# WEATHER EXTREMES AND CLIMATE RISK:

# STOCHASTIC MODELING OF HURRICANE DAMAGE

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**Reference:** **Katz, R.W., 2002: "Stochastic Modeling of Hurricane Damage",** ***Journal of Applied Meteorology*****, V. 41, pp. 754-762**
**(*www.isse.ucar.edu/HP_rick/damage.pdf*)**

# QUOTE

**Sir Gilbert Walker (1927):**

> ***"There is, to-day, always a risk that specialists in two subjects, using languages full of words that are unintelligible without study, will grow up not only, without knowledge of each other's work, but also will ignore the problems which require mutual assistance."***

**(Katz, *Statistical Science*, 2002)**

# OUTLINE

(1) Background

(2) Economic Damage from Hurricanes

(3) Stochastic Model for Damage

(4) El Niño Phenomenon as Covariate

(5) Economic Value of Hurricane Forecasts

(6) Resources

# (1) Background

- Hurricanes (“Typhoons”)

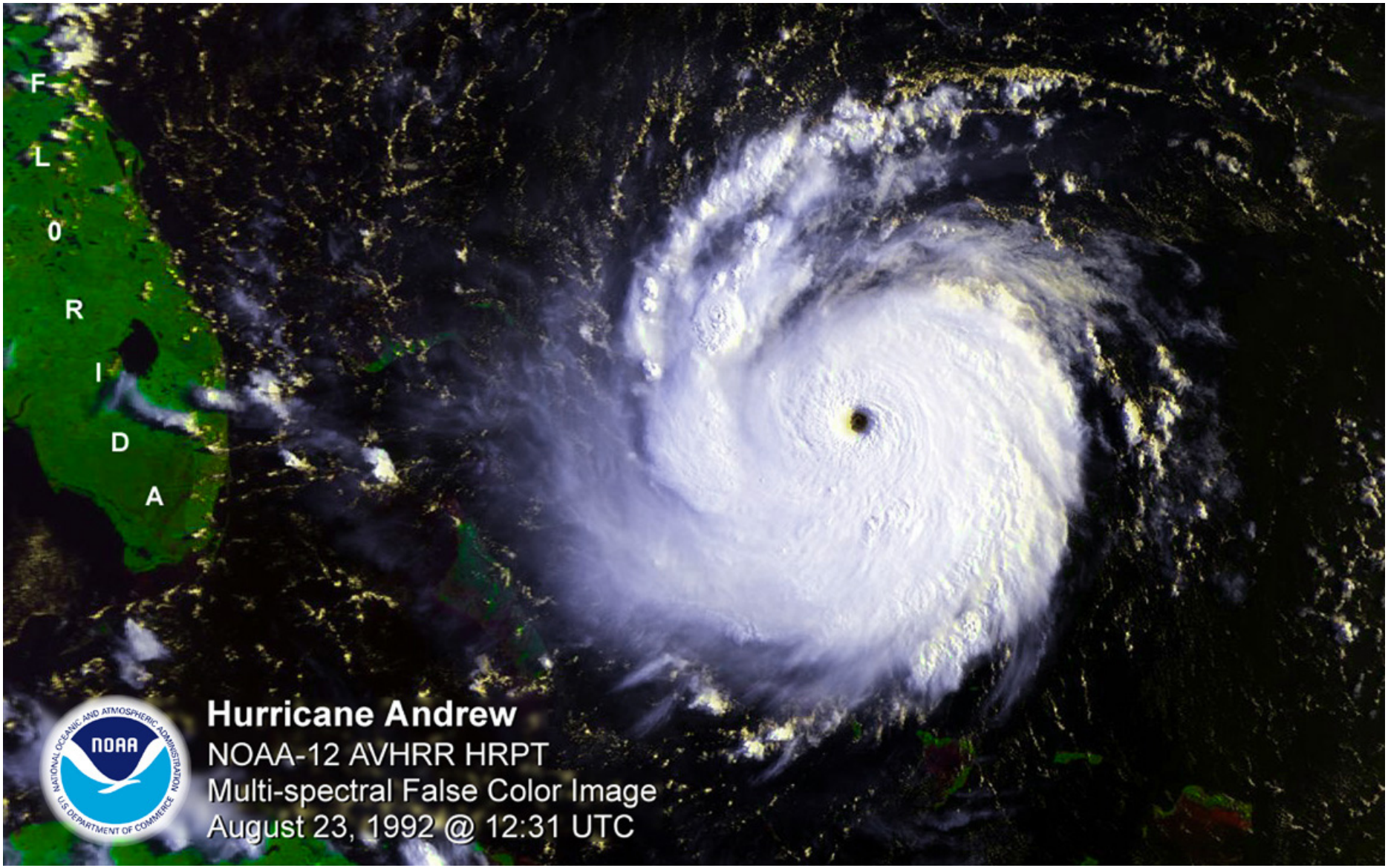
-- Definition / Categories / Season

-- Example of Hurricane Andrew (1992)

- Societal Impact

-- Winds, Storm surge, Precipitation / Inland flooding

-- Hurricane Andrew (Economic damage: 26.5 billion US$)


