Global Assessment of Nutrient Export Through Submarine Groundwater Discharge (NExT SGD)

Figure 1: Submarine groundwater discharge in a coral reef in Lombok, Indonesia.

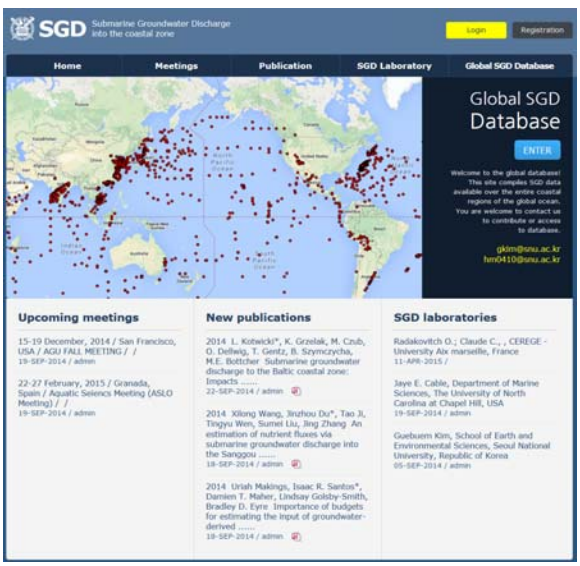
Summary

We propose to establish a new working group that will foster interactions between modelers on one hand and field observations and data collection scientists on the other. Through interactive meetings they will work together to *set the guidelines* *and needs for creating a data base* (including metadata) for the development of a new global model to assess nutrient and constituent export through submarine groundwater discharge (SGD) to *nearshore coastal areas* - the NExT SGD models (reflecting several different constituent fluxes). The proposed multi-national NExT SGD working group consists of scientists whose research crosses disciplinary boundaries including: hydrogeology, geochemistry, oceanography, and the global water cycle. Local data on SGD and associated nutrient fluxes is extensive in many regions and has increased exponentially during the last 15-20 years. For example, more SGD data is available now than what previously existed for rivers at the initial stage of the NEWS global river flux model 10 years ago and it is representative of a broad array of aquifer, coastal zone and climate regimes. To ensure the success of this working group, we will build on and interact with other working groups and programs (e.g., GEOTRACES, GlobalNEWS and LOICZ, UNESCO IHP, BCO-DMO) as well as specifically with members of the former SCOR group 112, "*Magnitude of Submarine Groundwater Discharge and its Influence on Coastal Oceanographic Processes***"**. Our working group will benefit from their experiences in compiling large databases, identifying and filling potential data gaps and developing and distributing protocols for best practices. The SCOR WG 112 focused on the validation of radiotracer techniques versus conventional hydrogeological approaches for assessing magnitude of water flux to coastal areas. It is in part due to the effort and findings of WG 112 that the radiotracer

techniques are now widely applied in local studies throughout the world. Building on the results of WG112, which focused SGD volume, the new group will set up guidelines for creating a uniform user-friendly database of literature data on both SGD quantity and quality that will be instrumental for building global models (the NExT SGD models) to estimate nutrient fluxes entrained by SGD to coasts. Numerous local studies show that the behavior of constituents in the subsurface (subterranean estuary) is not conservative. For example, geochemical transformations often challenge coastal hydrogeologists when defining groundwater “end-members”. When summarizing data, our goal is to help the community to set clear guidelines and best sampling practices on such challenging aspects. This will ultimately result in more uniform data set that can be used by modelers on large scales.

Rationale

The overarching goal of this proposed SCOR working group is to set the guidelines and requirements for the development of global models for assessing constituent (nutrients, gases, carbon, metals) fluxes to the ocean via groundwater (NExT SGD). Current data availability (**Fig 1**) and conceptual understanding of the processes controlling groundwater-derived material fluxes is sufficient for formulating a numerical global model for assessing land–ocean material transport fluxes, similar to the river flux global model (GlobalNEWS) constructed about a decade ago (*Seitzinger and Harrison*, 2005). Indeed, the first global models of river constituent fluxes were developed based on a far smaller database than available for SGD today (e.g., *Gibbs and Kump, 1994).*



← **Figure 1** Snap-shot of a newly created web site by the working group to compile the available data (>100 locations worldwide presented as red dots). More data are available but not plotted on the map yet. (*from http://sgd.snu.ac.kr/home/gis_main.jsp*).

The global NExT SGD models will be based on the guidelines and metadata created by this working group, and will not only enable prediction of SGD-associated material fluxes for any location worldwide for present, past and future climate conditions, but also provide the tools to *test potential feedbacks* in the ocean-land-atmosphere earth system. Such a global model will transform our predictive abilities of this important, yet poorly constrained part of the hydrological cycle. Indeed, one of the pioneers in the SGD field advised that, “*The* ***oceanographic and hydrogeologic*** *communities should recognize the* ***local and global*** *importance of SGD and* ***work together*** *to achieve a better understanding of the processes that control SGD and its constituents*” (*Moore*, 2010).

