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QuikSCAT Analysis of Hurricane Force Extratropical Cyclones in the Pacific Ocean

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1. Introduction

Since June 1999, the National Aeronautics and Space Administration (NASA) Quick Scatterometer Spacecraft (QuikSCAT) has been providing forecasters at the Ocean Prediction Center (OPC) with near-real-time surface wind speed and direction data over the world's oceans. It replaced NSCAT which was lost in 1997 and currently carries the SeaWinds scatterometer instrument. QuikSCAT is a near-polar orbiting satellite with an 1800-kilometer wide measurement swath on the earth's surface. Its angle of inclination is about 98 degrees, which means that according to a compass it is flying north by north-west at a directional angle of 352 degrees when it is ascending (i.e. south to north). It flies in a circular orbit at an altitude of approximately 800 km above sea level. QuikSCAT provides coverage of about 90% of the world's oceans each day and twice per day coverage over a given geographic region, completing a full orbit of the Earth in approximately 101 minutes (just over 14 orbits per day).

(Callahan, 2006)

The SeaWinds scatterometer transmits high-frequency microwave pulses of 13.4 GHz at a rate of one pulse every 5.4 milliseconds. It is able to estimate wind speed and direction over the Earth's oceans at ten meters above the surface of the water by analyzing the backscatter from the small wind-caused ripples, called cat's paws, on the water surface. When the microwave pulses strike the ocean surface, backscatter occurs. A rough ocean surface returns a stronger signal because the waves reflect more of the radar energy back toward the scatterometer antenna. A smooth ocean surface returns a weaker signal because less of the energy is reflected (JPL at Nasa, 2003). QuikSCAT is much more effective than ship and buoy observations, as it is able to provide hundreds of times more observations each day, as well as continuous, high-resolution measurements regardless of weather conditions.

SeaWinds uses a rotating dish antenna with two pencil beams that sweep in a circular pattern. The pulses are alternately polarized, vertical and horizontal. It uses the same parabolic antenna for both pulses, with different feeds. The antenna rotates at a rate of 18 rotations per minute. The feeds on the antenna are set up so that the vertical polarized beam has an elevation angle of 45 degrees and the horizontal polarized beam an elevation of 39 degrees (JPL at Nasa, 2003). This creates an outer and an inner beam shown in the figure below.

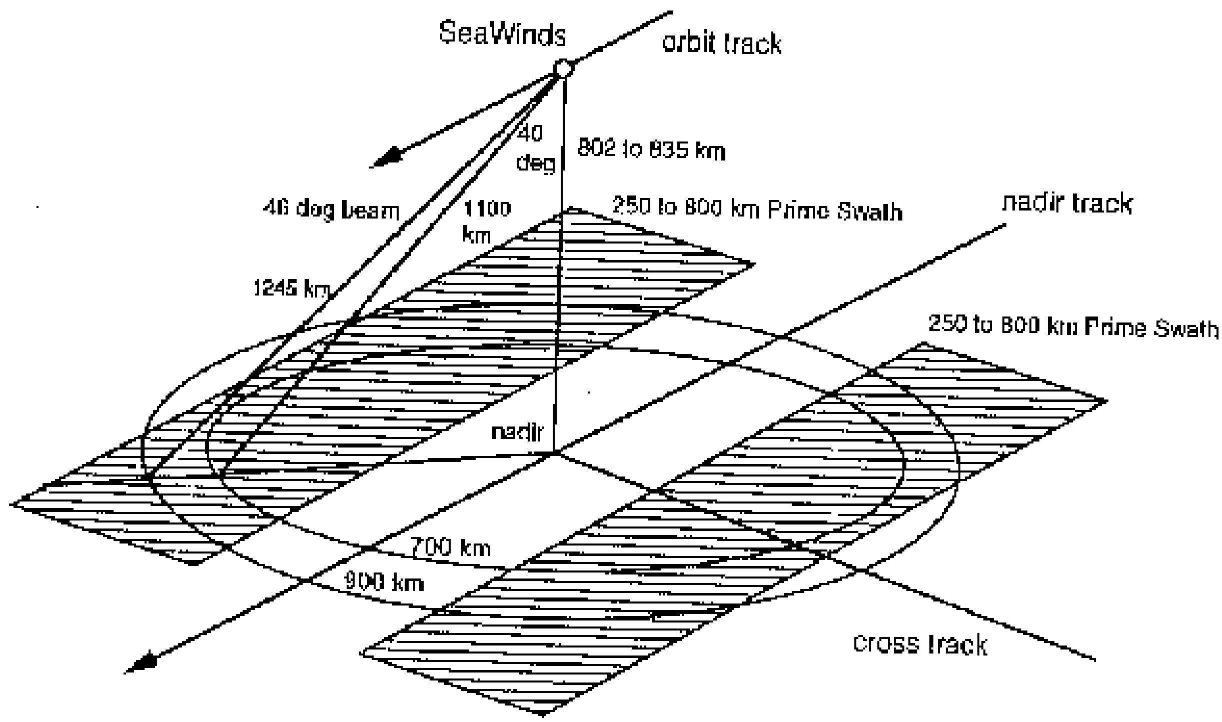


Figure 1: The QuikSCAT scatterometer design

As the antenna rotates, the instrument pulses form a circular footprint on the ground. The outer beam covers a circle on the surface of 1800 km diameter while the inner beam covers about 1400 km. When the circular rotation of the antenna is combined with satellite movement of approximately 25 km per rotation, a helical shape is traced out on the ground.

(JPL at Nasa, 2003)

QuikSCAT and the SeaWinds scatterometer have allowed forecasters to better predict potential hazards such as storm surges and issue warnings when necessary. The implementation of QuikSCAT into the OPC's daily analysis led to the initiation of Hurricane Force Wind Warnings in December 2000. Currently, the Beaufort wind speed scale defines the categories for wind warnings: gale warning, 34-47 knots; storm warning, 48-63 knots; and hurricane force warning, 64 knots or greater (Bowditch, 2005). Over the past ten years, QuikSCAT has received a number of upgrades which improved the forecasters' abilities to predict the weather more accurately and issue warnings, accordingly. These improvements include the availability of the QuikSCAT data right within the forecasters' workstations starting in October 2001 (rather than an online database), the introduction of higher resolution satellite data (12.5 kilometer rather than 25 km) in May 2004, and an improved wind algorithm and rain flag in October 2006 (Sienkiewicz et al., 2008).

Now with four accessible sets of QuikSCAT data (Near-real-time 12.5 km and 25 km and Science-level 12.5 km and 25 km), the OPC must determine which data set, or combination of data sets, best accurately represents current wind conditions. This information will be useful for the launch of the next satellite after QuikSCAT, which will continue to improve on the recent wind algorithm and rain flag put into place.

In this paper, I will provide both a quantitative and qualitative analysis of hurricane force extratropical cyclones in the Pacific Ocean. Using the 12.5 km Science-level data, I will determine the number of hurricane force extratropical cyclone events for given storm seasons. In addition, I will compare the four QuikSCAT data sets by providing a case-by-case analysis of hurricane force extratropical cyclones during January 2007. From these two objectives, I will look to normalize the data of hurricane force extratropical cyclone events for years prior to the implementation of the higher resolution QuikSCAT data and the improved wind algorithm and rain flag, as well as provide a detailed comparison of QuikSCAT data levels. As of right now the data shows an increasing trend in the number of cyclone events per cyclone season. Part of this increasing trend is due to the aforementioned implementations in addition to forecaster familiarity and data availability.

