RAPPORT N° 1 : Septembre 2024 – Actions menées dans le projet CECC, volet ANDES (resp. Thomas CONDOM)

1 – Détail de la réunion de lancement à Santiago le 02/05/2023

Programme de Recherche Agence Française pour le Développement / IRD : Cycle de l'Eau et Changement Climatique (CECC)

Programme Réunion – CECC ANDES - Santiago du Chili le 02/05/2023

ZOOM MEETING :

https://univ-grenoble-alpes-fr.zoom.us/j/93929911130?pwd=N29CcjZ0czRPa0QwaG9VSGZ0UElsZz09

Lieu de la Reunión: Oficina Colegio de Geólogos (Santiago du Chili)

COLEGIO DE GEOLOGOS DE CHILE A.G.
Valentín Letelier 20, of 404 Santiago, Chile

Estacion de metro : MONEDA

Google Map : https://goo.gl/maps/6GDF7iwDNRa5j8BA8

Participants confirmés en présentiel à Santiago:

Sylvain LEFEVBRE (AFD) / Clémentine JUNQUAS (IRD-IGE) / Jhan-Carlo ESPINOZA (IRD-IGE) / Johana AGUDELO (IRD-IGE) / Thomas CONDOM (IRD-IGE) / Denis RUELLAND (CNRS-HSM) / Nilo LIMA QUISPE (IRD-IGE) / Lluis FITA (CONICET-CIMA) / Jorge MOLINA (UMSA) / Waldo LAVADO (SENAMHI)

8 :45 – 9 :00 (heure Santiago du Chili): Début de l'évènement CECC

9 :00 – 9 : 30 (heure Santiago du Chili)

- **Projets de l'AFD dans les Andes sur les ressources en eau (Sylvain Lefebvre)**

9:30 – 9: 50

- **Description du projet CECC (Thierry Lebel - IRD)**

9 : 50 – 10 : 50

- Réunion partagée par Zoom avec les collègues de France de l'IGE (Grenoble) travaillant dans les Andes - Activités scientifiques en lien avec le projet CECC (collègues IGE)

Confirmé : **AUDREY GOUTARD** – PhD – "SNOW/RAIN TRANSITION: THE IMPORTANCE OF ALBEDO"

Confirmé : **ALEXIS CARO** – PhD - "ANDEAN CATCHMENTS HYDROLOGICAL RESPONSE TO RECENT GLACIER MASS LOSS"

10 : 50 – 11 : 00

- Pause

11 :00 – 12 : 30

- Atelier de travail autour de la Thèse : Ressource en eau

PhD : NILO LIMA QUISPE : "Modeling hydrological processes of the Lake Titicaca hydrosystem under changing climate and anthropogenic conditions" (Supervision : T. Condom & D. Ruelland)

12 :30 – 14 :00

- Pause méridienne

14 : 00 – 15 :00

- Budget – volet administratif.

15 :00 – 16 :30

- **Atelier de travail autour de la Thèse : Climat**

PhD: **JOHANA AGUDELO** Future projections of rainfall in the region and production of disaggregated and debiased scenarios (Supervision Clémentine Junquas Jhan Carlo Espinoza, Paola Arias).

16 :30 – 16 : 45

- Pause

16 : 45 – 17 :45

- Perspectives et coopérations en cours

17 :45 – 18 :00

- Clôture de la réunion

En fichier joint vous trouverez toutes les présentations de la journée. Par la suite nous présentons le détail des deux thèses du projet AFD, volet ANDES.

2 – Résumé des activités de la doctorante Johana Agudelo

PHD 1 : Johana Agudelo

Un article est en cours de préparation (Agudelo et al.) sur les projections futures des structures de circulation atmosphérique et ses impacts sur la précipitation en Amérique du Sud tropicale. L'article devrait être soumis début 2023.
Cette étude a permis de sélectionner un modèle globale pour forcer les simulations régionales dans la région de l'Altiplano dans le cadre d'un scénario de changement climatique. Ces simulations sont en phase de test et devraient commencer début 2023.
Par ailleurs, le projet CLIMAT Amsud « HighRes-AmSur : Continental-scale high-resolution climate modeling over South America in a future climate change scenario », dont je suis la coordinatrice, vient d'être accepté. il s'agit d'une collaboration entre l'Argentine, le Chili, le Pérou, la Colombie, et la France (IRD et CNRS). L'objectif principal du projet est d'organiser des activités de modélisation régionale du climat à haute résolution en Amérique du Sud à l'échelle continentale. Ce projet, prévu pour 2 ans, viendra en appui aux activités de CECC concernant la modélisation régionale dans les Andes et permettra de renforcer les partenariats en cours.

Publication

Un article a été soumis (Agudelo et al.) à la revue « JGR Atmospheres » intitulé "Future projections of low-level atmospheric circulation patterns over South Tropical South America: Impacts on precipitation and Amazon dry season length". L'objectif principal de l'article est d'identifier les projections futures des structures de circulation atmosphérique et ses impacts sur la précipitation en Amérique du Sud tropicale. Cette étude a permis de sélectionner un modèle global pour forcer les simulations régionales dans la région de l'Altiplano dans le cadre d'un scénario de changement climatique.

