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Supplement of

Controls on Early Cretaceous South Atlantic Ocean circulation and carbon burial – a climate model–proxy synthesis

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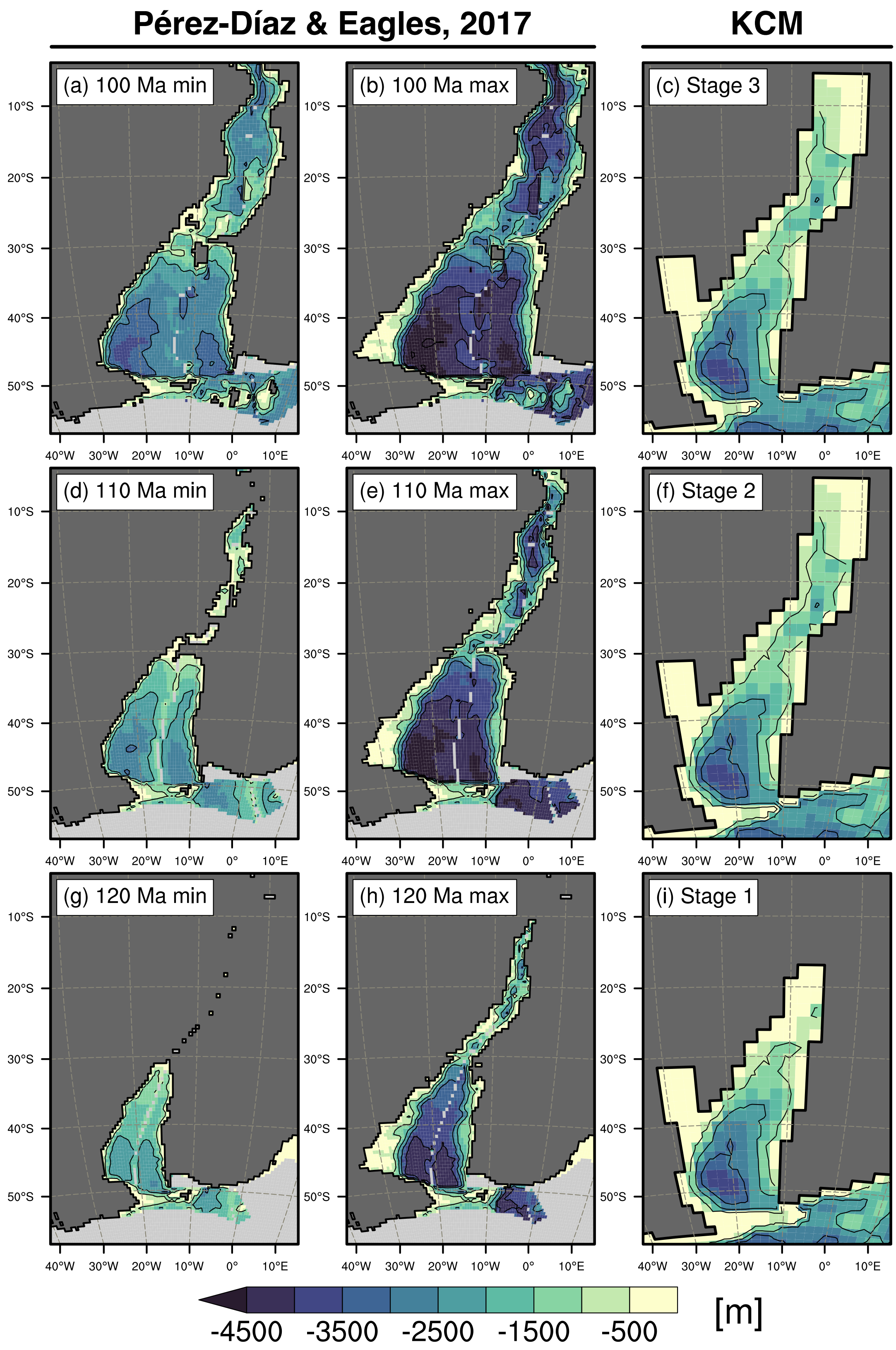

Figure S1. Comparison of available reconstructions for the Early Cretaceous South Atlantic[1] with the model bathymetries used in this study. Only the minimum and maximum reported water depths are shown for each stage. KCM bathymetries are shown on the native model grid, while the reconstructions have been re-gridded to a 0.5° x 0.5° horizontal grid. Contour line interval is 1000 m.

