I. Introduction

The primary responsibility of The Ocean Prediction Center (OPC) at the National Centers for Environmental Prediction (NCEP) is the issuance of marine 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. Until recently, the primary sources of surface wind observations over the oceans have been ship reports through the VOS Program and data buoys. Ship observations are extremely useful to forecasters but are limited in number. The current network of data buoys is nowhere near optimal density therefore a substantial data void remains over the oceans.

Many attempts have been made to measure surface wind speed and direction using remote sensing instruments flown onboard satellites. The most recent has been the SeaWinds Scatterometer on NASA's Quick Scatterometer Spacecraft (QuikSCAT), which was launched in June 1999. The instruments on QuikSCAT can acquire thousands of times more observations of surface wind speed and direction each day than can ships and buoys combined. By providing continuous, high-resolution measurements of both wind speed and direction, regardless of weather conditions, QuikSCAT has been able to fill in much of the data void over the oceans. Since the data was incorporated into the National Oceanic and Atmospheric Administration's (NOAA) operational global weather analysis and forecast systems model in July 2001 the forecasters at the OPC have had near real time access to this data right at their computer workstations. The inclusion of the QuikSCAT winds in the forecast process has proved invaluable. During the period from 15Nov – 15Dec 2002 the OPC performed a study to quantitatively evaluate the influence of QuikSCAT winds in the issuance of marine warnings. Preliminary results indicate that using QuikSCAT winds in the forecast process has a significant and positive effect on the amount and type of marine warnings issued by the OPC forecasters. Several cases demonstrating the positive impact of QuikSCAT winds on the forecast process in the OPC have been examined and the results are presented in this article.

II. Background

History of Scatterometers

During World War II it was noted that radar measurements over the oceans contained noise or "sea clutter". It wasn't until the 1960's that this noise was related to wind velocity. Scatterometers are microwave radar sensors that were developed to measure this type of backscattering from an aircraft or a satellite. Scatterometers were first flown in space on board the Skylab missions in 1973 and 1974. In 1978, the Seasat-A Satellite Scatterometer (SASS) was flown on the Seasat-A satellite. However, due to a malfunction the mission only lasted four months. The European Space Agency flew a Scatterometer (SCAT) onboard its European Remote Sensing Satellite-1 (ERS-1) in 1991. Data was gathered for an 8-year period but coverage was limited due to the design of the scatterometer. In 1998, The NASA Scatterometer (NSCAT) was launched onboard the Advanced Earth Observing Satellite (ADEOS-I) and provided 90% coverage of the ocean areas within a 2-day period until the satellite lost power in 1997. The Quick Scatterometer Satellite (QuikSCAT) carrying the SeaWinds Scatterometer was launched in 1999 to fill the gap created when NSCAT data was no longer available. QuikSCAT provides complete coverage of the world's ocean surface every two days. Due to the success of NSCAT and QuikSCAT another SeaWinds Scatterometer on the ADEOS-II Satellite was launched in December 2002.

Date of Mission	Satellite	Instrument	Facts
1973-74	Skylab	• Simple scatterometer • Single measurements at one location at any given time	• First time a scatterometer was flown in space • Wind direction had to be calculated from another source.
1978	Seasat-A	• Seasat-A Satellite Scatterometer (SASS) • Ku-band scatterometer (14GHz) • Four fanned beamed antennas • 2 swaths (600Km each)	• Operational for 4 months until the spacecraft malfunctioned • Proved that accurate wind speed and direction measurements could be made from space
1991	European Space Agency Remote Sensing Satellite-1 (ERS-1)	• Scatterometer (SCAT) • C-band (5 GHz) • Single swath (500 km)	• Provided the longest record of global scatterometer data yet obtained.
1996	Advanced Earth Observing Satellite (ADEOS-I)	• NASA Scatterometer (NSCAT) • Ku-band (14GHz) • Two swaths, 600 km wide	• Provided measurements of ocean surface winds in all weather and cloud conditions. • Operated for 10 months until the solar panel failed. • Obtained 190,000 measurements per day mapped 90% earth's oceans every 2 days.
1999	QuikScatterometer Satellite (QuikSCAT)	• SeaWinds scatterometer • Ku-band, (13.4GHz) • Rotating dish antenna • One swath, 1800 km wide	• Quick fix for the loss of NSCAT data 400,000 measurements in one day • Provides measurements of ocean surface winds in all weather and cloud conditions. • Maps 90% earth's oceans every 2 days.
2002	ADEOS-II	• SeaWinds scatterometer • Ku-band, (13.4GHz) • Rotating dish antenna • One swath, 1800 km wide	• Launched in December 2002 • Will provide measurements of ocean surface winds in all weather and cloud conditions. • Will map 90% earth's oceans every 2 days.

III. QuikSCAT winds in the Ocean Prediction Center

The Ocean Prediction Center (OPC) is a part of the National Centers for Environmental Prediction (NCEP) located at the NOAA Science Center in Camp Springs, MD. The OPC is operational 24hours per day, 7 days per week. The staff consists of 20 experienced meteorologists along with small technical development and administrative branches. The primary responsibility of the OPC is the issuance of marine warnings, forecasts, and guidance in text and graphical format for maritime users for the of protection of life and property, safety at sea, and the enhancement of economic opportunity These products cover the North Pacific and North Atlantic Oceans on three scales: high seas, regional and offshore and are prepared and disseminated on a fixed, recurring schedule. The OPC also quality controls marine observations globally from ship, buoy, and automated marine observations for gross errors prior to being assimilated into computer model guidance.

The OPC forecasters use the (National Centers - Advanced Weather Interactive Processing Systems (N-AWIPS) workstations to view model output, satellite, observational data, and OPC graphical and text products. These workstations are also used to generate graphics and text products. To prepare their analyses and forecasts the OPC forecasters look at observational data from satellites, ships, buoys and other NCEP surface analyses. As previously stated, observational data over the ocean areas is sparse. When QuikSCAT data was made available to OPC Forecasters on the N–AWIPS workstations in 2001 they were able to get near real-time observations over much of their forecast areas. This proved invaluable in locating centers of high and low pressure, frontal systems and areas of gale force winds (and stronger.) Forecasters quickly realized that QuikSCAT enabled them to get a better handle on their analyses. They were also able to more confidently issue, raise or lower gale, storm, and hurricane force wind warnings. Currently OPC is in the process of quantitatively evaluating the influence of QuikSCAT winds in the verification of issued warnings.

IV. The Impact of QuikSCAT on the forecast process

During the late fall of 2002 a month long study was conducted to quantify the effects of QuikSCAT wind data on the listing of marine warning labels on the surface analyses produced by OPB of the NCEP (see fig1). Warning labels are listed according to the following criteria:

- Gale Warning - Refers to an extratropical low with an area of sustained surface winds (one minute) of 34 knots (39 mph) to 47 knots (54 mph).
- Storm Warning - Refers to an extratropical low with an area of sustained winds (one minute) in excess of 48 knots (55 mph).
- Hurricane Force Warning- Refers to an extratropical cyclone with an area of sustained surface winds (one minute) of 64 knots (74 mph) or greater

Forecasters were provided shift logs and were asked to note when QuikSCAT winds were the deciding factor in the issuance or change of a warning label as shown on surface analyses.

Two forecast areas were used- the Atlantic High Seas and the Pacific High Seas. The data was collected from 15 NOV thru 15 DEC 2002 for four forecast periods daily (00Z, 06Z, 12Z, 18Z). Forecasters were asked to document how many times they used QuikSCAT winds during their shift according to the following categories:

- Upgrade to Gale – without QuikSCAT would have issued no warning
- Upgrade to Storm- without QuikSCAT would have issued a gale warning.
- Upgrade to Hurricane Force- without QuikSCAT would have issued a Storm warning.
- Downgrade from Gale – without QuikSCAT would have issued a Gale warning
- Downgrade from Storm- without QuikSCAT would have issued a Storm Warning
- Downgrade from Hurricane Force – without QuikSCAT would have issued a Hurricane Force Warning
- Maintain current warning- without QuikSCAT would have issued the same warning.

At the end of the test month the data was collected and entered into a spreadsheet for analysis. The total number of warnings issued per forecast area was first determined. Then for each forecast area the total number of warnings issued was broken down by type (Gale, Storm, Hurricane Force) this dataset was labeled The Number of Warnings Issued With QuikSCAT Winds. Using the forecasters shift logs and the corresponding surface maps any warnings that were based solely on QuikSCAT Data were added or removed from the original dataset. This second dataset was labeled The Number of Warnings Issued Without QuikSCAT Winds.

Upon examining the results it was noted that for each forecast area more warnings were issued when QuikSCAT winds were used in the forecast process – 30% in the Atlantic and 22% in the Pacific (see figure 2). 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 figures 3 and 4),

When the data was analyzed according to warning type it became apparent that QuikSCAT had a greater impact with the more significant warning types (see figures 5 - 7). The greatest impact was noted in the Pacific with a 42% increase in the issuance of Hurricane Warnings.

These results are very encouraging. For the first time we can quantitatively document the fact that QuikSCAT winds do indeed have a positive and significant impact on the forecast process.

V. Case Studies

Ocean	Date	Time	Location of Low	Situation
Atlantic	04Dec	12Z	46N 52W	Ship reports all 35kts or less indicating the issuance of a Gale Warning. The QuikSCAT pass from 0945Z indicated an area of storm force winds. The forecaster upgraded his warning to Storm Force. (See figures 8a,b, c)
Atlantic	10Dec	12Z	56N 52W	Ship reports all 40kts or less, indicating the issuance of a Gale Warning. The QuikSCAT pass from 1045Z showed Hurricane force winds. The forecaster upgraded his warning to Hurricane Force. (See figures 9a,b, c)
Pacific	15Nov	00Z	54N 172E	Ship reports all 35kts or less except for one report indicating 50kts. This appeared too high. Forecaster used QuikSCAT passes from 11/14 1900Z, 1930Z to check ship report. QuikSCAT showed an area of 50kt winds, so the forecaster upgraded his warning to Gale/Developing Storm. (See figures 10a,b, c)
Pacific	03Dec	12Z	43N 175E	Ship reports indicated winds of 40kts, with one report of 60kts. Forecaster used QuikSCAT passes from 0750Z, 0830Z, which indicated Hurricane force, winds. Forecaster issued Hurricane Force Warning. (See figures 11a,b, c)

VI Summary

Upon completion of the month long study of QuikSCAT in the OPB it was obvious that using QuikSCAT winds in the OPB Forecast Process did indeed make a positive and significant impact on the issuance of Marine Warnings. Not only were more warnings issued, but also forecasters were able to issue the stronger warnings with more confidence.

