An update of anthropogenic CO_2 storage rates in the western South Atlantic basin and the role of Antarctic Bottom Water

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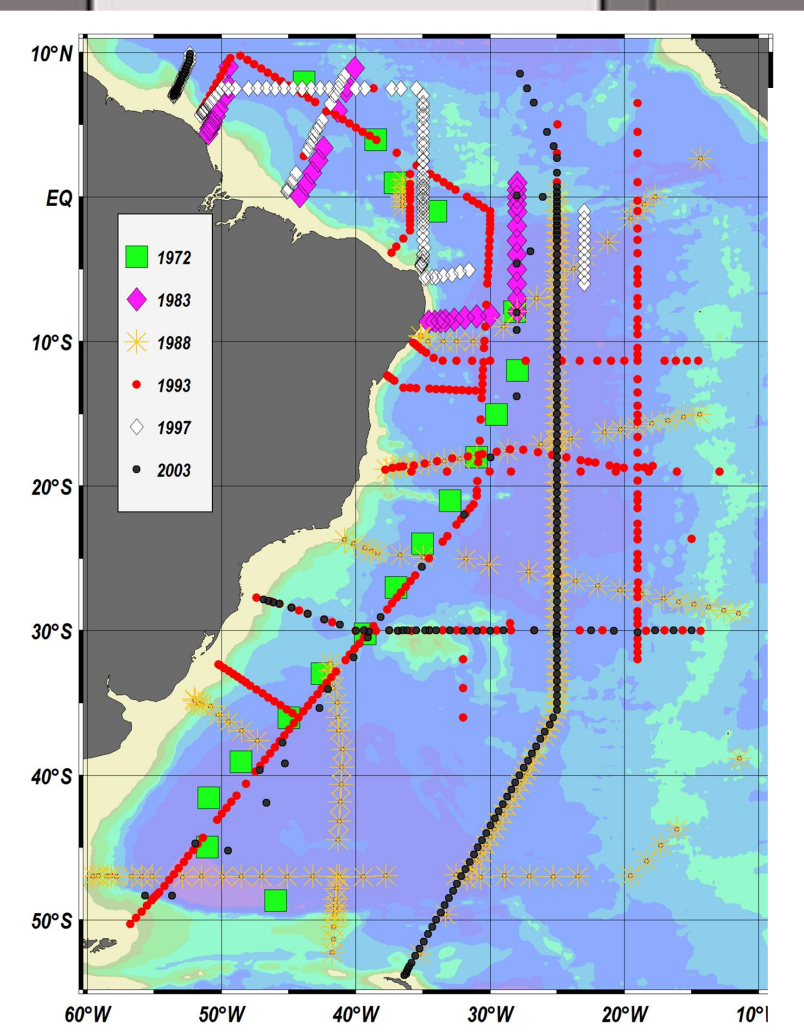
Abstract: The western South Atlantic (WSA) basin is a region with large uncertainties as to the storage of anthropogenic CO_2 (Cant). Our analysis of data of the last three decades provides a Cant storage rate of 0.92 ±0.13 mol m^{-2} y^{-1}, i.e., 13/%-35/% higher than previous estimates in this area. The low but significant Cant concentrations in the large volume of relatively well ventilated Antarctic Bottom Water (AABW) may well be the underlying cause of this higher storage rate. In fact, the significant contribution in terms of Cant of this ventilated AABW that enters the WSA was calculated to be 0.055 ± 0.02 Pg C y^{-1} or 0.20 mol m^{-2} y^{-1}. Instead of being based on the annual trend, the Cant specific inventory evolution is more consistently computed as a function of the atmospheric xCO2 perturbation (0.64 mol m^{-2} ppm^{-1}). This methodology allows improved projections of Cant storage rates over long periods.

Data and Methods: A total of twenty cruises belonging to the GLODAP and CARINA databases (Hoppema et al., 2009; Key et al., 2010; Tanhua et al., 2008, 2010a, 2010b) with high-quality carbon system measurements were selected to study the temporal evolution of the Cant storage in the western South Atlantic basin. Data from 100 m depth to the bottom were considered in order to avoid the high variability of near-surface measurements. The combined dataset covers 33-years (1972-2005). The cruises were grouped in 6 nominal or reference years to improve the spatial coverage by year.

