CONTEMPORARY MEASUREMENTS OF A GROUND-BASED WEATHER RADAR AND BALLOON-BORNE LIDAR AT BAURU DURING THE HIBISCUS CAMPAIGNS: A POWERFUL SYNERGY IN CLOUD PHYSICS STUDIES

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1. INTRODUCTION

During February 2003 and February 2004 two balloon campaigns have been performed in the central State of São Paulo in Bauru (Brazil) in the framework of the European project HIBISCUS, which is a project studying the impact of tropical convection on the upper troposphere and lower stratosphere (Held *et al*., 2004). Among several short-duration stratospheric flights, two of them had as payload a miniaturized optical radar (LIDAR), taking continuous measurements of clouds below the stratospheric floating platform (Di Donfrancesco *et al*., 2004). The balloons were launched during late afternoon (Figure 1), around 17:00 to 18:00 LT (LT = UT-3h) and generally reached their cruising level at between 20 and 23 km height about one hour after the launch, drifting with the easterly stratospheric winds towards the western part of the State for 3 – 5 hours and starting a slow descent through the lower stratosphere and upper troposphere.

Figure 1. Typical short-duration stratospheric balloon launched from IPMet, Bauru, with a variety of scientific payloads (experiments).

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Figure 2 shows a picture of the Lidar developed during the HIBISCUS project, capable of performing aerosol and cloud backscattering and depolarization measurements during night time, with more than 30 km of range and a vertical resolution of 30 m. Its light weight, compact size and reduced power consumption make it suitable for flying on stratospheric balloons, sounding downward.

Figure 2. Micro-Lidar used for short-duration balloon flights during the HIBISCUS field campaigns in 2003 and 2004.

The lidar observations of such flights are compared with contemporary measurements obtained by a ground-based meteorological radar operated by IPMet. The S-band Doppler radar at Bauru is operated continuously, with volume scans between 0.3º and 34.9º elevation (11 PPI scans) at 7.5 min intervals, up to a range of 240 km (surveillance up to 450 km). The beam width is 2º. For this comparison, the radar data were analyzed in 3 dB intervals, starting at –18 dBZ in order to attempt the detection of thick cirrus clouds.

Although the sensitivity of the radar is nominally –32 dBZ at the radar, it decreases rapidly with distance, as expected, viz. –18 dBZ can be seen up to about 15 km radius, while –15 to –12 dBZ can be detected up to 20 to 25 km.

Another limitation is caused by the highest elevation being 34.9º, thus cutting nearby echoes at about 10-12.5 km height. This is more than ample for operational purposes, but in this specific application a vertically scanning radar would have been preferable. However, with careful extrapolation, based on the vertical reflectivity gradient, the base of the cirrus clouds could usually be estimated.

2. THE FLIGHT "*VOL0503"*

The first case study is the flight VOL0503 on February 19th 2003, launched from Bauru at 17:31 LT. The flight pattern was first towards east-north-east while ascending, then it changed to west-south-west reaching the stratospheric easterly winds at 23 km. While floating, it passed almost over the Bauru radar at a distance of few km to the north, finally traveling towards west and descending far away from Bauru (>100 km).

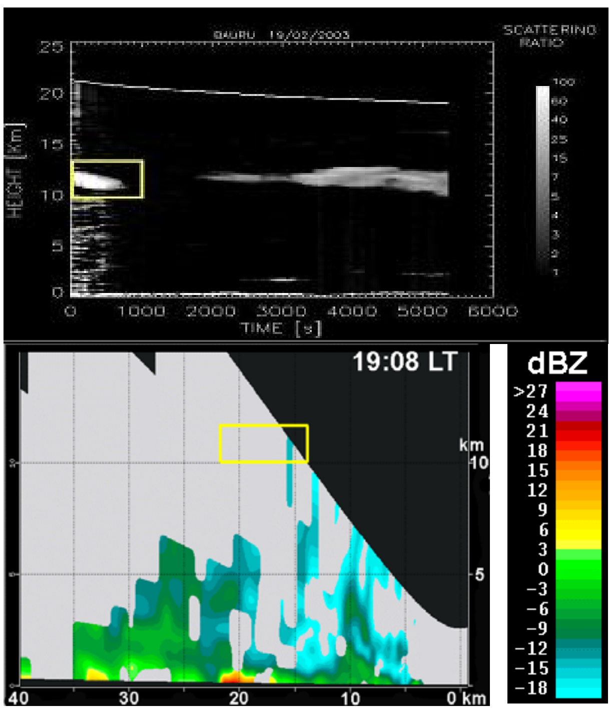

Figure 3. Flight VOL0503, 19 February 2003.
Top: Lidar data acquired during the beginning of descent of the balloon, along a linear path. Colour code refers to the scattering ratio, vs height on the vertical axis and time of flight on the horizontal axis. *Bottom:* vertical transect (orientation 261°-81°) from Bauru radar along the balloon descent linear trajectory. The yellow box highlights the -18 dB signal corresponding in time and space to the lidar observations of the upper panel.

