Investigations of hypoxic areas in the Baltic Sea during the MCA and LIA using RCA3 forced with ECHO-G

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Motivation: Inflow events of salty water from the North Sea into the Baltic Sea are crucial for the Baltic ecosystem. A lack of inflow events reduces the concentration of oxygen which can lead to hypoxia with adverse effects on the marine ecosystem. Proxy data show that such conditions occurred during the Medieval Climate Anomaly (MCA, see Fig. 1).

The goal of this study is to identify atmospheric drivers which are responsible for the changes in inflow events. Therefore, a climate simulation of the last 1000 years including MCA and the Little Ice Age (LIA) has been carried out with a Regional Climate Model. Inflow events are forced mainly by characteristic series of atmospheric patterns with strong easterly wind during the preconditioning phase of about 20 days followed by strong westerlies during the inflow phase of about the same duration. Here, we focus on the two extreme periods during the last millennia to highlight and understand differences for the Baltic Sea.

Finally, climate projections until the end of the 21st century suggest similar conditions in the future as has been during MCA. Thus, exploring the MCA may help to understand future changes in the Baltic Sea.

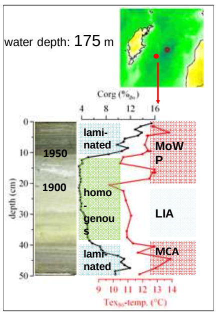

Fig 1: Borehole from the Gotland Deep indicating the sea surface temperature evolution from the MCA until present day (Copy from Kabel et al. (2011)[3])

Results from sediment cores

- sediment core from the Gotland Deep (175m) as proxy for the evolution of past temperature and oxygen concentration
- homogenous layers in the LIA indicates that there was enough oxygen for bio-activity, therefore mixing of the top sediment levels inhibit the formation of layers
- during MCA and modern warm period (MoWP) a lack of oxygen led to a stop of bio-turbulence producing laminated layers
- annual sea surface temperatures in the Gotland Sea are approximately 2-3 K higher during MCA and MoWP compared to the LIA

Model description and experimental setup

For the simulation of the climate in Europe over the last millennia the regional climate model RCA3[1] (Rossby Centre Atmosphere model version 3) is used. RCA3 operates on a rotated longitude-latitude grid with a resolution of 0.44° (50kmx50km) and 24 vertical levels. Lateral boundary conditions (including SST and sea ice) are taken from ECHO-G[2] whereas the outermost 8 boxes are used as relaxation boxes. ECHO-G is an atmosphere-ocean general circulation model with a horizontal resolution of T30 (3.75°x3.75°) in the atmosphere and T42 in the ocean. We use O etzi II[3] as external boundary for the regional model RCA3. Oetzi is a ~9000 year long simulation covering the period 7000 BP until 1998 using orbital changes, reconstructed solar variability and changing greenhouse gas concentrations (CO_2 and CH_4) as only drivers.

RCA3 performance forced with ERA40 and ECHO-G

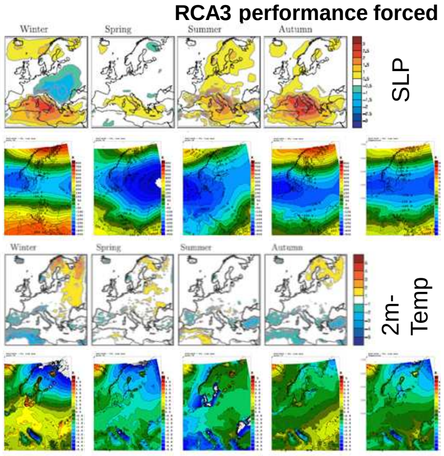

Figure 2: SLP and Temperature anomalies. First and third row RCA3 forced with ERA40 compared to ERA40 and CRU-data, respectively (cf. Samuelson et al. 2011). Second and forth row RCA3 forced with ECHO-G (Oetzi II, years 1968-1998) compared to RCA3 forced with ERA40. Columns reflect seasonal and annual means.

