OA timeseries observations in the California Current Ecosystem LTER region

Uwe Send, Mark Ohman, Todd Martz
Scripps Institution of Oceanography

Carbonate system measurements in the CCE-LTER/CalCOFI region supported by NOAA and NSF

CalCOFI SHIPBOARD

- CalCOFI shipboard sampling , 4X y^{-1}
  14 stations, 0-500 m – (Andrew Dickson)

- Continuous underway pCO_2 , pH on CalCOFI cruises (Todd Martz; Chris Sabine)

PROXY RELATIONSHIPS

Alin et al. (2012) carbonate system proxies, developed mainly from CalCOFI measurements

MOORINGS (N=3) (Uwe Send, Mark Ohman)

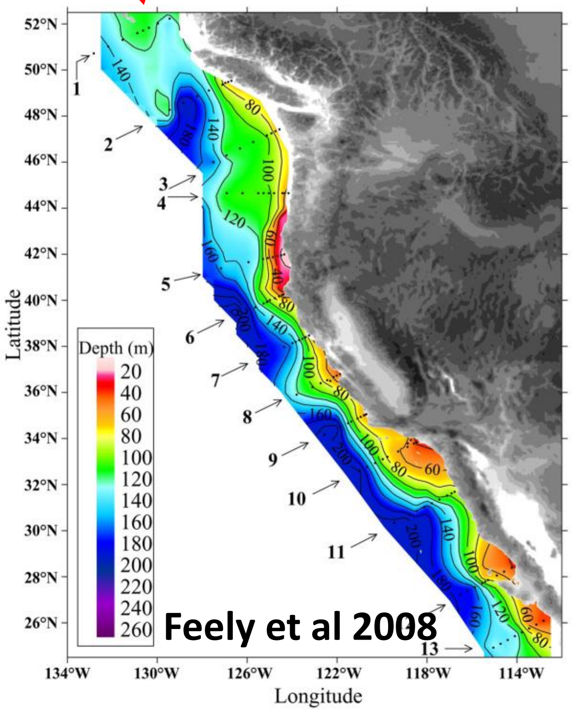
	pCO_2	pH, O_2
CCE1 (Core of CA Current)	Nov. 2008-	Dec. 2009-
CCE2 (Pt. Conception upwelling)	Jan. 2010-	Jan. 2010-
Del Mar (continental shelf)	---	O_2 (~2006-), pH (~2010-) [not continuous]

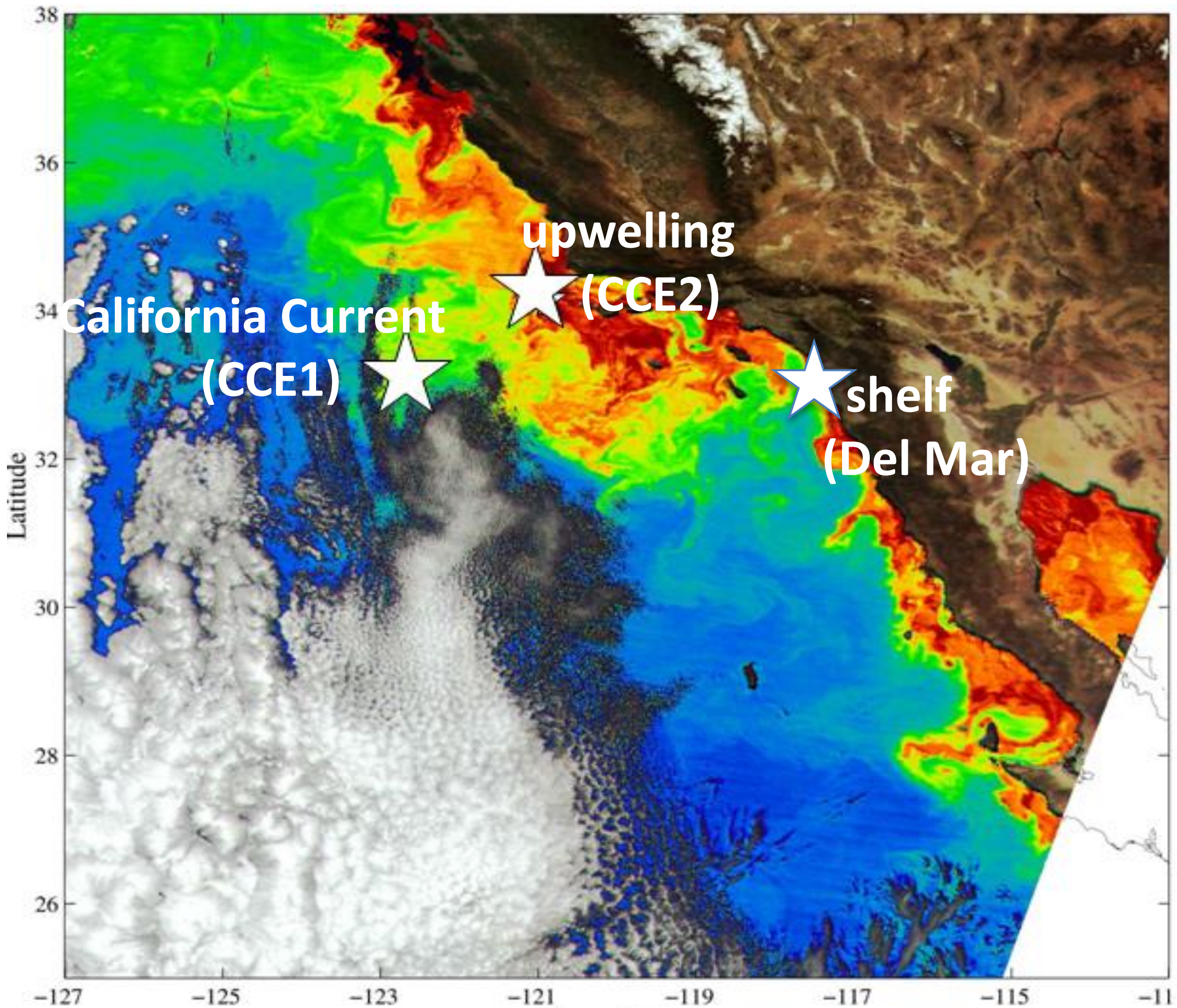
Spray GLIDERS

~ 2012- [some missions equipped with O_2 sensors; combined with Alin et al. (2012) proxy]
(Dan Rudnick and Mark Ohman working toward making all glider missions on CalCOFI lines 80 & 90 O_2-equipped)