Figure 3 shows the lidar observations obtained during this short-duration flight (top) and a simultaneous radar cross-section (bottom). Clearly visible in the yellow box is the presence of a high altitude cloud at the beginning of the descent, also reflected in the radar records (-18 dBZ in the near radar range).

A thick cirrus at 11 km was detected by the lidar in the very first part of the balloon descent. We investigated the radar capability to detect the cirrus bottom simultaneously with the balloon-borne micro-lidar, using the radar observations of the reflectivity at -18dBZ, at different times during the flight. As shown in Figure 3, a range of 15 km is enough to reduce the radio echo from the cirrus just below the radar detection limit. As expected, the contemporary radar measurement at –18 dBZ indicates a faint signal at 10-11 km of height when the lidar was close to Bauru. Then the cirrus disappeared for several kilometers and appeared again at the same level during the last part of the flight, but too far for allowing a detection by the Bauru radar.

3. THE FLIGHT *"SF4"*

The second case study is the flight SF4 on Feb 24th 2004. The balloon was launched from Bauru at 17:03 LT and reached an altitude of 20.2 km, shortly before sunset, followed by a 3½ hour float and slow descent, initially westwards, then veering to southeast, down to 10.7 km, when it was cut down. The total flight time was 4 hours 52 minutes. Due to the strong background light during the balloon ascent, the lidar started to profile only one hour and half after the launch when at sunset the balloon began the descent. Before this time only the close range signal (100 meters below the platform) is emerging above the noise, and was used to assess the presence of clouds in the ascent path.

During the descent, the lidar detected two cirrus layers, at 13 km and 11 km respectively, as shown in Figure 4.

We again first investigated the radar capability to detect the cirrus bottom in coincidence with the balloon-borne micro-lidar, using the radar reflectivity at -18dBz at different times during the flight. As shown in Figure 5, the cirrus layer at 13 km height is below the radar sensitivity, while the radar detects the cirrus layer at 11 km. The 15 km range for the radar echo is the limit for the radar detection of cirrus clouds. In fact looking at the lidar close range signals acquired during the fast ascent above Bauru (Figure 6), we see that in a range shorter than 15 km, the radar sensitivity is able to detect all the cloud layers encountered by the lidar, including a cirrus at 12 km of altitude.

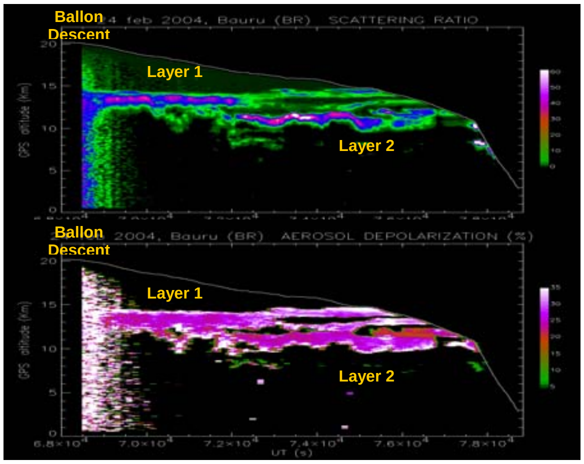

Figure 4. Lidar data acquired during the linear slow descent and parachute descent of SF4. The upper chart shows the color coded scattering ratio vs height and time-of-flight, while the lower chart shows the color coded depolarisation ratio. Clearly discernible on both panels are two detached cloud layers.

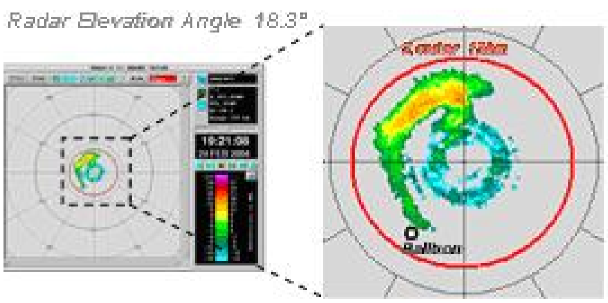

Figure 5. Echoes of Bauru radar on 24 February 2005 at 18.3° elevation angle at the time of lidar detection of layer 1 (13 km of altitude). The 13 km altitude for such radar elevation is indicated by a red circle, and the balloon position by a white point.

