The Seasonal Cycle of CO_2 fluxes in the Southern Ocean as a rigorous mode to test model sensitivity

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Introduction

The exchange of gases between the atmosphere and the ocean is an important part of the global carbon cycle and it forms a critical determinant for the future evolution of Earth Systems (Gruber et at., 2009).

The spatial and temporal characteristics of air-sea flux of CO_2 in particular are a major factor in the changing ocean uptake of anthropogenic CO_2 and the future evolution of atmosphere CO_2 and global warming (Mikaloff Fletcher et al.,2007).

The Southern Ocean (SO) is an important conduit for the exchange of gasses between the atmosphere and ocean interior through the formation of deep and bottom waters, upwelling of Circumpolar Deep Water and biologically mediated carbon fluxes.

The calculated mean annual uptake of CO_2 by the Southern Ocean still has a wide range from 0.4 $PgCy^{-1}$ from models to 1 $PgCy^{-1}$ (Lenton et al., 2013: L13) from data- based products (Takahashi et al., 2012)

This study is builds on L13, L13 studied the seasonal cycle of sea-air CO_2 fluxes in the Southern Ocean from 1990-2009 using five Biogeochemical models (Inter alia NEMO PISCES using ORCA2($2^o \times 2^o \cos \Theta$) , ocean inversion models, atmospheric inversion models and observation data.(Fig 1 &3)

L13 defined SO as south 44^{o}S, this definition however cut a major part of the SO CO_2 sink zone (Sub-Antarctic Zone (SAZ)) hence this approach can result in an under/overestimation of the CO_2 uptake and a distorted seasonal cycle of air-sea CO_2 fluxes (Séférian et al., 2012)

