Pressure fluctuations associated to rainy days during BLLAST campaign

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1. INTRODUCTION

- During the summer of 2011, the Boundary Layer Late Afternoon and Sunset Turbulence (**BLLAST**) field campaign was carried out over Lannemezan (France). The purpose of this campaign was to improve the knowledge about the late afternoon transition in the planetary boundary layer (PBL). However, several **stormy and rainy days** were observed during the campaign over the zone. In this study, one of these days has been deeply analyzed and related with wave events, taking advantage of the **large amount of available instrumentation**, three high resolution **microbarometers** among them. Different sources can be associated to impulse-generated gravity waves such a flow over an obstacle or thunderstorms [1]. Several gravity waves related with thunderstorms have been reported and they have been shown to be an **important hazard for commercial aircrafts** [2]. Some of these waves have been study and related with wind and pressure fluctuations [3], [4]. On the other hand, these waves are important because they **affect the fluxes of momentum and scalars** in the interface that separate the stable layer [5].

- In this poster, **two different events** concerning periodic fluctuations in pressure have been studied during one rainy and stormy day (**21 June 2011**) at Lannemezan. Wavelet analyses and wave parameters calculations have been carried out in order to draw some conclusions about the **features** and the possible **origin of these wave-like disturbances**.

- The **first** wave-like structure had a relatively wide range of wave parameters (phase speed, wavelength and direction of propagation), making its study difficult. It seemed to be a **mesoscale** wave that came from a place far away from our measuring point. The signal was not too much monochromatic and it could not be related with a specific storm or other events using the available data for this day.

-The **second** wave was a **microscale** wave, with a clear signal in the pressure fluctuation and with the repetition of some cycles. Wave parameters showed a short range of values. **Related fluctuations in other parameters** (temperature, wind speed and wind direction) have been found **at some heights**. The **origin** of the wave have been proposed to be the descending vertical currents associated to rainfall acting over a stable layer near the surface, previously formed by the surface cooling caused by the evaporation of the drops close to the ground.

- The poster is divided in two main parts separating the two different wave events.

2. BLLAST CAMPAIGN AND DATA

- Data used for this study were taken from different instruments deployed over CRA (Centre for Atmospheric Research) in Lannemezan during the BLLAST campaign. This campaign took place from 14 June to 8 July 2011, and it was the result of an effort of several international researchers with the aim of improving the knowledge about the late afternoon transition in the PBL (see http://bllast.sedoo.fr for more information). Data employed for this study are listed below:

1. A triangular array of three high resolution Paroscientific **microbarometers** (Model 6000-16B) separated about 150m and at 1m a.g.l with the objective of detecting small scale surface pressure fluctuations. This triangular configuration was used to characterize wave events by means of lag analysis, cross-correlation or methods based on wavelets decompositions, allowing the calculation of wave parameters (wavenumber, wavelength, phase speed and direction of propagation of these waves). A sampling rate of 2Hz was used, enabling a resolution of around 0.002 hPa.

2. Temperature, wind and rainfall data from **instrumentation** placed at different heights in a nearly **60m tower**.

3. **RADAR** and **IR satellite images**, helping to relate the found waves with storms near the zone.

4. Vertical velocity measurements from **UHF wind profiler**, used to give an idea of the vertical motions in the lower troposphere.

3. OVERVIEW

-Two different wave-like events are observed looking at the records of absolute and filtered pressure showed in Figure 1. The filtered pressure is calculated using a first-order Butterworth filter with a cut-off frequency of 1/2700 s^{-1} (all periods higher than 45 minutes are removed from the time series, i.e. diurnal oscillation and synoptic tendency in pressure).

- **EVENT 1** – Periodic oscillations in pressure from 13:00 UTC to 15:00 UTC.

- **EVENT 2** – Periodic oscillations in pressure from 21:15 UTC to 22:00 UTC.

- These two events are going to be deeply analyzed in sections 4 and 5.

