University of Massachusetts Amherst

HYDROGEOLOGY — University of Massachusetts Amherst

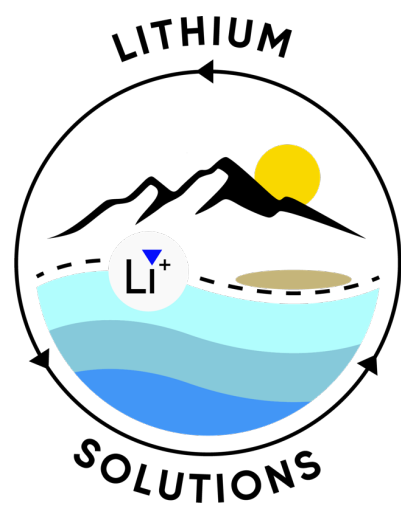**Observed Climatic and Environmental Variability**

Past and Future

Presenter: Brendan Moran

LITHIUM SOLUTIONS
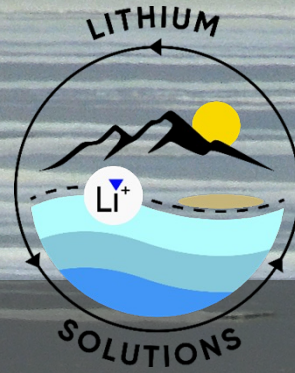
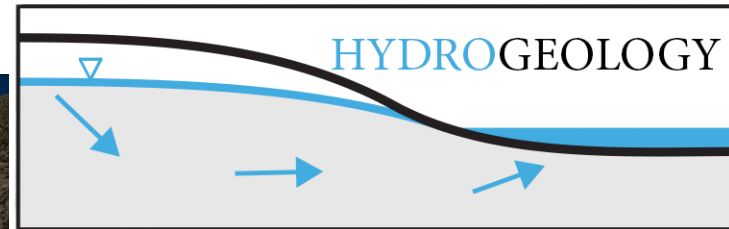**SUSTAINABILITY OF THE LITHIUM INDUSTRY:**

Monitoring and environmental challenges in the face of climate change

Santiago, Chile
15/03/2024

Acknowledgments
Our entire amazing research team
and our sponsors & partners

LITHIUM SOLUTIONS

HYDROGEOLOGY

University of Massachusetts Amherst

UNIVERSITY OF ALASKA ANCHORAGE

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für Internationale
Zusammenarbeit (GIZ) GmbH

Trópico de Capricornio
Lat. 23° 26' 16"
Desierto y Arqueología

Outline

Part 1

Part 2

Salar de Atacama Basin Hydrological System

Observed Changes in Climate and Hydrology/Environment

01

Salar de Atacama Basin Hydrological System
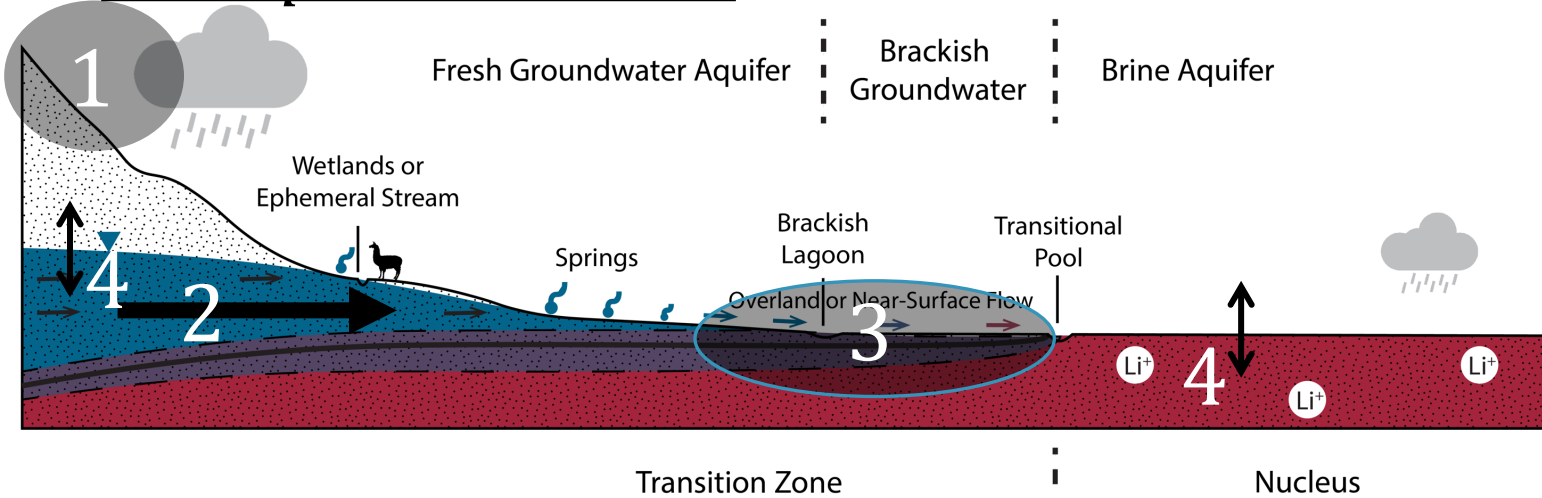
Water Cycle of the Basin

Hydroclimatology
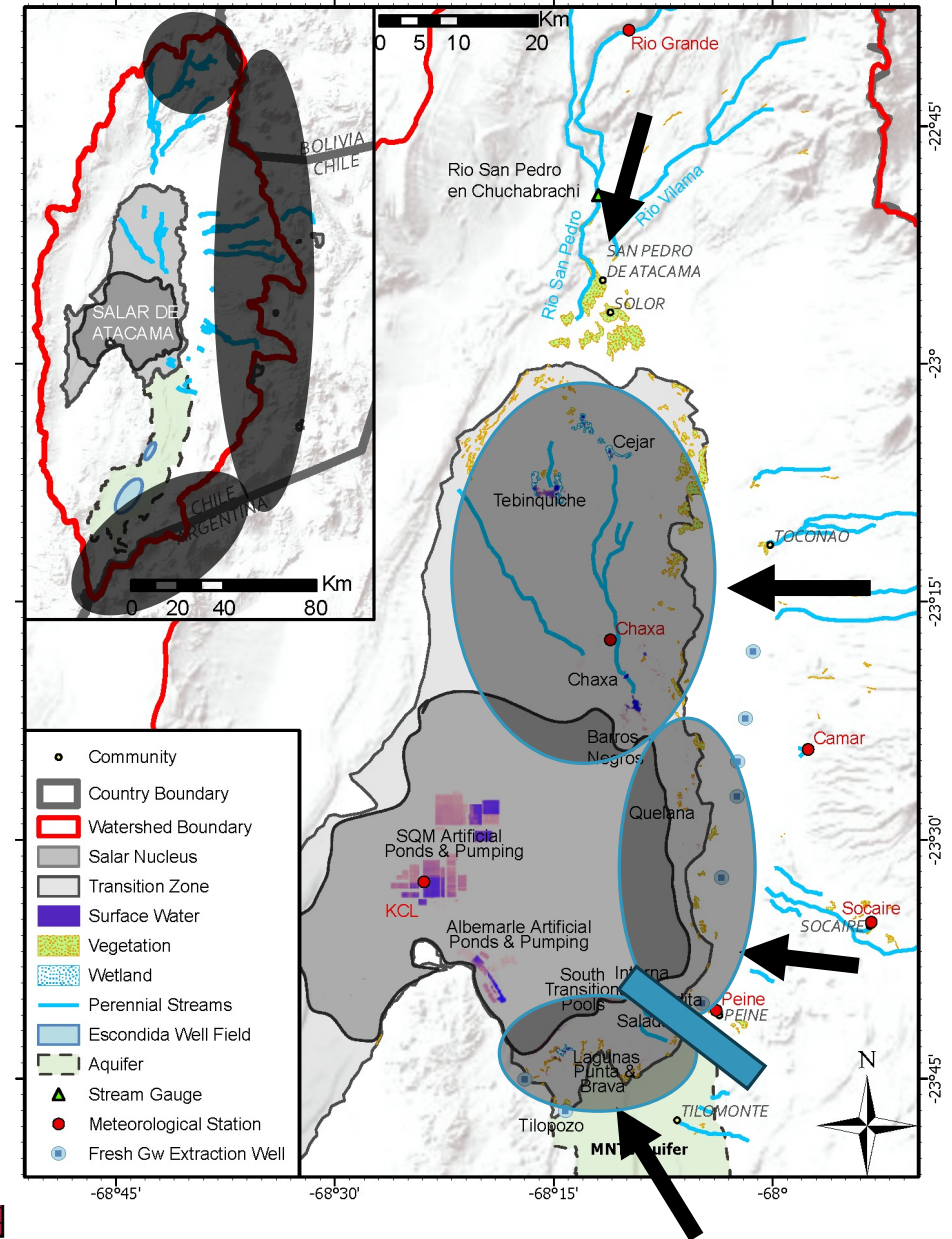
1. Precipitation & Recharge
2. Fresh Inflow

