



Supplement of

Summer trends and drivers of sea surface fCO₂ and pH changes observed in the southern Indian Ocean over the last two decades (1998–2019)

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Table S1. Published long-term trends of fCO₂ 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 ₂ [μatm yr ⁻¹]	Trend pH [yr ⁻¹]	Reference
5	1986-2007	Winter	0.8-6.5 °C	+2.10 (0.60)	NR	Takahashi et al. (2009) ¹
	1986-2007	Winter	SO 50-60°S	+2.13 (0.64)	NR	Takahashi et al. (2009) ²
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) ⁴
	1991-2000	Summer	IO PFZ 50-55°S	+2.21	-0.0024	Xue et al. (2018) ⁴
	2001-2011	Summer	IO PZ 55-60°S	+1.41	-0.0016	Xue et al. (2018) ⁴
	2001-2011	Summer	IO PFZ 50-55°S	+1.61	-0.0016	Xue et al. (2018) ⁴
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) ³
	1986-2010	Winter	1.5°C - 4.5°C	+2.44 (0.33)	NR	Takahashi et al. (2012) ³
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) ⁵
50	1970-2011	Annual	SO >45°S	+1.45 (0.05)	NR	Tjiputra et al. (2014) ⁶
	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)
55	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)
55	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)
60	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)
60	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)

Notes Table S1: (a) Latitudinal band or SST range depending on the study. ¹Mean trend for SST range 0.8-6.5 °C (Table 4 in Takahashi et al. (2009); ²Mean trend for the band 50-60°S (Table 5 in Takahashi et al. (2009); ³Same as Takahashi et al. (2009) revisited for the period 1986-2010; ⁴same as Xue et al. (2015) but using slightly different periods. ⁵Based on observations or ⁶multi-model mean from five models.