F
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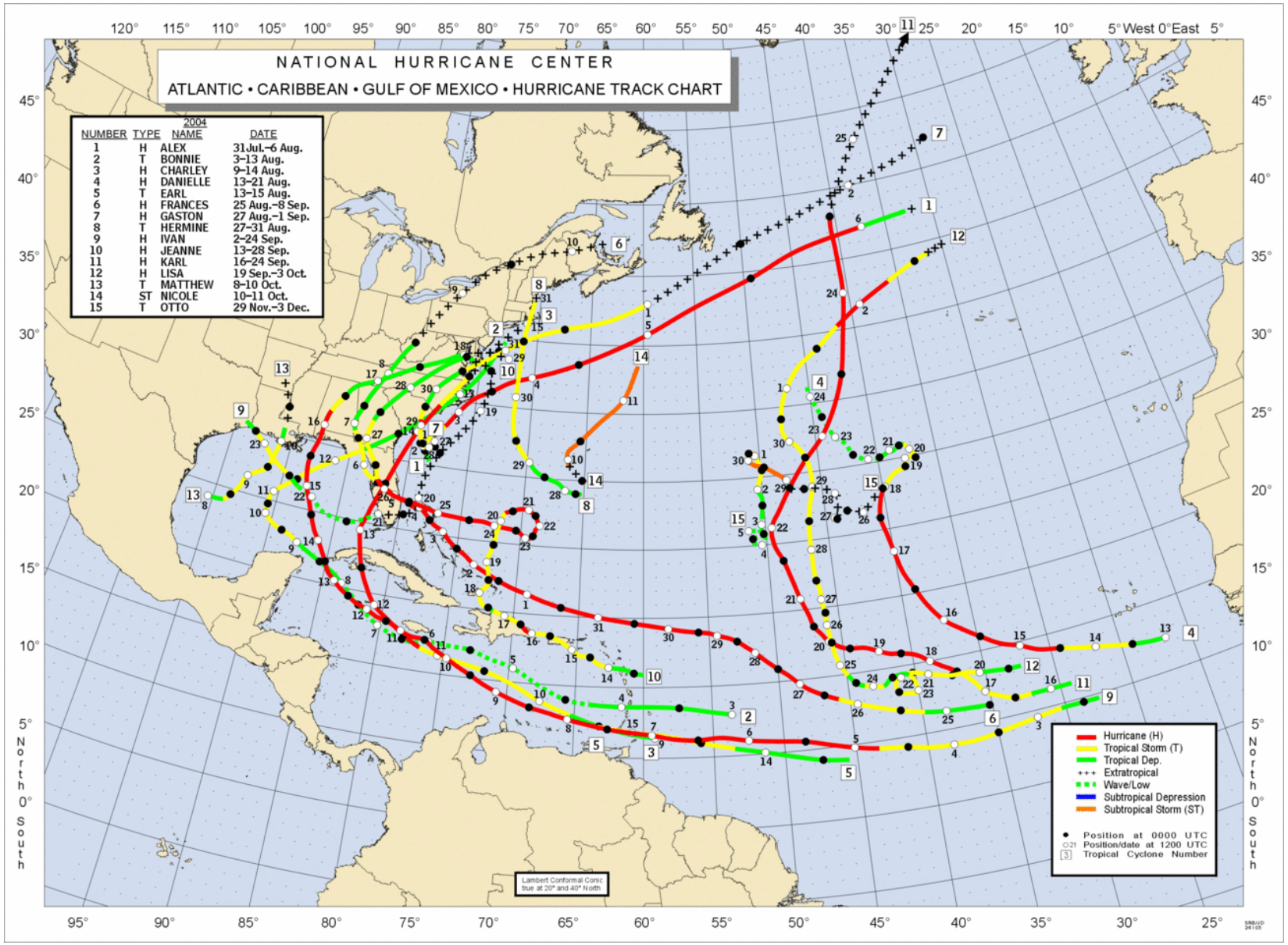
Hurricane Andrew
NOAA-12 AVHRR HRPT
Multi-spectral False Color Image
August 23, 1992 @ 12:31 UTC


NATIONAL HURRICANE CENTER
ATLANTIC • CARIBBEAN • GULF OF MEXICO • HURRICANE TRACK CHART
2004
NUMBER TYPE NAME DATE
1 H ALEX 31Jul.–6 Aug.
2 T BONNIE 3–13 Aug.
3 H CHARLEY 9–14 Aug.
4 H DANIELLE 13–21 Aug.
5 T EARL 13–15 Aug.
6 H FRANCES 25 Aug.–8 Sep.
7 H GASTON 27 Aug.–1 Sep.
8 T HERMINE 27–31 Aug.
9 H IVAN 2–24 Sep.
10 H JEANNE 13–28 Sep.
11 H KARL 16–24 Sep.
12 H LISA 19 Sep.–3 Oct.
13 T MATTHEW 8–10 Oct.
14 ST NICOLE 10–11 Oct.
15 T OTTO 29 Nov.–3 Dec.
Hurricane (H)
Tropical Storm (T)
Tropical Dep.
Extratropical
Wave/Low
Subtropical Depression
Subtropical Storm (ST)
Position at 0000 UTC
Position/date at 1200 UTC
Tropical Cyclone Number
Lambert Conformal Conic
true at 20° and 40° North
5° West 0° East 5°
5° North 0° South

