Mode-S Enhanced Surveillance derived observations from multiple Air Traffic Control Radars and the impact in hourly HIRLAM

Siebren de Haan

1 Introduction

Upper air wind is one of the most important parameters to obtain a good analysis using a data assimilation method. High resolution observations are beneficial for Numerical Weather Prediction with a rapid update cycle [1, 6]. Local observations have a localized and short term effect [4, 5]. For numerical nowcasting, rapid availability is also a crucial factor. Furthermore, numerical nowcasting will become more accurate on longer forecasting time-scales when more data from a larger area becomes available. Since 2008, KNMI is receiving Mode-S Enhanced Surveillance (EHS) data from the Air Traffic Control (ATC) radar at Schiphol airport. This dataset is made available by the ATC The Netherlands (LVNL). The coverage of this dataset is the Dutch airspace, retrieving information from all aircraft within a 200 NM range of the tracking radar. This data can be used to derive wind information with good quality when compared to NWP and AMDAR [2, 3]. However, one should note that temperature information derived from Mode-S EHS is of less quality. Assimilation of wind and temperature observations derived from data received from LVNL in the HIRLAM model showed a positive impact up to four hours into the forecast [6].

This short report addresses the first attempts to assimilate Mode-S EHS derived wind information from a larger area exploiting the Dutch, German and Belgium Mode-S EHS radar information. A very straightforward thinning scheme is applied. When assimilated in the hourly update cycle of HIRLAM7.4, an improvement in wind forecast is observed up to a forecast time of 9 hours for wind speed and wind direction. Especially, below 700 hPa a large improvement is observed up to 18 to 24 hours in range for wind direction forecasts.

2 Mode-S EHS

The Mode-S project started in 2008. Since then several studies have been performed on the quality of the data [2, 3] and the usage in numerical weather prediction [6, 4].

The concept of Mode-S EHS is created to become the next generation of air traffic management systems. A Mode-S EHS systems consists of a user segment and a ground segment by exploiting (amongst others) the GNSS positioning technique. The user segment is an aircraft equipped with a Mode-S transponder; the aircraft determines its position using GNSS satellites. The ground segment consists of a Mode-S Enhanced Surveillance tracking radar which is capable of interrogating the Mode-S transponders for specific registers.

Within the European designated EHS airspace, all fixed wing aircraft, having a maximum take-off mass greater that 5,700 kg or a maximum cruising true airspeed in excess of 250 kts, intending to fly instrument flight regulation (IFR) must be Mode-S EHS compliant. An aircraft is compliant with Mode-S EHS when it provides basic functionality features (such as position and flight number) plus eight downlinked aircraft parameters. The downlinked parameters are selected altitude, roll angle, track angle rate, true track angle, ground speed, magnetic heading, true airspeed, and Mach number.

