



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

Cisco de Bruijn¹, Fred Bosveld¹, Siebren de Haan¹, Gert-Jan Marseille¹ and Bert Holtslag²

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 special case with strong baroclinicity and it is shown that a HAB observation can improve the initial state of the model.

Introduction

Numerical Weather Prediction (NWP) models with a horizontal grid size of 2 km or less need detailed 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.

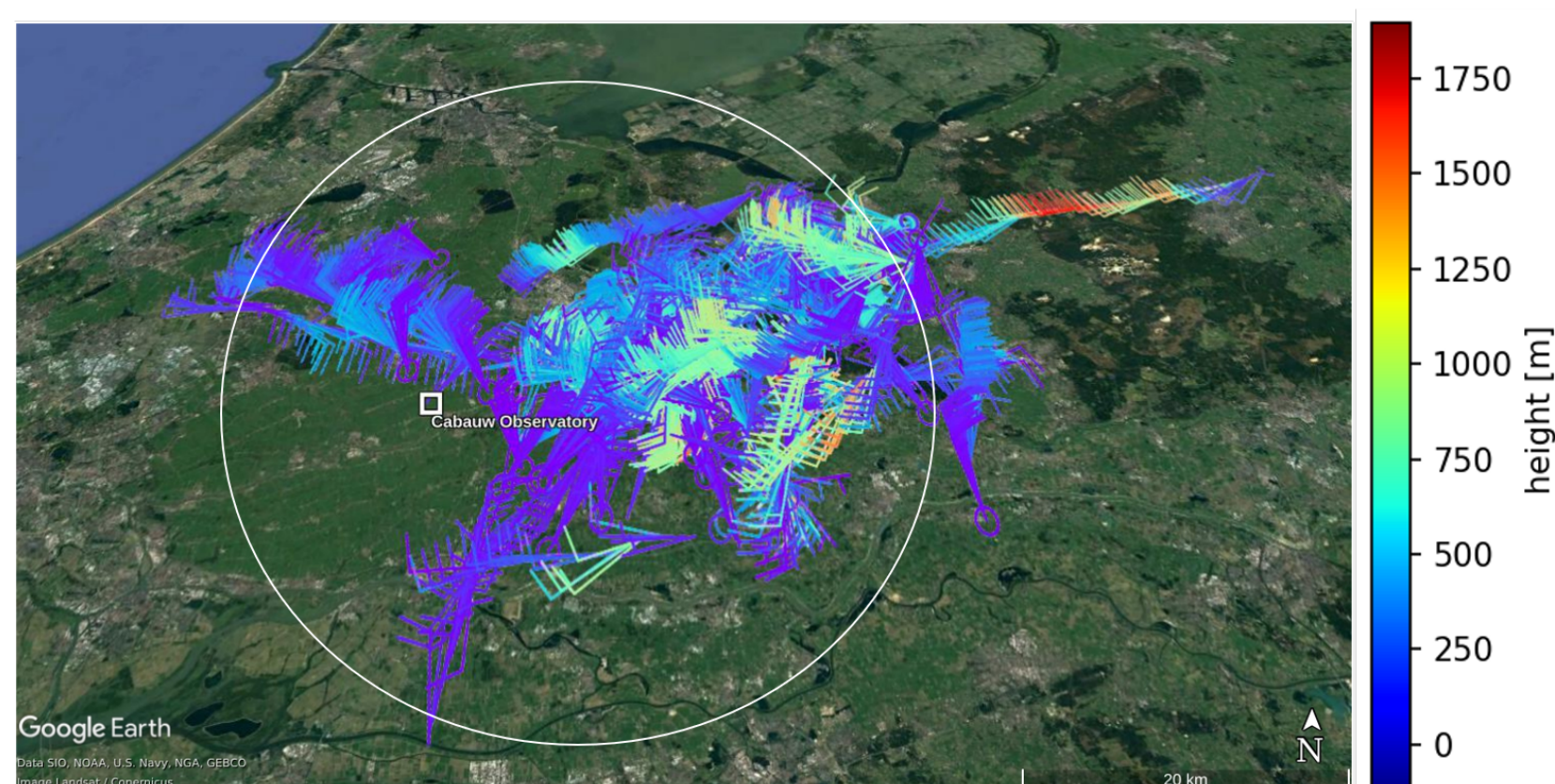


Figure 1: Hot-air Balloon (HAB) flights in the surroundings of Cabauw (The Netherlands) during May-September 2018.