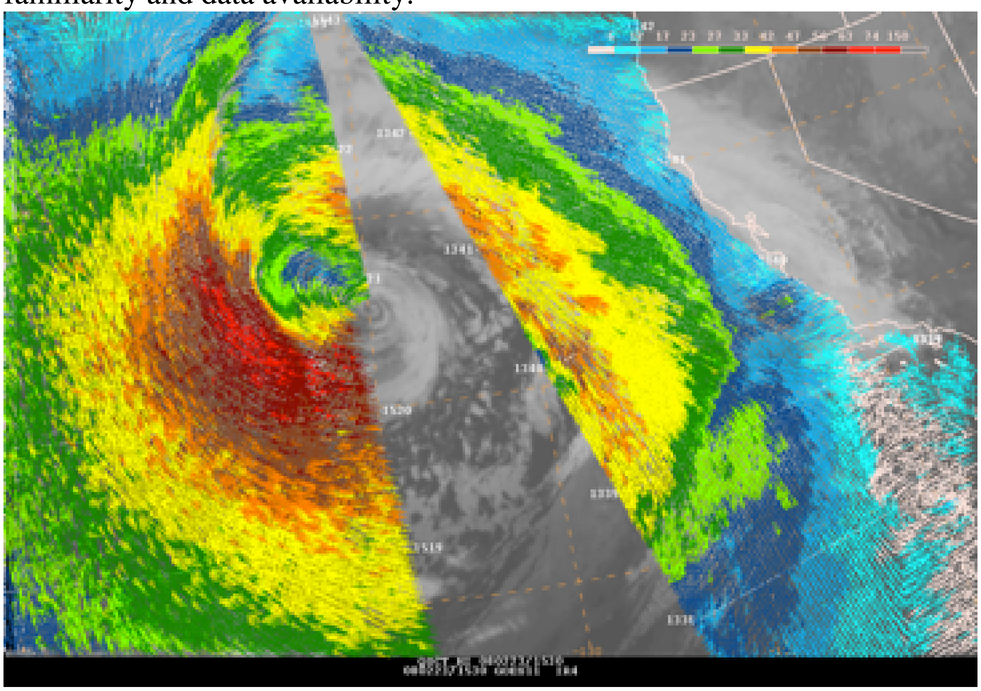
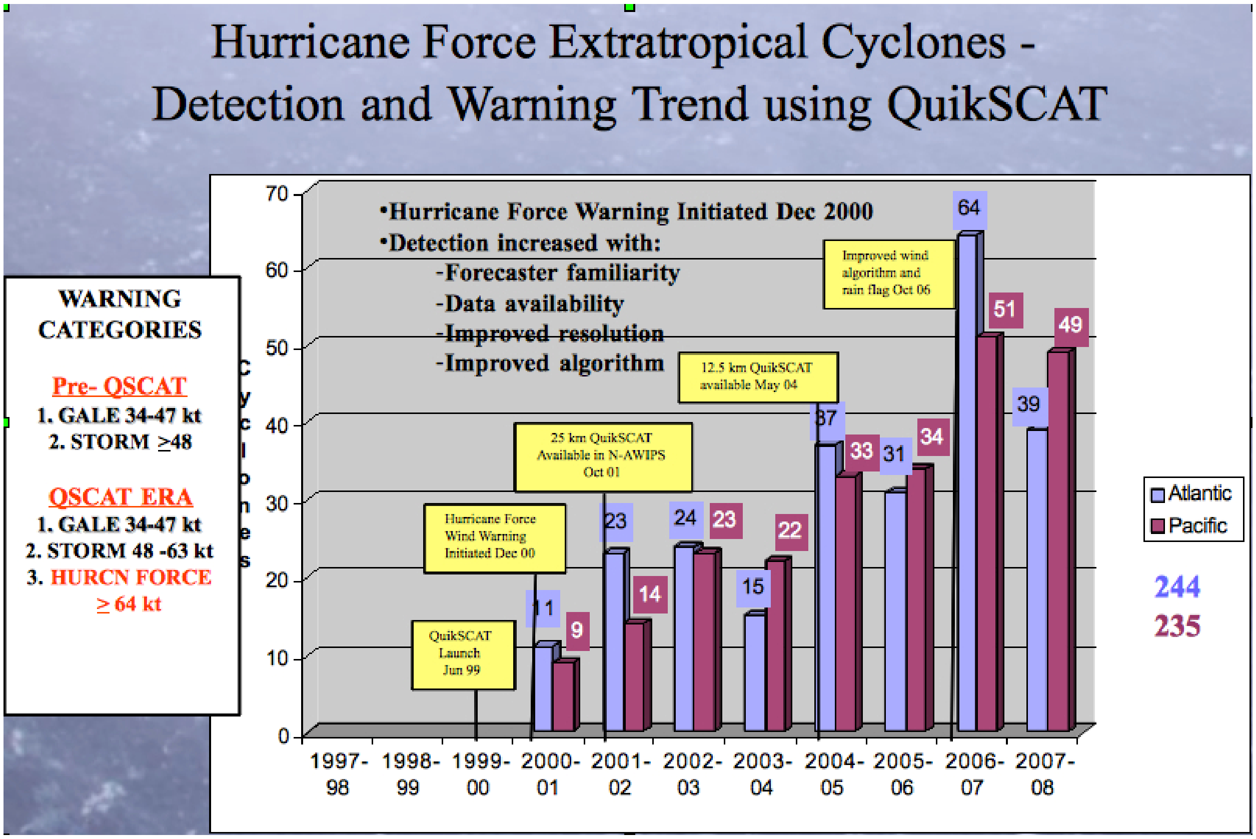


Figure 2: Intense, non-tropical cyclone with hurricane force winds Feb 23, 2008, North Pacific (Sienkiewicz et al., 2008)



2. Methodology

2.1 Area of Study/Definition of Terms

The active storm season for the North Pacific Ocean occurs from September to May each year. Consequently, this was the period of study chosen for determining the number of hurricane force extratropical cyclone events in the North Pacific. Extratropical refers to a cyclone that has lost its "tropical characteristics." The term implies a poleward displacement of the cyclone and a transition of the cyclone's primary energy source. The cyclone's original primary energy source, the release of latent heat of condensation, is instead converted into baroclinic (the temperature contrast between warm and cold air masses) processes (National Hurricane Center, 2009). Extratropical cyclones are also referred to as mid-latitude or baroclinic cyclones and for the Northern Hemisphere, are defined by the Ocean Prediction Center to be north of 30ºN latitude. It is important to note that extratropical cyclones can remain at hurricane force or tropical storm force wind levels and are just as dangerous as tropical cyclones.

2.2 Procedure

In order to begin the research, a Virtual Private Network (VPN) was established with the Ocean Prediction Center at the National Centers for Environmental Prediction. VPN Client by Cisco Systems was used to establish a connection to a workstation. From here, the QuikSCAT satellite data and Vector Graphics Files (VGFs) were uploaded to my workstation. These files were then accessed through NMAP, the operational product generation software package at NCEP. NMAP has both "display" and "product generation" capabilities. The "display capabilities" include the ability to display observational and prognostic data as well as those graphical products generated using NMAP's "product generation" capability. In this instance, the QuikSCAT data would be observational data whereas the VGFs, which are the forecasters' surface analyses, would correspond to a generated product.

My primary objective was to count the number of hurricane force extratropical cyclone events observed for the given years. Hurricane force winds are noted on QuikSCAT as having red wind barbs. Not all red wind barbs corresponded to a hurricane force extratropical cyclone, however. Backscatter from ocean ice, rain contamination, ambiguity removal errors and the swath edge all could result in showing hurricane force wind strength.

