February 2, 2024

Dr. Gordon Zhang,
Chair, Coastal Numerical Model
Independent Review Panel

Dear Dr. Zhang,

Michael Baker International (MBI) was commissioned by South Orange County Wastewater Authority to review the Regional Ocean Modeling System with Biogeochemical Elemental Cycling (ROMS-BEC). These findings were presented by Dr. Scott Jenkins at the January 18, 2024 Independent Review Panel (IRP) meeting in Costa Mesa, CA. As you suggested at that meeting, please find below our response to this critique.

Summary of MBI Critiques

That review, found here, concluded that there were *"two significant omissions in the model code of the Southern California Coastal Water Research Project (SCCWRP) variant of their Regional Ocean Modeling System (ROMS) / Biogeochemical Elemental Cycling (BEC) model, which biases its results toward over stimulation of plankton growth rates and under-prediction of outfall dilution rates, both of which provoke plankton blooms that ultimately contribute to ocean acidification and hypoxia (OAH) through the decay processes following bloom die off. "*

[Claim 1]: *"The SCCWRP variant of ROMS/BEC omits scattering physics in the formulation of light attenuation throughout the water column. In coastal waters, back scattering by tiny, suspended particulate (particle sizes in the range of 0.1 μm D ≤ ≤1 μm) accounts for 70% to 80% of total light attenuation, while absorption attenuates only the remaining 20% or 30% of the downwelling irradiance. Consequently, omission of back scattering in the formulation of available light leads to a deeper photic zone with higher light intensity at any given depth, both of which result in higher photosynthetic rates and growth rates than would otherwise be predicted if back-scattering had been included."*

[Claim 2]: *"The schematization of the dilution of effluent discharges from ocean outfalls is lacking in the SCCWRP variant of ROMS/BEC by assuming a fixed, time-invariant mixing volume. The schematization of the dilution of effluent discharges from ocean outfalls is lacking in the SCCWRP variant of ROMS/BEC by assuming a fixed, time-invariant mixing volume which never occurs in Nature. The mixing volume of a prototypic scale outfall plume in Nature varies continuously over time in response to the vertical variations in temperature/salinity profiles, winds, waves, currents and outfall specific parameters such as discharge rates, diffuser length, numbers and size of discharge ports; none of which the assumed fixed, time invariant ROMS/BEC formulation of the mixing volume can replicate or even adequately approximate. Consequently, the SCCWRP variant of ROMS/BEC under-predicts the dilution that occurs in the modeled outfall plumes; which in turn, leads to higher undiluted nitrate and ammonia concentrations in the outfall plumes, thereby imparting a bias in favor of excessive plankton photosynthetic rates and growth rates stimulated by excessive nutrient concentrations of anthropogenic origins. In other words, this significant flaw leads directly toward implicating ocean outfalls as the cause of plankton blooms and OAH. "*

Response of the Science Team

The Science Team disagrees with MBI's critiques. Their two main critiques regarding backscattering and initial dilution are unfounded. Moreover, they are not relevant on the spatial and temporal scales at which ROMS-BEC is currently being applied to investigate the regional effect of anthropogenic nutrients on ocean acidification and hypoxia. In the following paragraphs, we elaborate on these ideas.

Claim #1a "BEC does not include backscattering physics." This is false. The BEC is formulated to include the diffuse attenuation of downwelling irradiance (light) from both the absorption and scattering by plankton cells (mostly phytoplankton) and marine snow (i.e., dead cells and detrital organic matter, Morel et al., 1988; Bricaud et al., 1998; Morel and Maritorena, 2001). BEC adopts an optical formulation that is widely accepted in ocean numerical modeling (Fasham et al., 1990). First it focuses on the fraction of downwelling radiation that is relevant for photosynthesis, i.e., the photosynthetic available radiation, PAR. Diffuse attenuation of downward irradiance is modeled by applying a diffuse attenuation coefficient for PAR (in units of 1/m). This attenuation coefficient is an apparent optical property (rather than inherent optical property) that encapsulates the effects of scattering and adsorption by diverse water components under a varying light field (Spinrad et al., 1994). Following standard practices, the attenuation coefficient is incorporated into BEC by considering two components. The first reflects attenuation by seawater, and the second by all material of biological origin, using a function that is dependent on modeled chlorophyll concentration, consistent with field observations (Morel et al., 1988; Fasham et al., 1990; Morel et al., 2001). While chlorophyll in the model represents "live" algal biomass, in this optical formulation it is intended as an empirical proxy of total organic matter in waters dominated by phytoplankton (i.e., for Case 1 waters, Morel and Prieur 1977). This formulation provides an excellent representation of primary production and vertical profiles of chlorophyll in BEC.

