Climate change and number of Atlantic tropical cyclones

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Outline

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Extremes in changing climate

- In recent years there have been generally evident increases in the number of flooding events, hot spells and tropical cyclones.

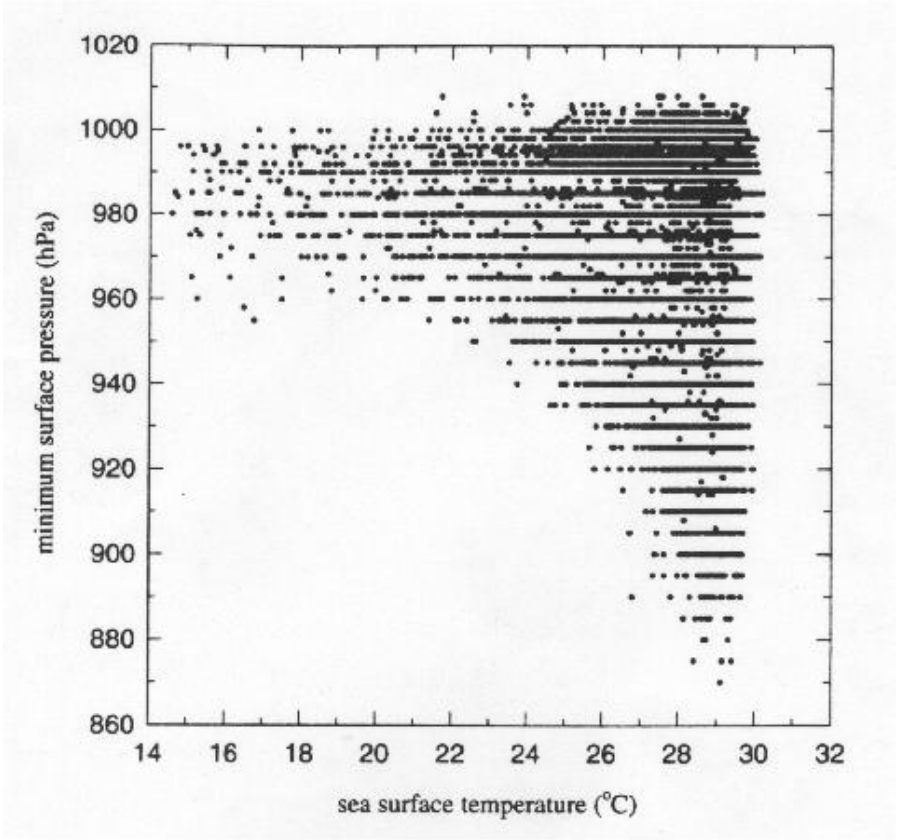
- The economic consequences of changes in frequency of extreme events in weather far outweigh any change in mean climate.

- One of the central questions in climate research is:

Will extreme events be more frequent due to a warmer climate?

Theory

NW Pacific Basin: Intensity vs. SST



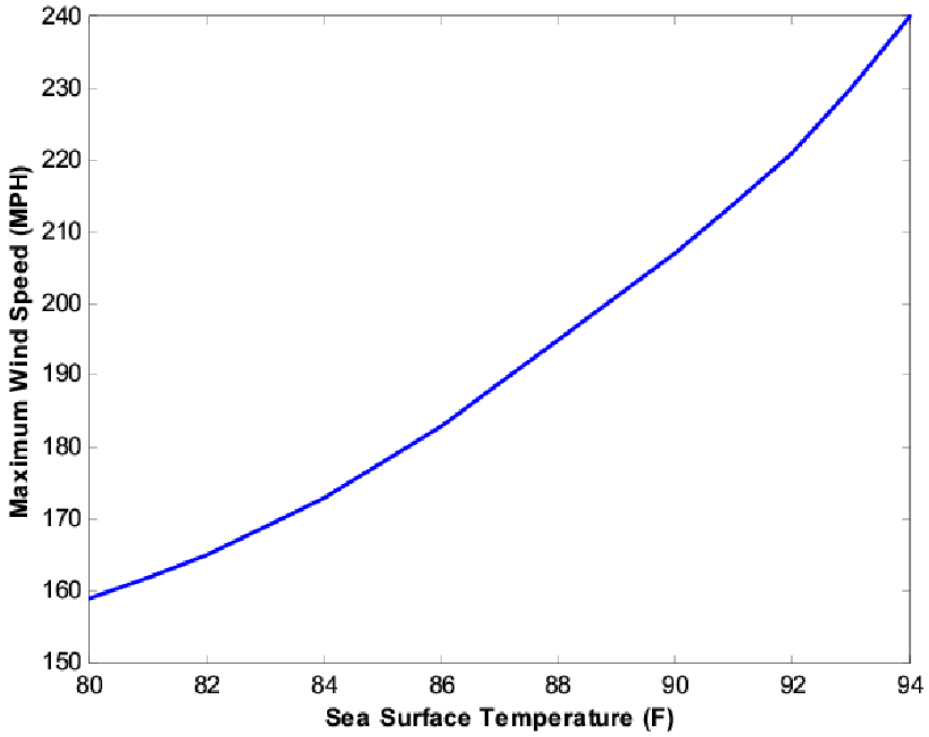
Sea surface temperature (deg C)

The most intense storms occur at high SSTs

Source: Baik and Paek, *J. Meteor. Soc. Japan* (1998).

Theory

Potential Intensity theories simulate an increase in the intensity of hurricanes for higher sea surface temperatures



Source: Kerry Emanuel

What do the models show?

Intensity

- GFDL Model wind speed intensity, V vs SST: ~**4-5% per ºC** (Knutson and Tuleya, 2004)

- Theoretical wind speed intensity, V (hurricane theory) vs SST:
  ~ **8-16 % per ºC** (Emanuel, 2006; Holland, 1997)

