Upper Air Climatology of Amsterdam FIR, using ERA-Interim 1989-2008
Part 1

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Abstract

This report, part 1, presents upper-air climatology below 150 hPa (Flight level 430) for the Flight Information Region of the Netherlands (Amsterdam FIR). Climatology of the planetary boundary layer below 850 hPa will (in more detail) be presented in part 2. The climatology is based on analysis of twenty years ERA-interim 1989-2008 and on observations. ERA-Interim is a recent reanalysis-project of the European Centre for Medium Range Weather Forecast ECMWF. The climatology is produced under the program Kennis-voor-Klimaat-project Climatology and Climate scenarios for Hotspot Mainport Schiphol, HSMS02 on request of Air Traffic Control the Netherlands (LVNL).

Contents

Chapter 1

Introduction

Knowledge for Climate is a research programme for the development of knowledge and services of climate and climate change in the Netherlands. Governmental organisations (central government, provinces, municipalities and water boards) and businesses, actively participate in research programming through the input of additional resources (matching).

Knowledge is developed within the research programme that is necessary to be able to assess investments to be made in spatial planning and infrastructure in terms of their resistance to climate change, and for making changes where necessary.

The research programme focuses on eight areas, called hotspots, like Hotspot Schiphol Mainport. Schiphol airport and the surrounding area, Schiphol Mainport and Region, are very vulnerable to climate change. The airport is situated, from a hydrological point of view, in one of the most complex and fragile urban areas in the world.

Climate change and the resulting change in weather conditions not only affect daily operations at Schiphol airport, but are also a determining factor in possible future expansion. Schiphol needs to anticipate such changes in weather and climate if it is to maintain its competitive position as a mainport. Climate change is a driving force for research into adaptation possibilities, to enable the Schiphol region to find solutions for the strain placed by Schiphol on the region [Kennis voor Klimaat, 2009].

Air Traffic Control the Netherlands (LVNL) requested climatology of the upper air for their Flight Information Region (FIR) for the parameters wind (-speed and -direction), temperature and humidity in local profiles as well as on a spatial scale covering the FIR as input for air traffic control monitoring. This report focuses on the climatology for the layer between 850 and 150 hPa, the planetary boundary layer will be discussed in more detail in a separate report.

In this report chapter 2 introduces the Flight Information Region of the Netherlands (Amsterdam FIR). Chapter 3 presents the reanalysis ERA-Interim of the European Centre for Median Range Weather Forecast ECMWF as tool for local and spatial climatology. Results of climatological research are presented in chapter 4 to 8, chapter 9 contains detailed climatology of the upper air in Amsterdam FIR.

The report has been reviewed and accepted by LVNL and KNMI.

Chapter 2

Amsterdam FIR

Amsterdam Flight Information Region (Amsterdam FIR) is the air traffic controlled airspace of the Netherlands.

Airspace is a general term for the area above ground level used for aviation purposes. Air traffic is internationally regulated by the International Aviation Organisation ICAO.

National authorities regulate their own airspace. On a European scale the project Single European Sky (SES) is in force, leading to functional airspace blocks. It covers the land-area as well as parts of the Northsea. ICAO has established seven categories of airspace, in the Netherlands five are in force ([Luchtruim, 2009]).

The air traffic control division of Dutch airspace is the responsibility of Air Traffic Control the Netherlands (LVNL) ([IVW, 2009]). Both aspects of controlled airspace division are illustrated in figure 1.

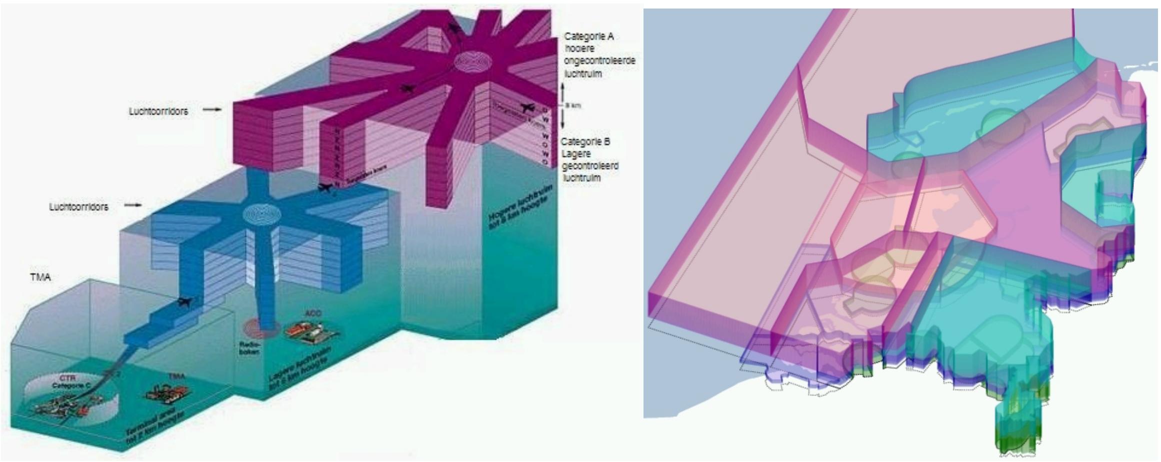


Figure 1. Illustrating airspace categories and schematic division of Amsterdam FIR

Climatology of winddirection, windspeed, temperature and humidity is requested by LVNL for Amsterdam FIR, up to a level of 150 hPa, on a specified horizontal and vertical resolution. As detailed observations of the upper air are sparse (main source of information are radiosonde soundings every twelve hours in De Bilt) it was decided to analyse model climatology from the reanalysis of ECMWF (chapter 3) with a quality check using the radiosonde soundings.

Chapter 3

Reanalysis ECMWF

3.1 Introduction reanalysis

Over the past decade, a reanalyses data set of multi-decadal series of past observations is established as an important and widely utilised resource for the study of atmospheric and oceanic processes and predictability.

Modern versions of the data assimilation systems developed for numerical weather prediction are also applied in fields that require a record of the state of the atmosphere. High-resolution operational forecasting systems provide good quality reanalysis for study of past conditions.

Two major ECMWF reanalyses have exploited the substantial advances made in the ECMWF forecasting system and technical infrastructure since operations began in 1979. The first project, ERA-15 (1979–1993), was launched in 1993 and the second "extended" reanalysis project, ERA-40 (1957–2002), in 1998.

The products of these reanalyses have been used extensively within the Member States and by the wider user community. Production of ERA-Interim, from 1989 onwards, began in summer 2006. Enhanced computer power enabled horizontal resolution to be increased to T255 (T255 stands for the spectral horizontal truncation wavenumber 255). Vertical resolution was kept at the 60 levels as used for ERA-40 ([Simmons, 2009]).

3.2 ERA-Interim

ERA-Interim is a reanalysis of the global atmosphere covering the data-rich period since 1989, and continuing in real time. The ERA-Interim project was initiated in 2006 to provide a bridge between ECMWF's previous reanalysis, ERA-40 (1957-2002), and the next-generation extended reanalysis envisaged at ECMWF.

The main objectives of the project were to improve on certain key aspects of ERA-40, such as the representation of the hydrological cycle, the quality of the stratospheric circulation, and the handling of biases and changes in the observing system.

These objectives have been largely achieved as a result of a combination of factors, including many model improvements, the use of 4-dimensional variational analysis, a revised humidity analysis, the use of variational bias correction for satellite data, and other improvements in data handling.

The ERA-Interim atmospheric model and reanalysis system uses cycle 31r2 of ECMWF's Integrated Forecast System (IFS) ([ECMWF-IFS, 2009]), which was introduced operationally in September 2006, configured for the following spatial resolution:

- 60 levels in the vertical, with the top level at 0.1 hPa;
- T255 spherical-harmonic representation for the basic dynamical fields;
- Reduced Gaussian grid with approximately uniform 0.5^o spacing for surface and other grid-point fields.

The ERA-Interim data assimilation and forecast suite produces:

- four analyses per day, at 00, 06, 12 and 18 UTC;
- two 10-day forecasts per day, initialised from analyses at 00 and 12 UTC.

The analysis produced at 00 UTC on a given day involves observations taken between 15 UTC on the previous day and 03 UTC on the present day; the analysis at 12 UTC involves observations between 03 UTC and 15 UTC. The vertical resolution in pressure levels, starting at 1013.25 hPa, is 25 hPa up to 750 hPa, 50 hPa between 750 and 250 hPa and 25 hPa between 250 hPa and 100 hPa.

Documentation of the IFS is published on the ECMWF website, main characteristics of the ERA-Interim system and many aspects of its performance are described in ECMWF Newsletters 110, 115, and 119. With some exceptions, ERA-Interim uses input observations prepared for ERA-40 prior to 2002, and for ECMWF's operational forecast system thereafter ([Berrisford, 2009]).

As the name suggests, ERA-Interim represents a step towards ECMWF's next generation reanalysis system. This reanalysis, tentatively called ERA-75, will span at least a 75-year period, extending back in time to the first half of the 20th century when substantial numbers of upper-air meteorological observations began to be made available on a regular basis. Depending on available resources, the target is to begin producing ERA-75 in 2013.

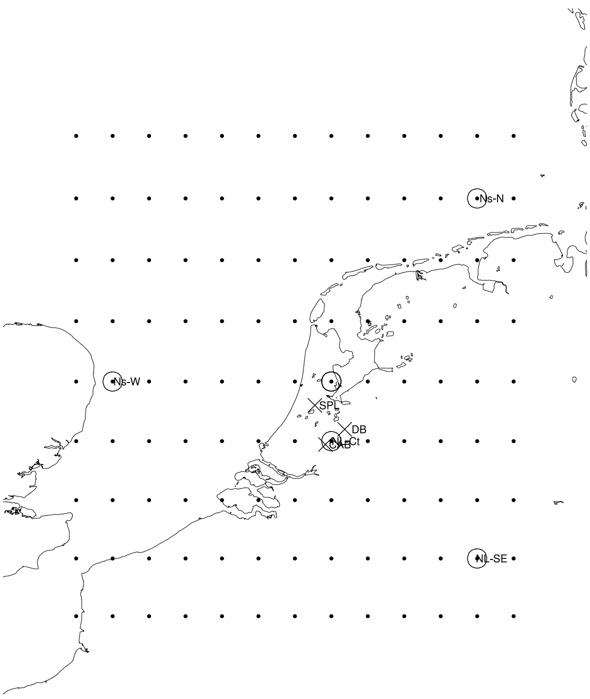


Figure 2. ERA-interim horizontal grid.
Circled ERA-gridpoint are used for Schiphol, De Bilt/Cabauw, Northsea-west, Northsea-north and Netherlands-southeast.

In figure 2 illustrates the horizontal grid, used for climatological calculations of wind, temperature and humidity with the model. The locations and gridpoints for De Bilt, Cabauw, Schiphol and requested locations over sea and in the southeast of the Netherlands are marked. The gridpoint for location Schiphol is the nearest gridpoint available, 25 km northeast of the airport and 5 km further away from the westcoast.

From spatial climatology (appendix 9.2) the four gridpoint around Schiphol indicate small deviations from the absolute values at this gridpoint at 850 hPa, the lowest and most sensitive level for spatial difference of the requested parameters in this analysis. Seasonal average windspeed deviates at most 2% (between +0.2 and -0.4 knots or 0.1 to 0.2 m/s), seasonal average temperature at most 2% (between 0 and $+0.2^oC$) and seasonal average relative humidity at most 4% (between -0.8 and +2.2%).

These deviations indicate negligible deviation for the choice of the gridpoint from surrounding gridpoints for location Schiphol.

3.3 ERA-Interim quality aspects

Based on ECMWF evaluations and comparisons with other reanalyses, the quality of ERA-Interim products is generally good and its long-term homogeneity has improved considerably over that of ERA-40 ([Uppala, 2008]).

The ERA-Interim project has reached a major milestone after completing 20 years of reanalysis, from 1989 to 2008. The production so far has taken approximately 2.5 years, involved the use of more than 29^{109} meteorological observations, and generated 60 terabytes of reanalysis products.

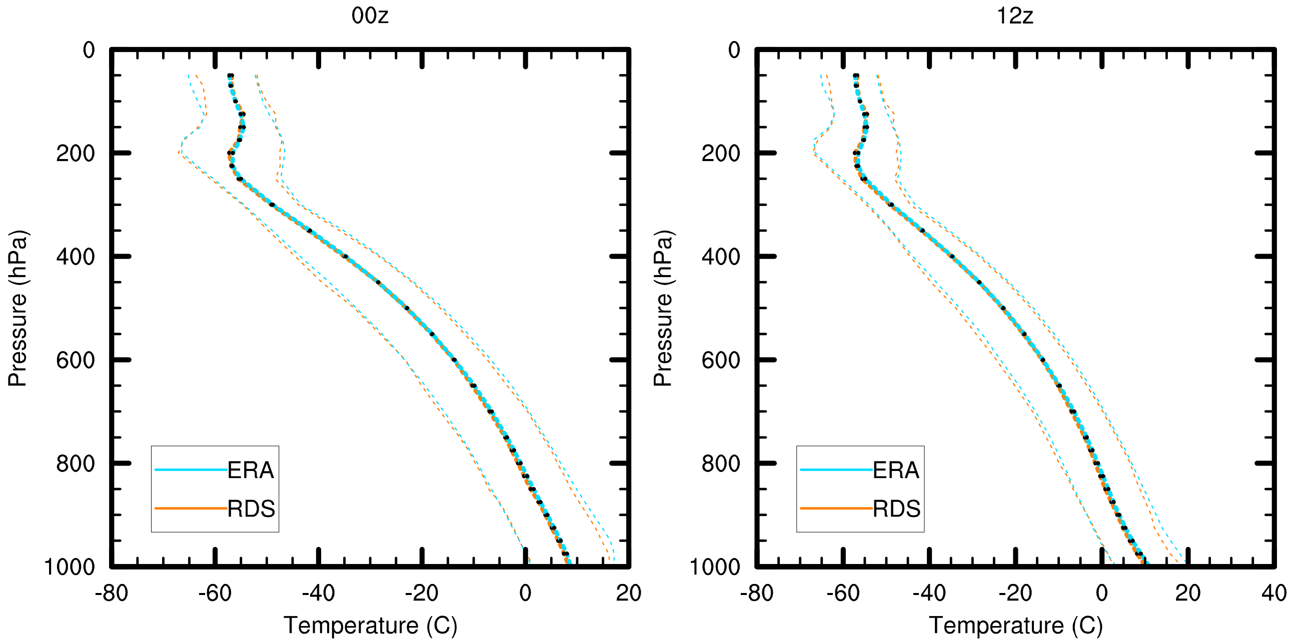
Most importantly, ERA-Interim represents the combined expertise and experience of a large number of present and past colleagues at ECMWF and elsewhere. The ERA-Interim reanalysis will be extended forward in time using the same version (Cy31r2) of the Integrated Forecast System (IFS) to maintain a consistent product quality ([Dee, 2009]).

