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High resolution wind regimes over Tahiti, French Polynesia, using the WRF-ARW mesoscale model

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Abstract

Assessing natural ventilation potential on a tropical island such as Tahiti (French Polynesia), where strong climatic constraints apply on buildings constitute a challenge due to the scarcity of wind measurements. Indeed, only one in situ automatic weather station provides high quality wind speed and direction data records. To overcome this lack of information, a dynamical downscaling using WRF-ARW model has been performed to assess 10 m wind speed and direction at high spatial resolution in Tahiti. A weather type classification is used to highlight the main regimes prior to the downscaling process. First of all, daily 700 hPa geopotential and 10 m horizontal wind components from reanalysis dataset undergo a clustering technique resulting into six wind classes. Then, the five closest dates to the center of each wind class are selected. Simulations with the model WRF-ARW are then performed for selected days over 3 interactively nested domains over French Polynesia, with finest horizontal mesh size of 1.33 km over Tahiti Island. The initial and coupling fields are derived from the ERA Interim reanalysis dataset. The only one in situ station is then used to assess the performance of the downscaling. The higher resolution obtained with this model set-up allowed to highlight the contrast between the leeward and windward side of the island. Better resolving the complex topography of the volcanic island, these high resolution recurrent wind regimes would be useful to support low environmental impact construction policies.

Keywords – natural ventilation; wind regimes; dynamical downscaling; tropical climate constraints

1. Introduction

Solar radiation and wind flow constitute critical forcings on buildings in the tropics. They determine the thermal comfort of a construction. Over a remote island such as Tahiti, small and with steep orography, few meteorological data records are available. In fact, only one automatic weather station is operating over a surface area as big as Europe. Tahiti (french Polynesia) enjoys a tropical climate characterized by two seasons: a wet season from November to April and a dry season from May to October. The island is mainly exposed to trade winds, which cause a rainfall contrast between the eastern and western coasts [1]. The reduction of energy consumption of French Polynesia and its dependence on fossil fuel imports is largely based on energy demand side management . This involves, in particular, limiting the use of air conditioning in buildings by promoting eco design rules. Technical solutions enabling a thermally comfortable building in a tropical climate without using air conditioning are well known [2] [3] . They are mainly based on the cross natural ventilation and therefore require to know the wind conditions on the periphery of the building.

The aim of this study is therefore to provide wind speed and direction at higher spatial resolution in order to estimate natural ventilation potential for buidings throughout Tahiti Island. In a first step, the main wind regimes are identified using a classification technique, then, a downscaling approach is set up with the model WRF to obtain these wind regimes at higher resolution.

2. Data and Methods

A. Observed and Reanalysis Datasets

Tahiti is a volcanic island located in the Society Archipelago of French Polynesia (17°40'S – 149°28'W) in the South Central Pacific Ocean. The only meteorological station able to provide hourly values of wind speed and direction is located at the international airport of Tahiti-Faaa in the northwestern part of the island (Fig. 1). These observed data records would be used to assess the performance of the model in section 4.

ERA Interim dataset available online at http://apps.ecmwf.int/datasets is a reanalysis product of the European Centre for Medium-Range Weather Forecasts thereafter ECMWF. ECMWF periodically uses its weather forecast models and data assimilation systems to 'reanalyse' archived observations, creating global gridded data sets describing the history of the atmosphere, land surface, and oceans since 1979 [4]. In this study we used daily fields of 700 hPa geopotential (thereafter Z700) which is representative of the horizontal wind. These fields have been selected over 20 years (1979-2009) on a large domain encompassing French Polynesia (0-30°S/160-130°W) in order to capture the main synoptic regimes near Tahiti.

B. The classification method

The twenty years of Z700 daily fields undergo a two-step classification method to derive the most frequent wind regimes in Tahiti.

First, an Empirical Orthogonal Function (EOF) analysis is performed on the Z700 (centered and scaled) to isolate the principal components that explain most of the variance. The first 6 principal components explain 50% of the variance.

Then, a clustering technique, the k-means [5], is applied on Z700 (centered and scaled), imposing 6 centroids, according to the EOF results, for the aggregation of the individuals. For the 6 regimes, the 10 closest days to the centroid are selected and averaged before plotting. Fig. 2 shows the 6 wind regimes highlighted by the classification method, they have been recognized by the Tahitian Meteorological Service. Tahiti is located in the green square. The frequency of each regime, that is to say the percentage of time (over 20 years) for each regime to occur, is indicated in blue at the right bottom corner of each plot.

