

# **Trends and drivers of sea surface fCO<sub>2</sub> and pH changes observed in the Southern Indian Ocean over the last two decades (1998-2019)**

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## **Supplementary Material**

**Table S1.** Published long-term trends of fCO<sub>2</sub> and pH in the Southern Ocean (SO) based on observations. IO: Indian Ocean sector. PO: Pacific Ocean sector. AO: Atlantic Ocean sector. SO-SPSS: Southern Ocean SubPolar Seasonally Stratified biome. PZ: Polar Zone. PFZ: Polar Frontal Zone. NR: Not Reported.

	Period	Season	Zone (a)	Trend fCO <sub>2</sub> [μatm yr <sup>-1</sup> ]	Trend pH [yr <sup>-1</sup> ]	Reference
5	1986-2007	Winter	0.8-6.5 °C	+2.10 (0.60)	NR	Takahashi et al. (2009) <sup>1</sup>
	1986-2007	Winter	SO 50-60°S	+2.13 (0.64)	NR	Takahashi et al. (2009) <sup>2</sup>
10	1991-2007	Summer	IO 50-55°S	+2.39 (0.16)	NR	Metzl (2009)
	1991-2001	Winter	IO 50-52°S	+2.10 (0.26)	NR	Metzl (2009)
15	1998-2011	Summer	IO 47°S-72°E	+4.2 (NR)	NR	Lourantou and Metzl (2011)
	1991-2000	Winter	IO 47°S-72°E	+2.0 (NR)	NR	Lourantou and Metzl (2011)
20	1993-1999	Summer	IO PZ 55-60°S	+4.48 (1.04)	NR	Xue et al. (2015)
	1993-1999	Summer	IO PFZ 50-55°S	+5.20 (2.55)	NR	Xue et al. (2015)
	2000-2011	Summer	IO PZ 55-60°S	+0.92 (0.51)	NR	Xue et al. (2015)
	2000-2011	Summer	IO PFZ 50-55°S	+0.72 (0.82)	NR	Xue et al. (2015)
25	1991-2000	Summer	IO PZ 55-60°S	+2.93	-0.0035	Xue et al. (2018) <sup>4</sup>
	1991-2000	Summer	IO PFZ 50-55°S	+2.21	-0.0024	Xue et al. (2018) <sup>4</sup>
	2001-2011	Summer	IO PZ 55-60°S	+1.41	-0.0016	Xue et al. (2018) <sup>4</sup>
	2001-2011	Summer	IO PFZ 50-55°S	+1.61	-0.0016	Xue et al. (2018) <sup>4</sup>
30	1969-2003	Summer	PO 45-52°S	+1.0 (0.2)	-0.0011 (0.0004)	Midorikawa et al. (2012)
	1969-2003	Summer	PO 52-55°S	+1.1 (0.2)	-0.0013 (0.0003)	Midorikawa et al. (2012)
	1969-2003	Summer	PO 55-62°S	+1.7 (0.2)	-0.0020 (0.0003)	Midorikawa et al. (2012)
35	1986-2010	Winter	0.8°C - 5.5°C	+2.14 (0.42)	NR	Takahashi et al. (2012) <sup>3</sup>
	1986-2010	Winter	1.5°C - 4.5°C	+2.44 (0.33)	NR	Takahashi et al. (2012) <sup>3</sup>
40	1995-2008	Summer	IO PO 45-62°S	+2.1 (0.3)	NR	Lenton et al. (2012)
	1995-2008	Winter	IO PO 45-62°S	+2.3 (0.3)	NR	Lenton et al. (2012)
	2001-2008	Summer	AO 45-62°S	-0.9 (2.5)	NR	Lenton et al. (2012)
	2001-2008	Winter	AO 45-62°S	+2.2 (1.1)	NR	Lenton et al. (2012)
45	1986-2010	Winter	SO SPSS	+1.27 (0.26)	NR	Fay et al. (2014)
	1970-2011	Annual	SO >45°S	< +0.9	NR	Tjiputra et al. (2014) <sup>5</sup>
50	1970-2011	Annual	SO >45°S	+1.45 (0.05)	NR	Tjiputra et al. (2014) <sup>6</sup>
	2002-2012	Annual	Drake North	+2.21 (0.55)	-0.0023 (0.0007)	Takahashi et al. (2014)
55	2002-2012	Annual	Drake South	+1.50 (0.65)	-0.0015 (0.0008)	Takahashi et al. (2014)
	2002-2015	Summer	Drake North	+1.95 (0.55)	-0.0021 (0.0006)	Munro et al. (2015)
60	2002-2015	Winter	Drake North	+1.92 (0.24)	-0.0018 (0.0003)	Munro et al. (2015)
	2002-2015	Summer	Drake South	+1.30 (0.85)	-0.0017 (0.0010)	Munro et al. (2015)
	2002-2015	Winter	Drake South	+0.67 (0.39)	-0.0008 (0.0004)	Munro et al. (2015)
	2002-2015	Annual	Drake North	+1.74 (0.15)	-0.0019 (0.0002)	Munro et al. (2015)
	2002-2015	Annual	Drake South	+1.16 (0.27)	-0.0015 (0.0003)	Munro et al. (2015)
	1981-2011	Annual	SO-SPSS	+1.44 (0.10)	-0.0020 (0.0002)	Lauvset et al. (2015)
	1991-2011	Annual	SO-SPSS	+1.46 (0.11)	-0.0021 (0.0002)	Lauvset et al. (2015)
	2002-2016	Annual	SO-SPSS	+1.44 (0.12)	NR	Fay et al. (2018)
	2002-2016	Summer	SO-SPSS	+1.23 (0.22)	NR	Fay et al. (2018)
	2002-2016	Winter	SO-SPSS	+1.80 (0.26)	NR	Fay et al. (2018)