# (2) Economic Damage from Hurricanes

- **Data**

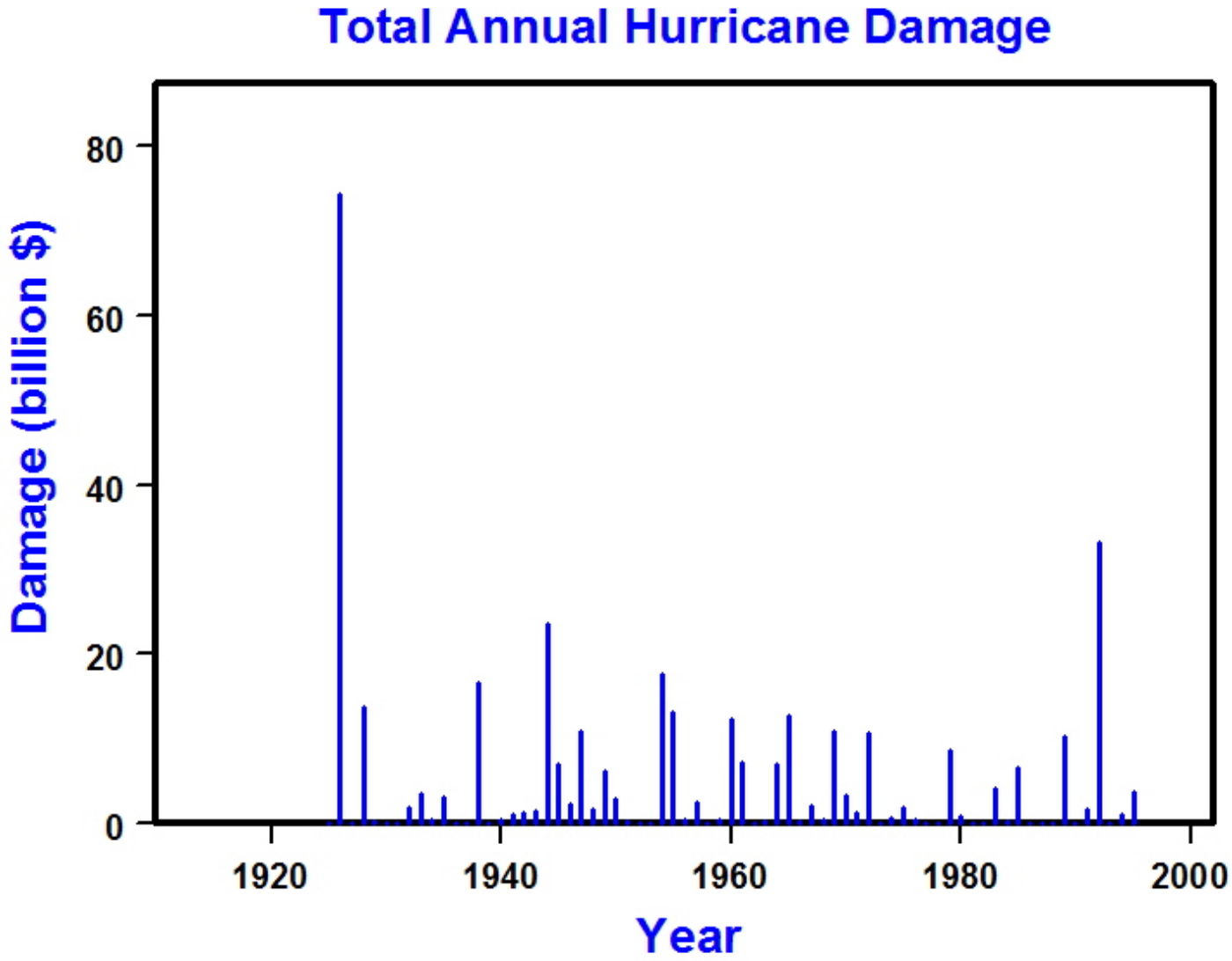
-- **Pielke and Landsea (1998)**

**Web site:** ***sciencepolicy.colorado.edu/homepages/roger_pielke/hp_roger/hurr_norm/data.html***

- **“Normalized” Data**

-- **Adjusted for inflation & changes in societal vulnerability**

-- **“Residual” intended to reflect only climate**


Total Annual Hurricane Damage
Damage (billion $)
80
60
40
20
0
1920
1940
1960
1980
2000
Year

# (3) Stochastic Model for Damage

- **Random Sum Model**

-- **Embrechts et al. (1997):**

**"Bread and butter of insurance mathematics"**

- **Number of Events**

-- **Poisson distribution (Trend? Covariates?)**

- **Damage for Individual Storm**

-- **Lognormal distribution (Trend? Covariates?)**

-- **Generalized Pareto distribution for upper tail**

- **Statistics of Random Sums**

-- **Notation**

$N(t)$ number of events in $t$th yr

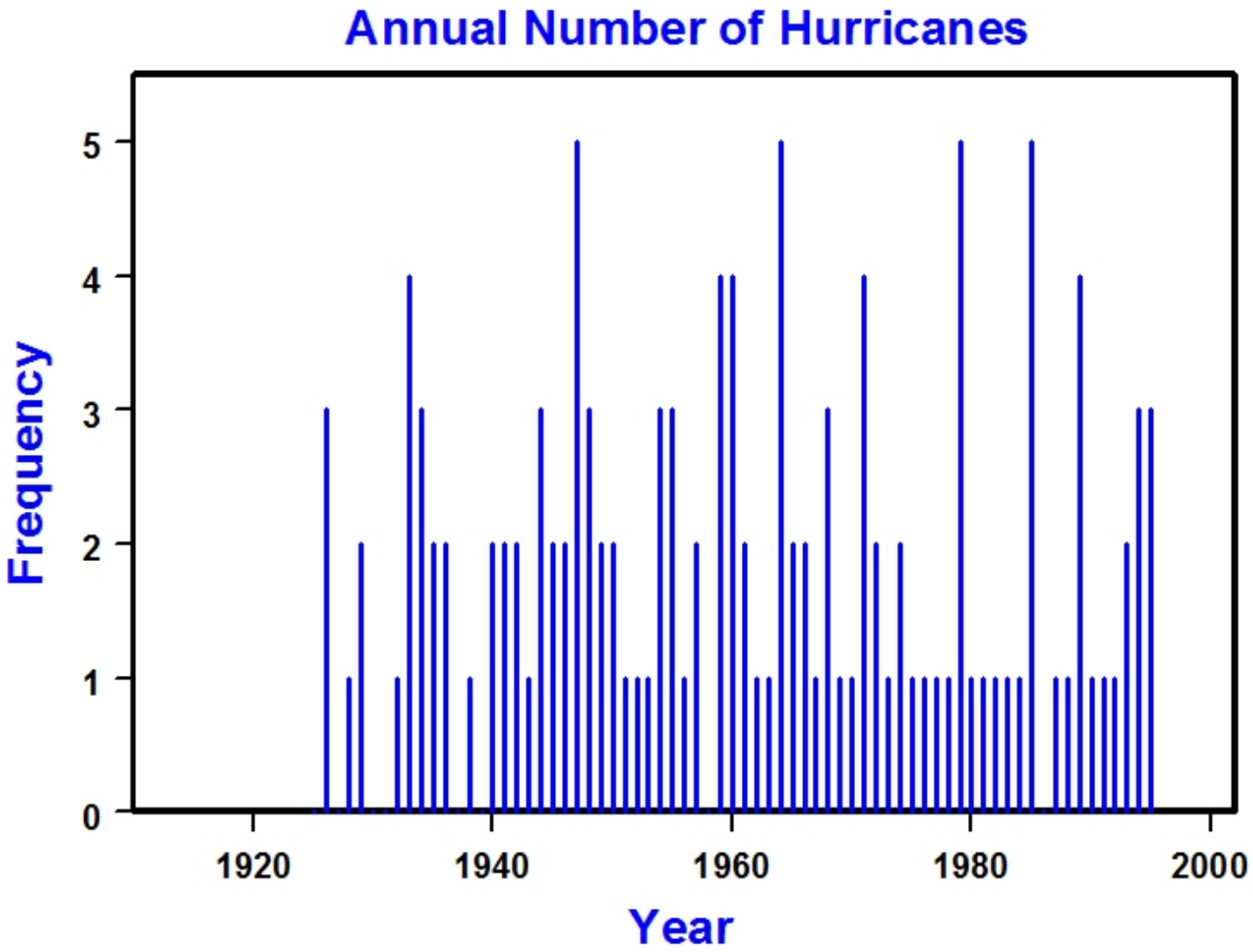
$X_k$ damage from $k$th event in $t$th yr (i. i. d.)

