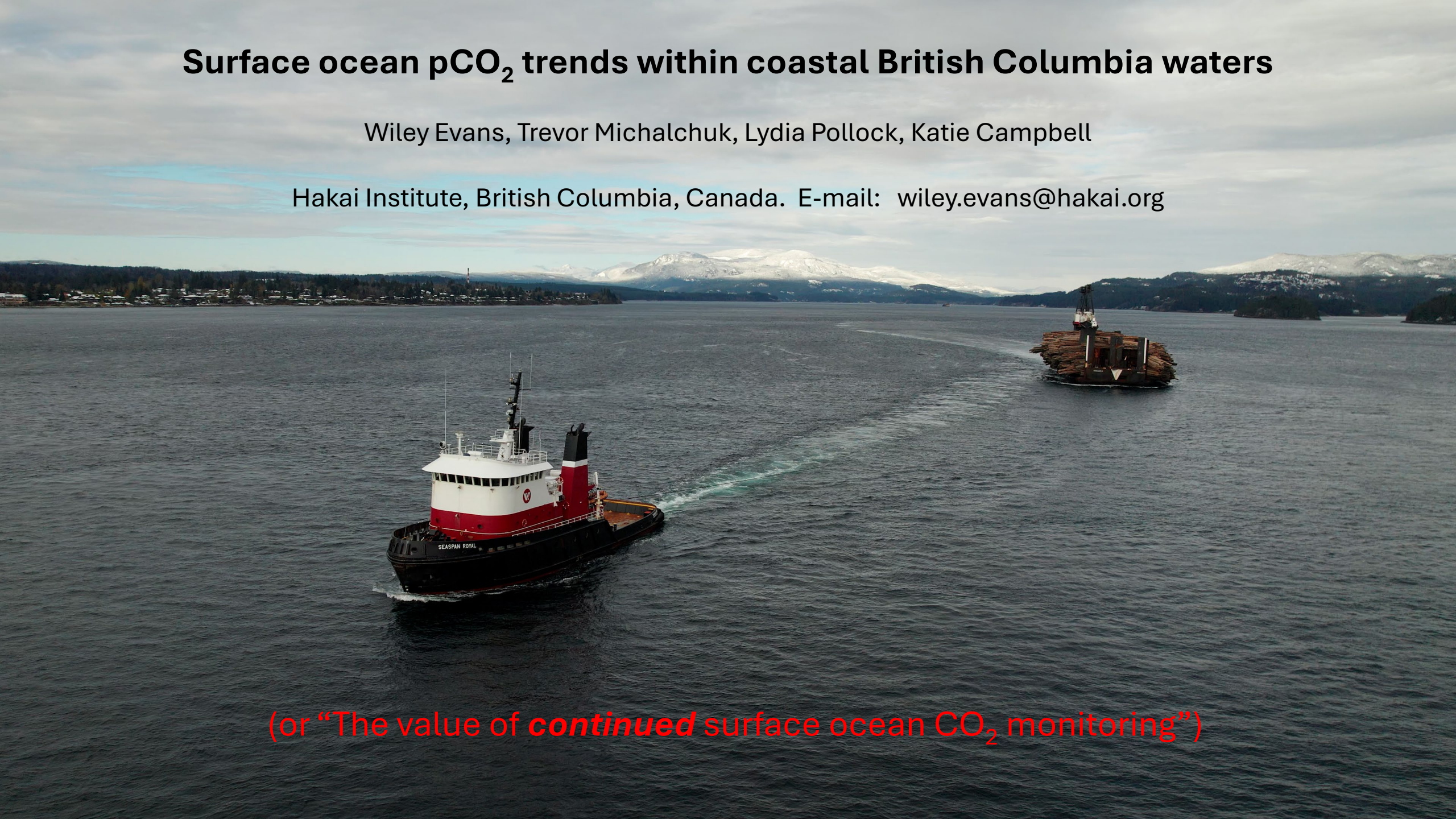
Surface ocean pCO_2 trends within coastal British Columbia waters

Wiley Evans, Trevor Michalchuk, Lydia Pollock, Katie Campbell

Hakai Institute, British Columbia, Canada. E-mail: wiley.evans@hakai.org



(or "The value of ***continued*** surface ocean CO_2 monitoring")

Why do this work?

- Patterns in $pCO_{2,SW}$ data provide information on ocean acidification – continued uptake of CO_2 emissions each year are driving increases and intensifying extremes
- The ocean absorbs ~30% of human-caused CO_2 emissions each year – collecting high-quality $pCO_{2,SW}$ data is essential for constraining the ocean's role
- Baseline information on sea-air CO_2 exchange is essential for marine CO_2 interventions to be realized



Hakai ERDDAP
Easier access to the Hakai Institute data

CIOOS PACIFIC
REGIONAL ASSOCIATION OF THE
CANADIAN INTEGRATED OCEAN OBSERVING SYSTEM

SOCAT
· SURFACE OCEAN CO_2 ATLAS ·

Global Carbon Budget 2025

Pierre Friedlingstein[1,2], Michael O'Sullivan[1], Matthew W. Jones[3], Robbie M. Andrew[4], Dorothee C. E. Bakker[5], Judith Hauck[6,7], Peter Landschützer[8], Corinne Le Quéré[3], Hongmei Li[9,10], Ingrid T. Luijkx[11], Glen P. Peters[4], Wouter Peters[11,12], Julia Pongratz[13,10], Clemens Schwingshackl[13], Stephen Sitch[1], Josep G. Canadell[14], Philippe Ciais[15], Kjetil Aas[4], Simone R. Alin[16], Peter Anthoni[17], Leticia Barbero[18], Nicholas R. Bates[19,20], Nicolas Bellouin[21], Alice Benoit-Cattin[22], Carla F. Berghoff[23], Raffaele Bernardello[24], Laurent Bopp[2], Ida Bagus Mandhara Brasika[1,25], Matthew A. Chamberlain[26], Naveen Chandra[27], Frédéric Chevallier[15], Louise P. Chini[28], Nathan O. Collier[29], Thomas H. Colligan[30], Margot Cronin[31], Laique M. Djeutchouang[32,33,34], Xinyu Dou[35], Matt P. Enright[19,20], Kazutaka Enyo[36], Michael Erb[37,38], Wiley Evans[39], Richard A. Feely[16], Liang Feng[40,41], Daniel J. Ford[1], Adrianna Foster[42], Filippa Fransner[43,44], Thomas Gasser[45], Marion Gehlen[15], Thanos Gkritzalis[8], Jefferson Goncalves De Souza[1], Giacomo Grassi[46], Luke Gregor[47,48], Nicolas Gruber[47], Bertrand Guenet[49], Özgür Gürses[6], Kirsty Harrington[50], Ian Harris[51], Jens Heinke[52], George C. Hurtt[28], Yosuke Iida[36], Tatiana Ilyina[53,9,10], Akihiko Ito[54], Andrew R. Jacobson[55,56], Atul K. Jain[57], Tereza Jarníková[3], Annika Jersild[38], Fei Jiang[58], Steve D. Jones[8], Etsushi Kato[59], Ralph F. Keeling[60], Kees Klein Goldewijk[61], Jürgen Knauer[62], Yawen Kong[63,64], Jan Ivar Korsbakken[4], Charles Koven[65], Taro Kunimitsu[4], Xin Lan[55,56], Junjie Liu[66,67], Zhiqiang Liu[68], Zhu Liu[69], Claire Lo Monaco[70], Lei Ma[28], Gregg Marland[37,38], Patrick C. McGuire[71], Galen A. McKinley[72], Joe R. Melton[73], Natalie Monacci[74], Erwan Monier[75,76], Eric J. Morgan[60], David R. Munro[55,56], Jens D. Müller[77], Shin-Ichiro Nakaoka[78], Lorna R. Nayagam[78], Yosuke Niwa[78], Tobias Nutzel[13], Are Olsen[43,44], Abdirahman M. Omar[79,44], Naiqing Pan[80], Sudhanshu Pandey[66], Denis Pierrot[81], Zhangcai Qin[82], Pierre Regnier[83], Gregor Rehder[84], Laure Resplandy[85], Alizée Roobaert[8], Thais M. Rosan[1], Christian Rödenbeck[86], Jörg Schwinger[44,79], Ingunn Skjelvan[79,44], T. Luke Smallman[40,41], Victoria Spada[87], Mohanan G. Sreeush[6], Qing Sun[88], Adrienne J. Sutton[16], Colm Sweeney[56], Didier Swingedouw[89], Roland Séférian[90], Shintaro Takao[78], Hiroaki Tatebe[91,92], Hanqin Tian[80], Xiangjun Tian[93,94], Bronte Tilbrook[26,95], Hiroyuki Tsujino[96], Francesco Tubiello[97], Erik van Ooijen[26], Guido R. van der Werf[11], Sebastiaan J. van de Velde[98,99], Anthony P. Walker[100], Rik Wanninkhof[81], Xiaojuan Yang[100], Wenping Yuan[101], Xu Yue[102], and Jiye Zeng[78]

