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SOUTHERN OCEAN CARBONATE DYNAMICS UNDER GLACIAL AND INTERGLACIAL CONDITIONS

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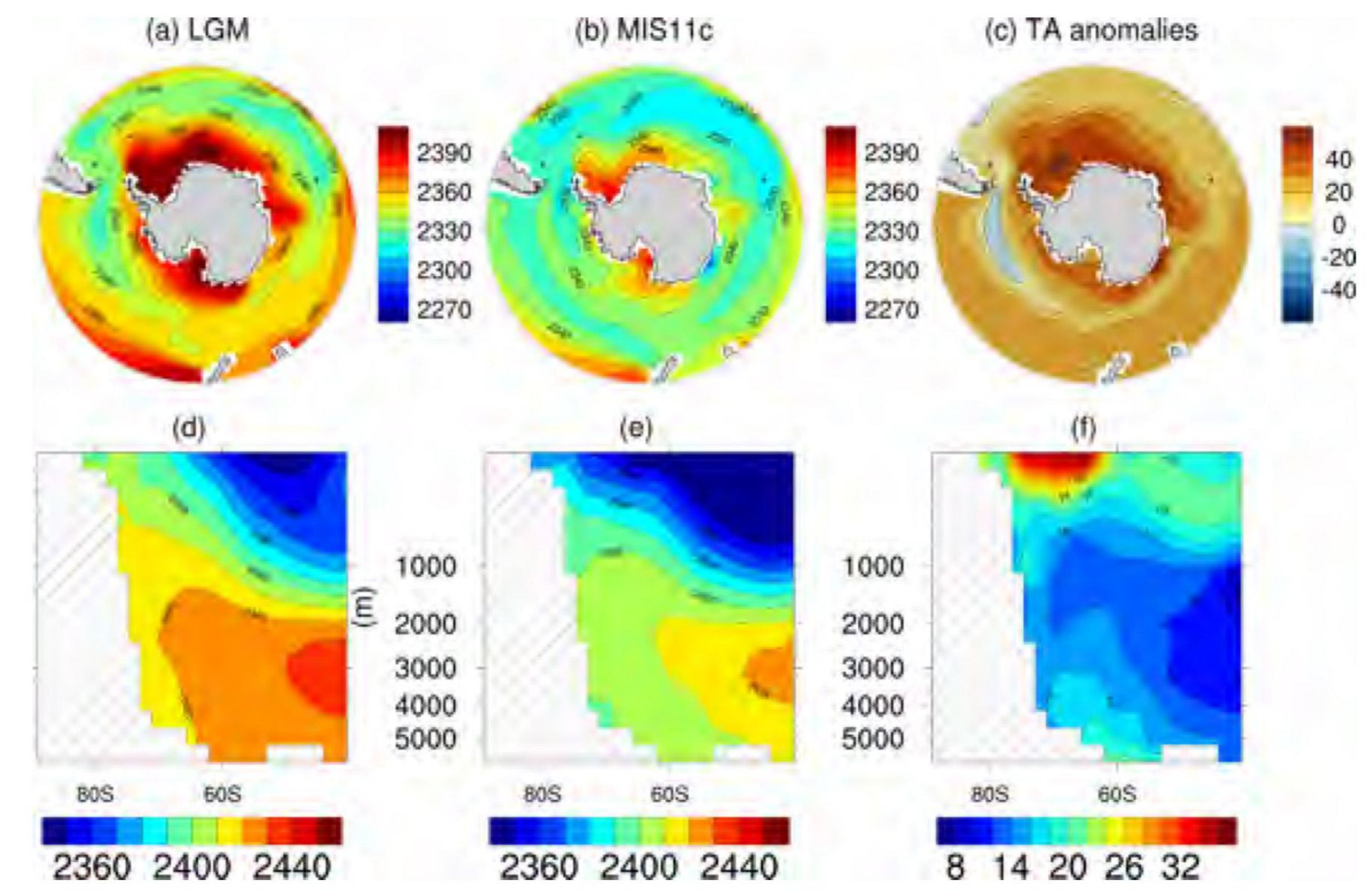
Introduction

