The Road to Paris
Climate Change Science and Policy

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We are inadvertently conducting an experiment on our planet.
This December, the international community will meet in Paris to address global warming.
Why is global warming happening?

How does global warming impact people and the environment?

What is being done about global warming?
Why is global warming happening?
The Earth receives energy from the sun, mostly as visible light, and re-emits it to space as infrared radiation.

Conservation of Energy:
Energy in = Energy out
visible light

infrared radiation
Coffee cup demonstration
The details of the energy flow is complicated, but adding greenhouse gases increases the surface temperature.

Trenberth et al, 2009
Carbon dioxide accounts for the bulk of the increased greenhouse warming.
Most of the CO2 emissions come from the burning of fossil fuels.
Emissions come from a variety of economic sectors.
Humans have increased the amount of CO₂ in the atmosphere by 40% since the beginning of the Industrial Age.

An atlas of pollution: the world in carbon dioxide emissions
About 40% of the carbon dioxide emitted from fossil fuels stays in the atmosphere, while the rest goes into the ocean and land.
We have been measuring carbon dioxide in the atmosphere since the 1950s.

Latest CO$_2$ reading
September 26, 2015

397.43 ppm

Carbon dioxide concentration at Mauna Loa Observatory

Full Record ending September 26, 2015
Atmospheric CO$_2$ concentration is higher than it has been in the past 800,000 years.

EPICA Dome C, Antarctic Ice Core
Temperature and carbon dioxide have been increasing together over the 20th century.

Global average temperature increased by 1.5°F (0.85°C) since 1880.
Global average temperature increased by 0.85°C (1.5°F) since 1880.
How does global warming impact people and the environment?
The IPCC regularly publishes reports on the current state of climate science.
Scientists use climate models to predict future warming and impacts.

Conservation of momentum
\[ \frac{\partial \vec{V}}{\partial t} = - (\vec{V} \cdot \nabla) \vec{V} - \frac{1}{\rho} \nabla p - \vec{g} - 2\vec{\Omega} \times \vec{V} + \nabla \cdot (k_m \nabla \vec{V}) - \vec{F}_d \]

Conservation of energy
\[ \rho c_v \frac{\partial T}{\partial t} = - \rho c_v (\vec{V} \cdot \nabla) T - \nabla \cdot \vec{R} + \nabla \cdot (k_T \nabla T) + C + S \]

Conservation of mass
\[ \frac{\partial \rho}{\partial t} = - (\vec{V} \cdot \nabla) \rho - \rho (\nabla \cdot \vec{V}) \]

Conservation of \( H_2O \) (vapor, liquid, solid)
\[ \frac{\partial q}{\partial t} = - (\vec{V} \cdot \nabla) q + \nabla \cdot (k_q \nabla q) + S_q + E \]

Equation of state
\[ p = \rho R_d T \]
Dozens of modeling centers around the world make GCMs and collaborate in the Coupled Model Intercomparison Project (CMIP).
Projections of fossil fuel emissions are needed for GCMs.
The largest uncertainty in our climate projections for 2100 is future emissions.

RCP = Representative Concentration Pathway
Temperature increases with the amount of emissions.

Global average surface temperature change
(relative to 1986–2005)

IPCC, AR5
Land warms more than ocean.

(a) Change in average surface temperature (1986–2005 to 2081–2100)

IPCC, AR5
Heat waves become more likely and hot records will be broken.

More extreme heat records

Fewer extreme cold records
Heat waves become more likely and hot records will be broken.
Extreme heat poses a serious public health risk.
Over the oceans, wet places will get wetter and dry places will get drier, but over land, models often don’t agree.
Extreme rainfall will increase, as will aridity.
Increases in flooding and in drought have a human cost.
More communities will be dealing with water shortages and flooding.

‘They are grappling with solutions’ ... Bangladeshi villagers repair a vital flood-protecting embankment after Cyclone Aila struck in 2009. Photograph: Munir Uz Zaman/AFP/Getty Images
Sea levels are rising and will continue to rise.

Milne et al. 2009
Sea levels are rising and will continue to rise.

IPCC, AR5
Low-lying island nations face an existential threat.

Republic of the Marshall Islands
100-year flood event with 6-inches of sea level rise.
Arctic Summer sea ice extent is at record lows and will continue to decrease.
The loss of summer sea ice brings ecosystem and societal changes.
Ocean Acidification Demo

Lower pH = higher acidity
$\text{CO}_2 + \text{H}_2\text{O} = \text{H}_2\text{CO}_3$

Carbon Dioxide + Water = Carbonic Acid
What happens when you add carbon dioxide to water?

\[ \text{CO}_2 + \text{H}_2\text{O} = \text{H}_2\text{CO}_3 \]

Carbon Dioxide + Water = Carbonic Acid
Increasing ocean acidification is also a consequence of carbon dioxide emissions.

Ocean acidity has increased by 25%
Waters in the Pacific Northwest are already naturally acidic, and becoming more acidic.
Thinner, smaller clam and scallop larvae in low pH waters

Washington State Blue Ribbon Panel on Ocean Acidification 2012
Thinner, smaller clam and scallop larvae in low pH waters

Washington state shellfish production is an important state industry worth $76 million!
In the Pacific Northwest, winter precipitation will fall more as rain than as snow.

