

## **Description of SODAR data storage**

### **WISE PROJECT WP 2**

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## Acknowledgement/Preface

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## SUMMARY

The partners in the WISE project are investigating whether application of the SODAR measurement technique in wind energy experimental work is feasible as a replacement for cup anemometers and wind direction sensors mounted on tall meteorological masts both from the view of accuracy and cost. In Work Package 2 of the WISE project extensive controlled experiments with the SODAR have been performed. For example SODAR measurements have been compared with measurements from nearby masts and different brands of SODARs have been compared. Part of the work package was the creation of a database to gather the measured SODAR data. The database was created by ECN in order to enable further analysis by the partners in the project. ECN made the choice to create a database structure in SQL.

The database structure that has been defined by ECN is described in full detail. The database is based on SQL, and care is taken that data that is unchanged during a measurement period is only stored once. The logic behind the structure is described and the relations between the various tables are described. Upto now the description of the database is limited to include SODAR data measured close to a meteorological mast. Power measurements from wind turbines are not yet included. However, the database can easily be extended also to include these data.

The data measured by means of the ECN SODAR have completely been re-processed. A new directory structure was defined which is accessible from both the Unix (Linux) and the Microsoft Windows platform. The processed and validated data have been stored in a database to make retrieval of specific data sets possible. The database is also accessible from the Windows platform. The defined format is available for the WISE project, so that the database containing data from all partners can be created.



# 1. INTRODUCTION

## 1.1 Background

Wind measurements for wind energy applications are generally done with cup anemometers mounted on meteorological masts. This is becoming increasingly difficult due to the following reasons:

- Due to the increasing height of wind turbines and the placement of wind turbines offshore masts are becoming extremely expensive. This means that in the near future they are no longer a practical solution. Remote sensing measurements with SODAR (SODAR = sound detection and ranging) systems are possibly a more affordable alternative.
- Instrumentation of large masts is becoming increasingly difficult.
- Getting building permits for large masts is becoming time consuming and in some cases impossible.

At the moment SODAR equipment can be bought commercially “off the shelf”. However, the SODAR was designed to operate in different circumstances than can be encountered for wind energy applications. Specific problems are:

- For wind energy applications stricter requirements exist for uncertainty, reliability and validity of the data than for other SODAR applications.
- Calibrations of SODAR systems have never been done and there exists no calibration procedure; different brands of SODAR use different measurement techniques and may give different data.
- At the moment low wind speeds (below 4 m/s), high wind speeds (over 18 m/s) and other atmospheric phenomena cause difficulties with SODAR measurements. This needs to be addressed because power performance measurements require wind speeds up to 30 m/s.
- SODAR is designed for use on land. Offshore use introduces vibrations from supporting structures and an increased level of background noise, which can influence the measurements.
- At the moment it is not clear whether SODAR can be used to detect oncoming gusts. It might be necessary to make small adjustments to commercial SODARs in order to enable this.
- Historically, SODARs are used for example near airports and nuclear power plants with easy access for maintenance. For wind energy applications there may be problems with easy access to equipment and data (especially with SODARs at remote sites), electricity from the grid and operation in complex terrain. Autonomous operating SODAR systems are not yet common practice.

Therefore a lot of work needs to be done before SODAR can become an accepted and practical alternative for measurements with a meteorological mast with cup anemometers. SODAR needs a thorough theoretical basis for wind energy applications including work on calibrations and filtering techniques for data analysis. SODAR needs to be tested in difficult circumstances such as complex terrain and offshore use. Technical issues like data communication and power supply have to be solved for operation in remote sites. Furthermore, the possibility to use SODAR measurement techniques to detect gusts has to be explored.

