Royal Netherlands
Meteorological Institute
Ministry of Infrastructure and Environment

Mode-S EHS data usage in the meteorological domain:

- derivation of Wind and Temperature observations; and
- assimilation of these observations in a numerical weather prediction model.

Jan Sondij, MBA
Senior Advisor Aviation Meteorology
KNMI – The Netherlands

Meteorological Technology World Expo October 15th 2013

Acknowledgements

This presentation is prepared by Jan Sondij, Senior Advisor Aviation Meteorology, and Siebren de Haan, who has the scientific lead in the Mode-S EHS research at KNMI.

Siebren de Haan
Senior Scientist
siebren.de.haan@knmi.nl

Jan Sondij
Senior Advisor Aviation Meteorology
jan.sondij@knmi.nl

The initial research on Mode-S EHS has been funded by the Knowledge Development Center Mainport Schiphol (KDC) http://www.kdc-mainport.nl

Knowledge partners and data provided by:

EUROCONTROL

Luchtverkeersleiding Nederland
Air Traffic Control the Netherlands

KLM Royal Dutch Airlines

SKYTEAM

BOEING

Content

- Acknowledgements
- About KNMI
- Introduction
- Mode-S Enhanced Surveillance (EHS)
- How to derive Wind and Temperature observations from Mode-S EHS data
- Quality of Mode-S EHS derived observations
- Current coverage of Mode-S EHS observations
- Impact of assimilation in a Numerical Weather Prediction Model (HIRLAM)
- Conclusions
- Next steps
- Publications
- Questions

- KNMI is the national institute for weather, climate research and seismology.

- KNMI is to provide weather information to the public at large, the government, aviation and the shipping industry in the interest of safety.

- KNMI is an agency of the Ministry of Infrastructure and the Environment (Ministerie van Infrastructuur en Milieu).

- KNMI's duties are set forth in Act on KNMI (Wet op het KNMI).

- KNMI is designated as air navigation service provider for meteorology in The Netherlands.

- KNMI represents The Netherlands in the World Meteorological Organisation.

Introduction

- Accurate wind information is a key need for many SESAR and NextGen applications

- Upper air atmospheric wind and temperature information is crucial for numerical weather prediction and nowcasting.

- Current observation systems are:
  - Radiosonde
  - Wind profilers
  - Doppler radar
  - Satellites
  - Aircraft via the AMDAR program of the World Meteorological Organization (WMO)

- A novel method is the use of Mode-S Enhanced Surveillance Data to derive wind and temperature observations.

Mode-S Enhanced Surveillance (EHS)

Within 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 IFR as GAT, must be Mode-S EHS compliant.

- Functionality

  Aircraft compliant with Mode-S EHS provide basic functionality features plus the following eight downlinked aircraft parameters (DAPs):

BDS Register	Basic DAP Set (if Track Angle Rate is available)	Alternative DAP Set (if Track Angle Rate is not available)
BDS 4,0	Selected Altitude	Selected Altitude
BDS 5,0	Roll Angle	Roll Angle
	Track Angle Rate	
	True Track Angle	True Track Angle
	Ground Speed	Ground Speed
BDS 6,0	Magnetic Heading	Magnetic Heading
	Indicated Airspeed (IAS) / Mach no. (Note: IAS and Mach no. are considered as 1 DAP (even if technically they are 2 separate ARINC labels). If the aircraft can provide both, it must do so).	Indicated Airspeed (IAS) / Mach no. (Note: IAS and Mach no. are considered as 1 DAP (even if technically they are 2 separate ARINC labels). If the aircraft can provide both, it must do so).
	Vertical Rate (Barometric rate of climb/descend or baro-inertial)	Vertical Rate (Barometric rate of climb/descend or baro-inertial)
		True Airspeed (provided if Track Angle Rate is not available)

Source:

EUROCONTROL website

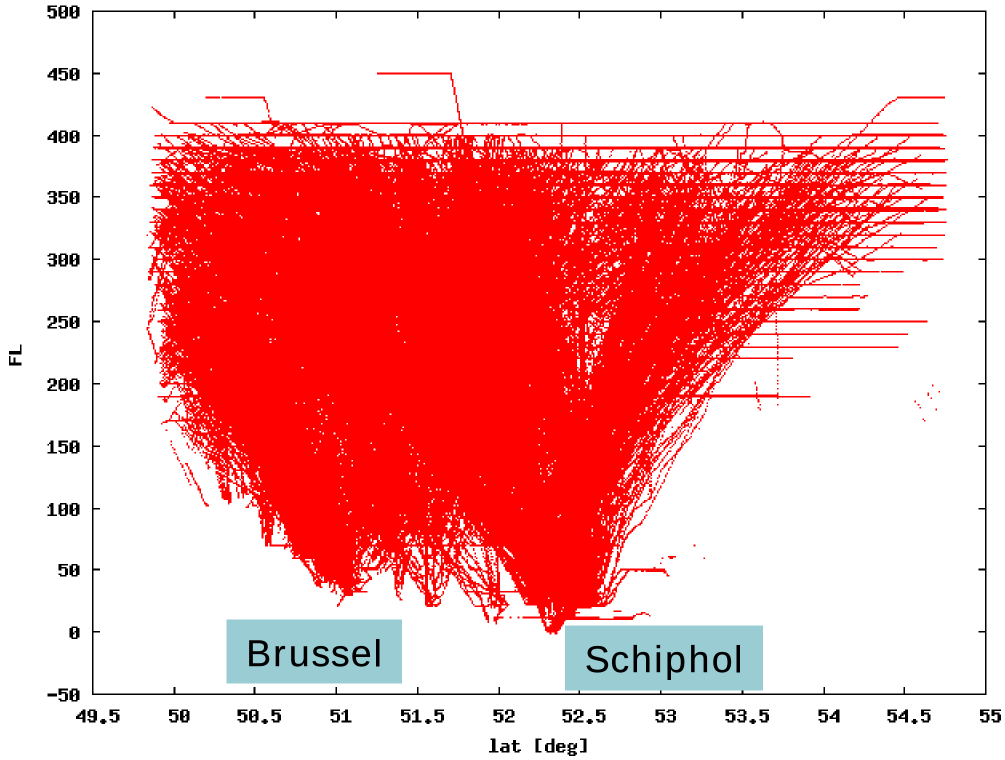
Aircraft observations: Mode-S EHS

Mode-S EHS radar of ATC (LVNL) reports information, every 4 seconds, for each aircraft **interrogated** by the radar on:

- Flight level (F),
- Machnumber (M),
- Roll, True Airspeed (Vt or TAS),
- Heading (t),
- Groundspeed (Vg), and
- Track Angle (g).

Other information is available, but not relevant within this context.

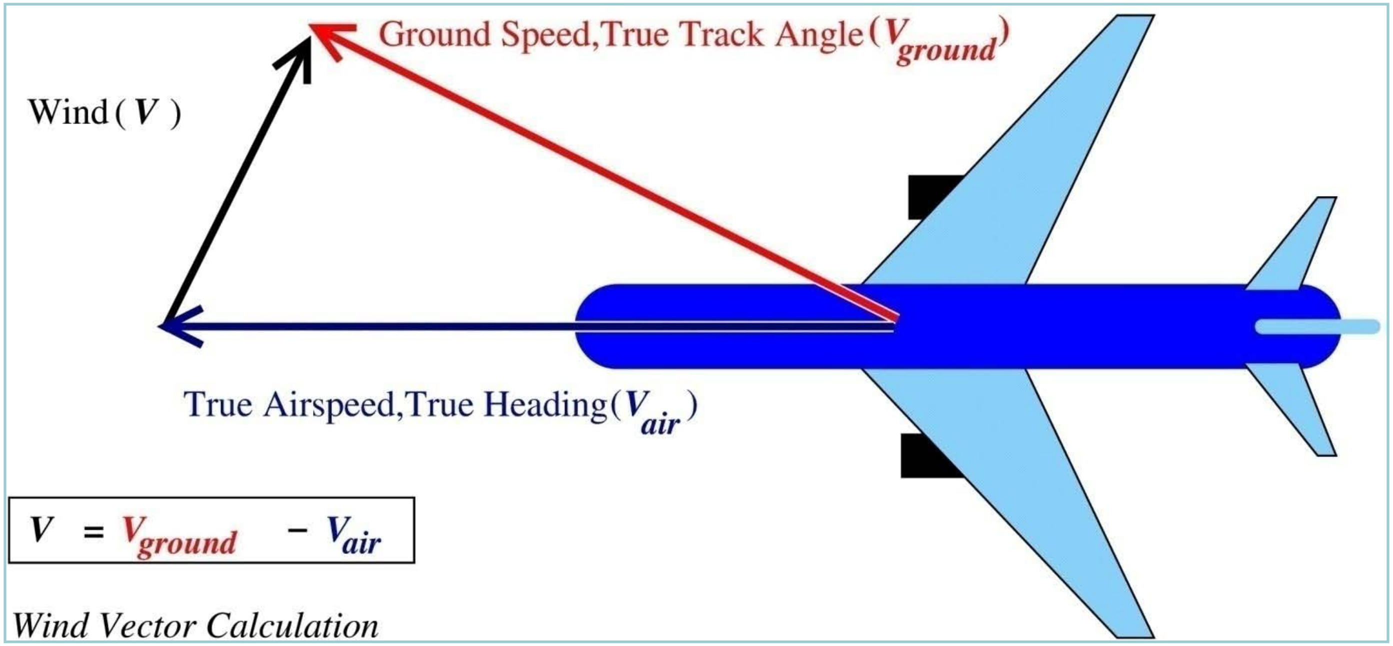
Note: the update frequency can vary for each ATC radar.