Profile comparison

We checked the quality of ERA-Interim for the climatology of the upper air for the Netherlands by comparing ERA-Interim versus soundings for location Netherlands-central (De Bilt). Radiosonde sounding of De Bilt are part of the initialisation of the model. We compared average and 5 and 95 percentile (about 2 standard deviation) for the parameters windspeed and -direction, temperature and relative humidity for the period 1989-2008.

As stated before this report concentrates on climatology for the pressure levels 850 to 150 hPa.Climatology of the lower troposphere will be presented in part 2.

An example of profile comparison for temperature is given in figure 3. Seasons are indicated by the related months, Spring as MAM (March-April-May), etc.



Figures 3. Example of profile-comparison of the soundings (RDS) and ERA-Interim from location De Bilt with average, 5 and 95 percentile of the parameter temperature in spring (months MAM) 00 and 12 UTC.

Results for profile comparison

- Temperature differs on average less than 1^oC,
- Windspeed differs on average about 1 m/s,
- Winddirection shows less difference than 10 degrees,
- Relative humidity differs less than 10 percentage points up to 500 hPa, but shows increasing difference above 500 hPa up to tropopause level (low maximum absolute humidity values).

The increasing difference of relative humidity in the upper half of the troposphere is probably due to different definitions at low temperatures, but this question needs further research beyond this project (not relevant for LVNL-demands within this project).

In Appendix 9.1 the profiles are presented per season for winddirection, windspeed, temperature and relative humidity for the period 1989-2008 for 4 locations Nothsea-north (54.0N 07.0E), Northsea-west (52.5N 02.0E), Netherlands-central, Netherlands-southeast (51.0N 07.0E). For Netherlands-central the information from soundings of De Bilt is also shown for comparison.

Notice in appendix 9.1 in the profile of winddirection that in summer the impact of the radiative cycle in the stratosphere changes winddirection. The radiative cycle in the stratosphere means that during winter the mean flow is westerly and during summer it is easterly as the polar vortex winds changes sign, related to the sudden stratospheric warming.

Summary profile comparison

Profile comparison from sounding information for the requested parameters to information from the gridpoint for location De Bilt between 850 and 150 hPa shows excellent agreement, excluding information for relative humidity above 600 hPa.

Chapter 4

Upper air climatology

4.1 Wind at pressure levels

For the required locations wind roses have been calculated on four standard pressure levels, 850, 700, 500, 400, 300 and 200 hPa, for four locations per season, available in appendix 9.3. Alternatively, vertical profiles of wind (windspeed, direction and 5 and 95 percentiles) for four locations per season are presented in appendix 9.1, climatology of wind distribution in tabular form in appendix 9.4.

As an example figure 4 shows the wind rose on 850 hPa for location 54N07E, period 1989-2008.

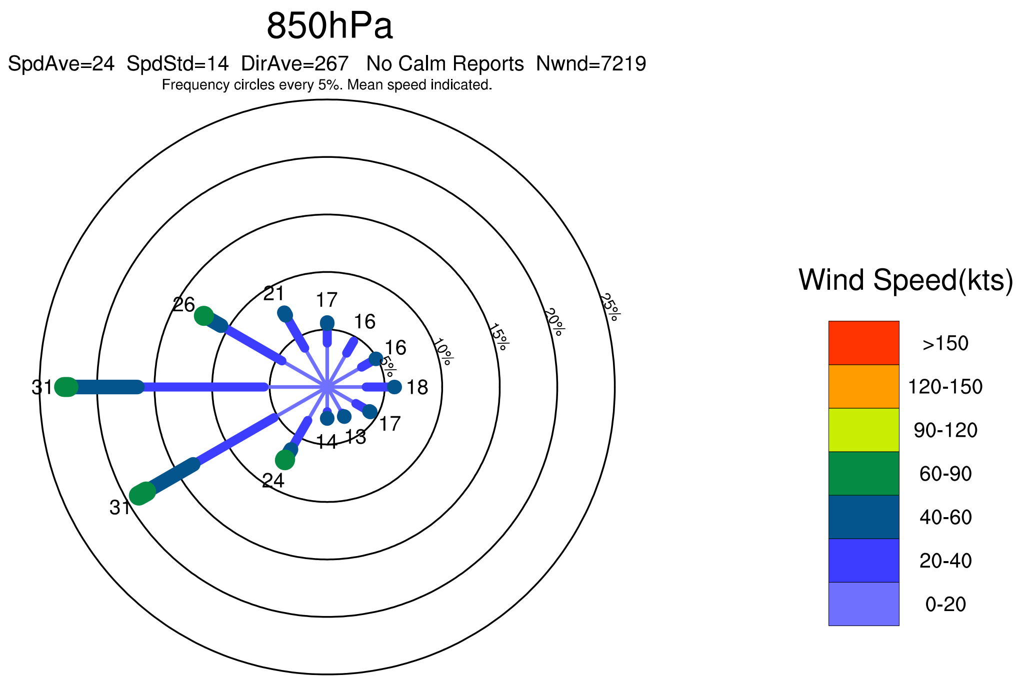


Figure 4. Example of a climatological wind rose.
Average windspeed is 24 knots, standard deviation 14 knots, average direction is 267 degrees, no calm reports and 7219 reports are used. Coloured bars indicate the windspeed distribution per 30-degree-sector from less than 20 to more than 150 knots, as shown in the right legend.

Climatology of winddirection shows that the predominant winddirection for the Netherlands is southwest to west, veering (clockwise turning) about 30-40 degrees and increasing speed with increasing height.

Thermal wind

Veering wind with increasing height indicates dominant advection of warm air from thermal wind theory.

The thermal wind is the difference vector of the geostrophic winds at two levels, representing the orientation and strength of the density (temperature) distribution in that layer (figure 5).

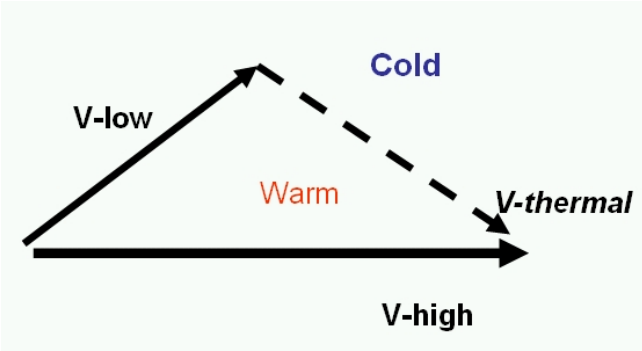


Figure 5. The thermal wind is the difference vector of the geostrophic winds in a layer of air, representing the temperature distribution (thickness) in that layer. In warm advection the geostrophic wind veers with height in the Northern Hemisphere.

If, like in the illustration, warm air is advected, the geostrophic wind will veere and increase with height (winddirection rotates clockwise, northern hemisphere) [Holton, 2004].

If cold air advection is occurring, the geostrophic wind rotates counterclockwise (for the northern hemisphere) with height.

In practise, we may observe this situation when a warm front is approaching: the lower stratocumulus clouds can move to northeasterly directions whilst the high cirrus-clouds move faster southeasterly, so wind is veering and increasing with height, indicating warm air advection with the approaching warm front.

4.2 Temperature and humidity profile

In appendix 9.1 the profiles for location De Bilt (example in figure 6) show on average a decrease in temperature (average, 5 and 95 percentile) with height to tropopause in summer from +17^oC (+/- 7) near surface to -55^oC (+/- 9) near 200 hPa. In winter the decrease is from +4 (+/- 6) near surface to -61 (+/- 10) near 200 hPa.

In summer relative humidity in Netherlands-central is on average near surface about 75% at midnight with a variation in daytime of about 10%. In the vertical relative humidity decreases with increasing height to about 45% near 600 hPa. Near tropopause relative humidity is (in all seasons) on average close to 65%. In wintertime near surface average relative humidity is about 84%, diurnal variation is small.

The 95-percentile of the distribution of relative humidity is close to 100 %, the 5 percentile about 30% lower than the average value, indicating strong variations in relative humidity during a season in the Netherlands.

As stated in section 3.3 the deviation of relative humidity above 600 hPa requires further research beyond this report.

Profiles per season for all four locations are presented in appendix 9.1. Seasons are indicated by the related months, Spring as MAM (March-April-May), etc.

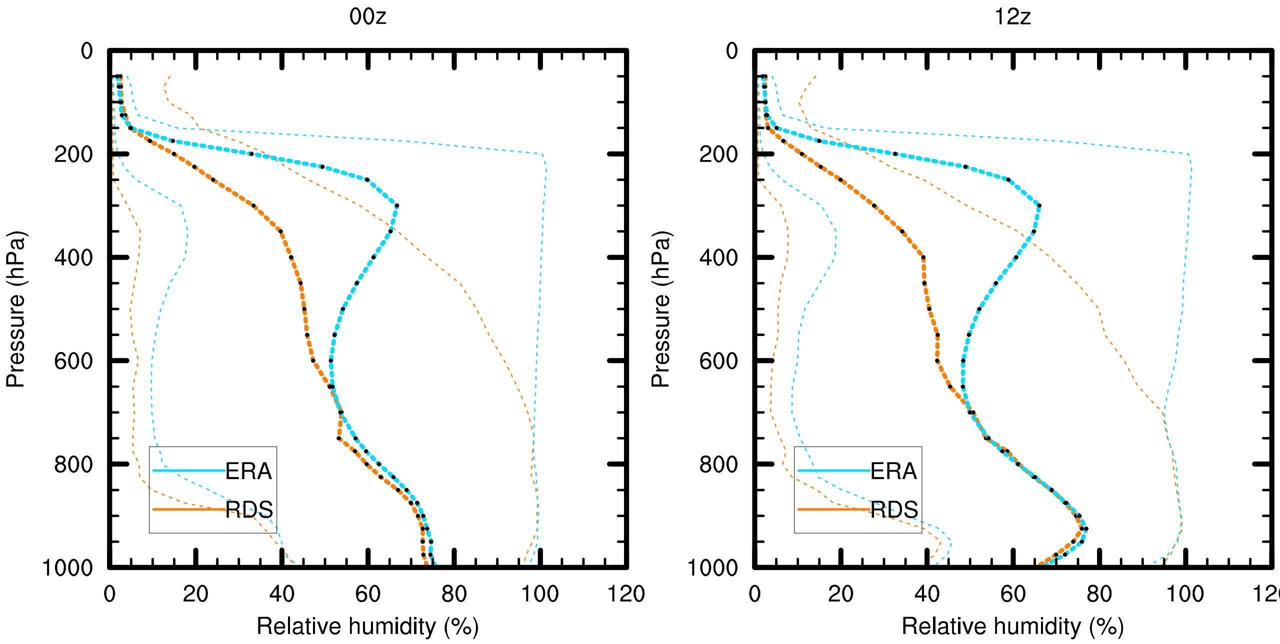


Figure 6. Example of profile-comparison of the soundings (RDS) and ERA-Interim from location De Bilt.
Average, 5 and 95 percentile of the parameter relative humidity in spring (months MAM) 00 and 12 UTC

4.3 Spatial climatology Amsterdam FIR

For standard flight levels charts with upper air climatology have been produced, plotted in the configuration as used by aviation in flight documentation, for the pressure levels 850, 700, 500, 400, 300 and 200 hPa. In appendix 9.2 these charts are presented for these levels per season. In figure 7 an example of one gridpoint information is shown.

Note that vectorial average windspeed is lower than absolute average windspeed, as the average vectorial wind is composed from the average of the u-component (X-axis) and v-component (Y-axis) of individual windvectors. As components can be positive or negative, the average vectorial windspeed will be lower than the average absolute windspeed (which is always positive).

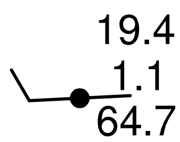


Figure 7. Gridpoint information in spatial climatology. For this gridpoint average vector winddirection is about 260 degrees and vector windspeed around 10 knots (10 knots=5.1 m/s), average (absolute) windspeed 19.4 knots, average temperature +1.1^oC and average humidity 64.7%.

Results for spatial climatology on standard levels

The spatial difference at all presented standard levels shows a north/northwest - south/southeast gradient of wind, temperature and humidity.

Vectorial average winddirection is hardly changing in the spatial area of Amsterdam FIR, windspeed is higher in northwest than in the southeast.

