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The role of mean ocean salinity in climate

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We describe numerical simulations designed to elucidate the role of mean ocean salinity in climate. Using a coupled atmosphere-ocean general circulation model, we study a 100-year sensitivity experiment in which the global-mean salinity is approximately doubled from its present observed value, by adding 35 psu everywhere in the ocean. The salinity increase produces a rapid global-mean sea-surface warming of 0.8 °C within a few years, caused by reduced vertical mixing associated with changes in cabbeling. The warming is followed by a gradual global-mean sea-surface cooling of 0.4 °C within a few decades, caused by an increase in the vertical (downward) component of the isopycnal diffusive heat flux. We find no evidence of impacts on the variability of the thermohaline circulation (THC) or El Niño/Southern Oscillation (ENSO). The mean strength of the Atlantic meridional overturning is reduced by 20% and the North Atlantic Deep Water penetrates less deeply. Nevertheless, our results dispute claims that higher salinities for the world ocean have profound consequences for the thermohaline circulation.

In additional experiments with doubled atmospheric carbon dioxide, we find that the amplitude and spatial pattern of the global warming signal are modified in the hypersaline ocean. In particular, the equilibrated global-mean sea-surface temperature increase caused by doubling carbon dioxide is reduced by 10%. We infer the existence of a non-linear interaction between the climate responses to modified carbon dioxide and modified salinity.

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1. Introduction

Salinity is the ocean signature of the global water cycle (Schmitt, 1995). Salinity affects ocean circulation, stability and variability (e.g. Fedorov et al., 2004; Huang et al., 2005) and hence plays a major role in climate. The basic physical mechanisms in which salinity participates derive from its influence on ocean density. At high latitudes, salinity modifies the vertical convective stability and is a major factor in the density-driven global thermohaline circulation (Manabe and Stouffer, 1995; Oka and Hasumi, 2004; Swingedouw et al., 2007). Brine rejection associated with sea-ice formation also modifies the density structure (Martinson, 1990; Gordon, 1991; Martinson and Iannuzzi, 1998; Marsland and Wolff, 2001). At low latitudes, the effects of salinity are more subtle, but significant impacts may arise through its roles in the control of density surfaces and the formation of barrier layers (Vialard and Delecluse, 1998a,b; Maes et al., 2002, 2005). Salinity depends on the surface fresh water flux, which is predicted to intensify in response to increased greenhouse-gas forcing (Cubasch et al., 2001; Yang et al., 2003; Bosilovich et al., 2005; Held and Soden, 2006). Therefore, processes involving salinity may be influential in determining the future climate.

Observations have revealed large-scale salinity changes in each of the major ocean basins during recent decades. Large amounts of fresh water have been added to the northern North Atlantic Ocean since the mid-1960s (Curry and Mauritzen, 2005). A freshening of the eastern half of the North Atlantic subpolar gyre has been observed during the same period (Josey and Marsh, 2005). Curry et al. (2003) have reported a systematic freshening between the 1950s and the 1990s at both poleward ends of a 50°S–60°N transect through the western Atlantic Ocean, accompanied by a systematic salinification at low latitudes. The observed salinity increase in recent decades in the 20°N–50°N latitude band of the Atlantic ocean is attributable to human influence (Stott et al., 2008). Wong et al. (1999) have reported a large-scale freshening of intermediate waters in the Pacific and Indian Oceans between the period 1930–1980 and the period 1985–1994. Bindoff and McDougall (2000) have reported a basin-wide freshening of the Indian Ocean below the mixed layer in 1987 compared to the 1950s and 1960s. Lukas (2001) has reported a freshening of the upper thermocline in the North Pacific subtropical gyre between 1991 and 1997. Whether due to natural variability or an anthropogenic trend, the impact of these basin-scale salinity changes on ocean circulation, stability and variability remains poorly understood.

The change in globally-averaged salinity during recent decades has been small and is probably not measurable, although Antonov et al. (2002) attempt to quantify it. The change has been caused by the addition to the ocean of a few centimetres of fresh water from melting land ice and sea ice. On geological timescales, however, the mean salinity of the world ocean has varied widely. Some variations have been caused by changes in the total water content of the ocean, such as occurred during the large-scale extraction of water to form the Antarctic ice sheet. Other variations have been caused by changes in the total salt content. Salt from rocks is conveyed to the ocean by rivers, ground water and glaciers, and it is extracted from the ocean by the formation of evaporite salt deposits, of which there are many in the geological record. The input and extraction processes are not in instantaneous balance, however, and so the total global salt content may vary. Hay et al. (2006) have used data on the volumes and masses of evaporite deposits to construct a proxy record of the mean salinity of the ocean. They conclude that there have been significant changes in the mean salinity throughout the Phanerozoic eon (i.e. the most recent 545 million years). In particular, there were relatively few large extractions of salt during the early Palaeozoic era (i.e. the earliest era of the Phanerozoic eon), suggesting slowly increasing global-mean ocean salinities exceeding 50 psu.

Waters of salinity greater than 40 psu are referred to as hypersaline or hyperhaline. It has been suggested that such high salinities may have profound consequences for the thermohaline circulation of the past. For example, Hay et al. (2006) argue that at present observed salinities, the density of sea water is only slightly affected by cooling as the freezing point is approached, and so salinization (through sea-ice formation or evaporation) is generally required in order for deep convection to occur. At salinities above about 40 psu, however, water continues to become more dense as the freezing point is approached, and so salinization is no longer needed for deep convection. Therefore, the phase changes involved in sea-ice formation and evaporation, which consume energy and thereby reduce the deep water formation rate, are also no longer needed. Much less energy would be required to drive