CCE Moorings

(Moored Climate, Carbon, Biogeochemical, and Ecosystem Observations in the Southern California Current)

Uwe Send[1], Mark Ohman[2], David Demer[3]
[1,2]Scripps Institution of Oceanography, La Jolla, CA
[3]NOAA Southwest Fisheries Science Center, La Jolla, CA

1. Project Summary

The California Current is a region of large ecological significance and known sensitivity to climate forcing. Climate processes, complex physical systems, carbon and nutrient chemistry, and ecosystem dynamics all interact to create a rich, societally important, and scientifically fascinating ocean environment off the west coast of the US. The CCE mooring project has established a unique highly multidisciplinary timeseries presence in the southern California Current, to complement ship-board observations from LTER and CalCOFI, glider observations, and the flow and transport monitoring system that has been initiated under CORC, and to start building a comprehensive continuous real-time monitoring system for this region.

The two moorings now operating, called CCE(California Current Ecosystems)-1 and CCE-2, are located in the offshore core and the coastal upwelling regime of the California Current along CalCOFI line 80, and measure

- **atmospheric conditions** (x(CO_2), wind, temperature, humidity, precipitation, irradiance),
- **upper ocean conditions** (temperature, salinity, p(CO_2), O_2, pH, currents, point and integrated measures of phytoplankton chlorophyll content over the euphotic zone, and nitrate supply),
- **multi-frequency active-acoustic observations** of zooplankton and fish biomass.

Most of the data are telemetered in real-time and publicized via websites to other researchers, agencies, and the public.

The CCE moorings are intended to serve as an example and nucleus for enhanced autonomous observations of the California Current climate system, carbon cycle, ocean acidification processes, and ecosystem changes. It also represents a real step towards a recognized need in the sustained ocean climate observing system – techniques and implementations of observing infrastructure that addresses the societal challenges driving the climate, biogeochemical and ecosystem community. This was clearly identified as a major need at the OceanObs09 conference in Venice. The merging of many new technologies, the highly collaborative nature, and merging of several funding sources, is a promising example of how to enable such observations in the future.

The supported activities include operation of the two highly instrumented real-time moorings along CalCOFI line 80 and limited processing of the data. This includes construction of moorings, execution of cruises, servicing and calibration of sensors, upgrading of technology, and participation in west coast wide ocean acidification research.

The anticipated products and outcomes include:

- long records of the processes and variability in the physical, biogeochemical, and ecosystem conditions in the southern California Current

- data sets to develop and validate biogeochemical models
- integration of the data with other OA and ecosystem programs along the US west coast.

The users/applications include the carbon, OA, ecosystem, and fisheries research community and agencies, modeling centers, fisheries management programs. The data complement and add value to the regular ecosystem and stock assessment ship surveys along the west coast.

2. Scientific and Observing System Accomplishments

a) Field Work and Data Holdings

The FY2012 funding was used for the recovery and new installation of two nearly identical moorings CCE1 and CCE2 along CalCOFI line 80, see figure 1 for the locations in the offshore and the upwelling regimes off Pt.Conception. The previously deployed CCE2 mooring had broken loose and started drifting in December 2011, due to a loose eye-splice on a nylon rope in the lower part of the mooring (this caused gradual chafing of the nylon by the aluminum thimble). We managed to recover the drifting mooring a few days later by chartering a small boat, but service, refurbishment, and redeployment had to wait until March 2012 due to manpower and shiptime limitations. The CCE2 mooring location remains a serious mechanical mooring design challenge due to the water depth – not deep enough to allow sufficiently long stretchy nylon below fish-bite depth for maintaining mooring tension, too deep to just have a large weight near the anchor for maintaining tension. We have therefore now included a load-cell which measures mooring tension just below the buoy, the data being telemetered and displayed on the CCE mooring web page. In severe wave conditions it shows the tension cycling between nearly 0kg and 1800kg over a wave cycle, meaning that we are still not safely avoiding snap loading in strong winter storms yet (over 6m wave height). This remains a challenge and concern, but the data collected will allow more realistic mooring design simulations now. Figure 2 shows the newly deployed CCE2 sensors in the upper 150m.

Ship time funding for recovery and redeployment of the CCE1 mooring was a very serious problem. This caused a delay of the service cruise until September 2012, meaning the mooring remained deployed for 18 months instead of the expected 12-13 months. The mooring survived mechanically, but some sensors had run out of battery. Also, the telemetry connection had been lost in December of 2011, but all data were retrieved after recovery of the mooring.

The resulting data holdings from all deployments to date, for the main water column instruments (excluding the acoustic backscatter Echotag/AOS sensors whose data inventory is given in table 2) are shown in figures 3 and 4. It should be noted that this figure does not do justice to the richness of information due to the compressed scale, it is only meant to indicate when at what depths which data are available. Shown are the radiometer absorption between the surface and a deeper level (plotted for a single wavelength), air-water pCO2 difference measurements by the PMEL system installed on the moorings, salinity at several levels (where temperature is also available), currents from the ADCP which cover 600m of the water column (only one depth shown here), chlorophyll fluorescence at 1-2 depths, nutrient concentrations, dissolved oxygen at several depths and pH at 1-2 levels. The realtime data telemetry from the currently deployed CCE1 40m depth instruments failed shortly after deployment so we cannot show data form that depth currently, but we believe the instruments are functioning and recording internally.

Further, we have again installed the acoustic zooplankton/fish backscatter systems by D.Demer from SWFSC on the moorings. The current deployment at CCE1 and CCE2 is the first instance where backscatter data covering the upper 300m of the water column is being telemetered in real-time as well (and displayed on the CCE mooring website). The summary of deployments of these acoustic backscatter systems is given in the later table 2.

b) Data Processing and Scientific Analyses

A lot of effort is going into calibration and quality control efforts of the data. Some instruments have large offsets and/or drifts, others need a lot of work to convert the raw data (such as chlorophyll fluorescence) to the quantities that are sought. We are pursueing multiple methods for such calibration efforts, in particular lab calibrations and attaching the sensors to a CTD rosette (for comparing the sensors readings with analyzed values from water samples at the site). This is done before and after the deployments, in order to verify the linearity of instrument response, record instrument drift, and assess the effects of biofouling. Together with factory calibrations this gives a complicated set of information that needs to be used in the most objective way and also requires careful management.

Examples of ongoing analyses are shown in the following.

Carbon events with impact on ecosystem

The continuous observations with oxygen and pH data allow the characterization of periods and events that are believed to have an impact on the ecosystem. These include hypoxic periods, and events with sufficiently low pH that the aragonite saturation levels drops below 1 (which means that calcium-forming organisms would be seriously affected). The latter so-called "corrosive" conditions have been found over wide shelf areas along the US west coast in the NOAA OA acidification surveys. Moorings now allow to collect temporal information about such events. An example of preliminary analyses is shown in table 1, comparing the offshore conditions at CCE2 with those observed on the shelf with a similar mooring off Del Mar in terms of event statistics.

