Boundary-layer drifting balloons for chemistry-dynamics studies in the Mediterranean region

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1. Introduction

Drifting balloons are invaluable tools for the documentation of air parcels trajectories, and the measure of the evolution of their characteristics along the time (Lagrangian evolution). They are used at various levels in the atmosphere, from low troposphere (boundary layer) up to lower stratosphere. The kind of the envelope (e.g. open or over-pressurized), as well as its dimension, vary according to the targeted flight level and to the mass and energy consumption of the scientific payload. The Centre National d'Etudes Spatiales (CNES, French Space Agency) has developed for a long time the capacity of designing, building and equipping drifting balloons, among which BLPBs (boundary layer pressurized balloons) used for meteorological and/or air chemistry studies. Spherical balloons were launched over the Indian Ocean during the BALSAMINE (Cadet et al., 2001) and INDOEX (Ethé et al., 2002) projects, whereas cylindrical envelopes were used for the documentation of orographic flows over and around the Pyrenees and Alps mountains (Koffi et al., 2000; Bénech et al., 2002). For chemistry-dynamics studies, BPLBs serve as tags of the air masses, which can thus be analysed by aircraft at different periods of their life cycle. Such a strategy has been used over the Atlantic Ocean during the ASTEX/MAGE experiment for marine chemistry analyses (Huebert et al., 1996), over continental Europe for transport/dispersion studies during the ETEX campaign (Koffi et al., 1998), or for photo-oxidant pollution studies in coastal Mediterranean areas (Bénech et al., 2008).

2. The BLPB (Boundary layer pressurized balloon)

The current system consists in a spherical, 2.5 m diameter envelope, and gondolas in which are embarked the sensors, the acquisition system and the data transmission unit via the Iridium satellite communication network (Fig. 1). The « generic » instrumentation

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consists of a package for pressure, temperature and moisture measurement, installed on the top of the balloon. The central gondola, including data recording and satellite transmission unit, is installed inside the envelope. The measures on the top of the balloon are transmitted to the central gondola with a wireless communication system. Additional instrumentation, according to the objectives of the campaign, can be installed in a gondola hanged below the balloon.

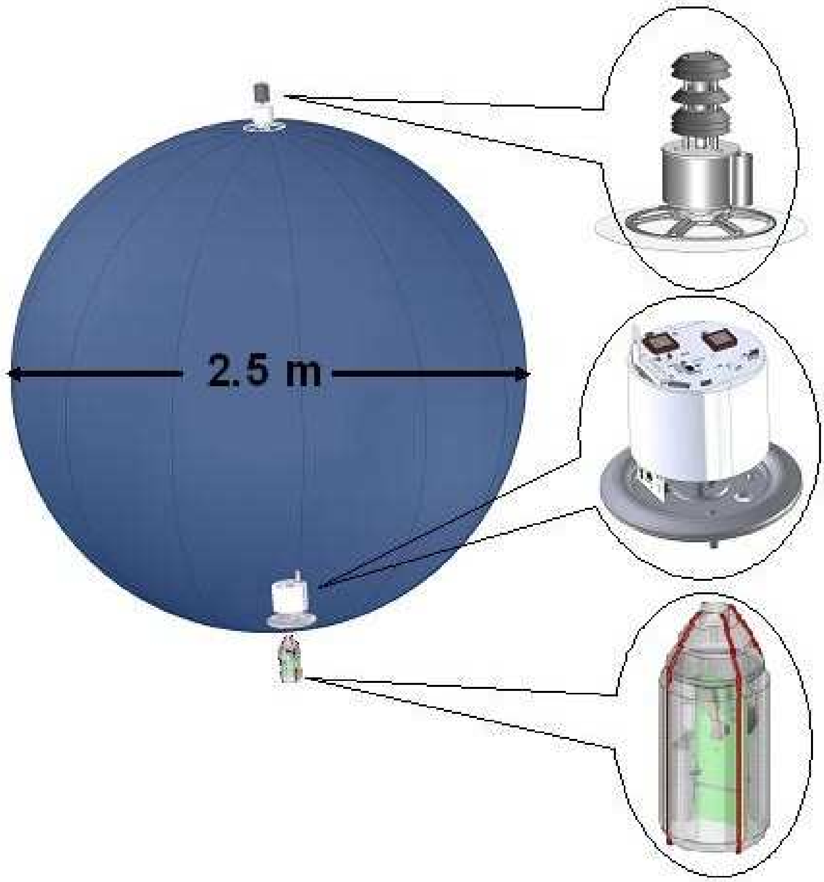

Figure 1: The BLPB envelope, with the generic instrumentation (on the top), the system gondola (inside the envelope) and the additional instrumentation (on the bottom).