The deliverables of these workshops will ensure that the models developed will be capable of capturing nutrient and flow changes triggered by short and long-term anthropogenic activities and climate, hence the models will allow the examination of various scenarios and their *ecological effects on ecosystems and economic effects on societies*. For example, excess nutrient loading due to SGD can initiate and sustain harmful algal blooms (HABs) in coastal areas (*Lee et al*., 2010, *Lecher et al.*, 2015). The predictive power of a large-scale model will allow the identification of locations susceptible to HABs triggered by SGD. Thus, the models developed based on the needs identified and database created from the results of this working group will not only significantly improve our understanding of the magnitude of groundwater-derived constituent budgets for the global coastal ocean, but will be extremely useful as a tool to highlight the need for water management assessments in some areas where no data are available.

We expect that the global NExT SGD models will enable us to *improve Earth System Models (ESMs)*, which at this stage neglect groundwater as a transport pathway from land to sea. For example, alkalinity supplied by groundwater may change the modeled pH response to increased atmospheric CO_2 concentrations (*Cyronak* et al. 2013). Given the potential importance of SGD for material fluxes into the ocean, its inclusion in the ESMs improve prediction accuracy of global change effects, including changes in sea-level on the oceans, and a global SGD model is a necessity to enable that inclusion. ESMs, like the ORCHIDEE model (http://orchidee.ipsl.jussieu.fr/) could easily be extended to include subsurface material fluxes by forcing existing parameters with outputs from the NExT SGD models.

Scientific Background

What is SGD and where does it occur? Submarine groundwater discharge (SGD) "*includes any and all flow of water on continental margins from the seabed to the coastal ocean, regardless of fluid composition or driving force*" (*Burnett et al.* 2003, *Moore* 2010) (**Fig. 2*a*,*b***).

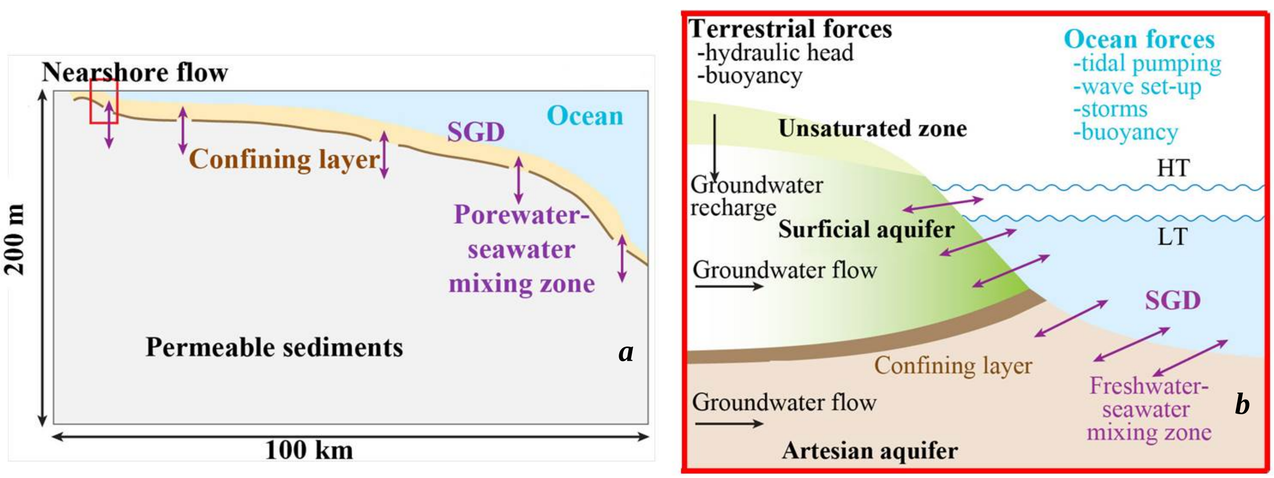


Figure 2 (***a***) SGD extends from the red box labeled "*Nearshore flow*" throughout the continental shelf. The offshore flow on the continual shelf is driven by interactions of ocean forces with geothermal heating and over-pressurized zones beneath discontinuous confining layers. ***(b)*** Near the shoreline SGD (red box) is driven by a combination of terrestrial and ocean physical forces operating in a complex geological environment (*modified from Moore, 2010*).

The outputs (including a database) of this working group will set the needs and guidelines to enable modeling of *nearshore fluxes (**Fig. 2b**)* of (*i*) fresh and (*ii*) recirculated seawater where most of the SGD data were collected and where most of the terrestrial groundwater-derived constituents are discharged (**Fig. 1**).

