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Tracking hydroclimate extremes from deep in the tropics

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Around 9% of the world population lives in southeast Asia, e.g. Philippines, Indonesia and Malaysia. The effects of climate change through severe typhoons, tropical droughts and extreme rainfall associated with the monsoon system and El Niño Southern Oscillation (ENSO) are expected to severely impact water resources, infrastructure, and the agrarian economy in southeast Asia.

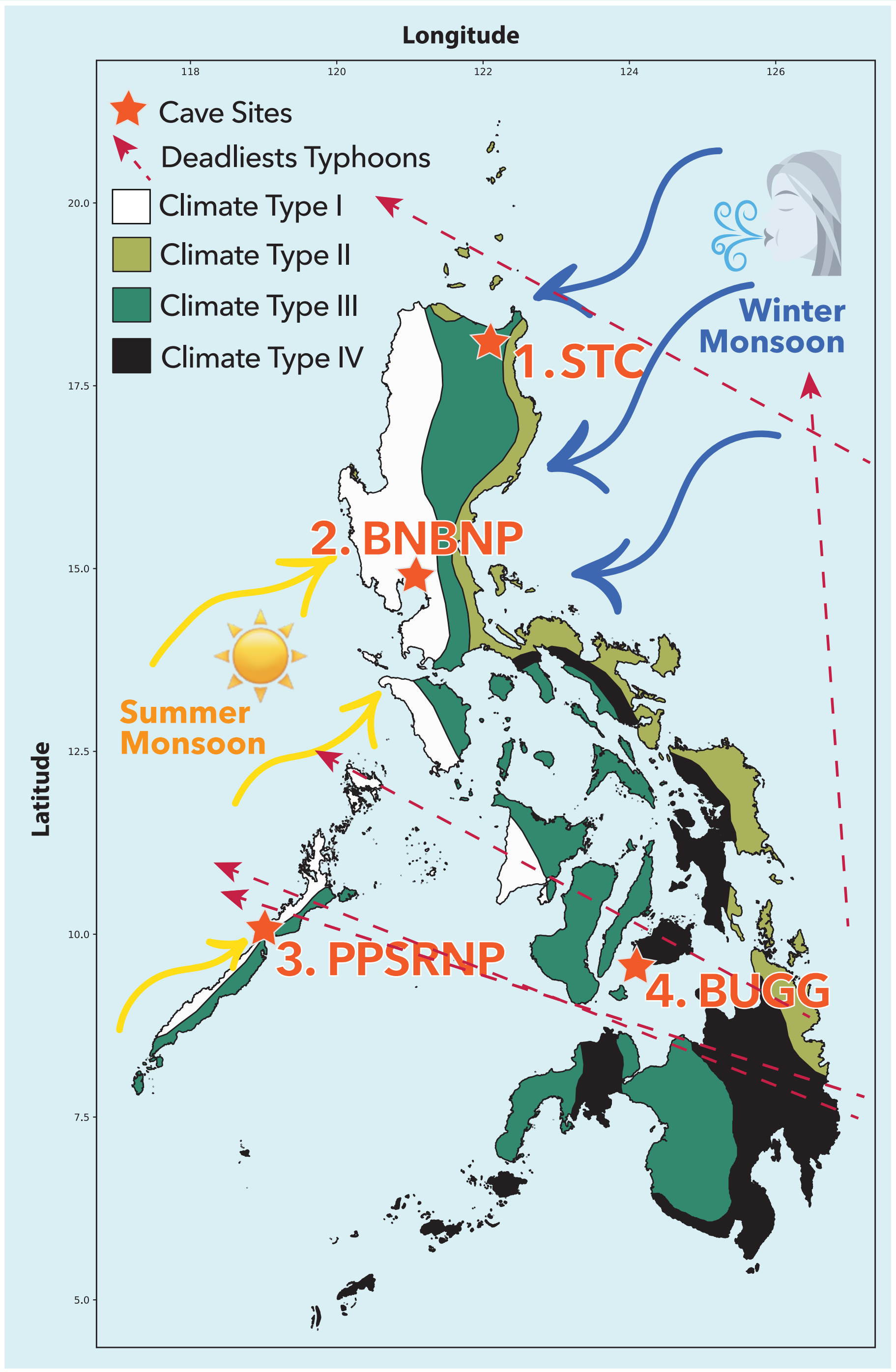


Figure 1:
Map of the Philippines with the major climate types. The summer monsoon (Climate Type I) impacts the western seaboard and the winter monsoon (Climate Type II) impacts the eastern seaboard.

