Classifying Extratropical Cyclone WIND Extremes in the Northeast: A Probability Based Approach

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Introduction and Motivation

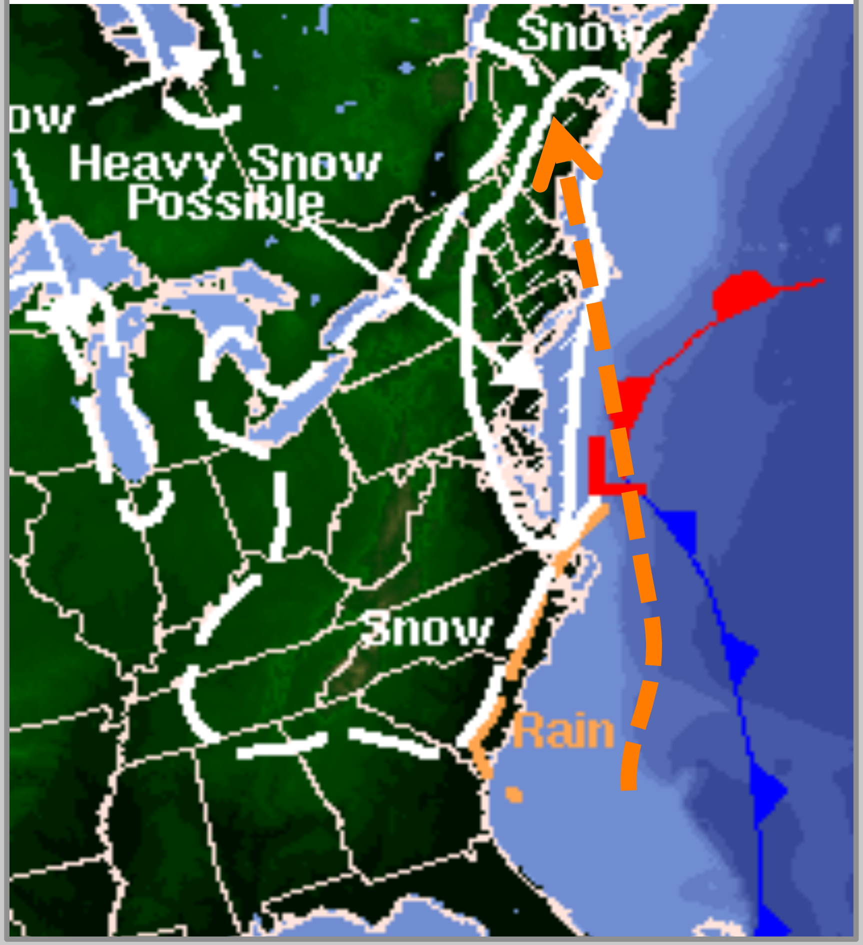
- ***What is an Extratropical Cyclone?***
  Frontal-storm, driven primarily by the equator-to-pole temperature contrast.

- ***Why do they matter?***
  Most frequent storm-type occurring in the Northeast

  These storms can deliver :
  HEAVY RAINS
  BLIZZARDS
  WIND STORMS

- **Why classify them now?**
  - There is growing concern regarding trends of extreme storms.
  - Availability of gridded data and tracking algorithms has improved.

Forecast for Dec. 26, 2010



Weather Forecast for Sun, Dec 26, 2010, issued 3:03 AM EST
DOC/NOAA/NWS/NCEP/Hydrometeorological Prediction Center
Prepared by Hamrick based on HPC, SPC, and TPC forecasts

Motivation

Previous Track-based Storm Classification Schemes

Dolan and Davis 1992 (DD92)

Classify storms for coastal impact to North Carolina/Chesapeake

Metric: (wave height)^2 * duration (based on track)

Zielinski 2002

Classify storms for snow/wind impacts

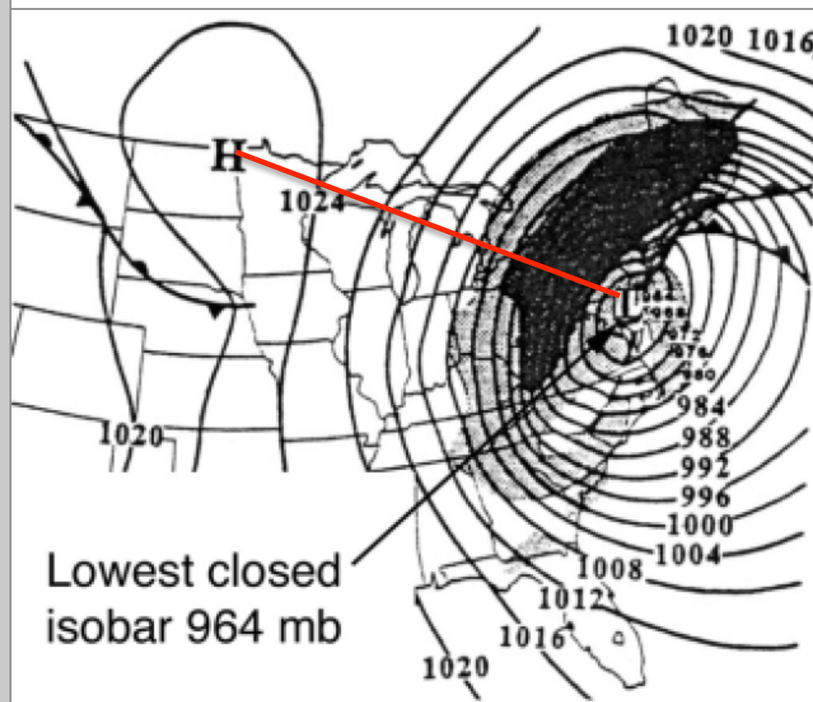
Metric:

