DEPARTMENT OF ECONOMICS
College of Management and Economics
University of Guelph
Guelph Ontario, Canada N1G 2M5
(519) 824-4120 Ext. 52532
http://www.uoguelph.ca/~rmckitri/ross.html
rmckitri@uoguelph.ca

Ross McKitrick, Ph.D.
Associate Professor and Director of Graduate Studies

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US House of Representatives
Committee on Energy and Commerce
Washington DC 20515-6115

Dear Chairman Dingell

Thank you for the opportunity to answer some additional questions.

1. *In your testimony, you state that "a considerable amount of work has gone into estimating potential economic consequences of global warming induced by greenhouse gas emissions." You cite a survey by R.S.J. Tol of 211 estimates of the marginal cost of greenhouse gas emissions. Is any of your work included in that survey of 211 estimates?*

   Table A1 from

   > Tol, R.S.J. (2007) "The Social Cost of Carbon: Trends, Outliers and Catastrophes" Discussion Paper 2007-44, Economics e-journal, September 19 2007.

   provides the listing of the 211 studies in Tol's meta-analysis. I am not an author or coauthor on any of them.

2. *I understand that you have published critiques of other economists' analysis of the marginal cost of greenhouse gas emissions. Have you published your own analysis of the marginal costs of greenhouse gas emissions? If so, please provide a citation to your paper.*

   My coauthored critique of the Stern review's estimates of the marginal costs of greenhouse gas emissions is

   > Byatt, I., R. M. Carter, I. Castles, et al. 2006. The Stern Review: A Dual Critique. *World Economics* 7, no. 4: 165-232.

I have not published an estimate of the marginal damages of greenhouse gas emissions. I have published analyses on the related matter of how pricing instruments for internalizing the marginal costs of greenhouse gas emissions should be tied to estimated marginal damages. Citations include:

McKitrick, Ross R. (2001) "Mitigation versus Compensation in Global Warming Policy." *Economics Bulletin*, Vol 17 no. 2 pp. 1-6, 2001.

McKitrick, Ross R. (2008) "A Simple State-Contingent Pricing Rule for Complex Intertemporal Externalities." Social Sciences Research Network Discussion Paper No. 1154157, July 1, 2008.

3. *Is the tropical troposphere more or less sensitive to climate change than the troposphere at the poles?*

I believe you mean "more or less sensitive to *greenhouse gases*". I will answer the question first with reference to the predictions of models and then with reference to the observed data.

MODELS

Climate models in which greenhouse gases are assumed to be capable of causing significant global warming show greater sensitivity to greenhouse gases in the troposphere over the tropics than over the poles.

The 2007 Intergovernmental Panel on Climate Change (IPCC) Report, Working Group I, Figure 9.1 (p. 675) presents a "backcast" analysis of the atmospheric response to observed changes in major forcings (greenhouse gases, solar radiation, volcanoes, aerosols and ozone depletion) over the interval 1890 to 1999 using the Parallel Climate Model (PCM), a large general circulation model sponsored by the US Department of Energy. The IPCC Figure is reproduced on the next page. I have added titles to the panels for ease of reading. All models are similar in behaviour, as the IPCC Report states (p. 674) that "The major features shown in Figure 9.1 are robust to using different climate models."

The format of each panel is as follows. Latitude goes from left to right, with the North Pole at the left, the equator in the middle and the South Pole at the right. Altitude is on the vertical axis, beginning at the surface and rising through the troposphere and into the stratosphere. The colour represents the predicted temperature change in response to the forcing. Dark blue and purple represent strong cooling. As the shading moves through light blue, light yellow and into orange and red the implied temperature change moves upwards towards strong warming.

I have added a horizontal line in the Greenhouse Gases panel indicating the approximate height of the mid-troposphere: just over 8 km at the poles, rising to about 12 km in the tropics.

As is clear from the coloring gradient, the model troposphere over the tropics shows greater sensitivity to greenhouse gas accumulation than does the troposphere over the polar region. The color tones indicate that, in response to 20th century greenhouse gas accumulation, the model says there ought to have been a warming rate of over 1 C per century in the troposphere over the tropics, and about 0.4 C per century in the troposphere over the poles. This pattern is sufficiently large in comparison to all other forcings that it dominates the Total forcing pattern in the bottom right panel.