The temperature distribution indicates, as expected, that temperature is lower in northwestern than in southeastern part of the area (except for winter at 850 hPa due to colder lower planetary boundary layer in that season).

Relative humidity below 600 hPa is also lower in northwest, as expected from the general distributions of air masses around the Netherlands. Relative humidity above 600 hPa needs further research beyond this project.

Chapter 5

Temperature profile deviation from ICAO-standard atmosphere.

5.1 International Standard Atmosphere

The International Standard Atmosphere (ISA) is defined by an atmospheric model of average vertical distribution of pressure, temperature and density of the Earth's atmosphere over a wide range of altitudes. It consists of tables of values at various altitudes, plus some formula's by which those values were derived.

The International Organisation for Standardisation (ISO), publishes the ISA as an international standard, ISO 2533:1975. Other standards organisations, such as the International Civil Aviation Organisation (ICAO) and the United States Government, publish extensions or subsets of the same atmospheric model under their own standards-making authority.

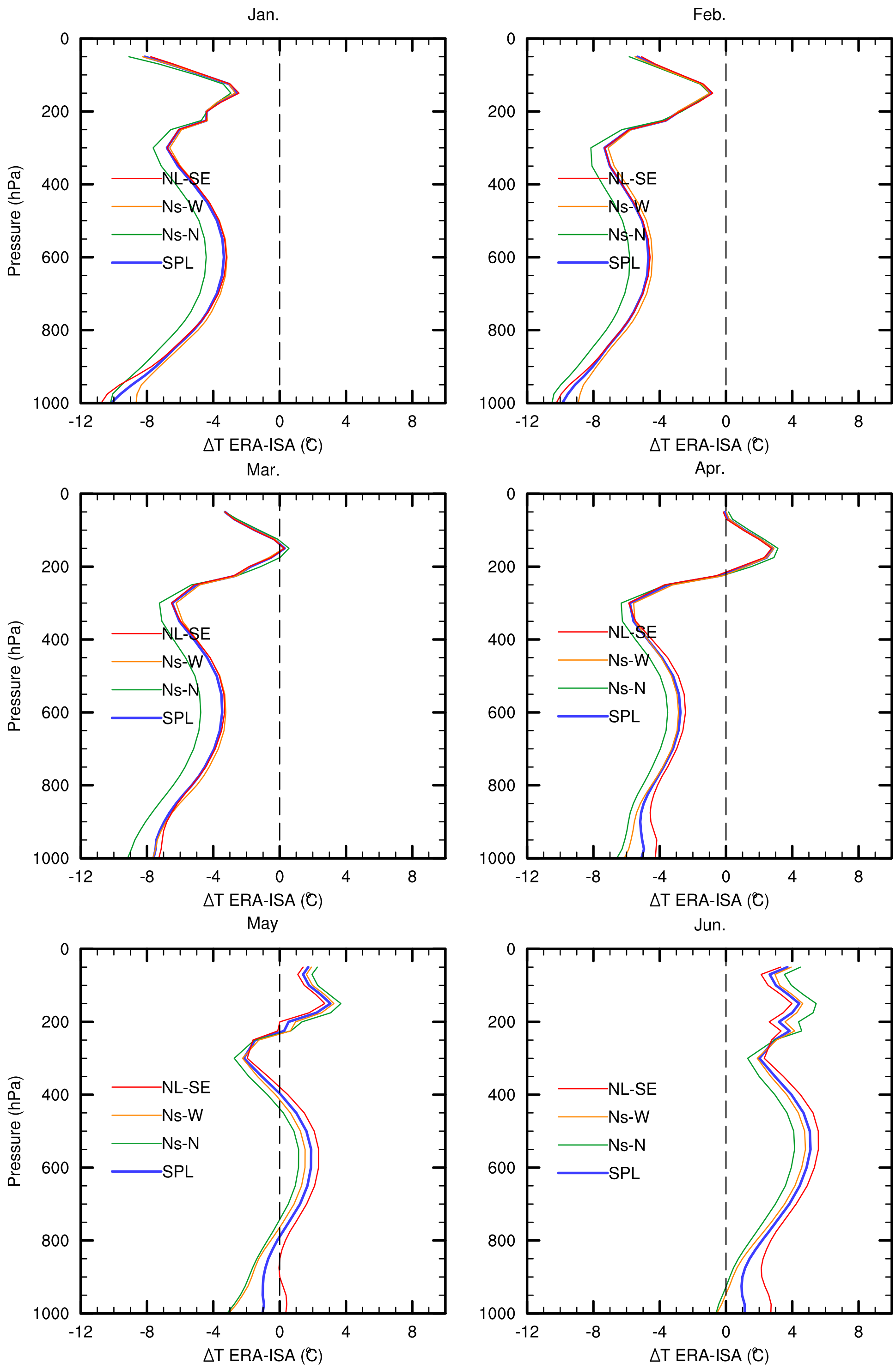
The ISA model divides the atmosphere into layers with linear temperature distributions. At sea level the standard gives a pressure of 1013.25 hPa (1 atm) and a temperature of 15^oC, and an initial lapse rate of -6.5^oC/km. The tabulation continues to the tropopause at 11 km where the pressure has fallen to 225 hPa (Flight Level 360) and the temperature to -56.5^oC. Between 11 km and 20 km the temperature remains constant.

The International Civil Aviation Organisation (ICAO) published their "ICAO Standard Atmosphere" as Doc 7488-CD in 1993. It has the same model as the ISA, but extends the altitude coverage to 80 kilometres (262,500 feet) [ICAO, 1975].

Many aviation standards and flying rules are based on the ICAO Standard Atmosphere, altimetry being a major one. The standard is very useful in meteorology for comparing actual values like the climatology of the upper air and deviation of climatology from ICAO standard atmosphere is requested by Air Traffic Control the Netherlands (LVNL).

5.2 Temperature deviation from ICAO Standard Atmosphere

The deviation of the seasonal average temperature profile from the ICAO Standard Atmosphere for the period 1989-2008 for 4 locations per month in the Amsterdam Flight Information Region (Northsea-north (54.0N 07.0E), Northsea-west (52.5N 02.0E), Netherlands-central and Netherlands-southeast (51.0N 07.0E)) is shown in figure 8, presenting the seasonal cycle and spatial dfferences is temperature deviation profiles from ICAO-standard atmosphere.



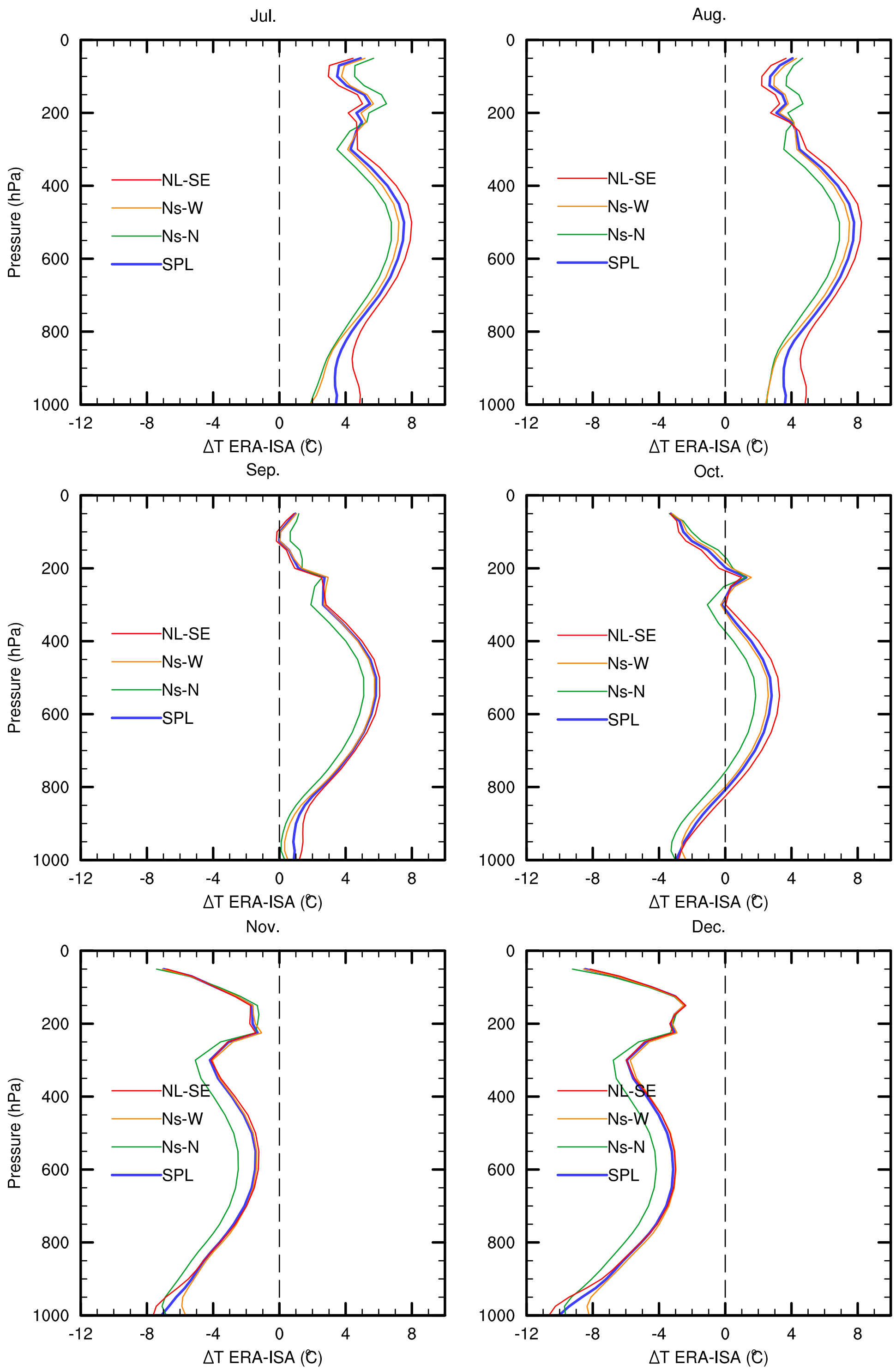


Figure 8. Deviation of temperature per month from ICAO Standard Atmosphere for requested locations.

The seasonal cycle and regional differences in the temperature difference profiles

Results for the deviation from ICAO standard atmosphere

Surface observations (1971-2000, not shown) from location Schiphol present an average year temperature of 9.8^oC (deviation from standard atmosphere -5.2^oC) and average surface level pressure 1015.3 hPa (deviation from standard atmosphere + 2.05 hPa).

The seasonal average temperature from surface observations show a deviation of -11.5^oC in winter, -6.2^oC in spring, +1.4^oC in summer and -4.5^oC in autumn.

ERA-Interim climatology 1989-2008 shows for the temperature profile of Schiphol near surface seasonal deviation from ICAO-standard atmosphere between -10.2^oC in January to +3.7^oC in August. The vertical profile of temperature shows a yearly cycle, varying from below ICAO-standardatmosphere (ISA) in winter to above ISA in summer. The deviation for several locations below 2 km deviates between land and sea locations, to be analysed in part 2. More details for the lower troposphere will be reported in part 2, the climatology below 850 hPa.

Halfway troposphere, at 600 to 500 hPa, the seasonal deviation of temperature in ERA-Interim from standard varies for Schiphol between +7.6^oC in August and -4.7^oC in winter. At the presssure level of the tropopauze, (between 249 hPa in spring and 218 hPa in autumn, in ISA standard tropopauze pressure level is 225 hPa or flightlevel FL360), temperature varies between -53.9 in mid-summer and -63.1^oC in mid-winter, in ISA the standard temperature at tropopauze is -56.5^oC .

The spatial pattern between sea and land as well as between north and south is also observed in the deviation from ICAO-standard atmosphere for the requested four locations.

Chapter 6

Climatology of tropopause

Tropopause temperature and pressure level is computed from observations and model by using the WMO-definition ([WMO, 1957]): The first tropopause (i.e. the conventional tropopause) is defined as the lowest level at which the lapse rate decreases to 2 K/km or less, and the average lapse rate from this level to any level within the next higher 2 km does not exceed 2 K/km.

The tropopause (pressure and temperature) from observations (radiosonde soundings of De Bilt) and ERA-Interim is extracted for the period 1994-2008 at 00 en 12 UTC, excluding extreme values in pressure above 350 hPa (below FL 270) and temperature (warmer than -42^oC or 14.5 degrees warmer than ICAO standard tropopause temperature). The period is chosen on data-availability of radiosonde soundings.

In figure 9 temperature and the tropopause pressure level (and their standard deviation) and average values are presented.

