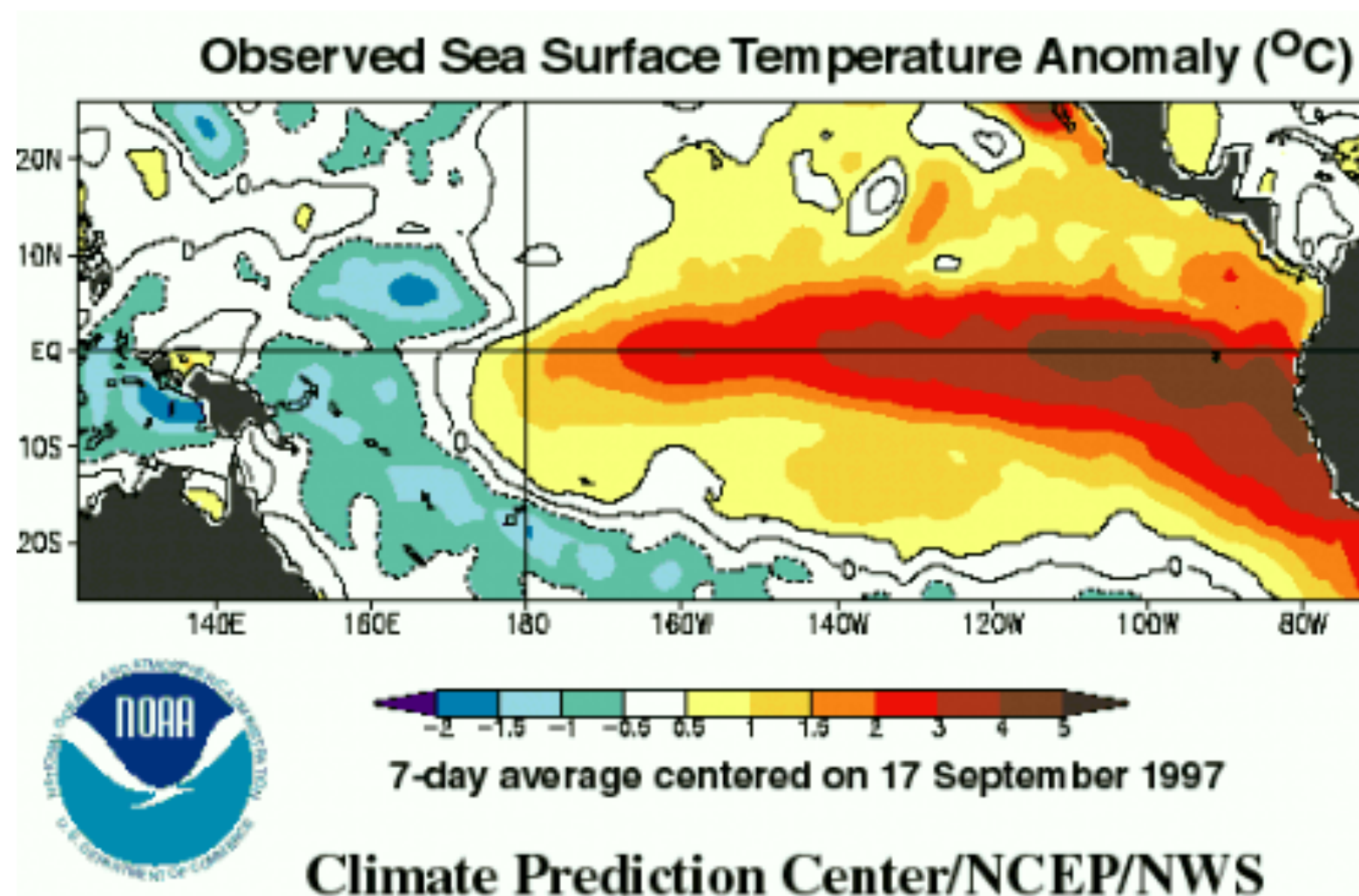


Air-sea interaction: Hurricane/Typhoon2

ATM2106

Hurricanes and El Nino

- El Nino: warmer sea surface temperature in the eastern equatorial Pacific Ocean



Eastern Pacific hurricanes

- During 1980-2010
 - 15.4 named storms on average
 - 8.4 hurricanes
 - 3.9 major hurricanes (category 3 and above)

Measuring overall activity: ACE index

- The Accumulated Cyclone Energy (ACE) index
 - Represents the wind energy
 - Defined as the sum of u_{\max}^2 every six hours for all eastern Pacific named system
 - The mean ACE from 1981 to 2010 is $113.3 \times 10^4 \text{ kt}^2$
 - The median ACE from 1981 to 2010 is $100.4 \times 10^4 \text{ kt}^2$

Classifications for the eastern Pacific hurricane season

- **Above-normal season :**

- An ACE index above $115 \times 10^4 \text{ kt}^2$

AND

- at least two of the following three conditions:
 - Named storms ≥ 17
 - Hurricanes ≥ 9
 - Major hurricanes ≥ 5

Classifications for the eastern Pacific hurricane season

- **Near-normal season :**

- $80 \times 10^4 \text{ kt}^2 \leq \text{An ACE index} \leq 115 \times 10^4 \text{ kt}^2$

OR

- An ACE index $\geq 115 \times 10^4 \text{ kt}^2$ but less than two of the following three conditions:
 - Named storms ≥ 17
 - Hurricanes ≥ 9
 - Major hurricanes ≥ 5

