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CLIMATE CHANGE PAPERS YOU SHOULD READ

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This is an annotated anthology of published, refereed papers that, in my view, are fundamental to an understanding of the science of climate change. Millions of papers are published each year, and thus it is difficult to reduce the myriad of articles to just forty-four fundamental papers. Moreover, this annotated anthology is compiled from a climate change realist perspective, rather than an alarmist one. Its purpose is to present a list of the cadre of articles that convey the current understanding of climate change and to provide an interpretation of their significance from a layman's perspective. To be included, these papers must have been published in reputable refereed journals.

Although the papers span 128 years (from 1896 to 2023), most of the articles were written during the last fifteen. In part, this is because the science is developing and more papers are written each year than the year before. Moreover, it also takes several years before the full importance of a paper becomes apparent and it is vetted by the larger scientific community. But also contributing has been the nature of the development of the field of climatology over the past seventy-five years.

Originally, the study of climate, or climatology, was largely an actuarial science. Research usually focused on climate classification (identification of the various climates of the earth) by examining the average and variability of weather conditions for a given region. In addition, much research was focused on applied climatology—the description, definition, interpretation, and explanation of the relationship between climate and a wide variety of weather-sensitive activities. Since it overlapped with many disciplines, applied climatology is very broad and eclectic, and thus the climatologist had to be conversant not just in climatology, but also in studies affected by weather and climate, such as agriculture, business, and engineering.

Climate change was not usually a topic of discussion since climate was described as "average weather." But in the middle of the last century, it became clear that climate itself was variable and subject to changes caused by natural variability and human-induced effects. This led to a new area of inquiry related to the study of climate dynamics, which fostered a plethora of questions related to climate change. Although recent research exhibits an inordinate focus on the impact of greenhouse gases and the behavior of climate models, climatology has emerged as a complex and sophisticated area of research, far removed from its roots as the simple study of the statistics of local climates.

Selection of these forty-four papers was a very difficult task and reflects my biases on what constitutes the cadre of important papers on climate change. I have tried to provide a viable cross-section of papers that addressed important questions as well as those which have provided breakthrough research that changed the course of climate change research. If I have omitted or missed a paper that you feel would be a better choice, you have my apologies.

Putting this list together has been enjoyable; I hope you find the articles and their layman's abstracts interesting as well.

1896	**Arrhenius, S.** On the influence of carbonic acid in the air upon the temperature of the ground. *Philosophical Magazine and Journal of Science*, **41,** 237-276.

Svante August Arrhenius is largely viewed as the father of the "greenhouse effect" based on his work in this 1896 paper. It is often argued that this paper first quantified the contribution of carbon dioxide (or "carbonic acid" as carbon dioxide was called at the time) to the greenhouse effect and made significant speculations about whether long-term climate variability could be influenced by changes in atmospheric carbon dioxide. Although Arrhenius does not suggest that global warming will result from a burning of fossil fuels, he is aware that burning of fossil fuels will increase the amount of carbon dioxide in the atmosphere and explicitly suggested this in his later writings.

Although earlier important papers on this topic do exist (*e.g.*, J. Fourier in 1822 and J. Tyndall in 1859), this paper is important over these other works because, unlike these other works that were largely chemistry experiments, Arrhenius tried to connect carbon dioxide effects to nebulosity (*i.e.*, obstruction of the atmosphere energy transmission by changes in carbon dioxide concentrations) by latitude and land versus oceans. Thus, this paper transformed the influence of carbon dioxide from a mere evaluation of atmospheric chemistry to a forcing of climate change within environmental science.

The latter portion of this paper argues strongly that proof must be found for the argument that carbon dioxide is largely responsible for the variation in ice ages. The paper dedicates much discussion to rejecting the hypothesis of James Croll regarding the importance of orbital parameters, which was generally discredited at the time but later modified by Milankovitch and subsequently Milankovitch cycles prevailed in 1976.

1920	**Gradenwitz, A.** Carbonic acid gas to fertilize the air. *Scientific American*, **123,** 549, 557.

Gradenwitz's paper is a bit obscure, but I included it here because it is one of the first papers to note that carbon dioxide ("carbonic acid") provides a beneficial effect to plant life. By the time this paper was published, the utility of carbon dioxide in photosynthesis from intake through the stomata of leaves had long been known and the assumption that carbon was acquired through the root system had been abandoned.

But Gradenwitz noted that the carbon dioxide concentration of the atmosphere was relatively low in 1920 (~0.03%) but it had been much higher in earlier periods when lush vegetation was prevalent. He "suggested the idea of heightening the fertility of the soil by increasing [the carbon dioxide content] and thus producing conditions resembling those of antediluvian ages."

To validate his claim, Gradenwitz cites research from Germany where combustion gases from blast furnaces were purified (to remove sulfur compounds) and then pumped into test greenhouses (with two others as a control group). Cucumbers and tomatoes within the enhanced-carbon dioxide greenhouse grew to almost twice the size of those in the control group. He concludes "careful analysis has shown the increase in the percentage of carbonic acid in the air to remain far below the limit where the gas becomes liable to endanger the health of man."

1967	**Manabe, S., and R.T. Wetherald**: Thermal equilibrium of the Atmosphere with a Given Distribution of Relative Humidity. *Journal of the Atmospheric Sciences,* **24**(3), 241-259.

The importance of this paper by Manabe and Wetherald is that it began the era of four-dimensional (three spatial dimensions and time) climate modeling. The paper discusses the development of the climate model using the current knowledge of climate at the time and explored the impact of a doubling of carbon dioxide on the global climate.

Crude by today's standards, the model focused primarily on the radiative convective equilibrium of the atmosphere using the moisture content of the atmosphere as an initial boundary condition. The model illustrated that it was highly dependent on the moisture content of the atmosphere and how it was specified, as this early model used prescribed initial conditions of moisture content. The model also suggested that the surface equilibrium temperature was sensitive to forcings such as the solar constant, the concentration of ozone and carbon dioxide, and cloudiness.

Nevertheless, this early model suggested that "a doubling of the carbon dioxide content in the atmosphere has the effect of raising the temperature of the atmosphere (whose relative humidity is fixed) by about 2°C" (3.6°F). The authors also noted that the model lacked the extreme sensitivity to changes in carbon dioxide concentrations that others had suggested at the time.

1974	**Bryson, R.A.**: A perspective on climatic change. *Science*, **184,** 753-760.

Bryson was an early climatologist who focused on climate change. This article appears during the height of the global cooling discussion but nevertheless provides a prescient evaluation of the processes that drive climate change.

