Wave-like events detected from microbarometers measurements during BLLAST campaign

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1. INTRODUCTION

Boundary Layer Late Afternoon and Sunset Turbulence (**BLLAST**) field campaign in Lannemezan (France) → Improve the knowledge about the late afternoon transition in the planetary boundary layer (PBL).

Three high resolution microbarometers and a large amount of available instrumentation were available.
Two detected wave-like events were studied.

WAVE EVENT 1 - 21st June

- Rainy and stormy day (gravity wave[1],[2] related to thunderstorms[3]) – Important hazard for commercial aircraft[4]
- Pressure fluctuations up to 0.5 hPa . (very clear signal, good monochromatic wave)
- Fluctuations in other parameters (temperature, wind, vertical velocity)
- Stable layer until 45m approx.
- POSSIBLE ORIGIN – Descending vertical currents associated to rainfall acting over a stable layer near the surface (this stable layer was previously created by the surface cooling caused by the evaporation of the rain drops over the ground).

WAVE EVENT 2 – 2nd July

- Sunny and clear day (gravity wave related to wind) – These waves can affect the fluxes of momentum and scalars[5] by oscillations in parameters.
- Pressure fluctuations up to 0.06 hPa.
- Fluctuations in other parameters (temperature, wind, vertical velocity)
- Stable layer until 45-60m approx.
- Two distinct waves (10 minutes and 18 minutes of period, both from south, same direction than wind).
- POSSIBLE ORIGIN – Wind acting over a stable layer near the surface.

2. BLLAST CAMPAIGN AND DATA

CRA (Centre for Atmospheric Research) in Lannemezan during the BLLAST campaign (14 June to 8 July 2011) http://bllast.sedoo.fr

Instrumentation used:

- A triangular array of three high resolution Paroscientific **microbarometers** (Model 6000-16B) separated about 150m and at 1m a.g.l (Figure 1) with the objective of detecting small scale surface pressure fluctuations. This triangular configuration was used to characterize wave events by means of methods based on wavelet transform, allowing the calculation of wave parameters[6] (period, wavelength, phase speed and direction of propagation). A sampling rate of 2Hz was used, with a resolution of around 0.002 hPa.
- Temperature, wind and rainfall data - 60m and 8m towers and a set of thermocouples close to the ground.
- RADAR and IR satellite images.
- **UHF wind profiler.**

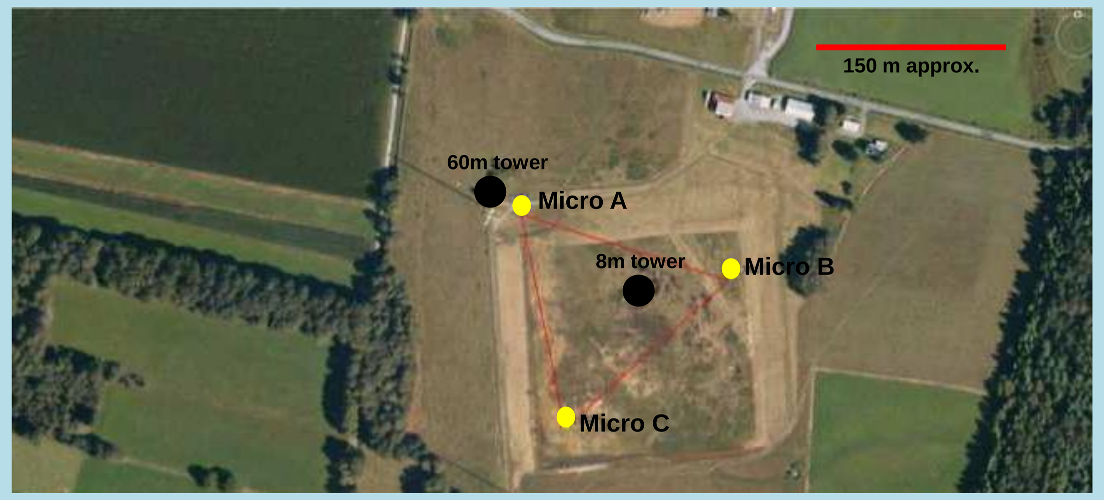

Figure 1. Deployment of the microbarometers array in BLLAST campaign (Supersite 1). The positions of the 60m and 8m towers are also shown. Picture from Google Earth.

