Mariners WEATHER LOG

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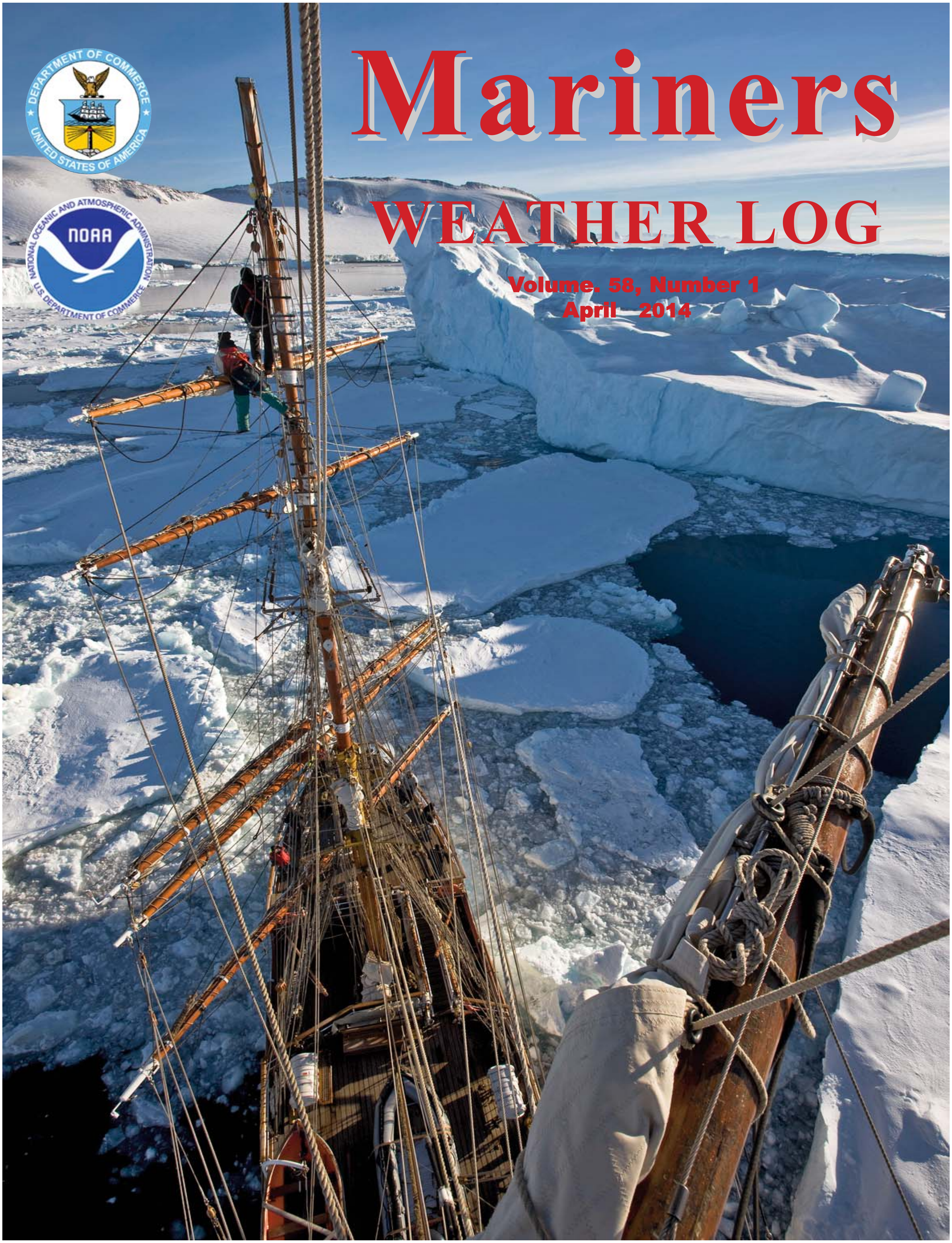

Mariners Weather Log

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From the Editor

Hello and welcome once again to another great edition of the Mariners Weather Log. It has been a busy year for VOS with all the changes and upgrades as well as working around our budget constraints. With all this at hand, you, our marine weather observers remain true to the cause and we appreciate all that you do. Our data is getting better than ever and our goal remains quality over quantity.

On the cover, I have a wonderful article submitted from one of our European comrades, Margot Choquer from "OceanoScientific". Margot was introduced to me via email by Martin Kramp; Martin is Ship Coordinator for Ship Observations Team (SOT), JCOMMOPS (WMO/IOC-UNESCO). Martin's association with this ongoing project gave me a perfect opportunity to showcase their story. The **Bark EUROPA** travels some of the most data sparse regions of the world, including the austral ocean, and below the Cape Good Hope, Cape Leeuwin as well as Cape Horn; some of the most hostile areas to be found. The overall approach is a solid collaboration between French and Germany institutes as well as the University of Maine, USA. The entire article is impressive, from the science to the dedicated crew and one of the oldest sailing vessels in existence, which in itself, is a sight to behold.

Nicknamed the "White Hurricane", Freshwater Fury", and "Great Storm of 1913", this story of the 1913 storm remains the most devastating natural disaster to ever strike the Great Lakes. Richard Wagenmaker, Meteorologist from Detroit Forecast office submitted this great piece. One hundred years later, NOAA commemorates the Storm of 1913, not only for the pivotal role it plays in the history of the Great Lakes, but also for its enduring influence. The article is amazing and it is hard to believe how little we had to create forecasts and our limited ability to communicate these events. Everything back then was manual and other than "past experiences" one could fall back on, there was a lot of "unknowns" that the mariner had to deal with. Communications were a vital link that held a huge impact on the inability to relay critical information to the mariners in a timely fashion. This article really captures the importance of our National Weather Service launching a comprehensive initiative to build a "Weather Ready Nation". It also showcases the need for good marine weather observations, they do matter!

A special thanks to Christopher Landsea for his contribution on Supertyphoon Haiyan; "Mean Circulation Highlights and Climate Anomalies by Anthony Artusa". Chris is the Science Operations Officer at the National Hurricane Center in Miami, Florida. We appreciate all that you do!

I know you will find this issue interesting. If you have any comments or questions, please send them on! I love getting articles submitted and those photographs I receive are really magnificent. Thank you so much. Remember…Only YOU know the weather, report it!

Regards,

Paula

On the Cover:
Bark EUROPA crew members climbing the mast to guide the helmsman through the ice. Photo **Bark EUROPA**

Mariners Weather Log

Volume. 58, Number 1, April 2014

Table of Contents

Departments:

Marine Weather Review

VOS Program

Bark EUROPA: The *OceanoScientific*® System onboard the three-master

Margot Choquer - OceanoScientific®
***Bark EUROPA** crew and shore team*
Martin Kramp - Ship Observations Team, JCOMMOPS (WMO/IOC-UNESCO)

Technical Details

Built: 1911
Home port: The Hague, The Netherlands
Length overall: 56 m
Beam: 7.45 m
Draft: 3.9 m
Air draft: 33 m
Max sail area: 1250 m2
Engines: 2 x 365 hp
Call sign: PDZS

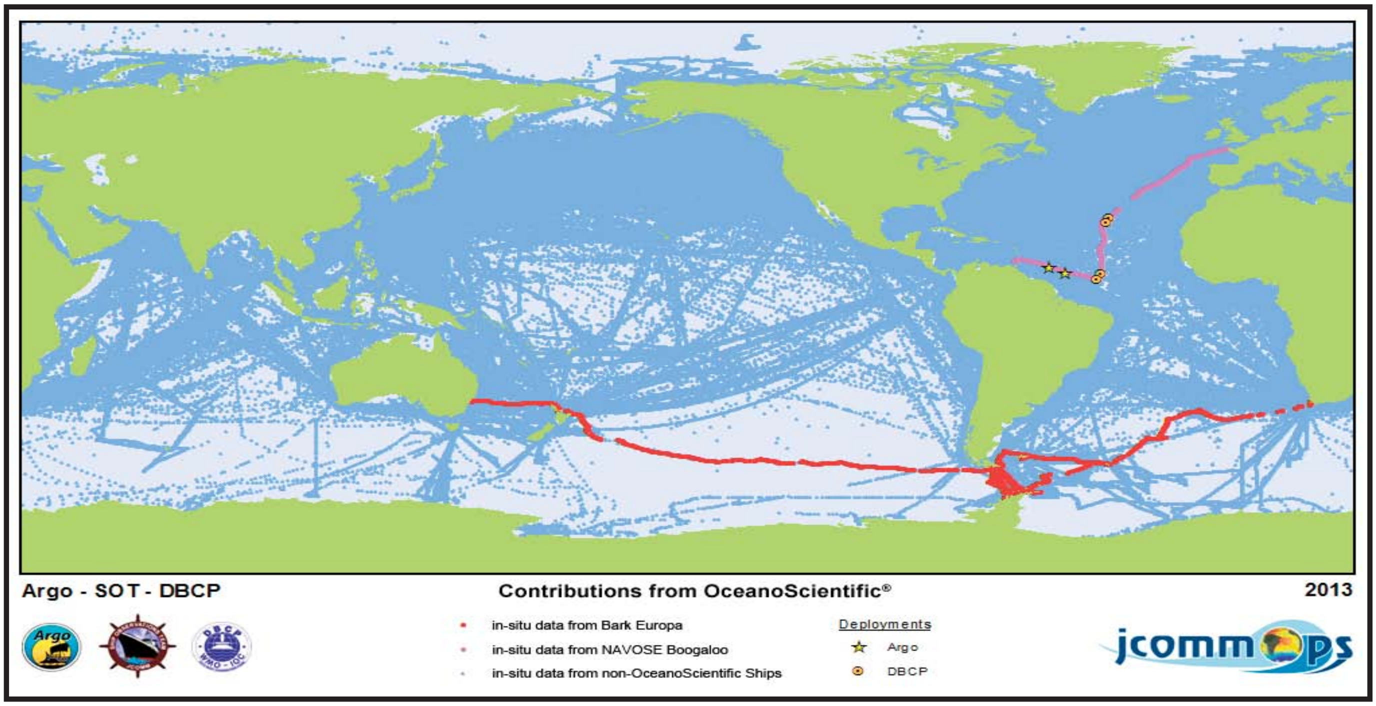
The three-master **Bark EUROPA** was built in 1911 in Hamburg (Germany) and fully rebuilt and re-rigged in 1994 in Amsterdam (the Netherlands). Since she started her new life as a cruising ship, the three-master has roamed the seas of the world. A professional crew combined with a voyage crew of all ages and nationalities sail her. Tall Ship enthusiasts, some with no sailing experience, take the wheel, hoist the yards, navigate and much more. Participating in sailing and running the **Bark EUROPA** is part of the overall experience on board.

Bark EUROPA* in Antarctica, among the icebergs. Photo copyright Hajo Olij - *Bark EUROPA

Bark EUROPA follows the favorable winds of traditional sailing routes. Since the year 2000 **Bark EUROPA** has been crossing oceans on a regular basis and has a reputation of a ship that really sails. Everyone on board is assigned to the watch duties to navigate and steer the ship and to hoist and lower the sails. On board everybody is given the opportunity to experience all aspects of the life of a sailor. From December to March, in the Southern summer, she sails to the Antarctic Peninsula. These voyages appeal to the sailing enthusiasts, the birdwatchers, the photographers, the artists, and the nature-lovers who want to discover the unspoiled environment. The expeditions start in Ushuaia, Argentina, the most southern city in South America. From there, the ship must cross ‘the Drake Passage’, known to sailors all over the world. Albatrosses and Petrels accompany the ship on her way to the Antarctic paradise. In the Antarctic waters, the three-master anchors in sheltered bays almost every day. The crew takes groups ashore in the dinghies to see glaciers, seals, birds and penguin rookeries. In the mean time, the adventurers waiting onboard are given lectures by experienced guides about the flora, the fauna and where to find bird and sea elephant colonies. The boat meets there the most loyal visitors of the Southern Ocean: enormous Humpback and Minke whales and even Orcas may well come close to the ship, curious to see who ventures into their waters as steep glaciers, walls of ice with magical shapes and surreal colours surround the vessel.

The *OceanoScientific® Programme* is currently carrying out expeditions on 2 sailing vessels: onboard a 16-meter sailing ship especially designed for scientific use, the **NAVOSE®** - that is to say in French: **N**avire **A V**oile d'**O**bservation **S**cientifique de l'**E**nvironnement (meaning: Sailing Vessel for the Scientific Observation of the Environment) and the three-master **Bark EUROPA**. Based on first trials in former years, successful expeditions onboard the **NAVOSE®** (North Atlantic) and the three-master **Bark EUROPA** (Drake Passage, Cape Horn, Antarctic, South Pacific) were recently carried out in 2013 and early 2014. The emerging data proved to be of good quality and were gathered on transocean transects partially without any observation from other vessels throughout 2013.

The *OceanoScientific® Programme* developed its own tool: The *OceanoScientific® System* (OSC System), which is an innovative "Plug & Play" equipment for the automatic acquisition and transmission by satellite of ten to twelve scientific parameters on platforms not suitable for existing systems (such as "Ferryboxes") due to size, weight, power consumption and other issues. Methods



Spatial distribution of the data gathered thanks to the OceanoScientific® Programme in 2013 onboard two vessels - **Boogaloo** and **Bark EUROPA** - both members of the Voluntary Observing Ships (VOS) programme as part of the JCOMM's Ships Observation Team (WMO/IOC-UNESCO). Chart JCOMMOPS

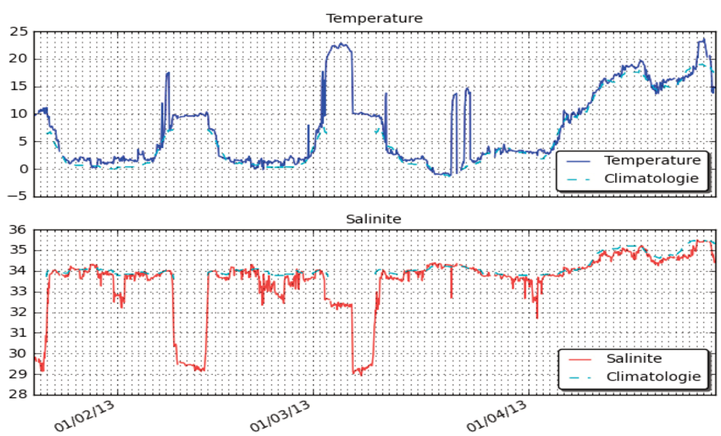
and data formats follow the recommendations and standards of UN agencies related to climate change and operational oceanography/meteorology, in particular JCOMM's Ship Observations Team (WMO/IOC-UNESCO). Data collected during the *OceanoScientific® Campaigns* are complementary to data from other sources (scientific cruises, VOS, drifters, buoys and satellite observations) and will participate in enhancing the knowledge of ocean-atmosphere fluxes in particular, as well as bridge the gaps in the global data coverage.

The overall approach is based on a solid collaboration with the French institutes IFREMER (French Institute for the Exploitation of the Sea), Météo-France (French Meteorological Institute) and LOCEAN (IPSL - INSU/CNRS - French institute for physical and bio-chemical study of the ocean and climatic variability). Other international institutes such as GEOMAR (Helmholtz Centre for Ocean Research, institute investigating the chemical, physical, biological and geological processes of the seafloor, oceans and ocean margins and their interactions with the atmosphere, in Germany) and the University of Maine (USA) also joined the collaboration.

OceanoScientific® Team and the **Bark EUROPA** crew met in August 2012, in Amsterdam to see how the OSC System could fit onboard. **Bark EUROPA** is a large vessel and the crew was easy to convince so the deal was quickly celled: an OSC System was to be installed onboard for the Antarctica Expeditions to come. Back to France, the *OceanoScientific®* team together with the SubCtech workshop had to make a few adjustments into the OSC System so it would match a few technical points such as power voltage, pipes and hoses for water intake and outlet, cable lengths between sensors and modules, etc. which were specific to that vessel. The OSC System prototype version 2.1 was then ready to be mobilised onboard the three master in Ushuaia in January 2013.

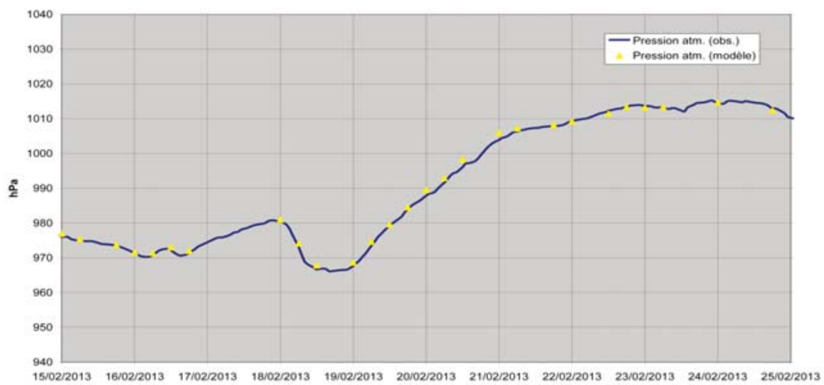
From left to right: Eric Kesteloo (Captain), Gary Hogg (Chief-Engineer) and Klaas Gaastra, also Captain, back to back with Eric, are posing with the OSC System in Cape Town (South Africa), on Saturday 4 May 2013. Photo SailingOne

It was designed to collect the following parameters: Atmospheric pressure, Air temperature, Humidity, True wind direction and True wind speed, Water temperature, Salinity, and Partial pressure of carbon dioxide (pCO2).



The Ocean Physics Laboratory (LPO - IFREMER Brest) has automatically carried out the comparison of the sea surface temperature (SST) and salinity (SSS) data to the climatology models of the international scientific community. Here displayed for the first deployment of the OSC System onboard, from January to April 2013, discrepancies between the in-situ data and the climatology happened subsequently to a mechanical failure of the pumping system (while testing various pumps), measurements being then done in the air instead of the sea water. Graphs LPO - IFREMER

The atmospheric sensors were installed on a spreader of the mizzenmast (first mast from the rear, third from the bow) as the oceanographic sensors were fitted into the sea-chest room, close enough to a vessel water intake to have a small dedicated bypass. On the atmospheric side, the wind sensor was not clear enough from the windage so the wind data were biased because of the position of the sensor, even though, at that time, no better location on that mast was available and installing the sensor on another mast was not an option for technical reasons. Appart from that, the atmospheric data were collected every 6 seconds and transmitted on the GTS (Global Telecommunication System) in the SHIP format once an hour. However, due to the bias, wind data were disabled on the GTS so only the proper atmospheric data from the humidity, temperature, and barometer were made available on the network. On the oceanographic side, the OSC System onboard was collecting Sea Surface Temperature (SST) and Sea Surface Salinity (SSS) with a Seabird 45 embedded in a water circuit together with a relatively new partial pressure of carbon dioxide sensor. This device is pretty small compared to the benchmark General Oceanics sensor used onboard most scientific cruises. It is currently getting acquainted with the international scientific community as it has been deployed onboard the German research vessel **PolarStern**.



Comparison from the in-situ pressure data collected onboard from the OSC System barometer to the pressure model, performed by Pierre Blouch from Météo-France and E-Surfmar. Here, zoomed in aver a 10 day-period over the 96 days of sailing. Graph Météo-France

The OSC System was later demobilised in May in Cape Town as the Antarctica expeditions were over for the austral summer 2012-2013 and were due to resume in December 2013. The OSC System came back to Europe for its regular maintenance and calibration period over which the thermosalinograph, the barometer and the air humidity and temperature probe went through calibration protocols to be ready for the remobilisation in October 2013 prior to the next Antarctica trips. In the mean time, **Bark EUROPA** top mizzenmast was chopped off during rough weather prior to the the ship arrival in Australia. The ship navigation sensor was damaged and the crew asked the *OceanoScientific®* team for help to replace it quickly. *OceanoScientific®* provided the crew with a wind sensor to be installed on top of the mizzenmast after the mast was fixed. When the OSC System was remobilised in October 2013, the wind sensor was already in place and ideally placed, away from any windage disturbance.

After crossing the Indian Ocean, **Bark EUROPA** landed in Sydney where the OSC System was mobilised onboard for the second time. Same sensors, same places except for the windmeter. After re-routing the wind data from the navigation computer on the bridge, wind data were hooked up in the OSC System as well. However, the air humidity and temperature failed during remob, so the ship cast off Sydney to New Zealand and across the Pacific Ocean with a broken probe. Before its next port call in Stanley (Falkland Islands), **Bark EUROPA** rounded Cape Horn safely. A new air humidity and temperature probe was mounted in Stanley. Since then, the OSC System is fully up and running and **Bark EUROPA** sailed back and force to the Antarctic Peninsula and is now on her way back to Europe collecting the full set of scientific parameters.

Christophe Chaumont (SailingOne) in Cape Town (South Africa) while demobilising the OSC System. Before leaving *Bark EUROPA*, he receives the comments and advices of the Chief-Engineer Gary Hogg, who took good care of the functioning of the material onboard. Photo SailingOne

(left) Bark EUROPA* navigating between the ice, all sails rolled up. Photo Lisa Bolton - *Bark EUROPA

(right)Bark EUROPA* moored in Ushuaia harbour. Photo Patrick Hamilton - *Bark EUROPA

Bark EUROPA* withstanding a gust in an Antarctica bay. Photo Peter Holgate - *Bark EUROPA

Bark EUROPA is also fitted with the European software for in situ data logging and transmission ashore: TurboWin developed by KNMI (Royal Netherlands Meteorological Institute) with contributions from several National Meteorological Services and endorsed by the WMO (World Meteorological Organization) and E-SURFMAR (European Surface Marine Programme), so the crew is also transmitting its visual observation of the weather conditions as well as - weather permitting - some SST measurements from a bucket, up to four times a day. TurboWin and the OSC System mobilised onboard make the **Bark EUROPA** a double member of the VOS Programme, where it is known under the callsign PDZS for its TurboWin input and under the callsign OSCFR05 for the OSC System data input.

Bark EUROPA* crew at work, adjusting the sail settings. Photo *Bark EUROPA

Bark EUROPA* sailing downwind. Photo Matt Maples - *Bark EUROPA

After the second *OceanoScientific® Campaign* is completed, later this year, the OSC System will be demobilised for calibration and maintenance. However, the common history between the *OceanoScientific® Programme* and the mighty ship will not stop there, as we already look forward to our next venture together, probably as soon as August 2014! ⚓

Return to Table of Contents

Reconstructing the Great Lakes “White Hurricane” Storm of 1913

Wagenmaker, R ., Mann, G.[1], Pollman, R. [1], Elliott, D. [1], Smith, B. , Keysor, J. [2], Boris, J. [2], Bardou, M. , Brody E. , Green, R.[4], Waters, S. [4], Clark, K. , Jamison, S. [5], Lombardy, K. [5], Levan, J ., Hintzen, K .