5-9 years of OA timeseries from moorings covering 3 regimes

Gives time evolution of this over days to years





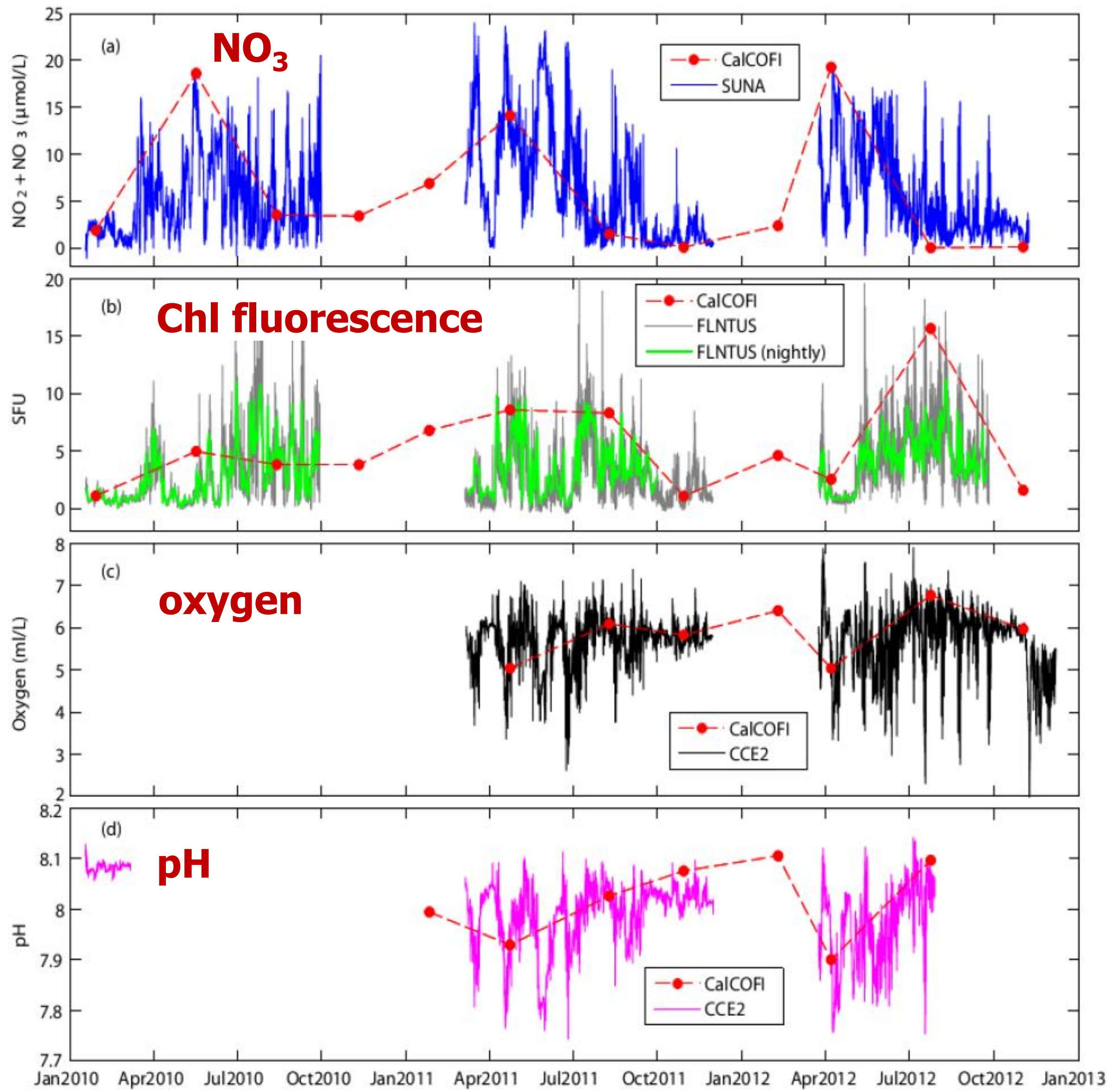
data views on http://mooring.ucsd.edu/CCE
http://mooring.ucsd.edu/DelMar

Information content of continuous autonomous timeseries

With very careful calibration, processing, and quality control, some autonomous sensors can now give data comparable to ship sampling.

Continuous measurements from moorings are an important complement to occasional sampling from ships.

Timescales:
- Diurnal and tidal (1 day)
- Upwelling/mixing events (1 week)
- Changes in source water masses (months to a year)
- Climate variability, e.g. ENSO, NPGO, warm anomaly (multi-year) (tracking time evolution and how the low-frequency changes affect high-frequency events)