Claim #1b. "The effects of riverine sources of turbidity on light attenuation and productivity are not considered, and for this reason the model overpredicts coastal productivity." Coastal modeling of primary productivity and its consequences involves deliberate choices how to represent the effects of terrestrial influences (colored dissolved organic matter, mineral turbidity) across the land-sea interface. The version of BEC used in Kessouri et al. (2021a, 2021b and submitted) does not account for mineral turbidity. We chose not to consider riverine sources of turbidity, because this effect can only matter for some SCB rivers for some storm events and even then, only at local scales, for three reasons:

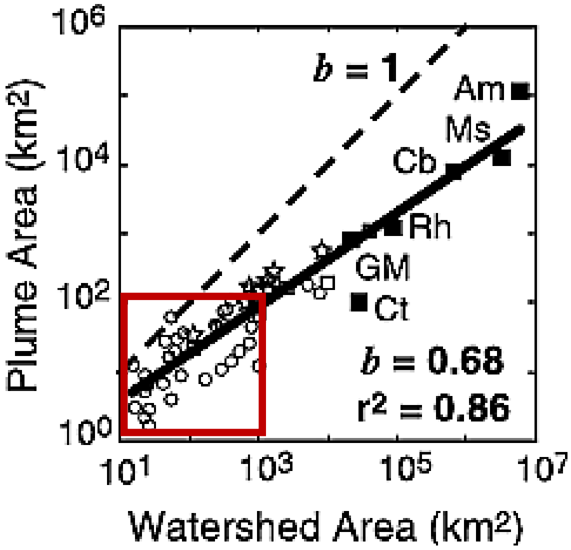


Fig. 1 From Warrick and Fong 2004 DOI: **10.1029/2003GL019114** , modified to include red box that shows the range of southern California waterside sizes, with the range of corresponding plume size.

1) The Bight is a Mediterranean climate with low rainfall (5-25 inches per year) that occurs during the wet season (October -April), with 3-7 major storms per year of ~2-4 days in duration (Ackerman and Schiff, 2003). So, at most, the total rain days in which storm events result in riverine plumes are generally 6-10% of the days per year.

2) Most southern California watersheds are small, ranging from 100s to 1000s of square kilometers (Ackerman and Schiff 2003). Warrick and Fong (2004) documented the footprint of riverine turbidity plumes in the coastal waters of California watersheds. They found that turbidity plumes scale with the watershed size. Applying their regression (Fig. 1), we can

derive that the typical range of coastal turbidity plumes is on the order of 1 to 10 km^2, which is the equivalent of one to ten 300 m resolution grid cells of the Bight ROMS model. With the exception of extreme events, this means that the effect of riverine turbidity is largely contained within the first one or two cells of the horizontal grid ROMS along the coast.

3) Southern California coastal watersheds have highly modified sediment transport characteristics (Ulibarri et al. 2020), due to changes in both land cover (Syvitski et al., 2005; Trimble, 1997; Warrick et al., 2013) and construction of dams and debris basins that trap sediment and alter streamflow (Kondolf et al., 2014; Willis and Griggs, 2003). According to Ackerman and Schiff (2003), about 50% of the area of California coastal watersheds are behind dams (Fig. 2), which trap peak flows and dampen the magnitude of sediment transport capable of producing coastal sediment plumes, particularly during early season storm events when the dams are at lowest capacity.