[1]NOAA/National Weather Service, Detroit MI
[2]NOAA/National Weather Service, Gaylord MI
[3]NOAA/National Weather Service, Chicago IL
[4]NOAA/National Ocean Service, Thunder Bay National Marine Sanctuary, Alpena MI
[5]NOAA/National Weather Service, Cleveland OH
[6]NOAA/National Weather Service, Buffalo NY
[7]University of Michigan, Ann Arbor MI

Prologue: *“No lake master can recall in all his experience a storm of such unprecedented violence with such rapid changes in the direction of the wind and its gusts of such fearful speed! Storms ordinarily of that velocity do not last over four or five hours, but this storm raged for sixteen hours continuously at an average velocity of sixty miles per hour, with frequent spurts of seventy and over. Obviously, with a wind of such long duration, the seas that were made were such that the lakes are not ordinarily acquainted with. The testimony of masters is that the waves were at least 35 feet high and followed each other in quick succession, three waves ordinarily coming one right after the other. They were considerably shorter than the waves that are formed by an ordinary gale. Being of such height and hurled with such force and such rapid succession, the ships must have been subjected to incredible punishment!”* - Lake Carriers Association report on the Storm of 1913

Artwork by Debra Elliott (embedded image of the Henry B. Smith from Edward H. Hart, Detroit Publishing Co.)

1. Introduction

In November of 1913, the Great Lakes were struck by a massive storm system combining whiteout blizzard conditions and hurricane force winds. The storm lasted for four days, from the 7th to the 11th, during which it was reported that Great Lakes mariners endured 90 mile per hour winds and waves reaching 35 ft in height. It is likely that 4 of the 5 Great Lakes experienced hurricane force wind gusts for a minimum of 10 hours, and potentially as long as 20 hours. With only basic technology available, shipping communication and weather prediction systems were not prepared for a storm of such devastating force. When the skies finally cleared, the Great Lakes had seen a dozen major shipwrecks **(Figure 1)**, an estimated 250 lives lost, and more than $5 million in damages - the equivalent of more than $117 million today. Several of the ships lost were the pride of the Great Lakes being among the newest and largest in the fleet **(Figure 2)**.

Figure 1: Great Storm of 1913 Shipwrecks; Those circled sank between 6 pm to midnight on Nov. 9th (image is public domain)

Nicknamed the "White Hurricane", 'Freshwater Fury", and "Great Storm of 1913", the 1913 storm remains the most devastating natural disaster to ever strike the Great Lakes. One hundred years later, NOAA commemorates the Storm of 1913, not only for the pivotal role it plays in the history of the Great Lakes, but also for its enduring influence. Modern systems of shipping communication, weather prediction, and storm preparedness have all been fundamentally shaped by the events of November 1913.

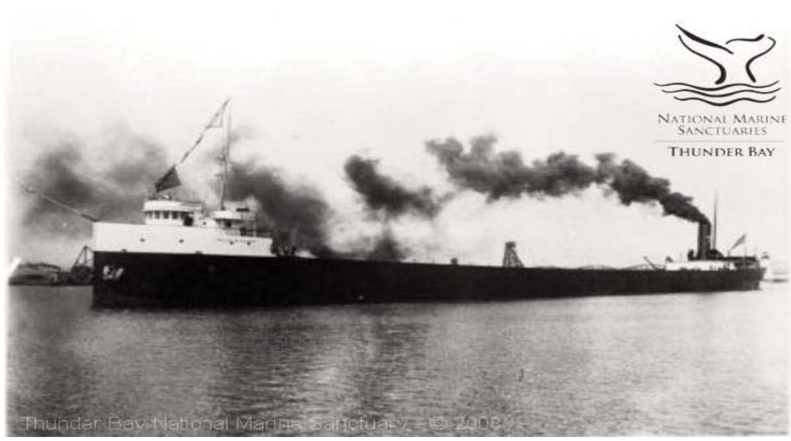


Figure 2: The *Isaac M. Scott*; sank near Alpena MI November 9, 1913. (image courtesy of NOAA Thunder Bay National Marine Sanctuary).

What follows is a description of the unusual synoptic weather pattern that led to the storm, the impacts and legacy of the storm, and a unique forensic reconstruction of winds and waves via a numerical model retrospective simulation. Given the lack of marine observations 100 years ago, it is hoped the retrospective simulation will give new and detailed insights to meteorologists and historians as to what happened and when.

The Weather Bureau had been in existence for a number of years prior to 1913. In the early 20th Century several important inventions such as Marconi’s wireless telegraph, Edison’s telephone, and the Wright Brothers air flight opened new doors to weather forecasting and dissemination. In fact, many improvements occurred in the field of weather forecasting shortly after the 1913 storm, primarily because of complaints lodged against the U.S. Weather Bureau for inaccurate weather forecasting and slow communication of storm warnings.

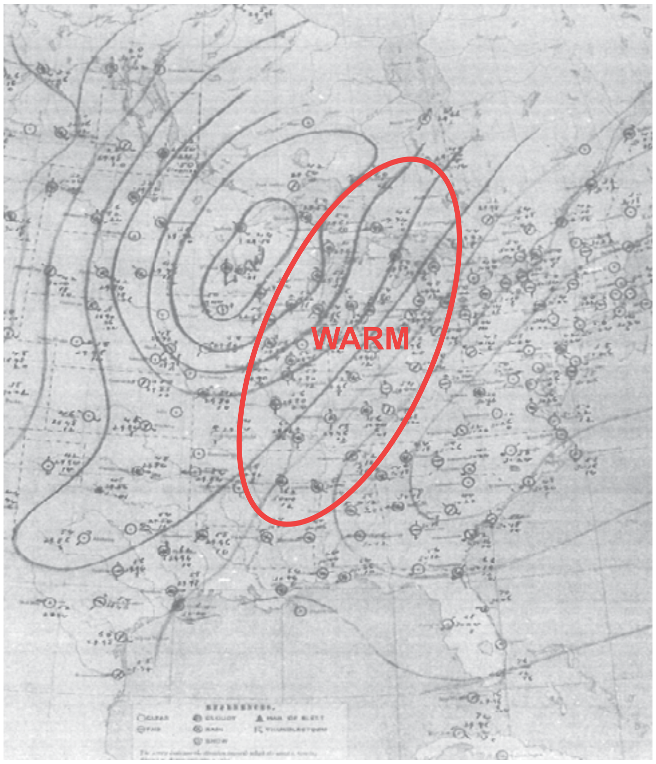


Figure 3: Clipper system approaching the Great Lakes valid at 8 am November 7, 1913 (image courtesy Environment Canada)

Although these technological advances were changing the landscape of weather forecasting in the United States, many Great Lakes weather warnings were still communicated via flags and pennants. The Weather Bureau would individually notify coastal locations on when to raise and lower signals based on the hazard threat to mariners. This Coastal Warning Display program was used for over 100 years and was finally discontinued on February 15, 1989. Despite the official retirement of the Coastal Warning Display program, the U.S. Coast Guard and some other stations continued to display the warning signals without direct participation from the National Weather Service.

In the early 1900’s, the Weather Bureau began mailing one to two week forecast maps to hundreds of locations across the United States. These forecasts were based primarily upon volunteer observations, kite instruments and a sparse weather balloon network. Although this was a significant step forward in the amount of weather information a mariner might have at their disposal, the lack of Great Lakes observations or access to real time data resulted in large unknowns. The first weather balloon sounding in the United States occurred in St. Louis in 1904. In the early 1900s, weather balloon data was not easily incorporated into real time forecasts because balloons had to be retrieved after launch and the data manually recovered.

To help fill in these “unknowns”, the mariner of 1913 relied on past experience, as well as various natural clues to help identify approaching weather. Many of these clues were rooted at least partially within good science. These natural clues were particularly important once you left port and were over the open lakes, too far away from shore to view hazard flags or pennants.

Wireless communications were available on the Great Lakes at this time, and were expanding rapidly with the erection of a number of wireless stations. Unfortunately, it appears that in all likelihood, most of the ships that sank during the 1913 storm did not have this new technology installed. The Weather Bureau issued weather warnings for the Great Lakes in advance of the 1913 storm. As the storm raged over the coming days, these forecasts and warnings were updated. But without the wireless equipment installed on many of the ships, mariners would have no access to this updated information once they left port and traveled into the open lake.

3. Overview of the Great Storm of 1913

The Great Storm of 1913 is really a tale of two storms. On November 6th and 7th, a low pressure system, sometimes referred to as a “Clipper”, and an associated Arctic cold front crossed the northern U.S. Plains and Canada and moved in the Upper Great Lakes the morning of November 7th **(Figure 3)**. Ahead of the front, mild southwesterly winds were bringing near record warmth into much of the Great Lakes region. However, by 10 am on the 7th, the Weather Bureau had hoisted Storm Warning flags for the entire region for southwesterly gales and the anticipated Clipper. Also that morning, the Arctic cold front passed Duluth MN and Thunder Bay ON, and spilled across western Lake Superior during the day. By Friday evening deeper Arctic air spread across the lake bringing Storm Force northerly winds that would eventually spread across Lake Michigan in the early morning hours of Saturday, November 8th. This Clipper storm was impressive in its own right as several large ships were driven ashore from Lake Superior onto Michigan’s Upper Peninsula. These included the **Turret Chief**, the passenger ship **Huronic (Figure 4)**, the **L.C. Waldo**, the **William Nottingham**, and others. The **Louisiana** was driven aground by 70 mph wind in the early morning hours of November 8th in Green Bay – and subsequently caught fire and burned while wrecked along the rocky shoreline (Henning 1992).

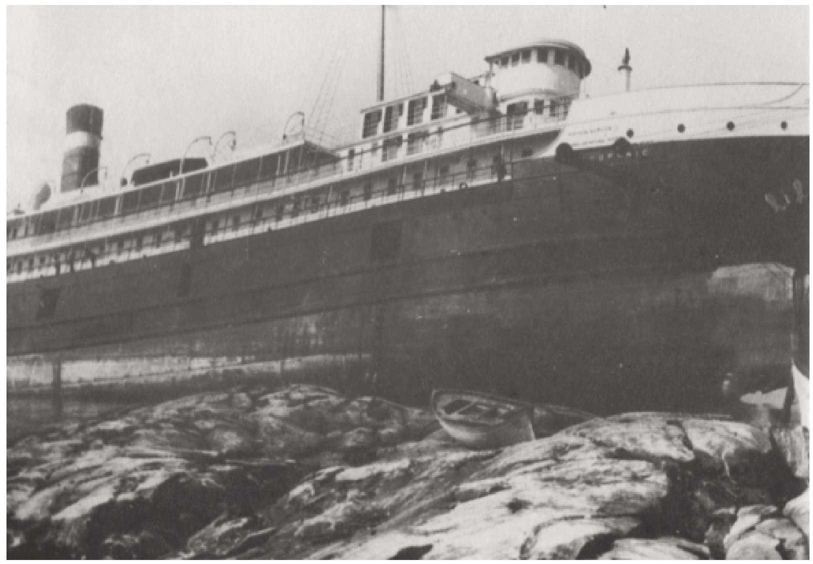
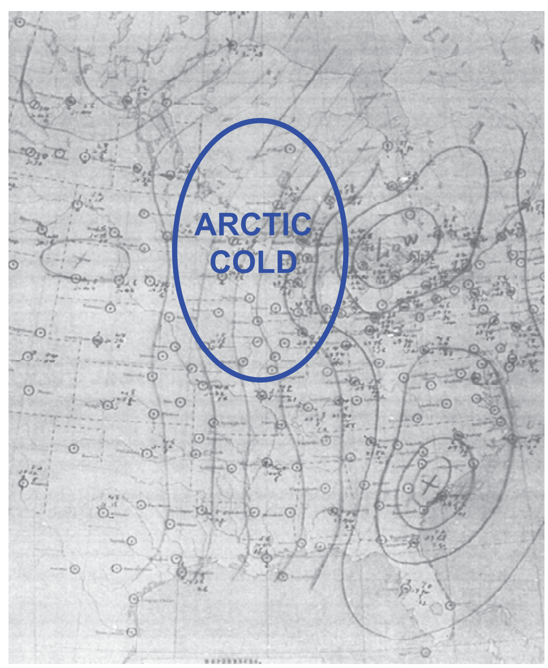


Figure 4: Great Lakes passenger ship *Huronic* driven ashore (image public domain in the United States)

On November 8th the Clipper storm center had moved into northern Lake Huron, stalled and slightly weakened, albeit while still producing Gale and Storm Force wind gusts over the upper Great Lakes. **(Figure 5)**. However, unknown to all, a new storm was developing across the southeast United States and interacting with a strong jet stream aloft. On the morning of November 9th, the southern storm system began to intensify over northern Virginia as the Arctic front pushed southeast through the Ohio Valley. The central pressure dropped to 985 millibars (hPa)/29.10 inches and phased with the weakening Clipper storm system approaching from the north **(Figure 6)**. By this time, the newer southern storm had become the dominant system. As the much colder air fed into the system, the storm began

Figure 5: Surface map valid at 8 pm November 8, 1913 showing two storms and arctic cold over the Great Lakes (image courtesy of Environment Canada)



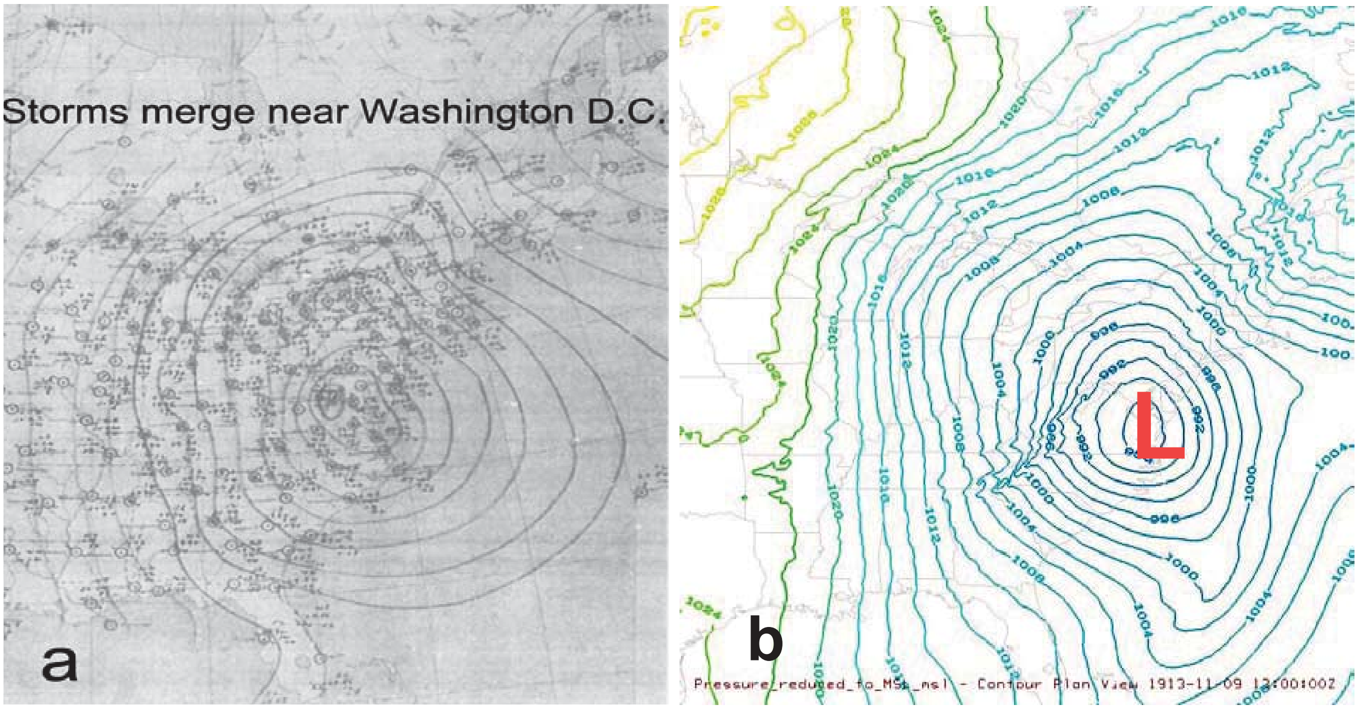


Figure 6a and 6b: a) Observed surface low position near Washington D.C. at 8 am November 9, 1913 (image courtesy of Environment Canada); b) computer simulation of mean Sea Level Pressure (MSLP) valid at 8 am November 9, 1913.

strengthening and backing to the north-northwest towards its cold air supply, becoming a meteorological monster, growing and feeding on moisture from the north Atlantic and mixing with the Arctic cold across the Great Lakes.

This phase of the storm is commonly referred to as the “White Hurricane”, and was the deadliest portion of the Great Storm of 1913. The “White Hurricane” portion of the storm will also be the focus of the computer simulation and analysis presented later in this paper.

By the evening of November 9th, the storm deepened to a very intense central pressure of approximately 969 hPa/28.60 inches as it tracked north-northwest to eastern Lake Erie **(Figure 7)**. At the same time, strong Arctic high pressure 1034 hPa/30.54 inches was approaching northwest Minnesota.

The close proximity of the two weather systems resulted in strengthening of the pressure gradient, producing a prolonged and intense wind across the Great Lakes. The storm finally began to weaken on November 10th and shifted to the St. Lawrence Valley on November 11th. A dozen major shipwrecks resulted from this storm, including 8 ships on Lake Huron and 1 in Lake Superior that sank in the 6 hour period between 6 pm and midnight on November 9th. These included the **Isaac M. Scott**, **Charles S. Price**, **James C. Carruthers**, **Argus**, **Hydrus**, **John A. McGean**, **Regina**, **Wexford**, and the **Henry B. Smith** (Brown 2002).

Few wind reports are available from the lakes themselves but hourly observations are available at some of the ports downwind of the lakes. Winds measured downwind of Lake Huron at Port Huron MI, increased to 50 to 60 mph during the afternoon of the 9th and persisted until almost midnight. Winds were even stronger downwind of Lake Erie with speeds of 50-70 mph with gusts near 80 mph.

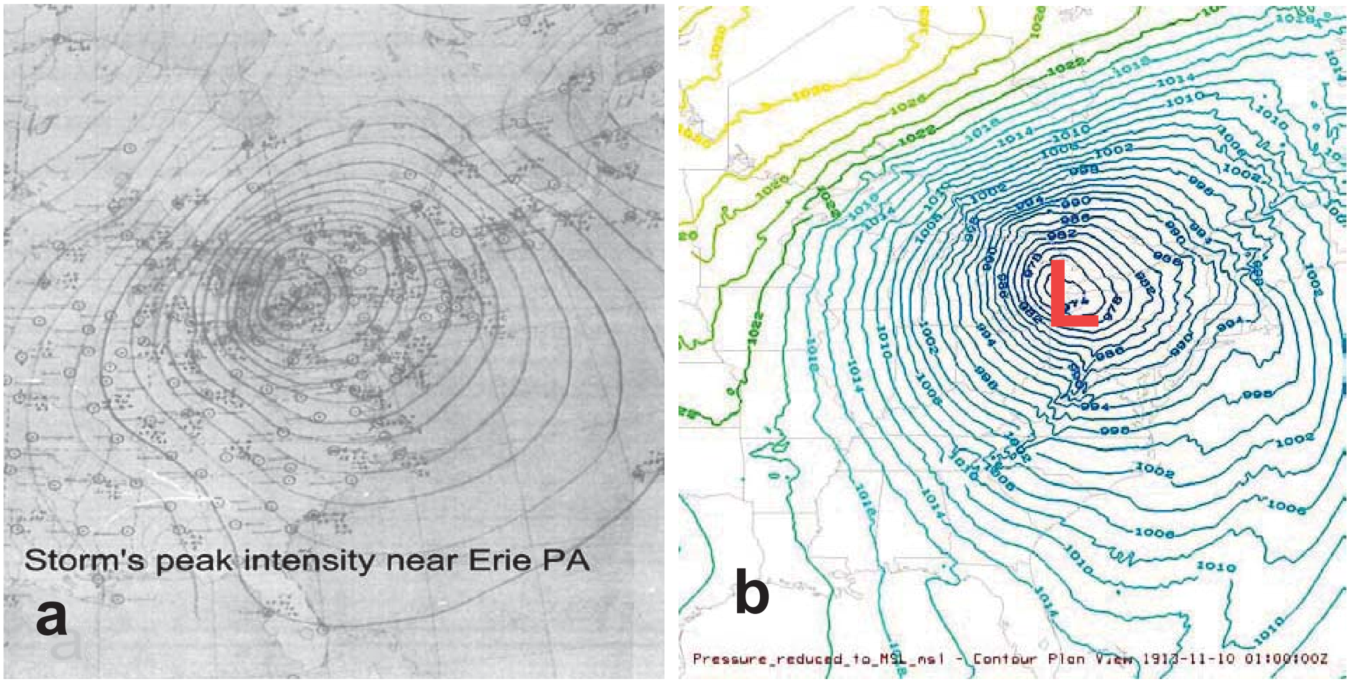


Figure 7a and 7b: a) Observed surface low position near Erie PA at 8 pm November 9, 1913 (image courtesy of Environment Canada); b) computer simulation of Mean Sea Level Pressure (MSLP) valid at 8 pm November 9, 1913.

4. A Retrospective Computer Simulation

Extreme weather events, like the Great Lakes Storm of November 7-11, 1913, provide unique challenges to meteorologists. They are usually rare events and often behave in ways that are not easily predictable. Sometimes meteorologists are able perform “forensic” studies of significant weather episodes in order to better understand how they occur and to gain greater context into the extreme conditions they produce. One of the most prominent tools in these studies is the computer model. Atmospheric and oceanic motions of air and water are governed by highly complex physical processes that can be described through mathematical relationships.

The emergence of advanced computer processing over the last half century has revolutionized weather forecasting by allowing real-time calculations of weather patterns and sea states through these mathematical relationships. This has allowed modern-day meteorologists to predict weather patterns with a remarkable degree of accuracy – provided the observed weather, or “initial conditions”, can be accurately measured and injected into the start of the computer simulation.

One hundred years ago weather forecasters did not have the luxury of computer models, nor the detailed surface and upper-air observations needed to make the most accurate predictions. The lack of observations, especially upper air and satellite-derived data, are also major obstacles to accurately simulating historic weather episodes like the Great Storm of 1913. Fortunately, within the last decade, a group of meteorologists developed an ingenious method of estimating upper atmospheric conditions for historical periods prior to the advent of weather balloon and satellite observations. The 20th Century Reanalysis Project (Compo, et.al. 2011) now provides us with an adequate representation of the state of the atmosphere in early November 1913 to prescribe “initial conditions” from which to generate a computer simulation.

The main purpose of the numerical model retrospective of the Great Storm of 1913 was to gain insights into the timing and severity of the conditions experienced by Great Lakes mariners.

Of particular interest were wave conditions, as several large boats were caught unprepared for such extreme conditions. In any sort of numerical model simulation, there can be several sources of error and a perfect simulation is usually unattainable. This is especially true of a one hundred year retrospective. Nonetheless, even a less-than-perfect simulation affords important context into what happened and when.