Ability to study events

Upwelling/ relaxations in 2011 at CCE2

CO_2

NO_3

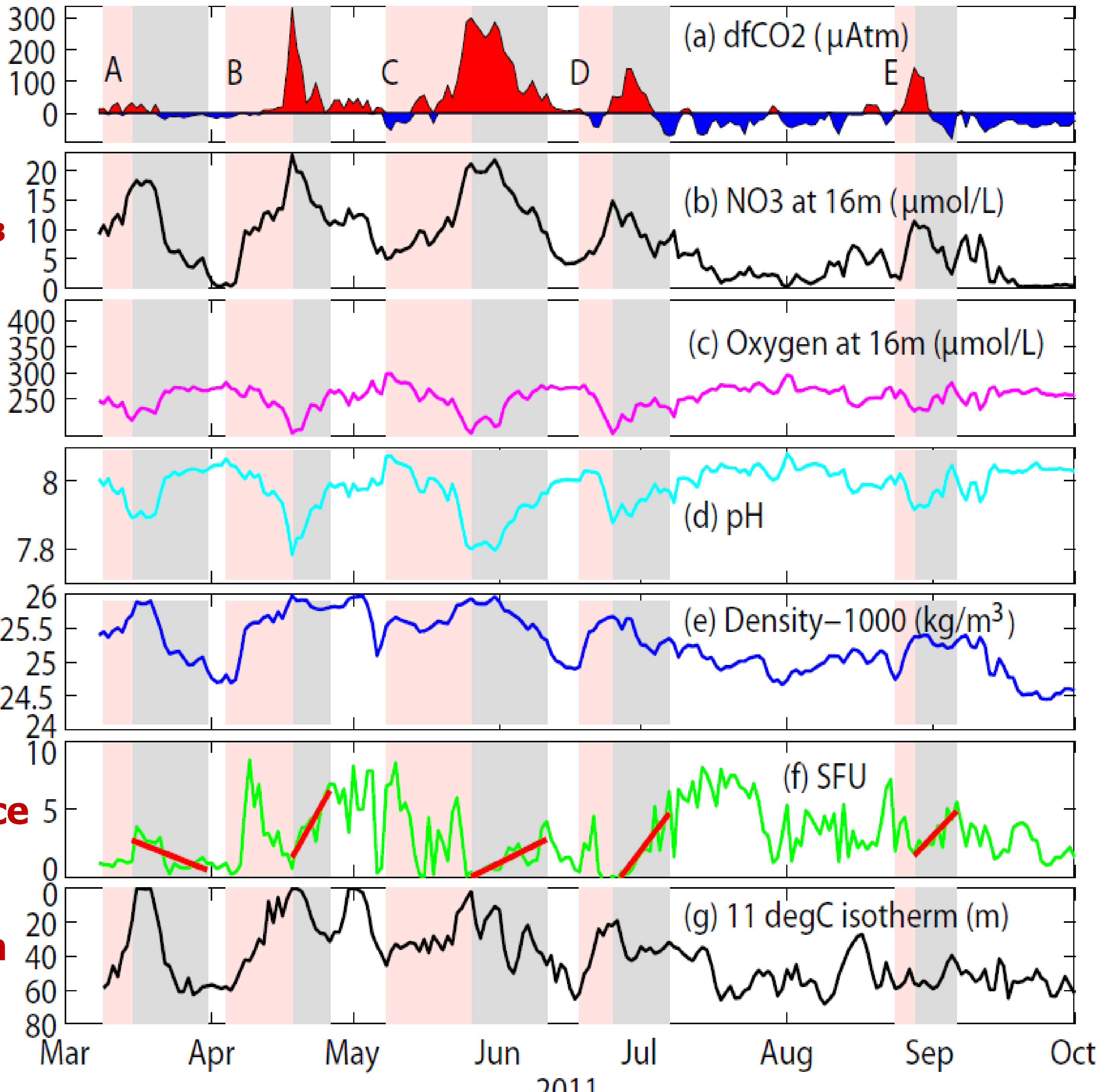
O_2

pH

density

Chl fluorescence

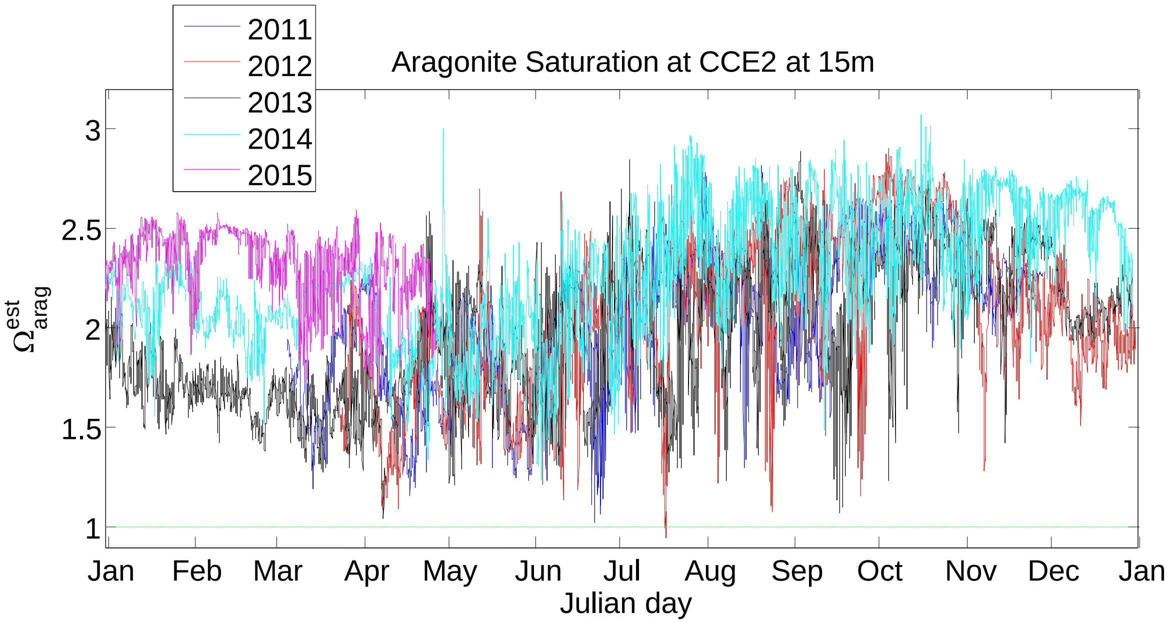
isotherm depth

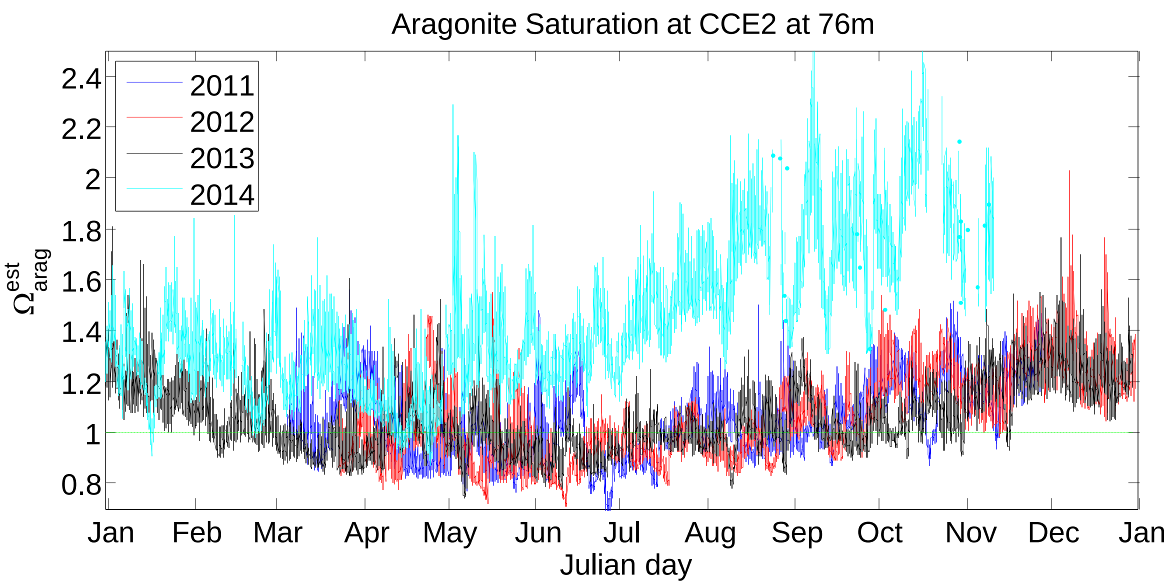


Statistics of upwelling events (3 years) at CCE2, 15m

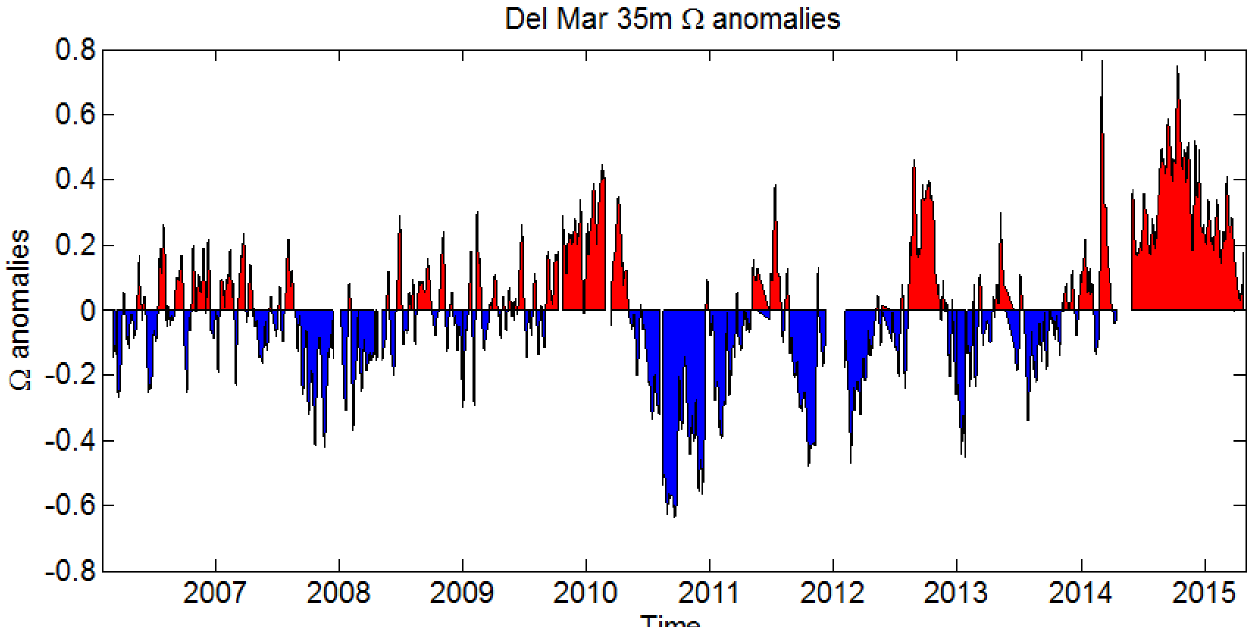
2011-2013 (Mar-Aug)	Total Observational Duration (days)		561
	Total Event Durations (days)		144
	Time Mean & Std. Dev. of Event Duration (days)		10.3 ± 4.4
	DO (μM/L)	Time Mean & Std. Dev.	274.6 ± 41.9
		Min. & Max.	145.5 & 376.7
		Time Mean & Std. Dev. of Event Intensity	86.0 ± 33.0
	pH	Time Mean & Std. Dev.	8.03 ± 0.09
		Min. & Max.	7.78 & 8.26
		Time Mean & Std. Dev. of Event Intensity	0.18 ± 0.06
	Ω_{arag}	Time Mean & Std. Dev.	2.04 ± 0.37
		Min. & Max.	1.21 & 3.14
		Time Mean & Std. Dev. of Event Intensity	0.67 ± 0.20

