Royal Netherlands
Meteorological Institute
*Ministry of Infrastructure
and Water Management*

Sensing the wind with hot-air balloons and their application in NWP models

Evert I.F. (Cisco) de Bruijn [1] , Fred Bosveld [1] , Siebren de Haan [1] , Gert-Jan Marseille [1] and Bert Holtslag [2]

We report about a novel 3rd party observation, namely wind measurements derived from Hot-Air Balloon (HAB) tracks. At first we compare the HAB winds with other upper air observations, namely wind measurements from the meteorological mast situated at the Cabauw observatory in the Netherlands. Subsequently, we validate the HAB data with the Background Model state of the mesoscale HARMONIE NWP model during late spring and summer of 2018. The deviations are relatively small and subsequently we use the HAB wind in data assimilation. We study the impact of typical summer evening flight with moderate winds and it is shown that HAB observations can improve the forecast.

Introduction

Numerical Weather Prediction (NWP) models with a horizontal grid size of 2 km or less need detailed observational information for estimating the initial state of the atmosphere. Ground-based remote-sensing instruments like Sodars, Doppler lidars and Profilers provide already meteorological information of the Atmospheric Boundary Layer (ABL). The observational network has been extended over the years, but there are still gaps and it is not cost-efficient to extend the network infinitely.

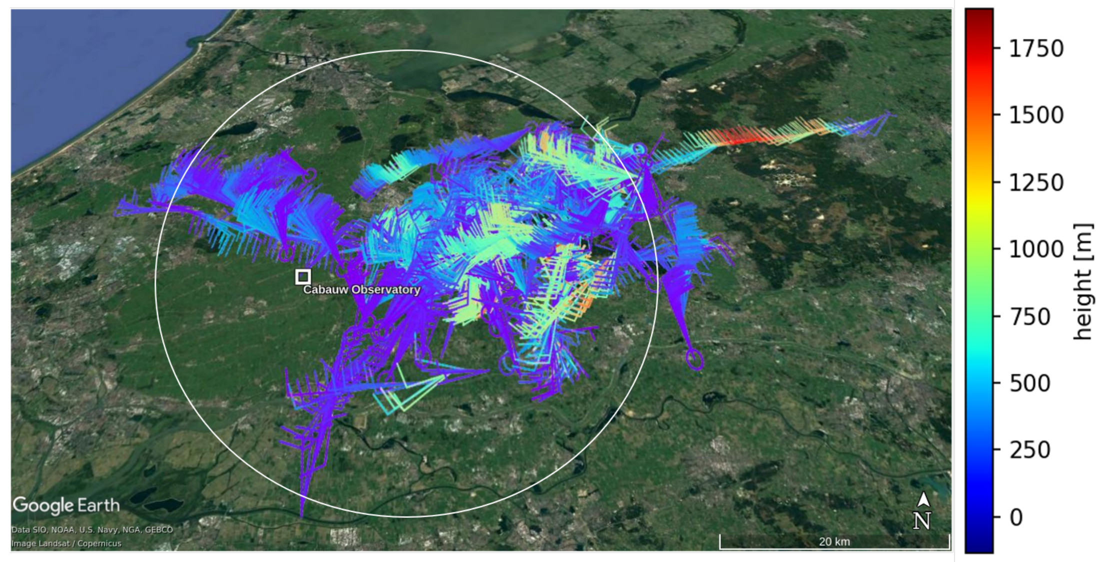

Figure 1: *Hot-air Balloon (HAB) flights in the surroundings of Cabauw (The Netherlands) during May-September 2018.*

Therefore we have commenced research to investigate data from third parties. We focus on wind-information of the ABL from recreational Hot-air Balloon (HAB) flights. In the basic equipment of a HAB-pilot there is a professional navigator, which is compulsory for safety reasons. Similarly to routinely launched weather balloons, the Global Navigation Satellite System (GNSS)-data from consecutive positions and the elapsed time are the basis of the calculation of the horizontal wind vector. The HAB responds to changing wind with a response length of approximately 100 m. This response length which comprises the physical properties of the HAB, is derived theoretically in [1] and validated empirically in [2].

