Royal Netherlands
Meteorological Institute
Ministry of Infrastructure
and Water Management

Status of the European Meteorological Aircraft Derived Data Centre (EMADDC)

SESAR Deployment IP 2015_137_AF5 EMADDC

ABO Workshop – ECMWF Reading

12 – 13th February 2020

Inputs from the EMADDC team: Siebren de Haan, Paul de Jong, Michal Koutek and Jantine Bokhorst

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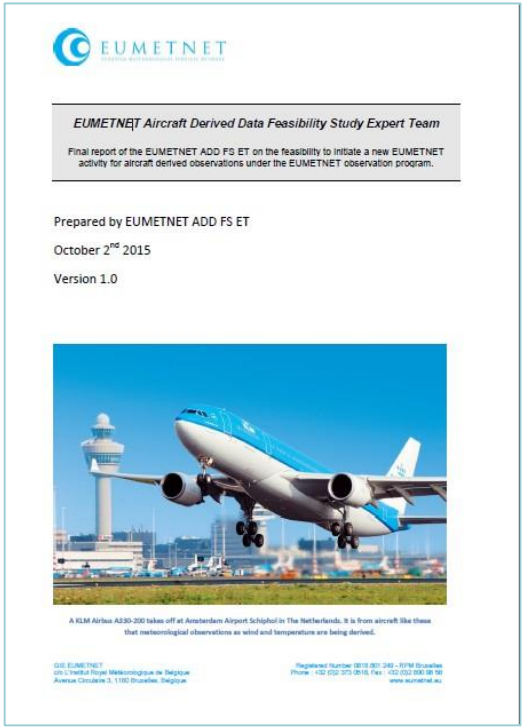
KNMI

Content

- Mode-S data and use for meteorology
- EMADDC
  - use cases, status, data characteristics, input quality control and data output
- Heading correction methods
- Data providers and data users
- Issues
- Next steps
- Acknowledgments and partners
- Contact


EUMETNET

EUMETNET Aircraft Derived Data Feasibility Study Expert Team

Final report of the EUMETNET ADD FS ET on the feasibility to initiate a new EUMETNET activity for aircraft derived observations under the EUMETNET observation program.

Prepared by EUMETNET ADD FS ET

October 2nd 2015

Version 1.0

Mode-S EHS Enhanced Surveillance

Start in 2007 with research on the use of Mode-S EHS data

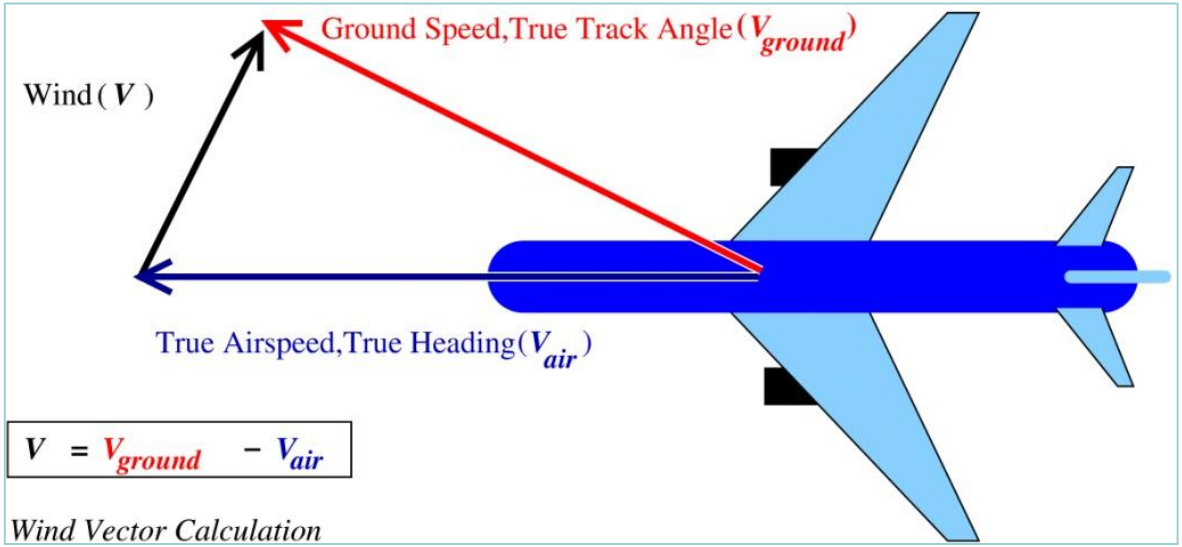
Secondary Surveillance Radar data used by Air Traffic Management to obtain situation information from aircraft.

Result: it is possible to derive wind and temperature observations of good quality.

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
		True Airspeed (provided if Track Angle Rate is not available)
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)

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: EUROCONTROL.

Method Mode-S EHS Wind

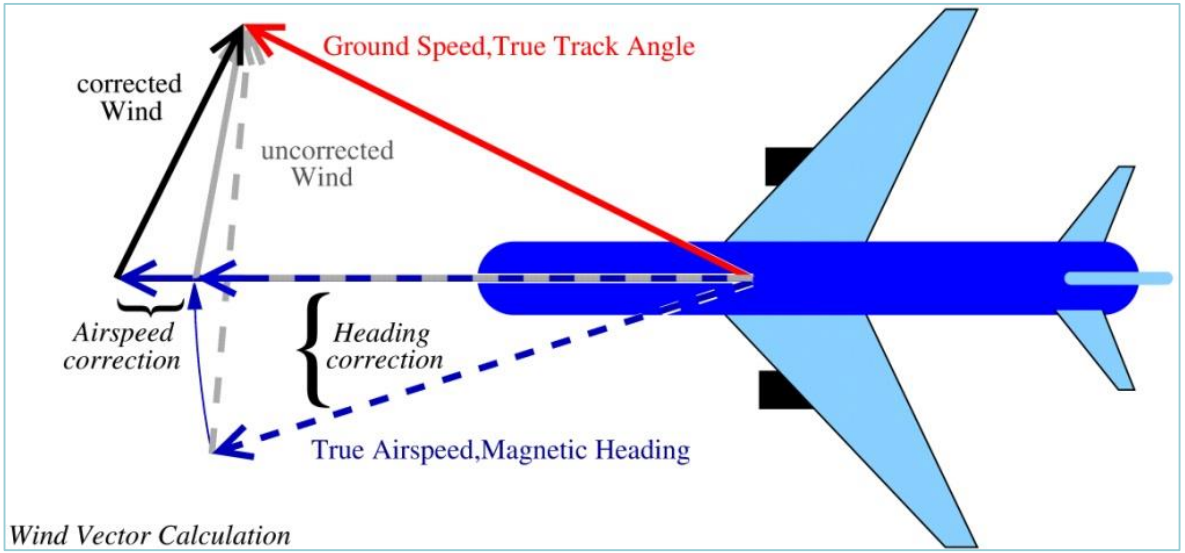


Schematic representation of wind derivation from aircraft flight information

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 Mode-S EHS Wind



Schematic representation of wind derivation from aircraft flight information including individual aircraft corrections

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.

Method Mode-S EHS Temperature

Observed:

- Mach-number (M)
- Speed of Sound depends on Temperature (T)
  - $c = (C/\rho)^{1/2}$, C = constant en ρ airdensity
  - $\rho = p/(R\,T)$, R = constant

Thus: $V_{true} = K\,M\,T^{1/2}$ with K constant

MET perspective ☺
- Mach resolution to low
- TAS resolution to low

Temperature <u>derivation</u> from aircraft flight information including individual aircraft corrections

Note: V_{true} = TAS

About EMADDC

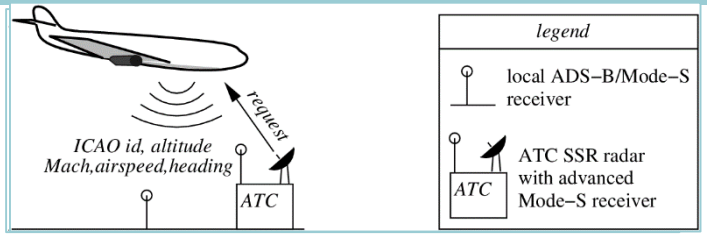
The European Meteorological Aircraft Derived Data Center

New air traffic control surveillance technologies present opportunities to obtain or **derive** observations for:

- Wind direction
- Wind speed
- Temperature

EMADDC objective: to obtain as many high quality meteorological upper air observations for Europe at large for as little cost as possible

by installing an operational service for collecting, processing and disseminating Mode-S EHS derived, quality controlled meteorological data.



