Comments on "Environmental Effects of Increased Atmospheric Carbon Dioxide" by Arthur B. Robinson, Noah E. Robinson, and Willie Soon, J. Am. Physicians and Surgeons (2007), **12**, 79-90.

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I. INTRODUCTION

The paper under review was published in a free-access journal and can be obtained at http://www.jpands.org/vol12no3/robinson600.pdf. The download is paginated starting from page 1, not from page 79 as in the journal reference. The download pagination, from pages 1 to 12, will be used in what follows. The authors (RRS for short) purport to show that recent warming is largely if not totally natural, the most important factor being an increase in solar activity. In Section II, I will state the RRS thesis, and then in Section III I will analyze a number of figures and claims. Section IV will end with a few conclusions.

The reader is advised to download a copy of RRS's paper, since some of their figures are not reproduced here but will be referred to. The RRS figures reproduced here will include the original captions, but figures from other studies will also be shown. All figures will be numbered with the prefix "M" to avoid confusion with figure numbers from the original sources.

II. THE RRS THESIS

RRS recognize that global temperature has been increasing, and claim (p. 2) that the cause of the increase is solar activity, the greenhouse effect from water vapor, and "other phenomena that are more poorly understood…minor greenhouse gases (GHG for short) such as CO_2 have little effect…". RRS also recognize that atmospheric CO_2 has increased in recent years because of human (anthropogenic) use of hydrocarbons and, over longer periods of time, because of ocean out-gassing of CO_2 (presumably because increased ocean temperature reduces CO_2 solubility) has also contributed. On page 6, they state:

> Between 1900 and 2006, Antarctic CO2 increased 30% per 0.1 °C temperature change (72), and world CO2 increased 30% per 0.5 °C. In addition to ocean out-gassing, CO2 from human [anthropogenic] use of hydrocarbons is a new source. Neither this new source nor the older natural CO_2 sources are causing atmospheric temperature to change.

RRS's reference to the Antarctic draws a contrast of temperatures there to global temperature and CO_2, leaving the impression that CO_2 is not responsible for global warming since Antarctica temperatures have not followed the global temperature experience, even though the CO_2 experience is the same. This is a point I will return to later (see Section C.1). The second sentence of the paragraph addresses sources and sinks of CO_2 and makes the claim that increased atmospheric CO_2 is *not* responsible for temperature change.

On page 8, the authors pose a question:

> How high will the CO_2 concentration of the atmosphere ultimately rise if mankind continues to increase the use of coal, oil, and natural gas?

Their answer:

> At ultimate equilibrium with the ocean and other reservoirs there will probably be very little increase. The current rise is a non-equilibrium result of the rate of approach to equilibrium.
>
> One reservoir that would moderate the increase is especially important. Plant life provides a large sink for CO_2.

The authors foresee that increased CO_2 levels will increase plant growth. They cite a 1989 study[1] to claim that resulting increased biomass will increase CO_2 absorption from the current level of 3 gigatonnes of carbon (GtC) per year to 10 GtC/yr, thus stabilizing the atmospheric CO_2 level at 600 parts per million compared to the current level of 390 ppm.

RRS propose that the U.S. can attain energy independence by expanding nuclear power, particularly by reprocessing spent nuclear fuel to extract fissionable plutonium and developing breeder reactor technology which will ensure nuclear fuel for the next thousand years.

III. ANALYSIS OF THE RRS PAPER

The following analysis revolves around figures in the RRS paper, which are used to illustrate their argument. I will also address what appear to me to be erroneous statements regarding a number of interpretations of data and climate concepts.

A. RRS'S 1ST section: SUMMARY

A.1. RRS Figure 1: Temperatures in the Sargasso Sea over the past 3,000 years.

The time scale in RRS Figure 1 (Figure M1), derived from the original article in their reference 3, is off by 50 years since the scale in the reference is taken "before present," with "present" being 1950, not 2006 as RRS assume. But this is an inconsequential error.

The temperatures in Figure M1 are reconstructions based on oxygen isotope ratios in marine organisms. Isotope ratios are one example of temperature "proxies," i.e., indirect methods of determining temperature. By contrast, instrumental temperatures determined by thermometers or other modern temperature-measuring instruments provide the most reliable data, but the instrumental record only covers the past 150 years, and even then the coverage is truly global for only about the past 100 years. According to RRS, the data show that Earth's temperature has varied over a range of about 3°C over the past 3000 years, and current temperatures are well below three previous peaks occurring approximately 3000, 2500, and 1000 years ago. The figure and RRS's deductions from it raise a number of important concerns.

(a) The 1987 edition of *Encyclopedia Britannica*[2] includes the following description of the Sargasso Sea:

The sea reaches depths of 5,000-23,000 ft (1,500-7000 m) and is characterized by weak currents, low precipitation, high evaporation, light winds, and warm, saline waters, all combining with the lack of thermal mixing to create a biological desert largely devoid of plankton, a basic food supply for fish.

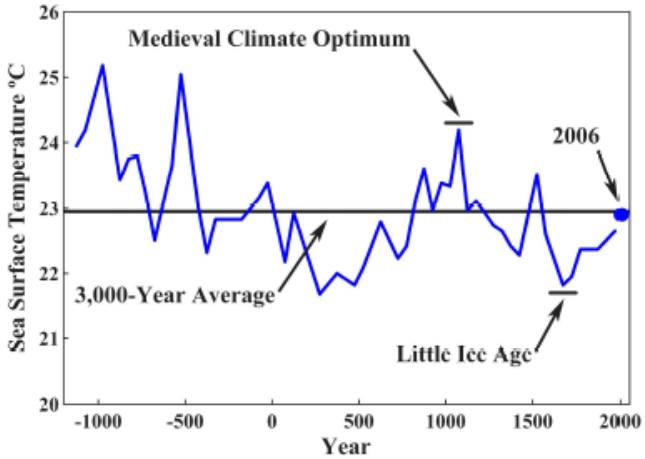

Figure 1: Surface temperatures in the Sargasso Sea, a 2 million square mile region of the Atlantic Ocean, with time resolution of 50 to 100 years and ending in 1975, as determined by isotope ratios of marine organism remains in sediment at the bottom of the sea (3). The horizontal line is the average temperature for this 3,000-year period. The Little Ice Age and Medieval Climate Optimum were naturally occurring, extended intervals of climate departures from the mean. A value of 0.25 °C, which is the change in Sargasso Sea temperature between 1975 and 2006, has been added to the 1975 data in order to provide a 2006 temperature value.

Figure M1: Temperatures in the Sargasso Sea over the past 3000 years. SOURCE: RRS Figure 1.

From this description, the Sargasso Sea would seem to be a poor example of *global* temperature.

(b) The work from which RRS Figure 1 is taken is "The Little Ice Age and Medieval Warm Period in the Sargasso Sea," by Lloyd D. Keigwin.[3] Despite the title, Keigwin's work does not cover the entire 2-million-square-mile Sargasso, but focuses on the much smaller Bermuda Rise portion of it. The Bermuda Rise is a good place to obtain sea floor cores, because the relatively high sedimentation rate there makes it possible to determine times to an accuracy of a few decades or so.

(c) Keigwin's work is included in a National Academy of Sciences (NAS) study[4] of "multiproxy" reconstructions of ancient temperature, made from proxies such as isotope ratios, tree rings, and historical records. A reading of the NAS study suggests two problems with Figure M1. First, the most accurate "multiproxy" reconstructions are made by combining information from a wide variety of reconstruction techniques covering as much of the globe as possible. Keigwin's Bermuda Rise study is valuable as a contribution to this broader effort, but by itself it is of limited value. Figure M2, which reproduces Figure 11-1 from the NAS study, shows temperatures reconstructed from three multiproxy studies and tree ring analysis. Note the variability in temperature

estimates more than about 400 years ago. It appears that multiproxy temperature reconstructions are reliable only for approximately the past 400 years. Note in particular that current instrumental temperatures are higher than any earlier ones, contrary to the Bermuda Rise data. Only the tree ring data and Moberg, *et al.* reconstruction curves show temperatures about 1200 years ago to be moderately above these same curves for the latest years, and then only about 0.2°C above, only 1/10th of what the Keigwin data shows. Furthermore, most of the Moberg *et al.* proxies are before 1990, and only one goes up to 1996, after which we have experienced additional warming. In any case, difficulty of calibrating reconstructions with modern instrumental temperatures should be kept in mind.

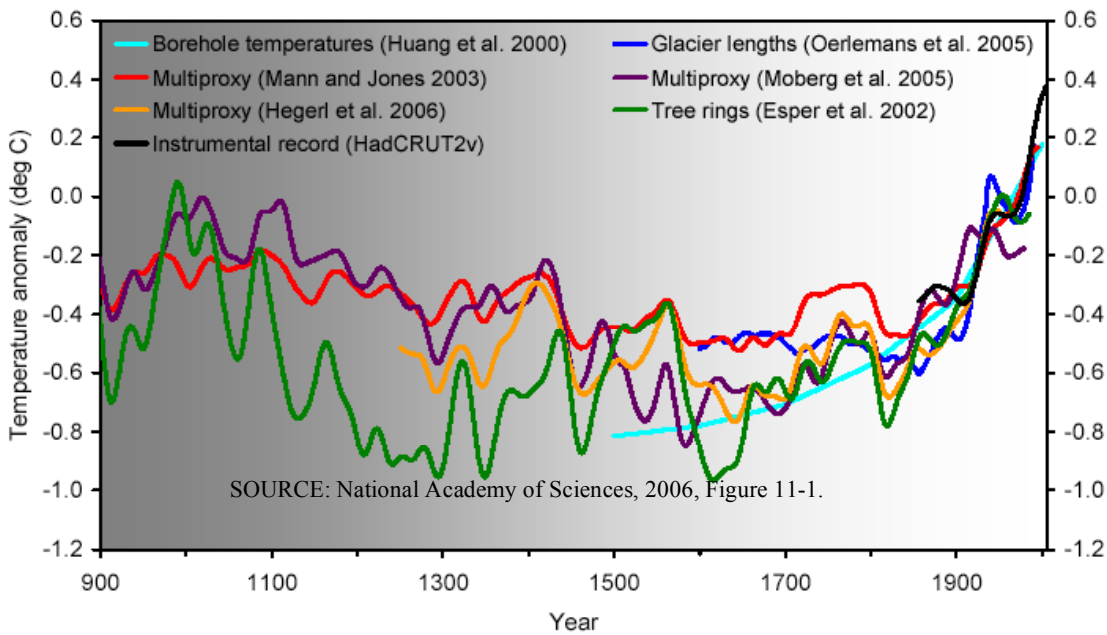

FIGURE S-1 Smoothed reconstructions of large-scale (Northern Hemisphere mean or global mean) surface temperature variations from six different research teams are shown along with the instrumental record of global mean surface temperature. Each curve portrays a somewhat different history of temperature variations, and is subject to a somewhat different set of uncertainties that generally increase going backward in time (as indicated by the gray shading). This set of reconstructions conveys a qualitatively consistent picture of temperature changes over the last 1,100 years, and especially the last 400. See Figure O-5 for details about each curve.

