What is the Correct Level of National Investment in Climate Science?

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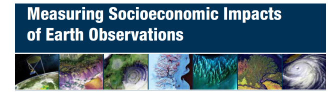

RESOURCES FOR THE FUTURE

Conclusion: ***An advanced higher accuracy climate observing system would return $50 for every $1 invested in the improved observations***

Why?

Science is an economic investment by the public. We will be managing Earth's climate until civilization moves elsewhere. We currently have no national or international climate observing system, nor a plan to create one. Should we invest in one? Is it worth it?

What is the economic value of an advanced climate observing system? How would you estimate it?

We have a few traceable estimates of the economic value of weather prediction for severe storms, hurricanes, floods and droughts. Climate scientists often say that the results from their research ***"will inform societal decisions with trillion dollar impacts".***

But is this statement verified and traceable in any way? How could we quantify an economic value to climate science? Recall that climate change science value exists decades into the future. Its value has to be treated as a risk/benefit economic analysis. A rigorous analysis must take into account the uncertainties in climate science, economic impacts, and policy (see Figure 1 below).

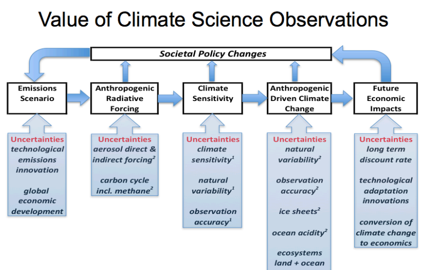

Figure 1

Science value and economic frameworks are potentially valuable for strategic planning of the Earth observing system, as well as communicating climate research value to society. We present in this paper a new methodology to estimate the economic value to society of advanced climate observing systems.

How?

The uncertainty of societal decisions on climate change is strongly affected by the uncertainty in the future predictions of climate change. For example, the 90% confidence bound for equilibrium climate sensitivity is a factor of 4 (IPCC, 2013). Climate sensitivity defines the relationship between an increase in carbon dioxide in the atmosphere and the amount of global surface air temperature change. Studies of the economic impacts of climate change (Interagency Social Cost of Carbon Memo, 2010, hereafter SCC) suggest a quadratic relationship between amount of global temperature change and the magnitude of economic impacts.

In this case the factor of 4 uncertainty in climate sensitivity causes a factor of 16 uncertainty in long term economic impacts, which leads to inefficient and uncertain solutions for climate change.

Society (and climate science) views past climate change through two sets of "fuzzy" lenses. The first is natural variability in the climate system which acts as noise to confuse early signals of anthropogenic climate change. The second is uncertainty in our observations of climate change, including drifting calibration of instruments or orbit sampling uncertainties. Figure 2 below shows an example of these uncertainties for observing one of the critical measures of climate sensitivity: changes in the amount of global mean solar energy reflected back to space by clouds as climate changes.

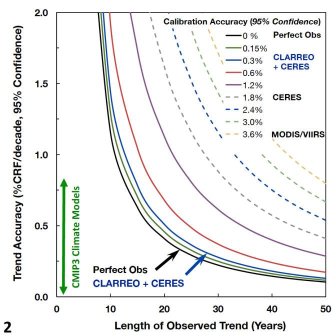

Figure 2

The black line shows climate trend uncertainty for a perfect observing system limited only by one fuzzy lens: that of natural variability. The dashed lines add the absolute calibration uncertainty of the current highest accuracy cloud related space instruments including MODIS (cloud physical properties) and CERES (broadband reflected solar radiation to observe SW CRF directly). The blue line shows the accuracy from the future CLARREO (Climate Absolute Radiance and Refractivity Observatory) mission which advances accuracy a factor of 5 to 10 over current instruments (Wielicki et al., 2013).

CLARREO is designed to serve as reference calibration spectrometers for the entire reflected solar and thermal infrared spectrum. Its orbit is designed to underfly all geostationary and low earth orbit satellites with matched time/space/angle of view observations, and thereby provide the SI standard reference calibration system in orbit to allow instruments such as CERES, MODIS, VIIRS, CrIS, IASI, Landsat and others to maintain highly stable calibration over decades, even if gaps in observations occur (Wielicki et al., 2013)

The IPCC climate model range of trend values are shown in the green arrow at the lower left of Figure 2. ***Figure 2 shows that advances in accuracy can advance by 20 years the ability to observe cloud feedbacks and thereby narrow uncertainty in climate sensitivity.***

Figure 3 shows a similar example for observations of global mean temperature trends from space-borne instruments. The conclusions are similar.