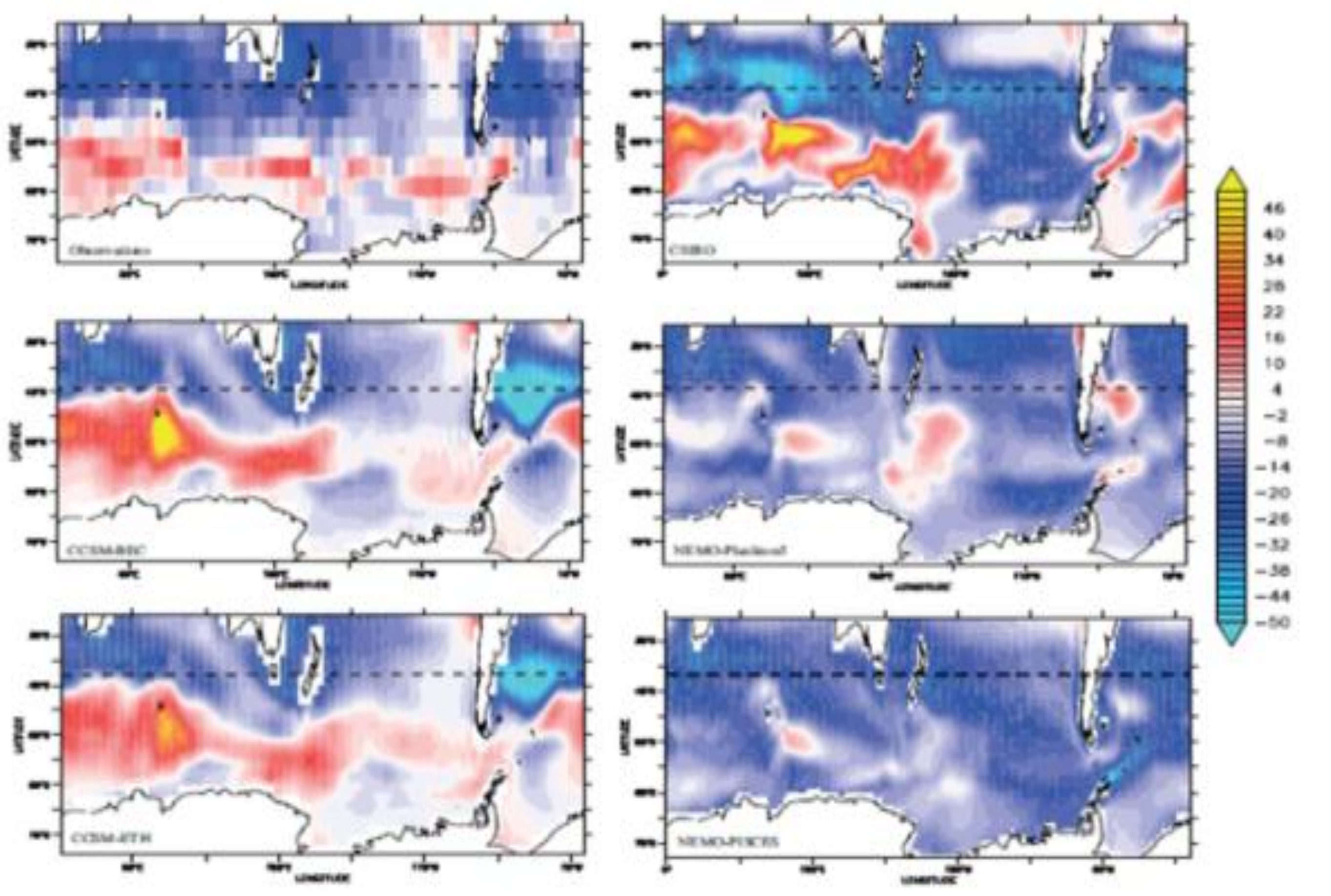

Figure 1. Spatial maps of the annual mean sea-air CO_2 flux, in $gCm^{-2}yr^{-1}$, from the five ocean. biogeochemical models and observations; negative values reflect fluxes into the ocean. The dashed line represents the RECCAP boundary at 44^{o}S.(taken from L13)

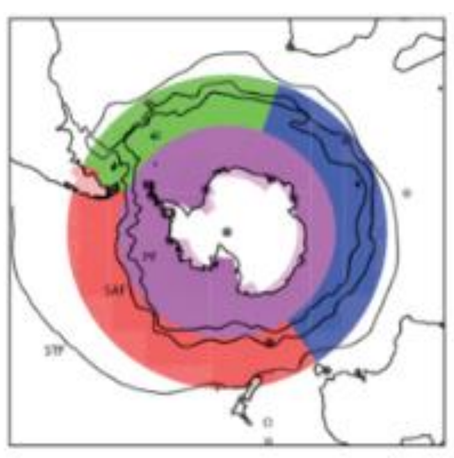

Figure 2. Sub-regions of the Southern Ocean used in Lenton et al 2013, 44^{o}S – 58^{o}S (green, red and blue are the major basins of the SO i.e. Atlantic, Indian and Pacific basin), circumpolar region from 58^{o}S – 75^{o}S (purple). Overlain are mean frontal positions from the north; Subtropical front (STF), sub-Antarctic front (SAF) and the Polar front (PF).

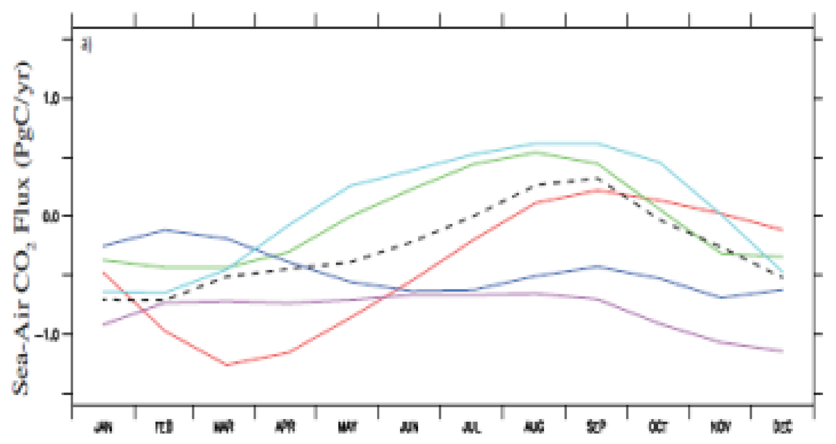

Figure 3. The seasonal cycle of sea-air CO_2 fluxes for the Southern Ocean (44^{o}S–75^{o}S) from BGM models in $PgCyr^{-1}$, observations are overlain by the dashed black line. Negative values reflect flux into the ocean (taken from L13)

Objectives

- Investigate the sensitivity of air-sea CO_2 flux seasonal cycle to model resolution.
  Compare the ORCA2-LIM-PISCES ($2^o \times 2^o \cos \Theta$) and PERIANT05 (NEMO-PISCES) ($0.5^o \times 0.5^o \cos \Theta$)model configurations with relative to decadal mean observations for the year 2000 (Takahashi et al., 2009).
- Assess the sensitivity of air-sea CO_2 flux seasonal cycle to zonal boundary definition.
  Compare air-sea CO_2 flux seasonal cycle and annual fluxes at the Lenton 2013 RECCAP boundaries (44^{o}S –58^{o}S and south of 58^{o}S), geographic boundaries (40^{o}S – 50^{o}S and south of 58^{o}S) and dynamic boundaries (SAZ and Antarctic zone (AZ) defined by climatological mean frontal positions)

