US CLIVAR Working Group: Observations and Modeling of Water Isotopes in the Climate System

Duration: April 1, 2018-March 31, 2021

Motivation and Background:
The abundance of stable oxygen and hydrogen isotopes in water are hydrologic cycle tracers. Fractionation during evaporation and precipitation, advective transport in the atmosphere and ocean, and land processes all affect water isotope concentration and reflect hydrological variability. Monitoring of water isotopes in the climate system has occurred for over 60 years, initially for early terrestrial water studies [Dansgaard, 1964], and increasingly for understanding oceanic water masses [LeGrande and Schmidt, 2006; 2011; Craig and Gordon, 1965], evaluating climate of the past [Hays et al., 1976; Andersen et al., 2004; Lachniet, 2009], and elucidating atmospheric pathways of water vapor in the modern [Berkelhammer et al, 2012]. Through a combination of three approaches - modern observations, past climate records, and model simulations - water isotopes hold vast potential to advance our understanding of the global hydrological cycle and how it will respond to anthropogenic greenhouse gases.

With recent innovations in measurement technologies, improvements in theoretical understanding, and refinement of advanced modeling and synthesis techniques, water isotope ratios are powerful tools for climate research in hydrology. Even small collections of isotope ratio measurements in precipitation and seawater provide details of exchange processes that are difficult to obtain from conventional meteorological or oceanographic measurements [Benway and Mix, 2004; Conroy et al., 2014;2016]. Paleoclimate archives that preserve water isotopes extend these tracer records back in time and provide insight into climate variability prior to the instrumental era.

NASA, NCAR, Hadley, LMD, and other modeling groups simulating future and past climate have incorporated water isotopes to connect modern observations and paleoclimate records. This framework can be applied to diagnose shortcomings in the representation of critical processes (including clouds and air-sea gas exchange) and limitations in the representation of transport by both large-scale and turbulent flows [Steen-Larsen et al., 2017]. Water isotopes provide another degree of freedom (in addition to temperature, precipitation, and ocean salinity, to name a few) that can be used to constrain the fluxes of heat and moisture through the earth system – both in the modern as well as in model parameterizations of key processes in the ocean and atmosphere. Water isotope observations are an increasingly important diagnostic tool for assessing accuracy of i) ocean and atmospheric circulation patterns [Stevenson et al., 2015; Nusbaumer et al., 2017], ii) atmospheric convective and cloud physics [Field et al., 2014], iii) land surface hydrology [Risi et al. 2016; Wong et al., 2017], and iv) the global water budget in coupled climate models.

Most paleoclimate reconstructions are based on water isotope ratios in corals, stalagmites, lake sediments, trees, and ice. These archives help constrain weather extremes: ENSO [Cobb et al., 2013], prolonged drought [Steinman et al., 2012], and hurricanes [Frappier et al., 2007], and their evolution over time. Reconstructions also enable the quantification of anthropogenic trends in temperature and rainfall from data-poor regions. Data assimilation efforts have made progress

towards transforming networks of paleoclimate datasets into dynamically constrained reconstructions of global climate variability over the last millennium [Hakim et al., 2016].

However, to identify the mechanisms responsible for past isotopic signals, we must document, understand, and accurately model how large-scale climate signals of interest imprint upon spatio-temporal variability in modern-day. Lack of a coherent observational-modeling framework inhibits data assimilation, which limits detection and attribution studies of anthropogenic climate change impacts. A focused synthesis effort of observational and modeling water isotope fields addresses this shortfall:1) satellite vapor isotope observations are yielding fundamental insights into the global water cycle [Worden et al., 2007; Frankenberg et al., 2009]; 2) field deployable laser-based technologies are enabling rapid, cost effective measures of water isotopes in liquid and vapor phases, making ambitious observational programs that were cost-prohibitive, now feasible [Kurita et al., 2011; Bailey et al., 2013; Conroy et al., 2016]. Water isotope studies have matured to merit incorporation into the science plans of large-scale modeling and observational efforts, guided by a strategic plan that prioritizes investments of limited resources into key new capabilities and partnerships to support sustained, novel research.

Currently, the climate information contained in the distribution of water isotopes is underutilized. The only global isotope network available to the community [IAEA/WMO, 2017], designed in the 1960's, is comprised mainly of monthly averaged rainfall and river water isotopes, without a coherent framework for high-resolution studies that include event-based data. It is inadequate for applications of the pressing climate science questions outlined above; it does not include water isotope measurements of seawater and water vapor, despite their importance as model diagnostic tracers, or sub-daily measurements that provide insight into dynamics of individual convective events [Conroy et al., 2016]. Individual PIs have maintained small, uncoordinated, temporary networks of observations that supplement the sparse global IAEA database (many led by WG team members under NASA, NOAA, and NSF grants), but the scientific value of water isotopes to scientists from many different disciplines warrants a coordinated scaling-up of these efforts that recognizes the above-mentioned technological breakthroughs in measurement capability.

