Re-examining the Southern Ocean CO_2 sink with an improved method for modelling wintertime pCO_2

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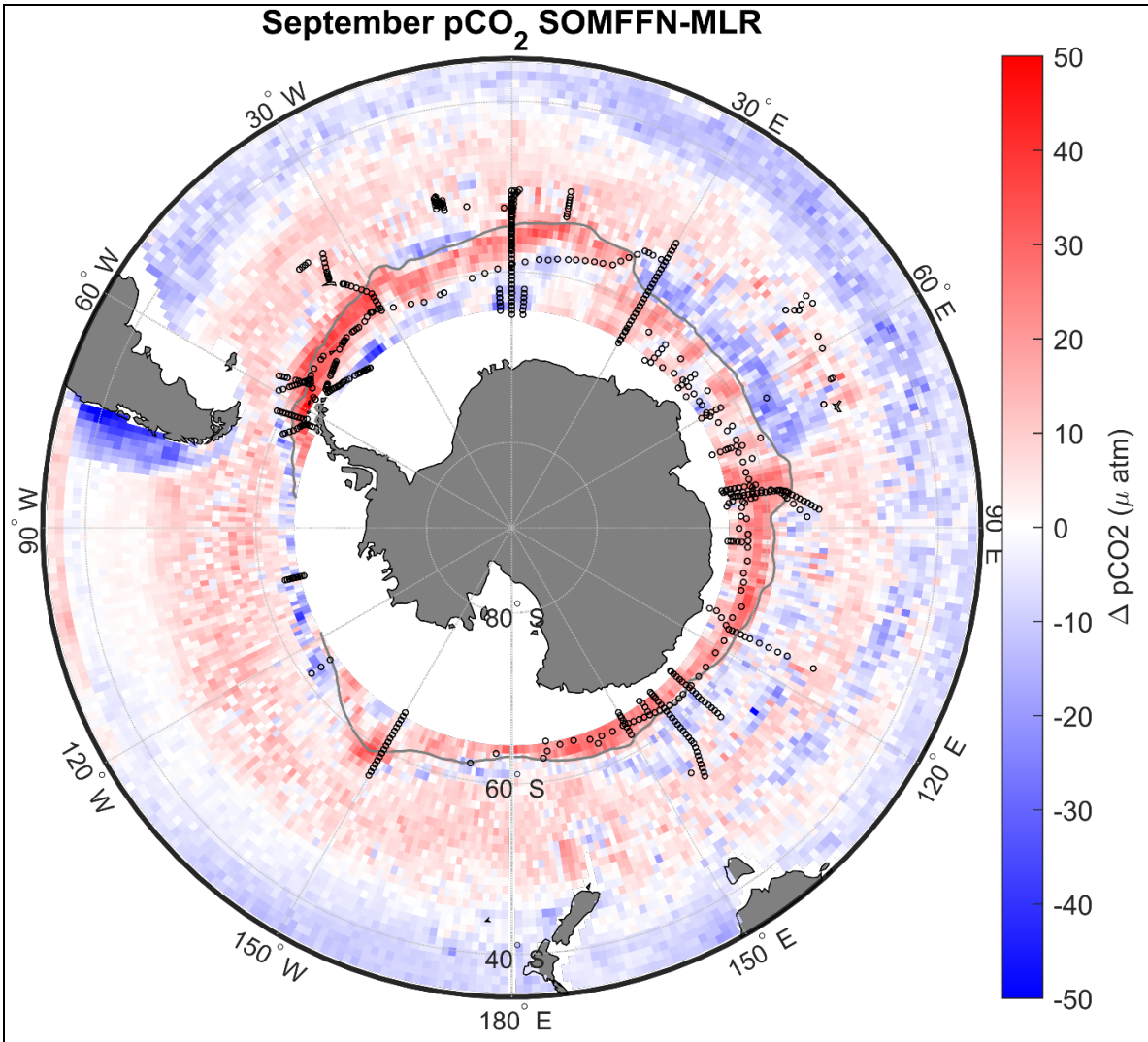
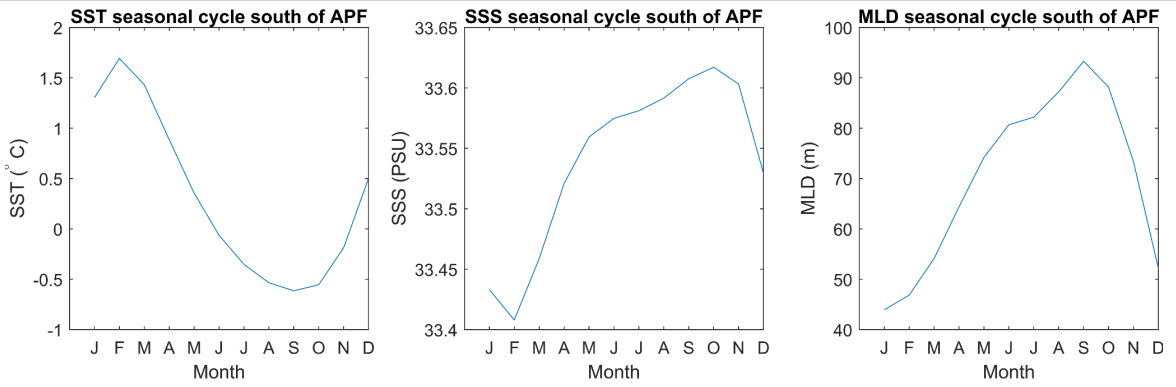
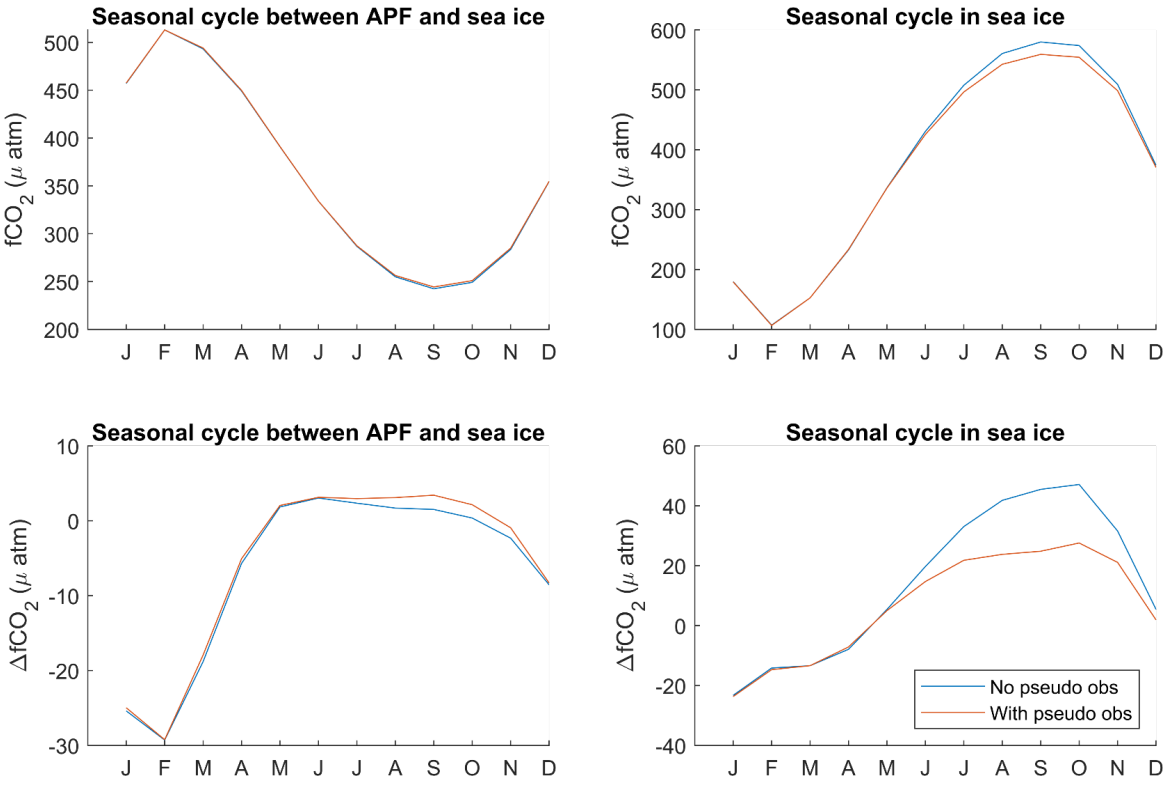