This study leveraged the capabilities of the Weather Research and Forecast (WRF) modeling system (Skamarock, et. al. 2005) to produce a detailed reconstruction of atmospheric conditions; and the NOAA Great Lakes Environmental Research Laboratory – Donelan Wave Model (GDM) to reconstruct the resultant sea state (Schwab, et. al. 1984). The GDM wave model was configured using a 5km rectangular grid on all of the Great Lakes to simulate the wave conditions during the November 1913 storm. Surface wind and temperature output from the WRF atmospheric simulation was used as inputs to drive the wave model simulation.

The GDM provides approximations for significant wave height (average of the highest ⅓), dominant wave period, and wind wave direction. A climatological average of lake surface water temperature was also used in the GDM simulations. Finally, as a companion

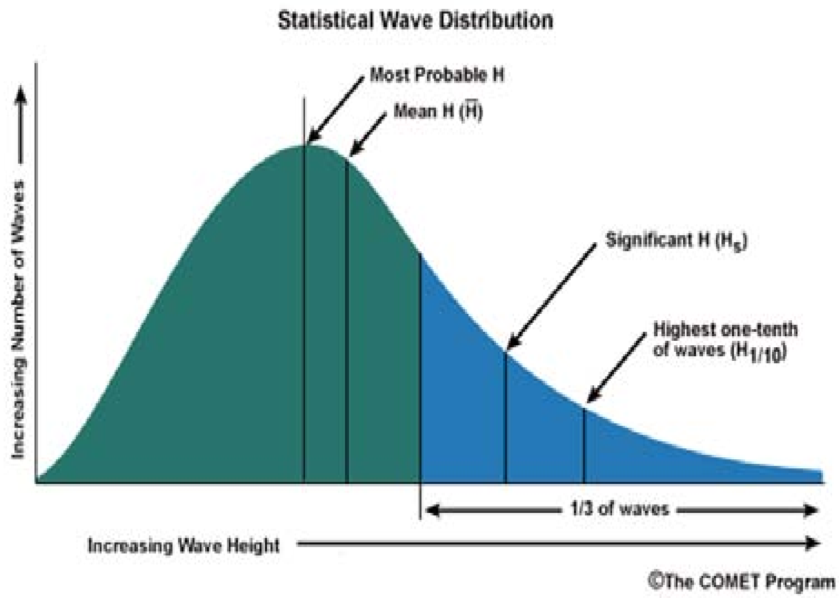


Figure 8: Statistical wave height distribution; "peak" or "maximum" waves defined as the average of the highest 5% in the distribution (image courtesy of The COMET Program).

calculation, an estimate of the average highest 5th percentile wave height from wave energy distribution (Thornton, et. al. 1983) is produced to characterize reasonably observed “peak” or “maximum” wave conditions (**Figure 8**). The return frequency of the peak wave is also calculated based upon the dominant wave period and the statistical occurrence of the average highest 5th percentile wave. The return frequency gives an estimate of how frequently ships experienced larger waves during the storm.

a. Evaluating the Computer Simulation

The “White Hurricane” simulation starts just prior to the time the new southern storm and the “Clipper” storm phase into one large storm over the eastern United States. By 8 am EST Sunday, November 9th, the storms merged into one large system centered near Washington D.C. and the simulation reasonably captured both the location of the low and the central pressure **(Figure 6)**. Just 12 hours later, the storm reached its most intense period (969 hPa/28.60 inches central pressure near Erie, PA). The low deepened 31 hPa in 24 hours as it moved northward toward the Great Lakes, making this a true “meteorological bomb” (Sanders et. al. 1980).

At this point, strong high pressure over southern Canada and the northern U.S. Plains created a very strong pressure gradient across the Great Lakes region resulting in hurricane force wind gusts. “Meteorological bombs” are relatively rare events, but the computer simulation matches reality fairly well, placing the low center between Erie PA and Buffalo NY and strengthening it to a central pressure of 974 hPa/28.76 inches **(Figure 7)**. In the subsequent 12 hours (8 pm Sunday, November 9th to 8 am Monday, November 10th), the storm barely moved north while maintaining its strength. At 8 am Monday, the storm was centered just north of Toronto ON with a central pressure near 975 hPa/28.79 inches. The computer simulation was slightly west of that location with a forecast central pressure of 972 hPa/28.70 inches. After an incredible period of hurricane force gusts lasting anywhere from 10-20 hours, the storm finally began to weaken on Monday evening and move to the northeast toward central Quebec.

Again, the computer simulation was quite accurate in capturing the strength and location of the storm center as it moved northward across Virginia, Pennsylvania, and southwest Ontario. This is remarkable for a 100 year retrospective simulation. The absence of upper air and satellite observations make it difficult to prescribe upper atmospheric conditions necessary for a viable simulation, yet the model appears to have performed well in this case. This gives confidence that the wind and wave conditions derived from the simulation will be representative of what mariners actually encountered 100 years ago.

b. Analysis of Simulated Wind and Wave Conditions

Although the Great Storm of 1913 was essentially a 4 day event, the wind and wave simulation results will focus on the most intense 18 hour period of the storm from roughly 1 pm EST Sunday, November 9th to 7 am EST, Monday, November 10th **(Figures 9-11)**.

In fall, the waters of the Great Lakes try to hold their summer warmth. When cold air passes over warmer water, the water releases heat into the atmosphere making the boundary layer above the water unstable with respect to vertical motions. When this happens, mixing processes occur within the boundary layer and bring stronger winds aloft downward to near the water surface. This frequent combination helps give rise to the “Gales of November”, when surface winds in fall storms are much stronger over water than they would otherwise be in a normal stable flow over the water.

By November 9th, 1913, arctic air had spread over all but Lake Ontario, and in many locations near blizzard conditions were raging over and downwind of the Great Lakes. Eventually, places like Port Huron MI downwind of Lake Huron and Cleveland OH, downwind of both Lake Huron and Lake Erie, would see storm total snowfalls up to 2 ft, with drifts as high as 4-5 ft.

Early on November 9th, Gale Force winds were already blowing across all of the upper lakes, as they had for nearly two continuous days prior. But unknown to everyone, conditions were about to rapidly deteriorate into a “White Hurricane”.

The computer simulation allows us to view, on an hour-by-hour basis, the details of how quickly the storm intensified and how bad conditions may have gotten; resulting in 9 ships sinking with over 200 lives lost in the 6 hour period from 6 pm EST, November 9th through Midnight EST, November 10th **(Figure 1)**. This 6 hour period has been described by many as one of the deadliest weather events in North American history. Of the 9 ships lost during those 6 hours, 8 were lost on Lake Huron with 187 on-board.

From 8 am to 8 pm on November 9th, the storm center moved across Pennsylvania in a north-north-westerly direction ending up over eastern Lake Erie by Sunday (9th) evening. The atmospheric simulation showed Lake Huron northerly winds sustained at 20-25 knots and gusts to around 40 kts at 10 am **(Figure 9)**, but building to 35-40 kts gusting to 50-55 kts by 4 pm EST Sunday **(Figure 10)**. During the same time frame the GDM wave model simulation indicated waves building to a robust 12 to 18 ft. During the day Sunday, many ships were

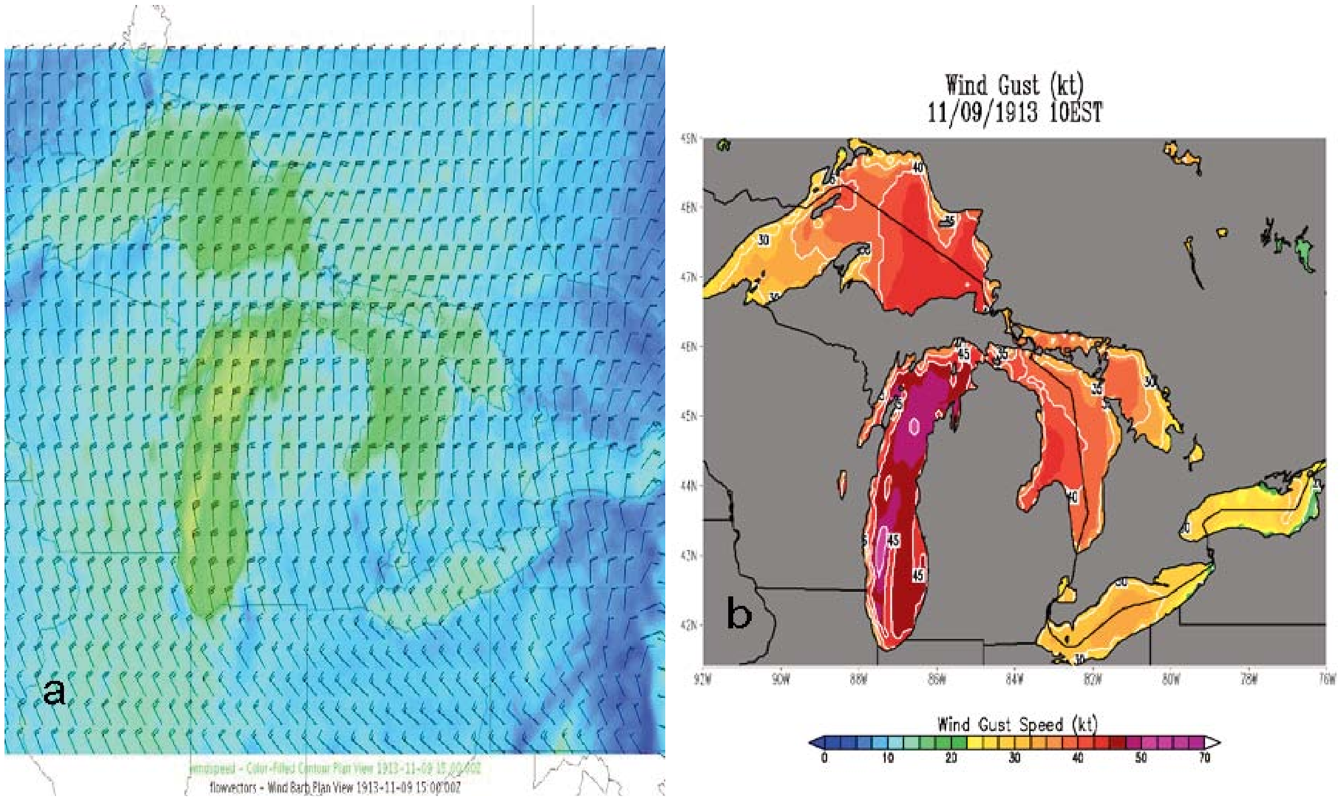


Figure 9a-b: Computer simulated surface wind and wind gusts valid at 10 am EST November 9, 2013.

making their final runs of the year through Lake Huron either downbound from Sault Ste. Marie or upbound from Port Huron and may have been misled concerning the imminent threat by the marginal Gale conditions during the morning hours. Indeed, after 4 pm, November 9th, winds were predicted in the computer simulation to build to widespread hurricane force gusts – and by 10 pm, north-northwesterly winds sustained at 45-50 kts with gusts to over 70 kts were predicted over Lake Huron. The wave model predicted significant waves to 16 ft at 6 pm with peak waves to 24 ft. But, just 6 hours later, by midnight on the 10th, significant waves were predicted to 24 ft with peak waves exceeding 36 ft near the tip of the thumb in Lake Huron. With seas running north to south, the dominant wave period estimated by the model was around 10 seconds. This means waves were very steep (as is common in the Great Lakes), and according to wave theory the “return frequency” on maximum or peak waves would have been between 3 and 3 ½ minutes **(Figure 10k-l)**. Waves to 24 ft at least once per minute and to 36 ft every 3 minutes would have provided a tremendous pounding to even the largest ships on the lakes at that time. Those caught in a wave trough would have been in great danger of rolling and capsizing. At least 2 of the ships that sank on the evening of November 9th, were found lying upside down at the bottom of Lake Huron. In that 6 hour period from 600 pm on the 9th until midnight on the 10th, the following ships were lost along with over 200 crew; The **Argus** (436 ft, built in 1905), **James C. Carruthers** (550 ft, built in 1913), **Hydrus** (436 ft, built in 1903), **John A. McGean** (432 ft, built in 1908), **Charles S. Price** (504 ft, built in 1910), **Isaac M. Scott** (504 ft, built in 1909), The **Wexford** (250 ft), The **Regina** (269 ft), and the **Henry B. Smith** (lost on Lake Superior, 525 ft, built in 1906). Many other ships were severely damaged or destroyed during the storm when they were driven ashore by high seas.

After midnight on November 10th, the highest winds and waves in the computer simulation moved westward into eastern Lake Superior and Lake Michigan. Between midnight and 7 am, wind gusts over 70

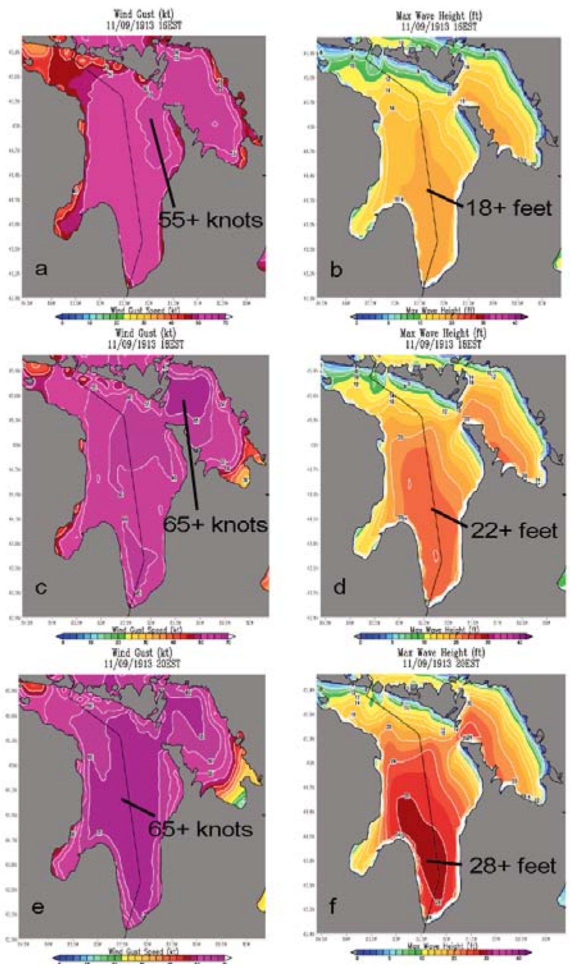


Figure 10a-f: Surface wind gusts and "maximum" wave height on Lake Huron valid at 4 pm EST, 6 pm EST, 8 pm EST November 9, 1913.

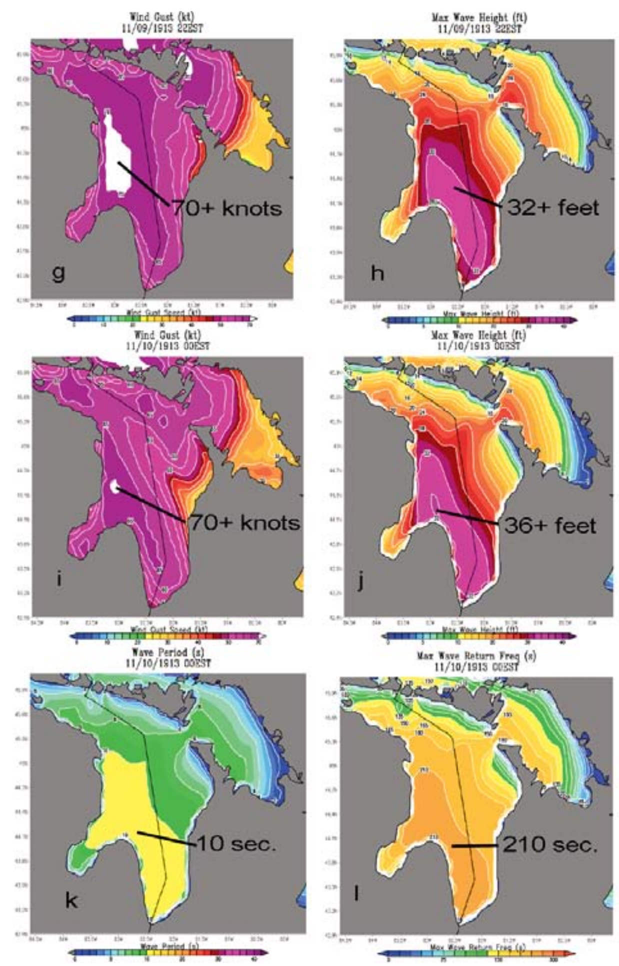


Figure 10g-j: Surface wind gusts and "maximum" wave height over Lake Huron valid at 10 pm Nov. 9 and midnight Nov. 10. Figure 10k: Dominant wave period (seconds). Figure 10l: "Maximum" wave return frequency (seconds).

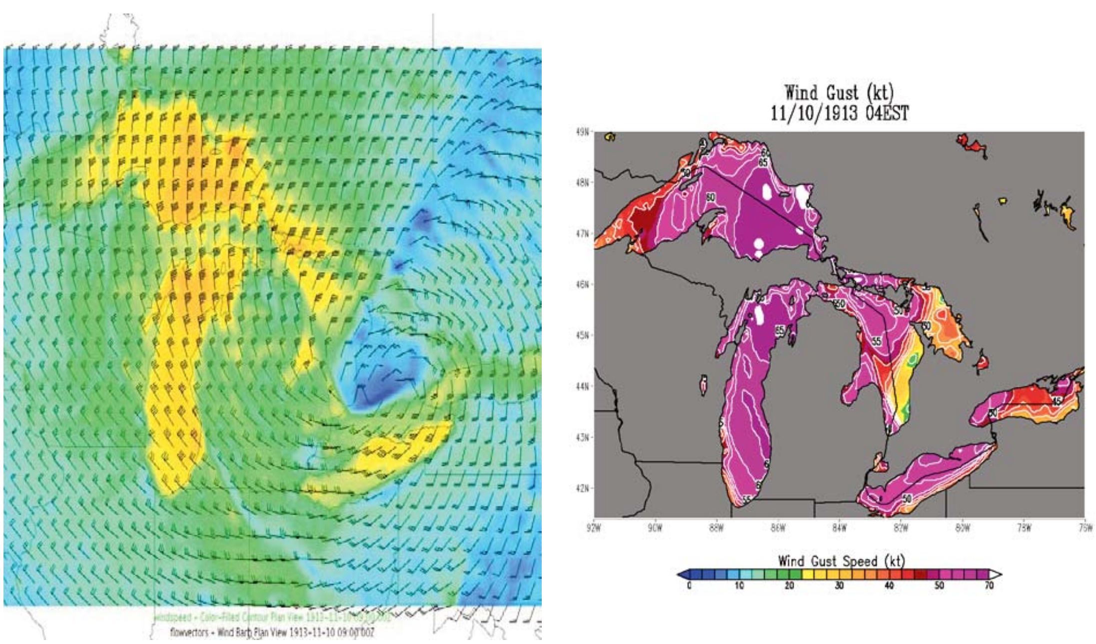


Figure 11a-b: Computer simulated surface winds and gusts valid 4am EST November 10, 1913.

kts were indicated over the two lakes, with maximum waves projected as high as 36 ft near Pictured Rocks on the Michigan shore of Lake Superior **(Figure 11)**. At 430 am, the **Harvester**, a new 525 ft freighter which survived the storm, estimated wind gusts to near 100 mph (86 kts) on Lake Superior just west of Michipicaten Island. Throughout the day on the 10th, winds and waves were projected to remain high over all of the lakes, especially Lake Erie where strong southwesterlies roared down the long axis of the lake. At 2 pm EST a wind gust to 80 mph (70 kts) was recorded in Buffalo NY. Monday evening and into Tuesday the 11th, the low gradually weakened moved off to the northeast and winds and waves gradually began to decrease.

Given the results of the simulation, survivor estimates of wind gusts during the storm around 90 mph or greater were not unreasonable. Likewise, survivor estimates of waves as high as 35 ft were also supported by the simulation. Moreover, during a critical period from Sunday afternoon on November 9, 1913, to midnight on Monday, November 10th, 1913, it was shown that winds and wave heights dramatically increased to levels that were extremely dangerous to even the largest and most robust ships in the Great Lakes fleet. From 1 pm to 9 pm on November 9th, wind gusts were predicted by the model toincrease from 45 knots to over 70 knots, and peak wave heights likely doubled in height to 36 ft between 6 pm and midnight that evening. The maximum values appear to have occurred mostly over Lake Huron in the area between Alpena MI to near Grand Bend ON – coinciding with the area where most ships foundered or were forced ashore by high seas. Ships attempting to find shelter by crossing westward into Saginaw Bay on the evening of November 9th were likely met with some of the worst conditions of the storm.

Analysis of the computer simulation makes it easy to see the disadvantages mariners of the early 20th century faced compared to modern times. Advances in communication, meteorological knowledge, and computer technology make it unlikely such a marine disaster could happen today.

5. Modern Marine Forecasting and Communications

Mariners on the Great Lakes today have access to high speed, wireless satellite and cellular communications which allow them to access observed and forecast weather information in real-time. As weather forecasts or conditions change, mariners learn about it very quickly. *National Weather Service Marine Forecasts* are updated at least four times per day and extend out to five days. These forecasts are available in a variety of formats, including traditional text and graphic presentations. Marine "headlines" including Gale Warnings and Storms Warnings are still used but Gale Watches and Storm Watches are now issued with greater lead time prior to the onset of these conditions. Also, Heavy Freezing Spray Watches and Warnings are now available to highlight the risk for heavy ice accumulation on ships.

a. Advanced Forecasting Technology

Forecasters have access to both observed weather information, as well as computer generated guidance that allows them to monitor conditions across the Lakes in real-time and to more quickly and accurately assess how conditions will change. Some of these observational and forecast tools include:

1) A network of highly sophisticated Doppler Radars (WSR-88D) maintained by NOAA. These radars constantly scan the skies for developing storms, allowing mariners to see these storms as they form.

2) NOAA satellites high above the earth's surface send images of cloud structures, thunder storms, hurricanes, and other developing storms to the ground. The first weather satellites were launched in 1960.

3) Sophisticated Numerical Weather Prediction (NWP) models perform a myriad of calculations based on observed weather conditions and known theory of atmospheric processes to create a forecast of various weather parameters. Some models focus on the first few hours or first few days of the forecast while others extend out to more than 7 days. Forecasters combine NWP output with current observed conditions, conceptual understanding of various weather patterns, and past experience to develop forecasts.

4) Frequent observations from buoys, shore-based platforms, and a volunteer network of weath er observations (VOS) taken aboard freighters, tugs, and other vessels. In the Great Lakes alone, the VOS program has grown from 11,297 observations in 2001 to 27,136 observations per year in 2010.

b. Infrastructure & Public Engagement

NOAA Weather Forecast Offices are located throughout the Great Lakes region, and are staffed around the clock by highly trained professionals whose job it is to monitor and predict how weather conditions will change on the Great Lakes. NOAA Weather Radio (NWR)is a nationwide network of radio stations broadcasting continuous weather information directly from NWS offices. Official warnings, watches, forecasts and other hazard information is broadcast 24 hours a day, 7 days a week. NWR includes approximately 1000 transmitters, many of which are located around the Great Lakes and are easily accessible by mariners.

