The consensus position on Climate Change

- The climate is changing (Detection)
- Due to humans (Attribution)
- Impacts now, with worse to come (Projection)
- We must act now (Response)

UN IPCC Fifth Assessment Report (AR5, 2014)
US Climate Science Special Report (CSSR, 2017)
US Fourth National Climate Assessment Vol II (2018)

Katharine Hayhoe
@KHayhoe

Our 600 page climate report in one tweet:
It's real
It's us
It's serious
And the window of time to prevent dangerous impacts is closing fast

5:36 AM - 11 Aug 2017
From *The Princess Bride*

*YOU KEEP USING THAT WORD*

*I DO NOT THINK IT MEANS WHAT YOU THINK IT MEANS*
Presentation outline

• The “Consensus view” on the science
  • Detection
  • Attribution (and models)
  • Projection
  “... But” interspersed

• Impacts observed and impacts projected

• Response (and But’s)

This is a complex/nuanced subject
Completeness/detail suffer for brevity
Detection: Unusual global warming in recent decades

Other indications
- Warming atmosphere
- Warming oceans
- Rising sea levels
- Shrinking Arctic ice
- Shrinking glaciers
- Growing humidity

CSSR, Figure ES.1, pg. 13
Detection: “Unusual global warming in recent decades” … But perhaps not so unusual?

HadCRUT3 Temperature Anomalies
1957-2008 (Human caused) 1895-1946 (Natural)

Temperature and time scales for the two time series are identical. One time series has been displaced vertically to give equal means over the 52-year warming period.
Detection: “Unusual global warming in recent decades” ... But temperature varies on its own.
Attribution: “Humans have caused at least half of the warming since 1951”

- Human influences on the climate include:
  - Greenhouse gas emissions
  - Aerosols
  - Land use

- Natural influences include:
  - Solar variability
  - Volcanic and natural aerosols
  - Changes in the carbon cycle

We find no convincing evidence that natural variability can account for the amount of global warming observed over the industrial era – CSSR, pg. 35
Attribution: “Humans are increasing the CO$_2$ concentration”
Human influence growing with time; “Radiative Forcing” currently net +2.5, or <1%
Attribution: “Human influences have grown since 1750”

- CO$_2$ warms
- Aerosols cool
Attribution: ... But Human influences were much weaker before ~1950
Attribution: Climate models

• “Our models are useful, but imperfect”
• “They’re the best we’ve got and they’re improving”

... But
• They’re not “just physics”- subjective judgements about small scale phenomena
• They fail to reproduce important aspects of the changing climate

Model issues include:
• Subgrid scale parameterization of clouds, convection
• Ocean initial conditions
• Greenhouse-aerosol degeneracy
• Multidecadal modes of the climate system
Attribution:
... But the models are unphysical
Attribution: ... But multidecadal variability is not present in the models.
Attribution: “Models reproduce the historical record” …**But** not very well and “run hot”

CMIP5 = Climate Model Intercomparison Project, 5th Ensemble

“It remains difficult to quantify the contribution to this warming from internal variability, natural forcing and anthropogenic forcing, due to forcing and response uncertainties and incomplete observational coverage.” – IPCC AR5 WGI, p. 887
Attrition: “Models reproduce the historical record” ... **But** not very well and “run hot”
Projection: “We can usefully project future climates”

• Assume future trajectories for human influences
  • Demography, development, technology, economics, regulation, ...
  • GHG and aerosol concentrations, land use
  • Embodied in Representative Concentration Pathways (RCPs)
    \[ \text{RCP}_n \text{ has forcing of } n \text{ W/m}^2 \text{ in 2100} \]

• Run the models forward from today

• Average results over ensembles of models
Projection: “Alternative future population, GDP”

Projection: “Higher emissions mean higher temperatures sooner”
Projection: ...But uncertain response to human influences

“Key remaining uncertainties relate to the precise magnitude and nature of changes at global, and particularly regional, scales, and especially for extreme events and our ability to observe these changes at sufficient resolution and to simulate and attribute such changes using climate models.”

– CSSR, pg 58

• “Estimated temperature response to increasing CO₂ is uncertain by a factor of 3”(!)