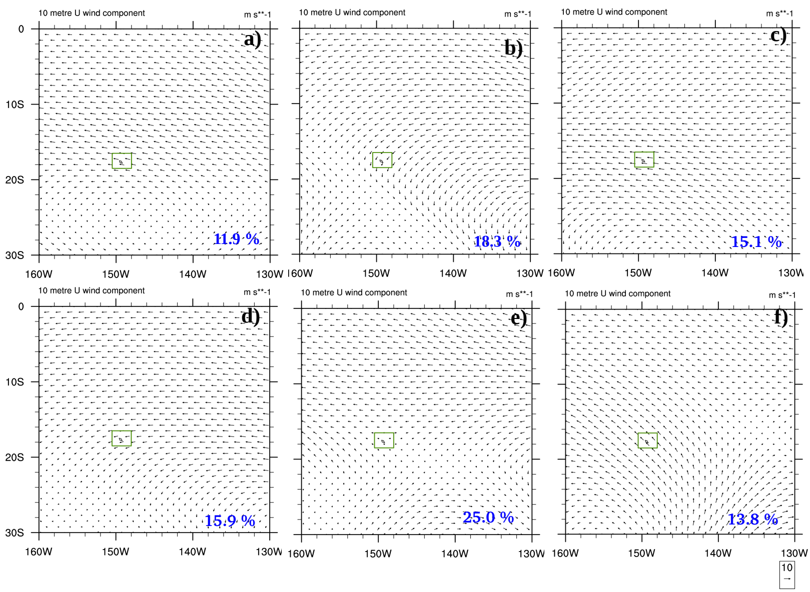

Fig. 2 Era Interim 6 wind regimes over French Polynesia (10 m horizontal wind components) derived from the classification method. a) Regime 1, b) Regime 2, c) Regime 3, d) Regime 4, e) Regime 5, f) Regime 6.

3. The Downscaling Experiment

The WRF-ARW mesoscale model used in this study [6], solves the nonhydrostatic compressible equations of the atmosphere dynamics on increasing resolution nested domains. WRF is a limited area model which most common use is to be implemented within a global climate model to obtain higher resolution over a specific region. The global model provides the boundary conditions for WRF. In the climate modeling community, it is also very common to use reanalysis datasets (which result from weather forecast models) as boundary conditions for limited area model such as WRF. Then, the simulation over a specific region obtained with WRF can host one or several nests. A nest is a finer-resolution model run. It may be embedded simultaneously within a coarser-resolution model run (called parent). The nest covers a portion of the parent domain, and is driven along its lateral boundaries by the parent domain.

In this study, WRF covers a large portion of the central Pacific we would refer to as domain 1, with a horizontal resolution of 20 km (Fig. 3). Then, a first nest is embedded inside domain 1, called domain 2, with a mesh size of 4 km. Finally, domain 3 corresponds to the nest embedded inside domain 2, with a 1.33 km horizontal mesh. Domain 3 covers an area of 300 km $\times$ 300 km, centered at Tahiti. All three domains have the same vertical grid with 41 levels between the surface and the 50 hPa pressure level. The datasets of static fields (topography, land-use, land-water masks, land cover classification, albedo) were obtained and interpolated from the NCAR database. In domain 2, the highest point of Tahiti is less than 900 meters, it is 1230 m in domain 3 (Fig. 4a)b)). Although a real improvement has been made by implementing a finer topography, it is still far from the complexity of the real topography which peaks at 2241 m.

