Developing a Dataset of Wind Gust Factors to Improve Forecasts of Wind Gusts in Tropical Cyclones

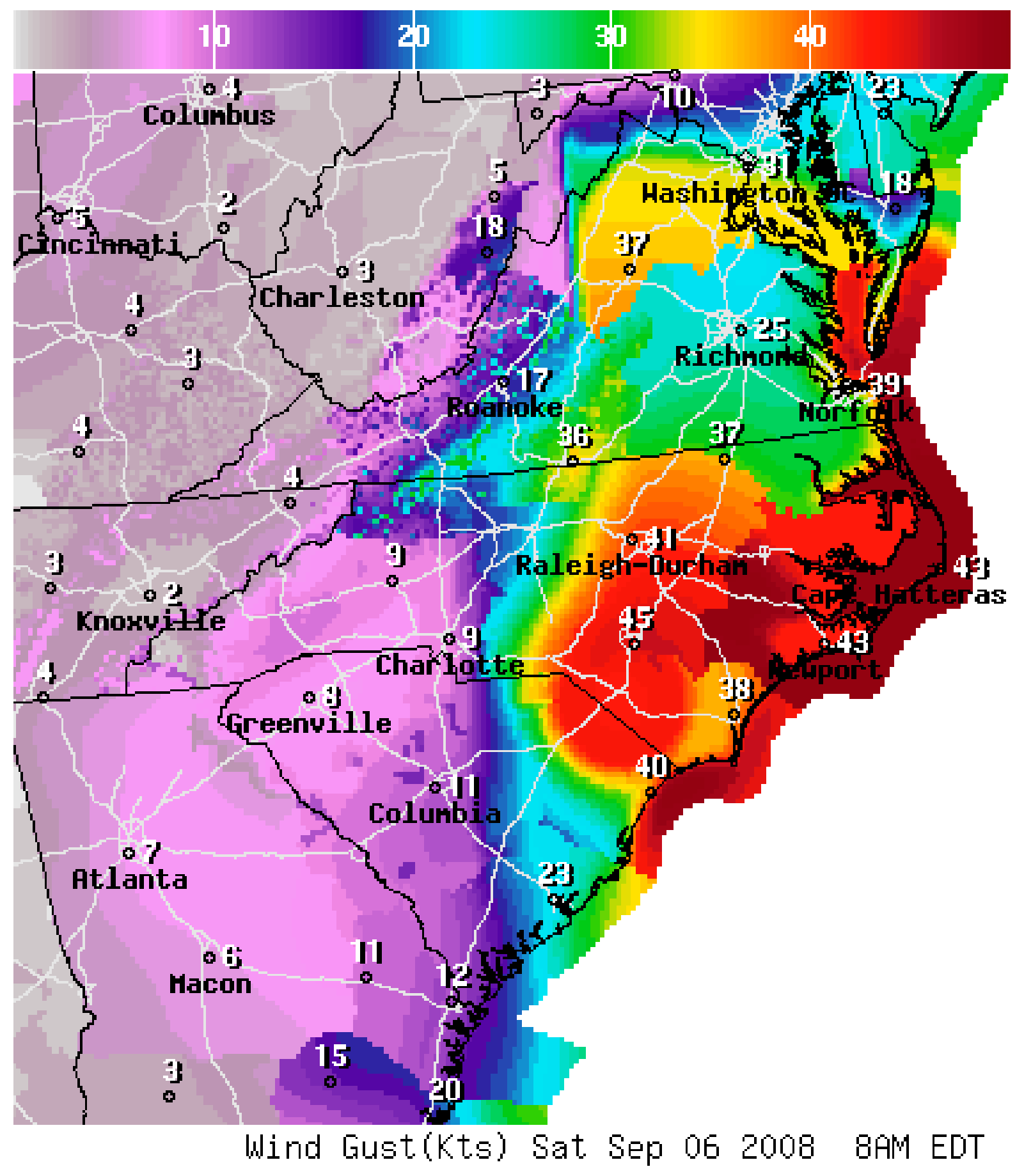
Jonathan Blaes and Ryan T. Ellis, NOAA/National Weather Service, Raleigh, NC
Donald Reid Hawkins, NOAA/National Weather Service, Wilmington, NC
David A. Glenn, NOAA/National Weather Service, Newport, NC
Victoria Oliva, North Carolina State University, Raleigh, NC

Introduction and Problem

Tropical cyclones (TCs) are a dangerous and high impact weather phenomena which result in numerous forecast and warning challenges for National Weather Service (NWS) forecasters. A survey of 9 NWS Weather Forecast Offices (WFOs) in the Southeast and Mid-Atlantic revealed that the prediction of TC winds and precipitation was a top priority for collaborative research. This project was motivated by this need and was conducted to support a NWS-NC State University Collaborative Science, Technology, and Applied Research (CSTAR) project.

