Working Group Proposal to SCOR 2023

Oceanic Salt Intrusion into Tidal Freshwater Rivers (SALTWATER)

Co-Chairs:

Ming Li
University of Maryland Center for Environmental Science, USA
mingli@umces.edu

Hans Burchard
Leibniz Institute for Baltic Sea Research, Germany
hans.burchard@io-warnemuende.de

Abstract

About two-thirds of global freshwater supplies come from surface waters such as the tidal fresh region of estuaries. Although much is understood of the salt transport by residual circulation and shear dispersion in the mesohaline region of estuaries, little is understood of the salt transport in the oligohaline and tidal fresh regions of estuaries where tidal dispersion and river flows are expected to be more important. This gap in scientific understanding has recently been exposed in a number of headline news reports on the salt contamination of drinking water supplies in tidal rivers. Three outstanding issues have been identified. First, there is a paucity of observational data to document the salt intrusion into tidal rivers. Second, the riverine/seawater mixture includes dissolved salts produced during runoffs from the land surface and has a relative salt composition different from that of seawater. Third, hydrodynamic models used to study the saltwater intrusion employ a number of numerical schemes, varying grid resolutions, and different parameterization schemes for unresolved subgrid processes. Given the general lack of observational data for the model validation, it is unclear how well these models capture the salt intrusion.

This SCOR Working Group will bring together an international team of experts to discuss recent research on the saltwater intrusion into tidal rivers around the world. Our goal is to develop a global synthesis of this emerging topic, discern the roles of climate change and local anthropogenic processes, and develop tools for observing, modeling and analyzing salt intrusion into tidal rivers.

1. Scientific Background and Rationale

1.1 Problem statement

About two-thirds of global freshwater supplies come from surface waters, such as the tidal fresh region of estuaries. Prolonged drought and rapid sea level rise in a changing climate create a vulnerable combination that increases saltwater intrusion into tidal rivers. Salt contamination of drinking water intakes has made headline news around the world. For example, a temporary emergency barrier was placed on the West False River in 2021 to slow down salt intrusion from the San Francisco Bay. Salt intrusion also occurred in the Changjiang River in 2022, contaminating drinking water supplies and leading to panic stockpiling of bottled water in Shanghai. The 2022 drought in Europe led to strong salt intrusion into the Rhine River and triggered emergency water conservation measures in Netherlands.

Indeed, salt intrusion into tidal rivers is a global problem affecting many countries. Several rivers in Africa are affected, including the Pungue River between Zimbabwe and Mozambique and the Incomati River in southeast Africa (Hoguane 2000). The impact on Europe spreads from the Mediterranean countries to Western Europe, including the Po River Delta in Italy (Bellafiore et al. 2021), the Garonne, Loire and Seine Rivers in France, the Rhine River in Netherlands, and the Elbe, Weser and Ems estuaries in Germany (Kolb et al. 2022). Many of Asia's mega cities are vulnerable to salt contamination of water supplies, including the Changjiang River (Zhu et al. 2020) and the Pearl River (Payo-Payo et al. 2022) in China, the Indus River Delta in Pakistan, and the Ganges-Brahmaputra-Meghna Delta in India (Bricheno et al., 2021). In South America, salt intrusion affects the Valdivia River in Chile (Garcés-Vargas et al. 2020), the São Francisco River in Brazil and the Magdalena River in Colombia (Ospino et al. 2018). In North America, the salt intrusion affects rivers that drain into all three coasts, including the Delaware River, the Hudson River (Hogland et al. 2020), San Francisco Bay–Delta and the Papaloapan River. Despite major metropolitan regions around the world being threatened by the saltwater intrusion, we have little understanding of the commonalities and distinctive challenges faced by these systems.

Tidal rivers, part of a river-estuary system where there are strong interactions between tides and river flow, are a poorly studied nexus between physical oceanography and hydrology (Hoitink and Jay 2016). Most of our understanding of estuarine salt transport is based on studies in the mesohaline region of estuaries where estuarine residual circulation and shear dispersion typically dominate salt transport (Geyer and McCready 2014). In contrast, tidal pumping, oscillatory shear dispersion, lateral trapping, and riverine transport are expected to be more important in driving salt transport in the oligohaline and tidal fresh zones, but these processes are not well understood and quantified (Fig. 1). Moreover, the effects of salt inputs from land (Kaushal et al., 2021) and estuarine temperature variations (Kobayashi et al. 2022) on salt intrusion are mostly unknown. Recently, an analysis approach using the isohaline coordinates has yielded new insights into estuarine circulation and produced a relation that links the volume-integrated mixing to the exchange flow salinity classes (MacCready et al. 2018; Burchard et al. 2019). A further extension produced a simpler expression for the mixing within an estuarine volume bounded by an isohaline (Burchard 2020). However, such analysis has not yet been applied/extended to the oligohaline and tidal fresh regions where salinity approaches zero.

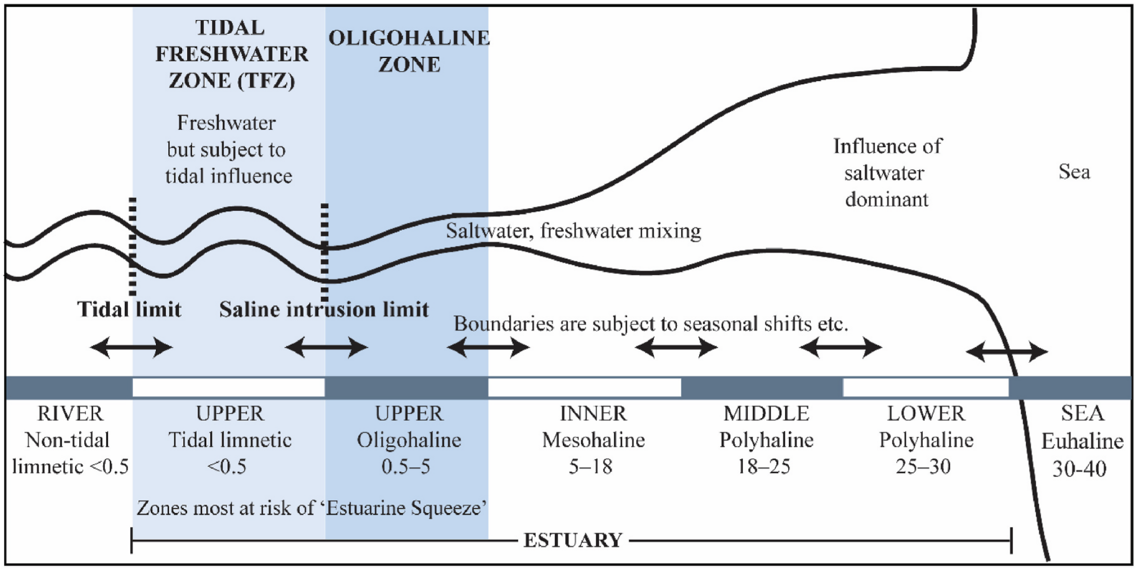

Fig. 1. A schematic of an estuary showing different subregions including the tidal freshwater zone where many drinking water intakes are located.