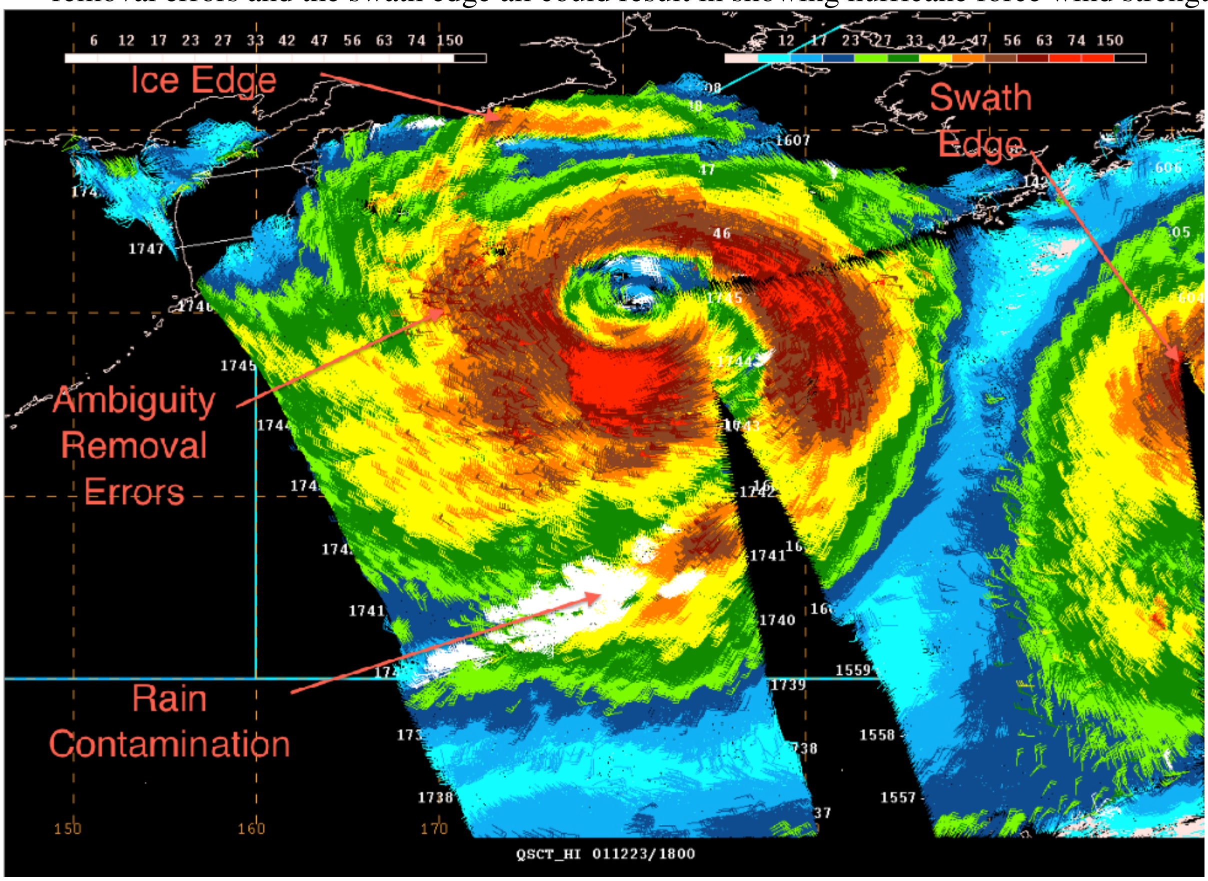


Figure 3: Hurricane force extratropical cyclone on 12-23-01: Ice and swath edge, ambiguity removal errors, and rain contamination are noted. Legitimate hurricane force winds observed to the right and below the center of circulation.

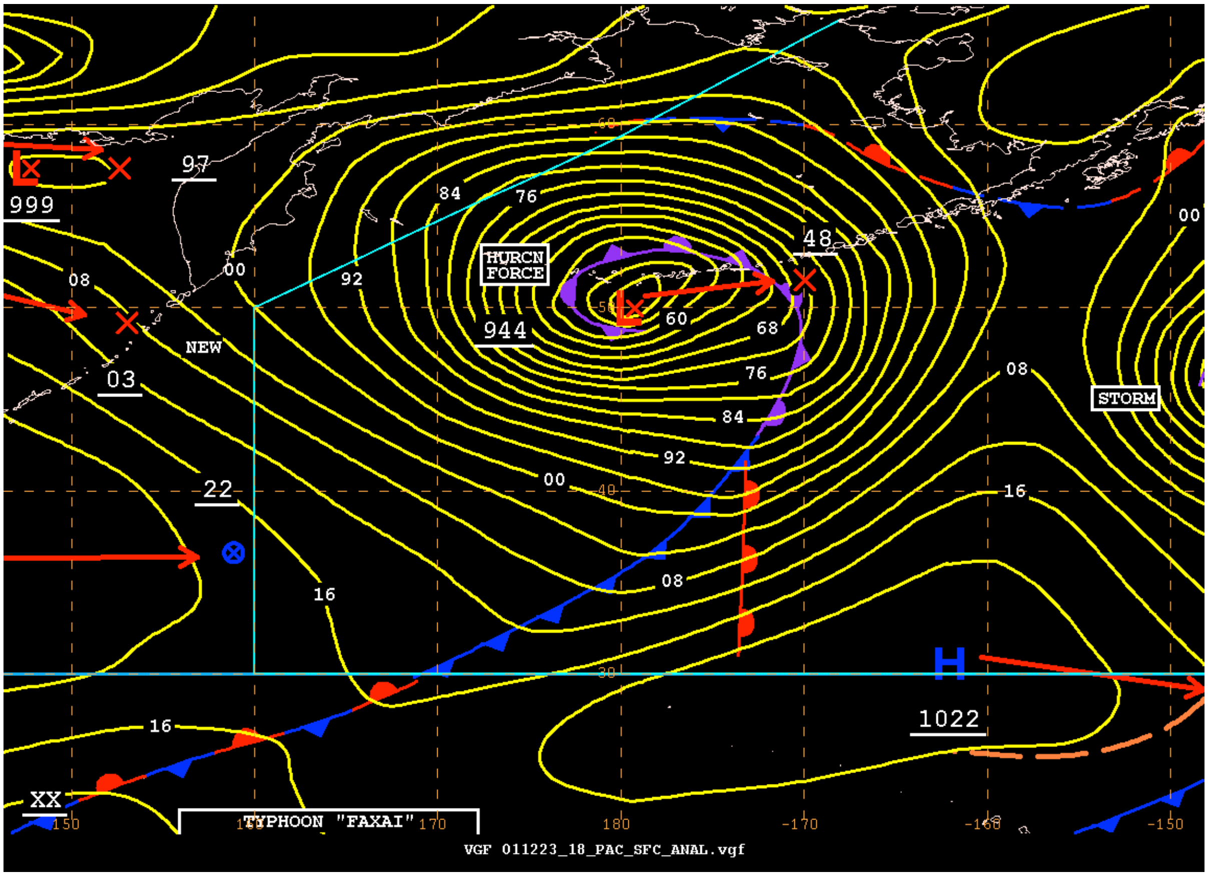


Figure 4: Forecaster's corresponding surface analysis to previous hurricane force extratropical cyclone on 12-23-01

My goal was to account for only legitimate hurricane force winds. When a hurricane force extratropical cyclone was observed, I recorded the date and time when reaching hurricane force intensity, the starting latitude and longitude of hurricane force (HF) intensity, the maximum wind speed during the cyclone's life at HF intensity and the ending date, time, latitude and longitude when the cyclone dissipated below HF intensity. In addition, I recorded notes on particular or peculiar storms, such as if a storm started as a typhoon or tropical cyclone and transitioned into an extratropical cyclone or if a cyclone fell below HF intensity and then restrengthened. From this, I generated monthly cyclone distributions as well as distributions of the maximum winds for all of the cyclones.