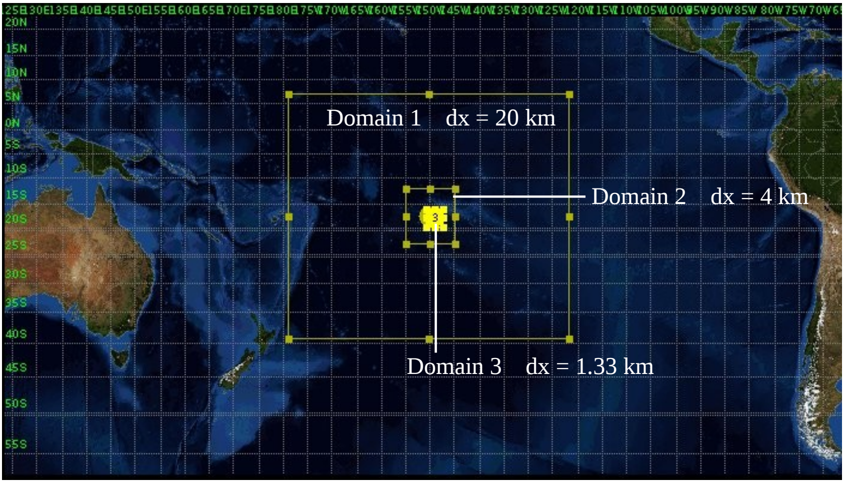

Fig. 3 WRF domains, domain 3 is nested in domain 2 itself nested in domain 1

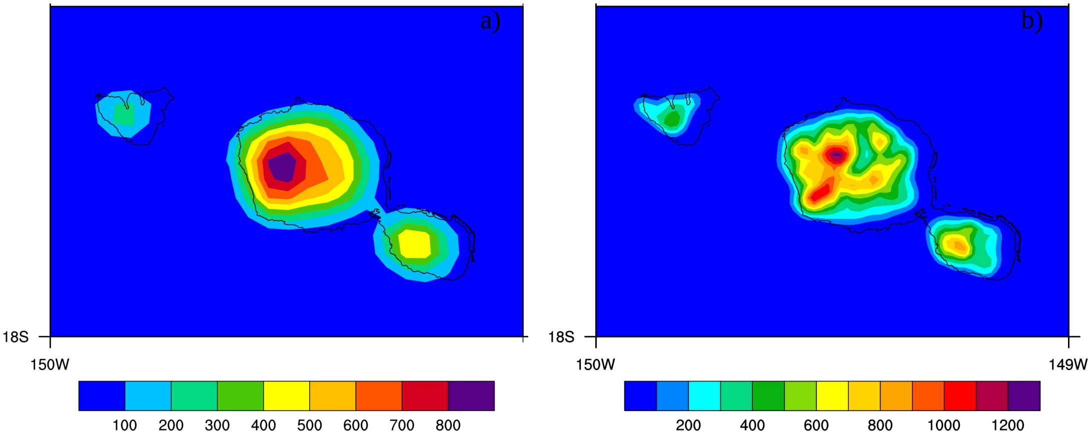

Fig. 4 Terrain height in meters for a) domain 2 (3.7 km resolution) and b) domain 3 (0.93 km resolution).

Subgrid processes have been parameterized using physical schemes in Table 1. The convection scheme has only been used for domains 1 and 2.

Table 1.

Parameterization	Description
Convection	Grell (Grell et al, 1995)
Surface Layer	MM5 (Hong et al, 2006)
Planetary Boundary Layer	YSU (Hong et al, 2006)
Shortwave radiation	Dudhia (Dudhia, 1989)
Longwave radiation	RRTM (Mlawer et al, 1997)
Microphysics	Eta Ferrier (NOAA, 2001)
Land-surface model	Noah (Chen and Dudhia, 2001)

The choice of the parameterization schemes has been done acknowledging previous studies on Hawaii, New Caledonia and Tahiti [7], [8], [9].
Initial and boundary conditions of the first WRF domain come from Era Interim reanalysis atmospheric and surface fields. The five days that are closest to each regime center have undergone the downscaling process, 24 hours before each date have also been run to initialize the model. Then, the five runs are averaged to derive the downscaled wind regime. The 6 downscaled regimes are presented in section 5.