3. WAVE EVENT 1. 21st June

1. Pressure fluctuations and wavelet analysis (Figure 2)

- Clear peak in wavelet analysis from 21:15 UTC to 21:55 UTC (wave period of 8-11 minutes)
- Several cycles in the filtered pressure records -> 0.3-0.5 hPa (values much higher than those usually produced by waves in stable boundary layers (see wave event 2).

2. Rainfall record and vertical velocity from UHF wind profiler (Figure 3)

- Rainy period from 20:10 UTC to 21:35 UTC with strong negative vertical velocities due to the fall of droplets.
- Indirect effect of the rain -> To create a stable stratification in the lower layers

3. Stable stratification of temperature profile in lower layers (Figure 4)

- Stable stratification caused by a decrease in temperature near the surface due to the effect of the latent heat absorbed by the evaporation of the drops over the ground.
- Brunt Väisälä frequencies (N_{BV}) (Figure 4b) allow the development of this gravity wave[7],[8] (frequency of 0.0021 s^{-1} (corresponding to a period of 8 minutes)) for all layers except for the layer between 45m and 60m. Wave trapped in the lower layers, below 45m.
- Other stable layers higher? Not expected because of the precipitation in the first kilometers (no radiosoundings to confirm it)

4. RADAR images showing the pass of a convective system (Figure 5)

- Wave detected in the last part of a convective system and with opposite direction of propagation than the storm. Different case than those related to cold currents or gust fronts ahead a thunderstorm[9]

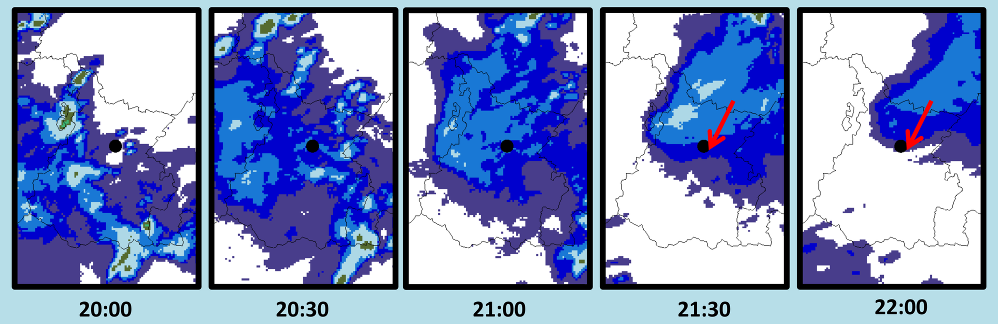

Figure 5. RADAR images for wave event 1 (time in UTC). Black point indicates Lannemezan and red arrows indicate the approximated direction of propagation of the waves.

5. Relations with other parameters (Figure 6)

- Relationships found between pressure fluctuations with other parameters (wind speed (Figure 6), wind direction and temperature (not shown)) at different heights(15m, 45m and 60m), especially at 45m.

6. Calculation of wave parameters (Figure 7)

- Short range of values (good indicator of clear and monochromatic wave)
  - Wavelength –> 500-550m
  - Phase speed –> 1 m/s
  - Direction of propagation -> 216º (the wave came from NE direction)

7. Proposed origin

- Strong downdrafts due to precipitation impinging over a previously formed stable layer

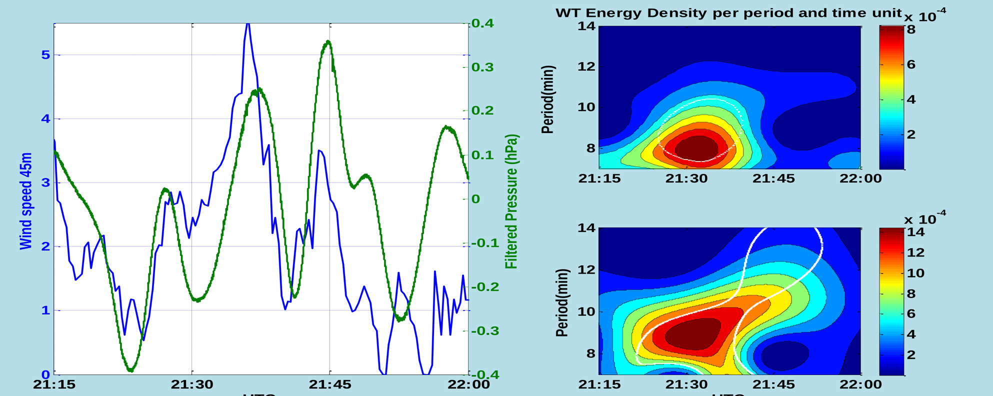

Figure 6. Left - Wind speed at 45m (blue) and filtered pressure (green). Right – Wavelet analysis for wind speed (up) and for pressure (down)

