RECOMMENDATIONS TO THE TRUMP TRANSITION TEAM INVESTIGATING ACTIONS TO TAKE AT THE ENVIRONMENTAL PROTECTION AGENCY (EPA)

A Report of The Right Climate Stuff Research Team

www.therightclimatestuff.com

Harold H. Doiron, Chairman

November 30, 2016

Houston, Texas

TABLE OF CONTENTS

SUMMARY OF RECOMMENDATIONS……..……2

1.0 INTRODUCTION……..……..7

2.0 INDEPENDENT TRCS CLIMATE MODEL ……....9

2.1 Independent TRCS Model Provides Baseline for Critique of SCC
2.2 TRCS Climate Model and Model Validation
2.3 Forecasting GMST Change AND SCC with the TRCS Climate Model
2.4 ESTIMATING TCS FROM TCS(1+β) = 1.8C

3.0 SCIENTIFIC CRITIQUE OF THE SCC CALCULATION METHODOLOGY ……...16

3.1 Un-validated Integrated Assessment Models
3.2 Un-Validated GCMs Used to Calculate ECS Uncertainty
3.3 Un-validated Model Used to Convert ECS to GMST Vs. Time
3.4 Speculative ECS Statistical Distribution Used to Compute SCC
3.5 Obsolete GHG Emission Scenarios Used to Compute SCC
3.6 Applying “Sanity Checks” to the SCC Calculation Process
3.7 More Research Needed on GHG Emissions Scenarios
3.8 Detailed Assessment Needed for Economic Impacts of Clean Power Plan
3.9 Need to Remove Uncertainty from Climate Projections

4.0 NEED FOR VALIDATED MODELS TO SUPPORT PUBLIC POLICY DECISIONS……22

5.0 NEED FOR DISCIPLINED ROOT CAUSE ANALYSIS AND DECISION-MAKING ……22

6.0 REFERENCES……25

APPENDIX-A DERIVATION OF THE TRCS CLIMATE MODEL……..26

Abstract

The TRCS goal is to determine the extent to which burning fossil fuels can cause harmful global warming. To determine if this is the root cause of the slight amount of observed global warming, we did a simple bounding analysis based on the physics of interaction of currently increasing atmospheric CO2 with heat radiating from the sun and the earth. In accordance with "The Scientific Method," we compared our results with the best available global temperature data measured since the beginning of widespread use of fossil fuels. Our analysis fits the measured Global Mean Surface Temperature (GMST) data for the past century and a half very well and we predict that CO2 emissions will continue to have no significant effect on global warming. In our report, our validated model predicts at most, only 1 deg C additional warming above current levels by 2100. This is in clear contrast to the poor, unvalidated models used for justification by the EPA to start unilateral CO2 emission controls that have a serious potential for wrecking the US economy without having any effect at all on climate.

The power and uniqueness of our approach is that the measured data reflects the results of the actions and interactions of the numerous climate forcing functions which have confounded attempts to solve this complex problem by use of computerized climate models for the last 37 years. We believe our analysis has the same quality of accuracy as many of the analyses we performed for manned space flights during the Apollo program.

TRCS Motto

"In God we trust, all others bring data"

It doesn't matter how beautiful your theory is, it doesn't matter how smart you are. If it doesn't agree with experiment, it's wrong.

Richard Feynman 1918-1988

RECOMMENDATIONS TO THE TRUMP TRANSITION TEAM INVESTIGATING ACTIONS TO TAKE AT THE ENVIRONMENTAL PROTECTION AGENCY (EPA)

Harold H Doiron

Chairman, The Right Climate Stuff Research Team

November 30, 2016

SUMMARY OF RECOMMENDATIONS

It is imperative that the scientific and threat risk arguments used to justify the EPA's CO2 Endangerment Finding and Social Cost of carbon (SCC) values, be reviewed by a scientific panel composed of members from broad scientific backgrounds and experience, and without conflicts of interest. Our research team of retired NASA Apollo Program veterans has such a broad base of scientific expertise and experience, without conflicts of interest, as we have reached our conclusions from an unfunded, all-volunteer, independent and objective study of these issues as documented in various reports and climate conference presentations posted on our website: www.TheRightClimateStuff.com

We recommend:

- NASA's Independent Program Assessment Office (IPAO) as a model federal government office experienced in vetting and selecting a broad spectrum of qualified review team members without conflicts of interest.
- Using NASA-STD-7009 as a guideline for model validation and configuration control requirements for models used for design or operational decisions involving human safety. The unilateral GHG emissions regulations the EPA has decreed and proposed have potentially far greater consequences for our nation than loss of manned spacecraft crewmembers, as devastating as that has been in past.
- Establishing a moratorium on CO2 emissions regulations for the next 5 years to allow for more focused research and independent scientific reviews to remove excessive uncertainty from current un-validated models used to compute SCC. Our independent assessment with validated models and CO2 emission scenarios constrained by actual data presented herein, proves we do not have a rapidly developing climate problem requiring swift corrective action in the face of very large uncertainty regarding whether a climate problem exists, or not.
- EPA use proven, disciplined processes successfully employed within other US government agencies, such as NASA and the US military, for defining and specifying problems and proving their root cause, before deciding through a rational decision process, the optimal approach for mitigating the specifically

defined problem. Despite irrational claims to the contrary, we do not have a global climate problem defined by GMST variations outside of the very stable normal variations of the last 10,000 years that had nothing to do with atmospheric CO2 variations. There is not one specific location on earth with a current climate deviation outside of normal variations of the last 10,000 years.

- Problems to be mitigated should be defined in terms of data indicating deviations outside of normal limits and should be specified in terms of What? Where? When? and How Much? are the deviations occurring. Only then will there be enough data available to determine true root cause(s) to guide optimal mitigation strategies.
- If a specific climate problem is identified and specified, evaluate a broader range of mitigation options than CO2 emissions regulations, as a possible solution option with lower cost and higher probability of success. For example, if sea level rise is a specific threat to a specific region, evaluate the cost, schedule and probable success of building a sea wall to mitigate the threat, as opposed to the probable cost and success of enforcing world-wide GHG emissions controls. SCC cannot be used intelligently as a universal metric for deciding mitigation options for more specifically defined problems than a vaguely proposed "global climate problem".
- Using the HadCRUT4 surface temperature anomaly database as the best available proxy for long-term Global Mean Surface Temperature (GMST) change for climate model validation, as it is the only thermometer record dating back as far as 1850. Also, for years since 1978 when better spatial global temperature coverage from satellites has been available, the HadCRUT4 data are in better agreement with NASA's UAH-LT and NOAA's RSS satellite temperature measurements than other available long term databases such as NASA's GISTEMP surface temperature database that begins in 1880.
- Forecasts of future GMST increase with rising atmospheric Greenhouse Gas (GHG) concentrations depend on two key variables:
    - GMST sensitivity to atmospheric GHG concentrations, typically discussed in climate science publications in terms of "climate sensitivity" metrics such as Equilibrium Climate Sensitivity (ECS) and Transient Climate Response (TCR). Neither of these two metrics can be verified with actual data as their official definitions depend on un-validated climate model simulations. We recommend a new metric for GMST forecasting that can be verified with available data, Transient Climate Sensitivity (TCS), similar in definition and value to TCR, but with much less uncertainty than the speculative ECS metric.
    - A forecast of atmospheric GHG and aerosol concentrations for the future

- Results of validated models, where these key forecasting variables are constrained by available data, are required for public policy decisions devoid of excessive speculation.

- We recommend:
  - The TRCS Climate Model presented herein as a validated climate model utilizing the data-derived TCS metric, as a model suitable for forecasting GMST change as a function of atmospheric CO2 concentration. TCS in this model is estimated to be 1.2C and is close to TCR values published in other recent peer reviewed published literature where the TCR estimates are based on actual climate data. However, our TRCS Climate Model uses an even less uncertain metric, TCS(1+β) = 1.8C for forecasting, where β is the somewhat uncertain historical fraction of CO2 radiative forcing contributed by the history of other atmospheric GHG and aerosol concentrations, that is by far the largest factor contributing to uncertainty in recent publications for TCR.
  - The TRCS RCP6.0 "Business As Usual" atmospheric GHG and aerosol concentration forecast presented herein as a world-wide fossil fuel reserves data-constrained baseline forecast, if world-wide GHG emissions controls are not implemented. The recent IPCC AR5 Report also published a similar RCP6.0 scenario that assumed only modest world-wide CO2 emission controls would ever be implemented. In contrast, our RCP6.0 emissions scenario assumes a market-driven transition to alternate fuels will be required as currently known world-wide reserves of fossil fuels are consumed.
- With respect to the recommended scientific review of the current Social Cost of Carbon (SCC) calculation methodology, we recommend for review the following specific issues identified from our independent, objective assessment of the SCC Monte Carlo calculation process:
  - Choice of ECS instead of the much less uncertain TCR metric that is much better suited for 300 year forecasts of GMST. ECS is a climate sensitivity metric based on highly speculative GMST temperature rise occurring more than 1000 years after atmospheric CO2 levels are suddenly doubled and artificially held at the doubled value. The TCR metric defines GMST rise from a doubling of CO2 concentration at a slowly rising 1 percent per year rate that takes 70 years for the doubling to occur. Our proposed TCS metric would be an even better choice, as it is verifiable with actual data and is defined by the actual slow, but variable

rise rate of CO2 concentration in our atmosphere, that will take about 230 years to double its 1850 value.

- SCC dependence on un-validated General Circulation Models (GCMs) as a basis for developing a highly speculative statistical uncertainty distribution for the ECS metric.
- Design of the highly speculative Baker-Roe statistical distribution for ECS that has 20 percent of samples higher than the United Nations (UN) Intergovernmental Panel on Climate Change (IPCC) recommended upper range of 4.5C for ECS and allows statistically sampled values as high as 10C. Arbitrarily deciding 20 percent of ECS samples should be higher than 4.5C, skews statistically "expected SCC" values produced from the Monte Carlo process to be arbitrarily high. This decision effectively offsets much of the relatively certain economic damage that could be attributed to imposing GHG emissions regulations. The technical publications used to justify the ECS statistical distribution are obsolete. Many recent publications since 2010, where ECS and TCR uncertainty ranges are constrained by climate data, provide much lower mean and upper range limits for ECS and TCR than older publications referenced in the SCC TSDs. Any statistical distribution used should be validated by actual analysis of climate data, not the speculation of un-validated GCMs as employed in the current SCC calculation process.
- The model validation concern issue for the critical step in how the various Integrated Assessment Models (IAMs) compute a forecast of 300 years of transient temperature rise from statistically sampled ECS values. The details of this important aspect of the SCC calculation process were not disclosed in the three Technical Support Documents (TSDs) describing the current SCC calculation process. These details are crucially important to the SCC results produced.
- Uniform sampling of the 5 selected emissions scenarios in the Monte Carlo process instead of other possible statistical distributions that would weigh more likely scenarios with higher probability. The statistical treatment of emission scenarios is just as important as statistical samples of ECS values for computing statistically expected values of SCC. Outlier scenarios such as the "MERGE-optimistic" scenario used in the current SCC calculation are not as probable as data-constrained scenarios such as our RCP6.0 scenario. The selection of emission scenarios and their statistical treatment needs careful, independent scientific review
- SCC values are computed in terms of $/Gt of GHG emissions, but GMST warming and damage is computed as a function of atmospheric GHG concentrations. The critically important model validation step for how

each IAM converts emissions to atmospheric GHG concentrations was not disclosed nor discussed in the SCC TSDs. Our independent study identified this as a critical aspect of future atmospheric CO2 concentration and GMST forecasting that needs to be constrained by available data.

