Welcome

CHM1051 is the second of two honors general chemistry courses that provide a strong chemistry foundation for undergraduate students majoring in chemistry, biochemistry and other “hard” science fields. The major objective is to develop a thorough understanding of chemistry and how it relates to everyday life. A great deal of information will be covered over the course of the semester; it is essential that you keep up with the work if you want to do well in the course – I strongly suggest you do the assigned reading in advance of lectures, review lecture notes afterward, and keep up with practice problems. DON'T FALL BEHIND!

The Liberal Studies for the 21st Century Program at Florida State University builds an educational foundation that will enable FSU graduates to thrive both intellectually and materially and to support themselves, their families, and their communities through a broad and critical engagement with the world in which they live and work. Liberal Studies offers a transformative experience; this course has been approved as meeting the Liberal Studies requirements and thus is designed to help you become a critical appraiser of scientific theories and the facts that support them.

Course Description

CHM 1051. Honors General Chemistry II (3). Prerequisites: CHM 1050 and 1050L, each with a grade of "C-" or better, or CHM 1045 and 1045L, each with a grade of "C-" or better and instructor permission. Corequisite: CHM 1051L. Lecture. This course is a continuation of general chemistry for honors students. Topics include solution equilibria; acid/base chemistry; oxidation, reduction, and electrochemical cells; chemical analysis; hydrides and oxides of the elements; kinetics; advanced bonding and structure.

Course Objectives:

Upon completion of this course students will demonstrate the ability to...

- Think critically and cogently about causal relationships with scientific reasoning. [Chapter Summaries 11-20]
- Assess previous experimentation and published scientific results. [Chapter Summaries 11-20]
- Critically examine and evaluate scientific observation, hypothesis or model construction. [Chapter Summaries 11-20]
- Articulate a variety of issues created by the complex interactions among science, technology, and society. [Chapter Summaries 11-20]
- Use scientific perspectives to evaluate contemporary problems facing society. [Chapter Summaries 11-20]
- Define and understand the types of intermolecular forces present in inorganic and simple organic molecules; describe and predict the intermolecular forces for a particular compound;
predict the effects of such forces on the physical and chemical properties of the compound. [Chapter Summaries 11, Homework 1-4, Exam I]

- Perform quantitative analysis of the colligative effects of a solute in a solution, including effects on boiling point, melting point and osmotic pressure. [Chapter Summaries 12, Homework 5-7, Exam I]

- Describe the variables which affect the rate of a chemical reaction; use experimental data to determine a rate law; use rate laws to calculate the relationship between concentration and time for a chemical reaction. [Chapter Summaries 13, Homework 8-11, Exam II]

- Define and understand the equilibrium constant for a chemical reaction, and the related concepts of LeChatelier’s Principle and Equilibrium shift. Use experimental data to calculate values for an equilibrium constant and equilibrium concentrations. [Chapter Summaries 14, Homework 12-15, Exam II]

- Use the pH scale and pH relationships to determine hydrogen ion concentrations, hydroxide ion concentrations, pH or pOH for a solution, based on experimental data; perform buffer calculations for acid/base mixtures. [Chapter Summaries 15, Homework 16-19, Exam III]

- Use the appropriate equilibrium constants to determine solubility and/or precipitation point of an inorganic solute, in water or a solution. [Chapter Summaries 16, Homework 20-22, Exam III]

- Define and understand the equilibrium constant for a chemical reaction, and the related concepts of LeChatelier’s Principle and Equilibrium shift. Use experimental data to calculate values for an equilibrium constant and equilibrium concentrations. [Chapter Summaries 14, Homework 12-15, Exam II]

- Define and describe the types of electrochemical cells, and their individual components; predict the potential of an electrochemical cell under standard and non-standard conditions; use the quantitative relationship between current, charge and time to perform calculations. [Chapter Summaries 18, Homework 26-29, Exam IV]

- Define and describe the processes of nuclear fusion and fission, predict the products of a nuclear decay and calculate the nuclear binding energy. [Chapter Summaries 19, Homework 30-33, Exam IV]

**Instructor**

Dr. Stephanie R. Dillon  
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Phone: (850) 644-0166  
E-mail: sdillon@chem.fsu.edu  
Office Hours: T 9-11am or by appointment
<table>
<thead>
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<th>Week</th>
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**Typical Course Schedule:**

- 1/15 Introduction to class
- 1/17 Dr. Martin Luther King Day (No Classes)
- 1/17 Spring Break
- 3/17 Spring Break
- 4/27 Final Exam 10AM - Noon
***NOTE*** Schedule is subject to change. Changes will be announced in class in advance and corrections to the schedule will be made online.

