The Carbon Budget of the California Upwelling System

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Motivation and objectives

Coastal upwelling regions are very dynamic in terms of **carbon cycling**: the upwelled water is rich in dissolved inorganic carbon (DIC) and nutrients, which stimulates phytoplankton growth and the drawdown of atmospheric CO_2. However, enhanced DIC levels also lead to high oceanic pCO_2 and potential outgassing of CO_2. This makes these areas highly complex in terms of biogeochemical cycling. Currently, coastal carbon budgets are still poorly quantified, with substantial regional and global uncertainties.

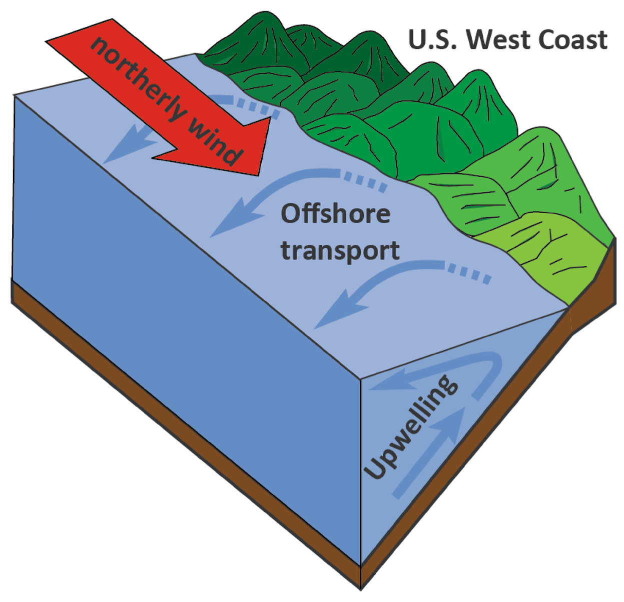


Fig. 1: Upwelling-related processes along the U.S. West Coast

Our aim is to use a highly-resolved regional ocean model (ROMS) to quantify the carbon budget of the **California Upwelling System (CUS)** and in particular address the following questions:

Question 1: **How large are the lateral, vertical and air – sea carbon fluxes in the CUS?**

Question 2: **How large is the seasonal variability of the air – sea carbon fluxes?**

Conclusions

Question 1:

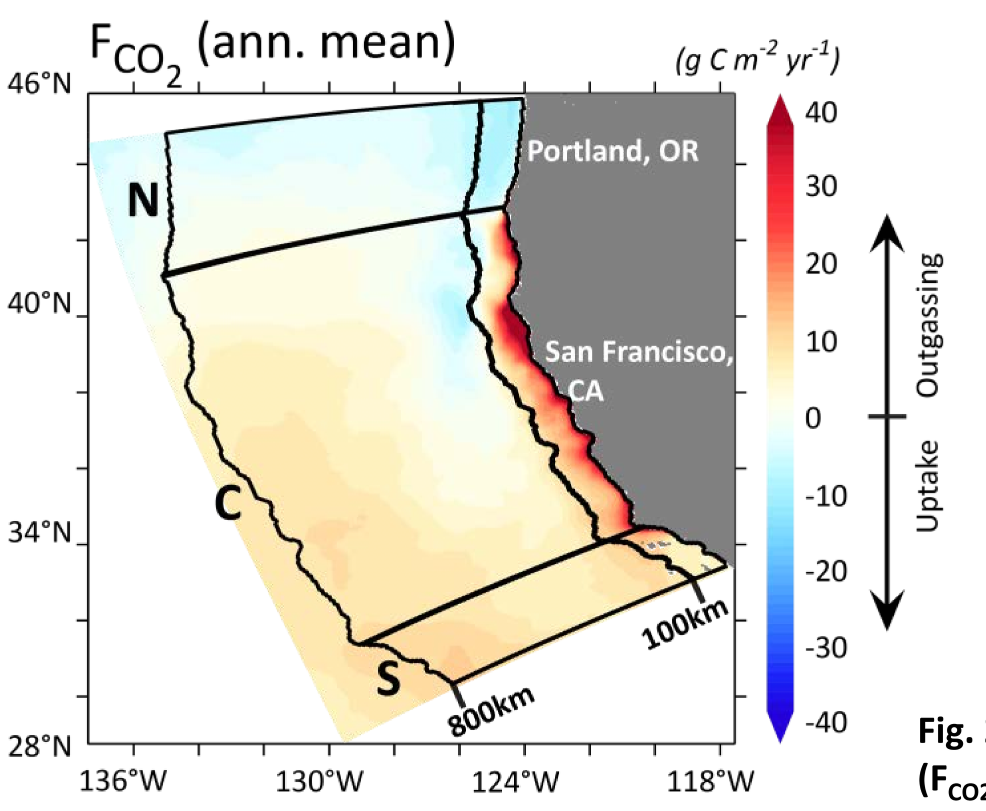
- The inorganic carbon cycle of the CUS is dominated by large offshore transport and upwelling fluxes:~50% of offshore transport stems from nearshore upwelling, the rest from alongshore advection (Fig. 3).
- The CUS (all 6 analysis domains; Fig. 2) currently acts as a source of CO_2, outgassing 7.5 ±0.6 Tg C yr^{-1} (Table 1).