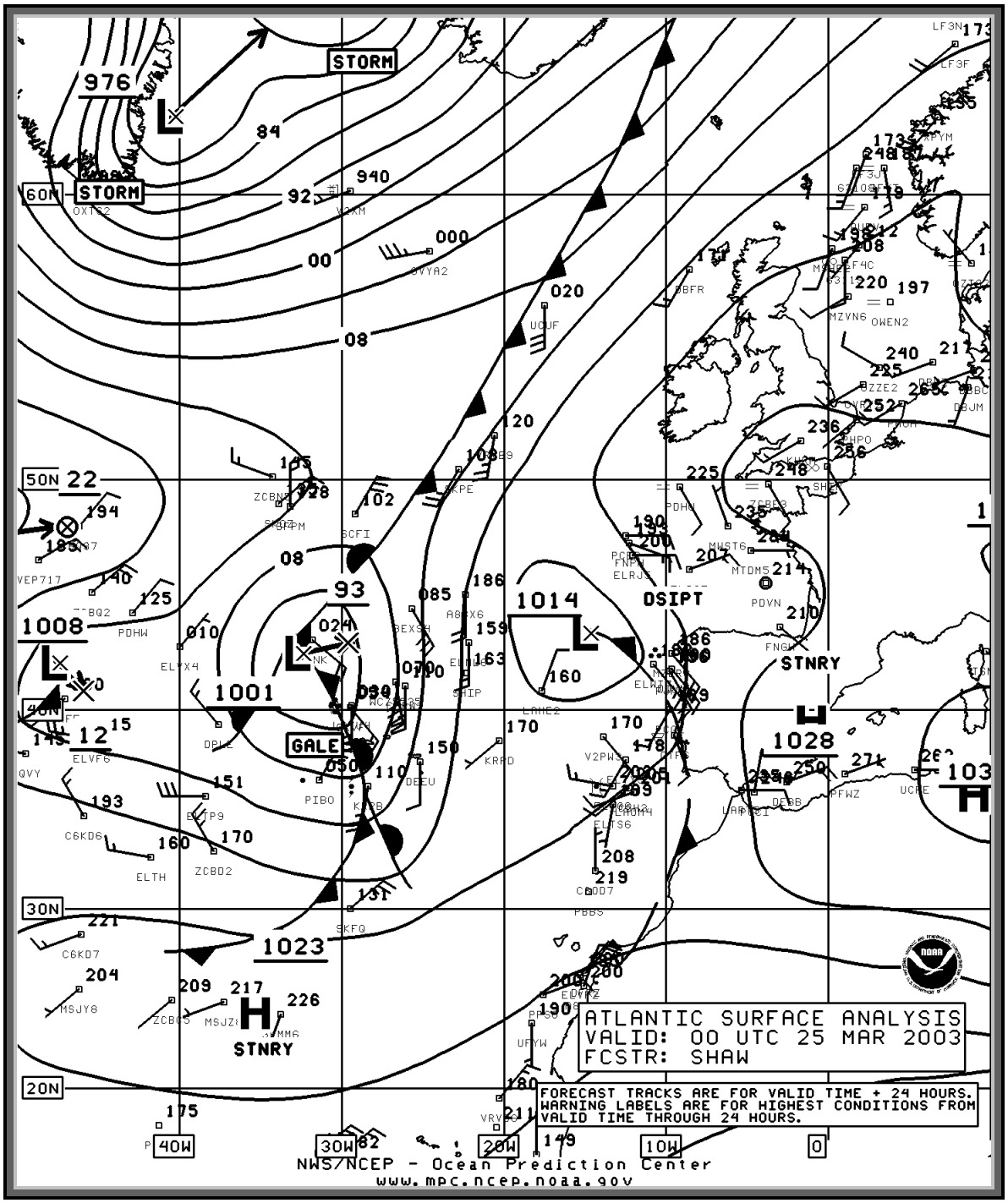

Figure 1

Marine Warnings are indicated on the Surface Analysis by a box with the warning type inside. In this example there are two Storm Warnings and one Gale Warning.

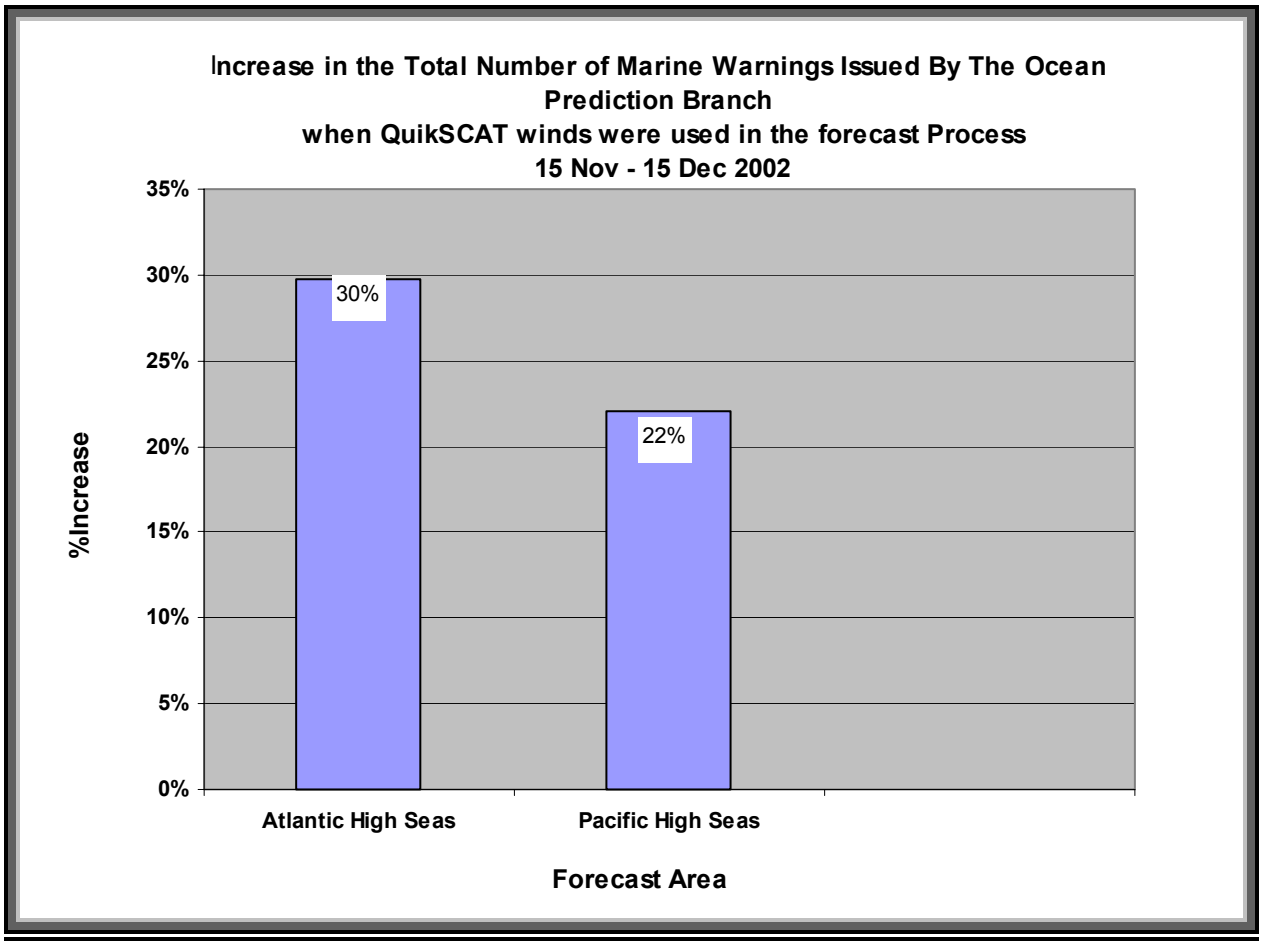

Figure 2

When QuikSCAT winds were used in the forecast process the number of Marine warnings increased by 30% in the Atlantic Ocean and by 22% in the Pacific Ocean.

