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# Multi-decadal $fCO_2$ trends in Western Boundary Current- and Eastern Boundary Current-Dominated Margins


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## Introduction

Determination of the rate of change of sea surface $CO_2$ fugacity ($fCO_2$) is important, as the $fCO_2$ gradient between the atmosphere and the ocean determines the direction of $CO_2$ flux. While substantial efforts have been dedicated to studying oceanic $fCO_2$ trends, little is known about how $fCO_2$ varies in ocean margins.

Recent studies suggest that warming rates in the Western Boundary Current-influenced area (WBCs) are higher than the global mean. At the same time, global warming can strengthen coastal upwelling in Eastern Boundary Current-influenced areas (EBCs). The enhanced upwelling should decrease sea surface temperature and alter primary productivity by bringing up more cold, nutrient-rich water to the surface. Based on the empirical relationship between temperature and $fCO_2$, different temperature change regimes in WBCs and EBCs could affect $fCO_2$ differently [*Takahashi et al.*, 2002], while the change of primary productivity could further change surface ocean $fCO_2$. However, the net effect of global warming on $fCO_2$ variation and $CO_2$ sink/source capacity in WBCs and EBCs is still unclear.

## Methods

### Data

$fCO_2$, sea surface salinity (SSS), sea surface temperature (SST), sampling coordinates and date were obtained from the SOCAT Version 5 Coastal databases.

Monthly dry air $CO_2$ ($xCO_2$, ppm) data were downloaded from NOAA's Earth System Research Laboratory, and monthly air $fCO_2$ was calculated based on averaged SSS, SST, and atmospheric pressure in each of the 1°×1° grid.

### Trend calculations

Generalized Additive Mixed Modeling (GAMM) was used to analyze the $fCO_2$ trend (Wang *et al*, 2016).

$fCO_2$= Seasonal term + environmental covariates term + trend term + errors

**Cyclic penalized splines** were used to fit seasonal cycle. **A second order polynomial model** was used to fit non-linearity in the relationship between $fCO_2$ and SSS, SST, and their interactions. **Sampling date was included as a linear effect**, and its coefficient represents the $fCO_2$ rate change not accounted for by seasonal and environmental factors. Models included **an explicit autoregressive term of lag 1 (AR(1))** to account for the lack of independence of consecutive observations taken close together in time.

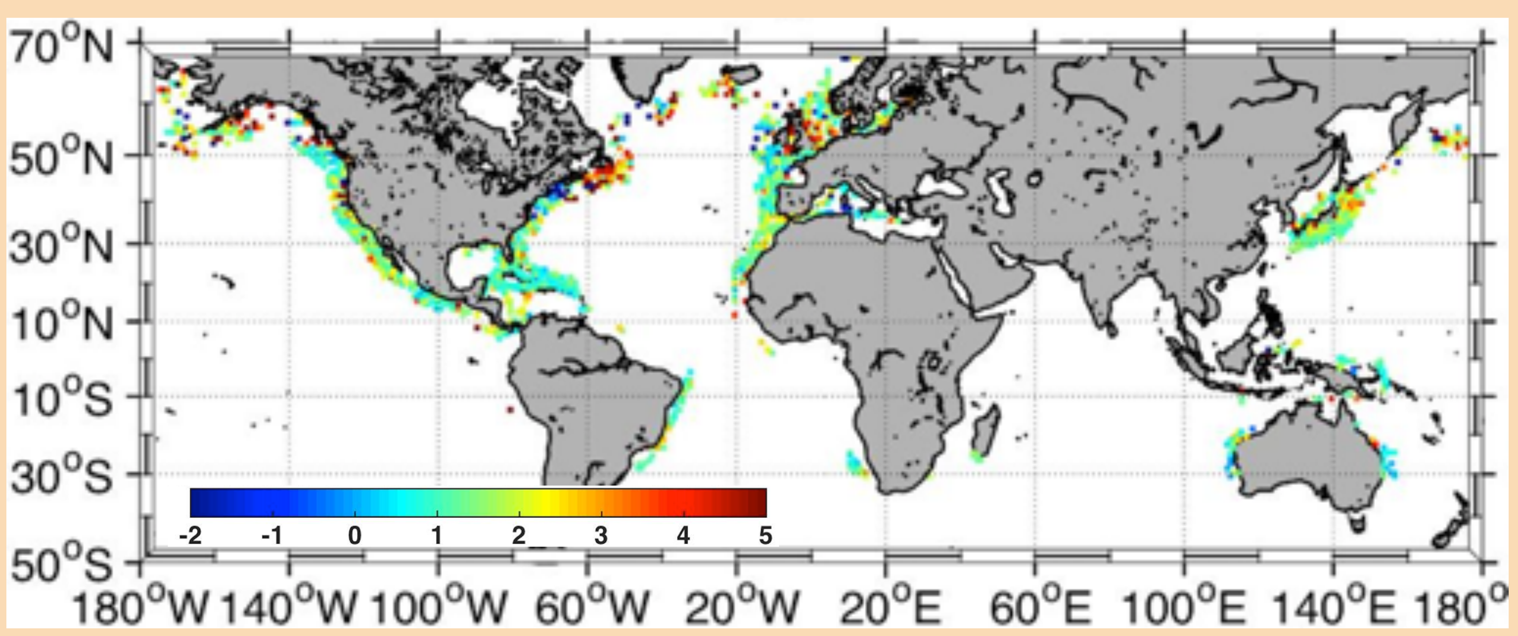
### Thermal and non-thermal trend calculation