Another task was to compare the four levels of QuikSCAT data on a case-by-case basis. I chose four hurricane force extratropical cyclones from the January 2007 time period. This particular time period was chosen due to the availability of all four levels of data. I recorded the number of HF events in the month for each level, as well as the maximum wind speed and number of HF wind barbs.

3. Findings

Lists of cyclone events for the 2001-2002 and 2003-2004 seasons are included in Appendix A.

2001-2002 Results

Month	# of HF Xtrop Cyclones
Sept.	4
Oct.	8
Nov.	14
Dec.	18
Jan.	12
Feb.	8
Mar.	7
Apr.	4
May	2

Table 1: Number of North Pacific HF extratropical cyclones in 2001-2002 season

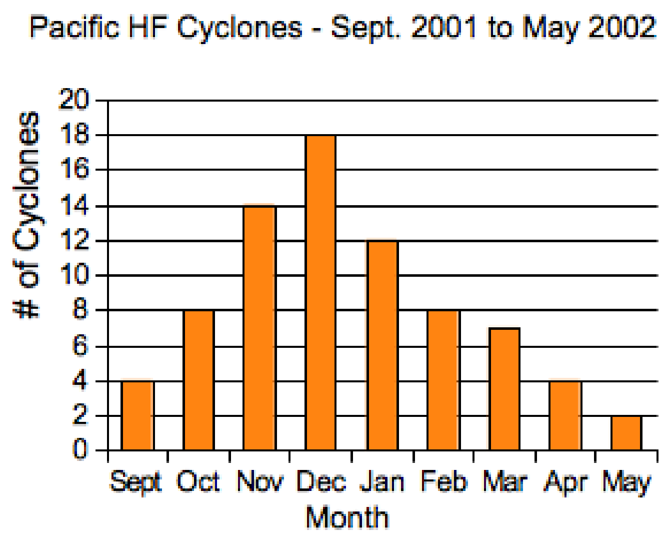


Figure 5: Number of North Pacific HF extratropical cyclones in 2001-2002 season

Max. Wind Speed	Number of Cyclones
65 kts.	17
70 kts.	22
75 kts.	20
80 kts.	8
85 kts.	5
90 kts.	2
95 kts.	3

Table 2: Wind speed distribution for 2001-2002 North Pacific HF extratropical cyclones

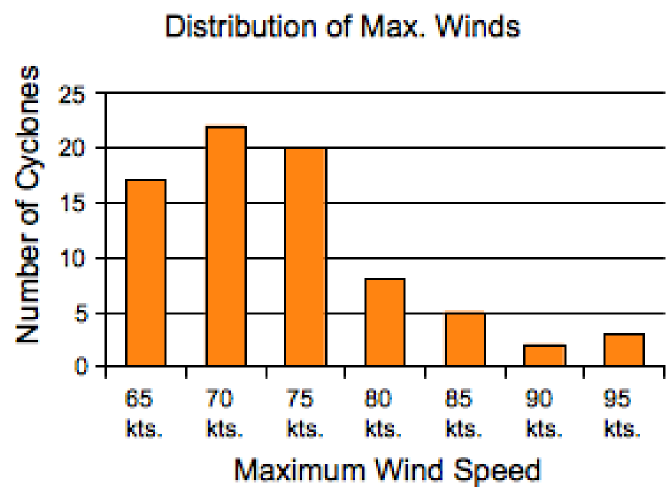


Figure 6: Wind speed distribution for 2001-2002 North Pacific HF extratropical cyclones

2003-2004 Results

Month	# of HF Xtrop Cyclones
Sept.	5
Oct.	10
Nov.	12
Dec.	17
Jan.	14
Feb.	14
Mar.	16
Apr.	8
May	0

Table 3: Number of North Pacific HF extratropical cyclones in 2003-2004 season

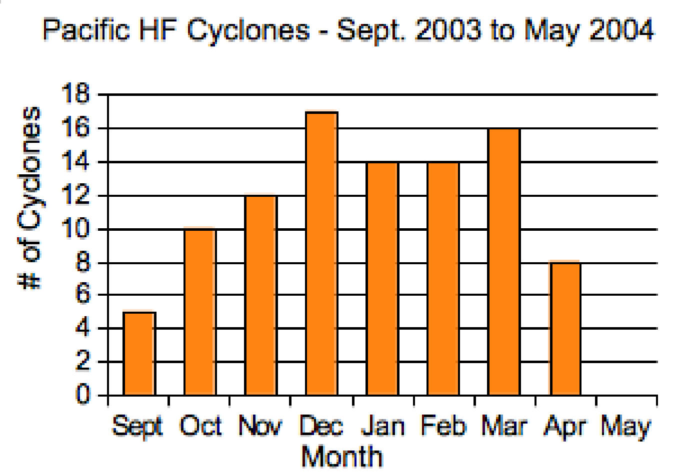


Figure 7: Number of North Pacific HF extratropical cyclones in 2003-2004 season

Max. Wind Speed	Number of Cyclones
65 kts.	30
70 kts.	21
75 kts.	17
80 kts.	16
85 kts.	6
90 kts.	2
95 kts.	4

Table 4: Wind speed distribution for 2003-2004 North Pacific HF extratropical cyclones

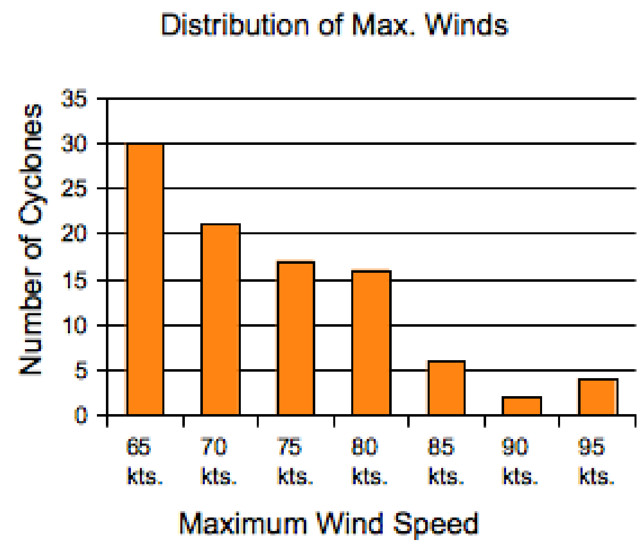


Figure 8: Wind speed distribution for 2003-2004 North Pacific HF extratropical cyclones

January 2007 Case-by-Case Analysis

The following graph shows the results of the January 2007 case-by-case analysis. The near-real-time low-resolution (25 km) QuikSCAT data observed six hurricane force extratropical cyclones while the high-resolution (12.5 km) observed twelve. For the science-level data, the low-resolution QuikSCAT data observed ten hurricane force extratropical cyclones while the high-resolution observed fifteen.

