39 Hurricane Ida Wind Record

The remnants of Hurricane Ida swept through Norfolk, Virginia during the period 10-15 November 2009, with 25cm of rain and high winds.The data file `homework9.txt` contains wind data recorded at Weather Station "Larchmont-Cornicks," in Norfolk. There are three columns, with average wind direction $\bar{\theta}$ in degrees (CW positive from north; zero is wind coming from the north), average wind speed $\bar{u}$ in miles per hour, and gust wind speed $\tilde{u}$, also in miles per hour. $\bar{\theta}$ and $\bar{u}$ are average values taken over five-minute intervals, and $\tilde{u}$ denotes the peak speeds taken over these same intervals. Each row corresponds with one five-minute period.

1. Make some nice annotated plots of the data, and write a few paragraphs to describe what features you can see in the three data channels. Notice that there are approximately six days' worth of data here - it was a long storm!

   Between calm wind conditions, this weather event lasted about 7000 minutes, or 4.8 days.

   The wind started from the northeast and then gradually came around the the northwest. Interestingly, there was a short period of no wind direction data near time 1700 minutes (lack of noise is a dead giveaway), and also some odd five-degree quantization effects near the zero direction.

   Looking at the speeds now, we see immediately a one-mph quantization in the gust speed. In the intensifying phase there was a temporary drop in wind speed at time 2000 minutes, but winds quickly built up again by time 3000 minutes. The mean wind speed reached a maximum value of fifty miles per hour, near time 4000 minutes, with a gust in that bin of 57 mph. In the first half of the storm event, gust speed beyond the mean speed seems to be about ten mph, whereas in the second half of the event, it is less; this may indicate that turbulence was highest at the beginning of the storm and lower at the end. Also, we notice that starting at about 4000 minutes, there were several dramatic, one-hour-scale changes in the wind speed (but not the direction). These correspond with various fronts moving through the area.

   More broadly, wind data has some subtleties not shared directly by ocean wave data. A major distinction is that ocean waves are taken with respect to a zero level, whereas wind events are typified by a mean wind and a varying, additive component.[1] We could debate whether the mean wind or the absolute gusts, or some combination of them, should be used in design. The point of view in our present question is that the gusts relative to the mean winds are most important. The interested reader can look at a histogram of the absolute gusts, but will find that the statistics are ruined by the non-stationarity of the weather event.

2. For the purpose of assessing gust size relative to the mean wind speed, we first need to filter (or smooth) $\bar{u}$ while also allowing for some low-frequency content, e.g., on the

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[1]Spectral content of some other hurricane data is given in another of the worked problems, **Hurricane Winds**.

one-hour scale. You can make a simple filter as follows: Suppose the raw, bin-indexed input data is $[\bar{u}_1, \cdots, \bar{u}_n]$. We'll call the filtered version of this $[y_1, \cdots, y_n]$. Initialize $y_1 = \bar{u}_1$, and then recursively apply $y_k = (1 - \alpha)y_{k-1} + \alpha \bar{u}_k$, for $k = 2, \cdots, n$, and some fixed α, $0 \leq \alpha \leq 1$. You see that with $\alpha = 0$, y_k gets only information from y_{k-1}; the input $\bar{u}_k$ is never used, and so y is a flat line for all time, at x_1. With $\alpha = 1$, y simply matches the input. The first case allows NO frequency content of the input signal $\bar{u}$ to come through, whereas the second case allows ALL of its frequency content through. As α takes intermediate values, you will see that you can control how much filtering is occurring.

Select a specific α for the purpose of smoothing the average wind speed data $\bar{u}$. Show a time plot overlaying the raw data and the smoothed version, and list your chosen value for α.

