A multi-model study on **Southern Ocean CO_2 uptake** and the role of the **biological carbon pump** in the 21st century

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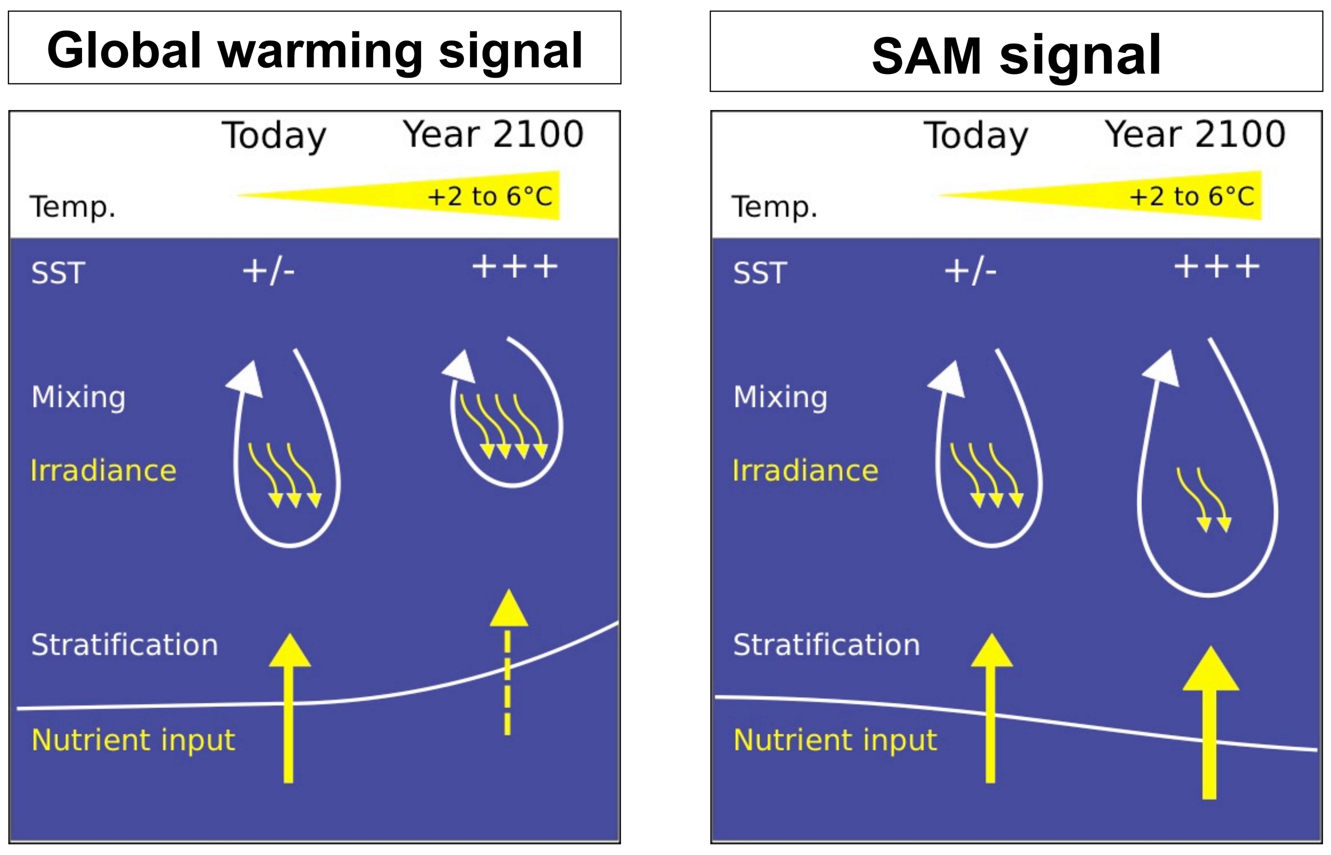
Motivation



→ Which signal will be dominant in the future?