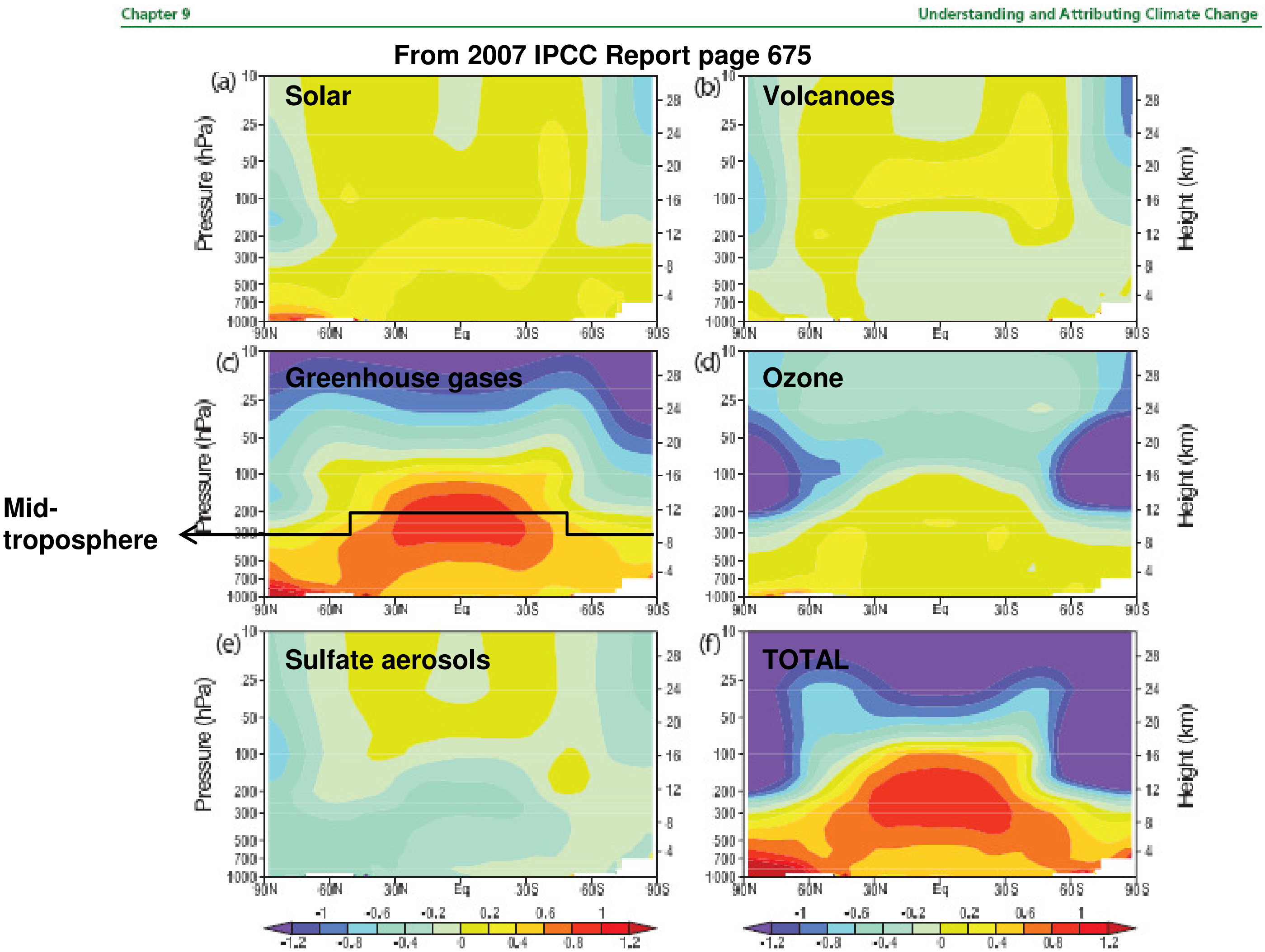
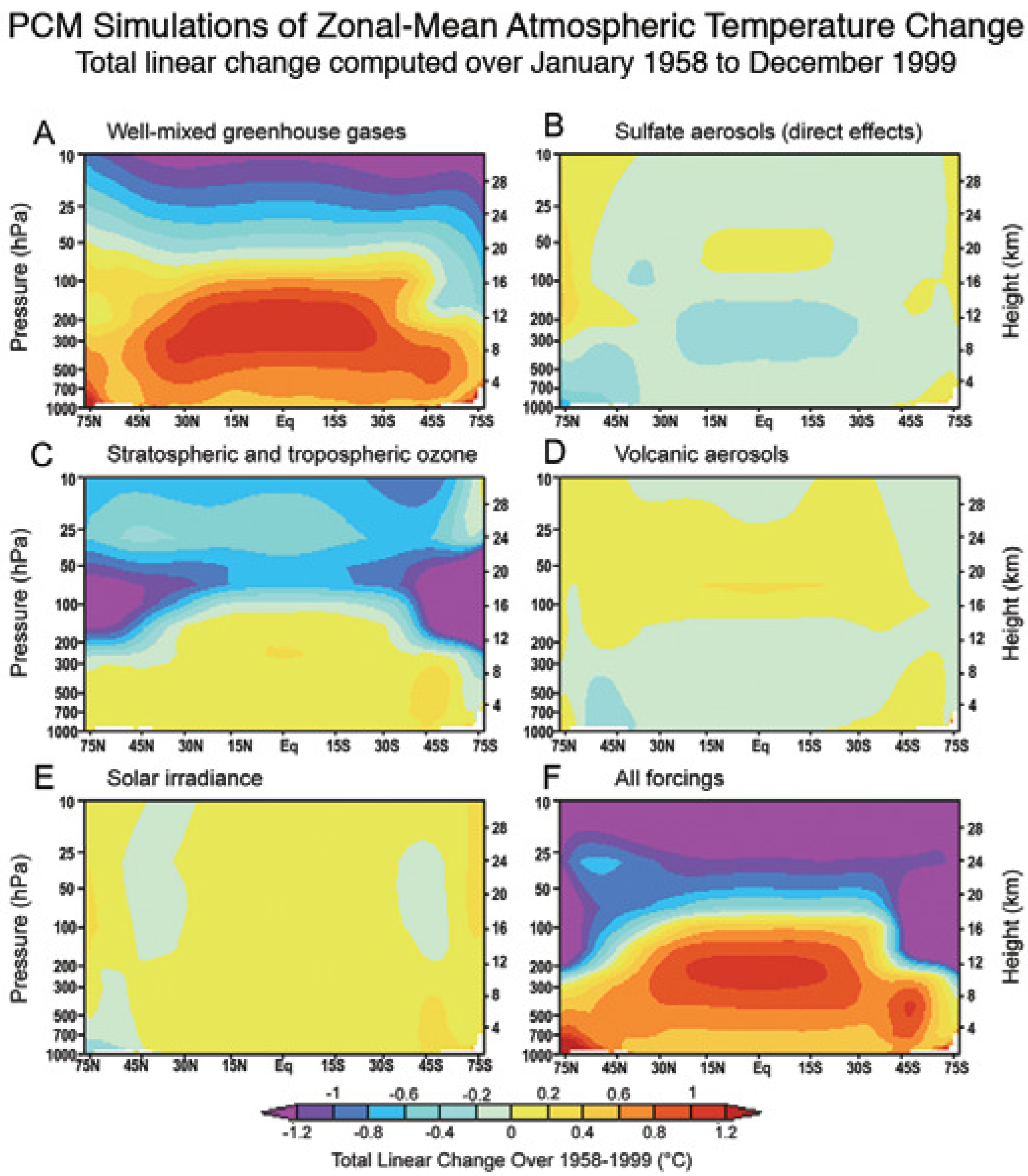