Active interrogation by ATC

Aircraft data that are broadcasted

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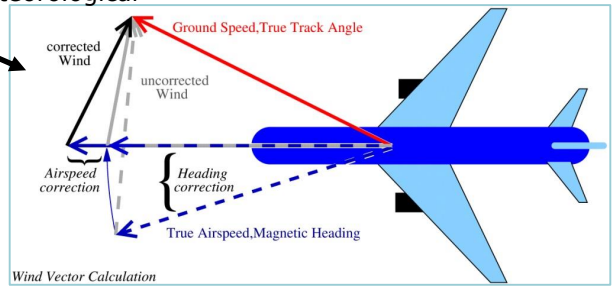
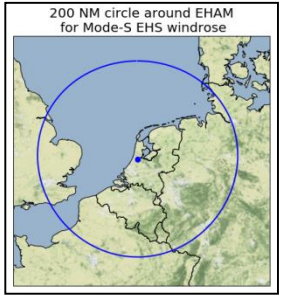
Quality control process to improve the quality of derived meteorological observations

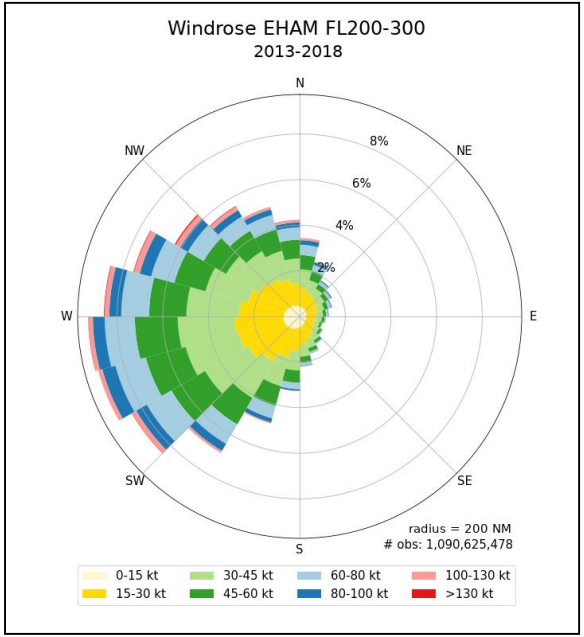


Use cases of derived meteorological observations from Mode-S EHS data

Use cases of input quality controlled derived wind and temperature observations:

- to improve the quality of NWP nowcasts and forecasts (impact up to 15 hours for wind)
- to support meteorological forecaster by providing actual wind and temperature profiles
- to generate upper air wind and temperature climatology
- to support air traffic management (ATM) applications like CDO and TBS
- to validate satellite wind observations
- to …….



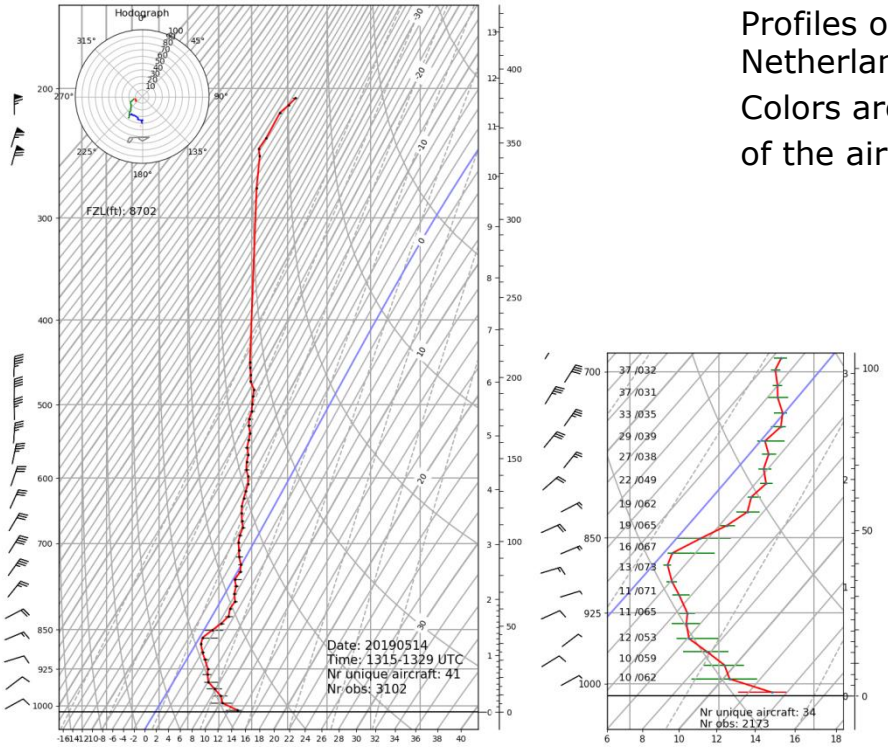


Windrose for Amsterdam Airport for FL200-300 over the period 2013-2018.

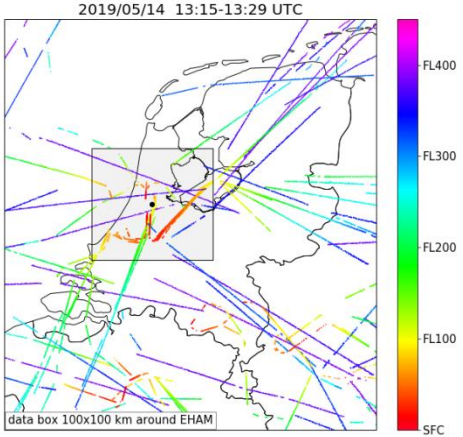
Source: input quality controlled derived observations from Mode-S EHS (MUAC area)

Data is complimentary to other observations like AMDAR and radiosonde. Unique features of Mode- S EHS derived observations compared to these sources is high spatial and temporal resolution, as well as timeliness, around airports and at cruising level.

Use case: actual wind and temperature profiles for use by aeronautical meteorological forecaster



Profiles of aircraft flying in The Netherlands at May 14th 2019 →
Colors are related to the height of the aircraft.



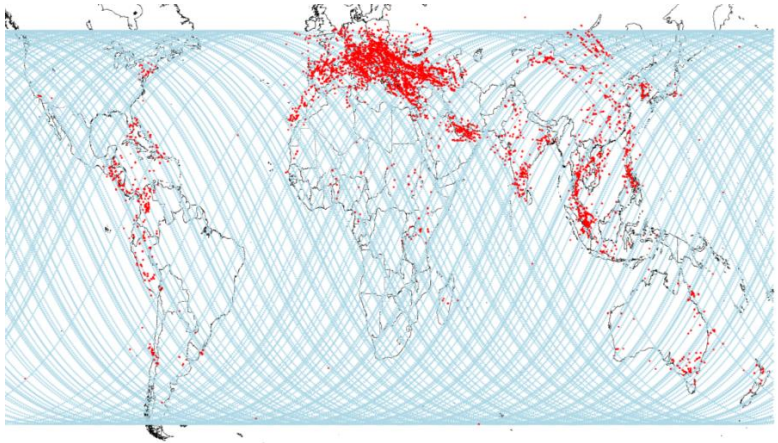
← Vertical wind and temperature profiles based on near real time Mode-S EHS observations.

Every 15 minutes, observations are collected within a 100x100 km box around airport EHAM. Per level, the median of the observations is shown. For temperature, a horizontal bar has been added indicating the 25- en 75-percentile. Red error bar: less than 10 observations. Green error bar: 10 observations or more.