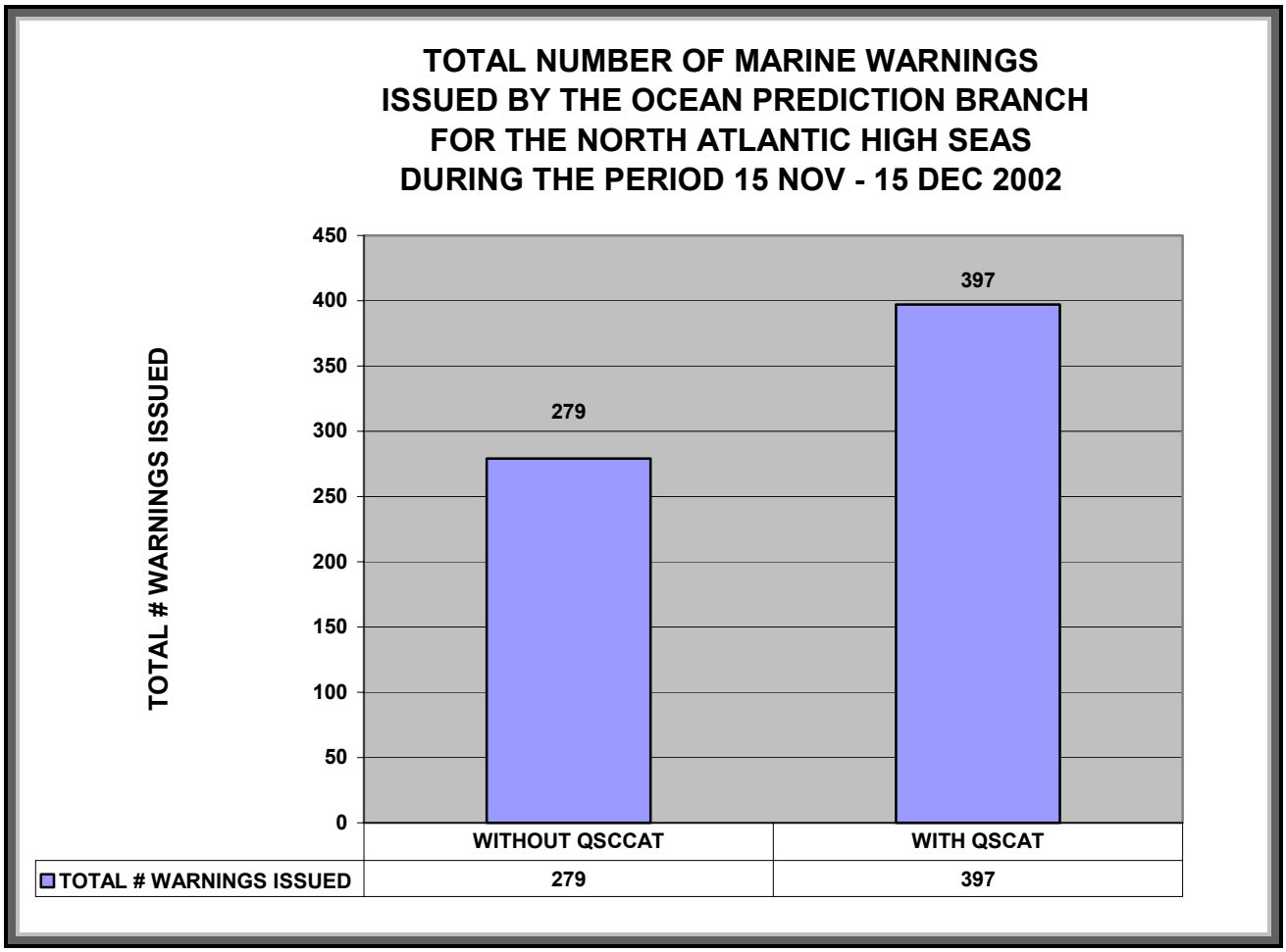

Figure 3

In the Atlantic Ocean, 397 Marine Warnings were issued with QuikSCAT versus only 279 without QuikSCAT.

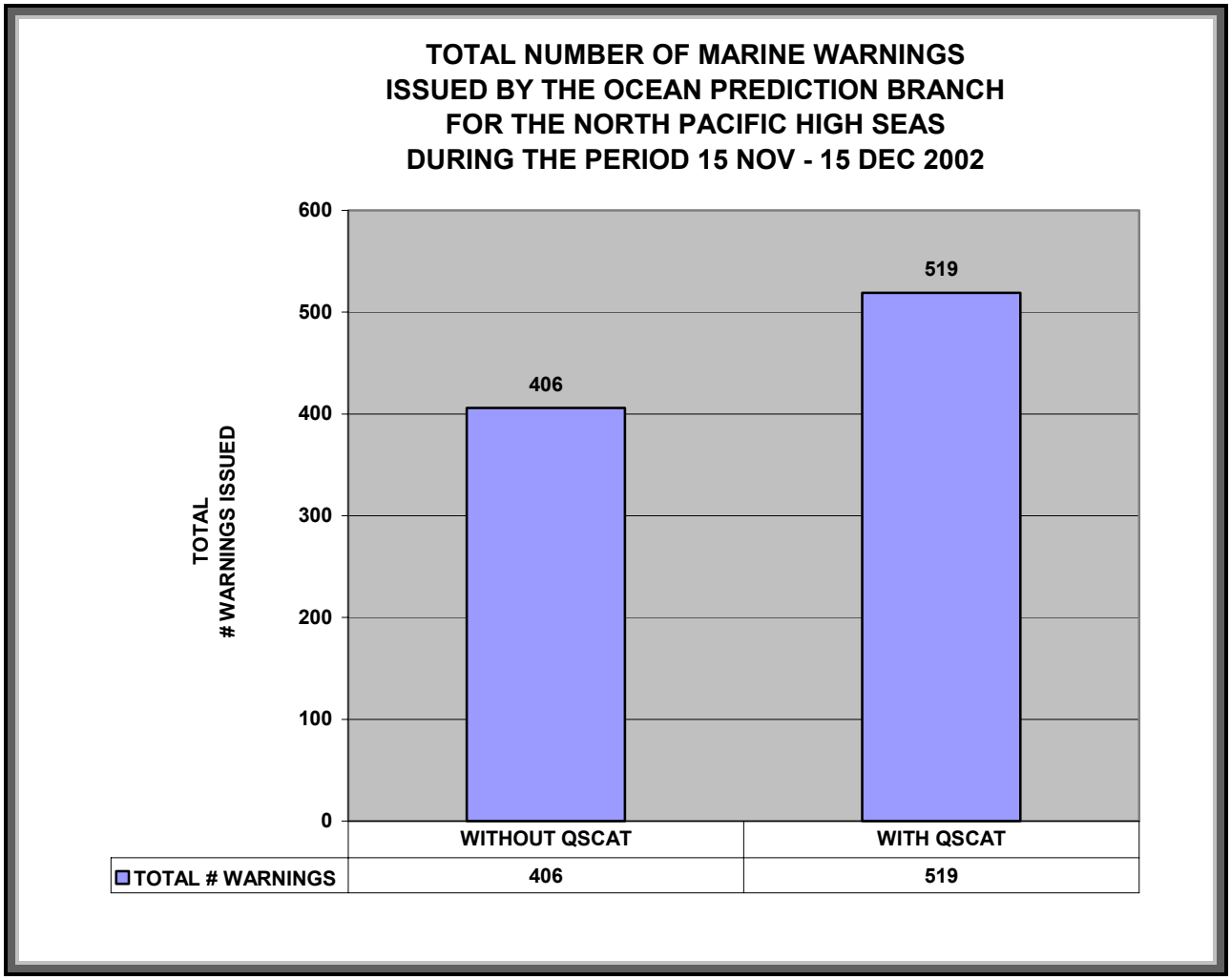

Figure 4

In the Pacific Ocean 519 Marine Warnings were issued with QuikSCAT versus 406 without QuikSCAT.

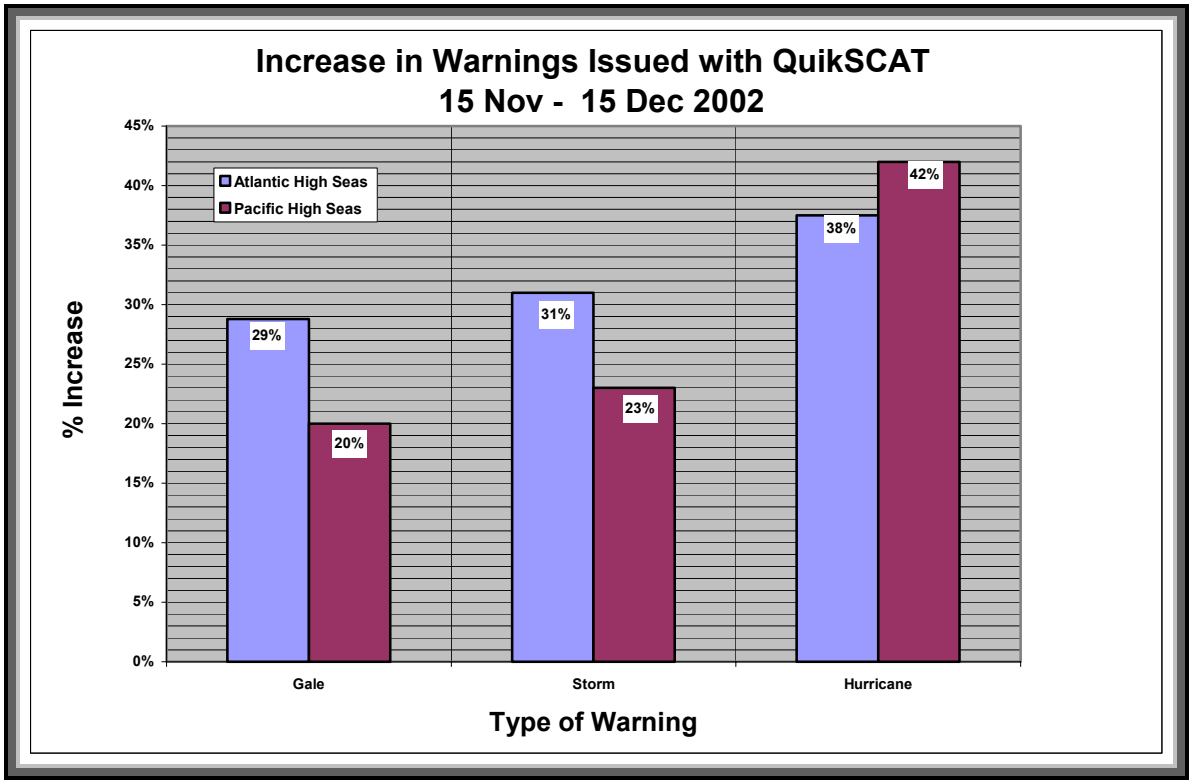

Figure 5

The increase in the number or marine warnings issued with QuikSCAT was greater with the more significant warning types. The greatest impact was noted in the Pacific Ocean with the issuance of Hurricane Force Warnings.

