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Evidence of advective pore water transport through a Mediterranean barrier beach using geochemical tracers

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Groundwater may flow between two hydraulically-connected water bodies separated by a permeable barrier; such flow is a type of submarine groundwater discharge (SGD) in marine environments. Despite recent advances in the study of SGD, flow through permeable barrier beaches has been largely overlooked. Using geochemical tracers, we investigated pore water distributions beneath a narrow ($<$100 m wide) barrier beach, which separates a small, shallow coastal lagoon from the French Mediterranean Sea. Pore waters were sampled monthly *via* drive-point piezometer in a shore-perpendicular transect across the beach, from May to September 2017, and again in November when strong winds forced an opening through the beach. Lagoon water levels were highest in May, providing the greatest hydraulic gradient to drive pore water from the lagoon toward the sea. In May, shallow ($\leq$1 m) pore water residence times beneath the beach were estimated to be between $\sim$2 and 30 days from dissolved ^{223}Ra, ^{222}Rn and DSi, and were generally greatest within the center of the beach. The lagoon continuously increased in salinity and decreased in water level throughout the summer from high evaporation rates. Integrated horizontal pore water flow velocity, derived from ^{223}Ra and Na, decreased from $\sim$55 cm d^{-1} in June to $\sim$43 cm d^{-1} in July from a decreasing hydraulic gradient. Flow was either stagnant or reversed direction in August and September, where conservative solute distributions began to represent patterns of dispersion. When the barrier beach was breached in November, pore water flow reversed direction, from the sea toward the lagoon. Regardless of the season, pore water residence times were sufficiently long for DOC to be consumed and produce DIC; thus, water exchange through barrier beaches can act as a new solute source to the Mediterranean Sea when there is a sufficient hydraulic gradient. Irrespective of pore water flow through the barrier beach, solutes may be transferred to the Mediterranean Sea *via* wave-setup, a flow path separated from exchange through the barrier beach from long-lived ^{228}Ra. Vertical profiles of dissolved ^{223}Ra reveal that wave-setup recirculates seawater through the first $\sim$10 m of the beach-face to depths of $\geq$1.5 m, and is highly dependent upon the prevailing wind speed and direction. Taken together, wind-driven wave-setup and water exchange through barrier beaches drive highly transient solute fluxes to the coastal Mediterranean Sea.