The balloons fly at a constant density level, except when their mass changes due to gas leakage or liquid water presence on the envelope in rainy or dew deposit conditions. The buoyancy of the balloon is adjusted in order to reach the required flight level by the air/He ratio inside the envelope. This technique offers a good accuracy, provided that the pressure, temperature and moisture at the drifting level are precisely known. A radiosonde profile realized within one hour before launching is therefore highly recommended. In flight, low energy consumption allows a balloon lifetime as high as several weeks. The main limitation results from the restrictions for safety reasons: the flights are authorized over the seas, but are generally prohibited over continental areas. In the Mediterranean region, the expected trajectories would therefore rarely exceed 2-3 days.

3. Additional measurements

3.1 Ozone concentration

The ozone probe is an adaptation of a commercial unit (electrochemical concentration cell (ECC) sonde) generally used with a radiosonde for ozone profiling. Such ECC sondes have already been used on drifting balloons and demonstrated their capacity to measure the Lagrangian rate of concentration (Bénech et al., 2008). However, the data were limited to few hours, because of 1) energy consumption, 2) limited volume of the solutions used for redox reaction, and 3) the maximum distance to which the radio-transmission was possible. The two first drawbacks were by-passed by operating the sonde in an intermittent mode (e.g. two min. every quarter-hour). After a spin-up period of less than one minute, the ECC sonde has demonstrated its capability to correctly measure the ozone concentration once switched on. Comparison done at ground with a UV TEI analyser revealed that the sonde was able to reproduce, in the intermittent mode, both the rapid (few min.) and slow (diurnal cycle) variations for a time period as long as 4 days (Fig. 2). The horizontal range is no longer limited, since the data transmission system uses a satellite connection (Iridium).

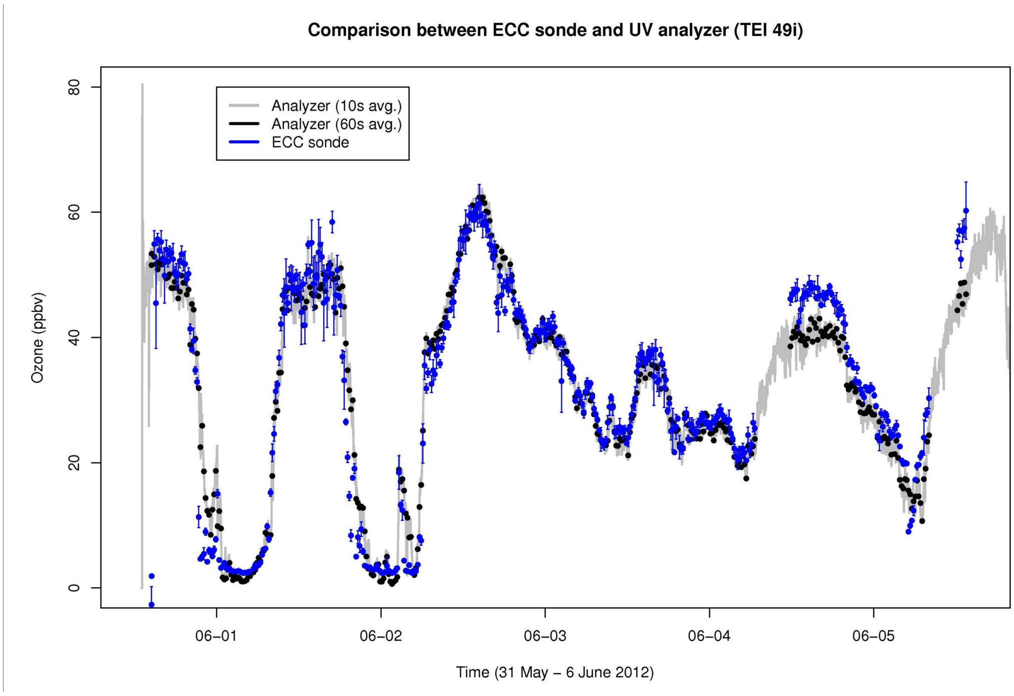

Figure 2: Time series on a 6-day period of the ozone concentration measured by a UV analyser (at 10-s and 1-min average, gray and black dots, respectively), and the intermittent ECC sonde (blue).

3.2 Aerosol measurement: light optical aerosol counter (LOAC)

Jointly developed by Environment SA company, and the LPC2E Lab. in Orléans (France), the LOAC for BLPB is a miniaturized, low-energy consumption version of a counter developed for air quality monitoring concerns. From the light scattered at two different angles, the number of particles in 20 bins of size larger than about 0.5 µm in diameter, as well as the nature of the particles (purely scattering, mineral dust, soot), can be estimated. The design of the sonde can be seen below, as well as an illustration of the size distribution observed at the two angles of observation.

