The sensitivity of primary productivity to intra-seasonal mixed layer variability in the Sub-Antarctic Zone of the Atlantic ocean

Warren R. Joubert*#, Sebastiaan Swart*, Alessandro Tagliabue#+, Sandy J. Thomalla*, Pedro M.S. Monteiro*#

SUMMARY

The influence of iron and light in controlling phytoplankton productivity in the Southern Ocean (> 40°S) are well established but their link to the mixed layer dynamics remains elusive. Here we show, using high resolution *in situ* biological oxygen supersaturation (ΔO_2/Ar), net community production (NCP) and mixed layer (MLD) data sets collected in the austral summers of 2008 – 2010, a remarkable non-linear relationship of ΔO_2/Ar with MLD with surprisingly high variability associated with shallow MLDs. We propose that NCP variability in the SAZ may be driven by alternating states of synoptic-scale deepening of the mixed layer, leading to the entrainment of iron (dFe), followed by restratification, allowing rapid growth in an iron replete, high light environment.

INTRODUCTION

- Light and iron regulates PP in the S.O with varying roles over the summer season (Boyd et al., 2007, Venables and Moore, 2010).
- Mixed layer changes are critical (Sverdrup, 1953), but role in changing Fe/light limitation and thus PP are unclear.
- We investigate variability in net community production (NCP), and variability in MLD characteristics and hypothesise intra-seasonal drivers in MLD in the SAZ of the Atlantic Ocean

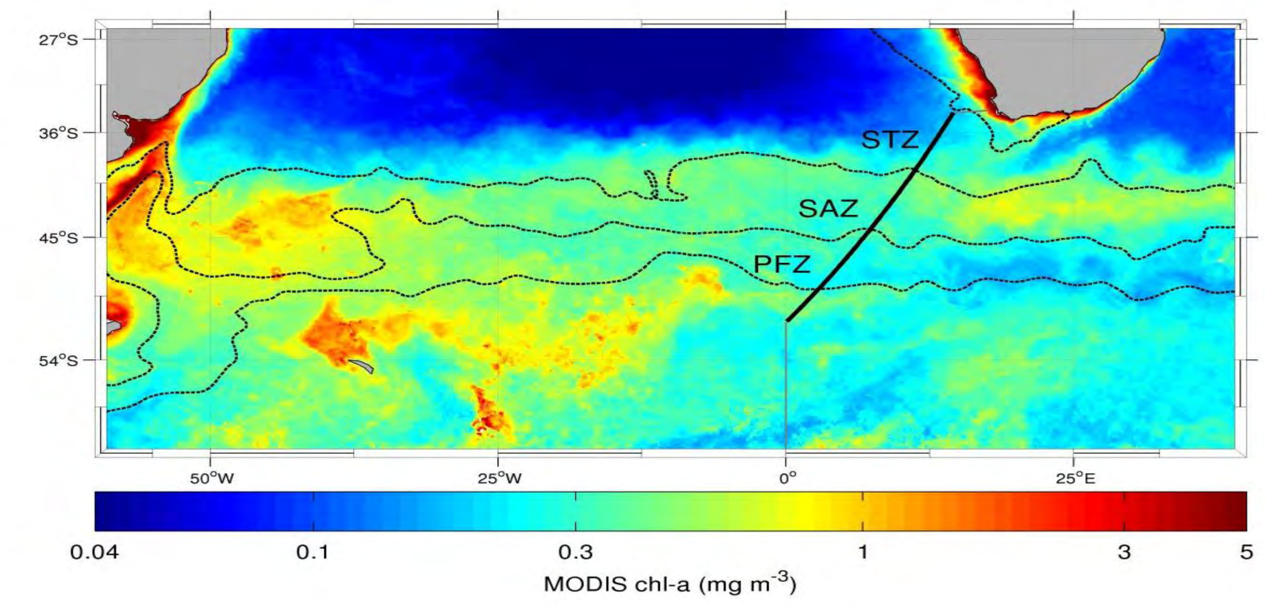

Fig. 1. Chl-a concentration climatology taken from MODIS for the study region.