Tidal rivers are also hotspots of climate change impact. They are affected both by changing river flow regimes and by rising sea levels. While extended drought reduces the freshwater flows, sea level rise and the associated amplification of tidal ranges enhances the saltwater intrusion (Hilton et al. 2008; Lee et al. 2017). Moreover, local anthropogenic activities such as channel deepening to accommodate larger container ships have amplified tides and salt intrusion (Ralston and Geyer 2019). Often, increased salt intrusion leads to an upstream shift of the estuarine turbidity zone, which can in turn modify tidal propagation (Jalón-Rojas et al. 2018). Regulated water storage and release from reservoirs are commonly used to manage salt intrusion, but sediment trapping behind dams may lead to seabed erosion and amplify salt intrusion into estuaries (Gong et al. 2022). The combined effects of local anthropogenic activities and climate changes are occurring in estuaries worldwide but these effects are little understood.

Despite the global impacts, there have been few process-oriented investigations into the physical mechanisms that regulate the salt transport and distribution from the oligohaline region (0.5 – 5 g/kg) to the tidal fresh zone (< 0.5 g/kg) in estuaries. In the later region salinity and density gradients decrease to small values, such that processes driving estuarine exchange flows may not be relevant. Small density gradients due to temperature and riverine salts may affects the dynamics of salt intrusion. Several outstanding issues have been identified. First, there is a paucity of observational data that could provide a full documentation of salt intrusion into the tidal rivers. Most of our current knowledge is based on monitoring chloride concentration and specific conductance at a limited number of water intakes at water treatment plants, and yet such monitoring data are often buried in grey literature or not made publicly available.

Second, the salt content of the riverine/seawater mixture includes dissolved salts in rivers that are produced during runoffs from the land surface (Kaushal et al. 2018). It has a relative salt composition different from that of seawater (Pawlowicz 2015). Standard seawater equation of state may not be accurate enough for calculating water density distributions (Pawlowicz and Feistel 2011). Furthermore, there is no uniform standard for measuring salts in tidal rivers. Reports of salt contamination of freshwater supplies are based on measurements of various quantities, including specific conductance, chloride concentration, and sodium concentration etc.

Third, hydrodynamic models used to study saltwater intrusion employ a number of numerical schemes, varying grid resolutions, and different parameterization schemes for subgrid processes. Given the general lack of observational data for the model validation, it is unclear how well these models capture the salt intrusion. Small-scale (10-100 m) interactions between the flow and bathymetry affect the drag, mixing and dispersion but are rarely simulated in these estuary-wide models. An additional challenge is projecting the impacts of climate change on saltwater intrusion. Many studies simulate the effects of sea level rise using a "bathtub" approach, but this is unlikely to represent the actual morphological evolution.

1.2 Rationale for the SCOR working group

Over the past few years there has been active research activities on the salt intrusion problem, but many are site-specific studies. Little is known of the commonalities among these systems. With the salt contamination of freshwater supplies making headline news, it is urgent and timely to bring together an international community of researchers to share and discuss recent studies on the saltwater intrusion.

The proposed study topic is so rich and complex that it is impossible to address it at a session in a conference or even a dedicated workshop. It requires sustained discussions over time. The SCOR Working Group (WG) provides an ideal platform for bringing together an international team of experts to engage in regular discussions over 4 years. The WG members have in-depth knowledge of various estuaries and tidal rivers in North America, South America, Europe, Asia and Africa. By exchanging insights on these diverse systems, we aim to gain new understanding of the fundamental processes that underpin all these systems.

2. Terms of Reference (ToR)

This SCOR WG will synthesize case studies of salt intrusion into tidal rivers around the world and develop best practice approaches for observing, modeling and analyzing the salt intrusion. The overall goal is to advance scientific understanding and produce actionable scientific information. Specifically, it aims to:

ToR1 Conduct a comparative analysis of selected case studies on the salt intrusion into tidal fresh rivers, identify gaps in knowledge and priorities for future research, and gain a better understanding of the physical processes that drive the salt transport from the oligohaline to tidal fresh zones of estuaries.

ToR2 Synthesize existing modeling studies of estuaries and tidal rivers and produce a best practice manual for model configurations such as grid resolutions and mixing/dispersion parameterizations.

ToR3 Analyze chemical composition of riverine/oceanic water mixtures and develop rules for converting specific conductance to chloride concentration. Develop a best practice manual for measuring salts in tidal rivers.

ToR4 Construct a global dataset of long-term records of salt intrusion in tidal rivers, such as the time series of chloride concentration and specific conductance. Conduct data analysis to identify conditions conducive to enhanced salt intrusion in different types of estuaries. Build a Github for sharing the data analysis programs.

ToR5 Develop a global synthesis of oceanic salt intrusion into tidal rivers and quantify the roles of global climate change and local anthropogenic processes.

ToR6 Build capacity, share knowledge and transfer technical skills, particularly to scientists in developing nations.

3. Working plan

To deliver ToR1
We will collate existing studies on salt intrusion into tidal rivers. Initially each WG member will lead case studies in Asia, Europe, Africa, South America and North America. We will then identify similarities and commonalities among these systems and group them in terms of physical characteristics and forcing regimes such as the magnitudes of river flow and tidal range, the topography of estuaries and rivers (e.g. dendritic versus axonic, sinuosity of rivers, presence or absence of intertidal flats and salt marshes) and estuarine stratification strength. We will analyze how different mechanisms (e.g. tidal pumping, oscillatory shear dispersion, lateral trapping, and riverine transport) affect the salt transport from the oligohaline to the tidal fresh zone. We will also investigate the dynamic role of riverine salinity and temperature. Gaps in understanding and key unknowns will also be identified.

To deliver ToR2
We will assemble the modeling papers on salt intrusion. A large volume of papers has been published in recent years. We will perform a literature review in the Web of Science and conduct a meta-analysis by framing queries and searches. This will be complemented by model inter-comparison exercises on selected estuaries and tidal rivers where multiple models are available. These analyses will reveal how numerical schemes, grid resolutions and choices of subgrid-scale parameterization schemes affect the model's prediction. We will produce a best practice manual for the model configuration.

To deliver ToR3
We will collect the records of salt measurements in tidal rivers. The equation of state for seawater will be adapted to include the dissolved salts in rivers produced by chemical weathering and human inputs. Many rivers in Europe and North America have experienced significant freshwater salinization whereas most of Africa and significant regions of South America and Asia have older soils that can store major ions and salts over a longer time. We will select the rivers that have

experienced varying degrees of freshwater salinization, analyze the chemical composition of the riverine/seawater mixture, and develop a modified equation of state. A best practice manual will be written up to provide guidance on the salt measurements in tidal rivers.

