The CREDOS Project

EDDF 6-Month Wake and Weather Dataset RWY25L/R [EDDF-2]

Abstract:
A long term measurement campaign of vortices from departing aircraft has been conducted at Frankfurt airport between January and June 2007. Meteorological as well as aircraft trajectory data have been collected in parallel. Data from the various sensors have been fused and correlated in order to characterize the vortices in an operational and meteorological context. More than 10.000 cases mostly due to heavy aircraft taking off runway 25R have been collected. The data is delivered on a separate data carrier. This document describes the different formats of the collected data, summarizes the definitions and gives additional guidance for further analyses.

Contract Number:	**AST5-CT-2006-030837**	**Proposal Number:**	**30837**
Project Acronym:	**CREDOS**		
Deliverable Title:	**EDDF 6-Month Wake and Weather Dataset RWY25L/R [EDDF-2]**		
Delivery Date:	**09/2007**		**Deliverable Nr.: D1-2**
Responsible:	**DFS Deutsche Flugsicherung GmbH**		
Nature of Deliverable:	**O (Other = Data + Document)**		
Dissemination level:	**PU (document only, data remains restricted to the consortium)**		
File Id N°:	**CREDOS_120_DFS_DLV_D1-2_EDDF-2_Data_v1a_Nov2009**		
Status:	**approved**	**Version: 1a**	**Date: 26 November 2009**

Approval Status		
Document Manager	**Verification Authority**	**Project Approval**
DFS	**DFS**	**PMC**
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DFS Deutsche Flugsicherung

CREDOS

Crosswind-reduced Separations for Departure Operations

EDDF 6-Month Wake and Weather Dataset RWY25L/R [EDDF-2]

26. November 2009
D1-2 Version 1a

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Revision Table

Version	Date	Changes	Comments
0j	19.09.2007		For approval
1	26.09.2007	p. 8 p. 20 p. 33 document	Definition of tangential plane corrected Paragraph about take-off clearance modified "right" instead of "left" plot Harmonisation of some notations, elimination of misprints, some additions to the list of acronyms
1a	26.11.2009	Table 1 Table 6 Table 9	x-coordinate of the WTR/RASS shading of items no. 23 and 25 description of items no. 7 and 8 dissemination level of document changed from RE to PU following SC7/PMC12 decision

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1 Introduction

The CREDOS project will study operational feasibility of a reduction of the wake turbulence separation minima between departures on a single runway based on the crosswind induced lateral transport of the vortices [1].

The approach is based on data collection campaigns at two target airports, St. Louis, USA and Frankfurt, Germany. At Frankfurt two different campaigns took place:

1. EDDF-1, where two different lidars measured vortices shed by departures on runways 07L and 07R. The lidar operated by DLR measured 142 vortex pairs of heavy departures during 7 days. In addition to that, meteorological profiles had been measured using a SODAR/RASS and an ultrasonic anemometer. For details see [2]. Moreover an experimental lidar deployed by ONERA has been operated for a couple of weeks. However, no results were available when this document was completed.
2. EDDF-2, a longer measurement campaign, capable of collecting a statistically meaningful number of vortices: A Windtracer operated for nearly 6 months between January, 5th and June, 30th 2007 and tracked more than 10.000 vortices mainly from heavy departures on runway 25R. Apart from the collection of vortex tracks, DFS measured other relevant data, i.e. meteorological profiles from a wind-temperature radar and other meteorological data as well as surveillance data to characterise the aircraft trajectories. These latter items have been collected for more than a year, i.e. from June 1st 2006 until June 30th 2007.

2 Purpose of this document

This document describes the content and format of the various datasets recorded at Frankfurt airport during CREDOS' long term measurement campaign EDDF-2. It constitutes the reference for those CREDOS partners, who intent to use these data for analysis purposes or for correlation with other CREDOS data.

In addition to that the document contains a brief description of the type and position of the sensors at Frankfurt/Main airport, EDDF.

Several different datasets have been prepared within the context of the CREDOS project. Basically three different classes of datasets can be distinguished:

1. Datasets characterising the meteorological situation and the real operational practise at Frankfurt airport. Typically these data are available for a period of almost 13 months and allow for in-depth analyses of the meteorological circumstances, e.g. the wind distributions, frequency and magnitude of wind changes etc. Most of these data are derived from equipment, which is available 'common of the shelf' already today. Within CREDOS EDDF-2 meteorological data is analysed by DFS only. It will therefore not be part of D1-2, but it is available for the partners upon sufficiently justified request. Due to its confidential nature, surveillance data will not be disclosed at all.

2. The 'correlated dataset', which constitutes the best available characterisation of departure vortices as measured by the Windtracer together with the operational and meteorological context in which the vortices have evolved. The correlated dataset, together with this report, constitutes the CREDOS deliverable D1-2 'EDDF 6-Month Wake and Weather Dataset RWY25L/R [EDDF-2].
3. Auxiliary datasets are necessary to obtain parts of the information that is contained in the correlated dataset, e.g. the aircraft type. Auxiliary datasets are not part of the deliverable.

Note that for research purposes such as the EDDF-2 data collection it was not possible to get access to the operational systems themselves. Bypasses of the data streams or test systems have been employed instead. Therefore data availability might have been lower than in a truly operational environment. Data quality, however, is not affected by these procedures.

3 Coordinate system and sensor sites

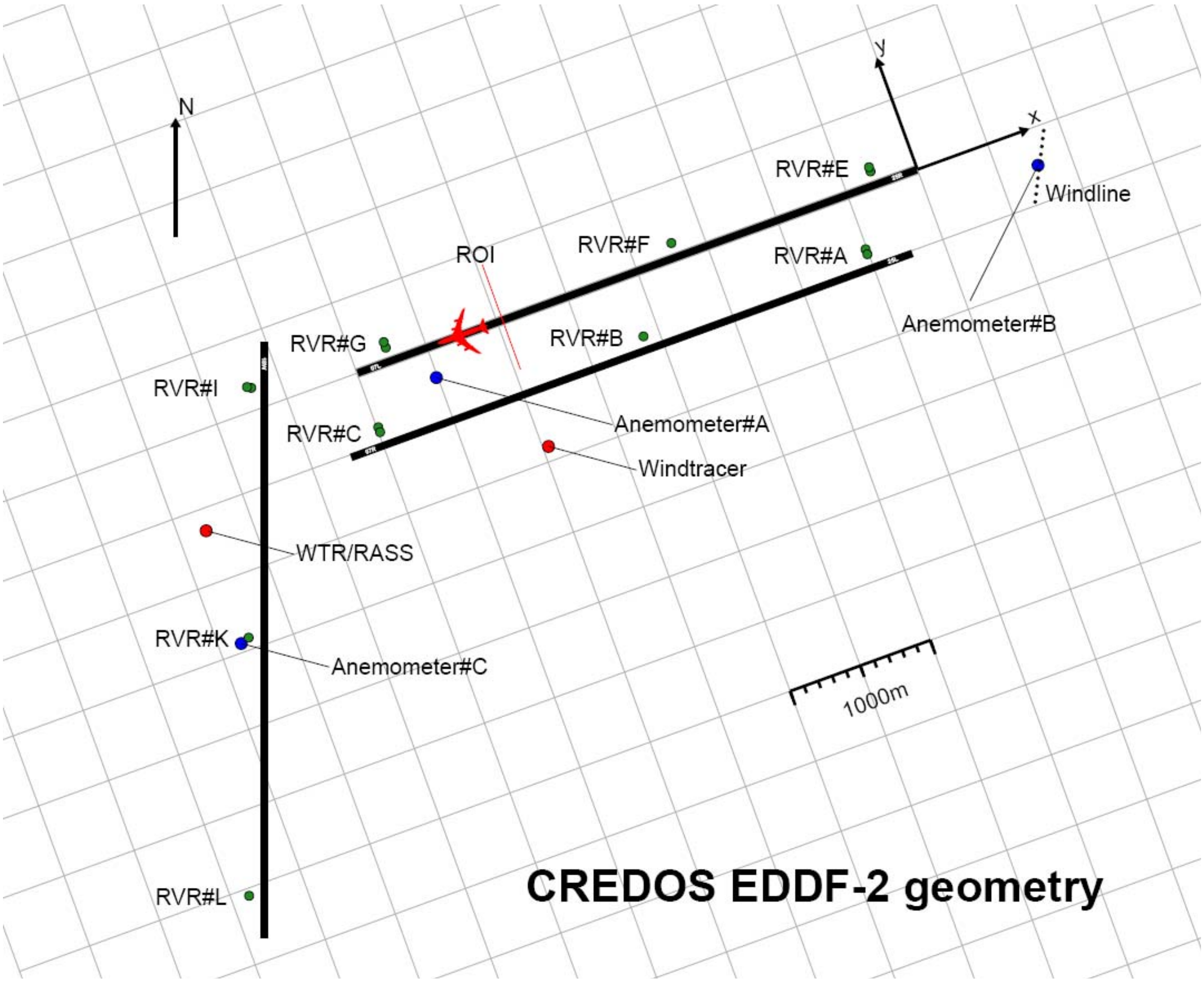

Figure 1: Coordinate system and sensor sites during EDDF-2 campaign.

The coordinate system of the EDDF-2 campaign is a right-handed system with the x-axis along the runway centreline (positive x-direction is roughly pointing to 70° true bearing), y-axis perpendicular to runway centreline (positive y-direction is roughly pointing to 340° true bearing), and z-axis perpendicular to the surface (positive z-direction is pointing upwards). The origin of the coordinate system is threshold of runway 25R. x- and y-axes span a horizontal plane tangential to the earth's surface. The coordinate system together with the locations of the various sensors which have been used during EDDF-2 is depicted in Figure 1. Some important coordinates may be also found in Table 1.

	x in m	y in m
THR25R (by definition)	0.00	0.00
WTR/RASS	−5312.60	−648.37
Anemometer #A	−3510	−210
Anemometer #B	770	−250
Anemometer #C	−5350	−1440
Windtracer beam intersection with centreline of RWY25R	−2960.76	0.00

Table 1: Important coordinates used in EDDF-2.

Coordinated Universal Time, UTC, has been used for time-stamping data from all sensors involved in EDDF-2. In most cases data is provided in SI-units (metric system), except where another notation is more commonly used: pressure altitude in ft, some wind speeds as well as the aircraft's speed are given in kt. Anemometers #A, #B, and #C measure wind at 10 m above ground level.