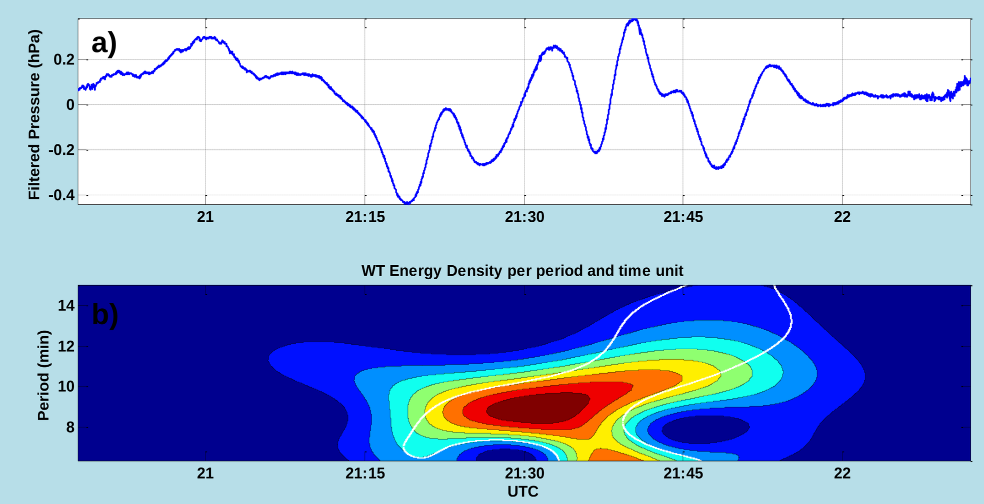

Figure 2. a) Filtered pressure for wave event 1. b) Wavelet transform energy density per period and time unit for wave event 1.

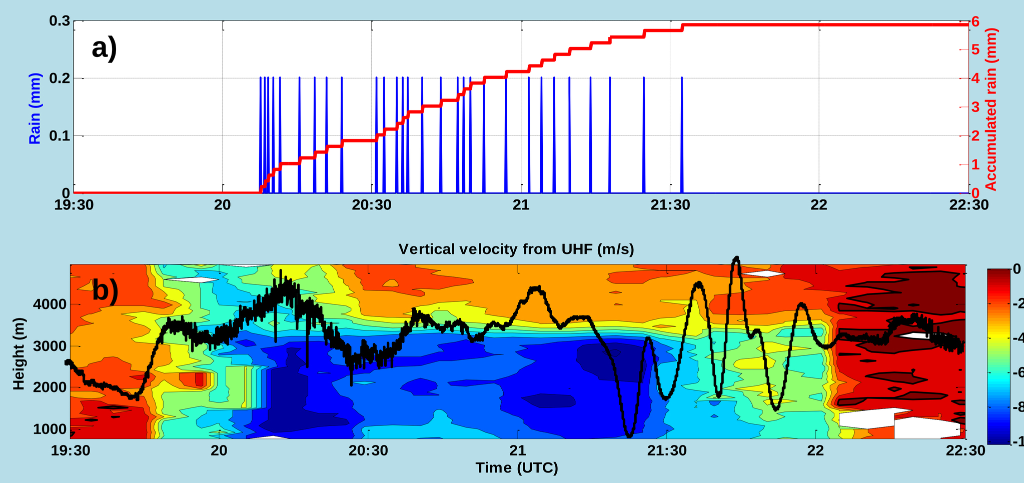

Figure 3. a) Rainfall (blue) and accumulated rainfall (red). b) Vertical velocity from UHF wind profiler (Filtered pressure is overlying this figure to show the wave event from 21:15 to 22:00 UTC)