- The computed damages and benefits from increasing GHG emissions cannot possibly be a validated aspect of the IAMs, as they all give widely differing results for SCC. Averaging widely varying results from models whose authors claim compute the same SCC metric, cannot provide a safe and reliable approach for serious public policy decisions with potentially severe unintended consequences. This practice can be compared to computing the structural strength of a commercial airplane wing with three different models that give widely varying results and then averaging the results to determine if the wing strength satisfies Federal Aviation Administration (FAA) requirements. Who would feel safe as a passenger on this airplane? By what rationale did the Dept. of Transportation (DoT) representatives to the Interagency Working Group (IWG) that developed the SCC computation process concur with this decision? Did they represent the position of the DoT's FAA that enjoys wide support and high public trust for ensuring safety of airline travel with FAA imposed regulations?
- The SCC TSDs did not provide adequate information on key SCC calculation process variables and statistics vs. time that could be used as "sanity checks" on reasonableness of the SCC values obtained from the process. For example, statistics on GMST vs. time and atmospheric CO2 concentrations vs. time that drive the SCC calculation process were not disclosed. Much of the current SCC damage results from projected sea level rise, but nothing was disclosed in SCC TSDs regarding model output statistics of sea level rise rates and whether they were reasonable within available data. A reasonable sanity check on only the statistics for ECS, computed GMST vs. time, and computed sea level rise aspects of the IAM computations, would be to:
    - Use the median of the IPCC AR5 atmospheric GHG and aerosol concentration history from 1850 through 2015 as the baseline atmospheric GHG history since 1850
    - Start the GMST prediction process in 1850 using the AR5 estimate for the actual past atmospheric GHG history and compare the IAM statistics to GMST and sea level rise trends since 1850.
- Review the issues related to compliance with OMB Circular A-4 guidance on use of domestic vs. global damage and benefits from domestic CO2 emissions

- Review issues related to non-compliance with OMB guidance on use of discount rates for the published SCC values.

1.0 INTRODUCTION

The Right Climate Stuff (TRCS) Research Team is an all-volunteer research group comprised primarily of NASA retiree veterans of Apollo, Skylab, Space Shuttle and International Space Station manned space programs. We have been joined by other experienced research leaders from US industry and universities, in our goal to determine to what extent unrestricted emissions of Greenhouse Gases (GHG) can warm the Earth's surface. We have more than 30 members on our research team. Our conclusions from 4.5 years of independent, unfunded, objective research and independent scientific investigation, are posted on our website, www.TheRightClimateStuff.com, in various reports and video presentations our members have made at international climate conferences and university lectures.

As most of our research team are former Federal Government employees in NASA's manned space programs, we are intimately familiar with how scientific and engineering research and development, and related government decision-making, where human safety was involved, was carried out by responsible and accountable NASA government officials during our careers. We have unique experience in scientific investigations supporting root cause analyses and rational decision-making, to address threats to astronaut safety under limited time constraints, and where poor decisions on complex technical issues with incomplete understanding and large uncertainties, can have severe un-intended consequences, including loss of spacecraft and crews. We believe our research team of highly trained and experienced scientists and engineers, represents a national asset that should be utilized by our nation's leaders to develop more rational responses to the perceived threat from rising atmospheric GHG concentrations.

Although we are not climate scientists per se, our research team has internationally recognized experts in chemistry, physics, geology, geo-physics, engineering, applied mathematics and computer simulation of complex phenomena. We had no difficulty reading, understanding and discussing strength and weaknesses of climate science publications that apply basic knowledge from our competency fields of science to the climate change issue. While the theorized effects of atmospheric GHG concentration are relatively simple to model, we observe that the other natural processes affecting climate change are not well-understood and are questionably accounted for in current General Circulation Models (GCM) that have been the primary modeling tool in climate science. Most of the federally funded climate research has been focused on the GHG concern, while clearly the changing climate is affected by many parameters whose effects are not well-understood nor completely modeled in GCMs. We consider it scientifically foolish to try to control the climate with one minor parameter, GHG

emissions, when so much atmospheric GHG and aerosol concentration variations are due to natural processes and many more important parameters affecting our climate cannot be controlled. In aerospace engineering practice, this ill-advised approach is known as trying to control a system with very poor control authority. It is rarely ever successful.

Our review of the scientific work supporting the Environmental Protection Agency's (EPA) Endangerment Finding and SCC valuation, used to justify the cost/benefit assessment of GHG emissions regulations, finds they are seriously lacking in scientific reasoning consistent with The Scientific Method. As former Federal Government employees with responsibility for scientific and economic assessments for critical decisions involving human safety, we are extremely disturbed by an apparent lack of scientific rigor and integrity in both the EPA Endangerment Finding and SCC calculation methodology. Given the potentially severe impacts to our nation's economy and harm to US citizens from proposed EPA GHG emissions regulations, we believe it is imperative that the scientific and threat risk arguments used to justify the Endangerment Finding and SCC values, be reviewed by a scientific panel composed of members from broad scientific backgrounds and experience, and without conflicts of interest.

It appears to us that the current EPA prefers to let lawsuits against it from companies and states play out in the US court system, to adjudicate the scientific and economic issues involved. The US Congress seems to be under the impression that it has sufficient laws and rules in place to force agencies such as the EPA, to resolve these issues internally using independent, objective peer-review teams. Our research team members have often participated in such independent scientific reviews on either side of many issues NASA regularly submitted to independent "non-advocacy" reviews. Based on that experience it is our opinion that neither the independent peer reviews conducted by the Interagency Working Group (IWG) that developed the SCC computation methodology, nor the EPA have used truly objective independent peer review teams with no conflicts of interest, to review and concur with their scientific conclusions. We recommend NASA's Independent Program Assessment Office (IPAO) as a model federal government office experienced in vetting and selecting a broad spectrum of qualified review team members without conflicts of interest.

https://www.nasa.gov/sites/default/files/files/IPAO_Brochure-508-1_Tagged.pdf

We also recommend such independent review teams be convened to review climate research findings at NASA and NOAA, since the technical publications from federal employees in these agencies are often used by the EPA as scientific justification for its decisions. NASA has informed NASA manned space program retirees who expressed concern about public announcements regarding conclusions of climate research within NASA, that NASA as an agency does not take an official position on climate research published by its employees…….

http://www.huffingtonpost.com/2012/04/11/nasa-global-warming-letter-astronauts_n_1418017.html

We do not believe NASA is managing its climate research nor vetting its technical publications used in EPA decision-making, with the same level of independent, "non-advocacy" assessment scrutiny, used for decisions in its manned and major un-manned space programs. This report will summarize the independent research and conclusions our research team achieved after 4.5 years of independent, objective study as suggested by the official NASA response to our initial NASA retiree letter discussed at the above link.

2.0 INDEPENDENT TRCS CLIMATE MODEL

2.1 Independent TRCS Model Provides Baseline for Critique of SCC

The opinions and recommendations expressed in this report are based in part on results of our own simple TRCS Climate Model, rigorously derived from Conservation of Energy principles and basic radiation heat transfer physics used in our manned space program to compute internal and external touch temperatures of orbiting spacecraft. Like the earth, the transient thermal environments of orbiting spacecraft are determined from incoming radiation heat transfer from the Sun balanced by energy radiated from the spacecraft surface to deep space and heat stored within the spacecraft. The spacecraft surface temperature increases until the radiation to deep space can balance the incoming and stored energy transfer rates. Also, like the earth, we often rotate spacecraft in a "bar-b-que mode" to control internal and external temperatures. We validated our model with 165 years of atmospheric GHG, aerosol and Global Mean Surface Temperature (GMST) data using System Identification methods analogous to methods we use for spacecraft orbit determination.

2.2 TRCS Climate Model and Model Validation

Our very simple model, that conservatively assumes all the observed long-term increase in GMST is caused by rising atmospheric GHG concentrations, is given by the algebraic equation that predicts yearly average GMST, GMST(year) as a function of yearly average CO2 concentration, CO2(year),

$$GMST(year) = GMST(1850) + TCS(1+\beta)LOG[CO2(year)/CO2(1850)]/LOG[2] + 0.021(year-1850)/155 \quad (1)$$

The derivation of this equation is presented in Appendix A. The last term accounts for the warming due to Total Solar Insolation (TSI) increase from 1850 to 2005 and becomes a constant 0.021C for years after 2005. This provides some conservatism in the equation for projections after 2005, as TSI rise ended in about 2005 and is forecast to decrease for the next 200 years or more. For an even simpler equation, this last term can be ignored as it accounts for only 0.021C of the GMST rise since 1850. The model was validated by determining the constant $TCS(1+\beta)$ that provided a best fit of equation (1) to the HadCRUT4 temperature anomaly data set for which yearly average values

are published for 1850 and subsequent years. The changes in this global earth surface temperature anomaly provides an approximation to the actual GMST change over time.

2.2.1 Transient Climate Sensitivity (TCS) and Transient Climate Response (TCR)

We defined Transient Climate Sensitivity (TCS) in equation (1) to be the GMST increase that will occur due to a doubling of the atmospheric CO2 concentration by the actual concentration rise history from 1850 until the year when CO2(year) is twice its 1850 value. TCS is a verifiable metric and includes effects of all feedbacks on transient GMST response to rising atmospheric CO2 levels. TCS is similar in value and definition to the United Nations (UN) Intergovernmental Panel on Climate Change (IPCC) definition of Transient Climate Response (TCR) discussed in many climate science publications. However, the IPCC defines TCR as the GMST temperature change caused by a hypothetical atmospheric CO2 concentration rise rate of 1 percent per year that can only be computed with climate simulation models and that cannot be directly verified with actual data. While CO2 concentration doubles in about 70 years in the TCR definition, we estimate that it will take about 230 years for atmospheric CO2 to double its 1850 value in the verifiable TCS definition.

Our analysis of the actual CO2 rise rate history and the hypothetical 1 percent per year rise rate used to define TCR, concluded they were both sufficiently slow rise rates that there should be minimal dynamic overshoot in the transient temperature response; and therefore, both TCS and TCR should have the same value. This slow forcing function application argument to the earth's climate system dynamics is analogous to the case of a simple spring-mass-damper dynamic system where a slowly increasing force is applied to the mass to double its original applied force, and the final equilibrium static displacement of the mass is measured to determine the spring constant, K. If the factor of 2 force change is applied at an even slower rate of increase, the negligible dynamic overshoot of the equilibrium displacement counteracted by system damping, is even smaller, and the final static equilibrium displacement of the mass is observed to be the same, and yields the same value for the spring constant, K, where

K = (change in applied force)/(change in mass displacement)

2.2.2 Atmospheric CO2 Concentration Data Used for TRCS Model Validation

We used National Oceanic and Atmospheric Administration (NOAA) published data from East Antarctica Law Dome ice core samples to determine CO2(1850) = 284.7 ppm in equation (1). The ice core data were also used to determine CO2(year) for subsequent years until 1959 when more accurate NOAA Mauna Loa Hawaii atmospheric CO2 concentration measurements began. The 20 overlapping years from 1959 to 1978 where both the ice core and Mauna Loa data are available and are in good agreement, provides confidence in the use of the smoothed ice core CO2 data for the 1850-1958 period. The logarithmic terms in equation (1) model the increasing radiative forcing of the increasing atmospheric CO2 concentration over time. The parameter β is the somewhat uncertain net fraction of CO2 radiative forcing contributed

by aerosols and effects of GHG other than CO2. In general, when data are available, β can be treated as a variable with different yearly average values denoted by β(year). However, in equation (1) we have used β to represent a constant of somewhat uncertain value representing the average radiative forcing effects of GHG and aerosols relative to CO2 over the time it will take CO2 to double its 1850 value. The uncertainty in β however, does not affect the uncertainty in the constant TCS(1+β) determined from GMST data.

Note that equation (1) is scaled such that when CO2(year) doubles its CO2(1850) value, the logarithmic expression evaluates to 1.0 and the total GMST change since 1850 will be equal to TCS(1+β). This states that the total GMST change measured is due to the CO2 concentration doubling (The TCS contribution) plus the net effects of increased concentrations of other GHG and aerosols since 1850.