Bryson argues that all climate forcings pale in comparison to the effect of the Sun. He notes that climate is thermodynamically forced; therefore, the overall response of the atmosphere "is an internal response to this forcing." Nevertheless, he shows that even small changes in climatic variables can produce significant changes in the environment. In particular, he argues that past climates can result from slight modifications to the general atmospheric circulation. He also notes that human activity can affect several of these so-called "control variables"; he cites atmospheric turbidity (*e.g.*, haze or volcanic activity) and carbon dioxide concentration as examples.

Moreover, Bryson further suggests that climate can change very rapidly. Although some parameters vary on long time-scales (*e.g.*, orbital forcings), others (*e.g.*, volcanic activity) may change the atmosphere both rapidly and sporadically. Indeed, he argues that the speed of climatic change is dictated by "the time constant of the active layer at the surface of the Earth and the time constant of glaciers."

Overall, this is an excellent overview of climate change, even though it was written almost fifty years ago.

1976	**Keeling, C.D., R.B. Bacastow, A.E. Bainbridge, *et al.***: Atmospheric carbon dioxide variations at Mauna Loa observatory. *Tellus*, **28**(6), 538-551.

This paper touted the continuation of a long-term project to measure atmospheric carbon dioxide concentrations from a continuously recording, nondispersive infrared gas analyzer. The site—the Mauna Loa high altitude observatory on the island of Hawaii—is situated 3,400 meters (~11,155 ft) above sea level on the north slope of the active volcano. The purpose is "to document the effects of the combustion of coal, petroleum, and natural gas on the distribution of carbon dioxide in the atmosphere."

This paper established (along with a companion paper documenting an observatory on Antarctica) an ongoing program that continues to this day. The existing record was extended by eight years (thus, analyzed in the paper from 1959 to 1971), suggested the rise in carbon dioxide was about 1 ppm per year with a significant seasonal cycle, owing to the use and release of carbon dioxide by land plants and the soil.

The importance of this paper is its argument for a significant secular increase in carbon dioxide concentrations, in addition to its diurnal and annual oscillations. This analysis of the long-term increase in carbon dioxide set the stage for carbon dioxide to become a variable worthy of further study and research. The authors conclude "the air…may be slightly influenced by local processes which cannot be expunged from the record, but the observed long term trend of rising carbon dioxide appears clearly to be in response to increasing amounts of industrial carbon dioxide in the air on a global scale."

1981	**Namias, J., and D.R. Cayan**: Large-Scale Air-Sea Interactions and Short-Period Climatic Fluctuations. *Science*, **214**(4523), 869-876.

Namias was a pioneer in the study of interactions between the atmosphere and the ocean. Beginning in the late 1950s, he began to realize that long-range weather forecasting required a "memory" of events beyond the time frame that the atmosphere could provide. While listening to a series of presentations on recent oceanic oscillations at a conference, he concluded that long-range weather forecasting might be driven by the coupled air-sea system. He noted the disparate time scales between the ocean and the atmosphere and that the "memory" could be imparted to the atmosphere by the longer time-scale of the oceans. This paper is an overview of the research that followed that observation.

Coupling between the atmosphere and the ocean can provide keys to observed patterns present in the other. Anomalies in sea surface temperature "are about an order of magnitude more persistent than those of atmospheric circulations" and the article describes the process of including sea surface temperature patterns in long-range weather prediction. Despite these advances, however, the authors conclude that "our understanding is woefully inadequate to achieve reliability in prediction." Describing the phenomena is one thing; determining a dependence of the atmosphere on the oceans (or vice versa) is a level to which the authors believe that the science has not yet advanced. Nevertheless, we have seen some success in prediction on seasonal time scales due to the scientific advances in explaining climatic fluctuations. The authors conclude that "the present rapid pace of research implies that much better understanding will be achieved in the years to come." It has.

1983	**Philander, S.G.H.**: El Niño Southern Oscillation phenomena. *Nature*, **302,** 295-301.

Initial realization of the conclusion of Namias and Cayan (1981) came quickly. Much research had been focused on explaining the periodic warming of the central and western Equatorial Pacific Ocean, the concomitant relaxation of the Walker circulation in the Equatorial Pacific, and associated global teleconnections that arise from it. Although the seeds of what is known as the El Niño–Southern Oscillation (ENSO) had been sown in the early years of the twentieth century, Philander's paper codified the extensive research in this seminal paper.

Philander presents the combined El Niño (the ocean) and Southern Oscillation of the Walker Cell circulation (the atmosphere) phenomenon. An ENSO event occurs at a time scale that varies from between two and ten years. In the tropical Pacific Ocean, both sea surface temperatures and rainfall are anomalously high with weakened trade winds (east-west). This warming of the tropical Pacific waters leads to changes in atmospheric circulation which can cause severe winters over North America or create heavy rainfall in western South America, for example. Interestingly, these teleconnection patterns tend to develop in a remarkably predictable manner.

The paper discusses the 1982-1983 ENSO event which developed in a manner far different from the canonical ENSO events that had preceded it. This began research as to whether the oceans drive the atmosphere (more likely the usual pattern since the oceans have far more mass and momentum) or whether the atmosphere may, at times, drive the oceans (in this particular case, due to the eruption of the El Chichón volcano in Mexico in 1982).

1990	**Lindzen, R.S.**: Some coolness concerning global warming. *Bulletin of the American Meteorological Society*, **71,** 288-299.

By the end of the 1980s, global warming had taken hold in the climate community and many scientists were getting in on the research and funding bandwagon. Lindzen was one of the first scientists to raise concern publicly that a consensus on global warming may be unhealthy for climate science. Self-identifying as a skeptic, Lindzen presented his arguments as to why some issues left him unconvinced.

In particular, Lindzen noted that our considerable lack of understanding of climate processes does not justify a consensus. He cast doubt on whether the models would ever be capable of modeling the climate to the degree necessary to determine accurately the small increase in energy storage arising from a doubling of CO_2 with the inability to model the oceans at sufficient resolution being a formidable stumbling block.

The conclusion alludes to research on the Earth's adaptive infrared iris that Lindzen would expand upon more than a decade later. He suggested that model developments and observations over the next decade or two (*i.e.*, through 2010) should provide insight as to whether we would ever have a definitive answer to the question of the impacts of global warming, short of experiencing it directly. He concludes by stating "there is one thing that is surprisingly clear right now; it is difficult to envision any practical action that will make much difference to the final outcome."

1990	**Spencer, R.W., and J.R. Christy**: Precise monitoring of global temperature trends from satellites. *Science*, **247,** 1558-1562.

Global air temperature reconstructions were usually based on surface observations which are limited, for example, by station moves, instrumentation and observational changes, and the fact that weather stations are most often located where people live – in mid-latitudes, at lower elevations, and along the coasts. This paper presents a summary of one of the major efforts to measure air temperature from satellite data.