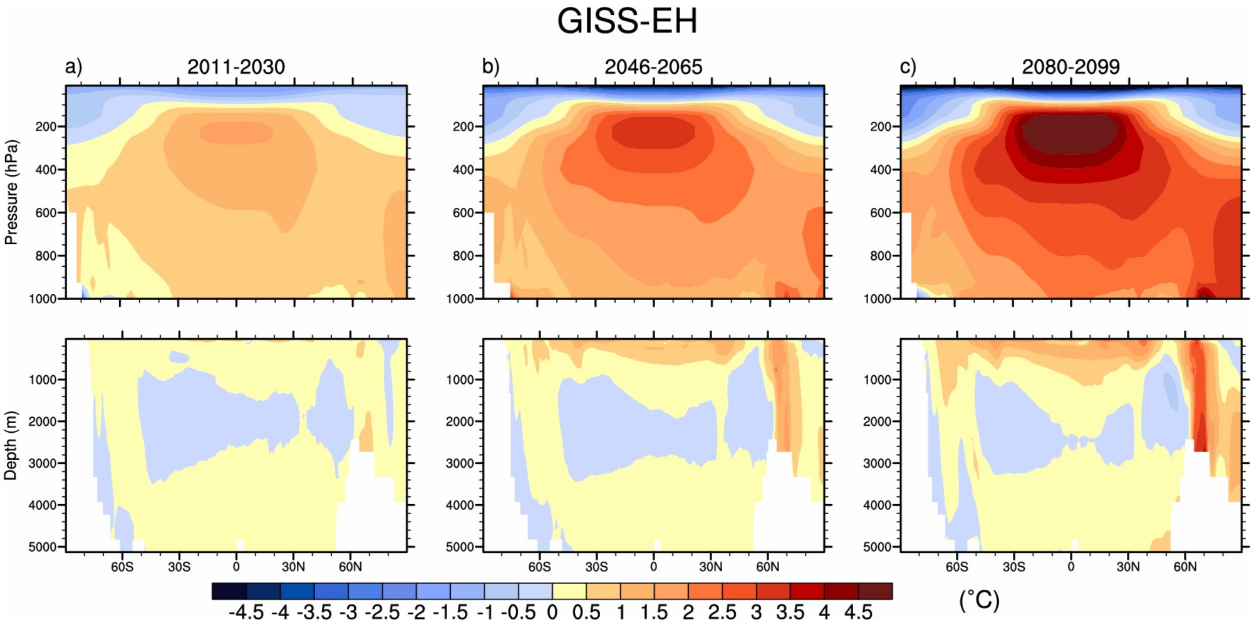
Figure 9.1. *Zonal mean atmospheric temperature change from 1890 to 1999 (°C per century) as simulated by the PCM model from (a) solar forcing, (b) volcanoes, (c) well-mixed greenhouse gases, (d) tropospheric and stratospheric ozone changes, (e) direct sulphate aerosol forcing and (f) the sum of all forcings. Plot is from 1,000 hPa to 10 hPa (shown on left scale) and from 0 km to 30 km (shown on right). See Appendix 9.C for additional information. Based on Santer et al. (2003a).*

The US Climate Change Science Program (CCSP) presented very similar results for a more recent interval. On the next page I have reproduced Figure 1.3 (p. 25) from the 2006 CCSP Report *Temperature Trends in the Lower Atmosphere: Steps for Understanding and Reconciling Differences*. It is similar in structure to the above IPCC diagram, and comes from the same model (PCM), but covers the interval 1958-1999. The color coding indicates once again that the troposphere is expected to be more sensitive to greenhouse gases over the tropics than over the polar regions (though note that regions beyond 75N and 75S are not displayed). In this case the warming rate in the mid-troposphere over the tropics is projected to be between 1.0 and 1.2 C over a 40 year span, or about 0.25-0.30 °C/decade, versus about 0.05-0.10 °C per decade over the poles, in the decades ending at 1999.



Turning now to projections of the climatic response to future increases in greenhouse gases, on the next page I have reproduced one of the 12 climate model projections used for Figure 10.7 of the IPCC Report (p. 765). The models show the response to the A1B emissions scenario, which is in the middle of the group of IPCC climate simulations (see IPCC Figure 10.4). All 12 model runs are available on-line at http://ipcc-wg1.ucar.edu/wg1/Report/suppl/Ch10/Ch10_indiv-maps.html. The printed version of Figure 10.7 uses stippling to show the uniformity of results across models, but this makes it harder to see the color gradients, so I have selected the output from a single model, the Goddard Institute of Space Studies (GISS) model EH, for increased clarity.

The panels in the top row are each in the same format as those in the PCM diagrams above, except that, going from left to right, latitude runs from South to North, and the vertical axes do not extend as far up into the stratosphere. The bottom three panels show projected oceanic changes.



Source: http://ipcc-wg1.ucar.edu/wg1/Report/suppl/Ch10/indiv_maps/html/GISS-EH_10.7.html

The color coding indicates, over the indicated interval, the predicted change in the mean temperature compared to the observed mean temperature over the 1980 to 1999 interval. As before, the mid-troposphere over the tropics (300-200hPa) is projected to be more sensitive to increased greenhouse gas levels than the troposphere over the polar regions, in all time intervals. The accompanying text (pp. 764-765) states:

> Upper-tropospheric warming reaches a maximum in the tropics and is seen even in the early-century time period. The pattern is very similar over the three periods, consistent with the rapid adjustment of the atmosphere to the forcing. These changes are simulated with good consistency among the models.

As of the 2011-2030 interval the troposphere over the tropics is projected to be about 1.5 ^{o}C warmer than the average temperature over the 1980 to 1999 interval. Comparing interval midpoints (1990, 2020) this implies a current average warming of 0.5 ^{o}C per decade, noting once again the statement in the IPCC text that this change should be observed even in the early-century time period.