2.2.3 TCR Uncertainty vs. TCS(1+β) Uncertainty

As discussed in Lewis and Curry (2014), the TCR value (which they tacitly use to mean our definition of TCS) has uncertainty due primarily to the uncertainty in the history of atmospheric aerosol concentration and the large uncertainty regarding warming and cooling effects of atmospheric aerosols. However, TCS(1+β) has much less uncertainty than TCS = TCR, and is due only to the uncertainty in the GMST change since 1850 and uncertainty in CO2(1850) = 284.7 ppm. We don't need to quibble about uncertainty related to whether the Mauna Loa yearly average CO2 concentration is an accurate representation of the global average CO2 concentration, as we can just choose to make the TCS definition in terms of the Mauna Loa published data.

2.2.4 TRCS RCP6.0 "Business As Usual" GHG Emissions Scenario

The green curve in Figure 1.0 is the atmospheric CO2 concentration history from 1850-2015 together with our projection for 2016 to 2100 read from the scale on the right hand vertical axis. Our GHG emissions scenario on which this projection is based has a Representative Concentration Pathway (RCP) rating of RCP6.0, meaning its radiative forcing in 2100 will be 6.0 W/m^2 due to all atmospheric GHG and aerosol concentration increases since 1750.

This RCP6.0 emissions scenario is similar to the IPCC AR5 Report RCP6.0 scenario that assumes some modest world-wide CO2 emissions controls will be implemented later in this century. In contrast, our RCP6.0 "business as usual" scenario with no effective world-wide CO2 emission controls enforced, assumes a gradual market-driven transition to non-CO2 emitting energy sources will be required beginning about 2050, to supply growing world-wide energy demand, as costs to recover these rapidly depleting fossil fuel reserves increase over time. The scenario uses US Energy Information Administration (EIA) data on current world-wide reserves of coal, oil and natural gas, that when recovered and burned, will result in a maximum atmospheric CO2 concentration of 600 ppm in about 2130. The RCP6.0 scenario projects 585 ppm CO2

in 2100 and assumes that other atmospheric GHG and aerosols will continue to contribute their net average historical value of 50 percent of the more accurately known CO2 concentration radiative forcing. The 50 percent historical value, represented by β = 0.5, was determined from analysis of IPCC AR5 Report data on radiative forcing of atmospheric aerosols and GHG other than CO2 during the 1750 to 2010 time period.

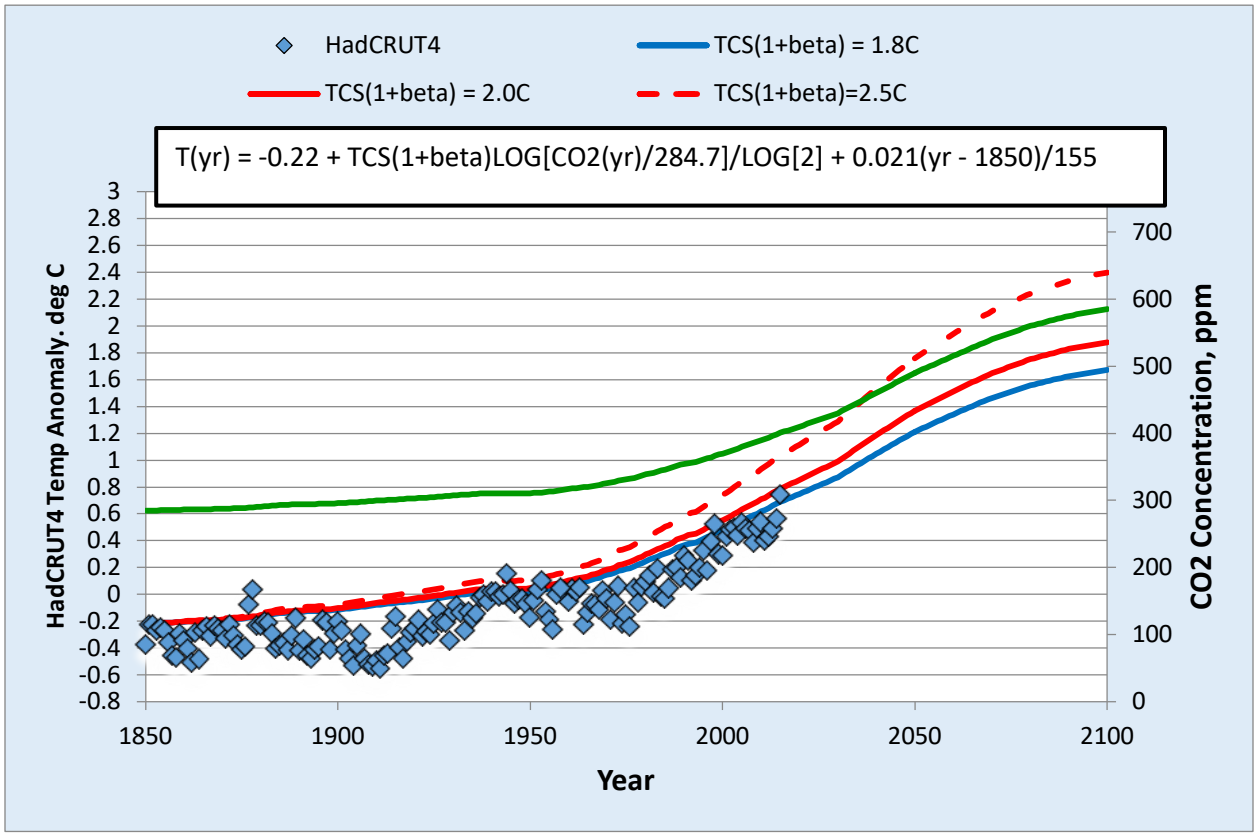

Figure 1.0 TRCS Climate Model results compared to HadCRUT4 temperature anomaly

2.2.5 Determining A Best Data Fit Value for TCS(1+β) = 1.8C

Since CO2 concentration has already increased its 1850 value by more than 40 percent, it is possible to estimate an accurate value for the constant TCS(1+β) by determining its value that provides a best fit of equation (1) to the actual long-term GMST change since 1850. This is demonstrated in Figure 1.0 where "trajectories" of GMST(year) are computed for different values of TCS(1+β) and compared to actual temperature data. We used the HadCRUT4 surface temperature anomaly database as a proxy for GMST temperature, as it is the only thermometer record dating back as far as 1850. Also, for years since 1978 when better spatial global temperature coverage from satellites has been available, the HadCRUT4 data are in better agreement with NASA's UAH-LT and NOAA's RSS satellite temperature measurements than other

available long term databases such as NASA's GISTEMP surface temperature database that begins in 1880.

As observed in Figure 1.0, the HadCRUT4 temperature anomaly for yearly average values has a data scatter of about 0.4 K from min to max over any 5-year period. This data scatter is about half of the long-term temperature increase of about 0.8C from 1850 through 2014. Choice of an appropriate baseline value for the HadCRUT4 temperature anomaly in 1850 can have a significant effect on the value of TCS(1+β) that will cause eq. (1) to provide a best fit to the long-term HadCRUT4 temperature rise trend.

After analysis of the entire HadCRUT4 dataset, it was observed that the maxima of the HadCRUT4 data scatter in the 1850-1900 period, except for the "outlier" data points for 1877 and 1878, provided a sharp baseline from which to measure long-term temperature change. The HadCRUT4 outlier data points for 1877 and 1878 were determined to be associated with a Super El Nino weather event, not due to GHG related temperature rise and were ignored in establishing the baseline. Analysis of HadCRUT4 data points for years with recent Super El Nino events of 1998 and 2015 also exhibited a narrow separation from maxima of HadCRUT4 data points of neighboring years. Therefore, it was reasoned that a fit of equation (1) to the narrow path between maxima of the HadCRUT4 data scatter and HadCRUT4 data points of Super El Nino years would provide the most accurate interpretation of the data set for long-term temperature rise that could be associated with monotonically rising atmospheric GHG concentrations.

The blue curve in Figure 1.0, with TCS(1+β) = 1.8C, provides this type of "best fit" to the data with the initial value for GMST(1850) selected to be -0.22C. This choice for GMST(1850) caused all curves to tightly bound the maxima of the HadCRUT4 data scatter in the 1850 – 1900 time period except for the Super El Nino weather event years of 1877 and 1878. The blue curve continues to "thread the needle" between upper levels of HadCRUT4 data scatter and the outlier data points of Super El Nino years, including the more well-known recent Super El Nino years of 1998 and 2015. Based on the 10 months through October 2016 for HadCRUT4 data, also affected by the most recent Super El Nino event, the HadCRUT4 data point for 2016 will be close to the 2015 value and will also lie close to or below this blue curve.

This blue curve has accurately followed the long-term GMST rise that could be attributed to rising atmospheric GHG concentration over the last 165 years, and in our opinion, provides a high-confidence determination for GMST sensitivity to atmospheric GHG concentration changes. This bounding approach in fitting the data points helps reduce the uncertainty in TCS(1+β) created by the choice of beginning and ending periods for averaging a number of HadCRUT4 yearly data points to determine long term GMST rise (as examined in Lewis and Curry (2014) for different beginning and ending periods) or that would be obtained by a Least-Squared-Error (LSE) fit of all data points that are clearly affected by periodic variations in the HadCRUT4 data. Because of the large data scatter in HadCRUT4 data points, this type of "bounding" data fit is easier to

recognize as an accurate long term fit of the warmest years of HadCRUT4 data. Selection of the constant TCS(1+β) = 1.8C that provides an accurate "best fit" to the HadCRUT4 data provides the validation of the TRCS Climate Model presented in eq. (1). The equation was rigorously derived from first principles and agrees with the available 165 years of data on atmospheric CO2 concentrations and earth surface temperature. Therefore, we claim this is a validated climate model suitable for forecasting GMST change as a function of atmospheric CO2 concentration and the type of model that should be used to support public policy decisions.

The future projection of the blue curve also provides a similar temperature bounding curve for the projected CO2(year) trajectory provided by the green curve in Figure 1.0. The curves with higher values of TCS(1+β) can be detected to provide too much CO2 sensitivity, as they begin to rise above the HadCRUT4 data of the most recent years when atmospheric CO2 concentrations increased to recent higher levels.

This behavior for recent years points out another important observation in Figure 1.0. As atmospheric CO2 concentrations continue to increase over the next 5 to 10 years, the true sensitivity of GMST increase to atmospheric CO2 concentration increase, as measured by metrics such as TCR and TCS(1+β), will become more readily apparent in plots like this, will help remove excessive uncertainty in current peer-reviewed literature estimates for these sensitivity parameters, and will allow scientists to agree on a more reasonable uncertainty range to be used in policy decisions. The excessive uncertainty in CO2 climate sensitivity employed in current SCC calculations has driven the computed statistical SCC "expected values" to unreasonably large values that have much more to do with politically driven speculation than rigorous science.

2.3 Forecasting GMST Change AND SCC with the TRCS Climate Model

The somewhat conservative bound for GHG-driven warming for the remainder of this century, provided by the blue curve of Figure 1.0, projects GMST will not increase more than 1C above recent levels by 2100. Our RCP6.0 emissions scenario on which this projection is based, is constrained by current official US Government EIA data regarding currently estimated world-wide reserves of coal, oil and natural gas. Coal is by far the major driver of CO2 emissions in this scenario and EIA world-wide coal reserves estimates vary by a factor of 3 from low to high estimates. We have used the highest of these estimates to construct the RCP6.0 scenario. However, current trends in Europe have coal mines being closed with less than 20 percent of their reserves included in the high EIA world-wide reserves estimates ever being recovered. Lending even more confidence to realism of this RCP6.0 scenario, are two independent 25 year forecasts for world-wide energy consumption published in 2015 by Exxon Mobil and BP. We converted their similar estimates for growth in fossil fuel consumption over the next 25 years to future yearly increases in atmospheric CO2 concentration and obtained the same 460 ppm CO2 concentration for 2040 predicted by this RCP6.0 scenario. We

believe that energy consumption forecasts by such large energy companies with large capital spending decisions based on these forecasts, are much more likely to be accurate than the speculative emissions scenarios developed by international academics in the peer-reviewed literature that are unconstrained by actual data on world-wide fossil fuel reserves.

