Wind-shear analysis at Innsbruck Airport (LOWI)

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Zusammenfassung

This report gives a summary on my tasks during the four weeks internship at the meteorological department of Austro Control (ACG) in Innsbruck. It aims to examine wind shear (WS) events defined by ICAO Annex 3 based on measurements obtained by wind sensors located around the airport. It is written in a manner, so that even non *Matlab* users can do the following analyis for other airports or measurement sites around LOWI. These measurements will then be compared to WS WRNG's declared in Met-Reports, and how the measurements and warnings match. Obviously the comparison and evaluation of WS WRNG'S with such coarse measurements can only be a first step regarding WS. But as pilot reports on WS are not regularly reported and 'Aircraft Meteorological Data Relay' (AMDAR) was not consecutively available (e.g. one AMDAR per day) at LOWI before 2014 the measurements from sensors around the airport in conjunction with Met-Reports are a reasonable first approach to find and evaluate WS events.

1. Introduction

As this analysis should be useful for all meteorological offices within Austro Control GmbH (ACG) easy to use routines were intended. I decided to handle these measurements with *Matlab* as it is a language which offers good interfaces for reading and writing from and to the filesystem of the OS as well as good calculation performance and comprehensive easy to use visualization tools.

The aim of this report is to evaluate wind shear warnings at LOWI and if there is a possibility to find characteristics of these events based on the measurements of wind sensors located around LOWI. Therefore the scope is to read out wind measurements from six measurement sites around LOWI at different levels. These files can be downloaded from within the ACG intranet [1] for each international airport in Austria. Just make sure that you download the files in an **10min intervall** so that all the routines work properly! Each wind sensor measures a whole bunch of values including

- Winddirection
- Windvelocity
- Virtual Temperature

So for the download of the `.csv` file select all parameters measured by a specific station (14 parameters). Among them are the mean, maximum and minimum values for both wind direction and wind velocity are measured momentarily as in two and ten minutes intervals.

2. Characteristics of shear

Shear is defined as a difference in wind speed and direction over a certain distance in the atmosphere.

[1] medmasi.austrocontrol.net

Wind shear can be devided into vertical and horizontal components, but for aviation especially vertical wind shear is critical during approach and takeoff (Haverdings et al. 1995). The vertical component is defined as the difference vector over a vertical distance

$$\overrightarrow{k} \times \nabla \overrightarrow{v}. \tag{1}$$

As stated in the document "Verfahrensanweisungen für Flugwetterwarnung[2]" issued by Austro Control GmbH encountered or expected wind shear below **3100aal** must be reported by the Pilot as a Air-Report or as a wind shear warning in the Met-Report for Innsbruck Airport (LOWI). There are three categories of wind shear warnings:

- **SEV WS** ... (**12kt** pro 100ft)
- **STRONG WS** ... (**12kt** pro 100ft)
- **MOD WS** ... (**5-8kt** pro 100ft)

Due to the relatively coarse vertical grid of wind measurements around most airports, it is quite difficult for meteorologists to forecast exact warnings of wind shear conditions, for example along the approach sector, within the accuracy of the upper definitions. In addition, for example during "Föhn"conditions at LOWI, encountered wind shear on final approach is not reported by most of the pilots.

3. The *Matlab* Routines for reading wind shear files

Altough the datasets downloaded from *medasi* is not complete at each station within a year (at least for 2012/13), one have to think about how this datasets can be resampled/fitted so that it is possible to compare the datasets against each other. The routine `resize.m` ensures that the comparison between any of the datasets becomes possible. If this routine should once make problems, don't hesitate to contact me via mail.

a. *Download and modify input files*

Select and download files with chosen parameters and timerange from the *medasi-database* from the ACG intranet. After the download is completed open the files with an texteditor of your choice and do the following in order to garantee a smooth readout with the *Matlab* routines provided.

- find ',' and replace as '.'
- find '-;' and replace as '9999;'
- find '99;-' and replace as '99;9999;'

This will asure that *Matlab* reads the full file and do handling of missing values. With these steps done, one can start *Matlab* and continue with the next section which discribes how to read input files.

b. *Reading input files with* Matlab

To start with the data analysis the content of each downloaded measurement file has to be placed into the existing *Matlab* folder called ../ws-analysis which includes all the functions and documentation. Next one have to define or modify the existing `infile.txt` [3] where all filenames of the inputfiles are located as `.txt` or `.csv` files. There is a *Matlab* script called `mainroutine` which calls the reading function called `readwma.m`. As a first step before executing scripts and functions in the ../ws-analysis folder becomes possible in *Matlab*, make sure to put a statement addpath('..yourpath/ws-analysis') into the *Matlab* command line.Now to read the whole bunch of files defined in the `infile.txt` simply type

```
>> mainroutine
```

into the *Matlab* command line. This function reads the files specified in `infile.txt` and stores the data as a structure array in the *Matlab* workspace. You can access the files and their respective data fields for example as follows [4]

```
>> files.wma_city_2013.
   WMA_City_Windgeschwindigkeit_momentan.
   value
```

Don't be confused by the extra field called `sdate` which is added in each file. Because of how *Matlab* handles dates it was necessary to introduce that extra field, in our case called `sdate`. This `sdate` is further used to compare dates between different files for wind shear calculations. The user will not get in contact with this further on.

[2] see ACG internal document 'VA MET FCST 003/Version: 15.0' for further details

[3] First line in the `infile.txt` has to be blank or better leave as a commentline

[4] use tabulator after each '.' to list available fields

4. Results of wind shear measurements

In this section, an overview of the measurements made at the measurement sites Igls and City-Nord for the year 2013 are presented.

a. *Distribution of data*

As all files are stored in the workspace, you can plot histograms for each datafield of the respective inputfile. The function `statisticsdir.m` and `statisticsvel.m`will provide the respective routines. This means that you have to define an input for these functions [5] from which you want to see the histogramm. This can be done as shown in the following example

```
[max_val, min_val, bincounts] =
statisticsvel(files.wma_city_2013.
    WMA_City_Windgeschwindigkeit_10_min_Mittel
    .value)
```

The algorithm will then store a `.pdf` file in the current working directory of the figure. Maybe you have to adapt the annotations and axes labels accordingly.