Simulations climatiques :

Les simulations climatiques continentales à 20km de résolution avec le modèle couplé WRF-ORCHIDEE ont démarré et 4 ans ont déjà été tournés sur la période 2050-2053 avec le scénario SSP3 7.0. Suite à une vérification, un ajustement doit être fait dans le modèle ORCHIDEE afin d'améliorer les interactions surface-atmosphère dans la région du lac Titicaca avant de continuer ces simulations.

Des tests ont été effectués avec le modèle WRF pour un domaine à 4km de résolution comprenant l'Altiplano. Les tests sont terminés et 15 ans de simulations seront effectués à la rentrée pour la période de validation 2000-2014.

Réunion CECC – Santiago :

Une réunion de projet a été organisé à Santiago du Chili le 02/05/2023 concernant le volet andin du projet. Cette réunion a permis d'initier des interactions entre les divers participants travaillant dans la région de l'Altiplano. Une sortie de terrain faisant intervenir les deux doctorants des volets « climat » et « ressource en eau » est organisé fin Juillet dans la partie péruvienne du lac Titicaca.

3 – <u>Résumé des activités du doctorant Nilo Lima</u>

PHD 2 :

Extended abstract of the PhD thesis:

Modeling hydrological processes of the Lake Titicaca hydrosystem under changing climate and anthropogenic conditions

PhD student: Nilo Alberto LIMA QUISPE

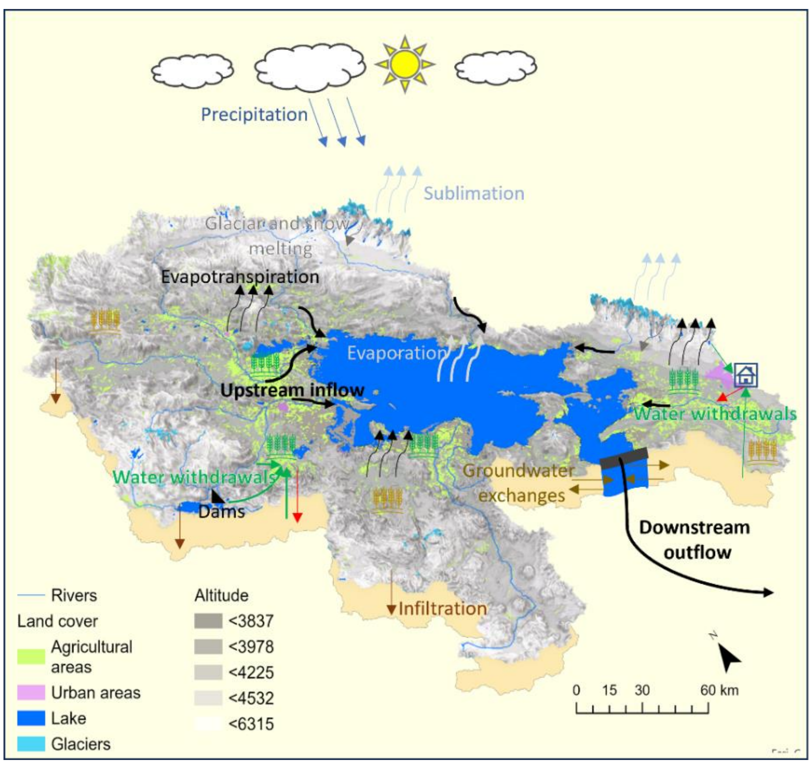
Doctoral school: Sciences de la Terre, de l'environnement et des planètes, University of Grenoble-Alpes (UGA)

Supervisors:

- Thomas CONDOM, IRD, Institut des Géosciences de l'Environnement (IGE)
- Denis RUELLAND, CNRS, HydroSciences Montpellier (HSM)

Project framework:

AFD Project: The PhD is funded over the 2022–2025 period in the framework of an AFD/IRD (Agence Française de Développement /Institut de Recherche pour le Développement) project entitled Water cycle and climate change in the intertropical region" (CECC for the French acronym). This project focuses on two regions of the world: West Africa and the tropical Andes. As far as the tropical Andes are concerned, the project includes two PhDs, one on the hydrological functioning of the Lake Titicaca (this tesis), and the other on bias corrections for future projections of precipitation (PhD student Jhoana Agudelo; IGE, Grenoble).



Graphical abstract: Representing and quantifying the main hydrological processes in the Lake Titicaca hydrosystem.

Climate change and anthropogenic pressures as drivers of changes in the lake water levels