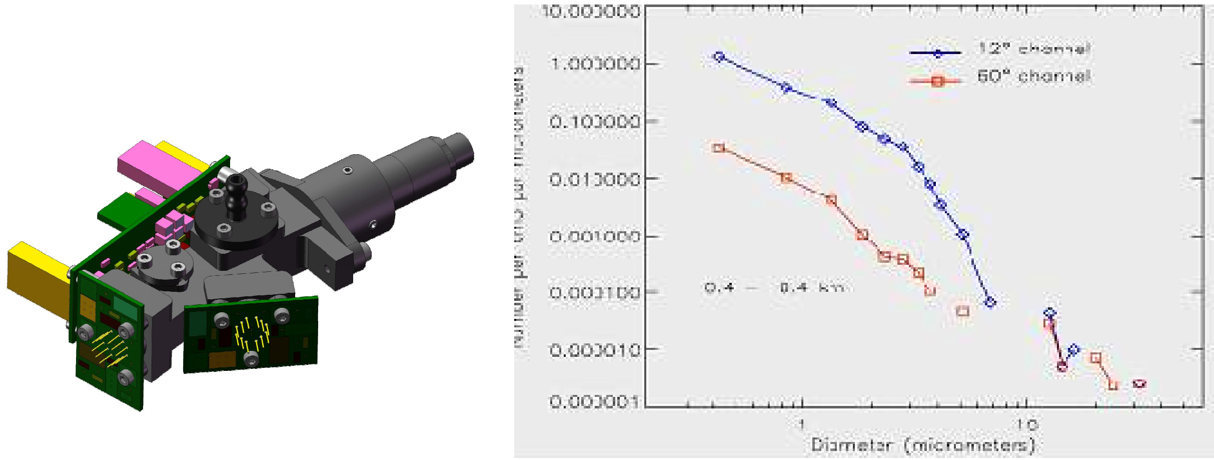

Figure 3: Model of the LOAC system (left) and example of aerosol size distribution observed at the two light scattering angles (right). The 12-deg channel is relatively insensitive to the refractive index and is calibrated in size, whereas the ratio between the two channels provides an indication of the nature of particles.

4. The 2012 and 2013 Mediterranean operations: the Chemistry and Aerosol Mediterranean Experiment (ChArMEx)

4.1 The 2012 pre-ChArMEx/TRAQA campaign

In summer 2012, a joint aircraft-balloon experiment aimed at following a pollutant plume issued from highly industrialized areas (the Rhone valley and the industrial complex of Fos-sur-Mer/Etang-de-Berre close to the French Mediterranean shoreline). BLPBs documented the Lagrangian evolution of the ozone concentration, and served as targets for the plume chemical documentation by the French ATR-42 aircraft. This experiment was a part of a wider project, named TRAQA (TRansport and Air QuAlity), the goal of which was to study how the major anthropogenic sources along the western Mediterranean shoreline (e.g. the Barcelona, Marseilles and Genoa gulf areas) are transported and chemically evolve over the sea.

Two days were documented with combined aircraft-balloons operations. The BLPB trajectories are indicated on Fig. 4: On June 27, a strong-to moderate north-westerly wind (Mistral) transported the balloons from the launch site towards Sardinia where they were sent down to the surface before the shoreline for safety constraints after ~10 flight hours. On July 6, a moderate-to-weak flow transported the three balloons more easterly. The flights lasted longer (~15 hours), and were ended because of the proximity of the Corsica shoreline. On both situations, the BLPBs flew between 500 and 600 m above the sea surface. On June 27, the two BLPBs were launched at the same time and flew at about the same level, whereas on July 6 the three BLPBs flew at the same level but only the two first were launched simultaneously whereas the third followed two hours later.

One aircraft flight was realized on June 27 and two on July 6 in the vicinity of the balloons. Thanks to the aircraft profile through the boundary layer and lower troposphere, we observed on June 27 a stable stratification with the temperature at the balloon flight level warmer than the sea surface by about 5 K. As a consequence, gravity waves developed and the balloons were solicited at the corresponding Brunt-Vaisala (BV) frequency. Since its density is quite constant, the balloon is not able to follow the wave through its complete vertical extension, and thus exhibits a damped oscillation at the BV period (Fig. 5). Such oscillations were not observed on the 6 July flights, where a well mixed layer developed above the sea surface.

