BOUNDING GHG CLIMATE SENSITIVITY FOR USE IN REGULATORY DECISIONS

A Report of The Right Climate Stuff Research Team

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ABSTRACT

Examination of the official US Government method for establishing economic justification for regulations to control Carbon Dioxide (CO_2) and other Greenhouse Gas (GHG) emissions reveals their computational approach to be scientifically flawed. Further, these regulations will impose a significant economic penalty on the USA, but will have negligible effects on climate unless all nations with significant GHG emissions also begin to restrict their emissions. The scientifically flawed Social Cost of Carbon (SCC) computational process attempts to compute the future global warming damage to the entire world-wide population that would be avoided by each ton of CO2 not emitted by US sources and count that highly uncertain world-wide avoided damage as a benefit of the regulation. But the SCC cost/benefit analysis only burdens the US economy and population (not the entire world) with the immediate cost impacts from issuance of the US regulations. These impacts to the US economy result in part from effective elimination of coal fired power plants, our most inexpensive electrical power source. This will result in much higher US energy costs and loss of jobs to other countries with lower coal-produced energy costs that do not choose to bear the burden of CO2 emissions control. Only the Legislative and Justice Branches of our government, duly protecting interests of US citizens, can sort out the wisdom of US citizens paying for the GHG emission sins of other nations that choose not to restrict their emissions, while willingly accepting the transfer from the USA of energy intensive industries to their lower-cost energy economies.

However, the science on which these CO2 emissions regulations are based is very immature, uncertain and not clearly understood by regulating agencies of the US government. An independent scientific review is required to ensure that the best science the USA has to offer is being used to obtain a more accurate SCC calculation that may allow less burdensome regulations to be imposed. The speculative nature of the SCC process, without any constraints easily imposed from scientific observations of physical data is a major flaw. Another major issue is that reasoned, scientific analysis has shown that the regulations proposed could not actually prevent the extreme lower probability, but significant "statistically expected" global warming damage computed in the SCC process. Such statistical SCC values result from high speculative values of ECS that CO2 emissions control regulations cannot influence. Therefore, if such high speculative values of climate sensitivity actually exist, total curtailment of all US CO2 emissions could not prevent the speculative damage from the sea level rise that would occur only from CO2 emissions of other countries.

Very little independent scientific or legislative review of the process by which CO2 emissions control regulations are being economically justified has occurred, considering the enormous impact to the US economy that will result from such regulations. When high stakes are involved,

accuracy in the cost/benefit analysis supporting public policy decisions is critical. American citizens have finally been granted an opportunity to comment on these matters and our research team has prepared this report to document the scientific basis for official comments we will submit to the Office of Management and Budget (OMB) in response to their official call for comments.

A key GHG climate sensitivity metric, Equilibrium Climate Sensitivity (ECS), is being misused by an Interagency Working Group (IWG) of US government agencies in the process they developed to compute the SCC used for economic cost/benefit analysis of new GHG emissions control regulations. The ECS metric is a purely academic concept, not at all suited for predicting global warming resulting from CO2 emissions between the present time and year 2300, the period of interest for regulatory action. This is because ECS is defined to be the global temperature rise that will occur after CO2 concentration is suddenly doubled from pre-industrial levels to 550-560 ppm (parts per million by volume) and then held at that level for 1000 years or more until the climate equilibrates with the new elevated CO2 level. This is not a realistic scenario, it is purely an academic concept conceived and used to compare results of different climate simulation models! In addition, without any independent scientific verification, the IWG has relied on a statement in the 2007 AR4 report published by the Intergovernmental Panel on Climate Change (IPCC) political committee of the United Nations (UN), as a basis for the uncertainty range of the critical ECS parameter.

The scientific reasoning for why the IWG ignored this AR4 report's recommendation to use its Transient Climate Response (TCR) metric for studies of near term climate change, in lieu of the inappropriate ECS metric has not been explained. To quote the AR4 report, ***"The TCR is therefore indicative of the temperature trend associated with external forcing, and can be constrained by an observable quantity, the observed warming trend that is attributable to greenhouse gas forcing. Since external forcing is likely to continue to increase through the coming century, TCR may be more relevant to determining near-term climate change than ECS."*** Perhaps because of political biases that always seem to plague the editing of the IPCC reports, the following more accurate statement was not used, ***"TCR is definitely more relevant to determining near-term climate change than ECS"***. This recommendation also appears in peer-reviewed published literature by US scientists and we strive to explain in this report why this is a true and critical point for accurate SCC calculations.

The large uncertainty range for ECS, that is critical to the high SCC calculated, is based primarily on results of 23 different un-validated climate models developed in many UN member countries and a few from the USA. For these same models, the ECS value predicted is on average, 1.8 times greater than the TCR value predicted, and most of the large difference results from hypothesized changes in climate that would occur over 1000's of years after the CO2 level was doubled! Moreover, most of the uncertainty in the ECS value results from climate model

speculation about climate changes that might occur far into the future, not in the next 300 years! The IWG also arbitrarily exaggerated the IPCC ECS uncertainty range based on unscientific speculation. This arbitrarily exaggerated its SCC computation of possible future damage from global warming. The net effect of arbitrarily exaggerating SCC damages with wild speculation, is a much more burdensome regulation for US citizens to bear, as a gift to economically competing nations, without any scientifically-based expectation of significant reduction in future global warming or avoidance of the extreme damages used to justify the regulation.

Moreover, without any actual statistical data, the IWG created an arbitrary and highly speculative statistical distribution for their exaggerated ECS uncertainty range. This statistical distribution allows ECS values in Monte Carlo statistical analyses that are almost four times greater than any ECS value that can be supported by actual physical data. Good science is based on physical data, not un-validated climate models. All of this very creative and complicated SCC process was apparently implemented without conducting any "sanity checks" on the overall end-to-end results of the process. Sanity checks would have revealed that the vast majority of SCC costs resulted from the IWG arbitrary and speculative decision to create their ECS statistical distribution with significant probability of absurdly high ECS values that could rapidly melt the stable ice sheets on the planet. The common scientific practice of a sanity check on computational results of complex models should have revealed to the IWG that the high SCC costs obtained from such speculation could not be supported by the best science the USA has to offer. The IWG's obvious lack of scientific guidance and maturity in this matter, while risking great potential economic harm to the US population, demands that an independent scientific review of the IWG SCC computation process be conducted.

The IWG also misuses ECS for economic justification of CO2 regulations because, as published by the IPCC, ECS includes warming effects of all GHG, not CO2 only. This causes up to a 50 percent greater inflated estimate of CO2-caused warming and the calculated SCC value. Further, ECS is sensitivity to a doubled atmospheric GHG level, while only a fraction of CO2 emitted, approximately half, is retained in the atmosphere each year. How this fact is considered in the SCC $/ton emitted calculation for each statistically selected value of ECS is not clear. At each step of its SCC computation process, the IWG made decisions that misused the uncertain science of CO2 global warming to exaggerate SCC computed, without the constraint of any common sense scientific observations.

This report provides scientific proof that the IPCC published ECS uncertainty range can be confidently reduced to below the mid-point of the range though analysis and interpretation of physical data from the last 163 years of earth surface temperature warming trends. Moreover, we develop herein a Transient Climate Sensitivity (TCS) metric that can be verified by physical data, and that is far superior to ECS for forecasting GHG warming trends over the next 300 years for SCC purposes. We demonstrate the use of maximum possible values (upper bounds) of TCS

to bound maximum possible GHG temperature rise before 2300, and recommend this more appropriate TCS metric be used in the SCC calculation process to put it on a more firm, physical data-constrained, scientific foundation. To determine the TCS metric, we use actual physical data for the: 1) average surface temperature anomaly of 1850-2012, 2) atmospheric CO2 concentration history, and 3) rise in Total Solar Irradiance over the same period of time. We demonstrate how TCS is related to ECS and TCR metrics to reduce uncertainty in ECS and TCR, and prove ECS uncertainty is much less than claimed in the IPCC AR4 report consulted by the IWG. Based on a TCS upper bound of 1.6^{o} C that we determined from actual data, we compute a 2.9^{o} C upper bound for GHG ECS that is below the mid-point of the latest IPCC GHG ECS uncertainty range of $1.5 < ECS < 4.5^{o}$ C and 71 percent lower than maximum 10^{o} C ECS values obtained from the IWG statistical distribution for ECS. We were also able to determine a separate, significantly lower TCS and ECS upper bounds for CO2 only, and that would be more appropriate for computation of SCC in cost/benefit analyses for CO2 regulations.

Using the new TCS metric, we demonstrate that burning all remaining economically recoverable fossil fuel reserves on earth cannot raise global average surface temperatures more than 1.2^{o} C above current levels. This AGW limit results from the much lower climate sensitivity range defined by TCS for the next 300 years, and a necessary market-driven transition to alternative fuels caused by escalating fossil fuel prices that result from dwindling world-wide reserves and rising energy demand of growing economies. This transition must begin before 2080 to meet energy demand, and should be completed by 2150 when alternative fuels will be more economical than recovery of any remaining fossil fuels. We demonstrate use of the GHG TCS metric that has an upper bound of 1.6^{o} C, to compute "worst case" transient global temperature rise from all GHG for a realistic atmospheric CO2 scenario, where the concentration rises from the present value of 397 to a maximum of 600 in 2130 due to dwindling, more expensive fossil fuel use, and then declines back to below current levels by 2300.

PURPOSE

The purpose of this report is to provide a rigorous scientific basis for official comments to be submitted to the Office of Management and Budget (OMB) by The Right Climate Stuff (TRCS) Research Team in response to OMB's official request for comments on the overall approach for computing Social Cost of Carbon (SCC). We believe that a metric, the Equilibrium Climate Sensitivity (ECS), is being misused by the Interagency Working Group (IWG) that developed the SCC calculation process. The IWG included participants from a number of US Government agencies in their attempt to justify the economics of CO2 and other "Green House Gas" (GHG) emissions control regulations. The use of this metric is described in three Technical Support Documents (TSDs) issued by the IWG in 2010 [1], and followed by a May 2013 Update [2] and a November 2103 Revision to the Update [3]. This report provides rigorous scientific documentation of how the ECS metric is being misused in a number of ways as described in the TSDs and proposes a more scientifically based metric to replace ECS use in regulatory activity.

The ECS metric has been popularized in academic climate science circles since the 1979 Charney Report [4] estimated a range of global warming from 1.5 to 4.5^{o} C that could occur if atmospheric CO2 levels were doubled. Much of the peer-reviewed research in climate science since that time has been focused on estimating the uncertainty range of this purely academic metric, that attempts to predict global temperature rise 1000 years or more after a sudden and totally unrealistic doubling of CO2 in the atmosphere is imposed on the climate system. The United Nation's Intergovernmental Panel on Climate Change (IPCC) publishes an uncertainty range for ECS in its various reports [5 - 9] issued every few years. The last two reports were published in 2007 (the AR4 Report [8]) and 2013 (the AR5 Report [9]). After more than 30 years of intense study, and billions of dollars in research, the IPCC AR5 report uncertainty range for ECS has not changed from the original 1979 Charney Report. Furthermore, the IPCC stated in a footnote of its most recent report, ***"No best estimate for equilibrium climate sensitivity can now be given because of a lack of agreement on values across assessed lines of evidence and studies".***

In February 2010, the Federal Government's Interagency Working Group (IWG) published its first Technical Support Document (2010 TSD) describing how it used the ECS uncertainty range published in the IPCC 2007 AR4 Report, to economically justify CO2 emissions regulations issued by the Environmental Protection Agency (EPA), Department of Energy (DoE) and other regulating agencies of the US Government. The metric the IWG uses to justify the regulations is

called the Social Cost of Carbon (SCC), expressed in the $-cost per ton of CO2 emitted into the atmosphere. The SCC is computed for anticipated damage in the future that one ton of CO2 emitted from USA sources only, will cause to the entire population on the planet i.e., "society". The unilateral USA CO2 emissions regulations justified by the SCC, commit the USA population to bear the increased costs imposed by the regulations (a "hidden carbon tax" expressed by some critics) for highly uncertain future damages to be incurred not only in the USA, but by the entire world-wide society. This certainly inflates the cost of SCC with respect to the cost that would accrue to the US only. Furthermore, the SCC calculation assumes there is only one, and as yet unproven, solution to all potential problems that a warming planet might cause, CO2 emissions control. Clearly there may be other approaches to mitigating specific problems that global warming may cause, such as building sea walls in the US to prevent coastal flooding from sea level rise. Such alternatives may be much less costly than the impact of unilateral USA CO2 emissions control regulations. The rational decision process normally used in US government and industry to weigh cost and benefits of several competing alternative solutions to anticipated problems appears to be absent from the SCC methodology.

The IWG issued another TSD in May 2013 (2013 TSD) documenting how it had updated its process for computing SCC that caused 60 percent or more increases in its computed value, depending on year of emission and dollar discount rate applied. The TSDs indicate the critical ECS metric was being misused in the initial formulation of the SCC computation method described in the 2010 TSD and its subsequent revisions in both 2013 TSD updates. One major issue regarding misuse of ECS use is documented in Footnote 9 of the original 2010 TSD where the IWG indicates it believes that ECS ***"includes the response of the climate system to increased greenhouse gas concentrations over the short to medium term (up to 100-200 years), but it does not include long-term feedback effects due to possible large-scale changes in ice sheets or the biosphere, which occur on a time scale of many hundreds to thousands of years (e.g. Hansen et. al. 2007)".*** From this statement we believe the IWG did not understand that the ECS temperature change does include many effects that will add significantly to the ECS value beyond a 300 year horizon, in a thousand years or more, but do not "***include long-term feedback effects due to possible large-scale changes in ice sheets or the biosphere, which occur on a time scale of many hundreds to thousands of years"***

The IWGs SCC are computed for climate changes they expect only from the present until the year 2300, while at present global atmospheric CO2 levels are only about 397 ppm and increasing at about 0.5 percent per year. But, ECS is defined by the IPCC to be the climate response that would occur after the atmospheric CO2 level is suddenly doubled from pre-industrial levels to about 550-560 ppm and held at that level until the climate stabilizes at a new equilibrium condition. Because of long feedback responses of the oceans to give up even more CO2 as they gradually warm, and cause amplified GHG warming, the final equilibrium state

imbedded in the ECS value is not reached until 1000 or more years later as discussed by Bryan [10]. It is not clear how the IWG recognizes this fact in how it predicts global temperature rise and related damages for each ton of CO2 emitted between now and 2300.

Moreover, in the same section of the IPCC AR4 report that the IWG 2010 TSD attributed for determining its ECS uncertainty range, the IPCC also describes its Transient Climate Response (TCR) metric which it indicates is more appropriate for assessment of climate changes in the near future by this quote, ***"The TCR is therefore indicative of the temperature trend associated with external forcing, and can be constrained by an observable quantity, the observed warming trend that is attributable to greenhouse gas forcing. Since external forcing is likely to continue to increase through the coming century, TCR may be more relevant to determining near-term climate change than ECS."*** The official IPCC TCR simulation uses an atmospheric CO2 rate of increase of 1 percent per year, although the real CO2 rise rate is variable and currently about 0.5 percent per year.

ECS and TCR metrics are purely academic concepts based on hypothetical scenarios that differ from reality in important aspects. The inability to determine values for these metrics without the use of un-validated climate simulation models, inflates their uncertainty ranges and should impose severe limitations on their use, especially for important matters such as high impact regulations development. The IPCC models are constantly in a state of being modified, hopefully to improve the output, but so far have been unable to predict results that match the real world dataset. The current state of climate models used by the IPCC for their 2013 AR5 report was described to the US Congress in the December 2013 testimony of Dr. John Christy, the Alabama State Climatologist and head of the climate research department at the University of Alabama-Huntsville. His assessment of their extremely large errors in forecasted temperatures vs. actual temperature measurements over a 35 year period, should cast great scientific doubt on their ability to simulate an ECS value over a 1000 year simulation or even a 70 year simulation required for the TCR metric. Since neither ECS nor TCR can be verified with empirical data, we developed an alternate Transient Climate Sensitivity (TCS) metric that was verified by empirical data in a rigorous process documented in this report. An independent, objective scientific review will be required to ensure the SCC calculation process is placed on a sound scientific foundation. Our independent, objective, experienced and completely volunteer research team without conflicts of interest, is prepared to support such a scientific review as evidenced by our research documented in this report.

The IWG 2010 TSD [1] gave no indication of how the actual warming from present to 2300 is computed from ECS in the Integrated Assessment Models (IAM) it used to compute SCC. The first 2013 TSD [2] update did give more hints as to how the ECS metric was used. It indicated that warming rates from present global temperatures until the full ECS value is realized, at least for the FUND IAM, were based on the statistical value of ECS selected in the Monte Carlo

analysis and that a previous decreasing linear function of warming rate vs. ECS had been replaced by a quadratic function of ECS. However, this update gave no numerical values that could be used for a detailed assessment of the degree of ECS misuse involved. This TSD update did indicate that changes in how the ECS metric was used was an important contributing factor to why SCC values increased so much from the original 2010 TSD to the 2013 TSD updates.

TCR and TCS use the word "transient" to acknowledge that in contrast to the climate change that results from suddenly doubling CO2 levels used to define ECS, and waiting 1000's of years for a new equilibrium to be reached, realistic global warming trends should follow the slowly changing transient GHG levels in the atmosphere. This report explains why atmospheric CO2 levels cannot remain above the "doubled" level of 550-560 ppm for more than one century due to burning fossil fuels. Our research on economically recoverable fossil fuels summarized in this report, indicates with no world-wide CO2 emissions control agreements, CO2 concentration in the atmosphere will rise to about 600 ppm in the 2130-2150 time period and will decline below current levels by 2300. Because ECS is defined for a hypothetical situation where atmospheric CO2 levels remain above 550 ppm for more than 1000 years, ECS is clearly not a suitable metric for evaluating the more realistic transient case of CO2 levels rising from the current 397 ppm to 600 ppm and then declining again to current levels by 2300.

Another apparent IWG misuse of ECS in SCC computation is that ECS values published by the IPCC actually include effects of all GHG, not only CO2. As demonstrated in this report, the radiative warming effects of all atmospheric GHG at the present time can be 40-50 percent higher than CO2 alone. Therefore, attributing all GHG temperature increase to only CO2 for the SCC calculation via the ECS metric, clearly inflates the SCC value by a substantial amount.

The above mentioned problems with both the IPCC ECS and TCR climate sensitivity metrics is why we have defined and demonstrated use of a more appropriate Transient Climate Sensitivity (TCS) metric in this document, similar in value to TCR, but based on available empirical data, and not subject to large uncertainties that result from computation by un-validated climate models. As we demonstrate in this report, separate warming effects from CO2 and other GHG can be extracted from available data to define separate TCS values for CO2 and other GHG with low uncertainty, and are recommended to replace ECS in economic justification computations for separate regulations focused on these separate GHG.

Unsolicited public comments on the May 2013 TSD led to discovery of technical errors that would reduce the SCC values by a few percent and resulted in a November 2013 revision entitled, Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis under Executive Order No. 12866. The Office of Management and Budget (OMB) then issued a notice of this TSD revision and a request for public comments on the revision as well as comments on the strengths and limitations of the overall SCC computation

approach dating back to the original 2010 TSD. According to the official publication in The Federal Register explaining the request for public comments, "The SCC is used to estimate the value to society of marginal reductions in carbon emissions". http://www.gpo.gov/fdsys/pkg/FR-2013-11-26/pdf/2013-28318.pdf

The purpose of this report is to provide a rigorous scientific basis for official comments to be submitted to OMB by The Right Climate Stuff (TRCS) Research Team in response to OMB's official request for comments on the overall approach for computing SCC. The SCC is a statistically "expected cost" obtained from a Monte Carlo analysis approach that merges estimated costs of global warming event damages and benefits with the probability of the event occurring, that is related to the global temperature attained in the year the event occurs. However, it is unclear from the TSDs whether the very strong, proven benefits of higher atmospheric CO2 concentration CO2 for forest and crop growth have been properly accounted for in the IAMs. The ECS metric is useful in an academic sense because it allows a single metric comparison of the performance of the various models which attempt to simulate the earth's climate. However, we are very concerned that this purely academic metric with great uncertainty, has been grossly misused for high impact regulatory activity. While the computer models can accelerate time, the real world cannot. Therefore, when the IPCC and others quote an ECS range of temperature increase due to doubling CO2 in the atmosphere, they often neglect to note that it will take the real world centuries to millennia for that temperature change to happen. The details of how, and if, such climate and economic issues are considered in the SCC calculation process have not been clearly disclosed within the three TSDs issued by the IWG. These are key issues that need to be reviewed in detail by an independent scientific review team to ensure that no unnecessary harm to the US population results from unilateral US CO2 emission regulations.

The SCC attempts to weigh possible future damage to the world-wide society from US CO2 emissions, against the immediate and certain increases to US energy and related economic cost created by issuance of each new regulation. Such unilateral US CO2 emissions regulations imposed on US citizens, without an enforceable world-wide agreement to limit CO2 emissions, will have insignificant effect on global warming, and will almost certainly cause a migration of US energy intensive manufacturing jobs to other countries that do not impose CO2 emission regulations on themselves. Total curtailment of US-only CO2 emissions could not prevent the joint statistical probability of high climate sensitivity to CO2 and high global CO2 levels that lead to high computed values of SCC. Such near catastrophic conditions are related to high temperatures that could melt permanent ice sheets on Greenland and West Antarctica, therefore the assumptions in the SCC process that lead to high values of SCC must be carefully scrutinized.

The nature of the earth's climate system includes at least two features that make accurate modeling of the CO2 and other GHG effects difficult: (1) the feedback effect of water vapor (by far the most dominant GHG that can't be controlled) and clouds, and (2) the slow reactions of the oceans to distribute heat, causing long delays in experiencing the total effects. Since 1850, a set of actual temperature measurements has been collected over various parts of the world, unfortunately not uniformly distributed, but which provide a basis for deriving the climate sensitivity metric we defined as Transient Climate Sensitivity (TCS). The major advantage of this metric is that it is based on real-world data, not models. The real world incorporates all the phenomena the modelers try to incorporate in their models but which they will never get perfect, or even near perfect. This derived metric, being based on actual temperature and GHG data is a far more rational metric to be used for any policy and regulatory development. This report provides the derivation and basis for the TCS metric and its use. The relationship and relative magnitude of TCS to TCR and ECS is established for comparison with peer-reviewed research focused on ECS and TCR. The uncertainty range for TCS can be bounded using a straightforward method and easily used without the aid of complex climate models to predict the maximum possible temperature rise for any scenario of varying atmospheric CO2 and other GHG.

1.0 INTRODUCTION

The Right Climate Stuff (TRCS) research team is a volunteer group composed primarily of more than 25 retired NASA Apollo Program veterans, who joined together in February 2012 to perform an objective, independent study of scientific claims of significant global warming caused by human activity, known as Anthropogenic Global Warming (AGW). We believe our TRCS research team represents an important national asset, developed through our manned space program, and that can and should "weigh-in" on the important AGW issues facing our nation. We are a group of mostly retired scientists and engineers, highly trained and experienced in making critical decisions on complex issues where human safety is involved, and have the requisite education and experience to comprehend the critical issues in AGW research.

AGW is hypothesized to result from various human activities on earth, primarily from emissions of Greenhouse Gases (GHG) into the atmosphere as a result of fossil fuel burning. The GHG, also known as Tyndall gases, by virtue of vibrations of their molecular structure, have the ability to absorb and re-emit Infrared Radiation (IR). The Sun radiates energy to the earth's climate system at high frequencies in the visible light spectrum. Some of this incoming energy is reflected back to space in the visible spectrum but most of it is absorbed within the earth's climate system and re-radiated back to deep space within the same 24 hour period. One critical fact that helps the earth's surface maintain an almost constant global average temperature over a 24 hour period is that the surface and atmosphere receive the Sun's energy over a disc area of πR^2 but radiate that energy back to deep space in the lower temperature IR spectrum over the earth's complete spherical surface area of $4\pi R^2$, where R is the radius of the earth. GHG in the atmosphere can absorb and re-emit some of the IR energy radiated from the earth's surface and slow the net rate of heat rejection back to deep space. It is this special characteristic of the trace amounts of these gases in our atmosphere that have climate scientists concerned about the possibility of significant AGW, if we don't control the concentrations of these gases in our atmosphere.

Water vapor is by far the most abundant and important GHG in our atmosphere, but since it is naturally occurring and naturally varying with climate dynamics, it is not considered to be a GHG that could be controlled to limit global temperature rise due to GHG emissions. The well-mixed GHG in our atmosphere that have almost a constant volumetric concentration with altitude are carbon-dioxide (CO_2), methane (CH4) and Nitrous Oxide (N_2O). Together, these trace gases comprise far less than one percent of our atmosphere and are never expected to approach one percent. Ozone is also a GHG believed to have a small net warming effect with increasing atmospheric concentration, but it is not well-mixed in the atmosphere and tends to be more important to climate effects through its higher concentration in the stratosphere. Since stratospheric ozone can prevent incoming energy from the sun from reaching the lower atmosphere, it can also have a cooling effect.

Excluding water vapor from the discussion, as is common in AGW science, CO_2 is the most important of the well-mixed GHGs and currently contributes about 65 percent of all the warming effects of CO_2, CH_4 and N_2O combined. This issue is discussed in more detail in Section 4.4 where we demonstrate how to account separately for the climate sensitivity of CO2 and other GHG. When we refer to effects of GHG other than CO_2 in this document we are primarily referring to effects of CH_4 and N_2O.

While theoretically, through Quantum Mechanics considerations, there should be some small warming effect from rising levels of GHG in the atmosphere, the extent to which related warming of the planet will occur is not settled science. This report studies and bounds this extent by analyzing available data on GHG and climate. One of the most studied issues in climate science is the Equilibrium Climate Sensitivity (ECS) metric defined to be ***"the change in global mean surface temperature at equilibrium that is caused by a doubling of the atmospheric CO_2 concentration."*** A critical factor in this ECS definition that is often overlooked or left unsaid, is that it takes on the order of 1000 years, as discussed by Bryan [10], for the oceans to equilibrate with the sudden doubling of atmospheric CO2 concentration simulated in various climate model simulations to determine ECS.

To aid the reader, Table 1.1 provides a list of related metrics and their definitions used in this report. One of the first scientific collaborations to place a numerical value on ECS was documented in the 1979 Charney Report [4] that estimated the ECS range between 1.5 ^{o}C and 4.5 ^{o}C. The evolution of this ECS uncertainty range in peer reviewed research has been summarized in a series of reports issued every few years by the UN's Intergovernmental Panel on Climate Change (IPCC) [5 - 9]. In the ensuing 34 years since the Charney report, and despite billions of dollars spent on climate research, the range of ECS uncertainty has not been narrowed as reported in the IPCC's Fifth Assessment Report (AR5) [9] issued in 2013. Although not clear in its 2007 AR4 Report and slightly different 2013 AR5 report definitions of ECS provided in the metrics definitions of Table 1.1, the ECS values published in IPCC reports include climate sensitivity to all GHG, but are referenced to only the CO_2 level in the atmosphere.

