Seeking cyclonic activity records in speleothems from central Pacific: preliminary sample screening

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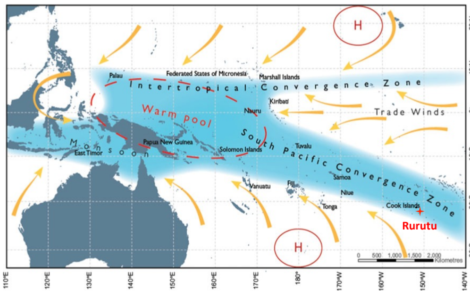


Figure 1. Atmospheric circulation in southern, central and western Pacific (ABOM-CSIRO, 2011).

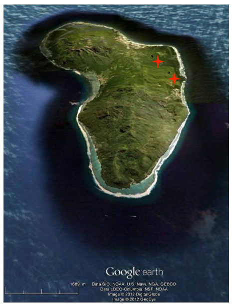


Fig 2. Rurutu island and cave locations

INTRODUCTION

The western half of Tropical Pacific is the planet's hot spot of cyclogenesis, with an average of 10 cyclones impacting the SW Pacific region per year. During El Niño years, cyclone activity migrates eastwards and affects the islands and populations of the central Pacific (Terry & Etienne, 2010). To evaluate the spatial and temporal evolution of this hazard in the context of global climate change, it is necessary to improve our knowledge about its natural evolution, on longer time-scale and at high resolution.

Speleothems can register, under given hydrological and geomorphological conditions, cyclonic events as abrupt variations of their oxygen isotope ratios or as mud-layers (e.g. Benoit Frappier et al., 2007, 2014; Nott et al., 2007).

Focusing on the Australes archipelago, a frequently hit region of southern Polynesia, this exploratory projects aims at: 1) identifying speleothems capable of recording cyclones; 2) reconstructing a chronicle of cyclonic activity over the past few millennia.

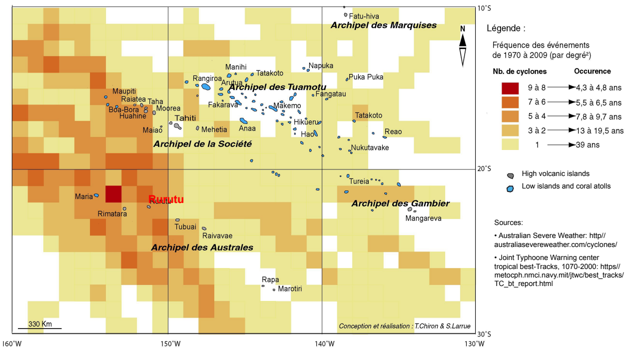


Figure 3. Frequency of tropical cyclones between 1970 and 2009 in French Polynesia (Larrue & Chiron 2010).

SITE and METHODS

We found caves hosting speleothems on the uplifted atoll of Rurutu (Fig.2), located in the eastern part of the South Pacific Convergence Zone (SPCZ; Fig.1). Activity and position of the SPCZ are essentially controlled by ENSO on annual scale, and by the IPO (Interdecadal Pacific Oscillation) on longer scales (Sallinger et al. 2014). Maximal cyclone occurrence is during El Niño periods (Wang et Fiedler, 2006). Rurutu has been hit every 7 to 10 years along the period 1970-2009 (Fig. 3).

In order to evaluate the capacity of the sampled speleothems to register cyclones hitting the island, we need to study the response of the hydrological system to meteorological variations, and the physico-chemical conditions of calcite precipitation. We will then identify among the sampled speleothems the most suitable specimens for detailed study according to their growth period and rate.