Many lakes around the world are drying very rapidly (Wang et al., 2018; Wurtsbaugh and Sima, 2022) and others are experiencing a sustained increase (Song et al., 2014; Zhang et al., 2017). This may generate severe local and regional consequences on the ecosystem services provided by lakes. These changes are due to a water imbalance between inputs (upstream inflow and precipitation) and outputs (evaporation and downstream outflow) (Niedda and Pirastru, 2013). Changes in inflows have been attributed to climatic and anthropogenic factors (Alemayehu et al., 2007; Lima-Quispe et al., 2021; Schulz et al., 2020; Wang et al., 2022). In addition, it can be attributed to other causes such as direct withdrawals from the lake for different uses and natural outflow that in some cases are controlled. In contrast, some lakes have increased their water volumes due to changes in precipitation and increased glacier melt (Song et al., 2014). The phenomenon of decreasing and then increasing water levels in lakes has also been observed in Qinghai Lake where since the 1970s there has been a dramatic decline, but from the beginning of the 21st century water levels showed a sustained increase (Fan et al., 2021). Studying the hydrological processes that control the functioning of lakes is crucial to better understand the drivers of the extreme changes these water bodies are experiencing. However, assessing the impacts of climate variability and the relative contribution of anthropogenic activities is challenging due to limited information on streamflow records and net upstream water withdrawals (Wang et al., 2022). Moreover a very difficult component to determine is the exchange of the lake with groundwater (Bouchez et al., 2016). Then, understanding the characteristics and drivers of lake variations has been a priority for the scientific community to better guide lake ecosystem management policies and the improvement of lake functions (Wu et al., 2022).

Extreme fluctuations of large lakes in the Andean Altiplano

In the central Andes of South America, Lake Titicaca, considered one of the highest large freshwater lakes in the world, has experienced extreme fluctuations in its water levels. Historical measurements show that the variation of the lake's water level has been approximately five meters, with the lowest levels occurring in 1944 and the highest in 1986 (Ronchail et al., 2014). These fluctuations have repercussions throughout the Andean Altiplano. For example, when the water level drops below the lake's discharge level, this generates significant impacts, especially in the drying of Lake Poopó, which depends mainly on the inflow from Titicaca (Lima-Quispe et al., 2021; Pillco Zola and Bengtsson, 2006). The drying of this lake had consequences in the massive die-off of fish and shorebirds (Perreault, 2020). In very wet years, floods are generated around the lake as well as downstream. Drought and flood management has been one of the challenges of water resource management, in addition to transboundary management (Revollo, 2001; Rieckermann et al., 2006), which also makes it difficult to implement the strategies of a plan developed more than three decades ago. Despite the efforts of both Peru and Bolivia, these countries still face major problems in terms of water quantity and quality , for example, it has been identified that there is a concentration of mercury in the muscle tissue of several varieties of fishs due to mining activities in the contributing catchments (Gammons et al., 2006). In addition, the potential impacts of climate change could generate other challenges in the future such as drying of Lake Titicaca which means that the water levels would be below the discharge level, so it could become a terminal lake. This could have devastating consequences in the downstream catchments, mainly in irrigation and Lake Poopó. It is therefore important to improve knowledge about the hydrological processes that control the functioning of this lake.

Technical challenges for an analysis of complex hydrological processes in a poorly-gauged context

Studying the hydrological processes of Lake Titicaca and its catchment area faces technical challenges linked to the limited availability and quality of measures on the hydroclimatic conditions (precipitation, temperature, evaporation, melt, groundwater levels, runoff, etc.) and on water withdrawals for irrigation. Most of the meteorological stations and streamflow gauges are located in the lower part (Satgé et al., 2019), and in some cases the quality of the information is questionable (Hunziker et al., 2017). This makes it difficult to quantify the different flows of the hydrological cycle, especially when the hydrosystem has been exposed to non-stationary conditions (e.g. glacier retreat and increase in water withdrawals). Having information in the upper part is crucial due to the presence of tropical glaciers, which have been little studied so far. As a result, their role in the hydrological functioning of the lake is poorly known. As far as water withdrawals are concerned, many of the irrigation systems are self-managed by the farmers themselves according to acquired rights and uses, which establish a relationship between water management and local governance (Bustamante and Vega, 2006). Water withdrawals are thus not measured, and no information is available on the evolution of irrigation over the last decades. A recent study based on the water balance approach in past conditions at the monthly time step has quantified the role of climate and irrigation in the fluctuations of the lake (Lima-Quispe et al., 2021). The findings suggest that the evolution of water levels responds mostly to climatic variability. However, this study did not consider some important processes of mountain hydrology such as the contribution of snow and glaciers. High temporal resolution is usually recommended for modeling these processes (Hock, 2003). It would be most appropriate to model the physical processes at high temporal resolution, but glacier-scale data for melt drivers such as solar radiation, albedo, and turbulent energy exchange processes is not available in this region. Therefore, empirical approaches such as the degree-day (Hock, 2003) are a good option because they are more parsimonious in terms of data requirements. It is therefore important to find the balance between data availability and the need to represent processes at a finer time step. In the Lake Titicaca hydrosystem, the finest temporal resolution of the available data is daily.

PhD objectives

In this context, the PhD objective is to model the hydrological processes that control the interannual and seasonal variations of the water level of Lake Titicaca at the daily time step over a past (1985–2015) and future (2040–2070 and 2070–2100) 30-year periods. Basically, the PhD seeks to answer the following two research questions:

I. How to represent and quantify the hydrological processes and their dynamics in space and over time to simulate the interannual and seasonal water level variations of the lake?
II. How could these processes be altered by the possible effects of climate change and the expected management options? In terms of management scenarios, it is expected to evaluate the increase of irrigated area, crop intensification, water use consumption evolution in link with population dynamics, and lake releases.