The authors demonstrate that problems associated with air temperature measurements from surface-based thermometers can be alleviated by using passive microwave from satellites. Satellites provide a near complete coverage of the Earth's surface (except for the extreme polar regions) in both space and time and are devoid of biases resulting from the local environment surrounding the thermometer. The authors conclude "because of their demonstrated stability and the global coverage they provide, these radiometers should be made the standard for the monitoring of global atmospheric temperature anomalies since 1979."

Their methodology relies on passive microwave radiometers onboard NOAA satellites. These instruments measure the emitted energy from atmospheric ozone at frequencies between 50 and 70 Ghz. Specific frequencies can be related to different levels in the atmosphere so that a vertical temperature profile can be estimated. Instruments are continually calibrated in orbit and new satellites overlap in time with old satellites to provide intra-satellite consistency. In sum, this methodology has allowed the development of the best time-series of atmospheric temperatures dating back to 1979.

1996	**Michaels, P.J., and P.C. Knappenberger**: Human effect on global climate? *Nature*, **384,** 522-523.

In the Second IPCC report, the phrase "…The balance of evidence suggests that there is a discernible human influence on global climate" was inserted. This phrase was supported by a pattern-correlation-based paper written by Santer *et al*. This comment was one of the first to falsify the results of the Santer *et al.* research and, as a result, raise considerable doubt of the major message provided by the Second IPCC report.

Santer *el al.*'s research focused on correlating the observed spatial patterns of atmospheric temperature change with those predicted by climate models driven by carbon dioxide, aerosols, and ozone. They found that since the correlation between the models and the observations increased during the period from 1963 to 1987, it was likely that the observations were driven by the changing conditions represented by the climate models.

The authors demonstrated that Santer *et al.*'s research conclusions were based on their cherry-picked selection of data only from 1963 to 1987. By extending the time period to include all the data—from 1958 through 1995—the authors were able to show that the correlation was valid only for the time period chosen by Santer *et al.* Outside of this time period, the correlation did not suggest a causal relationship existed between the observations and the model simulations.

1997	**Legates, D.R., and R.E. Davis**: The continuing search for an anthropogenic climate change signal: Limitations of correlation-based approaches. *Geophysical Research Letters*, **24,** 2319-2322.

To address the inserted phrase in the Second IPCC report, these authors focused on the statistics associated with the centred-pattern-correlation-based paper written by Santer *et al*. While Michaels and Knappenberger focused on cherry-picking of the time period, Legates and Davis demonstrated that the centred pattern correlation coefficient is a limited and biased statistic in that it does not represent what Santer *et al.* purport that it does.

Their demonstration used a simple example to illustrate these problems. The authors took two spatial fields that change over time – one called "the observations" and the other called "the model." The two fields were identical at the beginning, but diverged over time. Surprisingly, the centred pattern correlation coefficient increased over time, suggesting that the correlation between the two fields was increasing when, in fact, it was decreasing.

This example shows that the statistic "does not fundamentally indicate cases where a strong agreement exists between the model and observations" due to a number of well-known issues associated with simple linear correlation. The authors suggest an alternative approach to assessing pattern correlation that alleviates these problems.

2001	**Lindzen, R.S., M.-D. Chou, and A.Y. Hou**: Does the Earth have an adaptive infrared iris? *Bulletin of the American Meteorological Society*, **82,** 417-432.

This paper describes the interaction between water vapor and clouds in the Tropics, thereby suggesting that high cirrus clouds (due to their absorption of heat energy and limited impact on reflected sunlight) modulate changes in temperature. This provides strong negative feedback where changes in temperature is mitigated by changes in high cloud cover (~ –22% $°C^{-1}$).

Using high-resolution satellite data and a two-dimensional radiative convective model, the authors documented changes in cloud coverage concomitant with changes in sea surface temperatures, which were mimicked within the model. The loss of infrared radiation to space as sea surface temperature increased was facilitated by the shrinkage of the area covered by cirrus clouds in the vicinity of cumulus towers.

Reasons for this are quite detailed but are based largely on detrainment (*i.e.*, the transfer of air from rising motions to the surrounding atmosphere) of cirrus clouds decreases as a result of convection arising from increasing temperature. Calculations by the authors show that this negative feedback potentially cancels all positive feedbacks in overly-sensitive climate models, or at least model water vapor feedbacks. Calling this an "adaptive infrared iris," the authors demonstrate that this process controls outgoing longwave radiation in response to surface temperature changes much like the iris of one's eye controls light on the optic nerve. Although the paper was initially met with strong criticism, a number of papers have since been published that confirm the existence of an adaptive infrared iris.

2003	**Kalnay, E., and M. Cai**: Impact of urbanization and land-use change on climate. *Nature*, **423,** 528-531.

Urban effects are one of the major influences on surface air temperature records. But since the early work of Landsberg and others, urbanization and land use changes have been known to have a significant effect on the local climate. This article serves to highlight the impact of these important influences.

The authors note that both the increase in greenhouse gases and land use changes including the effects of urbanization and agriculture are more likely to increase global temperatures. To assess the impact of land use, the authors compare the difference between observed air temperatures in the United States and surface temperatures derived from a 50-year reanalysis (a combination of weather forecasts and data assimilation) that does not use observations of air temperature, moisture, and winds. These data were omitted from the reanalysis to guarantee the reanalysis product is insensitive to land use changes but reflects larger-scale climate changes (due to observations above the surface).

Results indicate that land use changes are responsible for a temperature rise of about 0.27°C per century, or about a third of the total warming since 1880s. Moreover, land use changes are responsible for about half of the observed decrease in the diurnal (*i.e.,* day versus night) temperature range.

2003	**Soon, W., S.L. Baliunas, C.D. Idso, *et al.***: Reconstructing climatic and environmental changes of the past 1000 years: A reappraisal. *Energy & Environment*, **14,** 233-296.

Following the advent of the Mann *et al.* hockey stick, existence of the Medieval Warm Period and the Little Ice Age were called into question. To assess whether the extensive research on site-specific paleoclimatic reconstructions over the last millennium indicate the presence of these warm and cold periods, respectively, the authors posed three questions to numerous individual climate proxies: Is there an objectively discernible climatic anomaly occurring (1) during the Medieval Warm Period (800-1300 A.D.), (2) during the Little Ice Age (1300-1900 A.D.), and (3) within the 20th century (that is the warmest period in the record)? The disparate nature of proxy indicators means that the results cannot be summarized as a hemispheric or global composite value.

The preponderance of the evidence from this extensive compendium of climate proxies "establishes the reality of both the Little Ice Age and the Medieval Warm Period as climatic anomalies with world-wide imprints" and corroborates the viewpoints held by Bryson, Lamb, and numerous other researchers over the preceding forty years. Moreover, many of the existing proxy records do not suggest that the 20th century is the warmest period over the last 1000+ years, thereby indicating that the temperature during the Medieval Warm Period was higher than it is today. The authors also conclude "that human activity has significantly impacted some local environments."

