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2009-2010 PROJECTS

SE ALASKA - EXHUMATION OF THE COAST MOUNTAINS BATHOLITH DURING THE GREENHOUSE TO ICEHOUSE TRANSITION IN SOUTHEAST ALASKA: A MULTIDISCIPLINARY STUDY OF THE PALEOGENE KOOTZNAHOO FM.

Faculty: Cameron Davidson (Carleton College), Karl Wirth (Macalester College), Tim White (Penn State University)

Students: Lenny Ancuta, Jordan Epstein, Nathan Evenson, Samantha Falcon, Alexander Gonzalez, Tiffany Henderson, Conor McNally, Julia Nave, Maria Princen

COLORADO – INTERDISCIPLINARY STUDIES IN THE CRITICAL ZONE, BOULDER CREEK CATCHMENT, FRONT RANGE, COLORADO.

Faculty: David Dethier (Williams) Students: Elizabeth Dengler, Evan Riddle, James Trotta

WISCONSIN - THE GEOLOGY AND ECOHYDROLOGY OF SPRINGS IN THE DRIFTLESS AREA OF SOUTHWEST WISCONSIN.

Faculty: Sue Swanson (Beloit) and Maureen Muldoon (UW-Oshkosh)

Students: Hannah Doherty, Elizabeth Forbes, Ashley Krutko, Mary Liang, Ethan Mamer, Miles Reed

OREGON - SOURCE TO SINK – WEATHERING OF VOLCANIC ROCKS AND THEIR INFLUENCE ON SOIL AND WATER CHEMISTRY IN CENTRAL OREGON.

Faculty: Holli Frey (Union) and Kathryn Szramek (Drake U.)

Students: Livia Capaldi, Matthew Harward, Matthew Kissane, Ashley Melendez, Julia Schwarz, Lauren Werckenthien

MONGOLIA - PALEOZOIC PALEOENVIRONMENTAL RECONSTRUCTION OF THE GOBI-ALTAI TERRANE, MONGOLIA.

Faculty: Connie Soja (Colgate), Paul Myrow (Colorado College), Jeff Over (SUNY-Geneseo), Chuluun Minjin (Mongolian University of Science and Technology)

Students: Uyanga Bold, Bilguun Dalaibaatar, Timothy Gibson, Badral Khurelbaatar, Madelyn Mette, Sara Oser, Adam Pellegrini, Jennifer Peteya, Munkh-Od Purevtseren, Nadine Reitman, Nicholas Sullivan, Zoe Vulgaropulos

KENAI - THE GEOMORPHOLOGY AND DATING OF HOLOCENE HIGH-WATER LEVELS ON THE KENAI PENINSULA, ALASKA

Faculty: Greg Wiles (The College of Wooster), Tom Lowell, (U. Cincinnati), Ed Berg (Kenai National Wildlife Refuge, Soldotna AK)

Students: Alena Giesche, Jessa Moser, Terry Workman

SVALBARD - HOLOCENE AND MODERN CLIMATE CHANGE IN THE HIGH ARCTIC, SVALBARD, NORWAY.

Faculty: Al Werner (Mount Holyoke College), Steve Roof (Hampshire College), Mike Retelle (Bates College)

Students: Travis Brown, Chris Coleman, Franklin Dekker, Jacalyn Gorczynski, Alice Nelson, Alexander Nereson, David Vallencourt

UNALASKA - LATE CENOZOIC VOLCANISM IN THE ALEUTIAN ARC: EXAMINING THE PRE-HOLOCENE RECORD ON UNALASKA ISLAND, AK.

Faculty: Kirsten Nicolaysen (Whitman College) and Rick Hazlett (Pomona College)

Students: Adam Curry, Allison Goldberg, Lauren Idleman, Allan Lerner, Max Siegrist, Clare Tochilin

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**Keck Geology Consortium: Projects 2009-2010
Short Contributions – SVALBARD**

**HOLOCENE AND MODERN CLIMATE CHANGE IN THE HIGH ARCTIC,
SVALBARD, NORWAY**

Project Faculty: *AL WERNER*: Mount Holyoke College
STEVE ROOF: Hampshire College
MIKE RETELLE: Bates College