Environmental Conditions

3. Transition Zone – Wetlands & Lagunas
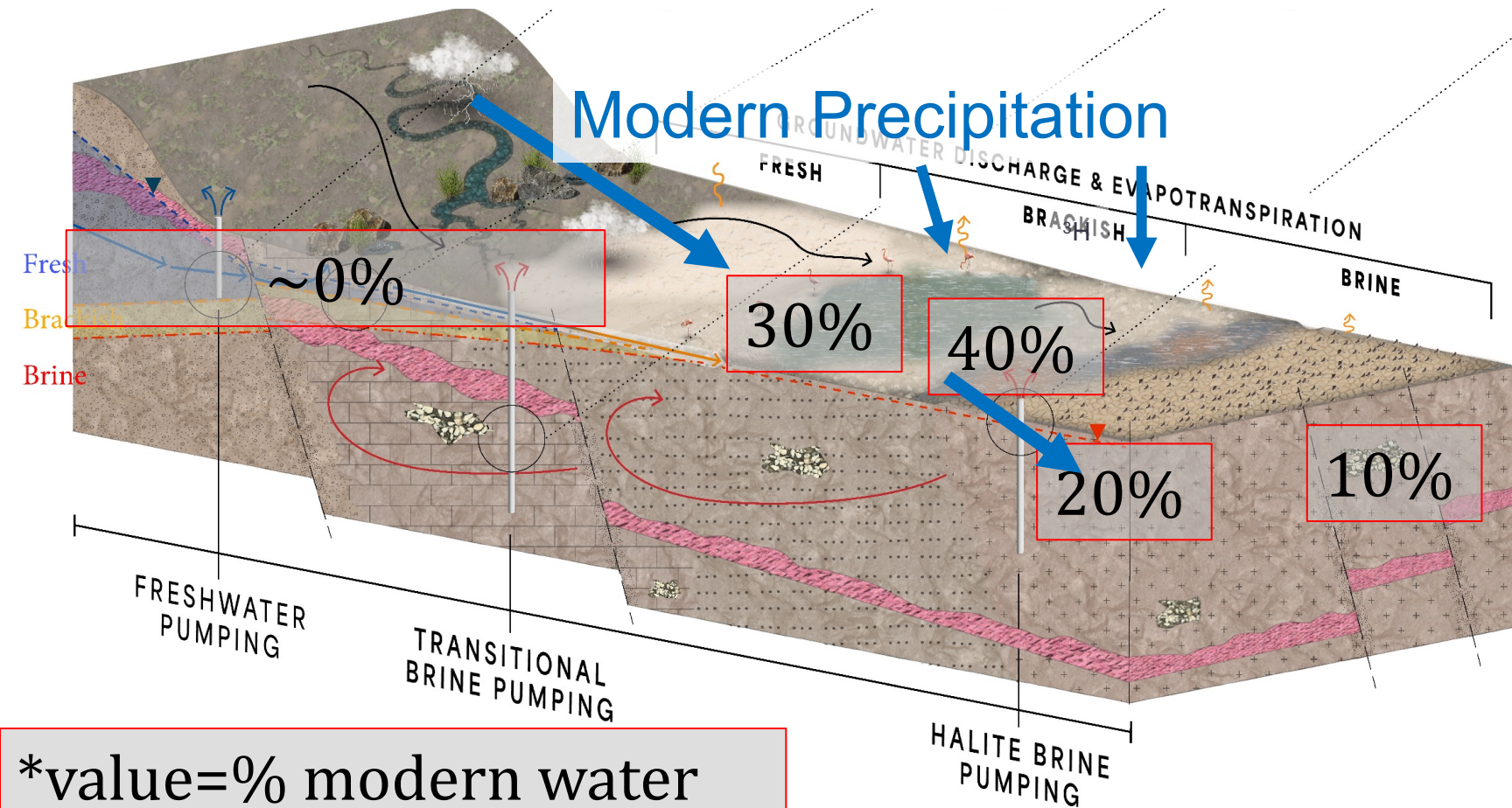4. Groundwater Storage

Conceptual Transect

Salar de Atacama Watershed

Water Sources

How water moves into the basin and through the marginal zones

Modern Precipitation

~0%

30%

40%

20%

10%

*value=% modern water

- *³H sampling:* Consistent patterns by water type, >10 years of repeat sampling (112 samples)

- **Nearly all inflow** to the basin is relic

- Surface waters (except springs) are **very unique**

- *Takeaway:* Relic water is dominant but short-term climate has a major influence by contributing recent water component of input – **very focused**

02

Observed Changes in Climate and Hydrology/Environment

Climate Variability

- Has been much wetter in the past
- Prevailing wisdom is **wet areas → wetter, dry areas → drier**
- But evidence that precipitation & especially **large events** and **droug[ht]** will increase

MONSOONS AND CLIMATE (Y MING, SECTION EDITOR)

Current and Future Variations of the Monsoons of the Americas

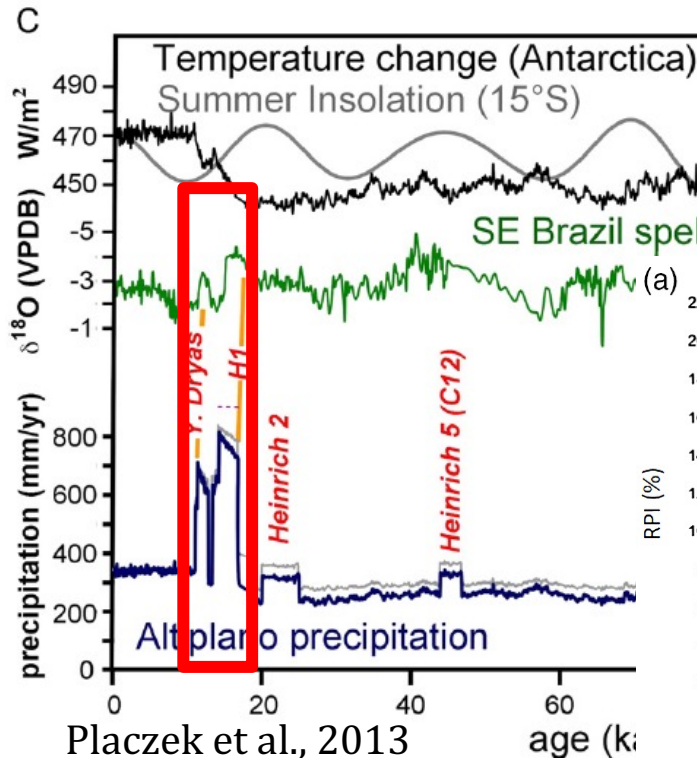RESEARCH ARTICLE

The Central Chile Mega Drought (2010–2018): A climate dynamics perspective

René D. Garreaud[1,2] | Juan P. Boisier[2] | Roberto Rondanelli[1,2] | Aldo Montecinos[3,4] |
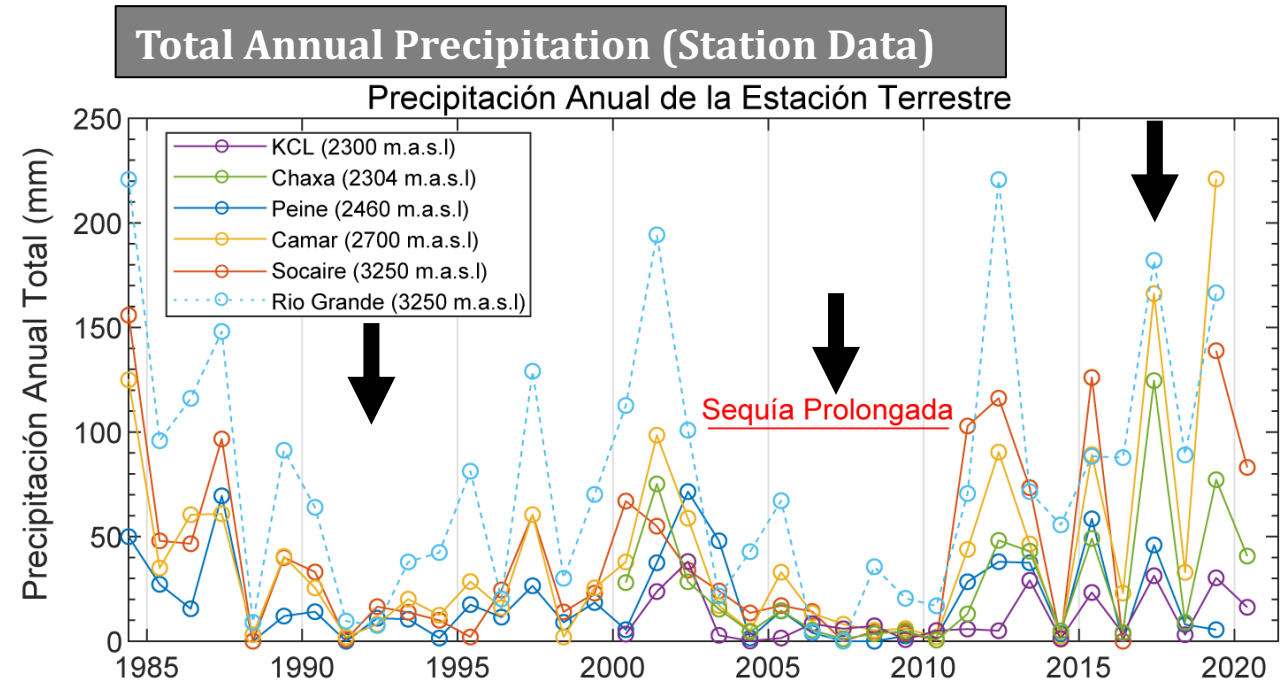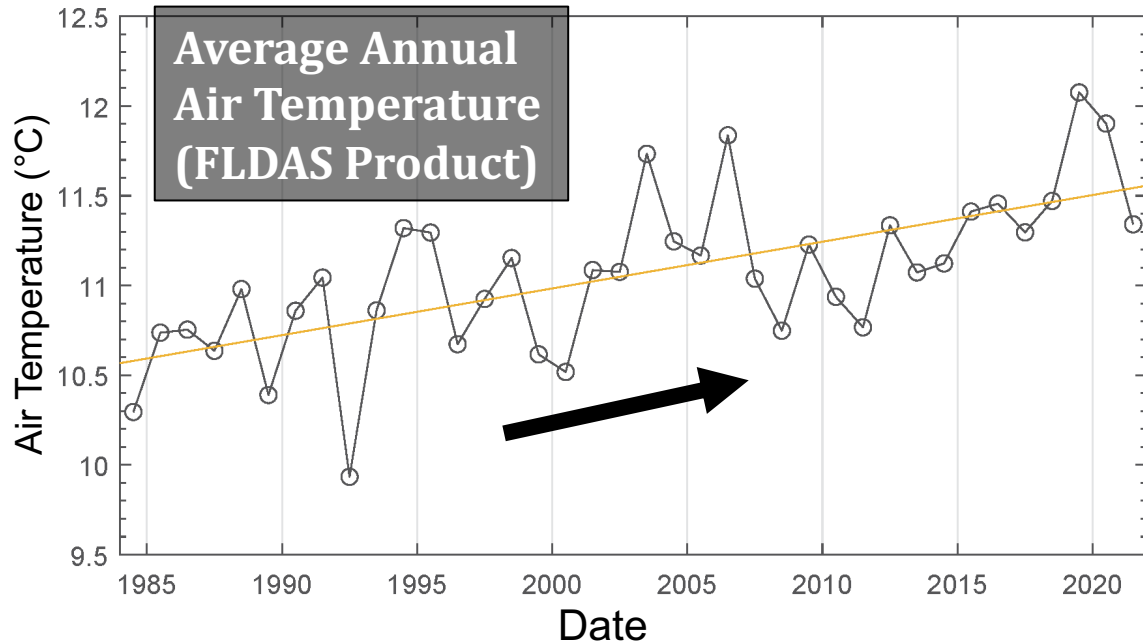Hector H. Sepúlveda[3] | Daniel Veloso-Aguila[3]