Materials Required –

(1) Chang and Goldsby, Chemistry, 11th Edition
(2) Access code for Connect and Learnsmart online Homework System
(2) A NON-PROGRAMMABLE Scientific Calculator

Assignments and Grading:

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<th>Description</th>
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<td>Quizzes (Best 10 at 10 pts each)</td>
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<td>Exams (Best 4 of 5 at 100 pts each)</td>
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<td>Chapter Summaries (10 Chapters 5pts each)</td>
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<td><strong>Total</strong></td>
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Grading Scale:

Final grades in the course will be assigned based on the percentage of total possible points in the course, according to the following percentile scale:

- 90-100% A
- 80-89% B
- 70-79% C
- Below 70% D/F

The above scale represents the minimum grade for that percentile range, and the instructor may modify the grade cut-off percentiles downward if necessary to compensate for problematic exams or other factors. The instructor may also wish to provide modified grading scales for individual exams that deviate from the above scale in order to help students track their performance in the course; however, any adjustments to the final grading scale will be based on point totals at the end of the course.

University Attendance Policy: Excused absences include documented illness, deaths in the family and other documented crises, call to active military duty or jury duty, religious holy days, and official University activities. These absences will be accommodated in a way that does not arbitrarily penalize students who have a valid excuse. Consideration will also be given to students whose dependent children experience serious illness.
Missed Quiz or Exam Policy:

If you are aware that you must miss an exam or quiz prior to the day of the exam or quiz, contact the instructor or your recitation TA to see if arrangements to take the exam/quiz may be made in advance. If you miss an exam or quiz due to unforeseen circumstances, this missed exam or quiz will count as one of your dropped grades.

If you miss more than one exam or an excessive number of quizzes, the missed exam or quiz may be prorated if you have a documentable and reasonable excuse. The decision as to whether or not to prorate the missing grade is at the discretion of the instructor. Notification of the missed exam or quiz should be made as soon as humanly possible. No make-up exams will be given after the date and time of the regular exam.

Examples of Reasonable Excuses (Documentation) Include:

- Illness (Note from Doctor or Thagard)
- Jury Duty or Court Date (Copy of Summons)
- Car Accident or Breakdown (Accident report or bill including time of incident)
- Death in Family (Copy of Obituary or service Document)

This is not an all-inclusive list but should give you a general idea of the magnitude of an acceptable excuse and the type of documentation required to substantiate it. Other problems will be dealt with on an individual basis.

Academic Honor Policy

The Florida State University Academic Honor Policy outlines the University’s expectations for the integrity of students’ academic work, the procedures for resolving alleged violations of those expectations, and the rights and responsibilities of students and faculty members throughout the process. Students are responsible for reading the Academic Honor Policy and for living up to their pledge to “. . . be honest and truthful and . . . [to] strive for personal and institutional integrity at Florida State University.”

(Florida State University Academic Honor Policy, found at http://fda.fsu.edu/Academics/Academic-Honor-Policy)

Americans With Disabilities Act: Students with disabilities needing academic accommodation should: (1) register with and provide documentation to the Student Disability Resource Center; and (2) bring a letter to the instructor indicating the need for accommodation and what type. This should be done during the first week of class. This syllabus and other class materials are available in alternative format upon request. For more information about services available to FSU students with disabilities, contact the:

Student Disability Resource Center 874 Traditions Way 108 Student Services Building Florida State University Tallahassee, FL 32306-4167 (850) 644-9566 (voice) (850) 644-8504 (TDD) sdrctrfsu.edu http://www.disabilitycenter.fsu.edu/