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].

Cross validation

Our data-set consists of 90 HAB flights during the May-September 2018. They were provided by two 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 and by considering data not exceeding the height of the mast. The Cabauw mast has booms with cup anemometers and wind vanes at 10, 20, 40, 180, 120 and 200 m. The mast measurements are processed, validated and gap-filled. In Figure 1 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.

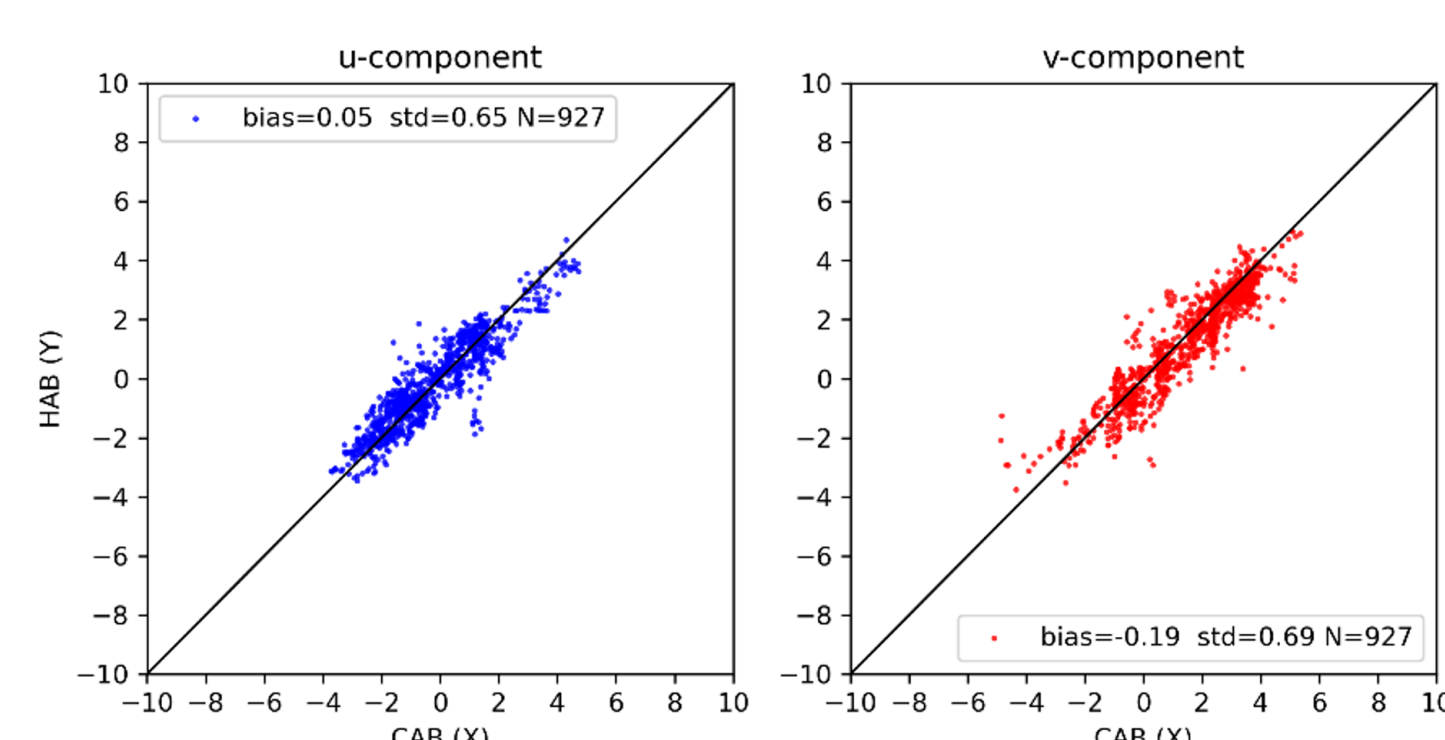


Figure 2: HAB flights as depicted in Figure 1, but cross validated with mast observations at Cabauw (The Netherlands).

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 wind regime with diminishing turbulence.

Observation-Background statistics

In Figure 2 we compare HAB-winds with First Guesses of the HARMONIE model for a period of 5 months in spring/summer 2018. 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.

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].

