Climate and Land Use Change
Earth Resources Observation and Science (EROS) Center

Drought, Fire, Flood: Monitoring and Modeling more Frequent Catastrophes
Walter Orr Roberts Memorial Public Lecture

Chris Funk, Director, Climate Hazards Center

Chris Funk, USGS/UCSB Climate Hazards Center
Background

In 1995 I had a dream ....

In 1996 I drove to California and started graduate school ....

In 1997 became fascinated by potential humanitarian applications of climate science and satellite data ....

And remain so today ....
Famine Early Warning Systems Network

An activity of the USAID Office of Food for Peace

“to ensure that appropriate...emergency food aid is provided to the right people, in the right places, at the right time, and in the right way”
Climate Hazards Center

~28 papers 2018/19
~14 training workshops 2018/19
~20K downloads per month
Monthly input to FEWS NET, Harvest, SERVIR
Somalia Example:
Food Shocks Can Kill, Early Warning Can Help

Figure 4. Retail price of sorghum, Baidoa, Bay

Risk of Famine (IPC Phase 5) persists in Somalia
February 2017 to September 2017
Near Term: February - May 2017

IPC 2.0 Acute Food Insecurity Phase
1: Minimal  2: Stressed  3: Crisis  4: Emergency  5: Famine

Would likely be at least one phase worse without current or programmed humanitarian assistance
Context – unprecedented levels of Food Insecurity – 85 million people

Eight-Five million people is equivalent to the combined population of New York, Los Angeles, Washington, Boston, Chicago, London, Rome, Mexico, Tokyo, Delhi, Sydney, Moscow and Shanghai.
How many people is 85 million?

Enough people to circle the globe ~13 times!

~1 out of 100 face severe food insecurity now
Overview

- Understanding HOW Warmer Temperatures Contribute to Extremes
- Increasing Food Insecurity and More Frequent Catastrophes
- Designing and Implementing Integrated Systems to Monitor and Predict Extremes
Climate Hazards operate on multiple dimensions

- Climate change can increase atmospheric drying
- Climate change can increase precipitation extremes
- Warming surface temperatures can trigger droughts
Global Air Temperatures Have Jumped Dramatically since the 1990s

Global Land Temperature Anomalies [°C]

-1
-0.5
0
0.5
1
1.5

1880 1900 1920 1940 1960 1980 2000 2020

+0.7°C

USGS
The number of weather-related loss events

Based on the Munich Re reinsurance company’s natural catastrophe database
The number of $1 Billion Dollar US Disasters is increasing

Total 2015-2018 CPI Adjusted Losses: $481 billion
Aon Benfield Loss Events

Exhibit 1: Top 10 Global Economic Loss Events

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
<th>Location</th>
<th>Deaths</th>
<th>Economic Loss (USD)</th>
<th>Insured Loss (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug 25 - Sept 2</td>
<td>Hurricane Harvey</td>
<td>United States</td>
<td>90</td>
<td>-100 billion</td>
<td>-30 billion</td>
</tr>
<tr>
<td>September 16-22</td>
<td>Hurricane Maria</td>
<td>Caribbean Islands</td>
<td>900</td>
<td>-65 billion</td>
<td>-17 billion</td>
</tr>
<tr>
<td>September 4-12</td>
<td>Hurricane Irma</td>
<td>U.S., Caribbean Islands</td>
<td>134</td>
<td>-55 billion</td>
<td>-73 billion</td>
</tr>
<tr>
<td>October</td>
<td>Wildfires</td>
<td>United States</td>
<td>43</td>
<td>13 billion</td>
<td>11 billion</td>
</tr>
<tr>
<td>Summer</td>
<td>Flooding</td>
<td>China</td>
<td>116</td>
<td>7.5 billion</td>
<td>300 million</td>
</tr>
<tr>
<td>Summer &amp; Autumn</td>
<td>Drought</td>
<td>Southern Europe</td>
<td>N/A</td>
<td>6.6 billion</td>
<td>700 million</td>
</tr>
<tr>
<td>September 19</td>
<td>Earthquake</td>
<td>Mexico</td>
<td>320</td>
<td>4.5 billion</td>
<td>1 billion</td>
</tr>
<tr>
<td>July</td>
<td>Flooding</td>
<td>China</td>
<td>37</td>
<td>4.5 billion</td>
<td>125 million</td>
</tr>
<tr>
<td>August 23-25</td>
<td>Typhoon Haiyan</td>
<td>China</td>
<td>22</td>
<td>3.5 billion</td>
<td>250 million</td>
</tr>
<tr>
<td>May 8-11</td>
<td>Severe Weather</td>
<td>United States</td>
<td>0</td>
<td>3.4 billion</td>
<td>2.6 billion</td>
</tr>
</tbody>
</table>

All Other Events: 90 billion, 38 billion

Totals: 353 billion, 134 billion

Exhibit 2: Significant 2017 Economic Loss Events

- California Wildfires
- Hurricane Harvey
- Hurricane Maria

Exhibit 2: Significant 2018 Economic Loss Events

- Drought
- Earthquake
- Flooding
- Severe Weather
- Tropical Cyclone
- Wildfire
- Winter Weather

Economic Loss
- ≥ 100 M
- ≥ 1,000 M
- ≥ 1 billion

2017

2018
Warmer air amplifies disasters by holding more water at a given relative humidity.

Nitrogen & Oxygen

H₂O

Cold Air

Warm Air

~ +7% per degree Celsius
Increasing air temperatures can dry soils, plants and increases the magnitude of fires
Warmer air holds more water supporting enhanced evapotranspiration.
Relating Aridity to Wildfire Extent

Abatzoglou and Williams’ Figure 1 from *Impact of anthropogenic climate change on wildfire across western US forests*. The x-axis shows a measure of aridity, taking into account both precipitation and temperature. The vertical y-axis shows the total area burned in each year since 1984.
US Wildfire extents increasing

Annual US Fire Extent - acres. Trend shown with a dashed line ($R^2=0.42$) - along with a regression estimate for 2030 wildfire extent.
Warmer air holding more water can increase the frequency of intense flood events.