Predicting TC wind gusts are problematic for several reasons:

- There are gaps in our understanding of the spatial and temporal distribution of wind gusts associated with landfalling TCs.
- Wind gust forecasts are typically derived from the sustained wind forecast which can be problematic itself.
- Results from previous studies have not been routinely used by NWS forecasters.
- A survey of forecasters from the CSTAR WFOs revealed that the methods used to develop wind gusts grids during TC events can lack consistency and scientific discipline.
- Most forecasters surveyed suggested using a percentage above the sustained wind speeds to use as a gust factor (GF). These values ranged wildly with large discrepancies even noted within several of the same WFOs.
- Including wind gust variations across spatial and temporal scales is difficult using the previous methodology.
- The end result is often an inconsistent and poorly collaborated forecast with limited foundation in science that may be inaccurate and is difficult for users to interpret as in this example from Tropical Storm Hanna.



NDFD 48 hour wind gust forecast valid 8AM EDT on 06 September 2008 during Tropical Storm Hanna.

Methods

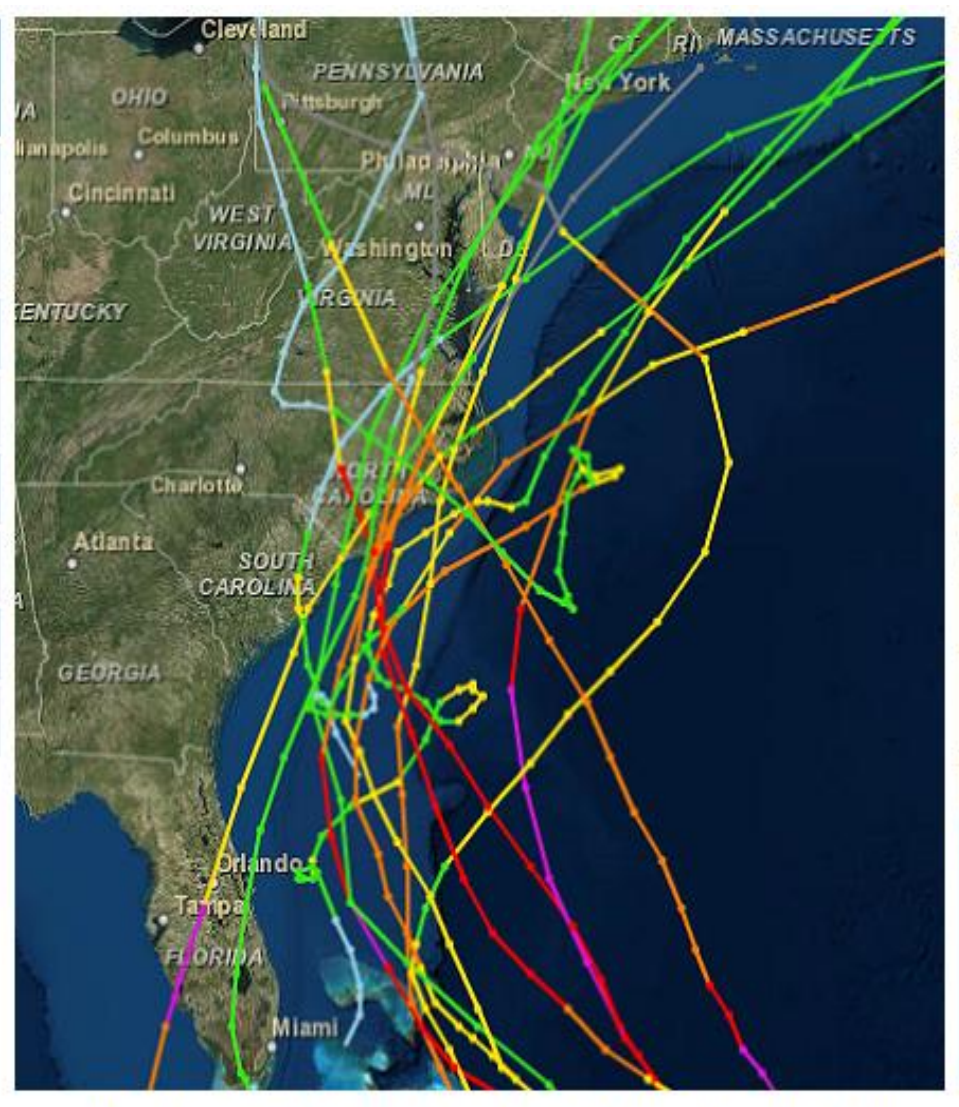
- We examined the sustained winds, wind gusts, wave heights, and gust factors for fifteen tropical cyclones that impacted the Carolinas, Virginia and Maryland. Only hourly observations with wind speeds of 10 kts or more were included. Data analysis was conducted in two groups: land observations and marine observations. The hourly wind gust factor for each location was computed as the ratio of the wind gust to the sustained wind speed (Vickery and Skerlj 2005).