Figures a to a show an output of the statistics function for wind direction and velocities for Igls and City-Nord measurement site. They display the distribution of wind direction and velocities prevailing at both sites during 2013. With these figures one gets an idea of what are the most dominant wind regimes within this sector as well as what are the extreme values measured. As a first step, I decided to analyse the measurements of two wind sensors i.e. Igls and City-Nord, which are both located beside the approach path on runway 26 at different altitudes.[6]

[5]e.g. a direction field value for `statisticsdir` and a velocity field value for `statisticsvel`

[6]WMA Igls: **2970ft**; WMA City-Nord: **2330ft**

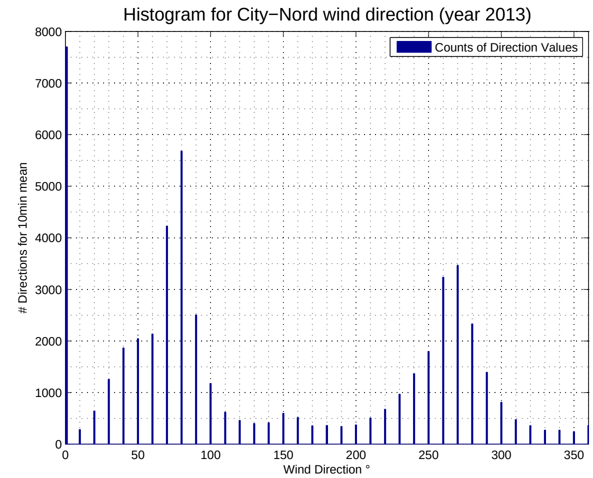

ABB. 1. The distribution of the mean winddirection over the year 2013 for a 10min period shows a typical regime for an west-east extended valley. Therefore most of the time wind is coming from easten and western directions. Values of 0 indicate no wind / variable in direction.

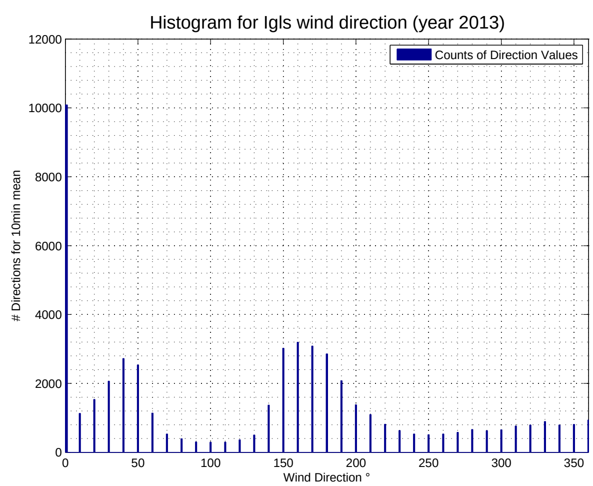

ABB. 2. The distribution here shows a local maximum for southern directions. The 'Wipptal' with its north-south alignment is contributing to this fact. Values of 0 again indicate no wind / variable in direction.

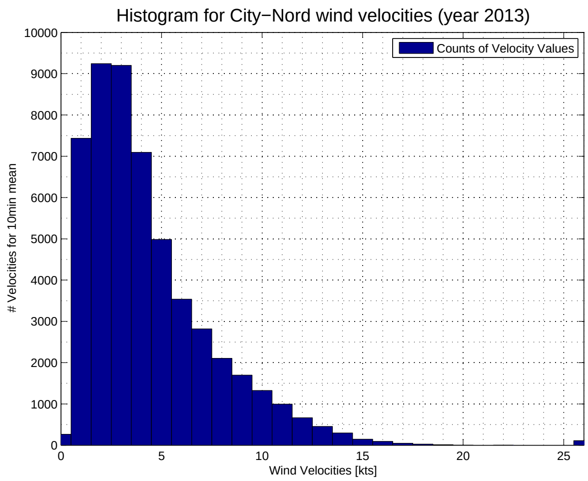

Abb. 3. For wind velocities the distribution shows a maximum at small values around 3kts with some rarely occuring winds up to 25kts for a 10min mean period, which is quite remarkable

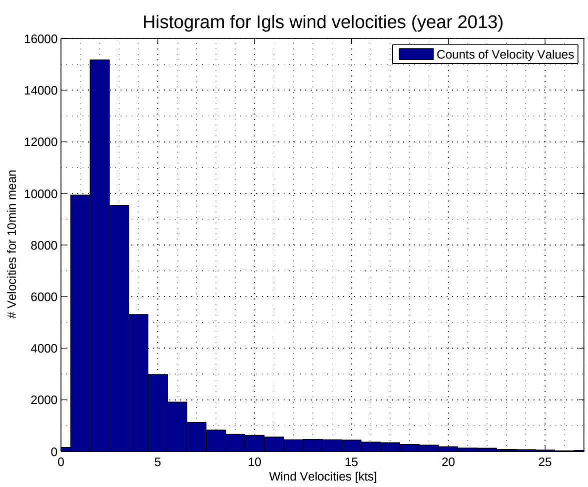

Abb. 4. For wind velocities the distribution shows an quite isolated maximum at small values around 3kts with some rarely occuring winds up to 28kts for a 10min mean period.

b. Shearvectors

In this chapter a first look of the wind shear on LOWI for the final approach on RWY26 is made. As a first lookup, Igls and City-Nord are well located on the northern and southern site of the approach sector. The routine `shearvelocity.m` is used to obtain the shearvectors and associated figures. As an example of how to call the routine see the following

```
[windcomponents, sheararray] = shearvelocity(
    files.wma_igls_2013.Zeit.value,files.
    wma_igls_2013.sdate.value,files.
    wma_city_2013.sdate.value,files.
    wma_igls_2013.
    WMA_Igls_Windgeschwindigkeit_10_min_Mittel
    .value,files.wma_city_2013.
    WMA_City_Windgeschwindigkeit_10_min_Mittel
    .value,files.wma_igls_2013.
    WMA_Igls_Windrichtung_10_min_Mittel.value,
    files.wma_city_2013.
    WMA_City_Windrichtung_10_min_Mittel.value)
```

With this set of input parameters (e.g. Igls and City-Nord) the routine will calculate the shearvector and components between these two locations for the 10min mean wind. Within the output parameter *shearcomponents* the u and v components for each station is listed. In contrast to the output parameter *sheararray*, *shearcomponents* will remain in the *Matlab* workspace and will not be written into a file. If you open the file the format within should look like

```
Zeit Velocity Direction
01-01-2013 00:00;3.00;350.00;
01-01-2013 00:10;3.00;350.00;
01-01-2013 00:20;7.00;350.00;
01-01-2013 00:30;3.00;340.00;
01-01-2013 00:40;6.00;340.00;
01-01-2013 00:50;4.00;350.00;

...

31-12-2013 21:50;0.00;0.00;
31-12-2013 22:00;0.00;0.00;
31-12-2013 22:10;0.00;0.00;
31-12-2013 22:20;1.00;20.00;
31-12-2013 22:30;1.00;270.00;
31-12-2013 22:40;1.00;340.00;
```

The output parameter *sheararray* comprises all the information regarding shear between the stations given to the input parameter list (e.g. Igls and City-Nord). A file called `shearvectors.txt` is written to the current directory. Look into the files header to get information about what each column stands for. For further data analysis on a subsequent (for example after computer shutdown - workspace is deleted) you can simply read the file into the matlab workspace by the command

```
shearvectors = textscan(fid,'%s %f %f','
    headerlines',1,'delimiter',';')
```

You can now plot the output but up to now all shearvectors for a 10min period over the year 2013 are included. So it would be nice to have a filter which sorts out all for example all vectors which do not comprise certain criteria.

