Mid-Term results and *Tentative* Scale

Average score: 24.15 (max possible 33)
High: 32
Low: 9

Tentative Curve

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Projections of Climate in the 21\textsuperscript{st} Century

- The projected forcings
- The projected climate change: 2000 to 2100
  - Global
  - Regional
  - Sea Level
  - Cryosphere
  - Extreme Events
- The long term outlook 2100 - 2300
- Uncertainty in the projections
  - Climate model uncertainty
  - Emission uncertainty
- Valid Arguments over the Science
- Summary of the 21\textsuperscript{st} Century Climate
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4. What’s new in Climate Science?
   A better understanding of the reasons for uncertainty in the models

Estimates for the change in global temperature for a doubling of carbon dioxide

Arrhenius 1896
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Estimates for the change in global temperature for a doubling of carbon dioxide

The *Expected* Distribution of Climate Sensitivity

Roe and Baker (2007) provide a simple theory for estimating the the *expected* distribution of model responses due to model uncertainty.
Source of Model Uncertainty?

Mainly things that we don’t explicitly model (we have to parameterize them in terms of the ‘resolved physics’

• Physics of individual clouds
• Sea Ice dynamics
• Turbulence near the surface (boundary layers)

By far, the most important uncertainty in the models is clouds.

Magnitude of the feedbacks in AR4, and in previous assessments

*Double CO$_2$?*

No feedbacks: +1.2°C

Albedo feedback: +0.1°C

H$_2$O + lapse rate feedback: +0.6°C

Cloud feedback: +0.2°C to +0.6°C

Feedbacks add ~ linearly, but the total response (temperature change) doesn’t
In today’s climate, the net effect of clouds is to cool the planet (albedo affect wins over greenhouse effect).
Clouds are the major source of uncertainty in the models

What happens when you double CO$_2$?

- With no feedbacks: 1.2°C
- With all feedbacks except clouds: +1.9°C +/- 0.15°C
- With all feedbacks (incl. clouds): +3.2°C +/- 0.7°C

Clouds are a major positive feedback (i.e., clouds cool less than today when CO$_2$ is doubled), but amplitude is uncertain.

More of these …. …and/or… … less of these.

Uncertainty in Emissions (2000-2100)

… due to uncertainty in projections of population, technology, choice of energy, economic development (material or sustainable, regional or balanced) and governance (regional or global emphasis)
Uncertainty in Climate Response (models)

... due to uncertainty in climate models: uncertainty in radiative forcing, clouds (type, distribution, brightness), sea ice physics, etc.

Uncertainty in Projected Global Average Temperature, 2090-1900:
half due to model uncertainty and half due to emission uncertainty

IPCC 2007 WG I Fig TS.27
Ocean Acidification (more later)

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Valid Arguments over the Science

1. Lindzen’s (1982) proposed negative water vapor feedback: the so-called Iris Effect.
2. The apparent inconsistency in the surface and atmospheric temperature trends the tropics (circa 2000)

Arguments over the Science

1. The hypothesized Iris Effect

   • Prof. Richard Lindzen (MIT) suggested in 2001 that perhaps in a warmer climate, clouds would be more efficient at removing water from the atmosphere
     – Warmer surface -> less vapor and therefore less high, thin cirrus clouds (which warm).

   • Lindzen hypothesized that increased CO₂ would cause warming (greenhouse effect) but precipitation would be more efficient so there would be less water vapor high in the tropical troposphere -- a negative feedback.
     – Dubbed the “Iris effect” (based on the analog: more incident sunlight causes the iris to close)

   • Suggested this effect could reduce the response to a doubling of CO₂ to < 1C.

Arguments over the Science

1. The hypothesized Iris Effect

- Many experiments were done to measure this feedback
  - It is positive: water vapor in the upper troposphere (10-15km up) *increases* when surface temperature increases, and the net amount of energy trapped in the atmosphere increases.

- Climate models also show that it is positive
  - Also, when forced by the observed increases in CO₂ over the 20th Century, the AR4 climate models show an increase in water vapor in the upper troposphere that is consistent with that observed


Arguments over the Science

2. The apparent inconsistency of the observed and predicted (by theory) 20th century temperature trends in the tropical troposphere

- In about 2000, it appeared that there had been little to no warming of the tropical atmosphere (mid-troposphere, about 5-12km up), as measured by satellites (1980-2000).

- Surface temperature was well measured and clearly increasing over the same time period.

- These differences, if real, are inconsistent with theoretical and modeling expectations of the response to increasing CO₂
Arguments over the Science

2. The apparent inconsistency of the observed and predicted (by theory) 20th century temperature trends in the tropical troposphere

• Theory and models predict that in the tropics, temperature trends between ~ 5-20km up in the atmosphere should be greater than those at the surface.

Arguments over the Science

• Findings:
  – The observed upper air data span too short a period to discern the impacts of CO₂ from natural variability (e.g., ENSO), natural forcing (two volcanoes) and human-induced decreases in stratospheric ozone (the latter two processes cool the atmosphere more than the surface).
  – The satellite-derived temperatures should under-represent the true temperature trend due to global warming because
    • algorithm that related what the satellites measured (microwave emitted from oxygen molecules) to temperature reflected the temperature averaged over the upper troposphere and lower stratosphere.
Arguments over the Science

Summary:

- The satellite data agree with the instrumental data -- at the surface and within the atmosphere.
- The observed temperature trends (1980-2000) in the atmosphere (satellite) and at the surface are not inconsistent with what is expected due to increased CO₂-- given the measurement error, the short duration of the time series and the presence of natural variability and decreased stratospheric ozone.