The plot shows smoothed mean wind data for a choice of $\alpha = 0.25$. This setting takes off a good amount of the noise, but doesn't eliminate too many of the details. Other values of α will give quite different results in the fit below.
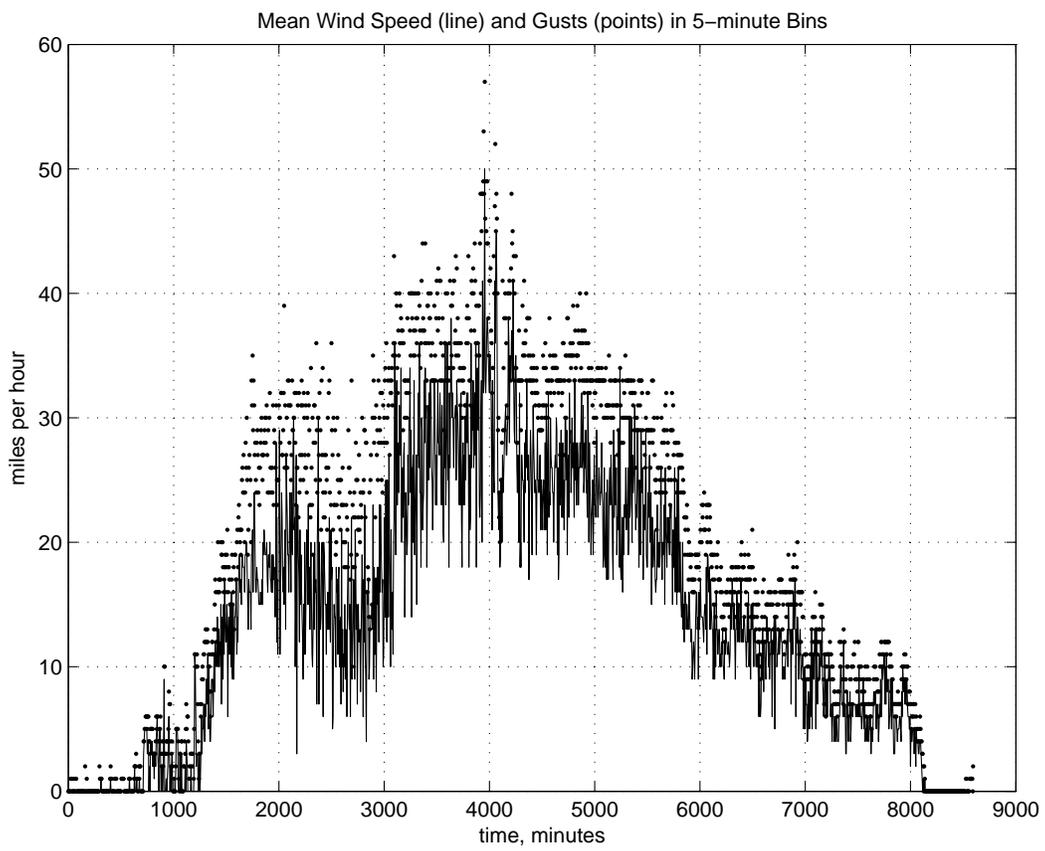
3. With $\bar{u}$ suitably filtered, we can now estimate the sizes of the gusts more accurately, namely as $g_k = \tilde{u}_k - y_k$. We are subtracting off the smoothed mean wind data from the recorded gusts.
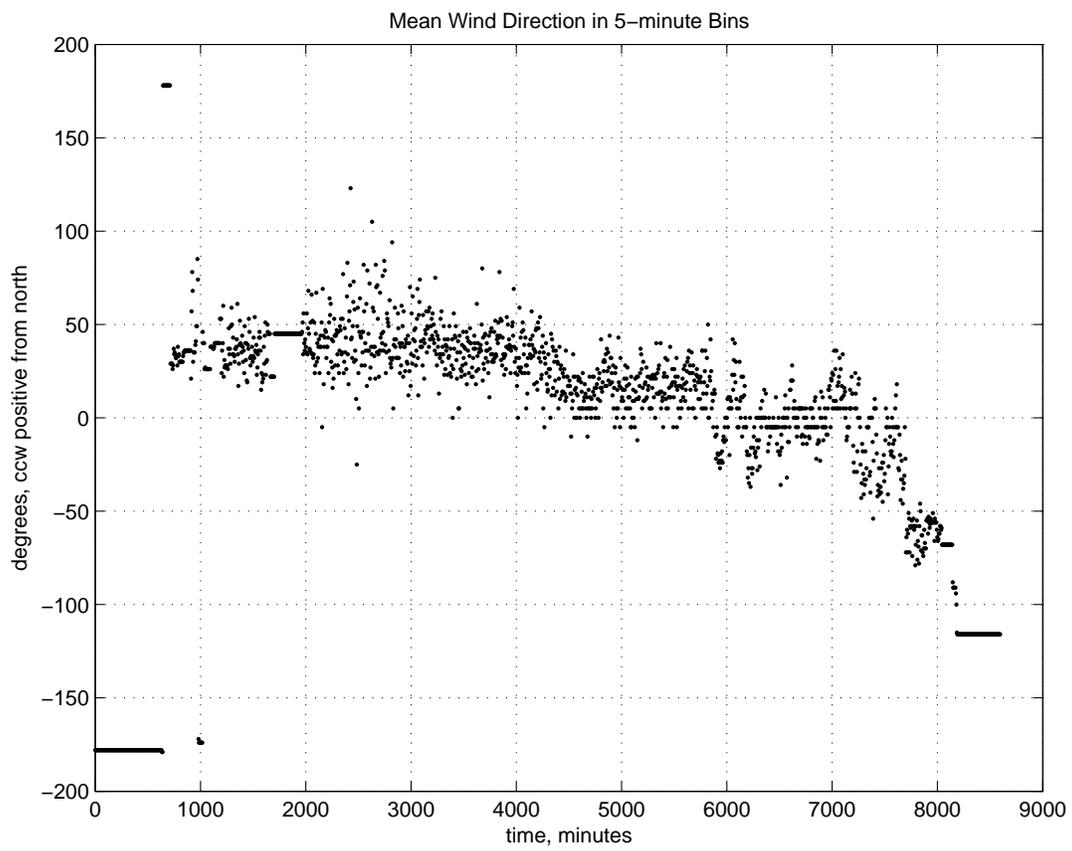
   Show a histogram of g, and discuss how it does or does not look like the Gaussian and Rayleigh distributions. Notice that this data set is clearly non-stationary, so there is no reason up front that either should fit. (Because of