$$T - fCO_2 = \overline{fCO_2}\times[0.0423(SST - \overline{SST})];\ NT - fCO_2 = fCO_2\times[0.0423(\overline{SST} - SST)]$$

### $CO_2$ sink/source categorization

| Condition | | Category |
|---|---|---|
| $fCO_2$sea<$fCO_2$air | $fCO_2$sea trend<$fCO_2$air trend | **Increasing Carbon Sink** |
| | $fCO_2$sea trend>$fCO_2$air trend | **Decreasing Carbon Sink** |
| $fCO_2$sea>$fCO_2$air | $fCO_2$sea trend<$fCO_2$air trend | **Decreasing Carbon Source** |
| | $fCO_2$sea trend>$fCO_2$air trend | **Increasing Carbon Source** |

## Results and Discussion-Global Ocean Margins



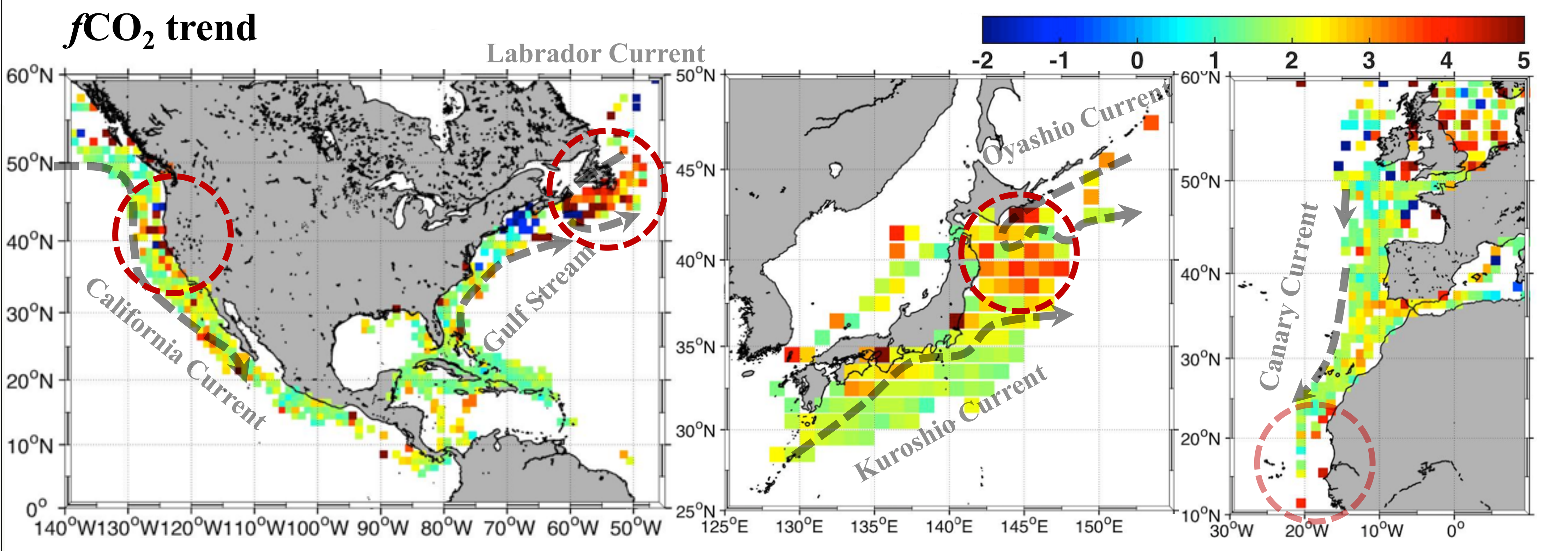
The averaged $fCO_2$ trend in global ocean margins was 2.1±1.5 μatm yr$^{-1}$, which was significantly higher than the atmospheric trend (1.97±0.08 μatm yr$^{-1}$), while the seawater $fCO_2$ trend is insignificantly different from atmospheric trend based on SOCAT V3 (Wang *et al*, 2017).

