On the role of external forcing for the Atlantic Multidecadal Oscillation

UNIVERSITÄT BERN
OESCHGER CENTRE CLIMATE CHANGE RESEARCH

Stefan Muthers [1,2]*, Christoph C. Raible[1,2], Andreas Born[1,2]

(1) Climate and Environmental Physics, University of Bern, Switzerland; (2) Oeschger Centre for Climate Change Research, University of Bern, Bern, Switzerland

* email: muthers@climate.unibe.ch

MOTIVATION

- In observations of the last 150 years a coherent, basin-wide pattern of SST variability in the North Atlantic has been found [1]. This Atlantic Multidecadal Oscillation (AMO) is characterized by a periodicity of 65-70 years. Prior to the observational periods, the persistence of multidecadal variability is less well know and reconstructions of the AMO came to different results [2-6]. Furthermore, it is still under discussion whether internal variability or external forcing acts as a driver for the AMO [7-9].
- We analyze on which timescales, external forcings influences the AMO and which periodicities are dominated by internal modes of the Atlantic basin. Furthermore, the different patterns of internal and external variability are analysed and the results are tested using different reconstructions of the AMO.

QUESTIONS

- What are the characteristic periodicities of the AMO (in a model simulation)?
- How is the periodicity changed, by (stronger) solar forcing?
- What drives the AMO on different timescales?
- Are the model results supported by reconstructions of the AMO?

DATA & METHODS

Millenium Simulations [10]

- Earth System Model (ESM): **ECHAM5** T31L19, **MPIOM** GR30L40, HAMOCC5, JSBACH
- 3 member ensemble (analyzed for the period: 800-1850)
  - solar forcing with an amplitude of 0.25% (3.5 W/m2; [11,12]) between Maunder Minimum and present day. Other forcings described in [10].
- Control simulation (3100 years)

AMO-Reconstructions:

- 5 AMO reconstructions covering different periods of the last millenium [2-6]

Reference	Period	based on
Chylek et al. 2011	1303 – 1961	5 arctic ice cores $\delta^{18}O$
Gray et al. 2004	1600 – 1990	tree-rings
Mann et al. 2009	550 – 2000	multiproxy
Saenger et al. 2009	1552 – 1991	corals → Bahamas SST
Wang et al. 2011	1558 – 2007	tree-rings (Northeast Asia)

- 5 TSI reconstructions for the last millenium [11-16]

Methods

- The AMO is calculated based on SSTs for the Atlantic basin (80°E - 10°W, 0°N -60°N), no detrending or decomposition.
- Multitaper Method (MTM) for the estimation of the power spectrum with red noise assumption for significance testing [17].
- Wavelet and Covariance Wavelet Analysis
- Filtering and decomposition of the AMO signal is done using Fast-Fourier-Transformation.

RESULTS - Model Simulations

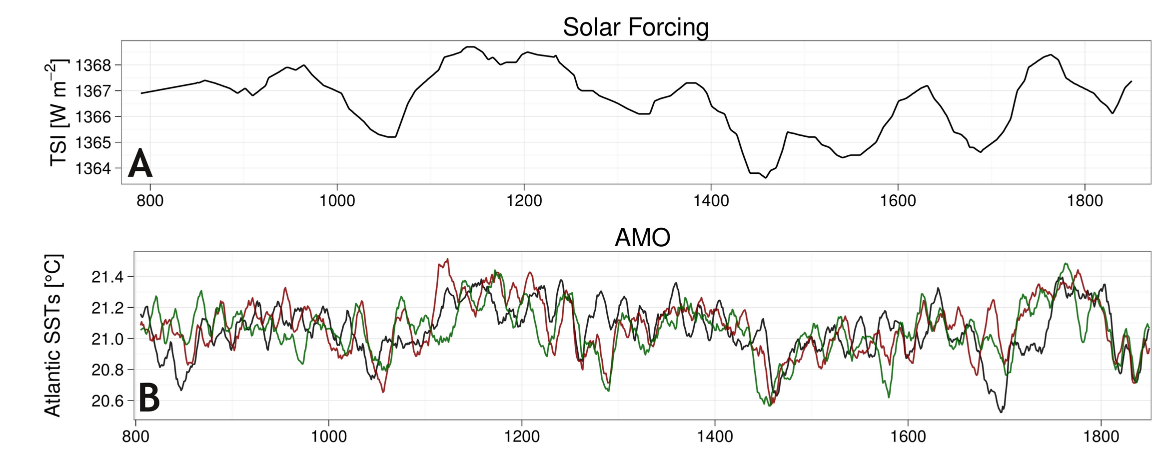


Fig. 1: (A) Solar forcing time series [11,12] and 11 year running mean filtered AMO (Atlantic SSTs: 80°E - 10°W, 0°N -60°N) for the three ensemble members (B).