To deliver ToR4

We shall extract from the case studies long-term time series of chloride concentration and specific conductance in tidal rivers and archive the dataset in an open-access repository. This may involve digitalizing published data and assembling data from unpublished reports and monitoring programs at drinking water intakes. The WG members will be assigned to collect the data that are most closely related to their research. We will then construct a global dataset of long-term records of salt intrusion in tidal rivers. We will also incorporate supplementary information on environmental changes that may have contributed to the long-term changes in the salt concentration, such as long-term records of mean sea level, changes in bathymetry and coastline due to engineering activities, changes in tidal range and river flow, and regional climate and climate variability etc. We will analyze these time series and supplemental data to better understand salt intrusion under different estuarine conditions, ranging from well-mixed estuaries to highly stratified salt wedge and bar-built estuaries.

To deliver ToR5

We will discuss the findings from the case studies and develop a global synthesis of salt intrusion into tidal rivers. Specifically, we will quantify the impacts of global climate change (e.g. drought and sea level rise) and local anthropogenic processes (e.g. channel deepening, shoreline hardening, river flow regulation and diversion) on the salt intrusion. Given the diversity of estuaries and tidal rivers, we may group them into different categories and conduct cross-comparisons. For example, we may compare large rivers with high river flows and strong tides, dendritic delta systems, rivers and estuaries in arid climate that may turn hypersaline during the dry seasons, and systems that have been subjected to major engineering activities.

To deliver ToR6

We will organize online workshops and in-person tutorials on salt measurements, data analysis and numerical modeling. We will establish peer-to-peer mentoring of early career scientist and promote research collaborations between the developed and developing countries.

Timeline:

Year 1 – 2024

Hold bi-monthly zoom meetings to review the existing observational and modeling studies of salt intrusion into tidal rivers around the world (ToR 1 and 2). This may alternate with the bi-monthly virtual panel discussions that are being planned for a related conference project on the salt contamination of water supplies funded by the US National Science Foundation (NSF) (Li as the lead PI). The SCOR WG members will serve as panelists at these virtual discussions and interact with a larger group of oceanographers, hydrologists and water resource managers. A workshop will be held in October 2024, possibly associated with the Physics of Estuaries and Coastal Seas (PECS) which estuarine oceanographers including most of the WG members attend regularly. Prepare an initial review/perspective paper summarizing the current research on the salt intrusion into tidal rivers and identifying key unknowns and future research directions (Deliverable 1).

Year 2 – 2025
Hold bi-monthly zoom meetings to review the modeling studies of salt intrusion and write up the review paper on the modeling (Deliverable 2). Produce the best practice manual for model configuration (Deliverable 3) and offer an on-line tutorial (ToR 2 and 6, Deliverable 10).

Year 3 – 2026
Hold bi-monthly zoom meetings to review the existing observational techniques, analyze the riverine/oceanic water mixtures for a revised equation of state, and assemble a global dataset of salt measurements in tidal rivers (ToR 3 and 4, Deliverable 6). Complete the methods paper and best practice manual on salt measurements (Deliverables 4, 5, 10, ToR 6). Hold the second SCOR workshop in October 2026, possibly associated with the PECS conference.

Year 4 – 2027
Hold bi-monthly zoom meetings to develop a global synthesis of salt intrusion into tidal rivers and prepare the case-study manuscripts for a special journal issue (ToR 5, Deliverables 8 and 9). Hold the final workshop, conduct a review of salinity management in tidal rivers, and organize a side event at the UN Ocean/Water Conference (ToR 6 and Deliverable 10).

4. Deliverables

From ***ToR1***:

1. An initial review/perspective paper summarizing the current research on salt intrusion into tidal rivers, highlighting the key unknowns and suggesting priority future research directions.

From ***ToR2***:

2. A review paper on modeling salt intrusion into estuaries and tidal rivers.
3. A best practice manual for model configuration.

From ***ToR3***:

4. A methods paper on measuring salts in tidal rivers and developing a revised equation of state for the riverine-seawater mixture.
5. A best practice manual for measuring salts in tidal rivers.

From ***ToR4***:

6. A global dataset of long-term records of salt intrusion into tidal fresh rivers and an open-access data repository.
7. A GitHub repository for the data analysis codes used to analyze and interpret the salt intrusion into tidal rivers.

From ***ToR5***:

8. A high-impact paper to provide a global synthesis of salt intrusion in tidal rivers and discern the effects of global climate change and local anthropogenic activities.
9. A special journal issue on the case studies of salt intrusion into estuaries and tidal rivers around the world.

From ***ToR6***:

10. On-line training courses and resources (e.g. video recordings, data and GitHub repositories) on modeling, data-analysis and observational approaches to study salt intrusion for scientists and water resource managers, particularly those from developing nations.

5. Capacity Building

This SCOR WG will bring together scientists to share knowledge, insights and lessons. The twenty WG members come from 17 countries in Asia, Europe, Africa, and South and North America, consisting of 7 developed countries and 10 developing countries. Our reach to developing countries is not limited to these 10 countries, however. Some of our WG members have established international collaborations or are leading regional or international programs. For example, John Largier (USA) has long term collaborations with African countries such as South Africa, Senegal and Mozambique. Arnoldo Valle Levinson (USA) has mentored many young scientists in Central and South America. We will leverage these international relationships to foster knowledge sharing and research collaborations.

We plan to promote capacity building by pursuing the following activities:

5.1 Enhancing research capacity in developing countries by fostering research partnerships

Although estuaries are highly diverse, there are similarities among certain types of estuaries in which research progress in some can inform understanding of less studied systems. For example, the Hudson River, the São Francisco River, the Lorie River, the Rhine River, the Seine River, the Changjiang River, the Mekong River, and the Fraser River have all undergone significant bathymetric changes due to human activities such as channel deepening, shoreline hardening, land reclamation and land use changes. A comparative study of these systems may shed lights on the effects of local anthropogenic processes on the salt intrusion. Another group of estuaries well suited for a comparative study are estuaries located in the arid climate, including the Pearl River Delta, the Indus River Delta, the Po River Delta, the Guadalquivir River, and San Francisco Bay-Delta. A third group consists of relatively smaller estuaries where mouth closure or shoaling can trap a lower layer of saline water and lead to strong stratification, such as those in the mountainous coasts in South Africa, Chile and California. The case studies and synthesis proposed for this SCOR WG will identify these common characteristics. Subgroups of the WG will be formed to collaborate on these different types of estuaries and form research partnerships between the developing and developed nations. This collaboration can take various forms, such as joint authorships on papers or joint applications for research grants to international programs.