- Monitoring:
  - meteo station: Pluvimate + min-max thermometer + cumulative rain gauge
  - $\delta^{18}O$ and δD of daily rain water and monthly drip water + trace elements
  - ibuttons for cave temperature (3h interval) and Stalagmate for drip counting (20 min interval)
  - modern calcite for $\delta^{18}O$ and $\delta^{13}C$ comparison with drip water and cave temperature
- Speleothem analyses:
  - in caves, screening of candidates to provide useful proxy-records of recent cyclone activity
  - stratigraphy and petrography
  - $\delta^{18}O$ and $\delta^{13}C$ variations (increment 50-100 µm or 1mm; CF-IRMS Univ. of Innsbruck & Univ. de Savoie)
  - fluorescence imaging for layer counting (Univ. de Savoie)
  - dating by $^{230}Th/^{234}U$ (MC-ICP-MS Univ. of Melbourne) and ^{14}C (AMS ANSTO).

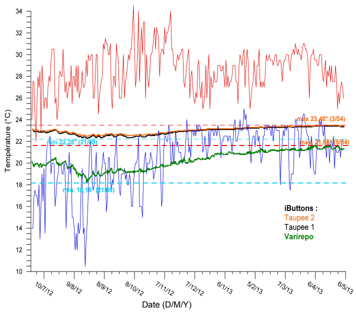


Figure 4. Records of daily min. (blue) and max; (red) temperatures on Rurutu island and in caves of Varirepo (green) and Taupee (orange and black). The hatched lines (light blue and orange) mark the min. and max. values reached in the caves during the year.

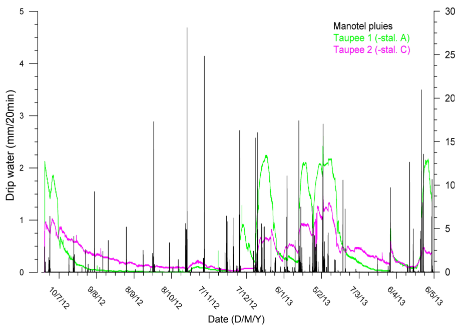


Figure 5. Rainfall (black) and drip rate under two stalactites (green and pink) in Taupee cave, recorded every 20 min.

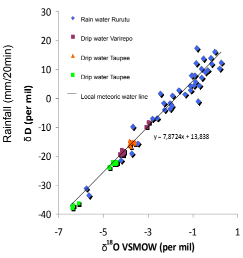


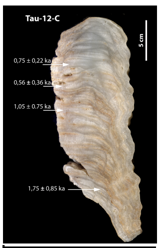
Figure 6. $\delta^{18}O$ and δD (‰ vs. SMOW) of rainwater and dripwaters in Taupee and Varirepo caves.

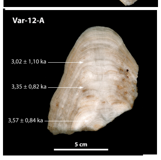
MONITORING DATA

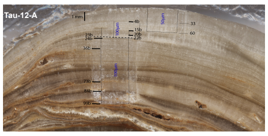
Taupee cave:
- temperature is stable over the year (~1°C maximal amplitude);
- isotopic analyses of modern calcite and drip water provide calculated temperature consistent with the measured one.
⇒ The cave atmosphere is buffered and calcite precipitation occurs in near-equilibrium conditions.

- Dripping can get low but never stops, even during dry season.
- 2 drip counters show synchronous variations but differing in amplitude
- rainfall signal is buffered and modulated by the karst filter
⇒ Two porosity systems in the vadose zone, giving slow or fast response to recharge events
⇒ The buffering effect of the vadose zone on Taupee2 gives more regular drip rates, probably more mineralised waters leading to faster stalagmite growth rate, but more water mixing and smoother isotopic signals, inconvenient for targeting abrupt events.
- Drip water isotopic composition falls on the local meteoric water line => it still reflects rainwater composition.

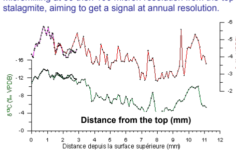
Varirepo cave:
- Larger T° amplitude (3,5°C): the cave is more ventilated.
- Cooler T° than in Taupee due to its pit-shaped morphology (cold air trap)
- Modern calcite and dripwater provide a calculated T° slightly inferior (~2°C) to the mean temperature: maybe ventilation is not strong enough to generate strong kinetic fractionation and isotopic signal could still be exploitable.