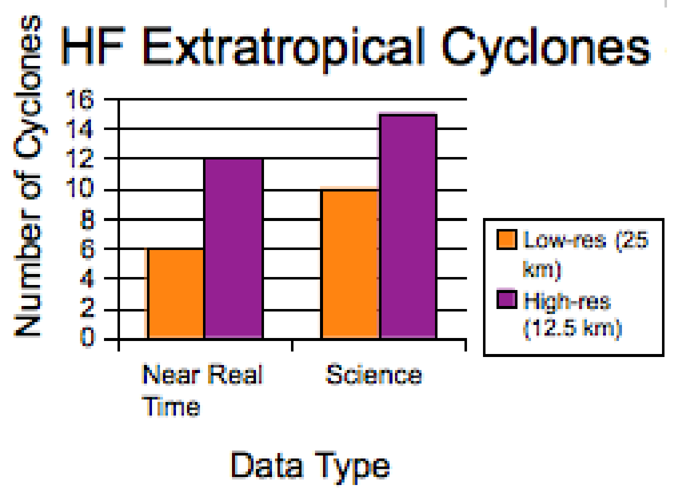
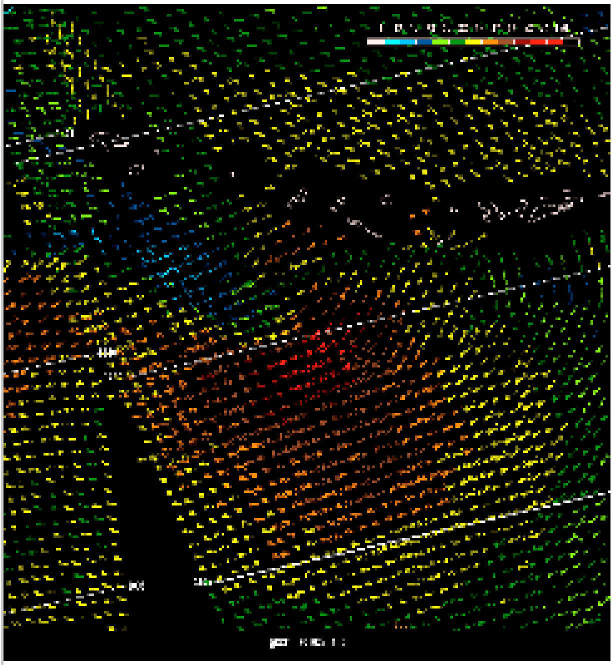


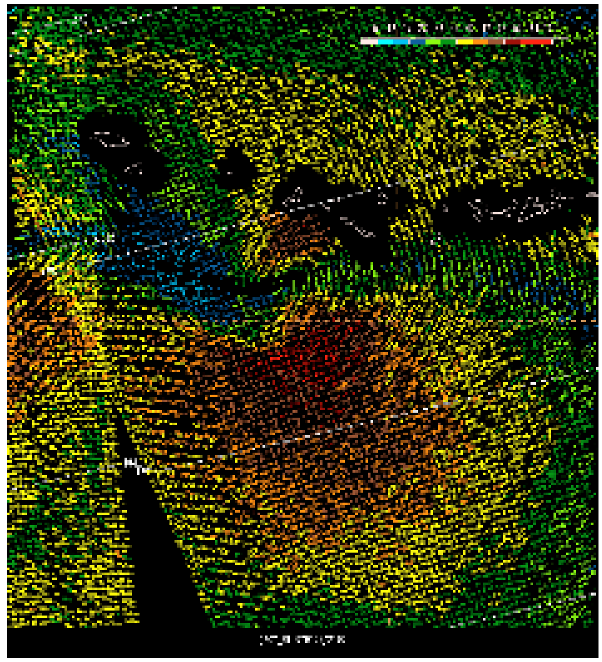
Figure 9: Data-type comparison of January 2007 North Pacific HF extratropical cyclones

The QuikSCAT imagery of the four cases can be found on the following pages.

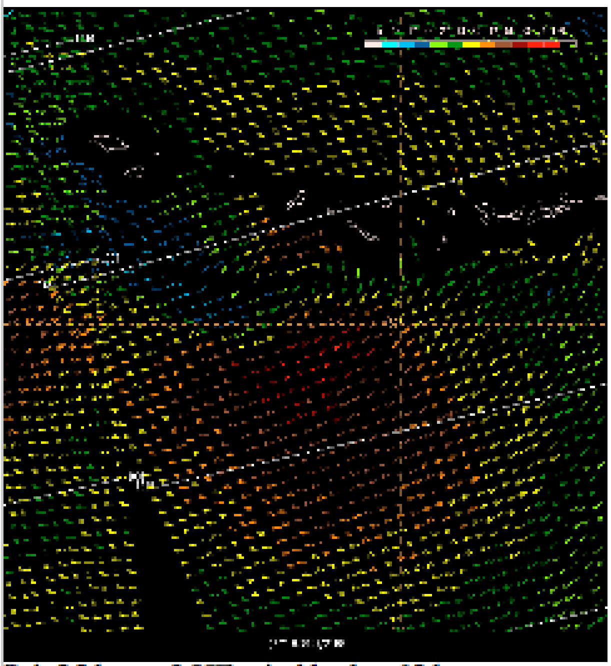
Case 1: January 3, 2007 - 2100



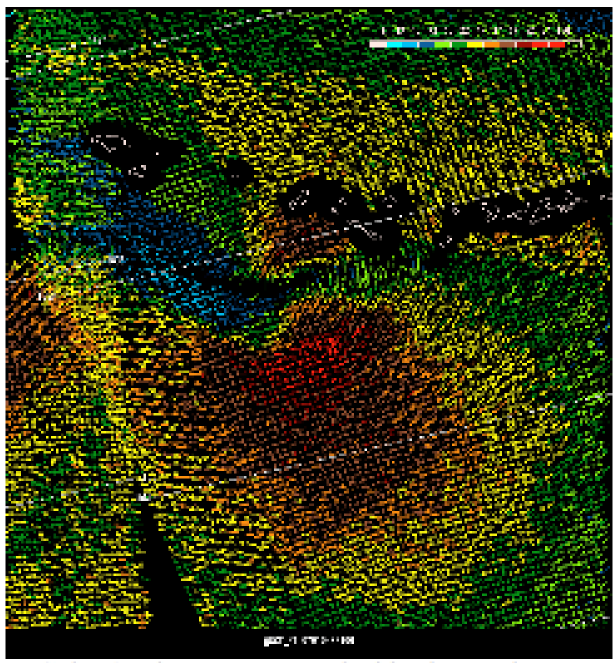
N.R.T. 25 km – 2 HF wind barbs – 65 kts.



N.R.T. 12.5 km – 11 HF wind barbs – 65 kts.

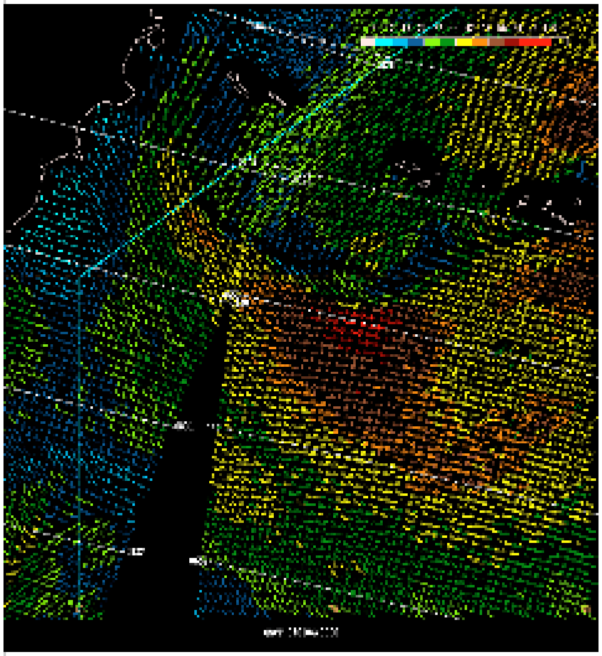


Sci. 25 km – 9 HF wind barbs, 65 kts.

