Responses to Reviewer 2

We thank you for the thoughtful comments and changes suggested in your careful review of our manuscript. Our point-to-point responses are developed hereafter.

Major Comments

1. Overall I think that the manuscript is lack of technical details. Most of time it only contains qualitative descriptions of the systems. See below for a few specifics on this.

The manuscript has been improved through the addition of technical details about the conception and functioning of the system following your recommendations. This includes, in particular, a better description of the release mechanism and radiosonde protection. The following text was added in Section 2.1 of the revised manuscript:

"In order to be reused, the instrumentation is protected against possible damage arising from contact with the ground and vegetation. The protection (fig. 2c) consists in a 15 cm diameter sphere encompassing the radiosonde that was designed to minimize the disruption of the flow around the sensors. It is made of a plastic net wrapped around thin strips of rigid plastic (6 mm x 1 mm, ABS). The potential impact of this protection on measurements was estimated at ground level through comparisons between a regular and a protected radiosonde, with 850 W/m^2 incoming solar radiation and 3.5 ms^{-1} wind speed. Each probe was used alternately with and without the protection to take into account a possible bias between the two radiosondes. The temperature difference was lower than 0.1 °C and no difference could be detected in relative humidity measurements.

The release of the carrier balloon is performed by cutting the wire that ties the balloon to the probe. The light weight separation device was laboratory tested down to a temperature of -20 ° C. It is composed of both a Microship microcontroller PIC 16F88 and a Freescale MPX4515A analog pressure sensor that performs measurements in the range 1150-150 hPa with an accuracy of 15 hPa. Raw pressure data are collected by rounds of 9 measurements performed every 100ms. The separation order is based upon the median value of those nine samples to mitigate the impact of noisy measurements. The set release is coded on 6 bits, which provides a resolution of 10 hPa between 1050 and 420 hPa. The separation is achieved by fusion of a nylon wire wrapped around a resistance of 15 Ohm ¼ W powered at 8.2 V. The mean delay between the pressure measured by the sensor and the target separation is 3 hPa (STD of 2 hPa)."

2. "What are the advantages of this system comparing with a regular radiosonde with a parachute, which can be designed to have the balloon popped at preset pressure, and then use the parachute to make descending profiles? "

The burst altitude of a meteorological balloon depends mainly of its properties and the way it is inflated. For a given type of balloon, the uncertainty on the burst altitude is generally high and the burst level is particularly difficult to adjust for altitudes below 4000 m such as those targeted for the BLLAST experiment. A more accurate estimation of the separation altitude also allows to reduce the uncertainty in the landing point of the system and improves the odds to recover the sensor. The descent rate achieved when using a parachute is also significantly higher than that achieved with the two-balloon sounding device described in this paper. A slower descent speed thus allows for a better measurement resolution in the vertical.

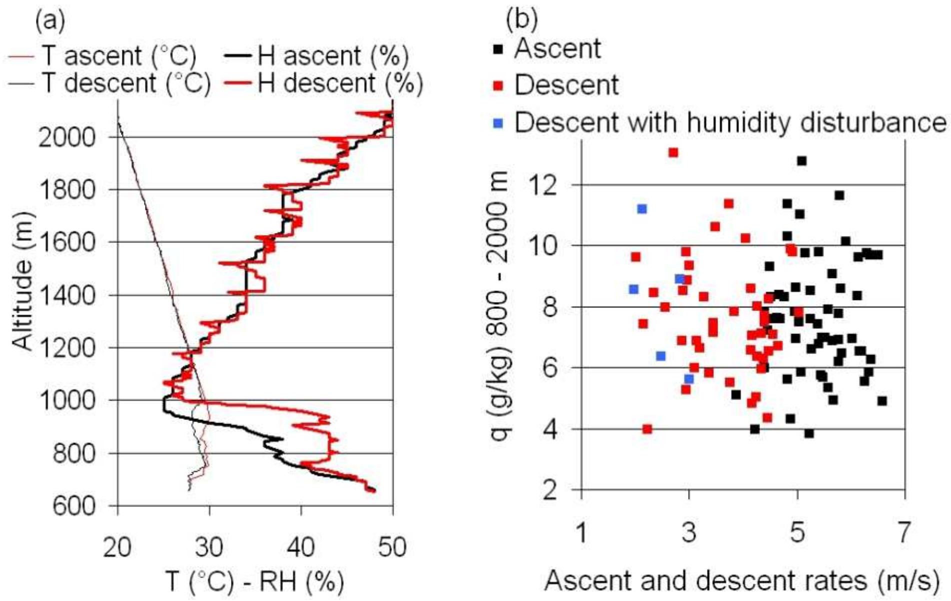
3. Section 2.3: Accurate prediction of the balloon trajectory is important to achieve the desired pressure level, separation and landing point. More quantitative analysis on how sensitive the trajectory to the input parameters, such as wind speed and balloon rise rate. The balloon rise rate in still air is sensitive to the drag coefficient and other factors (see Wang et al. 2009, JTECH; Gallice et al. 2011, AMT). In addition, the vertical air motion affects the actual balloon rise rate. Such information is necessary for the researchers to decide whether it can achieve their scientific goals given the uncertainty in the desired pressure level and the location of the descending profile.