In addition to its scientific and technical capabilities, the National Weather Service has been working to raise awareness of the needs of the marine community and to better understand what information is needed to make operational decisions on the Great Lakes. This is being accomplished through:

1) Building relationships with a variety of external partners including the United States Coast Guard, Lake Carriers Association, the international Shipmasters Association, and local yacht and sailing clubs.

2) Familiarization Floats and ship visits which allow forecasters to meet with crews aboard various vessels to discuss weather and forecast impacts.

3) Finally, given advancements in technology, communication, and coordination between meteorologists and the marine community – were the Great Storm of 1913 to happen today, mariners would undoubtedly be safer than they were 100 years ago.

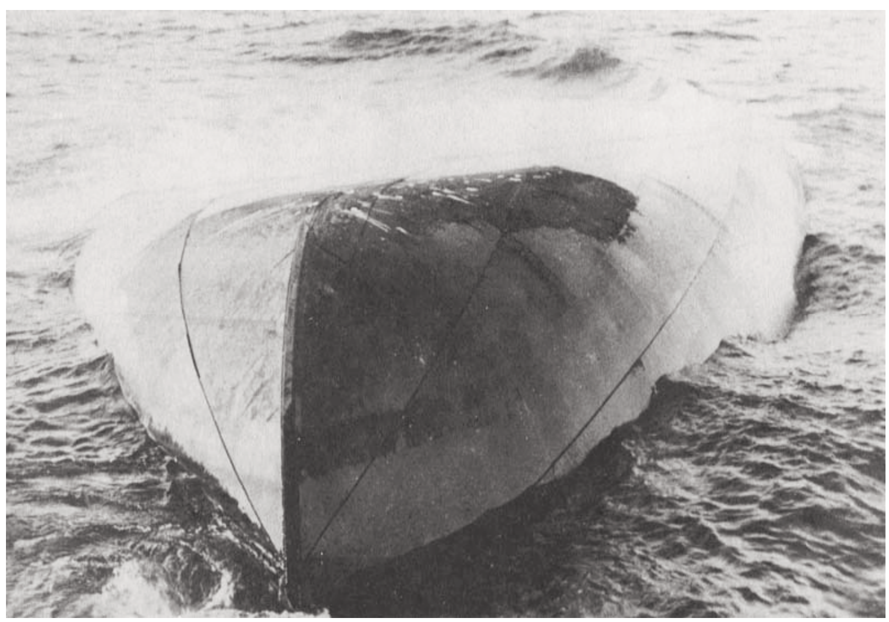


Figure 12: Capsized *Charles S. Price* in the wake of the storm (image is public domain in the United States)

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Return to Table of Contents

Shipwreck: MORMACPINE

By Skip Gillham

Photo: MORMACPINE is shown transiting the Welland Canal during October 1965 in a photo by Jim Kidd, courtesy of Ron Beaupre.

The enemy claimed a heavy toll on Allied shipping during the battles of World War Two. Danger lurked from above, on and beneath the surface of the seas and oceans as aircraft, battleships and submarines sought to inflict heavy damage and claim numerous targets.

The United States sought to augment the fleet of ships needed to carry supplies, military equipment, fuel and personnel to the war zones. The first standard class of cargo carriers were the Liberty Ships and these were very useful in the early years of America's participation in the war. A new class of slightly larger, but much faster, vessels was designed and the first of these, called Victory Ships, was completed in February 1944.

There were 531 Victory Ships built. Most were cargo carriers but some were modified as attack transports and others to carry troops. They were 455 ft long by 62 ft wide and could handle 10,850 tons of cargo.

Their big advantage over Liberty ships was speed as the Victories were powered by two steam turbine engines. These ships were operated by merchant sailors but also carried naval personnel to maintain communications equipment and handle the military duties that might come their way.

After the war, some of these vessels were sold to private interests, some were placed in the U.S. Reserve fleet and some went to U.S. Army service. Victory Ships were pulled from the Reserve fleet for both the subsequent Korean and Vietnam conflicts.

The early Victory ships were named for allied countries, such as the **Costa Rica Victory**. Many others were named for American universities such as the **Brown Victory**.

The latter vessel had been launched at Portland, Oregon, on February 23, 1945, and was ready for service before the end of March.

While owned by the United States Maritime Commission, it was operated on their behalf by the Alaska Packers Association and spent most, if not all, of its time on the Pacific.

In 1946, the ship moved under the management of the Moore-McCormack Lines and they were well known for providing excellent service between U.S. Gulf Coast ports south to the West Indies and South American destinations. When Moore-McCormack purchased **Brown Victory** in 1947, it was renamed **Mormacpine**.

The vessel proved to be a good carrier for the company but also had one weather related and one fire related incident. The first occurred in the Strait of Juan de Fuca, off the west coast of the United States, on September 27, 1959. The ship was en route from San Pedro, CA, to Seattle, WA when it encountered a fog bank that quickly reduced visibility to under 1,000 yards.

The working radar did not pick up the 49 ft fishing boat **Jane** and by the time a watchman saw it, the inbound freighter, with the propeller thrashing full astern, crashed into the starboard side of the wooden vessel. It sank within minutes with the loss of two lives, including the Master, but three on board were rescued.

Mormacpine was not damaged and, in 1960, made the first of at least thirteen voyages into the Great Lakes through the then, year old, St. Lawrence Seaway. The vessel often delivered general cargo before loading grain for the outbound passage.

Fifty years ago this spring, on March 27, 1964, fire broke out in the cargo hold while **Mormacpine** was bound for Bermuda. The blaze was contained and the U.S. Coast Guard ship **Half Moon**, escorted the ship to port and safety.

Mormacpine carried on in service until a sale to Taiwanese shipbreakers in 1970. It arrived at the port of Kaohsiung on July 18 and was broken up for scrap by the Tong Cheng Steel Manufacturing Co.

Three Victory Ships, **Lane Victory**, **American Victory** and **Red Oak Victory** survive as museum ships.

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Return to Table of Contents

Practical Formulas for Estimating Winds and Waves during a Tropical Cyclone

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Abstract: Practical formulas for estimating winds and waves generated by a tropical cyclone are presented. These equations have been verified for Atlantic and eastern Pacific hurricanes and western Pacific typhoons when the measurements are available. During the validation process, it is found that the radius of tropical storm, R34 kt, can be used as a surrogate for the fetch parameter in wave estimation.

1. Introduction

For the safety of ship operations, mariners must know the danger of strong winds and high waves, particular during a tropical cyclone. While the forecasts of winds and waves are available from numerical predictions, it is prudent for the mariners to have some practical knowledge to estimate these high winds and waves rather than relying on the forecast guidance totally. The purpose of this article is to provide such knowledge. The data used are based on Powell and Reinhold (2007) as provided in **Table 1**.

Table 1. Validations of Equations (1), (4) and (6) based on data provided in Powell and Reinhold (2007). Pmin is the minimum sea-level pressure, Vmax is the maximum wind, R34kt is the radius of 34 kts, and Hs is the maximum significant wave height.

Hurricanes	Year	Month	Pmin	Vmax	Vmax	R34 kt	Hs, m	Hs, m
		Day	mb	m/s	m/s, Eq.1	km	Eq.4	Eq. 6
Andrew	1992	24-Aug	922	68	60	191	15	18
Camille	1969	18-Aug	909	65	64	230	16	21
Charley	2004	13-Aug	941	63	53	156	13	14
Dennis	2005	10-Jul	946	51	52	296	14	13
Emily	2005	20-Jul	948	54	51	291	15	13
Fabian	2003	5-Sep	941	51	53	380	16	14
Frances	2004	5-Sep	960	46	46	319	13	11
Hugo	1989	22-Sep	934	58	56	317	17	16
Iris	2001	9-Oct	948	43	51	165	9	13
Isabel	2003	18-Sep	957	47	47	532	17	11
Ivan (AL)	2004	16-Sep	946	49	52	326	14	13
Ivan (Jamaica)	2004	11-Sep	925	70	59	314	20	18
Jeanne	2004	26-Sep	950	46	50	317	13	13
Katrina (FL)	2005	25-Aug	984	33	34	115	6	6
Katrina (LA)	2005	29-Aug	920	52	61	454	18	19
Katrina Peak Wind	2005	28-Aug	909	71	64	349	21	21
Keith (Belize)	2000	1-Oct	959	50	46	154	10	11
Michelle	2001	4-Nov	949	50	50	335	15	13
Opal	1995	4-Oct	942	50	53	353	15	14
Rita	2005	24-Sep	937	49	55	357	15	15
Wilma Peak Wind	2005	19-Oct	892	62	69	326	18	24
Wilma (FL)	2005	24-Oct	951	51	50	380	16	12
Wilma (Mexico)	2005	22-Oct	930	59	57	394	19	17

2. Estimating Hurricane Winds

To estimate the maximum wind induced by a tropical cyclone, Equation (1) can be applied (for derivation, see Hsu, 2005).

$$Vmax = 6.3\ (1013 - Pmin)\ \hat{}\ (1/2) \qquad (1)$$

Where Vmax is the maximum wind in m/s and Pmin is the minimum sea-level pressure in mb.

Validation of Eq. (1) is shown in **Figure 1**. If we accept that the correlation coefficient R (=0.82) is reasonable based on those diversified hurricanes and that the estimated Vmax is nearly identical to that provided by Powell and Reinhold (2007) as listed in **Table 1**, Eq. (1) should be very useful for practical applications. Note that Eq. (1) is also used in Simpson and Riehl (1981, p.278). In 2013, Li et al (2013) provided a dataset covering tropical cyclones over both Atlantic and North Pacific Oceans. This dataset is also employed for our verification of Eq. (1), which is presented in **Figure. 2**. Since the R value (=0.89) is even higher than that of **Figure. 1** and the estimated Vmax values again are nearly identical to those as listed in Li et al (2013) , we can say that Eq. (1) is a practical formula to use.

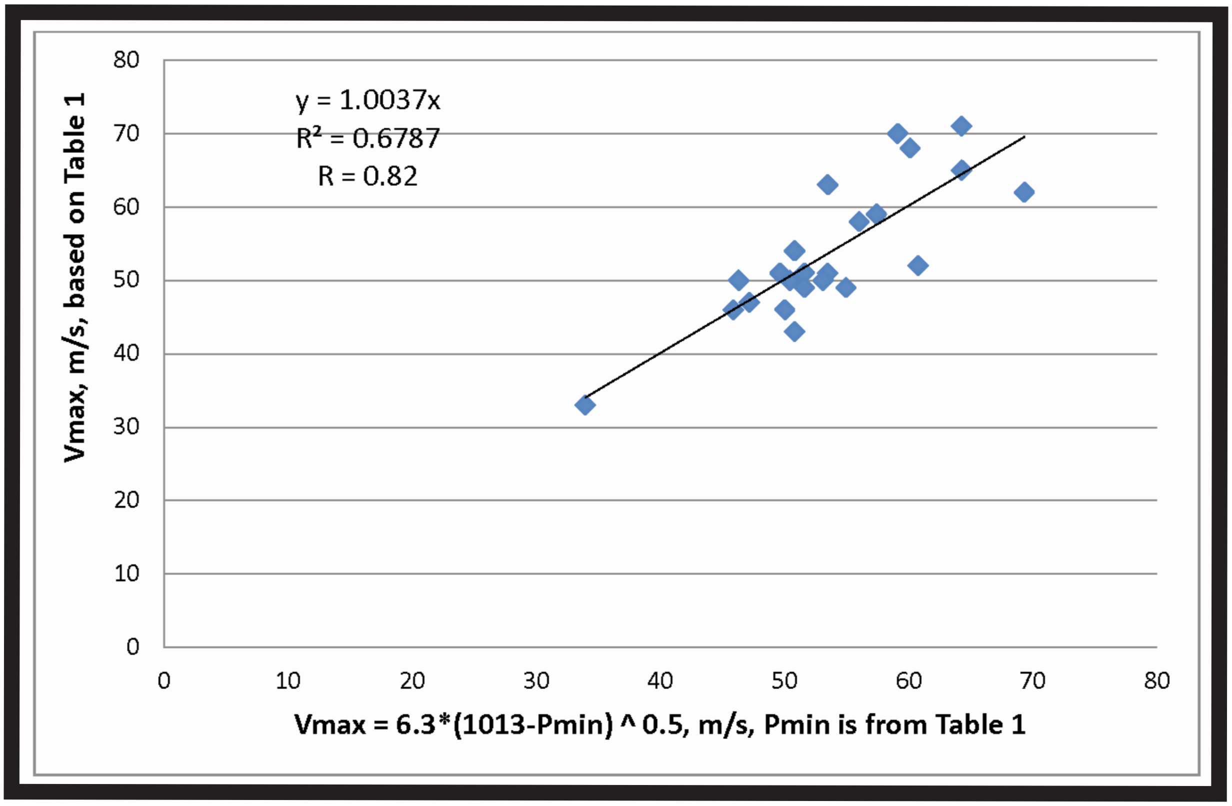

Figure1. A verification of Eq. (1) based on data provided in Table 1

The wind speed at the distance, r, from the Vmax has also been derived and verified in Hsu (2005) as follows:

$$Vr = Vmax\ *(Rmax/r)\ \hat{}\ (1/2) \qquad (2)$$

$$Rmax/r = Ln\ ((1013 - Pmin)/\ (Pr - Pmin)) \qquad (3)$$

Where Vr is the wind speed at the distance r where the pressure is Pr. The symbol “Ln” stands for natural logarithm.

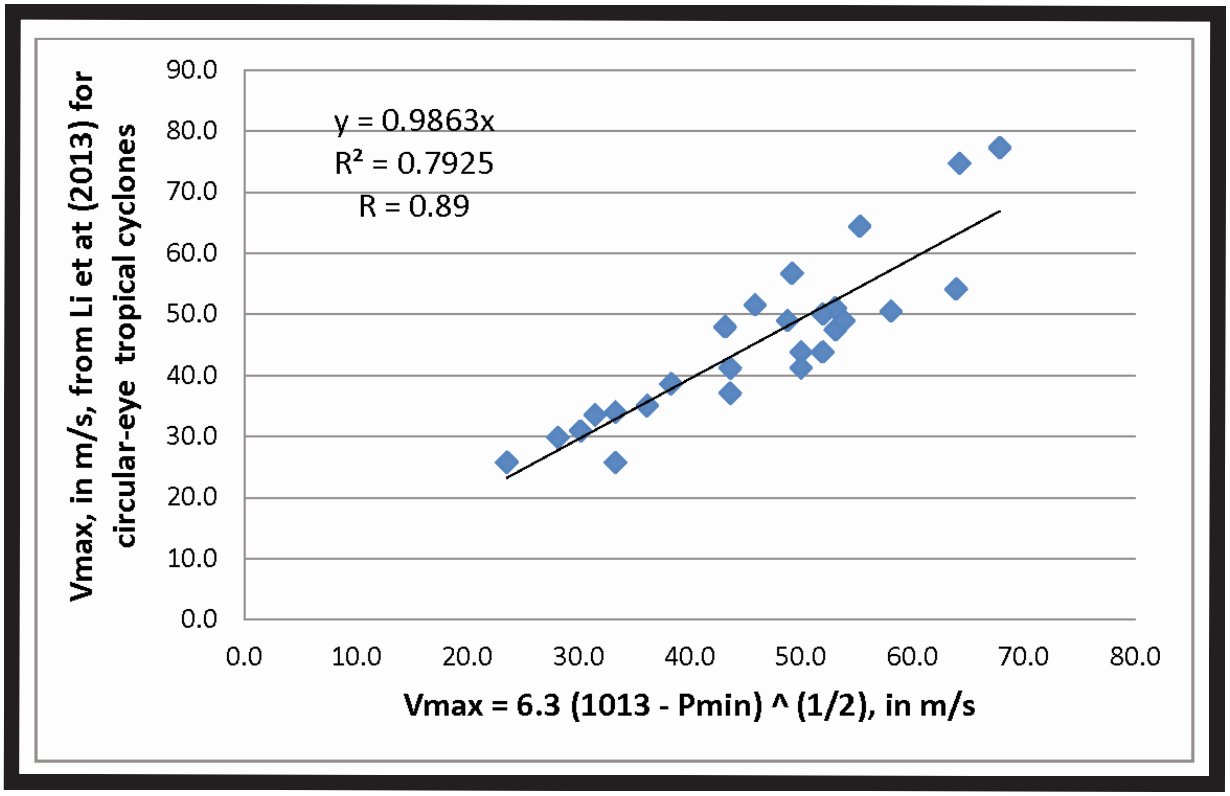

Figure 2. Further validation of Eq. (1) based on the data provided in Li et al. (2013)

3. Estimating Hurricane Waves

According to Hsu (2005), the maximum wave height induced by a tropical storm is

$$\mathbf{Hsmax = 0.2\ (1013 - Pmin)} \qquad \mathbf{(4)}$$

Where Hsmax is the maximum significant wave height in meters.
A verification of Eq. (3) is provided in Hsu (2006) for Atlantic hurricanes. In the western Pacific, during Super Typhoon Krosa in 2007, a buoy recorded the maximum trough-to-crest wave height of 32.3m near the north-east Taiwan (Liu et al, 2008) near the typhoon center of 929hPa (based on the Annual Cyclone Report issued by the Joint Typhoon Warning Center, JYWC). According to WMO (1998), the significant wave height is approximately 32.3/1.9 = 17m. Since Pmin was 929hPa and from Eq. (4), we have 16.8m.This value is in excellent agreement with the measured value of 17m. Therefore, Eq. (4) is now further validated during a super typhoon. In addition, Eq. (4) is used to compare with a numerical model to estimate the significant wave height generated by Typhoon Muifa in the South China Sea. Good agreement was found (See Chu and Chen, 2008).

According to the Shore Protection Manual (see USACE, 1984),

$$\mathbf{Hs = 0.016\ Vr^*(F)\ ^\wedge\ (1/2)} \qquad \mathbf{(5)}$$

Where Hs is the significant wave height at the fetch F. The unit for Hs is in meters, Vr in m/s and F in kilometer.

Now, if we use the radius of the tropical storm (at 34 kts), or R34 kt, as a surrogate for the fetch parameter F, we have

$$\mathbf{Hsmax = 0.016\ Vmax\ *(R34kt)\ ^\wedge 0.5} \qquad (6)$$

Where the unit of R34 kt is in km. If R34 kt is in nautical mile (nm), it needs to be converted to km, since one nm is approximately 1.85 km. Since R34kt is provided in the warning advisories by JTWC, it can now be incorporated into Eq. (6) to estimate the maximum significant wave height in meters. According to the advisory issued by the National Hurricane Center (NHC), the radius of tropical storm force winds, R34 kt or R18m/s, is available in miles. Then, one needs to convert it to km by using one mile = 1.61 km.

Now, on the basis of **Table 1**, a validation of Equations (4) and (6) is provided in **Figure 2**, which illustrates that both formulas are nearly identical.

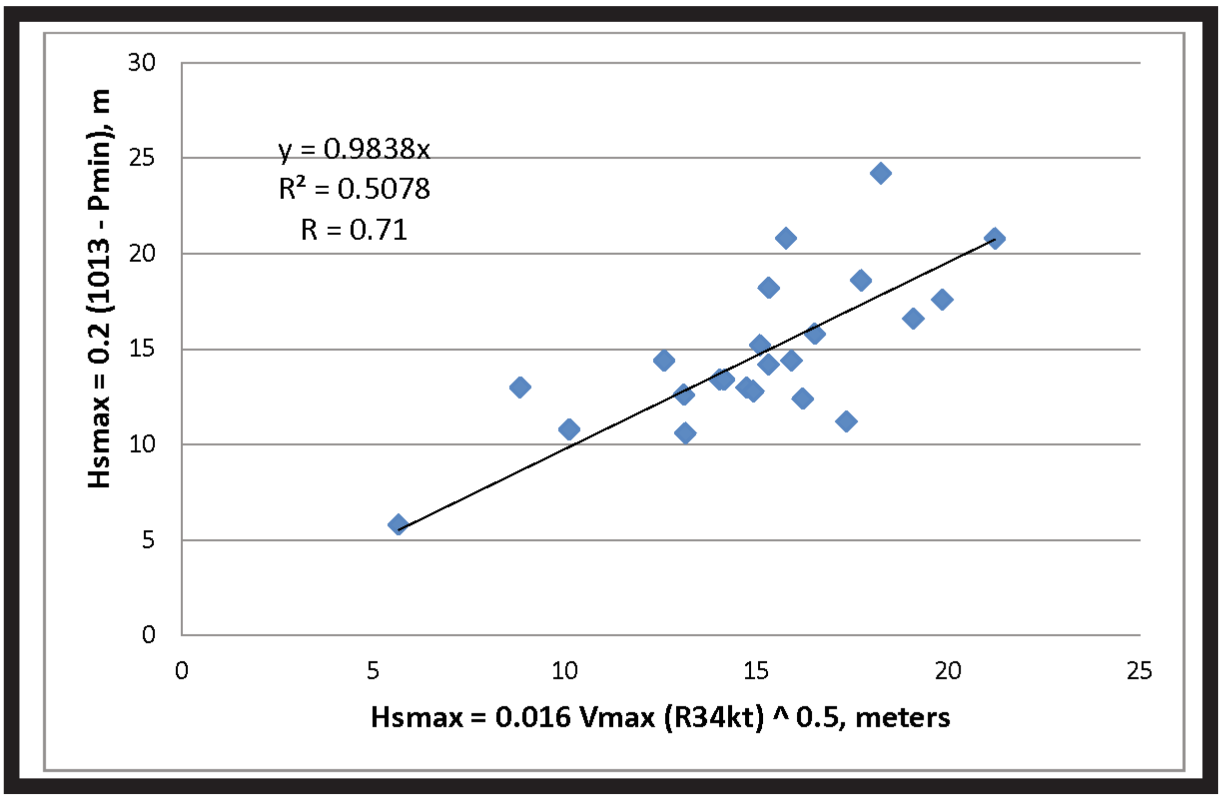

Figure 3. A relationship between Equations (4) and (6)

Now, returning to **Table 1**, we see that the Hsmax (=21m) was induced by Katrina. Since there were no on-site measurements, the numerical simulations by Wang and Oey (2008, Figure 6, left panel for 22m and right panel for 20m by NCEP) are adopted. Their results showed that the Hsmax was between 20 and 22m, which are in good agreement with our results of 21m as shown in **Table 1**. Therefore, Eq. (4) can be used if Pmin is available. On the other hand, Eq. (6) can be applied if both Vmax and R 34kt are known.

According to Hsu et al. (2000), the waves at the distance, r, away from Rmax is

$$\mathbf{Hs = Hsmax\ (1.06\ -0.11/\ (Rmax/r))} \qquad (7)$$

Note that the parameter (Rmax/r) can be calculated from Eq. (3).
A validation of Eq. (7) during Hurricane Katrina in 2005 is provided in Hsu (2006).

5. Conclusions

Several conclusions can be drawn from aforementioned study:

(a) to estimate the maximum wind generated by a tropical cyclone, use Eq. (1);
(b) for the wind speed away from the radius of max wind, use Eqs. (2) and (3);
(c) to estimate the maximum significant wave height, use Eqs. (3) or (6);
(d) for the significant wave height away from the radius of max wind, use Eq. (7); and
(e) the most important finding is to use the radius of tropical storm force winds available routinely in the advisories issued by NHC or JTWC as a surrogate for the fetch parameter in wave estimations, since the "fetch" is difficult to determine for practical applications.

