# Extreme Weather:

## Causes, Effects, and Connections With Climate

Ethan Butler, Harvard University
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Andy Rhines, Harvard University

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# Roadmap for the evening

1. Types and impacts of extreme weather

2. Storms, rain, and climate change: observations and expectations

3. Heat waves: causes and connections with climate change

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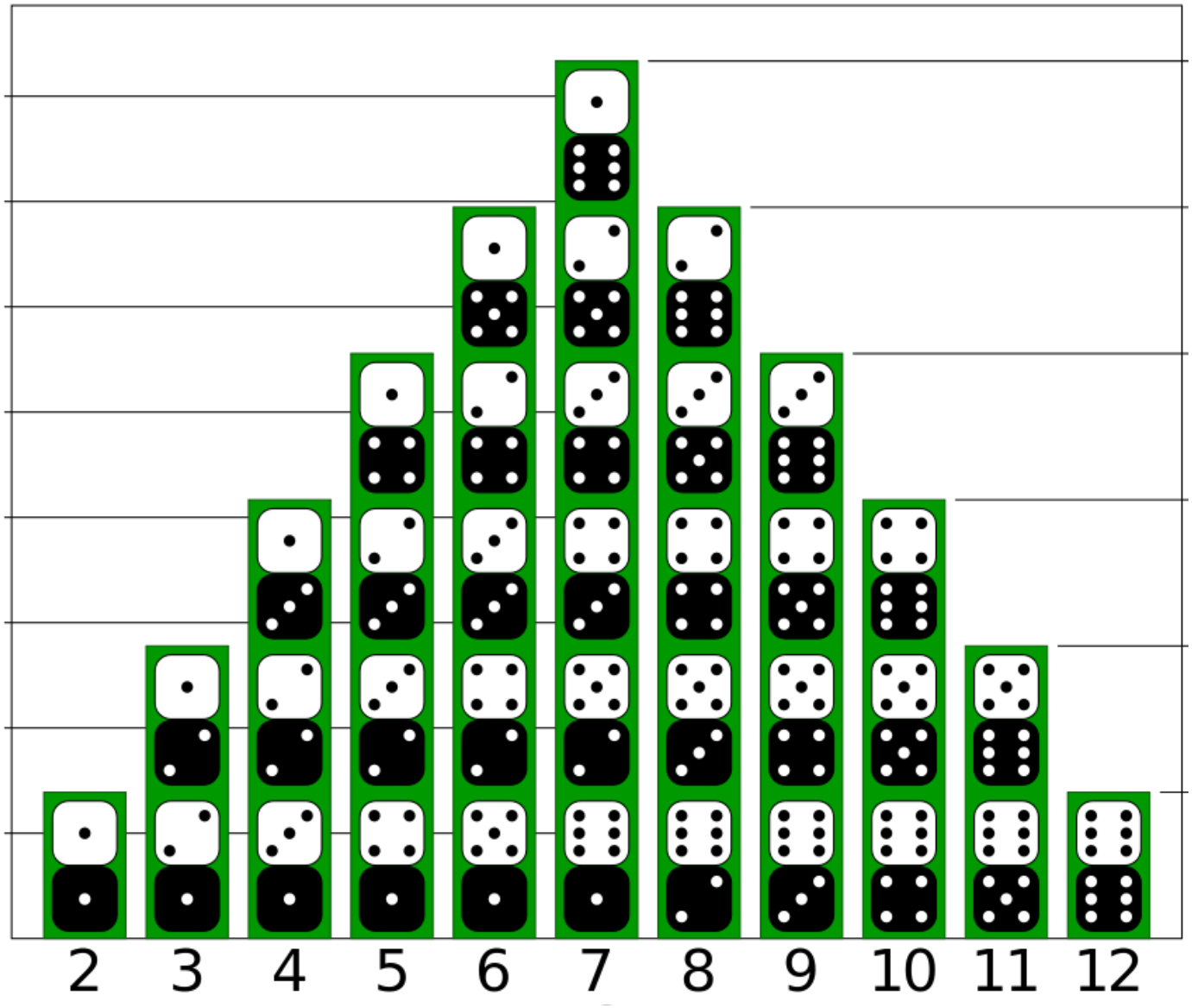
# Dicing with Extremes




Wikimedia (http://commons.wikimedia.org/wiki/File:Dice_Distribution_(bar).svg)

# Biological temperature extremes

## NOAA's National Weather Service

### Heat Index

Temperature (°F)

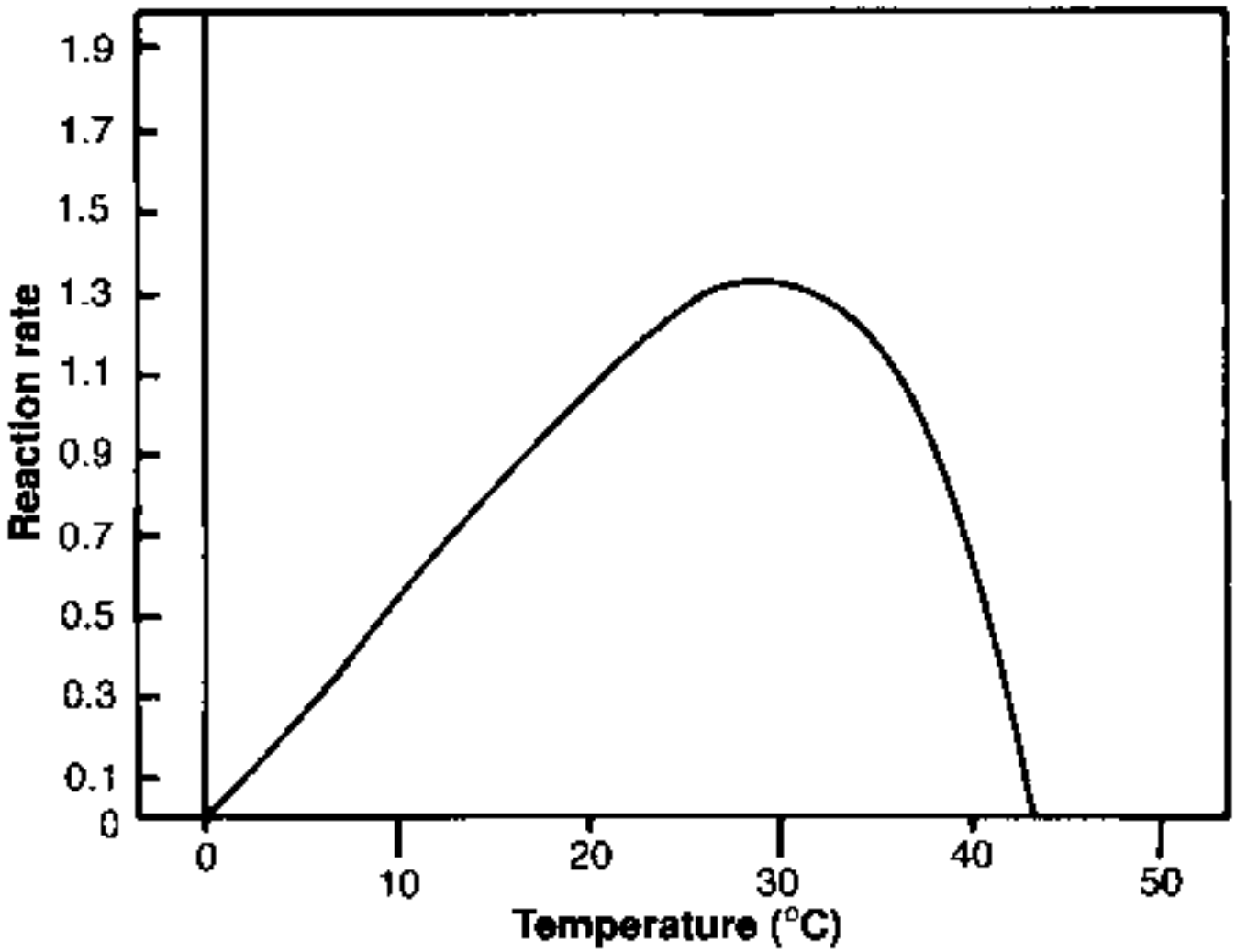
| Relative Humidity (%) | 80 | 82 | 84 | 86 | 88 | 90 | 92 | 94 | 96 | 98 | 100 | 102 | 104 | 106 | 108 | 110 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 40 | 80 | 81 | 83 | 85 | 88 | 91 | 94 | 97 | 101 | 105 | 109 | 114 | 119 | 124 | 130 | 136 |
| 45 | 80 | 82 | 84 | 87 | 89 | 93 | 96 | 100 | 104 | 109 | 114 | 119 | 124 | 130 | 137 | |
| 50 | 81 | 83 | 85 | 88 | 91 | 95 | 99 | 103 | 108 | 113 | 118 | 124 | 131 | 137 | | |
| 55 | 81 | 84 | 86 | 89 | 93 | 97 | 101 | 106 | 112 | 117 | 124 | 130 | 137 | | | |
| 60 | 82 | 84 | 88 | 91 | 95 | 100 | 105 | 110 | 116 | 123 | 129 | 137 | | | | |
| 65 | 82 | 85 | 89 | 93 | 98 | 103 | 108 | 114 | 121 | 128 | 136 | | | | | |
| 70 | 83 | 86 | 90 | 95 | 100 | 105 | 112 | 119 | 126 | 134 | | | | | | |
| 75 | 84 | 88 | 92 | 97 | 103 | 109 | 116 | 124 | 132 | | | | | | | |
| 80 | 84 | 89 | 94 | 100 | 106 | 113 | 121 | 129 | | | | | | | | |
| 85 | 85 | 90 | 96 | 102 | 110 | 117 | 126 | 135 | | | | | | | | |
| 90 | 86 | 91 | 98 | 105 | 113 | 122 | 131 | | | | | | | | | |
| 95 | 86 | 93 | 100 | 108 | 117 | 127 | | | | | | | | | | |
| 100 | 87 | 95 | 103 | 112 | 121 | 132 | | | | | | | | | | |

**Likelihood of Heat Disorders with Prolonged Exposure or Strenuous Activity**

Caution | Extreme Caution | Danger | Extreme Danger

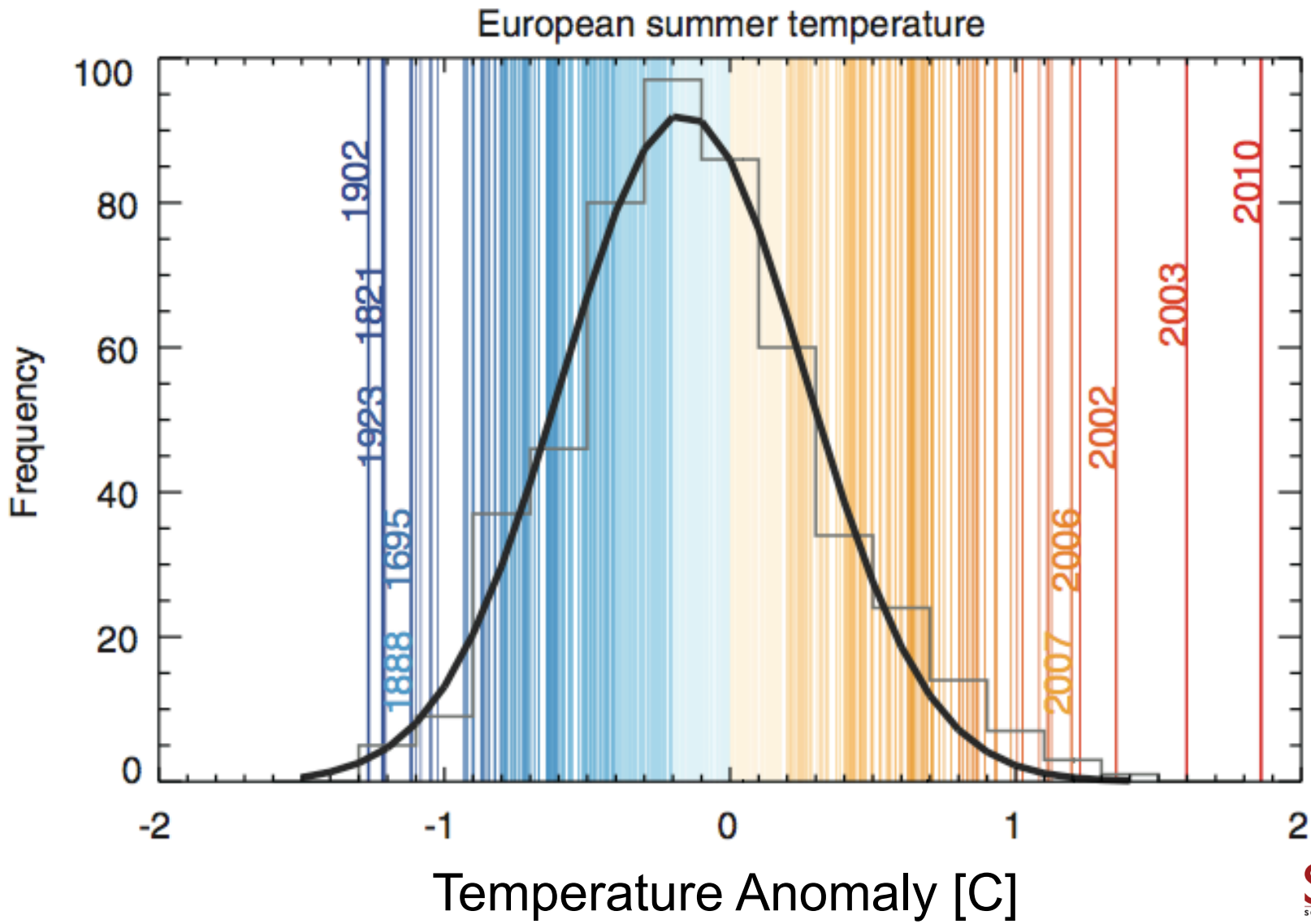
NOAA (http://www.nws.noaa.gov/om/heat/index.shtml)