Placzek et al., 2013
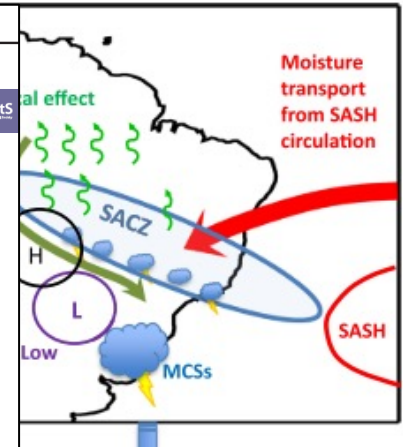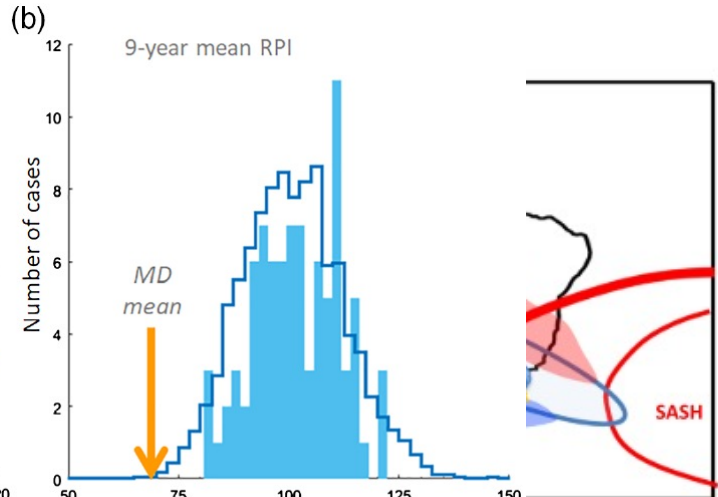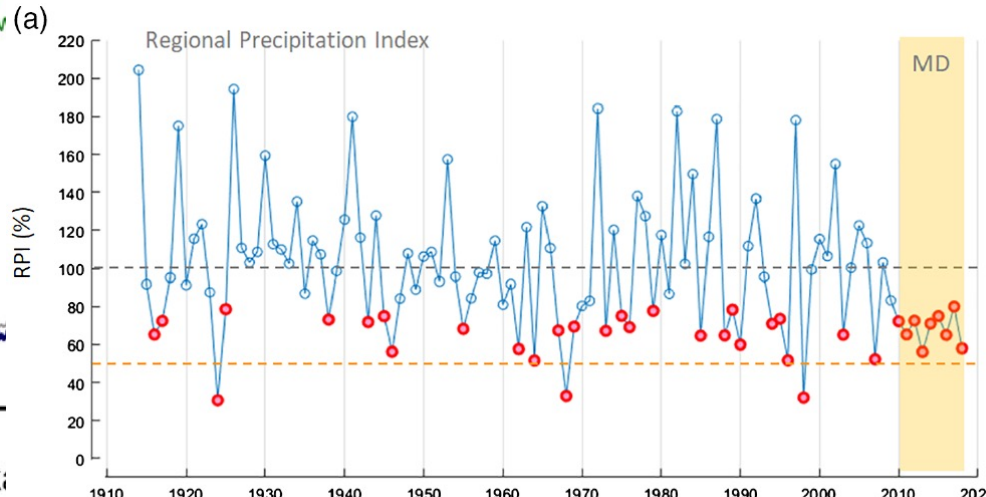
Modern Climate

Since the mid-1980's:
- Basin-wide air temperature: +1.0° C
- Two major drought periods
- Anomalous precipitation since 2011
- Significant decrease in Rio San Pedro flow
- Consistent with *global climate change* signals

Total Annual Precipitation (Station Data)

Precipitación Anual de la Estación Terrestre

Legend:
- KCL (2300 m.a.s.l)
- Chaxa (2304 m.a.s.l)
- Peine (2460 m.a.s.l)
- Camar (2700 m.a.s.l)
- Socaire (3250 m.a.s.l)
- Rio Grande (3250 m.a.s.l)

Sequía Prolongada

Average Annual Air Temperature (FLDAS Product)

Satellite-based Remote Sensing

- Remote **precipitation** products (Spectral-derived climatology and/or interpolation models)

- Landsat & Sentinel (spectral imagery)
  - Surface Water Extent **(SWE)** [JRC data]
  - Vegetation **(NDVI)** = (NIR - R) / NIR + R]
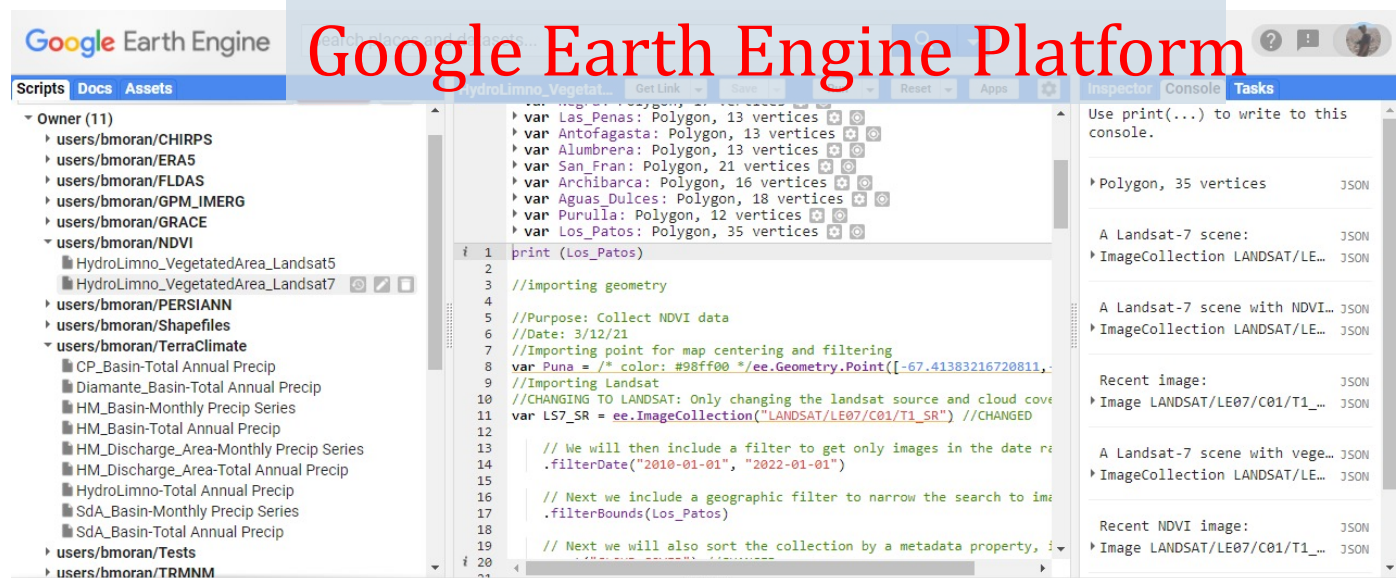
LETTER   Global Surface Wa

High-resolution mapping of global su and its long-term changes

Jean-François Pekel[1], Andrew Cottam[1], Noel Gorelick[2] & Alan S. Belward[1]

