Climate Change Risks and Opportunities for Actuaries

Rob Erhardt, Ph.D., A.C.A.S.
Wake Forest University

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Overview

1. **Background on Measuring and Projecting Climate Change**
2. Insurance: Mitigation, Adaptation, or Geoengineering?
3. Weather Derivatives as a Risk Management Tool

Weather and Climate

"Climate is what we expect, weather is what we get." Robert Heinlein.

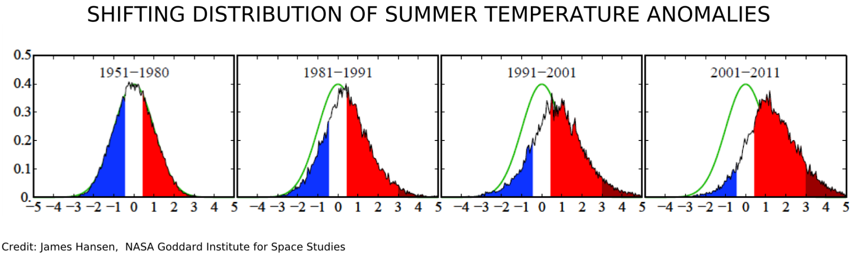
(image: Monument Valley)

Weather and Climate

Climate change is "any systematic change in the long-term statistics of climate elements (such as temperature, pressure, or winds) sustained over several decades or longer." American Meteorological Association.

(image: Glacier National Park)

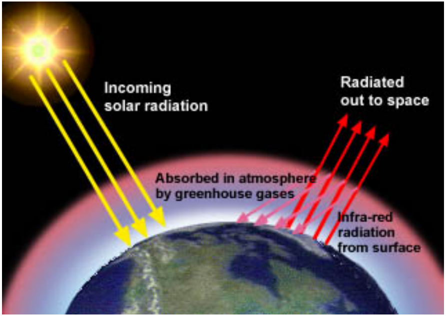
Weather and Climate



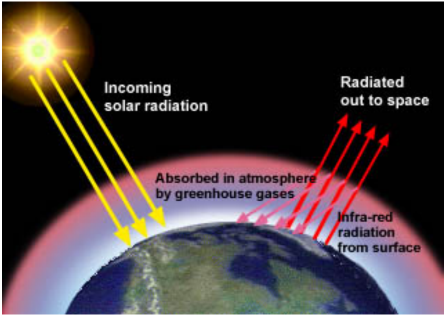
(Image credit: NASA/GISS).

“Climate is the distribution of weather.”
American Statistical Association, 2010.

Energy:


Incoming
solar radiation
Radiated
out to space
Absorbed in atmosphere
by greenhouse gases
Infra-red
radiation
from surface

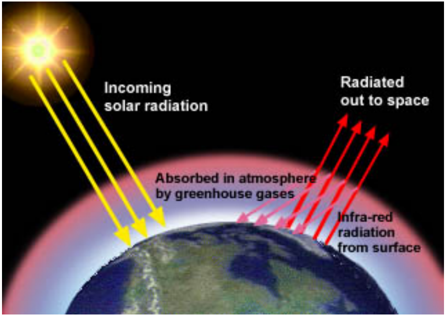
What goes in...



$$S \cdot \pi r^2 (1 - a) =$$

- $S = 1360 \; W/m^2$ is the solar constant.
- $r = 6400 \; km$ is the radius of the earth
- a is the earth's albedo (reflectivity)

... must go out.



$$= 4\pi r^2 \cdot \epsilon \cdot \sigma \cdot T^4$$

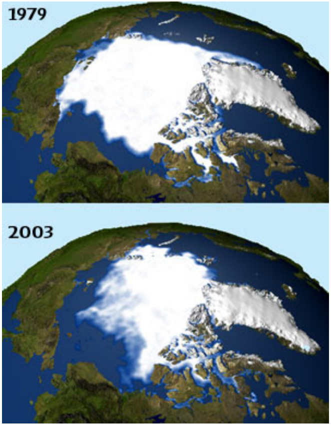
- ϵ is the *emissivity* (transparency of atmosphere)
- σ is the *Stefan-Boltzman* constant
- T is temperature