Question 2:

The air – sea CO_2 fluxes are highly variable, with substantial seasonal differences in sign and magnitude between domains (Fig. 4):

- The central nearshore and the southern domains act as year-round sources of CO_2, while the northern domains are on average sinks.
- With an outgassing flux of 2.1 mol C m^{-2} yr^{-1} (global uptake: 0.5 mol C m^{-2} yr^{-1}), the central nearshore domain is the most important contributor to the local carbon budget.

Results Question 1



Analysis done for:

- 6 analysis domains (Fig. 2): north (N), central (C) and south (S); nearshore (0-100km) and offshore (100-800km)
- Euphotic zone: 1% light limit; average depth ~78m

Fig. 2: Background: annual mean air – sea CO_2 flux (F_{CO2}). Superimposed black lines: analysis domains.

Lateral offshore fluxes are responsible for a large transport of DIC to the open ocean, whereof roughly 50% stems from upwelling.

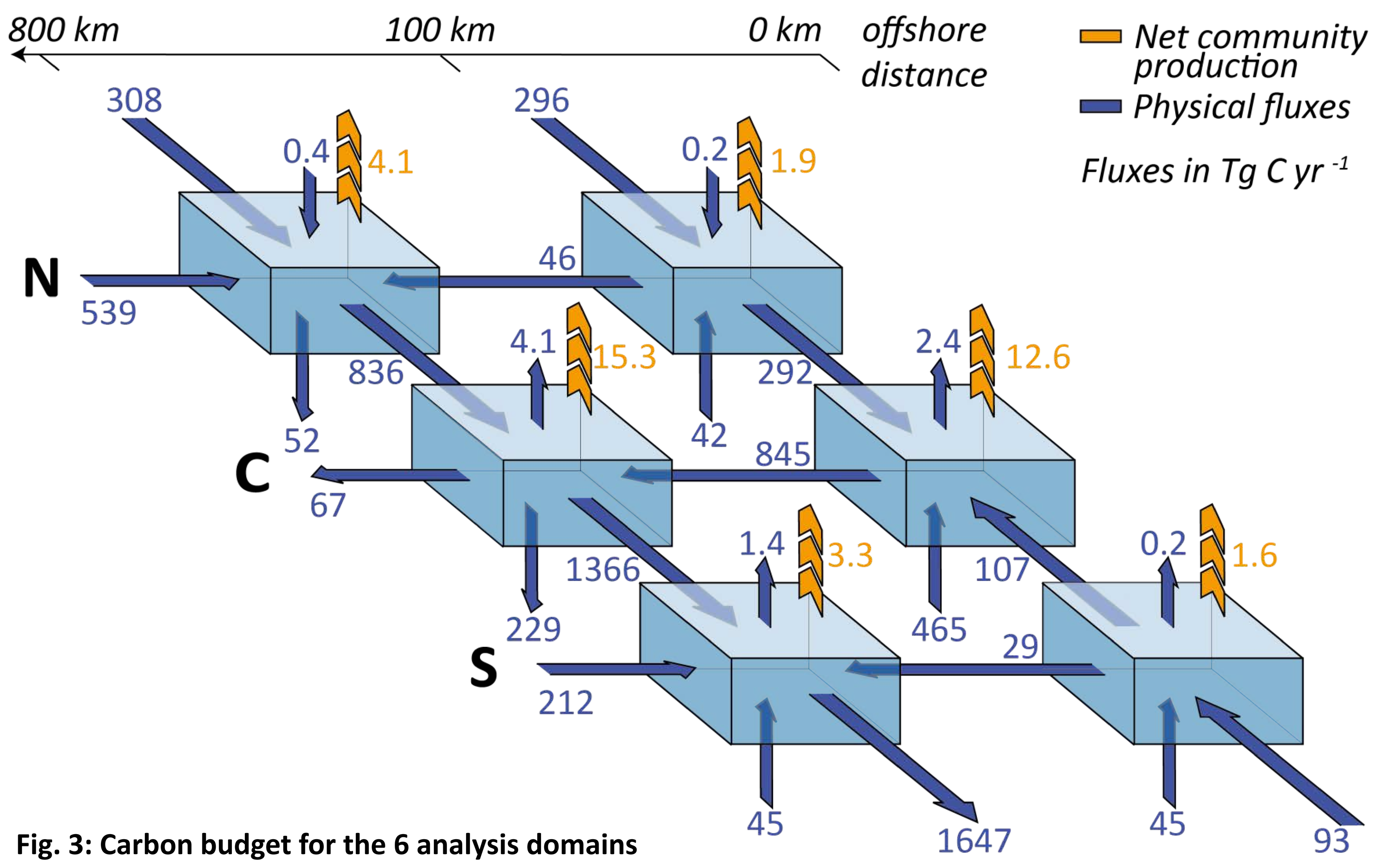


Fig. 3: Carbon budget for the 6 analysis domains (Fig. 2): blue arrows denote DIC and air – sea CO_2 fluxes, orange arrows indicate net community production.