## 1.2 Objectives

The general aim of the WISE project is to investigate whether application of the SODAR measurement technique in wind energy experimental work is feasible as a replacement for cup anemometers, wind direction sensors and tall meteorological masts. Measurements for wind energy applications such as power performance testing, load measurements, site assessment are

standardised, carefully calibrated and controlled. Up to the beginning of the WISE project some trials with SODAR have been held but due to various reasons this has not resulted in the general acceptance of SODAR for wind energy applications. What is needed is development of a calibration technique for SODAR, a good understanding of SODAR operational characteristics and its limitations. When this has been done SODAR should be tested by performing a power performance measurement including a rigorous uncertainty analysis. Also the operation of the SODAR in difficult conditions (complex terrain, offshore) has to be tested. This project will attempt to do this and thus help to make SODAR an accepted method in the wind energy field.

Work Package 2 of the WISE project aims at doing extensive controlled experiments with the SODAR. For example SODAR measurements are compared with measurements from nearby masts and different brands of SODARs are compared. Part of the work package is the creation of a database. The measured data should be gathered in this database. The database must be created by ECN in order to enable further analysis by the partners in the project. Especially the SODAR data from the power performance assessments should be added to this database. ECN made the choice to create a database structure in SQL. The database structure is defined and the ECN data measured with the SODAR are added to the database.

### 1.3 Description of the work

The database for the SODAR data should provide a simple and flexible tool to do necessary operations on the SODAR data. For example, the database should include mechanisms to make selections of the data based on SODAR settings, or other parameters such as rain. For this purpose a SQL database is created, so that for example existing tools like Excel can access the data. Important part of the database is a predefined structure of the data. This is described in the present report.

The next step is filling the database with SODAR data. In order to test all assumptions and check the viability of the choices, all SODAR data measured by ECN is added to the database. The target of ECN was to create a database with 10-minute averaged validated wind data in which all processing steps are known and documented.

After the raw data are processed, the 10-minute averaged validated SODAR data are stored in the database. ECN has measured with the SODAR at Cabauw, a place near Lopik. Here, a 213m high meteorological mast from the Royal Meteorological office of the Netherlands (KNMI) is located.

The database is located on server 'panoramix' (Linux panoramix.ecn.nl 2.4.18-19.7.xsmp) in directory /data/sodar/mysql/CabauwSodar.

The web site of the Royal Meteorological office of the Netherlands (KNMI) provides more information on the Cabauw measurement site.

(<http://www.knmi.nl/onderzk/atmoond/cabauw/cabauw.html>)

In order to add SODAR data to the database, following sequence of actions must be followed:

1. Process the raw data
2. Create tables in the database
3. Fill the tables with data

After these actions, a selection can be made on the data, taking into account availability of both SODAR and mast, meteorological conditions, status signals of the SODAR and for example signal to noise ratio.

The next chapter describes the directory structure on the computer panoramix. Chapter 3 describes the database tables, chapter 4 the processing of the raw data, chapter 5 the creation of the database tables, chapter 6 describes the filling of the tables and in chapter 7 the retrieval of data from the database is handled.



## 2. DIRECTORY STRUCTURE

The Sodar data is stored on the computer panoramix in directory /data/sodar. This directory is made available for the Microsoft Windows platform and can be connected as a share:

<\\panoramix\sodar>

The layout of this share is shown in Figure 1.