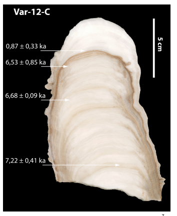


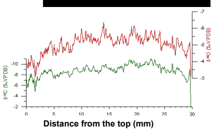
Micromilling at 50 then 100 micron resolution from the top of the stalagmite, aiming to get a signal at annual resolution.



$\delta^{13}C$ and $\delta^{18}O$ of Tau12A stalagmite, as a function of distance to the top. Ages are unknown yet but growth was active at the time of sampling.

Figure 7. Examples of speleothems collected, with preliminary U-Th dating and stable isotope profiles (high resolution micromilling).





$\delta^{13}C$ and $\delta^{18}O$ of Var12-C stalagmite, as a function of distance to the top. The base of the record is dated to 0,87 ±0,33 ka BP. Top age is unknown yet.

SPELEOTHEM ANALYSES: PRELIMINARY RESULTS

Ideal cyclone-sensitive speleothems would have the following properties: active at the time of sampling and recording the past few millenia, with fast growth rate, made of clean primary calcite, precipitated without kinetic fractionation, and fed by water with a short residence time allowing for the isotopic signal of short events like cyclones to be transferred but long enough for the drip water to be supersaturated.

The screening for this type of speleothem is still in progress and the results presented here are very preliminary.

U-Th dating: low U concentration (9-40ng/g; host rock is reef limestone) ; significant detrital content, involving large corrections and large final age uncertainties.

Growth rate is highly variable, from ~0.12 mm/yr to ~0.03mm/yr.

Tau12A: $\delta^{18}O$ profile shows some quite large variations (~3‰), with several abrupt events that we will try to identify in other archives. $\delta^{13}C$ signal amplitude is very large (~-4 to ~-14‰) suggesting the effect of prior calcite precipitation. The $\delta^{18}O$ signal gets heavier when the $\delta^{13}C$ does, which could reflect the rainfall amount in this context.

Var12C: $\delta^{18}O$ profile shows values between -3.1 and -6.3‰, with decadal or centennial fluctuations, superimposed on a general trend which is consistent with the one of the $\delta^{13}C$ profile without being correlated, which implies that calcite precipitation could occur in conditions close to isotopic equilibrium. Once properly dated, this record should provide interesting information about past rainfall regimes on the island.

Var12-A: $\delta^{18}O$ and $\delta^{13}C$ profiles are very similar, signalling the effect of kinetic fractionation altering the record of the climate signal. Moreover, the $\delta^{13}C$ values are very high (~+2 to -9‰) compared to the other stalagmites and to what would be expected under such soil. However, if kinetic processes are linked to the variations in drip rate or to the cave hygrometry, they may inform us qualitatively about the effective rainfall through time. In such a case, we could focus on the longer term trends.

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PERSPECTIVES

Dating (in progress): more U-Th dates will be run on the oldest parts; ^{14}C dating will take place at ANSTO. It will focus on finding the 'bomb pulse' and defining the dead carbon proportion for constraining calcite growth during recent centuries until it is viable to use U-Th dating. The potential for dating by lamina counting needs to be tested; petrographic changes are too faint so fluorescent lamina are being investigated.

Hydrologic monitoring indicates storage and mixing of the order of several weeks to months. Sampling is continuing in both caves to clarify this, as water transfer rate may change with the recharge, thus according to the season. This aspect needs consideration when looking for single abrupt events such as cyclones, as the signal of the ^{18}O-depleted rainwater may be masked unless the quantity is large enough to flush and replace the stored water.

Different drip sites in the same cave react differently to rainfall events. Water residence time and mineralization will change accordingly: some speleothems grow faster than others, some stop seasonally while others grow steadily. Thus, some of these speleothems will be more suitable to provide interannual climate variation records whilst others, despite a noisier signal, will be capable to inform us about seasonal evolution or even the occurrence of cyclones, if their growth rate is sufficient to allow the necessary sampling.

These speleothems will also be useful to establish climate reconstructions of multi-annual resolution across the last millenium in the Australes archipelago, extending instrumental data about the hydrological variability in the Central pacific linked to shifts in the SPCZ.

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