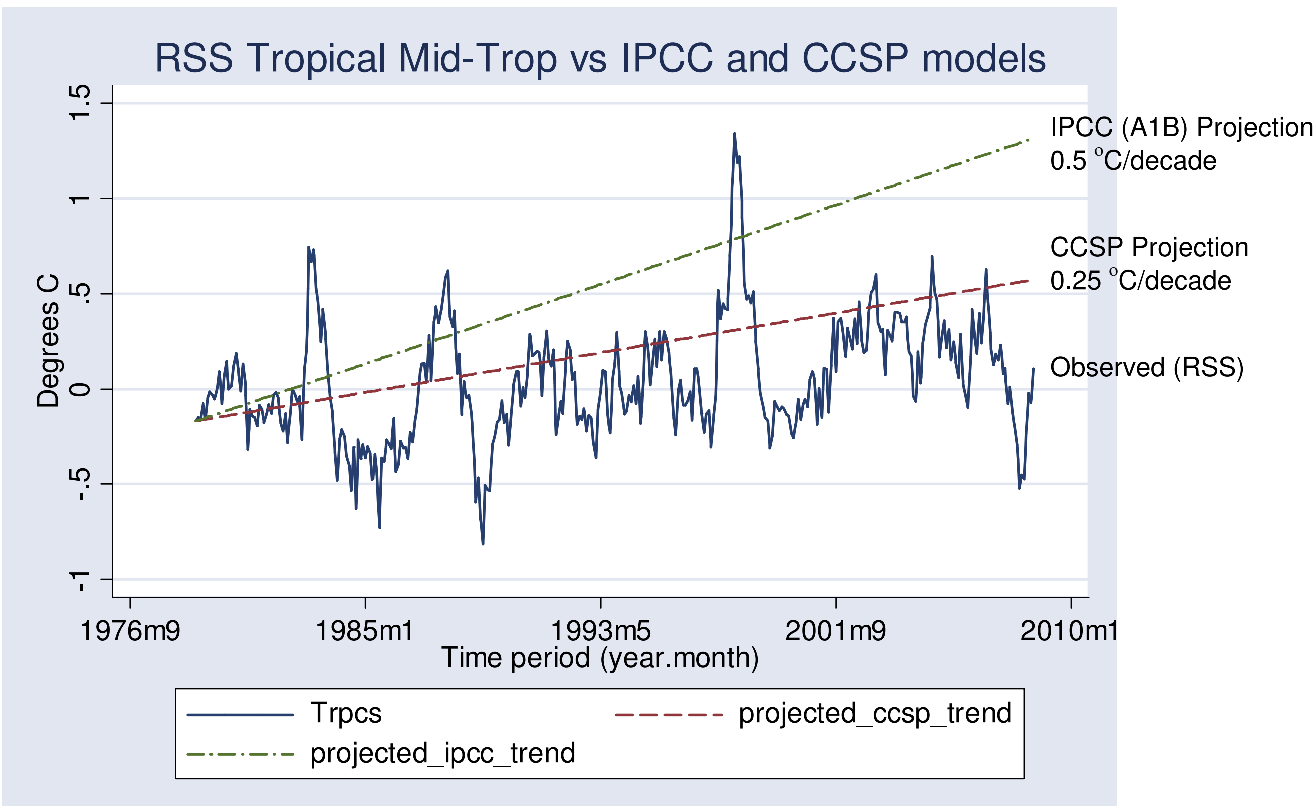
To summarize thus far, all the models which have been used for the IPCC and CCSP reports embed parameterizations that yield the following predictions:

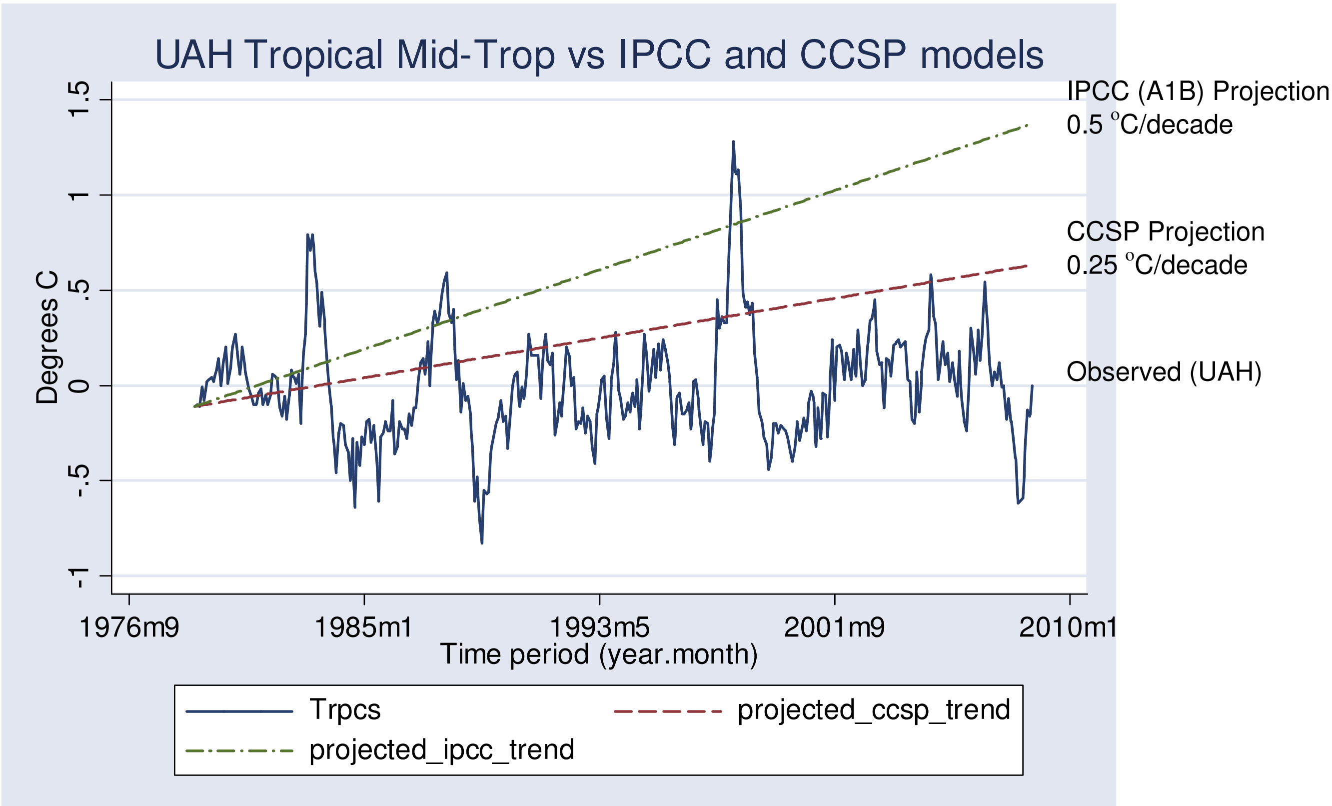
» The troposphere over the tropics should exhibit greater warming (more than double the rate) than the troposphere over the polar regions.
» The effects induced by greenhouse gases are so large relative to other forcings (positive and negative) that the total pattern is predominantly a reflection of the contribution of greenhouse gases.
» The tropical troposphere should have been heating up at a rate of at least 0.25 ^{o}C/decade over the past few decades in response to historical greenhouse gas emissions. A middle-range warming projection scenario in the IPCC report predicts warming of about 0.5 ^{o}C/decade should now be observable in the tropical mid-troposphere.