Figure from Climate Change Impacts and Adaptation in Washington State
Current Climate

Area accumulating snow → SNOWFALL

Area contributing overland runoff to stream

RAINFALL

Elevation $Z_1$

RUNOFF → RUNOFF → RUNOFF

Slide by Mark Raleigh

Photo credit: Flickr.com User: Lucas – K Lu
Warmed Climate

Area accumulating snow decreases SNOWFALL

Area contributing overland runoff to stream increases RAINFALL

Elevation $Z_2$
Elevation $Z_1$

RUNOFF

RUNOFF

RUNOFF

Slide by Mark Raleigh
Photo credit: Flickr.com User: Lucas – K Lu
Under a “business as usual” scenario, the seasonal streamflow in basins such as the Yakima will change dramatically.

Changes in streamflow affect energy production, agriculture, and water availability.
What is being done about global warming?
Scientists have synthesizing these results many years as part of the Intergovernmental Panel on Climate Change (IPCC)
The IPCC regularly publishes reports on the current state of climate science.
Climate change is a global problem that calls for international cooperation.
UNFCCC is one important initiative in a larger effort that will continue after December.

Source: Figure 13.1 in *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to Fifth Assessment Report of the IPCC*. 
The UNFCCC assigns national responsibilities to address climate change.

*** Acknowledging that the global nature of climate change calls for the widest possible cooperation by all countries and their participation in an effective and appropriate international response, in accordance with their common but differentiated responsibilities and respective capabilities and their social and economic conditions,

*** The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

*** Prevent danger
The UNFCCC alone is inadequate to prevent dangerous climate change.

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<thead>
<tr>
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<th>Mandate</th>
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<tbody>
<tr>
<td>✓</td>
<td>Report emissions</td>
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<tr>
<td>×</td>
<td>Meet emissions reduction targets</td>
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<tr>
<td>✓</td>
<td>Report mitigation measures</td>
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<td>×</td>
<td>Deadlines, incentives, consequences</td>
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<tr>
<td>✓</td>
<td>Manage forests sustainably</td>
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<tr>
<td>×</td>
<td>Fulfill financial commitments</td>
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<tr>
<td>✓</td>
<td>Promote research &amp; information sharing</td>
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<tr>
<td>✓</td>
<td>Educate the public</td>
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<tr>
<td>✓</td>
<td>Meet annually (Conference of the Parties)</td>
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The Kyoto Protocol is a binding agreement to reduce emissions, but it isn’t sufficient, and it expires soon.
The goal of COP 21 is a new, binding international plan to reduce GHGs.

Another essential goal in Paris is to mobilise 100 billion dollars a year (about 78 billion euros) contributed by states, international organisations and the private sector from 2020.

COP 21 is to keep warming within the limit of 2°C compared with the pre-industrial era (about 1850)
Many nations have already submitted their intended contribution to the effort.

http://cait.wri.org/indc/
Countries can choose from a wide range of national policies to contribute.

- Forest Management
- Technology Investments
- Industry Regulation
- Vehicle Emissions Standards
- Carbon Capture & Storage
- Emissions Prices
- Adaptation Planning
INDC role play

Which types of policies does the country intend to use to address the problem of climate change?

- Forest management
- Technology investments
- Industry regulation
- Vehicle emissions standards
- Emissions pricing
- Carbon capture and storage
- Adaptation planning
- Other

What domestic factors do you think contribute to the country’s decision to pledge these actions and not the others?

- Wealth
- Natural resources
- Political ideology of the delegate
- Political opposition of other leaders
- Overriding policy goals
- Public opinion
- Lack of authority
- Culture, ethics, and morals
- Vulnerability to climate change impacts
- Other
Many developing countries can improve carbon sinks through sustainable forest management.

- Russia
- China
- Kenya
Investments in clean technology and infrastructure require financial resources and authority to spend.
Industry regulations require political will to regulate industry and confidence in economic growth.
Vehicle emissions standards can be effective in countries where many people buy new cars.

- USA
- Canada
Several nations have put a price on carbon emissions through a tax or cap and trade system.

- EU & Switzerland
- China
Some leaders are taking interest in carbon capture and storage as a geoengineering solution.

Carbon Capture & Storage

climatechange.ca.gov
Many countries have urgent concerns about coping with the impacts of climate change.

Kenya
Russia
China
All of these options could be discussed at COP 21 in Paris this December.

- Forest Management
- Technology Investments
- Industry Regulation
- Vehicle Emissions Standards
- Carbon Capture & Storage
- Emissions Prices
- Adaptation Planning
UNFCCC is one important initiative in a larger effort that will continue after December.

Source: Figure 13.1 in *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to Fifth Assessment Report of the IPCC.*
In conclusion, climate change is a big problem that calls for international cooperation and a wide range of national policies. To be continued...

Thank you!
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EXTRA SLIDES
EXTRA/ALTERNATE SLIDES THAT WE DID NOT USE
COP 21 Delegates will meet from November 30-December 11, 2015.
Scientists will continue to quantify current climate change, refine climate models, and understand impacts.
Most strategies are described as either mitigation or adaptation.

- ADAPTATION
- MITIGATION
Emissions per head of population of the main GHG emitting countries in 2011*

*1 CO₂ per capita

According to the IPCC's 5th report, global GHG emissions caused by human activities rose to 49 Gt* of CO₂ equivalent in 2010.

* 1 gigatonne = 1 billion tonnes

Source: U.A.E (European countries) - CAIT/Will (other countries)
Geoengineering has been proposed as one strategy, though it may be risky.
GCMs are powerful tools, but their sequence of climate events is different from those of the observed world.

Deser et al, 2014
Global predictions have less variability than local predictions.
Local precipitation trends for the next 100 years are highly variable.

Deser et al, 2010
The amount of warming is tied to the total cumulative emissions.