Temporary densification of a rain gauge network to gain knowledge about orographic rain enhancement on the Island of Tahiti - French Polynesia

Lydie Sichoix[1] and Lionel Benoit[2]

[1]University of French Polynesia - GEPASUD Lab
[2]INRAE Avignon

November 22, 2022

Abstract

In tropical islands, interactions between atmospheric circulation and island topography generate complex patterns of orographic rain. Despite recent advances, numerical weather models are still challenged by orographic rain enhancement, in particular because the physical processes responsible for rain generation over tropical islands vary at spatial and temporal scales that are not yet fully resolved in these numerical models. A large part of our knowledge about tropical island precipitation patterns therefore relies on rain observations. However, observing strongly variable rain fields is not an easy task. It requires instruments able to capture rain fluctuations at fine temporal (1 min - 1h) and spatial (100 m - 1 km) scales. To reach these requirements, state of the art rain observation methods rely on remotely sensed weather radar images and in-situ rain gauge measurements, or solely on rain gauge observations in the many areas like Tahiti where radar observations are not available (mainly due to financial cost). In this study we investigate to which extent a temporary densification of the rain monitoring network of Tahiti (lon = 149.5°W, lat = 17.6°S, area = 1042 km2, max altitude = 2241 m) can help us gaining new insights about orographic rain enhancement on a high altitude tropical island with complex topography. To this end, 10 low-cost but high resolution rain gauges have been deployed for one year (Aug 2020 - Aug 2021) in addition to the long term network of around 20 rain gauges operated by the Direction de l'Equipement Tahiti (Groupement d'Etudes et de Gestion du Domaine Public) and the French Weather Service (Météo France Polynésie). Based on this new dataset, we first characterize the space-time patterns of orographic rain enhancement over Tahiti at an unprecedented resolution, and link these emerging patterns to local features of the atmospheric circulation. Next, we investigate the added value of our temporary network for purposes of rain mapping (i.e., spatial interpolation of point observations). Finally, we explore the benefits and limitations of temporary rain gauge network densification for orographic rain enhancement observation.

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AGU Fall Meeting 2021 New Orleans
B35B-1426

Lydie SICHOIX[1] & Lionel BENOIT[2]

[1] University of French Polynesia, GePaSud laboratory, Puna'auia, French Polynesia (correspondance: lydie.sichoix@upf.pf)

[2] French National Research Institute for Agriculture, Food and Environment (INRAE), BioSP, Avignon, France (correspondance: lionel.benoit@inrae.fr)

Context

- In the Island of Tahiti, recent evaluations have shown that uncertainty in precipitation data propagates throughout the hydrological modelling chain.
  - ➢ Stochastic rainfall simulator to emulate rain fields and their uncertainty.
  - ➢ Parsimonious event-based conceptual rainfall-runoff model.
  - ➢ Results highlight that the uncertainty in precipitation can translate into strong uncertainties and biases in simulated streamflow.
- Precipitation data uncertainty caused by network sparsity is further amplified by orographic effects, which the present study aims to better quantify.

Photography by B. Capron

Rain climatology of Tahiti

- In Tahiti, rainfall is mostly driven by (1) the position of the South Pacific Convergence Zone (SPCZ), and (2) the strength and precise orientation of the trade winds.
- At the vicinity of the island, wet marine air masses rise and trigger orographic rainfalls, in particular on windward slopes (Fig 1). However, the way orographic enhancement arises at the slope scale remains poorly understood.
- In this study we propose to investigate how a temporary densification of the rain gauge network of Tahiti can help us gaining new insights about orographic rain enhancement, in particular:
  - ➢ **What are the main rainfall patterns over the inner mountains of Tahiti?**
  - ➢ **What is the daily rain cycle associated with these patterns?**
  - ➢ **Do orographic gradients differ between slopes and patterns?**

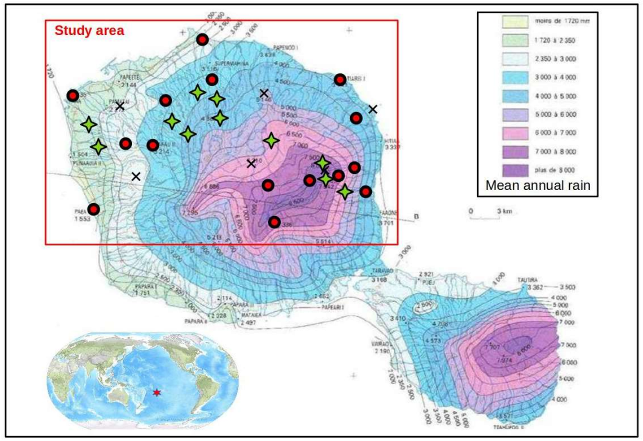

Figure 1: Temporary densification (green diamonds) of the long term rain gauge network of northern Tahiti Nui (red dots: active gauges, black crosses: malfunctioning gauges). Background rain map from: Lafforgue (1993), Atlas de la Polynésie.

Temporary network densification

- Focus on northern Tahiti Nui, where are found the highest mountains of French Polynesia, culminating at Mt Orohena (2241 m).
- High mountains create dramatic rain gradients, with annual rain ranging from 1500 mm to almost 10 m (Fig 1) with a record value of 14 m at Hitia'a..
- The long term sub-daily resolution rain gauge monitoring network over the study area encompasses 21 gauges divided into 3 sub-networks: Météo France (weather agency) along the coast, GEGDP (Direction of Equipment) in the hills, and Engie-EDT-Marama Nui (hydropower company) in wet mountain valleys.