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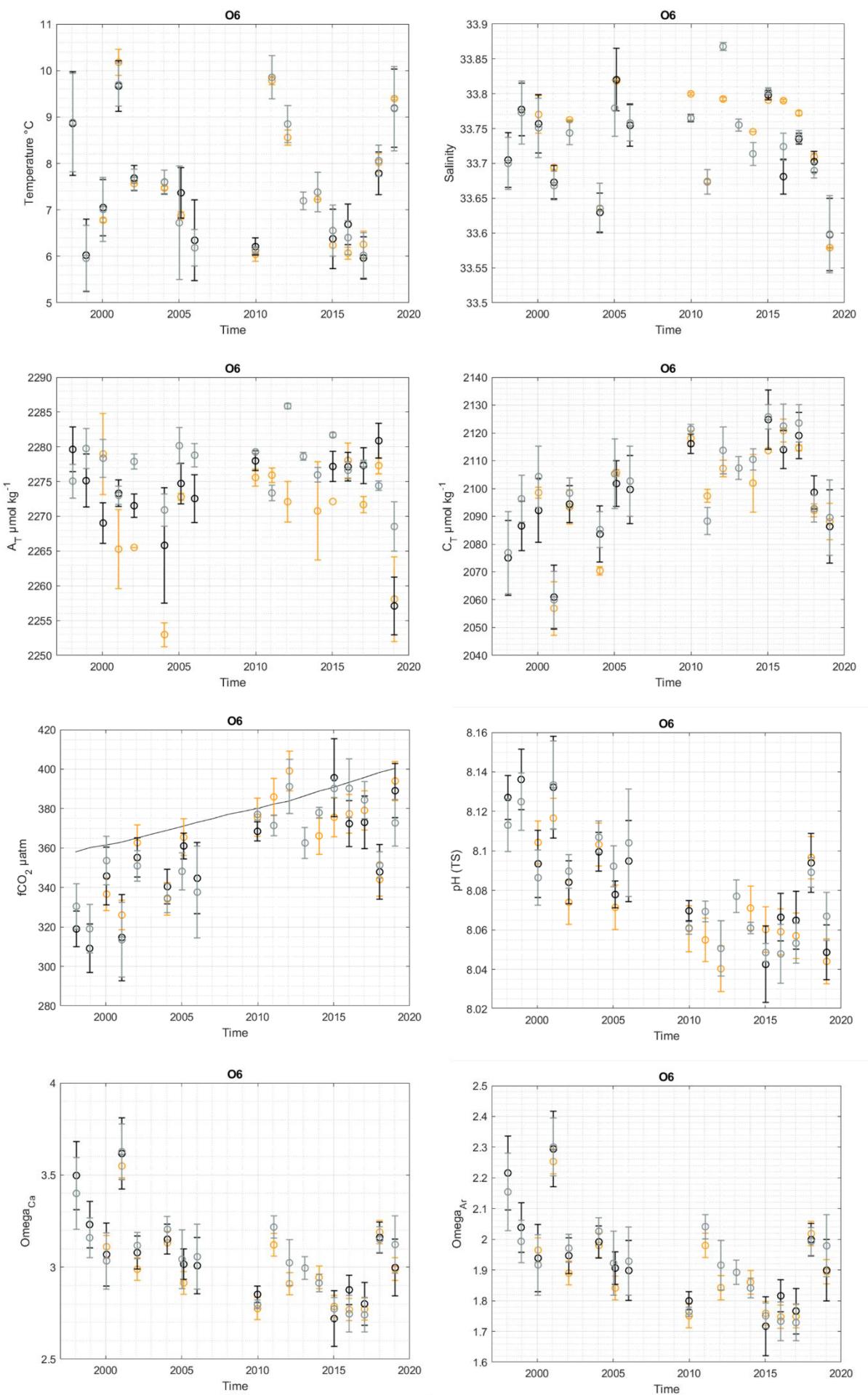
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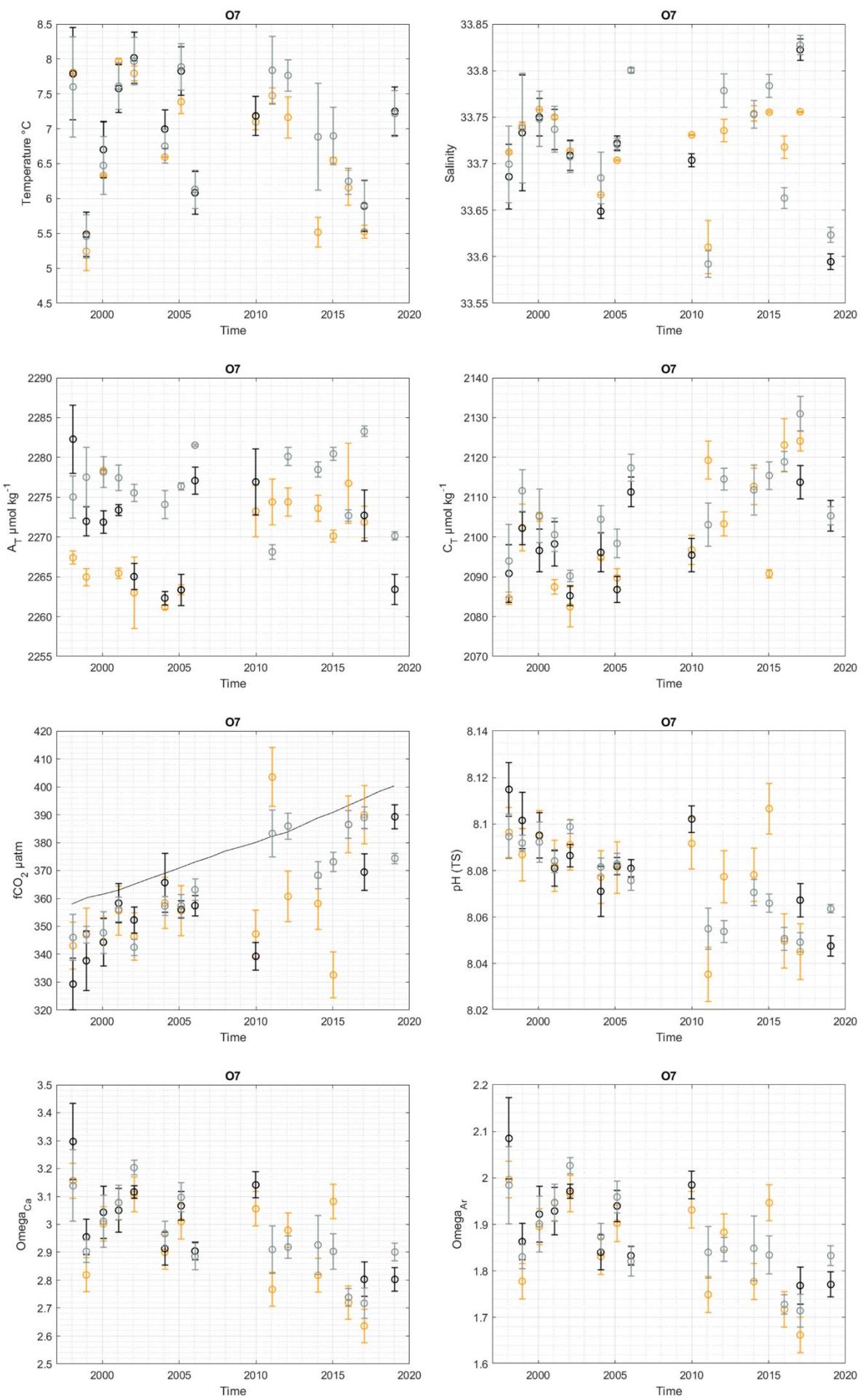
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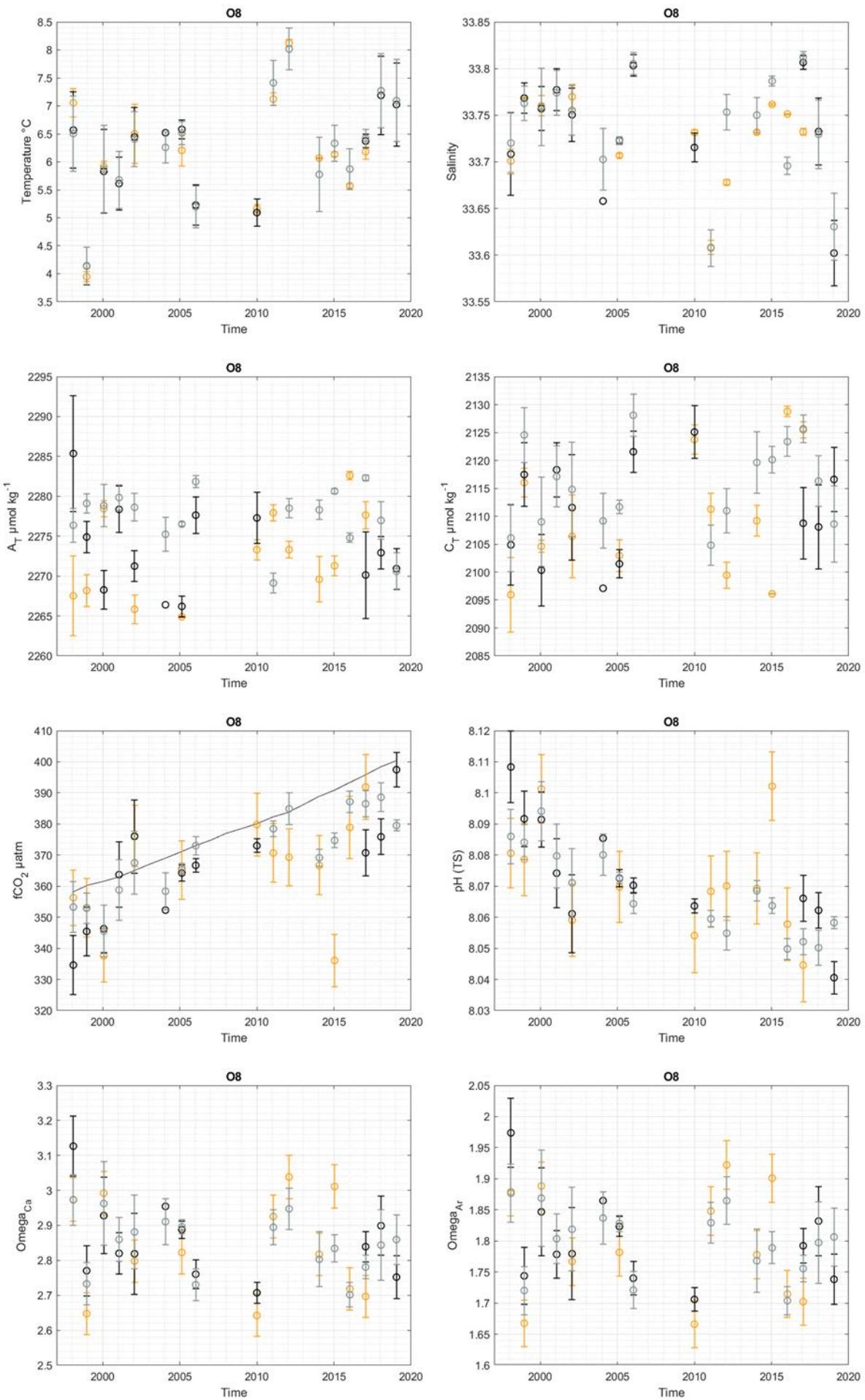
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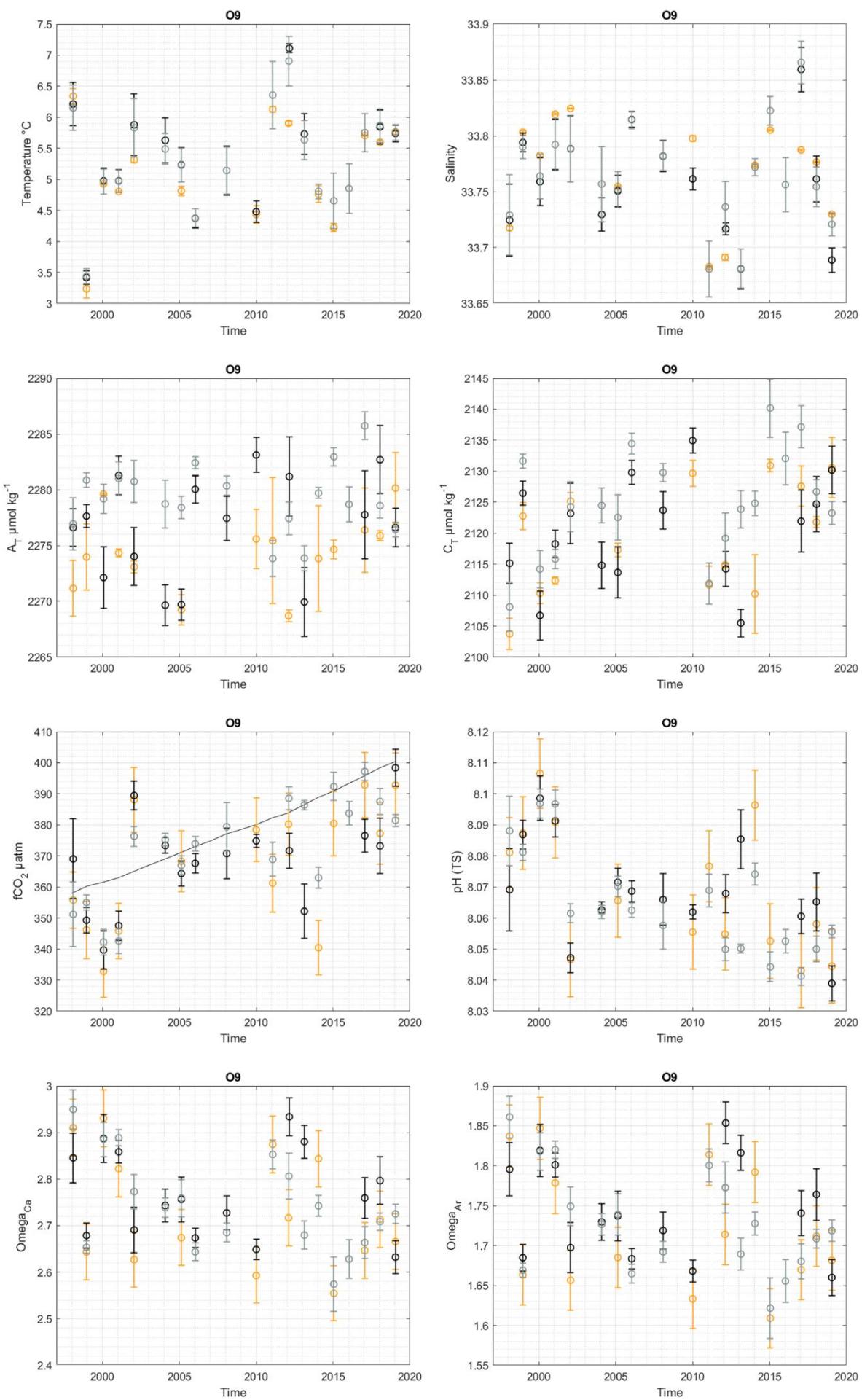
Figure S1. 1998 to 2019 evolution of temperature, salinity, AT, CT, fCO₂, pH, Omega(Ca) and Omega(Ar) evaluated during summer from the fCO₂ surface dataset (in grey), the AT CT surface dataset (in black) and the AT CT data in the mixed layer (in orange). Atmospheric fCO₂ evolution is identified in black solid line (in situ atmospheric measurements from Crozet Island, available on <http://www.esrl.noaa.gov/gmd/dv/iadv/>). Each point (black or grey) corresponds to the surface average around the station (average in the mixed layer). Each page corresponds to a station: O6 (p.4), O7 (p.5), O8 (p.6), O9 (p.7), O11 (p.8), O10 (p.9), A3 (p.10) and O12 (p.11).

