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Contextualizing time-series data: Quantification of short-term regional variability in the San Pedro Channel using high-resolution *in situ* glider data

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Abstract

Oceanic time-series have been instrumental in providing an understanding of biological, physical, and chemical dynamics in the oceans and how these processes change over time. However, the extrapolation of these results to larger oceanographic regions requires an understanding and characterization of local versus regional drivers of variability. Here we use high-frequency spatial and temporal glider data to quantify variability at the coastal San Pedro Ocean Time-series (SPOT) site in the San Pedro Channel (SPC) and provide insight into the underlying oceanographic dynamics for the site. The dataset was dominated by four water column profile types: active upwelling, offshore influence, subsurface chlorophyll maximum, and surface bloom. On average, waters across the SPC were most similar to offshore profiles. On weekly timescales, the SPOT station was on average representative of 64% of profiles taken within the SPC, and SPOT was least similar to SPC locations that were closest to the Palos Verdes Peninsula. Subsurface chlorophyll maxima with co-located chlorophyll and particle maxima were common in 2013 and 2014 suggesting that these subsurface chlorophyll maxima might contribute significantly to the local primary production. These results indicate that high-resolution *in situ* glider deployments can be used to determine the spatial domain of time-series data, allowing for broader application of these datasets and greater integration into modeling efforts.

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1. Introduction

Time-series sites have been invaluable for providing insights into the biological, chemical, physical, and ecological processes that occur in the world's oceans. These sites provide *in situ* measurements that are critical for model development, validation, and ongoing improvement (Fasham et al., 1990;Doney et al., 1996;Spitz et al., 2001;Boyd and Doney, 2002;Moore et al., 2002;Dugdale et al., 2002;Doney et al., 2009). To date, a small number of open ocean time-series sites (e.g. Hawaii Ocean Time-series and Bermuda Atlantic Time-series Study) have been heavily utilized by the oceanographic community while coastal time-series (e.g. San Pedro Ocean Time-series), which are more cost effective to run and so more numerous, have typically been under-utilized. One primary reason for this discrepancy is that the representativeness of these coastal sites to larger regions has been unclear. Here we demonstrate that characterizing fine-scale temporal and spatial variability at an individual site relative to a larger region may provide a path for leveraging numerous local time-series sites in order to gain an understanding of larger scale oceanographic dynamics.

Since most time-series are sampled at a single fixed location approximately once per month, the overall dataset is assumed to represent the mean state of a given geographical region as it varies with seasonal and annual cycles. To determine the accuracy of this assumption and to allow for the extrapolation of coastal time-series data to a larger region, high-resolution spatial and temporal monitoring of the physical and biological variability around these time-series sites is required. Because of the limitations with traditional *in situ* approaches, satellite imagery is frequently used to characterize spatial and temporal variability, assuming a tight coupling between surface and sub-surface variability (e.g., DiGiacomo and Holt, 2001;Kahru et al., 2009;Nezlin et al., 2012). However, for many coastal regions satellite observations may be insufficient for assessing the biological and environmental variability due to decoupling between surface and sub-surface dynamics, the importance of fine spatial scale (<1 km) variability, and the presence of terrestrially derived chromophoric dissolved organic matter (CDOM).

High-frequency *in situ* sampling with gliders can provide uninterrupted monitoring of the surface 100 to 1000 meters vertically over tens of kilometers horizontally. These datasets provide both an understanding of kilometer-scale spatial and sub-monthly temporal dynamics as well as insight into the connectivity between surface and subsurface dynamics, thereby aiding in the interpretation of satellite data. Here, we use an eight month Slocum electric glider dataset from the San Pedro Channel (SPC) to investigate the representativeness of the coastal San Pedro Ocean Time-series (SPOT) site for the region. We demonstrate that high frequency sampling can be used to generate a framework for understanding spatial and temporal variability in a region and to gain a better understanding of the representative nature of a given time-series location

The SPOT station, which is located at 33˚ 33' 00" N and 118˚ 24' 00" W, sits in the SPC between Catalina Island and the Palos Verdes Peninsula where the water depth is approximately 900 meters (Figure 1). The SPC lies within the larger Southern California Bight (SCB), which extends from Point Conception to Mexico (Noble et al., 2009). The Channel Islands and submarine canyons oceanographically define the SCB. Within the SCB, the Southern California Eddy is a dominant, persistent feature that generates poleward-flowing surface currents that break off from the California Current (Oey, 1999;Noble et al., 2009;Dong et al., 2009). The SCB is characterized by strong seasonal variation, including a spring upwelling season and subsequent phytoplankton blooms. Within the SPC, however, local upwelling and post-upwelling bloom formation are less persistent or predictable than observed farther north. Post-upwelling blooms occur on the timescales of days to a couple of weeks, and can be quickly followed by periods of very low surface chlorophyll (Supplemental Figure S1). The SPOT station has been sampled monthly for environmental and biological parameters since 1998. Microbial communities at SPOT have been found to have annually and seasonally recurring membership (Fuhrman et al., 2006;Steele et al., 2011;Chow et al., 2013;Chow et al., 2014). Daily sampling at this site has shown that dominant microbial taxa vary at much shorter time-scales, indicating that monthly sampling may only represent a persistent background community (Needham et al., 2013;Needham and Fuhrman, 2016).

2. Methods

2.1 Glider Deployments

The vertical physical and biological characteristics of the SPC were characterized using a Teledyne-Webb G1 Slocum electric glider that was deployed from March through July of 2013 and 2014. The deployment period was selected in order to maximize the likelihood that both coastal and offshore processes would be captured in the dataset (Hayward and Venrick, 1998;Di Lorenzo, 2003;Mantyla et al., 2008;Schnetzer et al., 2013). The glider was deployed on a 28 km cross-channel path between Catalina Island and the Palos Verdes Peninsula (Figure 1) and completed a single cross-channel pass every 1.5-2 days (average speed 1 km hr^{-1}). Data were collected between ~3 and 90 meters, with the exception of when the glider crossed the major shipping lanes where the glider was constrained to depths below 20 meters to avoid damage or loss from ship traffic. Chlorophyll-a fluorescence was measured by a WetLabs EcoPuck FL3 fluorometer, backscatter at wavelengths of 532, 660, and 880 nanometers was measured by a WetLabs EcoPuck BB3 sensor, and temperature, salinity, and pressure were measured with a SeaBird flow-through CTD. Vertical resolutions for the WetLabs pucks were approximately 0.3 m, while the vertical resolution for the SeaBird CTD was approximately 0.6 m. The glider was recovered every 3-4 weeks for cleaning, battery replacement, and recalibration using standard methods published in Cetinić et al (2009).