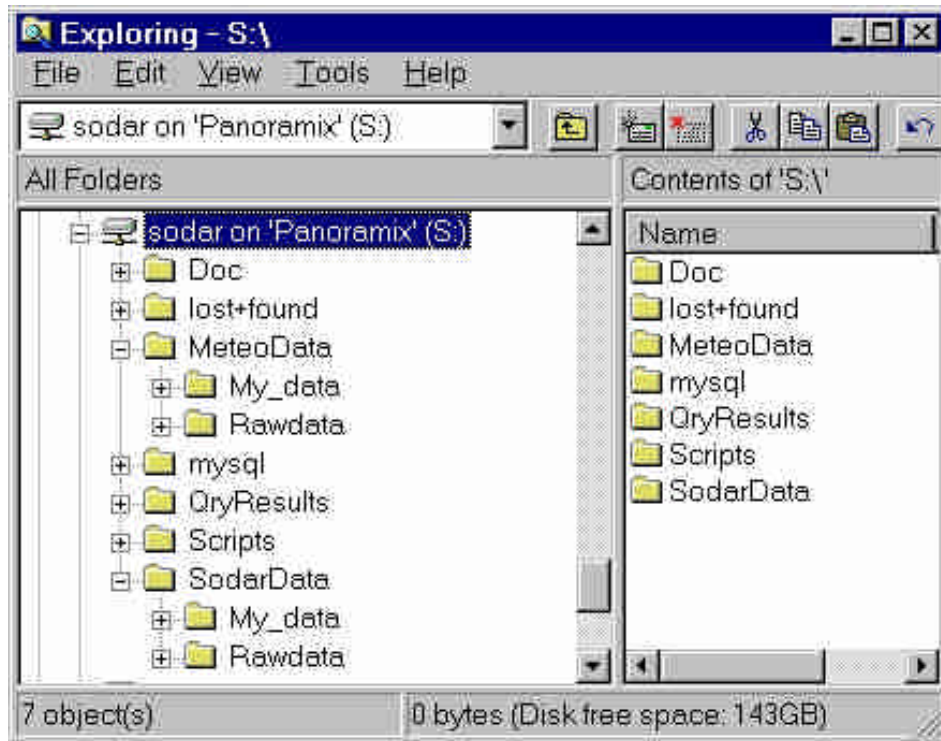


Figure 1. Directory structure of the SODAR database.

Table 1. Description of the contents of the directories and subdirectories in the defined directory structures.

Directory	Description
Doc	contains documentation
lost+found	Linux specific directory
MeteoData	contains the meteorological data
• My_data	.my files to fill de MySQL database with
• Rawdata	raw data from meteorological mast (in .lot files)
mysql	contains the MySQL database(s)
QryResults	contains the results from database queries
Scripts	contains the scripts to create and fill the database tables and to retrieve data from the database
SodarData	contains the Sodar data
• My_data	.my files to fill de MySQL database with
• Rawdata	raw data from Sodar (in .dat files)

### 3. DATABASE

The SODAR database contains both meteorological data and SODAR data. It must be noted that although the database is not limited, only 10-minute averaged data are included in the database. The tables defined in the database are summed in Table 2 and are further described in the forthcoming paragraphs.

Table 2. The tables inside the SODAR database.

Table name	Description
MeteoData1	meteorological data for different heights
MeteoData2	remaining meteorological data
SodarPeriods	information about each period
SodarSettings	settings of Sodar equipment for each period
SodarParams	parameters generated by Sodar for each measurement
SodarProcessedData	data generated by Sodar for each measurement

#### 3.1 MeteoData1

This table contains meteorological information measured on different heights. In order to enable the comparison between the meteorological wind speed and wind direction data with the SODAR data, the Height field is introduced. Each measurement constitutes a period of 10 minutes. The table is filled with information from files *cabmast.1datYYYYMM.my* where *YYYY* represents the year and *MM* the month.

Table 3. Structure of MeteoData1

Field	Type	Null	Key	Default	Unit	Description
DataDate	datetime		PRI	0000-00-00 00:00:00		Date and time
Height	int(4)		PRI	0	m	Height
F	double(9,3)	YES		NULL	m/s	Wind speed (mean)
SF	double(9,3)	YES		NULL	m/s	Wind speed standard deviation
PF	double(9,3)	YES		NULL	m/s	Maximum wind speed
MF	double(9,3)	YES		NULL	m/s	Minimum wind speed
D	double(9,3)	YES		NULL	°	Wind direction
TA	double(9,3)	YES		NULL	°C	Temperature
TD	double(9,3)	YES		NULL	°C	Dew point

### 3.2 MeteoData2

This table also contains meteorological information but it is not height specific. The relationship between the two meteorological tables is through the `DataDate` field. (See also Figure 2 in section 3.7).