Status

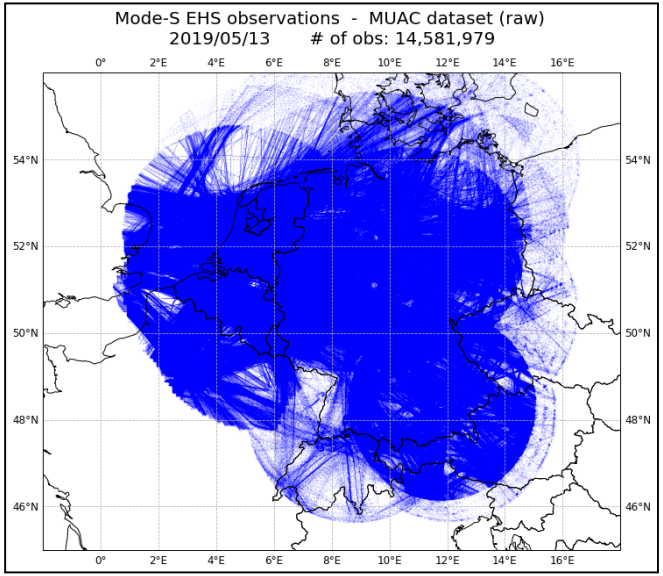
EMADDC v1.0 operational as of 15/01/2019

- DTAP system operational at Equinix (government datacenter in Amsterdam)
- Operational processing of EUROCONTROL MUAC data per 15 minutes
- 24x7 operational monitoring by KNMI

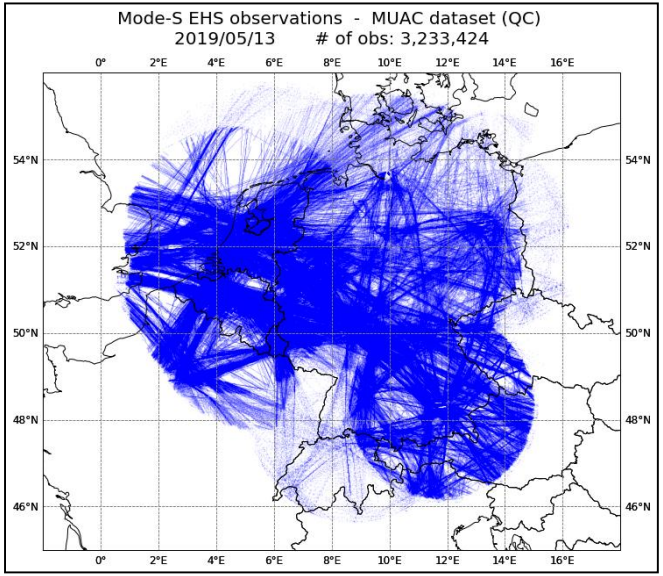


Global applicability of Mode-S EHS surveillance data (courtesy UK MET Office)

Number of ‘raw’ and ‘input quality controlled’ observations Mode-S EHS data (MUAC area)

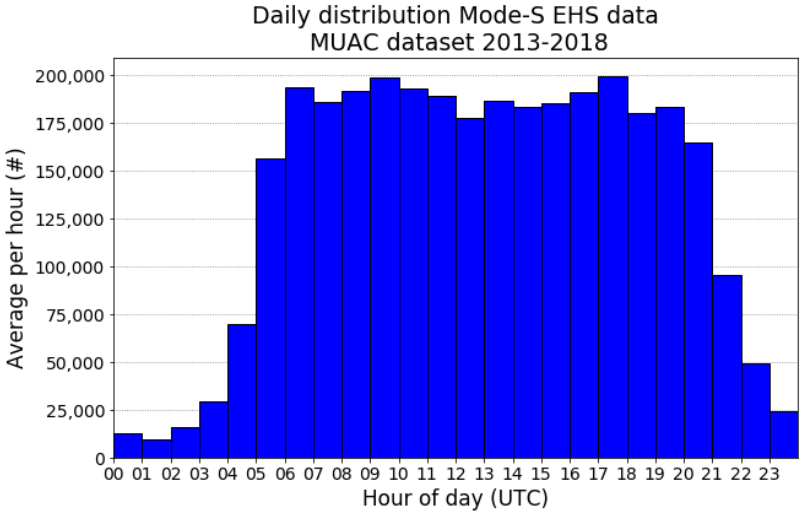


Over 14 million raw Mode-S EHS observations per day in the EUROCONTROL MUAC area.

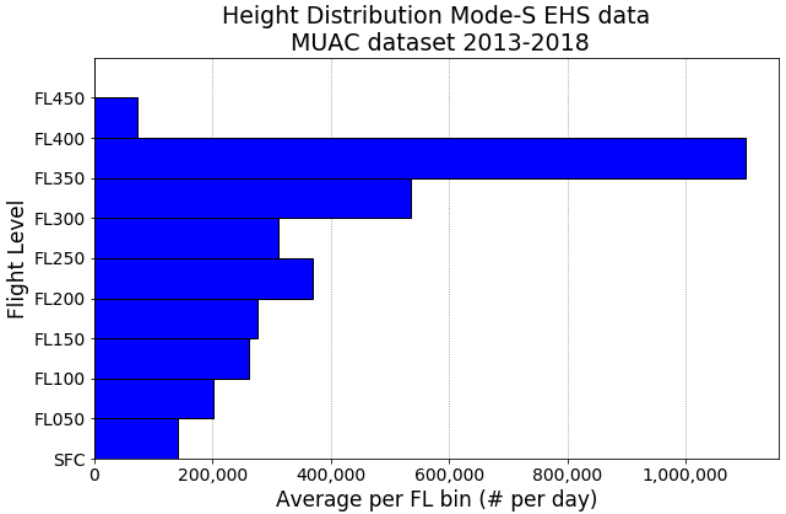


Resulting in over 3 million input quality controlled derived observations for wind direction, wind speed and temperature.

Distribution of ‘input quality controlled’ derived observations from Mode-S EHS data (MUAC area)

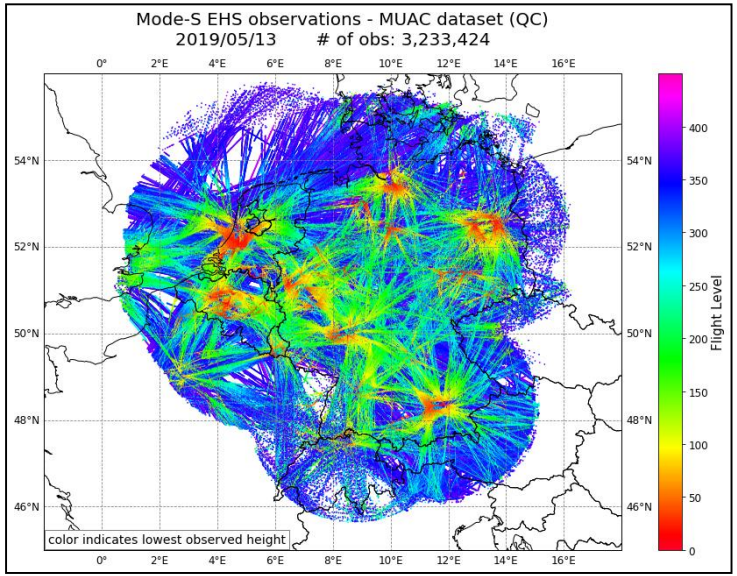


Up to 200.000 input quality controlled derived observations (wind speed, wind direction, temperature) per hour for the EUROCONTROL MUAC area.

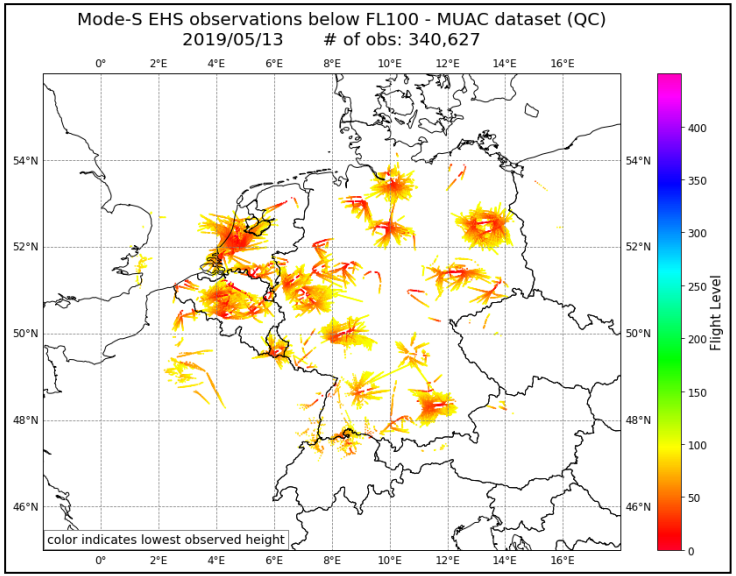


The distribution of input quality controlled observations per Flight Level. The highest amount of data are available at aircraft cruise level.

