State of observations

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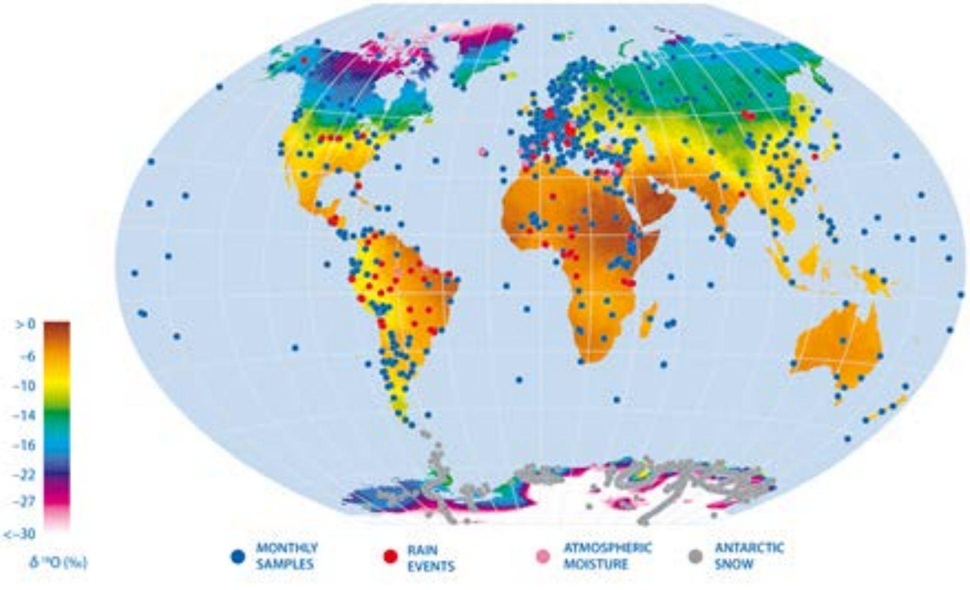
Objectives of the working group

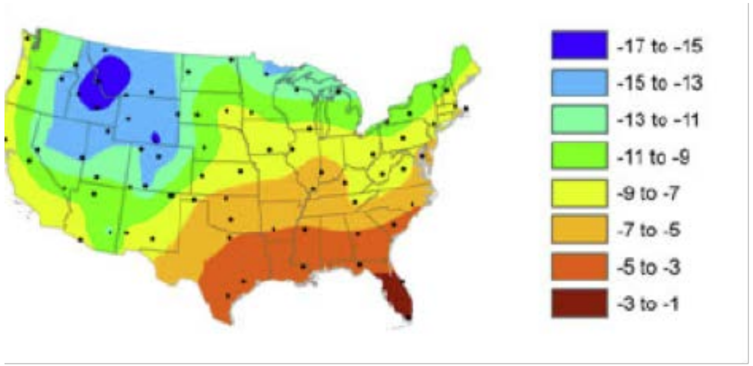
- Synthesize water isotope research
- Identify research critical to climate variability & change
- Set goals for coordinated climate simulations
- **Identify targets for next generation observations**
- **Plan for integrated observations & modeling**
- Design data archive