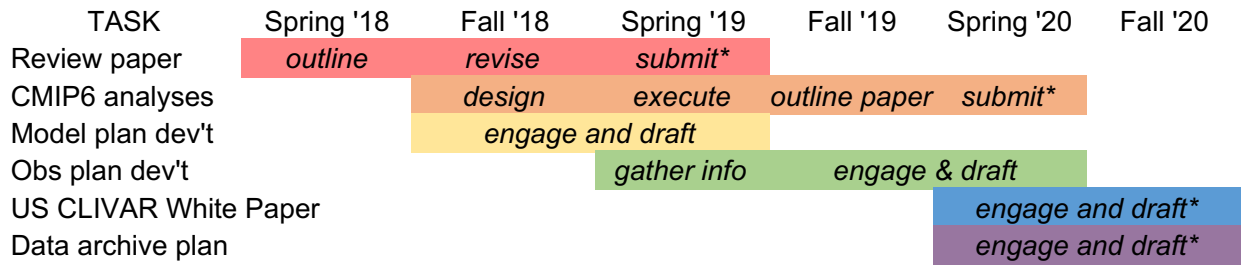
The time is ripe for water isotope ratios, as a "climate variable," to be routinely measured on established observational platforms such as ships, buoy arrays, airplanes, satellites, and meteorological stations across the ocean and land, and throughout the atmosphere. This goal reflects the appreciable infrastructure already dedicated to the measurement of a range of climate variables (domestic and international) through many different programs, but few include water isotopes in their design and operation. Adding them to a standard sampling protocol would be trivial - measured discretely it only requires a 4mL water sample without special treatment or preservation. Continuous measurement (in seawater or vapor on a ship, airplane, or weather station) occurs by field-deployable units permanently installed alongside other instrumentation.

A new isotopic data archive that recognizes diverse input sources (water vapor data from airborne platforms, bottle measurements from ocean cruises, river and lake water time-series, etc) and diverse user needs (atmospheric scientists, climate modelers, groundwater hydrologists, oceanographers) is also critical. Right now PIs are maintaining their own ad-hoc archives for huge datasets that the community at large is not aware of, hindering the progress in this field significantly. As we design the parameters for a new public archive for water isotope data, we

will leverage ongoing work with the SPATIAL isotope database, designed and maintained by Working Group member Gabe Bowen, as a starting point for our discussions [Bowen, 2017].

Objectives:
The main objectives of the proposed Working Group include the following:
i) compile and distill the latest scientific findings from the water isotope research community
ii) assess near-term opportunities for water isotope related research to accelerate our understanding of climate variability
iii) identify high-priority research goals for water isotopes in atmosphere and ocean models
iv) identify a set of high-priority scientific targets for the next generation water isotope observational systems and model simulations;
v) design an integrated scientific plan for water isotope observations and modeling designed to make progress towards key targets identified in iv)
vi) identify designs for a novel isotope data archive to meet the needs of diverse user groups

Tasks and Timeline:
1) Engage researchers from different fields of climate science and review emergent frameworks for characterizing the role of water isotopes in the global water cycle in both observations and models; outline review paper & assign lead authors - (**In-person Meeting 1, Year 1**)
2) Develop priorities for the near-term analyses of CMIP6 archive (to include analyses designed to inform and justify an optimal observational network for water isotopes), and discuss future coordinated modeling efforts (i.e. PMIP4, isoMIP, SWING3, etc); revise review paper - (**Open Workshop Meeting*, end of Year 1**)
3) Gather information about platforms and methodologies (existing and in development) to inform the development of a next-generation water isotope observation network - (**Tele-Meeting 1, Year 2**); submit review paper (**Deliverable 1**)
4) Develop strategy for new observational capacity building to support modeling and data assimilation priorities (Science Strategic Plan); outline paper for CMIP6-based modeling results (**In-person Meeting 2, Year 2**)
5) Identify core set of recommendations for new water isotope data archive, begin drafting of recommendations (**Tele-Meeting 1, Year 3**); submit modeling results paper (**Deliverable 2**)
6) Draft a US CLIVAR White Paper for water isotope observations and modeling (**Deliverable 3**); Delegate follow-on activities to engage key stakeholders in strategic plan & long-term capacity building (**In-person Meeting 2, Year 3**)



* indicates key deliverable for the Working Group

Open Community Workshop at end of Year 1:
The goal of this community workshop is to share the progress of the Working Group with a broad range of existing water isotope researchers and users as well as to engage scientists from disciplines that could uniquely benefit from water isotope methodologies. We will also invite key stakeholders from the observational as well as modeling disciplines such as program managers at relevant national and international agencies/programs to learn about our initiatives and provide feedback on feasibility and discuss upcoming opportunities for further engagement.

Benefits and Relevance to US CLIVAR:
Water isotopes are vital tracers of modern and past climate in earth system models. Coordinated observational and modeling programs will further our understanding of anthropogenic and natural climate trends and extremes, advance data assimilation efforts with water isotope-based proxies, and, via data-model intercomparisons, provide a check on the accuracy of future climate projections. The proposed WG addresses all four Questions and all five Goals outlined in the most recent US CLIVAR Science Plan; in particular, closely aligning with the following: 1) Understand processes that contribute to climate variability and change in the past, present, and future; and 2) Improve the development and evaluation of climate simulations and predictions, which is especially timely given the upcoming release of CMIP6 archive (some of which will contain water isotope tracers, especially through the NCAR-CESM and NASA-GISS models).