5.2 Training the next-generation modelers on salinity management

Many countries rely on numerical models to develop strategies to manage salt contamination of water supplies in tidal rivers, particularly in anticipation of extended drought and rapid sea level rise under climate change. The synthesis paper and the best practice manual for modeling salt intrusion into tidal rivers will provide much needed guidance on the appropriate use of numerical models in designing salinity management strategies. Some of the WG members are seasoned modelers and will take a lead in organizing online tutorials that will be open to everyone. Towards the end of year 2, we plan to offer a live zoom tutorial which will be recorded and made available online. Depending on the feedback from audiences, we may give another online modeling tutorial that will include an extensive Q&A session.

5.3 Capacity building on salinity measurements in tidal fresh rivers

Currently reports of salt contamination of water supplies are based on measurements of various quantities. The proposed methods paper and best practice manual on salt measurements will help set a standard approach for detecting salt contamination of water supplies. The manual and paper will be made available to everyone. Some of the WG members have extensive experience in observational techniques and will take a lead in developing the online training tutorials. In year 3 we plan to offer a live zoom tutorial and make the recording available. A follow-up Q&A session will also be offered in year 4 to solicit feedback from the user community.

5.4 Enhancing data analysis skills

We will build an open-access data repository to store records of salt intrusions into tidal rivers. The WG members will initially assemble a global dataset from their own sources, demonstrating the value of such salinity/chloride time series. We will then invite submissions of relevant data records from the international community and encourage investments in new time series. We will also develop and share tools for the data analysis such as machine learning algorithms. The salinity time series will be accompanied by the time series of river flows, sea level fluctuations, and winds as well as other environmental changes, with the goal to interpret the salinity time series data, identify the conditions conducive to the salt intrusion, and develop empirical statistical models for forecasting salt intrusion. A Github repository will be set up to share computer codes and will be made freely available.

5.6 Mentoring early-career scientists

Eight WG members are early-career scientists (ECRs), consisting of 5 female members and 7 members from developing countries. We will pair them up with senior WG members with similar research interests for one-to-one peer mentoring as well as group meetings devoted solely to issues related to career developments. The senior WG members will listen to the concerns raised by the ECRs and share their successes and lessons in fund-raising and peer-reviewed publications. The mentoring could also have a more technical focus. For example, senior modelers (Burchard, Li, Pietrzak, Wu, Gong, Bellafiore) could team up with ECR modelers (Cordona, Vijith, Sanay, Ndoye) to discuss how to develop research projects that has a modeling focus. Senior observational oceanographers (Valle-Levinson, Largier, Pawlowicz, Diez-Minguito, Carlos Augusto Schettini) could team up with ECR observationalists (Rojas, Williams, Zia, Guerra) to explore how to develop a field program.

5.7 Enhancing salinity management strategies through knowledge sharing at UN

Although SCOR WGs focus primarily on advancing the oceanographic research, the scientific advances to be made in this WG will not only build scientific capacity but also may contribute to better strategies for managing freshwater supplies under climate change. A common salinity management approach is the storage and regulated releases of freshwater from reservoirs during low river flows, but this approach is becomeing difficult to implement in regions featuring a long duration of drought punctuated by short periods of intense precipitation (e.g. California and Mediterranean-like climate). Alternative measures have been implemented. For example, a pipeline has been constructed in the Greater Bay Area, China to transport water from upstream reservoirs to downstream cities such as Macau and Zhuhai. Physical barriers, whether temporary or permanent, have been used to separate freshwater from oceanic water, but at the risk of jeopardizing ecosystems and fish migration. Other approaches involve water resource planning rather than engineering. For example, the U.S. Army Corps of Engineers is studying whether to release water from a Pennsylvania reservoir to the Delaware River during times of drought. Additional options include building desalination plants, curbing water consumption by industrial users such as nuclear power plants and agriculture, or even moving drinking intakes farther upstream. All these water management strategies are costly and involve tradeoffs and difficult decisions.

Another potential but often overlooked mitigation strategy is the management of saltwater intrusion from the ocean side where this SCOR WR is well positioned to contribute. Tides and tidal-induced dispersion are ultimately responsible for the salt intrusion into tidal rivers. It is now well known that channel deepening increases tidal ranges whereas land reclamation/infilling reduces tidal ranges, such as in the Changjiang River estuary. This prompts an economic evaluation on the costs and benefits of ports and shipping versus those of water supplies. Similarly, hardening shorelines using sea walls and levees to protect against coastal flooding tends to amplify tides whereas nature-based flood mitigations such as salt marshes and water retention ponds can reduce tides and hence the upstream salt transport. Consequently, the mitigation strategy developed to bolster coastal resilience against sea level rise and coastal flooding must be weighted against the salinity management strategy intended to protect water supplies further upstream.

We will discuss these strategies and summarize our findings on salinity management as a side event at a UN Ocean/Water Conference in year 4 (2027). Annual UN Ocean Conferences are hosted by different countries: Panama (2023), Spain (2024), and France (2025). We will reach out to UNESCO and conference organizers, and inquire about the possibility of a side event at the UN Ocean Conference in 2027. UN holds its first-ever water conference in New York City in March 2023. We will also make inquires to the organizers of the UN Water Conference and explore the feasibility of incorporating our theme. This outreach to UN will serve multiple purposes: (1) raise the awareness of this issue as salt contamination has not received as much attention as other water quality issues (e.g. metals, coliforms, harmful algal blooms) in some countries; (2) promote research and monitoring of salt intrusion across both developing and developed countries; (3) provide a source of reliable and actional information for countries that are resource-limited.

6. Working Group composition (as table).

This WG has expertise in the fields of estuarine and coastal oceanography, climate change, anthropogenic impacts on estuaries, ocean observations, data analysis, numerical modeling, and interdisciplinary research on water quality.

Geographical spread: The 20 members originate from 17 countries, including 7 developed and 10 developing countries.

Participation of early-career researchers: Early-career researchers (ECRs) are well represented in our working group, with 3 ECRs among the Full members (Cardona, Guerra, Jalon-Rojas), and 5 ECRs among the Associate members (Ndoye, Sanay, Vijith, Williams, Zia).

Gender balance: Our WG is comprised of 4 female and 6 male Full members, and 3 female and 7 male Associate members. Five out of 8 ECRs are female. Overall, 35% of members are female, hence moderately imbalanced but well above the average percentage of females (20%) in Earth Sciences. Furthermore, our representation of women at 35% is significantly higher than the percentage of women in prestigious roles such as journal editorial board members (15% women).