Central Pressure+Pressure Gradient+Intensification

PLUS

Subjective rank based on storm forward speed

Surface chart at 0000 UTC 14 Mar 1993



Limitations

Dolan and Davis 1992

-optimal for the Carolinas;

Zielinski 2002

-relies on hand drawn map analysis;

-might include too much info;

-derived using small set of events

Can we refine/supplement these metrics?

Research Question

Can we classify the storm conditions that accompany strong wind events over the Northeast Corridor region?

TWO APPROACHES:

(1) First identify the Extratropical Cyclones, then examine their wind fields.

(2) Area average the winds over a region, then identify the cyclones.

Why start with winds only?

- We have more trust in reanalysis winds than precipitation.
- Different metrics respond differently to warming (Booth et al. 2013).

** No focus on wind direction in this analysis, only wind amplitude.

Methods

Metric I :: CYCavg – cyclone-based area averaged winds

(1) Use automated tracking scheme (Hodges 1994) to track storm centers.

TERMINOLOGY

- **storm path:** *entire life cycle of extratropical cyclone.*
- **cyclone**: *6-hourly snapshot of the storm at a given time.*

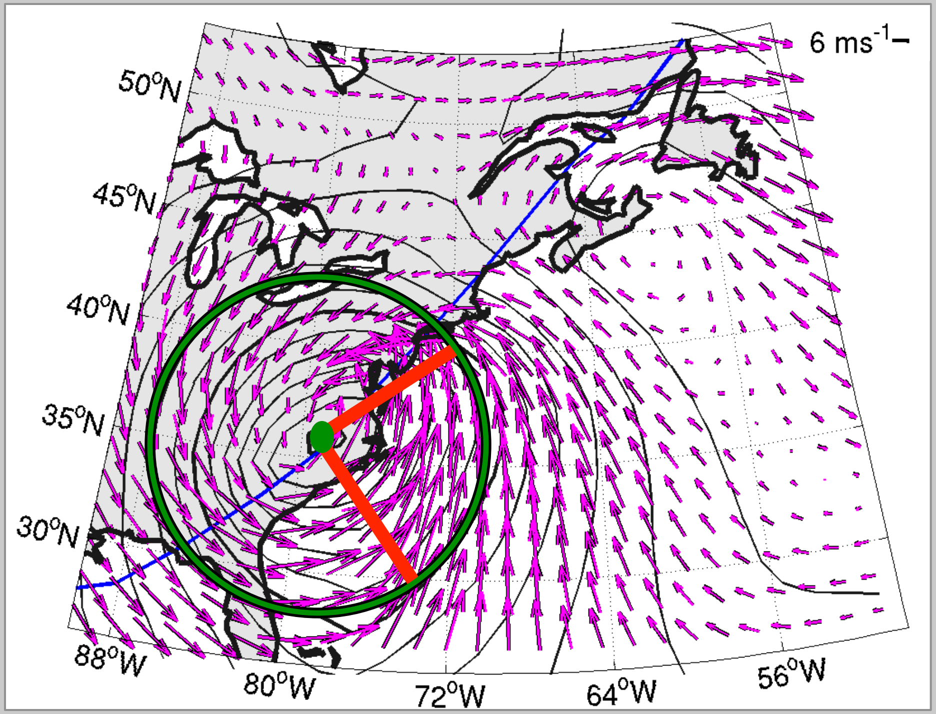
(2) For each cyclone, area average 925 hPa wind speed around storm center (1000 km radius)

- Use quadrants not the full circle
- Keep the value from the strongest quadrant.

2 Types:

(a) using all points.

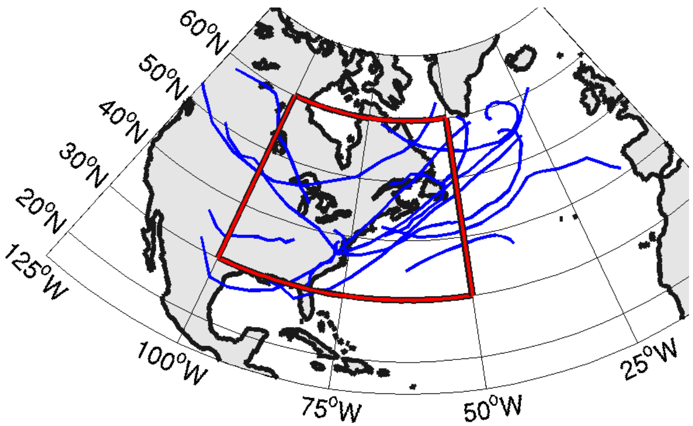
(b) using only points over land.