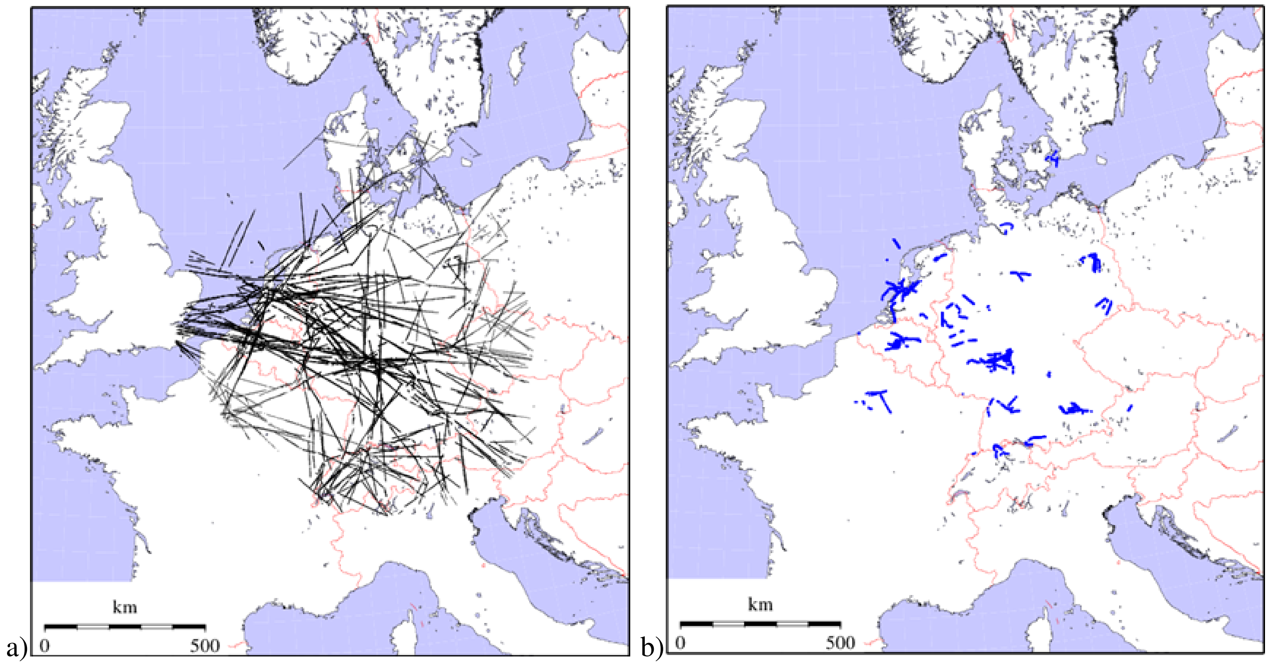

Figure 1: An example of the quality controlled and corrected wind observations in a 15 minute interval. Panel a) shows all observations; panel b) shows the observations below FL100.

An aircraft observation closely linked to Mode-S EHS is Mode-S MRAR. It uses the same ground and user segment, but the ATC radar interrogates a different register, the so-called Meteorological Routine Air Report. This register contains already wind and temperature information of good quality. Unfortunately, although aircraft are obliged to respond to a Mode-S radar request, only around 5% of the aircraft transmit this requested information since it is not obligatory [8].

2.1 Observations from Mode-S EHS

From the downlinked information wind and temperature can be derived.

Wind information is inferred from the vector difference between the air vector (airspeed and heading) and the ground vector (ground speed and track angle). Temperature is calculated using the Mach number and the observation of the airspeed. After heading correction and airspeed correction the wind information derived from Mode-S EHS information has good quality compared to AMDAR and NWP. Details of the derivation and quality can be found in [2] and [3]. In short, the wind vector $\mathbf{V}$ is the difference between the ground vector $\mathbf{V}_g$ and the air vector $\mathbf{V}_a$.

$$\mathbf{V} = \mathbf{V}_g - \mathbf{V}_a, \tag{1}$$

and

$$T = K(V_a/M)^2, \tag{2}$$

where K is a constant, V_a is the airspeed and M is the Mach number.

Since the heading is reported with respect to the magnetic north, a heading correction must be applied to obtain a heading with respect to true north. Additionally, an aircraft dependent heading correction needs to be employed [2]. On top of the heading correction, an airspeed correction is deployed. The accuracy of an airspeed observation should be within 3%, according the FAA regulations (FAA). The error in airspeed and error in wind are directly related (see 1). Airspeed correction can improve the wind observation by roughly 2%, see [3]. Therefore a dynamic heading correction lookup table and a static airspeed correction lookup table were constructed. Both tables were based on continuous comparison of the measured heading and airspeed

Figure 2: Model domain used in this study.

using Numerical Weather Prediction (ECMWF) data. These lookup tables are aircraft dependent and the heading correction table needs to be updated regularly.

2.2 Mode-S EHS MUAC observations

The Mode-S EHS radar dataset used in this study is collected by EUROCONTROL Maastricht Upper Area Control (MUAC). The data set consists of all Mode-S EHS radars from the Dutch, German and Belgium ATC organizations. A copy of the operational radar dataset is made available in 15 minute batches with a delay of approximately 10 minutes. Figure 1 shows an example of the locations of all quality controlled and corrected wind observations in a 15 minute interval. In total more than 73 thousand observations are available 1a), with more than 6.6 thousand observations below Flight Level 100 (approximately 3km) 1b).

3 Numerical Weather Prediction

A hourly cycle of HIRLAM (v7.4) is used to show the impact of assimilating Mode-S EHS. The resolution of the model is 11 km with 40 atmospheric levels. The hourly cycle uses a re-forecast every hour in order to be able to assimilate observations that generally have a long latency (scatterometer and AMSU-A observations from polar orbiting satellites, and radiosonde). The one hour forecast of the delayed run is then used as the first guess in the "real-time" run. The delayed run has (obviously) a cycle of one hour. The assimilation method deployed here is the HIRLAM 3D variational method, see for example [7].

Figure 2 shows the domain of the hourly run. A first order, rather basic, thinning procedure is applied to the MUAC derived observations. The model domain is separated into 50 squared kilometre boxes each with a thickness of 300 m and only one single observation is selected per box; the observation closest to the assimilation time.