The routine `shearfilter.m` exactly does that for us! The syntax for calling the routine is

```
filteredshear = shearfilter(sheararray, 10)
```

In this case the output parameter filteredshear will only contain shearvectors which have a velocity greater than 10kts. In addition to filtering the routine plots winddirection prevailing at both measurement sites at the times which meet the criteria stated in the input and also plots the velocity of the shearvector as well as the direction of the shearvector. With this information, one gets the whole bunch of information for shearanalysis

5. MetRepots

As a next step in the wind shear analysis, we want to look at Met-Reports [7] . These reports are published by the national aeronautical weather services (e.g. in Austria the Austro Control GmbH) for every international airport. Two Met-Reports per hour, at HH:20 and HH:50, are disseminated to airmen via the so called 'Automatic Terminal Information Servics' known as ATIS. It is broadcasted via VHF-RTF at a seperated frequency for busy terminal areas. Pilots monitor this frequency prior departure and approach.
Reports disseminated on ATIS include valuable information for crews regarding

- available runway
- transition level

[7] thanks to Andreas Lanzinger (ACG) for providing the data

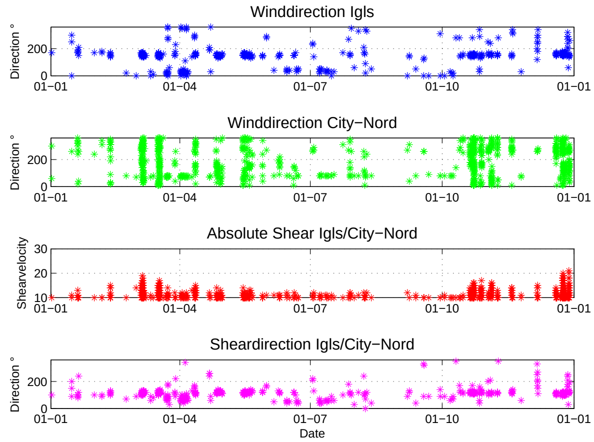

Abb. 5. The upper two plots of the figure show wind directions of each wind sensor (e.g. Igls & City-Nord) for events where windvelocities were >10kts for a 10min mean. For these events the shear velocity and the shear direction (together yield the shear vector) are calculated and depicted in the two plots beneath. Most of the time shear values are below 20kts with a predominant eastern to southern direction.

- wind
- visibility
- clouds
- temperature and dewpoint
- QNH
- trend
- SIGMETS / AIRMETS within a FIR/UIR
- WS WRNG's
- ...

As pilots rely on this information it is important that if wind shear is prevailing within the vicinity of an airport and meets the criteria listed in Chapter 2 at the time of arrival/departure, a WS WRNG is declared within the Met-Report and so on ATIS.

Up to now, due to the coarse measurement grid as stated at the beginning of this article, WS WRNG's are dependent on the observer in duty and his assessment to the current situation. As a result, some WS WRNG's are not declared while a warning would be justified in accordance to the upper criteria and vice versa. Even it is likely that the vice versa case (e.g. a WS WRNG's is declared while a warning would not be justified) occures more often and therefore the safety is sustained in most of the cases, it would be desireable to have a tool which gives an impartial number to the observer regarding wind shear.

As a first approach to get an idea of how such a characteristic number can be developed I used Met-Reports available for each month within the year 2013 and compared the wind situation measured by the sensors City-Nord and Igls at times a WS WRNG was declared within the Met-Report by the weather service.

As a second step I have filtered measurements which meet the criteria for WS WRNG's (with linear interpolation which is not optimal because (vertical) wind shear is often concentrated over a short verical extend) and related them to Met-Reports published at this time.

6. The *Matlab* Routines for reading Met-Report files

In this section I want to give a short guidance on how to use the routines for reading Met-Report files. First make sure that the Met-Reports are available in a line by line format. This means that every report should be represented in one line. In the *medasi* database this is not the case but Andreas Lanzinger has written a *Pearl* script which does this conversion for us. The script also gives you one Met-Report file per month! This is necessary because within the Met-Reports only the day of the month and the so called '**Z**ulu' (UTC) time in the format *ddHHMM***Z** are available. So for analysing a year (e.g. 2013 in our case) the date/time information available within the reports would be ambiguous. How the routine is handling this issue is shown further down in this document.

As you have guaranteed the upper requirements for the input file, you can read the Met-Report file by simply typing

```
>> reports = metreportread('
   MetRep_LOWI_201301.txt')
```

into the *Matlab* command line. The output variable `reports` will be a cell array.

7. Results of Met-Reports and wind shear analysis

In this section I demonstrate how the results for the Met-Reports and wind shear comparison are obtained.

a. *Filter Met-Reports by key-words*

As a next step you may want to filter reports which contain certain values or strings. For example in our case we are interested in reports which contain the keyword *WS WRNG* for wind shear warning. To isolate these reports type the following

```
[filterreps, filterdates, repexpression] =
   metreportfilter(reps, 'WS WRNG')
```

In return this function will add the variables `filterreps`, `filterdates`, `repexpression` to the *Matlab* workspace. `filterreps` lists all the reports containing the designated key-word. `filterdates` contains the dates in a *Matlab* defined format and is used in a later stage for matching. Finally `repexpression` simply holds the key-word as a string.

b. *Match filtered Met-Reports with coincidented WS-vectors*

As the Met-Reports are issued at fixed times (see 6) but are valid for a period of 30min it would be nice to match all measurements withn the period of reports validity, not only the WS-vectors at times of report issue. The following function will do that - so it will assign all WS measurements within the reports validity period![8]

Now with the following function you have the possibility to match dates and times of the filtered 'WS WRNG' Met-Reports with the in chapter 4 section b(in our case) calculated WS-vector. Before doing that you have to check the month of the Met-Report file you have read in section 6. Done that you can define a variable for example called `month` as a string from `'01'` for January to `'12'` in the command line or simply type `'01'` directly into the input parameter list. Now you can match the filtered reports with the coincidented wind shear vectors by putting the following into the *Matlab* command line

[8] in our case we have calculated the WS-vectors with the 10min mean measurements, so there are three measurements within the validity period of one report (however for completeness I took four measurements assigning to each report to get all values within the 30min period from one report to the next (e.g. HH:50, HH:00, HH:10, HH:20

```
repshearmatch = matching2(sheararray,
    filterreps,filterdates,repexpression,month
    )
```

Be aware of the names of input parameters in your workspace. Adapt them to the appropriate name if they differ from the upper example.