The orange stars and associated numbers indicate the location of cave systems that are being monitored:

1. Santa Teresita Cave (STC)
2. Biak Na Bato National Park (BNBNP)
3. Puerto Princessa Subterranean River National Park (PPSRNP)
4. Bohol UNESCO Global Geopark (BUGG)

The red dashed lines are typhoon tracks for the deadliest typhoons that have hit the Philippines over the last 10 years. Climate Type III and IV do no have distinct wet and dry seasons and are impacted by both the monsoon systems.

Cavers and researchers are checking the status of temperature and drip-rate loggers using a field computer.

From left to right:
Edralin P. Orpilla,
Bibem L. Jalam,
Sharon Tabujara,
Natasha Sekhon,
Bryce K. Belanger

Our research team is investigating extreme wet and dry phases in southeast Asia to aid our understanding of the past in order to be better prepared for future flood and drought phases in the tropics.

A complex climate, characterized by seasonal change in wind circulation and precipitation driven by the winter monsoon and an anti-phased summer monsoon persists in the Philippines. El Niño and La Niña are phases of an ocean-atmosphere coupled system called El Niño Southern Oscillation (ENSO). In southeast Asia, the El Niño phase is characterized by cooler sea-surface temperature and a high pressure system that leads to drier climate.

Conversely, the La Niña phase is characterized by warmer sea-surface temperature and a low pressure system that leads to wetter climate. By analyzing the geochemistry of stalagmite growth layers, the chemistry of modern cave-drip water and modern calcium carbonate, we can quantify the hydroclimate history of the Philippines. We also install instruments to monitor changes in drip rate, temperature and CO_2 concentrations.

Sharon Tabujara takes notes while Natasha Sekhon prepares to change the plate sitting on top of an actively dripping stalagmite. Images are from PPSRNP, which is an 8-km-underground river system, and UNESCO World Heritage Site.

Data from these measurements help us assess the water-residence time in the bedrock, cave ventilation regimes and seasonality in calcite growth. This all ultimately dictates patterns in the ancient rainfall signal encoded in the stalagmites.

Figure 2:
(A) In northeastern Philippines, the dry season (pre-monsoon; April 2022) is highlighted with corn grains lying across the road for drying purposes.

(B) Flooded agricultural fields are a common sight during the wet season (peak monsoon; December 2022). Cave systems in this region (Location 1 in Fig. 1) sit under the karst hills seen in the background.

In April 2022, through close collaboration with the University of Philippines Diliman, Biak-Na-Bato National Park (BNBNP), Puerto Princesa Subterranean National Park (PPSNP; UNESCO World Heritage Site), and the Sierra Outdoor Club, we started our ongoing monitoring effort deep in the tropics.

By covering a large spatial distance of 10° in latitude, we target regions impacted by both the winter and summer monsoon, regions that are in the path of typhoons, and different types of karst (formed by calcium carbonate) landscapes.