References

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Results

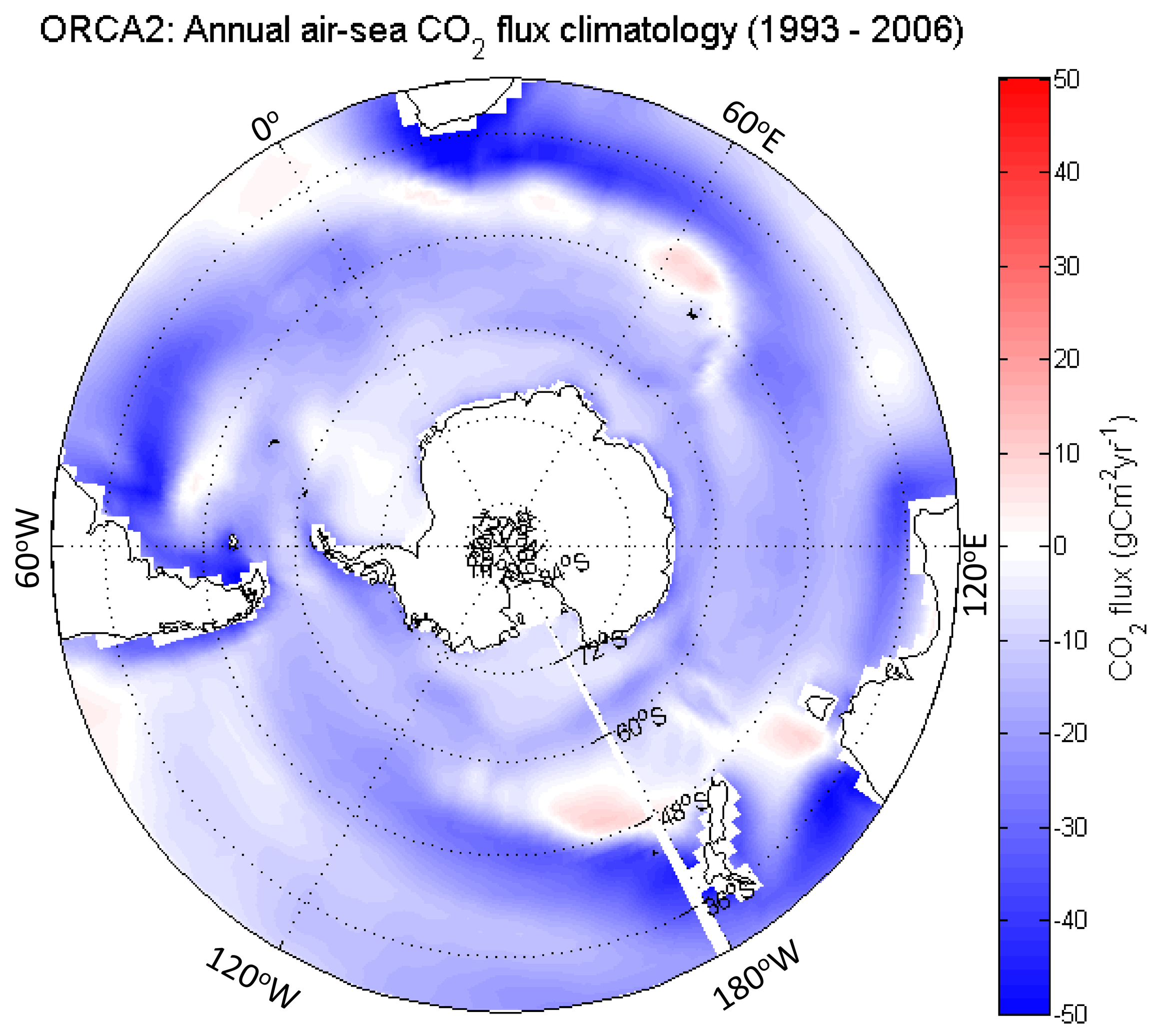

Figure 4. Spatial map of the climatological mean sea-air CO_2 fluxes over 1993 - 2006, in $gCm^{-2}yr^{-1}$, from NEMO PISCES (ORCA2 $2^o \times 2^o \cos \Theta$); negative values reflect flux into the ocean. ORCA2 shows a negative bias of the CO_2 fluxes in SO, it has an average CO_2 flux of -10 $gCm^{-2}yr^{-1}$ for most part of the SO, only a few zones show positive flux hotspots.