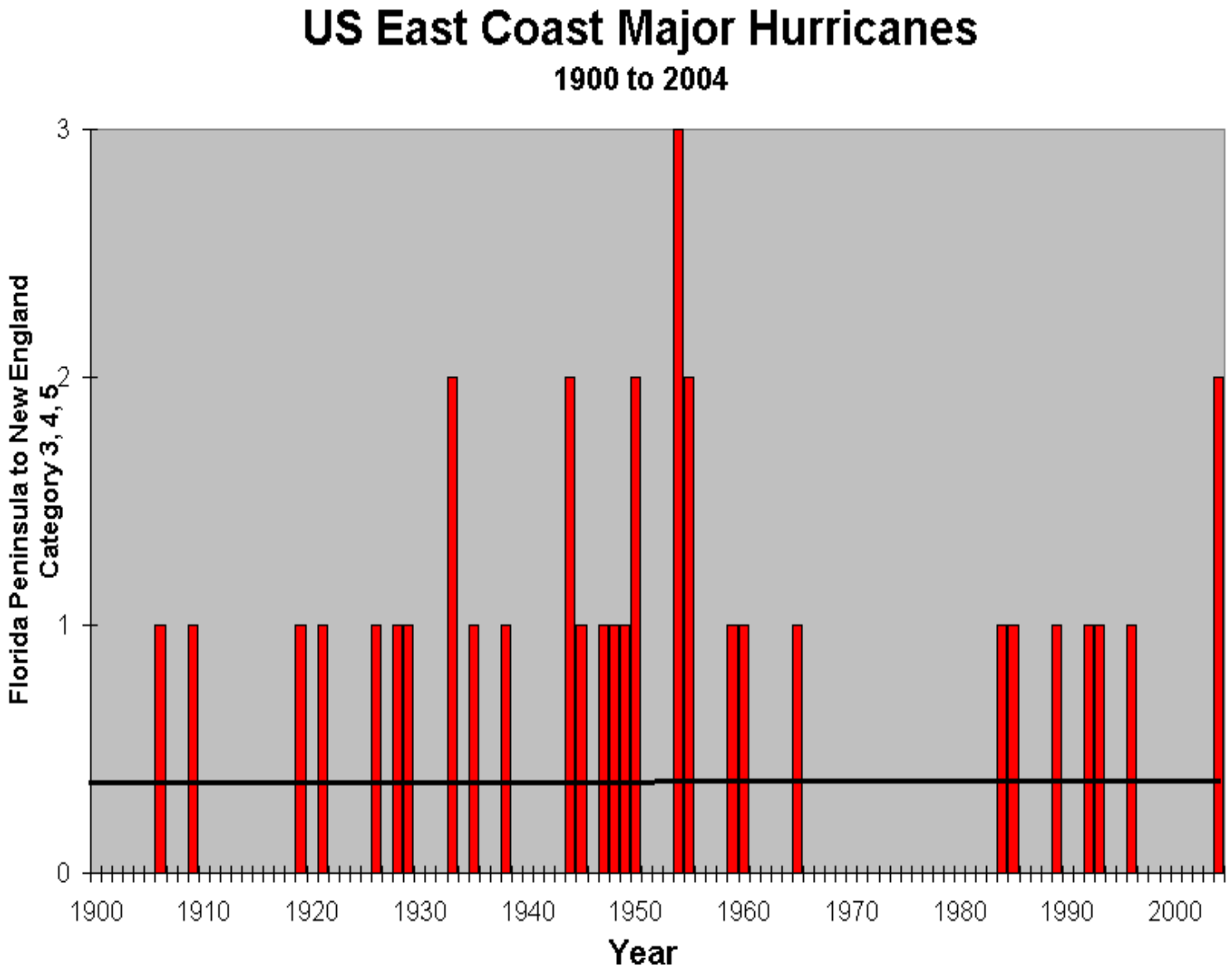
- Observations **????**

  Century-scale data: V increases **~10% per ºC;**

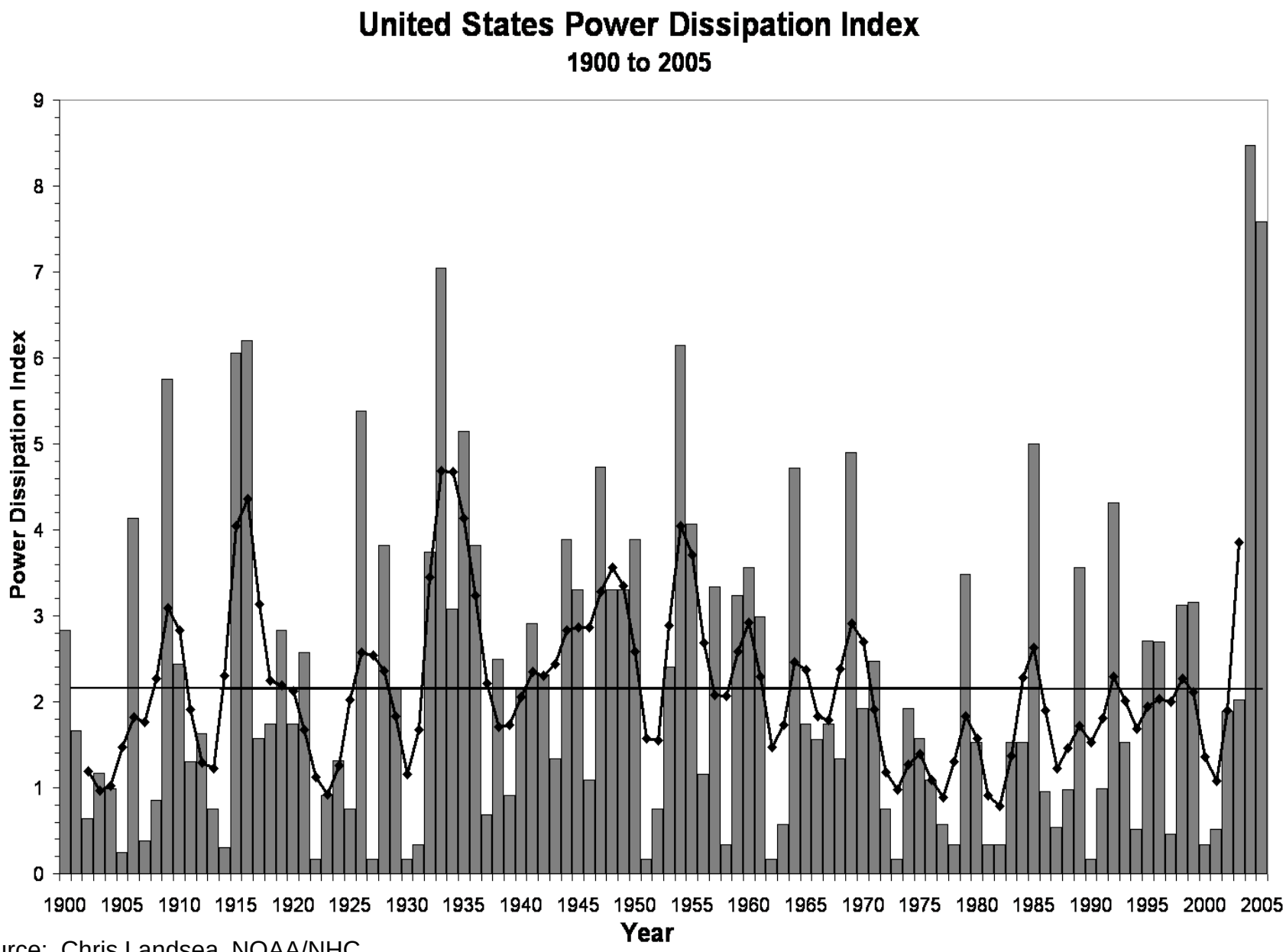
  Data since 1980 only: **~30% per ºC**

Number of tropical cyclones

- reduction of 20% of number of tropical cyclones in 21st century (Bengtsson et al., 2007)
- no changes in frequency



Source: Chris Landsea (NOAA/National Hurricane Center)



Source: Chris Landsea, NOAA/NHC

Tropical cyclones and rising global temperature

The nature of the link between hurricanes and the rising global temperatures is controversial:

1. Links to natural climate variability (e.g. AMO), not climate related changes
   - Goldenberg et al 2001 (Science);

2. Climate change is the main driving force for the increase in tropical cyclones
   - Emanuel 2005 (Nature), Webster et al., 2005 (Science);
   - Landsea 2005; Landsea et al. 2006;
   - Mann and Emanuel 2006;
   - Elsner 2006.

Short summary

- Tropical SSTs (including tropical North Atlantic):
  - Substantial warming (~0.6^{o}C) occurred in 20th century, roughly tracking global mean temperature
  - Substantially greater 21st century warming (~2^{o}C) is anticipated due to anthropogenic forcing (greenhouse gas emissions, etc.)

- Intensity simulations with a high-resolution hurricane prediction model:
  - Maximum intensities increase (roughly 4% -- per deg Celsius SST increase)
  - Reduction of number of tropical cyclones or no changes

- Historical hurricane observations give conflicting information on past trends:
  - Several Atlantic hurricane activity measures are dominated by multi-decadal “cycles” or noise -not trends. Some basin-wide indices show unprecedented levels in recent years.
  - Hurricane intensity sensitivity implied by some studies greatly exceeds that of current model simulation and theory, a discrepancy that remains unresolved at this time.