Despite the rich body of literature characterizing the transport of material fluxes via SGD to the nearshore environments at local scale (**Fig. 1**), to date attempts to upscale and evaluate water fluxes on regional or global scales are limited. In a recent study attempting global upscaling, *Kwon et al*. (2014) estimated SGD to amount to 3-4 times the river flux. However, the radium mass-balance approach used in this and other studies is not based on a mechanistic understanding of driving forces; hence its predictive and extrapolative abilities are limited. The *lack of a process-oriented model* is a very substantial knowledge gap, especially considering the links between ***SGD, the global carbon cycle, and climate change***. For example, in a key study, *Cole et al*. (2007) showed that SGD could contribute a similar amount of dissolved inorganic carbon (DIC) to the coastal ocean as rivers. *Beusen et al*. (2013) developed a global model for SGD-derived nitrogen fluxes, but neglected the marine recirculated SGD component, which often has a much larger volume than freshwater SGD and could contribute significantly to the magnitude of the material fluxes (e.g., *Burnett et al.*, 2003; *Waska & Kim* 2011). In all cases, the outcomes of these models were impeded by the limited understanding of either the coastal oceanographers of the specifics of the global modeling work or of the modelers about the nature of the collected data (i.e., mechanisms and geochemistry).

A multifaceted modeling approach based on recommendations from this workshop will be able to connect ***hydrogeological and marine factors*** (e.g., net precipitation, surface runoff, recharge, groundwater pumping rates, hydraulic heads, aquifer size and aquifer characteristics, topography, lithology, beach morphology, the presence and level of development of stream systems, waves, and tides) affecting SGD to ***nutrient and other constituents loading controls*** (e.g., land use, sewage and agriculture influxes, population growth, groundwater redox state and residence time) in coastal areas on a global scale. For most of the above-named controls, spatial data are available at very high resolution but there is a need to establish the controls on and sensitivity of SGD constituent fluxes to each of these processes to enable effectively incorporating into models. A similar approach was used by *Seitzinger and Harrison* (2005) to estimate export from ~6,000 watersheds globally. Results from these modeling efforts demonstrated the power of numerical models, which can be used not only *to create geospatial databases* of the magnitude of water fluxes but also *to reveal relationships* between controlling factors and drivers, which, in turn, transform our understanding about the coupled nature of these export fluxes at larger scales.

As emphasized before physical measurements from field-based studies are crucial for calibrating models and performing sensitivity analyses. Sufficient data are now available through the abundant SGD tracer-based coastal oceanographic studies of the last 20 years (**Fig. 1**) and the assimilation of many local studies in larger databases (e.g., *Moosdorf et al.*, 2015). However, the available SGD data is *highly heterogeneous*; it was produced by many different research groups and government agencies employing a multitude of measurement techniques and reporting standards. For these reasons, this extremely valuable information is currently practically unusable. Hence, the planned NExT SGD working group will set the guidelines for establishing an effective data compilation process that will facilitate data-use for models. Specifically, needs and guidelines for data compilation in a unified manner will be set. Equally important, the working group will also suggest best practices for future data collection. In addition, the parameters needed for the NExT SGD model development will be identified and assessed and model feasibility tested in a cutting-edge *proof-of-concept* study.

Terms of Reference

Disciplinary boundaries in the scientific community working at the land-ocean interface (i.e., oceanography community, hydrogeologists, and experts in global water flux modeling) have hindered the advancement of the mechanistic understanding of the significance of groundwater-derived nutrient fluxes to the ocean on a global scale. The NExT SGD workgroup recognizes SCOR as the perfect platform to encourage and stimulate the unique and timely collaboration between these disciplines. NExT SGD would build on the results of SCOR WG112 by collecting the observation data inspired by its results and adding the dimension of constituent fluxes to it.

The group's work will focus on the following terms of reference:

1. Collaborate with other working groups and projects (GEOTRACES, Global NEWS, BCO-DMO, etc.) to understand the needs and process for establishing a database useful for improving the representation of SGD in earth system models (e.g. ORCHIDEE) (*deliverable 1*, **Table 1**).

2. Produce a "*best practices*" technical note paper to be published in a peer reviewed journal recommending sampling strategies, parameter measurements, and guidelines for sample processing, metadata standards and sharing of acquired data (*deliverable 2*, **Table 1**).

3. Set the guidelines and expectation for establishing a permanent database of available SGD data including criteria for data quality control with the intention of this database to be usable for the planned NExT SGD Models. We will use these guidelines to request funds (NSF, EU) to establish and maintain such a database. (*deliverable 3*, **Table 1**).

We foresee the initiation and development of this unique collaboration proceeding in several stages (as shown **Table 1**) which will be centered on in-person meetings, and 2 out of 3 meetings held in conjunction with international conferences. We will organize a virtual seminar series (Webinar) to be delivered quarterly, by different members of the SCOR WG with focus on the progress of the data synthesis and analysis. At its completion, the recommendations will be distributed to the broader oceanographic community for input and feedback through established list servers (OCB, AGU, ASLO, etc.).