Free Tutoring from FSU: For tutoring and writing help in any course at Florida State University, visit the Academic Center for Excellence (ACE) Tutoring Services’ comprehensive list of tutoring options - see http://ace.fsu.edu/tutoring or contact tutor@fsu.edu for more information. High-quality tutoring is available by appointment and on a walk-in basis. These services are offered by tutors trained to encourage the highest level of individual academic success while upholding personal academic integrity.
SEXUAL HARRASSMENT POLICY:

It is the policy of the University that its employees and students neither commit nor condone sexual harassment in any form. http://registrar.fsu.edu/bulletin/grad/info/university_notices.htm

STUDENT ELIGIBILITY FOR AN INCOMPLETE GRADE:

Incomplete (“I”) grades will not be assigned, except in the case of exceptional unforeseen circumstances that occur within the last three weeks of the semester and your work has otherwise been satisfactory (C average).

Syllabus Change Policy

Except for changes that substantially affect implementation of the evaluation (grading) statement, this syllabus is a guide for the course and is subject to change with advance notice.
Global warming 'pause' since 1998 reflects natural fluctuation

Date: 
July 21, 2014
Source: 
McGill University

Statistical analysis of average global temperatures between 1998 and 2013 shows that the slowdown in global warming during this period is consistent with natural variations in temperature, according to research by McGill University physics professor Shaun Lovejoy.

In a paper published this month in Geophysical Research Letters, Lovejoy concludes that a natural cooling fluctuation during this period largely masked the warming effects of a continued increase in human-made emissions of carbon dioxide and other greenhouse gases.

The new study applies a statistical methodology developed by the McGill researcher in a previous paper, published in April in the journal Climate Dynamics. The earlier study -- which used pre-industrial temperature proxies to analyze historical climate patterns -- ruled out, with more than 99% certainty, the possibility that global warming in the industrial era is just a natural fluctuation in Earth's climate.

In his new paper, Lovejoy applies the same approach to the 15-year period after 1998, during which globally averaged temperatures remained high by historical standards, but were somewhat below most predictions generated by the complex computer models used by scientists to estimate the effects of greenhouse-gas emissions.

The deceleration in rising temperatures during this 15-year period is sometimes referred to as a "pause" or "hiatus" in global warming, and has raised questions about why the rate of surface warming on Earth has been markedly slower than in previous decades. Since levels of greenhouse gases have continued to rise throughout the period, some skeptics have argued that the recent pattern undercuts the theory that global warming in the industrial era has been caused largely by human-made emissions from the burning of fossil fuels.

Lovejoy's new study concludes that there has been a natural cooling fluctuation of about 0.28 to 0.37 degrees Celsius since 1998 -- a pattern that is in line with variations that occur historically every 20 to 50 years, according to the analysis. "We find many examples of these variations in pre-industrial temperature reconstructions" based on proxies such as tree rings, ice cores, and lake sediment, Lovejoy says. "Being based on climate records, this approach avoids any biases that might affect the sophisticated computer models that are commonly used for understanding global warming."

What's more, the cooling effect observed between 1998 and 2013 "exactly follows a slightly larger pre-pause warming event, from 1992 to 1998," so that the natural cooling during the "pause" is no more than a return to the longer term natural variability, Lovejoy concludes. "The pause thus has a convincing statistical explanation."

The methodology developed in Lovejoy's two recent papers could also be used by researchers to help analyze precipitation trends and regional climate variability and to develop new stochastic methods of climate forecasting, he adds.

Story Source:
The above story is based on materials provided by McGill University. Note: Materials may be edited for content and length.