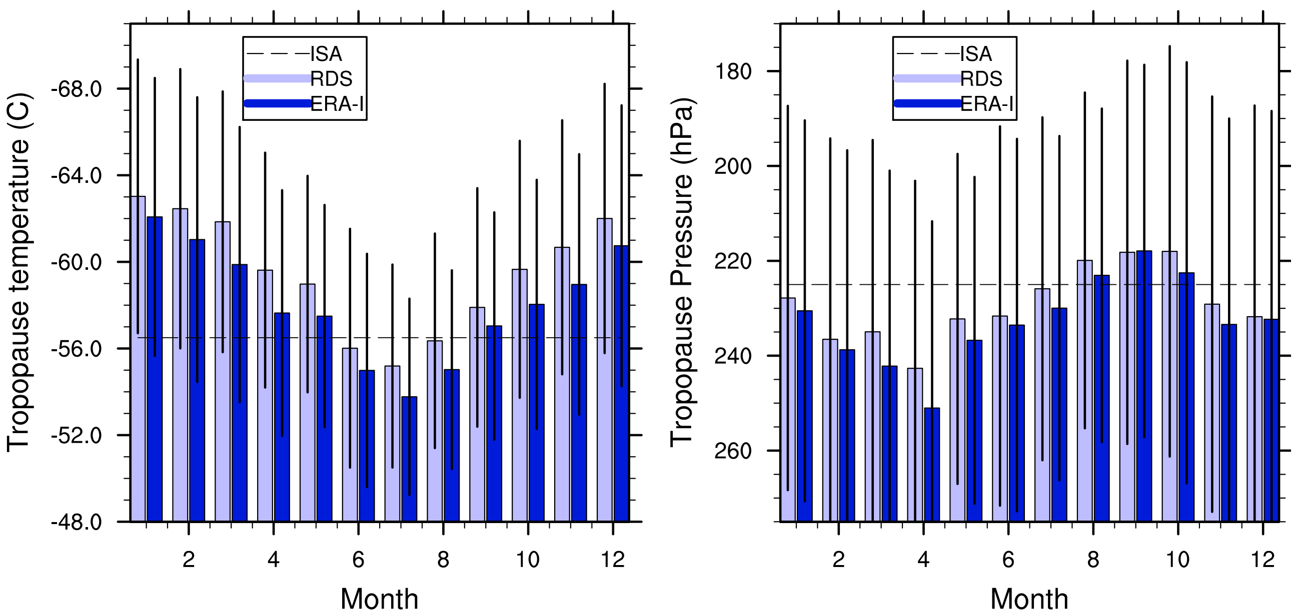


Figure 9. Climatology of average tropopause temperature (left) and pressure level (right) per month with standard deviation from De Bilt (left bar) and ERA-Interim (right bar). ICAO standard atmosphere values are presented in the horizontal broken lines.

Results for climatology of tropopause

Pressure:

The ERA-Interim reanalysis monthly average pressure level values of the tropopause are 0 to 8 hPa lower than the radiosonde values, most likely due to larger vertical resolution of the model.

The monthly average tropopause pressure level from both sources is close to 230 hPa, varying in the yearly cycle from 250 hPa in April to 215 hPa in September.

The standard deviation is between 34 and 45 hPa.

Deviation from ICAO standard atmosphere of the tropopause level thus varies trough the year from +25 (or about -2500 ft) in April to -10 hPa (or about +1000 ft) in September.

Temperature:

The ERA-Interim reanalysis monthly average temperature values of the tropopause are 1 to 2 degrees lower than the radiosonde values, most likely due to larger vertical resolution of the model.

The monthly average tropopause temperature from both sources is close to -58^oC , varying in ERA-I in the yearly cycle from -62^oC in January to -54^oC in July.

The standard deviation is between 4 and 6 degrees.

The yearly average values for tropopause temperature values indicate year-to-year variations around 2 degrees in ERA-Interim as well as in radiosonde observations.

Chapter 7

Upper Air Trends

For indications of future changes (next twenty years) in upper air parameters wind, temperature and relative humidity a separate report will be produced, based on trend analysis of ERA-data and observations and consistent with research for KNMI'06 scenarios.

For illustration purposes trend analysis in tropopause will be presented in this report. Detailed analysis of trend in tropopause height and temperature requires further research beyond this report.

7.1 Trend in tropopause from ERA-Interim and soundings De Bilt

In the previous chapter the pressure level and temperature of the first tropopause with standard deviation were presented. We found in the past recent period an average tropopause pressure level is close to 230 hPa, varying between about 250 and 215 hPa and for temperature an average of -58^oC, varying between -62^oC and -54^oC.

In figure 10 tropopause pressure level and tropopause temperature are presented per year.

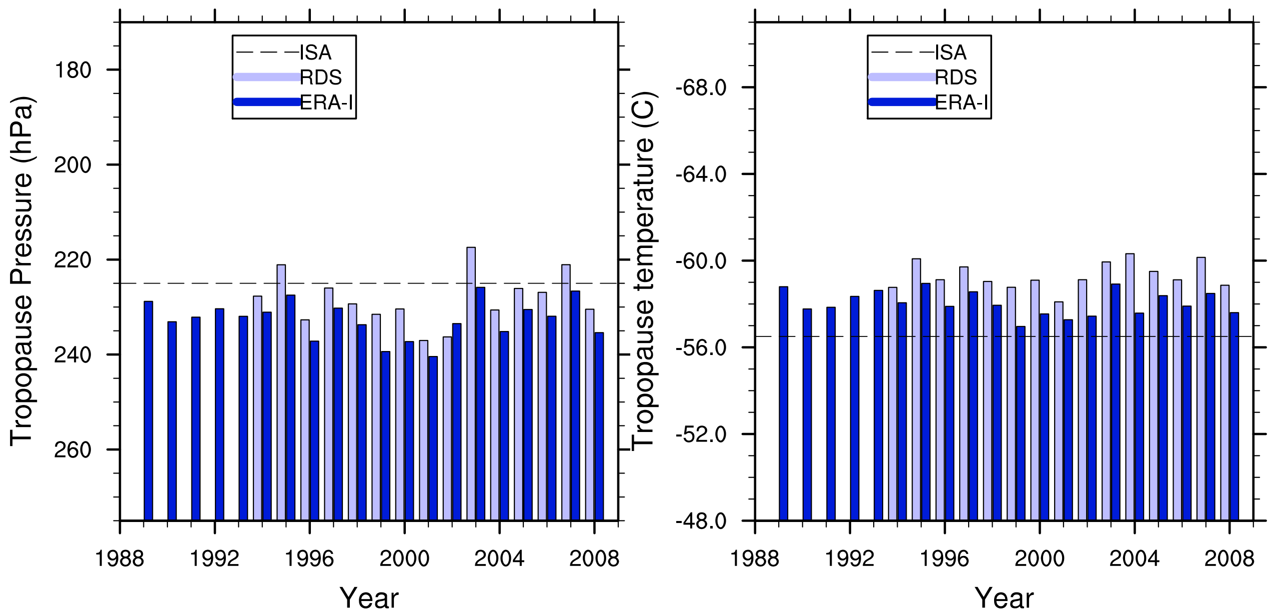


*Figure 10. Average and standard deviation of tropopause pressure level (left) and temperature (right)
per year in De Bilt 1994-2008 and ERA-Interim 1989-2008 for Netherlands-central.*

Tropopause pressure level varies trough the years in ERA and RDS between about 215 and 240 hPa, a significant trend can not be observed by visual inspection. Tropopause temperature varies trough the years in ERA and RDS between approximately -61 and -57^{o}C, a significant trend can not be observed.

By visual inspection we do not observe a significant trend in tropopause pressure level and temperature over the recent period of 15 to 20 years for Netherlands-central in observations or reanalysis.

7.2 Trend in tropopause in southern Germany

Some tropopause analysis are found in literature. Birner et al analysed ten years of high-resolution radiosonde data with fifteen years of ECMWF reanalysis (ERA) data to explore the tropopause region above two midlatitude stations (Munich and Stuttgart) in Southern Germany. They presented time-averaged vertical profiles of several meteorological parameters relative to the tropopause.

Birner et al finds an average height of the thermal tropopause for Munich between 10.9 km (almost FL 360) in winter to 11.7 km (between FL 380 and FL 390) in summer, average through the year 11.1 km (just above FL 360). Figure 11 shows mean atmospheric profiles and corresponding relative standard deviations of the radiosonde and ERA data for Munchen. Stuttgart does not differ significantly from Munchen. The ERA data underestimate the strength of the tropopause-inversion by a factor of 2. This is certainly an effect of the much coarser vertical resolution.

The small (<1 K) differences of temperature between reanalysis ERA and radiosonde data RDS might result from the different and longer time period of the ERA data. Moreover, the standard deviation of the ERA-profile is somewhat larger in the troposphere. The vertical gradients from the ERA data of temperature in the tropopause-region differs remarkably from those of the radiosonde sounding data. These differences certainly result from the much higher (factor 20) vertical resolution of the sounding profiles [Birner, 2002].

The southern latitude with a warmer troposphere for Munich could explain the increase in tropopause level compared to Netherlands-central.

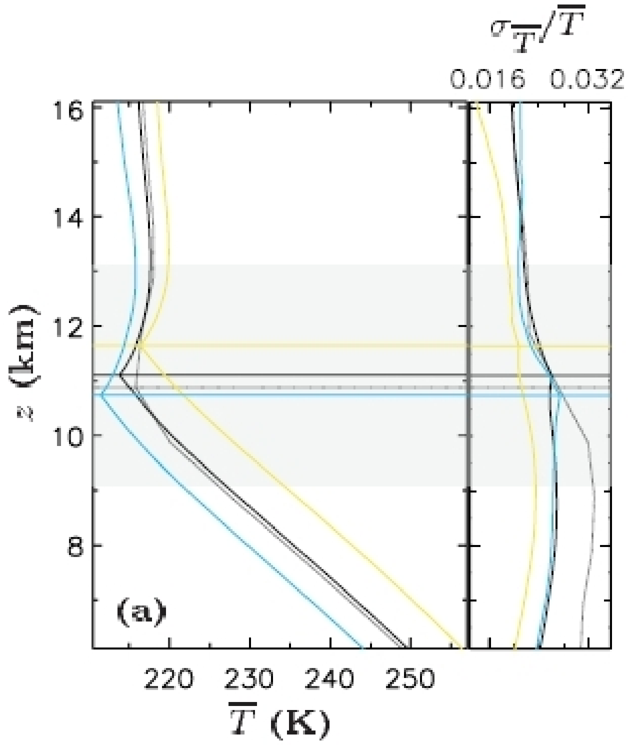


Figure 11. Mean profile and corresponding relative standard deviations of temperature for Munich. Orange, blue, and black full lines represent averages for JJA, DJF, and all, respectively. Dotted lines denote mean ERA-profiles. Profiles are time-averaged (denoted by the overbar) relative to the respective tropopause height (horizontal lines), the gray shading indicates the tropopause-region.

We compared the strength of the tropopauze inversion from model and observations and observe an understimation of tropopauze strength in ERA-Interim of at most 1.2. This difference is mainly caused by a warmer tropopauze in the reanalysis, but much less than in ERA-40 (factor 2, [Birner, 2002]). The tropopauze temperatures in ERA-Interim are still 1-2 degrees warmer than in obervations (as illustrated in figure 3, profile comparison of temperature, and figure 10, tropopauze temperature).

7.3 Trends in jetstream from ERA-40 and NCEP/NCAR

Archer and Caldera analysed historical trends of jet stream properties based on the ERA-40 and the NCEP/NCAR reanalysis data sets for the period 1979 to 2001. They defined jet stream properties based on mass and mass-flux weighted averages and found that, in general, the jet streams have risen in altitude and moved poleward in both hemispheres. In the northern hemisphere, the jet stream weakened. In the southern hemisphere, the sub-tropical jet weakened, whereas the polar jet strengthened. Exceptions to this general behaviour were found locally and seasonally.

The northern hemisphere jet forms a nearly continuous band between northern Africa and Hawaii in winter (DJF) as a combination of the subtropical jet and the jet belonging to the polar font. This jet shifts northward, fragments, and weakens in summer (JJA) (figure 12). The pressure trends of the jetstreams (not shown) are overall negative on average, to indicate that they are rising in altitude, for the Northern Hemisphere about 0.165 hPa/decade (about 4 meters/decade). The jets have risen more in the summer than in the winter ([Archer and Caldere, 2008]). For the Netherlands the annual trend and winter trend for the polar jetstream seems positive and small (< 0,5 m/s/decade), the summer trend for jetstream windspeed is larger, 0.5-1.0 m/s/decade for the period 1979-2001, using ERA-40 reanalyses.

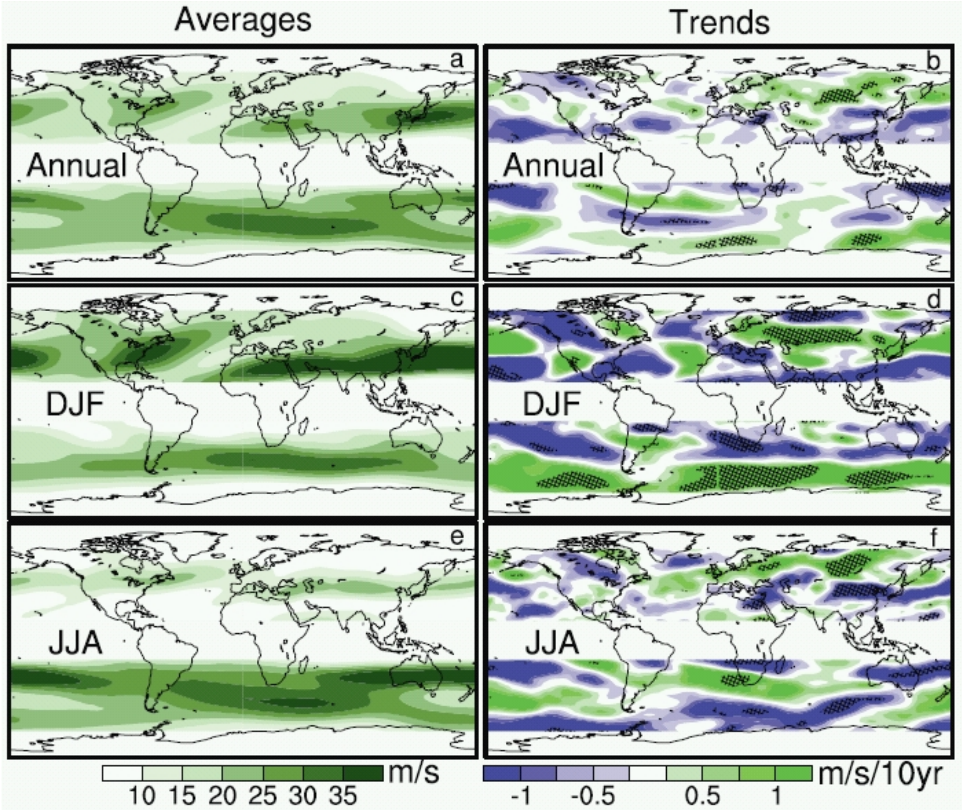


Figure 12. Jet stream wind speed from the ERA-40 reanalyses in 1979–2001: (a, c, e) annual, winter (DJF), and summer (JJA) averages (m/s); (b, d, f) linear regression trends (m/s/decade), hatched where statistically significant (P-value <0.15), taking auto-correlation into account.