Methods

To investigate these questions, a modeling chain based on the water balance approach will be implemented to simulate the following components:

I. Snow and glaciers: a degree day approach (Condom et al., 2012; Ruelland, 2023) will be used because there is not enough information in space and over time on radiation, albedo, wind speed, humidity, and other data commonly used for physically based approaches. The degree day approach has the advantage to be very simple to implement based on precipitation and temperature data. For spatial representation the models will be implemented in a semi-distributed manner using elevation bands. For the dynamic simulation in time of the morphometric variables of glaciers (e.g. thickness, volume and area), globally available data sets will be used (RGI Consortium, 2017; Farinotti et al., 2019).

II. Rainfall-Runoff: it is planned to use two conceptual models that have been successfully implemented in the region in previous studies (Lima-Quispe et al., 2021; Satgé et al., 2019). The first model is the Soil Moisture Model (SMM) (Yates et al., 2005), which is part of the Water Evaluation And Planning System (WEAP) and has seven calibration parameters. The second is GR4J (Perrin et al., 2003), a parsimonious model with four calibration parameters. These models will be dynamically coupled with the snow and glacier models. In addition, both models have the flexibility to consider groundwater exchanges with other basins or with the lake. The models will be forced by precipitation and potential evapotranspiration data. The latter estimated with the Penman-Monteith method (Allen et al., 1998) and Oudin formula (Oudin et al., 2005). Catchment areas will also be disaggregated by elevation bands.

III. Irrigation: the FAO crop evapotranspiration approach (Allen et al., 1998) will be adopted due to the scarce information. Following this approach the SMM has a dynamically coupled irrigation model where irrigation requirements are defined as a function of crop evapotranspiration and soil moisture (Mehta et al., 2013; Yates et al., 2005). For this it is necessary to calibrate two parameters referred to the irrigation threshold corresponding to the volumetric percentage of soil moisture below which irrigation must occur.

IV. Lake: the water balance equation of water bodies will be used considering main components such as precipitation, direct evaporation, upstream inflow, downstream outflow. This type of model is incorporated in WEAP (Yates et al., 2005). The balance will be a function of water level changes considering the bathymetry and releases. Exchanges with groundwater will not be considered since it is a very difficult component to estimate and mainly because there is very little data available. In fact, previous studies have found that losses due to infiltration in Lake Titicaca would only represent only 2% of total losses (Carmouze and Aquize Jaen, 1981).

These models will be forced with gridded precipitation and temperature data sets generated from ground stations. For this it is planned to evaluate and compare two datasets, one based on a probabilistic approach such as GMET-Bolivia (Clark and Slater, 2006; Newman et al., 2015; Wickel et al., 2019) and another generated using a deterministic method considering lapse rate (Ruelland, 2020). The models will be calibrated using control data such as streamflow and lake water levels. For the ungauged catchments, regionalization methods available in the literature will be used (e.g. see Oudin et al., 2008). An important stage of the modeling will be the analysis and quantification of the uncertainty associated with the input data, model structure, and parameter identifiability (Guse et al., 2020; Hublart et al., 2015; McMillan et al., 2018). To address this issue, the use of two sets of input data and the two hydrologic models will be very useful.

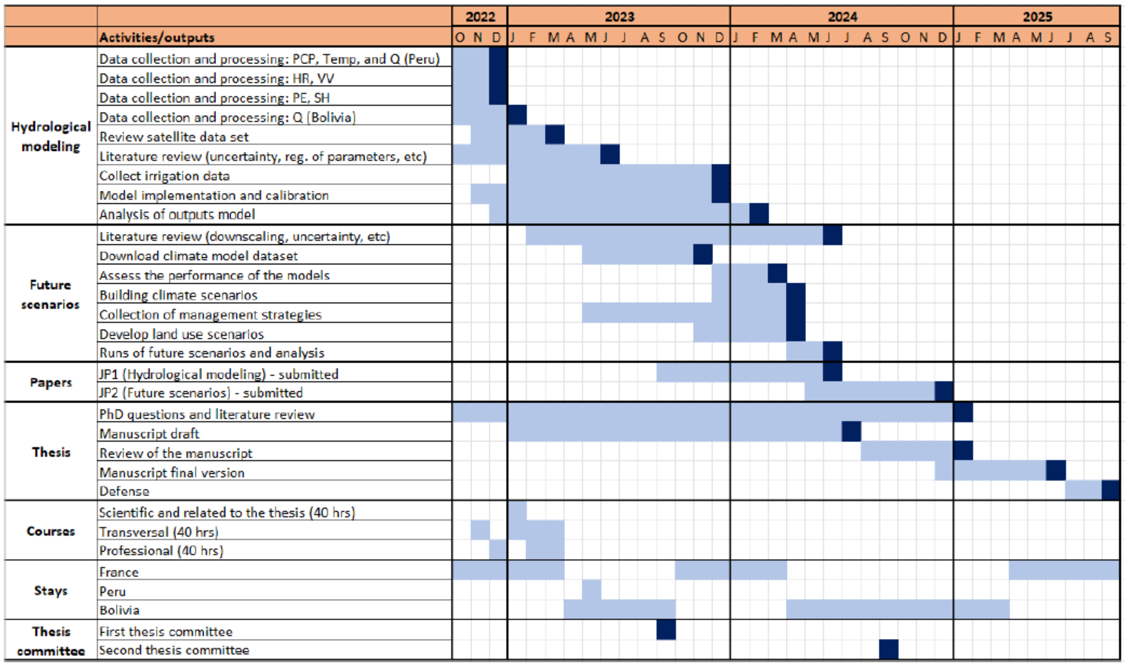
The dynamic and integrated simulation of hydrology, irrigation and lake water level evolution will firstly help to understand how hydrological processes interact and how they impact functioning on interannual and seasonal time scales over the last decades. Second, it will allow evaluating the impact of future climate scenarios and management options on hydrological processes and on water balance. Climate simulations from the coupled model intercomparison project (phase 6) (CMIP6) (Eyring et al., 2016; O'Neill et al., 2016) will be used to generate scenarios under different radiative concentration pathways for precipitation and temperature in the region under study. The management scenarios will be closely related to the increase of irrigated areas, crop intensification and lake releases as well as the changes of domestic water uses.