Journal Reference:
Return periods of global climate fluctuations and the pause

S. Lovejoy

1Physics, McGill, Montreal, Canada

Abstract An approach complementary to General Circulation Models (GCMs), using the anthropogenic CO₂ radiative forcing as a linear surrogate for all anthropogenic forcings [Lovejoy, 2014], was recently developed for quantifying human impacts. Using preindustrial multiproxy series and scaling arguments, the probabilities of natural fluctuations at time lags up to 125 years were determined. The hypothesis that the industrial epoch warming was a giant natural fluctuation was rejected with 99.9% confidence. In this paper, this method is extended to the determination of event return times. Over the period 1880–2013, the largest 32 year event is expected to be 0.47 K, effectively explaining the postwar cooling (amplitude 0.42–0.47 K). Similarly, the “pause” since 1998 (0.28–0.37 K) has a return period of 20–50 years (not so unusual). It is nearly cancelled by the pre-pause warming event (1992–1998, return period 30–40 years); the pause is no more than natural variability.
1. Introduction

A massive effort to prove anthropogenic warming has recently culminated in the conclusion that it is “extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century”, with the term “extremely likely” referring to a 95–100% probability (International Panel on Climate Change, IPCC, Fifth Assessment Report, AR5). Yet this effort may be facing diminishing returns. It is surely significant that the 1979 National Academy of Science’s climate sensitivity estimate (1.5–4.5 K/CO₂ doubling) was re-iterated in all the Assessment reports (with a minor variation in the AR4). More troubling, the models over-estimated the post-1998 El Nino global temperatures: they did not anticipate the “global slow-down” [Guemas et al., 2013], “hiatus” [Fyfe et al., 2013], or “pause” [Slingo et al., 2013]. Even if the ex-post facto reconciliations proposed by Guemas et al. [2013], Schmidt et al. [2014], or Mann et al. [2014] are correct, the damage has been done. Climate change deniers have been able to dismiss all the model results and attribute the warming to natural causes.

Whereas scientific theories can never be proven true “beyond reasonable doubt”, they can be falsified by single decisive experiments. This was the approach taken in Lovejoy [2014] where a GCM-free methodology was proposed to determine the amount of the warming, the effective climate sensitivity, and—most importantly—the probability of the warming being due to natural causes. For the first two, the results were close to those of the AR5: for global temperature changes, compare 0.87 ± 0.11 K (1880–2004) with 0.85 ± 0.20 K (1880–2012), and for CO₂ doubling, 3.08 ± 0.58 with 3 ± 0.75 K (one standard deviation). However, the probability of a centennial scale giant fluctuation was estimated as ≤0.1%, a new result that allows a confident rejection of the natural variability hypothesis. At the moment, the necessary preindustrial centennial scale probabilities can only be reliably determined from multiproxy reconstructions (and for the extremes, with the help of some nonlinear geophysics theory). While the falsity of the natural variability hypothesis does not veracity the anthropogenic one, it certainly raises its credibility. The two most cogent remaining skeptic arguments—that the models are wrong and the variability is natural—are thus either irrelevant or are disproved by the new approach.

The key innovations were the use of the CO₂ radiative forcing as a linear surrogate for all the anthropogenic effects and the use of scaling fluctuation analysis on multiproxy temperatures to deduce bounds on the extreme probability tails of centennial scale fluctuation probability distributions. The first was justified by the tight relationship between global economic activity, emissions (both warming and cooling: greenhouse gases and aerosols) and other anthropogenic effects and confirmed by statistical analysis of the residuals. The second was justified by an empirical determination of probability distributions of fluctuations and the well
documented scaling of preindustrial temperatures in the macroweather regime (≈10 days to ≈100 years, e.g., Lovejoy and Schertzer [1986], Monetti et al. [2003], Pelletier [1998], Bunde et al. [2004], Huybers and Curry [2006], Rybski et al. [2008], Lennartz and Bunde [2009], Franzke [2010], Franzke [2012], and Freidrich et al. [2009]); for reviews, see Lovejoy [2013] and Lovejoy and Schertzer [2013].

GCM and GCM-free approaches are thus complementary; in this paper, we further demonstrate the potential of the latter by estimating the return periods for natural fluctuations of the global scale atmospheric temperature, in particular for the industrial epoch warming, the postwar cooling (1944–1976), the pre-pause warming (1992–1998), and the "pause" (1998–2013).