Classifications for the eastern Pacific hurricane season

- **Below-normal season :**
 - An ACE index $\leq 80 \times 10^4 \text{ kt}^2$

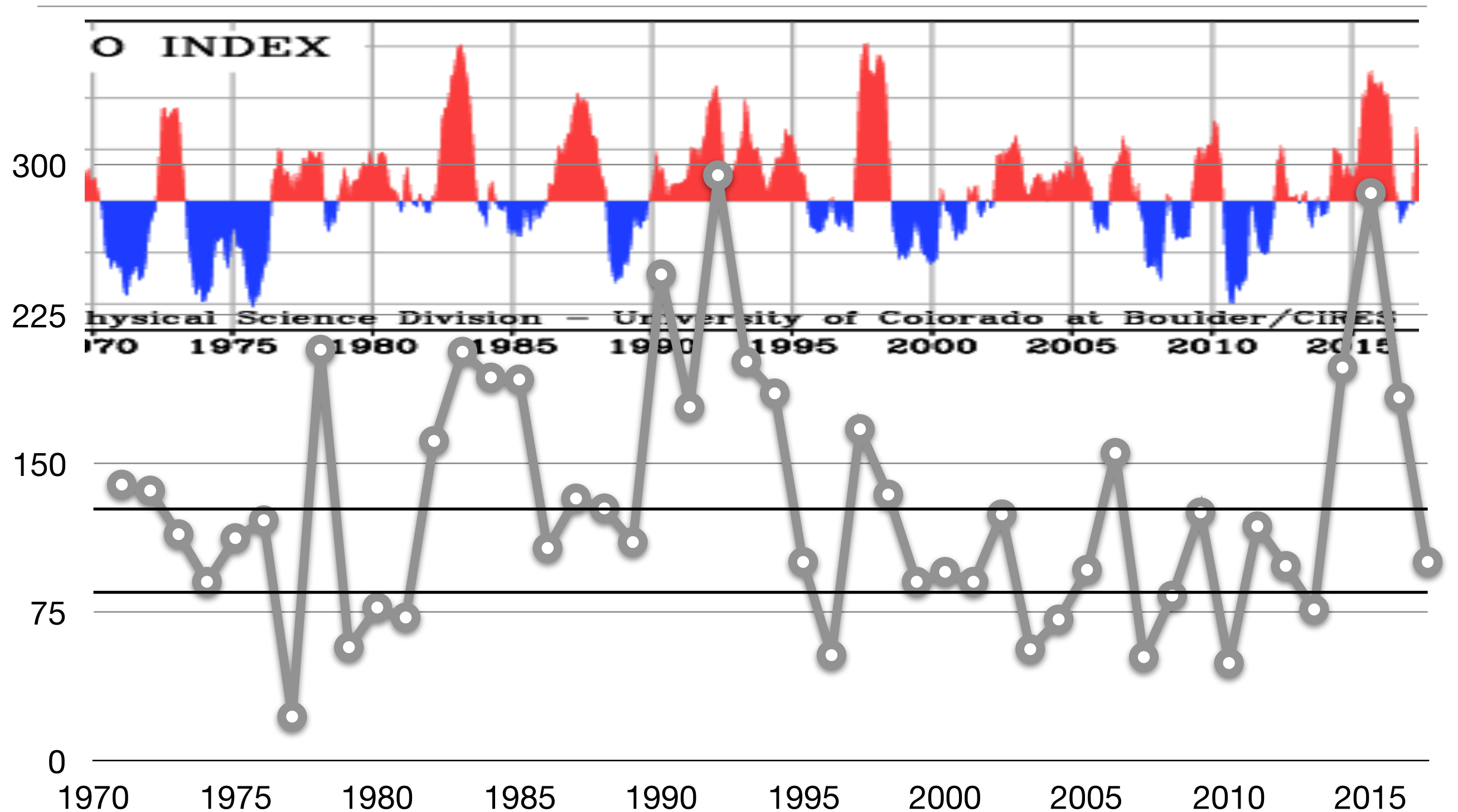
Classifications for the eastern Pacific hurricane season

Season type	Mean # of tropical storm	Range of tropical storm	Mean # of hurricanes	Range of Hurricanes	Mean # of major hurricanes	Range of major hurricanes
Below-normal	12.4	7 ~ 17	6.0	3 ~ 8	1.7	0 ~ 4
Near-normal	15.4	10 ~ 18	7.6	6 ~ 9	3.2	2 ~ 5
Above-normal	18.2	13 ~ 24	11.2	9 ~ 16	6.4	4 ~ 8
All seasons	15.4	7 ~ 25	8.4	3 ~ 16	3.9	0 ~ 9

Eastern Pacific hurricanes and ENSO

- El Nino \implies favorable condition for hurricanes
 - The shift of Hadley circulation to the east
 - Weakening of Walker circulation
 - Reduction of the upper level winds and vertical wind shear
 - Warmer than normal sea surface temperature
- La Nina \implies not favorable for the hurricane formation
 - Increased vertical wind shear
 - Cooler SST

The time series of the ACE index



Classifications for the eastern Pacific hurricane season by ENSO status

Season type	Mean # of tropical storm	Range of tropical storm	Mean # of hurricanes	Range of Hurricanes	Mean # of major hurricanes	Range of major hurricanes
La Nina	13.1	7 ~ 22	6.4	3 ~ 11	3.0	1 ~ 7
Neutral	16.3	9 ~ 24	9.3	5 ~ 16	4.0	0 ~ 8
El Nino	15.4	12 ~ 19	8.4	6 ~ 11	4.4	3 ~ 7

The ENSO impacts can be strongly influenced by the background climate patterns.

2015 Pacific hurricane season

- 26 named storms,
- 16 hurricanes (record high)
- 11 major hurricanes (record high)
- The second most season according to the ACE index
- Three category-4 hurricanes at the same time (for the first time!)
- Hurricane Patricia : The most intense hurricane ever recorded in this region
- El Nino was attributed to the high hurricane activities.

Atlantic hurricanes

- During 1981-2010
 - 12.1 named storms on average
 - 6.4 hurricanes
 - 2.7 major hurricanes (category 3 and above)

Classifications for the Atlantic hurricane season

- **Above-normal season :**

- An ACE index above $111 \times 10^4 \text{ kt}^2$

AND

- at least two of the following three conditions:
 - Named storms ≥ 13
 - Hurricanes ≥ 7
 - Major hurricanes ≥ 3

Classifications for the Atlantic hurricane season

- **Below-normal season :**

- An ACE index $\leq 66 \times 10^4 \text{ kt}^2$

OR

- An ACE index above 71.4% of the median ACE and all three conditions are met:
 - Named storms ≤ 9
 - Hurricanes ≤ 4
 - Major hurricanes ≤ 1

Classifications for the Atlantic hurricane season

- **Near-normal season :**
 - $66 \times 10^4 \text{ kt}^2 \leq \text{An ACE index} \leq 111 \times 10^4 \text{ kt}^2$