- RCA3 generally reproduces the large scale circulation of ERA40 quite good, but too high SLP (+2hPa) in the Mediterranean region
- larger SLP biases in RCA3-Oetzi are connected to shortcomings in ECHO-G, general too high SLP in northern Scandinavia (+3hPa) and too low over the Southern Baltic Sea (-2hPa)
- There is a warm bias in the northeastern part of the ERA40-driven simulation, especially during winter up to 3-4K (underestimation of snow)
- winter temperature anomalies in RCA3-Oetzi are to a large degree connected to circulation anomalies, e.g. too cold in the North (more than 4K) and too warm over Germany (~1.5K)
- local biases over the Baltic Sea are connected to interpolated SSTs

Atmospheric anomalies during MCA and LIA

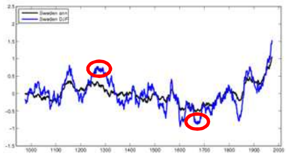

Fig. 3: Temperature evolution in RCA3 for Sweden from 1000BP until 2000. 50-year running means for DJF and annual means. Marked periods are used for comparison of MCA and LIA in figure 5.

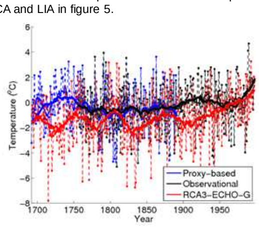

Fig. 4: JFMA temperature anomalies in Stockholm for the model integration, observational data from the observatory in Stockholm (Moberg et al., 2002) and from a reconstruction based on ice in harbours (Leijonhufvud et al., 2008)

- long-term temperature variability is in general agreement with ECHO-G and corresponds to external forcing parameters, e.g. coldest temperatures during the LIA and warmest conditions in the pre-industrial area during the MCA (see Fig. 3)
- higher decadal variability for winter than annual means
- temperature differences in Sweden between MCA and LIA are greater than 1.5K for winter means and below 1K in the annual mean
- strong rise in the 20th century leads to higher temperature than during the MCA
- proxy and observational data agree fairly well for the common period (correlation higher than 0.8)
- the model is colder on average and has a higher variability, especially cold winters are exceptional cold

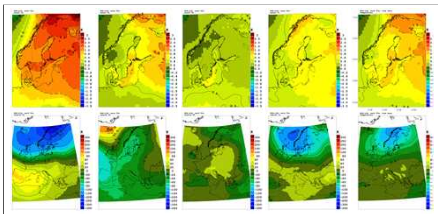

Fig. 5: Temperature (upper row) and SLP (lower) differences between 50 year periods of MCA and LIA as defined in Fig 3. Anomalies are shown for DJF, MAM, JJA, SON and annual means (from left to right)

Differences between MCA and LIA:

- spatial pattern reveals the typical increase of temperature changes to the northeast in winter (up to 3K)
- this is partly related to a stronger pressure gradient during the MCA over the Atlantic/European sector
- this is in agreement with the observed lack of oxygen in MCA since stronger mean westerlies lessens the inflow

Projected changes

- RCA3 was forced with climate projection scenarios until 2100 whereas lateral boundary conditions were taken from ECHAM5 and HadCM3 A1B runs (Meier et al. 2011)
- Temperature response pattern at the end of the 21st century is similar to MCA-LIA anomalies, but the projected increase is larger (more than 4K in Northern Scandinavia in winter with ECHAM5 forcing, cf. Figure 6). Note that the temperature response is even stronger with HadCM3 forcing (not shown).
- Forcing a Baltic Sea model with the projected changes from RCA3 simulates a widespread decrease of bottom oxygen at the end of this century (Figure 8). This is likely to be connected with an decrease of inflow into the Baltic Sea. Local increase of bottom oxygen is suggested to be connected with increased wind speeds and therefore stronger mixing. A similar lack of bottom oxygen is also presumed for the MCA.

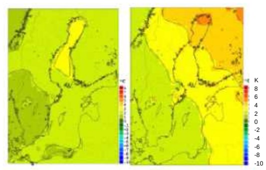

Fig. 6: Summer (left) and winter (right) temperature changes in the period 2061-2090 compared to 1970-1999. Copy from Meier et al. (2011, their figure 10)

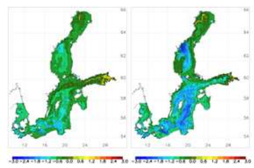

Fig. 7: Anomalies in bottom oxygen concentrations for the period 2061-2090 compared to 1960-1990. Annual means for a simulation forced with ECHAM4 (left) and HadCM3 A1B (right). Copy from Meier et al. (in preparation)

Outlook

The next step is to run a physical-biogeochemical model for the entire Baltic Sea for time-slices of the last millennia. This will allow to investigate changes in ocean dynamics in detail. Besides fluctuations in the pressure gradient across the North Sea (following Gustafsson and Anderson, 2001), we will investigate in how far also changes of wind direction, mean wind speed or gustiness are likely to contribute and how important smaller salt water inflows are. Finally, results will be compared to projected changes as shown in Fig. 7.

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Acknowledgments

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