Full Members

Name	Gender	Place of work	Expertise relevant to proposal
Ming Li	M	University of Maryland Center for Environmental Science, Co-Chair. **USA**	Estuarine and coastal dynamics, regional impacts of climate change, interdisciplinary research on water quality
Hans Burchard	M	Leibniz Institute for Baltic Sea Research, Co-Chair. **Germany**	Estuarine and coastal physics, anthropogenic impacts on coastal oceans, sediment dynamics, turbulence modeling, ocean modeling
Julie Pietrzak	F	Delft University of Technology. **Netherlands**	Physical oceanography, shelf and coastal dynamics, salt intrusion into estuaries
Isabel Jalon-Rojas	F	Bordeaux University. **France**	Coastal oceanography, morphodynamics, impacts of climate change on estuaries
Yuley Cardona	F	Universidad Nacional. **Colombia**	Ocean modeling, mesoscale processes, estuarine dynamics
Carlos Augusto Schettini	M	Universidade Federal do Rio Grande. **Brazil**	Dynamics of estuaries, coastal plumes and inner shelf, observations
Gisselle Guerra	F	Universidad Tecnologica de Panama. **Panama**	Environmental and coastal engineering, salt intrusion
Rich Pawlowicz	M	University of British Columbia. **Canada**	Coastal oceanography, observations, salinity measurements
Antonio M. Hoguane	M	Eduardo Mondlane University. **Mozambique**	Estuaries, hydrology, climate change
Wenping Gong	M	Sun Yatsen University. **China**	Modeling and field measurements of saltwater intrusion

Associate Members

Name	Gender	Place of work	Expertise relevant to proposal
John Largier	M	University of California, Davis. **USA**	Estuarine dynamics, field observations, data analysis

Arnoldo Valle-Levinson	M	University of Florida. **USA**	Coastal hydrodynamics, sea level rise, data collection & analysis, salt intrusion
Debora Bellafiore	F	National Research Council - Institute of Marine Sciences **Italy**	Modelling, coastal and transitional environment oceanography
Manuel Diez-Minguito	M	University of Granada. **Spain**	Environmental fluid dynamics, estuarine dynamics
Ibrahim Zia	M	National Institute of Oceanography. **Pakistan**	Physical oceanography, sea level rise, salt intrusion
Vijayakumaran Vijith	M	Cochin University of Science and Technology. **India**	Salinity dynamics of monsoonal estuaries
Hui Wu	M	East China Normal University. **China**	Estuarine dynamics, coastal circulations, biophysical interactions
Rosario Sanay	F	Universidad Veracruzana. **Mexico**	Coastal oceanography, microtidal salt wedge estuaries, data analysis
Megan Williams	F	Pontificia Universidad Católica de Chile. **Chile**	Estuarine dynamics, salt transport, field observations
Siny Ndoye	M	Université Amadou Mahtar Mbow. **Senegal**	Coastal oceanography, ocean modeling, climatology

7. Working Group contributions

Ming Li is a physical oceanographer who studies the impacts of climate change on estuaries and conducts interdisciplinary research on water quality, hypoxia, harmful algal blooms and ocean acidification. He has recently established a Research Coordination Network to advance interdisciplinary research for building resilient communities and infrastructure in estuaries and bays in the US and is leading a NSF-funded synthesis of salt contamination of water supplies in tidal rivers.

Hans Burchard is a coastal ocean hydrodynamic modeler who has developed and applied numerical models of various complexity to understand mixing and exchange flow in estuaries. He has recently developed diahaline mixing concepts that explain processes of salt intrusion into estuaries and consequences for sediment transport.

Julie Pietrzak is a physical oceanographer who has worked on shelf seas and ocean basins using field observations and numerical models. She is currently leading a large Dutch research project titled SALTISolutions "Salt Intrusion in urbanising deltas – Solutions" that seeks to understand and mitigate salt intrusion in the Dutch Delta under current and future climate conditions.

Isabel Jalon-Rojas studies the hydro-morpho-sedimentary evolution of tidal rivers, with a focus on French hyper-turbid systems. She investigates the impact of climate variability and human activities on the retroactions between hydrodynamics, sediment transport, morphology and saltwater intrusion.

Yuley Cardona uses various numerical models to understand regional and coastal ocean processes, with a particular interest in mesoscale ocean dynamics and their connection with tracer transport. She has also investigated transport of nutrients and sediment in the Mississippi and Magdalena river plumes.

Antonio Hoguane conducts interdisciplinary research on tropical estuaries including physics, ecology, and energy in these systems. He has also worked on salt intrusion and environmental flows for the health and integrity of marine coastal ecosystems.

Richard Pawlowicz studies river plumes and salt wedge dynamics, especially in the Fraser River, Canada where concerns are being raised about the effects of deepening the river to expand port facilities. He is also a world-leading expert on the relationship between the chemical composition of salts in rivers and coastal seawaters, and their density and conductance, co-authored the TEOS-10 standard, and is the current chair of the Joint SCOR/IAPSO/IAPWS Committee on the Properties of Seawater (JCS).

Carlos Schettini uses *in-situ* observational and remote sensing approaches to investigate dozens of estuaries along the coast of Brazil, including the issue of saltwater intrusion. He was a technical advisor in a large project seeking to solve the problem of water capture for the City of Itajai (Brazil).

Gisselle Guerra is an environmental and coastal engineer who studies the saltwater intrusion into the estuaries on the Pacific Coast of Panama. She is a member of Panamanian Research System and a lead researcher on climate change and coastal related projects.

Wenping Gong has expertise in numerical modelling, field measurements and theoretical analysis, with a focus on estuaries and coastal oceans. Recently he has investigated how climate change and human activities affect the salt intrusion into the Pearl River estuary.

8. Relationship to other international programs and SCOR Working groups

UN Decade of Ocean Science for Sustainable Development (2021-2030) seeks transformative ocean science solutions for sustainable development. This SCOR WG addresses Challenge 5 to generate knowledge and solutions to mitigate, adapt and build resilience to the effects of climate change since extended drought and sea level rise are two main drivers of salt intrusion into tidal rivers. The WG also addresses Challenge 6 to enhance community preparedness and resilience to climate and anthropogenic coastal hazards as salt contamination of water supplies affects the lives of many millions of people around the world.

The UN General Assembly convened a Water Conference in 2023, culminating in the development of the Water Action Agenda that calls for voluntary commitments to address the global water challenges. Safe-guiding water supplies in coastal regions has been recognized to be an important issue. The scientific advances to be made by this SCOR WG will help address this issue.

Rich Pawlowicz chairs the Joint Committee on the Properties of Seawater among SCOR, IAPSO and IAPWS which provides the official source of information about the Thermodynamic Equation of Seawater – 2010 (TEOS-10) adopted by the Intergovernmental Oceanographic Commission. The modified equation of state for the riverine/seawater mixtures to be developed in this WG will be added to TEOS-10.