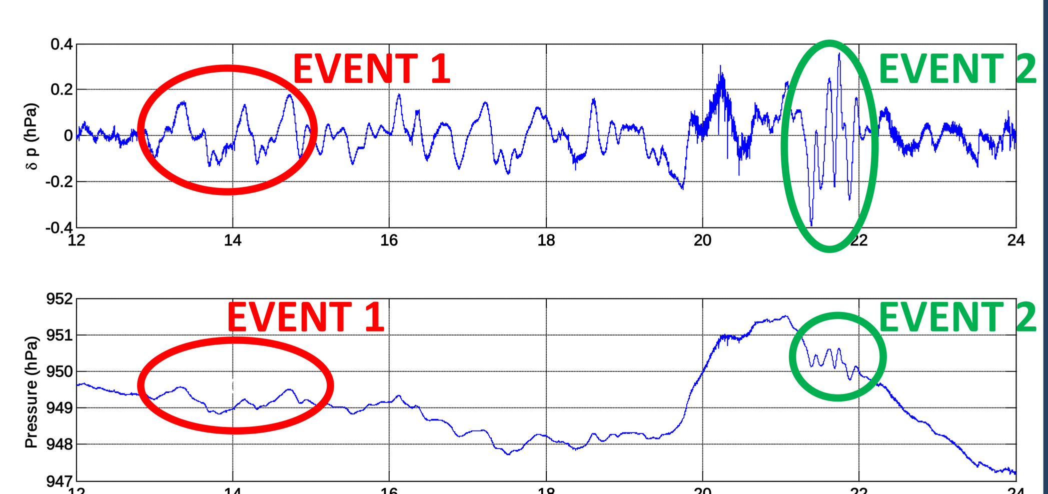

Figure 1. Filtered (a) and absolute (b) pressure from 12.00 UTC to 24:00 UTC during 21 June at Lannemezan

4. EVENT 1

- Fig 2a shows filtered pressure for the time period when the wave-like structure was detected and Figure 2b is the wavelet transform energy density per period and time unit, showing when the maximum in energy was detected. A **clear peak** was observed between **30 and 40 minutes** during 13:30 -14:30 time interval.

- Wave parameters have been calculated [6] for this event and they are shown in Table 1. It can be seen how the origin of the waves was in the **SE-E direction** most of the time. The period of the waves ranges from 30 to 40 minutes, the wavelength between 30 and 50 km and the phase velocity was around 10-20 m/s.

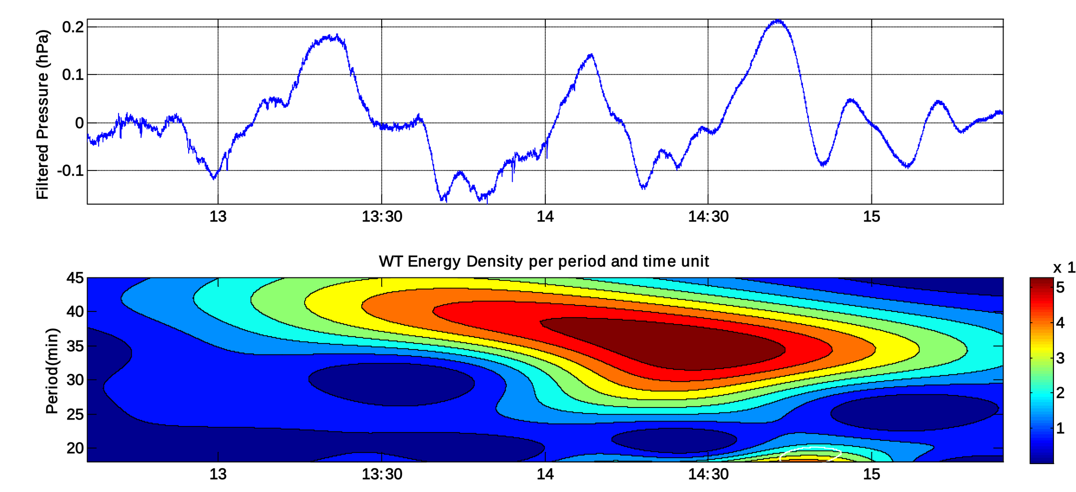

Figure 2. a) Filtered pressure for wave event 1. b)Wavelet transform energy density per period and time unit for wave event 1.

TIME (UTC)	13:18 – 13:42	13:48 – 14:12	14:18 – 14:42	14:48 – 15:12
PERIOD (min)	**39 - 43**	**37 - 42**	**33 - 37**	**33 - 37**
Wavelength (km)	30 - 40	35 - 45	44 - 48	32 - 40
Phase speed (m/s)	11 - 16	14 - 22	22 - 20	20 - 16
Direction of origin (º)	135	135	135 - 90	90

Table 1. Wave parameters calculated for different time and wave period intervals.

