Amendment Extending the Agreement Between the Orange County Sanitation District and Southern California Coastal Water Research Project Regarding Ocean Outfall Plume Modeling

This Amendment ("Amendment") Extending the Agreement Between the Orange County Sanitation District and Southern California Coastal Water Research Project Regarding Ocean Outfall Plume Modeling dated October 24, 2018 (the "Agreement") is entered into by the Orange County Sanitation District ("OC San") and Southern California Coastal Water Research Project ("SCCWRP") as of November 17, 2021 on the terms described below. OC San and SCCWRP are referred to individually as a "Party" and collectively as "Parties."

Recitals

A. OC San requires the services of SCCWRP to model OC San's ocean outfall plume, to provide environmental assessments of OC San's existing and post-GWRS Final Expansion discharges, which assists to ensure compliance with Ocean Plan standards.

B. Per the Regional Water Quality Control Board, OC San is required to participate in Bight'13, a large co-operative regional monitoring component, as a condition to OC San's NPDES ocean discharge permit.

C. A coupled physical-biogeochemical model (ROMS-BEC) is used by SCCWRP in this process. No other system exists for Bight' 13 that can perform the level of resolution needed for OC San staff and managers and local, state, and federal environmental managers to evaluate OC Sans existing and future ocean discharges to optimize OC San's monitoring program in future permit renewal cycles.

D. SCCWRP is the lead agency, funded by the state and federal governments, which has developed and applied ROMS-BEC to model present conditions and predict future conditions including investigations on the effect of anthropogenic nutrient inputs on ocean water quality.

E. Contracting with SCCWRP provides OC San with the opportunity to leverage outside funds exceeding $4 million and create focused modeling to provide additional context and support for environmental impact assessment that will be readily accepted at both the state and federal level.

F. In light of the foregoing recitals, OC San and SCCWRP entered into the above-described Agreement for an initial three-year term expiring November 18, 2021.

G. OC San and SCCWRP, by this Amendment, wish to continue the Agreement for an additional term of approximately three years, through and including December 31, 2024.

Amendment

Therefore, OC San and SCCWRP agree as follows:

1. **Extension of Agreement**. The Agreement is hereby extended through and including **December 31, 2024**, unless sooner terminated.

2. **Compensation**. Additional compensation to SCCWRP under this Amendment shall not exceed One Hundred Thirty-Five Thousand Dollars (**$135,000**).

3. **Scope of Work**. During the term of this Amendment, and notwithstanding Paragraph 1 of the Agreement, SCCWRP will complete the following scope of work:

   (a) Validate ROMS simulations of the OC San modified outfall against available observations and conduct a model ensemble comparison with the RSB model.

   (b) Utilize the validated ROMS model to investigate how different stages of GWRS operation alters the resulting wastewater plume visitation frequency and dispersal**.**

   (c) Investigate the effect of GWRS Final Expansion on seasonality of the plume distribution with varying ocean conditions using realistic ROMS forcing between 1997 and 2017.

   (d) Synthesize the findings in a draft and final report, including recommendations for a suite of monitoring elements to assess dispersal of the effluent plume.

4. **Prior Agreement Remains in Effect**. All other terms of the Agreement shall remain in full force and effect.

5. **Entire Agreement**. The Agreement, as modified by this Amendment, constitutes the entire understanding between the parties and supersedes all prior negotiations or agreements between them pertaining to the subject matter hereof.

IN WITNESS WHEREOF, these Parties have executed this Amendment on the day and year shown below.

[SIGNATURE PAGE FOLLOWS]

ORANGE COUNTY SANITATION DISTRICT

Date: ____________________ By: ____
John B. Withers
Chair, Board of Directors

ATTEST:

Date: ____________________ By: _______________________________
Kelly A. Lore, MMC
Clerk of the Board

APPROVED AS TO FORM:

Date:______________________ By: ________________________________
Bradley R. Hogin
General Counsel

Date: ________________

SOUTHERN CALIFORNIA COASTAL WATER RESEARCH PROJECT

By____

Name:____

Title: ____

SOUTHERN CALIFORNIA COASTAL WATER RESEARCH PROJECT
A Public Agency for Environmental Research

George Robertson
Environmental Compliance Services
Ocean Monitoring Program Division
Orange County Sanitation District
10844 Ellis Avenue, Fountain Valley, CA 92708

August 12, 2021

RE: "Outfall Plume Modeling in Support of Orange County Sanitation District Water Reclamation Study"

Dear Mr. Robertson:

This letter is to submit to you the revised project titled "*Outfall Plume Modeling in Support of Orange County Sanitation District Water Reclamation Study.*"

The proposed study would provide technical support to evaluate the impact of implementation of Groundwater Replenishment System (GWRS) Final Expansion on the dispersion of the effluent plume of Orange County Sanitation District Ocean outfall under differing ocean circulation regimes.

If you have any questions, please contact me at (714) 755-3222 or marthas@sccwrp.org.

Sincerely,

Martha Sutula, Ph.D.