Current Observational Networks

GNIP



USNIP



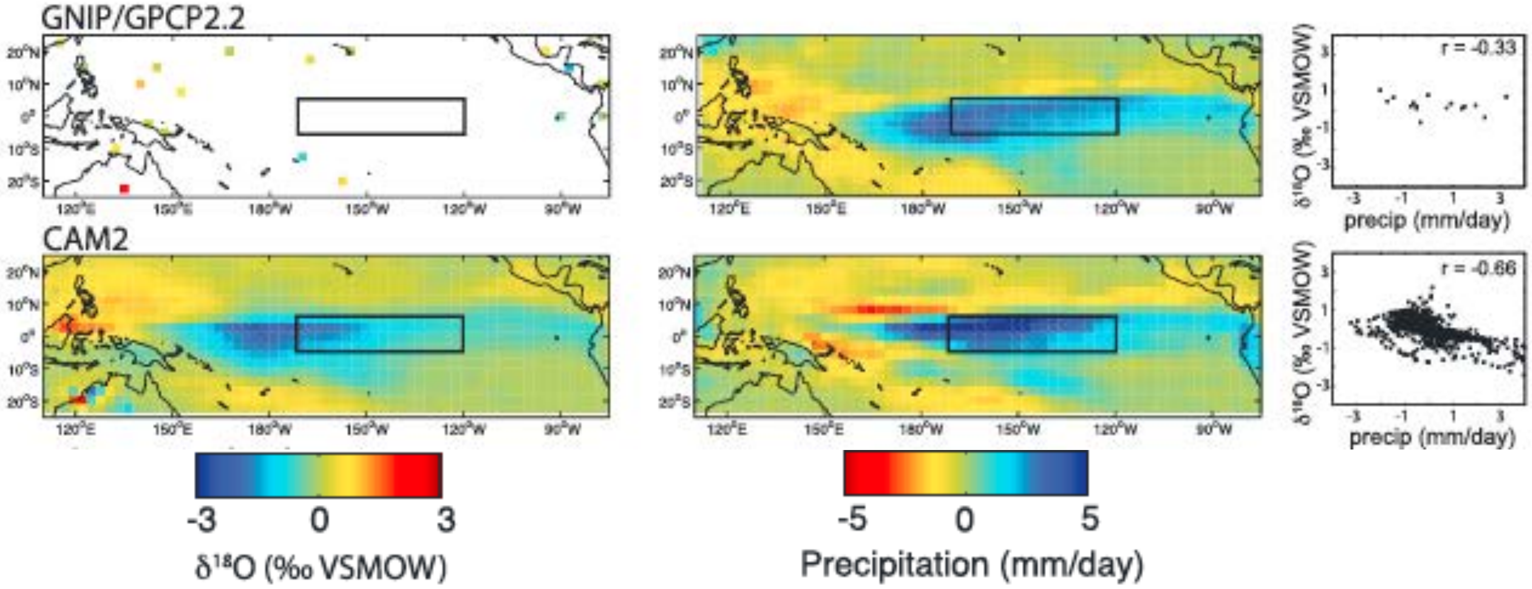
Welker, 2012

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

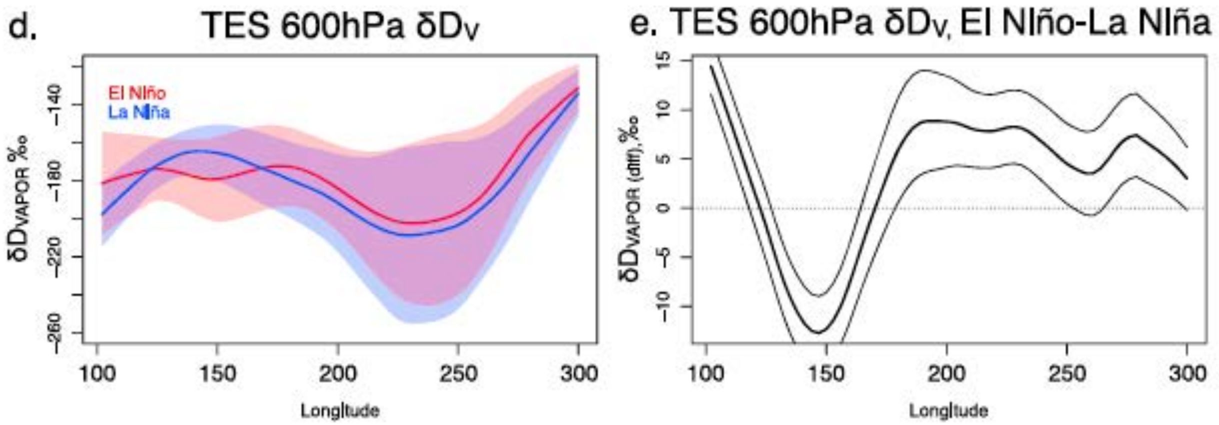


Conroy et al., 2013 JGRA

Liu et al. 2014, Liu et al. 2017:PNA pattern in North American d18Op, Stevenson et al. 2018: interannual variations in Pacific δ^{18}Osw

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)



Dee et al. 2018 JGRA

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

$\boldsymbol{\delta} \sim a + b\boldsymbol{D^*} + c\boldsymbol{L}$

D* = local drying "efficiency"

L = mean distance remote moisture travels

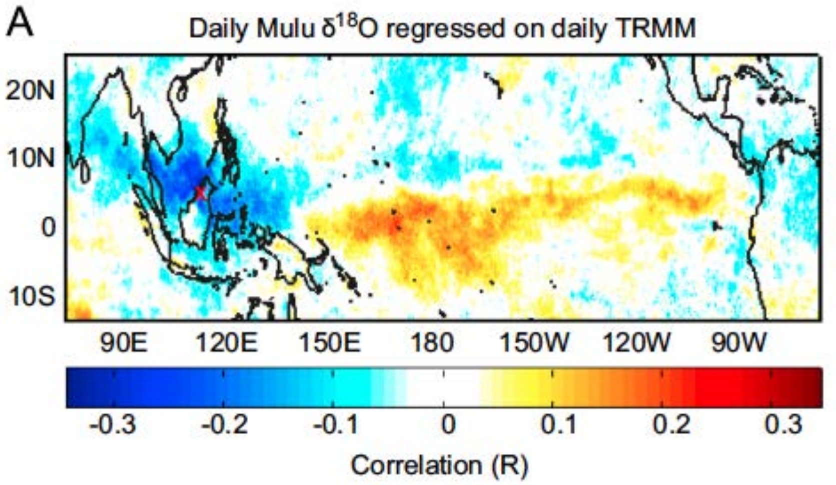
Bailey et al. (2018) *GRL*

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

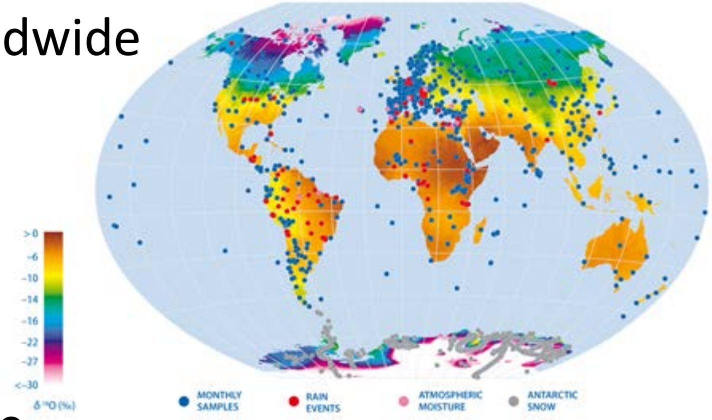
Network value - *in the context of 21st century science targets*

- **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
- $\delta^{18}O$, δD, ^{3}H in monthly precipitation worldwide



Limitations

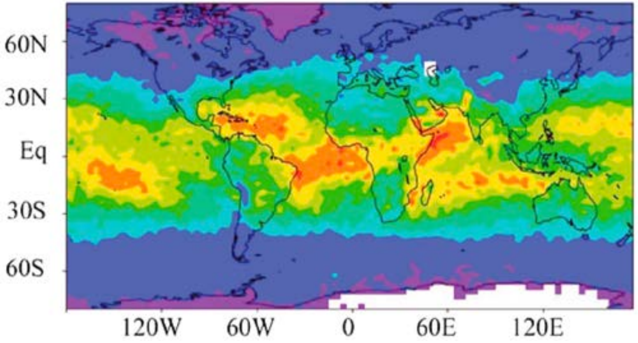
- Few stations contemporaneous
- Few stations with long time series
- Undersampled areas (tropics)
- No specific design to target explicit climate questions

Remote-sensing of water vapor isotope ratios

- <u>Satellite instruments</u>
  - **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 Transforr Spectrometer; Canadian Space Agency)
- <u>Ground-based FTIR</u>
  - **TCCON** - Total carbon column observing network
  - **NDACC** - Network for the Detection of Atmospheric Compositi