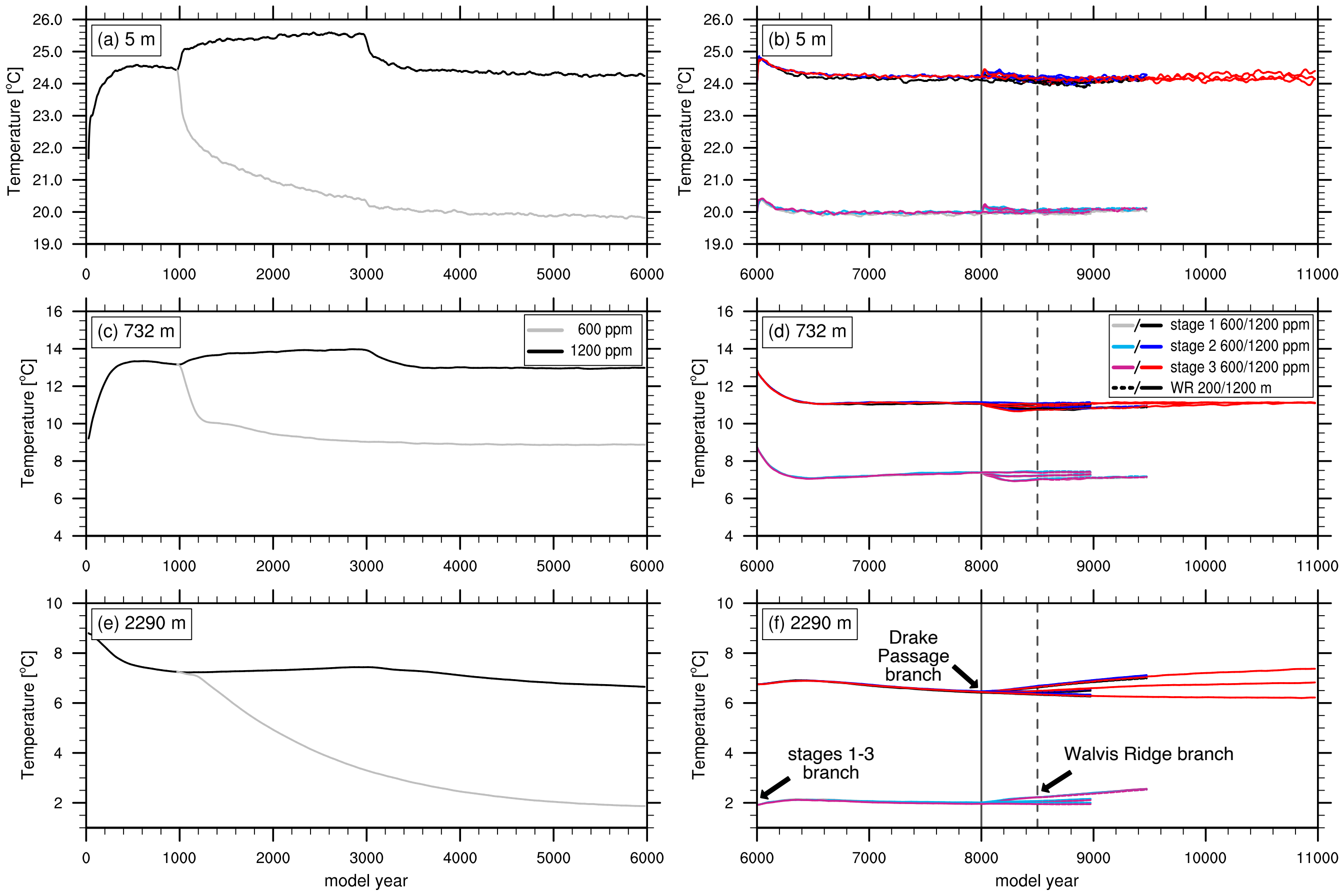

Figure S2. Overview of ensemble spin-up phases. Time series of annual mean ocean temperatures at different depths are averaged globally. Color coding represents the different stages defined in the main text and the two levels of atmospheric CO_2. The sudden shifts in temperature at years 1000 and 3000 of the initial spin-up are related to a temporary increase of the atmospheric time step length, which has been reversed to improve model stability.