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Notes: (a) Latitudinal band or SST range depending on the study. <sup>1</sup>Mean trend for SST range 0.8-6.5 °C (Table 4 in Takahashi et al. (2009); <sup>2</sup>Mean trend for the band 50-60°S (Table 5 in Takahashi et al. (2009); <sup>3</sup>Same as Takahashi et al. (2009) revisited for the period 1986-2010; <sup>4</sup>same as Xue et al. (2015) but using slightly different periods. <sup>5</sup>Based on observations or <sup>6</sup>multi-model mean from five models.

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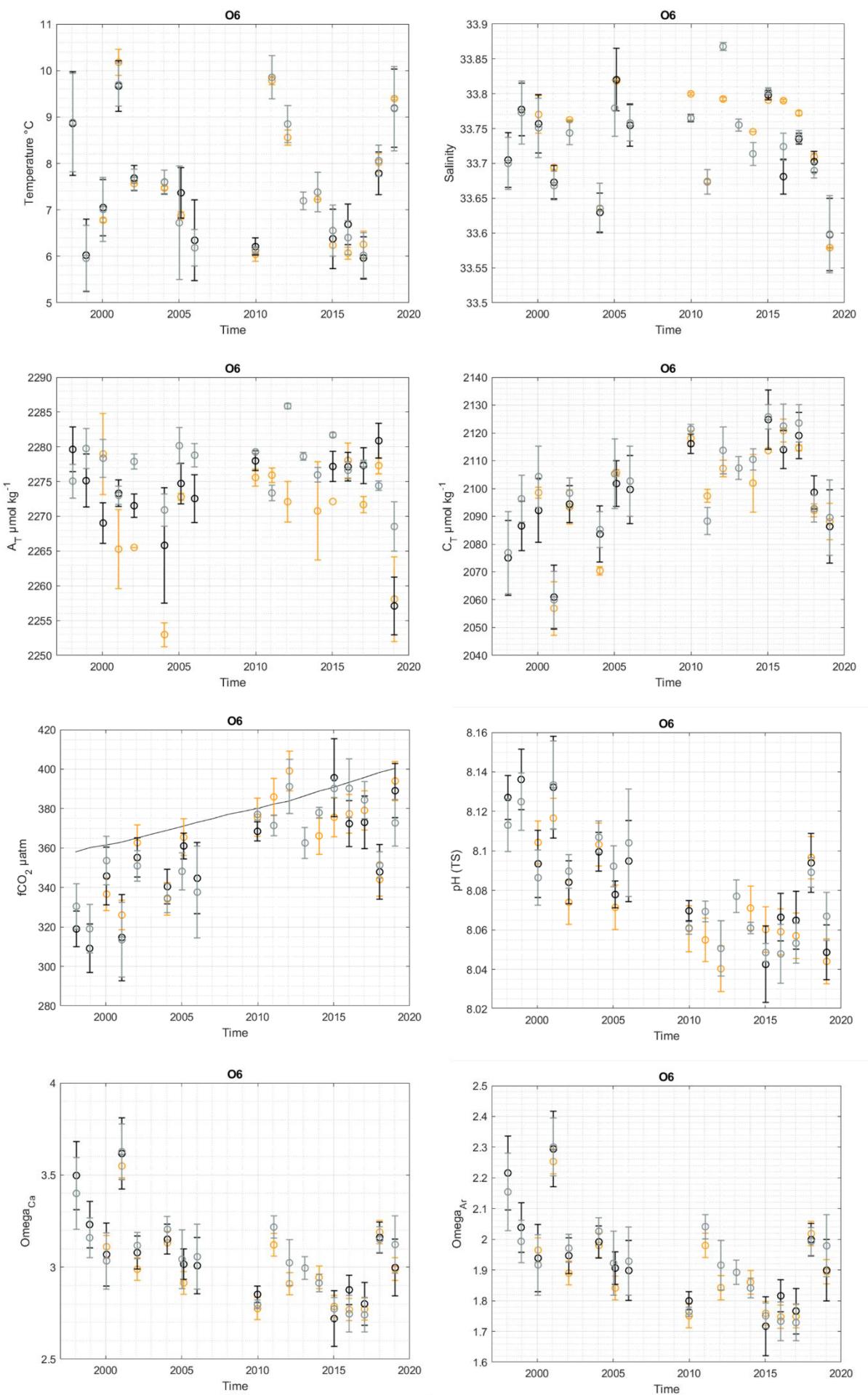
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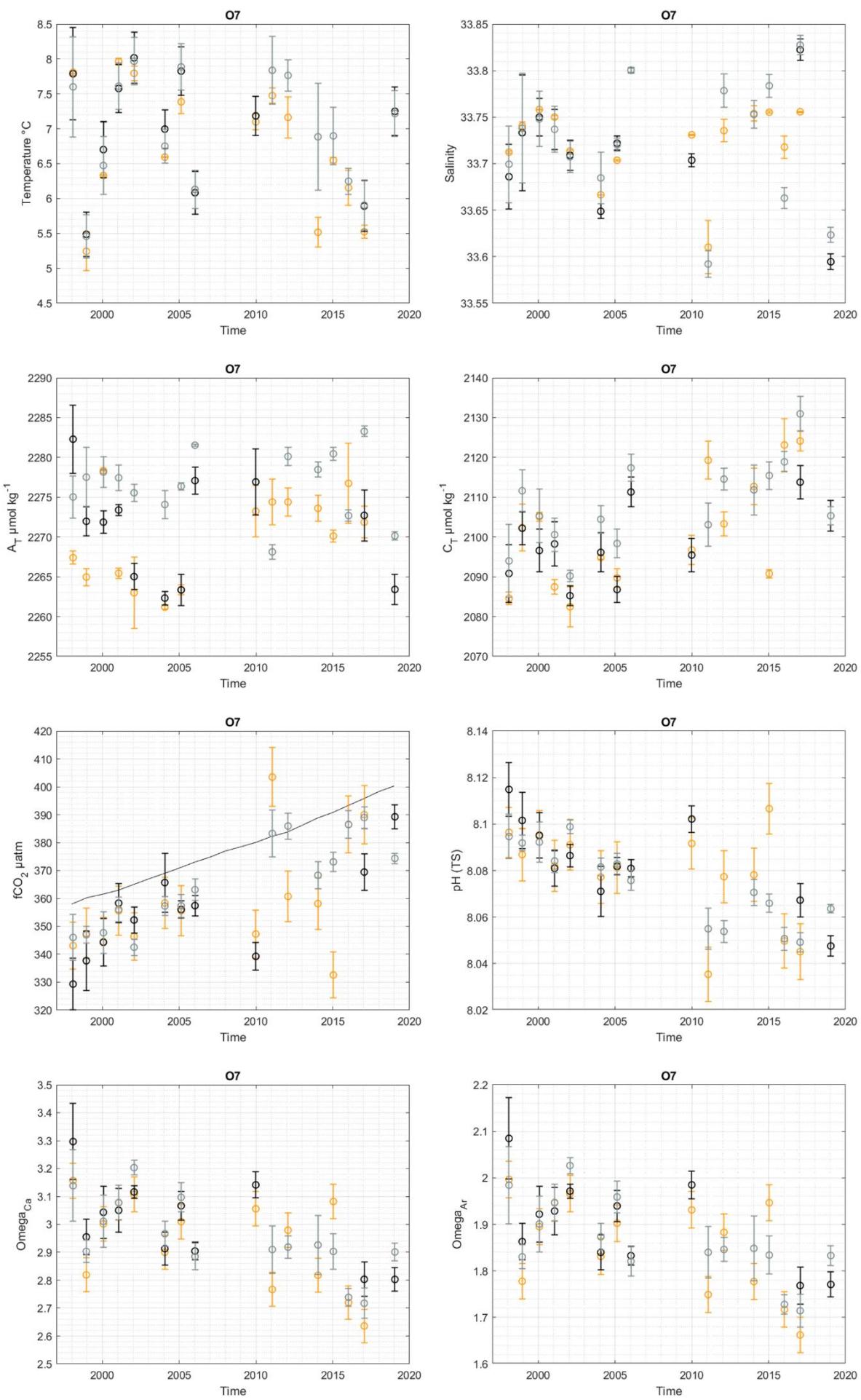
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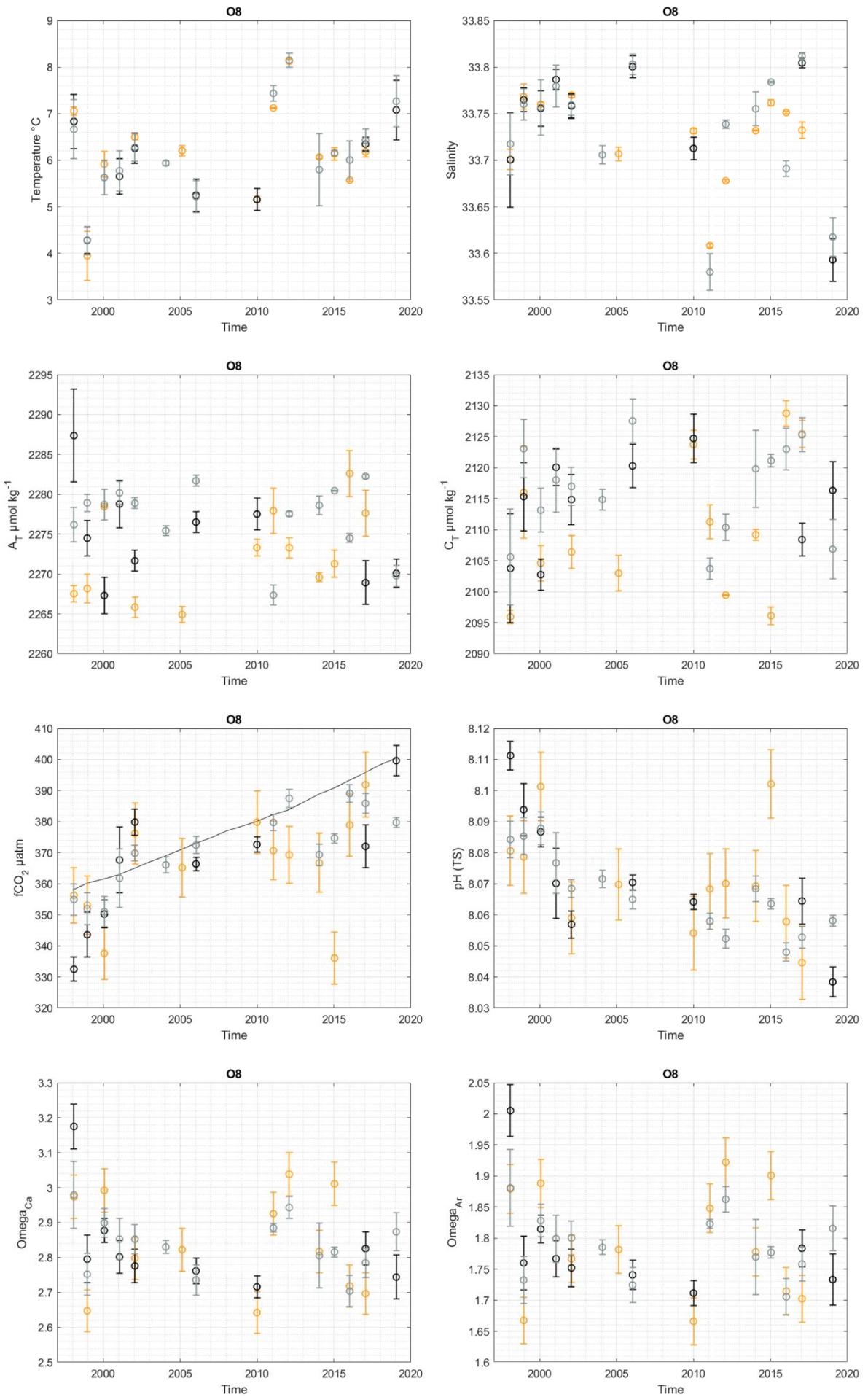
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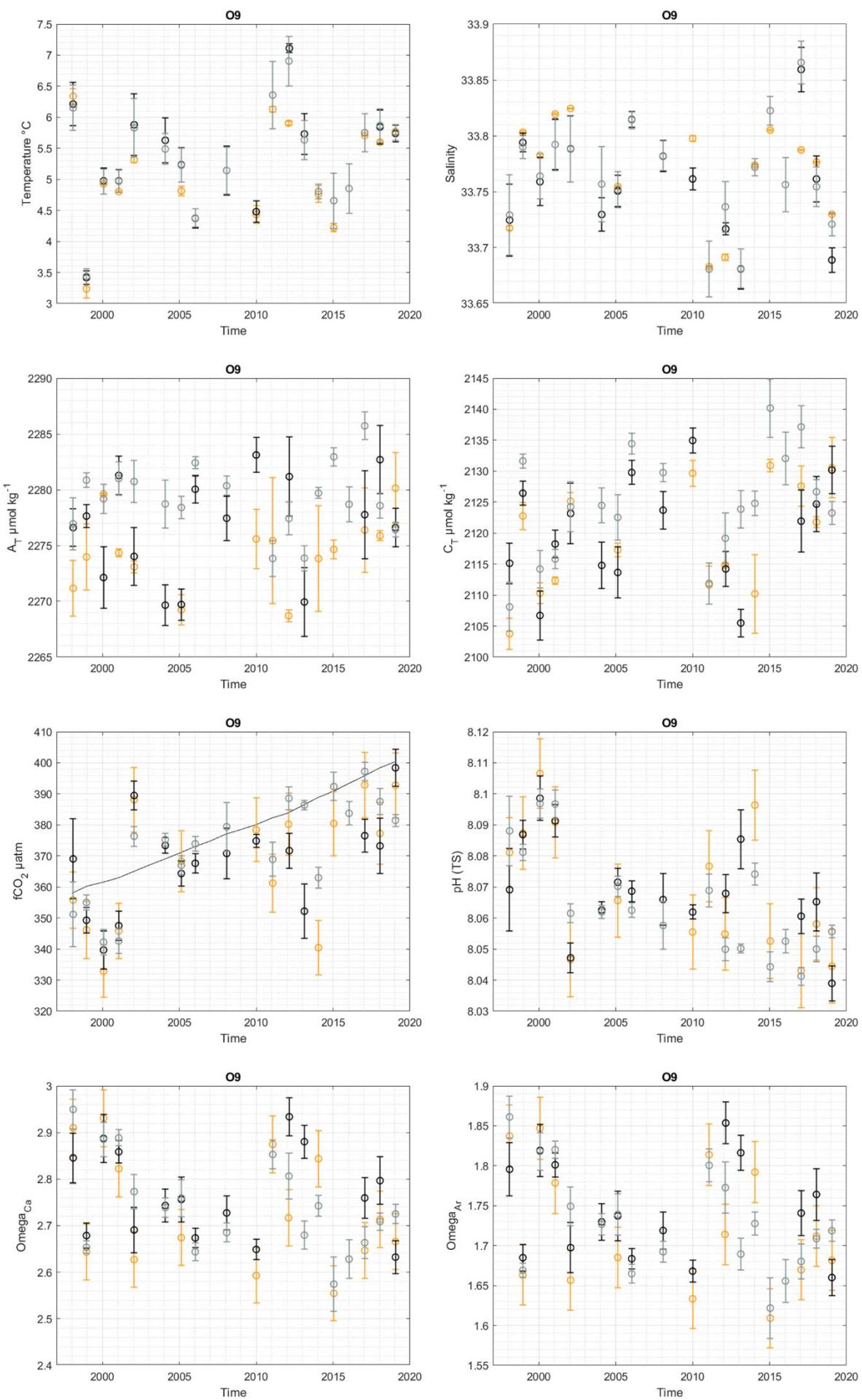
**Figure S1.** 1998 to 2019 evolution of temperature, salinity, AT, CT, fCO<sub>2</sub>, pH, Omega(Ca) and Omega(Ar) evaluated during summer from the fCO<sub>2</sub> surface dataset (in grey), the AT CT surface dataset (in black) and the AT CT data in the mixed layer (in orange). Atmospheric fCO<sub>2</sub> evolution is identified in black solid line (in situ atmospheric measurements from Crozet Island, available on <http://www.esrl.noaa.gov/gmd/dv/iadv/>).