The validated TRCS Climate Model and RCP6.0 emissions scenario provide a maximum 1C temperature rise above current levels by 2100. According to the 2010 SCC TSD Figure 1A reproduced here as Figure 2.0, the effects of a 1C temperature increase by 2100 as computed by the current Integrated Assessment Models, is either beneficial or neutral.

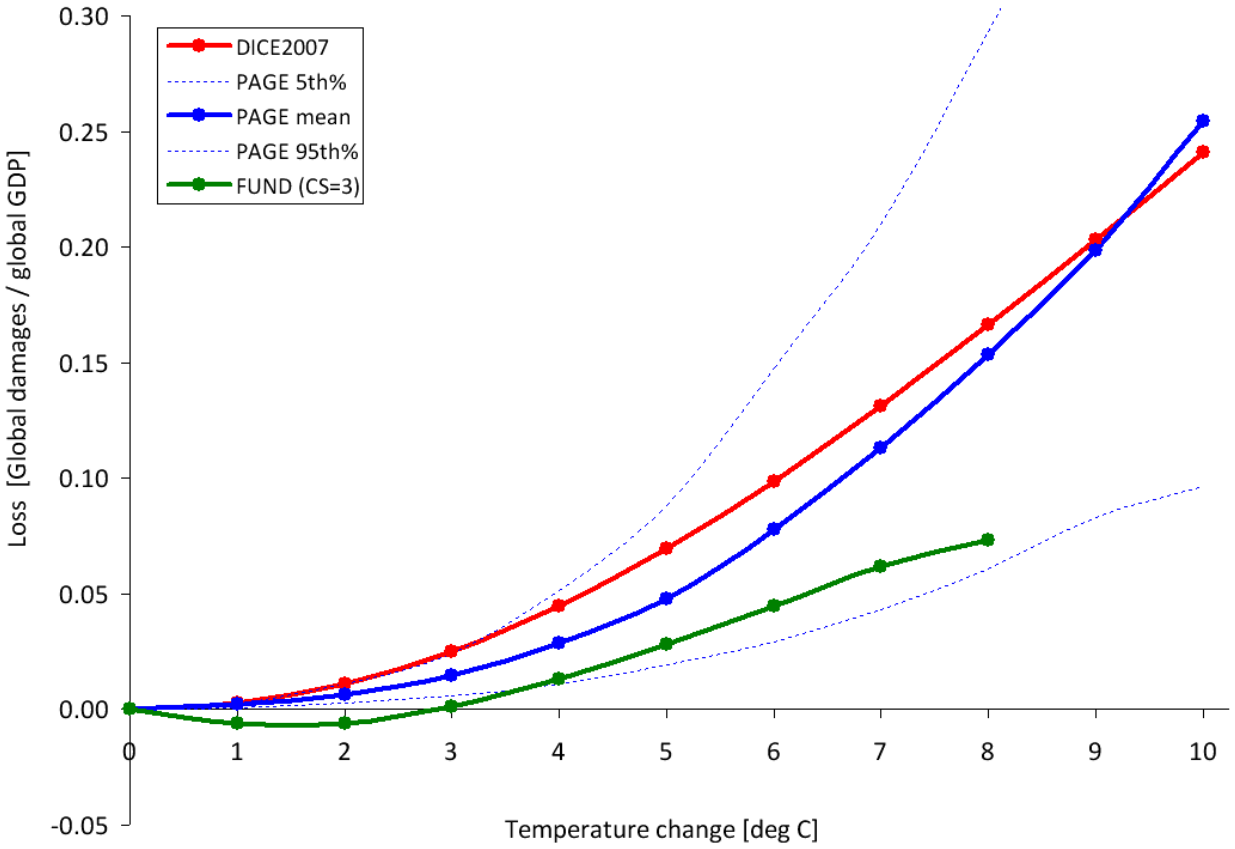

Figure 2.0 Effects of temperature change in 2100 on as computed by IAMs

These results for temperature rise forecast based on the validated TRCS Climate Model and RCP6.0 emissions scenario, constrained by official US Government EIA data, contrast with the much higher and speculative values for SCC the EPA has used to justify its CO2 emissions regulations. These results clearly demonstrate that the SCC calculation process needs an in-depth review and critique by a scientific review board

with members selected from broad fields of science and mathematics and without conflicts of interest.

2.4 ESTIMATING TCS FROM TCS(1+β) = 1.8C

Using TCS(1+β) = 1.8C as determined from Figure 1.0 and an average historical value for β = 0.5 determined from IPCC AR5 Report data, TCS is estimated to be 1.2C and is close to TCR values published in other recent peer reviewed published literature where the TCR estimates are based on actual climate data, not climate simulation models. See for example, Ring et. al. (2012), Otto et. al. (2013) and Lewis and Curry (2014). Even though this TCS estimate has considerable uncertainty because of the uncertainty in β, we only compute it to compare with values published in the peer-reviewed literature. As shown in Figure 1.0, with the assumption that β will continue to hold to its historical value of the last 165 years (whatever that somewhat uncertain value actually is), an accurate GMST projection to 2100 and beyond for any proposed CO2(year) projection can be made using the constant, TCS(1+β) = 1.8C, that does not have the uncertainty attached to β.

Based on the results of Figure 1.0 where a value of TCS(1+β) = 2.0C, only 11.1 percent higher than 1.8C, causes equation (1) to begin to noticeably deviate from actual temperature data, we do not believe use of extremely large uncertainty in earth surface temperature sensitivity to atmospheric GHG concentration, as employed in the Interagency Working Group (IWG) SCC calculations, is scientifically justified. This will be discussed in greater detail in the following section of this report.

While the long-term GMST projections to 2100 and beyond are impossible to make precisely, the key conclusion from a conservative bounding approach employed in our analysis, is that we do not have a rapidly developing climate problem requiring swift corrective action. We have time to study this issue in a more disciplined manner and to develop a true broad-based scientific position with minimal uncertainty, regarding GMST sensitivity to atmospheric GHG concentrations, before trying to take risky and ineffective unilateral GHG emission control actions based on a far-too-incomplete scientific and economic impact understanding of the issue. As mentioned above, the next 5 to 10 years of atmospheric GHG and GMST data should allow the US scientific community to agree on a much-needed reduction in uncertainty regarding GMST sensitivity to atmospheric GHG concentrations for use in public policy decisions regarding GHG emissions.

3.0 SCIENTIFIC CRITIQUE OF THE SCC CALCULATION METHODOLOGY

The current Monte Carlo calculation process for SCC as described by the three Technical Support Documents (TSD) the IWG has published to document the process, is overly complex, highly speculative, and hides from critical review key important variables that could be used to assess the reasonableness of the results. There are numerous serious issues with lack of model validation required for use in public policy decisions for the various models used in the SCC calculation.

3.1 Un-validated Integrated Assessment Models

First, the Integrated Assessment Models (IAMs) used to calculate benefits and damages of CO2 emissions are clearly not validated, as they yield widely differing SCC values for the same assumed GMST vs. time and atmospheric GHG vs. time histories used to drive all IAMs as shown in Figure 2.0. The IWG deals with this issue by averaging the different SCC calculations of the three different IAMs and using the averaged result to guide policy decisions. Averaging widely varying results from models whose authors claim compute the same SCC metric, cannot provide a safe and reliable approach for serious public policy decisions with potentially severe unintended consequences. This practice can be compared to computing the structural strength of a commercial airplane wing with three different models that give widely varying results and then averaging the results to determine if the wing strength satisfies Federal Aviation Administration (FAA) wing strength requirements. Who would feel safe as a passenger on this airplane? By what rationale did the Dept. of Transportation (DoT) representatives to the Interagency Working Group (IWG) that developed the SCC computation process concur with this decision? Did they represent the position of the DoT's FAA that the public trusts for ensuring safety of airline travel with FAA imposed regulations? We have no further comment on the lack of rigor on the benefit and damage calculation aspects of the IAMs and will leave this critique to others who we know have studied these issues in more detail.

3.2 Un-Validated GCMs Used to Calculate ECS Uncertainty

We have major concerns regarding the "front end" assumptions and statistical calculations in the IAMs that compute GMST vs. time for 300 years into the future. In each IAM, the benefits and damages are computed for 10,000 different trajectories of GMST vs. year and GHG emissions vs. year for 300 years into the future. Each of these 10,000 samples of GMST vs. time trajectories are determined from a random sample of key parameters from two different statistical distributions. The first key statistically treated parameter is Equilibrium Climate Sensitivity (ECS) that is a CO2 climate sensitivity metric defined by the UN IPCC as the GMST temperature increase that would eventually occur when a new climate equilibrium is achieved after a sudden doubling of atmospheric CO2 concentration. Not widely advertised to policy decision makers is that the idealized equilibrium state would not be achieved in more than 1000 years after CO2 is doubled. The selection of a statistically treated ECS parameter only

provides an endpoint estimate for total GMST rise more than 1000 years into the future. Because of highly speculative processes modeled in climate simulation models to compute ECS after 1000 years or more of climate simulation, ECS has much more uncertainty than TCR or TCS(1+β) and selection of this metric for the SCC calculation process injects unnecessary uncertainty into the SCC calculation process. The TCR metric is scientifically more appropriate for use in GMST projections in the 300 years horizon.

3.3 Un-validated Model Used to Convert ECS to GMST Vs. Time

The SCC calculation process needs a GMST estimate for each of the next 300 years into the future. The transient temperature increase in the first 300 years after a sudden CO2 doubling, as simulated in GCM ECS simulations, is nothing at all like the transient temperature increase that occurs from the actual slowly rising CO2 concentration. The undisclosed method(s) used in IAMs to compute GMST vs. time from the statistically selected ECS and emission scenarios need to be reviewed in detail to determine their validation status. We propose from a scientific viewpoint, that our validated TRCS Climate Model compared to actual data in Figure 1.0, is much better suited for computing a projection of GMST vs. time for a selected emissions and GHG concentration scenario.

3.4 Speculative ECS Statistical Distribution Used to Compute SCC

The scientific reasoning used by the IWG to establish the ECS statistical distribution it assumed for ECS is highly suspect. This statistical distribution decision started with the UN IPCC publication of its 2007 AR4 Report that gave the uncertainty range for ECS as,

$$2 < ECS < 4.5C$$

This ECS uncertainty range was based on climate simulation results of 18 different un-validated climate simulation models from various international organizations studied for the AR4 Report, and certainly does not represent the best science that US scientists can contribute to this issue. The climate science publications through about 2004 were used to compile this AR4 report and are now more than 10 years old in this rapidly developing field of science. The more recent 2013 IPCC AR5 Report lowered the lower end of this ECS uncertainty range to 1.5C and stated that information from multiple lines of evidence prevented it from reaching any conclusions regarding the mean value of this range. If a mean value for ECS cannot be supported by the current state of climate science, how can one claim scientific validity for the much more detailed statistical distribution for ECS that is a primary driver of the SCC calculation process? The currently computed SCC are no more believable than wild speculation! How can the EPA defend its decision to ignore the potential serious damage to the US economy and

risks to the US electrical power grid on the basis of such frivolous and speculative computations?

The IWG decided to use the highly uncertain ECS metric for public policy decision-making even though the same AR4 Report noted that the much less uncertain TCR metric would be more appropriate to use for near term GMST projections. But, the next decision made by the IWG when the AR5 Report scientists said they couldn't even comment on a reliable mean value for the ECS uncertainty range needs even more scientific probing. The IWG arbitrarily decided that the statistical distribution it would create for sampling ECS values to compute SCC should have values as high as 10C. This ECS distribution published in the 2010 SCC TSD has 20 percent of the ECS values in the 4.5 - 10C range. Justifying this decision as using caution on the high side of potentially high GMST damages was an arbitrary decision with unnecessary speculation that skewed the statistically computed SCC "expected values" to speculatively high values. The 20 percent probability that ECS would be higher than the upper limit of the published IPCC ECS uncertainty range leads to extremely high damage calculations with a small probability of occurrence that results in an overly high and totally speculative statistically "expected value" for SCC. It appears that the IWG's arbitrary assumptions and questionable decisions to use the highly uncertain ECS metric in an arbitrarily biased statistical distribution with little scientific justification, was orchestrated to get the unnecessarily complex Monte Carlo process to compute the high value of expected SCC that would be needed to justify GHG emissions regulations.