# Plants and Temperature Stress




FAO (http://www.fao.org/docrep/w5183e/w5183e08.htm)

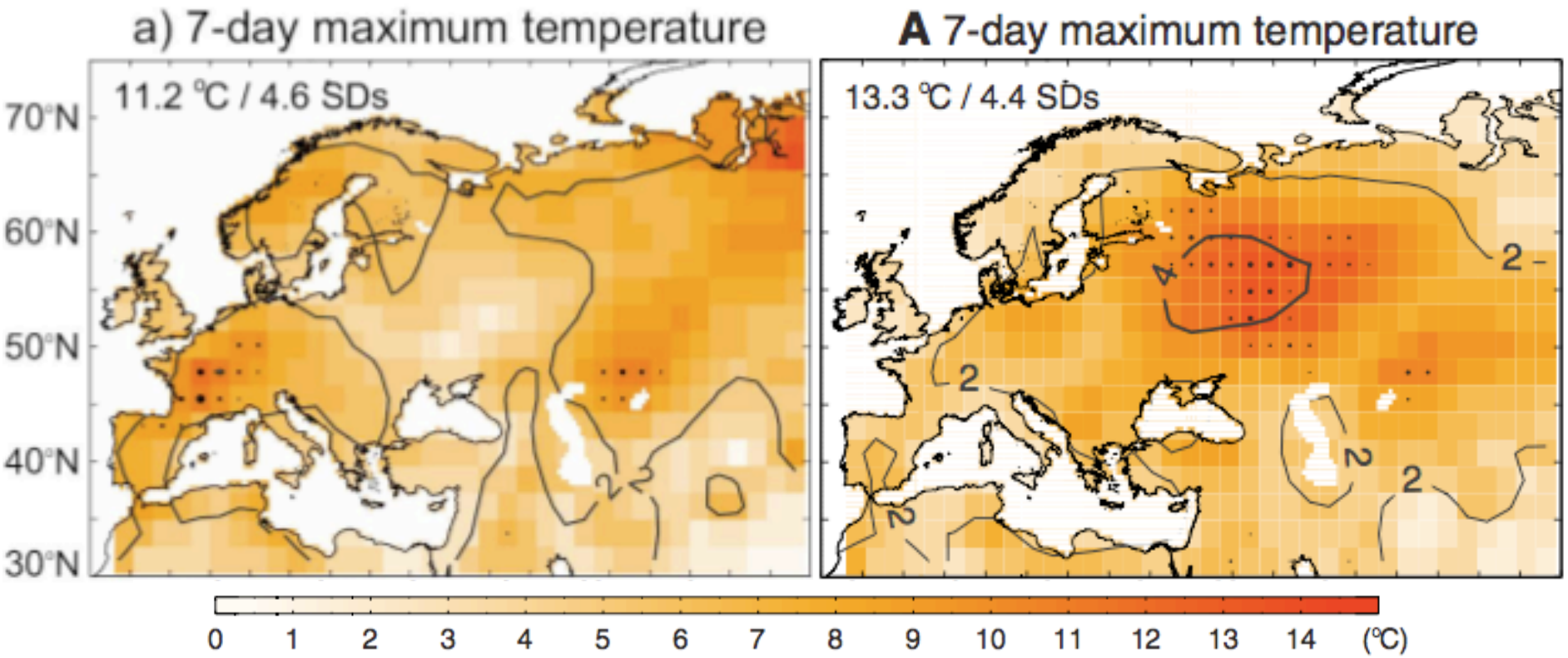
# Heat waves : Europe 2003 & 2010




Barriopedro, et al. (Science, 2011) Fig 2

# 2003 and 2010 Heat waves Mapped

2003 2010




Black dots indicate record breaking values

Barriopedro, et al. (Science, 2011) Fig 1a and S7a

# Impacts of European heat waves

- In 2003 more than 46,000 and as many as 70,000 people died
- Total EU wheat production declined by 10%
- In 2010 nearly 16,000 people died in the countries around western Russia
- Grain harvests declined by 20%

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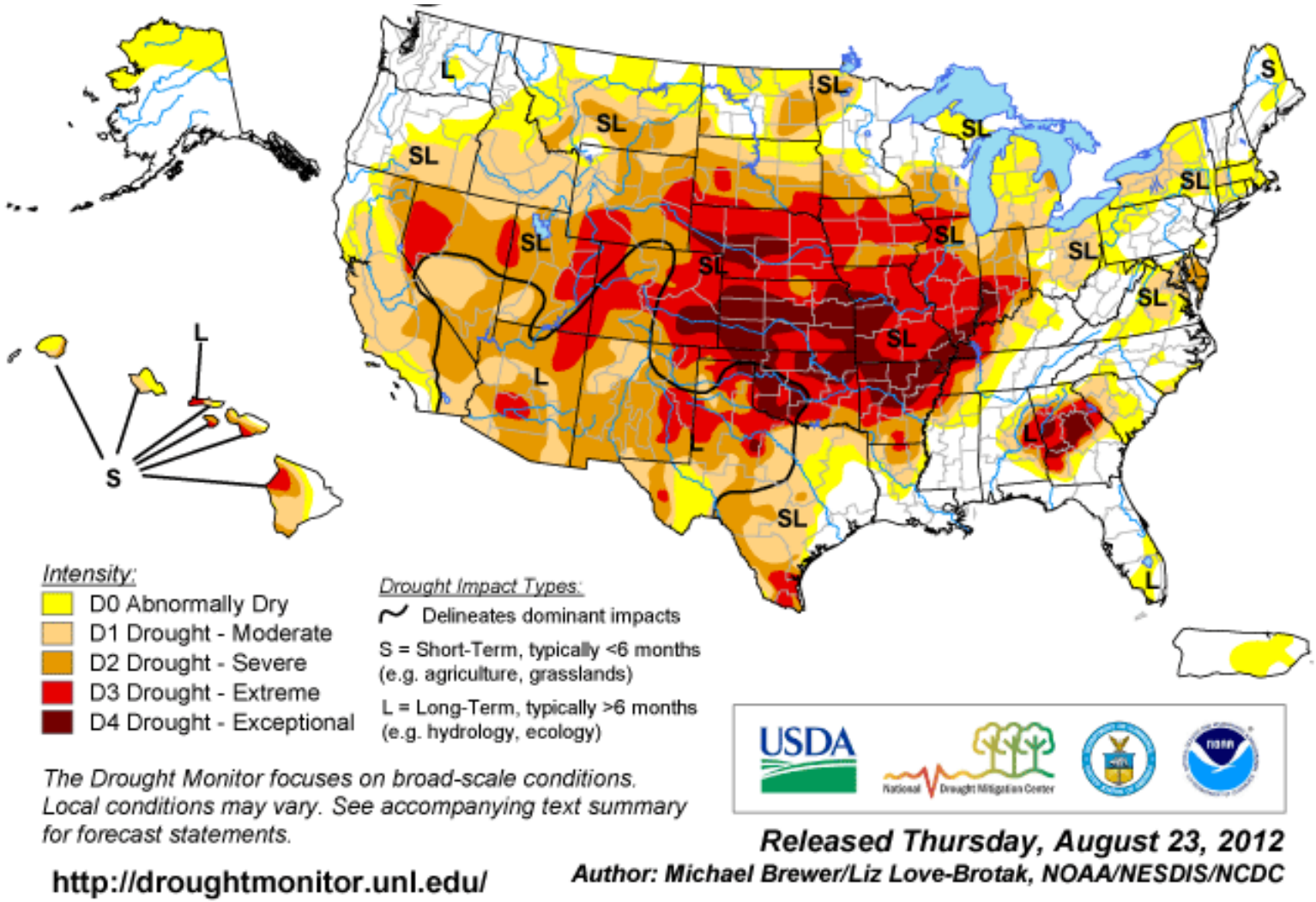
# American Heat wave 2012

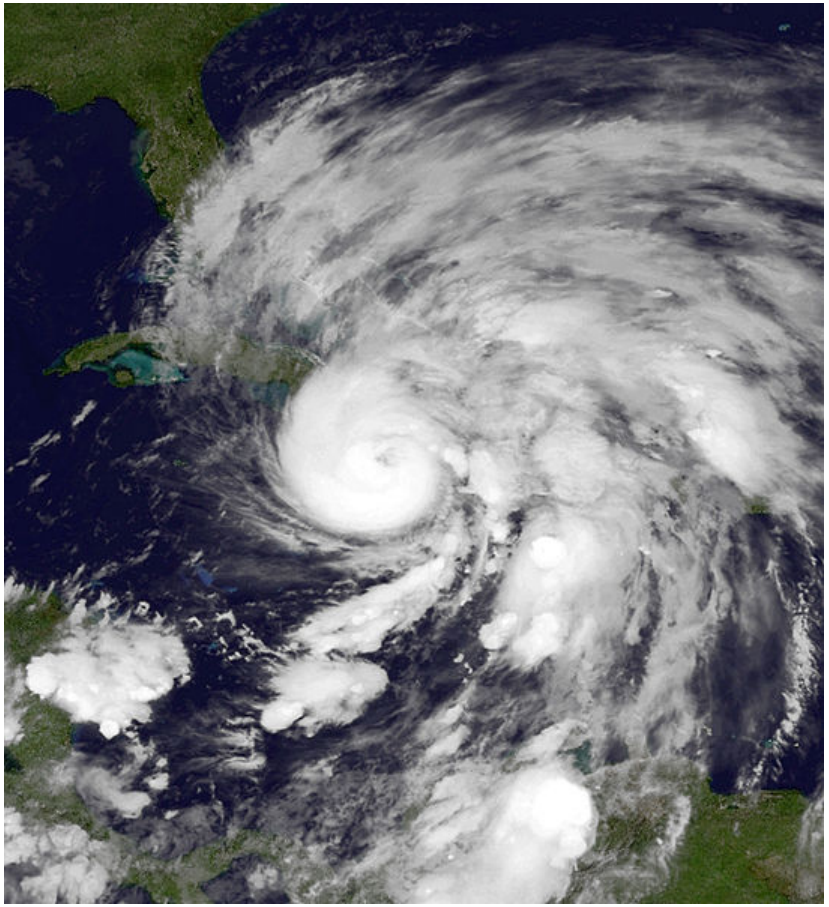



Over 80 deaths and corn yields declined by over 25%

# Hurricanes

Katrina: 2005

Sandy: 2012



NASA (visibleearth.nasa.gov/view.php?id=74693) and NOAA (en.wikipedia.org/wiki/File:Sandy_Oct_25_2012_0400Z.JPG)