Figure 2: Rain gauge setup in the Tuauru valley with Lydie, Lionel and Ulysse.

- 11 low-cost drop-counting rain gauges called Pluvimates (PiTech Research Ltd) have been setup in remote and high altitude locations (up to 1800 m, Fig 2).
- Data are available from Aug 2020 to present. For this study we focus on the one-year period Oct 2020 - Oct 2021. Raw data have been aggregated at 1h resolution, and gaps caused by gauges malfunction have been filled using squared inverse distance interpolation.

Rain features of 'La Niña' year 2020-2021

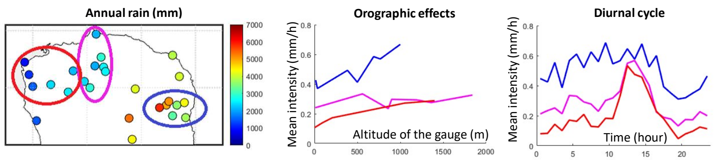

Figure 3: Annual mean rain accumulation (left), diurnal cycle (center), and orographic gradient observed for the period Oct 2020 - Oct 2021.

- We investigate rainfall features during a 'La Niña' year, which usually leads to drier than usual conditions over Tahiti (Fig 3).
- Slope scale rainfall features are investigated for three areas typical of the different climates of northern Tahiti Nui (from West to East):
  - ➢ Puna'auia - Fa'a'ā sector (Red in Fig 3): this leeward slope is one of the driest of the island, has a strong diurnal cycle, and moderate orographic gradient.
  - ➢ Tuauru valley (Purple in Fig 3): this transition zone between windward and leeward has a moderate diurnal cycle, and a weak orographic gradient.
  - ➢ Hitia'a sector (Blue in Fig 3): this windward slope is the wettest of the island (up to 10 m rain during wet years), has almost no diurnal cycle, but a strong orographic gradient.

Main rainfall patterns

- How do the annual rainfall features of figure 3 build-up at the daily scale?
- Classification of rainy days (at least one gauge records more than 5mm/day) according to slope-scale daily mean rainfall:
  - ➢ Feature space: daily rain averaged over the three slopes defined in Fig 3.
  - ➢ Unsupervised classification (GMM with model selection using BIC).
- Four main patterns are identified (Fig 4): scarce showers under low trade winds (Type 1), widespread rains under strong trade winds (Type 2), light rains under weak north-westerlies (Type 3) and SPCZ-related storms (Type 4).
  - ➢ Orographic gradients occur mostly on windward slopes.
  - ➢ Diurnal cycle is stronger on leeward slopes, and is inhibited by strong winds.

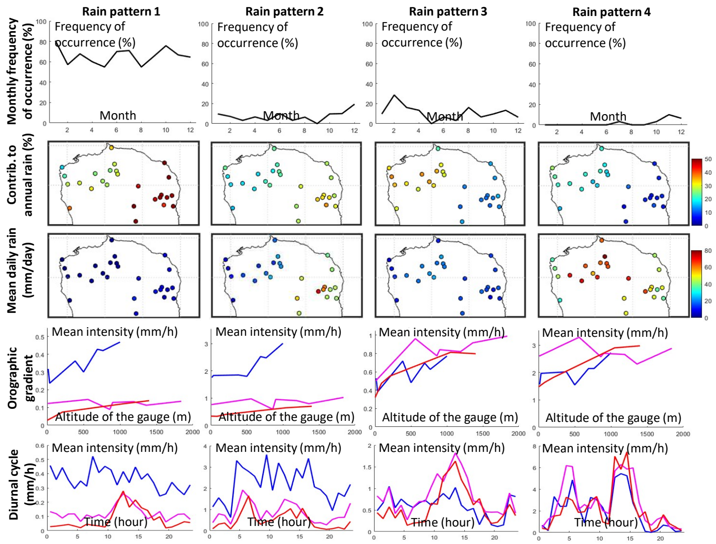

Figure 4: Rainfall features for the four main rain patterns identified in Tahiti.

Conclusions and future work

- We observed strong non-stationarities of rain properties in both space and time. This is a challenge for statistical rainfall modelling (in particular stochastic weather generators).
- This experiment of densification will continue over two more years, and be extended to the neighboring Island of Moorea (background context picture).
  - ➢ Better documentation of orographic rain enhancement on both islands.
  - ➢ Characterization of extreme rain events (often linked to SPCZ-related storms), which often trigger severe floods.

Acknowledgments. The authors especially thank Pr. G. Mariéthoz from the University of Lausanne, for providing a set of pluvimates. The Direction of Equipement-GEGDP, Météo France Polynésie, and Engie-EDT-Marama Nui are gratefully acknowledged for the provision of their data. The authors also thank Bernard, Henry, Herehia, Jean-Yves, Manava, Stéphane, Ulysse, and Gepasud lab's PhD students who helped collecting data. This work is funded by the Fonds National Suisse and the Ministère de la Recherche – Polynésie Française under the program E-CRQEST.