Scientific Research Publishing

Atmospheric and Climate Sciences, 2022, 12, 297-312
https://www.scirp.org/journal/acs
ISSN Online: 2160-0422
ISSN Print: 2160-0414

Effects of On-Site Weather Conditions on the Detection Capability of the Infrasound Station of Madagascar I33MG

Andry Harifidy Ramanantsoa[1], Elisabeth Blanc[2], Gérard Rambolamanana[3], Andriniaina Tahina Rakotoarisoa[1], Fanomezana Randrianarinosy[1], Jean Bernardo Andrianaivoarisoa[1]

[1]Institute and Observatory of Geophysics of Antananarivo, University of Antananarivo, Antananarivo, Madagascar
[2]Commissariat à l'Energie Atomique et Energies Renouvelables, DASE/LDG, Bruyères Le Châtel, France
[3]Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO), Vienna, Austria
Email: ahramanantsoa@gmail.com

How to cite this paper: Ramanantsoa, A.H., Blanc, E., Rambolamanana, G., Rakotoarisoa, A.T., Randrianarinosy, F. and Andrianaivoarisoa, J.B. (2022) Effects of On-Site Weather Conditions on the Detection Capability of the Infrasound Station of Madagascar I33MG. *Atmospheric and Climate Sciences*, **12**, 297-312.
https://doi.org/10.4236/acs.2022.122019

Received: January 3, 2022
Accepted: March 19, 2022
Published: March 22, 2022

Abstract

Noise due to surface wind and temperature is a problem in infrasound. Efficiency of IMS network concerns scientists. It is obvious to find the causes of deficiencies of detection of infrasound station by studying background noise power with respect to the surface wind and the temperature. Data measured by MB2000 microbarometer of infrasound station I33MG are used for the study. Infrasound records are separated into 4 frequency bands centered respectively at: 1 Hz, 0.25 Hz, 0.0625 Hz and 0.0156 Hz. Effects of surface wind and temperature are studied by plotting the variations of the background noise power with respect to the temperature or wind speed in the four considered frequency bands and compared with the median of background noise power. The influence of temperature is manifested by a reduction in the number of low-frequency detection. The surface wind reduces the number of detection at a high frequency. An exponential function is proposed to predict the variations of the noise power in different observation frequencies and temperature and wind conditions. The views expressed herein are those of the authors and do not necessarily reflect the views of the CTBTO Preparatory Commission.

Keywords

Temperature, Wind Speed, Noise Power, Detection, Infrasound

1. Introduction

The wind speed near the surface is most highly correlated with the temperature and pressure [1]. The recorded noise associated with increasing winds is also a severe problem in the infrasonic band [2].

Assessing the efficiency of the IMS network detection has been of interest to many scientists. Some were preoccupied with the study of the background noise [3] [4] [5] whereas Walker *et al.* focused on the identification of the sources of noises [6]. The characteristics of noise are currently obtained from local measurements at the IMS stations or statistical analysis at a global scale [7].

Mc Donald *et al.* demonstrated in 1971 that the turbulence of wind at the ground surface is the main source of infrasound noise in the frequency band between 0.01 and 1 Hz [8]. Hedlin *et al.* have highlighted the effect of wind on the infrasound background noise during site exploration in Cape Verde [9]. In 2008, Le Pichon *et al.* showed that for the IMS network in Central Europe, the detection capability was controlled by the variation in time of the stratospheric winds which influence the infrasound propagation in the stratospheric wave guide [10]. The effects of the surface winds on the noise at the stations were integrated into these computations. Walker and Hedlin inferred that the surface wind is the most dominant source of noise in the infrasound data [6].

The I33MG infrasound station recorded data since the end of 2001. The analysis of infrasound bulletin of Madagascar from 2003 to 2011 showed a significant decrease in the number of infrasound detection during the day. Therefore, it is very important to determine the cause of these deficiencies in the detection of the station IS33.

In this paper, the effects of both local temperature and surface wind on the infrasound detections performed at this station are discussed. For that, background noise power variations are studied at scales of day and season with respect to the local temperature and surface wind variations. The objective of this work is to quantify and to show the effect of local temperature and the surface wind on the detectability of the infrasound station.

2. Data and Methods

Infrasound data from 2005 to 2021 recorded by MB2000 microbarometer at the infrasound station I33MG have been used in this study. The infrasound station is a 4-element array station with elements arranged in a centered triangle configuration. The operation of this microbarometer is based on the use of a linear variable differential transformer (LVDT) to measure the displacement of a temperature independent aneroid bellows. A high-sensitivity output for nuclear explosion monitoring in the passband from 0.01 to 27 Hz is obtained by filtering the absolute pressure output signal (0 - 40 Hz). The sensor is installed in a vault in order to avoid ambient temperature variation [11]. Temperature inside the vault varies between 0.5˚C to 1˚C which does not affect the sensor operability.

In order to study the effect of weather conditions on the infrasound detections we investigate the impacts of the surface wind and local temperature, measured in the collocated meteorological station, on the infrasound background noise.

The treatment of the background noise is done in three steps: first, infrasound records are smoothed to eliminate non-representative particular points of the noise and extract the actual background noise. Then, the background noise is separated into 4 frequency bands corresponding to the different detection frequencies in which the data processing is performed to provide the infrasound bulletins. The third step consists of calculating the powers of background noise in the 4 different frequency bands, previously defined, in order to estimate the effect of local weather conditions on the background noise level.

The frequency separation is done by using the Z filter and the output is a linear combination of the inputs as:

$$S_n = f_0 e_n + f_1 e_{n-1} + \cdots - g_1 S_{n-1} - g_2 S_{n-2} - \cdots \quad (1)$$

S_n represents the output of the filter;

e_n: represents the input;

f_n et g_n are the filter coefficients;

The frequency response of the filter is:

$$F(\omega) = 1 \Big/ \left(1 - a\mathrm{e}^{-i\omega\Delta t}\right) \quad (2)$$

This filter passes four bands of frequencies centered at 1 Hz, 0.25 Hz, 0.0625 Hz, and 0.0156 Hz respectively. These frequency bands are selected to allow the analysis of different infrasound sources currently observed in the infrasound bulletins: Band of 1 Hz is the frequency of the explosions and other high-frequency sources. Band 0.25 Hz corresponds to the frequency of microbaroms, whereas the bands of 0.0625 Hz and 0.0156 Hz correspond to the frequencies of mountain associated waves.

Equation (3) governs the computation of the power of variations in step 3:

$$P_{s-m_s} = \lim_{T\to\infty} \frac{1}{T} \int_{-T/2}^{+T/2} \left[s(t) - \overline{s(t)} \right]^2 \mathrm{d}t = P_s - \overline{s(t)}^2 \equiv \sigma_s^2 \quad (3)$$

The effect of temperature or wind speed on background noise is illustrated by noise power with respect to temperature or wind speed. An exponential fit is used to determine the law of noise with respect to weather conditions.

3. Temperature Effect on Background Noise

The variations of the background noise power are plotted in color with respect to the temperature in the four considered frequency bands and compared with the median of background noise power (in red).

Specific analyses were performed to study the daily (**Figure 1**) and seasonal variations (**Figures 2-5**). The seasonal variations are represented in quarterly well represent the seasonal temperature conditions.

Figures 1-5 show that the effect of the temperature contributes to the noise trend in the lower frequency range (0.0156 Hz) as the observed variations in this frequency range correspond to the trend in the noise variations. The deviations between the noise and the trends are larger at the other higher frequency ranges, suggesting the absence of effect in these frequency ranges. The differences which