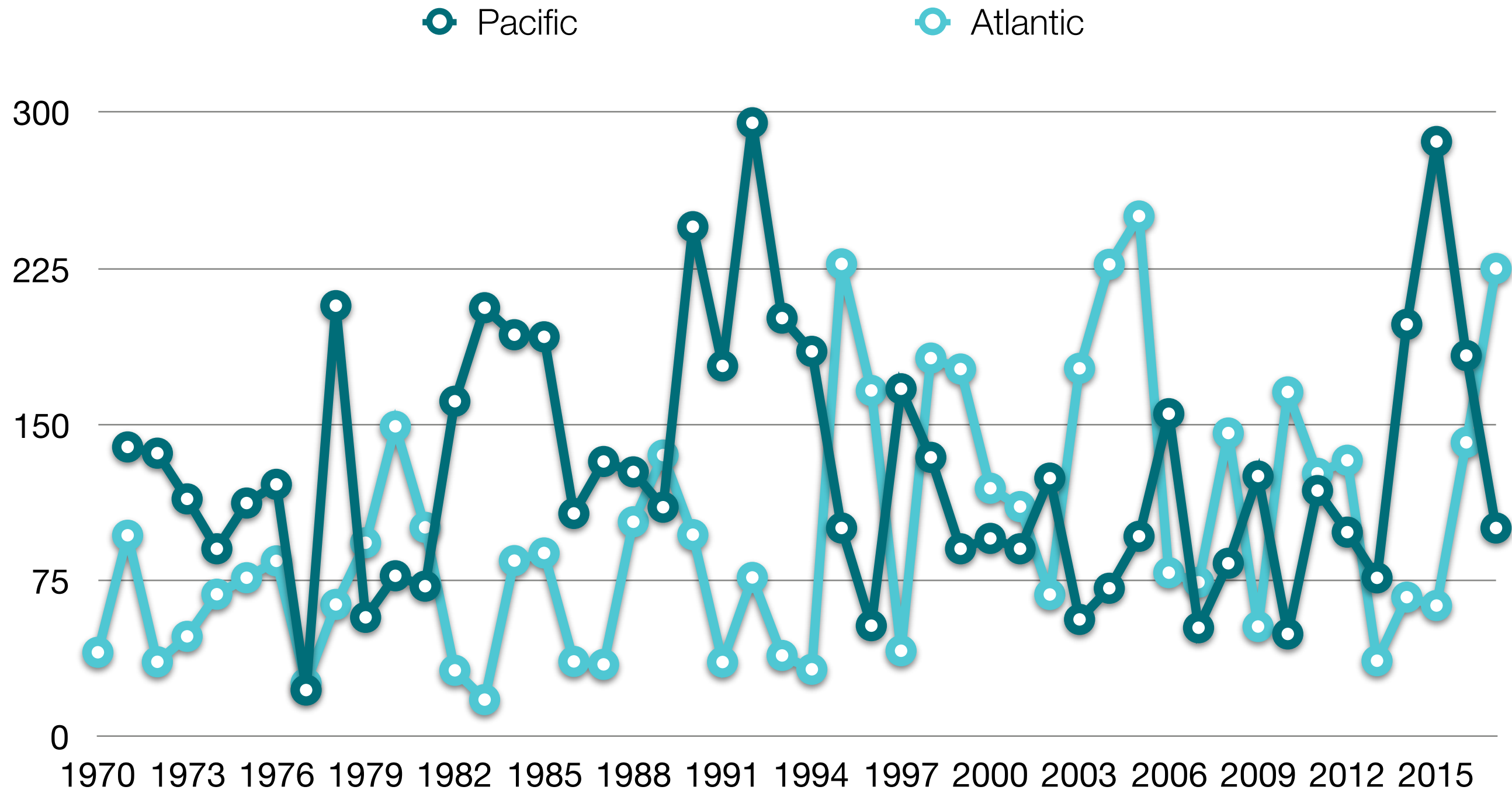
Classifications for the Atlantic hurricane season

Season type	Mean # of tropical storm	Range of tropical storm	Mean # of hurricanes	Range of Hurricanes	Mean # of major hurricanes	Range of major hurricanes
Above-normal	16.5	12 ~ 28	9.7	7 ~ 15	4.8	3 ~ 7
Near-normal	12.3	10 ~ 15	6.3	4 ~ 9	2.3	1 ~ 4
Below-normal	6.7	4 ~ 9	3.3	2 ~ 4	1.0	0 ~ 2
All seasons	12.1	4 ~ 28	6.4	2 ~ 15	2.7	0 ~ 7

