Climate change is happening

Climate change is no longer a hypothesis;

It is a fact.

We have seen changes in rainfall, resulting in more floods, droughts, or intense rain, acidic depositions, ice caps are melting, and sea levels are rising, as well as more frequent and severe heat waves.
Background

Evidence

Of Climate Change
Figure SPM.3
Multiple observed indicators of a changing global climate

(a) Northern Hemisphere spring snow cover
(b) Arctic summer sea ice extent
(c) Change in global average upper ocean heat content
(d) Global average sea level change

Figure SPM.5
Radiative forcing estimates in 2011 relative to 1750

All Figures © IPCC 2013
Figure SPM.6
Comparison of observed and simulated climate change

Rate of Temperature Change in US (EPA)
Rate of Precipitation Change in US (EPA)

Figure 3. Rate of Precipitation Change in the United States, 1901–2012

Global Average Absolute Sea Level Rise (EPA)

Figure 1. Global Average Absolute Sea Level Change, 1880–2013
CO₂, CH₄ and N₂O Concentrations Far exceed pre-industrial values

Increased markedly since 1750 due to human activities

Show Relatively little variation before the industrial era

Fate of Anthropogenic CO₂ Emissions (2010)

9.1±0.5 PgC/y

5.0 ± 0.2 PgC/y 50%

2.6 ± 1.0 PgC/y 26%

2.4 ± 0.5 PgC/y 24%

Calculated as the residual of all other flux components

Average of 5 models

Global Carbon Project 2010; Updated from Le Quéré et al. 2009,
Nature Geoscience; Canadell et al. 2007, PNAS
Top 20 CO₂ Fossil Fuel Emitters & Per Capita Emissions 2010

Impacts of Climate Change

- Air Quality
- Public Health
- Agriculture and Food
- Energy
- Ecosystem, Water Resources and Water Quality
- (Extreme events)
Since 1950, extreme hot days and heavy precipitation have become more common.

There is evidence that anthropogenic influences, including increasing atmospheric greenhouse gas concentrations, have changed these extremes.

A changing climate leads to changes in extreme weather and climate events.
Heat Waves in Europe

Deaths in Chicago heat wave in 1995

Deaths in West Europe heat wave in 2003

MODIS Image about 45,000 died


Heat Waves in Europe

Risk Factors
- lack of access to cooling
- age
- pre-existing health problems
- poverty and isolation
- infrastructure

Risk Management/Adaptation
- cooling in public facilities
- warning systems
- social care networks
- urban green space
- changes in urban infrastructure

IPCC SREX, 2012
Hurricanes in the US and Caribbean

- Risk Factors:
  - population growth
  - increasing property value
  - higher storm surge with sea level rise

- Risk Management/Adaptation:
  - better forecasting
  - warning systems
  - stricter building codes
  - regional risk pooling

Fires in the Western US

(AP Photo/The Denver Post, RJ Sangosti)
Sea Level Rise in Islands and Coastal Areas

<table>
<thead>
<tr>
<th>Risk Factors</th>
<th>Risk Management/Adaptation</th>
</tr>
</thead>
<tbody>
<tr>
<td>shore erosion</td>
<td>early warning systems</td>
</tr>
<tr>
<td>saltwater intrusion</td>
<td>maintenance of drainage</td>
</tr>
<tr>
<td>coastal populations</td>
<td>regional risk pooling</td>
</tr>
<tr>
<td>tourism economies</td>
<td>relocation</td>
</tr>
</tbody>
</table>

IPCC SREX, 2012

Flash Flooding in Cleveland, Ohio, July 2007

Drought in Texas (2011 and 2013), now California

Source: Businessinsider.com

Impact of storm over pavement

Design factors of pavement

- Geometry
- Traffic
- Climate
- Pavement material
- Subgrade soil

Impact of Stormwater to Bioretention

Source: https://jiayulu.wordpress.com/2013/12/09/traditional-bioretention-system/
Impact of Cold Climate to Bioretention


Distribution of pH over US

Impact of acid (nitrogen + sulfur) depositions

- Lower the pH of surface water
- Weaken the vegetation and agriculture
- Decreases biodiversity and damage animals

Source:

Total (wet + dry) nitrogen and sulfur depositions over US

Multi-model mean from global climate-chemistry models, averaged from 2000 to 2009
Drought at Northeast Ohio in 2012

Precipitation over U.S. Great Lakes region
Snowfall over U.S. Great Lakes region

Source: http://gliss.umich.edu/climate/precipitation

Extreme Precipitation over U.S. Great Lakes region

Source: http://gliss.umich.edu/climate/extreme-precipitation
Extreme Precipitation over U.S. Great Lakes region

Observed Changes (%) in the Intensity of the 1% Heaviest Precipitation Days (1951-1989 vs. 1981-2010)

Precipitation over Northeastern Ohio

Annual Precipitation: Northeastern Ohio

Source: http://glsb.umich.edu/climate/extreme-precipitation

Source: http://glsb.umich.edu/division/oh03
Precipitation over Northeastern Ohio

Seasonal Precipitation: Northeastern Ohio

Source: http://glis.umich.edu/division/oh03

Temperature over Northeastern Ohio

Annual Temperature: Northeastern Ohio

Source: http://glis.umich.edu/division/oh03
Temperature over Northeastern Ohio

![Graph showing seasonal temperature changes over Northeastern Ohio](http://gliss.umich.edu/division/oh03)

Source: [http://gliss.umich.edu/division/oh03](http://gliss.umich.edu/division/oh03)

Temperature over Great Lakes Region

<table>
<thead>
<tr>
<th>Average Temperature</th>
<th>Total Precipitation</th>
<th>Heavy Storm Precipitation</th>
<th>Great Lakes Ice Coverage</th>
<th>Frost-free Season</th>
</tr>
</thead>
</table>

