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PEGASO: LONG DURATION BALLOONS FROM NORTH POLE

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ABSTRACT

In a joint effort, the Italian Space Agency (ASI) and Andoya Rocket Range (ARR) have initiated the development of a European balloon center in Svalbard, Norway that is an ideal location for performing Long Duration Balloon (LDB) flights. After the identification of the launch location several light balloon flights have been performed since 2003. The 2004 campaign utilized a 10000 m³ balloon produced for the program by Aerostar of Sulfur Springs, Texas USA. This flight lasted 40 days and was an excellent test of the small PEGASO payload, developed (for use in Antarctica) by the National Institute of Geophysics and Volcanology (INGV) with the PNRA (Progetto Nazionale di Ricerche in Antartide) sponsorship. This payload uses an IRIDIUM based bi-directional telemetry system. During summer 2005 two flights have been performed using balloons of the same size. They carried an updated telemetry and a scientific payload which analyzed the magnetic field of the Earth. The Institute of Information Science and Technology (ISTI-CNR) team computed predictions of the balloons trajectories, both before and during flights, as well as statistical evaluations of the seasonal flight windows at the beginning of the ASI LDB program. The 2004 and 2005 missions have been defined to investigate the stratospheric winds structure and they tested the possibility for future heavy LDB flights. The Italian scientific community foresees this kind of missions from 2007-2008 campaigns.
Next sections, starting from a general overview of the Italian LDB program, give the description of the Pegaso flights and, in particular, the adopted technical solutions for the on-board and ground-based equipments.

1 INTRODUCTION: ITALIAN LDB PROGRAM

Science teams worldwide have made use of stratospheric research balloons to conduct experimentation through various disciplines and for as many reasons. High altitude balloons have been the vehicle to carry on investigations of space, our atmosphere, and our planet. Balloons have proven to be a cost efficient and rapidly deployable carrier. In a joint effort, the Italian Space Agency (ASI) and Andoya Rocket Range (ARR) have initiated the development of a European balloon center in Svalbard, Norway that is an ideal location for performing Long Duration Balloon (LDB) flights.
In the development phase of the program the interest in the idea of launching LDB was driven by the science teams. ASI then has taken the requirements and began the investigation process by conducting site surveys in the appropriate geographic areas. One of the primary criteria was to develop a program that would mirror the NASA launch base in McMurdo, Antarctica.

The first step along this effort was the identification of the launch location. A site visit was made to Ny-Alesund (78º 55'N), which is located in the group of islands of Svalbard Norway, in 2002. However it was determined that the location would not fully support an LDB launch program. A second site visit was done in March of 2003 to Longyearbyen, Svalbard 78º 14'N. This location, done with the cooperation of members of the Andoya Rocket Range (ARR), proved to confirm Longyearbyen as a location with airfields and the facilities that could support the requirements of a LDB campaign. Fig. 1 shows a map of Svalbard.
At that step an analysis of local surface winds was compiled from information gathered from the meteorological office in Longyearbyen. The computed ten years profile gave a positive information: an average no lower than 13 days and a maximum of 22 days per month (June/July) have had winds low enough and from a steady direction to support a balloon launch. For launching LDB payloads, a wind speed of less than 3 m/s (6 knots) is desirable [1].