In addition to the output `repshearmatch` in the workspace a so called `repshearmatchfile.txt` is created in the current working directory (e.g. the directory in which the function was called). This file contains all of the valuable information regarding verification of WS WRNG advices in the Met-Reports in conjunction with the WS-vector calculated from WS measurements around (in our case LOWI) but in general any airport. I choose to match the reports with the calculated WS-vectors from the 10min and (better) 2min mean values because then you have enough measurements (represented within the mean-number) and also (especially for the 2min mean) have kept visible a portion of the maximum values. For further details on how the data is structured within the file look into the created `repshearmatchfile.txt` by using a text editor. My intention was to deliver a file in an easy to access format so it can be used for further analysis on the subject. On that basis, studies regarding the derivation of an index number on which WS-WRNG's are disseminated could be made. By for example do statistics on what values WS-vectors show when WS-WRNG's were effective and so on. If WS values show significant context between the measurements of the two measurement stations it could be used as an indicator when publish a WS-WRNG. I had not the time to do this additional analysis within these 4 weeks but with this documentation and the obtained`repshearmatch` files someone, if he/she is interested, could certainly do this.

8. Aircraft Meteorological Data Relay (AMDAR)

The AMDAR system predominantly utilises existing aircraft onboard sensors, computers and communications systems to collect, process, format and transmit meteorological data to ground stations via satellite or radio links World Meteorological Organisation (2003).

The AMDAR system is defined by the characteristic that it is a meteorological observing system that utilizes aircraft innate sensors and onboard avionics and communications systems in order to collect process and transmit meteorological data that has been defined, sampled and processed according to WMO meteorological specifications. Once on the ground, the data is relayed to National Meteorological and Hydrological Services (NMHS), where it is processed, quality controlled and transmitted on the WMO Global Telecommunications System (GTS).

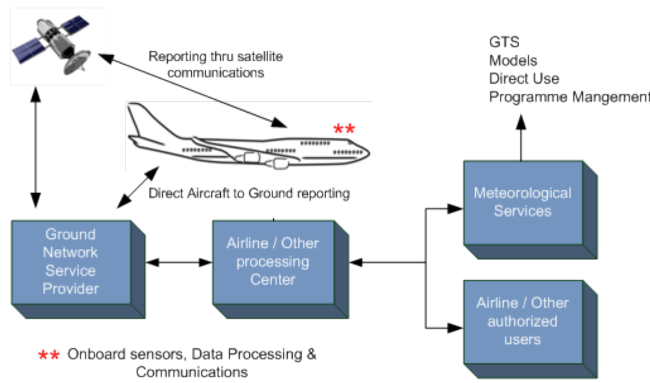

Abb. 6. The essential components and basic building blocks of the AMDAR system

Vertical profiles of AMDAR data are derived as the aircraft is on ascent or descent and en-routed data is derived as the aircraft flies at cruise altitudes of around 35,000 feet (10,500 metres). From the innate Onboard AMDAR System, the following meteorological parameters can be measured or derived:

- Air temperature (static air temperature)
- Wind speed and direction
- Pressure altitude (barometric pressure)
- Turbulence (Eddy Dissipation Rate or Derived Equivalent Vertical Gust)
- Air temperature (static air temperature)

Additional non-meteorological parameters that can be reported, measured or derived include:

- Latitude position
- Longitude
- Time
- Icing indication (accreting or not accreting)

- Departure and destination airport
- Aircraft roll angle
- Flight number

It was intended to even use these AMDAR datasets for WS evaluation, but as this datasets were only present as BUFR-format on the database it was not possible to analyse them in such a short period of time.

Literatur

Haverdings, H. ., W. . Rouwhorst, K.-U. Hahn, R. König, H. . Huynh, und F. . Descatoire, 1995: Windshear occurences in europe. - some annotated cases and inquiry into a windshear database -. Tech. rep. URL `http://elib.dlr.de/30201/`, lIDO-Berichtsjahr=1995,.

World Meteorological Organisation, 2003: Aircraft meteorological data relay (amdar) reference manual. Tech. rep.

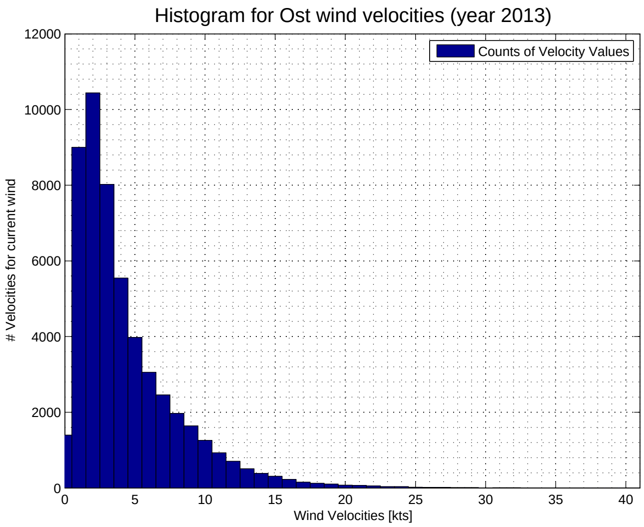

ABB. 7. Histogram for wind velocity of current values on measurement site 'Ost'

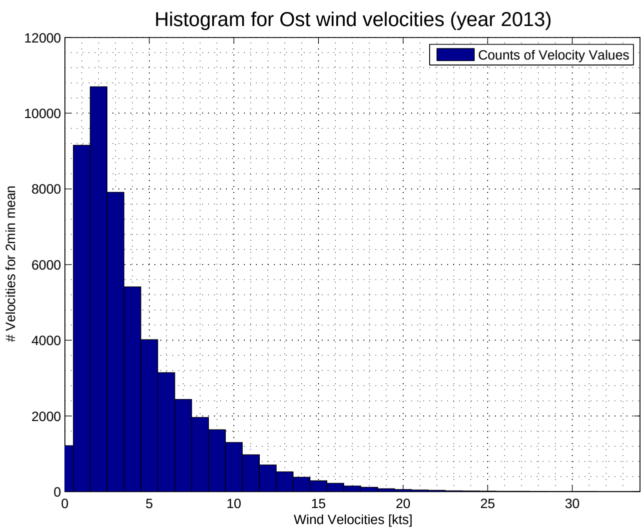

ABB. 8. Histogram for wind velocity of 2min mean values on measurement site 'Ost'