2. Estimating the Post Industrial Natural Variability

The basic hypothesis is that the global temperature anomaly \(T_{\text{global}}(t)\) is the sum of an anthropogenic component—assumed proportional to the observed CO\(_2\) forcing—and a residual representing the natural variability \(T_{\text{nat}}(t)\):

\[
T_{\text{global}}(t) = \lambda_{2xCO_2,\text{eff}} \log_2 \left( \frac{p_{CO_2}(t)}{p_{CO_2,\text{pre}}} \right) + T_{\text{nat}}(t)
\]

\(\lambda_{2xCO_2,\text{eff}}\) is the “effective” sensitivity of the climate to a CO\(_2\) doubling, \(p_{CO_2}\) is the global mean CO\(_2\) concentration, and \(p_{CO_2,\text{pre}}\) is the preindustrial value (277 ppm). The logarithmic form is a basic semi-analytic result [Archerius, 1896]. The hypothesis is that while the actual series \(T_{\text{nat}}(t)\) does depend on the forcing, its statistics do not. From the point of view of numerical modeling, this is plausible since the anthropogenic effects primarily change the boundary conditions not the type of internal dynamics and responses. This is consistent with Nicolás [1988] who investigated the relationship between the temperature variability and increasing CO\(_2\) levels in stochastically forced energy balance models. She found that unless the noise is multiplicative, the temperature variance is insensitive to CO\(_2\).

Two things should be noted: first, \(T_{\text{nat}}\) includes any temperature variation that is not anthropogenic in origin, i.e., it includes both “internal” variability and responses to any natural (including solar and volcanic) forcings. This is thus different from approaches that attempt to separate internal variability from external natural and anthropogenic forcings such as Lean and Rind [2008] and Rohde et al. [2013]. Second, \(\lambda_{2xCO_2,\text{eff}}\) is the “effective climate sensitivity,” i.e., it is the sensitivity to the actual (historical) doubling of CO\(_2\); it is thus conceptually different from the theoretical/model notions of “equilibrium” and “transient” sensitivity. Our approach is thus different from empirical approaches that attempt to infer the “equilibrium” climate sensitivities (e.g., Gregory et al. [2002], Gregory and Forster [2008], and Bengtsson and Schwartz [2013]) or “transient” sensitivities (e.g., Dufresne and Bony [2008], Held et al. [2010], Padilla et al. [2011], and Schwartz [2012]) and that require additional (and different) assumptions and interpretations. Note that it is only the effective climate sensitivity that permits one to estimate the natural variability during the industrial epoch (as a residue); this is the key to the estimates presented here.

The relatively accurate CO\(_2\) concentration \(p_{CO_2}\) reconstructions from [Frank et al., 2010] were used to determine \(\log_2 p_{CO_2}\). Since the reconstruction was only up to 2004, we extended it to 2013 using annually averaged Mauna Loa (i.e., local) concentrations and subtracted 5.3 ppm in order to estimate the global average concentration in optimal accord with the CO\(_2\) reconstruction over their common period, 1959–2004.

For the temperature series, we used the annually averaged global and northern hemisphere series from NASA GISS [Hansen et al., 2010]. Spectral analysis showed that the northern hemisphere series had a slight excess variability at the highest frequencies—presumably associated with imperfect removal of the annual cycle—this was removed using a 1-2-1 running filter (equivalent to using the data at a 2 year resolution).