• Impacts beyond temperature largely not evident (“yet”?)
**Impacts:** “Already bad and will get worse”

### Consensus Schematic

<table>
<thead>
<tr>
<th>Global temperature change (relative to pre-industrial)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°C</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td><strong>Food</strong></td>
</tr>
<tr>
<td>Falling crop yields in many areas, particularly developing regions</td>
</tr>
<tr>
<td><strong>Water</strong></td>
</tr>
<tr>
<td>Small mountain glaciers disappear – water supplies threatened in several areas</td>
</tr>
<tr>
<td><strong>Ecosystems</strong></td>
</tr>
<tr>
<td>Extensive Damage to Coral Reefs</td>
</tr>
<tr>
<td><strong>Extreme Weather Events</strong></td>
</tr>
<tr>
<td>Rising intensity of storms, forest fires, droughts, flooding and heat waves</td>
</tr>
<tr>
<td><strong>Risk of Abrupt and Major Irreversible Changes</strong></td>
</tr>
<tr>
<td>Increasing risk of dangerous feedbacks and abrupt, large-scale shifts in the climate system</td>
</tr>
</tbody>
</table>

- “Global temperature change is a proxy for other impacts”
- “2°C is the safe limit”, ... But is an ill-defined threshold
Impacts: “IPCC on weather extremes”
(modest paraphrases from AR5 WGI, Chapter 2)

• ...since about 1950 it is very likely that the numbers of cold days and nights have decreased and the numbers of warm days and nights have increased ... there is medium confidence that globally the length and frequency of warm spells, including heat waves, has increased since the middle of the 20th century

• ... likely that since 1951 increases in the number of heavy precipitation events in more regions than there have been decreases, but there are strong regional and subregional variations

• ... low confidence regarding the sign of trend in the magnitude and/or frequency of floods on a global scale.

• ... low confidence in a global-scale trend in drought or dryness since the middle of the 20th century,

• ...low confidence in trends in small-scale severe weather phenomena such as hail and thunderstorms

• ... low confidence in any longterm (centennial) increases in tropical cyclone activity, ... virtually certain increase in the frequency and intensity of the strongest tropical cyclones since the 1970s in the North Atlantic.

• ... low confidence in large scale changes in the intensity of extreme extratropical cyclones since 1900
Impact: “Temperature extremes becoming more common; certain to increase” ... But it isn’t so simple

- Coldest temperatures increasing;
- Warmest temperatures unchanging
- Not “warming” but milding
- Agricultural intensification plays a role
Impact: “Sea level is rising”

Tide gauges

Satellites

http://rsta.royalsocietypublishing.org/content/372/2025/20130336

https://www.star.nesdis.noaa.gov/sod/Lsa/SeaLevelRise/LSA_SLR_timeseries_global.php
Impact: “Sea level is rising”, ... But that’s not unusual

https://commons.wikimedia.org/wiki/File:Post-Glacial_Sea_Level.png

CSSR Figure ES.8, pg 26
Impact: “Sea level is accelerating”, ...But not obviously

Tide gauge analysis derived from Hay et al., Nature Climate Change 7, 492–495 (2017) doi:10.1038/nature14093

Satellite data from Chen et al., https://www.nature.com/nclimate/journal/v7/n7/full/nclimate3325.html

- Global average precipitation is ~1,000 mm/yr
- Atmosphere holds 25 mm H₂O

What would it take to convince Koonin:
- Good explanation of prior variability
- A several-σ signal
Impact: “Rapid sea level rise projected”, …But discordant with observations

Sea level rises more rapidly with warmer temperatures

https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8518750

... there is still low confidence that any reported long-term (multidecadal to centennial) increases in TC activity are robust ... – CSSR, p 258

“It is premature to conclude that human activities—and particularly greenhouse gas emissions that cause global warming—have already had a detectable impact on Atlantic hurricane or global tropical cyclone activity. ...”


Posted Spring, 2016
Impact: “Artic sea ice is disappearing”
Impact: “Arctic sea ice is disappearing”

...**But** it is highly variable

From a NYTimes report:

*The Artic seems to be warming up. Reports from fishermen, seal hunters, and explorers ... all point to a radical change in the climatic conditions, and hitherto unheard of temperatures in that part of the earth. Old glaciers have disappeared and land once covered with field ice is bare.*

*The [Eastern] Artic is not recognizable as the same region fifty years ago.*

*Formerly Spitzbergen held an even Summer temperature up to 3C; this year recorded temperatures up to 15 degrees and last Winter the ocean did not freeze over even on the north coast of Spitzbergen.*

- Published February 23, 1923 (!)
Impact: “Agriculture will be impacted”,...But plants love CO₂ and farmers aren’t dumb

https://climate.nasa.gov/news/2436/co2-is-making-earth-greenerfor-now/

Rising CO₂ concentration has made the earth greener (for now?)