- Gravity Recovery & C Experiment **(GRACE**
  - Liquid Water Equ Thickness

Earth's Future

RESEARCH ARTICLE
10.1029/2021EF002555

Relic Groundwater and Prolonged Drought Confound Interpretations of Water Sustainability and Lithium Extraction in Arid Lands

Key Points:
- Freshwater inflows and the modern water budget at Salar de Atacama are dominated by relic groundwater

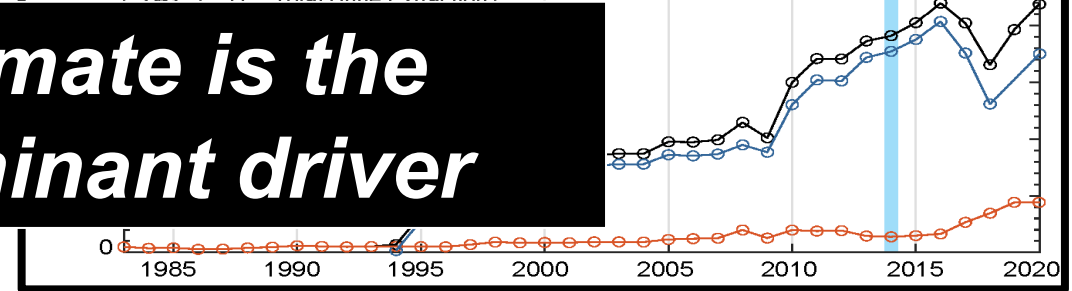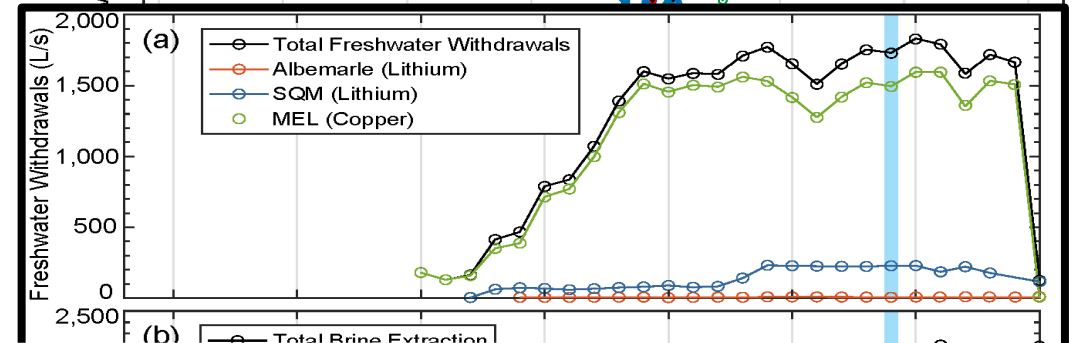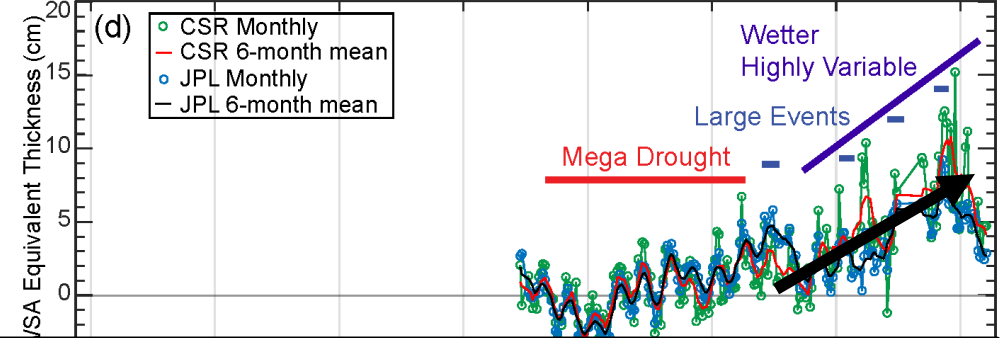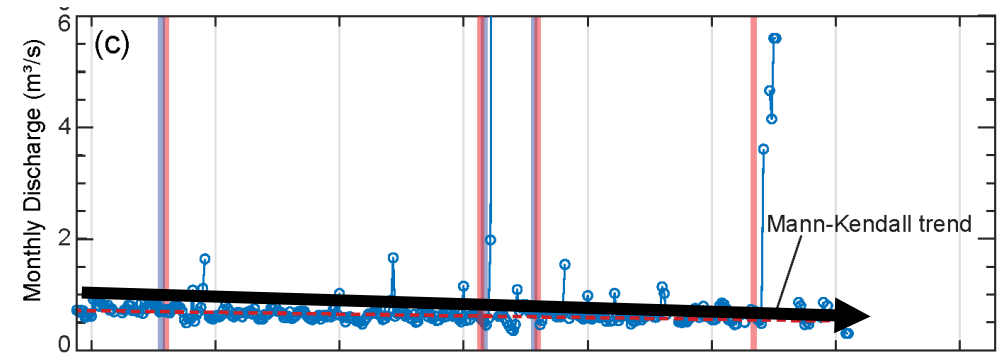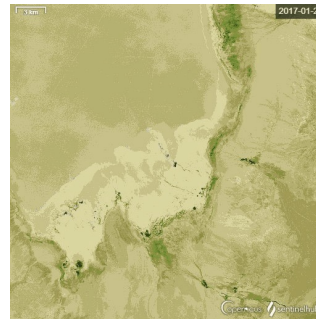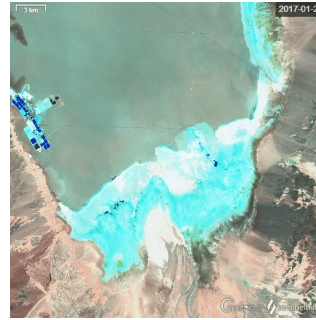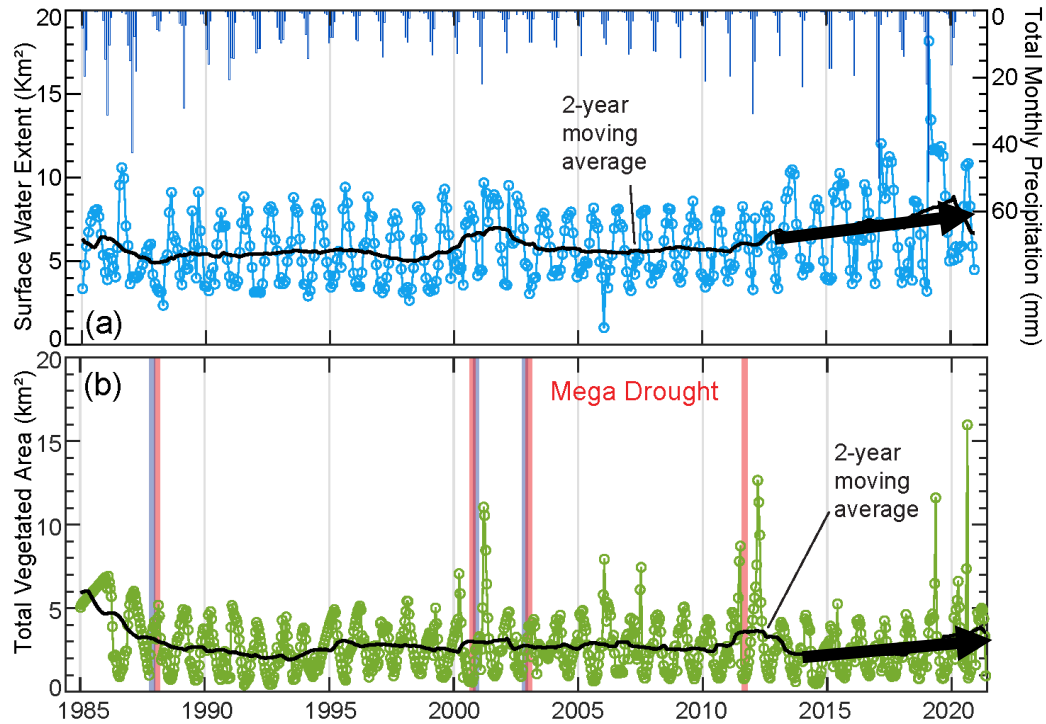Brendan J. Moran[1], David F. Boutt[1], Sarah V. McKnight[1], Jordan Jenckes[2], Lee Ann Munk[2], Daniel Corkran[1], and Alexander Kirshen[1]