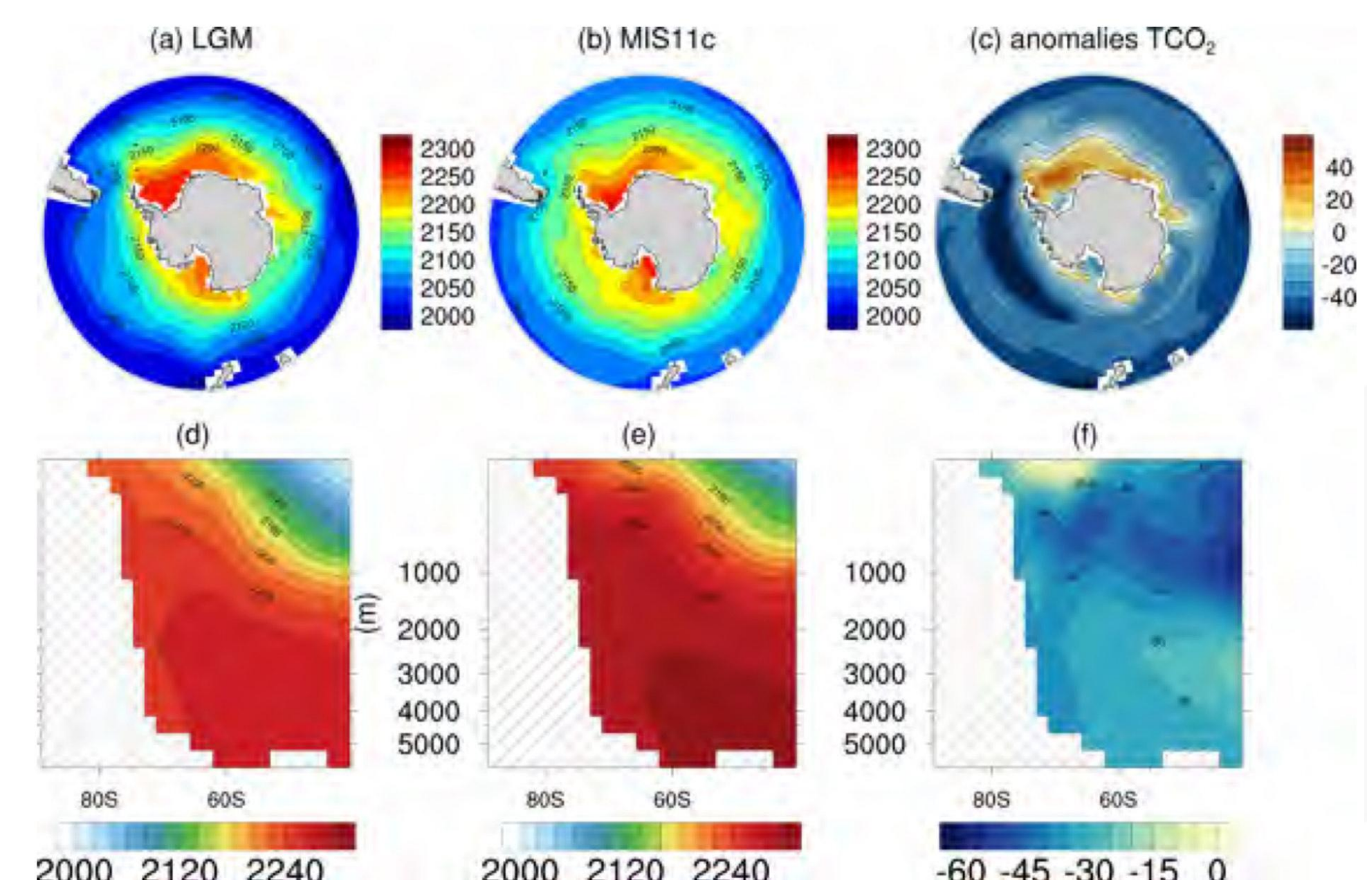
The Pleistocene epoch experienced cyclical shifts between glacial and interglacial periods, driven by variations in Earth's orbit and CO_2 levels. The ocean absorbs atmospheric CO_2, storing it as dissolved inorganic and organic carbon, and calcium carbonate. CO_2 solubility in seawater depends on atmospheric pressure, temperature, and salinity, with higher atmospheric CO_2 resulting in increased oceanic concentrations (Leonardo et al.,2023) . This study examines how CO_2 and orbital variations impacted Southern Ocean (SO) carbonate dynamics during the Last Glacial Maximum and the Marine Isotope Stage 11c interglacial with three sensitivity experiments with the UVic ESCM2.9.