→ What does that mean for export production?

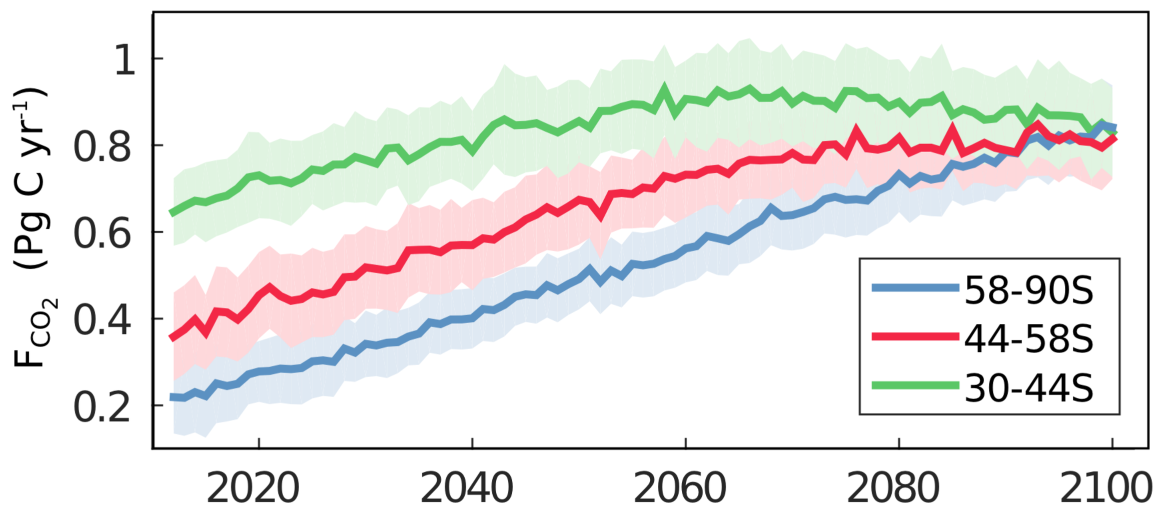
→ And how will that translate into CO_2 flux?

Possible scenarios for export production and CO_2 flux

	Global warming signal	SAM signal	
	Shallower MLD: more light (less nutrients), more NPP and export, enhanced summer CO2 uptake	Deeper MLD: less light (more nutrients), less NPP and export, reduced summer CO2 uptake (wrt annual mean)	light-driven
	Shallower MLD: (more light) less nutrients, less NPP and export, reduced summer CO2 uptake (wrt annual mean)	Deeper MLD: (less light) more nutrients, more NPP and export, enhanced summer CO2 uptake	nutrient-driven

Results

Multi-model mean CO_2 flux (positive = into ocean). Regions 44-58°S and south of 58°S will contribute more to Southern Ocean (south of 30°S) CO_2 flux in the future due to larger impact of biology at higher Revelle factor (Hauck&Völker, 2015) and increase in export. The larger uptake in the south limits uptake in the north (northward Ekman transport).