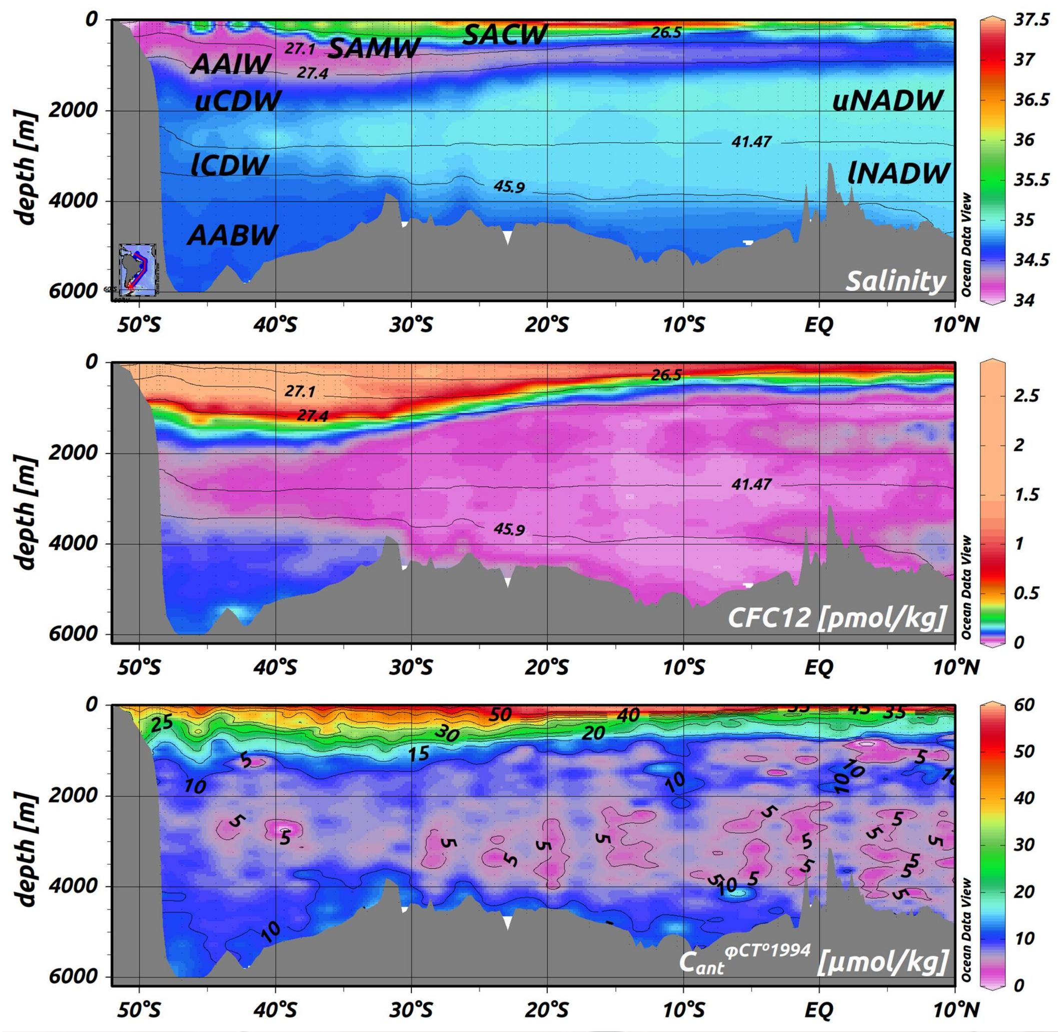
The main water masses found in the western South Atlantic basin were identified by Mémery et al. (2000) and Ríos et al. (2010) on the basis of their hydrographic properties, ventilation and tracers (CFCs). Shown are the salinity and CFC distributions including the isopycnal surfaces which separate the main water masses found in the region. In order to evaluate the variation of [Cant] increase rates and Cant storage rates, the water column was divided into six layers by potential density (σ_0) intervals following Mémery et al. (2000) and according to the spreading of the different water masses.