DATA

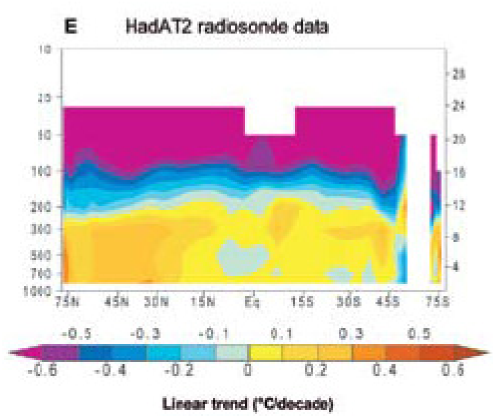
Weather satellite records for the mid-troposphere are available from Remote Sensing Systems (RSS) in California and the Earth Systems Science Center at the University of Alabama-Huntsville (UAH). I obtained the data from each lab for the mid-troposphere layer covering January 1979 to September 2008. Over this interval the annual average atmospheric concentration of CO_2 measured at Mauna Loa Hawaii rose from 337 ppm to 384 ppm (http://cdiac.ornl.gov/ftp/trends/co2/maunaloa.co2), a 14% increase. I have graphed the RSS and UAH tropical mid-troposphere series and compared them to the CCSP- and IPCC-predicted trends (0.25 °C/decade and 0.5 °C/decade respectively).

In contrast to climate model predictions the data indicate neither significant warming in the tropics nor greater warming than at the poles.





The CCSP report (Figure 5.7, p. 116) presented an atmospheric weather balloon series for the interval 1979-1999, (Hadley AT2) in a format similar to the backcast panels. Note that data over Antarctica is not shown.



From the color coding one can readily tell that, like the satellites, this balloon record exhibits no overall warming pattern in the tropical troposphere: instead there is slight cooling at lower altitudes, and minimal warming at the upper altitudes. The tropospheric warming is at a lower rate than in the troposphere as a whole and lower in comparison to the North Pole region. The CCSP text (fn 66, p. 115) points out that this data span includes the 'end-point effect' of the powerful 1998-1999 El Nino so the absence of tropical tropospheric warming is an even more conspicuous discrepancy with the models.

I computed linear trends (in ^{o}C/decade) for the most up-to-date RSS and UAH data, which are as follows. An asterix (*) denotes the trend is statistically significant, i.e. distinguishable from random fluctuations.

Atmospheric Region	Remote Sensing Systems	University of Alabama
	Temperature trend in C/decade, 1979:1 to 2008:9 (Std Error of trend in parentheses)	
Globe	0.09* (0.042)	0.04 (0.040)
North Pole	0.25* (0.058)	0.23* (0.058)
Northern Hemisphere	0.15* (0.045)	0.09* (0.040)
Tropics	0.11 (0.074)	0.03 (0.071)
Southern Hemisphere	0.03 (0.036)	-0.01 (0.034)
South Pole	-0.11 (0.070)	-0.12 (0.073)

Temperature trends in mid-troposphere, January 1979 to September 2008. Sources: http://www.remss.com/pub/msu/monthly_time_series/RSS_Monthly_MSU_AMSU_Channel_TMT_Anomalies_Land_and_Ocean_v03_2.txt http://vortex.nsstc.uah.edu/data/msu/t2/uahncdc.mt Trend regression computed using STATA arima(1,0,1) specification: code posted at http://ross.mckitrick.googlepages.com/S.Dingell.zip.

The satellite data reveal warming in the mid-troposphere over the northern high latitudes but little elsewhere: in particular none over the Southern Hemisphere and a cooling trend at the South Pole. Both satellite series confirm the absence of a significant warming trend in the tropical mid-troposphere.

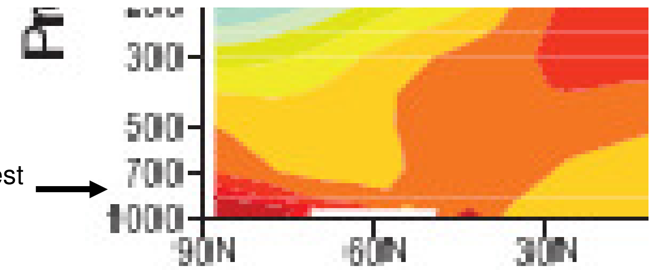
In both the RSS and UAH data sets there is a slight upward global trend, which in neither case exceeds 0.1 ^{o}C per decade over the past 30 years, despite the addition of 47 ppm CO_2 to the atmosphere. This is well below the range of 0.25-0.5 ^{o}C/decade predicted by climate models. In both the RSS and UAH series the tropical trend about equals the global trend, whereas models predict it should exceed the global trend and be at least double that over each pole. In neither data set does the tropical region exhibit a larger trend than the North Pole; and in both data sets the South Pole has cooled, opposite to the backcast results in the IPCC and CCSP reports.

The satellite series differ in part because of their treatment of inter-satellite calibration in the early segment, with the RSS series initially tracking lower than the UAH series, yielding higher trend values over the entire sample. But over the past decade (January 1999 to September 2008) the UAH series has exhibited larger warming trends than the RSS data, and no region exhibits statistically significant warming in either data set. The RSS series since 1999 shows cooling over the Southern

Hemisphere, and a global trend of only 0.006 °C/decade, despite a 4% rise in atmospheric CO_2 over this interval.