The overall conclusion of the article is that the Mann *et al.* hockey stick misrepresents the extensive literature from site-specific paleoclimatic reconstructions with a marked Medieval Warm Period and a marked Little Ice Age.

2005	**McIntyre, S., and R.R. McKitrick**: Hockey sticks, principal components, and spurious significance. *Geophysical Research Letters*, **32**.

McIntyre and McKitrick also evaluated the Mann *et al.* hockey stick representation of Northern Hemisphere air temperatures. Through their research, the authors had uncovered that although undocumented, Mann *et al.* had employed a data transformation that had strongly adversely affected the results, of which the authors characterized as "unusual."

Principal components analysis (PCA), used by Mann *et al.* to develop their global air temperature reconstruction, is a linear decomposition of the data; thus, derived components can be affected if the raw data are subjected to linear transformations prior to the application of PCA. Mann *et al.* subtracted the 1902-1980 mean from the raw data (a linear transformation) and since that mean is likely different from the mean of the entire time series (*i.e.*, from 1400-1980), the residuals are increased which, in turn, inflates the series variance (a function of the square of the residuals). As principal components are calculated using a maximum-variance-explained criterion, hockey stick-shaped patterns are likely to be selected. That, conveniently, downplayed or removed the presence of the Medieval Warm Period and the Little Ice Age in the data.

The authors tested the Mann *et al.* method on red noise (data with a long-term signal) and found that the method "nearly always produces a hockey stick shaped first principal component" (used by Mann *et al.*). It also inflates the variance explained by that component as well (thereby increasing its apparent influence). In particular, the authors concluded that the reconstruction during the 15th century is not statistically significant.

2007	**McKitrick, R.R., and P.J. Michaels**: Quantifying the influence of anthropogenic surface processes and inhomogeneities on gridded global climate data. *Journal of Geophysical Research*, **112,** D24809.

Trends in observed air temperature data are affected by changes in local land use but these effects are not induced by climate change and must be filtered out of the data. The authors argue that if such effects are properly removed, the filtered time-series should be uncorrelated with socioeconomic variables since they, effectively, determine these extraneous trends. This article tests that hypothesis.

The authors' premise is that trends in a linear regression using lower tropospheric temperatures, atmospheric pressure, humidity, and coastal and latitude locations should be uncorrelated with population and gross domestic product. Results indicate that this premise is rejected with a high degree of statistical significance, thereby leading to the conclusion that non-climatic signals contaminate the gridded climate data. In addition, the contamination exists in countries regardless of their financial status but tends to be greater for countries where a growth in real income exists. After assessing for spurious correlations and intra-variable dependencies, the authors conclude that the influence of anthropogenic surface processes and inhomogeneities "leads to an overstatement of actual trends over land" and that "nonclimatic effects [reduce] the estimated 1980–2002 global average temperature trend over land by about half."

2007	**Wunsch, C., R.M. Ponte, and P. Heimbach**: Decadal trends in sea level patterns: 1993-2004. *Journal of Climate*, **20,** 5889-5911.

Combining oceanographic and meteorological observations with a general circulation model, sea level rise is addressed over the twelve-year period from 1993 to 2004. This database contains an extensive number of observations to provide the most detailed decadal assessment of sea level trends and factors that influence sea levels—including "about 100 million ocean observations and many more meteorological estimates." The data includes all types of observations including altimetric variability, profiles taken from Argo floats, measurements of sea surface temperature, and current hydrography.

Results indicate that although few locations exhibit statistically significant trends, some regions show spatially correlated signals with regional sea level change being driven directly by the general oceanic circulation. The author's assessment is that estimates of global sea level rise is about 1.6 mm yr^{-1} (6.3 in. $century^{-1}$) of which about 70% results largely from melting ice. Their conclusion is that thermal expansion of sea water through warming of ocean waters is dominated by meltwater, even for interannual global variations. This estimate of 1.6 mm yr^{-1} is only about 60% of the pure altimetric estimate (*i.e.,* pure measurement of height) but, as the authors conclude, "the widely quoted altimetric global average values may well be correct, but the accuracies being inferred in the literature are not testable by existing *in situ* observations." Moreover, "systematic errors are likely to dominate most estimates of global average change: published values and error bars should be used very cautiously."

The telling quote from this extensive assessment by a well-recognized expert in sea level trends is "it remains possible that the database is insufficient to compute mean sea level trends with the accuracy necessary to discuss the impact of global warming—as disappointing as this conclusion may be."

2010	**Koutsoyiannis, D.**: "A random walk on water." *Hydrology and Earth System Sciences*, **14,** 585-601.

The usual scientific viewpoint is that natural phenomena (*e.g.*, air temperature, precipitation, streamflow) can be decomposed into deterministic (cause-and-effect) and stochastic (random) components. Science usually pursues identifying and explaining the deterministic component while the stochastic component is little more than "noise" which must be removed or otherwise dealt with.

Koutsoyiannis argues that uncertainty is an intrinsic property of all natural phenomena and is not simply noise in the system. Consequently, causality implies predictability but that uncertainty can grow over time to degrade predictability. This is a statement of how the uncertainty in initial conditions propagate to make predictability virtually impossible after some time period—like the chaos found by Lorenz. Koutsoyiannis goes further, suggesting that the deterministic and stochastic components are neither independent nor separable but which one is dominant depends on the time scale of the prediction. He concludes that "long horizons of prediction are inevitably associated with high uncertainty, whose quantification relies on the long-term stochastic properties."

2011	**Curry, J. A.**: Reasoning about climate uncertainty. *Climatic Change*, **108,** 723-732.

Regarding the concept of uncertainty, Curry suggests that climatologists, in general, and the IPCC, in particular, have underestimated uncertainty through oversimplification of processes and conclusions. This has resulted in "misleading overconfidence" as to assertions of climate processes and their conclusions within the IPCC assessments.

To improve the representation of our uncertainty about the climate system within the IPCC reports, Curry argues that a better characterization of it is required—confidence levels must be portrayed in a more realistic manner. In particular, the "noise and animosity portrayed in the media that fuels the public distrust of climate science that is clouding the policy process." In her view, the challenge of communicating uncertainty will reap benefits in the development of policy options and with policy makers and communicators. Moreover, she argues that a consensus approach, such as that used by the IPCC, enforces "overconfidence, marginalization of skeptical arguments, and belief polarization.

Curry concludes that "a concerted effort by the IPCC is needed to identify better ways of framing the climate change problem, explore and characterize uncertainty, reason about uncertainty in the context of evidence-based logical hierarchies, and eliminate bias from the consensus building process itself."