- For the land locations, observations from between 22 and 53 ASOS or AWOS METAR locations impacted by the various storms were included. The locations varied for each storm and were selected to capture the variations in the wind field. A total of 13,121 gust factors were computed.

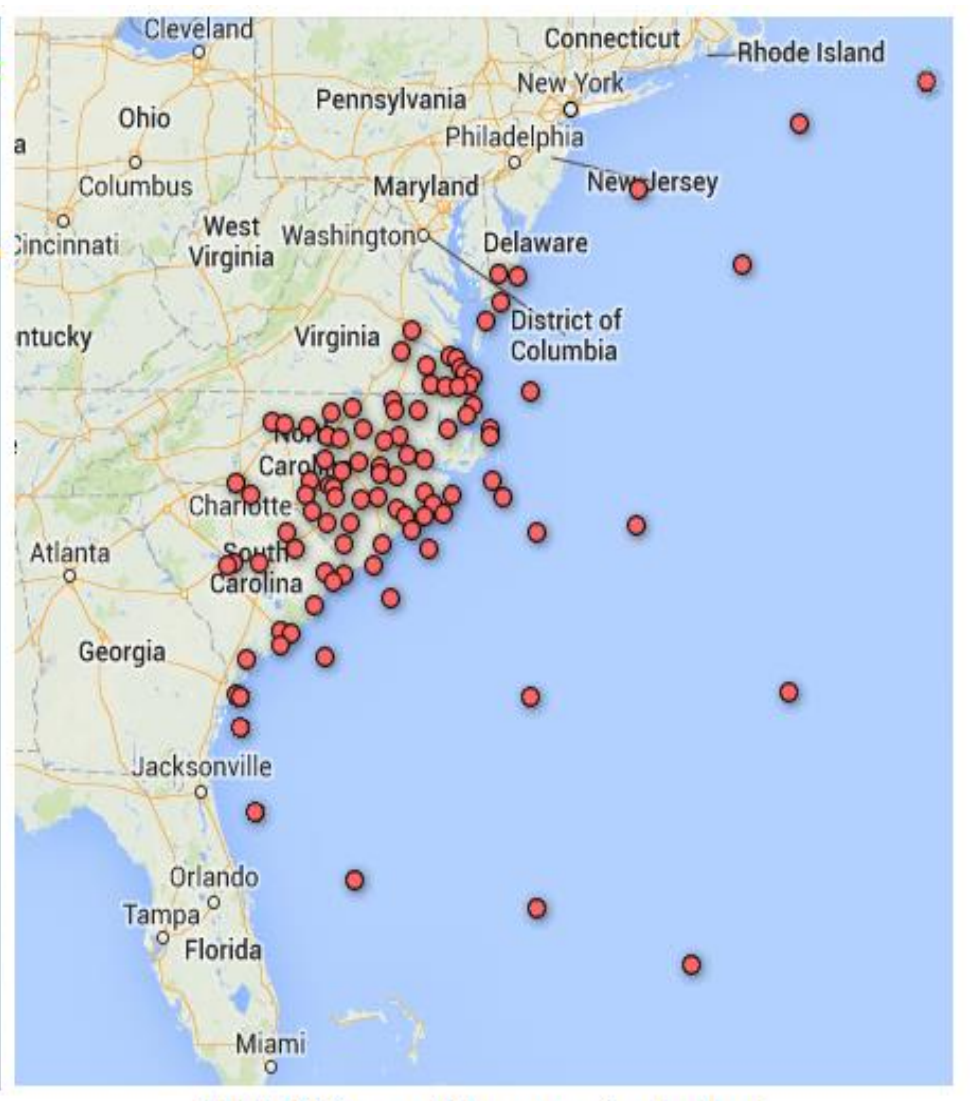
- For the marine locations, only observations from buoys that have an anemometer height of 5m were included to remove the variability introduced by different observational heights. Only observations in which the wave heights observed were less than 5 meters were included, to remove any uncertainty in the quality of the wind observations in large waves as high sea states associated with high surface winds can shelter the buoy and reduce the buoy's wind speed observation (Skey et al. 1995). A total of 3,026 marine gust factors were calculated.