Distribution of ‘input quality controlled’ derived observations from Mode-S EHS data (MUAC area)



The distribution of one day of input quality controlled derived observations (wind speed, wind direction, temperature) per altitude for the EUROCONTROL MUAC area.



The distribution of input quality controlled observations below FL 100, correlating with aircraft departing and landing at aerodromes.

Surveillance data provision

Surveillance types

Mode-S EHS - BDS 4.0, 5.0, 6.0

- to derive wind and temperature
- many ATS ANSP interrogate
- aircraft obliged to respond
- update frequency dependent on frequency of radar interrogation

Mode-S MRAR - BDS 4.4

- Meteorological Routine Air Report
- contains wind and temperature
- few ATS ANSP interrogate
- few aircraft are able to respond

Surveillance data provision

ATS ANSP

Data formats

- ASTERIX CAT048
  - Resolution MACH number 0.004
- ASTERIX CAT062
  - Resolution MACH number 0.008

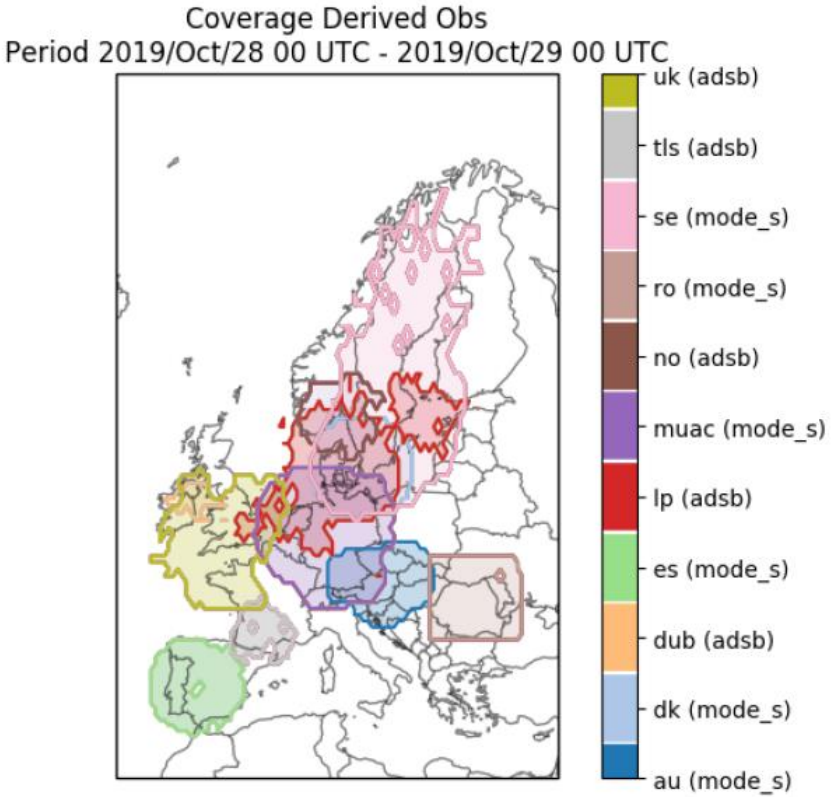
Position relative to the radar

Local ADS-B/Mode-S receiver

- position from ADS-B (DF17)

Commercial receiver operator

Overview of current test data streams + MUAC



stream
adsb/dub/
adsb/lp/
adsb/no/
adsb/tls/
adsb/uk/
mode_s/au/
mode_s/dk/
mode_s/es/
mode_s/muac/
mode_s/ro/
mode_s/se/

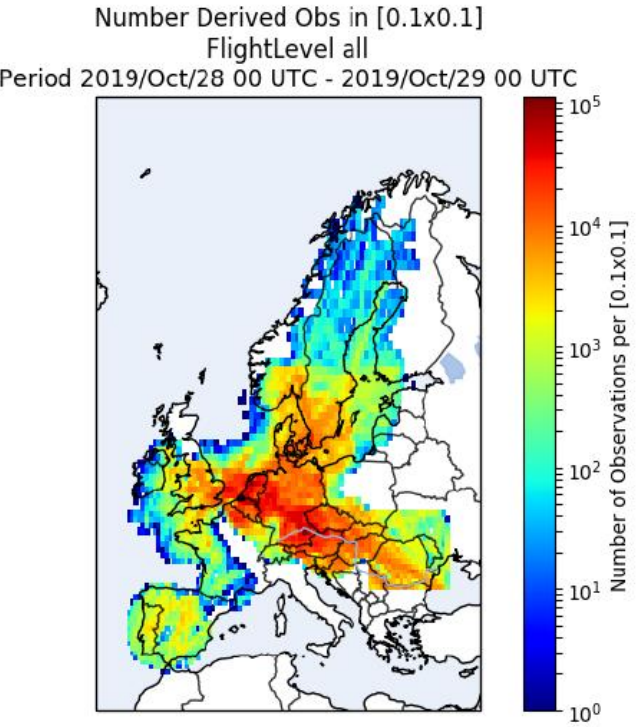
Current data streams running on the DTAP-system.

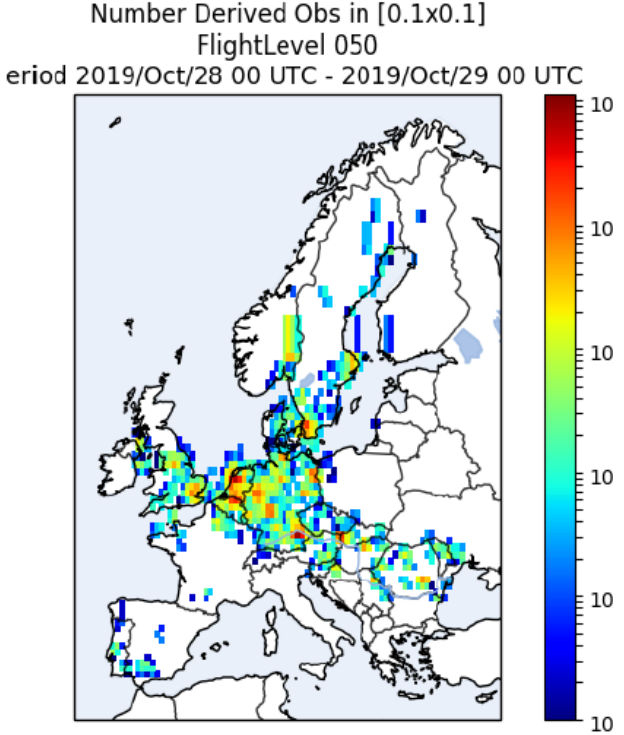
MUAC is operational and runs on the A and P.

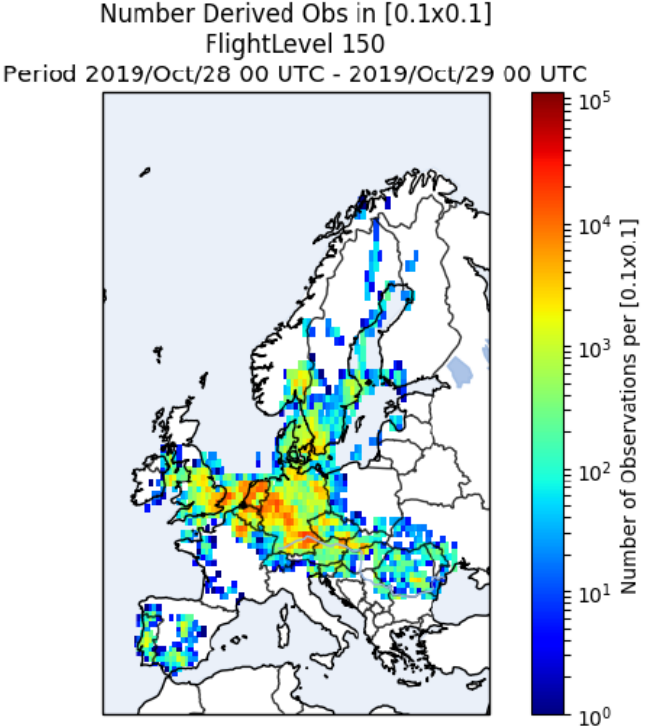
The other streams are in test mode and are running on the D and T systems.