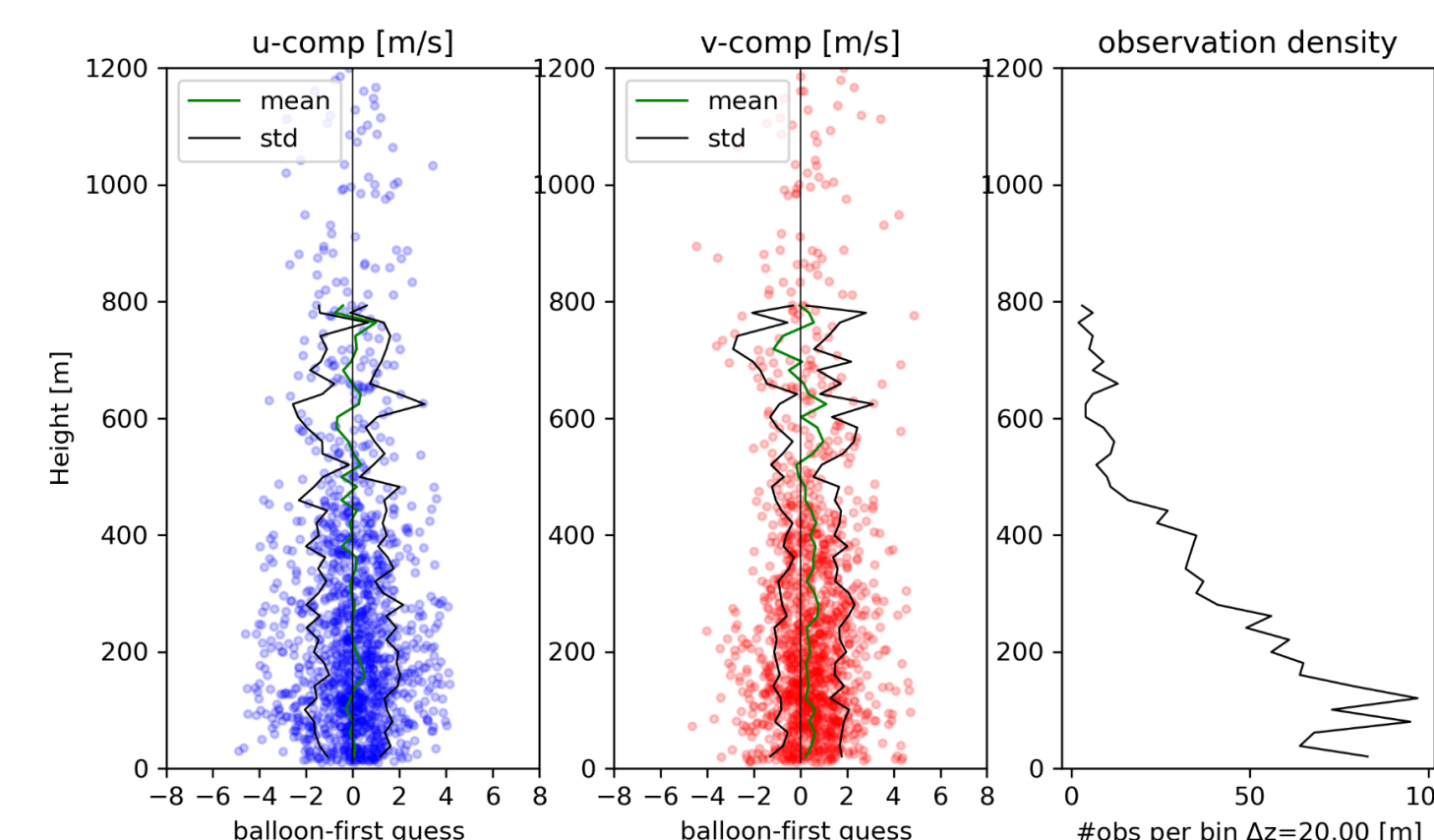


Figure 3: Observation-Background statistics of HAB-winds during May-September 2018. $\sigma_u = 1.9 \text{ ms}^{-1}$, $\sigma_v = 2.1 \text{ ms}^{-1}$. Note that bias and standard deviation are only displayed as long as they are significant.

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 are shown and 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

A complete data assimilation experiment is not a trivial task for a new observation type. In [3] a first attempt was made with the HIRLAM model using a predecessor of the 4DVAR assimilation scheme. In HARMONIE the 4DVAR system is not operational, so yet we have used the 3DVAR scheme. A 3DVAR system cannot optimally handle the temporal information of asynoptic observations and to mitigate the timing issue, we have used an observation at exactly 18:00 UTC, which is the analysis time. We have conducted a special data assimilation experiment to study the impact of a single wind observation. From Figure 4, the background innovation for a single observation shortly denoted as (o-b), equals 2 ms^{-1} and -0.8 ms^{-1} for the u and v wind component respectively.