Conservation of Energy

$$T^4 = \frac{S(1-a)}{4\epsilon \cdot \sigma}$$

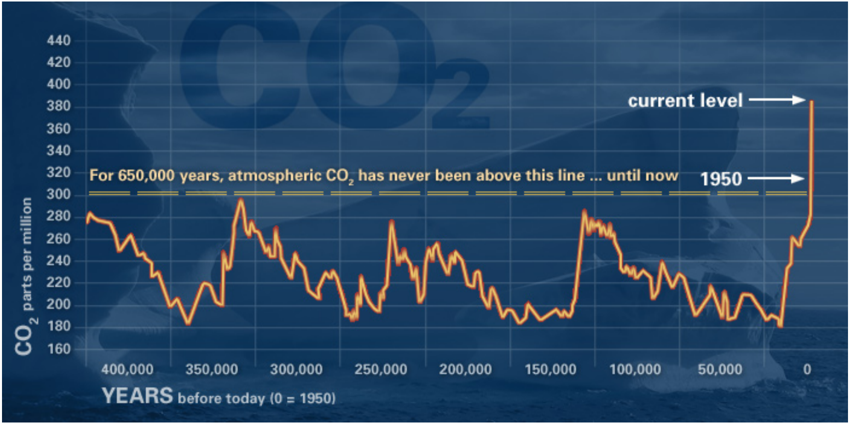
- Plug in actual a, σ, ϵ, S, get $T = 14.8^\circ C \quad (58^\circ F)$
- Start changing stuff:
  - If S went up 1%, T goes up $0.7^\circ C \quad (1.3^\circ F)$
  - If a went down 1%, T goes up $0.3^\circ C \quad (0.55^\circ F)$
  - If ϵ went down 1%, T goes up $0.7^\circ C \quad (1.3^\circ F)$

Why Would the Albedo Change?



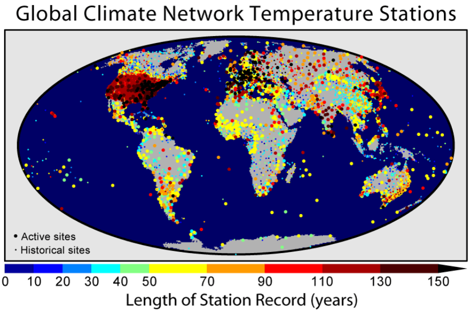
(source: NASA/Goddard Space Flight Center)

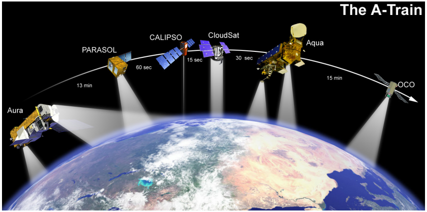
Why Would the Emissivity Change?



(source: NASA)

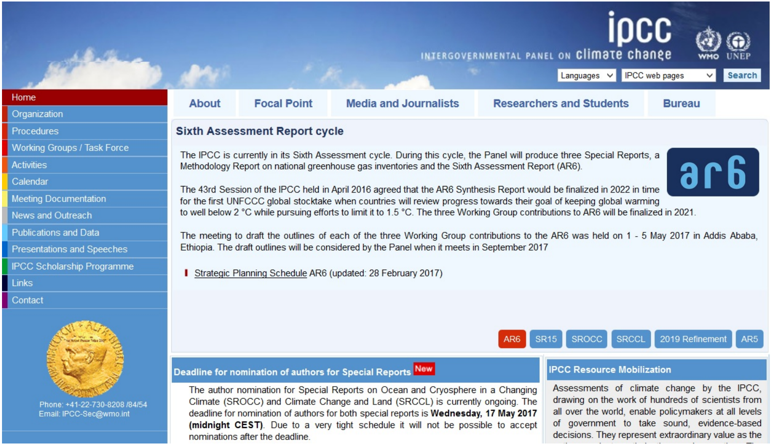
Where does data come from?