Storm Name	Date	Winds at Landfall	Storm Name	Date	Winds at Landfall
Bertha	Jul-96	85 kts	Gaston	Aug-04	65 kts
Fran	Sep-96	100 kts	Ophelia	Sep-05	75 kts
Bonnie	Aug-98	100 kts	Ernesto	Aug-06	60 kts
Dennis	Sep-99	55 kts	Hanna	Sep-08	60 kts
Floyd	Sep-99	90 kts	Earl	Sep-10	90 kts
Isabel	Sep-03	90 kts	Irene	Aug-11	75 kts
Alex	Aug-04	85 kts	Sandy	Oct-12	85 kts
Charley	Aug-04	70 kts			

Table of the tropical cyclones included



Tracks of the tropical cyclones included

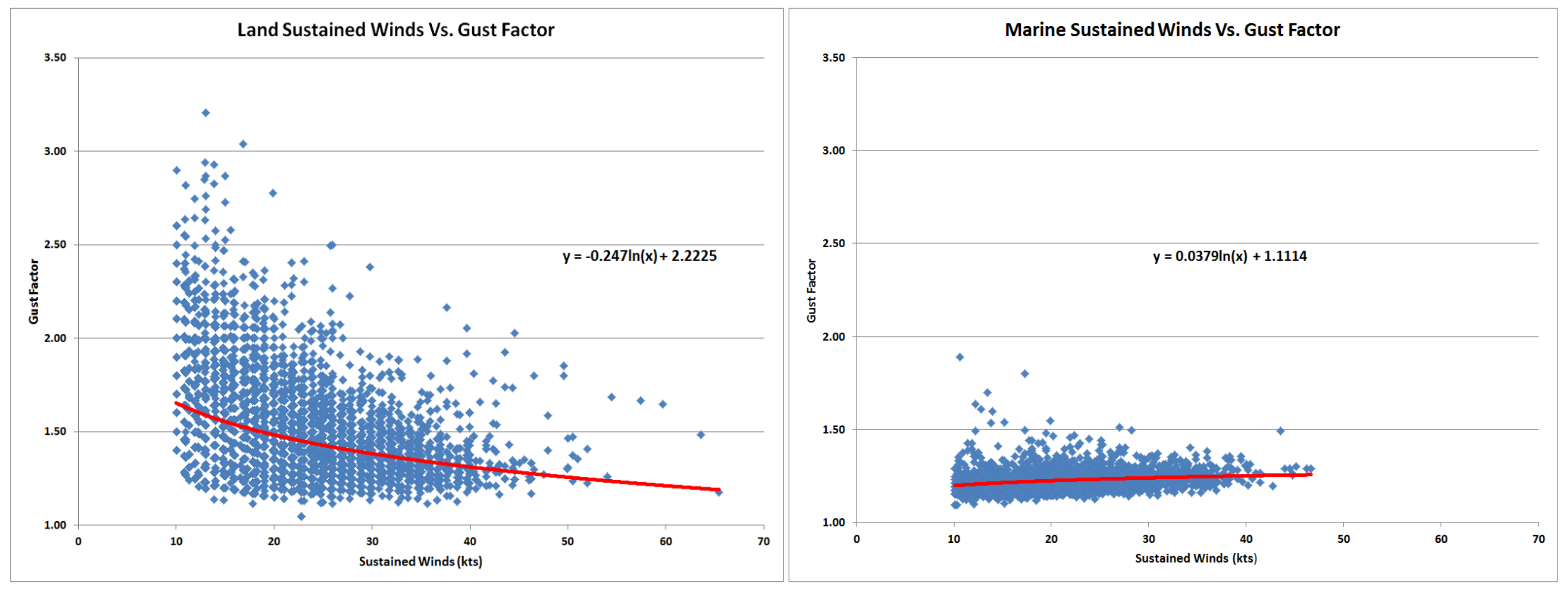


METARs and buoys included

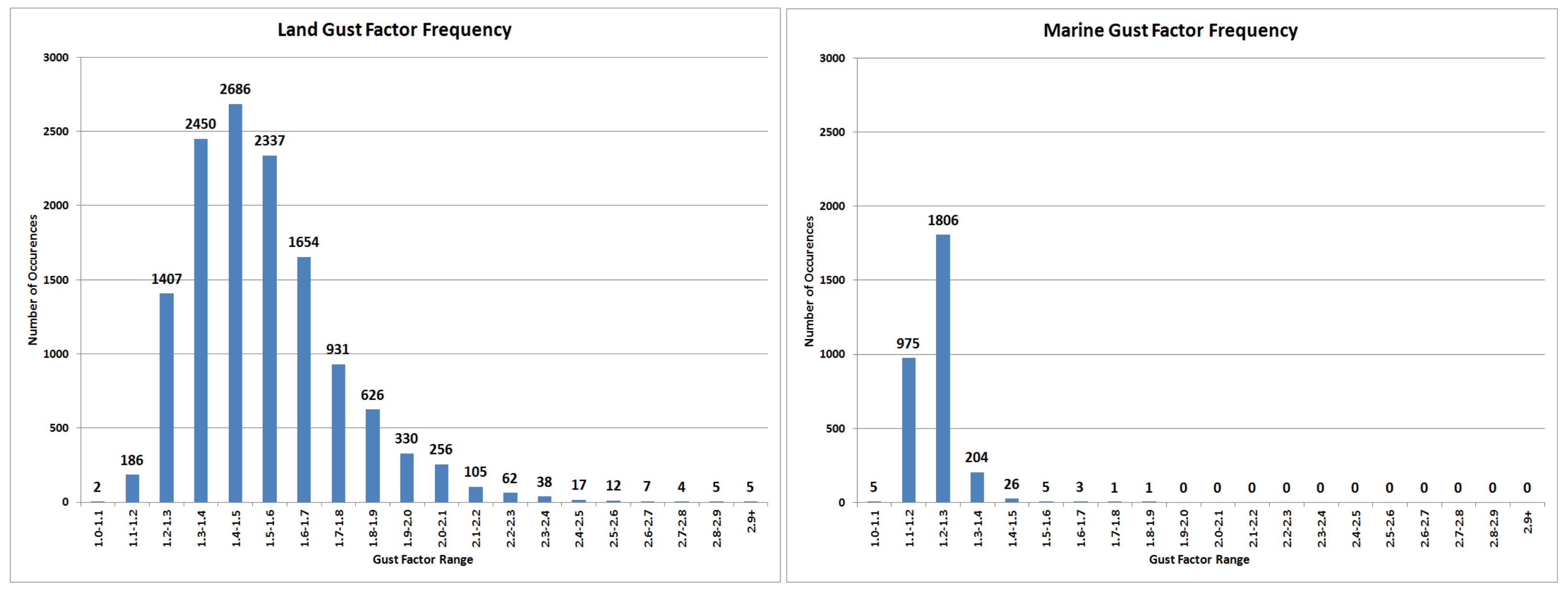
Results

	Number of Gust Factors	Average Gust Factor	Standard Deviation	Max Sustained Wind	Max Wind Gust