Carbon budgets

A novel approach has been explored for estimating carbon budgets in the dynamic upwelling regime around CCE2. The mixed-layer conditions (depth, currents, oxygen, and pH or DIC) are continuously available, allowing analysis of typical mixed-layer budgets such as

air-sea gas flux — Mixed-layer deepening — cross-shelf advection — net community production

$$\frac{\Delta DIC}{dt} = \frac{f_{gas} + f_{ent} + \cancel{f_{diff}} + f_a + NCM(DIC)}{MLD}$$

$$\frac{\Delta O_2}{dt} = \frac{f_{gas} + f_{ent} + \cancel{f_{diff}} + f_a + NCM(O_2)}{MLD}$$

mixed-layer depth

where all quantities except the diffusive terms can be estimated from the moored observations. The advective terms could be shown to be dominated by the cross-coast advection which has been estimated very crudely using both the difference between the CCE1 and CCE2 moorings,

and also using as static gradient from the NOAA OA surveys. The resulting cross-shelf advection term is expected to have a large uncertainty, but dominates the DIC equation together with the NCM term. However, it is negligible in the oxygen equation since the horizontal gradients in oxygen are very small (always near 100% saturation). As a test, we used the above equations and observations of $\Delta DIC/dt$ and $\Delta O_2/dt$ to calculate the NCM from the DIC equation and from the O_2 equation. On short timescales, these are very similar, as shown in figure 5.

With this knowledge, we can now try to estimate the NCM from oxygen and use that in the DIC equation to make a prediction of the DIC evolution. On short timescales, this appears to work, as shown in figure 6 for periods up to 10 days. This means that with the moorings, we can approximately close the mixed-layer carbon budget on the diel and upwelling event timescale.

Climate effects

Even though our timeseries at CCE are still short, we have covered part of the recent El Nino/La Nina events and we can start to analyze impacts of these climate processes on the biogeochemical system and ecosystem conditions at the moorings. This is still in the early stages, but some first steps can be shown.

We have calibrated the dissolved oxygen data from our optode sensor, and it compares well with coincident CalCOFI observations (not shown her). This allows us to use the long CalCOFI data set from 1950 to 2010 to construct a mean seasonal cycle (or a climatology). We can then compare the oxygen data from the moorings, including the El Nino and La Nina years 2009/2010 and 2010/2011 with the typical climatological conditions in terms of the anomaly, figure 7. Both temperature and oxygen show clear anomalies that appear correlated with the climate events. However, the processes behind these changes still need analysis. For example, it not clear yet whether these anomalies in temperature and oxygen are due to changes in water masses (or their origin), in upwelling strength, or in preconditioned isopycnal depths.

Acoustic backscatter analyses

New Acoustic-Optical Sampler (AOS) deployments occurred during spring 2012 (CCE2) and early fall 2012 (CCE1). The overall recovered acoustic backscatter data sets to date are listed in table 2 and since the new deployments acoustic backscatter data are being telemetered ashore from CCE1 and visualized in real-time (Figs. 8, 9, and 10). Real-time data are displayed on the website http://mooring.ucsd.edu/CCE. Diel vertical migration (DVM) of sound scatterers is apparent, extending throughout the observation range (Figs. 8 and 9). The DVM pattern varies, likely as a function of the lunar cycle, and changes dramatically mid-October with a change in oceanographic conditions, indicated by the AOS temperature sensor positioned at 150 m depth (Fig. 11). During fall, the environment is highly dynamic at the location of the CCE1 mooring. For example, the potential sardine habitat (Zwolinski et al., 2011), a function of sea-surface temperature, chlorophyll-a concentration, and the gradient of sea-surface height, in the vicinity of CCE1 was unstable during October and November (Figs. 12 and 13). During this period, the CCE1 mooring was temporarily surrounded by a filament of good sardine habitat from mid-October through mid-November (Fig. 12). Concomitantly, the AOS echogram (Fig. 10) recorded a distinct increase in backscatter and an intense scattering aggregation circa 150 m, near the AOS. During mid-late November, when the habitat became unsuitable for sardine, the aggregation left the mooring and the backscattering returned to a lower level. The AOS on CCE1

and CCE2 allow monitoring of the dynamic presence of fish and zooplankton in an important pathway between the spring spawning grounds and the summer feeding grounds of coastal pelagic fish species (CPS) in the California Current (Demer et al., 2012).

Cited Material:

A.S. Brierley, R.A. Saunders, D.G. Bone, E.J. Murphy, P. Enderlein, S.G. Conti, and D.A. Demer, "Use of moored acoustic instruments to measure short-term variability in abundance of Antarctic krill," Limnol. Oceanogr. 4:18–29. (2006).

J.P. Zwolinski, R.L. Emmett, and D.A. Demer, "Predicting habitat to optimize sampling of Pacific sardine (*Sardinops sagax*). ICES Journal of Marine Science, 68: 867–879. (2011).

c) Data Management

All raw data is archived and made available to all collaborators on the server of the Send group. The calibration information for all sensors is collected and shared via the Ohman group Wiki site. Realtime data is displayed on the website http://mooring.ucsd.edu/CCE. Within the available resources we make a best effort at quality controlling the CCE mooring data set and providing it to OceanSITES. Much of the temperature/salinity data are mostly processed, and will soon be available in OceanSITES format via OceanSITES through 2011 (more will follow on a best-effort basis). As explained above, the quality control and calibration for so many multi-disciplinary and novel sensors are challenging and a part of ongoing research efforts. The lack of resources/funding is a definite constraint in this activity. Submission of data to OceanSITES is planned, also for the real-time data streams, but again is limited by manpower.

Summary Information:

a. Project deliverables serving the observing system's program deliverables

- Long timeseries with high temporal resolution of the physical conditions, processes and forcing, representing controls of the carbon and ecosystem in the California Current
- Long timeseries with high temporal resolution of components of the carbon system and ocean acidification processes in the California Current, enabling climate impact research
- Long timeseries with high temporal resolution of ecosystem variability and processes, yielding the response to changes in the physical and biogeochemical conditions

b. Achievements during FY2012

- Continued operation of two equivalent highly instrumented realtime moorings across the California Current ecosystem with physical, chemical, carbon, and ecosystem sensors
- First real-time sustained telemetry of acoustic backscatter from up/downlooking sensors at 150m depth
- Improvements in sensor calibration and data quality control techniques, allowing intercomparisons with other data sets (e.g. CalCOFI)
- Analyses of carbon (DIC) budgets
- analyses of climate anomalies in subsurface oxygen
- quantification of carbon events in timeseries

c. Scientific advances made and/or facilitated through the project activities

- Understanding of time variability and events in the processes governing the biogeochemical and ecosystem
- Impact of climate variability on the carbon and ecosystem in the California Current
- Analyses of the offshore boundary conditions affecting the shelf regime through upwelling transport of low oxygen/pH water into near-shore regimes
- The AOS on CCE moorings allow real-time monitoring of the coastal pelagic fish, their essential oceanographic habitat, and their seasonal dynamics. An array of such moorings could serve as a monitoring toll gate, perhaps allowing estimations of CPS-stock biomasses by measuring fish densities as they pass (e.g., Brierley et al. 2006).

