

WEDNESDAY PM: Climate Change

Climate Change: Past, Present, Future

- How is climate prediction different from weather prediction?
- Why it's simpler than you think
- Future climate predictions, uncertainties

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Weather ↔ Climate

“*Weather* tells you what to wear, *Climate* tells you what clothes to buy”

- x Weather: the condition at a specific location at a specific time
- x Climate: the average conditions and their variability (includes extremes); the statistics of weather
- x Climate is an “envelope of possibilities” within which the weather bounces around
- x Weather depends very sensitively on the evolution of the system from one moment to the next (“**initial conditions**”)
- x Climate is determined by the properties of the Earth system itself (“**boundary conditions**”)

Weather Prediction and “Chaos”

- Weather prediction is a **deterministic** problem, yet 100% certainty is impossible
- this is because of the so-called “**sensitivity to initial conditions**”: an ever so slight change/error in the initial conditions (e.g. the currently observed state of the atmosphere) can lead to completely different future states
- Often referred to as the “**butterfly effect**” (the flap of a butterfly's wings in Brazil setting off a tornado in Texas)
- Edward Lorenz (meteorologist, pioneer of chaos theory):
 - **Chaos**: When the present determines the future, but the approximate present does not approximately determine the future.



Henri Poincaré, the Three-Body Problem, and the Discovery of Chaos

- The “n-body problem”: *given the quasi-steady orbital properties (instantaneous position, velocity, time) of a group of celestial bodies, predict their interactive forces; and consequently, predict their true orbital motions for all future times* [wikipedia]
- Oscar II, King of Sweden in 1887: prize for anyone who could solve this problem
- Henri Poincaré (famous French mathematician and physicist) could not completely solve the problem, but his work “is nevertheless of such importance that its publication will inaugurate a new era in the history of celestial mechanics” [Karl Weierstrass, one of the judges]
- Indeed, Poincaré's work led to the theory of chaos
- “It may happen that small differences in the initial positions may lead to enormous differences in the final phenomena. **Prediction becomes impossible.**”



Weather ↔ Climate

- x Today's sunset: 8:30 pm
- x Today's 7-day forecast: 85 / 57 F
- x July Long-Term Climatology: 75 F / 54 F
- x June 2015: average temperature 70 F (9th warmest in 127 year record), minimum: 49 F (on 1 & 8 June), maximum: 94 F (on 19 June)

- x Weather: minutes to weeks, ~ the time scale to which a specific event may be forecast
- x Climate: seasonal, annual, decadal, centurial, millennial, ...

Climate & Climate Change

- Climate is the accumulation of daily and seasonal weather events over a long period of time (**climate is the statistics of weather**)
- Climate can change on various **time-scales**: millions of years, thousands of years, hundreds of years, decades
- Climate can change in response to different factors:
 - **Natural**
 - **Human-induced ("Anthropogenic")**

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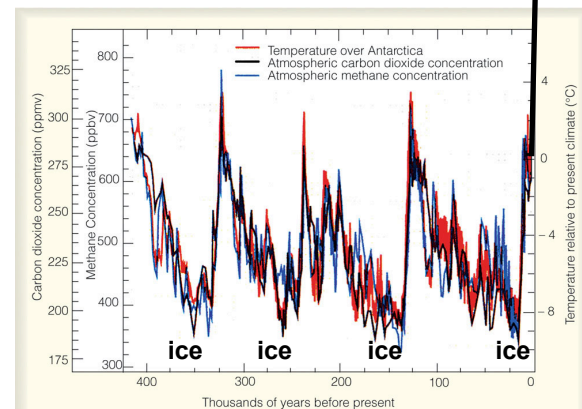
Factors in Climate Variability/Change

- External Factors (Astronomical)
 - Solar output
 - Orbital changes
 - Interplanetary dust
 - Collisions with other interplanetary bodies
 - Comets
 - Asteroids