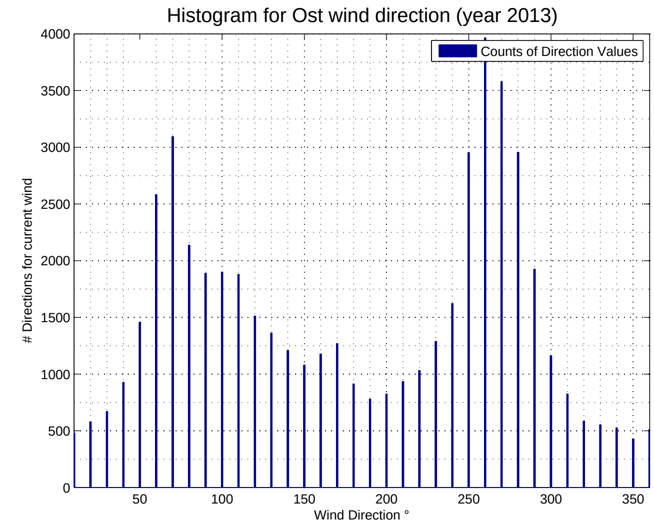

ABB. 9. Histogram for wind direction of current values on measurement site 'Ost'

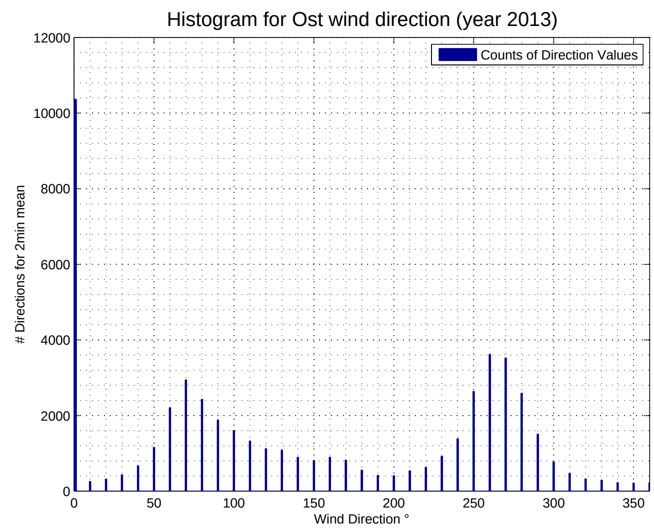

ABB. 10. Histogram for wind direction of 2min mean values on measurement site 'Ost'

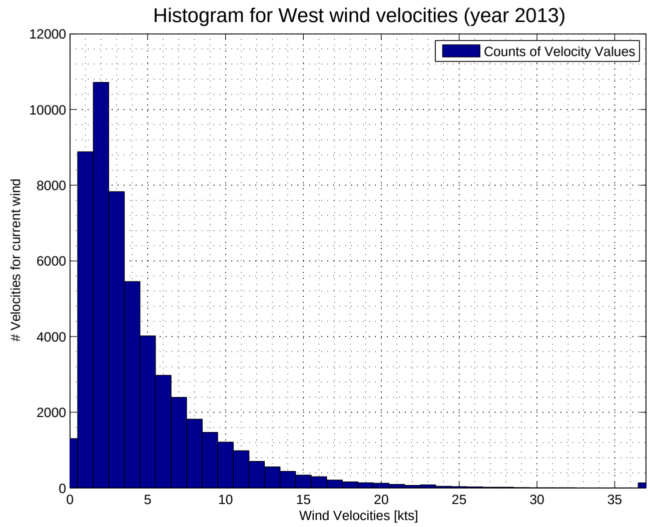

Abb. 11. Histogram for wind velocity of current values on measurement site 'West'

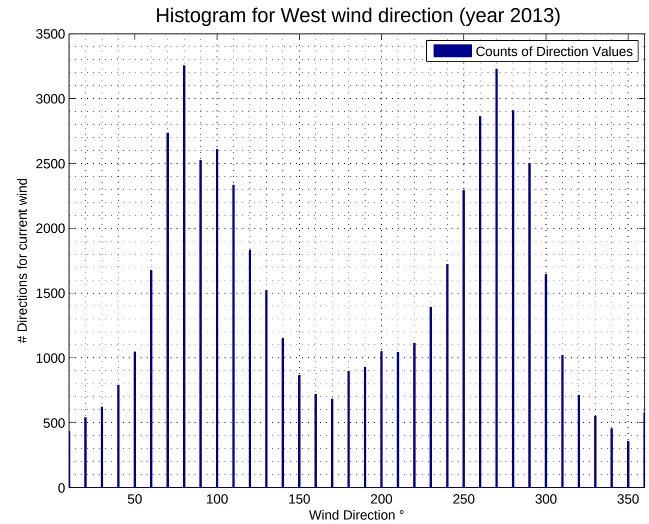

Abb. 13. Histogram for wind direction of current values on measurement site 'West'

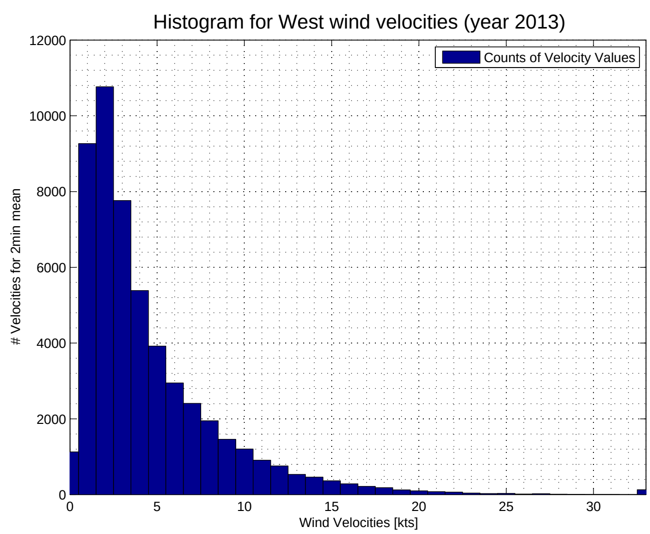

Abb. 12. Histogram for wind velocity of 2min mean values on measurement site 'West'

