Quantifying Wind Risk: Present and Future

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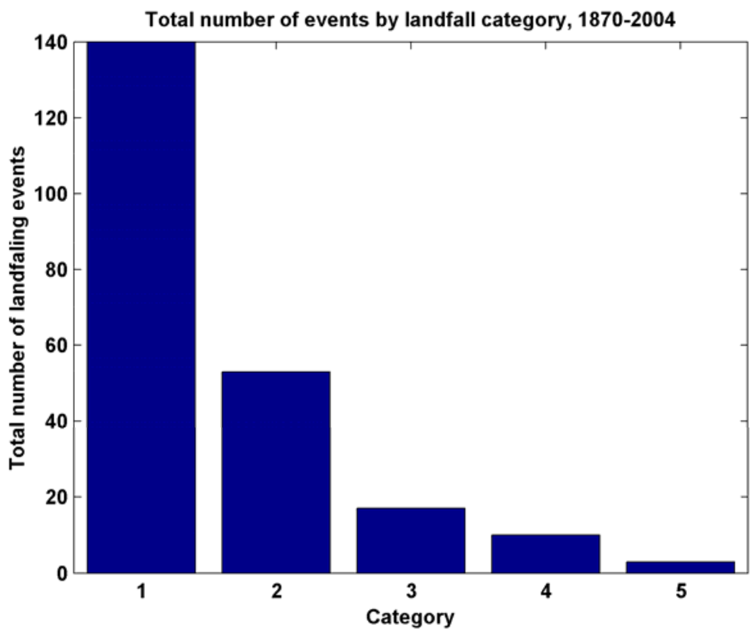
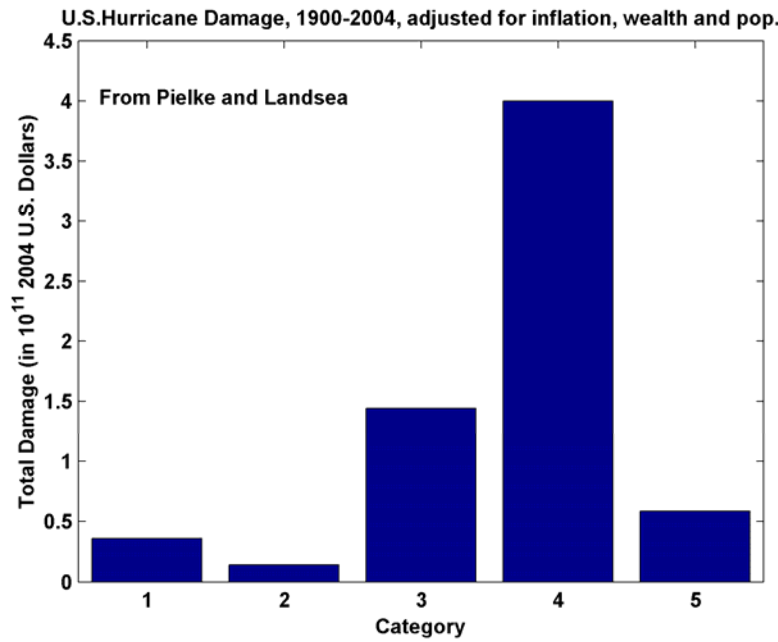




- >50% of all damage caused by top 5 events, all category 4 and 5
- >90% of all damage caused by storms of category 3 and greater
- Category 3,4 and 5 events are only 13% of total landfalling events; only 30 since 1870
- ∴ ***Landfalling storm statistics are grossly inadequate for assessing hurricane risk***

Current Methods of Hurricane Risk Assessment

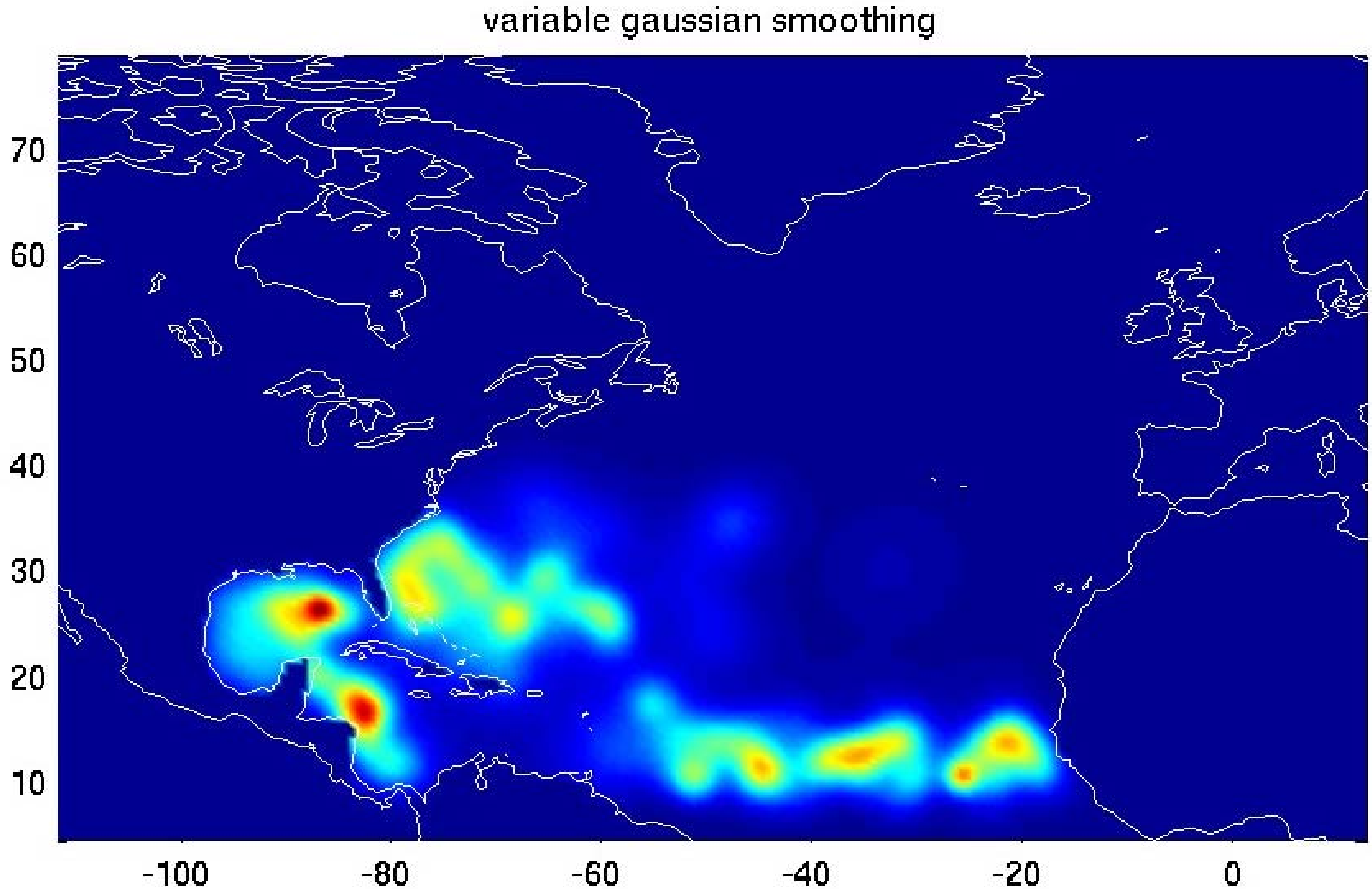
- Fit standard (e.. Weibull) distribution functions to peaks winds within a specified radius of point of interest, taken from historical hurricane data (Georgiou et al, 1983; Neumann, 1987)
- Find universal distribution functions of wind normalized by potential intensity and interpolate to specific locations based on historical frequency (Darling, 1991; Chu and Wang, 1998)
- Generate large database of synthetic storm tracks using previous track history and local climatology; couple to historical intensity data (Vickery et al., 2000)

Statisical-Deterministic Approach

- **Step** 1: Generate large (~10^4) numbers of synthetic tropical cyclone tracks passing within specified radius of point of interest
  - Method 1: Use the Record (Markov Chain)
  - Method 2: Use large-scale winds (Markov Random Field)

- **Step 2**: Run a deterministic coupled tropical cyclone intensity model along each synthetic track
- **Step 3**: Directly deduce wind speed exceedence probabilities at point of interest.
  - Couple with surge models.