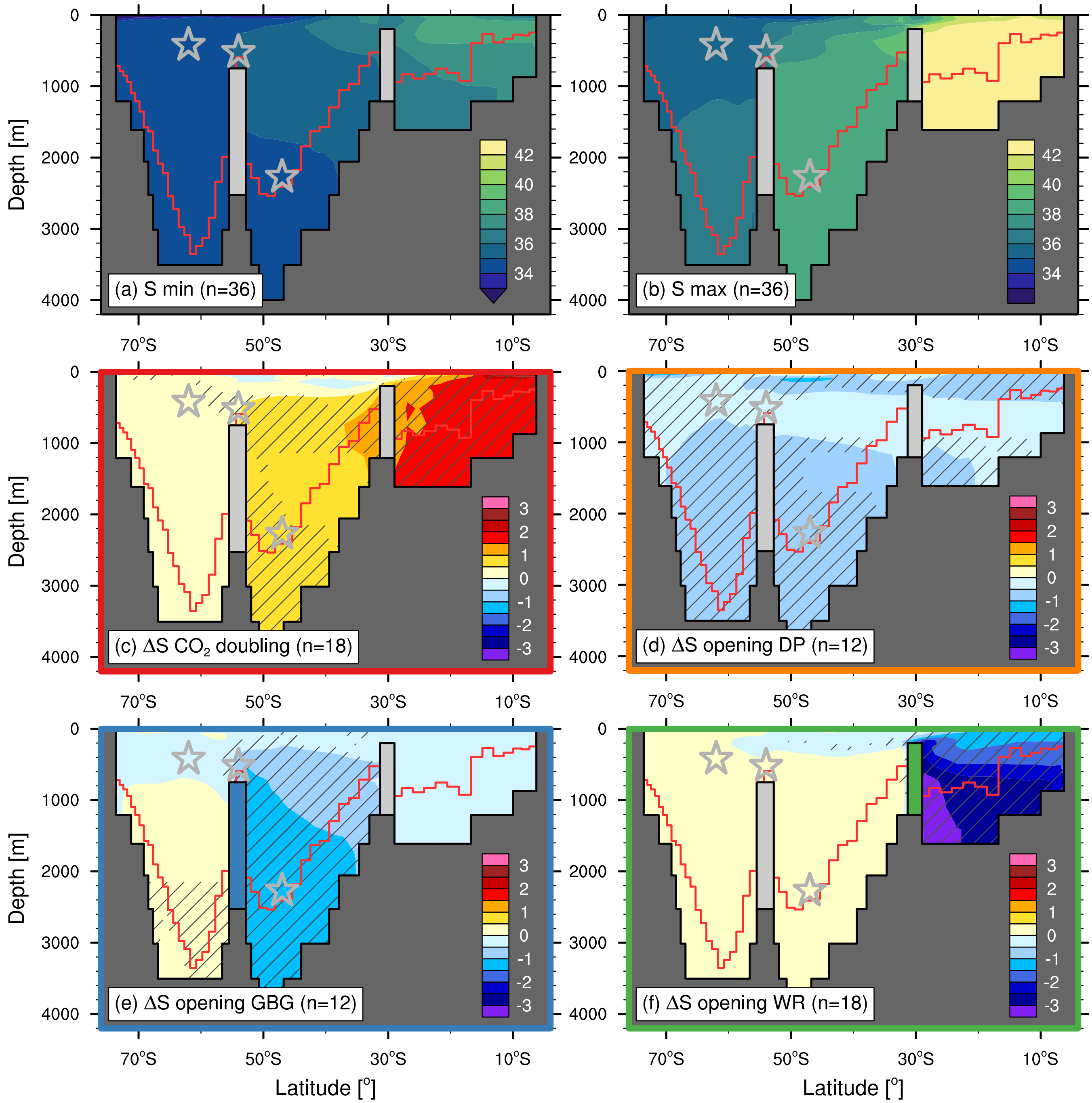

Figure S3. Zonal mean salinity sections for the South Atlantic and Southern Ocean. Values are averaged between 30°W and 10°W at the Falkland Plateau and between 30°W and 0° elsewhere. Black (red) lines indicate maximum (average) water depth at the respective latitude. Panels show the (a) minimum and (b) maximum simulated value across all 36 ensemble members and (c-e) the mean change associated with the individual processes defined in Section 2.3 of the main text. Hatching indicates areas where all the respective 12 or 18 model responses agree on the sign of the change.