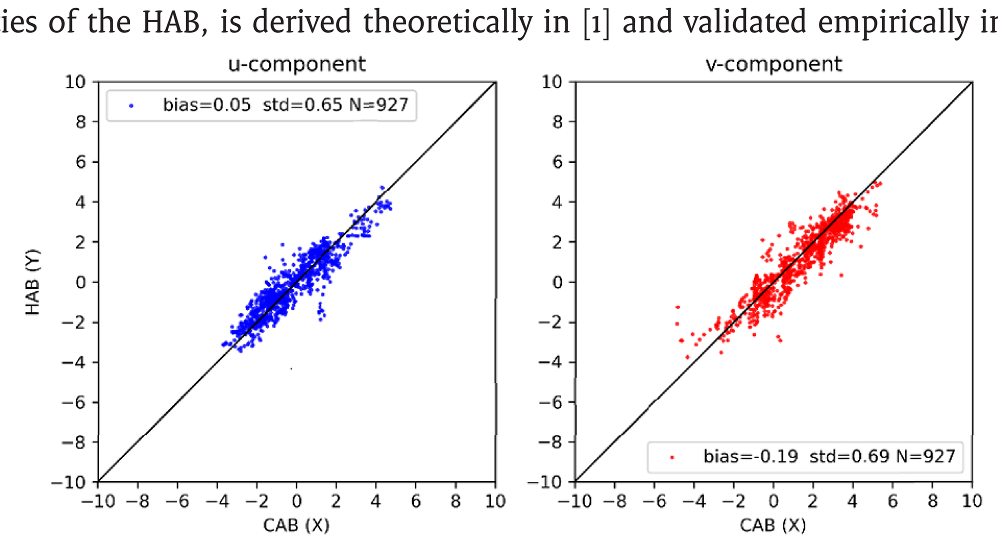

Figure 2: *HAB flights as depicted in Figure 1, but cross validated with mast observations at Cabauw (The Netherlands).*

Cross validation

Our data-set consists of 90 HAB flights during the May-September 2018. They were provided by local balloon operators as a response to our request of data. The flights took predominantly place in the late afternoon when the ABL stabilized and were located in The Netherlands. We have created a subset of the HAB dataset by selecting by a circular area with a 30 km radius, centered at Cabauw (Figure 1) and by considering data not exceeding the height of the mast. The start location can be inside or outside this zone and is determined by the balloonist. A part of the flight should be in the circular area. A good start location should have no tall obstacles and an undisturbed wind. The pilot makes an estimate of where he could possibly land using predicted winds, payload and the amount of fuel. A favourable landing place is an uninhabited area far away from obstacles. The Cabauw mast has booms with cup anemometers and wind vanes at 10,20,40,80,140, and 200 m. The mast measurements are processed, validated and gap-filled. In Figure 2 the HAB and Cabauw wind observations are presented in a scatter diagram. The cloud of points is close to the 1-to-1 line, which means that the uncertainty in both observational systems is small. Both systems are sampling a neutral-stable PBL with a rather homogeneous wind field. Further the maximum u,v components are not beyond 6 ms^{-1}, which confirms the light wind regime.

Mountain flight with a HAB

We launched a HAB flight in a mountainous region (Figure 3) in Austria[3] to determine whether this method would also work in more complex terrain, and used data from an automated weather station (AWS) 10 km south-southwest of the eventual landing point, in Hahnenkamm, as a basis for comparison. The takeoff was at 1018 UTC 16 January 2005 from Sankt Johann (Tyrol), and the flight lasted 96 min.

