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# Trends and drivers of sea surface $fCO_2$ an pH changes observed in the Southern Indian Ocean over the last two decades (1998-2019)

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The decadal changes of the fugacity of $CO_2$ ($fCO_2$) and pH in surface waters are investigated in the Southern Indian Ocean (45°S-57°S) using repeated summer observations, including measurements of $fCO_2$, total alkalinity ($A_T$) and total carbon ($C_T$) collected over the period 1998-2019 in the frame of the French monitoring program OISO. We used three datasets (underway $fCO_2$, underway $A_T$-$C_T$ and station $A_T$-$C_T$) to evaluate the trends of $fCO_2$ and pH and their drivers, including the accumulation of anthropogenic $CO_2$ ($C_{ant}$). The study region is separated into three domains based on the frontal system and biogeochemical characteristics: (i) High Nutrients Low Chlorophyll (HNLC) waters in the Polar Front Zone (PFZ), (ii) HNLC waters south of the Polar Front (PF) and (iii) the highly productive zones in fertilized waters near Crozet and Kerguelen Islands. Almost everywhere, we obtained similar trends in surface $fCO_2$ and pH using the $fCO_2$ or $A_T$-$C_T$ datasets. Over the period 1998-2019, we observed an increase in surface $fCO_2$ and a decrease in pH ranging from +1.0 to +4.0 µatm $yr^{-1}$ and from -0.0015 to -0.0043 $yr^{-1}$, respectively. South of the PF, the $fCO_2$ trend is close to the atmospheric $CO_2$ rise (+2.0 µatm $yr^{-1}$) and the decrease in pH is in the range of the mean trend for the global ocean (around -0.0020 $yr^{-1}$). These trends are driven by the warming of surface waters (up to +0.04°C $yr^{-1}$) and the increase in $C_T$, mainly due to the accumulation of $C_{ant}$ (around +0.6 µmol $kg^{-1}$ $yr^{-1}$). In the PFZ, our data show slower $fCO_2$ and pH trends (around +1.3 µatm $yr^{-1}$ and -0.0013 $yr^{-1}$, respectively) associated with an increase in $A_T$ (around +0.4 µmol $kg^{-1}$ $yr^{-1}$)that limited the impact of a more rapid accumulation of $C_{ant}$ north of the PF (up to +1.1 µmol $kg^{-1}$ $yr^{-1}$). In the fertilized waters near Crozet and Kerguelen Islands, $fCO_2$ increased and pH decreased faster than in the other domains, between +2.2 and +4.0 µatm $yr^{-1}$ and between -0.0023 $yr^{-1}$ and -0.0043 $yr^{-1}$. The fastest trends of $fCO_2$ and pH are found around Kerguelen Island north and south of the PF. These trends result from both a significant warming (up to +0.07°C $yr^{-1}$) and a rapid increase in $C_T$ (up to +1.4 µmol $kg^{-1}$ $yr^{-1}$), mainly explained by the uptake of $C_{ant}$.