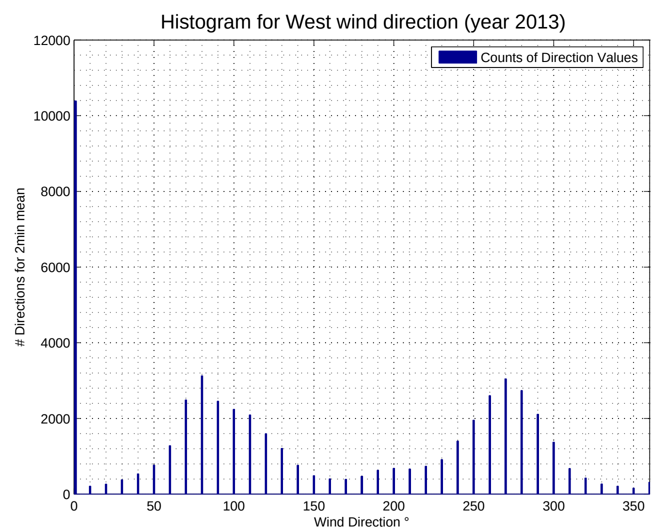

Abb. 14. Histogram for wind direction of 2min mean values on measurement site 'West'

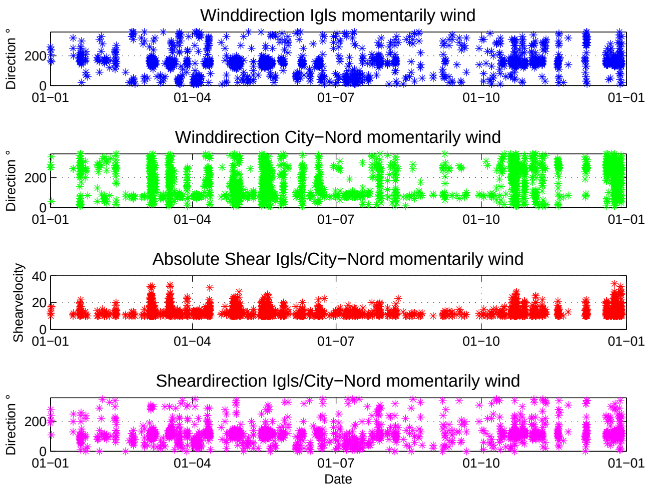

Abb. 15. Filtered values where shearvector of current wind is greater than 10kts 'Igls/City-Nord'

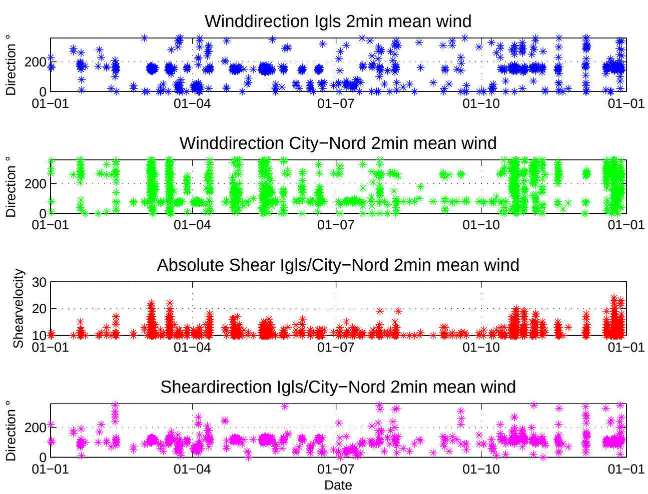

Abb. 16. Filtered values where shearvector of 2min mean wind is greater than 10kts 'Igls/City-Nord'

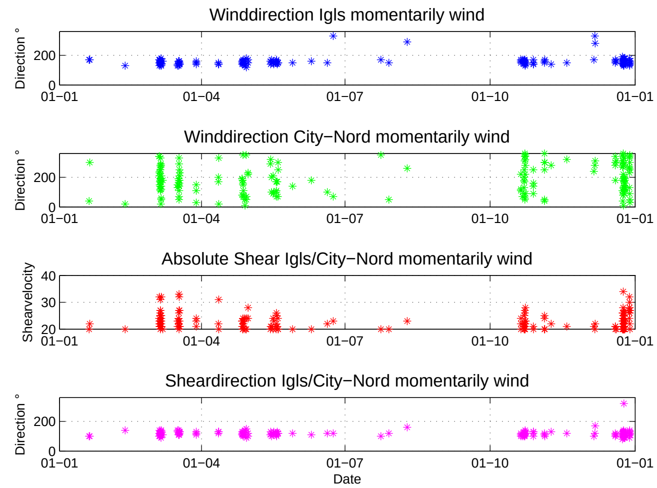

Abb. 17. Filtered values where shearvector of current wind is greater than 20kts 'Igls/City-Nord'

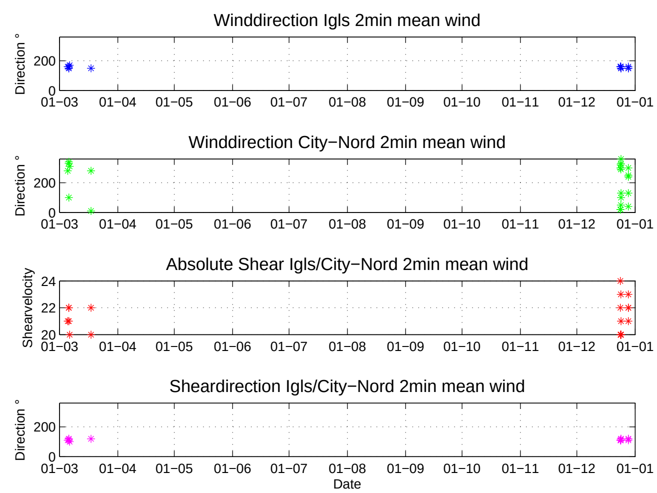

Abb. 18. Filtered values where shearvector of 2min mean wind is greater than 20kts between location 'Igls/City-Nord'

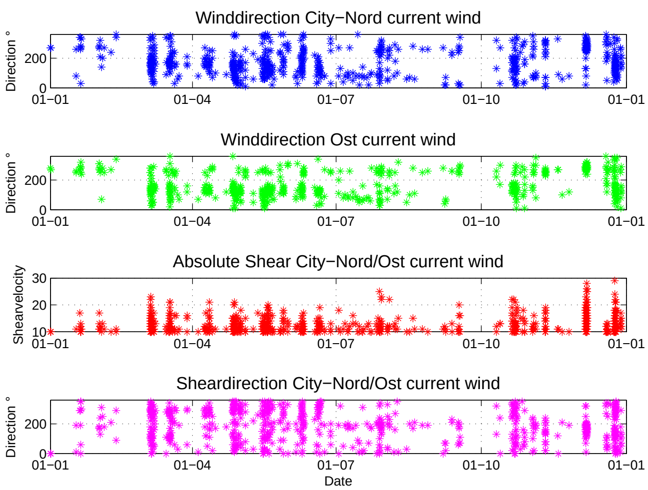

Abb. 19. Filtered values where shearvector of current wind is greater than 10kts between location 'City-Nord/Ost'

