RESTRICTION ON USE AND DISCLOSURE OF PROPOSAL INFORMATION

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1 Scientific/Technical/Management Plan

Coastal environments are more and more challenged through increased human activity and climate change impacts. Giant kelp (*Macrocystis pyrifera*) is a key component of many coastal ecologies that is directly affected by these changes in the environment. Kelp populations are decreasing due to increased ocean warming, marine heat waves, more frequent and stronger storms (Cavanaugh et al., 2019, Smale 2020). At the same time, inputs from land are increasing and can have both positive and negative effects on kelp growth (Shaffer & Parks 1994, Traiger & Konar 2017).

In addition to being a key component of the ocean ecosystem, kelp offers great potential for increasing coastal resilience in general and mitigating climate change impacts (Bayley 2021, Eger 2021). The giant kelp *Macrocystis pyrifera*, which naturally grows in coastal waters from Mexico to northern California, has the potential to significantly mitigate ocean acidification, enhance marine biodiversity, buffer coastal erosion, and sequester carbon dioxide derived from anthropogenic activities. Giant kelp biomass has great potential to be used for multiple purposes such as food source for farmed animals, nutritious supplement, and efficient fertilizer for organic agriculture. These benefits could be increased by expanding giant kelp habitat through kelp cultivation. However, to successfully cultivate kelp it is crucial to better understand and quantify impacts on kelp populations in coastal regions. Especially, risks and opportunities related to coastal inputs such as nutrient input from runoff and sediment transport from watersheds into the ocean need to be addressed in more detail to inform any successful intervention.

New techniques offer an opportunity to expand kelp cultivation beyond the immediate coastal zone. Mobile kelp cultivation platforms use deep-water irrigation - i.e., from below the mixed layer - to mitigate some of the impacts of the warming ocean on kelp. Offshore kelp farms may also be less impacted by coastal runoff. Determining the ideal scale, location, and impacts on the ocean environment is key for optimizing future kelp cultivation.

In the proposed work, we aim to assess interactions between the land-ocean continuum and naturally occurring and actively cultivated kelp populations. For this effort, it is important to reiterate that not only do land-ocean processes have an impact on kelp growth but also kelp itself has impacts on the oceanic and coastal land environment. We propose to study and quantify these feedback mechanisms to provide a path for future kelp cultivation that benefits ocean health and increases coastal resilience.

In particular, we will use satellite data from multiple sensors to assess biogeochemical and physical processes that impact kelp growth such as:

- Sediment loads (as for example amplified by wildfires)/coastal darkening
- Nutrient influx from coastal runoff
- Marine heat waves

And in turn the impact of kelp on the oceanic and coastal environment:

- Nutrient flow
- Ecosystem function
- Ocean acidification and carbon sequestration

Having quantified external parameters influencing kelp, we will then use this knowledge as input to a biogeochemical ocean model to further our understanding of kelp cultivation practices and their impacts and benefits on the ocean and coastal ecosystems.

1.1 Objectives and Expected Significance

The work as outlined in this proposal directly responds to the ***goal of this solicitation to advance our understanding of key physical, biological, biogeochemical, geological, and hydrological coastal processes and their interactions within the interface of the ocean-land-human system, and to enhance our understanding of how these processes will be compounded in rapidly changing coastal environments.*** We will specifically ***study the impacts of human activity on coastal physical, geomorphological and ecological variability***. In particular, we will investigate both human impacts as witnessed for example by agricultural runoff as well as human impacts through active kelp cultivation that can lead to restoring ocean health and further regenerative practices to strengthen coastal resilience. Furthermore, we will address current gaps in knowledge of ***linkages between ocean dynamics and its impacts on coastal ecosystems***. Through the combination of ocean and hydrologic modeling, we will also advance the understanding of ***biophysical coupling and feedback within the ocean-land interface***. In particular, we propose to study the role of *extreme events such as marine heat waves* on naturally occurring kelp populations and determine the role of these events for future kelp cultivation.

1.1.1 Goals

The goals of this investigation are:

Goal 1: Quantify the coastal feedback mechanisms related to kelp

- sources and events contributing to coastal darkening
- relationship between kelp and turbidity caused by coastal erosion and runoff

Goal 2: Provide an assessment of regional ocean conditions as they favor or inhibit kelp growth

- determine and locate spatial and temporal threshold conditions off the coast of California
    - for naturally occurring kelp
    - for cultivated kelp off-shore
- evaluate and compare the potential impact of marine heatwaves and wildfire runoff on both, naturally occurring and cultivated kelp

Goal 3: Evaluate impacts of cultivated kelp on the oceanic environment

- impacts on nutrient flow and ocean ecosystems
- impacts on various aspects of the ocean carbon cycle

1.1.2 Expected Significance

The proposed research has wide-ranging implications not only for NASA's goal to advance Earth System science through the use of satellite observations but also for expanding into new areas for cross-disciplinary applications that actively contribute to climate change solutions and the planet's regeneration. Our research will provide new insights into the interaction between land and ocean and the role of these coastal processes on kelp. Taking advantage of the wide range of satellite observations as well as biogeochemical and physical modeling capabilities, this work will advance knowledge on and quantify the impact of human activities in the form of marine permaculture that can actually lead to not only restoring ocean health but also help planning for expanding coastal resilience. The research proposed supports the ***development of practical solutions to increase resilience in coastal communities*** through kelp cultivation and conservation that has the potential to protect from coastal erosion and preserve marine ecosystems as well as economic benefits that are associated with marine permaculture.

In particular, we will focus on the area along the coast of California (Figure 1-1) where impacts of climate change and human activity impact coastal communities and ecosystems and where we expect further ***high potential population growth***.

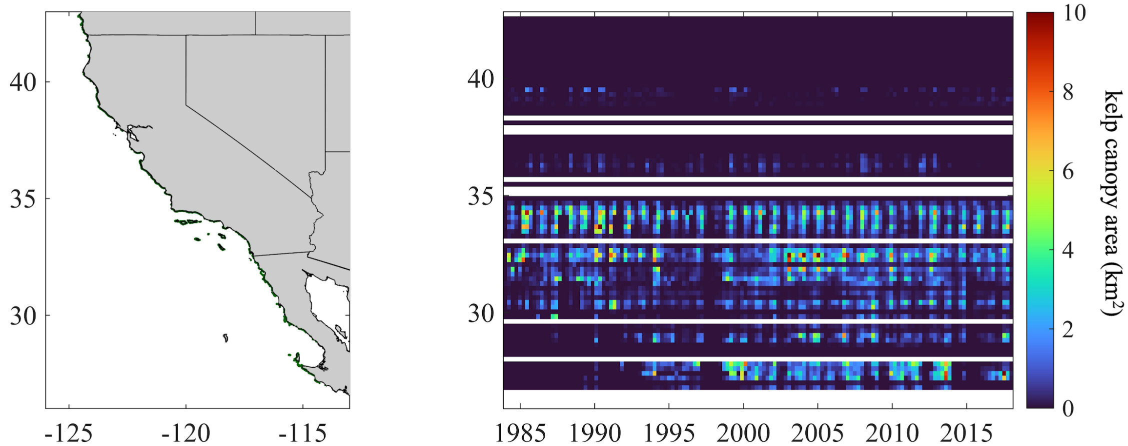

Fig. 1-1. Kelp canopy area along the coast of California (1984-2020). Kelp extent and canopy area time series data is provided from analysis of Landsat imagery (from Bell et al. 2020, 2022)

El Niño events and marine heat waves have regularly decimated kelp populations along the coast. Primarily, resulting higher surface temperatures and limitations in nutrient supply through reduced upwelling have led to these decreases in kelp forest density (e.g., Dayton et al. 1992, Cavanaugh et al. 2019, Edwards 2019). Less well understood are impacts from coastal runoff and erosion that increase with more frequent and higher intensity storms. Runoff not only influences nutrient supply in the coastal ocean but also associated sediment loads impact light availability that is a limiting factor for kelp growth. Here, we take advantage of ***existing and upcoming observational and modeling assets*** to develop a ***better conceptual and digital ocean-land framework that enables the dynamical coupling of key processes*** that promote or inhibit kelp growth in the coastal oceans.

As humanity faces the climate change and biodiversity loss crises, innovative and regenerative solutions are being developed to help to tackle both in a unified approach. For regenerative kelp mariculture, the Climate Foundation has developed and implemented kelp cultivation platforms that can overcome some of the challenges outlined above that naturally

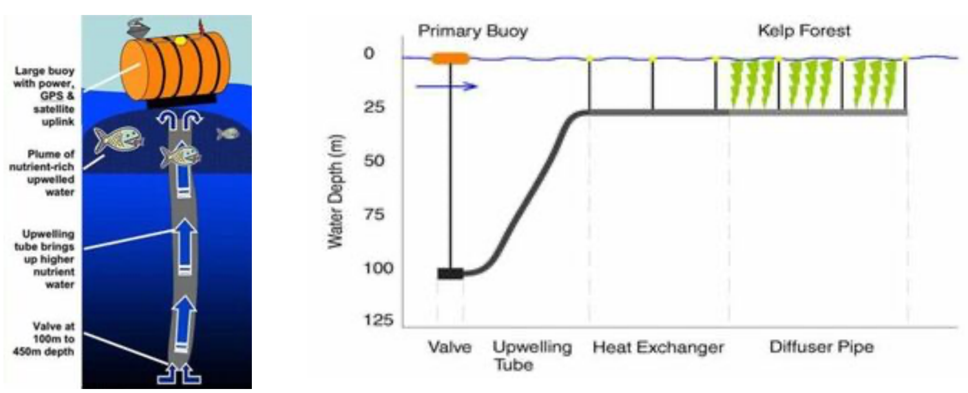

Fig. 1-2: Mariculture platform design. Bio-irrigation system (left) and over platform design (right). (Source: https://climatefoundation.org)

occurring kelp is facing. The platforms are utilizing a system powered by wave and solar energy for deep-water irrigation, i.e., they are able to pump colder water including nutrients from depths as deep as 500 m to irrigate the kelp growing at or near the surface (Fig. 1-2). They are also capable of navigating ocean currents using vertical shear at depth to travel to a desired location.

In this study, we investigate the challenges giant kelp is facing at the land-ocean continuum along the coast of California and explore the opportunities for cultivated kelp to not only overcome these challenges but also actively support and regenerate the ocean environment. By focusing on these two aspects, we will develop a land-ocean coupled framework that provides insights into how human activities on land influence kelp growth, helping to identify opportunities for change (e.g., managing agricultural runoff, wildfires, coastal erosion) and also insights into how climate change in the ocean can be actively mitigated. Our framework will provide a building block for fostering coastal resilience and moving toward a sustainable future.

To achieve our research goals, we will use a suite of satellite observations and physical and biogeochemical modeling. Products and new capabilities that come out of the investigation will be directly transferable to other coastal areas around the globe. In the description of our Technical Approach below, we will elaborate on what datasets and models will be used for the analysis and validation.

1.2 Perceived Impact to State of Knowledge

For Goal 1 - to quantify coastal feedback mechanisms - we aim to enhance our understanding of processes and events at the land/ocean continuum that are impacting kelp growth on and offshore. In particular, the impacts of increased coastal darkening are not well understood and quantified. A recent study (Blain et al., 2021) discussed impacts on kelp growth in the Hauraki Gulf, New Zealand. This work provides insights into processes related to impacts of light availability due to darkening on primary production and associated carbon sequestration capabilities of kelp. However, on a regional to global scale we require more insights into the processes behind the darkening and their impact in conjunction with other factors such as temperature and nutrients to project carbon uptake potential into the future. Satellite observations and models are the ideal means to study larger scales and help identify underlying processes. In this work, we will utilize a suite of existing and upcoming observational platforms to investigate the impact of events on land (e.g., erosion, wildfires) on coastal darkening. We aim to combine the land and ocean information along the California coast to get a more complete picture of the influences of these land and ocean processes on light availability, which will be used to inform a more detailed analysis of the impacts on kelp.

For Goal 2 - to provide a regional assessment of ocean conditions and impacts on kelp primary production - we build on the work of Co-Is Cavanaugh and Manizza to provide an overview of threshold conditions for favoring and inhibiting kelp growth along the coast of California. We will assess onshore conditions including the impacts from runoff as established through Goal 1 and quantify how these affect offshore conditions. We will then use the information to 'deploy' cultivation platforms at a range of different spatial scales and study impacts of the ocean conditions on the platforms under various scenarios (e.g., El Niño, wildfires). This can help to demonstrate the robustness of the platforms under various conditions and find most favorable placement with respect to not only biogeochemical but also physical conditions.