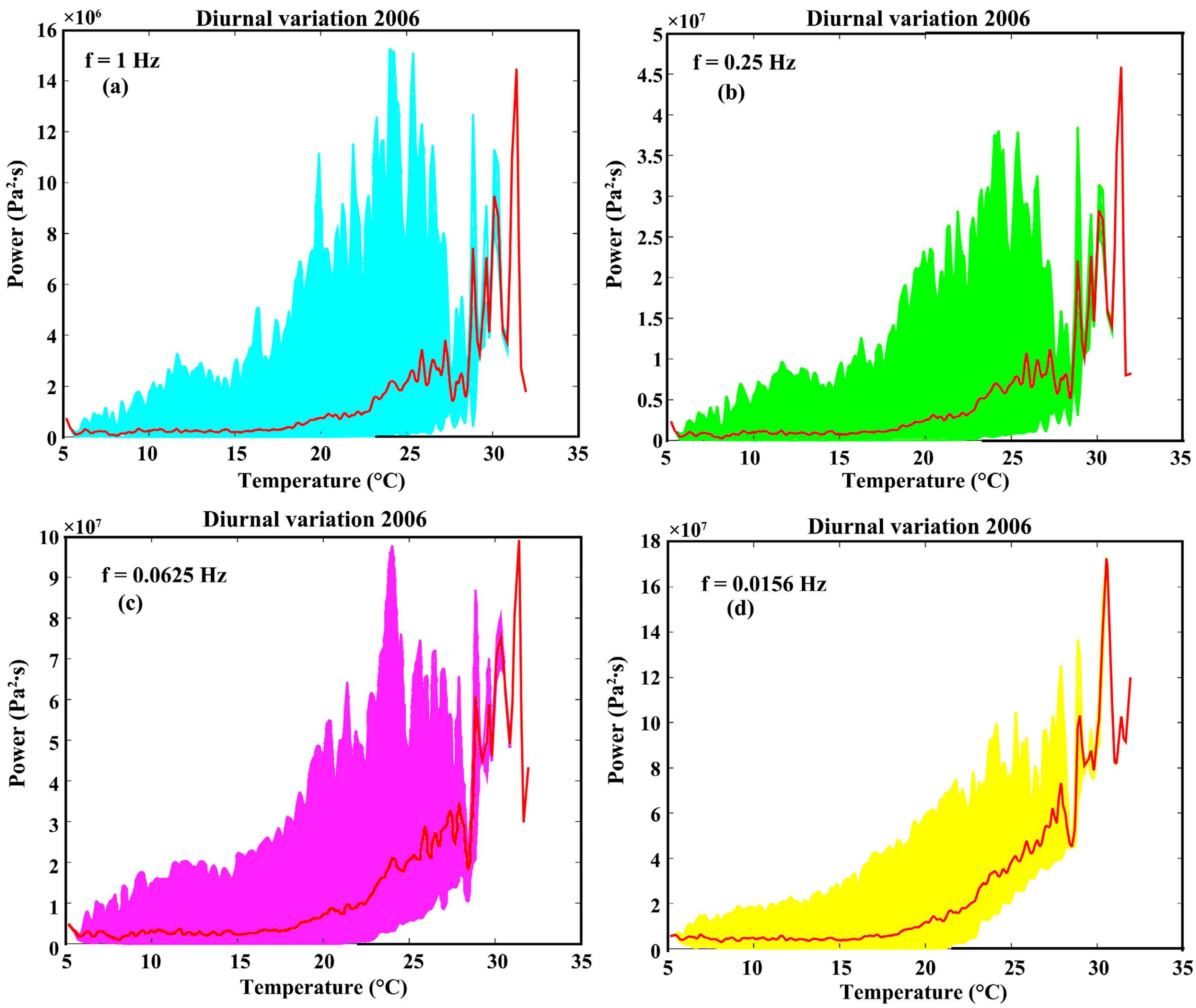
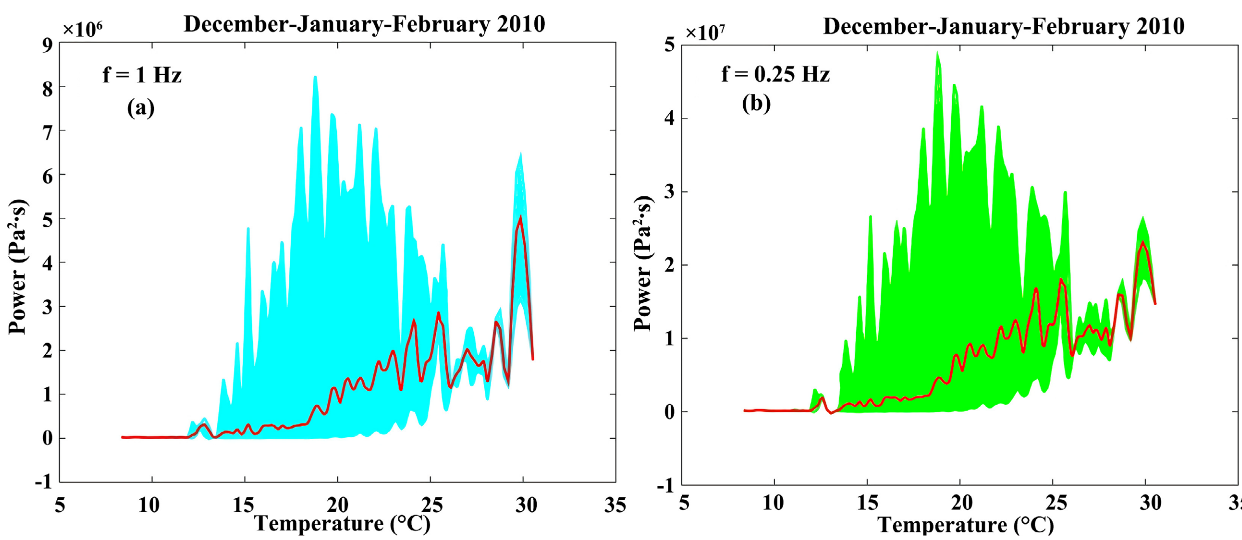


Figure 1. Power variations of background noise temperature by band of frequencies 1 Hz, 0.25 Hz and 0.0625 Hz 0.0156 Hz (color coded). Red line represents the trends of the power spectrum of the background noise. (a) Frequency range 1 Hz; (b) Frequency range 0.25 Hz; (c) Frequency range 0.0625 Hz; (d) Frequency range 0.0156 Hz.



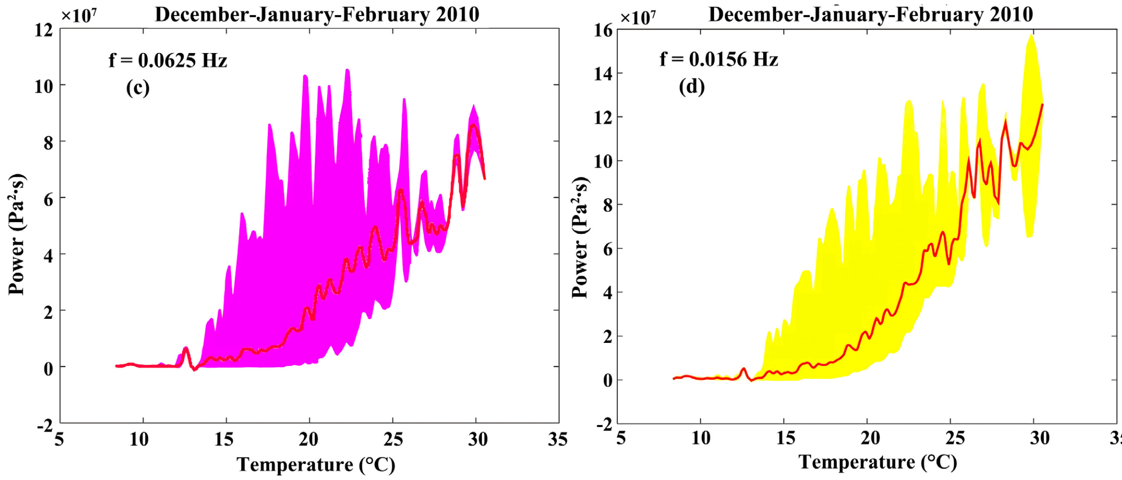


Figure 2. The power variations of the background noise based on the temperature in the bands of frequencies 1 Hz, 0.25 Hz and 0.0625 Hz 0.0156 Hz. An example of the quarterly averages (December, January and February) of the background noise power and temperature is presented. (a) Frequency range 1 Hz; (b) Frequency range 0.25 Hz; (c) Frequency range 0.0625 Hz; (d) Frequency range 0.0156 Hz.