d. Significance of these advances
- The results allow evaluations of the carbon cycle role and impact in the California Current
- The observations allow assessments of the ocean acidification processes and impacts in the region
- Understanding of ecosystem controls and improvement of forecasts, including fisheries management
- Improvement of biogeochemical and ecosystem models, and model validation
- Real-time monitoring of coastal pelagic fish, their habitat, and migrations could serve fisheries surveys, management, and conservation efforts.

e. Information jeopardized due to a lack of funding, lack of instrumentation, or inability to carry out the work
- Due to the IDC rate change at SIO and due to reduced funding for this project in FY2012, the CCE mooring program currently operates at a loss and needs voluntary free contributions from several collaborators and borrowed equipment. This is not sustainable.
- Lack of a duplicate set of hardware for two moorings (buoys, sensors) means we cannot service both moorings on a single cruise. This means increased need of shiptime (which we do not have) and/or gaps in the mooring timeseries (when we bring hardware to shore for service)
- The instrument array must be larger to span the migration route of coastal pelagic fish and should use several frequencies, which is not possible with present funding. Insufficient funding for data integration/analysis has limited applications of this valuable data resource.
- Data management and calibration efforts are behind and lacking funding, especially the QC and dissemination of biogeochemical and ecosystem sensors.

f. Web sites for the program
- http://mooring.ucsd.edu/CCE

g. Data Management
- Data not distributed on GTS
- Realtime data are shown in graphical form on the website. They are backed up on institutional computers. Data are not publicly available in realtime at present.
- Delayed-mode data is on institutional computer with backup system, plots are provided on the website. Processed data are made available through OceanSITES ftp servers and this implemented for microcat (T/S).
- Archival on institutional backup system happens daily; transfer of newly processed data to OceanSITES repository approx yearly. Data can be retrieved from the OceanSITES ftp

server ftp://data.ndbc.noaa.gov/data/oceansites/DATA/CCE* and we have successfully retrieved our own data from there.
- Data plots are shown on http://mooring.ucsd.edu/CCE

2.1. Outreach and Education

The CCE mooring effort was presented to young researchers via multiple presentations at the ASLO/OceanSciences Conference in Salt Lake City in 2012. The recent results, including the ones shown in this report, were also communicated during an invited oral presentation at the fall AGU meeting in December 2012. The program is communicated to the public via various websites and also contributes to the CCE LTER program.
One postdocs and several graduate students are being trained via work on the CCE program and data. Wherever possible, we invite students to participate in CCE cruises. In our teaching, and during visits of prospective students, CCE is used as a demonstration of exciting and relevant research. Many potential new students contact us as a result of their interest in the CCE mooring program as explained on our websites.

3. Publications and Reports

Demer, D.A, J.P. Zwolinski, K.A. Byers, G.R. Cutter, J.S. Renfree, T.S. Sessions, B.J. Macewicz, "Prediction and confirmation of seasonal migration of Pacific sardine (*Sardinops sagax*) in the California Current Ecosystem," Fisheries Bulletin, 110:52-70 (2012).

Kim, H.-J., and U. Send, 2012: Physical and biological responses during the 2009-2011 ENSO events in the Southern California Current. Ocean Sciences Meeting, Salt Lake City, UT.

Kim, H.-J., SH Nam, U. Send, M. Ohman, C. Sabine, and R. Feely, 2012: Temporal variability of pCO2 in the California Current driven by coastal upwelling and El NiÑo/La NiÑa Southern Oscillation. The third international symposium on the Ocean in a high CO2 world, Monterey, CA.

Nam, S. H., H. J. Kim, U. Send, T. Martz, D. Demer, A. Dickson, M. Ohman, C. Sabine, and R. Feely, 2012: Significance of circulation change and horizontal advection on temporal changes in dissolved inorganic carbon and relevant biochemical parameters in California Current LTER region, *Third international symposium on the Ocean in a High CO2 World, Monterey, CA, USA*.

Send, U., and S. Nam, 2012: Relaxation from Upwelling: the effect on dissolved oxygen on the continental shelf. J. Geophys. Res. VOL. 117, C04024, doi:10.1029/2011JC007517

Send, Uwe, Mark Ohman, Todd Martz, Andrew Dickson, Richard Feely, David Demer, Libe Washburn, 2012: Use of multi-disciplinary mooring data to extend intermittent OA observations from ship surveys. Invited talk, AGU Fall Meeting, San Francisco.

Wilson, S.J. and Uwe Send, 2012: MOORED OPTICAL ATTENUATION MEASUREMENTS IN THE CALIFORNIA CURRENT SYSTEM, Poster, Ocean Sciences Meeting, 2012

Wilson, S.J., Uwe Send, and Mark D. Ohman, 2012: Chlorophyll timeseries in the California Current System measured through wavelength-specific optical attentuation. Poster, The Ocean in a High CO2 World: Ocean Acidification Monterey, CA. 2012

Manuscripts in Preparation:

H.-J. Kim et al: calibration of biogeochemical moored sensors

U. Send et al: CCE moored observations as a contribution to the California Current LTER program

T.Martz et al: Accuracy of moored pH sensors and comparison with empirical relations

T. Martz et al: Carbon budgets in the southern California Current

D. Demer et al: Continuous acoustic backscatter observations for inferring the impact of biogeochemical conditions on zooplankton and coastal pelagic fish

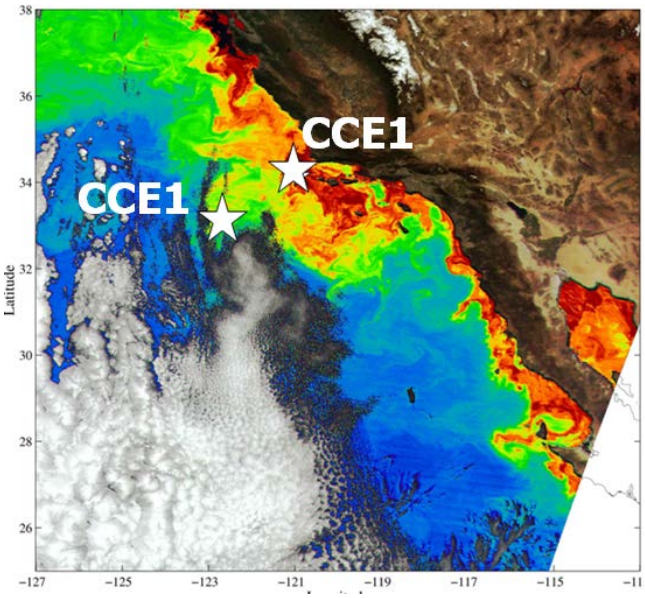

Figure 1 *(above): Locations of the CCE1 and CC2 moorings off Pt.Conception. Color shows chlorophyll abundance.*