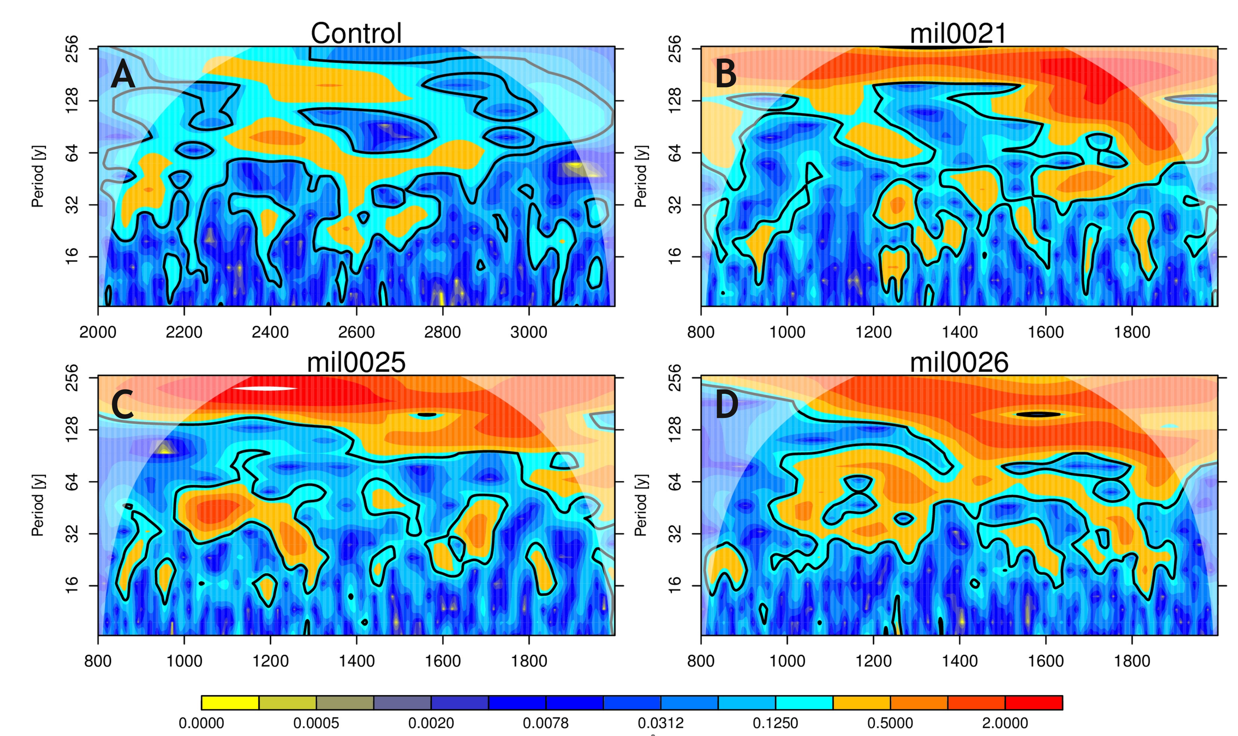
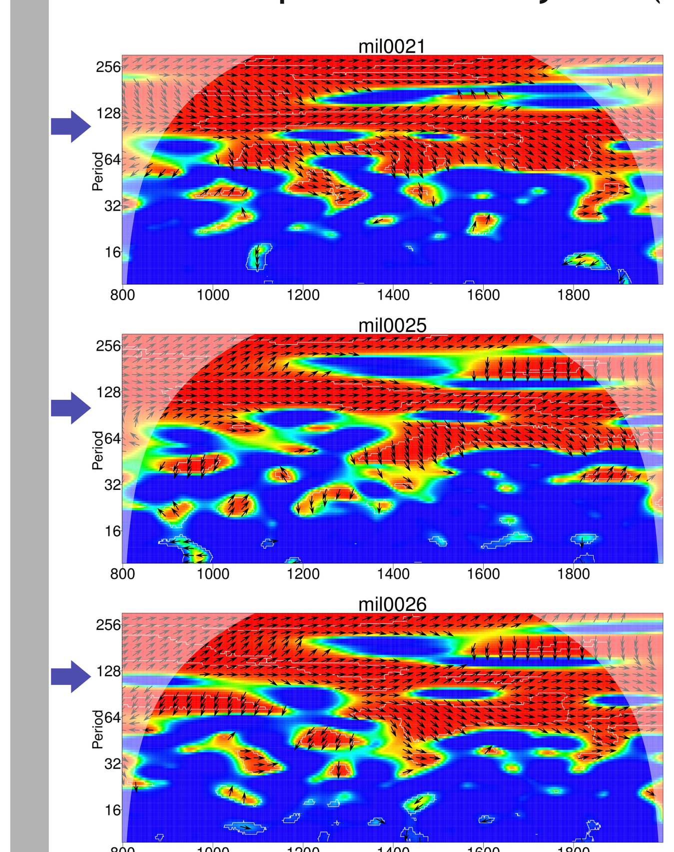


