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Supplementary Materials for

South Atlantic Surface Boundary Current System during the Last Millennium in the CESM-LME: The Medieval Climate Anomaly and Little Ice Age

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Figure S1 shows the model-derived LM-mean zonal velocity field compared to the literature (i.e., Figure 2 from Stramma and England, 1999 [1]).

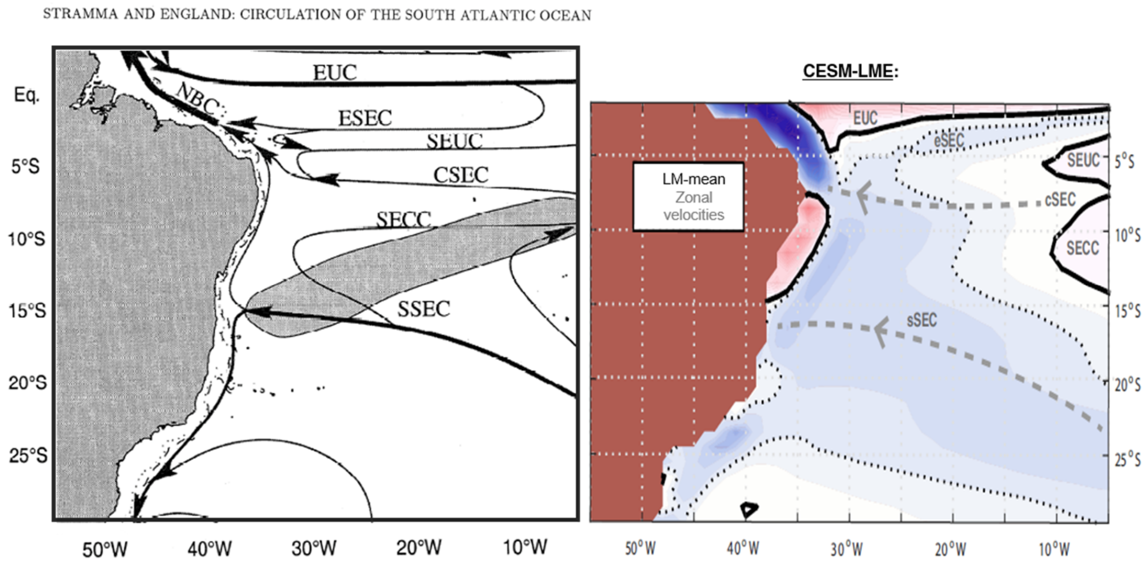

Figure S1. Scaled comparison of Figure 2 from Stramma and England (1999) [1] with Figure 2b of the original manuscript. **Left:** Schematic representation of the large-scale, upper 100-m geostrophic currents based on observations from the World Ocean Circulation Experiment (WOCE). **Right:** Depth integrated mean zonal velocities (m/s) over the top 200 m from the CESM-LME simulation results.

Figure S2 compares the CESM model results with those of five ocean reanalysis products: the European Center for Medium-Range Weather Forecasts (ECMWF) ocean analysis/reanalysis system 4 (ORAS4), the Geophysical Fluid Dynamics Laboratory (GFDL), the Simple Ocean Data Assimilation version 2.1.6 (SODA216), the Global Ocean Data Assimilation System (GODAS) and the Climate

Forecast System Reanalysis (CFSR) from the National Centers for Environmental Prediction (NCEP) (Table S1).

Table S1. Time period, horizontal resolution and number of vertical layers above 1000 m of the 5 ocean reanalysis products.

Product	Period	Horiz. Resolution	Vertical Layers-1000 m
ORAS4	1960–2010	1° × 1°	26
GFDL	1961–2010	1° × - *	34
SODA216	1960–2008	0.5° × 0.5°	22
GODAS	1980–2010	1° × 1/3°	31
CFSR	1980–2010	0.5° × 0.5°	31

* The latitudinal resolution of the GFDL reanalysis varies between approximately 0.33° near the equator to 1° near 30° S.