Motivation

- What is the link between the SST and numbers of tropical cyclones?
- Alternative data
- Need for new statistical methods

Objectives

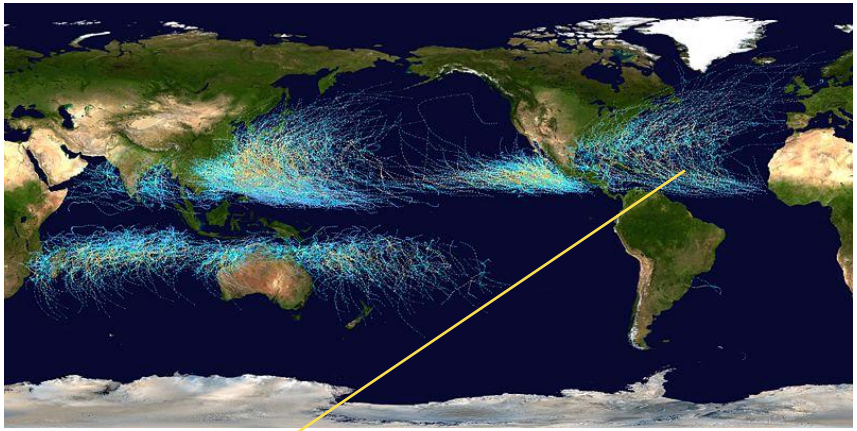
The main objective:

to identify the possible link between the SST and long-term observational record (135 years) of numbers of tropical cyclones using the advanced statistical methods, assuming that relationship most probably is

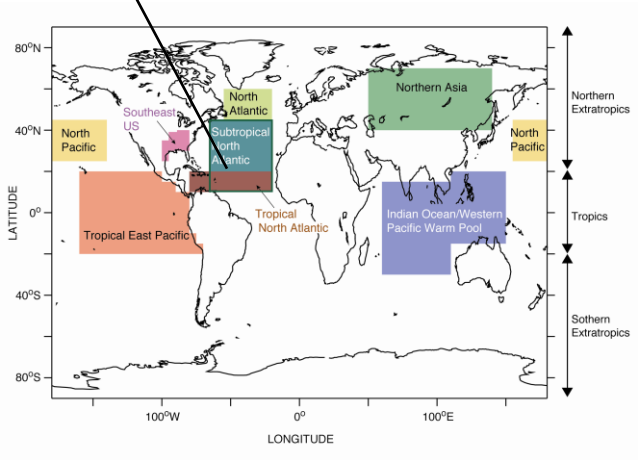
- non-stationary,
- non-linear,
- may be chaotic,
- and as well develop over many years.

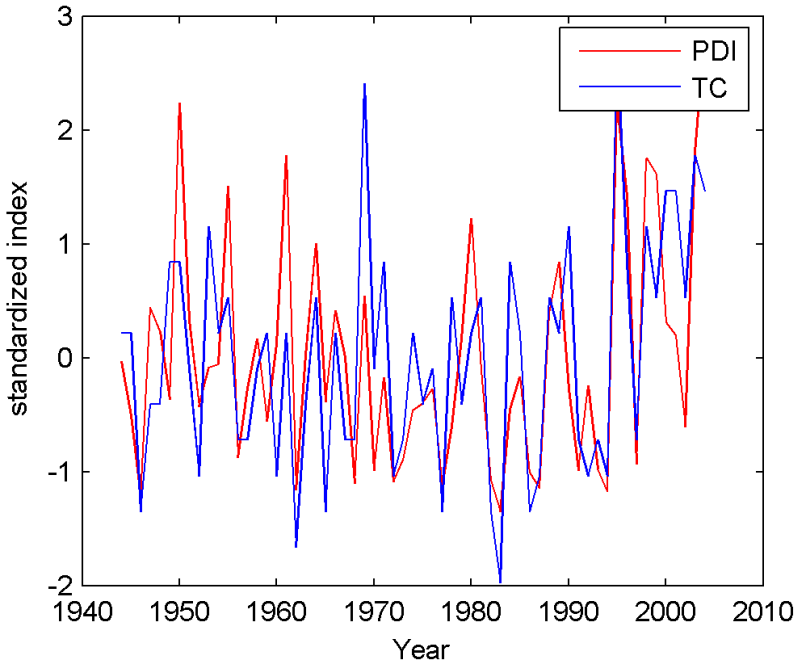
Data

- Numbers of Atlantic tropical cyclones per year (TC), defined as non-frontal, synoptic-scale cyclones over tropical or sub-tropical waters (Jarvinen et al. 2005).
- SSTs for the Atlantic averaged over the area 6-18˚N, 20-60˚W, defined as the cyclone main development region (MDR), during the months of August, September, and October, **(SST_C).**
- HadISST2 data (Rayner et al. 2003) which extends from 1870 to 2004



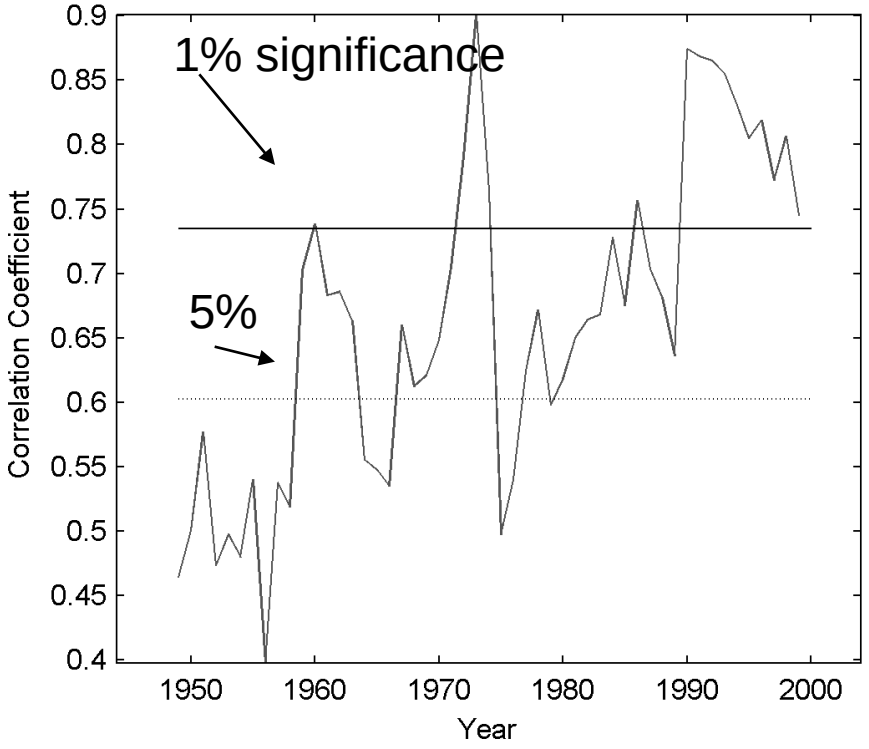
Main Development Region (MDR)