4 Meteorological datasets

4.1 IDVS data

IDVS is an acronym for 'Integriertes Datenverarbeitungssystem', a DFS-internal term. Apart from other data, IDVS is used for distribution of local meteorological data measured with the standard meteorological equipment of the Deutscher Wetterdienst, DWD, i.e. the German Meteorological Service Provider for aviation weather.

Each file contains the IDVS data of one calendar day. Data is stored in ASCII format. Each file contains a header line followed by a number of lines with data. Each line ends with a CR LF, hexadecimal $0D0A. Data are listed in a fixed format.

Ideally the data is output every 10 s. However due to transmission failures some records are missed. Even outages as long as several hours have been recognized. The percentage of data which has been logged successfully was not meeting the DFS-internal expectations. As a consequence, the relevant surface meteorological data has also been retrieved from another system, ANBAS, see section 4.2.

Beside other items the IDVS dataset contains in particular wind measurements at 10 m AGL of three different anemometers and RVR of several transmissiometers. The locations of the anemometers and transmissiometers can be read off Figure 1.

Data is collected according to the provisions set out in ICAO Annex 3 [3]. For more details on averaging intervals and accuracy of the data see there.

4.1.1 File name convention

File names are `log_`*`yyyy_mm_dd`*`.txt`, where *`yyyy_mm_dd`* denotes year, month and day respectively.

4.1.2 Expected file size

The header line contains 495 characters. Each data record consists of 500 characters. Together with 2 bytes for CR LF for each line, the total file size is

File size = number of records multiplied by 502 bytes per record + 497 bytes

Thus the size is limited to a maximum of 4.337.775 bytes.

4.1.3 Header line

The first line describes the content of the records to follow. It is always the same and it reads:

```
TIME SENSOR DIRAV SPDAV DIRL DIRR SPDMIN SPDMAX SENSOR DIRAV SPDAV DIRL DIRR
SPDMIN SPDMAX SENSOR DIRAV SPDAV DIRL DIRR SPDMIN SPDMAX SENSOR DIRAV SPDAV
DIRL DIRR SPDMIN SPDMAX SENSOR RANGE SENSOR RANGE SENSOR RANGE SENSOR RANGE
SENSOR RANGE SENSOR RANGE SENSOR RANGE SENSOR RANGE SENSOR RANGE SENSOR
RANGE SENSOR RANGE SENSOR RANGE SENSOR HHMM SENSOR HHMM SENSOR  QNH_METAR
QFE_METAR  QNH_CURR  QFE_CURR SENSOR CEILING SENSOR CEILING SENSOR CEILING
SENSOR CEILING SENSOR CEILING SENSOR CEILING
```

4.1.4 Data record

An example is given below. Each record contains 74 elements. The content of any of these elements is given in Table 2.

```
060610184210      A    073    06  045  088      04      08      A    082    02
029  118      02      03      A    114    03  023  145      02      05      C    -
--    --  ---  ---      --      --      P  1500      P  1500      P  1500
C  ----      P  1500      P  1500      P  1500      C  ----      P  1500
C  ----      P  1500      P  1500      A 0316      A 1934      A      1021
1008      1021      1008      C      ---      C      ---      C      ---      C
---      C      ---      C      ---
```

No.	Description	Example	Columns	Comments
1	TIME	060610184210	1-12	Date and time (UTC) yymmddhhmmss
2	SENSOR	A	13-19	Sensor status (see Table 3) of Anemometer #A
3	DIRAV	073	20-25	Anemometer #A average wind direction of the last 2 minutes in °
4	SPDAV	06	26-31	Anemometer #A average wind speed of the last 2 minutes in knots
5	DIRL	045	32-37	Anemometer #A leftmost wind direction of the last 10 minutes in °
6	DIRR	088	38-43	Anemometer #A rightmost wind direction of the last 10 minutes in °
7	SPDMIN	04	44-49	Anemometer #A minimum wind speed of the last 10 minutes in knots
8	SPDMAX	08	50-55	Anemometer #A maximum wind speed of the last 10 minutes in knots
9	SENSOR	A	56-62	Sensor status (see Table 3) of Anemometer #B
10	DIRAV	082	63-68	Anemometer #B average wind direction of the last 2 minutes in °
11	SPDAV	02	69-74	Anemometer #B average wind speed of the last 2 minutes in knots
12	DIRL	029	75-80	Anemometer #B leftmost wind direction of the last 10 minutes in °
13	DIRR	118	81-86	Anemometer #B rightmost wind direction of the last 10 minutes in °
14	SPDMIN	02	87-92	Anemometer #B minimum wind speed of the last 10 minutes in knots
15	SPDMAX	03	93-98	Anemometer #B maximum wind speed of the last 10 minutes in knots
16	SENSOR	A	99-105	Sensor status (see Table 3) of Anemometer #C
17	DIRAV	114	106-111	Anemometer #C average wind direction of the last 2 minutes in °
18	SPDAV	03	112-117	Anemometer #C average wind speed of the last 2 minutes in knots
19	DIRL	023	118-123	Anemometer #C leftmost wind direction of the last 10 minutes in °
20	DIRR	145	124-129	Anemometer #C rightmost wind direction of the last 10 minutes in °

21	SPDMIN	02	130-135	Anemometer #C minimum wind speed of the last 10 minutes in knots
22	SPDMAX	05	136-141	Anemometer #C maximum wind speed of the last 10 minutes in knots
23	SENSOR	C	142-148	Sensor status (see Table 3) of Anemometer #D
24	DIRAV	---	149-154	Anemometer #D average wind direction of the last 2 minutes in °
25	SPDAV	--	155-160	Anemometer #D average wind speed of the last 2 minutes in knots
26	DIRL	---	161-166	Anemometer #D leftmost wind direction of the last 10 minutes in °
27	DIRR	---	167-172	Anemometer #D rightmost wind direction of the last 10 minutes in °
28	SPDMIN	--	173-178	Anemometer #D minimum wind speed of the last 10 minutes in knots
29	SPDMAX	--	179-184	Anemometer #D maximum wind speed of the last 10 minutes in knots
30	SENSOR	P	185-191	Sensor status (see Table 3) of transmissiometer #A
31	RANGE	1500	192-197	Transmissiometer #A runway visual range in m
32	SENSOR	P	198-204	Sensor status (see Table 3) of transmissiometer #B
33	RANGE	1500	205-210	Transmissiometer #B runway visual range in m
34	SENSOR	P	211-217	Sensor status (see Table 3) of transmissiometer #C
35	RANGE	1500	218-223	Transmissiometer #C runway visual range in m
36	SENSOR	C	224-230	Sensor status (see Table 3) of transmissiometer #D
37	RANGE	----	231-236	Transmissiometer #D runway visual range in m
38	SENSOR	P	237-243	Sensor status (see Table 3) of transmissiometer #E
39	RANGE	1500	244-249	Transmissiometer #E runway visual range in m
40	SENSOR	P	250-256	Sensor status (see Table 3) of transmissiometer #F
41	RANGE	1500	257-262	Transmissiometer #F runway visual range in m
42	SENSOR	P	263-269	Sensor status (see Table 3) of transmissiometer #G
43	RANGE	1500	270-275	Transmissiometer #G runway visual range in m
44	SENSOR	C	276-282	Sensor status (see Table 3) of transmissiometer #H

45	RANGE	----	283-288	Transmissiometer #H runway visual range in m
46	SENSOR	P	289-295	Sensor status (see Table 3) of transmissiometer #I
47	RANGE	1500	296-301	Transmissiometer #I runway visual range in m
48	SENSOR	C	302-308	Sensor status (see Table 3) of transmissiometer #J
49	RANGE	----	309-314	Transmissiometer #J runway visual range in m
50	SENSOR	P	315-321	Sensor status (see Table 3) of transmissiometer #K
51	RANGE	1500	322-327	Transmissiometer #K runway visual range in m
52	SENSOR	P	328-334	Sensor status (see Table 3) of transmissiometer #L
53	RANGE	1500	335-340	Transmissiometer #L runway visual range in m
54	SENSOR	A	341-347	Status (see Table 3) sunrise
55	HHMM	0316	348-352	Time (UTC) of sunrise in hhmm
56	SENSOR	A	353-359	Status (see Table 3) sunset
57	HHMM	1934	360-364	Time (UTC) of sunset in hhmm
58	SENSOR	A	365-371	Status pressure sensor
59	QNH_METAR	1021	372-381	QNH air pressure as reported in the most recent ATIS report, in hectopascal
60	QFE_METAR	1008	382-392	QFE air pressure as reported in the most recent ATIS report, in hectopascal
61	QNH_CURR	1021	393-401	Current QNH air pressure as measured locally, in hectopascal
62	QFE_CURR	1008	402-410	Current QFE air pressure as measured locally, in hectopascal
63	SENSOR	C	411-417	Not used
64	CEILING	---	418-425	Not used
65	SENSOR	C	426-432	Not used
66	CEILING	---	433-440	Not used
67	SENSOR	C	441-447	Not used
68	CEILING	---	448-455	Not used
69	SENSOR	C	456-462	Not used
70	CEILING	---	463-470	Not used
71	SENSOR	C	471-477	Not used
72	CEILING	---	478-485	Not used
73	SENSOR	C	486-492	Not used
74	CEILING	---	493-500	Not used

Table 2: IDVS data record. Marked elements are part of the correlated data set.

#D, #H and #J are placeholders for transmissiometers which are currently not installed. Sensor status can assume one of 5 possible values (see Table 3).

Character	Meaning
A	Sensor is OK, valid data
B	Sensor is in test mode, data may not be valid. In particular the value must not be used in air traffic control.
C	Sensor is defect. Normally no value shall appear; field is filled with dashes instead. If a numerical value is specified, the datum has to be considered invalid.
P	Sensor is OK, data is valid. Its true numerical value is exceeding the value specified in the field. E.g. RVR P 1500 means RVR is exceeding 1500 m.
M	Sensor is OK, data is valid. Its true numerical value is smaller than the value specified in the field.

Table 3: Sensor status.

4.2 ANBAS data

ANBAS is an acronym for 'Alphanumerisches Bedien- und Anzeigesystem', a DFS-internal term. ANBAS data to some extent overlaps with IDVS data. The ANBAS data set contains actual wind, temperature, dewpoint, visibility, QNH and RVR information.