**DIRECTLY-CONTROLLED LICHEN GROWTH CURVES FOR WESTERN
SPITSBERGEN, SVALBARD**

TRAVIS BROWN: College of Wooster
Research Advisor: Greg Wiles

**METEOROLOGICAL AND GLACIAL ABLATION CONTROLS ON ANNUAL
SEDIMENT ACCUMULATION AT LINNÉVATNET: SVALBARD, NORWAY**

CHRISTOPHER FISHER COLEMAN: Wesleyan University
Research Advisor: Suzanne O'Connell

**LINNÉ GLACIER METEOROLOGICAL STUDY OF SURFACE ABLATION
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FRANKLIN DEKKER: Franklin & Marshall College
Research Advisor: Christopher J. Williams

**MODERN SEDIMENTATION PROCESSES IN A PROGLACIAL LAKE,
LINNÉVATNET, SVALBARD, NORWAY**

JACALYN GORCZYNSKI: Mount Holyoke College
Research Advisor: Al Werner

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SEDIMENTS: LINNEVATNET, SVALBARD**

ALICE NELSON: Williams College
Research Advisor: Mea Cook

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BASIN OF PROGLACIAL LINNÉVATNET, WESTERN SPITSBERGEN,
SVALBARD**

ALEXANDER NERESON: Macalester College

Research Advisor: Karl Wirth

**ALKENONE-INFERRED TEMPERATURE RECONSTRUCTION FROM
KONGRESSVATNET, SVALBARD**

DAVID A. VAILLENCOURT: University of Massachusetts Amherst

Research Advisors: William J. D'Andrea and Steven T. Petsch

Funding provided by: Keck Geology Consortium Member Institutions and NSF (NSF-REU: 0648782)

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DAVID A. VAILLENCOURT

University of Massachusetts Amherst

Research Advisors: William J. D'Andrea and Steven T. Petsch

INTRODUCTION

Recent observations show that climate change is happening at an unprecedented rate, and a wide range of evidence indicates it is likely due to anthropogenic forcings aided by the rise of greenhouse gas emissions since the industrial revolution (IPCC, 2007). The High Arctic is especially susceptible to climate change and recent studies have shown a dramatic rise in the last century after a prolonged late Holocene cooling period (Holmgren et al., 2010, Kaufman et al., 2009). The lack of long-term records make it difficult to put the present climate changes into the context of past natural climate variability, which is vital for modeling future climate predictions. Natural recorders of climate variability found in geologic archives are being used to extend the instrumental period back thousands of years.

These natural recorders from geologic archives are able to assist in reconstructing key climate variables such as temperature, precipitation, and glacier advance/retreat. The best reconstructions use multiple proxies to add confidence to proposed interpretations. Lake sediments are one of many archives that preserve these natural recorders, and with the help of radioactive isotopes and varves (visibly countable annual layers of sediment) that help to constrain proper age chronology; one can place these changes of climate in a temporal context.

One such recorder is a fat produced by unique algae known as the haptophyte who are ubiquitous in the world's oceans (Brassell et al., 1986, Conte et al., 1994, Muller et al., 1998) and recently being discovered in lake sediments from places around the globe from Antarctica's Lake Vostok, to mid-latitude Germany, arctic Greenland and now Kongressvatnet, Svalbard (D'Andrea et al., 2006, D'Andrea, pers.

comm., Muller et al., 1998, Schouten et al., 2001, Zink et al., 2001, and others). Core top studies from a meridional transect in the Atlantic Ocean have shown a linear relationship with an alkenone unsaturation ratio to sea surface temperatures (Muller et al., 1998). Culture experiments in the lab have also confirmed that haptophytes respond to changes in temperature by altering their ratio of alkenones produced linearly (Conte et al., 1998 and references within).

Alkenones are straight-chained lipids (a fat) with 37-carbon atoms, produced with different levels of unsaturation, the more double bonds in the structure, the more unsaturated they are and vary in the form of di- tri- and tetra-unsaturations (henceforth referred to as 37:2, 37:3 and 37:4 respectively) (Fig. 1). Higher abundances of the more unsaturated (tetra) to the lesser unsaturated (di-) make up the U_{37}^K index that relates to temperature (see Fig. 1). Because alkenones produced by different haptophytes may result in different calibrations of temperature (Conte et al., 1998), being able to calibrate the U_{37}^K index to a nearby weather station allows the index to become a powerful proxy that extends temperature records when the meteorological data ends. Using the available data from the weather station in Longyearbyen, approximately 40 km northeast of Lake Kongressvatnet, we calibrated the unique alkenone signature and reconstruct climate variability over the last 1,200 years.