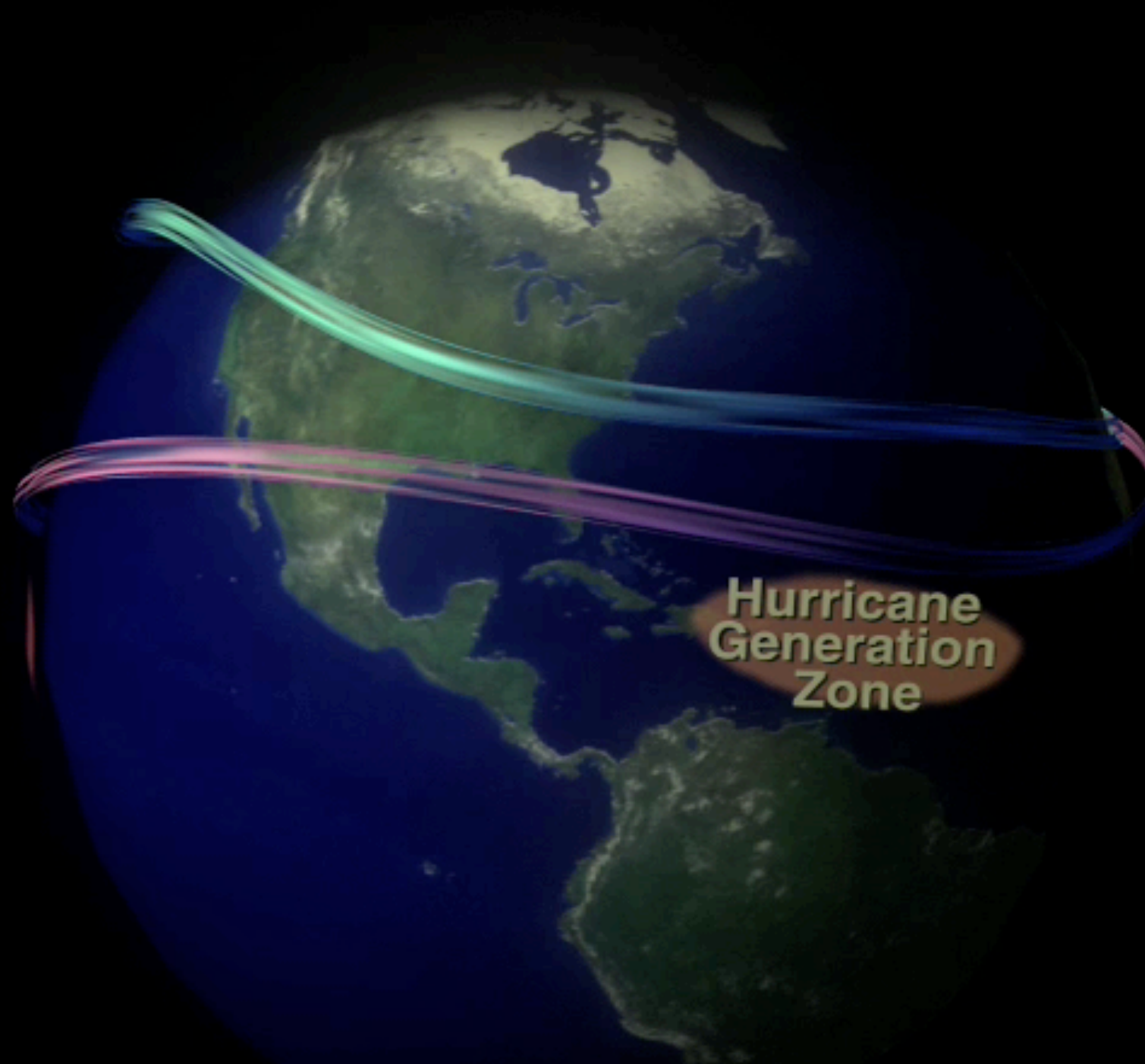
Atlantic hurricanes and ENSO

- El Nino: less favorable condition for the hurricane genesis
 - A shift of Hadley and Walker circulations changes the upper-level winds
 - Wind aloft increases, leading to stronger vertical wind shear which inhibits tropical cyclone genesis and intensification
- La Nina: more favorable condition for the hurricane genesis