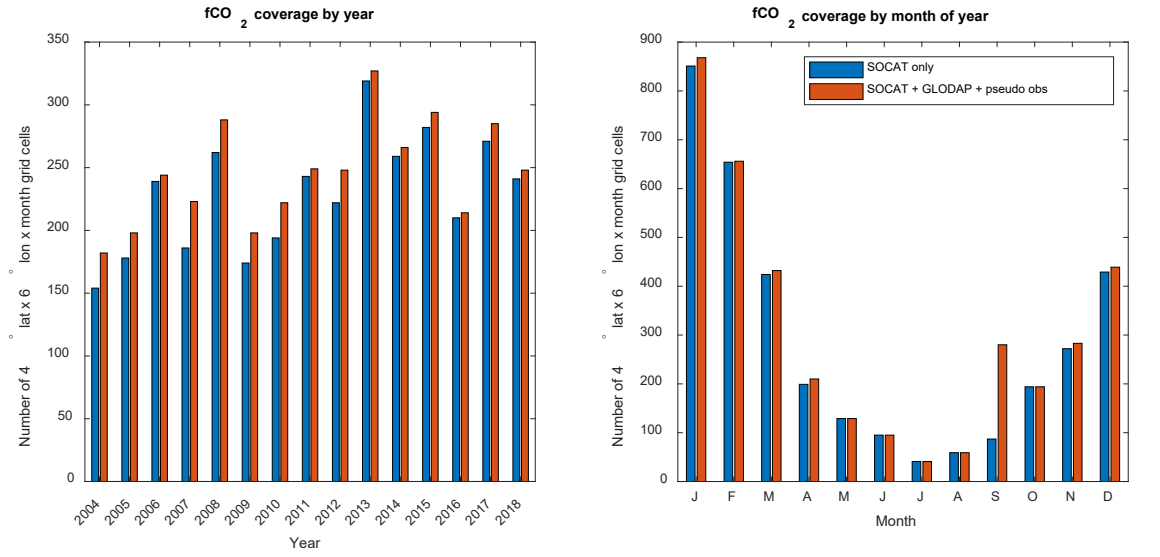
Supplementary Figure S1: The difference between mapped surface pCO_2 with pseudo observations (in micro-atmosphere, μ atm), from this study using the SOM-FFN gap-filling technique, and the earlier method of Mackay and Watson[1] using a multiple linear regression (MLR). The colour map shows the month of September (to which the pseudo observations correspond) averaged over the period 2004-2018; the black circles show the positions of the pseudo observations; and the grey line shows the average position of the September ice extent based on NOAA/NSIDC v3[2,3] (15% concentration contour).



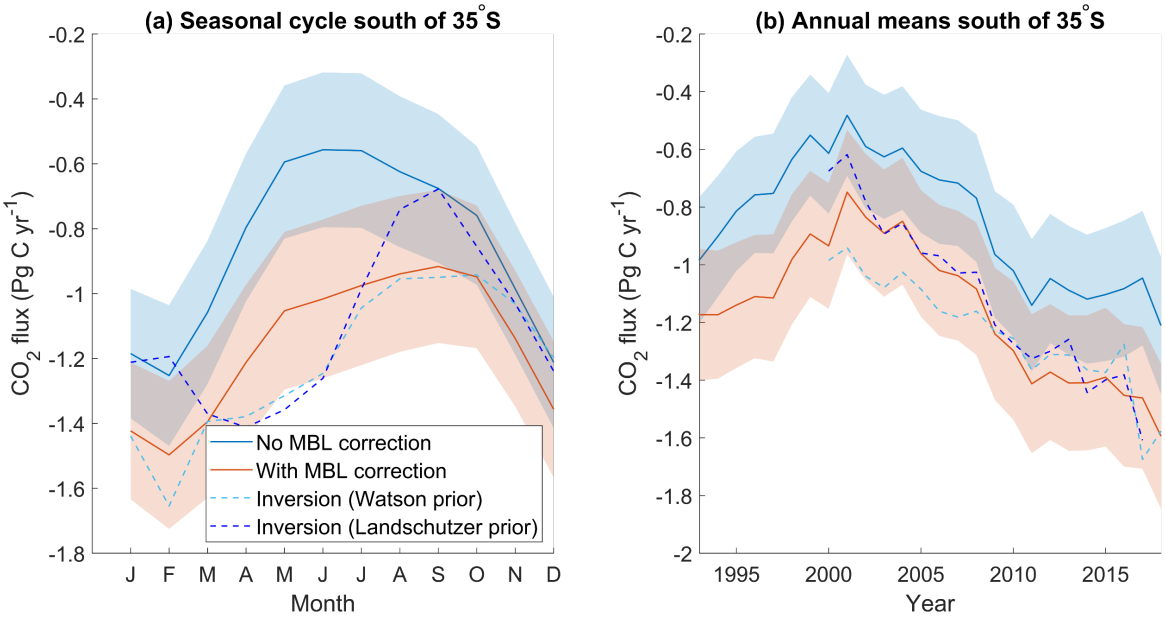
Supplementary Figure S2: Mean seasonal cycles of SOM-FFN driver variables sea surface temperature in degrees celsius (SST), sea surface salinity in Practical Salinity Units (SSS), and mixed layer depth in metres (MLD), averaged over the region south of the Antarctic Polar Front (APF) and for the period 1993:2018.