Findings from this SCOR WG will be of interest to the International Centre for Advanced Studies on River-Sea Systems (DANUBIUS-RI), a pan-European distributed research infrastructure supporting interdisciplinary research on River-Sea Systems. Debora Bellafiore is a member of the Italian team working on a report assessing the impacts of saltwater intrusion on coastal communities.

Case studies of the delta systems in this WG will be of interest to the Mega Delta program endorsed by the UN Ocean Decade, involving comparative studies between the Chanjiang Delta, the Ganges Delta, the Indus Delta, Nile Delta and the Danube Delta.

This SCOR WG topic is closely related to the US NSF-funded conference project "salt contamination of water supplies in tidal rivers" that involves oceanographers as well as hydrologists (Ming Li as the PI). Through joint virtual panel discussions, the WG members can hear more about hydrological processes and water resource managements while the US researchers will be exposed to more case studies in other countries.

We will also seek collaborations with the World Association for Waterborne Transport Infrastructure (PIANC) which had a working group on saltwater intrusion mitigation in inland waterways.

This SCOR WG will also benefit smaller international projects, including a joint France-Canada (Quebec) EMPHASE program on hydro-sedimentary dynamics in harbor-estuaries (Isabel Jalon-Rojas), the Colombia-Germany collaboration on the Rio Magdalena Delta (Yuley Cardona), and the China-U.K.-Netherlands collaboration on the Pearl River estuary (Wenping Gong).

Related SCOR Working Groups are listed below:

SCOR Working Group 145. Modelling Chemical Speciation in Seawater to Meet 21st Century Needs (MARCHEMSPEC)

SCOR Working Group 127. Thermodynamics and Equation of State of Seawater

SCOR Working Group 122. Mechanisms of Sediment Retention in Estuaries

SCOR Working Group 121. Ocean Mixing

SCOR Working Group 111. Coupling Waves, Currents, and Winds in Coastal Models

9. Key References

Bellafiore, D. et al. 2021. Saltwater intrusion in a Mediterranean delta under a changing climate. *J. Geophys. Res.*, 126, e2020JC016437.

Bricheno, L.M. et al. 2021. Saline intrusion in the Ganges-Brahmaputra-Meghna megadelta. *Estuar. Coast. Shelf Sci.*, 252, 107246

Burchard, H. 2020. A universal law of estuarine mixing, *J. Phys. Oceanogr.*, 50, 81–93.

Burchard, H. et al. 2019. Mixing estimates for estuaries. *J. Phys. Oceanogr.*, 49, 631–648.

Garcés-Vargas, J. et al. 2020. Tidally forced saltwater intrusions might impact the quality of drinking water, the Valdivia River, Chile Estuary Case. *Water* 12(9): 2387.

Geyer, W.R., P. MacCready. 2014. The estuarine circulation. *Annu. Rev. Fluid Mech.,* 46, 175–197.

Gong, W. et al. 2022. The effects of mouth bar on salt intrusion in a partially mixed estuary. *J. Hydrol.*, 612:128261.

Hilton, T.W. et al. 2008. Is there a signal of sea-level rise in Chesapeake Bay salinity? *J. Geophys. Res.*, 113: doi:10.1029/2007JC004247.

Hoagland, P. et al. 2020. Salinity intrusion in a modified river-estuary system: an integrated modeling framework for source-to-sea management. *Front. Mar. Sci.* 7:425.

Hoguane, A.M. 2000. Salt intrusion in the Incomati River. Proceedings of the Second National Conference on Coastal Zones Research. Maputo, pp. 29e35.

Hoitink, A.J.F., D.A. Jay. 2016. Tidal river dynamics: Implications for deltas. *Rev. Geophys.*, 54, 240–272.

Jalón-Rojas, I. et al. 2018. To what extent multidecadal changes in morphology and fluvial discharge impact tide in a convergent tidal river. *J. Geophys. Res.* doi:10.1002/2017JC013466.

Kaushal, S.S. et al. 2018. Freshwater salinization syndrome on a continental scale. *Proc. Natl. Acad. Sci. USA*, 115:E574–E583.

Kaushal, S.S. et al. 2021. Freshwater salinization syndrome: From emerging global problem to managing risks. *Biogeochemistry*, 154, 255-292.

Kobayashi, S. et al. 2022. Seasonal changes of estuarine gravitational circulation: response to the annual temperature change. *Estuar. Coast.*, 45(3), 737-753.

Kolb, P. et al. 2022. Modelling the impact of anthropogenic measures on saltwater intrusion in the Weser estuary. *Ocean Sci.* 18(6), 1725-1739.

Lee, S.N. et al. 2017. Impact of sea-level rise on tidal ranges in Chesapeake and Delaware Bays. *J. Geophys. Res.*, 122, doi:10.1002/ 2016JC012597.

MacCready, P. et al. 2018. Estuarine exchange flow is related to mixing through the salinity variance budget. *J. Phys. Oceanogr.*, 48, 1375–1384.

Ospino, S. et al. 2018. Saltwater intrusion into a river with high fluvial discharge: a microtidal estuary of the Magdalena River, Colombia. *J. Coast. Res.*, 34, 1273–1288.

Pawlowicz, R. 2015. The Absolute Salinity of seawater diluted by riverwater. *Deep-Sea Res. I.*, 101:71-79.

Pawlowicz, R., R. Feistel 2012. Limnological applications of the Thermodynamic Equation of Seawater 2010 (TEOS-10). *Limnol. Oceangr.–meth.*, 10, 853-867.

Payo-Payo, M. et al. 2022. Multiscale temporal response of salt intrusion to transient river and ocean forcing. *J. Geophy. Res.*, *127*, https://doi.org/10.1029/2021JC017523

Ralston, D.K., W.R. Geyer. 2019. Response to channel deepening of the salinity intrusion, estuarine circulation, and stratification in an urbanized estuary. *J. Geophys. Res.*, 124, 4784–4802.

Zhu, J. et al. 2020, Dynamic mechanisms of an extremely severe saltwater intrusion in the Changjiang Estuary in February 2014. *Hydrol. Earth Sys. Sci.*, 24(10), 5043-56.

Appendix

Five key publications related to the proposal are indicated for each Full Member. Bold face is used to highlight the name of each WG member within her/his list of publications. The google scholar or research gate profiles of WG Full Members can be found by clicking the hyperlinks attached to their names.

Ming Li (Co-Chair):

Ross, A.C., R.G. Najjar, **M. Li**. 2021 A metamodel-based analysis of the sensitivity and uncertainty of the response of Chesapeake Bay salinity and circulation to projected climate change. *Estua. Coast.*, 44, 70-87, https://doi.org/10.1007/s12237-020-00761-w.