Figure M2: Temperature reconstructions for the past 1100 years. SOURCE: *Surface Temperature Reconstructions for the Last 2,000 years* (National Academy of Sciences, Washington, D.C., 2006), Figure S-1.

(d) NAS's temperature reconstruction study[5] draws the following conclusions: (1) Instrumental temperature measurements are reflected in various proxy measurements based on boreholes, glacier retreat, …etc. (2) Large-scale temperature reconstructions yield a consistent picture of temperature trends. (3) "It can be said with a high level of confidence that global mean surface temperature was higher during the last few decades

of the 20th century than during any comparable period during the preceding four centuries." (4) "Less confidence can be placed in large-scale surface temperatures reconstructions for the period from A.D. 900 to 1600. Presently available proxy evidence indicates that temperatures at many, but not all, individual locations were higher during the past 25 years than during any period of comparable length since A.D. 900." (5) "Very little confidence can be assigned to statements concerning the hemispheric mean or global mean surface temperature prior to about A.D. 900 because of sparse data coverage and because the uncertainties associated with proxy data and the methods used to analyze and combine them are larger than during the more recent time periods."

In summary, sea floor cores, such as Figure M1 are based on, are but one technique for reconstructing temperatures, and although the Bermuda Rise is one of the better places to obtain such cores, the temperatures reconstructed from these cores are not representative of global temperatures. The best data for temperature comes either from modern temperature-measuring devices, such as thermometers, and, over longer periods, temperatures derived from a *combination* of a number of methods of reconstructing temperatures, as has been done in a number of multiproxy studies which do *not* support the conclusions of RRS regarding current temperatures compared to temperatures over the past 2000 years. Nevertheless, RRS state: "Comprehensive surveys of published temperature records confirm the principle features of Figure 1, including the fact that current Earth temperature is approximately 1°C lower than that during the Medieval Climate Optimum 1,000 years ago..." Figure M2 above, which is the state of the art of temperature reconstruction at this time, disagrees with this RRS claim about the Medieval Optimum. It is also important to keep in mind the NAS conclusion that reconstructed temperatures more than 400 years ago are not very accurate. Maybe temperatures in the Medieval period were higher than today's and maybe they weren't. In any case, it is misleading to offer Keigwin's localized Bermuda Rise data as representative of global temperatures.

A.2. RRS FIGURE 2: Glacier lengths. RRS's Figure 2 (shown here as Figure M3) is an adaption of a figure from a glacier length study by Oerlemans.[6] The data is not very reliable prior to 1900 due to small sample size and deficiencies in reporting reliability. RRS interpret the data to mean that glacier shortening began well before the massive use of hydrocarbons, and conclude that "Hydrocarbon use could not have caused this shortening trend." To drive their point home, RRS added a straight-line trend to the graph and a separate graph of annual use of hydrocarbon fuels, suggesting there has been no significant change in the rate of glacier shortening in the last 60 years or so despite a large increase in hydrocarbon use. But upon examination of Oerlemans' work, it appears that RRS have misinterpreted it.

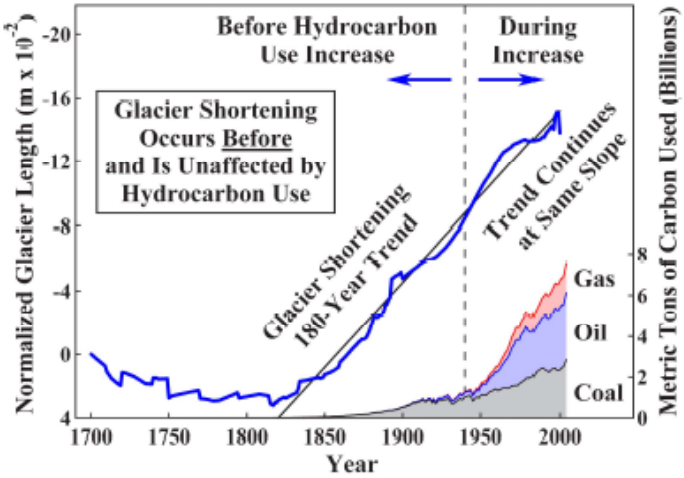

Figure 2: Average length of 169 glaciers from 1700 to 2000 (4). The principal source of melt energy is solar radiation. Variations in glacier mass and length are primarily due to temperature and precipitation (5,6). This melting trend lags the temperature increase by about 20 years, so it predates the 6-fold increase in hydrocarbon use (7) even more than shown in the figure. Hydrocarbon use could not have caused this shortening trend.

Figure M3: Glacier shortening and hydrocarbon use.
SOURCE: RRS Figure 2.

Oerlemans' main goal was to determine if glacier length could be used to infer temperature. Towards this end, he used a phenomenological model of glacier length which, when solved for temperature, yields:

$$T'(t) = -\frac{1}{c}\left[L'(t) + \tau\frac{dL'(t)}{dt}\right],$$

where L' = glacier length and T' is temperature deviation from a baseline (the baseline appears to be average temperature between about 1940 to 1970). The fit parameters for each particular glacier are c = climate sensitivity = decrease in equilibrium glacier length per degree of temperature increase, which depends on surface slope and annual precipitation; and τ = response time which depends on both surface slope and the rate at which mass gain or loss changes with elevation. Both fit parameters vary by a factor of 10 over the range of all 169 glaciers. Figure M4 is a graph of Oerlemans' results[7] for temperature, compared to the instrumental temperature and a temperature reconstruction using a number of temperature proxies.

Figure S3

A comparison of global mean temperature series.

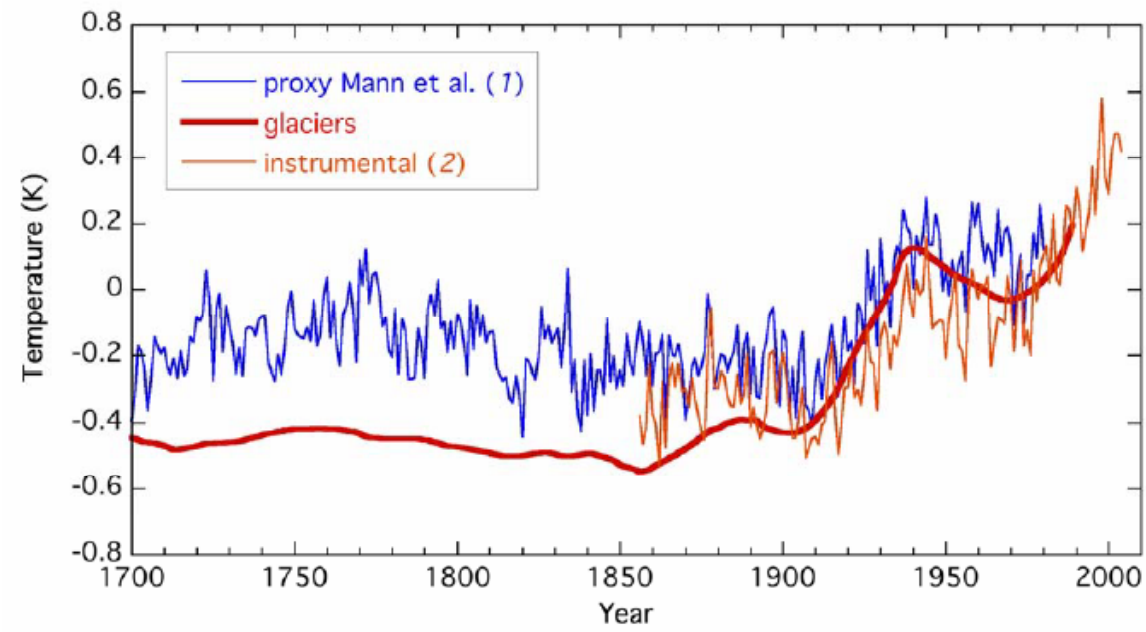

Figure M4: Oerlemans' results for temperatures derived from glaciers, compared with instrumental temperatures and a multiproxy reconstruction. Note that the match degrades prior to 1900, when data was scarce. SOURCE: Oerlemans (2005) (Supporting Online Material 1107046), Figure S3.

Clearly, Oerlemans' reconstruction shows that temperature can be inferred from glacier length, and conversely, glacier length depends on temperature, but note that this work says nothing about why temperature changes. Nevertheless, RRS try to draw the conclusion that hydrocarbon use is irrelevant by contrasting two periods where glacier length decreased: the first, from about 1850 to 1940 when hydrocarbon use grew but was low relative to today; the second from 1940 to 2000, when hydrocarbon use was high. They are, in effect, testing the hypothesis *via* glacier length that temperature change is caused only by an increase in atmospheric CO_2. But no serious climatologist would entertain such a hypothesis, because every one understands that temperature is affected by a number of factors, most importantly, solar irradiance, volcanic activity, GHG, the reflectivity of Earth, aerosols, Earth's orbital parameters, etc. RRS are begging the question unless they account for as many factors as possible that affect temperature, including those that cause cooling. This is the great task of climate modeling, which RRS claim is currently "markedly unreliable" (p. 7). Given a multitude of factors affecting temperature, it is quite possible that glacier length decreased from 1850 to 1940 due to a variety of factors, including (perhaps at different times) increased solar activity, decreased precipitation, and volcanic activity; while it decreased after 1940 because of similar factors plus the effect of hydrocarbon use. To the credit of RRS, they have looked at one of these factors, *viz*., solar activity, but they have failed to mention any other factors.

CONCLUSION: Oerlemans' work by itself is silent on the causes of temperature changes. RRS's conclusion that hydrocarbon use is irrelevant would follow only if there were only one factor determining global temperature at any time. They fail to recognize

that the dominant effect on temperature might be solar irradiance at one time, volcanic eruptions at another, and anthropogenic GHG at another, or any combination of these three factors as well as others. *The challenge of global warming science is to measure or reconstruct values of as many determinants of global temperature as possible to properly understand temperature change.* The following analysis of RRS Figure 3 will look at such determinants.

A.3. RRS FIGURE 3: Solar activity. This figure, shown here as Figure M5, graphs solar activity, Arctic air temperature, and hydrocarbon use as a function of time. (Lines identifying the period 1978 to 2000 have been added.) There appears to be a strong correlation between solar activity and Arctic temperatures. Furthermore, RRS's Figure 3 shows the Arctic temperature in the mid-1930s to be *higher* than in recent years. To evaluate this presumed correlation, it is necessary to take a closer look at the temperature and solar data.

