Hurricanes and Climate: Our growing understanding

Gabriel A. Vecchi
NOAA/Geophysical Fluid Dynamics Laboratory
Princeton, NJ 08540
Key concepts

• Established vs. Developing understanding
  – Multiple factors impact hurricanes
  – Observational uncertainties
  – Pushing the limits of our theory and computers

• False choice: global warming OR climate variability

• Not about one storm or one season (“Katrina effect”).

• How do we develop our understanding?
  – Observations
  – Theoretical understanding
  – Numerical Modeling

• As we learn more, interpretation of total evidence changes: this is how science works

• Interpretations of sum of evidence can differ between scientists: not a “debate” - an ongoing inquiry.
NOAA ATTRIBUTES RECENT INCREASE IN HURRICANE ACTIVITY TO NATURALLY OCCURRING MULTI- DECADAL CLIMATE VARIABILITY *

Nov. 29, 2005 — The nation is now wrapping up the 11th year of a new era of heightened Atlantic hurricane activity. This era has been unfolding in the Atlantic since 1995, and is expected to continue for the next decade or perhaps longer. NOAA attributes this increased activity to natural occurring cycles in tropical climate patterns near the equator. These cycles, called “the tropical multi-decadal signal,” typically last several decades (20 to 30 years or even longer). As a result, the North Atlantic experiences alternating decades long (20 to 30 year periods or even longer) of above normal or below normal hurricane seasons. NOAA research shows that the tropical multi-decadal signal is causing the increased Atlantic hurricane activity since 1995, and is not related to greenhouse warming. (Click NOAA Research by NOAA scientists [...] and [...], currently in press with the Journal of Climate, describes the tropical multi-decadal signal and shows that it accounts for the entire inter-related set of conditions that controls hurricane activity for decades at a time.)
*EDITOR’S NOTE: This consensus in this on-line magazine story represents the views of some NOAA hurricane researchers and forecasters, but does not necessarily represent the views of all NOAA scientists. It was not the intention of this article to discount the presence of a human-induced global warming element or to attempt to claim that such an element is not present. There is a robust, on-going discussion on hurricanes and climate change within NOAA and the scientific community.
Katrina's real name

By Ross Gelbspan | August 30, 2005

THE HURRICANE that struck Louisiana yesterday was nicknamed Katrina by the National Weather Service. Its real name is global warming.
What about 1947 Hurricane and Betsy (1965)...oh and Camille (1969)? Focus on long-term, not events.
News search on global warming and impacts

- global-warming | greenhouse-effect | climate-change
- flood and
  global-warming | greenhouse-effect | climate-change
- rainforest and
  global-warming | greenhouse-effect | climate-change
- puppies and
  global-warming | greenhouse-effect | climate-change
- hurricane and
  global-warming | greenhouse-effect | climate-change
There is some recent evidence that overall Atlantic hurricane activity may have increased since in the 1950s and 60s in association with increasing sea surface temperatures…

Source: Emanuel (2007)

PDI is proportional to the time integral of the cube of the surface wind speeds accumulated across all storms over their entire life cycles.
One Temperature Predictor of Atlantic Hurricane Activity

Observed Activity
Absolute Atlantic Temperature

Vecchi, Swanson and Soden (2008, Science)
Two Temperature Predictors of Atlantic Hurricane Activity

Vecchi, Swanson and Soden (2008, Science)
Two Statistical Projections of Atlantic Hurricane Activity

Observed Activity
Absolute Atlantic Temperature

Observed Activity
Relative Atlantic Temperature

Vecchi, Swanson and Soden (2008, Science)
Requirements for understanding the hurricane-climate connection

Interconnected, complement/limit each other.

• Well-defined measure of hurricane activity

• Observations:
  – As homogeneous as possible
  – Uncertainty assessment

• Comprehensive dynamical models

• Theory:
  – Theories exist for intensity
  – Theory for cyclone frequency still lacking
Measure of Activity

• Which measure?
  – Hurricane count
  – Landfalling storm count
  – Extremes in intensity
  – Shifts in mean intensity
  – Integrated intensity

• Must balance demand with current understanding
  – Obs, models and theory limit.

• Differences must be communicated.

Observations

- Hurricane databases **NOT** built as climate data records.

- Efforts continue to:
  - Identify issues
  - Homogenize
  - Estimate uncertainty

**Uncorrected global activity**

**Activity corrected for changes in satellites**

*Kossin et al (2007, GRL)*
Raw record of Atlantic tropical storms shows strong century-scale increase

Atlantic Hurricanes, Tropical and Subtropical Storms

Vecchi and Knutson (2008, J. Climate)
Can we be sure the long-term increase is real? Observational methods have changed with time.