Working Plan and Deliverables

Constructing a global model to assess constituent fluxes via SGD is a pressing task. Our in-person meetings (as shown in **Table 1**) will be structured to address specific needs for model development necessary to establish the foundation for successful model outcomes. The groundwork for the NExT SGD models will be achieved through the following specific goals:

***Deliverable 1:* Set up a global network of scientists and SGD-"task force" across disciplines.**

The working group will bring together oceanographers, hydrologists, biogeochemists and modelers to discuss the needs and set the guidelines for the construction and incorporation of SGD water and nutrient fluxes into new or existing models. The group thus ensures information transfer both between the multidisciplinary participating members regarding the needs for the establishment of useful NExT SGD models. In particular, potential ecosystem feedbacks of SGD will be discussed, which have recently been highlighted in the literature (*Garcia-Orellana* et al, 20016*; Utsunomiya et al,* in press). Relevant factors for inclusion in the NExT SGD models will be identified by combining field knowledge of the submarine groundwater discharge community with factor needed for the setup of existing models (e.g. Global NEWS *Seitzinger and Harrison*, 2005). The unique combination of terrestrial and marine factors and their interplay is a special challenge to this working group. This will be reflected in the identification of model input data (e.g., land cover and population density, as well as tidal range and wave intensity). The planed meetings and interactions ensures the compatibility of the NExT SGD models with other global scale nutrient flux models and Earth System models, and the identification of gaps in data or model parameterization.

***Deliverable 2* Establish a handbook of best practices for sampling strategies, sample processing, and data handling and reporting for SGD data collection to be used in the NExT SGD models**

SCOR working group 112 has established sampling techniques of SGD water flux which are used until today. However, these methods do not consider upscaling of SGD and associated constituent fluxes. Due to the large spatial and temporal variability of SGD fluxes and its constituent concentrations, we need to evaluate the currently applied techniques and formulate best practices for future fieldwork. This can be only archived if the two working bodies of the proposed working group, the scientists collecting actively the data and the global modelers, become engaged in interactive close-group meetings such as the SCOR ones. Past experience had proved that only through close personal interactions this international network of hydrogeologists and biogeochemists could compare, assess, and optimize *in situ* investigations of SGD magnitudes and associated constituent fluxes from local to regional scales and lay the foundation for a uniform comprehensive database to be utilized for building global material fluxes model (s). Furthermore, our working group will collaborate with the GEOTRACES community to plan for the collection of offshore SGD data and make sure it is compatible with the model requirements (http://www.geotraces.org/science/science-highlight/1019-submarine-groundwater-discharge-as-a-major-source-of-nutrients-in-the-mediterranean-sea). Based on the identified recommendations and model needs a best practice technical paper will be composed and disseminated broadly.

***Deliverable 3:* Establish recommendations to set up a database that will be used in the global NExT SGD models**

The NExT SGD SCOR working group will develop specific technical guidelines in the form of *metadata forms* that will be embedded in the global SGD webpage (*from http://sgd.snu.ac.kr/home/gis_main.jsp)* and will be filled out for each site. We will discuss the requirements of a database and how to establish and maintain it. We envision a product in the form of a draft proposal for establishing a database that will be shared with the community for feedback and then developed into a proposal to obtain funding.

Establishing a database for SGD will ensure (*i*) *quality control* of the data to be used for the model; and (*ii*) the creation of a *uniform record* that will be independent of the field data collection and techniques.

The database will likely be stored in cooperation with a partner to ensure its permanent availability. As partners, the UNESCO IHP (which is represented in the group), the WHYMAP, or CUAHSI are envisioned. At the first group meeting the best fitting data host will be selected and afterwards contacted.

Table 1 Detailed timetable of the scientific activities, and expected deliverables of the working group

	Group activities and deliverables	Deadlines/meeting reports
Initial coordination and data management	1. Classifying sites into the 6 major domains based on aquifer type and dividing the working areas into several groups. 2. Developing specific technical guidelines for building a uniform metadata base of hydrogeological and nutrient parameters and topology. 3. Making initial decisions on governing parameters and boundary conditions for groundwater flow model. 4. Decide on data storage and data access.	SPRING: 2017 EGU Vienna (23–28 April 2017)
Global Model Development	1. Decisions on constituents adjustments and data gaps: a) Land coverage and use. b) Identifying sources and sinks of nutrients: natural (non-point-) versus anthropogenic (point-) sources. c) Climate change effects via sea level change and permafrost melting. 2. Refining decisions on scale constrains: upscaling/downscaling issues.	SPRING 2018: Ocean University of China, hosted by the Key Laboratory of Marine Chemistry Theory and Technology, Ministry of Education, Qingdao, China
Model Calibration	1. Further model parameterization and refinement. 2. Finalization of the SGD database V1.0 3. Working on dissemination of results in publications and meetings. 4. Writing and dissemination of the *best practices technical paper*.	FALL 2019: Final meeting December 2019 AGU Special session, San Francisco, USA

Capacity Building

Within the proposed group, we bring together global modeling experts from the riverine and groundwater modeling communities (e.g., Slomp, Cohen, Harrison, Michaels) with specialists in large database creation and management and holders of large SGD datasets (e.g., Kim, Moosdorf, Michaels) as well as field scientists for SGD from the terrestrial (Dimova, Cable, Santos) and marine (Dimova, Paytan, Burnett, Waska) realm. In addition to the broad scientific backgrounds, the proposed working group was assembled on the principle of geographical, economical (developed and countries in transition), gender and career stage diversity. The WG includes members from 14 countries spanning four continents with 40% female representation, and 30% members from developing and transition countries (**Tables 2 and 3**). Opportunity for broader involvement of the scientific community will be possible through open thematic sessions in large meetings and via open Webinars.