Figure M6 shows the number of Arctic Ocean temperature-measuring stations over the past half century.[8] Prior to the International Arctic Buoy Programme (IABP) in 1979, the sources for Arctic temperature consisted mainly about 50 coastal locations as shown in Figure M7.[9]

Figure M8[10] shows a graph of temperature from a comprehensive and authoritative 2005 study on Arctic climate. Keeping in mind the sparcity of data prior to 1979, there are minor differences between annual temperature values in Figure M8 compared to RRS's Figure 3 (Figure M5 above). But the main difference is that, while temperatures for individual years (based on sparse data) were occasionally higher in the mid-1930s, the moving average shows that temperatures have been more consistently higher in recent years. There is additional evidence that any reduction in the extent of ice in the mid-1930s was negligible compared to today, as evidenced by the lack of coastal erosion at that time.[11]

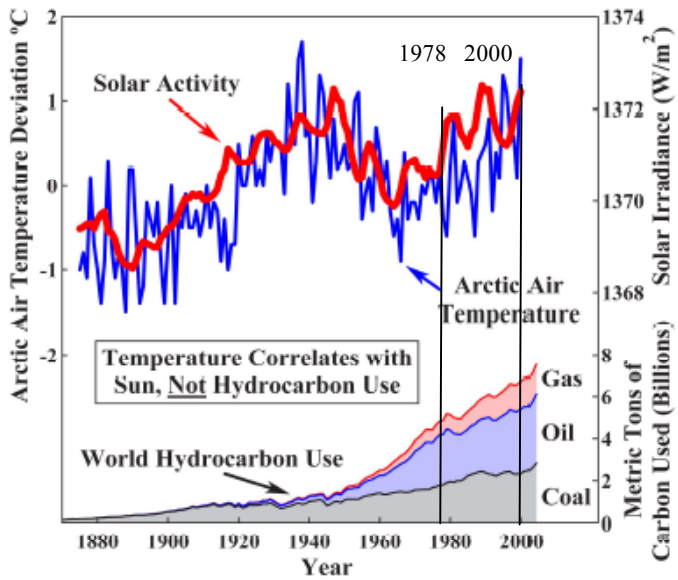

Figure 3: Arctic surface air temperature compared with total solar irradiance as measured by sunspot cycle amplitude, sunspot cycle length, solar equatorial rotation rate, fraction of penumbral spots, and decay rate of the 11-year sunspot cycle (8,9). Solar irradiance correlates well with Arctic temperature, while hydrocarbon use (7) does not correlate.

Figure M5: Solar activity, Arctic air temperature, and hydrocarbon use as functions of time. SOURCE: RRS Figure 3. Vertical lines for 1978 and 2000 have been added for comparison with Figure M9 below..

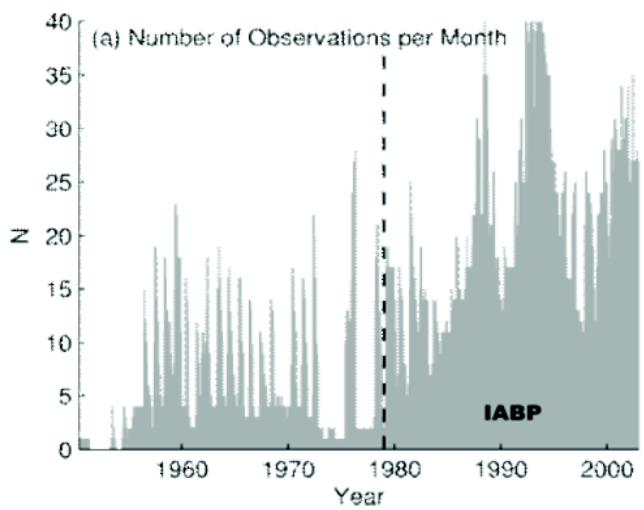

Figure M6: Number of observations of Arctic air temperature as a function of time. SOURCE: http://seaice.apl.washington.edu/

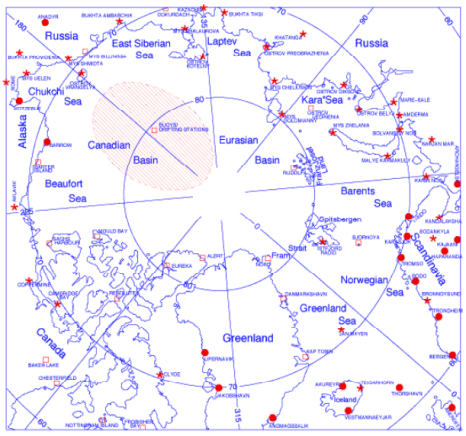

Figure M7: Locations where Arctic temperatures were measured prior to 1979. There are about 50 locations in total. From the original source: "*Red circles show stations with L > 100 years of observations, red stars represent stations with 65 < L < 100, and red squares indicate stations with L < 65. The red cross-hatched oval denotes the region represented by data from the NP manned stations and IABP drifting buoys.*" SOURCE: I. Polyakov et al., "Variability and Trends of Air Temperature and Pressure in the Maritime Arctic," Jour. Climate **16**, 2067-2077 (June 15, 2003), available at: http://www.frontier.iarc.uaf.edu/~igor/research/warm/warm_apr02.pdf

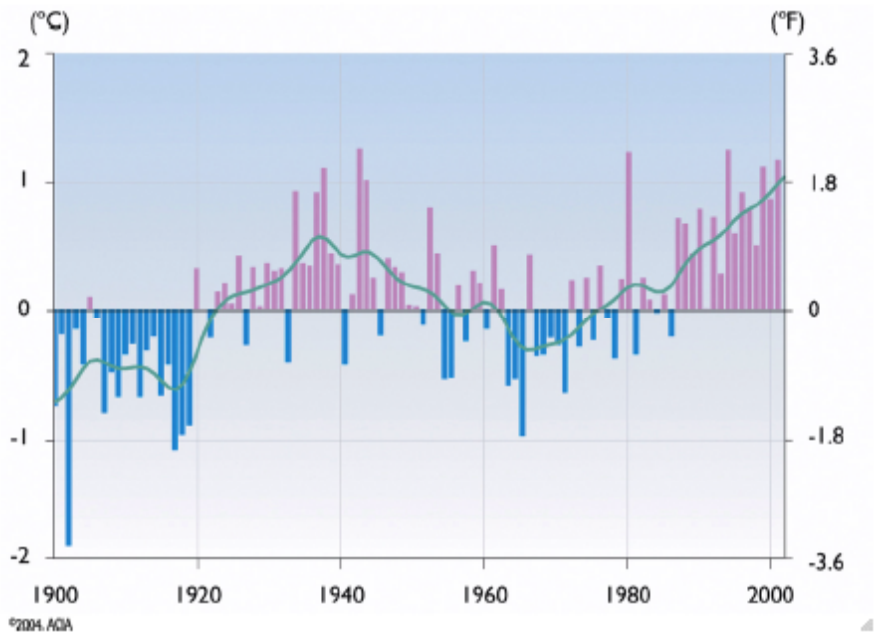

Figure M8: From the source: "Annual anomalies of land-surface air temperature in the Arctic (60o to 90o N) for the period 1900 to 2003. Anomalies are calculated relative to the 1961–1990 average. The smoothed curve was created using a 21-point binomial filter, which approximates a 10-year running mean." SOURCE: *Arctic Climate Impact Assessment*, Edited by Carolyn Symon, Lelani Arris and Bill Heal (Cambridge University Press, New York, 2005), Figure 2.6. Free downloads of chapters are available at http://www.acia.uaf.edu/pages/scientific.html.

Turning to the solar activity data in RRS Figure 3 (Figure M5 above), we should note that satellite observations of solar activity are available only since 1979. Figure M9

shows the satellite data for this period.[12] The smooth curve represents my attempt to depict RRS Figure 3 data for this period. The RRS data comes from an article by Soon (Soon, 2005 GRL), and is a reconstruction based on five proxies of sunspot activity: sunspot cycle amplitude, sunspot cycle length, solar equatorial rotation rate, fraction of penumbral spots, and decay rate of the 11-year sunspot cycle. (Beryllium-10 and carbon-14 isotopes are other tools commonly used to reconstruct solar activity but are not included by Soon for some reason.) Clearly, the satellite data shows no upward trend from 1979 to 2007, even though this is a period of most rapidly increasing global temperature.

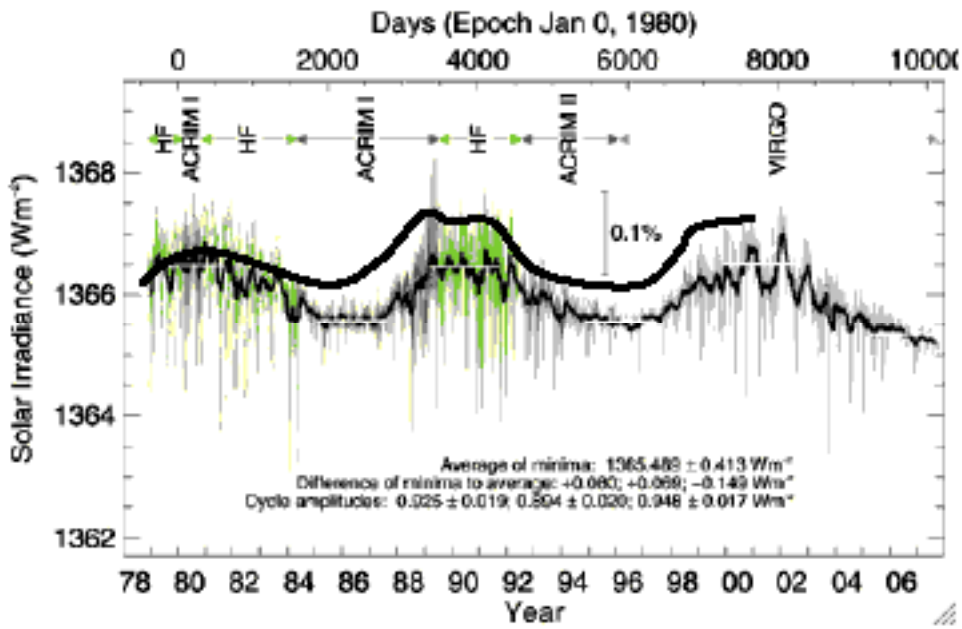

Figure M9: Solar Irradiance derived from satellite-measured values. SOURCE: Physikalish-Meteorologisches Observatorium Davos World Radiation Center,http://www.pmodwrc.ch/pmod.php?topic=tsi/composite/SolarConstant. The heavier smooth black curve is a reconstruction of RSS's Figure 3 data for this period.

There is general agreement that solar activity can affect climate. The challenge is to determine the contributions the major determinants of Earth's surface temperature, the three most important of which are solar activity, GHG and atmospheric pollutants from anthropogenic activity, and volcanic activity. This task was attempted by Ammann *et al.,*[13] and the result is shown in Figures 10(a) and 10(b). Figure 10(a) shows the effects in 25-year periods; Figure 10(b) shows annual data, and breaks out sulfate pollutants. The results of Ammann et al. in Figure 10(a) show that solar irradiance is definitely important, but volcanic and anthropogenic effects also are. Most importantly, their results show that anthropogenic GHG are a major factor, in the last 25 years, thus leading to conclusion that we are in the "anthropogenic age" (more recently denoted as the "anthropocene period").