Methodology

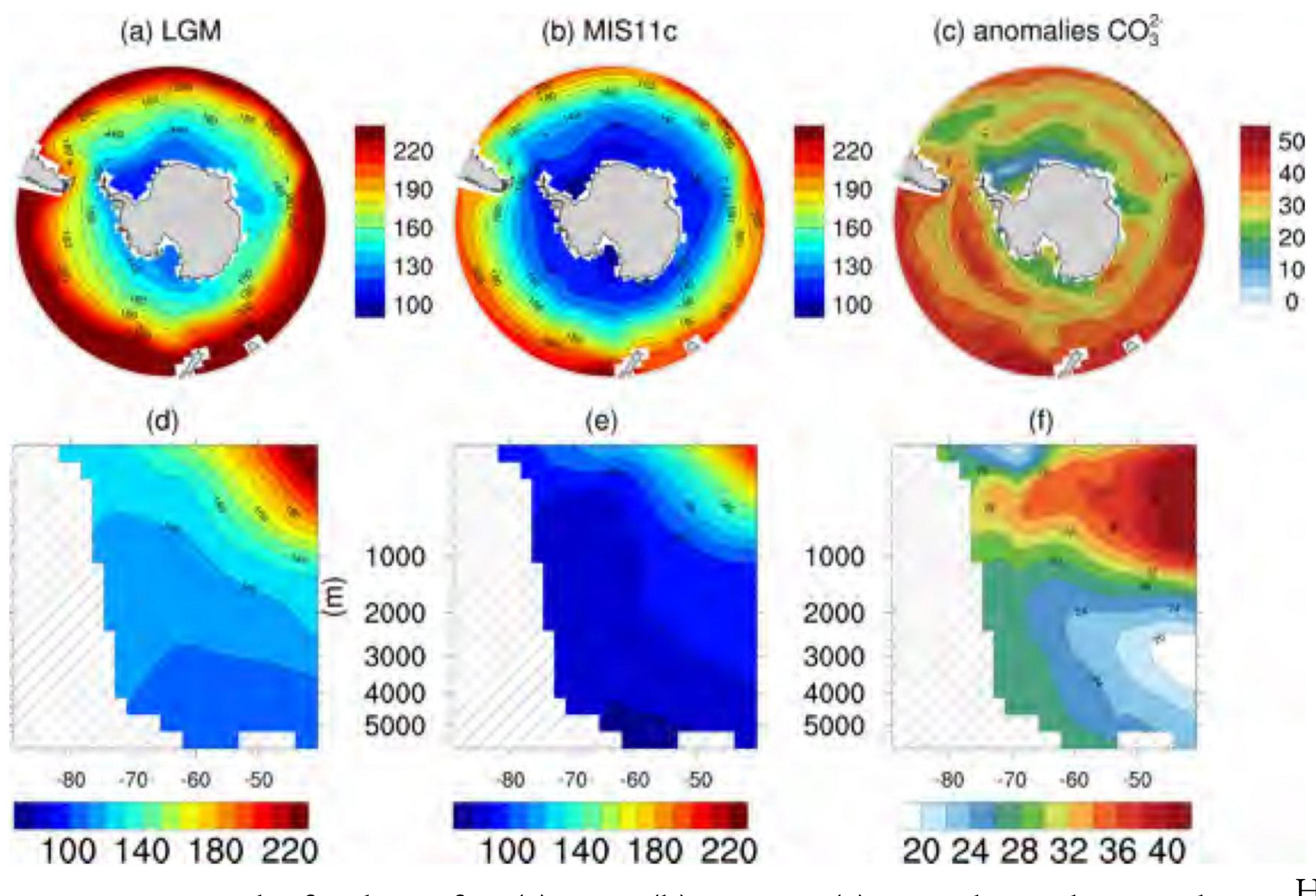
To investigate the southern carbonate dynamics, three sensitives simulations were conducted with the UVic ESCM2.9. The UVic ESCM is a intermediate complexity climate model that couples a 3D ocean circulation model, sea ice, biogeochemical and atmospheric models. It uses a 1.8° latitude by 3.6° longitude resolution. The present-day simulation (PD) was initialized applying the atmospheric CO_2 concentration of the 380ppm and current orbital forcing. The MIS11c (428-383 ky BP) climate used an atmospheric CO_2 value of 285 ppm, eccentricity 0.01932, obliquity 23.781° and precession 277.67°. The LGM (20 ky BP) climate was atmospheric CO_2 value of 180 ppm, eccentricity 0.018994, obliquity 22.949° and precession 114.42°, and the ICE6G ice sheet topography (Argus et al., 2014; Peltier et al., 2015). The UVic ESCM marine biogeochemical cycle includes the inorganic carbon model and the e CO2SYS were used to calculate the pH, ion carbonate (CO2 3−) and bicarbonate (HCO− 3) and solubility of calcite (Ω).