3.5 Obsolete GHG Emission Scenarios Used to Compute SCC

In addition to the statistically sampled CO2 climate sensitivity metric, a GHG emissions scenario for the future that allows calculation of atmospheric CO2, other GHG and aerosol concentrations for each year in the future, is required to compute a future GMST temperature time history. In the SCC calculation process, each of 10,000 samples of statistically calculated benefits and damages in the IAMs begin with a 300 year GMST time history computed from statistical sampling from the highly questionable ECS distribution and a statistical distribution for the emissions scenario. Five widely differing emissions scenarios from the Stanford Energy Modeling Forum exercise, EMF-22, were selected for use in SCC calculations. However, since the IWG put no effort into assessing which of these scenarios might be more relevant and likely than others, they decided to make the statistical distribution from which the 5 scenarios would be sampled, a uniform distribution. That is, the SCC calculation process assumed any one of these widely varying scenarios had an equal probability of occurrence. This is tantamount to concluding "we have no idea what might happen" and we will base our policy decisions on this kind of foolish speculation without true scientific investigation and deliberation. This decision can be compared on a scientific basis to the RCP6.0 scenario our research team developed as a data-driven baseline for what we believe is most likely to happen, and what a realistic GMST time history for the remainder of this century should look like.

Making validity assessments even more difficult for this decision by the IWG to use a uniform distribution for the GHG emissions scenarios was lack of information provided on the details of these scenarios. The 2010 TSD only presented GHG emissions vs. year for the 5 selected scenarios and did not present the atmospheric concentrations of GHG vs. year derived from these emissions scenarios that drive the GMST trajectory. Since SCC is defined in terms of emissions and there is lots of science to be dealt with in the methods used to convert emissions to atmospheric GHG concentrations that cause temperature rise, important related scientific issues were not discussed in the SCC TSDs.

The most information supplied on this issue from the 2010 TSD indicated that 4 of the 5 scenarios used had 2100 atmospheric CO2 levels ranging from 612 to 889 ppm. These values compare to our RCP6.0 scenario with 585 ppm CO2 in 2100 and 600 ppm maximum possible by 2130 from burning all currently known fossil fuel reserves on the planet. A key aspect in our development of the RCP6.0 scenario was data analysis that showed since 1980, when accurate data on world-wide fossil fuel production became available, the annual rise in atmospheric CO2 concentration is a consistent and constant 48 percent of CO2 emitted from burning the annual production. We assumed all this production was burned in the year produced and we computed the number of CO2 molecules released into the atmosphere from burning each of the fossil fuel types to determine the 48 percent value in terms of the annual average Mauna LOA CO2 concentration data. This 48 percent value has stayed constant in 5 year averages of the data, even though CO2 emissions in recent years were much greater than in 1980. This 48 percent fraction was assumed to stay constant in our projection of a maximum of 600 ppm atmospheric CO2 concentration when all currently known fossil fuel reserves are consumed. The 5th emissions scenario used in the SCC calculation process, the “550 ppm average” scenario, had much lower emissions than the other 4 scenarios and a 2100 GHG radiative force of only 550 ppm CO2-equivalent for all GHG. However, since 4 of the 5 scenarios used had radiative forcing higher than our data constrained RCP6.0 scenario, and the 5 scenarios were sampled with a uniform probability of occurrence, the expected value computed for SCC would be higher than if our RCP6.0 scenario were used and that is constrained by official US Government EIA published maximum estimated world-wide fossil fuel reserves data.

3.6 Applying “Sanity Checks” to the SCC Calculation Process

The intent of the US Congress that only validated models should be used for public policy decision-making by regulating agencies was egregiously violated when the IWG decided to use its totally “made-up” and highly speculative statistical distribution for ECS together with un-validated GHG emissions scenarios as key drivers of the SCC calculation process. Moreover, the TSDs describing the SCC calculation process never revealed key process output that could be used to assess the validity of the methodology. For example, no output was provided for interim steps of the process that

would reveal GMST vs. time trajectories that could be assessed for reasonableness against actual GMST data.

Also not presented as a "sanity check" on the results, were statistics on atmospheric CO2 and other GHG and aerosol concentrations vs. time that could be compared to actual data trends. Much of the current SCC damage results from projected sea level rise, but nothing was disclosed in SCC TSDs regarding model output statistics of sea level rise rates and whether they were reasonable compared to available data as reviewed by Mörner (2016). A reasonable sanity check on the ECS and sea level rise aspects of the process, would be to:

1. Use the median of the IPCC AR5 atmospheric and aerosol GHG concentration history and radiative forcing from 1850 through 2015 as a test emissions scenario.

2. Start the GMST prediction process in 1850 using the AR5 median estimate for the past atmospheric GHG history compare the IAM output statistics to actual GMST and sea level rise trends since 1850

If there is a high temperature/high damage bias in the current SCC calculation process as suggested based on our independent assessment, it will be evident in this reasonable check that should be made for something as serious as public policy decisions with potentially severe adverse consequences for the entire US population.

3.7 More Research Needed on GHG Emissions Scenarios

The emissions scenario aspect of the current SCC calculations needs a more in-depth scientific review and determination for what should be used in this critical step of the process for determining true cost/benefits of not regulating GHG emissions or specific proposed GHG emissions regulations. Four of the the emissions scenarios used in the current SCC calculation process are "business as usual" scenarios, but all have higher atmospheric CO2 concentrations in 2100 than our RCP6.0 scenario. The only updated emissions scenario published in the 2013 AR5 Report that does not assume some level of world-wide GHG emissions controls will be implemented, has an RCP8.5 rating indicating its radiative forcing will be 8.5/6.0 = 1.42 times our RCP6.0 scenario in 2100. RCP8.5 is similar to the highest emissions scenario, MERGE Optimistic, used in the current SCC calculation. All published information regarding the RCP8.5 scenario indicate it was created to represent a 90^{th} percentile high emissions scenario; it is not constrained in any way by current estimates or discovery trends in world-wide fossil fuel reserves.

We propose our RCP6.0 scenario as a baseline for discussion for the most likely scenario that would represent future atmospheric CO2 level trends if no world-wide CO2 emission controls are enforced. We believe our RCP6.0 scenario could be improved through a study of EIA data that would correlate annual increases in world-wide fossil fuel reserves estimates to annual world-wide fossil fuel production. This study would be used to perform a data-constrained estimate of how EIA estimates of total world-wide

fossil fuel reserves would trend for the future and how much our 600 ppm maximum atmospheric CO2 concentration from burning fossil fuels could be increased.

3.8 Detailed Assessment Needed for Economic Impacts of Clean Power Plan

Given the potentially severe economic impacts to the coal industry and US electrical power generation industry depending on coal fired power plants, it seems prudent that EPA should be required to perform a more in-depth assessment of economic impacts of its proposed Clean Power Plan than can be gleaned from the current highly uncertain, and we believe high-biased, SCC values. The specific economic impact arguments are being developed through lawsuits against the EPA by states and companies affected by the proposed Clean Power Plan regulations, while it appears that the EPA has not performed the serious scientific and economic analyses Congress expects for justifying new regulations.

3.9 Need to Remove Uncertainty from Climate Projections

While the long-term GMST projections to 2100 and beyond are impossible to make precisely, the key conclusion from a conservative bounding approach employed in our analysis, is that we do not have a rapidly developing climate problem requiring swift corrective action. We have time to study this issue in a more disciplined and focused research manner with the goal of developing a true broad-based scientific position with minimal uncertainty, regarding possible GMST rise due to GHG emissions in the future. This broadly based scientific position of the US scientific community is required before our government tries to take risky and ineffective unilateral GHG emission control actions based on a far-too-incomplete scientific and economic impact understanding of the issue.

4.0 NEED FOR VALIDATED MODELS TO SUPPORT PUBLIC POLICY DECISIONS

We believe the key mistake that has been made in climate research funded by the US government so far, is that too many studies with un-validated models have been funded. In our experience with manned space exploration, such extremely complex and un-validated models cannot be believed for any rational public policy decision-making with potentially severe unintended consequences. There is no true scientific information, consistent with The Scientific Method, to be learned from such poorly allocated research funding. We observe that overly complex and un-validated models are being used to estimate important climate change metrics such as TCR and Equilibrium Climate Sensitivity (ECS), when much more accurate metrics, without uncertainty added by un-validated models, can be determined more directly from climate data, as we and several other researchers have done. The data indicate low climate sensitivity to atmospheric CO2. All other un-validated model determinations of climate sensitivity that result in much higher CO2 climate sensitivity uncertainty estimates published by the IPCC, are

worthless speculation and should not be used in decision-making with potentially severe unintended consequences.

A basic flaw in the current Federal government response to the AGW threat is that climate scientists are basing their concerns on complex, un-validated climate simulation model results, rather than using available data in a more scientifically based assessment of the threat. NASA has strict policies documented in NASA-STD-7009 against the use of un-validated models for design or operational decisions regarding human safety. We believe the national assets represented by NASA and the US military regarding decision making for mitigation of threats should be employed by the US government to deal with the AGW concern.

5.0 NEED FOR DISCIPLINED ROOT CAUSE ANALYSIS AND DECISION-MAKING

In dealing with safety related threats in the manned space program, we use disciplined processes to define Problems in terms of parameter deviations outside of normal or safe limits. We analyze and prove root cause(s) of Problems by analyzing the specific data of the Problem definition and specifications in terms of What?, Where?, When? and How Much? these deviations occur, as well as answers to these same questions related to similar situations where deviations don't occur. The entire anthropogenic global warming (AGW) "Problem" the EPA has been trying to mitigate with GHG emissions regulations, is not a Problem for which root cause can currently be determined, within our strict Problem definition, as GMST has not deviated beyond the normal range of the last 10,000 years that had nothing to do with GHG emissions. What we have is a Potential Problem or AGW threat that we should, as a nation formally address, but this threat is developing slowly enough that a more rational government response to the threat would be to focus near term research on removing excessive and unnecessary scientific uncertainty regarding magnitude and timing of the threat.

If disciplined Problem Solving and Decision-Making processes were used at the EPA as they are in other agencies focused on scientific matters, the EPA would need to define environmental Problems in terms of metrics that define deviations in harmful substance concentrations outside of well-established safe limits. They need to demonstrate their knowledge of the science that defines safe limits. Once these limits are established, they need to determine true root cause(s) for the deviations beyond safe limits. The EPA should develop a broad array of options that could be considered to mitigate the defined problem. Imposing new regulations might represent several possible options with varying degrees of effectivity and economic costs, but these may not be the optimal actions for the government to take considering cost, schedule and effectiveness of all options identified and evaluated. The EPA should not take the view that its charter is to impose new regulations. Instead, the EPA should assess environmental concerns, determine root cause of Problems and recommend to our federal government the optimal solution the government should take to resolve the issue.

Our research team has investigated the scientific arguments on either side of the complex climate issues leading to the EPA Endangerment Finding regarding GHG emissions, as well as the scientific work and documentation of the Interagency Working Group (IWG) and the EPA in Technical Support Documents (TSD) describing computation of the Social Cost of Carbon (SCC) metric. The EPA and other regulating agencies use SCC to represent a cost/benefit analysis of specific regulations aimed to reduce GHG emissions. We find the scientific work by the IWG and EPA on these issues to be extremely poor and dangerously inadequate, given the possible severe economic damage to the US economy and US citizens from EPA regulations being justified by the current SCC metric. We have previously expressed our concerns and specific scientific issues regarding the SCC computation assumptions and methodology in Office of Management and Budget (OMB) and EPA official calls for public comment on the SCC issue, and proposed regulations economically justified to Congress with the current SCC values. We have had no response to our serious, legitimate concerns that are summarized once again, in this report. This part of the public comment process intended by Congress to be somewhat of a check on unbridled authority of the EPA seems to be dysfunctional.