CONCLUSION. Given the paucity of Arctic temperature data prior to 1979, the lack of other evidence for sustained high Arctic temperatures in the 1930s, and the preference for direct satellite measurements of solar activity, it is hard to accept RRS's claims that solar activity is a major determinant of Arctic temperatures in recent years, that current temperatures are a repeat of the mid-1930s experience, or that human use of hydrocarbons has had a negligible effect. The recent work of Ammann et al. suggests, rather, that anthropogenic activity is important in recent surface temperature trends while solar and volcanic effects are minor in comparison. The accelerated melting of Arctic ice observed last year has accentuated concern that the Arctic is experiencing *novel* warming conditions.

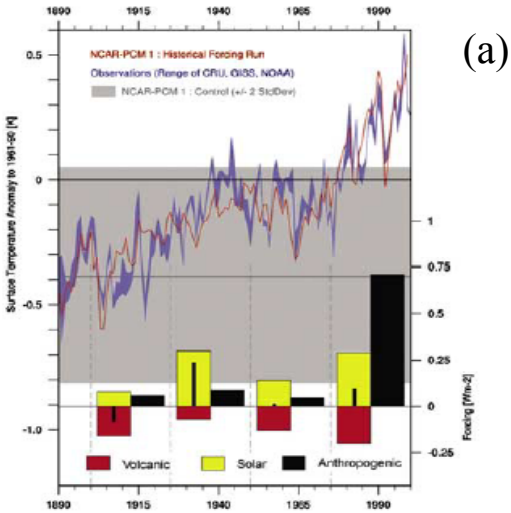

Figure M10(a): Contributions of solar, volcanic and anthropogenic effects on global temperature. SOURCE: C. Ammann et al., "A monthly and latitudinally varying volcanic forcing dataset in simulations of 20th century climate," GEOPHYSICAL RESEARCH LETTERS, VOL. 30, NO. 12, 1657, doi:10.1029/2003GL016875, 2003

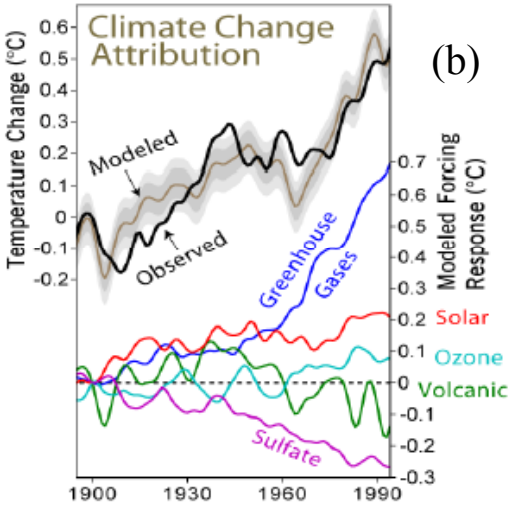

Figure M10(b): Annual data for Figure 10(a) based on the data of Ammann et al. SOURCE: Global Warming Art (Robert Rohde), http://www.globalwarmingart.com/wiki/Image:Climate_Change_Attribution_png.

A.4. The U.S. temperature record and solar activity. RRS's Figure 4 (Figure M11(a) below) shows surface air temperatures for the contiguous U.S. (lower 48) states. RRS are impressed that there are intermediate trends up and down in US temperature. This calls for two comments. First, RRS Figure 4 shows temperatures for 1.5% of Earth's surface and can in no way be considered global. More seriously, RRS have set up a straw man, because all climatologists recognize that climate includes cyclical ("intermediate") behaviors with periods of 5, 10, or more years. No climatologist believes that a long-term upward trend in atmospheric gases, such as has occurred, will obviate cyclical behavior. We have to live with natural cycles and hope not to aggravate them by fossil fuel use.

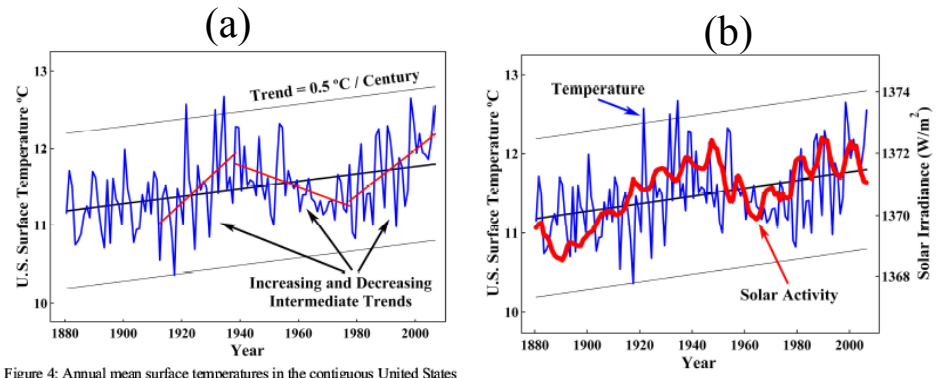

Figure 4: Annual mean surface temperatures in the contiguous United States between 1880 and 2006 (10). The slope of the least-squares trend line for this 127-year record is 0.5 °C per century.

Figure 5: U.S. surface temperature from Figure 4 as compared with total solar irradiance (19) from Figure 3.

Figure M11 (a): Temperature as a function of time for the contiguous 48 US states. (b): Same as (a) but showing solar activity. SOURCE: RRS, Figures 4 and 5.

RRS Figure 5, shown in Figure M11(b), shows US temperatures (again only for the lower 48 states) and solar irradiance over the period running approximately from 1880 to 2005. RRS attempt to establish the physical proportionality between the increase in solar irradiance and increase in temperature during this period: "Between 1900 and 2000, on absolute scales of solar irradiance and degrees Kelvin, solar activity increased 0.19%, while a 0.5 °C temperature change is 0.21%. This is in good agreement with estimates that Earth's temperature would be reduced by 0.6 °C through particulate blocking of the sun by 0.2% (18)." Their reference (18) is a study by E. Teller *et al.*[14] on modulation of global warming by putting particles in the atmosphere to reduce solar irradiance. The Teller *et al.* paper assumes solar irradiance could be reduced by about 1% in this way to modulate global warming. They never say explicitly what temperature rise this would negate, but they do mention a 3°C increase resulting from a doubling of CO_2. This would not be a reasonable interpretation, because from the Stefan-Boltzmann law, Earth's temperature is proportional to the inverse fourth power of the irradiance: $T \sim S^{1/4}$, so $\ell n(T) = \ell n(S)/4$. Taking differentials, we get: $\frac{dT}{T} = \frac{dS}{4S}$. So a dS/S of 0.01 corresponds to a dT/T only ¼ of this, or 0.0025 and for T = 287 K, dT = 0.7 K. Since the global temperature increase in the past century was about 0.5 K at the time Teller *et al.* wrote, it is more reasonable that their round-figure estimate of a 1% reduction in solar irradiance would correspond to a temperature change of about 0.5 K. None of this squares with RRS's simple percentage equivalences, since the Stefan-Boltzmann law shows that the percentage change of temperature is only ¼ of the percentage change in solar irradiance.

To repeat a crucial point: in the real world, global temperatures are determined not just by natural cycles and solar irradiance but also, as shown in Figure 10, by volcanic activity and anthropogenic use of fossil fuels. As with RRS Figure 3, the challenge is to amass data on as many relevant factors as possible and determine which factors are operative in recent years. RRS's attempt to pin all of the increase of temperature on solar activity is wrong theoretically and practically.

A.5. Change in annual temperature compared to temperature ranges. RRS Figure 6 compares the *change* in the annual average US temperature, 0.5 ^{o}C in the last century, with a number of temperature *ranges*. For example, one of the ranges is "Earth Day-Night & Seasonal." I assume RRS have constructed this range by subtracting the lowest nighttime temperature (in winter) from the highest daytime temperature (in summer). The result is about 110 ^{o}C, or over 200 times the temperature change in the last century. RRS's purpose appears to be to minimize the importance of the increase in temperature, but they are comparing apples and oranges. Yes, Earth rotates and we have day and night, but this has nothing to do with an increase in the yearly average. The futility of the RRS comparison can be appreciated by noting that an increase in average annual global temperature of 110 ^{o}C would destroy almost all life forms on Earth. Indeed, an increase as small as 5 ^{o}C would be devastating. So the comparisons in this figure are meaningless.

A.6. Climate indicators and global warming. RRS Figures 7 to 10 show time series of various climate indicators: Figure 7, annual precipitation in the US, 1895-2006; Figure 8, number of severe tornadoes in the US, 1950-2006; Figure 9, Atlantic hurricanes that make landfall, 1900 to 2006; and Figure 10, maximum hurricane wind speed and violent hurricanes in the Atlantic, 1944 to 2006. Note that figures 7 and 8 refer to the U.S., 1.5% of Earth's surface. All climate researchers are agreed that there will be winners and losers in the global warming game, and it is important to evaluate the climate situation in terms of global data, not on U.S. data as RRS are doing here.

The authors claim (p. 2) the data in Figures 7 to 10 show that U.S. climate "has improved somewhat," under the reasonable assumption that the Atlantic hurricane data implies improvement in US climate. But it is hard to see how Figure 7's 1.8-inch increase in precipitation in the US represents anything positive or negative unless the distribution of the rainfall change is investigated. If rainfall increased in an already-saturated area and decreased in a dry area, chances are that societies in both areas will feel the worse for it.

The decrease in tornadoes in Figure 8 may indeed be a benefit of global warming for the US, but it is hard to say. The National Climatic Data Center[15] says of the data in RRS's graph: "The bar chart below [from which RRS Figure 8 is taken] indicates there has been little trend in the strongest tornadoes over the past 55 years."

Figures 9 and 10 show no increase in number of Atlantic hurricanes making landfall, maximum wind speed of Atlantic hurricanes, and number of violent Atlantic hurricanes. As mentioned previously, it is important to look at the global picture. When this is done, it appears that violent (category 4 and 5) "hurricanes" have increased over the years.[16] So again, RRS have drawn a conclusion to suit their thesis by limiting their consideration to a portion of the globe while ignoring the larger picture.

It is important to keep an open mind on the hurricane question. Recent evidence indicates that increased warming of the Atlantic has created cross-winds that prevent hurricanes from building up to high energies. It is unclear if such an effect will develop in the Pacific and other oceans. The data on hurricanes is not all in, so it is wise to

suspend judgment. This admonition applies both to those claiming hurricane intensity is increasing because of global warming and those who claim it is ameliorating.