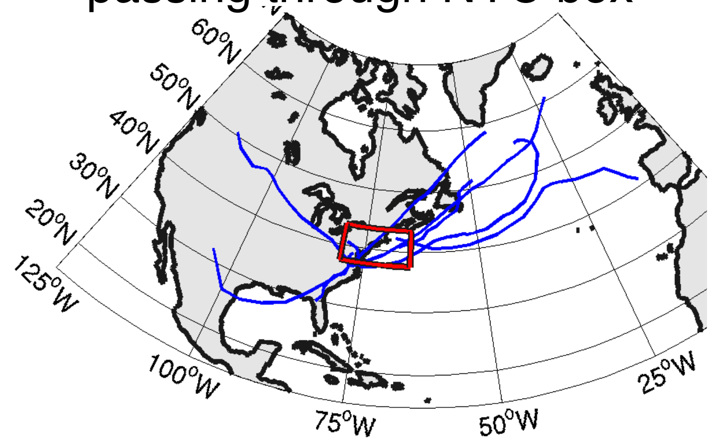
(3) Focus only on storms with path over NY region.

Visual Example: Tracking storms and focusing on NYC region.

March 1993 Storm Paths
for all east coast



March 1993 Storm Paths
passing through NYC box

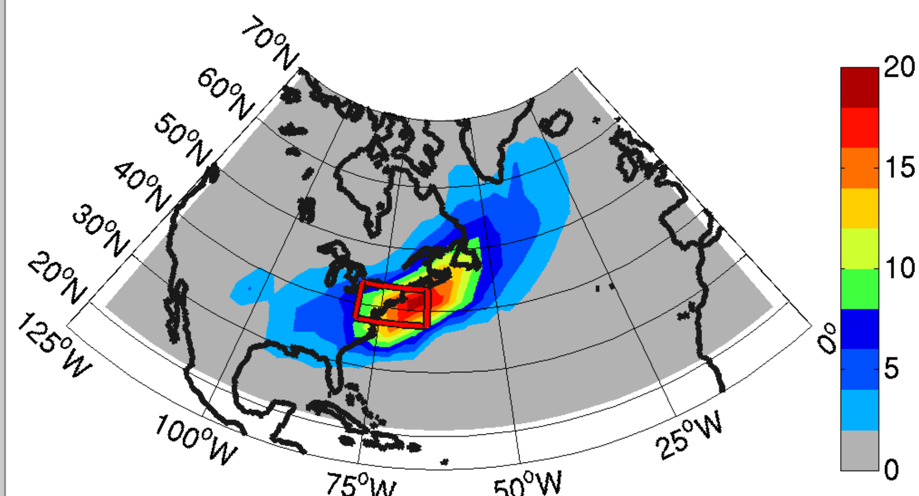


<u>NYC Storm Set</u>
801 total storms.
Nov ‘79 – Apr ’10

12567 ***cyclones***
1778 ***cyclones***
over NY box

Recall: cyclones are snapshots of the storm

Track Density for NYC storm set



UNITS:
tracks per 2.5 X 2.5 grid per cold season

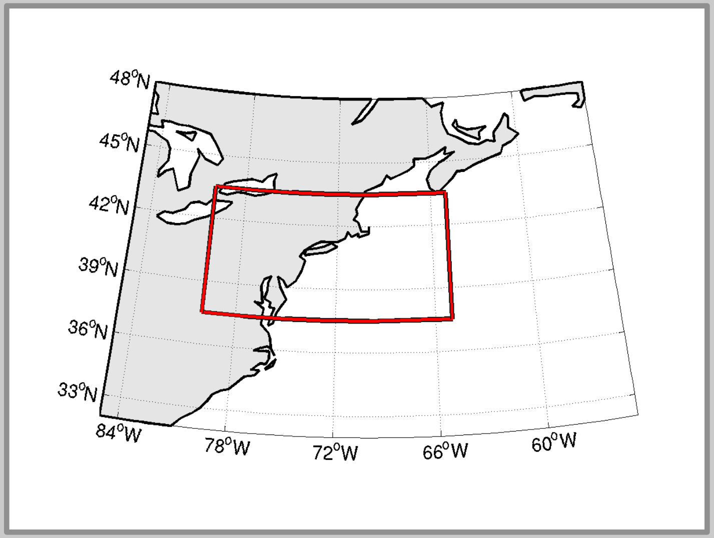
Methods

Metric II :: NYavg – area average 925 hPa winds over NY Region

(1) Area average the 925 hPa winds over a fixed region.