-Figure 3 shows the RADAR images during the wave event 1 in order to try to **relate the waves with storms near the zone**. Several storms were formed in the Pyrenees mountains during this day and they were moving from SW to NW direction. During this period, some **storms were located in the direction of the origin of the waves** showed in the wave parameters (Table 1) and approximately indicated with red arrows in Figure 3. Taking into account the phase speeds of the waves and the location of the storms, an hypothetical wave would take between 20 minutes (from the SE) and 40 minutes (from the SW) to reach Lannemezan. However, it is **difficult to precise the true source of these waves**, but they seem to be **related with convection and with the formation of storms** (in a "normal" day without such convection, waves like these are not usually observed). Fluctuations in temperature, wind or other parameter in the 60m tower were not appreciated, which may be an indicator that the event is produced at higher levels. **Convective updrafts** acting over the stable top of the PBL could be a wave generator source, which would be different of what happens when precipitation appears.

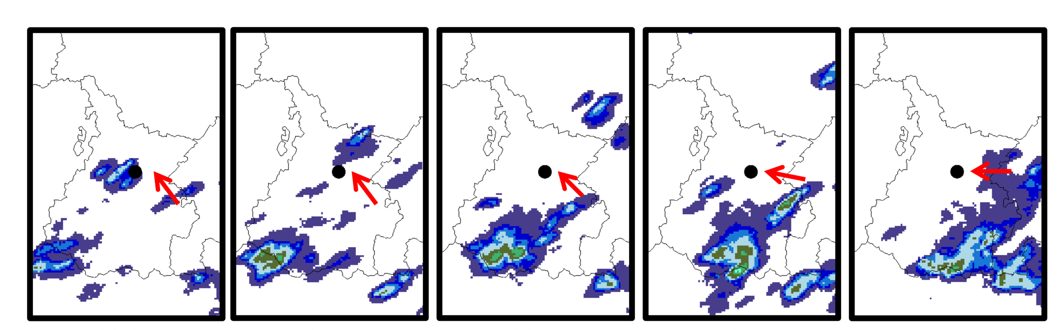

Figure 3. RADAR images for wave event 1 (time in UTC). Black point indicates Lannemezan and red arrows indicate the approximated direction of propagation of the waves.

5. EVENT 2

- Figures 4a and 4b show the filtered pressure and the wavelet analysis respectively for event 2. A **clear peak** is seen in the wavelet image from 21:15 to 21:55 UTC, with a **wave period of 8-11 minutes**, corresponding with **several cycles** observed in the pressure records. These fluctuations in pressure are of the order of **0.5 hPa** of variation in a few minutes, which are values of remarkable importance compare to those usually produced by waves in the stable boundary layer (one order of magnitude larger).

- Figure 5 indicates the rainfall record (a) and the vertical velocity from UHF wind profiler (b) for the studied period. It can be seen how there exist a **rainy period from 20:10 to 21:35** with **strong negative vertical velocities** (-6 to -10 m/s) due to the velocity of the rain droplets. The indirect **effect of this rain** in the temperature profile was to **create a stable stratification in the lower layers**, with a **decrease of temperature** near the surface due to the effect of the latent heat absorbed by the **evaporation** of the drops on the ground, as it can be seen in Figure 6a (temperature profile up to 60m height). Figure 7 shows RADAR images from 20:00 to 22:00. In this case, the **wave** was **detected behind the convective system** passing through the zone, and not ahead the storm with a cold current or gust front as it is usually observed in thunderstorms [7].