Principal Scientist, Biogeochemistry Department

Scope of Work

Outfall Plume Modeling in Support of Orange County Sanitation District Water Reclamation Study

1. Introduction

Orange County Sanitation District (OC San) discharges approximately 100 million gallons per day (MGD) of combined secondary and advanced primary treated wastewater from its outfall located at 55 m depth and approximately 8.2 km (5.1 miles) offshore of the Huntington Beach area, just north of the Santa Ana River. For the past 18 years, OC San and the Orange County Water District (OCWD) have partnered to enable the Groundwater Replenishment System (GWRS) to provide a drought-proof water supply for Orange County. OC San and OCWD have started planning for the GWRS Final Expansion, which supports OC San's strategic goal of maximizing water recycling and OCWD's goal to produce 130 MGD of purified recycled water. By supporting the GWRS Final Expansion, OC San will be able to recycle the majority of the wastewater generated in its service area and treated at its two wastewater treatment plants, thus reducing the volume discharged to the ocean outfall. While volume discharges are reduced, the mass loads of nutrient and other contaminants will stay constant, resulting in an effluent that is higher in concentrations of these contaminants of concern.

This scope of work details technical support that the Southern California Coastal Water Research Project Authority (SCCWRP) will provide to OC San to evaluate the impacts of implementation of GWRS Final Expansion and ocean state on effluent plume transport and dispersal.

Previous Work and Status of Ocean Modeling System

Two numerical modeling studies previously evaluated the nearfield mixing of the wastewater plume and the transport and deposition of its particulate material (SAIC, 2002). The Roberts-Snyder-Baumgartner (RSB) plume model was used to estimate time series of the following characteristics of the nearfield wastewater plume: depth to the top and bottom of plume and to the maximum concentration, the range of dilution of the plume, and the initial mixing length. The RSB model was calibrated from empirical relationships and its velocities fields approximated using observations from fixed level current meters, acoustic doppler current profilers (ADCPs), and a dispersion map of the material released by the OC San outfall. The particle model used the results of the nearfield model to estimate the vertical extent of the plume and combined this with one year of current profiles measured near the diffuser and the actual local bathymetry to simulate, and hence, estimate particle transport, settling and bottom accumulation of material having the effective size classes that occurred in the wastewater plume. These modeling studies were based on data collected in 1999-2000.

Previous studies have also used ocean model ROMS (Regional Ocean Model System) simulations to assess the 3-dimensional dispersal and dilution of urban wastewater effluents from subsurface outfalls for San Pedro and Santa Monica bays (Uchiyama et al., 2014) as well as Orange

County (Ho et al. 2017). UCLA has been leading the systematic development of the ROMS over the past decade (Shchepetkin and McWilliams, 2003, 2005, 2008, 2011) with a specific focus on the North American and South American West Coast regions (Marchesiello et al., 2003; Colas et al., 2012). ROMS solves the hydrostatic, free-surface primitive equations in three-dimensional (3D) curvilinear coordinates that exactly follow the bottom topography and coastline. It contains state-of-art, numerical algorithms that provide an accurate and stable representation of physical processes and allow for "nesting" of high-resolution sub-domains within larger domains. The UCLA group has successfully tested ROMS in various applications to regional circulations with strong upwelling and mesoscale eddies (Marchesiello et al., 2003; Capet et al., 2004, 2008; Dong et al., 2009; Colas et al., 2013, Renault et al., 2016). The current ROMS configuration consists of multiple nested model domains (Fig. 1) with an offline one-way nesting that downscales from 4 km horizontal resolution (USW4, green box in Fig. 1) of the U.S. West Coast with 60 vertical levels (Deutsch et al., 2021; Renault et al., 2021) to 1 km resolution (USSW1, blue box in Fig. 1) with 60 vertical levels for California state-wide (Kessouri et al., 2020), to 300m resolution (USSW03, red box in Fig. 1) for the southern California Bight with 50 vertical levels (Kessouri et al., 2021a, b) with a parameterization of point sources (Kessouri et al., 2021b; Sutula et al., 2021). Each solution has a topography that follows levels vertically stretched such that grid cell refinement occurs most strongly near the surface and the bottom.

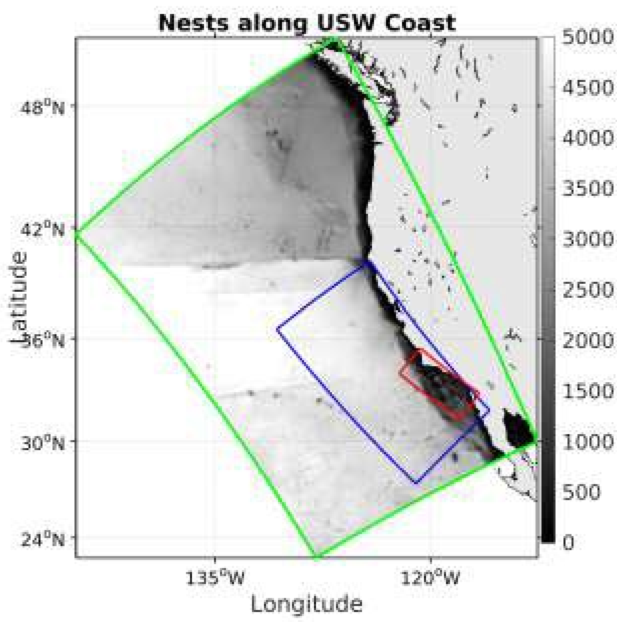


Figure 1. ROMS new generation of nests in the U.S. West coast. Green box is the 4km horizontal resolution grid (dx=4km), blue is dx=1km and red is dx=300m. (Kessouri et al 2021a, b).

