World Health Organization estimates that climate change already kills 150,000 people annually
- death rates are greatest in Africa
WHO estimates that climate change already causes 5.5 million DALYs (disability adjusted life years)

How can climate change affect human health?

1. Increased heat stress and/or decreased cold stress
2. Change in frequency and/or severity of disease
3. Change in air quality
4. Change in rates of malnutrition
5. Change in frequency and/or severity of conflict
Increased heat stress
- severe heat waves are now four times more likely

European heat wave of 2003 killed up to 80,000 people

By 2100 in Europe, every other summer could be like 2003
Large increases in “extremely hot” winters, summers, and years in US during 2071-2100

Future summers are very likely to be hotter than any experienced thus far
By 2100 under B1: Michigan climate would be like present-day Arkansas

under A1FI: Michigan climate would be like present-day Texas/Oklahoma

The number of days >90° will increase in Michigan
By 2100, Detroit is predicted to have 5 (B1) to 23 (A2) days per year over 100°C

Similar increases are predicted for other cities
For many Midwestern cities, the number of Chicago 1995-like heat waves is predicted to increase dramatically - responsible for ~ 700 deaths

<table>
<thead>
<tr>
<th>City</th>
<th>1961-1990</th>
<th>2010-2039</th>
<th>2040-2069</th>
<th>2070-2099</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lower</td>
<td>Higher</td>
<td>Lower</td>
<td>Higher</td>
</tr>
<tr>
<td>CHICAGO</td>
<td>0.11</td>
<td>1.33</td>
<td>2.56</td>
<td>11.78</td>
</tr>
<tr>
<td>CINCINNATI</td>
<td>0.11</td>
<td>0.61</td>
<td>0.67</td>
<td>7.78</td>
</tr>
<tr>
<td>CLEVELAND</td>
<td>0.00</td>
<td>0.17</td>
<td>0.11</td>
<td>2.78</td>
</tr>
<tr>
<td>DES MOINES</td>
<td>0.56</td>
<td>2.22</td>
<td>3.11</td>
<td>15.11</td>
</tr>
<tr>
<td>DETROIT</td>
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<td>0.83</td>
<td>1.00</td>
<td>7.00</td>
</tr>
<tr>
<td>INDIANAPOLIS</td>
<td>0.22</td>
<td>0.61</td>
<td>1.00</td>
<td>9.78</td>
</tr>
<tr>
<td>MILWAUKEE</td>
<td>0.00</td>
<td>0.22</td>
<td>0.67</td>
<td>4.44</td>
</tr>
<tr>
<td>MINNEAPOLIS</td>
<td>0.11</td>
<td>0.50</td>
<td>0.89</td>
<td>7.33</td>
</tr>
<tr>
<td>ST LOUIS</td>
<td>1.33</td>
<td>6.44</td>
<td>10.11</td>
<td>29.56</td>
</tr>
</tbody>
</table>

Detroit is predicted to experience nearly two Chicago 1995-like heat waves per summer

- and worse ones (7 consecutive days > 95°F) every other summer
In addition to increases in frequency, increases in duration are also predicted.

Present: 6.3 days  
Future: ~9 days  

Present: 8.3 days  
Future: ~14 days  

Mortality increases dramatically as heat waves continue.
How will heat stress affect mortality?
- 10-40 fold increase in deaths in Montreal and Toronto
- much larger increases among elderly

Annual Deaths Due to Heat if Carbon Dioxide in the Atmosphere Doubles

By 2030, increased heat-related mortality in many European cities

By 2030, up to 164 additional deaths/yr (Rome)

B1 total: +409 deaths/yr

A2 total: +863 deaths/yr
By 2100, greatly increased heat-related mortality in many cities

With no acclimatization:
- in Boston, 351 more deaths per 100,000
- in Lisbon, 557 more deaths per 100,000

With “more” acclimatization:
- in Boston, 98 more deaths per 100,000
- in Lisbon, 111 more deaths per 100,000

How will reduced cold stress affect mortality?