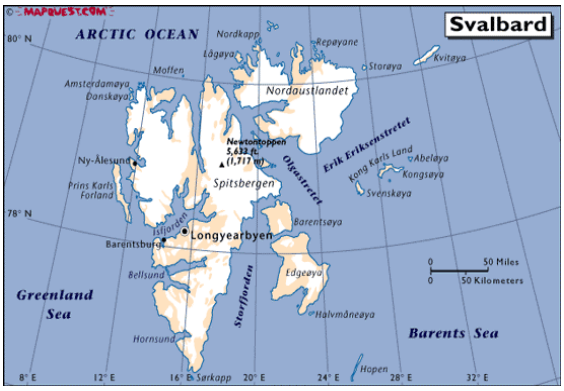

Fig. 1: Svalbard, Norway

As second step small balloons flights started to be performed in 2003. At that time balloons of 3000 m³ volume were used, with a payload of approximately 3 kg composed of a ARGOS transponder with a GPS board and a Lithium battery pack. By the trajectory analysis a first investigation of the stratospheric wind structure could be done [1].
During the 2004 summer season [2], a 10000 m³ balloon (Pegaso-A) was launched to again investigate the circumpolar trajectory but at a later date in the season (launch took place the 21st of July). Although it was anticipated the high-pressure system over the northern polar region would be weakening during this period, the trajectory maintained a westward path for 40 days before termination. The payload communicated through the IRIDIUM satellite system, while ARGOS was used to obtain the balloon position (in this way it could be tracked also after the balloon-payload separation which is performed at the recovery). The flight was an excellent test of the small IRIDIUM based telemetry.
The two 2005 missions (Pegaso-B and C) have flown an update of the same telemetry, which was connected, as scientific payload, to a magnetometer, devoted to the Earth magnetic field analysis. As new feature of the ground based tracking system, we tested our trajectory prediction software.

2 STATISTICAL STRATOSPHERIC WIND ANALYSIS

Statistical stratospheric wind analysis and its impact on the balloon trajectories were evaluated for 2000, 2001 and 2002 summers, as support at the ASI programs in 2003 [1]. The wind data analysis for each year spans a period from May through August. The analysis data utilized for these procedures came from the European Centre for Medium-Range Weather Forecast (ECMWF). A complete set of data derived from satellite and radio sounding measurements was available every 6 hours, for each degree of latitude and longitude in the area of interest. For the three years period we have constructed the geopotential altitude graphs at 5 mb (Fig. 2 shows the typical isobaric behaviour in the Polar Regions that allows LDB flights) and ground track trajectories. They were simulated through a 20 days cycle by using a linear interpolation in space and time with a step of 0.5 hours and considering the balloon at a constant pressure level of 5 mb (Fig 3). The summary of the favourable LDB period for the considered three years is shown in Table 1 [1].

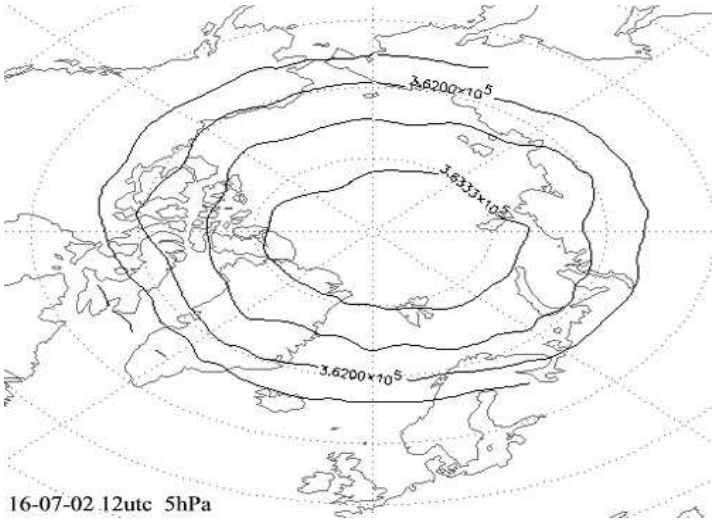

Fig. 2: Anticyclonic circulation, 16 July 2002, 5mb

YEAR	START	FINISH	DURATION (days)
2000	30 May	20 July	50
2001	10 June	20 July	40
2002	20 May	30 July	70

Table 1: Anticyclonic period

This summary indicates the number of potential days the circulation pattern would support a circumpolar trajectory of a stratospheric balloon in the 5mb range. Table 1 depicts an average of around 50 days per summer season. Given this averaged period, it was reasonable to expect up to 1200 hours at float altitude per payload.