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2.2 Data Analyses

Glider data were processed, calibrated, and quality controlled following Cetinić et al. (2009) and Seegers et al (2015). To correct for current induced drift, the glider data from each 2-day transect were then gridded onto an idealized glider transect with 500 m horizontal resolution and 1m vertical resolution that was perpendicular to the mean flow and the coastline (Figure 1). Only glider data within 5 km of the idealized transect were used in this analysis (Figure 1). Each 500 m bin (N=62) corresponded approximated with a single downcast and upcast. Only profiles with data for >85% of the vertical bins were used for further analyses, thereby excluding partial profiles from under the shipping lanes. The remaining missing data (< 15% of each profile) were filled using 2D interpolation from all neighboring bins. A total of 557 profiles from 2013 and 1049 profiles from 2014 were accepted for further analyses.

The temperature, salinity, and chlorophyll a data from each of the 1606 glider profiles were used to calculate secondary metrics that were used for statistical analyses. Specifically, maximum chlorophyll fluorescence (MaxCHL), depth of maximum chlorophyll fluorescence (zMaxChl), 70 meter integrated chlorophyll (ChlInt70), depth of maximum backscatter (zMaxBB), maximum backscatter (MaxBB), and ratio of integrated chlorophyll in the top 70 meters relative to the integrated chlorophyll in the top 20 meters (ChlInt70Per20) were calculated. In addition, the maximum stratification index (MaxBVF) and depth of maximum stratification (zMaxBVF) were estimated using the Brunt Vaisala Frequency (BVF):

$$BVF = \sqrt{\frac{g*\partial\rho}{\rho*\partial z}} \qquad \text{(eq. 1)}$$

where g is Earth's gravitational acceleration in meters per squared second, ρ is the ambient density in kilograms per cubic meter, ∂z is depth interval in meters, and ∂ρ is the change in density over that interval (Mann and Lazier, 2013). The mixed layer depth (MLD) was defined as the depth where density change exceeded the equivalent of a 0.4˚C temperature drop relative to the density at 5 m (modified from Sprintall and Tomczak, (1992)). The mixed layer temperature (MLTemp) was calculated as the mean temperature within the mixed layer. Finally, the depth of the 12.5˚C isotherm (z12p5) was used as a proxy for the top of the nutricline, which indicated nutrient-rich sub-thermocline waters in the SPC (Hayward and Venrick, 1998).

Principal component analysis (PCA) was used to differentiate between the major water column profile types observed within the glider dataset. Specifically, 54 end-member profiles were selected to define each of four dominant water column profile types observed in the SPC: early upwelling, surface phytoplankton bloom, subsurface chlorophyll maximum, and offshore influence (Table 1, Figure 2). These profile types had been observed qualitatively in glider curtain plots, and were selected from the dataset using MLTemp, ChlInt70Per20, ChlInt70, z12p5, maxCHL, zMaxChl, and MLD criteria (Supplemental Table S1). A step-wise PCA was conducted to determine the relative influence of each of the secondary characteristics on total observed variance within the end-member profile dataset. Based on this analysis, four characteristics (zMaxBB, MaxBB, zMaxBVF, and MaxBVF) were omitted from further PCA analyses as they did not strongly affect overall dataset variance or the resulting PCA distribution. The remaining 1552 glider profiles were then projected onto the PC1 and PC2 coordinates based on their secondary characteristics (Figure 4).

2.3 Ancillary Satellite Data

Level 3 mapped MODIS Aqua daily 9km photosynthetically active radiation (PAR) measurements were acquired from the NASA Ocean Biology (https://oceandata.sci.gsfc.nasa.gov/MODIS-Aqua/Mapped/Daily/9km/par/). MODIS Aqua daily 1 km chlorophyll (ChlSat) data and were acquired from NOAA CoastWatch West Coast Regional Node (http://coastwatch.pfeg.noaa.gov/coastwatch/CWBrowser.jsp). These data were then matched geographically and temporally with the *in situ* glider data. Of the 1606 final glider profiles from 2013 and 2014, 1170 matching PAR measurements and 571 matching ChlSat measurements were available. PAR measurements were then used in combination with the glider chlorophyll profiles to estimate the light field at depths between 1 and 80 m for each glider profile (Jacox et al., 2015). The diffuse attenuation coefficient was calculated as a function of chlorophyll a concentration at each depth (Jacox et al., 2015). The 1% light level, hereafter referred to as the euphotic depth, and the first optical depth were then calculated for each glider profile from these light profiles (Kirk, 1994).

3 Results

3.1 Cross-Channel Oceanographic Trends

Cross-channel comparisons of mixed layer temperature (MLTemp), mixed layer depth (MLD), depth of the 12.5°C isotherm (z12p5), and integrated chlorophyll over the upper 70 m (ChlInt70) were used to identify persistent oceanographic gradients across the transect (Figure 3). Observed physical properties in both spring 2013 and spring 2014 displayed an onshore-offshore gradient, where onshore direction was defined as towards the Palos Verdes Peninsula (PV) and offshore was defined as towards Catalina Island. This gradient could be seen most clearly in the z12p5 data, where there was a strong offshore tilt in the mean depth of this isotherm (Figure 3c). This tilt is consistent with equatorward flow through the channel, but could also have been amplified closest to shore with periods of active upwelling. Though the average depth of the cold, high-nutrient waters was shallowest close to shore, the cross-channel data for ChlInt70 displayed only a weak cross-channel gradient (Figure 3d). Rather, ChlInt70 had fairly constant cross-channel values of about 100 mg/m^2. It is important to note that integrated chlorophyll alone cannot be used to assess the productivity of a location, because it does not account for the vertical chlorophyll distribution and its overlap with the vertical light field. These cross-channel analyses also highlight high intra-bin temporal variability over the course of the deployments, especially for ChlInt70 and MLD (Figure 3). The importance of this temporal and spatial pattern of variability for SPOT is two fold: 1) a monthly time-series sampling

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scheme may under-sample both biological and physical variability at SPOT, but 2) the similarity in variance across the SPC suggests that, given sufficient sampling, SPOT data could be representative of the average state of the SPC.

To look specifically at variability between glider profiles during these deployments, we first identified four common water column profiles within our dataset (Table 1, Figure 2). The identification of these 'end member' profiles was done without consideration of location within the channel. These four profile types were hallmarks of specific oceanographic events within the channel with each profile uniquely defined using physical and biological criteria (Supplemental Table S1): early upwelling prior to a significant biological response, surface phytoplankton blooms, subsurface chlorophyll maximum, and offshore influence of relatively oligotrophic water. These four profile types represented the extremes that occurred within the channel during these glider deployments.

Early upwelling profiles were characterized by MLTemps that were cooler than 12.5˚C, a shallow chlorophyll maxima, and integrated chlorophyll that did not exceed 85 mg chl m^{-2}. The combination of these characteristics indicated that the deep, cold, nutrient-rich water had been recently advected into the surface mixed layer. During this study, the strongest surface bloom signals occurred after upwelling had begun to relax and the 12.5 ˚C isotherm had returned to a depth of greater than 20 m. These surface blooms were characterized by MLTemps between 13°C and 17˚C, MLDs deeper than 10 m, and ChlInt70 values above 150 mg chl m^{-2}. To further differentiate these surface blooms from subsurface chlorophyll maxima within the dataset, the integrated chlorophyll within the surface 20 m was directly compared to that within the top 70 m. Here we define surface blooms as those with at least 50% of the total integrated chlorophyll within the top 20 m and subsurface chlorophyll maxima as having less than 5% of integrated chlorophyll in the top 20 m of the profile. Both subsurface chlorophyll maximum profiles and offshore influence profiles shared high MLTemp, shallow MLD, and deep z12p5. The offshore influence profiles were relatively oligotrophic and had values of ChlInt70 less than 80 mg chl m^{-2} while the subsurface chlorophyll maximum profiles had values of ChlInt70 up to 142 mg chl m^{-2}. On average, the MLD and zMaxChl were deeper during subsurface chlorophyll maxima than during offshore influence.