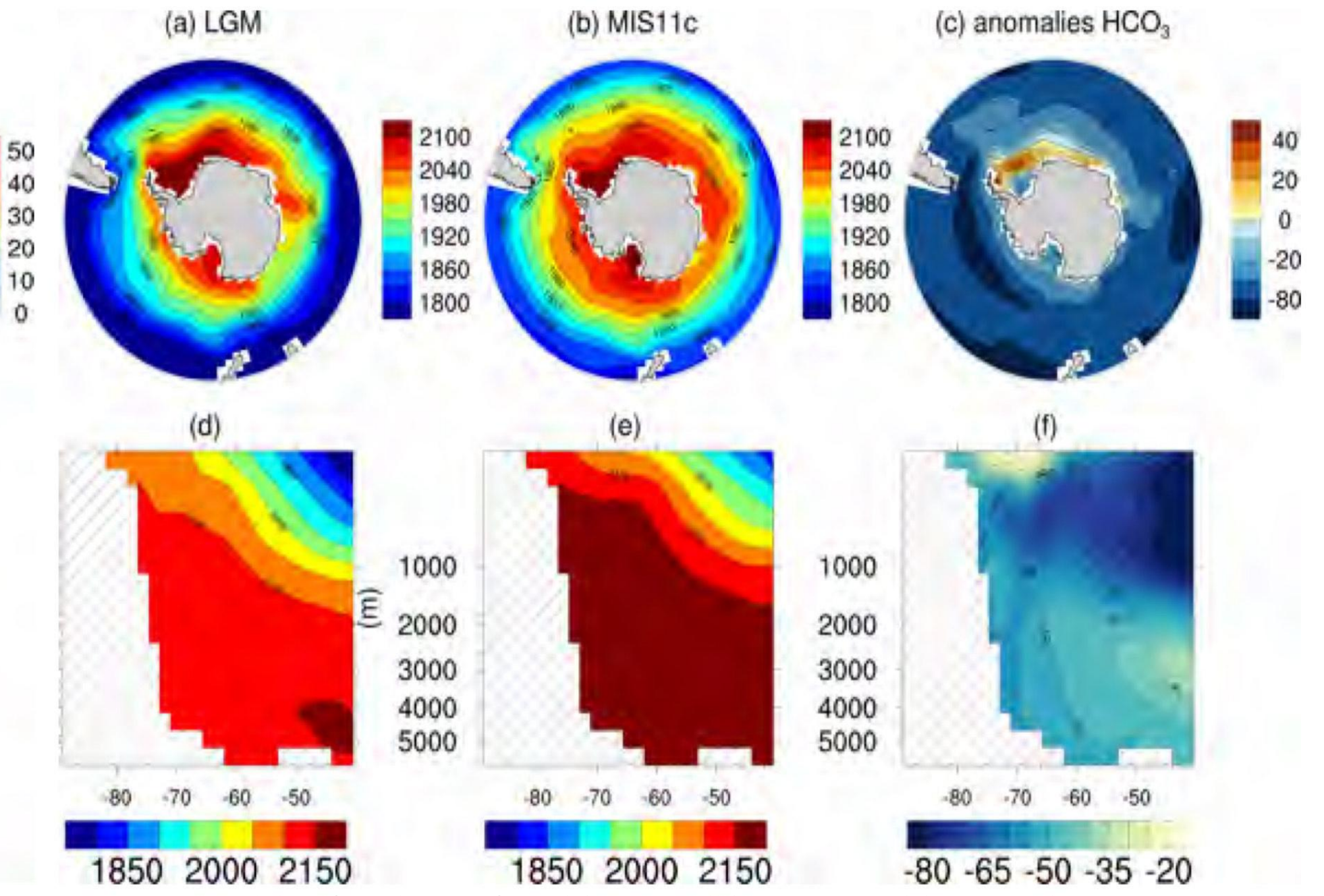
TA in µmol/kg for the surface (a) LGM,(b) MIS11c, (c) anomalies and averaged meridional crosscut for (d) LGM, (e) MIS11c and (f) anomalies.