Land	13,121	1.53	0.22	65 kts	98 kts
Marine	3,026	1.23	0.06	47 kts	65 kts

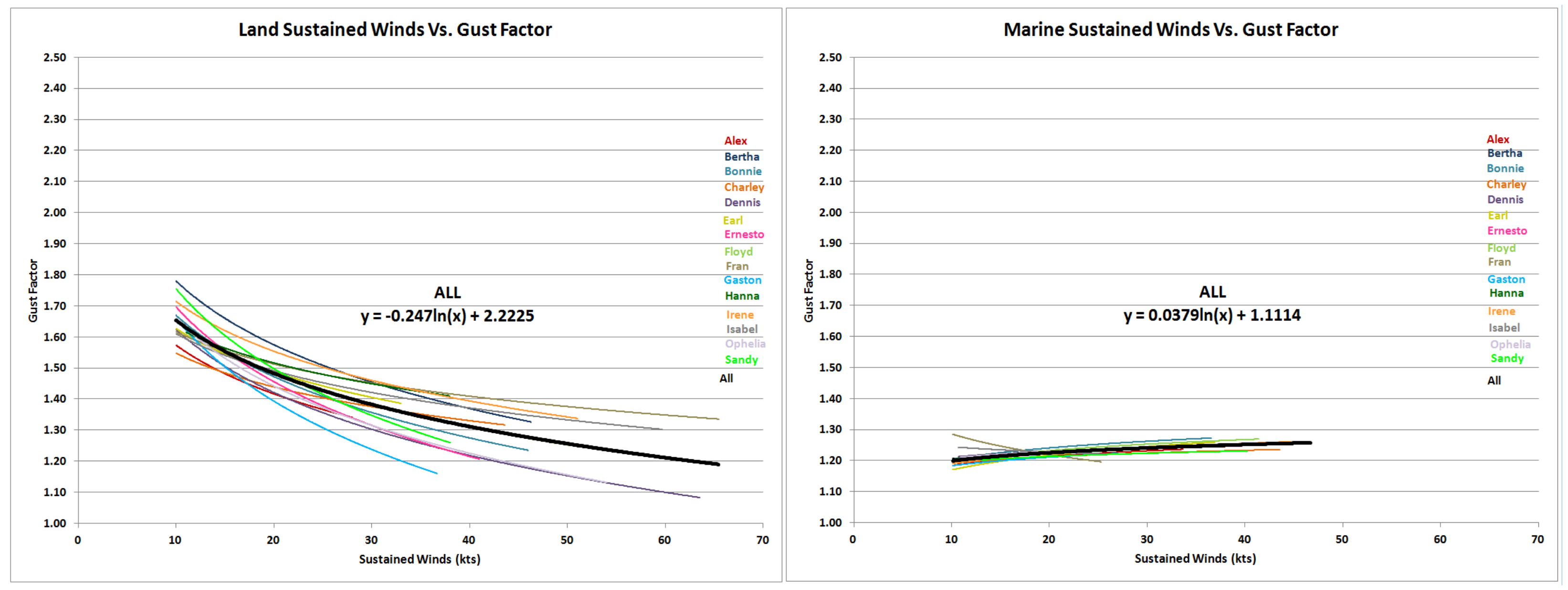
The charts below are scatter plots of the sustained winds versus gust factors for all fifteen storms for land locations (left) and marine locations (right) along with a best fit regression curve. Note the greater variation in gust factors for the land locations which show an inverse relationship between the wind speed and gust factor as well as a decrease in the variability of observations as wind speeds increase. The marine locations depict a much more compact distribution with less variability and a slight upward trend in gust factors as the wind speed increases.



