Clim. Past Discuss., 10, C1755–C1764, 2014
www.clim-past-discuss.net/10/C1755/2014/

Climate of the Past
Discussions

Interactive comment on "An abrupt slowdown of Atlantic Meridional Overturning Circulation during 1915–1935 induced by solar forcing in a coupled GCM" *by* P. Lin et al.

P. Lin et al.

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Received and published: 28 October 2014

Interactive comment on "An abrupt slowdown of Atlantic Meridional Overturning Circulation during 1915–1935 induced by solar forcing in a coupled GCM" by P. Lin et al.

Anonymous Referee #1 Received and published: 31 July 2014

This paper describes variations of the Atlantic Meridional Overturning Circulation (AMOC) in historical and control simulations using the FGOALS-s2 coupled model. The authors find relatively large-amplitude changes in the overturning stream functions in the early 20th century. These anomalies appear first at higher latitudes and

then propagate to lower latitudes. The authors claim that the "abrupt slowdown" is caused by variations in solar radiation. In particular, the weak insolation from 1900 to 1914 is made responsible for changes in atmospheric circulation and deep water formation in the ocean. The link between the modified solar-induced atmospheric circulation changes and the AMOC reduction is given by a negative NAO phase lasting for a couple of years.

The relative role of forced and internal variability and of natural vs. anthropogenic forcing is still important and analysis of model simulations have come to quite different conclusions. Therefore, studies looking in detail into selected processes or forcing mechanism are needed. Unfortunately, the present study is not at all convincing and lacks scientific rigor in many aspects (as explained in detail below).

I therefore cannot recommend publication in Climate of the Past. The authors should go back to the model results and find out what is robust and what is just happening by chance. I recommend very much that the authors read carefully the paper by Menary and Scaife (2014, in the present's paper reference list). I am not an author of the Menary & Scaife study and I am not happy with all their conclusions. However, that paper is an example of providing solid evidence for the claims, based on statistical tests and sensitivity experiments.

Reply: As suggested, we have done the sensitivity experiments to examine the effect of solar radiation on the abrupt change of AMOC. The sensitivity experiments are summary in Fig. 1. As shown in Fig. 2, CTL is forced by fixed 11-year solar cycle (1860-1870), SOL is forced by observed 11-year solar cycle from 1880-1940. Through these experiments, the roles of solar forcing can be identified. As shown in Fig. 3, not only SOL experiment, a significant rapid change of AMOC after 1910 also appears in the experiment only forced by fixed 11-yr cycle solar radiation (CTL). This implies the change of solar radiation may not the most important reason to cause the abrupt change during 1910-1935 in the model.

Major Points: The arguments are not based on any solid statistics. The author show composites and changes, but no effort is made to relate this to internal variability in the unforced control run. The least thing one would expect is a comparison with the standard deviations found in the PiCtrl run for similar time-scales. In fact, the authors show in their paper, that a very similar slowdown of the AMOC happens in the PiCtrl run. So what would be needed here is to show that TSI changes could somehow kick the system into a transition state.

Reply: Thanks. When using the MTT approach, the significant test is done. In figure 1c, only the passing 95% test is shown. By comparing the difference of abrupt change between historical runs and pi-control run, the similar behaviors are found. To test the effect of solar radiation, we have done the four experiments. The abrupt change during 1915-1935 can not caused by the change of solar radiation during this period. See the reply to the general comment for further discussion.

The proposed mechanism appears not to be very robust through the three historical simulations. The authors claim that the main ingredient is that the low TSI in 1900-1914 leads to changes in the atmosphere that finally produces a lasting negative NAO. At least in the r2 experiment there is no NAO- in the 1910, but already earlier. Expt r1 and r3 show also strong NAO- situations later without any effect on the AMOC. Also, why does the strong NAO reduction in r2 around 1900 does not lead to an AMOC shutdown, say in 1905? The argumentation is partly very confusing.

Reply: Thanks. This is a good suggestion for us. As the reply to general comment, the solar forcing is not the important reason to cause the abrupt change during 1910-1935. But, it is possible the internal variability (NAO-) may play an important role. Actually, in the r2 experiment, the strong NAO- appears during 1891-1905, which may slow down the AMOC at 60N, and then at 36N and 26.5N. We suggest the lag response of AMOC to the NAO- is due to the cumulative melting of sea ice, and the slow mean ocean advection.