15 March 2008 (1500K obs)

Method to derive wind from EHS data

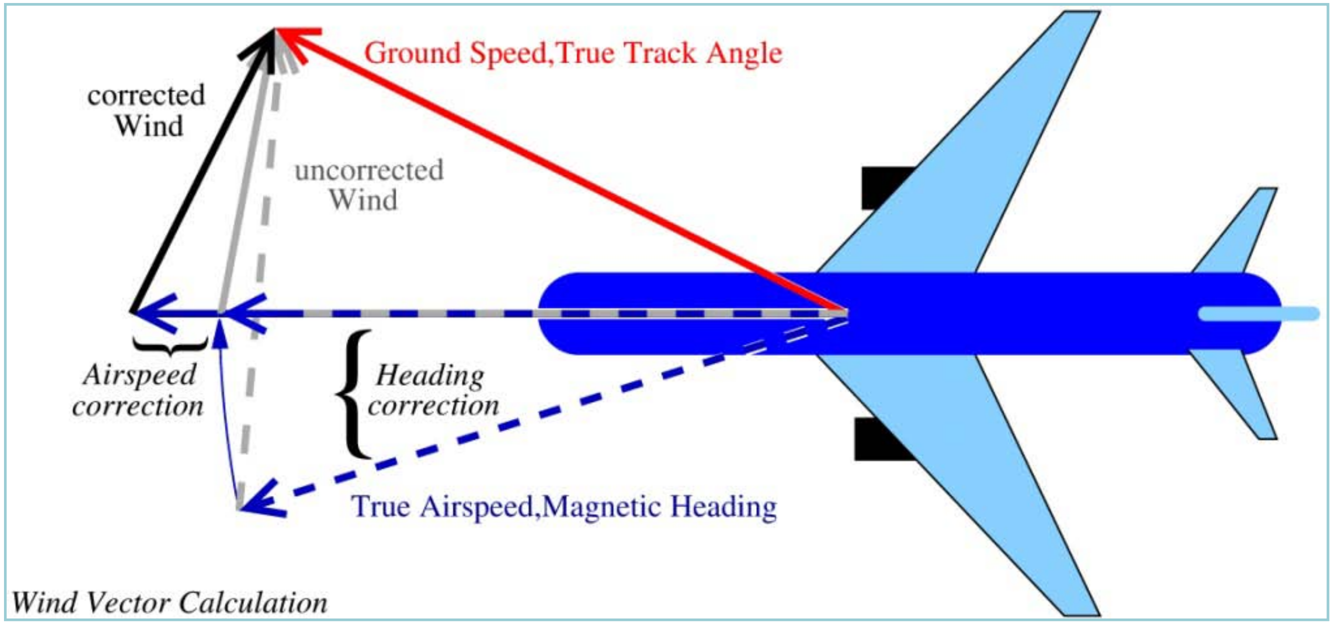
“in an ideal world”



Schematic representation of wind derivation from aircraft flight information. The wind vector (black) is deduced from the difference between the ground track vector (red) and the orientation (heading) and speed of the aircraft relative to the air (dark blue). The ground track vector is constructed by ground speed and true track angle. Note that both heading and ground track angle are defined with respect to true north.

Method to derive wind from EHS data

“applied corrections”



Schematic representation of used heading and airspeed corrections to derive high quality wind estimate from aircraft flight information. The dashed white-blue vector (uncorrected vector) is constructed using aircraft downlink information of magnetic heading and true airspeed. The dashed grey-blue vector is the result of the proper heading correction being applied to correct for heading offsets and to convert to true heading. The solid blue vector denotes the air vector after heading and airspeed correction. In black is the resulting wind after corrections and in grey are the intermediate wind estimates - in dashed gray without any corrections and solid grey with only heading correction applied. The ground track is assumed to be correct.

Corrections on wind

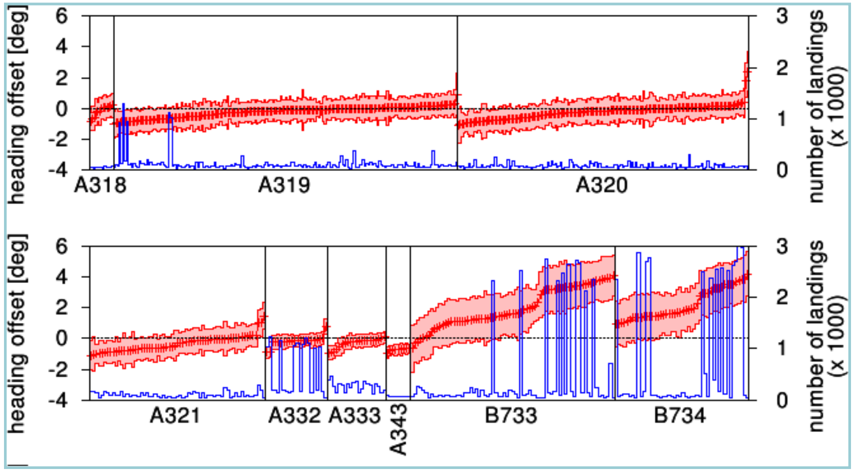
Using NWP wind as truth estimate (ECWMF)

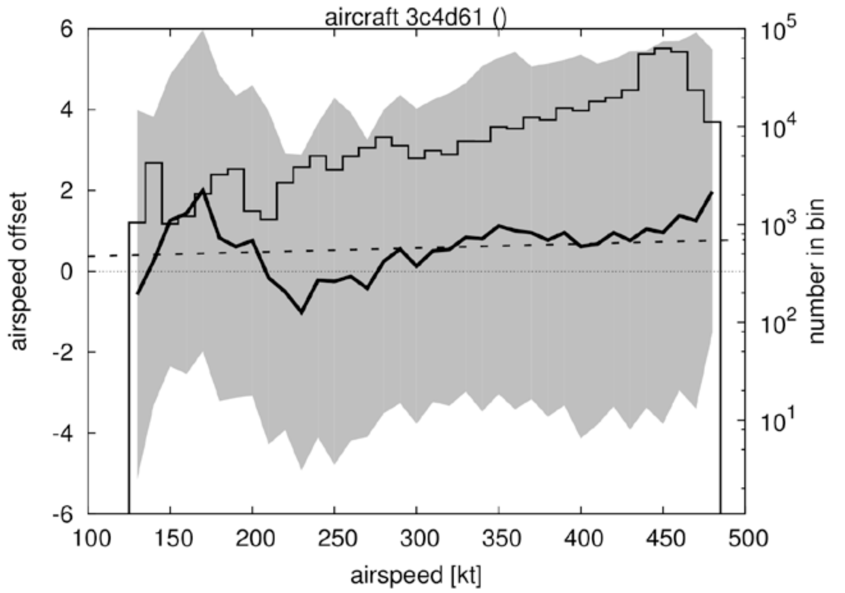
- Heading correction
  - “Magnetic” North versus “true” North
  - Dynamic lookup table for heading correction (aircraft specific and time dependent heading offsets)