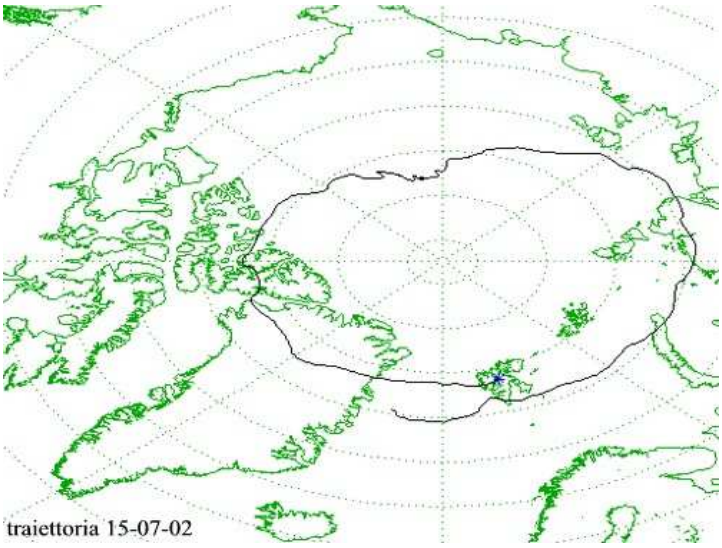

Fig. 3: Ground Track Trajectory, 15 July 2002, 5mb constant level

3 TRAJECTORY PREDICTIONS

Already used during the Trasmediterranean and local flights managed by the ASI base in Trapani (Sicily) [3,4], the predictions of stratospheric balloons trajectories have been applied at the 2005 Pegaso missions. We have used the National Centers for Environmental Prediction (NCEP) forecast data. Its greed steps are 1° in latitude and longitude and 3 hours in time. The balloon's float altitude was considered constant around the maximum pressure level of the available data (10 mb). Fig. 4 shows the 6 days predictions made before flights, obtained by linear interpolations in space and time.

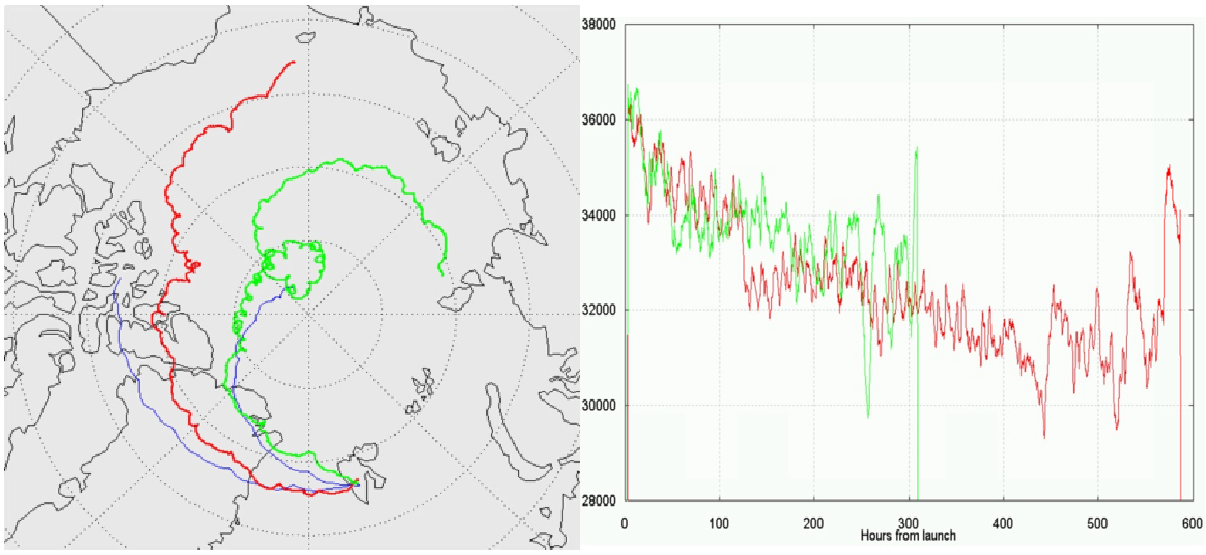

Fig. 4: Left: Pegaso 2005 ground track and preflight predictions. Right: balloons' altitude

4 TELEMETRY

The basic idea that brought to the PEGASO design was to build an expansible payload (recovering costs much more than the payload itself) capable to conduct scientific measurement at the affordable cost of a stratospheric pathfinder. PEGASO (Polar Explore for Geomagnetism And other Scientific Observations) was originally thought just as a flying magnetometer. Like in a pathfinder ARGO was the first communication system evaluated for data downloading. ARGOS PPT is light, affordable and reliable. Unfortunately ARGO suffers of some lack of communication at the required data rate for magnetometry, and the project moved toward the Iridium System. Iridium offers the power of a bi-directional communication, which is highly desirable for 2 reasons:

- A local data buffer may be easily managed with bi-directional communication; this allows to reduce the communication time establishing a connection only when required (near to buffer full)
- It is possible to remotely control the payload.