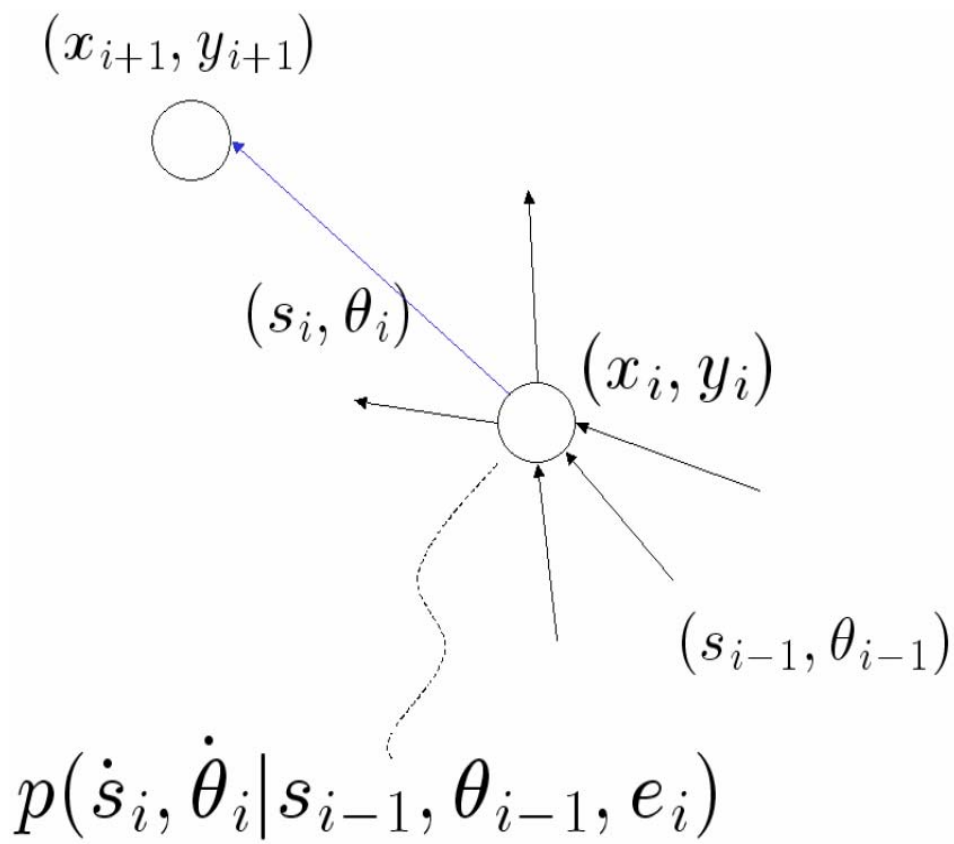
Genesis PDFs based on post-1970 historical tracks

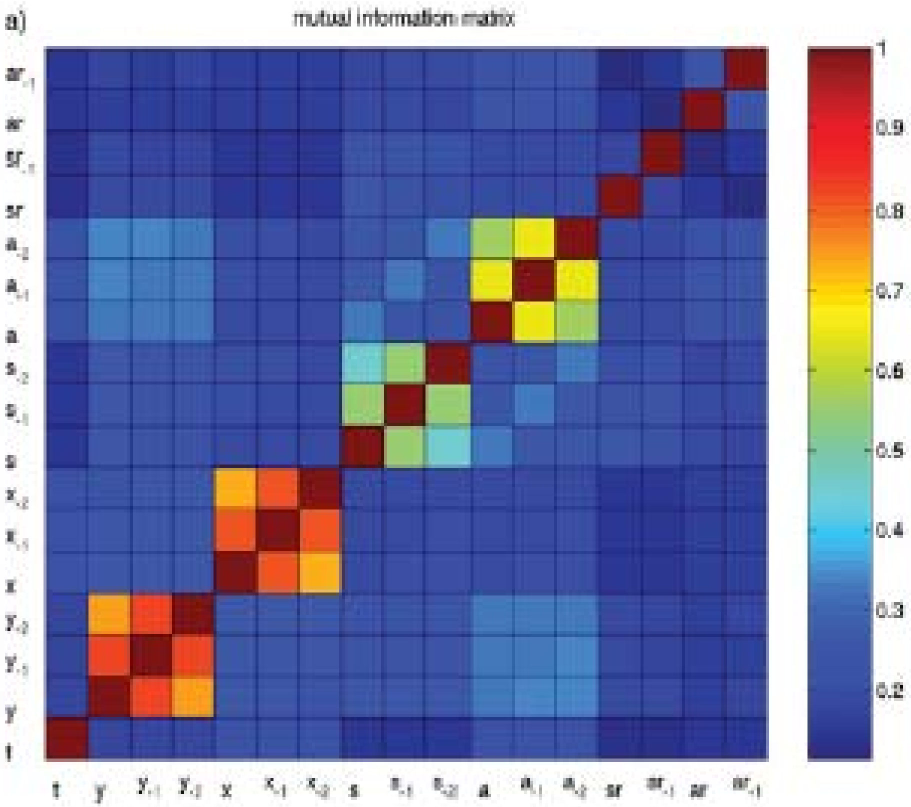


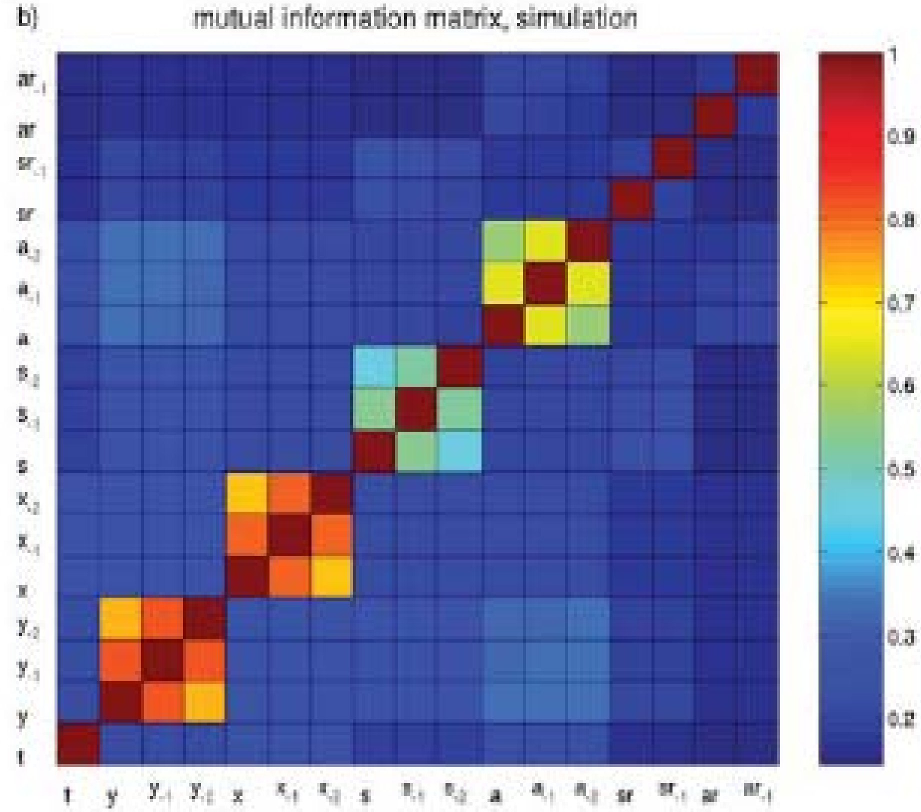
Tracks initiated by random draws from space-time PDF based on historical genesis data smoothed using a three-dimensional anisotropic space-varying Gaussian kernel

- Markov Chain
  - Tracks propagated in 6-hour steps by integrating in time the rates of change of direction and speed, by randomly drawing from the probability distribution

Note: Probabilities of rates of change based on previous direction and speed, not their rates of change. Only last 6-hour step used.







Observed

Simulated

$$N(X_i, X_j) = \sqrt{\frac{I(X_i, X_j)}{\mathbf{MIN}\left[H(X_i), H(X_j)\right]}}.$$

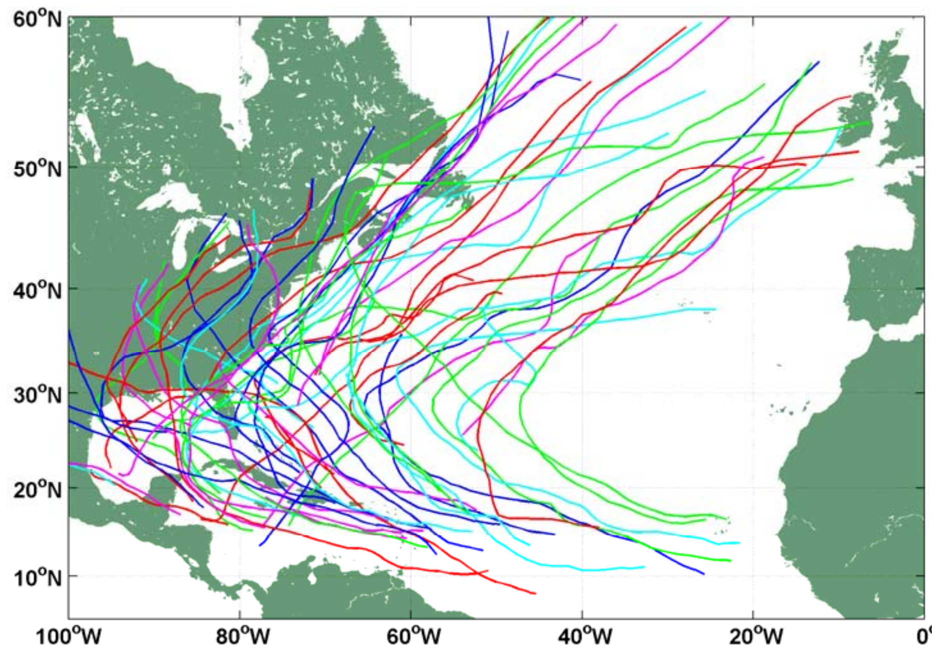
$$H(X) = -\sum_i P(X = x_i)\ln\left[P(X = x_i)\right]$$