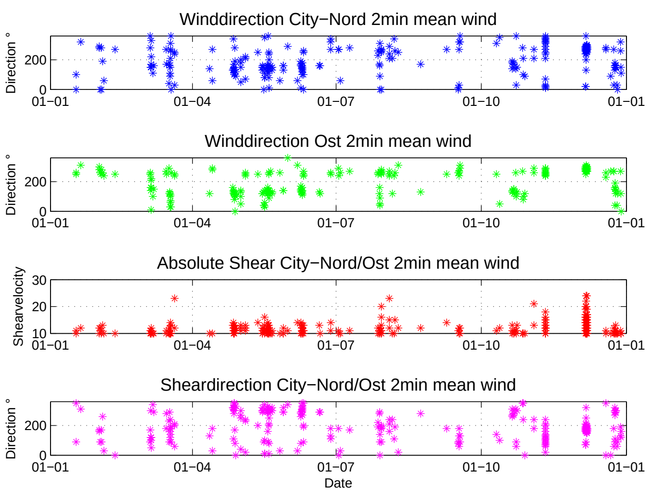

Abb. 20. Filtered values where shearvector of 2min mean wind is greater than 10kts between location 'City-Nord/Ost'

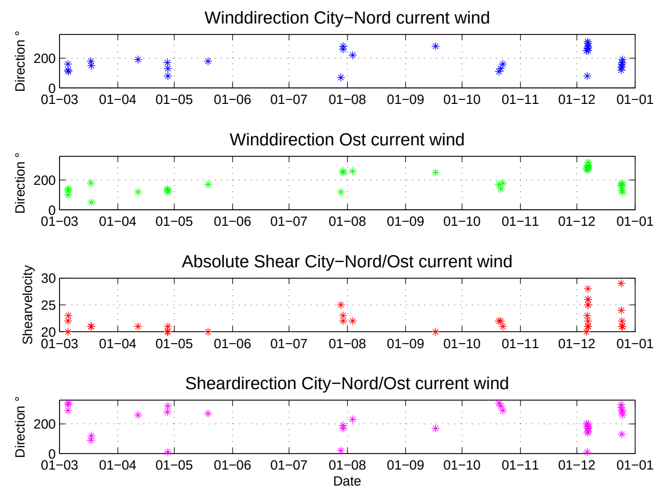

Abb. 21. Filtered values where shearvector of current wind is greater than 20kts between location 'City-Nord/Ost'

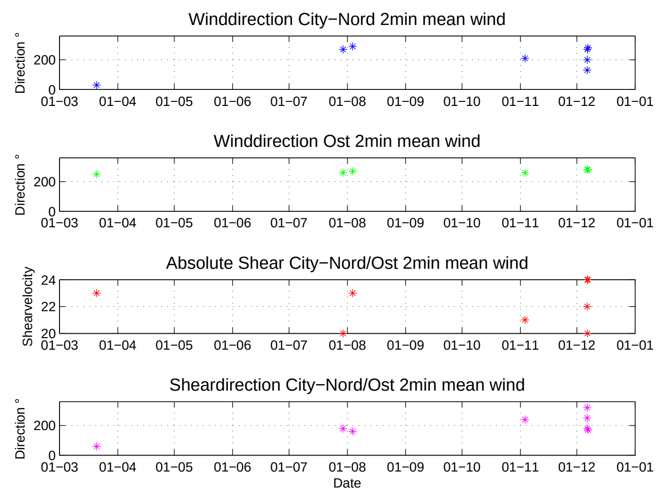

Abb. 22. Filtered values where shearvector of 2min mean wind is greater than 20kts between location 'City-Nord/Ost'

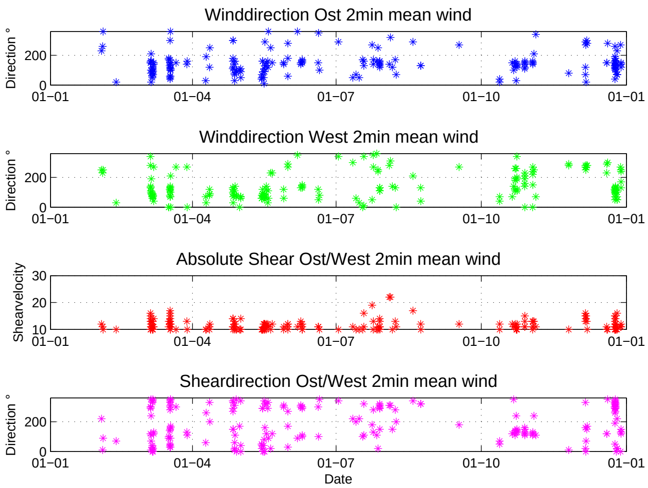

Abb. 23. Filtered values where shearvector of 2min mean wind is greater than 10kts between location 'Ost/West'

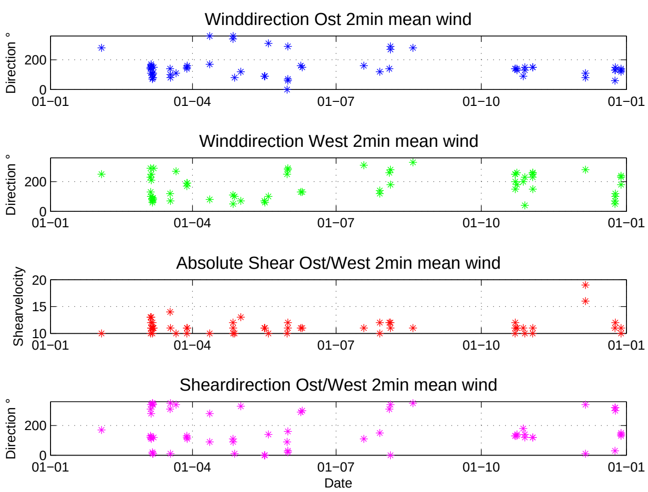

Abb. 24. Filtered values where shearvector of 10min mean wind is greater than 10kts between location 'Ost/West'