The time series of the ACE index

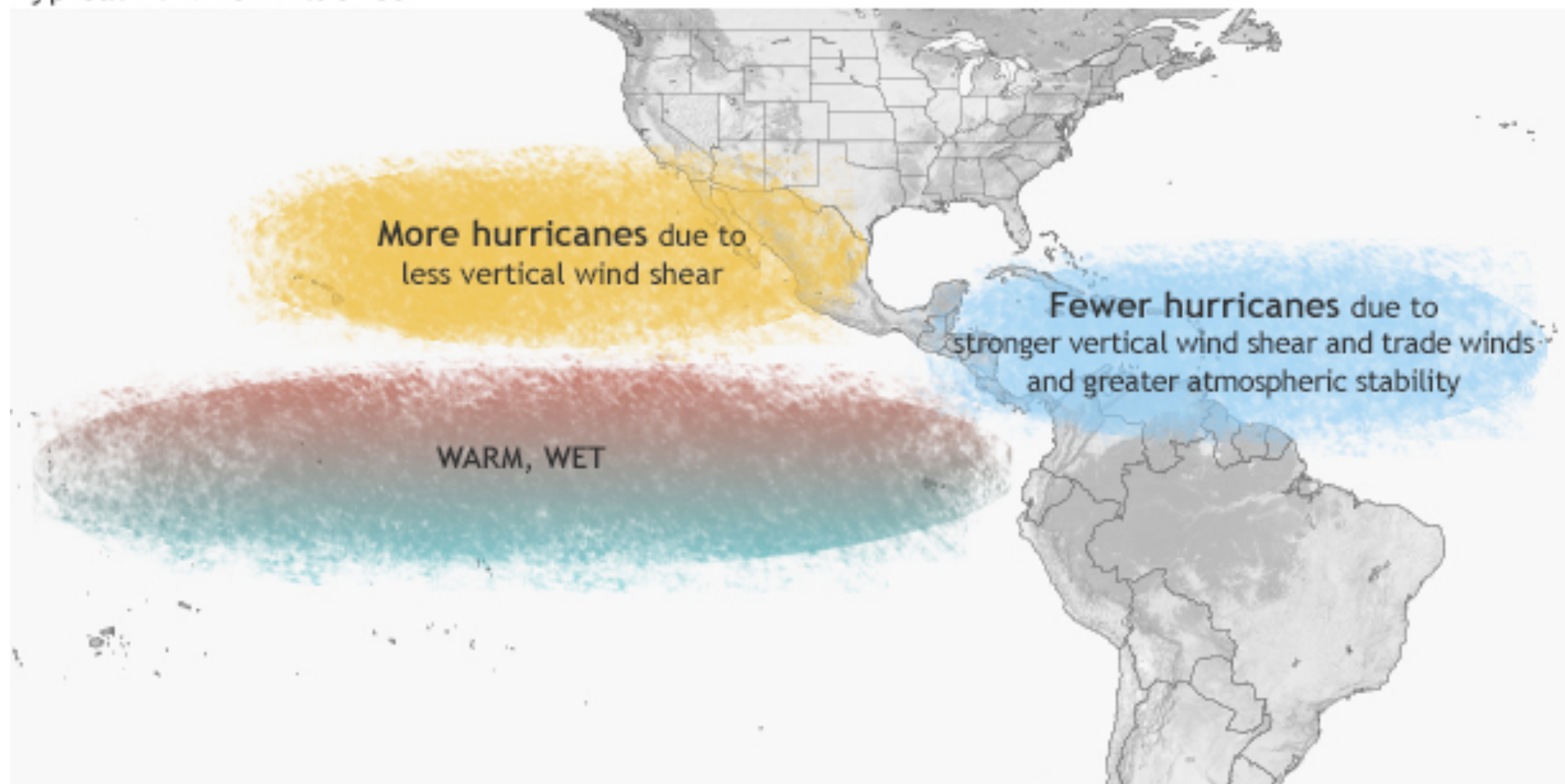


Hurricanes and ENSO



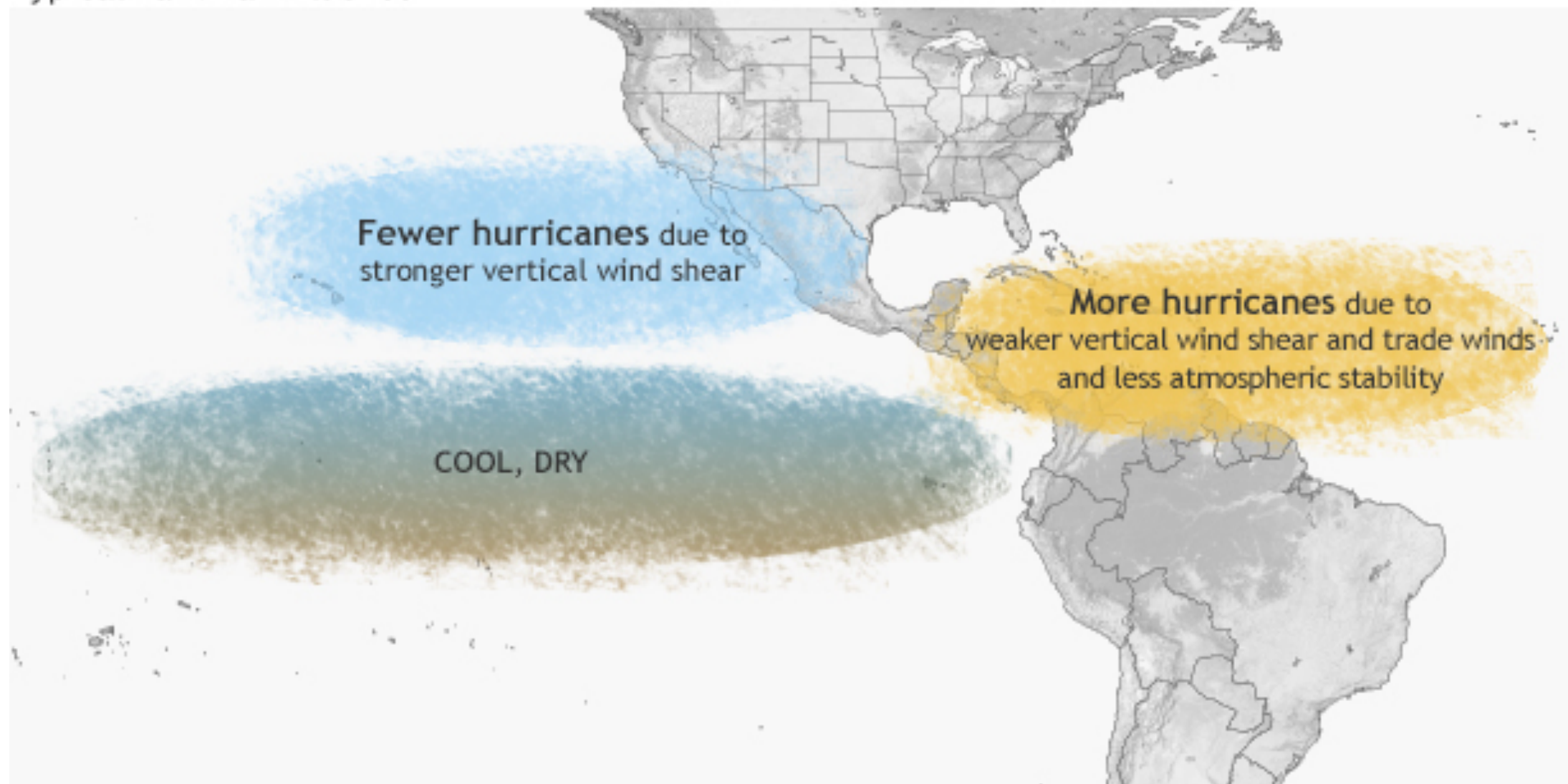
Typical El Nino

Typical El Niño influence



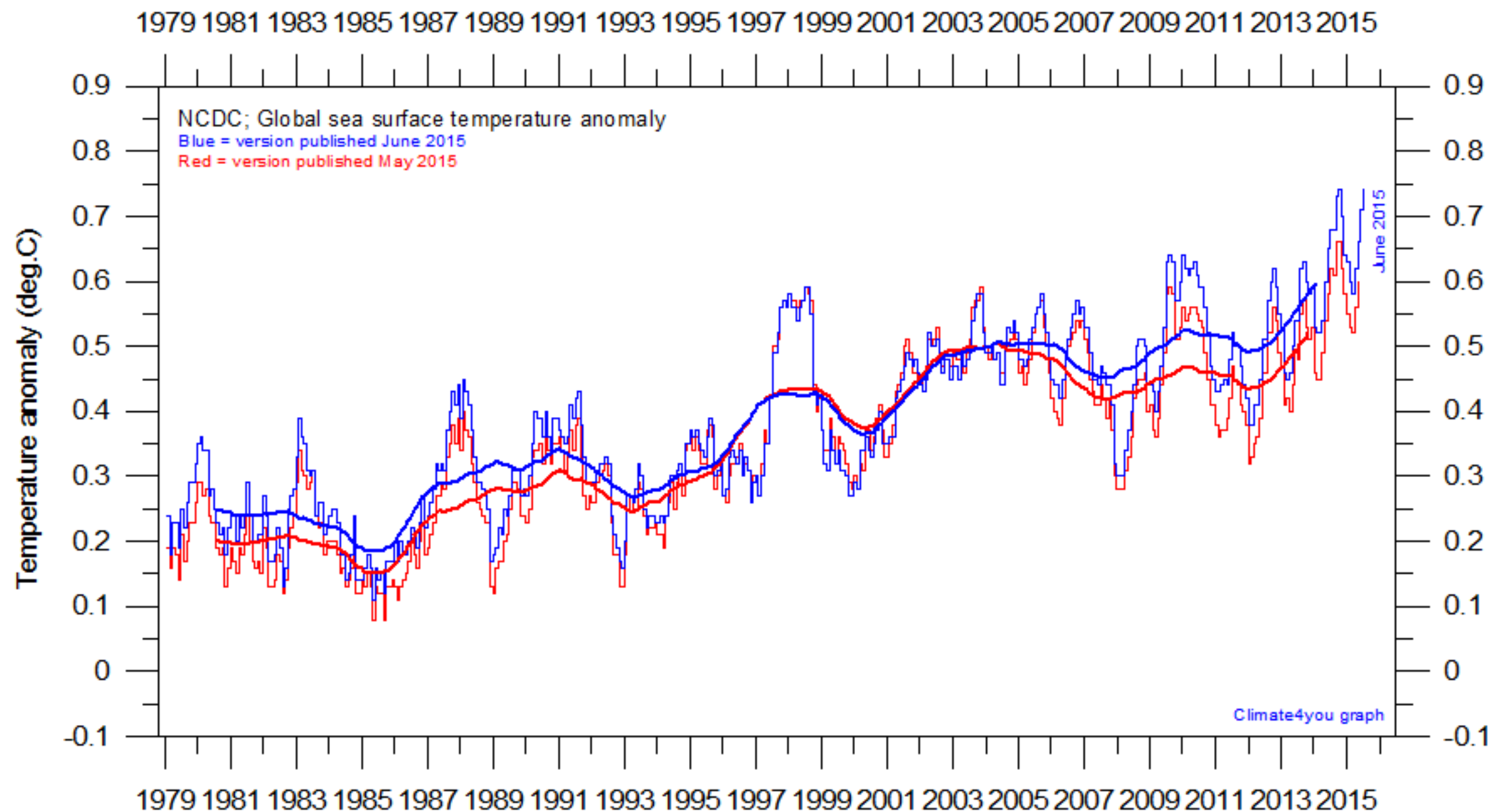
Typical La Nina