Histograms of the frequency of gust factors are shown below for land locations (left) and marine locations (right). For the land observations, note the large number of observations with a large distribution and considerable spread. This results in a standard deviation of 0.218 around the mean of 1.53 with the most frequent land GF ranging between 1.4 and 1.5. The GF for the marine locations show a much smaller range. The marine GF is most frequently located between 1.2 and 1.3 with 1,806 of the total 3,026 gust factors (60%) ranging between 1.2 and 1.3. The marine observations contain a standard deviation of 0.056 around the mean of 1.23.

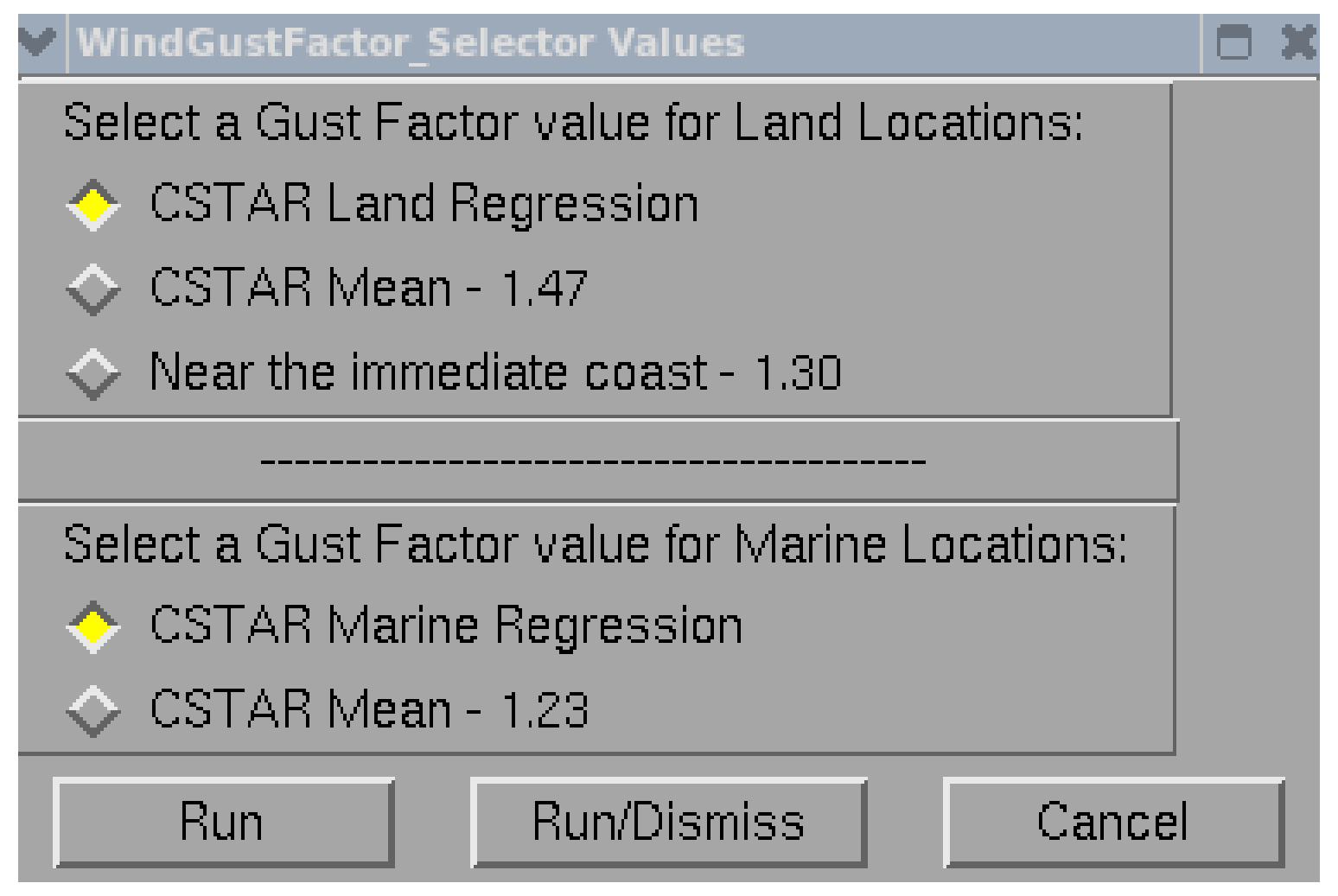


Regression equations for each of the storms are shown individually in colors below with a combined curve, merged for all storms, shown in black for land locations (left) and marine locations (right). The land observations show large variations but a similarly shaped curve likely indicating the variations in gust factors driven by air mass, terrain, roughness and other factors. The marine locations are very consistent which is not surprising given the similar air mass and surface roughness in the marine environment with wave heights less than 5 meters.