Environmental Changes

Basin-wide Assessment of key hydrological indicators
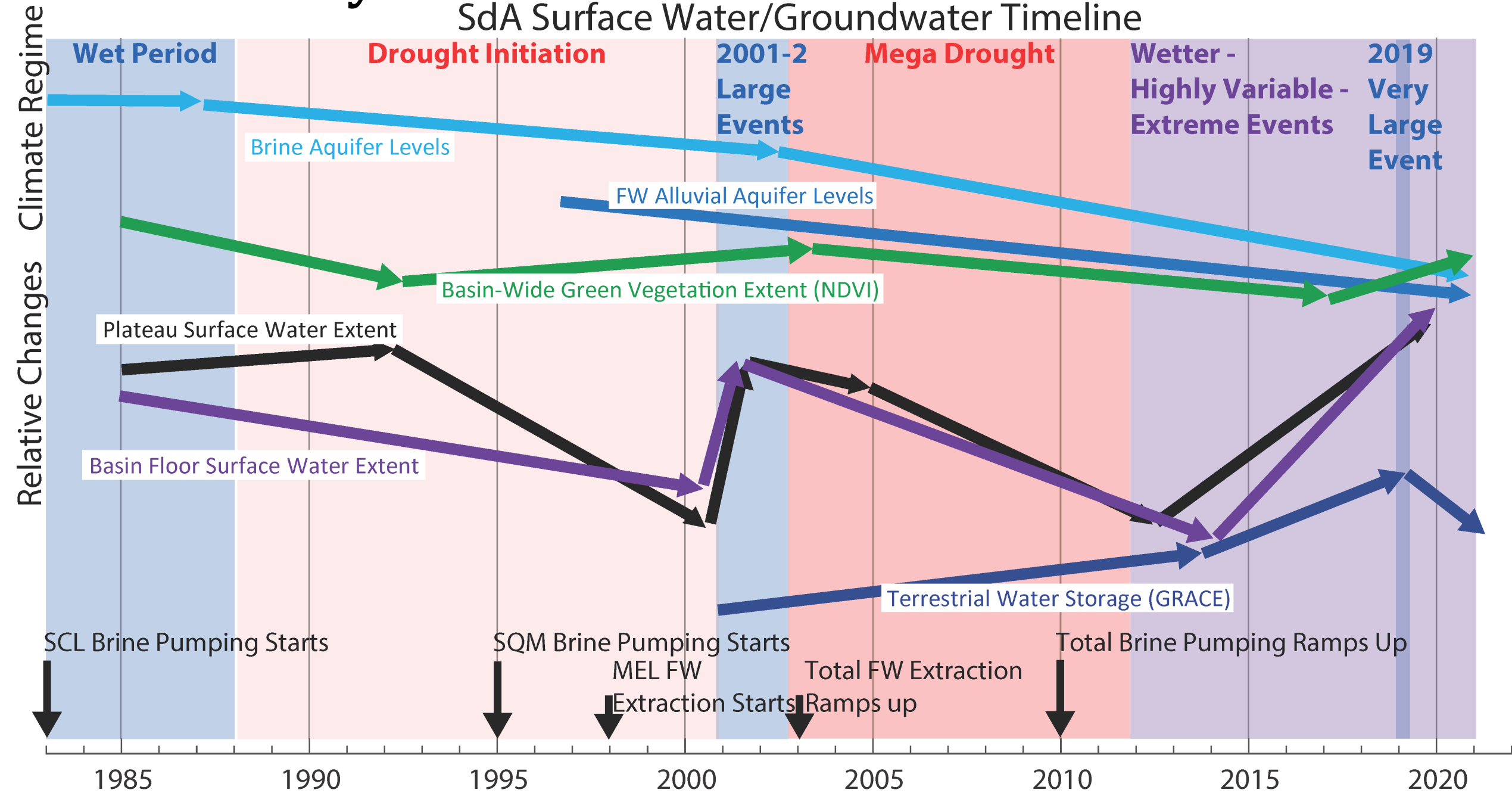

- Strong responses to climate variations
- Since major drought:
  - Wetland extent has increased
  - Streamflow has decreased
  - Groundwater storage has increased

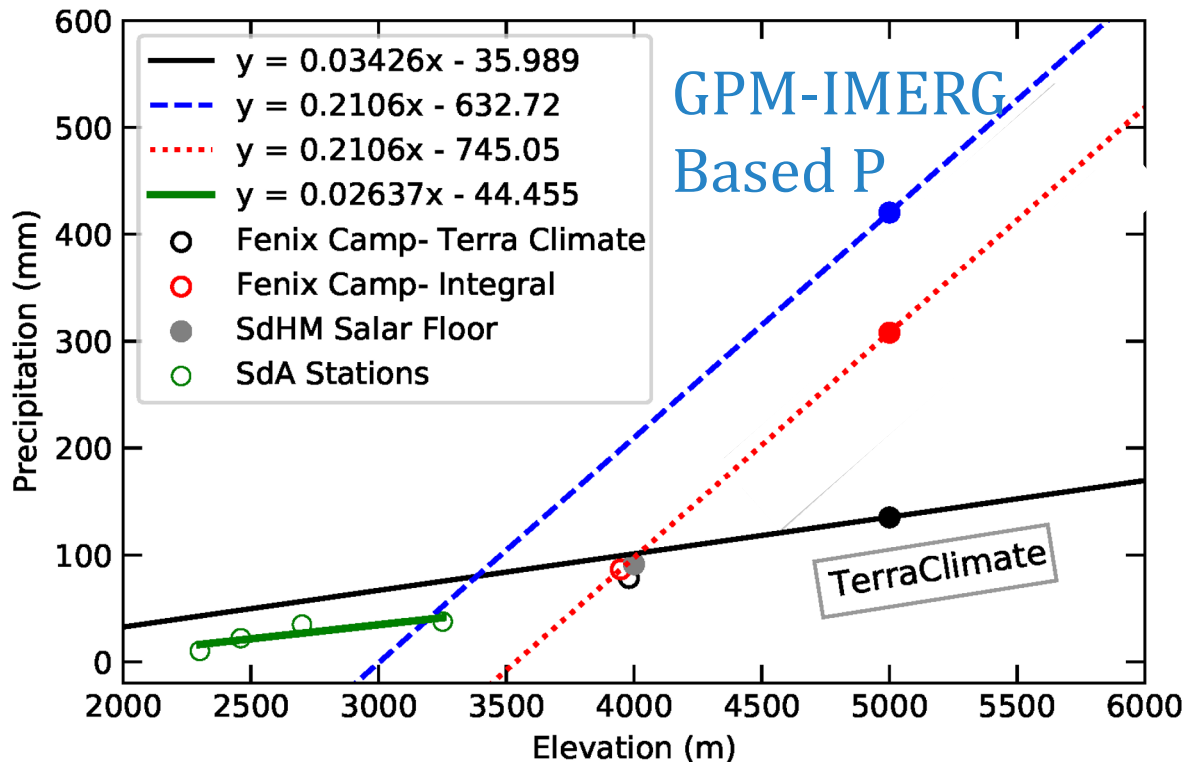**Climate is the dominant driver**

Water extraction has continued

Summary

SdA Surface Water/Groundwater Timeline

Climate Regime

Wet Period | Drought Initiation | 2001-2 Large Events | Mega Drought | Wetter - Highly Variable - Extreme Events | 2019 Very Large Event

Relative Changes

Brine Aquifer Levels

FW Alluvial Aquifer Levels

Basin-Wide Green Vegetation Extent (NDVI)

Plateau Surface Water Extent

Basin Floor Surface Water Extent

Terrestrial Water Storage (GRACE)

SCL Brine Pumping Starts

SQM Brine Pumping Starts

MEL FW Extraction Starts

Total FW Extraction Ramps up

Total Brine Pumping Ramps Up

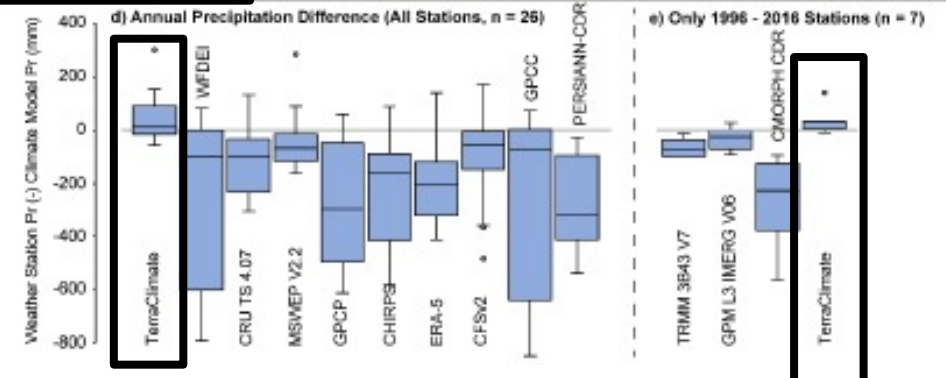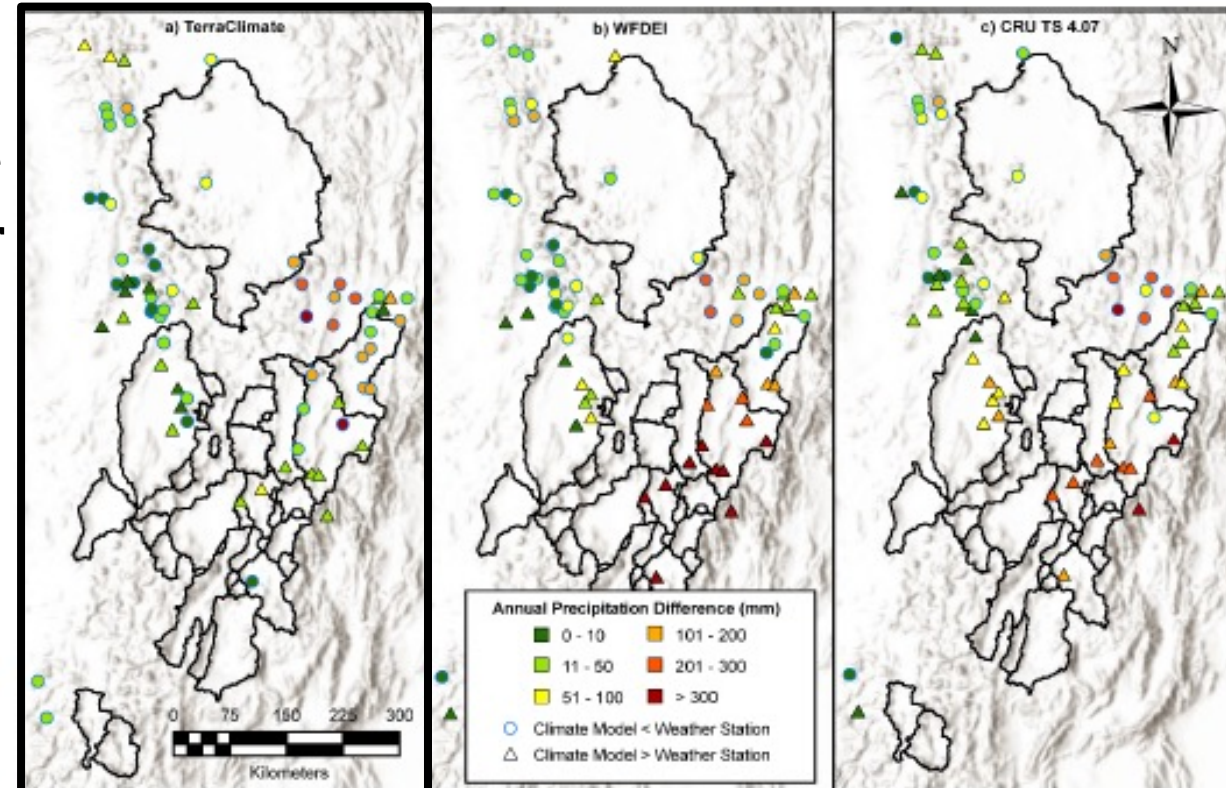1985   1990   1995   2000   2005   2010   2015   2020