The uniqueness of this working group is its initiation largely by early-career young scientists, which has helped crossing traditional boundaries between the research fields of coastal oceanography, hydrology, and global numerical modeling. During the meeting planned in conjunction with the AGU Fall meeting in San Francisco 2019, we will hold a workshop in the form of a field trip as a training event for fellow interested scientists to expand their knowledge on the good practice of SGD measurement. However, in addition, we will expand this traditional outreach approach, by actively including social media via Facebook, Twitter, NExT SGD webpage Blogs, virtual seminars (Webinars) and crowdsourcing as part of our portfolio. Establishing the SCOR NExT SGD working group will foster further interdisciplinary collaboration and is intended catalyze new studies in areas where data gaps are identified during the compilation process. Developing this network will facilitate information exchange between scientists from developed countries and countries in transition. In most developing countries, nutrient enrichment of coastal waters due to SGD is unknown. Interactions among group members will create opportunities for student exchange and contribute to the enhancement of graduate programs in counties in transition. This, in turn, will promote wider public understanding of the effects of groundwater discharge. To optimize the educational effects, excursions will be held associated with the workgroup meetings. In particular at the last workshop at the AGU Fall meeting, a training excursion should transfer the developed knowledge from the project into practice.

Working group meetings will be organized on annual basis (as shown in **Table 1**). To allow broader participation, we plan to meet each year at different locations utilizing already established large international scientific meetings (e.g., EGU, AGU). The location of these meetings will rotate between the USA, Europe and Asia to distribute the cost of participation among group members.

We will seek funding from additional sources such as UNESCO, IAEA, LOICZ, as well as national and bi-national organizations (NSF, NERC, etc.). We will also establish a donation link on our web page to create an opportunity for private organizations to support our group. Funding through these alternative sources will be independent of that provided by SCOR.

Table 2 Full Members of the SCOR Working Group on Global Groundwater Fluxes to the Ocean

	Member	Gender	Place of work	Expertise relevant to proposal
1	Natasha Dimova (co-chair)	female	University of Alabama, USA	Radionuclides, coastal hydrology
2	Nils Moosdorf (co-chair)	male	Leibniz Center for Tropical Marine Ecology (ZMT), Bremen, Germany	Global empirical modeling
3	Guebuem Kim	male	Seoul National University, Korea	Radionuclides and nutrient cycling
4	Isaac Santos	male	Southern Cross University, Australia	Carbon cycling
5	Holly Michael	female	University of Delaware, USA	Numerical & field modeling of coastal groundwater dynamics
6	Caroline Slomp	female	Utrecht University, The Netherlands	Geochemical modeling
7	Makoto Taniguchi	male	Research Institute for Humanity and Nature, Japan	Regional and global groundwater hydrology
8	Bo Chao Xu	male	Ocean University of China	Coastal hydrology, geochemistry
9	Sara Purca	female	Institutto del mar del Peru (IMARPE)	Physical oceanography, fisheries, water resources
10.	Robert Delinom	male	Indonesian Institute of Sciences, Indonesia	Hydrogeology and geochemistry

Table 3 Associate Members of the SCOR Working Group on Global Groundwater Fluxes to the Ocean

	Member	Gender	Place of work	Expertise relevant to proposal
1	Hannelore Waska#	female	University of Oldenburg, Germany	Groundwater hydrology and geochemistry
2.	Adina Paytan#	female	UC Santa Cruz, USA	Biogeochemistry and nutrient cycling
3.	Jaye Cable	female	University of North Carolina, USA	Groundwater hydrogeology
4	Sagy Cohen	male	University of Alabama, USA	GIS, global numerical modeling, geomorphology
5	Kazi Matin Uddin Ahmed	male	University of Dhaka, Bangladesh	Groundwater contamination
6	Howard Waldron	male	University of Cape Town South Africa	Coastal zone water quality
7	Thomas Stieglitz	male	Centre for Tropical Water & Aquatic Ecosystem Research (James Cook University) Australia Centre de Recherche et d'Enseignement de Géosciences de l'Environnement CEREGE (European Centre for Teaching and Research In Geosciences) France	Geophysics and SGD
8	Yishai Weinstein	male	Bar-Ilan University, Israel	Hydrogelogy
9	Felipe Luis Niencheski	male	Fundação Universidade Federal do Rio Grande, Brazil	Environmental Chemistry
10	Alice Aurelie	female	UNESCO IHP, Paris	Hydrology

 # We would like to acknowledge specially HW and AP whose insightful comments were critical in preparation of this proposal.

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Appendix

Natasha Dimova (co-chair): Dr. Dimova is a coastal oceanographer and hydrogeologist with expertise in the radon-based tracer techniques in marine and freshwater systems. Dimova initiated the SCOR NExT SGD working group proposal and has been *working on compilation of SGD data* with Sagy Cohen (associate member) and Nils Moosdorf for establishing a global SGD model. She is an early-career female scientist who has been collaborating with scientists worldwide, including Asia, USA and Europe.