We used the same three annual resolution multiproxies as in Lovejoy [2014] over the more reliable recent (but mostly preindustrial) period 1500–1900 [Huang, 2004; Moberg et al., 2005; Ammann and Wahl, 2007]. The exact choice is not important since as shown in Lovejoy and Schertzer [2012] (eight multiproxies were analyzed)—although multiproxy statistics often differ substantially at long time lags \(\Delta t\)—over the macroweather regime \(\Delta t \approx <125\) years of interest here—multiproxy statistics are very close to each other (to within ±0.09 K, unpublished analyses). It is worth noting that the Huang [2004] series is based on boreholes and is thus independent of the usual paleo calibration issues.
Figure 1. (a) Global (top, green), northern hemisphere (middle, red) temperature anomalies [NASA, GISS, 1880–2013] and (bottom, black) the average of the three multiproxies discussed in the text (1880–1979) as functions of radiative forcing using the CO₂ forcing as a linear surrogate. Each curve has been displaced in the vertical by 0.3 K for clarity, and the regressions have slopes 2.33, 2.55, and 1.98 (top to bottom). Some of the dates and corresponding annually, globally averaged CO₂ concentrations are indicated for reference; the dashed vertical lines indicate the beginning and end of the events discussed in the text (1944, 1976, 1992, and 1998). (b) \( T_{\text{globe}} \) as a function of date with the smooth line corresponding to the regression in Figure 1a with the same vertical dashed lines. Each curve has been displaced in the vertical by 0.2 K for clarity. (c) The residuals from Figure 1b (solid) and from the corresponding curves with a 20 year lag (dashed). Green is global, red is northern hemisphere, and black is the multiproxy average. Each curve has been displaced in the vertical by 0.2 K for clarity. The vertical dashed lines are the same as in Figure 1a. The arrows indicate the events discussed in the paper. (d) The bottom three series are the average multiproxy temperatures for the indicated 125 year preindustrial periods, each with the mean removed and displaced in the vertical by 0.3 K for clarity. The top (red) curve is the global average for 1880–2013 (dashed) and residuals from Figure 1c (no lag). The dashed arrows are vectors 15 years wide, ±0.28 K in amplitude corresponding to positive or negative “pause” events. Several are shown; from their number we may roughly deduce that the return period of unsigned “pauses” is about 25–30 years, for a signed pause (double: 50–60 years).
The linearity of Figure 1a confirms equation (1) and shows that the sensitivities (slopes) for the global and northern hemisphere curves (2.33, 2.55; see Table 1) are close to those determined in Lovejoy [2014] for three (different) surface series from 1880 to 2004 (which yielded 2.33 and 2.59, respectively); in Figure 1a, we also considered the mean of the multiproxies over their period of overlap, 1880–1979. As in Lovejoy [2014] scaling, fluctuation analysis was used to confirm that the statistics of $T_{nat}(t)$ were nearly the same as those of preindustrial multiproxies, and this is up to centennial scales.

However, the strongest immediate effect of anthropogenic forcings is to heat the oceans, and only after some delay does this in turn heat the atmosphere; cross correlation analysis showed that the corresponding lag was between 0 and 20 years, see Table 1 where we note that whereas the sensitivities are significantly different, the correlations and residuals (Figure 1c) are hardly changed (the lagged and unlagged residuals differ by ±0.046 K compared to the temperature measurements accuracy = ±0.03 K, [Lovejoy et al., 2013]).

Figure 1b plots $T_{globe}$ in the familiar way as a function of time with the (regression based) anthropogenic contribution superposed (Figure 1b) and Figure 1c the residual, natural fluctuations, $T_{nat}$. Figure 1c directly displays any unusual natural fluctuations, events. Consider the postwar cooling (1944–1976); it stands out at magnitude ≈0.4–0.5 K depending somewhat on the lag and the series (Table 1). In comparison, the pause

<table>
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<th>Global</th>
<th>Northern Hemisphere</th>
<th>Multiproxy</th>
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<tr>
<td></td>
<td>0</td>
<td>20 years</td>
<td></td>
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<td>Sensitivity (K/CO$_2$ doubling)</td>
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<td>3.73 ± 0.13</td>
<td>2.35 ± 0.097</td>
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<td>Correlation (t)</td>
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<td>0.940</td>
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<td>Postwar (1944–1976) (K)</td>
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<td>-0.42</td>
<td>-0.50</td>
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<tr>
<td>A</td>
<td>0.21</td>
<td>0.16</td>
<td>0.24</td>
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<td>Prepause (1992–1998) (K)</td>
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<td>+0.46</td>
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<td>-0.37</td>
<td>-0.20</td>
</tr>
<tr>
<td>A</td>
<td>0.27</td>
<td>0.36</td>
<td>0.30</td>
</tr>
</tbody>
</table>

*Below, the amplitudes of the postwar cooling, the pre-pause warming, and the pause as estimated by the various series; “O” is for the observed temperature change, “N” is the “natural variability” contribution (from the residuals), and “A” is the anthropogenic contribution (O = N + A). The accuracy is estimated as ±0.03 K.
(1998–2013)—a natural cooling of \(-0.3\) K—is not exceptional. This impression is reinforced by considering the 1992–1998 “pre-pause” warming event, which is of nearly equal magnitude: to within the margin of error, they cancel each other out.