METHODS

Three cruises in austral summer in the Southern Ocean (Fig. 1). Biological oxygen supersaturation (O_2/Ar ratios) measured using continuous Equilibrator Inlet Mass Spectrometry (EIMS) Cassar et al., 2009. $\Delta O_2/Ar = [(o2ar)_{sample}/(o2ar)_{sat}] - 1$. ΔO_2/Ar = biological supersaturation , with physical saturation processes removed (Ar not affected by biology). $NCP = k_w (\Delta O_2/Ar) [O_2]_{sat} \rho$

In situ MLD determined by XBT and uCTD from temperature criteria ($\Delta T < 0.2^oC$ in reference to T_{10m}) as per De Boyer-Montégut et al., (2004).

Monthly climatological MLD from Hadley EN3 v.2a (Ingleby and Huddleston, 2007).

Iron fluxes in the SAZ are calculated from glider MLD data and published dissolved iron concentrations (Tagliabue et al., 2012) according to:

$$F_{Fe-syn} = N/n \int_0^{MLD} (([dFe]_{subMLD} - [dFe]_{euphotic}) \times \frac{\Delta MLD_{45}}{MLD_t}) dz$$

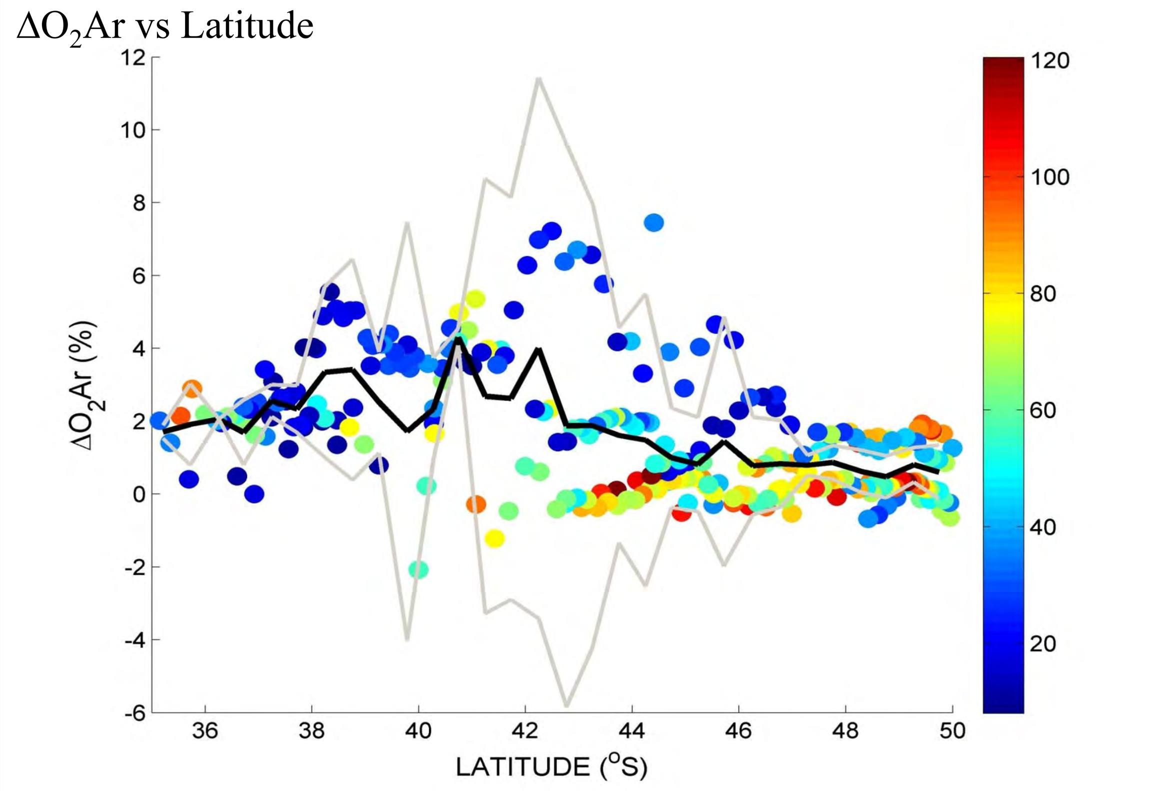

Fig. 2. Latitudinal ΔO_2/Ar ratios (%) show the highest variance (grey lines) in the Sub-Antarctic Zone between 38 – 46°S