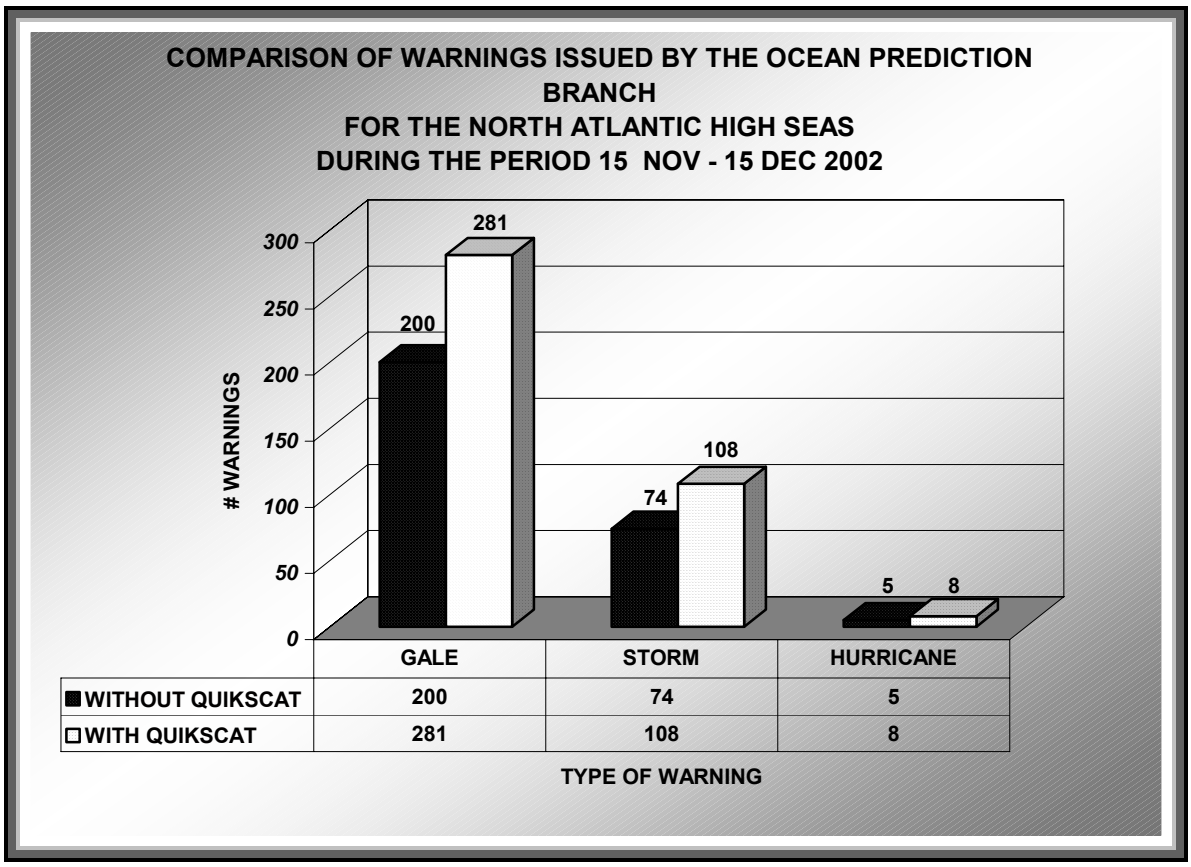

Figure 6

The Number of warnings issued with QuikSCAT compared to the number of warnings issued without QuikSCAT by warning type in the Atlantic Ocean.

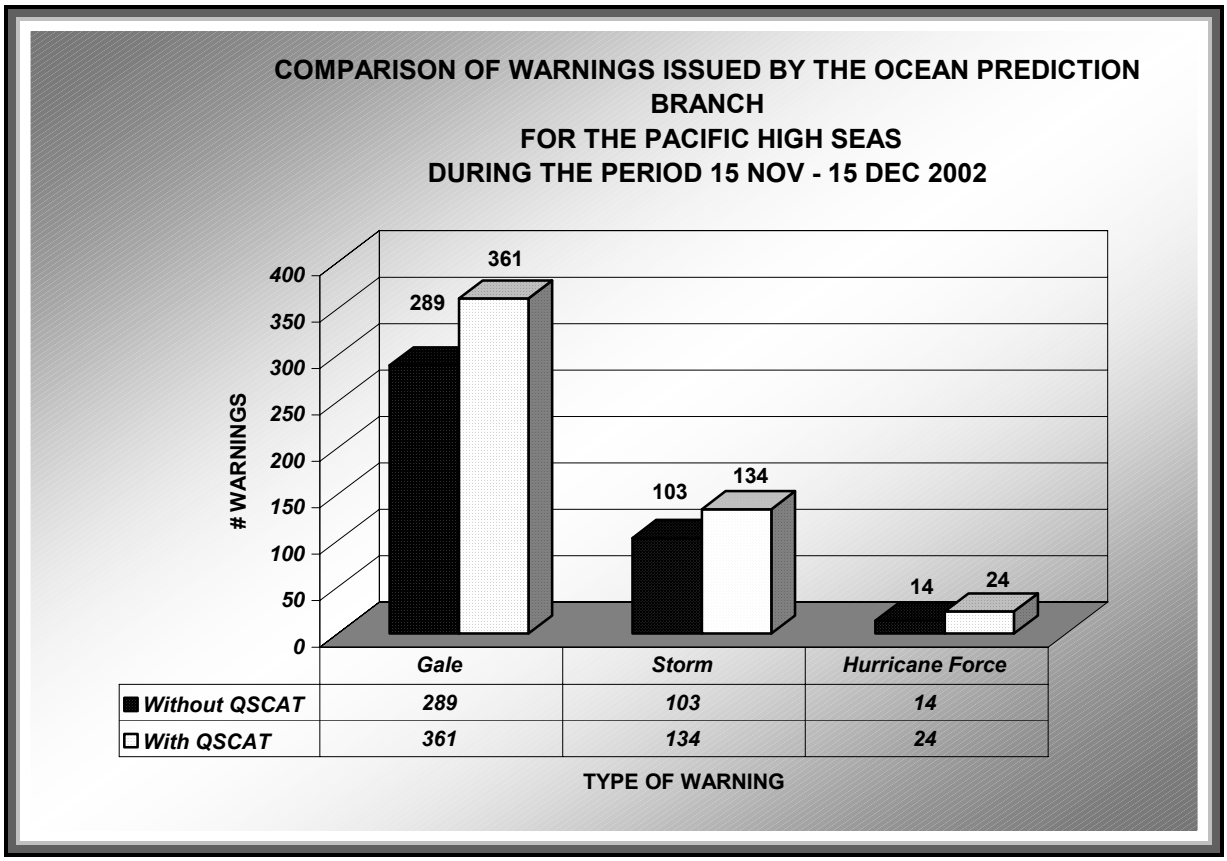

Figure 7

The Number of warnings issued with QuikSCAT compared to the number of warnings issued without QuikSCAT by warning type in the Pacific Ocean.

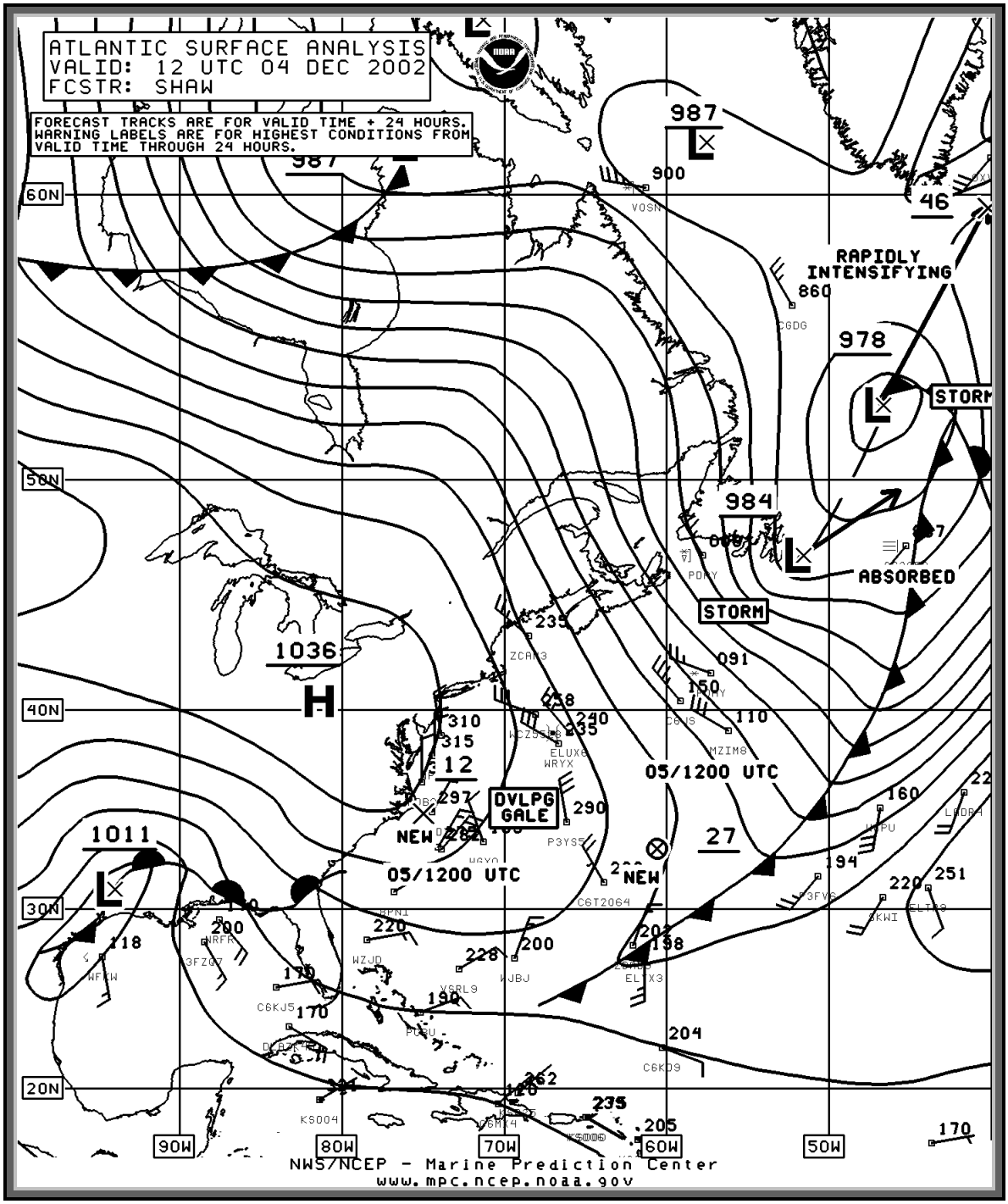

Figure 8a. Surface Analysis for 04 Dec 2002 12Z

Ship reports indicated 30-35kt winds around the Low just south of Newfoundland, which would have resulted in the issuance of a Gale Warning.

