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Analysis and prediction of stratospheric balloons trajectories

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Abstract. The first step to manage a balloon flight from a trajectory point of view is the definition of launch location and period. Analysis data are used to realize a statistical study of the trajectories that can be obtained. The goal is define the conditions able to maximize the probability to respect mission objectives and constrains. Ones started with operations the balloon control centre has to manage the flight respecting safety and science. To predict stratospheric balloon trajectories we must utilize data from different forecast models and real-time measurements of wind and other meteorological entities. These sources of information have to be merged along the simulation of the balloon flight. Great attention has be paid for long duration flight from Pole and Equator, where QBO plays an important role.

Key words. Balloon trajectories – Quasi Biennal Oscillation – Flight safety – Numerical Prediction Models

1. Introduction

Safety requirements and the increase in balloons flights duration make computerized balloons trajectory prediction and control essential. Managing a balloons flight entails being able to predict its trajectory and altitude variations. Forecast, sounding and satellite data and an efficient thermodynamic model of the balloon are necessary. First, analysing the statistical wind properties, meteorologists chose period and location of the launch in order to maximise the probability to satisfy mission requirements. Then specific predictions have to be done just before and during the flight to monitor the balloon trajectory, schedule operations and maintain a high global safety level. The paper gives a general overview of the methodologies adopted to define and predict balloons trajectories.

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2. Winds models data

In order to perform a good balloon trajectory prediction is necessary to have a lot of information on atmosphere variables (winds, temperatures, relative humidity, etc...), with high spatial and vertical resolution at different times. In this contest, regular gridded data supplied by Numerical Weather Prediction (NWP) model

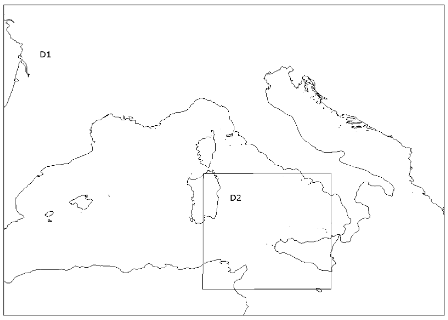

Fig. 1. Examples of MM5 27km (D1) and 9km (D2) grid domains adopted for a Transmediterranean flight. D2 is utilized for the ascending phase and recovery in case of local flight.

represent an optimal tool for trajectories calculation. We have used data mainly from three different data models:

1. MM5 data forecast.
2. NCEP data by GFS model.
3. ECMWF analysis and forecast data.

The fifth generation of Mesoscale Model (MM5) was developed by Pennsylvania State University and National Centre for Atmospheric Research (PSU/NCAR). It is operated by CETEMPS (Center of Excellence of L'Aquila University) with two two-way nested domains having a grid size of 27 and 9 km (Fig. 1), hourly time step, 30 unequally spaced vertical levels with a finer resolution at the lower levels and decreasing upward. The lowest model level is approximately at 4 m from terrain and the top at approximately 30000 m from sea level. The model is initialized using NCEP (National Centers for Environmental Prediction) analyses and forecasts respectively for the initial and boundary conditions Grell et al. (1994); Dudhia (1993).

NCEP supplies analysis and forecast performed by the Global Forecast System Model (GFS). Used data have a time resolution of 3 hours, a spatial resolution of 1 or 0.5 degree, 25 and 47 pressure vertical levels from 1000 up to 10 or 1 mbar Kanamitsu (1989); Kalnay et al. (1990); Kanamitsu et al. (1991).