$$H(X|Y) = \sum_i P(Y = y_i)H(X|y_i)$$

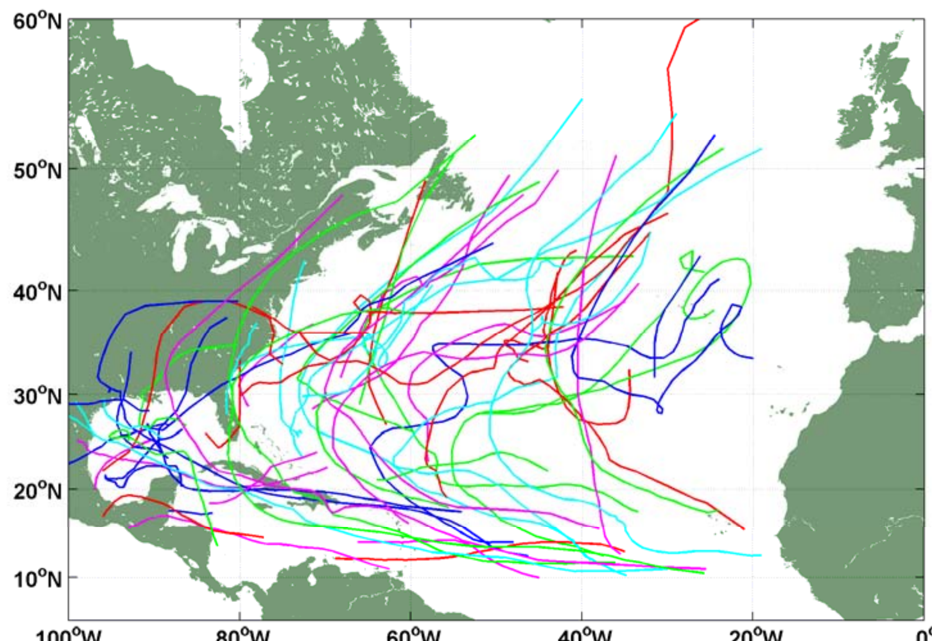
$$I(X,Y) = H(X) - H(X|Y) = H(Y) - H(Y|X).$$

Results:

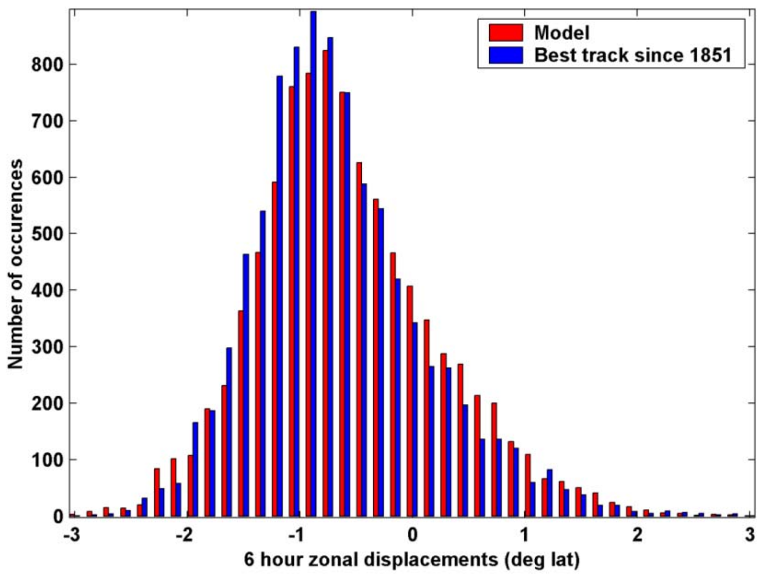
60 Markov tracks



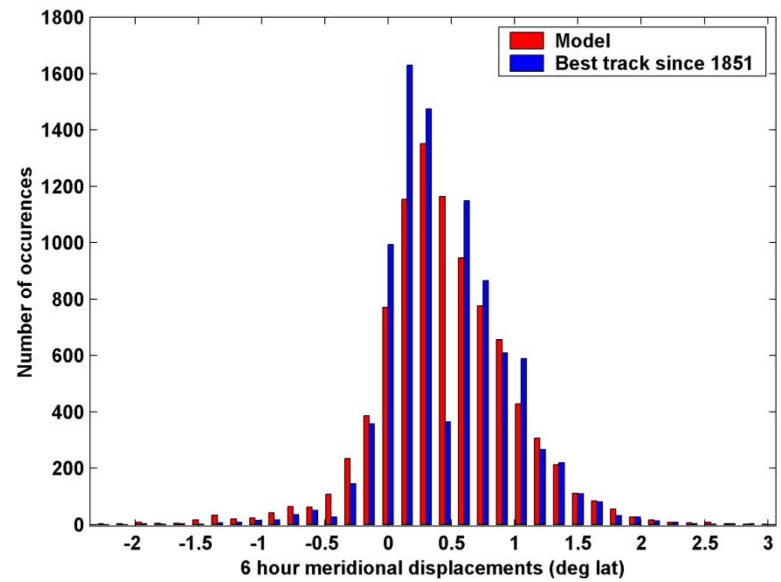
60 HURDAT tracks



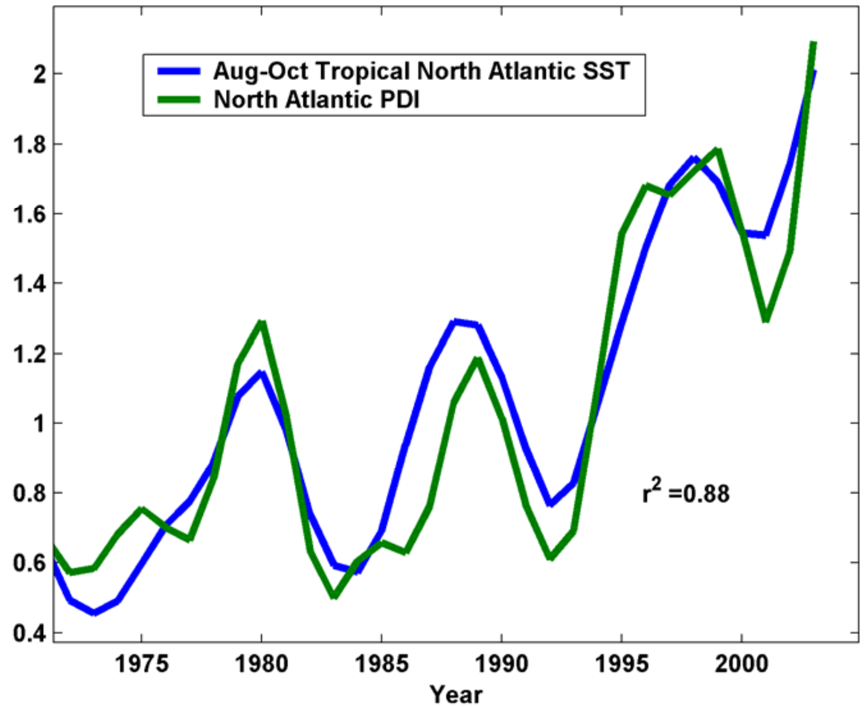
6-hour zonal displacements in region bounded by 10^o and 30^o N latitude, and 80^o and 30^o W longitude



6-hour meridional displacements in region bounded by 10^o and 30^o N latitude, and 80^o and 30^o W longitude



Current methods of hurricane risk assessment are based strictly on history, which is too short and may not be a good guide to the future



Atlantic Hurricane Power and Sea Surface Temperature

Synthetic Track Generation, Method 2: Use of Synthetic Wind Time Series

- **Use genesis technique as in Method 1**
- Postulate that TCs move with vertically averaged environmental flow plus a "beta drift" correction (Beta and Advection Model, or "BAMS")
- Approximate "vertically averaged" by weighted mean of 850 and 250 hPa flow

Synthetic wind time series

- Monthly mean, variances and co-variances from NCEP re-analysis data

- Synthetic time series constrained to have the correct mean, variance, co-variances and an ω^{-3} power series

250 hPa zonal wind modeled as Fourier series in time with random phase:

$$u_{250}(x,y,\tau,t)=\overline{u}_{250}(x,y,\tau)+\sqrt{\overline{\overline{u'^{2}_{250}(x,y,\tau)}}}F_1(t)$$

$$F_1\equiv\sqrt{\frac{2}{\sum_{n=1}^{N}n^{-3}}}\sum_{n=1}^{N}n^{-3/2}\sin\left(2\pi\left({nt}/{T}+X_{1n}\right)\right)$$

where T is a time scale corresponding to the period of the lowest frequency wave in the series, N is the total number of waves retained, and X_{1n} is, for each n, a random number between 0 and 1.