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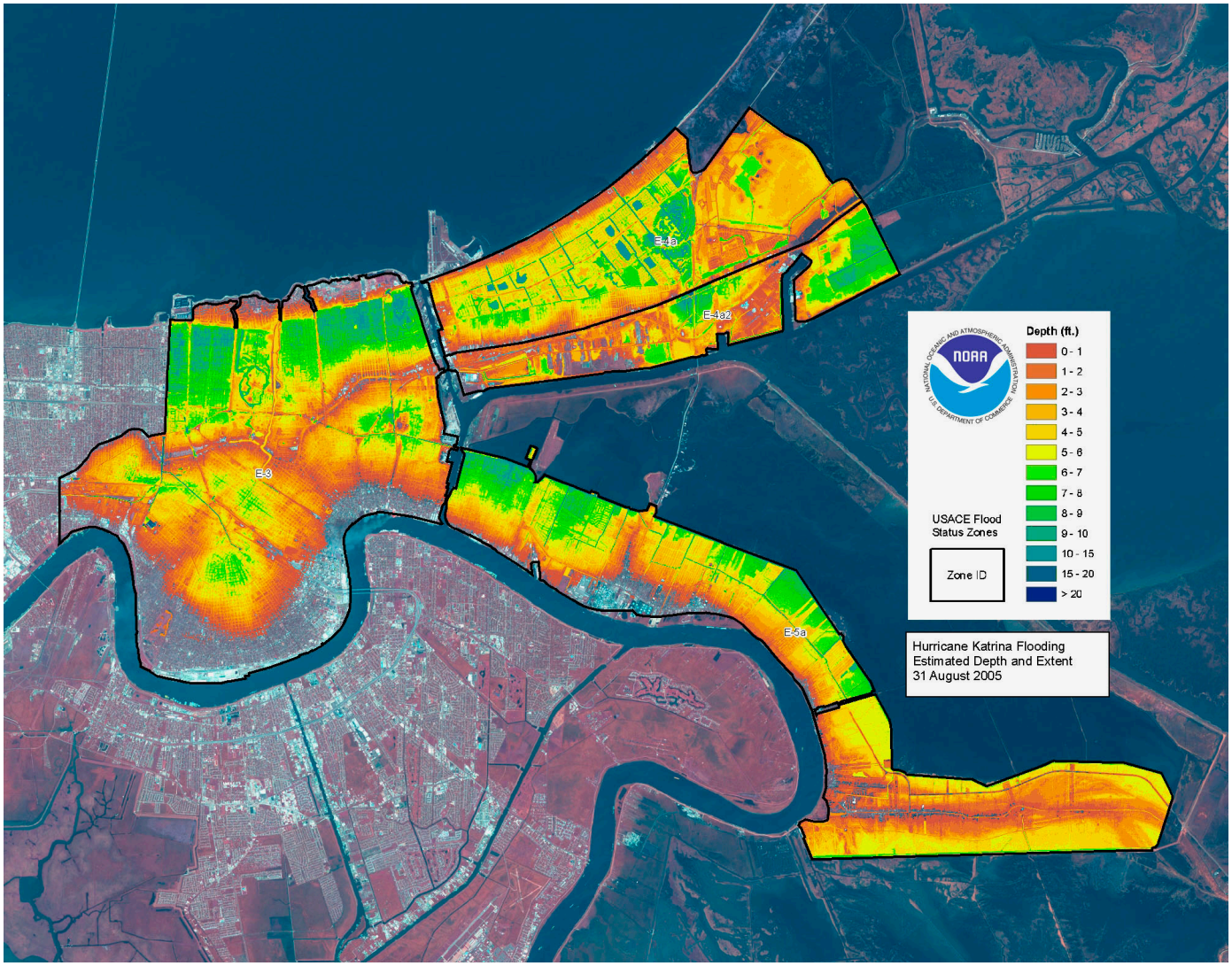
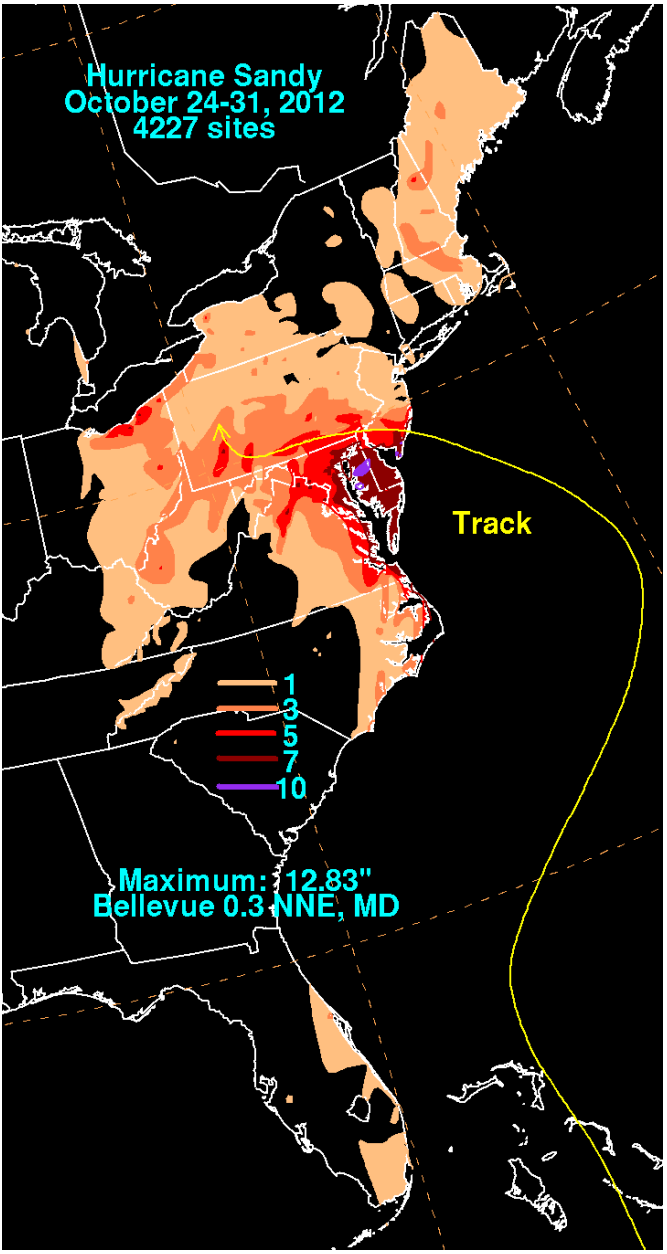
# Hurricanes: Katrina, New Orleans Flooding




Nearly 2000 deaths and over $100 billion in property damage

http://www.katrina.noaa.gov/maps/maps.html

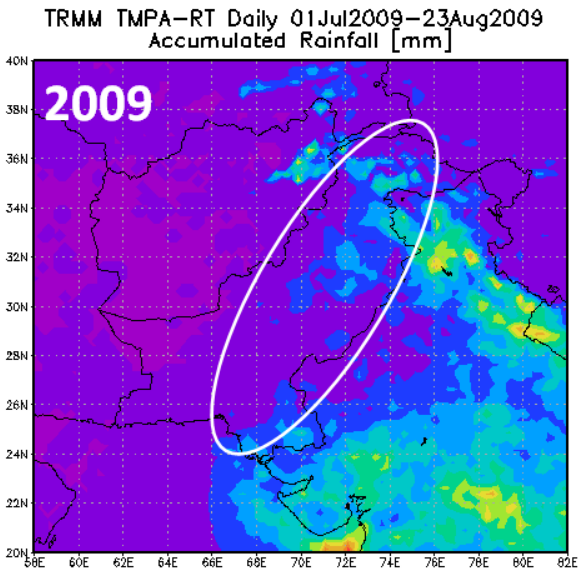


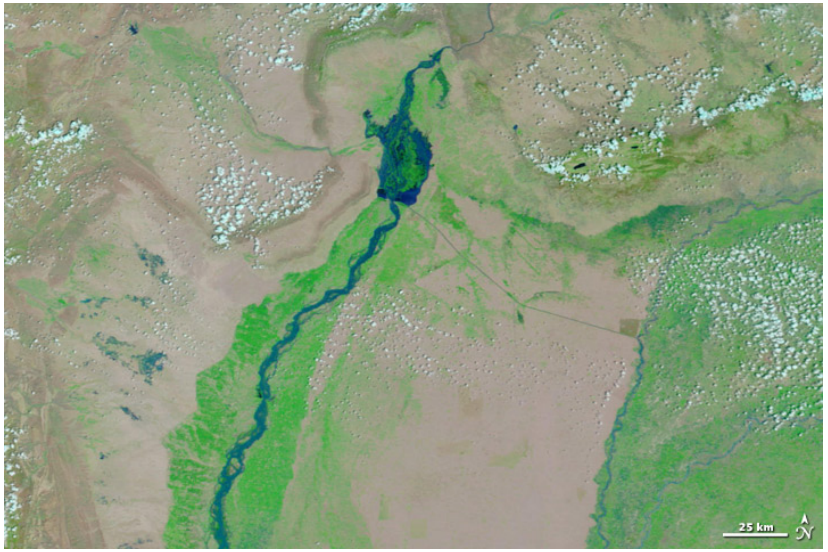

# Hurricanes: Sandy United States Rainfall

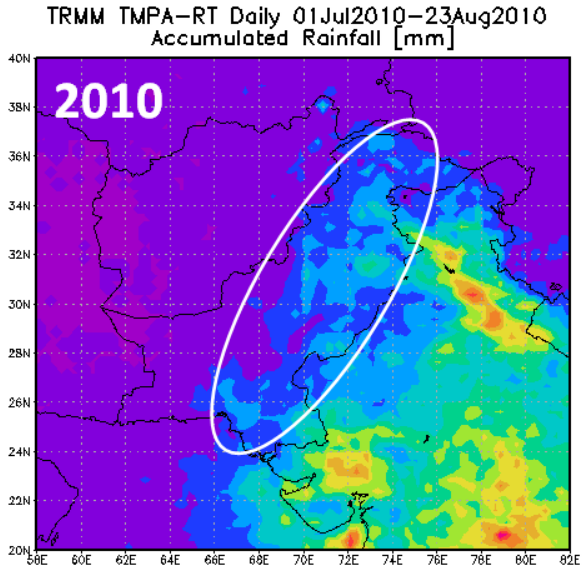
- Nearly 300 deaths (direct and indirect)
- Over $68 billion in damage (2nd after Katrina)
- Widespread death and damage across Caribbean nations as well as the US
- Largest Atlantic Hurricane on record (winds spanning 1800 kilometers)

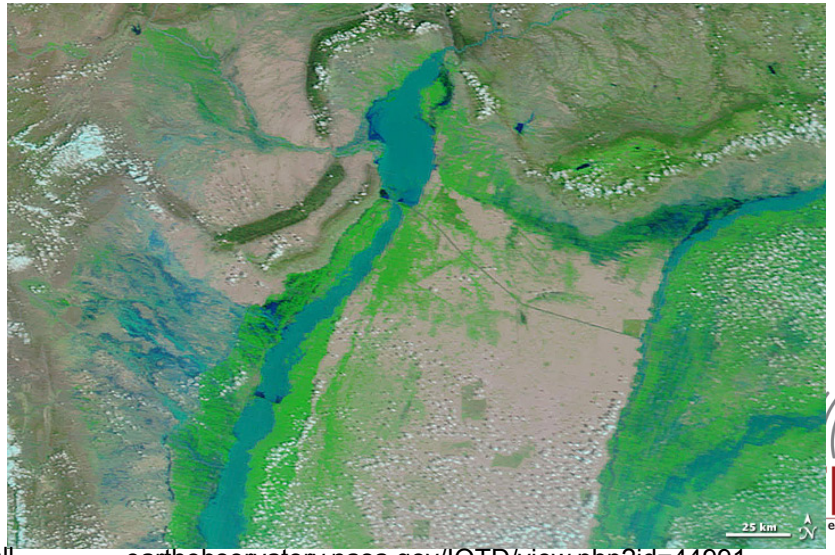
NOAA www.wpc.ncep.noaa.gov/tropical/rain/sandy2012filledrainblk.gif