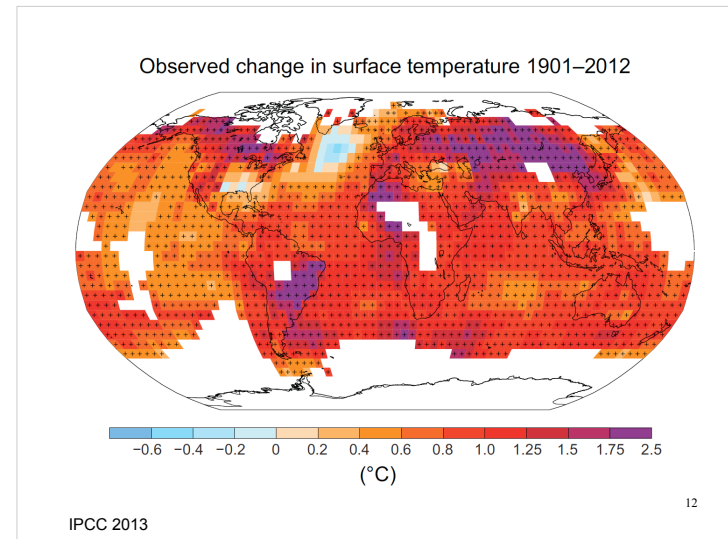
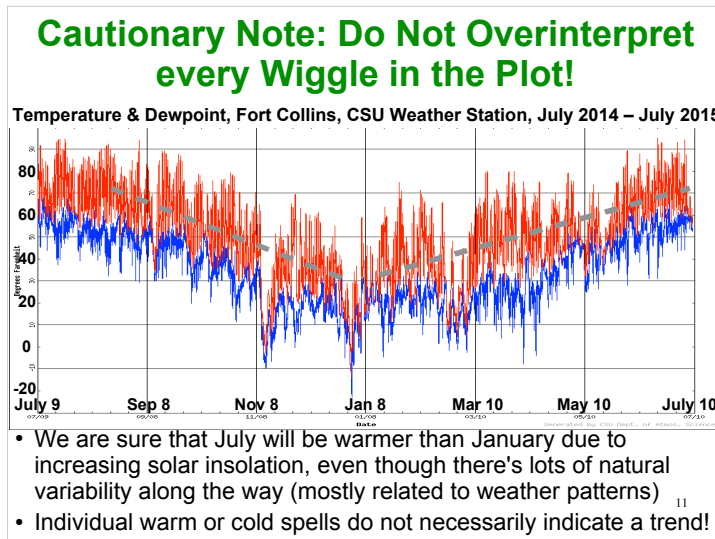
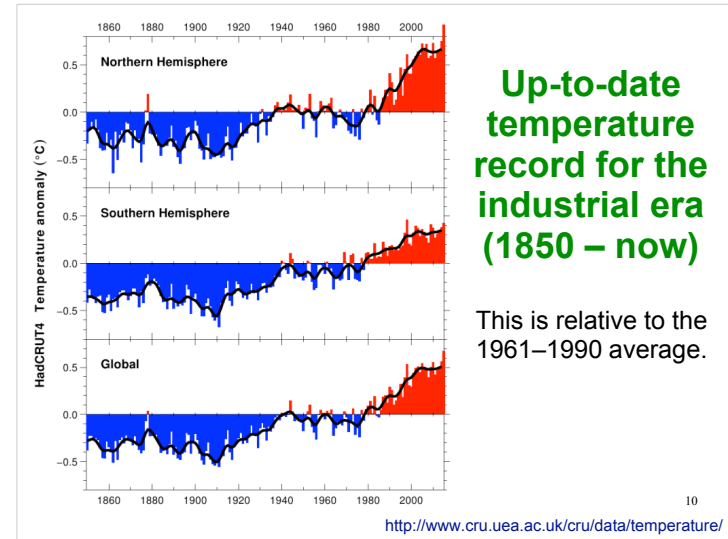
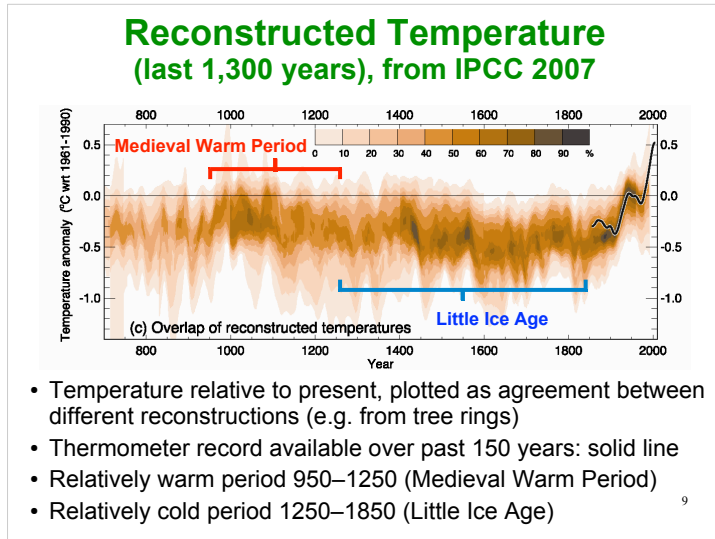
- Internal Factors
 - Atmospheric transparency
 - Surface characteristics
 - Ocean currents, ocean chemistry
 - Volcanic activity
 - Continental drift