- most cold-related deaths due to coronary and cerebral thrombosis (~50%) and respiratory disease (~50%)
- cold causes blood to thicken, so more likely to clot
- few existing studies suggest that modest declines in winter mortality will be smaller than increases in summer mortality
How could climate change affect human health?

1. Increased heat stress and/or decreased cold stress
2. Change in frequency and/or severity of disease
3. Change in rates of malnutrition
4. Change in air quality
5. Change in frequency and/or severity of conflict

Likely increase in vector-borne diseases

e.g. malaria

Malaria, countries or areas at risk of transmission, 2010

up to 20% incidence in Africa

Source: WHO 2011. All rights reserved.
WHO estimates 250,000,000 cases annually, resulting in 1,000,000 deaths

- an African child has on average 1.5 to 5.5 episodes of malaria fever each year
- every 30 seconds a child dies from malaria

How can climate change affect malaria incidence?
1. Change in geographic range of vector (*Anopheles*)
2. Change in length of transmission season

*Anopheles gambiae* *Anopheles arabiensis* *Plasmodium falciparum*
Anopheles range predicted to increase, but change depends on climate scenario

+2°C
+10% summer rain
-10% winter rain

+4°C
+20% summer rain
-20% winter rain

In Zimbabwe, Anopheles range increases mostly to higher altitudes
In Zimbabwe, *Anopheles* range increases mostly to higher altitudes

- simultaneous forest clearing and rapid population growth also increase number of infected people

Some models predict poleward spread of malaria

- most new range by 2050 is poleward of current range
- some parts of current range become too dry by 2050
**Plasmodium** develops faster at higher temperatures

- developmental thresholds are 15-18°C
- relationship is non-linear

**Malaria incidence also depends on transmission season**

- under A1FI, 84 million more people exposed (+19%)
- 858 million more person-months of exposure (+28%)
  ~ 30% of increase is within current infected range
What’s the global outlook for future malaria incidence?
- likely to increase due to climate change, but magnitude of increase is uncertain
- possible ~20% global increase with 2°C rise
- possibly 300,000,000 more people at risk globally

Malaria endemicity has decreased markedly since 1900

Change 1900-2007
Likely increase in dengue (and dengue hemorrhagic fever, DHF)

Dengue symptoms include fever, severe headache, muscle and joint pain, rash, and low WBC and RBC counts

DHF symptoms include shock and hemorrhage, sometimes lethal

Caused by a virus (*Flavivirus*)

Transmitted predominantly by *Aedes aegypti*

WHO estimates 50,000,000 cases annually, including ~22,000 deaths due to DHF

- *Aedes* mosquitoes occur outside current range of dengue
Range of dengue is likely to expand poleward - climate change is predicted to put an additional 2 billion people at risk by 2085

But schistosomiasis is expected to decrease

~15% decrease with 1.2 °C rise

~90 million fewer people at risk
Developed countries are causing the problem, but developing countries experience most health costs

Countries proportional to CO₂ emissions

Developed countries are causing the problem, but developing countries experience most health costs

Countries proportional to climate-related health effects
How could climate change affect human health?

1. Increased heat stress and/or decreased cold stress
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Stratospheric ozone ($O_3$) is beneficial, but tropospheric $O_3$ is harmful
Formation of tropospheric O₃ requires sunlight, NO or NO₂ (NOₓ), and hydrocarbons

- NOₓ and hydrocarbons are produced by the burning of fossil fuels

Tropospheric O₃ is highest in middle latitudes of Northern Hemisphere
Climate change has contributed to a 2-5 % per decade increase in average O₃ levels in Europe since 1958

- exceptionally high levels during first half of August 2003

Tropospheric O₃ is predicted to continue increasing

- up to 10 ppb increase in average levels by 2085 under A2
Increases predicted in the United States also

- why regional differences in O₃ increase?