# Flooding: Pakistan, 2010



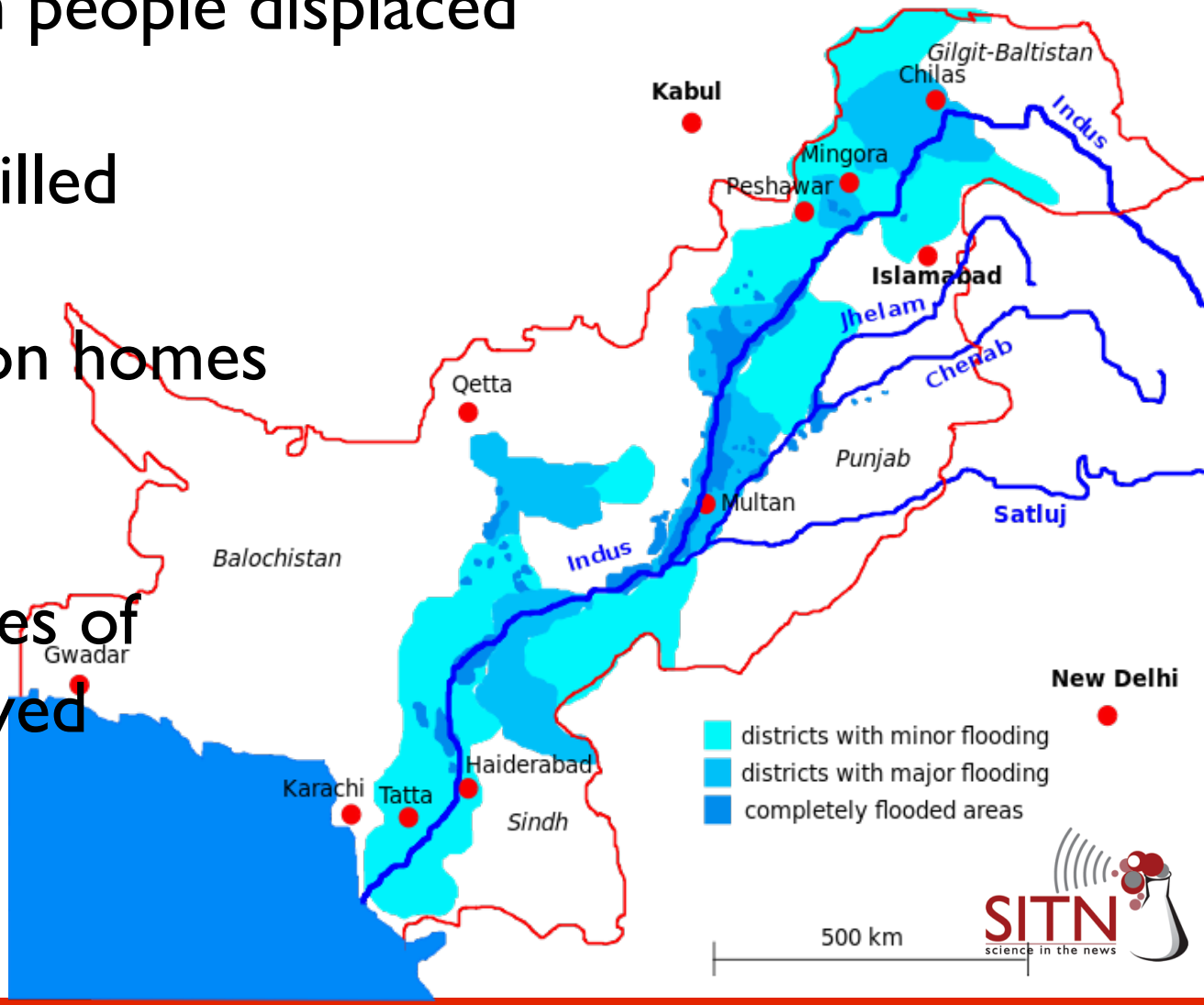




disc.sci.gsfc.nasa.gov/gesNews/pakistan_flooding_monsoon_rainfall

earthobservatory.nasa.gov/IOTD/view.php?id=44991

# Pakistan Flooding: Impacts

- Over 6 million people displaced
- Nearly 2000 killed
- Nearly 2 million homes destroyed
- 1.4 million acres of cropland destroyed




Wikipedia: en.wikipedia.org/wiki/File:Indus_flooding_2010_en.svg

# From Impacts to Understanding

- Heatwaves and hurricanes are responsible for widespread death and damage
- Understanding the physics and statistics behind their occurrence helps us to predict their behavior and (hopefully) minimize their effects
- Attribution of these events to global warming is challenging, but a changing climate only makes understanding these events harder

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# Storms, rain, and climate change: Observations and expectations

Karen McKinnon, Ph.D. student,
Department of Earth and Planetary Sciences
Harvard University

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# Outline

1. Recent extreme storms
2. Observed changes in heavy precipitation
3. Intermission: from probabilities to events
4. Connecting temperature and precipitation

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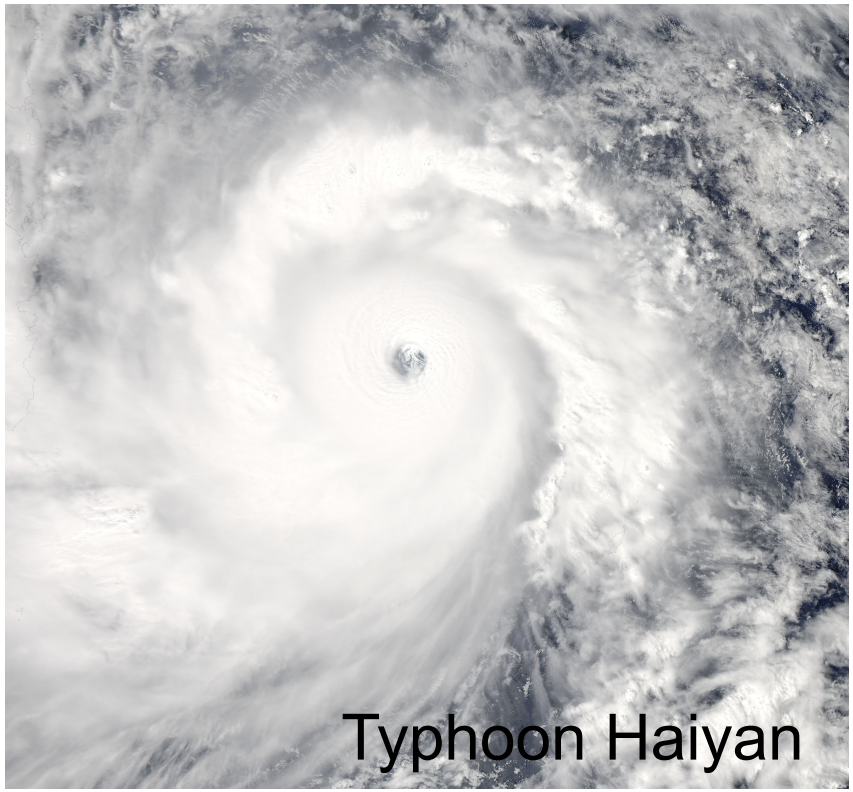
Is there a connection between storms and climate change?




http://en.wikipedia.org/wiki/Typhoon_Haiyan_(2013)

News for **storms climate change**


**Climate Change** Didn't Cause Supertyphoon Haiyan. But the **Storm** Is Still a Reason to Fight Warming
TIME - by Bryan Walsh - 1 hour ago
Some 6000 miles away from the Philippines, where 10000 people or more may have been killed by Supertyphoon Haiyan , the Filipino ...

Philippines blames **climate change** for monster typhoon
Grist - by John Upton - 5 hours ago

Philippines calls for **climate** justice after world's worst **storm**
eco-business.com - 11 hours ago

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# Defining a storm: extreme rain


http://en.wikipedia.org/wiki/Autumn_2000_western_Europe_floods


http://www.climate.gov/news-features/event-tracker/historic-rainfall-and-floods-colorado


http://en.wikipedia.org/wiki/2010%E2%80%9311_Queensland_floods

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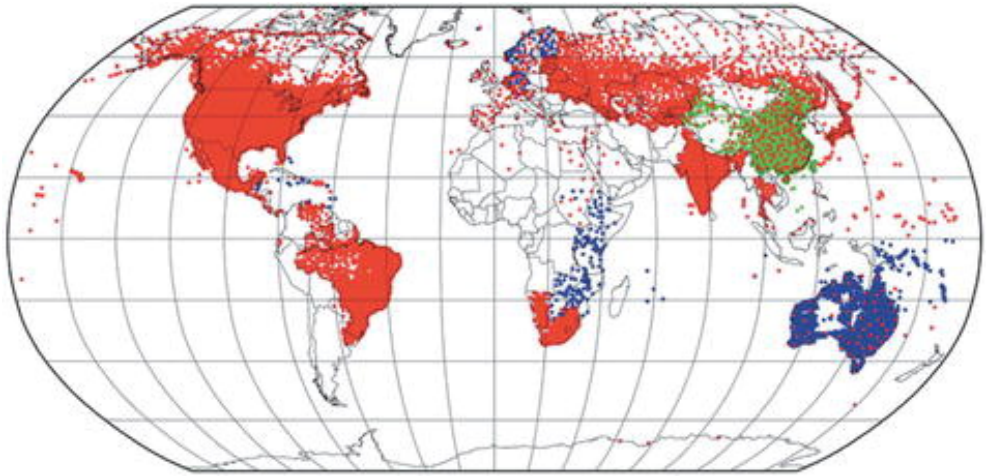
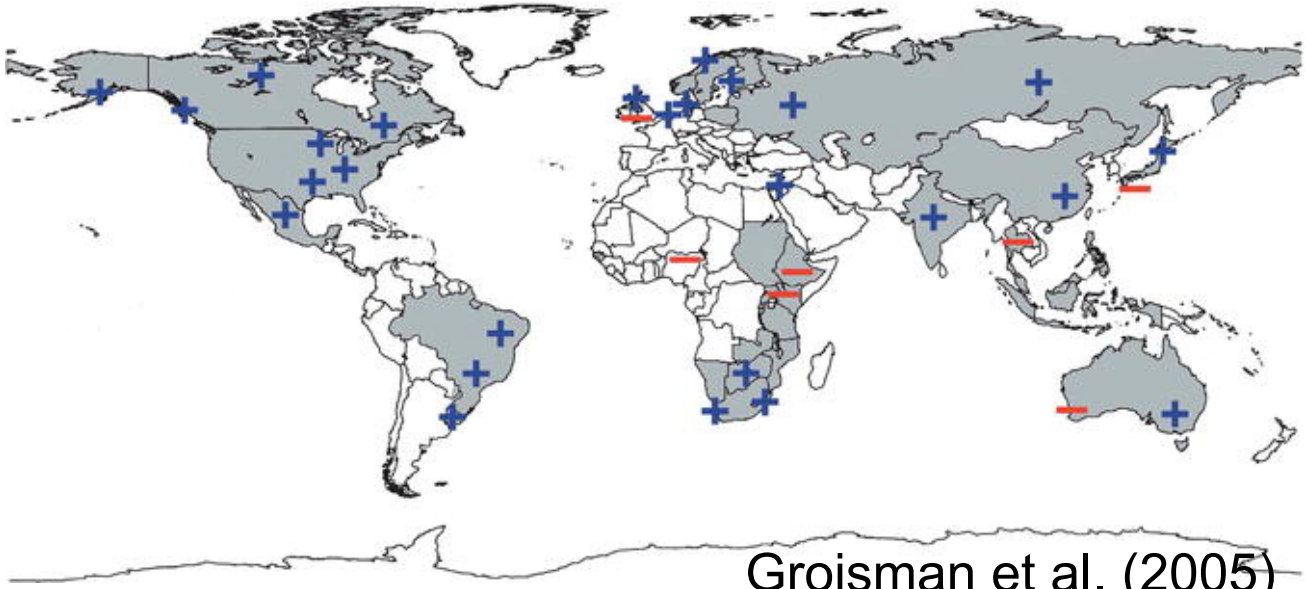
# Has heavy precipitation increased?