Each file contains the ANBAS data of one calendar day. Data is stored in ASCII format. Each file contains a number of lines with data. Each line ends with a CR LF, hexadecimal $0D0A. Data are listed in a fixed format.

Ideally the data is output every 10 s.

Data is collected according to the provisions set out in ICAO Annex 3 [3]. For more details on averaging intervals and accuracy of the data see there.

ANBAS specifies one more digit of the QNH as compared to IDVS, moreover it contains surface temperature. The wind is taken from the anemometer #A, #B or #C according to the following logic:

RWY25 in use: #B is used; if #B fails, #A is used; if #A fails as well, #C is used.

RWY07 in use: #A is used; if #A fails, #B is used; if #A fails as well, #C is used.

Note, in the data processing ANBAS data is preferred over IDVS data.

4.2.1 File name convention

File names are `anbas`*`yyyymmdd`*`.out`, where *`yyyymmdd`* denotes year, month and day respectively.

4.2.2 Expected file size

Each data record consists of 61 characters. Together with 2 bytes for CR LF for each line, the total file size is

File size = number of records multiplied by 63 bytes per record

Thus the size is limited to a maximum of 544.320 bytes.

4.2.3 Header line

ANBAS data sets do not contain a header line.

4.2.4 Data record

No.	Description	Example	Columns	Comments
1	DATE	2006-09-28	1-10	Date yyyy-mm-dd
2	TIME	12:56:30	11-19	Time (UTC) hh:mm:ss
3	WINDDIR	220	20-23	Average wind direction of the last 2 minutes in °. This value is used as the reference in the ATC tower.
4	WINDSPD	05	24-26	Average wind speed of the last 2 minutes in knots. This value is used as the reference in the ATC tower.
5	GUSTS	08	27-29	Gust speed of the last 10 minutes in knots. This value is used as the reference in the ATC tower.
6	QNH	1013.0	30-36	Current QNH in hectopascal
7	TEMP	20.7	37-42	Current air temperature in °C
8	DEWPT	13.6	43-48	Current dewpoint in °C
9	RWY	25R	49-52	Runway in use. 25R or 07L might appear here.
10	SENSOR	E:	53-55	Sensor which measured the RVR given in the next field. For sensor locations see Figure 1.
11	RVR	P1500m	56-61	Runway visual range. In this example the RVR is exceeding 1500m (P).

Table 4: ANBAS data record. Marked elements are part of the correlated data set.

4.3 WTR/RASS data

DFS has installed a windprofiler system at the western end of the airport. For the exact location of this instrument see section 3. WTR/RASS (see Figure 2) is a wind-temperature radar supplemented with a radio acoustic sounding system. The system provides ATC with wind- and temperature profiles between 60 and 1650 m above ground level in real time. Furthermore the WTR/RASS is used for wake vortex related research in several projects such as CREDOS. A detailed description of its technology is beyond the scope of this document. A summary of the system's essentials can be found in [4].

When uncompressed each file contains the WTR/RASS data of one calendar day. Data is stored in ASCII format. The measurement interval is almost 2 minutes. Normally there are 722 data compilations per day.

The data format, called "Format 1" is flexible and adjustable in a variety of ways. However during the measurement campaign CREDOS EDDF-2 the format had been kept fixed. This particular format is described below.

Figure 2: WTR/RASS of DFS at Frankfurt airport.

4.3.1 File name convention

File names are `yymmdd.mnd.bz2` for the compressed main data file, which contains the various profiles in ASCII format and where *yymmdd* denotes year, month and day respectively. A graphical summary of the data of one day is stored in the Bulletin files, pdf-files following the file name convention `Bulletinyyyymmdd.pdf`.

4.3.2 Expected file size

The regular file size of one day uncompressed data amounts 11.7 MBytes. Zipping the files reduces the size to 1.3 Mbytes on average.

4.3.3 File structure and header lines

Each WTR/RASS data file consists of 2 header sections and at least one data record. A regular file, containing data of one day, encompasses approximately 722 data records. The general file structure is a bit more complicated than in the cases of IDVS and ANBAS data:

HEADER 1
HEADER 2
DATARECORD 1
DATARECORD 2
..
DATARECORD N

The first header (HEADER 1) comprises 9 lines, inclusive 1 blank line, see example below:

```
FORMAT-1
2007-02-13 00:01:55 0
AP
2 42 54

LOCATION ID: FFM
REPROCESS LEVEL: A
file generated by APRun 2.38.02c
Main Data
```

The second line contains three items: date and time of file creation and the constant value “0”. The content of the other lines ensures complete traceability in the case the data needs to be reprocessed from raw data.

HEADER 2 describes the content of the data records in detail. In the data collected within the CREDOS campaign EDDF-2, HEADER 2 comprises 43 lines, each describing the content and format of a relating data item in the data record section. In general each line contains 6 fields separated by #:

```
height # z # m # Z1 # 1 #
wind speed # speed # m/s # G1 # 1 # 99.99
wind direction # dir # deg # R1 # 1 # 999.9
<wind speed> # <speed> # m/s # G2 # 1 # 99.99
<wind direction> # <dir> # deg # R2 # 1 # 999.9
……
……
```

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
Name	short name/ abbreviation	Unit	S – scalar value; X,Y,Z,R,G – vector component	Always 1	error value
wind direction	dir	deg	R1	1	99.99

Table 5: WTR/RASS header 2 description and example.

As data is formatted in rows (height) and columns (related data), one line of HEADER 2 describes data in one column of the data record. A short description of the different items is given below:

Header 2 line no:	Name	Description
1	height	Height above ground level in meters
2	wind speed	Wind speed in m/s
3	wind direction	Wind direction in °. The value refers to system reference! The system reference is rotated 20° counter clockwise referred to magnetic north.
4	<wind speed>	Average wind speed of approximately 2 hours in m/s
5	<wind direction>	Average wind direction of approximately 2 hours in °
6	wind U (east)	Wind speed vector component in m/s system east
7	wind V (north)	Wind speed vector component in m/s system north
8	wind W (vertical)	Wind speed vector component in m/s vertical
9	std.dev. signal U	Instantaneous wind speed variation – vector component u in m/s
10	<std.dev. signal U>	Standard deviation of (9). Time interval is approximately 2 hours.
11	<std.dev. means U>	Average wind speed variation (9). Time interval is approximately 2 hours.
12	std.dev. U	=SQRT[<std.dev. signal U>^2 + <std.dev. means U>^2]
13	std.dev. signal V	See (9)-(12)
14	<std.dev. signal V>	See (9)-(12)
15	<std.dev. means V>	See (9)-(12)
16	std.dev. V	See (9)-(12)
17	std.dev. signal W	See (9)-(12)
18	<std.dev. signal W>	See (9)-(12)
19	<std.dev. means W>	See (9)-(12)
20	std.dev. W	See (9)-(12)
21	std.dev. direction	See (9)-(12)
22	turbulent kinetic energy	= 3/2*(std.dev. W)^2
23	Temperature	Virtual temperature in °C derived from speed of sound measurement. It is assumed that the average vertical wind is 0.
24	<temperature>	Average temperature of approximately 2 hours in °C.
25	<std.dev. means temperature>	Temperature standard deviation in °C. Time interval is approximately 2 hours.
26	inversion layer ID (derived from	System internal value

	temperature profile)	
27	precipitation fallspeed	Rate of fall of precipitation in m/s.
28	confidence	System internal quality control regarding wind speed and direction measurement as well. A value of 3 and 4 implies good quality, 1 and 0 poor quality.
29	confidence U	System internal quality control. A value of 3 and 4 implies good quality, 1 and 0 poor quality.
30	confidence V	System internal quality control. A value of 3 and 4 implies good quality, 1 and 0 poor quality.
31	confidence W	System internal quality control. A value of 3 and 4 implies good quality, 1 and 0 poor quality.
32	confidence T	System internal quality control. A value of 3 and 4 implies good quality, 1 and 0 poor quality.
33	significance U	System internal value
34	significance V	System internal value
35	significance W	System internal value
36	significance T	System internal value
37	delta_z_U	System internal value
38	delta_z_V	System internal value
39	delta_z_W	System internal value
40	delta_z_T	System internal value
41	backscatter	System internal value
42	backscatter (avg)	System internal value
43	errorcode	System internal value

Table 6: WTR/RASS data items. Marked elements are part of the correlated data set.

4.3.4 Data record

Each data record is introduced with a blank line following a line containing 4 items separated by spaces.

Item	Description
1	Date of measurement
2	Calculated end of measurement interval
3	Timestamp
4	Duration of measurement

Table 7: WTR/RASS data record, description of the first line.

The following lines contain the data as described in header 2. The number of height or range gates is specified in the fourth line of header 1. Within CREDOS EDDF-2 campaign the number of height gates has been fixed to 54, thus corresponding to gates from 60 m up to 1650 m in 30 m increments.

```
2007-02-13 08:56:31 08:56:31 00:01:25
   60   8.14  257.0   9.51   …  1
   90   8.50  257.0   9.65   …  0
  120   8.66  257.0  10.29   …  0
…
…
 1650  20.11  308.0  21.79   … 17

2007-02-13 08:58:31 08:58:31 00:01:25
   60   8.59  262.0   9.51   …  1
```

4.3.5 Confidence

It must be emphasized that the various data items have to be considered only together with the corresponding confidence classification. It is strongly recommended to use only data belonging to confidence classes 3 and 4 for further analyses.

For example the wind component U listed in column 6 may only be used if confidence U in column 29 of the same line is greater or equal to 3. Wind direction may only be considered if confidence U and confidence V are greater or equal to 3.

For those elements, which are part of the correlated data set, this filter has already been applied.

Note that in the Bulletin-files, pages 3-26, wind measurements belonging to classes 0 and 1 are not displayed at all (red squares), wind measurements belonging to class 2 are marked by yellow square and wind measurements with high or very high confidence are just printed on white background. The colour code of the arrows is for internal use only.

4.4 METAR

METAR (Meteorological Aviation Routine Weather Report) data are provided in two files. `METAR-2006.dat` and `METAR-2007.dat` contain the METARs collected from June 1st, 2006 – December 31st, 2006 and January 1st, 2007 – June 30th, 2007, respectively. The data are stored in ASCII files. One line contains one METAR. Each line ends with a CR LF, hexadecimal $0D0A.