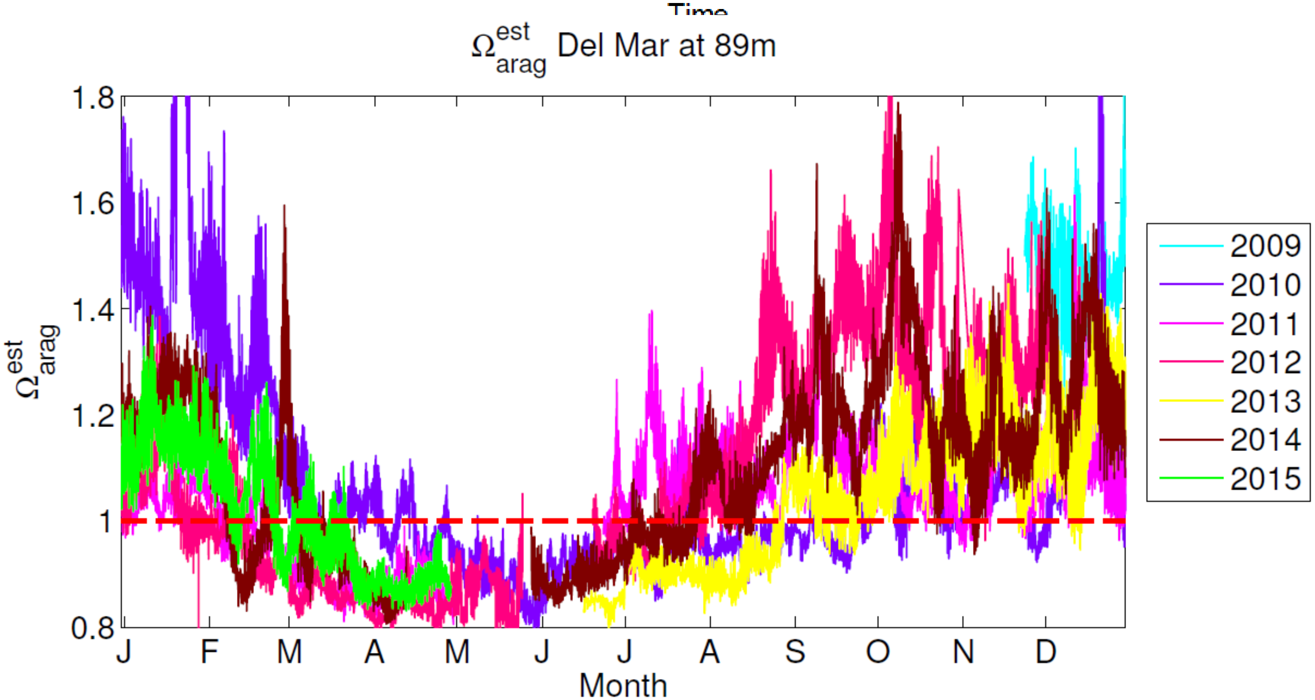
Interannual changes in pH and Ω_{arag}



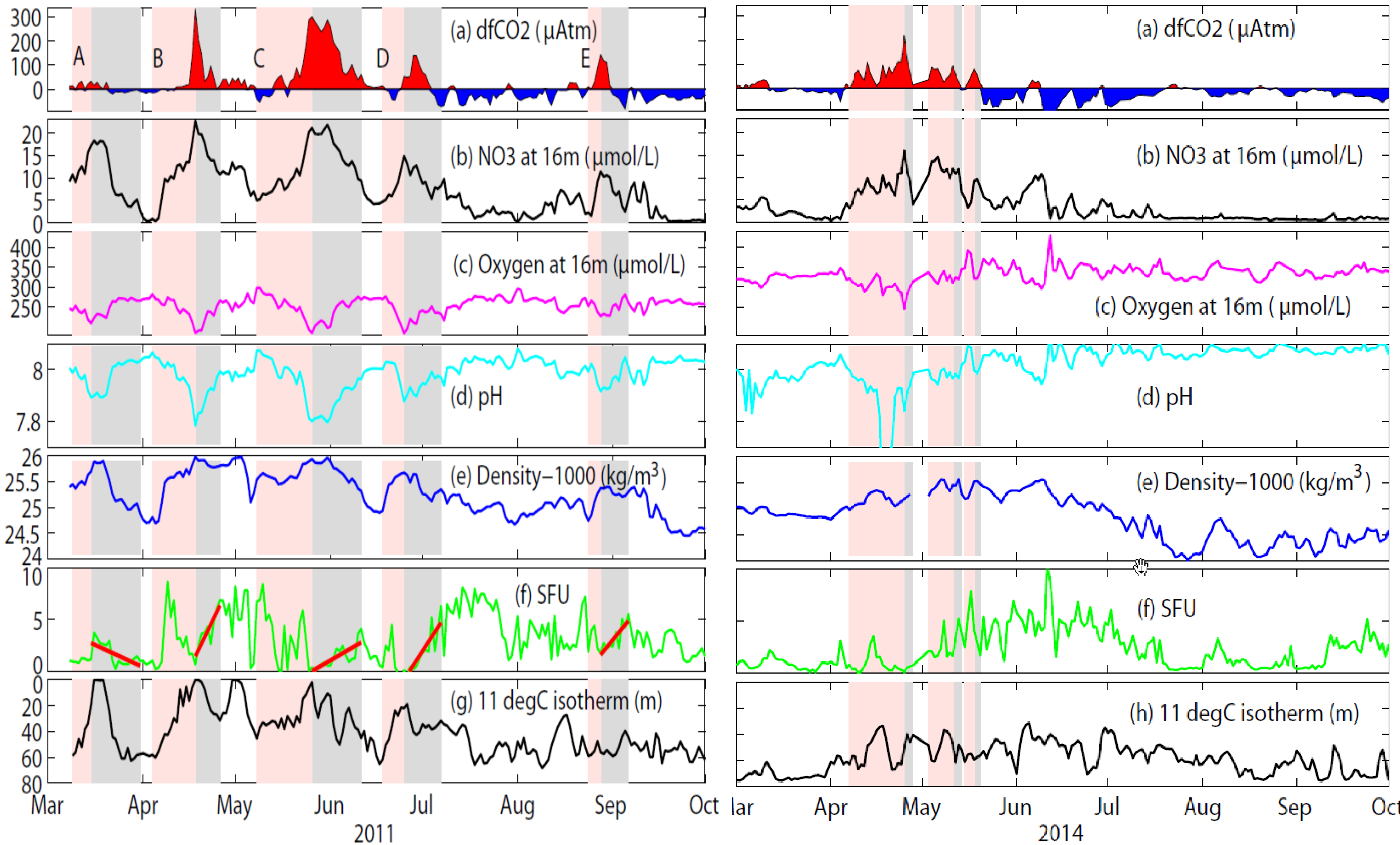


Interannual changes in pH and Ω_{arag}

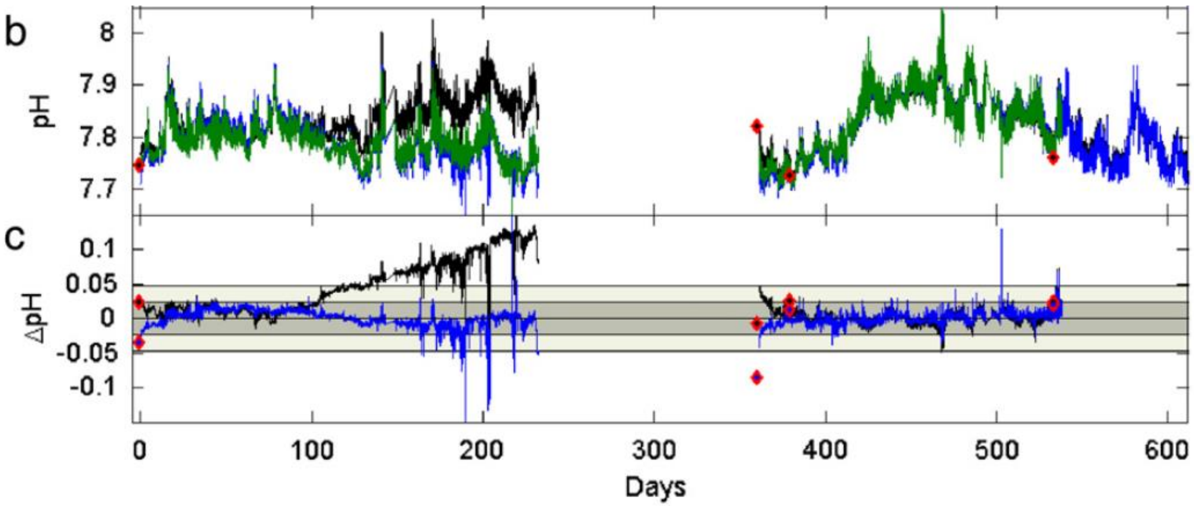




Low density, depressed isotherms, etc, already present at beginning of the season…

