at Hurricane Force intensity. Since the analyses were made every six hours, we counted the number of 6hr increments that each storm maintained Hurricane Force. The results for each ocean are shown in figures 10 and 11. There average duration of Hurricane Force winds was very similar in both oceans. The average in the Atlantic was 3.5 six-hour periods - roughly 21 hours.

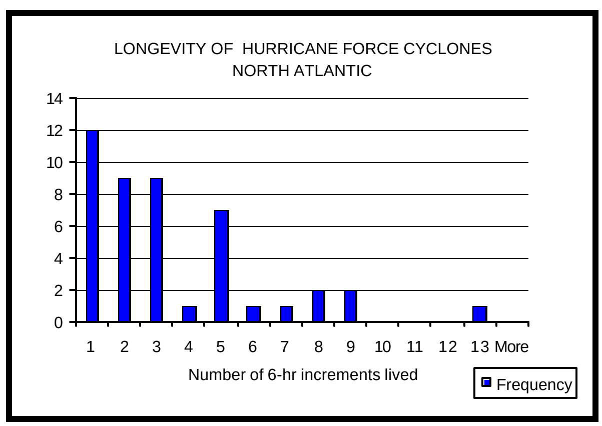

Figure 10. Longevity of HF cyclones in the North Atlantic.

In the Pacific the average life at Hurricane Force was 3.35 six-hour periods - approximately 20 hours.

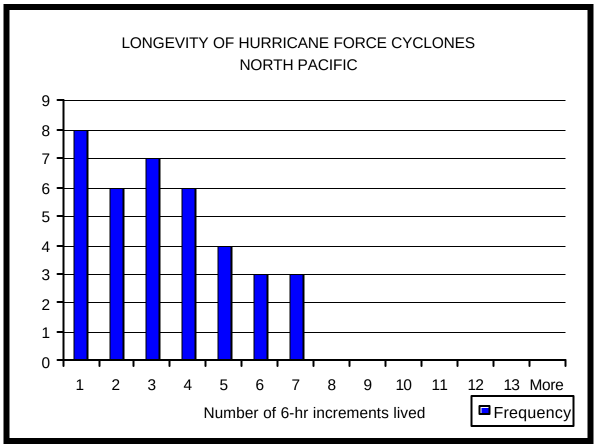

Figure 11. Longevity of HF cyclones in the North Pacific.

The distribution of the central pressure of each storm while at Hurricane Force intensity is shown in Figure 12.

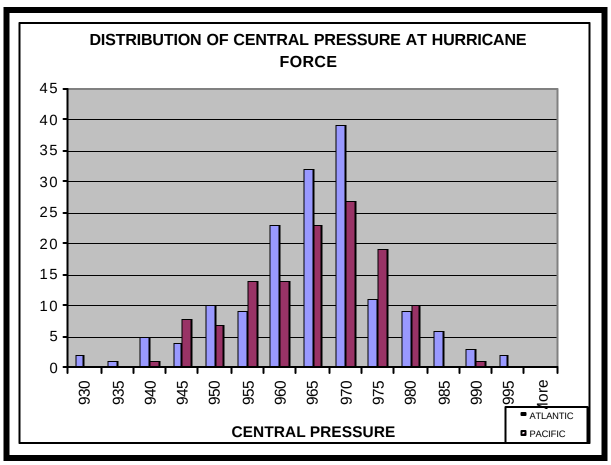

Figure 12. The frequency distribution of the central pressure for each storm while at Hurricane Force intensity.

We found that the pressure distribution for both the Atlantic and Pacific were similar with peak occurrence in the 965 to 970 hPa range. This surprised the OPC forecasters as it was thought to be lower. We also observed that the Atlantic produced several HF cyclones deeper than 940 hPa (deeper than the North Pacific). The Atlantic also produced weaker (pressure wise) HF storms than the Pacific. These are assumed to be due to the orographic influences of Greenland.

We examined the 24 hour deepening rates over the two year period and identified the maximum deepening rate for each storm as shown in Table 3. Sanders and Gyakum (1980) defined a rapidly intensifying cyclone as one with a 24 hour deepening rate of 1 bergeron or greater. Of the 45 HF cyclones observed in the Atlantic 35 were classified as rapidly intensifying (78%). In the Pacific 30 out of the 37 (81%) observed HF cyclones are rapidly intensifying. These results are shown in Figure 13.

STORM	ATL01_02	ATL02_03	PAC01_02	PAC02_03
1	1.26	1.15	0.83	1.56
2	N/A	0.54	1.70	0.57
3	1.27	1.24	1.13	1.93
4	0.77	1.38	1.24	1.91
5	2.46	1.04	1.88	1.16
6	2.29	1.54	2.23	1.91
7	2.88	1.11	2.38	0.77
8	0.72	1.65	2.36	0.41
9	1.9	1.65	1.76	2.47
10	2.15	0.99	1.33	1.57
11	1.95	0.59	1.23	1.12
12	1.37	1.73	0.90	0.89
13	1.43	1.75	1.28	1.59
14	3.02	1.39	2.02	2.00
15	0.14	2.87	0.88	2.41
16	1.3	2.09		1.71
17	1.28	3.11		1.17
18	1.28	0.96		1.90
19	1.27	0.84		2.01
20	0.04	2.6		1.21
21	1.19	1.85		1.50
22	1.5	1.1		1.84
23		1.66		

Table 3. The Maximum 24hr-deepening rate was recorded for each HF storm over the two seasons of study.