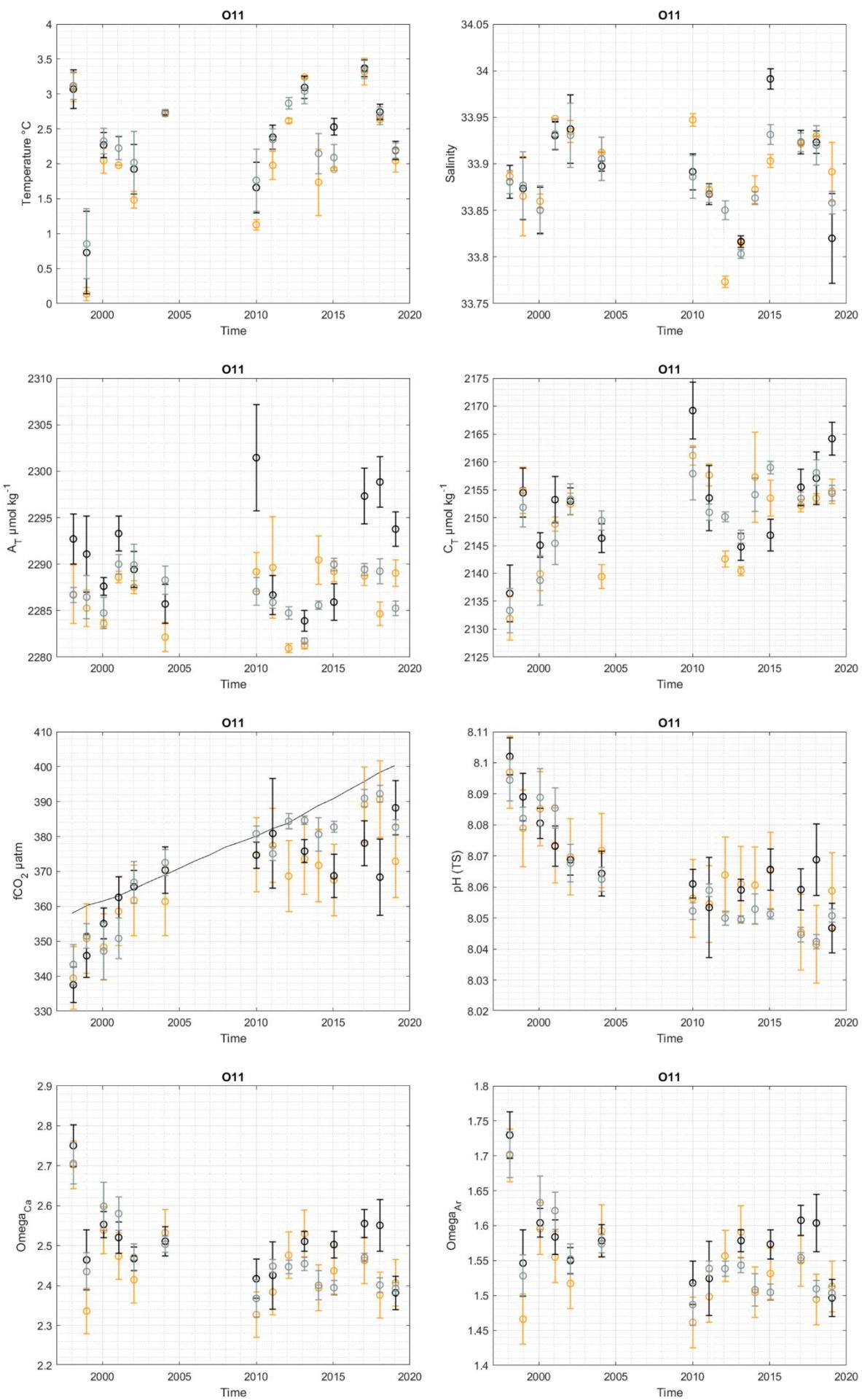
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