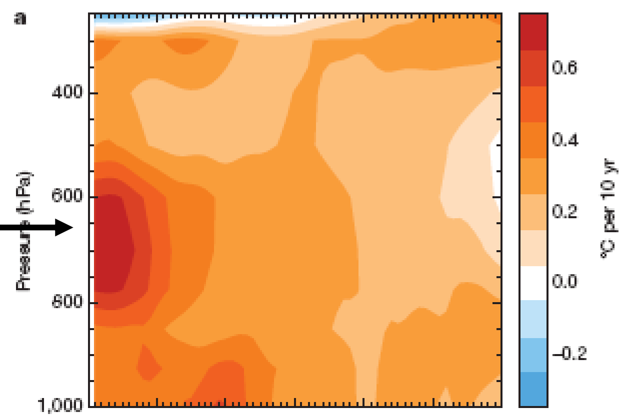
The strong warming in the mid-troposphere over the North Pole deserves some comment. Models predict amplified warming over the North Pole due to an “albedo” effect: as snow and ice melt the reflectivity of the surface declines and more heat is absorbed, increasing the local infrared radiation and the subsequent greenhouse warming. Because the mechanism operates at the surface there is a distinct vertical pattern to it: the GHG-induced warming is supposed to be strongest at the surface, then weaken with altitude.

From IPCC Figure 9.1:
Models predict GHG warming is strongest at the surface then weakens higher up



But a recent paper in *Nature* (Graversen et al. “Vertical structure of recent Arctic warming, *Nature* vol 541, 3 Jan 2008, 53—57) reported that, except in the Spring, the warming is stronger aloft than at the surface, opposite to the expected pattern (in the Spring the warming is uniform up to 700 hPa).

Observed summer half-year warming (1979-2001, April-Oct) concentrated in lower troposphere, not at surface



(Fig. 4a, Graversen et al. 2008)

They also noted that amplified North Pole warming is observed in winter months when there is so little sunshine that the albedo effect cannot be influential. This vertical and seasonal warming structure is inconsistent with the albedo mechanism in climate models. Graversen et al. showed that the trends can largely be explained by variations in atmospheric energy transport, in particular the atmospheric northward energy transport (ANET) index, a measure of wind-borne heat crossing the 60th parallel latitude. The ANET index has increased in recent decades. Graversen et al. do not determine why this is so, but point to its connection with cloud cover, large-scale oscillations and planetary waves. Carbon dioxide may affect these processes but such a connection would be indirect and obscure, and is not represented in climate models. The authors conclude that much of the present

Arctic warming appears linked to processes other than the albedo-driven greenhouse amplification mechanism in climate models.

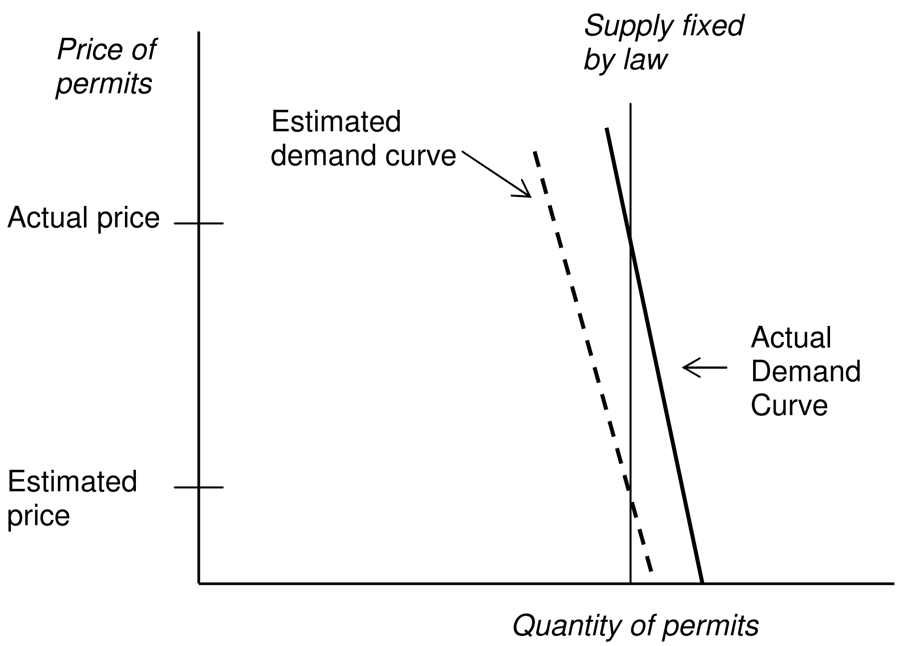
Overall, in answer to your question, climate models project that, if greenhouse gases dominate the climate, the troposphere over the tropics and over both poles should be warming; the tropical troposphere should be warming two to three times faster than the polar tropospheric regions, namely at a rate of about 0.25 to 0.5 ^{o}C/decade, and the polar warming should be strongest at the surface. The data, however, do not support any of these hypotheses. They show, at most, a trend of about 0.1 ^{o}C/decade in the tropical mid-troposphere, it is statistically insignificant and recently the annual mean temperature has fallen below the level observed in the early 1980s, despite an overall 14% increase in the atmospheric CO_2 content since that time. The trend observed in the tropics over the past 30 years is less than half that observed over the North Pole, and the troposphere over the South Pole is cooling, not warming. The enhanced trend over the North Pole has been attributed to variations in atmospheric heat transport, and the vertical structure is inconsistent with the pattern predicted in models as an amplified response to greenhouse gases.

One of my biggest concerns about cap-and-trade systems is that they ask the people of the US to commit to permanently higher energy costs based global warming forecasts from models that appear systematically to overestimate climate sensitivity to greenhouse gases and hence the environmental costs of emissions. In a subsequent question you ask about pricing in risk, so I will return to this issue below.

4. *Your testimony states that carbon taxes can more easily alleviate the regressivity of higher energy prices (from either a carbon tax or a cap-and-trade system) because offsetting tax reductions can be directed towards low-income houses. Do you agree that, if the Government auctioned all allowances in a cap-and-trade system (instead of giving them away for free) then the Government could address regressivity by directing offsetting tax reductions to low-income households? If you disagree please explain why.*

I would agree with this statement if the auction were a one-time event and the demand curve for permits were not too steep. But what is being proposed is a repeated (annual) event in which a fixed supply of permits is auctioned into a market with a very steep demand curve, the position of which is closely tied to output and energy consumption and which therefore is prone to shift over time. This makes it difficult to forecast the permit price and the resulting revenue from the auction. Therefore the size of the necessary tax reductions cannot be estimated from year to year except with large error.

The diagram below uses the geometry of demand-supply analysis to show a hypothetical example. A steep demand curve means that relatively large price increases are needed to reduce the quantity demanded. A small error in forecasting the demand for permits (the gap between the dotted and solid demand curves) translates into a large error in the estimate of the permit price. This would cause a correspondingly large error in the estimated total auction revenues and the corresponding estimate of the required compensation for low-income compensation households. Hence it would be difficult to write a budget that commits to compensatory tax cuts of anywhere near the correct magnitude from one year to the next.