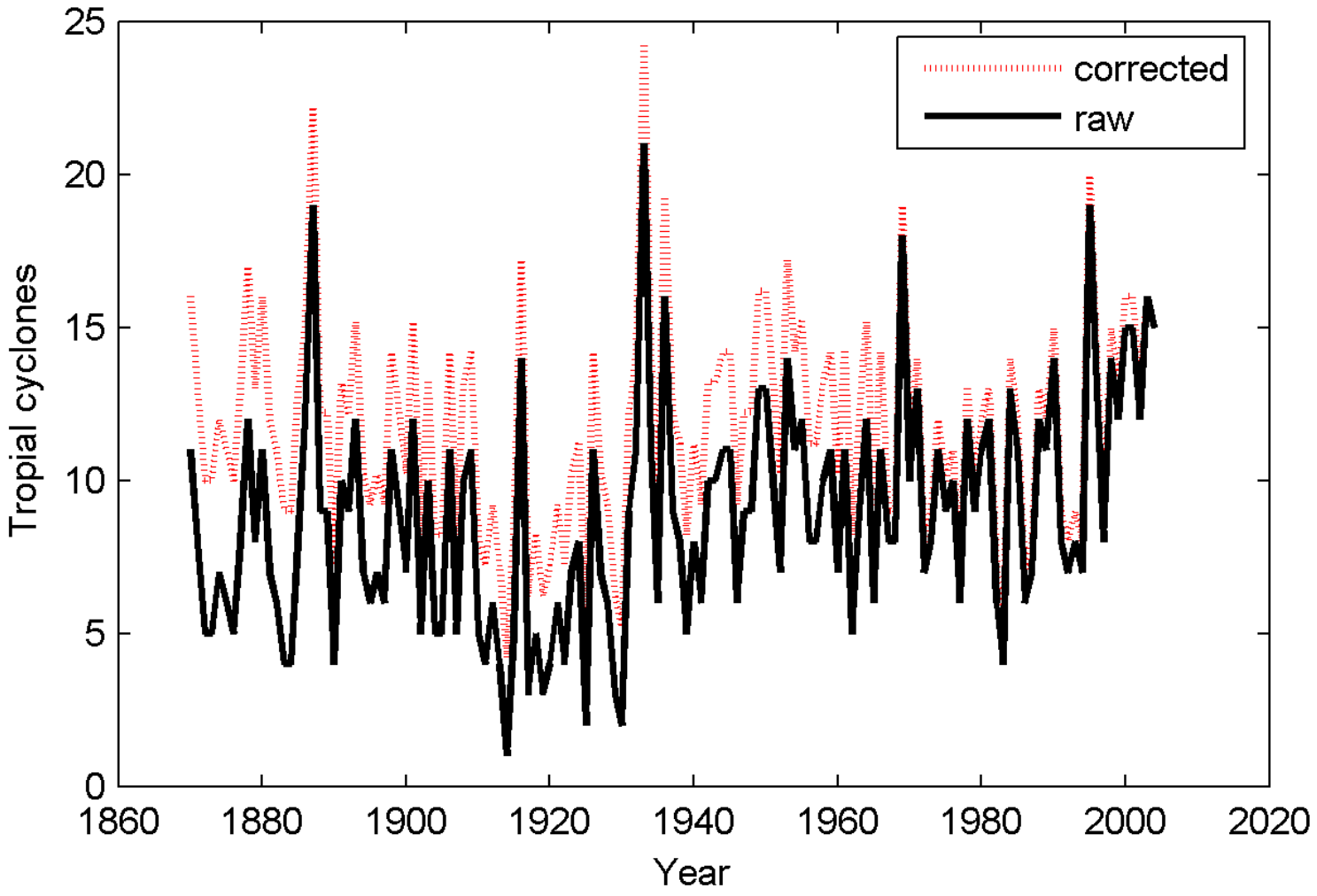
Atlantic tropical cyclone count (TC) and Power Dissipation Index (PDI); correlation coefficient (r=0.7)

Correlation between PDI and TC in 10-year moving windows.



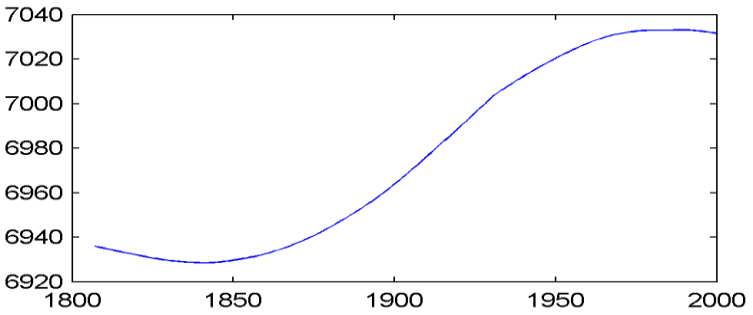
TC extends back to 1851

Historical record of Atlantic tropical cyclones

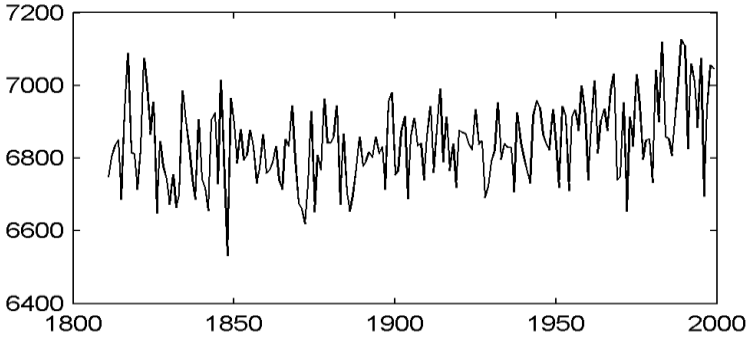


Lots of variability – needs sophisticated analysis

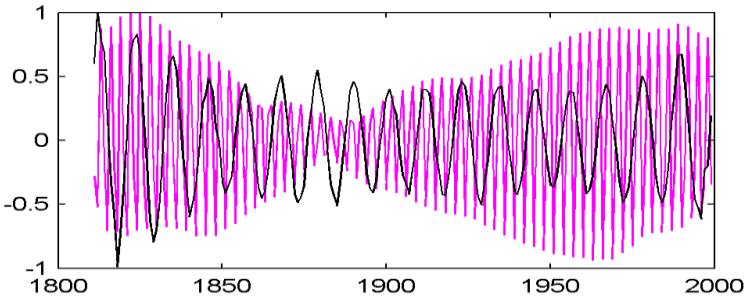
Advanced statistical methods



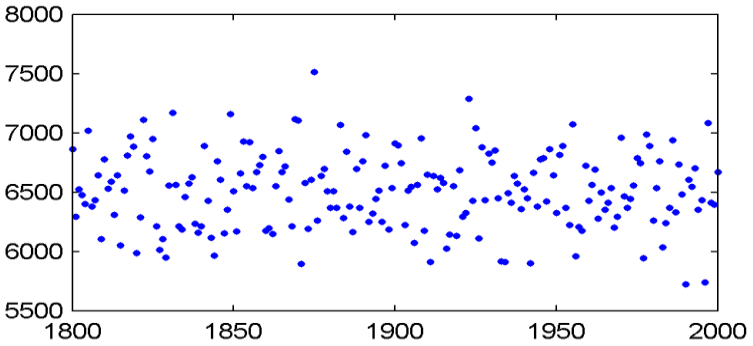
Trend



Original time series



Oscillations



Noise

Methods

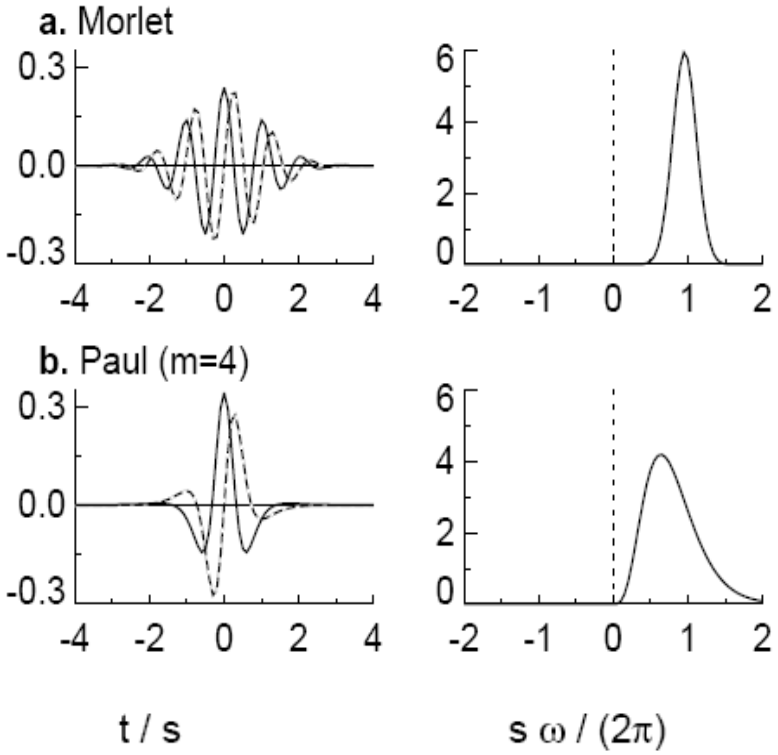
- Granger causality
- Wavelet coherence
- Wavelet lag coherence

Granger-causality

- A variable *X* is said to Granger-cause a variable *Y* if it can be shown that time series values of *X* provide significantly improved predictions of future values of *Y* than predictions based on *Y* alone would.