- Airspeed calibration
  - Static lookup table for airspeed calibration

Please note that a lot of data is filtered out as part of the quality control process

- » roll angle, angle difference between track angle and heading within 15 degrees
- » groundspeed > 50 knots
- » true airspeed > 40 knots
- » and so on





Method to derive temperature from EHS data + corrections

Observed:

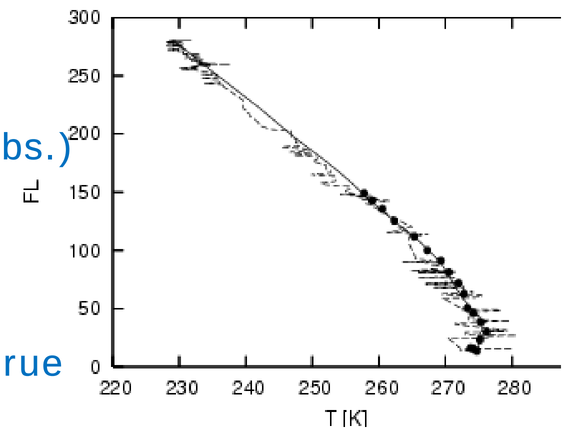
- Mach-number (M)
- M = V air / V sound
- Speed of Sound depends on Temperature (T)

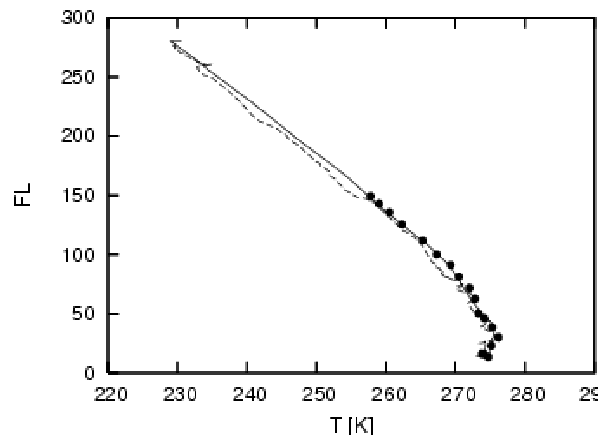
$$T = \textit{constant} * (V_{air} / M)^2$$

But as resolution of M is low the calculated T is less accurate.

Solution: smoothing over 60 seconds for Temperature (15 obs.)

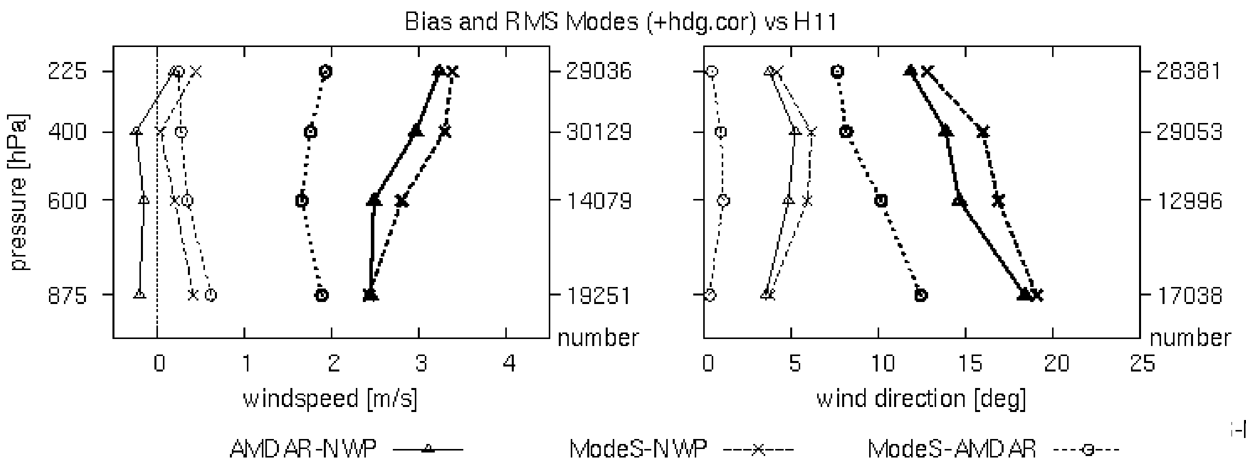
- Linear approximation of T and V true over 60 sec
- Reduction of noise in T and V true

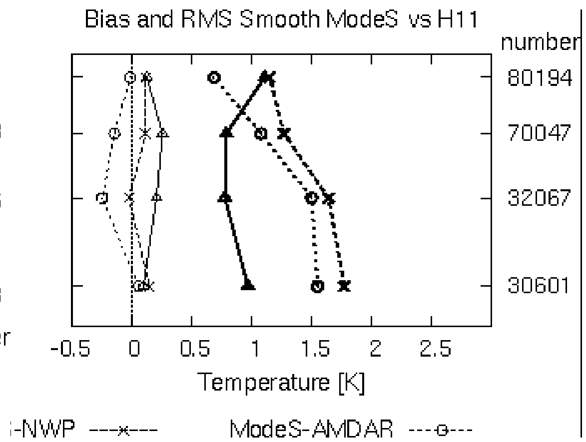




Alternative is to interrogate BDS register 4.4 containing a direct read out of the T (similar to AMDAR) !