Where we are measuring



Where heavy precipitation has increased more than the mean

Groisman et al. (2005)

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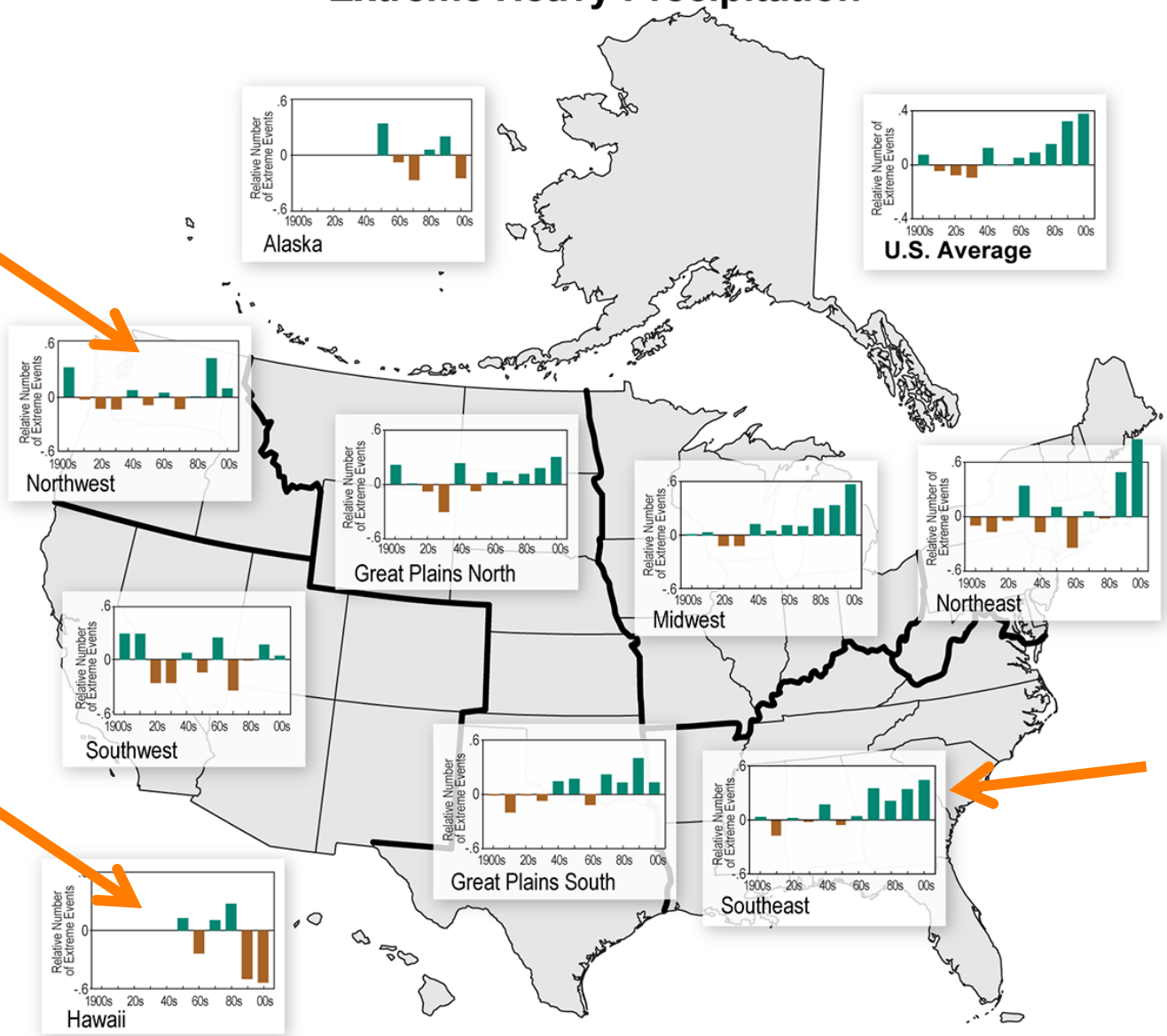
# Extreme Heavy Precipitation

Trend?




Less heavy precip

More heavy precip

Kunkel et al. (2013), U.S. National Climate Assessment.

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# Intermission: From probabilities to events

- Imagine someone tells you that you live in a floodplain that will be affected by the local 'ten-year flood'.
- Interpretation: every year, there is 10% chance of a flood of a certain size.

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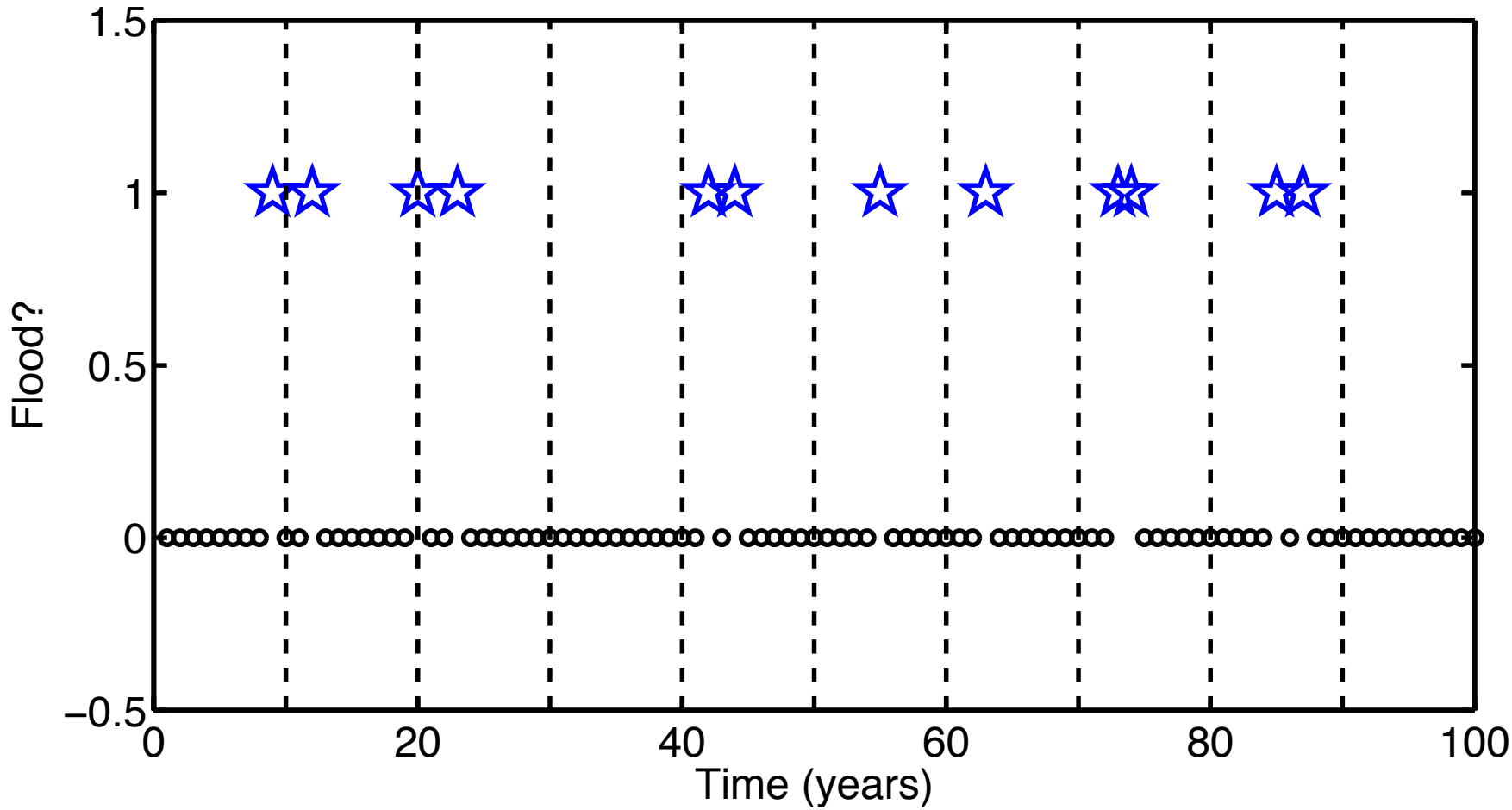
1.5
1
0.5
0
−0.5
Flood?
0
20
40
60
80
100
Time (years)

# Intermission: From probabilities to events

- Now, with some climate change, we expect that this 'ten-year flood' is going to become more common, a 'nine-year flood'
- What will our observations of the flood look like?

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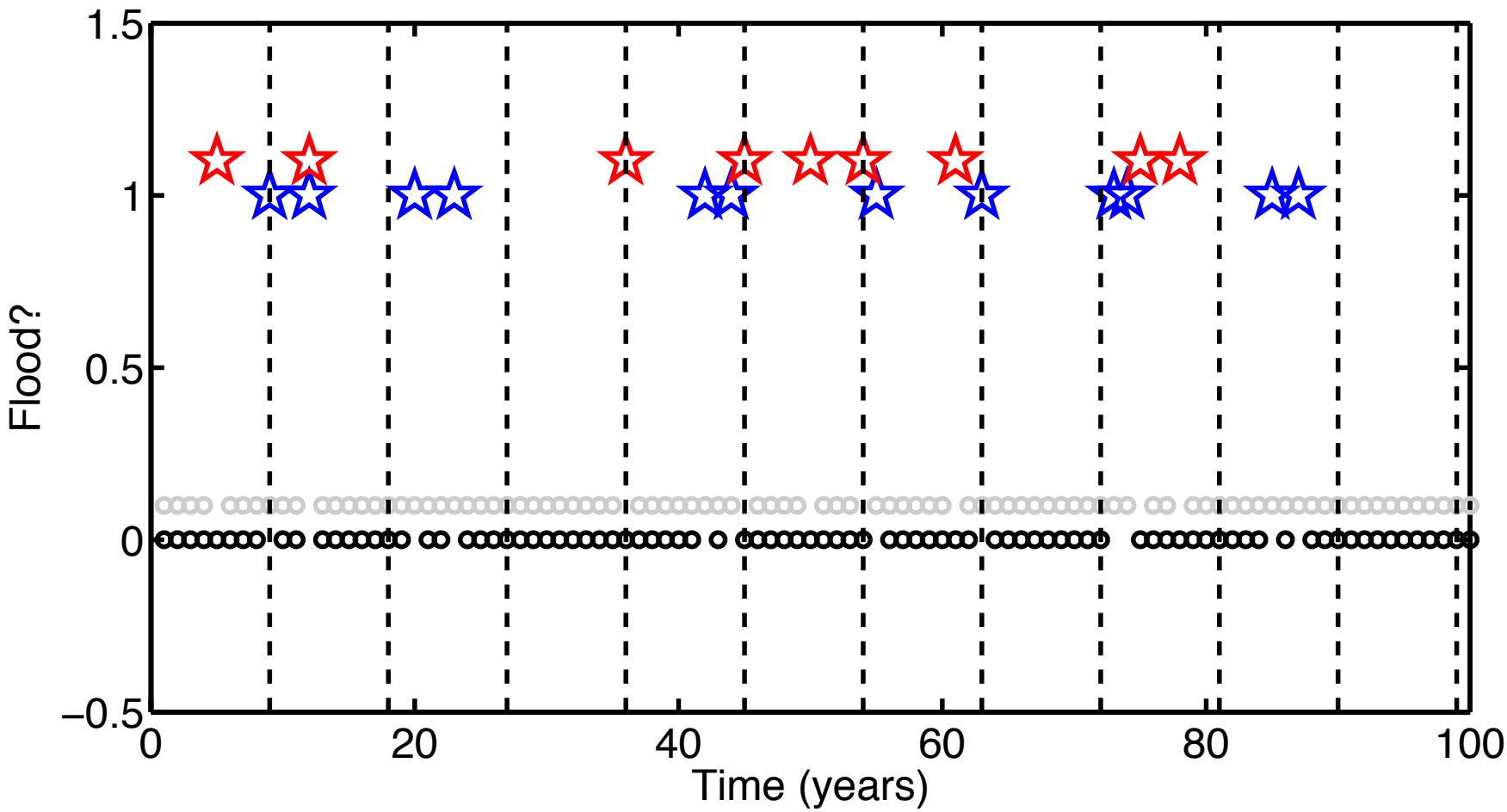


Can be challenging to detect changes in probability given a ‘short’ record!