Transitioning Research to a New Methodology

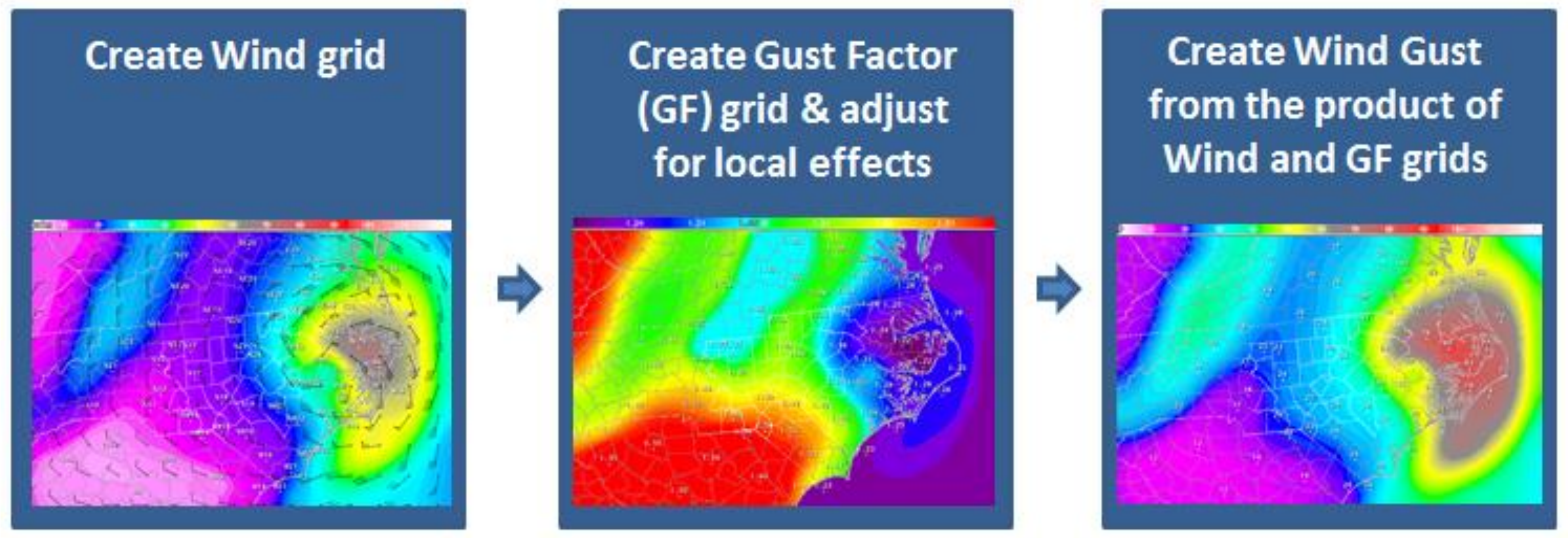
- The distribution of gust factors and the mean values for both land and marine locations in our results were similar to other studies giving us confidence in our empirical data set.
- We developed a methodology that includes a new GFE element called the WindGustFactor (WGF) grid which is the ratio between the wind gust and the sustained wind speed for a specific period of time.
- The WGF is initially populated via a GFE tool that uses the sustained winds as an input into the regression equation and produces the WGF grid.
- After the WGF grid is initially created, forecasters can spatially and temporally edit the WGF grid for impacts from boundary layer stability, friction, exposure, etc.
- In addition, the WGF grid allows forecasters to collaborate with other WFOs much more efficiently



Select a Gust Factor value for Land Locations:
◆ CSTAR Land Regression
◇ CSTAR Mean - 1.47
◇ Near the immediate coast - 1.30

Select a Gust Factor value for Marine Locations:
◆ CSTAR Marine Regression
◇ CSTAR Mean - 1.23

- The primary steps in this new methodology are shown in the cartoon below. Two new GFE tools have been developed for the second step (WindGustFactor_Selector tool) and the third step (WindGust_from_WindGustFactor tool).