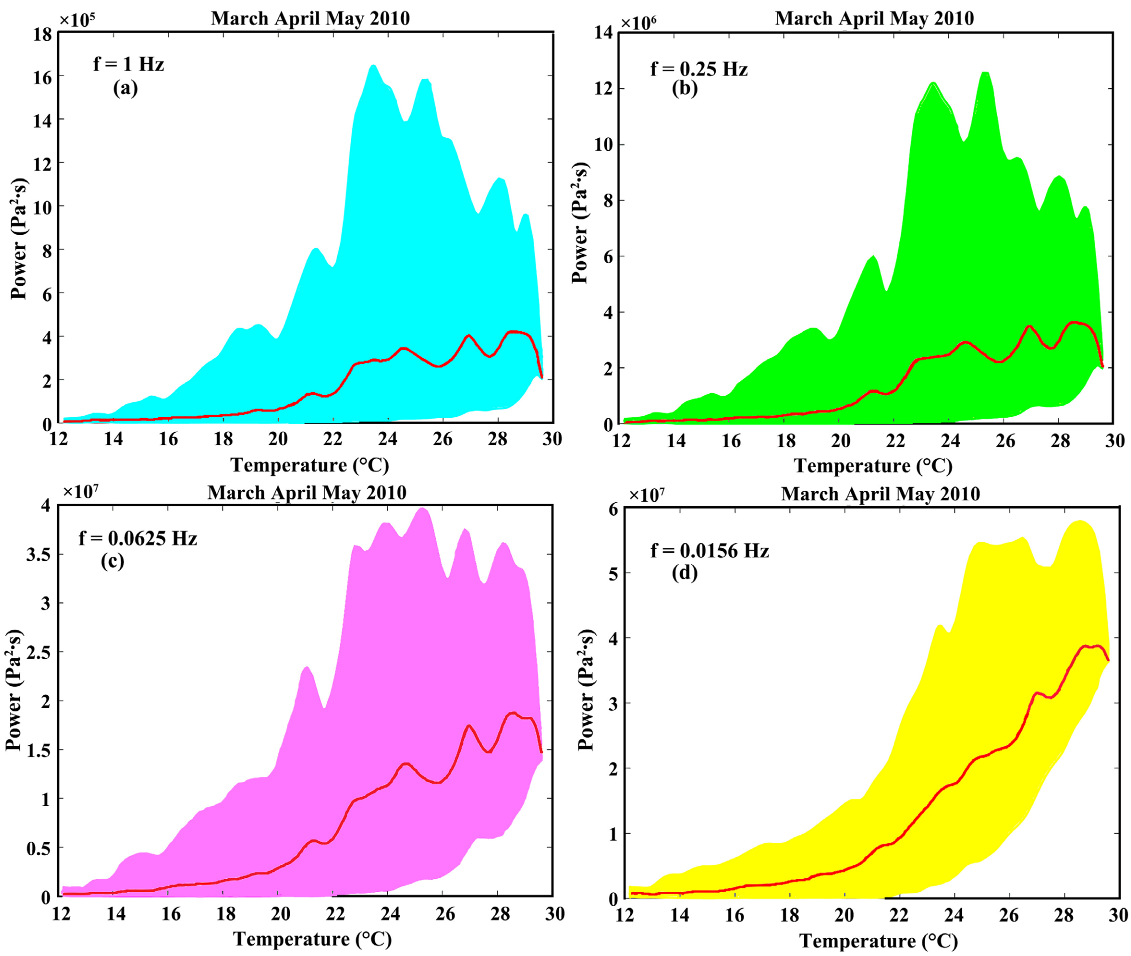


Figure 3. The power variation of background noise based on the temperature in the bands of frequencies 1 Hz, 0.25 Hz and 0.0625 Hz 0.0156 Hz. (March, April and may) quarterly averages for the background noise power and temperature are calculated for the year 2010. (a) Frequency range 1 Hz; (b) Frequency range 0.25 Hz; (c) Frequency range 0.0625 Hz; (d) Frequency range 0.0156 Hz.

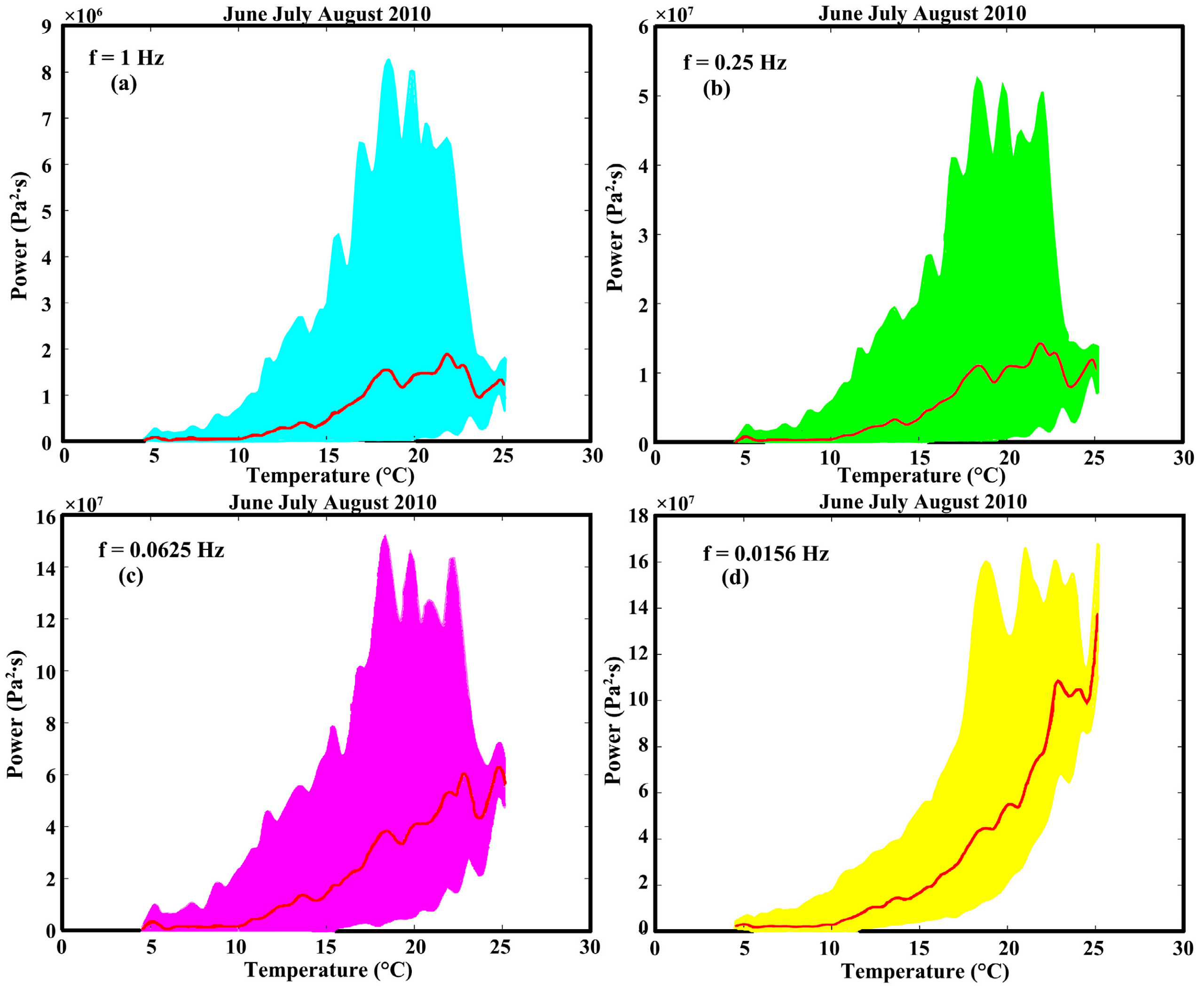
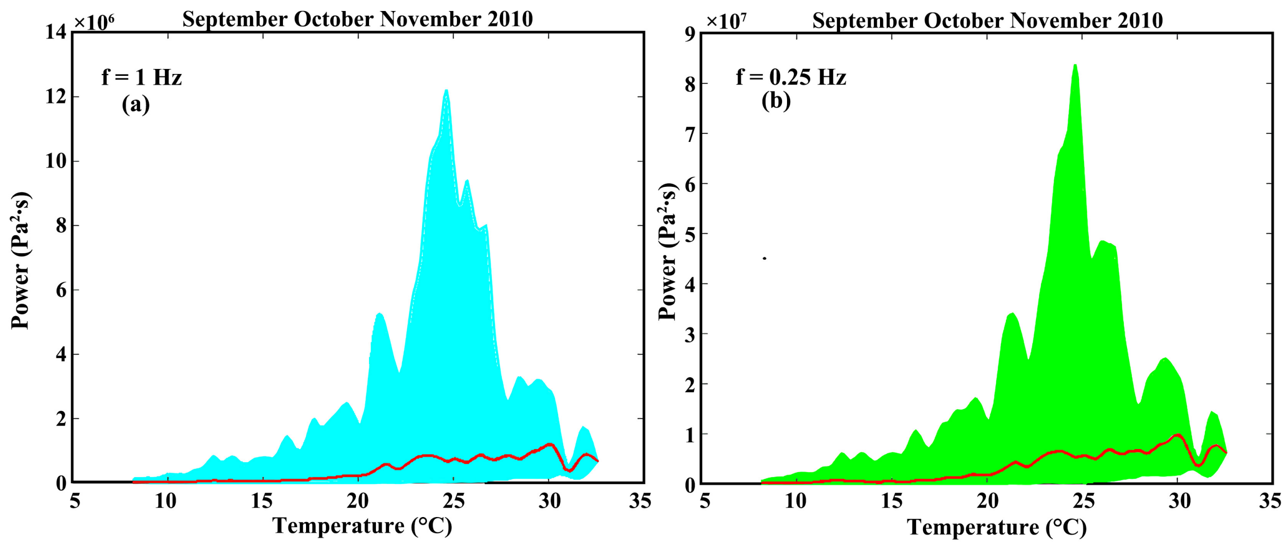


Figure 4. The power variation of background noise based on the temperature in the bands of frequencies 1 Hz, 0.25 Hz and 0.0625 Hz 0.0156 Hz. (June, July and August) quarterly averages for the background noise power and temperature are calculated for the year 2010. (a) Frequency range 1 Hz; (b) Frequency range 0.25 Hz; (c) Frequency range 0.0625 Hz; (d) Frequency range 0.0156 Hz.