Since we suspect a critical, subtle error related to the IPCC's official ECS definition vs. published ECS values was made by the IWG in developing its SCC computation methodology, we clarify this fact in this report by referring to the IPCC reports' ECS values as GHG ECS, or ECS_{GHG}, which has a larger value than CO_2 ECS, or ECS_{CO2}. Although we do not recommend that ECS be used in the SCC process, it would be more accurate to use the ECS_{CO2} metric computed in Section 4.4 of this report for CO2 emissions regulation economic cost/benefit analyses that would produce substantially lower values of SCC. If global warming sensitivity to CO2 is based on ECS_{GHG} as the IWG has assumed in its SCC computation process, and all of the related warming is used to account for the "global warming damage" of only CO2 emitted into the atmosphere, then SCC of CO2 emitted is over-estimated.

TABLE 1.1 METRICS USED AND DERIVED IN THIS REPORT

Metric	Description
ECS	**Equilibrium Climate Sensitivity** - In the 2007 IPCC AR4 report, ECS is defined as: *"ECS is the equilibrium global mean temperature change that eventually results from atmospheric CO_2 doubling"*. In the most recent IPCC AR5 report [9], ECS is defined as: *"the change in global mean surface temperature at equilibrium that is caused by a doubling of the atmospheric CO2 concentration."*
GAST	**Global Average Surface Temperature** - Absolute temperatures for the Earth's average surface air temperature have been derived, with a best estimate by GISS of roughly 14 °C (57.2 °F) for the global mean surface air temperature for the period 1951-1980. However, the correct temperature could easily be anywhere between 13.3 and 14.4°C (56 and 58 °F) and uncertainty increases at smaller (non-global) scales. See http://data.giss.nasa.gov/gistemp/abs_temp.html and Global Surface Temperature Change - Hansen, J.E. (3 August 2010).
GATA	**Global Average Temperature Anomaly -** An average of the change in temperature of each reporting station in the dataset that forms an average temperature deviation or "anomaly" from a defined base period average. For the HadCRUT4 dataset we use here, the base period is 1961-1990 average. This is described in Jones, et. al. 2012, and Rayner et. al. 2006 - http://www.metoffice.gov.uk/hadobs/crutem4/CRUTEM4_accepted.pdf http://www.metoffice.gov.uk/hadobs/hadsst2/rayner_etal_2005.pdf
RCP	**Representative Concentration Pathways -** Four greenhouse gas concentration (not emissions) trajectories adopted by the IPCC for its 2013 Fifth Assessment Report (AR5)
TCR	**Transient Climate Response** - The official definition of a TCR climate sensitivity value for doubling CO2 concentration in the atmosphere, provided in the IPCC AR4 report [8] is: *"TCR refers to the global mean temperature change that is realised at the time of CO_2 doubling under an idealised scenario in which CO_2 concentrations increase by 1% yr^{-1} (Cubasch et al., 2001).* The IPCC AR4 Report explains further that: *"The TCR is therefore indicative of the temperature trend associated with external forcing, and can be constrained by an observable quantity, the observed warming trend that is attributable to greenhouse gas forcing. Since external forcing is likely to continue to increase through the coming century, TCR may be more relevant to determining near-term climate change than ECS."*
TCS	**Transient Climate Sensitivity (TCS) (Derived Herein) -** The actual rise in GAST caused by actual increases in atmospheric CO2 levels in the year that atmospheric CO2 concentration reaches 560 ppm, thereby doubling the pre-industrial CO2 atmospheric concentration of 280 ppm.
TRF	**Total Radiative Forcing -** The additional radiative heat load on the earth's system from all contributing factors with respect to a reference year, expressed in watts per square meter - W/m^2
TSI	**Total Solar Irradiation -** The radiant heat load from the sun, in watts per square meter - W/m^2. In this paper, we primarily address changes in TSI and its possible effects.
ΔRF	**Change in Radiative Forcing -** Change in Radiant heating - W/m^2
	Note: In several instances, the above metrics will have subscripts for specific cases such as GHG. For example: $\mathbf{\Delta RF_{GHG}(max)}$ would refer to the maximum change in Radiative Forcing due to GHG

By performing an independent and objective scientific review of the AGW controversy, with a clear objective in mind as evidenced by this report, we have been able to confidently reduce the ECS_{GHG} uncertainty range below a conservative upper bound of 2.9^{o} C. A $TCS_{GHG} = 1.6^{o}$ C upper bound value was used to compute the more well-known, but impractical ECS_{GHG} value using a relationship derived in the report,

$$ECS = 1.8(TCS) = 1.8(TCR)$$

The TCS_{CO2} upper bound value is only 1.0^{o} C and the corresponding ECS_{CO2} upper bound value is 1.8^{o} C.

Our TRCS research team has previously published on our website:

1. A one page summary of its preliminary findings from our first year of study of this issue http://www.therightclimatestuff.com/SummaryPrelimReport.html and
2. A 21 page report entitled, "AGW Science Assessment Report", that expanded on the findings of the above one-page Preliminary Report with supporting data and references http://www.therightclimatestuff.com/AGW%20Science%20Assess%20Rpt-1.pdf

This report will be published on the website at the following link:
http://www.therightclimatestuff.com/BoundingClimateSensitivityForRegDecisions

The AGW Science Assessment Report concluded that the extent to which human activity was warming the earth's surface was unsettled science. The current report presents the data and methodology we used to reduce the uncertainty and bound the extent of GHG warming. The report also critiques various methods used in the past to determine the extent and uncertainty range of GHG warming, as well as the faulty scientific basis for GHG warming estimates used in the current CO2 emissions regulation development process [1 - 3]. This process was developed by an Interagency Working Group (IWG) and computes Social Costs of Carbon (SCC) based on previous overstated uncertainty ranges for ECS. The IWG SCC calculation method provides highly uncertain and very large future SCC damage estimates to offset virtually certain immediate damage to the US economy from higher energy costs that will result from GHG emission control regulations. Therefore, to justify the imposition of GHG emissions regulations with potentially severe adverse consequences, it is important to make more accurate SCC calculations with higher confidence limits. This is an important aspect of critical decision-making that we have learned from more than 50 years of service in our manned space program by most of our team members.

The primary reason for the significant uncertainty in the sensitivity of the earth's surface temperature to atmospheric GHG concentrations, as measured by the ECS parameter, is that climate simulation models that compute ECS have never been validated by demonstrating they can accurately forecast the future. The wide range of ECS estimates is well-documented in the peer-reviewed scientific literature, and on-going research on this issue has been summarized in the various IPCC reports.

In recent testimony to the Subcommittee on Environment of the US House – Science, Space and Technology Committee [11], Dr. John Christy, the Alabama State Climatologist, presented stark evidence that none of the climate models referenced in the 2013 IPCC AR5 Report accurately predicted the earth's temperature history over the last several decades. Yet these are the same models that are the basis for calculating ECS. A key graphic used in Dr. Christy's testimony to demonstrate the very poor performance of these models compared to actual climate responses, is presented in Figure 1.1. He used this Figure to report on his analysis of results from 73 different climate models used by the IPCC to support its recent revisions to the ECS uncertainty range as reported in its 2013 AR5 report [9]. The GHG warming hypothesis predicts a significant increase in atmospheric temperatures in tropical regions that will lead to an increase in global average surface temperatures (GAST). Dr. Christy compared the model forecasts of GHG warming tropical mid-Troposphere temperature rise over the last 35 years to actual temperature trends measured by US satellites and weather balloons over the same 35 years. He is very familiar with these data as he leads the team at the University of Alabama-Huntsville (UAH) that maintains one of the satellite temperature measurement databases for NASA.

The models computed a wide range of tropical mid-Troposphere temperature variation due to GHG warming and other natural climate behavior for the last 35 years. All 73 models had biased over-prediction errors for GHG warming effects compared to the actual small amount of tropical atmosphere warming recorded. By the year 2013, the average mid-Troposphere temperature error of all the models had gradually increased to a factor of 5 larger than the actual data. Clearly, models with such large error, are falsified and their ECS output is suspect and inappropriate for critical decisions regarding public policy on GHG emissions control. In place of model-derived ECS, we suggest that the historical data base can be used to construct a climate sensitivity uncertainty range that could serve as a solid foundation for GHG control regulations.

Although many of the climate models were developed by scientists from other UN countries, the USA developed models had more error than the group average. The absolute worst performing model, GFDL-CM3, yielding a predicted temperature for 2013 about 8 times greater than actual (more than 1.5^{o} C vs about 0.2^{o} C actual), was developed by a US government agency. http://www.gfdl.noaa.gov/coupled-physical-model-cm3

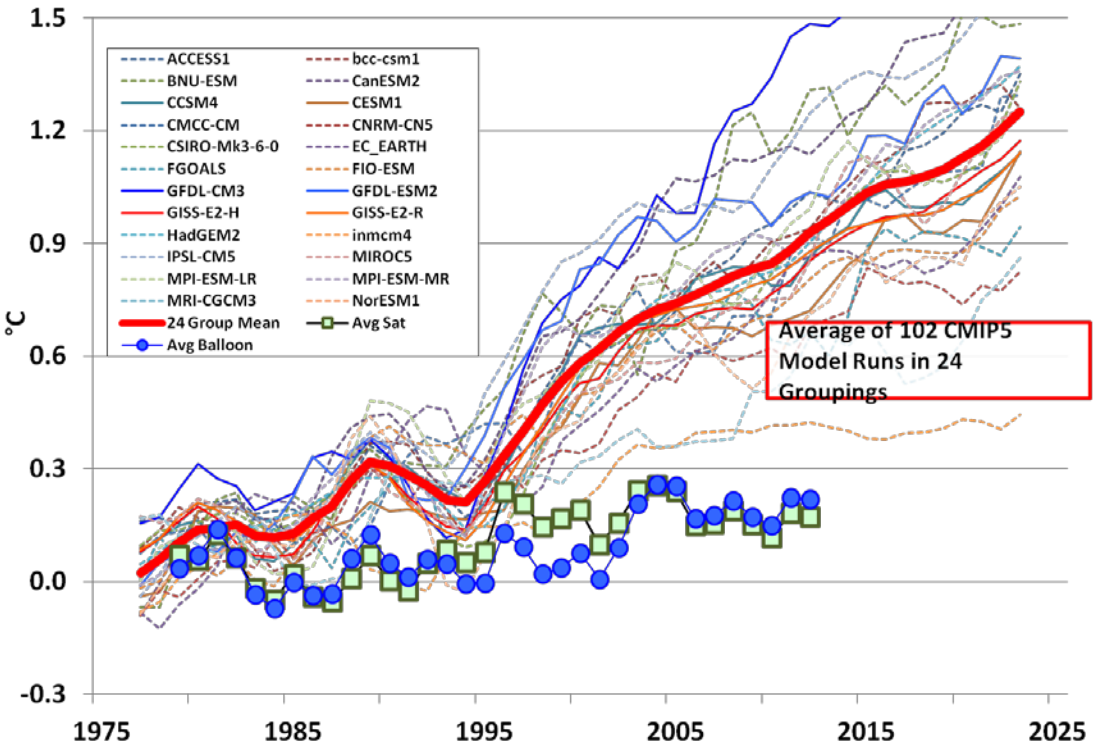

Figure 1.1 - Dr. John Christy Study - Climate Model Comparison to Actual Physical Data of the mid- Troposphere Temperature Anomalies

A simple process for confidently forecasting GHG driven global temperature increases is demonstrated in this report. However, this process does not use ECS, as we do not believe that ECS is an appropriate metric to forecast global temperature changes in the 300 year time period considered in current SCC calculations. We propose a better climate sensitivity parameter, Transient Climate Sensitivity (TCS) based on historical data, to support SCC calculations. Since neither the IPCC ECS nor TCR climate sensitivity metrics can be verified by data, we defined TCS in terms of the data so it can be verified. We define the transient climate sensitivity for CO2, TCS_{CO2}, to be ***The actual rise in GAST caused by actual increases in atmospheric CO2 levels in the year that atmospheric CO2 concentration reaches 560 ppm, thereby doubling the pre-industrial CO2 atmospheric concentration of 280 ppm.*** The definition can also be modified to describe TCS_{GHG} based on appropriate GHG data for any or all components of GHG.

In part, the rational for this improved metric is that by 2300 GHG emissions will have started to decline because economically recoverable fossil fuel reserves will have peaked before 2200. We discuss this claim in Section 3.0 of this report. In Sections 4.0 – 4.5 we demonstrate how to

determine climate sensitivity using historical data. In Section 4.6, we also demonstrate how to use TCS to bound the possible GHG warming effects from the present until the year 2300. Using our recommended approach, our calculations indicate the global average temperature anomaly will not increase more than 1.2^{o} C above current levels over the next 300 years.

1.1 Un-Validated Models Should Not Be Used for Critical Decision-Making

Our opinion that output of un-validated models should not be used for critical decision-making results from more than 50 years of experience with complex models in our manned space program. To underscore this opinion, based on common sense and practical experience, we refer to the results of Figure 1.1 comparing model forecasts to actual climate response to increasing GHG in the atmosphere over the last 35 years. If you have adequate empirical data to make the decision, then you don't need to confuse the decision-making process with unknown error introduced by un-validated models.

After Christy's evaluation of these IPCC model results became widely known in mid-2013, the IPCC added a footnote to the earlier circulated draft of its 2013 AR5 Summary for Policymakers (SPM) on page 14 stating**: *"No best estimate for equilibrium climate sensitivity can now be given because of a lack of agreement on values across assessed lines of evidence and studies".***[9] This footnote basically admits ***"we just can't figure out the correct answer using our models".*** We agree. The models are useless, perhaps even dangerous, and should be ignored for serious decisions to be made regarding bounding and mitigating the threat of GHG warming.

But, there is general agreement in the historical data base used as input data to these models and we use this empirical data to establish a confident upper bound on GHG climate sensitivity. A confident upper bound supported by actual physical data and without the use of models, is needed to reduce uncertainty in climate sensitivity reported in many peer-reviewed publications.

A climate model can only be validated in retrospect, as time will show if the model's predictions matched reality. It is generally accepted that a period of about 30 years is needed for any climate change signal to emerge from the background noise of weather variability. This includes any anthropogenic-induced climate signal which may be amplified or masked by natural cycles. The 30-year period is based, in part, on evidence of a natural cycle of about 62 years (see Figure 4-4). This cycle appears to involve a peak-to-valley temperature swing of about 0.3 ^{O}C.

The importance of naturally occurring cycles and oscillations on our climate is becoming increasingly recognized. For example, it appears that the warm phases of coupled ocean-atmosphere cycles of the Pacific Decadal Oscillation (PDO) and the Atlantic Multi-decadal Oscillation (AMO) were operative in the latter ~three decades of the last century and thus

contributed a significant portion of the rapid temperature rise from 1970 to 2000. The PDO and AMO began cycling into "cool phases" around 2000, which would explain, in part, the lack of global warming over the last 17 years. (As will be discussed later, a decrease in TSI in the current solar cycle is also a likely contributor to the current hiatus in global warming.) Such natural climate cycles are not well-modeled by current climate simulation codes focused on the GHG issue.

1.2 Defining the Problem, Finding Root Cause, and Choosing a Course of Action

This report provides a partial response to our first research objective, established at the beginning of our investigation in February 2012: ***"Determine to what extent human-related releases of CO2 into the atmosphere can cause earth surface temperature increases that would have unacceptably harmful effects."*** http://www.therightclimatestuff.com/Objectives.html

In responding to this research objective **we have concluded that the sensitivity of the earth's climate to atmospheric CO2 and other GHG concentrations can be accurately bounded by empirical data, and that such bounded sensitivity for ECS is below the 3 ^{o}C mid-point of the IPCC "official" ECS uncertainty range of 1.5 to 4.5 ^{o}C.** However, the transient climate sensitivity that will determine actual temperature trends over the next several hundred years is much lower and more tightly bounded. Our upper bound established for TCS_{GHG} is 1.6^{o} C and led us to conclude that the maximum additional warming from anthropogenic greenhouse gases (AGHG) will stay below 1.2^{o} C. The world has benefited from the warming since the Little Ice Age, and it is likely that the benefits of the additional modest warming would be substantial.

Clearly, whether some modest warming is beneficial or harmful is a local question and must, at least, be addressed at the regional level. The primary global threat of GHG warming, is rapid melting of the earth's permanent ice sheets on Greenland and Antarctica leading to significant sea level rise and world-wide coastal flooding. But, the location of this vast storage of ice on the planet is important, considering regional atmospheric and water surface temperatures that may melt this ice. While global ocean currents and atmospheric jet streams can transport heat around the globe, it is only the resulting ocean surface temperature near these vast ice deposits that can directly threaten them. For example, higher temperatures in the tropics will may affect air and water temperatures near these ice deposits but tropical temperatures cannot directly melt this ice. Preventing this ice from melting is also a regional issue and does not necessarily require global prevention measures. The cost, performance, and reliability of a global solution for a local problem, where local solutions may exist, need to be carefully considered. We do not see that this issue has been given enough consideration in the constant calls from climate scientists and the IPCC that we need a global GHG emissions control policy to control a global temperature problem. If a problem exists, it will need to occur at multiple specific locations around the globe

before it can be declared to be a global problem. A deviation from "normal" is really not a problem that needs to be mitigated if it causes no harm and has net benefits.

Since realistically, we won't experience a sudden onset of sustained higher temperatures as in the hypothetical ECS scenario, problems that could occur would develop slowly. This would allow time for adaptive solutions to be considered and evaluated in cost/benefit analyses against the uncertainty and potential ineffectiveness of global solutions. For example, if we need to protect US interests from rising sea levels caused by rising world-wide atmospheric GHG levels that the US cannot currently control with high confidence, unilateral US GHG emissions control with high costs to our economy does not seem to be an effective policy to protect the US from sea level rise. We need effective, high confidence solutions to real problems.

In our manned space program experience, Problem definition and root cause analysis must follow a very disciplined process that proves root cause before mitigation actions are taken that could result in serious adverse consequences, like death of a crew of astronauts. We do not detect that such necessary discipline has been applied to the postulated AGW "problem" whose existence and root cause(s) are clearly in doubt, given the results of Figure 1.1 and other historical data evaluated in this report.

One of the disciplined Problem Analysis processes that we have learned and have successfully applied to many space mission anomalies where human lives were (and continue to be) at stake, was developed by Kepner and Tregoe [12, 13] and requires that a deviation from normal has already occurred. Then, a precise Problem Statement describing the deviation from normal can be written and the Problem specified in terms of the dimensions What?, Where?, When?, and How Much?, before root cause can be determined. But just as important to complete specification of the Problem, is data on very similar items (products, other spacecraft, regions, populations, etc.) where the deviation from normal has not occurred in one or more of the four dimensions. The Distinctions between items that are experiencing the Problem and very similar items that are not experiencing the Problem are critical to proving the true root cause(s) of the Problem. Therefore, to our team of experienced aerospace scientists and engineers, familiar with disciplined problem identification and root cause analysis, a Problem cannot be specified unless we have identified particular locations where the Problem is occurring and where it is not.

In evaluating the instrumental temperature record of the contiguous 48 states of the USA, temperature deviations from the normal range have not occurred. Our analysis of temperatures over the last 10,000 years, as determined from ice cores taken from both Greenland and Antarctica, could not identify a present harmful temperature deviation from normal in the naturally occurring temperature variations of this relatively very stable period of the earth's climate history. In ice core data, temperature variations are inferred from the stable isotope $^{18}O/^{16}O$ variation. Analyses of these data from both Greenland and Antarctica indicate that the

yearly average temperature often varies by +/- 1^{o} C from the 10,000 year average, and at most +/- 2^{o} C. We do not state these facts to classify ourselves as "climate change deniers". We are attempting to be accurate in our assessment and measured in our responses as we practice what we have been taught and know from experience is a successful way of identifying and solving problems where great risks to human safety are concerned, both from non-action and hasty over-reaction.

Potential Problems that have not actually occurred, as presented by the AGW concern, are tackled by a different Potential Problem Analysis process that does not involve root-cause determination, but that does involve planning to identify threats and vulnerabilities and to ensure adequate data is available to monitor the concern. In addition, some contingency planning is performed to deal with the Potential Problem should it actually begin to occur by approaching "out of bounds" limits of the normal range.

The most recent warming trend since the beginning of the Industrial Age appears to be at least partly associated with a warming trend that began in about 1650 AD, as the Northern Hemisphere (NH) began to naturally warm from the Little Ice Age (LIA) that was one of the coldest periods in the recent 10,000 years since we warmed up from the last glacial maximum. This temperature minimum was clearly associated with several centuries of reduced solar radiation output known as the Maunder Minimum. Temperatures in the 1600's were abnormally cold (see Figure 4.2). But because of some naturally occurring climate change forcings, and of late probably some forcing produced by human activity, earth surface temperatures have warmed up a bit, but not to intolerable or catastrophic levels. The 1.2^{o} C maximum additional GHG warming bounded by the scientific analyses of this report does not indicate that temperatures will rise above levels experienced in the last 10,000 years. This observation also needs to be reviewed in the context of other scientific observations that indicate we are entering a period of reduced solar activity that would provide cooling effects.

Before very expensive public policy changes are made in an attempt to avoid the GHG warming Potential Problem that is not well-specified, we believe a much more disciplined approach needs to be taken to first determine if an actual Problem exists, and where or when it will exist, with root cause(s) confidently established. Then, a broader range of potential mitigation approaches, including local mitigation approaches, should be weighed for performance, cost and schedule requirements and the best solution(s) selected in a disciplined Decision Analysis.

GHG regulations unilaterally imposed by the US, such as the EPA penalty on fossil fuel combustion, will at best trivially lower global temperature. There are two primary reasons for this:

1. Success would require an iron-clad agreement and implementation from all nations with significant GHG emissions to actually limit atmospheric GHG emissions to prescribed limits. Such action will not happen in the foreseeable future, as Germany and developing economies are engaged in a coal fired power plant building binge. Thus, unilateral GHG emissions control by the USA will have no material impact on atmospheric GHG levels. A study by Knappenberger [14] has shown that, using IPCC projections, if all USA GHG emissions were curtailed as of 2012, GAST would only be lowered by 0.08^{o} C in 2050 and 0.17^{o} C in 2100, a negligible amount!

2. GHG emissions control does not appear to have good control authority for GAST since atmospheric CO2 concentrations have increased by over 8 percent since 1998 [15], but GATA has actually declined slightly in the 15 year period from 1998 through 2013, as measured by HadCRUT4 and the USA satellite databases, and consistent with the well-documented 15-17 year "pause" in global warming.

Social Benefits of Carbon

But unassailable, is one universal benefit of higher CO2 levels in the atmosphere that is well-researched and documented. Plants thrive on more atmospheric CO2. Atmospheric CO2 is rising above the very lowest values needed to allow plants to grow and satellite data show there is a current "greening trend of the planet", most likely due to rising atmospheric CO2 levels. [16] For a quick overview of more facts regarding plant growth and CO2 see: http://www.plantsneedco2.org/default.aspx/MenuItemID/103/MenuGroup/Home/CO2IsGreenAndGood.htm For scientific research references supporting these views, see the Nongovernmental International Panel on Climate Change (NIPCC) 2011 report, Chapter 7. [17]

Atmospheric CO2 levels higher than the present 397 ppm could help with the existing Problem of how to feed the planet's growing population, with large segments of population already severely under-nourished. Starvation and malnutrition are terrible costs that could be mitigated with a higher atmospheric CO2 concentration. It is not clear from the TSDs how this benefit is incorporated into the IWG SCC models.

What is more critical now? Should our national priority be more concerned about a fear of highly uncertain GHG warming 100 years into the future, or responding to the immediate Problem of large starving populations of humans on this planet? Where should our priorities lie? What is the best present sequenced course of action to address both issues?

1.3 Can We Bound GHG Climate Sensitivity with Actual Data?

The most recent IPCC ECS uncertainty range of $1.5 < ECS < 4.5^{o}$ C was reported in its 2013 IPCC AR5 SPM report [9], page 14. In some earlier issues of its various reports, IPCC gave 2^{o} C as a lower limit for its ECS uncertainty range, but lowered it to 1.5^{o} C in the 2013 AR5 report, the lowest value discussed in its First FAR Assessment Report [5]. However, the IPCC did not also choose to lower the upper end of its uncertainty range in AR5, despite many recent papers since 2010 indicating lower values for upper limits of this uncertainty range. This more recent trend of the published literature is discussed in Section 4.5 of this report.

In contrast to the AR5 report, and in agreement with several recently published papers, our least upper bound for all GHG ECS is 2.7^{o} C, as derived in Section 4.5 of this report. This upper bound value and our more conservative ECS upper bound of 2.9^{o} C are both below the 3.0^{o} C mid-point of the IPCC ECS uncertainty range. In this ECS bounding analysis, we used readily available and adequate data from the last 163 years of GATA, atmospheric GHG concentration rise, and TSI rise. Even more important to CO2 emissions regulation is an upper bound value for $ECS_{CO2} = 1.8^{o}$ C that measures climate warming sensitivity to CO2-only to provide a more accurate cost for SCC.

The basic problem with the IPCC's extensive analysis of peer-reviewed, published research, from which it draws its conclusions regarding climate sensitivity to CO2 and other GHG, is that it makes the critical mistake of giving any credence whatsoever to projections of future climate changes, and attribution of those changes, from output of un-validated climate simulation models. Moreover, in our opinion, the results of computer model studies should only be published in scientific journals if they are accompanied by supportive empirical observations. This conclusion is based on over a half-century of experience from many of our research team members, using models for critical decision-making in design and operation of spacecraft, where human safety was involved.

Although computer models based on first principles are used extensively for design of commercial airplanes, bridges and buildings, engineers never base design decisions on output of un-validated computer models, and for good reasons supported by a grateful public. For what possible reason would it be appropriate to base public policy decisions regarding climate, with potentially severe unintended consequences, on un-validated climate simulation models, as the IPCC advocates and as adopted by the IWG for SCC calculation?

Before getting into more detail, it would be helpful to discuss some of the different ways climate scientists define climate sensitivity to CO2 and other GHG, and critique the usefulness of the different climate sensitivity parameters for forecasting climate behavior. While the following definitions are often referred to as different measures of CO2 Climate Sensitivity, as the radiative

forcing potential of other GHG such as methane have become more important, the definitions can be generalized to GHG Climate Sensitivity by replacing CO2 with GHG to include effects of any or all GHG in the definitions. Typically, as with the IPCC practice, the GHG sensitivity is still referenced to the CO2 concentration level in the atmosphere, but it can be referenced to a higher "equivalent" CO2 concentration that that adjusts the actual CO2 concentration upwards to include the radiative force of all GHG in the atmosphere. Careful attention to definitions and computational practice of individual researchers is required to interpret published numerical values correctly.