Predicted to cause ~2 million deaths by 2050

- health costs estimated to be $580 billion/yr
- substantial agricultural costs also
How could climate change affect human health?

1. Increased heat stress and/or decreased cold stress
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About 40% of the Earth’s surface is used for cropland and pasture - about 27% of the land surface is too dry for rain-fed agriculture, almost all of which cannot be effectively irrigated.
About 450 million of the world’s poorest people depend entirely on agriculture

- most widely grown crops are wheat, rice, and corn (maize) (“cereal crops”)
- grains provide ~ 2/3 of the total human direct and indirect protein intake

UN Food and Agriculture Organization estimates 1.02 billion hungry people worldwide

- in developing countries, one third of children under 5 are chronically malnourished
Mostly in India, China, and Sub-Saharan Africa

IPCC predicts that, in the short run, climate change will increase yield of corn in mid-high latitudes
However, climate change will decrease yield of corn in low latitudes - up to 30% decrease in yield with 4° rise

IPCC predicts similar regional differences in the effect of climate change on yield of rice - maximum increase of ~10% at 3° warming with adaptation in mid-high latitudes
And for the effect of climate change on yield of wheat

- maximum increase of ~20% at 2.5° warming with adaptation in mid-high latitudes

These predictions include a “CO₂ fertilization effect”

- when grown under elevated CO₂, most plants grow bigger and, if they do, can produce greater yields
- however, the increase in quantity can be negated by a decrease in quality
  
  - for wheat and barley, protein (N) decreases by ~20%
And several recent studies are less optimistic about increased yields

- for barley by 2030, 9% to 2% decrease in global yield

- for corn by 2030, ~14% decrease in global yield

UN has defined 12 “food insecure” regions
By 2030, most of the important crops in South Asia (SAS region) are predicted to have reduced yields

SAS = India, Pakistan (30% of world’s malnourished people)

Most of the important crops in China (CHI region) are predicted to have increased yields by 2030

CHI = China (18% of world’s malnourished people)
Most of the important crops in Southeast Asia (SEA region) are predicted to have decreased yields by 2030

SEA = 13% of world’s malnourished people

The important crops in East Africa (EAF region) are predicted to have increased or decreased yields by 2030

EAF = 9% of world’s malnourished people
Climate change may already be reducing yields

- since 1981, climate change may have caused a combined loss of wheat, maize, and barley of ~$5 billion/yr

To some extent, adaptation measures can mitigate the adverse effects of climate change

- others adaptation measures include better crop selection, better pest control, better planting and harvesting technology, and genetic engineering of crops
Under most scenarios, number of people at risk of hunger is predicted to decrease, due to technological and economic developments—but climate change is predicted to result in more hungry people than would otherwise have been the case.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Reference</th>
<th>AEZ-BLS</th>
<th>DSSAT-BLS</th>
<th>AEZ-BLS</th>
<th>DSSAT-BLS</th>
<th>AEZ-BLS</th>
<th>DSSAT-BLS</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Year 2020</td>
<td>Year 2050</td>
<td>Year 2080</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A1</td>
<td>663</td>
<td>663</td>
<td>208</td>
<td>208</td>
<td>108</td>
<td>108</td>
<td></td>
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<tr>
<td>A2</td>
<td>782</td>
<td>782</td>
<td>721</td>
<td>721</td>
<td>768</td>
<td>769</td>
<td></td>
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<tr>
<td>B1</td>
<td>749</td>
<td>749</td>
<td>239</td>
<td>240</td>
<td>91</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>B2</td>
<td>630</td>
<td>630</td>
<td>348</td>
<td>348</td>
<td>233</td>
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<td></td>
</tr>
<tr>
<td>CC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>+28 million</td>
<td>+262 million</td>
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</tr>
<tr>
<td>A1</td>
<td>666</td>
<td>687</td>
<td>219</td>
<td>210</td>
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<td></td>
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<tr>
<td>A2</td>
<td>777</td>
<td>805</td>
<td>730</td>
<td>722</td>
<td>885</td>
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</tr>
<tr>
<td>B1</td>
<td>739</td>
<td>771</td>
<td>242</td>
<td>242</td>
<td>99</td>
<td>102</td>
<td></td>
</tr>
<tr>
<td>B2</td>
<td>640</td>
<td>660</td>
<td>336</td>
<td>358</td>
<td>244</td>
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<tr>
<td>CC, no CO₂</td>
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<td></td>
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<tr>
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<tr>
<td>A2</td>
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<td>950</td>
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<tr>
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<td>275</td>
<td>NA</td>
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<td></td>
</tr>
<tr>
<td>B2</td>
<td>652</td>
<td>685</td>
<td>356</td>
<td>415</td>
<td>257</td>
<td>384</td>
<td></td>
</tr>
</tbody>
</table>