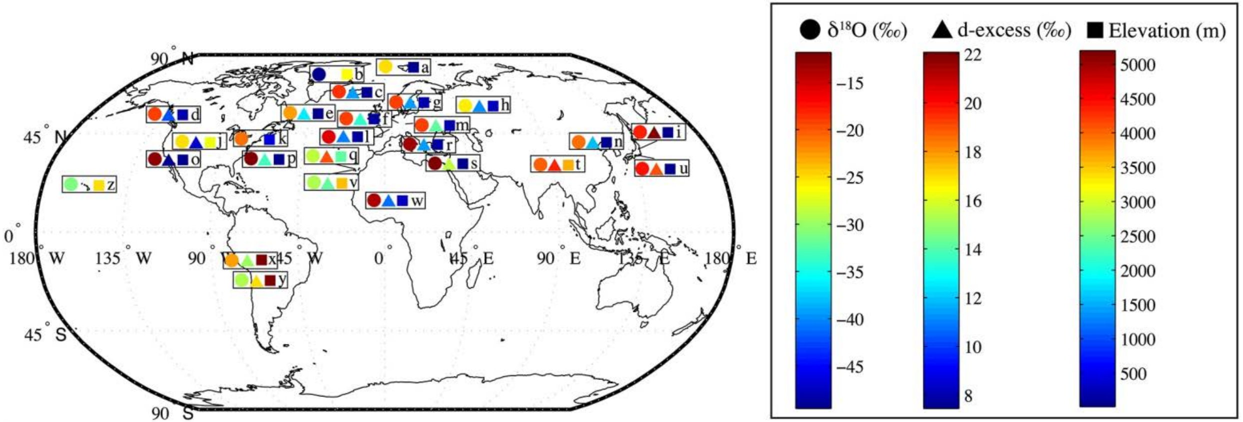
NDACC FTIR

TES



In situ water vapor studies: PI-led, uncoordinated

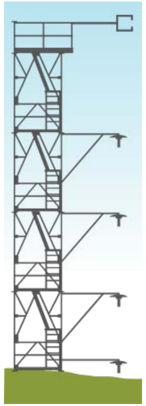
See Galewsky et al., *Rev. of Geophysics*, 2016

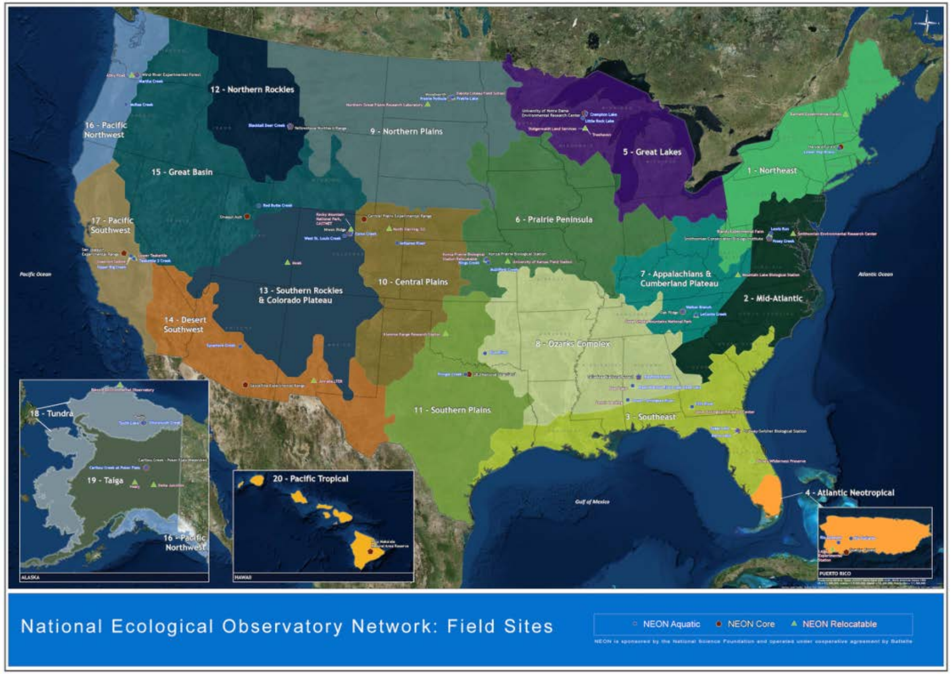


a Ny-Ålesund, Masson-Delmotte et al. (2015)
b Summit, Greenland, Bailey et al. (2015a)
c Iceland, Steen-Larsen et al. (2015)
d Wind River, WA, USA, Lai et al. (2014)
e Iviuttuut, Greenland, Bonne et al. (2014)
f Karlsruhe, Germany, Christner (2015)
g Heidelberg, Germany, Jacob and Sonntag (1991)
h Kourovka, W. Siberia, Bastrikov et al. (2014)
i Tsukuba, Japan, Wei et al. (2015), Wei et al. (2016)
j Niwot Ridge, CO, USA, Berkelhammer et al. (2013)
k New Haven, USA, Lee et al. (2005), Lee et al. (2006)
l SIRTA, France, Vimeux et al. (2014)
m Vienna, Austria, Kurita et al. (2012)
n Beijing, China, Wen et al. (2010)
o San Diego, USA, Lai et al. (2014)
p Bermuda, Steen-Larsen et al. (2014a)
q Izanha, Tenerife, González et al. (2016)
r Patras, Greece, Salamalikis et al. (2015)
s Rehovot, Israel, Angert et al. (2008)
t Lhasa, Tibet, Tian (2014)
u Nagoya, Japan, Kurita et al. (2015)
v Teide, Tenerife, González et al. (2016)
w Niamey, Niger, Tremoy et al. (2012, 2014), Okazaki et al. (2015)
x Chacaltaya, Bolivia, Vimeux et al. (2015)
y Chajnantor Plateau, Chile, Galewsky and Samuels-Crow (2014)
z Mauna Loa, Hawaii, Bailey et al. (2015a)