4. Model Validation

In order to assess the performance of the downscaling technique, a few consecutive days in regime 3, from the 16^{th} to the 20^{th} January 2001, have been run and compared to the same chronology from the in situ station. Temperature and 10 meter wind speed and wind direction from the Faaa station have been correlated with temperature and 10 meter wind components at specific grid points. Fig. 5 displays time series of observed and modeled temperature and 10 meter zonal wind component along with correlation and root mean square error calculated over the last 72 hours of the run (18-20^{th} January) to avoid any discrepancies due to the model initialization. Not surprisingly, temperature from the model grid point that is closest to the in situ station shows the highest correlation: 0.65. However, this is not the case for wind components, correlation is the highest (0.46) between a grid point located to the south-west of the meteorological station (see Fig. 6). This could be due to the coarse topography that has been taken into account by WRF. In fact, the nearest grid point is higher (117 m) than the real altitude (2 m). The most correlated grid point, for wind, is 7 meters high, still higher than the real altitude but the real wind flow is better replicated. Root mean square errors (RMSE) are of 2°C for temperature and 2.4 m/s for zonal wind. Indeed, time series in Fig. 5 show good correlation between observed and modeled temperature with lower amplitudes for the model, which explains the high RMSE. In the case of zonal wind, correlation and RMSE are worse than for temperature. This is not surprising since wind is a noisier variable than temperature. In addition, it is highly dependent on the orography, which should be as realistic as possible in the model. In domain 3 of the simulation, the topography resolution is only of nearly 1 km, which is clearly not enough to accurately reproduce the wind flow.

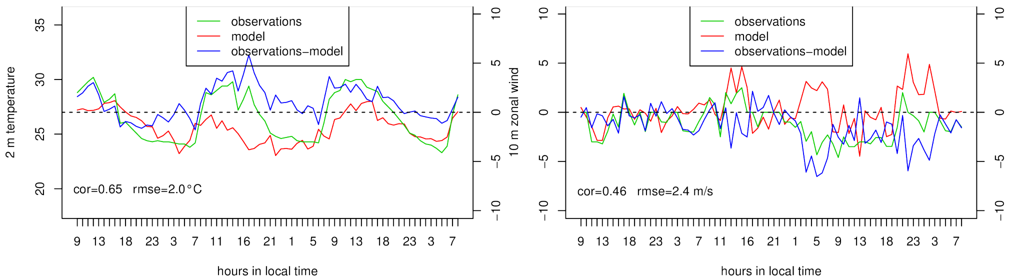

Fig. 5 Time series of 1) left: model and observed temperature (closest grid point) and 2) right: model and observed 10 m zonal wind component (south-west grid point).

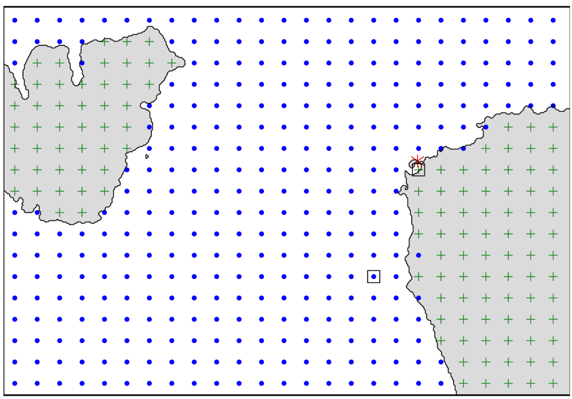

Fig. 6 Zoom on the north-western part of Tahiti with the mesh of the domain 3 (1.33 km resolution). Blue dots correspond to the model grid points considered as sea, green crosses correspond to “land” grid points. The red asterisk is located at the meteorological station. A black box surrounds the grid point closest to the station, this grid point is best correlated with the station, in terms of temperature. Another black box is located further south-west, it surrounds the grid point that is best correlated with the station, in terms of zonal wind.

5. Results and Discussion

Results from the downscaling of the 6 wind regimes are displayed in Fig. 7. The 1.33 km downscaling allows a better simulation of the wind flow which interacts with a better resolved topography of the islands. The improvement is particularly obvious if one compares Fig. 7 with Fig. 2 which shows the wind fields from the reanalysis Era Interim. The mesh of Era Interim is coarse, about 80 km, and has a poor topography resolution but the landmask is also limited, all the Polynesian islands are considered as ocean.