the smoothing, there may occur a few instances where $\tilde{u}$ is lower than y, and hence $g < 0$; you can ignore these.)
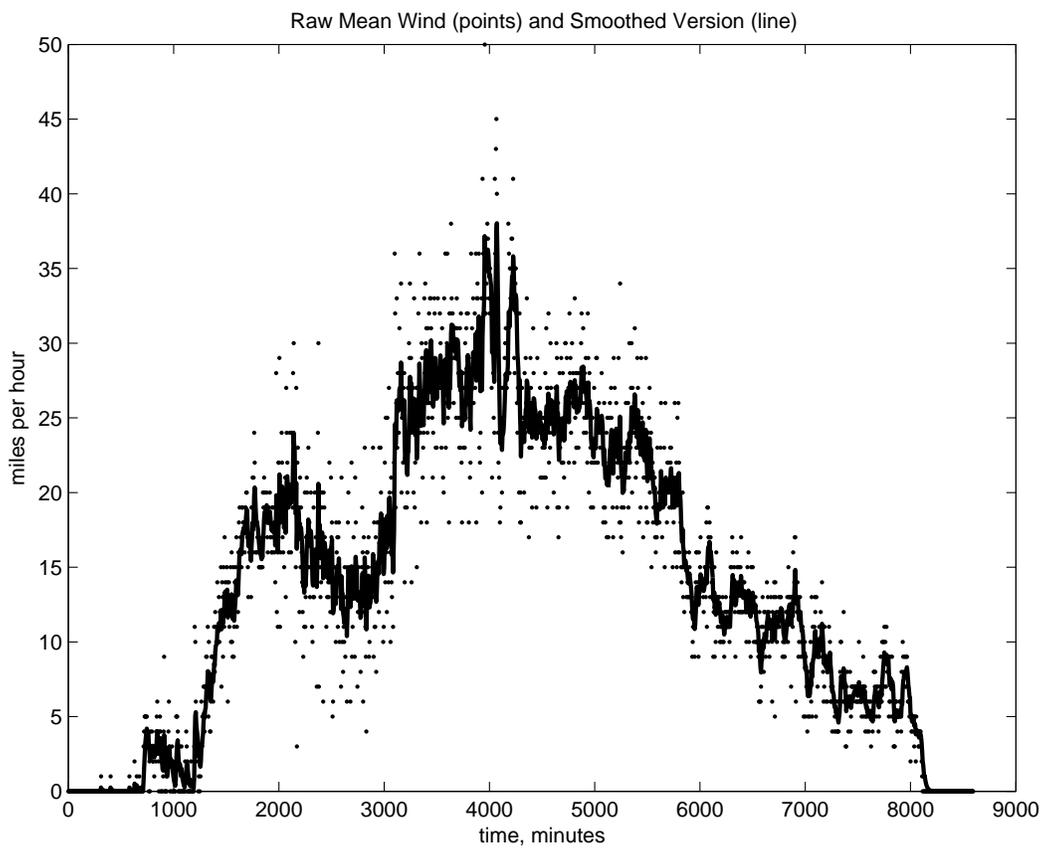
   The histogram is Rayleigh-like at first look. The extra area near zero and below zero speed is due to our smoothing of the mean wind data, which puts some mean values above the associated gust values.
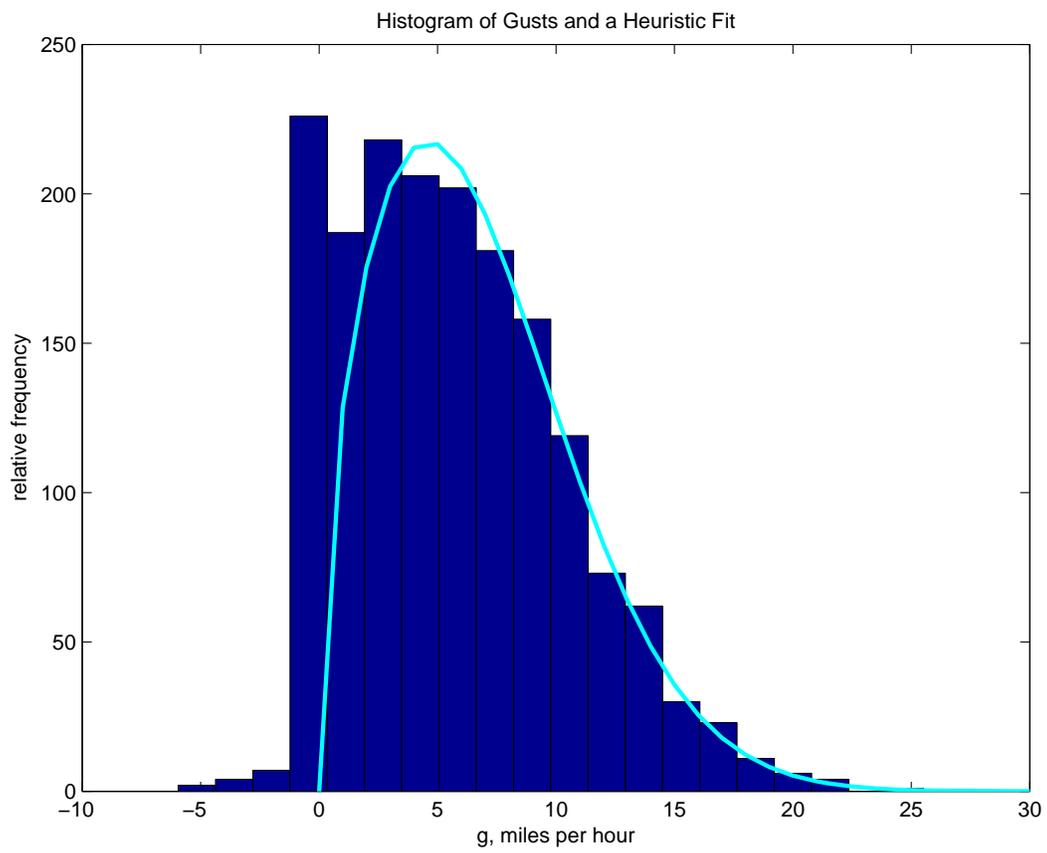
4. Make a plot showing a reasonable fit to the histogram (or pdf), using one of the distributions we have encountered in this class or perhaps a new one. State whether you think this fitted curve could effectively capture extreme events in a storm like this one, and why. You can answer this question based entirely on the graph showing the curve fit.