- Strong Granger-causality, that is the causality relation applies in only one direction. Only one of the two time series appears to be a significant predictor of the other

The methods we use rely on filtering the data using the Continuous Wavelet Transform



$$\psi_0(\eta) = \pi^{-1/4} e^{i\omega_0\eta} e^{-\frac{1}{2}\eta^2}$$

Useful for the wavelet coherence as scales are similar sizes in period and time

$$\psi_0(\eta) = \frac{2^m i^m !}{\sqrt{\pi(2m)!}} (1 - i\eta)^{-(m+1)}$$

Useful for broad-band filtering - ami and phase coherence tests. Fourier wavelength, $\lambda = 4\pi s/(2m+1)$

Wavelet Coherence

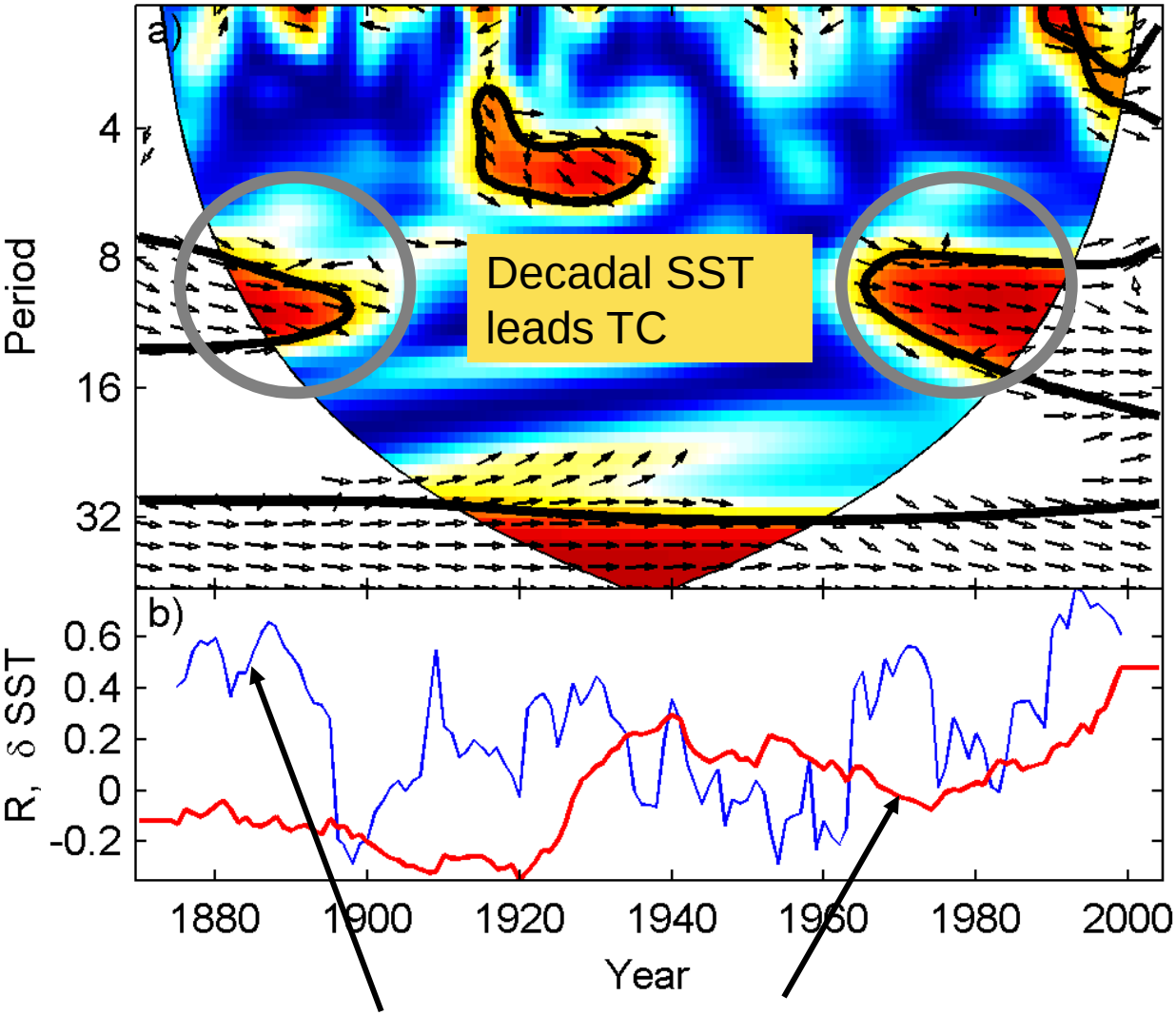
- The definition of wavelet coherence closely resembles that of a traditional correlation coefficient, and it is useful to think of it as a localized correlation coefficient in time frequency space.

- Wavelet coherence gives relative phase relationships between two time series over a wide spectrum of temporal scales

- Morlet wavelet provides good balance between time and frequency localization.

Jevrejeva et al., 2003; Grinsted et al., 2004;

http://www.pol.ac.uk/home/research/waveletcoherence/



Wavelet coherence between SST_C and TC

5% significance level against red noise

Relative phase relationship

In-phase →

SST_C leading TC by 90º ↓

Running correlation (blue), and SST_C anomaly (red) 10 year windows.

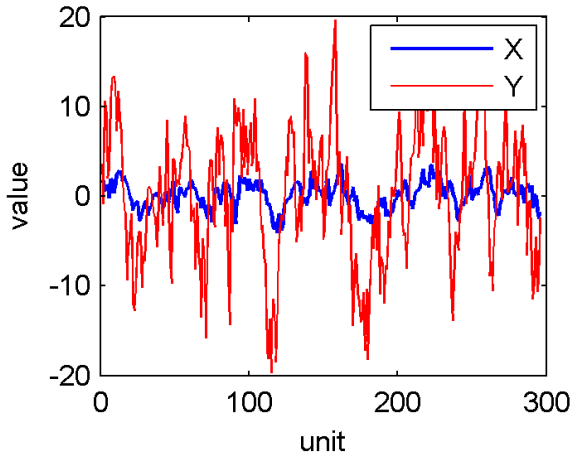
Wavelet lag coherence

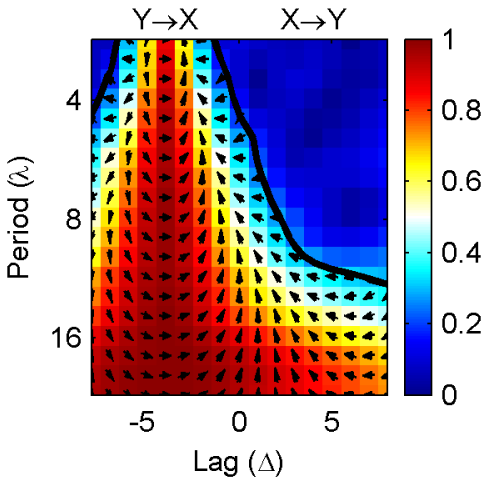
- A measure of coherence between two time series ***X*** and ***Y*** with respective phases **φ** and ***θ*** is the angle strength of the phase angle difference between the series, **ρ** (mean phase coherence):

