Simulation the impact of shifts in Southern Ocean westerlies at LGM on ocean physics and atmospheric CO_2

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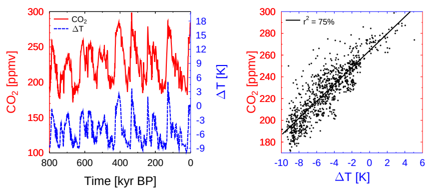
Abstract

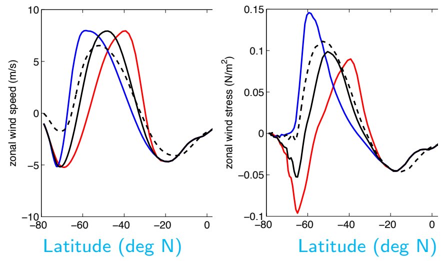
We explore the impact of a latitudinal shift in the westerly wind belt over the Southern Ocean (SO) on the Atlantic meridional overturning circulation (AMOC) and on the carbon cycle for Last Glacial Maximum background conditions using a state-of-the-art ocean general circulation model. For this "westerly wind hypothesis" (Toggweiler et al. 2006) we find that a southward shift in the westerly winds leads to an intensification of the AMOC (northward shift to a weakening). This agrees with other studies (Sijp & England 2009) starting from pre-industrial background, but the responsible processes are different. During deglaciation a gradual shift in westerly winds might thus be responsible for a part of the AMOC enhancement, which is indicated by various studies. The net effects of the changes in ocean circulation lead to a rise in atmospheric pCO_2 of less than 10 μatm for both a northward and a southward shift in the winds. For northward shifted winds the zone of upwelling of carbon and nutrient rich waters in the Southern Ocean is expanded, leading to more CO_2 out-gassing to the atmosphere but also to an enhanced biological pump in the subpolar region. For southward shifted winds the upwelling region contracts around Antarctica leading to less nutrient export northwards and thus a weakening of the biological pump. A shift in the southern hemisphere westerly wind belt is probably not the dominant process which tightly couples atmospheric CO_2 rise and Antarctic temperature during deglaciation which is suggested by the ice core data.

Motivation



Ice core data of CO_2 and Antarctic temperature.

Scenarios



Latitude (deg N) Latitude (deg N)

CTRL:broken, LGM:bold, shift10S:blue, shift10N:red.
We shift **wind**, not wind stress,.
because of fully-prognostic sea-ice model.

Key Points

(1) We used the full OGCM MITgcm, forced with LGM surface fields from an atmosphere-ocean coupled GCM run of COSMOS (Zhang et al. 2013).

(2) Southward shifted westerly winds at LGM increase the AMOC: decrease in temperature and salinity in intermediate waters (AAIW, SAMW) accompanied by increased northward Ekman transport ⇒ stronger SO upwelling. AMOC increase is driven by pulled upwelling in the South, not by pushed down-welling in the north.

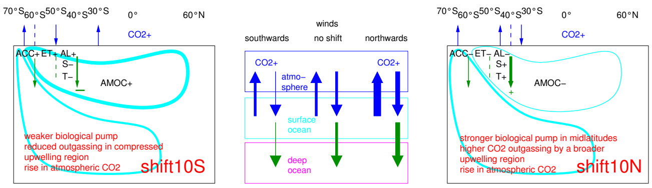
(3) Same AMOC change in (d'Orgeville et al. 2010) for pre-industrial background, but for different reasons: stronger Agulhas leakage ⇒ stronger influx of warm and salty water in South Atlantic, excess heat lost at northward transport, but excess salinity finally leads to stronger deep water formation in North Atlantic (more northern push than southern pull).

(4) Opposing effects on different carbon pumps:

(5) **Northward**: Extension of upwelling area in SO leads to larger CO_2 out-gassing. Enhanced nutrient upwelling & transport north ⇒ stronger biological pump in subpolar region, but less than what was released to the atmosphere further south ⇒ net gain of CO_2 in atmosphere.

(6) **Southward**: Contraction of upwelling area in SO reduces amount of upwelling nutrient that travel north, weakening biological pump in the subpolar region. Out-gassing of CO_2 is changed only slightly ⇒ atmospheric CO_2 rises.