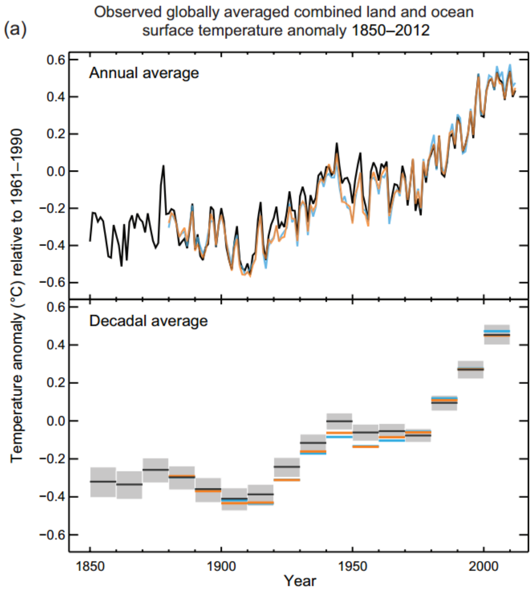
(sources: National Center for Atmospheric Research, NASA)

Who oversees this science?

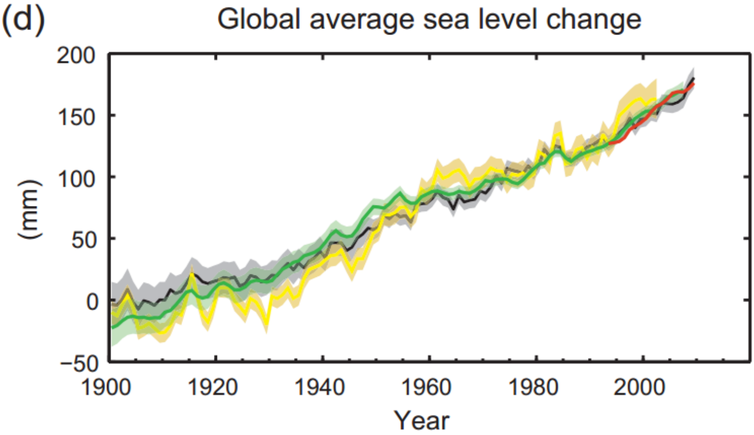


(www.ipcc.ch)

Global surface temperatures have been rising...



… and sea levels have been rising.



(source: IPCC AR5 2014)

Conclusions:

"Warming of the climate system is unequivocal." (IPCC, 2007)

"It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century."

[WGI AR5 SPM Section D.3, 2.2, 6.3, 10.3-6, 10.9]

How Does the IPCC Attribute the Change to Humans?

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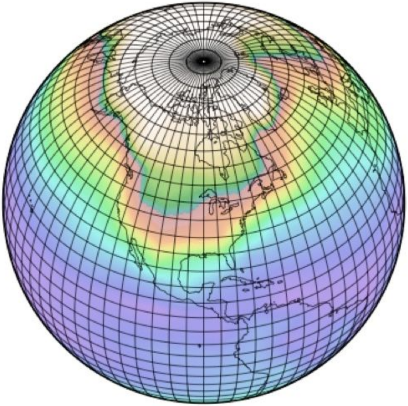

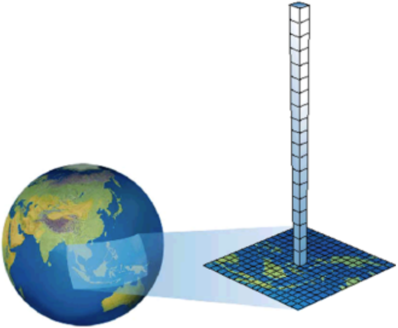

How Does the IPCC Attribute the Change to Humans?

1. Discretize space on earth ($\approx 66,000$ grid cells on surface, times 20 layers is 1.32 million cells.)
2. Discretize time to 3-hour intervals (8 per day, 2920 per year)
3. Model relationship of climate variables (temperature, pressure, wind, atmospheric carbon content, etc.) as **partial differential equations** in discretized time and space.
4. Run under 4 different **scenarios** of atmospheric CO2.