Study Goals

The updated ROMS becomes a key tool to investigate the dispersion of the OC San wastewater plume as GWRS Final Expansion is implemented and to investigate the impact of varying ocean climate condition on plume transport. The goals of the proposed work are two-fold:

1) to provide an evaluation of the transport and fate of the plume and plume contaminants, based on available data, using the ROMS model, and 2) recommend a suite of monitoring elements to assess the impact of the modified effluent plume on ocean receiving waters in the context of climate change and to serve as a basis for modifying future NPDES-permit required sampling.

Scope of Work

The proposed scope of work consists of three distinct work elements:

Task 1. Validate ROMS simulations of the OC San modified outfall against available observations and conduct a model ensemble comparison with the RSB model.

Task 2. Utilize the validated ROMS model to investigate how different stages of GWRS operation alters the resulting wastewater plume visitation frequency and dispersal**.**

Task 3. Investigate the effect of GWRS Final Expansion on seasonality of the plume distribution with varying ocean conditions using realistic ROMS forcing between 1997 and 2017.

Task 4. Synthesize the findings in a draft and final report, including recommendations for a suite of monitoring elements to assess dispersal of the effluent plume.

A detailed task description, including deliverables, is given below.

Task 1. Validate ROMS simulations of the OC San modified outfall against observational data and conduct a model ensemble comparison with the RSB Model.

This task builds on the detailed validation of the ROMS model that is being conducted within the nearshore zone of the Southern California Bight (SCB), including the region of the OC San outfall. The purpose of this task is to utilize the observational data collected by SAIC in 1999-2000 and in 2007 to validate the model predictions of nearfield plume characteristics (nearfield wastewater plume: depth to the top and bottom of plume and to the maximum concentration, the range of dilution of the plume, and the initial mixing length) and the dispersion of wastewater contaminants, utilizing the ROMS in particle tracking mode to estimate Lagrangian dispersal. A model ensemble comparison will be made of the outputs of the ROMS model and SAIC models.

Deliverables:

Oral presentation of findings, with key graphs illustrating results of ROMS model validation

1. Electronic database of model output
2. Draft chapter summarizing findings

Task 2. Utilize the validated ROMS model to investigate how different stages of GWRS operation alters the resulting wastewater plume visitation frequency and dispersal.

ROMS will provide outputs of velocities (horizontal, u and v, and vertical, w), temperature, salinity, and density. An offline Lagrangian model will use these velocity fields to advect particles. Details of the Lagrangian model can be found in Dauhajre et al., 2019.

Realistic hourly effluent discharge from the OC San outfall will be input to the model for each scenario. We will also consider realistic discharge from other local outfalls and rivers in the SCB (Sutula et al., 2021) for every scenario because they can interact with and influence the effluent coming from OC San. Particles will be seeded in OC San effluent water masses to solely track its movement.

The goals of this task are to: 1) simulate the transport and fate of the modified OC San effluent plume with progressive stages of GWRS Final Expansion and to 2) explore the sensitivity of design and operation of GWRS on the plume dispersion**.** We will use the Lagrangian plume particle tracking tool to quantify plume visitation frequency over a period of 1 day and 3-days after release.

Plume visitation frequencies (Csanady 1983, SAIC 2002) will be mapped for 1-day plumes and 3-day plumes for all model simulations in Task 2 and 3.

- 1-day plumes are considered "fresh plume" with immediate close-to-outfall impacts and readily observable with CTD casts. The core monitoring program can reflect plume extent within this period.
- 3-day plumes are more diluted and have been observed during weak currents. The primary reason for selecting 3-day duration is to identify potential public health concerns based on stormwater health guidelines during wet weather (e.g., Arnold et al, 2017).
- Bacterial concentrations can be approximated based on particle density per grid cell.

The hourly GWRS discharge of the following phases will be simulated during the ocean base year 2000:

i. Pre-GWRS (2000)

ii. GWRS Phase 1 (2008)