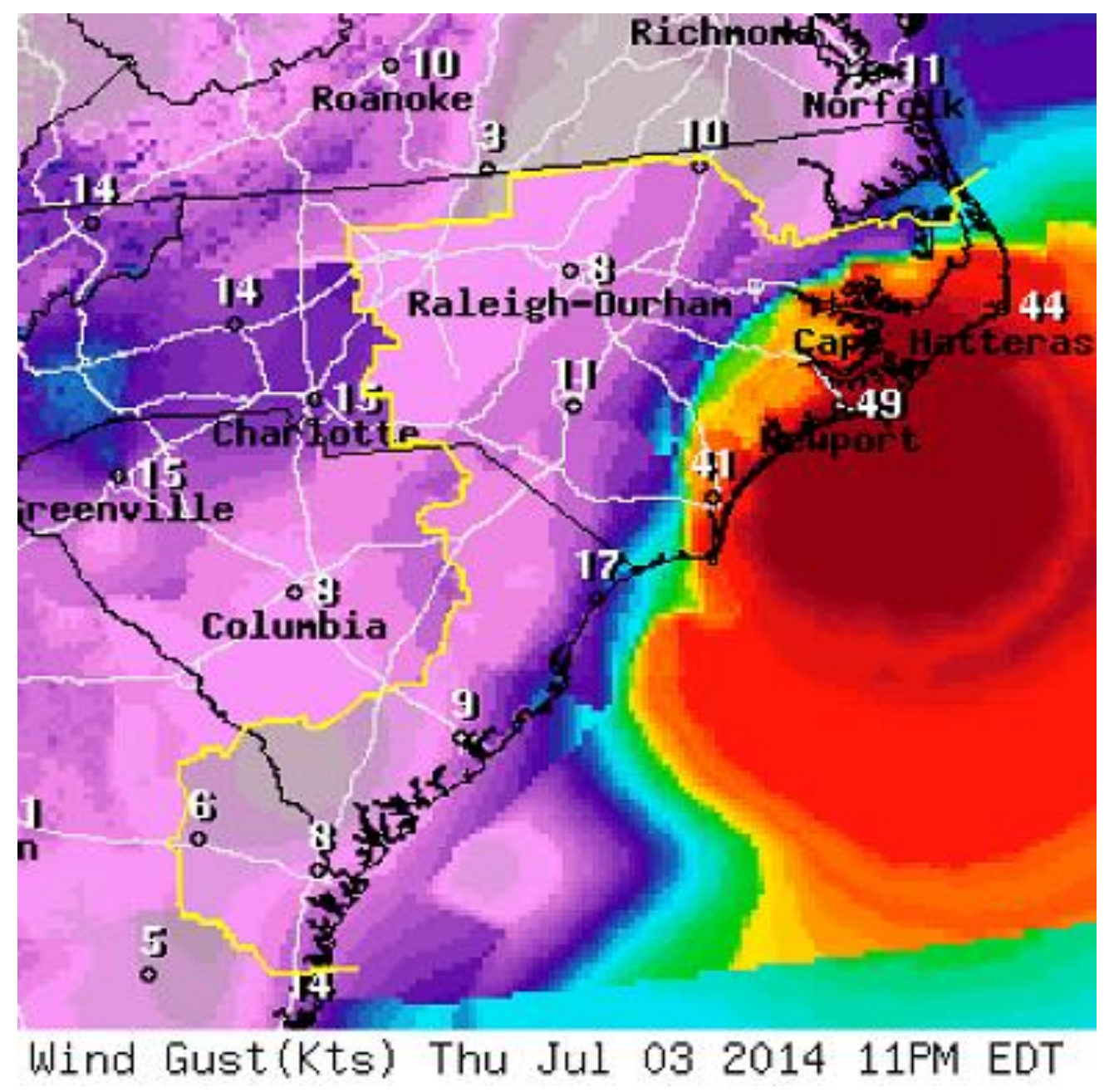


Advantages

- A more science-based and consistent process is provided to forecasters which should result in an improved wind gust forecast.
- Forecasters can more efficiently integrate the impacts of boundary layer stability, friction, exposure, etc. into the forecast process.
- The gust factor grids can be edited spatially and temporally across the GFE domain.
- Forecasters can visually collaborate with other WFOs in GFE.

Application with Hurricane Arthur (2014)

- This new methodology was tested by NWS WFOs in Charleston S.C., Newport N.C., Raleigh N.C., and Wilmington N.C. during Hurricane Arthur in July 2014.
- The 23-hour wind gust forecast from 12am EDT on 3 July valid at 11pm EDT on 3 July, 2014 is shown to the right and demonstrates a consistent and well collaborated wind gust forecast from the 4 WFOs using the new methodology. The area to the right or east of the thin yellow line encompasses the WFOs that used this experimental methodology.
- Forecasters provided positive feedback on this methodology and noted the much improved consistency and improved quality of the forecast.
- This event demonstrates a notable research to operations success.



Acknowledgements

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