The table is filled with information from files `cabmast.2datYYYYMM.my` where `YYYY` represents the year and `MM` the month.

Table 4. Structure of MeteoData2

Field	Type	Null	Key	Default	Unit	Description
DataDate	datetime		PRI	0000-00-00 00:00:00		Date and time
TA002	double(9,3)	YES		NULL	°C	Temperature (2 meter height)
TD002	double(9,3)	YES		NULL	°C	Dew point (2 meter)
CPO	double(9,3)	YES		NULL	hP	Air pressure
CNI	double(9,3)	YES		NULL	mm	Rain amount
CND	double(9,3)	YES		NULL	s	Rain duration
GLOBCL	double(9,3)	YES		NULL	W/m <sup>2</sup>	Solar radiation

### 3.3 SodarPeriods

This table contains administrative information for each period. It holds e.g. the start and end date of the period, the time and angle shift that has been used to adjust the data measured in that period. The table is filled with information from file `sodar.periods.my`.

Table 5. Structure of SodarPeriods

Field	Type	Null	Key	Default	Unit	Extra
Period	int(4)		PRI	0		Period number
Location	varchar(40)			Null		Location of measurements
ArrayType	int(4)			0		can be: 3000, 4000
PeriodStartDate	datetime			0000-00-00 00:00:00		Date and time of start of period
PeriodEndDate	datetime			0000-00-00 00:00:00		Date and time of end of period
Frequency	int(4)			0	Hz	Sound frequency
TimeShift	int(4)			0	s	Number of seconds the measurements are adjusted with.
AngleShift	int(4)			0	°	Number of degrees the measurements are adjusted with.
Comment	varchar(40)	YES		NULL		

### 3.4 SodarSettings

This table contains the settings of the Sodar equipment for each period. The settings remain the same during the whole period. The table is filled with information from the files *sodar.setPnn.my* where nn represents the period number.

Table 6. SodarSettings

Field	Type	Null	Key	Default	Unit	Description
Period	int(4)		PRI	0		Period number
Location	varchar(8)	YES		NULL		
Doplmain Version	varchar(16)	YES		NULL		
Freq	int(4)	YES		NULL	Hz	Operating frequency
Bw	int(4)	YES		NULL	Hz	Analogue filter bandwidth
Damp	int(4)	YES		NULL	%	Percentage of max. pulse amplitude used
Pulw	int(4)	YES		NULL	ms	length of pulse
Rise	int(4)	YES		NULL	%	Pulse amplitude taper time
Rofs	int(4)	YES		NULL	mV	Offset of in phase signals
Jofs	int(4)	YES		NULL	mV	Offset of the quadrature signal
Sec	int(4)	YES		NULL	s	Averaging time
Avdst	int(4)	YES		NULL	m	Spatial sampling distance
Amp	int(4)	YES		NULL	mV	Amplitude acceptance threshold
Snr	int(4)	YES		NULL		Signal-to-noise ratio acceptance threshold
Back	int(4)	YES		NULL	%	Adaptive noise threshold
Noms	int(4)	YES		NULL	s	Time delay before taking noise sample
Nwt	int(4)	YES		NULL	s	Time running average of background noise sample
Gd	int(4)	YES		NULL	%	Minimum acceptable percentage of good samples
Nfft	int(4)	YES		NULL		FFT size
Srate	int(4)	YES		NULL	Hz	Digital sampling rate
Clut	int(4)	YES		NULL		Clutter rejection flag
Nbini	int(4)	YES		NULL		Number of FFT bins used for Doppler shift
Ngav	int(4)	YES		NULL		Number of pulses used for Gust detection
Mincr	int(4)	YES		NULL	cm/s	Minimum radial velocity accepted for vertical beam
Maxcr	int(4)	YES		NULL	cm/s	Maximum radial velocity accepted for vertical beam
Minbr	int(4)	YES		NULL	cm/s	Minimum radial velocity accepted for y beam
Maxbr	int(4)	YES		NULL	cm/s	Maximum radial velocity accepted for y beam
Minar	int(4)	YES		NULL	cm/s	Minimum radial velocity accepted for x beam
Maxar	int(4)	YES		NULL	cm/s	Maximum radial velocity accepted for x beam
Wdog	int(4)	YES		NULL		Watchdog timer flag