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Nils Moosdorf (co-chair): Dr. Moosdorf is a hydrogeologist, specialized in estimating large scale geochemical material fluxes via statistical methods based on large datasets. His experience lays *in large scale river constituent flux modeling*. Since August 2014 he leads a junior research group on ecological impacts of SGD at different scales. He also specialized on global scale datasets based on lithological information. He is involved in several cooperative projects with scientists primarily in the USA, but also in Europe and Asia.

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Guebuem Kim: Dr. Kim's expertise is in radionuclides (Rn and Ra), organic matter, REE and *nutrient cycling in subterranean estuaries on a regional and global scale*. Dr. Kim established a webpage for SGD data compilation for initiating the NExT SGD working group.

1) Yan, G., and G Kim, 2015. Sources and fluxes of organic nitrogen in precipitation over the southern East Sea/Sea of Japan, *Atmospheric Chemistry and Physics*, 15(5): 2761-2774.

2) Kwon, E. Y., G. Kim, F. Primeau, W. S. Moore, H-M. Cho, T. DeVries, J. L. Sarmiento, M. A. Charette, Y-K. Cho, 2014. Global Estimate of Submarine Groundwater Discharge Based on an Observationally Constrained Radium Isotope Model, *Geophysical Research Letters*, 41(23): 8438–8444.

3) Kim, I, and G. Kim, 2014. Submarine groundwater discharge as a main source of rare earth elements in coastal waters, *Marine Chemistry*, 160 (20): 11-17.

4) Kim, T-H., and G. Kim, 2013. Changes in seawater N:P ratios in the northwestern Pacific Ocean in response to increasing atmospheric N deposition: Results from the East (Japan) Sea, *Limnology and Oceanography*; 58(6): 1907-1914.

5) Kim, T-H., H. Waska, E. Kwon, I. Gusti Ngurah Suryaputra, G. Kim, 2012. Production, degradation, and flux of dissolved organic matter in the subterranean estuary of a large tidal flat, *Marine Chemistry* 142-144: 1-10.

Isaac Santos: Dr. Santos was invited to be part of the NExT SGD working group because of the wide spectrum of research topics he has been involved with and his knowledge of the *carbon and* *nutrient cycling in subterranean estuaries*, specifically in carbonate sandy aquifers and coral reef environments.

1) Atkins, ML, I.R, Santos, S Ruiz-Halpern, DT Maher, 2013. Carbon dioxide dynamics driven by groundwater discharge in a coastal floodplain creek, *Journal of Hydrology* 493: 30-42

2) Santos, IR., B.D Eyre, and M. Huettel, 2012. The driving forces of porewater and groundwater flow in permeable coastal sediments: A review, *Estuarine, Coastal and Shelf Science* 98: 1-15

3) Santos, IR, R.N. Glud, D. Maher, D. Erler, B.D Eyre, 2011., Diel coral reef acidification driven by porewater advection in permeable carbonate sands, Heron Island, Great Barrier Reef, *Geophysical Research Letters* 38 (3), doi: 10.1029/2010GL046053.

4) Santos, IR, D Erler, D Tait, B.D Eyre, 2010. Breathing of a coral cay: Tracing tidally driven seawater recirculation in permeable coral reef sediments, *Journal of Geophysical Research*: *Oceans*, 115, C12, doi: 10.1029/2010JC006510

5) Santos, IR, W. C Burnett, J. P. Chanton, B. Mwashote, and IGNA Suryaputra, 2008. Nutrient biogeochemistry in a Gulf of Mexico subterranean estuary and groundwater-derived fluxes to the coastal ocean, *Limnology and Oceanography* 53 (2): 705-718

Holly Michael: Dr. Michael was invited to this working group because of her unique expertise in both *numerical modeling and radio tracer field techniques*. Holly has established a connection between the two fields and plays an important role in breaking the boundaries between hydrogeology and coastal oceanography.

1) Sawyer, AH, O Lazareva, KD Kroeger, K Crespo, CS Chan, T Stieglitz, and HA Michael, 2014. Stratigraphic controls on fluid and solute fluxes across the sediment-water interface of an estuary, *Limnology & Oceanography*, 59(3):997–1010.

2) Michael, HA, CJ Russoniello, and LA Byron, 2013. Global assessment of vulnerability to sea-level rise in topography-limited and recharge-limited coastal groundwater systems, *Water Resources Research*, 49 (4): 2228-2240.

3) Michael, HA, MA Charette, and CF Harvey, 2011. Patterns and variability of groundwater flow and radium activity at the coast: a case study from Waquoit Bay, Massachusetts, *Marine Chemistry*, 127: 100-114.

4) Michael, HA, AE Mulligan, and CF Harvey, 2005. Seasonal oscillations in water exchange between aquifers and the coastal ocean, *Nature*, 436: 1145-1148.