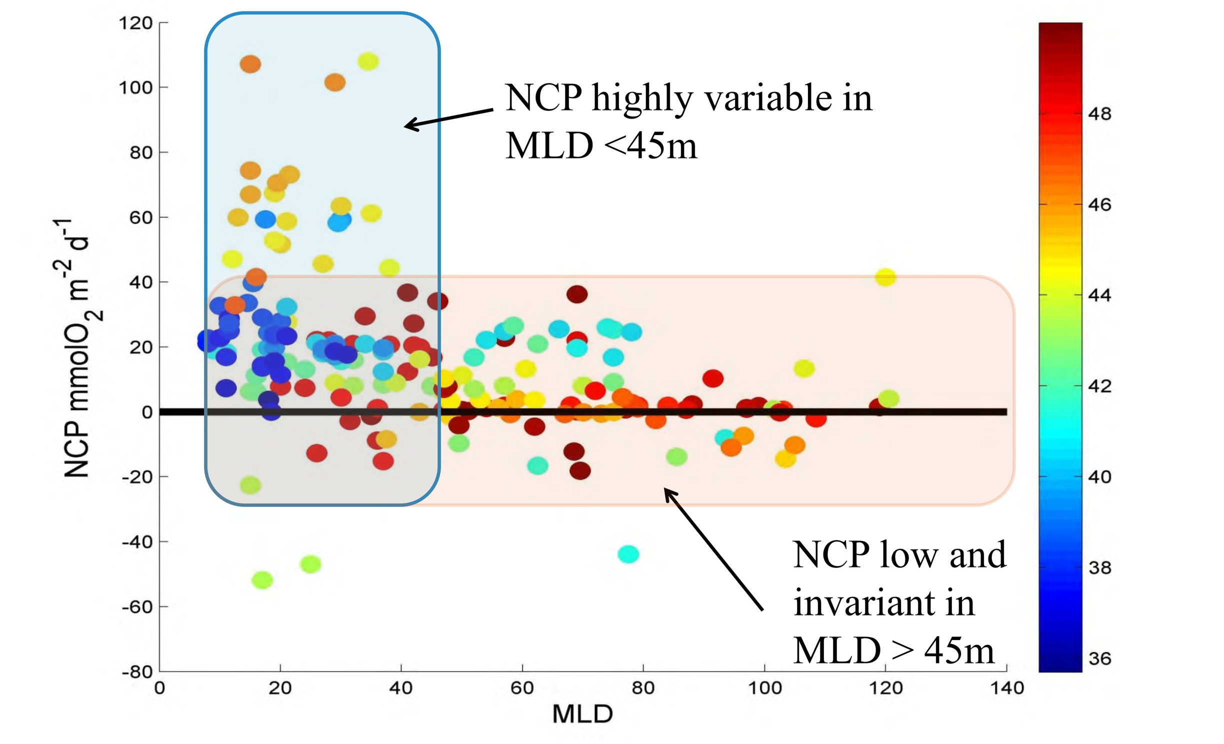

Fig. 3. Net community production (NCP) in the surface mixed layer reflect high variable NCP in shallow mixed layers.