Quality of Mode-S EHS derived observations





Wind observations are of good quality (after correction)

- STD wind direction = 15 – 20 degrees
- STD wind speed = 2 m/s

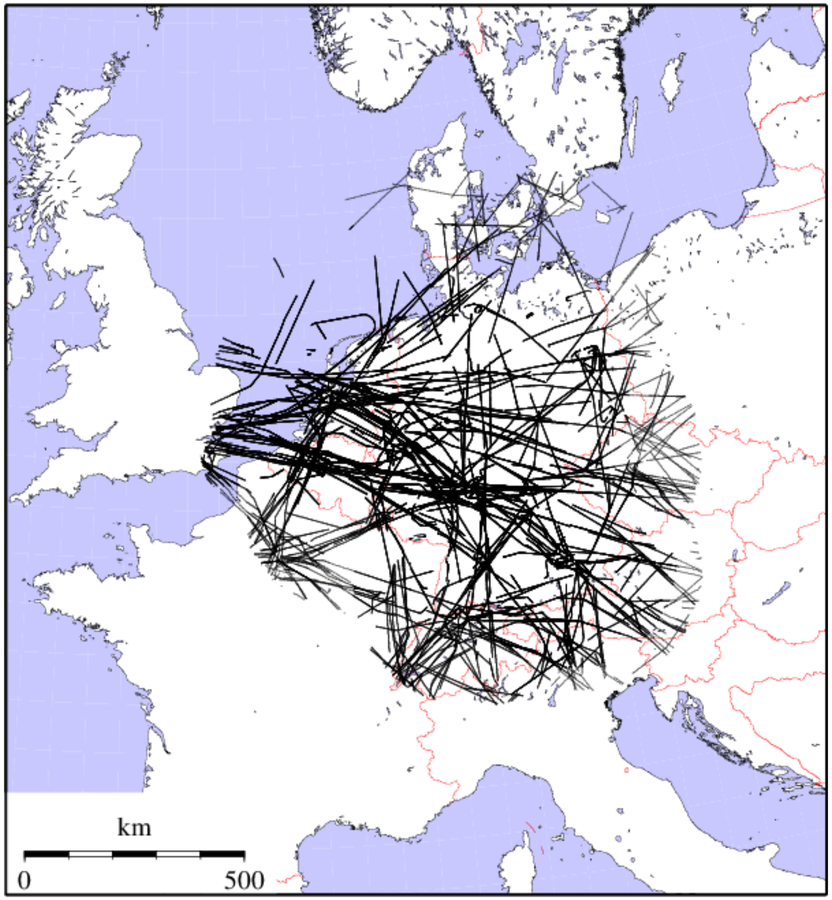
Temperature observations are not as good as AMDAR

- STD temperature = 1,5 – 3 K (AMDAR STD = 1 K)

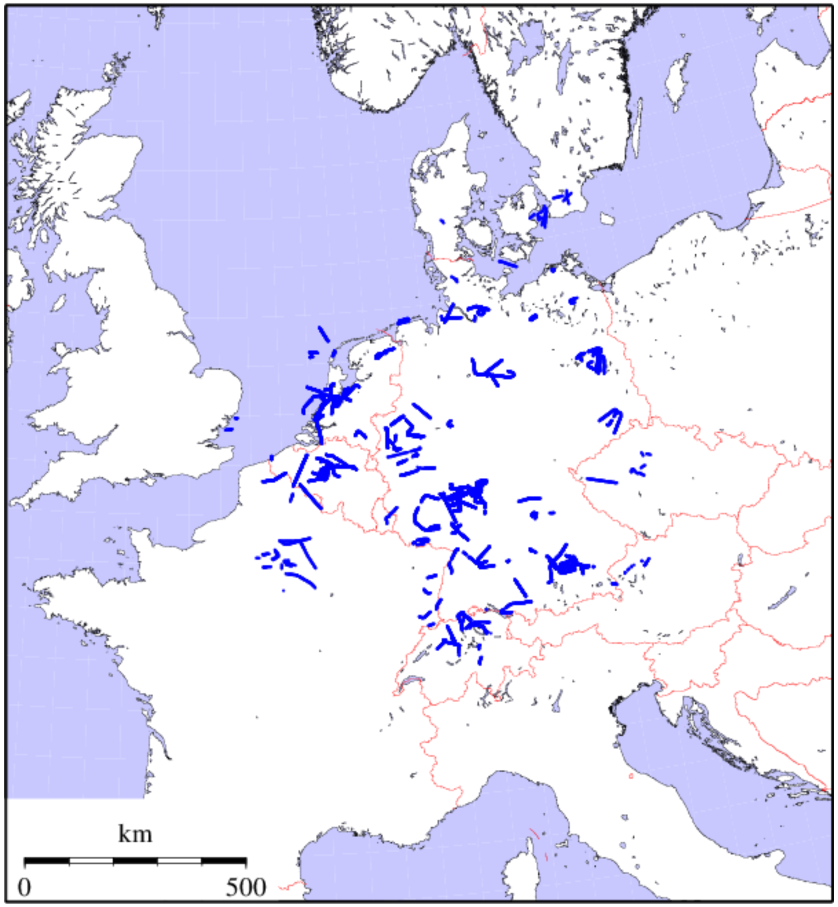
Quality of Mode-S EHS derived wind observations is comparable to AMDAR observations