7.4 Trends in jetstream and tropopause from GPS radio occultation

Schmidt et al analysed six years of GPS radio occultation data (May 2001- December 2007) and found a global increase of the tropopause height between 26–44 m during the observation period (4–7 m/yr) depending on the binning method (5 or 10 latitude bands) and the used tropopause detection algorithm. The corresponding trend errors (2 standard deviation) vary between 19–21 m. Global tropopause height variations are positively correlated with upper tropospheric (500–100 hPa) temperature variations ([Schmidt etal, 2008]). For our latitude (50-55N) the trend is smaller than the global trend, about 20 m (3 m/yr).

7.5 Trends in tropopause from soundings

Seidal and Randel performed an analysis of variability and trends in the global tropopause from radiosonde data on synoptic, monthly, seasonal, and multidecadal timescales using 1980–2004 radiosonde data. On synoptic and monthly timescales, tropopause height variations are positively correlated with tropospheric temperature variations and stronger in the extratropics and for the upper troposphere (500–300 hPa) than for tropics and lower troposphere. Tropopause height trends over 1980–2004 are upward at almost all of the (predominantly extratropical) stations analysed, yielding an estimated global trend of 64 ($\pm$ 21 at 2 standard deviation) m/decade, a corresponding tropopause pressure trend of 1.7 $\pm$ 0.6 hPa/decade, and tropopause temperature decrease of 0.41 $\pm$

0.09 K/decade [Seidel and Randal, 2006]. For our latitude (50-55N) we estimated from this analysis a trend close to the global averages.

Chapter 8

Uncertainty

8.1 ERA-Interim

ECMWF is currently producing ERA-Interim, a global atmospheric reanalysis of the data-rich period since 1989. Relative to the ERA-40 system, ERA-Interim incorporates many important model improvements such as increased resolution and physics changes, the use of four-dimensional variational (4D-Var) data assimilation, and various other changes in the analysis methodology. The configuration of the ERA-Interim system and many aspects of its performance are described in ECMWF Newsletters 110 and 115.

From the oceanic point of view the main differences to ERA-40 are in the fresh water flux and in the solar radiation. Largest differences occur over the convective areas, where more solar radiation reaches the surface, and over the stratocumulus regions, where the surface solar radiation is less in ERA-Interim.

There are also differences in the surface winds, which are generally stronger in ERA-Interim as a consequence of the increased horizontal resolution. Two ocean models have been used to evaluate the quality of ERA-Interim forcing fluxes, using ERA-40 forcing fluxes as a baseline. Such exercises are fraught with danger, because model and forcing error cannot be separated and there is always a distinct possibility of compensating error. Nevertheless, both models indicate a reduction of the mean SST error, especially over the warm pool area, which is likely a consequence of the improved solar radiation in ERA-Interim.

Both models indicate that the inter annual variability of the ERA-Interim winds is better than ERA-40 (which was already a big improvement over other wind products). Seasonal forecast experiments exhibit better skill scores when initialised with ERA-Interim fluxes versus those initialised with ERA-40. Reanalysis has proved to be as valuable for monitoring climate, climate research and applications as was believed when it was proposed twenty years ago. However, as the scope of global reanalysis grows, the research effort needed to optimise the benefits is so large that international cooperation will be essential [Trenberth, 2009].

Our comparison of radio sonde souding observations and ERA-Interim gridpoint data indicates little uncertainty regarding the quality aspects of the reanalysis for the production of upper air climatology for Amsterdam FIR for the parameters wind, temperature and relative humidity, keeping the mentioned differences in mind.

8.2 Observations

The observational network in the Netherlands (surface and upper air) meet international standards of the World Meteorological Organisation WMO, the demands are nationally stated in the handbook on observations (Dutch only) [Handboek Waarnemingen, 2000].

Climatology for the upper air from ERA-Interim has limited checkpoints regarding observations, for the Flight Information Region above the planetary boundary layer the soundings of De Bilt are available, these data indicate positive results in the comparison for most parameters requested by LVNL. Increasing deviation with height above 600 hPa is accepted as non-significant by LVNL, regarding this topic more research is needed beyond this project.

For the boundary layer Cabauw data (up to 200 meters) are very useful for comparison, indicating more uncertainty on climatology of the boundary layer with increasing distance and changing environment from Cabauw and demand of increasing details; this uncertainty is studied in part 2.

Chapter 9

Appendices

9.1 ERA-interim climatology 1989-2008

Vertical profiles of windspeed, winddirection, temperature and relative humidity per season for Northsea-north (54.0N 07.0E), Northsea-west (52.5N 02.0E), Netherlands-central, Netherlands-southeast (51.0N 07.0E). Seasons are indicated by the related months, Spring as MAM (March-April-May), etc.

Summary of results

Results for profile comparison (chapter 3)

- *Temperature differs on average less than 1^oC,*
- *Windspeed differs on average about 1 m/s.*
- *Winddirection shows less difference than 10 degrees,*
- *Relative humidity differs less than 10 percentage points up to 500 hPa, but shows increasing difference above 500 hPa up to tropopause level (low maximum absolute humidity values).*

Explanation of the increasing difference of relative humidity in the upper half of the troposphere is not relevant for LVNL-demands within this project.

Results for spatial climatology on standard levels (chapter 4)

The spatial difference at all presented standard levels shows a north/northwest - south/southeast gradient of wind, temperature and humidity.

Vectorial average winddirection is hardly changing in the spatial area of Amsterdam FIR, windspeed is higher in northwest than in the southeast.

The temperature distribution indicates, as expected, that temperature is lower in northwestern than in southeastern part of the area (except for winter at 850 hPa due to colder lower planetary boundary layer in that season).

Relative humidity below 600 hPa is also lower in northwest, as expected from the general distributions of air masses around the Netherlands. Relative humidity above 600 hPa needs further research beyond this project.

Results for the deviation from ICAO standard atmosphere (chapter 5)

Surface observations (1971-2000, not shown) from location Schiphol present an average year temperature of 9.8^oC (deviation from standard atmosphere -5.2^oC) and average surface level pressure 1015.3 hPa (deviation from standard atmosphere + 2.05 hPa).

The seasonal average temperature from surface observations show a deviation of -11.5^oC in winter, -6.2^oC in spring, +1.4^oC in summer and -4.5^oC in autumn.

ERA-Interim climatology 1989-2008 shows for the temperature profile of Schiphol near surface seasonal deviation from ICAO-standard atmosphere between -10.2^oC in January to +3.7^oC in August. More details for the lower troposphere will be reported in part 2, the climatology below 850 hPa.

Halfway troposphere, at 600 to 500 hPa, the seasonal deviation of temperature in ERA-Interim from standard varies for Schiphol between +7.6^oC in August and -4.7^oC in winter.

The spatial pattern between sea and land as well as between north and south is also observed in the deviation from ICAO-standard atmosphere for the requested four locations.

Result for climatology of tropopause (chapter 6)

Pressure:

The monthly average tropopause pressure level from both sources is close to 230 hPa, varying in the yearly cycle from 250 hPa in April to 215 hPa in September. The standard deviation is between 34 and 45 hPa.

Deviation from ICAO standard atmosphere of the tropopause level thus varies trough the year from +25 (or about -2500 ft) in April to -10 hPa (or about +1000 ft) in September.

The ERA-Interim reanalysis monthly average pressure level values of the tropopause are 0 to 8 hPa lower than the radiosonde values, most likely due to larger vertical resolution of the model.

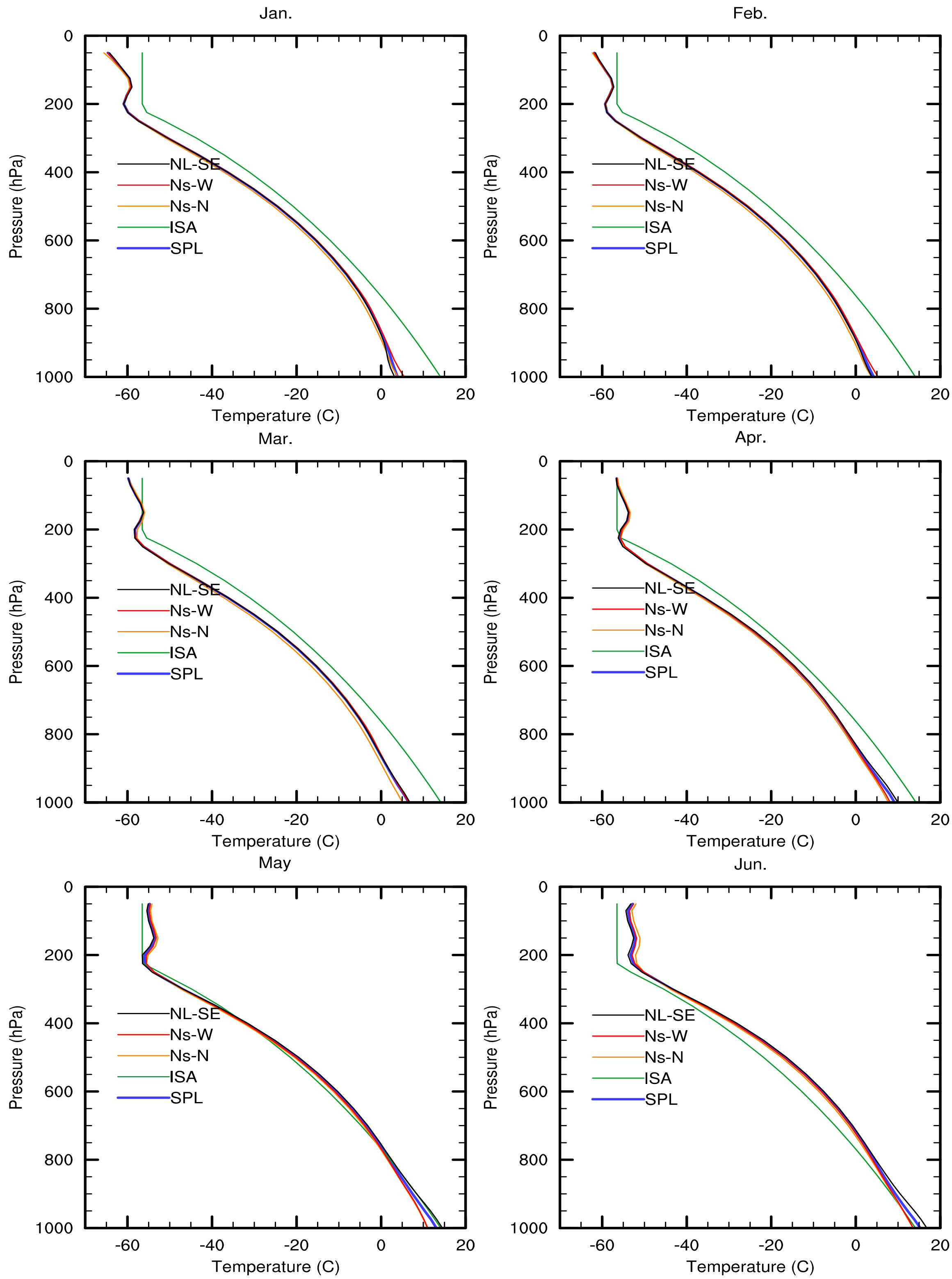
Temperature:

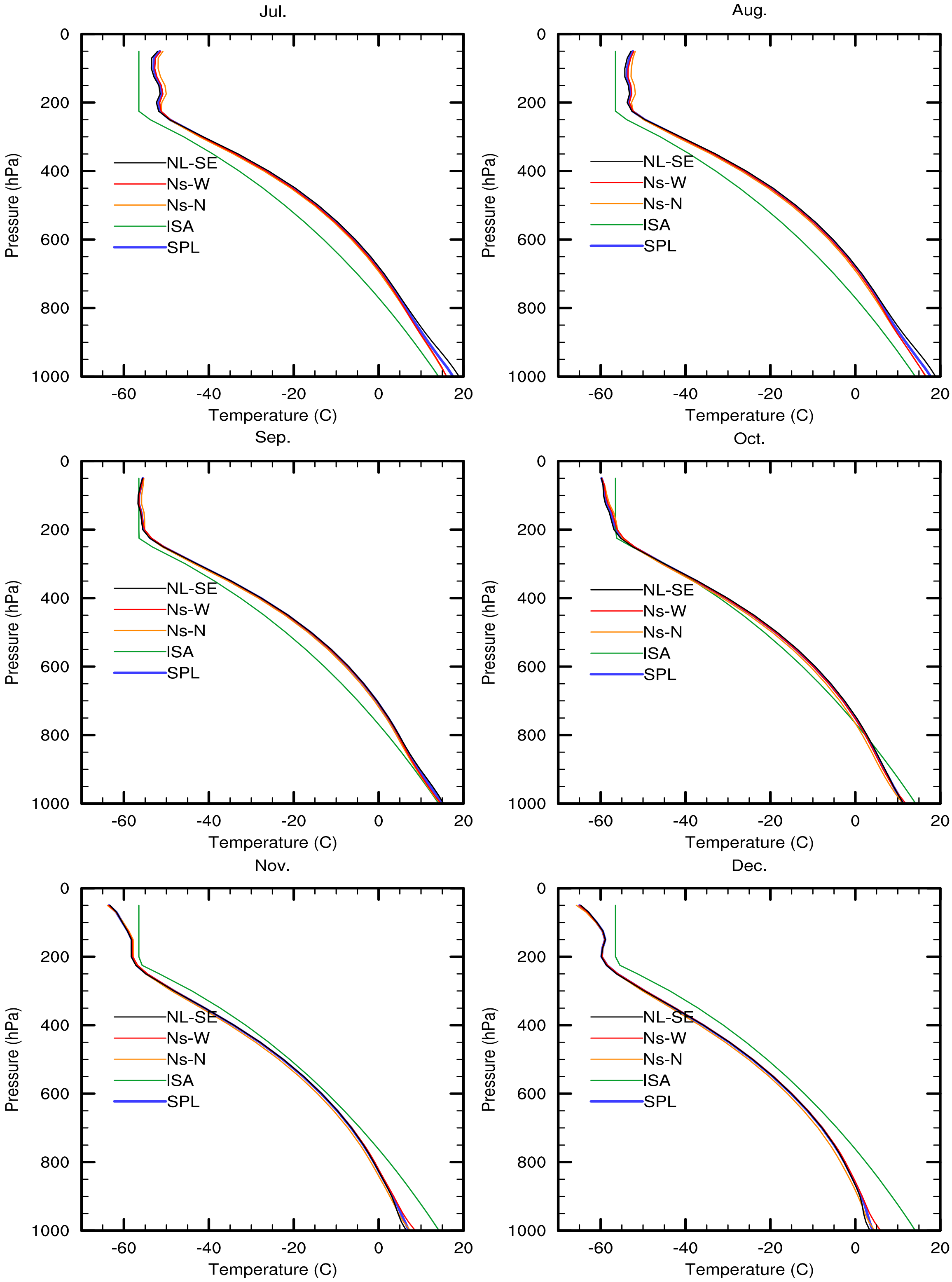
The vertical profile of temperature shows a yearly cycle, varying from below ICAO-standardatmosphere (ISA) in winter to above ISA in summer. The deviation for several locations below 2 km deviates between land and sea locations, to be analysed in part 2.

The monthly average tropopause temperature from both sources is close to -58^oC , varying in ERA-I in the yearly cycle from about -63^oC in January to -53^oC in July. The standard deviation is between 4 and 6 degrees.

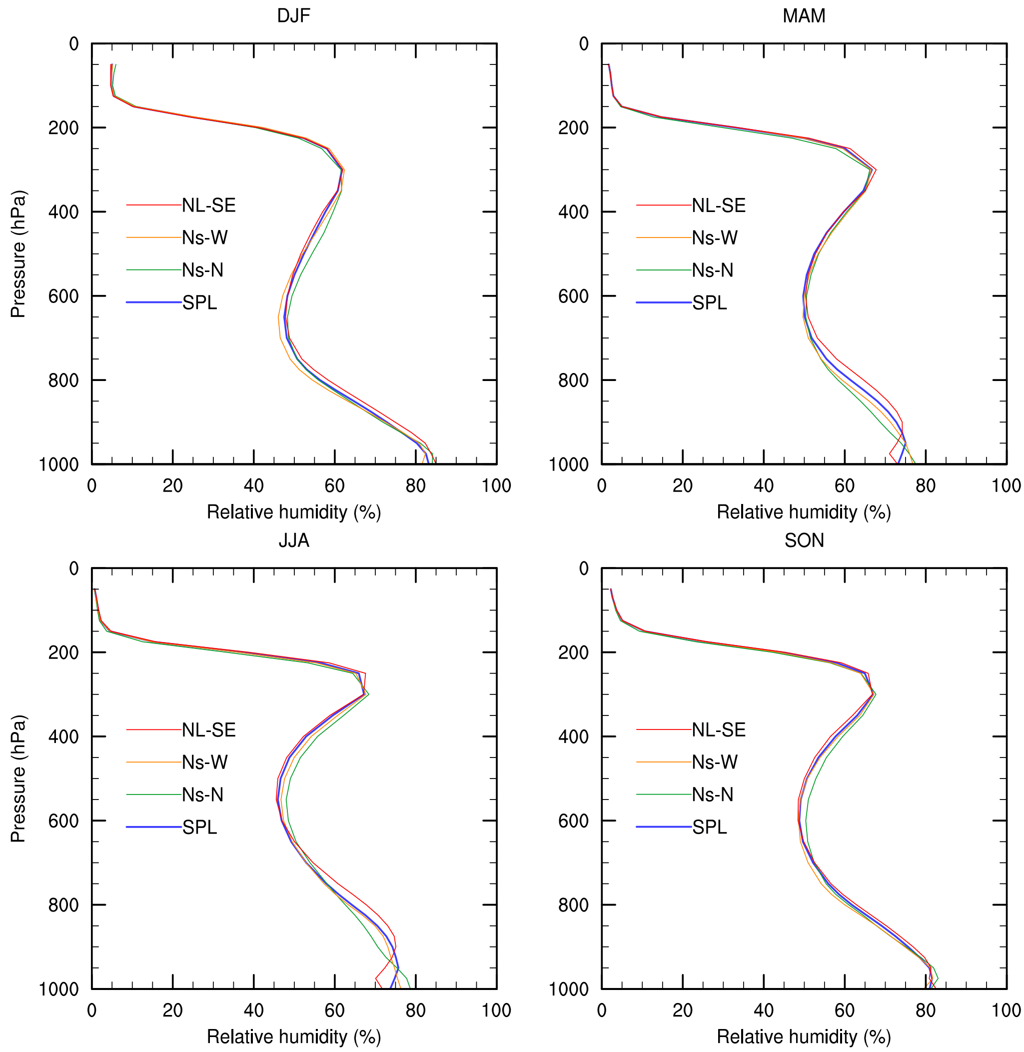
The ERA-Interim reanalysis monthly average temperature values of the tropopause are 1 to 2 degrees lower than the radiosonde values, most likely due to larger vertical resolution of the model.

9.1.1 Vertical profile climatology for temperature for four requested locations (Northsea-north (54.0N 07.0E), Northsea-west (52.5N 02.0E), Netherlands-central (de Bilt) and Netherlands-southeast (51.0N 07.0E), period January-June and period July-December.

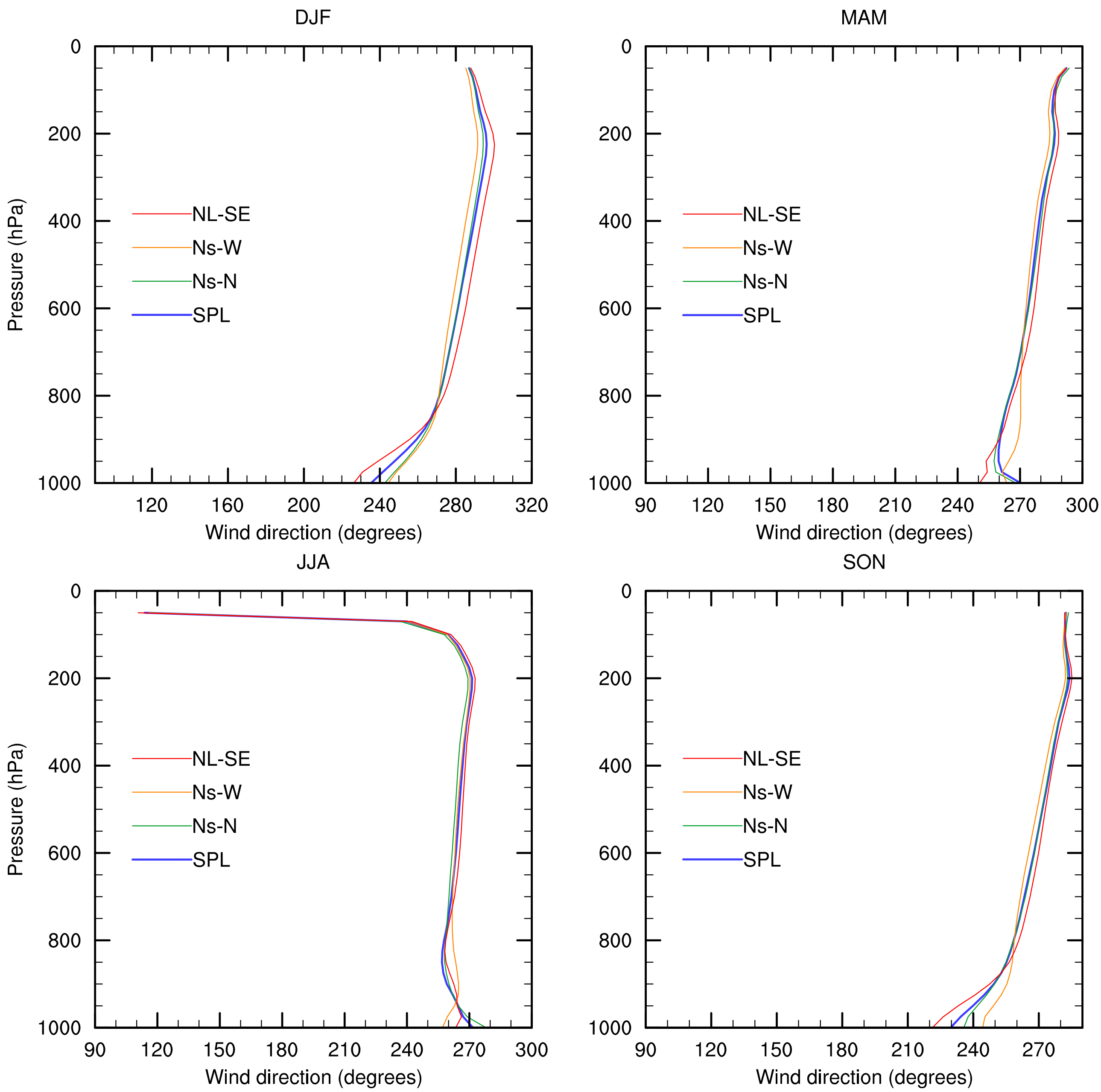



Jul.
Aug.
Sep.
Oct.
Nov.
Dec.
Pressure (hPa)
Temperature (C)
0
200
400
600
800
1000
-60
-40
-20
0
20
NL-SE
Ns-W
Ns-N
ISA
SPL

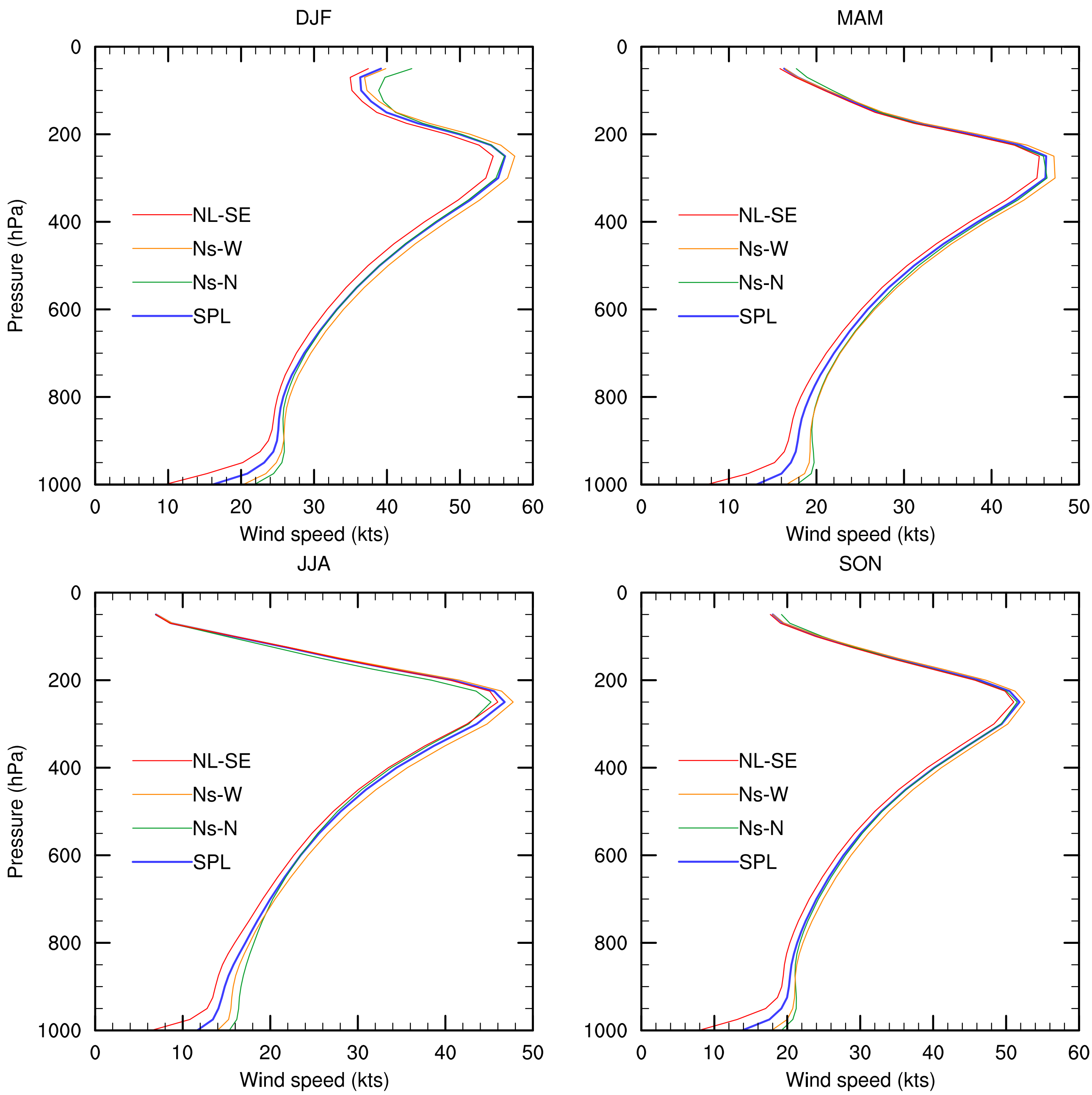
9.1.2 Vertical profile climatology for relative humidity for four requested locations (Northsea-north (54.0N 07.0E), Northsea-west (52.5N 02.0E), Netherlands-central (de Bilt) and Netherlands-southeast (51.0N 07.0E), winter (DJF), spring (MAM), summer (JJA) en autumn (SON).