Typical La Niña influence

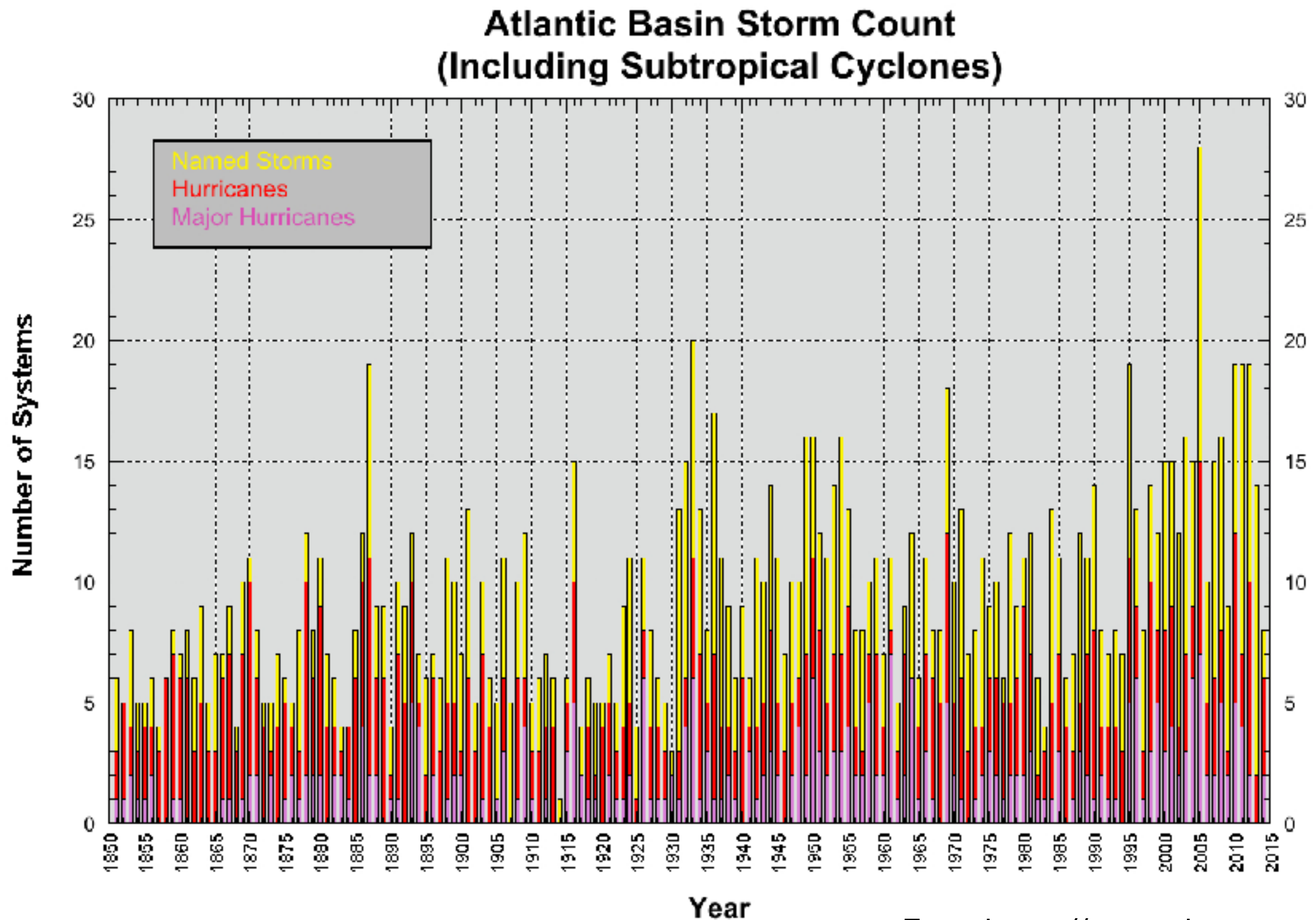


Hurricanes in a warmer world

Sea surface temperature

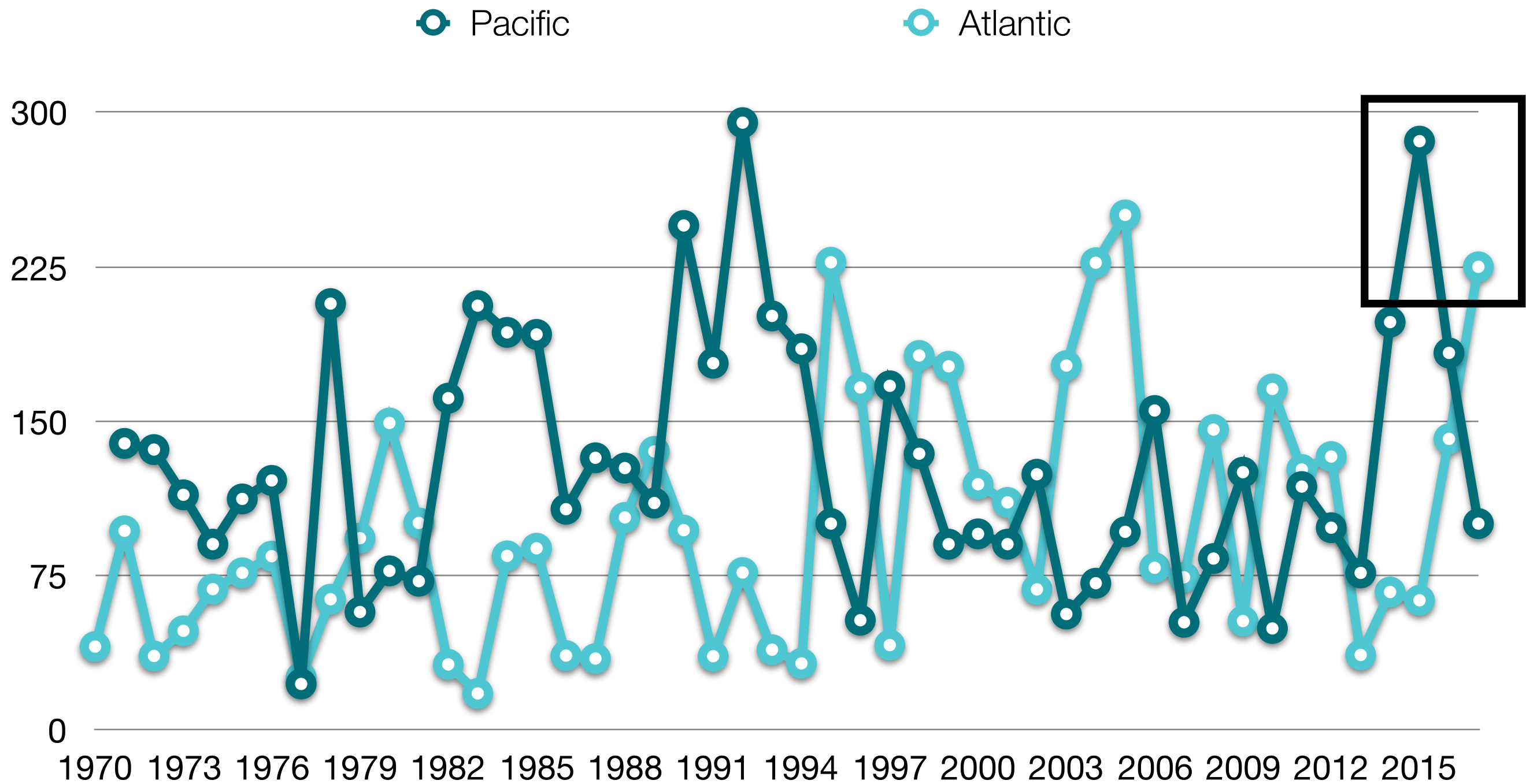


A Storm count in the Atlantic basin



From <https://www.nhc.noaa.gov/climo/>