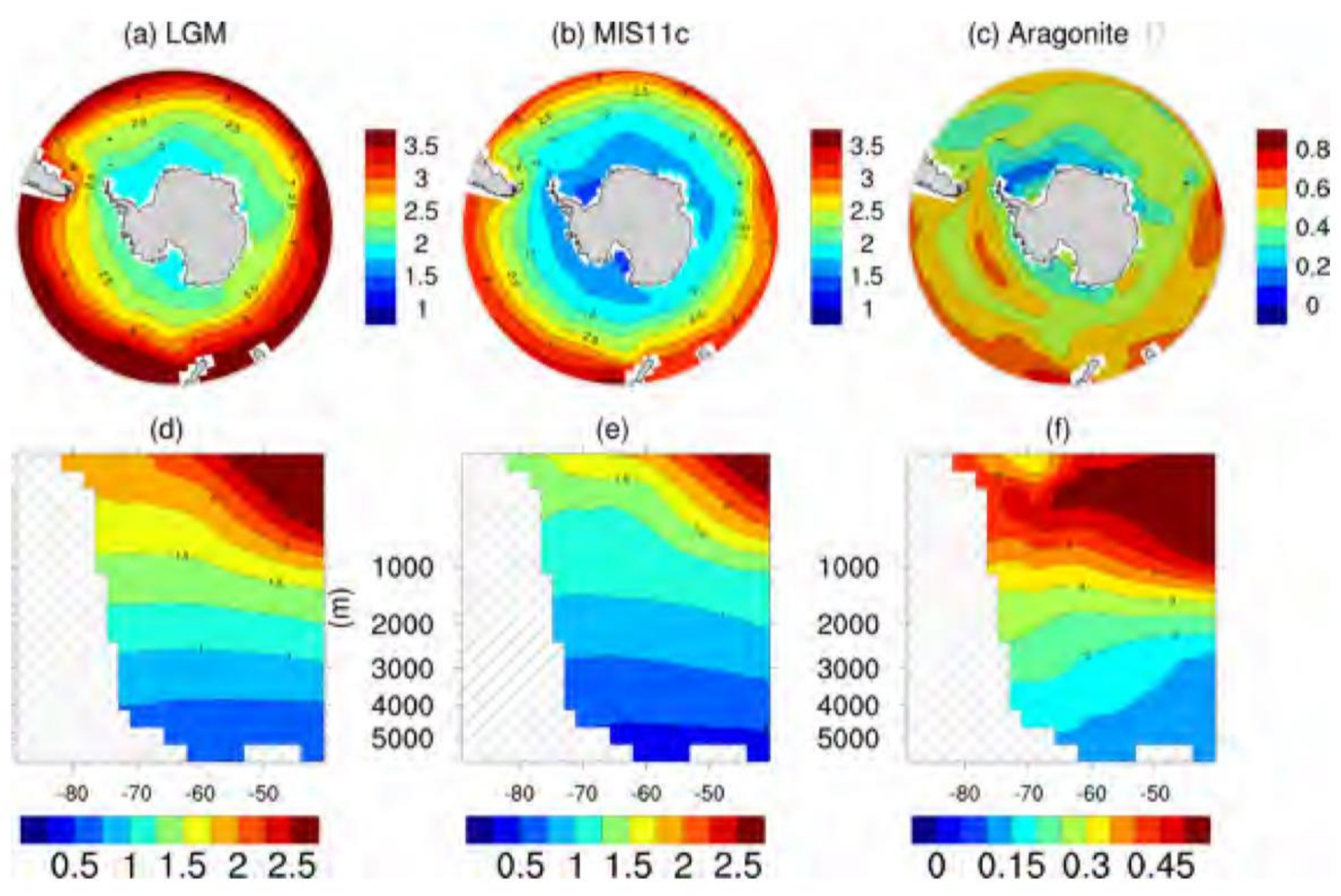
TCO2 in µmol/kg for the surface (a) LGM,(b) MIS11c, (c) anomalies and averaged meridional crosscut for (d) LGM, (e) MIS11c and (f) anomalies.



