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RADIv2: an adaptable and versatile diagenetic model for coastal and open-ocean sediments

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Overview

This document provides additional material that supports the main manuscript. Section S1 presents a porewater-profile validation and a vertical-resolution sensitivity test for RADIv2 at a coastal Iberian Margin station. Section S2 illustrates transient RADIv2 behaviour with a tidal-forcing experiment including episodic POM blooms, demonstrating how to implement time-dependent boundary conditions and how they can influence benthic fluxes.

S1. Porewater profile validation at Iberian Margin station 99–6

We illustrate RADIv2's ability to resolve porewater profiles using the shallow Iberian Margin station 99–6 described by Epping et al. (2002). This station was chosen because it lies in a coastal margin environment and is the shallowest station (108 m water depth) with porewater profiles, and the organic-matter degradation rates and particulate organic carbon (POC) flux are relatively well constrained. Bottom-water concentrations of oxygen (O_2), nitrate (NO_3^-) and ammonium (NH_4^+), as well as temperature and the POC deposition flux, were directly used as boundary conditions and input parameters from Epping et al. (2002). The total reactivity of the degradable POC rain is constrained between 1.5 and 2.25 a^{-1}, consistent with the reactivity inferred from in-situ O_2 microprofiles reported by Epping et al. (2002). Physical settings such as bioturbation, irrigation and the carbonate-kinetics parameters were kept at the standard RADIv2 values rather than tuned to this specific site or adopted from the model set-up of Epping et al. (2002). Dispersion was disabled for this run, because no permeability data are available to constrain it and led to too strong supply of O_2 into the sediment compared to the observed profiles.

Figure S1 compares the simulated and observed porewater profiles of O_2, NO_3^- and NH_4^+ at station 99–6. RADIv2 reproduces the main structure and magnitude of the O_2, NO_3^- and NH_4^+ profiles. To assess the sensitivity of the vertical resolution (dz) on these results, we repeated the 99–6 simulation with three different uniform layer thicknesses in the upper sediment (dz = 1, 2 and 5 mm), keeping all other parameters and boundary conditions identical. Across this range of dz, the simulated porewater profiles for O_2 and NO_3^- remain relatively similar, while coarser grids mainly affect the deeper part of the NH_4^+ profile.

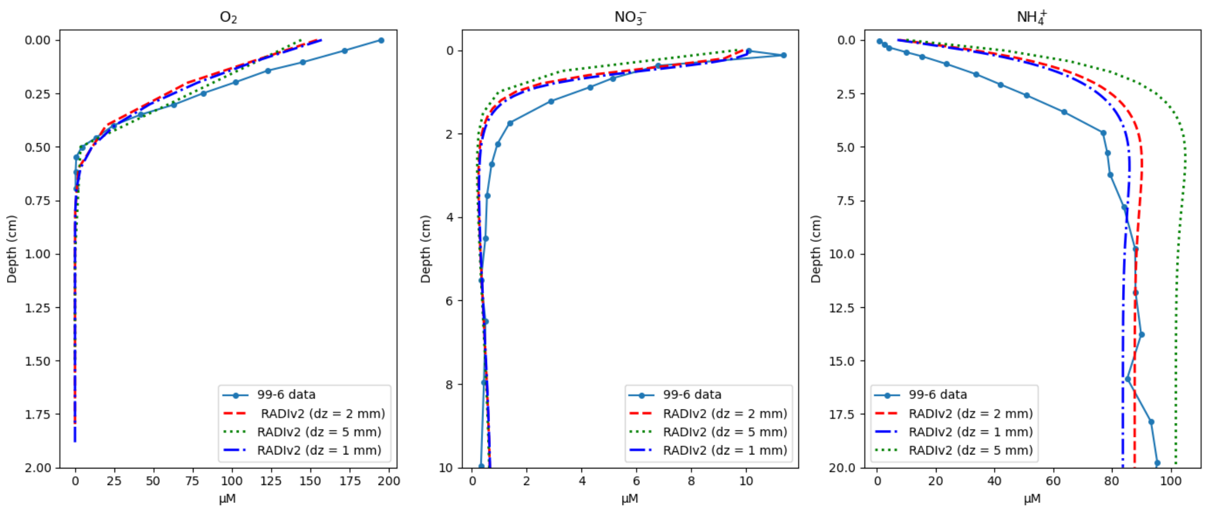

Fig. S1. Porewater-profile validation and vertical-resolution sensitivity at the Iberian Margin coastal station. Lines show RADIv2 simulations using three different uniform grid spacings (dz = 1, 2 and 5 mm), and the dotted lines denote observed porewater concentrations.

S2. Transient simulations

To illustrate the transient behaviour of RADIv2 and its response to time-dependent forcing, we performed an experiment combining both physical and biogeochemical variability. We imposed two types of time-varying forcing: (i) a sinusoidal tidal current signal at M2 frequency that modulates the bottom-current speed and, through the RADIv2 parameterisations, the diffusive boundary-layer (DBL) thickness and the dispersive transport, and (ii) two prescribed phytoplankton blooms centred around mid-April and mid-October, each lasting for 20 days and increasing the POM rain to the seafloor by 400%.