For Goal 3 - to evaluate the impact of cultivated kelp on the oceanic environment, we will analyze the experiments using ECCO-Darwin as performed for Goal 2 and study kelp growth as it impacts nutrient flow, carbon content (Ikawa et al., 2015), and the oceanic ecosystem. Mariculture - especially if considered at large scales - has the potential to significantly contribute to solving many challenges caused by climate change. In particular, it has been recognized to play a role in carbon sequestration and counteracting ocean acidification. However, challenges still exist to quantify impacts not only on carbon but also on the oceanic environment in general. Here, we study the potential benefits and influences Climate Foundation's platforms have on the ocean at various temporal and spatial scales. Particularly interesting is the question of how the ocean responds with regards to the overall ocean carbon cycle, the distribution of nutrients and influences on ecosystems if mariculture efforts work at large spatial scales.

1.3 Relevance to Element Programs and Objectives in the NOFO

As outlined above, the proposed research directly responds to the interdisciplinary nature of the solicitation (details as they respond to the solicitation marked as ***cursive and bold***). We combine satellite observations with hydrologic and biogeochemical modeling to study the impacts of climate change impacts (e.g., marine heatwaves, wildfires) on coastal environments. In particular, we will use the land/ocean framework that we will develop in this effort to advance knowledge of the effects of coastal darkening on kelp growth. The study will inform not only coastal stakeholders and decision makers on the future of coastal kelp populations but also provide important insights into how solutions like marine permaculture can help restore ocean health and help build coastal resilience.

1.4 Technical Approach and Methodology

In the following section, we will discuss our approach to achieve the three goals. For our study, we will approach our study area - the coastline of California - in two different ways:

- The entire coast of California and ocean spanning a distance of >1000 km on- and offshore
- Focusing on the area around Santa Barbara and the Santa Barbara Channel, which is the site where the Climate Foundation platforms will be deployed in the near term.

By taking this two-pronged approach, we will be able to take advantage of high-resolution datasets and modeling capabilities that will allow us to dive deeper into the processes on land and in the ocean that influence both natural and cultivated kelp and also explore the potential of kelp cultivation at a larger scale and its impacts on climate issues such as ocean acidification and biodiversity loss.

1.4.1 Impacts of Coastal Runoff on Kelp

To address Goal 1, we will use a combination of satellite observations and land and ocean modeling and study the impacts of physical processes on kelp growth, such runoff after wildfire events contributing to coastal darkening. Oceanic factors that promote and inhibit growth of giant kelp are largely known, however, processes at the land/ocean boundary such as impacts from coastal runoff resulting from changes in watersheds are less well studied. We aim to quantify the impacts after events along the coast of California such as runoff after wildfires. Those events can significantly change not only the nutrient composition of the coastal ocean but in particular the turbidity on and off-shore and cause coastal darkening. Increased turbidity leads to decreased light availability that in turn impacts kelp growth. In the proposed study, we will not only use satellite observations and the Soil and Water Assessment Tool (SWAT) to investigate this land impact on the ocean environment but also implement a representation of the impact of increased sediment loads on light availability into ECCO-Darwin (ED) (Section 1.4.2). This will give us the opportunity to further investigate temporal changes in the coastal ocean as well as study potential impacts offshore that can influence the productivity of kelp cultivation platforms.

On the regional level for the coast of California, we will use satellite datasets to quantify the impact of increased turbidity along the coast on kelp in contrast to other factors that are influencing and limiting kelp primary production.

Turbidity, a bulk measurement of the relative clarity within the water column, will be derived using two multispectral instruments, Landsat-8 and Sentinel-2 and accessed as a standard product from Sentinel-3 on a global scale. Measurement of turbidity is typically achieved by assessing optical properties using spectrophotometric methods. This is routinely conducted in laboratory and field settings with probes that are in direct contact with water. This study builds upon and extends workflows from an open-source software, ACOLITE (Vanhellemont & Ruddick, 2016), which can process raw radiance images from Landsat-8 and Sentinel-2, applying a Dark Spectrum Fitting atmospheric correction (Vanhellemont, 2019), and has been optimized for multispectral land imagers for aquatic studies as well as implemented in Google Earth Engine (https://github.com/NASA-DEVELOP/ORCAA). We will use a red band turbidity algorithm (Nechad et al., 2009), which we and others have been validated in optically complex waters (Caballero et al., 2018; Dogliotti et al., 2015; Kuhn et al., 2019; Novoa et al., 2017) including by Co-investigator Lee (Ade et al., 2021; Ayad et al., 2020; Lee et al., 2021). When the water column turbidity changes due to changes in particular load, water surface reflectance increases (Giardino et al., 2017), enabling estimates of particle load in red or near-infrared bands (Ruddick et al., 2006). This corresponds to a 664-nm band in Sentinel-2 and for 655-nm for Landsat-8. Datasets are accessed through USGS EarthExplorer.

Recent work by Co-I Lee includes mapping turbidity plumes associated with the Woolsey Fire in Malibu, CA which showed enlarged plume characteristics during wet weather (Cira et al., 2022) at beaches in the fire drainage area. This study also documents a threshold-based approach towards estimating plume surface extent which can be coupled with turbidity concentrations, which can be applied for the Santa Barbara Channel (described below). One goal of the proposed work is to investigate the degree to which turbidity plumes, particularly during storm and first flush events and compounded by wildfire events, impact kelp canopy extent and biomass.

In addition to the satellite-based turbidity data, we will use high resolution bathymetry data as a related predictor of kelp dynamics. Light at the bottom can be a limiting factor for the recruitment and growth of early stages of giant kelp, and so deeper areas are likely to be more impacted by turbidity. We will use a 1 m resolution multi-source topo-bathymetric digital elevation model produced by the USGS Coastal National Elevation Database to characterize bathymetry across our study area.

In particular, we will study the impacts observed after the 2017 Thomas Fire (Fig. 1-3) and 2021 Alisal Fire. In December 2017, California experienced the Thomas Fire, the largest wildfire since the Santiago Canyon Fire of 1889. The fire ignited on December 4, 2017, burning approximately 1,141 square kilometers (sq km) (282,000 acres) of land. Heavy rainfall in January brought relief from the fires, but also induced mudslides and floods in areas impacted by the Thomas Fire. The Alisal Fire has burned a total of more than 68 square kilometers (16,962 acres) in Santa Barbara County. The first rainfall followed soon after on October 25, 2021 with subsequent storms in the winter months contributing to debris flow down to the coast. The two fires and precipitation events thereafter will define our analysis time frame for the following study using satellite observations and models to link sediment loads, turbidity, and kelp primary production.

To distinguish between effects from turbidity/light availability and other factors, we will take advantage of new high-resolution datasets that help us quantify other dominant factors contributing to promoting or inhibiting kelp growth. Sea surface temperature (SST) is strongly negatively correlated with nitrate concentrations in our study area and so satellite SST data can be used to estimate nutrient conditions (Snyder et al. 2020). Such data has been used to explain variability in giant kelp abundance and productivity (Bell et. al. 2015). Landsat-8 (100-m native) and ECOSTRESS (70-m) represent the highest combined spatiotemporal resolution collection of SST to date, which will be used to resolve finer scale coastal processes not readily observed with

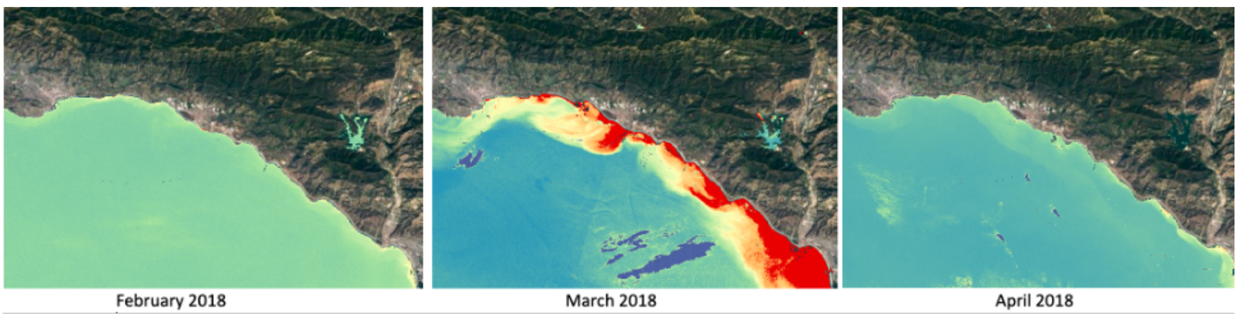

Fig. 1-3. *Wet weather turbidity plumes (March 2018) following the first wet weather event post Thomas Fire in Santa Barbara County.*

previous and coarse scale (1km+) SST products. (e.g., GHRSST) Landsat-8 Level 2 Collection 2 surface temperature products will be accessed through the U.S. Geological Survey and are distributed on a 30-m grid (resampled from the native 100-m). ECOSTRESS will be accessed through the USGS LP.DAAC AppEEARS data access tool and has a 70-m resolution and 1-5 day revisit. Landsat and ECOSTRESS temperature retrievals have been validated (Hulley et al., 2021; Malakar et al., 2018), with thermal radiometer measurements, with both comparable validation and evaluation demonstrated by Co-I Lee and colleagues (Gustine et al., 2021). Co-I Lee and colleagues (Halverson et al., 2022) have also demonstrated the use of Landsat surface temperature in evaluating California aquatic habitats.

We will compare these physical drivers to changes in giant kelp abundance as measured by Landsat imagery. We will utilize an existing dataset that provides giant kelp canopy area and biomass for the entire State of California at 30m resolution on seasonal timescales from 1984-2021 (Bell et al. 2022). We will use generalized linear regression and generalized additive models to identify relationships between kelp canopy area and biomass and turbidity, bathymetry, and sea surface temperature (as a proxy for nitrate). We will examine the impacts of turbidity, bathymetry, and nutrient availability on the recruitment and early development of giant kelp, by characterizing spatial variability in kelp forest abundance anomalies following the Thomas (2017) and Alisal (2021) fires.

For the local approach in the Santa Barbara area (Figure 1-4 - left), we will estimate sediment loads using the SWAT developed by the US Department of Agriculture (USDA) Agricultural Research Service.

SWAT is a continuous, watershed scale hydrologic model that can quantify streamflow and sediment loads from California coastal watersheds to adjacent nearshore kelp habitats (Douglas-Mankin et al., 2010). SWAT operates within a geographic information system (GIS) framework (i.e., using ArcGIS or QGIS platform). A modeled watershed is spatially separated into subbasins using digital elevation data (Fig. 1-4 - right). Subbasins are further broken down into nonspatial hydrologic response units (HRUs) that are made up of subbasin areas having similar slope, soil cover, land cover, and land management characteristics. SWAT yields daily estimates of streamflow and other water quality parameters (i.e., sediment loads) for every subbasin. Monthly and annual load estimates are generated from summed daily load estimates (Douglas-Mankin et al., 2010). *In situ* stream discharge and sediment observations are used for SWAT model calibration and validation (Arnold et al. 2012).

Elevation, land cover, soil cover, and daily precipitation and temperature input datasets will be acquired and pre-processed for SWAT compatibility for the watershed(s) of interest in this study. Examples of input datasets that may be acquired and applied in this study include the US Geological Survey (USGS) 3D Elevation Program (3DEP), USGS National Land Cover Database (NLCD), USDA Natural Resources Conservation Service Digital General Soil Map of

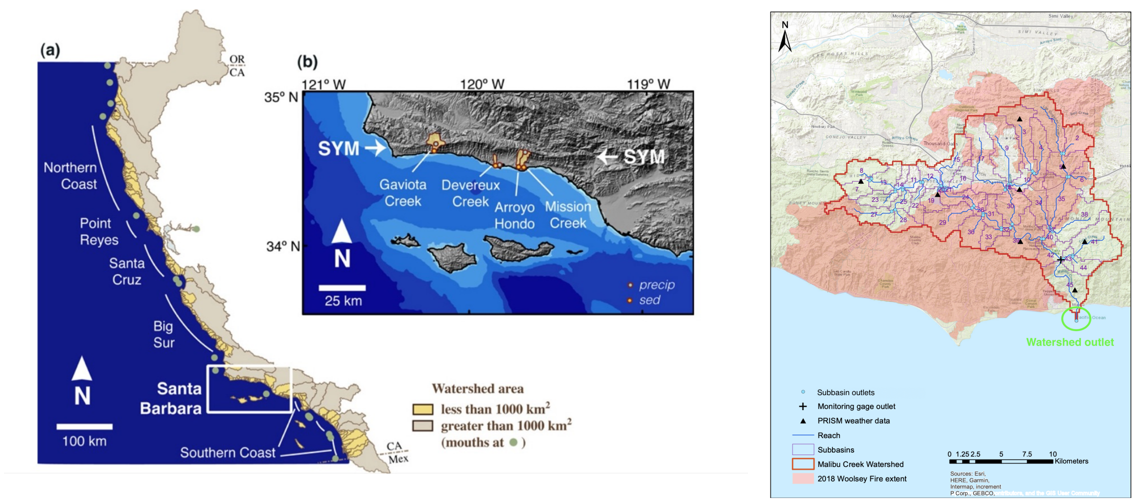

Figure 1-4. (Left) Area of interest for the local study (from Warrick et al., 2015). The Climate Foundation will deploy cultivation platforms in the near term offshore in the Santa Barbara basin. (Right) SWAT model configuration for the Malibu Creek Watershed.

the US (i.e., STATSGO), and Oregon State University Parameter-elevation Regressions on Independent Slopes Model (OSU PRISM) derived daily precipitation, maximum air temperature, and minimum air temperature. The USGS 3DEP digital elevation model (DEM) layers are a compilation of multiple source data such as light detection and ranging and interferometric synthetic aperture radar that are processed to a common coordinate system and vertical measure units as described in Fergason et al. (2020). Additional details about this dataset may be found via the USGS National Map portal (https://apps.nationalmap.gov/downloader/#/). The NLCD dataset is a compilation of Landsat satellite measurements collected across the US between 1992 and the present (Dewitz et al., 2021). The STATSGO database consists of localized ground soil surveys in conjunction with Landsat satellite measurements to create a merged national dataset (Soil Survey Staff, Natural Resources Conservation Service, USDA). The USGS National Water Information System offers *in situ* discharge and sediment monitoring data for stream gages throughout the US. Additional *in situ* observations may be acquired from state, regional, and local agencies (i.e., California Data Exchange Network, California State Water Resources Control Boards) or other research-based institutions.