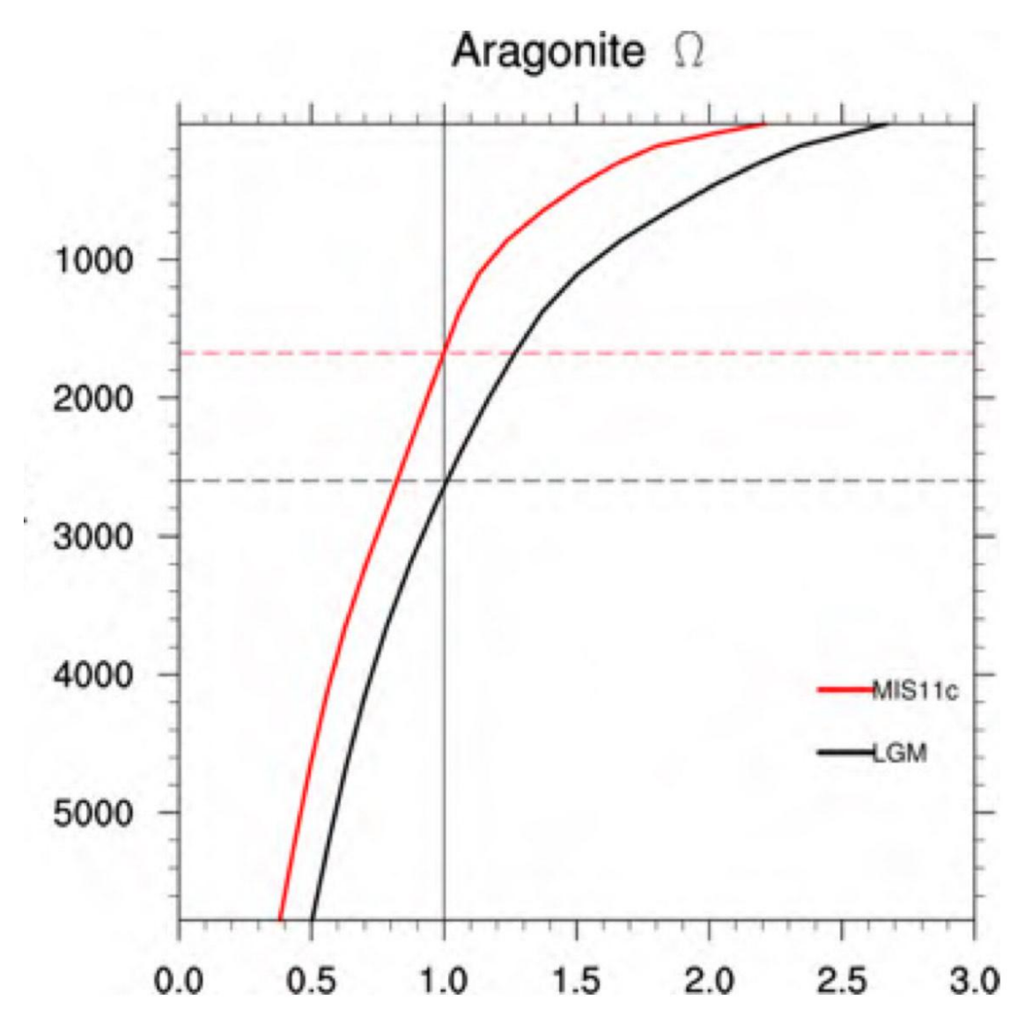
CO2− 3 in µmol/kg for the surface (a) LGM,(b) MIS11c, (c) anomalies and averaged meridional crosscut for (d) LGM, (e) MIS11c and (f) anomalies.