How do “we” do this?







Despite the array of configuration options, **surface ocean CO_2 data collection is on the decline globally**

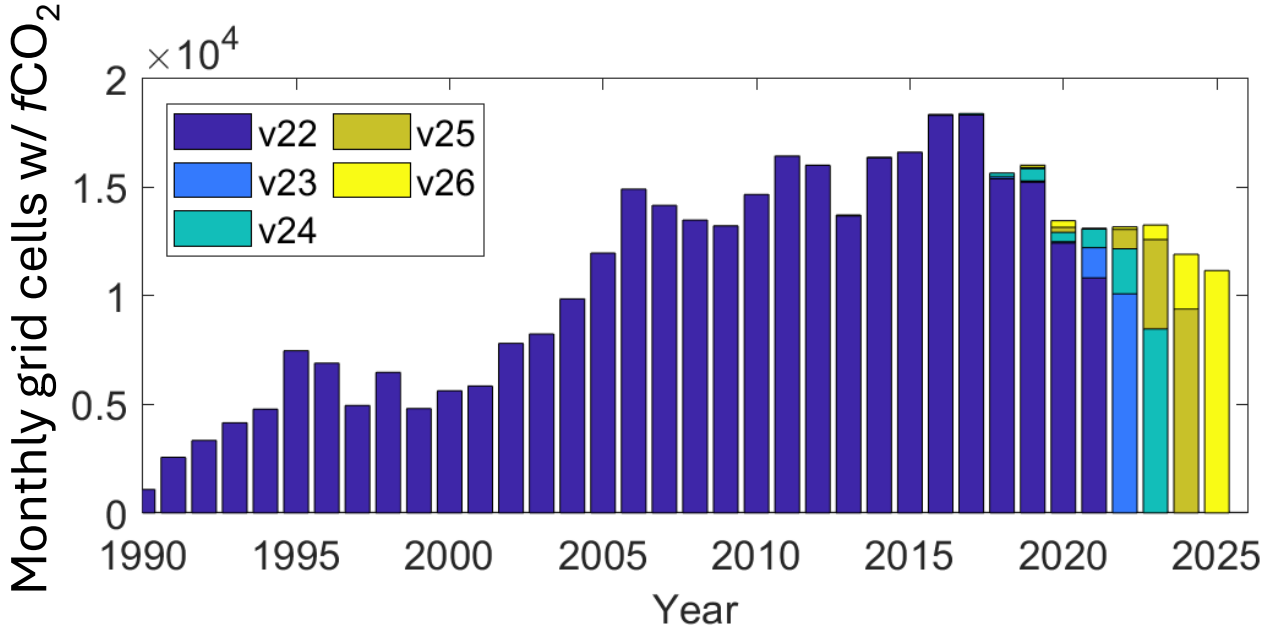


Figure from Dorothee Bakker

What do we know about pCO_2 trends in BC so far?

(1) *Open ocean trends*

Franco et al., 2021 (Line P measurements):

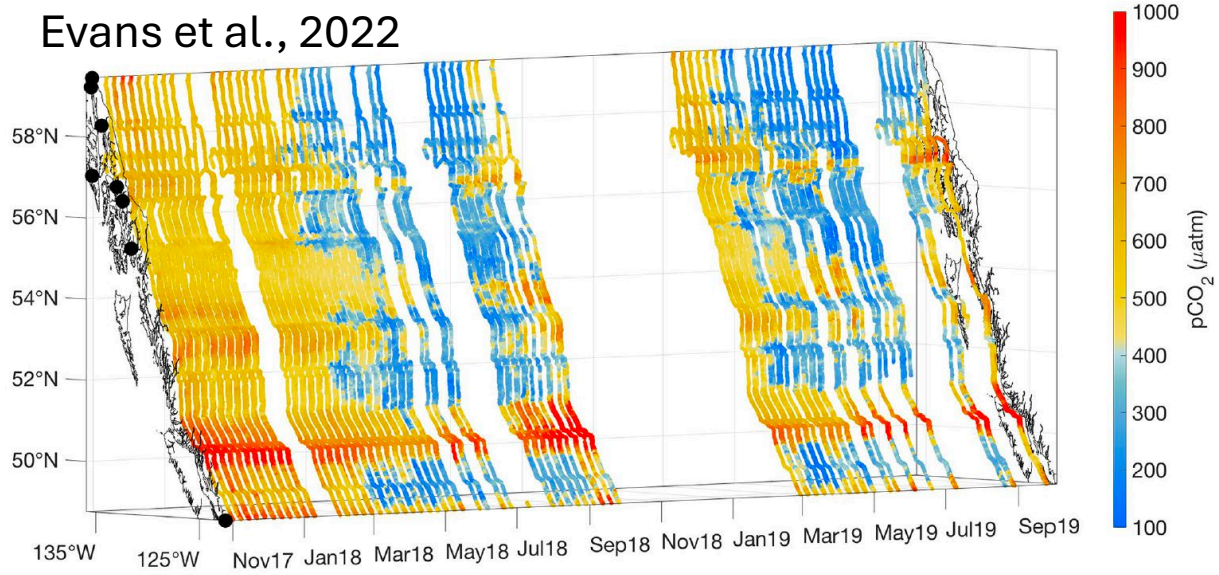
pCO_2 (µatm yr^{-1})	26	1.2 ± 0.8
	20	1.3 ± 0.6
	16	1.6 ± 0.8
	12	1.5 ± 0.6
	4	1.0 ± 1.4

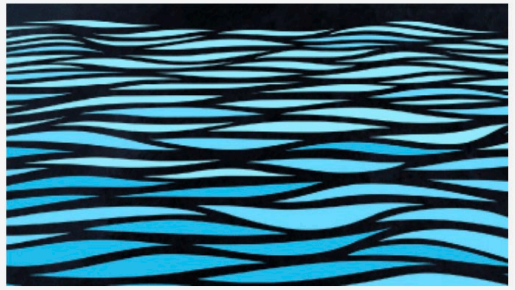
Sutton et al., 2017 (Station Papa mooring):