Maxdel	int(4)	YES		NULL	mV	Minimum amplitude change for mixing depth detection
Ptdir	int(4)	YES		NULL	°	Orientation w.r.t .True North of the antenna enclosure
Wmax	int(4)	YES		NULL	cm/s	Max. accepted vertical velocity
Phase	int(4)	YES		NULL	m <sup>-3</sup>	Spacing between the transducers
Speci	int(4)	YES		NULL		Spacing between the altitudes recorded
Specl	int(4)	YES		NULL		Number of sampling altitudes to be reported for the spectral data
Specm	int(4)	YES		NULL		Number of beams from which the spectral data is collected
Specn	int(4)	YES		NULL		Number of pulses to be averaged together for the spectral data output
Specs	int(4)	YES		NULL		First range gate from which the spectral data are stored
Cdia	int(4)	YES		NULL		Beam from which the DFS data is collected
Cdid	int(4)	YES		NULL		Number of data points averaged together for one DFS data point
Cdin	int(4)	YES		NULL		No. of pulses averaged together
NoComp	int(4)	YES		NULL		
Heights	int(4)	YES		NULL		Number of heights
Zenith	varchar(5)	YES		NULL	°	Angle of beams with respect to vertical
ARA	int(4)	YES		NULL	°	Antenna rotation angle
SEPANG	int(4)	YES		NULL	°	Angle between U and V beams.

### 3.5 SodarProcessedData

This table contains the processed data measured by the Sodar. In the case of ECN data, the values are adjusted with respect to the time variation (timeshift) and angle (angleshift) for these periods. The purpose is that the database only contains data that are synchronised with the meteorological tower data and that possible calibration in the angle of the SODAR with respect to North is included. This way, the database contains validated SODAR data that directly can be used for further analyses.

Each measurement in the database constitutes a period of 10 minutes.

The table is filled with information from files *sodar.datPnn.my* where nn represents the period number.

Table 7. SodarProcessedData

Field	Type	Null	Key	Default	Unit	Description
DataDate	Datetime		PRI	0000-00-00 00:00:00		Date and time of measurement (corrected with time shift)
HT	int(4)		PRI	0	m	Height
Period	int(4)			0		Period number
SPD	Decimal(9,3)	YES		NULL	m/s	Wind speed
DIR	int(4)	YES		NULL	°	Wind direction
GSPD	Decimal(9,3)	YES		NULL	m/s	Gust speed
GDIR	int(4)	YES		NULL	°	Gust direction
U	Decimal(6,2)	YES		NULL	m/s	Wind speed in U direction
SDU	Decimal(6,2)	YES		NULL	m/s	Standard deviation of U
NU	int(4)	YES		NULL		Number of successful measurements of U
IU	int(4)	YES		NULL		Intensity of U
SNRU	int(4)	YES		NULL		Signal-to-noise ration of U
V	Decimal(6,2)	YES		NULL	m/s	Wind speed in V direction
SDV	Decimal(6,2)	YES		NULL	m/s	Standard deviation of V
NV	int(4)	YES		NULL		Number of successful measurements of V
IV	int(4)	YES		NULL		Intensity of V
SNRV	int(4)	YES		NULL		Signal-to-noise ration of V
W	Decimal(6,2)	YES		NULL	m/s	Wind speed in W direction (vertical)
SDW	Decimal(6,2)	YES		NULL	m/s	Standard deviation of W
NW	int(4)	YES		NULL		Number of successful measurements of W
IW	int(4)	YES		NULL		Intensity of W
SNRW	int(4)	YES		NULL		Signal-to-noise ratio of W

### 3.6 SodarParams

This table contains the parameter information from each measurement of the Sodar. The parameter data are not related to the measurement height and therefore stored in a separate table. The table is filled with information from file *sodar.parPnn.my* where nn represents the period number.