3. The Return Times

The multiproxies were used to directly determine the empirical probabilities \(Pr(\Delta T(\Delta t) > s)\) of temperature changes \(\Delta T\) exceeding a threshold \(s\) for over periods \(\Delta t = 1, 2, 4, 8, 16, 32,\) and 64 years. From the empirical probability distributions, we estimate the waiting times as inverse probabilities (e.g., an event with probability 0.01/year has a waiting time of 100 years) (Figure 2). The return times are waiting times conditioned on an event, but for extremes, the conditioning is typically weak, and we follow standard practice and take the two as equal (strictly speaking our results are for waiting times). However, due to the scaling, we may expect some clustering of extremes which could lead to differences between waiting and return times, although much larger preindustrial global scale temperature data sets would be needed to quantify this. See the discussion in Schmitt and Nicolis [2002], Bunde et al. [2004], and Bunde et al. [2005], although note that our extreme events are temperature changes so that these results do not directly apply. Due to the scale invariance of the climate dynamics over this range (and up to 100–125 years) there are long range statistical dependencies so that the distributions are virtually independent of the time scale \(\Delta t\) over which the differences were estimated (especially for \(\Delta t \geq 4\) years), hence the near superposition of the curves in Figure 2.

Figure 2. The return periods for signed fluctuations of the amplitude indicated on the abscissa. The colored curves are the empirical curves for various durations up to 64 years as determined directly from the preindustrial multiproxies. The black curves are the bounding hyperbolically tailed distributions, the brown is from the classical (Gaussian) distribution, and the standard deviation is 0.18 K. The dashed vertical lines correspond to various events, from right to left: global warming since 1880 (green range 0.76–0.98 K), the largest event expected in the 134 years since 1880 (blue, 0.47 K); the postwar cooling (green, 0.42–0.47 K), the prepause 0.30–0.33 K (1992–1998), and pause 0.28–0.37 K (1998–2013). The horizontal lines indicate the corresponding return periods.
Since the warming from 1880 (≈0.87 ± 0.11 K, [Lovejoy, 2014]) is much larger than any observed preindustrial fluctuations, in order to estimate its return period, the probabilities of the extreme fluctuations (the “tail”) were bounded using (nonclassical) power law forms that are theoretically associated with scaling dynamics. This means that for low enough probabilities “Pr”—extreme enough fluctuations ΔT—we expect Pr (ΔT > s) ∝ s^-qD where s is a temperature threshold. It was found that qD ≈ 5 fit quite well but that in any case the actual tails were bounded: 4 ≤ qD ≤ 6 (the result qD ≈ 5 goes back to Lovejoy and Schertzer [1986] and was extended in Lovejoy and Schertzer [2013]; see also Katz et al. [2013]). Although only the tails (probabilities ≤0.03) were needed for testing global warming, a distribution with Gaussian shape for the high probability part that continuously merged with a power law with exponent qD was found to be reasonable over most of the range (Figure 2); the Gaussian corresponds to qD = ∞.

According to Figure 2, the anthropogenic warming (1880–2004, estimated as 0.76–0.98 K shown by the dashed green lines to the right) has a return period of 1000–20,000 years (using the bounding distributions with exponents qD = 4, 6). While this is a sufficiently long period that natural variability can confidently be rejected as an explanation for the warming, it is nevertheless much shorter than the 1–100 Myr return period obtained using the classical (Gaussian) assumption (the red line).