2050

1.8-5.4°F

Source: [http://gliss.umich.edu/division/oh03](http://gliss.umich.edu/division/oh03)
Overview of the study

Community Earth System Model
- CESM 1.0
  - Community Atmosphere Model (CAM-Chem)
  - Community Land Model (CLM)
  - Community Sea Ice Model (CSIM)
  - Ocean component (POP)

Regional Climate/Chem Model
- WRF 3.2.1/CMAQ 5.0

D1/D2/D3: 36-12-4 km

0.9 × 1.25 deg (~100 × 140 km lat/lon) > 36 km, 12 km, 4 km

The importance of the climate downscaling

- The methodology developed in this study can be easily applied to other models/regions but this is a temporary strategy.
- Provide important information for policy makers when taking actions on climate mitigation and adaptation.
- A large amount of data (~700 T) has been produced from this study, and the data can be used in a variety of studies:
  - The data is currently being investigated at Harvard University, Emory University and University of Michigan for predictions of Lyme disease and lung cancer.
  - The data can be used as input to the biogeochemical or hydrologic model, to further investigate hydrology and water quality response to changes of climate in US.
1. Timeline of the Evolution of Climate Modeling

2. Major focus study area

3. CAM5 Physics Package in WRF

Probability curve of precipitation over Northeastern Ohio for present (2001 to 2004)
The definitions of heat waves

- **Heat wave intensity**
  The highest three continuous night minimum temperature in a certain year

- **Heat wave duration and frequency**
  Two maximum daily temperature thresholds are used for the determination:
  - T1 and T2 can be
    - fixed values 30°C and 25°C
    - the 97.5th and 81st percentiles
  - A heat wave period is:
    1. the maximum daily temperature reached T1 for at least 3 days
    2. the mean daily maximum temperature remained above T1 while the daily maximum temperature reached T2 each day

More intense and frequent heat waves in future climate

- **Heat wave intensity** (°C)
- **Heat wave frequency** (events/year) (days/event)
City-level increase of heat waves

Among the top 50 cities by population in US, 20 are located in the eastern US


Extreme precipitation

<table>
<thead>
<tr>
<th>City</th>
<th>Present mm/year</th>
<th>RCP 8.5-mm/year</th>
<th>% increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Philadelphia</td>
<td>300.2</td>
<td>315.1</td>
<td>105%</td>
</tr>
<tr>
<td>Baltimore</td>
<td>297.2</td>
<td>227.3</td>
<td>67%</td>
</tr>
<tr>
<td>Virginia Beach</td>
<td>316.7</td>
<td>210.8</td>
<td>67%</td>
</tr>
<tr>
<td>Boston</td>
<td>302.7</td>
<td>207.4</td>
<td>69%</td>
</tr>
<tr>
<td>Washington, D.C.</td>
<td>257.7</td>
<td>170.1</td>
<td>66%</td>
</tr>
<tr>
<td>Indianapolis</td>
<td>319.3</td>
<td>168.8</td>
<td>53%</td>
</tr>
<tr>
<td>Columbus</td>
<td>259.8</td>
<td>130.2</td>
<td>50%</td>
</tr>
<tr>
<td>Chicago</td>
<td>224.0</td>
<td>121.7</td>
<td>54%</td>
</tr>
<tr>
<td>Milwaukee</td>
<td>222.4</td>
<td>120.7</td>
<td>54%</td>
</tr>
<tr>
<td>Charlotte</td>
<td>271.7</td>
<td>115.4</td>
<td>42%</td>
</tr>
<tr>
<td>New York</td>
<td>309.1</td>
<td>82.5</td>
<td>27%</td>
</tr>
<tr>
<td>Louisville</td>
<td>267.3</td>
<td>75.6</td>
<td>26%</td>
</tr>
<tr>
<td>Detroit</td>
<td>263.8</td>
<td>65.5</td>
<td>25%</td>
</tr>
<tr>
<td>Raleigh</td>
<td>316.8</td>
<td>58.5</td>
<td>18%</td>
</tr>
<tr>
<td>Cleveland</td>
<td>286.9</td>
<td>37.3</td>
<td>13%</td>
</tr>
<tr>
<td>Atlanta</td>
<td>370.3</td>
<td>22.9</td>
<td>6%</td>
</tr>
<tr>
<td>Memphis</td>
<td>239.5</td>
<td>2.3</td>
<td>1%</td>
</tr>
<tr>
<td>Nashville</td>
<td>299.6</td>
<td>-10.0</td>
<td>-3%</td>
</tr>
<tr>
<td>Miami</td>
<td>197.1</td>
<td>-17.9</td>
<td>-9%</td>
</tr>
<tr>
<td>Jacksonville</td>
<td>438.5</td>
<td>-36.2</td>
<td>-8%</td>
</tr>
</tbody>
</table>
Extreme precipitation over Northeastern Ohio

### Present (2001-2004) vs. RCP 8.5 (2057-2059) - P

#### Annual extreme precipitation (mm)

#### Annual extreme precipitation days

Heat Wave over Northeastern Ohio

<table>
<thead>
<tr>
<th></th>
<th>Heat Wave Intensity (K)</th>
<th>Heat Wave Frequency (events/year)</th>
<th>Heat Wave Duration (days/event)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present (2001-2004)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCP 8.5 (2057-2059) - P</td>
<td></td>
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Published paper

Projected changes of extreme weather events in the eastern United States based on a high resolution climate modeling system

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Early Computers - Weather and Climate are Signature Applications

Today:
peta-scale supercomputers

Kraken
JAGUAR
Thank you for your attention!

Questions ???????