Estimates of [Cant] were obtained for the western South Atlantic basin applying the φC_T^0 method (Vázquez-Rodríguez et al., 2009a, 2009b) with an uncertainty of ±5.2 µmol kg^{-1}. The highest [Cant] is found in shallow waters (σ_0 < 27.4) since Cant is introduced into the interior ocean by the ventilation of the water masses. Down to intermediate layers of the water column, [Cant] reduces progressively and so does the level of ventilation. However, in deep and bottom waters, significant values of [Cant] occur with a maximum at the bottom accompanied by only a slight increase in the level of ventilation compared to that of intermediate layers. The Cant specific inventory, in mol m^{-2}, was also calculated for the region of study following the methodology of Pérez et al. (2010).



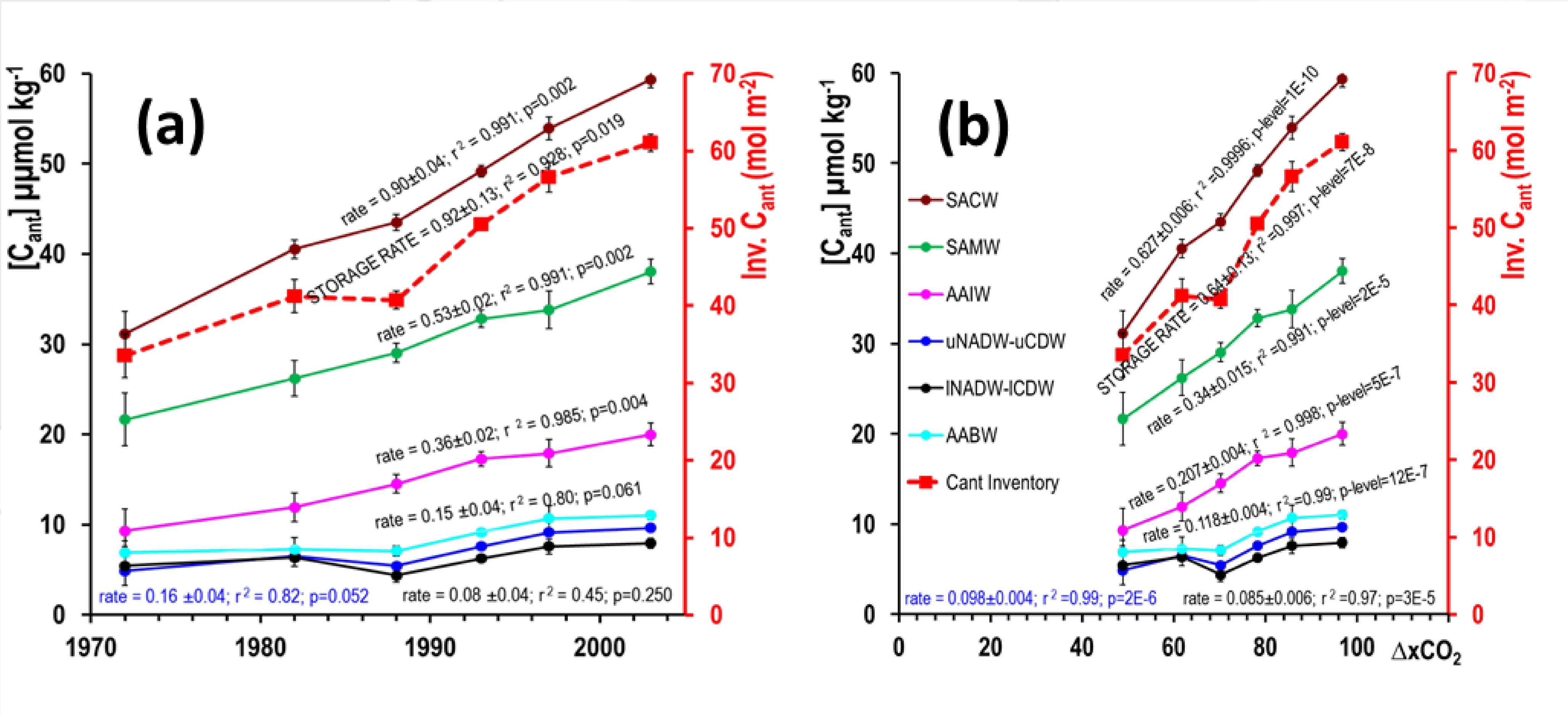
Western South Atlantic cruises used in this study