Operational use of the data is dependent on the improved correction algorithm currently under development.

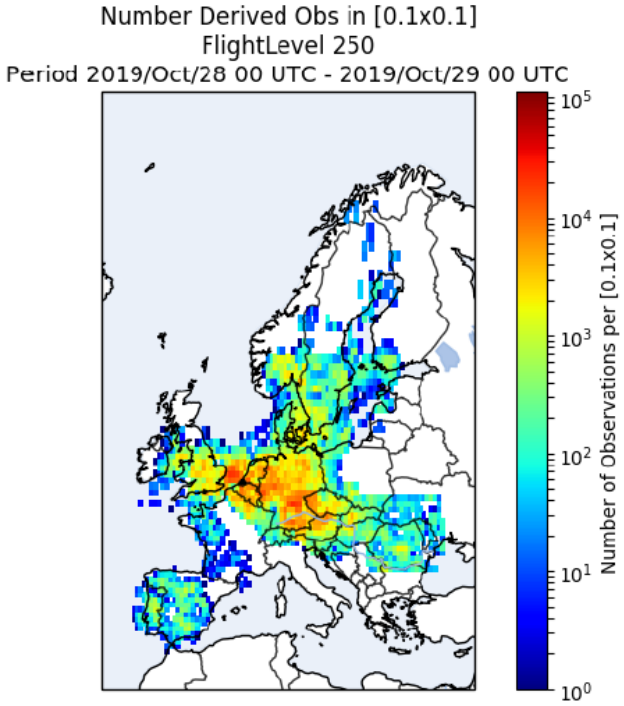
Overview of current test data streams + MUAC

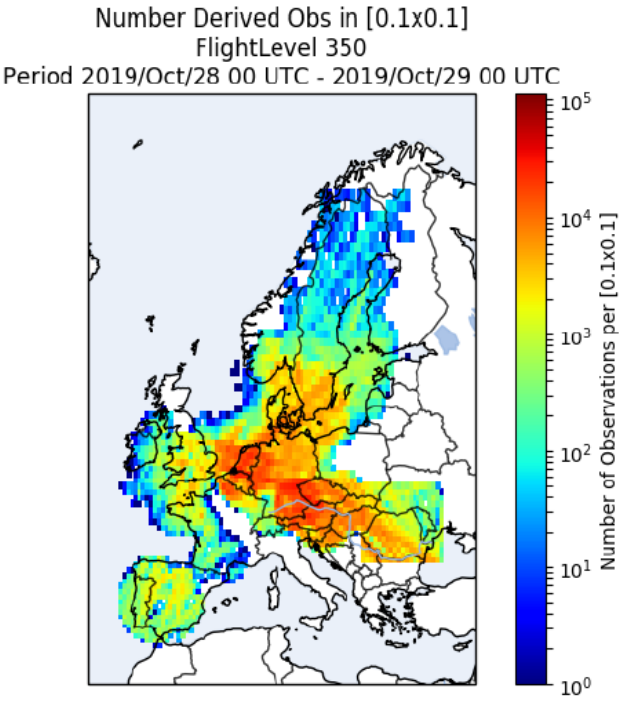


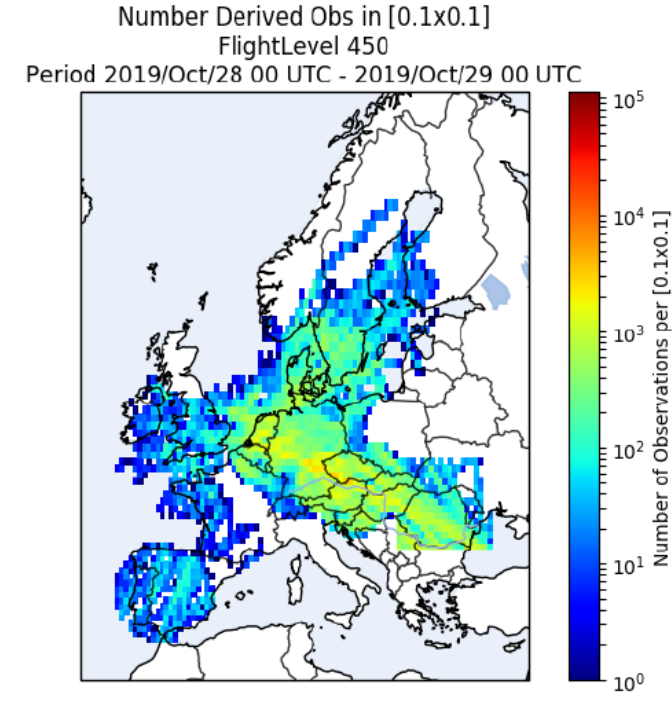




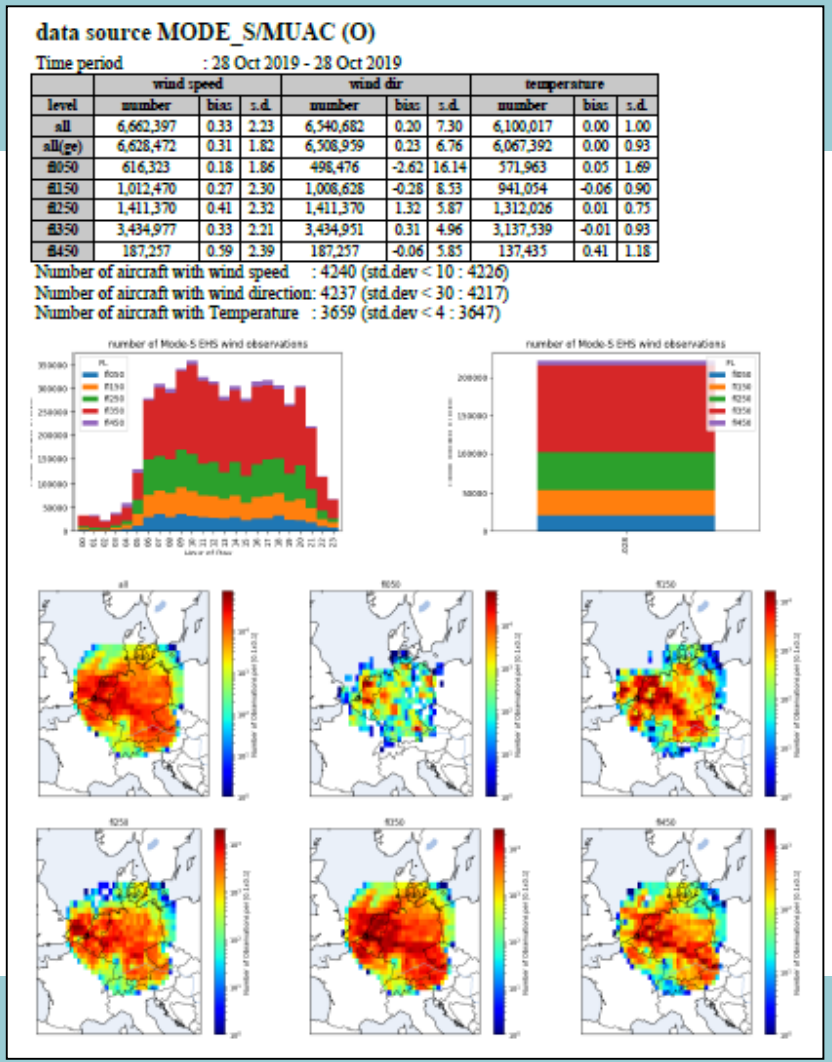
Overview of current test data streams + MUAC







Standardized and automated generation of data statistics of all data streams.



data source MODE_S/MUAC (O)