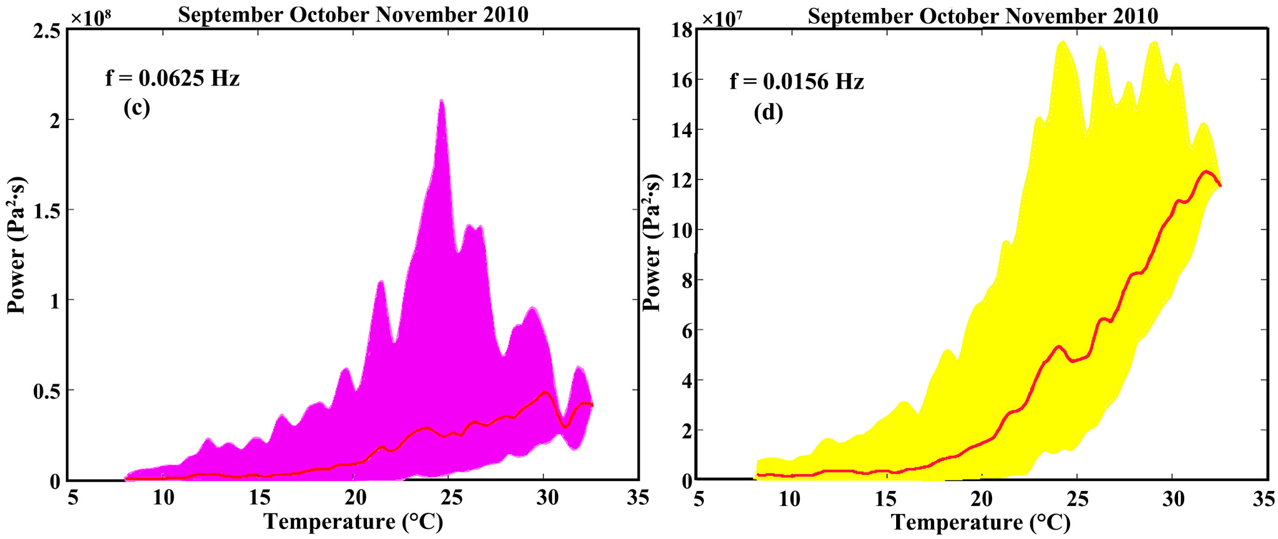


Figure 5. The power variation of background noise based on the temperature in the bands of frequencies 1 Hz, 0.25 Hz and 0.0625 Hz 0.0156 Hz. Quarterly averages (September, October, and November) for the background noise power and temperature are calculated from 2005 to 2011. (a) Frequency range 1 Hz; (b) Frequency range 0.25 Hz; (c) Frequency range 0.0625 Hz; (d) Frequency range 0.0156 Hz.

could be expected at scales of day or season are not visible. This could suggest a local effect in the local turbulence structures.

4. Effect of Wind Speed on Background Noise

A similar study was performed to study the effect of the surface wind on the infrasound background noise.

The background noise power is plotted with respect to the surface wind speed. Plots are shown in daily variation (Figure 6) and in seasonal variation (Figures 7-10). Seasonal variations are set in quarterly periods which correspond roughly to the change of season. Figures 6-10 show that the effect of the wind speed contributes to the noise trend in the higher frequency ranges (1 Hz and 0.25 Hz) as the observed variations in these frequency ranges correspond to the trend in the noise variations. The deviations between the noise and the trends are larger at the other lower frequency ranges, suggesting the absence of effect in these frequency ranges. The differences which could be expected at scales of day or season are not visible. This could suggest a local effect in the local turbulence structures.

5. Discussion

The values of background noise power with respect to temperature during a period (day or season) are shown in Figures 1-5. The median of background noise power values gives the general trend of variation of the background noise power. The temperature varies from 5˚C to 30˚C. In the low-frequency bands (0.0156 Hz and 0.0625 Hz), there is a correlation between the background noise power and the general tendency. In the high-frequency bands (0.25 Hz and 1 Hz), the power distribution does not show a distinct trend. Following these results, the

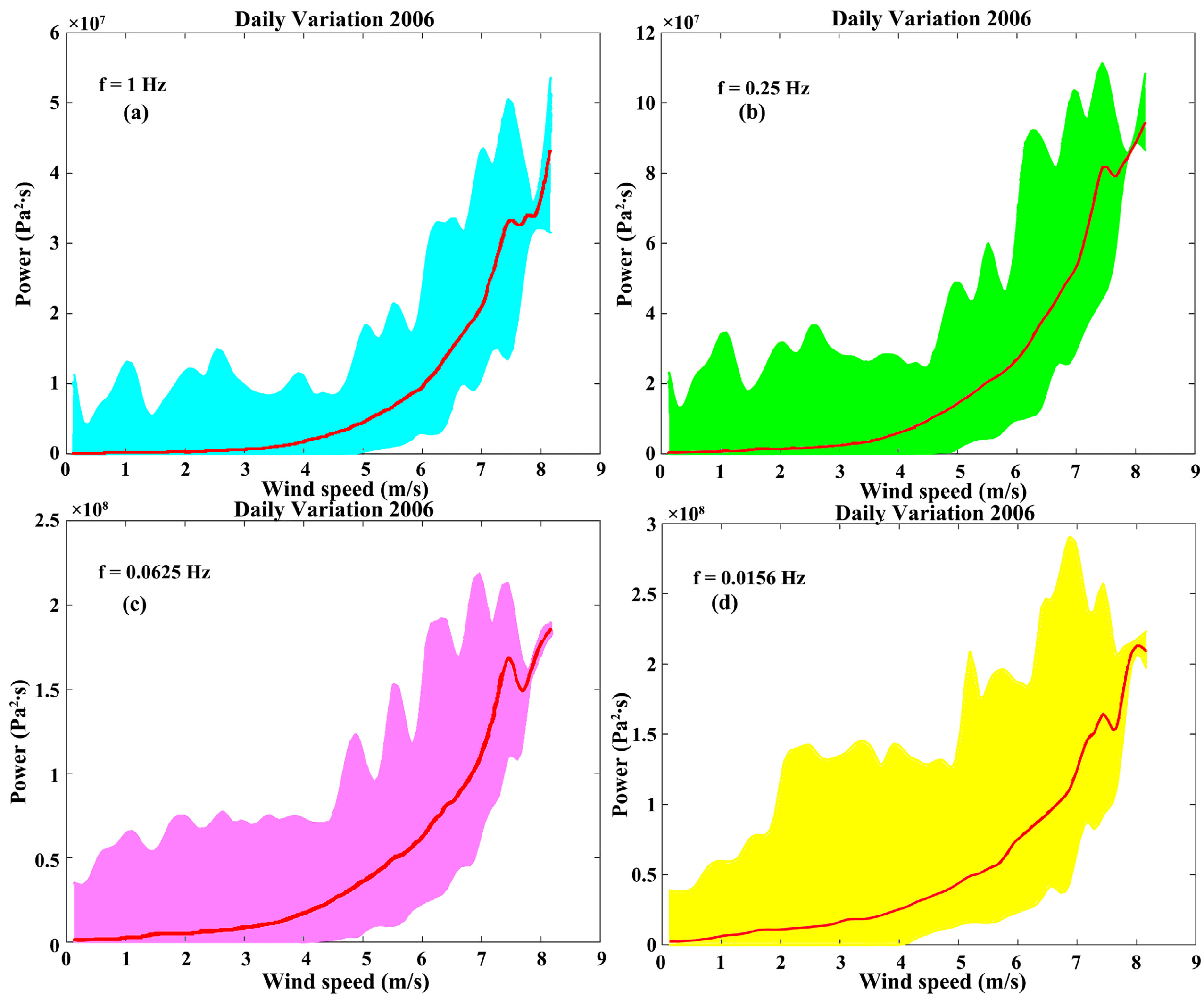
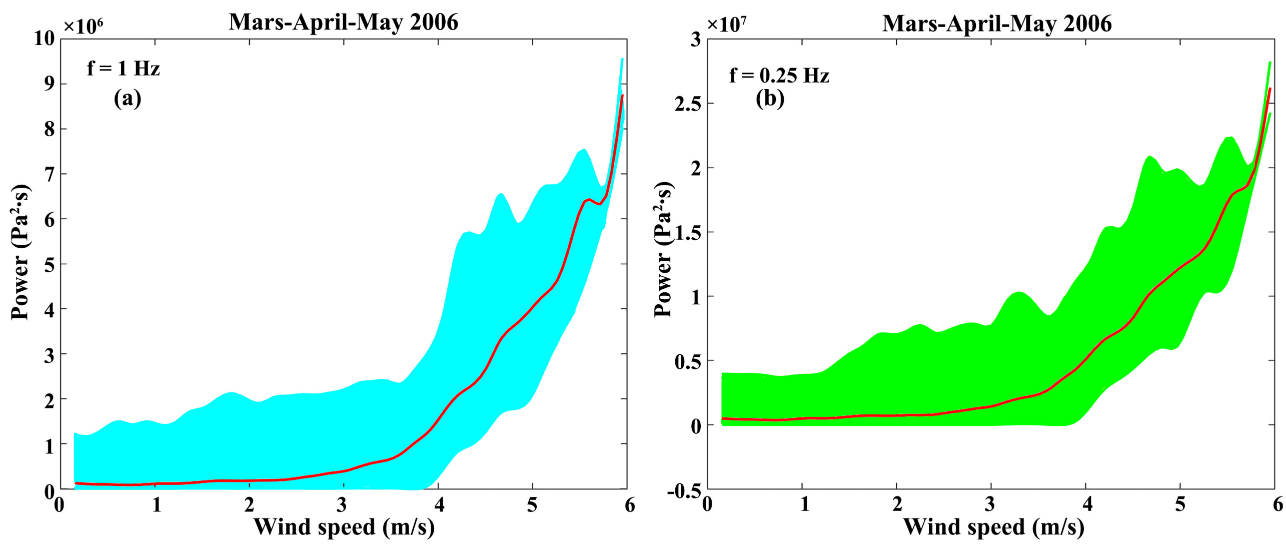