5) Michael, HA, JS Lubetsky, and CF Harvey, 2003. Characterizing submarine groundwater discharge: a seepage meter study in Waquoit Bay, Massachusetts, *Geophysical Research Letters*, 30 (6): doi: 10.1029/2002GL016000, 6.

Caroline Slomp: We invited Dr. Slomp as a full member because of her in-depth quantitative understanding of the cycling of elements in marine environments that will be essential in the mechanistic understanding of nutrient fluxes via SGD in nearshore coastal areas. Additionally, Dr. Slomp's research is broad in scope and involves field and laboratory work that is typically *integrated with large scale ocean and river modeling*.

1) Beusen, A.H.W., Slomp, C.P. and Bouwman, A.F., 2013. Global land-ocean linkage: direct inputs of nitrogen to coastal waters via submarine groundwater discharge, *Environmental Research Letters*, 8 (3), doi:10.1088/1748-9326/8/3/034035.

1) Dürr, H.H., Laruelle, G.G., van Kempen, C.M., Slomp, C.P., Meybeck, M., Middelkoop, H., 2011. Worldwide Typology of Nearshore Coastal Systems: Defining the Estuarine Filter of River Inputs to the Oceans. *Estuaries and Coasts*, 34(3): 441-458.

2) Spiteri, C., Slomp, C.P., Tuncay, K. and Meile, C., 2008. Modeling biogeochemical processes in subterranean estuaries: Effect of flow dynamics and redox conditions on submarine groundwater discharge of nutrients, *Water Resources Research*, *44*, W02430, doi:10.1029/2007WR006071.

3) Slomp, C.P. and Van Cappellen, P., 2007. The global marine phosphorus cycle: sensitivity to oceanic circulation, *Biogeosciences*, 4: 155-171.

4) Slomp, C.P. and Van Cappellen, P.S.J., 2004. Nutrient inputs to the coastal ocean through submarine groundwater discharge: controls and potential impact, *Journal of Hydrology*, 295: 64-86.

Makoto Taniguchi: Dr. Taniguchi has long-term experience in working on different aspects of groundwater and its significance for the global hydrological cycle. His contribution will be specifically in *connection between societies - water resources-climate change*. Dr. Taniguchi is also a former member of the SCOR 112 WG *Magnitude of Submarine Groundwater Discharge and its Influence on Coastal Oceanographic Processes***.** Dr. Taniguchi is also a member of the IAPSO Commission on Groundwater Seawater Interactions whose results we should build on.

1) Taniguchi, M., 2015. The basic act on the water cycle with groundwater, *Journal of Groundwater Hydrology* 57(1):83-90.

2) Taylor, RG, B. Scanlon, P. Döll, M. Rodell, R. van Beek, Y. Wada, L. Longuevergne, M. Leblanc, J. S. Famiglietti, M. Edmunds, L. Konikow, T.R. Green, J. Chen, M. Taniguchi, M. F. P. Bierkens, A. MacDonald, Y. Fan, R. M. Maxwell, Y. Yechieli, J. J. Gurdak, D. M. Allen, M. Shamsudduha, K. Hiscock, P. J.-F. Yeh, I. Holman & H. Treidel, 2013. Groundwater and climate change, *Nature Climate Change*. DOI:10.1038/nclimate1744.

3) Taniguchi, M., Yamamoto, K., and Aarukkalige, P. R. 2011, Groundwater resources assessment based on satellite GRACE and hydrogeology in Western Australia, *GRACE, Remote Sensing and Ground-based Methods in Multi-Scale Hydrology (Proceedings of Symposium J-H01 held during IUGG2011 in Melbourne, Australia, July 2011)* 343 :3-8.

4) Taniguchi, M, 2011. What are the Subsurface Environmental Problems? Groundwater and Subsurface Environmental Assessments Under the Pressures of Climate Variability and Human Activities in Asia, *Groundwater and Subsurface Environments: Human Impacts in Asia Coastal Cities* :3-18. DOI:10.1007/978-4-431-53904-9_1.

5) Taniguchi, M., A. Aureli, and J.L. Martin, 2009. Groundwater resources assessment under the pressures of humanities and climate change. *IAHS Publication* 334.

Bo-chao Xu: The contribution of Dr. Xu for this working group will be primarily in his understanding of *SGD impacts on large estuaries* and the geochemical transformations of nutrients at the sediment-water interface.

1) Meng, J., P. Yao, T. S. Bianchi, D. Li, B. Zhao, B. Xu, Z. Yu, 2015. Detrital phosphorus as a proxy of flooding events in the Changjiang River Basin, *Science of the Total Environment*, 517: 22-30.

2) J. Sui, Z. Yu, X. Jiang, B. Xu, 2015. Behavior and budget of dissolved uranium in the lower reaches of the Yellow (Huanghe) River: Impact of Water-Sediment Regulation Scheme, *Applied Geochemistry*, 61: 1-9.