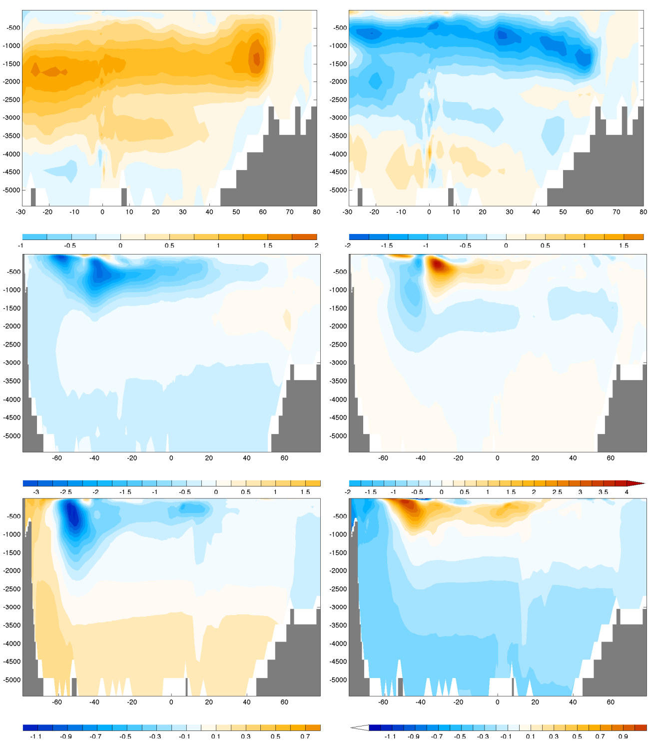
Summary



ACC: Antarctic Circumpolar Current, ET: Ekman transport, AL: Agulhas leakage.

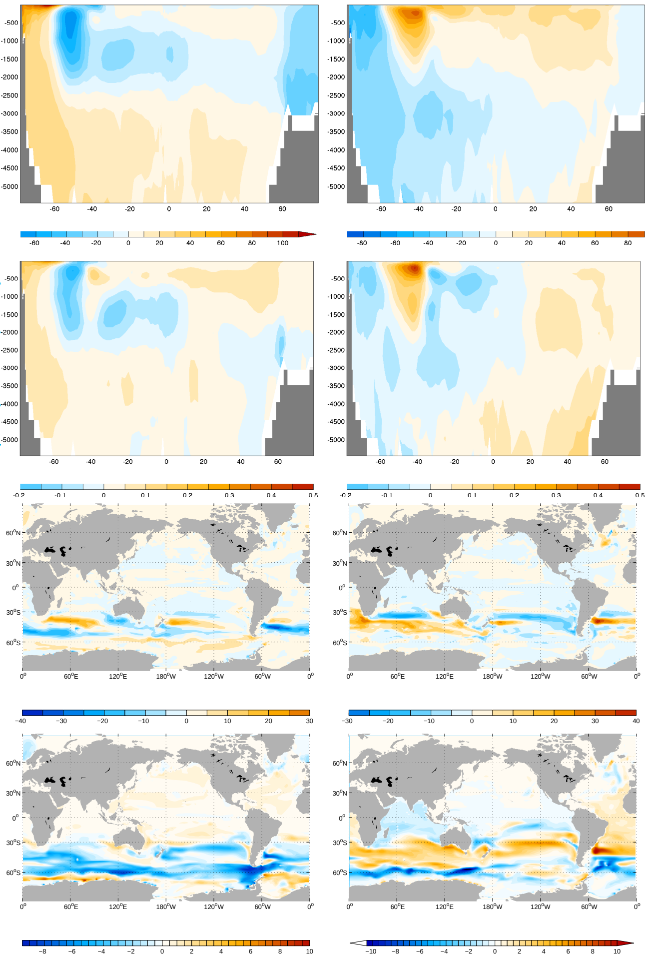
Physics

Southward (shift10S–LGM) Northward (shift10N–LGM)

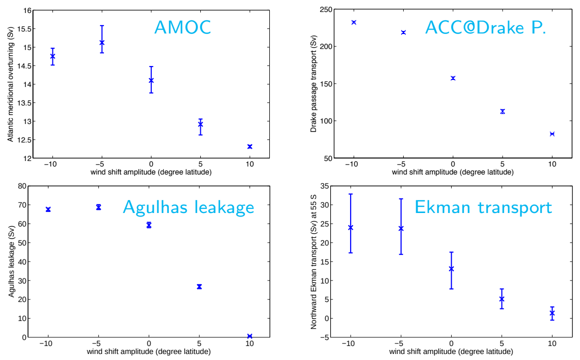


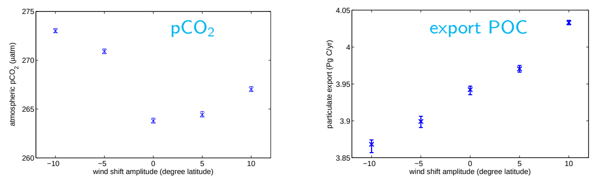
C Cycle

Southward (shift10S–LGM) Northward (shift10N–LGM)



Wind Shift Dependencies





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