Precipitation Products

- **Consistent biases**
- High elevation overestimated
- Better overall performance w/TerraClimate
- Annual magnitudes are important for water budgets – **different than seasonality**

Average Annual P – SdA Stations vs Elevation

Legend:
- y = 0.03426x - 35.989
- y = 0.2106x - 632.72
- y = 0.2106x - 745.05
- y = 0.02637x - 44.455
- ○ Fenix Camp- Terra Climate
- ○ Fenix Camp- Integral
- ● SdHM Salar Floor
- ○ SdA Stations

GPM-IMERG Based P

TerraClimate

Regional Assessment of Products

a) TerraClimate   b) WFDEI   c) CRU TS 4.07

Annual Precipitation Difference (mm)
- 0 - 10
- 11 - 50
- 51 - 100
- 101 - 200
- 201 - 300
- > 300

○ Climate Model < Weather Station
△ Climate Model > Weather Station

d) Annual Precipitation Difference (All Stations, n = 26)

e) Only 1996 - 2016 Stations (n = 7)

Recent work on SdA Irresponsibly Published

Liu et al., 2020 *Journal of Cleaner Production*

Liu et al., 2019 *International Journal of Applied Earth Observation and Geoinformation*
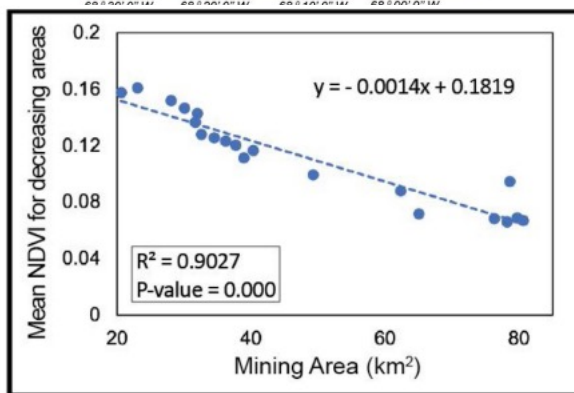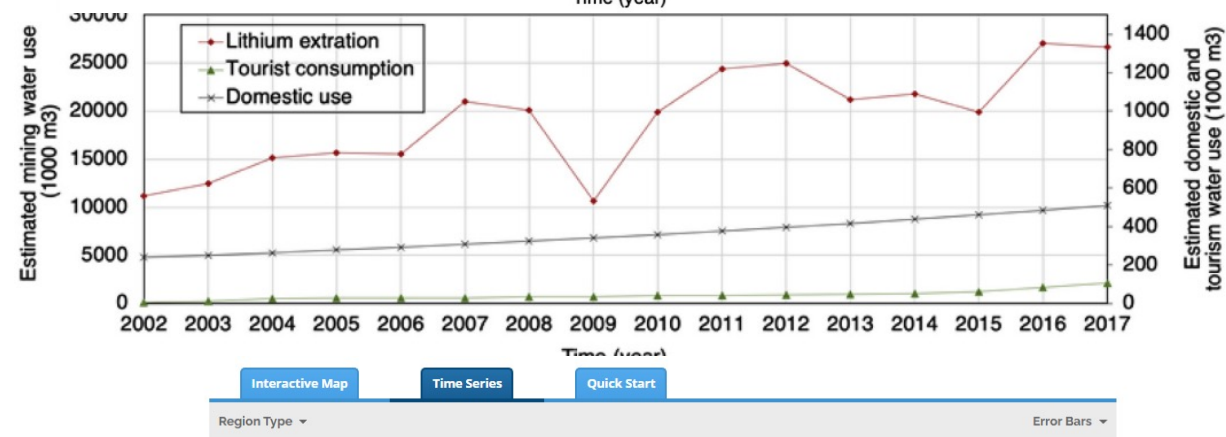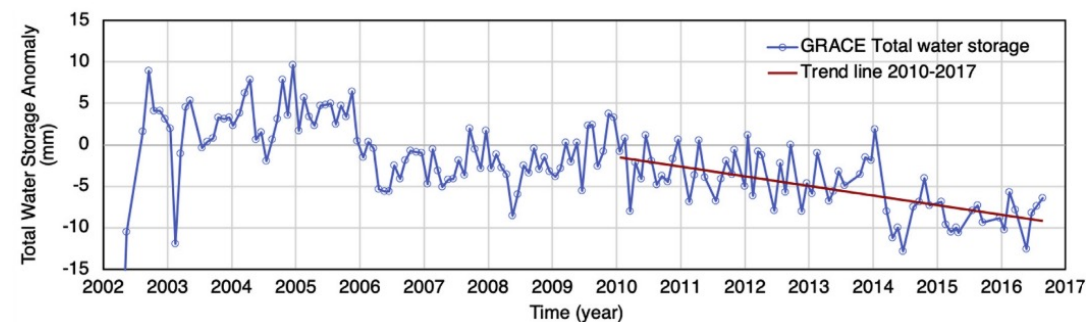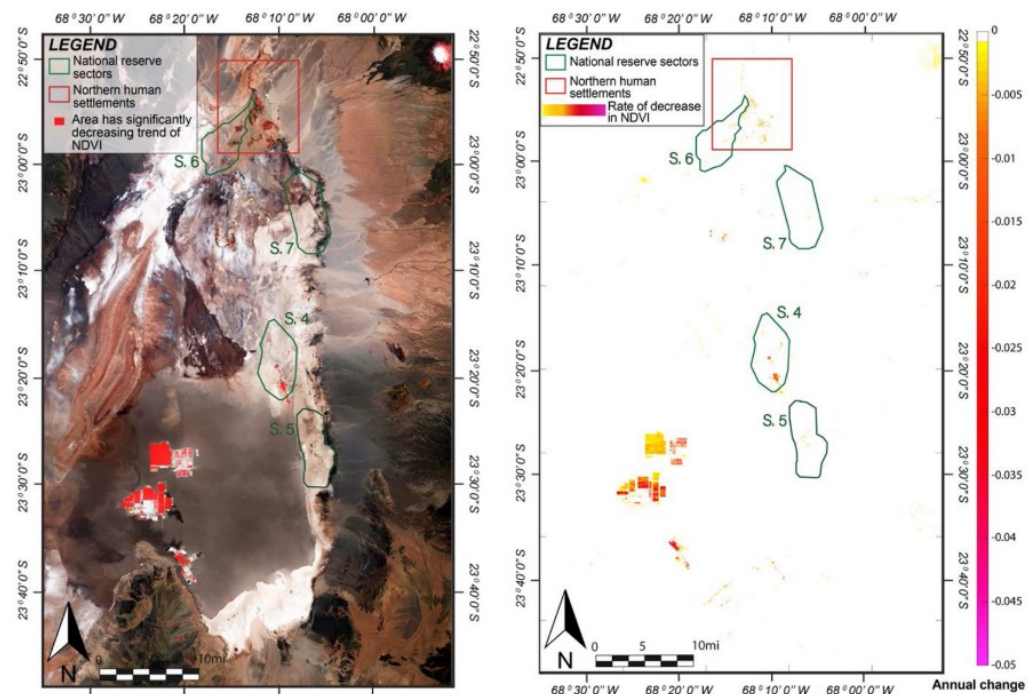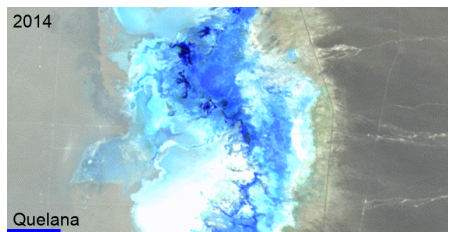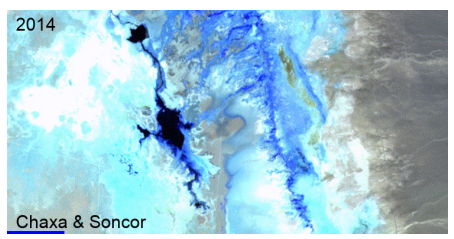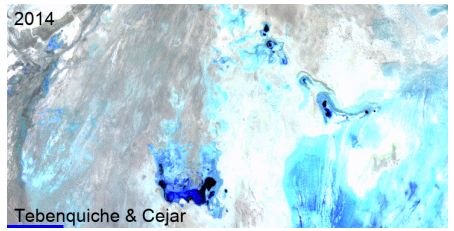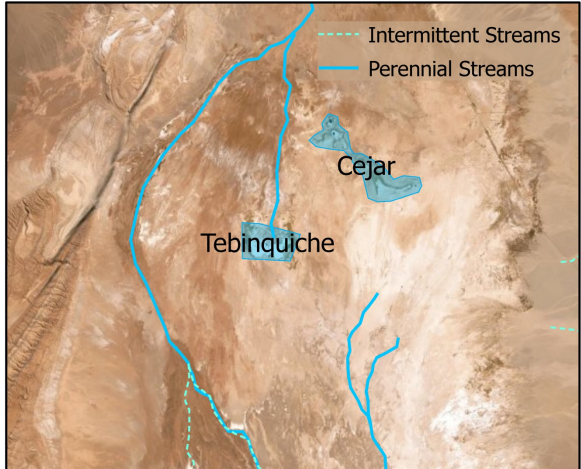