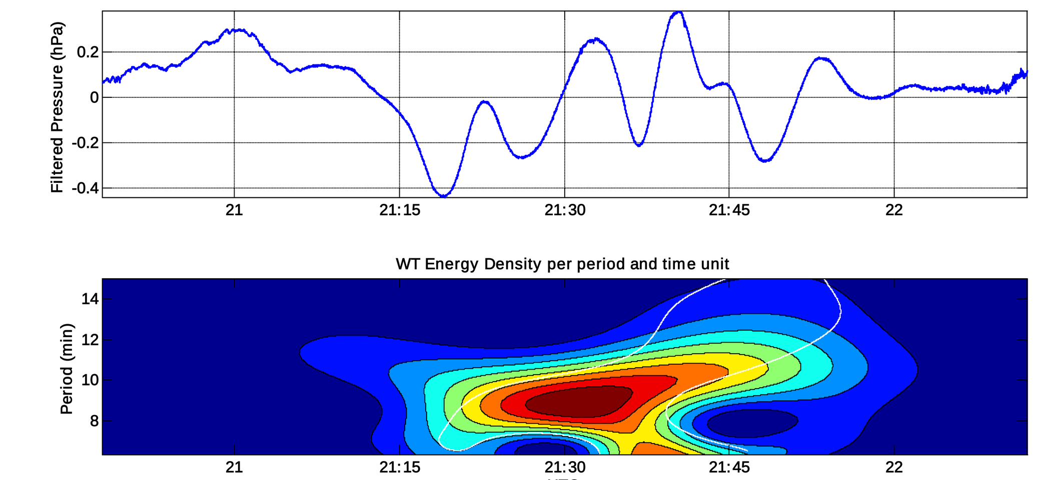

Figure 4. a) Filtered pressure for wave event 2. b) Wavelet transform energy density per period and time unit for wave event 2.

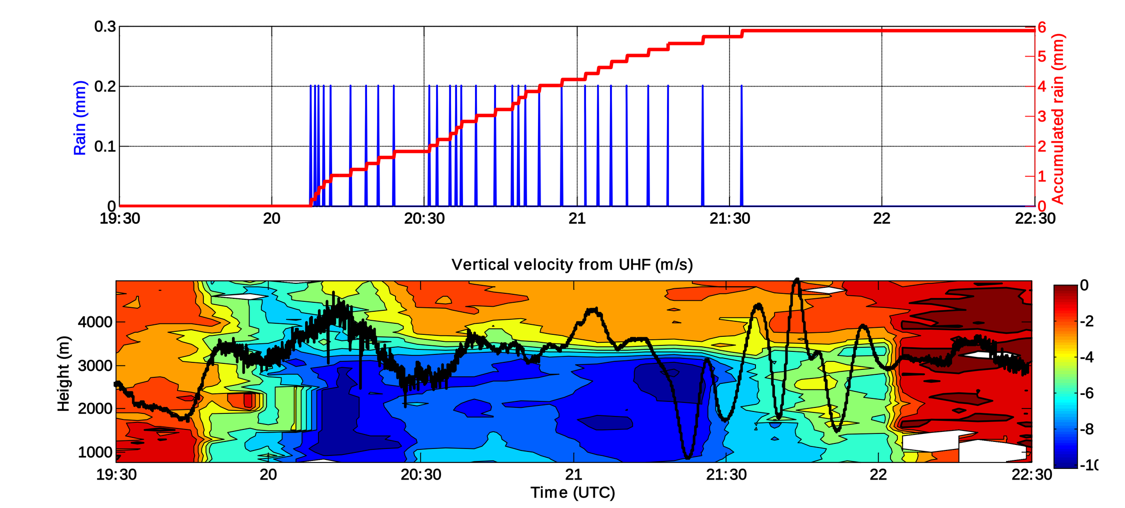

Figure 5. a) Rainfall (blue) and accumulated rainfall (red). b) Vertical velocity from UHF wind profiler (Filtered pressure is overlying this figure to show the wave event from 21:15 to 22:00 UTC)

- Brunt Väisälä frequencies (N_{BV}) have been calculated for different layers up to 60m, and their values are shown in Figure 6b. The condition for the development of gravity waves in a stable layer is that **N_{BV} must be higher than the frequency of the waves** [8]. In the studied case, the minimum frequency of the wave was **0.0021 s^{-1}** (corresponding with a period of 8 minutes). As can be seen in Figure 6b, **N_{BV} remained well above this value after 20:15 UTC except for the layer 45-60m**. This can be an indicator that **the wave was trapped in the lower layers, below 45 meters**, since in principle, no other stable layers are expected higher than 60m. This hypothesis is also supported by the **relations found between the pressure fluctuations with other parameters** measured at different heights in the 60m tower (see Figure 9). **Strong downdrafts due to precipitation could impinge over this layer and generate these gravity waves.**