The time series of other flow components:

$$v_{250}(x,y,\tau,t)=\overline{v}_{250}(x,y,\tau)+A_{21}F_1(t)+A_{22}F_2(t),$$
$$u_{850}(x,y,\tau,t)=\overline{u}_{850}(x,y,\tau)+A_{31}F_1(t)+A_{32}F_2(t)+A_{33}F_3(t),$$
$$v_{850}(x,y,\tau,t)=\overline{v}_{850}(x,y,\tau)+A_{41}F_1(t)+A_{42}F_2(t)+A_{43}F_3(t)+A_{44}F_4(t),$$

or

$$\mathbf{V}=\overline{\mathbf{V}}+\mathbf{AF}$$

where each F_i has a different random phase, and **A** satisfies

$$\mathbf{A}^{\mathbf{T}}\mathbf{A}=\mathbf{COV}$$

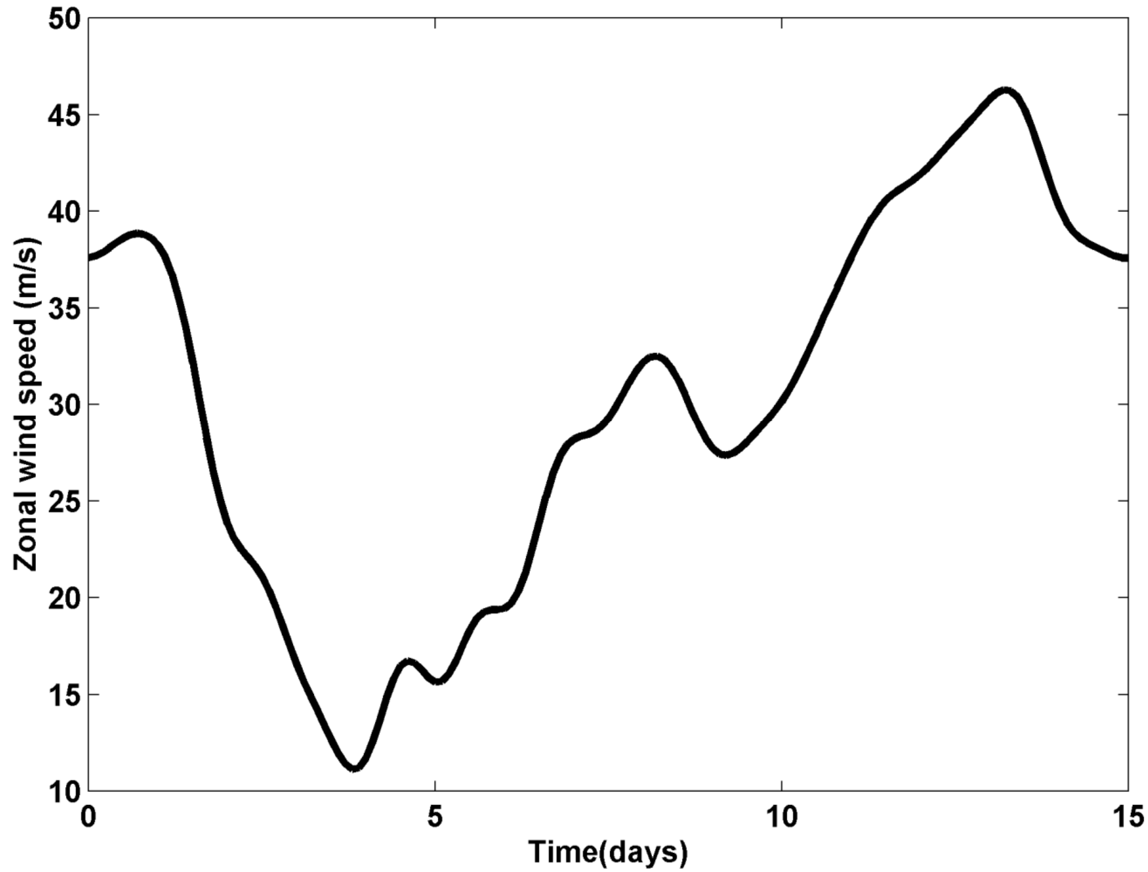
where **COV** is the symmetric matrix containing the variances and covariances of the flow components.

Example:

$$\overline{u}_{250} = 30\ ms^{-1} \qquad \sqrt{\overline{u'^2_{250}(x, y, \tau)}} = 10\ ms^{-1}$$

$$N = 15$$

$$T = 15\ days$$



Track:

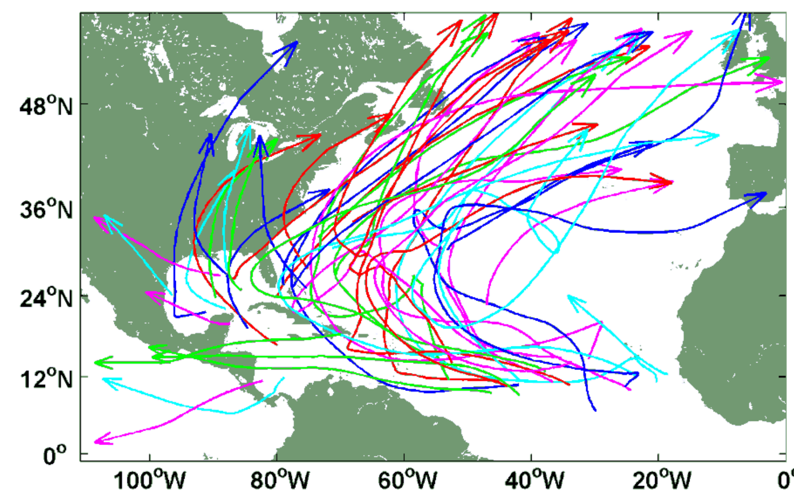
$$\mathbf{V}_{track} = \alpha \mathbf{V}_{850} + (1-\alpha)\mathbf{V}_{250} + \mathbf{V}_{\beta},$$

Empirically determined constants:

$$\alpha = 0.8,$$

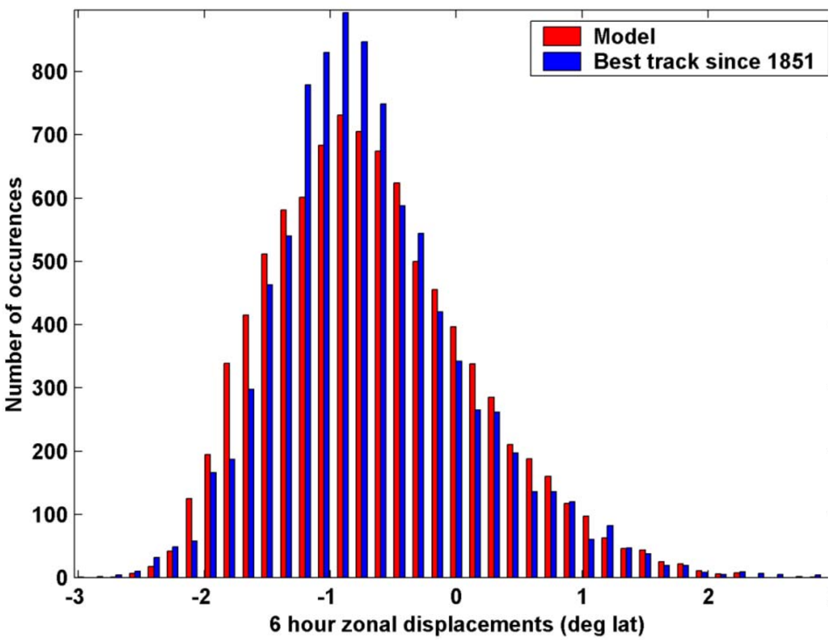
$$u_{\beta} = 0\, ms^{-1},$$

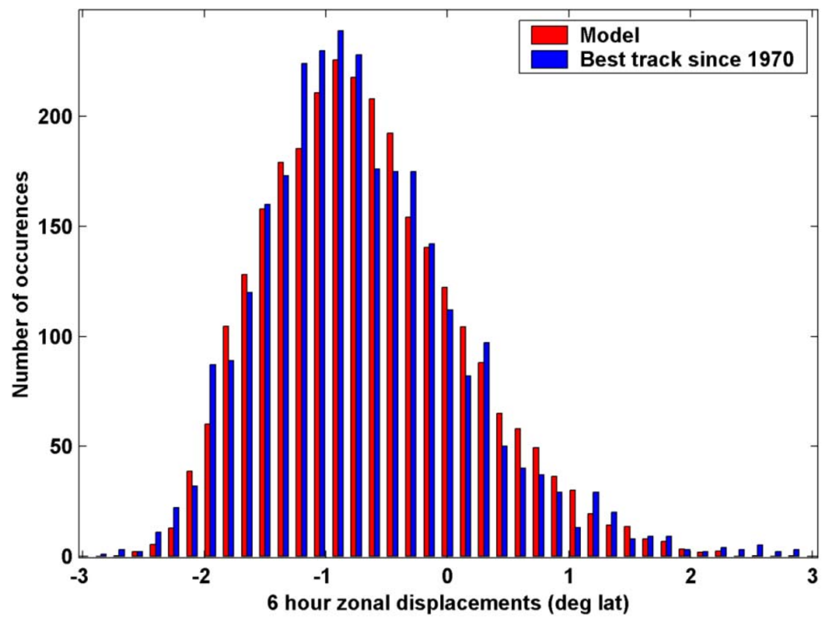
$$v_{\beta} = 2.5\, ms^{-1}$$



6-hour zonal displacements in region bounded by 10^o and 30^o N latitude, and 80^o and 30^o W longitude