pCO_2 (µatm yr^{-1}) 1.6±0.5

(2) *Coastal areas are variable*

Evans et al., 2022





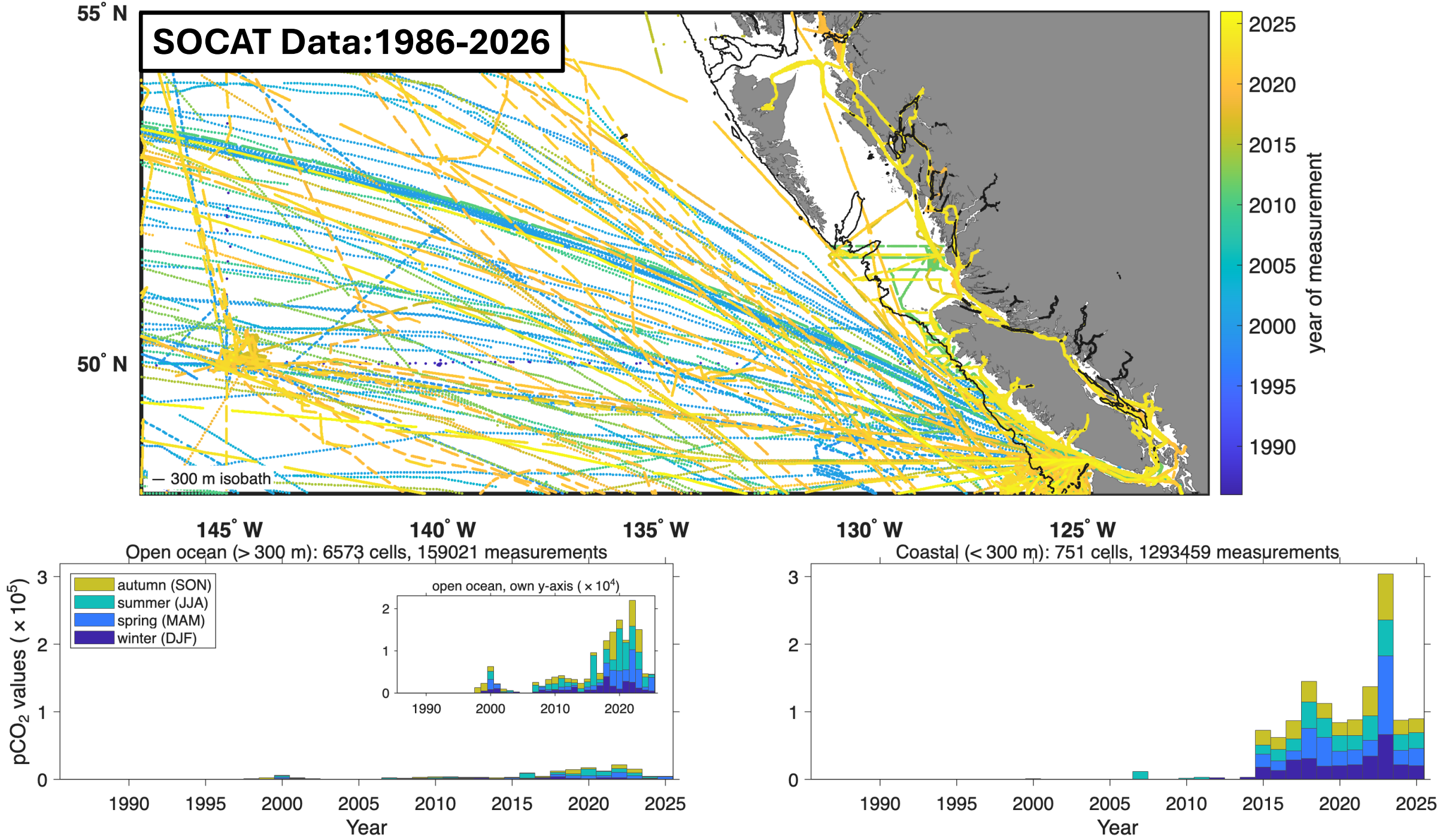
Canada's Changing Climate Report 2026

This second edition is a scientific assessment of past and future climate change in Canada

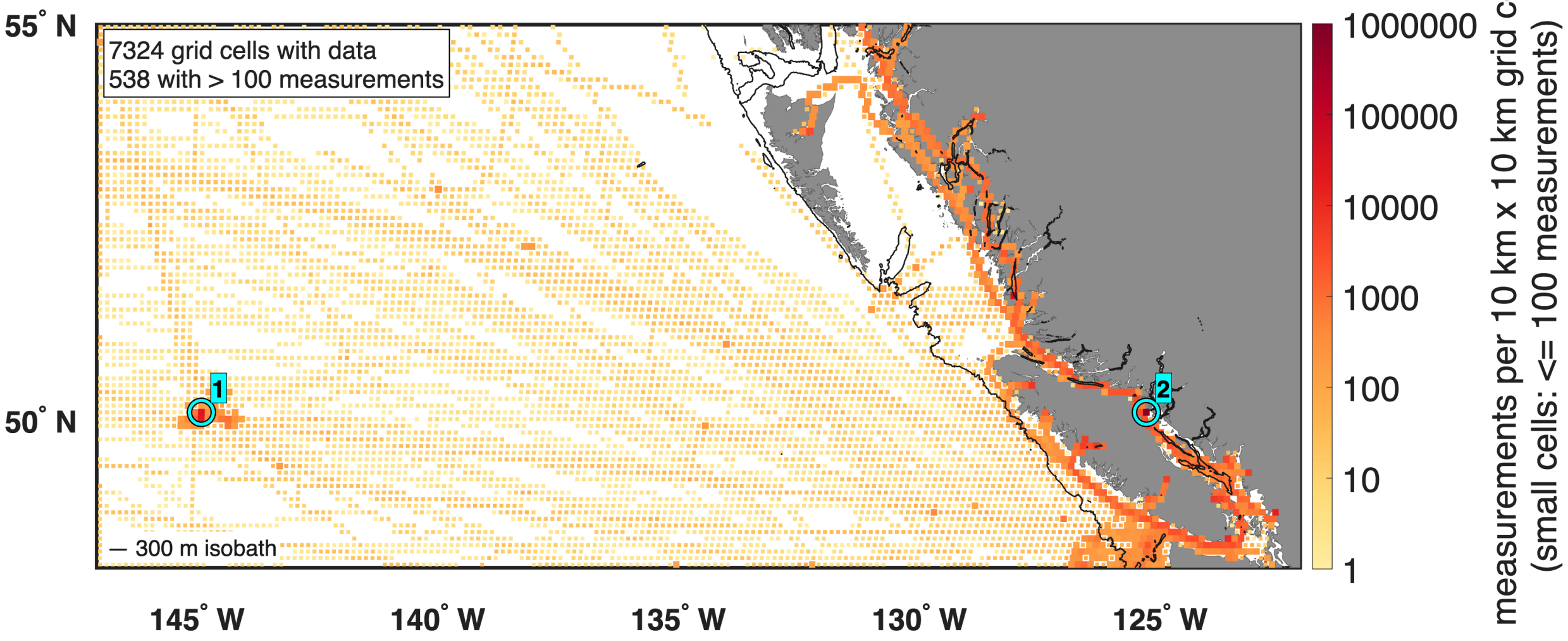
(3) *Perception more data are needed*

"**gaps in data collection prevent the identification of extreme** hypoxia and **acidification events** in many regions"

"waters of the central Scotian Shelf have also probably undergone acidification; however, **direct observations of acidity in this region are too recent to detect a long-term change**"