4.4.1 File name convention

See section 4.4.

4.4.2 File size

METARs are issued every 30 minutes at 20 and 50 minutes past a full hour. Since METARs do not contain a fixed number of entries, file sizes are not exactly proportional to the number of entries. Nevertheless it can be noted that for every day during the campaign 48 reports are listed, thus no METAR entry is missing in the files.

4.4.3 Header line

CREDOS METAR files do not contain a header line.

4.4.4 Data record

METAR information is stored in accordance with WMO standard notation [5], except that a report starts with “EDDF *yyyy mm*“, where *yyyy mm* denotes year and month, which are usually not part of METAR. An example is given below.

```
EDDF 2007 01 011050Z 26016G28KT 9999 -SHRA FEW018CB BKN030 BKN080 08/06
Q1016 NOSIG
```

5 Correlated data

For every departure a correlated data set is generated. It consists of several files, each describing some aspect of the event. Files belonging to the same event, i.e. the same departure are uniquely identified by an ID. The ID is part of the file name, the different elements are distinguished by the file name extension.

The first three characters or digits of the ID contain the runway identifier, characters/digits four to seven contain the aircraft type. The remaining 25 digits contain more information about the fight like callsign, Mode-S address of the aircraft, date and time in an encrypted form. Traceability is ensured, since DFS can reconstruct this information from the 32 character ID.

Technically the correlation is based on time as the only correlation parameter. Time t=0 is defined as the moment, when the aircraft (for departures on 25L/R) passes the plane x = −2961 m. This is the trigger to seek for vortices in the database provided by Volpe.

Also the most recent meteorological observations are stored. While this is probably not the optimal appropriate approach as far as the modelling of wake vortex behaviour is concerned, where the wind during the vortices life are required, these observables could become part of the concept of operation.

The decision of an air traffic controller, as to whether meteorological conditions such as crosswind would allow for suspension of the wake turbulence separation can only be based on the conditions/measurements known at the time when the take-off clearance is given. Since CREDOS is concerned with the take-off clearance for the following aircraft, this is implicitly taken into account, if the conditions are known at the time, when the vortices of the leading aircraft have been created.

A few remarks apply to any entry in the correlated data set:

- If a data item is missing, e.g. in case that there was no sufficiently confidence in a wind measurement by the WTR/RASS during the most recent measurement interval, an asterisk (*) is printed instead.

- The number of decimal digits does neither reflect the resolution of the sensor or the applied data collection and analyses means nor does it correspond to the accuracy of the data.

5.1 Departure track data

Departure track data are stored in an ASCII file named `ID.dat`. Its first line contains a disclaimer. All following lines are constructed in the same manner: Each line contains 11 items, which are specified in Table 8.

Item No.	Example	Columns	Description & Comments
1	16	1-3	Time in s relative to t=0
2	-4193.91	4-12	x-coordinate in m in local reference frame
3	-1.99	13-21	y-coordinate in m in local reference frame
4	112.18	22-30	z-coordinate in m in local reference frame
5	50.031994	31-42	Latitude in ° (WGS84 [6])
6	8.532106	43-54	Longitude in ° (WGS84 [6])
7	500	55-61	Mode-C pressure altitude of aircraft in ft (ICAO standard atmosphere)
8	246.9	62-68	Aircraft track in ° as output by the radar tracker
9	154.8	69-75	(Ground) speed in kt as output by the radar tracker
10	156.6	76-82	“True" airspeed in kt (vector sum of ground speed and WTR/RASS measured wind speed at the altitude of the aircraft)
11	156.4	83-89	Equivalent airspeed in kt (vector sum of ground speed and WTR/RASS measured wind speed at the altitude of the aircraft corrected for air density)

Table 8: Departure track data elements.

```
!(c) DFS Deutsche Flugsicherung GmbH 2007. Do NOT distribute outside the CREDOS consortium!
 16 -4193.91    -1.99   112.18   50.031994    8.532106    500  246.9  154.8  156.6  156.4
 21 -4642.72   -12.55   142.62   50.030500    8.526286    600  248.8  161.5  164.1  163.9
 26 -4995.88    20.42   173.11   50.029672    8.521506    700  251.8  165.2  168.1  167.8
 31 -5383.13    34.51   203.55   50.028578    8.516372    800  251.5  163.5  166.5  166.2
 36 -5774.29    57.91   233.96   50.027550    8.511142    900  253.6  160.1  164.2  163.8
 40 -6172.21   120.53   264.34   50.026831    8.505633   1000  260.2  159.8  163.9  163.6
 45 -6560.82   237.63   294.71   50.026600    8.499981   1100  267.7  160.5  165.2  164.8
 50 -6940.00   380.92   325.05   50.026619    8.494325   1200  270.7  161.4  165.1  164.7
 55 -7293.45   525.96   355.40   50.026733    8.488997   1300  271.4  161.4  166.1  165.7
 60 -7654.55   679.44   385.72   50.026894    8.483528   1400  273.1  160.6  165.8  165.5
 65 -8031.03   837.38   415.99   50.027044    8.477836   1500  273.5  160.2  164.7  164.4
 69 -8404.40  1009.37   477.00   50.027322    8.472117   1700  275.3  161.6  166.3  166.2
```

Radar track output is constrained to Mode-C pressure altitude lower or equal to 5000 ft and a corridor near the extended centrelines of runways 25L/R, roughly -1500 m < y < 1000 m.

5.1.1 Error estimates

A rigorous error analysis of all data generated in EDDF-2 would be large scale project itself. Nevertheless some estimates for a couple of observables will be given here. Items 5−9 (white background) of Table 8 are direct output by the Radar tracker. The other items 1−4 and 10+11 (grey background) have been derived from the surveillance and meteorological data.

One data item (7), the altitude, is determined by the aircraft itself. According to ICAO Annex 10 [7], the aircraft pressure altitude must be accurate to ±125 ft on 95% level. In practise, however, the accuracy appears to be much higher.

The aircraft's lateral position in terms of latitude/longitude or x/y is accurate to better than 50 m in 98% of the cases. This is an estimated average value and does not take into account the extreme difficulty to determine aircraft positions very close to the ground using conventional secondary surveillance radars for en-route and approach. Another complication appears because it was not logged during CREDOS, which radars fed the tracker. Thus the data quality is slightly changing with time.

The above estimate is corroborated by the analysis of aircraft trajectories. They appear very close to the runway centreline for aircraft which just have rotated and therefore must be just above the runway, i.e. y should be close to zero. For a quantitative assessment we refer to the CREDOS deliverable D2-4 [8].

The ground speed (item 9) is the result of a numerical differentiation, a technique which might yield large errors for particular examples. Erroneous values however would result in discontinuities of the time series of the velocities. From the fluctuations observed in these time series, an error on the order of ±5 kt is estimated.

For the other two aircraft speeds (items 10+11) contributions from the error of the WTR/RASS wind measurements have to be considered in addition to that.

Latitude, longitude and altitude are transformed into the CREDOS EDDF-2 reference frame. The pressure altitude of the aircraft is derived using the assumption that the aircraft operated in a standard atmosphere [9]. Normally the pressure at mean sea level deviates from the standard pressure of 1013.25 hPa and temperature is also not always equal to 15°C. Therefore the pressure altitude is corrected for these two effects and an estimate of the true height of the aircraft above ground level can be computed using the formulae given in [9].

Note that the effect of a non-adiabatic temperature gradient is not taken into account in the correction. Nor do we account for the slope of the terrain (the end of RWY25R, i.e. THR07L is roughly 10 m below THR25R). On the other hand, the curvature of the earth's surface, although a small effect locally, is taken into account.

These transformations together with the slope of the terrain are the causes for reported negative heights, which have been observed a few times in the first position report for some departures.

5.1.2 Determination of $t = t_0 = 0$

A few remarks need to be made concerning time. As stated before all times specified in the correlated data set refer to the instant $t=t_0=0$, when the aircraft crosses the x=−2961 m plane.

t_0 is determined by an inter- or extrapolation of the aircraft trajectory. Note that there is a wide spread distribution of where aircraft tracks show up for the first time in the data. When aircraft position reports are only at x<−5000 m for example t_0 has likely a larger error than for cases, where the aircraft track starts already before the lidar plane, e.g. at x=−2000 m.

Nevertheless in most of the cases the possible error of t_0 is around 1 s. This is corroborated by the distribution of the time of first vortex measurements by the Windtracer, which will be discussed in more detail in another CREDOS deliverable, D2-4 [8].

5.2 Meteorological data (IDVS, ANBAS, METAR)

All information related to meteorological data measured on the surface (actually 10 m AGL for wind) is stored in an ASCII file named `ID.met`. An example of such a file is listed below. It again starts with a disclaimer followed by three sections with IDVS, ANBAS and METAR data, respectively. A fourth section includes the parameters which have been employed to transform pressure altitudes in height AGL.

The content of the `.met` file is rather self-explanatory. It only needs to be mentioned that at the beginning of the first three sections the time when the data have been obtained is specified in seconds relative to t_0.

For more details about the data, see sections 4.1, 4.2, and 4.4.

```
!(c) DFS Deutsche Flugsicherung GmbH 2007. Do NOT distribute outside the CREDOS consortium!


*** IDVS section ***
time in s relative to crossing lidar plane (-2961m for 25, -1000m for 07)          -9
wind sensor       A   318    06  297  015     04     11
wind sensor       A   285    06  253  016     03     08
wind sensor       A   342    07  210  120     01     09
wind sensor       C   ---    --  ---  ---     --     --
transmissiometer       P  1500
transmissiometer       P  1500
transmissiometer       P  1500
transmissiometer       C  ----
transmissiometer       P  1500
transmissiometer       P  1500
transmissiometer       P  1500
transmissiometer       C  ----
transmissiometer       P  1500
transmissiometer       C  ----
transmissiometer       P  1500
transmissiometer       P  1500
pressure       A      1021       1008     1021     1008


*** ANBAS section ***
time in s relative to crossing lidar plane (-2961m for 25, -1000m for 07)          -9
wind direction in °           286
wind speed in kt                6
wind gusts in kt                8
QNH in hPa                 1021.7
```

```
temperature in °C            17.4
dewpoint in °C                6.0
RWY in use                    25R
RVR sensor and value in m E:P1500m


*** METAR section ***
time in s relative to crossing lidar plane (-2961m for 25, -1000m for 07) <=0s ^ >-1800s
METAR EDDF ######Z 31004KT 9999 FEW045 SCT060 BKN110 18/07 Q1021 NOSIG


*** aircraft height correction parameters ***
correction=ANBAS
pressure in hPa used for correction    1021.7
temperature in °C used for correction    17.4
```

5.2.1 Error estimates

Data is collected according to the provisions set out in ICAO Annex 3 [3]. For more details on averaging intervals and accuracy of the data see there.