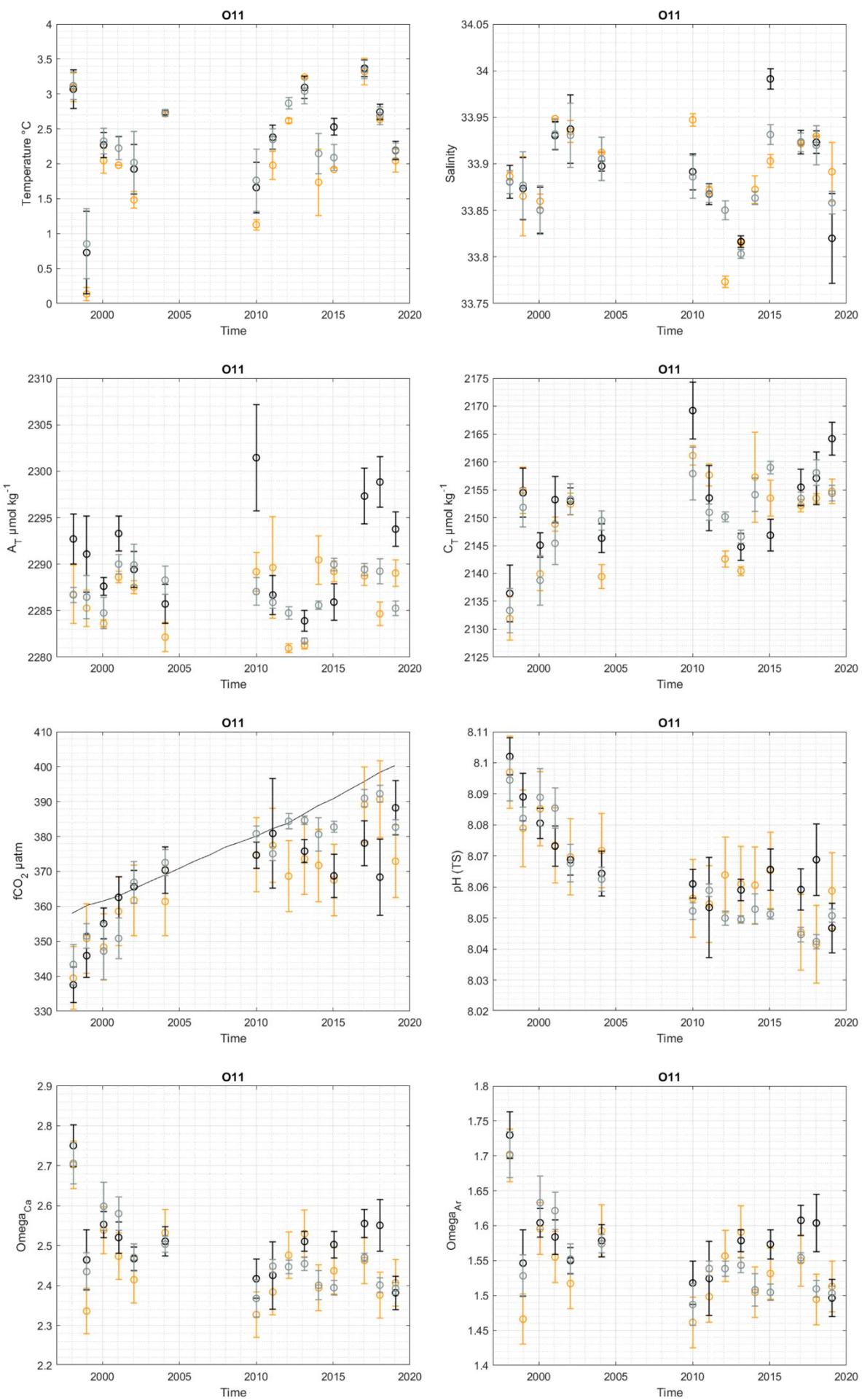
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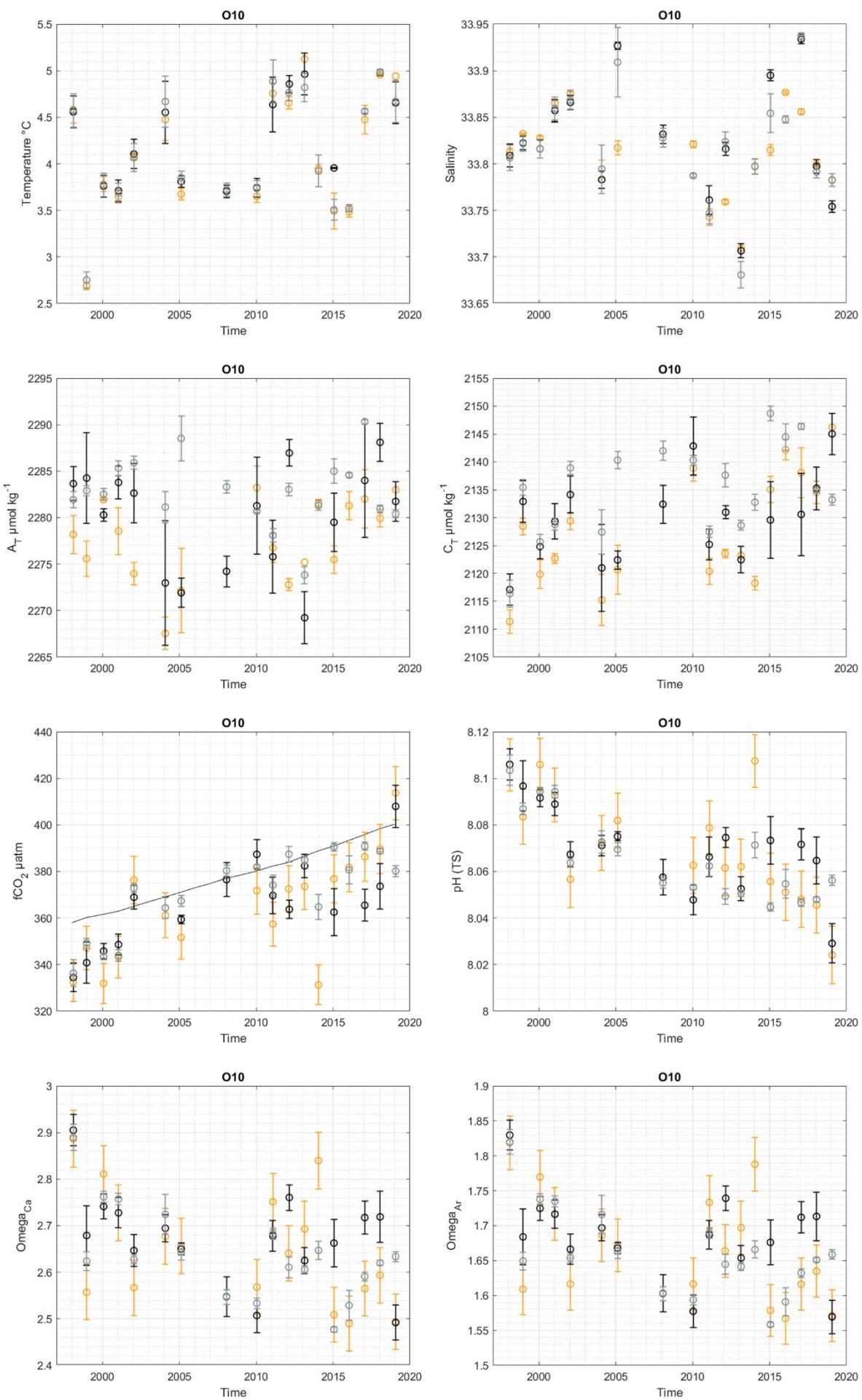