Expected results

This research seeks to contribute to new scientific findings on the functioning of lakes, methodological innovations and also flexible tools to support decision making. The expected results are presented below from different perspectives:

I. From the scientific point of view, this research will contribute with new findings on the functioning of large lakes in semi-arid and high mountain environments. Specifically, the processes that dominate and drive seasonal, interannual and multidecadal variations in lake water levels; and how they could be modified by the impacts of climate change, irrigation management and lake release.
II. From the methodological point of view, a procedure for the implementation of a modeling chain adapted to poorly gauged hydrosystems will be proposed. This procedure will be innovative for its dynamic and integrative character of mountain hydrology (including snow and glaciers), irrigation and evolution of lake water levels, and also for its flexibility to represent non-stationary processes and evaluation of future scenarios.
III. From the point of view of stakeholders, the data and models will be useful tools to support decision making to improve the management and development of water resources in the Lake Titicaca hydrosystem. In addition, the flexibility of the tools will allow the evaluation of scenarios of interest identified by stakeholders.

PhD prospects



References

Alemayehu, T., Furi, W., and Legesse, D.: Impact of water overexploitation on highland lakes of eastern Ethiopia, Environ. Geol., 52, 147–154, https://doi.org/10.1007/s00254-006-0468-x, 2007.

Allen, R. G., Pereira, L. S., Raes, D., and Smith, M.: Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56, FAO Rome, 300, D05109, 1998.

Bouchez, C., Goncalves, J., Deschamps, P., Vallet-Coulomb, C., Hamelin, B., Doumnang, J.-C., and Sylvestre, F.: Hydrological, chemical, and isotopic budgets of Lake Chad: a quantitative assessment of evaporation, transpiration and infiltration fluxes, Hydrol. Earth Syst. Sci., 20, 1599–1619, https://doi.org/10.5194/hess-20-1599-2016, 2016.

Bustamante, R. and Vega, D.: Normas indígenas y consuetudinarias sobre la gestión del agua en Bolivia, Wageningen University, IWE, 2006.

Carmouze, J.-P. and Aquize Jaen, E.: La régulation hydrique du lac Titicaca et l'hydrologie de ses tributaires, Rev. Hydrobiol. Trop., 14, 311–328, 1981.

Clark, M. P. and Slater, A. G.: Probabilistic quantitative precipitation estimation in complex terrain, J. Hydrometeorol., 7, 3–22, 2006.

Condom, T., Escobar, M., Purkey, D., Pouget, J. C., Suarez, W., Ramos, C., Apaestegui, J., Arnaldo, T., and Gomez, J.: Simulating the implications of glaciers' retreat for water management: a case study in the Rio Santa basin, Peru, Water Int., 37, 442–459, https://doi.org/10.1080/02508060.2012.706773, 2012.

Eyring, V., Bony, S., Meehl, G. A., Senior, C. A., Stevens, B., Stouffer, R. J., and Taylor, K. E.: Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization, Geosci. Model Dev., 9, 1937–1958, https://doi.org/10.5194/gmd-9-1937-2016, 2016.

Fan, C., Song, C., Li, W., Liu, K., Cheng, J., Fu, C., Chen, T., Ke, L., and Wang, J.: What drives the rapid water-level recovery of the largest lake (Qinghai Lake) of China over the past half century?, J. Hydrol., 593, 125921, https://doi.org/10.1016/j.jhydrol.2020.125921, 2021.

Farinotti, D., Huss, M., Fürst, J. J., Landmann, J., Machguth, H., Maussion, F., and Pandit, A.: A consensus estimate for the ice thickness distribution of all glaciers on Earth, Nat. Geosci., 12, 168–173, https://doi.org/10.1038/s41561-019-0300-3, 2019.

Gammons, C. H., Slotton, D. G., Gerbrandt, B., Weight, W., Young, C. A., McNearny, R. L., Cámac, E., Calderón, R., and Tapia, H.: Mercury concentrations of fish, river water, and sediment in the Río Ramis-Lake Titicaca watershed, Peru, Sci. Total Environ., 368, 637–648, https://doi.org/10.1016/j.scitotenv.2005.09.076, 2006.