The European Centre for Medium-Range Weather Forecasts (ECMWF) analysis data are generated considering a very large amount of observed data. The observations can roughly be divided into conventional, in situ observations, and non-conventional, remote-sensing observations. The earth-atmosphere system can be measured directly by conventional in situ instruments, and indirectly by remote sensing instruments. The various data types have different characteristics in terms of geographical coverage, vertical structure and temporal distribution, which determine their ability to affect the analysis. Moreover, with increased availability of non-conventional observations the analysis system has developed into higher sophistication to be able to cope with off-time data and, in particular, indirect measurements such as radiances from satellites instead of direct observations of temperature, humidity, pressure, ozone and wind. Finally, to ensure that only good quality data are used for the analysis an intricate quality control is applied

3. Monitoring software

The mission analysis has to define the launch locations and windows necessary to obtain a particular type of trajectory, as requested by technical and scientific requirements. Main outputs usually are: trajectories for several balloon altitudes launch time and coordinates, isobaric lines, winds intensity versus time and other specific meteorological graphs useful for a statistical wind analysis. The study adopts analysis data of at least a couple of years, searching for repeating cycles of trajectories and flight opportunities. Ones defined the period of the year when the desired type of trajectory appears with a reasonable probability, the information will be analyzed considering other requirements (i.e. ground wind intensity, recovery places and telemetry performances) to define the mission reliability.

During flight operations the main goal is define the predicted trajectory, together with its uncertainty or dispersion. To respect safety and scientific requirements the monitoring software must define in advance the over-flown zones and the balloon altitude variations. Now forecast models are necessary instead of meteorological analysis data, they are used to calculate the flight direction, albedo and predicted infrared radiation that affect the balloons altitude. Radiosoundings, that provide real-time measured winds, and satellite images, that give radiance in the infrared and visible fields, can be meshed with forecast data to reduce locally the prediction uncertainty.

It is important consider that the balloon altitude can not be exactly predicted, due to the thermodynamic model imperfection and, mainly, to the uncertainty on the prediction of air temperature, infrared radiance and albedo. For this reason a Monte-Carlo method, which performs a group of simulations with different border conditions and balloons altitude-time functions, usually is applied both during mission analysis and flight prediction.

4. Applications

We have analyzed several types of missions starting from local or mid-duration flights (up to 24 hours) to long duration flights (one to three weeks). The main launch locations have been: Sicily, Sardinia, Kenya, Arctic and Antarctic. For transmediterranean and local missions from Sicily and for the long duration flights from Svalbard the real-time predictions have been applied to the launches performed during the last six years.

4.1. Local flights

Local flights are governed by the low levels winds that usually are not affected by seasonal fluctuations, like in stratosphere, but mainly by regional meteorology. For a mission of less then three hours the floating phase does not influence the trajectory because the balloon remains above 25 km for a short period, therefore the most important forecast data are provided by the MM5 model and by radiosoundings Musso et al. (2004, 2003); Cardillo et al. (2006). Wind data measured during the balloon ascending phase can be used to predict the parachute reentry providing an uncertainty of few kilometers. Optimization of ballast and valve maneuvers as well as the reentry position can be adopted Musso et al. (2005, 2007).

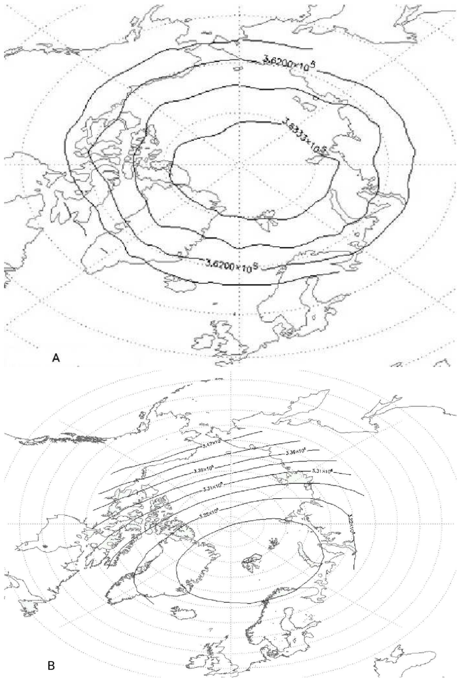

Fig. 2. Isobaric lines at 5 hPa for a summer (A) and winter (B) configuration. The winter trajectories are not centred around the Pole as happens in summer.