- 2 TYPES

(a) using all winds
(b) using winds over land only



RECAP

CYCavg :: cyclone-based area averaged winds. Storms must pass over NY

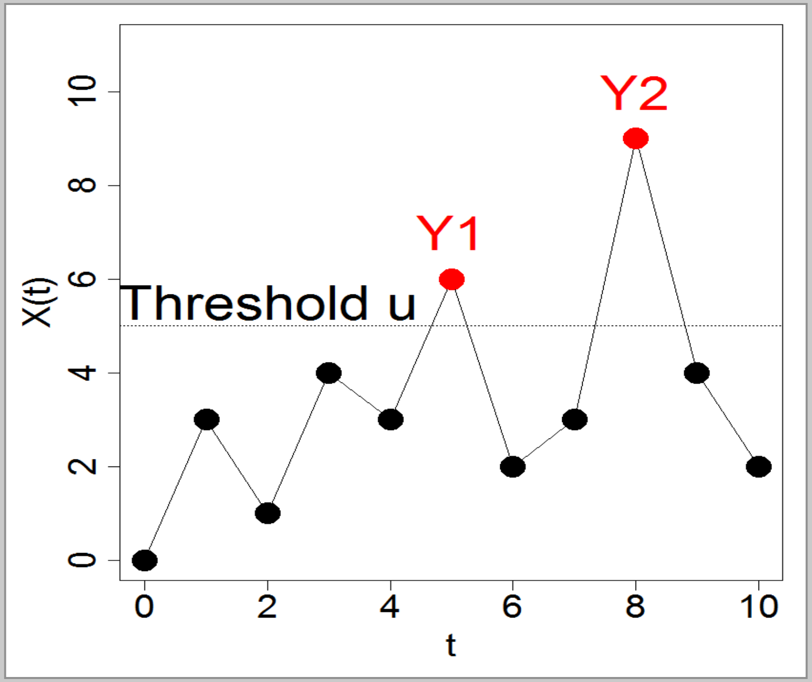
NYavg :: time-series of area averaged winds over the NY box.

Methods

Extreme Value Theory for Classifying the strongest events.

First we identify the top 10% of events.

Then, we use a Peak-Over-Threshold analysis and fit the data with a Generalized Paredo Distribution



Example: two extreme peaks above a threshold level *u*

$$F(x) = 1 - \left(1 + \xi \frac{(x-u)}{\sigma}\right)^{-1/\xi}$$

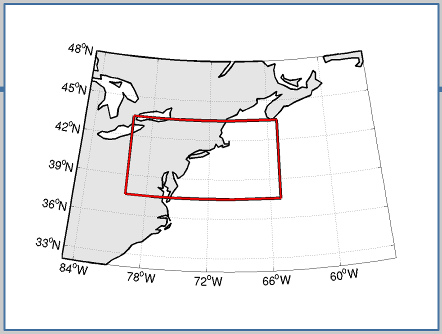
u is the threshold value

$\sigma > 0$ is the scale parameter

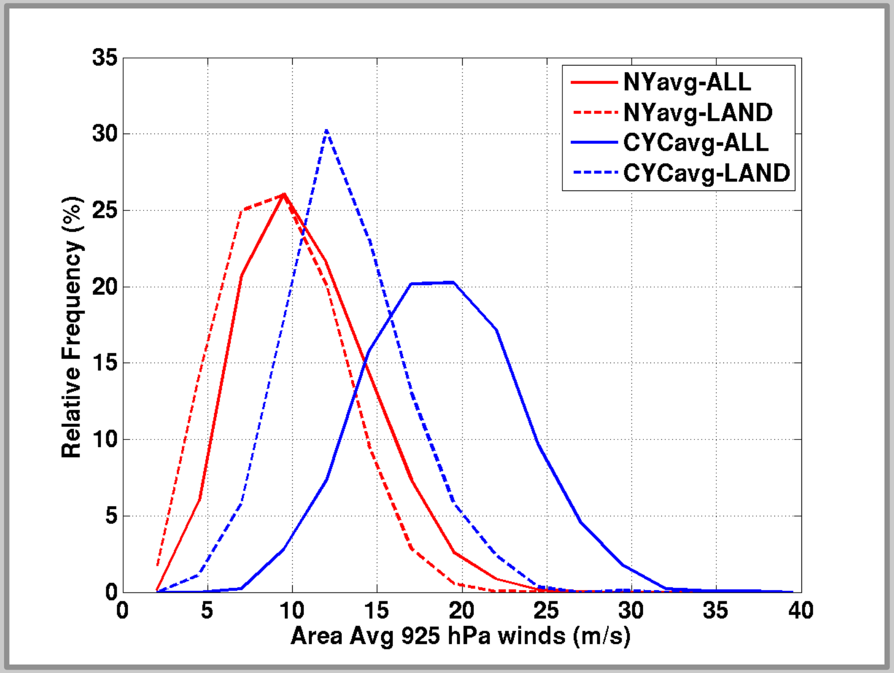
$\xi \in R$ is the shape parameter

maximal likelihood used estimation to optimize the <u>fitting parameters</u>.