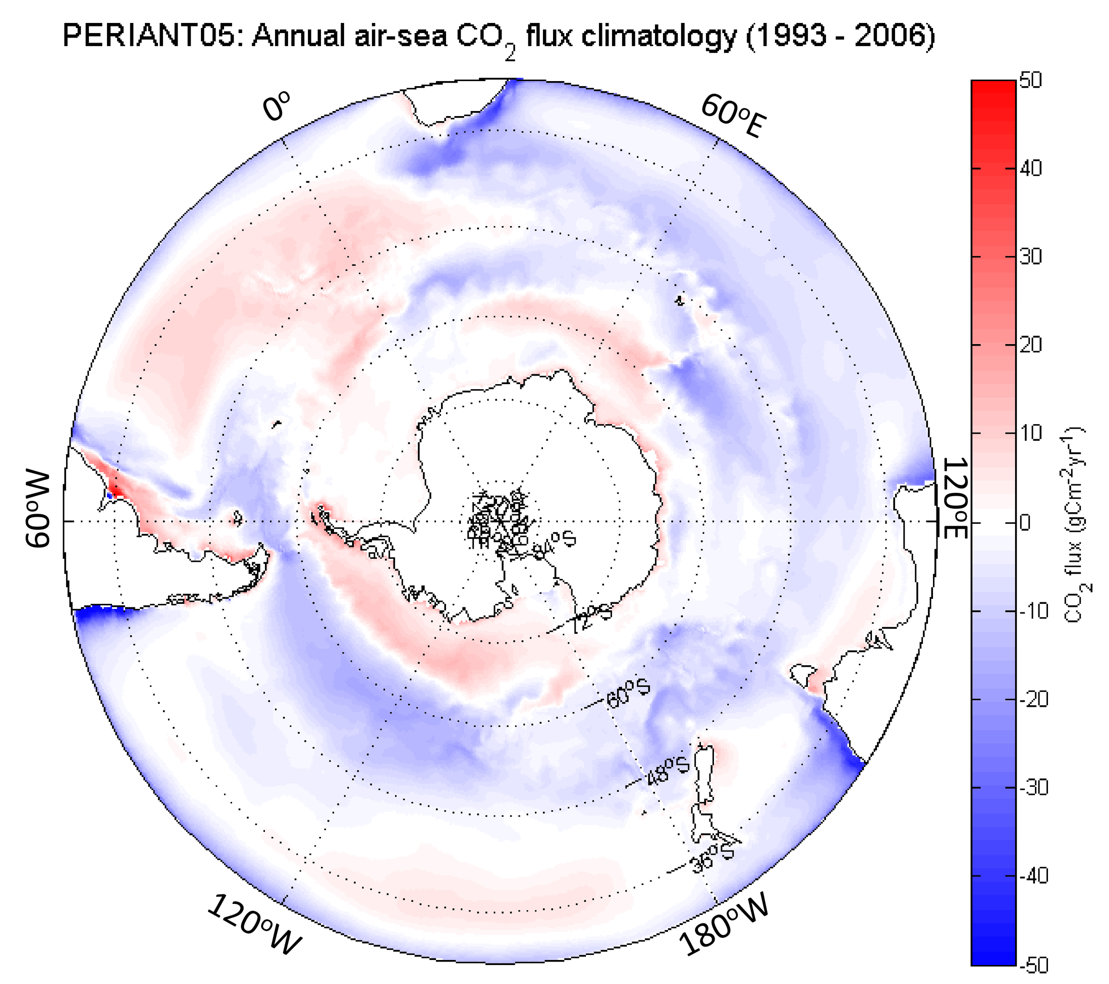

Figure 5. Spatial map of the climatological mean sea-air CO_2 fluxes over 1993 - 2006, in $gCm^{-2}yr^{-1}$, from NEMO PISCES (PERIANT05 $0.5^o \times 0.5^o \cos \Theta$); negative values reflect flux into the ocean. PERIANT05 shows a balance in in-gassing and outgassing features of the CO_2 fluxes in the SO, most of the regions in these features coincide with the CO_2 fluxes of the T09 observation at figure 1a.