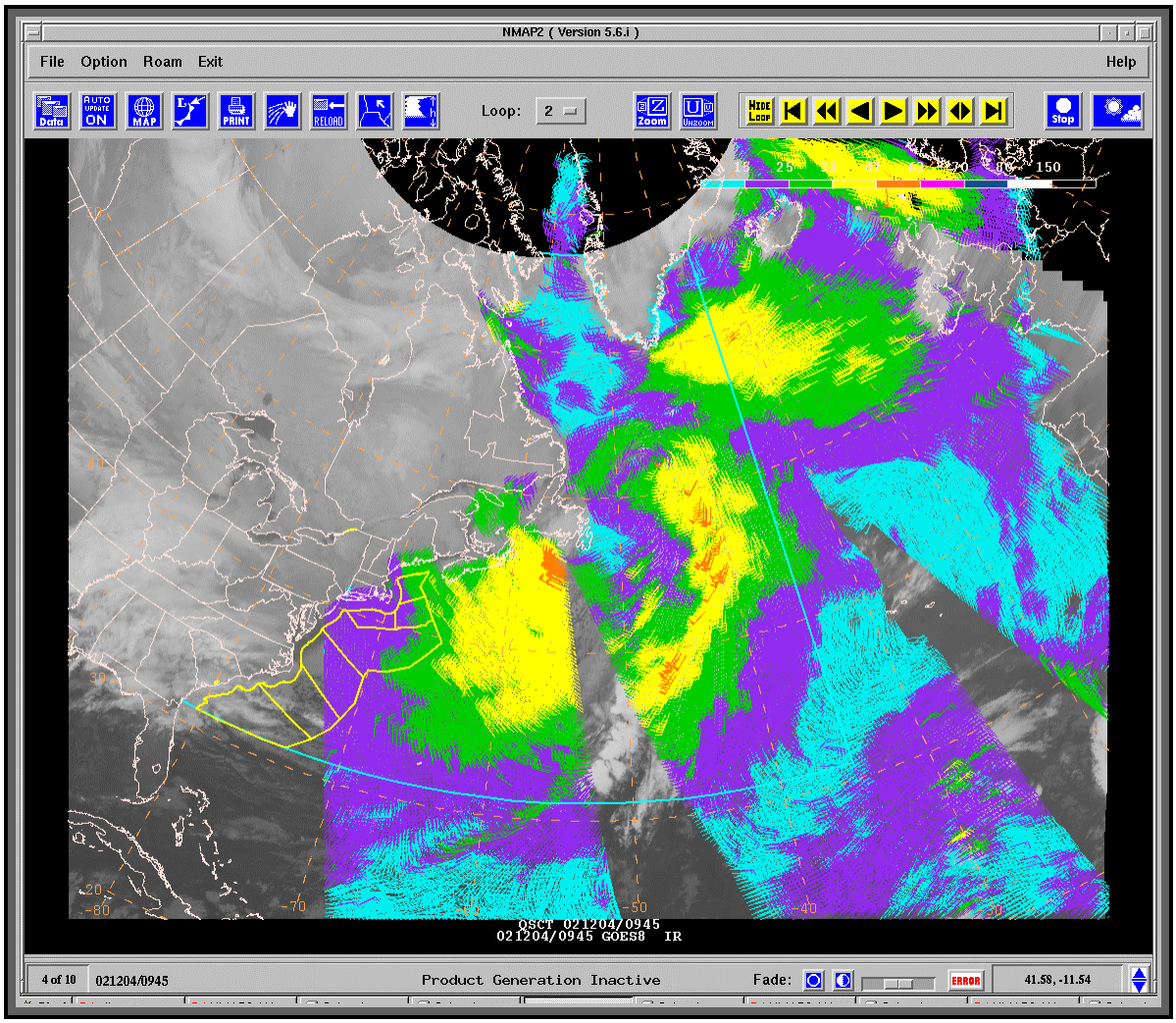

Figure 8b

The QuikSCAT pass from 04 Dec 2002 0945Z clearly shows an area of storm force winds around the Low south of Newfoundland. The forecaster upgraded his warning from Gale to Storm force .

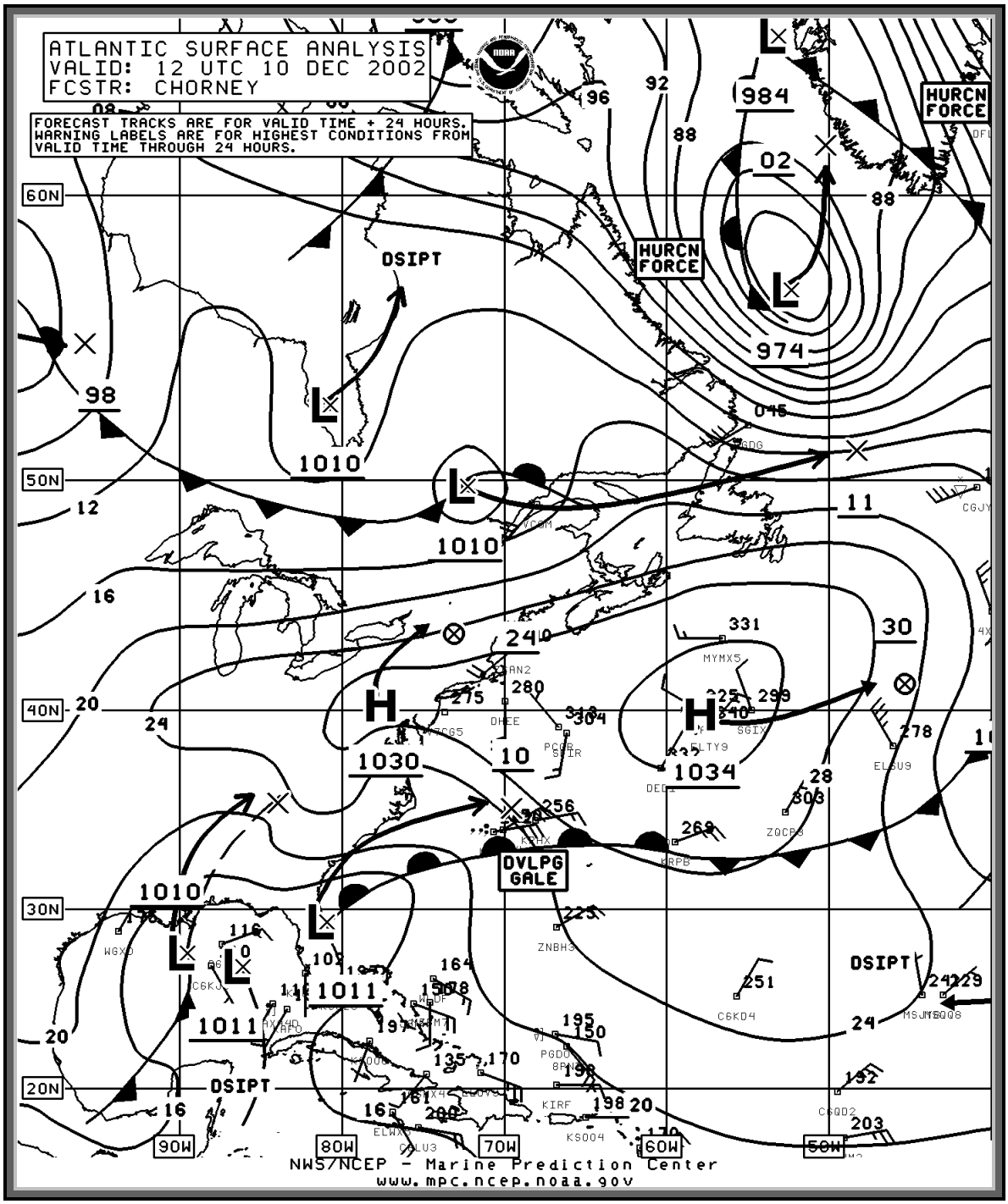

Figure 9a. Surface Analysis for 10 Dec 2002 12Z

Ship reports were sparse in the vicinity of Low southwest of Greenland. Reports indicated only 40Kt winds with this system, warranting the issuance of a Gale Warning.