Sediment loads estimated by SWAT will help us to more quantitatively assess the relationship between land disturbances, ocean turbidity, and impacts on kelp. In particular, for our studies of the impacts of the Thomas Fire in 2017 and Alisal Fire in 2021. The output will also be used to inform ocean model simulations for the region of Santa Barbara that give insights not only on impacts on naturally occurring but also cultivated kelp offshore (section 1.4.2).

1.4.2 Coastal and Open Ocean Conditions and Implications for Kelp Growth

To achieve Goal 2, we will use satellite products and ocean modeling output to describe conditions that favor or inhibit kelp growth. We will apply knowledge gained from the coastal runoff analysis to inform model simulations that in turn are providing insights into impacts on kelp. It is of particular interest to study and quantify the differences in resilience between naturally occurring and cultivated kelp off-shore. While naturally occurring kelp often suffers in extreme event conditions, kelp cultivation platforms have the potential to overcome these challenges. In particular, high surface temperatures along with limited nutrient supply during El Niño events and associated marine heatwaves are known to substantially decimate coastal kelp populations (Cavanaugh et al., 2019, Edwards 2020). Climate Foundation's kelp platforms have the unique capability to overcome challenging ocean environmental conditions. Utilizing wave and solar power, the platforms are able to draw water from depths as deep as 500 m below the surface. Colder nutrient-rich water enables kelp to thrive even under opposing circumstances. **Here, we will investigate to what extent not only naturally occurring kelp is affected by coastal runoff and extreme oceanic conditions but also see how those could affect off-shore mariculture**.

The ECCO-Darwin (ED) model is a highly-flexible ocean ecological and biogeochemical model (Dutkiewicz et al. 2015) that can be embedded in an ocean physical circulation model of both global and regional domains at different resolutions based on MITgcm (Marshall et al., 1997). The ED model was already extensively used for different biogeochemical studies (Brix et al., 2015, Manizza et al., 2019, Ganesan et al. 2020, Carroll et al. 2020). For this proposed study, we plan to start from the most recent global version developed by Carroll et al., (2020) based on hindcast simulations for the 1997-present period. This global version we plan to use for this study has a nominal horizontal resolution of 1/3 degree. It is forced by re-analyzed and optimized atmospheric forcing that can realistically represent the effect of climatic events as ENSO on the physical and biogeochemical properties of the ocean. Specifically for this study in the Eastern North Pacific Ocean the ED model realistically simulates the various El Niño events and Marine Heat Wave phenomena (Di Lorenzo & Mantua, 2016) in the North Pacific Ocean and its effects on ocean physical and biogeochemical properties. The ED model explicitly computes primary production by phytoplankton that is co-limited by light and multiple nutrients (Dutkiewicz et al., 2015) and it has an explicit ocean carbon cycle component directly coupled to plankton dynamics. These specific features make the ED model a highly suitable tool to assess the potential impact of marine algal cultivation on the biogeochemical dynamics of the Californian coastal waters.

To simulate both naturally occurring as well as cultivated kelp, we will first integrate modeling capability into ED that aims to estimate the potential growth rate and kelp production in the waters of the US West Coast and more specifically of the Southern California coast. In order to reach this goal, we will follow the approach adopted by Strong-Wright & Taylor (2022) where they developed a simple model of Kelp growth for an Atlantic species (*Saccharina Latissima*) and combined it with the output of an ocean physical-biogeochemical model output similar to the ED model as forcing fields. Their model is an already modified version of the model from a previous study relative to the Norwegian coastal waters (Broch & Slagstad, 2012, Broch et al., 2019). The kelp growth model uses environmental parameters obtained from ocean models comparable to the ED model such as seawater temperature, nitrate concentration, photosynthetically available radiation, and ocean currents. In their study, Strong-Wright & Taylor (2022) were then able to compute the frond area, carbon and nitrogen content of *Saccharina Latissima* and their corresponding time evolution at seasonal time scale.

The forcing fields from the ED model, that describe the physical and biogeochemical conditions of the Pacific Ocean waters in our specific case, will be used to force the kelp growth model to simulate the kelp growth on floating platforms. Specifically, we plan to acquire the code already made available on-line by Strong-Wright and Taylor (2020), to modify it for our Pacific Ocean kelp species and then to feed it with ocean variables from the ED model. We plan to implement this novel modeling system by using the output of the ED model both for the large-scale global version and for the high-resolution regional model of Southern California waters.

1.4.2.1 Implementation of Coastal Impacts on Naturally Occuring Kelp in ECCO-Darwin

After implementing and evaluating kelp primary production in ED through a comparison with our Landsat-based kelp canopy and biomass data (Bell et al. 2020, 2022), we are now ready to more deeply investigate the impacts of local runoff. To study the impacts of the oceanic and coastal environment on kelp, we first assess general threshold conditions that are known to impose limitations for kelp growth. In the following, we will outline our assumptions based on previous work and inputs from our coastal assessment that will then inform our model runs.

In general, kelp growth is limited by three main physical factors: temperature, nutrients and light availability. In our study area sea surface temperature and nutrients are strongly negatively correlated due to upwelling, and so it can be difficult to separate their impacts in natural systems. However, thresholds for each variable have been identified through experimental and observational studies. Giant kelp slows down its growth at ~20°C and temperatures above ~24°C can result in relatively rapid mortality (Rothäusler et al. 2011, Cavanaugh et al. 2019). Giant kelp growth becomes nutrient limited at dissolved inorganic nitrogen concentrations of 1 **μ**g/l (Zimmerman and Kremer 1984). Giant kelp requires an annual irradiance dose of >50 $E \cdot m^{-2}$ (Spalding et al. 2003); and light limitation at the seafloor can inhibit recruitment and early growth of juvenile kelp (Shaffer & Parks 1994, Traiger & Konar 2017). As kelp grows through the water column and develops a surface canopy light limitation becomes less of a factor.

Nutrient runoff data is provided globally through the GlobalNEWS project (Mayorga et al, 2010). Efforts are underway to integrate global nutrient runoff data as an input to the ED framework [D. Menemenlis, personal communication]. The proposed work is to add the riverine nutrient input to the current version of the ED model to be able to study the impacts on not only historical, naturally occurring kelp but also project how cultivated kelp can thrive in offshore environments and contribute to amplify coastal resilience.

Satellite data will be used to inform the implementation of kelp in the ED model as well as modeled light availability changes due to fluctuations in turbidity. Coastal inputs such as estimates of sediment loads from coastal runoff will come from a suite of satellite products and the SWAT model.

In the ED model, the light availability for marine photosynthesis is currently a function of depth where it is computed based on absorption properties of seawater and chlorophyll concentration only (Dutkiewicz et al, 2015). We plan to include the effect of the sediment load on light attenuation in the ED model so that we will be able to investigate on- and offshore influences on kelp growth in more detail. In particular, we will use the MODIS KD490 product to constrain light availability in the ED mode to evaluate his performance in different turbidity regimes.

1.4.2.2 Implementation of Cultivated Kelp in ECCO-Darwin

While naturally-occurring kelp is more susceptible to environmental changes, the Climate Foundation's kelp platforms are built to overcome some of these challenges. Using a solar- and wave-powered deep water irrigation system, the platforms can access water and nutrients from depths as low as 500 m. **Here, we describe the ocean conditions the platforms may encounter off of the coast of California (and Santa Barbara in particular) and the planned implementation of the kelp platforms in ECCO-Darwin (ED)**.

We will simulate cultivated kelp in our two scenarios, 1) for the entire coast of California and 2) for the region of Santa Barbara. For scenario 1), we will utilize the 1/3-degree global simulation (Carroll et al., 2020) that also introduces nutrient runoff and effects of turbidity as outlined above. The suite of experiments conducted with this setup will mainly focus on impacts large scale kelp mariculture can potentially have on ocean acidification, carbon sequestration, ecosystems, and nutrient availability (see 1.4.3). In general, we will base our experiments on the following assumptions:

- Kelp platforms can access water from depths >100 m, i.e., we will base our analysis of temperature and nutrients at these depths and adjust for mixing with the warmer surface water when the water is supplied through the irrigation system (https://www.climatefoundation.org/questions-and-answers.html)
- The platforms are at or near the ocean surface, i.e., light availability will have the same consideration as for naturally occurring kelp
- Given a mean ocean velocity of 0.01 m/s, we assume a <1 hectare platform array will stay within a 1/3x1/3 degree grid box for ~1month, i.e., we can integrate the effects of the platforms on the ocean environment over a month to arrive at quantitative estimates described in 1.4.3

For scenario 2), we plan to set-up a regional ocean physical model of Southern California waters mostly covering the Southern California Bight spanning from Point Conception to the northern portion of Baja California. In this physical model we will embed the same code of Darwin used for our global version of the ED model. For the physical and biogeochemical ocean properties at the boundaries of our regional domain we plan to use the already existing fields from the global version of ED that will be used in the same study. This regional version of the ED model has a horizontal resolution of 2 km and it will allow us to understand in greater detail the processes occurring in the Santa Barbara basin where the floating cultivation platforms are meant to be deployed. A more high-resolution model of the area allows us to further quantify the local impacts from coastal runoff and turbidity. It also enables us to look at influences on kelp growth that might be varying as the platform travels the ocean.

Note that while the platform has capabilities to navigate ocean currents, we will - to first order - treat platform motion like a passive tracer (Manizza et al., 2019). Given the focus of this study to perform a first assessment and comparison of coastal and open ocean influences on the platforms, we find that this assumption will likely suffice. While navigational abilities can help to more actively seek out areas most beneficial to kelp growth, as a first step our assumption will give us insights into what conditions the platforms encounter and how this might influence operations and navigation. Figure 1-6 illustrates the general conditions off of the coast of California the platforms will likely encounter.

1.4.2.3 Potential Impacts of Extreme Events

Having established a baseline model setup that includes coastal runoff and sediment load as well as the capability to simulate kelp growth, **we will now more closely explore the impacts extreme events and the land/ocean continuum have on naturally occurring and cultivated kelp**. Extreme events that likely affect kelp are a) oceanic changes in surface temperatures and nutrient supply driven by the El Niño Southern Oscillation (ENSO) and b) increased sediment load related to runoff after storms when the watershed had experienced wildfires.