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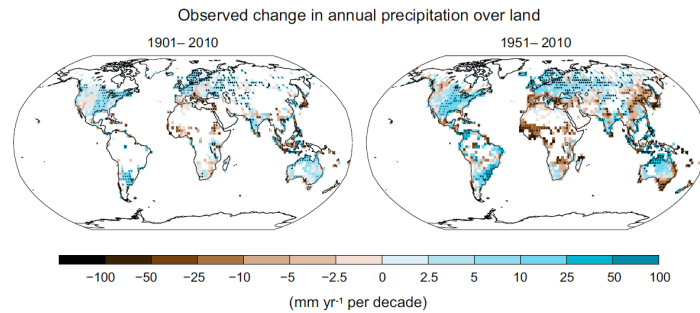
Climate through the Ages ↑ today



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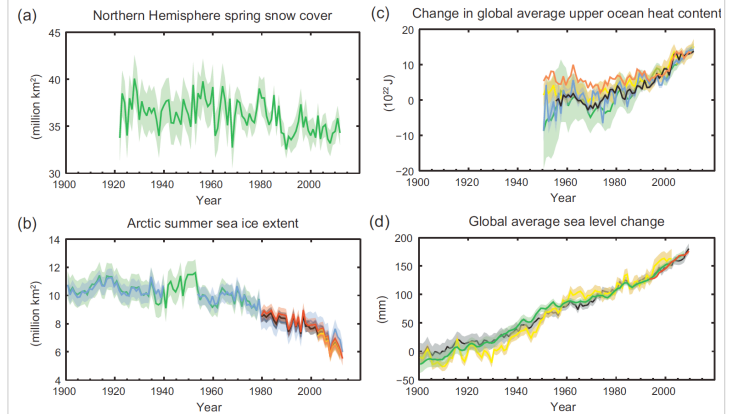
Climate Change is more than Surface Temperature Change!



IPCC 2013

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Climate Change is more than Surface Temperature Change!



IPCC 2013

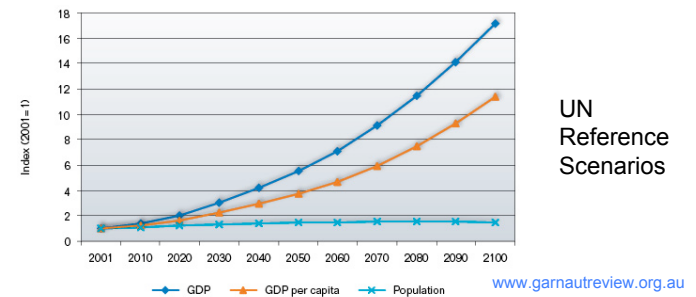
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Can we attribute the recent observed temperature changes to anthropogenic (human) forcing?

- To answer this scientists look at (amongst other things):
 - **Basic physics**
 - vertical/horizontal patterns of temperature changes
 - Oceanic temperature / heat content changes, sea level changes
 - Sea ice and glacier retreat
 - **Climate model response to imposed greenhouse gas forcing**

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Population growth is not the driver of future climate!



- Population to grow by 40% in 100 years
- Global **economy to grow by 1600%**
(assumes 2.8% annual GDP growth)