1.4 Equilibrium Climate Sensitivity (ECS)

The peer-reviewed published literature on GHG warming extent and uncertainty primarily focuses on Equilibrium Climate Sensitivity (ECS). In the 2007 IPCC AR4 report [8], ECS is defined as: ***"ECS is the equilibrium global mean temperature change that eventually results from atmospheric CO_2 doubling".*** In the most recent IPCC AR5 report [9], ECS is defined as: ***"the change in global mean surface temperature at equilibrium that is caused by a doubling of the atmospheric CO2 concentration."*** More specifically, ECS is computed from any particular climate simulation model in which an initial state with pre-industrial levels of atmospheric CO2 concentrations of about 280 ppm, is instantaneously forced with a "step function" by doubling the CO2 concentration to about 560 ppm and then letting the climate simulation run for 1000 years or more until the climate reaches a new equilibrium state. At the new equilibrium, much more CO2 has migrated to the atmosphere from the warming oceans in response to the initial warming effects of the doubled CO2, and CO2 and other GHG, especially methane, are released from warming permafrost and land masses. This detail of the definition is often not mentioned, as in the two recent IPCC definitions quoted above, and is typically not understood in press releases regarding new research paper results publishing new estimates of the hypothetical metric.

The direct radiative forcing of the climate system from this additional 280 ppm of CO2 has been computed from CO2 Infrared Radiation (IR) absorption band capacity to be in the range of 3.44 – 3.71 W/m^2 as reported by Otto et. al. (2013) [18]. It is generally agreed by climate scientists that the direct forcing (without climate feedbacks) of the earth's climate system from an increase of 3.71 W/m^2 in radiative energy balance would result in about 1.1 - 1.2^o C of average earth surface warming. We do not dispute this conclusion derived from considerations of Quantum Mechanics for behavior of IR energy-absorbing Tyndall gases. What we do dispute are the strength of climate feedback mechanisms simulated in climate models that take this direct radiative forcing and calculate much larger changes in earth surface temperature as characterized by large ECS values.

The empirical data from 163 years of the GHG warming record do not support large amplified climate responses to the direct radiative forcing of 3.7 W/m^2 as would be characterized by a climate simulation model that computes an ECS value > 2.9^o C. Moreover, for assessments focused on the next 300 years of GHG warming, climate sensitivity values much less than the ECS value are more appropriate to consider. This is because the ECS value is based on climate responses to elevated GHG levels lasting 1000 years or more.

The climate model forcing function used to compute ECS is typically a step function in radiative forcing assumed to be caused by a combination of CO2 and other GHG. After the step function in radiative forcing is applied, the climate model is used to simulate the relatively large oscillations of the climate responses for many centuries until a final new equilibrium state is reached with CO2 exchanges equilibrated between the atmosphere, oceans and land masses. Long simulation times are required in order for feedback loops in the simulation to allow the oceans and land masses to give up additional stored GHG to the atmosphere, as they slowly warm in response to the initial warming caused by the doubled radiative forcing level. These modeled feedback loops amplify the direct warming caused by the initial step increase in radiative forcing. Different assumptions and feedback loop formulations in different models result in a wide dispersion of ECS values computed by different models similar to the dispersion of modeled results presented in Figure 1.1, and leads to the large uncertainties in estimated values for ECS.

Such ECS simulations are totally academic in nature and are not very well suited to predicting GAST responses to more realistic slowly rising and falling levels of atmospheric GHG concentrations over the next 100 to 300 years. Nevertheless, this is the most popular climate sensitivity value discussed in the peer-reviewed published literature and invariably the one discussed in mass media outlets.

1.5 Transient Climate Response (TCR)

A Transient Climate Response (TCR) simulation provides a much more realistic climate response to slowly rising GHG levels in the atmosphere, and is more accurate in predicting global average surface temperature response vs. time over a few centuries. The official definition of a TCR climate sensitivity value for doubling CO2 concentration in the atmosphere, provided in the IPCC AR4 report is: ***"TCR refers to the global mean temperature change that is realised at the time of CO_2 doubling under an idealised scenario in which CO_2 concentrations increase by 1% yr^{-1}"*** The IPCC AR4 Report explains further that: ***"The TCR is therefore indicative of the temperature trend associated with external forcing, and can be constrained by an observable quantity, the observed warming trend that is attributable to greenhouse gas forcing. Since external forcing is likely to continue to increase through the coming century, TCR may be more relevant to determining near-term climate change than ECS."*** Somehow

this expert advice from the IPCC regarding suitability of TCR and ECS values for predicting near-term climate change, has been ignored by the US government IWG in its recent efforts to define how SCC should be computed [1, 2]. The rational for using an unrealistically broad ECS distribution is based on speculative statements regarding ECS uncertainty in the IPCC 2007 AR4 report. The result is that the IWC extends the upper uncertainty ECS boundary from the 4.5 ^{o}C of the AR4 to 10.0 ^{o}C for calculating the SCC. This is more than 5 times the upper bound for ECS_{CO2} = 1.8 ^{o}C we derived from empirical data, as demonstrated in Sections 4.0 – 4.4!

In the TCR simulation, a quasi-steady equilibrium state between earth surface temperatures and atmospheric GHG levels is maintained at all times during the simulation, in contrast to the ECS simulation approach. Climate variable rates of change are much smaller in the TCR simulation allowing much larger numerical integration step sizes to maintain simulation accuracy. Also, the doubled CO2 value is obtained in only about 70 years of simulation time compared to more than 1000 years for the ECS simulation to reach the equilibrium condition sought. Despite the TCR simulation's more realistic GHG forcing function and its numerical accuracy and computer run time advantages for determining a more realistic and accurate global average temperature vs. time, most of the peer-reviewed literature focuses on the larger, totally academic ECS value that can never be verified with actual data! The ECS metric is unrealistic because of the step function application and the fact that CO2 levels will never stay at elevated levels in the atmosphere for 1000's of years to reach a new equilibrium condition. Instead, atmospheric CO2 will rise to a concentration level that is only about 2 times pre-industrial levels within about 200 years and will then begin to decline as economically recoverable fossil fuel reserves are depleted, as discussed in Section 4.6. In 300 years, atmospheric CO2 levels should be considerably below their peak values (see Figure 4.10).

1.6 Relative Magnitude of ECS and TCR

The TCR value has a lower value than ECS and occurs in approximately the same year that the GHG level in the atmosphere attains its doubled value. Therefore, TCR does not include the long term feedback effects of more CO2 released into the atmosphere by oceans and land masses over thousands of years after they were warmed by the initial doubling of CO2. The relative magnitude of ECS and TCR can only be evaluated with a given climate model used to simulate results from each type of forcing. However, the relative magnitude of these academic metrics was important for us to study because we needed a way to compare our TCS metric derived from data to other published results of TCR and ECS. To determine an average value for the TCR/ECS ratio computed by climate models, we analyzed data in the IPCC AR4 report, where 23 different climate simulation models were studied. The models are described in AR4 Table 8.1 of Chapter 8. In AR4 Table 8.2, the results of the 23 different climate models in simulating

both ECS and TCR values were tabulated. Not all climate models provided both TCR and ECS values. For the 18 models that did, the ratio of TCR/ECS ranged from 0.43 to 0.76 and had an average value of 0.56. The climate model designations and ECS and TCR values obtained from IPCC AR4 Table 8.2, with a column added for the TCR/ECS ratio, are presented below in Table 1.2 of this report.

The average TCR/ECS ratio obtained from Table 1.2 will be used in Section 4.5 of this report to compute upper bounds for ECS based on TCS values derived from analysis of atmospheric GHG level variations and GATA variations over the 163 year period from 1850 – 2012.

In its 1990 First Assessment Report (FAR) [5], the IPCC explained that in performance of climate models at the time, that for high values of ECS = 4.5^{o} C, a TCR value would be only about 50 percent of the ECS value, but for low values of ECS near 1.5^{o} C, TCR value would be about 80 percent of the ECR Value. These general trends still hold for climate models used for the 2007 AR4 report as shown in Figure 1.2 that plots the data of Table 1.2. Figure 1.3 shows the trend in ECS/TCR vs. TCR of Table 1.2 data. The results of Figures 1.2 and 1.3 will be used in Section 4.5 to support our upper bound calculations for ECS in terms of corresponding values of TCS extracted from physical data. In Section 2.3 we present our arguments for concluding that our new TCS metric would equal TCR produced by an accurate climate model. Therefore, we use the average Table 1.2 value of TCR/ECS = TCS/ECS = 0.56, to conclude that that ECS/TCS = 1/(0.56) = 1.8. Since we can tightly bound TCS from empirical data, use of the typical climate model ECS/TCR ratio allows for a tighter bound on ECS estimates for comparison with other published results. We don't recommend that the ECS value actually be utilized for any type of realistic transient GHG warming predictions.

TABLE 1.2 - CLIMATE MODEL TCR/ECS RATIO

MODEL ID	ECS (°C)	TCR (°C)	TCR/ECS
1: BCC-CM1	n.a.	n.a.	-
2: BCCR-BCM2.0	n.a.	n.a.	-
3: CCSM3	2.7	1.5	0.56
4: CGCM3.1(T47)	3.4	1.9	0.56
5: CGCM3.1(T63)	3.4	n.a.	-
6: CNRM-CM3	n.a.	1.6	-
7: CSIRO-MK3.0	3.1	1.4	0.45
8: ECHAM5/MPI-OM	3.4	2.2	0.65
9: ECHO-G	3.2	1.7	0.53
10: FGOALS-g1.0	2.3	1.2	0.52
11: GFDL-CM2.0	2.9	1.6	0.55
12: GFDL-CM2.1	3.4	1.5	0.44
13: GISS-AOM	n.a.	n.a.	-
14: GISS-EH	2.7	1.6	0.59
15: GISS-ER	2.7	1.5	0.56
16: INM-CM3.0	2.1	1.6	0.76
17: IPSL-CM4	4.4	2.1	0.48
18: MIROC3.2(hires)	4.3	2.6	0.60
19: MIROC3.2(medres)	4.0	2.1	0.53
20: MRI-CGCM2.3.2	3.2	2.2	0.69
21: PCM	2.1	1.3	0.62
22: UKMO-HadCM3	3.3	2.0	0.61
23: UKMO-HadGEM1	4.4	1.9	0.43
		Average of 18 values =	**0.56**

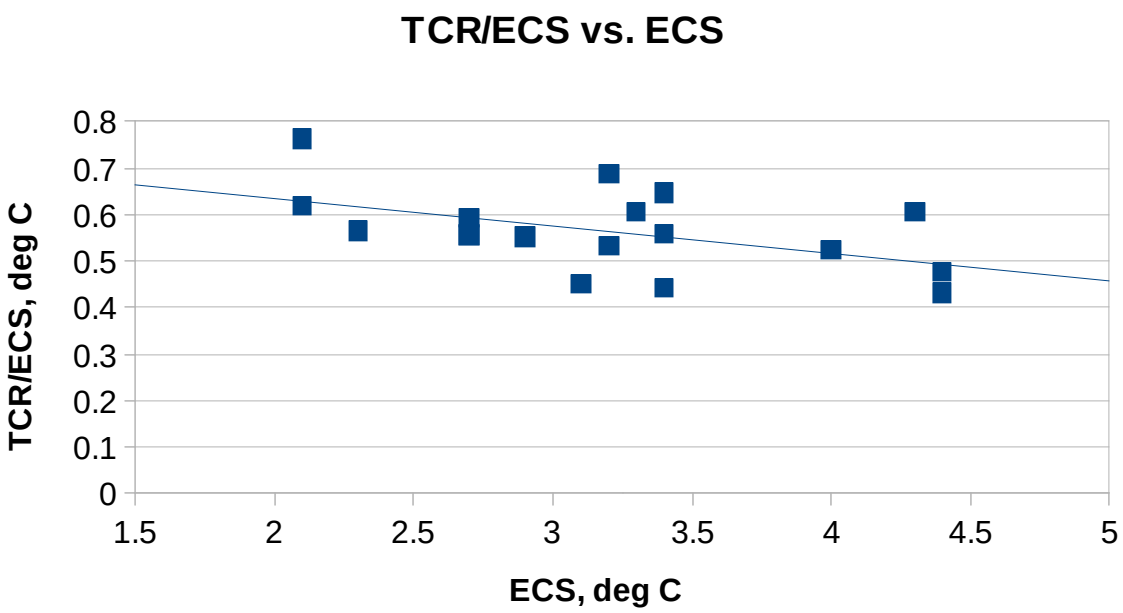

Figure 1.2 IPCC AR4 Climate Model TCR/ECS Trends Vs. ECS

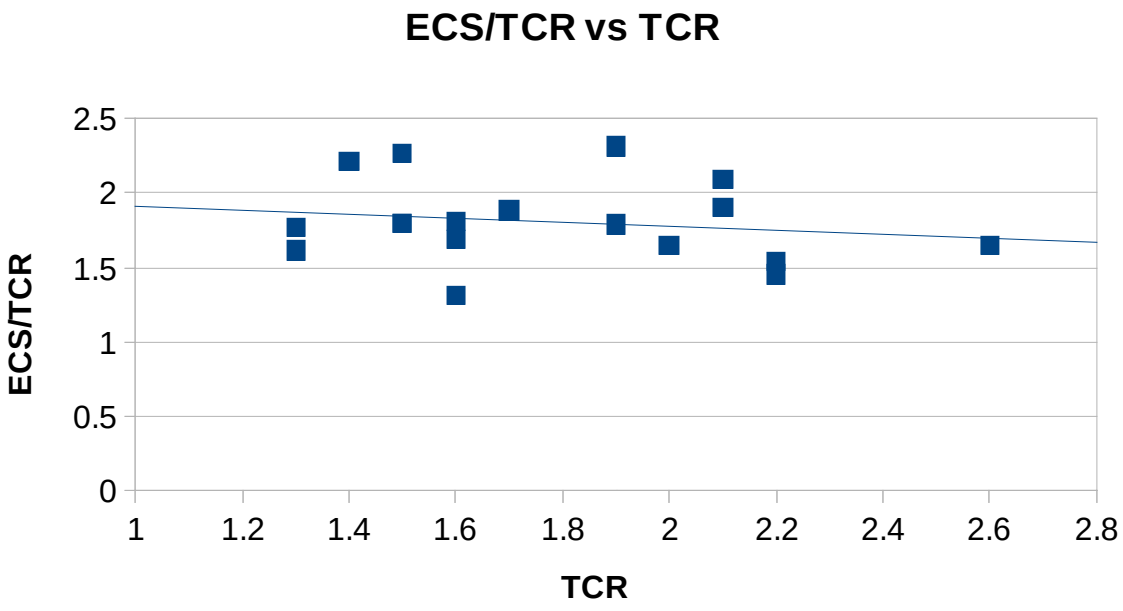

Figure 1.3 IPCC AR4 Climate Model ECS/TCR Trends VS. TCR

1.7 Transient Climate Sensitivity (TCS)

For purposes of this report, and to establish a climate sensitivity definition that can be verified by actual data, we define:

Transient Climate Sensitivity (TCS) = ***The actual rise in GAST caused by actual increases in atmospheric CO2 levels in the year that atmospheric CO2 concentration reaches 560 ppm, thereby doubling the pre-industrial CO2 atmospheric concentration of 280 ppm .*** TCS can also be defined for all GHGs (other than water vapor) individually or in aggregate as appropriate to specific studies, using appropriate pre-industrial levels and the doubled value of pre-industrial levels. For extraction of the TCS_{GHG} and TCS_{CO2} parameters from temperature data, we had to first define a Transient Climate Sensitivity metric for the Total Radiative Force (TRF), TCS_{TRF}, affecting the GATA. Since our GATA temperature dataset starts in 1850, we define TCS_{TRF} as the change in GAST from 1850 to the year in which CO2 in the atmosphere doubles from the 1850 value. We do not need to wait for the actual time it takes CO2 concentration to double in the atmosphere. We can estimate the TCS_{TRF} over a period of time since 1850 when significant changes in the CO2 concentration have occurred. This temperature change is due not only to the doubled CO2 concentration changes, but also due to other GHG radiative force level changes and TSI changes. The TCS_{CO2} and TCS_{GHG} values are computed from the extracted TCS_{TRF} value using data on GHG and TSI changes that occurred during the time period from 1850 used for the TCS_{TRF} extraction. The estimates obtained for TCS_{TRF}, TCS_{GHG} and TCS_{CO2} have a foundation of empirical data and are thus verifiable. Details of this process are demonstrated in Section 4.4.

The type of simulation used to define TCR is easily modified to force the model with actual slowly varying, measured atmospheric GHG concentration vs. time to simulate actual global warming from pre-industrial times to the present day. This would create a TCS type simulation whose output can be compared to actual GAST or GATA data for model validation purposes. Because the warming effects of GHG are theorized to establish new, slowly changing "quasi-steady" equilibrium conditions as GHG concentrations slowly rise in the atmosphere, the effects of the atmospheric GHG rise should be a gradual increase with time of troposphere temperature levels vs. altitude, as well as earth surface temperatures.

In climate simulations with a TCR or TCS slowly applied GHG forcing, natural forcing transients and internal climate dynamics will cause the climate system to deviate from its instantaneous equilibrium point and depart somewhat from the gradual rise in temperature caused by the slowly rising GHG level. However, with time according to GHG warming hypotheses, earth surface temperature should return to its quasi-steady equilibrium condition created by slowly rising atmospheric GHG levels. Quasi-steady equilibrium is a concept borrowed from our launch vehicle dynamics experience where even though a rocket steadily

loses mass with time, we can successfully model the launch vehicle vibration characteristics at a particular slowly changing equilibrium point in its trajectory. If the mass loss rate is small enough, we can assume the rocket has a constant mass during the short period of the lowest vibration frequency.

For example, if the lowest vibration frequency of interest is one Hz, and the total launch vehicle mass change is only a very small percentage change in the one second it takes for one vibration cycle, the quasi-steady "constant" equilibrium idealization has been found to be acceptable by comparing analytical predictions of vibration characteristics vs. time to actual flight data. Such small mass changes are on the order of the error in specifying the actual vehicle mass distribution for that period of time. By analogy, when analyzing climate dynamics in actual data or mathematical simulations, if GHG levels are changing by on the order of one percent per year, the average atmospheric GHG level can be assumed to be constant in one year, and the climate equilibrium point for GHG effects can be assumed to be constant for that year.

2.0 CLIMATE SENSITIVITY IMPORTANCE FOR FORECASTING AGW

Although CO2 and all-GHG ECS has been the most popular climate sensitivity value studied in climate science peer-reviewed literature, ECS really is unsuited for use in public policy decision-making that is focused on GHG warming and its mitigation in the 100 to 300 year horizon. First of all, the scenario considered in the ECS simulation of first doubling the CO2 level in the atmosphere and observing what happens in a climate model simulation of the climate response is a totally unrealistic scenario. Second, the simulation must be run for approximately 1000 years to allow the simulation to converge to a new hypothetical equilibrium condition with hypothesized higher earth surface temperatures. But this will never happen in reality because CO2 levels in the atmosphere will only continue to rise for less than another 200 years until economically recoverable fossil fuels are depleted and a gradual transition to other sources of energy must occur, at which time CO2 levels in the atmosphere will begin to decline (see Section 4.6 and Figure 4.10).

Rather than a sudden step function increase in atmospheric GHG levels, the actual possible scenarios would incorporate a gradual rise of GHG levels for 100 to 200 years to a maximum level that will be in the ballpark of doubling pre-industrial levels, followed by a gradual decrease in atmospheric GHG levels. Then, by 300 years from now, realistic scenarios would have atmospheric GHG levels significantly reduced from their peak levels. Therefore, the ECS scenario will never be realized as oceans and land masses will begin to cool down from reduced atmospheric levels of GHG and absorb even more CO2 from the atmosphere due to their cooler temperatures. In realistic climate change scenarios, the earth's surface will never release all of

the CO2 and other GHG assumed in the ECS simulation due to the unreasonable assumption of step function forcing that maintains GHG at elevated levels for a period of 1000 years or more.

For forecasting AGW effects over the next 100 to 200 years, the TCR type of simulation that assumes a gradual rise of GHG levels in the atmosphere, is much better suited than the ECS type of simulation, if it is modified to simulate a particular scenario of GHG level in the atmosphere vs. time for the next 200-300 years. The IPCC utilizes such simulations for the various Representative Concentration Pathway (RCP) scenarios discussed in its 2013 AR5 SPM. If any climate model can be modified/improved to accurately simulate naturally occurring processes that affect earth surface temperatures, and can reproduce the historical record of earth surface temperatures with the appropriate known input data, then one would expect the model forecast over the next 200-300 years to be reasonably accurate as GHG levels rise to the doubled value, exceed it somewhat and then begin to decline. However, the results displayed in Figure 1.1 for only a 35 year period, demonstrate that this level of climate model maturity has not been achieved at present. But, it is not necessary to use complex climate models to perform the estimates of GAST behavior over the next 300 years. If one assumes that the climate is in a slowly changing quasi-steady equilibrium for a slowly varying radiative forcing function, then the measured TCS value can be used to compute GAST for any radiative forcing level. The projected radiative forcing levels for each year in the future are defined by the average total atmospheric GHG concentration level projected for a given year in any proposed RCP scenario. This procedure is demonstrated in Section 4.6.

Even though TCR and TCS have different definitions, consideration of the vast differences in dynamic response characteristics of the ECS and TCR simulations, and much greater similarity of TCR and TCS definitions, will demonstrate that for all practical purposes, a true value of TCR = TCS. In the following sections, we analyze the differences in the dynamic characteristics of the ECS, TCR or TCS types of climate simulations using a simple spring-mass-damper dynamic system analogy that most technically trained individuals have some familiarity with, and can more readily comprehend the dynamic response characteristics.

2.1 Simple Spring-Mass-Damper Analog for the ECS Type Simulation

To use a simple spring-mass-damper dynamic system (Figure 2.1) as an analog for the more complex climate system dynamics, the ECS-type simulation starts with an initial condition of this simple system with the forcing function (externally applied force vs. time) created by blowing a steady stream of air upwards onto the mass that provides a constant upward force on the mass equal to 1/4 the weight of the mass in a 1-G gravity field. This creates the initial equilibrium state of the system with no motion or acceleration of the mass.

If this upward wind force is suddenly doubled to equal 1/2 the weight of the mass (the step function that doubles the magnitude of the applied external force), the mass will begin to move upward and will continue to gain upward velocity until it reaches its new static equilibrium position. After the mass moves up past the new equilibrium position, the downward gravity force acting on the mass will be greater than the combined upward directed forces of the wind and spring tension force, and the mass velocity will begin to decrease until it reaches zero at the maximum upward position of the mass

.

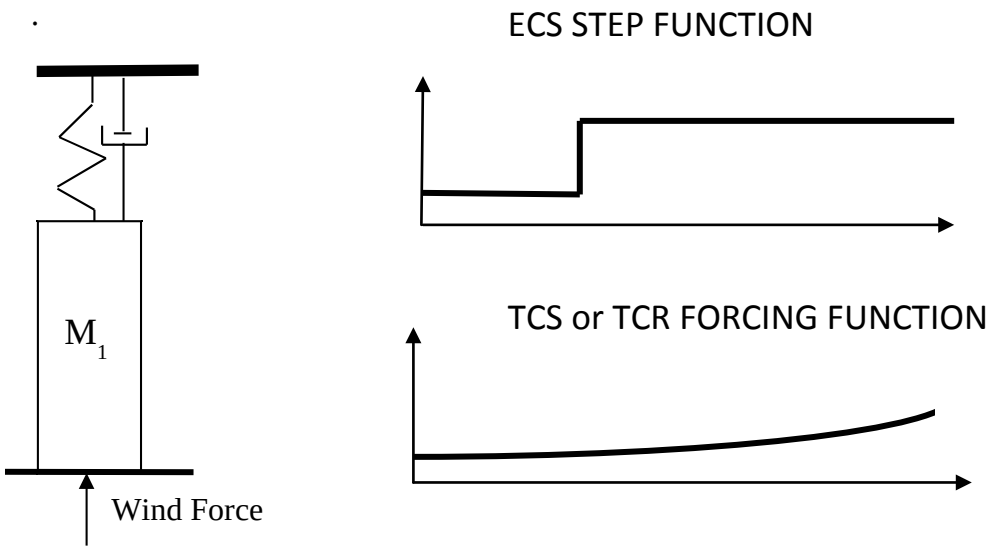

Figure 2.1 Simple Spring-Mass-Damper Dynamic System

The well-known analytical solution for this dynamics problem reveals that the upward motion of the mass will continue until the position of the mass is the same distance above the new equilibrium position, as it was below the new equilibrium position when the wind force was suddenly doubled. Without any damper forces, the mass would continue to oscillate forever about the new equilibrium position with constant amplitude of vibration and constant wind force equal to 1/2 the weight of the mass applied. However, with any small amount of damping from the system damper, the oscillatory motion will eventually decay to zero position and velocity amplitude, leaving the position of the mass at its new static equilibrium position, and with the wind still blowing upwards on the mass with a constant force equal to 1/2 the weight of the mass.

At this new equilibrium position, the downward stretch of the spring is only 1/2 of its initial stretched position because of the increased upward steady wind force. By analogy to a climate dynamic model, the new position of the mass can be visualized as representing a new temperature value for the new climate equilibrium condition with a new and different external radiative force level applied. The oscillatory dynamic response to a step function disturbance described above is one reason the ECS simulation must be continued for a long period of time to

find the new equilibrium condition. Another reason is due to the non-linear characteristics of the more complex climate system where due to a feedback mechanism, more CO2 and methane are released into the atmosphere from the warming oceans and land masses as they begin to warm from the initial doubling of the GHG radiative forcing. Since it takes on the order of 1000 years for the actual climate system to reach a new equilibrium condition with higher atmospheric GHG levels and warmer earth surface temperatures, the ECS simulation must be carried out for long periods to allow CO2 to slowly migrate from the earth's surface to the atmosphere and for the oscillations to damp out.

In climate model simulations, the ECS values are always higher than the TCR values because of the non-linearity of the climate system modeled where more GHG migrates to the atmosphere from the warming earth surface. This is somewhat analogous to a non-linear modification of the linear simple spring-mass-damper system where the spring gets weaker over a long period of time and as a result, the mass rises up higher to a final equilibrium state with the same 2x step function force applied.

