PANAMJAS
Pan-American Journal of Aquatic Sciences

Reply to Calliari: Evaluating alternative mechanisms of coastal salinity variability in La Paloma, Uruguay

RAFAEL SANTANA[1*] , GASTÓN MANTA[1], SANTIAGO SILVEIRA[2], ROMINA TRINCHIN[1], INÉS PEREYRA[2], MARTÍN LAPORTA[2.,3], ORLANDO SANTANA[2], GRACIELA FABIANO[2 ‡] & MARCELO BARREIRO[1 ‡]

[1] *Departamento de Ciencias de la Atmósfera y Física de los Océanos, Facultad de Ciencias, Universidad de la República, Montevideo, Uruguay, PC 11400.*
[2] *Dirección Nacional de Recursos Acuáticos, Ministerio de Ganadería Agricultura y Pesca, Uruguay.*
[3] *Campus do Mar, International Campus of Excellence, Universidade Santiago de Compostela, A Coruña, Spain.*

** Corresponding author: wuaffa@hotmail.com*

‡ lead authors in equal footing

Abstract: Dr. Calliari's commentary raises an important point regarding the possible influence of Submarine Groundwater Discharge (SGD) on coastal salinity and biogeochemistry in Uruguay. We acknowledge the relevance of this process and agree that its quantification would represent a valuable step toward a more comprehensive understanding of freshwater inputs to the coastal ocean. Nonetheless, the available evidence and regional hydrographic context suggest that large-scale physical mechanisms—specifically the advection of the Río de la Plata Plume (RPP) and wind-driven circulation—remain the dominant controls of salinity variability at La Paloma. While SGD may locally modulate background conditions, current data do not support its role as a primary driver. We view this discussion as a constructive step toward motivating future field measurements and modeling efforts to better assess groundwater–ocean interactions along the Uruguayan coast.

Key words: Submarine groundwater discharge, Rio de la Plata, brackish water, South America.

Respuesta a Calliari: evaluando mecanismos alternativos de la variabilidad de la salinidad en La Paloma, Uruguay. Resumen: El comentario del Dr. Calliari plantea un punto relevante sobre la posible influencia de las Descargas Submarinas Difusas (DSD) en la salinidad y biogeoquímica costera del Uruguay. Reconocemos la pertinencia de este proceso y coincidimos en que su cuantificación sería un avance valioso hacia una comprensión más integral de los aportes de agua dulce a la costa. Sin embargo, la evidencia disponible y el contexto hidrográfico regional indican que los mecanismos físicos de gran escala —en particular la advección de la Pluma del Río de la Plata y la circulación inducida por el viento— continúan siendo los principales controladores de la variabilidad de la salinidad en La Paloma. Si bien las DSD pueden modular localmente las condiciones de fondo, los datos actuales no respaldan su papel como forzante primaria. Consideramos que este intercambio constituye un aporte constructivo que refuerza la necesidad de futuras mediciones y esfuerzos de modelado orientados a evaluar las interacciones entre aguas subterráneas y el océano en la costa uruguaya.

Palabras clave: Descarga submarina de aguas subterráneas, Río de la Plata, agua salobre, América del Sur.

We thank Dr. Calliari for his constructive and insightful comments, which emphasize the potential role of Submarine Groundwater Discharge (SGD) in modulating coastal salinity and biogeochemistry along the Uruguayan coast. We agree that SGD may contribute locally to the freshwater balance and deserves further attention in future studies. The recognition of this potential process highlights the need for targeted field observations and modeling efforts aimed at quantifying SGD fluxes and their variability in Uruguay's nearshore zone.

However, based on current evidence and our data, we consider it unlikely that SGD represents a primary driver of salinity variability at La Paloma. Our analysis focused on large-scale, physically constrained mechanisms—namely, the advection of the RPP and regional wind forcing—because these processes are well established in the literature and can be quantitatively constrained from long-term oceanographic observations and modeling studies.

The Río de la Plata drainage basin, spanning over 3 million km², delivers an average freshwater discharge of approximately 2.6×10^4 m³ s^{-1}, generating one of the largest estuarine plumes in the world (Piola et al., 2005; Möller et al., 2008). The plume has been shown to propagate tens to hundreds of kilometers offshore, depending on the prevailing wind conditions and regional circulation (Simionato et al., 2001; Acha et al., 2008, Piola et al. 2008). Its dynamics have been repeatedly demonstrated to control the physical and biogeochemical structure of the continental shelf off Uruguay (Piola et al. 2008, Calliari et al., 2009; Calliari et al., 2018; Jackson et al., 2021). The RPP strongly modulates salinity gradients, nutrient distributions, and phytoplankton productivity along the southwestern Atlantic (Piola et al. 2008, Acha et al., 2008; Calliari et al., 2018), linking continental discharge variability with ecosystem processes at regional scales.