A.7. Sea level and glacier shortening. RRS Figures 11and 12 show sea level and glacier shortening as a function of time. RRS claim the increases in sea level and glacier shortening *before* heavy consumption of fossil fuels prove that fossil fuel use is not responsible for *current* climatic effects. They are making the same error they made in Figure 3: there are a number of causes for temperature rise, sea level rise, and glacier shortening, particularly solar irradiance, volcanic activity, and consumption of fossil fuels. To assume as they do that only past influences can be effective today ignores the possibility that new causes of changes (especially fossil fuel use and increased atmospheric CO_2) can add to the mix. RRS fail to take up the real challenge: to quantitatively determine (as the authors of Figure 10 did) what particular factors are important at this time.

A.8. Opinions on climatic anomalies in three periods of time. RRS Table 1 is derived from data in a paper by Soon *et al*.[17] Soon *et al*. posed three questions:

> (1) Is there an objectively discernible climatic anomaly occurring during the Little Ice Age, defined as 1300–1900 A.D.? This broad period in our definition derives from historical sea-ice, glaciological and geomorphological studies synthesized in Grove (2001a, 2001b) and Ogilvie and Jónsson (2001).
> (2) Is there an objectively discernible climatic anomaly occurring during the Medieval Warm Period, defined as 800–1300 A.D.? This definition is motivated by Pfister et al. (1998) and Broecker (2001) and is slightly modified from Lamb's original study (1965).
> (3) Is there an objectively discernible climatic anomaly occurring within the 20th century that may validly be considered the most extreme (i.e., the warmest) period in the record? An important consideration in answering this question is to distinguish the case in which the 20th century warming began early in the century versus after the 1970s, as recorded by surface thermometers. This criterion is necessary in order to judge the influence of 20th century warming by anthropogenic forcing inputs such as increased atmospheric carbon dioxide content.

To answer these questions, Soon, *et al.* reviewed over 100 reconstructions of temperatures over the past 1000 years. In the great majority of cases, the authors judge if the answers to each of the three questions are "Yes" or "No". They find that the great majority of studies answer "Yes" to questions (1) and (2), and "No" to (3). But note that the wording of question (3) is different: whereas (1) and (2) simply ask if there is an anomaly, (3) asks if an anomaly in the 20th century "may validly be considered the most extreme (i.e., the warmest) period" in the record. I propose that "Validly" should be interpreted to mean "statistically significant." If question (1) were worded to ask if the "discernable anomaly" were statistically different than the current anomaly and similarly for question (2), the answers to all three questions would very likely be "No." This is supported by Soon *et al.*'s statement that, because of "the general lack of climatic information extending back to the Medieval Warm period,…Therefore, our conclusions are provisional."

In the hands of RRS, the Soon, et al., 2003 "Yes" and "No" data is used to buttress the validity of the Sargasso Sea temperatures that begin their paper in Figure 1 which they use to claim that the Medieval Warm Period was global in scope and was warmer than now. They ignore the different wording of question (3), and simply offer a table of "Yes," "No," and "Yes/No" for each of the three time periods in Soon, *et al.*'s three questions. I was unable to reproduce the precise numbers in their table from the data in Soon, et al., 2003, Table 1, but the differences were small and don't affect the conclusions RRS try to draw. Their conclusions are in any case spurious.

A.9. Time series of a number of climatic variables, including global temperature. RRS Figure 13 shows time series of a number of climatic variables, particularly temperature. All of the time series were shown earlier in the paper except for global temperature, which increases most rapidly in the past 25 years. But this important point goes unmentioned by RRS. In this period, solar activity as determined by satellite measurements has leveled off while volcanic activity is high, which together would tend to cool global temperature. But temperature increases, which strongly implies that anthropogenic activity, especially fossil fuel consumption, is responsible for the current warming. This implication is ignored by RRS.

RRS Figure 13 shows that coal, oil, and gas consumption leveled off from approximately 1910 to 1940, but there were rises in sea level, arctic temperature, and several other indicators, particularly solar irradiance. They interpret this to mean that fossil fuel consumption is not responsible for warming then or now. But warming depends only on the total amount of CO_2 in the atmosphere, and this increases even if fossil fuel consumption is *constant* but above the level at which natural processes (especially diffusion into the ocean) can absorb it. Indeed, all atmospheric CO_2 data show CO_2 concentration to increase from 1910 to 1940, even though the yearly consumption of fossil fuels was constant. RRS are mistaken in their attempt to use the constant consumption of fossil fuels to prove that they do not affect global temperature.

B. RRS 2ND section: ATMOSPHERIC AND SURFACE TEMPERATURES

B.1.Satellite–derived temperatures. RRS Figure 14 shows satellite-derived temperatures for global, Northern and Southern Hemispheres, and tropics from 1979 to 2007. The caption for the figure refers to the 1998 temperature spike caused by an El Niño event. There is unanimous agreement that El Niño events are, by themselves, unrelated to CO_2 levels in the atmosphere, but RRS go on to claim, without any justification, that the overall upward trend in temperature during this period is likewise unrelated to CO_2. This is a straw man: nobody claims that every change in temperature is ascribable to CO_2.

RRS also mention a problem related to Figure 14: "Contrary to the CO_2 warming climate models, however, tropospheric temperatures are not rising faster than surface temperatures." This is not correct. First, not all models predict faster warming of the troposphere. Second, the U.S. Climate Change Science Program[18] has looked closely at this problem and concluded that there are no inconsistencies between models, or between

radiosonde (weather balloon) and satellite measurements, of tropospheric temperatures.[19]

B.2. The urban heat island effect. RRS Figure 15 illustrates the "urban heat island effect" (uhie for short) by plotting temperature trend per decade as a function of county population for 49 California counties. The uhie refers to the fact that cities, with asphalt "terrains" and other human constructions that tend to absorb heat, tend to be warming than more natural settings.

There is an undeniable trend in the Figure 15 data, but apart from the caption for the figure, the meaning of the trend is not discussed in the text. Many studies have been made of the uhie, and global temperatures published, for example, by NASA's Goddard Institute of Space Science (GISS), make corrections for it. In the caption, RRS show six unadjusted station records selected by NASA GISS "for use in their estimate of global surface temperatures." Three of NASA GISS's records are slightly below RRS's trend line, one is slightly above, and two are above the trend line by a bit more than two standard deviations as determined by RRS for grouped data. But grouped data have, by the central limit theorem, smaller standard deviations than a single station record. So it is not clear that, statistically speaking, there is anything wrong with the six stations selected by NASA GISS. But RRS say (in the caption): "Such selections make NASA GISS temperatures too high." This is true only if the adjustment NASA GISS derives from the six stations is used globally. The authors do not address this question.

There is general agreement that the uhie correction amounts to about 0.05 ^{o}C.[20] The correction is made by comparing urban temperatures with rural. In any case, ocean temperatures, which are unaffected by the uhie, track temperature increases on land, so this is a non-issue and it is unclear why RRS devoted one of their figures to it except to attempt to claim that NASA-GISS's temperature records are not perfect by the narrow criterion of agreement with RRS's pooled data.

C. RRS 3RD section: ATMOSPHERIC CARBON DIOXIDE

C.1. The proportionality between CO_2 and temperature increases. RRS Figure 16, shown here as Figure M12, shows a plot of Antarctic temperatures for the last 650,000 years, as reconstructed from isotope analysis of ice cores. The plot is accompanied by a bar graph showing that a temperature rise of about 6°C was accompanied by a 30% increase of CO_2 during interglacials, i.e., warm periods between ice ages. The atmospheric CO_2 is determined by the amount of CO_2 in ice core air bubbles. A text box in the figure states: "CO_2 Rise During Seven Interglacials Was Ocean Out-gassing Caused by Temperature Rise." Since this statement says that the CO_2 rises were *caused* by temperature rises via the oceans, the temperature rises were caused by something other than CO_2. Indeed they were, but the specific cause is not explored by RRS.

Note the periodic behavior of the Antarctic ice core temperatures. One of the most important causes of temperature change over very long periods of time is generally acknowledged to be the cyclical change in Earth's orbital parameters, known as "Milankovitch cycles." The eccentricity of Earth's orbit changes with a 100,000-year

period, the tilt of Earth's axis (currently at 23.5°) changes with a period of 41,000 years, and precession of Earth's axis (analogous to the wobble of a spinning top's axis) has a period of 26,000 years. These cyclical changes cause solar irradiance to change, and that is an important determinant of ice ages and interglacials. As the temperature rises over a few thousand years or so thus ending an ice age, the oceans warm up. This lowers the

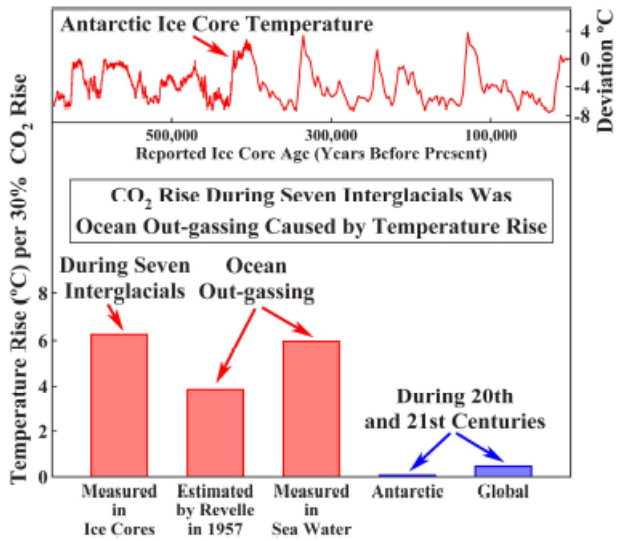

Figure 16: Temperature rise versus CO_2 rise from seven ice-core measured interglacial periods (63-65); from calculations (69) and measurements (70) of sea water out-gassing; and as measured during the 20th and 21st centuries (10,72). The interglacial temperature increases caused the CO_2 rises through release of ocean CO_2. The CO_2 rises did not cause the temperature rises.

In addition to the agreement between the out-gassing estimates and measurements, this conclusion is also verified by the small temperature rise during the 20th and 21st centuries. If the CO_2 versus temperature correlation during the seven interglacials had been caused by CO_2 greenhouse warming, then the temperature rise per CO_2 rise would have been as high during the 20th and 21st centuries as it was during the seven interglacial periods.