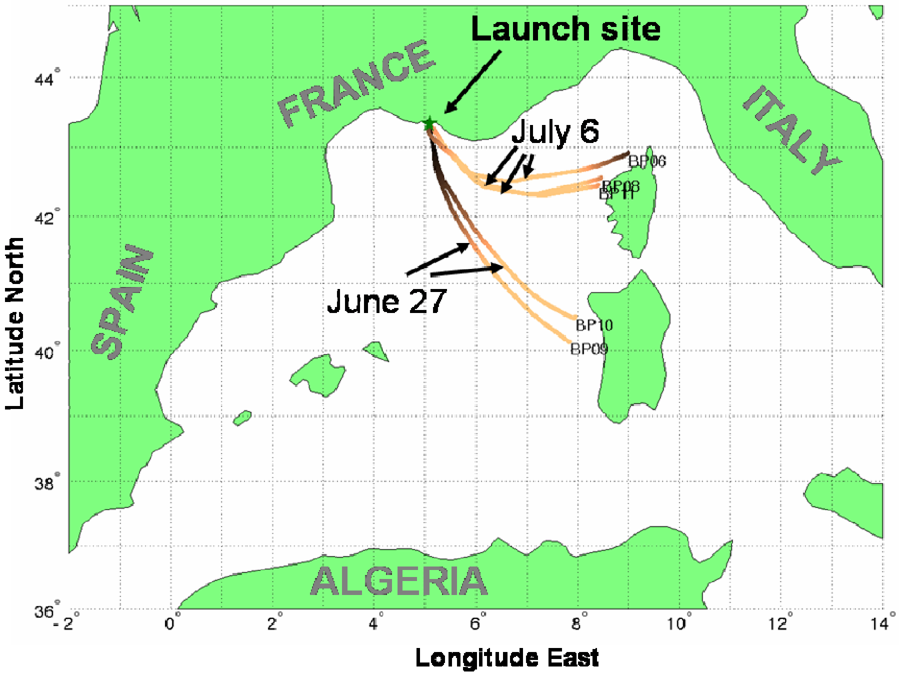

Figure 4: BLPB trajectories on June 27 and July 6.

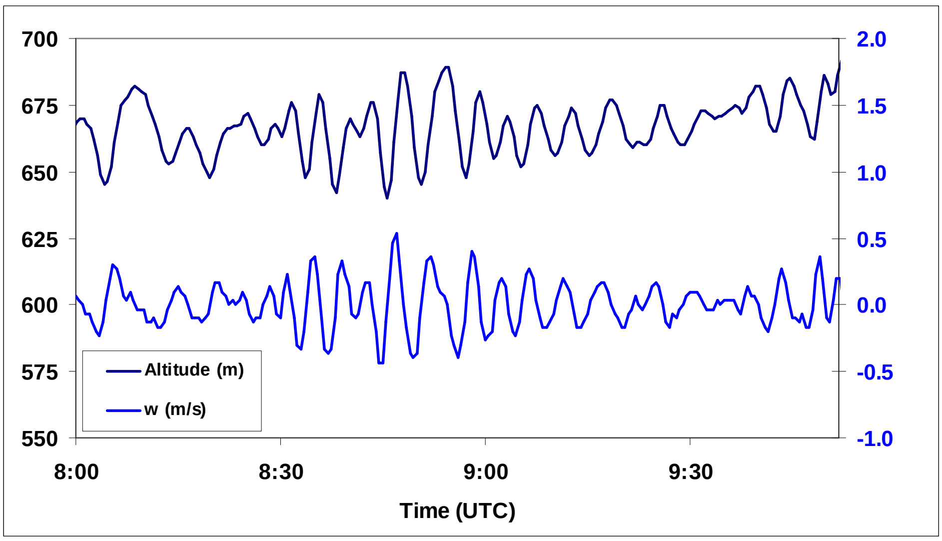

Figure 5: Example of BLPB oscillation in a gravity wave field. The time series of the BLPB altitude (black upper curve, left scale) and the corresponding BLPB vertical velocity (blue lower curve, right scale) are

shown.

The ozone concentration was very low during June 26. Persistent, strong wind dispersed ozone precursors and even in the photochemistry production period, the mixing ratio remained below 40 ppb at the flight level. The situation was quite different on July 6, where the seaward flow started just before the BLPB launch, and ozone precursors in the air mass allowed photochemistry to occur, increasing the ozone mixing ratio up to 60 ppb at noon (Fig. 6). The time series allows one to simply compute the Lagrangian production rate, which can be directly compared to the result of a chemistry-box model output.