We observe that Congress has granted the EPA extremely vast power to create regulations that can have severe negative consequences for US companies and citizens. This power has vastly increased in scope, certainly far beyond what Congress intended with its passage of the Clean Air Act, through activist moves by the Executive and Judicial branches of government, that remain unchecked by the US Congress. The US Congress needs to rectify usurpation of power by the EPA through its implementation of ideological political agendas of the Executive Branch, and through Supreme Court decisions upholding EPA's interpretation of power granted to it by the Clean Air Act. This will require longer term legislative action if Congress disagrees, as we do, with EPA claims upheld by the US Supreme Court, that CO2 is a pollutant in the sense Congress intended to define pollution in the Clean Air Act.

It is scientifically embarrassing to our team of experienced and accomplished Apollo Program scientists and engineers, that our government could officially declare that CO2 is a "pollutant" that needs to be regulated. CO2 is a colorless, odorless, non-toxic, trace gas in our atmosphere, essential to sustain all plant and animal life on this planet. Available data indicate that burning all fossil fuel reserves on the planet could only create an atmospheric CO2 concentration less than 10 percent of previous 7000 ppm naturally occurring levels experienced in our planet's history. At the last glacial maxima about 21,000 years ago, our planet came dangerously close through natural processes that reduce atmospheric CO2 levels, to the 150 ppm critical point where plant life cannot grow. This would have truly represented a climate disaster for our planet. Fortunately, increased atmospheric CO2 levels from natural warming out of the last glacial maximum, and perhaps some additional amount returned to the atmosphere previously sequestered in fossil fuels, has moved us away from the brink of a clear climate disaster due to too little atmospheric CO2 concentration. An optimal level of atmospheric CO2

concentration has not been scientifically established, considering all factors. We allow more than 10 times the current 400 ppm atmospheric concentration of CO2 on our International Space Station with no concerns for astronaut safety.

By upholding the EPA's Endangerment Finding, the Court has agreed that the EPA has authority to regulate CO2 emissions. The US Supreme Court does not have the scientific expertise to understand and adjudicate complex scientific matters. More appropriately, this should be the responsibility of scientific review boards, with membership from a broad spectrum of scientific expertise and experience selected by Congressional oversight to be free of any conflicts of interest. As pointed out in above discussions of this report, the EPA has demonstrated its lack of scientific expertise in the method it selected to compute SCC to justify the cost/benefits of its GHG emissions regulations, and has been scientifically irresponsible in its decisions to regulate this critical chemical compound without due regard for potential unintended consequences.

The scientific arguments used by the EPA to classify CO2 as a pollutant in its famous Endangerment Finding allowed by the US Supreme Court, need to be reviewed by an independent scientific review board composed of a broad range of US scientific, engineering and mathematical expertise, and whose members are carefully vetted for potential conflicts of interest.

6.0 REFERENCES

Lewis N, and Curry, J. A. (2014), The implications for climate sensitivity of AR5 forcing and heat uptake estimates, Climate Dynamics, August 2015, Volume 45, Issue 3, pp 1009–1023

Mörner, N.-A. (2016) Rates of Sea Level Changes—A Clarifying Note. International Journal of Geosciences, 7, 1318-1322.
http://dx.doi.org/10.4236/ijg.2016.711096

Otto et. al. (2013), "Energy Budget Constraints on Climate Response", Letter to the Editor, *NATURE GEOSCIENCE* , VOL 6, JUNE 2013

Ring, M. J., Lindner, D., Cross, E. F., and Schlesinger, M. E. (2012) "Causes of the Global Warming Observed since the 19th Century", *Atmospheric and Climate Sciences*, October 2012, 2, pp. 401-415 doi:10.4236/acs.2012.24

Trenberth, K. E, Fasullo, J. T, and Kiehl, J. (2009), Earth's Global Energy Budget, Bulletin of the American Meteorological Society, March 2009
DOI: http://dx.doi.org/10.1175/2008BAMS2634.1

APPENDIX A

DERIVATION OF THE TRCS CLIMATE MODEL

A1.0 ENERGY BALANCE OF THE EARTH CLIMATE SYSTEM

A1.1 Kiehl-Trenberth Energy Transport Diagrams

Figure A-1.0, adapted from Trenberth et. al. (2009), shows a diagram of the power in W/m^2 of the spherical earth surface area entering and leaving the Earth's climate system, and the various heat transport mechanisms of the Earth's surface and atmosphere that affect earth surface temperature. Kiehl and Trenberth introduced such energy flow diagrams in 1997 and have continued to update them as more data have become available.

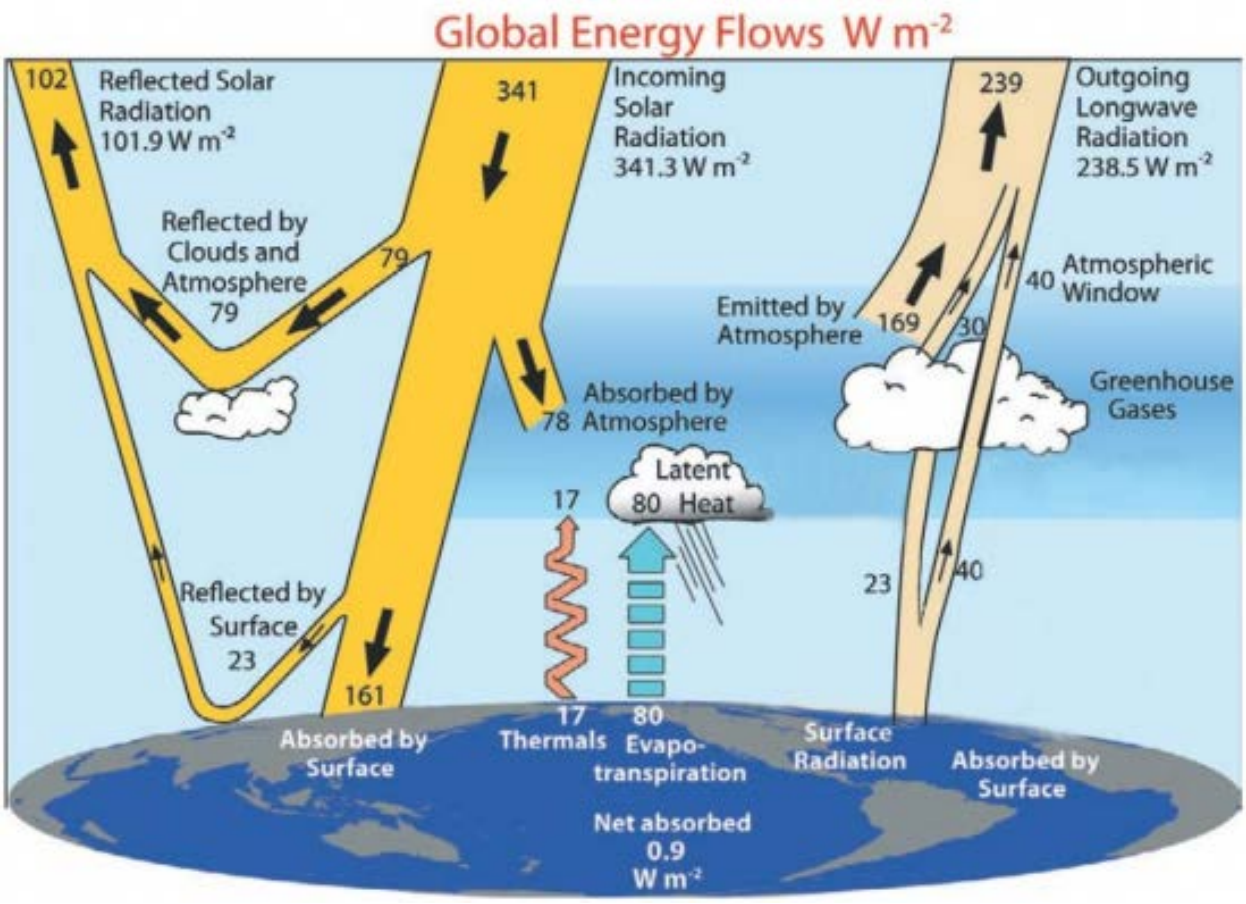

Figure A-1.0 Annual average instantaneous global energy flows

This diagram was updated in Trenberth et. al. (2009) based on satellite measurements for incoming and outgoing radiation at the Top of the Atmosphere (TOA) as explained in

detail in the referenced article. The only modification to this figure originally presented by the authors was to simplify it to show only the net power radiated from the surface and to delete the large 333 W/m^2 radiated in opposing directions between the surface and atmosphere. Although climate scientists prefer to show the energy radiated to the surface by the atmosphere because the atmosphere contains "heat trapping" GHG, this unnecessarily complicates the essential physics of radiation heat transfer leaving the surface and atmosphere and flowing to deep space that needs to be analyzed.

In engineering practice, when two surfaces at different temperature, such as the earth's surface and a cooler surface within the atmosphere, have a radiation exchange, it is common practice to only examine the net energy radiated out beyond the cooler body and to ignore the equal and opposite radiation exchanges between the warmer and cooler body. Also, provided in Fig. A-1.0 are annual average values for continuous rates of energy flow transported by these mechanisms based on measured data. Many diagrams such as Figure A-1.0 appear in climate science literature with only small variations of the numerical values appearing in various technical publications. These energy transport rates are generally accepted by the entire climate science community and for purposes used herein, we will use the values provided in Figure A-1.0

A1.2 Problems with General Circulation Models (GCM) Used in Climate Science

General Circulation Models (GCMs) used for studies in most climate science publications attempt to model in a forward time simulation the variations in all the complex chemistry and physics governing processes in Figure A-1.0 within the oceans, land masses and atmosphere, as well as exchanges between the oceans, land and atmosphere that affect all the energy transport quantities. They attempt to model how increasing concentrations of GHG in the atmosphere will affect these heat transport variables over periods of thousands of years. Many publications in climate science present computed results of these very complex, but un-validated, models that are of questionable scientific value as they don't adhere to principles of The Scientific Method that would require that the model be validated with physical data. From a scientific viewpoint, climate change is an extremely difficult problem to simulate with accuracy and thus far GCMs have not been developed to the point where they can be validated by actual climate data. Fortunately, GCMs are not the only way that science can determine the effects of atmospheric GHG on earth surface temperature changes. This can be accomplished with greater accuracy and certainty, through analysis of available data as will be demonstrated herein.

An obvious problem with the GCM climate simulation approach is revealed in Figure A-1.0 where just one very complex problem to simulate accurately is the approximate 80 W/m^2 of latent heat transported from the surface to colder levels of the atmosphere by water evaporation and condensation cycles. Water covers 71 percent of the earth's surface and water evaporation is a complex phenomenon to simulate accurately, as it is

a function of water temperature, relative humidity of the few inch thickness of air exchanging water vapor with the water surface, relative humidity of higher layers of the atmosphere, surface winds, water surface roughness, water droplets launched into the less humid layers of air by rough seas, etc. A popular simulation attempted by GCMs is to compute the increase in surface temperature caused by a doubling of CO2 concentration in the atmosphere. CO2 molecules constitute only about 0.04 percent of all molecules in our atmosphere, most often expressed as 400 ppmv (parts per million by volume, and also abbreviated by ppm). The basic quantum physics modeled in infrared radiation absorbed and re-radiated by GHG molecules indicates a 3.71 W/m^2 reduction in infrared energy leaving the TOA by doubling atmospheric CO2 concentration, before effects of other possible related climate changes (feedbacks) are considered. The GCMs attempt to compute how radiation heat transfer within the atmosphere out to deep space is affected by the change in atmospheric CO2 concentration, as well as other climate feedbacks that may also affect earth surface temperature due to change in the CO2 trace gas in our atmosphere. But to detect this effect in simulation results on earth surface temperature, an accurate simulation of all other heat transport mechanisms shown in Figure A-1.0 affecting earth surface temperature, plus others within the earth's oceans is required. To the extent that natural processes are not well-understood or cannot be simulated accurately, the effects of doubling CO2 cannot be determined accurately by GCMs.