If, however, the policy had taken the form of an emissions tax at the estimated price, the steepness of the demand curve ensures that, even with the gap between the estimated and actual demand curves, the resulting quantity of emissions would be close to the estimated quantity, and the resulting tax revenues and required compensation for low-income compensation households would be close to the initial estimate. For this reason, budgeting for compensatory tax cuts would be much more feasible under an emissions tax regime.

The demand curve for sulfur permits is not as steep as that for carbon permits, yet the price of US Acid Rain Allowances has nonetheless been extremely volatile: from July 2005 to January 2006 prices rose from just over $500 to over $1500 per tonne, then fell to below $500 by July 2006, spiking back to over $700 per tonne in July 2007 before retreating to about $550 per tonne in the fall of 2007. We can expect even greater volatility in carbon permit markets unless price guarantees are in place.[1]

The reason the demand curve for permits is likely very steep is that CO_2 control options are very limited compared to sulfur dioxide. All the reductions in SO_2 emissions during the first phase of compliance with the 1990 Clean Air Act Amendments came about through installing scrubbers and switching to low-sulfur sources of the same fuel. But there are no scrubbers for CO_2 and there is no "low-carbon" version of coal or oil. The only large-scale CO_2 abatement options, for the foreseeable future, are to reduce energy consumption or switch to different fuel types, which are very costly at the margin. This translates into a steep demand curve, i.e. a likelihood of rapidly increasing bid prices for permits.

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[1] See http://www.chicagoclimatex.com/news/publications/pdf/CCXQ_Spr06.pdf and http://www.chicagoclimatex.com/docs/publications/CCFE_sulfurmkt_V4_i11_nov2007.pdf

5. *Your testimony states that, in the economics literature, marginal cost estimates of greenhouse gases are in the range of \$20 a tonne of CO_2–equivalent. Do these estimates put a dollar value on loss of ecosystems or species extinction? If so, please explain.*

Yes, some studies do, though the methodologies differ. For example, Hope (2006) uses the PAGE2002 Integrated Assessment Model (the same one used for the Stern Review) and embeds valuation for risks to unique and threatened ecosystems as well as the possibility of abrupt or extreme events. This study yielded a marginal damage estimate of about US\$5 per tonne of CO_2 (or US\$19 per tonne of carbon). Also, as discussed in the Stern Review (Chapter 6 pp. 147—148) the models of Tol and Nordhaus include ecosystem changes.

The Stern Review obtained much higher numbers using the Page2002 model by programming in very high climate sensitivity parameters, and adding in new damage categories of a rather speculative nature, most of which do not begin to accumulate in the model until some time in the 22nd century. Then, by using a very low discount rate, high damages occurring 100 to 200 years from now are valued as being nearly equivalent to damages today. The Stern Review justified using high sensitivity parameters by referring to what it considers to be an increasing probability of global warming occurring at a rate of 5—6 ^{o}C/century (e.g. p. 151). A surface warming rate of 5—6 ^{o}C/century would imply warming in the tropical troposphere of approximately 1.0—1.2 ^{o}C/decade, some 10 times the actual, observed rate. The Stern Review does not explain how it concluded this outcome has become more likely even though the available data shows the opposite.

Reference: Hope, C (2006). "The Marginal Impact of CO_2 from PAGE2002: An Integrated Assessment Model Incorporating the IPCC's Five Reasons for Concern." *The Integrated Assessment Journal* 6(1) 19—56.

6. *Multiple leading scientists have warned us of potential "threshold" effects of climate change, where various temperature increases can provoke sudden and potentially self-reinforcing swings in environmental stability. One such example would be large-scale melting of the permafrost, which would release even more potent methane emissions. Another would be the collapse of Greenland and Antarctica ice sheets over land, which could dramatically raise sea level. How, if at all, does a marginal estimate of the value of any particular single tonne of CO_2 take the risk of surpassing these tipping points into account?*

Integrated Assessment Models attempt to price in the possibility of a dramatic climate change in much the same way as investment models try to price in the possibility of major default or other calamity: by adding a "risk premium" to the price based on the wideness of the range of possible outcomes and the losses or gains associated with extreme events. If it were known that damages due to global warming had a mean value of, say, \$10, the appropriate emissions price would be different if the possible range were -\$20 to +\$250 as opposed to \$5 to \$15. If we had to commit now to an emissions price, we would need to add a premium to the price in the former case to account for the risk that the damages might be far higher than forecast.

If a study appears in the literature that points to the possibility of abrupt or extreme climate change causing trillions of dollars in future damages, it does not mean the risk premium should automatically increase. It depends on how likely the scenario is and how credible the numbers are. That is why

Tol's surveys include efforts to assess the credibility of the study, based on whether it was peer reviewed, what discount rate was applied, and so forth.

I don't find these points very satisfactory as an answer to your question, however. The reality is that nobody can forecast major, abrupt climate changes, but if such events are possible, the cost of trying to prevent them through elimination of fossil fuel use would be extraordinarily high. Hence you and your colleagues must weigh uncertain warnings of massive ecological dangers against the more certain matter that the putative remedies would cause massive economic dangers. I do not believe that the science (such as it is) of computing risk premiums is the right tool for sorting this out. Instead, in my testimony I drew attention to the need to use what we call state-contingent strategies, which build into the policy framework a direct feedback between the observed severity of the problem and the stringency of the policy. If done right, a feedback mechanism would help you avoid the costs of taking too much or too little action by tying the emissions price (or cap) to the actual amount of warming that is observed.

None of the proposals before Congress do this. Instead they try to strike an impossible compromise between supporters of aggressive controls on CO_2 emissions who fear that weak targets will not be tightened in the future even if the situation looks more and more dangerous, and opponents of action who fear that restrictions on CO_2 will become an unchangeable status quo even if global warming is decisively refuted over the coming decade (as I expect it will be).