# Ingredients for (extreme) precipitation

1. Abundant water vapor in the atmosphere
   a. Provide a source of water for the precipitation
2. Upward motion
   a. Atmosphere gets colder with height
   b. Water vapor condenses as air cools

Changes in extreme precipitation will depend on which component is the limiting factor

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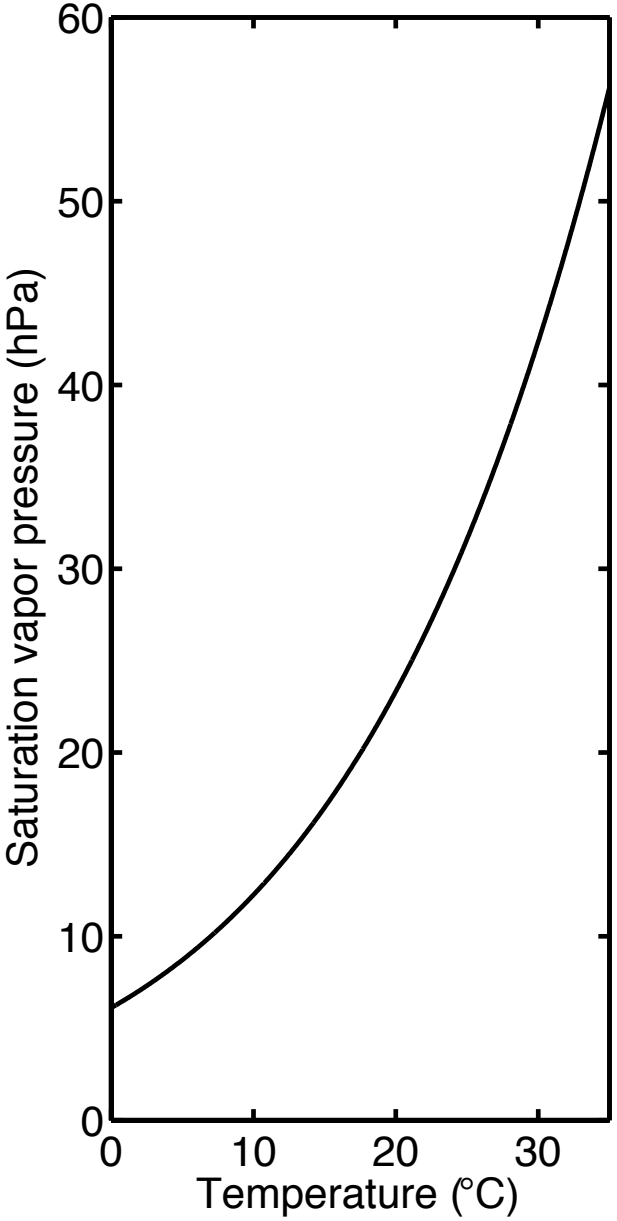
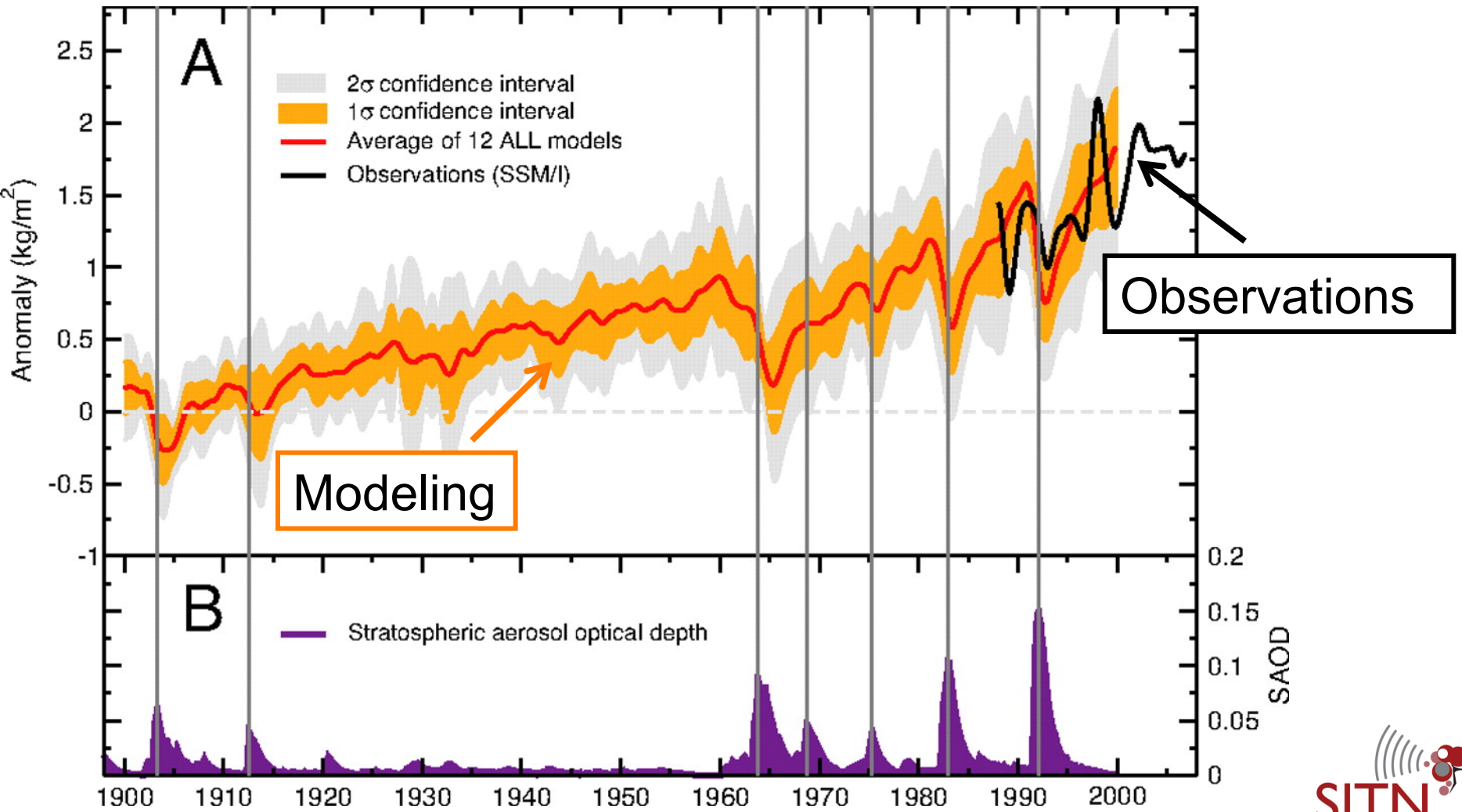



**Clausius-Clapeyron relationship**

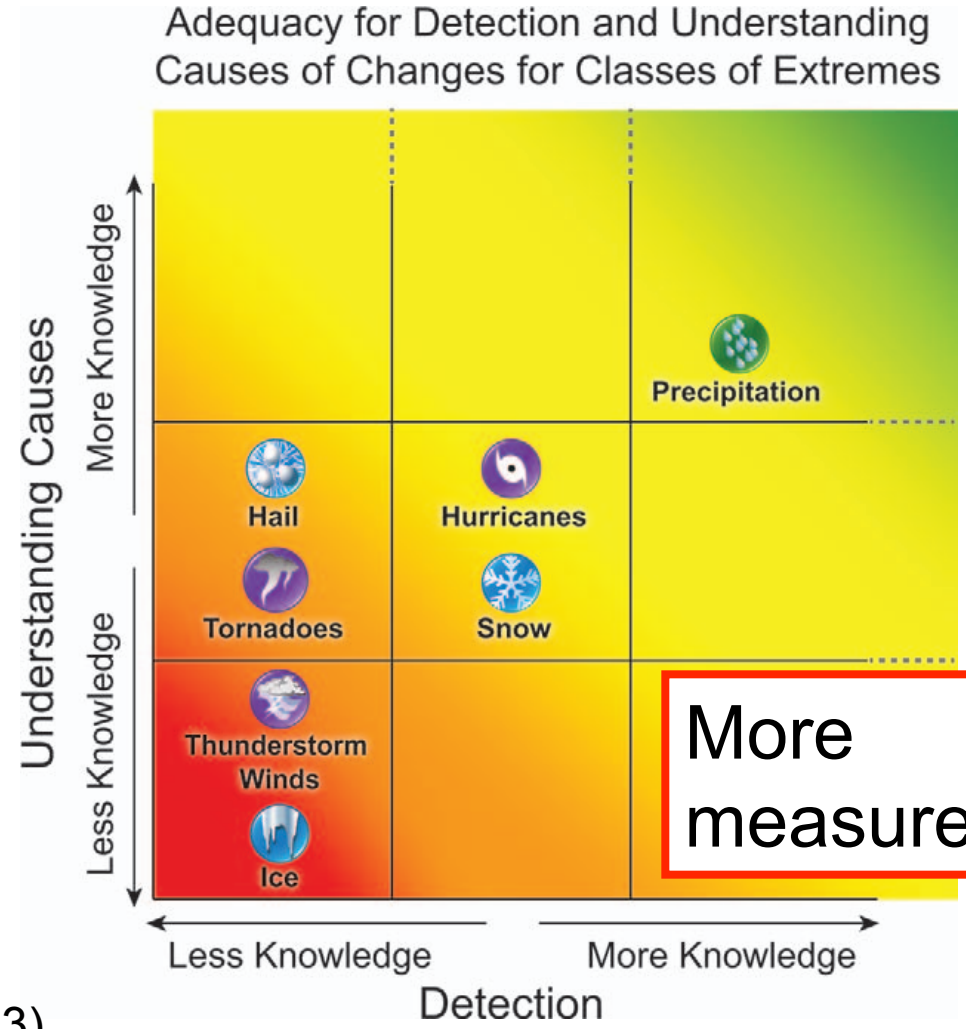
Exponential relationship between temperature and saturation vapor pressure, or how much water vapor air can ‘hold’.

# Increases in water vapor content




Santer et al. (2007)

# Other hydrological extremes




More research

More measurement

Kunkel et al. (2013)

# Summary

- High precipitation events can cause flooding, with large human impacts
- Heavy precipitation events are generally increasing…
  - …but there is a large amount of spatial variability
- Requirements for heavy precipitation
  - Sufficient water vapor & upward atmospheric motion
- Saturation vapor pressure an exponential function of temperature
- Water vapor in atmosphere is likely increasing
- Need better understanding and better measurements!

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# Heat Waves

## Causes, and Connections With Climate Change

Andy Rhines, Ph.D. student,
Department of Earth and Planetary Sciences
Harvard University

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# Outline – Heat Waves

1. Ingredients for extremely hot weather

2. Where do heat waves occur, and how frequently?

3. How are heat waves related to climate change?

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# What Controls Surface Temperature?