The four water column profile types described above capture the typical progression of seasonal traits for the SPC (Figure 2). In this region, local upwelling in the spring is followed by the appearance of surface phytoplankton blooms, which in turn is followed by an offshore influence of relatively oligotrophic waters due to seasonal heating and the spin-up of the Southern California Eddy (Hickey, 1979;Kim et al., 2014;Noble et al., 2009). These four water column profile types represent the end-members of these 'states' such that one would anticipate that a monthly time-series would, for the most part, capture intermediate states rather than these end members. Identifying these end-members both helps characterize the overall biological and physical variation seen in water column profiles within the SPC and provides a means for quantifying the influence of coastal versus offshore waters in the channel.

PCA axes based on the 54 end-member glider profiles were used to investigate the representativeness of SPOT to gauge the similarity between profiles collected at different locations and times. The first principal component (PC1) and second principal component (PC2) accounted for 49.8% and 32.7% of total variance, respectively (Figure 4; Supplemental Figure S2). MLTemp and the zMaxChl projected primarily onto PC1 while ChlInt70 and maxCHL projected onto PC2, suggesting that PC1 corresponded with an increased offshore signature while PC2 was inversely correlated with profile biomass (Figures 2 and 4; Supplemental Figure S2). Specifically, PC1 was most positive when MLTemp was greater than 19 ˚C and the seasonal thermocline was strongly defined (Figure 2). PC2 was most negative when the chlorophyll maximum was most clearly defined and ChlInt70 was greater than 120 mg chl m^{-3} (Figure 2). To determine the relative contribution of the 4 water column profile types to the observed glider profiles, the 1606 final glider profiles were projected onto these end-member axes (Figure 4a). As PC1 and PC2 explained similar amounts of variance within this dataset, 'distance' between points in PC coordinate space approximates dissimilarity between individual profiles. Conversely, decreasing distance between profiles in PC coordinate space can be attributed to increasing similarity in profile features.

3.2 Regional Similarity to SPOT Station

When all glider profiles were projected onto the PCA axes, 39.6% fell within one of the end-member profile types, as determined by 95% confidence intervals (Table 1). Similarly, 37% of the 54 SPOT glider profiles associated with an end-member subgroup. Of the four end-member profiles, the offshore-types were most prevalent with 24.8% of all glider profiles falling within the subsurface chlorophyll maximum group and 12.1% aligning with offshore influence profiles. SPOT profiles followed a very similar trend with 25.9% of profiles falling within the subsurface chlorophyll maximum group and 9.3% of profiles aligning with the offshore influence end-member. The two coastal end members, early upwelling and surface blooms, were rare in the overall dataset as well as in the SPOT profiles themselves with less than 4% of all profiles associated with these coastal end-members. These results indicate that, for the majority of locations and times sampled during the spring and early summer of 2013 and 2014, water column profiles within the SPC most closely resembled offshore profiles. These results most likely underrepresent the overall coastal influence within the SPC due to the exclusion of data from within the shipping lanes which influences 30% of the transect and are located close to the coast (Figure 1). However, these findings are consistent with previous research conducted at SPOT that indicated a general prevalence of open ocean bacterial groups (Chow et al., 2013) and a notable scarcity of land-derived organic matter (Collins et al., 2011). It is important to note that these glider profiles were affected by upstream processes, including potential upwelling near the Santa Barbara Channel or Point Dume. Coastal signatures from these upstream locations would appear within the glider profile data, but would be disconnected from the overall onshore-offshore gradient. While our end-member framework allows us to quantify the occurrence of upstream coastal signatures within the dataset, we cannot distinguish between local and remote sources of these water masses. To improve detection of upstream influence within the SPC in future deployments, the glider transect would need to be adapted to incorporate alongshore movement as well as cross-channel travel.

To compare cross-channel differences in water column profile properties, three bins were selected: bin 10 (near Catalina, n = 41 profiles), 28 (SPOT, n = 54 profiles), and 58 (near the mainland, n= 34 profiles). Physical and biological characteristics of the profiles collected at these three locations maintained an onshore-offshore gradient on average.

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However, when the variance at each location was taken into account, bins 10 and 28 were not significantly different from one another (two-sample *t*-test, p-value < 0.01) while bins 10 and 28 were both significantly different from bin 58 (two-sample *t*-test, p << 0.01). These findings suggest that, during this study, SPOT was at least partially detached from nearshore coastal dynamics, such as early upwelling or upwelling driven surface blooms. These results also indicate that samples taken at SPOT poorly represent nearshore variability but are a relatively good representation of the channel as a whole.

Due to seasonal variations in local upwelling and the spin-up of the Southern California Eddy, temporal dynamics and succession play an important role in driving regional productivity. To explore temporal connectivity between SPOT and nearshore coastal bins, the time-series of profile characteristics for individual bins were analysed in PCA space (Figure 5). Early in each deployment, there was a strong coastal mainland influence, which coincided with early upwelling events and surface blooms. This influence was more apparent in the nearshore bins, as expected, but also clearly affected the overall characteristics of vertical glider profiles taken at SPOT as well. During late April to early May of each deployment, the nearshore and SPOT bins collectively experienced a relative 'cross-over', when the profiles shifted from coastally dominated characteristics to offshore dominated (Figure 5; Supplemental Figure S1). These results imply cross-channel connectivity and suggests that, while the profiles at SPOT did not often resemble nearshore profiles, profile variability in both mid-channel and nearshore locations was likely forced by the same coastal and offshore oceanographic events.