Unfortunately the use of Iridium increased the weight and, for payloads exceeding 4 Kg it is required a termination system (parachute) that needs to be remotely operated. The possibility to control the payload may be useful to even to operate a ballasting system. This may prolong the flight (more data) or correct an imperfect launch. When the design started Iridium modems (for use in stratospheric condition) were not easy to get, and much more expensive than ready of the shelf Iridium phones. This brought to house the project in a pressurized vessel to allow all the electronic stuff to enjoy the lab room conditions (20°C, 1 bar) even in the stratosphere. An inexpensive GPS (Trimble Lassen), already checked in the stratosphere, supplies position data, and inexpensive and frameless flexible solar panels set (Uni-Solar) supplies the energy, keeping the battery charged during the flight.

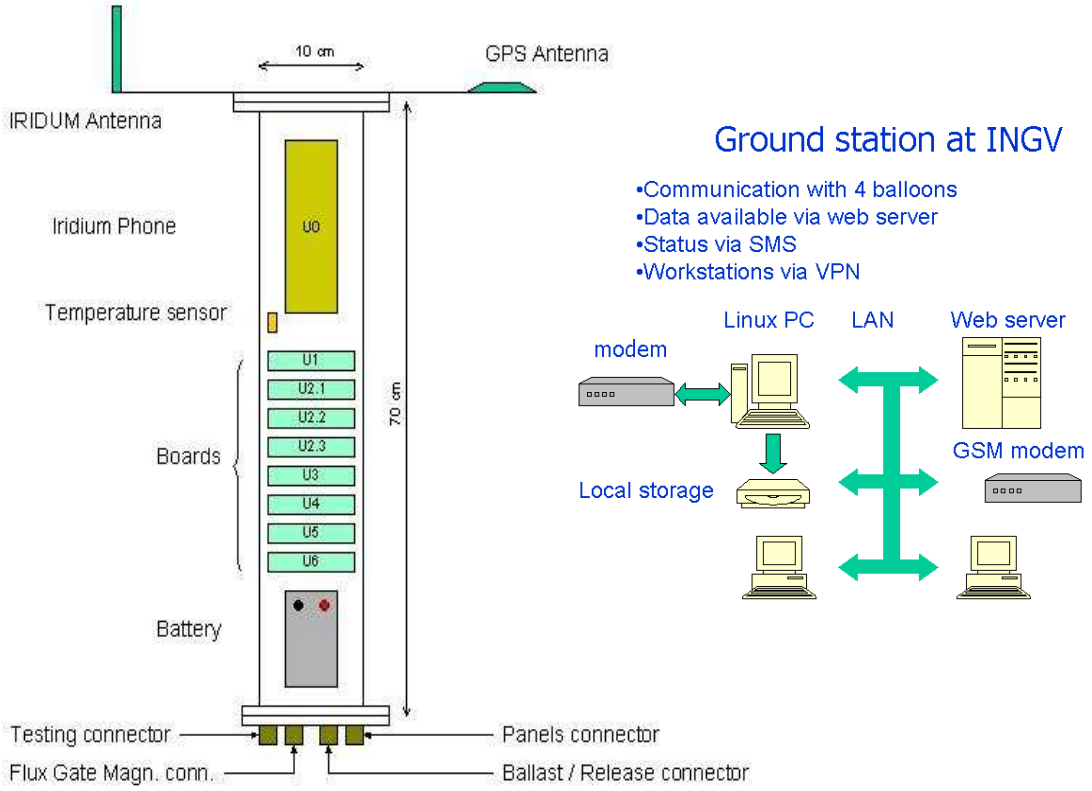

Fig 5: Vessel layout (left) and ground station block diagram (right)