1. Sunlight and infrared radiation

2. Ability of soil moisture to absorb energy

3. Weather conditions and winds

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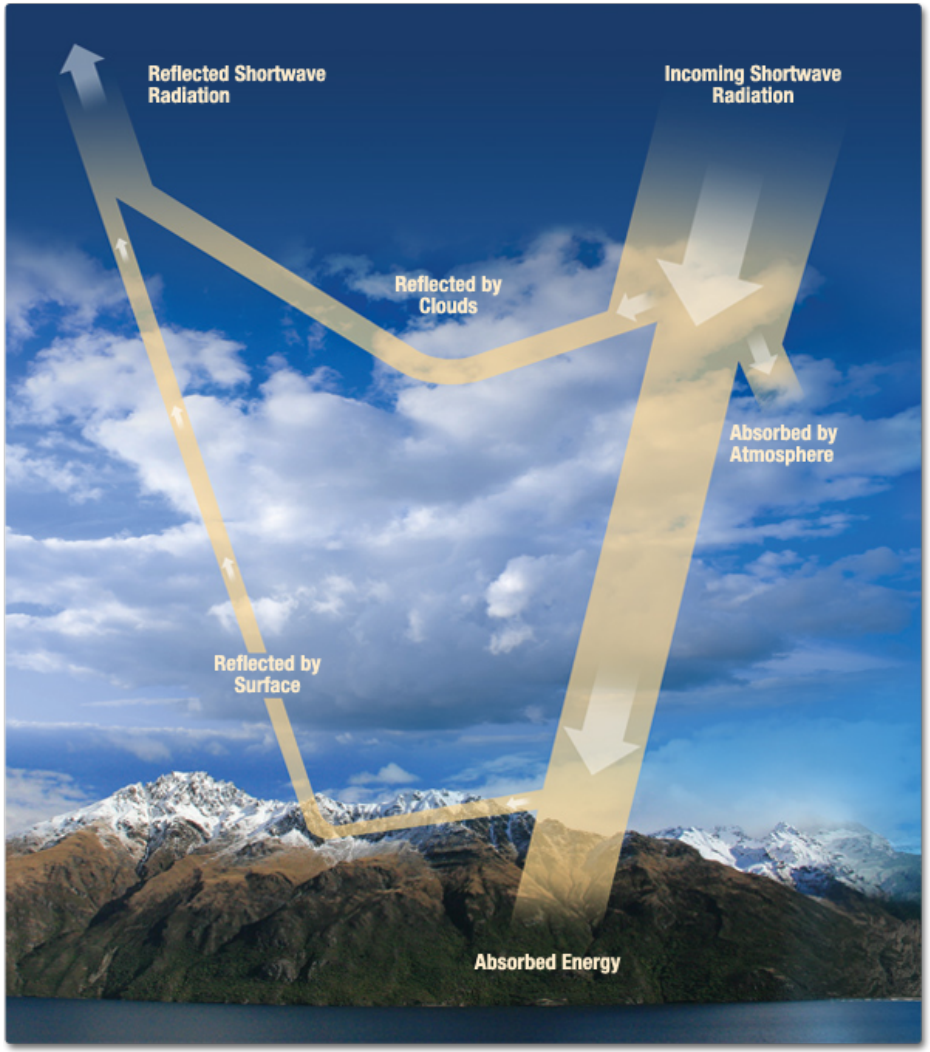
# Factors: Radiation




http://missionscience.nasa.gov/ems/13_radiationbudget.html

# Factors: Soil Moisture

Rainfall builds up a reservoir of water in the upper soil layers, providing a buffer against heating…

… over time, prolonged drought can exhaust the soil moisture supply, leaving the region susceptible to extreme temperatures.

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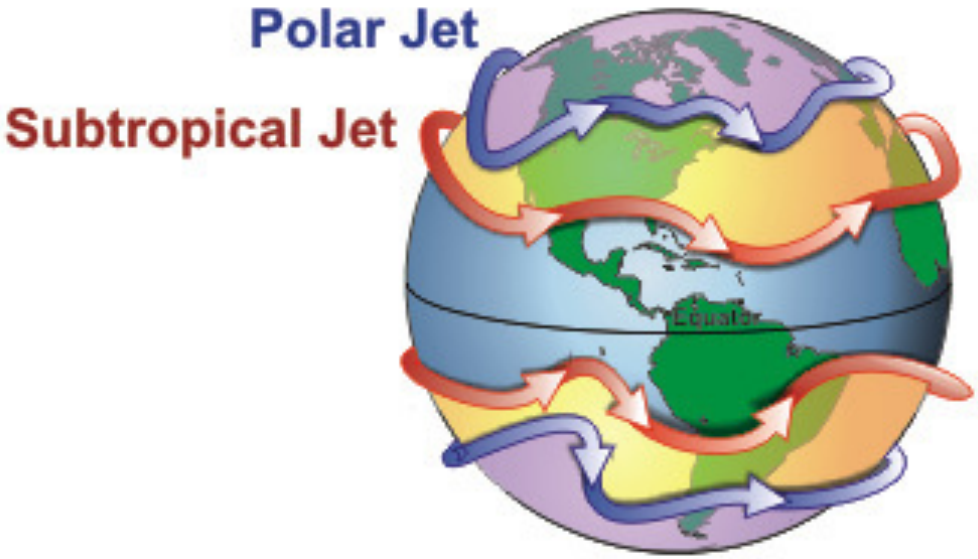
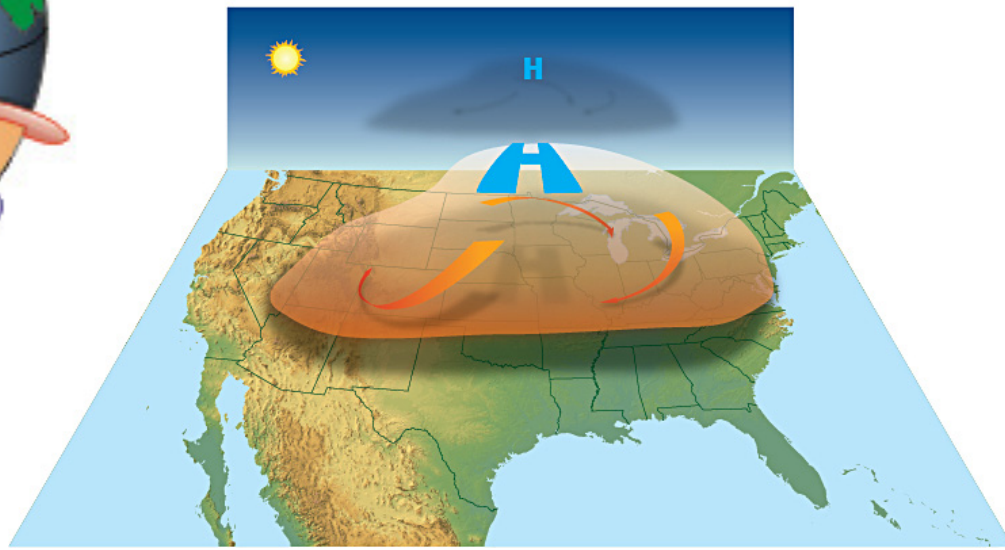
# Factors: Soil Moisture

- Land-use changes affect the temperature response to other factors:
  - Albedo (reflectivity)
  - Porosity and runoff pathways

# Factors: Winds




*http://www.srh.noaa.gov/jetstream/global/hi.htm*

# Intermission: The 1995 Chicago Heat Wave

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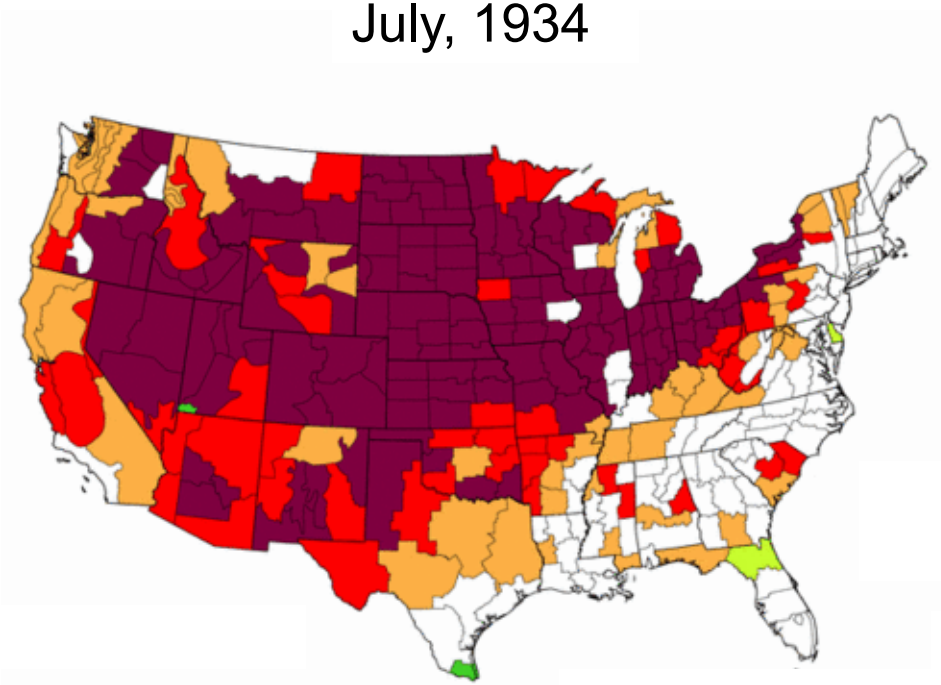
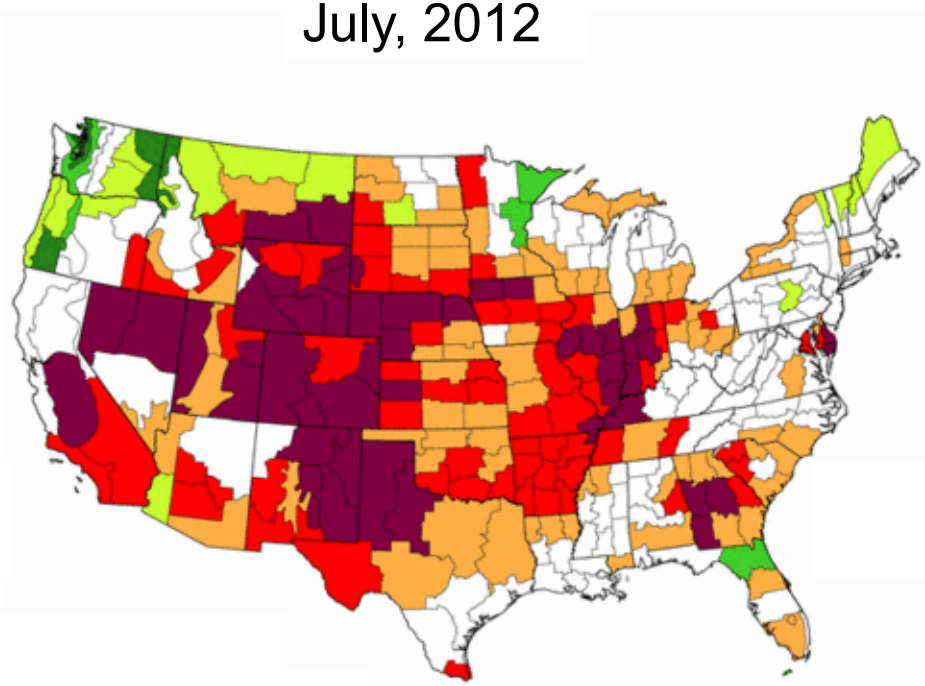
# Frequency of Heat Waves