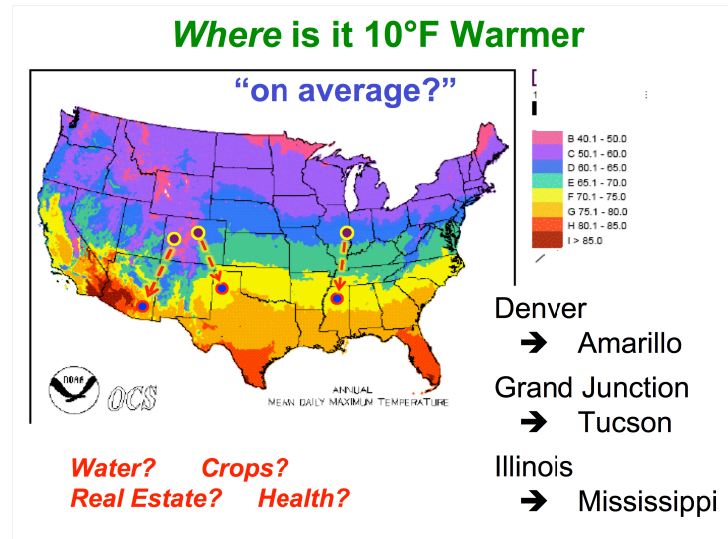
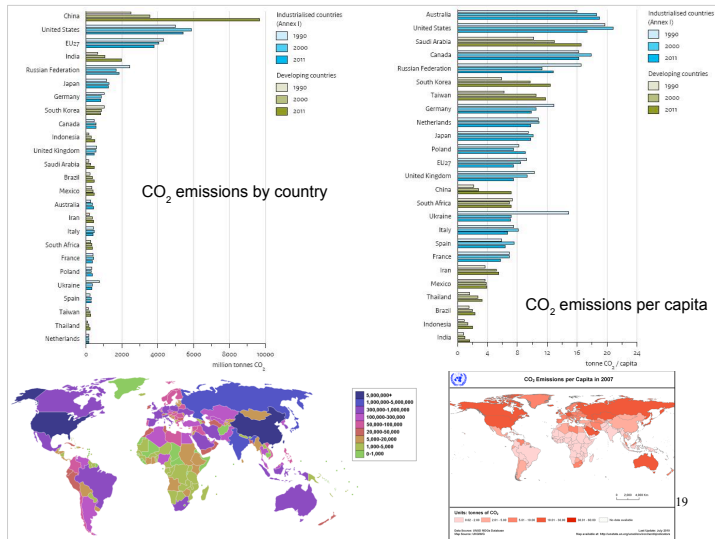
Wednesday PM, Explain: Climate Change



Shanghai, China 1990

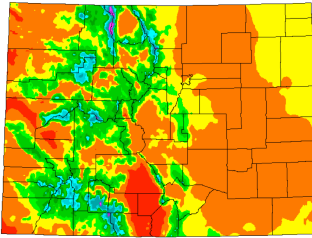
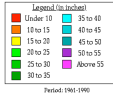


Shanghai, China 2012



A Region On the Edge

Average Annual Precipitation
Colorado



This map is a plot of 1961-1990 annual average precipitation estimates from NOAA's Cooperative Precipitation and Climate Experiment (CPCE). NOAA's National Climatic Data Center (NCDC) uses the PRISM model to generate the gridded estimates from 1948. The map was derived. The model grid was reprojected to 2.5 km using a Geographic Information System (GIS) and the resulting map was reprojected to the WGS84 datum. Funding was provided by USDA-NRCS National Water and Climate Center.



Much of the region already receives only **marginal precipitation**

Just enough **snow** to support forests and reservoirs

Just enough **irrigation water** to support farming

Just enough **water** to support 5.1 million people

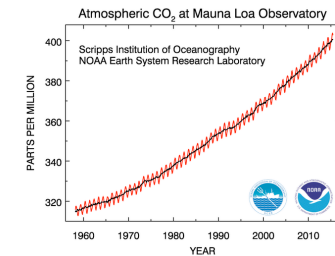
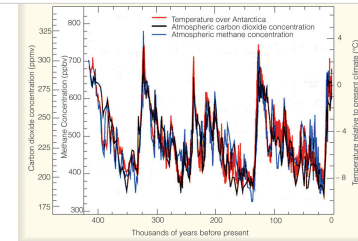
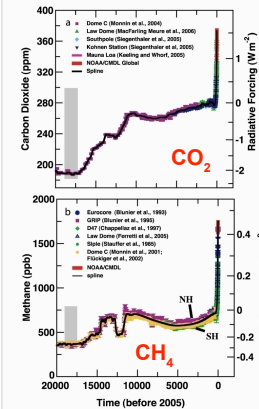
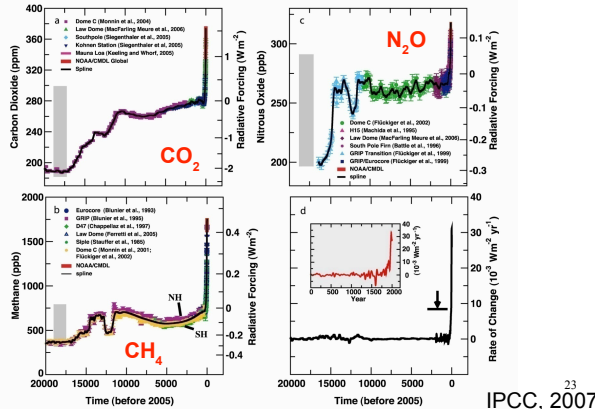
Anthropogenic Climate Variability and Change