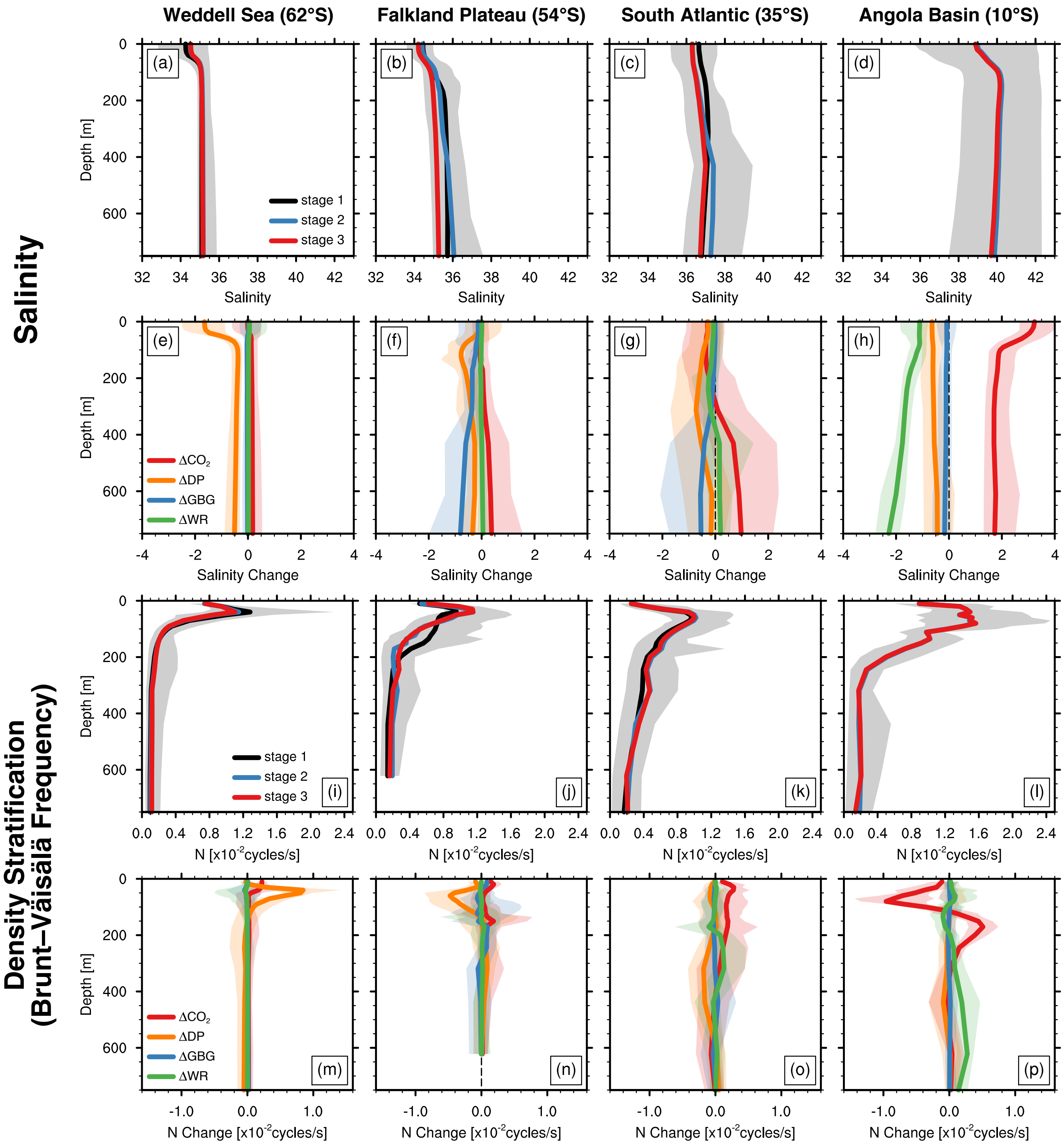

Figure S4. Simulated ocean salinity profiles and density stratification across the Southern Ocean and South Atlantic. Density stratification is expressed in terms of the Brunt–Väisälä frequency (buoyancy frequency) defined as: $N = \sqrt{-\frac{g}{\rho_0}\frac{\delta\rho(z)}{\delta z}}$, where ρ is the potential density. Solid lines represent regional averages (areas shown in Fig. 1g of the main text), while shading indicates the simulated maximum and minimum grid point values of the respective area across all simulations. The processes analysed are defined in Section 2.3 of the main text. The area used for averaging across the Falkland Plateau Basin in panels (b),(f),(j) and (n) moves westward for each consecutive model stage to allow comparison with the proxy record. N is calculated on the mid depths of the model and, therefore, only defined to 620 m on the Falkland Plateau. All simulations have a global mean salinity of 35.