HCO3 in µmol/kg for the surface (a) LGM,(b) MIS11c, (c) anomalies and averaged meridional crosscut for (d) LGM, (e) MIS11c and (f) anomalies.



Ω CaCO3 in µmol/kg for the surface (a) LGM,(b) MIS11c, (c) anomalies and averaged meridional crosscut for (d) LGM, (e) MIS11c and (f) anomalies.



Depth profile of Ω aragonite on Southern Ocean. Black line for LGM simulations and red for MIS11c. Gray line for Ω = 1 are the Aragonite Saturation Horizon (ASH), dashed lines show the depth of ASH for each simulation.

Results

The distribution of total alkalinity (TA) concentrations in the SO for two climate simulations shows similar spatial patterns for surface ocean TA and total dissolved inorganic carbon (TCO_2), but the concentrations differ. During the LGM, TA concentrations are higher than in MIS11c, while TCO_2 concentrations are slightly lower throughout the region, except for the Weddell Sea, where positive anomalies up to 40 µmol/kg are found. In contrast, TCO_2 concentrations are lower in the LGM compared to MIS11c, except in the Weddell Sea. The surface average of SO TA is higher for LGM than MIS11c, and vice versa for TCO_2. Surface TCO_2 concentrations are primarily driven by temperature, whereas TA concentrations are mainly a reflection of salinity. The lower salinity around 55 °S, caused by sea ice melting, leads to decreased TA concentrations in MIS11c compared to the LGM. Notably, MIS11c values are consistently lower than LGM values throughout the water column. High temperatures, low TA, and reduced CO_2 uptake in MIS11c generally result in higher TCO_2 concentrations across the basin compared to the LGM. Conversely, in the LGM simulation, low temperatures raise TA concentrations, but TCO_2 decreases throughout the SO water column. This decoupling may be due to decreased biological productivity, reduced organic carbon transport to deeper waters, or lower surface CO_2 concentrations. The reduced CO_2 concentrations from interglacial (285 ppm) to glacial (185ppm) conditions force a surface ocean equilibrium, lowering TCO_2 concentrations. Differences in TA and TCO_2 concentrations, particularly in intermediate waters, are linked to organic matter remineralization.

The maximum TA concentration occurs deeper than TCO2 due to the stronger influence of the biological pump on organic carbon remineralization, while TA is more affected by CaCO3 dissolution.

In the LGM simulation, the decrease in CO_2 partial pressure (pCO_2), consistent with ice core data, necessitates a glacial increase of carbonate ion (CO32-) concentration, primarily in the ocean's surface. The lower atmospheric CO_2 in the LGM causes a shift from bicarbonate (HCO3-) to CO32-, while the opposite occurs in the MIS11c simulation with higher CO_2 levels. The increase (decrease) of the CO32- to TCO_2 ratio in the LGM (MIS11c) simulation affects the ocean's buffering capacity for CO_2 perturbations.

During MIS11c, the increase in pCO_2 leads to increased consumption of CO_2 and higher production of HCO3-, while consuming CO32- for the carbonate shells of marine plankton. This pCO_2 increase also lowers pH due to a higher abundance of H+ ions.

Conclusions

The Southern Ocean, sensitive to climate changes and experiences higher salinity, lower stratification, and colder temperatures during the Last Glacial Maximum compared to interglacial periods. This results in increased Antarctic Bottom Water formation and CO_2 storage. The deep ocean shows increased vertical gradients of dissolved inorganic carbon species due to AABW, impacting the carbonate buffer system and calcium carbonate saturation depth. CO_2 uptake depends on carbonate ion concentration, and increased uptake leads to ocean acidification. Glacial periods exhibit higher pH, carbonate ion, and total alkalinity, potentially promoting deep-sea CaCO3 preservation and raising the aragonite saturation depth.