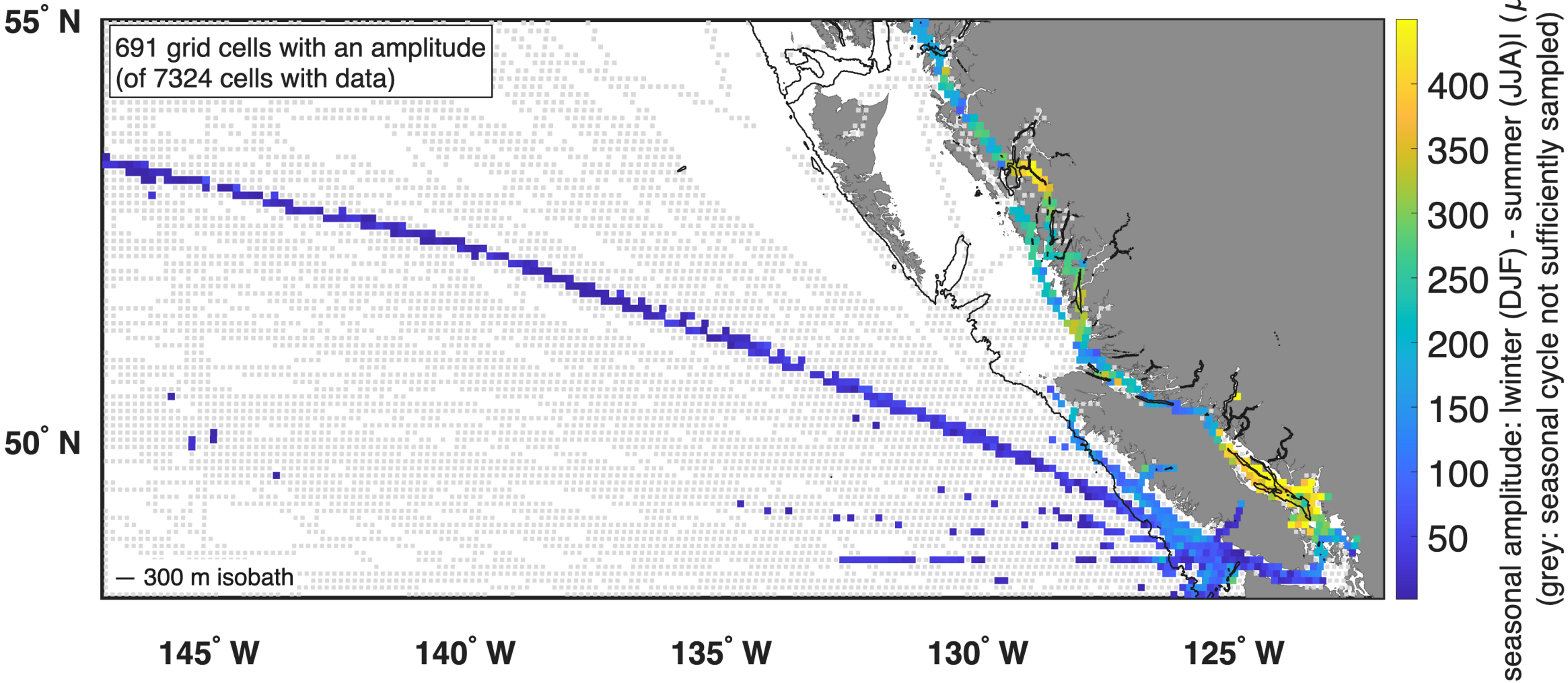

SOCAT Data:1986-2026
55° N
50° N
— 300 m isobath
2025
2020
2015
2010
2005
2000
1995
1990
year of measurement
145° W
140° W
135° W
130° W
125° W
Open ocean (> 300 m): 6573 cells, 159021 measurements
Coastal (< 300 m): 751 cells, 1293459 measurements
autumn (SON)
summer (JJA)
spring (MAM)
winter (DJF)
open ocean, own y-axis (× 10^4)
pCO2 values (× 10^5)
Year

Data density in 10 km x 10 km grid cells



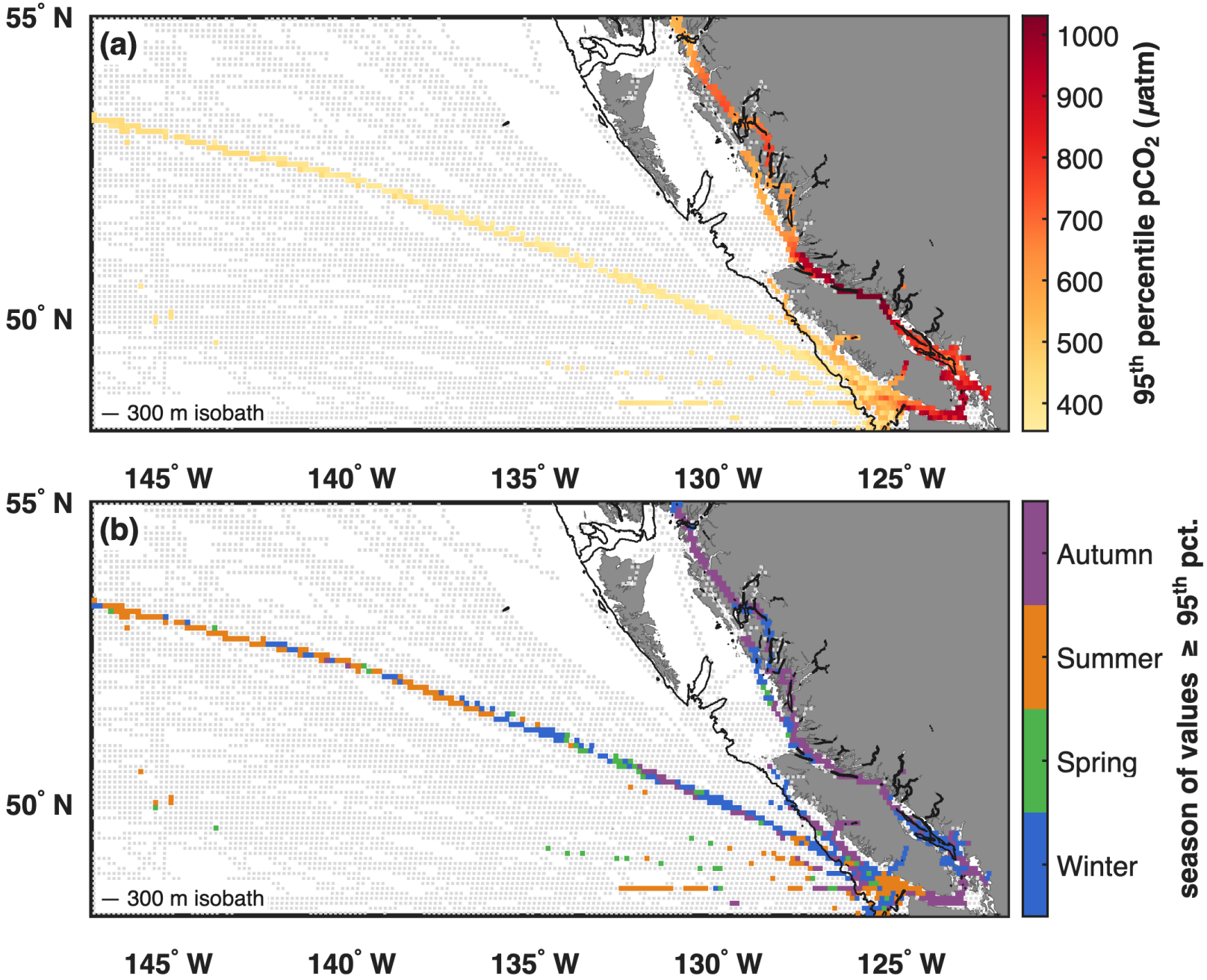
1. 50.113 N, -144.826 E: 25903 measurements, 112 monthly means, 25.8 yr span
2. 50.113 N, -125.194 E: 845876 measurements, 133 monthly means, 11.0 yr span