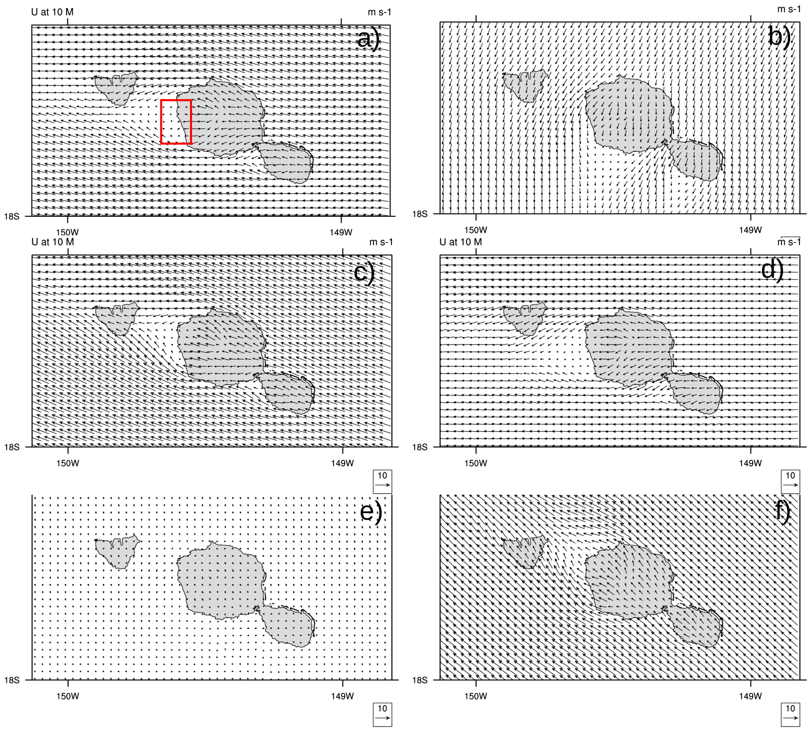

Fig.7 WRF downscaled regimes (10 m horizontal wind components), a) Regime 1 b) Regime 2, c) Regime 3, d) Regime 4, e) Regime 5, f) Regime 6. A red box has been placed on the western coast of Tahiti.

The first noteworthy regime is regime 5, which has the highest occurrence frequency of 25 %. In Fig. 2 it is associated with very light wind over a region encompassing Tahiti. The same feature is observed in Fig. 6 e).

In Fig. 2, an eastern wind component is observed in the vicinity of Tahiti for regimes 1, 3 and 4. Increasing the resolution with WRF shows these regimes have different spatial signatures on Tahiti. The mountainous central part of Tahiti force the splitting of air flow. On the western coast of Tahiti (red box on Fig. 6), regimes 1, 3 and 4 induce suppressed winds. Regime 3 shows a stronger south-eastern flow on the south-east of the island compared to regimes 1 and 4. Regime 4 exhibits the weakest upstream winds coming from the east. The western coast of Tahiti has therefore a very low wind potential, adding regimes 1, 3, 4 and 5 occurrence frequencies suggest there is no wind 67.9 % of the time in this area. A moderate north-eastward flow (regime 2) occurs 18.3 % of the time and a stronger south-eastern flow (regime 6) occurs 13.8 % of the time.

Eastern and northern coasts are characterized by:

- no wind (regime 5) 25 % of the time,
- strong winds (regime 1, 3, 6) 40.8 % of the time,
- moderate winds (regime 2, 4) 34.2 % of the time.

Southern coasts are characterized by:

- no wind (regime 2, 5) 43.3 % of the time,
- strong winds (regime 1, 3, 6) 40.8 % of the time,
- moderate winds (regime 4) 15.9 % of the time.

6. Conclusion and Perspectives

The objective of this work is to overcome the lack of meteorological data records over Tahiti, particularly wind measurements, that are useful to characterize climate constraints on buildings. The proposed method has identified 6 recurrent wind regimes in Tahiti and provided wind components, on a mesh size of 1.33 km. Therefore, we have a first estimate of wind stress at finest resolution. Modeled and observed zonal wind are not highly correlated and this could be due to the resolution of the topography implemented in WRF. Indeed, the in situ station is located 2 m above the sea level and the closest model grid point is 117 m high. These differences explains the low correlation and discrepancies between model and observation. Although downscaling clearly produces more realistic wind fields, compared to Era Interim dataset, accounting for the splitting of air flow due to topography, further improvements could be envisaged. This study allows to characterize natural ventilation potential on subregions of the island, which is particularly useful for the most occupied coastal zones of Tahiti. One of the perspectives of this study would be to implement a topography at higher resolution to improve the relevance of the model and derive more accurate natural ventilation potential. Another perspective would be to assess the potential for renewable energy.

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