State of observations

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Objectives of the working group

• Synthesize water isotope research
• Identify research critical to climate variability & change
• Set goals for coordinated climate simulations
• Identify targets for next generation observations
• Plan for integrated observations & modeling
• Design data archive
Current Observational Networks

GNIP

USNIP

Welker, 2012
Network value - *in the context of 21st century science targets*

- Observe and model spatiotemporal variability and its dynamical origins
  - Regional water budgets
  - Precipitation regimes
  - Large-scale patterns of smaller scale processes (e.g. mixing efficiencies, rain evaporation)
  - Modes of the climate system with distinct spatial fingerprints (e.g. ENSO, PDO, PNA)
Water isotopes track large scale climate patterns

$\delta^{18}O_p$ and P anomalies during El Niño events


Conroy et al., 2013 JGRA
Water isotopes track large scale climate patterns

Tracking changes in the strength of the Walker Circulation between cold and warm phases of ENSO using satellite-retrieved isotope ratios in water vapor (600 hPa)

Indian Ocean Zonal Mode or Dipole (Konecky et al. 2014; Lee et al. 2015), Antarctic annular mode (Noone & Simmonds 2002), NAO (Sodemann et al. 2008; Deininger et al. 2016), NAM and other modes (Schmidt et al. 2007), SAM (Abram et al. 2014)
Network value - *in the context of 21st century science targets*

- **Evaluate global changes in the water cycle**
  - **Water vapor and precipitation isotope patterns**
    - Atmospheric residence time
    - Moisture length scales
    - Moisture recycling efficiencies
  - **Seawater isotope patterns**
    - Salinity, atmospheric moisture budget

\[
\delta \sim a + bD^* + cL
\]

\[D^* = \text{local drying “efficiency”}\]
\[L = \text{mean distance remote moisture travels}\]

Mean moisture transport (Bailey et al., 2018), Walker Circulation (Dee et al. 2018), Moisture source regions (Feng et al. 2009), Atmospheric river origins (Nusbaumer & Noone 2018)
Network value - *in the context of 21st century science targets*

- Quantify scales of spatial continuity for interpretative purposes
  - What footprints do discrete observations (by extension, proxy records) represent?
Understand the spatial footprint of measurements

Moerman et al., 2013 EPSL
Network value - *in the context of 21st century science targets*

- **Improve observational statistics of key processes**
  - Convective organization
  - Cloud/rain processes
  - Oceanic/atmospheric mixing

- **Improve numerical predictions**
  - Evaluate parameterizations
  - Provide boundary conditions
  - Evaluate climate sensitivity
Existing “Networks”
Global **Network of Isotopes in Precipitation (GNIP)**

- Precipitation collection began in 1961 by International Atomic Energy Agency/World Meteorological Organization
- $\delta^{18}O$, $\delta D$, $^3H$ in monthly precipitation worldwide

**Limitations**

- Few stations contemporaneous
- Few stations with long time series
- Undersampled areas (tropics)
- No specific design to target explicit climate questions
Remote-sensing of water vapor isotope ratios

- **Satellite instruments**
  - TES (Tropospheric Emission Spectrometer, NASA)
  - AIRS (Atmospheric Infrared Sounder; NASA)
  - IASI (Infrared atmospheric sounding interferometer; EUMETSAT)
  - SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric Chartography; European Space Agency)
  - GOSAT (Greenhouse Gases Observing Satellite; Japan Aerospace Exploration Agency)
  - ACE-FTS (Atmospheric Chemistry Experiment-Fourier Transform Spectrometer; Canadian Space Agency)

- **Ground-based FTIR**
  - TCCON - Total carbon column observing network
  - NDACC - Network for the Detection of Atmospheric Composition Change
In situ water vapor studies: PI-led, uncoordinated

See Galewsky et al., Rev. of Geophysics, 2016
National Ecological Observatory Network (NEON)

- 20 core terrestrial sites
- 19 ecological domains
- Identical instrumentation
- Operating next 30 years
- 30-min water vapor isotopic data
- PI-led opportunities
Oceans/Marine Networks

- The only ocean networks are by individual PIs (not coordinated)
- Other seawater isotope data obtained opportunistically (cruises)
Oceans/Marine Networks

Conroy et al., 2017
Database and Atlas, 1,926 $\delta^{18}O_{sw}$ measurements to date

Schlitzer et al. (2018), *Chemical Geology*
New 2-page section contributed to TPOS 2020 2\textsuperscript{nd} report by US CLIVAR working group (Released May 2019)

Water isotope measurements contribute to several aspects of understanding tropical Pacific climate

- **Heat and moisture fluxes** (quantification of evaporation and precipitation fluxes, direct comparison to output from isotope-enabled climate models)

- **Ocean and atmosphere mixing** (atmosphere and ocean water masses carry unique isotopic signatures) – analogous to T-S plots in physical oceanography

- **Detection of changes in tropical Pacific climate** (water isotopes are sensitive indicator of changes in water budget)

- **Extending the record of tropical Pacific climate** (water-isotope based paleoclimate reconstructions require modern day observations of water isotopes for robust climate interpretations)
Integrating observations and models of water isotopes in the climate system

Galewsky et al., 2016, Rev. of Geophysics
Data-model comparisons for model evaluation

Mean annual $\delta^{18}O_p$: GNIP vs iCAM5

Nusbaumer et al. (2017), JAMES

Werner et al. 2016, GMD
Risi et al. 2010, JGRA
Schmidt et al. 2007, JGRA

Field et al., 2014
Galewsky et al., 2016
The water isotopic record in paleoclimate archives provides quantitative information about past climates on monthly to glacial-interglacial time scales.