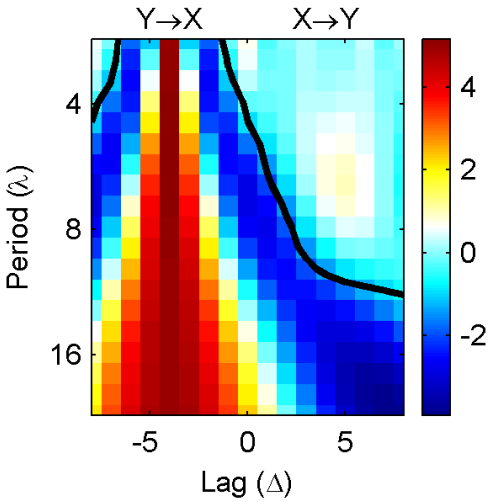
$$\rho = \frac{1}{N}\sqrt{\left(\sum_{t=1}^{N}\cos(\phi_t - \theta_t)\right)^2 + \left(\sum_{t=1}^{N}\sin(\phi_t - \theta_t)\right)^2}$$

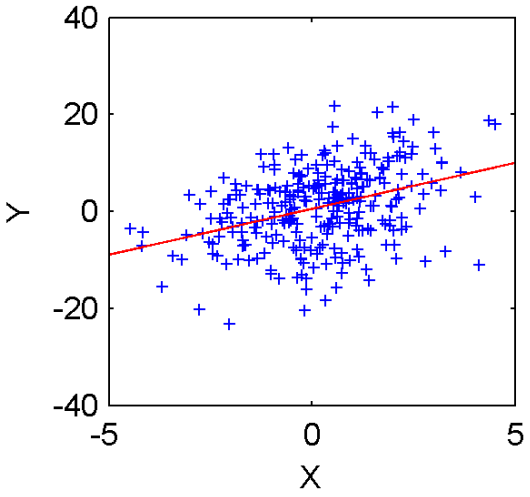
- This is a measure of the variability in the phase lag between ***X*** and ***Y***.

Wavelet Lag Coherence - Example









$Y = 1.9X + 0.61$

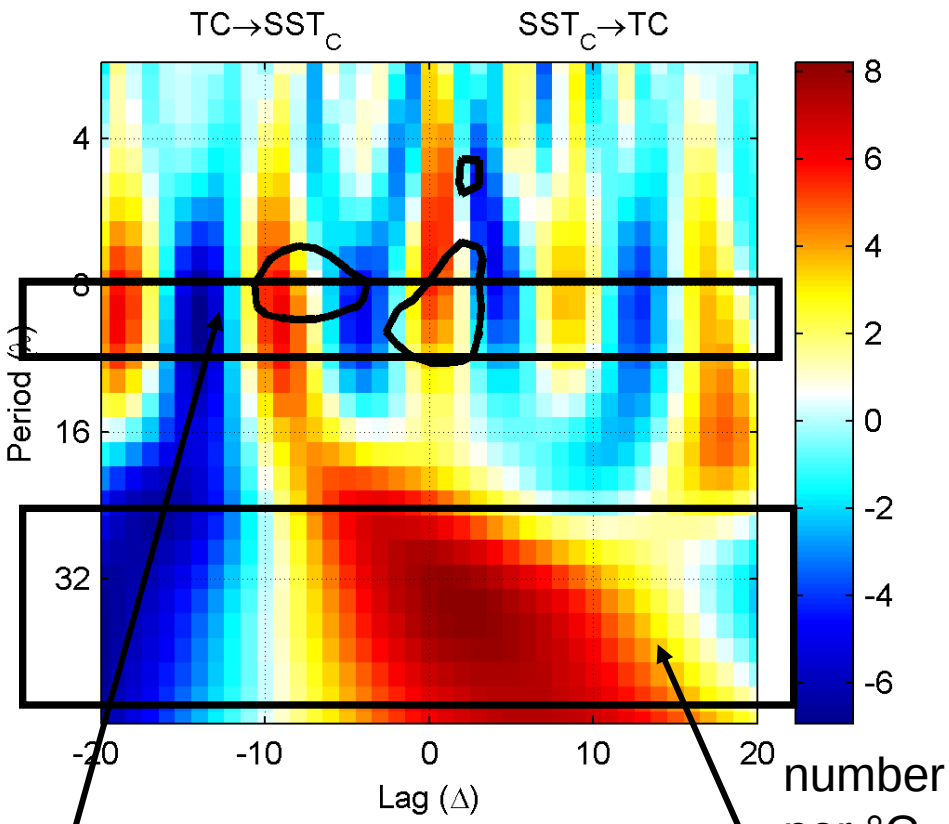
Wavelet lag coherence plot showing values of mean phase coherence (ρ) and its 95% confidence interval.

Arrows point to the right at a lag of -4 indicating that is when *X* and *Y* are in phase at all λ.

Sensitivity, *m*, in the equation $W_Y(\lambda,t+\Delta) = m\, W_X(\lambda,t)$.

Value of *m* =5 at a lag of -4 for all λ.

The confidence interval shown is that for ρ, as this is where the values of *m* have true predictive value.

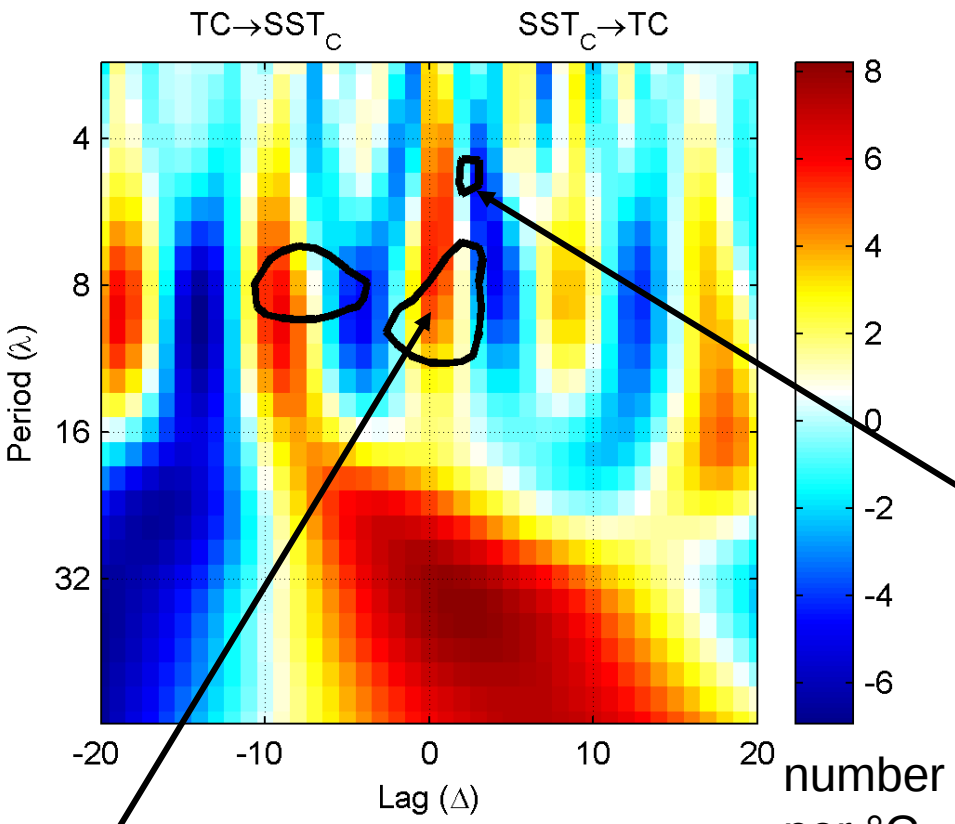


TC sensitivity on SST_C

Consistent that global temperatures drive PDI and TC (Mann and Emanuel 2006; Elsner 2006). This also contradicts the suggestion (Goldenberg et al. 2001) that long-period Atlantic cyclicity is a significant hurricane forcing mechanism