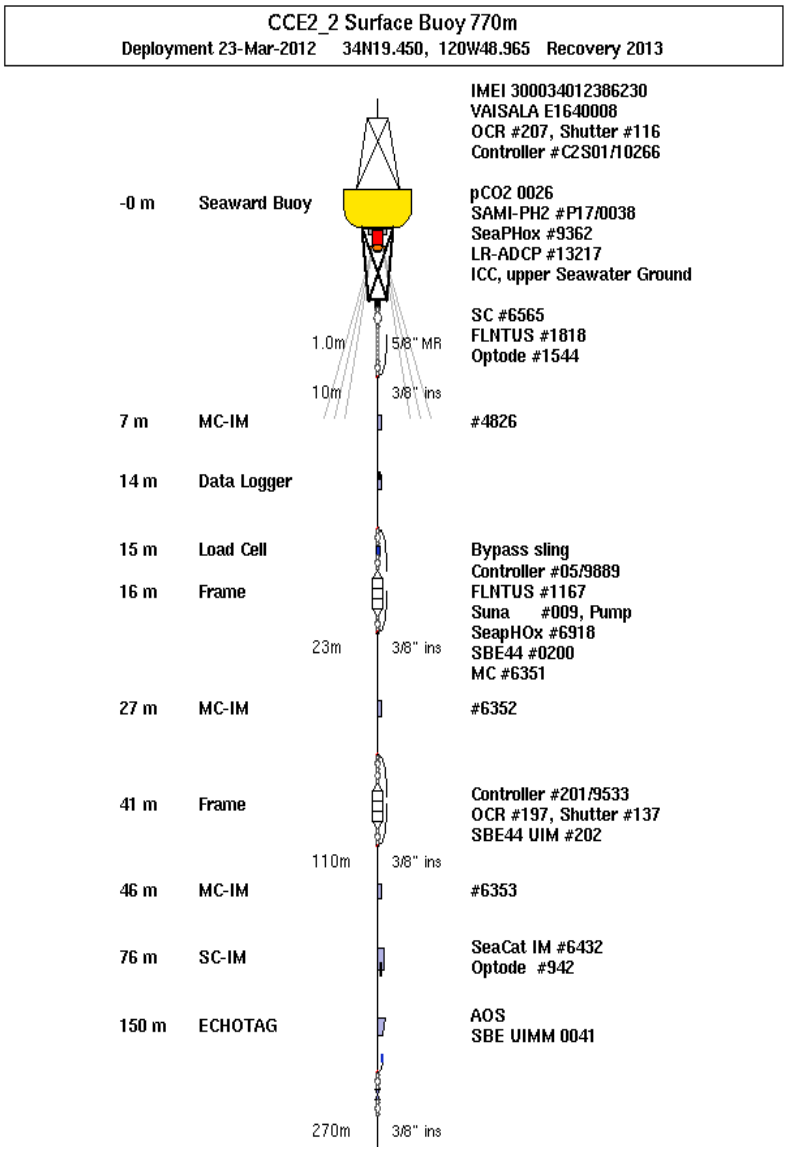

Figure 2 *(right): Design of the upper 150m of the new CCE2 mooring with a wide suite of sensors and T/S sampling (for mixed-layer depth estimates) to 76m.*

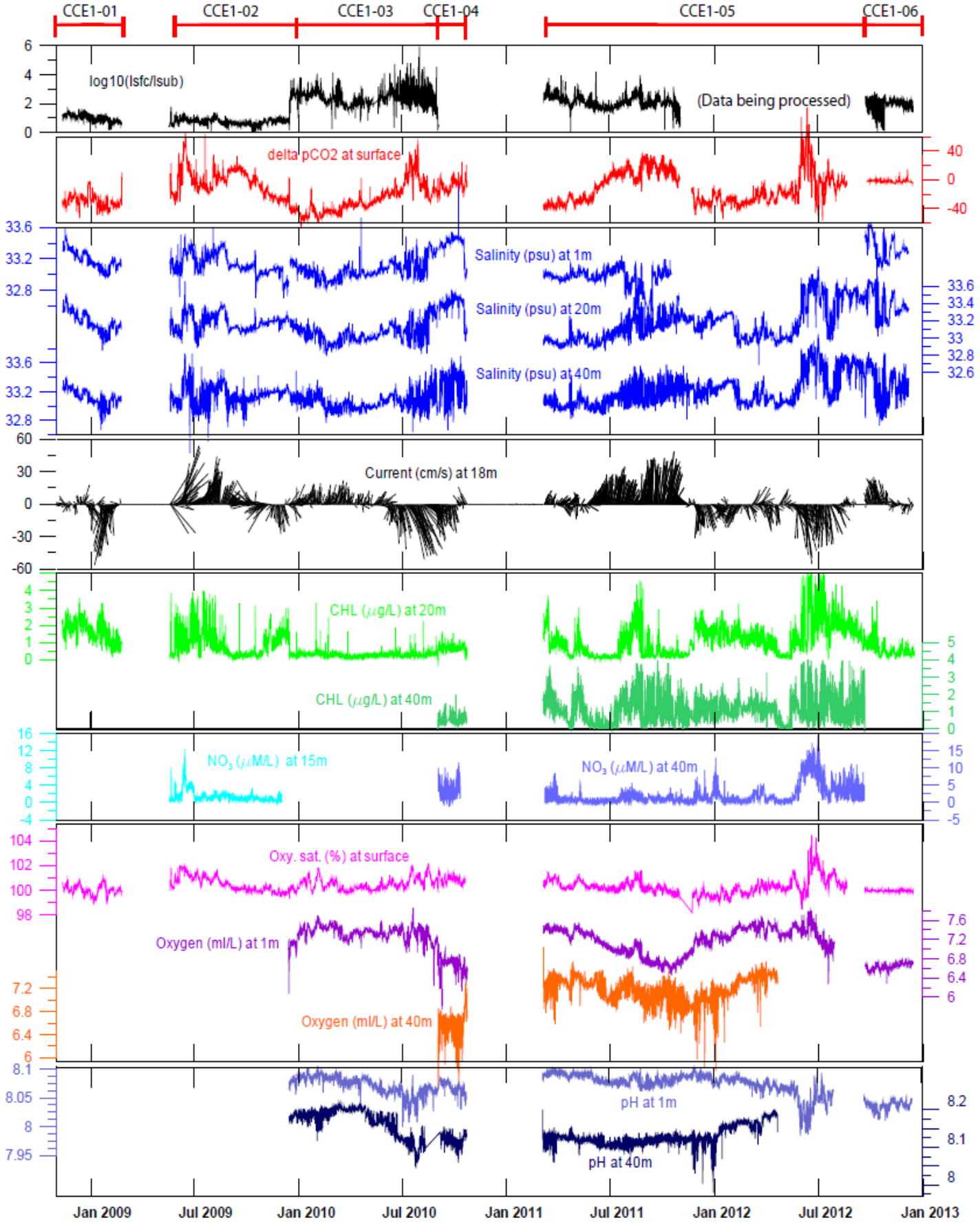
CCE1-01
CCE1-02
CCE1-03
CCE1-04
CCE1-05
CCE1-06
log10(Isfc/Isub)
(Data being processed)
delta pCO2 at surface
Salinity (psu) at 1m
Salinity (psu) at 20m
Salinity (psu) at 40m
Current (cm/s) at 18m
CHL (μg/L) at 20m
CHL (μg/L) at 40m
NO3 (μM/L) at 15m
NO3 (μM/L) at 40m
Oxy. sat. (%) at surface
Oxygen (ml/L) at 1m
Oxygen (ml/L) at 40m
pH at 1m
pH at 40m
Jan 2009
Jul 2009
Jan 2010
Jul 2010
Jan 2011
Jul 2011
Jan 2012
Jul 2012
Jan 2013