For example, only a 5 percent simulated error of 4 W/m^2 in how the latent heat transfer of 80 W/m^2 will change during the time the CO2 concentration doubles, would affect computed earth surface temperature as much as the expected change from doubling CO2 concentration. At current rates of CO2 concentration increase in our atmosphere, it will take about 230 years to double the 1850 CO2 concentration. In our experience with such complex models, GCMs cannot be expected to compute so many complex processes with less than 5 percent error in any of these energy transport mechanisms over a 230 year period required to compute our TCS = TCR metric, much less the more than 1000 years required to compute the ECS metric.

The widely varying numerical results from such GCMs are being used in the climate science literature and by the IWG and EPA to be indicative of the uncertainty in the TCR and ECS metrics. This kind of un-scientific uncertainty is being injected into public policy decisions at the EPA with potentially severe adverse consequences for our nation, if the wrong decision is made on either side of the AGW issue. The inability of climate scientists to reduce their factor of 3 uncertainty in the ECS metric in more than 35 years of study, is clear evidence that a new approach, devoid of un-validated GCM influences, is needed for public policy purposes. If only an accurate measure of how Global Mean Surface Temperature (GMST) will change with changes in atmospheric CO2 concentration to compute SCC, as is the case for current SCC calculations, then there are much simpler models with much less uncertainty in computed results that can and should be used for this purpose. Moreover, these simpler models can be validated

by climate data and are well-suited for use in public policy decision-making. We demonstrate the derivation and validation of one such model herein.

A1.3 A Data-Driven Approach for Determining CO2 Climate Sensitivity

We will herein demonstrate the rigorous derivation and validation of a much simpler modeling approach based on well-known Laws of Physics, and constrained by available data, that provides a much more accurate and less uncertain value for the TCS = TCR metric that is best suited for public policy decisions. Other researchers such as Ring et. al. (2012), Otto et. al. (2013), Lewis and Curry (2014) and Lewis (2016) and several others have demonstrated independent, but related data constrained models that can estimate both TCR = TCS and ECS metrics, and have close agreement with our model that determines TCS. Uncertainty in ECS is primarily associated with sparse data available required to determine more precisely variations in the 0.9 W/m^2 value in Figure A-1.0 for surface heat that is transported to the deep ocean and may be expected to be recovered at the surface in 1000 years or more. The transient climate sensitivity metrics of TCS and TCR are not affected by this poorly known value and, we submit, are much better suited than ECS for forecasting GMST in a 300 year horizon, as required in the SCC calculation.

A2.0 USING FIRST PRINCIPLES TO OBTAIN SIMPLE HIGH-CONFIDENCE MODELS

The First Law of Thermodynamics, that is a statement of the Conservation of Energy, requires that the difference between incoming and outgoing energy flows of a system as shown in Figure A-1.0 results in a change in internal energy of the system, as measured by internal temperature of the system. The average annual temperature of the earth's surface, also referred to as GMST, varies very little because of a powerful temperature regulating mechanism resulting from the Stefan-Boltzmann (SB) Law that determines energy radiated from the surface of a body that is a function of the surface absolute temperature raised to the 4^{th} power,

$$\text{(Radiation Heat Transfer)} = Ae\sigma T^4 \quad \text{Watts (W)}$$

$$\text{(Radiation Heat Transfer)}/A = e\sigma T^4 \quad W/m^2$$

where

A = radiation surface area, m^2

e = emissivity constant for specific surface characteristics and coatings

σ = Stefan-Boltzmann Constant = $5.67(10)^{-8}$ $W/m^2/K^4$

T = absolute temperature of the radiating surface, deg Kelvin (K)

This sensitive T^4 relationship provides a strong and smoothly continuous heat transport feedback mechanism for surface temperature control. The maximum local surface radiation heat transport to deep space occurs during daylight hours when local surface temperature is highest, but this heat transport process continues through the night time hours at reduced rates of heat transfer, as the surface temperature cools from outgoing radiation heat transfer, before surface re-heating during the next daylight period.

The climate model developed herein will use these basic Laws of Physics to quantify how yearly average changes in key system parameters are related to GMST change. The basic theory for how atmospheric Greenhouse Gases (GHG) can warm the earth's surface results in a lower rate of energy (power) being radiated to deep space by a given earth surface temperature. In engineering practice, this kind of decrease in radiated energy from a surface is modeled as a decrease in emissivity that can be measured, in lieu of the much more difficult and uncertain task of computing this emissivity decrease from models as GCMs attempt to do.

A2.1 Earth Surface Energy Balance Model

Note in Fig. A-1.0 at the TOA, the energy balance obtained by:

Short wave radiation in - Short wave radiation reflected = long wave radiation leaving

$$341\ W/m^2 - 102\ W/m^2 = 239\ W/m^2$$

This rough calculation ignores a small amount of energy transported from the surface to the cold deep oceans that should be recovered at the surface in some future state of equilibrium of incoming and outgoing radiation and earth surface and atmospheric temperatures.

A closer examination of values presented in Fig. A-1.0 for all energy transport quantities, reveals that currently, a small rate of heat energy ($Q = 0.9\ W/m^2$) is absorbed by the Earth's surface and transported to the deep cold ocean without being radiated back to space.

A 1000 mile arc of the Earth's surface and the top of the Stratosphere 14 miles above the surface are shown approximately to scale in Fig. A-1.1, revealing the very thin layer of the atmosphere that provides a very complex alteration of IR energy radiated from the earth's surface. GCMs spend much of their effort trying to simulate what happens in the

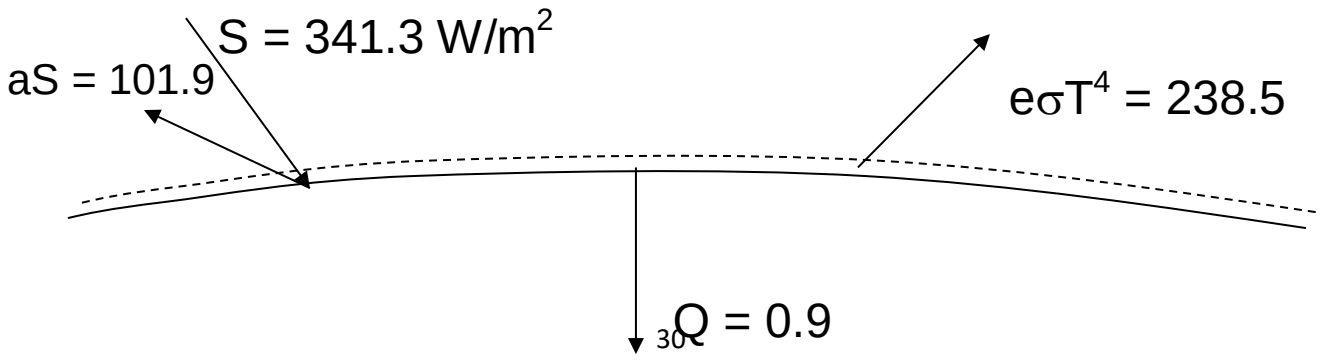

Figure A-1.1 Energy balance of the earth surface and atmosphere to top of Stratosphere

thin atmosphere region between the surface and top of the Stratosphere. But this is totally unnecessary to determine earth surface temperature sensitivity to atmospheric GHG and aerosol concentrations because relatively accurate measurements can be made to determine this sensitivity. Only simple models based on first principles are needed to reduce the data to determine this sensitivity relationship.

Fig. A-1.1 is a simplification of Figure A-1.0 showing only energy flows into and out of a different control volume (climate system) boundary defined by the Earth's surface and the top of the Stratosphere indicated by the dashed line. The GHG in the small thickness of the atmosphere below the top of the Stratosphere affects these energy flows. Once the IR radiated from the surface and absorbed and re-radiated by gases in the relatively thin thickness of atmosphere reaches the top of the Stratosphere, it is radiated out to deep space (238.5 W/m^2 in Fig. A-1.1) without being absorbed by GHG higher in the atmosphere. There is essentially no water vapor above the top of the Troposphere, ranging from 12 miles above the surface in the tropics to only 4.3 miles above the surface at the poles in winter. But there is still enough air density and well-mixed GHG in the Stratosphere to absorb and re-radiate IR trying to escape to deep space. However, there is only about 2 percent of the mass of the atmosphere located above the nominal 22 km (13.7 miles) altitude of the top of the Stratosphere, and the density of GHG molecules above the Stratosphere is too small to absorb and re-radiate significant amounts of IR escaping from the top of the Stratosphere. Therefore, it is the relatively thin thickness of the atmosphere up to 14 miles altitude that affects earth surface emissivity for surface IR energy radiation to deep space.

Drawing this new climate system boundary at the earth's surface changes the power balance equation above so that the rate of energy being absorbed within this climate system only applies to the atmosphere up to the 14 miles altitude. Because the heat storage capacity of the atmosphere is much, much less than the earth and its oceans, any rate of heat storage in the atmosphere can be ignored compared to the nominal 0.9 W/m^2 being stored below the earth's surface. Therefore, for this alternate definition of a climate system, we can assume a balance of heat flow entering and leaving the system defined within boundaries of the earth surface and top of the Stratosphere in Fig. A-1.1. We idealize this part of the atmosphere as a thin coating on the surface that affects the emissivity of the Earth's surface as a function of GHG and aerosol concentrations in the atmosphere. This allows us to write the SB equation for earth surface temperature in the power balance equation as:

$$e(W, C, G)\sigma T^4 = (1 - a)S - Q \qquad \text{(A-1)}$$

where,

emissivity (e) of the earth's surface, including atmospheric effects, is assumed to be a function of atmospheric concentrations of water vapor (W), carbon dioxide (C) and other well-mixed GHG and aerosols (G).

a = effective albedo of earth surface and atmosphere reflecting incoming short wave radiation back to deep space = 101.9/341.3 = 0.2986

σ = the Stefan-Boltzmann constant = $5.67(10)^{-8}$ W/m^2/K^4

T = Global Mean Surface Temperature GMST, deg, K

In the case of water vapor concentration in eq. (A-1), as in most complex climate simulation models, we will assume that the change in atmospheric water vapor concentration, W, is due only to atmospheric warming or cooling caused by changes in C and G. With this assumption, eq. (1) can be written as

$$e(W(C,G), C, G)\sigma T^4 = (1 - a)S - Q \qquad \text{(A-2)}$$

From the measured outgoing average IR = 238.5 W/m^2 and a current value for T = 288K, the current global mean emissivity of the Earth's surface including atmospheric effects can be computed from:

Outgoing long wave IR to deep space = $e\sigma T^4$ = 238.5 W/m^2

$$e = 238.5/[\sigma(288)^4] = 0.611 \qquad \text{(A-3)}$$

A2.2 Changes in The Earth Surface Energy Balance

If we take a total differential of the power balance equation (2), we obtain an equation that describes the relationship between changes in all variables, including GMST change, dT.

$$[(\frac{\partial e}{\partial W}\frac{\partial W}{\partial C} + \frac{\partial e}{\partial C})dC + (\frac{\partial e}{\partial W}\frac{\partial W}{\partial G} + \frac{\partial e}{\partial G})dG\ ]\sigma T^4 + 4e(W,C,G)\sigma T^3 dT = (1-a)dS - Sda - dQ$$

$$dT = [\ 1/(4e\sigma T^3)]\{- [(\frac{\partial e}{\partial W}\frac{\partial W}{\partial C} + \frac{\partial e}{\partial C})dC + (\frac{\partial e}{\partial W}\frac{\partial W}{\partial G} + \frac{\partial e}{\partial G})dG\ ]\sigma T^4 + (1-a)dS - Sda - dQ\ \} \qquad \text{(A-4)}$$

$$= \lambda\{- [(\frac{\partial e}{\partial W}\frac{\partial W}{\partial C} + \frac{\partial e}{\partial C})dC + (\frac{\partial e}{\partial W}\frac{\partial W}{\partial G} + \frac{\partial e}{\partial G})dG\ ]\sigma T^4 + (1-a)dS - Sda - dQ\ \} \qquad \text{(A-5)}$$

The terms in { } in eq. (A-5) are called radiative forcing terms in climate science that cause changes in T, denoted by dT, due to independent variations in all variables on the right hand side (RHS) of eq. (A-5). The terms involving changes in W due to changes in C and G are called "water vapor" feedback effects due to changes in C and G.