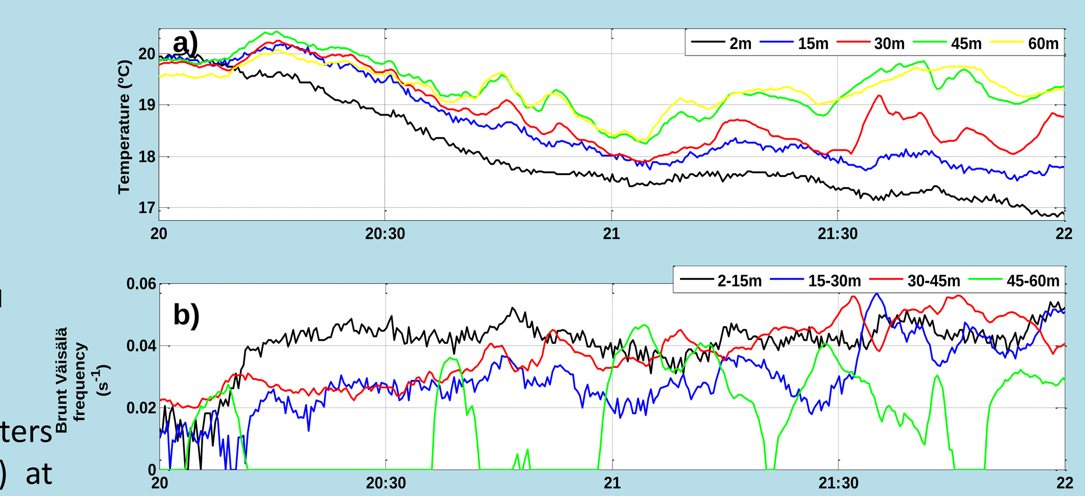

Figure 4. a) Temperature at different heights in the 60m tower from 20:00 UTC to 22:00 UTC. b) Brunt Väisälä freq. at different layers for the same period as in a.

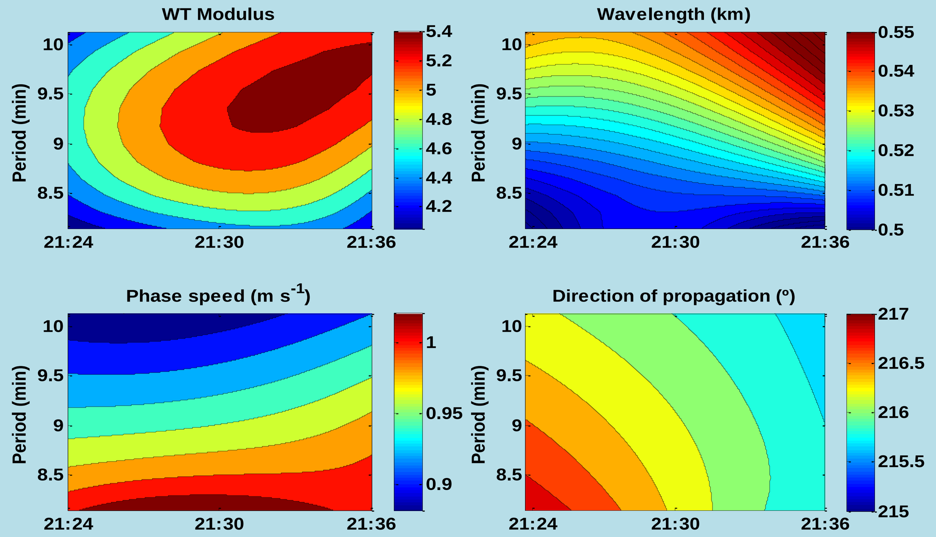

Figure 7. Wave parameters (WT modulus, wavelength, phase speed and direction of propagation) for a period within the wave event 1. (Note that direction of propagation is direction of origin + 180º).

4. WAVE EVENT 2. 2nd July

1. Pressure fluctuations and wavelet analysis (Figure 8)

- Two different waves found:
  - Wave a) - From 20:30 UTC to 21:00 UTC (wave period of 8 - 10 minutes).
  - Wave b) - From 20:15 UTC to 21:30 UTC (wave period of 18 - 20 minutes).
- Wave b) with higher wavelet energy during 21:00-21:30 UTC (studied period).
- Variations of pressure of 0.02 – 0.06 hPa (values much lower than wave event 1).

2. Characteristics of the day

- Fair weather day with surface cooling prior the sunset.
- Temperature inversion layer from surface to 45m – 60m (not shown).
- According to Brunt Väisälä criteria for the development of gravity waves, waves larger than 2 minutes of period can persist in this layer (not shown).
- Other stable layers higher? Looking at the radiosounding launched at 20:00 UTC (not shown), some stable layers appear at different heights, but not as important as the surface one
- Wind mainly from S-SE and increasing at 20:20 UTC above 45 meters (Figure 9).