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

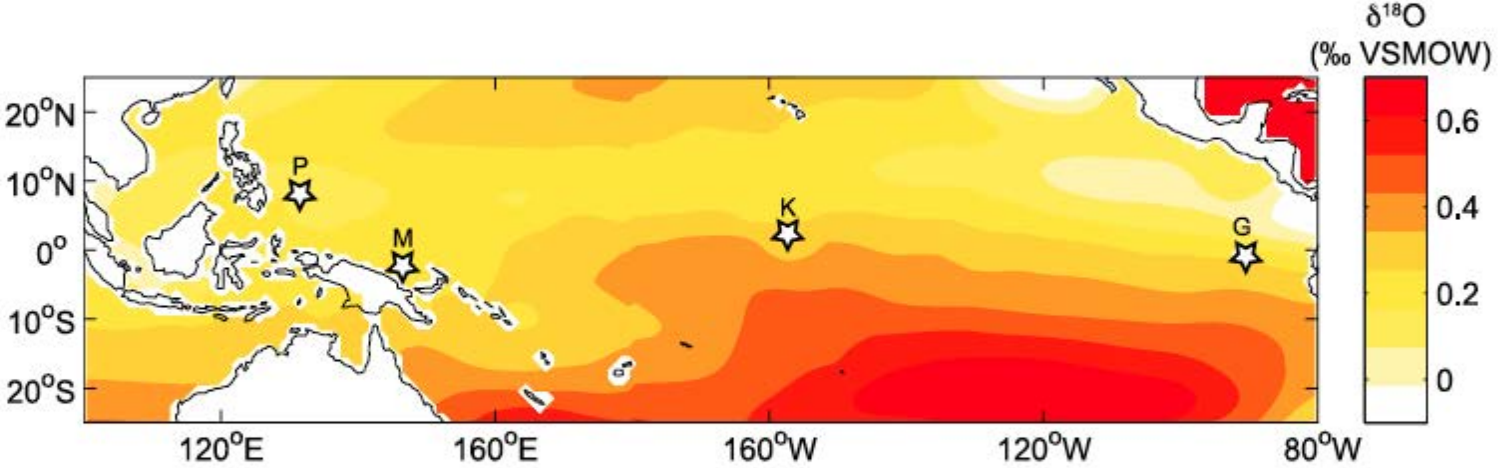




Oceans/Marine Networks

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

Oceans/Marine Networks



Conroy et al., 2017

GEOTRACES Intermediate Data Product 2017

Database and Atlas,
1,926 $\delta^{18}O_{sw}$
measurements to date

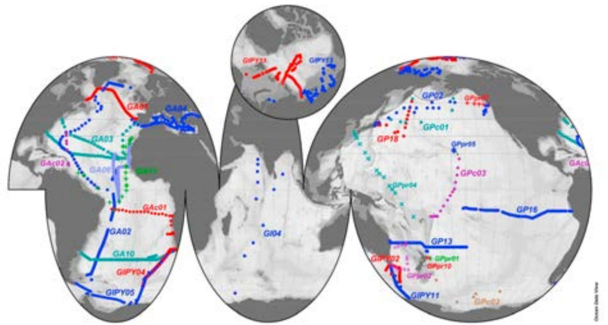
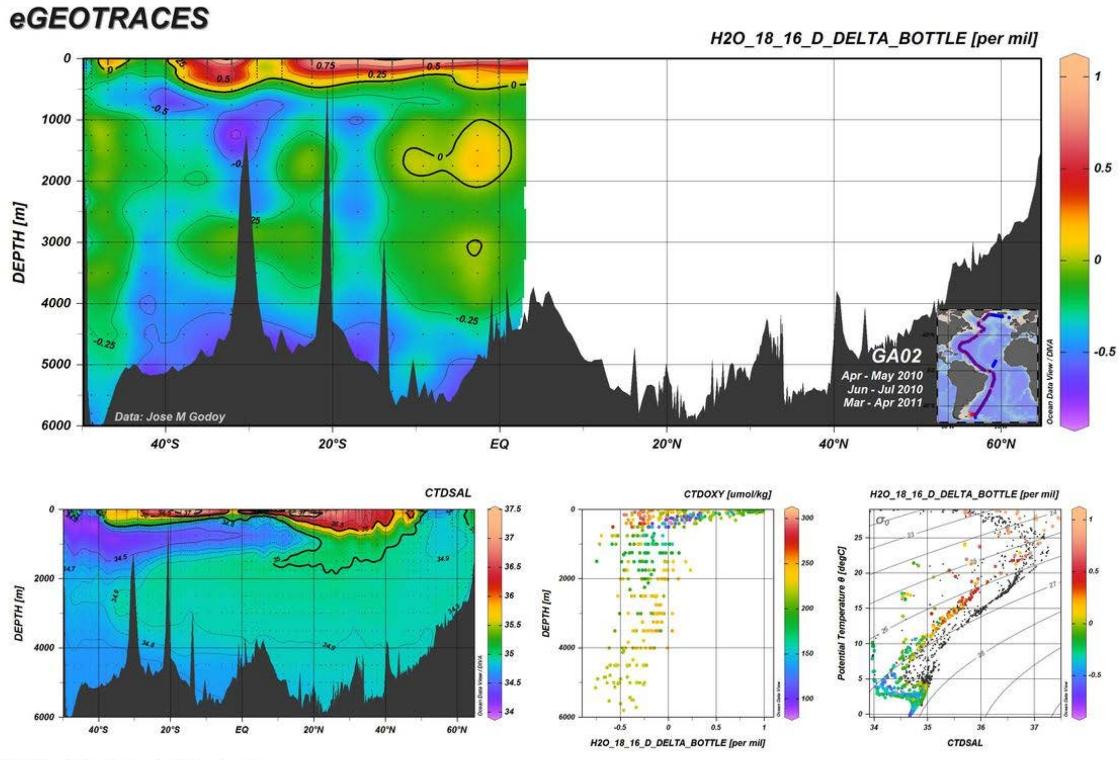


Fig. 2. Map of discrete sample stations included in the GEOTRACES Intermediate Data Product 2017. A lower case "c" in the section name (as in GAc01) indicates compliant data while a lower case "pr" (as in GPpr01) indicates a process study. Different colours and symbols are used to help distinguish between close-by sections. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