Results



Comparison of the full NYC datasets



<u>Winds over fixed region</u>

NYavg-ALL: land and ocean

NYavg-LAND: land only

<u>Cyclone-local, storm over NYC Box</u>

CYCavg-ALL: land and ocean

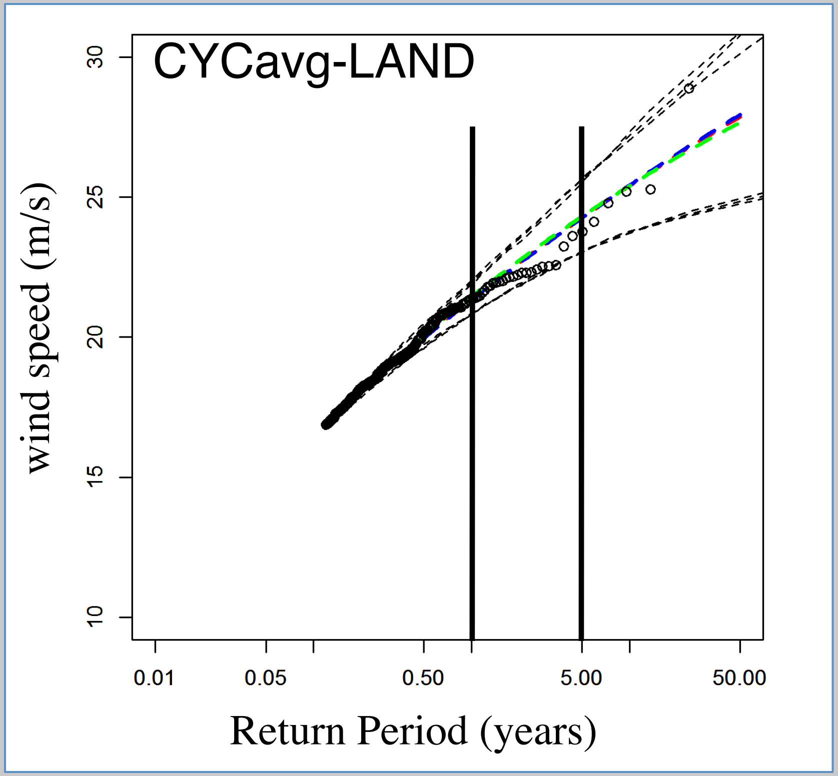
CYCavg-LAND: land only

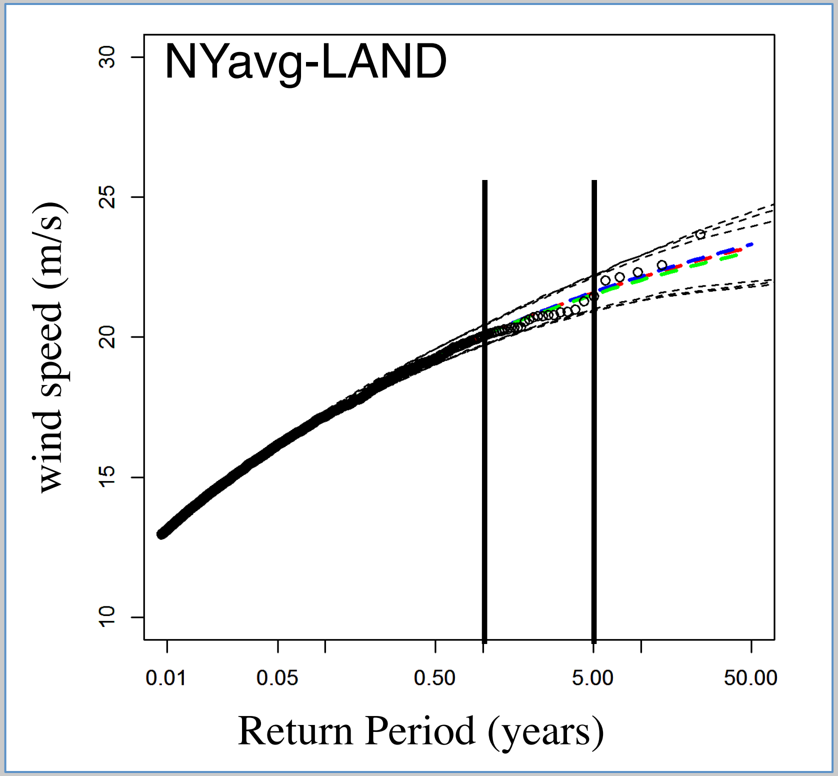
Avgs that include ocean points stronger; due to weaker surface friction of water.

CYCavg are stronger than NYavg, because the cyclone local winds are taken from the strongest wind quadrant under the storm.

For sake of societal impacts, we focus only on winds over land.

Fitting the strongest wind events to a generalized Pareto distribution





<u>Open circles</u>: wind speed averages
<u>Dashed-Colored line</u>: fitted generalized Paredo distribution (GPD)
<u>Return Period</u>: probability of exceeding a wind speed within a time window (years)
- calculated from the fitted GPD
- plotted on log10 axis

-Dashed-black lines show probabilistic uncertainties of the fit
-Overlapping blue/green/red lines show results using top 85/90/95 percentiles.