9.1.3 Vertical profile climatology for wind direction for four requested locations (Northsea-north (54.0N 07.0E), Northsea-west (52.5N 02.0E), Netherlands-central (de Bilt) and Netherlands-southeast (51.0N 07.0E), winter (DJF), spring (MAM), summer (JJA) en autumn (SON).

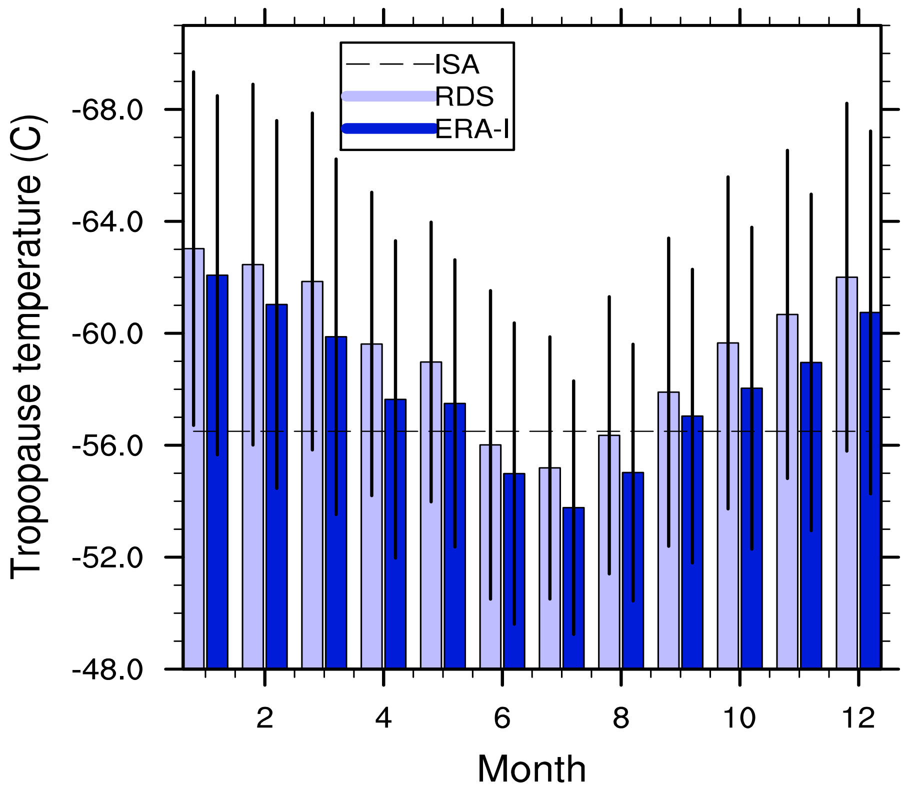


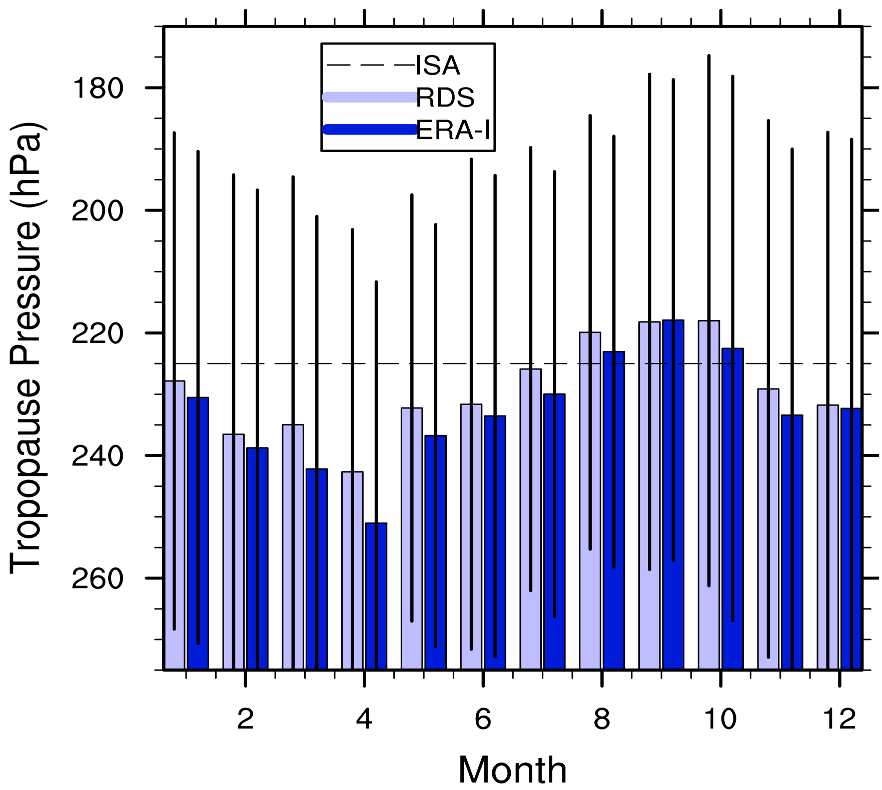
9.1.4 Vertical profile climatology for wind speed for four requested locations (Northsea-north (54.0N 07.0E), Northsea-west (52.5N 02.0E), Netherlands-central (de Bilt) and Netherlands-southeast (51.0N 07.0E), winter (DJF), spring (MAM), summer (JJA) en autumn (SON).



9.1.5 Climatology of tropopause pressure level and -temperature for Netherlands-central.

ISA represents the International Standard Atmosphere, RDS the obseravtions of radiosonde soudings and ERA-I the reanalysis with Era-Interim.





9.2 Spatial ERA-interim climatology 1989-2008 of upper wind, relative humidity and temperature per season

In the following subchapters spatial climatology of the upper air, derived from ERA-Interim 1989-2008, for several ICAO standard flight levels is shown. Per gridpoint average vectorial wind (in knots, 1 knot = 0.51 m/s), average absolute windspeed (in knots) and average temperature and relative humidity are presented per season. Figure 7 shows the explanation of such a gridpoint plot.

Note that vectorial average windspeed is lower than absolute average windspeed, as the average vectorial wind is composed from the average of the u-component (X-axis) and v-component (Y-axis) of individual windvectors. As components can be positive or negative, the average vectorial windspeed will be lower than the average absolute windspeed (which is always positive). Seasons are related to months, Spring as MAM (March-April-May), etc.

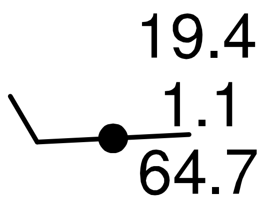
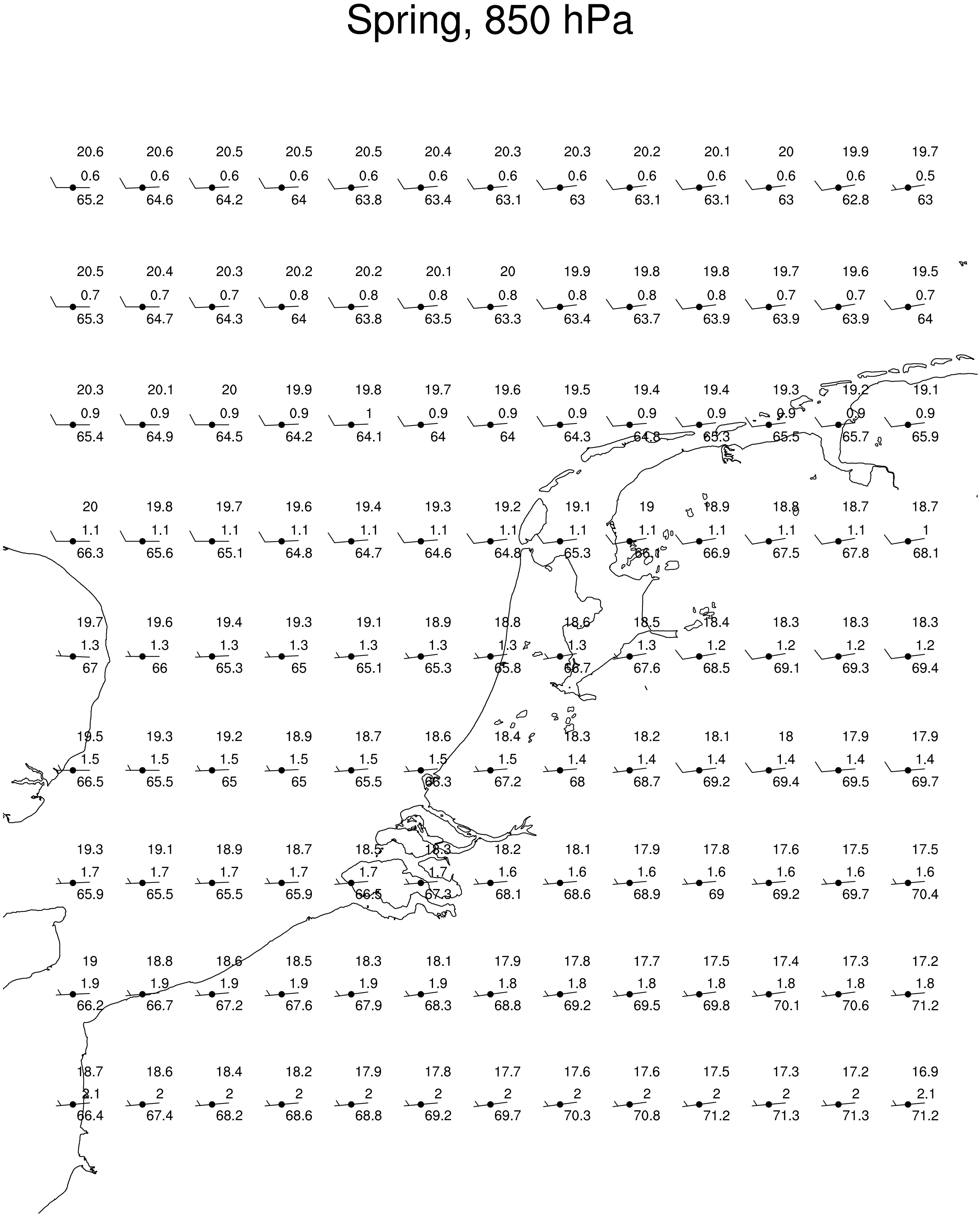


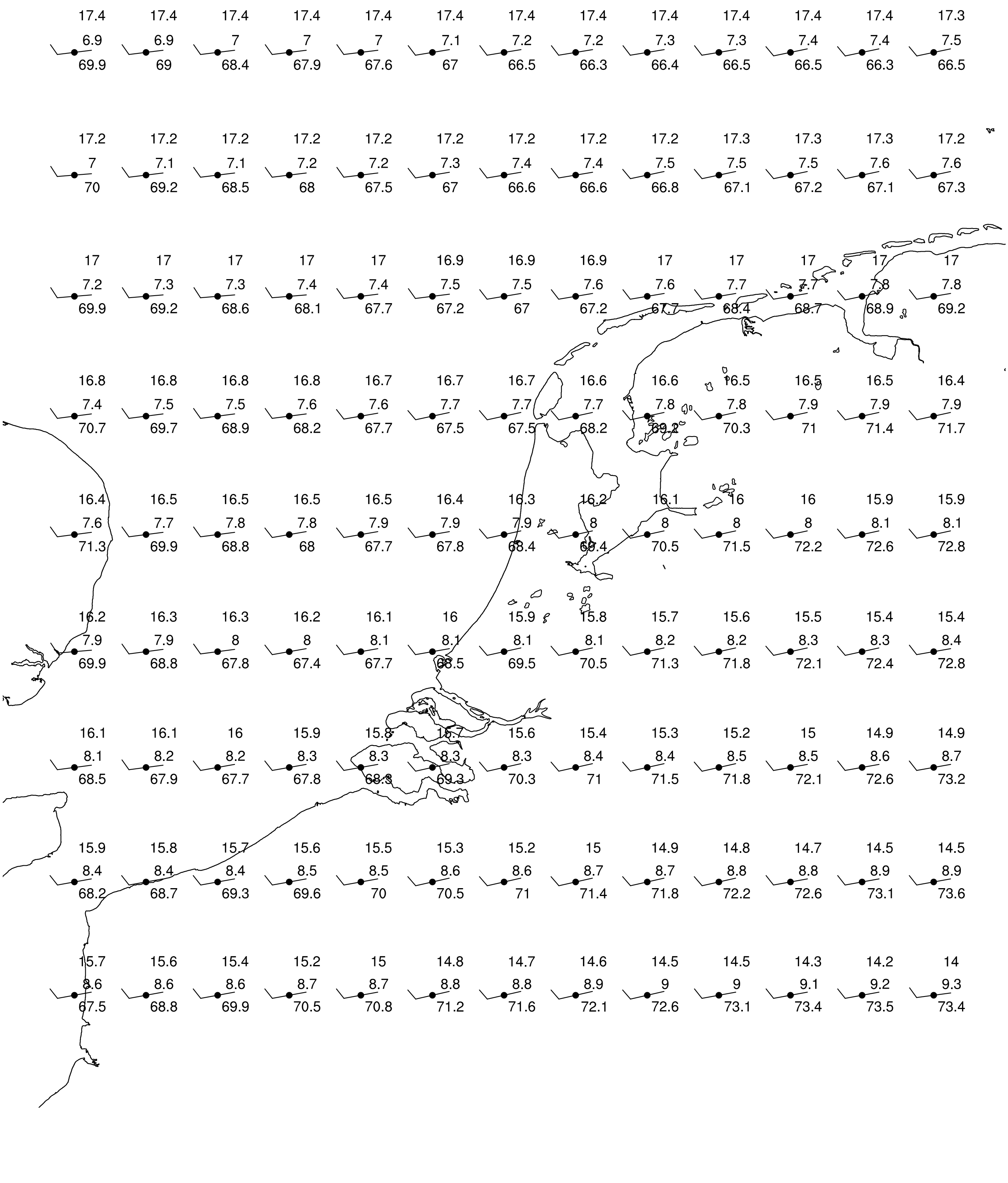
Figure 7. Gridpoint information in spatial climatology. For this gridpoint average vector winddirection is about 260 degrees and vector windspeed around 10 knots (10 knots=5.1 m/s), average (absolute) windspeed 19.4 knots, average temperature +1.1^oC and average humidity 64.7%.