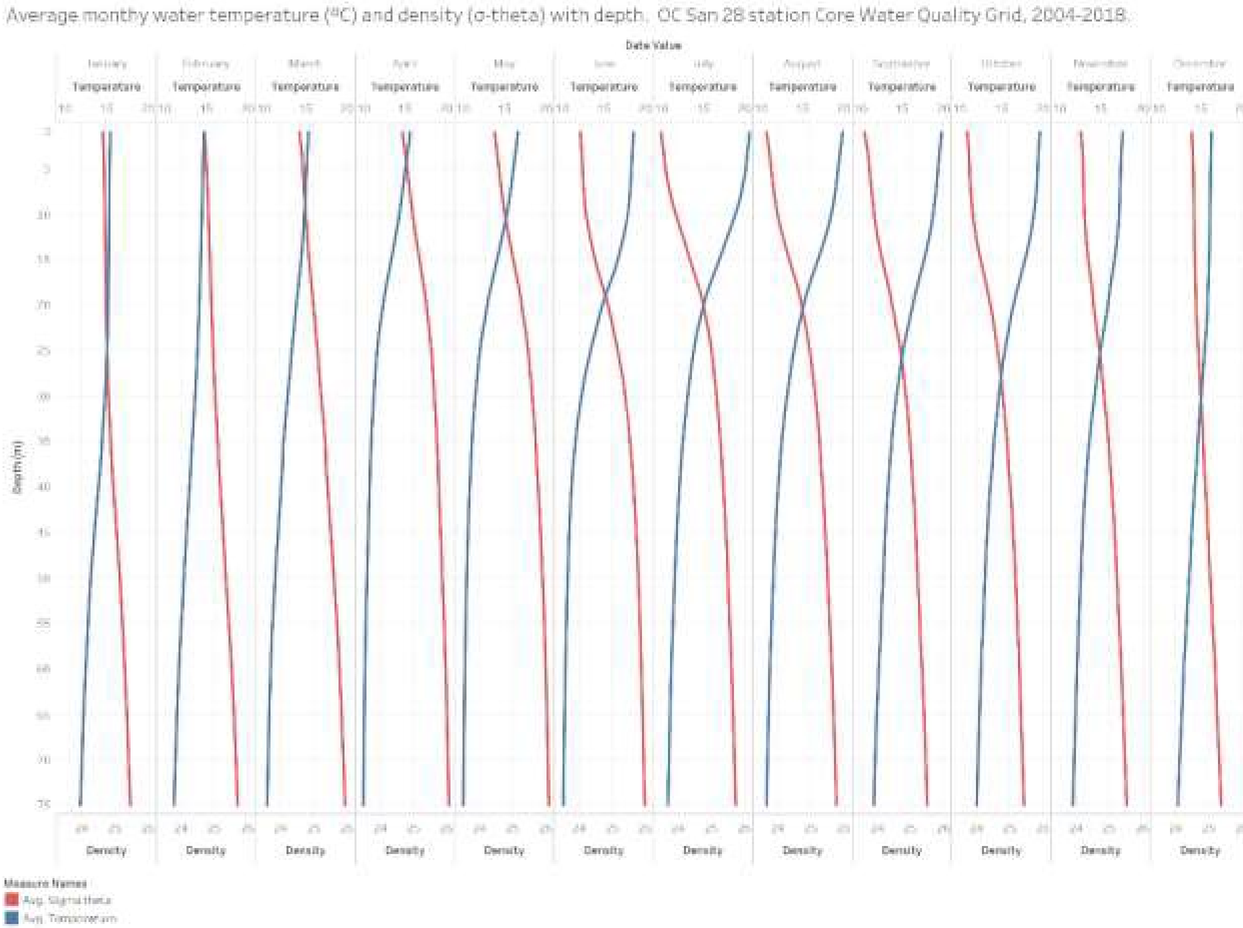
iii. GWRS Initial Expansion (2016)

iv. GWRS Final Expansion (estimated discharge for 2023)

The ocean base year 2000 is chosen because this year represents average conditions and no climate events. El Nino Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) are neutral. Sea surface temperature and the mixed layer depth (MLD) are average. This scenario will be completed in Task 2.

The plume statistical heatmaps will be applied on three seasons during the year 2000: winter (January/February) to characterize well mixed conditions, upwelling season (typically May/June, but may vary) to capture the maximum contribution of the vertical motion from upwelling, and summer (July/August) to characterize the most stratified season. These periods have been derived from in situ OC San monitoring (Fig. 2) and ROMS-BEC modeling results (BEC was only used to identify the impact on productivity; as an example of nitrogen utilization, like a passive indicator that is impacted by different climate phases, Fig 4 (supporting information).).

Figure 2. Monthly climatology of observed temperature and density profiles. Provided by OC San.



The suite of scenarios of interest, the final list of parameters assessed with environmental impact, and sensitivity analyses prioritized will be identified in a work plan, revised from the 2018 version based on discussions with the OC San project manager. Work will proceed once the revised work plan has been approved by the OC San project manager.

Deliverables:

2.1. Revised workplan outline agreed upon scenarios, plume visitation duration, and key graphics.

2.2. Oral presentation of findings, with key graphs illustrating results of ROMS model plume visitation frequency.

2.3 Electronic database of model output

2.4 Draft chapter summarizing findings

Task 3. Investigate the effect of GWRS Final Expansion on seasonality of the plume distribution with varying ocean conditions using realistic ROMS forcing between 1997 and 2017.

Fate of the OC San effluent plume will depend on ocean circulation that has inherent seasonal and interannual variability. The goal of this task is to simulate climate variability in the ocean and atmosphere and the effect that it has on plume dispersion. To understand this variability and serve as the basis for selecting scenarios, we analyzed a 21-year simulation of California coastwide ROMS to capture the wide range of variability in water masses and ocean circulation as well as multiple warming and cooling phases (Trenberth K. E., et al. 2007) that will have potentially important impacts on mass transport of the plume. We selected multiple ocean base years (Table 1) to run the experiments from this simulation.