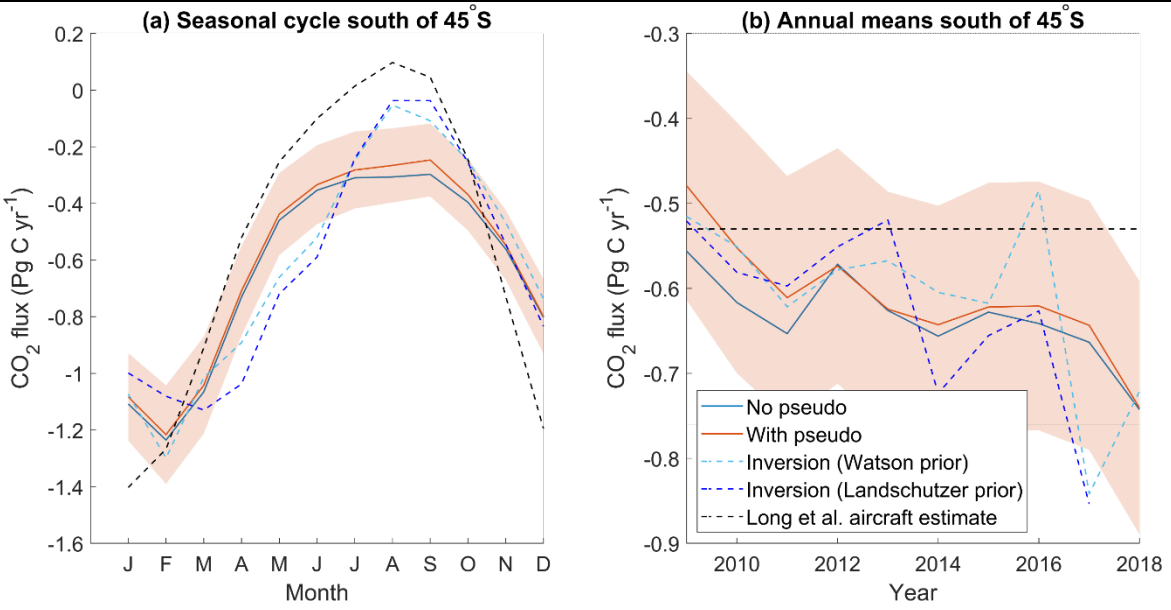
Supplementary Figure S3: Mean seasonal cycles of fCO_2 without pseudo observations (blue curves) and with pseudo observations (red curves), averaged over the region south of the Antarctic Polar Front where the sea ice concentration = 0 (left), and where the sea ice concentration > 0 (right) for the period 1993 to 2018. The top row shows the ocean surface fCO_2, and the bottom row shows ΔfCO_2, the difference between the atmosphere and ocean fCO_2, which drives the air-sea CO_2 flux.