2011	**Spencer, R.W., and W.D. Braswell**: On the misdiagnosis of surface temperature feedbacks from variations in Earth's radiant energy balance. *Remote Sensing*, **3,** 1603-1613.

The authors focus on the climate system and its sensitivity to radiative forcing which, they assert, is the "largest source of uncertainty in projections of future anthropogenic climate change." From an observational perspective, they argue that this uncertainty arises largely from internal climate variability, most likely due to natural variations in cloud cover.

Daily estimates of reflected solar radiation and outgoing thermal longwave were obtained from NASA's Terra satellite. Selected climate model data from CMIP3 for 1900 through 1999 also were used to provide radiative fluxes as well as surface temperatures. Lagged regression analysis between the surface temperature and the time-series of the net radiative flux (incoming shortwave minus the sum of the outgoing longwave and reflected shortwave) then was used to assess the magnitude of the internal radiative forcings and how (or whether) they corrupt estimates of feedbacks.

Results indicate that the satellite observations and climate models differ widely on the response of temperature versus variations in net radiation. This difference was even greater over the oceans. Moreover, the discrepancy points mildly toward a lower climate sensitivity of the real climate system. The authors conclude that "atmospheric feedback diagnosis of the climate system remains an unsolved problem, due primarily to the inability to distinguish between radiative forcing and radiative feedback in satellite radiative budget observations."

2012	**Lindzen, R.S.**: Climate science: Is it currently designed to answer questions? *Euresis Journal*, **2,** 161-192.

Here, Lindzen addresses the fundamental question of whether we are capable of actually solving problems of climate science. He laments that progress in climatology has moved at a much slower rate than should be expected, caused to a large degree, by the overbearing influence of politics. A change in the scientific paradigm of theory versus observation to an overt emphasis on model simulation and large observational programs.

This change, Lindzen argues, has obscured the potential for convergence of ideas and thoughts through scientific testing and analysis by replacing it with a much less effective emphasis on institutional expansion. A growing university administration and the quest for grant monies has fostered a scenario of perpetual programs that grow larger each year. Scientific organizations become empowered where a small executive council can declare the intent of thousands of scientists and punish scientists who dissent.

Facilitating this change is extensive financial support from the federal government who dictates scientific results through the establishment of the political agenda, and not the other way around. Throughout the paper, Lindzen discusses the origin of these changes and provides insight into the actions of both scientific institutions and scientists to bend data and theory to support the political narrative. He also discusses how dissention from the political agenda is dealt with.

2013	**Essex, C.**: Does laboratory-scale physics obstruct the development of a theory for climate? *Journal of Geophysical Research: Atmospheres*, **118,** 1218-1225.

Physical processes, including those that drive the climate, occur at a variety of temporal and spatial scales. Essex argues that climate modeling is akin to studying kinetic theory using laboratory scale calculations—just like climate and weather, these processes operate at quite disparate space and time scales.

The article suggests how climate science should proceed. Despite much work to the contrary, no physical theory of climate currently exists. Climate processes are not simply averages of weather events; therefore, any solution must address this fundamental issue. Climate-scale observations are quite disparate from our everyday world. Weather events are invisible at the scale of climate processes but climate processes are, in turn, invisible at the weather scale. Just as long exposure (or slow-shutter) photography ignores high-speed motion and focuses on slow, deliberate changes, Essex calls for a change in the paradigm from classical physics to equations that describe, for example, “generalized wind” which he defines as internal energy flows divided by the entropy density (entropy measures the degree of disorder while density is the closeness of the atoms) and is measured in ms^{-1}.

Essex notes this concept is still in its infancy since the equations are not closed, although the prospect of closing the system is possible; or maybe not. However, the article purports to study the climate from a more fundamentally appropriate perspective and freshen and revolutionize climate science.

2013	**Ridd, P.V., E.T. da Silva, and T. Stieglitz**: Have coral calcification rates slowed in the last twenty years? *Marine Geology*, **346,** 392-399.

The authors re-examine calcification rates of 328 Porites corals (a genus of stony coral) from the Great Barrier Reef. Previous researchers had concluded that between 1990 and 2005, a dramatic decline in coral calcification of 14% had occurred. This decline was attributed to a consequence of rising carbon dioxide concentrations and a subsequent decrease in ocean pH due to the absorption of carbon dioxide (*i.e.*, carbonic acid) which causes the degradation of calcareous marine organisms. This previous analysis suggested that 1990 represented a tipping point in coral decalcification.

The authors note that this result is surprising in that a previous comprehensive study which utilized a subset of the data demonstrated that the corals had grown by 4% over the 20th century. Research by the authors indicate that the apparent reduction in the calcification rates since 1990 was due to a combination of two factors. First, ontogenetic effects (*i.e.,* the development of an organism through tissue growth and cellular differentiation), coupled with the variable width of coral growth bands with age, were ignored. Second, "a systematic data bias [was] clearly evident in the last growth band of each core." In particular, the dramatic fall in calcification post-1990 disappeared when bands with a coral age of less than 20 years were excluded.

The authors caution that care must be taken to ensure that coral age must be held constant. Young corals are more susceptible to changes in their environment and thus future research must focus on sampling small colonies where early growth rates can be successfully measured. They conclude "whilst large data sets of calcification rates of massive corals are an excellent archive of environmental effects on reef building organisms, currently available data of coral calcification in the GBR cannot reliably resolve a systematic dramatic reduction in calcification in recent years."

2014	**Happer, W.**: Why has global warming paused? *International Journal of Modern Physics A*, **29,** 1460003.

Happer has written extensively on the absorption of electromagnetic radiation by the various molecules in the atmosphere, most notably carbon dioxide and water. This article, however, discusses these processes in less technical, but scientifically correct prose.

The question posed in the title of the article addresses the so-called global pause in the increase in air temperature that had been observed since 1999. Happer notes that both the popular press and scientific journals noted this pause and pondered its cause. Rather than address it from a statistical perspective, as was the case in many other articles, Happer focused on a comprehensive assessment of climate forcings, with particular attention to the absorption of radiation by gases in the atmosphere. Although scientifically complete, this presentation is much easier for laypeople to understand.

As to the answer to the question "why has global warming paused?", Happer shows that the popular notion that carbon dioxide is the climate control knob is a fallacy—carbon dioxide is a minor player in climate change.

2015	**Legates, D.R., W.W.-H. Soon, W.M. Briggs, and C.o.B. Monckton**: Climate consensus and 'misinformation': A rejoinder to agnotology, scientific consensus, and the teaching and learning of climate change. *Science & Education*, **24,** 299-318.