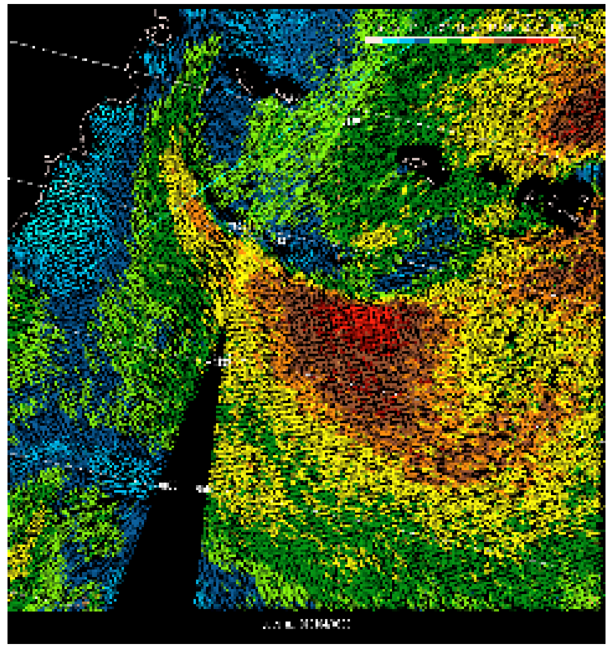


Sci. 12.5 km – 45 HF wind barbs, 75 kts.

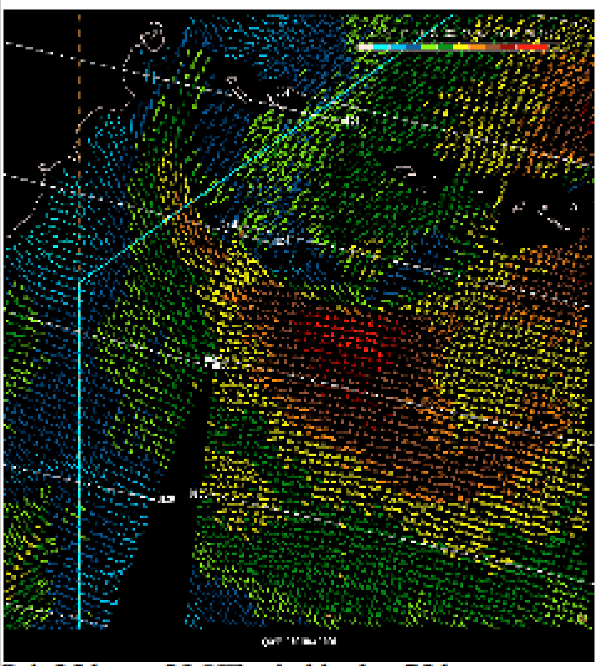
Case 2: January 4, 2007 - 0900



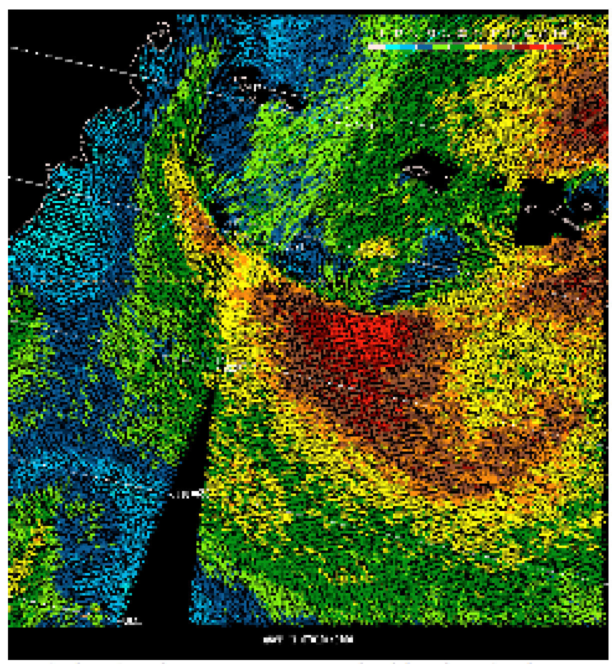
N.R.T. 25 km – 4 HF wind barbs – 70 kts.



N.R.T. 12.5 km – 50 HF wind barbs – 80 kts.

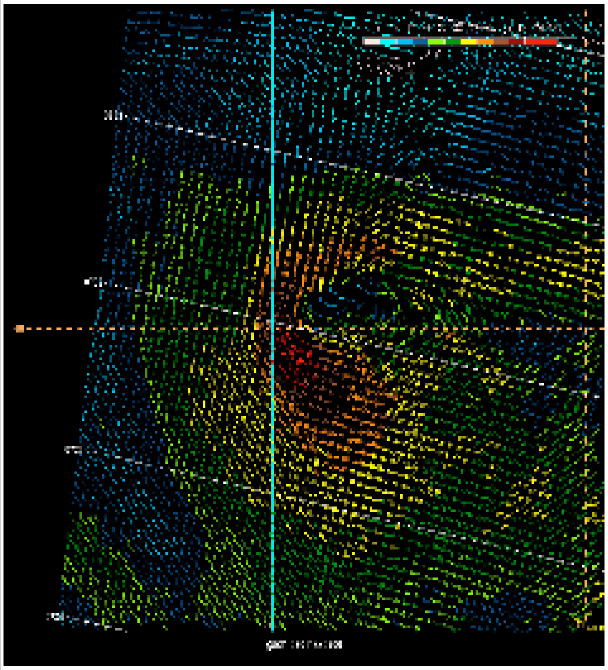


Sci. 25 km – 29 HF wind barbs, 75 kts.

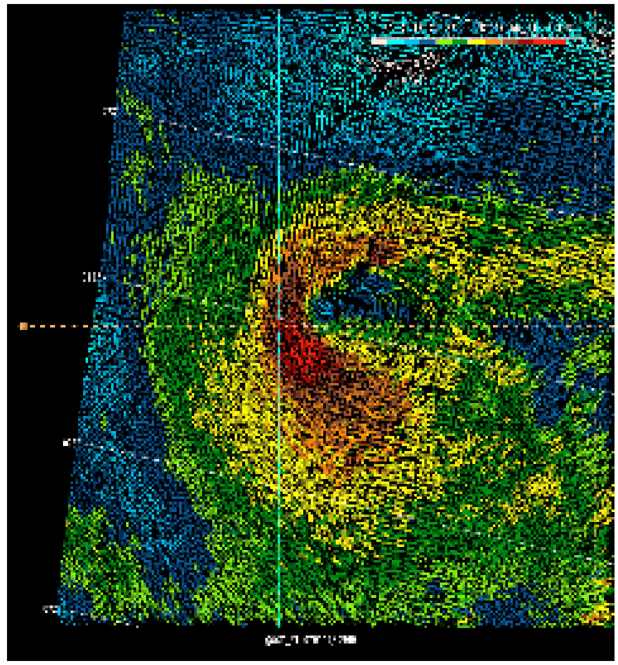


Sci. 12.5 km – 115 HF wind barbs, 85 kts.