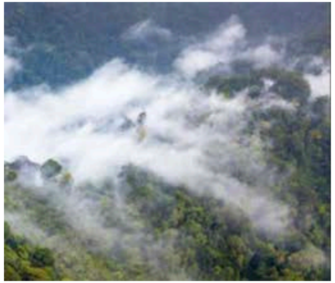


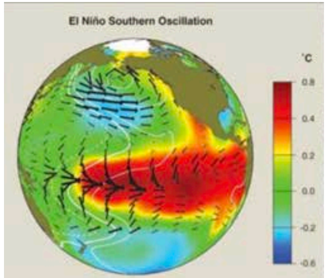
Schlitzer et al. (2018), *Chemical Geology*

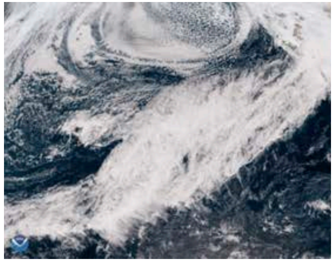
TPOS 2020 Tropical Pacific Observing System

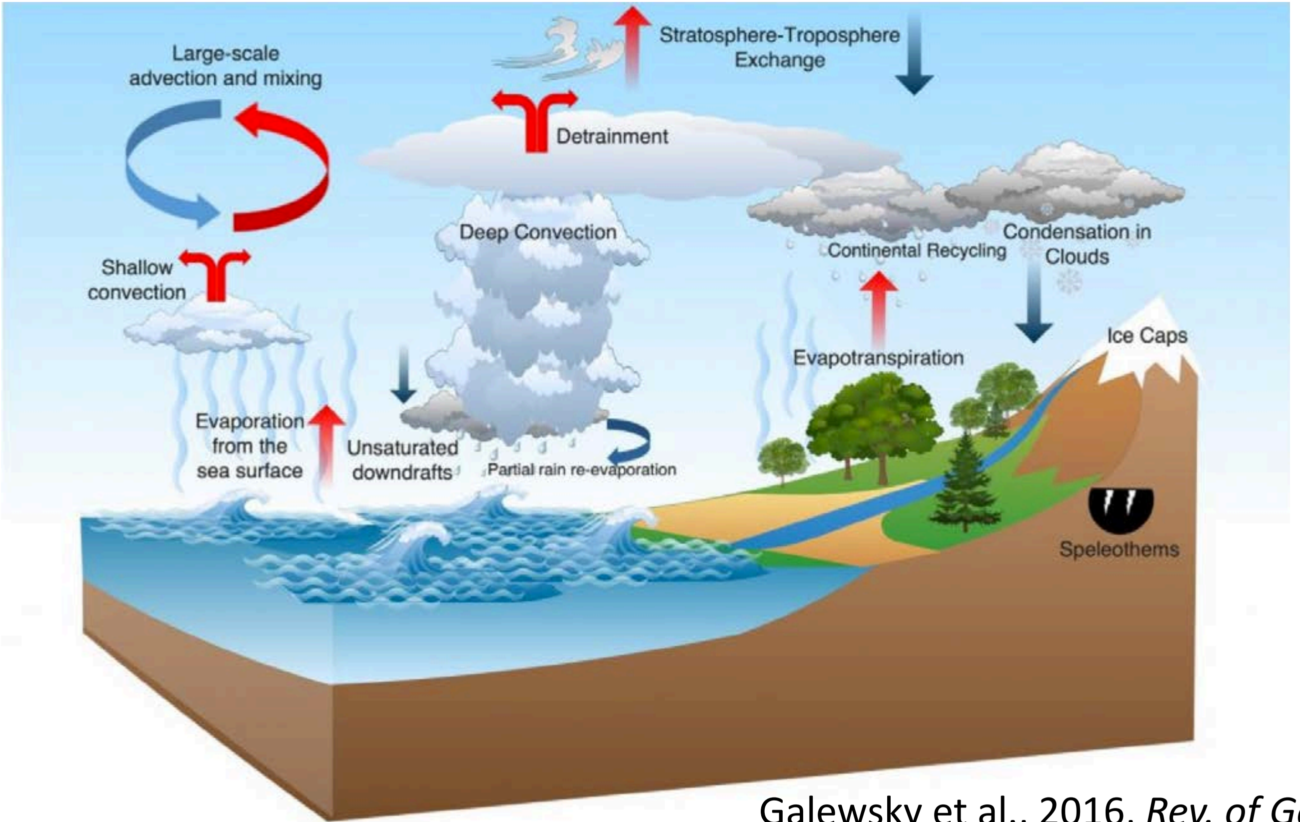
- New 2-page section contributed to TPOS 2020 2nd report by US CLIVAR working group (Released May 2019)
- Water isotope measurements contribute to several aspects of understanding tropical Pacific climate
    - **Heat and moisture fluxes** (quantification of evaporation and precipitation fluxes, direct 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







