Aircraft as a meteorological sensor
Using Mode-S Enhanced Surveillance data to derive upper air wind and temperature information
Photo cover:
A KLM Airbus A330-200 lands at Amsterdam Airport Schiphol in The Netherlands. Increased aircraft movements will result in a greater number of meteorological observations.
Aircraft as a meteorological sensor

Using Mode-S Enhanced Surveillance data to derive upper air wind and temperature information

Assimilation of Mode-S EHS derived observations in rapid update cycles of numerical weather prediction models will result in better nowcasts of wind information for the meteorological and air traffic management community.

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Introduction

Upper air atmospheric wind and temperature information is crucial for numerical weather prediction and nowcasting. The current observation systems which are exploited to collect this information are radiosonde, wind profilers, Doppler radar, satellites, and aircraft via the AMDAR program of the World Meteorological Organization (WMO). A novel method to measure wind and temperature is related to tracking and ranging by an enhanced surveillance (EHS) Air Traffic Control (ATC) radar. This EHS radar interrogates in a selective mode (Mode-S) all aircraft in sight on which the aircraft replies with a message containing for example magnetic heading, airspeed and Mach number. From this information wind and temperature can be inferred.

Origin of the initiative

The Royal Netherlands Meteorological Institute (KNMI) started research on utilizing Mode-S EHS data on request of Air Traffic Control The Netherlands (LVNL) in 2008. The objective was to develop and implement a system to provide nowcast and forecast of wind, temperature and air-density data in a 4D grid covering an area with a radius of about 250 NM around Schiphol, from sea-level to FL450. The prime use of this service will be the trajectory prediction function for arrival management of LVNL. A second goal is the provision of meteorological data to airlines and other users in the air traffic management domain. LVNL provided KNMI with a 10 minute update of the Mode-S EHS data containing the downlink aircraft parameters (DAPs) of the BDS registers 4.0, 5.0 and 6.0, see table 1.

The use of ADS-C data - another opportunity to collect meteorological observations

KLM aircraft transmit messages at standard positions or intervals or on request of the KLM dispatch department. These are called Automatic Dependent Surveillance Contract messages (ADS-C) and are different from AMDAR and Mode-S EHS but contain the same type of information. Based on a global set of 76 days of ADS-C messages from KLM a KDC study has been performed in 2011. It showed that around 23 % of the 71,832 messages contained meteorological information. The direct and derived wind observations are of good quality compared to ECWMF data and Mode-S EHS derived observations. The ADS-C temperature observations are of better quality than Mode-S EHS. The Mode-S EHS derived wind information is available with a temporal resolution of 4 seconds, while ADS-C reports are less frequent. Because of this difference in temporal resolution profile information of ADS-C in this data set is limited. Improving the vertical resolution of wind and temperature observations can be achieved by requesting more reports for ascending and descending aircraft, but will result in increased data communication costs.

Table 1: Mode-S EHS downlink aircraft parameters (DAPs). Fixed wing aircraft that can provide the list of 8 DAPs displayed in this table are considered to be Mode-S EHS capable. Where the parameter 'Track Angle Rate' cannot be provided 'True Air Speed' should be used instead. Source website EUROCONTROL.
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Derivation process and corrections developed

Since meteorological information is not directly measured in this way, preprocessing is necessary to obtain atmospheric information with adequate quality. Temperature is deduced from the Mach number and airspeed, see separate box. The wind vector is deduced from the difference between the ground track vector and the orientation and speed of the aircraft relative to the air, as is sketched in an idealized setting in figure 2. The ground track is observed accurately but the aircraft orientation contains systematic errors and preprocessing steps for heading and airspeed are essential (figure 3).

Since the magnetic heading is reported a correction to true north is necessary. It is very likely that (slightly) outdated magnetic variance tables are used in aircraft and thus an additional correction might be needed. Research also showed that aircraft have specific and time dependent heading offsets. The true north heading is obtained by a correction of the reported magnetic heading for each individual aircraft and taking into account a latitude and longitude dependent correction based on magnetic variance model as defined using the International Geomagnetic Reference Field by Maus and Macmillan. In order to determine the heading correction two methods have been developed. The first takes into account the heading of the aircraft when it (just) has landed on the runway. When on the runway with a significant speed the heading of an aircraft and the runway should match. The limitation of this method is that heading correction can only be applied for aircraft regularly landing at Amsterdam Airport Schiphol. The second method is by using external wind information and calculating backwards what the heading (and airspeed) of the aircraft should have been assuming that the external wind

Temperature derivation and correction

Mode-S EHS temperature is derived using the measurements of the downlinked Mach number and airspeed. The airspeed is not observed by the aircraft, but derived from the measured Mach-number (using a pitot-probe) and temperature (using a sensor), because the Mach-number is the quotient between the airspeed and the speed of sound. The latter is dependent on the temperature.