A risk premium formula cannot solve this dilemma, no matter how complex the calculations are. But a simple feedback (or state-contingent) mechanism can. For a cap and trade system it would work as follows. Since 1960, US greenhouse gas emissions intensity declined, on average by about 1.7% per year, while the US economy grew, on average, by about 3% per year. So without any regulation, if global warming were not an issue, you would expect an average increase in greenhouse gas emissions of about 1.3% per year. Now suppose we impose the following requirements on any emissions cap rule:

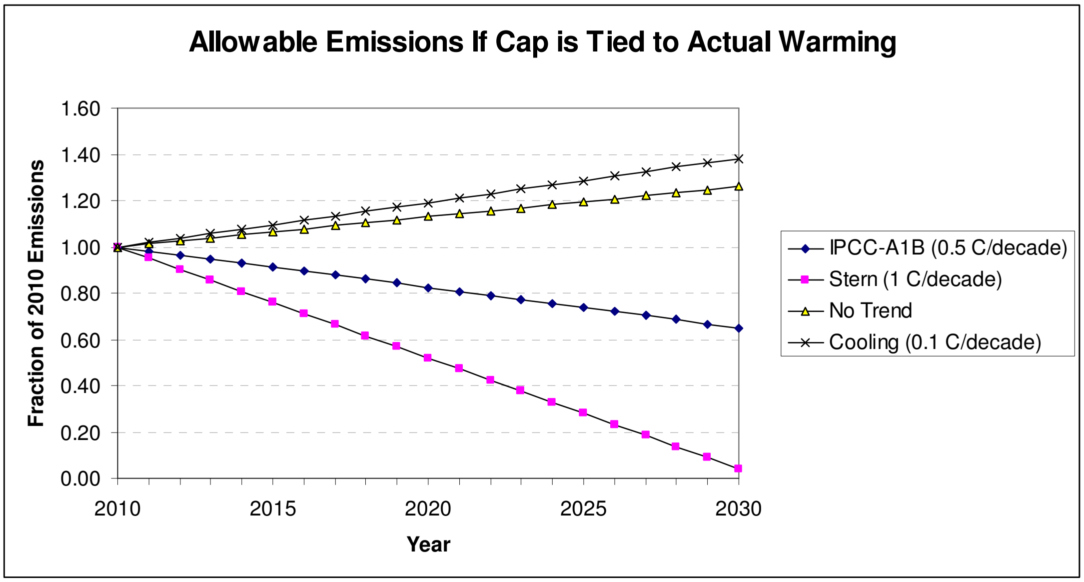
» If, as of 2010, the IPCC mid-range (A1B) scenario is true, the cap should decline by 35% between 2010 and 2030, in line with many of the proposals before Congress.
» If the Stern Review worst-case scenario is true (1 ^{o}C/decade in the tropical troposphere) the emissions cap should fall by 95% by 2030.
» If there is no trend in the mean temperature of the tropical troposphere between 2010 and 2030, the cap on emissions should grow by 1.3% per year.
» If the tropical troposphere starts cooling in 2010 the allowed emissions level could rise faster than 1.3% per year.
» If there is a sudden increase in global average temperatures the cap should suddenly tighten in response.

The formula that yields this outcome is

$$CAP(t+1) = CAP(t) + 0.013 - (CHANGE \times 0.61) \qquad (1)$$

where CAP(t) is the cap in year t, expressed as the fraction of 2010 emissions, CHANGE is the observed change in the mean temperature of the tropical troposphere from RSS or UAH (or both, averaged), and 0.061 is the number needed to yield the desired slopes. As of 2030, CAP would equal 0.65 (i.e. a 35% emissions reduction) if the A1B warming rate is observed after 2010, it would equal 0.04 (i.e. a 96% emissions reduction) if the Stern "High Sensitivity" rate is observed, it would equal

1.26 if there is no warming trend, and it would rise to 1.38 if there is a 0.1 ^{o}C/decade cooling trend. The paths look as follows.



By tying the cap to the actual warming rate it ensures you end up with the most appropriate outcome regardless of whose forecast is right. It would also force the private sector to make an unbiased assessment of the credibility of different forecasts and invest based on which ones are consistently the most accurate, since the actual abatement targets will depend on actual warming, not model forecasts.

Someone who believes in a Stern-type future would have every reason to support this formula since they would expect it to yield radically reduced greenhouse gas emissions over the next two decades. Likewise, someone who dismisses the possibility of global warming altogether should equally support this formula since they would expect the emissions cap to rise fast enough to ensure a permit price of zero. Hence the state-contingent approach avoids the political fight associated with trying to estimate a risk premium.

Tying the emissions cap to actual warming also provides a constructive way of dealing with the threat of abrupt climate changes, or "tipping points." If the future path of warming is minimal for a while, then suddenly switches to an abrupt warming trend, the above formula would instantly tighten the allowable emissions. More importantly, if science progressed to the point where such a change could be reliably *forecast*, then emitters would begin planning on higher permit prices as far in advance as the forecast could be made. Of course if science never permits such forecasts then no policy will anticipate them, but my suggestion will at least ensure a rapid, automatic response. If no such abrupt change ever takes place, then the feedback rule would avoid imposing unnecessarily the costs associated with trying to prevent it.

The chief objection to a feedback-based approach is that it seems to be backward-looking, taking action only after the problem has been revealed, yet warming may not happen right away in response to greenhouse gases. However, according to the IPCC, the tropical troposphere (in models) adjusts rapidly to changes in greenhouse gas changes, making it an appropriate metric for guiding changes in the cap. Also, investors and firms are forward-looking: they make decisions now based on expected market conditions years ahead. By tying the carbon dioxide emissions control policy to contemporary atmospheric conditions, it requires firms to take account of the best available climatic data and warming forecasts when making major investment decisions, which is precisely the goal of any long term policy.

Finally, another potential objection to the feedback approach is the fear that emissions today might commit us to warming a long way ahead, i.e. 20 or 30 years. However, those making this objection are asking us to trust climate models over actual data. The data show that models have demonstrated insufficient fidelity to the relevant data over the past 30 years to merit trusting them as the basis for a permanent commitment to reducing American energy consumption over the next 30 years. They consistently over-estimate tropospheric warming and project a spatial pattern that does not match the data. A feedback rule like the one I propose takes the models seriously enough to admit the possibility that greenhouse gases may need to be reduced in the coming years, but hedges that bet by ensuring the policy only gets stringent to the extent the problem is revealed to be serious.

Yours truly,

Ross McKitrick
Associate Professor of Economics