~+7% per degree Celsius
Observed changes in very extreme daily rainfall totals

Extremes may be increasing faster than 7% per degree Celsius
Water vapor may ‘concentrate’ climate change

- Hurricane Harvey struck the Houston area with 50” of rain in August 2017, causing ~$125 billion dollars in damage.
- 9 TRILLION gallons of water is equivalent to a cube of water two miles long, two miles wide and two miles high.
- The total energy associated with evaporating 9 billion gallons of water is about 76 quintillion Joules.
- In 2017, the world consumed about 630 quintillion Joules of energy – or just 8.3 times the amount of energy released by Harvey.
Patricola and Wehner Hurricane Attribution (Nature)

Katrina

Irma

Maria

w.o. CC  with CC
Costs of US Hurricanes

>$700 billion over 20 years

~$100 billion over 20 years
Increased sea surface temperatures also cause droughts.

2. Strong El Niño continues through boreal fall and winter, disrupting rainfall across eastern SA. Negative observed DJF SA rainfall/NINO3.4 SST relationship supported with CAM5 and CESM1 simulations. Strong El Niño events produce large circulation anomalies. CESM1 simulations indicate that strong ENSO events may be ~2.5 times more frequent now that in the 1920s. 2016 Impact ~10 million people. 2017 Impact ~16 million people.

3. La Niña-like conditions form in OND of Year 2. Since the late 1980s, this transition has often been accompanied by an upward jump in WEP and WNP SST. Strong and persistent warm SST anomalies in the West Pacific have been important for recent back to back OND and MAM EA droughts. During OND, observations, CAM5 and CESM1 simulations indicate a negative relationship between warmer WEP SST and EA OND rains on an interannual basis. Unlike in MAM, the OND response has not involved a decrease in rainfall through time. This may have to do with the comparatively limited influence of WEP warming on the Indian and Pacific branches of the Walker Circulation during OND.

4. La Niña-like conditions and warm WNP conditions tend to persist into MAM of Year 3. Here we show that observations, CAM5 and CESM1 simulations all indicate that WNP SST plays an important role in modulating EA precipitation and the Indo-Pacific Walker Circulation. Increasing WNP SST and diabatic forcing are likely contributors to EA MAM rainfall declines. More frequent MAM droughts seem likely. Common West Pacific forcing may support consecutive OND/MAM droughts. 2017 Ethiopia/Kenya/Somalia Impacts ~13 million people.

Funk et al. QJRMS 2018
A climate hazards perspective – extremely warm SSTs produce droughts

FAR = 1 – \( \frac{P0}{P1} \)
(Allen, 2003)
2015/16 El Nino

Climate Change enhanced strength of El Nino & droughts in Ethiopia and Southern Africa

BAMS 2016, BAMS 2017, QJRMS 2018
2017/18 El Nino

Climate Change enhanced West Pacific SSTs and droughts in East Africa

BAMS 2018, QJRMS 2018
Integrated monitoring-prediction systems can help anticipate extremes.

Designing and Implementing Integrated Systems to Monitor and Predict Extremes.
Sources of predictive skill

Ocean – Since sea surface temperatures change very slowly, they can be used to inform seasonal climate forecasts.

Atmosphere – on one-to-two week time scales storms, heat waves and rainfall deficits are often predictable.

Land – Soil moisture and vegetation extremes and deficits build up and persist over time, this persistence supports predictions.
How climate change can exacerbate weather extremes

Ocean – Exceptionally warm sea surface temperatures can drive terrestrial precipitation extremes and drought

Atmosphere – Warmer air can hold more water, contributing to more extreme precipitation events

Land – A warmer atmosphere can draw more water from plants and soils, increasing the intensity of droughts
Integrated systems can provide effective early warning by using the best tools at the right time – drought example

- **Climate Model Predictions**
  - Provide alerts based on large scale climate conditions

- **Satellite Precipitation Observations**
  - Quantify early-to-mid season rainfall deficits

- **Weather model Rainfall predictions**
  - Predict mid-season rainfall deficits

- **Veg. Anomalies**
  - Support late-season assessment

- **CHC Early Estimates**
  - CHC Estimate May 20

**Images:**
- Earth models
- Satellite image
- Weather model

**Map:**
- Vegetation Anomalies

**USGS Logo:**

**Legend:**
- NDVI Anomaly
- Negative
- No Difference
- Positive
Drought Example CHC Estimate May 20th

45 days CHIRPS + 15 days CHIRPS-GEFS = CHC Estimate May 20th
High Resolution Satellite Vegetation Anomalies
Percent of normal rainfall for the Period Feb dek 1 - May dek 2, 2019

Percent of normal rainfall up to the 2nd dek of May 2019. Rainfall totals to the current dekad have been below normal for most of southeast region, with severe epicenter is confined over Borena and Guji Zones of Oromia, and Liban Zone of Somali, where Ganna/Gu is the major rainy season.

Rainfall in far eastern Ethiopia is expected to improve based on forecast of dek 14.

Source SMPG
Closing thoughts

Climate change is amplifying extreme events – now (and people are being hurt)

We can understand how warming temperatures amplify extremes

We have a tremendous array of new satellite and modeling tools – but we need to link and use them well
Thanks!

Climate Change Increasing Hazard Risks

Humanitarian Earth Systems Science?

‘Climatological’ Satellite-enhanced Datasets + Models

Effective Early Warning & Adaptation

[Image with USGS logo]