Agriculture has thrived despite climate change to date
Impact: Climate change will crash the economy

Ref: SEK WSJ 11/26/18

NCA4, vol II, Fig 29.3 (global T; 2080-2099 rel 1980-2010)

AR5 WGII Figure 10.1
... but at worst a bump in the road

- At 2% CAGR, 10% decrement in 2090 = 5 years delay
- $550B = 0.6% in 2090 = 4 months delay

Climate-induced growth delay
Response: “We can (and must) reduce GHG emissions promptly to prevent the worst impacts” ... But that’s very hard

And it’s only one of three strategies

• **Mitigation** of human influences – reduce GHG emissions
  • GHG-lite energy sources (stationary, transport); energy efficiency
  • Aerosols; Land use; Agriculture

• **Adaptation**
  • Adapt infrastructure (e.g., sea walls); adapt processes (e.g., crops)

• **Geoengineering** – intentional intervention to counteract GHG influence
  • Carbon-dioxide removal? Solar radiation management?

• **For each**: Costs? Efficacy? Collateral effects (positive and negative)? Perception?
Response: “Diverse GHG sources”


- Electricity and Heat Production: 25%
- Agriculture, Forestry and Other Land Use: 24%
- Transportation: 14%
- Industry: 21%
- Buildings: 6%
- Other Energy: 10%

Response: Global CO\textsubscript{2} emissions
Response: “Half of the CO₂ emitted stays in the atmosphere for centuries”

\[
\begin{align*}
\text{Fossil Fuel Burning} & \quad 30 \text{ billion tons go in} \\
\text{ATMOSPHERE} & \quad 15 \text{ billion tons added every year} \\
3000 \text{ billion tons CO₂} & \quad \approx8 + \approx7 = 15 \text{ billion tons go out}
\end{align*}
\]
Cumulative Fossil Fuel with Atmospheric CO₂ Increase

Atmospheric CO₂ trend parts per million Dec 2016
Fossil fuel CO₂ emissions

Amount of CO₂ (PgC)

1650 1700 1750 1800 1850 1900 1950 2000 2020
Year

Dec 2016
Response: ... But the long CO_2 lifetime is highly problematic.
Response: IPCC says severe emission reductions just to stabilize human influences

Post-2075: NO oil, NO gas, NO coal, NO agricultural emissions (absent sequestration or biological offsets)
Response: CO₂ emissions and GDP per capita (1980-2005)

Source: DOE EIA database (2008)

Today's global average

Required for stabilization

Singapore in 2005
GDP ~ $40,000
CO2 ~ 9 t
Response: “The Paris Agreement is important,”
...But won’t much reduce emissions

**INDC** = “Intended Nationally Determined Contributions” (pledges)

**Paris agreement:**
- Has 5-year reviews with self-reporting
- Has no enforcement mechanism
- Is non-binding
  - US, EU, Japan will not meet their 2030 commitments without further policy changes
- Chinese commitment to peak CO$_2$ emission by 2030 appears on track
Response: Adaptation is good for all seasons

• It is agnostic
  – indifferent to natural vs human-caused

• It is proportional
  – adapt more if the change is greater

• It is local
  – politically palatable as spending is “here and now”
  – does not require global consensus

• It is autonomous
  – It will happen on its own

• It is effective

But adaptation is much easier if you’re richer
Koonin’s takeaways (descriptive)

- **Climate continues to change** under natural and growing human influences

- The “**consensus**” is not as solid as popularly perceived

- Beyond rising temperature, most **projected impacts have not clearly emerged**

- We are **unlikely to even stabilize human influences** this century; **adaptation** will be the dominant response.
Response: “If I were in charge” (normative)

- Clarify the policy discussion and the science that underpins it
  - Sustain and bolster climate observations
  - Reframe the discussion to “values”; don’t use alleged certainty as a club
  - A scientific “red team” exercise to accurately portray “the science” (SEK, WSJ 4/20/17)
- Pursue “easy” emissions reductions
  - Non-CO₂ GHGs
  - Cost-effective efficiencies
    - Leverage credible side benefits (local environment, energy security)
  - RD&D for low-cost, emissions-free technologies
    - Fission, solar, storage/grid management, biofuels, CCS, fusion, …
- Reduce emissions further if/when
  - the science becomes more certain (signal emerges from the noise) or
  - a values consensus emerges or
  - zero-emissions technologies become more feasible
- Pursue adaptation vigorously
  - Modes of adaptation (“wedges”)? What are we adapting to?
- Investigate geoengineering as a last-resort option
  - Research program? Feasibility tests? Governance?
Questions? Comments?