3. Relations with other parameters (Figure 10 (wave a) and Figure 11 (wave b))

- Relationships found between pressure fluctuations with other parameters:
  - Wave a - Good relations in temperature from very close to the surface (1.5cm) up to 2m and in wind until 4.8m.
  - Wave b - Good relations in temperature up to 4.8m and in wind up to 8.3m.
- Wind relations with pressure well explained by the Tailor Goldstein´s polarization equations (no phase lag). Study more difficult for temperature variations.
- The higher oscillations in temperature in layers near the ground are explained because the variation in temperature with height is higher near the surface.

4. Calculation of wave parameters (Figure 12 (wave a) and Figure 13 (wave b))

- Short range of values (good indicator of clear wave)
  - Wavelength –> 1.4km (wave a) and 2.1km (wave b)
  - Phase speed –> 2.2 m/s (wave a) and 1.8 m/s (wave b)
  - Direction of propagation -> Approx. 0º (waves coming from South)

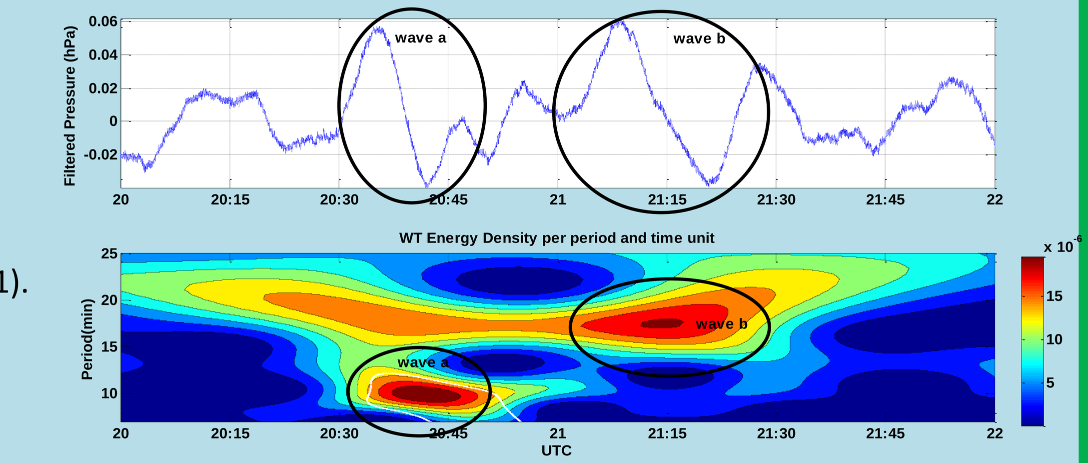

Figure 8. a) Filtered pressure for wave event 2. b) Wavelet transform energy density per period and time unit for wave event 2. The two different waves analyzed are marked with circles.

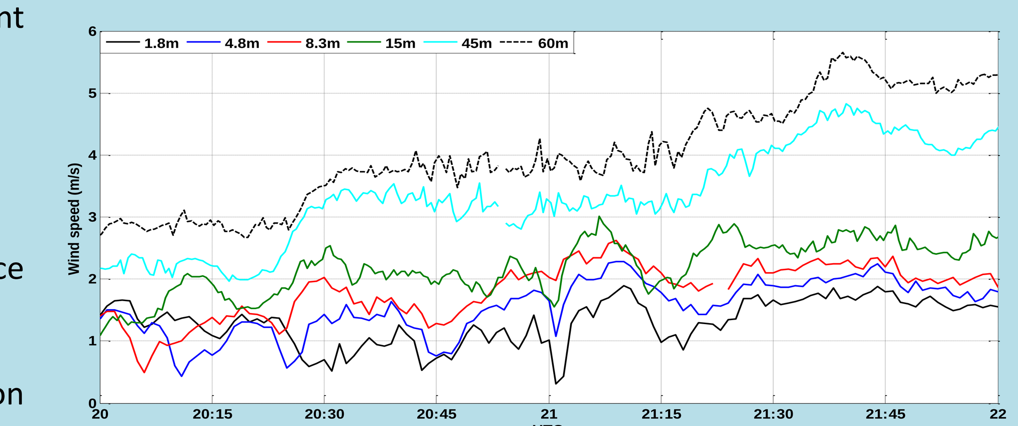

Figure 9. Wind speed at different heights from 8m and 60m towers.