Reference year	Cruise year	Cruise code	Carina expo code/ GLODAP CODE	WOCEsection or original name
1972	1972	43	GEOSECS_1-	GEOSECS
1983	1982-3	46	6 TTOTAS_1-3	TTO-TAS
1988	1987-8	48	318MSAVE_1-5 318MHYDROS	SAVE
1993	1991	13	06MT15_3	A09
1993	1991	22	OACES91_1-2	A16S
1993	1993	14	06MT22_5	A10
1993	1993	23	OACES93	A16N
1993	1994	12	**06MT19941012**	
1993	1994	21	316N142_	A15
1993	1994	24	24 3230CITHER2_1-2	A17
1993	1995	95	**35LU19950909**	
1997	1996	84	**33LK19960415**	
1997	1997	25	316N151_3	A20
1997	1999	106	**35TH19990712**	
2003	2001	61	**29HE20010305**	FICARAM
2003	2002	62	**29HE20020304**	FICARAM
2003	2003	68	**316N20030922**	
2003	2003	86	**33RO20030604**	
2003	2003	113	**49NZ20031106**	Beagle
2003	2005	87	**33RO20050111**	



Potential density intervals (σ) for the six layers where the main water masses of the region spread.

Layers	Potential density intervals (kg m^{-3})
SACW	100 m to σ_0 < 26.5
SAMW	26.5 < σ_0 < 27.1
AAIW	27.1 < σ_0 < 27.4
uNADW-uCDW	σ_θ > 27.4 and σ_3 < 41.47
lNADW-lCDW	σ_3 > 41.47 and σ_4 < 45.90
AABW	σ_4 > 45.90



Storage Rates of Anthropogenic CO_2

[Cant] averages (µmol kg^{-1}) and Cant specific inventories (mol C m^{-2}) versus year (a) and versus the excess of atmospheric xCO_2 (ΔxCO_2) (b). The solid lines between [Cant] averages (dots) and the dashed line between specific inventories (squares) indicate the temporal evolution of both variables in each layer (legend in plot b). The [Cant] increase rates (µmol kg^{-1} y^{-1}) and the Cant storage rates (mol m^{-2} y^{-1}) are shown above the lines.

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Conclusions: The Cant storage rate observed for the western South Atlantic is higher than previous estimates. A closer inspection of these differences suggests the low but significant [Cant] in the high volume of AABW that enters the South Atlantic as the reason of the higher Cant storage rate. The Cant storage rate associated to the AABW that enters the western South Atlantic Ocean was calculated to be 0.055 ±0.02 Pg C y^{-1} (0.20 mol m^{-2} y^{-1}) which represents a 22% of the Cant storage rate observed here. The deviations in the Cant storage rate estimates observed between previously used methods (isopycnal surfaces, MLR and eMLR) and the backcalculation φC_T^0 method are due to the penetration of deep and bottom waters with low [Cant] from the Southern Ocean and the North Atlantic. This low [Cant] are almost undetectable, mainly by MLR methods, when using data from cruises carried out less than two decades apart.

Comparison of Cant storages (mol m^{-2} y^{-1}) for the western South Atlantic basin (10° N to 55° S)

Author	Method	Storage rates (mol m^{-2} y^{-1})
Murata et al., 2008	Isopycnal	0.80
Peng and Wanninkhof (2010)	MLR (eMLR)	0.74 ± 0.3 (0.35)
Wanninkhof et al. (2010)	eMLRdens	0.60
Rios et al. (JMS, 2011)	Backcalculation (φC_T^0).	0.92 ± 0.13

Furthermore, because the exponential atmospheric CO_2 increase can affect the linear long-term trend estimation, a more reliable Cant storage rate was computed as a function of the excess of atmospheric xCO_2 increase (0.64±0.13 mol m^{-2} ppm^{-1}). This storage rate is also very useful in terms of future projections of Cant inventories according to the different scenarios of atmospheric xCO_2 due to the linearity between both terms. The analysis done here for the western South Atlantic Ocean highlights the need to continue with programs of repeated sections with high accuracy carbon measurements (e.g., Van Heuven et al., 2011). This kind of studies allows better detection of the variations of Cant in the thick deep and bottom waters, which are of high relevance for obtaining more reliable Cant storage rates.