Fig. 2: AMO-Wavelets for Control (A) and the transient simulations (B-D). For Control (A), a section of 1200 continuous years were selected. The thick black line denotes the 95% significance level against red noise.

- The AMO shows pronounced multidecadal and multi-centennial variability (Fig. 1)
- In the control run variability is found on many timescales, but no period shows persistent, significant variability (Fig. 2).
- The transient simulations are characterized by (occasional significant) multidecadal variability and highly significant and persistent (multi-)centenial variability (Fig. 2).
- On centennial periods solar forcing and Atlantic SSTs co-vary in all simulations, whereas no consistent relationship can be found for periods < 100 years (Fig. 3).



Assumption:

- Multidecadal Variability may represent an intrinsic mode of the Atlantic ocean, while the centennial scale is driven by changes in the external forcing.
- **Decompositions into multi-decadal (30-80 yr) and (multi-)centennial (> 100 yr) signal.**

Fig. 3: Wavelet coherence between AMO and solar forcing. Arrows are shown for regions with wavelet coherence power > 0.975; white lines denote statistical significance (p < 0.1).

multidecadal vs. centennial AMO

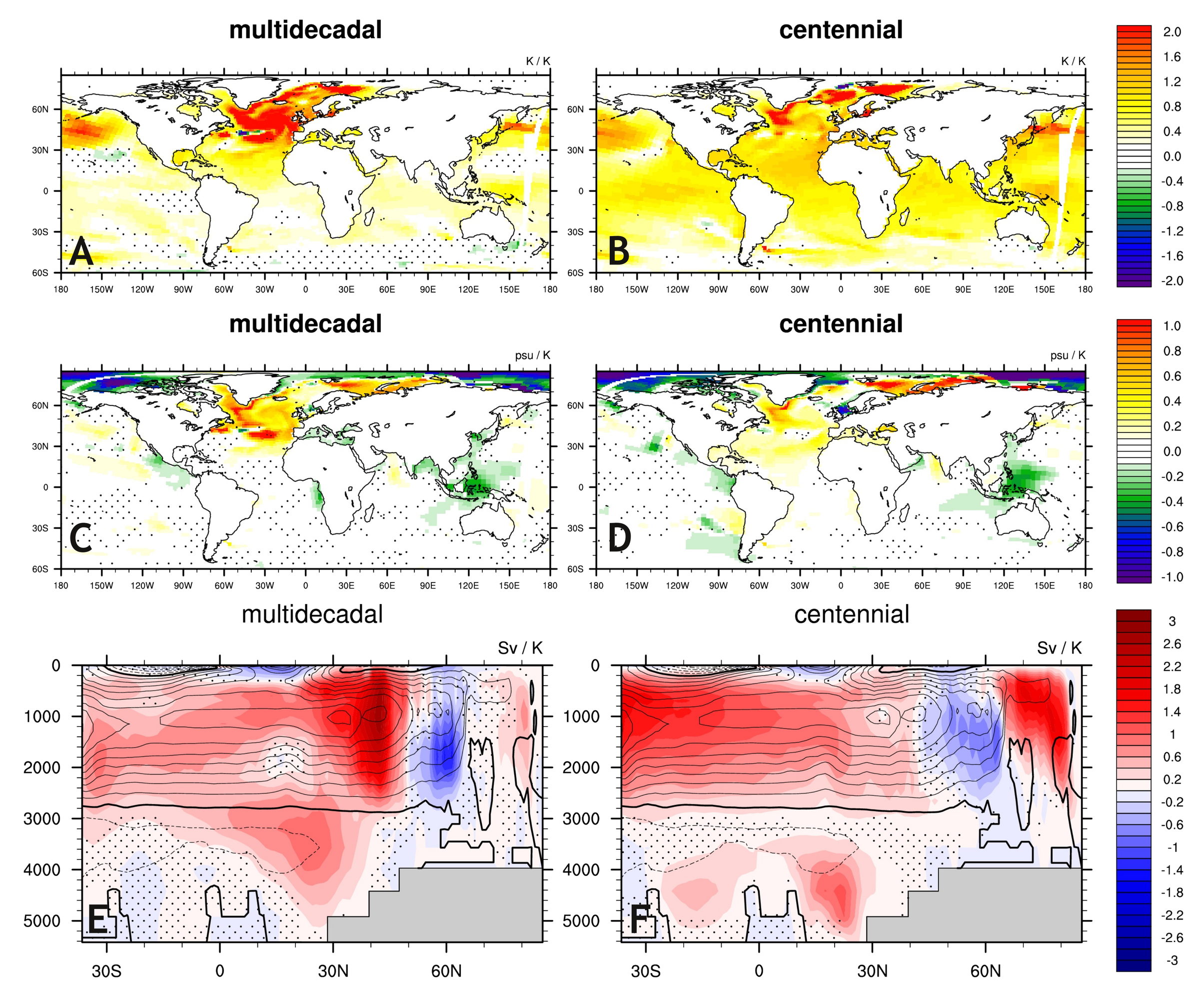
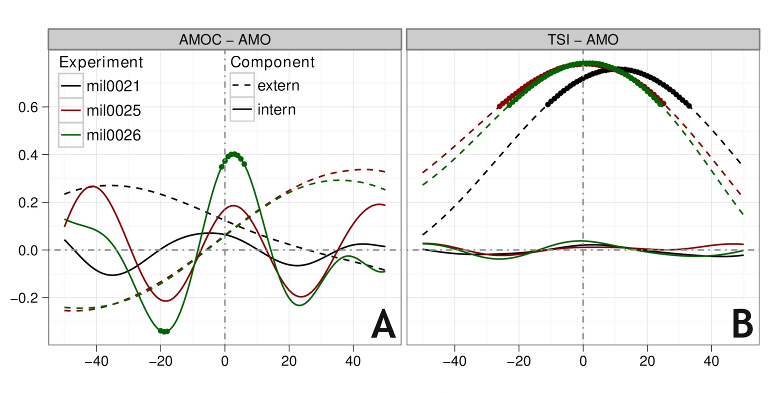