- **Fundamentally flawed methods of using NDVI and GRACE**
- **Results and conclusions should <u>not be considered valid</u> or cited**
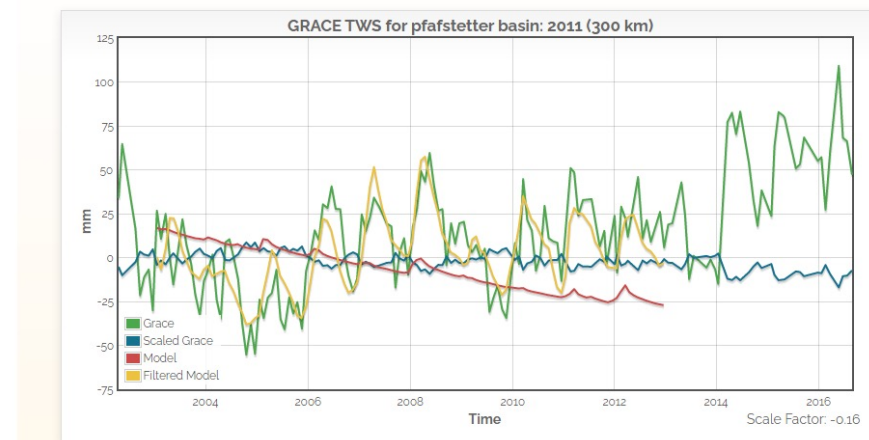
RECENT AND FORTHCOMING WORKS

Surface Water in the Transition Zone
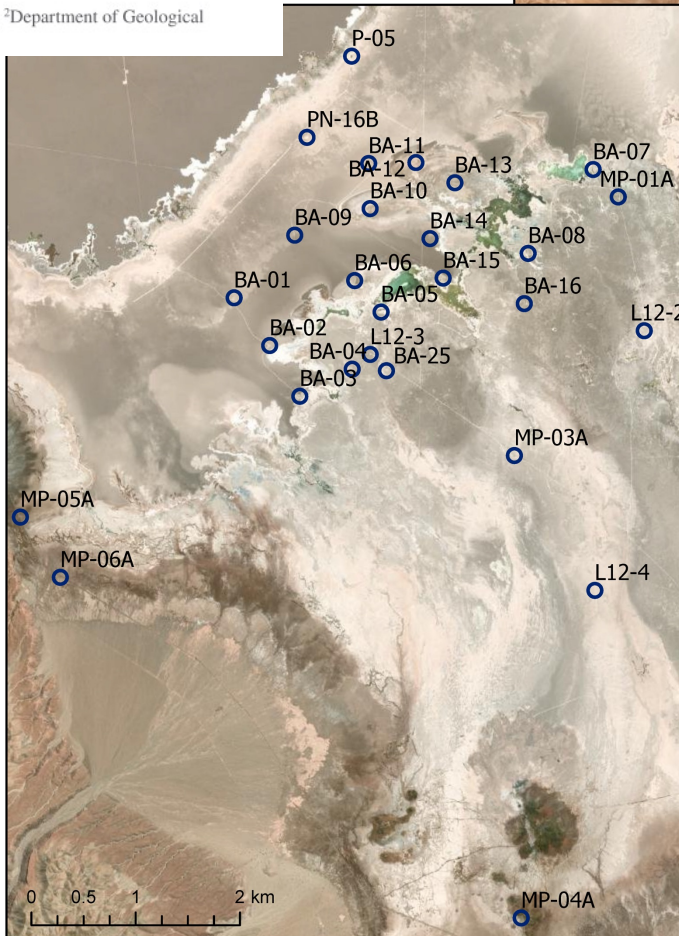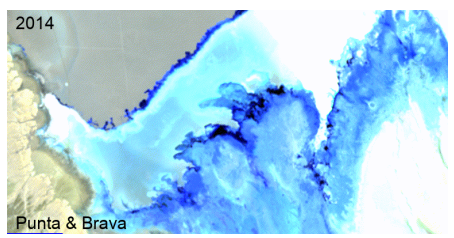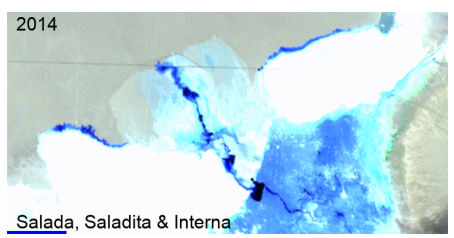
S. V. McKnight[1], D. F. Boutt[1], L. A. Munk[2], and B. Moran[1]

[1]Department of Geosciences, University of Massachusetts Amherst, Amherst, MA, USA, [2]Department of Geological Sciences, University of Alaska Anchorage, Anchorage, AK, USA