5. Proposed origin

- Waves formed by the action of a katabatic stronger wind above a stable layer with weaker winds or by the action of the wind over an obstacle

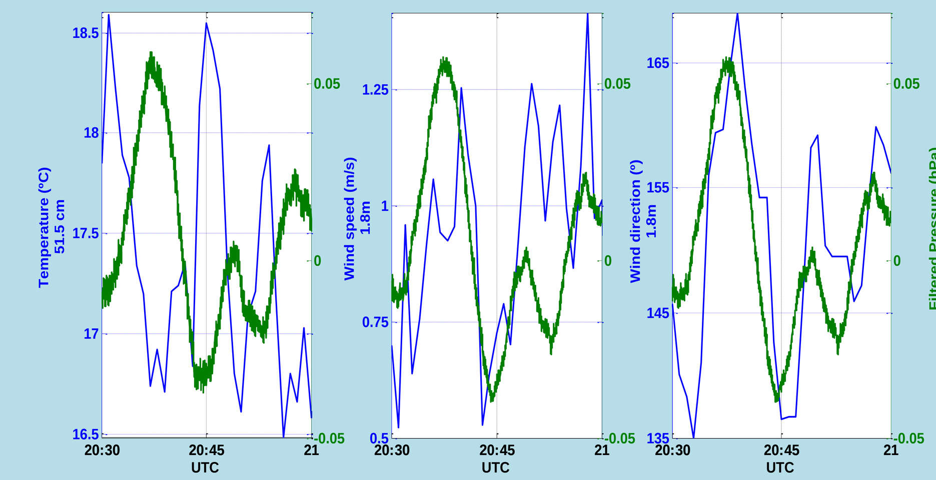

Figure 10. Relations for wave a between filtered pressure (green) and other parameters (blue): temperature at 50.1cm (a), wind speed at 1.8m (b) and wind direction at 1.8m (c).

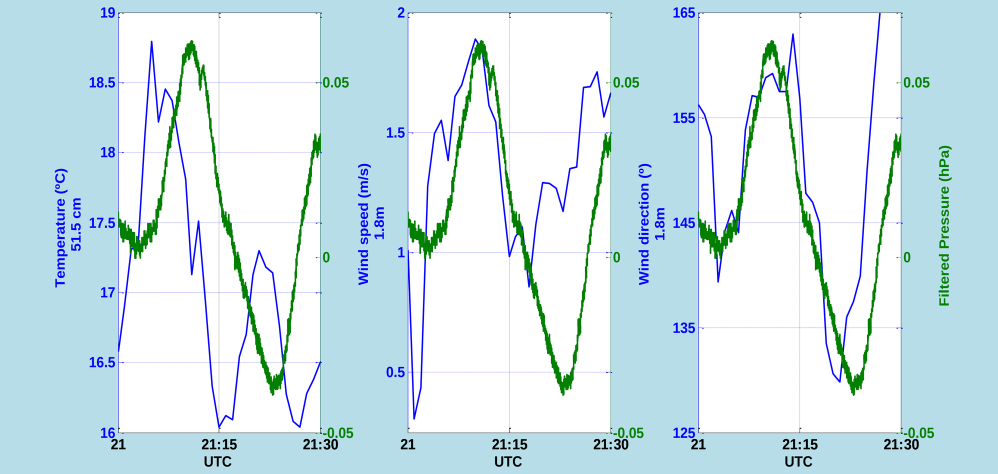

Figure 11. Relations for wave b between filtered pressure (green) and other parameters (blue): temperature at 50.1cm (a), wind speed at 1.8m (b) and wind direction at 1.8m (c).