Figure 3 *(previous page): Available data from all CCE1 mooring deployments for: surface-subsurface radiometers (showing a logarithmic ratio), water-air pCO2 difference (PMEL sensors), some of the T/S sensors (showing salinity), currents at 20m (mostly from an ADCP covering the upper 500m),chlorophyll estimates, nitrate concentration, dissolved oxygen data from several depths, and pH readings from two depths. All data are raw with factory calibration.*

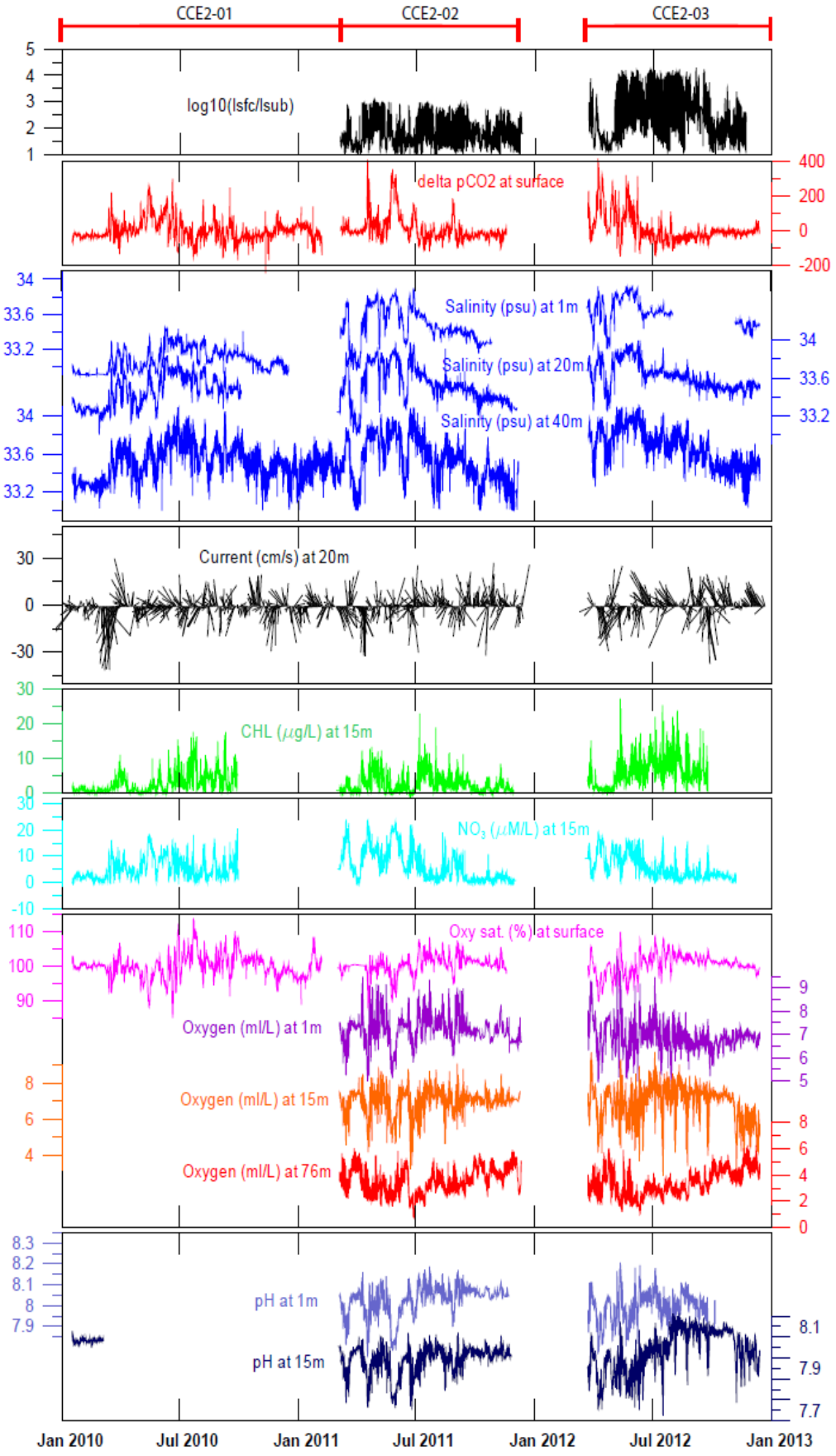

Figure 4 *(right): Same as figure 3 but for the CCE2 mooring. The x-axis is the same as figure 3 so can be directly compared/overlaid.*

Table 1: *Mooring statistics of corrosive events (measured in aragonite saturation values) at CCE2 (76m depth), compared to near-bottom data from a mooring on the shelf off Del Mar in 100m water depth.*

	Ω_{arag}	
76 m at CCE2	**Time Mean & Std. Dev.**	**1.07 ± 0.165**
	Min. & Max.	**0.68 & 1.76**
	Total time (days) below 1.0 (Percentage of total measurements, %)	**201.2 (39%)**
	Maximum continuous duration (days) below 1.0	**26.2**
88 m at DM (on shelf)	**Time Mean & Std. Dev.**	**1.16 ± 0.222**
	Min. & Max.	**0.62 & 2.31**
	Total time (days) below 1.0 (Percentage of total measurements, %)	**220.1 (29%)**
	Maximum continuous duration (days) below 1.0	**81.6**