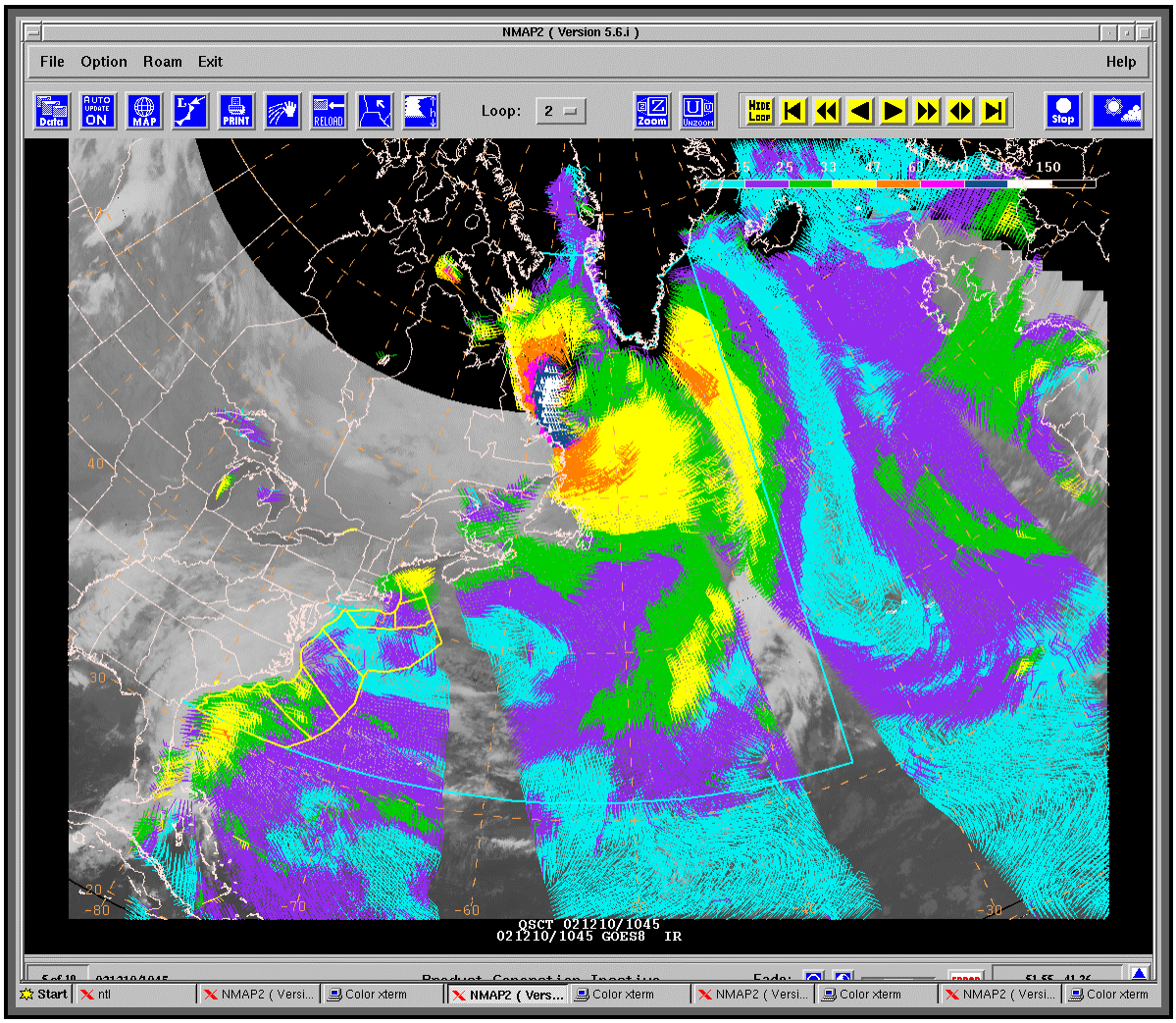

Figure 9b.

The QuikSCAT pass from 10 DEC 2002 1045Z showed an area of winds >65kts. The forecaster upgraded his warning from Gale to Hurricane Force.

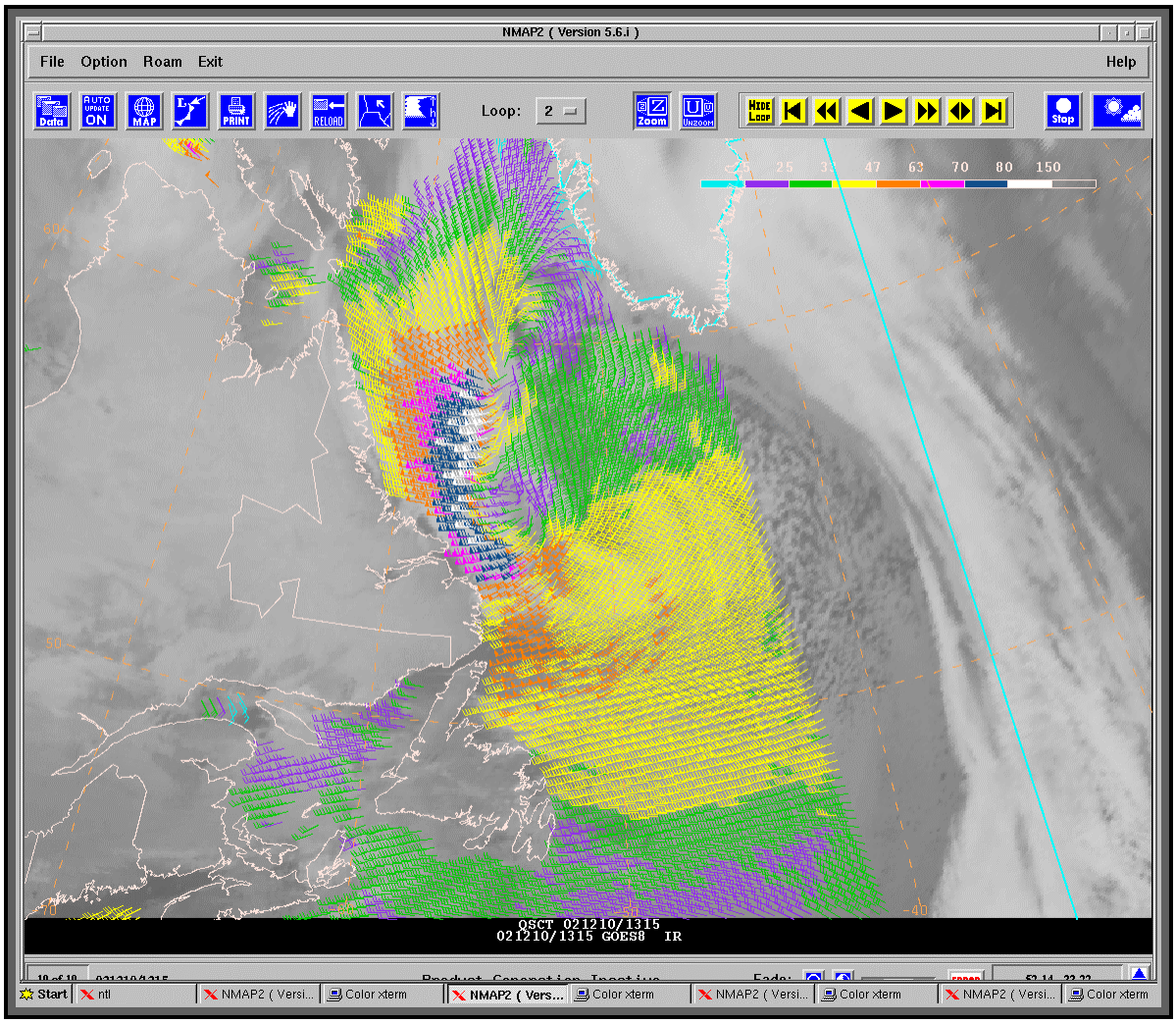

Figure 9c.

QuikSCAT pass from 10 DEC 2002 1315Z continued to show Hurricane Force winds with the Low, confirming the forecasters decision to upgrade the warning.

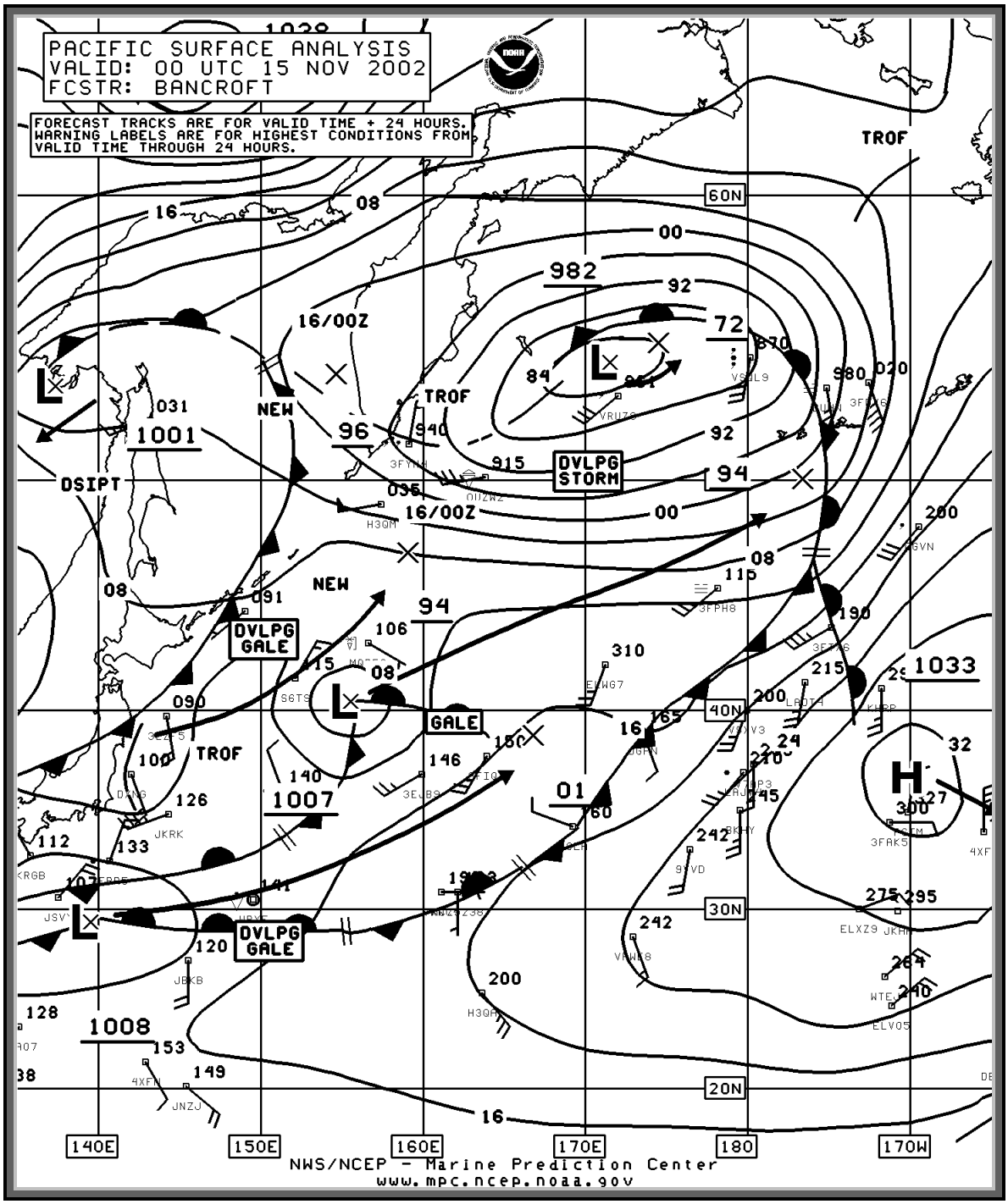

Figure 10a. Surface Analysis for 15 NOV 2002 00Z

Ship reports in the vicinity of the Low were mostly 35kts or less. One 50kt wind was noted, but it seemed to be too high. Based on the surface analysis alone, the forecaster would have been inclined to ignore the 50kt wind and not issue a warning.