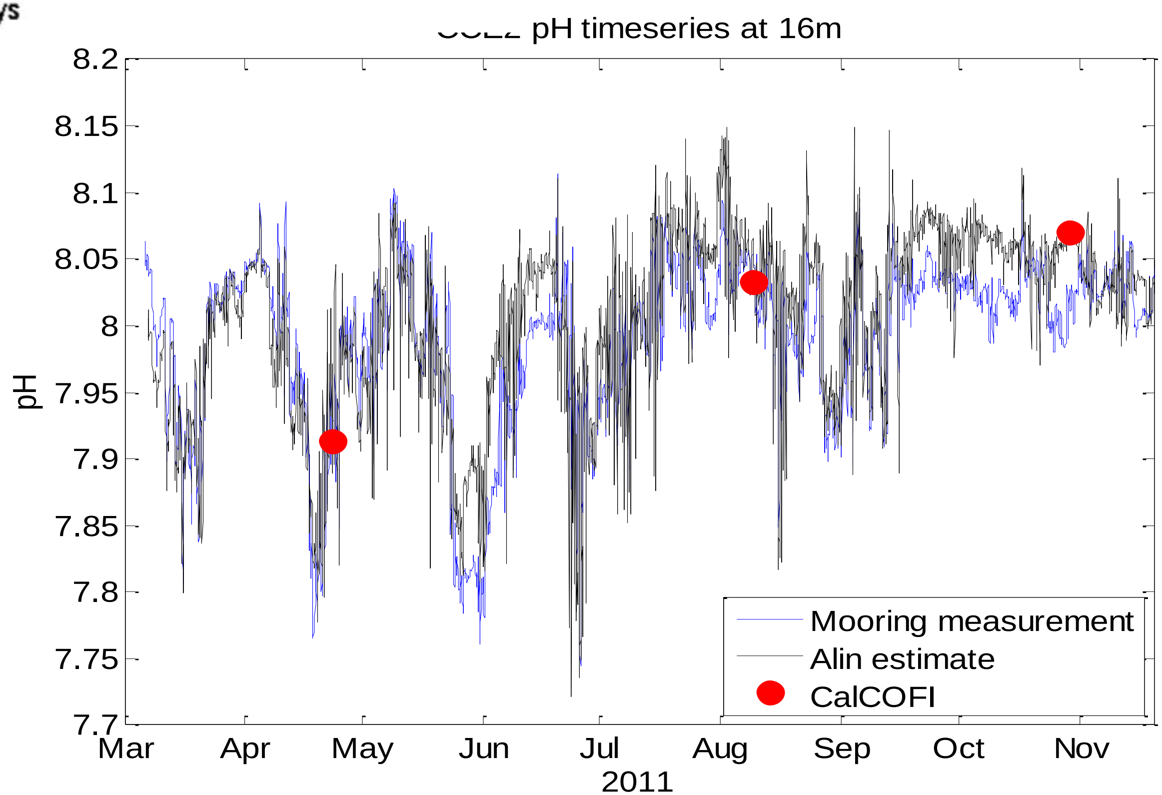


Evaluation and monitoring of algorithm accuracy

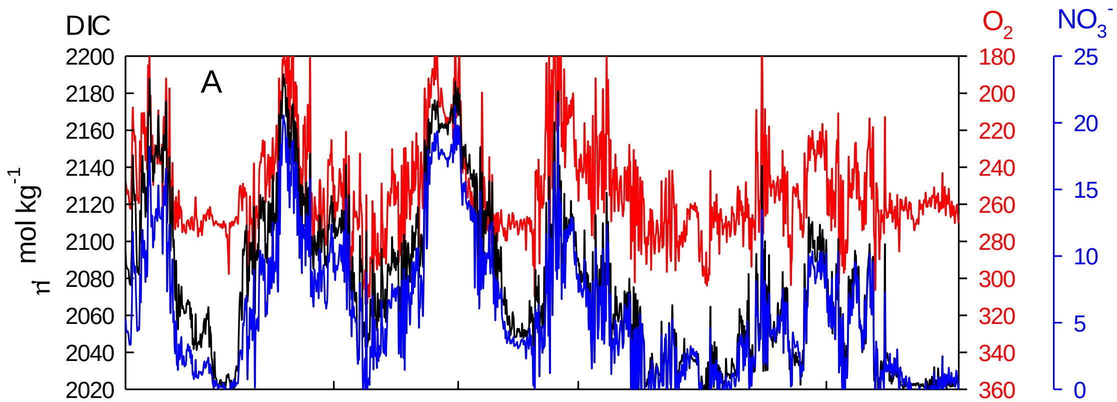


Alin et 2012 algorithm for pH (calculated from O2, T) tested at Del Mar mooring at 100m.

15m (at CCE2) is the limit of validity, tested here at the CCE2 mooring.