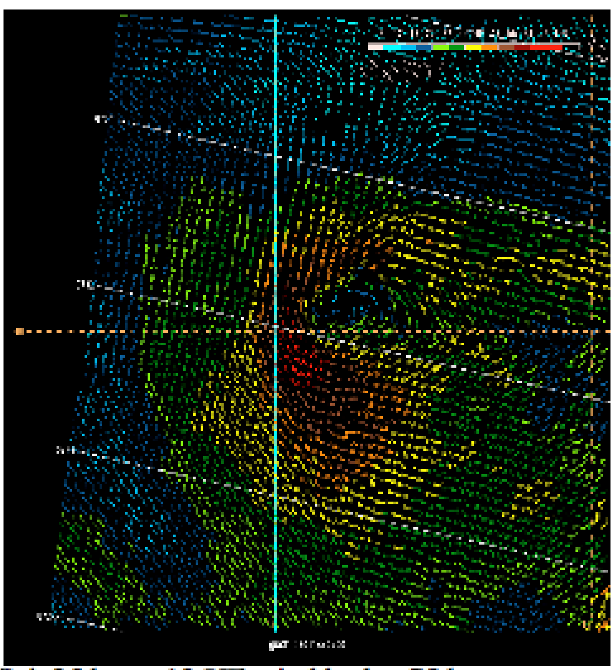
Case 3: January 14, 2007 - 0900



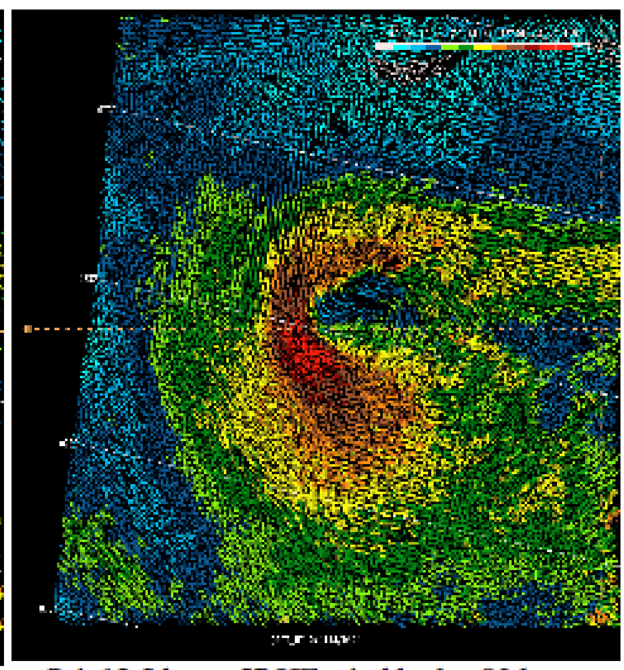
N.R.T. 25 km – 3 HF wind barbs – 65 kts.



N.R.T. 12.5 km – 27 HF wind barbs – 75 kts.

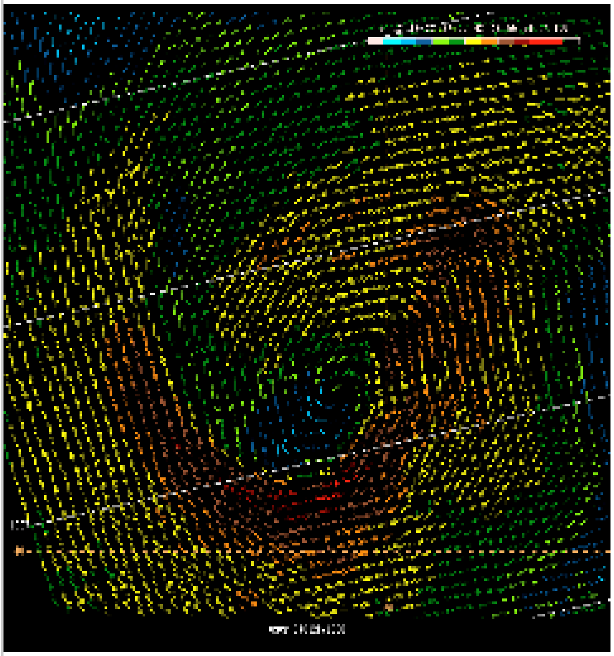


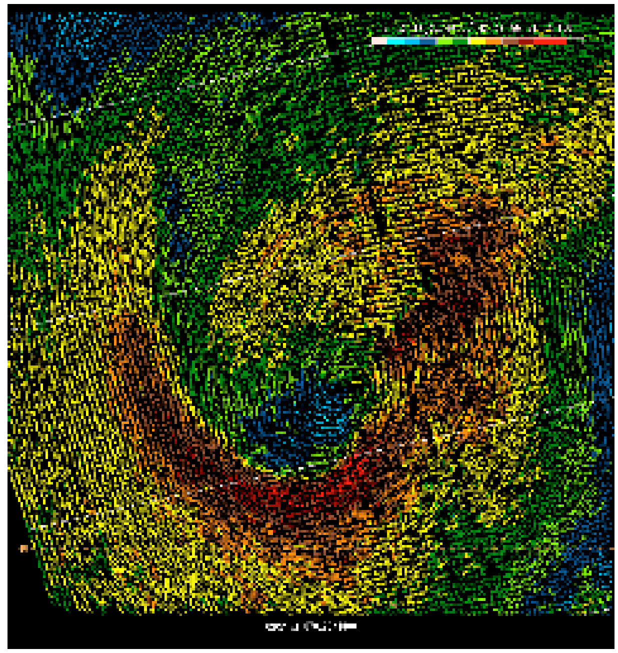
Sci. 25 km – 13 HF wind barbs, 75 kts.



Sci. 12.5 km – 57 HF wind barbs, 80 kts.