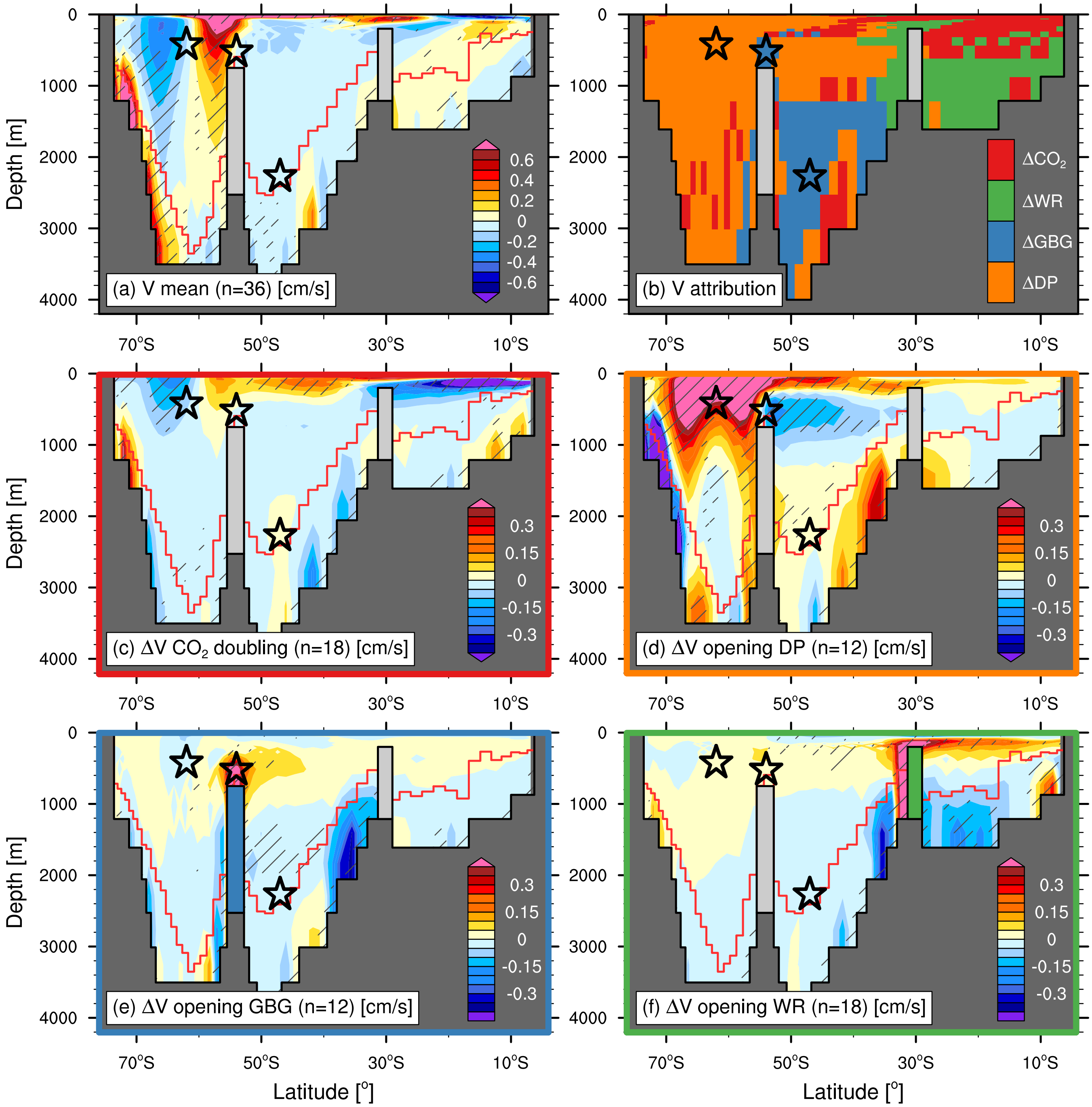

Figure S5. Meridional ocean circulation. Panels show the (a) ensemble mean, (b) the respective boundary condition resulting in the largest mean change, and (cf) the mean change associated with the individual processes defined in Section 2.3 of the main text. Fields are smoothed with a nine-point average for figure clarity and are shown in cm/s. Positive (negative) values represent northward (southward) flow. Contour range only shows a subset of the data to focus on changes in the South Atlantic. Hatching indicates region where all ensemble members agree on the sign of the shown field. Black (red) lines indicate maximum (average) water depth at the respective latitude.