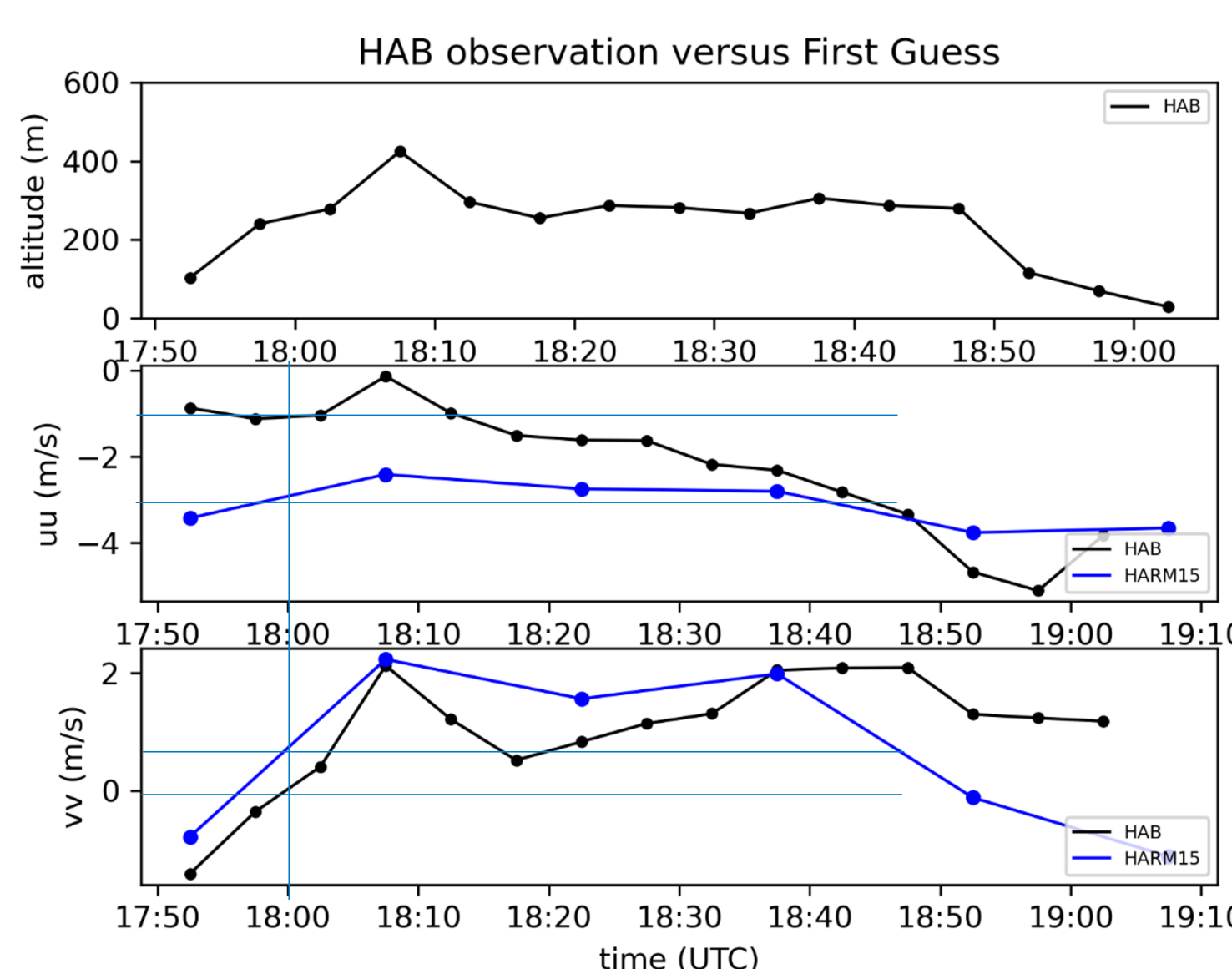


Figure 4: First Guess at 15:00 UTC and wind data from a Hot-air Balloon during 7 August 2018, a single wind observation at 18:00 UTC is assimilated.