Table 2. *Summary of echosounder deployments on CCE moorings.*

Unit	Location Deployed	Lat/Long	Date Deployed	Date Recovered	Data Status
EchoTag 1	CCE1-01	33 28.75 N, 122 31.97 W	11/10/2008	2/23/2009	\\pacifica\Static_2\CCE1\01\EchoTag 1
EchoTag 1	CCE1-02	33 28.73 N, 122 31.58 W	5/18/2009	12/14/2009	\\pacifica\Static_2\CCE1\02\EchoTag 1
EchoTag 2	CCE1-03	33 25.6 N, 122 29.0 W	12/14/2009	9/1/2010	\\pacifica\Static_2\CCE1\03\EchoTag 2
EchoTag 3	CCE1-03	33 25.6 N, 122 29.0 W	12/14/2009	9/1/2010	\\pacifica\Static_2\CCE1\03\EchoTag 3
EchoTag 1	CCE2-01	34 19.46 N, 120 48.86 W	1/16/2010	3/5/2011	Unable to read data from SD card
EchoTag 2	CCE1-04	33 27.29 N, 122 29.79 W	9/2/2010	10/23/2010	Unit flooded, data lost
AOSI-1	CCE1-04	33 27.29 N, 122 29.79 W	9/2/2010	10/23/2010	Unit flooded, data lost
AOSII-8	CCE2-02	34 18.55 N, 120 48.16 W	3/5/2011	12/20/2011	\\pacifica\Static_2\CCE2\02\AOSII-8
AOSII-1	CCE1-05	33 29.56 N, 122 31.07 W	3/6/2011	9/20/2012	\\pacifica\Static_2\CCE1\05\AOSII-1
AOSII-3	CCE2-03	34 19.45 N, 120 48.98 W	3/23/2012	Currently deployed	
AOSII-5	CCE1-06	33 28.87 N, 122 30.89 W	9/21/2012	Currently deployed	

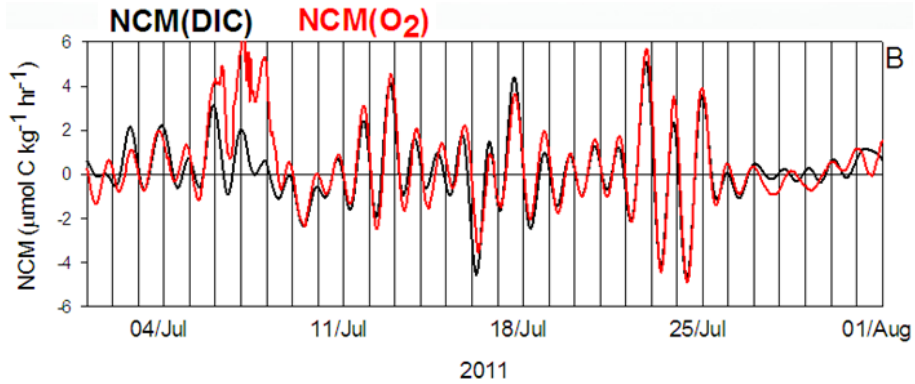

***Figure 5**:Diel-band estimates of net community production at CCE2 using the DIC balance (domimated by advection) and the O2 balance (dominated by air-sea flux). The agreement suggests that on short timescales, NCM can be estimated from O2 and then be used in the DIC balance.*

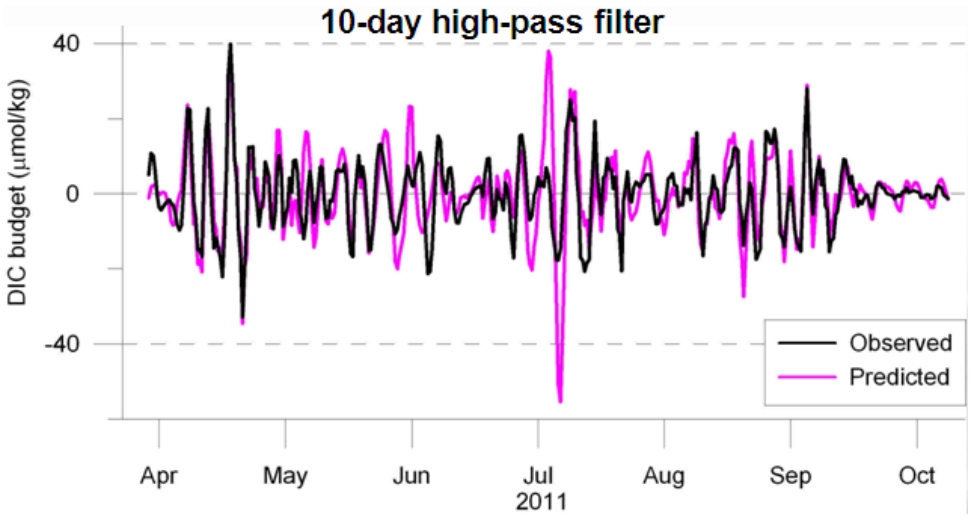

***Figure 6**:DIC predicted on timescales up to 10 days, using the DIC equation with NCM from the O2 equation, compared with the observed DIC at the CCE2 mooring.*