Key Points:
- Post-precipitation inflow and outflow mechanisms of salar-adjacent surface water are distinct from recharge and discharge in local aquifers
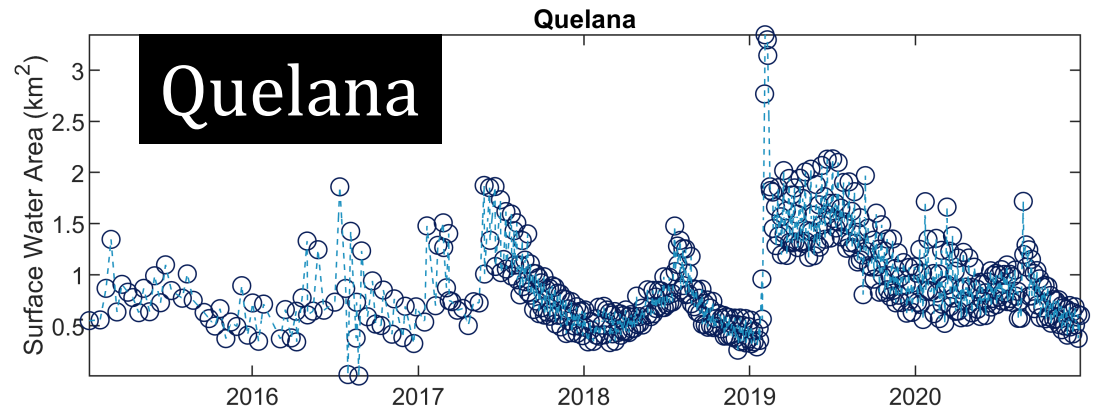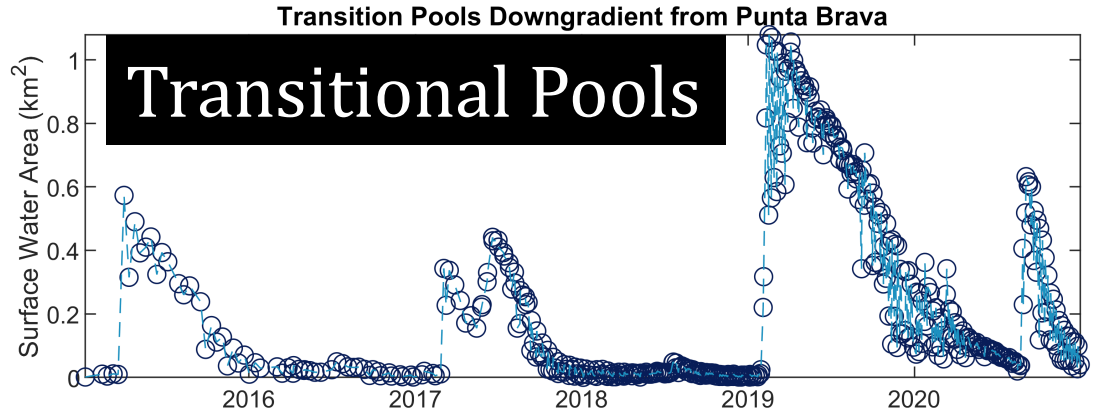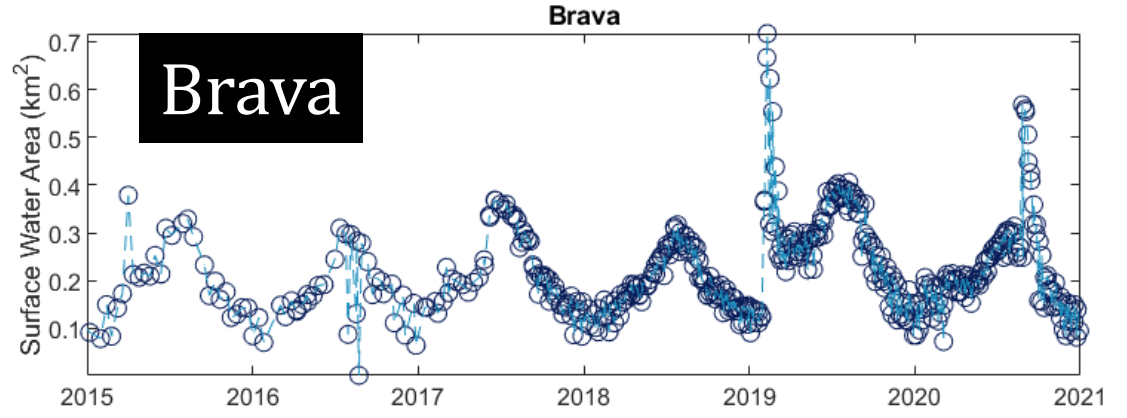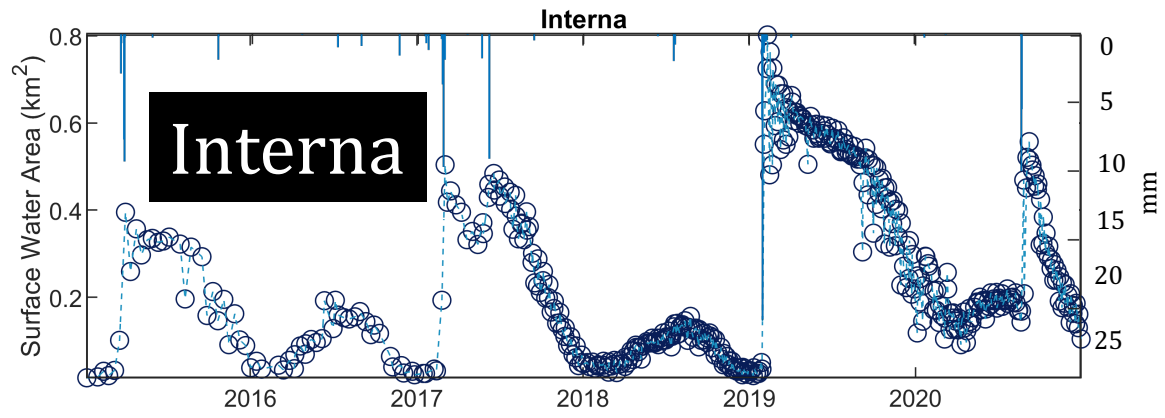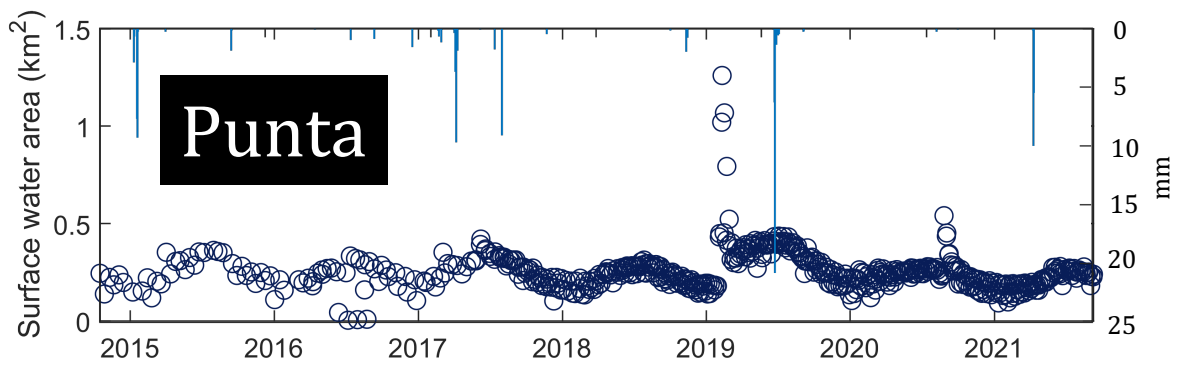
**Shallow Groundwater, Precipitation, and
Sentinel Satellite Multispectral Imagery**

- 2015-present
- Hi-resolution (up to 10-meter)
- Short return period (~10 days)

Response to P & lag time; Seasonality; Baseflow

COMPARISON OF SURFACE WATER INUNDATION AT SALAR DE ATACAMA

Surface waters have distinct response and recession behavior to precipitation events.

nature water

Hydrological signatures in wetlands in the lithium-rich salar basins of the Andes, South America

Sarah McKnight[1*†], Jordan Jenckes[2†], David Boutt[1], Brendan Moran[1], Lee Ann Munk[2], Daniel Corkran[1] and Alexander Kirshen[1]

- Investigate trends and correlations among **surface water bodies, vegetation, temperature, and precipitation**

- *Key takeaway:* Low-elevation water body extents increased over the last decade (following drought)
  - Indicates local recharge provides an important buffer to droughts and increasing T/ET
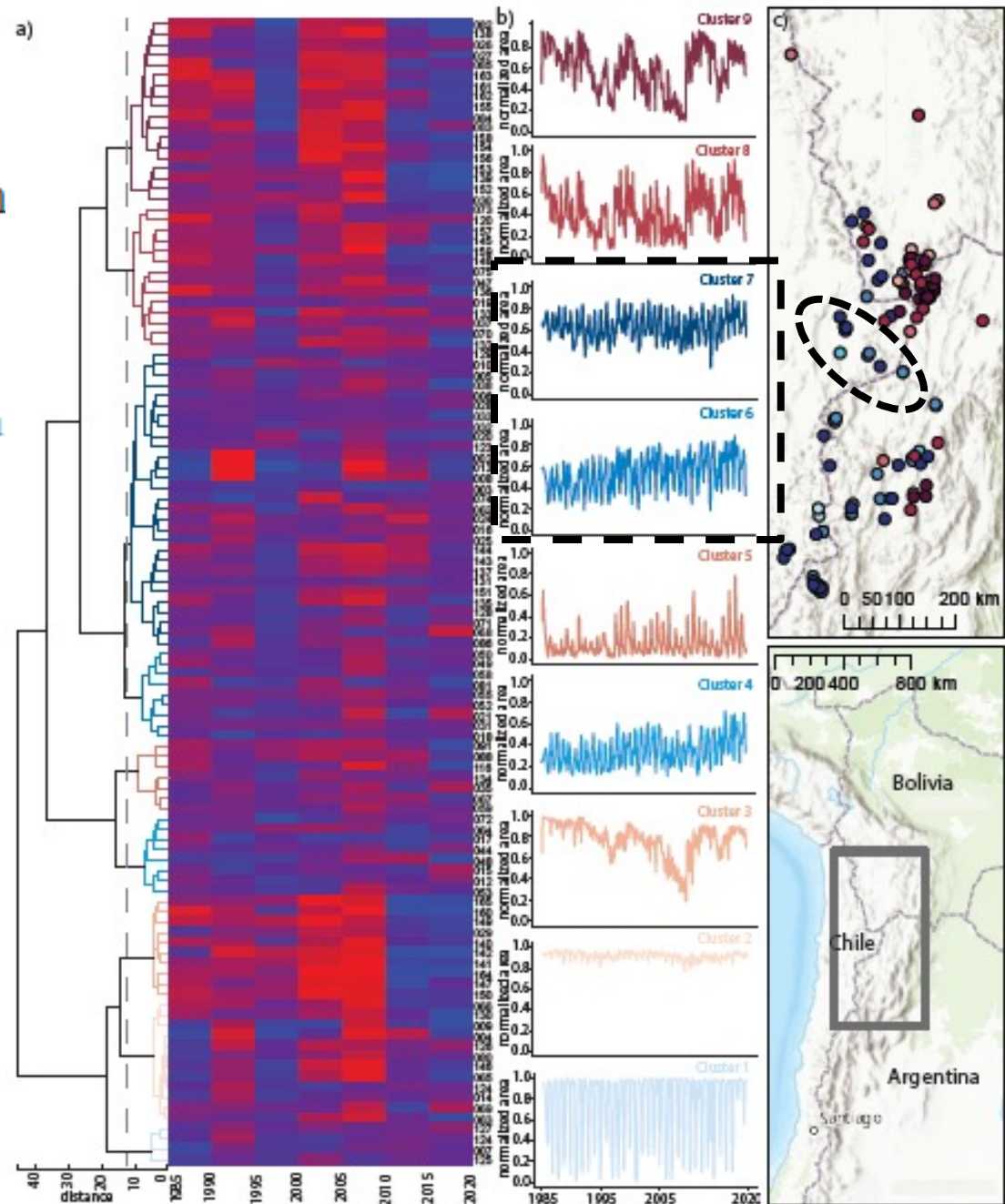
Future Perspectives   + + +

- Continue to monitor hydrological changes and integrate them into conceptual models and planning

- Explore climate change's effects on evapotranspiration and shallow groundwater dynamics

- Disentangle the interplay between anthropogenic pressures and climate change

Thank You!

Photo by Brendan Moran