2.2 Simple Spring-Mass-Damper Analog for the TCR Type Simulation

In contrast to an ECS simulation, for a TCR or TCS type simulation, the upward wind force is very gradually increased from an initial steady state value of 1/4 the weight of the mass at a rate on the order of 1 percent per year and the response of the mass is to very slowly and steadily rise upwards (without significant oscillation activity) until the upward wind force is equal to 1/2 the weight of the mass, and the mass comes to rest at its new static equilibrium position. In this type of climate simulation, the new equilibrium condition is achieved in about the same year the external radiative force is doubled, and occurs within about 70 years ($1.01^{(70)} = 2$) rather than 1000's of years of an ECS simulation waiting for the final equilibrium state to be achieved. In the TCR type of simulation of the simple system, the upward velocity of the mass is very slow and it does not have a significant overshoot of its constantly changing equilibrium position due to the slowly rising external force. Therefore, there is insignificant oscillation of the mass as it rises to its new static equilibrium position when the externally applied force finally reaches its doubled value.

2.3 Discussion on Why TCR Approximately Equals TCS

For TCR type simulations with our simple, linear dynamics model, it wouldn't matter if the wind force was only applied at half the 1 percent per year rise rate. The mass would still slowly and steadily rise upwards until the new equilibrium position with the wind force equaling half the weight of the mass is achieved. The only difference in the solutions is that for the slower rise rate simulation, it takes about 139 years to reach the new equilibrium position ($1.005^{(139)} = 2$), but the final equilibrium state is the same for either case.

A subtle point should be addressed here regarding differences in the definitions of TCR and TCS and how non-linear dynamic response of climate models differ in one important respect to the simple model discussed above. The TCS value defined herein is the actual total temperature rise achieved due to CO2 or GHG effects when the rising atmospheric GHG level attains its doubled value. The total doubled amount of GHG in the atmosphere at that time will be the externally added GHG plus the nonlinear feedback of the net GHG transferred to the atmosphere from the warming oceans and land masses in the time period involved. It is not only the externally added GHG that causes the doubled GHG level to be reached. Due to the warming surface GHG release nonlinear feedback mechanism, total externally added GHG from the forcing function should be less than double the initial concentration level.

If we are careful to define TCR in the same manner such that the 1 percent per year rise rate in externally added GHG is discontinued whenever the atmospheric GHG concentration reaches its doubled value, then TCR and TCS should be approximately equal because the new equilibrium state with the same doubled level of GHG in the atmosphere is the same. This is true even though a TCS simulation with actual slower GHG rise rate than 1 percent/yr of the TCR simulation would need to be carried out for about 230 years (see discussion in Section 2.4). However the amount of externally added GHG to the climate system may be different in the two different cases with the longer simulation of the TCS case having a larger percentage of its atmospheric GHG released from the surface.

The official TCR definition is based on the average surface temperature measured in a 20 year period centered on the year when the doubled atmospheric CO2 level is attained, as some small oscillatory amplitude behavior may be excited by the forcing function. Any additional GHG to be released to the atmosphere in the 10 year period after the doubled GHG value is reached would also contribute to the total warming in the TCR definition and may cause TCR to be slightly higher than TCS.

Considering that ECS values are an average of 80 percent higher than TCR values, [(1/0.56)(100) = 1.8] due to the approximately 1000 years required to release all of the equilibrium condition GHG from the earth's surface to the atmosphere, this effect over a 10 year period was estimated to create on the order of a (10/1000)(80) = 0.8 percent difference. Therefore, an accurate official TCR value should be less than one percent greater than a true TCS value. Based on these arguments, we will assume in this document that TCS, as we have defined it herein, equals TCR for comparing our TCS extraction results with other published values of TCR and ECS. As will be demonstrated in following sections of this report, TCS is a verifiable value using actual physical data; while TCR, as it is officially defined by the IPCC, is not. But since we have demonstrated herein that TCS and TCR are approximately equal, the TCR value of a climate model can also be tested and verified with actual data, while clearly the ECS value, cannot.

2.4 ECS Simulations Are a Waste of Resources

The discussions above in Sections 2.0 – 2.3 cast serious doubt on the usefulness and benefit of such a large portion of climate research dollars being utilized for ECS simulations with un-validated climate models. Based on our modeling experience in the manned space program, significant resources spent on use of un-validated models other than attempts to improve the models and validate them, have no practical value and only waste resources and generate unnecessary and distracting uncertainty for critical decision-making, often under severe time constraints with flight anomaly scenarios.

In addition, from basic dynamic response considerations and our experience in modeling complex dynamic phenomena, ECS simulations are wasteful of computer time compared to TCR or TCS simulations. Since the rates of change of all climate variables are much higher in the more violent dynamics of a step-function forcing, the numerical integration step sizes of the ECS simulations must be small to maintain numerical integration accuracy, and the simulated time length of the ECS simulation is much longer than the TCR type of simulation. Therefore, without ever having run such climate simulations, we estimate that the ECS simulation with only half the integration step size and 5 times the simulation time period, must take at least an order of magnitude more computer time than a TCR simulation to reach a final equilibrium state. Solution "tricks" discussed by Bryan [10] have been considered to reduce the inordinate ECS computer solution times.

Even more important, the ECS solution cannot be compared to actual physical data for validation of the model, while the TCR simulation can, with a small change in the forcing function. These obvious practical issues raise serious doubt regarding the judgment and objectives of those who use taxpayer resources to fund and perform studies with un-validated models running ECS simulations. Other questions of climate science objectives arise when in over 30 years and billions spent on climate research, the IPCC has not been able to reduce the uncertainty range for ECS from the 1979 Charney report's original estimates of 1.5 to 4.5^{o} C. This fact suggests that reduction of the ECS uncertainty range was never the goal of the IPCC or USA climate research activities. When one analyzes the SCC computed by the IWG Integrated Assessment Models (IAM), one realizes that it is the uncertainty in ECS used in the ECS statistical distribution as input to the IAMs, that causes computation of significant expected damage values for SCC.

3.0 BOUNDING GHG LEVELS FROM BURNING FOSSIL FUELS

It has taken 163 years from 1850 when atmospheric CO2 levels were about 285 ppm , to rise 39 percent to 397 ppm in 2013, an average rise rate of 0.21 percent per year ($1.0021^{(163)}$ = 1.40). This rise rate has been increasing with time, and over the last 15 years, average annual atmospheric CO2 levels (measured at the NOAA Mauna Loa station) [15] have increased from 369.3 in 1998 to 396.5 in 2013, a 7.4 percent increase in 15 years, or average rise rate of 0.48 percent per year ($1.0048^{(15)}$ = 1.074). This rise rate is expected to increase to a peak rise rate of less than 1 percent per year and then fall off a bit even before the atmospheric CO2 doubled value of 560 ppm is reached due to an orderly market-driven transition to alternative fuels that should begin about mid-century. These trends are shown in Figure 3.1, where Antarctica Law Dome data 1832-1978 [19] and Mauna Loa data from 1859 – 2013 are plotted, with an estimated atmospheric CO2 concentration rise scenario from present until 2100.

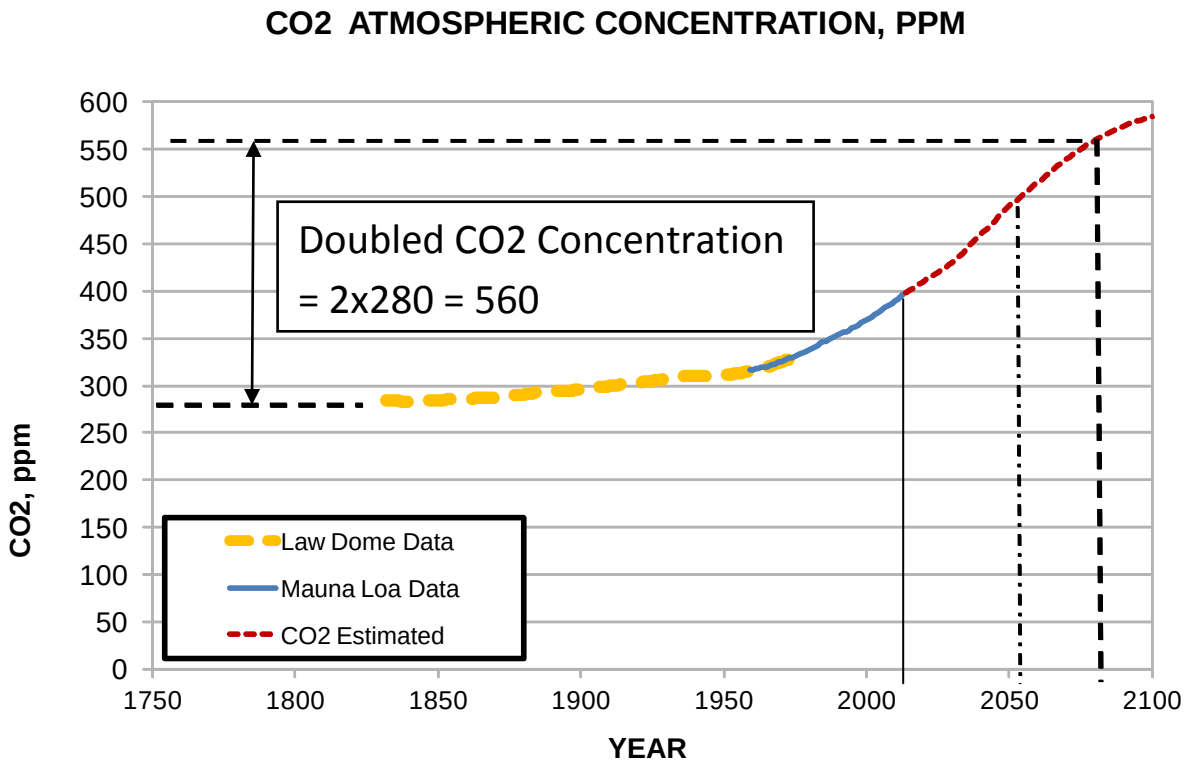

Figure 3.1 Atmospheric CO2 Concentration 1832-2013 and Projections to 2100

Atmospheric CO2 concentration trends after 2012 were projected assuming persistence of recent acceleration in rise rate trends, followed by our best estimate scenario of a flattening of the curve as it approaches a maximum CO2 concentration level of 600 ppm, sometime after 2100. The

Figure 3.1 projection assumes an orderly market-driven transition to non-fossil fuel energy sources will begin before economically recoverable fossil fuel reserves are depleted at a peak CO2 concentration level of 600 ppm. The rise rate of the CO2 curve begins to decline when atmospheric CO2 concentration reaches 500 ppm just after 2050, indicating a gradual market driven transition to alternative energy sources will begin to occur as alternative energy sources become more cost competitive with rising costs of fossil fuels. As with any scarce commodity, we expect costs of fossil fuels will continue to rise as world-wide reserves are depleted and costs rise to develop less financially attractive reserves. By the time atmospheric CO2 concentrations have reached their doubled value in about 2080, the market driven transition to alternative fuels will be well underway.

3.1 Representative Concentration Pathways (RCP)

In its 2013 AR5 report, the IPCC studied several RCP scenarios based on various GHG emission control policies that might be implemented [9]. The numeric part of the RCP designation, e.g. RCP4.5, refers to the change in GHG and aerosol radiative forcing in W/m^2 in the year 2100 relative to the year 1750. For comparison with our Figure 3.1 scenario and results published in this report, we will assume GHG radiative forcing, but not TSI, was constant from 1750 to 1850. For example, the IPCC RCP4.5 scenario assumes world-wide CO2 emissions stabilization policy is implemented soon, and achieves a maximum CO2 concentration of 538 ppm at 2100 before it begins to decline thereafter. The equation for computing the atmospheric radiative forcing change in W/m^2 for the atmospheric CO2 concentration level in any year, with respect to a reference year, $CO2_{REF}$, is derived in Appendix A as eq. (A-2):

$$\Delta RF_{CO2}(year) = \{Log[(CO2(year)/CO2_{REF}]/Log[2]\}(3.71)\ W/m^2$$

In this report we have used the pre-industrial atmospheric CO2 concentration, $CO2_{REF}$ = 280 ppm. Therefore, for the IPCC's RCP4.5 scenario that peaks with a 538 ppm atmospheric CO2 concentration level in 2100, the increase in radiative forcing relative to the pre-industrial equilibrium point is computed,

$$\Delta RF_{CO2}(2100) = \{Log[538/280]/Log[2]\}(3.71) = 3.50\ W/m^2$$

However the IPCC RCP4.5 scenario assumes additional radiative forcing in 2100 will result from increased concentrations of other GHG and forecasted aerosol concentration in 2100, that adds a net 1.0 W/m^2 to the CO2 radiative forcing, for a total of 4.5 W/m^2 for the scenario.

Therefore, CO2 provides only [3.5/4.5](100) = 77.8 percent of the total radiative forcing in this scenario.

We named the CO2 concentration pathway of Figure 3.1, RCP5.1, using the IPCC AR5 report nomenclature. The scenario reaches a CO2 concentration of 585 ppm in 2100 and CO2 climbs to a peak concentration of 600 ppm sometime after 2100 when all currently projected world-wide fossil fuel reserves are developed and burned. The IPCC ratio of

(CO2 radiative forcing)/(Total GHG and Aerosol Forcing) = 0.778

from their RCP4.5 scenario was used to compute the 5.1 W/m^2 value obtained to name the RCP5.1 scenario for its radiative forcing level in 2100,

$$\Delta RF_{GHG} = \{Log[585/280]/Log[2]\}(3.71)/0.778 = 5.07 \text{ rounded to } 5.1 \text{ W/m}^2$$

For comparison with the IPCC RCP4.5 scenario based on a moderately aggressive GHG emissions control policy, and that reaches its max radiative forcing level of 4.5 $W.m^2$ in the year 2100, our market-driven scenario provides a (5.07/4.5 = 1.133) 13.3 percent higher radiative forcing level in 2100 that will create a 13.3 percent higher GHG warming temperatures in 2100. We will demonstrate in following sections of this report that this will be an insignificant difference of about 0.15^o C in actual GAST levels without the unknown and uncertain costs, and implementation enforcement issues of a world-wide GHG emissions control agreement.

Our RCP5.1 scenario does not reach its peak radiative forcing level associated with 600 ppm atmospheric CO2 levels until after 2100; the maximum radiative forcing of the scenario is:

$$\Delta RF_{GHG}(max) = \{Log[600/280]/Log[2]\}(3.71)/0.778 = 5.24 \text{ W/m}^2$$

The RCP5.1 scenario of Figure 3.1 assumes no world-wide GHG emissions control policy, while the IPCC RCP4.5 scenario assumes implementation of a moderately aggressive world-wide atmospheric GHG concentration "stabilization" policy that must begin soon. The possibility of achieving agreement on even such a moderate world-wide stabilization policy in the near future is very unlikely because of the current rapid GHG emissions growth in China and India from the rapid addition of coal burning power plants. Also, there are no indications from China and India that they would consider an agreement to limit GHG emissions any time soon. Furthermore, countries like Germany that have already implemented GHG emissions control policies, have experienced rapidly rising energy costs that threaten their manufacturing cost competitiveness. They are having to add coal fired power plant back-up capacity in addition to the massive government subsidized investment they have made in wind and solar power, that have not

proven to be sufficiently reliable and dependable. Therefore, we believe the RCP5.1 scenario of Figure 3.1 is more likely what will actually happen to atmospheric CO2 levels regardless of the effects of any USA unilateral GHG emissions control regulations.

The current USA emissions control policy has very low probability of achieving success in lowering GAST by more than a negligible amount as demonstrated by Knappenberger [14] using IPCC projections, because the USA GHG emissions are rapidly becoming a smaller percentage of world-wide GHG emissions as China, India and Australia increase theirs.

3.2 Bounding Atmospheric CO2 Levels

The 600 ppm maximum atmospheric CO2 concentration value used to limit the atmospheric CO2 concentration rise rate scenario RCP5.1 of Figure 3.1 was derived by Stegemeier [20] of our TRCS research team, using historic cumulative production trends to estimate remaining world-wide reserves of crude oil, natural gas and coal. The ultimate world fossil fuel reserves were computed using Hubbert production decline curve methodology [21] together with production data from the DOE - Energy Information Agency (EIA) data base [22]. When all of these remaining reserves are produced and burned, Stegemeier computed that the atmospheric CO2 level would peak at 600 ppm, which we have used for our RCP5.1 scenario.

The assumptions in the maximum 600 ppm CO2 concentration calculations were as follows:

1. All of the remaining world-wide fossil fuel reserves are burned.
2. CO2 produced by a fuel is dependent on its carbon to hydrogen ratio.
3. Future improvements in methods of recovery will not surpass the 150+ year record of improvements in the fuel industries. (That is, the future Hubbert decline slope is unchanged).

The sources of data in the world-wide reserves calculation were:

1. The historic world cumulative crude oil produced and burned, originally estimated by Juvkam-Wold and Dessler in 2008 [23], was updated in 2012 to 1.3 trillion barrels. The remaining world oil reserves, by extrapolation of the EIA 1980-2012 production data [22] are 1.5 trillion barrels.

2. The historic cumulative production of natural gas, was calculated from the cumulative oil production with an average gas oil ratio of 2500 Standard Cubic Feet (SCF)/ bbl, to be equal

to 3.8 $x10^{15}$ (quadrillion) SCF. The estimated remaining 6.2 x $(10)^{15}$ (SCF) natural gas reserves are derived from extrapolation of EIA 1980-2011 gas production. The EIA prediction of current natural gas reserves was not available.

3. The historic cumulative coal production and reserves have reported values that are widely divergent. Accurate estimates of recoverable coal reserves are available in well-developed countries from Hubbert analyses of production decline rates, but the large uncertainty arises from uncertain estimates of coal reserves in lesser developed countries. Estimates of cumulative world coal production as of about 2006 are calculated from Patzek [24] to have been $330x10^{9}$ (gigatons). The Hubbert analysis, using EIA production data from 1980 to 2011, failed to achieve a straight line decline. In the past ten years high rates of coal production in China, India, and Australia have resulted in an unusual upward trend on the Hubbert plot. Estimates of remaining world coal reserves range from 500 to 950 gigatons. In the absence of a Hubbert prediction of future coal reserves, the value reported by EIA (948 gigatons) was used in the prediction of the max atmospheric CO2 level from burning future production.

Recent production rate increases in crude oil and natural gas in the USA achieved from technology improvements in hydraulic fracturing of horizontally drilled wells are expected to be adopted world-wide. This could alter the world-wide Hubbert production decline curve trends used in estimating total recoverable reserves in the above calculations. This would result in somewhat higher estimates of total economically recoverable crude oil and natural gas reserves. However other significant technology improvements of the past affecting economically recoverable reserves, are already incorporated into the Hubbert production decline analysis methodology, and it remains to be seen how much these more recent technology improvements can alter the well-established production decline slope of the Hubbert analysis method. In addition, according to Stegemeier's calculations [20], the GHG forecasts of the RCP scenarios are more sensitive to burning the planet's vast and uncertain coal reserves, than any current uncertainty in the remaining world-wide crude oil and natural gas reserves.

3.3 AGW and a Required Market-Driven Transition to Alternative Fuels

The RCP5.1 scenario of Figure 3.1 due to burning of all world-wide fossil fuel reserves, assumed no CO2 emission control implementation, but instead assumed an orderly market driven transition to alternative fuels. The 600 ppm peak CO2 concentration scenario has a total GHG radiative forcing value of 5.07 W/m^2 in 2100 AD and 5.24 W/m^2 at the 600 ppm peak that occurs after 2100. The 2100 forcing level is about 15.5 percent lower than the IPCC AR5 RCP6.0 scenario that assumes a GHG stabilization policy using moderately aggressive world-wide implementation of GHG emission controls.

The IPCC AR5 RCP8.5 scenario has an 8.5 W/m^2 increase in GHG radiative forcing with respect to 1750 levels in 2100 and assumes no GHG emissions control. It has a (8.5/5.07 = 1.677) 67.7 percent higher radiative forcing in 2100 than our RCP5.1 scenario. Also, this scenario stabilizes at a radiative forcing level of about 12.3 W/m^2 in 2250 and holds constant at that value through 2300. Therefore at its peak radiative forcing level, RCP8.5 has (12.3/5.24) = 2.35 times the radiative forcing and AGW temperature rise of our RCP5.1. Since Stegemeier's calculations are consistent with well-established methods used in the energy and financial industries to accurately value reserves, the IPCC RCP8.5 scenario appears to be impossible to achieve and wildly speculative based on current data and estimates for the remaining world-wide reserves of fossil fuels. Concerns regarding AGW warming from such speculation as incorporated into RCP8.5 should not drive US GHG emissions control regulations. The conservative RCP5.1 scenario only results in a maximum of less than 1.2^o C warming above current levels, depending on how conservative one feels is necessary. For an appropriate level of conservatism in analysis, and using a 1.5 factor of safety, if 1.5(1.2) = 1.8^o C of additional warming cannot be found to be harmful, weighed against the well-known benefits of modest warming and more CO2 in the atmosphere, then the GHG warming alarm should be "put to bed" so that we, as a nation, can focus on more serious matters.

Our RCP5.1 scenario of Figure 3.1 assumes that an orderly market driven transition to alternative fuels must begin about 2055 as the CO2 concentration rise rate begins to slow down. Based on past performance of major energy companies in providing a non-disruptive supply of energy for the demands of a growing world-wide population, we expect that they have developed internal, proprietary plans for developing the necessary transition to alternative fuels to prevent their companies from going out of business. Therefore, we expect these companies can successfully execute the necessary transition to alternative energy sources that must begin before 2080 when atmospheric CO2 levels are expected to double from pre-industrial levels. We believe the rapid depletion of the world's fossil fuel energy sources, which is already affecting us with a rapid rise in price of crude oil, is a much more critical concern than AGW. This report, that bases its conclusions on actual data and rather simple scientific calculations, not wild speculation of un-validated climate models, demonstrates that the AGW alarm is over-hyped and relatively unimportant compared to the issue presented by the current rapid depletion of fossil fuel energy sources. This is a critically important issue for the world economy that needs government cooperation, not interference based on the over-hyped AGW alarm.

It would be helpful to calm citizen concerns regarding energy sources and AGW, if we had a sound national energy plan that would ensure US citizens that this transition to viable alternative fuels can and will occur before any harmful effects of AGW can occur. Based on our successful Apollo Program experience, we would like to see a technically viable plan for this great challenge, with features similar to the detailed plan we used to meet the challenge of landing

astronauts on the moon and returning them safely in the decade of the 1960's. Such a plan would define the necessary government funded research and development, and national facilities development timetable required, but would probably not involve government intervention in energy markets with subsidies for non-competitive alternative energy sources. The plan would ideally avoid if at all possible, GHG emissions control regulations that disrupt and distort the most efficient market driven path transition to the most viable alternative energy solutions.

4.0 DETERMINING TCS FROM BEST AVAILABLE DATA

The earth atmosphere and surface temperatures are affected by many naturally occurring phenomena, with various time spans ranging from a few days or months to centuries while AGW Theory predicts a gradual rise in surface temperatures as GHG levels in the atmosphere continue to increase. Therefore, the true effects of GHG warming are most accurately extracted from long period data sets, during which time larger percentage changes in GAST, GATA and atmospheric GHG levels can occur, and shorter term transient oscillations in GAST and GATA tend to cancel out. Various research papers using paleo-climate data have been presented in an attempt to determine ECS and this work has been reviewed and considered by the IPCC in establishing its uncertainty range for the ECS value. However, we do not believe the paleo-climate data is as reliable as the available instrumental temperature records, or as suitable for extracting CO2 warming effects in the very stable quasi-equilibrium state of the climate system that developed over 10,000 years ago after the rapid warm-up from the last glacial maximum of about 20,000 years ago. The instrumental data records of GATA since the pre-industrial period began in 1850 and cover the period when GHG levels in the atmosphere began to rise significantly. We have concluded these are the best available climate data to extract climate sensitivity to CO2.

It is important to note here that GATA is not GAST. GATA is an average of the change in temperature of each reporting station in the dataset that forms an average temperature deviation or “anomaly” from a defined base period average. But the average temperature of all reporting stations is not the GAST for that date because of the non-uniform earth surface distribution of measurement stations used to compute GATA. GAST would require an evenly distributed array of measurement stations over the surface of the earth. Satellite data with almost continuous temperature measurement coverage over the entire earth’ surface and atmosphere approaches the desired GAST metric. The reader is referred to the references provided for each temperature anomaly database discussed in this report to determine details of how the anomaly, or deviation in temperature from a specified base period average, is determined. The anomaly is computed differently for different databases maintained by different research groups in different countries, and those differences become discriminators in choosing one database as more desirable than others for use in specific research projects.

Ideally, we would prefer to have a dataset of GAST, as that is the variable that is hypothesized to increase with increasing atmospheric GHG levels. However, here we will be limited to working only with GATA and recognize that some error is introduced into our climate sensitivity parameter identification to the extent that changes in GATA are not precisely equal to changes in GAST. We will be concerned with which dataset is more likely to provide results closer to the desired GAST metric.

The most popular and widely followed thermometer record databases have received considerable scrutiny in recent years as a result of the "Climategate" http://wattsupwiththat.com/climategate/ controversy. In this controversy some researchers were suspected of tampering with the data records based on internal email correspondence that was made public as a result a computer hacking incident. Other technical issues were involved in the entire Climategate controversy such as instrument siting concerns, concerns regarding accuracy and world-wide coverage of sea surface and land measurements, and issues over decisions to include or exclude certain measurements in maintaining a GATA database that would better approximate GAST trends.

In the wake of Climategate, at a time when considerable doubt was cast on the validity, maintenance and configuration control documentation for the instrumental databases, an objective and independent audit on the various popular instrumental temperature databases was performed by the Berkeley Earth Surface Temperature (BEST) research project http://www.berkeleyearth.org/index.php. The results of this research project indicated that the popular thermometer databases such as HadCRUT4 maintained by the Hadley Climate Research Unit (CRU) of the UK Met Office [25] and the GISTEMP database [26] maintained by the NASA Goddard Space Flight Center, Goddard Institute for Space Studies (GISS) were sufficiently accurate for research purposes.

We do not consider the satellite measurement databases such as UAH-LT [27] maintained for NASA by the University of Alabama-Huntsville and RSS Temperature Lower Troposphere (TLT) [28] maintained by Remote Sensing Systems for NOAA, to provide sufficiently long data records to accurately extract CO2 climate sensitivity values. However, because of their more extensive coverage of global temperature measurements, especially atmospheric Lower Troposphere temperatures above the vast oceans of the planet that cover 71 percent of the earth's surface, as well as remote land locations, the satellite databases provide a good check on the other instrumental databases during their overlap period since 1978.

In Figure 4.1, the HadCRUT4 and GISTEMP temperature anomalies are plotted against anomalies from the satellite based RSS and UAH measurements. The base period zero anomalies for RSS and UAH in Figure 4.1 were selected to closely agree with the longer period databases over the first 5 years of their record overlap from 1979-1984. The data in Figure 4.1 uses the versions of these various databases that were current though the end of 2012.