Current coverage of Mode-S EHS observations available at KNMI

All BDS 4.0 / 5.0 / 6.0 observations (258.940)
valid 2012 / 08 / 09 1000 1015 UTC



BDS 4.0 / 5.0 / 6.0 observations below FL100 (30.647)
valid 2012 / 08 / 09 1000 1015 UTC

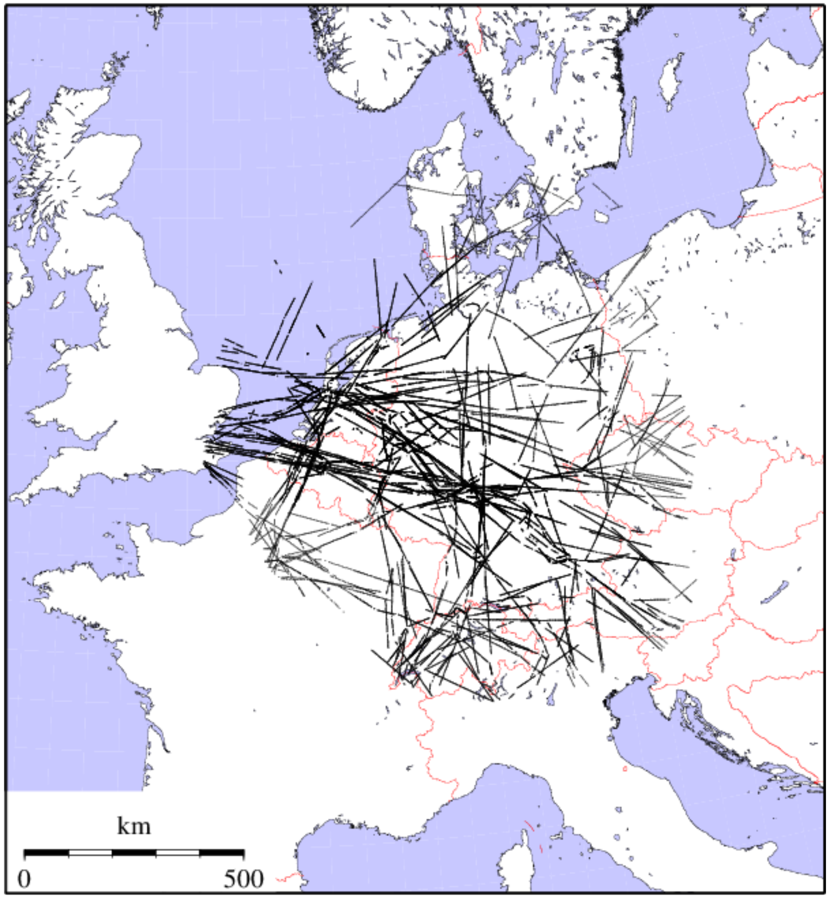


Example of 15 minutes of “raw” Mode-S EHS data of a day in August 2012 over Western Europe, source MUAC EUROCONTROL, processed by KNMI

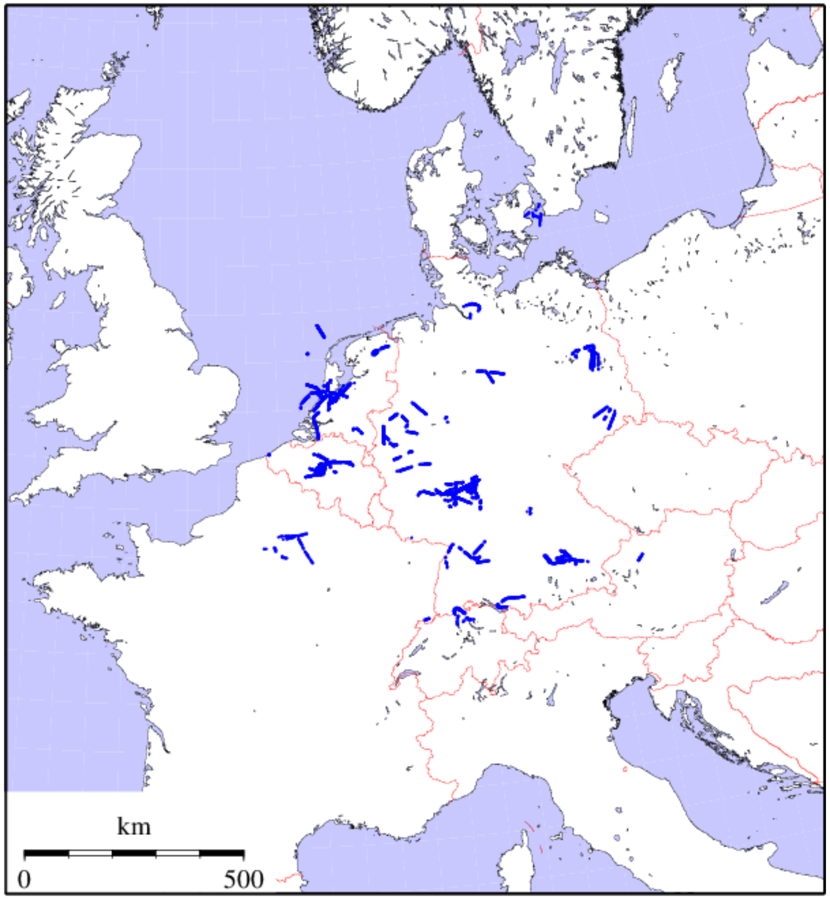
Current coverage of Mode-S EHS observations available at KNMI

derived Wind and Temperature (quality controlled)