Hurricane activities



Hurricanes in other ocean basins

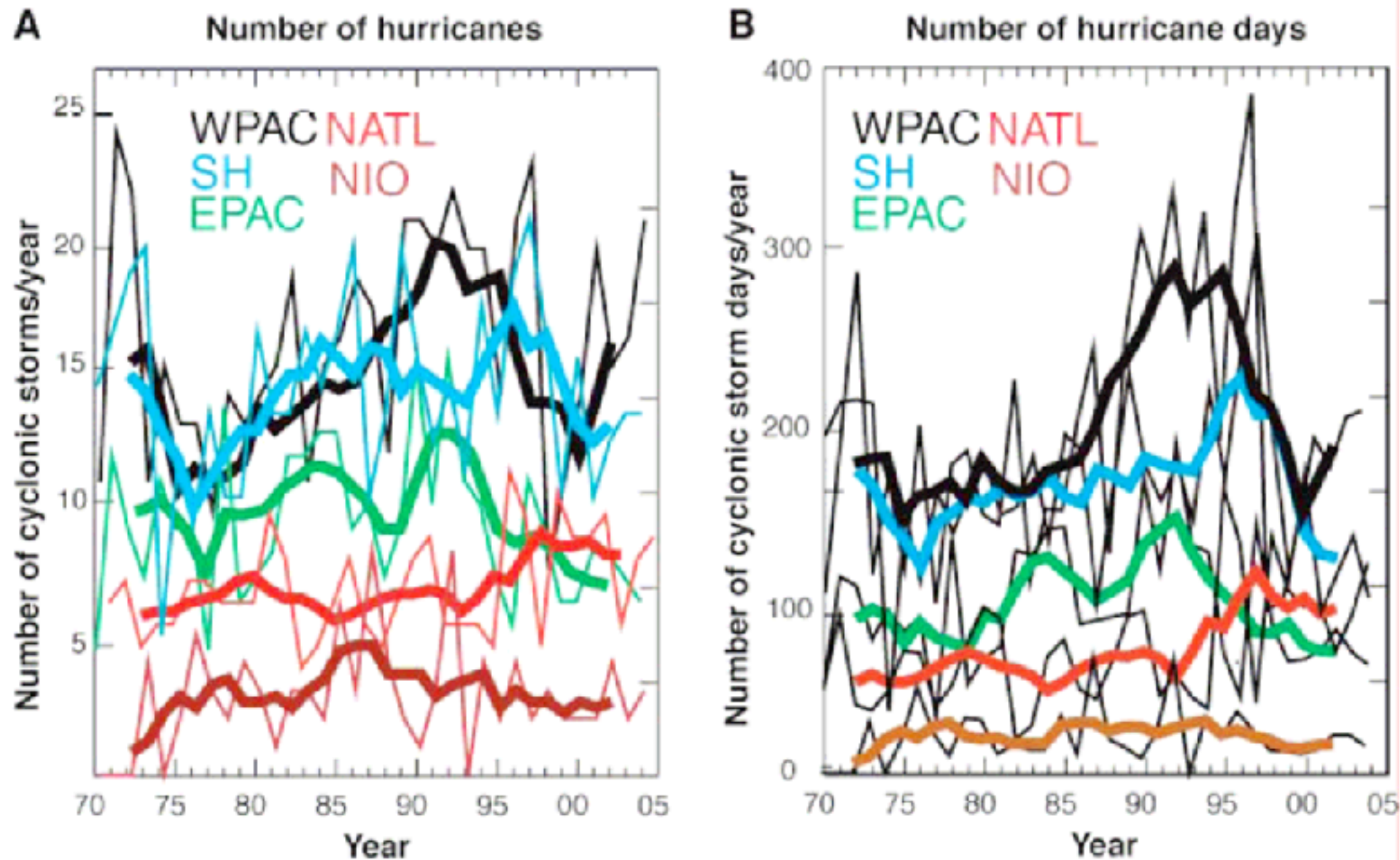


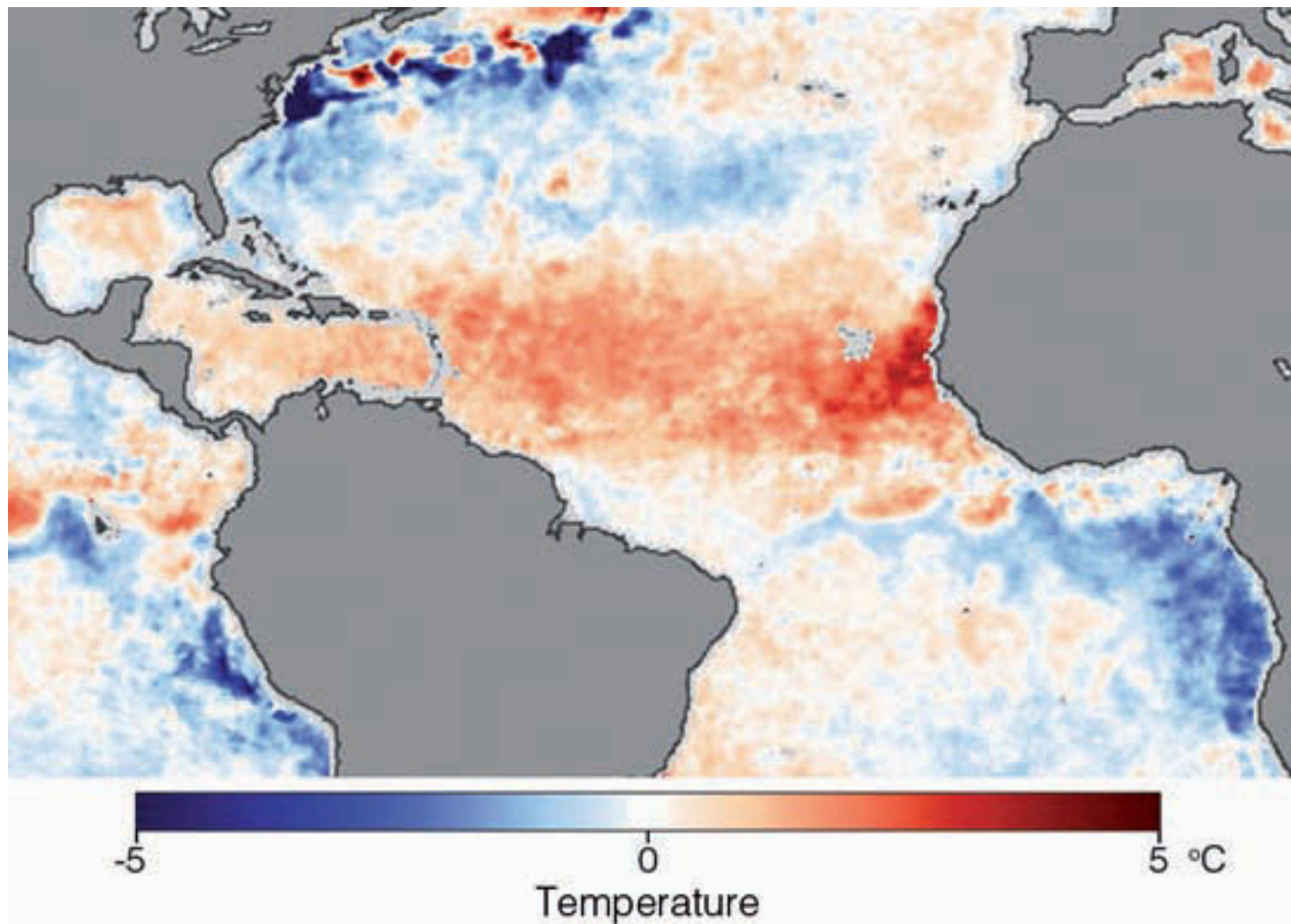
Figure 5. Plot from Webster et al of the number of hurricanes and hurricane days by tropical ocean basin.