**Storm positions**

- **1966-2006 Storms**
- **1915-1945**
- **1946-1965**

**Pre-WWII Ships**

- **1878-1914**
- **Pre-Satellite Ships**

**Pre-Panama Canal Ships**

- **Vecchi and Knutson (2008)**
...but we can estimate number of “missed” storms

Landsea (2007): Assumes constant landfall fraction. Is this justified (see Holland, 2007)?

- Adjusted storm count trend since 1878 not distinct from “noise”
- Decadal swings not a simple “cycle”, either.
Understanding: what controls hurricanes?

• Potential Intensity theory exists:
  – e.g. Emanuel, Holland…
  – What are limitations?

• What is theory for genesis? Duration? …

• Why are there about 100 cyclones a year globally? Why not 200?
Can global climate models give guidance about changes in Atlantic storm activity?
But, current computing power limits ability of global climate models to represent hurricanes.

Hurricane Rita (2005): orange grid is representative of current *global* climate model resolution.

Size of grid limited by power of computers.
Nonetheless, tropical storms are affected by *large-scale* conditions that today’s climate models *can* represent.

**Factors that favor storm development and intensification:**

- Warm ocean surface
- Cool upper atmosphere
- Low vertical wind shear
- Moist middle atmosphere
- etc.

Over swath of tropical Atlantic and East Pacific, increased wind-shear.

What is net effect of increased potential intensity and wind shear?

*Vecchi and Soden (2007, GRL)*
Hurricane Katrina Coupled Model Forecast
Aug 27 02:30 UTC

Courtesy Morris Bender and Tim Marchok, NOAA/GFDL
Hurricane models project increasing hurricane intensities and rainfall rates with greenhouse climate warming...

Source: Knutson and Tuleya, *J. Climate*, 2004 (left); Knutson and Tuleya, 2008; Cambridge Univ Press (right).
High-Resolution Comprehensive models

Assess TC sensitivity to climate change in a physically-consistent manner

GFDL regional model simulation.

Knutson et al (2007, BAMS)

Models ranging in 100km to 18km resolution.

GFDL global model simulation.

Zhao, Held, Lin and Vecchi (2009, J. Climate)
Comprehensive models

Given “large-scale” conditions, high-resolution models can reproduce observed changes in hurricane frequency.

Use these models to assess impact of model-projected large-scale response to doubled CO2.

Frequency of weakest storm projected to decrease. Frequency of strongest storms may increase.

Adapted from Knutson et al (2008, Nature Geosci.)
21st Century Hurricane Activity Change: Four possibilities

Red/yellow = increase
Blue/green = decrease

Regional increase/decrease much larger than global-mean.
Pattern depends on details of ocean temperature change.
Sensitivity of response seen in many studies

e.g., Emanuel et al 2008, Knutson et al 2008, etc

Adapted from Zhao et al. (2009, J. Climate)
Two Statistical Projections of Atlantic Hurricane Activity

Observed Activity
Absolute Atlantic Temperature

Vecchi, Swanson and Soden
(2008, Science)
...Add Dynamical Projections of Atlantic Hurricane Activity

Observed Activity
Absolute Atlantic Temperature

Dynamical Model Projections

Observed Activity
Relative Atlantic Temperature

Vecchi, Swanson and Soden (2008, Science)
My current interpretation of evidence

• Observations:
  – Data issues and short records
  – We will never know how many storms we didn’t see, or what they were like. We can only estimate it.

• Multiple factors affect change in hurricane activity:
  – Pattern of temperature changes is key.

• Projected changes depend on measure chosen, e.g.:
  – Atlantic TC Frequency: small change, possible decrease
  – Atlantic TC Intensity: projected increase

• Year-to-year and decade-to-decade variations will still exist.
• Increased coastal population and wealth: increased vulnerability
• Sea level rise: same storm greater potential impact.
• This is a topic of vigorous scientific inquiry.

Gabriel.A.Vecchi@noaa.gov

www.gfdl.noaa.gov
Key concepts

- Established vs. Developing understanding
  - Multiple factors impact hurricanes
  - Observational uncertainties
  - Pushing the limits of our theory and computers

- False choice: global warming OR climate variability

- Not about one storm or one season (“Katrina effect”).

- How do we develop our understanding?
  - Observations
  - Theoretical understanding
  - Numerical Modeling

- As we learn more, interpretation of total evidence changes: this is how science works

- Interpretations of sum of evidence can differ between scientists: not a “debate” - an ongoing inquiry.

www.gfdl.noaa.gov
Gabriel.A.Vecchi@noaa.gov