Fig. 4: Regression pattern for sea surface temperature (A,B), salinity (C,D) and the Atlantic meridional streamfunction (E,F) upon the decomposed multidecadal (30-80 years, left column) and centennial (>100 years, right column) AMO index time series. Shown are the regression pattern for member 'mil0025', other simulations are similar. Stippling regions indicate unsignificance (p>0.05).

- The multidecadal SST signal is mainly confined to the North Atlantic (NA), whereas the centennial signal acts on a global scale and is only regionally enhanced by sea ice feedbacks (Fig. 4, A,B). The centennial pattern is very similar to the solar forcing — SST response (not shown).
- On both time scales, salinity responds mainly in the NA and in the Arctic ocean (Fig. 4, C,D).
- The combined effect on density (not shown) is for the multidecadal AMO a density increase in the NA and a decrease in the tropical Atlantic. On centennial scales density decreases globally with slight increases in parts of the NA.
- Due to this the strongest effect on the Atlantic meriodional overturning (AMOC) is found in the NA (around 40°N) for the multidecadal AMO. The centennial response is strongest in the South Atlantic (Fig. 4, E,F).
- Lagged correlations (Fig. 5, B) indicate a strong relation between centennial AMO and TSI. The AMOC shows a significant correlations to the multidecadal AMO in one simulation (Fig. 5, A), whereas it is not significant for the centennial AMO.