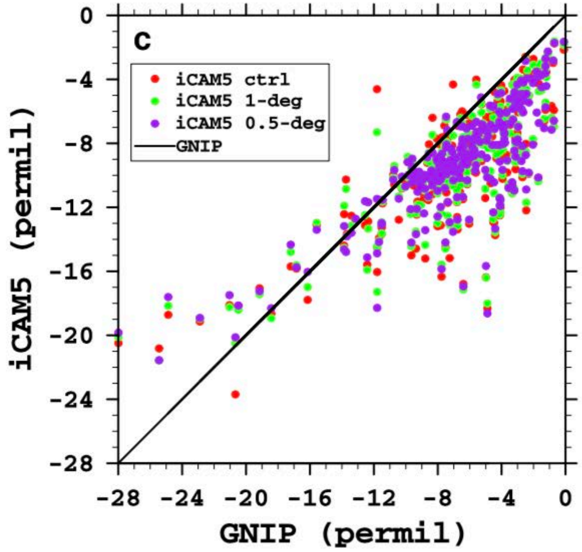


Galewsky et al., 2016, *Rev. of Geophysics*

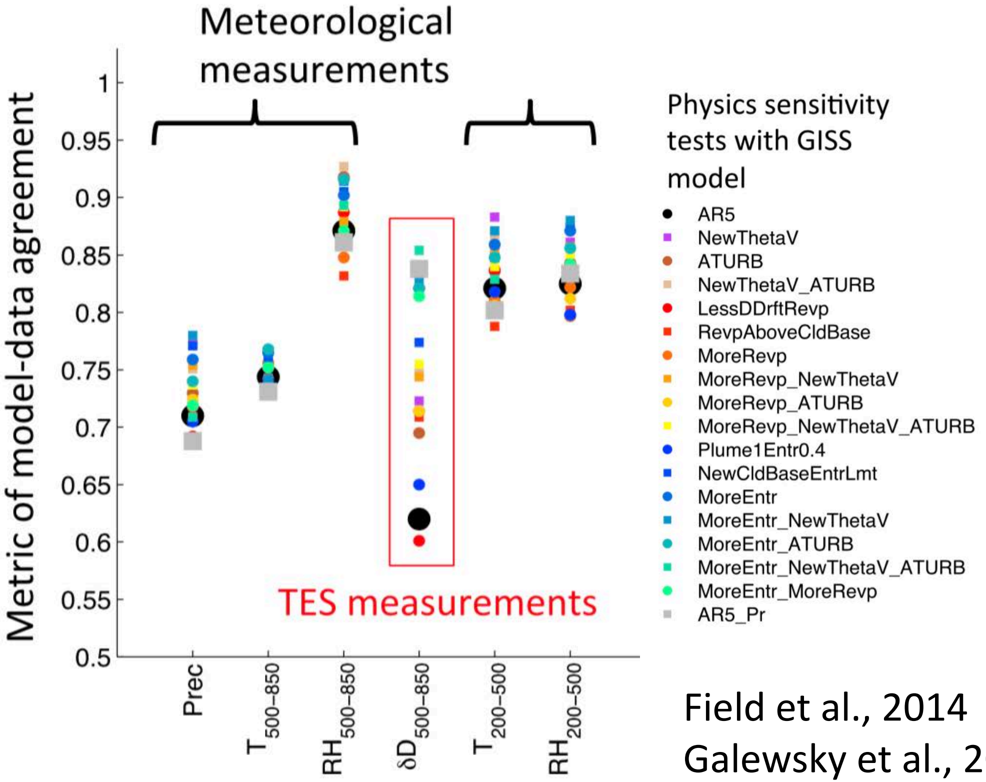
Data-model comparisons for model evaluation

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

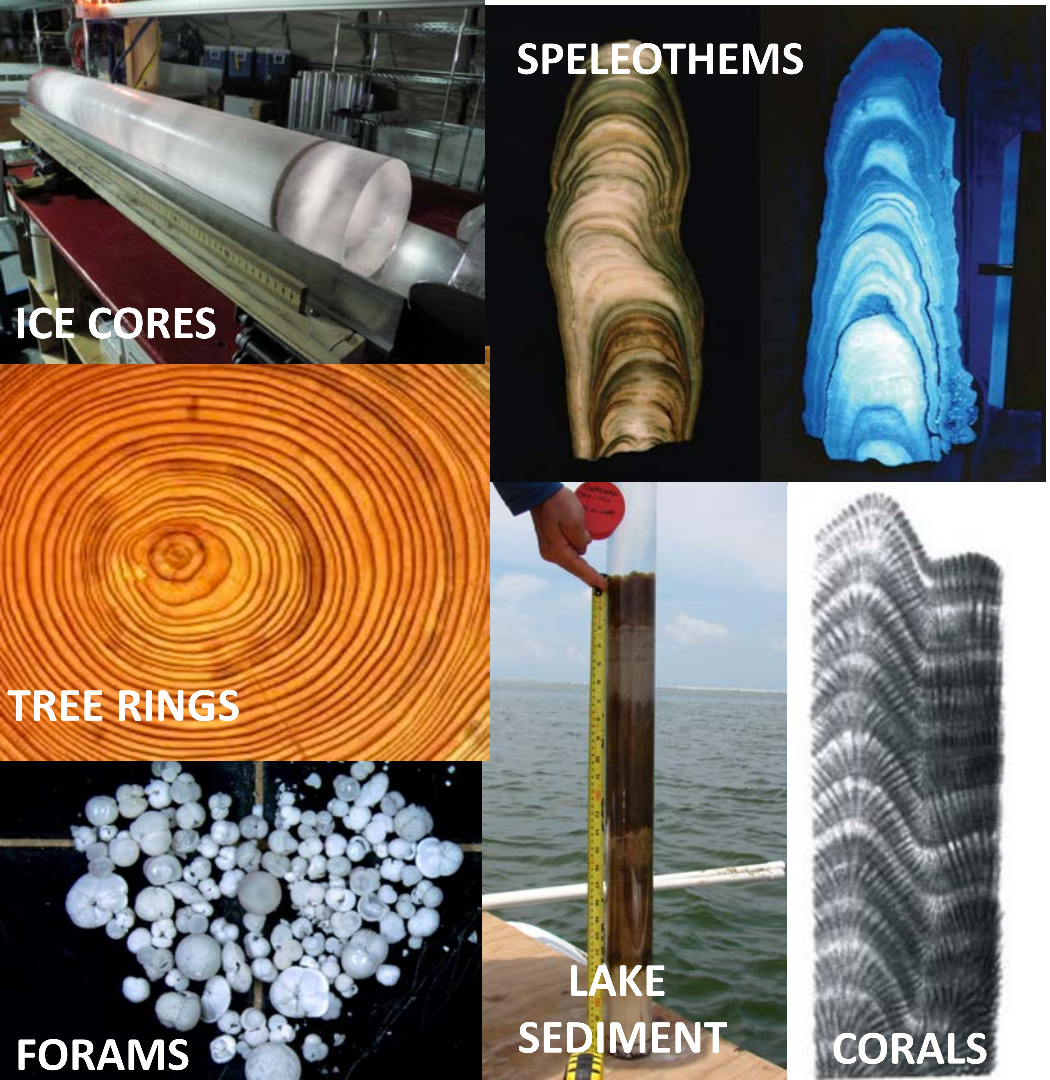
Mean annual $\delta^{18}O_P$: GNIP vs iCAM5



Nusbaumer et al. (2017), *JAMES*



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 <u>proxy-model comparisons</u>

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

Clim. Past Discuss., doi:10.5194/cp-2017-37, 2017
Manuscript under review for journal Clim. Past
Discussion started: 7 April 2017