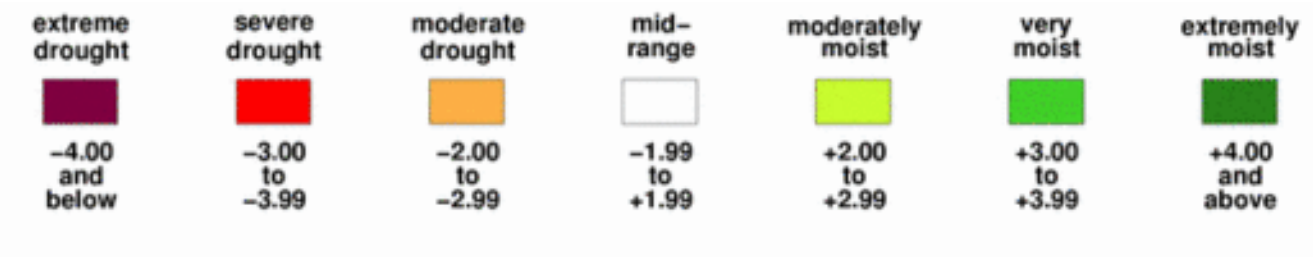
July, 1934



July, 2012



Palmer Drought Severity Index




*http://www.ncdc.noaa.gov/temp-and-precip/drought/historical-palmers.php*

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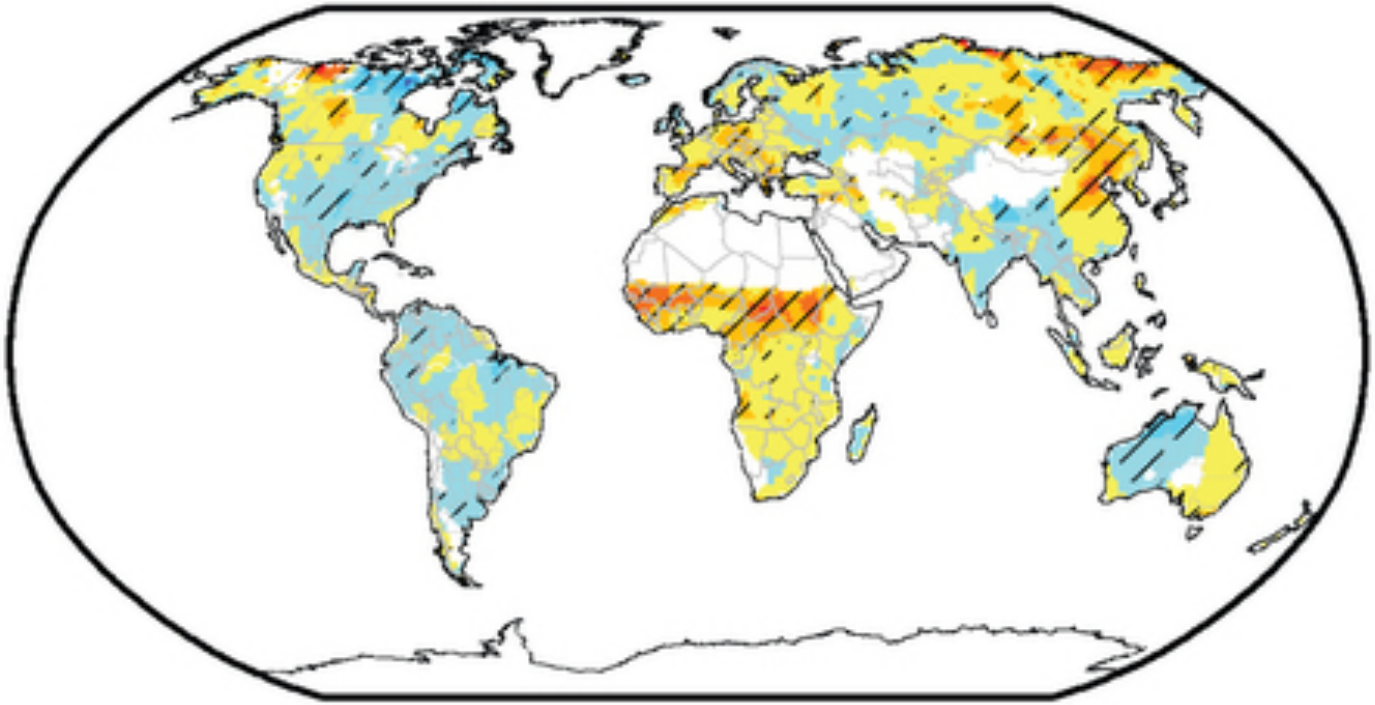
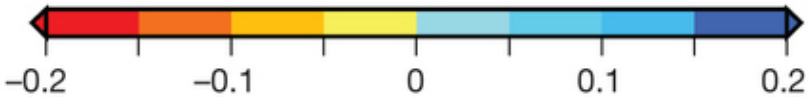
# Frequency of Heat Waves



Drought Severity Index Trend (1950 – 2011)




*J. Sheffield, "Little change in global drought over the past 60 years", Nature 491(7424):435-438 (2012)*

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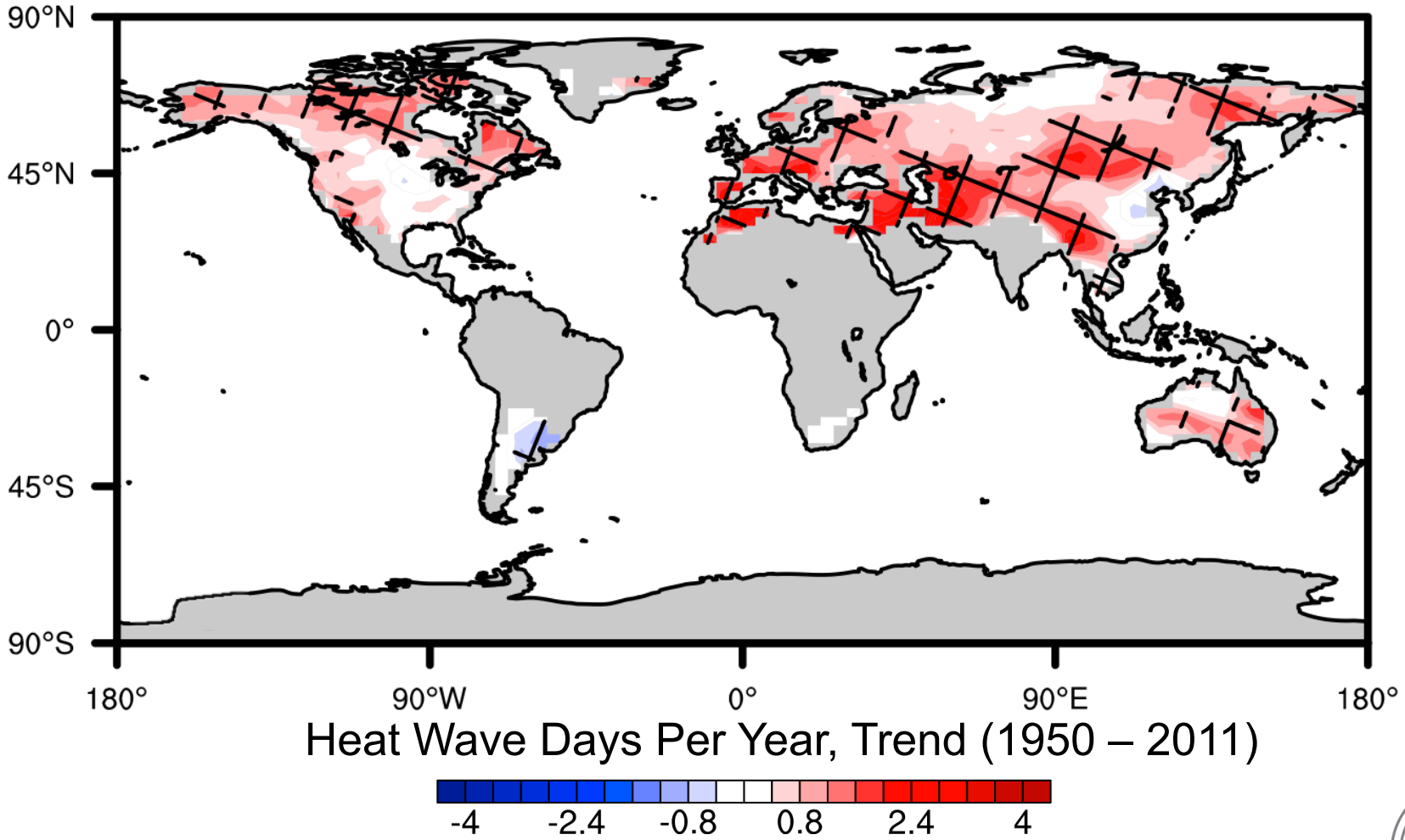
# Frequency of Heat Waves




*S.E. Perkins et al., "Increasing frequency, intensity and duration of observed global heatwaves and warm spells" (2012), doi:10.1029/2012GL053361.*

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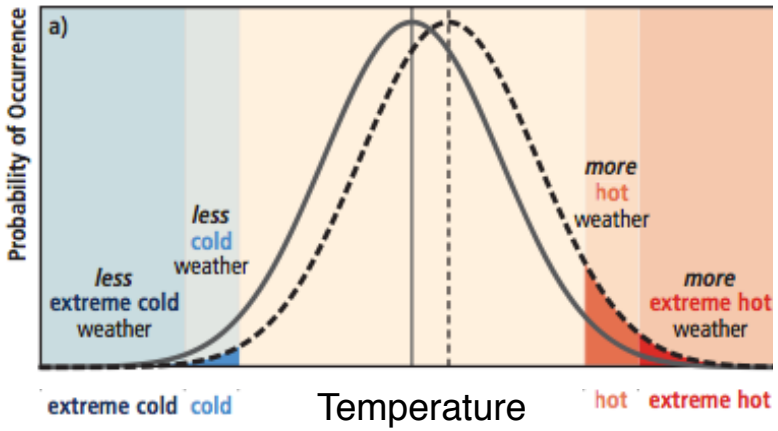
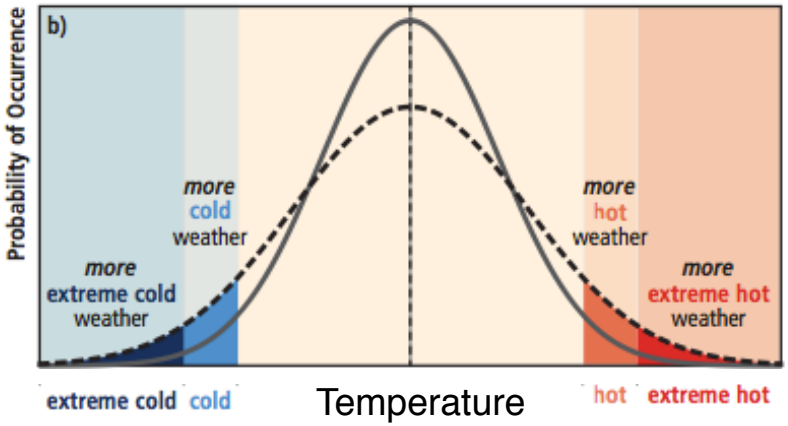
# Connections to Climate Change

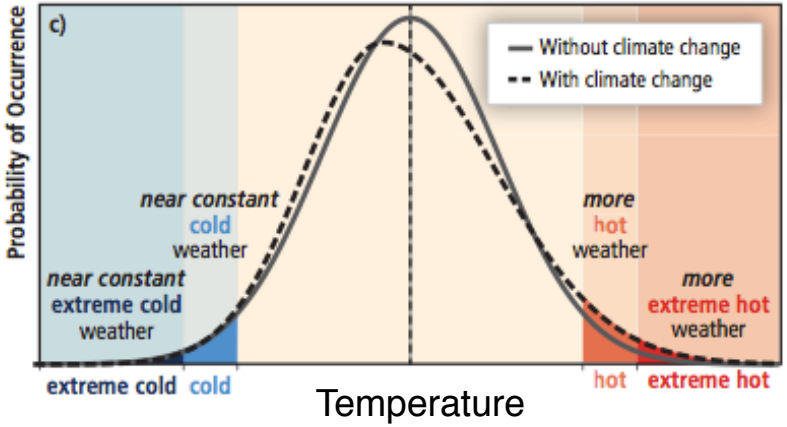
Changing Mean




Changing Variance




Changing Shape




*IPCC SREX Report (2012)*

# Summary – Heat Waves

1. Ingredients for extremely hot weather

   *a. Lots of radiation*
   *b. Low soil moisture*
   *c. Stagnant winds, or winds from a hotter region*

2. Where do heat waves occur?

   *Heat waves are more common:*
   *a. Away from the ocean.*
   *b. Places with little soil moisture.*

3. How are heat waves related to climate change?

   *a. Heat waves are difficult to predict, and a given heat wave is mostly related to specific weather conditions.*
   *b. By most measures they are increasing in frequency in the global average, and are likely to continue to do so.*

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# Thank you!

*SITN would like to acknowledge the following organizations for their generous support.*

**Harvard Medical School**
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**The Harvard Graduate Student Council (GSC)**

**The Harvard Biomedical Graduate Students Organization (BGSO)**

**The Harvard/MIT COOP**