Decadal signal dominates

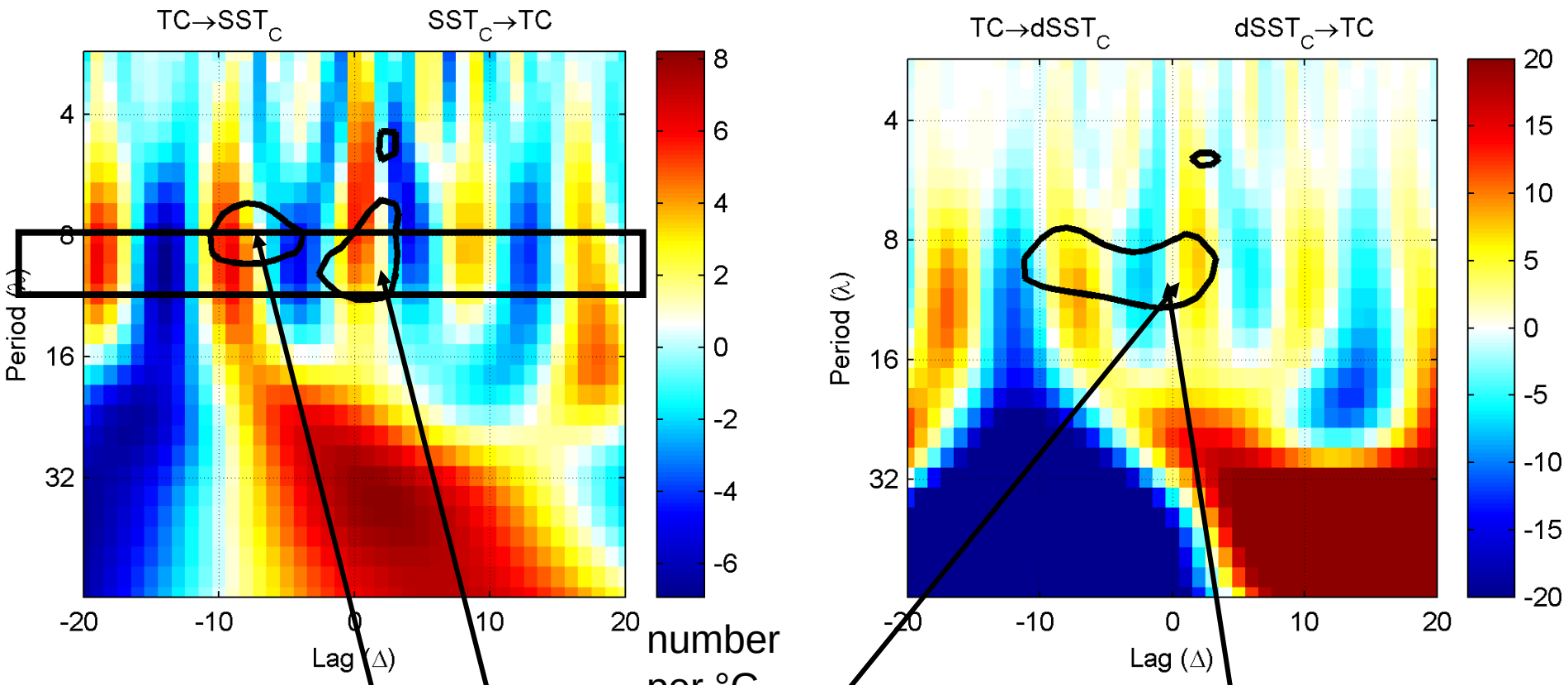
At long periods which should be related to the Atlantic Multidecadal Oscillation (AMO), there is no significant region of ρ



TC sensitivity on SST_C

5-year period:
negative *m*

Decadal signal:
positive *m*



number per °C

TC sensitivity on SST_C

TC sensitivity on $d(SST_C)/dt$

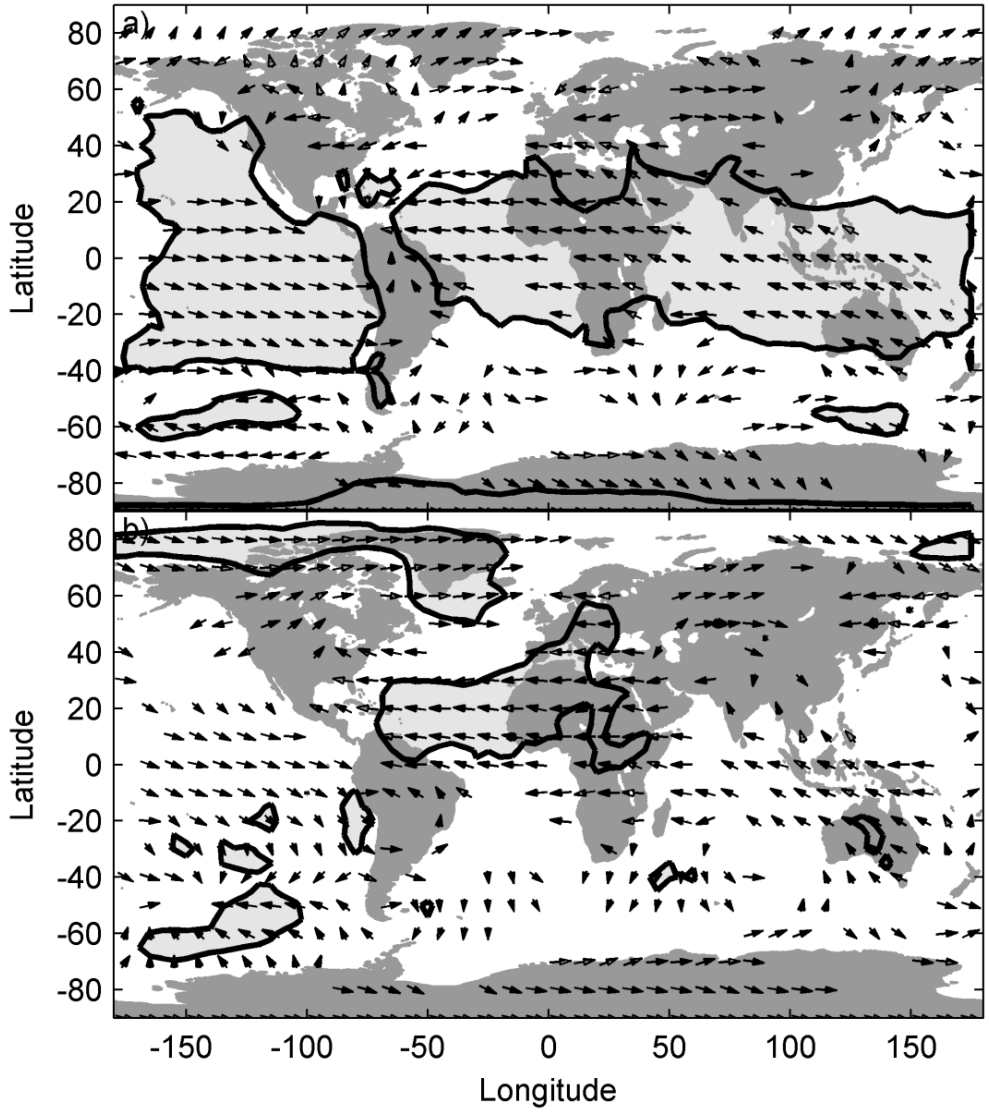
Decadal signal dominates

– but complex signal. Is TC driving SST_C?