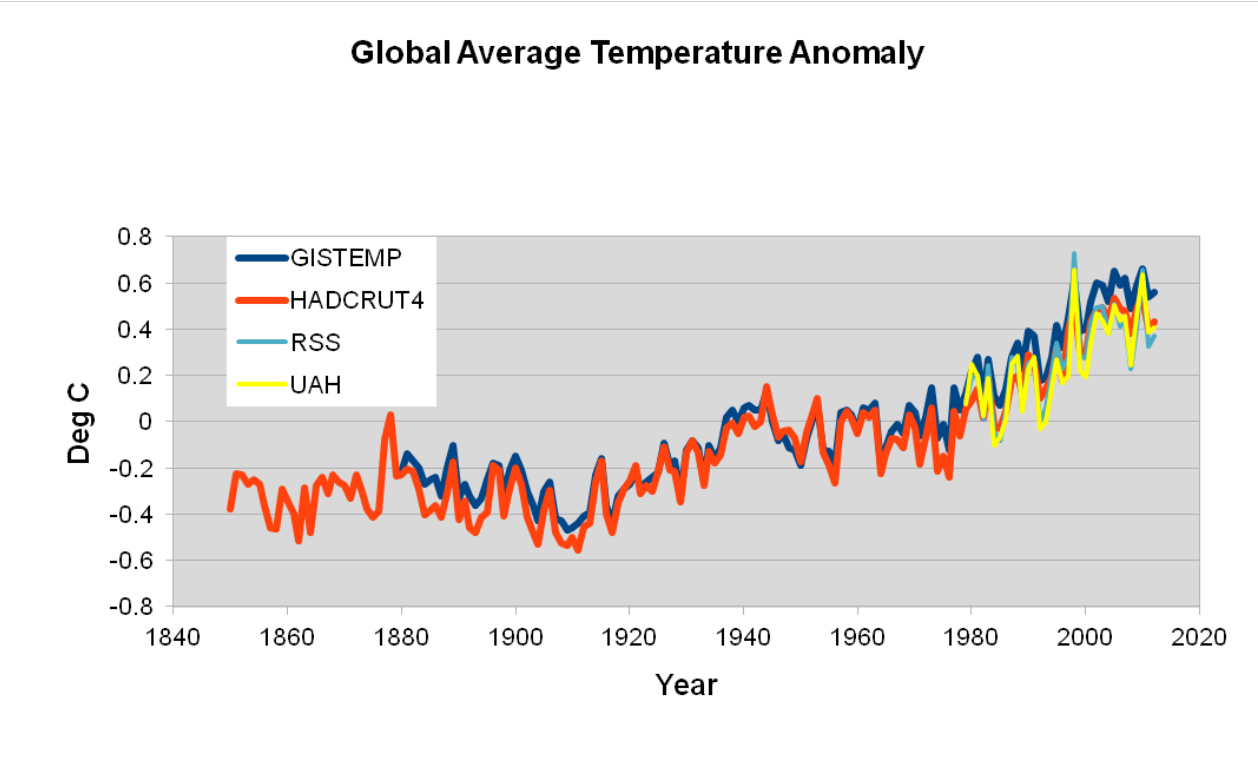

Figure 4.1 Comparison of Several Popular Global Average Temperature Databases

4.1 Best Available Data

In reviewing the data of Figure 4.1, it was noted that the satellite records closely agree with each other and more closely agree over their shorter period of overlap with the HadCRUT4 database. Toward the end of the data record, the GISTEMP GATA values are trending higher than HadCRUT4 and both satellite databases. In 2012, the GISTEMP GATA value is 0.13^{o} C higher than HadCRUT4 while both satellite databases are below HadCRUT4, agree with each other within 0.035^{o} C, and are below HadCRUT4 by an average of 0.04^{o} C. This indicated a preference for accuracy of the HadCRUT4 database compared to GISTEMP. HadCRUT4 is also preferred because it does not interpolate between stations over unmonitored areas; therefore, its data can be validated and traced back to actual station readings. Also, the HadCRUT4 database provides the longest available thermometer record of yearly average global surface temperature anomalies (30 years longer than GISTEMP), a feature important to extraction of the long-term CO2 climate sensitivity effects from the temperature data. In addition, the climate sensitivity extraction process from data assumes that the GATA is a close approximation to actual GAST. Since the satellite databases should come closest to producing a true GAST anomaly and they agree more

closely with HadCRUT4 than GISTEMP, we chose the HadCRUT4 GATA as the preferred database for GHG climate sensitivity determination.

Another important observation regarding climate sensitivity extraction from the HadCRUT4 database relative to GISTEMP, is that the total temperature rise in their common overlap period from 1880 – 2012 was 0.77^{o} C for GISTEMP and 0.72^{o} C for HadCRUT4, a difference of only 0.05^{o} C, or 6.7 percent. This difference was obtained by using average readings for the first and last five years of their overlap period.

Tom Wysmuller http://www.colderside.com/Colderside/HadCRUT4.html of our TRCS research team has observed that the HadCRUT4 GATA database has an upward bias in temperatures of more than 0.05^{o} C in recent years compared to the former HadCRUT3 version of this database [29]. This bias is believed to be caused by over 400 new reporting stations being added to HadCRUT4 vs. HadCRUT3. In addition to 125 new reporting stations in northern Russia, northern Canada and Alaska, data from Greenland, Denmark, and the Alps, were also added, all in all totaling over 400 additions to HadCRUT4 and some of those were stations affected by local heat island effects. Only 8 new SH temperature stations were added to the HadCRUT4 database, at least 3 of which were within 20 degrees of the equator. The imbalance between the number of new stations for the NH and SH caused an upward bias in reported temperature trends between HadCRUT4 to HadCRUT3. The bias is also caused by the fact that existing Antarctic stations are reporting colder temperatures as the NH is warming faster than the SH, because the NH has 41 percent land coverage compared to the SH 19 percent land coverage. However, the Hadley Centre has decided to discontinue the HadCRUT3 database and to only maintain the HadCRUT4 database for the future. Therefore, for conservatism and continued monitoring of our climate sensitivity calculations, we selected the HadCRUT4 database as the best available data from which to extract upper bounds for TCS_{TRF}, TCS_{GHG} and TCS_{CO2}.

The tabulated data for atmospheric CO2 levels over the 1850-2012 period, as plotted in Figure 3.1, together with the HadCRUT4 GATA database temperature variation, provide the primary physical data required to assess long-term GATA sensitivity to atmospheric CO2 and other GHG concentration levels. Other important data are the total rise of other GHG levels in the atmosphere and solar irradiance changes that can affect GAST and GATA over long periods. These additional data are presented and discussed in Section 4.4.

4.2 Determining Total Radiative Forcing (TRF) TCS from Best Available Data

The total TCS value for all GHG radiative forcing can be determined by correlating the yearly average temperature changes due to atmospheric CO2 changes, as well as effects other than CO2, such as other GHG, solar irradiance, atmospheric aerosols, and quasi-periodic oscillations

in global average temperatures believed to be related to ocean currents. Such an attempt has previously been accomplished by Ring et. al. (2012) [30]. They used a simplified climate model and singular spectrum analysis of the temperature data, to obtain a Long-Lived GHG (LLGHG) ECS value of 1.6^{o} C from the HadCRUT4 temperature database over the period 1850-2010. Surprisingly, they determined an even lower LLGHG ECS value of 1.45^{o} C for the GISTEMP database over the 1880-2010 period. Even though, as we have discussed above, the GISTEMP database has a higher temperature rise than HadCRUT4 over the 1880 – 2012 time period, other varying factors over the entire analysis period of each database, such as volcanoes, aerosols, quasi-periodic oscillations in global temperatures, and solar irradiance were also considered in extracting the ECS values.

One conclusion from the Ring et. al. (2012) study is that effects of volcanoes, aerosols, Quasi-Periodic Oscillations and other short term effects tend to cancel out over long data records such as HadCRUT4 and GISTEMP. This supports our general preference for longer data records for determination of climate sensitivity. It also allows us to use a simple, easy-to-understand, curve fitting approach to determine an upper bound for GHG effects on our climate since the beginning of the industrial age.

The oscillatory and long-term GATA rise trend behavior of the HadCRUT4 data can be observed in the plot of Figure 4.2. Our independent observations of these data trends suggested four primary factors could account for the observed behavior:

1. A long period naturally occurring climate cycle of approximately 1000 years that would be consistent with the Roman Warm Period (RWP) of about 100 AD, the Medieval Warm Period (MWP) of about 1100 AD and the Little Ice Age (LIA) that had a temperature minimum about 500 years later in 1600 AD. If we were still experiencing the effects of such a climate cycle, then global average temperatures would have been rising in this cycle since about 1600 AD and would be peaking out in 2100 AD.

2. A shorter term climate cycle with period of 62 years and amplitude of +/- 0.15^{o} C.

3. CO2 and other GHG increases in the atmosphere

4. TSI changes over the data record time period

Ljungqvist [31] published the temperature reconstruction shown in Figure 4.2 from proxy data as accurate thermometers were not used until the early 1700's. This plot shows a cyclical variation in Northern Hemisphere (NH) temperatures with peaks centered on about 100 AD, 1000 AD and a minimum at 1650 that provides the motivation for considering an approximate 1000 year sinusoidal climate cycle.

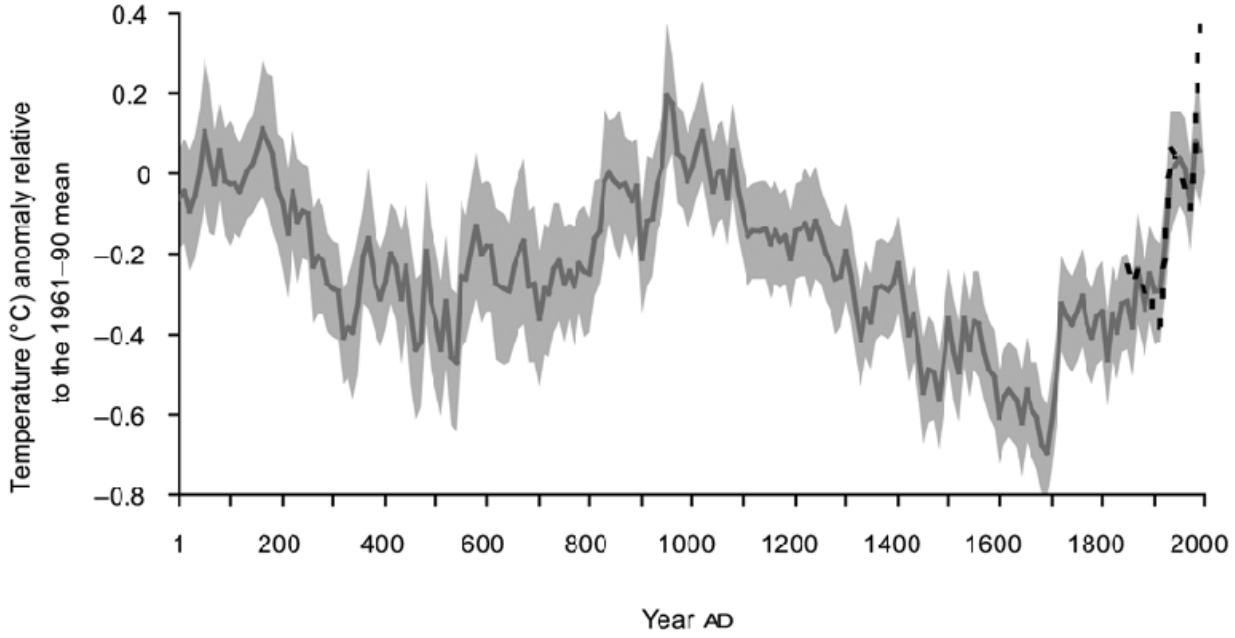

Figure 4.2 Ljungqvist Temperature Reconstruction for the Northern Hemisphere

Lohle [32, 33] performed some of the earlier temperature reconstructions going back as far as the RWP that are well-known in climate research literature. He commented on the later Ljungqvist paper and plot of Figure 4.2 in a guest article at the popular climate online forum at Watt's Up With That. http://wattsupwiththat.com/2010/09/28/loehle-vindication/ He basically agreed that the Ljungqvist reconstruction using different data was a valid confirmation and improvement over of his earlier work in this area, so we provide the more recent Ljungqvist plot here. Since Lohle's earlier reconstructions indicated the MWP was warmer than the current climate, this became a hotly debated issue with those scientists who were convinced the current climate was warmer than at least the MWP and perhaps even the RWP because of human activity. But, all three of these temperature reconstructions reveal a cyclical pattern of NH temperatures that would suggest a natural temperature variation modeled by eq. (1).

$$\text{Delta } T = A_L \text{Sin}[2\pi(\text{Year}-1850)/P_L] \quad (1)$$

Although many climate scientists including those who contribute to IPCC reports, claim that most of the warming since 1850 is due to human activity, similar changes in earth surface temperature occurred over the 0 – 1850 time period during a time when atmospheric GHG levels were almost constant at pre-industrial levels. Therefore, there is evidence for existence of a natural climate cycle with about an 800-1000 year period that was affecting global temperatures before CO2 began to rise in the atmosphere, and that could also be affecting recently observed global temperature changes since 1850. The function with P_L = 1000 years would produce a

natural climate cycle warming trend since 1600 that would peak out in 2100. Such a climate cycle could be directly due to solar irradiance changes and internal climate system feedback to such changes. If the earth climate has a natural tendancy to oscillate with a period of about 1000 years due to, for example, the slow response of ocean dynamics, any small amplitude variation in TSI with that 1000 year period could amplify earth climate responses at that period over multiple cycles and could cause earth surface temperature changes much larger than could be computed by static considerations of those small TSI changes. The ability for small amplitude sinusoidal forcing functions to excite a dynamic system to large amplitude responses, when the frequency of the excitation is at or near the frequency of a natural mode of vibration of the system, is well known. This aspect of climate science needs more attention.

A curve fitting exercise was performed to see how well one or more of these factors in combination could fit the observed HadCRUT4 temperature data. To curve the data for possible effects of a long term climate cycle of period, P_L years, and amplitude A_L ^oC, eq. (1) was used. With a cycle period of P_L = 1000 years, this function would have temperature maximums in 100 AD at the time of the RWP and in 1100 AD at the time of the MWP; and would also have a temperature minimum in 1600 AD at the time of the LIA. Earth surface temperature variations dating back to the RWP require temperature reconstructions from proxy data that are not as accurate as thermometers used since the early 1700's.

Since the HadCRUT4 data in Figure 4.3 clearly exhibited a shorter term oscillatory behavior, a function similar to eq. (3) but using short period amplitude, A_S, and short period, P_S, was used to fit this aspect of the data:

$$\text{Delta T} = A_S \text{Sin}[2\pi(\text{Year}-1988)/P_S] \quad (2)$$

The year in which this short period cycle has a zero value could also be adjusted in an attempt to improve the data fit, but the year 1988, together with P_S = 62 years, and $A_S = 0.15^o$ C was found to be "good enough".

To curve fit the CO2 rise effects, a logarithmic function suggested by Arrhenius [34] in the first publication to predict an atmospheric GHG warming effect, was modified to explicitly include the TCS value:

$$\text{Delta T} = \text{TCS}\{\text{Log}[\text{CO2 Level(year)}/284.7]/\text{Log}[2]\} \quad (3)$$

The values for [CO2 Level(year)] in eq. (3), were taken from the merged NOAA Law Dome ice core and Mauna Loa data for the 1850 – 2012 values plotted in Figure 3.1. The value of 284.7 appears in eq. (3) because that is the value for the atmospheric CO2 concentration in 1850 extracted from the data in Figure 3.1. The logarithmic functional relationship between earth

surface temperature changes and CO2 concentration level changes has been widely accepted in the climate science literature, as reviewed in the IPCC reports and derived in Appendix A.

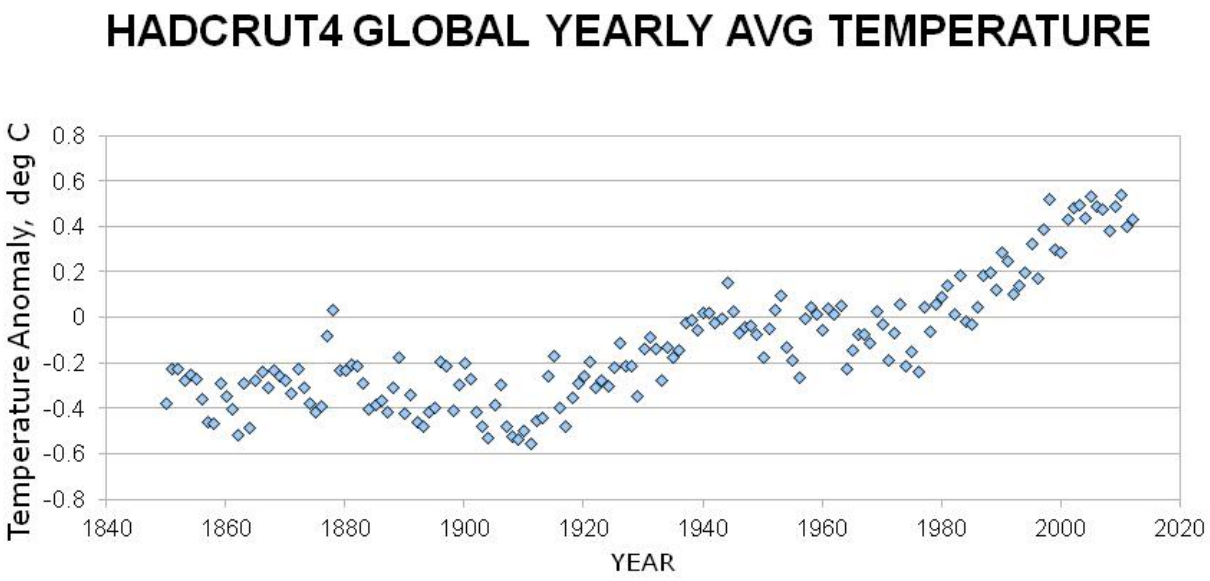

Figure 4.3 HadCRUT4 Global Yearly Average Temperature Anomaly

In some cases presented herein, the extrapolated estimates of the data plotted in Figure 3.1, are used in to bound forecast expected HadCRUT4 GATA behavior for the remainder of this century, assuming constant TSI through 2100. In the 30 years between 1850 and 1880, when atmospheric CO2 levels ranged from 284.7 to 290.7 ppm, the temperature change function of eq. (3) has a very small insignificant value since

$$\text{Delta T} = \text{TCS}\{\text{Log}[290.7/284.7]/\text{Log}[2]\} = 0.03(\text{TCS})$$

In the year the atmospheric CO2 level reaches the doubled value of 560 ppm from the pre-industrial level of 280 ppm (estimated to be the year 2080 in Figure 3.1), the function has a value of:

$$\text{Delta T} = \text{TCS} \qquad (4)$$

The value of TCS that fits the long term temperature rise in the HadCRUT4 data set will be due to effects of all GHG and long-term TSI variations over the data analysis period and will be defined as TRF TCS, or TCS_{TRF}. Note that a data set long enough for CO2 concentration to double in the atmosphere is not required to extract TCS_{TRF} from the data by this process. It is only required that the TCS value fit the long term temperature rise trends in the best available data from 1850 to present. However, a long period of time where GHG levels and HadCRUT4 GATA change by significant percentages, allows for a more accurate determination of TCS.

The logarithmic form of eq. (3) results from the fact that according to AGW Theory, as GHG levels are increased in the atmosphere, some Tyndall gas IR energy absorption bands become partially or completely saturated, and higher levels of atmospheric GHG will not cause as much additional total IR absorption and warming, allowing the IR emitted from the earth in those saturated absorption band frequencies to escape from the climate system directly to deep space. The logarithmic function models this aspect of the AGW Theory where, for example, the first 10 percent of GHG rise in the atmosphere produces more IR absorption and more warming than the next equal amount of GHG level rise, etc., until the full doubled GHG level is attained. Because of the ratios of logarithms used in eq. (3), a logarithm of any consistent base value can be used. For example the natural logarithm function will provide the same results when used consistently in eq. (3).

The combined curve fitting function utilizing the primary three components from equations (1), (2) and (3) is therefore:

$$\text{HadCRUT4(Year)} = (1850\ \text{value}) + A_L \text{Sin}[2\pi(\text{Year}-1850)/P_L] + A_S \text{Sin}[2\pi(\text{Year}-1988)/P_S]$$

$$+ TCS_{TRF}\{\text{Log}[\text{CO2 Level(year)}/284.7]/\text{Log}[2]\} \qquad (5)$$

Since the components of eq. (5) modeling the long period climate cycle and GHG effects are both increasing after 1850, when the HadCRUT4 thermometer data record starts, any attribution of the observed global warming to the long term climate cycle would reduce the TCS_{TRF} value in eq. (5) used to fit the data. If zero effects from the proposed natural long period climate cycle are assumed ($A_L = 0$), one can obtain an upper bound estimate for the TCS_{TRF} value that best fits the long term temperature rise in available data. This will be demonstrated in the remainder of Section 4.2 and in Sections 4.3 and 4.4. This TCS_{TRF} captures the long term radiative forcing effects and climate feedback responses through any year of interest. The primary long-term radiative forcing effects are from GHG and TSI effects from 1850 – 2012, and will be examined in Section 4.4

CASE 1: GHG EFFECTS + 62 Year Cycle Only, $A_L = 0$

In the Case 1 fit of the HadCRUT4 data shown in Figure 4.4, the effects of a possible long period climate cycle were ignored and only the short period and GHG and TSI effects were considered. The solid red and green curves of Figure 4.3 were created by eq. (5) with $A_L = 0$ and using different constants for the initial HadCRUT4 temperature value near 1850 that would form approximately upper and lower bounds of the data over the entire 163 years from 1850 - 2012. The excellent data fit was obtained with a short term natural climate cycle with amplitude As = 0.15 ^oC and period $P_S = 62$ years, and with the zero value of this sine wave occurring at the year 1988. A $TCS_{TRF} = 1.5\ ^oC$ value provided the best fit to the long term temperature rise due to the rising CO2 level of Figure 3.1.

The solid green curve is exactly the solid red curve with a constant 0.4^{o} C lower starting value. This 0.4^{o} C difference in the solid red and green curves indicates the very short term data scatter in the HadCRUT4 GATA data, assumed to be caused by short term events such as volcanoes, atmospheric aerosols, TSI variation due to sunspot cycles, or El Nino and La Nina short period climate events, and are independent of the long term climate sensitivity to GHG. Only a few data points violate these upper and lower bounding curves that tightly follow the HadCRUT4 GATA trends. The solid red curve minus 0.2^{o} C would clearly provide an excellent fit to the centerline of the HadCRUT4 data over the entire 163 year period and would have the same TCS_{TRF} value of 1.5^{o} C. Note that this data fit interpretation of the HadCRUT4 GATA predicts and offers an explanation for the current "pause" in global warming. This data fit suggests the cooling effects of the 62 year cycle are offsetting the temperature rise from GHG effects.

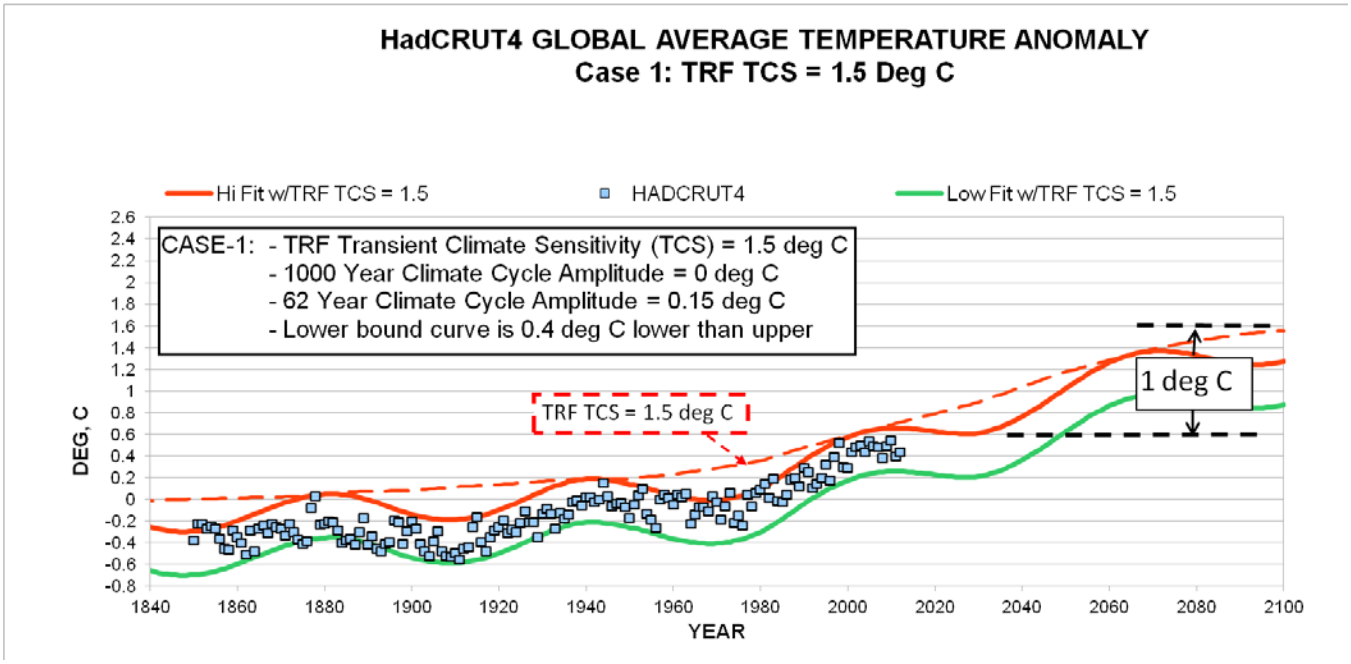

Figure 4.4 Case 1 HadCRUT4 Data Curve Fit, TCS_{TRF} = 1.5^{o} C

More sophisticated least squared error fits could be used to determine the "best fit" constants in eq. (5), but in the interest of simplicity and easier comprehension by the general public, these "eyeball" fits are clearly "good enough" and will not differ significantly from curve fitting results using more sophisticated mathematical methods.

Several other features incorporated into Figure 4.4 should be discussed. The dashed red line uses only the CO2 effects component of eq. (5) which has a zero value in 1850. The TCS_{TRF} value was selected so that this function fits the three major peaks of the solid red curve that provides the upper bound of the HadCRUT4 data. If the effects of the natural 62 year cycle are not

recognized in this type of data analysis, and arbitrary time periods are used to extract the TCS_{TRF} value, considerable error will accrue. A minimum least squared error fit using equation (5) should produce very similar values for all constants used in the fit.