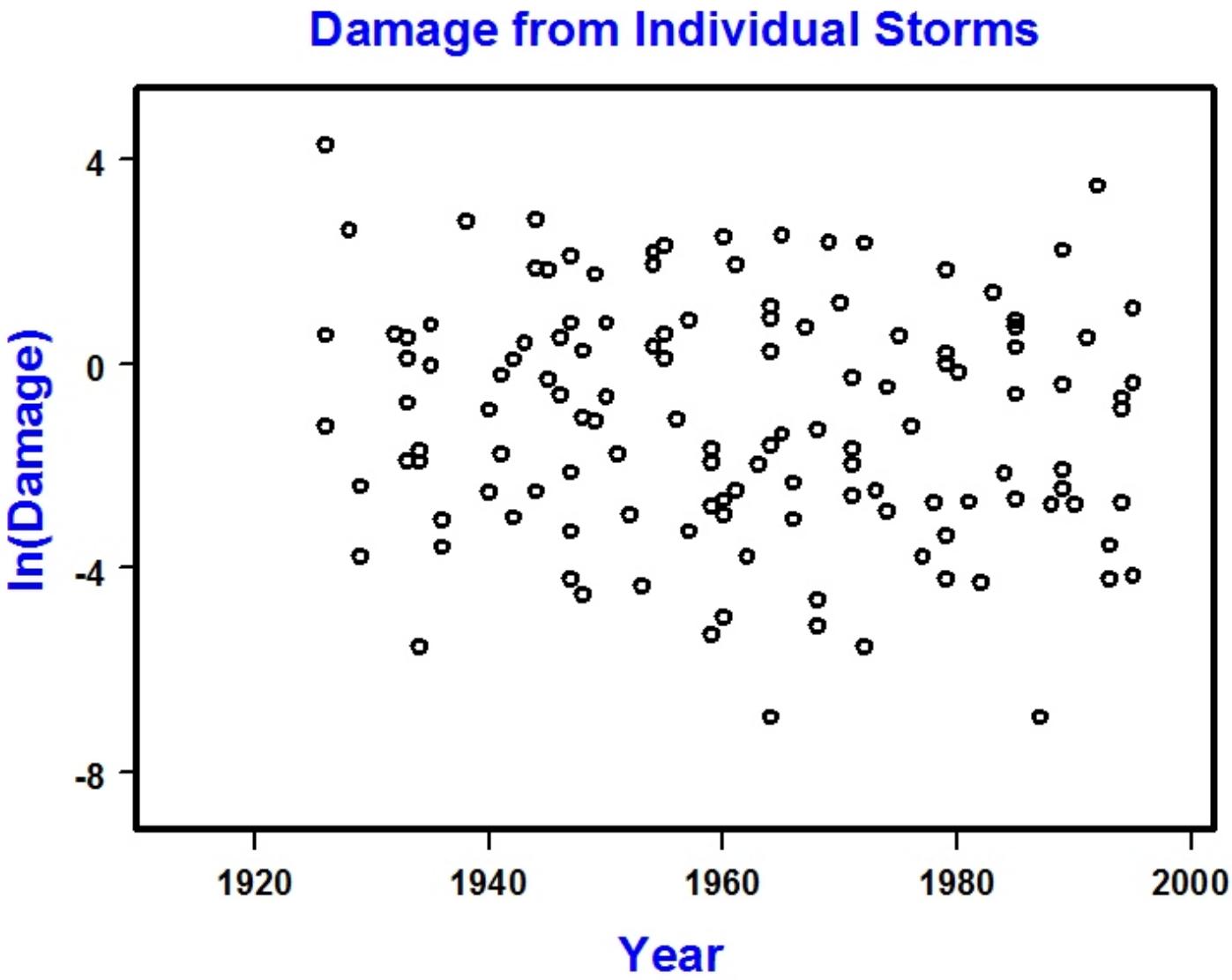
$S(t) = X_1 + X_2 + \cdots + X_{N(t)}$ total damage in $t$th yr