On the one hand, the weak TSI in 1900-1914 is made responsible for the NAO(-), convection (-), AMOC (-) mechanism. Then the authors say that the increasing TSI in 1918 warmed the SSTs in the tropics and led to higher ocean heat transport that would further warm the subpolar North Atlantic and further weaken the AMOC (so why did the WEAK TSI in 1905-1910 NOT reduce the OHT?). It seems therefore that the authors just select whatever they find convenient to explain the sun-AMOC connection. What would be needed here is a careful analysis of solar (-) vs. solar (+) states, eg. From composites over the 11-yr cycle, or, more preferable, dedicated sensitivity studies as in Menary and Scaife.

Reply: Thanks. As suggested, the experiments were done to examine the effect of changing solar radiation during 1900-1914. Although similar abrupt changes were found, the abrupt change was also found in the experiment forced by fixed 11-yr cycle solar radiation. In this reason, we rethink the abrupt change of AMOC is likely due to the internal variability NAO-.

A new submission should also come with improved writing and grammar.

Reply: We have changed accordingly.

Other comments: General: use the word “significant” only when demonstrated by statistical test

Reply: We have changed accordingly.

Abstract Ln 6, better “weakened by”

Reply: Thanks. We have changed accordingly.

Ln 9, and other places use standard acronym “TSI” throughout the text

Reply: We have changed accordingly.

Ln 13: release of heat, not of heat fluxes Reply: Thanks. We have changed accordingly.

§2: The MTT test is not well explained. What is tested against what? How arbitrary is the choice of alpha?

Reply: Thanks. We have changed accordingly. MTT is used to detect the time of abrupt change by identifying whether the significant difference exists in the mean values of two subsamples in a time series. To do this, two subsamples (with equivalent time lengths n1 = n2 = 12) are chosen before and after the change point. For a significance level alpha = 0.05, we define the ith change point as the abrupt change year if this point is the wave crests or troughs and t(i) exceeds the significance limits.

§3, page 2523, ln 13: Is that lagged correlation?

Reply: Yes. The lagged correlation coefficients (r) between AMOC at 60N and that at 26.5N is 0.51. The lagged r is 0.8 between AMOC at 36N and that at 26.5N.

Page 2526: the authors speak about freshwater contribution from high latitudes, but discuss only contributions from Davis Strait and Baffin Bay; what about the east Greenland Current and contribution from the Arctic via Fram and Denmark Strait?

Reply: We also check the sea ice over the Fram and Denmark Strait. In this region, differing from the changes of sea ice over Davis Strait and Baffin Bay, the increased ice cover appears.

Page 2527, ln 15ff: the OHT at 30N has been shown to reflect the heat transport by the overturning circulation. Thus the time evolution here would just reflect the AMOC and give no further evidence of the mechanism slowing it down. Moreover, the OHT changes at 60N appear to be pretty small.

Reply: Yes, we have deleted the analysis about the importance of OHT.

Page 2528, ln 15ff. would it be not more appropriate to show composites for weak-strong solar phase for several cycles?

Reply: We have changed accordingly.

§4, page 2530, ln 5: If the imprint of the solar forcing is so significant, we would expect the negative NAO phase to occur simultaneously in all three realizations? What is so “significant” about the 1918 increase? There is a drop of similar amplitude right after. Why not comparing the weak TSI phase 1900-1920 with the generally stronger one, say 1960-1990?

Reply: We have changed accordingly. For testing this part, four experiments were done to examine the effect of changing solar radiation during 1900-1914. Although similar abrupt changes were found, the abrupt change was also found in the experiment forced by only the 11-yr cycle solar radiation. In this reason, we rethink the abrupt change of AMOC is likely due to the internal variability NAO-.

Page 2531, ln 5ff: In figure S2, I don’t see anything special in the NAO around ear 180th. There are also negative phases in the 160th and later:

Reply: Negative NAO phases appear between 179-182 and in 177. Although the NAO anomalies do not present very strong, they last for coupled years. This is important for the change of sea ice and convection.

Page 2532, ln 11. The paper by Schott et al. discusses the SODA reanalysis data from 1992-2008, how can this give us information on the 1920?