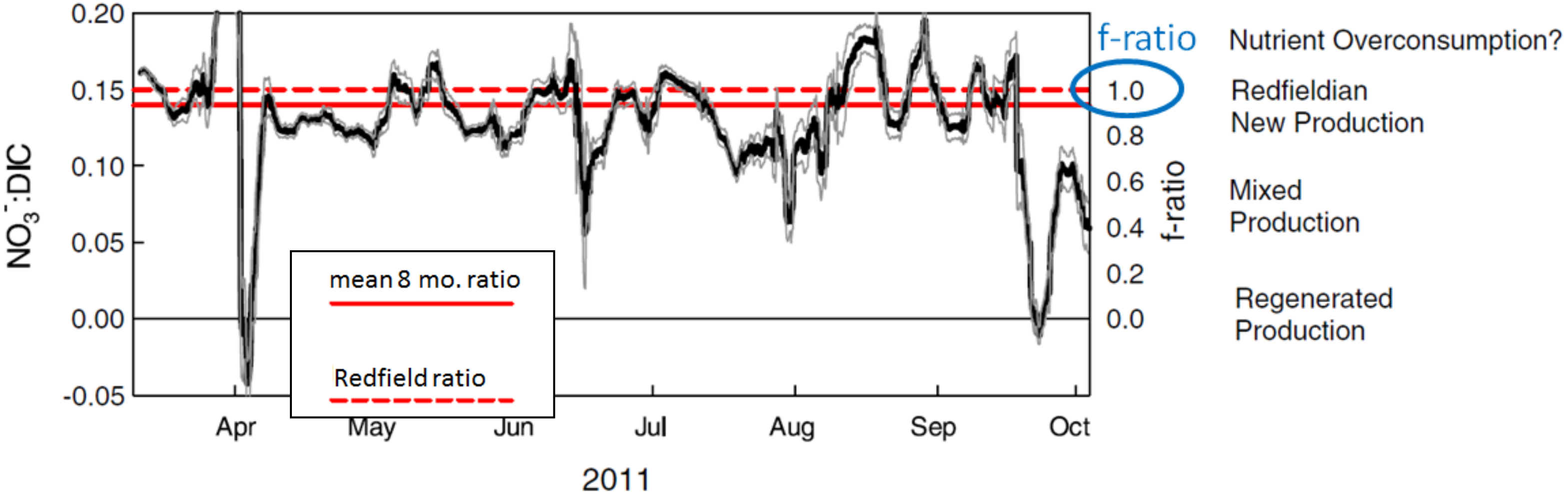


Dynamic variability of elemental ratios: new production



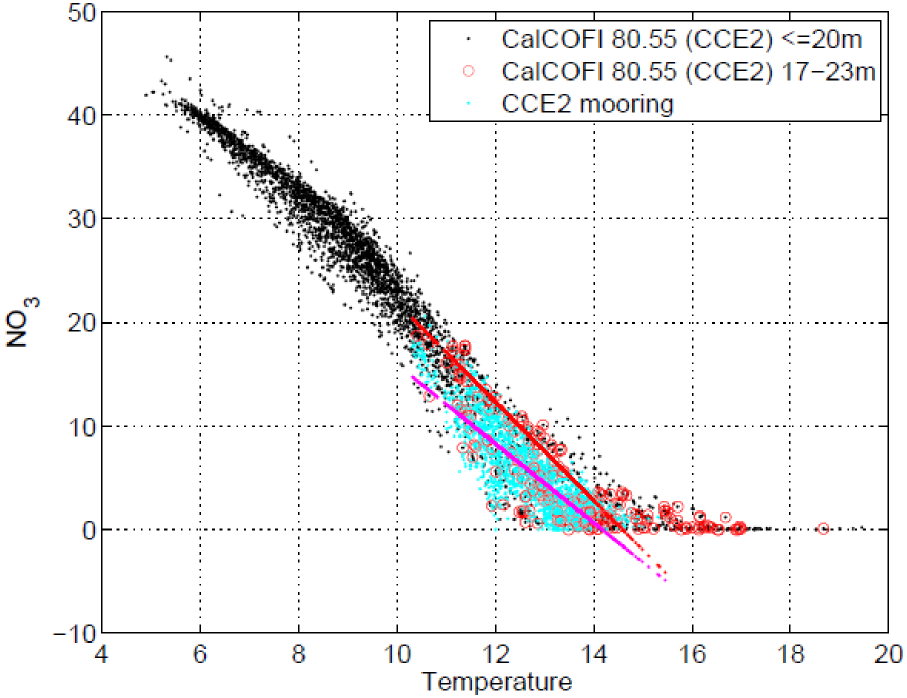
Can estimate uptake and remineralization ratios estimated from high-passed sensor data.

(Martz et al, 2014)



- mean is close to traditional Redfield Ratios, but large daily to weekly changes
- suggests regime shifts between Redfieldian New Production, Regenerated Production, and Nutrient Overconsumption.

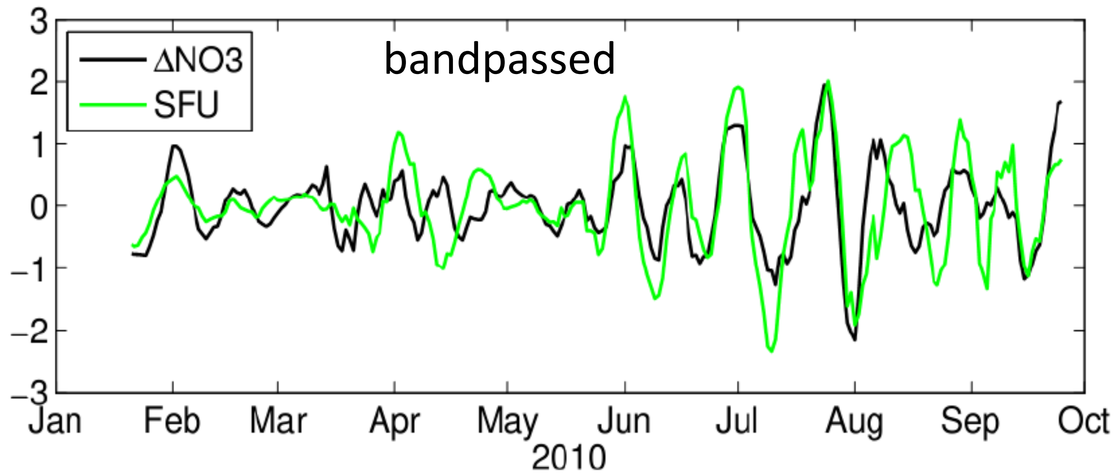
Nutrient/chlorophyll budgets for upwelling events



Infer NO_3 of freshly upwelled water from temperature (not changing fast)

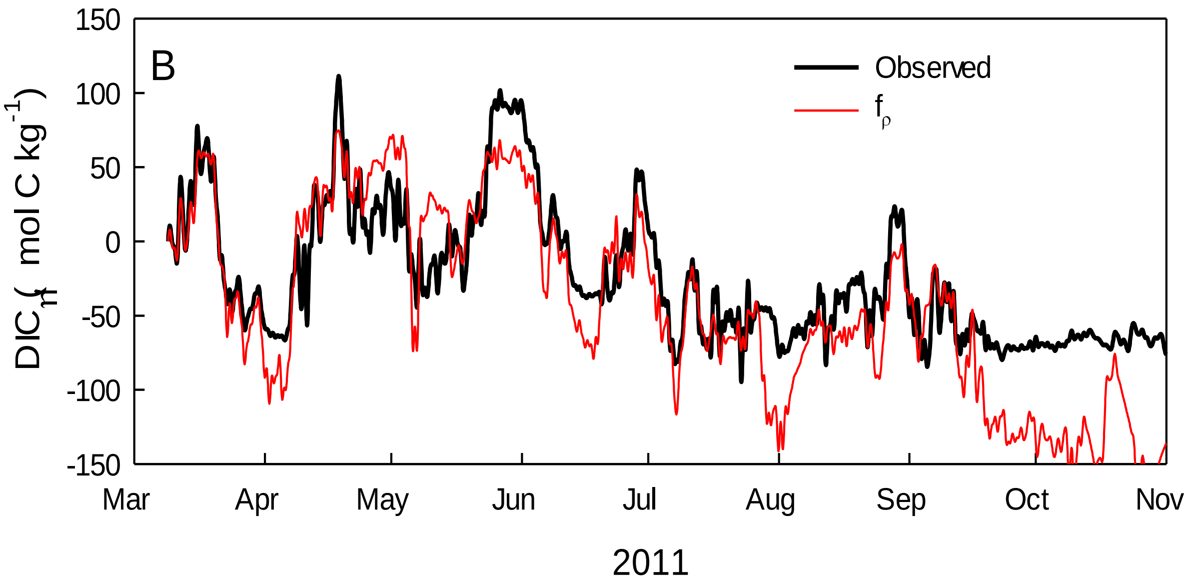
By the time water arrives at CCE2 mooring NO_3 has been used→ deficit/usage

quantitative relation between “used” nutrients and created phytoplankton



Carbon budgets for upwelling events

Use density to infer DIC of freshly upwelled water, and compare to actual DIC



Difference on event timescales is due to air-sea flux and Net Community Production (NCP).