To further investigate how changes in the SPOT profile characteristics were related to changes in cross-channel profile types, we looked at the relationship between all non-SPOT profiles and the corresponding SPOT profile. For this analysis, the PCA coordinate plane was divided into four quadrants representing low biomass and coastal dynamics (positive PC2, negative PC1), low biomass and offshore dynamics (positive PC2, positive PC1), high biomass and offshore dynamics (negative PC2, positive PC1), and high biomass with coastal dynamics (negative PC2, negative PC1) (Figure 6). These four quadrants were then used to investigate the cross-channel distribution relative to the most recent SPOT profile. The majority of profiles (64%) fell into the same PCA quadrant as the most recent SPOT profile suggesting that the majority of the channel displayed similar profile characteristics and that SPOT in general captured across channel variability. Broken down by profile type, SPOT profiles were most similar to cross-channel profiles when SPOT displayed subsurface chlorophyll maximum profile characteristics (78% of cross-channel profiles in the same quadrant as the SPOT profile, Figure 6d). SPOT profile characteristics coincided with 55% of other profiles when exhibiting characteristics of offshore influence, 48% when displaying surface bloom characteristics, and 33% of the channel in the one instance when the SPOT profile displayed more coastal physical properties (Figure 6). The sample distributions in each of these four cases were statistically different from one another (two-tailed *t*-test, p<0.01), demonstrating that the profile characteristics at the SPOT station were indicative of the state of the SPC as a whole. For example, when SPOT profiles displayed highly offshore characteristics (Figure 6a), no channel profiles displayed surface bloom profile characteristics. Conversely, during periods when SPOT profiles were most similar to surface bloom profiles, no channel profiles were found to be representative of either the offshore influence or subsurface chlorophyll maximum profile types. These results are consistent with the observed simultaneous shifts in both SPOT and nearshore bins and support cross-channel oceanographic connectivity (Figure 5).

Due to strong alongshore currents within this region, it is not surprising that the nearshore and offshore sides of the channel would differentially experience local oceanographic changes. With these analyses, however, it was possible to verify that the data collected at SPOT are generally representative of the SPC. The largest variation was found when comparing the mainland coastal bins to SPOT or other offshore bins, with increased differences observed during periods of early upwelling in the spring of 2013 and 2014. Without sampling the surface data within the shipping lanes, it was not possible to determine the full profile behaviour of locations between the coastal and SPOT bins. However, subsurface glider temperature data showed that patterns of weakened stratification during early upwelling events often extended across the entire SPC (Supplemental Figure S3). These observations suggest that there is connectivity across the shipping lanes during upwelling events. This is also consistent with the finding that changes in profiles taken at SPOT are in general representative of the entire channel (Figure 6).

3.3 Surface to Subsurface Connectivity

Our analyses indicated that subsurface chlorophyll maximum characteristics were a dominant profile type within the SPC (occurring ~25% of the time), and that these subsurface chlorophyll maxima may appear similar to offshore water intrusion from surface characteristics alone. In this study, the subsurface chlorophyll maximum was on average only 5 m deeper than the particle maximum, determined using the back-scatter maximum. The subsurface particle maxima observed within this study are consistent with previous regional findings (Cullen and Eppley, 1981). The close proximity between the particle and chlorophyll maxima suggests that these subsurface phytoplankton communities may contribute significantly to local primary production (Cullen and Eppley, 1981). Since satellites will theoretically not detect integrated chlorophyll below the first optical depth (OD1), *in situ* integrated glider chlorophyll was analysed above and below OD1 to assess how subsurface chlorophyll maxima might impact satellite estimates of chlorophyll and primary productivity.

The OD1 was calculated from satellite PAR and glider chlorophyll-based diffuse attenuation coefficients for PAR (Kirk, 1994;Jacox et al., 2015). This method provides a conservative estimate of OD1 by ignoring light attenuation caused by dissolved organic matter. Average OD1 for these deployments was 12.3 m while the average euphotic depth, as defined by the 1% light level, was 38.3 m. This is consistent with *in situ* measurements of the euphotic depth from temporally overlapping cruises at the SPOT site that observed an average euphotic depth of 40 m (Haskell et al., 2016). Our estimates for the first optical and euphotic depths are also within the range of regional data collected during the CCE LTER process cruises from 2006-2008 (Mitchell, 2014). Here we compare glider estimates of chlorophyll over the entire euphotic depth to glider estimates over the first optical depth. This provides an internally consistent dataset to investigate the potential bias in quantifying chlorophyll only over OD1. MODIS Aqua *chlorophyll a* data was also acquired and compared with the *in situ* glider data. However, a low correlation between glider and satellite integrated chlorophyll over OD1 was observed which could be due to high subsurface biomass, inaccurate CDOM corrections, poor atmospheric correction, or temporal mismatch between datasets (Supplemental Figure S4).

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Overall 87% of integrated chlorophyll within the euphotic zone was located beneath the OD1 during the 2013 and 2014 deployments. This percentage increased to 92% for subsurface chlorophyll maxima and decreases to 82% for surface blooms. For these deployments, zChlMax was generally at or below the 10% light level, deepening with more oligotrophic conditions. To determine the local oceanographic scenarios that were least likely to be accurately observed by satellites, total integrated chlorophyll below OD1 for the 2013 and 2014 deployments was compared with the profile characteristics using the end-member principal component axes in order (Figure 7). By mass, the majority of the integrated chlorophyll that fell below OD1 was associated with surface blooms (up to 130 mg m^{-2}), rather than subsurface chlorophyll maxima. In these cases, the first optical depth was shallower than the bloom thickness, causing underestimation of the surface chlorophyll layer. During subsurface chlorophyll maxima, fewer PAR match-ups were available, hindering the comparison of above-and-below OD1 integrated chlorophyll. However, within the observed profiles, integrated chlorophyll a values of up to 63 mg/m^2 existed between the first optical depth and the euphotic depth (Figure 7).

With the observed frequency of subsurface chlorophyll maxima within the SPC during this study and their colocation with backscattering maxima, it is probable that the primary production associated with chlorophyll beneath the OD1 during subsurface chlorophyll maxima is a non-negligible portion of the regional carbon budget. Furthermore, an underestimation of integrated chlorophyll during surface blooms will also likely significantly impact estimates of regional carbon export

4. Discussion

4.1 Regional Application of SPOT Data

This study identified four major profile types within the SPC during March through July of 2013 and 2014, early upwelling, surface bloom, subsurface chlorophyll maximum, and offshore influence. These four types represented the end-members of vertical profiles observed within the SPC during consecutive glider deployments. The statistical analysis of these profile types allowed for the identification of temporal and spatial trends in local variability within the SPC and the contextualization of the SPOT station within the SPC. Our results highlight both the similarity between the SPOT station and offshore profiles and the similarity in water mass characteristics across the channel. This suggests that data collected at SPOT during monthly time-series sampling should be representative of the SPC. As such, ecological or physical trends that are found to be consistent for the entirety of the SPOT time-series may be assumed to be applicable for the SPC and could give relevant insight into offshore regions within the Southern California Eddy as well. While infrequent events such as coastal upwelling and surface blooms do occasionally extend across the channel, our findings suggest that monthly sampling at SPOT will under-sample these biogeochemical fluctuations even during the coastally-dominated early Spring which experiences the most coastal influence.

During this study, glider deployments were timed to sample only during the most dynamic months for the SPOT station. This sampling scheme may have missed some seasonal variability caused by non-upwelling driven events, such as submesoscale eddies. However, our results suggest that a year-long sampling scheme would likely find similar relationships, given that the sampling occurred during the season when coastal processes (local upwelling) were most likely to occur but still concluded that SPOT was most representative of offshore water types. Building on these findings, and understanding the rarity of coastal events in the SPC, higher-frequency time-series sampling at SPOT during the spring season could be used to better monitor the effects of nearshore processes on the physical and biological oceanography of the SPC. However, even sub-monthly sampling at SPOT may underestimate productivity and export within the SCB, as most of the observed upwelling signature occurred inshore of SPOT.