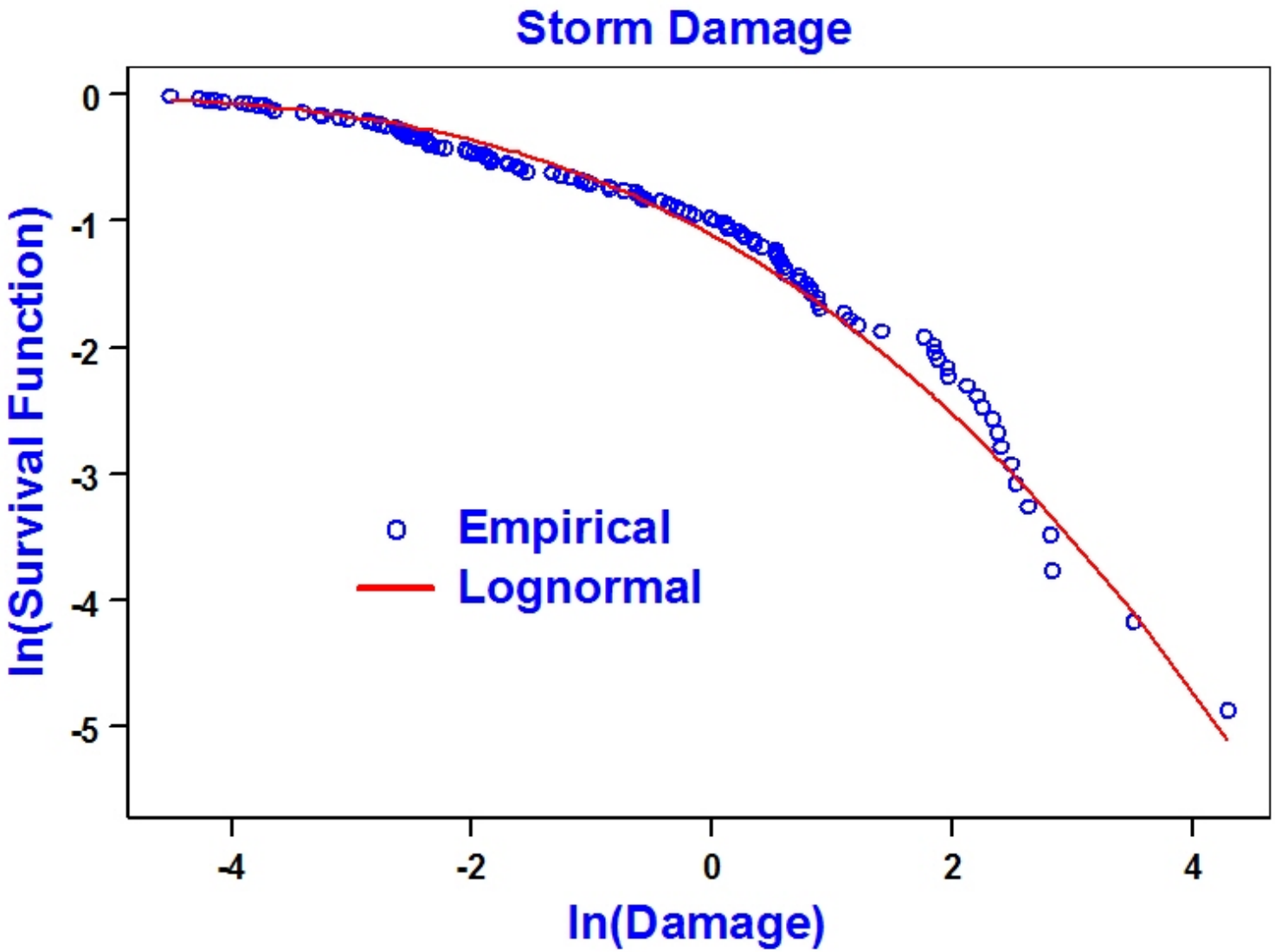
-- **Mean of total annual damage** $E[S(t)] = \mathrm{E}[N(t)]\, E(X_k)$