3) Xu, Bo-Chao, W. C. Burnett, N. T. Dimova, H. Wang, L. Zhang, M. Gao, X. Jiang, Z. Yu, 2014. Natural ^{222}Rn and ^{220}Rn Indicate the Impact of the Water-Sediment Regulation Scheme (WSRS) on Submarine Groundwater Discharge in the Yellow River Estuary, China, *Applied Geochemistry*,http://dx.doi.org/10.1016/j.apgeochem.2014.09.018

4) Xu, Bo-Chao, W. C. Burnett, N. T. Dimova, G. Liu, T. Mi, Z. Yu, 2013. Hydrodynamics in the Yellow River Estuary via radium isotopes: ecological perspectives, *Continental Shelf Research*, doi.org/10.1016/j.csr.2013.06.018.

5) Xu, Bo-Chao, N. T. Dimova, L. Zhao, X-Y. Jiang, and Z.-G. Yu, 2013. Determination of water ages and flushing rates using short-lived radium isotopes in large estuarine system, the Yangtze River Estuary, China, *Estuarine, Coastal and Shelf Science*, 121-122: 61–68.

Sara Purca: Dr. Purca is an *oceanographer* whose research focus is in coastal water management and biological (fisheries) modeling. Her extended experience in coastal hydrodynamics along the Peruvian coastline will fill the gap of "*volcanic aquifers*" and the effects of upwelling to quality of coastal waters.

1. Graco M., S. Purca, B. Dewitte, O. Moron, J. Ledesma, G. Flores, C Castro, D Gutierrez (2016) The OMZ and nutrients features as a signature of interannual and low frequency variability off the peruvian upwelling system. *Biogeosciences Discuss*, 12, 1-37, doi: 10.5194/bgd-12-1-2015.

2. Carre M., JP Sachs, S Purca, AJ Schauer, P Braconnot, R Angeles, M Julien, D Lavallée (2014) Holocene history of ENSO variance and asymmetry in the Eastern tropical Pacific. *Science*. 345, 1045. DOI: 10.1126/science.1252220.

3. Illig. S.; B. Dewitte; K. Goubanova; G. Cambon; J Boucharel; F Monetti; C. Romero; S. Purca; R Flores (2014) Forcing mechanisms of intraseasonal SST variability off central Peru in 2000-2008. *Journal of Geophysical Research: Oceans*. 119, Doi: 10.1002/2013JC009779.

4. Vazquez-Cuervo, J., B. Dewitte, TM Chin, E. M. Armstrong, S. Purca , E. Alburqueque (2013) An analysis of SST gradients off the Peruvian Coast: The impact of going to higher resolution, *Remote Sensing of Environment*, 131 , 76-84.

5. Dewitte, B. J. Vazquez-Cuervo, K. Goubanova, S. Illig, K. Takahashi, G. Cambon, S. Purca, D. Correa, D. Gutierrez, A. Sifeddine, L. Ortlieb (2012) Changes in El Niño flavours over 1958-2008: Implications for the long- term trend of the upwelling off Perú. *Deep Sea Research II*, doi:10.1016/j.dsr2.2012.04.011.

Robert Delinom: Prof. Delinom is *hydrogeologist* who leads a working group which researched submarine groundwater discharge on different Indonesian islands. His perspective will highlight the *tropical regions*, where particularly tropical islands can contribute significantly to global fluxes and show strong local impacts of SGD.

1) Bakti, H., Naily, W., Lubis, R.F., Delinom, R., Sudaryanto, S., 2014. PENJEJAK KELUARAN AIRTANAH DI LEPAS PANTAI (KALP) DI PANTAI UTARA SEMARANG DAN SEKITARNYA DENGAN ^{222}RADON. Riset Geologi dan Pertambangan, 24(1): 43-51. (In Indonesian)

2) Bakti, H., Lubis, R.F., Delinom, R., Naily, d.W., 2012. Identifikasi keluaran air tanah lepas pantai (KALP) di pesisir aluvial Pantai Lombok Utara, Nusa Tenggara Barat (Identify on submarine ground water discharge (SGD) on the alluvial coast of North Lombok, West Nusa Tenggara), *Jurnal lingkungan dan bencana geologi*, 3(2): 133-149.

3) Umezawa, Y., Onodera, S., Ishitobi, T., Hosono, T., Delinom, R., Burnett, W.C., Taniguchi, M., 2009, Effects of urbanization on groundwater discharge into Jakarta Bay, Trends and Sustainability of Groundwater in Highly Stressed Aquifer. IAHS Publication 329, IAHS Press, Vamsi Art Printers Pvt. Ltd. Hyderabad.

4) Lubis, R., Sakura, Y., Delinom, R., 2008. Groundwater recharge and discharge processes in the Jakarta groundwater basin, Indonesia. *Hydrogeology Journal*, 16(5): 927-938.

5) Umezawa, Y., Hosono, T., Onodera, S., Siringan, F., Buapeng, S., Delinom, R., Yoshimizu, C., Tayasu, I., Nagata, T., Taniguchi, M., 2008. Sources of nitrate and ammonium contamination in groundwater under developing Asian megacities. *Science of the Total Environment*, 404(2-3): 361-376.