Results Question 2

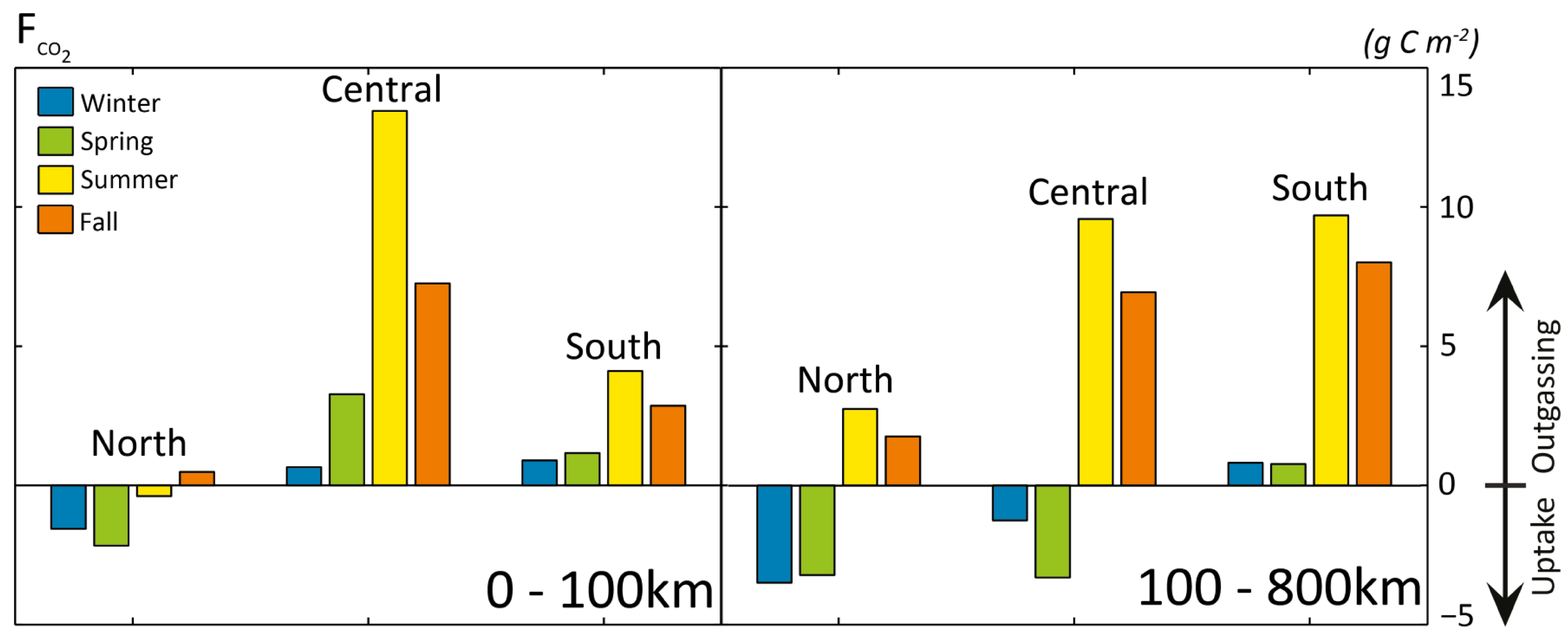


Fig. 4: Seasonal air – sea CO_2 fluxes (F_{CO2}) for the 6 analysis domains.

The air – sea CO_2 fluxes are highly variable in space and time.

- Substantial seasonal differences in sign (north & central) and magnitude (central & south)
- South acts as a year-round source of CO_2 to the atmosphere; north is on average a sink
- Central nearshore domain is the most important source with strong seasonality (evident upwelling signal)

Table 1:	Total air – sea CO_2 flux	Air – sea CO_2 flux per unit surface
CUS 0-800km	7.5 ± 0.6 Tg C yr^{-1}	0.4 mol C m^{-2} yr^{-1} 2.1 mol C m^{-2} yr^{-1} (Central 0-100km)
Global *(Le Quéré et al., 2009)*	-2.3 ± 0.4 Pg C yr^{-1}	-0.5 mol C m^{-2} yr^{-1}

The CUS currently acts as a source of CO_2 to the atmosphere, with the central nearshore domain outgassing the largest flux per unit surface.

Tool: Coupled physical – biogeochemical model

Physical/circulation model:

- Regional Ocean Modeling System (ROMS)
- 5km horizontal resolution, 32 vertical layers
- Climatological boundary forcing
- 5 year spin-up, 7 year averages

Biogeochemical-ecosystem model:

- Nitrogen-based Nutrient-Phytoplankton-Zooplankton-Detritus (NPZD) model
- 2 detritus pools with fast and slow sinking
- Carbon & nitrogen cycle linked with fixed Redfield ratio

References

- Cai, W.-J. et al (2006). Air – sea gas exchange of carbon dioxide in ocean margins: A province-based synthesis. *Geophysical Research Letters*, 33, L12603
- Le Quéré, C. et al (2009). Trends in the sources and sinks of carbon dioxide. *Nature Geoscience*, 2: 831 – 836