Fig. 5: Lagged correlations between the multidecadal (solid line) and centennial (dashed) AMO signal vs. the Atlantic Overturning index (AMOC, A) and the solar forcing (TSI, B). Points depicts significant correlations (p<0.05). For negative lags the AMO is leading.



CONCLUSIONS

- The model results reveal a notable differences in the periodicity and power between the unforced (Control) and transient AMO. In the transient simulations a multidecadal and a centennial variability can be distinguished. The former is limited to the North Atlantic and connected to other internal modes (AMOC). The centennial AMO is related to global changes and shows high correlation (r > 0.7) to the solar forcing.
- In some AMO reconstructions a comparable covariance (on centennial time scales) between solar forcing and AMO is found.

outlook

- In new simulations the influence of moderate to strong solar forcing [13] on the AMO will be analysed (FUPSOL project). First results (Fig. 7) reveal, that also volcanic forcing might play an important role on the multidecadal time scale (compare [18]).

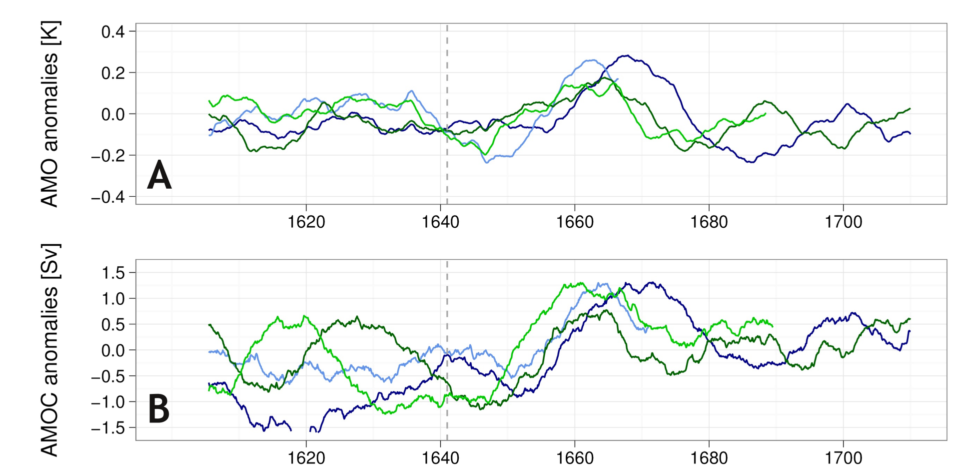


Fig. 7: 11 year running mean AMO (A) and AMOC (B) anomalies from an ensemble of simulations with a coupled ocean-atmosphere-chemistry model. The colors denote the solar forcing used: green simulations were forced by a moderate solar forcing (3 Wm^{-2} MM to PD); blue by a strong forcing (6 Wm^{-2} MM, [13]). The gray vertical line marks a volcanic eruptions.

RESULTS - AMO Reconstructions

- 5 AMO reconstructions [2-6] and 5 solar forcing reconstructions [11-16] where used to identify solar influences on a centennial time scale. In two reconstructions, a persistent covariance between solar forcing and the AMO is found (Fig. 6). These two are not calibrated using the observed AMO.
- Another reason for the difference could be, that tree rings, which are used in the other reconstructions, have difficulties in representing low frequency variability.