5.3 WTR/RASS wind-, temperature- and turbulence profiles

Meteorological profiles measured by the WTR/RASS are stored in an ASCII file named `ID.wtr`. An example of such a file is listed at the end of this section. The first line contains a header, in the second line the time when these data have been measured is specified in seconds relative to t_0. All following lines are constructed in the same manner: Each line contains 10 items, which are specified in Table 9.

Item No.	Example	Columns	Description & Comments
1	90	1-3	Height above ground level in m
2	2.99	4-12	Wind speed in m/s
3	319.00	13-20	Wind direction in °. In contrast to the data in the WTR/RASS main data files, this value refers to true north.
4	1.07	21-28	Wind speed vector component in m/s system east
5	-2.79	29-36	Wind speed vector component in m/s system north
6	-0.70	37-44	Wind speed vector component in m/s vertical
7	14.91	45-52	Virtual temperature in °C derived from speed of sound measurement. It is assumed that the average vertical wind is 0.
8	16.00	53-60	Average temperature of approximately 2 hours in °C.
9	4.21	61-68	'TKE short' = 10*3/2*(instantaneous variation of vertical wind speed as derived from the spectral width of the backscattered electromagnetic pulse)^2 (see line 17 of Table 6). Unit is m^2/s^2, note the factor of 10.

10	4.70	69-76	'TKE' long', 10 times the value of the variable explained in line 22 of Table 6. Unit is m^2/s^2. In contrast to the previous variable, this one also takes fluctuations of the vertical wind on longer timescales into account. Note the factor 10.

Table 9: WTR/RASS data elements.

```
!(c) DFS Deutsche Flugsicherung GmbH 2007. Do NOT distribute outside the CREDOS consortium!
!         -34
  60      *       *       *       *       *       *       *       *       *
  90    2.99  319.00    1.07   -2.79   -0.70   14.91   16.00    4.21    4.70
 120    3.80  319.00    1.38   -3.54   -0.62   14.64   15.74    2.05    5.00
 150    3.89  320.00    1.33   -3.65   -0.53   14.60   15.53    1.73    5.20
 180    4.01  320.00    1.38   -3.77   -0.46   14.48   15.25    0.73    5.50
 210    3.66  309.00    1.87   -3.15   -0.30   14.42   14.95    0.94    5.10
 240    3.50  313.00    1.56   -3.13   -0.17   14.35   14.64    1.18    4.50
 270    3.64  316.00    1.47   -3.33   -0.10   14.15   14.37    1.63    4.30
 300    2.23  303.00    1.35   -1.78    0.09   13.94   14.11    1.94    3.20
 330    3.19  313.00    1.47   -2.83   -0.07   13.67   13.84    1.84    3.60
 360    3.59  316.00    1.49   -3.27   -0.14   13.35   13.52    2.05    4.20
 390    3.30  320.00    1.14   -3.10   -0.14   13.01   13.28    2.17    3.80
 420    2.90  323.00    0.84   -2.78   -0.19   12.67   13.02    2.40    3.80
 450    3.45  321.00    1.12   -3.26   -0.31   12.21   12.75    2.40    3.80
 480    3.28  318.00    1.20   -3.06   -0.39   11.80   12.50    2.52    4.00
 510    2.88  320.00    1.00   -2.70   -0.48   11.49   12.25    1.94    4.20
 540    2.62  323.00    0.77   -2.50   -0.49   11.28   12.01    1.63    4.70
 570    2.75  317.00    1.08   -2.53   -0.40   11.12   11.75    1.63    5.10
 600    3.13  304.00    1.86   -2.52   -0.38   10.89   11.46    1.73    5.30
 630    3.39  304.00    1.97   -2.75   -0.37   10.58   11.18    1.63    5.60
 660    3.50  306.00    1.94   -2.91   -0.42   10.22   10.90    1.63    5.60
 690    3.42  312.00    1.59   -3.02   -0.44    9.91   10.69    1.63    6.30
 720    3.42  317.00    1.34   -3.15   -0.43    9.65   10.44    1.44    6.80
 750    3.74  318.00    1.39   -3.47   -0.36    9.51   10.19    1.18    6.60
 780    4.04  321.00    1.34   -3.81   -0.31    9.34    9.83    1.09    5.60
 810    4.33  326.00    1.04   -4.21   -0.26    9.10    9.53    1.09    5.80
 840    4.76  335.00    0.40   -4.74   -0.21    8.90    9.17    1.09    4.70
 870    5.14  338.00    0.22   -5.14   -0.13    8.71    8.86    1.18    3.00
 900    4.95  339.00    0.08   -4.95   -0.07    8.48    8.66    1.26    2.50
 930    4.94  340.00    0.02   -4.94   -0.04    8.27    8.36    1.35    3.30
 960    4.77  341.00   -0.05   -4.77    0.04    8.10    8.11    1.44    5.20
 990    4.66  338.00    0.16   -4.66    0.02    7.83    7.76    1.54    5.20
1020    4.64  336.00    0.36   -4.63    0.01    7.61    7.48    1.54    3.60
1050    4.65  331.00    0.71   -4.59    0.01    7.39    7.15    1.44    3.30
1080    4.78  330.00    0.80   -4.71    0.05    7.18    6.86    1.44    2.80
1110    4.76  330.00    0.83   -4.68    0.05    6.91    6.62    1.26    2.80
1140    4.73  331.00    0.74   -4.67    0.01    6.56    6.37    1.26    2.70
1170    4.71  330.00    0.81   -4.64    0.00    6.30    6.11    1.09    2.60
1200    4.47  330.00    0.79   -4.40   -0.02    6.07    5.90    1.09    2.60
1230    4.79  330.00    0.87   -4.71   -0.04    5.78    5.58    1.09    2.50
1260    5.15  327.00    1.16   -5.01    0.00    5.64    5.33    1.18    2.20
1290    5.52  326.00    1.38   -5.34    0.03    5.47    5.09    1.09    2.60
1320    5.85  325.00    1.54   -5.64    0.10    5.40    4.76    0.94    2.20
1350    5.96  327.00    1.39   -5.80    0.12    5.17    4.50    1.09    1.70
1380    6.03  326.00    1.44   -5.86    0.11    4.91    4.28    1.01    1.60
1410    6.15  332.00    0.91   -6.08    0.10    4.55    4.11    1.09    1.70
1440    5.88  333.00    0.74   -5.84    0.09    4.43    3.88    1.09    1.70
1470    6.11  332.00    0.82   -6.06    0.08    4.24    3.65    1.26    1.70
1500    6.17  334.00    0.66   -6.13    0.08    4.16    3.40    1.09    1.70
1530    6.40  335.00    0.57   -6.38    0.04      *       *     0.86    1.40
1560    6.39  336.00    0.47   -6.37    0.01      *       *     0.94    1.30
1590    6.37  338.00    0.22   -6.37   -0.09      *       *     0.49    1.60
1620    5.75  343.00   -0.31   -5.75   -0.01      *       *     0.54    1.20
1650    6.61  338.00    0.23   -6.61   -0.15      *       *     0.79    1.30
```

5.3.1 *Error estimates*

WTR/RASS wind- and temperature radar is derived from radar waves which have been reflected by the atmosphere. The velocity in beam direction is derived from the Doppler-shift of the backscattered versus the outgoing electromagnetic wave. Combining the signals from different oblique beam directions also the horizontal wind can be derived. Several assumptions about the homogeneity and stationarity of the wind are applied.

A theoretical error analysis starting from first principles is currently not available. However the WTR/RASS of DFS as well as other windprofilers have been validated by comparison with other sensors. Also within the CREDOS project there were opportunities to compare the WTR/RASS data with data from other remote sensing technologies, like the SODAR/RASS used by DLR and the Windtracer's measurements of the crosswind, see 5.5. Even this approach can only provide indications, because usually the measurements are not done in the same volume of air nor during exactly the same time. Last not least also the data from the other instruments are subject to various errors.

In view of these reasons, only some indications may be given:

Observable	**Remark**
Height	30 m are "numerical" range gates, the radar signal is transmitted in 330 ns pulses, corresponding to a pulse width of 50 m.
Vertical Wind	Vertical wind, and any other in-beam component of the wind has an estimated error of 0.3 m/s below 1200 m.
Horizontal Wind	Any component of the horizontal wind has an estimated error of 0.5 m/s below 1200 m.
Temperature	Temperature differences between different height gates in the same measurement cycle have an estimated error of 0.05 K/100 m.
TKE	"TKE" is derived from a very specific observable. It may be used as indicator of the degree of turbulence, small/large values suggesting low/high turbulence. Therefore no error estimate is specified.

Table 10: WTR/RASS error estimates.

5.4 *Wake vortex track data*

Wake vortex data belonging to the Windtracer are stored in an ASCII file named `ID.trk`. An example of such a file is listed at the end of this section. Wake vortex tracks are provided to DFS in two different formats by Volpe Center. Volpe is analysing the Windtracer under contract of the Federal Aviation Administration, FAA. DFS correlates the vortex tracks with aircraft and other data. Doing so, time is transformed according to the definitions given in section 5.1.2. For any vortex pair a number of records may be produced. Those records have ten data items as explained in Table 11.

Vortices are tracked in the region of interest, ROI. The lidar settings including the selection of the ROI have been tuned to optimize detection of heavy aircraft's vortices. Due to technical reasons it is not possible to track vortices very close to the lidar. Finally, the line of sight in particular at low elevations is potentially inhibited by aircraft parking positions and buildings north of runway 25R. Considering these factors altogether leads to the ROI depicted in Figure 3.