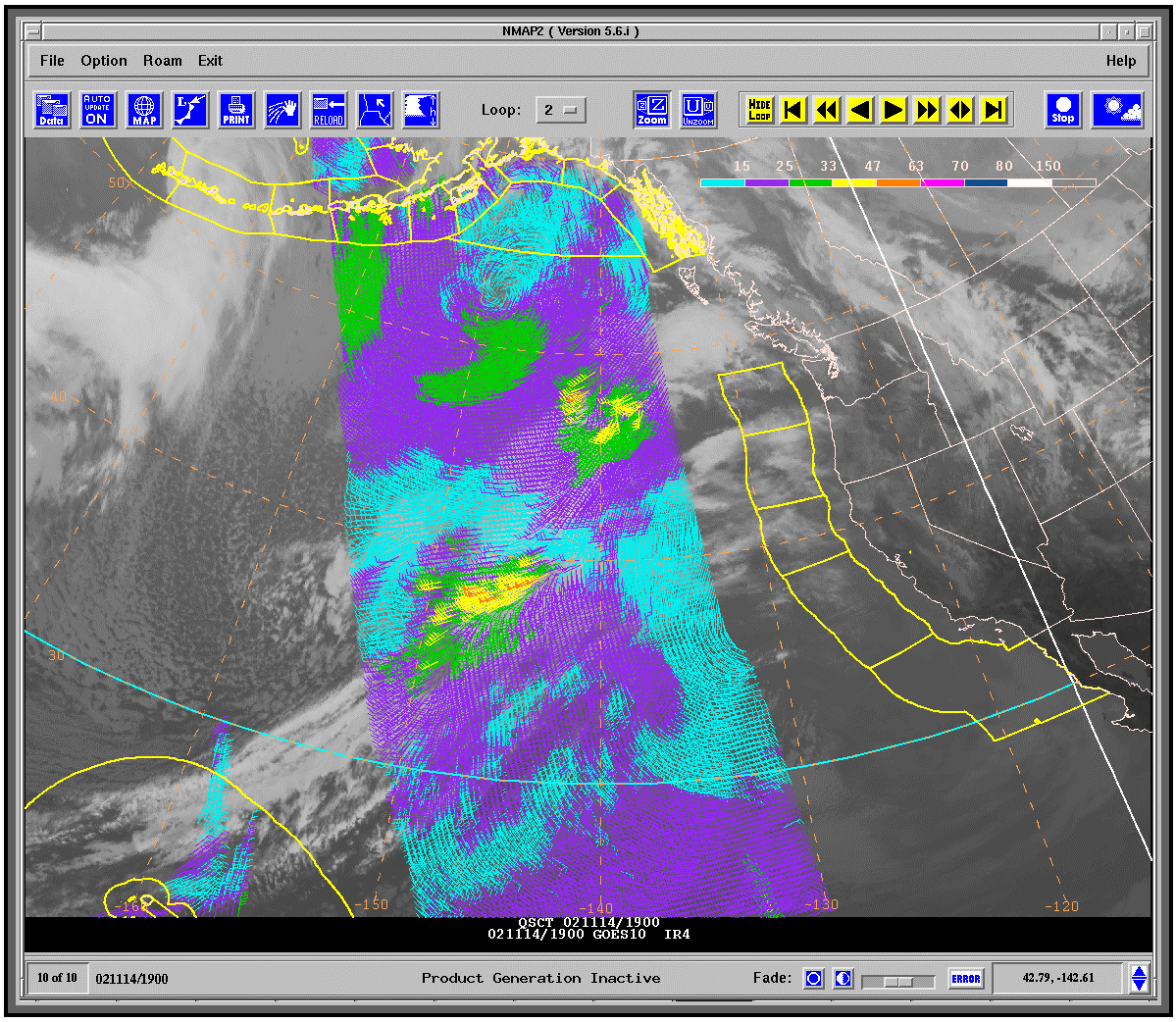

Figure 10b.

The QuikSCAT pass from 14 NOV 1900Z indicated an area of winds speeds in excess of 50kts in the vicinity of the Low. The forecaster decided to issue a warning Developing Storm (Gale) Warning.

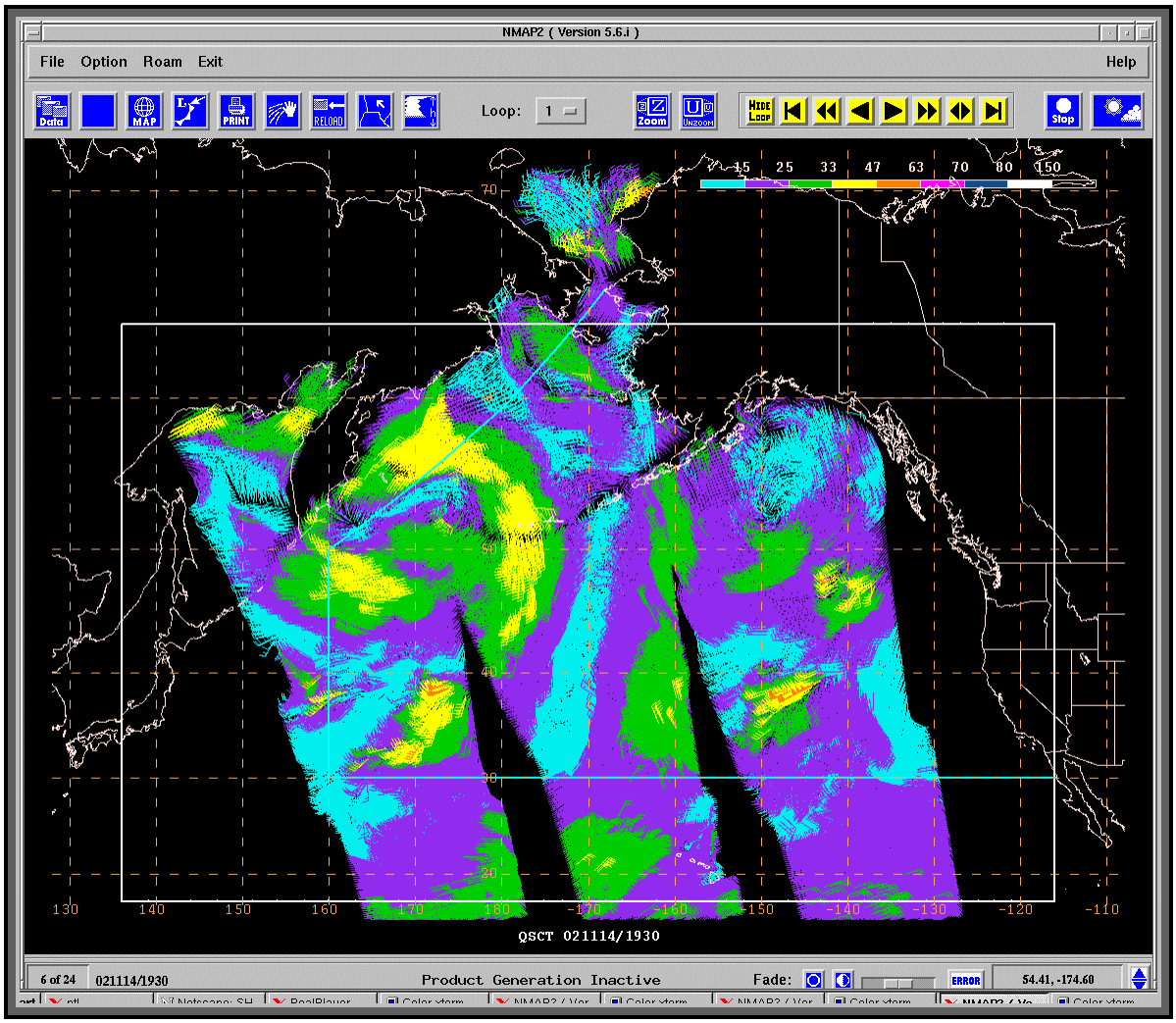

Figure 10c

QuikSCAT pass from 11 NOV 2002 1930Z continued to show winds in excess of 50kts around the low, confirming the forecasters decision to issue the Gale Warning.