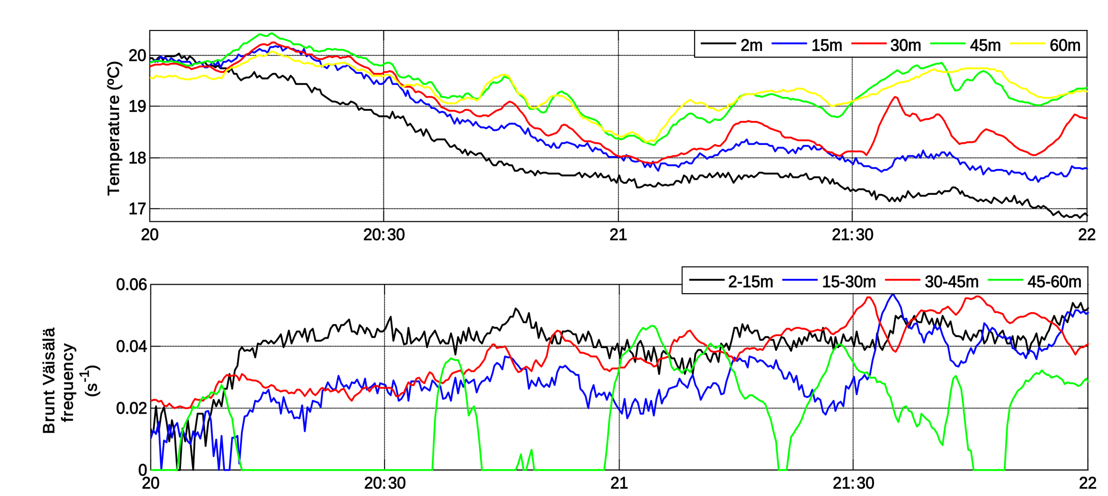

Figure 6. a) Temperature at different heights in the 60m tower from 20:00 UTC to 22:00 UTC. b) Brunt Väisälä frequency at different layers for the same period as in a.

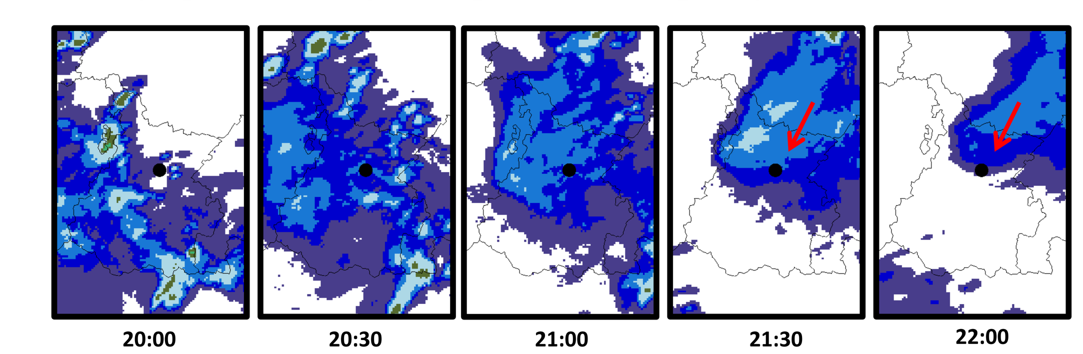

Figure 7. RADAR images for wave event 2 (time in UTC). Black point indicates Lannemezan and red arrows indicate the approximated direction of propagation of the waves.

Wave parameters have been calculated and they are shown in Figure 8. It can be seen how this case is **different to event 1**, with shorter ranges of the values: a defined **wavelength between 500 and 550m**, **phase speed** of approximately **1 m/s** and a well marked direction of propagation of 216º (i.e. **the wave came from 36º, near the NE direction**). These values and the wave period of 9 minutes indicate the wave to be a **microscale event** and are slightly lower to other gravity waves related with thunderstorms reported in different works (Miller (1999)).