All Wind and Temperature observations (73.370)
valid 2012/08/09 1000 1015 UTC



Wind and Temperature observations below FL100 (6.673)
valid 2012/08/09 1000 1015 UTC

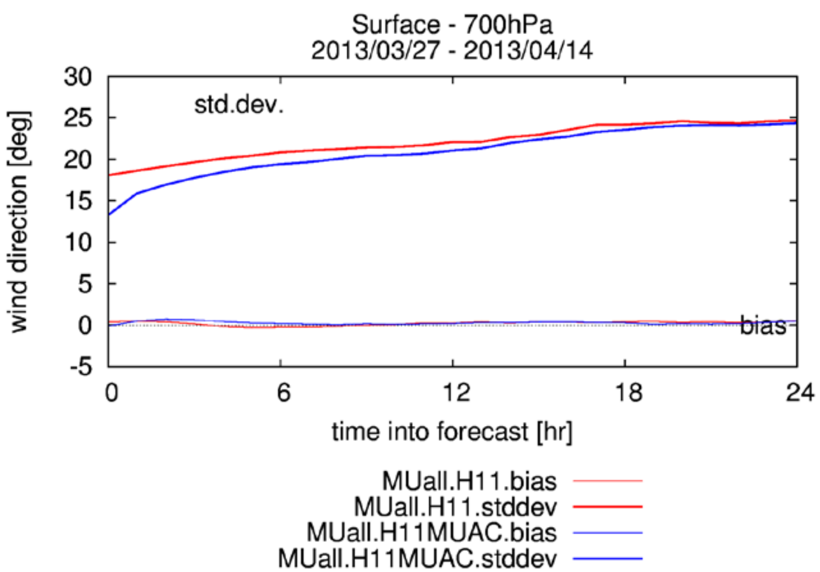


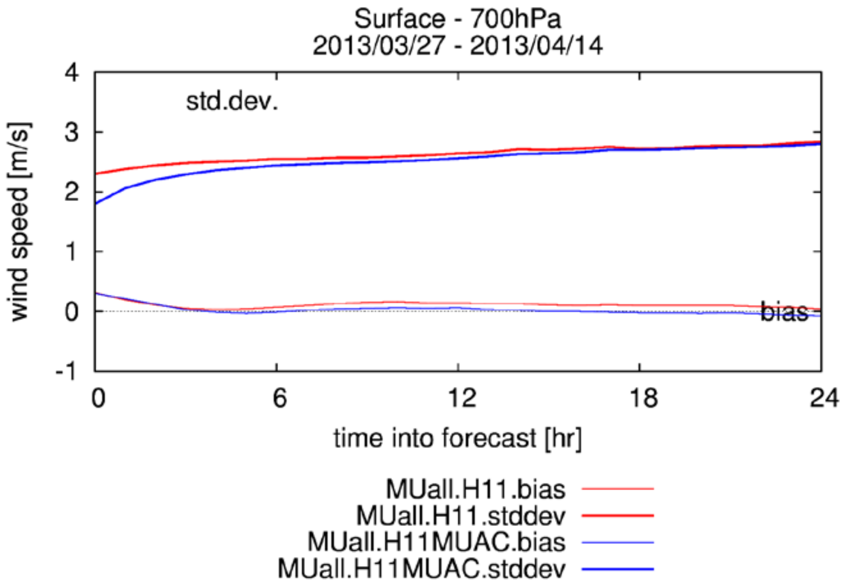
Example of 15 minutes of derived Wind and Temperature observations from Mode-S EHS data of a day in August 2012 over Western Europe, source MUAC, processed by KNMI

Impact of MUAC Mode-S EHS derived observations on NWP

HIRLAM v7.4 / 11km / hourly
- Rapid cycle (start HH:12)
  - Operational observation data set
- ECMWF hourly boundaries
- Additional MUAC Mode-S EHS derived obs.

Compare assimilated Mode-S MUAC derived wind data with forecasts





Conclusions

1. Mode-S EHS can be used to derive high quality wind observations but correction, calibration and validation is essential
   - High spatial resolution (except night time)
   - High temporal resolution (except night time)

2. Assimilation of Mode-S EHS derived Wind and Temperature observations is most beneficial
   - For short range weather forecasting
   - When an hourly assimilation cycle is applied
   - Impact up to 12-15 hours for wind direction
   - Impact up to 6 hours (lower levels) and up to 9 hours for wind speed

3 The wind forecast improves even more when more wind observations from a larger area can be used

Foreseen benefits

Possible benefits of the usage of Mode-S EHS data in air navigation service provision for meteorology could be:

- to improve the boundaries of numerical weather prediction (NWP) resulting in improved and more accurate weather forecasts;
- to contribute to concepts such as 4D Trajectory Management, Arrival Managers (AMAN), Departure Managers (DMAN) and Continuous Descent Operations (CDO);
- to contribute to Functional Airspace Blocks Wind Aloft service provision;
- to update aircraft FMS in flight with updated wind nowcasts and forecasts;
- to save costs on the current WMO AMDAR programme or result in an optimization of AMDAR observations in relevant geographical areas.