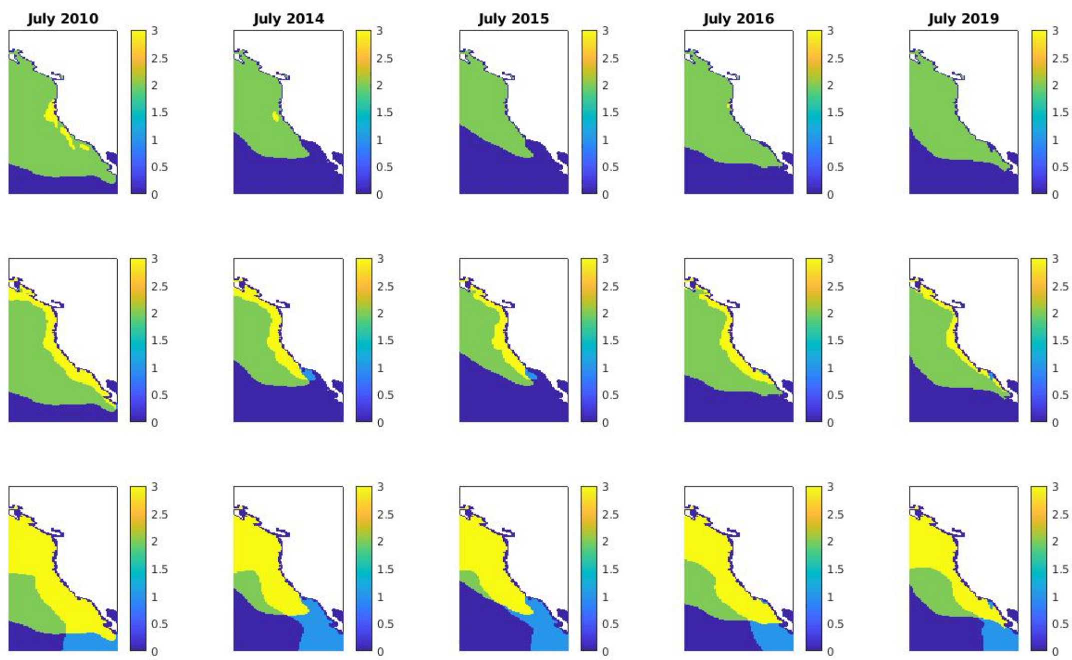

Figure 1-6 The maps were obtained by combining ED-simulated SST fields (all the panels) and dissolved inorganic nitrogen (DIN= nitrate + nitrite) selected at (top panels) 5 m, (middle panels) 55 m, and (bottom panels) 95 m. 20 C and 1 microM were set as threshold values to compute the maps. Yellow = Optimal Growth; Green = Nutrient Limited Growth; Pale Blue = Temperature Limited Growth; Dark Blue = No Growth. This approach has been adopted based on the use of technology of bio-irrigation implemented in the floating cultivation platforms (See the text for more specific details).

To quantify the effects of a) we have identified 2015/16 as an El Niño year where kelp growth usually decreases under the influence of increased surface and mixed layer temperatures in the Eastern Pacific low latitude ocean. 2010/11 was a La Niña year that may amplify favorable conditions for kelp growth along the California coast, and 2019/20 a 'neutral' year that serves as a reference. Fig. 1-6 provides first insights into which oceanic areas might be most favorable for Kelp cultivation along the coast of the Eastern North Pacific Ocean as simulated by the use of the output from the ECCO-Darwin global model for different years.

The ED experiments that will be conducted as part of this study will shed more light on how kelp is impacted during ENSO events - both on- and offshore and through open ocean and coastal influences. The satellite data we use in our study will here be used as a metric to evaluate how closely model simulations resemble past events and variability. This will then also help to inform the interpretation of results we obtain for the mariculture platform and kelp growth variability they might experience. We will study conditions at different depths - as indicated by Figure 1-6 - to account for the bioirrigation capabilities that help the platforms potentially overcome adverse extreme conditions.

For exploring b), we will analyze model outputs particularly around the wildfire events of 2017 and 2021. In the regional, high-resolution model runs, we use tracer experiments to investigate the reach of coastal runoff as they may potentially impact the mariculture platforms. This adds to our analysis of variables traditionally provided by ED.

1.4.3 Impacts of Cultivated Kelp

To achieve Goal 3, we will utilize the ECCO-Darwin model and provide insights into how cultivation platforms are interacting with the physical and biogeochemical ocean environment. We will investigate the impacts on the nutrient flow and ocean ecosystem by simulating platforms at a range of spatial scales. At larger scales, the simulations will also provide insights into the carbon drawdown potential.

1.4.3.1 Assessing Nutrient Flow and Ecosystem Impacts

The system of bioirrigation that will be employed in the floating platforms we plan to use in the coastal waters of Southern California will generate an artificial upward flux of inorganic nutrients into the euphotic zone. It is not clear yet which fraction of this net amount will be used by the floating kelp biomass due to the effect of horizontal advection caused by local ocean currents. It is highly possible that a fraction of these macronutrients will be advected away from our structures and dispersed into the natural environment with potential beneficial effect for the local planktonic ecosystem. It is known that the area of Southern California Bight is not fertilized by summer seasonal upwelling as in the area north of Point Conception. We expect that the local patterns of ocean circulation will determine which parts of our domain will be fertilized and we expect with the use of the ED model to quantify the potential increase in primary production that potentially could be scaled up to fish production (Carozza et al., 2016). Due to uncertainty of the fraction of unutilized nutrients coming from artificial bioirrigation we plan to run sensitivity tests to verify if there is a linear scaling relationship between this fraction and enhanced productivity. However, the non-linearity of patterns of ocean circulation at the scale of motion we plan to resolve with our regional model might provide unexpected results on this relationship intrinsic to ocean biogeochemical dynamics.

1.4.3.2 Quantifying Carbon Drawdown and Competing Effects

The system of artificial bio-irrigation that will be implemented in the floating cultivation platforms is meant to pump from deeper depths water that is richer not only in macronutrients but also in dissolved inorganic carbon (DIC) than the surrounding surface waters. This means that once at the ocean surface these DIC-rich waters will promote disequilibrium and CO_2 outgassing, lowering the CO_2 uptake of these waters compared to normal conditions.

At the same time this process of DIC water enrichment is expected to promote acidification not only of those waters where the platforms are floating but also in their proximity due to the ocean circulation effect. Therefore, the fertilizing effect mentioned in the previous section might theoretically counteract these two effects by removing the DIC in excess from the ambient water both by local plankton and by the kelp biomass too.

Due to the complexity of these two processes occurring at the same time and also considering the important role of local circulation, we think that the ED model will be the perfect tool to explore how the competing effects of these processes will determine the final outcome of enhanced carbon removal and mitigation of ocean acidification. Even for this section of the project we will need to run a set of numerical experiments where the sensitivity of the system will be explored by modifying some key parameters as, for instance, the density of floating platforms in our grid cell.

1.5 Contributions of Principal Investigator and Key Personnel

Principal Investigator

Dr. Carmen Blackwood will be responsible for the overall coordination of the team effort. She will actively support and facilitate team communication and coordinate deliveries of products between team members as well as ensure delivery of software and data as described in the DMP. To make the results available to the scientific and kelp cultivation communities that are interested in the data products and models, Dr. Blackwood will coordinate and organize presentations at key meetings and workshops and the preparation of peer-reviewed articles as well as outreach products. She will provide her expertise in physical oceanography, satellite remote sensing, and ocean modeling to support analysis, evaluation, and interpretation of results.

Key Personnel

Dr. Manfredi Manizza of UCSD, Co-I, will lead the development of the ECCO-Darwin model.

Dr. Christine Lee of JPL, Co-I, will lead the satellite data analysis and provide her expertise in satellite remote sensing of coastal oceans.

Dr. Amanda Lopez of JPL, Co-I, will lead the development of the SWAT model experiments and support the satellite data and ocean model output analysis.

Dr. Brian Von Herzen of the Climate Foundation, Co-I, will advise on technical specifications of the cultivation platforms as they inform model experiments and interpretation of the results.

Dr. Kyle Cavanaugh of UCLA, Co-I, will provide his expertise on the growth cycle and environmental impacts on kelp to satellite data analysis and model development.

Dr. Dimitris Menemenlis of JPL, Co-I, will provide his expertise in ocean modeling to assist the development of the new algorithms within ECCO-Darwin

1.6 Collaborators and Consultants

Dr. James Leichter, Collaborator, will provide consultation in coastal oceanography and ecology of kelp ecosystems and impacts of coastal darkening and water column light attenuation on kelp demography in the region of San Diego CA.

1.7 Work Plan

During Year 1 of the project, we will focus on the regional analysis using satellite observations and models as described above. Co-Is CL and KC will start the analysis of satellite turbidity data as it impacts kelp growth along the California coast. Co-I MM will start setting up the kelp growth model using the already existent output of the global version of ECCO-Darwin model. With this task the aim is to estimate the potential growth of coastal and floating kelp in the waters of Southern California/US West Coast. In this part of the project, Co-I MM will closely interact with Co-Is BVH and KC in order to optimize the kelp model based on knowledge of naturally occurring kelp and the results from ongoing kelp cultivation activity during the first and then second year. The global version of the ED model will be also used to test hypotheses relative to the impact of kelp cultivation and local biogeochemical processes. Co-

I AML will gather the data required for the SWAT model runs. PI CB will help facilitate team discussions, define interfaces for and hand-offs of products. CB will also support experiment, analysis, and model design for all elements and in all years of the project.

During Year 2 of the project, the results from the satellite data-based studies will inform the development of the local models. Co-I AML will set up the SWAT model for the Santa Barbara area and perform a set of experiments for the timeframe of the recent California wildfires. MM will work in close collaboration with Co-I DM to set up the new regional version of the ED model adapted to the Southern California coastal waters. MM will also work with Co-Is CL and AML to implement in the same model the terrestrial sources of suspended sediments and turbidity as it impacts light availability in the model. BVH will advise on technical details of the mariculture platforms as they inform the regional model runs. CB will support the evaluation of ocean model runs against satellite observations.

During Year 3 of the project, we will focus on the analysis of the model simulations and satellite observations for specific extreme events, i.e., ENSO and wildfires. Co-I MM will mostly focus on the use of the new regional ED model and together with CB and other team members explore some of the potential effects of runoff and of marine heat waves both on artificially cultivated kelp and on the natural kelp forests of the California coast. CL and AML will work in collaboration with KC on the interpretation of the SWAT model results for coastal kelp in the Santa Barbara area. During the development of the project during Years 2 and 3, the team will jointly produce scientific publications relative to these topics.

1.7.1 *Key Milestones*

The schedule in (Figure 1-7) shows the workflow to achieve the key publications and model output delivery dates (shown as diamonds).

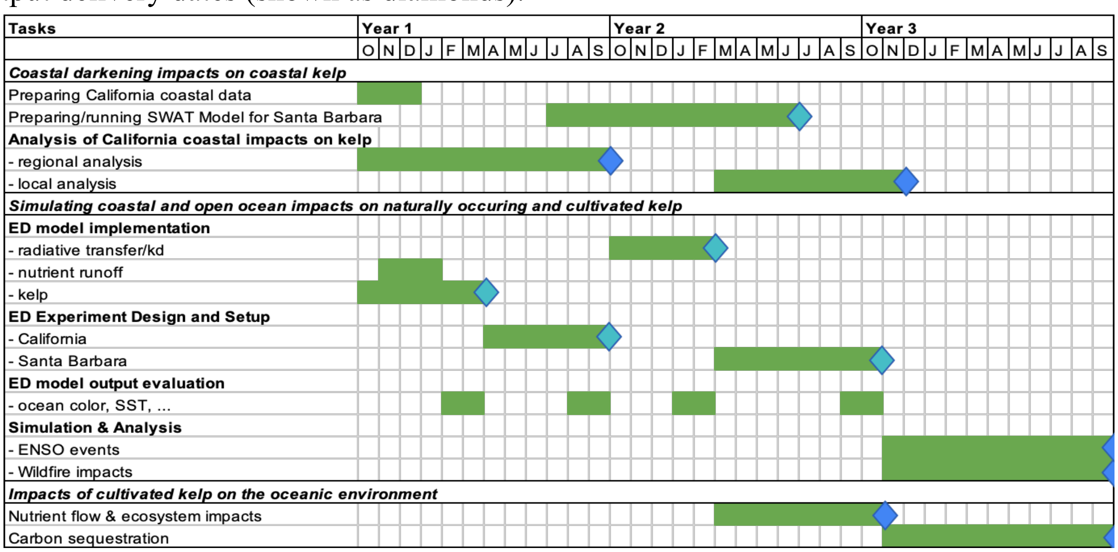

Figure 1-7. Project Schedule (publications - blue, model output delivery - light blue)

1.7.2 *Management Structure*

Dr. Carmen Blackwood of JPL is the PI of the proposed investigation. She is solely responsible for the quality and direction of the proposed research and the proper use of all awarded funds. She is also responsible for all technical, management, and budget issues and is the final authority for this task. The Co-Is report to and take direction from the PI and will provide all the management data needed to ensure that she can effectively manage the entire task.

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3 Data Management Plan (DMP)

3.1 Data types, volume, formats, and (where relevant) standards

The SWAT model outputs daily, monthly, and/or annual estimates of streamflow (cubic meters per second and sediment loads (metric tons per unit time) for the watershed of interest. These data are generated in Microsoft Access database format and can be made available in text file or Excel file formats.

The section of our proposed investigation based on the use of ECCO-Darwin will generate the following scientific material:

1) Model output of potential kelp cultivation and its rates of biomass production of the US West coast for the 2010-present periods generated by the use ECCO-Darwin model at 1/3 degree.

2) Model output of the ECCO-Darwin version at 2 km of horizontal resolution of Kelp production for the area of the Santa Barbara basin for the 2010-present period.

3) Model output of the ECCO-Darwin version at 2 km of horizontal resolution of natural kelp forest habitat and its abundance for the southern California coastal waters for the 2010-present period.

The model output generated by this project will be made available in netCDF format.

Data products that are results presented as part of publications will be made available in an EOSDIS-compliant format (e.g., netCDF or ASCII).