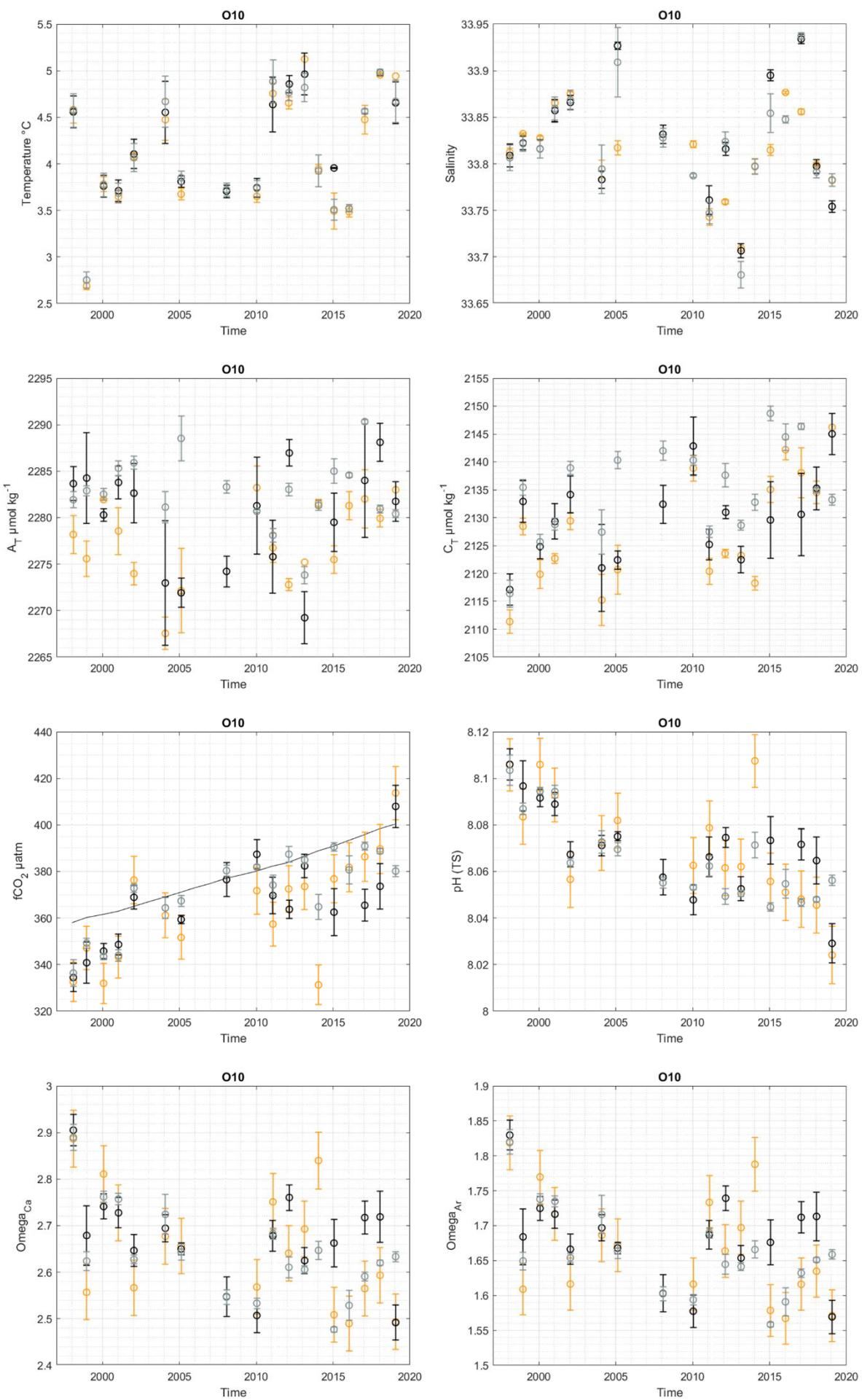