Guse, B., Kiesel, J., Pfannerstill, M., and Fohrer, N.: Assessing parameter identifiability for multiple performance criteria to constrain model parameters, Hydrol. Sci. J., 65, 1158–1172, https://doi.org/10.1080/02626667.2020.1734204, 2020.

Hock, R.: Temperature index melt modelling in mountain areas, J. Hydrol., 282, 104–115, https://doi.org/10.1016/S0022-1694(03)00257-9, 2003.

Hublart, P., Ruelland, D., Dezetter, A., and Jourde, H.: Reducing structural uncertainty in conceptual hydrological modelling in the semi-arid Andes, Hydrol. Earth Syst. Sci., 19, 2295–2314, https://doi.org/10.5194/hess-19-2295-2015, 2015.

Hunziker, S., Gubler, S., Calle, J., Moreno, I., Andrade, M., Velarde, F., Ticona, L., Carrasco, G., Castellón, Y., Oria, C., Croci-Maspoli, M., Konzelmann, T., Rohrer, M., and Brönnimann, S.: Identifying, attributing, and overcoming common data quality issues of manned station observations, Int. J. Climatol., 37, 4131–4145, https://doi.org/10.1002/joc.5037, 2017.

Lima-Quispe, N., Escobar, M., Wickel, A. J., von Kaenel, M., and Purkey, D.: Untangling the effects of climate variability and irrigation management on water levels in Lakes Titicaca and Poopó, J. Hydrol. Reg. Stud., 37, 100927, https://doi.org/10.1016/j.ejrh.2021.100927, 2021.

McMillan, H. K., Westerberg, I. K., and Krueger, T.: Hydrological data uncertainty and its implications, WIREs Water, 5, e1319, https://doi.org/10.1002/wat2.1319, 2018.

Mehta, V. K., Haden, V. R., Joyce, B. A., Purkey, D. R., and Jackson, L. E.: Irrigation demand and supply, given projections of climate and land-use change, in Yolo County, California, Agric. Water Manag., 117, 70–82, https://doi.org/10.1016/j.agwat.2012.10.021, 2013.

Newman, A. J., Clark, M. P., Craig, J., Nijssen, B., Wood, A., Gutmann, E., Mizukami, N., Brekke, L., and Arnold, J. R.: Gridded ensemble precipitation and temperature estimates for the contiguous United States, J. Hydrometeorol., 16, 2481–2500, 2015.

Niedda, M. and Pirastru, M.: Hydrological processes of a closed catchment-lake system in a semi-arid Mediterranean environment, Hydrol. Process., 27, 3617–3626, https://doi.org/10.1002/hyp.9478, 2013.

O'Neill, B. C., Tebaldi, C., van Vuuren, D. P., Eyring, V., Friedlingstein, P., Hurtt, G., Knutti, R., Kriegler, E., Lamarque, J.-F., Lowe, J., Meehl, G. A., Moss, R., Riahi, K., and Sanderson, B. M.: The Scenario Model Intercomparison Project (ScenarioMIP) for CMIP6, Geosci. Model Dev., 9, 3461–3482, https://doi.org/10.5194/gmd-9-3461-2016, 2016.

Oudin, L., Michel, C., and Anctil, F.: Which potential evapotranspiration input for a lumped rainfall-runoff model?: Part 1—Can rainfall-runoff models effectively handle detailed potential evapotranspiration inputs?, J. Hydrol., 303, 275–289, https://doi.org/10.1016/j.jhydrol.2004.08.025, 2005.

Oudin, L., Andréassian, V., Perrin, C., Michel, C., and Le Moine, N.: Spatial proximity, physical similarity, regression and ungaged catchments: A comparison of regionalization approaches based on 913 French catchments, Water Resour. Res., 44, https://doi.org/10.1029/2007WR006240, 2008.

Perreault, T.: Climate Change and Climate Politics: Parsing the Causes and Effects of the Drying of Lake Poopó, Bolivia, J. Lat. Am. Geogr., 19, 26–46, https://doi.org/10.1353/lag.2020.0070, 2020.

Perrin, C., Michel, C., and Andréassian, V.: Improvement of a parsimonious model for streamflow simulation, J. Hydrol., 279, 275–289, https://doi.org/10.1016/S0022-1694(03)00225-7, 2003.

Pillco Zola, R. and Bengtsson, L.: Long-term and extreme water level variations of the shallow Lake Poopó, Bolivia, Hydrol. Sci. J., 51, 98–114, 2006.

Revollo, M. M.: Management issues in the Lake Titicaca and Lake Poopo system: Importance of developing a water budget, Lakes Reserv. Sci. Policy Manag. Sustain. Use, 6, 225–229, https://doi.org/10.1046/j.1440-1770.2001.00151.x, 2001.

RGI Consortium: Randolph Glacier Inventory—a dataset of global glacier outlines, Version, 2017.

Rieckermann, J., Daebel, H., Ronteltap, M., and Bernauer, T.: Assessing the performance of international water management at Lake Titicaca, Aquat. Sci., 68, 502–516, https://doi.org/10.1007/s00027-006-0863-0, 2006.