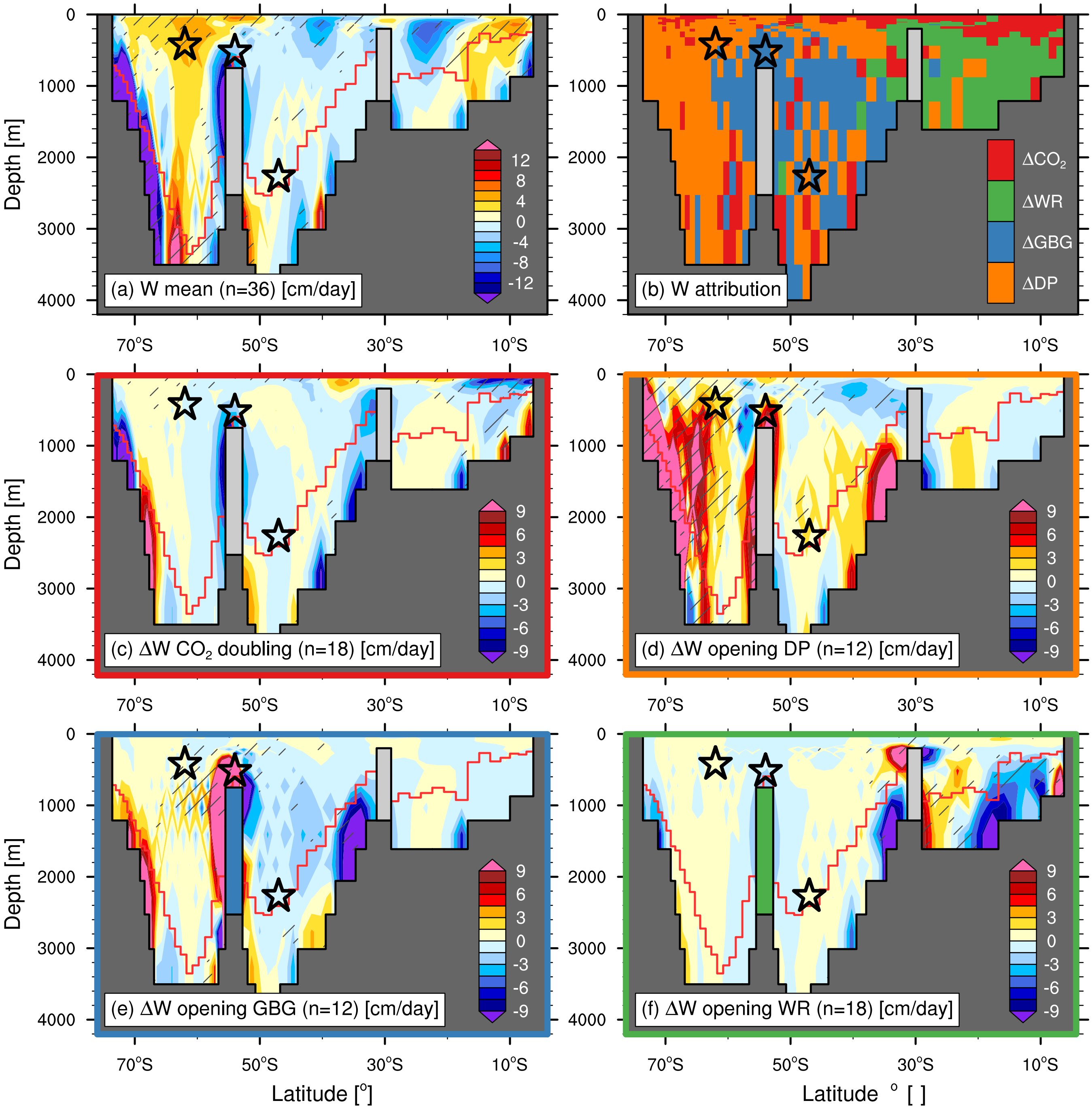

Figure S6. Vertical ocean circulation. Panels show the (a) ensemble mean, (b) the respective boundary condition resulting in the largest mean change, and (cf) the mean change associated with the individual processes defined in Section 2.3 of the main text. Fields are smoothed with a nine-point average for figure clarity and are shown in cm/day. Positive (negative) values represent upward (downward) flow. Contour range only shows a subset of the data to focus on changes in the South Atlantic. Hatching indicates region where all ensemble members agree on the sign of the shown field. Black (red) lines indicate maximum (average) water depth at the respective latitude.