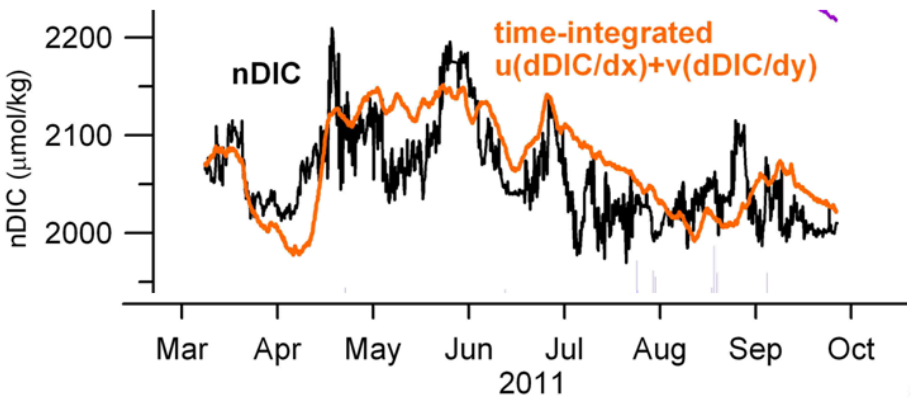
Doing the same for oxygen gives another estimate for NCP → consistency check

Full budgets (on longer timescales and away from active upwelling) requires spatial gradients for advection estimates:

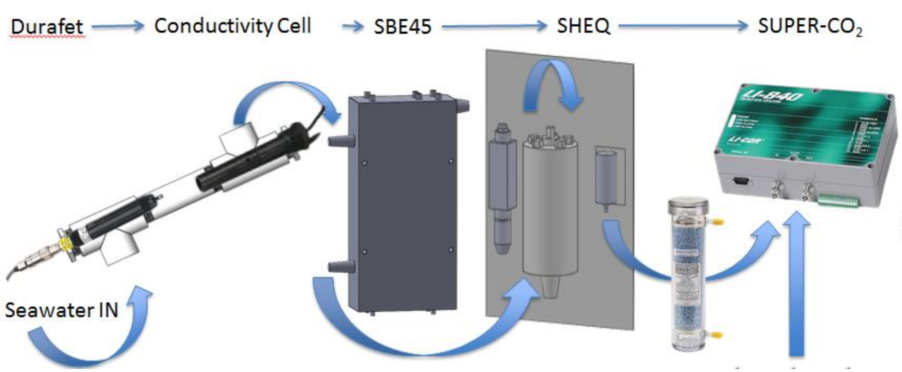
$$\frac{\Delta X}{dt} = \left(f_{gas} + f_{ent} + f_{diff} + f_{adv} + f_{u/r} + f_{NCM}\right)/MLD$$

Spatial DIC gradients from ship surveys

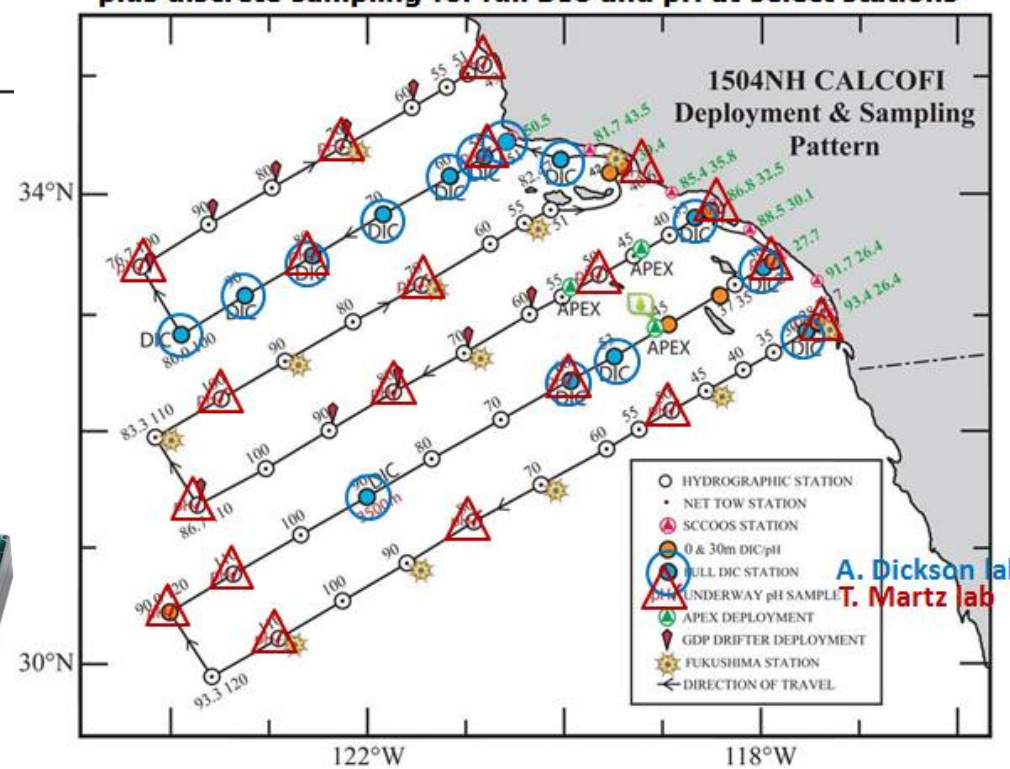
Early very crude attempt for DIC advection estimate was promising:



LTER supplement funded a new underway system



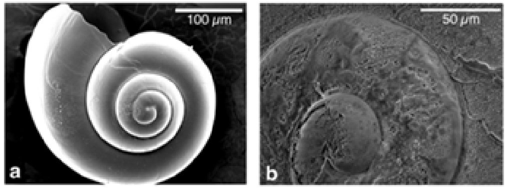
Continuous underway pH/pCO2 measurements on CalCOFI grid, plus discrete sampling for full DIC and pH at select stations