The offshore state of SPOT during this study also suggests that time-series data collected at SPOT would be sensitive to climate-derived changes to major current patterns and wind patterns, but may be insensitive to local terrestrial changes such as decreased freshwater discharge or increased sedimentation. Within the SPC, the spin-up of the Southern California Eddy is a major driver of oceanographic change. We hypothesize that the eddy is the primary driver of the profile shift during late April and early May of 2013 and 2014 observed at both SPOT and nearshore locations. Utilizing our framework to identify transitions from coastally-dominated to offshore-dominated profile types, the timing of the spin-up could be monitored historically or prospectively within previous ship-based sampling at the SPOT site.

4.2 Determining Regional Domains for Time-Series Sites

The framework developed to study the applicable domain for SPOT samples and the sensitivity of SPOT samples to regional oceanographic dynamics could easily be applied to other time-series sites. The glider deployments in this study were designed to sample a dynamic period within the SPC with high-spatial and high-temporal frequency. These high frequency samples enabled identification and statistical analysis of regional connectivity and response to local oceanographic events. In the case of the SPC, these events were upwelling, surface blooms, subsurface chlorophyll maxima, and offshore influence. We expect these dominant water column profile types will vary with oceanographic region. For example, at an open ocean site such as the Bermuda Atlantic Time-Series site these features could include winter mixing, and cyclonic or anti-cyclonic eddies. We have shown that high-frequency data can be used to identify the major regional modes and water column profile types, which could then be used to determine long-term trends within the time-series site itself. These profile signatures therefore allow for a more quantitative description of time-series observations and therefore a more accurate method for detecting deviations within the time-series. In the example of the SPOT station, increased nearshore upwelling or delayed spin-up of the Southern California Eddy would each increase the overall coastal signature of vertical profiles collected at SPOT. Historical ship-based vertical profiles as well as future profiles could be analyzed with reference to coastal and offshore signals to determine changes in the relative influences over time.

Spatial contextualization of time-series sites using *in situ* glider deployments, such as those used during this study, can help to identify potentially uncharacterized sources of biological complexity within the time-series location. In the case of the SPOT station, the temporal switch from coastally-influenced profiles to offshore-influenced profiles implies that samples collected during late April may vary significantly from samples collected in early May simply due to changes in local currents. In addition, the glider profiles were able to identify subsurface dynamics that were not detectible in remote sensing products. Our findings suggest that these subsurface signatures could contribute significantly to regional carbon cycling.

5. Conclusions

In situ high-frequency regional data collection can contextualize time-series sites and identify the major modes of regional variation. This not only allows for the data to be more accurately extrapolated to provide larger scale estimates of critical dynamics such as primary production or carbon export, but also identifies the most crucial regional signals that would need to be correctly simulated to produce accurate regional modeling. In the case of the San Pedro Ocean Time-series (SPOT) station, this study identified four major regional water column profile types and suggests that time-series samples collected monthly would in general be most representative of offshore profiles. However, due to cross-channel connectivity within the San Pedro Channel (SPC), higher frequency sampling at SPOT may also capture coastal signals from nearshore events such as upwelling and surface blooms. Glider profile data from the SPC also indicate that the integrated biomass of surface bloom and subsurface chlorophyll maxima profiles would be underestimated by satellite chlorophyll measurements, suggesting that accurate observation of regional dynamics within the SPC requires *in situ* sampling. Finally, this study suggests that time-series data collected at SPOT would be relatively insensitive to coastal anthropogenic change but that the site should be well positioned to identify a regional response to climate change.

Without context for time-series data, physical or temporal under-sampling at time-series stations may mask local drivers of variability making it difficult to accurately scale-up local results to inform larger-scale analyses and modeling efforts. In addition, monthly sampling is likely to miss infrequent events that could be important for local processes making single (monthly sampled) time-series fairly ineffective for understanding dynamic regions such as coastal systems. The methods described in this study can be applied to other coastal and oceanic time-series sites in order to identify the major modes of local variability, the region represented by the time-series data, and the sensitivity of the site to anthropogenic change. Better understanding of the spatial domain represented by global marine time-series sites will aid in the extrapolation of local findings, in the improvement of regional modeling, and in the coupling of regional and global modeling efforts.

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Diehl, T. Gunderson, D. Kim, the Fuhrman lab, the Sukhatme lab, the Caron lab, the Southern California Coastal Water Research Project, the crew of the Yellowfin, and many others at USC who helped with SPOT data collection and with glider deployment, recovery, and maintenance.

Figure Captions:

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Table 1: Distribution of profile types. The number of glider profiles corresponding with each end-member group (95% confidence interval) for the total dataset and SPOT specific profiles.

	All samples		SPOT samples	
	N	Percentage	N	Percentage
Total Sample Size	1606	--	54	--
Surface Bloom	19	1.2%	1	1.8%
Subsurface Chlorophyll Maximum	398	24.8%	14	25.9%
Offshore Influence	194	12.1%	5	9.3%
Early Upwelling	25	1.6%	0	0.0%
Not Within 95% CI	970	60.4%	34	63.0%

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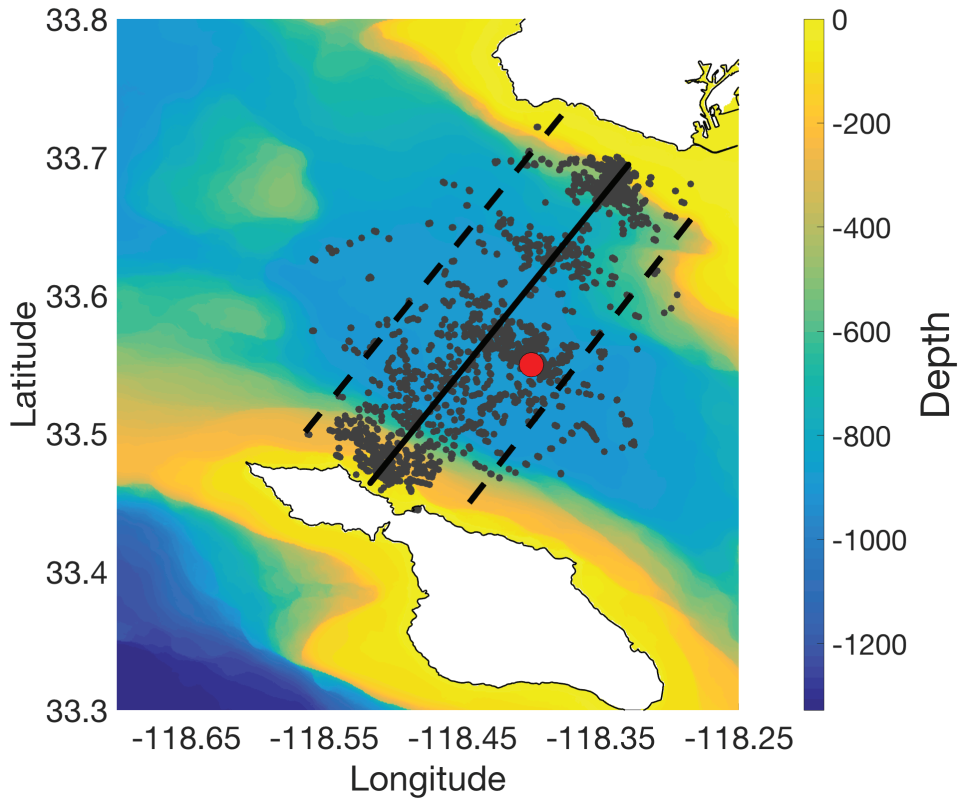