Various resources at the Intergovernmental Panel on Climate Change (IPCC) Website:

<http://www.ipcc.ch/report/ar5/index.shtml>

Concentrations of most GHGs have been increasing in the modern age

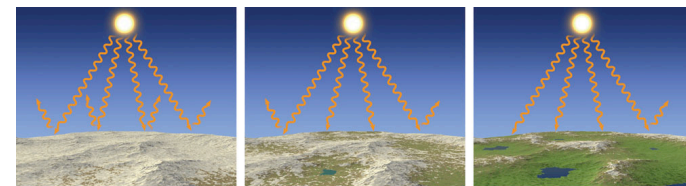
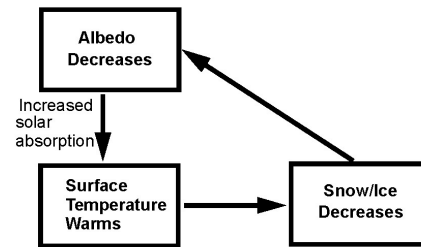


Feedbacks

- A process that changes the sensitivity of the climate response to an external forcing
- **Positive feedback:** increase the magnitude of the response to the forcing
 - Ice/albedo feedback
 - Water vapor feedback
 - Ocean carbon cycle feedbacks
- **Negative feedback:** decrease the magnitude of the response to the forcing
 - Stefan-Boltzmann feedback (i.e. warmer Earth emits more radiation out to space)

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Ice-Albedo Feedback (Positive)

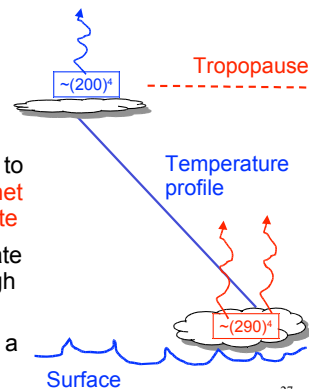


- (a) • High surface albedo
• Low absorption of sunlight
• Gradual surface warming
- (b) • Lower surface albedo
• Higher absorption of sunlight
• Surface warming increases
- (c) • Very low surface albedo
• Much higher absorption of sunlight
• Surface warming enhanced

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- Effect of clouds on climate: thick vs thin, high vs low
- High, very thin clouds warm the climate (let most sunlight through, emit at low temperature)
- Low, thick clouds cool the climate (emit a lot of terrestrial radiation, reflect a lot of solar radiation)
- Recall: in the net clouds contribute to Earth's albedo, i.e. **clouds have a net cooling influence on average climate**
- Cloud *feedback* in a warming climate depends on relative changes of high vs low clouds
- Currently, clouds are thought to be a slight positive feedback, but big uncertainties

Cloud Feedback

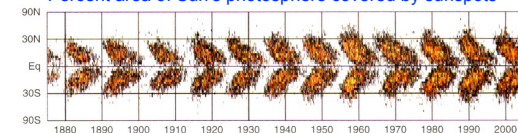


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Solar Variability

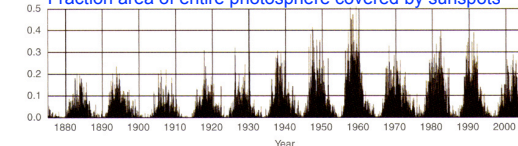
- The Sun's output is not exactly constant at 1366 W/m^2 – it does show some modest variation in time
- 11-year cycle in output, corresponding to variations in sunspots (large number of spots = high output)