+ & - *m* ?

m=0 at Δ=0

Negative Feedback between TC and SST_C

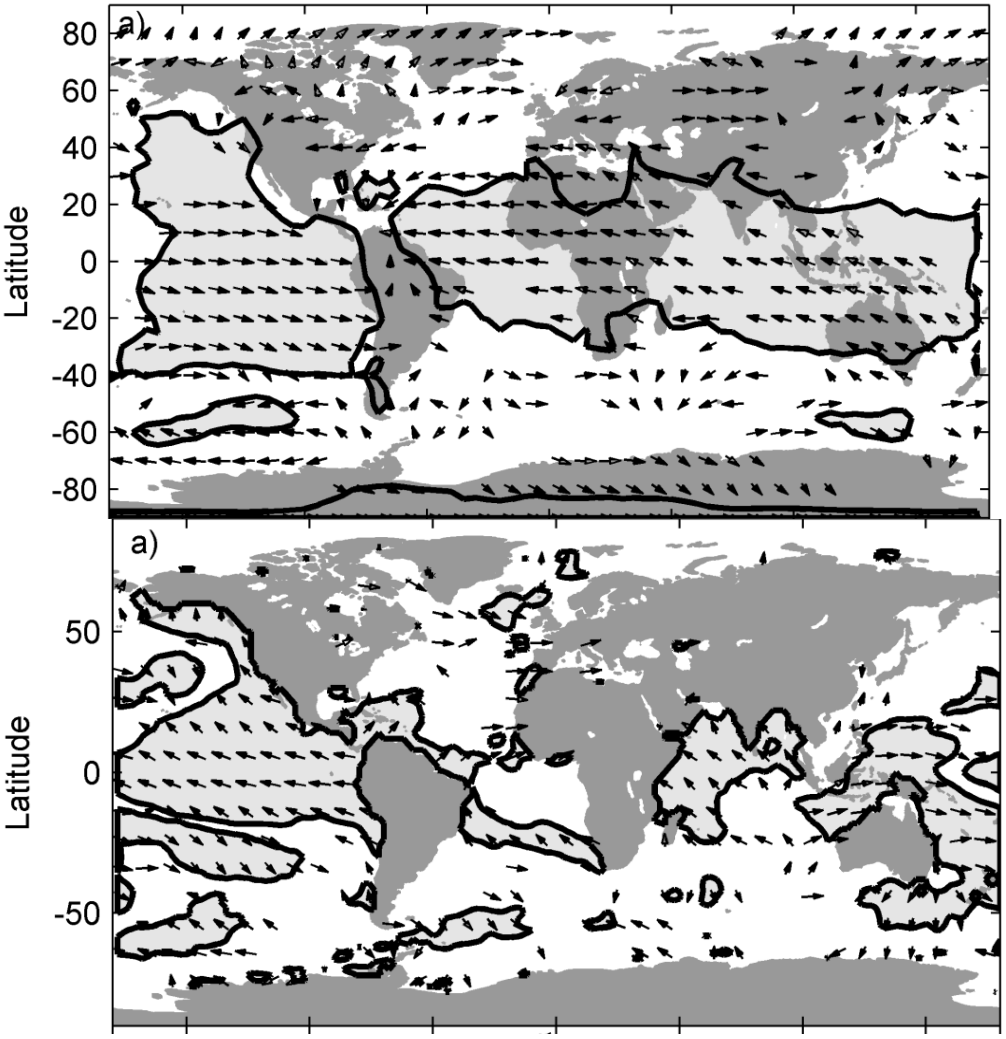


Link to Global SST

5-year periods

Decadal periods

Phase-aware teleconnections between TC and global SST 1870 to 2004



5 year periods

Phase-aware teleconnections between TC

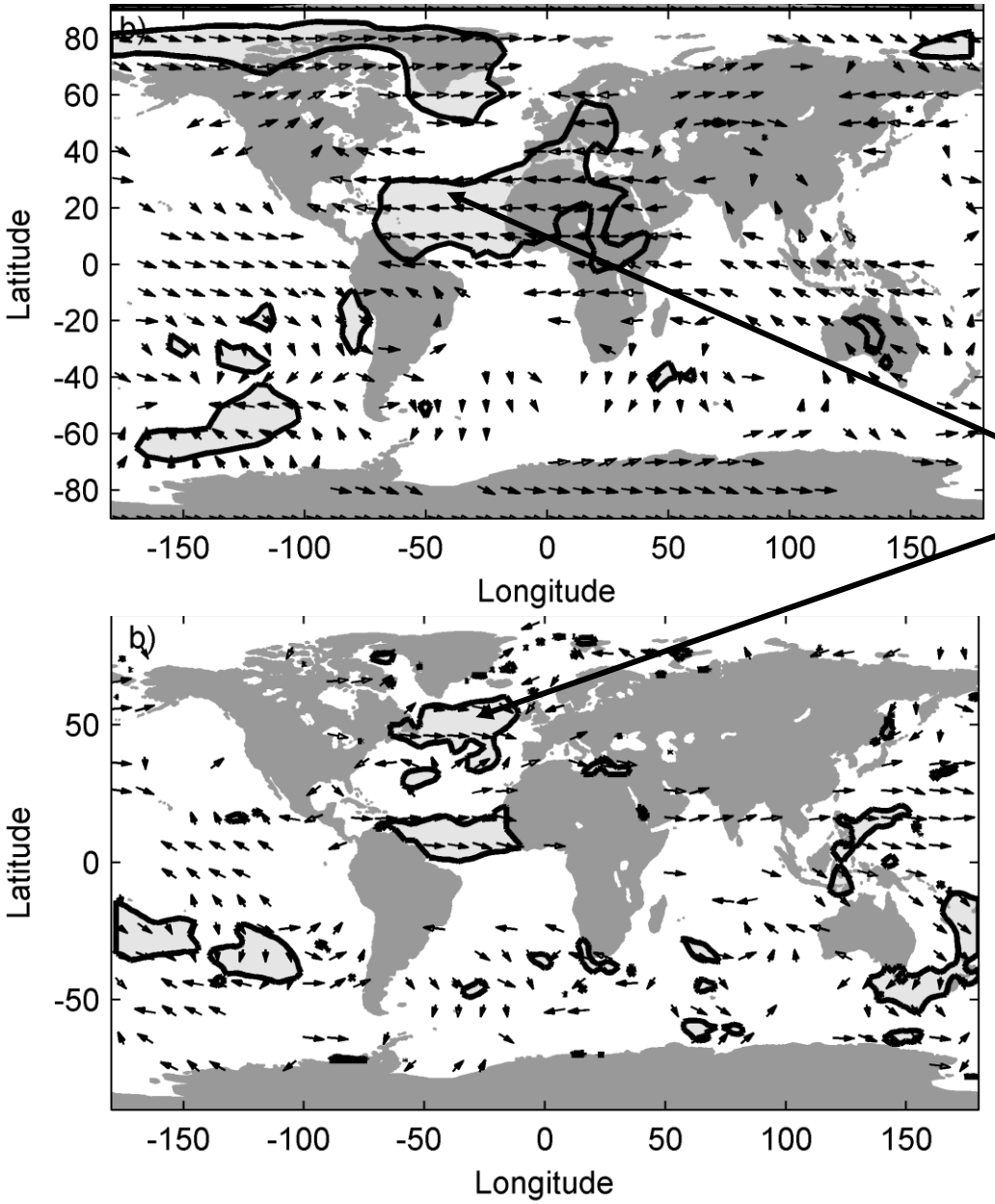
SST

SLP

Tropics:
ENSO-like pattern

Well-known ENSO impact on Atlantic tropical cyclones Gray (1984), Wang et al (2006)

Decadal periods



Phase-aware teleconnections between TC

SST

Gulf Stream, North Atlantic Drift pattern of variability

SLP

Gulf Stream meandering has 7.8 year periodicity (Dijkstra and Ghil 2005)

Conclusions

- The there is a link between the SST and TC via 5 – year and 10-year variability.
- 5- year variability links to ENSO activity and increasing numbers of El Nino cause the reduction of tropical cyclones in North Atlantic
- Decadal variability in SST is mostly associated with North Atlantic variability (heat transport by the Gulf Stream) and it is a dominant factor for increase of TC
- This increase of TC is enhanced when the Gulf Stream is effectively exporting less heat northwards from the cyclone main development area than in previous decades.

For more information

"Gulf Stream and ENSO increase the temperature sensitivity of Atlantic tropical cyclones", *Journal of Climate (In print)*

"Wavelet-lag regression analysis of Atlantic tropical cyclones and snow cover and their dependence on ENSO and Atlantic thermohaline variability", JGR (in review)