Liu, W., **M. Li**, R. Chant, E. Hunter and A. Valle-Levinson. 2018. Time and scale dependence in estuarine longitudinal dispersion. *J. Geophys. Res.*, doi: 10.1029/2017JC013397.

Lee, S.N., **M. Li** and F. Zhang. 2017. Impact of sea-level rise on tidal ranges in Chesapeake and Delaware Bays. *J. Geophys. Res.*, 122, doi:10.1002/ 2016JC012597.

Schulte, J.A., R.G. Najjar and **M. Li**. 2016. The influence of climate modes on streamflow in the Mid-Atlantic Region of the United States. *J. Hydrol.-Reg. Stud.*, 5, 80-99.

Ross, A.C., R.G. Najjar, **M. Li**, M.E. Mann, S.E. Ford and B. Katz. 2015. Influences on decadal-scale variations of salinity in a coastal plain estuary. *Estua., Coast. Shelf Sci.*, 157, 79-92.

Hans Burchard (Co-Chair):

Burchard, H. 2020. A universal law of estuarine mixing. *J. Phys. Oceanogr.*, 50, 81-93.

Burchard, H., X. Lange, K. Klingbeil, and P. MacCready, 2019. Mixing estimates for estuaries. *J. Phys. Oceanogr.*, 49, 631-648.

Kolb, P., Zorndt, A., **Burchard, H.**, Gräwe, U., and Kösters, F. 2022. Modelling the impact of anthropogenic measures on saltwater intrusion in the Weser estuary. *Ocean Sci.*, 18, 1725–1739.

Lange, X., **H. Burchard**, K. Klingbeil. 2020. Inversions of estuarine circulation are frequent in a weakly tidal estuary with variable wind forcing and seaward salinity fluctuations. *J. Geophys. Res.*, 125, 10.1029/2019JC015789.

Li, X., M. Lorenz, K. Klingbeil, E. Chrysagi, U. Gräwe, J. Wu, **H. Burchard**. 2022 Diahaline mixing and exchange flow in a large multi-outlet estuary with islands. *J. Phys. Oceanogr.*, 52, 2111-2127.

Julie Pietrzak:

Safar, Z., C. Chassagne, S. Rijnsburger, M. Ibanez Sanz, A.J. Manning, A.J. Souza, T. van Kessel, A. Horner-Devine, R. Flores, M. McKeon, **J.D. Pietrzak**. 2022. Characterization and classification of estuarine suspended particles based on their inorganic/organic matter composition. *Front. Mar. Sci.*, DOI 10.3389/fmars.2022.896163

Rijnsburger S., R. P. Flores, **J. D. Pietrzak**, K. G. Lamb, N. L. Jones5, A. R. Horner-Devine, A. J. Souza. 2021. Observations of multiple internal wave packets in a tidal river plume. *J. Geophys. Res.,* 126, https://doi.org/10.1029/2020JC016575

Rijnsburger, S., Flores, R. P., **Pietrzak, J. D.**, Horner-Devine, A. R., Souza, A. J., & Zijl, F. 2021. The evolution of plume fronts in the Rhine region of freshwater influence. *J. Geophys. Res.,* 126. https://doi.org/10.1029/2019JC015927

Nijs, M.A.J. de and **J.D. Pietrzak**. 2012. Saltwater intrusion and ETM dynamics in a tidally-energetic stratified estuary. *Ocean Model.*, 49-50, 60-85.

Nijs, M.A.J. de, **Pietrzak, J.D.**, Winterwerp, J.C. 2011. Advection of the salt wedge and evolution of the internal flow structure in the Rotterdam Waterway. *J. Phys. Oceanogr.*, 41, 3-27. doi: 10.1175/2010JPO4228.1

Isabel Jalon-Rojas:

Jalón-Rojas, I., Dijkstra, Y.M., Schuttelaars, H.M., Brouwer, R.L., Schmidt, S., Sottolichio, A. 2021. Multi-decadal evolution of the turbidity maximum zone in a macrotidal river under climate and anthropogenic pressures. *J. Geophys. Res.*, 126, e2020JC016273.

Jalón-Rojas, I., Sottolichio, A., Hanquiez, V., Fort, A., Schmidt, S. 2018. To what extent multidecadal changes in morphology and fluvial discharge impact tide in a convergent (Turbid) tidal river. *J. Geophys. Res.*, doi:10.1002/2017JC013466.

Ja**lón-Rojas, I.**, Castelle, I. 2021. Climate control of multidecadal variability in river discharge and precipitation in western Europe. *Water*, 13(3), 257.

Cheng, Z., **Jalón-Rojas, I.**, Wang, X.H., Liu, Y. 2020. Impacts of land reclamation on sediment transport and sedimentary environment in a macro-tidal estuary, *Estuar. Coast. Shelf Sci.*, 221, 106861. doi: https://doi.org/10.1016/j.ecss.2020.106861.

Jalón-Rojas, I., Schmidt, S., and Sottolichio, A. 2015. Turbidity in the fluvial Gironde Estuary (S.-W. France) based on 10-year continuous monitoring: sensitivity to hydrological conditions**.** *Hydrol.Earth Syst. Sci.*, 19, 2805-2819.

Yuley Cardona:

Arevalo, F., Alvarez-Silva, O., Caceres-Euce, A., **Cardona, Y.** 2022. Mixing mechanisms at the strongly-stratifed Magdalena River's estuary and plume. *Estua., Coast. Shelf Sci.* 277, 108077. https://doi.org/10.1016/j.ecss.2022.108077

Cardona, Y., Alvarez-Silva, O., Barrios, Y., Saavedra, V., Cantero, M., Caceres-Euce, A., Osorio, A. 2023. Influence of river discharge and tides on the salinity structure at the Magdalena River estuary. *Estuar. Coast.*, submitted

Lopera, L, **Cardona Y.**, Zapata-RamÃrez, P. 2020. Circulation in the Seaflower Reserve and Its Potential Impact on Biological Connectivity. *Front. Mar. Sci.* https://doi.org/10.3389/fmars.2020.00385.

Luo H, Bracco, A, **Cardona, Y.**, McWilliams, J. 2016. The submesoscale circulation in the Northern Gulf of Mexico: Surface processes and the impact of the freshwater river input. *Ocean Model.*, 101, 68–82v http://dx.doi.org/10.1016/j.ocemod.2016.03.003

Cardona, Y., Bracco A, Villareal T, Subramanian A, Weber S, y Montoya J. 2016. Nutrient concentrations along the river plume salinity gradient in the Northern Gulf of Mexico over the past 30 years. *Deep Sea Res. - Part II,*129, 20-30.

Antonio Hoguane:

Haddout, S. **Hoguane, A.M.** ,Priya, K.L. 2023. Sebou estuary (Morocco) - a potential site for deployment of pressure retarded osmosis convertor for salinity gradient power production. *ISH J. Hydrau. Eng.*, doi: 10.1080/09715010.2023.2180330.