This is a follow-up to an article written two years earlier that had questioned the application of agnotology to politically-charged debates. Agnotology is defined as "the study of how ignorance arises via circulation of misinformation calculated to mislead." A charge levelled against the first article was that the "overwhelming" climate consensus was being undermined by the fossil-fuel industry and its allies through their "campaign of obfuscation." This so-called "climate misinformation" was based on post-modernist assertions that truth is determined solely by expert consensus, of which near unanimous agreement on climate alarmism exists.

The authors evaluated this so-called consensus determined by research from their detractors—that most warming since 1950 is anthropogenic in origin—and found that their claim of a 97.1% was attained only by asserting that all research that did not explicitly state their opposition to the consensus was, in fact, in agreement with it. Using data provided by the detractors in developing the consensus, the authors showed that just 0.3% of their sampled articles explicitly agreed with their consensus.

The authors concluded that agnotology and the definition of "misinformation" is a bogus claim since either side can accuse the other that their dissenting views are misleading. Nevertheless, the authors suggest that all sides should be presented in any scientific debate and silencing opposing views has no place in educating the public.

2016	**Parker, A., and C.D. Ollier**: Coastal planning should be based on proven sea level data. *Ocean and Coastal Management*, **124,** 1-9.

Absolute sea level is the average height of the ocean above a fixed reference height whereas relative sea level is the sea level recorded by gauges. Absolute sea level is much more difficult to measure since the land elevation may also be changing due to land subsidence or rise, groundwater depletion, or sediment compaction. The authors argue that relative sea level is a better measure for proper coastal management as the computations of absolute levels are fraught with substantial errors that are greater than the observed rise.

Using data from 570 tide gauges of varying length, the authors show that the global relative sea level rise is +1.04 mm yr^{-1} but if the analysis is limited to gauges with more than 80 years of data (100 gauges), the rise is only +0.25 mm yr^{-1}. Thus, sea levels are slowly rising but they are not accelerating. Moreover, the authors show that larger trends in sea level rise using satellite altimetry can only be achieved by arbitrary adjustments to the raw data.

They conclude that "the effects of climate change are negligible" and "local patterns may be used for local coastal planning without any need of purely speculative global trends." Relative sea level rise is stable worldwide such that coastal planning should focus on tangible short-term threats.

2016	**Zhu, Z., S. Piao, R.B. Myneni, *et al.***: Greening of the Earth and its drivers. *Nature Climate Change*, **6,** 791-795.

If carbon dioxide is indeed plant food, then one would expect that the Earth would exhibit significant greening. Using three long-term satellite records of leaf area index (LAI), the authors examined changes in vegetation greenness between 1982 and 2009. Results demonstrate "a persistent and widespread increase of growing season integrated LAI (greening) over 25% to 50% of the global vegetated area, whereas less than 4% of the globe shows decreasing LAI (browning)."

In an attempt to explain the reason for the relative greening of the Earth, the authors employed factorial simulations from ten global ecosystem models. The results indicated that fertilization from carbon dioxide increases explain 70% of the observed greening trend while nitrogen deposition, climate change (*i.e.*, temperature increase), and land use changes accounted for 9%, 8%, and 4%, respectively. Latitudinally, increases in carbon dioxide provided the dominant effect in the tropics while climate change was most responsible for greening in high latitudes and over the Tibetan Plateau. In the eastern United States and southeast China, the dominant reason for greening was land-use, land-cover changes.

Further results of this paper included that future ecosystem models must include "the impacts of forest demography, differences in regional management intensities for cropland and pastures, and other emerging productivity constraints such as phosphorus availability."

2017	**Ahlstrom, A., G. Schurgers, and B.E. Smith**: The large influence of climate model bias on terrestrial carbon cycle simulations. *Environmental Research Letters*, **12,** 10.

In the quest to make climate models more realistic, detailed models of global vegetation and the terrestrial carbon cycle are being developed and used to study the carbon balance of terrestrial ecosystems. Unfortunately, the disparate models that have been developed exhibit large discrepancies in their predictions of changes in the carbon balance. This is because the large magnitude of carbon flows within the terrestrial biosphere affect the model-simulated feedbacks associated with changing atmospheric concentrations of carbon dioxide.

The authors suggest that the reasons for model biases and uncertainties include the implicit structure of ecosystem models as well as errors in specification of parameters and the concomitant forcing from the atmospheric component of climate models. They conclude that "the relative importance of these contributing factors to the overall uncertainty in carbon cycle projections is not well characterised." From model diagnostics, the authors show that biases and uncertainties in the parameterization of the carbon cycle bias the annual means of air temperature, precipitation, and solar radiation receipt. Consequently, changes in carbon sinks are affected by climate biases which could be responsible for up to 40% of the uncertainties in model simulations of carbon flows and sinks. As a result, the authors suggest "that climate bias-induced uncertainties must be decreased to make accurate coupled atmosphere-carbon cycle projections.

2017	**Christy, J.R., and R.T. McNider**: Satellite bulk tropospheric temperatures as a metric for climate sensitivity. *Asia-Pacific Journal of Atmospheric Science*, **53,** 511-518.

Climate sensitivity is how much the Earth's temperature will change following a specified change in the climate system, usually a doubling of atmospheric carbon dioxide. To estimate the climate sensitivity to human-induced forcings, the authors removed natural variability (caused by, for example, volcanism and El Niño) from the global mean lower tropospheric air temperatures from January 1979 through June 2017 and used the resulting time series to estimate the anthropogenic component.

After natural variability was removed (primarily affected by volcanic cooling in the early years), the estimated trend was +0.096°C per decade—a reduction of 0.059°C per decade over the raw trend. This updated value is essentially the same rate that the authors had calculated 23 years earlier using less than half the current time series. From this value, the authors estimated the transient climate sensitivity (*i.e.*, the change in temperature when carbon dioxide doubles) for the lower troposphere to be +1.10 ± 0.26°C, or about half the sensitivity obtained from climate models used in the Fifth Assessment Report of the IPCC.

Results indicate that climate models considerably overestimate the radiative forcing. Additional analysis shows that the enhanced sensitivity arises in the tropics, most likely due to the way models parameterize deep tropical convection or the partitioning of heat between the ocean and the atmosphere. Additional unknown natural variability in the models also could account for this enhanced sensitivity.

2017	**Dayaratna, K.D., R.R. McKitrick, and D. Kreutzer**: Empirically constrained climate sensitivity and the social cost of carbon. *Climate Change Economics*, **8,** 1750006.

This article focuses on assessment models that integrate the projected effects of climate change (including ocean heat uptake and equilibrium climate sensitivity—the effect that a doubling of carbon dioxide will ultimately have on air temperature) and socioeconomic projections (*e.g.*, population changes) with the economic response. The purpose of these models is to determine how much the adaptation to prognostications of climate change will cost and the discount rate (*i.e.*, the rate at which society will trade present benefits for future ones).