The red and green solid curves of Figure 4.4 were extended to 2100 AD using the extrapolated CO2 concentration values of Figure 3.1. This "persistence" forecast for the 62 year cycle and 1.5^{o} C TCS_{TRF} value indicate the HadCRUT4 GATA will not rise more than 1^{o} C from the present to 2100. This forecast, that includes effects of the 62 year cycle, also predicts the current pause in global warming, and indicates there should be another period of rapid warming in the 2035 to 2065 time period before another pause in global warming will occur from 2070 – 2100.

After we had developed this method of bounding the HadCRUT4 data to extract climate sensitivity, and had given several public forum briefings on the method over an 8 month period, a brief guest article by an anonymous person, "Jeff L.", was posted at the popular climate website: Watts Up With That (WUWT), that demonstrated a very similar, but completely independent approach for extracting climate sensitivity from the HadCRUT4 dataset.

http://wattsupwiththat.com/2014/02/13/assessment-of-equilibrium-climate-sensitivity-and-catastrophic-global-warming-potential-based-on-the-historical-data-record/

Jeff L did not consider effects of the 62 natural climate cycle, but assumed all long temperature rise in the data was due to GHG effects. He fit all of the data points in Figures 4.3 and 4.4 using eq. (3) with TCS replaced with a variable he suggested was ECS. He used different values of his ECS variable to compute the sum of the squared error between eq. (3) and each temperature data point in the entire dataset. An ECS value of 1.8^{o} C provided the minimum squared error fit and was selected as the best value that fit the entire dataset. Jeff L received many comments from WUWT readers that an ECS value would be much larger and that the variable he extracted was closer in value to the IPCC TCR metric. We also posted a long comment on his excellent article at WUWT that are now part of the public record, using insight we had gained from preparing this report. In particular, we suggested the climate sensitivity variable of 1.8^{o} C he extracted was not ECS, but was the metric we have defined in this report as TCS_{TRF}, and that can be used to determine TCS_{GHG} or TCS_{CO2} by correcting for TSI effects as demonstrated in Section 4.4.

We alerted the WUWT website moderator, Anthony Watts, to the similarity of Jeff L.'s approach and our own approach detailed here. Through the assistance of Mr. Watts, Jeff L. contacted our research team, explained his preference to remain anonymous, and we have continued to exchange ideas about this approach for defining climate sensitivity exclusively from data without the use of climate models. We provided Jeff L with a review draft of this report to provide him with a rigorous derivation of the TCS_{TRF} metric we believe he extracted, and to explain the differences between his results and the TCS_{TRF} value of 1.5^{o} C that also fits the data of Figure

4.4. We have also had email discussions with Jeff L regarding finer points and interpretations what is actually extracted with this data analysis approach.

We liked the way Jeff L. blended the results of the Law Dome and Mauna Loa datasets of atmospheric CO2 concentration for his analysis, and adopted his recommendations for using this dataset in the results presented in this final version of our report. Previously, we had used a less well-documented dataset for atmospheric CO2 concentration prior to the start of the Mauna Loa data record in 1959. That dataset provided a constant CO2 concentration of 280 ppm from 1850-1880. Changing to Jeff L's recommended data set for the CO2 history caused our extracted TCS_{TRF} climate sensitivity value to increase by about 0.1^{o} C from previous values extracted. This resulted from the 4.4 percent smaller change in atmospheric CO2 levels over the 1850-2010 time period in the new data set. The differences between the TCS_{TRF} value of 1.5^{o} C in Fgure 4.4 and the 1.8^{o} C value reported by Jeff L are related to our different data fit approaches, primarily to data in the 1850-1880 time period. We had recognized that a higher, more conservative value of TCS_{TRF} could be extracted if one did not try to bound the extraneous HadCRUT4 data points near 1875 and had previously developed Figure 4.6 of Section 4.3 to demonstrate this point. Figure 4.6 is very similar to a Figure Jeff L presented in his article that showed how eq. (3) fit the data with different values of his ECS variable. Interestingly, our conservative upper bound of 1.8^{o} C for TCS_{TRF} extracted from Figure 4.6, exactly matches the 1.8^{o} C value reported by Jeff L for his minimum squared error extraction method.

CASE 2 – 1000 Year Climate Cycle + 62 Year Cycle + Reduced GHG Effects

In Case 2, we investigate how well one could fit the HadCRUT4 data with a lower TCS value, while attributing some of the temperature rise to a continued warming from the LIA due to a natural climate cycle of about 1000 year period. In this case, a +/- 0.4^{o} C amplitude, 1000 year natural climate cycle with the last minimum centered on the LIA in 1600 AD was assumed, and a TCS_{TRF} value of 0.8 deg C provided a good fit of the data. The same 62 year natural climate cycle was assumed as used in Case 1. The data fit of Figure 4.5 was judged by "eyeball" evaluation to be almost as good as the Case 1 fit, even better than Case 1 if data only after 1880 is considered.

There is a reasonable question as to how accurate the earliest HadCRUT4 data in the 1850-1880 period can be, especially since the NASA GISTEMP and other popular databases do not include it. Moreover, since CO2 did not start a significant rise in the atmosphere until after 1880, a temperature record that started in 1880 and with better accuracy, would be highly desirable for TCS extraction.

Comparison of the data fits in Figures 4.4 and 4.5 demonstrates how difficult it is to confidently separate the natural and human-caused global warming effects since 1850. A TCS_{TRF} value in the range of 0.8 to 1.5° C is about as close as one can narrow its true range with this type of data analysis, if the possibility is considered that the earth is still continuing to experience warming effects of a long term natural cycle. That same natural cycle could explain the RWP, MWP and LIA and would have provided the natural warming from the minimum temperatures of the LIA before 1850 as shown in Figure 4.2, before CO2 concentration in the atmosphere began any significant rise. The Case 2 scenario also predicts the current pause in global warming and a return to warming trend after 2030. If we project from current conditions to 2100 with the Case 2 scenario, only 0.4° C temperature rise through 2100 occurs. This is because TCS_{TRF} is only 0.8° C and the 1000 year cycle temperature rise from now until 2100 is only 0.06° C. The Case 2 scenario would forecast a 500 year cooling trend starting after about 2110 as CO2 levels in the atmosphere max out with consumption of all remaining fossil fuels by 2130, and the 1000 year cycle will enter a cooling phase after 2100.

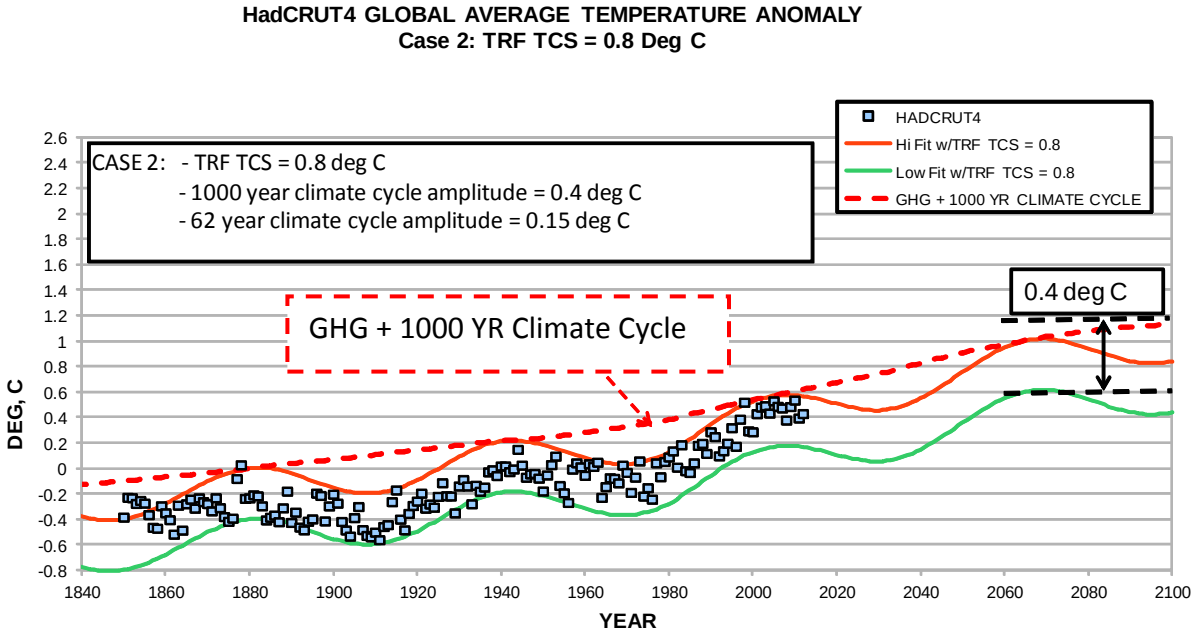

Figure 4.5 HadCRUT4 Data Fit with TCS_{TRF} = 0.8° C and 1000 Year Climate Cycle

An additional case was investigated where TCS_{TRF} was assumed to be zero and all of the long-term warming in the HadCRUT4 data base was attributed to the 1000 year natural climate cycle with amplitude of 1.0° C. While this assumption provided a reasonable fit to the data, it was clearly not as good as the eq. (5) functional fits of Figures 4.4 and 4.5. Therefore, with some issues regarding TSI variations over the data analysis period still to be evaluated, we concluded that the HadCRUT4 GATA data suggests some GHG warming is occurring, but at much lower

levels than previously estimated in much of the research literature and with much less climate sensitivity uncertainty provided by these data fits.

When models vary as much from one another and vary as much from actual climate data as shown in Figure 1.1, all model predictions of ECS and TCR are no better than speculation and should be disregarded in favor of climate sensitivity determined from data-only, as demonstrated here. This certainly must be the rule for determining climate sensitivity for any regulatory activity that can have severe negative consequences for American citizens.

4.3 Establishing an Upper Bound for Total Radiative Forcing (TRF) TCS, TCS_{TRF}

While a TCS_{TRF} value of 1.5^{o} C provides an excellent fit to the HadCRUT4 data for the conservative case of no long term climate cycles effects, as discussed in Section 4.2 and Figure 4.4, other possible fits to the data can provide a more conservative estimate for TCS_{TRF} in search for a confident upper bound value for transient climate sensitivity. To simplify the data bounding curve fits, we used only the eq. (3) component of eq. (5) to determine a bounding fit to the HadCRUT4 GATA in Figure 4.6

We note that the HadCRUT4 data include effects of the TRF of all GHG and TSI. That is, the resulting temperatures are higher vs. time than they would have been due to CO2 or all-GHG radiative forcing alone because there was an overall increase in TSI between 1850 and 2012. As was decided for the data fits of Figures 4.4 and 4.5, we determined TCS_{TRF} in Figure 4.6 assuming the radiative forcing of the CO2-only data in Figure 3.1, similar to the way IPCC defines ECS, and then after the extraction of TCS_{TRF}, to correct that value for both other GHG and TSI effects. Equations are developed in Appendix A and used in Section 4.4 to derive the TCS_{TRF} correction procedure to obtain TCS_{GHG} or TCS_{CO2}.

The conservative TCS_{TRF} bounding function approach using eq. (3) only, and with a HadCRUT4 GATA initial value of -0.2^{o} C, is demonstrated in Figure 4.6 where the two “out of family” high values of HadCRUT4 data near 1875 are ignored.

With the family of data bounding curve fit functions in Figure 4.6, we attempted to envelope all but a few extraneous data points in the HadCRUT4 GATA to be most conservative with the TCS_{TRF} value extracted from the data, so that we could defend the value extracted as an upper bound value. The bounding curve fits of the HadCRUT4 data are shown for TCS_{TRF} values of 1.4, 1.6, 1.8, 2.0 and 2.5^{o} C. In this case, a lower initial bounding value of -0.2^{o} C in the 1850-1880 time period is used for the HadCRUT4 GATA that envelope the bulk, but not all of the data. This data fit provides a 0.2^{o} C larger temperature rise from 1850-2005 due only to GHG effects than the Figure 4.4 data fit with $TCS_{TRF} = 1.5^{o}$ C, and produces a higher, more

conservative, climate sensitivity value. Note that in this more conservative treatment of the HadCRUT4 data, that a curve with a TCS_{TRF} = 1.5° C, would not bound all of the recent data. (The TCS_{TRF} curve for 1.5° C needs to be interpolated between the curves given for 1.4 and 1.6° C.) However, the curve for TCS_{TRF} = 1.8° C does bound these data except for the few extraneous data points near 1875, 1945, 1955 and 1998. The TCS_{TRF} = 1.8° C curve was selected to be a conservative upper bound for GHG effects. The extraneous data points that are not fitted were assumed to be caused by natural variations as the recent 1998 data point was known to have been caused by an extremely large El Nino event that year. Further research may uncover explanations for the other few extraneous data points. Using interpolation, a TCS_{TRF} = 1.7° C value was chosen as a least upper bound. The TCS_{TRF} = 1.7° C curve would pass right through the high temperature data points of 2002, 2003 and 2005 and would clearly bound HadCRUT4 GATA since 2005. Bounding the data points near 1875 would provide a lower estimate for TCS and bounding the more recent data points provides a higher estimate for TCS.

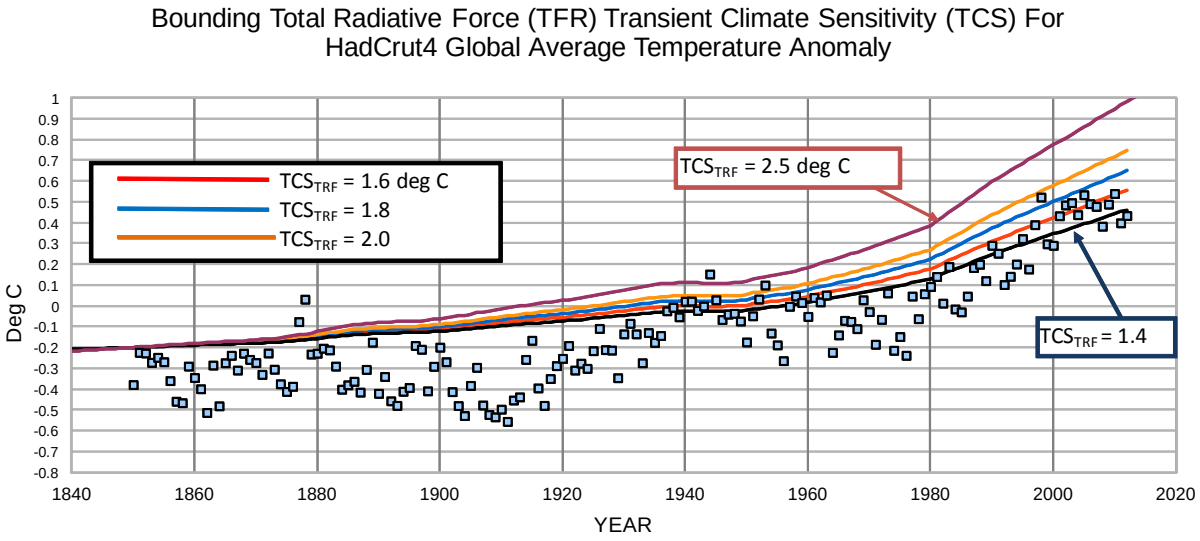

Figure 4.6 Determining an Upper Bound for Transient Climate Sensitivity, TCS_{TRF}

Zooming in on Figure 4.6 in the 1980-2012 region of the plot will allow a closer examination of the curve fits to the data in that critical area of the plot. The Figure 4.6 bounding curves with TCS_{TRF} values of 2.0 and 2.5° C diverge higher from the HadCRUT4 data with increasing time and clearly are not as good a fit to the data as curves with TCS_{TRF} values of 1.7 or 1.8° C. For the remainder of this report we shall use the terminology:

Conservative HadCRUT4 Data Upper Bound for TCS_{TRF} = 1.8° C

HadCRUT4 Data Least Upper Bound for TCS_{TRF} = 1.7° C

4.4 Correcting TCS_{TRF} to TCS_{GHG} Due to TSI Variation

Total Solar Irradiance (TSI) increased over the 1850-2012 time period and caused a higher value of TCS_{TRF} to be extracted from the HadCRUT4 data compared to a situation where TSI remains constant. In this section we develop a method to correct TCS_{TRF} to TCS_{GHG} or TCS_{CO2} metrics for the TSI variation by accounting for the TSI radiative force change over the entire 1850-2010 time period.

An historical reconstruction of TSI dating back to 1610 AD was performed by Kopp [35] as shown in Figure 4.7. The high frequency oscillations in TSI shown in Figure 4.7 are attributed to the 11 year sunspot cycle. Eyeballing the long term trend from the late 1800's until 2010, as indicated by the black straight lines on Figure 4.7, a TSI increase of 0.65 W/m^2 was estimated for the 1850-2010 time period. This TSI change was also confirmed in a recent paper by Steinhilber and Beer [36] that presented Figure 4.8 with an historical reconstruction of TSI dating back to 1650 and a forecast through 2500. Their forecast was based on multi-period oscillations they identified in the past data and that they expect will persist into the near future. This persistence forecast is similar to the reasoning used to forecast behavior for the HadCRUT4 temperature anomaly through 2100 for the 62 year cycle indicated in Figures 4.4 and 4.5.

Although the logarithmic scale of TSI variation on the right hand side of Figure 4.8 is a bit difficult to read accurately, there was approximately 0.6 W/m^2 TSI increase from the late 1800's (point G in Figure 4.8) until the peak about 2000, confirming the 0.65 value extracted from Figure 4.7. The forecasted trend for TSI is decreasing from the peak measured in about 2000 to present. Note that the forecasted behavior for TSI in Figure 4.8 is consistent with the observed warming "pause" in the HadCRUT4 data since 1998. Not only the 62 year climate cycle is forecasting a current pause in global warming as indicated in Figures 4.4 and 4.5, but predicted near-term solar irradiance decreases by Steinhilber and Beer also help support this forecast.

The sunspot cycle effects make it difficult to determine the long term trend TSI variation in the 2000-2010 range of Figure 3.7. If we consider the forecasted TSI decrease through 2005 in Figure 4.7, the HadCRUT4 year data point that the bounding curves in Figure 4.5 must satisfy, there is only a TSI increase of about 0.45 W/m^2 over the period from the minimum at point G through 2005. For conservatism in our bounding calculations we round this down to 0.4 W/m^2 and confirm this conservative value with the data in Figure 4.7 through 2005. We account for all of the long-term radiative forcing increases affecting the HadCRUT4 data from 1850 - 2010 as follows:

TSI radiative forcing (ΔRF_{TSI}) = + 0.4 W/m^2 TSI changes from about 1880 through 2005

GHG radiative forcing (ΔRF_{GHG}) = + 2.62 W/m^2 Value taken from Ring et. al. (2012) Table 1.

CO2 radiative forcing (ΔRF_{CO2}) = +1.8 W/m^2 Calculated from {Log[391/280]/Log[2]}(3.71) =1.79

Total Radiative Forcing (ΔTRF) = ΔRF_{TSI} + ΔRF_{GHG} = 3.0 W/m^2

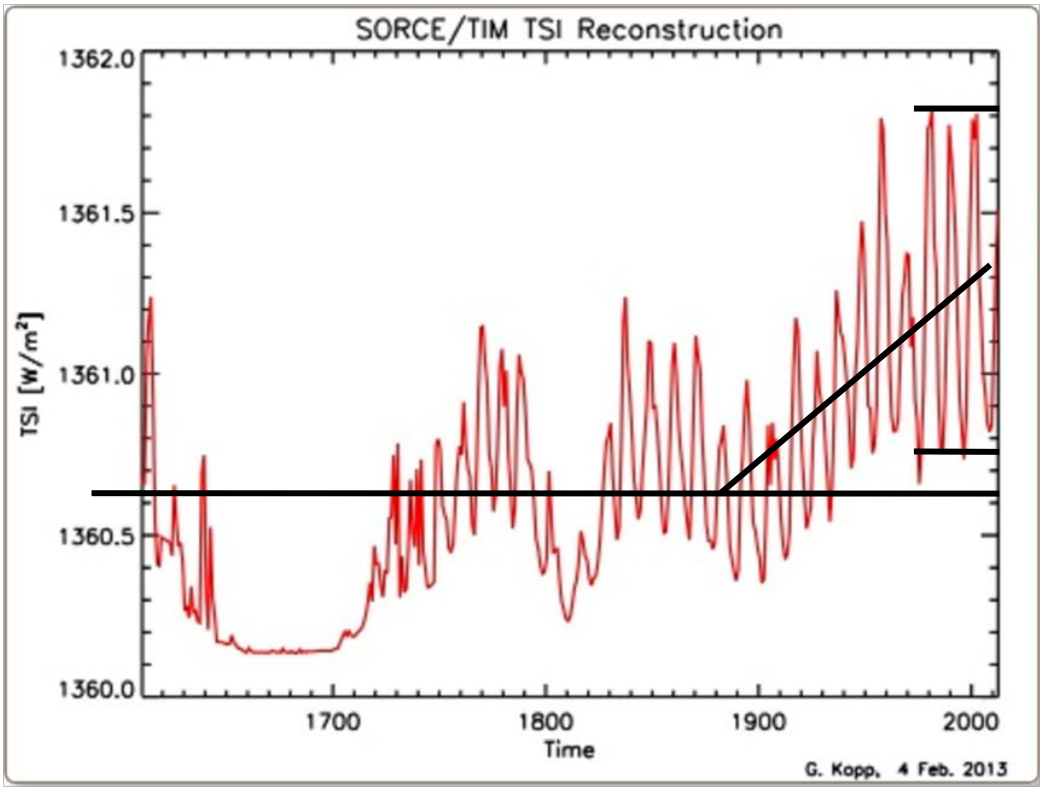

Figure 4.7 Historical Reconstruction of TSI by Kopp – (1610 – 2010)

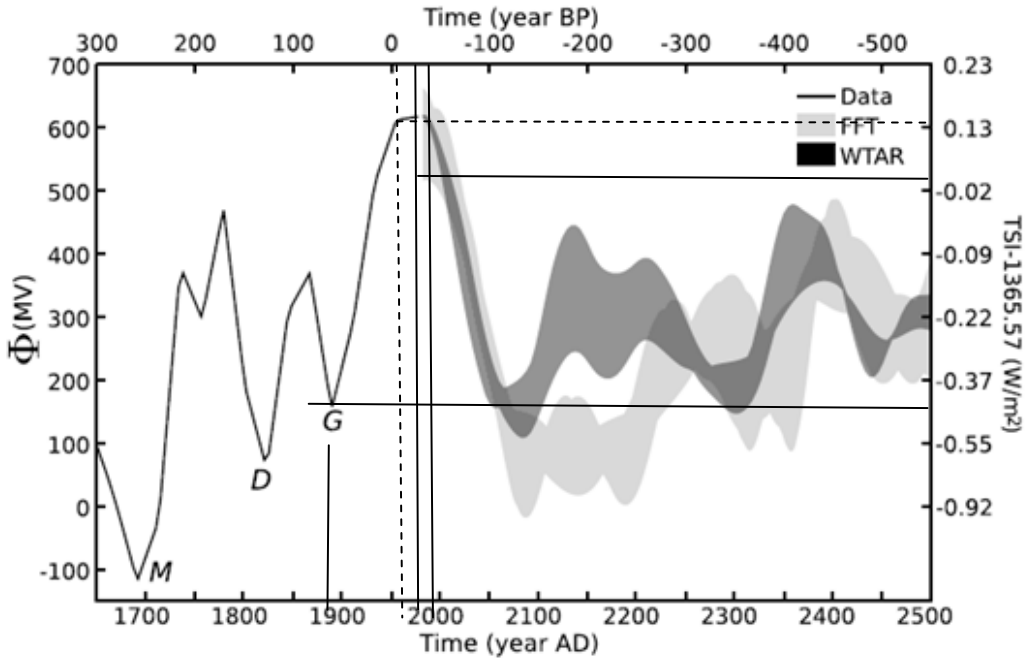

Figure 4.8 Total Solar Irradiance (TSI) Variation: 1650 - Present and Beyond

Using arguments and derivations presented in Appendix A, we can treat the total radiative force at the quasi-steady equilibrium point of each year as a constant force that can be separated into its component parts to determine the contribution of each component to the total TCS_{TRF}. This allows us to compute different TCS values for each component. For example,

Using eq. (A-3) from Appendix A, we can define a constant, λ_{TCS}, that provides a linear relationship for total change of surface temperature due to the change in total radiative forcing,

$$\lambda_{TCS} = (\Delta T_{S\_TRF})/(\Delta TRF) \qquad (6)$$

Using $\Delta TRF = 3.0$ W/m^2 for 2010 from above, and a conservative estimate of ΔT_S from the bounding curves of Figure 4.6, we can compute a conservative value for the λ_{TCS} that is not corrupted by warming and cooling effects of the 62 year climate cycle. The solid blue line for $TCS_{TRF} = 1.8^o$ C in Figure 4.6 envelopes all of the HadCRUT4 data after 1998 and predicts a GATA of 0.62^o C in 2010 vs. the actual measured value of 0.54^o C. Only data points through 2012 are plotted in Figure 4.6 so the data point for 2010 can be determined by counting backwards from 2012. Therefore,

$$\lambda_{TCS} = (\Delta_{TS\_TRF}\ ^oC)/(\Delta TRF\ W/m^2) = (0.62 - (-0.2)\ ^oC)/(3.0\ W/m^2) = 0.27^o\ C/(W/m^2)$$

If we used the least upper bound value of $TCS_{TRF} = 1.7^o$ C in Figure 4.6 to obtain a conservative 2010 HadCRUT4 temp of 0.58^o C, in lieu of the measured value of 0.54^o C, the calculation for λ_{TCS} would be:

$$\lambda_{TCS} = (\Delta_{TS\_TRF}\ ^oC)/(\Delta TRF\ W/m^2) = (0.58 - (-0.2))/(3.0\ W/m^2) = 0.26^o\ C/(W/m^2)$$

Therefore, there is not a significant difference for λ_{TCS} computed with either bounding value of TCS_{TRF}.

The ΔRF_{CO2} during the 1850 – 2010 period for which the Ring et. al, total LLGHG ΔRF value of 2.62 W/m2 was provided was,

$$\Delta RF_{CO2} = 3.71\{Log[CO2(2010)/CO2_{REF}]/Log[2]\}\ W/m^2$$

$$= 3.71\{Log[391/284.7]/Log[2]\} = 1.7\ W/m^2 \quad (7)$$

In this case ,

$$\Delta RF_{CO2}/\ \Delta RF_{GHG} = (1.7)/(2.62) = 0.649$$

Thus, the radiative force of all GHG is (2.62)/(1.7) = 1.45, or 45 percent greater than the radiative force of CO2 alone. As we have seen for the IPCC RCP4.5 scenario discussed in Section 3.1, where in 2100, $\Delta RF_{CO2}/\Delta RF_{GHG} = 0.778$ and where (1/0.778) = 1.285, the effects of all GHG considered are only 28.5 percent greater than CO2 alone. Other GHG concentration trends and radiative effects are not as well understood as CO2, and there are some differences in the way different researchers account for projected differences in radiative forcing from CO2 alone and from all GHG. The uncertainty in the ratio of $\Delta RF_{CO2}/\Delta RF_{GHG}$ for the future will introduce some uncertainty to the maximum AGW temperatures we compute for the future. In the future we will examine results for these ratios determined from the Ring et. al.(2012) paper and for the IPCC AR5 RCP4.5 scenario and other RCP scenarios to understand importance of the uncertainty for $\Delta RF_{CO2}/\Delta RF_{GHG}$ in forecasting temperature rise due to GHG. The sources of the various GHGs differ and some are much easier to control than CO2. Therefore projections for radiative forcing from all GHG in the future are less reliable than projections for CO2.