Hoguane, A.M., Francisco, R.P., Simbine, R.L., Mabota, H.S. 2021. Community perception of the value of the ecosystems of the Bons Sinais Estuary, Mozambique, Southern Africa. *J. Integ. Coast. Zone Manag.* 21(4): 249-263. DOI: 10.5894/rgci-n435.

Hoguane, A.M., Gammelsrød, T., Furaca, N.B., Cafermane, A.C., António, M.H.P. 2021. The residual circulation profile of the Bons Sinais Estuary in central Mozambique - potential implications for larval dispersal and fisheries. *WIO J. Mar. Sci. Spe. Iss.* 1:17-27. doi: http://dx.doi.org/10.4314/wiojms.si2021.1.2

Hoguane, A.M., Gammelsrød, T., Mazzilli, S., Antonio, M.H., da Silva, N.B.F. 2020. The hydrodynamics of the Bons Sinais Estuary: The value of simple hydrodynamic tidal models in understanding circulation in estuaries of central Mozambique. *Reg. Stud. Mar. Sci*., 37:101352. doi:https://doi.org/10.1016/j.rsma.2020.101352.

Brockway, R.; Bower, D.; **Hoguane, A.**; Dove, V. and Vassele, V. 2006. A note on salt-intrusion in funnel-shaped estuaries: Application to the Incomati Estuary, Mozambique. *Estua., Coast. Shelf Sci.*, 66, 1-5.

Richard Pawlowicz:

F. Ji, F., **R. Pawlowicz**, X. Xiong, 2021, Estimating the Absolute Salinity of Chinese offshore waters using nutrients and inorganic carbon data. *Ocean Sci.*, 17, 909–918.

Pawlowicz, R., R. Feistel, T.J. McDougall, P. Ridout, S. Seitz, H. Wolf, 2016. Metrological challenges for measurements of key climatological observables Part 2: Oceanic salinity. *Meterologia*, 53: R12-R25.

Pawlowicz, R. 2015. The Absolute Salinity of seawater diluted by riverwater. *Deep-Sea Res., PART I.* 101:71-79.

Pawlowicz, R., and R. Feistel 2012. Limnological applications of the Thermodynamic Equation of Seawater 2010 (TEOS-10). *Limnol. Oceangr. – methods*, 10:853-867.

Tedford, E.W, Carpenter, **J.R, Pawlowicz**, R, Pieters, R., Lawrence, G.A. 2009. Observation and analysis of shear instability in the Fraser River estuary. *J. Geophys. Res.*, 114, C11006, 10.1029/2009JC005313

Carlos Schettini:

Paiva, B.P., **Schettini, C.A.F.**, Siegle, E. 2023. Effect of hydropower dam flow regulation on salt-water intrusion: São Francisco River, Brazil. *J. Mar. Syst.*, acceptable after minor revision.

Guerra-Chanis, G. E.m Laurel-Castillo, J. A., **Schettini, C.A.F.**, Kakoulaki, G., Souza, A. J., Valle-Levinson, A**.** 2022, Saltwater intrusion in estuaries with different dynamic depths. *Reg. Studies in Mar. Sci.*, v. 51, p. 102186.

Paiva, B.P., **Schettini, C.A.F.** 2021, Circulation and transport processes in a tidally forced salt-wedge estuary: The São Francisco river estuary, Northeast Brazil. *Reg. Studies in Mar. Sci.*, v. 41, p. 101602.

Couceiro, M.A.A., **Schettini, C.A.F.**, Siegle, E. 2021. Modeling an arrested salt-wedge estuary subjected to variable river flow. *Reg. Studies in Mar. Sci*., v. 47, p. 101993.

Schettini, C.A.F. Valle-levinson, A., Truccolo, E. C. 2017. Circulation and transport in short, low-inflow estuaries under anthropogenic stresses. *Reg. Studies in Mar. Sci.*, v. 10, p. 52-64.

Gisselle Guerra:

Guerra-Chanis, G.E., Laurel-Castillo, J. A., Schettini, C.A.F., Kakoulaki, G., Souza, A. J., Valle-Levinson, A. 2022, Saltwater intrusion in estuaries with different dynamic depths. *Reg. Studies in Mar. Sci.*, 51 (1) , 102186.

Guerra-Chanis, G.E., M. Diez-Minguito, A. Valle-Levinson, M.A. Reyes-Merlo. 2019. Saltwater intrusion in a subtropical estuary. *Estua. Coast. Shelf Sci.*, 217, 28-36.

Broce, K., A.C. Ruiz-Fernández, A. Batista, A.K. Franco-Ábrego, J.A. Sanchez-Cabeza, L. H. Pérez-Bernal, **G.E. Guerra-Chanis.** 2022. Background concentrations and accumulation rates in sediments of pristine tropical environments. *CATENA,* 106252, ISSN 0341-8162, https://doi.org/10.1016/j.catena.2022.106252.

Broce, K., D. Latta, **G.E. Guerra-Chanis**. 2023. Seawater quality assessment of the marine ecosystem of Punta Galeta in Panamá, Panamá, *Boletín de Investigaciones Marinas y Costeras,* 52, Número 1, ISSN 0122-9761/ISSN [en línea]: 2590-4671.

Guerra-Chanis, G.E., S. So, A. Valle-Levinson. 2021. Effects of Hurricane Irma on residual flows and saltwater intrusion in a subtropical estuary. *Reg. Stud. Mar. Sci.*, 41, doi: 10.1016/j.rsma.2020.101568.

Wenping Gong:

Gong, W., Zhang, G., Zhang, H., Yu, X.L., Zhu, L., Li, S., 2022. The effects of mouth bar on salt intrusion in a partially mixed estuary. *J. Hydrol.*, 612, 128261.

Gong, W., Zhang, G., Yuan, L., Zhang,H., & Zhu, L. , 2021. Effect of the Coriolis force on salt dynamics in convergent partially mixed estuaries. *J. Geophys. Res.*, 126, e2021JC017391. https://doi. org/10.1029/2021JC017391.

Lin, Z., H. Zhang, H. Lin, **W. Gong**. 2019. Intraseasonal and interannual variabilities of saltwater intrusion during dry seasons and the associated driving forcings in a partially mixed estuary. *Cont. Shelf Res.* 174, 95-107.

Gong, W., Y. Chen, H. Zhan, Z. Chen, 2018. Effects of wave-current interaction on salt intrusion during a typhoon event in a highly stratified estuary. *Estua. Coast.* doi:10.1007/s12237-018-0393-8.

Gong, W., Z. Lin, Y. Chen, Z. Chen, H. Zhang. 2018. Effect of winds and waves on salt intrusion in the Pearl River estuary. *Ocean Sci.* 14, 139-159.