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Return to Table of Contents

Mean Circulation Highlights and Climate Anomalies

September through December 2013

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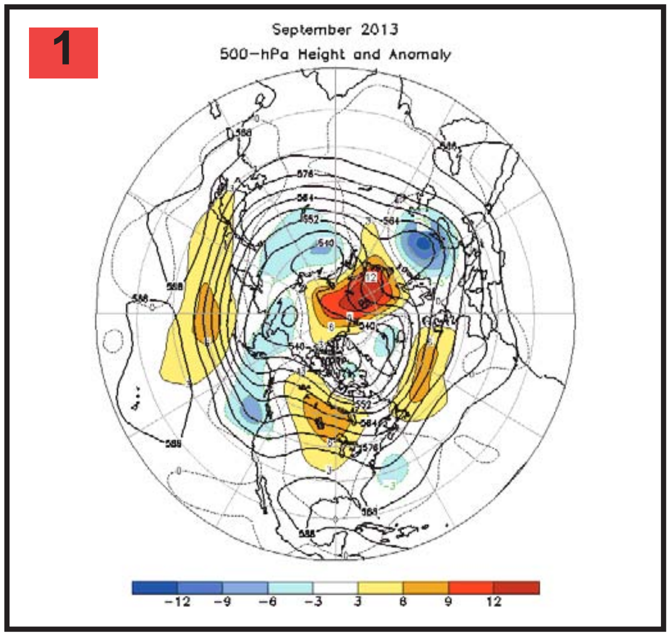
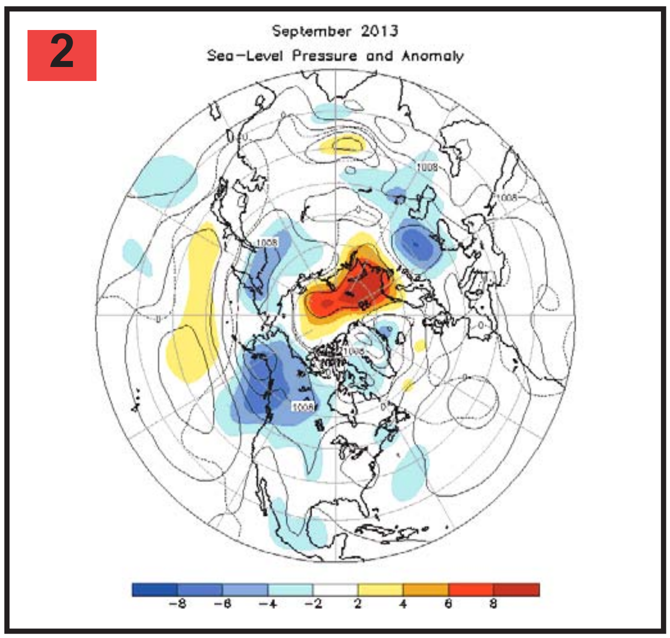
All anomalies reflect departures from the 1981-2010 base period.

September-October 2013

The 500 hPa circulation during September featured above average heights over central North America, the central North Atlantic, Scandinavia, and the western North Pacific. It also featured below average heights over the Gulf of Alaska, just off the East Coast of the United States, the Caspian Sea/Black Sea region, and north central Asia (**Figure 1**). Interestingly, the sea level pressure (SLP) pattern was substantially different from the mid-tropospheric circulation pattern (**Figure 2**). Above average SLP was observed over northern Scandinavia and much of the Russian side of the Arctic Ocean. Below average SLP was observed over the Gulf of Alaska, western Russia, and eastern Siberia.

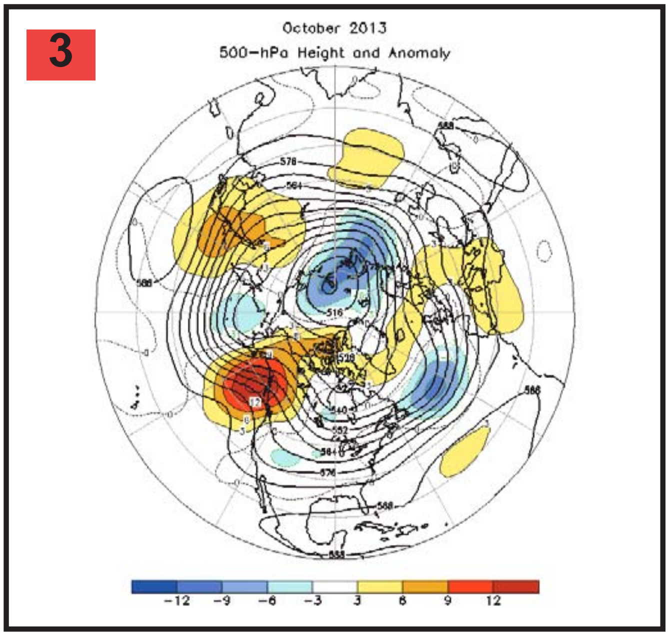
The October 500 hPa circulation featured a zonal wave 4 pattern of height anomalies (**Figure 3**). This pattern included above average heights over the Gulf of Alaska, the Mediterranean Sea, and eastern Asia, and below-average heights over the high latitudes of the central North Pacific, the western contiguous U.S., the central North Atlantic and central Russia. The SLP map depicts the more intense anomalies pole ward of about 50N (**Figure 4**). Above average SLP was observed over the Gulf of Alaska, and below average SLP prevailed over the central North Atlantic, north-central Russia, and the Bering Sea.

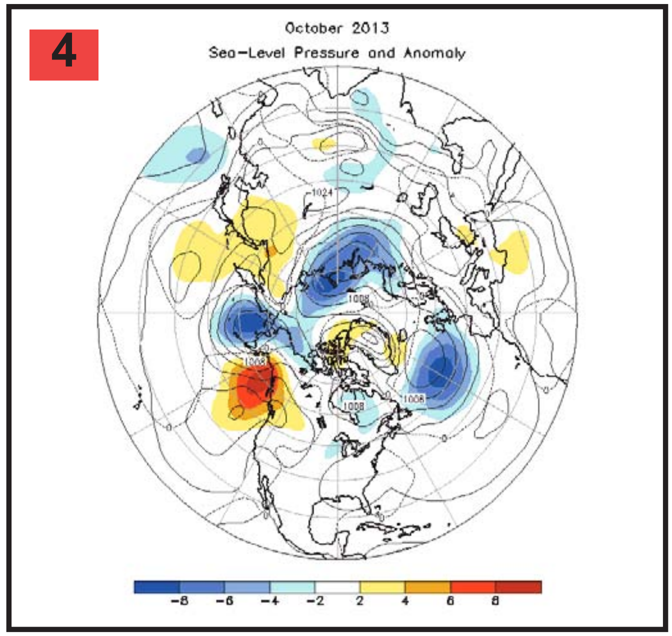




Caption for 500 hPa Heights and Anomalies: Figures 1,3,5,7
Northern Hemisphere mean and anomalous 500-hPa geopotential height (CDAS/Reanalysis). Mean heightsare denoted by solid contours drawn at an interval of 6 dam. Anomaly contour interval is indicated byshading. Anomalies are calculated as departures from the 1981-2010 base period monthly means.

Caption for Sea-Level Pressure and Anomaly: Figures 2,4,6,8 Northern Hemisphere mean and anomaloussea level pressure (CDAS/Reanalysis). Mean values are denoted by solid contours drawn at an interval of 4hPa. Anomaly contour interval is indicated by shading. Anomalies are calculated as departures from the1981-2010 base period monthly means.





The Tropics

Sea surface temperatures (SST) remained near average across the central and east-central equatorial Pacific and below average in the eastern equatorial Pacific during both September and October. The latest monthly Nino 3.4 indices were -0.1C (September) and -0.3C (October), well within ENSO-neutral territory. The depth of the 20C isotherm (oceanic thermocline) remained near average across the central and east-central equatorial Pacific during this two month period. Equatorial low level easterly trade winds remained near average across the equatorial Pacific (September and October), and tropical convection was slightly enhanced over Indonesia during this same two month period, and suppressed over the central equatorial Pacific (September). These oceanic and atmospheric anomalies collectively reflect a continuation of ENSO-neutral conditions.

November-December 2013

The 500 hPa circulation during November featured below average heights throughout the polar region, and a zonal wave 3 pattern of height anomalies in the middle latitudes (**Figure 5**). This wave 3 pattern reflected above average heights over the high latitudes of the North Pacific, the eastern North Atlantic, western and central Russia, and below average heights over eastern North America, Europe and Japan. The sea level pressure and anomaly map (**Figure 6**) generally mirrors the 500 hPa pattern.

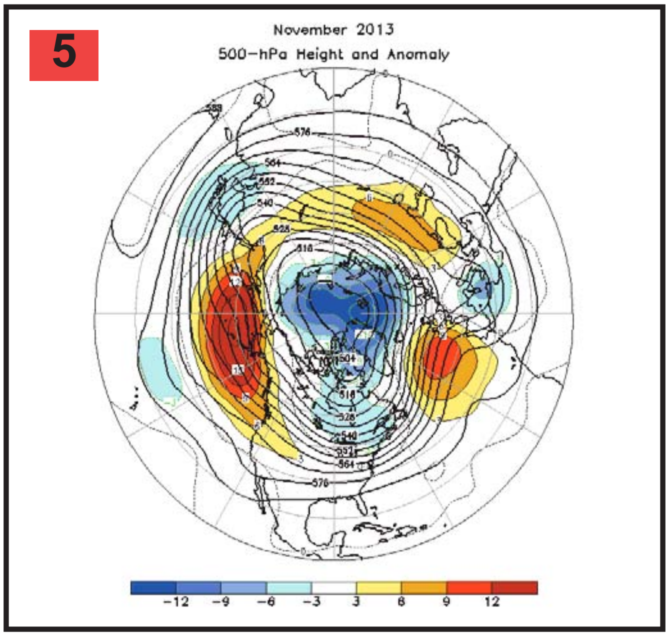
The month of December was characterized by above average heights across the high latitudes of the North Pacific, northeastern Asia, the Gulf of Alaska, the central North Atlantic, and Europe (**Figure 7**). It also featured below average heights across the western North Pacific, eastern Canada, and the high latitudes of the North Atlantic. The SLP and anomaly field (**Figure 8**) largely mirrored the middle tropospheric circulation pattern.

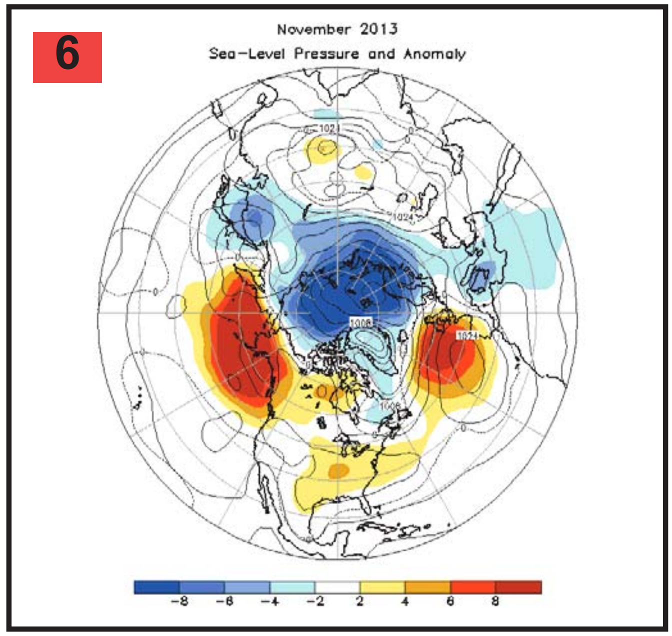
The Tropics

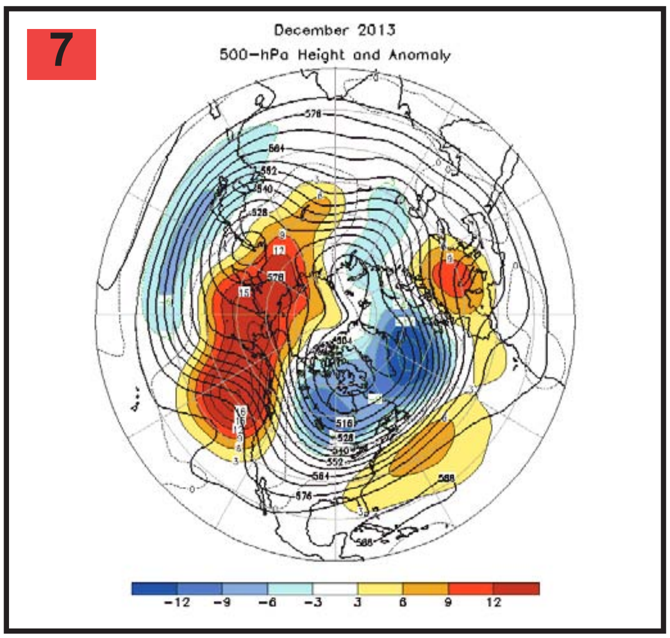
ENSO-neutral conditions continued during November and December 2013. Sea surface temperatures (SST) remained near average across the central and east central equatorial Pacific, and (in November) below average in the eastern equatorial Pacific.

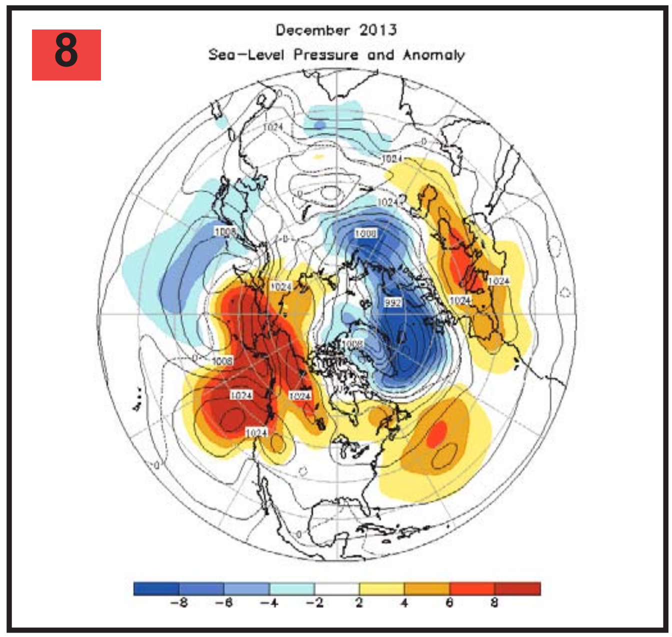
Caption for 500 hPa Heights and Anomalies: Figures 1,3,5,7 Northern Hemisphere mean and anomalous 500-hPa geopotential height (CDAS/Reanalysis). Mean heightsare denoted by solid contours drawn at an interval of 6 dam. Anomaly contour interval is indicated byshading. Anomalies are calculated as departures from the 1981-2010 base period monthly means.

Caption for Sea-Level Pressure and Anomaly: Figures 2,4,6,8 Northern Hemisphere mean and anomaloussea level pressure (CDAS/Reanalysis). Mean values are denoted by solid contours drawn at an interval of 4hPa. Anomaly contour interval is indicated by shading. Anomalies are calculated as departures from the1981-2010 base period monthly means.









The latest monthly Nino 3.4 indices were 0.0C for both months. The depth of the 20C isotherm (oceanic thermocline) remained near average in the central and east-central equatorial Pacific. Equatorial low level easterly trade winds remained near average across the central and eastern equatorial Pacific, and above average over the western equatorial Pacific. Equatorial low level easterly trade winds remained near average across the central and eastern equatorial Pacific, and above average over the western equatorial Pacific. Tropical convection remained enhanced over Indonesia and suppressed over the central equatorial Pacific.

Caption for 500 hPa Heights and Anomalies: Figures 1,3,5,7
Northern Hemisphere mean and anomalous 500-hPa geopotential height (CDAS/Reanalysis). Mean heightsare denoted by solid contours drawn at an interval of 6 dam. Anomaly contour interval is indicated byshading. Anomalies are calculated as departures from the 1981-2010 base period monthly means.

Caption for Sea-Level Pressure and Anomaly: Figures 2,4,6,8 Northern Hemisphere mean and anomaloussea level pressure (CDAS/Reanalysis). Mean values are denoted by solid contours drawn at an interval of 4hPa. Anomaly contour interval is indicated by shading. Anomalies are calculated as departures from the1981-2010 base period monthly means.

On November 8, 2013, Super typhoon Haiyan moved across the Philippines, resulting in the loss of thousands of lives, and causing tremendous damage. From a meteorological perspective, the preliminary numbers on this cyclone suggest Haiyan may have been one of the strongest tropical cyclones ever recorded. However, as of this writing, significant discrepancies exist between the peak sustained (1-minute average) wind speeds estimated by the Japanese Meteorological Agency (143 kts) and those estimated by the Joint Typhoon Warning Center in Guam (169 kts); due to differences in interpretation of satellite imagery as no direct measurements were available from aircraft reconnaissance **Reference 1**.

The preliminary value for the minimum central pressure currently stands at 895 hPa. This issue is expected to be officially resolved very soon by the various Meteorological Centers in this region. For comparison purposes, Typhoon Tip (1979) had the lowest recorded central pressure ever measured in a typhoon (870 hPa) and peak sustained 1-minute average winds in the 165-170 kt range. In the Atlantic basin, Wilma (2005) holds the minimum SLP record at 882 hPa, and, along with hurricanes Allen (1980) and Camille (1969), had similar peak sustained wind speeds in the 160-165 kt range.

References

1. Personal Communication with Dr. Christopher Landsea, Science and Operations Officer, National Hurricane Center, Miami, Florida, January 29, 2014.

Much of the information used in this article originates from the Climate Diagnostics Bulletin archive:
(http://www.cpc.ncep.noaa.gov/products/CDB/CDB_Archive_html/CDB_archive.shtml)

Return to Table of Contents

Marine Weather Review – North Atlantic Area

September through December 2013

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Introduction

The fall to early winter period of September to December 2013 featured mainly a progressive and increasingly active pattern of developing cyclones moving from southwest to northeast across the North Atlantic, with cyclones less frequently taking a more northerly track toward the Davis Strait, and even less frequent, a southeastward track from north of Iceland. Beginning in late October eighteen lows developed hurricane force winds detected by satellite, conventional surface observations, or model data. Ten of these occurred in December, and five cyclones developed central pressures below 950 hPa.

The four month period includes the last half of the hurricane season in the Atlantic basin. It turned out to be a quiet season with no hurricanes forming or moving into OPC's marine area north of 31N. Tropical activity occurring north of 31N included three tropical storms and one unnamed subtropical storm. One of these, Humberto, was a hurricane south of 31N early in September but moved north of 31N as a weakening tropical storm in mid September. More complete information on tropical cyclones including activity south of 31N may be found in the National Hurricane Center website (2013 Tropical Cyclone Reports) listed in the References.

Tropical Activity

Tropical Storm Gabrielle:

Gabrielle formed from a non-tropical low near 27N 65W at 0000 UTC September 10th which moved north and became a tropical storm 30N 65W the next morning with maximum sustained winds of 35 kts. Gabrielle reached maximum strength on the evening of the 10th with maximum sustained winds of 50 kts while passing near Bermuda. The cyclone then continued on a northward track as mostly a 40 kts then 35 kts tropical storm from the morning of the 11th through the night of the 12th, before being downgraded to a tropical depression while passing near 38N 66W on the morning of the 13th, with maximum sustained winds of 30 kts. The **Caribbean Princess** (ZCDG8) reported south winds of 35 kts and 2.4 m seas (8 ft) near 41N 64W at 0600 UTC on the 13th. Gabrielle became a post tropical low while passing near Halifax the following evening before merging with a front early on the 14th.

Tropical Storm Humberto:

The second named tropical cyclone of the period moved north into OPC's high seas waters as a weakening tropical storm, passing near 31N 44W on the morning of September 18th with maximum sustained winds of 35 kts. Humberto weakened to a tropical depression twenty four hours later when passing near 33N 44W with sustained winds of 30 kts. The cyclone then turned toward the northeast and became post tropical the following evening while passing near 34N 43W, before merging with a front in the central North Atlantic on the afternoon of the 20th.

Tropical Storm Melissa:

A non tropical gale force low formed at the end of a southwest to northeast oriented front near 21N 54W at 0000 UTC November 17th and moved north while intensifying, and developed subtropical characteristics just south of OPC's marine area near 29N 54W on the morning of the 18th. It was named Subtropical Storm Melissa at that time, with a 987 hPa central pressure and maximum sustained winds of 45 kts.

Melissa moved north northwest over the following twenty four hours and developed a maximum intensity of 55 kts for sustained winds as a subtropical storm while crossing 31N early on the 19th, with a central pressure of 982 hPa. The cyclone turned toward the northeast on the night of the 19th with top winds weakening to 45 kts. Melissa then re-intensified as a tropical storm, passing near 36N 48W at 1500 UTC on the 20th with maximum sustained winds of 50 kts. Tropical Storm Melissa then passed near 41N 32W with 55 kts sustained winds and a lowest central pressure of 980 hPa at 2100 UTC November 21st before weakening into a post tropical gale the following night, while passing near 42N 28W. Blocked by high pressure to the northeast, Post tropical Melissa turned toward the southeast and continued to weaken, before dissipating near the Strait of Gibraltar early on the 24th.

Unnamed Subtropical Storm:

A reanalysis after the event by the National Hurricane Center determined that a cutoff low pressure system that formed south of the Azores Islands in early December acquired subtropical characterisics and classified it as a subtropical storm at 0000 UTC December 5th and through 0000 UTC on the 7th. **Figure 1** shows this system as a storm force extratropical low with fronts at 0600 UTC on the 4th, and the second part of Figure 11 depicts the nearly stationary cyclone thirty six hours with fronts dissipated. Its convection became better organized by the 5th. Winds were strongest when it was extratropical, with ASCAT imagery revealing winds to 50 kts in the west semicircle at 2239 UTC December 3rd, and OceanSat-2 (OSCAT) imagery from 0052 UTC December 4th returning winds of 50 to 55 kts on the west and north sides. The cyclone subsequently weakened to a remnant low 90 nm south of the Azores 0600 UTC on the 7th and then dissipated as a trough north of the Azores later on the 7th.

Other Significant Events of the Period

Northeastern Atlantic Storm, September 14-16:

The strongest non-tropical low of September originated near the southern Labrador coast at 1800 UTC on the 13th and tracked northeast, becoming a storm with a lowest central pressure of 961 hPa east of Iceland two days later (**Figure 1**). The central pressure fell 35 hPa in the twenty four hour period ending at 1200 UTC on the 15th. This is well above the 24 hPa needed for a “bomb” at 60N and, occurring early in the season, is quite impressive. The ASCAT image in **Figure 2** reveals a swath of gale to storm force north to northwest winds in the west semicircle of the low with the center east of Iceland. The cyclone weakened while turning toward the southeast the next day and then on the 17th turned north with winds below gale force. The center moved north through the Norwegian Sea by the 20th.