Climate of the Past
Discussions
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EGU

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

Hydro2k Consortium: Jason E. Smerdon[1], Jürg Luterbacher[2,3], Steven J. Phipps[4], Kevin J. Anchukaitis[5], Toby Ault[6], Sloan Coats[7,8], Kim M. Cobb[9], Benjamin I. Cook[1,10], Chris Colose[10], Thomas Felis[11], Ailie Gallant[12], Johann H. Jungclaus[13], Bronwen Konecky[8], Allegra LeGrande[10], Sophie Lewis[14], Alex S. Lopatka[15], Wenmin Man[16], Justin S. Mankin[1,10], Justin T. Maxwell[17], Bette L. Otto-Bliesner[7], Judson W. Partin[18], Deepti Singh[1], Nathan J. Steiger[1], Samantha Stevenson[7], Jessica E. Tierney[19], Davide Zanchettin[20], Huan Zhang[2], Alyssa R. Atwood[9,21], Laia Andreu-Hayles[1], Seung H. Baek[1], Brendan Buckley[1], Edward R. Cook[1], Rosanne D'Arrigo[1], Sylvia G. Dee[22], Michael Griffiths[23], Charuta Kulkarni[24], Yochanan Kushnir[1], Flavio Lehner[7], Caroline Leland[1], Hans W. Linderholm[25], Atsushi Okazaki[26], Jonathan Palmer[27], Eduardo Piovano[28], Christoph C. Raible[29], Mukund P. Rao[1], Jacob Scheff[1], Gavin A. Schmidt[10], Richard Seager[1], Martin Widmann[31], A. Park Williams[1], Elena Xoplaki[2]

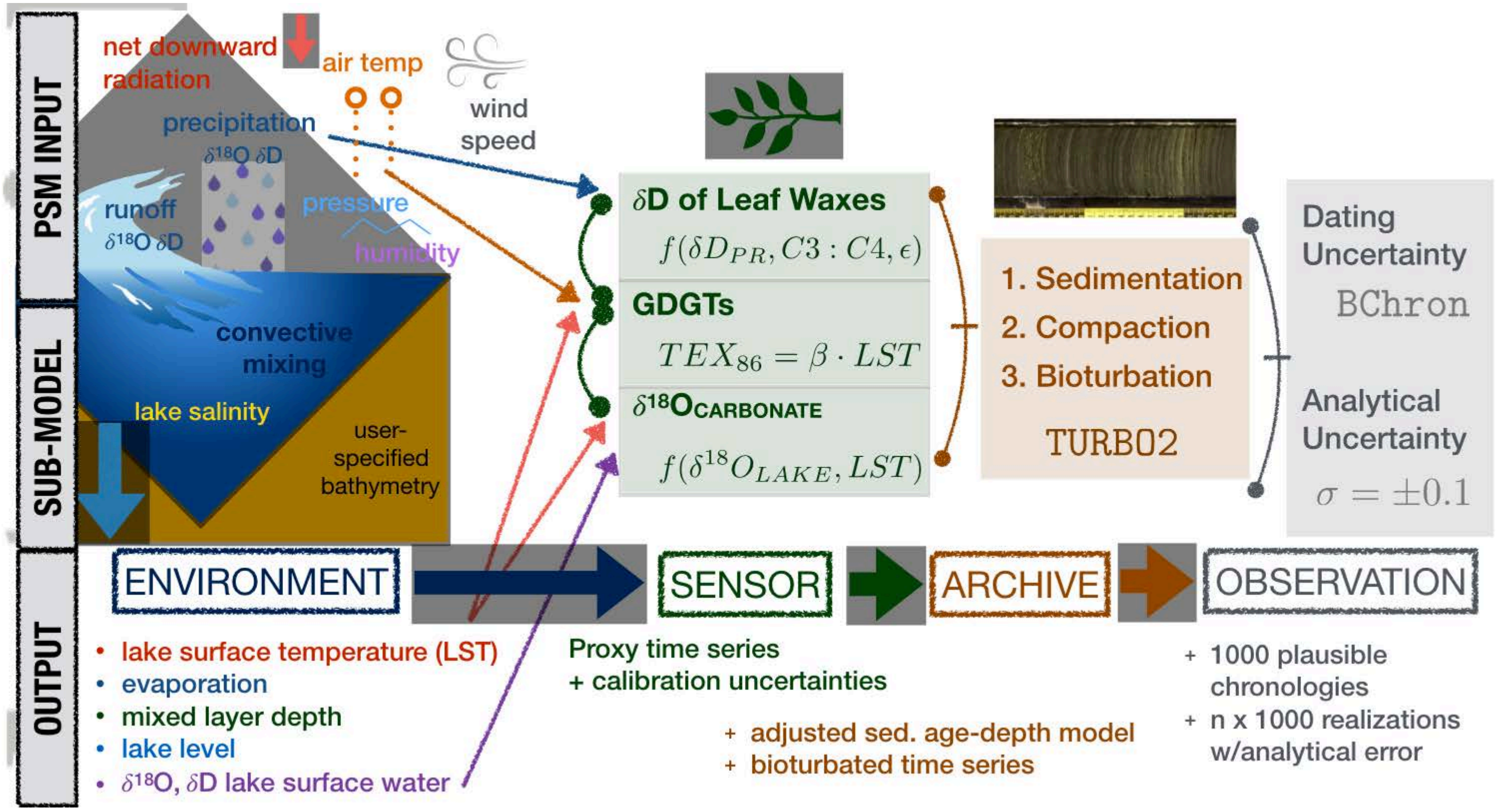
<u>Other proxy-model comparisons of the Common Era</u>: Mann et al., 2009; Anchukaitis et al., 2010; Goosse et al., 2012; Schmidt et al., 2014; Coats et al., 2015; Cook et al., 2015; Neukom et al., 2015; PAGES 2k, 2015; Luterbacher et al., 2016

