OBSERVED SUBSURFACE SIGNATURE OF SOUTHERN OCEAN SEA LEVEL RISE

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1/Background on global seal level rise

Recent studies:
(based on satellite altimetry data)

STRONG INCREASE IN SEA LEVEL
Where -> in the Southern Ocean
When -> over the period 1993-2003

Previously: Steric expansion in the upper 700 m
(calculated from global in situ data)

Only explains 50-60% of the observed global sea level rise

Question:
Could subsurface warming or freshening contribute to the difference?

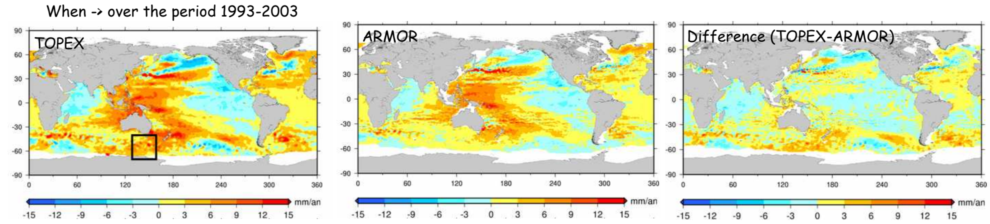


Figure 1. *Global distribution of sea level rise (in mm/yr) from (left panel) Topex-Poseidon altimetric observations over 1993-2003 (middle panel) sea level rise over the upper 700 m calculated from the ARMOR in-situ data projection of Guinehut et al (2004) (right panel) difference map Topex – ARMOR (after Lombard et al., 2006). The study region is outlined in black.*

2/Data

-> 13 years of repeat hydrographic data (WOCE-SR3)
+
SURVOSTRAL XBT and SSS data (Figure 2)

-> Satellite data and surface meteorological forcing

-> AVISO 1/3° gridded altimetry, Reynolds SST, ERS & QUICKSCAT winds, NCEP heat flux, ECMWF evaporation and Xie & Arkin precipitation data.

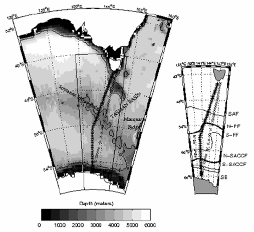


Figure 2. *Position of the WOCE SR3 CTD transects (+) and SURVOSTRAL XBT and TSG transects (x) between Tasmania and Antarctica. The zoom on the right shows the location of the main fronts from Sokolov and Rintoul (2002).*

3/Surface Salinity in the Antarctic Zone

In the Antarctic Zone (AZ), S of the Polar Front (PF)

SSS ↘ by ~0.1 psu over the period
&
E-P ↘ from 1992 to 2002

Drop in salinity explained by: P ↗ by ~20 mm/month

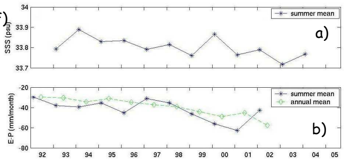


Figure 3. *a) summer mean TSG sea surface salinity data along the SURVOSTRAL line, averaged over the AZ; b) surface E-P : evaporation from ECMWF and precipitation from Xie and Arkin monthly climatology.*

4/Mean Temperature Changes between 2000-2004 and 1992-1996

In the SAZ: - STF (position of the 11°C isotherm at 150 m) shifted from 46°S to 47°S

Large warming over the upper 500m in the northern part

- SAF shifted from 50.5°S to 51.5°S

Warming for depths > 500m

So part of the observed warming and sea level rise in the SAZ may be due to a southward shift in these fronts.

In the AZ: Net warming and freshening in the surface mixed layer

Tongue of Winter Water is shallower and thinner at the end of the period – explains the alternate cooling and warming layers in the difference plot

Deeper warming underneath the WW layer

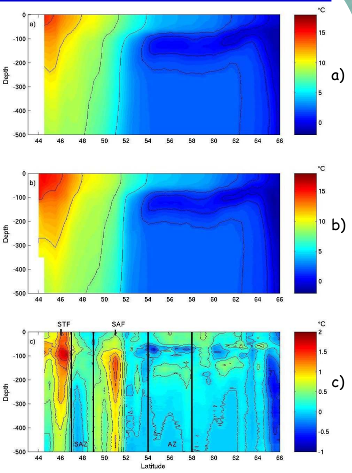


Figure 4. *Mean XBT temperature structure over 0-500 m depth averaged over the summertime SURVOSTRAL sections for the period a) 1992-1996, b) 2000-2004 and c) the temperature difference between these two mean summer periods.*

Cooling of the layers from 80-120 m on the top of the tongue
&
Warming of the layers from 150-250 m at the base of the tongue

5/ Subsurface T and S Changes between 2000-2004 and 1992-1996

Temperature and salinity changes over the **upper 2000 m** are calculated from WOCE SR3 CTD sections for the same period.