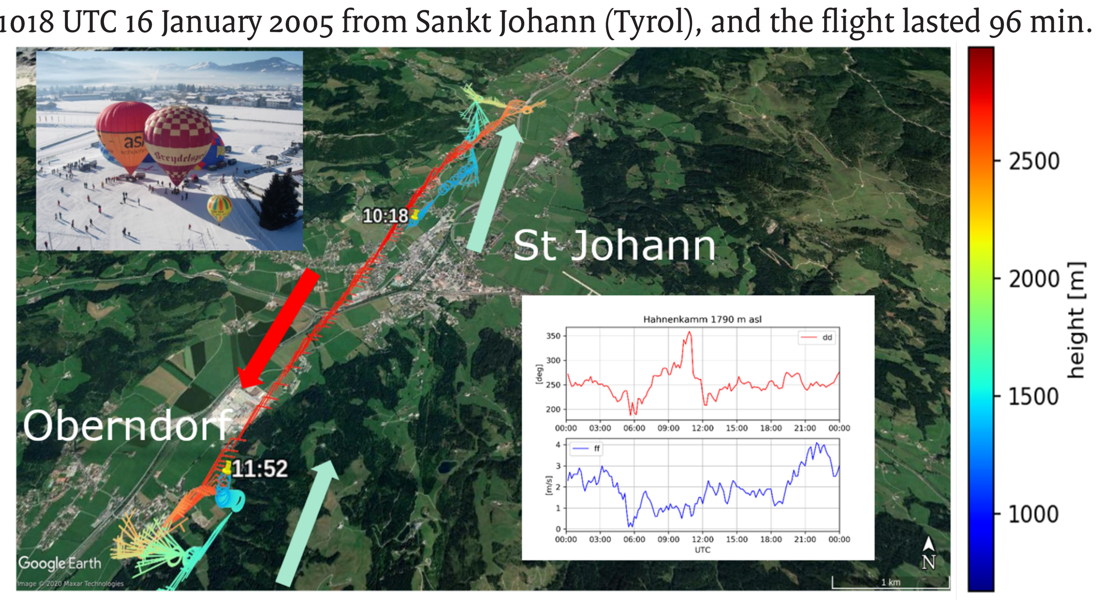

Figure 3: *16 January 2005 10:18-11:52 UTC, Mountain HAB flight near Sankt Johann (Tyrol, Austria), in the valley the winds are opposite to the winds above the inversion. The left and right subplots show respectively the take-off and the nearby Hahnenkamm AWS wind observations*

During the time of this flight, high pressure was centered over eastern Europe with a secondary center over northern Italy. The synoptic influence on the region was sufficiently weak to allow local wind effects to dominate. The surface was covered with snow, preventing development of thermals, and an inversion was in place in the valley. Nearer the ground, the HAB path was toward the north, but above the inversion it entered a different wind regime and began drifting to the south under the influence of a ridge set up by the synoptic pressure distribution. Descending after 1 h, southerly winds prevailed and the HAB passed through a layer with considerable wind shear. Close to the surface the HAB was again advected northward. The collected balloon data were in some agreement with the local AWS in this case.

Observation-Background statistics

In Figure 4 we compare HAB-winds with First Guesses of the HARMONIE model for a period of 5 months in spring/summer 2018 [4]. The dataset has many gaps, because HAB flight require light winds and take place just after dawn or a couple of hours before dusk. The First Guess or Background state is the +03 h forecast of the previous cycle. HARMONIE runs every three hours and the time window is 1.5 hours.

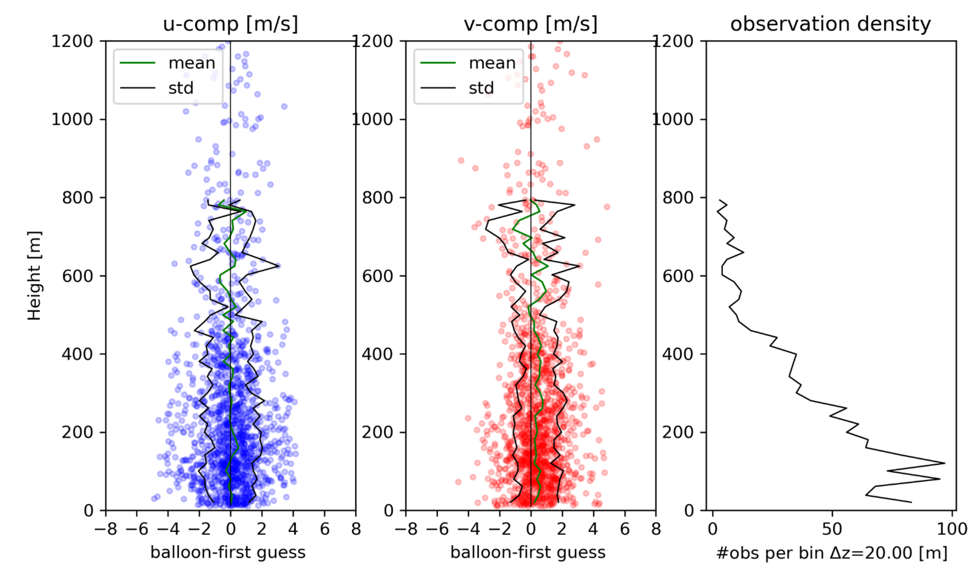

Figure 4: *Observation-Background statistics of HAB-winds during May-September 2018.* σ_u=1.9 ms^{-1}, σ_v = 2.1 ms^{-1}. *Note that bias and standard deviation are only displayed as long as they are significant.*

For this exercise we have applied all available data in the dataset. This means that also data beyond the 30 km radius and above 200 m are used. Note that the data are derived from navigation devices of HAB-pilots and they are not real time collected. However real time collection, essential for data assimilation is feasible with smartphones which has been investigated in [2]. The data are binned in vertical bins of 5 m and the observation density is given in right panel. Most of the data are below 1000 m. The bias and standard deviation in Figure 4 reveal that the observations are realistic. The relatively large bias is not fully understood. Perhaps the turbulence scheme of HARMONIE has difficulties with the mixing during the transition from neutral to weakly stable conditions.