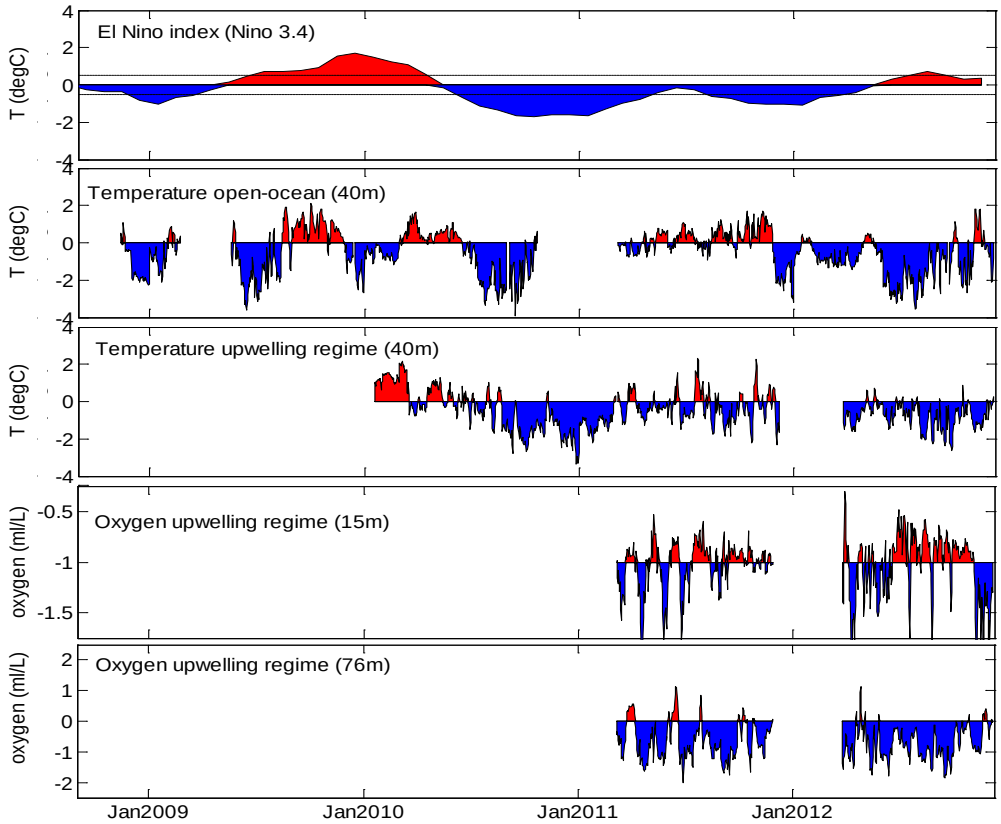

***Figure 7**:El Nino index as a measure of El Nino/La Nina activity, and CCE mooring anomalies for temperature and oxygen, relative to the long CALCOFI records at the same locations and depths. Large and significant anomalies in oxygen are observed at the moorings, which will be analyzed to understand their forcing and their impact.*

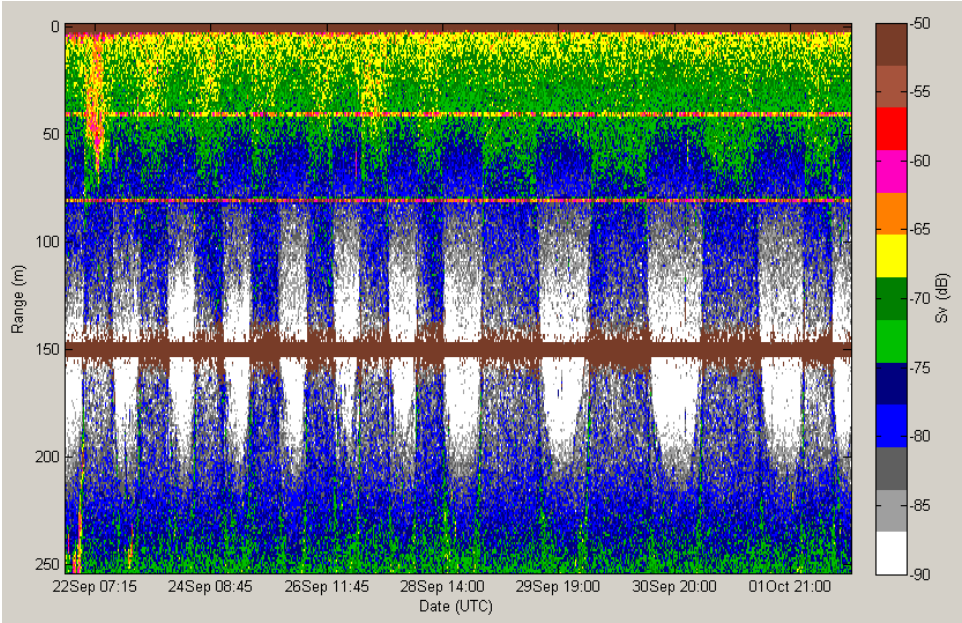

Figure 8: *CCE1 AOS echogram showing diel vertical migration of sound scatterers, likely modulated in duration by the lunar cycle.*

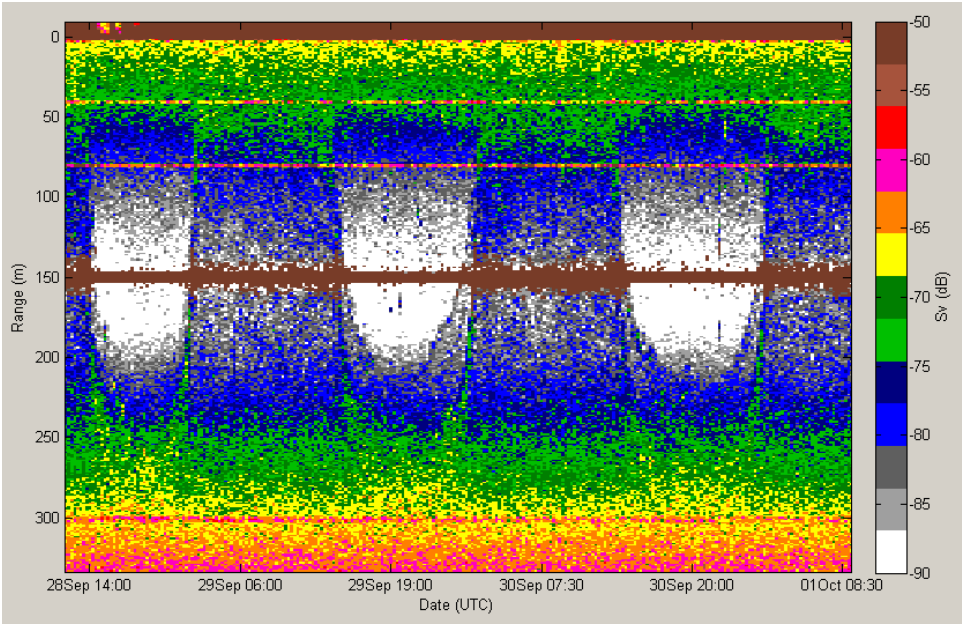

Figure 9: *Zoomed CCE1 AOS echogram showing diel vertical migration of sound scatterers, likely modulated in duration by the lunar cycle.*

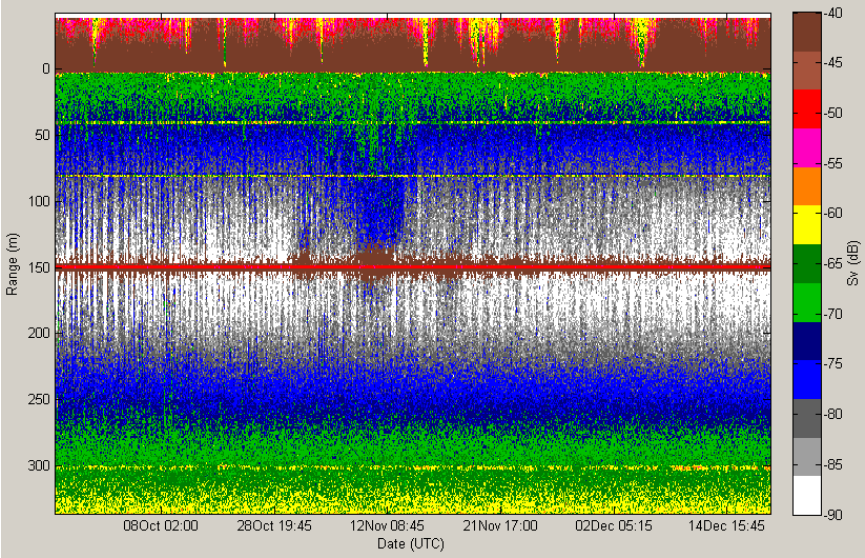

Figure 10: *CCE1-AOS echogram showing a distinct increase in backscattering intensity during late-October to mid-November.*