Figure M12: Antarctic temperatures and temperature rises at various times associated with a 30% rise in CO_2. SOURCE: RRS, Figure 16.

solubility of CO2 in ocean waters, and as RRS point out, CO_2 out-gasses from the oceans. Under the reasonable assumption that the additional CO_2 in the atmosphere adds to the warming, we can say that CO_2 is a *feedback* effect associated with an increase in solar irradiance, which is the original cause of warming. The main cause of warming is the change in solar irradiance, and while the additional CO_2 in the atmosphere does add to the warming, its effect is smaller. So it would be wrong to say that a 30% increase in CO_2 *by itself* must 6° warming. And yet, this is the mistake RRS make in their attempt to show that the current temperature rise of 0.5°C is smaller than it should be given the 30% increase of CO_2 over historical levels:

> Between 1900 and 2006, Antarctic CO_2 increased 30% per 0.1 °C temperature change…, and world CO_2 increased 30% per 0.5 °C. In addition to ocean out-gassing, CO_2 from human use of hydrocarbons is a new source. *Neither this new source nor the older natural CO_2 sources are causing atmospheric temperature to change."* [Emphasis added.]
>
> The hypothesis that the CO_2 rise during the interglacials caused the temperature to rise requires an increase of about 6 °C per 30% rise in CO_2

> as seen in the ice core record. If this hypothesis were correct, Earth temperatures would have risen about 6 ^{o}C between 1900 and 2006, rather than the rise of between 0.1 ^{o}C and 0.5 ^{o}C, which actually occurred. This difference is illustrated in Figure 16.
>
> The 650,000-year ice-core record does not, therefore, agree with the hypothesis of "human-caused global warming," and, in fact, provides empirical evidence that invalidates this hypothesis.

Assuming that a 30% increase of CO_2 over the pre-industrial level is responsible for the 0.5^{o}C increase in global temperature, it remains to explain why Antarctic temperature rose only 0.1^{o}C. One reason for the smaller increase is the ozone hole which occurs over Antarctica every spring. Ozone is a GHG that absorbs infrared radiation from Earth, but it is also a strong absorber of higher-frequency solar radiation. Depletion of ozone in the spring dampens the temperature increase there. Furthermore, human use of chlorofluorocarbons (CFC) has exacerbated the depletion of Antarctic ozone, which further reduces temperature. Finally, it should be realized that Antarctica is a very special continent. It is the highest by far, with an average altitude of 9,000 ft above sea level. Furthermore, it is more or less sealed off from external climate by the circumpolar wind and sea currents. This is not true of the Antarctic Peninsula, which has a much lower altitude and protrudes extensively from the Antarctic land mass. So Antarctica as a whole has its own climate and it is no surprise that the temperature rise there is less than for the globe as a whole.

C.2. Ocean outgassing vs. ocean acidification. RRS make another mistake in the first paragraph just quoted when they say: "In addition to ocean out-gassing, CO_2 from human use of hydrocarbons is a new source." If oceans were out-gassing CO_2, the pH of the oceans would be rising, i.e., the alkalinity of the oceans would be increasing. All of the evidence is to the contrary.[21] Yamashita *et al.*,[22] whose work serves as a reference for RRS's Figure 16, even measured the *absorption* of CO_2 by the Seto Inland Sea of Japan, but RRS chose to ignore this important point that oceans are net absorbers of CO_2, not outgassers.

C.3. Residence time vs. relaxation time. We are left to doubt if RRS really understand or care what the nature of "human-caused global warming" is about. Our doubts are confirmed by their next statement:

> Carbon dioxide has a very short residence time in the atmosphere…These [estimates of residence time] range between 2 and 25 years, with a mean of 7.5, a median of 7.6, and an upper range average of about 10. Of the 36 values, 33 are 10 years or less…
>
> …There is no experimental evidence to support computer model estimates (73) of a CO_2 atmospheric "lifetime" of 300 years or more.

RRS are seriously confused about two separate concepts: residence time and relaxation time or half-life, which they call "lifetime." There are as many residence times as there are places for a CO_2 molecule to reside. An important one is the atmospheric residence

time of a CO_2 molecule, which is the average time a CO_2 molecule stays in the atmosphere before being absorbed by a reservoir such as the ocean or "eaten" by a leaf on a tree and then incorporated into the body of the tree. The residence time for a CO_2 molecule, or more appropriately a carbon atom, in a tree is, as RRS say, about 7 years or so. But the relaxation time is something entirely different. For the atmosphere, it is the time it takes an excess of atmospheric CO_2 above the equilibrium level as determined by natural processes (e.g., photosynthesis and diffusion into the oceans) to come back to the equilibrium level if no additional CO_2 is put into the atmosphere. This is accepted to be about 100 years or so. Figure M13 shows how it decays:[23]

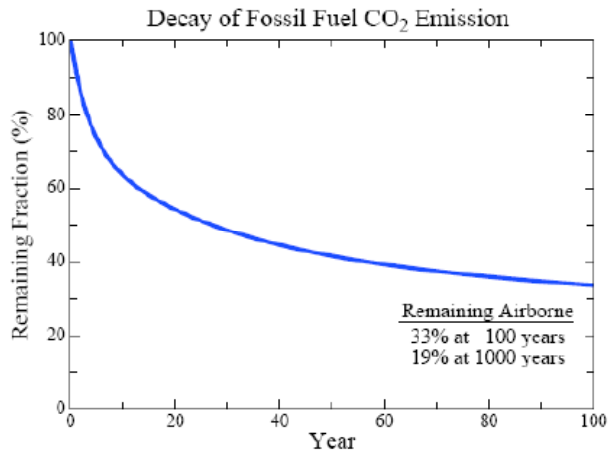

Figure M13: Relaxation of a pulse of CO_2 into the atmosphere, showing that it takes about 100 years for the excess to decline to 1/3 of its original value.
SOURCE: Atmos. Chem. Phys. 7, 2287-2312, 2007.

C.4. Confusion of added CO_2 to stored CO_2. In the second-to-last paragraph of this section, RRS say "Human production of 8 Gt C [gigatonnes of carbon] per year of CO_2 is negligible as compared with the 40,000 Gt C residing in the oceans and biosphere. At ultimate equilibrium [which, as mentioned in Section II above, RRS peg at 600 ppm of CO_2], human-produced CO_2 will have an insignificant effect on the amounts in the various reservoirs." This statement is devoid of relevance for the question of the effect of human emission of CO_2 on climate, because the only reservoir that matters for temperature change is the atmospheric reservoir. It is irrelevant that 40,000 Gt of carbon reside in the oceans and biosphere while only 780 Gt reside in the atmosphere, because only the latter contribute in the short term to global warming; and only the imbalance between natural absorption of CO_2 from the atmosphere and the total CO_2 from natural and human sources affects the total CO_2 in the atmosphere and the warming it produces. RRS's meaningless comparison has the effect of diverting attention from the real issue and confusing readers not versed in climate science.

D. RRS 4TH section: CLIMATE CHANGE

This section starts out with the statement that temperature rises are small "as the Earth recovers from the Little Ice Age," but "its environmental effects are measurable."

After recounting a number of such effects, RRS states:

> All of the observed climate changes are gradual, moderate, and entirely within the bounds of ordinary natural changes that have occurred during the benign period of the last few thousand years.

RRS can make this statement only if they take the Sargasso Sea temperatures of their Figure 1 as representative of global temperatures, and if they neglect more serious reconstructions of past temperatures as shown above in Figure 2 and the more reliable instrumental temperatures of Figure 10(a).

RRS end this short section with these words:

> There is no indication whatever in the experimental data that an abrupt or remarkable change in any of the ordinary natural climate variables is beginning or will begin to take place.

Recent data[24] on melting of the Greenland Ice Sheet does suggest that an abrupt change might be in the works, contrary to RRS's claim. RRS's complacent attitude towards climate change ignores the wild swings in climate prior to 12,000 years ago. This point is returned to below in section E.4.

E. RRS 5TH section: GLOBAL WARMING HYPOTHESIS

There are a number of errors and misleading impressions in this section, from a harmless underestimate of warming from water vapor to a misunderstanding of the nature of climate modeling.

E.1. Warming from water vapor and other GHG. If there were no GHG in the atmosphere, solar irradiance by itself would leave Earth's temperature at a maximum of -18°C, or about 0°F—very cold, too cold for life as we know it! (I say "maximum," because an absence of GHG would not just cool Earth, but would incite feedback effects, particularly the growth of the polar ice caps, which would cause Earth to reflect more sunlight and lead to an even lower temperature.) But natural greenhouse gases, especially water vapor (H_2O_v) and, to a lesser extent, CO_2, come to the rescue, raising Earth's temperature about 32°C to about 14°C. Roughly speaking, the warming effect from H_2O_v is about 20°C, but RRS incorrectly give it as 14°C. a simple mistake with no further consequences.

E.2. H_2O_v feedback. RRS go on to discuss H_2O_v as a feedback effect in climate models. The idea is fairly simple: an initial heating of Earth, and particularly its oceans, by an increase of CO_2 increases evaporation, which adds to the initial heating—a positive feedback. But a number of climatologists, particularly R. Lindzen of MIT (see references 81, 84, and 91 in RRS), have claimed that H_2O_v feedback could be negligible or even negative. This issue has been resolved in the last few years in favor of a positive feedback,[25] but RRS ignore this important work.

E.3. H_2O_v feedback vs. CO_2 temperature rise. RRS's Figure 18, shown here as Figure

M14, is a "qualitative" graph of hypothetical warming due to a doubling of CO_2. The figure also contains the much larger total greenhouse effect from all of the H_2O_v, CO_2, methane, etc. in the atmosphere. The total effect is irrelevant to the effect of increased GHG, and its presence in the graph serves only to diminish the effect of the increase. RRS say "The hypotheses that the IPCC…has chosen to adopt predict that the effect of CO_2 is amplified by the atmosphere, especially by water vapor, to produce a large temperature increase." This is shown as Hypothesis 1 in RRS Figure 18. It is roughly five times the radiative effect of doubled CO_2. This is somewhat misleading. The H_2O_v feedback by itself less than doubles the effect of CO_2. According to Held and Soden,[26] "Models of the Earth's climate indicate that this is an important positive feedback [of water vapor] that increases the sensitivity of surface temperatures to carbon dioxide by nearly a factor of two when considered in isolation from other feedbacks, and possibly by as much as a factor of three or more when interactions with other feedbacks are considered." The "other feedbacks" refer to such things as the increased absorption of solar energy due to melting of the polar icecaps, a factor which plays a role regardless of the cause of warming. Since RRS are looking only at the feedback from GHG, particularly H_2O_v , they have significantly exaggerated its effect. Hypothesis 2, which shows the warming from doubling of CO_2 to be negligible, is associated with MIT climatologist R. Lindzen's H_2O_v work, but as mentioned in the previous section, it appears that Lindzen is incorrect.