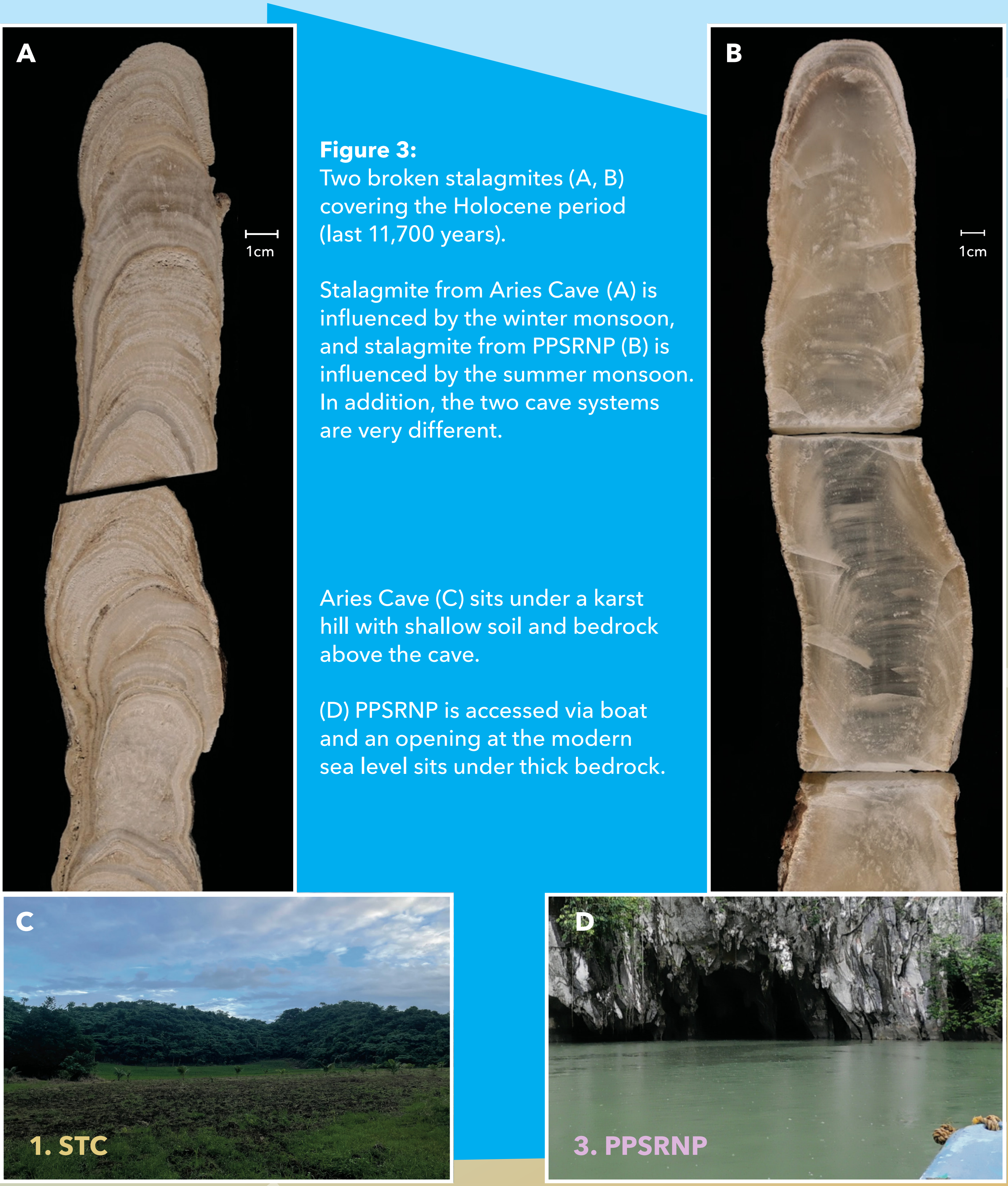


Figure 3:
Two broken stalagmites (A, B) covering the Holocene period (last 11,700 years).

Stalagmite from Aries Cave (A) is influenced by the winter monsoon, and stalagmite from PPSRNP (B) is influenced by the summer monsoon. In addition, the two cave systems are very different.

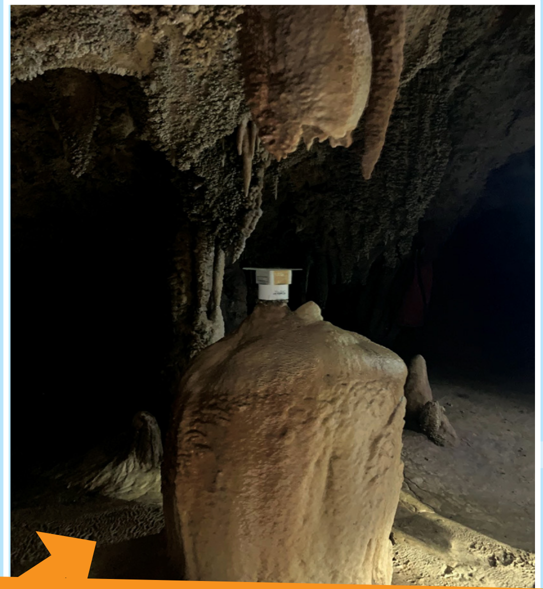
Aries Cave (C) sits under a karst hill with shallow soil and bedrock above the cave.

(D) PPSRNP is accessed via boat and an opening at the modern sea level sits under thick bedrock.

Our initial results demonstrate a relationship between rainfall above the cave to the drip rate in the cave. This is very exciting because it suggests that speleothems (mineral deposits formed from groundwater within underground caverns) that form in these cave systems would have responded to similar changes in rainfall in the past.

Initial stable isotope data of cave drip water points to a different moisture source between the caves in the eastern and western seaboard. Therefore, the growth of speleothems, which is sensitive to infiltrating rainfall, in the eastern cave systems will reflect the winter monsoons. Conversely, speleothems from the western seaboard will be impacted by the summer monsoon.

Monitoring data from instruments is downloaded every six months. Here, Sharon and Natasha investigate cave-air temperature and CO_2 measurements.



A drip-rate logger captures variation in drips through time. The data is then compared against surface-weather station data to discern correlations.