Results

Classification scheme using quantiles and Return Periods (RP)

Strength (RP= return period)	Class/ Rank	CYCavg		NYavg	
		number of events	wind speed lower bound (m/s)	number of events	wind speed lower bound (m/s)
$avg_i < 50^{th}$ %tile	0	835	--	11200	--
50^{th} %tile <= $avg_i < 75^{th}$ %tile	1	444	13	5800	9.2
75^{th} %tile <= $avg_i < 90^{th}$ %tile	2	266	15.3	3500	11.6
90^{th} %tile <= avg_i < 1 year RP	3	145	17.8	2288	13.8
1 year RP <= avg_i < 5year RP	4	28	22	26	20
5 year RP <= avg_i	5	5	24	6	22.5

Quantiles are used for rankings up to the top 10^{th} %tile
Using Return Periods for strong events has multiple advantages:

- Values are less sensitive to adding a new year of data.
- Allows for strength estimation beyond the strongest observed events.

For all ranks: CYCavg > Nyavg
Differences highlight issue of using cyclone tracking for “targeted” impacts.

Results

Do the events found from the NYavg correspond to actual damage?

Yes. Examples:

February 10-11, 1981: Damaged trees, utility poles down, buildings and bridges. Two dams failed. A massive ice jam on the Delaware River.

- Historical Weather Facts for the Philadelphia/Mt.Holly,NJ Forecast Area

April 1, 1997: "The April Fool's Day Storm"

- http://en.wikipedia.org/wiki/April_Fool's_Day_Blizzard

Jan 09, 2008: Wind storm in Rochester lifts airplane off ground
-http://www.airliners.net/aviation-forums/general_aviation/read.main/3786291/

What do the storm paths, winds and circulation look like for the extreme events? …

Storms Paths and Composites for the Extreme Events

CYCavg-LAND

-No clear path or genesis region.

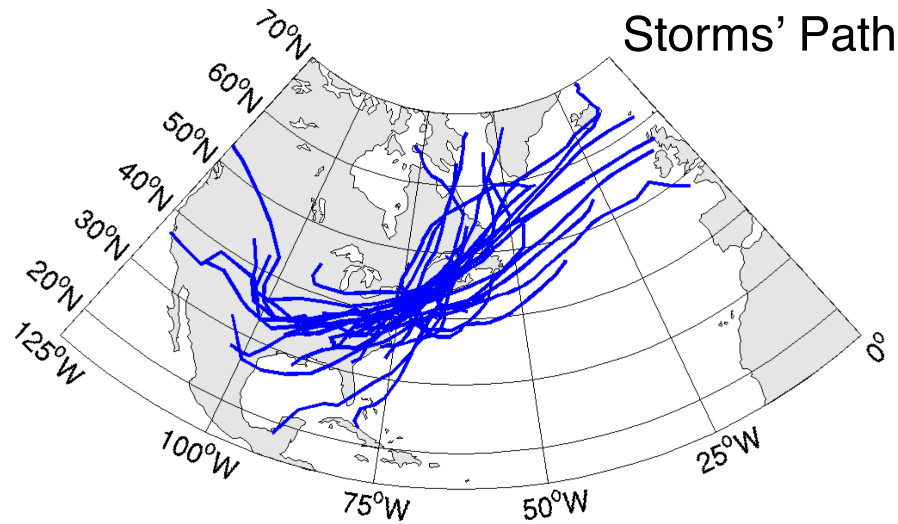
-Events have no correlation to the monthly NAO index

-Events have no trend in time

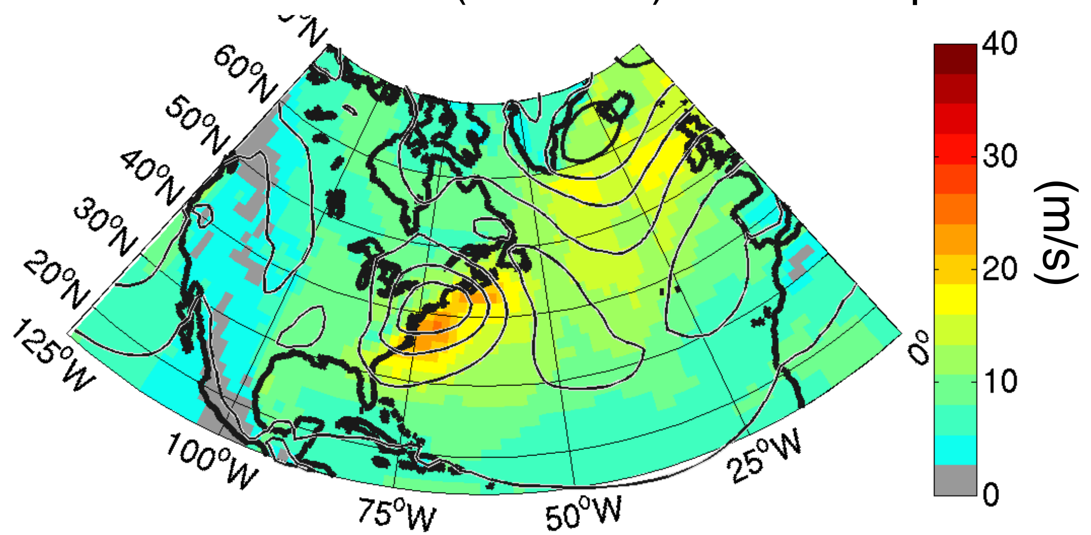
-Events occur more frequently in Mar and Apr as compared to the frequency of all storms.