Conclusions

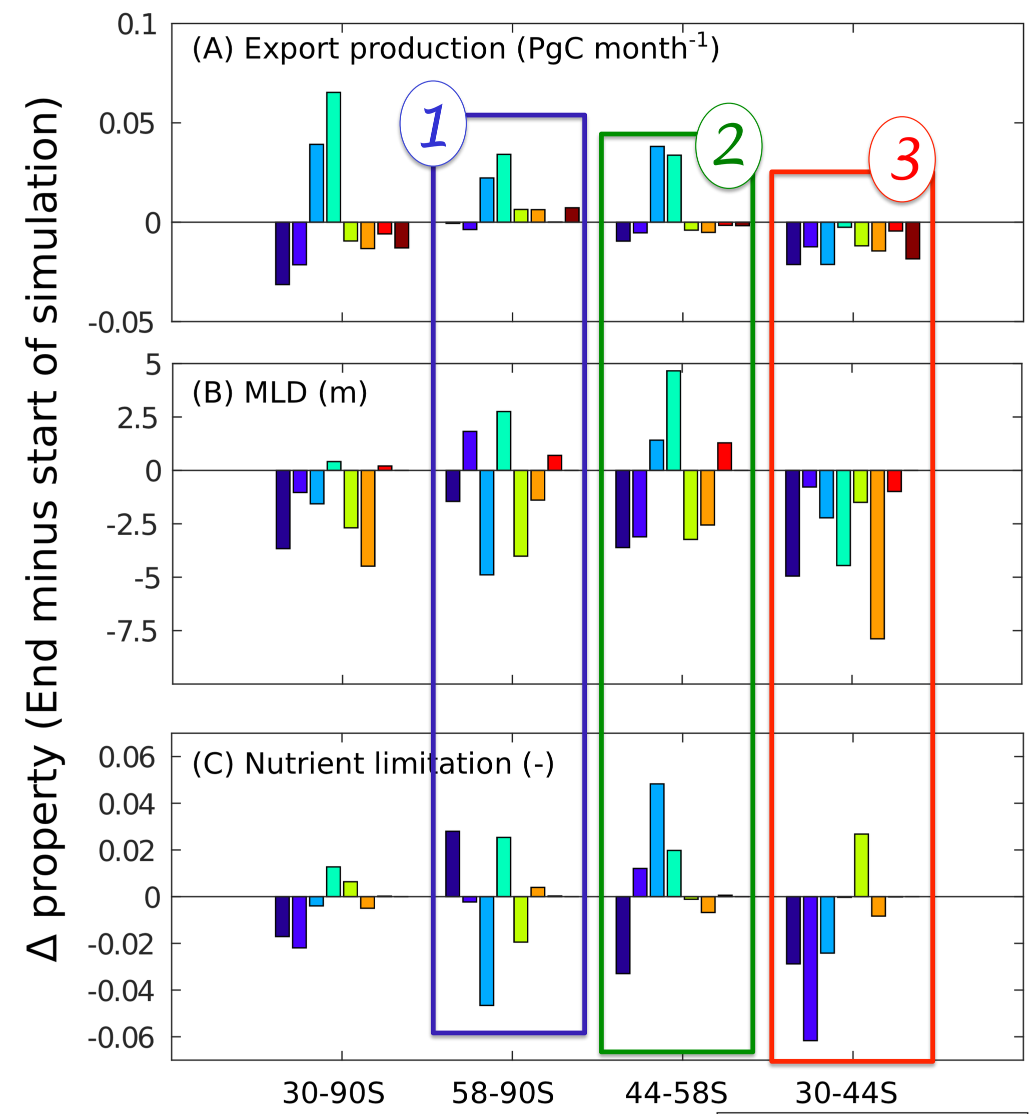
No agreement among models whether system south of 44°S will be controlled by SAM or warming signal.