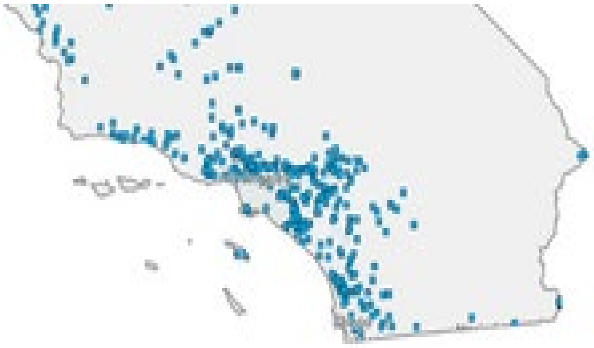


Fig. 2 *https://damsafety.org/california*, image showing locations of southern California watershed dams that meet criteria of greater than 25’ in height or storing more than 50-acre feet

Riverine and outfall discharges are quickly mobilized by ocean currents and carried far afield from their points of origins; their effects are broad, not plume scale. Thus, very nearshore turbidity is not relevant at the scales in which we are modeling, a point upon which we elaborate further below in Claim #2 below. Adding it would increase the computational burden and data requirements without a meaningful improvement in ROMS-BEC predictions. We may choose to include it for some applications at specific scales in the future, depending on the application question.

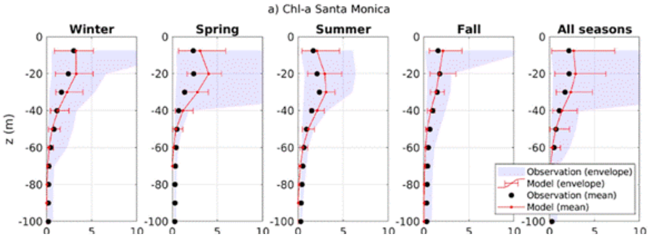
Claim #2. “Schematization of the dilution of effluent discharges from ocean outfalls is lacking in the SCCWRP variant of ROMS/BEC by assuming a fixed, time-invariant mixing volume.” This characterization of our approach is incorrect. As we presented in our January 17, 2024 'inputs talk', near-field plume mixing occurs at scales of cm to 10 meters. Modeling at 300 m resolution means that nearfield mixing is not resolved, so it was necessary not only to define the outfall pipe with diffuser configurations, but also to establish a location representing the initial rise and spread of the plume on the vertical axis to represent this unresolved initial dilution. We chose to represent this spread using a gaussian shape centered at a depth of 10 m above the outfall pipe (i.e., the bottom). This does not mean that the plume location stays fixed in time or space. ROMS predictions of time-varying ocean conditions then modulate the plume’s vertical rise, during which the plume continues to mix with ambient water, until the plume reaches its neutrally buoyant depth. If the plume encounters the thermocline, then it will stay trapped below it. If the water column is well mixed, then it will mix up on the surface. Plume filaments spread out by horizontal advection and straining of the plume by currents.

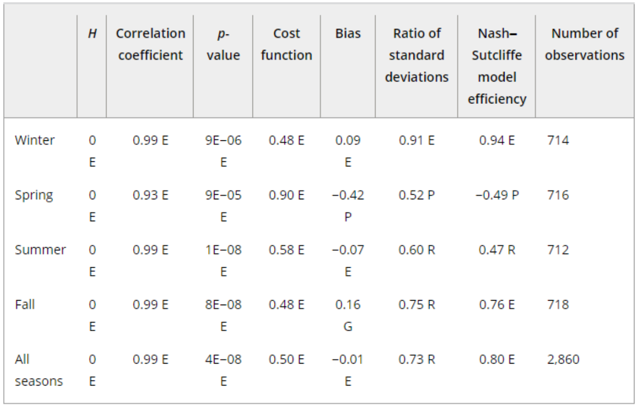
The choice to position of the initial plume spread at 10 m above the seafloor was informed by checking hundreds of plume observations of colored dissolved organic matter (CDOM), temperature and salinity profiles provided by SCCWRP member agencies. Furthermore, we conducted a sensitivity analysis on the pipe distance, using depth ranges of 25-70 m. We concluded that plume dispersion and final dilution in the intermediate field of hundreds to thousands of meters was insensitive to choose of initial placement height of the shape function, as long as its position is below the thermocline for deep outfalls. Outfalls that discharge to above the thermocline water are treated similarly. In addition, Kessouri et al. (2021b) describes that for outfalls discharging greater than 100 MGD, there was also an additional horizontal distribution of the initial plume to allow for greater dilution, again informed by observational data. This approach means that the initial dilution of the outfall plume represents roughly 10,000:1.