Composites are generated by averaging snapshots of each event.

Storms' Paths



Sea Level Pressure (contours) and wind speed



Storms Paths and Composites for the Extreme Events

NYavg-LAND

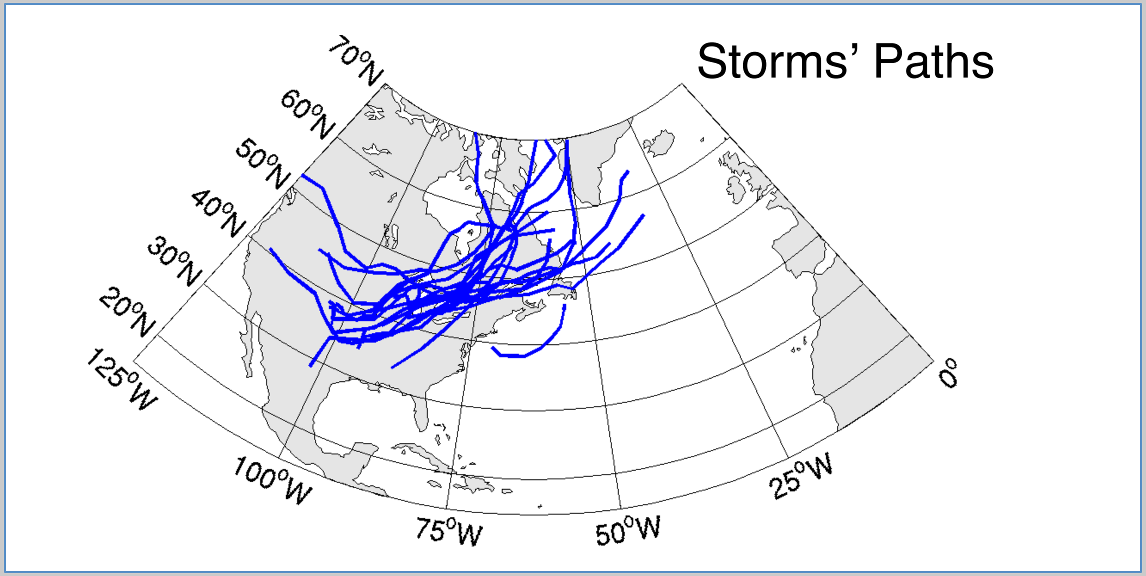
-Also no correlation to the monthly NAO index