SITE AREA

Kongressvatnet is located on Svalbard, an archipelago north of Norway, halfway between mainland Norway and the North Pole bounded by the Barents Sea, Norwegian Sea and the Arctic Ocean. The

A core 60 cm in length was recovered by gravity corer, and based on the clear sediment-water interface I am confident that we captured the most recent sediment deposited from the 2009 spring melt. Using an extruding device, samples were taken at ¼ cm intervals from the top 9 cm in the field before prior to dewatering and compaction. This sampling represents sub-decadal sample resolution

Samples were subsequently dewatered, and safely transported back to Mt. Holyoke College in South Hadley, MA where they were sliced open and photographed before being stored in a cold room facility at 4 °C at the University of Massachusetts Amherst. The remaining sediment was sampled at ¼ cm increments for the top 18-cm and ½ cm for 18 to 60 cm, freeze-dried, homogenized and the organics extracted using a Dionex Accelerated Solvent Extractor (ASE200) with a 9 to 1 mix of Dichloromethane to Methanol (DCM:MeOH). The resulting total lipid extract (TLE) was saponified to isolate the alkenones that may co-elute with other similar length molecules by methods proposed by W.J. D'Andrea (pers. comm.). A predetermined mass of standard was added to the toluene sample containing the alkenones and injected into a Gas Chromatograph coupled to a Flame Ionization Detector (GC-FID) following the protocol of Huang and D'Andrea (unpublished). The abundance of the respective unsaturated alkenones was quantified and measured relative to the mass of sediment as well as used to calibrate into summer temperature.

In order to accurately and confidently calibrate core depth with age, total carbon was analyzed with a Costech Elemental Analyzer and compared to data from Guilizzoni et al., 2006, who published an extensive review of Kongressvatnet lake sediments, and derived an age model from a combination of lead and cesium peaks, varve counting and paleomagnetic reconstruction. Total carbon results from the top of the recovered core were matched to the age model of Guilizzoni et al. (2006) to create the age model (Fig. 4). Guilizzoni reports an average sedimentation rate of 30 yrs/cm, which was applied to my model for any dates pre-1800 where total carbon matching is not available.

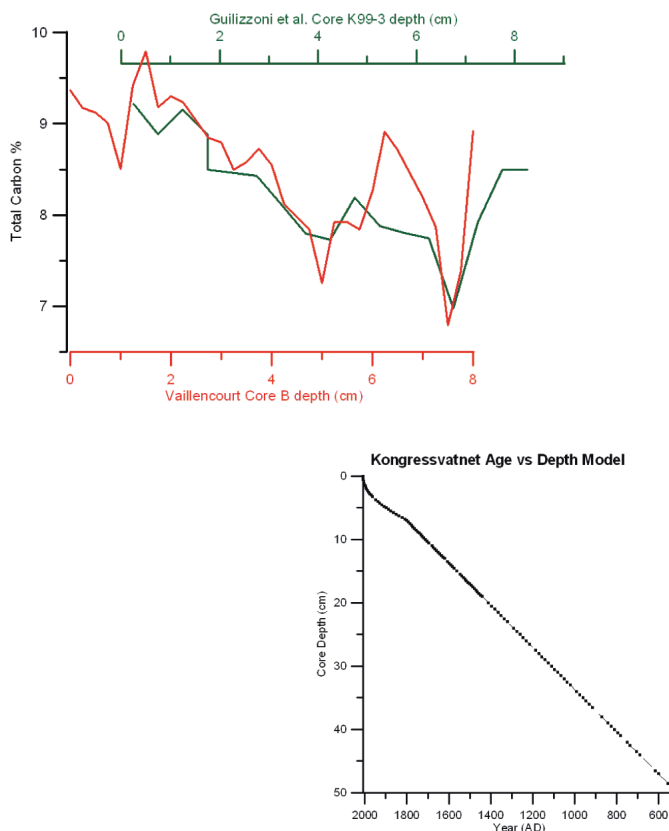


Figure 4: Comparison of Total Carbon % between our recovered core and Guilizzoni et al.'s core (top) that was used to generate the age vs depth model (bottom).