In most climate science publications, including IPCC Reports, λ, is treated as a constant relating changes in surface temperature due to radiative forcing changes. A value for

λ is typically determined from empirical data relating surface temperature changes to radiative force changes over a certain period of time. Here we recognize from eq. (A-4) that due to consequences of conservation of energy and mathematical manipulation by the rules of differential calculus, λ can be computed from other known quantities as,

$$\lambda = [\ 1/\{4e\sigma T^3\}] = [1/\{(4)(0.611)(5.67)(10)^{-8}(288)^3\}] = 0.302\ K/(W/m^2) \qquad (A\text{-}6)$$

Now, let us examine the partial derivative terms in equation (A-5) and consider their meaning. According to Quantum Mechanics considerations and the ability of GHG to absorb and re-radiate IR emanating from the Earth's surface, increases in atmospheric concentration of C or G should decrease the rate of IR leaving our atmosphere. This is modeled in eq. (A-5) as decreases in emissivity, e, caused by increases in the concentrations represented by C and G. Therefore, the partial derivatives of e multiplying positive GHG concentration changes, dC and dG, have negative values. However. the minus (-) sign in front of these terms from transposing them to the RHS of the equation, and the negative value of the partials, indicate these terms contribute to increases in T (positive radiative forcing) as would also be expected from an increase in T required to offset a decrease in emissivity and maintain a constant heat rejection to deep space.

Note also that the differentials for GHG concentrations in eq. (A-5) multiply the quantity, σT^4, giving these terms radiative force units of W/m^2. With reduced emissivity for the earth's surface, the power flow balance equation requires an increase in earth surface temperature to maintain the necessary balance to continue to radiate to deep space, the energy absorbed from the Sun each day that isn't transported to the deep cold oceans.

It is generally accepted by most climate scientists that doubling CO_2 concentration in the atmosphere, will result in 3.4 to 3.71 W/m^2 radiative forcing without the water vapor and other feedback effects. This range of values has been determined by calculations of how the narrow wave length bands for which IR is absorbed and re-radiated by CO_2 molecules in the atmosphere, are affected by greater concentrations of CO_2. At certain CO_2 concentration levels, all the IR radiated from the surface in certain narrow wave length bands is absorbed and re-radiated. Therefore, further increases in atmospheric CO_2 concentration will not increase absorption of IR radiated from the surface, and the remaining outgoing IR will escape to deep space without further warming of the atmosphere and earth surface.

The overlap of IR absorption bands for water vapor and CO_2 are also considered in computing the IR absorbed in specific common absorption bands by nominal concentrations of water vapor, and considering the additional IR that could be absorbed in the common absorption bands by increases in CO_2 concentration. This "saturation" of IR absorption frequency bands at specific CO_2 concentration levels, results in a radiative forcing function that is logarithmic with respect to increasing concentrations of CO_2.

Using a conservatively high value of 3.71 W/m^2 radiative forcing for a doubling of CO2 concentration, C ppm, the following function for the yearly radiative forcing due to the increasing yearly average value of atmospheric CO_2 concentration, C(year), since 1850 can be written:

$$[\frac{\partial e}{\partial C}dC(year)]\ \sigma T^4 = 3.71\{LOG[C(year)/C(1850)]/LOG[2]\}\quad W/m^2 \qquad (A\text{-}7)$$

$$[\frac{\partial e}{\partial C}dC(year)]\ \sigma T^4 = 3.71\{LOG[C(year)/284.7]/LOG[2]\}\quad W/m^2 \qquad (A\text{-}8)$$

where 284.7 ppm is the best estimate for atmospheric CO_2 concentration in 1850 determined from East Antarctica Law Dome ice core data published by NOAA. Equation (A-8) shows that when C(year) reaches 569.4 ppm, double the 1850 value of 284.7, then the total radiative force change due to atmospheric CO2 will be

$$3.71\{LOG[569.4/284.7]/LOG[2]\} = 3.71\ W/m^2 \qquad (A\text{-}9)$$

For continued simplicity, and illustrative purposes, we assume that the radiative forcing due to long-lived and well-mixed GHG, other than CO_2, can be modeled with a function that is proportional to CO_2 radiative forcing, as the concentrations of these GHG have also generally increased with increases in population and industrial activity,

$$[\frac{\partial e}{\partial G}dG(year)]\ \sigma T^4 = (\beta)3.71\{LOG[C(year)/284.7]/LOG[2]\}\quad W/m^2 \qquad (A\text{-}10)$$

and where the average value for β since 1850, based on IPCC AR5 GHG and aerosol historical data, is about 0.5. Alternatively, we could model the total radiative forcing of other GHG separately, based on their actual measured concentrations each year, or in terms of an equivalent increased concentration of CO_2 that would compute the radiative force of these other GHG. If sufficient data were available, we could also define $\beta(t)$ as a known function of time.

Now let's examine the terms in eq. (A-5) that model the effects of atmospheric water vapor increase due to the effects of increasing concentrations of C and G. We will model this water vapor feedback effect with a parameter, w, that computes the radiative forcing of increased atmospheric water vapor proportional to the combined radiative forcing of CO_2, other well-mixed GHG, and aerosols,

$$[(\frac{\partial e}{\partial W}\frac{\partial W}{\partial C})dC + (\frac{\partial e}{\partial W}\frac{\partial W}{\partial G})dG]\ \sigma T^4 = w(1+\beta)(3.71)LOG[C(year)/284.7]/LOG[2] \qquad (A\text{-}11)$$

In addition to water vapor feedbacks, there may be other climate feedbacks affecting earth surface temperature in response to the radiative forcing of CO_2, other well-mixed GHG, and aerosols. We model the radiative force of these feedbacks that may result from the net of albedo changes caused by aerosol concentrations and other factors as a

fraction, f, of the radiative forcing of CO2, other well-mixed GHG and aerosol concentrations:

$$\text{Other radiative force feedbacks} = f(1+\beta)(3.71)\text{LOG}[C(\text{year})/284.7]/\text{LOG}[2] \quad \text{(A-12)}$$

Substituting equations (A-8), (A-9), (A-11) and (A-12) into eq. (A-5) yields

$$dT(\text{year}) = [0.302]\{(1+w+f)(1+\beta)(3.71)\text{LOG}[C(\text{year})/284.7]/\text{LOG}[2]+(1-a)dS–Sda–dQ\}$$

……(A-13)

All variables in eq. (A-13) are considered to be annual global average values, although for brevity, this notation was dropped for the a, da, S, dS, and dQ variables.

From eq. (A-13) we note that the temperature change due only to the direct doubling of CO_2 concentration with no response of climate feedbacks can be written,

$$dT_{CO2} = [0.302](3.71) = 1.12\text{K}$$

This is a well-known value in climate science given as the direct amount of surface warming that will occur for doubling atmospheric CO2 levels, without any of the complex feedback mechanisms modeled in very complex climate simulation models.

Using eq. (A-13), we can write a function describing our definition for Transient Climate Sensitivity (TCS) as the annual GMST change resulting from the doubling of atmospheric CO2 levels by the actual slow yearly increase in atmospheric CO2 levels, including all climate feedbacks:

$$TCS = [0.302]\{(1+w+f)(3.71)\} \quad \text{(A-14)}$$

This definition for TCS includes the temperature change due to water vapor and all other feedback effects, as represented in the actual temperature data. Using this definition for TCS we can now write eq. (A-15) describing the relationship between annual average values of the independent variables affecting GMST as,

$$dT(\text{year}) = TCS(1+\beta)\text{LOG}[C(\text{year})/284.7]/\text{LOG}[2] + 0.302\{(1-a)dS – Sda – dQ\} \quad \text{(A-15)}$$

where dT(year) is taken to mean the total GMST change since 1850, since that is the reference year for computing radiative force changes of all atmospheric GHG and aerosols.

The change in solar radiation, dS, arriving at the Earth's orbit increased by about 0.4 W/m^2 from 1850 to 2005. Using a nominally accepted value of (1-a) = 0.7 and computing dS for a Total Solar Irradiance (TSI) increase of 0.4 W/m^2 referenced to the entire surface area of the Earth, as 4 times the circular disc area of the Earth intercepting sunlight:

$$(1-a)dS = (0.7)0.4/4 = 0.07\ W/m^2$$

Assuming a gradual linear increase in TSI over the time period 1850-2005, we can write for the temperature rise due to the (1-a)dS term in eq. (15),

$$0.302\{[1-a]dS(year)\} = 0.302\{0.7(0.1)(year-1850)/(2005-1850)\ K$$

$$= 0.021(year-1850)/(155)\ K$$

Since the forcing terms due to GHG and TSI are monotonically increasing functions (ignoring much smaller TSI oscillations due to the 11 year sunspot cycle) over the period 1850-2005, we can write a monotonically increasing component of dT(year) as,

$$dT_m(year) = TCS(1+\beta)LOG[C(year)/284.7]/LOG[2] + 0.021(year-1850)/(155) \quad (A-16)$$

$$dT_m(year) = TCS(1+\beta)LOG[C(year)/284.7]/LOG[2] + 0.021, \quad year > 2005 \quad (A-16a)$$

The solar TSI has fallen since about 2005 and is forecast to continue to fall for the next several hundred years. Therefore, when used to forecast HadCRUT4 temperatures beyond 2005, equation (A-16a) should provide some extra conservatism with respect to temperature rise due only to GHG effects.

Since random and cyclic patterns of temperature variation are observed in the surface temperature datasets with long histories such as HadCRUT4 and GISTEMP, the cyclic behavior in surface temperature must result from the da, dS, and/or dQ terms in eq. (A-15). Some short lived random effects are due to variations in da caused by large volcanic eruptions that seem to occur at random intervals. Therefore, using eqs. (A-16) and (A-16a), the equation for variations in earth surface temperature can be separated into terms providing monotonically increasing and cyclic components as shown in eq. (A-17).

$$dT(year) = dT_m(year) + dT_c(year)$$

$$= TCS(1+\beta)LOG[C(year)/284.7]/LOG[2] + 0.021(year-1850)/(155) + dT_c(year) \quad (A-17)$$

In Section 2.2.5 of this report, the $TCS(1+\beta)$ undetermined constant in the $dT_m(year)$ function is evaluated on the basis of the long term GMST rise since 1850 that is approximated by the HadCRUT4 temperature anomaly. The value $TCS(1+\beta) = 1.8C$ was determined from this parameter identification approach. Analysis of the atmospheric GHG and aerosol concentration increases since 1850 in the IPCC AR5 Report and the radiative force contributed by GHG other than CO2 and aerosols indicated over the period since 1850, β is approximately 0.5. Although $TCS(1+\beta) = 1.8C$ only has uncertainty due to the long term GMST rise since 1850 and the CO2 concentration in 1850, TCS = 1.2C, has more uncertainty as it is estimated from

$$TCS(1+0.5) = 1.8C$$

However, long term GMST rise due to atmospheric GHG and aerosols can be more accurately forecast with,

$$dT(year) = dT_m(year) = 1.8LOG[C(year)/284.7]/LOG[2] + 0.021 \quad year > 2005$$

$$dT(year) = GMST(year) - GMST(1850)$$

$$GMST(year) - GMST(1850) = 1.8LOG[C(year)/284.7]/LOG[2] + 0.021 \quad year > 2005$$

……(A-18)