North Atlantic Storm, October 24-27:

The weather became quite active in late October and early November, producing several hurricane force lows in close succession. The first of these, shown at maximum intensity in Figure 3, originated as a weak low on the U.S. mid Atlantic coast three days prior. The cyclone rapidly intensified east of Newfoundland on the 24th with the central pressure lowering by 33 hPa in the twenty four hour period ending at 1200 UTC on the 25th. Winds increased from gale force at 1800 UTC on the 24th to hurricane force twelve hours later. **Hibernia Platform** (VEP717, 46.7N 48.7W) reported southeast winds of 55 kts at 0900 UTC on the 24th (anemom height 139 m) and **Modu Henry Goodrich** (YJQN7, 46.7N 48.0W) encountered southwest winds of 60 kts and 4.6 m seas (15 ft) at 0000 UTC on the 25th. The **Knorr** (KCEJ) encountered west winds of 50 kts near 54N 45W nine hours later. An ASCAT (METOP-A) pass from 2252 UTC on the 25th returned a swath of west winds 50 to 60 kts on the south side and north to northeast winds 50 to 55 kts on the northwest side near the southern tip of Greenland, similar to the image in **Figure 6** for the October 28-31 event. Hurricane force winds lasted until the afternoon of the 26th. The system weakened beginning on the 26th while tracking east northeast. **Figure 4** shows the cyclone passing north of the British Isles as a gale, and **Figure 5** depicts the system inland over Scandinavia two days later.

North Atlantic Storm, October 28-31:

Figure 5 shows this cyclone near maximum intensity near 55 kts on the northwest side near the southern tip of Greenland. The low bias of ASCAT at high wind speeds means that actual winds were at least 65 kts. The weakening cyclone subsequently passed south of Iceland on the 31st and east of Iceland late on November 1st (**Figure 7**).

OBSERVATION	POSITION	DATE/TIME UTC	WIND	SEAS (m/ft)
Charleston Express (WDD6126)	53N 4E	28/1100	W 80	
BATEU01	54N 8E	28/1300	W 75	
Weser Pilot (DBEB)	54N 8.3E	28/1300	SW 60	
BATFR02	50.5N 1W	28/0600	SW 50	
BATFR17	54N 5E 54N 5E	28/0900 28/1200	SW 50 NW 55	
Buoy 62305	50.4N 0W	28/0600 28/0800	SW 55	4.3/14 Maximum 5.5/18
Buoy 62304	51.2N 1.8E	28/0800	SW 60	3.7/12

Table 1. Selected ship and buoy observations taken during the Northeastern Atlantic/North Sea storm of October 27-28, 2013

Northeast Atlantic/North Sea Storm, October 27-28:

Figures 3 and **Figure 4** show this developing storm moving as an open wave from south of Nova Scotia to its approach to the British Isles over a two day period. Eighteen hours later it was in the North Sea near 56N 6E with the central pressure down to 968 hPa, a drop of 28 hPa in twenty four hours. Ship reports and ASCAT imagery indicated a brief period of hurricane force winds over a small area south of the center on the 28th. **Table 1** lists the most notable ship and buoy reports during passage of this fast moving low. The cyclone quickly passed east of 10E and off the chart area late on the 28th.

the location of a similar cyclone four days earlier. The lowest central pressure was 964 hPa reached six hours earlier. The cyclone originated as a new low that formed in the Gulf of Maine early on the 27th, and **Figure 4** shows the cyclone as a rapidly intensifying gale over Nova Scotia six hours later. The central pressure fell 29 hPa in the twenty four hour period ending at 0000 UTC on the 29th. Hurricane force winds lasted from 0600 UTC until the afternoon of the 30th, after which a weakening trend set in. The ASCAT image in **Figure 6** reveals a swath of west winds 50 to 60 kts south of the center and north to northeast winds to

Northeastern Atlantic Storm, November 1-2:

The rapid development of this small but potent cyclone over a twenty four hour period is shown in **Figure 7**. Much of the intensification occurred during the twenty four hour period ending at 0600 UTC November 2nd when the central pressure fell 27 hPa. The ASCAT image in **Figure 8** reveals a compact circulation containing a small area of winds 50 to as high as 70 kts on the south and southwest sides of the center. The ship **BATFR60** (53.5N 4.5W) reported south winds of 50 kts at 1200 UTC on the 2nd. Buoy 62029 (48.8N 12.0W) reported west winds of 34 kts and 8.0 m seas (26 ft) at 1000 UTC on the 2nd, followed by a report of 9.5 m seas (31 ft) three hours later. The cyclone subsequently moved northeast across the British Isles and into the North Sea, where winds weakened to gale force in spite of the lowest central pressure of 970 hPa being reached there, at 0600 UTC on the 3rd. The cyclone weakened and moved into southern Norway the following night.

Northwestern Atlantic Storm, November 2-3:

Figure 7 shows initial development of this low as it tracked from the Great Lakes into central Quebec with the second part of **Figure 7** showing the eastern edge of the system with a "developing hurricane force" label, when the center was near 51N 68W with a 970 hPa central pressure. The cyclone moved into the Labrador Sea where it developed a lowest central pressure of 964 hPa and hurricane force winds at 1800 UTC on the 2nd and 0000 UTC on the 3rd. ASCAT imagery from 0020 UTC on the 3rd revealed east winds 50 to 60 kts ahead of a front approaching southern Greenland. Winds weakened to storm force the following night as the system drifted east, and became absorbed by another low passing to the east late on the 3rd.

North Atlantic Storm, November 9-12:

Initial development was as a new low on a front which moved off the southern Labrador coast at 0600 UTC November 8th and then out over the north central waters, to be overtaken and absorbed by a new wave of low pressure coming from near the island of Newfoundland. **Figure 9** depicts the merging of the two lows to form the hurricane force low at maximum intensity in the second part of the figure. This was the first of several lows to develop central pressures below 950 hPa. The central pressure fell 37 hPa in the twenty four hour period covered by **Figure 9**. The ASCAT-B image in **Figure 10** returned southwest winds of 50 kts on the southeast side of the cyclone with the center near the left edge of the image, and even stronger winds northwest of the occluded front (up to 60 kts). The cyclone then moved northeast on the 11th and weakened, and passed northeast of Iceland early on the 12th.

Northeastern Atlantic Storm, November 18-20:

This cyclone already was well developed when it moved out of the Arctic on a southeastward track, and passed near the Faroe Islands late on the 19th as a hurricane force 980 hPa low. An ASCAT pass from 0954 UTC on the 20th detected north winds of 50 kts between the Faroe Islands and Scotland. The cyclone subsequently moved southeast and weakened in the southern North Sea late on the 20th.

Western North Atlantic Storm, November 27-30:

This developing cyclone moved from New England on the morning of November 27th northeast across southern Labrador, and into the northwest Labrador Sea on the afternoon of the 28th while maintaining storm force winds. It briefly developed hurricane force winds with a 960 hPa center near 61N 57W at 0600 UTC on the 29th. It was similar in intensity and associated winds to the November 2-3 storm which followed a similar track. The ship **MSC Monterey** (D5BL4) near 41N 70W reported southeast winds of 40 kts and 9.0 m seas (30 ft) at 1700 UTC on the 27th. The **Arctic** (VCLM) near 58N 60W encountered northwest winds of 56 kts and 13.7 m seas (45 ft) at 0900 UTC on the 29th. Buoy 44024 (42.3N 65.8W) reported south winds of 35 kts and 9.0 m seas (30 ft) at 0300 UTC on the 28th. The cyclone subsequently moved northeast into the Davis Strait and weakened early on the 30th.

Northeastern Atlantic/North Sea Storm, December 4-5:

The rapid development of this relatively short lived system is displayed in **Figure 11**. The open wave south of Greenland in the first part of the figure deepened by 44 hPa in the next twenty four hours into a hurricane force low, and reached a maximum intensity of 960 hPa inland near 59N 12E at 1800 UTC on the 5th. The cyclone then continued to move away leading to diminishing winds. **Table 2** lists selected ship, buoy and platform observations during this event.

OBSERVATION	POSITION	DATE/TIME UTC	WIND	SEAS (m/ft)
ZQSD5	58.3N 0.8E	05/1200		10.0/33
Buoy 64045	59.1N 11.7W	05/0300 05/0500	NW 46	10.0/33 Maximum 10.5/34
Buoy 62102	57.9N 1.8E	05/1200 05/1400	NW 62	7.0/23 Maximum 9.0/30
Buoy 62128	58.7N 1.4E	05/1200 05/1400	NW 59	7.0/23 Maximum 9.0/30
Buoy 63119	58.2N 0.2W	05/1000	NW 70	
Buoy 62152	57.0N 1.8E	05/1300 05/1400	NW 50	7.5/25 Maximum 9.5/31
Buoy 62123	56.3N 2.2E	05/1100	NW 58	
Buoy 62122	57.3N 1.6E	05/1100 05/1500	NW 58	7.5/25 Maximum 10.0/33
Fino 3 (DJ2400)	55N 7E	05/1200	SW 54 G66	
Troll A (LF4B)	60.6N 3.7E	05/1200	NW 50 G61	6.0/18
Sleipner A	58.4N 1.9E	05/0600 05/1200 05/0900	SW 39 G46 Gust 70	5.5/18 Maximum 6.5/21

Table 2. Selected ship, buoy and platform observations taken during the Northeastern Atlantic/North Sea storm of December 4-5, 2013

North Atlantic Storm, December 10-14:

A developing low originating off the southeast coast of the U.S. on the afternoon of December 8th moved northeast, crossed the island of Newfoundland two days later and then rapidly intensified while turning north toward Greenland (**Figure 12**). The central pressure dropped 35 hPa in the twenty four hour period ending at 0600 UTC on the 12th. The second part of **Figure 12** shows the cyclone at maximum intensity. An ASCAT-B image containing passes from 1223 and 1404 UTC on the 12th revealed a swath of west to southwest winds of 50 to 60 kts south of the image in **Figure 6** for the October 28-31 event. A satellite altimetry image in **Figure 13** shows satellite sensed significant wave heights along satellite tracks, with times close to the valid time of the second part of **Figure 12**. A wave height of 13.2 m

the low and similar winds from the northeast near the southern tip of Greenland, similar to the image in **Figure 6** for the October 28-31 event. A satellite altimetry image in Figure 13 shows satellite sensed significant wave heights along satellite tracks, with times close to the valid time of the second part of **Figure 12**. A wave height of 13.2 m (43.57 ft) appears off the east coast of Greenland, similar to

(43.57 ft) appears off the east coast of Greenland, and a height of 12.2 m (40.16 ft) is south of the low near 49N 50W. The **Maersk Palermo** (PDHW) near 47N 45W reported west winds of 50 kts and 7.0 m seas (23 ft) at 0600 UTC on the 12th, while **Hibernia Platform** (VEP717, 46.7N 48.7W) encountered west winds of 65 kts and 7.3 m seas (24 ft). Three hours prior, **Terra Nova FPSO (VCXF, 46.4N 48.4W)** reported west winds of 50 kts and 6.0 m seas (20 ft). The cyclone subsequently drifted northwest and weakened, with its top winds lowering to gale force on the 14th, and then dissipated in the Davis Strait while a new center formed east of Greenland and drifted toward Iceland (**Figure 14**).

Northeastern Atlantic Storms, December 13-16:

Figure 14 depicts two significant events occurring in close succession. The lead low northwest of the British Isles in the first part of **Figure 14** originated near Bermuda at 1200 UTC on the 12th and rapidly intensified after 0000 UTC on the 14th, with the central pressure dropping 28 hPa in the twenty four hour period ending at 0000 UTC on the 15th, when the cyclone passed near 64N 8W with a lowest central pressure of 957 mb. It briefly developed hurricane force winds at 1800 UTC on the 14th. An ASCAT-B pass from 1953 UTC on the 14th with partial coverage showed an area of southwest winds 50 to 60 kts south of the Faroe Islands. The ship **BATEU08** (59N 6W) encountered southwest winds of 50 kts at 1800 UTC on the 14th. The buoy 62023 (51.4N 7.9W) reported southwest winds of 53 kts with gusts to 68 kts at 1400 UTC on the 14th, and highest seas of 8.0 m (26 ft) two hours later. Buoy 62081 (51.0N 13.3W) reported southwest winds of 36 kts and 10.0 m seas (33 ft) at 0900 UTC on the 14th.

The cyclone moved rapidly northeast of Iceland by the 15th. The second cyclone is shown in **Figure 14** with the central pressure dropping 50 hPa in twenty four hours, or more than 2 hPa per hour on average. It originated in the St. Lawrence Valley late on the 12th, passed south of the island of Newfoundland late on the 13th and then moved out over the central North Atlantic by the 14th. The second part of **Figure 14** shows the cyclone at maximum intensity. The ASCAT (METOP-A) image in **Figure 15** reveals a swath of west to south winds 50 to 70 kts in the southeast side of the low. Hurricane force winds lasted from 1800 UTC on the 14th through 1800 UTC on the 15th, after which the cyclone passed northeast of Iceland while weakening. Buoy 64045 (59.1N 11.7W) reported southwest winds of 50 kts at 1400 UTC on the 15th, and one hour later maximum seas of 13.7 m (45 ft).

North Atlantic Storms, December 17-19:

Figure 16 shows the next significant event developing from the merging of northern and southern lows near and south of the island of Newfoundland. The central pressure fell 35 hPa in the twenty four hour period ending at 1800 UTC on the 18th. Hurricane force winds lasted from 1200 UTC on the 18th to 0600 UTC on the 19th. Six hours later the center eveloped a lowest central pressure of 940 hPa near 64N 12W. Buoy 62023 (51.4N 7.9W) reported south winds 48 kts with gusts to 57 kts and 5.0 m seas (16 ft) at 1500 UTC on the 18th, a peak gust of 67 kts one hour later, and highest seas 6.5 m (21 ft) at 0300 UTC on the 19th. Buoy 62105 (55.0N 13.2W) reported northwest winds of 47 kts and 7.0 m seas (23 ft) and maximum seas of 10.5 m (34 ft). The cyclone then passed north of Iceland late on the 19th and weakened to a gale. Also, a second low formed in the east Greenland waters near 63N 35W at 1200 UTC on the 18th and moved southeast, briefly developing hurricane force winds six hours later near the southern tip of Greenland before dissipating.

North Atlantic Storm, December 18-21:

The next major storm originated as the frontal wave of low pressure seen in the first part of **Figure 16** south of the Great Lakes. It moved offshore late on the 17th and rapidly intensified after passing east of the Gulf of Maine. The central pressure fell 34 hPa in the twenty four hour period ending at 1200 UTC December 19th when the center passed near 50N 52W with a 966 hPa central pressure. The cyclone intensified further and developed hurricane force winds six hours later, which lasted until early on the 20th. An ASCAT-B pass from 2308 UTC on the 19th returned an area of west winds 50 to 70 kts on the south side to near 44N. The cyclone dissipated early on the 21st or became absorbed by a secondary low to the north near Iceland. Some notable surface observations taken in this event are listed in **Table 3**.

North Atlantic Storm, December 22-25:

Low pressure originating as a frontal wave just south of Nova Scotia on the morning of the 21st tracked east into the the central North Atlantic over the next day before turning northeast and rapidly intensifying, with **Figure 17** depicting final development into the deepest low of the period with a central pressure of 929 hPa (27.43 inches). The central pressure fell 52 hPa in the twenty four hour period ending at 1800 UTC on the 23rd.The 500 mb analysis for 0000 UTC on the 23rd (**Figure 18**) precedes the period of most rapid intensification and, although not shown, a short wave trough is apparent southwest of the surface low position at that time, near 51N 22W. The jet stream and short wave trough support rapid development. More information on the use of the 500 hPa chart may be found in the References (Sienkiewicz and Chesneau, 2008). An ASCAT-A pass from 2230 UTC on the 23rd showed a swath of west winds 50 to 55 kts on the south side of the cyclone between 50N and 53N. To the northwest a second cyclone formed in the east Greenland waters at 1200 UTC on the 22nd and moved southwest, briefly developing hurricane force winds near the southern tip of Greenland with a 960 hPa center at 0000 UTC on the 23rd before turning southeast. The second part of **Figure 17** shows the cyclone at 54N 30W moving away from Greenland. The main cyclone northwest of the British Isles subsequently moved north and passed east of Iceland as a weakening gale late on the 25th. The **Maersk Ohio** (KABP) near 44N 30W reported southwest winds of 55 kts and 8.2 m seas (27 ft) at 1800 UTC on the 22nd. The **Jaeger Arrow** (C6RM7) encountered west winds 35 kts and 10.7 m seas (35 ft) near 46N 33W at 0400 UTC on the 23rd.

OBSERVATION	POSITION	DATE/TIME UTC	WIND	SEAS (m/ft)
Queen Mary 2 (ZCEF6)	43N 40W 43N 43W	19/1100 19/1700	S 65 W 50	6.5/21 10.7/35
Oranjeborg (PIAG)	59N 30W	20/2100	NW 50	
Jaeger Arrow (C6RM7)	47N 23W	21/1100	W 40	12.8/42
Hibernia (VEP717)	46.7N 48.7W	19/1500	W 80	
Terra Nova FPSO (VCXF)	46.4N 48.4W	19/1500 20/0000	W 69	 10.0/33
Henry Goodrich (YJQN7)	46.7N 48.0W	19/1500 19/1800	SW 73	 10.7/35
Buoy 64045	59.1N 11.7W	21/0700 21/1200	SW 38	 Maximum 11.5/38
Buoy 62095	53.1N 15.9E	20/2000 21/0800	SW 40	8.5/28 Maximum 12.0/39
Buoy 62105	55N 13.2E	20/2300 21/0600	SW 38	9.0/30 Maximum 13.5/44

Table 3. Selected ship, buoy and platform observations taken during the North Atlantic storm of December 18-21, 2013

North Atlantic Storm, December 28-31:

The final significant weather event of the period originated near the southern New England coast on the afternoon of the 26th and moved northeast across the island of

Newfoundland on the morning of the 27th. Rapid intensification in the following twenty four hours and then a turn to the north with slowing led to a cyclone over the northern waters at maximum intensity (**Figure 19**). The central pressure fell 30 hPa in the twenty four hour period ending at 1200 UTC on the 28th. The system became complex by 0000 UTC on the 30th. The ASCAT-A image in **Figure 20** shows two areas of strong winds with the highest winds of up to 60 kts near the south-east coast of Greenland. There were two cyclone centers at that time, one near 59N 37W and the other near 59N 30W. The centers slowly weakened and merged with another cyclone passing to the south (**Figure 19**) by the 31st when winds weakened to gale force.

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Return to Table of Contents

Marine Weather Review – North Pacific Area

March through August 2013

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Introduction

The most active storm track during the period was from the western North Pacific in the vicinity of Japan northeastward toward the central Aleutian Islands before weakening in the northeastern Pacific or southern Gulf of Alaska. Several moved into the Bering Sea, with the strongest one occurring in early March. Several cyclones reached or approached hurricane force strength during March and early April, developing central pressures in the 960s or below. After an unusually deep summer storm passed just south of the Aleutian Islands and southern Bering Sea late in June, high pressure aloft building over the North Pacific and parts of Alaska suppressed activity, with no cyclones developing storm force winds until early August, when late summer activity picked up. Tropical activity appearing in OPC's oceanic surface analysis area consisted of four named cyclones (two tropical storms and two typhoons), with one each in June and July and two occurring in August as late summer activity began to pick up. The late August event actually originated in the central Pacific warning area handled by the Central Pacific Hurricane Center in Honolulu and crossed 180W into the western Pacific warning area handled by the Joint Typhoon Warning Center at Pearl Harbor, HI. None of these cyclones later redeveloped as strong mid-latitude extratropical (post-tropical) lows.

Tropical Activity

Tropical Storm Yagi:

Yagi attained tropical storm strength while crossing 130E well south of Japan at 1800 UTC June 8th, heading northeast. Yagi gradually intensified over the next two days, developing a maximum intensity of 55 kts for sustained winds with gusts to 70 kts while passing near 28N 136E at 0000 UTC on the 11th. The MV **Safmarine Mafadi** (9VBB3) reported southeast winds of 40 kts and 4.0 m seas (13 ft) near 21N 134E at 1400 UTC on the 9th. The cyclone then drifted east and slowly weakened, becoming a tropical depression with 30 kts sustained winds near 31N 137E at 1200 UTC on the 12th and a post-tropical low six hours later. At 2100 UTC on the 11th the **Grebe Arrow** (C6OM7) reported east winds of 45 kts and 4.3 m seas (14 ft) near 29N 142E. The remains of Yagi became absorbed by a frontal zone southeast of Japan late on the 15th.

Typhoon Soulik:

A non-tropical low appearing near 20N 152E early on July 6th drifted west and became Tropical Storm Soulik near 19N 146E at 0000 UTC on the 8th with 40 kts maximum sustained winds. Soulik rapidly intensified into a typhoon near 20N 141E eighteen hours later with maximum sustained winds of 65 kts. Drifting west northwest and continuing to intensify, Soulik attained a maximum intensity of 125 kts with gusts to 150 kts near 21N 136E at 0000 UTC on the 10th. This placed Soulik in Category 4 of the Saffir-Simpson wind scale, with the highest being 5. The cyclone then continued to drift west with a slow weakening trend, and passed west of 130E, or the western edge of the National Weather Service's Unified Analysis, by 0600 UTC July 11th as a 95 kts typhoon. A satellite based altimetry detected significant wave heights of 33 ft (10.0 ms) near the center of Soulik at 2100 UTC on the 10th.

Tropical Storm Utor:

Utor originated as a non-tropical low which formed far to the south near 11N 137E at 1200 UTC August 8th, moved northwest and became Tropical Depression 11W six hours later, and then a tropical storm near 13N 134E 0600 UTC on the 9th with maximum sustained winds of 35 kts. It was given the name Utor twelve hours later before crossing 130E as a 45 kts tropical storm 0000 UTC on the 10th. Utor later became a typhoon west of the area.

Typhoon Pewa:

Originating in the central Pacific as Tropical storm Pewa near 10N 173W at 1200 UTC on August 16th, Pewa tracked slowly west northwest with gradual intensification over the next three days and retained its name while crossing 180W into the Joint Typhoon Warning Center's area of responsibility early on the 18th. Pewa briefly became a typhoon at 0600 to 1200 UTC on the 19th while passing near 15N 177E with maximum sustained winds of 65 kts with gusts to 80 kts. Pewa then gradually weakened while turning toward the northwest and then north over the next six days, and became a remnant low just south of OPC's high seas area near 29N 166E at 0600 UTC August 25th.