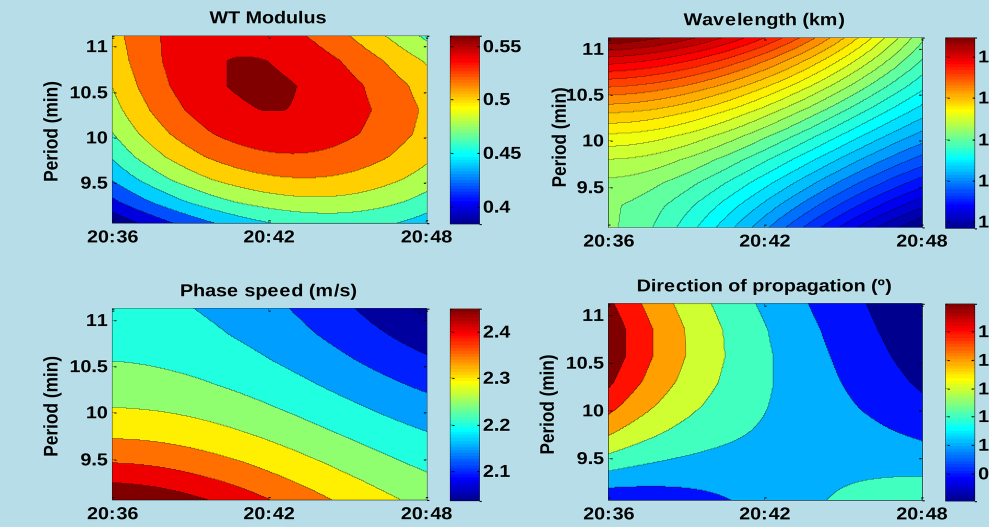

Figure 12. Wave parameters (WT modulus, wavelength, phase speed and direction of propagation) for a period within the wave event 2a. (Note that direction of propagation is direction of origin + 180º).

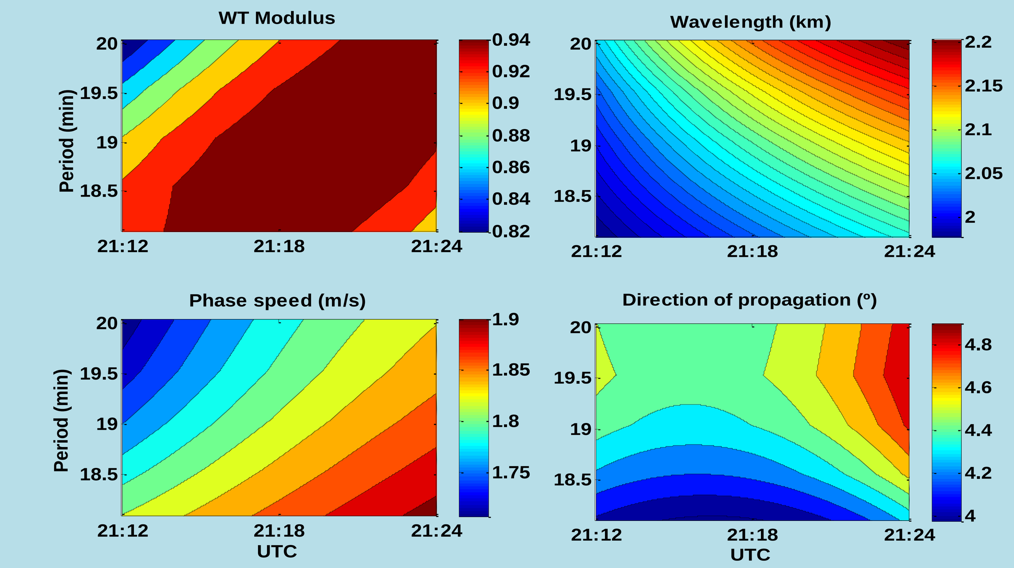

Figure 13. Wave parameters (WT modulus, wavelength, phase speed and direction of propagation) for a period within the wave event 2b. (Note that direction of propagation is direction of origin + 180º).

5. CONCLUSIONS

-Two days with different gravity waves during BLLAST campaign.
  - WAVE EVENT 1 – Associated to storms. Downdrafts acting over a stable layer near the surface formed by the evaporation of the rain droplets and causing oscillations in pressure of almost 1hPa.
  - WAVE EVENT 2 – Associated to wind acting over a stable layer near the surface formed by radiative cooling and causing oscillations in pressure of almost 0.1 hPa.
- Oscillations found in other meteorological parameters (temperature, wind, w). FURTHER ANALYSIS WITH THE LINEAR THEORY IS NEEDED.
- Important hazard for aircrafts (gravity wave very close to the surface in the last part of a convective system, important in landing/take off)
- Important oscillations in meteorological parameters than can affect their fluxes.

6. ACKNOWLEDGMENTS

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7. REFERENCES

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