The surface mixed layer changes should be ignored since the later section (Nov 2001) is from a different season.

Below the surface mixed layer, the difference plot shows :

In the SAZ: - the southward shift of the STF is both warmer and saltier in the upper 500 m

Also brings warmer and saltier water into the deeper layer 700 – 1500 m, replacing SAMW/AAIW

In the AZ: Again a thinner low salinity WW layer

Below 500 m, deep water is both warmer and saltier to 2000 m.

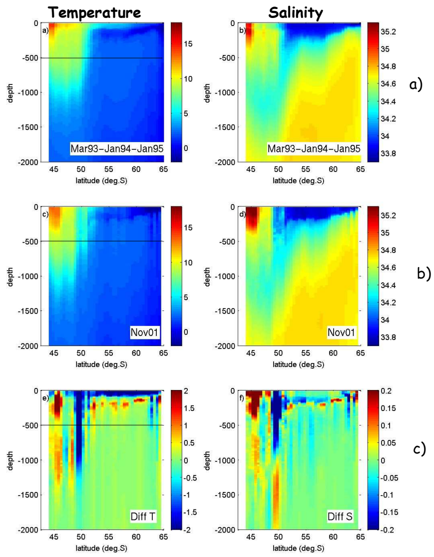


Figure 5. *Mean CTD temperature and salinity over 0-2000 m depth averaged over the summertime SR3 sections a) Mean of Mar 93, Jan 94 and Jan 95 sections, b) Nov 2001 section, and c) the difference between these two periods.*

6/Deeper Warming impacts on Steric Height and Sea level

Net increase in the 0/2000 dB steric height in the AZ between 54-63°S by 1-4 cm

The southward movement of the STF also increases 0/2000 dB steric height by ~4-5cm

The deep warming ↗ the steric height rise over 0/2000 dB by a factor of 2-3, compared to the steric height calculated from 0/500 dB.

Steric height calculated over 0/700 dB underestimate the real steric sea level rise by at least a factor of 2-3 in this part of the Southern Ocean.

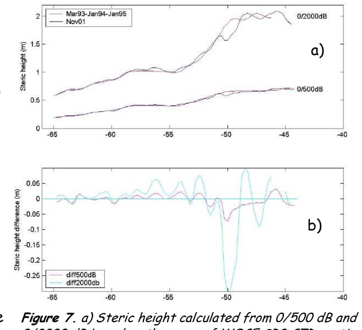


Figure 7. *a) Steric height calculated from 0/500 dB and 0/2000 dB based on the mean of WOCE SR3 CTD sections in March 1993, January 1994, and January 1995, and compared to the November 2001 section. b) Steric height difference (Nov 2001 – mean 93-94-95) from 0/500 dB and 0/2000 dB.*

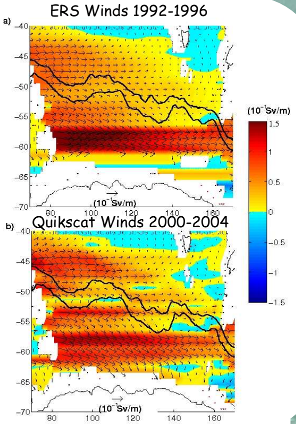
7/ Changes in wind forcing ➡ impact on the gyre-scale deep circulation

A simple wind-forced Sverdrup model is used to calculate the changes in the large-scale depth-integrated circulation over the period.

In 1992-1996, strong eastward circulation exists at 60°S during a positive SAM period (southward shift of the mean winds), transporting cool, low salinity water from near Kergeulen Plateau 80°E.

In 2000-2004, SAM has weakened (negative index) eastward circulation weakens near 60°S

Result : weakened depth-integrated transport of cool, low salinity water in 2000-2004 means the deeper waters appear warmer and saltier in the AZ along the SURVOSTRAL /SR3 line.



8/Conclusion

We have examined the causes of the observed sea level rise in the region south of Australia, using a combination of satellite and in-situ data.

-> The hydrographic data show a poleward shift in the position of the Subtropical and the Subantarctic Fronts over the period.

-> In the Antarctic Zone, the Antarctic Surface Water has become warmer and fresher, and the Winter Water tongue has become warmer, fresher, thinner and shallower. Increased freshening south of the Polar Front is linked to increased precipitation over the 1990s.

-> Temperature changes over the upper 500 m account for only part of the altimetric sea level rise. The CTD sections show that the deeper layers are also warmer and slightly saltier and the **observed sea level can be explained by steric expansion over the upper 2000 m.**

Reference: R. Morrow, G. Valladeau, J.-B. Sallee, 2006. Observed subsurface signature of Southern Ocean sea level rise. Prog Oceanogr. (submitted).
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