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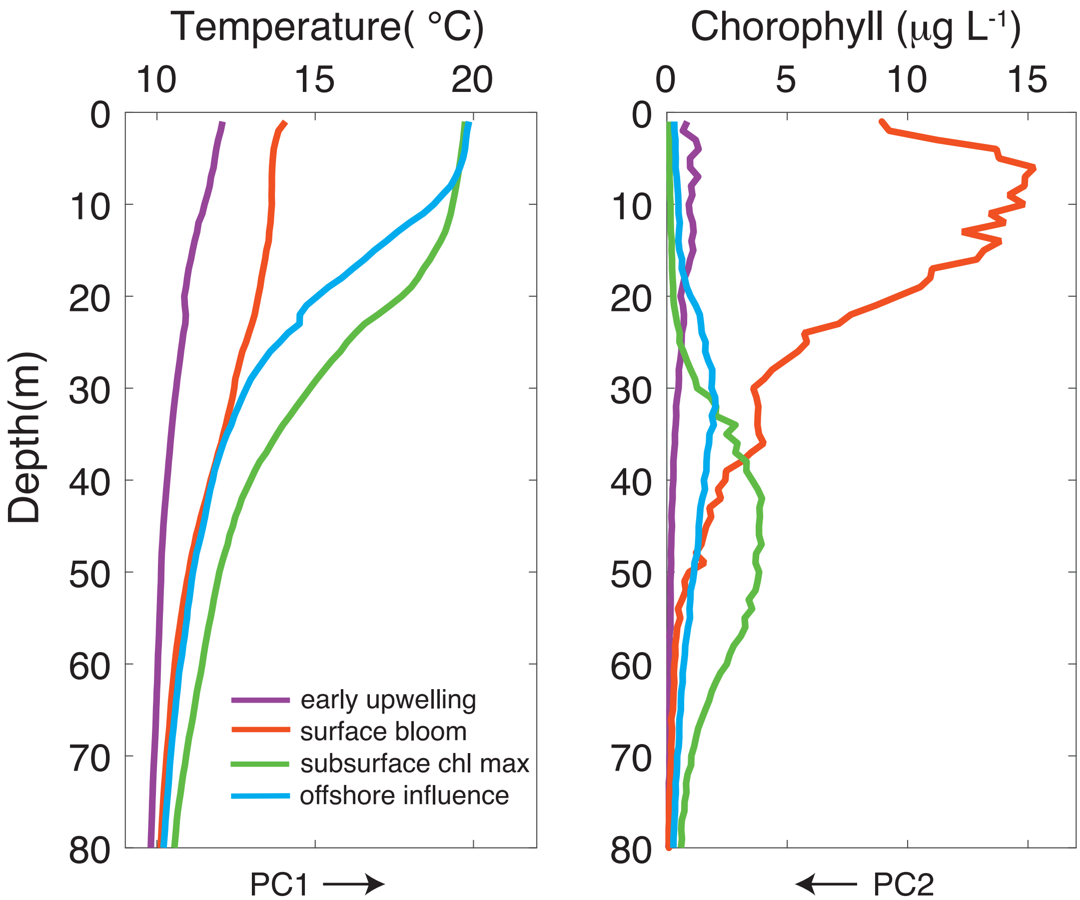

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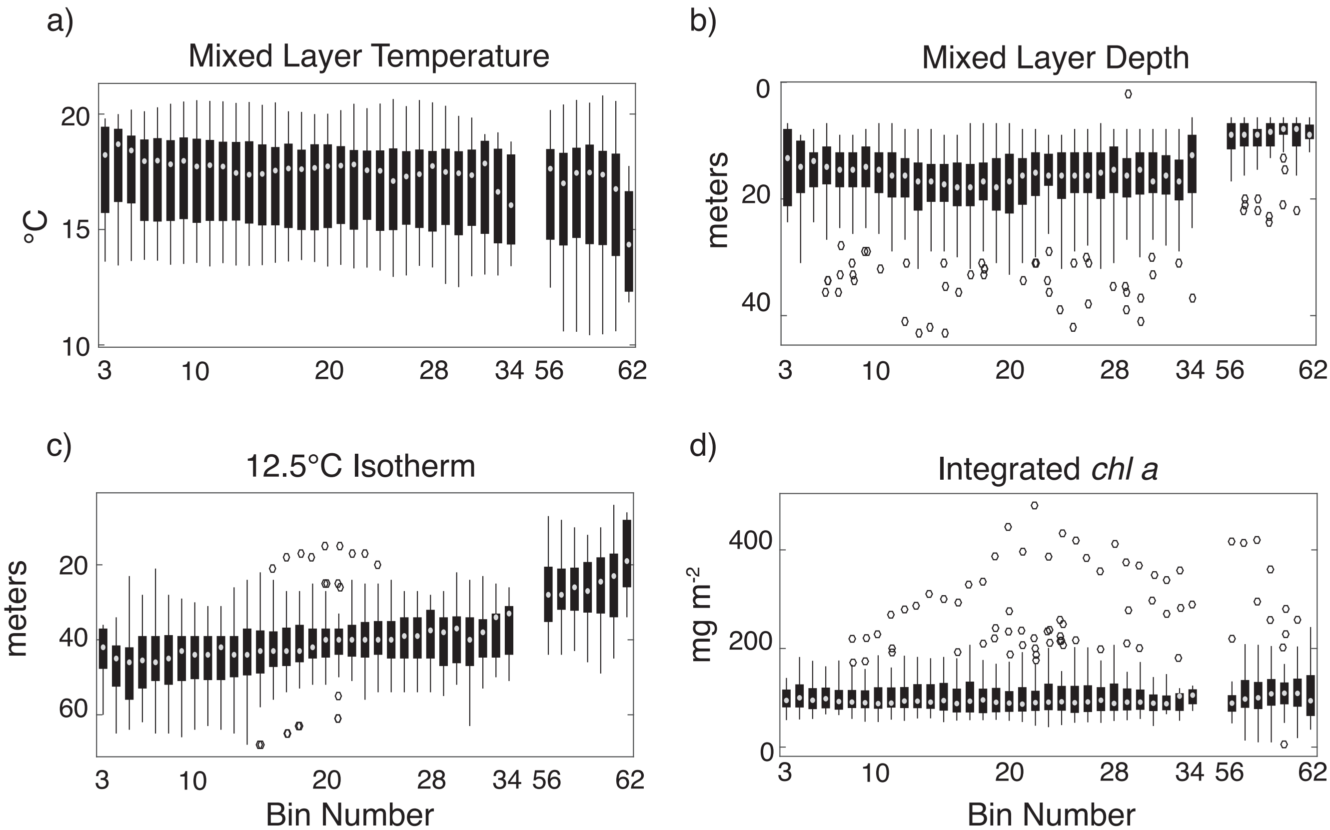