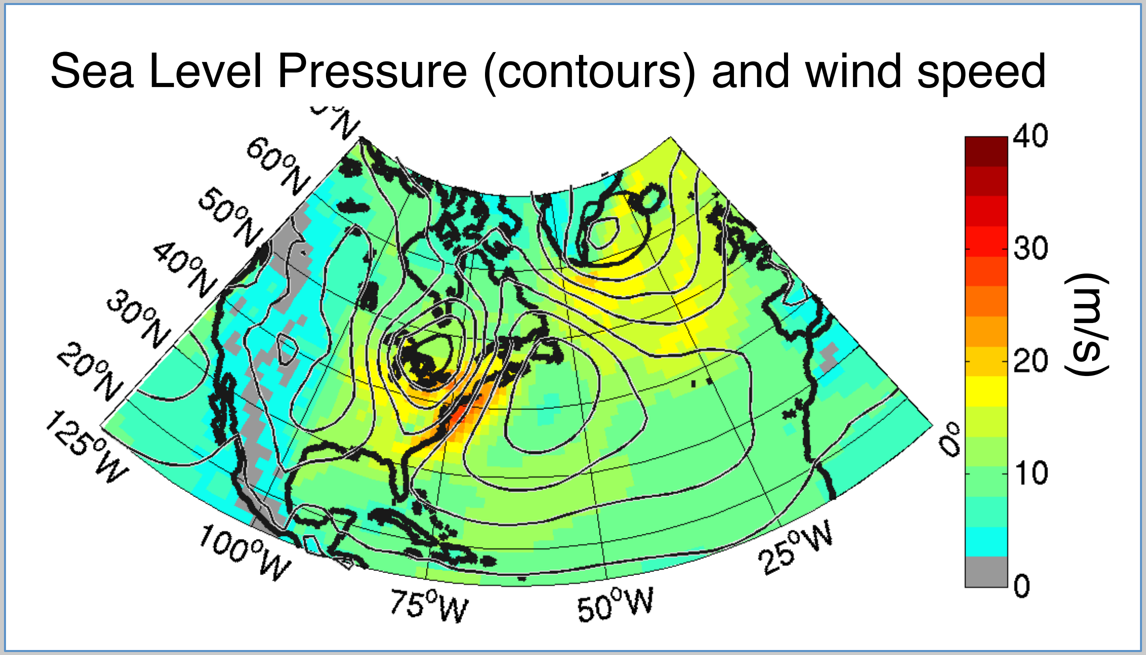
-No trend in time

-Events occur most frequently in JFM

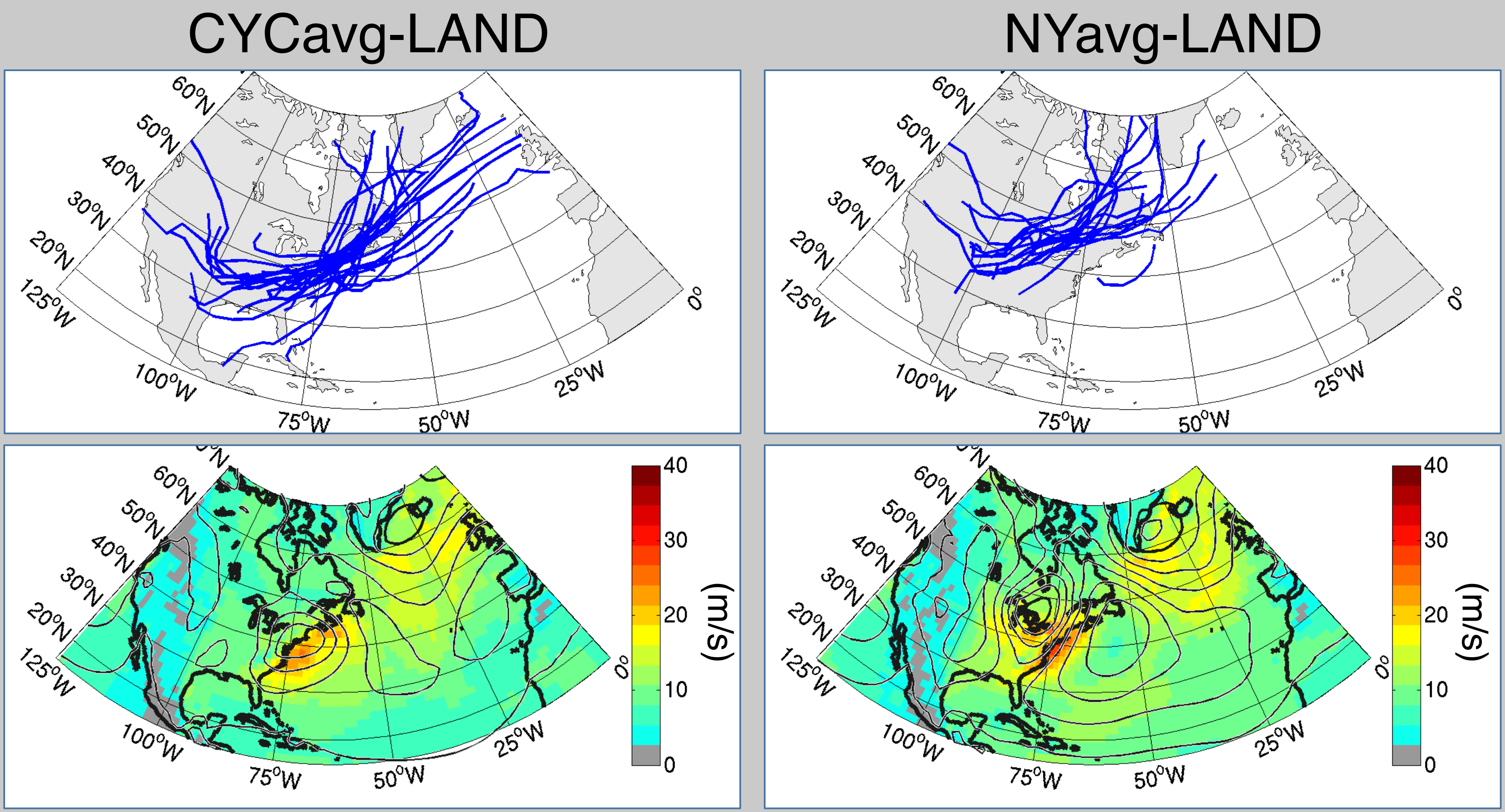
-Only 1 event has center pass over NYC box.

Not shown: lead/lag composites show that the NYCavg events have more temporal coherence than the CYCavg events.





Storms Paths and Composites for the Extreme Events



- The centers of Storms associated with NYavg do NOT travel over NY region.

- Strong winds over NY correspond to cold frontal region of storms.

Summary & Discussion

- For societal impact of wind speed it is important to distinguish between the impact over land vs. over sea.

  Note also that for impact over land one would also need to consider spatial variability*

  Over the sea, direction, duration and fetch are important.

- Tracking algorithms can be useful, but we must remember: track center is not necessarily the location of storm action.

- Area average of winds in a fixed location, followed by attribution to cyclones might be the better approach for impacts-based analyses. (Additional modeling tool such as wave and surge models are also needed)

- Historically, the strongest wind events in the NYC area were caused by storms that traveled over the Great Lakes (and not Nor'easters!)

<u>Relevant to recent modeling results:</u>

- IPCC Climate Models show a westward shift in storm path density: (i.e. more storms over land along the coast.) *Colle et al. J. Climate (in press)*
  - Colle et al. focus on path of the cyclone centers
  - Based on their work and ours, we need a second look that starts with the winds.