Time period : 28 Oct 2019 - 28 Oct 2019

	wind speed			wind dir			temperature		
level	number	bias	s.d.	number	bias	s.d.	number	bias	s.d.
all	6,662,397	0.33	2.23	6,540,682	0.20	7.30	6,100,017	0.00	1.00
all(ge)	6,628,472	0.31	1.82	6,508,959	0.23	6.76	6,067,392	0.00	0.93
fl050	616,323	0.18	1.86	498,476	-2.62	16.14	571,963	0.05	1.69
fl150	1,012,470	0.27	2.30	1,008,628	-0.28	8.53	941,054	-0.06	0.90
fl250	1,411,370	0.41	2.32	1,411,370	1.32	5.87	1,312,026	0.01	0.75
fl350	3,434,977	0.33	2.21	3,434,951	0.31	4.96	3,137,539	-0.01	0.93
fl450	187,257	0.59	2.39	187,257	-0.06	5.85	137,435	0.41	1.18

Number of aircraft with wind speed : 4240 (std.dev < 10 : 4226)
Number of aircraft with wind direction: 4237 (std.dev < 30 : 4217)
Number of aircraft with Temperature : 3659 (std.dev < 4 : 3647)

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Number of aircraft with wind speed : 4240 (std.dev < 10 : 4226)
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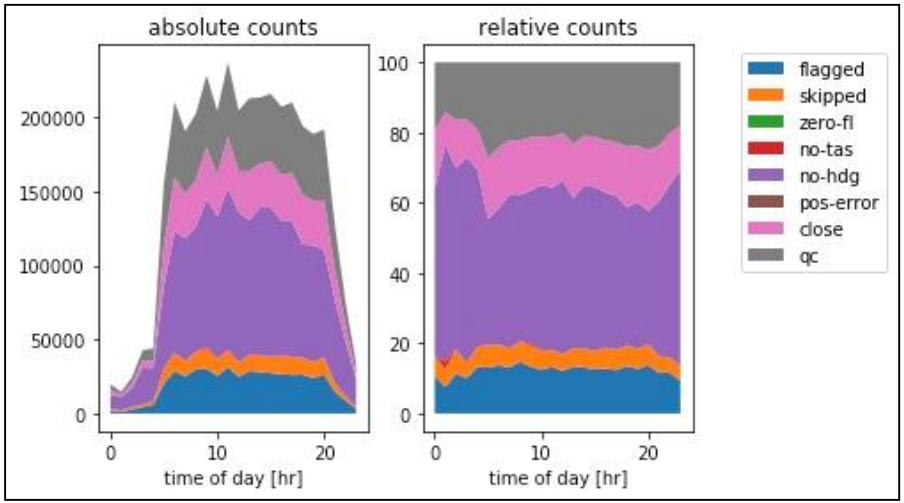
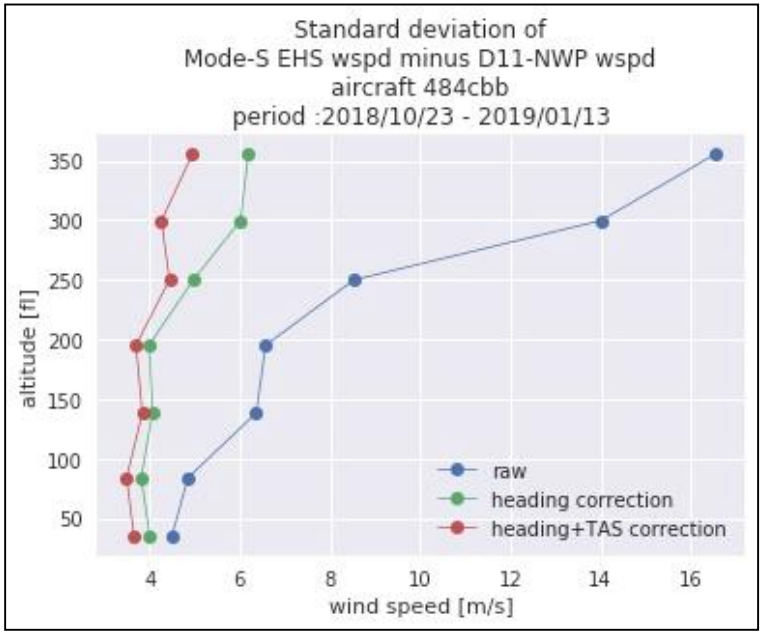
Number of aircraft with Temperature : 3659 (std.dev < 4 : 3647)

Impact of quality control on amount and quality of data



Impact of the different steps in input quality control process: flagged (e.g. roll angle, extreme angles, difference between true airspeed and ground-speed), skipped (double observations), no heading correction available, close (unreliable time/position) resulting in (input) quality controlled derived observations (qc).



Impact of input quality control on standard deviation of wind speed of an individual aircraft in comparison with NWP (extreme example)

Correction methods to derive true north from reported magnetic north

Data processing contains quality control and **aircraft specific** heading, air speed and temperature corrections. Currently 2 methods to determine heading corrections.

1) Aircraft regularly landing at Schiphol Airport
   - using known direction of runway
   - only aircraft that land regularly at Schiphol Airport can be used

2) Using external wind information from NWP, assuming the wind factor is perfect
   - after 30 days with minimum of 15 days observation of aircraft
   - corrections available for much more aircraft
   - dynamic aircraft database, updated every day
   - corrections not available for all aircraft

EMADDC output

Mode-S EHS ADD is available from 01/01/2013 till present for the MUAC air space

- in batches of 15 minutes
- with a latency of approximately 10 minutes

With the content

- Position (latitude/longitude/flight level)
- (anonymized) aircraft identifier
- Wind speed and direction
- Temperature

With the (estimated) absolute quality

- For wind speed : 1 - 1.5 m/s
- For wind direction: 5 – 10 degrees
- For temperature: 0,5 - 2 K

Formats : BUFR WMO7, NetCDF and ASCII

→ in 2020 also vertical profiles

Data providers and data users

Mode-S EHS data providers

Operational

- EUROCONTROL MUAC

Research/trial basis

- Toulouse, France – Meteo France
- Dublin, Ireland – Met Eireann
- Kastrup, Denmark – DMI
- Vienna, Austria – Austrocontrol
- De Bilt, Netherlands – KNMI
- Schiphol, Netherlands – LVNL
- Global - Air Support Denmark
- Oslo, Norway – Met Norway
- UK – UK Met Office
- Spain – AEMET
- Romania - Romatsa

Mode-S EHS derived observations users via FTP-service (research and/or operational use)

- KMI, Belgium
- DMI, Denmark
- DWD, Germany
- Lace Consortium, Czech Republic
- CNMCA, Italy
- Meteo France, France
- University Warsaw, Poland
- NLR, Amsterdam
- SMHI, Sweden
- ZAMG, Austria
- MeteoSwiss, Swiss
- Met Eireann, Ireland

Issue 1 – heading correction

Current algorithm is optimized for the MUAC area, and not geographical independent, hence not suitable outside MUAC area

Solution: implement updated and geographical independent heading algorithm

3) Estimate the magnetic declination table used onboard the aircraft (month/year).

Various technical methods are being investigated using NWP data. First results are promising.

Expectation: operational before summer 2020.

Advantage: location independent heading correction with global applicability and requiring fewer days (5-10) to generate the correction resulting in increased number of observations

Quality: similar to correction method 1 and 2

4) Work in progress – basically do the same as 3, but independent of the weather model.