For calibration of the U_{37}^K index to temperature, a 7-year running mean of June and July average temperatures from the Longyearbyen meteorological station was found to have the most statistically significant relationship to the U_{37}^K values generated (Fig. 5). The resulting data points ($n=17$) were used to generate a linear regression (see results) and were extrapolated back throughout the alkenone record.

RESULTS

Concentrations of alkenones are abundant down core until 38.5 cm depth where a stark change in total lipid extracts color and a significant drop in alkenone concentrations occurred (Fig. 6). Many samples below 38.5 cm depth have too low of alkenone concentrations and were thus discarded from the record.

Total carbon measurements from the top 10 cm of the core suggest that constant sedimentation has been occurring in Kongressvatnet over the last few

hundred years when compared to the data of Guilizzoni et al. (2006). The close correlation with the data of Guilizzoni et al (2006) shows that both cores accurately represent the same depositional rates in Kongressvatnet with no apparent hiatuses. This is also confirmed with visualization of the stratigraphy between photographs of Guilizzoni et al. (2006) and our core.

With a confident age model derived from Guilizzoni's published work, the Longyearbyen June/July temperature average vs alkenone U_{37}^K index for the time period of meteorological data available (since 1912) reveals a strong linear relationship $r^2 = 0.75$ $n = 17$ $p < 0.001$ (Fig. 5). Not only does the strong relationship reflect confidence in alkenones tracking June/July average temperature but also helps confirm that the age model is accurate for the most recent century. Had the age model been inaccurate, the inferred U_{37}^K values likely would not have shown such a strong relationship both visually and statistically.

Applying the temperature relationship back in time, alkenone paleothermometry reveals a cold period since at least 800 AD on through 1800 AD (i.e. the end of the Little Ice Age, Fig. 7). Very little variability is seen during the first half of the record, which changes dramatically as the end of the LIA approached (approximately 1600 AD). Continuing out of the LIA, the proxy highlights the warming that is seen in the instrumental record during the 20th century.

DISCUSSION

Based on the above calibrations, alkenones are present in Kongressvatnet since at least 800 AD, indicating that conditions have been favorable for haptophyte growth and preservation. This adds to the growing list of lakes that contain alkenone-producing haptophytes. A similar calibration of U_{37}^K versus temperature to Zink et al's published data (2001) confirms the speculation that alkenones are produced by a genetically similar species of haptophytes.