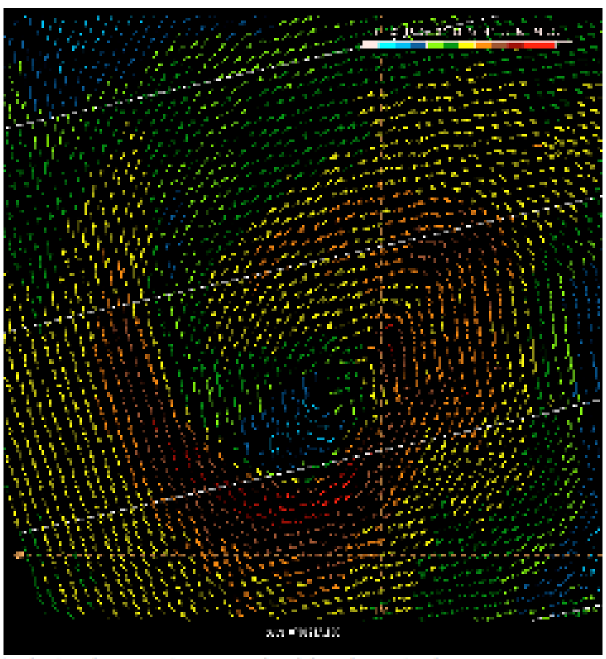
Case 4: January 28, 2007 – 1800

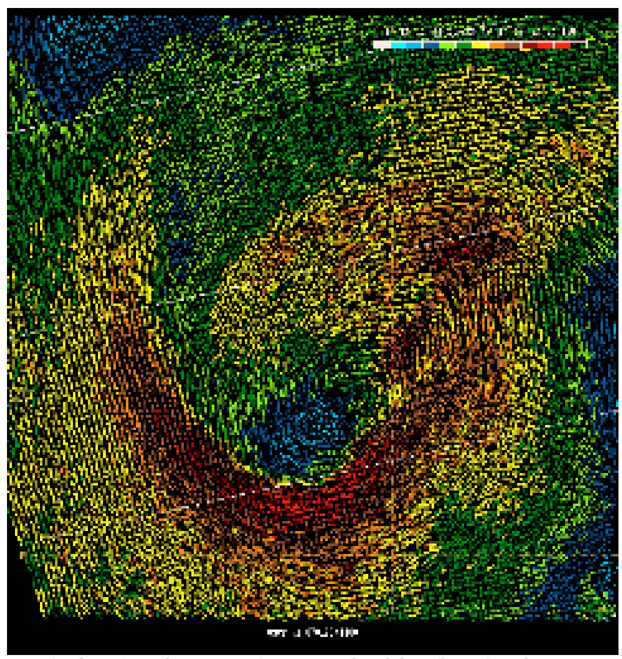




N.R.T. 25 km – 0 HF wind barbs

N.R.T. 12.5 km – 20 HF wind barbs – 70 kts.





Sci. 25 km – 9 HF wind barbs, 65 kts.

Sci. 12.5 km – 58 HF wind barbs, 85 kts.

Case	N.R.T. lo-res	Sci lo-res	N.R.T. hi-res	Sci hi-res
1	2	9	11	45
2	4	29	50	115
3	3	13	27	57
4	0	9	20	58

Table 5: Comparison of number of HF wind barbs for four QuikSCAT data-levels in January 2007 cyclone events

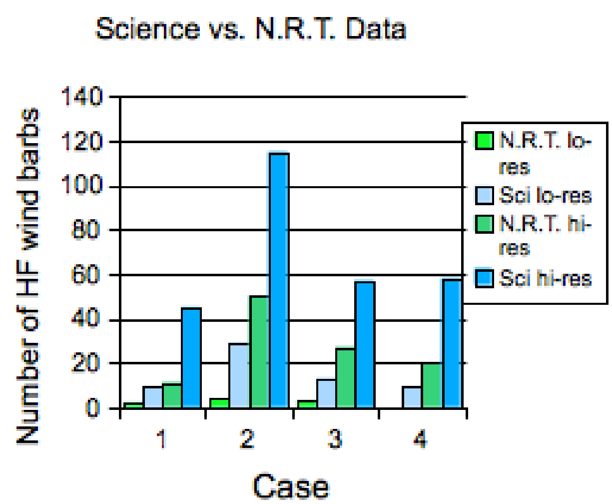


Figure 10: Comparison of number of HF wind barbs for four QuikSCAT data-levels in January 2007 cyclone events

Case	N.R.T. lo-res	Sci lo-res	N.R.T. hi-res	Sci hi-res
1	65	65	65	75
2	70	75	80	85
3	65	75	75	80
4	65	65	70	85

Table 6: Comparison of maximum wind speed for four QuikSCAT data-levels in January 2007 cyclone events

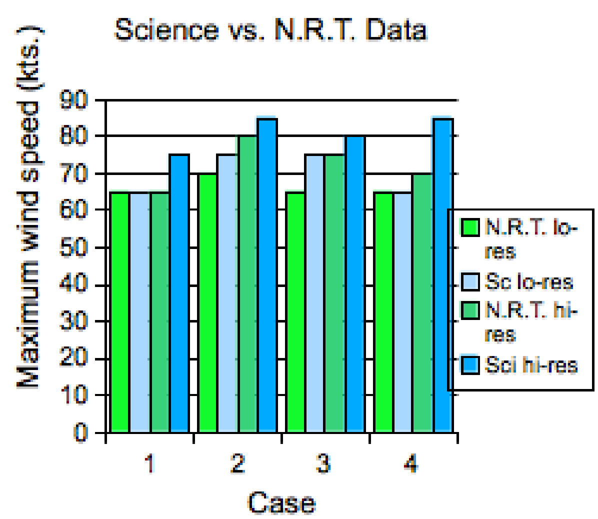


Figure 11: Comparison of maximum wind speed for four QuikSCAT data-levels in January 2007 cyclone events

4. Conclusions

Overall, a number of conclusions can be drawn from the results of the QuikSCAT research. It is evident that the Science-level data is composed of a stronger algorithm than the near-real-time data. When comparing the number of hurricane force extratropical cyclones per cyclone season, the Science-level data detected many more cyclones than the Near-real-time data. In the 2001-2002 season, the Science-level data found 77 cyclone events compared to the 14 found by the Near-real-time data. In the 2003-2004 season, the numbers were 96 and 22, respectively. In addition, the Science-level detected more hurricane force extratropical cyclones than the N.R.T. data in the month of January 2007 for both the 12.5 and 25 km resolutions (15 to 12 and 10 to 6, respectively). Maximum wind speeds were also greater for the Science-level data when compared to the N.R.T data. Furthermore, for hurricane force extratropical cyclone events detected by both Science-level and N.R.T. data, hurricane force winds remained on the science-level satellite imagery for longer periods of time.

Figures 5 and 7 support the 7-year average monthly distribution of hurricane force extratropical cyclones, as the majority of cyclone events occur between the months of November and February.

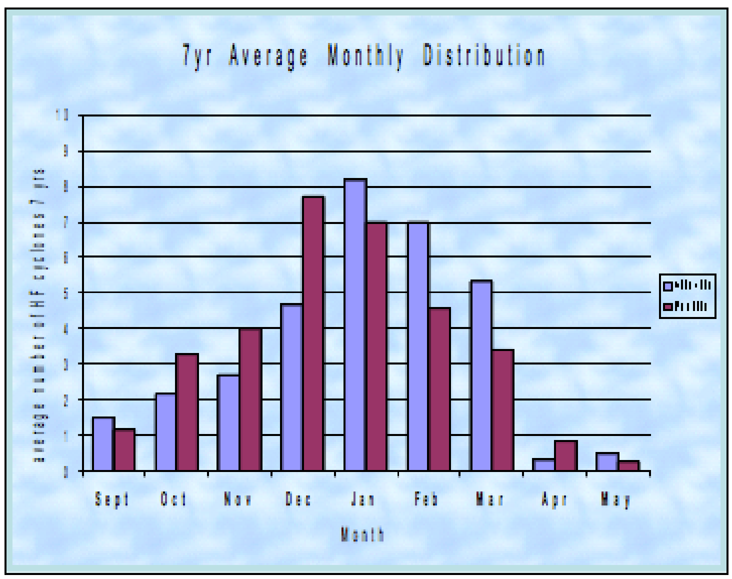


Figure 12: The 7-year average monthly distribution of hurricane force extratropical cyclones as detected by N.R.T. QuikSCAT.

At this stage in the research, the data for the 7 years looks to be normalized. Analysis from two seasons were given (the other seasons had similar results). The number of cyclones per storm season did not vary much season to season and there did not seem to be an increasing trend. The research will continue for normalization in the Atlantic. Time did not permit the Atlantic seasons to be covered. Nonetheless, it is clear that the use of high resolution data after May 2004 led to more detected cyclones as shown by my comparison of low-resolution to high-resolution QuikSCAT data

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Keywords
- **Extratropical Cyclones**
- **QuikSCAT**
- **Hurricane Force**