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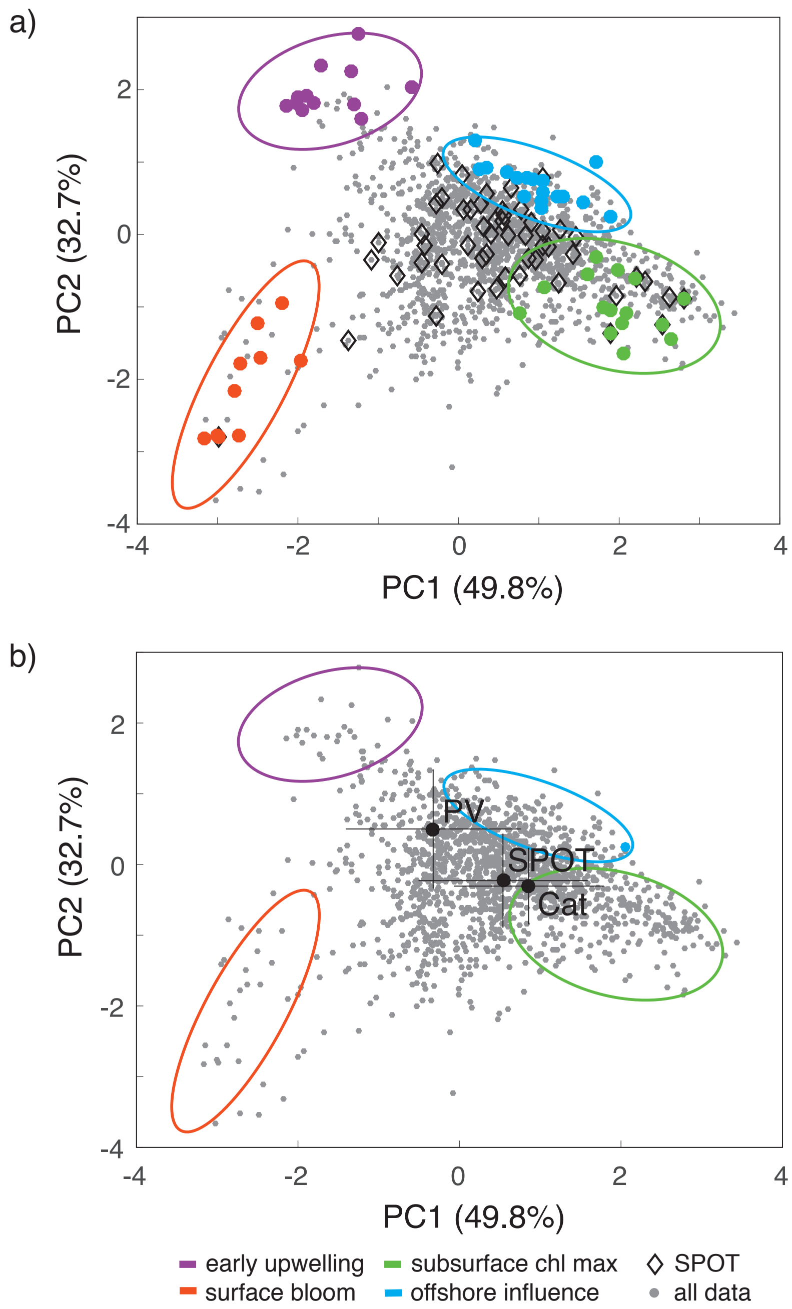

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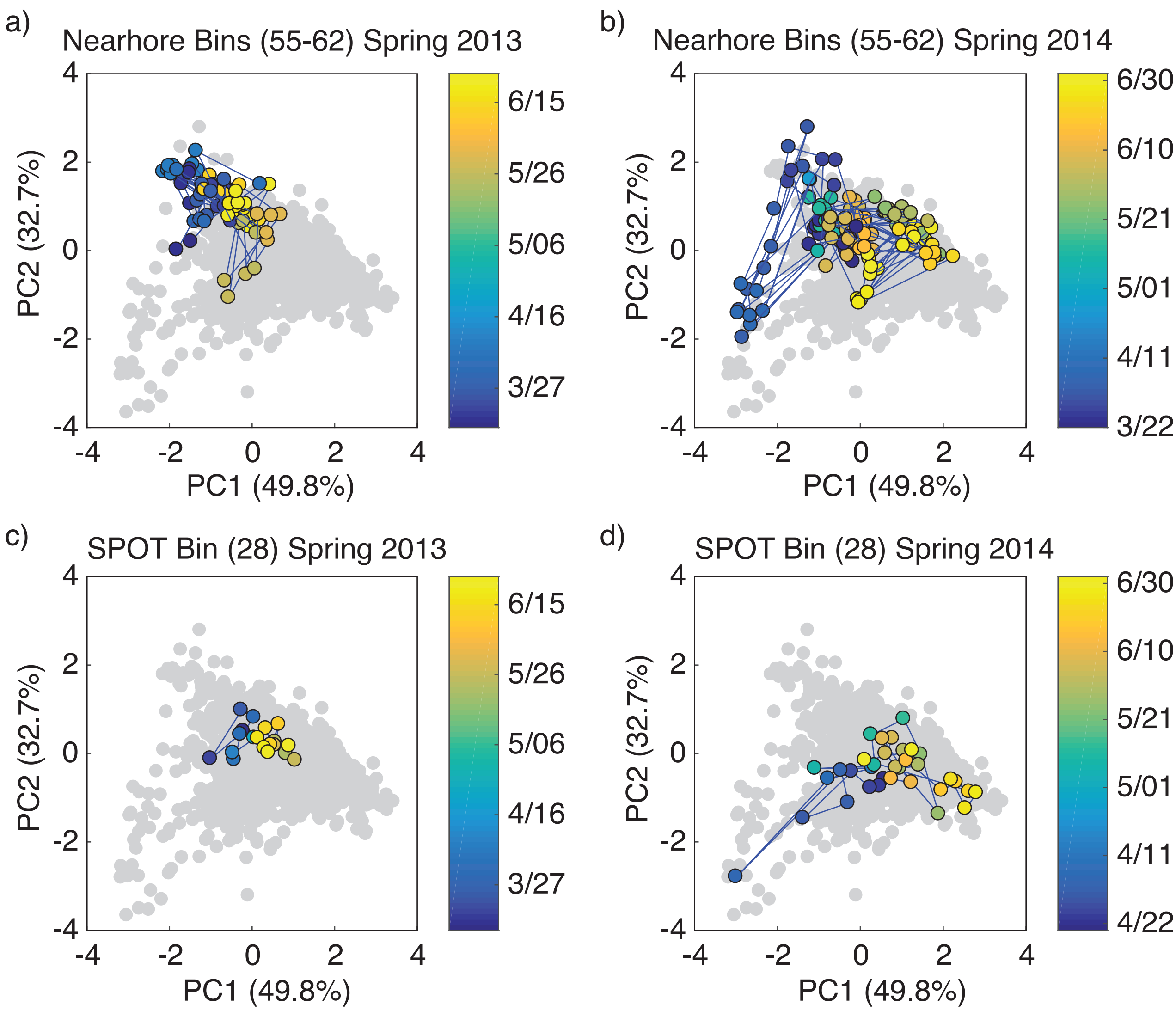