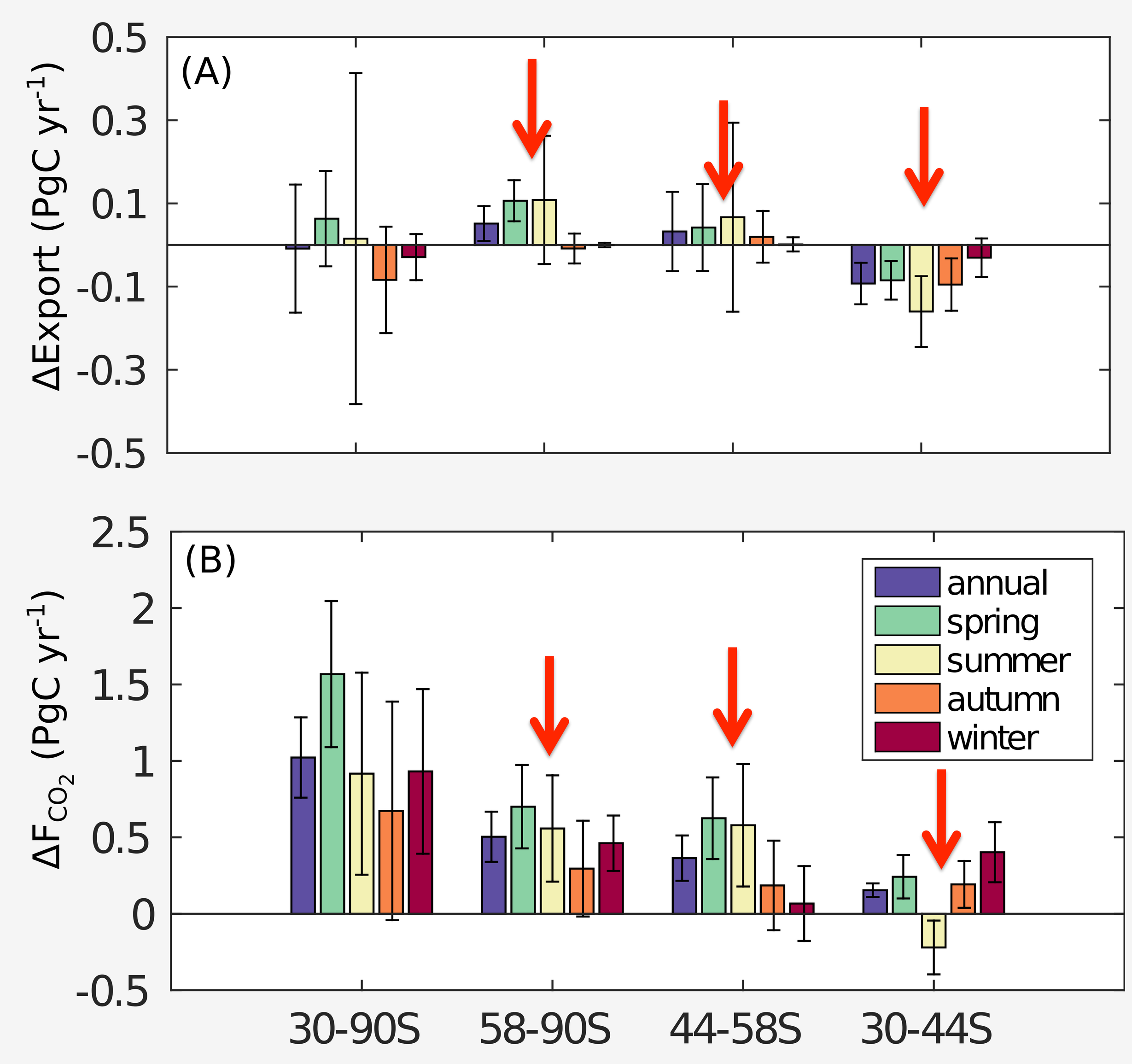
In the temperate region 30-44°S the warming signal with shallower mixed layer depths dominates.

The largest impact on future CO_2 uptake is by the atmospheric CO_2 increase.

All models show a larger effect of biological production on CO_2 uptake by interaction with high Revelle factor.

Increase of export production, effect of surface warming on CO_2 flux and enhanced upwelling of carbon-rich deep water at stronger winds are of similar magnitude and relative importance varies between models; effect of wind speed on gas-exchange is small.