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

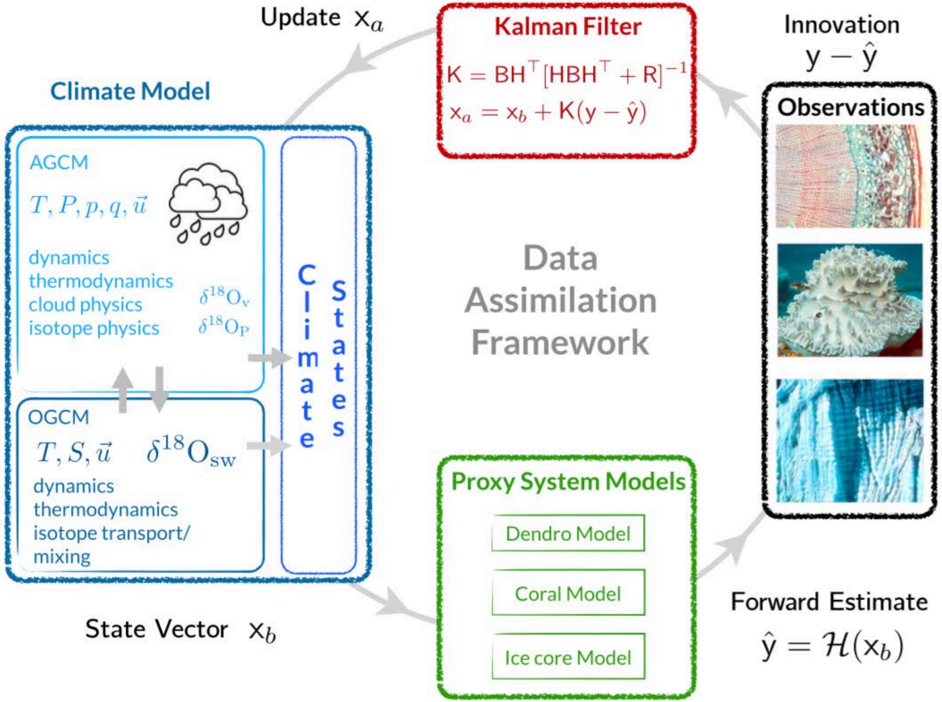
Paleoclimate data assimilation (PDA) uses model-simulated climate states to measure the climate information in proxy data and distribute that information to all climate variables subject to the dynamical constraints of the climate model.

Advantages:

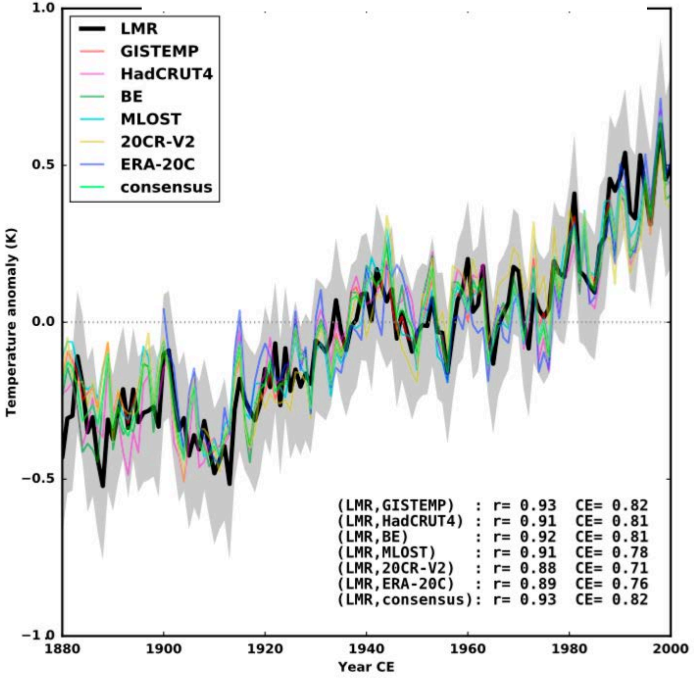
1. Infers multiple climate fields simultaneously
2. Generally does not assume stationary teleconnections (unlike most purely statistical approaches)
3. Uses dynamical models to infer spatial relationships within and between climate fields. The fields are thus dynamically consistent.
4. Includes proxies 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



Global mean temperature



1880 CE 2000 CE

Hakim et al., 2016

"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 δ^{18}Op 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?

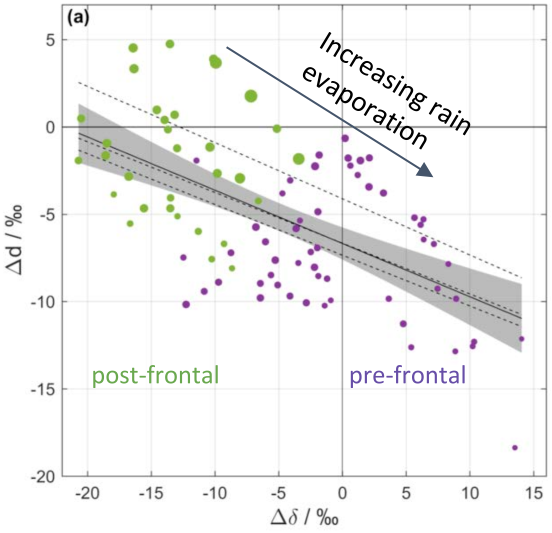
- Focal points for the larger community?
- Sites with pre-existing data
- Sites where local observations capture large-scale processes
- Multiple-purpose sites?

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?



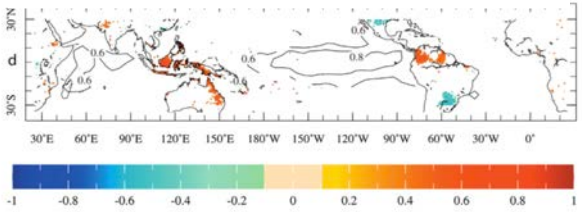
New measurements suggest isotopic differences between surface water vapor and rain indicate sub-cloud evaporation of falling hydrometeors.

Graf et al. (2018) *ACPD*

Precipitation biases (Nusbaumer et al. 2017), humidity biases (Risi et al. 2012), oceanic "boundary" conditions (LeGrande and Schmidt 2006)

Value of Proxy System Models

Optimal sampling network
for $\delta^{18}O$ in tree cellulose



Evans et al., 2013

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