Now we derive expressions for TCS_{GHG} in terms of other known quantities. From eq. (A-4) derived in Appendix A,

$$\Delta T_{S\_GHG}(year) = \lambda_{TCS}(\Delta RF_{GHG}(year)) = TCS_{GHG}\{Log[CO2(year)/284.7]/Log[2]\}$$

$$TCS_{GHG} = \lambda_{TCS}\,(\Delta RF_{GHG}(year))/\{Log[CO2(year)/284.7]/Log[2]\} \quad (8)$$

$$= (0.27)(2.62)/(0.458) = 1.54^o\ C$$

which is a conservative upper bound since we used $\lambda_{TCS} = 0.27$ determined from the conservative upper bound solid blue curve of Figure 4.6.

A least upper bound for $TCS_{GHG} = (0.26)(2.62)/(0.458) = 1.49^{o}$ C (9)

Another useful expression for computing TCS_{GHG} from TCS_{TRF} is obtained from eq. (A-5)

$$TCS_{GHG} = TCS_{TRF} \{[\Delta RF_{GHG}(year)]/[\Delta RF_{TRF}(year)]\} \quad (10)$$

Similarly we can derive expressions for TCS_{CO2} that would be a more accurate metric for analyzing cost and benefits of CO2 regulations than the current IPCC ECS values used by the IWG. By definition, and using Appendix A eq. (A-4),

$$\Delta T_{S\_CO2}(year) = TCS_{CO2}\{Log[CO2(year)/284.7]/Log[2]\} = \lambda_{TCS}[\Delta RF_{CO2}(year)]$$

$$TCS_{CO2} = (\lambda_{TCS}\{Log[CO2(year)/284.7]/Log[2]\}3.71)/\{Log[CO2(year)/284.7]/Log[2]\}$$

$$= 3.71\ (\lambda_{TCS}) = 3.71(0.27) = 1.00^{o}\ C \quad (11)$$

Therefore, this conservative upper bound for transient climate sensitivity of CO2-only is

$$(TCS_{CO2})/(TCS_{GHG}) = 1.0/1.54 = 0.649, \text{ or } 64.9 \text{ percent of the GHG sensitivity}$$

Using eq. (A-5) of Appendix A, another useful expression for TCS_{CO2} in terms of TCS_{TRF} is,

$$TCS_{CO2} = (TCS_{TRF})[(\Delta RF_{CO2})/(\Delta RF_{TRF})] \quad (12)$$

$$= (1.8)[(1.7)/(3.0)] = 1.0^{o}\ C$$

Summarizing these calculations,

<u>Convert TCS_{TRF} values determined in Section 4.3 to TCS_{GHG} Values:</u>

Conservative Upper Bound for $TCS_{GHG} = (TCS_{TRF})[\Delta RF_{GHG}/\Delta RF_{TRF}] = (1.8)[0.87] = 1.6^{o}$ C

Least Upper Bound for $TCS_{GHG} = (TCS_{TRF}) = (1.7)[0.87] = 1.5^{o}$ C

<u>Convert TCS_{GHG} Values to ECS_{GHG} Values Using TCS = TCR and TCR/ECS = 0.56</u>

Conservative Upper Bound for $ECS_{GHG} = TCS_{GHG}/0.56 = (1.6^{o}\ C)/0.56 = 2.86^{o}\ C = 2.9^{o}\ C$

Least Upper Bound for $ECS_{GHG} = TCS_{GHG}/0.56 = (1.5^{o}\ C)/0.56 = 2.7^{o}\ C$

Note: After studying the trends of Figures 1.2 and 1.3 and considering the low values of TCS in the range of 1.0 – 1.6^{o} C that we want to convert to ECS values, only for purposes of comparison with other published results, we concluded the best approach was to use the average ratio of TCR/ECS = 0.56 obtained from Table 1.0 as a conversion factor.

Convert TCS_{TRF} values Determined in Section 4.3 to TCS_{CO2} Values:

$TCS_{CO2} = TCS_{TRF}\ \{[\Delta RF_{CO2}(year)]/\ [\Delta RF_{TRF}(year)]\}$

$TCS_{CO2} = TCS_{TRF}\ \{[\Delta RF_{CO2}(2010)]/\ [\Delta RF_{TRF}(2010)]\} = TCS_{TRF}[(1.7)/(3.0)]$

Conservative upper bound for $TCS_{CO2} = [1.8](1.7/3) = 1.0^{o}$ C

Least upper bound for $TCS_{CO2} = [1.7](1.7/3) = 0.96^{o}$ C

Convert TCS_{CO2} Values to ECS_{CO2} Values Using TCS = TCR and TCR/ECS = 0.56

Conservative Upper Bound for $ECS_{CO2} = 1.0/0.56 = 1.8^{o}$ C

Least Upper Bound for $ECS_{CO2} = 0.96/0.56 = 1.7^{o}$ C

The Conservative Upper Bound for ECS_{GHG} determined from actual physical data with a value of 2.9^{o} C, is below the mid-point of the IPCC ECS uncertainty range of $1.5 < ECS_{GHG} < 4.5^{o}$ C.

4.5 Trends in Lower ECS Estimates from More Recent Peer-Reviewed Climate Research

The determination of lower ECS values in more recently published papers since 2010 has been a consistent trend. The more recent IPCC AR5 Report did not consider papers published in 2010 for review in preparation of their 2013 report. Examples of such decreasing ECS determination trends have been discussed by Idso et. al [37] and Knappenberger and Michaels [38].

Knappenberger and Michaels presented Figure 4.8, graphically demonstrating the recent research literature trends in lower estimated values for ECS and ranges of uncertainty. We modified Figure 4.9 near the bottom to indicate the 2.7^{o} C Least Upper Bound for ECS_{GHG} determined by the data analysis method presented in this report. ECS_{GHG} is the metric being reported in these peer-reviewed papers. The leftward pointing arrow representing our TRCS research team results is not intended to present an uncertainty range for ECS_{GHG}, but only to indicate that ECS_{GHG} is lower than our Least Upper Bound of 2.7^{o} C.

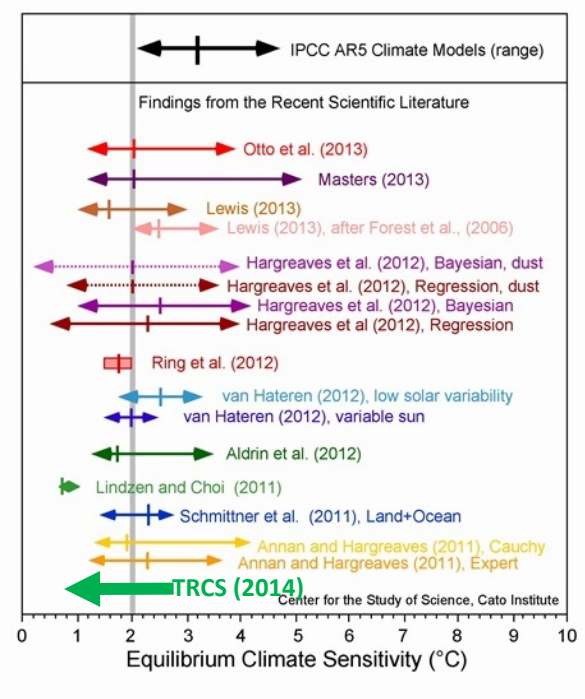

Figure 4.9 Recent Published Trends in ECS Uncertainty Range

There is some confusion in IPCC reports regarding use of the term ECS referenced to a doubling of CO2 levels, when effects of other GHG may be included in the radiative forcing simulation. For example, in the definitions of ECS quoted from the IPCC AR4 and AR5 reports in Table 1.0 on metrics used in this report, the stated definitions of ECS are for a doubling of CO2 concentration in the atmosphere, but this is not always what is modeled in an ECS simulation. Therefore, for clarity we have computed a separate ECS for CO2 effects only and have shown that the Least Upper Bound for the ECS_{CO2} value is only 1.8^{o} C, essentially at the lower limit of the IPCC ECS_{GHG} uncertainty range.

Since separate regulations to control CO2 emissions and other GHG emissions are proposed, the separate TCS values for CO2 and other GHG should be considered for the specific regulation when computing global warming benefits and damages from that particular GHG. For example, a regulation to control CO2 should not be based on ECS values published by the IPCC that involve effects of all GHG, as that will overestimate the computed global warming damage effects of CO2 emissions by ECS_{GHG}/ECS_{CO2} = 2.9/1.8 = 1.61, or 61 percent!

4.6 Recommended Approach to Replace ECS in Social Cost of Carbon Calculations

Bounding of TCS and ECS with available data as presented in Section 4.4 demonstrate why un-validated climate models should not be used to establish ECS values and uncertainty ranges that drive SCC in regulatory activity. Moreover, as discussed in the PURPOSE and Section 2.4, ECS values based on climate feedbacks operating for 1000 years are not well-suited to assess AGW warming in a 100-300 year horizon, the time range considered in SCC calculations. The TCS_{GHG} value defined in Section 4.4 can be used with any reasonable RCP scenario having a slowly changing radiative forcing function, to compute quasi-steady transient equilibrium temperature responses to changing GHG levels in the particular RCP scenario. We recommend this method to conservatively bound the AGW effects over the next 300 years, as atmospheric GHG levels rise to a peak value near the time all fossil fuels on the planet are consumed and will then decline after the transition from depleting fossil fuels to alternative fuels must occur.

The quasi-static equilibrium upper bound temperature for any year in the future due to GHG effects can be computed from eq. (5) with A_L and A_S equal zero.

$$\text{HadCRUT4 Temp Anomaly(Year)} = 0.1 + (TCS_{GHG})\{\text{Log[CO2(year)/284.7]/Log[2]}\} \quad (13)$$

The radiative forcing level due to GHG other than CO2 is incorporated into the TCS_{GHG} value that is greater than the TCS_{CO2} value. This equation only forecasts temperature changes due to GHG effects, assumes solar output remains at the current level, and that GHG levels other than CO2 increase in the same proportions that CO2 levels increase.

A somewhat different and also conservative bounding equation based on the conservative bounding curves of Figure 4.6 and assuming constant solar output from current levels is,

$$\text{HadCRUT4 GATA(year)} = -0.2 + TCS_{TRF}\{\text{Log[CO2(year)/284.7]/Log[2]}\} \quad (14)$$

With TCS_{GHG} determined as demonstrated in this report, equation (13) using various RCP projections, should compute a bounding value for GHG caused temperature rise in the HadCRUT4 temperature anomaly in any given year of the future, and with much better accuracy and less uncertainty than an un-validated climate model.

For example, substituting the following values into eq. (13):

(1850 Temp) = 0.1^{o} C

(TCS_{GHG}) =1.5^{o} C

CO2 data of Figure 3.1 through 2100

computed the red dashed HadCRUT4 bounding curve of Figure 4.4, which is an excellent bounding fit of the HadCRUT4 GATA data over a 163 year period, augmented with projections for the remainder of the century due to AGW from all GHG effects.

The TCS value can be updated each year, if necessary, as more data becomes available to refine the TCS value. Any changes in these TCS metrics before the next forecast peak of the 62 year cycle in about 2070, would need to consider the effects the natural 62 year cycle is having on the HadCRUT4 GATA. Changing TSI levels as forecast in Figure 4.8 can also be used to refine the TCS_{GHG} calculation. Also, the TSI forecasts can be incorporated into the TRF projections of any RCP using eq. (6) to assess the impacts of TSI forecasts on bounding temperature forecasts for HadCRUT4 GATA

To demonstrate how to use eq. (13) to compute a bound on temperatures for any RCP scenario that extends at least 300 years into the future, we extended the range of our RCP5.1 forecast of the CO2 concentration plot of Figure 3.1, to its peak value of 600 ppm in 2130 and its decline to 325 ppm by the year 2300. This extended projection of atmospheric CO2 levels is provided in Figure 4.10 with CO2 concentration values given on the vertical axis at the right side of the plot. Also shown is the dashed red curve for $TCS_{GHG} = 1.5^{o}$ C in eq. (13) that is exactly the same dashed red curve of Figure 4.4, extended to 2300 and following the atmospheric CO2 concentration rise and fall in the atmosphere. This curve forecasts that the HadCRUT4 GATA due to GHG effects can only rise about 1.0^{o} C higher than current temperatures at the atmospheric CO2 peak level in 2130, before it will begin a slow decline.

The solid red curve shows the projected temperature bound for the higher conservative bound of $TCS_{GHG} = 1.6^{o}$ C. It peaks at less than 1.2^{o} C above current temperatures. The alternate conservative bounding equation (14) is plotted on Figure 4.10 as the green dashed line. This is exactly the same extended blue curve of Figure 4.6 with the same conservative TCS value of 1.8^{o} C that even includes some warming effects of increased TSI changes. Because this curve has greater sensitivity to GHG levels, it rises and falls more steeply than the two red curves with lower TCS values. However, since this conservative, but tighter data bounding curve starts with a 0.2^{o} C lower value, it does not peak any higher than the solid red curve with a conservative TCS_{GHG} value of 1.6^{o} C. These are all conservative, but not alarming, forecasts of the maximum possible AGW temperature rise from now until 2300. These conservative bounding curves are based on the best physical data available and are not corrupted by inappropriate ECS estimates from un-validated climate models published in IPCC reports.

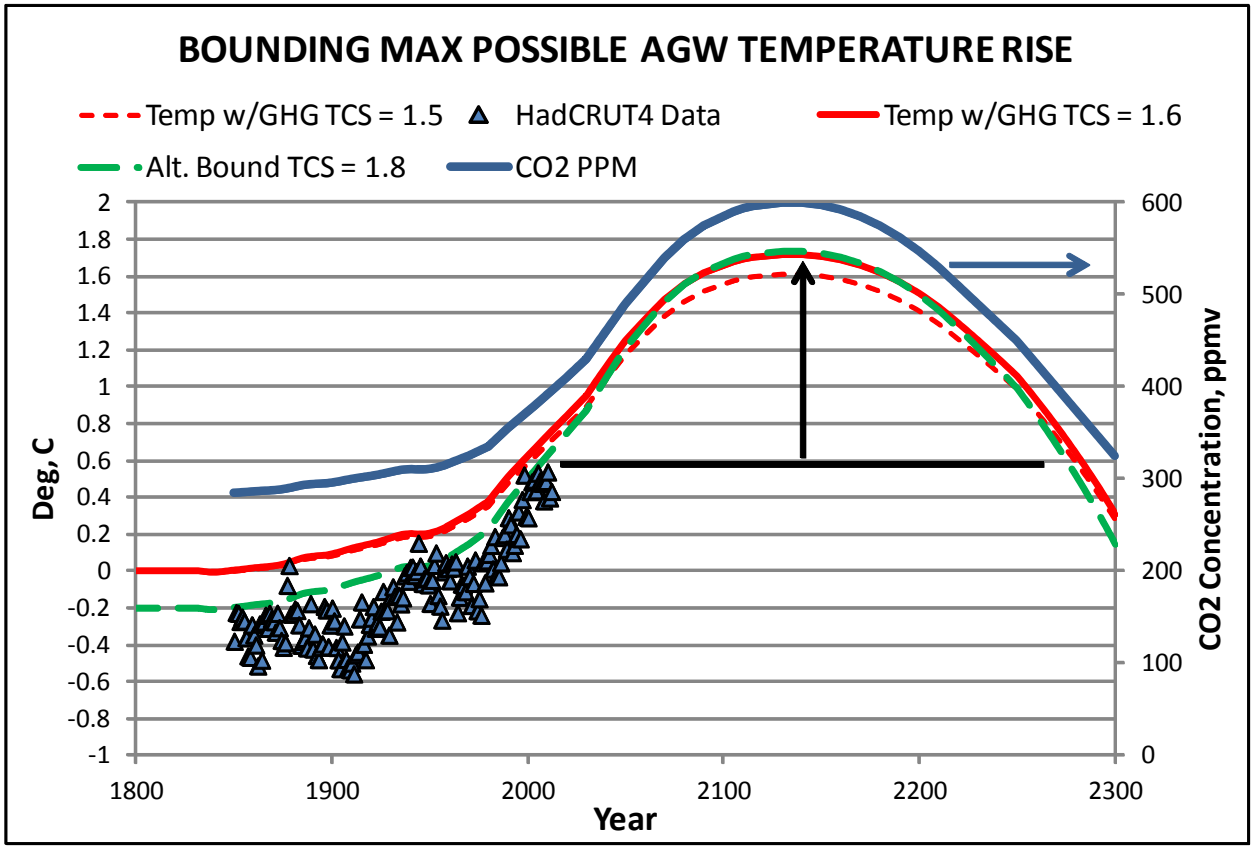

Figure 4.10 Bounding Maximum Possible AGW Temperature Rise

Figure 4.10 projects that peak AGW warming without world-wide GHG emissions control agreements, is not forecast to be significantly more than forecast for the year 2100 in Figure 4.3.

If we incorporate the forecasted drop in TSI of Figure 4.8 into these projections, the TSI level will be approximately 0.4 W/m^2 lower than now in the 2100-2200 time frame when GHG radiative forcing is at its peak. This TSI level is about the same as the 1850 level.

We now demonstrate the use of eq. (6) for making such projections for changes in HadCRUT4 GATA for such changes in TSI. However, for better accuracy with this linear equation we will make all TRF changes with respect to 2010 levels and using GHG and CO2 radiative forcing values for 2010 previously used in Section 4.4.

$$\text{HadCRUT4 GATA (2130) - HadCRUT4 GATA(2010)} = \lambda_{TCS}[\text{TRF(2130)-TRF(2010)}] \qquad (15)$$

$$\text{HadCRUT4 GATA (2130) - 0.6} = (0.27)(\text{TRF(2130)} - 3.0)$$

To determine TRF(2130) values, we use our RCP5.1 scenario when the atmospheric CO2 concentration reaches its peak of 600 ppm in the year 2130 to calculate:

$$\Delta RF_{CO2}(2130) = (3.71)\{Log[600/284.7]/Log[2]\}$$

$$= (3.71)\{1.076\} = 3.99\ W/m^2$$

We adjust this value upwards to account for the projection of radiative force from all other GHG. If we use the IPCC RCP4.5 scenario as a guide, the ratio of CO2 to all-GHG radiative forcing was 0.778 as computed in Section 3.1.

Case 1: $\Delta RF_{GHG}(2130) = \Delta RF_{CO2}(2130)/0.778 = 3.99/0.778 = 5.13\ W/m^2$

However, if we use the Ring et. al. (2013) Table 1.0 data employed in our bounding calculations for TCS_{GHG}, we obtain a different estimate for this ratio at the present time that will be more conservative for forecasting 2130 AGW conditions,

$$\Delta RF_{GHG}(2010) = 2.62,\ \Delta RF_{CO2}(2010) = 3.71\{Log[391/284.7]/Log[2]\}=1.7\ W/m^2$$

$$\Delta RF_{GHG}(2010)/\Delta RF_{CO2}(2010) = 2.62/1.7 = 1.54$$

If we assume this same ratio holds until 2130, then

Case 2: $\Delta RF_{GHG}(2130) = \Delta RF_{CO2}(2130)[1.54] = (3.99)[1.54] = 6.14\ W/m^2$

Incorporating the 0.4 W/m^2 forecasted drop in TSI from now until the 2130 time period, we note that we need to compute ΔRF_{TSI} with respect to 2010 that is the reference year we selected for radiative force levels. From Figure 4.8, TSI is expected to drop by 0.4 W/m^2 by 2130

$$\Delta RF_{TSI} = -0.4\ W/m^2$$

Case 1: TRF(2130) - TRF(2010) = (5.13 - 3.0) – 0.4 = 2.13 – 0.4 = 1.73 W/m

Or, Case 2: TRF(2130) - TRF(2010) = (6.14 – 3.0) – 0.4 = 2.74 W/m^2

We now use eq. (15) to evaluate the forecasted TSI effect on a new value of GATA

HadCRUT4 Temp Anomaly(2130) - 0.6 = λ_{TCS} (ΔTRF) (2010 is ref. year for ΔTRF)

Case 1: HadCRUT4 Temp Anomaly(Year) - 0.6 = 0.27(1.73) = + 0.47^o C

Case 2: HadCRUT4 Temp Anomaly(Year) - 0.6 = 0.27(2.74) = + 0.74^o C

Therefore, Case 1 yields a temperature rise less than 0.5^o C above current levels. This TSI drop would offset half of the max possible GHG caused temperature rise by 2130. Case 2 yields a total 0.74^o C temperature rise above current levels and is a significant reduction of the most conservative 1.2^o C max temperature rise above current levels indicated in Figure 4.10. Thus

even though TSI is only forecast to drop by 0.4 W/m^2 by 2130 when AGW temperature levels are at their peak, that TSI change is a significant fraction of the total GHG radiative force rise between current levels and 2130 and makes a significant difference in forecasted peak temperatures.

For those believing that public policy decisions should be made on more conservative forecasts of AGW, we recommend that a Factor of Safety be applied to the above temperature forecasts that are based on current excellent data of the last 163 years of GHG warming. A reasonable Factor of Safety based on aerospace structures design practices would be 1.5.

Therefore, we recommend that "worst case" SCC be calculated for an AGW temperature profile as shown in Figure 4.10 with a Factor of Safety 1.5 applied to the projected rise in temperatures above present values, to first evaluate whether GHG emissions control regulations are worth the risk that they present to the US economy.

In any event, the data-based projections of this report do not suggest an impending GHG catastrophe requiring drastic measures now. We have time to improve the return on our research investment and get more confident answers before we proceed with implementing a solution to a problem that doesn't currently exist. As with any Potential Problem, we need to ensure we have the necessary climate monitoring system in place to detect key changes that threaten current satisfactory conditions, and that would change the physical data-based forecasts of this report. In the meantime, the climate research community needs to focus on work that would reduce the uncertainty in how much GHG temperature increase we should expect above current levels. We have shown one straightforward way to do this in this report, and we need to build a scientific consensus around the current research trends of lowering the estimates and uncertainty ranges for climate sensitivity. In this effort, we would also recommend a research focus on Transient Climate Sensitivity (TCS) values and uncertainty ranges instead of Equilibrium Climate Senstivity (ECS), since we have demonstrated here that it is TCS that will determine the actual GHG warming temperature profile over the next several centuries.

Applying a Factor of Safety of 1.5 to the most conservative temperature profile of Figure 4.9 results in a max HadCRUT4 GATA rise above current levels of $(1.2^o\ C)(1.5) = 1.8^o\ C$. If cost/benefit calculations for atmospheric CO2 rise and a very conservative AGW temperature rise of 1.8^o C do not create potential problems, especially when weighed against the positive benefits of CO2 in the atmosphere, then we have high confidence that GHG emissions control regulations should not be implemented at the present time. A decision not to implement such emissions controls can be reviewed periodically to determine if changing conditions and improved understanding of the problem from further, more focused research on reducing uncertainty, would change this decision.

We submit for climate science scrutiny our claim that equations (13) or (14) and their plots in Figure 4.10, based on empitical data, will provide a more accurate and more confident bound on HadCRUT4 GATA trends through 2300 than could be expected from any current climate simulation model represented in Figure 1.1.

5.0 IMPACT OF LESS ECS UNCERTAINTY ON GHG REGULATION ACTIVITY

As summarized in the Technical Support Documents (TSDs) of references [1, 2, 3], an Interagency Working Group (IWG) on Social Cost of Carbon (SCC) composed of membership from the following US government agencies:

Council of Economic Advisers
Council on Environmental Quality
Department of Agriculture
Department of Commerce
Department of Energy
Department of Transportation
Environmental Protection Agency
National Economic Council
Office of Management and Budget
Office of Science and Technology Policy
Department of the Treasury

has jointly agreed on the official method all regulatory agencies shall use to value the Social Cost of Carbon (SCC) due to CO2 and other GHG emitted into the atmosphere. Although the TSD references provide some insight into the SCC computation methodology as instituted in 2010 [1] and revised in 2013 [2,3], there is insufficient information provided in these documents to perform a detailed and independent review of the input data used for the SCC calculations nor to review the precise process by which the SCC calculations are made in each Integrated Assessment Model (IAM) employed for the SCC calculations.

What we can determine from our review of the TSDs is that:

1. The global warming estimates due to CO2 emissions in the SCC calculations rely heavily on a statistical distribution for ECS based on the 2007 IPCC AR4 report's stated uncertainty range and discussion of that uncertainty range.

2. The statistical samples for ECS are produced by a Roe and Baker (2007) [39] statistical distribution described in Table 4.0 and taken from the 2010 TSD [2] Table 1.

3. The Baker-Roe distribution is truncated so that no possible ECS values less than 0^{o} C nor greater than 10^{o} C are possible.