The modeling experiment will follow the methodology utilized in Task 2 (each ocean base year will simulate 3 seasons) in order to characterize the full range of variability for every climate period. Plume visitation frequencies will also be calculated in this task. Therefore, our analyses will cover a range of climate phases to understand the effect on ocean circulation and plume dispersion (Table 1, with additional detail in Appendix 1 and Fig. 3-4).

Table 1. List of climate variability simulations. Abbreviations are as follows: El Nino Southern Oscillation (ENSO); Pacific Decadal Oscillation (PDO); mixed layer depth (MLD), North Pacific Gyre Oscillation (NPGO), California Current System (CCS).

Scenario Base Year	Period (M-M / YYYY)	Ocean climate conditions	Season
		Task 2	
1	**1-2 / 2000**	Neutral climate signals Average temperature and MLD	Winter
	5-6 / 2000		Upwelling
	7-8 / 2000		Summer
		Task 3	
2	**11-12 / 1997**	Negative to neutral NPGO Positive PDO Positive ENSO (El Niño, very strong) Deep MLD	Max (ENSO) Fall 97
	1-2 / 1998		Winter [most mixed]
	5-6 / 1998		Upwelling
	7-8 / 1998		Summer [most stratified]
3	**1-2 / 1999**	Positive NPGO Negative PDO Negative ENSO (La Niña, very strong) Deep MLD	Winter
	5-6 / 1999		Upwelling
	7-8 / 1999		Summer
4	**1-2 / 2004**	Neutral climate signals Warm Weak ocean transport	Winter
	5-6 / 2004		Upwelling
	7-8 / 2004		Summer
5	**1-2 / 2008**	Positive NPGO Negative PDO Neutral ENSO Cold and shallow MLD	Winter
	5-6 / 2008		Upwelling
	7-8 / 2008		Summer
6	**1-2 / 2009**	Positive NPGO Neutral PDO	Winter
	5-6 / 2009		Upwelling
	7-8 / 2009		Summer

		Transition to a quick positive ENSO event (El Niño) Cold and shallow MLD	
7	**7-8 / 2014**	Strong marine heatwave Neutral climate signal	Summer
8	**1-2 / 2015**	Strong marine heatwave Negative NPGO Positive ENSO (El Niño) starting in summer Positive PDO Deep MLD	Winter
	5-6 / 2015		Upwelling
	7-8 / 2015		Summer
9	**1-2 / 2016**	Marine heatwave Neutral NPGO Positive (winter) to negative (summer) ENSO and PDO	Winter
	5-6 / 2016		Upwelling
	7-8 / 2016		Summer

Task 4. Synthesize findings in a technical report, including recommendations for a suite of monitoring elements to assess the environmental impact of the effluent plume

The results of Task 1 and 2 will be synthesized into a draft report, which may include an executive synthesis, an appendix with a draft manuscript for publication in a peer-reviewed journal, plus supplemental or supporting information. The report will include a suite of recommended monitoring elements needed to characterize environmental impact of the modified plume in the future. The draft report will be submitted to the OC San project manager. OC San feedback on the report will be addressed and a final report submitted.

Deliverables:

3.1. Draft technical report.

3.2. Final technical report

Schedule of Milestones and Deliverables

Item	DESCRIPTION	ESTIMATED DUE DATE
Project Administration		
A1.	quarterly reports of progress and obstacles	quarterly
Task 1 Model validation		
1.1	Oral presentation of findings, with key graphs illustrating results of ROMS model validation	Completed

1.2	Electronic database of model output	Completed
1.3	Draft chapter in technical report documenting model validation	Completed
Task 2 Apply ROMS to quantify GWRS Final Expansion dispersal		
2.1	Oral presentation of findings, with key graphs illustrating visitation frequency on 1 and 3 days and results of sensitivity analyses	12 months
2.2	Electronic database of model output	18 months
2.3	Draft chapter in technical report documenting model application to assess environmental impact	18 months
Task 3 Investigate the effect of GWRS Final Expansion on seasonality of the plume distribution with constant discharge varying ocean conditions		
3.1	Key findings and illustrations	24 months
3.2	Electronic database of model output	24 months
3.3	Draft chapter on range of variability of plume dispersal over two decades	24 months
Task 4 Draft and final technical report		
4.1	Draft technical report, including recommendations for monitoring	30 months
4.2	Final technical report	34 months

3.0 Budget

Task budget. Task 1 is complete. Remaining project funds will cover Task 2 with existing funds. An augmentation of $135,000 is requested to complete Tasks 3 and 4.

Task 1 Model validation[1]	$0
Task 2 Apply ROMS to quantify GWRS Final Expansion dispersal	$75,000
Task 3 Investigate the effect of GWRS Final expansion on seasonality of the plume distribution with constant discharge varying ocean conditions	$105,000
Task 4 Draft and final technical report	$30,000
Total	$210,000
[1]Work is 100% complete	

Line-Item Budget. The line-item budget provides the costs of Tasks 2-4.