Data logged by PAGASO (every 30 seconds) are stored in a circular buffer, waiting for a call from the ground station. This happens hourly. The system acquires the 3 magnetic field component and GPS position as well as house keeping data (power, temperature, pyrotechnic devices status). Fig. 5 shows the vessel layout (left) and the ground station block diagram, at the INGV Data Center (right). A subset of the ground station can be easily implemented on a laptop (connected to an Iridium phone). The communication to the balloon happens in plain ASCII. Although more expensive in terms of data transfer this choice allows a ground operator to contact the balloon and (knowing the vessel password) to operate remote controls without a specialized ground station.

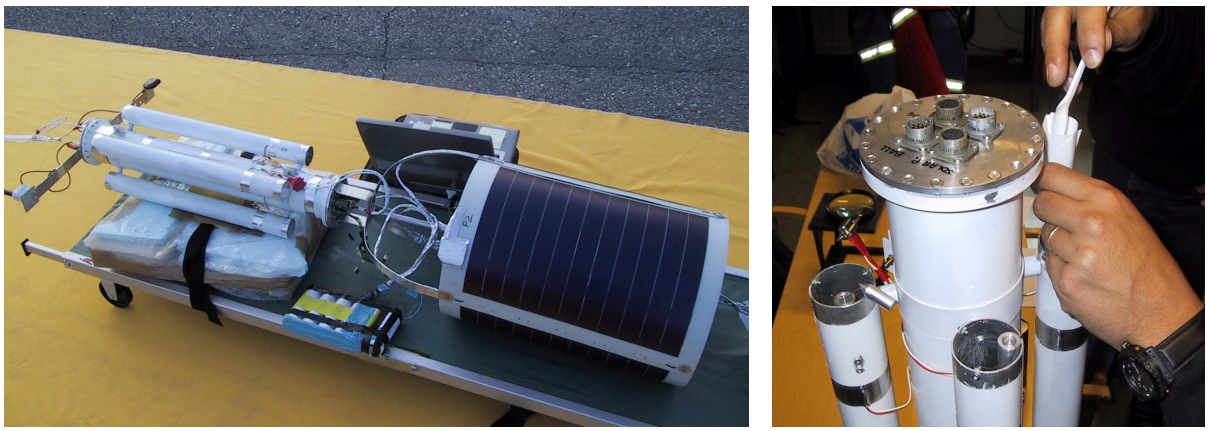

Fig. 6: Left: Pegaso 2004 ready to fly. Right: Filling the pyro explosive in the ballast tubes.

Fig. 6 (left) shows the payload ready for launch. Te central vessel is surrounded by 4 ballast tubes, operated with a pyrotechnic actuator [6]. On the right, in the same picture, there is detail of the vessel during the pyro charging. The effect of the ballast releasing during the 2004 flight is shown in Fig. 7.