using only post-1970 hurricane data



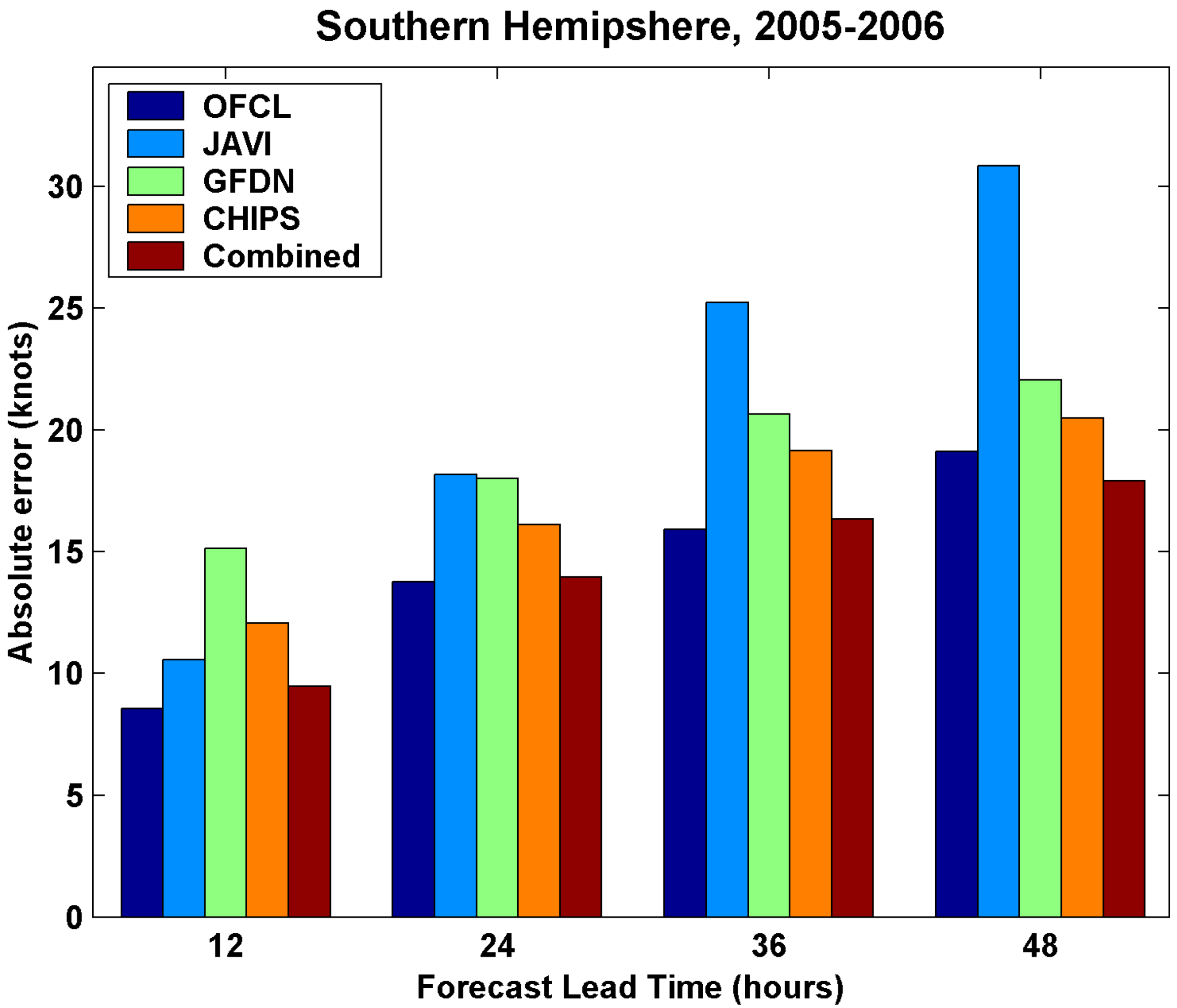


Step 2: Tropical Cyclone Intensity (Both methods)

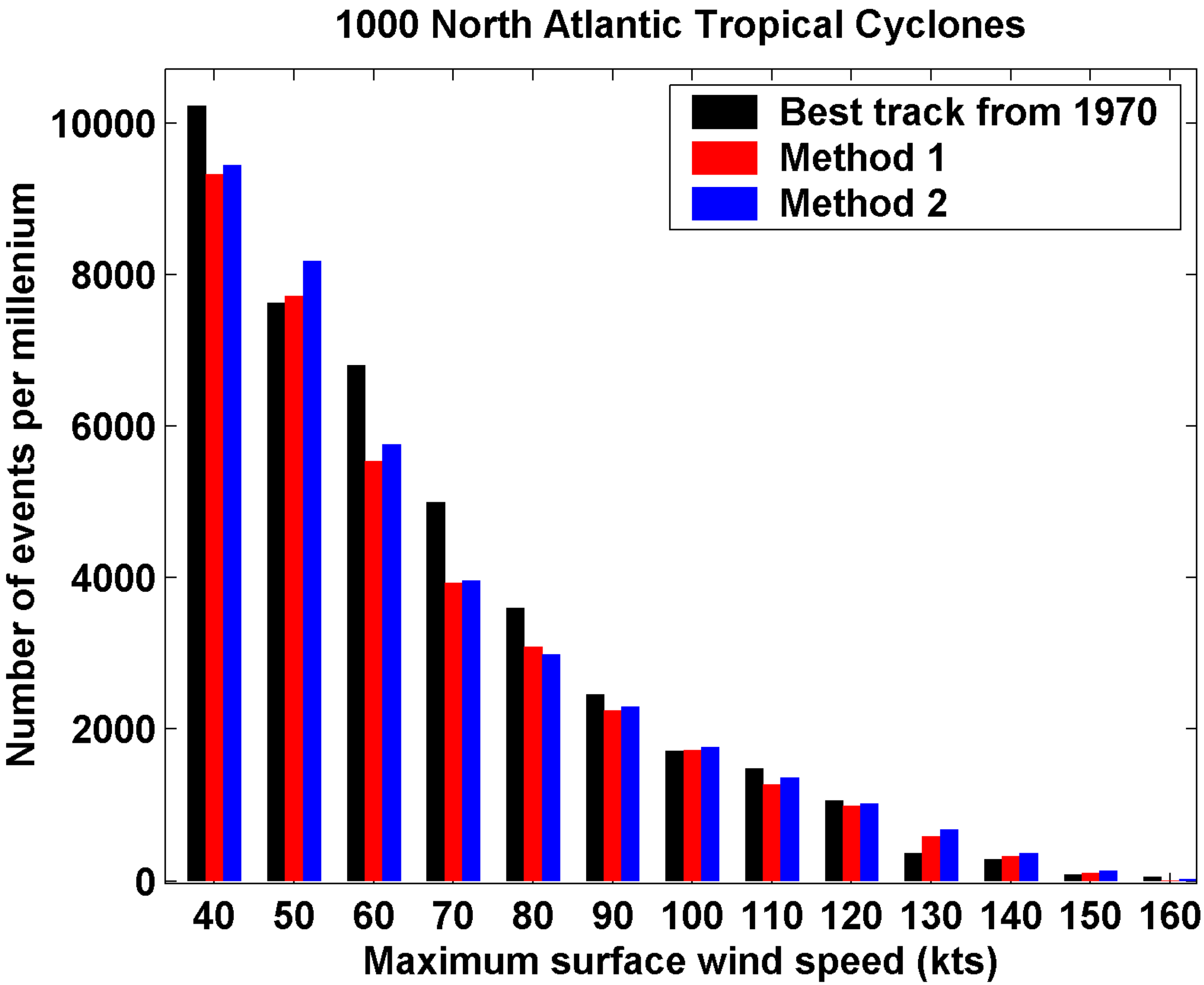
- Run coupled deterministic model (CHIPS, Emanuel et al., 2004) along each track
- Use monthly mean potential intensity, ocean mixed layer depth, and sub-mixed layer thermal stratification
- Use shear from synthetic wind time series
- Initial intensity and rate of intensification specified as $15\ ms^{-1}$ and $6\ ms^{-1} day^{-1}$
- Tracks terminated when $v < 17\ ms^{-1}$

Coupled Hurricane Intensity Prediction System (CHIPS)

- Operational at JTWC
- Unique initialization based on entire storm history
- Major improvements in late 2005