A. Personnel			2021-22		2022-23		2023-2024		
	Position Title	Rate	Hours	Amount	Hours	Amount	Hours	Amount	Total
	Principal Scientist	$ 77.89	40	$ 3,116	40	$ 3,209	20	$ 1,605	
	Senior Scientist	$ 55.60	120	$ 6,672	120	$ 6,872	40	$ 2,291	
	Scientist	$ 44.84	320	$ 14,349	320	$ 14,779	160	$ 7,390	
	Total Personnel:		480	$ 24,136	480	$ 24,860	220	$ 11,285	$ 60,282
B. Fringe Benefits				$ 12,505		$ 12,880		$ 5,847	$ 31,232
	(51.81% of personnel services)								
C. Operating Expenses								$ 3,500	$ 3,500
	publication costs							$ 3,500	
D. Equipment				$32,028		$ -		$ -	$32,028
	Computer server computing nodes			$30,000		$ -		$ -	
	Storage			$2,028					
D. Travel				$ -		$ 4,000		$ -	$ 4,000
	Conference travel-Ocean Sciences Meeting								
	2 person attending 1 conference					$ 4,000			
E. Subcontracts									$ -
F. Indirect Costs				$ 31,614		$ 32,563		$ 14,781	$ 78,958
	(86.28% of personnel & fringe benefits)								
	Total Contract			$ 100,284		$ 74,303		$ 35,413	$ 210,000

4.0 References Cited

Arnold BF, Schiff KC, Ercumen A, Benjamin-Chung J, Steele JA, Griffith JF, Steinberg SJ, Smith P, McGee CD, Wilson R, Nelsen C. Acute illness among surfers after exposure to seawater in dry-and wet-weather conditions. American journal of epidemiology. 2017 Oct 1;186(7):866-75.

Colas, F., J.C McWilliams, X. Capet, and J. Kurian, 2012: Heat balance and eddies in the Peru Chile Current System. Climate Dynamics 39, 509-529.

Colas, F., X. Capet, J.C McWilliams, and Z. Li, 2013: Mesoscale eddy buoyancy flux and eddy induced circulation in eastern-boundary currents. J. Phys. Ocean. 43, 1073-1095.

Csanady, G.T., 1983. Dispersal by randomly varying currents. Journal of Fluid Mechanics 132, 375-394.

Dauhajre, D. P., McWilliams, J. C., & Renault, L. (2019). Nearshore Lagrangian connectivity: Submesoscale influence and resolution sensitivity. Journal of Geophysical Research: Oceans, 124, 5180–5204. https://doi.org/10.1029/2019JC014943

Deutsch, C, W. Berelson, R. Thunell, T. Weber, C Tems, J. McManus, J. Crusius, T. Ito, T. Baumgartner, V. Ferreira, J. Mey, A. van Geen, 2014. Centennial changes in North Pacific anoxia linked to tropical trade winds, Science, 345(6197), 665-668.

Dong, C, E.Y. Idica, and J.C. McWilliams, 2009: Circulation and multiple-scale variability in the Southern California Bight. Prog. Oceanography 82,168-190.

Ho M., Dauhajre D., Kessouri F., Bianchi D., McWilliams. J.C. 2017. Net primary production from nitrate and ammonium from wastewater effluent using Lagrangian metrics. Undergraduate Report, UCLA.

Kessouri F, Bianchi D, Renault L, McWilliams JC, Frenzel H, Deutsch CA. Submesoscale currents modulate the seasonal cycle of nutrients and productivity in the California Current system. Global Biogeochemical Cycles. 2020 Oct;34(10):e2020GB006578.

Kessouri F, McWilliams JC, Bianchi D, Sutula M, Renault L, Deutsch C, Feely RA, McLaughlin K, Ho M, Howard EM, Bednaršek N. Coastal eutrophication drives acidification, oxygen loss, and ecosystem change in a major oceanic upwelling system. Proceedings of the National Academy of Sciences. 2021 May 25;118(21).

Kessouri F, McLaughlin K, Sutula MA, Bianchi D, Ho M, McWilliams JC, Renault L, Molemaker J, Deutsch CA, Leinweber A. Configuration, and validation of an oceanic physical and biogeochemical model to investigate coastal eutrophication: case study in the Southern California Bight.

Marchesiello, P., J.e. McWilliams, and A. Shchepetkin, 2003: Equilibrium structure and dynamics of the California Current System, J. Phys. Ocean. 33), 753-783.

Oliver, E. C. J. Mean warming not variability drives marine heatwave trends. Climate Dynamics, 53, 1653-1659, doi: 10.1007/s00382-019-04707-2, 2019.

SAIC, 2002. Nearfield and Particle Tracking Model Report. Prepared for Orange County Sanitation District.

Shchepetkin, A.F., and J.c. McWilliams, 2003: A method for computing horizontal pressuregradient force in an ocean model with a non-aligned vertical coordinate. J. Geophys. Res. 108,35.1-35.34.

Shchepetkin, A.F., and J.c. McWilliams, 2005: The Regional Oceanic Modeling System (ROMS): split-explicit, free-surface, topography-following-coordinate oceanic model. Ocean Modelling 9,347-404.

Shchepetkin, A.F., and J.c. McWilliams, 2008: Computational kernel algorithms for fine scale, multiprocess, longtime oceanic simulations. In: Handbook of Numerical Analysis: Computational Methods for the Ocean and the Atmosphere, R Temam & J. Tribbia, eds., Elsevier Science, 119-181.