Many research efforts now combine paleoclimate data with isotope-enabled climate models.
Value & challenges of **proxy-model comparisons**

**Paleoclimate data-model comparisons critical for:**

- Interpreting paleoclimate records, including testing common assumptions about what proxies record
- Understanding the dynamical context of reconstructed climate changes
- Testing hypotheses developed from theoretical principles and/or model simulations beyond the limited scope of the instrumental period
- Testing climate models outside the range of 20–21st century variability (since the future will likely be very different than today)

**Challenges:**

- Sparseness of proxy data
- Downscaling GCM data to specific proxy site
- Apples-to-apples comparison of model output and proxy data
Best practices for proxy-model comparisons of hydroclimate during the Common Era

Comparing proxy and model estimates of hydroclimate variability and change over the Common Era

Hydro2k Consortium: Jason E. Smerdon¹, Jürg Luterbacher²,³, Steven J. Phipps², Kevin J. Anchukaitis⁵, Toby Ault¹, Sloan Coats⁷,⁸, Kim M. Cobb⁹, Benjamin I. Cook¹⁰,¹¹, Chris Colose¹⁰, Thomas Felis¹¹, Ailie Gallant¹², Johann H. Jungclaus¹³, Bronwen Konecky³, Allegra LeGrande¹⁰, Sophie Lewis¹⁴, Alex S. Lopatka¹⁵, Wmmin Man¹⁶, Justin S. Mankin¹⁷,¹⁰, Justin T. Maxwell¹⁷, Bette L. Otto-Bliesner⁷, Judson W. Partin¹⁸, Deepi Singh¹, Nathan J. Steiger¹, Samantha Stevenson⁷, Jessica E. Tierney¹⁹, Davide Zanchettin¹⁰, Huan Zhang⁵, Alyssa R. Atwood²⁰,²¹, Laia Andreu-Hayles¹, Seung H. Bae⁵, Brendan Buckley¹, Edward R. Cook¹, Rosanne D'Arrigo¹, Sylvia G. Dee²², Michael Griffths²³, Charuta Kulkarni²⁴, Yochanan Kashir², Flavio Lehner², Caroline Leland¹, Hans W. Linderholm²⁵, Atsushi Okazaki²⁶, Jonathan Palmer²⁷, Eduardo Piovanò²⁸, Christoph C. Raible²⁹, Mukund P. Rao¹, Jacob Schef², Gavin A. Schmidt¹⁰, Richard Seager¹, Martin Widmann³¹, A. Park Williams¹, Elena Xoplaki⁷

Other proxy-model comparisons of the Common Era: Mann et al., 2009; Anchukaitis et al., 2010; Goosse et al., 2012; Schmidt et al., 2014; Coats et al., 2015; Cook et al., 2015; Neukom et al., 2015; PAGES 2k, 2015; Luterbacher et al., 2016
Current tools and recent developments aiding proxy data-model comparisons

Increasing number of isotope-enabled climate models

- Coupled general circulation models
- Intermediate complexity models (e.g. Dee et al., 2015; Bailey et al., 2018)
- Regional models (e.g. IsoROMS; Stevenson et al., 2018)
PRYSM – A Proxy System Model for lake sediment records

Dee et al., 2018
Paleoclimate Data Assimilation

Paleoclimate data assimilation (PDA) uses model-simulated climate states to measure the climate information in proxy data and distribute that information to all climate variables subject to the dynamical constraints of the climate model.

Advantages:
1. Infers multiple climate fields simultaneously
2. Generally does not assume stationary teleconnections (unlike most purely statistical approaches)
3. Uses dynamical models to infer spatial relationships within and between climate fields. The fields are thus dynamically consistent.
4. Includes proxies with dependence on multiple parameters (e.g., tree-ring width sensitivity to temperature and moisture) and with different temporal resolution (e.g. annual and decadal) without interpolation or smoothing

Goosse et al., 2010; Widmann et al., 2010; Goosse et al., 2012b; Steiger et al., 2014; Steiger and Hakim, 2015; Hakim et al., 2016
The Last Millennium Climate Reanalysis Project

Hakim et al., 2016

Global mean temperature

1880 CE 2000 CE
“Unfortunately, the current measurement network is inadequate to address 21st century isotopic research challenges, and the scarcity of the available observational data across the tropics is a real hindrance for many studies and applications.”

Vuille et al. (2018) *Hydrological Processes*

“Unfortunately, the tropical Pacific still lacks the decades-long, continuous time series of $\delta^{18}O_p$ needed to understand the isotopic response to key elements of the climate system, especially ENSO.”

Conroy et al. (2013) *JGRA*
Thoughts moving forward

Why design a new network of observations?
What network do we need to answer our science targets?
Where can we leverage planned efforts or influence planning processes?
Are there “gold” sites?
  - Focal points for the larger community?
  - Sites with pre-existing data
  - Sites where local observations capture large-scale processes
  - Multiple-purpose sites?

How will we tackle funding, calibration coordination, supervision, curation?
Questions?
Improve numerical predictions

Climate sensitivity in NCAR’s newest GCM is higher than ever and sensitive to rain evaporation. Can we use isotopic observations in surface vapor and precipitation to constrain re-evaporation?

New measurements suggest isotopic differences between surface water vapor and rain indicate sub-cloud evaporation of falling hydrometeors.

Graf et al. (2018) *ACP*
Value of Proxy System Models

1. Improve data-model comparisons
   • Identify deficiencies in (1) process-level understanding of the proxy sensors, (2) paleo-observing network, and/or (3) climate model simulations

2. Apply proxy system models to observations to test consistency of proxy interpretations

3. Model the total uncertainty in the response of proxy systems to environmental forcing

4. Designing optimal sampling networks for paleoclimate reconstruction