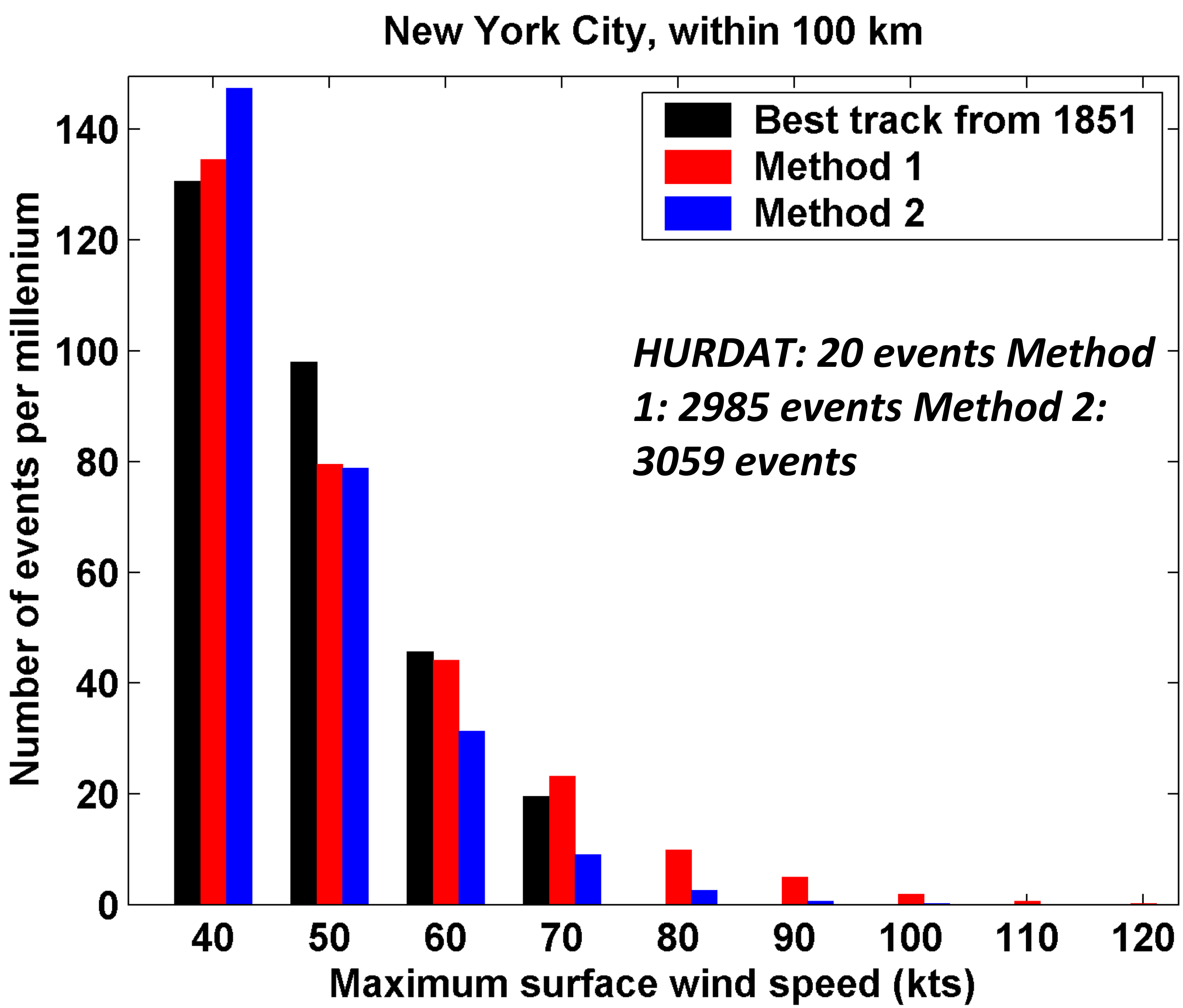

Southern Hemipshere, 2005-2006
OFCL
JAVI
GFDN
CHIPS
Combined
Absolute error (knots)
0
5
10
15
20
25
30
12
24
36
48
Forecast Lead Time (hours)

Results

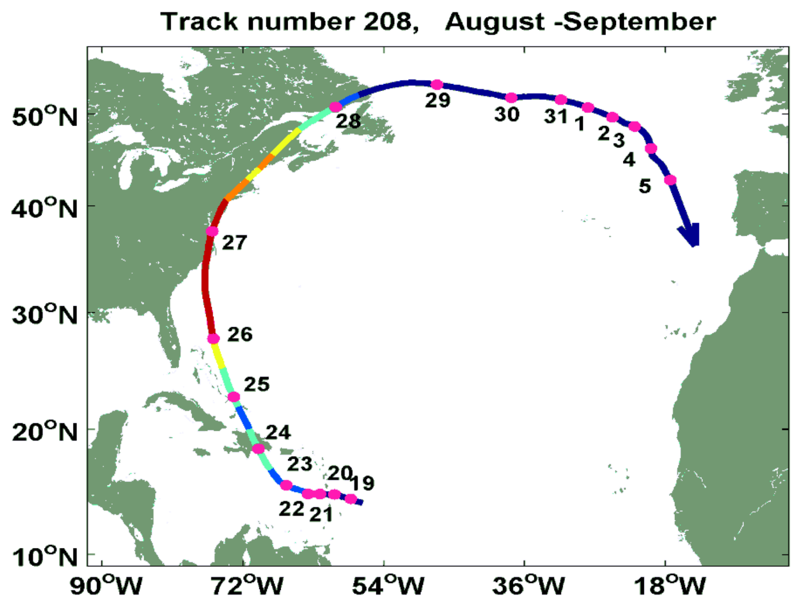


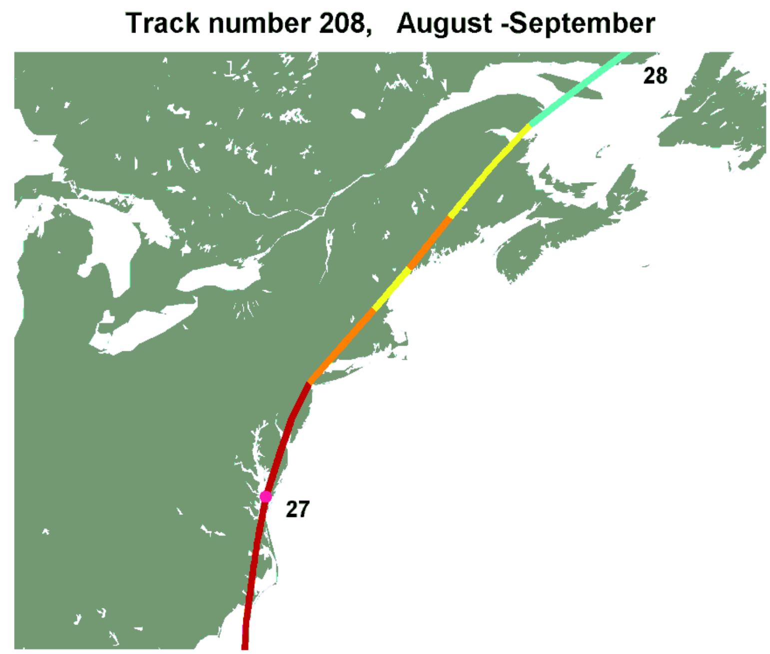
1000 North Atlantic Tropical Cyclones
Best track from 1970
Method 1
Method 2
Number of events per millenium
0
2000
4000
6000
8000
10000
40
50
60
70
80
90
100
110
120
130
140
150
160
Maximum surface wind speed (kts)