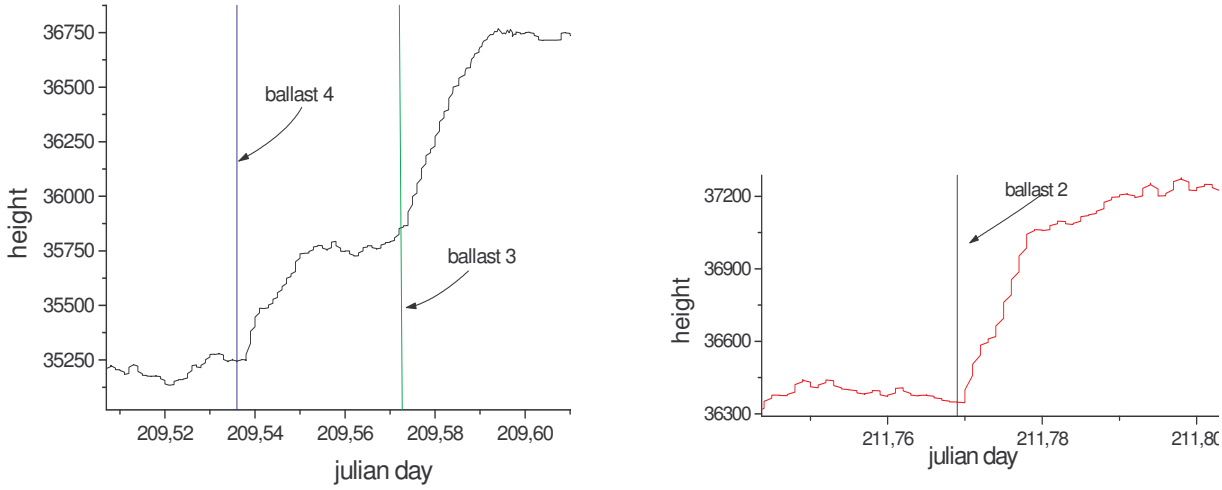

Fig. 7: Effect of ballast releasing on the balloon height during the 2004 flight.

5 STRATOSPHERIC MAGNETOMETRY

The mathematical description of the Earth's magnetic field and its variations is usually performed by the mean of stable observatories. To increase the coverage measurement are periodically performed (every 5 years) using mobile instruments. Anyway there are large uncovered surfaces (oceans, polar areas) where partial measurements are conducted by ships, airplanes and satellites. Satellite measurements are too far from the Earth's surface to investigate wavelengths shorter than 1000 Km, and ground measurement are affected by errors induced by short-wavelength crustal anomalies. This results in errors in the field model which, for wavelength of 100-1000 Km, may suffer of an excessive indetermination. A measurement operated at 35 Km of altitude will permit to investigate large crustal anomalies and medium mantle-core anomalies in the ambiguous wavelength range.

Actually PEGASO uses a 3-axys-fluxgate magnetometer to detect the module of the magnetic field, and to separate the vertical field component. The use of a proton magnetometer is also possible, since the circular flight over a polar area will never bring the instrument to work out the operating angle (which is the negative characteristic of a nuclear magnetometer).

The proposed data treatment will consist of a measurement reduction using geomagnetic observatories (diffused in the northern hemisphere) to separate the internal from the external field; existing spherical harmonic models will be used to study anomalies (IGRF2000). Here a truncated Taylor series will solve the non-linear relationship between the total field and the Gauss coefficients. Data process will take into account the increasing of the external field contribution and the decreasing of the internal one (roughly 10%) at the flight height.

6 FUTURE SCIENTIFIC MISSIONS

Interest in polar flight opportunities has been expressed by atmospheric physics, planetary science, biology, and high-energy astrophysics groups. In Italy several teams are developing science payloads for LDB flights. In various states of development are:

1) the OLIMPO microwave/sub-mm telescope, an experiment devoted to the measurement of the Cosmic Microwave Background in the direction of Clusters of Galaxies and the anisotropy of the far IR background radiation. The instrument features arrays of 19, 37, 37, 37 bolometric detectors respectively at frequencies of 150, 240, 350, 540 GHz. The resolution is few arcminutes [7].

2) the BAR-SPORT experiment, a proposed balloon-borne microwave polarimeter aimed at the measurement of the polarization of the Cosmic Microwave Background at 90 GHz, with extremely low instrumental polarization [8].
3) the BOOMERanG experiment, after the successfull flights from Antartica [9], will map foregrounds polarization at 350GHz: this measurement is propedeutic to a B-modes polarization of CMB satellite.
4) the PEGASO experiments will be repeated from the Antarctic PNRA base.

7 CONCLUSIONS

Polar LDB Experiments provide access to space at a reasonable cost. The interest in this technology is rapidly growing and ASI, in a cooperative effort with ARR, is developing a program of balloon launches from the Svalbard site of Longyearbyen. The LDB program is an established activity in the southern hemisphere, carried out by NASA/NSBF. This complementary one in the Northern Polar regions will add significant flight opportunities to scientific groups worldwide.
The 2004 and 2005 Pegaso missions are the first step in this direction. They have just achieved important scientific and technical results, measuring the Earth magnetic field and testing telemetry systems.

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