Other Significant Weather of the Period

North Pacific and Bering Sea Storm, February 28-March 2:

A developing cyclone coming from just south of Japan early on February 27th rapidly intensified out over the North Pacific over a thirty six hour period as depicted in **Figure 1**. The central pressure fell 29 hPa in the twenty four hour period ending at 1800 UTC on March 1st, when the system reached maximum intensity. The swath of west to northwest winds of up to 60 kts detected by satellite (**Figure 2**) actually extended into the southern Bering Sea while the center was passing just south of the central Aleutians at this time. The low bias of ASCAT imagery at these high wind speeds prompted OPC analysts to give this system a hurricane force label. The **Dominator** (WBZ4106) near 54N 166W reported east winds of 50 kts and 4.0 m seas (13 ft) at 0700 UTC on the 2nd. The ship **4XIM** (56N 172W) reported 8.8 m seas (29 ft) along with 35 kts northeast winds eleven hours later. The cyclone subsequently weakened while turning east and then southeast over the next several days with its winds dropping to gale force by the 3rd, and moved inland over Oregon on the 6th.

Western Pacific and Bering Sea Storm, March 1-4:

This cyclone, already with storm force conditions while passing over northern Japan on March 1st (**Figure 1**), tracked northeast near the Kurile Islands and developed a lowest central pressure of 964 hPa near 52N 164E at 1800 UTC on the 3rd. The ASCAT imagery in **Figure 3** reveals a swath of east winds up to 55 kts across the northern Kurile Islands, indicating actual winds approached hurricane force with this cyclone. The center was over the southern Kurile Islands with a 968 hPa central pressure at this time. The storm subsequently weakened over the western Bering Sea on the 4th with its winds diminishing to gale force, before moving inland over eastern Russia on the 5th.

North Pacific Storm, March 6-8:

Low pressure originating just south of Japan on March 3rd tracked northeast, developing storm force winds over the central waters early on the 6th before passing near 53N 163W with a lowest central pressure of 954 hPa early on the 7th. This was the deepest non-tropical cyclone of the period in the North Pacific. A high resolution ASCAT pass valid at 2128 UTC March 7th revealed a broad circulation with winds up to 45 kts with some higher east winds of 50 kts detected between Kodiak Island and the Kenai Peninsula associated with an approaching front. The cyclone moved north into the southeast Bering Sea late on the 7th and weakened rapidly over Alaska late on the 8th.

Western North Pacific Storm, March 31-April 3:

A developing low pressure system east of Japan rapidly intensified over a twenty four hour period as two frontal systems merged (**Figure 4**), with the central pressure falling 39 hPa. The lowest central pressure was 964 hPa, reached six hours later. The winds increased from gale force to hurricane force in the six hour period ending at 1200 UTC April 1st. Hurricane force winds with this system lasted through 1800 UTC on the 2nd, when the center passed near 48N 180W. **Figure 5** is a high resolution ASCAT image showing a swath of west to northwest winds as high as 65 kts on the south side of the cyclone's center. The **APL Brazil** (C6TL7) near 49N 167E reported north winds of 45 kts and 5.8 m seas (19 ft) at 0600 UTC on the 2nd. The **Houston Express** (DCCR2) encountered east winds of 45 kts and 10.7 m seas (35 ft) near 53N 174W) at 2300 UTC on the 2nd. One hour later the **Nyk Triton** (3FUL2) reported east winds of 35 kts and 9.5 m seas (31 ft) near 53N 172W. The cyclone then slowly weakened while turning east along 49N south of the central Aleutian Islands with its winds lowering to gale force on the afternoon of the 3rd. Dissipation followed, south of the eastern Aleutians, later on the next day.

North Pacific Storm, April 2-6:

The next cyclone passed just south of Japan early on April 2nd with its expected presence implied by a twenty four hour track position just southeast of Japan in the second part of **Figure 4**. The center developed storm force winds as it passed east of Japan near 36N 143E with a 981 hPa central pressure at 0600 UTC on the 3rd. The cyclone developed a lowest central pressure of 974 hPa while passing near 40N 180W at 0000 UTC on the 6th. ASCAT imagery from 2135 UTC April 5 revealed west winds of 50 kts south of the center. The system then moved northeast and weakened, with its winds diminishing to gale force well south of the central Aleutian Islands early on the 6th, and on the 8th became absorbed by a new cyclone forming to the northeast in the Gulf of Alaska on the 8th.

Western North Pacific Storm, May 8-9:

A complex area of low pressure with multiple centers to the east and southeast of Japan at 1800 UTC on the 7th consolidated into a single center twenty four hours later near 40N 157E, where it stalled and developed storm force winds and a 992 hPa center six hours later. ASCAT imagery available at 2245 UTC on the 8th revealed a small area of 50 kts east winds on the north side of the system. A vessel reporting with the **SHIP** call sign near 39N 151E encountered northwest winds of 50 kts at 1200 UTC on the 9th. The center developed a lowest central pressure of 982 hPa near 40N 156E at 1800 UTC on the 9th, but its top winds had weakened to gale force by that time. The cyclone then drifted northeast and weakened late on the 9th and its winds lowered to below gale force early on the 12th. The cyclone dissipated later that day as a new center formed near the western Aleutian Islands.

Western North Pacific Storm, May 17-19:

An unseasonably intense cyclone formed in the western waters in the middle of May as depicted in **Figure 6**. It originated as a complex area of low pressure with multiple centers east and southeast of Japan late on May 15 which consolidated into one center at 0000 UTC on the 17th. The central pressure rapidly dropped, by 26 hPa in the twenty four hour period ending at 0600 UTC on the 18th. The second part of **Figure 6** shows the cyclone at maximum intensity and the visible satellite image in **Figure 7** shows a mature occluded system with well defined frontal bands wrapping around the center. The cyclone was still near maximum intensity at that time. The high resolution ASCAT image in **Figure 8** returned some winds of 50 kts on the south side at the edges of adjacent passes. It is possible the data free gap between passes misses higher winds.

A ship using the call sign **SHIP** near 35N 152E reported northwest winds of 45 kts at 1800 UTC on the 17th. Six hours later the **Starlsmene** (LANT5) encountered southeast winds of 35 kts and 11.3 m seas (37 ft). The cyclone subsequently weakened while tracking northeast into the Bering Sea with its top winds lowering to gale force early on May 19th and to below gale force in the southern Bering Sea on the afternoon of the 21st. Dissipation followed on the 23rd, in the northern Bering Sea.

Eastern North Pacific Storm, June 4-6:

This event began as a wave of low pressure near 36N 167E early on June 3rd which gradually intensified while moving east northeast over the next two to three days, developing storm force winds and a lowest central pressure of 972 hPa near 49N 158W at 0000 UTC on the 6th. An ASCAT pass from 0753 UTC on the 6th returned winds up to 45 kts on the south side in an image similar to that of the June 20-21 event (**Figure 10**). The low bias of ASCAT winds supports analysis as a storm force low. The **Hanover Express** (DFGX2) near 54N 154W reported east winds of 45 kts at 0600 UTC on the 6th. The drifting buoy 46246 (50.0N 145.1W) reported seas of 7.6 ms (25 ft) at 0500 UTC on the 7th. The cyclone's top winds diminished to gale force by the afternoon of the 6th as a weakening trend began. The cyclone dissipated near southern Southeast Alaska on the 9th.

North Pacific Storm, June 20-21:

The last storm force event to occur until late summer featured an unusually intense summer storm developing from a complex of low centers east of Japan over a forty eight hour period as depicted in **Figure 9**. The lowest central pressure of 963 hPa was the second lowest of the period in the North Pacific. The high resolution ASCAT image in **Figure 10** reveals winds as high as 45 kts on the south side of the cyclone when the system was approaching maximum intensity. The **Hanover Express** (DFGX2) near 51N 170E reported northwest winds of 45 kts and 6.5 m seas (21 ft) at 0000 UTC June 22nd, while the **Star Evviva** (LAHE2) encountered north winds of 35 kts and 8.5 m seas (28 ft) near 52N 170E. The cyclone subsequently passed near the central Aleutian Islands late on the 21st with its winds weakening to gale force, before reaching the eastern Aleutians early on the 23rd. Upper level high pressure over Alaska then forced the cyclone to drift southeastward over the next several days, and stall west of Washington and Oregon by the 29th. Dissipation followed late on the 30th.

Eastern North Pacific Storm, August 5-6:

After a relatively quiet July, the weather became more active in August with two storm force lows. The first of these originated as a secondary development on a front with the primary low well to the west (**Figure 11**). The new cyclone gradually intensified over the next two days, developing a lowest central pressure of 981 hPa south of the Alaska Peninsula as shown in the second part of **Figure 11**. ASCAT imagery (**Figure 12**) detected winds as high as 45 kts on the south side of the center approximately 0600 UTC on the 6th with OPC analyzing the cyclone as a storm force low at 0600 and 1200 UTC on the 6th. The buoy 46075 (53.9N 160.8W) reported northwest winds of 33 kts with peak gusts of 43 kts and 4.0 m seas (13 ft) at 2100 UTC on the 6th. The cyclone subsequently weakened while turning northward into the southeast Bering Sea by the 7th, where it stalled through the 9th before moving inland on the 10th.

Northwestern Pacific Storm, August 27-29:

Low pressure originating south of Japan early on August 26th moved northeast over the next two days, developing storm force winds with a 977 hPa central pressure near 47N 157E at 1200 UT C on the 28th. The cyclone then turned north into the Sea of Okhotsk later on the 28th, developing a lowest central pressure of 972 hPa near 50N 156E at 0000 UTC on the 29th. ASCAT imagery from 2314 UTC on the

28th returned winds to 45 kts in the south semicircle near the Kurile Islands.The **Paris Express** (DIHE) near 45N 161E reported southeast winds of 40 kts at 1200 UTC on the 28th. The **Westwood Columbia** (C6SI4) near 46N 158E encountered seas of 7.9 ms (26 ft) along with southwest winds of 30 kts at 0600 UTC on the 29th. The cyclone subsequently weakened rapidly while moving northeast into the western Bering Sea later on the 29th and the 30th, and then became absorbed by a gale force low passing to the south on the 31st.

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Return to Table of Contents

2014 Marine Meteorological Monitoring Survey (MMMS)

The World Meteorological Organization (WMO) conducts the Marine Meteorological Monitoring Survey (MMMS) on a regular basis to improve the level of metorological support coordinated by the Joint WMO-IOC Technical Commission of Oceanography and Marine Meteorology (JCOMM). We kindly seek your assistance in disseminating information on the ongoing survey. To participate in the survey online please go to: http://www.jcomm.info/MMMS2014. Any questions or enquires can be directed to WMO Marine Meteorology and Oceanography Programme by email at: mmo@wmo.int

Return to Table of Contents

Tropical Atlantic and Tropical East Pacific Areas

September through December 2013

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North Atlantic Ocean to 31N and Eastward to 35W, including the Caribbean Sea and the Gulf of Mexico

Atlantic Highlights

The autumn period of September through December 2013 proved to be very active in terms of gale conditions across the TAFB Area of Responsibility (AOR). The 26 non-tropical warnings issued for the Tropical North Atlantic during this period were well above the average of 16 warnings issued during the past 7 years.

Table 1 below shows the non-tropical warning events that occurred across the Tropical Atlantic, Gulf of Mexico, and Caribbean Sea during this period. While only 3 events occurred in October, November and December proved very active, with 12 and 11 events occurring, respectively.

Table 1. Non-tropical Warnings issued for the Atlantic Basin between 01 Sept 2013 and 31 Dec 2013.

Onset	Region	Peak Wind Speed	Duration	Forcing
1800 UTC 02 Oct	Caribbean	35 kts	21 hr	Pre TS Karen
0600 UTC 23 Oct	Gulf of Mexico	35 kts	30 hr	Cold front
1200 UTC 25 Oct	Gulf of Mexico	35 kts	12 hr	Frontal trough
1800 UTC 02 Nov	Gulf of Mexico	35 kts	12 hr	Cold front
1800 UTC 07 Nov	Gulf of Mexico	35 kts	33 hr	Cold front
0000 UTC 13 Nov	Gulf of Mexico	40 kts	42 hr	Cold front
0600 UTC 13 Nov	SW N Atlc	35 kts	24 hr	Cold front
0000 UTC 16 Nov	Gulf of Mexico	35 kts	12 hr	Trough
0600 UTC 16 Nov	Central Altc	45 kts	54 hr	Pre ST Melissa
0600 UTC 23 Nov	Gulf of Mexico	35 kts	36 hr	Cold front
1800 UTC 24 Nov	SW N Atlc	35 kts	06 hr	Cold front
0600 UTC 25 Nov	Central Atlc	35 kts	06 hr	Cold front
0600 UTC 26 Nov	Gulf of Mexico	35 kts	36 hr	Cold front
1200 UTC 27 Nov	SW N Atlc	40 kts	18 hr	Cold front
0000 UTC 28 Nov	NW Caribbean	35 kts	06 hr	Cold front
1800 UTC 06 Dec	Central Atlc	35 kts	54 hr	Cold front
0600 UTC 07 Dec	Gulf of Mexico	35 kts	24 hr	Cold front
1500 UTC 10 Dec	Gulf of Mexico	35 kts	15 hr	Cold front
0600 UTC 15 Dec	SW N Atlc	35 kts	12 hr	Cold front
0600 UTC 15 Dec	Gulf of Mexico	40 kts	18 hr	Cold front
1200 UTC 20 Dec	Caribbean	35 kts	54 hr	Pressure gradient
1800 UTC 21 Dec	Gulf of Mexico	35 kts	06 hr	Cold front
0000 UTC 23 Dec	Gulf of Mexico	40 kts	48 hr	Cold front
0600 UTC 23 Dec	Caribbean	35 kts	12 hr	Pressure gradient
1200 UTC 27 Dec	Gulf of Mexico	35 kts	24 hr	Low pres
1200 UTC 30 Dec	Gulf of Mexico	35 kts	48 hr	Cold front and low pressure

The upper atmospheric pattern spanning North America and the adjacent ocean basins contributed strongly to the very active weather across the TAFB AOR during November and December of 2013. Upper level ridging centered across the Gulf of Alaska during much of October strengthened, shifted slightly northwest, then expanded northwest to southeast during most of November and December to create a strong persistent blocking pattern, yielding the positive phase of the North Pacific Oscillation. This forced cold Arctic air to be funneled into central and eastern portions of the U.S. and provided the forcing for frequent cold fronts and gale conditions to spill into the Gulf of Mexico and through the Pacific Ocean's Gulf of Tehuantepec, and occasionally to sweep across portions of the Southwest North Atlantic. The development of persistent east to west upper level ridging across the mid latitudes of the Atlantic during December combined with the Pacific blocking pattern to force the cold weather intrusions into a more southerly trajectory, resulting in gale conditions mainly occurring across the Gulf of Mexico. **Figure1** shows the mean 500 hPa height anomalies across the Atlantic and Pacific Oceans during November and December, and illustrates the prevailing upper tropospheric patterns across both basins.

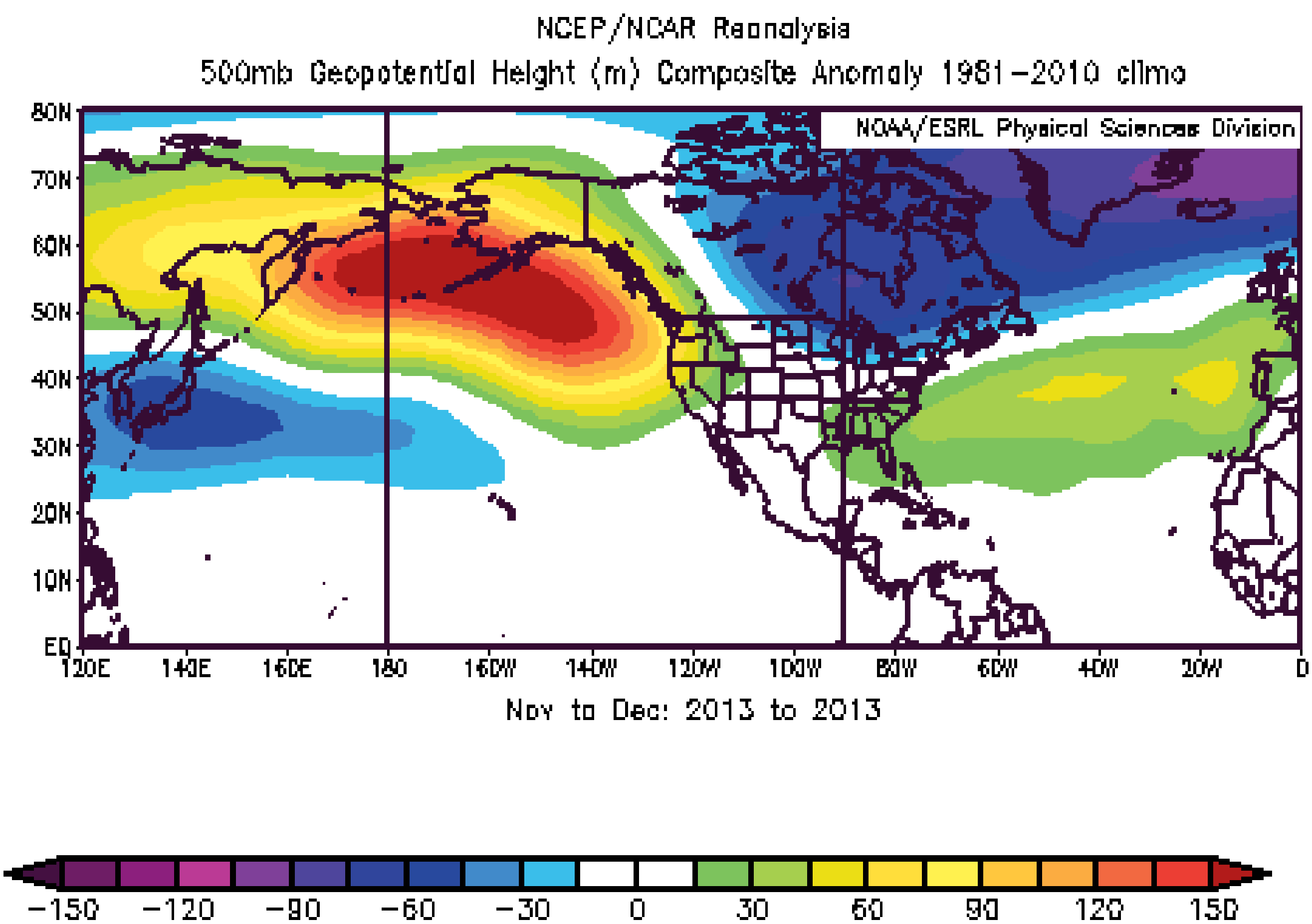

Figure 1. NOAA ESRL Reanalysis plot of mean 500 HPa height anomalies for Nov through Dec 2013, where warm colors represent above normal heights and cool colors below normal heights. Note the strong and broad high pressure ridge prevailing across much of the NE Pacific and broad deep trough extending from east of Greenland into the Great Lakes region. The teleconnection between the Atlantic and Pacific upper level patterns forced the prevalent upper trough across eastern Canada to make frequent intrusions southward between the two upper level ridges during the period, transporting surface cold fronts and very cold continental polar air.

13-14 November Gulf of Mexico/Southwest North Atlantic Gale

A series of strong cold fronts swept southeastward across the Gulf of Mexico and portions of the Southwest North Atlantic during the month of November, producing several periods of northerly gales. One of the more interesting events occurred 13-14 Nov, when gales spread as far southeastward as the northwestern Bahamas through the Straits of Florida. A weak cold front moved southeast into the extreme northern Gulf waters on 11 Nov and stretched east-northeastward across north Florida, where it stalled then drifted slowly south and weakened through 12 Nov. A strong cold front shifting southward through central portions of the U.S. then entered the central Gulf shortly after 1800 UTC 12 Nov, followed by a 1047 hPa surface high shifting southeastward across the Missouri Valley. Winds quickly reached gale force behind the front by 0000 UTC on 13 Nov, from north central to western Gulf waters, where 0200 to 0400 UTC ASCAT passes showed north to north-northeast gales spreading from the outer coastal waters between Apalachicola, FL and the mouth of the Mississippi river southwestward to the offshore waters of Tampico, Mexico. By 0600 UTC 13 Nov, the front had shifted offshore of the southeastern U.S. and north Florida, where northerly gales to 40 kts with higher gusts extended from the coastal waters of Jacksonville, FL well offshore into the open SW N Atlantic, and were depicted entering north portions of this area by a 0411 UTC 13 Nov OSCAT pass. The front continued moving southeastward across the eastern Gulf of Mexico, the Florida peninsula and the SW Atlantic through 0000 UTC 14 Nov, reaching from Bermuda through the northwest Bahamas and Straits of Florida to the central Bay of Campeche, (**Figure 2**). Northerly gales to 40 kts persisted across southwest portions of the Gulf through this time, while gales across the SW Atlantic continued to shift southward behind the front.

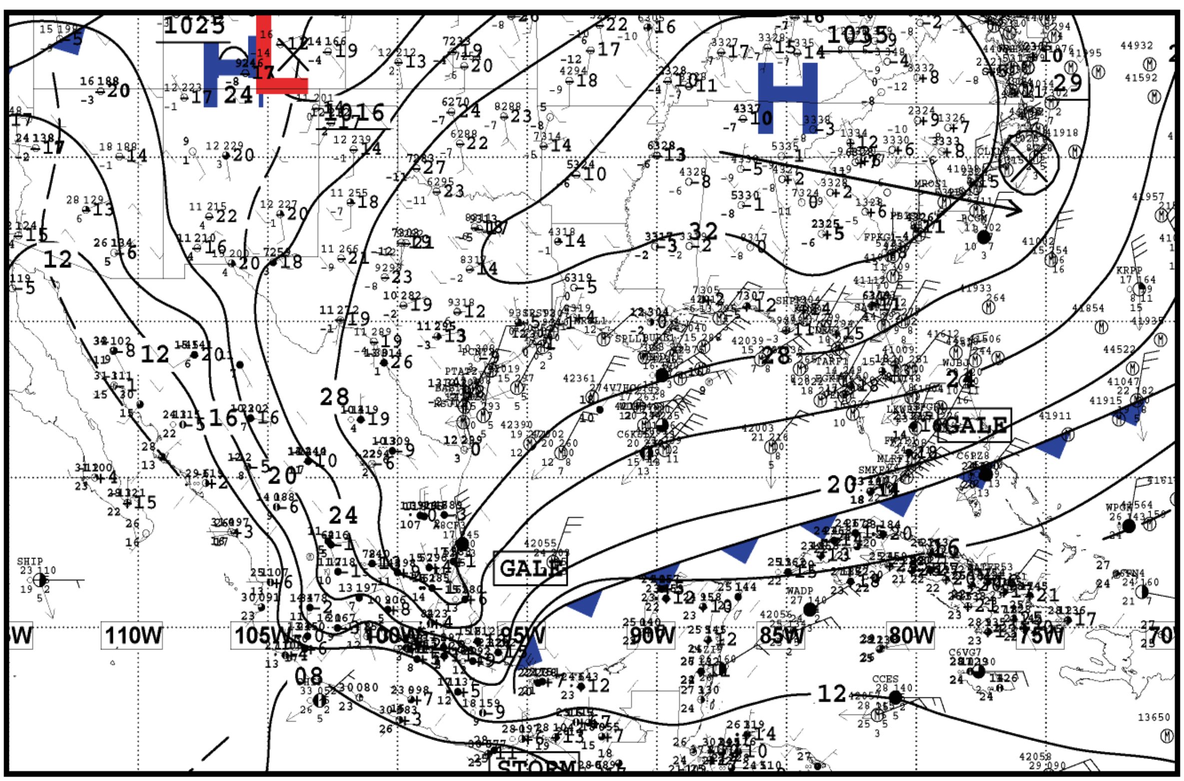

Figure 2. NWS Unified Surface Analysis for 0000 UTC 14 Nov showing cold front stretched from near Bermuda (not shown) through the northwest Bahamas and Straits of Florida, and 1035 HPa high pressure centered across eastern U.S. promoting strong pressure gradient north of the front. Gale symbols indicate general areas of NHC Gale Warnings.