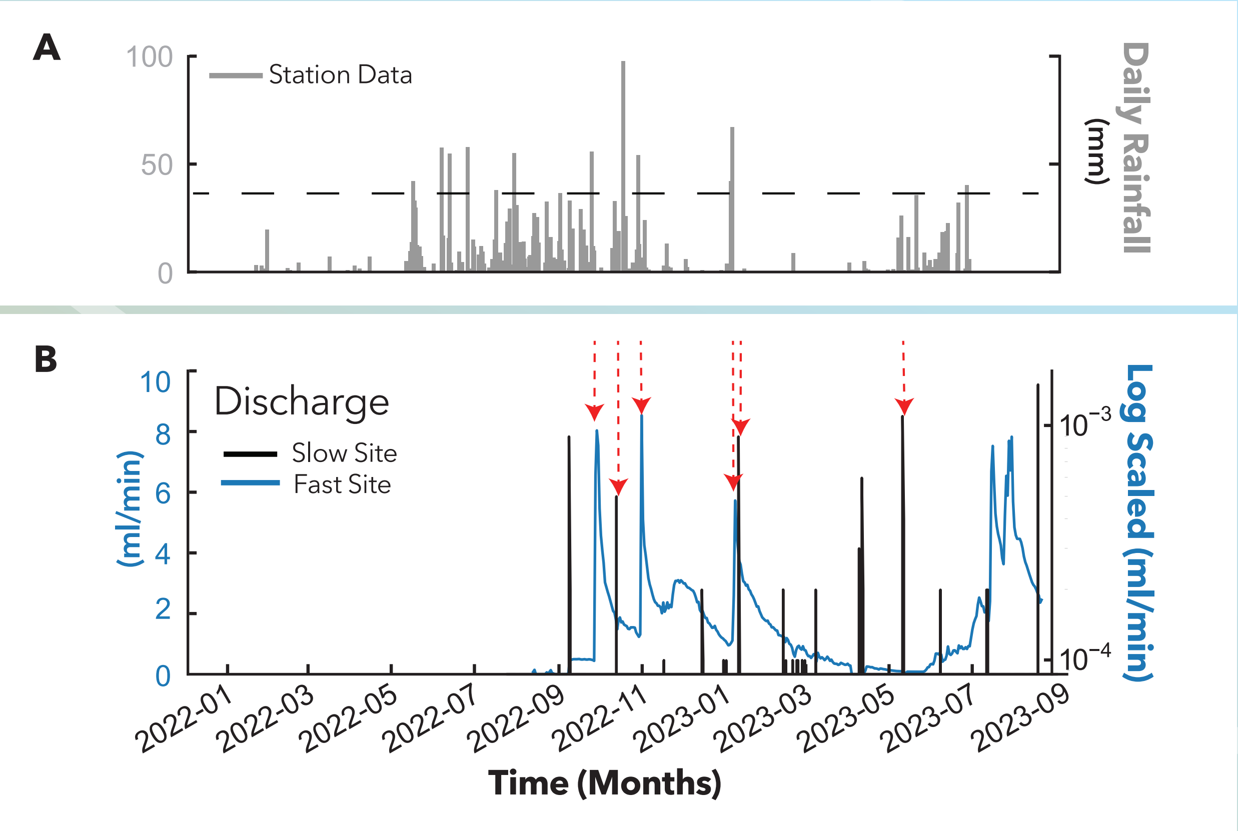


Figure 4:
(A) Daily rainfall data from weather-station data outside Manila, plotted against time. (B) Discharge/drip-rate time series for two (slow and fast) sites in BNBNP (Location 2 in Fig. 1). The red dashed arrows highlight spikes in the drip rate following heavy rainfall events at the surface. This suggests that stalagmite growth layers will be sensitive to wet periods through time. Our goal is to continue this monitoring effort for multiple years to discern climate variability as opposed to weather conditions.