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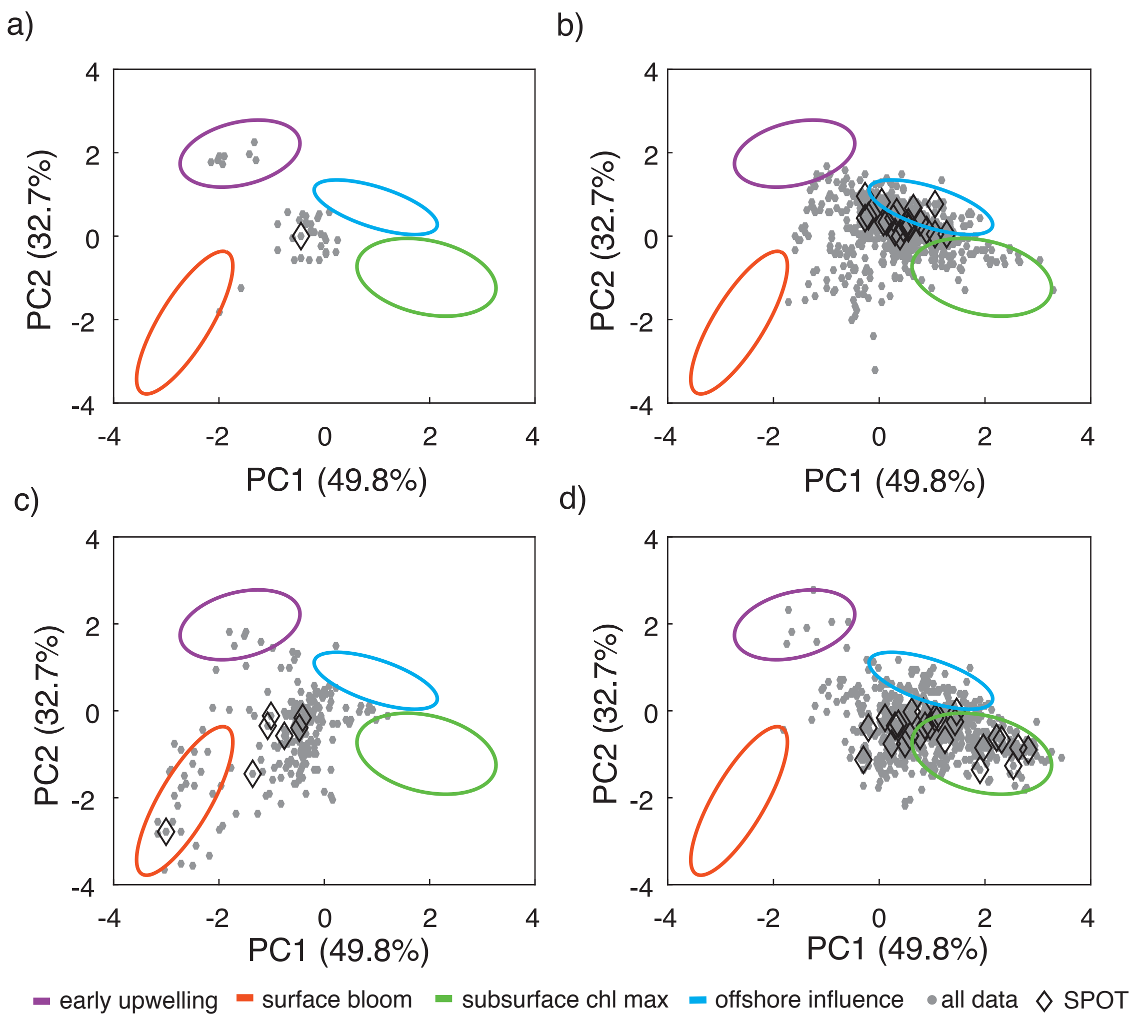

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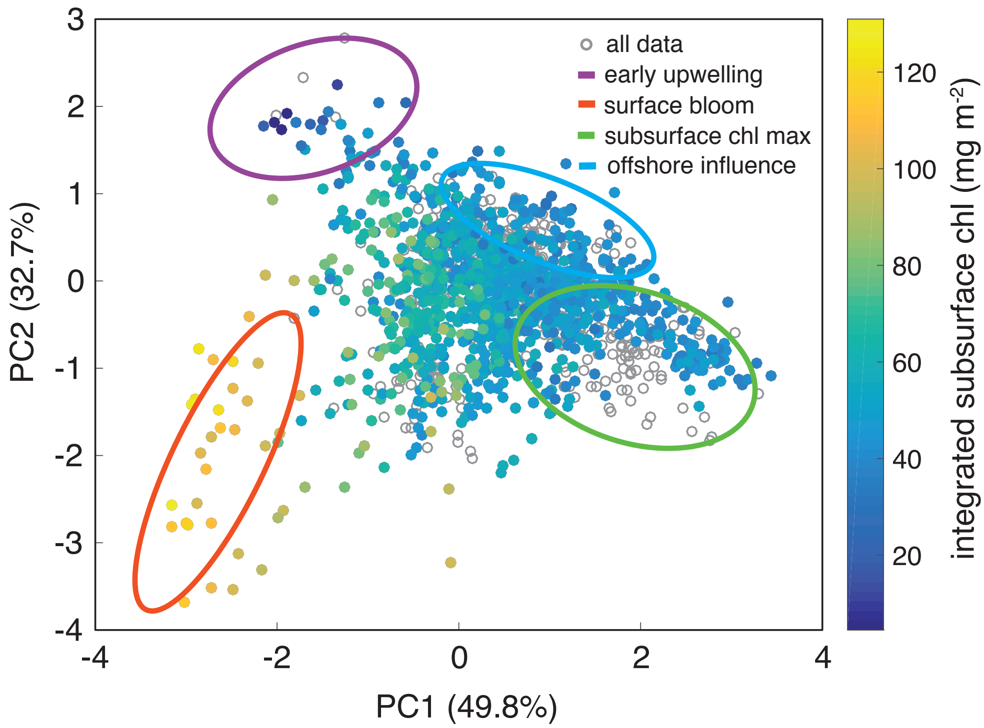

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