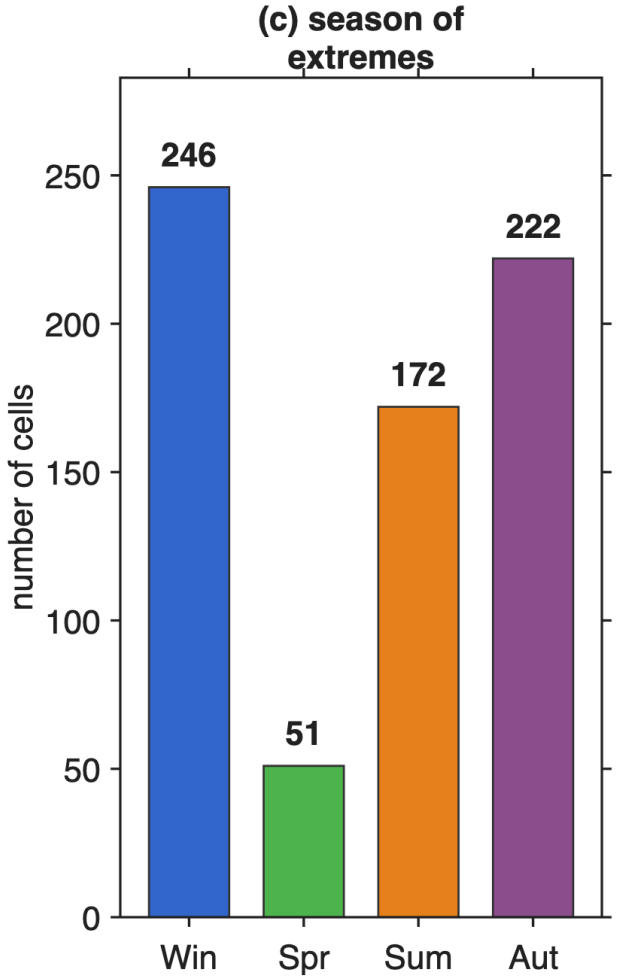
Seasonal amplitude in 10 km x 10 km grid cells



Criteria to estimate seasonal amplitude: (A) ≥6 monthly means, (B) ≥6 different calendar months

Extremes in 10 km x 10 km grid cells



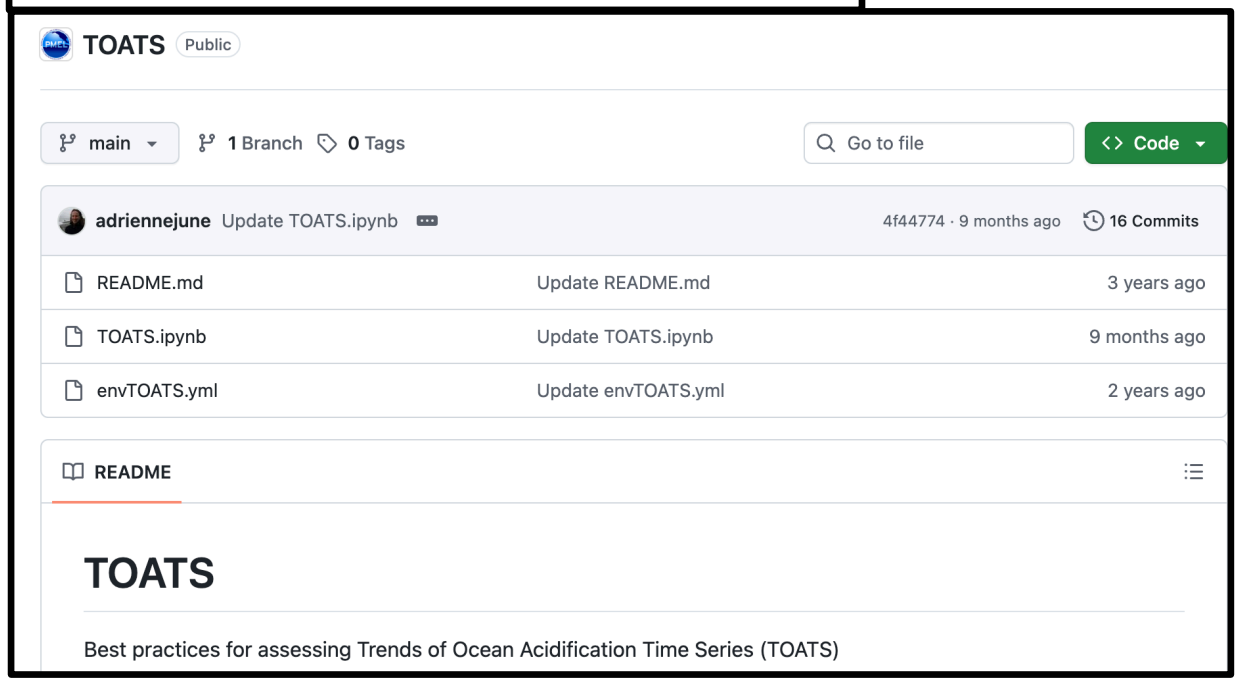


Trends of Ocean Acidification Time Series (TOATS) as a starting point

Advancing best practices for assessing trends of ocean acidification time series

Adrienne J. Sutton[1*], Roman Battisti[1,2], Brendan Carter[1,2], Wiley Evans[3], Jan Newton[4], Simone Alin[1], Nicholas R. Bates[5,6,7], Wei-Jun Cai[8], Kim Currie[9], Richard A. Feely[1], Christopher Sabine[10], Toste Tanhua[11], Bronte Tilbrook[12] and Rik Wanninkhof[13]

https://github.com/NOAA-PMEL/TOATS



Approach (per cell):

1. Compute monthly means
2. Remove preliminary linear trend
3. Compute monthly climatology
4. Compute linear trend of deseasoned monthly means with Newey-West standard errors
5. Compute trend detection time

Thresholds:

1. Significance: Slope > SE; $p < 0.05$
2. Time series length > Trend Detection Time

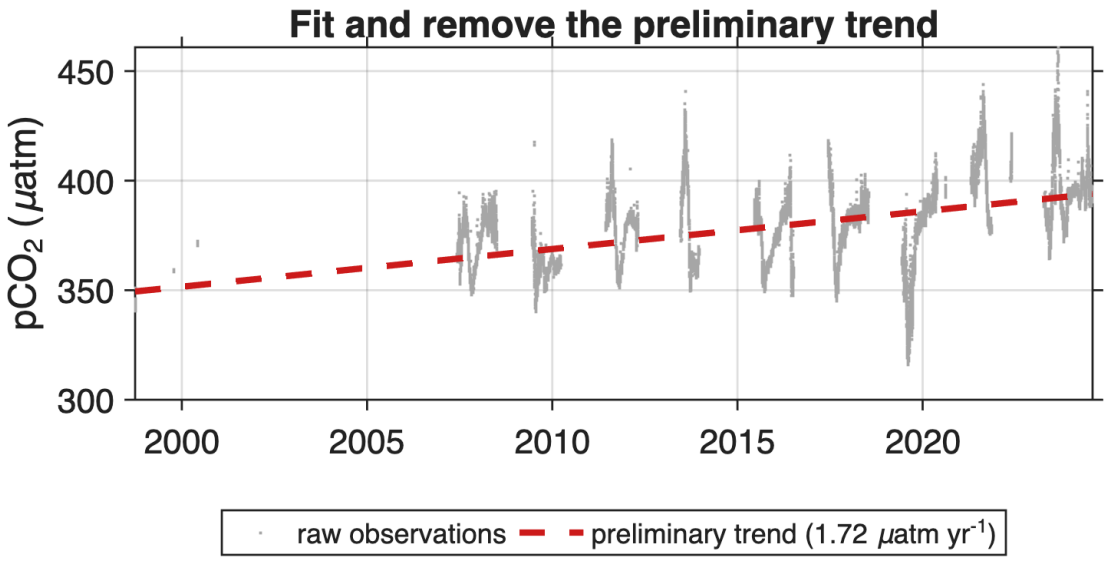
TDT = when the slope is clearly different from zero