Shchepetkin, A.F., and J.C McWilliams, 2011: An accurate Boussinesq modeling with a practical, "stiffened" equation of state. Ocean Modelling 38, 41-70.

Sutula M, Ho M, Sengupta A, Kessouri F, McLaughlin K, McCune K, Bianchi D. A baseline of terrestrial freshwater and nitrogen fluxes to the southern california bight, usa. Marine Pollution Bulletin. 2021 Sep 1;170:112669.

Trenberth KE, Jones PD, Ambenje P, Bojariu R, Easterling D, Klein Tank A, Parker D, Rahimzadeh F, Renwick JA, Rusticucci M, Soden B. Observations. Surface and atmospheric climate change. Chapter 3.

Uchiyama, Y., J.C McWilliams, and A.F. Shchepetkin, 2010: Wave-current interaction in an oceanic circulation model with a vortex-force formalism: Application to the surf zone. Ocean Modelling 34, 16-35.

Supporting figures

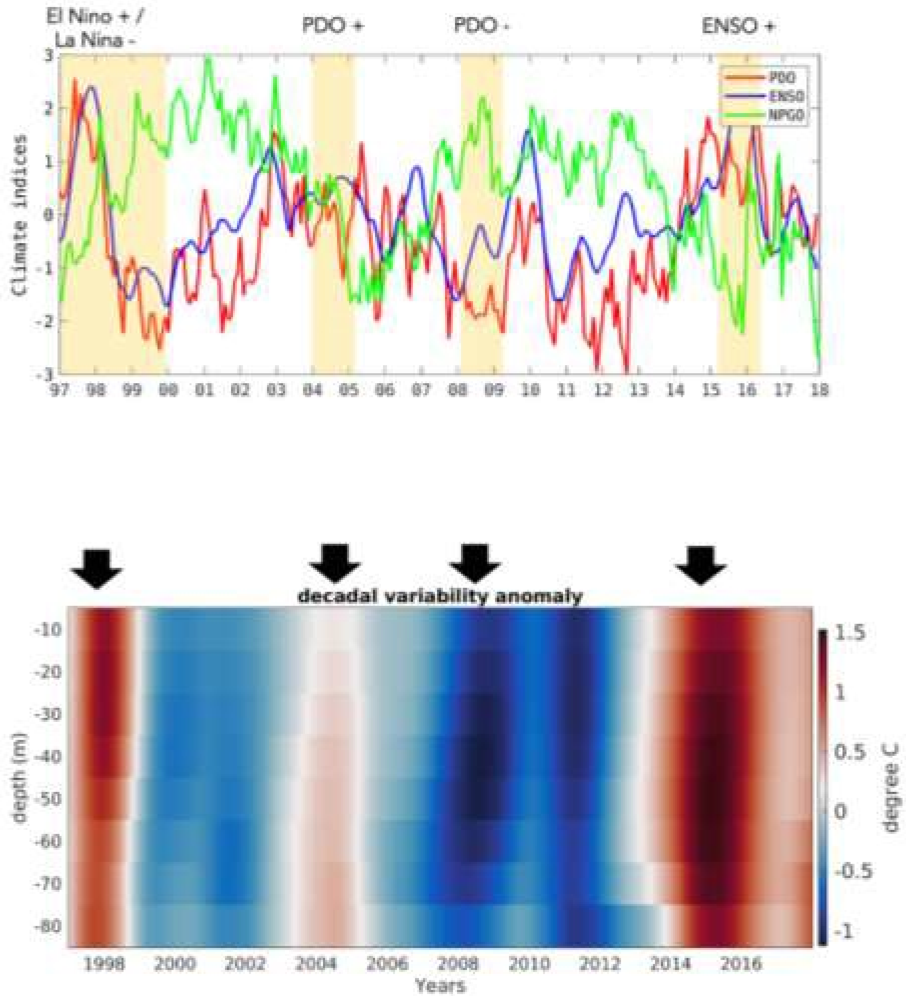


Figure 3: Upper panel: climate index in the North Pacific Ocean (NOAA). Lower panel: multi-annual anomalous average temperature in the SCB. Seasonal variability is excluded.