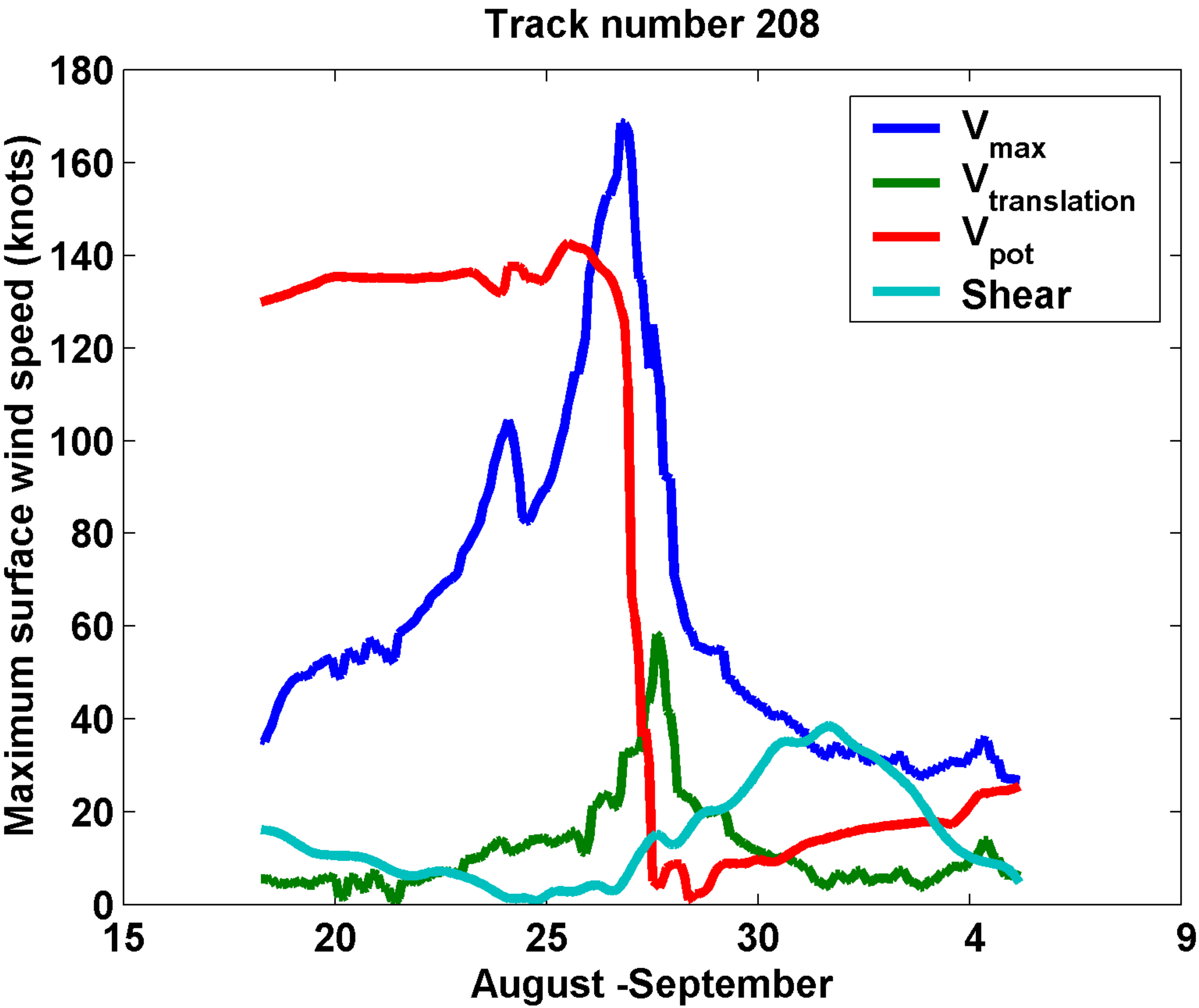
New York City



New York, worst event, Method 1

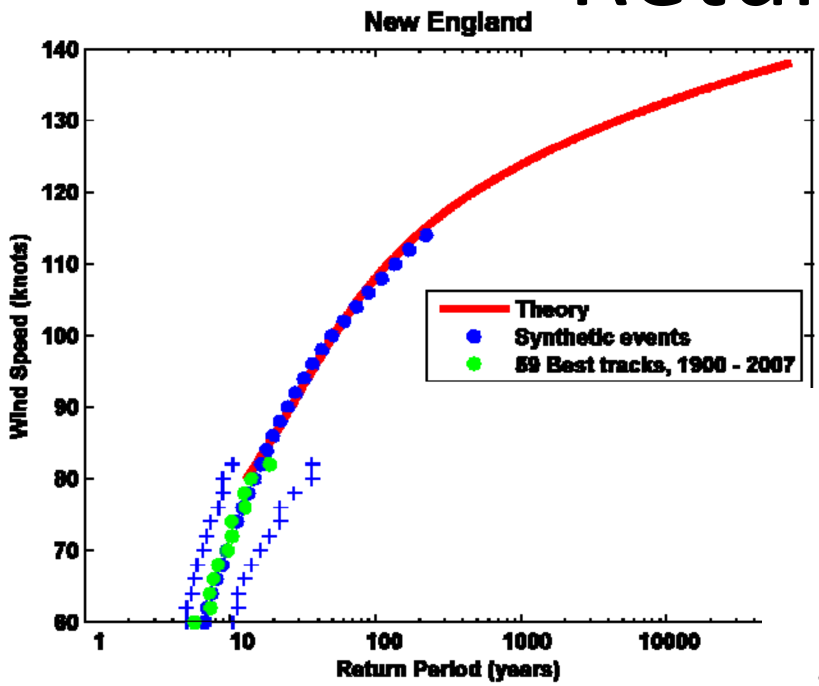


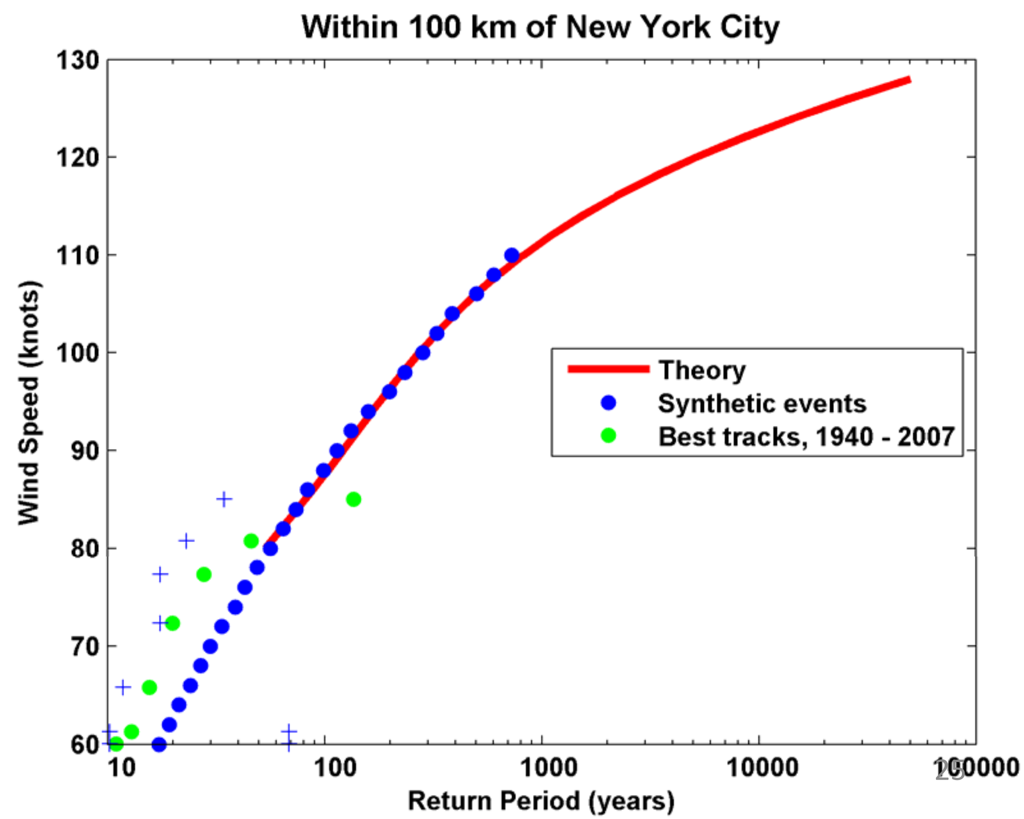




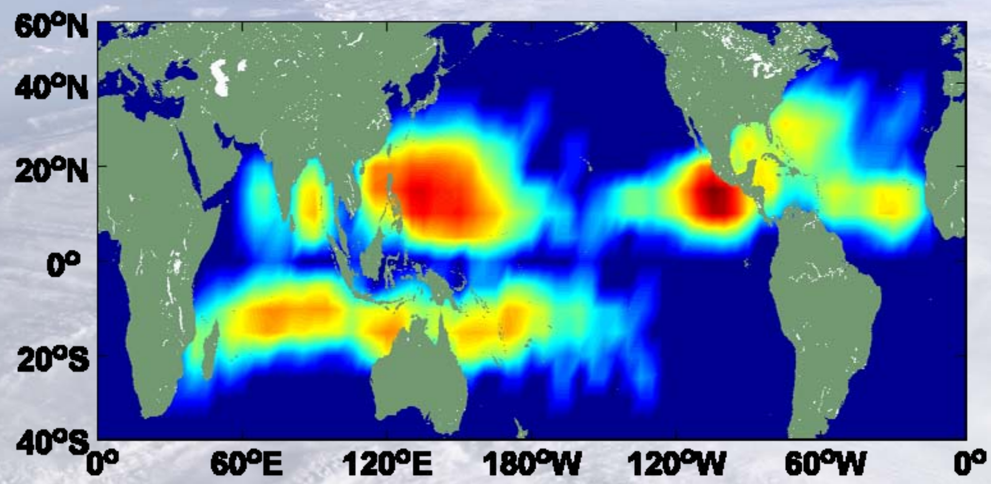
Track number 208
Maximum surface wind speed (knots)
180
160
140
120
100
80
60
40
20
0
15
20
25
30
4
9
August -September
V_{max}
$V_{translation}$
V_{pot}
Shear