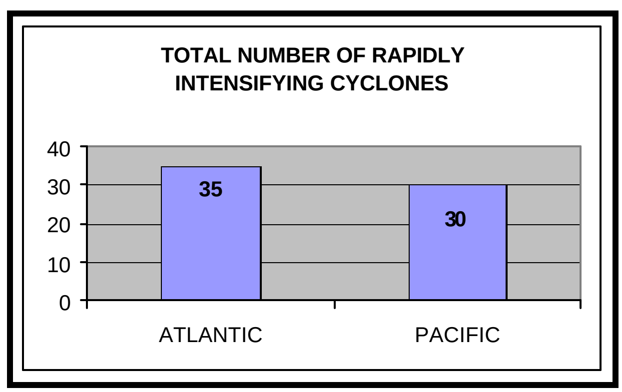

Figure 13. Total number of rapidly intensifying storms over the two year period for each ocean.

The average maximum deepening rate for each period of study was approximately 1.5 bergeron in both the Atlantic and the Pacific as shown in Figure 14. Upon examination of the individual maximum deepening rates we found that the largest observed value was higher in the Atlantic (3.1bergeron) than in the Pacific (2.5 bergeron) as shown in Figure 15. In the Atlantic, sea surface temperature gradients are nearly double those in the Pacific. This may be a contributing factor to the more intense maximum deepening rates in the North Atlantic.

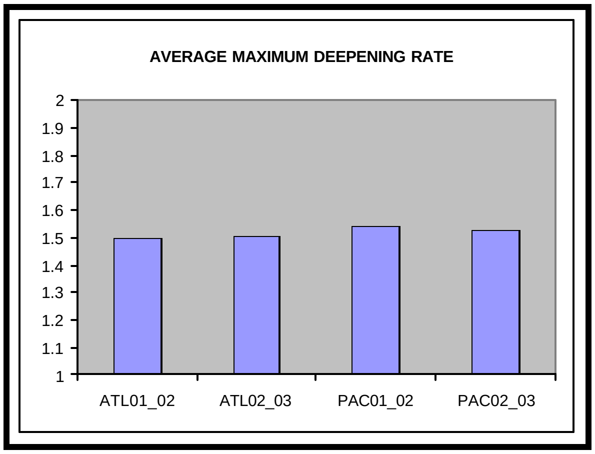

Figure 14. The seasonal average of the maximum deepening rate for each ocean is approximately 1.5 bergeron.

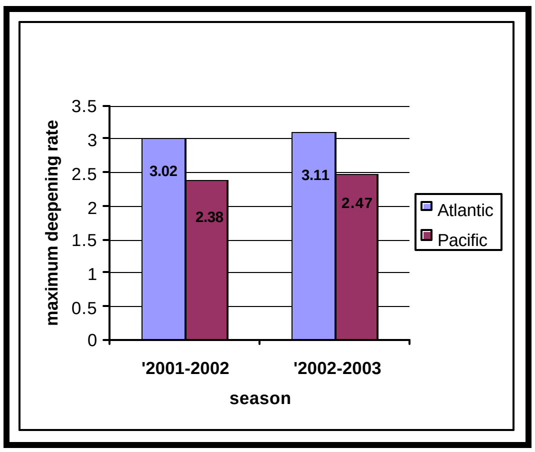

Figure 15. Largest maximum 24 hr deepening rate was higher in the Atlantic than in the Pacific for each season of study.

4. CONCLUSIONS

Since QuikSCAT was made available to OPC forecasters, much of the void in surface wind observations over the open oceans has been filled. QuikSCAT retrievals are the first data set to consistently reveal winds of 32.9 m s^{-1} and greater (Hurricane Force) within extratropical cyclones. This consistency has given the forecasters the confidence to identify extreme extratropical cyclones. Using QuikSCAT enabled us to build a database of HF extratropical cyclones over a two-year period from October to April of 2001 to 2003. Our examination of this database enabled us to study the climatology of these intense storms.

The majority of these storms developed in November and December in the Pacific, while In the Atlantic the preferred month of development was January. It was also noted that in January the occurrence of the storms was a minimum in the Pacific. Preferred areas for occurrence were observed. In both oceans maximum activity was observed over the western portions for each basin. Minimums were noted in the Pacific near 170W and in the Atlantic near the European continent. The average life of the cyclones at hurricane strength was the same for both oceans - approximately 18 to 20 hours.

Of the 82 cyclones that were observed over the two-year period, 65 were rapidly intensifying storms. Within the past six years, cargo loss from single vessels such as the APL China due to one of these storms has exceeded 50 million dollars (Ginsberg, 1998) with damage to the ship exceeding 100 million dollars (Ahern, 1998). The need to forecast and warn for these storms is of the utmost importance.

This is still a work in progress. We will continue this study for this winter season. We also plan to use the QuikSCATscatterometer data to create storm relative composites of the Hurricane Force wind field.

5. References

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