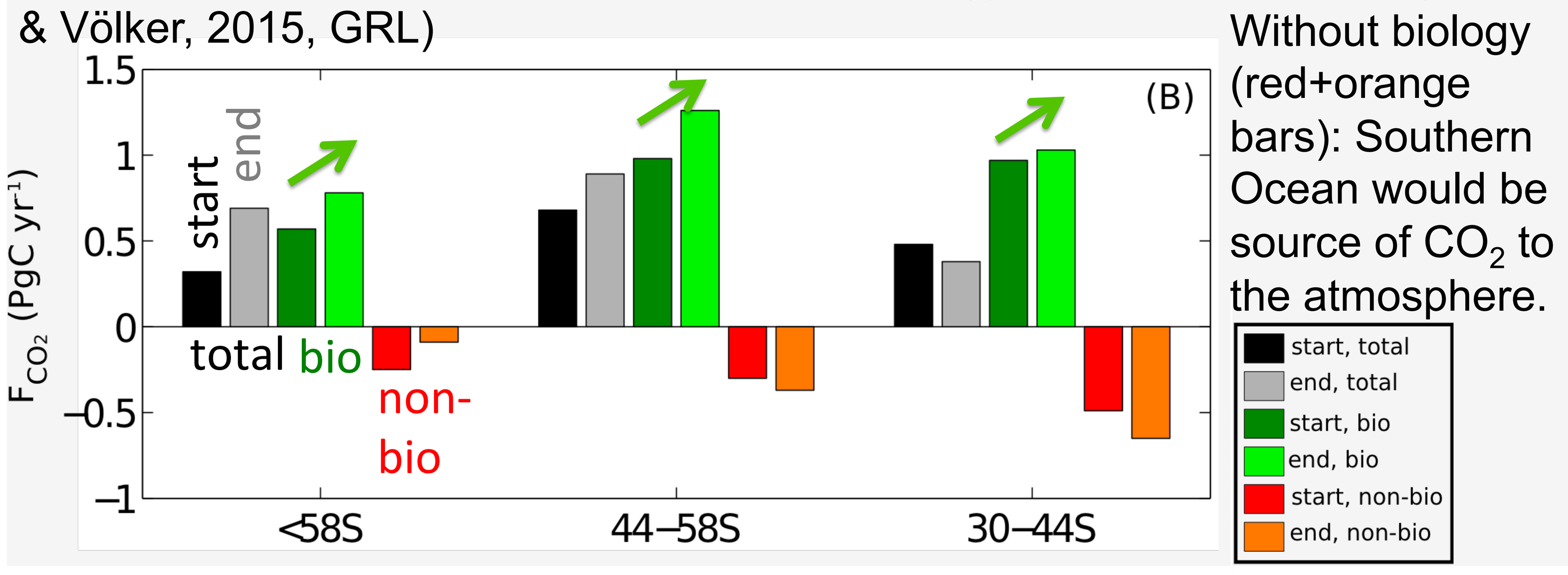
Multi-model CO_2 flux and export. The **largest increase in multi-model mean FCO_2** occurs with the multi-model mean **increase in export production in spring and summer south of 44°S**. In addition, the models agree on a **reduction of export north of 44°S**, exactly the same region where **FCO_2 grows the least** (despite the largest areal extent of the region), and where the ocean turned into **a source of CO_2** in summer.

Figure: ΔExport production (a) and ΔFCO2 (b), calculated as the average for period 2081-2100 minus the average for 2012-2031. Bars depict the multi-model mean, and error bars denote one standard deviation.

Causes for export production changes

1. No model agreement on dominance of SAM or global warming signal, but agreement on **increase of export** in spring or summer in the region south of 58°S
2. No model agreement on dominance of SAM or global warming signal, no agreement on sign of export change in the region 44-58°S
3. Model agreement on **dominance of global warming signal**, nutrient-driven **decrease of export production** in the region 30-44°S

Role of biology. Increase of biologically-driven CO_2 uptake until 2100 and twice as large (not shown) as F_{CO2} increase due to increase of export production → due to **interaction between biology and Revelle factor** (Hauck & Völker, 2015, GRL)



Without biology (red+orange bars): Southern Ocean would be source of CO_2 to the atmosphere.