3.2 Schedule for data archiving and sharing

SWAT model outputs will be made available in year 2 quarter 3 as outlined in the project schedule with the conclusion of the model experiments (see Fig. 1-7). Data will be made publicly available via the online Hydrologic and Water Quality System (HAWQS) at: https://hawqs.tamu.edu/#/.

ECCO-Darwin model output will be made available after each evaluation phase (see Fig. 1-7). The data will be made publicly available on the NASA portal at: https://data.nas.nasa.gov/ecco/data.php?dir=/eccodata/llc_270/ecco_darwin_v5/output/bin_average

3.3 Intended repositories for archived data and mechanisms for public access and distribution

SWAT output will be stored and made available at:

https://hawqs.tamu.edu/#/.

ECCO-Darwin outputs will continue to be available at: https://data.nas.nasa.gov/ecco/data.php?dir=/eccodata/llc_270/ecco_darwin_v5/output/bin_average

3.4 Plan for enabling long-term preservation of the data

The new output generated by the use of ECCO-Darwin model for this study will be archived on the LOU machine at NAS and MM will also store it on the at SIO server (pipeline.ucsd.edu) to make it available upon request. We will also plan to add any outcomes from R&A analyses to the EOSDIS system following the guidelines under: https://earthdata.nasa.gov/collaborate/new-missions/adding-competitive-other#research-and-analysis-r-a-and-applied-science-products

3.5 Roles and responsibilities of team members in accomplishing the data management plan

Co-I AL will be responsible for creating and distributing the SWAT outputs according to the plan as described above. Co-I MM will be responsible for archiving the ECCO-Darwin outpus as outlined above. PI Blackwood will be responsible for overseeing the overall archiving and publication of data products. At the end of the project, she will ensure all data is archived and publicly accessible.

4 Software Development Plan

4.1 Software development and management

The new code of ECCO-Darwin based on MITgcm and relative to the regional version of Southern California waters at high resolution that will be developed for this project will be made available via GitHub. The code will be place in the same section where the Co-Is DM and MM have made available all the previous configurations (both global and regional) that can be freely downloaded by any potential user interested in this specific topic here: https://github.com/MITgcm-contrib/ecco_darwin

The GitHub repository will also include the documentation for the new code development.

Work with the SWOT model mainly involves adjustments of input parameters and datasets, as well as boundary conditions and subsequent calibration and validation activities. We do not expect any changes to the overall implementation.

Analysis code that is used to produce results for publications as well as documentation will be made available at the time of publication.

5 Biographical Sketch(es)

5.1 Principal Investigator

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Relevant Experience

Over 15 years of experience in physical oceanography and satellite remote sensing science. Led various interdisciplinary science projects spanning oceanography, hydrology, glaciology, and solid earth science. Published peer-reviewed publications advancing the field of sea level science by connecting different types of Earth system processes to fluctuations in global and regional sea level. New techniques for utilizing satellite remote sensing data for oceanography.

Education

- Ph. D., Physics, University of Bremen, Germany, 2009
    - Thesis: Validation of ocean mass variability derived from the Gravity Recovery and Climate Experiment - Studies utilizing in-situ observations and results from a Finite Element Sea ice - Ocean Model
- M.Sc., Mathematics, University of Bremen, Germany, 2005

Professional Experience:

Current Positions:

2015–present GRACE Project Scientist, JPL
2013–present PI NASA Sea Level Web Portal
2011–present Research Scientist

Previous Positions:

2018–2021 Deputy Section Manager, Earth Science, JPL
2015–2018 Group Supervisor, Sea Level and Ice, JPL
2009-2011 Postdoctoral Scholar, Oceanography, JPL
2005-2009 Research Assistant, Alfred Wegener Institute for Polar and Marine Research, Bremen, Germany

Professional Activities:

Vice President, Intercommission Committee on Geodesy for Climate Research (ICCC) of the International Association of Geodesy (IAG)

Associate Editor, AGU Journal of Geophysical Research, Solid Earth

IAF GEOSS Subcommittee

Selected Publications

Tapley, B. D., Watkins, M. M., Flechtner, F., Reigber, C., Bettadpur, S., Rodell, M., Sasgen, I., Famiglietti, J. S., Landerer, F. W., Chambers, D. P., Reager, J. T., Gardner, A. S., Save, H., Ivins, E. R., Swenson, S. C., Boening, C., Dahle, C., Wiese, D. N., Dobslaw, H., Tamisiea,

M. E., & Velicogna, I. (2019). Contributions of GRACE to understanding climate change. Nature Climate Change, 9(5), 358–369. https://doi.org/10.1038/s41558-019-0456-2

Schlegel, N.-J., Seroussi, H., Schodlok, M. P., Larour, E. Y., Boening, C., Limonadi, D., Watkins, M. M., Morlighem, M., and van den Broeke, M. R.: Exploration of Antarctic Ice Sheet 100-year contribution to sea level rise and associated model uncertainties using the ISSM framework, The Cryosphere, 12, 3511–3534, https://doi.org/10.5194/tc-12-3511-2018, 2018.

Mazloff, M. R., and C. Boening (2016), Rapid variability of Antarctic Bottom Water transport into the Pacific Ocean inferred from GRACE, Geophys. Res. Lett., 43, 3822–3829, doi:10.1002/2016GL068474.

Hughes, C.W., J. Williams, A. Hibbert, C. Boening, J. Oram (2016), “A Rossby Whistle: A resonant basin mode observed in the Caribbean Sea”, Geophysical Research Letters, 43, 7036–7043, doi:10.1002/2016GL069573.

Bentel, K., F. W. Landerer, and C. Boening. "Monitoring Atlantic overturning circulation variability with GRACE-type ocean bottom pressure observations–a sensitivity study." Ocean Sci. Discuss 12 (2015): 1765-1791.

Landerer, F. W., D. N. Wiese, K. Bentel, C. Boening, and M. M. Watkins (2015), North Atlantic meridional overturning circulation variations from GRACE ocean bottom pressure anomalies, Geophysical Research Letters, 42(19), 8114-8121, doi: http://dx.doi.org/10.1002/2015gl065730.

Boening, C. (2014) Oceanography: Detecting sea-level rise, Nature Climate Change, 4, 327–328, doi:10.1038/nclimate2205

Fasullo, J. T., C. Boening, F. W. Landerer, and R. S. Nerem (2013), Australia's unique influence on global sea level in 2010–2011, Geophys. Res. Lett., 40, 4368–4373, doi:10.1002/grl.50834.

Boening, C., M. Lebsock, F. Landerer, and G. Stephens (2012), Snowfall-driven mass change on the East Antarctic ice sheet, Geophys. Res. Lett., 39, L21501, doi:10.1029/2012GL053316.

Boening, C., J. K. Willis, F. W. Landerer, R. S. Nerem, and J. Fasullo, (2012) The 2011 La Niña: So Strong, the Oceans Fell, Geophys. Res. Lett., 39, L19602, doi:10.1029/2012GL053055

Boening, C., T. Lee, and V. Zlotnicki (2011), A record-high ocean bottom pressure in the South Pacific observed by GRACE, Geophys. Res. Lett., 38, L04602, doi:10.1029/2010GL046013.

Böning, C., Timmermann, R., Danilov, S., Schröter, J. (2010). On the representation of transport variability of the Antarctic Circumpolar Current in GRACE gravity solutions and numerical ocean model simulations, In Flechtner F, Gruber T, Güntner A, Mandea M, Rothacher M, Schöne T, Wickert J (eds) Satellite Geodesy and Earth System Science, Springer-Verlag, Berlin, Heidelberg, Part 2, 187-199, DOI: 10.1007/978-3-642-10228-8_15

Timmermann, R., Danilov, S., Schröter, J., Böning, C., Sidorenko, D., Rollenhagen, K.(2009). Ocean circulation and sea ice distribution in a finite element global sea ice -- ocean model, Ocean Modelling, doi:10.1016/j.ocemod.2008.10.009., doi:10.1016/j.ocemod.2008.10.009

Böning, C., Timmermann, R., Macrander, A., Schröter, J.(2008). A pattern-filtering method for the determination of ocean bottom pressure anomalies from GRACE solutions, Geophysical Research Letters, 35, L18611, doi:10.1029/2008GL034974 .

5.2 Co-Investigator(s)

Manfredi Manizza
Project Scientist
Scripps Institution of Oceanography
University of California San Diego, La Jolla, CA
Tel: 858-534-7094 Email: mmanizza@ucsd.edu

Education

Polytechnic University of Marche, Ancona, IT	Biological Oceanography	Laurea Degree, 1998
University of Southampton, UK	Oceanography	M.Sc., 2002
University of East Anglia, UK	Environmental Sciences	Ph.D., 2006

Professional Experience

2022-present Project Scientist, Scripps Institution of Oceanography, La Jolla, California
2013-2022 Staff Research Associate IV, Scripps Institution of Oceanography, La Jolla, CA
2011-2013 Assistant Project Scientist, Scripps Institution of Oceanography, La Jolla, CA
2009-2011 Scripps Post-Doctoral Fellow, SIO, UCSD, La Jolla, CA
2006-2009 Post-doctoral Research Associate, Mass. Instit. of Technology, Cambridge, MA

Publications

Morgan, E. J., Manizza, M., Keeling, R. F., Resplandy, L., Mikaloff-Fletcher, S. E., Nevison, C. D., et al. (2021). An atmospheric constraint on the seasonal air-sea exchange of oxygen and heat in the extratropics. Journal of Geophysical Research: Oceans, 126, e2021JC017510. https://doi.org/10.1029/2021JC017510

Carroll, D., Menemenlis, D., Adkins, J. F., Bowman, K. W., Brix, H., & Dutkiewicz, S., et al. (co-author) (2020). The ECCO-Darwin data-assimilative global ocean biogeochemistry model: Estimates of seasonal to multidecadal surface ocean pCO2 and air-sea CO2 flux. Journal of Advances in Modeling Earth Systems, 12, e2019MS001888. https://doi.org/10.1029/2019MS001888

Ganesan, A.L., Manizza, M., Morgan, E.J., Harth, C.M., Kozlova, E., Lueker, T., Manning, A.J., Lunt, M.F., Mühle, J., Lavric, J.V., Heimann, M., Weiss, R.F. and Rigby, M. (2020), Marine Nitrous Oxide Emissions From Three Eastern Boundary Upwelling Systems Inferred From Atmospheric Observations. Geophys. Res. Lett., 47: e2020GL087822. https://doi.org/10.1029/2020GL087822

Manizza, M., Menemenlis, D., Zhang, H., & Miller, C. E. (2019). Modeling the recent changes in the Arctic Ocean CO2 sink (2006–2013). Global Biogeochemical Cycles, 33, 420– 438. https://doi.org/10.1029/2018GB006070

Professional Activities

Dr. Manizza is an ocean biogeochemical modeler who has been using both global and regional biogeochemical models embedded in ocean general circulation models. He conducted research on ocean biogeochemical cycles of carbon, oxygen, sulphur and nitrous oxide. He is currently involved in the following research activity:

1) The variability of carbon uptake of the Arctic Ocean (with S. Yasunaka).
2) The carbon and oxygen air-sea fluxes in the Kuroshio current (with S. Bushinsky).
3) The changing carbon sink, phytoplankton blooms phenology, and ecosystem composition in the Arctic Ocean (with D. Menemenlis and C. E. Miller)
4) The changing phytoplankton phenology in the the polar and subpolar northern oceans (with A. Matsuoka and A. Winter)

Kyle C. Cavanaugh

Department of Geography, University of California, Los Angeles 90095
Phone: 310-825-3122 Email: kcavanaugh@geog.ucla.edu

Education and Training

Trinity University	San Antonio, TX	Geosciences & History	B.S., 2003
University of California	Santa Barbara, CA	Marine Science	Ph.D., 2011
Smithsonian Institution	Edgewater, MD	Coastal Ecology	Postdoc, 2012-2014

Research and Professional Experience

2020-present **Associate Professor,** Department of Geography, University of California Los Angeles, Los Angeles, CA

2014-present **Assistant Professor,** Department of Geography, University of California Los Angeles, Los Angeles, CA

2006-2012 **Research and Teaching Assistant,** Departments of Marine Science & Geography, University of California, Santa Barbara, CA

2004-2006 **Remote Sensing/GIS Analyst,** Earth Satellite Corporation, Rockville, MD

Selected Publications Related to Proposed Project

Cavanaugh K.C, Reed, D.C., Bell, T.W., Castorani, M.C., Beas-Luna, R. (2019). Spatial variability in the resistance and resilience of giant kelp in southern and Baja California to a multiyear heatwave. *Frontiers in Marine Science, 6,* 413

Bell, T. W., Allen, J. G., **Cavanaugh, K. C.**, & Siegel, D. A. (2018). Three decades of variability in California's giant kelp forests from the Landsat satellites. *Remote Sensing of Environment*, 110811.