Predictions of future agricultural productivity do not include several important factors:

Increased yield due to genetic engineering

Decreased yield due to:
- decreased quality of grains (wheat > rice > corn > soybean)
- increased pests
- increased frequency of severe weather events
Future summers are very likely to be hotter than any experienced thus far

Land area in extreme drought predicted to increase from 1% → 30% by 2100 in the A2 scenario

- in at least severe drought: 5% → 40%
- in at least moderate drought: 20% → 50%
Severe weather events are likely to reduce yields

- in US Midwest, probability of a flood event at least as damaging as the 1993 flood is predicted to double by 2030 and quadruple by 2090
How could climate change affect human health?

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Climate change is predicted to increase civil wars in six African regions by 5-10% by 2030

- and, overall, in sub-Saharan Africa by
  - 44% (B1)
  - 48% (A2)
  - 54% (A1)
In 2006 Center for Naval Analyses (CNA) convened a Military Advisory Board of 11 retired three-star and four-star admirals and generals to assess the national security implications of climate change

Major Findings:
1. Projected climate change poses a serious threat to America's national security.
2. Climate change acts as a threat multiplier for instability in some of the most volatile regions of the world.
3. Projected climate change will add to tensions even in stable regions of the world.
4. Climate change, national security and energy dependence are a related set of global challenges.

Recommendations:
1. The national security consequences of climate change should be fully integrated into national security and national defense strategies.
2. The U.S. should commit to a stronger national and international role to help stabilize climate changes at levels that will avoid significant disruption to global security and stability.
3. The U.S. should commit to global partnerships that help less developed nations build the capacity and resiliency to better manage climate impacts.
How could climate change affect human health?

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5. Change in frequency and/or severity of conflict

What are the biggest climate change effects on human health?

<table>
<thead>
<tr>
<th>Negative impact</th>
<th>Positive impact</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Very high confidence</strong></td>
<td></td>
</tr>
<tr>
<td>Malaria: contraction and expansion, changes in transmission season</td>
<td></td>
</tr>
<tr>
<td><strong>High confidence</strong></td>
<td></td>
</tr>
<tr>
<td>Increase in malnutrition</td>
<td></td>
</tr>
<tr>
<td>Increase in the number of people suffering from deaths, disease and injuries from extreme weather events</td>
<td></td>
</tr>
<tr>
<td>Increase in the frequency of cardio-respiratory diseases from changes in air quality</td>
<td></td>
</tr>
<tr>
<td>Change in the range of infectious disease vectors</td>
<td></td>
</tr>
<tr>
<td>Reduction of cold-related deaths</td>
<td></td>
</tr>
<tr>
<td><strong>Medium confidence</strong></td>
<td></td>
</tr>
<tr>
<td>Increase in the burden of diarrhoeal diseases</td>
<td></td>
</tr>
</tbody>
</table>
Stern Review concludes that the cost of unabated climate change would be $5-70 trillion/year by 2100

Equivalent of a continuous

WWII  Great Depression

Cost of inaction is 5-20 times the cost of action