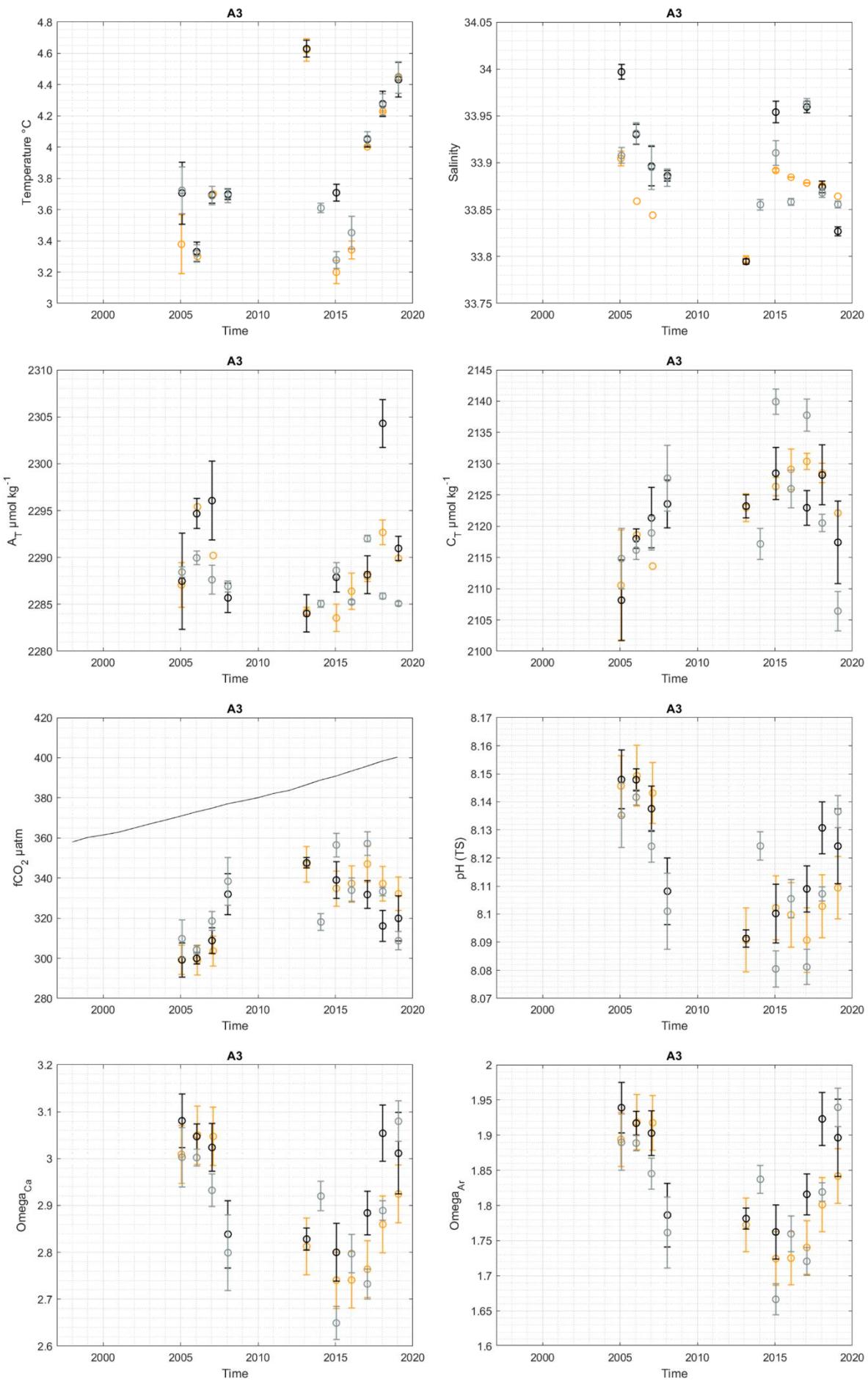


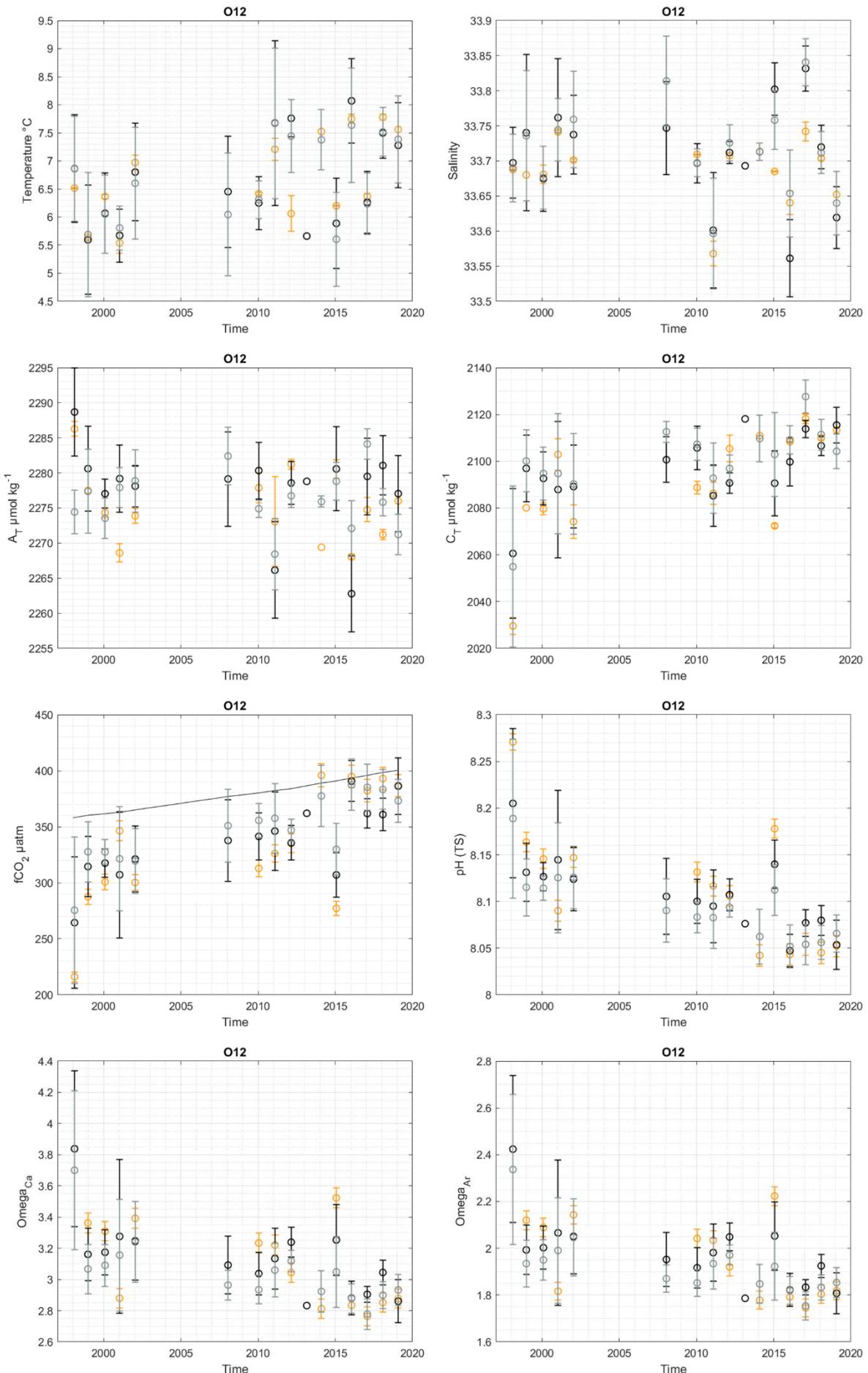












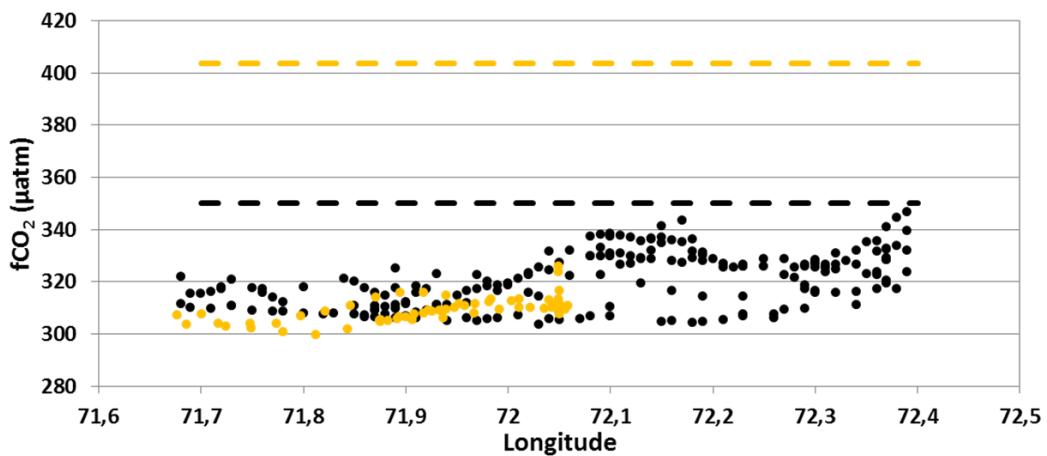


Figure S2. Surface ocean fCO₂ monitoring around station A3 in summer 1991 (black dot) and summer 2019 (yellow dot). The atmospheric average fCO₂ is represented by the dotted line for summer 1991 (black) and summer 2019 (yellow).

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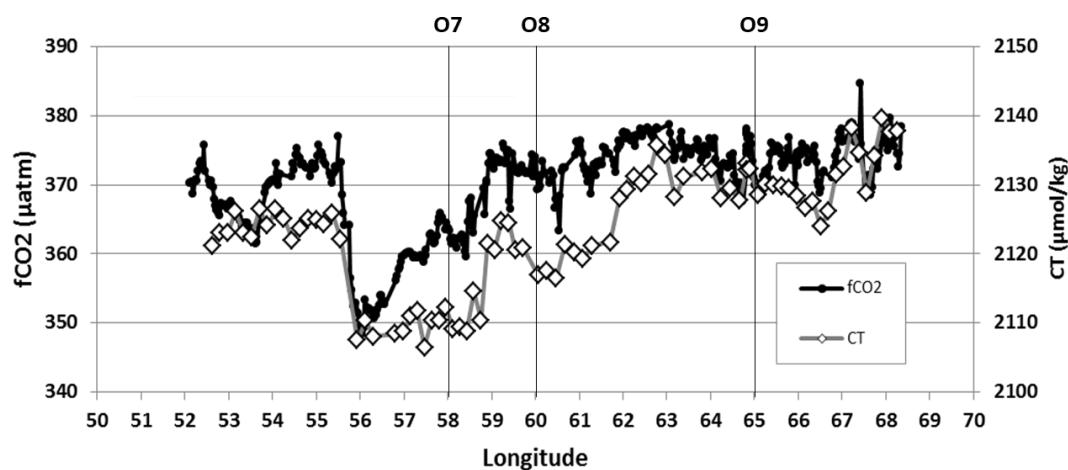