By contrast, the evidence for significant SGD inputs along the Uruguayan coast remains absent. No direct measurements of SGD fluxes (via seepage meters, radium/radon isotopes, groundwater piezometry, or marine continuous resistivity profiling (Tur-Piedra et al. 2024)) have yet been reported for this region (Paiva & Niencheski, 2018). While analogies to the Patos Lagoon barrier system in southern Brazil (Niencheski et al., 2007) suggest that SGD may occur under similar geological conditions, the hydrogeological setting of eastern Uruguay is highly heterogeneous, with variable aquifer confinement and uncertain hydraulic gradients toward the sea. Without local measurements, any quantitative attribution of SGD's role remains speculative.

Quantitatively assessing the contribution of SGD to coastal salinity variability would require a comprehensive coastal salt budget—including horizontal and vertical salt transport, precipitation, evaporation, and subsurface inputs—together with reliable estimates of groundwater fluxes. None of these datasets are currently available for the Uruguayan coast. In addition, a global synthesis by Luijendijk et al. (2020) estimated that fresh SGD contributes on average only ~0.6% (range 0.004–1.3%) of the total global riverine freshwater input to the ocean, implying that globally, SGD is a minor component of the marine water balance, albeit with potentially strong local relevance in specific hydrogeological contexts.

The low explanatory power (<10%) of the correlation between La Paloma salinity and Río de la Plata discharge reported in our study does not necessarily indicate dominance of alternative mechanisms such as SGD. Rather, it reflects the distance of La Paloma from the estuarine mouth, where the Río de la Plata Plume primarily accounts for the large, episodic drops in salinity associated with extreme discharge events. In contrast, smaller-scale fluctuations in salinity at the site are likely influenced by a combination of local and regional factors, including wind-driven mixing, small scale variability, and potentially submarine groundwater discharges (SGD) and even the occasional discharge from the Rocha lagoon as a point source of brackish water. These processes may modulate background salinity on shorter time scales, yet do not diminish the fundamental role of the plume as the dominant driver of large-scale salinity variability along the Uruguayan coast.

We share Dr. Calliari's perspective that initiating dedicated SGD studies in Uruguay would significantly advance our understanding of coastal hydrology and biogeochemistry. We hope that our 25-year dataset provides a valuable reference baseline for these future efforts.

References

Acha, E. M., Mianzan, H., Guerrero, R., Favero, M., & Bava, J. (2008). Marine fronts at the continental shelves of austral South America: Physical and ecological processes. **Journal of Marine Systems**, 79(1–2), 9–21.

Calliari, D. L., Brugnoli, E., Ferrari, G., & Vizziano, D. (2009). Phytoplankton distribution and production along a wide environmental gra-

dient in the South-West Atlantic off Uruguay. **Hydrobiologia**, 620(1), 47–61.

Calliari, D. L., Gómez-Erache, M., Vizziano, D., & Alonso, C. (2018). Near-surface biogeochemistry and phytoplankton carbon assimilation in the Río de la Plata Estuary. In Hoffmeyer, M. S., Sabatini, M. E., Brandini, F., Calliari, D., & Santinelli, N. H. (Eds.), **Plankton Ecology of the Southwestern Atlantic** (pp. 135–158). Springer.

Jackson, L. C., et al. (2021). Continental shelf processes and salinity variability in the southwestern Atlantic Ocean. **Ocean Science**, 17(3), 845–862.

Luijendijk, E., Gleeson, T., & Moosdorf, N. (2020). Fresh submarine groundwater discharge insignificant globally but locally important. **Nature Communications**, 11(1), 1230. https://doi.org/10.1038/s41467-020-15064-8

Möller, O. O., Piola, A. R., Freitas, A. C., & Campos, E. J. D. (2008). The effects of river discharge and seasonal winds on the shelf off southeastern South America. **Continental Shelf Research**, 28(13), 1607–1624.

Niencheski, L. F. H., Windom, H. L., Moore, W. S., & Jahnke, R. A. (2007). Submarine groundwater discharge of nutrients to the ocean along a coastal lagoon barrier, Southern Brazil. **Marine Chemistry**, 106(3–4), 546–561.

Paiva, M., & Niencheski, F. H. (2018). Advances of submarine groundwater discharge studies in South America. **Journal of the Brazilian Chemical Society**, 29(5), 916–924.

Piola, A. R., Möller, O. O., Guerrero, R. A., & Campos, E. J. D. (2005). Variability of the subtropical shelf front off eastern South America: Winter 2003 frontogenesis. **Geophysical Research Letters**, 32(3), L03608.

Piola, A. R., Romero, S. I., & Zajaczkovski, U. (2008). Space–time variability of the Plata plume inferred from ocean color. **Continental Shelf Research**, 28(13), 1556–1567.

Simionato, C. G., Guerrero, R. A., & Piola, A. R. (2001). Tidal currents and residual flow at the Río de la Plata estuary. **Continental Shelf Research**, 21(1), 97–118.

Tur-Piedra, J., Ledo, J., Diego-Feliu, M., Queralt, P., Marcuello, A., Rodellas, V., & Folch, A. (2024). Spatial and seasonal fluctuations in fresh submarine groundwater discharge revealed by marine continuous resistivity profiling. **Scientific Reports**, 14(1), 24854.

Received: October 2025
Published: December 2025