Traditionally, the equilibrium climate sensitivity has been taken from climate model simulations but these authors used empirically-derived estimates in these integrated assessment models. Their resulting estimates of the resulting social cost of carbon are much lower—by 40% to 50% in one integrated assessment model and more than 80% in another. The reason for the much lower estimates in the latter model is because it takes into account the potential regional benefits from carbon dioxide fertilization and increased agricultural productivity. This leads to the conclusion whether carbon dioxide emissions are even a social cost. The authors conclude that the "use of empirically constrained parameters reduces uncertainty [in] the shrinking of the social cost of carbon range across discount rates."

2017	**Harde, H.**: Scrutinizing the carbon cycle and CO_2 residence time in the atmosphere. *Global and Planetary Change*, **152,** 19-26.

Traditional assessments of climate change purport that the Earth's carbon cycle has been adversely affected by anthropogenic combustion of fossil fuels and changes in land use. This has rapidly and dramatically increased atmospheric carbon dioxide concentrations which will remain resident for millennia. However, Harde argues the classic representation of the carbon cycle is incorrect and he proposes an alternative concept.

Harde suggests that the rate of uptakes by the natural sinks of carbon dioxide is proportional to the concentration of carbon dioxide. Moreover, paleoclimatic variations in carbon dioxide and the actual growth rate of carbon dioxide are strongly temperature dependent, driven by the vegetative response to enhanced carbon dioxide. Harde concludes that the anthropogenic contribution to the concentration of carbon dioxide in the atmosphere is only 4.3% and the increase in carbon dioxide for the Industrial Age is only 15% with an average residence time of four years.

Although the results of this paper may be controversial, the article is nevertheless useful for its overview of the IPCC representation of the carbon cycle and for Harde's discussion of the uncertainties associated with the carbon cycle. His assumption for a temperature dependency on carbon dioxide which is proportional to the actual carbon dioxide concentration is food for thought.

2017	**Hourdin, F., T. Mauritsen, A. Gettelman, *et al.***: The art and science of climate model tuning. *Bulletin of the American Meteorological Society*, **98,** 589-602.

Most of the general population (and many climate scientists) assume that climate models take our current understanding of climate physics, parameterize that into a computer code model, and then run the model and present the results. What some knew and many others suspected was that climate models are tuned to provide certain results and that the outcome of model simulations may, to some degree, be pre-determined.

Most modeling centers tune the global net radiation at the top-of-the-atmosphere as well as global mean surface temperature, focusing primarily on cloud parameterizations and its optical properties and fraction, convective processes, the reflectivity of ice, and the treatment of ocean-atmosphere interactions. This is a rather extensive list of components, most of which are the main uncertainties in our understanding of climate processes.

The authors conclude "some diversity and subjectivity [exists] in the tuning process because of the complexity of the climate system and because of the choices made among the equally possible representations of the system." Moreover, the conclusion indicates that higher-order estimates made by the model—the equilibrium climate sensitivity, for example—also are tuned to keep it within the "anticipated acceptable range."

2017	**Lindzen, R.S.**: Straight talk about climate change. *Academic Questions*, **30,** 419-432.

Rather than focus on a technical issue regarding climate change, Lindzen departs from a scientific discussion to engage in a presentation of why, despite an overwhelming lack of evidence for terrestrial warming, alarmists succeed with their illogical arguments and, at times, blatant dishonesty. He is amazed that much of the general public believe the alarmist claims and attempts to explain why they are evidence of willful dishonesty.

Lindzen identifies a number of examples how the alarmist claims are accepted without proof. They include the 97% consensus meme, the "Warmest Years on Record" meme, the extreme weather meme, sea level rise, Arctic sea ice, the polar bear meme, ocean acidification, and the death of coral reefs. Despite evidence to the contrary, and even defying the logic of physics at times, these memes and issues dominate the public discourse and are taken as proven fact. Recently, almost everything imaginable has been attributed to global warming. Spurious correlations aside, the EPA has made a considerable number of specious claims that global warming is responsible for numerous health issues and air quality deterioration.

Lindzen discusses that the climate system is a highly complex system with lots of flows and variability—and we are supposed to believe that a 2% perturbation just one variable (carbon dioxide) can wreak havoc on the climate system. He concludes that believing in this is akin to believing in magic, not science, and that "science is a mode of inquiry rather than a belief structure."

2018	**Christy, J.R., R.W. Spencer, W.D. Braswell, and R. Junod**: Examination of space-based bulk atmospheric temperatures used in climate research. *International Journal of Remote Sensing*, **39,** 3580-3607.

In the IPCC Fifth Assessment Report, tropospheric temperatures were identified as key variables in climate change since they are an indicator of heat accumulation, and thereby an indicator of the impact of additional greenhouse gases on the Earth's climate. The authors examine four satellite data records that estimate bulk temperature of the tropics; all have been updated since the Fifth Assessment Report. While all four datasets are highly correlated, as expected, they provide different estimates of the linear trend—the most important consideration.

Satellite assessments show that global trends range from +0.07 to +0.13°C per decade with the rates being slightly greater in the tropics (+0.08 to +0.17°C per decade). This latter range is considerably less than the IPCC model simulations for the same period where the rate is about twice the satellite estimate. In the tropics, the satellite estimates are less than that obtained from the models in the Fifth Assessment.

The authors conclude that satellites in the 1990s exhibit spurious warming although this influence is minimized by the UAH estimates due to its merging process. Climate model simulations likely overstate the rate of warming due largely to "a misrepresentation of the basic model physics of the tropical hydrologic cycle (*i.e.*, water vapour, precipitation physics and cloud feedbacks)."

2018	**Lewis, N., and J.A. Curry**: The impact of recent forcing and ocean heat uptake data on estimates of climate sensitivity. *Journal of Climate*, **31,** 6051-6071.

Best assessments of climate forcings and estimates of their uncertainty are used to evaluate the equilibrium climate sensitivity (ultimate temperature increase due to a doubling of greenhouse gases) and the transient climate response (the temperature increase when greenhouse gas concentrations double). Such evaluations include the contribution from aerosol forcing and ozone, including contributions from volcanic activity and internal variability.

Results show the range of equilibrium climate sensitivity (at a 90% level of confidence) lies between 1.05 and 2.34°C with a median value of 1.50°C. The transient climate response is between 0.9 and 1.7°C with a median value of 1.20°C. Although the lower bounds are increased slightly over a previous study ending in 2011, the upper bounds have been greatly reduced. When time-varying climate feedbacks are assumed, the equilibrium climate sensitivity lies between 1.2 and 3.1°C with a median value of 1.76°C. Biases from the estimation of future air temperatures, the variability in sea surface temperatures, and non-unit forcing efficacy. Thus, models are almost twice as warm than these observationally-derived values.