Please keep in mind that this system was initially designed to be used in a field experiment (BLLAST) that had limited funds for radiosonde operations. Thus, our goal was not to perfectly predict the trajectory of the balloon, but to maximize the odds of recovering the radiosonde by making sure, to the extent possible, that it will not fall in hardly accessible regions such as forests, urbanized area or water. Also, the impacts of input parameters such as wind speed or balloon vertical speeds have been investigated, at least partly, in Figure 7, which shows that the uncertainty of the landing point and hence balloon trajectory depends principally on the accuracy of the input horizontal wind speed rather than on the actual ascent and descent speeds of the balloons.
This said there are several possibilities to improve the accuracy of the flight simulation software. One could use measurements provided by the radiosonde to update the expected trajectory in real-time, use the model developed by Gallice et al. (2011) or findings of Wang et al. during T-REX – thanks for pointing out these references - to better simulate the ascent and descent rates of the balloon, use 3-D wind fields for long balloon flight, … All these areas for improvement are now discussed in Section 5 of the paper (cf. point 6 below).

4. "One of the advantages of this system is to obtain the descending profiles. The authors should specifically discuss the differences between ascending and descending profiles and the quality and value of the descending profiles. Vaisala RS92 is designed to make the ascending profile with a certain bending angle for the sensor module. How is the sensor module oriented during the descent? How does it affect the measurement? Is there enough ventilation? I think that during the descent, the heating cycle for RS92 twin humidity sensors would not work. How does it affect the measurement if the sonde goes through clouds with water/ice on the sensor? "

Inadequate ventilation of the radiosonde definitely has an impact on the accuracy of the humidity measurement. We did notice a few descending soundings for which humidity measurements became instable. This is illustrated in the figure below, which shows the existence of unrealistic peaks in humidity measurements collected at descent on 6 June 2011 at 20 UTC (left panel). All peaks are separated from about 55 seconds which indicates that the heating cycle of the twin humidity sensors is not functioning properly – As you know, the RS92 twin humidity sensors alternatively measure humidity over a cycle of 110 seconds.
After a careful review of all soundings performed during BLLAST, we found that this problem has occurred 5 times. This is also illustrated in the figure below (right panel) where blue dots indicate the 5 soundings that show unrealistic humidity peaks. According to this figure, the problem only occurs at descent, which is likely due to the slowest relative speed of the system (3.5 m/s vs. 5 m/s). More precisely, we found that this problem only occurred when the mean descent speed of the radiosonde was lower than 3 m/s. For this reason, we suspect that measurements could be biased if the system goes through clouds during the descent. In order to mitigate this issue, one could use a lighter slowing balloon to increase the descent speed of the system. Using a balloon with a weight of 50 g would for instance increase the descending speed of about 20% with respect to the 100g weight balloons used in BLLAST and HYMEX. Both this figure (now Fig. 8) and the discussion have been included in a new dedicated subsection (3.5 "accuracy of measurements").

As for the bending angle: The point of attachment of the carrier and slowing balloons is the same and is identical to that of a classical sounding. The value of the bending angle recommended by Vaisala (45°) is thus maintained during the descent. This has also been mentioned in section 2.1 of the revised paper.



Caption: Effect of insufficient ventilation on radiosonde measurements. (a) Example of disturbed sounding made during BLLAST on June 26 2011 at 20:08 TU. (b) Ascent and descent rates vs. mean specific humidity between 800m and 2000 m for ascending soundings (black), descending soundings (red) and disturbed descending soundings (blue).

5. "Cost-effectiveness: Yes, it is great to reuse the recovered radiosondes to save the cost of the expendable. The question is what the cost is for separation device, protection system, extra balloons and other things, and the labor cost to recover the sondes. If you add all of them together, is it still cost-effective? How easy is this to operate given extra gadgets added to the operational radiosondes?"

The extra cost can be separated into two components: costs resulting from the modification of the original sounding system and costs associated with in-situ implementation. The modification of the system costs approximately 40€ - this includes the second balloon, the separation device and the protection system - and requires about 1 hour of work. Its implementation in the field requires about 30 extra minutes to inflate the 2nd balloon, to check the radiosonde, to perform the flight simulations and to program the separation device. The extra labor cost to recover the radiosonde obviously depends on both the distance travelled by the radiosonde and weather conditions, but can be roughly estimated to about 1 hour per sounding. The cost-effectiveness increases with the frequency of the soundings and the value of the instrumentation (cf. LOAC for instance). If the launch and landing sites are far apart and the sounding frequency is low, emphasis should primarily be put on scientific objectives, such as during HyMeX. If the sounding frequency is high, such as during BLLAST, then cost-effectiveness can be very high. Details about the cost of the system were added in the revised version of the manuscript under a new subsection (2.5 "Cost effectiveness").