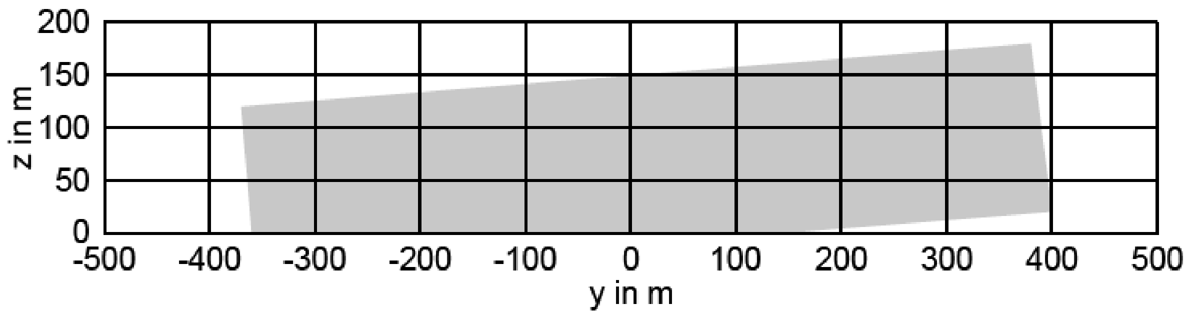

Figure 3: Windtracer's 'region of interest' for vortex tracking.

Item No.	Example	Columns	Description & Comments
1	5.0	1-8	Time of left vortex' detection in s relative to t=0.
2	-2960.2	9-16	x-coordinate in m of the left vortex in local reference frame
3	-22.9	17-24	y-coordinate in m of the left vortex in local reference frame
4	14.9	25-32	z-coordinate in m of the left vortex in local reference frame
5	485.6	33-40	Circulation in m^2/s of the left vortex
6	5.0	41-48	Time of right vortex' detection in s relative to t=0. Note this time may be different from the time in the first column.
7	-2960.2	49-56	x-coordinate in m of the right vortex in local reference frame
8	27.1	57-64	y-coordinate in m of the right vortex in local reference frame
9	12.4	65-72	z-coordinate in m of the right vortex in local reference frame
10	531.7	73-80	Circulation in m^2/s of the right vortex

Table 11: Vortex track data elements.

```
!Do NOT distribute outside the CREDOS consortium!
     5.0 -2960.2    -22.9     14.9    485.6      5.0 -2960.2     27.1     12.4    531.7
    11.3 -2960.2    -51.2     11.0    425.6     11.3 -2960.2     16.9      9.8    453.4
    17.6 -2960.2    -81.2     12.4    443.4     17.6 -2960.2      4.8     10.3    454.8
```

```
23.9 -2960.2  -117.4    10.6   381.8    23.9 -2960.2    -3.0    10.8   412.7
30.2 -2960.2  -149.0    17.8   423.5    30.1 -2960.2    -5.8    11.3   418.4
36.6 -2960.2  -173.2    20.8   414.1    36.4 -2960.2   -15.2    12.3   428.1
43.0 -2960.2  -200.5    26.7   418.8    42.7 -2960.2   -18.2    13.5   391.0
49.4 -2960.2  -218.4    32.4   315.8    49.1 -2960.2   -25.4    18.7   410.2
55.6 -2960.2  -255.6    24.1   241.6    55.3 -2960.2   -53.8    13.5   285.5
  *       *       *       *       *     61.5 -2960.2   -61.9     3.3   182.1
  *       *       *       *       *     67.8 -2960.2   -70.8     3.1   192.7
  *       *       *       *       *     74.0 -2960.2   -98.5     4.4   170.1
  *       *       *       *       *     80.3 -2960.2  -133.0     4.4   153.3
  *       *       *       *       *     86.7 -2960.2  -134.1     9.8   183.3
```

5.4.1 Error estimates

Time differences within the vortex track data are surely better than 0.1 s. In terms of vortex age, the largest contribution to time error is due to the determination of t_0.

Vortices' x-position is directly related to the accuracy of the positioning of the aperture of the laser beam. It has been determined from a 24h averaged GPS measurement and may thus have an error of 1 m or less.

Error estimates for y, z and circulation are much less obvious to determine. Several investigation of this issue have been published [10-12], however not all of those findings can be directly translated to the circumstances in EDDF-2. Considering these studies the following assumption deem reasonable: The accuracy of a single y- and z-measurement is on the order of a few meters, typically 5 m for y- and 2 m for the z-component. The accuracy of a single circulation value is on the order of a few tens m^2/s, typically 10% of the value but varying with the signal to noise ratio.

5.5 In-plane wind measured by the Windtracer

Other data products of the Windtracer system are profiles of the crosswind measured during the lifetime of the vortices, the so called in-plane wind, IPW. Two profiles are output: the first one has been taken during the scan when the vortex track was initiated, the second one during the scan when the vortex has been observed for the last time. This information is stored in an ASCII file named `ID.ipw`. An example of such a file is listed at the end of this section. Data elements are described in Table 12.

Item No.	Example	Columns	Description & Comments
1	1.65	1-10	Height in m above ground. Note that the slope of the terrain between the Windtracer site and the intersection of the laser beam with RWY 25R has been neglected.
2	-3.18	11-20	Crosswind at the beginning of the vortex track in m/s
3	-2.97	21-30	Crosswind at the end of the vortex track in m/s

Table 12: In-plane wind data elements.

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1.65	-3.18	-2.97
3.52	-3.17	-3.01
5.39	-3.29	-3.06
7.26	-3.37	-3.10
9.13	-3.46	-3.13
11.01	-3.46	-3.17
12.88	-3.57	-3.18
14.75	-3.57	-3.19
16.62	-3.56	-3.19
18.50	-3.67	-3.19
20.37	-3.72	-3.22
22.24	-3.70	-3.21
24.11	-3.75	-3.21
25.98	-3.84	-3.24
27.86	-3.86	-3.27
29.73	-3.85	-3.26
31.60	-3.91	-3.27
33.47	-3.96	-3.25
35.34	-3.95	-3.26
37.22	-3.92	-3.25
39.09	-3.97	-3.24
40.96	-4.01	-3.23
42.83	-4.04	-3.25
44.71	-4.07	-3.26
46.58	-4.14	-3.26
48.45	-4.16	-3.29
50.32	-4.19	-3.33
52.19	-4.19	-3.35
54.07	-4.22	-3.40
55.94	-4.23	-3.42
57.81	-4.25	-3.45
59.68	-4.25	-3.48
61.56	-4.27	-3.52
63.43	-4.30	-3.54
65.30	-4.34	-3.56
67.17	-4.37	-3.59
69.04	-4.39	-3.60
70.92	-4.41	-3.59
72.79	-4.42	-3.57
74.66	-4.43	-3.59
76.53	-4.44	-3.60
78.41	-4.47	-3.60
80.28	-4.48	-3.60
82.15	-4.49	-3.63
84.02	-4.49	-3.63
85.89	-4.48	-3.62
87.77	-4.48	-3.59
89.64	-4.48	-3.57
91.51	-4.49	-3.56
93.38	-4.50	-3.54
95.25	-4.51	-3.51
97.13	-4.50	-3.52
99.00	-4.51	-3.54
100.87	-4.51	-3.53
102.74	-4.52	-3.52
104.62	-4.53	-3.53
106.49	-4.55	-3.51
108.36	-4.56	-3.51
110.23	-4.58	-3.48
112.10	-4.57	-3.50
113.98	-4.57	-3.50
115.85	-4.57	-3.52
117.72	-4.57	-3.50
119.59	-4.56	-3.53
121.47	-4.55	-3.49
123.34	-4.55	-3.50
125.21	-4.56	-3.46
127.08	-4.57	-3.45
128.95	-4.57	-3.39
130.83	-4.59	-3.38
132.70	-4.58	-3.35
134.57	-4.57	-3.30
136.44	-4.58	-3.31

138.32	-4.57	-3.30
140.19	-4.57	-3.31
142.06	-4.56	-3.28
143.93	-4.57	-3.32
145.80	-4.53	-3.27
147.68	-4.55	-3.30
149.55	-4.51	-3.27
151.42	-4.52	-3.30
153.29	-4.49	-3.29
155.16	-4.51	-3.33
157.04	-4.48	-3.32
158.91	-4.48	-3.33
160.78	-4.46	-3.32
162.65	-4.46	-3.31
164.53	-4.45	-3.29
166.40	-4.46	-3.31
168.27	-4.45	-3.29
170.14	-4.46	-3.29
172.01	-4.46	-3.27
173.89	-4.46	-3.28
175.76	-4.46	-3.28
177.63	-4.47	-3.30
179.50	-4.47	-3.29
181.38	-4.48	-3.33
183.25	-4.48	-3.31
185.12	-4.49	-3.32
186.99	-4.44	-3.31
188.86	-4.43	-3.32
190.74	-4.42	-3.28

5.5.1 Error estimates

Since the in-plane wind is determined using techniques very similar to those for the vertical wind measurements with a windprofiler, the accuracy of the in-plane in wind is likely on the same order or better. Therefore the estimate of 0.3 m/s is adopted.

5.6 Graphical summary (Summary plots)

For every departure and in particular for every departure where vortices have been tracked a graphical summary is produced. It will be provided in the portable document format, the file name follows the same logic as for the elements of the correlated data set: `ID.pdf`. An example of such a summary is shown in Figure 4.

Due to time constraints it was not possible to prepare the entire set of more than 10.000 summary plots already together with the delivery of the data itself. It is planned to provide the summary plots of the cases with vortices together with the CREDOS deliverable D2-4. Note that according to the CREDOS Description of Work [1] these graphics are not formally required. Of course, the summary plots will be provided only electronically.

The graphical summary contains 11 graphs plus some alpha-numeric information. The individual elements are explained in subsequent paragraphs.