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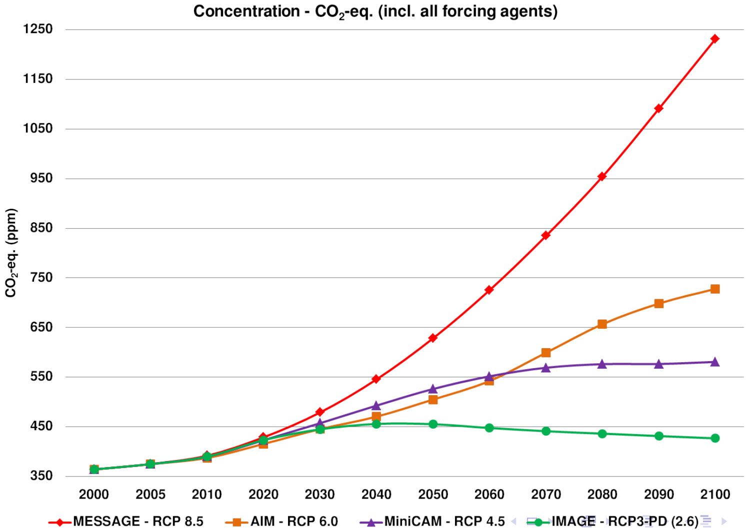

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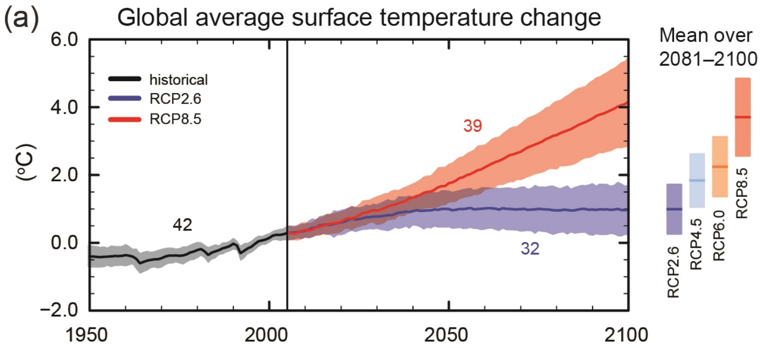

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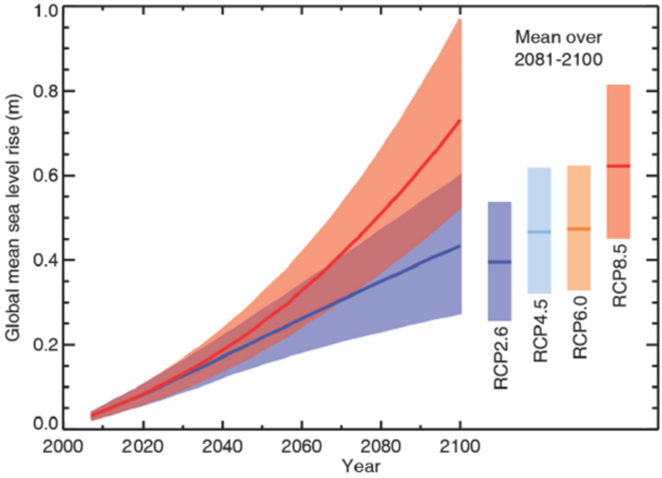

(source: IPCC AR5 2014)

How Does the IPCC Attribute the Change to Humans?

1. Only changing input across model runs is the emissions scenario
2. Difference *across* scenarios is very large as compared to the (random) difference *within* a scenario
3. Changes are projected for multiple climate variables, over periods of many decades.

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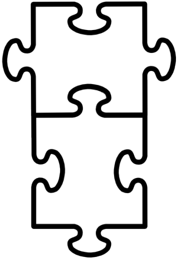
Mitigation, Adaptation and Geoengineering



- **Mitigation**: addressing the *causes* of climate change. Attempting to slow or stop the changes themselves.
- **Adaptation**: addressing the *consequences* of climate change. Attempting to minimize the impacts.
- **Geoengineering**: actively intervening in the climate system to modify it

Mitigation, Adaptation, and Geoengineering

- "Climate change as the ultimate ERM challenge" Mills (2009)
- " "Green" customers tend to present better risk profiles, which can be translated into lower rates." (AXA Response to 2006 Carbon Disclosure Project Survey)