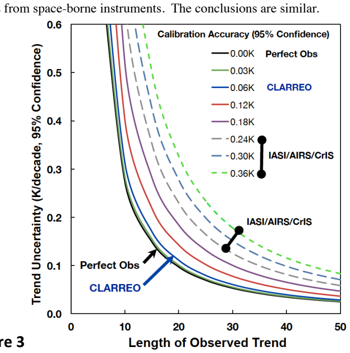

Figure 3

Given these results, what would an advance of 15 to 20 years in climate change knowledge mean in terms of economic impacts of climate change? The schematic below shows how to test such a concept. The concept uses the climate accuracy framework from Wielicki et al. 2013 developed for the CLARREO mission, and combines it with the SCC, 2010 estimates of future climate impacts for varying levels of warming, and the DICE 2009 integrated assessment model (Nordhaus, 2008) which links models of climate physics, economic development, and economic impacts. The schematic below shows the dependence of economic impacts from climate change on societal decision points, which are in turn dependence on the accuracy of climate observations.

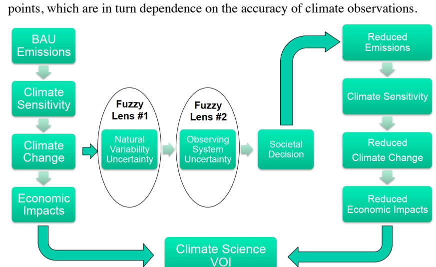

Figure 4

The DICE model is run for 1000s of simulations varying climate sensitivity (SCC, 2010 distribution), natural variability realizations, and emissions scenarios.

Results

Before we discuss the results, we need a quick version of Economics 101. First, the global Gross Domestic Product (GDP) per year is about $70 Trillion U.S. dollars. Second, economics calculations use a concept called Net Present Value (NPV) to equate investments and returns over long time intervals. To do this, a Discount Rate is used, which varies in the SCC, 2010 report from 5% to 3% to 2.5%. The effect of using the nominal 3% Discount Rate is that the economic benefits gained in the future are discounted by 3% per year, so that benefits gained 50 years from now are "discounted" by a factor of 1.03^{50}, or a factor of 4.4. This means that economic benefits 50 years into the future are decreased by a factor of ~ 4.4, while benefits 100 years into the future are decreased by a factor of ~ 20. Finally, the recent financial crisis affected worldwide GDP by a few percent. This is similar to the economic impacts of climate change in the second half of this century, which are expected to range from 0.5% to 5% of GDP per year depending on climate sensitivity and the amount of warming realized. ***Therefore future climate change impacts can range from $0.4T to $3.5T per year.***

The calculations in this study use a baseline scenario of a societal trigger when 95% confidence is reached for a global average temperature increase of 0.2C/decade, and an advanced full climate observing system begins in 2020. All initial calculations use a simple switch from higher to lower emissions scenarios.

Table 1

Discount Rate	CLARREO/Improved Climate Observations VOI (US 2015 dollars, net present value)
2.5%	$17.6 T
3%	$11.7 T
5%	$3.1 T

Table 1 summarizes the results, and ***shows a NPV of $12 Trillion U.S. dollars*** for the nominal 3% discount rate. While the CLARREO example of advanced accuracy has been used in this initial estimate, society would never base a decision on any one set of instruments, so ***this economic value should be viewed as that of an advanced full Climate Observing System***, which CLARREO would be a key part of. If we estimate that such a system would cost 4 times the current investment in world climate research of about $4B/yr., then over 30 years, the additional cost in NPV would be about 1/50th of the benefits shown in Table 1. ***Every $1 invested returns $50.*** We also examined sensitivity of the results to the assumed baseline parameters by changing the warming rate from 0.2C to 0.3C/decade for the societal decision trigger, by varying the statistical confidence required (80 to 99%) and the severity of the emissions reduction scenario (moderate or severe). In all cases, the economic value remained within about 30% of the values in Table 1. The results of this study have been published in the *Journal of Environment, Systems, and Decisions* (Cooke et al., 2013). Future developments of this new framework will use recent updates in the social cost of carbon estimates, add mitigation costs, improve the realism of societal decision triggers and consider the uncertainties of additional key climate change observations including ice sheets, aerosol forcing, and carbon cycle.

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