Percent area of Sun's photosphere covered by sunspots



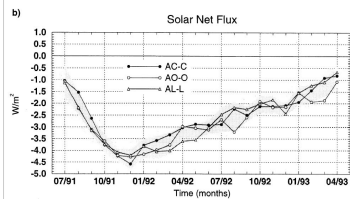
Yellow > 1%

Fraction area of entire photosphere covered by sunspots



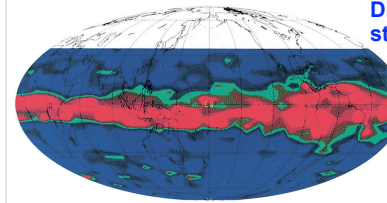
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Volcanoes



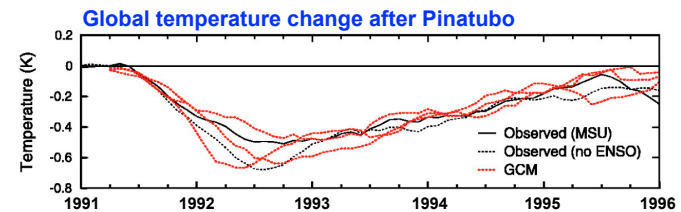
- Volcanoes emit sulfur dioxide that become aerosols (airborne solids) in the stratosphere → reflect sunlight, increase earth's albedo reducing the solar radiation absorbed by the climate system
- For example, lower-left: globally-averaged reduction in absorbed solar radiation after Mt. Pinatubo eruption in summer 1991
- Some are advocating man-made stratospheric injections of aerosols to mitigate anthropogenic climate warming

Volcanoes



Distribution of Mt. Pinatubo stratospheric forcing

- Reduction in solar radiation due to Mt. Pinatubo led to a cooling of the globally-averaged temperature ~ 0.5-0.7 C

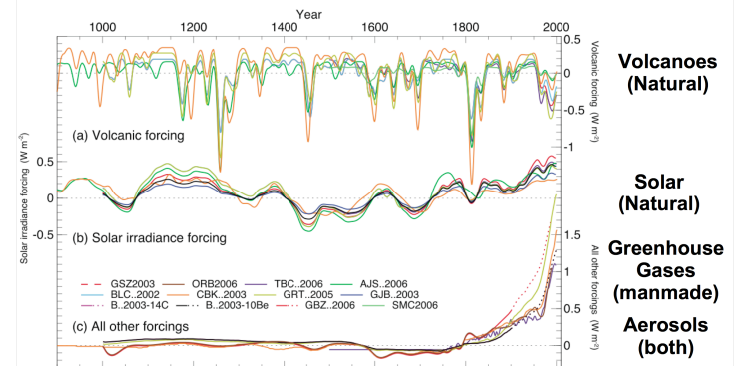


Force “full-blown” climate model with past radiative perturbations → what is the response?

- Greenhouse Gases
- Volcanoes
- Solar variations
- Land use changes
- Aerosols
- Ozone changes

