Ocean and Climate Change Institute
Final Report

Discriminating Solar vs. Ocean Forcing of Holocene Climate from Observations of ^{14}C in the Ocean Mixed Layer

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What were the primary questions you were trying to address with this research? (Or, if more appropriate, was there a hypothesis or theory that you were trying to prove or disprove?)

Primary Question:
What processes act to amplify the Holocene climate response to possible solar forcing? **The ocean is an important climate change amplifier in the North Atlantic region during glacial times. Did a similar ocean amplification process act on proposed solar forcing during the Holocene?**

What have you discovered or learned that you didn't know before you started this work? What were the most unusual or unexpected results in this investigation?

The century-scale peaks in atmospheric ^{14}C (and ^{10}Be) observed throughout the Holocene are thought to have been caused by increased production, due to solar variability similar to the Maunder Minimum, a period of low sunspot number during the end of the Little Ice Age, ~1600-1850. Such changes in production should result in 14C changes in the ocean that are only 60-70% of the amplitude of the atmospheric peaks. However, high-resolution reconstruction of marine ^{14}C from the annually laminated seiments of the Cariaco Basin show the same amplitude as the atmospheric peaks (Fig. 1 below). This suggests that there was a change in oceanic circulation associated with the ^{14}C peaks. Since there is also evidence for changes in solar irradiance during these events (i.e., from ^{10}Be; Fig. 1), this suggests a link between solar variability and global climate, via changes in ocean circulation.

What is the significance of your findings for others working in this field of inquiry and for the broader scientific community? What is the significance of this research for society?

Our work indicates a possible connection between solar variability and ocean circulation, leading to widespread changes in climate. There have been suggestions of a solar-climate link before, but always lacking a mechanism to amplify the weak solar signal to a level sufficient to influence climate. We suggest that deep ocean ventilation in the North Atlantic may be that amplifying mechanism. If true, this has profound implications for the potential sensitivity of the ocean circulation to small changes in forcing (i.e., solar variability), and its ability to slow down and dramatically affect climate in the future.

When and where was this investigation conducted? (For instance, did you conduct new field research, or was this a new analysis of existing data?)

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For this research on sediments from the Cariaco Basin off Venezuela, we sampled cores taken earlier but that had not been previously investigated. We embedded sediments in epoxy to make thin sections and identify annual laminations, and sampled for ^{14}C dating at high temporal resolution, ~10 years.

What were the key tools or instruments you used to conduct this research?

We made use of ^{14}C to evaluate solar vs. oceanic or "mostly ocean" forcing of Holocene climate and atmospheric ^{14}C variability. Our analysis rests on the simple proposition that any atmospheric ^{14}C change arising from a change in production will be significantly attenuated in the ocean mixed layer. On the other hand, changes in the overturning component of the ocean circulation have a nearly identical influence on the ^{14}C signature of the surface ocean and atmosphere.

What were the greatest challenges and difficulties?

The data generation for constraining marine ^{14}C changes across multiple solar minimum-type events was much more difficult than we anticipated. We were challenged by high-resolution sampling and obtaining enough foraminiferal shells for 14C dating. In addition, we found that it was extremely difficult to identify and count accurately the annual layers in weakly laminated sediments.

Is this research part of a larger project or program?

Records from the Cariaco Basin are an integral part of both marine and atmospheric ^{14}C calibration datasets for use in the "official" Intcal04 calibration programs. This OCCI research project is important for determining past marine ^{14}C reservoir ages, and their causal mechanisms, for application to timescales deeper in the past.

What are your next steps?

The research supported by this generous grant has provided important preliminary data that we intend to use to support a full-scale proposal to NSF or another external funding agency. We would propose a longer-term effort to complete this project, and construct high-resolution marine ^{14}C records to complement known atmospheric ^{14}C spikes throughout the Holocene.

Have you published findings or web pages related to this research? Please provide a citation, reprint, and web link (when available).

Hughen, K., 2007, Sunspots, Sea Changes, and Climate Shifts, *Oceanus*, Jan. 5, 2007. <http://www.whoi.edu/oceanus/printArticle.do?id=18371>

Please provide photographs, illustrations, tables/charts, and web links that can help illustrate your research.

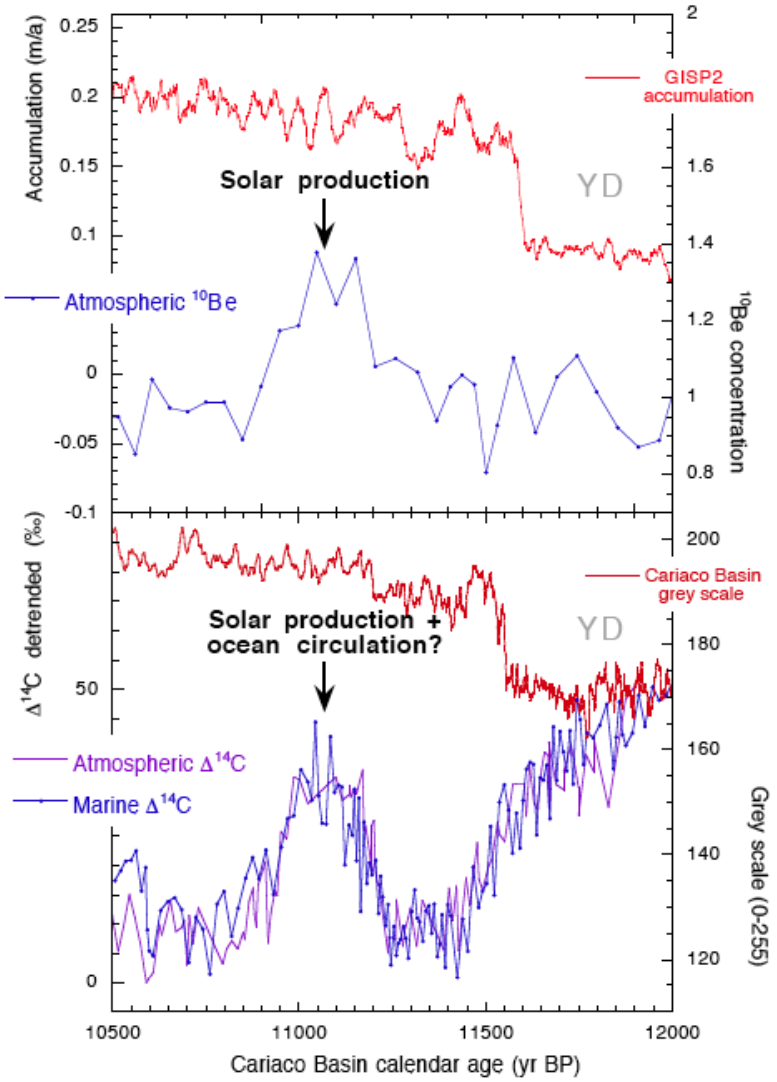

Figure 1. Records of cosmogenic nuclides ^{10}Be and ^{14}C, from archives in ice cores, tree rings and marine laminated sediments. Peaks in atmospheric ^{10}Be and ^{14}C (from tree rings) are believed to result from changes in production, due to shifts in solar irradiance. Marine ^{14}C should show a 60-70% smaller signal, due to attenuation of the atmospheric signal in the ocean mixed layer. However, the marine ^{14}C peak is observed to be ~100% of the amplitude of the atmospheric ^{14}C peak (lower panel), indicating that changes in ocean circulation occurred at the same time. The synchronous timing of these changes suggests a causal relationship, which may have implications for the sensitivity of ocean circulation and future climate change.