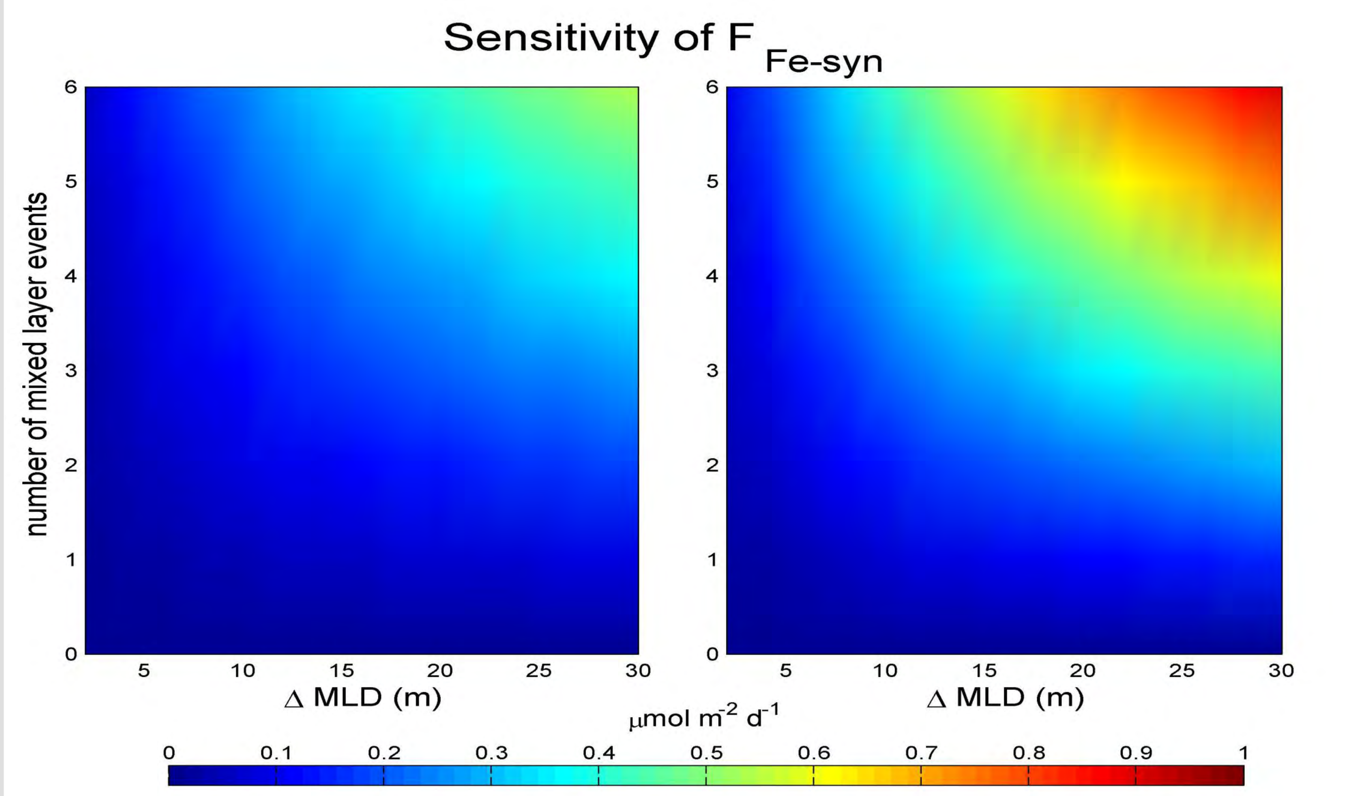

Fig. 4. Sensitivity of synoptic dFe flux rates to number of deepening events and change in the MLD.