Several ship reports from across the northwest Bahamas and the Florida Keys began to indicate gale force winds by 0000 UTC 14 Nov, and were later confirmed by 0200 to 0400 UTC ASCAT passes. At 0000 UTC the **Carnival Fascination** (C6FM9) was moving through the Straits of Florida offshore of the central Florida Keys and reported NE winds at 40 kts, while at 0300 UTC the **Norwegian Sky** (C6PZ8) reported NNE winds at 39 kts in the Northwest Providence Channel. Surprisingly, the coastal and offshore waters of the northwest Bahamas, south Florida, and the Straits of Florida remain devoid of any buoy observations, and have limited wind platforms, making ship observations and opportune scatterometer wind data crucial in verifying significant marine events such as this. **Figure 3** shows a 0200 through 0500 UTC scatterometer wind compilation across the region on 14 Nov, with ship, buoy and C-MAN observations depicted with large aqua colored wind flags. Note the broad swath of red scatterometer wind barbs extending from offshore of extreme southeast Florida through the Straits, indicating winds 30-34 kts, and several aqua colored ship and C-MAN reports indicating 30 to 40 kts. These gale force winds blowing against the Florida Current are optimum conditions for creating extreme waves in the Straits of Florida. Also shown are persistent gales to 40 kts across the west half of the Bay of Campeche, depicted in red and dark blue wind barbs. Gales across the Bahamas and adjacent Atlantic ended by 0600 UTC as the front continued southward across the region and slowed its forward progress. By 1800 UTC 14 Nov the front had become nearly stationary from the southeast Bahamas westward across Cuba and north coastal portions of the Yucatan Peninsula and into the eastern Bay of Campeche, where the last of gales associated with front ended. As mentioned previously, gales across the Gulf of Mexico are typical behind fronts during the months of November and December, but are rare occurrences behind fronts moving through the Bahamas and the Straits of Florida.

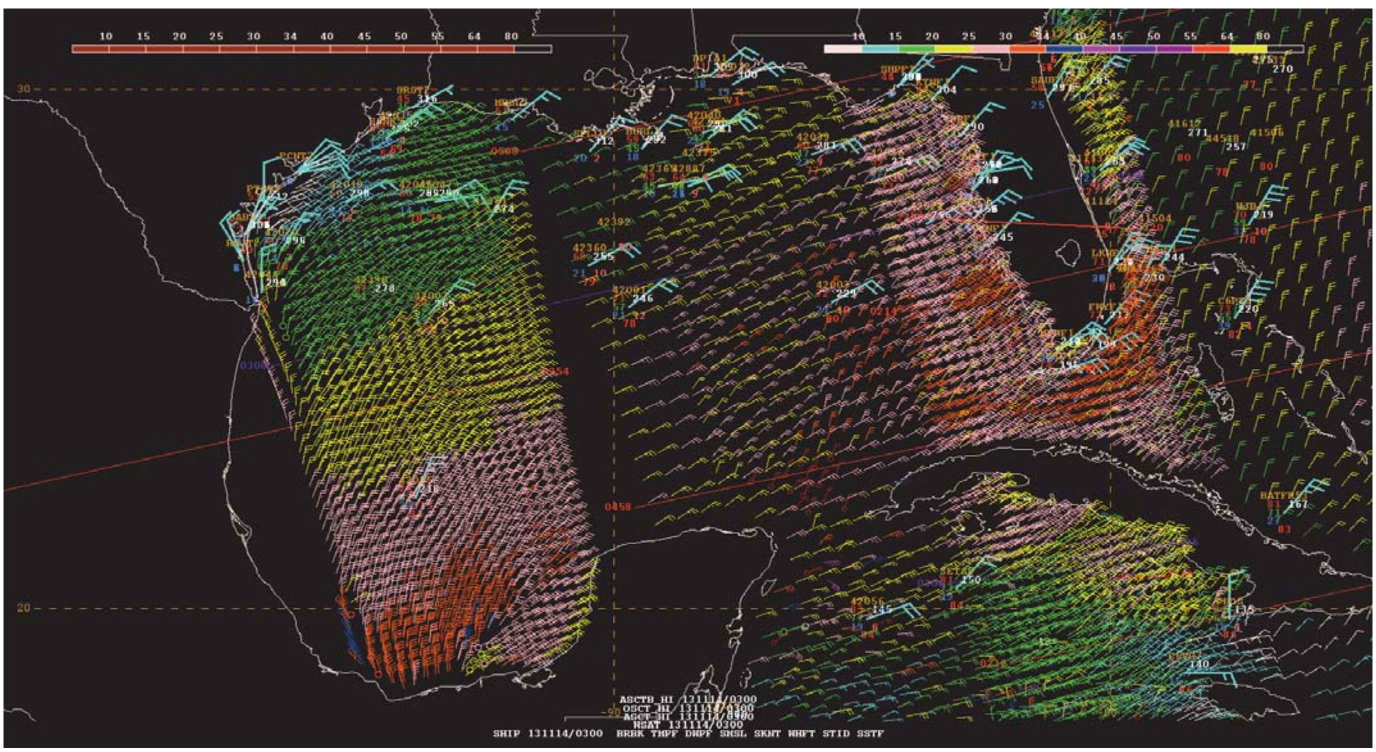

Figure 3. A 0200 through 0500 UTC compilation of scatterometer wind data in multi colored wind barbs, with legend at top right (kts), and buoy, C-MAN and ship observations in large aqua colored wind flags. Note NE gales wrapping around the south end of Florida Peninsula and through the Straits of Florida, and persistent north gales to 40 kts in Bay of Campeche.

Eastern North Pacific Ocean to 30N and East of 140W

The fall and winter months are an active time for gale and storm events in this portion of the Eastern Pacific. The majority of the events typically occur in the Gulf of Tehuantepec. Thus far in the 2013-14 cool season, there were 11 Gulf of Tehuantepec gale and storm events, two (2) Gulf of California gale events, and one other Eastern Pacific gale event near 22N 131W.

Table 2. Non-tropical cyclone Warnings issued for the Pacific Basin between 01 Sep 2013 and 31 Dec 2013.

Onset	Region	Peak Wind Speed	GALE/ STORM Duration
0000 UTC 24 Oct	Gulf of Tehuantepec	40 kts	42 hr
0600 UTC 03 Nov	Gulf of Tehuantepec	40 kts	18 hr
0000 UTC 08 Nov	Gulf of Tehuantepec	40 kts	48 hr
0600 UTC 10 Nov	Gulf of Tehuantepec	50 kts	102 hr / 24 hr
0000 UTC 24 Nov	Gulf of Tehuantepec	40 kts	36 hr
0600 UTC 27 Nov	Gulf of Tehuantepec	55 kts	84 hr / 30 hr
1200 UTC 02 Dec	Eastern Pacific 22N 131W	35 kts	12 hr
0000 UTC 08 Dec	Gulf of Tehuantepec	40 kts	18 hr
0000 UTC 10 Dec	Gulf of California	35 kts	12 hr
0000 UTC 11 Dec	Gulf of Tehuantepec	45 kts	66 hr
1800 UTC 14 Dec	Gulf of California	35 kts	36 hr
1800 UTC 15 Dec	Gulf of Tehuantepec	50 kts	96 hr / 18 hr
1800 UTC 23 Dec	Gulf of Tehuantepec	50 kts	42 hr / 06 hr
1200 UTC 31 Dec	Gulf of Tehuantepec	35 kts	12 hr

Ship reports received through the Voluntary Observing Ship (VOS) program are a vital source of data in verifying gale and storm events. Some select ship reports that directly verified some of this season's gales are enumerated in **Table 3**.

Table 3. Ship reports verifying warning events over the Gulf of Tehuantepec 01 Sep 2013 and 31 Dec 2013.

TIME/DATE	SHIP	LOCATION	WIND SPEED and SEAS
0600 UTC 25 Oct	RDO Concert (A8TH7)	13.8N 94.5W	37 kts 26 ft (8 m)
1000 UTC 25 Oct	Westerdam (PINX)	15.3N 94.1W	51 kts 6 ft (2 m)
0800 UTC 04 Nov	Veendam (PHEO)	15.3N 94.8W	38 kts
0200 UTC 09 Nov	Eagle Sydney (3FUU)	18.5N 94.2W	35 kts 26 ft (8 m)
0300 UTC 10 Nov	Statendam (PHSG)	15.4N 95.0W	52 kts 16 ft (5 m)
0500 UTC 10 Nov	Island Princess (ZCDG4)	15.5N 94.0W	35 kts 13 ft (4 m)
0800 UTC 19 Nov	Norwegian Star (C6FR3)	15.3N 94.8W	40 kts
1500 UTC 24 Nov	London Express (DPLE)	14.0N 95.5W	44 kts
1300 UTC 28 Nov	Statendam (PHSG)	14.3N 93.5W	35 kts 16 ft (5 m)
1700 UTC 28 Nov	Statendam (PHSG)	14.6N 94.4W	50 kts 26 ft (8 m)
2300 UTC 30 Nov	Atlantis (KAQP)	15.0N 95.6W	38 kts
0300 UTC 30 Nov	Norwegian Star (C6FR3)	15.3N 94.9W	65 kts
0200 UTC 01 Dec	Atlantis (KAQP)	14.7N 95.1W	48 kts
0200 UTC 17 Dec	Norwegian Star (C6FR3)	14.9N 93.4W	36 kts
0900 UTC 17 Dec	Norwegian Star (C6FR3)	15.4N 95.2W	52 kts
0600 UTC 24 Dec	Ludwigshafen Express (DILE)	13.8N 94.5W	50 kts

The Gulf of Tehuantepec wind events are usually driven by mid-latitude cold frontal passages through the narrow Chivela Pass in the Isthmus of Tehuantepec between the Sierra Madre de Oaxaca Mountains on the west and the Sierra Madre de Chiapas Mountains on the east. The northerly frontal winds from the southwest Gulf of Mexico produce a gap event through the pass delivering stronger winds into the Gulf of Tehuantepec. The events are of various duration with the longer events associated with reinforcing secondary fronts in the Gulf of Mexico. The events are usually void of precipitation in the Gulf of Tehuantepec, thus the OSCAT scatterometer imagery depicts winds without rain contamination problems.

The Gulf of Tehuantepec gale and storm events this season totaled 642 hours, a 30% increase over the previous two seasons.

A gale event in the Gulf of Mexico behind a cold front on 27 Nov 2013 produced a storm event in the Gulf of Tehuantepec, (**Figure 4**). Note that the 1030 hPa High over north Mexico significantly increased the surface pressure gradient over the Isthmus of Tehuantepec. This wind event started on 27 Nov 2013 at 0600 UTC as a gale. Winds increased to storm force six hours later and lasted until 28 Nov 1800 UTC when winds once again decreased to gale force. The event ended on 2 Dec 2013 when gale conditions abated.

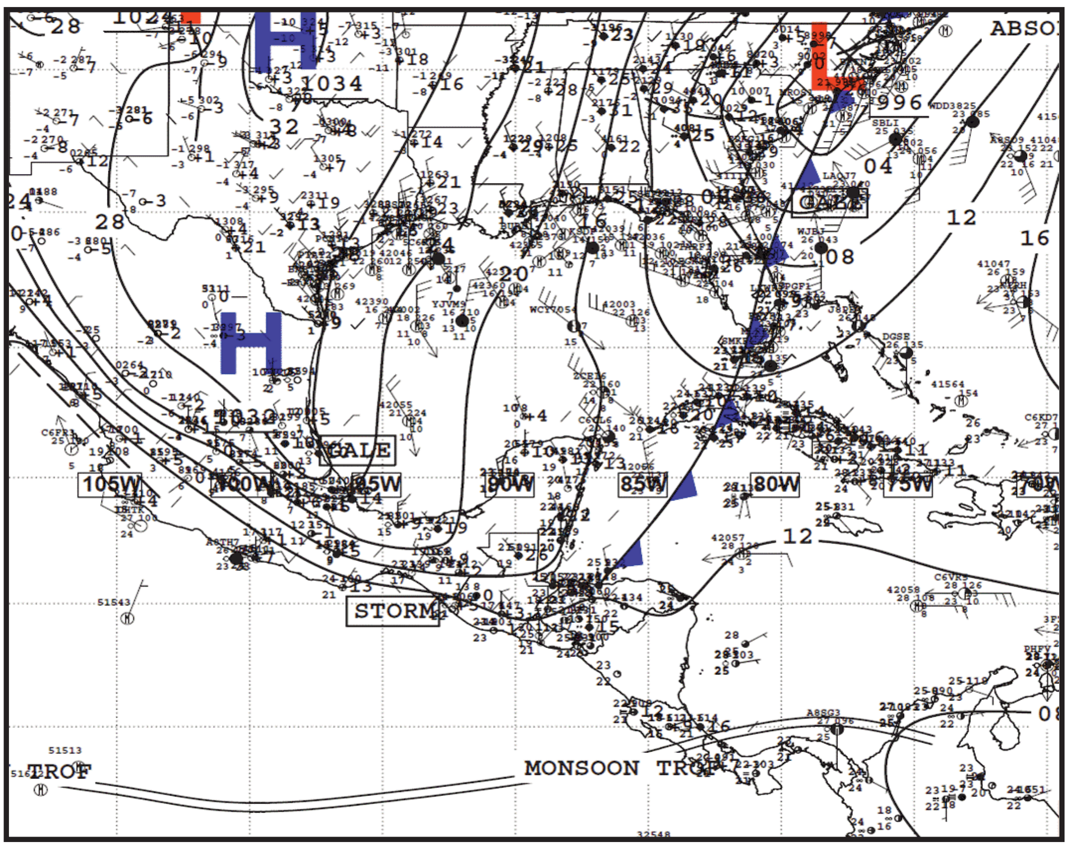

Figure 4. National Weather Service Unified Surface Analysis (USA) valid 1200 UTC 27 Nov 2013.

An Indian Oceansat-2 Scattereometer (OSCAT) pass captured the event in both the Bay of Campeche and the Gulf of Tehuantepec, (**Figure 5**). Storm force winds were depicted in the Gulf of Tehuantepec with numerous 50 kts wind barbs noted. Gale force winds extended southward to 13N between 93W and 96W, while 20 kts winds reached 10N between 94W and 100W. The ship **Statendam** (PHSG) traversed both the gale and storm areas while sailing WNW on 28 Nov 2013.

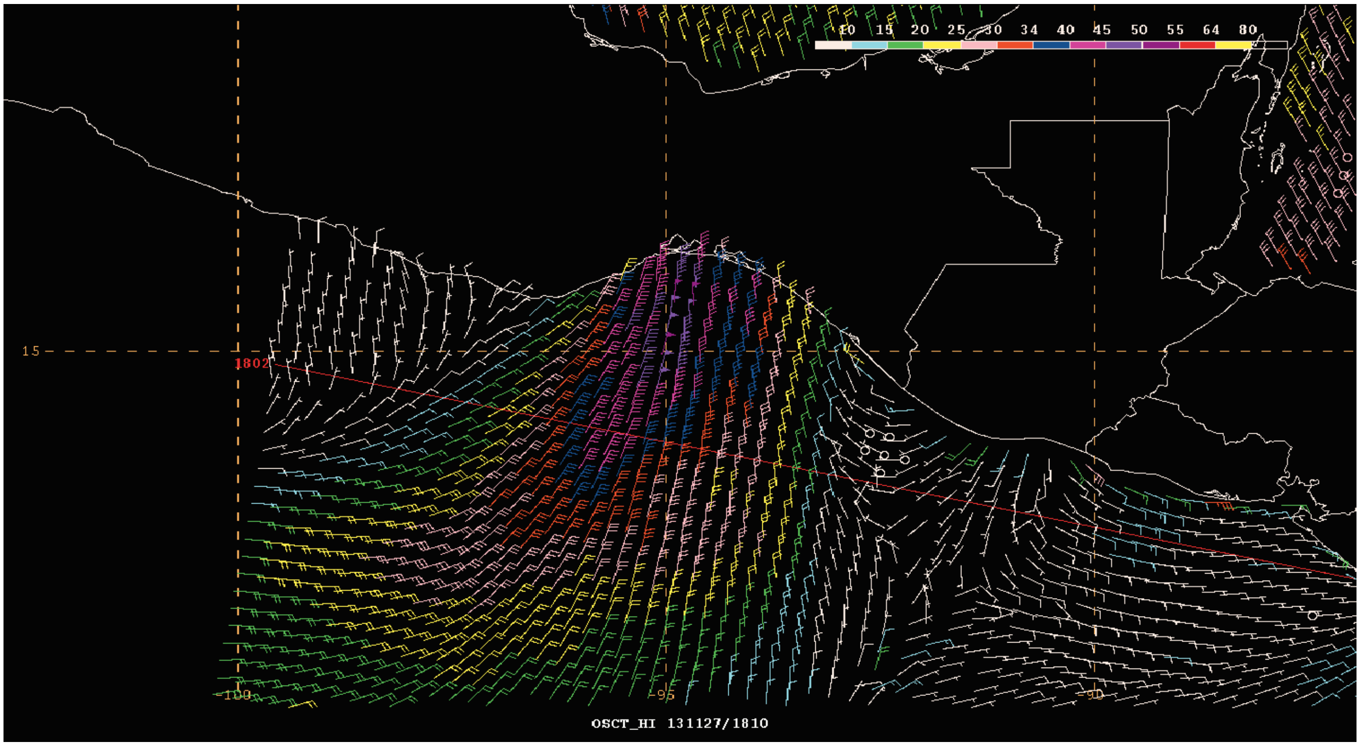

Figure 5. Indian Oceansat-2 Scatterometer (OSCAT) pass valid at 1802 UTC 27 Nov 2013. Note the 50 kts wind barbs that extend south of the Gulf of Tehuantepec to 14N95W.

References

Rogers, J. C. (1981), The North Pacific Oscillation. J. Climatol., 1: 39–57. doi: 10.1002/joc.3370010106

NOAA Ships **Rainier** and **HI'IALAKAI** at the ship yard.
Lake Union WA

Photograph by PMO Matthew Thompson of Seattle Washington.

Return to Table of Contents

National Weather Service

VOS Program New Recruits: July 1, 2013 through February 28, 2014

Ship Name	Call Sign
ALGOMA EQUINOX	XJBH
AM HAMBURG	V7ZZ5
ANTARES VOYAGER	C6ZJ5
APL SAVANNAH	9V9919
BLS ABILITY	ELXX8
BOB FRANCO	WDG8180
BRASIL VOYAGER	C6ZJ8
BRAZOS	V7UU4
BUNGA KELANA 3	9MCY6
CAPE AZALEA	9V9450
CLIPPER TRITON	3FSC3
CMB MAXIME	VRHM4
COSTA FASCINOSA	ICPO
CRYSTAL SUNRISE	9V2024
DARYA GAYATRI	VRKC8
DARYA MA	VRJH5
DARYA RADHE	VRKX5
EAGLE ATLANTA	S6TE
EAGLE MILAN	3FBJ6
FAIRCHEM EAGLE	V7UB6
FAIRCHEM MAVERICK	3EXT8
FEDERAL KIVALINA	VRWK5
FEDERAL SETO	VRZT5
FEDERAL SEVERN	V7WS8
FEDERAL TAMBO	V7YW3
FEDERAL TIBER	V7YW2
FMG GRACE	VRJZ9
GENCO COMMODUS	V7RP7
GENCO MAXIMUS	V7SJ3
GUADALUPE	V7UT6
HYDRA VOYAGER	C6AB8
KOTA JUTA	VRWY9
LIBERTY DESIRE	V7AB6
LOWLANDS PHOENIX	9HIY9
MAERSK HAYAMA	9V9745
MAERSK HEIWA	9V9746
MAERSK NIAGARA	VREO9
MAERSK PITTSBURGH	WMPP
MINERAL FAITH	VRKS4
MINERAL KYOTO	ONFI

Ship Name	Call Sign
MINERAL NEW YORK	ONGI
NORWEGIAN GETAWAY	C6ZJ4
NYK FUSHIMI	9V8741
NYK VERONICA	3EYJ5
OSHIMANA	9VAH9
OVERSEAS ANTIGMAR	V7HP5
PETROJARL FOINAVEN	C6NR7
PSU EIGHTH	9V6346
RTM DHAMBUL	2GOY3
SAGA DISCOVERY	VRBR8
SAGA FUTURE	VRKX8
SAGA PIONEER	VRED4
SAN SABA	V7UT8
SEABOURN LEGEND	C6FR6
SEABOURN ODYSSEY	C6XC6
SEABOURN QUEST	C6YZ5
SEABOURN SOJOURN	C6YA5
SHANDONG DA CHENG	9V9131
SHANDONG DA DE	9V9128
SONANGOL BENGUELA	C6YM7
SONANGOL ETOSHA	C6YM5
SONANGOL SAMBIZANGA	C6YM6
TARGET	PJLL
TUG DEFIANCE	WDG2047
UNIQUE HARMONY	VRJM7
USCGC BRISTOL BAY	NRLY
USCGC MACKINAW	NBGB
VALE BRASIL	9V9127
VALE DONGJIAKOU	9V9116
VALE ITALIA	9V9129
VENEZIA	VRDI6
YACHT EXPRESS	PJVV
ZIM TEXAS	V7VE3

Return to Table of Contents

The Cooperative Ship Reports can now be found online by clicking here.

Return to Table of Contents

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NOAA Weather Radio Network

(1) 162.550 mHz
(2) 162.400 mHz
(3) 162.475 mHz
(4) 162.425 mHz
(5) 162.450 mHz
(6) 162.500 mHz
(7) 162.525 mHz

Channel numbers, e.g. (WX1, WX2) etc. have no special significance but are often designated this way in consumer equipment. Other channel numbering schemes are also prevalent.

The NOAA Weather Radio network provides voice broadcasts of local and coastal marine forecasts on a continuous cycle. The forecasts are produced by local National Weather Service Forecast Offices.

Coastal stations also broadcast predicted tides and real time observations from buoys and coastal meteorological stations operated by NOAA's National Data Buoy Center. Based on user demand, and where feasible, Offshore and Open Lake forecasts are broadcast as well.

The NOAA Weather Radio network provides near continuous coverage of the coastal U.S, Great Lakes, Hawaii, and populated Alaska coastline. Typical coverage is 25 nautical miles offshore, but may extend much further in certain areas.

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Return to Table of Contents