Krumhansl, K. A., Okamoto, D. K., Rassweiler, A., Novak, M., Bolton, J. J., **Cavanaugh, K. C.,** ... & Micheli, F. (2016). Global patterns of kelp forest change over the past half-century. *Proceedings of the National Academy of Sciences*, *113*(48), 13785-13790.

Cavanaugh K.C., Siegel D.A., Reed D.C., Dennison P.E. (2011) Environmental controls on giant kelp biomass in the Santa Barbara Channel, CA. *Marine Ecology Progress Series* 429:1-17

Cavanaugh, K. C., **Cavanaugh, K. C.**, Bell, T. W., & Hockridge, E. G. (2021). An Automated Method for Mapping Giant Kelp Canopy Dynamics from UAV. Front. *Environ. Sci*, *8*, 587354.

Bell, T. W†., **Cavanaugh, K. C.**, † & Siegel, D. A. (2015). Remote monitoring of giant kelp biomass and physiological condition: An evaluation of the potential for the Hyperspectral Infrared Imager (HyspIRI) mission. *Remote Sensing of Environment*. *†Authors contributed equality to this work*

Bell, T. W., **Cavanaugh, K. C.**, Reed, D. C., & Siegel, D. A. (2015). Geographical variability in the controls of giant kelp biomass dynamics. *Journal of Biogeography*.

Cavanaugh K.C, Kendall B.E, Siegel D.A., Reed D.C., Alberto, F., Assis J. (2013) Synchrony in dynamics of southern California giant kelp forests is driven by both local recruitment and regional environmental controls. *Ecology* 94:499-509

Cavanaugh K.C., Siegel D.A., Kinlan B.P., Reed D.C. (2010) Scaling giant kelp field measurements to regional scales using satellite observations. *Marine Ecology Progress Series* 403:13-27.

Christine M. Lee, Ph.D.

NASA Jet Propulsion Laboratory
300-329, 4800 Oak Grove Dr., Pasadena, CA 91109
+1(818) 354-3343 | christine.m.lee@jpl.nasa.gov

Professional Experience

2014-Present Scientist (2019-), Water and Ecosystems Group, JPL

Associate Program Manager, NASA Water Resources Program, NASA Earth Science, Applied Sciences

Applications Lead, NASA's ECOSTRESS Mission (ecostress.jpl.nasa.gov)

JPL Lead for applications, NASA Surface Biology and Geology Mission Concept (sbg.jpl.nasa.gov)

PI (2016-2021), Maximizing Remote Sensing for Water Quality Monitoring in California's Water Systems

PI (2019-present), ECOSTRESS surface temperature for aquatic applications

Co-I (2018-present), Sustainable Development Goals for Belize's Coasts

Co-I (2021-present), Wildfire Impacts on Watershed Transport of Carbon to Coasts)

Co-I (2018-present), CONUS wide DisALEXI ET uncertainty estimates

2012-14 AAAS Science and Technology Policy Fellow, NASA Headquarters

Education

2010-12 Postdoctoral Researcher, JPL

2010 Ph.D. Environmental Engineering UCLA
2006 M.S. Environmental Engineering UCLA
2005 B.S. Chemical Engineering UCLA

Selected peer-reviewed Publications

1. Pascolini-Campbell M., **Lee C.M.,** Stavros E.N., Fisher J.B. ECOSTRESS reveals pre-fire vegetation controls for CA Wildfires of 2020. Accepted, *Global Ecology and Biogeography*.
2. **Lee, C. M.,** Glenn, N. F., Stavros, E. N., Luvall, J., Yuen, K., Hain, C., & Uz, S. S. Systematic integration of applications into SBG Earth mission architecture study. *AGU JGR-B*. (2022)
3. Martin-Arias, … **Lee, C. M.**, et al. (2022). Modeled Impacts of LULC and Climate Change Predictions on the Hydrologic Regime in Belize. *Frontiers in Environmental Science*.
4. Cira, M., Bafna, A., **Lee, C.M.** *et al.* Turbidity and fecal indicator bacteria in recreational marine waters increase following the 2018 Woolsey Fire. *Nature Sci Rep* **12,** 2428 (2022).
5. Gustine R.N., **Lee C.M.,** et al. Using ECOSTRESS to Observe Diurnal Variability in Water Temperature Conditions in the San Francisco Estuary. *IEEE TGRS.* (2022)
6. Halverson G., **Lee C.M.,** et al. Decline in Thermal Habitat Conditions for the Endangered Delta Smelt as Seen from Landsat Satellites (1985-2019). *Environmental Science and Technology*,
7. **Lee C.M.**, Hestir E.L., Tufillaro N., Palmieri B., Acuna S., Osti A., Bergamaschi B., Sommer T., Monitoring turbidity in San Francisco Estuary using satellite remote sensing. *JAWRA,* 2021.
8. Ade C., Hestir E.L., **Lee C.M.**, Assessing Fish Habitat and the Effects of an Emergency Drought Barrier on Estuarine Turbidity Using Satellite Remote Sensing. *JAWRA, 2021.*
9. Callejas I., **Lee C.M.**, Effect of COVID-19 Anthropause on Water Clarity in Belize Coastal Lagoon. *Frontiers in Marine Science,* 2021.https://doi.org/10.3389/fmars.2021.648522
10. Ayad M., Li J., Holt B., **Lee C.M.**, Analysis and Classification of Stormwater and Wastewater Runoff from Tijuana River Using Remote Sensing Imagery, Frontiers Env Sci, 2020. https://doi.org/10.3389/fenvs.2020.599030

Selected Community and Professional Service

5 Ph.D. committees (UCLA, Boise State, Washington State University, UC Santa Cruz), all in progress

2 M.S. committees (Cal State Los Angeles), M. Ayad (2020), J. Vellanoweth (2021)

Guest Associate Editor, J. American Water Resources Association

Guest Associate Editor, Frontiers in Marine Science

Convener / Co-chair, AGU Fall Meeting, Remote Sensing for Water Resources, 2012-present

Member, UCLA Civil and Environmental Engineering Advisory Board 2020-present

Amanda Mulcan Lopez 954.554.0646 amulcanlopez@gmail.com

EDUCATION

2021 Ph.D. in Geology University of Houston (Houston, TX) *Dissertation: Heavy Metal Geochemistry of Sediments and Oysters from Galveston Bay, Texas*

2014 M.S. in Environmental Science Florida Atlantic University (Boca Raton, FL) *Thesis: Environmental Siting Suitability Analysis for Commercial Scale Ocean Renewable Energy: A Southeast Florida Case Study*

2011 B.A. in Geological Sciences & History University of Miami (Coral Gables, FL) *Minors in Ecosystem Science-Policy & Art*

EXPERIENCE

Nov 2021 – present Visiting Researcher, Univ. of California, Los Angeles
Jul 2021 – present NASA Postdoctoral Program Fellow, NASA Jet Propulsion Laboratory
Jan 2020 – May 2021 Research Assistant, Dept. Earth & Atmospheric Science, Univ. of Houston
Jan 2017 – Jun 2017 NASA Intern, Experimental Petrology Group, NASA Johnson Space Center
Aug 2016 – Dec 2019 Teaching Assistant, Dept. Earth & Atmospheric Science, Univ. of Houston
Jan 2016 – Jun 2016 Adjunct Professor of Environmental Science, Broward College (online campus)
Aug 2015 – May 2016 Adjunct Professor of Environmental Science, Lone Star College
May 2014 – Jun 2015 Project Geologist, Tierra Consulting Group, Inc.
Jan 2013 – May 2014 Teaching Assistant, Dept. of Geosciences, Florida Atlantic Univ.
Sep 2011 – Dec 2012 Research Assistant Univ. of Miami Rosenstiel School of Marine & Atmospheric Science

PUBLICATIONS

Lopez A.M., Lee C.M., Mohammed I.N., Hestir E.L., and Harmon T.H. (2022b). Woolsey Fire Impacts on Coastal Water Quality in Southern California. *In Preparation.*

Lopez A.M., Fitzsimmons J.N., and Jensen C.C. (2022a) Lead isotopes and heavy metal concentrations in Galveston Bay oyster tissues (Crassostrea virginica): Implications for estuarine heavy metal cycling. *In Preparation.*

Lopez A.M., Fitzsimmons J.N., Dellapenna T.M., Adams H.A., and Brandon A.D. (2021b) A time-series of heavy metal geochemistry in sediments of Galveston Bay estuary, Texas, 2017-2019. *Science of the Total Environment* 806(2022): 150446.

Lopez A.M., Brandon A.D., Ramos F.C., Fitzsimmons J.N., Dellapenna T.M., and Adams H.A. (2021a) Lead geochemistry of sediments in Galveston Bay estuary, Texas. *Environmental Advances* 4: 100057.

Mulcan A., Mitsova D., Hindle T., Hanson H., and Coley C. (2015) Marine benthic habitats and seabed suitability mapping for potential ocean current energy siting offshore southeast Florida. *Journal of Marine Science and Engineering* 3(2): 276-298.

Wdowinski S., Hong S.H., **Mulcan A**., and Brisco B. (2013) Remote sensing monitoring of tide propagation through coastal wetlands. *Oceanography* 26(3): 64-69.

Brian von Herzen, Ph.D.

3 Little Harbor Road, Woods Hole, MA 02543,
+1-650-942-9630 Brian@ClimateFoundation.org

Education

1989 Doctor of Philosophy, Engineering and Applied Science Division, Computer Science, Planetary Sciences, Caltech, Supervisor: Prof. Alan H. Barr.
1984 Master of Science, Caltech
1980 Bachelor of Arts in Physics, Princeton University
Thesis: The Response of Global Climate Models to Orbital Variations

Experience

2020-2021 **Board Member**, C-Combinator
2019-2021 Board Member- Prime Coalition
2016-pres. **Advisory Board Member**, UCSF Center for cellular construction CCC
2013-pres. **Guest Lecturer**, Stanford University, Caltech, Marine Biological Laboratory
2010-pres. **Board Member**, Bright Energy Storage Technologies, LLC
2007-pres. **Executive Director**, Climate Foundation
1994-2017 **CEO**, Rapid Prototypes, Inc.
1992-1994 **Machine Learning Applications Lead**, Synaptics, Inc.
1989-1992 **Principal Investigator**, Caltech Submillimeter Observatory
1977-1980 **Research Analyst**, Geology and Geophysics, Woods Hole Oceanographic Inst.

Selected Publications, Video, Public Outreach

2022 Restoring Healthy Climate, Peter Fiekowsky et al., Marine Permaculture Chapter 4
2021 Regeneration, Paul Hawken, SeaForestation Section, p.22
2019 FEATURE DOCUMENTARY / 2040: The Regeneration / Directed by Damon Gameau
2019 2040 / Seaweed: The Regeneration / Crowdfunding campaign, raised AU$663,911
2017 Drawdown, Paul Hawken, editor, 100 best ways to restore carbon balance on the planet, Marine Permaculture, Drawdown.org, April 18, 2017, pp. 178-180.
2016 National Geographic, From Seaweed to Fish Feed, How Aquaculture Meets the Future,
2016 Harvard University, Guest Lecture, Biodiversity for a Livable Climate, Ocean Permaculture,
2015 Stanford University, Guest Lecture, "Balancing Gigatons of Carbon in Soils and Seas,"
2014 Biochar processing to restore soils and provide Sanitation in developing nations,
2014 US Biochar Initiative, Large-Scale Biochar Devices processing high-moisture feedstock,
2014 Bill and Melinda Gates Foundation Reinvent the Toilet Fair, New Delhi, India, Biochar reactor for human waste processing,
2013 Hertz Fellow Brian von Herzen,
2012 Reversing coral bleaching in two species of Acropora on reefs in American Samoa, International Coral Reef Symposium 2012, Cairns, Australia.
2009 Restoring overturning circulation and CO2 recycling using wave-driven ocean pumps,
2008 Lead Scientist, Discovery Channel documentary, "Project Earth: Hungry Oceans,"

Selected Awards

2022 Elon Musk Milestone XPRIZE for Carbon Removal Hertz Fellow, Edmund Hillary Fellowship, Hughes Doctoral Fellowship, Advanced Standing, Princeton University

Dr. von Herzen is an inventor on 31 US Patents, with an additional 10 Patents Pending

Selected Patent Numbers	**Titles**
10,364,938	Underwater energy storage using compressed fluid
9,733,230	Multi-modal fluid condition sensor platform and system therefor
9,022,692	System for underwater compressed fluid energy storage and method of deploying same
7,567,702	Data processing system and method
7,066,023	Distributed sensor array for fluid contaminant monitoring

Dimitris MENEMENLIS
Jet Propulsion Laboratory, California Institute of Technology
Mail Stop 300-323, 4800 Oak Grove Dr., Pasadena CA 91109, U.S.A.
Tel: 818–354–1656, E-mail: menemenlis@jpl.nasa.gov

Relevant Experience:

25+ years of experience working with ocean circulation models and state estimation technology. Developer of Massachusetts Institute of Technology general circulation model (MITgcm) and contributor to Estimating the Circulation and Climate of the Oceans (ECCO) and Carbon Monitoring System Flux (CMS-Flux) projects.