What is the largest fluctuation that we should expect over the period 1880–2013? Such an event would have a return period of 134 years; hence, according to Figure 2, an amplitude of ≈0.47 K (this may be a slight underestimate since beyond about 125 years, the distribution is no longer exactly independent of scale—see Lovejoy [2014]). Comparing this estimate with Table 1, we see that—as expected—it is comparable to the postwar (1944–1976) cooling event of 0.42–0.47 K. Turning to the “pause,” we see that it is more of a global than a northern hemisphere fluctuation (the latter is ≈0.1 K smaller), so we only considered the global pause of 0.28–0.37 K. From the figure, we see that the return period for such an event is 20–50 years—in reasonable agreement with Figure 1d. While in themselves such cooling events are not unusual, they become altogether probable when they immediately follow comparable warming events. Figures 1a, 1b, 1c, and Table 1 confirm that there was indeed a 6 year “pre-pause” warming event of almost the same magnitude (≈+0.3 K) with a similar return period (30–40 years). Since in this “macroweather” regime—successive fluctuations tend to cancel (e.g., Lovejoy [2013]), this is already a statistical explanation for the pause; in a future publication, we show how it can be made more rigorous using stochastic simulations and conditional forecasts.

We can also obtain a rough estimate of the frequency with which “pause” sized events occur by comparing the estimated global natural fluctuations with preindustrial multiproxy series of comparable length. In Figure 1d we show the vectors (15 years, ±0.28 K) corresponding to a 15 year cooling or warming of 0.28 K (the positive and negative fluctuations have nearly the same probability distributions). We can see that in the preindustrial period pause events were relatively frequent—five or six per 125 years, i.e., a return period of about 20–30 years for an event of either sign.
4. Conclusions

As data and models have improved, the thesis of anthropogenic warming has become increasingly convincing, and today we appear to be reaching a state of small incremental improvements. Unless other approaches are explored, the AR6 may simply reiterate the AR5’s “extremely likely” assessment (and possibly even the range 1.5–4.5 K). We may still be battling the climate skeptic arguments that the models are untrustworthy and that the variability is mostly natural in origin. To be fully convincing, GCM-free approaches are needed: we must quantify the natural variability and reject the hypothesis that the warming is no more than a giant century scale fluctuation. With the help of nonlinear geophysics ideas on fluctuations and scaling, this has been done. By lumping all sources of natural variability together (i.e., internal and external) and by using the CO₂ forcing as a surrogate for all anthropogenic effects, it is possible to avoid assumptions about the radiative effects of aerosols, cloud radiation feedbacks, and other difficult issues.

Since 1998, the warming has noticeably slowed down—and due to a lack of a convincing model based explanation—the IPCC AR5 resorted to the vague: “Due to natural variability, trends based on short records are very sensitive to the beginning and end dates and do not in general reflect long-term climate trends” (see Hawkins et al. [2014]). In this paper, we have shown that the pause has a short return time and that it follows an equal magnitude pre-pause warming event: the pause thus has a convincing statistical explanation.
This approach can profitably be extended to other fields—notably precipitation—and to the spatial domain—to regional variability. Finally, it is possible to make stochastic climate forecasts using multifractal models whose strengths and weaknesses will complement the GCMs. These applications promise to enrich both our understanding of the climate of its models.

References


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Slingo, J., et al. (2013), The recent pause in global warming parts 1-3Rep., The Met Office, FitzRoy Road, Exeter, U. K.
Sample Assessment Questions:

Competencies

A. think critically and cogently about causal relationships with scientific reasoning.
B. assess previous experimentation and published scientific results.
C. critically examine and evaluate scientific observation, hypothesis or model construction.
D. articulate a variety of issues created by the complex interactions among science, technology, and society.
E. use scientific perspectives to evaluate contemporary problems facing society

Questions (5 pts each):

1) CO₂ is the chemical at the center of the Global Warming debate. What is the theory of Global Warming? How does CO₂ fit into the debate? As a chemist, what do you feel should be done about CO₂ emissions? Do you support or deny the theory of global warming? Support your answer. A, C, E

2) What does the term Anthropogenic mean? Why is this term at the center of the Global Warming Debate? A, E

3) Looking at Figure 1: What does each graphic tell you? B

4) In the article, the author’s state that the cooling period the Earth has experienced since 1998 is just a normal fluctuation and that warming will continue based on their model and analysis. Based on what you have read, discuss whether or not you believe their analysis and support your arguments with scientific reasoning. A, B, C

5) Based on analysis shown in Figure 2, the cooling fluctuations return periods) in the global warming trends according to the paper could last over 100 years, discuss how this could affect the world’s response to the global warming ‘crisis’. C, D, E