Data assimilation

Based upon the above results, we take the next innovative step namely the application of HAB data in a NWP model [3]. We conducted a 3DVar data assimilation study with data from a HAB flight from The Netherlands (Figure 5), which started in De Bilt at 15 September 2012 16:02 UTC and ended in Amersfoort at 17:03 UTC with a traveled distance of 19.5 km. At 16:30 UTC the HAB reached the ceiling of the flight which was at 1428 m. At that point we see a remarkable change in direction. Apparently the balloon has entered a layer with a different wind regime. We now study a trajectory which is based on hindcasted NWP wind fields and which is depicted by the red line in Figure 5. For a fair comparison, the vertical displacement is completely prescribed by the HAB. Clearly, the NWP trajectory is different and the position error at the endpoint is 8.8 km. We have assimilated the observed HAB winds during 28 min of the flight and interpolated the observations to the analysis time at 16:00 UTC. In the pre-processing we have rejected the HAB data just after take-off, because the HAB cannot move freely at that stage. With the updated run, we calculate the trajectory which is depicted in blue in Figure 5. The deviation at the endpoint reduces to 2.9 km.

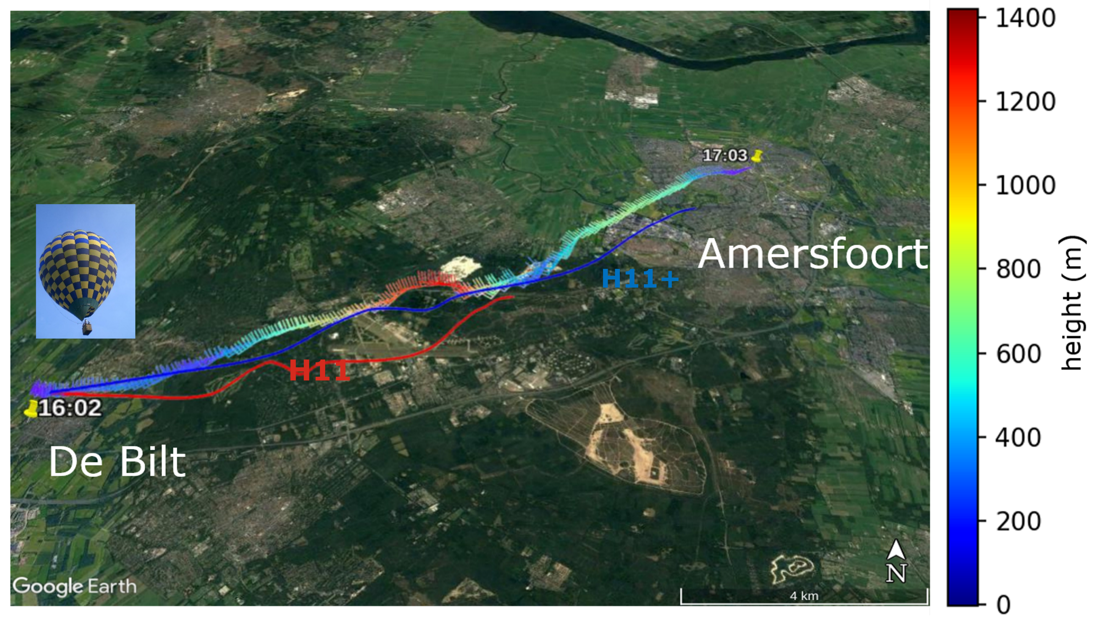

Figure 5: *15 September 2012 16:02-17:03 UTC, Trajectories from a HAB flight depicted in wind flags, calculated trajectories from NWP depicted in a red solid line, calculated trajectories from NWP with assimilated HAB data, depicted as a blue solid line.*

Conclusions

HAB flights provide interesting wind information in the ABL and are in agreement with the high quality Cabauw mast observations. Observation minus Background statistics reveals that the errors in HARMONIE are relatively small i.e. σ_u =1.9 ms^{-1} and σ_v =2.1 ms^{-1}. The HAB wind observations can be used in data assimilation and the first results are promising. Of course HAB observations can be applied to validate longer lead times, revealing the model's performance in light to moderate wind conditions. Finally, third party observations are a welcome supplement to existing wind information systems and can be applied for the improvement of short term weather forecasts.

References

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[1] R&D Department of Observations and Data Technology, Royal Netherlands Meteorological Institute. PO Box 201, 3730 AE De Bilt, The Netherlands. [2] Wageningen University and Research, Wageningen, The Netherlands.Contact: cisco.de.bruijn@knmi.nl