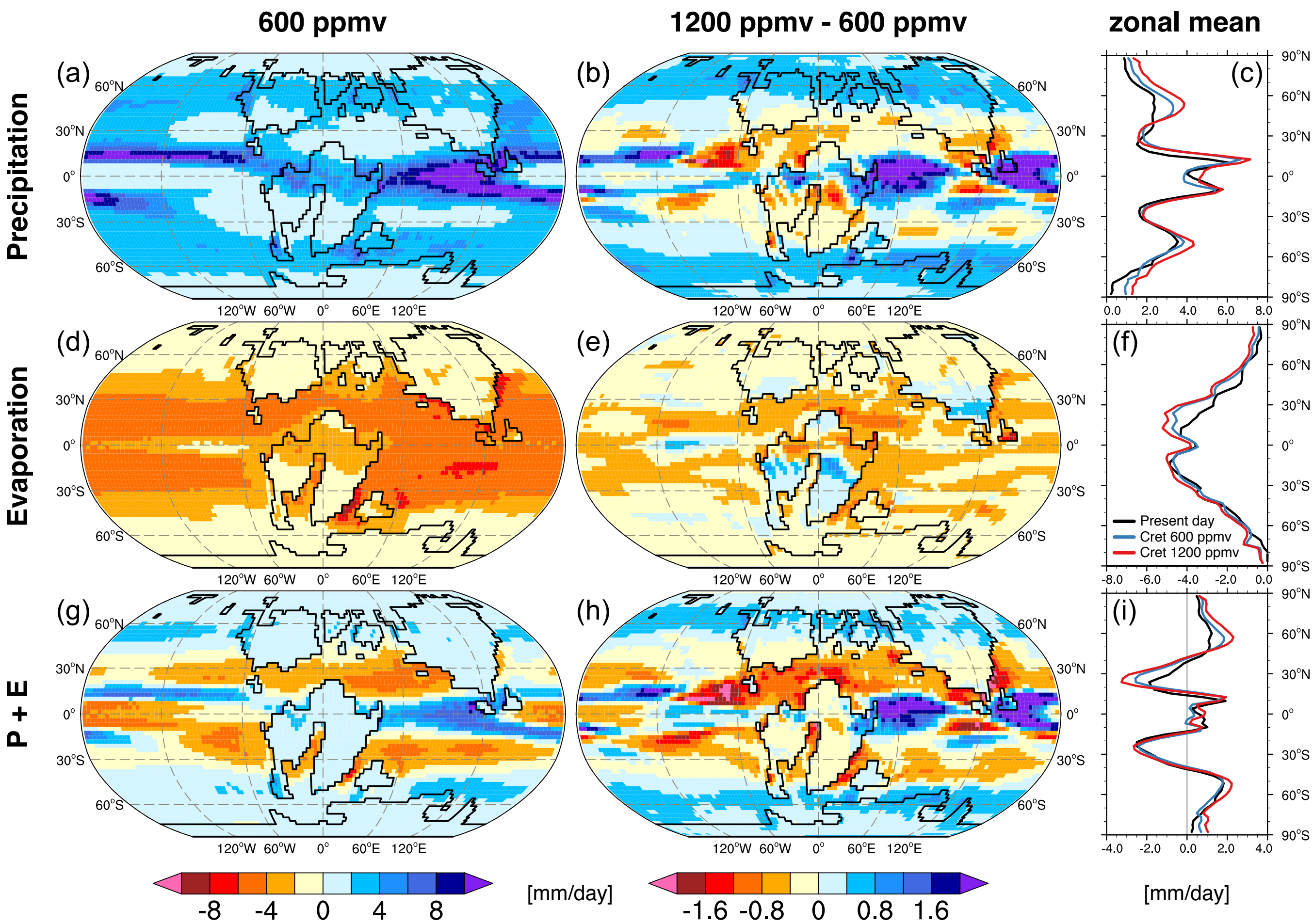

Figure S7. CO_2 sensitivity of the global hydrological cycle. Panels show ensemble mean (n=18) precipitation, evaporation and the sum of both for (left) 600 ppmv CO_2, (middle) the respective change for doubling CO_2 and (right) the zonal mean values for the 600 and 1200 ppmv ensembles as well as for the same model configuration under present-day boundary conditions. Note that the P+E term is identical to the E-P flux described in the main manuscript due to the negative evaporation sign used in panels (d-e). All values are given in mm/day.

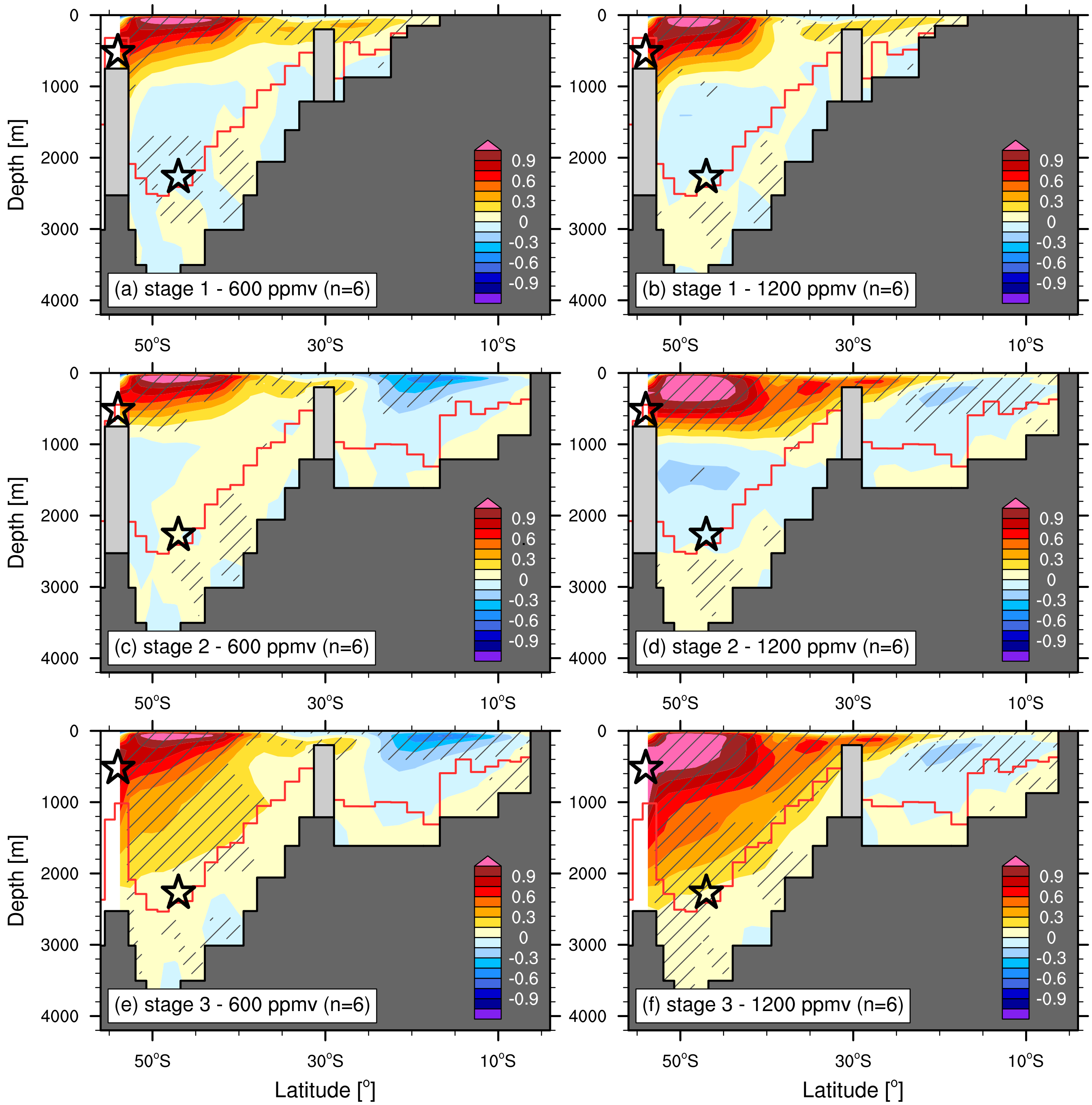

Figure S8. South Atlantic meridional overturning circulation (MOC). Panels show the respective ensemble means for stages 1 to 3 integrated at (left) 600 ppmv and (right) 1200 ppmv. Values are in Sv with 1 Sv = 10^6 m^3/s. Positive (negative) values represent clockwise (counterclockwise) circulation. Hatching indicates region where all 6 ensemble members agree on the sign of the MOC. Black (red) lines indicate maximum (average) water depth at the respective latitude.