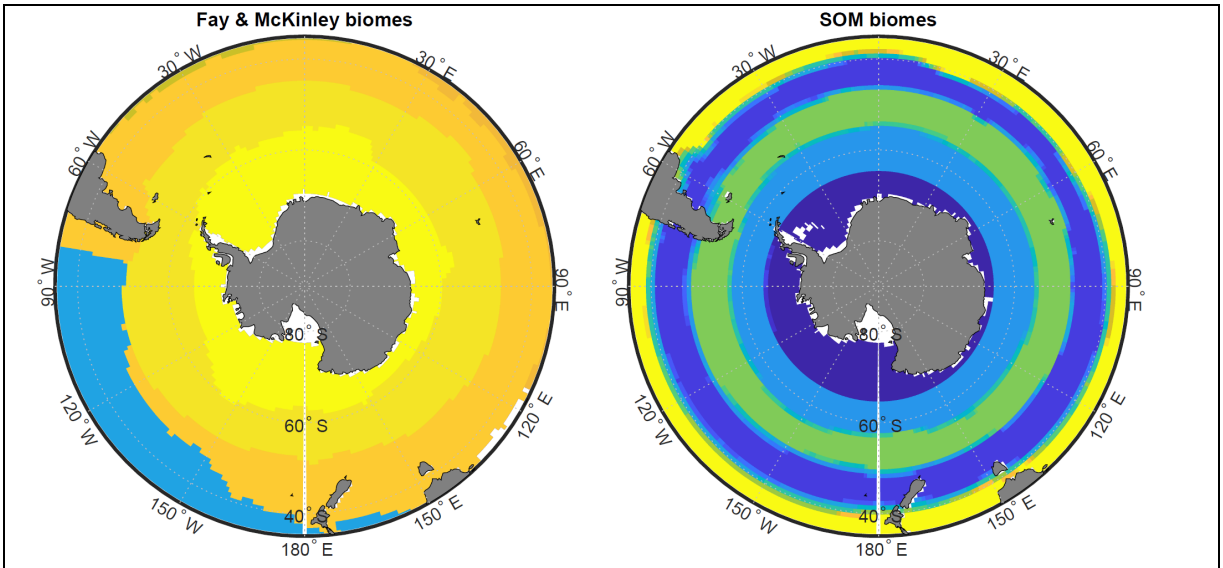
Supplementary Figure S4: Distribution of fCO_2 data coverage south of the Antarctic Polar Front by year (left) and by month (right). The data are monthly averages further binned onto a 4° latitude by 6° longitude grid, as on Figure 1. The blue bars show the number of monthly bins containing SOCAT fCO_2 data, and the red bars show the number with fCO_2 data either from SOCAT, a pseudo observation, or calculated from surface GLODAP observations. Note that the September data coverage is high due to the choice of that month as corresponding to the pseudo observations, which are constructed using profiles from all non-winter months.



Supplementary Figure S5: (a) 2000-2017 mean seasonal cycle and (b) annual mean air-sea CO_2 fluxes (negative into the ocean) for the Southern Ocean south of 35°S based on sea surface fCO_2 from the SOM-FFN with and without a Mass Boundary Layer (MBL) correction. Values are Petagrams of carbon per year (Pg C yr^{-1}). Each line represents an ensemble mean (see Methods), and the shaded areas are the 1-σ uncertainties. Also plotted are the same quantities derived from an atmospheric inversion using two different priors (coloured dashed lines; see Methods).



Supplementary Figure S6: (a) 2009-2018 mean seasonal cycle and (b) annual mean air-sea CO_2 fluxes (negative into the ocean) for the Southern Ocean south of 45°S based on sea surface fCO_2 from the SOM-FFN with and without pseudo observations. Values are Petagrams of carbon per year (Pg C yr^{-1}). Each line represents an ensemble mean (see Methods), and the shaded area is the 1-σ uncertainty on the SOM-FFN result with pseudo observations. Also plotted are the same quantities derived from an atmospheric inversion using two different priors (coloured dashed lines; see Methods), and a further inversion constrained by aircraft data from Long et al[4] (black dashed line with uncertainty bounds given by black dotted lines).



Supplementary Figure S7: Biome definitions used in different configurations of the SOM-FFN for grouping the fCO_2 data before regression and gap filling. Each different colour represents a different biome. Left panel shows the fixed-in-time biomes from Fay and McKinley[5] and right panel shows biomes generated by the Self Organising Map (SOM) of the SOM-FFN method (note that the biome edges are blurred because the SOM biomes are not fixed in time).

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