Trend in tropical cyclone frequency

- Globally there has been no increase in tropical cyclone frequency over at least the past several decades.
- If the warming of the ocean is the reason for the increasing hurricane numbers and days in the North Atlantic, other basins should show the similar trend.
- A lack of theory for future changes in storm frequencies
- Contradicting results from climate models

We know that...

- Hurricanes are fueled by warm tropical water.
- Warming the ocean by 0.6°C will increase the maximum wind speed by 5 knots.



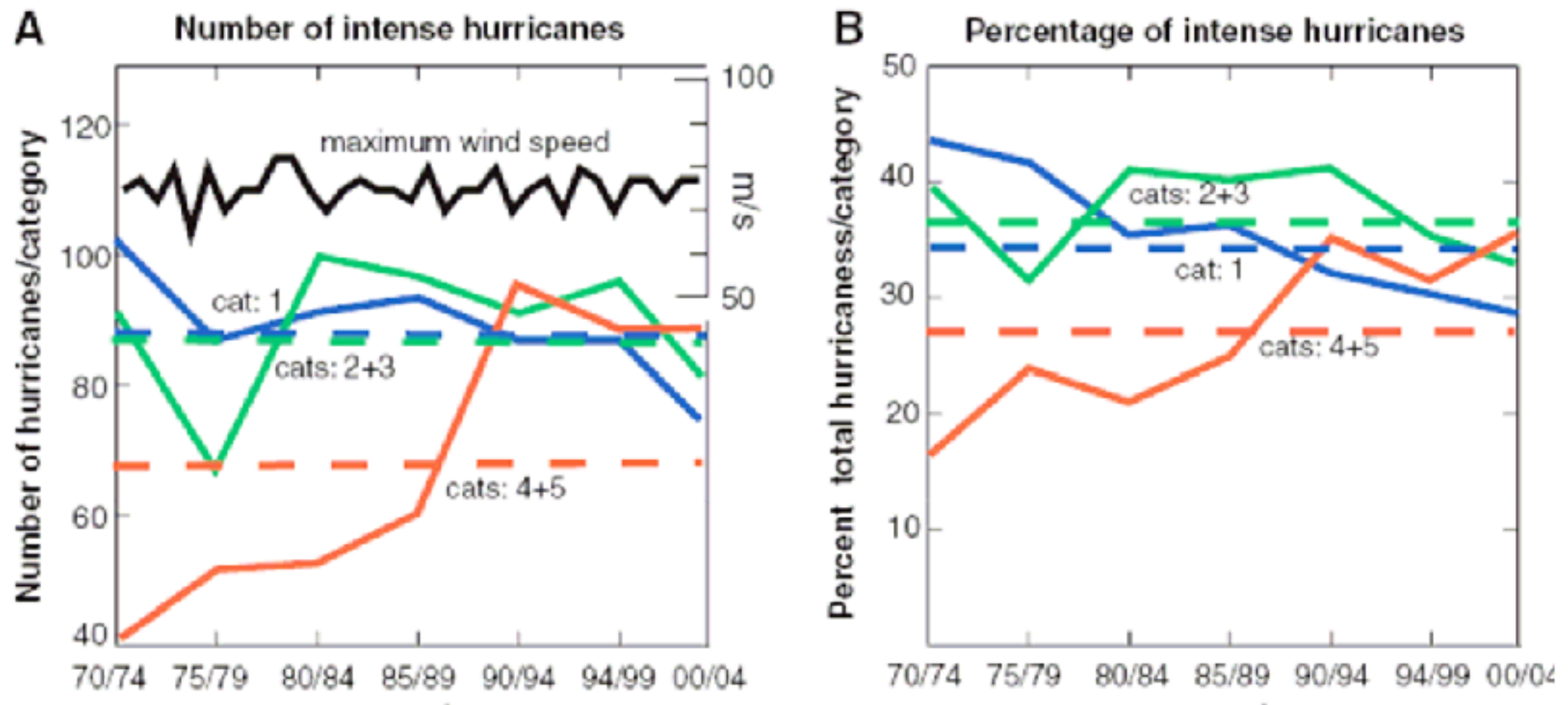
Sea surface temperature anomaly on May 30, 2005. The reference sea surface temperature is the mean from 1985-1997

Sea surface temperature anomaly on May 30, 2005 was about 1°C warmer than the long-term mean from 1901 to 1970.

This year has the record of the most active hurricane activity.

The warmer the water, the more the energy

- Climate models suggest the increase of the sea surface temperature by about 2°C by the end of this century.
- More energy input to hurricanes with warmer water



The warmer the water, the more the energy

- Power dissipation index (by Kerry Emanuel)

$$PDI = \int_0^{\tau} V_{max}^3 dt$$

Uncertainty...