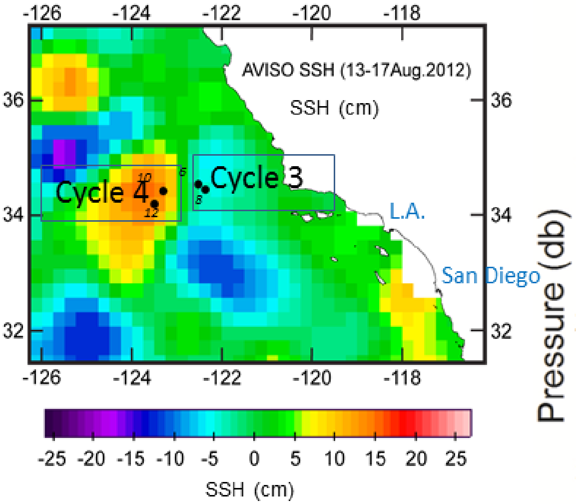


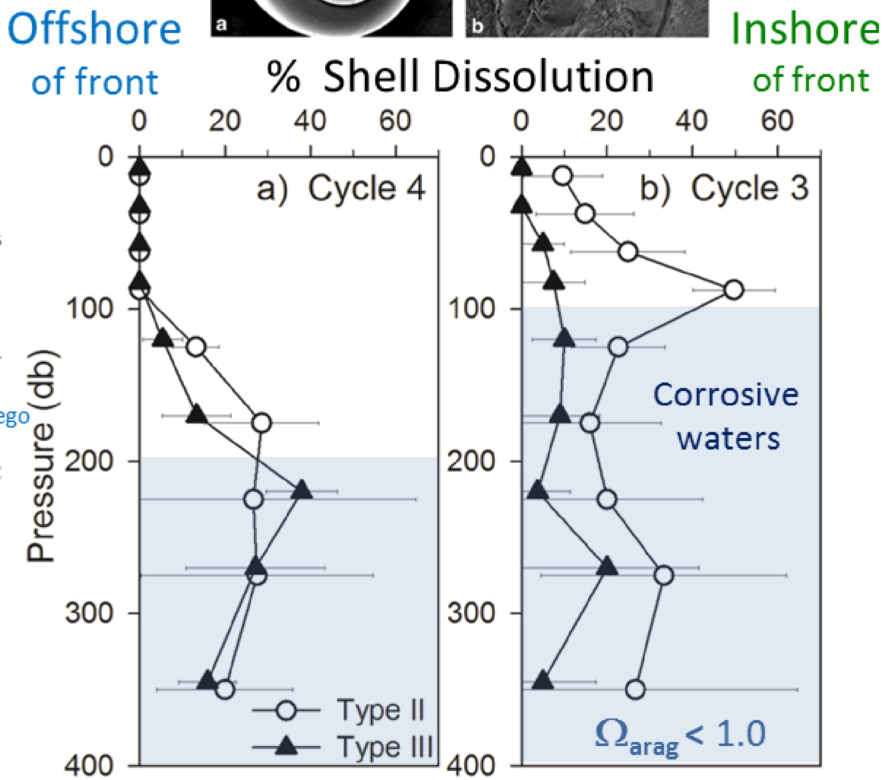
Will enable: - annual air-sea fluxes;
- gradients for budgets;
- validation of mooring data

Effect of acidification on organisms

Shell dissolution of
Limacina helicina





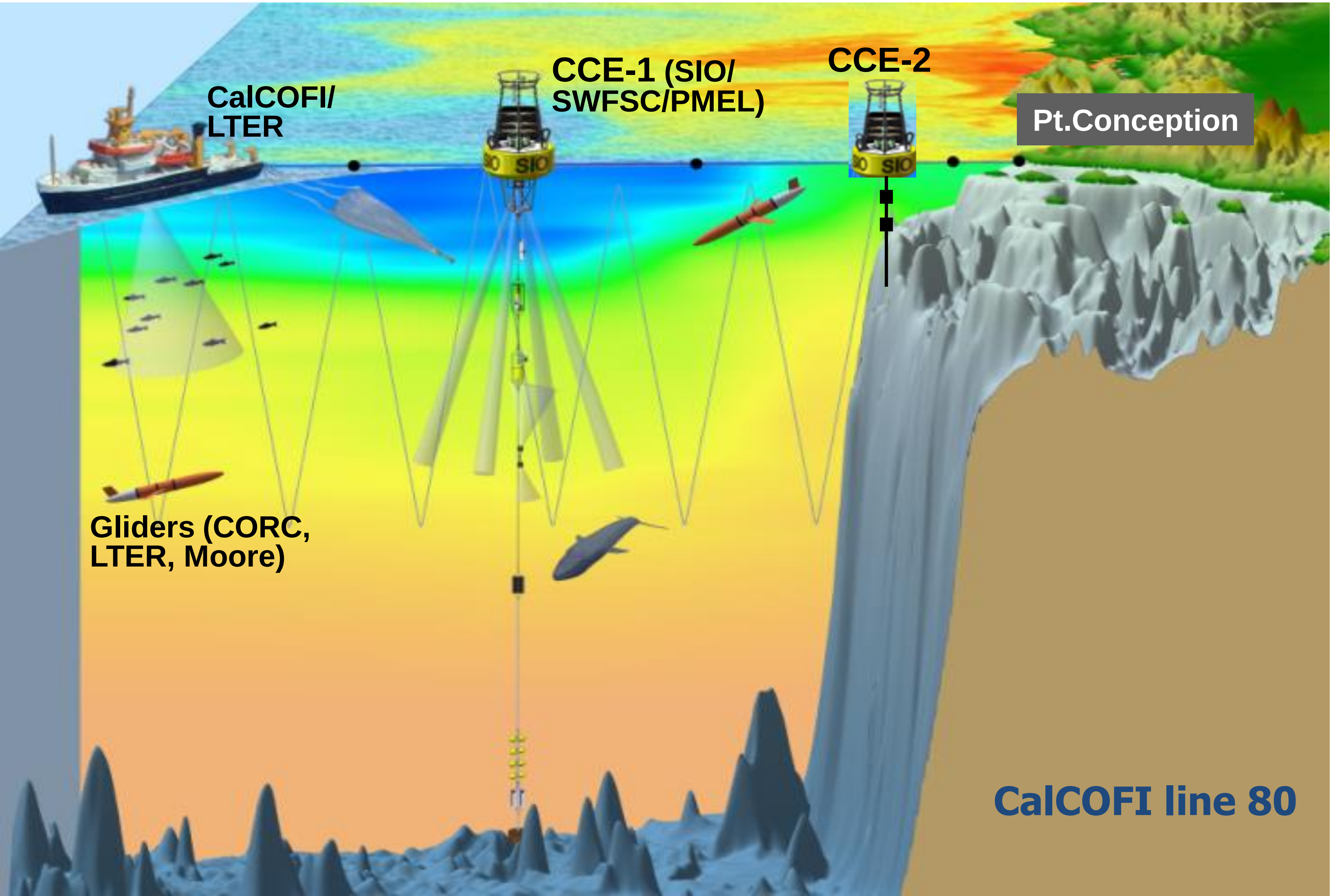


Bednaršek and Ohman (2015) *Marine Ecology Progress Series*

Continuous pH variability from moorings has been used to control/force experiments in the Levin lab at SIO.

Complementarity of timeseries with other observations

- Ships sample many variables and provide ground truth
- Gliders provide cross-shelf sampling with a few variables
- Moorings give full time sampling, wide range of variables



Summary

Timeseries enable understanding of events and extremes, and their statistics.

Real-time monitoring of surface-to-bottom conditions possible which can trigger responses (targeted sampling, mitigation of impacts, etc).

Continuous observations can observe evolution of anomalies and their origin.

Need to observe sub-surface in upwelling and undercurrent regimes.

Combined observations with density, oxygen, nitrate allow budget and new production estimates.

Observed changes in pH are being used for experiments about impact on organisms.

Combination with autonomous fisheries acoustic sensors starting to assess impact of habitat changes on populations, migrations, stock.