Figure S3. Surface fCO₂ and C_T recorded in January 2006 (OISO-14) between Crozet and Kerguelen. The low fCO₂ and
10 C_T around 56-59°E (around station O7) were regularly observed in 1998-2019.

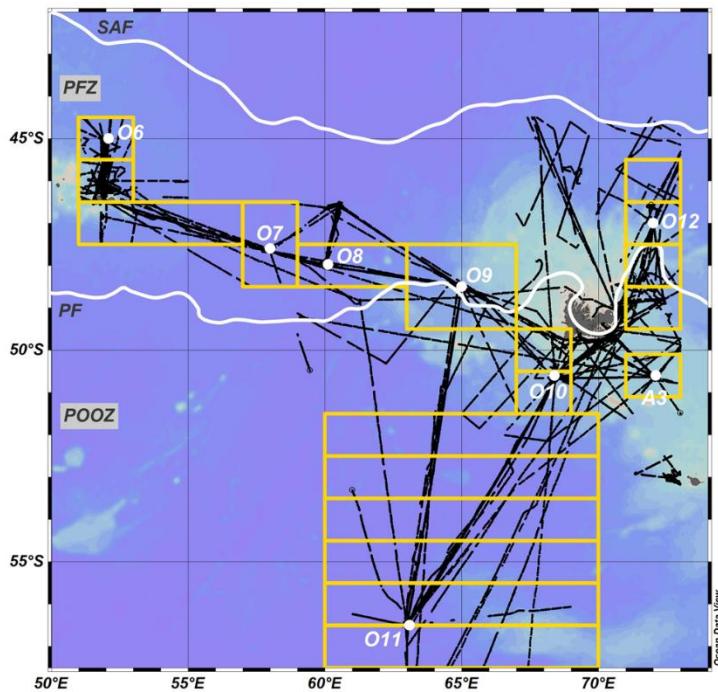


Figure S4. Tracks of summer cruises in 1998–2019 with sea surface fCO₂ data (black dots) from SOCAT version v2020 (Bakker et al., 2020). The yellow boxes represent the grouping by latitude and longitude done to construct Figure 4. Some boxes are centered at stations location (white circles). SAF and PF indicated in white. PFZ stands for Polar Front Zone and POOZ for Permanent Open Ocean Zone (i.e. north of the winter ice edge). Bathymetry is plotted as background based on GEBCO-2019 (figure produced with ODV, Schlitzer, 2021).

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