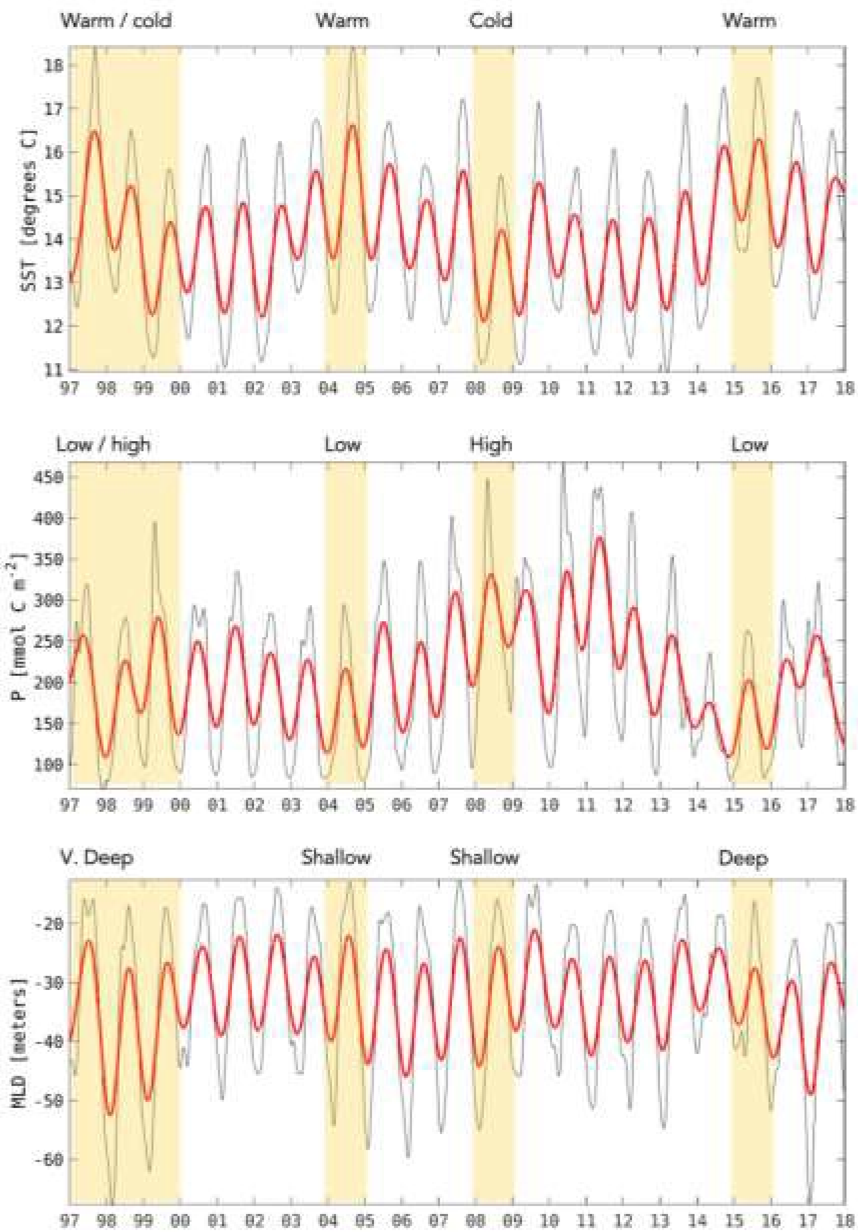


Figure 4: Upper panel: ocean surface temperature. Middle panel: phytoplankton biomass integrated vertically. Lower panel: depth of the mixed layer. All panels express averages over Orange County coast (coast to 80km offshore, between Newport and Seal Beach). Black line is a 7-day Gaussian filter and red curve is a seasonal Gaussian filter.

Appendix 1. Additional detail on ocean base years that support selection of scenarios (also see the supporting Fig. 4 to illustrates surface temperature, mixed layer, nutrients utilization with respect to various climate phases).

Ocean Base Year	Rationale
1997-1999:	The water column changes from intense warming and stratification to rapid cooling and mixing. Between the fall 1997 and summer 1998, the ocean was nutrient-poor, during which the thermocline was quite deep (> 60 m on average), but 1999 was one of the most productive years in the last 20 years, so conditions were antagonistic among these years.
2000	This year represents average conditions and no climate events. El Nino Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) are neutral. Sea surface temperature and the mixed layer depth (MLD) are average. This scenario will be completed in Task 2.
2004	The ensemble ENSO-PDO-NPGO (North Pacific Gyre Oscillation) signal was insignificant for the entire year, and yet it was a warm year, poor in nutrients and planktonic production. This year is characterized by weak winds and weak oceanic transport potentially caused by the slowing down of the activity of the California Current System (CCS). The reverse cycle happens four years later (see below).
2008:	This is a cold, nutrient-rich, and very productive year. PDO is negative and NPGO is positive which causes intense dynamic CCS activity and shallow MLD. During positive NPGO, activity of the tropical and the subpolar gyre is intensified and affects the CCS (Joh and Di Lorenzo 2017, Di Lorenzo et al 2008). Vertical velocities (and fluxes) are also more intense.
2009	The SCB experienced a high positive NPGO, an El Nino, and an insignificant PDO. This year was cool, moderately productive (nitrate flux was mild), and had a shallow MLD
2014	This year marked the beginning of the 2014-2016 heatwave. Climate indices PDO, NPGO, and ENSO were all insignificant for a brief winter/spring. We will run the summer period only because winter and spring have similar conditions as 2004 (see #3). However, summer is under the effects of a marine heatwave, causing some of the highest temperature anomalies outside of El Niño periods.
2015	Winter of 2015 is the warmest winter between 1997-2017 because of the heatwave. As marine heatwaves are expected to increase in frequency with climate change (Oliver 2019), understanding the plume transport under these events is necessary for future monitoring. The summer of 2015 is under the effects of both the heatwave and El Niño. The interest to study this period is to compare with the El Niño of 1998/1999, in which a heatwave was absent (Figure 3, lower panel).
2016	This period represents the end of the most recent El Nino season, which also coincided with a prolonged heatwave. The reasons to analyze this year is to compare to the aftermath of the 1999/1999 El Niño and quantify the consequences of the heatwave combined with El Nino on the water masses.