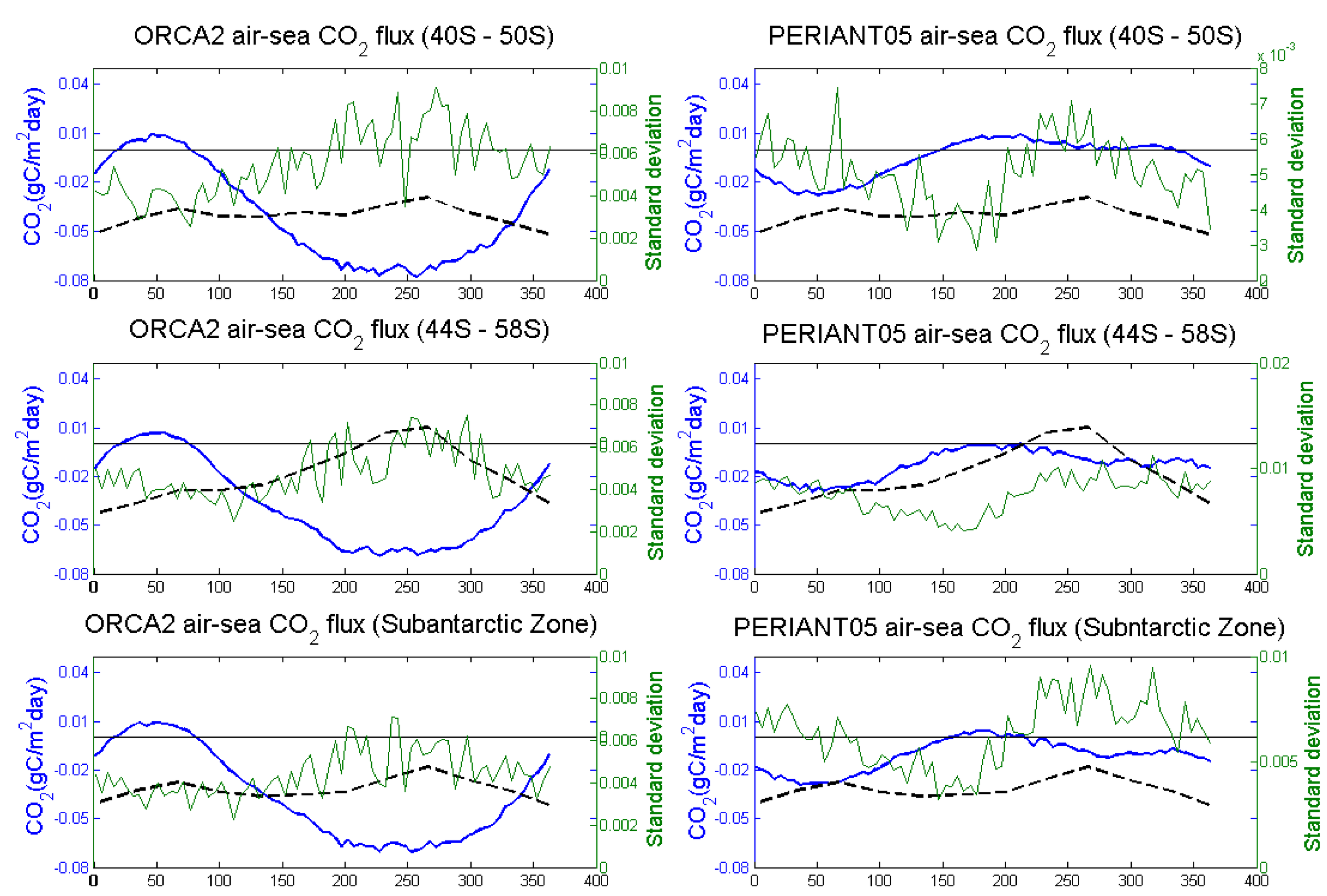

Figure 6. The seasonal cycle of air – sea CO_2 flux at the Lenton RECCAP 2013, geographic and dynamic boundaries for the Permanent Open Ocean Zone (POOZ). The x-axis in all figures reflects time in days. The dotted line in each figures above show the T09 observations. It shows that the seasonal cycle of air-sea CO2 flux phasing is relatively similar between the three sub-regions in both ORCA2 and PERIANT05 however T09 observations show significant differences between the three sub-regions.

Summary and conclusions

ORCA2 does not resolve observations air-sea CO_2 fluxes in the SO, generally show a CO_2 in-gassing bias (Fig 4)

PERIANT05 moderately resolve observations air-sea CO_2 fluxes of the SO, however still show some weaknesses in some zones of the Southern Ocean (e.g. Atlantic Ocean), PERIANT05 generally show a CO_2 out-gassing bias (Fig 5)

The use of dynamic boundaries does not improve resolving observations air-sea CO_2 flux seasonal cycle in both ORCA2 and PERIANT05 (Fig 6)

Poor air-sea seasonal cycle in ORCA2 is mainly due to lack or weak winter CO_2 entrainment and summer biological CO_2 uptake.