Appointments:

Jet Propulsion Laboratory	Research Scientist	1998 to present
Massachusetts Institute of Technology	Research Scientist	1993 to 1998

Education:

Univ. Victoria, British Columbia	Electrical Engineering	Ph.D., 1993
Waterloo Univ., Ontario	Electrical Engineering	M.A.Sc., 1987
McGill Univ., Montreal, Quebec	Electrical Engineering	B.Eng. Honours, 1984

Selected Relevant Publications:

Chandanpurkar, H. A., T. Lee, X. Wang, H. Zhang, S. Fournier, I. Fenty, I. Fukumori, D. Menemenlis, et al. 2022. "Influence of Nonseasonal River Discharge on Sea Surface Salinity and Height." *Journal of Advances in Modeling Earth Systems* **14**: 1–27.

Sulpis, O., M. Humphreys, M. Wilhelmus, D. Carroll, W. Berelson, D. Menemenlis, et al. 2022. RADIv1: a non-steady-state early diagenetic model for ocean sediments in Julia and MATLAB/GNU Octave. *Geoscientific Model Development* **15**: 2105–2131.

Carroll, D., D. Menemenlis, S. Dutkiewicz, J. Lauderdale, J. Adkins, K. Bowman, H. Brix, I. Fenty, et al. 2022. "Attribution of Space-Time Variability in Global-Ocean Dissolved Inorganic Carbon." *Global Biogeochem. Cycles* **36**: 1–24.

Liu, J., L. Baskaran, K. Bowman, D. Schimel, A., Bloom, N. Parazoo, T. Oda, D. Carroll, D. Menemenlis, et al. 2021. "Carbon Monitoring System Flux Net Biosphere Exchange 2020 (CMS-Flux NBE 2020)." *Earth System Science Data*: **13**: 299–330.

Feng, Y., D. Menemenlis, et al. 2021. "Improved representation of river runoff in Estimating the Circulation and Climate of the Ocean Version 4 (ECCOv4) simulations: implementation, evaluation, and impacts to coastal plume regions." *Geoscientific Model Development* **14**: 1801–1819.

Carroll, D., D. Menemenlis, J. Adkins, K. Bowman, et al. 2020. "The ECCO-Darwin Data-Assimilative Global Ocean Biogeochemistry Model: Estimates of Seasonal to Multidecadal Surface Ocean pCO_2 and Air-Sea CO_2 Flux. *Journal of Advances in Modeling Earth Systems* **12**: 1–28.

Manizza, M., D. Menemenlis, H. Zhang, and C.E. Miller. 2019. "Modeling the Recent Changes in the Arctic Ocean CO_2 Sink (2006–2013)." *Global Biogeochem. Cycles* **33**: 420–38.

Van der Stocken, T., D. Carroll, D. Menemenlis, D., Simard, M., & Koedam, N. (2019). Global-scale dispersal and connectivity in mangroves. Proceedings of the National Academy of Sciences, 116(3), 915–922. https://doi.org/10.1073/pnas.1812470116D.

Hutter, N., M. Losch, and D. Menemenlis. 2018. "Scaling Properties of Arctic Sea Ice Deformation in a High-Resolution Viscous-Plastic Sea Ice Model and in Satellite Observations." *J. Geophys. Res.* **123**: 672–87.

Fenty, I.G., D. Menemenlis, and H. Zhang. 2017. "Global Coupled Sea Ice-Ocean State Estimation." *Climate Dynamics* **49**: 931–56.

Spreen, G., R. Kwok, D. Menemenlis, and A.T. Nguyen. 2017. "Sea-Ice Deformation in a Coupled Ocean-Sea-Ice Model and in Satellite Remote Sensing Data." *The Cryosphere* **11**: 1553–73.

Brix, H., D. Menemenlis, C. Hill, S. Dutkiewicz, et al. 2015. "Using Green's Functions to Initialize and Adjust a Global, Eddying Ocean Biogeochemistry General Circulation Model." *Ocean Model.* **95**: 1–14.

Ott, L., S. Pawson, J. Collatz, …, D. Menemenlis, et al. 2015. "Assessing the Magnitude of CO_2 Flux Uncertainty in Atmospheric CO_2 Records Using Products from NASA's Carbon Monitoring Flux Pilot Project." *J. Geophys. Res.* **120**: 734–65.

Manizza, M., M. Follows, S. Dutkiewicz, D. Menemenlis, C. Hill, and R. Key. 2013. "Changes in the Arctic Ocean CO2 Sink (1996–2007): A Regional Model Analysis." *Global Biogeochemical Cycles* **27**: 1108–18.

Manizza, M., M. Follows, S. Dutkiewicz, D. Menemenlis, J. McClelland, C. Hill, B. Peterson, and R. Key. 2011. "A Model of the Arctic Ocean Carbon Cycle." *J. Geophys. Res.* **116**: C12020.

Manizza, M., M. Follows, S. Dutkiewicz, …, D. Menemenlis, et al. 2009. "Modeling Transport and Fate of Riverine Dissolved Organic Carbon in the Arctic Ocean." *Global Biogeochem. Cycles* **23**: GB4006.

Gruber, N., M. Gloor, S. Mikaloff Fletcher, S. Doney, S. Dutkiewicz, …, D. Menemenlis, et al. 2009. "Oceanic Sources, Sinks, and Transport of Atmospheric CO2." *Global Biogeochem. Cycles* **23**: GB1005.

Menemenlis, D., J. Campin, P. Heimbach, C. Hill, T. Lee, A. Nguyen, et al. 2008. "ECCO2: High Resolution Global Ocean and Sea Ice Data Synthesis." *Mercator Ocean Quarterly Newsletter* **31**: 13–21.

6 Table of Personnel and Work Efforts

Table of Work Effort

Name	Role	Commitment (months per year)											
		Year 1			Year 2			Year 3			Sum		
		This Project		Other Funded Projects	This Project		Other Funded Projects	This Project		Other Funded Projects	This Project		Other Funded Projects
		NASA Support	Total		NASA Support	Total		NASA Support	Total		NASA Support	Total	
Carmen Blackwood	PI	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	0	7.2	7.2	7.2
Manfredi Manizza	Co-I	4	4	8	4	4	8	4	4	8	12	36	24
Christine Lee	Co-I	7.2	7.2	4.8	7.2	7.2	4.8	7.2	7.2	4.8	21.6	21.6	14.4
Amanda Lopez	Co-I	3	3	9	10.2	0	0	4.8	4.8	0	18	18	0
Kyle Cavanaugh	Co-I	1	1	2	1	1	2	1	1	2	3	3	6
Brian Von Herzen	Co-I	1	1	11	1	1	11	1	1	11	3	3	33
Dimitris Menemenlis	Co-I	1.2	1.2	10.8	0.6	0.6	11.4	0.6	0.6	11.4	2.4	2.4	33.6
Sum of work effort:		**19.6**	**19.6**	**48.2**	**24.4**	**24.4**	**39.6**	**21**	**21**	**37.2**	**65**	**65**	**125**
Comments:													

Total - The total number of months that will be committed to this project by the team member (including time not funded by this proposal and time funded by this proposal).
NASA Support - The number of months committed to this project that will actually be funded by this proposal.
Other Funded Projects - The number of months that are committed to other currently funded proposals.

7 Current and Pending Support

Current and Pending Support	
The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.	
Investigator: Carmen Blackwood	Other agencies (including NASA) to which this proposal has been/will be submitted.
Support: ☒ Current ☐ Pending Project / Proposal Title: A NASA Web Portal for Sea Level Change PI: Carmen Blackwood Source of Support: NASA PO, Nadya Vinogradova-Shiffer, nadya@nasa.gov Total Award Period Covered: 2020 - 2024 Person-Months Per Year Committed to the Project: 2.4	
Support: ☐ Current ☒ Pending Project / Proposal Title: USDA-NIFA AI Institute: Multi-domain AI for Climate-smart Agriculture (MAICA) PI: Bingbing Li Source of Support: NSF/USDA Total Award Period Covered: June 2023 – September 2027 Person-Months Year Committed to Project: 2.16	

Current and Pending Support

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Kyle Cavanaugh	Other agencies (including NASA) to which this proposal has been/will be submitted.

Support: ☒ Current ☐ Pending
Project/Proposal Title: Scalable Aquaculture Monitoring System - SAMS

Source of Support: DOE/ARPA-E
Total Award Period Covered: 5/1/2018 - 4/30/2022 (pending NCE approval); Total Award: $277,831
Person-Months Per Year Committed to the Project: 0.25 (Calendar)
Program Contact: Marc G. Von Keitz, marc.vonkeitz@hq.doe.gov, (202) 287-5513

Support: ☒ Current ☐ Pending
Project/Proposal Title: Using Citizen Science to Understand Thirty Years of Change in Global Kelp
Expanding the Zooniverse to NASA Satellite Imagery

Source of Support: NASA/UMass
Total Award Period Covered: 6/29/2018 - 6/28/2022; Total Award: $284,272
Person-Months Per Year Committed to the Project: 0.5 (Calendar)
Program Contact: Kevin James Murphy, kevin.j.murphy@nasa.gov, (202) 358-3042

Support: ☒ Current ☐ Pending
Project/Proposal Title: Remote Sensing of Kelp Dynamics

Source of Support: The Nature Conservancy
Total Award Period Covered: 10/4/2021 – 8/31/2022; Total Award: $66,744
Person-Months Per Year Committed to the Project: 1.0 (Calendar)
Program Contact: Vienna Saccomanno, v.r.saccomanno@tnc.org

Support: ☒ Current ☐ Pending
Project/Proposal Title: Vulnerability of Giant Kelp Populations to Climate Change

Source of Support: NASA/Woods Hole Oceanographic Institution
Total Award Period Covered: 6/29/2021 – 6/28/2024; Total Award: $279,306
Person-Months Per Year Committed to the Project: 0.5 (Calendar)
Program Contact: Tom Bell, tbell@whoi.edu, (617) 857-1233

Support: ☒ Current ☐ Pending
Project/Proposal Title: Restoring Rocky Intertidal Foundation Species Across California

Source of Support: California Ocean Protection Council/UCSB
Total Award Period Covered: 4/5/2020 – 3/30/2024; Total Award: $44,284
Person-Months Per Year Committed to the Project: 0.25 (Calendar)
Program Contact: Robert J. Miller, miller@msi.ucsb.edu, n/a

Support: ☒ Current ☐ Pending
Project/Proposal Title: Global Mangrove Forest Degradation Hotspots

Source of Support: NASA
Total Award Period Covered: 1/1/2021 – 12/31/2023; Total Award: $170,579

Person-Months Per Year Committed to the Project: 0.5 (Calendar)
Program Contact: Garik Gutman, ggutman@nasa.gov, (202) 358-0276

Current and Pending Support

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.	
Investigator: Amanda Mulcan Lopez	Other agencies (including NASA) to which this proposal has been/will be submitted.
Support: ☒ Current ☐ Pending Project/Proposal Title: Wildfires and Coastal Water Quality (Proposal Title “Impacts of Wildfires on Columbia River Discharge and Coastal Water Quality”) Source of Support: NASA Postdoctoral Program Fellowship Total Award Period Covered: July 12, 2021 – July 11 2023 Person-Months Per Year Committed to the Project: 12	

Current and Pending Support

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Christine Lee	Other agencies (including NASA) to which this proposal has been/will be submitted.