Reply: Yes. This reference is uncorrected. We have changed accordingly. The correct reference is Menary et al. (2013).

Ln 15ff: The Menary& Scaife paper does NOT argue that the 1920s weakening was part of a multidecadal variability. They show a strengthening of the AMOC until 1920 that is caused, in their model, by a WEAK TSI, and then relaxes. Thus the come to the opposite conclusion as the present paper and this needs to be discussed.

Reply: We have changed accordingly. We discussed this part although the conclusions in the study are changed.

Interactive comment on Clim. Past Discuss., 10, 2519, 2014.

Summary of simulations performed during this analysis

	Length or period	Ensemble size	11-year solar cycle	
CTL	90	1	Yes	Fixed 11-year solar cycle
SOL	1880-1940	3	Yes	Observed 11-year solar cycle

Fig. 1. Summary of simulations performed during this analysis

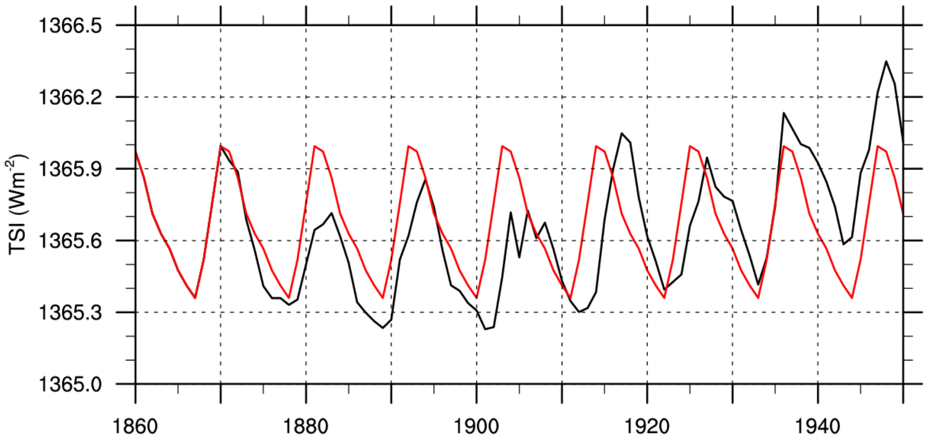

Fig. 2. The time series of annual mean total solar irradiance (TSI) in CTL (red) and SOL (black).

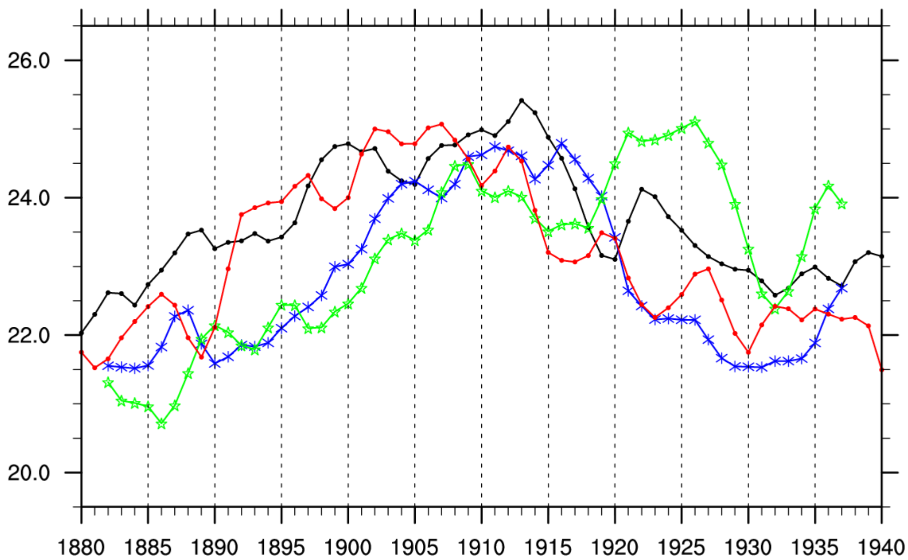

Fig. 3. ime series of maximal Atlantic meridional overturning circulation (AMOC) obtained from 500m to 3000m at 26.5N in CTL (red line) and SOL (black, blue and green lines). The values are for the 5 year run