The model employed in the 300-m configuration of ROMS-BEC makes the hydrostatic approximation, which means that it solves for velocities by a combination of acceleration for horizontal velocities and mass conservation for vertical velocity. This is a more efficient and sufficiently accurate method, compared to fully nonhydrostatic dynamics, for the scales investigated in Kessouri et al. (2021a,b).

Ho et al. (2021) was invoked in the critique of plume parameterization, so we clarify the intent of that work. We utilized a 1-m resolution non-hydrostatic ROMS, as part of a study for the Orange County Sanitation District to investigate how their outfall plume distribution may change as a function of the increased recovery of outfall freshwater volume. The work was requested to document how well predictions by ROMS match of those of engineering models that guided outfall design (e.g., from Visual Plumes, Frick et al. 2004). The study concluded that an idealized nonhydrostatic ROMS matched the observations of the laboratory experiments by Roberts, Sndyer and Baumgartner (1989), which is the basis for the Visual Plumes modeling approach. Our conclusion is that this represents a reasonable handshake between the engineering and ocean numerical modeling worlds, albeit with ROMs providing much greater functionality and ability to represent realistic ocean conditions.

Summary Claim "The combined effect of these errors would lead to an under-dilution of outfall nitrogen and an overprediction of phytoplankton production." We disagree for all the reasons explained above, but the model performance assessment provides an independent check on our model approach. We see no evidence of consistent overprediction of NH_4^+ or Chl-a in our coastal assessment, including areas directly influenced by plumes. Horizontal and vertical gradients in Chl-a and NH4 observations are appropriately reproduced in the model, despite noted concerns with NH_4^+ data paucity, Chl-a fluorometry calibration, and mismatch in spatial and temporal scales of averaging. Detailed graphics and results of performance statistics (e.g. Fig. 3) are available for all subregions in Kessouri et al. (2021b). supplemental information found here. In fact, our conclusion was that "the model may provide a conservative estimate of phytoplankton biomass in the Bight, while reproducing accurate spatial and temporal patterns in that biomass".





	H	Correlation coefficient	*p*-value	Cost function	Bias	Ratio of standard deviations	Nash–Sutcliffe model efficiency	Number of observations
Winter	0 E	0.99 E	9E−06 E	0.48 E	0.09 E	0.91 E	0.94 E	714
Spring	0 E	0.93 E	9E−05 E	0.90 E	−0.42 P	0.52 P	−0.49 P	716
Summer	0 E	0.99 E	1E−08 E	0.58 E	−0.07 E	0.60 R	0.47 R	712
Fall	0 E	0.99 E	8E−08 E	0.48 E	0.16 G	0.75 R	0.76 E	718
All seasons	0 E	0.99 E	4E−08 E	0.50 E	−0.01 E	0.73 R	0.80 E	2,860

Fig 3. From Kessouri et al. (2021b). Top Panel: Average seasonal profiles of chl-a in the Santa Monica Bay (SMB). The red lines and red bars show the spatiotemporal mean and the variability from the model, respectively. The black dots and the gray shading show the spatiotemporal mean and the variability from in situ data, respectively. Bottom panel: statistical comparison between in situ data and model outputs for chlorophyll profile in SMB

We are glad to provide additional details if you would like to engage us further on MBI’s critiques.

Sincerely yours,

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