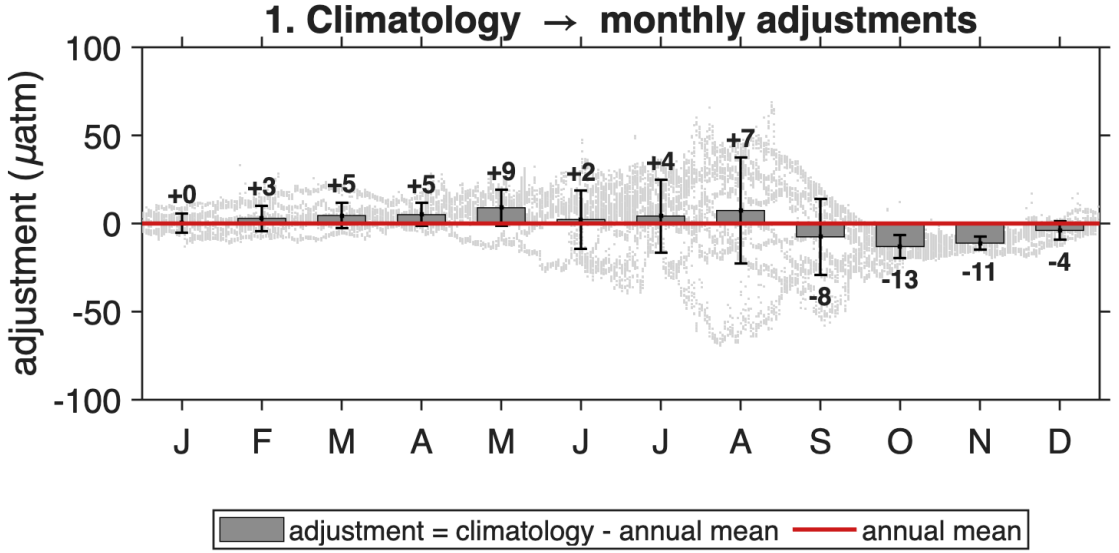
$TDT = [3.3 \cdot \sigma/|\omega| \cdot \sqrt{((1+\phi)/(1-\phi))}]^{(2/3)}$

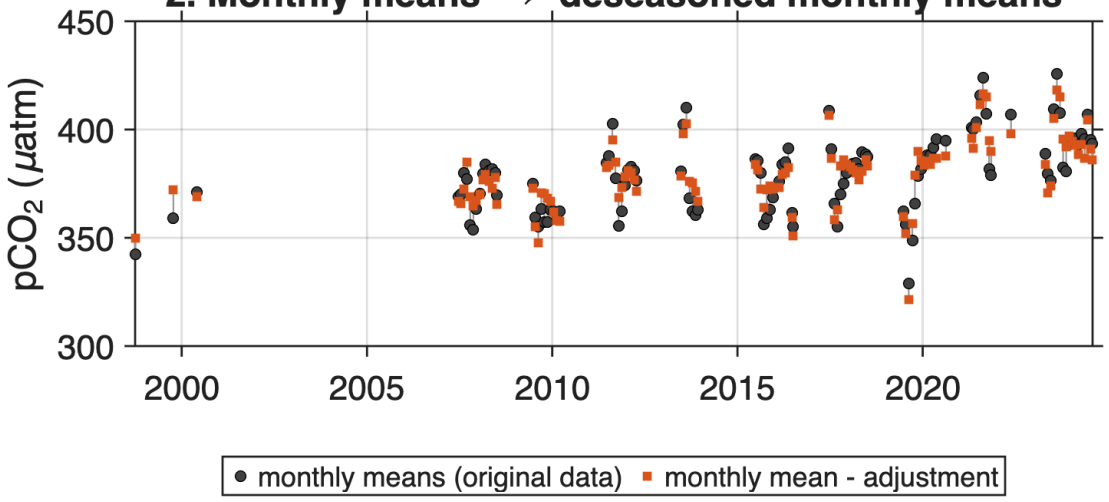
σ = standard dev. of monthly means

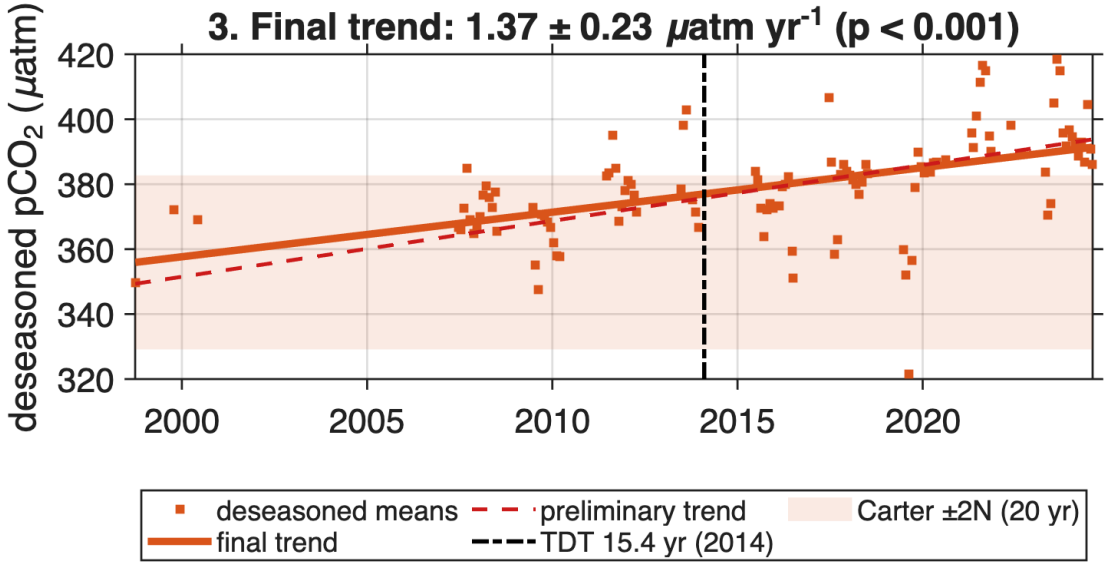
$|\omega|$ = slope (or 2 µatm yr^{-1})