Figure 6. Diurnal variation the power of noise depending on the wind speed for the bands of frequencies 1 Hz, 0.25 Hz and 0.0625 Hz, 0.0156 Hz. Average changes in the power of the noise are plotted in red line. (a) Frequency range 1 Hz; (b) Frequency range 0.25 Hz; (c) Frequency range 0.0625 Hz; (d) Frequency range 0.0156 Hz.



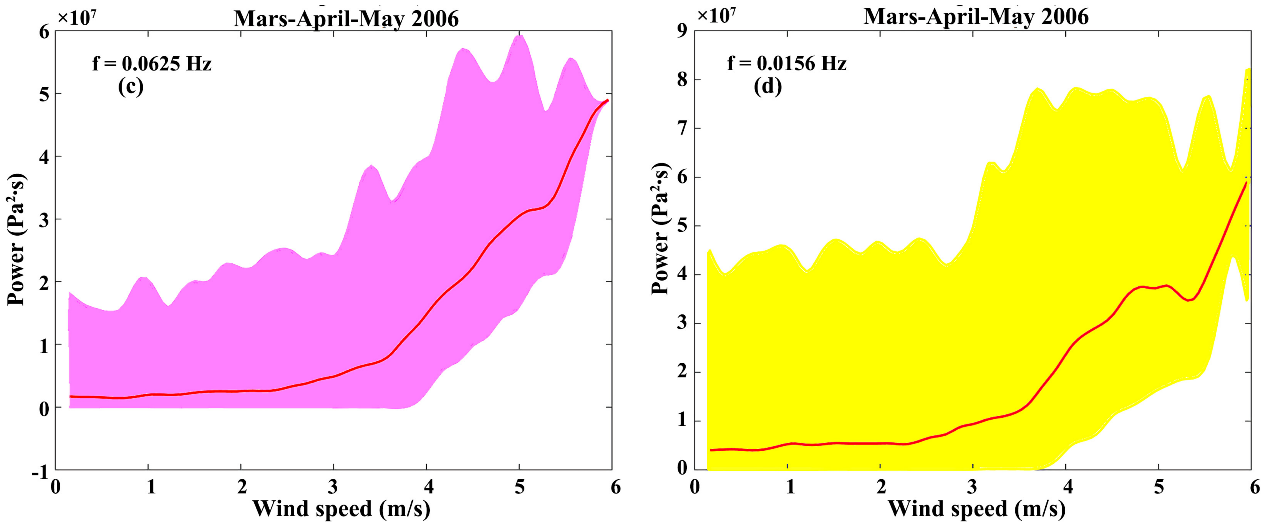


Figure 7. Quarterly change (March-April-May) powers of background noise based on the speed of the wind on the ground. (a) Frequency range 1 Hz; (b) Frequency range 0.25 Hz; (c) Frequency range 0.0625 Hz; (d) Frequency range 0.0156 Hz.

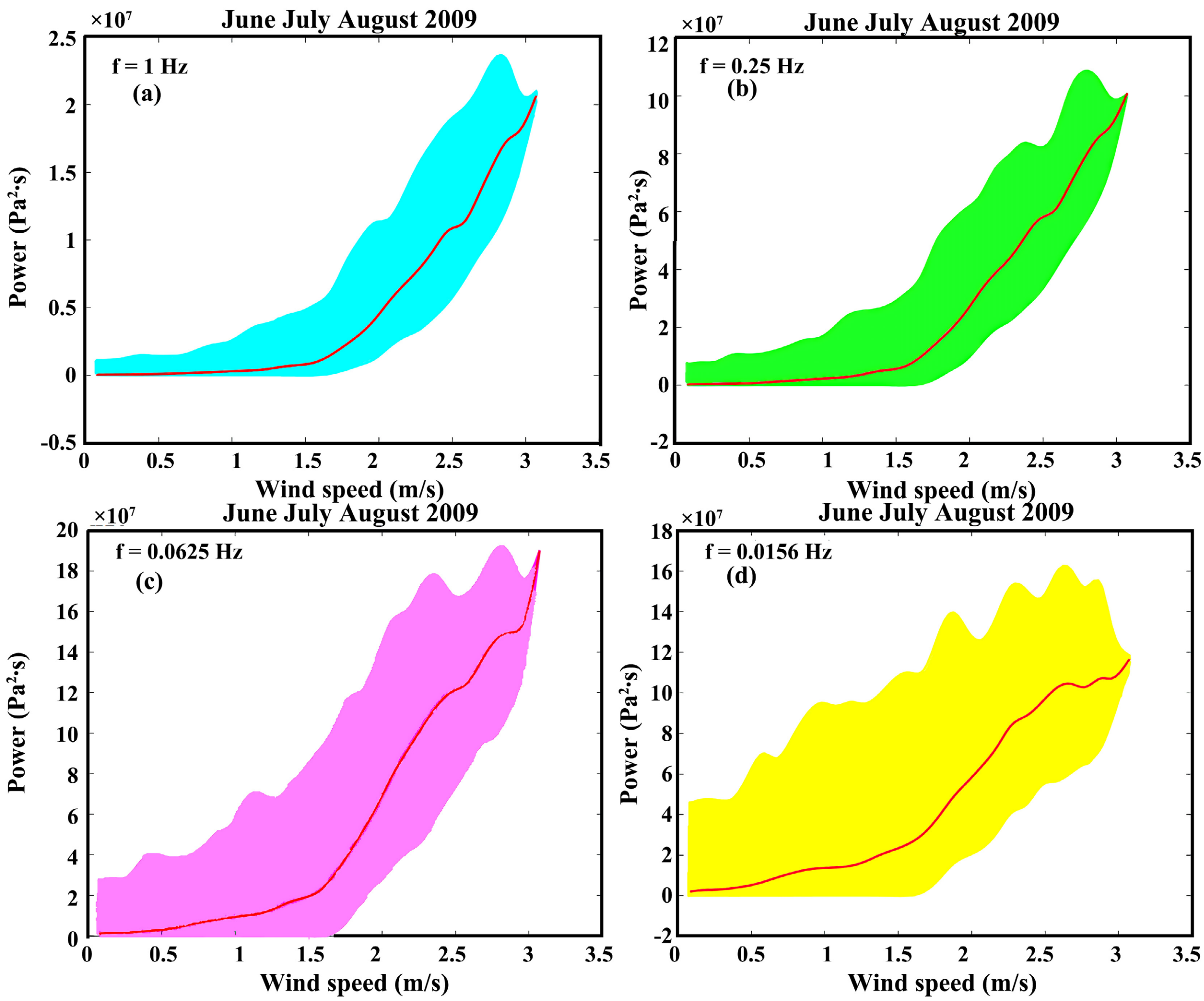


Figure 8. Quarterly change (June-July-August) powers of background noise based on the speed of the wind on the ground. (a) Frequency range 1 Hz; (b) Frequency range 0.25 Hz; (c) Frequency range 0.0625 Hz; (d) Frequency range 0.0156 Hz.