Table 8. SodarParams

Field	Type	Null	Key	Default	Unit	Description
DataDate	Datetime		PRI	0000-00-00 00:00:00		Date and time of setting
Period	int(4)			0		period number
FileOriginalDate	Varchar(45)	YES		NULL		
MXHT	Int(4)	YES		NULL		
ITOP	Int(4)	YES		NULL		
STABILITY	Varchar(10)	YES		NULL		
MIXHT	Int(4)	YES		NULL		
UNOISE	Int(4)	YES		NULL		
VNOISE	Int(4)	YES		NULL		
WNOISE	Int(4)	YES		NULL		
ANTENNA_STATUS	Varchar(6)	YES		NULL		
AC_STATUS	Varchar(6)	YES		NULL		

### 3.7 Relationship between the tables in the database

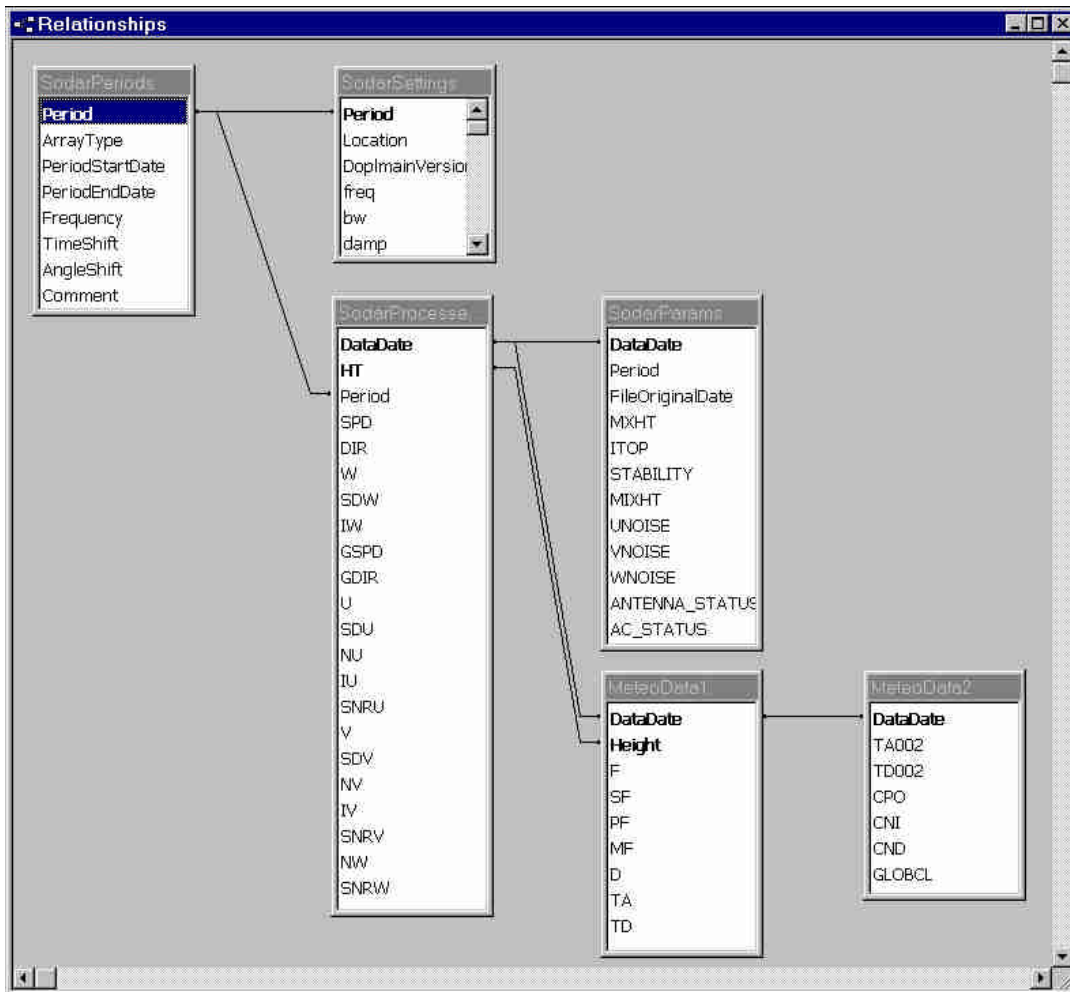


Figure 2. Relationships between SODAR tables

The relationships between the described tables are shown in Figure 2. Every time the settings of the SODAR are changed, a new period is defined. The period information is stored in the SodarPeriods, the settings information is stored in the SodarSettings table. There exists a one-to-one relationship between these tables through the Period field.

Every measurement of the SODAR device results data that depends on height and data independent of height. The height related values are stored in the SodarProcessedData table. Per measured height a record with corresponding values is added, so that both the DataDate and the height (HT) field form a unique key. The values that do not depend on height are stored in the SodarParams table. In this table the DataDate field forms the unique key.

There exists a one-to-many relationship between the SodarParams and SodarProcessedData tables. Of course there also exists a one-to-many relationship between the SodarPeriods and SodarParams tables and thus also between the SodarPeriods and SodarProcessedData tables.

The meteorological measurements are divided in height dependent and height independent values. The values depending on height are stored in table Meteodata1; the values independent of height are stored in table Meteodata2. Both DataDate and Height fields form a unique key in table Meteodata1. In table Meteodata2 the DataDate field is the unique key. There exists a one-to-many relationship between the Meteodata2 and Meteodata1 tables. There is a one-to-one relationship between the SodarProcessedData and Meteodata1 table.