How the trend is computed (TOATS): Ocean Station Papa, 50.11°N, 144.83 ° W





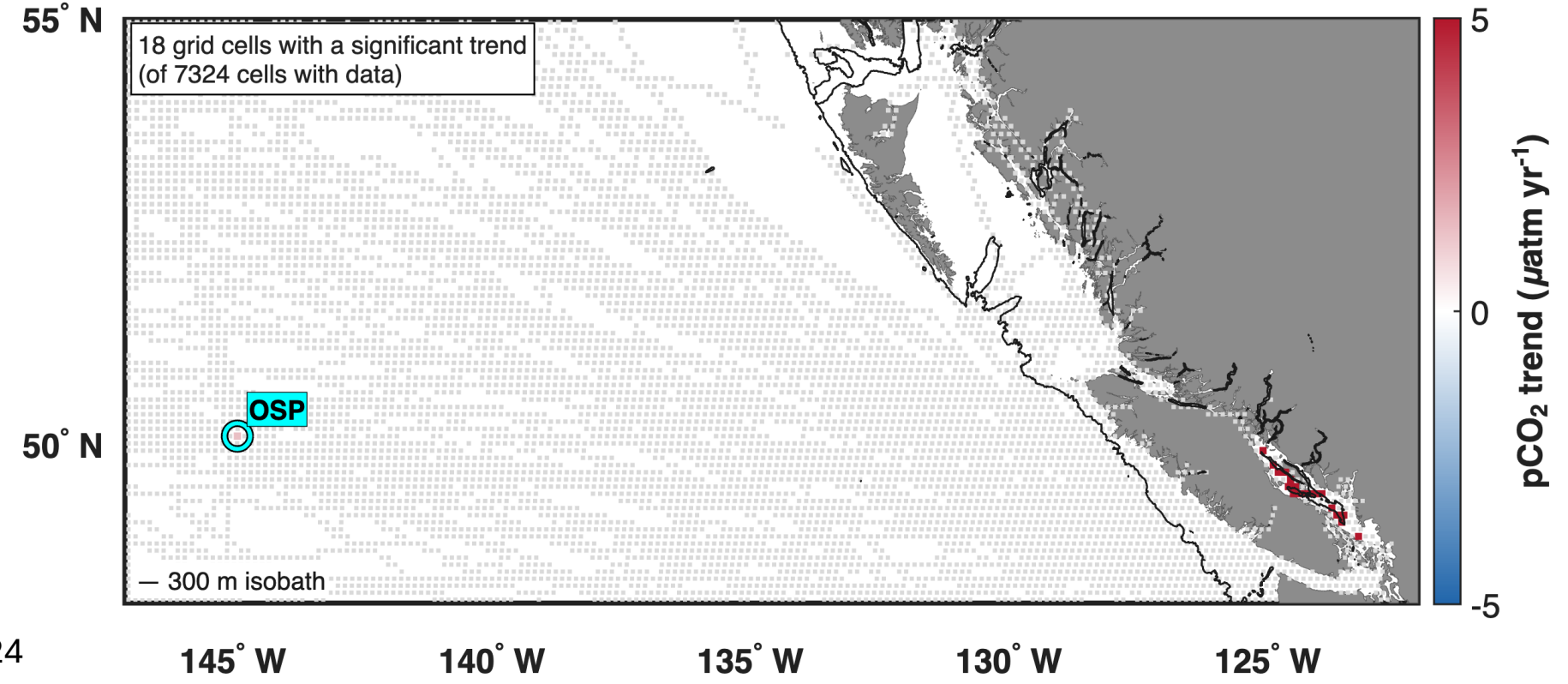


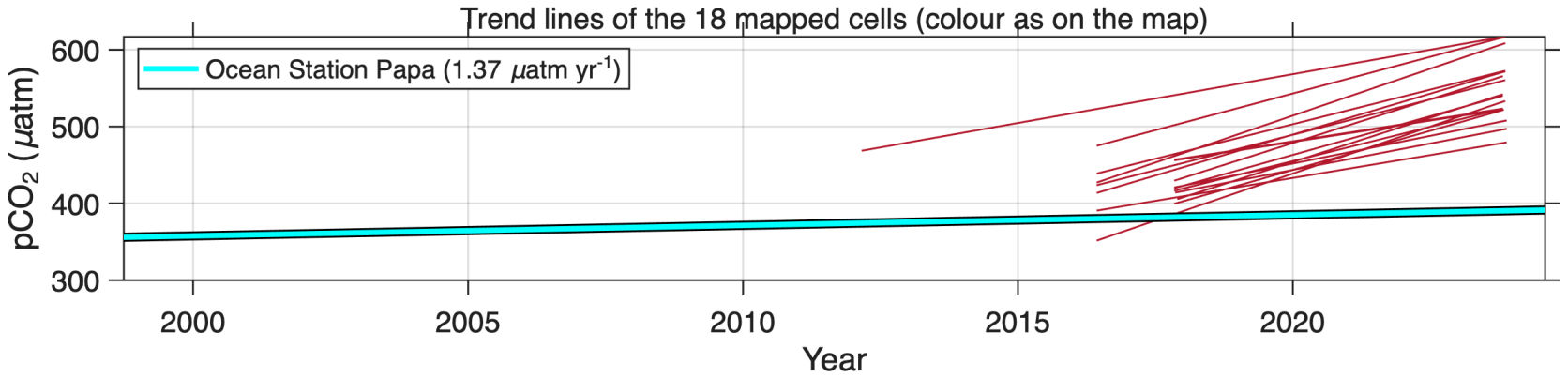


Has the change been enough to grow beyond the natural variability?

pCO_2 trends in 10 km x 10 km grid cells

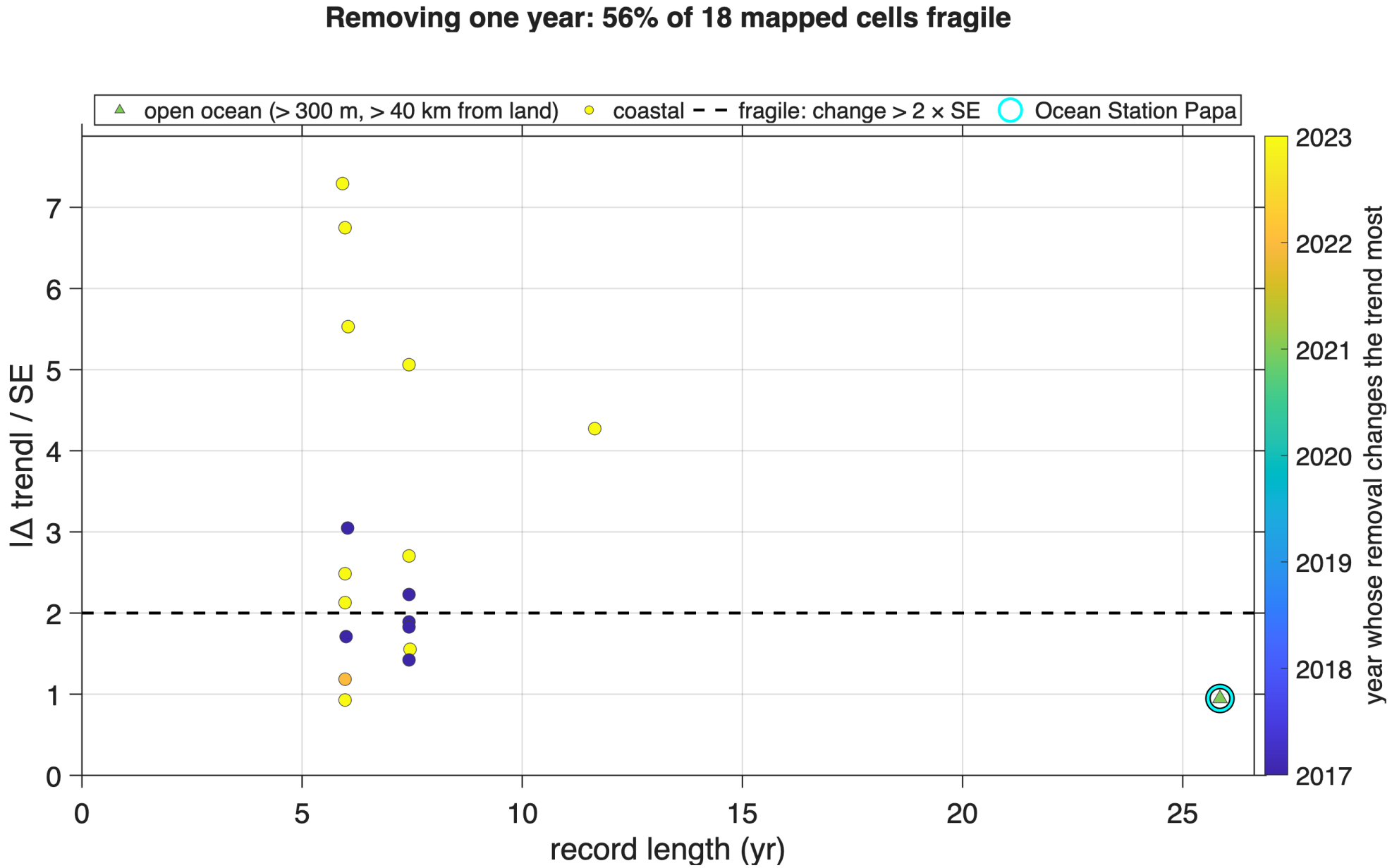
Additional criteria for each cell:
time span > 3 yr: 3616
>= 12 monthly means: 284
>= 6 calendar months: 736
4 seasons sampled: 819
no gap > 9 yr: 1996
>= 2 well-sampled years: 174
well-sampled years span > 3 yr: 89
a trend fit: 1209
cells meeting all coverage criteria: 82
...of which time span > TDT: 21
...of which p < 0.05 and SE < |trend|: 24
meeting all criteria: 18 of 7324