The comparisons are made based on the periods covered by the reanalysis products, displayed in Table S1; on the 1948–2015 period for the ocean component of the CESM, the Parallel Ocean Program version 2 (CESM1-POP2, here as CESM-OCN) and on the interval of 1960–2010 for the CESM-LME.

The results are also quantitatively compared to those of Rodrigues et al. (2007) [2] (hereinafter R2007), who characterized the sSEC bifurcation vertical structure at the western boundary from hydrographic observations and numerical model results, providing a description of its annual mean depth dependence. The authors showed that the bifurcation occurs at about 10°–14° S in the top 100 m and shifts poleward with increasing depth, reaching 27° S at 1000 m (Figure 3 in their manuscript).

Among the reanalysis products that were examined, the structure that more closely resembles the contour from R2007 hydrographic observations is the one reproduced by ORAS4. A previous investigation which evaluated the products' performance in terms of the mean circulation field for different levels in comparison to the available observations of R2007 (not shown), also suggested that ORAS4 better captures the dynamics of the SBL.

The mean SBL for individual levels up to 600 m is listed in Table S2. Despite some small differences, all data-sets reproduce the poleward tilting of the sSEC bifurcation with increasing depth. The total shift up to 600 m of the R2007 observations and of ORAS4, CESM-OCN and CESM-LME are within the range of 9°–13.1°.

Table S2. SBL values obtained by R2007 from hydrographic observations; derived from ocean reanalysis products and obtained from the CESM-models results.

	Surface	100 m	200 m	400 m	600 m	Total shift
Obs. *	14° S	14° S	18.6° S	21° S	23.6° S	9.6°
ORAS4	13° S	19.6° S	21.3° S	23.3° S	24.7° S	11.7°
GFDL	18.3° S	20.1° S	21.2° S	25.5° S	27.1° S	8.8°
SODA216	13° S	18.1° S	22.1° S	25.1° S	27.6° S	14.6°
GODAS	7.2° S	16.9° S	19° S	22.2° S	24.1° S	16.9°
CFSR	8.4° S	14.4° S	16.5° S	20.5° S	22.6° S	14.2°
CESM-OCN	14.7° S	19° S	23.3° S	25.7° S	27.8° S	13.1°
CESM-LME	17.8° S	20.3° S	22.3° S	24.9° S	26.8° S	9°

* Hydrographic observations from R2007: geostrophic velocities determined from dynamic heights relative to 1000 dbar, calculated with an annual mean climatology of temperature and salinity constructed from observations (quality-controlled CTD and bottle data obtained from HydroBase (Curry, 1996) [3]). The authors' calculations do not include the Ekman current, which would affect the bifurcation latitude near the surface. They clarify that adding the Ekman currents to the geostrophic currents (calculated from observations) moves the bifurcation latitude northward by about 1° (i.e., the bifurcation occurs at 13° at the surface).

Therefore, the simulation results from CESM-OCN and CESM-LME are similar to the results derived from ORAS4 and to R2007 hydrographic observations, suggesting that the model simulates well the sSEC bifurcation and the region of study.