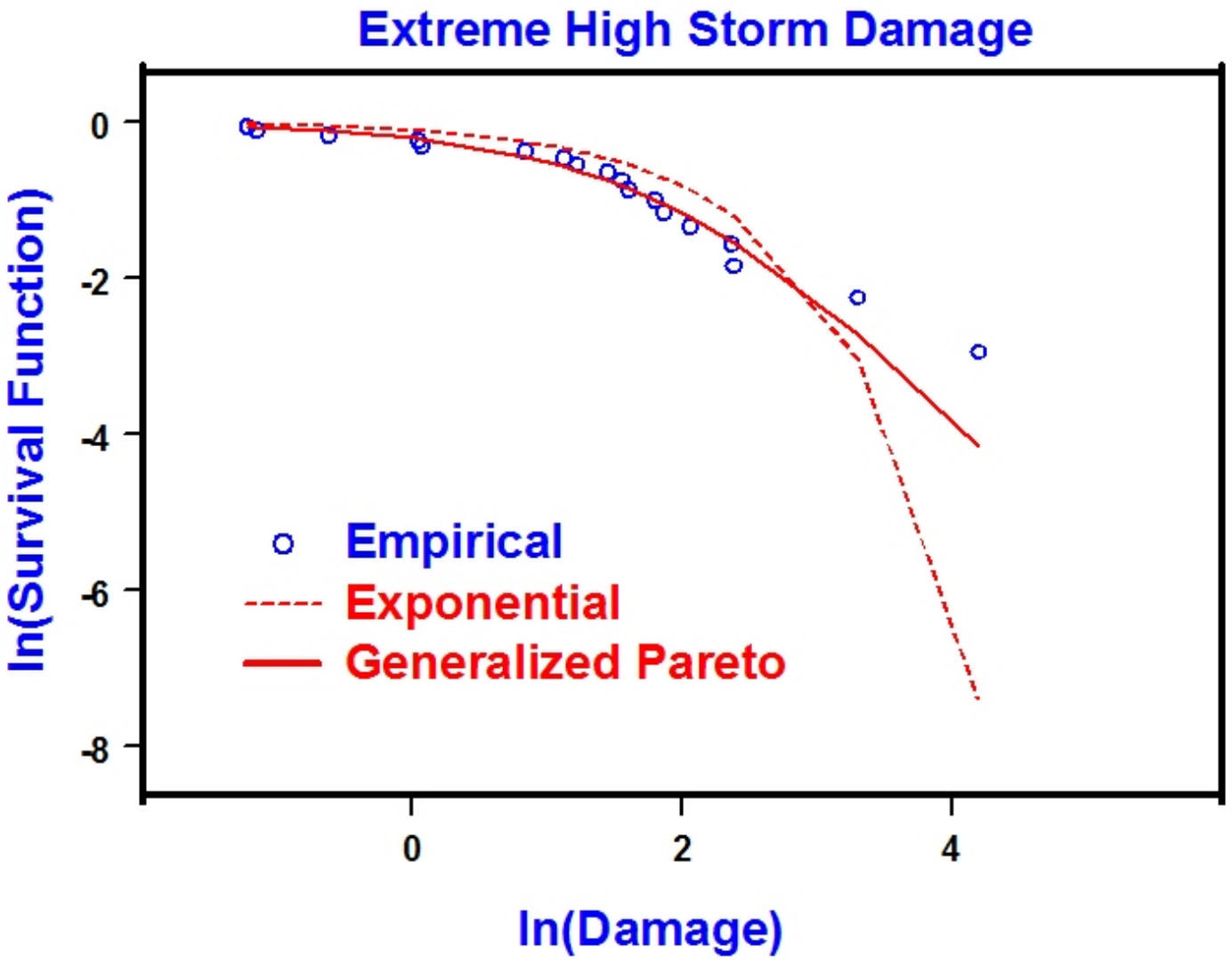
-- **Variance of total annual damage**

$$\mathrm{Var}[S(t)] = \mathrm{E}[N(t)]\, \mathrm{Var}(X_k) + \mathrm{Var}[N(t)]\, [E(X_k)]^2$$


Annual Number of Hurricanes
Frequency
0
1
2
3
4
5
1920
1940
1960
1980
2000
Year


Damage from Individual Storms
ln(Damage)
4
0
-4
-8
1920
1940
1960
1980
2000
Year


Storm Damage
ln(Survival Function)
0
-1
-2
-3
-4
-5
-4
-2
0
2
4
ln(Damage)
Empirical
Lognormal


Extreme High Storm Damage
ln(Survival Function)
0
-2
-4
-6
-8
0
2
4
ln(Damage)
Empirical
Exponential
Generalized Pareto

- **Heavy Tail**

-- **Estimated shape parameter of GP distribution ≈ 0.5**

- **Origin of Heavy Tail**

-- **Underlying geophysical phenomenon?**

-- **Inherent feature of distribution of income or wealth?**

**(Recall origin of Pareto distribution)**

- **Chance Mechanisms**

-- **Mixture of light-tailed distributions can induce heavy-tailed distribution (e. g., exponential to Pareto)**

# (4) El Niño Phenomenon as Covariate

- El Niño Phenomenon

-- Statistical characteristics (“quasi-periodic”)

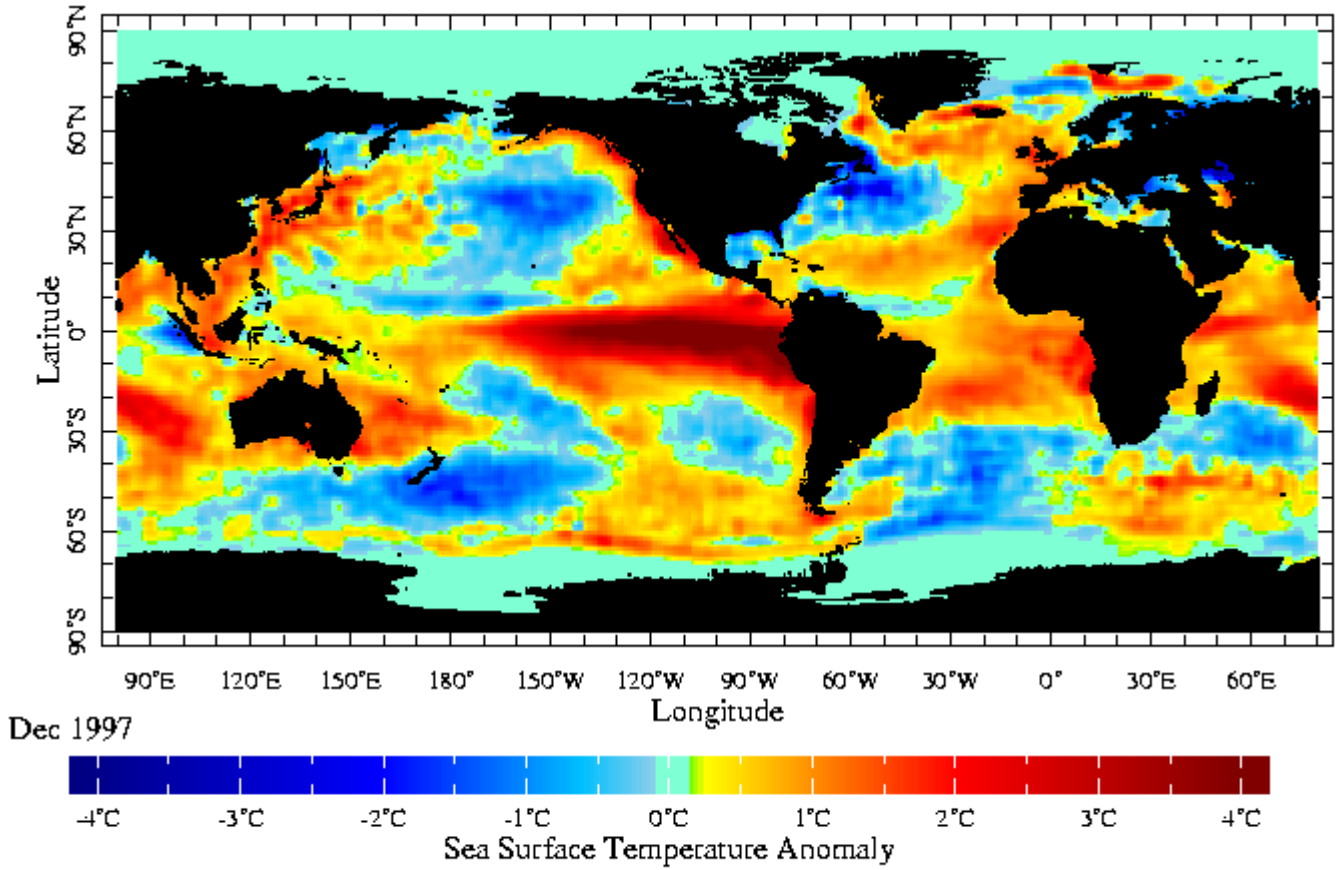
-- Teleconnections (interannual variability)