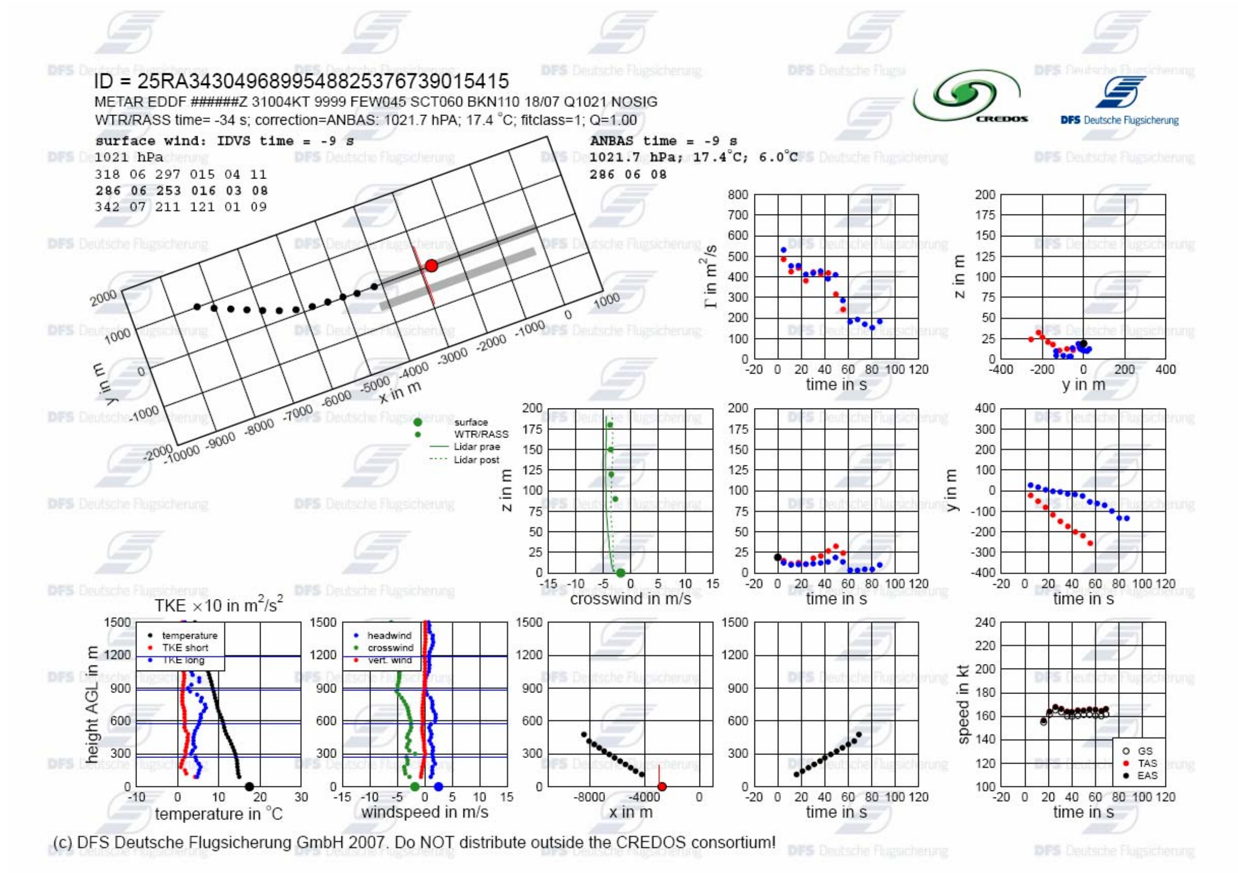


Figure 4: Graphical summary of event 25RA3430496899548825376739015415.

5.6.1 Elements of the graphical summary

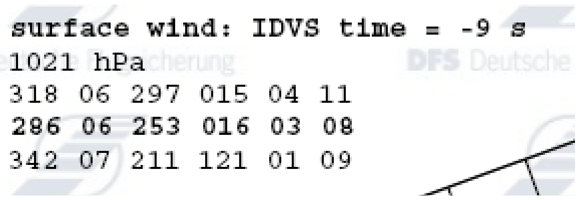
The first line, printed somewhat larger than the rest, contains the ID, see Figure 5. In the next line the most recent METAR can be found, however time is replaced by ######. The first item third line states that the most recent WTR/RASS profile has been measured 34 s before the aircraft passed the Windtracer's scan plane. The aircraft Mode-C pressure altitudes have been transformed into height AGL using the ANBAS data 1021.7 hPa and 17.4 °C. Fitclass and Q are for internal quality control.


ID = 25RA3430496899548825376739015415
METAR EDDF ######Z 31004KT 9999 FEW045 SCT060 BKN110 18/07 Q1021 NOSIG
WTR/RASS time= -34 s; correction=ANBAS: 1021.7 hPA; 17.4 °C; fitclass=1; Q=1.00

Figure 5: Graphical summary: ID, METAR etc.

IDVS wind information (Figure 6) is found on the left hand side of the graphical summary below the line starting with surface wind. Most recent IDVS data is 9 s old.

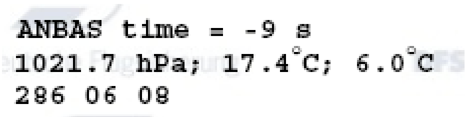
IDVS pressure is truncated to full hPa. The last three lines contain the IDVS wind data, the data to be used for the runway in use is printed bold.



surface wind: IDVS time = -9 s
1021 hPa
318 06 297 015 04 11
286 06 253 016 03 08
342 07 211 121 01 09

Figure 6: Graphical summary: IDVS wind data.

ANBAS time, QNH, temperature, dewpoint and wind (Figure 7) is found right of the IDVS data. Note, in this example, wind direction, wind speed and gust speed are identical (as they refer to the same measurement) with the 1st, 2nd and last number in bold printed IDVS line.



ANBAS time = -9 s
1021.7 hPa; 17.4°C; 6.0°C
286 06 08

Figure 7: Graphical summary: ANBAS data.

Aircraft lateral trajectory is shown in the plot (Figure 8), which has been rotated by 20°. An estimate of the rotation point is shown (red circle). The scan plane of the lidar is represented by the red line.

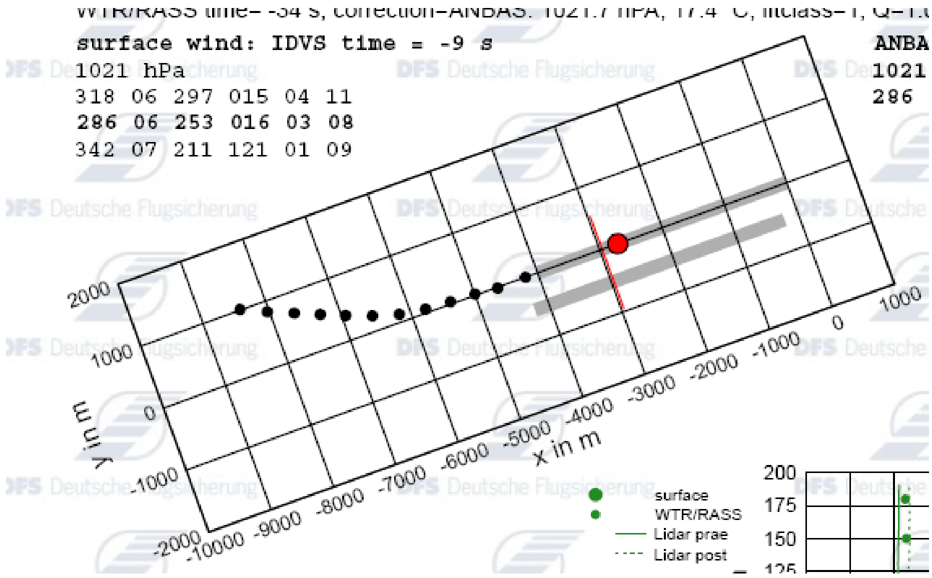


Figure 8: Graphical summary: Aircraft trajectory.

Figure 9 shows circulation as function of time (left) and positions of the vortices in the y-z plane. Red (blue) symbols always belong to left (right) vortex. Note that the vortex age shown in the plot is limited to 120 s. The data file contains the full information in case one or both vortices lived longer than 2 minutes. The right plot of Figure 9 shows the positions also for vortex ages larger than 2 minutes.

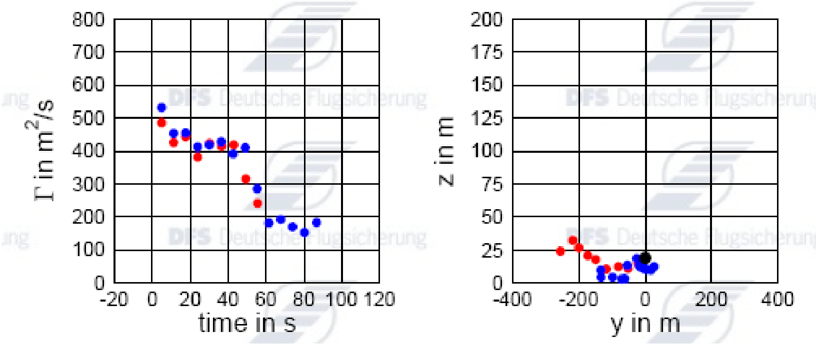


Figure 9: Graphical summary: Vortices circulations and positions in the y-z plane.

Several crosswind profiles (left) and time series of vortices height (middle) and lateral position (right) portion of Figure 10. The green symbols are belonging to surface wind and WTR/RASS measurements, the green lines show the in-plane wind profiles as measured at the begin (Lidar prae) and at the end (Lidar post) of the vortex track. Again the vortex age plots are limited to 120 s.

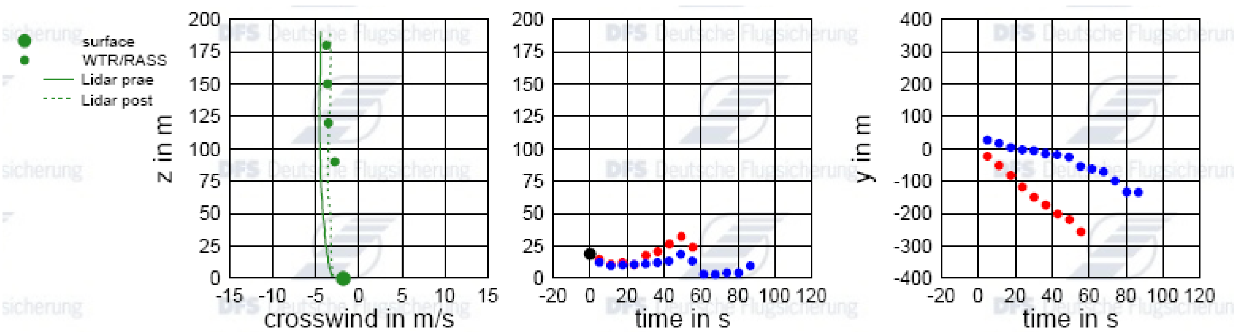


Figure 10: Graphical summary: Crosswind profiles and vortices position vs. time.