From Figure 5, the increment (a-b) at the observation location equals 0.8 ms^{-1} and -0.08 ms^{-1} for the u and v wind component

respectively. As a result we can write for the analysis innovation, for a single observation shortly denoted as (o-a): $o-a = (o-b) - (a-b)$. This equals 1.2 ms^{-1} and -0.72 ms^{-1} for the u and v wind component, respectively. In other words, assimilation of the hot-air balloon observation has drawn the model state toward the real atmospheric state, represented by the atmospheric observation.

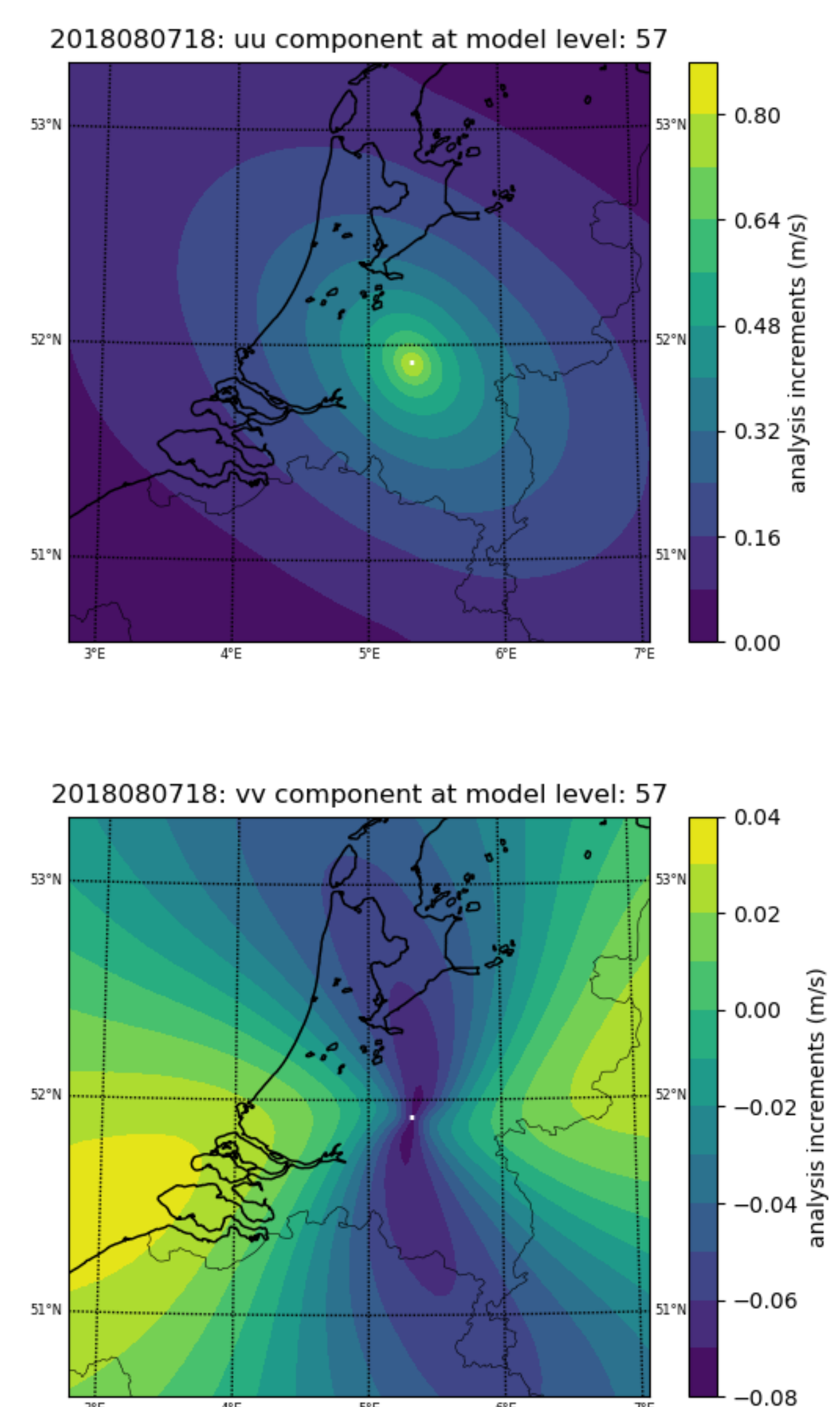


Figure 5: HARMONIE innovations of zonal and meridional wind components at model level 57 (245 m AGL). The white dot is the location of the observation.

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. $\sigma_u = 1.9 \text{ ms}^{-1}$ and $\sigma_v = 2.1 \text{ ms}^{-1}$. 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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