4 Impact

For a three week period two H11 runs have been run in parallel. Both are run in operational mode and use exactly the same boundaries and observations, except of course the MUAC Mode-S EHS derived observations. All observations used in the assimilation are also used to compare previous model forecasts at different

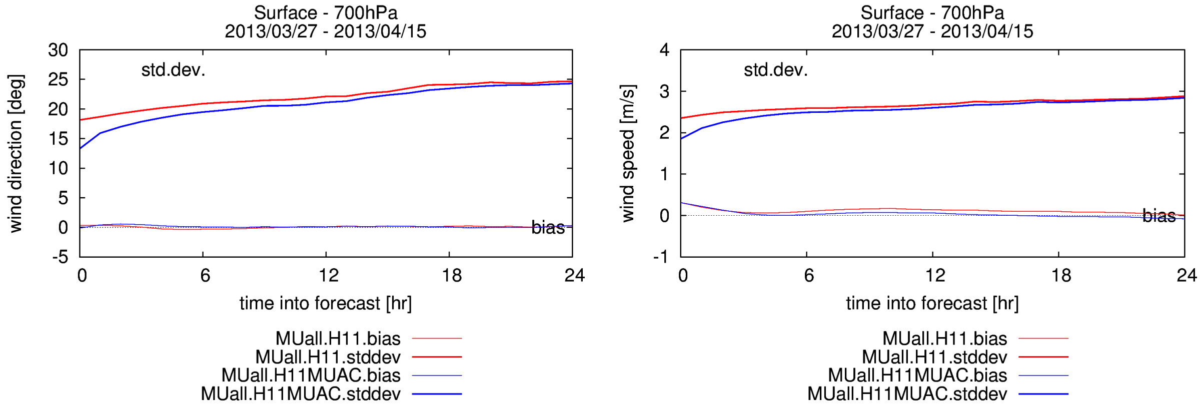

Figure 3: Impact on wind direction and wind speed. Comparison of Mode-S EHS MUAC observations between surface to 700hPa with independent forecasts ranging from +00 (analysis) to +24.

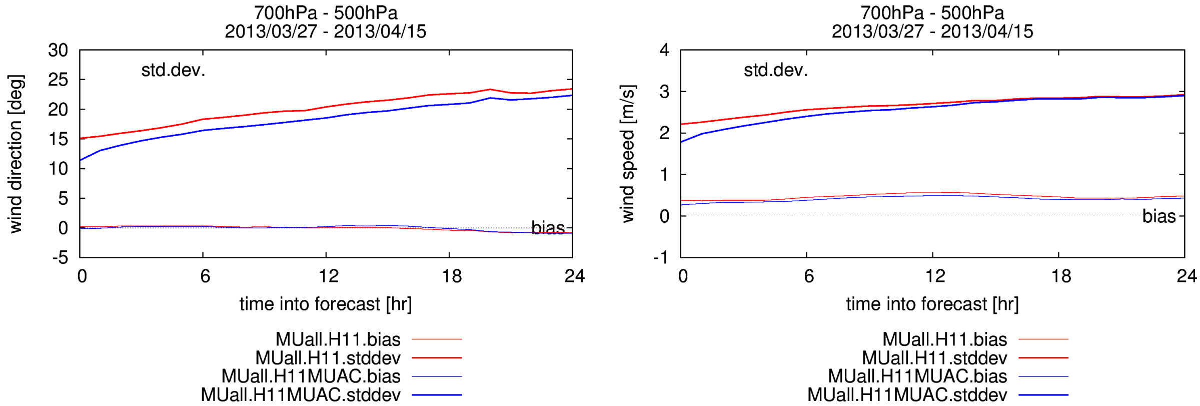

Figure 4: Impact on wind direction and wind speed. Comparison of Mode-S EHS MUAC observations between 700hPa and 500hPa with independent forecasts ranging from +00 (analysis) to +24.

forecast lengths. The standard HIRLAM 3DVAR routine is (slightly) adapted to be able to perform this dynamic forecast comparison.

Figure 3 shows the impact on wind speed and direction from the surface to 700hPa and Figure 4 shows the impact between 700hPa and 500hPa. Both model runs show comparable and small biases over the whole forecast range for both parameters indicating that there is no gross error in the observations. One remark has to be made on the small wind speed bias in the lowest level, which could be related to not optimal airspeed correction tables for lower airspeed; this will be investigated in future research. The positive impact on wind direction is most pronounced in the 700hPa to 500hPa layer and is visible over the whole forecast range. Also, the wind direction forecast in the lowest layer shows an improvement when MUAC data is assimilated, however after 12 to 15 hours the impact is neutral. Wind speed forecasts improve up to 6 hours in the lowest level and up to 9 hours in the level between 700hPa and 500hPa.

5 Conclusion and outlook

In this short paper it was shown that high resolution numerical weather prediction models benefit from high resolution observations of good quality. Impact on wind direction and wind speed forecast is observed in an operational comparison of two identical runs, one with Mode-S EHS MUAC derived observations assimilated and one without this data set.

The positive impact is still visible after 24 hours for wind direction in the level between 700hPa and 500hPa. For the surface level the impact on wind direction forecast is positive up to 12 hours.

The wind speed forecasts improve up to at least 9 hours into the forecast.

Despite the cruel thinning procedure a positive impact is observed. Only a fraction of the wind information is used in the assimilation. Next research steps, with HARMONIE within SESAR WP11.2, will be undertaken to improve the usage of Mode-S EHS derived observations.

5.1 Acknowledgement

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