Figure S2 shows (a) the DBL thickness and current speed over one week, (b) the corresponding O_2 flux over that week with tidal forcing, and (c) the O_2 flux over the full year with both tidal forcing and the two plankton blooms. Note that the dates shown in Figure S2 are arbitrary and used only to align the time series for plotting; they do not correspond to real-world forcing or a specific calendar period. The tidal current signal exerts a clear control on both the DBL thickness and the O_2 flux. The simulated benthic O_2 uptake varies by roughly 50-60% over a tidal cycle, driven by the combined effects of DBL thinning/thickening and the strengthening and weakening of dispersive transport. This magnitude of variability is comparable to estimates from measurements in Aarhus Bay, where O_2 uptake was found to vary by 30% or more due to DBL changes alone (Glud et al. 2007), but smaller than the roughly 25-fold variability over tidal cycles reported by McGinnis et al. (2014) in permeable, sandy systems. The non-linearity in O_2 uptake arises primarily from the dispersion term, which scales non-linearly with current speed (Equation 19 in the main text).

The experiment also shows the interplay between current speed and benthic fluxes in the present RADIv2 formulation. Higher current velocities increase dispersion and pump oxygen into the sediment, which tends to weaken the bottom-water–porewater gradient and thus the flux. At the same time, stronger currents thin the DBL, increasing transfer across the SWI. In permeable, high-energy environments, however, solute exchange across the sediment–water interface is not controlled by molecular diffusion alone: there are three diffusive transport regimes (molecular, dispersive and turbulent) that can dominate the mass flux of a tracer across the SWI (Voermans et al. 2018). These regimes, and the conditions under which each dominates tracer exchange, are not yet fully included in the current RADIv2 flux formulation. Adding them would improve SWI exchange in permeable, high-energy settings.

During the bloom periods, the O_2 uptake increases by about ∼20%, relative to baseline conditions. The magnitude and timing of this increase depend on the reactivity of the OM pulse: highly reactive carbon produces a stronger, near-instantaneous enhancement of O_2 uptake, whereas less reactive carbon is retained longer in the sediments and remineralizes gradually, leading to a more sustained increase in O_2 uptake over longer timescales. Together, these transient experiments demonstrate that the RADIv2 framework can simulate time-dependent forcings. In the current framework, transient simulations can be forced with any time-dependent boundary condition or model parameter, not limited to the examples shown here. The run file used for the transient test case is available on Zenodo (https://doi.org/10.5281/zenodo.18386461; (van der Zant et al. 2025))

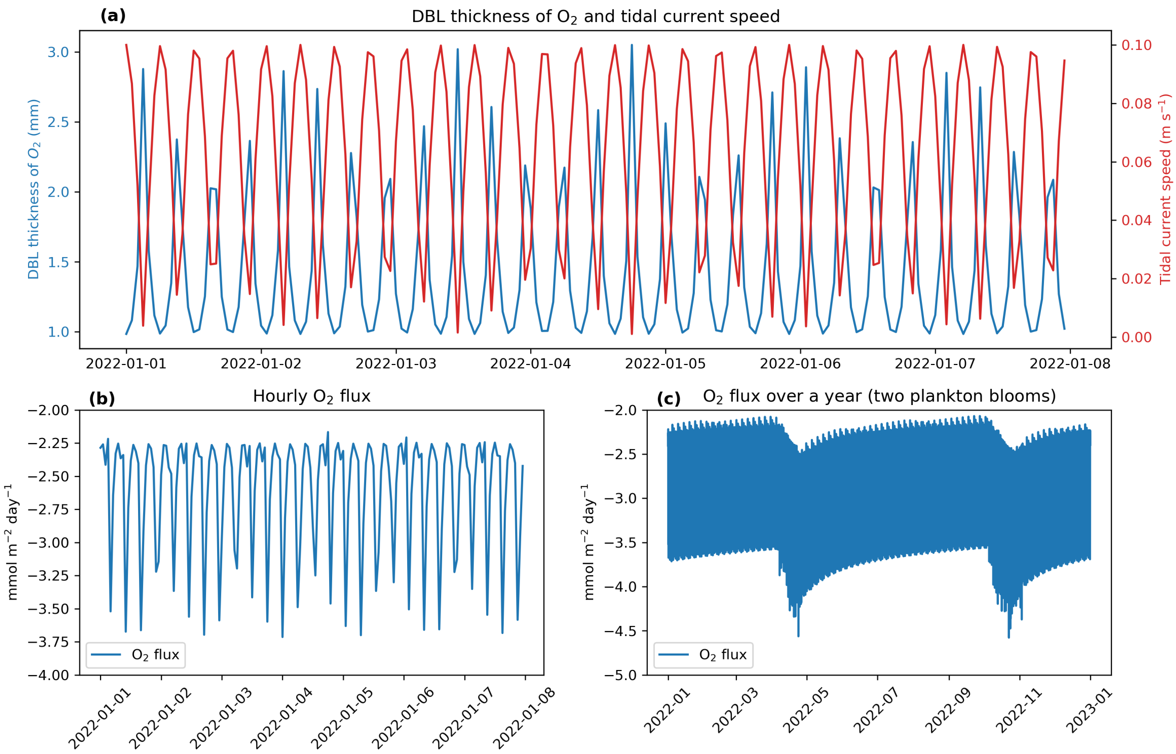

Fig. S2. DBL thickness, tidal forcing, and transient benthic O_2 flux in RADIv2. (a) Modelled diffusive boundary-layer (DBL) thickness of O_2 (blue, first y-axis) and tidal current speed (red, second y-axis) over one week. (b) Corresponding hourly benthic O_2 flux over the same week, showing tidal modulation of O_2 uptake. (c) Benthic O_2 flux over a full year, including the tidal forcing and two prescribed plankton blooms (mid-April and mid-October), which enhance O_2 uptake during and following the bloom periods (negative values indicate uptake into the sediment).

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