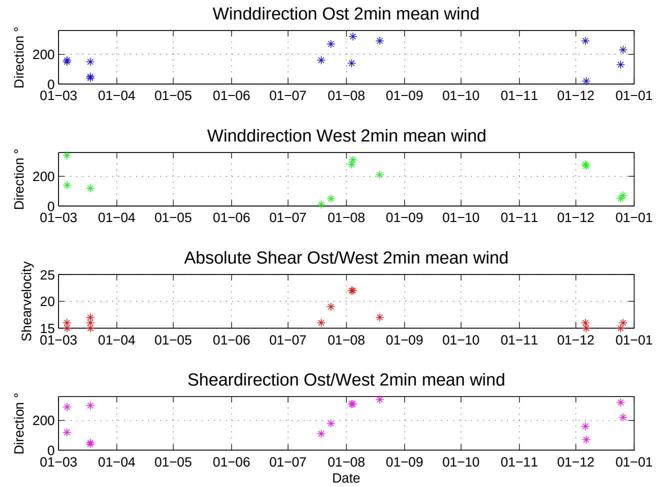

Abb. 25. Filtered values where shearvector of 2min mean wind is greater than 15kts between location 'Ost/West'

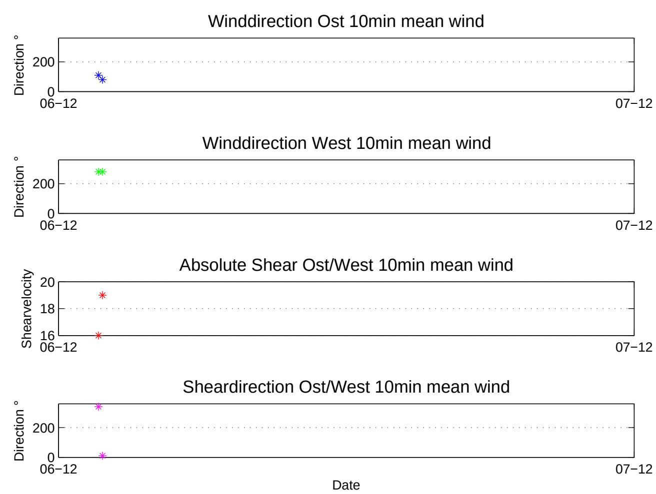

Abb. 26. Filtered values where shearvector of current wind is greater than 15kts between location 'Ost/West'

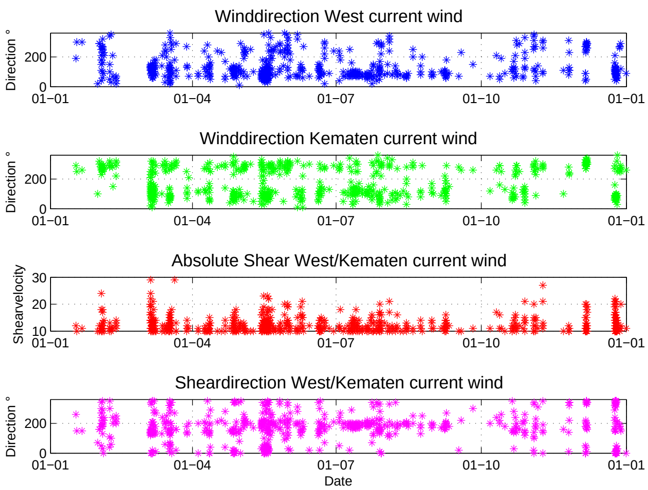

Abb. 27. Filtered values where shearvector of current wind is greater than 10kts between location 'West/Kematen'

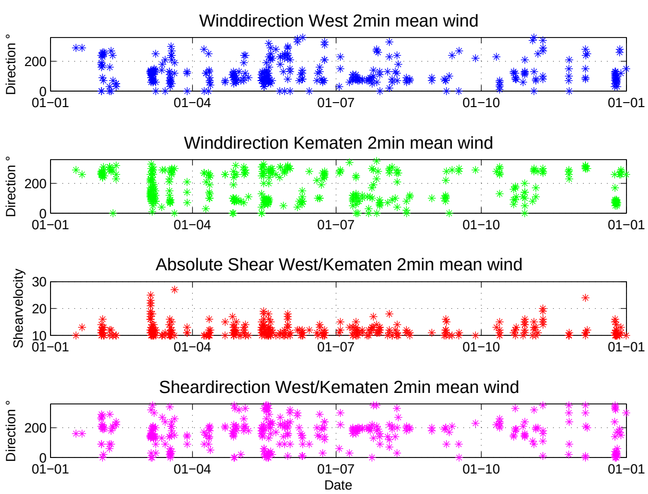

Abb. 28. Filtered values where shearvector of 2min mean wind is greater than 10kts between location 'West/Kematen'

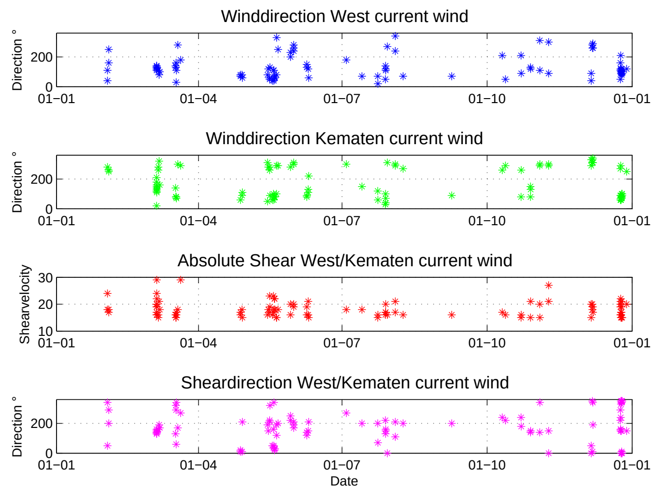

Abb. 29. Filtered values where shearvector of current wind is greater than 15kts between location 'West/Kematen'

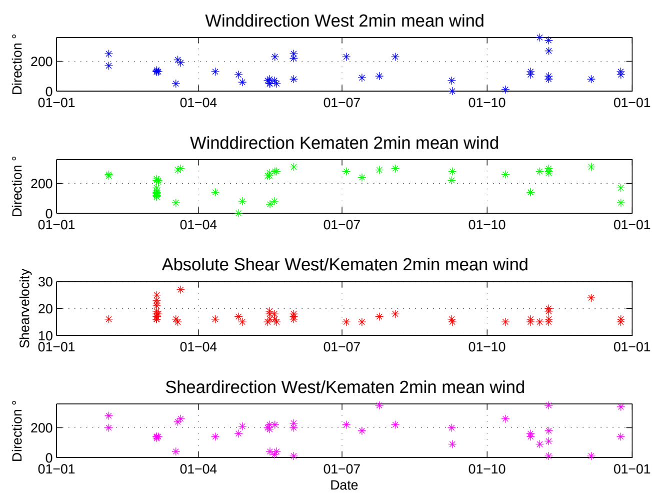

Abb. 30. Filtered values where shearvector of 2min mean wind is greater than 15kts between location 'West/Kematen'