6. "What is the future plan for this development? I have seen many experiments with different developments. Very often they end up just a few testing to show the proof-of-concept. I think

that it would be important to discuss the strength and weakness of the system and potential future improvement, which can be made by the authors or others. The ultimate goal would be to make the system more robust for more usage of the system either operationally or during field projects."

This system is very versatile and could be used in all field projects that require the use of radiosoundings. Detailed system specifications, software and assembly diagrams are freely available to the community upon request to the authors (this is now specified in the manuscript). The strengths (e.g., versatility, low cost, ease of implementation), weaknesses (e.g., uncertainty on landing and separation points, humidity measurement accuracy at descent) and sources for improvement (e.g., remote separation of the carrier balloon, trajectory update from real-time radiosonde measurements, accurate modelisation of the balloon ascent and descent speeds, remote separation of the carrier balloon) of the system are discussed in more details in the final part of the paper.

Specific comments

1. P3342, L25: Does this protection system affect the air flow and then the measurements for both ascending and descending profiles?

The potential impact of the protection on measurements was estimated at ground level through comparisons between a regular and a protected radiosonde, with 850 W/m2 incoming solar radiation and 3.5 m/s wind speed. Each probe was used alternately with and without the protection to take into account a possible bias between the two sondes. The temperature difference was lower than 0.1 °C and no difference could be detected in relative humidity measurements (see resp. to major comment 1).

Also, a potential inconvenient of the mechanical protection is its capacity to accumulate more ice than the original radiosonde during measurements in clouds. This effect has not been evaluated yet. A way to do so is to perform a dual sounding (with and without protection) under a single balloon, which will be done shortly.

2. P3343, L10-12: How do you decide whether the balloon reaches the required diameter? Do you weight the amount of helium put into the balloon or other ways?

Balloons are inflated using tares. We thus weight the amount of helium put in the balloon. Carrier (resp. slowing) balloons consist in 300 g (resp. 100g) Totex latex balloons. In our case, the rate of descent is limited by a compromise between the descent speed (ideally 5 m / s to ensure a correct ventilation of the system) and the lift of the balloon at the ground to mark the landing point. The compromise was 3.4 m / s for the descent. These rates were obtained by experimentation. The model proposed by Gallice (2011) should allow to better simulating the behavior of the balloons and better adjusting those settings. Those details have been added in section 2.1 of the manuscript.

3. P3343, L16: should "vertical wind profile" be "horizontal wind profile"?

We meant vertical profile of horizontal wind. This has been clarified in the text.

4. P3343, Fig. 3: More explanations are needed for this software, such as which "wind profile" should be selected, what the impact is, and whether this is easily adapted by other researchers?

The software to forecast balloons trajectories is written in C. Input wind profiles consist in 4 columns ASCII files that contain the altitude and the meridian, zonal and vertical wind components. All sources of wind profile can be considered. The user interface is written in PHP and Javascript. Wind profiles and hodographs are plotted using Grace (a WYSIWYG 2D plotting tool under GNU General Public License) while trajectory plots are make from KML files in the Google Earth user interface. This software is easily portable to any system providing the availability of above mentioned tools. Some details about this software are given in the text.

5. P3346, Fig. 6: It is hard to see the differences between ascending and descending profiles. What value does the descending profile add besides helping the recovery of the sondes?

We agree that the differences between ascending and descending profiles are not significant. This lack of variability is nevertheless an interesting result, which indicates the slow evolution of the PBL on this particular day. This is now mentioned in the new version of the manuscript. Those findings are also of great interest to evaluate the capability of high resolution numerical weather prediction models to properly reproduce the time evolution of the PBL during the afternoon, which was an objective of the BLLAST experiment.

6. P3346, L20: Why do 62 launches only give you 104 profiles rather than 124? What happened to missing 20 profiles?

The correct number is actually 114 profiles. The separation device did not work 10 times, which is the reason why 10 descending profiles are missing. We also noticed that some numbers were surprisingly missing in Table 1. The full statistics are given hereafter:

Table 1: BLLAST sounding statistics
(1) Probes visually identified but unrecoverable (trees, roofs, …)
(2) Release at a wrong pressure / height

# Probes available	**20**	
# Launches	**62**	
Spotted probes	**53**	**(85%)**
Recovered probes	**49**	**(79%)**
Unrecovered probes [(1)]	**4**	**(06%)**
Lost probes	**9**	**(15%)**
Re-used probes	**49**	**(79%)**

True release	**46**	**(74%)**
Faulty release [(2)]	**6**	**(10%)**
No release	**10**	**(16%)**

7. P3346, Section 3.3: The statistics on the deviation of actual separation distance from desired one would be useful (see major comment #3), similar to Section 3.4 on the landing point.

We did not compute those statistics, but one would expect the mean deviation to be about one third of the one on the landing point.

8. P3349, Fig. 8: The figure caption incorrectly says that the thin line represents the ascending profile.

This has been corrected. Thanks for pointing this out.