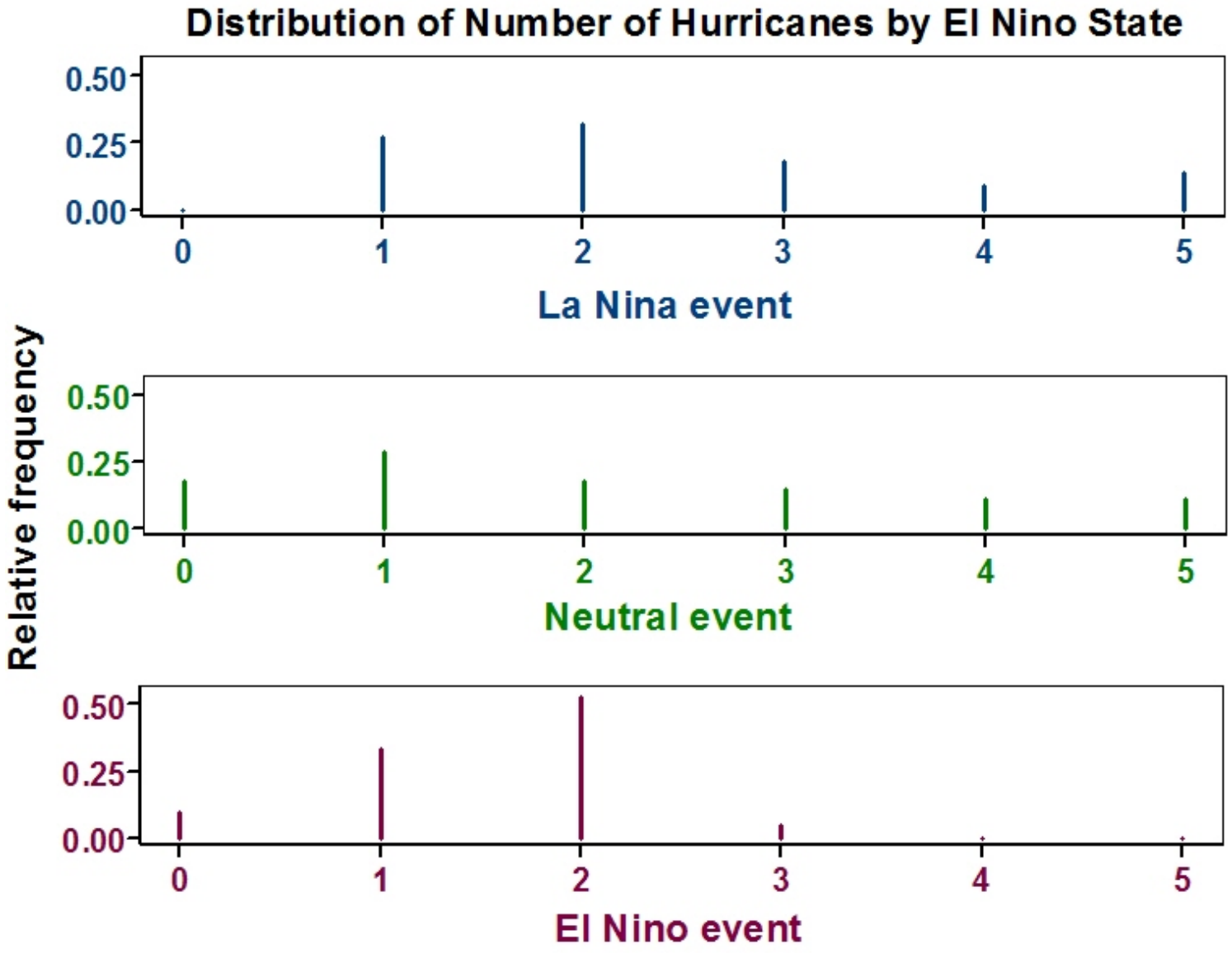
- Connections to Hurricane Statistics

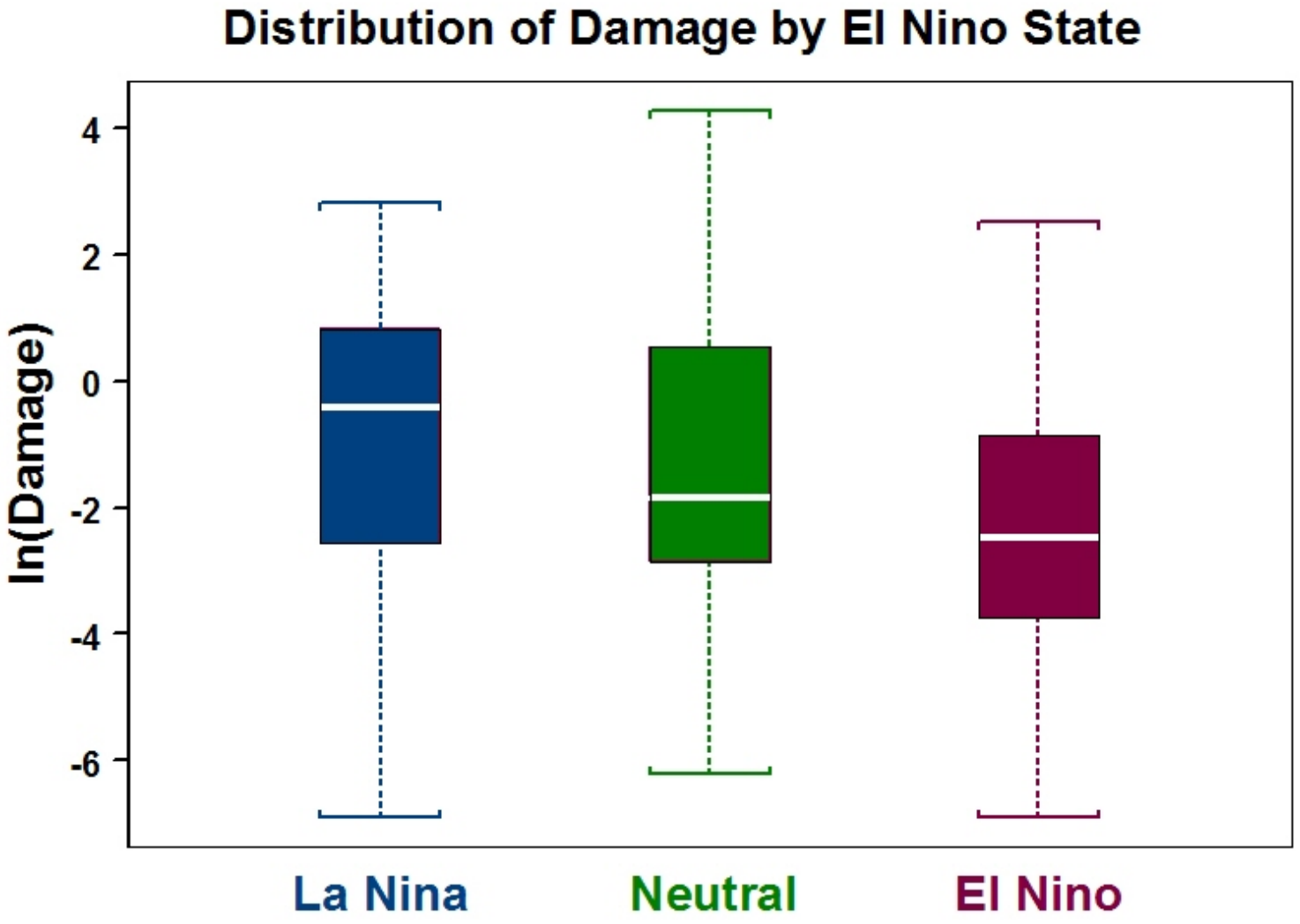
-- Hurricane frequency

-- Hurricane intensity

-- Hurricane path (North Atlantic Oscillation)


90°N
60°N
30°N
0°
30°S
60°S
90°S
Latitude
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
30°W
0°
30°E
60°E
Longitude
Dec 1997
-4°C
-3°C
-2°C
-1°C
0°C
1°C
2°C
3°C
4°C
Sea Surface Temperature Anomaly


Distribution of Number of Hurricanes by El Nino State
Relative frequency
0.50
0.25
0.00
0
1
2
3
4
5
La Nina event
Neutral event
El Nino event


Distribution of Damage by El Nino State
ln(Damage)
4
2
0
-2
-4
-6
La Nina
Neutral
El Nino

- **Tail Dependence on El Niño State**

-- **Unable to detect effect on parameters of generalized Pareto distribution**

-- **Unable to detect effect on frequency of high damage (parameter of Poisson distribution)**

- **Inconsistency between Extremal & Non-Extremal Modeling**

-- **Issue of parsimony**

-- **Chance mechanisms**

-- **Penultimate approximations**

# (5) Economic Value of Hurricane Forecasts

- **Insurance/Reinsurance Industry**

-- **Web sites mention El Niño**

**Fund research on El Niño / hurricanes**

-- **Any evidence of use of hurricane forecasts based on El Niño?**

-- **State of Florida (Example)**

**Hurricane Andrew: 7 insurance companies became insolvent**

**State insurance relief fund created**

- **Economic Value of Imperfect Information**

-- **General methodology**