## 4. PROCESSING RAW DATA

The raw data of both the SODAR and the meteorological measurements are processed with a number of scripts (written in Perl).

### 4.1 Meteorological data

The meteorological datafiles, used to fill the database, are processed by the script *cab280803.pl* which is located in directory */data/sodar/Scripts*.

It reads all files (.lot files) from subdirectories under directory

*/data/sodar/MeteoData/Rawdata* and generates for each subdirectory two *my* files; *cabmast.1dat<subdirname>.my* and *cabmast.2dat<subdirname>.my* where *<subdirname>* is the name of the subdirectory. The *my* files are stored in

*/data/sodar/MeteoData/My\_data*.

The *cabmast.1dat<subdirname>.my* files contain data to fill the *MeteoData1* table,

*cabmast.2dat<subdirname>.my* files contain data to fill the *MeteoData2* table.

### 4.2 Sodar data

The Sodar datafiles are processed by a number of Perl scripts. All processed data constitutes a period of 10 minutes. If the raw data is measured with 1-minute intervals, the scripts convert the data to 10-minute intervals. It is important to note the SODAR averaging is such that vector average of the wind speed is created. At ECN, it was decided to create 1-minute averaged data with the SODAR (which is a vector average). With ECN software, applying the averaging algorithm from Stuart Bradley [2, 4], a scalar 10-minute average is created. This would better resemble the data measured with cup anemometers.

The scripts are described in document ECN-Wind Memo-03-018 [2].

## 5. CREATION OF DATABASE TABLES

In order to create or recreate the database tables a number of scripts are developed. They reside in the directory `panoramix:/data/sodar/Scripts`.

All described database tables can be created with the scripts *CreateSodarDbTables.sh* and *CreateMeteoDbTables.sh*.