These results also agree with the available literature. From hydrographic data, Stramma and England (1999) [1] showed that the bifurcation latitude is 16° S in the near-surface layer (top 100 m), 20° S in the South Atlantic Central Water (SACW) layer (100–500 m), and 26° S in the intermediate layer (500–1200 m). Using isobaric RAFOS oats, Boebel et al. (1999) [4] showed that the Return Current (analog to the SEC, but within the Antarctic Intermediate Water (AAIW) layer) reaches the South American coast at approximately 28° S (called the Santos Bifurcation by the authors). Using data from the World Ocean Circulation Experiment (WOCE) hydrographic section A17, which was taken during the austral summer of 1994, Wienders et al. (2000) [5] estimated the transport of the SEC and its bifurcation latitude for several isopycnal layers: the SEC bifurcation latitude is 14° S at the surface, 24° S in the 26.7–26.9 layer (400–500 m), and nearly constant around 26°–28° S in the AAIW and Upper Circumpolar Water (UCPW: 600–1200 m). These results should be interpreted with caution because they are based on a single hydrographic section taken from 6°–10° from the western boundary. In the simulations by Harper (2000) [6], the bifurcation point in the near-surface layer at the western boundary of the SAO occurs at 18° S, and in those by Malanotte-Rizzoli et al. (2000) [7], it occurs at 17° S. From the results of two high-resolution ocean global circulation models (OGCMs), the Hybrid Coordinate Ocean Model-HYCOM and the Ocean Circulation and Climate Advanced Modeling Project-OCCAM, Pereira et al. (2014) [8] found that the latitude of bifurcation of the zonal ows reaching the coast (analog to the SEC), is 13°–15° S for the Tropical Water, 22° S for the Central Water, 28°–30° S for the Antarctic Intermediate Water. Cirano et al. (2006) [9], using data from the global circulation model Ocean Circulation and Climate Advanced Modeling Project (OCCAM), found that the bifurcation occurs between 9°–15° S in the TW (0–116 m), migrating to 25° S in the SACW (116–657 m) and 25°–30° S in the AAIW (657–1234 m).

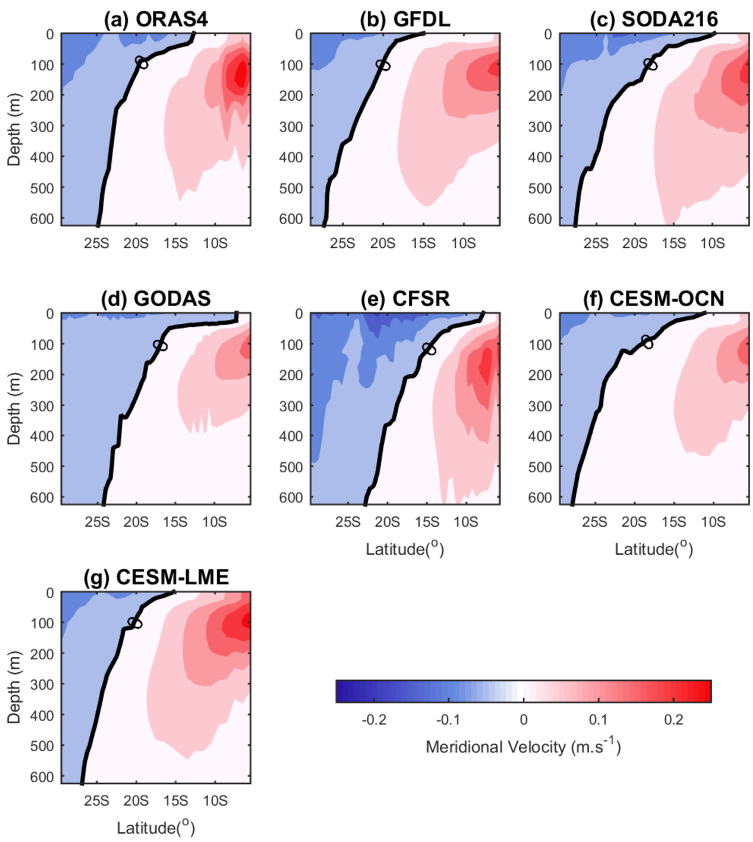

Figure S2. sSEC bifurcation vertical profile from reanalysis products and model results. Mean meridional velocity (m/s) averaged over the western boundary layer (<4° from the coast) from ocean reanalysis products (**a**–**e**) and from model results (**f**–**g**). Positive (negative) values indicate northward (southward) ow associated with the NBUC (BC), and the contour of zero velocity represents the bifurcation of the sSEC.

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