**Decision making under uncertainty (Maximize expected utility)**

**Relative to prior information (Climatology)**

**Increase in expected return (Willingness-to-pay)**

**Why does imperfect information have potential "value"?**

**Convexity / Jensen's inequality:**

$E[\max(\cdot)]$ **vs.** $\max[E(\cdot)]$

**Comparison of information systems:**

**Concept of "sufficiency" (Blackwell, DeGroot)**

-- **Issues for Insurance / Reinsurance**

***Actions***:

**Negotiate premiums annually for reinsurance**

**Borrowing for insurance relief fund**

***Optimization criteria***:

**Maximize expected return (Profit maximization)?**

**Maximize expected utility (Risk aversion)?**

**Subject to constraint on probability of ruin?**

# (6) Resources

- **NCAR Geophysical Statistics Project**

-- ***www.cgd.ucar.edu/stats***

- **Statistics of Weather & Climate Extremes**

-- ***www.isse.ucar.edu/extremevalues/extreme.html***

- **Case Studies of Economic Value of Weather & Climate Forecasts**

-- ***www.isse.ucar.edu/HP_rick/esig.html***

# QUOTE

**Sir Gilbert Walker (1918):**

***"The number of satisfactorily established relationships between weather in different parts of the world is steadily growing . . . and I cannot help believing that we shall gradually find out the physical mechanisms by which these are maintained, as well as learn to make long-range forecasts to an increasing extent."***

**(Glantz, Katz, and Nicholls, 1991)**

# Domo Arigato Gozaimasu