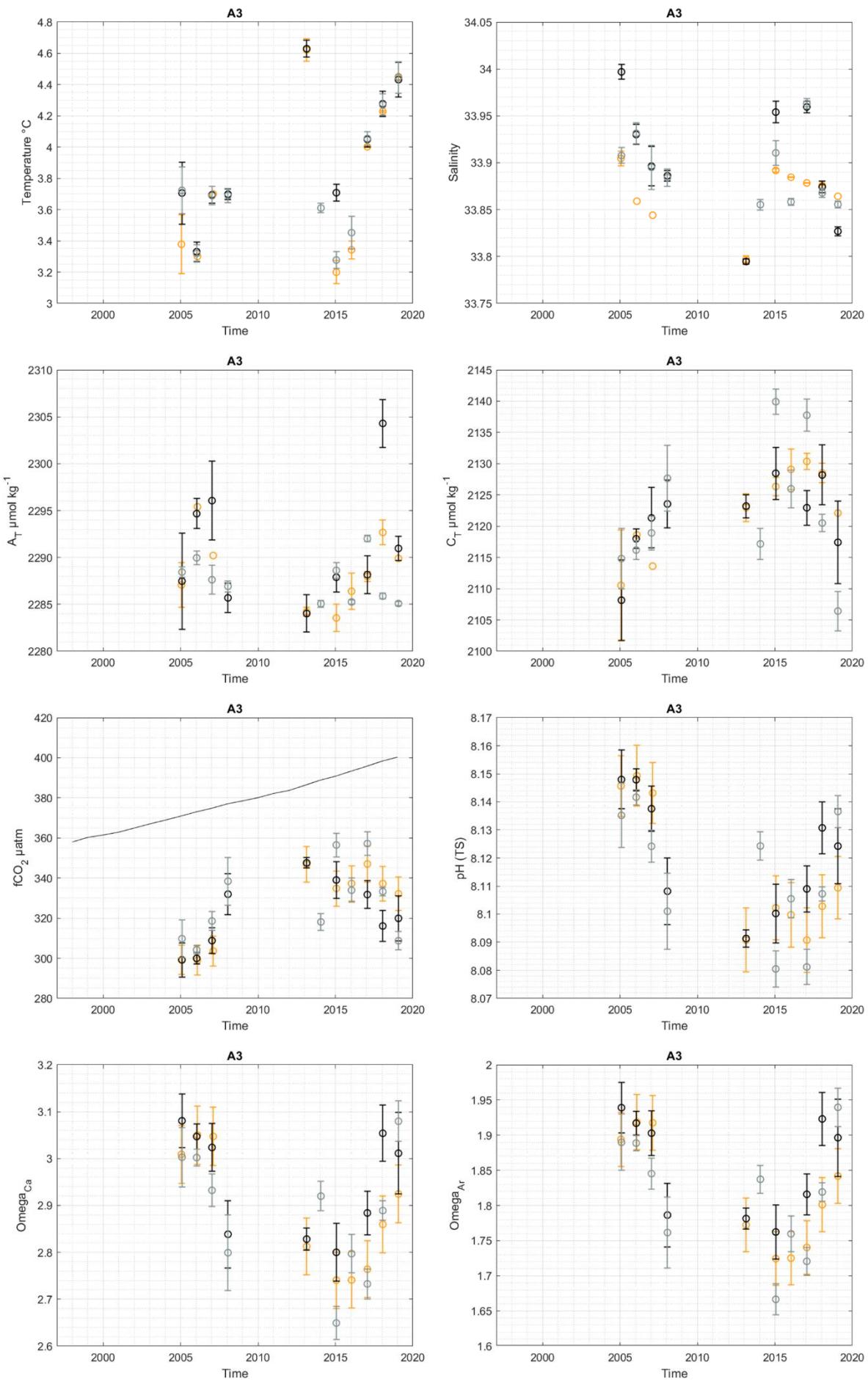


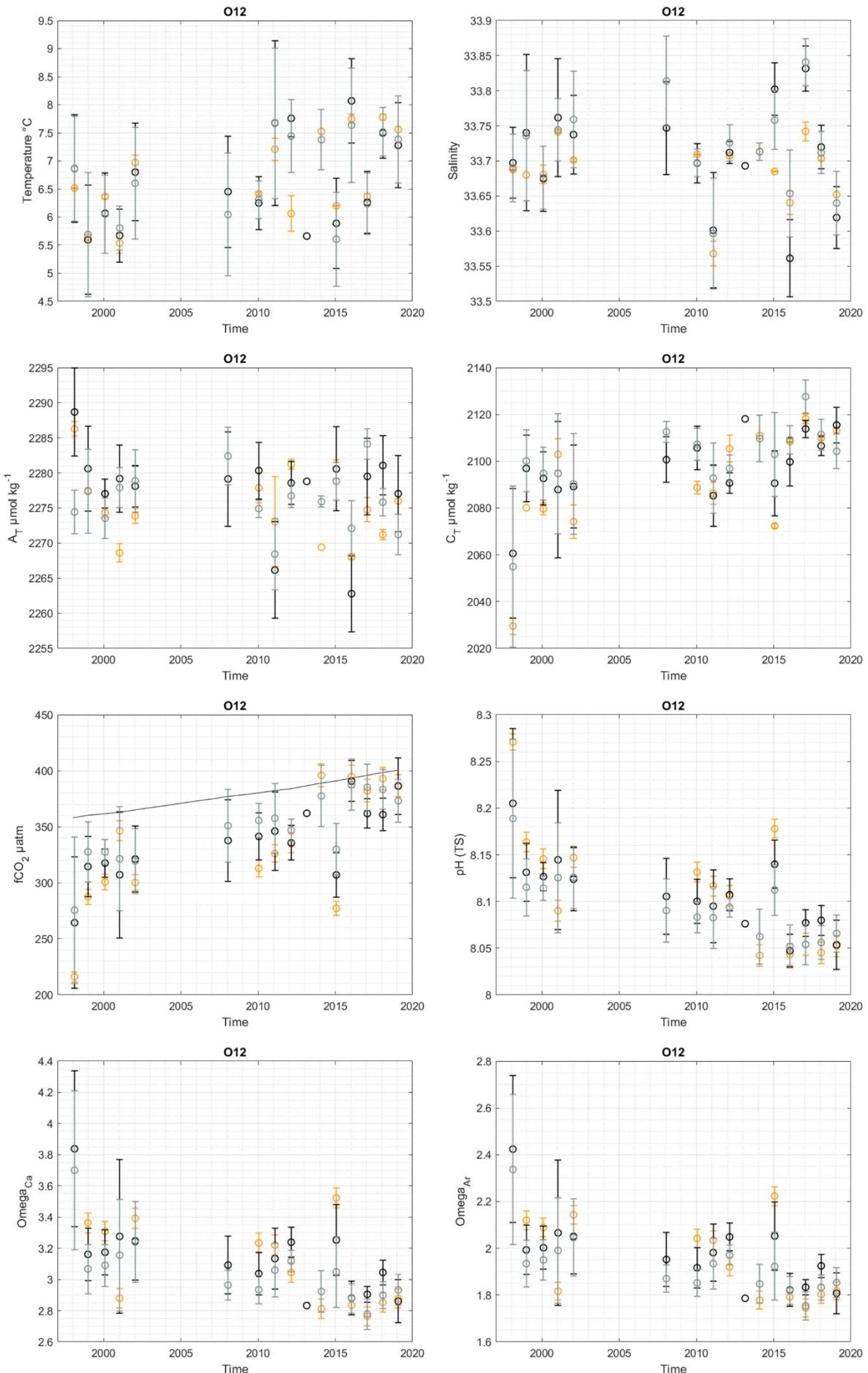


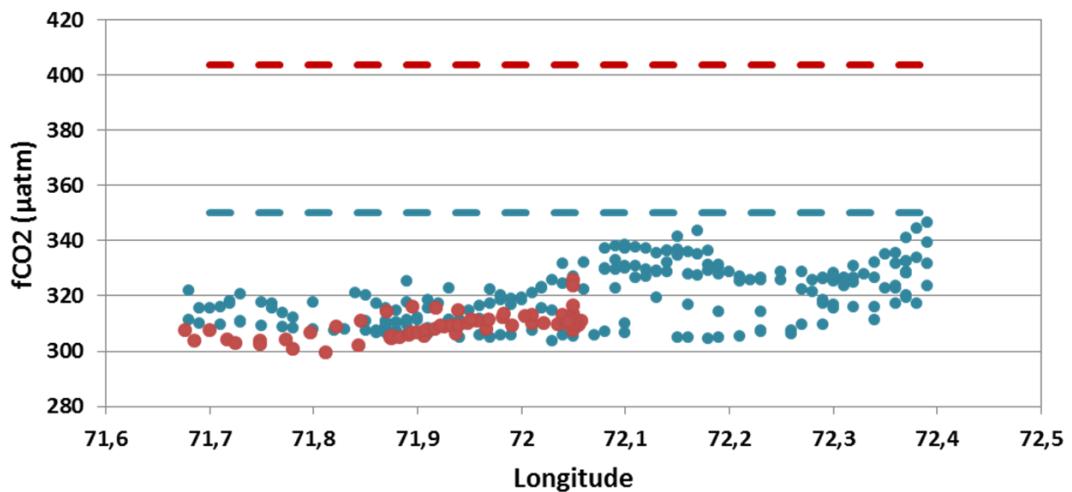




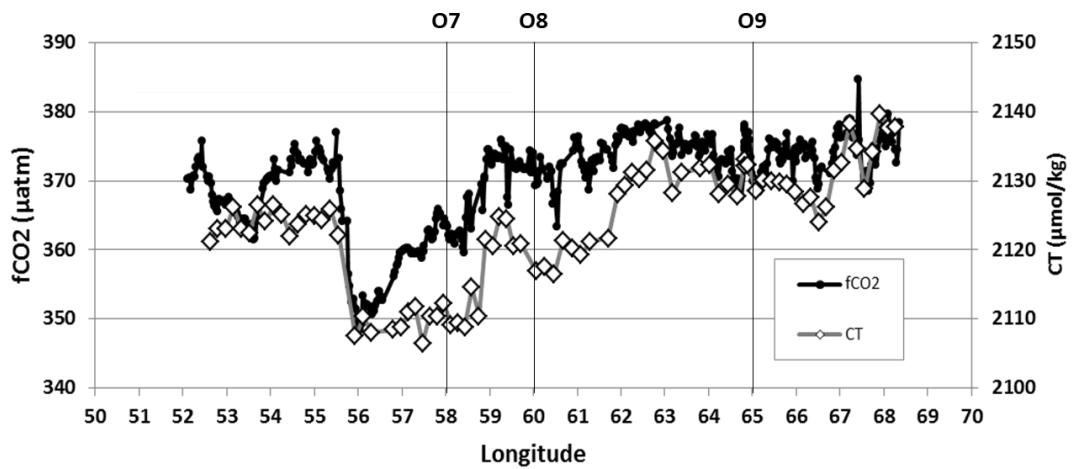








**Figure S2.** Surface ocean fCO<sub>2</sub> monitoring around station A3 in summer 1991 (blue dot) and summer 2019 (red dot). The atmospheric average fCO<sub>2</sub> is represented by the dotted line for summer 1991 (blue) and summer 2019 (red).



**Figure S3.** Surface fCO<sub>2</sub> and C<sub>T</sub> recorded in January 2006 (OISO-14) between Crozet and Kerguelen. The low fCO<sub>2</sub> and

5 C<sub>T</sub> around 56-59°E (around station O7) were regularly observed in 1998-2019.

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