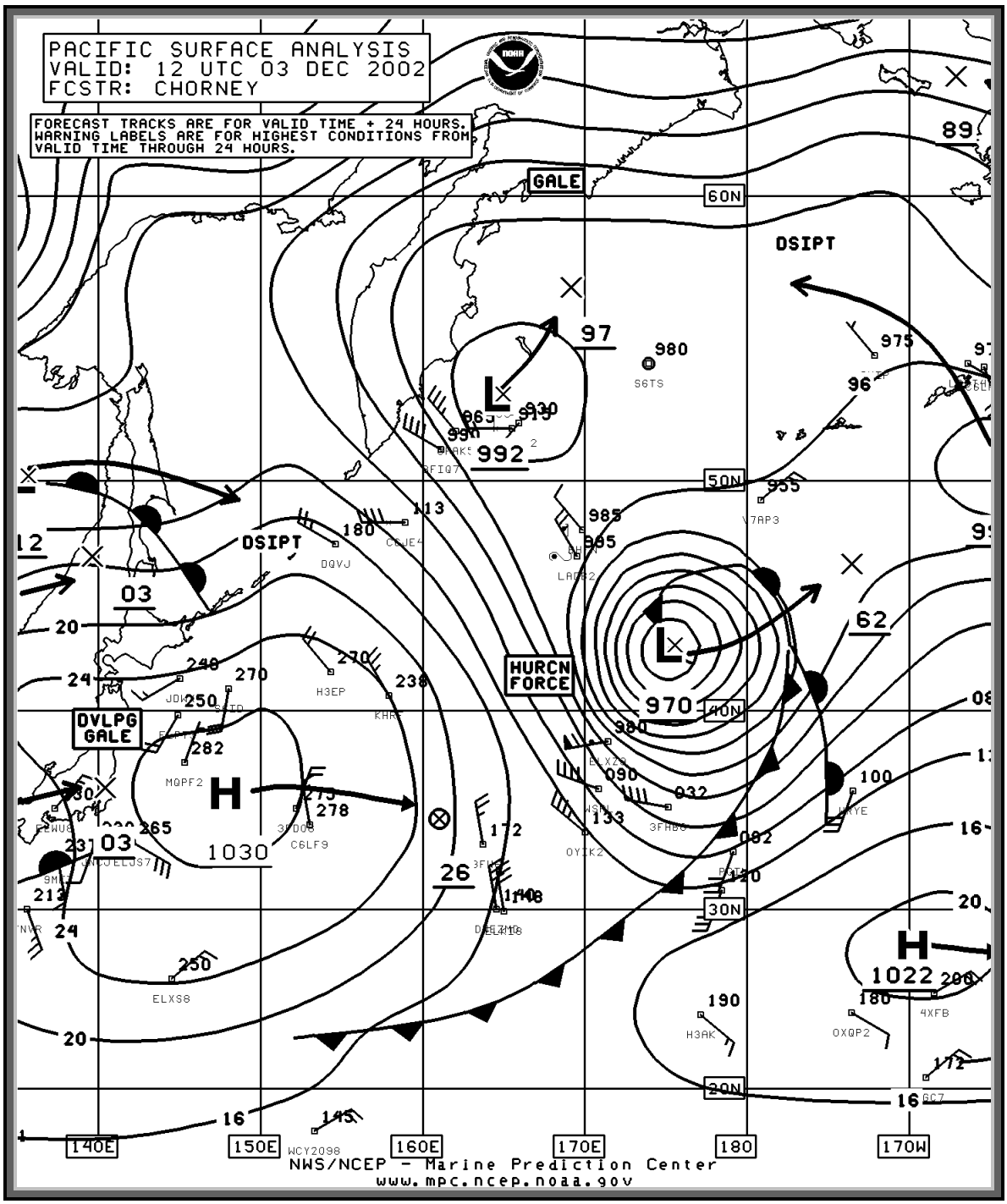

Figure 11a. Surface Analysis from 03 DEC 2002, 12Z

The majority of the ship reports in the vicinity of the Low indicated winds speed of 40kts or less. One 60kt report was thought to be inaccurate. Based on this wind field the forecaster would have only issued a Gale Warning.

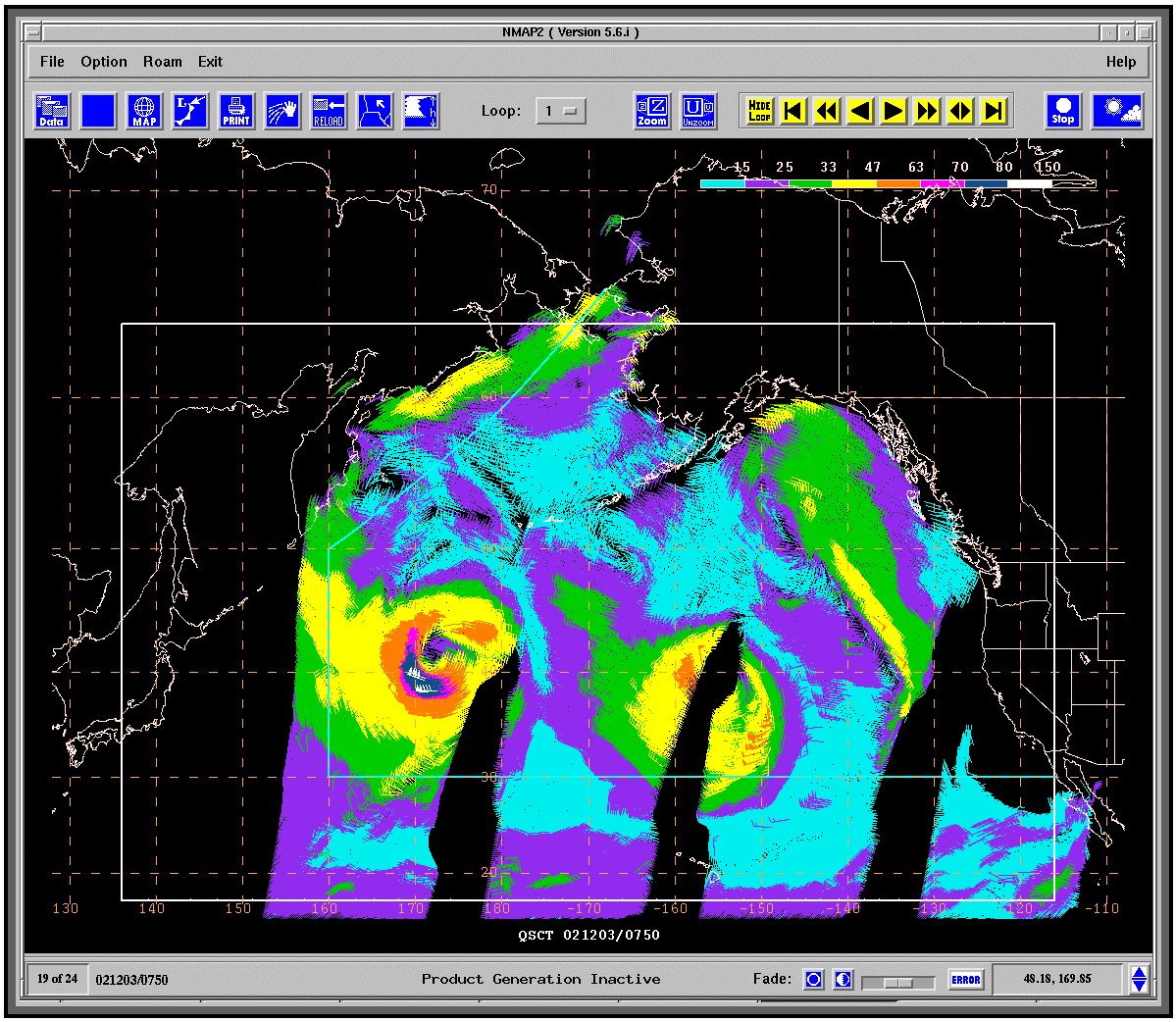

Figure 11b.

QuikSCAT pass from 03 DEC 2002 0750Z indicated an area of winds >70kts with a few measurements over 80kts. Based on this pass, the forecaster decided to issue a Hurricane Force Warning.

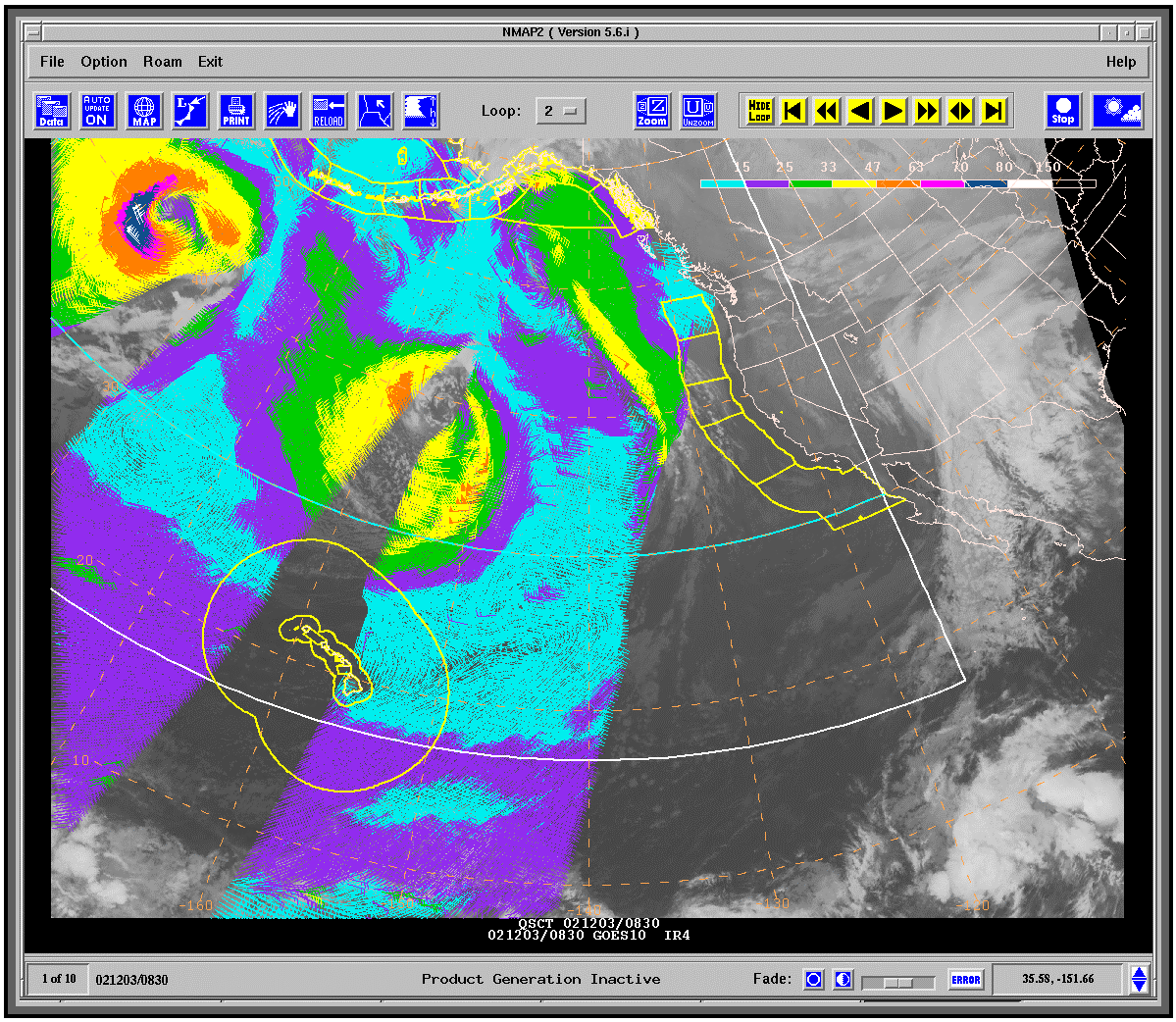

Figure 11c.

A second QuikSCAT pass from 03 DEC 2002 0830Z indicated that the winds were maintaining Hurricane Force strength.

Outline
Article for Mariner's Weather Log

The use of QuikSCAT winds in the Ocean Prediction Center Forecast Process

I. Introduction
    -Importance of marine forecasting
    -Need for more data
    -Use of QuikSCAT

II. Remote sensing and QuikSCAT background/history (include Seasat, etc)

III. Use of QuikSCAT in Ocean prediction center

II. Results of month long study/Case studies

III. Summary/conclusion