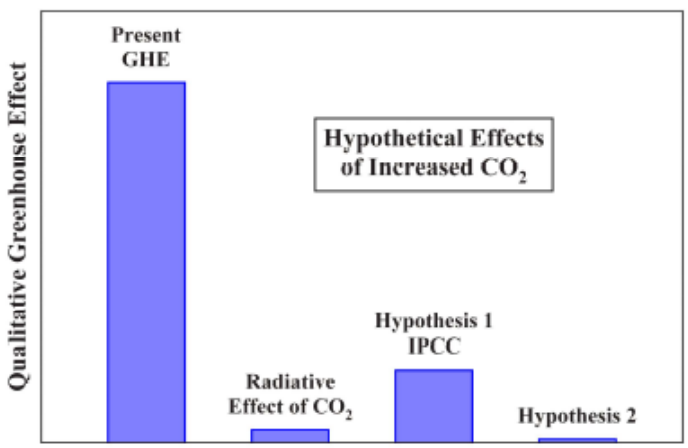

Figure 18: Qualitative illustration of greenhouse warming. "Present GHE" is the current greenhouse effect from all atmospheric phenomena. "Radiative effect of CO_2" is the added greenhouse radiative effect from doubling CO_2 without consideration of other atmospheric components. "Hypothesis 1 IPCC" is the hypothetical amplification effect assumed by IPCC. "Hypothesis 2" is the hypothetical moderation effect.

Figure M14: RRS's "qualitative" comparison of warming from natural greenhouse gases, from CO_2, and under an IPCC hypothesis based on a sizeable H_2O_v feedback and another by Lindzen, *et al.* (RRS ref. 81, 84, 91) and Spencer, *et al.* (RRS ref. 85, 92) based on negative H_2O_v feedback. If the bars were scaled properly and not just qualitatively, the bar for Hypothesis 1 would show that H_2O_v increases the effect of CO_2 by a bit less than a factor of 2, not the 5-fold increase suggested by this largely meaningless "qualitative" comparison.

E.4. Shortcomings of computer models. RRS next look at computer climate models upon which " 'human-caused global warming' is based". RRS claim the models "have substantial uncertainties and are markedly unreliable." The uncertainties are shown in Figure 19, shown here as Figure M15. Two references are given for the data in this figure, a personal communication from R. S. Lindzen,[27] and an article by Soon *et al*.[28]

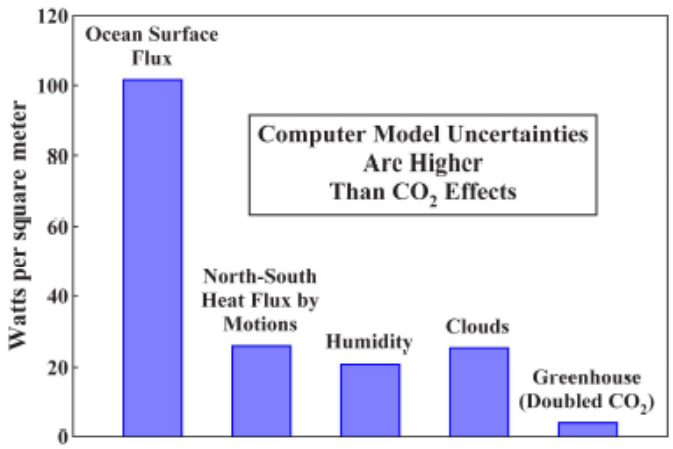

Figure 19: The radiative greenhouse effect of doubling the concentration of atmospheric CO_2 (right bar) as compared with four of the uncertainties in the computer climate models (87,93).

FIGURE M15: Uncertainties in climate models compared to the heating effect of a doubling of CO_2. SOURCE: RRS, Figure 19.

Soon, *et al.* correctly point out a number of uncertainties in climate modeling, a situation all climate modelers are familiar with. But there is nothing in Soon *et al.* that corresponds to the uncertainties shown in RRS's Figure 19, except for RRS's 100 W m^{-2} uncertainty in "Ocean Surface Flux." Soon *et al.* state: "…there are artificial energy or heat flux adjustments as large as 100 W m^{-2} that are used in some GCMs [General Circulation Models] to minimized unwanted drift in the ocean-atmosphere coupled system…" Perhaps the other RRS uncertainties concerning "North-South Heat Flux by Motions," "Humidity," and "Clouds" are from the personal communication from Lindzen. Only the 100 W m^{-2} value will be addressed here.

RRS's critique of climate models is similar to a "God of the Gaps" argument against evolution: Since evolution (climate models) can't explain everything, it (they) must be wrong. The trouble with a gaps argument is that gaps progressively disappear as science progresses. Much closer to the truth is climatologist James Hansen's statement that a scientist must sometimes "march with both feet in the air," i.e., work on assumptions that are more or less unjustified until something better comes along.[29] Indeed, the most recent CD2.0, .1, and .2 (or for short, CD2.x) climate models do not suffer from some of the 100 W m^{-2} flux adjustment that concerns RRS. According to Knutson *et al*.,[30] "The new models are substantially improved over previous GFDL [General Fluid Dynamics Lab] coupled climate models in that they provide much-

improved simulations of El Niño variability (Wittenberg et al. 2006), and they do not use flux adjustments." Gnanadesikan *et al.*[31] compare an older "R30" model requiring flux adjustments with the GFDL CD models and find the two roughly equivalent, thus showing that the flux adjustments that RRS decry have their place in improving climate models.

E.5. Sargasso Sea again, and a final RRS volley against computer models. RRS return to their Sargasso Sea temperatures in Figure 1 in another effort to imply that CO_2 is not important now, because Earth warmed a thousand years ago even though there was no increase in CO_2. But as mentioned above in section **A.1**, their use of temperatures in the Bermuda Rise, a small part of the Sargasso Sea, is no substitute for a more complete reconstruction of global temperature at that time. Also, reconstructions more than 400 years back are difficult if not impossible to calibrate accurately to match current temperatures.

Near the end of their section on Global Warming Hypothesis, RRS state: "The 'human-caused global warming'—often called the 'global warming'—hypothesis depends entirely upon computer model-generated scenarios of the future. There are no empirical records that verify either these models or their flawed predictions." As the old saw goes, "correlation does not imply causation." But there is not only correlation between the recent rise of CO_2 and temperature, there is also the *empirical* evidence on CO_2's infrared absorption spectrum, the additional *empirical* evidence in recent years on water vapor feedback, and suggestive *empirical* evidence on the cooling of the stratosphere which is a fingerprint of GHG-caused warming. In other words, there are many solid empirical results from physics embedded in the models. For that reason, they should be taken seriously while at the same time recognizing their limitations and the need for improvement.

F. RRS 6th section: WORLD TEMPERATURE CONTROL

This very short section talks about the possibility of injecting particulates into the upper atmosphere to scatter sunlight and cool Earth if it gets too warm. RRS dismiss out of hand the possibility that an increase of atmospheric CO_2 could warm Earth in the event of an impending ice age, and even claim there is no way to warm Earth if it experiences undesirable cooling. In other words, don't worry about warming, because we can counteract it. The real threat is cooling, which we are powerless to alter. They should read more carefully their reference for this section by Teller *et al.*[32] who propose modifying the scattering particulates so that they preferentially scatter the infrared radiation coming from Earth and as a result warm Earth up. In any case, we should be very wary of this grandiose idea of geoengineering which might exacerbate climatic problems in particular regions.

G. RRS 7th section: FERTILIZATION OF PLANTS BY CO_2

G1. An important point ignored by RRS. RRS argue that an increase of CO_2 in the atmosphere is a good thing, because it will cause plants to grow faster. If they are correct,

it should be kept in mind that all kinds of plants might benefit, including weeds, kudzu, and the like that we are not interested in and that might adversely growth of commercially valuable plants such as the species shown in RRS Figure 24.

G2. Evidence from tree ring growth. RRS Figure 21 shows how tree ring growth has increased moderately in the past 100 years or so ("moderately" in the sense that a deviation from the mean of less than two standard deviations is moderate). Their reference for this work, Graybill, *et al.*,[33] is discussed in a National Academy of Sciences study on temperature reconstruction.[34] The NAS study draws a number of important points from studies of the presumed effect of CO_2 on tree growth:

(1) Tree ring widths depend on temperature as well as CO_2 levels.

(2) "Stripbark" bristlecone pines (Considered in RRS's Graybill *et al.* reference), in which a band of trunk remains alive while the rest of the stem has died, are sensitive to higher CO_2 concentrations.

(3) The influence of CO_2 on "full-bark" trees is "less conclusive."

(4) The Duke University "Free-Air CO_2 Enrichment" data shows that conifer tree growth does increase, when CO_2 increases 50% over the present.

(5) Conifer tree ring records from Sierra Nevada in California and Rocky Mountains in Colorado did not show an increased growth rate due to CO_2.

(6) Pine growth at treeline is limited by factors other than CO_2.

(7) Nitrogen deposition from anthropogenic sources (e.g., fertilizer production and production of oxides of nitrogen by fossil-fuel burning) has a confounding effect when attempting to determine the effect of CO_2 on plant growth.

(8) In forest areas below treeline, such as in Scotland and Maine, there is a stable relationship between temperature and tree ring width.

It appears, therefore, that evidence for the effect of increased CO_2 on plant growth is mixed. Ironically, since temperature increases growth of plants, RRS's claim that CO_2 hardly affects global temperature means that we could have increased growth of plants even without CO_2 assuming, as they do, that increased CO_2 has little or no effect on global temperature.

G3. Tropical forest growth and CO_2. Further evidence against the RRS claim comes in a 2007 study by Feeley *et al.*[35] In an "all species" study in Panama and Malaysia, they found that growth rate was inversely related to local annual mean daily minimum temperatures but positively related to hours of sunlight, while CO_2 seems to have no

effect.

G4. Growth of U.S. timber. RRS Figure 22 graphs the volume (billions of cubic feet) of hardwoods and softwoods in the U.S. as a function of time, which shows timber volume to have increased 40% from 1952 to 2002. The source of the data in this figure is the U.S. Department of Agriculture Forest Service.[36] According to this document,

> By the 1940s, improving forest growth rates and modestly declining harvest rates resulted in timber growth and harvest coming into approximate balance. By 1952, timber growth nationally exceeded harvest by 17 percent. Since the 1950s, timber growth has consistently exceeded harvest.
>
> Net timber growth exceeded harvest by 54 percent in 1976, 36 percent in 1986, and 33 percent in 2001. Net growth rates have not been increasing as rapidly as in the past, while harvest levels have remained relatively stable since 1986. Additional resource demands have been met by increased imports."

The authors of this report do not mention increased CO_2 as a factor, though it is quite possible that some of the growth since 1952 is due to increased atmospheric CO_2. But the timber volume has increased at least partly because harvest rates are down in response to increasing timber imports. Again, a global perspective is necessary to avoid drawing misleading general conclusions from data on one country.

Another problem with the simple "more CO_2 is good" argument of RRS as applied to timberland is that growth rates of different plant species vary in response to an increase in CO_2. For example, fast-growing loblolly pines can crowd out slower-growing species like oak and hickory as CO_2 increases.[37] This can change the composition of timberland in unfavorable ways.

Finally, RRS have committed a gross error by failing to consider the global picture which shows a significant reduction of forest biomass due to significant deforestation.