Mitigation, Adaptation, and Geoengineering

"Certain measures that integrate climate change mitigation and adaptation can simultaneously reduce insurance losses." Mills (2005)

"Insurance is a form of adaptive capacity." Mills (2005)

- "Can insurers extend their self-chosen historical role in addressing root causes (as founders of the first fire departments, building codes, and auto safety testing protocols) to one of preventing losses at a much larger scale, namely, the global climate?" Mills (2005)

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Index-Based Insurance

Index-Based Insurance

Climate Risk Adaptation and Insurance in the Caribbean

ABOUT THE PROJECT

The Climate Risk Adaptation and Insurance in the Caribbean project seeks to address climate change, adaptation and vulnerability by promoting *weather-index based insurance as a risk management instrument in the Caribbean*. The project has developed two parametric weather-index based risk insurance products *aimed at low-income individuals and lending institutions exposed to climate stressors.*

TIME-FRAME:	2011–2014
COUNTRIES:	Jamaica, St. Lucia, Grenada, Belize, Guyana
BENEFICIARIES:	Low-income individuals, financial institutions
GOAL:	Managing and transferring risks associated with extreme weather events

THE LIVELIHOOD PROTECTION POLICY (LPP):
Targeted at individuals, this product helps protect the livelihoods of vulnerable low-income individuals by providing swift unbureaucratic cash payouts following extreme weather events (i.e. high wind speed and heavy rainfall). This crucial support will reduce poverty and vulnerability by enabling these groups to recover quickly following a disaster.

www.climate-insurance.org

Degree Days

- Captures the amount of energy needed for cooling or heating.
- Call $\bar{T}$ the average temperature on a day (deg F).

$$\begin{array}{ll} \text{Cooling Degree Day} & CDD = \max\left(0, \bar{T} - 65\right) \\ \text{Heating Degree Day} & HDD = \max\left(0, 65 - \bar{T}\right) \end{array}$$

- **Example**: If May 23, 2017 has $\bar{T} = 62$, it contributes 0 CDDs and 3 HDDs.

Degree Days

- Next, take a running sum over some time period $\mathcal{D}$:

$$cHDD = \sum_{t \in \mathcal{D}} \max\left(0, 65 - \bar{T}_t\right)$$

Can be weeks, months, several months, or longer.

- **Example**: Consider the November 1 - Feb 28 HDD Index at Atlanta Hartsfield International Airport

In 2012-13, it was **1784.5**
In 2013-14, it was **2328.0**.

Temperature Derivatives

1. Weather reporting station
2. Well-defined time period
3. Payment attached to settled index value

$$\begin{aligned} P &= 1000 \cdot \max\left(cHDD - 2000, 0\right) \\ &= 1000 \cdot \max\left(\sum_{t \in \mathcal{D}} \max\left(65 - \bar{T}_t, 0\right) - 2000, 0\right). \end{aligned}$$

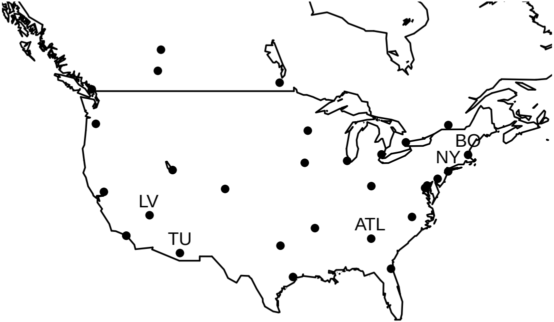
Payment is \$1000 for each additional HDD over 2000 in the period from November 1 through Feb 28, and 0 otherwise.

In 2012-13, payment would have been \$0.
In 2013-14, payment would have been \$328,000.

The Research Question

- How do you estimate distributions of payments? Once you have it, all actuarial pricing quantities (expected value, variance, VaR, CTE, ES, ...) are available.
- How do you incorporate spatial dependence of weather derivatives? How does this impact portfolio performance?