   The best fit I found is of the form $\sqrt{g}e^{-g^2}$, which is neither Weibull nor Rayleigh. It does a good job matching the histogram, at least away from $g = 0$, and up to the highest gust of about 25 mph. Certainly more data would be desirable for making this assessment of fit.

Mean Wind Speed (line) and Gusts (points) in 5−minute Bins

Mean Wind Direction in 5−minute Bins

Raw Mean Wind (points) and Smoothed Version (line)

Histogram of Gusts and a Heuristic Fit

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%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Study Nov 2009 Hurricane Ida wind data.
% FSH MIT ME 2.017 Nov 2009
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

clear all;
load homework9.txt;

n = length(homework9);
t = 0:5:5*(n-1); % time vector

dir = homework9(:,1); % direction
for i =1:n, % unwrap the direction data for a good plot
    if dir(i) > 180,
        dir(i) = dir(i) - 360 ;
    end;
end;

ubar = homework9(:,2); % mean wind in the bin
utilde = homework9(:,3); % peak gust in the bin

figure(1);clf;hold off;
plot(t,ubar,t,utilde,'.');
xlabel('time, minutes');
ylabel('miles per hour');
title('Mean Wind Speed (line) and Gusts (points) in 5-minute Bins');
grid;

figure(2);clf;hold off;
plot(t,dir,'.');
ylabel('degrees, ccw positive from north');
xlabel('time, minutes');
title('Mean Wind Direction in 5-minute Bins');
grid;

alpha = .25; % set the low-pass filter parameter ...
y(1,1) = ubar(1);
for i = 2:n, % ... and filter
    y(i,1) = (1-alpha)*y(i-1,1) + alpha*ubar(i);
end;

% plot the raw mean wind and the filtered values
figure(3);clf;hold off;
plot(t,ubar,'m.',t,y,'LineWidth',2);
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```
xlabel('time, minutes');
title('Raw Mean Wind (points) and Smoothed Version (line)');
ylabel('miles per hour');

g = utilde-y; % gusts relative to the smoothed mean values

% make histogram (pdf) of the gusts
figure(4);clf;hold off;
hist(g,20);

% make up a fitting line and overlay it
gsize = 0:30; % gust levels to evaluate the fitting function
fitCurve = 130*gsize.^(.5).*exp(-gsize.^2/85);

figure(4);hold on;
plot(gsize,fitCurve,'c','LineWidth',2);
xlabel('g, miles per hour');
ylabel('relative frequency');
title('Histogram of Gusts and a Heuristic Fit');

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