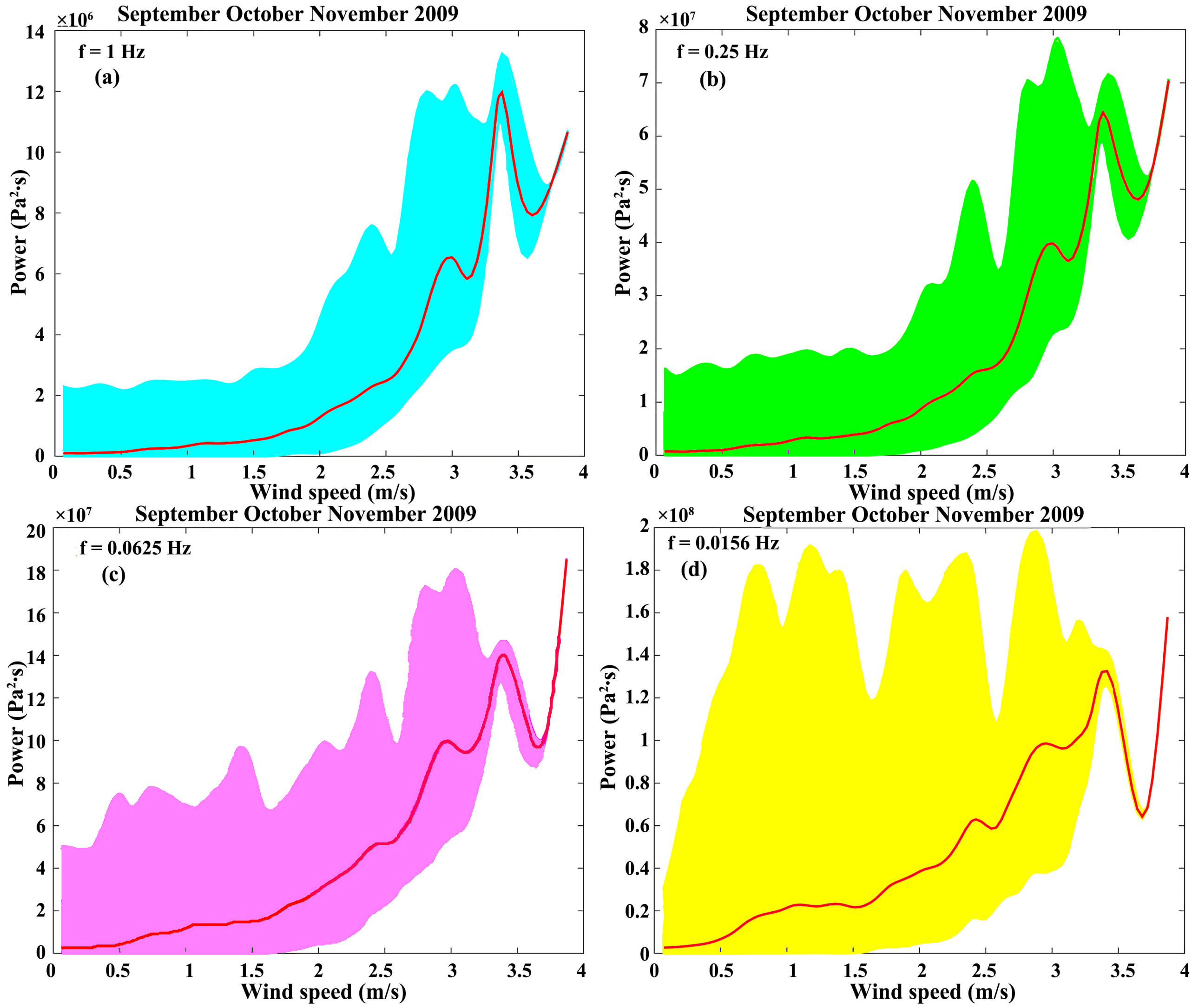
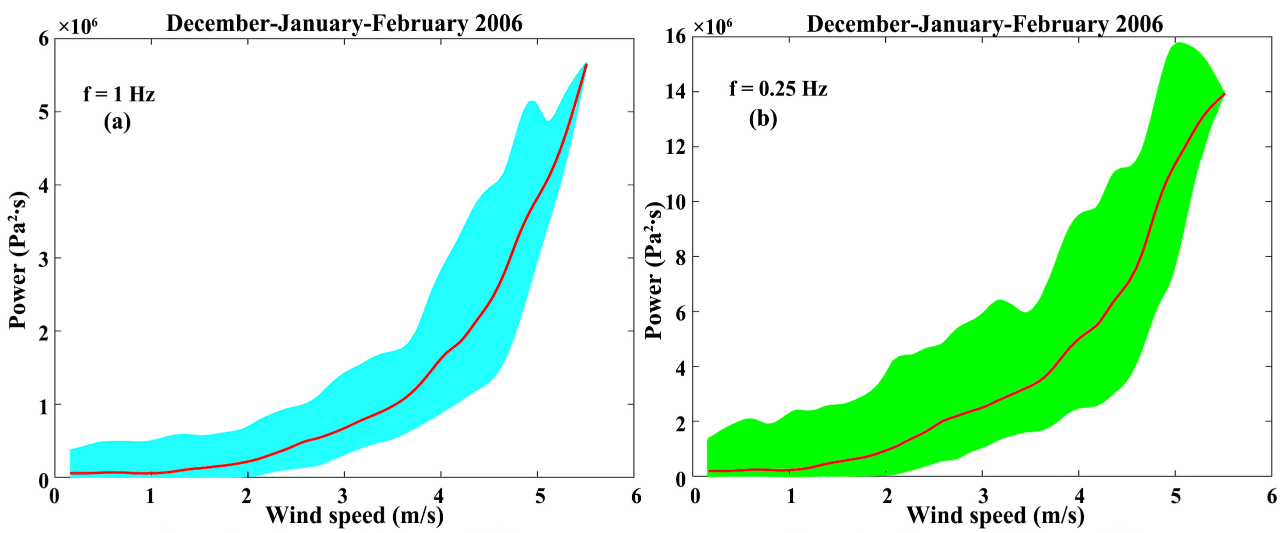


Figure 9. Quarterly change (September-October-November) powers of background noise based on the speed of the wind on the ground. (a) Frequency range 1 Hz; (b) Frequency range 0.25 Hz; (c) Frequency range 0.0625 Hz; (d) Frequency range 0.0156 Hz.



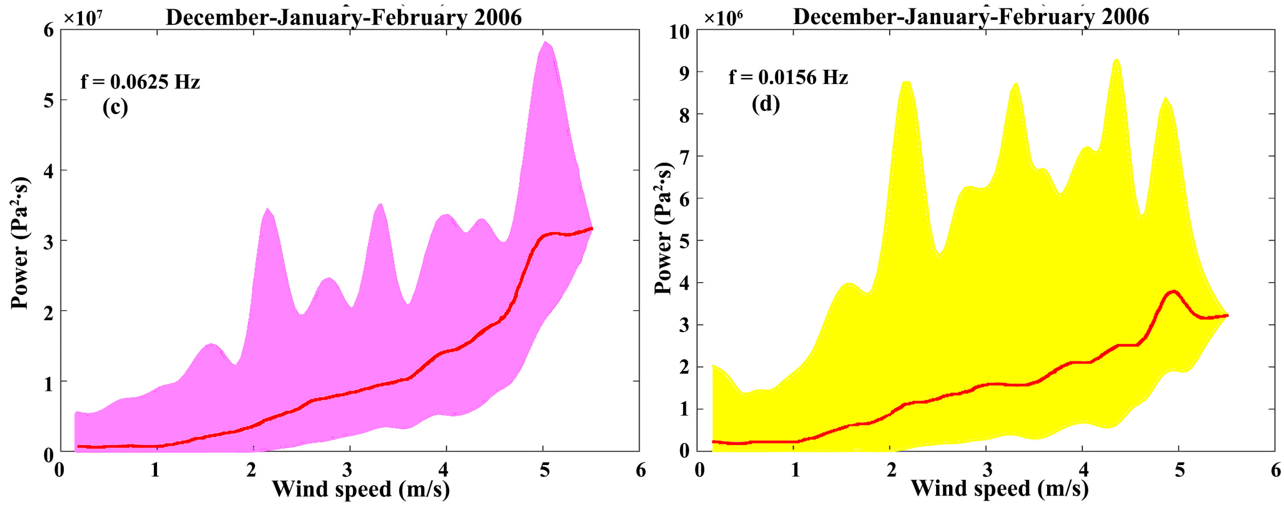


Figure 10. Quarterly change (December-January-February) powers of background noise based on the speed of the wind on the ground. (a) Frequency range 1 Hz; (b) Frequency range 0.25 Hz; (c) Frequency range 0.0625 Hz; (d) Frequency range 0.0156 Hz.

variations of the background noise power is represented by an empirical law. The median of each frequency band has been used to determine the mathematical function governing the variation.