Issue 2 – quality of derived temperature

The temperature observation is derived from the squared quotient of the true airspeed V_a and the Mach number M, $T_M = \frac{1}{\gamma R_d}\left(\frac{V_a}{M}\right)^2$

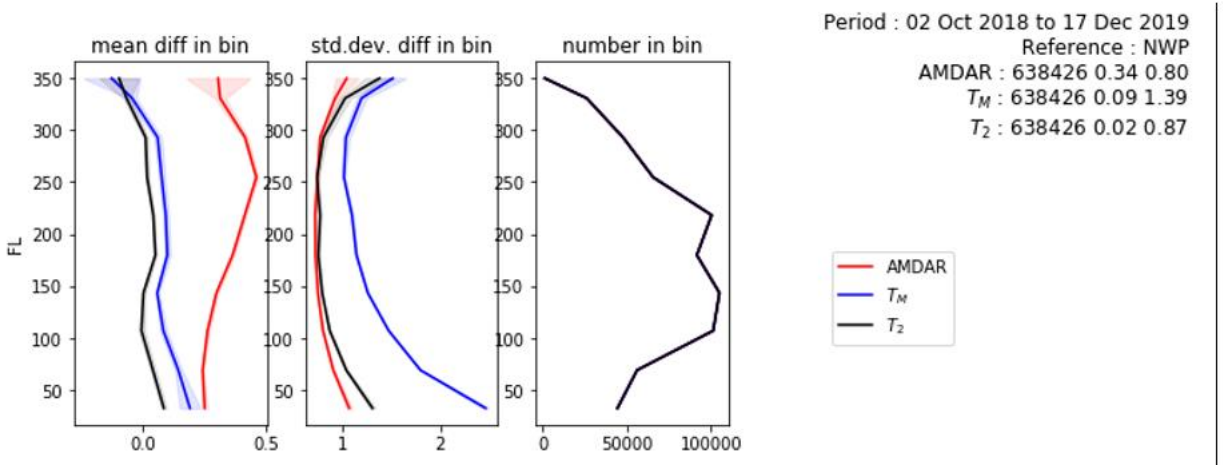
Both parameters are truncated values resulting in resolution of 2 knots for airspeed and 0.004 in Mach number. This truncation hampers the quality of the derived temperature, especially at lower altitudes when aircraft have a lower airspeed and corresponding lower Mach numbers.

Solution: ?

Issue 2 – quality of derived temperature

Solution: use IAS and static pressure instead of MACH number and average over 20 seconds.

Results: standard deviation close to AMDAR, and zero bias

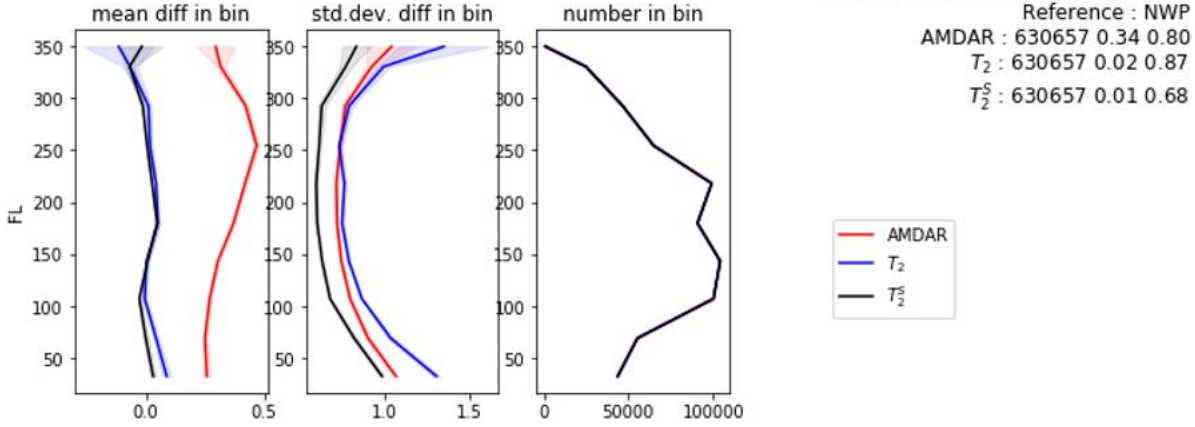


Issue 2 – quality of derived temperature

Solution: use IAS and static pressure instead of MACH number and average over 20 seconds.

Additional improvement via ‘super obbing’ in time window of 5 minutes

Results: a improvement of standard deviation from 0.9K to below 0.7 K; the standard deviation is over the whole profile smaller than AMDAR, when compared to NWP.



Issue 3 – anonymization of aircraft

Requirement of ATS ANSP is anonymization of aircraft due to agreements with staff unions.

EMADDC uses a lookup table to hide the original IACO aircraft ID.

Is this an issue?

Is raw surveillance data needed or is providing quality controlled EMADDC data (with known quality and quality flags) sufficient?

If need be ECMWF can probably be provided the raw data under an NDA.

Issue 4 – WIGOS Station Identifier

How to allocate a WIGOS Station Identifier to an aircraft used within EMADDC?

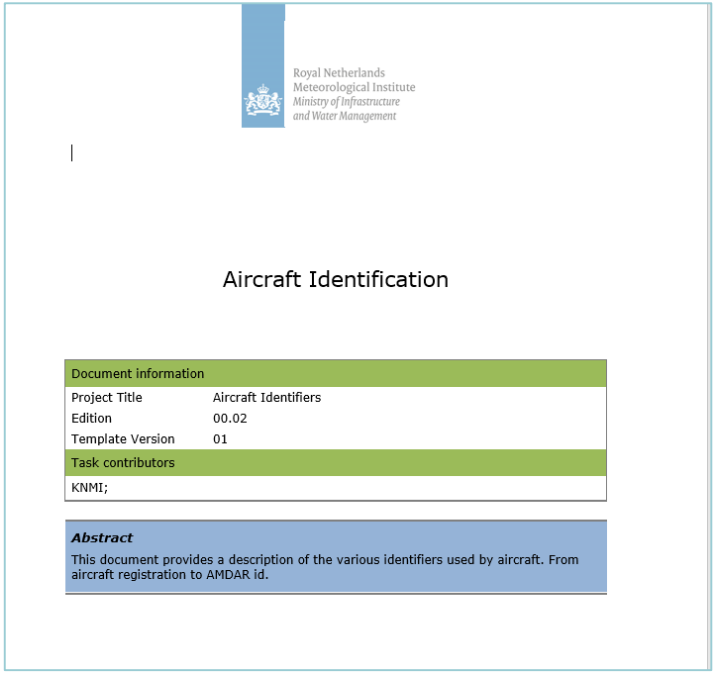
Study performed by EMADDC on implementation.

EMADDC is unable to assign an WSI since it does not have access to any form of unique (in time and place) identification of an aircraft. More specifically, EMADDC does not know with 100% certainty from which airframe an observation is retrieved as listed in the following section.

ICAO 24 bit address may vary in time, even every 6 months. There is no global ICAO database, national databases are dynamic and vary.

Finally, should a WSI be assigned to an airframe, or to a probe? Aircraft contain several sensors that measure the same quantity but with different quality. So what defines an unique observation?

Is there an issue? Do we need a WIGOS SI for EMADDC?



Royal Netherlands Meteorological Institute
Ministry of Infrastructure and Water Management

Aircraft Identification

Document information	
Project Title	Aircraft Identifiers
Edition	00.02
Template Version	01
Task contributors	
KNMI;	

Abstract

This document provides a description of the various identifiers used by aircraft. From aircraft registration to AMDAR id.

Next steps

- EMADDC v2.0
  - near real time processing instead of batch processing every 15 min
  - realisation of NewPENS connection to collect ATS data
  - could be hosted in the cloud (AWS)
  - geographical expansion (United Kingdom via UK MET Office, Europe)
  - output quality control (including improvement in quality of Temperature)

  - launch of EMADDC website
  - realization of data portal (web services)
  - further research on ADS-C data and turbulence
  - roll out of local ADS-B/Mode-S receivers
  - EUMETNET Business Case to include EMADDC in the E-ABO programme as of 2021

Partners and acknowledgements

EMADDC knowledge partners, funding or data provided by:

The initial research on Mode-S EHS (2007)
has been funded by the Knowledge Development Center
Mainport Schiphol (KDC) http://www.kdc-mainport.nl

Co-financed by the European Union
Connecting Europe Facility

Thank you for your attention.