Ronchail, J., Espinoza, J. C., Labat, D., Callède, J., and Lavado, W.: Evolución del nivel del Lago Titicaca durante el siglo XX, in: Línea base de conocimientos sobre los recursos hidrológicos e hidrobiológicos en el sistema TDPS con enfoque en la cuenca del Lago Titicaca, Quito, Ecuador, 320, 2014.

Ruelland, D.: Should altitudinal gradients of temperature and precipitation inputs be inferred from key parameters in snow-hydrological models?, Hydrol. Earth Syst. Sci., 24, 2609–2632, https://doi.org/10.5194/hess-24-2609-2020, 2020.

Ruelland, D.: Development of the snow- and ice-accounting routine (SIAR), J. Hydrol., 129867, https://doi.org/10.1016/j.jhydrol.2023.129867, 2023.

Satgé, F., Ruelland, D., Bonnet, M.-P., Molina, J., and Pillco, R.: Consistency of satellite-based precipitation products in space and over time compared with gauge observations and snow- hydrological modelling in the Lake Titicaca region, Hydrol. Earth Syst. Sci., 23, 595–619, https://doi.org/10.5194/hess-23-595-2019, 2019.

Schulz, S., Darehshouri, S., Hassanzadeh, E., Tajrishy, M., and Schüth, C.: Climate change or irrigated agriculture – what drives the water level decline of Lake Urmia, Sci. Rep., 10, 236, https://doi.org/10.1038/s41598-019-57150-y, 2020.

Song, C., Huang, B., Richards, K., Ke, L., and Hien Phan, V.: Accelerated lake expansion on the Tibetan Plateau in the 2000s: Induced by glacial melting or other processes?, Water Resour. Res., 50, 3170–3186, https://doi.org/10.1002/2013WR014724, 2014.

Wang, J., Song, C., Reager, J. T., Yao, F., Famiglietti, J. S., Sheng, Y., MacDonald, G. M., Brun, F., Schmied, H. M., Marston, R. A., and Wada, Y.: Recent global decline in endorheic basin water storages, Nat. Geosci., 11, 926–932, https://doi.org/10.1038/s41561-018-0265-7, 2018.

Wang, S., Xu, C., Zhang, W., Chen, H., and Zhang, B.: Human-Induced water loss from closed inland Lakes: Hydrological simulations in China's Daihai lake, J. Hydrol., 607, 127552, https://doi.org/10.1016/j.jhydrol.2022.127552, 2022.

Wickel, A., Ghajarnia, N., Yates, D., Newman, A., Escobar, M., Purkey, D., Lima, N., Escalera, A. C., and von Kaenel, M.: Developing a gridded high-resolution gauge based precipiation product for Bolivia, in: Geophysical Research Abstracts, EGU General Assembly 2019, Vienna, 18457, 2019.

Wu, C., Wu, X., Lu, C., Sun, Q., He, X., Yan, L., and Qin, T.: Characteristics and driving factors of lake level variations by climatic factors and groundwater level, J. Hydrol., 608, 127654, https://doi.org/10.1016/j.jhydrol.2022.127654, 2022.

Wurtsbaugh, W. A. and Sima, S.: Contrasting Management and Fates of Two Sister Lakes: Great Salt Lake (USA) and Lake Urmia (Iran), Water, 14, 3005, https://doi.org/10.3390/w14193005, 2022.

Yates, D., Sieber, J., Purkey, D., and Huber-Lee, A.: WEAP21—A demand-, priority-, and preference-driven water planning model: part 1: model characteristics, Water Int., 30, 487–500, 2005.

Zhang, G., Yao, T., Piao, S., Bolch, T., Xie, H., Chen, D., Gao, Y., O'Reilly, C. M., Shum, C. K., Yang, K., Yi, S., Lei, Y., Wang, W., He, Y., Shang, K., Yang, X., and Zhang, H.: Extensive and drastically different alpine lake changes on Asia's high plateaus during the past four decades, Geophys. Res. Lett., 44, 252–260, https://doi.org/10.1002/2016GL072033, 2017.

4 – Résumé des activités de terrain PhD1 & PhD2

ACTIVITE DE TERRAIN PHD1 Avril 2023 (participants, Nilo Lima, Denis Ruelland, Thomas Condom) :

Visites des stations hydrométriques du lac Titicaca en Bolivie, visite du site de mesure du niveau du lac à Huatajata.

ACTIVITE DE TERRAIN : PHD1 and PHD2 – Aout 2023 (participants : Jhoana Agudelo & Nilo Lima)

- Visite des stations de mesure de débit Ramis, Huancane, Rio Verde, Coata Unocolla, Lagunillas, Lampa et Ilave (Pérou).

- Réunions avec le SENAMHI, où le projet et les deux thèses du projet ont été présentés en général. L'idée est d'échanger des données. Un échange de courriere est en place opur formaliser les échanges. Ce contact a été très productif.

- La réunion avec IMARPE avec présentation du projet. Ils nous ont parlé de leurs recherches sur la qualité de l'eau, la météorologie et l'hydrobiologie dans le lac Titicaca. Ils ont des données à ce sujet, qu'ils ont dit pouvoir partager, mais il faut envoyer une lettre mentionnant qu'il existe actuellement un accord-cadre entre l'IRD et l'IMARPE.

- Visite au lac Titicaca à la station de Muelle Enafer (Niveau du lac au Pérou).