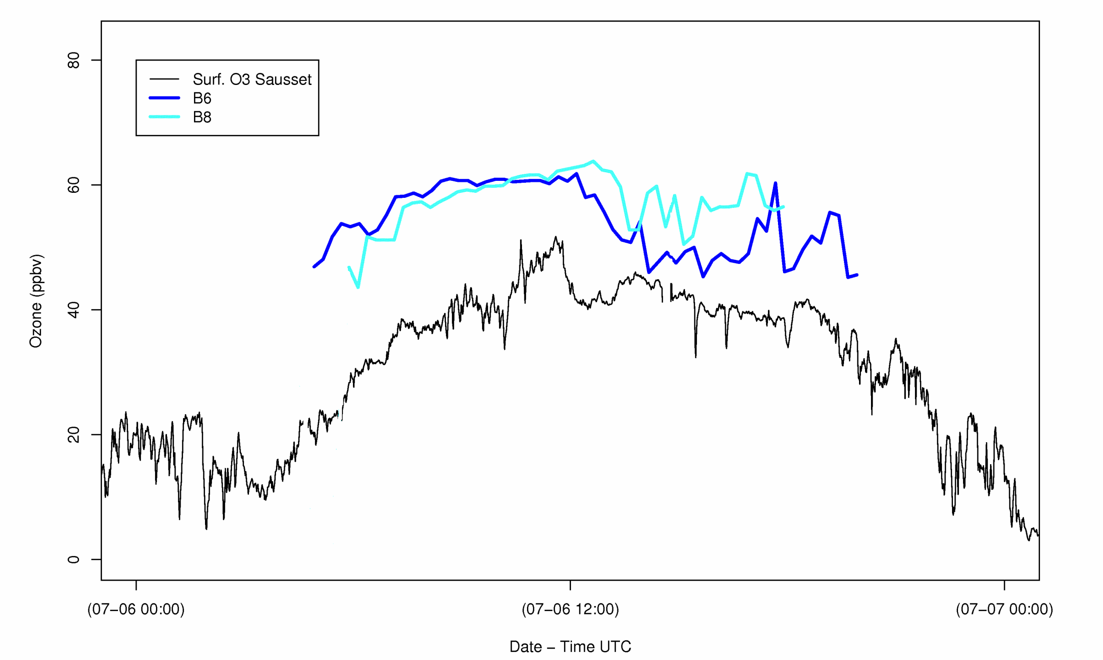

Figure 6: Time series of ozone mixing ratio on July 6 measured at ground level on the launch site (lower black curve) and during two BLPBs flights at about 500 m above the sea (upper curves).

4.2 Perspective: the ChArMEx 2013 campaigns (http://www.charmex.lsce.ipsl.fr).

In summer 2013, two campaigns will be based on a combined aircraft-balloon observation strategy (Fig. 7). The first one (ADRIMED) will document the radiative impact of desert dust laden air masses coming from Africa. The second campaign will mimic the TRAQA strategy, with a focus on secondary organic aerosol formation. For both campaigns, the balloon launching place will be chosen, among the a priori candidates indicated by the red and yellow pins on Fig. 7, according to the air mass trajectory study, based on operational analyses during the 2001-2011 period. Regarding additional instrumentation, aerosol measurements with the LOAC sonde will be privileged during ADRIMED, whereas ozonesondes will be embarked preferentially during the other campaign.

5. Conclusion

For chemistry-dynamics studies, BLPBs offer, with respect to other observational tools, three main advantages: 1) they track the air masses and thus give a field-truth of the air flow; 2) they tag an air mass and thus can guide the aircraft for ageing studies; and 3) they allow a monitoring of the Lagrangian rate of species like ozone or aerosol size distribution. During a campaign, they can be prepared well in advance such that several BLPBs can be launched simultaneously (at similar or different heights), which gives us a direct estimation of the horizontal dispersion and/or the impact of wind shear on the air mass trajectories spreading. The absence of gas leakage, at least for flights of several days (even weeks), allows the balloons to fly as low as few hundreds of meters, provided that buoyancy loss because of rain droplets on the envelope could be avoided. The main constraints are relative to the prohibition of flights above inhabited areas. Specific authorizations for trajectories crossing Mediterranean islands, under negotiation, might significantly increase the BLPB lifetime over the Mediterranean basin.

Figure 7: Sketch of the2013 ChArMEx campaigns. On the left: conditions of desert dust coming from Africa: on the right: export of anthropogenic pollution from the northern shoreline of the Mediterranean basin. Yellow and red pins indicate the potential launching stations, among which the choice will be done according to a trajectory study based on the 2001-2011 period.

Acknowledgements

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