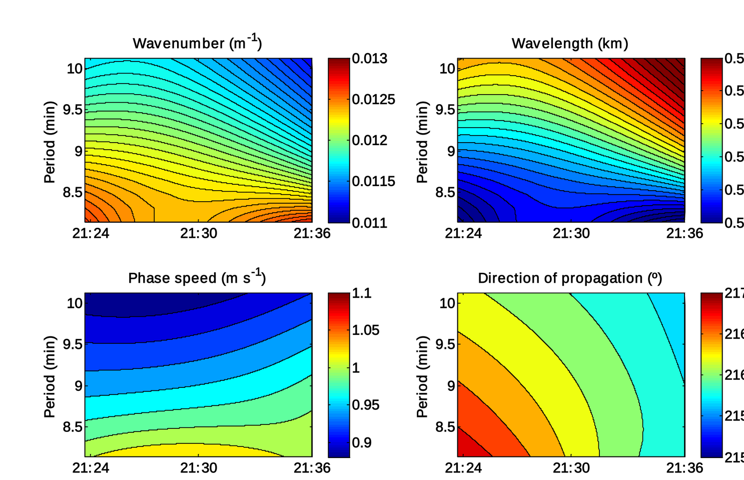

Figure 8. Wave parameters (wavenumber, wavelength, phase speed and direction of propagation) for a period within the wave event 2. (Note that direction of propagation is direction of origin + 180º).

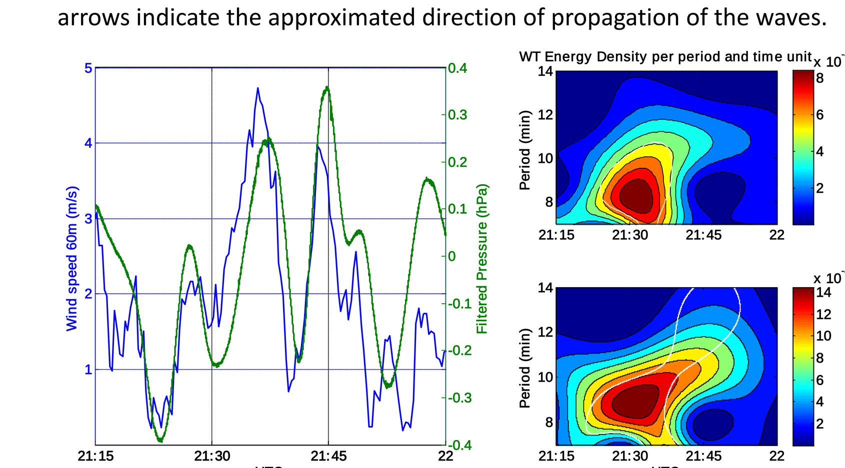

Figure 9. Left - Wind speed at 60m (blue) and filtered pressure (green). Right – Wavelet analysis for wind speed (up) and for pressure (down)

Figure 9 is an example of the **relationships that can be found between the oscillations in pressure and oscillation in other parameters** during this event. It concretely shows the pressure records together with the **wind speed at 60m** (left side). At the right side, wavelet analysis of this wind speed (up) and pressure (down) are shown in order to demonstrate the relation between these oscillations. Comparison with other parameters at different heights have also been calculated (not shown here), and the **best relations** have been found between **wind** (direction and speed) at 15, 45 and 60m (**specially at 45m**) and with oscillations in **temperature at 30 and 45m**.

7. ACKNOWLEDGMENTS

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8. REFERENCES

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6. SUMMARY AND CONCLUSIONS

- **Two different types of wave-like structures** have been found in the pressure records along 21 June over Lannemezan (a **stormy** day) during the **BLLAST** campaign. **Wave event 1** had a relatively wide interval for wave parameters values (within the mesoscale range) and it seemed to be formed by **storms located far away from the studied point**. However, it could not be related with a specific storm, at least with the available instrumentation. The **wave event 2 was different**. In this case, the signal of the wave in pressure fluctuations was very clear with some appreciable cycles. The parameters of this wave were include in the **microscale range**, and the event has been related with a **storm passing through the zone**. It seems that **strong downdrafts associated with rain** caused the gravity wave by the action of these downward movements **acting over a stable layer** in the lower part of the PBL. This stable layer was previously created by the cooling of the air near the surface due to the absorption of latent heat by evaporation of the drops in the ground. This **"double" effect of the rainfall** was a special feature of the event, first creating the necessary conditions to develop gravity waves by the stabilization of the layers near the ground and later forming these waves by the action of downward motions over the stable layer.
- Pressure fluctuations have been compared **with fluctuations in other parameters** (wind speed, wind direction and temperature) and their wavelet energy spectra have also been compared. Some **interesting relations** have been found and it will be interesting to **establish polarization relations** in a future work if the linear wave theory can be applied. Moreover, **WRF simulations** of these events are intended for the future.
- The comparison between these two events in the same day shows how storms can generate gravity waves with different features and by different mechanisms.