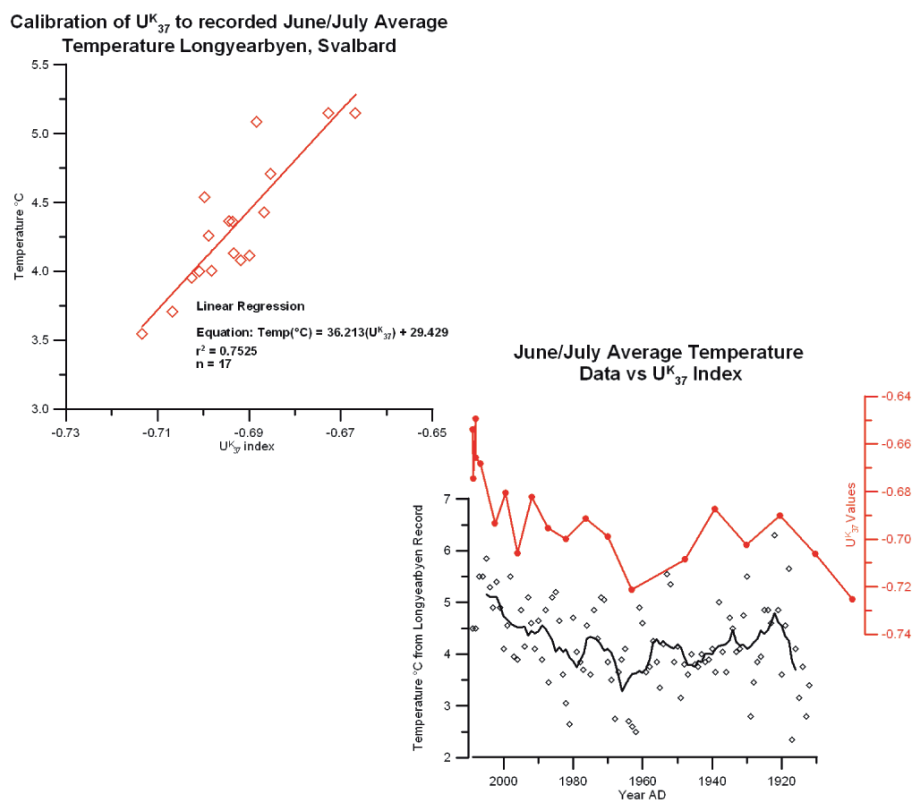


Figure 5: Linear regression of the alkenone unsaturation index to June/July temperature (top) based on data from meteorological data (bottom).

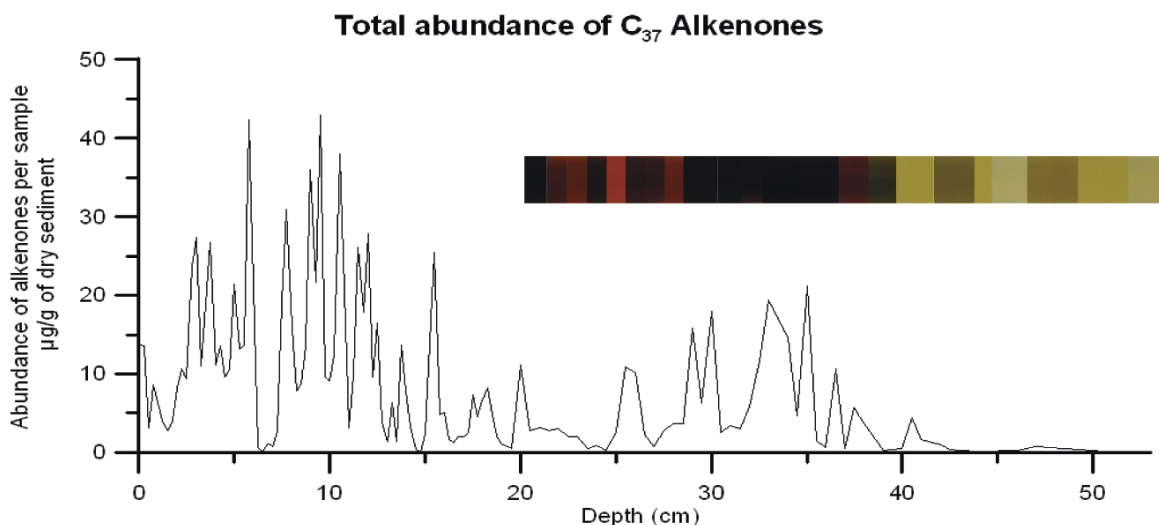


Figure 6: Graph of alkenone abundance per gram of sediment with an overlay of the total lipid extract (TLE) color just after extraction for selected depths down core.

phyte found in other lakes despite unavailable DNA replication. The results also suggest that haptophytes bloom shortly after ice melt that occurs in mid-June, explaining why alkenones track June and July temperature better than the whole summer, a signifier of alkenone production during the early and short bloom period

The record from Kongressvatnet suggests that temperatures in the last century are the highest on Svalbard than at any other time in the last 1,200 years. This is consistent with ice core data on Svalbard (Isaksson et al., 2005 and others), and many other records throughout the arctic. The alkenones capture the meteorological variability during the 20th century accurately, with a rise in temperatures from the 1910s until the 1940s and again in the last three decades.