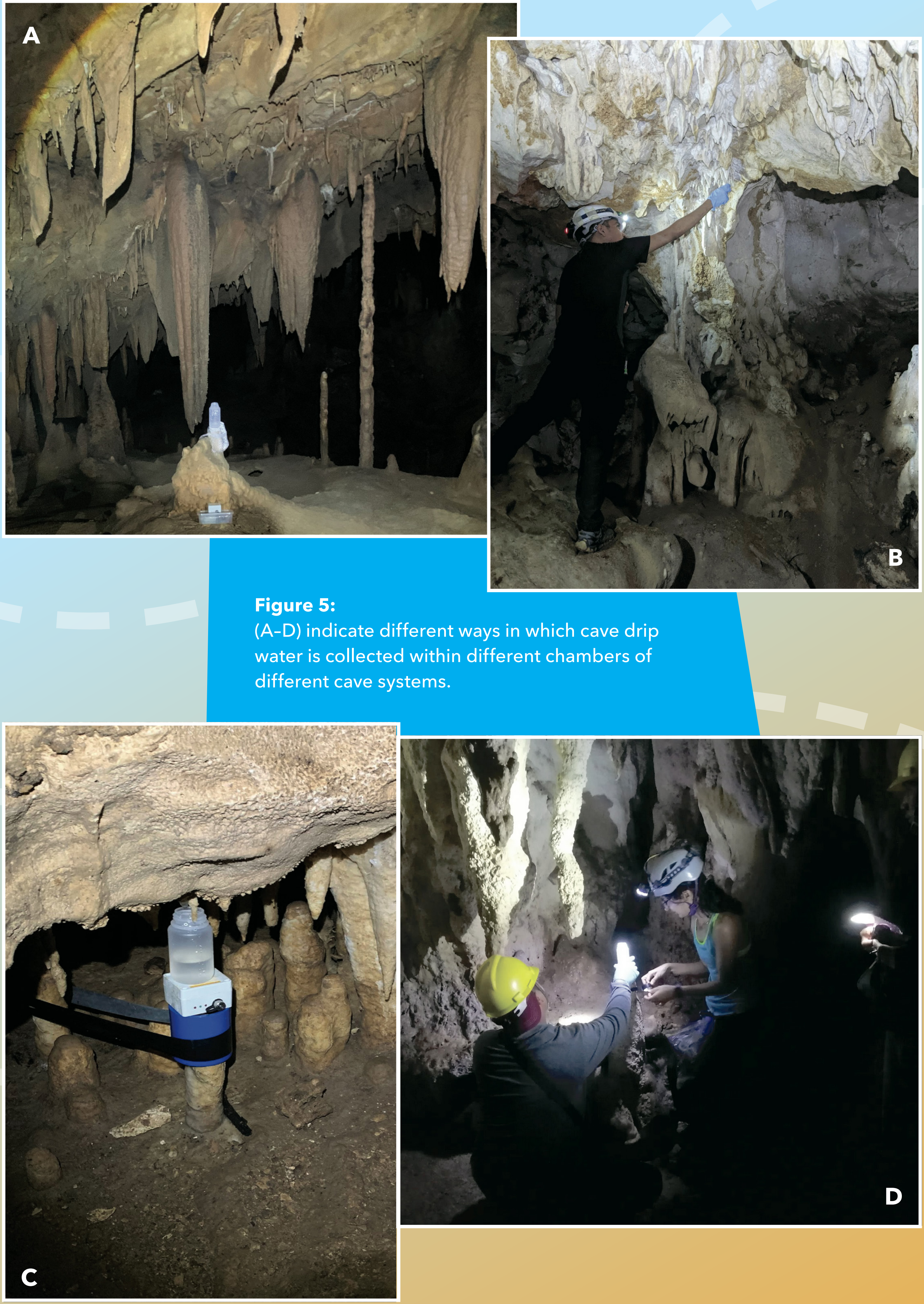


Figure 5:
(A–D) indicate different ways in which cave drip water is collected within different chambers of different cave systems.

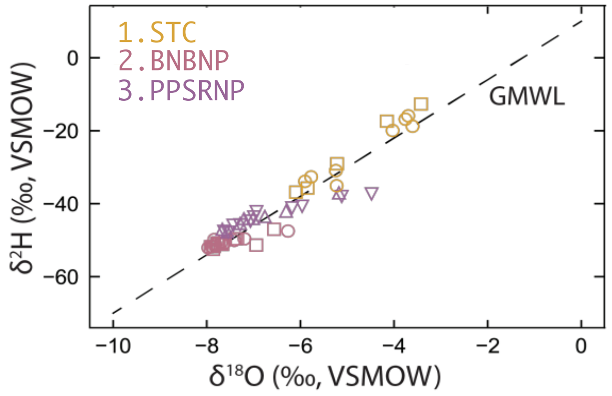


Figure 6: A scatter plot with hydrogen and oxygen isotopes analyzed in dripping water (δ^2H and $\delta^{18}O$, respectively). The colored symbols correspond to three different locations (STC, BNBNP, PPSRNP). The different symbols indicate different sites within each cave with an aim of monitoring at least two sites within each cave.

With promising preliminary results and a continued collaborative effort to monitor cave systems deep in the tropics, we are well equipped to use various geochemical tools to investigate periods of past hydroclimate variability.

By looking at anti-phased patterns in the geochemistry extracted from speleothem layers and corroborated by the monitoring efforts, we aim to disentangle the range of natural variability in the climate system through the Holocene (last 11,700 years).

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