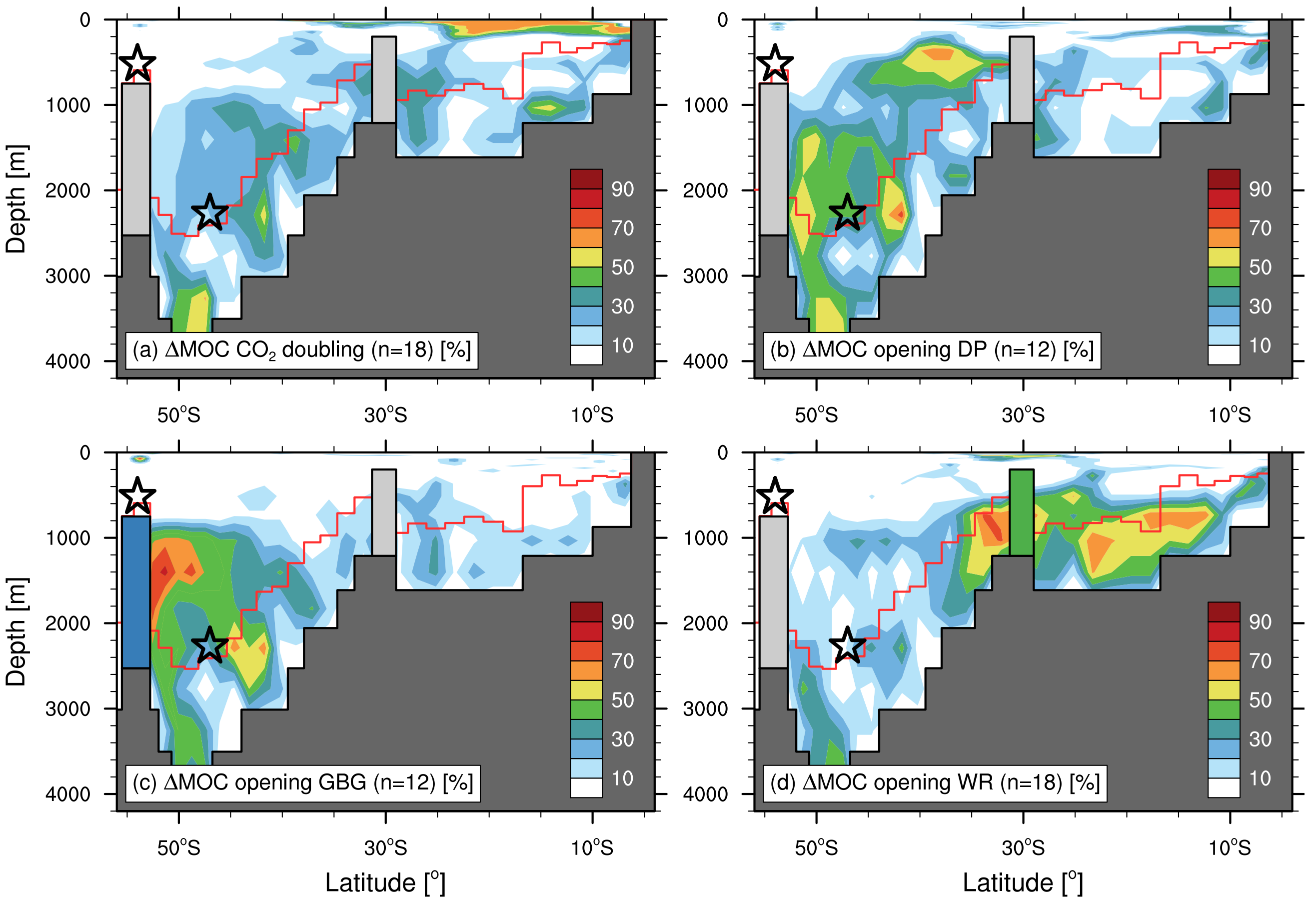

Figure S9. Analysis of the percentage of model pairs (12 or 18) in which the sign of the MOC in each location changes its sign, i.e. the overturning circulation reverses its direction, due a change of the individual boundary conditions defined in Section 2.3 of the main text. For example, panel (a) indicates that 60-70% of the 18 simulations at 600 ppm atmospheric CO2 have a different sign of the MOC in the upper 200 m of the Angola Basin (between 25°S to 10°S) than the equivalent simulations where only the CO_2 is increased to 1200 ppm.

References

1. Pérez-Díaz, L. & Eagles, G. South Atlantic paleobathymetry since early Cretaceous. *Sci. Reports* **7** (2017).