The inferred temperature reconstruction from my core in Kongressvatnet shows that from 800 to 1500 AD, summer temperatures were, on average, consistently more than 3 °C colder than present and much less variable than today. No evidence of Medieval Warming (MWP) was recognized during the 10th to 12th centuries and that in fact temperatures on Svalbard may have been colder during the MWP than during the LIA! The time of the LIA from 1500 through 1750 remained 1-2 °C colder than the 20th century, consistent with continued glacier growth

across Svalbard (Werner, 1993). However, just as Svalbard should have been in the heart of the LIA, a warm anomaly occurs with a spike in temperatures just before 1800 AD. Despite this warm period, no evidence in the literature suggests Svalbard glaciers receded during this time, although any evidence for this may have been obliterated by the continued advancement of the glaciers as the LIA didn't terminate until just before 1900 (Werner, 1993). Though significant, this warm period was likely not long enough lasting to have been recorded in other records of climate reconstruction on Svalbard.

It is, however, worth noting that proxies have captured warm anomalies in the Arctic before, similar to the one found in Kongressvatnet from the late 1700s, that are unable to be resolved with models (Crespin et al., 2009). Based on proxies from Mann et al. (2008), Crespin et al. (2009) compared proxy data with modeled forcings and were unable to explain a spike in temperatures during the 1470-1520 time period. Crespin et al. (2009) concludes that internal climate variability pertaining to some complex positive feedback between sea ice and the resulting heat flux changes. North Atlantic Oscillation (NAO) coupled with the Arctic Oscillation (AO) can easily result in warm water and air advection traveling to the polar region of Svalbard. More research into modeling would need to be done in order to determine if this was a possible mechanism for the anomaly observed

in this study.

The remainder of the Kongressvatnet temperature reconstruction during the LIA is consistent with above-mentioned records, revealing a period of temperatures colder than the sharp increase associated with 20th century anthropogenic caused warming. Nearing the end of the Little Ice Age into the 1800s, more variability is exhibited and temperatures average between 3-4 °C, which is 0.5-1.0 °C warmer than the previous 500 years, but still more than 2 °C colder than the most recent warming. Future studies of alkenones from other sites on Svalbard may help confirm some of these data, and resolve any local anomalies that may arise due to large topography differences across the glacier enveloped landscape.

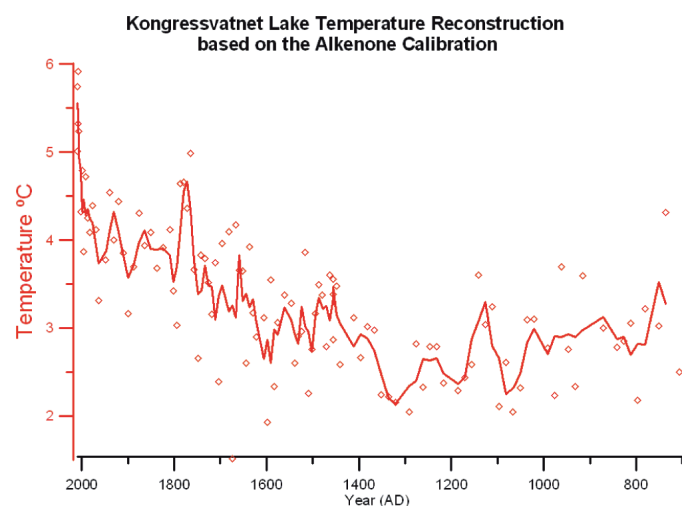


Figure 7: Final extrapolation of temperature based on the alkenone calibration.

CONCLUSION

This study highlights that the recent warming is the most significant in at least the last 1,200 years on Svalbard. There is no evidence of a Medieval Warm Period taking place on Svalbard, and reaffirms Kaufman et al. (2009) showing a steady state of cooling temperatures for the last millennium. Additionally, the work done on Kongressvatnet tests and confirms the continued robustness of alkenone paleothermometry in lake sediments. Future work may look at the bloom period in Kongressvatnet in more detail, and attempt to re-calibrate the index

with in-situ temperatures as the lake warms up throughout the bloom.

It is important to note that the age chronology was thoroughly backed up by multiple age calibrations from Guilizzoni et al. Transferring of age models was done easily and confidently with the use of tie points from total carbon results. Test results are forthcoming in a Plutonium peak that just like Cesium can be correlated to the rise of nuclear bomb testing in the late 1950s as well as the blast of Chernobyl in 1986. These new data will refine the proposed age model. This study accurately depicts the common themes of late Holocene Arctic climate change with the aid of alkenones including the unprecedented increase in temperatures during the 20th century.

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