Publications and Outreach:
The Water Isotope working group would seek to publish one high-profile peer-reviewed review paper (**Deliverable 1**; proposed co-Chair Cobb is already in conversation with Nature editor M. White, who has expressed interest in this idea). We will also publish the results of our analyses of CMIP6 model output as a peer-reviewed article (**Deliverable 2**). There may also be interest among working group members in compiling a review paper targeting past data assimilation, data-model comparisons of hydrological extremes, or other emergent topics from our syntheses. We will complete a US CLIVAR White Paper (**Deliverable 3**) for water isotope research that contains information about near-term, low-cost opportunities for accelerating water isotope research in both observational and modeling domains, as well as a core set of recommendations for a new data archive, complete with analyses of potential host institutions.

We propose to spread awareness of the unique value of water isotope investigations. Committee members represent many climate science sub-disciplines, and are well-poised to serve as spokespeople for the Water Isotope WG activities, disseminating and collecting relevant information while engaging a the broad cross-section of the climate science community. Also, many of the members maintain a robust and diverse portfolio of public engagement activities, including but not limited to public lectures (e.g. Tedx), K-12 encounters, media appearances, visits to Capitol Hill (e.g. "Climate Science on Capitol Hill Day"), and social media engagement. These efforts engage a broader audience of stakeholders in demonstrating how climate science research translates into economic value and public welfare for all Americans. We will also create several short videos that illustrate the wide variety of water isotope observational platforms, with a heavy emphasis on their ability to answer key questions in climate science.

Reporting Plan:
We will compile a report of each Working Group meeting to be submitted within one month of each tele-conference and meeting. At the end of the Working Group tenure, we will prepare a final report that will contain our US CLIVAR White Paper for water isotopes as well as an inventory of the national and international stakeholders that we engaged with over the course of the working group's activities, and a plan for continued capacity building over ensuing years.

Approved Membership:
Co-Chairs:
Kim Cobb (Georgia Tech; Member, Pacific Regional Panel, CLIVAR) - water isotope observations and paleoclimate reconstruction
David Noone (Oregon State University) – water isotope observations and modeling

Contributing Members:
Samantha Stevenson (UCSB; Member, CLIVAR) – water isotope modeling & climate dynamics
Jess Conroy (U. Illinois Urbana-Champaign) – water isotope observations & paleoclimate
Bronwen Konecky (Washington Univ.) – water isotope observations, modeling & paleoclimate
Allegra LeGrande (NASA-GISS) – water isotope modeling & climate dynamics
Alyssa Atwood (UC-Berkeley, Georgia Tech) – water isotope obs & paleoclimate and
Gabe Bowen (U. Utah) – water isotope obs & ecohydrology applications, data archives
Adriana Raudzens Bailey (NCAR) – water isotope observations & tropospheric processes
Jesse Nusbaumer (NASA-GISS) – water isotope modeling
Natalie Burls (George Mason) – coupled climate dynamics

International partners: (unfunded)
Valerie Masson-Delmotte (LSCE, France) – water isotope modeling
Camille Risi (LMD, France) – water isotope modeling & atmospheric circulation
Naoyuki Kurita (Nagoya University, Japan) – water isotope observations & modeling Ricardo Sanchez-Murillo (National University of Costa Rica) – water isotope observations
Nerilie Abram (Australian National University) – water isotope observations & paleoclimate
Martin Werner (AWI) – water isotope modeling & paleoclimate applications
Kei Yoshimura (U. Tokyo) – data assimilation using water isotopes

US CLIVAR synergies:
1) Phenomena, Observations, and Synthesis Panel (endorsement E. Di Lorenzo, Co-Chair):
The proposed working group's strategic goals advance those of this existing working group primarily in the integration of paleoclimate datasets, modern-day observations and climate models towards the improved understanding of climate variability and change.
2) Process Study and Model Improvement Panel (endorsement K. Karnauskas, Co-Chair):
The working group activities in advancing new model diagnostics for ocean and atmospheric models is highly relevant to the broad goals of this existing working group. Specifically, our focus on model diagnostics and data-model intercomparison adds value to their ongoing focus around 'Translating Process Understanding to Improve Climate Models'.

Funding Available: $75K
i) member travel to WG meetings (annually, 3yrs) + community-wide workshop = 4 meetings x $9,000/meeting = $36K
ii) community-wide workshop, end of year 1 ($30K to fund non-WG members, with funding allocated primarily to early career researchers)
iii) review article publication ($3K)
iv) production of 2-3 short videos explaining the science of water isotopes and their role in the global water cycle, for use in social media and K-12 outreach efforts ($5K)

NOTE: While the allocated costs for in-person meetings may appear quite low, this reflects our strategy to 1) enable tele-conferencing for working group members whenever feasible, 2) working group meetings will be co-located with AGU whenever feasible, and 2) encourage senior members of the Working Group to cost-share their travel by at least 50%.

Funding sources: US CLIVAR, NSF Paleoclimate, NSF MG&G

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