We use the following equation to determine the temperature \( T \) from the Mach-number \( M \) and airspeed \( V_{\text{air}} \). \[
T = \text{Constant} \times (V_{\text{air}}/M)^2.
\]

Investigation on temperature differences between numerical weather prediction temperature and Mode-S EHS temperatures revealed aircraft flight phase (ascending, level flight or descending) and time dependent signals. Therefore, for each aircraft, flight phase and time, a temperature correction is applied to the Mode-S EHS derived temperature which resulted in a decrease of the standard deviation by 50%.
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Quality of the derived meteorological observations

Assimilation in a numerical weather model
experiment to cope with the large observation densities. Research is ongoing to compute background error correlation structure based on the actual weather observation and by doing so increasing the added value of the new observations for improved weather forecasts.

**Benefits for ATM and meteorological community**

The future ATM system is developing towards performance based navigation as laid down in the ICAO Global Air Navigation Plan and the associated ICAO Aviation System Block Upgrades (ASBU). Important elements of this evolution, also described in the European ATM Master Plan, are the introduction of concepts such as 4D Trajectory Management, Arrival Managers (AMAN), Departure Managers (DMAN) and Continuous Descent Operations (CDO). An important enabler for these concepts is the availability of accurate and high quality wind nowcast and forecast information. It is envisaged that aircraft could downlink accurate wind information directly as a source for deriving these accurate forecasts. Until this will be implemented, deriving meteorological observations from e.g. Mode-S EHS data and to assimilate these into numerical weather models is an essential component in providing the ATM community with the accurate wind information they require.

KNMI will make available the derived meteorological data from Mode-S EHS sources to the global meteorological community free of charge in line with the WMO practice of sharing information between national meteorological services. Terms and conditions for the use of this information apply, including the disclaimer to not use the data for any commercial purpose.

**Limitations**

Using the aircraft as a sensor implies that observations are available only at those locations where aircraft are operating. Furthermore, it is essential that ATC interrogates aircraft to provide the EHS BDS registers 4.0, 5.0 and 6.0, and that aircraft are capable to respond to this interrogation. For this reason there are for example no Mode-S EHS data available over the oceans. In these regions other methods of collecting observations can be used like AMDAR or ADS-C, see separate box. And finally, that the meteorological community is able to retrieve the EHS information either directly via ATC or by using a public ADS-B Mode-S EHS receiver, see separate box.

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Figure 5: Current coverage of Mode-S EHS derived and quality controlled Wind and Temperature observations available at KNMI. The example shows 15 minutes of observations for a day in August 2012 over Western Europe, source MUAC in ASTE-RIX Cat 48 format, processed by KNMI. The left panel shows all derived observations, the right panel the derived observations below Flight Level 100. In total there were almost 4 times as many (258,940) BDS 4.0, 5.0 and 6.0 observations available in this time period. The reason that less derived observations are available is the fact that at that time heading correction was only available for aircraft regularly arriving and departing at Amsterdam Airport Schiphol. The number of derived observations will increase when the new correction method based on external sources of wind information will become operational.
**Next steps and foreseen developments**

Currently EHS designated airspace is notified by the Civil Aviation Authorities of Germany, United Kingdom, France, Belgium and The Netherlands. Within this airspace Mode-S EHS data is available in all countries except for France, where data is expected to be available in 2014. It is planned to expand the current geographical coverage of the observations, see figure 5, by exploiting the Mode-S EHS data of France and United Kingdom. The area can be further enlarged over the European area when more States are implementing Mode-S EHS.

A way forward to improve the quality of the temperature observations is the interrogation of BDS register 4.4 which contains a direct temperature read out of the aircraft and is of similar quality as AMDAR. A dialogue with ATC organizations is ongoing to explore opportunities in this regard.

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More detailed information on the Mode-S EHS program of KNMI can be found at mode-s.knmi.nl