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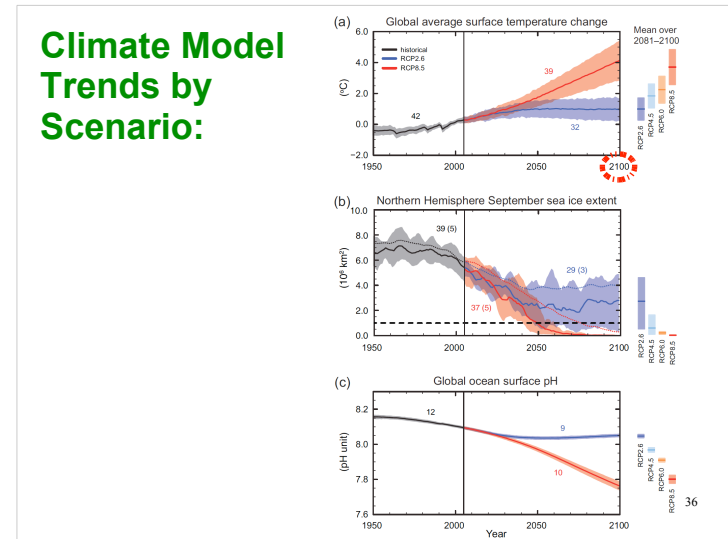
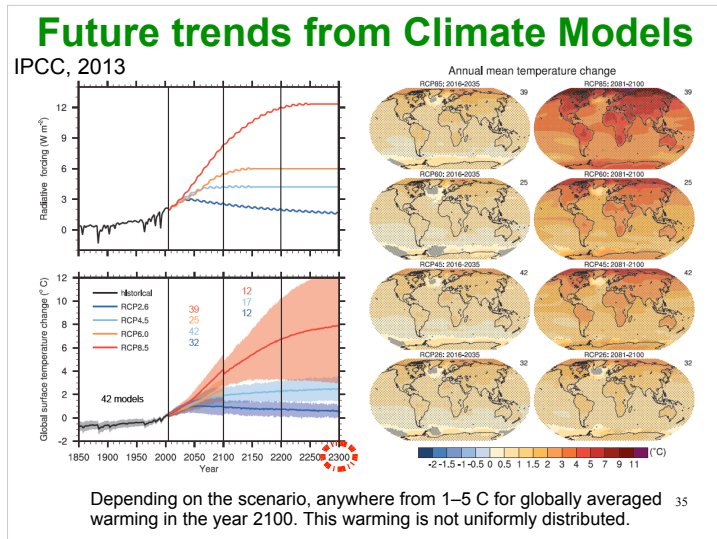
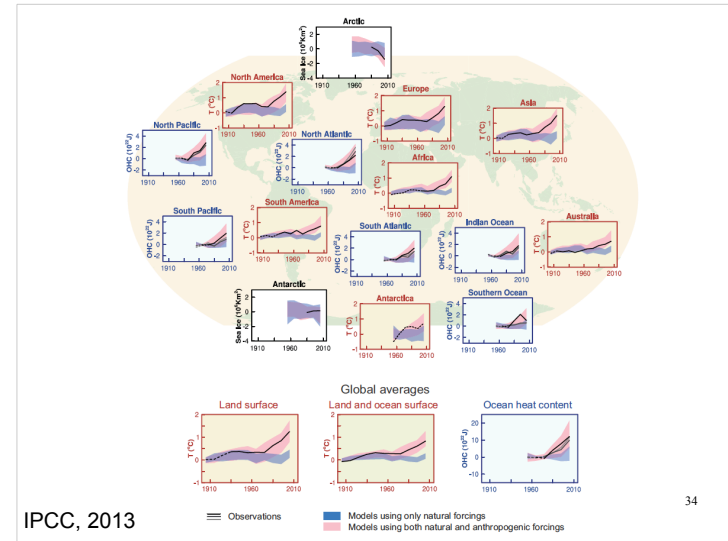
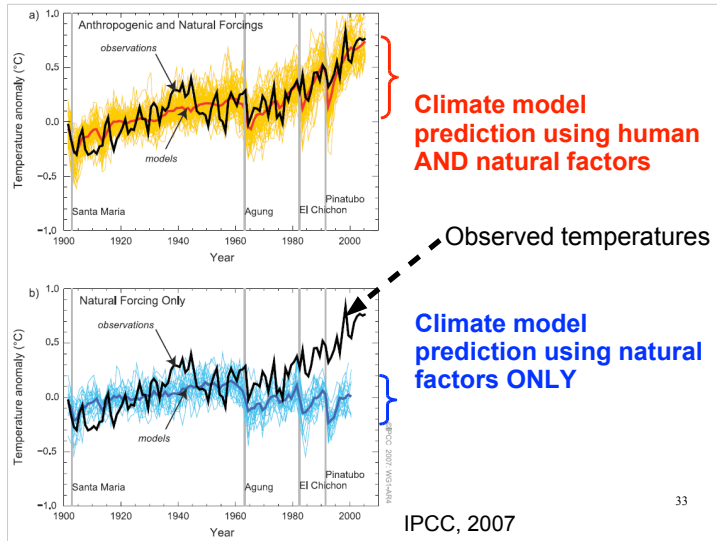
Past Radiative Forcing