5 - Meeting AFD 24 Avril 2023 – Un document de synthèse est en cours de Rédaction (Resp. : Marc Pouilly)

Actas del seminario IRD-AFD

sobre la Gestión Integral de Recursos Hídricos

24 de abril de 2023, La Paz, Bolivia -

I- OBJETIVOS y METODOLOGIA DEL SEMINARIO :

Objetivo general: Explorar el tema de la Gestión Integral de Recursos Hídricos (GIRH) en Bolivia, en el sentido de poder identificar las temáticas menos avanzadas y los retos socio-económicos, de gestión y científicos.

Objetivos específicos:

- Conocer la experiencia de la AFD en el tema
- Conocer las experiencias y los desafíos de la GIRH entorno al lago Titicaca identificados por una autoridad de gestión (ALT) y los científicos (socios e investigadores del IRD), específicamente:
    - **Los desafíos de gestión entorno al Lago**, *Presidente de la ALT, Autoridad Binacional Autónoma del Sistema Hídrico del Lago Titicaca, Rio Desaguadero, Lago Poopó, Salar de Colpasa*
    - ***Riesgos y eventos hidro-climatológicos en el Altiplano***, *Ramiro Pillco, Jorge Molina UMSA (UMSA-IHH) y Thomas Condom (IRD)*
    - ***Vulnerabilidad de recursos hídricos en la cuenca Katari***, *Álvaro Soruco, (UMSA – IGEMA)*
    - ***Monitoreo de la calidad de las aguas del lago Titicaca***, *Javier Nuñez, UMSA -IIGEO y Xavier Lazzaro (IRD)*
    - ***Monitoreo de la calidad de las aguas de los ríos, alternativas de saneamiento y gestión integrada ecológica***, Dario Acha y *Carlos Molina (UMSA – IE), y Marc Pouilly (IRD)*
    - ***Retos hidro químicos***, Oswaldo Ramos (UMSA-IIQ), Eléonore Resongles y Stéphane Guédron (IRD)
    - ***Retos hidrogeológicos***, *Céline Duwig (IRD) + EPSAS(?)*
    - ***Retos sociales***, *Franck Poupeau (CNRS-IFEA), Carlos Revilla (IIADI)*

Participantes :

AFD	IRD	UMSA
Alexia Levesque, Directora AFD	Marc Pouilly, Director IRD	Darío Acha Investigador UMSA Instituto de ecología
Florian Lafarge, Encargado de Misión Saneamiento	Thomas Condom Investigador glaciólogo	Javier Nunez Investigador UMSA Instituto Geología
Thais Vargas, Encargada de misión gestión de Recursos Naturales	Xavier Lazzaro Investigador Limnologo	Ramiro Pillco Investigador UMSA Instituto Hidrología
Pavel Barron, Encargado de misión Energía y Desarrollo económico	Eleonore Resongles Investigadores Hidro quimica	Oswaldo Ramos Investigador UMSA Instituto Química
Carla Baltzer, Encarga de misión Energia/Desarrollo urbano	Céline DUWIG Investigadora Hidrogeóloga (visio)	Alvaro Soruco Investigador UMSA Instituto Medio Ambiente
Alex Terrazas, asistente	Stéphane Guèdron Investigador Hidro químico (visio)	Carlos Molina Investigador UMSA Instituto de ecología (visio)
	Nilo Quispe Doctorante IRD-AFD- UMSA Modelizacion climatica en el Altiplano	Jorge Molina Investigador UMSA Instituto Hidrología (visio)
	Denis Ruelland (CNRS-HSM, Montpellier) Hidrologia	
ALT	***IIADI (ONG)***	
Juan Ocola *Presidente de la ALT*	*Carlos Revilla*	

Metodología :

Mañana : presentación institucional general de los objetivos, hoja de ruta, proyectos y de la visión del desarrollo de la GIRH en Bolivia por la autoridad de gestión (ALT), la cooperación para el desarrollo (AFD), los científicos (IRD y UMSA). (30' cada una , seguida por un tiempo de preguntas y discusión).

Tarde : más allá de ponencias científicas detalladas, se propuso reflexionar alrededor de 3 o 4 preguntas estructurantes:

- ❖ Relevancia de soluciones alternativas de saneamiento adaptadas a las áreas rurales características técnicas, gobernanza, modelo económico, E&S etc
- ❖ Oportunidad y relevancia de obras multi-uso en agua ¿gobernanza pluri-actor, modelo económico, incidencias en el desarrollo económico etc
- ❖ Gestión integrada ecológica: retos climáticos, ambientales y sociales, soluciones basadas en la naturaleza, resistencias posibles etc
- ❖ Retos de la evolución, pronostico y seguimiento de la calidad de las aguas del lago

Esta reflexión se armó en base a dos presentaciones iniciales con el fin de ilustrar los objetivos, retos y preguntas así también que la forma de abordar el problema de parte de AFD y de los científicos. La primera fue realizada por el IRD sobre la temática de los retos científicos entorno al conocimiento, la observación y la modelización del clima; la segundo fue presentada por el AFD sobre la problemática de implementación de sistema de saneamiento y PTAR en el rio Rocha (Cochabamba).