G5. Adverse impact of other factors on CO_2's effect on plant growth. A number of studies have shown that while CO_2 increases plant growth when multiple factors such as temperature, precipitation, and nitrogen deposition (see item (6) in subsection G2. above) are held constant, the situation is reversed when multi-factor studies are done.[38]

H. RRS 8th section: ENVIRONMENT AND ENERGY

RRS discuss the possibility of making the U.S. energy-independent. Their main points are: (1) Energy is necessary for human welfare; (2) Calls for sharp reductions of hydrocarbon fuel use are unrealistic; (3) The cost of nuclear electrical energy is cheaper than coal, gas, wind, and solar electrical energy; (4) A mix of hydrocarbon fuel and nuclear energy can satisfy energy needs far into the future if breeder reactors and fuel reprocessing are used. (5) A large expansion of nuclear power can produce enough

energy to make the U.S. an energy exporter. (6) Hydrocarbon energy sources are necessary to ensure that developing countries can escape from poverty.

H.1. Energy and human welfare. It is obvious that energy is necessary for human welfare. There are currently six billion human beings on Earth, and many will reasonably ask if a high energy consumption per capita, equal to that of the U.S., can be achieved for the entire human population of Earth without drastically changing Earth's biosphere and possibly undermining the conditions for human life. RRS raise some interesting points about the use of hydroponic greenhouse food production and desalination of seawater, but it is all premised on cheap and plentiful energy.

The wider impact of human consumption at ever-increasing levels on Earth's biosphere is ignored by RRS, so it is reasonable to assume that they are comfortable with a "humanizing" of the planet, i.e., converting ever-growing areas of Earth's surface to human use at the expense of natural habitats. This is a controversial philosophical and moral position that deserves justification.

H.2. Sharp reductions of hydrocarbon fuel use. The authors say "Political calls for a reduction of U.S. hydrocarbon use by 90% (123), thereby eliminating 75% of America's energy supply, are obviously impractical." Their reference 123 is "The Seven Point Live Earth Pledge" by Gore *et al.* The Seven Point Pledge includes the demand that the U.S. "join an international treaty within the next 2 years that cuts global warming pollution by 90% in developed countries and by more than half worldwide in time for the next generation to inherit a healthy earth." Note that the demand is to cut global warming *pollution*, especially CO_2. If carbon sequestration (e.g., by pumping CO_2 emissions into geologically stable repositories or as recently suggested, absorbing it into) can be realized, then the cut in use of hydrocarbons could be much less than 90%. Note also that the demand is not for an immediate cut, but a cut carried out over years so that the next generation can "inherit a healthy earth."

H.3. Cost of nuclear electricity vs. coal, gas, etc. RRS claim in their Figure 26 (Figure M16) that electrical energy produced by nuclear reactors is cheaper than coal- and gas-produced electrical energy. This claim will come as a surprise to many. Consider, for example, the 2003 report by MIT on nuclear power.[39] This authoritative study, done by 10 investigators assisted by three student research assistants and chaired by a committee represented by individuals ranging from a member of the Natural Resources Defense Council to a former chair of the World Association of Nuclear Operators, can hardly be accused of prejudice against nuclear power. In fact, the report favors nuclear power as one of several energy sources for the future. But regarding costs, Table 5.1 of the report gives the cost per kilowatt hour of electrical energy (kWe-hr) for 40-year plant lifetimes as 6.7 cents for nuclear, 4.2 cents for coal, and from 3.8 (low) to 5.6 cents (high) for gas. The three values for gas refer to a real (above inflation) increase in gas prices of 0.5%, 1.5%, and 2.5%. The only scenario that puts nuclear in the running is a heavy carbon tax of $200 per ton, but even then gas loses out to nuclear only in the high-cost cast (5.6 cents per kWe-hr; p. 42), and the switch will probably be to coal and not nuclear.[40]

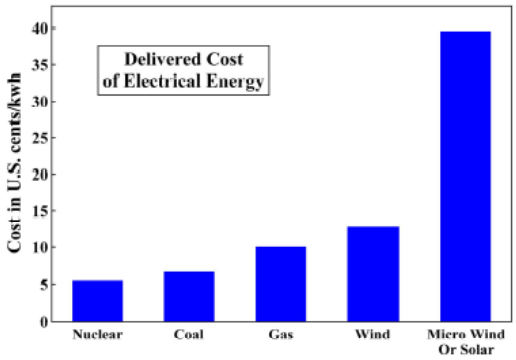

Figure 26: Delivered cost per kilowatt hour of electrical energy in Great Britain in 2006, without CO_2 controls (126). These estimates include all capital and operational expenses for a period of 50 years. Micro wind or solar are units installed for individual homes.

Figure M16: RRS's electrical energy cost graph mistakenly showing that nuclear is cheaper than gas.

Another problem with RRS Figure 26 is the very high cost for "micro wind or solar" to the exclusion of a separate price for centrally-produced solar electricity. For example, a planned solar-thermal plant in California promises to produce electricity for 6 cents per kWh. [ENDNOTE: http://www.treehugger.com/files/2006/08/worlds_largest_4.php.] Promises are promises, but this is such a far cry from the 40 cent figure shown in Figure 26 that the latter cannot be a fair representation of solar energy cost.

H.4. Satisfying energy needs into the far future. Existing uranium reserves, from which the fissionable U-235 isotope (only 0.7% of uranium) is extracted, can provide nuclear fuel only for about a hundred years or so at current rates of usage. [ENDNOTE: "Supply of Uranium," UIC Nuclear Issues Briefing Paper # 75 (Uranium Information Centre Ltd., Melbourne, Australia, 2007), available at http://www.uic.com.au/nip75.htm.] So RRS call for the development of breeder reactors and fuel reprocessing which can create plutonium fuel from the plentiful uranium-238 isotope and ensure nuclear fuel for a thousand years or more at current rates power production. But breeder reactors have never caught on as a commercial mode of production. France, for example, failed in its Phoenix and Superphoenix breeder programs. At the same time, some breeder reactors have been used to produce commercial electricity, but they are not economic. According to Australia's Uranium Information Center,[41] "Today there has been progress on the technical front, but the economics of FBRs [fast breeder reactors] still depends on the value of the plutonium fuel which is bred, relative to the cost of fresh uranium." Given all these considerations, the exploitation of breeder technology is anything but a done deal. RRS are wrong to blame government regulation as a main factor prohibiting the development of breeder technology.

H.5. Using nuclear power to make the U.S. a net energy exporter. RRS propose an expansion of U.S. nuclear energy production large enough to make the U.S. a net energy exporter. It is unclear how energy from a nuclear reactor can be exported. Currently, energy from a reactor is electrical in form, and this can be transported over electrical cables, perhaps even in great quantities overseas, but then with great transmission loss

which would make the cost of production per kilowatt-hour prohibitively expensive. Electrical energy production is best decentralized, which makes the RRS "export" scenario unrealistic, barring cheap and reliable superconducting networks. It is also unclear how much nuclear-produced electricity can substitute for other fuels. As RRS say, "Solid, liquid, and gaseous hydrocarbon fuels provide, however, many conveniences, and a national infrastructure to use them is already in place." It does not seem practical for nuclear energy to replace gas-fueled vehicles until all-electric vehicles are developed. Ironically, the one force driving this development is concern for the very fossil fuel-caused global warming that RRS want to deny.

H.6. Energy and alleviation of poverty. RRS address the problem of global poverty and development in terms of their access to hydrocarbon sources of energy:

> "Across the globe, billions of people in poorer nations are struggling to improve their lives. These people need abundant low-cost energy, which is the currency of technical progress.
>
> In newly developing countries, that energy must come largely from the less technologically complicated hydrocarbon sources. It is a moral imperative that this energy be available. Otherwise, the efforts of these peoples will be in vain, and they will slip backwards into lives of poverty, suffering, and early death."

RRS never specify if the "less technologically complicated hydrocarbon sources" for developing countries should be imported or obtained from their own domestic resources. Granted there are some countries without domestic resources, but the most important countries, China and India, do have their own resources. Those that don't must pay the market price for energy, unless there are assistance programs in place to provide "abundant low-cost energy" to help them avoid "lives of poverty, suffering, and early death." Are RRS advocating such assistance programs? Or are they intent on the free market working its Panglossian magic?

The 1997 Kyoto Protocol excludes China, India, and other developing countries from carbon emission limits. This feature, the most controversial of the Protocol, should be favored by RRS since it allows these and other developing countries to exploit their natural resources unhindered by carbon emission limits until a follow-on agreement including specifically China and India is negotiated. But they are silent on Kyoto or any other international agreement to limit carbon emissions, except in their lead paragraph which frames Kyoto in terms of a fear of global warming from CO_2, which they later claim is unrealistic.

H.7. Water cooling, proliferation, and other concerns. A few additional comments are in order regarding RRS's push for more nuclear power. First, nuclear power plants require large amounts of water for cooling purposes. The recent drought in Georgia threatened to reduce nuclear power plant output because their sources of water were shrinking.[42] Second, nuclear weapon proliferation is a concern with the fast breeder reactor or reactors using reprocessed fuel. Breeders and reactors using reprocessed fuel,

use plutonium, which is also the easiest material to make a nuclear bomb with. Unless plutonium fuel is subject to the strictest controls, there is a danger that some of it will be diverted to weapons development by non-nuclear states or groups. This is a real concern, since it takes so little plutonium to make a weapon. Third, the radioactive waste problem is real, particularly if the breeder route is excluded for the reasons just stated. Fourth, as mentioned above, breeder reactors are not as of now economically competitive. And fifth, RRS's claim about reactor safety ("Reactor accidents are much publicized, but there has never been even one human death associated with an American nuclear reactor incident") is valid only as a result of rigorous government regulation, not in spite of it as they seem to suggest when they include regulation (along with taxation and litigation) as a factor responsible for inhibiting energy production.

IV. CONCLUSIONS

In their own final "Conclusions" section, RRS repeat their claim that there is no experimental data to support the hypothesis that increased anthropogenic greenhouse gases in the atmosphere will cause unfavorable changes on Earth, and that an increase in global temperature will not cause problems but on the contrary will extend growing seasons, bring warmth to colder regions, and allow our children to "enjoy an Earth with far more plant and animal life than that with which we now are blessed." This is a foolhardy attitude to take, because RRS must assume they know with certainty how increased warming of the planet will affect the biosphere and global climate. The climate system has exhibited chaotic behavior in the past, and it is unacceptably risky to tempt fate by subjecting the climate to a disturbance whose effects are unknown and possibly very dangerous.

It is particularly perverse of RRS to say that increased use of hydrocarbon fuels will increase plant and animal life for our children when the tremendous expansion of population and unregulated economic activity in the last century has caused extinctions and threatened extinctions of plant and animal species and massive deforestation. The last thing our children need is a perturbation to a climate system that has shown chaotic behavior in the past.

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