The authors conclude that high values of the equilibrium climate sensitivity and the transient climate response from IPCC models "are inconsistent with observed warming during the historical period." In addition, these estimates suggest that warming will be only 55% to 70% of the warming proffered by the IPCC models.

2018	**Zeng, Z., S. Piao, L.Z.X. Li, *et al.***: Impact of Earth greening on the terrestrial water cycle. *Journal of Climate*, **37,** 2633-2650.

This article opens with the statement "leaf area index is increasing throughout the globe, implying Earth greening." It then proceeds to evaluate this statement by comparing satellite observations of Earth greening with climate model projections. Using a coupled land-climate model, model simulations are evaluated with satellite observations to determine the impact of greening on the terrestrial water cycle.

Results show that the increase in leaf area index over a thirty-year period (early 1980s to early 2010s) has caused increases in both land evapotranspiration (water put into the atmosphere through the transpiration of plants) and precipitation (because what goes up, must come down). In areas where moisture was prevalent, this greening did not lead to decreased streamflow and soil moisture content because of the increase in both evapotranspiration and precipitation. In dry areas, soil moisture content was simulated to decrease, but the authors note that model biases may have played a role since precipitation is badly simulated, particularly in areas where precipitation is low.

This article suggests that increasing leaf area index has an unexpected contribution to hydrological enhancement (*i.e.*, more water fluxes) although some would argue this fact was expected. The authors conclude that a proper assessment of the hydrological cycle in land surface models demands an accurate representation of precipitation, which models do not simulate well.

2020	**Koutsoyiannis, D.**: Revisiting the global hydrological cycle: Is it intensifying? *Hydrology and Earth System Sciences*, **24,** 3899-3932.

One of the persistent claims associated with globally warming air temperatures, is the intensification of the hydrologic cycle. With the proliferation of databases and advances in monitoring environmental processes, Koutsoyiannis revisited the global hydrological cycle to better quantify it and to test climatological hypotheses. He concludes that the data do not confirm established hypotheses.

Expected trends of most hydrologic variables, based on increasing carbon dioxide concentrations, should be monotonic; that is, a distinct trend should be present. By contrast, virtually all hydrological variables exhibit fluctuations from intensification to deintensification with less variability dominating since 2000. Koutsoyiannis notes that both the terrestrial water balance and the oceans exhibits less variability today but much greater in the climatic past. He points out that the largest effect on the hydrological cycle is both exploitation of groundwater reserves and the melting of glaciers. Although groundwater use is anthropogenic and has a noted effect on sea level rise, the impact of human activity on glacier melt is more difficult to assess as research on ice loss at the poles attributes mass loss to changes in ice dynamics.

Koutsoyiannis concludes by suggesting that hydrologists should play a more active role in assessing climate change. In the last century, hydrology supported hydrotechnology, water management, and risk assessment/reduction. They need to do the same in the arena of climate change, rather than taking a passive role by using questionable climate model simulations to assess hydrological impacts.

2020	**Koutsoyiannis, D., and Z.W. Kundzewicz**: Atmospheric temperature and CO_2: Hen-or-egg causality? *Sci*, **2,** 33.

In this article, Koutsoyiannis investigates the conventional assessment that an increase in greenhouse gases leads to global warming by evaluating the opposite; that global warming leads to an increase in greenhouse gases. He notes that since an increase in air temperature leads to an increase in carbon dioxide concentrations, the relationship between carbon dioxide and air temperature is a “chicken or egg” question where separating the cause from the effect is difficult.

Examining the relationship between the two variables from the instrumental record (*i.e.*, 1980 through 2019) using time lags and reducing the possibility that results are merely statistical artifacts, Koutsoyiannis determined that soil respiration (plant respired carbon dioxide) and sea respiration increases with air temperature. Moreover, chemical reactions, metabolic rate, and microorganism activity also increase with air temperature.

Noting that both directions of causality exist, the results show that the dominant direction is that increasing air temperature leads to enhanced carbon dioxide concentrations. Over the last thirty years, changes in carbon dioxide have lagged changes in air temperature by about six months to a year. Koutsoyiannis argues that due to the rise in air temperature, biochemical reactions through soil and sea respiration are largely responsible for increasing carbon dioxide emissions.

2021	**Connolly, R., W. Soon, M. Connolly, *et al.***: How much has the Sun influenced Northern Hemisphere temperature trends? An ongoing debate. *Research in Astronomy and Astrophysics*, **21,** 68.

Solar forcing of the surface temperature of the Earth has been of considerable interest since before climate change became a political issue. Here, the authors evaluate the effect of total solar irradiance on the surface air temperature trends in the Northern Hemisphere. The sixteen different measures of total solar irradiance fall into two distinct groups—those with low solar variability and those with high solar variability. Northern Hemisphere temperature trends were obtained from all available station data, rural-only stations, sea surface temperatures, and air temperature proxies obtained from tree-rings and glaciers. Although the estimates that include urban stations exhibit greater warming than other estimates, all sources indicate warming since the late 19th century.

Linear least-squares were used to remove the solar influence from the air temperature estimates; the residuals then were correlated with the time series of anthropogenic forcings recommended by the IPCC. The disparate estimates of total solar irradiance suggest a range of conclusions from recent warming being mostly human-induced to recent warming being mostly solar-induced. The authors conclude that previous studies have simply assumed humans were the cause of recent warming without considering all estimates of solar forcing.

The authors conclude that studies must consider all estimates of total solar irradiance, not just those which underestimate solar influence. Moreover, researchers much consider differences between and uncertainties in estimates of Northern Hemisphere air temperatures.

2023	**Lewis, N.:** Objectively combining climate sensitivity evidence. *Climate Dynamics*, 60, 3139–3165.

Assessments of climate sensitivity to a doubling of atmospheric carbon dioxide utilize many sources; the IPCC Sixth Assessment Report raised the lower limit from a likely value of 1.5°C to 2.5°C. Lewis evaluates the methods used to derive climate sensitivity and calls into question the use of a subjective statistical method where the researcher specifies an *á priori* distribution. Here, Lewis uses an objective method with computed prior distributions is considered.

Results show that the resulting estimates of long-term climate sensitivity are much lower and with a tighter range of values than has been obtained with subjective *á priori* methods (*i.e.*, 1.55 to 3.2°C for a 90% confidence interval with a median estimate of 2.16°C). Lewis suggests that “this sensitivity to the assumptions employed implies that climate sensitivity remains difficult to ascertain, and that values [for climate sensitivity] between 1.5°C and 2°C are quite plausible.”

This paper updates previous estimates of climate sensitivity by author and others using more representative carbon dioxide forcings, employing a more realistic carbon dioxide-radiative forcing relationship, and using better justified and more recent information. Although values are higher than an earlier estimate by the author, differences are largely attributable to the base period used by the two articles.