The Data



- Daily temperature from the National Climate Data Center (`http://www.ncdc.noaa.gov/cdo-web/`)

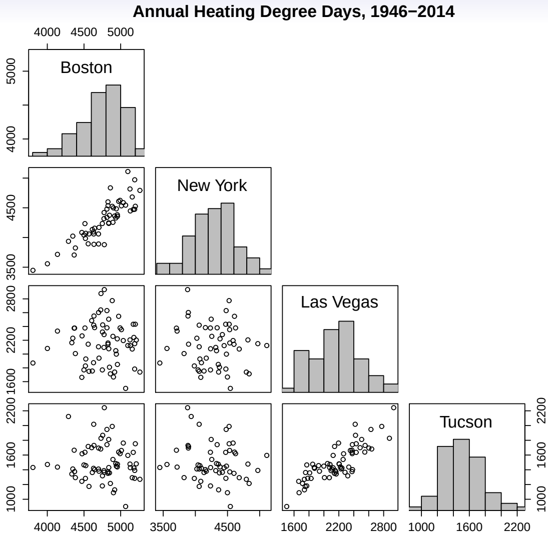


Figure: October-March cumulative heating degree days.

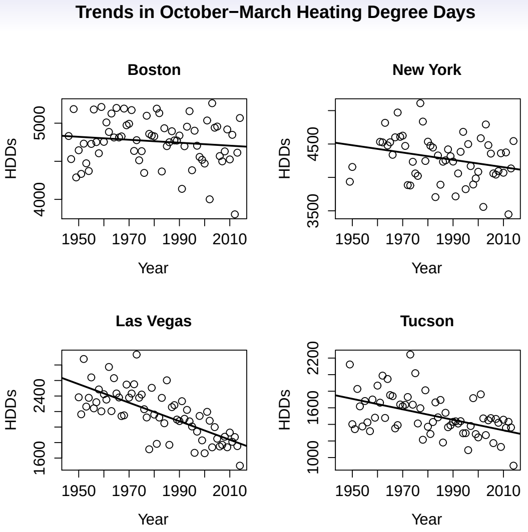


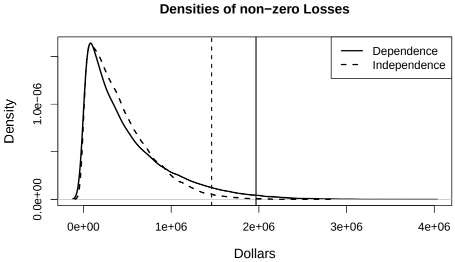
Figure: October-March cumulative heating degree day trends.

Pricing Model

- For a single location, call X_i the annual cHDDs for year i. Model as
$$X \sim \mathcal{N}\left(\mu_X, \sigma_X\right),$$
- Then
$$b\left(X - E\right) \sim \mathcal{N}\left(b\left(\mu_X - E\right), b\sigma_X\right),$$
where E is the entry level and b is the payment per degree day exceedance.
- Estimate $\widehat{\mu}_X$ and variance $\widehat{\sigma}_X$.
- Simulate outcome then payment
$$R_i \sim \mathcal{N}\left(b\left(\widehat{\mu}_X - E\right), b\widehat{\sigma}_X\right), \qquad P_i = max(R_i, 0)$$
- Repeat last step M times: $P_1, P_2, ..., P_M$

Pricing Model

- Repeat with a spatial model using covariance matrix Σ
- Portfolio with BO, LV, NY, TU.
- Payment is \$20 for each cCDD over 865, 3723, 1148, and 3442.
- Obtain numeric estimates $\widehat{VaR}$, $\widehat{CTE}$, etc.



	Dependence		Independence	
α	$\widehat{VaR}$	$\widehat{CTE}$	$\widehat{VaR}$	$\widehat{CTE}$
0.90	958,804	1,406,799	822,520	1,229,679
0.95	1,294,455	1,702,666	1,036,317	1,533,535
0.99	1,967,233	2,293,387	1,460,644	2,183,935

In Summary

- Basic climate science literacy for past, observed data.
- Rationale behind claim that anthropogenic greenhouse gas emissions is the cause
- Types of responses, and "insurance as adaptive capacity"
  - Weather derivatives as one tool to manage weather risk.

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Thanks.

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