4.2. Polar long duration flights

The Poles are the best locations for missions of several days for the very low density population and the stable solar radiation which makes the balloons altitude prediction easier Peterzen et al. (2005); Romeo et al. (2006). The best period is during summer when a stable westward wind forms and it lasts for 50-60 days. In winter a similar eastward wind arrives but now the circular isobaric lines are not centered around the Pole, therefore the balloon trajectory can reach latitudes below 60B0 (Fig 2).

For this kind of flights the ascending phase is not the most important part of the mission because the balloons altitude is greater than 30 km for several days. Now MM5 and ra-

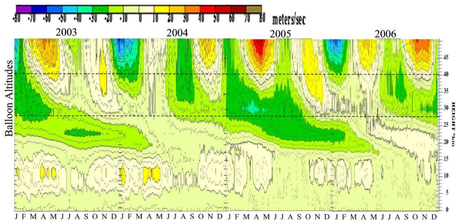

Fig. 3. Intensity of the west/east wind as function of time and altitude and for the years from 2003 to 2006. The west wind conditions (green) form almost every two years (NCEP data).

diosoundings are not important, the main meteorological data are the NCEP or ECMWF forecasts. The total trajectory uncertainty as been evaluated and it grows almost linearly for the first three days up to 200km Romeo et al. (2006). In summer the latitudinal component of the uncertainty is around 40% of the total one.

4.3. *Equatorial flights*

A balloon launched from low latitudes have to deal with a phenomenon called the Quasi-Biennial Oscillation (QSO). Into the stratosphere and near the Equator the east/west wind is affected by a oscillation of 26-28 months. The altitude of the balloon must be carefully chosen because QSO works differently for different heights, in particular at greater altitudes winds can follow seasonal oscillations, as for mid and high latitudes, meanwhile into the low stratosphere the biennial cycle is fundamental (Fig 3). Computing the trajectories we see that the missions calculated with analysis data for the periods of eastward winds are less stable than the westward cases (Fig 4). Finally we argue that there are phases during the transitions between west and eastward winds (or from east to westward winds) that admit missions of some days that remain few hundreds kilometers from the launch base (a sort of local flight of some tens of hours, or turn around case) (Fig. 5).

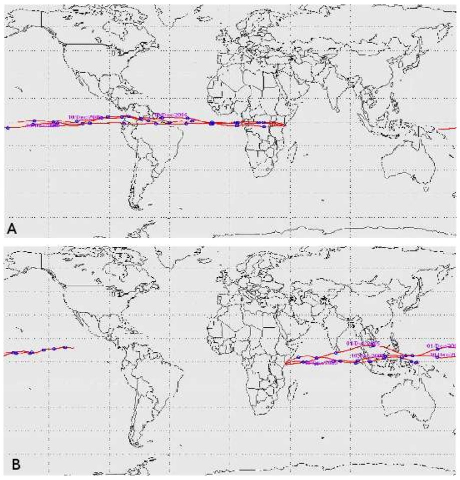

Fig. 4. Examples of west (A) and east (B) missions (12 days at 30C735 Km of altitude). The east winds have lower intensity and they allow greater oscillations in the north/south direction.

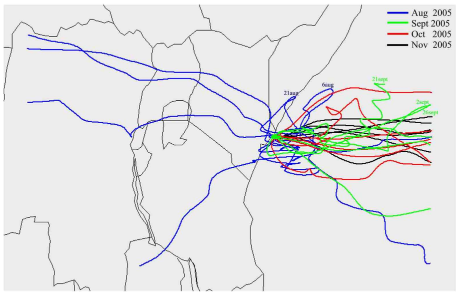

Fig. 5. Tree-four days missions during a biennial transition phase of the west/east wind at the equator. The balloon could remain near the launch area.

5. Conclusions

Meteorological computer based data are essential for stratospheric balloon missions.

Adopting ECMWF analysis data meteorologists and researchers can define the best launch location and period which allow a particular type of mission as requested by scientific and technical constrains.

During flight operations the operational team must use forecast data, satellite images and radiosoundings to predict the balloon trajectory. Particular attention at this phase of the Italian balloon activities are focused on long duration flights from Svalbard, both in summer and winter, and from Malindi (Kenya).

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