Figure 11 shows the summary of the profiles measured by the WTR/RASS. The blue horizontal lines correspond to pressure altitudes of 1000, 2000, 3000 and 4000 ft. The larger circles at the bottom are taken from ANBAS or IDVS respectively. Headwind and crosswind of course refer to the orientation of runway 25 rather than to the aircraft ground track or heading. TKE short and long have been explained in section 5.3. The profiles have been stretched by the factor of 10 in order to improve readability. The values for the crosswind measured at the lower heights are the same as shown in the left plot of Figure 10.

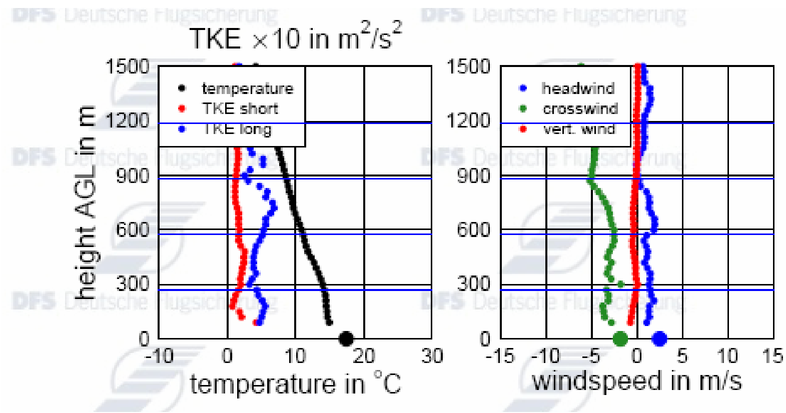


Figure 11: Graphical summary: WTR/RASS data.

The remaining elements of the graphical summary (see Figure 12) deal with the climb phase of the aircraft. Aircraft height above ground level in m is plotted against x-position and time, respectively. The anticipated rotation point is marked by the red circle. Ground speed as determined by the tracker as well as estimates of true airspeed and equivalent airspeed are shown in the rightmost plot.

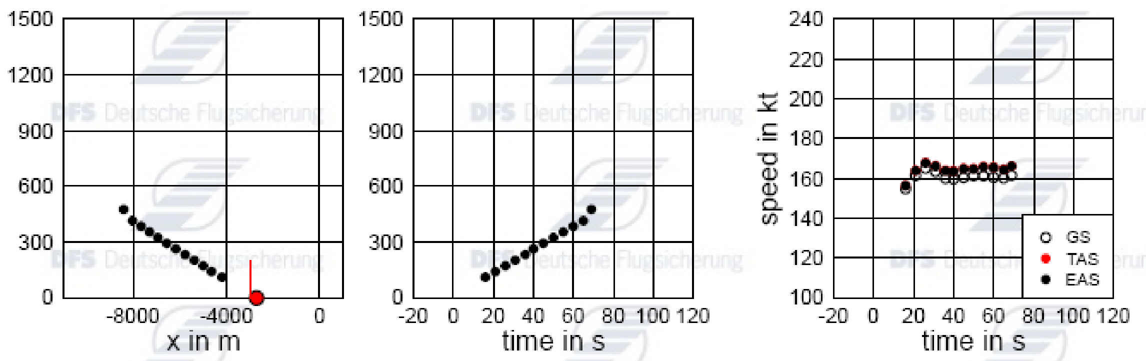


Figure 12: Graphical summary: Aircraft climb and speed information.

5.7 Amount of data and statistical representativeness

The correlated dataset contains 10.442 cases. In 731 cases only the right vortex (viewed in flight direction of the aircraft) has been detected, in 499 cases only the left vortex has been detected. Thus there are 9212 (88%) cases where both vortices have been measured. No significant difference in the ability of the Windtracer to detect upwind or downwind vortices has been observed.

Another CREDOS deliverable, D2-4, will include a more detailed discussion about how well the dataset represents the true statistical properties of wake vortices. One important aspect here is, how well the Windtracer could track any vortex that evolved in the region of interest (ROI) of the lidar.

The system has been setup in order to mainly measure vortices of heavy aircraft taking off RWY 25R at Frankfurt airport. Due to differences in aircraft performance, aircraft loading etc. there is a much larger dispersion of aircraft tracks also close to the runway than for landings.

The Windtracer's beam is pointing perpendicular to the runway axis. The intersection of the plane spanned by the scanning lidar beam (from now on called lidar plane) with the runway axis is 2961 m behind the runway threshold. At this point most medium aircraft are airborne already while there might be a fraction of heavy aircraft which not yet or just have rotated. This causes, together with various other reasons, that in general there are more departing aircraft than measured vortex pairs. Some causes of vortices not being tracked are listed below:

- Aircraft rotated early/climbed steeply: The vortices entered the ROI only lately or not at all.
- Aircraft not being airborne when intersecting the lidar plane: Vortices are generated as well, however due to the extreme influence of the ground they may behave differently and may not be identified as such by the data processing algorithms.
- Aircraft parking at the most western end of the general aviation apron can obstruct the line of sight of the lidar.
- Non-optimal settings of the lidar parameters before the system had been fully adapted to the site specific features.
- Meteorological conditions, like heavy rain, fog, and very low ceiling lead to a rapid damping of the laser beam over relatively short distances.
- Other technical reasons, like system failure, power outage etc.

To assess the performance of the overall setup the ratio of the number of measured B744 vortex tracks and the number of opportunities, i.e. the number of B744 departures on runway 25R has been computed on a daily basis. According to this performance indicator the EDDF-2 campaign can be divided into six distinct periods:

Period	**Performance indicator**	**Remarks/Problems**
Jan. 5th – Feb. 8th	47%	Sub-optimal parameter setting of the Windtracer, heavy fog or low ceiling for a couple of hours on several days
Feb. 9th – Feb. 16th	92%	
Feb. 17th – Feb. 20th	0%	Windtracer technical problem
Feb. 21st – Mar. 7th	90%	
Mar. 8th – Mar. 14th	0%	Windtracer technical problem, shutter not fully open
Mar. 15th – Jun. 30th	93%	A few automatic reboots of the Windtracer system have been triggered.

Table 13: EDDF-2 performance indicator.

Although the Windtracer measured unattended and a remote access monitoring was not available during the first three months of the campaign, the Windtracer overall showed an excellent performance. During the EDDF-2 campaign 2165 B744 aircraft took off RWY 25R. In 1680 (78%) cases at least one of the vortices has been tracked and analysed. In 1549 (72%) cases both vortices have been tracked. During times the system had no obvious technical problems routinely for more than 90% of the B744 departures at least one vortex has been measured.

References

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[6] WGS84 Implementation Manual, Eurocontrol and Institute of Geodesy and Navigation (IfEN) University FAF Munich, Version 2.4, February 12, 1998.

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[9] International Civil Aviation Organisation, DOC 7488-CD, Manual of the ICAO Standard Atmosphere: extended to 80 kilometres (262 500 feet), Third Edition, 1993.

[10] Köpp, Friedrich; Rahm, Stephan; and Smalikho, Igor, Characterization of Aircraft Wake Vortices by 2-µm Pulsed Doppler Lidar, Journal of Atmospheric and Oceanic Technology, 21, 194 (2004).

[11] Frehlich, Rod and Sharman, Robert, Maximum Likelihood Estimates of Vortex Parameters from Simulated Coherent Doppler Lidar Data, Journal of Atmospheric and Oceanic Technology, 22, 117 (2005).

[12] Köpp, Friedrich; Rahm, Stephan; Smalikho, Igor; Dolfi, Agnès; Cariou, Jean-Pierre; Harris, Michael; Young, Robert I., Comparison of wake-vortex parameters measured by pulsed and continuous-wave lidars, Journal of Aircraft, 42, 916 (2005).

List of Acronyms and Abbreviations

Acronym	Explanation
25R, 25L, 07L, 07R	Runway identifiers at Frankfurt Airport
ANBAS	Alphanumerisches Bedien- und Anzeigesystem
AGL	Above ground level
ASCII	American Standard Code for Information Interchange
ATC	Air Traffic Control
°C	Degree Celsius, non-SI unit of temperature
CR LF	Carriage return, line feed
DFS	DFS Deutsche Flugsicherung GmbH, German Air Navigation Service Provider
DLR	Deutsches Zentrum für Luft- und Raumfahrt e.V, German Aerospace Center
DWD	Deutscher Wetterdienst, German meteorological service
EAS	Equivalent airspeed
EDDF	Location indicator of Frankfurt Airport
FAA	Federal Aviation Administration
ft	1 ft = 0.3048 m, non-SI unit of length
GPS	Global Positioning System
hPa	Hectopascal, SI unit of pressure
ICAO	International Civil Aviation Organisation
IDVS	Integriertes Datenverarbeitungssystem
IPW	In-plane wind, crosswind profile measured by the Windtracer
K	Kelvin, unit of temperature

kt	1 kt ≈ 0.514 m/s, non-SI unit of velocity
m	Meter, SI unit of length
METAR	Meteorological Aviation Routine Weather Report
ns	Nanosecond = 10^{-9} s
QNH	Q-code for pressure at mean sea level (ICAO PANS Doc8400)
RASS	Radio acoustic sounding system, remote sensing technology based on simultaneous emission of radar and acoustic waves and detection of the backscattered radar signal
ROI	Region of interest, area where the Windtracer seeks and tracks vortices
RVR	Runway visual range
RWY	Runway
s	Second, SI unit of time
SI	Système international d'unités, the International System of Units, Metric System
SODAR	Sound detection and ranging, remote sensing technology based on transmission and detection of acoustic waves
SQRT	Square root, mathematical function
TAS	True airspeed
TKE	Turbulent kinetic energy
UTC	Coordinated Universal Time
Volpe	John A. Volpe National Transportation Systems Center
WGS84	World Geodetic System 1984, reference frame for the earth, for use in geodesy and navigation
WMO	World Meteorological Organisation
WTR/RASS	Wind-Temperature Radar with Radio Acoustic Sounding System, windprofiler of DFS at Frankfurt airport
<Z>	Time average of variable/observable Z
x^y	y^{th} power of x, mathematical operation

- End of document -