Return Periods

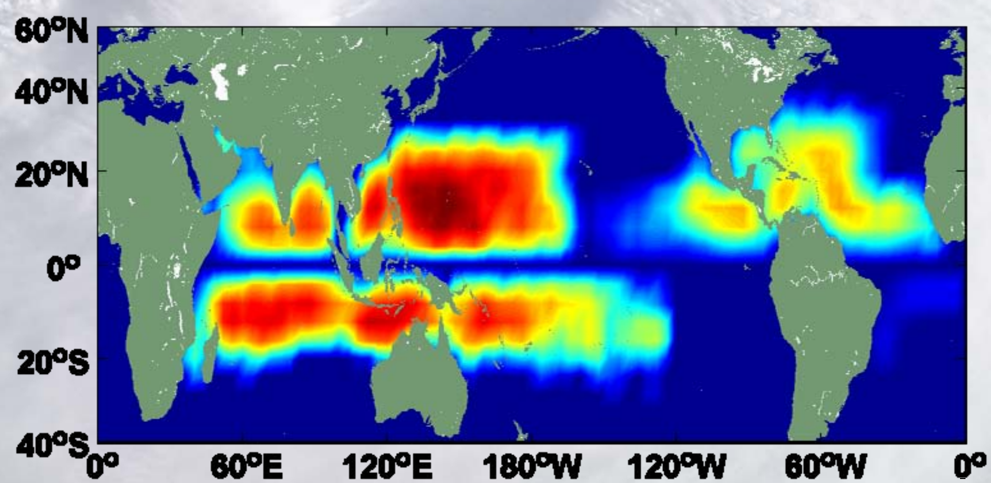




Random Seeding: Complete Independence from Record

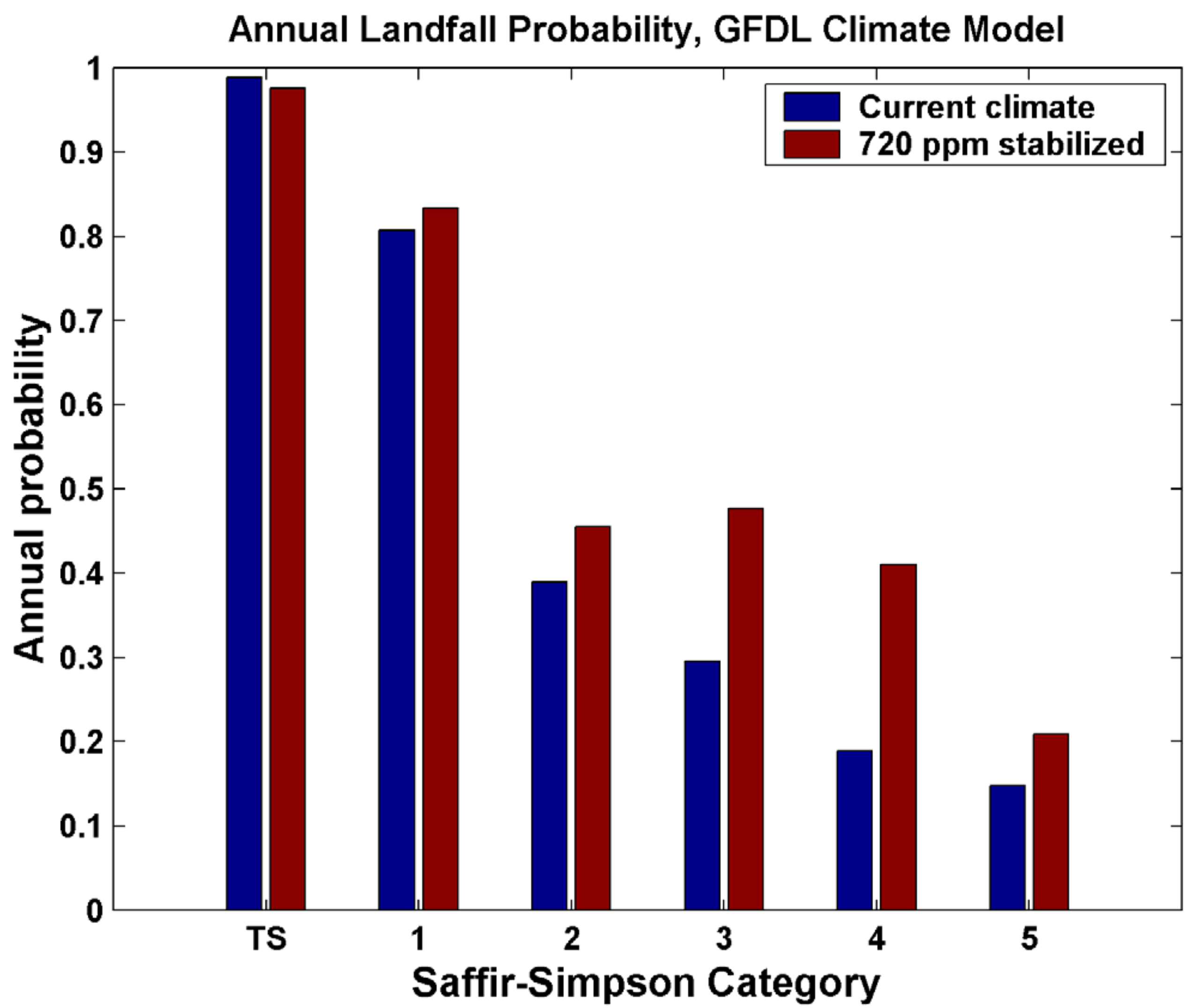


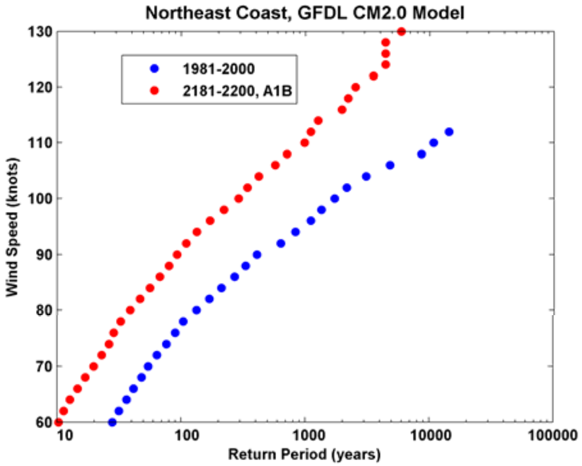
Observed

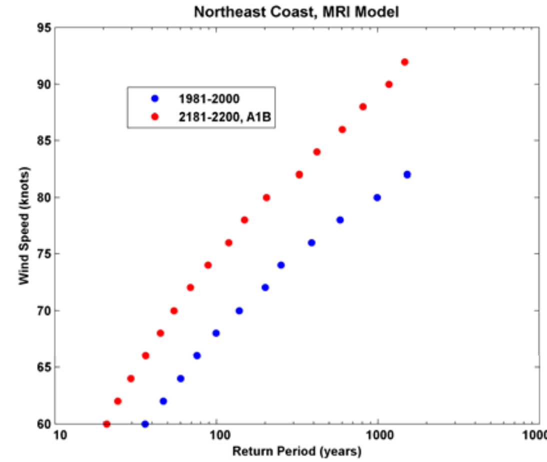


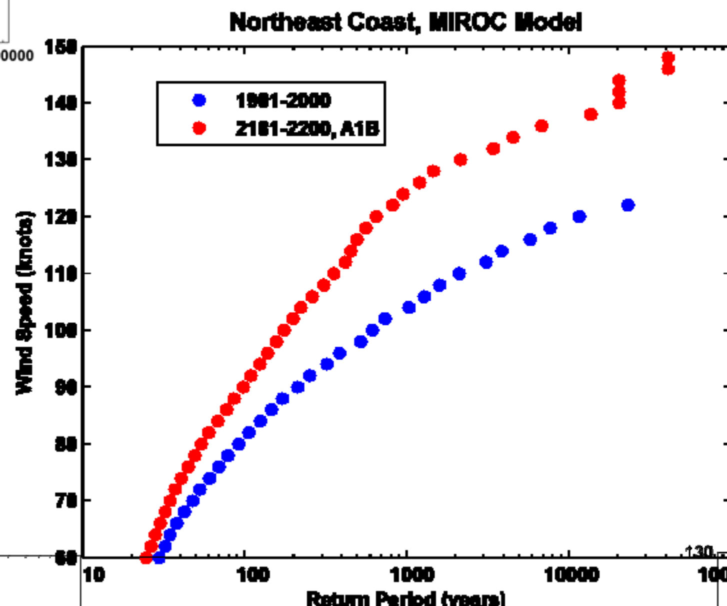
Synthetic

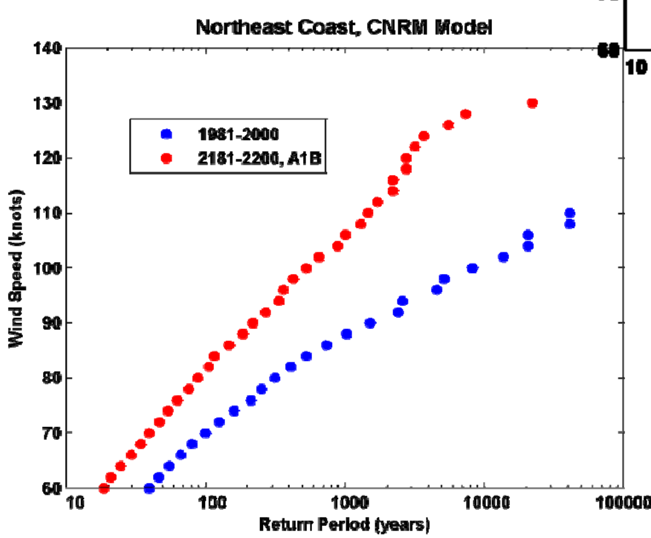
Change in U.S. Landfall Probability, by Category

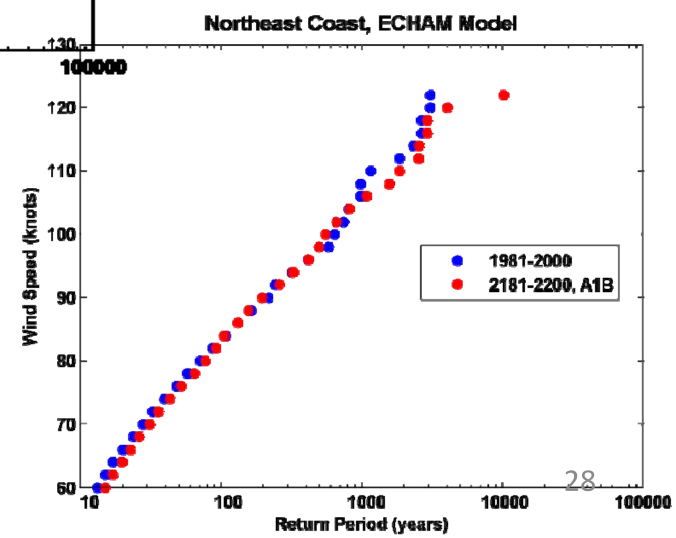



Northeast Coast, GFDL CM2.0 Model
1981-2000
2181-2200, A1B
Wind Speed (knots)
Return Period (years)


Northeast Coast, MRI Model
1981-2000
2181-2200, A1B
Wind Speed (knots)
Return Period (years)


Northeast Coast, MIROC Model
1981-2000
2181-2200, A1B
Wind Speed (knots)
Return Period (years)


Northeast Coast, CNRM Model
1981-2000
2181-2200, A1B
Wind Speed (knots)
Return Period (years)


Northeast Coast, ECHAM Model
1981-2000
2181-2200, A1B
Wind Speed (knots)
Return Period (years)

Summary

- Historical records of hurricane activity are not long enough to make robust estimates of hurricane risk, even in a stable climate
- Regardless of ultimate cause, climate change is clearly affecting hurricane activity
- Physics can be brought to bear to make more robust risk assessments, in this and in future climates
- Global warming poses a serious threat of increased hurricane risk