The derived meteorological observations can also be used to validate satellite wind observations.

KNMI will share the derived meteorological data from Mode-S EHS within the global meteorological domain in line with current WMO practice of cooperation between national meteorological hydrological institutes.

Next steps

- Expanding the area of Mode-S EHS coverage to France (DSNA) and United Kingdom (NATS)

- Creation of operational decoding and validation software of Mode-S EHS data

- Research on assimilation of Mode-S derived Wind and Temperature observations in non-hydrostatic weather model (AROME/HARMONIE at Meteo France and KNMI) in SESAR WP 11.2

- Provide more accurate weather forecasts for validation and verification test bed exercises of SESAR WP11.2 - Meteorological Services

Domain: 800 x 800 en 60 levels

Horizontal resolution: 2,5 x 2,5 km

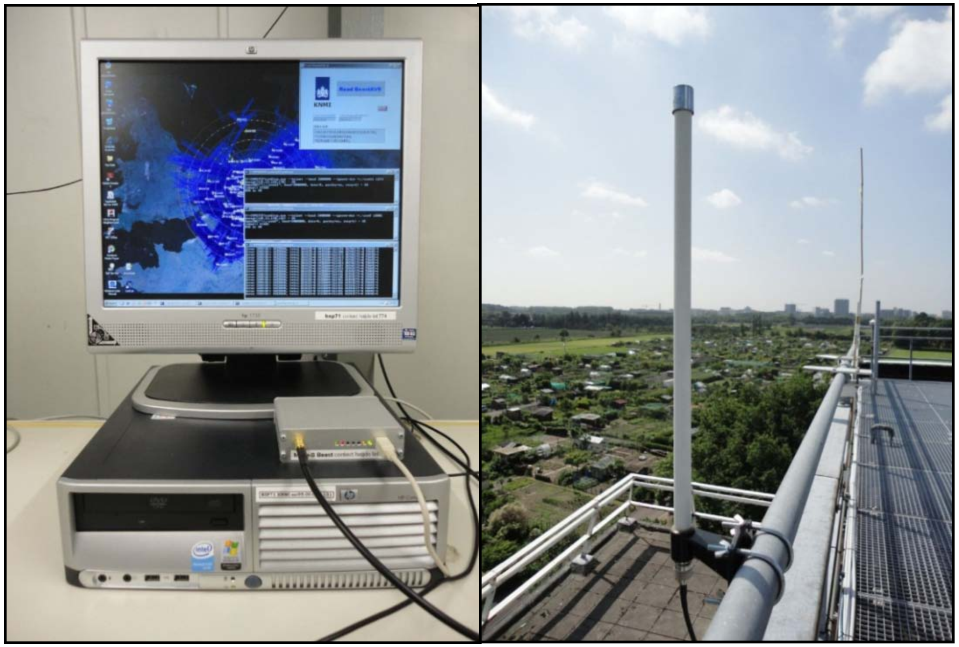
Future opportunities

- Potential opportunity to use other data sources such as ADS-C and ADS-B

- Investigate possibilities to use ADS-B Extended Squitter instead of Mode-S EHS → but information to filter data is missing (see slide 10)

- Use ADS-B receiver to acquire Mode-S EHS data without interference of ATC.

  Do note that ATC still has to interrogate the aircraft to start the EHS reply.



Data acquisition PC and Mode-S Beast (left) and GP1090 antenna on the roof of the KNMI premises (right).

Publications: http://mode-s.knmi.nl

Mode-S EHS

Royal Netherlands Meteorological Institute
Ministry of Infrastructure and the Environment

Home History Background Publications Mode-S EHS data Data status Contact

Home > publications

Mode-S EHS

Publications and Presentations

Publications

Sondij, J, and S. de Haan *Aircraft as a meteorological sensor*
KNMI brochure September 2013 (updated)
Complete text (pdf)

Sondij, J, and S. de Haan *Aircraft as a Sensor*
Meteorological Technology International
Complete text (html)

Haan, S. de *Mode-S Enhanced Surveillance derived observations from multiple Air Traffic Control Radars and the impact in hourly HIRLAM*
ALADIN - HIRLAM Newsleter: No. 1, September, 2013, p 4-8.
(Complete text)

Haan, S. de, *An improved correction method for high quality wind and temperature observations derived from Mode-S EHS*
KNMI publication: TR-338, 2013.
Complete text (pdf)

Haan, S. de, M. de Haij and J. Sondij, *The use of a commercial ADS-B receiver to derive upper air wind and temperature observations from Mode-S EHS information in The Netherlands*
KNMI publication: TR-336, 2013.
Complete text (pdf)

Haan, S. de, and L. J. Bailey, and J. E. Können, 2013: *Quality assessment of Automatic Dependent Surveillance Contract (ADS-C) wind and temperature observa tion from commercial aircraft*, Atmospheric Measurement Techniques, 6, 199 - 206,Complete text (html)

Research topics

- SESAR WP11.2
- UFO
- ADS-B research
- ADS-C research

More

- Acronyms
- Relevant links
- Acknowledgements

ANY QUESTIONS ?