Support: ☐ Current ☒ Pending
Project / Proposal Title: Predicting fire risk from plant stress in Amazonia
PI: Madeleine Pascolini-Campbell
Source of Support: NASA SERVIR, Nancy Searby, nancy.d.searby@nasa.gov
Total Award Period Covered: December 2022-January 2026
Person-Months Per Year Committed to the Project: 0.5

Support: ☐ Current ☒ Pending
Project / Proposal Title: Tracking and quantifying the cooling impacts of smart surfaces to improve community resilience to extreme heat in a changing climate
PI: Glynn Hulley
Source of Support: NASA Environmental Justice, Nancy SEraby, nancy.d.searby@nasa.gov
Total Award Period Covered: September 2022 – October 2025
Person-Months Year Committed to Project: 0.5

Support: ☒ Current ☐ Pending
Project/Proposal Title: **Wildfire Impacts on Watershed Transport of Carbon to Coasts**

PI: Erin Hestir, UC Merced
Source of Support: NASA Carbon Cycle Science, Ocean Biology and Biogeochemistry, Laura Lorenzoni, laura.lorenzoni@nasa.gov
Total Award Period Covered: July 2021-June 2024
Person-Months Per Year Committed to the Project: 1

Support: ☒ Current ☐ Pending
Project/Proposal Title: **Climate-induced Nutrient Flows and Threats to Biodiversity of Belize Barrier Reef**
PI: Robert Griffin, UAH
Source of Support: NASA Ecological Forecasting, Woody Turner, woody.turner@nasa.gov
Total Award Period Covered: October 2018 – September 2022
Person-Months Per Year Committed to the Project: 1.5

Support: ☒ Current ☐ Pending
Project/Proposal Title: **Evaluating CONUS-wide disALEXI Evapotranspiration Product**

PI: Kerry Cawse-Nicholson
Source of Support: NASA ECOSTRESS Science Team, Woody Turner, woody.turner@nasa.gov
Total Award Period Covered: October 2019-September 2022
Person-Months Per Year Committed to the Project: 0.5

Support: ☒ Current ☐ Pending
Project/Proposal Title: **ECOSTRESS Surface Temperature Over Inland Waters for Aquatic Ecosystem Applications**
PI: Christine Lee
Source of Support: NASA ECOSTRESS Science and Applications Team, Woody Turner, woody.turner@nasa.gov
Total Award Period Covered: October 2019-September 2022

Person-Months Per Year Committed to the Project: 1

Support: ☐ Current ☒ Pending
Project/Proposal Title**: Application of UAV and satellite based optical sensors to help preserve coral reefs of USVI**
PI: Tyler Burton Smith (Univ VI)
Source of Support: NASA EpSCOR, Mitchel Krell (mitch,krell@nasa.gov)
Total Award Period Covered: Jan 2023 – Dec 2025
Person-Months Per Year Committed to the Project: 0.5

Current and Pending Support

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Manfredi Manizza

Other agencies (including NASA) to which this proposal has been/will be submitted. None

Support: [x] Current [ ] Pending
Project/Proposal Title: Impacts of Changing Sea-Ice Regime on Arctic Ocean Biology
Source of Support: JPL
Total Award Period Covered: 7/1/20-6/30/23
Person-Months Per Year Committed to the Project: 3/3/3

Support: [x] Current [ ] Pending
Project/Proposal Title: Physical and biological controls on ocean carbon and oxygen uptake in the western North Pacific
Source of Support: NSF
Total Award Period Covered: 9/1/21-8/31/24
Person-Months Per Year Committed to the Project: 4/4/12

8 Statements of Commitment and Letters of Support

UNIVERSITY OF CALIFORNIA, SAN DIEGO UCSD

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INTEGRATIVE OCEANOGRAPHY DIVISION
SCRIPPS INSTITUTION OF OCEANOGRAPHY

9500 GILMAN DRIVE
LA JOLLA, CALIFORNIA 92093-0209
(858) 534-4333
(858) 534-0300 FAX

May 12, 2022

Dr. Carmen Blackwood
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA

Dear Dr. Blackwood,

Scripps Institution of Oceanography, University of California San Diego will provide partial academic support to during my collaboration with the project “Building a model for regenerative kelp cultivation in coastal oceans” should the proposal be selected by NASA. This support includes an academic office and access to computer facilities and will be available during the academic calendar years from 9/1/22 until 8/31/25.

Sincerely,

James J. Leichter

Prof. James Leichter
Scripps Institution of Oceanography
University of California San Diego

UNIVERSITY OF CALIFORNIA, LOS ANGELES **UCLA**

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PHONE: (310) 794-0102
FAX: (310) 794-0631
www.research.ucla.edu/ocga

May 12, 2022

Carmen Blackwood
Jet Propulsion Lab

Reference: Prime Sponsor: NASA

Dear Ms. Blackwood,

The Regents of the University of California, on behalf of the Los Angeles campus (UCLA), is pleased to submit the following proposal:

Title:	Building a model for regenerative kelp cultivation in coastal oceans
Period of Performance:	10/17/2022 – 10/16/2023
Amount Requested:	[redacted]
UCLA Principal Investigator:	Prof. Kyle Cavanaugh

This proposal is being submitted in contemplation of an agreement containing mutually agreeable terms and conditions applicable to educational institutions conducting unclassified fundamental research.

Should an award be made, kindly forward notification and/or an award agreement to awards@research.ucla.edu and reference UCLA internal number **20224827**. Technical questions should be directed to the UCLA Principal Investigator. Administrative or contractual questions should be directed to me at (310) 794-0393 or via email at yessenia.sarmiento@research.ucla.edu.

Sincerely,

DocuSigned by:
Yessenia Sarmiento
41CB935C87DF427...
Yessenia Sarmiento
Contract and Grant Officer
Office of Contract and Grant Administration
University of California, Los Angeles

9 Budget Justification

9.1 Budget Narrative

9.1.1 Rationale and Basis of Estimate

The "Building a model for regenerative kelp cultivation in coastal oceans" cost proposal was prepared using JPL's pricing/accounting system, which has been reviewed and approved by the DCAA. The rates applied in this proposal are JPL's current published rate set (version FY22-3), dated January 6, 2022.

The derivation of the cost estimate is a grassroots methodology based on the expert judgment from a team of experienced individuals who have performed similar work. The team provides the necessary relevant experience to develop a credible and realistic cost estimate. The cognizant individuals identify and define the products and the schedule needed to complete the tasks for each work element. The team developed the grassroots estimate using estimating methods and techniques (analogy, vendor quotes, historical experience) appropriate for each element of work. These methods are used to generate the detailed schedule and resource estimates for labor, procurements, travel, and other direct costs for each work element. The resource estimates are aggregated and priced using JPL's pricing/accounting system. JPL's process assures that lower-level estimates are developed and reviewed by the performing organizations and their management who will be accountable for successfully completing the proposed work scope within their estimated cost.

As of proposal submission, NASA SMD's open source policy set forth in SPD-41 dated August 4, 2021 is not included under Contract 80NM0018D0004 between NASA and Caltech/JPL. Therefore, JPL will perform the proposed work in accordance with SPD-41 on a best effort basis, and this proposal may not include cost for full compliance with SPD-41.

9.2 Budget Details – Year 1

Direct Labor – Year 1

- Dr. Carmen Blackwood is the PI and will oversee all aspects of the proposed work. She will support the satellite analysis and ocean model development and coordinate and facilitate exchanges between team members and tasks. Time Commitment is 0.30 wy
- Dr. Christine Lee, Co-I, will prepare datasets for the regional analysis and start the analysis of relationships between turbidity and kelp. She will also introduce Co-I Lopez to Time Commitment is 0.3 wy
- Dr. Amanda Lopez, Co-I, will set up the SWAT model and start working with Co-I Lee on the satellite data analysis. Time Commitment is 0.25 wy
- Dr. Dimitris Menemenlis, Co-I, will support the ocean model algorithm development. Time Commitment is 0.1 wy

Other Direct Costs – Year 1

Subawards:

- Subaward to Scripps Institution of Oceanography for Dr. Manfredi Manizza. Time Commitment is 0.3 wy.
- Subaward to UCLA for Dr. Kyle Cavanaugh. Time Commitment is 0.08 wy.
- Subaward to the Climate Foundation for Dr. Brian Von Herzen. Time Commitment is 0.08 wy.
- Desktop Network Chargebacks (calculated at $5.17/hr.): All JPL computers are subject to a monthly service charge that includes hardware, software, and technical support. ($9.1K)

Consultants:

- There are no consultants required for this task.

Equipment:

- There are no major equipment purchases necessary.

Services:

- There are no major equipment purchases necessary.

Supplies and Publications:

- There are no Supplies and Publications necessary.

Travel:

- There are no travel purchases necessary.

Total Redacted Costs Year 1: $9.1K

9.3 Budget Justification: Details – Year 2

Direct Labor – Year 2

- Dr. Carmen Blackwood will continue to oversee all aspects of the proposed work and facilitate team discussions and exchanges. She will also support the ocean model evaluation. Time Commitment is 0.2 wy
- Dr. Christine Lee will serve as a Co-Investigator. Time Commitment is 0.1 wy
- Dr. Amanda Lopez will design and run the SWAT model experiments. She will also work with Co-I Lee on the satellite data analysis. Time Commitment is 0.75 wy
- Dr. Amanda Lopez will work with Co-I Lee on the satellite data analysis. Time Commitment is 0.1 wy
- Dr. Dimitris Menemenlis will continue to support the ocean model development tasks. Time Commitment is 0.05 wy

Other Direct Costs – Year 2

Subawards:

- Subaward to Scripps Institution of Oceanography for Dr.Manfredi Manizza. Time Commitment is 0.30 wy
- Subaward to UCLA for Dr. Kyle Cavanaugh. Time Commitment is 0.08 wy.
- Subaward to the Climate Foundation for Dr. Brian Von Herzen. Time Commitment is 0.08 wy.
- Desktop Network Chargebacks (calculated at $5.17/hr.): All JPL computers are subject to a monthly service charge that includes hardware, software, and technical support. ($11.9K)

Consultants:

- There are no consultants required for this task.

Equipment:

- There are no major equipment purchases necessary.

Services:

- There are no major services necessary.

Supplies and Publications:

- Publication and Documentation: Miscellaneous publication and documentation charges ($4K)

Travel:

- The PI and Co-I will travel to the AGU, San Francisco, California, to participate in a conference for five days. ($6K)
- The PI and Co-I will travel to the EGU, Vienna, Austria, to participate in a conference for five days. ($10K)

Total Redacted Costs Year 2: $31.9K

9.4 Budget Justification: Details – Year 3

Direct Labor – Year 3

- Dr. Carmen Blackwood will continue to oversee all aspects of the proposed work. She will facilitate the analysis of the regional and local model outputs. She will lead and support the publication of the study's results. She will also organize the final project workshop. Time Commitment is 0.2 wy.
- Dr. Christine Lee will continue to support the interpretation of results from the regional and local analysis of turbidity impacts. Time Commitment is 0.1 wy.
- Dr. Amanda Lopez will support the analysis of the regional and local studies, in particular, the wildfire impacts on the local watershed and subsequently on kelp. Time Commitment is 0.4 wy.
- Dr. Dimitris Menemenlis will support ocean modeling effort. Time Commitment 0.05 wy.

Other Direct Costs – Year 3

Subawards:

- Subaward to Scripps Institution of Oceanography for Dr. Manfredi Manizza. Time Commitment is 0.3 wy.
- Subaward to UCLA for Dr. Kyle Cavanaugh. Time Commitment is 0.08 wy.
- Subaward to the Climate Foundation for Dr. Brian Von Herzen. Time Commitment is 0.08 wy.
- Desktop Network Chargebacks (calculated at $5.17/hr.): All JPL computers are subject to a monthly service charge that includes hardware, software, and technical support. ($7.1K)

Consultants:

- There are no consultants required for this task.

Equipment:

- There are no major equipment purchases necessary.

Services:

- There are no major services purchases necessary.

Supplies and Publications:

- Publication and Documentation: Miscellaneous publication and documentation charges ($4K)

Travel:

- The PI and Co-I will travel to the AGU, Washington DC, to participate in a conference for five days. ($6.5K)
- The PI and Co-I will travel to the EGU, Vienna, Austria, to participate in a conference for five days. ($10K)
- The PI and three Co-Is will travel to Washington DC, to participate in end of the period of performance workshop for two days. ($5.5K)

Total Redacted Costs Year 3: $33.1K

10 Facilities and Equipment

Facilities and equipment will be available for this research. The PI and all Co-Is have adequate laboratory, office, and conference space sufficient for students, collaborators and PI meetings.

10.1 Jet Propulsion Laboratory

Dr. Lopez will have access to a Windows OS laptop or desktop workstation, which is sufficient for running SWAT and SWATCUP. SWAT is the modeling software that works with the ESRI ArcGIS platform. SWATCUP is the calibration-validation software for the SWAT model output. Satellite data and model output analyses will be performed on local workstations and laptops. Dr. Menemenlis has access to the NASA Advanced Supercomputing Center through the ECCO project.

10.2 University of California San Diego/Scripps Institution of Oceanography

Local Computer Facilities: Computer facilities for processing, management, analysis of model output and data processing are available at SIO to Dr. Manizza. Dr. Manizza normally uses the workstation that he has in his office to remotely analyze the model output stored at the NASA machine where he runs the ECCO-Darwin model. He remotely uses the same machine for the coding work necessary to prepare model runs and perform numerical simulations to assist in the significant model output to be generated in the proposed research,

High Performance Computing (HPC) Facilities: Dr. Manizza has an active account at the NASA Advanced Supercomputing center (www.nas.nasa.gov) where he currently uses the Pleaides machine to run his jobs of ECCO-Darwin for the currently funded projects on global, tropical, and polar oceans biogeochemistry. For this project he will continue to access the code and output on the same system therefore we do not have to request to activate a new account at NASA AMES while additional disk space will be requested for storing the output during the project development.

10.3 University of California, Los Angeles (UCLA)

Satellite data analyses will be performed on local workstations and laptops. Dr. Cavanaugh has adequate equipment and resources to support the data analysis effort and advise the team and attend team meetings.

10.4 Climate Foundation

Dr. Von Herzen has adequate equipment and resources to support and advise the team and attend team meetings.