The increase in the power of the noise temperature is considered to be an exponential function:

$$P(T) = a \cdot e^{bT} \tag{4}$$

where P is the background noise power in $Pa^2 \cdot s$;

T is the temperature in ˚C;

a, b are coefficients representative of the exponential function;

The coefficient of determination R^2 indicates the quality of fit.

This statistic measures the total deviation of the response values from the fit to the response values. It is also called the summed square of residuals and is usually labeled as *SSE*.

$$SSE = \sum_{i=1}^{n} w_i \left(y_i - \hat{y}_i\right)^2 \tag{5}$$

This statistic measures how successful the fit is in explaining the variation of the data. Put another way, R^2 is the square of the correlation between the response values and the predicted response values. It is also called the square of the multiple correlation coefficient and the coefficient of multiple determination.

R^2 is defined as the ratio of the sum of squares of the regression (*SSR*) and the total sum of squares (*SST*). *SSR* is defined as

$$SSR = \sum_{i=1}^{n} w_i \left(\hat{y}_i - \bar{y}\right)^2 \tag{6}$$

SST is also called the sum of squares about the mean, and is defined as

$$SST = \sum_{i=1}^{n} w_i \left(y_i - \bar{y}\right)^2 \tag{7}$$

where $SST = SSR + SSE$.

Given these definitions, R^2 is expressed as:

$$R^2 = \frac{SSR}{SST} = 1 - \frac{SSE}{SST} \tag{8}$$

R^2 can take on any value between 0 and 1, with a value closer to 1 indicating that a greater proportion of variance is accounted for by the model (Table 1 & Table 2).

The quality of fit R^2 in the low-frequency bands is very strong. According to these values, the adjustment model (exponential function) determines the power distribution of the background noise versus temperature. Yet, the very strong determination means that the temperature has a significant effect on the frequency band. The temperature has a more significant effect in low-frequency bands than in high-frequency. The effect of the temperature is observed from low frequency ranges 0.0156 Hz up to 0.25 Hz (Figures 11(a)-(c)).

Table 1. Coefficients of the exponential function for each frequency band.

Frequency	*a*	*b*	R^2
0.0156 Hz	5.53×10^4	0.267	0.965
0.0625 Hz	2.00×10^5	0.193	0.904
0.25 Hz	2.00×10^5	0.140	0.813
1 Hz	6.97×10^4	0.121	0.626

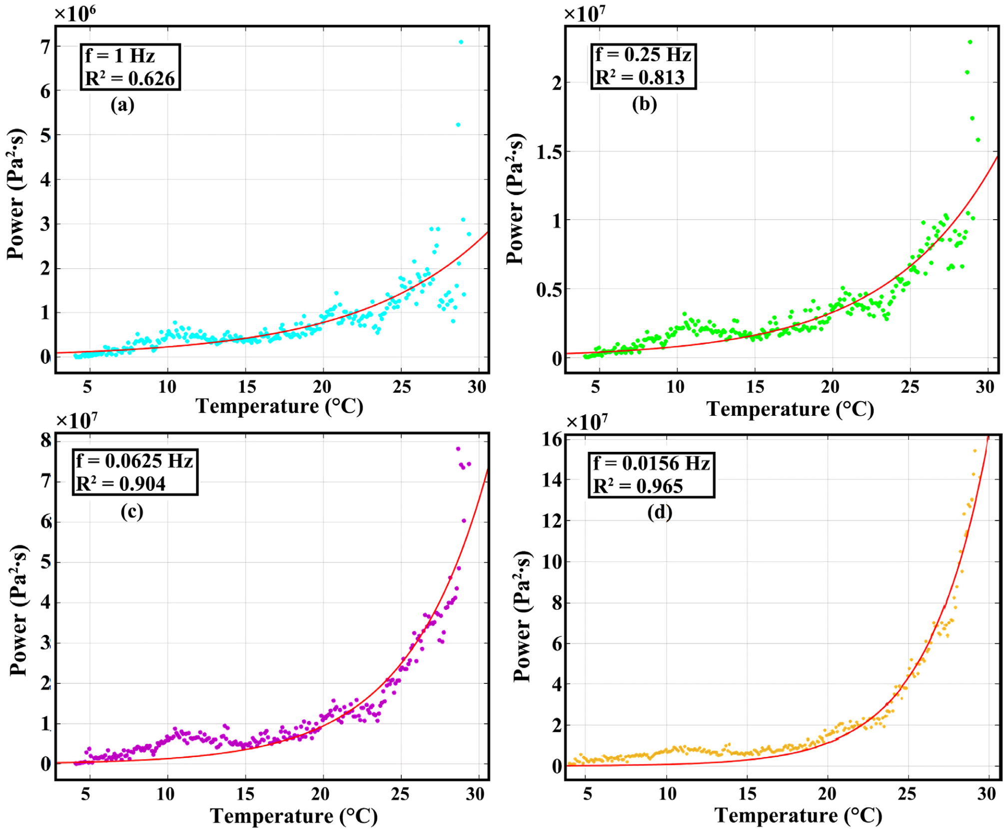


Figure 11. Adjustment of background noise power versus temperature. Exponential law fit is better at low frequencies than at high frequency. (a) Frequency range 1 Hz; (b) Frequency range 0.25 Hz; (c) Frequency range 0.0625 Hz; (d) Frequency range 0.0156 Hz.

The variation of the background noise power versus the wind speed is illustrated in Figures 6-10. The wind effect on the background noise power depends on the frequency bands. For 0.25 Hz and 1 Hz frequency bands, a variation of the background noise power versus wind speed follows an exponential trend. This is different for the other frequency bands. Similarly to the temperature, an exponential law was determined.

The variation of the background noise power based on the speed of the wind is also an exponential function:

$$P(V) = c \cdot e^{dV} \tag{9}$$

where P is the noise power expressed in $Pa^2 \cdot s$;

V is the wind speed on the ground in m/s;

c, d are coefficients whose values are provided in Table 2 below.

Adjustment in exponential for the influence of the wind on the ground on the background noise power is significant. This adjustment is mainly observed at high frequencies (1 Hz and 0.25 Hz, Figure 12(a), Figure 12(b)). We note that the effect of the wind is observed in a wide frequency band ranging from 1 Hz up to 0.0625 Hz.

At high temperature (up to 25˚C) or at high wind speed (up to 3 m/s), the background noise power is high and that can hide an infrasound signal. At 25˚C and wind speed equal to 3 m/s, background noise power is 3 times of signal power at the band of 0.0625 Hz and 8 times of the signal power at the band of 0.0156 Hz. The confrontation between the background noise power value and the level of signals infrasound registered according to different times of the day (Table 3) confirms that only strong infrasound signals could be registered.

The effect on different frequency bands is also highlighted in Table 3. In the high-frequency bands (1 Hz and/to 0.25 Hz), the signal level is always higher than that of the background noise at any time. For low bands frequency (0.0625 Hz and/to 0.0156 Hz), the level of the signal is above the background noise when the temperature is low whereas the signal is below the level of background noise when the temperature and the wind speed are high. The significant effect of the temperature and/or the speed of the wind in low-frequency bands is confirmed. The results given in Table 3 represent the power of the noise depending on the temperature or the wind speed (Figures 1-4 and Figures 5-8). The cover-up of the signals of infrasound to high temperatures or strong winds (Table 3) corresponds to the sudden increase in power from a threshold value (Figures 1-4

Table 2. Coefficients of the exponential function for each frequency band.

Frequency	c	d	R^2
0.0156 Hz	6.19×10^6	1.20	0.577
0.0625 Hz	3.70×10^6	1.28	0.819
0.25 Hz	7.97×10^5	1.43	0.870
1 Hz	1.02×10^5	1.49	0.872

Table 3. Comparison between signal and background noise powers 28/01/2005.