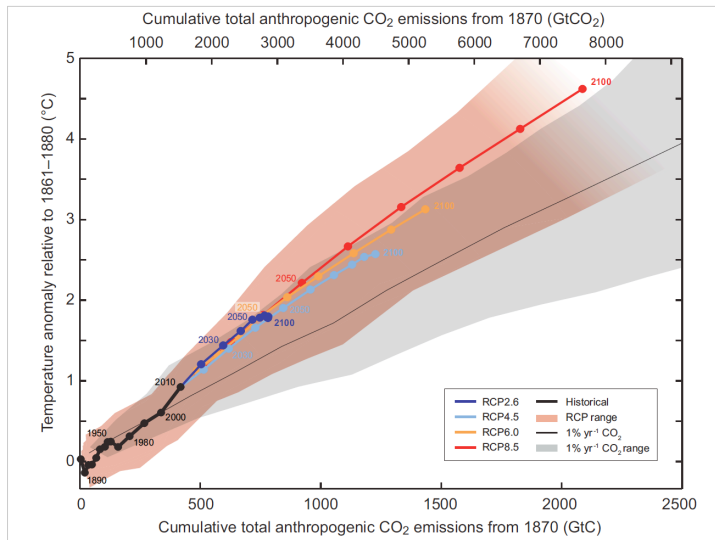
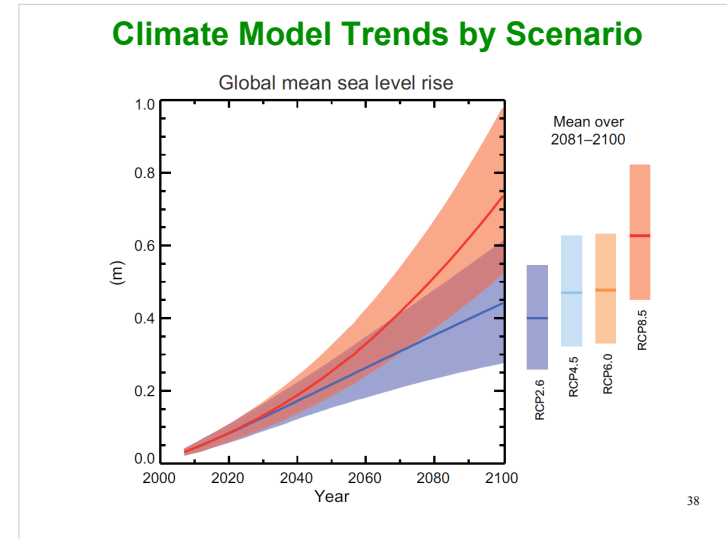
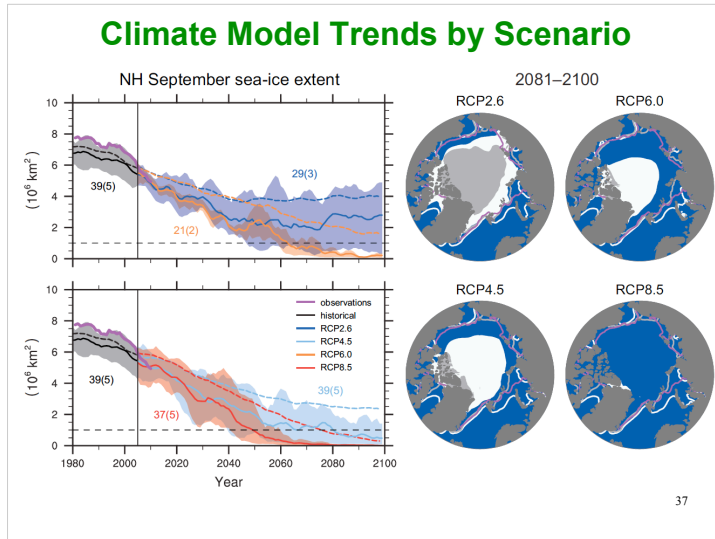


IPCC, 2007

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Wednesday PM, Explain: Climate Change





The Long Tail

- If China and India industrialize with coal ...
- CO₂ will rise to **4 times preindustrial**
- Extra CO₂ will remain for **millennia** after coal is gone

We Know for Sure

- CO₂ molecules absorb & re-emit thermal radiation (John Tyndall, 1859)
- Doubling the number of CO₂ molecules would add 4 W m^{-2} to the Earth 24/7 (Svante Arrhenius, 1896)
- If China and India industrialize with coal, CO₂ will approach ~400% of its preindustrial level by 2100
- Additional CO₂ will continue adding heat to Earth for thousands of years

What We're Not So Sure About

- By precisely how much the climate will change, especially locally
- How climate varies on relatively short time-scales (years to a couple of decades)
- The economic, political, and social consequences of these changes
- What to do about all of this

Solutions

- To provide a decent standard of living for billions of people on Earth ...
- ... we must generate huge amounts of energy without releasing CO₂.
- This is definitely possible (as an engineering task) ...
- ... but currently expensive and politically difficult.
- Can't do it by "tinkering around the edges."
- Requires profound changes to energy and economics