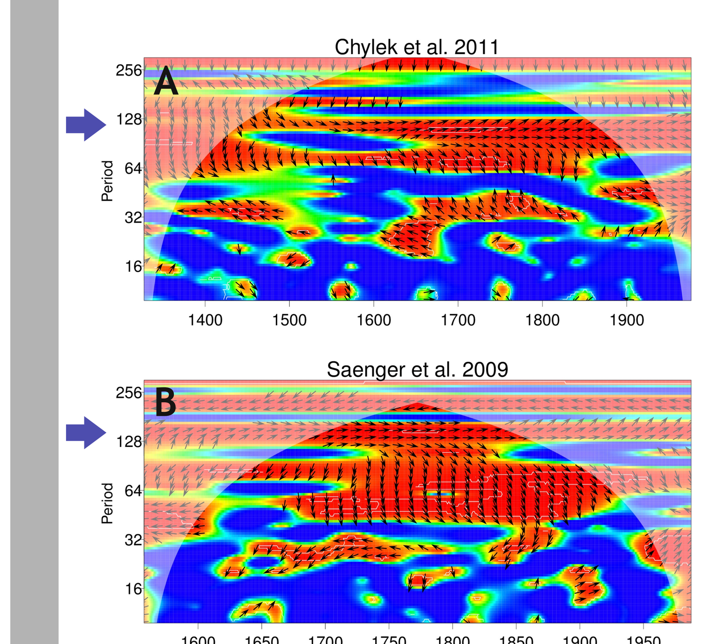


Fig. 6: Wavelets coherence between AMO reconstruction of [2] (A) and [3] (B) and the solar forcing shown in Fig. 1.A. Arrows are shown for regions with wavelet coherence power > 0.975; white line denotes statistical significance (p < 0.1). Please note the different scaling of the date axis.

Acknowledgements

We thank the Ocean Group at the Max-Planck-Institute Hamburg, especially Johann Jungclaus, for providing the data. This work has been supported by the Swiss National Science Foundation under grant CRSI122-130642 (FUPSOL).

REFERENCES

[1] Schlesinger & Ramankutty. An oscillation in the global climate system of period 65-70 years. Nature 367, 723-726 (1994).
[2] Saenger. et al. Surface-temperature trends and variability in the low-latitude North Atlantic since 1552. Nature Geoscience 2, 492-495 (2009).
[3] Chylek et al. Ice-core data evidence for a prominent near 20 year time-scale of the Atlantic Multidecadal Oscillation. GRL 38, 1-5 (2011).
[4] Mann et al. Global signatures and dynamical origins of the Little Ice Age and Medieval Climate Anomaly. Science 326, 1256-60 (2009).
[5] Gray et al. A tree-ring based reconstruction of the Atlantic Multidecadal Oscillation since 1567 A.D. GRL 31, 2-5 (2004).
[6] Wang et al. Imprint of the Atlantic multidecadal oscillation on tree-ring widths in northeastern Asia since 1568. PloS one 6, e22740 (2011).
[7] Knight et al. A signature of persistent natural thermohaline circulation cycles in observed climate. GRL 32, 2-5 (2005)
[8] Otterå et al. External forcing as a metronome for Atlantic multidecadal variability. Nature Geoscience 3, 688-694 (2010).
[9] Zanchettin et al. Multidecadal-to-centennial SST variability in the MPI-ESM simulation ensemble for the last millennium. (submitted)
[10] Jungclaus et al. Climate and carbon-cycle variability over the last millennium. Climate of the Past 6, 723-737 (2010).
[11] Bard et al. Solar irradiance during the last 1200 years based on cosmogenic nuclides. Tellus B 52, 985-992 (2000).
[12] Ammann et al. Solar influence on climate during the past millennium: Results from transient simulations with the NCAR Climate System Model. PNAS 104, 3713-3718 (2007).
[13] Shapiro et al. A new approach to the long-term reconstruction of the solar irradiance leads to large historical solar forcing. Astronomy & Astrophysics (2011).
[14] Steinhilber, Beer. & Fröhlich. Total solar irradiance during the Holocene. GRL 36, 1-5 (2009).
[15] Krivova, Balmaceda & Solanki. Reconstruction of solar total irradiance since 1700 from the surface magnetic flux. Astronomy & Astrophysics 467, 335-346 (2007).
[16] Crowley. Causes of Climate Change Over the Past 1000 Years. Science 289, 270-277 (2000).
[17] Mann & Lees. Robust estimation of background noise and signal detection in climatic time series. Clim. Change 33, 409-445 (1996).
[18] Mignot et al. Volcanic impact on the Atlantic Ocean over the last millennium. Climate of the Past 7, 1439-1455 (2011).