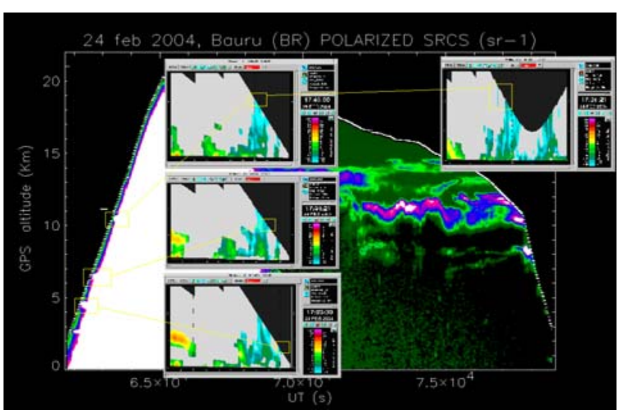

Figure 6. Plot of lidar signal vs. time, superimposed with four vertical cross-sections of Bauru radar echoes, each one at the time of the lidar detection of clouds during the balloon ascent.

A trajectory analysis was performed at different levels using FLEXTRA model (Stohl *et al.,* 1995) and ECMWF wind fields. It indicated that the two cirrus layers had different origins, the higher one being generated by a convective outflow and the lower one by a more recent air mass up-lift (Figure 7). There is a striking correspondence between estimated uplift (light colours) and presence of clouds as revealed by lidar. Both the two layers in the lidar backscattering observations had experienced uplifting: in the previous 24 hr for the lower layer (11-12 km), and more recently, in the previous 12 hr, for the higher layer (13-14 km).

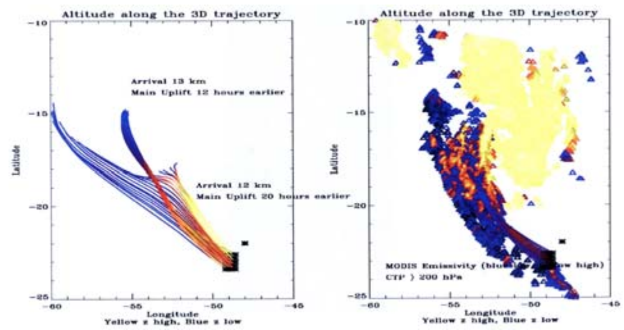

Figure 7. *Left:* 24-hour back-trajectories ending in the region of the lidar observations at 12 km and 13 km height, respectively. Colors represent the altitude evolution of air masses. *Right:* cloud emissivity from MODIS imager onboard the TERRA satellite at 13 UT, 24 January 2004. The color scale ranges from high emissivity (yellow) to low emissivity (blue).

Such different origins of investigated air masses appear evident in the radar echo, as illustrated by the vertical cross-sections in Figure 8, intersecting the balloon trajectory. Completely different meteorological situations below the two cirrus layers are detected, with the region below the lower cloud showing a strong convection going on, as expected.

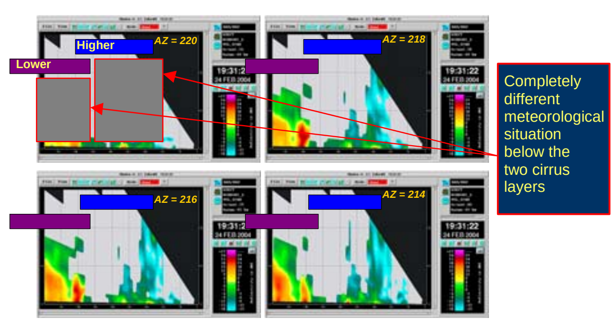

Figure 8. Cross-sections of echoes observed by the Bauru radar along the flight direction of the balloon at the time when the signature of the lower cirrus started to appear in the lidar signal.

4. CONCLUSIONS

As expected, the sensitivity of the Bauru meteorological radar was below the detection limit for high altitude cirrus clouds. Thus, it was not able to follow the cloud signatures of the balloon-borne microlidar during the two stratospheric flights. However, if the comparison is kept within 15 km of radar range, then the signatures of cirrus appear in the radar echoes as well.

The SF4 case study demonstrates, that despite the radar being unable to detect the cirrus layers farther than 15 km, it nevertheless is very useful with the capability to depict the meteorological situation below the cirrus. In fact, in that region usually the lidar signal has almost totally died out because of the cloud particles extinction. The simultaneous ground-based radar - balloon-borne lidar measurements showed to be a powerful tool, confirming different origins of apparently similar cloud layers.

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