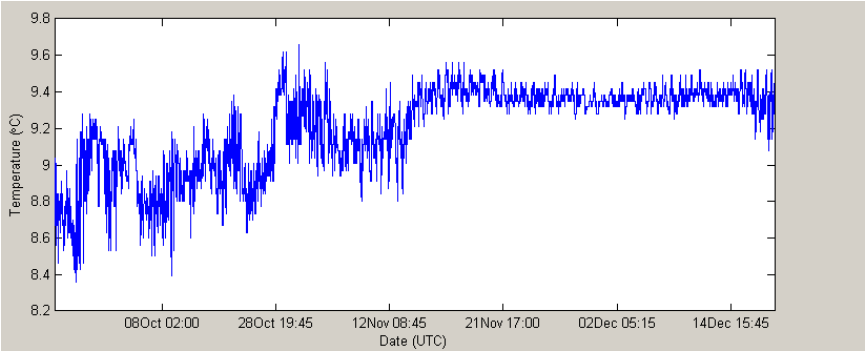

Figure 11: *CCE1-AOS sea temperature at 150 m. An abrupt change is apparent in late-October, coincident with an increase in backscatter (see* ***Fig. 3****). The temperature is relative stability from mid-November through mid-December.*

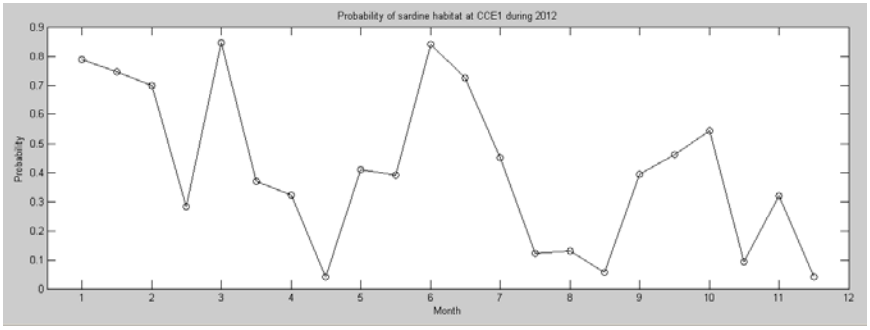

Figure 12: *Probability of sardine habitat, modeled from satellite-sensed sea-surface temperature, chlorophyll-a concentration, and the gradient of sea-surface height, during 2012, ca. CCE1.*

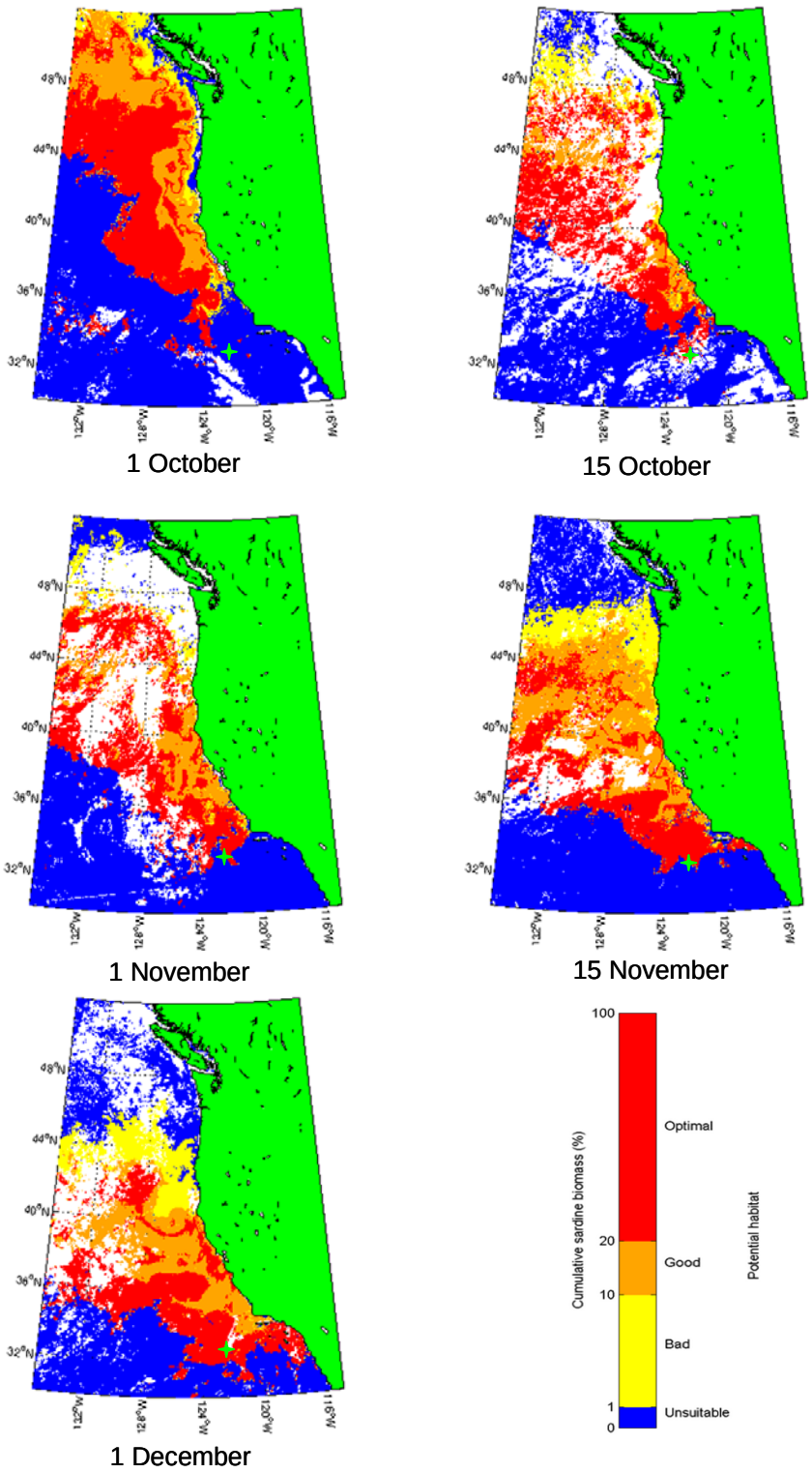

Figure 13: *Potential sardine habitat modeled from satellite-sensed sea-surface temperature, chlorophyll-a concentration, and the gradient of sea-surface height (Zwolinski et al., 2011) during October through early December, 2012. The images are 14-day averages centered on the indicated dates. The approximate location of the CCE1 mooring is indicated by the green cross.*