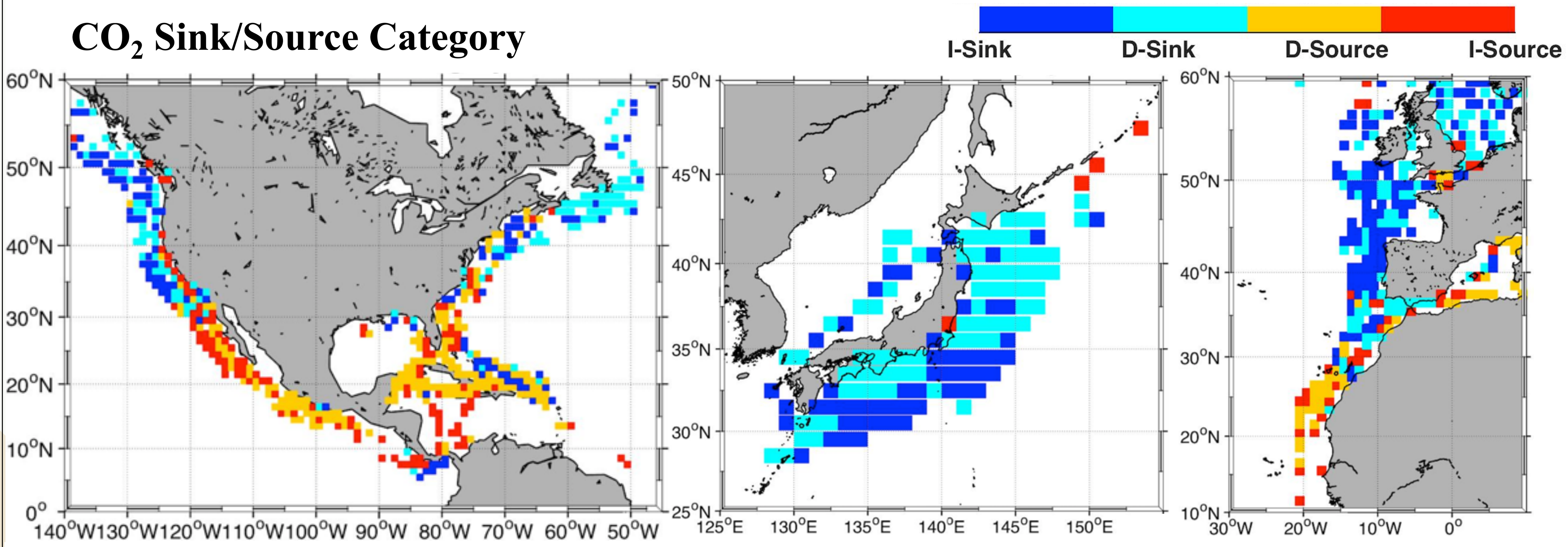

**Reference**

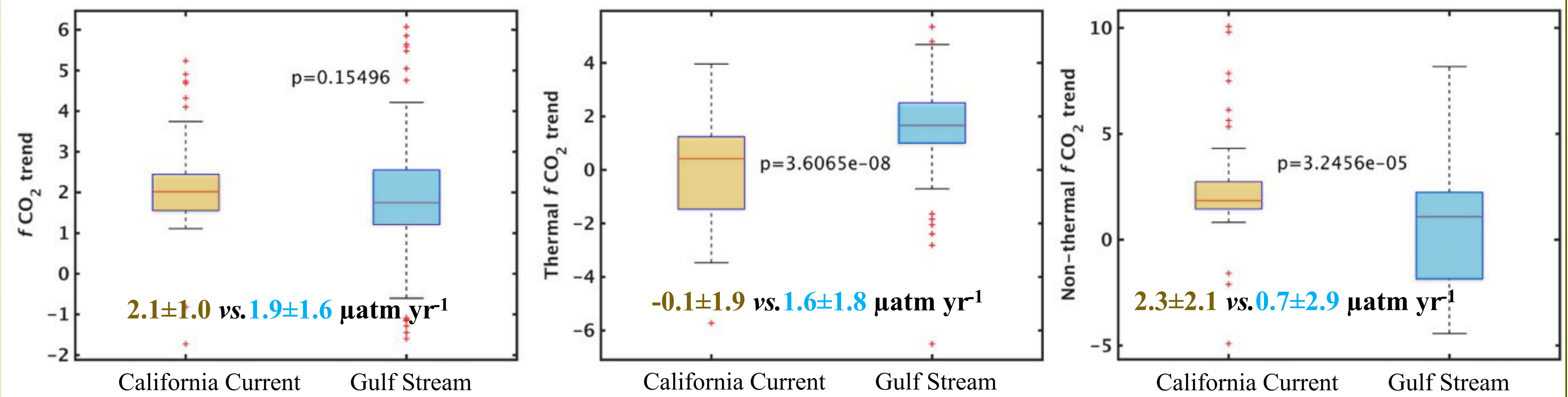
Wang *et al*, 2016, *Mar. Chem*. 183, 41-49.

Wang *et al*, 2017, *Geophys. Res. Lett*. 44, doi: 10.1002/2017GL074724


## Results and Discussion-Boundary Currents



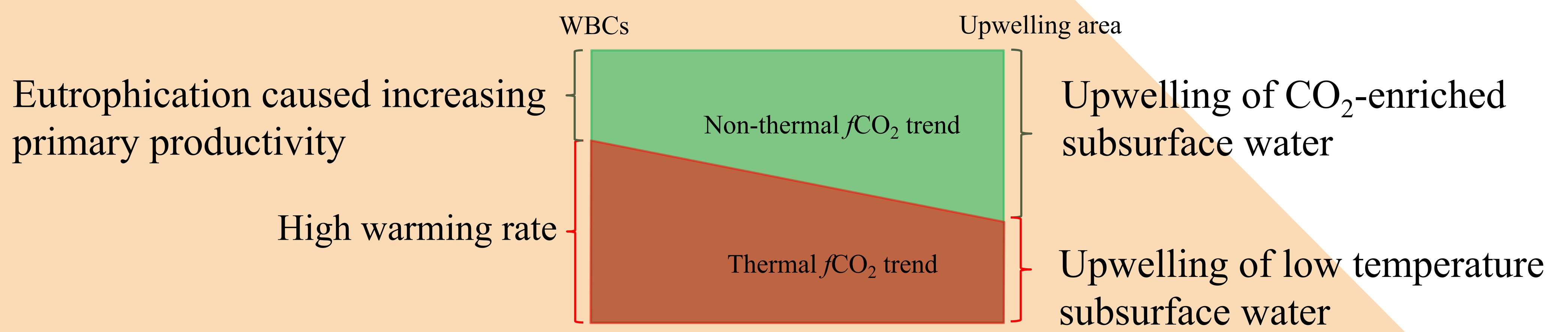




- ❖ The $fCO_2$ trends were higher than atmospheric trends in upwelling areas (California Current System, the Kuroshio/Oyashio transition zone, Gulf stream/Labrador transition zone);
- ❖ These upwelling areas have become increasing carbon source or decreasing carbon sink;
- ❖ The trends T-$fCO_2$ (or NT-$fCO_2$ ) were higher (or lower) in Gulf Stream than California Currents (WBCs *vs*. EBCs, Wang *et al*, 2017).

## Summary

The direct warming effect contributes more to T-$fCO_2$ increase in the WBCs, while intensified upwelling contributes more to NT-$fCO_2$ increase in upwelling area (EBCs and current transition zones).





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