Signal		Background noise				Temperature (˚C)	Wind speed (m/s)
Time	Power (10^5 Pa^2·s)	Power (10^5 Pa^2·s)					
		0.0156 Hz	0 - 0625 Hz	0.25 Hz	1 Hz		
01:57:24	1	3	0.9	0.7	0.1	15	0.83
04:23:00	17	23	7	2	0.6	19	1.15
07:22:00	22	187	71	16	6	25	3.49
10:05:12	28	386	197	47	21	27	4.25
13:49:27	64	121	84	23	10	26	3.00
16:36:57	64	87	26	5	1	21	1.98
19:29:09	18	44	9	5	0.1	19	1.41
22:30:24	14	2	0.6	0.5	0.1	16	0.76

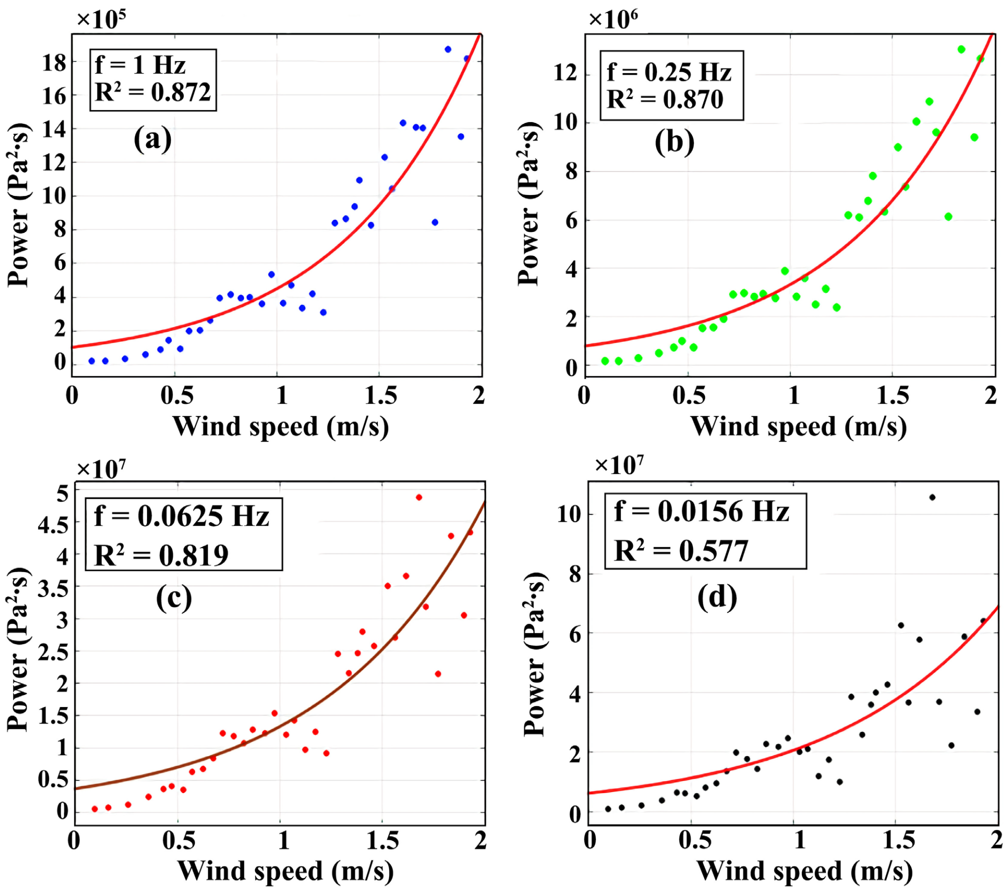


Figure 12. Adjustment of the background noise power variation with respect to the surface wind speed. Exponential adjustment fits more at high frequency band than at low frequency band. (a) Frequency range 1 Hz, (b) Frequency range 0.25 Hz, (c) Frequency range 0.0625 Hz, (d) Frequency range 0.0156 Hz.

and Figures 5-8) after a constant variation. For the temperature, the threshold value is estimated at 15˚C, whereas for the wind speed, the value can range from

0.5 m/s up to 3 m/s.

In summary, the influence of the temperature on the detection of the I33MG station for the daily variation is seen especially at low frequency (0.0156 Hz and 0.0625 Hz). For the wind, the effect is important at high frequency (1 Hz to 0.25 Hz). These influences are the cover-up of infrasound signals by the background noise that increases when the temperature or the wind speed increases.

6. Conclusion

The temperature rise contributes to an increase in the power of the low-frequency background noise (0.015 Hz). This influence is mostly observed when the temperature rises beyond the threshold temperature (generally estimated around 15˚C) and background noise can hide infrasound signal at 25˚C. This increase could hide some infrasound signals. The influence of temperature is manifested by a reduction in the number of low-frequency detection. This effect is not depending on seasonal variations. On the other hand, the surface wind controls as well the background noise power. The surface wind increases the power threshold when it reaches 0.5 m/s and background noise can hide infrasound signal at 3 m/s. The surface wind reduces the number of detection at a high frequency. However, the effect of the wind concerns the frequency band of 0.0625 Hz to 1 Hz and can be neglected at 0.015 Hz. An exponential function is proposed to predict the variations of the noise power in different observation frequencies and temperature and wind conditions.

Acknowledgements

The authors would like to express their appreciation for the collaboration between IOGA and CEA/DASE and also the discussion with our colleagues Dr. Barimalala Rondro and Dr. Raveloson Andriamiranto.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Wooten, R.D. (2011) Statistical Analysis of the Relationship between Wind Speed, Pressure and Temperature. *Journal of Applied Sciences*, **11**, 2712-2722. https://doi.org/10.3923/jas.2011.2712.2722

[2] DeWolf, S., Walker, K.T., Zumberge, M.A. and Denis, S. (2013) Efficacy of Spatial Averaging of Infrasonic Pressure in Varying Wind Speeds. *The Journal of the Acoustical Society of America*, **133**, 3739-3750. https://doi.org/10.1121/1.4803891

[3] Bowman, R. (2005) Meteorological Conditions at Infrasound Stations. *InfraMatics*, **9**, 17 p.

[4] Bowman, J.R., Shields, G. and O'Brien, M.S. (2007) Infrasound Station Ambient Noise Estimates and Models: 2003-2006. *Proceedings Infrasound Technology Workshop*, Tokyo, Japan, 13-16 November 2007.

[5] Raspet, R., Webster, J. and Dillion, K. (2006) Framework for Wind Noise Studies. *The Journal of the Acoustical Society of America*, **119**, 834-843. https://doi.org/10.1121/1.2146113

[6] Walker, K.T. and Hedlin, M.A. (2010) A Review of Wind-Noise Reduction Methodologies. In: Le Pichon, A., Blanc, E. and Hauchecorne, A., eds., *Infrasound Monitoring for Atmospheric Studies*, Springer, Dordrecht, 141-182. https://doi.org/10.1007/978-1-4020-9508-5_5

[7] Le Pichon, A., J. Vergoz, E. Blanc, J. Guilbert, L. Ceranna, L. Evers, and N. Brachet (2009) Assessing the Performance of the International Monitoring System's Infrasound Network: Geographical Coverage and Temporal Variabilities. *Journal of Geophysical Research*, **114**, Article ID: D08112. https://doi.org/10.1029/2008JD010907

[8] McDonald, J.A., Douze, E.J. and Herrin, E (1971) The Structure of Atmospheric Turbulence and Its Application to the Design of Pipe Arrays. *Geophysical Journal International*, **26**, 99-109. https://doi.org/10.1111/j.1365-246X.1971.tb03385.x

[9] Hedlin, M., Garcés, M., Bass, H., Hayward, C., Herrin, G., Olson, J. and Wilson, C. (2002) Listening to the Secret Sounds of Earth's Atmosphere. *Eos, Transactions American Geophysical Union*, **83**, 564-565. https://doi.org/10.1029/2002EO000383

[10] Le Pichon, A., Vergoz, J., Herry, P. and Ceranna, L. (2008) Analyzing the Detection Capability of Infrasound Arrays in Central Europe. *Journal of Geophysical Research*, 113, Article ID: D12115. https://doi.org/10.1029/2007JD009509

[11] Christie, D.R. and Campus, P. (2010) The IMS Infrasound Network: Design and Establishment of Infrasound Stations. In: Le Pichon, A., Blanc, E. and Hauchecorne, A., eds., *Infrasound Monitoring for Atmospheric Studies*, Springer, Dordrecht, 29-75. https://doi.org/10.1007/978-1-4020-9508-5_2