For more info consult the website mode-s.knmi.nl

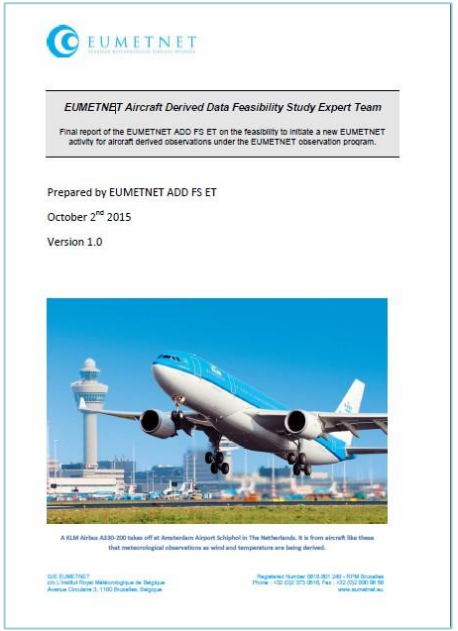
To join or participate in the EMADDC programme please contact mode-s@knmi.nl or sondij@knmi.nl

BACK GROUND SLIDES

EUMETNET

ADD data types

Type	Sub-type	Direct meteorological information	Derived meteorological information	Remarks
Automatic Dependent Surveillance (ADS)	ADS-B	✗	✓	- Only wind - Small number - Poor quality
	ADS-B ES	✗	✓	- Small number - Poor quality
	ADS-C	✓	✓	- Only small portion of messages - Good quality - Data only via ATC or airlines - Data communication costs
Secondary Surveillance Radar (SSR) Mode-S	Mode-S ELS	✗	✗	-
	Mode-S EHS	✗	✓	- Specific dynamic aircraft corrections and quality control required - Good quality wind - Lower quality of temperature - Exceptionally large amounts of observations - Data distribution costs still to be negotiated with ATM community
	Mode-S MRAR	✓	✗	- Small number - Good quality
	Mode-S MET Hazard Report	✗	✗	-
E-AMDAR (for comparison)	E-AMDAR	✓	✗	- Requires on-board AMDAR software - Contract with airlines - Data communication costs - Good quality


EUMETNET

EUMETNET Aircraft Derived Data Feasibility Study Expert Team

Final report of the EUMETNET ADD FS ET on the feasibility to initiate a new EUMETNET activity for aircraft derived observations under the EUMETNET observation program.

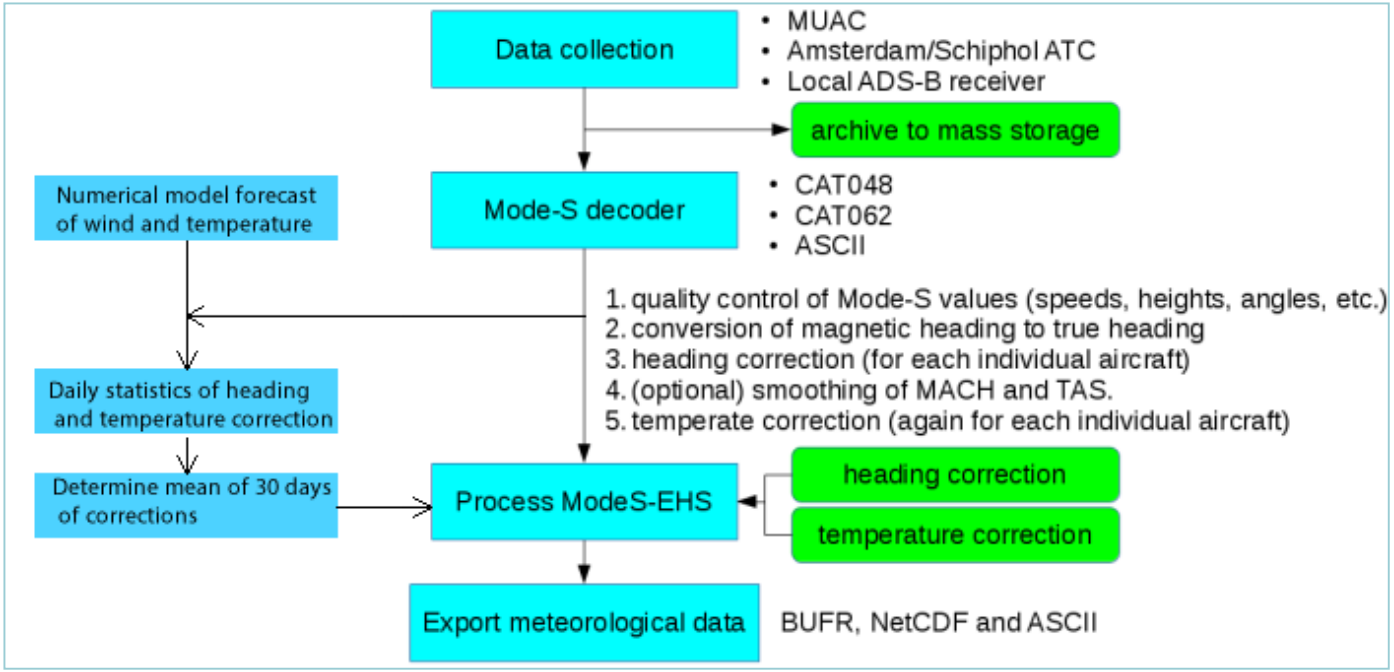
Prepared by EUMETNET ADD FS ET

October 2nd 2015

Version 1.0

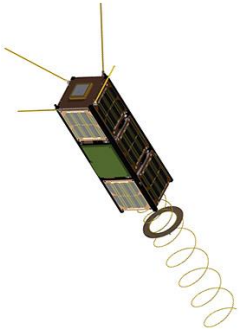
Mode-S EHS can be collected with low cost receivers

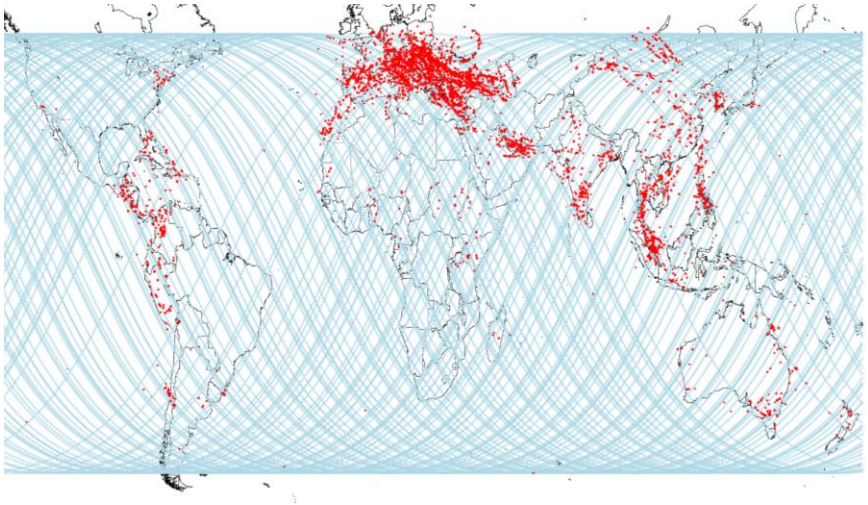
Flow of data processing

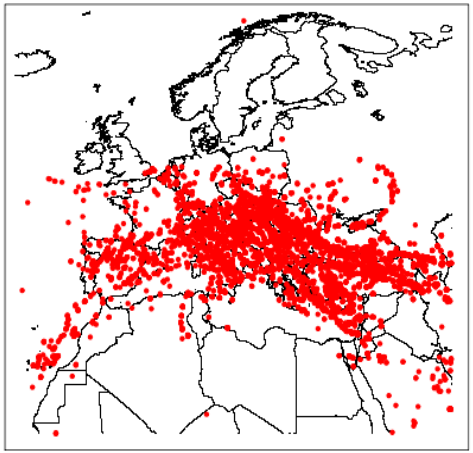


KNMI Mode-S EHS processing chain

Global applicability







Location of derived wind and temperature observations from Mode-S EHS observations (red dots), globally and over Europe, collected by the GomX-3 Cube Satellite.
Data was collected for a two week period during August 2016 with an orbital period of 90 minutes. The blue lines show the path of the satellite during the data collection period.
The limited coverage towards the north is due to the orbit not passing high enough North.

https://blog.metoffice.gov.uk/2016/11/30/can-space-tech-help-measure-the-weather/

UK Met Office

R&D Network

- 5 receivers across the UK (+1 in the Channel Islands)
- 5 are located at Weather Radar Sites, and one at Met Office HQ in Exeter
- Tuned antenna with amplifier using a Mode-S beast decoder
- Real time system using a Raspberry Pi