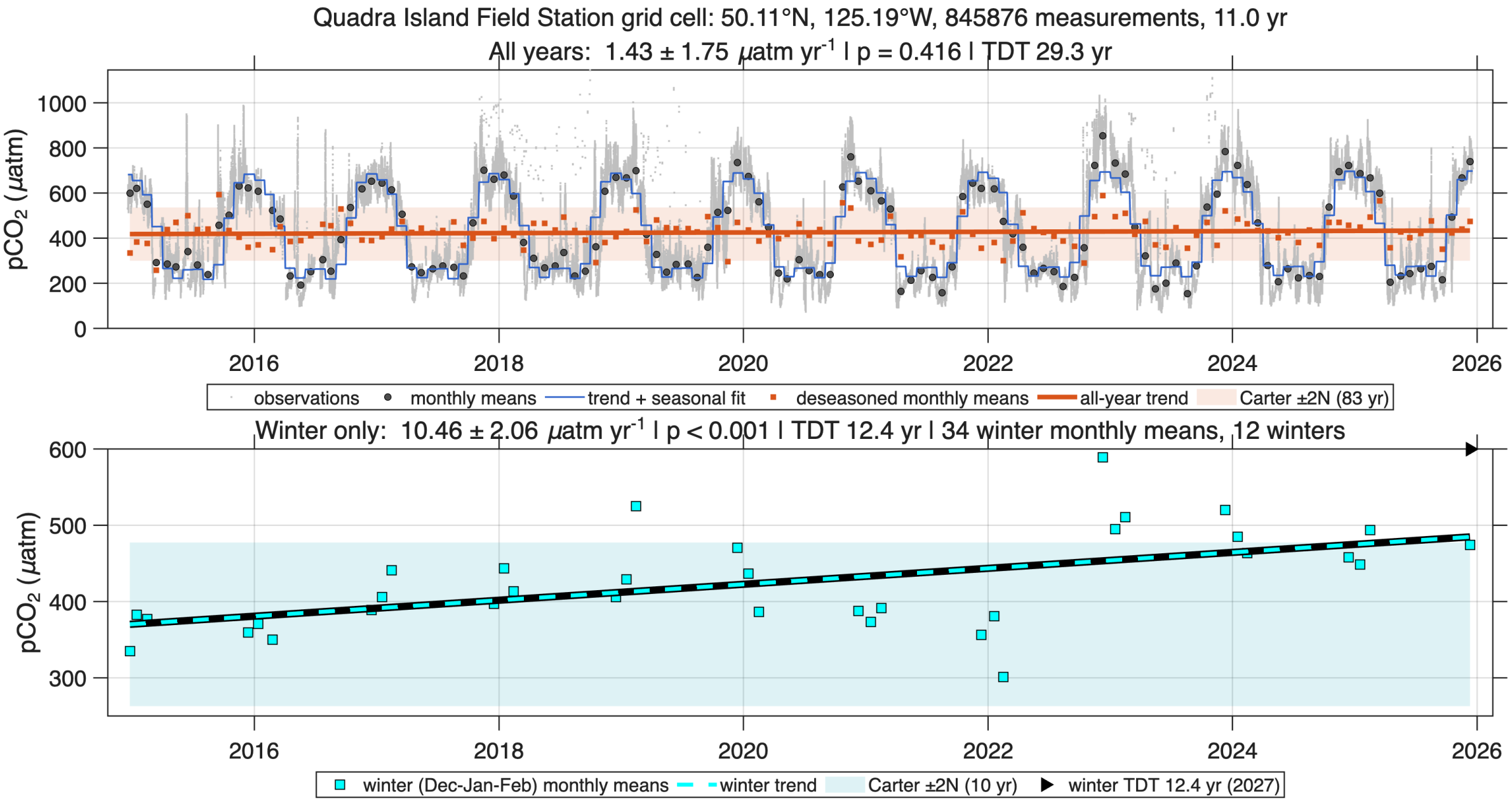


Large statistically-significant rates of change in coastal grid cells

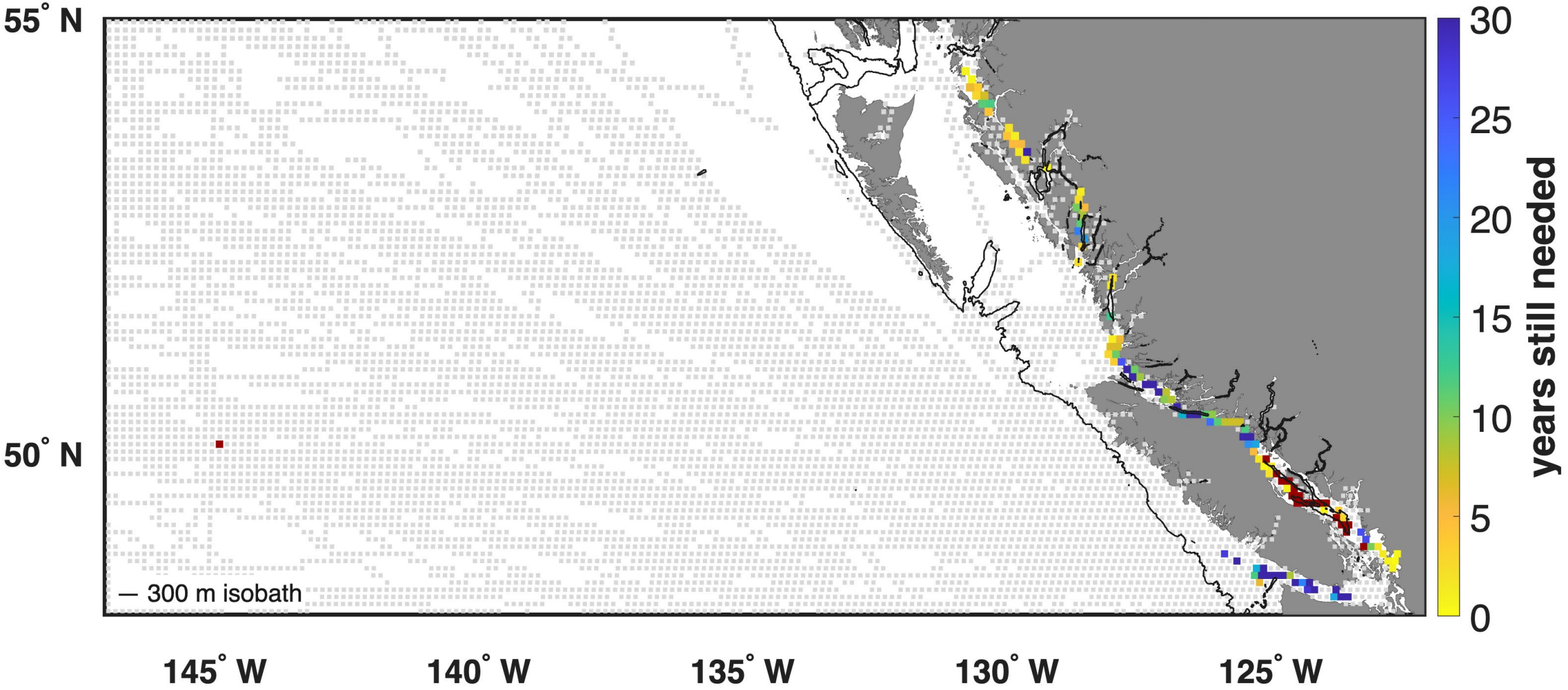
But are we confident in the signals? Jackknife approach indicates low confidence



Seasonally-specific rates in data dense grid cells provide confidence in high rates



Additional investment in data collection will increase coverage of coastal trends



Dark red: TDT reached and passes criteria for trend assessment

Coastal cells have:

- Coastal data is less sparse than we think
- Large seasonal amplitude
- Extremes in fall and winter
- High rates of change evident but with low confidence
- More confidence in high winter rates in data dense cells
- Additional investment will rapidly pay dividends

Better information on these large signals (extremes, rates, drivers) → better-informed action