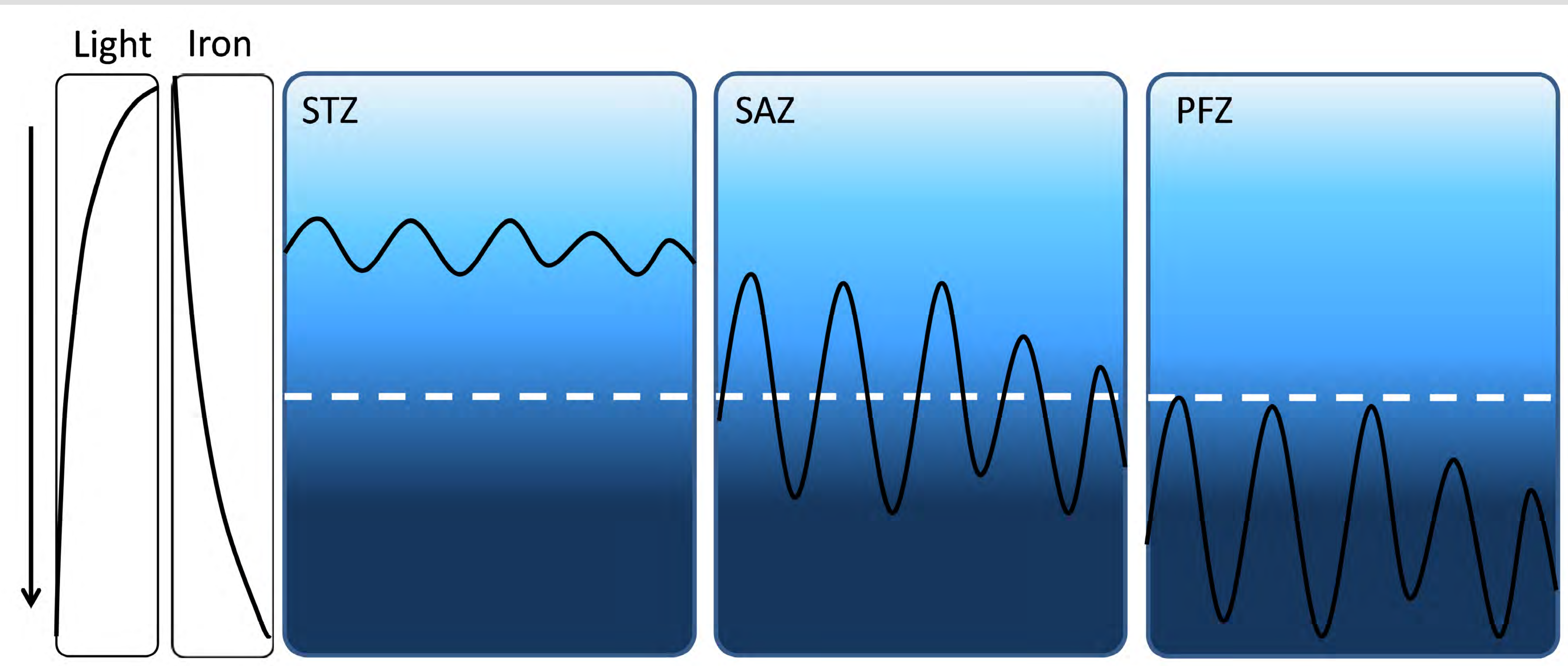

Fig. 5. Conceptual model shows MLD variability (black line) in the STZ, SAZ and PFZ, in relation to a water column irradiance depth threshold (dotted white line). This model proposes that the SAZ is the only region where the MLD deepening, driven by short term storm events, followed by shoaling during quiescent periods drives short term variability in phytoplankton production.

DISCUSSION

- Highest variability in NCP shallow mixed layers (< 45m) centered in the SAZ between 38 – 46°S, related to iron and light availability (Fig. 2,3).
- Contrasting effects of enhanced supply fluxes of iron from mesoscale dynamics of the Agulhas retroflection in the north (STZ) and the absence of such large input terms in the south (PFZ) as well as the late summer sampling therein.
- We estimate rates of synoptic Fe fluxes to range between 100 – 600 nmol Fe $m^{-2} d^{-1}$ (Fig. 4), which are in the same order of magnitude as the Fe requirements for the observed elevated NCP.
- We propose that elevated and highly variable and sustained primary production in the SAZ results from intraseasonal scale storm events, alternating between deepening of the mixed layer, that entrains Fe, followed by rapid shoaling that favours growth in a transient iron replete, high light environment. In the SAZ, reflects the same impact of intra-seasonal variability in mixing and stratification on PP phasing between dFe and light (Fig. 5).

SYNOPSIS

We show intra-seasonal variability are potentially linked by the high frequency alternate phasing of light and nutrient critical to sustain elevated but also more variable primary production in the SAZ. **We hypothesise that the critical factor driving spatial and temporal scales of variability in Southern Ocean primary production is the intra-seasonal variability and balance between buoyancy and momentum in the surface ocean**. This not only defines the seasonal mean MLD but also its intra-seasonal variability and associated productivity responses.

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* Southern Ocean Carbon and Climate Observatory, CSIR, P.O.Box 320, Stellenbosch, 7599, South Africa.
# Department of Oceanography, University of Cape Town , Rondebosch, 7700, South Africa.
+ School of Environmental Sciences, University of Liverpool, Liverpool L69 3GP, UK.
***CONTACT :* wjoubert@csir.co.za**