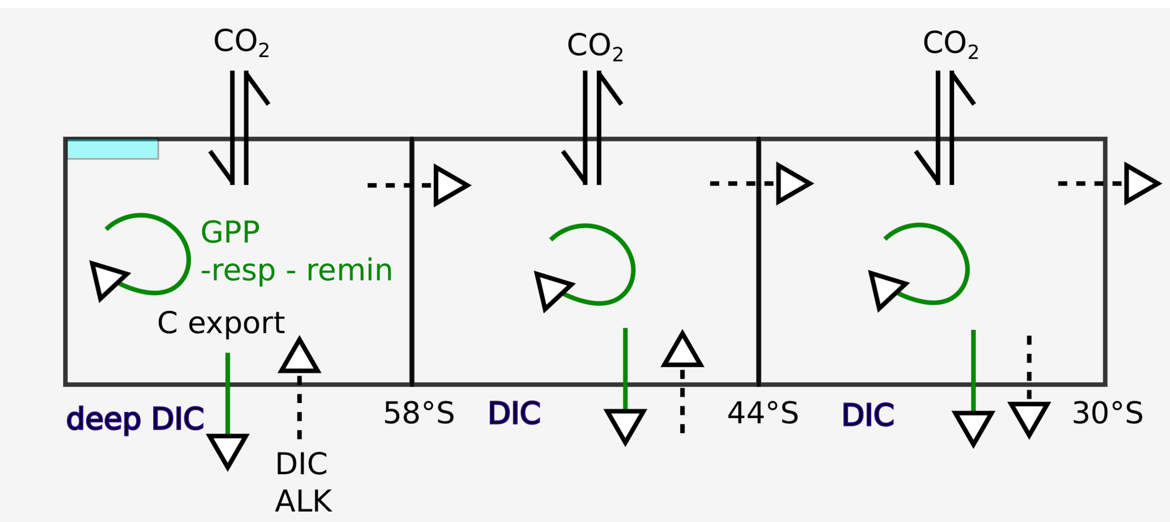
Models

❖ **MAREMIP/CMIP5 models**

- Atmospheric CO2 according to RCP8.5 scenario
- five fully coupled and three ocean-ice-ecosystem models
- models differ widely in mixed layer depth (MLD) definitions

Model name	ocean model	ecosystem model	Reference	atmospheric forcing	MLD criterion and threshold
PlankTOM5.3	NEMO	PlankTOM5.3	*Buitenhuis et al.* [2013]	IPSL-CM5A-LR	density,[a] 0.03 kg m^{-3}
CESM1	POP	BEC	*Moore et al.* [2013]	fully coupled	max. buoyancy gradient[c]
MEM	MRI.COM	MEM	*Shigemitsu et al.* [2012]	MIROC5	density, 0.125 kg m^{-3}
REcoM2	MITgcm	REcoM2	*Hauck et al.* [2013]	MIROC5	density,[b] ΔT=-0.8 K
CNRM-CM5	NEMO	PISCES	*Aumont and Bopp* [2006]	fully coupled	density, ΔT=-0.2 K
IPSL-CM5A-LR	NEMO	PISCES	*Aumont and Bopp* [2006]	fully coupled	mixing scheme
GFDL-ESM2M	MOM	TOPAZ	*Dunne et al.* [2013]	fully coupled	density,[a] 0.03 kg m^{-3}
HadGEM2-ES	MetUM	diat-HadOCC	*Collins et al.* [2011]	fully coupled	no data

[a] [*de Boyer Montégut et al.*, 2004]
[b] [*Kara et al.*, 2000]
[c] [*Large et al.*, 1997]



❖ **two additional REcoM2 simulations**

CONST: with constant preindustrial atmospheric CO_2 + changing climate

RCP85: with constant climate and increasing atm CO_2

❖ **Box model**

Prognostics: DIC and ALK concentration and CO_2 flux.

Forcing: output from REcoM2 RCP8.5 simulation, averaged over periods 2012-2031 and 2081-2100 as forcing: prescribed temperature, salinity, deep DIC and ALK, export as gross primary production (GPP) minus respiration minus remineralization, sea ice area. Wind speed from MIROC5 to calculate Ekman transport and up-/downwelling from mass balance. Atmosperic CO_2 from RCP8.5