4. Key values in the Cumulative Distribution Function (CDF) of the IWG's Roe and Baker distribution analyzed from information in Table 5.0 and statement 3. above are as follows:

Table 5.0 Statistical Distributions for ECS

Table 1: Summary Statistics for Four Calibrated Climate Sensitivity Distributions

	Roe & Baker	Log-normal	Gamma	Weibull
Pr(ECS < 1.5°C)	0.013	0.050	0.070	0.102
Pr(2°C < ECS < 4.5°C)	0.667	0.667	0.667	0.667
5th percentile	1.72	1.49	1.37	1.13
10th percentile	1.91	1.74	1.65	1.48
Mode	2.34	2.52	2.65	2.90
Median (50th percentile)	3.00	3.00	3.00	3.00
Mean	3.50	3.28	3.19	3.07
90th percentile	5.86	5.14	4.93	4.69
95th percentile	7.14	5.97	5.59	5.17

Pr ECS < 1.5 ^{o} C = 0. 013

Pr ECS < 1.72^{o} C = 0.05

Pr ECS < 1.91^{o} C = 0.10

Pr ECS < 2^{o} C approx. = 0.133

Pr 5.86 < ECS < 7.14^{o} C = 0.05

Pr 7.14 < ECS < 10^{o} C = 0.05

Pr 4.5 < ECS < 10^{o} C is 1-0.667 – 0.133 = 0.20

Pr 4.5 < ECS < 5.86^{o} C is 0.20 – 0.10 = 0.10

Note: The 0.133 value above was obtained by interpolation

Pr 2 < ECS > 4.5^{o} C = 0.667

Therefore, we conclude that:

- 20 percent of the ECS samples are greater than the IPCC 4.5^{o} C upper limit for ECS
- 10 percent of the ECS samples are between 4.5 and 5.86^{o} C,
- 5 percent of the ECS samples are between 5.86 and 7.14^{o} C
- 5 percent of the ECS samples are between 7.14 and 10^{o} C

The IWG preference for the Roe and Baker distribution shape is based on a 2007 paper [39] that through mathematical manipulation only, derived a functional form for the climate sensitivity uncertainty distribution based on how uncertainties in the strength of climate feedback

mechanisms in climate models drive uncertainty in the climate sensitivity calculation. This distribution is not based on any physical climate data that is Mother Nature's way of informing us what the actual net strengths of the climate model feedbacks should be to match actual physical data. **Our ECS distribution is based on conservative analysis of what the physical climate data says about the actual measured strength of the climate feedbacks to GHG radiative forcing in the 163 year data record from 1850 – 2012. What is more reliable and certain; actual data, or speculations based on un-validated computer model solutions? What laws, guidelines and policies must the IWG follow in deciding how to answer this question?**

Moreover, we have explained throughout this report why ECS values are not the most accurate way to determine GHG warming effects from the present until the year 2300 as is the focus of SCC calculations. We offer instead a much simpler, straightforward approach demonstrated in Section 4.6 that provides a bounding calculation on AGW effects that will be peaking out in the 2100-2200 time period before declining atmospheric GHG levels will reduce the earth's surface temperature to below current levels by 2300.

The sensitivity of SCC calculations to the ECS statistical distribution range used as input data to the DICE IAM was studied by Dayaratna and Kruetzer [40] where they replaced the Roe and Baker distribution of Table 4.0 with an ECS statistical distribution based on the results of the Otto et. al. (2013) paper [18]. Otto et. al. (2013) derived their ECS 5-95% confidence range of $1.2 – 3.9^{o}$ C using available physical data. They used the HadCRUT4 GATA database as we did and energy budget data on radiative forcing and ocean heat uptake to constrain their uncertainty range for ECS. This more constrained uncertainty range probability distribution for ECS, produced nearly a 90 percent reduction in the DICE IAM SCC cost estimates compared to the IWG's Roe and Baker distribution, considering all current discount rates considered in the various SCC projections for prescribed discount rates.

We also supplied Dayaratna and Kreutzer with a LogNormal statistical distribution for ECS based on the physical data ECS bounding analysis of this report. This distribution had an ECS mean value of 2.02^{o} C (very close to the Otto et. al. (2013) most likely value of 2^{o} C) and only a 0.00013 probability of exceeding our very conservative upper bound for ECS = 2.86^{o}. The Probability Density Function (PDF) of this "TRCS" distribution is compared to the PDF of the IWG's Baker and Roe Distribution in Figure 5.1. For comparing shape of the two distributions, different vertical axis scales are used for the two different distributions, with the IWG distribution scale on the right vertical axis. The 5-95% confidence range of ECS from Otto et. al. (2013) is also indicated on Figure 5.1. The 0.00013 probability of exceeding our conservative upper bound value of 2.86^{o} C, is based on the mean + 3-sigma value of a Gaussian PDF distribution that is a typical probability level used in determining design limit structural loads that will not be exceeded during the life of a manned launch vehicle or spacecraft. The conservatism embedded in establishing this level of confidence for structural design requirements is intended to protect lives of astronauts, consistent with a minimum weight design. Typically, a 1.5 Factor of Safety is applied to the Design Limit Load to compute an Ultimate Load for which the structure is allowed to have some deformation, but not a catastrophic collapse

of the structure. Without a major overhaul to the current SCC computation process, merely using a much more realistic probability distribution for ECS as input to the current IAMs, as shown in Figure 5.1, would give a quick estimate of much more realistic estimates of SCC. However, GHG warming temperatures based on the actual much lower bound on TCS that will actually determine temperatures between now and 2300, is highly recommended in lieu of ECS values. Such a reduced level of conservatism could be used to evaluate current proposed regulations to see if they expose the US population to higher than necessary energy costs and economic hardship than will result from regulations based on highly inaccurate and inflated estimates of SCC.

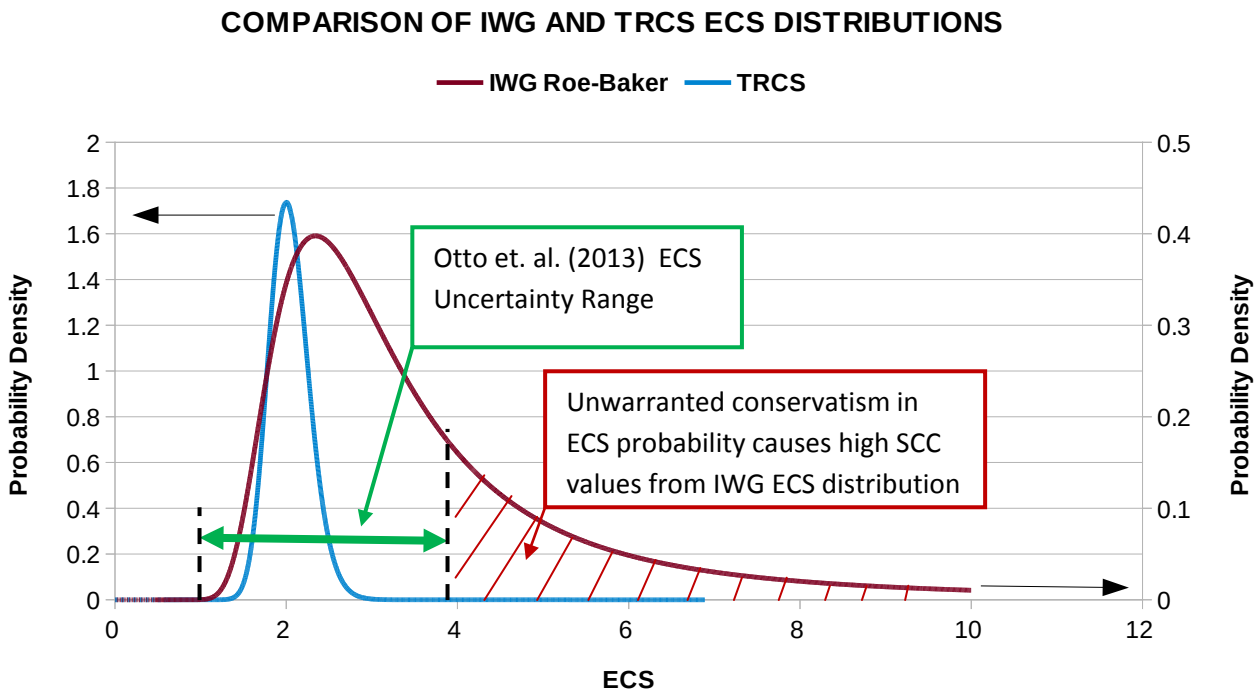

Figure 5.1 Comparison of ECS Probability Density Functions

The extreme ECS over-prediction statistics for ECS in the IWG Roe and Baker distribution, is evident in the PDF plots of Figure 5.1 compared to much lower uncertainty ranges for ECS constrained by actual data observations. The DICE IAM also computed very similar decreases in SCC for our TRCS LogNormal ECS distribution, as obtained with the Otto et. al. (2013) distribution results published by Dayaratna and Kreutzer [40]. This indicates that the large SCC values computed by the DICE IAM result from the more than 0.20 probability in the Roe-Baker distribution that $3.9 < ECS < 10^{o}$ C. We believe an investigation will reveal that the large "expected values of SCC" result from a IAM computation that such high temperatures resulting from ECS values larger than 3.9^{o} C will cause rapid melting of Greenland and West Antarctica ice sheets, causing massive sea level rise and very high world-wide coastal damage. This is speculative and not supported by actual data.

The IWG ECS distribution is not scientifically supported by the best available physical data. It only results from a highly questionable decision to assume "conservative" ECS values, higher than even the IPCC's un-validated climate models would suggest. Surely, the IWG must have performed some "sanity checks" on the SCC sensitivity to their assumptions that were not supported by actual data in developing their Roe and Baker distribution. If not, then this is clear evidence for why an independent, scientific review of the SCC computation process is required.

The question regarding which of these ECS statistical distributions is more appropriate for justifying CO2 emission regulations, should be addressed by an independent scientific review team that follows applicable laws, guidelines and policies for management and oversight of the regulatory process. We believe that the US scientific community is much less certain that unregulated AGW will result in significant melting of the Greenland and Antarctica ice sheets, than they are that humans are contributing to some of the observed modest, and clearly beneficial, global warming since 1850. Moreover, if one considers the analysis of Knappenberger [14], curtailment of all US GHG emissions now can at most reduce GAST in 2100 by only 0.17^{o} C. This would have absolutely no effect on whether the Greenland ice sheets ever melt or not! We need more rational thought in the GHG regulatory process based on input from the US scientific community, and less reliance on IPCC documents edited and published by a political committee of the UN, that is bent on achieving its political objectives that are not necessarily in the best interests of the USA.

Perhaps the IWG is not even aware that the IPCC ECS uncertainty range statements in the 2007 IPCC AR4 report are based primarily on un-validated climate models, since the IWG has apparently accepted the IPCC statements as truthful without conducting a more detailed scientific review as documented in this report. It is hard for us to believe that US regulations can be based on statements made in a report of the IPCC, a recognized political committee of the UN, without any independent US scientific verification conducted by the IWG. We have demonstrated with this report that objective, experienced US scientists and engineers can conduct a scientifically-based investigative assessment that finds significant errors in IPCC documented statements and that are critical to the IWG SCC calculation process.

However, as established in this report, we do not believe SCC calculations should be based on ECS values. We believe, as the IPCC has suggested [8], and that Otto et. al. (2013) [18] and others have suggested, that a transient climate sensitivity parameter is a more appropriate climate sensitivity metric to use for forecasting AGW temperatures over the next 300 years for use in public policy decisions. Otto et. al. (2013) provides a best estimate of TCR = 1.3^{o} C with an uncertainty range of 0.9 – 2^{o} C. This is in close agreement with our TCS_{GHG} least upper bound of 1.5^{o} C and conservative upper bound of 1.6^{o} C derived in Section 4.4. In Section 4.6 we demonstrated how our TCS_{GHG} parameter extracted from physical data, without the use of un-validated models, can be used to provide a worst case forecast of global average surface temperatures for specific atmospheric GHG concentration scenarios. Moreover, this method of forecasting GAST for various CO2 and GHG emissions control policies, is not statistical and does not require a complex Monte Carlo numerical experiment calculation as is currently the case for SCC calculations.

The obvious lack of a solid scientific basis for current SCC calculations demonstrates why public comments on the SCC calculation methodology and independent scientific review, are important for assuring that the GHG emissions control regulatory activity will not be unnecessarily harmful to US citizens.

To summarize: an objective, independent scientific review of the current SCC computation process is required to:

1. Determine if the current ECS distribution used in the SCC computational process and method for forecasting temperature trends until 2300 from ECS values, provides realistic statistical forecasts of temperature rise that are consistent with available data, and how those projected temperature variations relate to the bounding curves presented in Figure 4.10

2. Determine how the inflated GHG climate sensitivity of the IPCC ECS variable relative to CO2-only sensitivity affects the cost/benefit analysis for a proposed CO2 regulation.

3. Determine how the fact that only a fraction, about half, of the CO2 emitted into the atmosphere, actually contributes to the yearly rise in atmospheric CO2 concentration from which the ECS is derived and how this fraction issue is related to the $-cost of a ton of CO2 emitted.

4. Determine how the known beneficial aspects of increased CO2 in the atmosphere are incorporated into the SCC computation process.

5. Determine SCC sensitivity to a number of assumptions made in implementing the process

6. Determine if American citizens are being subjected to overly burdensome regulations because the best science the USA has to offer has not been incorporated into the cost/benefit analysis of the proposed regulations.

6.0 CONCLUSIONS AND RECOMMENDATIONS

We have documented analyses of available data that demonstrate that the IPCC ECS_{GHG} uncertainty range of 1.5^{o} C < ECS < 4.5^{o} C can be confidently reduced. Following is a summary of the upper bounds we have computed for various climate sensitivity metrics in this report.

Conservative Upper Bounds:

$ECS_{GHG} = 2.9^{o}$ C $TCS_{GHG} = 1.6^{o}$ C

$ECS_{CO2} = 1.8$ $TCS_{CO2} = 1.0$

We have explained why ECS is not the best metric of CO2 or GHG climate sensitivity to use for regulatory activity focused on AGW issues and mitigation in the 300 year horizon. We have recommended a more scientifically-based transient climate sensitivity alternative, TCS, verified by empirical data and, with very little uncertainty that the upper bound values can be exceeded. We recommend these upper bound values of TCS for forecasting worst case future CO2 and GHG induced global warming, rather than using results of complex un-validated models to assess the concerns regarding AGW.

We have demonstrated with physical data and world-wide fossil fuel reserves that the GATA from the HadCRUT4 database cannot rise more than about 1.2^{o} C above current values. The IPCC's RCP8.5 scenario, assumed for a no GHG emissions control policy, was shown to be only wild speculation compared to our conservative and scientifically defended RCP5.1 scenario on which we base our "worst possible case" AGW forecast through 2300.

Briefly discussed in this report, but deeply grounded in the experience of our successful manned space program careers, is a recommendation to use a more disciplined process to:

1) identify when AGW problems do or do not exist,
2) to determine true root cause of observed climate deviation from "normal",
3) to identify Potential Problems and develop plans to deal with them, and
4) to develop a wider range of possible mitigation strategies for any true problems identified after true root cause has been determined.

In our training and experience, a global warming problem cannot exist if there is not one location on the planet that is experiencing a harmful surface temperature deviation from a well-defined normal range. We do not currently observe any deviations from the normal range of global temperatures that have occurred during the last 10,000 years of a very stable climate. Root cause determination requires a specification in the deviation from normal regarding questions of What?, Where?, When? and How Much? the deviation is occurring, as well as, study of similar localities where the deviation is not occurring. If a number of problems in different localities can be identified with similar root causes, then one might declare that there is a global warming problem with a known root cause that could use a global mitigation strategy. Otherwise, we suspect local problems might be better addressed with local mitigation strategies such as building higher seawalls where they will definitely be needed and with ample time to decide such expenditures are necessary. At that point in the disciplined process, when true root cause(s) are known, more accurate performance predictions for different mitigation strategies can be made. Then, a number of problem solution options could be identified and the best alternatives selected in a decision process from which a workable response action plan could be formulated.

We do not believe that without iron-clad world-wide agreements to control GHG emissions, unilateral control of GHG emissions by the USA is a rational strategy. Harmful damage to our economy from unilateral GHG emissions control regulations cannot be justified by rational, scientific assessments that reveal such efforts will not avoid the SCC the regulation purports to

avoid. We believe that a broader array of options should be identified and evaluated for the potential problems envisioned for a warming or cooling planet.

We have concluded that the previous large uncertainty range for IPCC ECS values results from using un-validated climate simulation models to determine ECS, unconstrained by actual data observations. We have documented our analyses for independently computing upper bounds for atmospheric CO2 levels resulting from burning of all estimated recoverable fossil fuel reserves on the planet. We estimate fossil fuel reserves will be exhausted by 2130, after which time atmospheric CO2 levels will begin to decline. An orderly market driven transition to alternative fuels will be required before 2080 when we estimate atmospheric CO2 concentrations will have doubled from pre-industrial levels. Using physical data and persistence forecasting methods presented in this report, we do not expect global average surface temperatures will rise more than 1^{o} C from present levels before 2100 or by more than a maximum of 1.2^{o} C above current levels by 2130 when we forecast all world-wide economically recoverable fossil fuels on the planet will be exhausted.

Our research performed in preparation of this report leads us to believe that a rapid depletion of world-wide fossil fuel reserves is a more immediate and serious concern than AGW. A national energy plan, unfettered by AGW concerns, is necessary to ensure that any required government research facilities are created and that research and development is conducted according to a well-thought-out plan on a schedule that will ensure a smooth transition from fossil fuel energy generation to the most promising alternative fuels. We envision such a plan would result from a national commitment to achieve reasonable goals as we had for the successful Apollo Program.

Our atmospheric CO2 concentration bounding calculations, together with confidently bounded lower estimates of climate sensitivity developed in this report, should lead to significantly lower damage estimates for SCC currently being computed in the GHG emissions regulatory process. The possibility of an orderly market-driven transition to alternative fuel use with a defined role for government funded research and research facilities development, should be considered in contrast to the current emissions control public policy reacting to the AGW alarm, that offers very little chance of success in actually lowering global temperatures by a significant amount.

Our severe criticism of the current SCC computation methodology, indicates why a more in-depth and independent scientific review of this process is needed. The decision processes being used do not have the rigor and applicable experience of other agencies of government such as NASA, the NTSB and FAA that clearly know why un-validated models are never used for design or operations involving human safety and well-being. We offer this report to the IWG to carefully consider and scrutinize for any conclusions that they can refute with actual data. Confident that the IWG cannot disprove any conclusions about AGW stated in this report, we challenge the IWG to defend their current SCC methodology against the reasoned temperature forecasts made in this report that are grounded in the actual data on AGW for the last 163 years.

Our TRCS research team experience with the Shuttle Challenger and Columbia accident investigation boards, as well as numerous independent and non-advocacy review boards

regularly conducted on NASA manned and unmanned programs, leads us to believe that a similar independent review activity for the SCC calculation methodology is required. Following the template for successful independent review familiar to us, we recommend that in addition to climate science experts, numerous review board members selected from a broad array of technical fields that utilize the same basic technical disciplines, but are not directly involved in climate science research, are needed to achieve an adequate independent and objective review. Review board members should be vetted for identification and resolution of any possible conflicts of interest.

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APPENDIX A

SEPARATING TOTAL RADIATIVE FORCE AT EQUILIBRIUM AND TRANSIENT CLIMATE SENSITIVITY INTO THEIR COMPONENT PARTS

Any slow change in radiative forcing of the climate system will create a quasi-steady (slowly changing) equilibrium condition as discussed in Section 2.2. The average radiation forcing level of the climate in any year for slowly changing radiative forcing levels, will determine the approximate equilibrium state of the climate system for that year of climate change including any non-linear effects due to GHG that have entered or exited the atmosphere due to atmospheric and surface temperature changes. However, similar to the step function response discussed in Section 2.1, any significant change in external radiative forcing that occurs over the period of the lowest frequency vibration mode of the system, can excite dynamic responses of the system that would cause the actual state of the system at a particular instant of time (or yearly average) to vary from its instantaneous quasi-steady equilibrium condition.

The applied external forcing function of the climate system is a radiative forcing function composed of three primary components:

1. Atmospheric CO2 radiative forcing component
2. Other atmospheric GHG radiative forcing component
3. TSI radiative forcing component

If we assume near static equilibrium of the climate system in any year due to these slowly changing externally applied forces, then we may determine their separate percentage contributions to the long-term quasi-steady equilibrium temperature response of the system as studied in the long-term trend bounding curves of Figure 4.5. These bounding curves indicate the slowly changing static equilibrium condition of the climate to all externally applied forces, with the additional conservative assumption that there are no long term climate cycles of the climate system affecting the HadCRUT4 data, such as a 1000 year cycle associated with the RWP, MWP and LIA as assumed in Case 2 of Figure 4.4.

We now derive equations that can be used to separate out the climate sensitivity factors embedded in the HadCRUT4 data into their separate contributions.

In IPCC Reports (2001) and (2007) [7, 8], climate scientists agreed that radiative forcing due to atmospheric CO2 concentration could be approximately described by a natural logarithmic function,

$$RF_{CO2} = \beta \ln[CO2(year)/CO2_{REF}] = 5.35 \ln[CO2(year)/CO2_{REF}] \ W/m^2 \quad (A\text{-}1)$$

Using the relationship,

$\ln[A] = 2.303 \ Log[A]$, eq.(A-1) can be written as:

$$RF_{CO2} = (5.35)(2.303)Log[CO2(year)/CO2_{REF}] = 12.3 \ Log[CO2(year)/CO2_{REF}] \ W/m^2$$

This equation can also be written,

$$\Delta RF_{CO2} = 12.3 \ Log[2]Log[CO2(year)/CO2_{REF}]/Log[2]$$

$$= 3.71\{Log[CO2(year)/CO2_{REF}]/Log[2]\} \ W/m^2 \quad (A\text{-}2)$$

When CO2(year) has doubled from its reference value then eq. (A-2) reduces to,

$$\Delta RF_{2xCO2} = 3.71 \ \{Log[2]/Log[2]\} = 3.71 \ W/m^2$$

Climate scientists also use the following linear climate sensitivity relationship [6] for changes in surface temperature due to a radiative forcing (ΔRF) change,

$$\Delta T_S = \lambda(\Delta RF) \quad {}^oC \quad (A\text{-}3)$$

where λ has units of ${}^oC/(W/m^2)$.

The climate sensitivity value for λ is usually discussed in terms of an ECS scenario where all nonlinear responses to the RF are allowed to occur over 1000 years or more. In this case, the value for λ in most climate models, λ_{ECS}, ranges from 0.6 to 1.2 ${}^oC/(W/m^2)$ reported by Lenton and Vaughan (2009) [41] and is determined by the specific model's computation of ECS.

For example, since ECS for a doubled atmospheric CO2 concentration is defined as:

$$\Delta T_S = ECS\{Log[CO2_{2x}/CO2_{REF}]/Log[2]\} = ECS \ \{Log[2]/Log[2]\} = ECS$$

Even though the radiative forcing function in the above equation is only due to the CO2 concentration rise, ECS is usually understood to include the climate sensitivity of all GHG, since all GHG are contributing to ΔT_S. This tacitly assumes that the radiative force of all GHG are rising at a constant percentage of the CO2-only radiative force.

Then we can equate,

$$\lambda_{ECS}\,(\Delta RF_{2xCO2}) = ECS, \text{ or } \qquad \lambda_{ECS} = ECS/3.71\ ^{o}C/(W/m^2)$$

For an IPCC uncertainty range median value of ECS = 3 ^{o}C,

$$\lambda_{ECS} = 3/3.71 = .81\ ^{o}C/(W/m^2)$$

For our conservative upper bound value for ECS = 2.86^{o} C, derived in Section 4.4,

$$\lambda_{ECS} = (2.86/3.71) = 0.77\ ^{o}C/(W/m^2)$$

We can also use the same linear temperature and RF relationship of eq. (A-3), to write for the long term HadCRUT4 GATA rise from the ΔTRF during the 1850-2012 period:

$$\Delta T_{S\_TRF} = \lambda_{TCS}\,(\Delta TRF) = \lambda_{TCS}\,(\Delta RF_{GHG} + \Delta RF_{TSI}) = \lambda_{TCS}\,(\Delta RF_{CO2} + \Delta RF_{OTHER\_GHG} + \Delta RF_{TSI})$$

$$\Delta T_{S\_CO2} + \Delta T_{S\_OTHER\_GHG} + \Delta T_{S\_TSI} = \lambda_{TCS}\,\Delta RF_{CO2} + \lambda_{TCS}\,\Delta RF_{OTHER\_GHG} + \lambda_{TCS}\,\Delta RF_{TSI} \quad \text{(A-4)}$$

We equate equations (3) and (A-4) for the HadCRUT4 GATA long-term temperature rise since 1850 to obtain eq.(10)

$$\Delta T_{S\_TRF}\,(year) = \lambda_{TCS}\,[\Delta TRF(year)] = TCS_{TRF}\{Log[CO2(year)/284.7]/Log[2]\} \quad \text{(A-5)}$$

$$TCS_{TRF} = \lambda_{TCS}\,[\Delta TRF(year)]/\ \{Log[CO2(year)/284.7]/Log[2]\}$$

$$TCS_{TRF} = \lambda_{TCS}\,[\Delta RF_{CO2} + \Delta RF_{OTHER\_GHG} + \Delta RF_{TSI}]/\{Log[CO2(year)/284.7]/Log[2]\} \quad \text{(A-6)}$$

The actual earth surface temperature measured in the HadCRUT4 data include effects from the direct forcing function change as well as the cumulative effects of linear and non-linear dynamic responses of the climate system that occur in the particular measurement year, averaged over that entire year. Therefore the HadCRUT4 database should account for all linear and non-linear responses of the climate system due to the actual radiative forcing time history since 1850, and even before 1850, if long period oscillations were excited by external forcing functions prior to 1850. If the total change in radiative forcing is small enough each year, then the oscillatory dynamic responses recorded in the HadCRUT4 data should be muted unless such modes of oscillation have very low damping rates. The 62 year climate cycle emphasized in Figures 3.3 and 3.4 has been observed by Luedecke et. al. [42] in 6 different instrumental databases, all recorded in Europe, and in close agreement that stretch back to 1757 AD. They provide references to other published literature noting 60-70 year climate cycles in other data records, and there are many references to similar cycles in the vast internet blogosphere comments at various climate related websites. Such cycles have been noted to be correlated with many other observations of approximately 60 year cycles in the spin rate of the earth and Arctic Oscillation

Index http://blog.chron.com/climateabyss/2012/04/about-the-lack-of-warming/#comment-3678 as well as cycles in fish catches. http://www.fao.org/docrep/005/y2787e/y2787e00.pdf

More recent papers have begun to explore the cause of these observed climate cycles of temperature and precipitation variations that is beyond the scope of this report. The strong persistence of this 62 year climate cycle over long periods of time suggests it is easily excited by naturally occurring external forcing functions and/or it has very light system damping.

Just as the direct radiative forcing of atmospheric CO2 increases is postulated in AGW theory to excite feedback mechanisms of the climate system that would amplify the response, so can TRF changes from any cause be amplified or muted in the actual dynamic response, depending on the phasing of internal dynamic responses and timing of positive or negative changes in the external forcing function. If you doubt that statement, use the simple dynamic model of Sections 2.1 and 2.2 to digest it. Once the climate system is oscillating in one or more modes of vibration, the timing of positive or negative forcing from the TRF change will either amplify or damp the amplitude of the various modes of current oscillations. This effect is the same we experience when pushing a child in a swing. The timing of our "pushes" determines if the amplitude of the motions of the swing increases, just overcomes friction damping to maintain amplitude, or actually reduces the amplitude.

In the bounding analyses of Section 4.3, we assume that the radiative forcing of the climate system from all sources occurs slowly enough, so that a quasi-steady equilibrium state of the climate can be inferred from the long-term and slowly occurring changes in the external radiative forcing of the climate system. In this case, just as in the slowly applied eternal forcing function to the simple dynamic model of Section 2.2, the state of the system has a static equilibrium condition determined by the instantaneous applied external force. In such situations, the externally applied external force may be separated into its component parts to determine the contribution of each to the instantaneous equilibrium state of the system.