If only one table has to be (re)created use the corresponding *Create<tablename>.sh* script. The following scripts are available:

SODAR data:

- CreateSodarDbTables.sh
- CreateSodarParams.sh
- CreateSodarPeriods.sh
- CreateSodarProcessedData.sh
- CreateSodarSettings.sh

Meteorological data

- CreateMeteoDbTables.sh
- CreateMeteoData.sh

Note: If an existing table is recreated all data currently stored in the table will be deleted!

## 6. FILLING OF TABLES

The data used to fill the database are stored in *.my* files (files with extension *.my*).

Files to fill the Sodar tables are located in:

- `panoramix:/data/sodar/SodarData/My_data`

Files to fill the Meteo tables are located in:

- `panoramix:/data/sodar/MeteoData/My_data`

All tables can be filled with the scripts *FillSodarDbTables.sh* and *FillMeteoDbTables.sh*. If only one table has to be filled use the corresponding *Fill<tablename>.sh* script.

Available scripts are:

SODAR data:

- FillSodarDbTables.sh
- FillSodarParams.sh
- FillSodarPeriods.sh
- FillSodarProcessedData.sh
- FillSodarSettings.sh

Meteorological data

- FillMeteoDbTables.sh
- FillMeteoData1.sh
- FillMeteoData2.sh

Note: If an already filled table is filled again, lots of error messages will be generated!

## 7. CONCLUSIONS

The general aim of the WISE project is to investigate whether application of the SODAR measurement technique (SODAR = sound detection and ranging) in wind energy experimental work is feasible as a replacement for cup anemometers, wind direction sensors and tall meteorological masts. Work Package 2 of the WISE project aims at doing extensive controlled experiments with the SODAR. For example SODAR measurements are compared with measurements from nearby masts and different brands of SODARs are compared. Part of the work package is the creation of a database. The measured SODAR data should be gathered in this database. The database is created by ECN in order to enable further analysis by the partners in the project. Especially the SODAR data from the power performance assessments should be added to this database. ECN made the choice to create a database structure in SQL.

The database structure is defined and the ECN data measured with the SODAR are added to the database. Upto now the description of the database is limited to include SODAR data measured close to a meteorological mast. Power measurements from wind turbines are not yet included. However, the database can easily be extended also to include these data.

The data measured by means of the ECN SODAR have been re-processed completely. A new directory structure is defined which is accessible from both the Unix(Linux) and the Microsoft Windows platform. The processed and validated data are stored in a database to make retrieval of specific data sets possible. The database is also accessible from the Windows platform. The format is available for the WISE project, so that a database containing data from all partners can be created.

## 8. REFERENCES

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<b>Abstract</b>	<p>The partners in the WISE project are investigating whether application of the SODAR measurement technique in wind energy experimental work is feasible as a replacement for cup anemometers and wind direction sensors mounted on tall meteorological masts both from the view of accuracy and cost. In Work Package 2 of the WISE project extensive controlled experiments with the SODAR have been performed. For example SODAR measurements have been compared with measurements from nearby masts and different brands of SODARs have been compared. Part of the work package was the creation of a database to gather the measured SODAR data. The database was created by ECN in order to enable further analysis by the partners in the project. ECN made the choice to create a database structure in SQL.</p> <p>The database structure that has been defined by ECN is described in full detail. The database is based on SQL, and care is taken that data that is unchanged during a measurement period is only stored once. The logic behind the structure is described and the relations between the various tables are described. Upto now the description of the database is limited to include SODAR data measured close to a meteorological mast. Power measurements from wind turbines are not yet included. However, the database can easily be extended also to include these data.</p> <p>The data measured by means of the ECN SODAR have completely been re-processed. A new directory structure was defined which is accessible from both the Unix (Linux) and the Microsoft Windows platform. The processed and validated data have been stored in a database to make retrieval of specific data sets possible. The database is also accessible from the Windows platform. The defined format is available for the WISE project, so that the database containing data from all partners can be created.</p>		
<b>Key words</b>	wind measurements, SODAR		
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