9.2.1 Upper air climatology 850 hPa (FL 050) per season



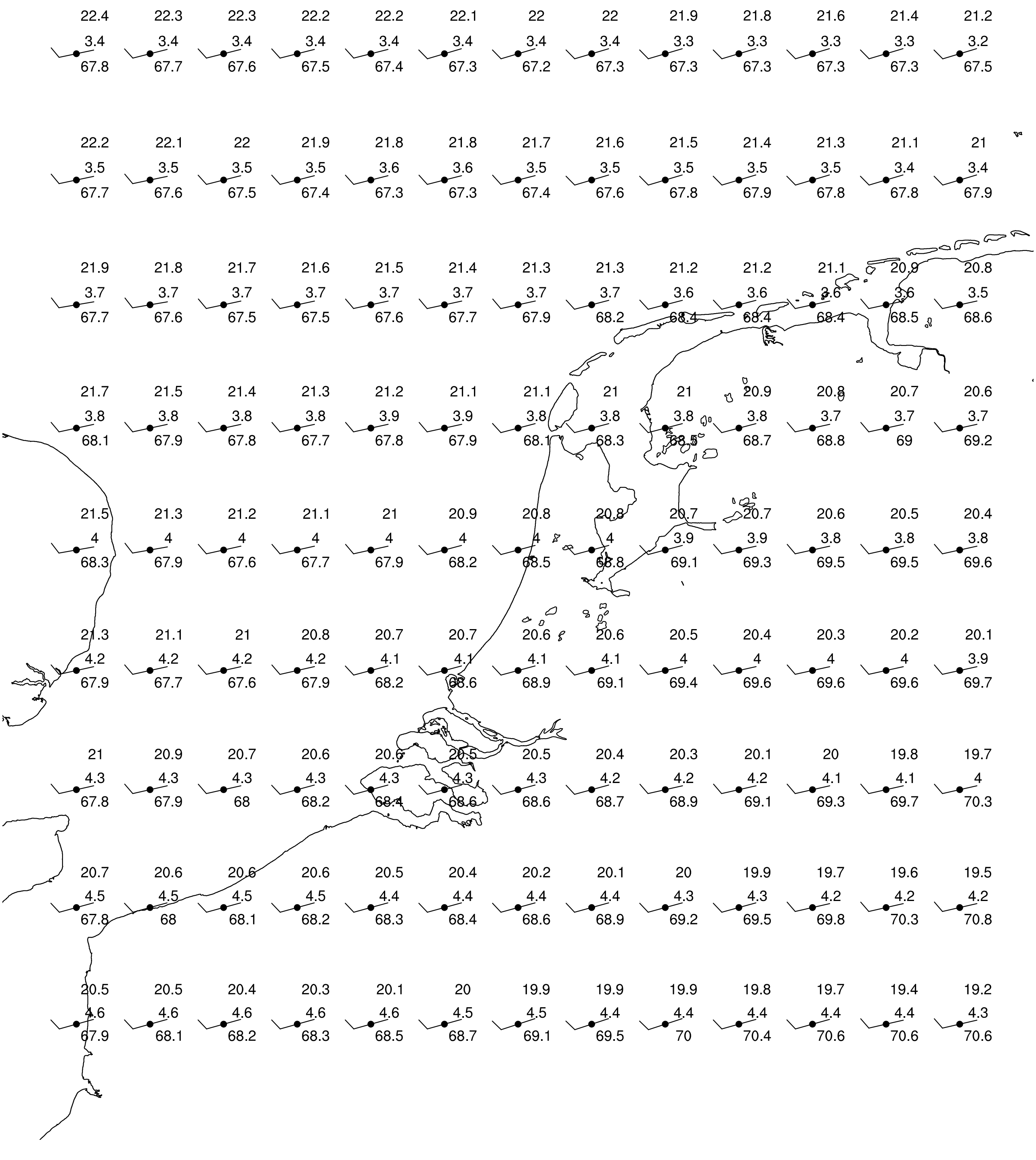
Upper air climatology 850 hPa (FL 050) per season

Summer, 850 hPa



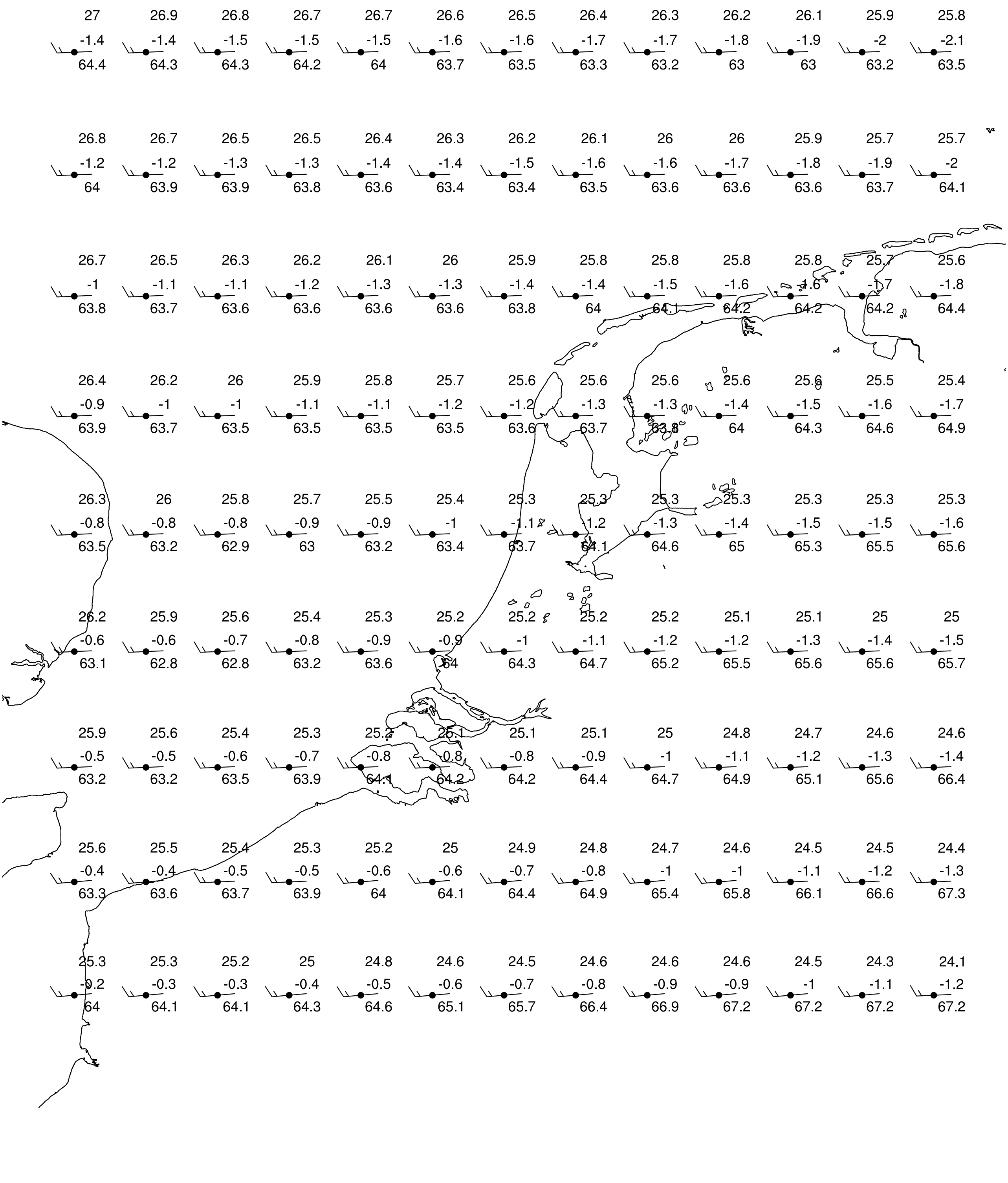
Upper air climatology 850 hPa (FL 050) per season

Autumn, 850 hPa



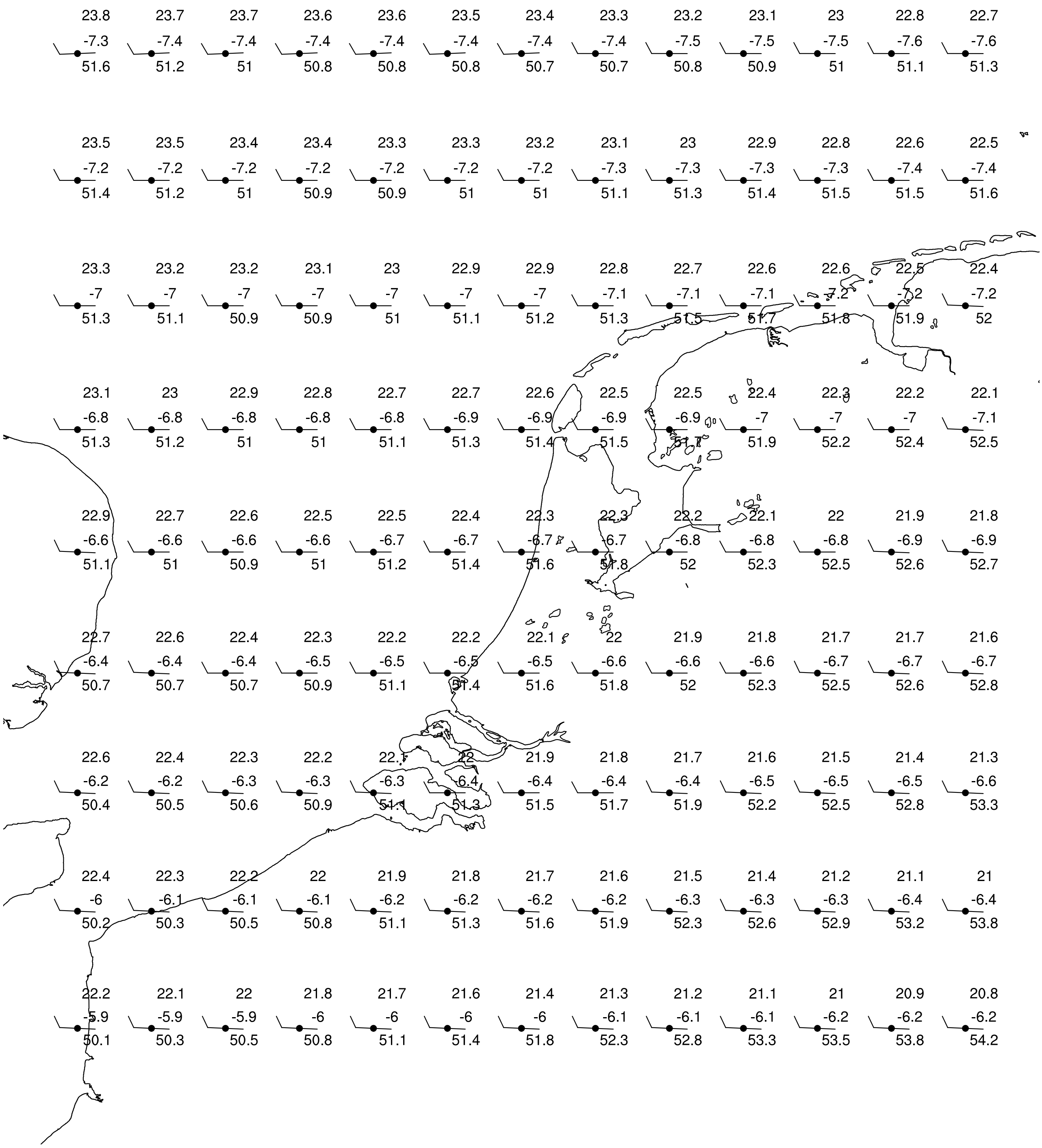
Upper air climatology 850 hPa (FL 050) per season

Winter, 850 hPa



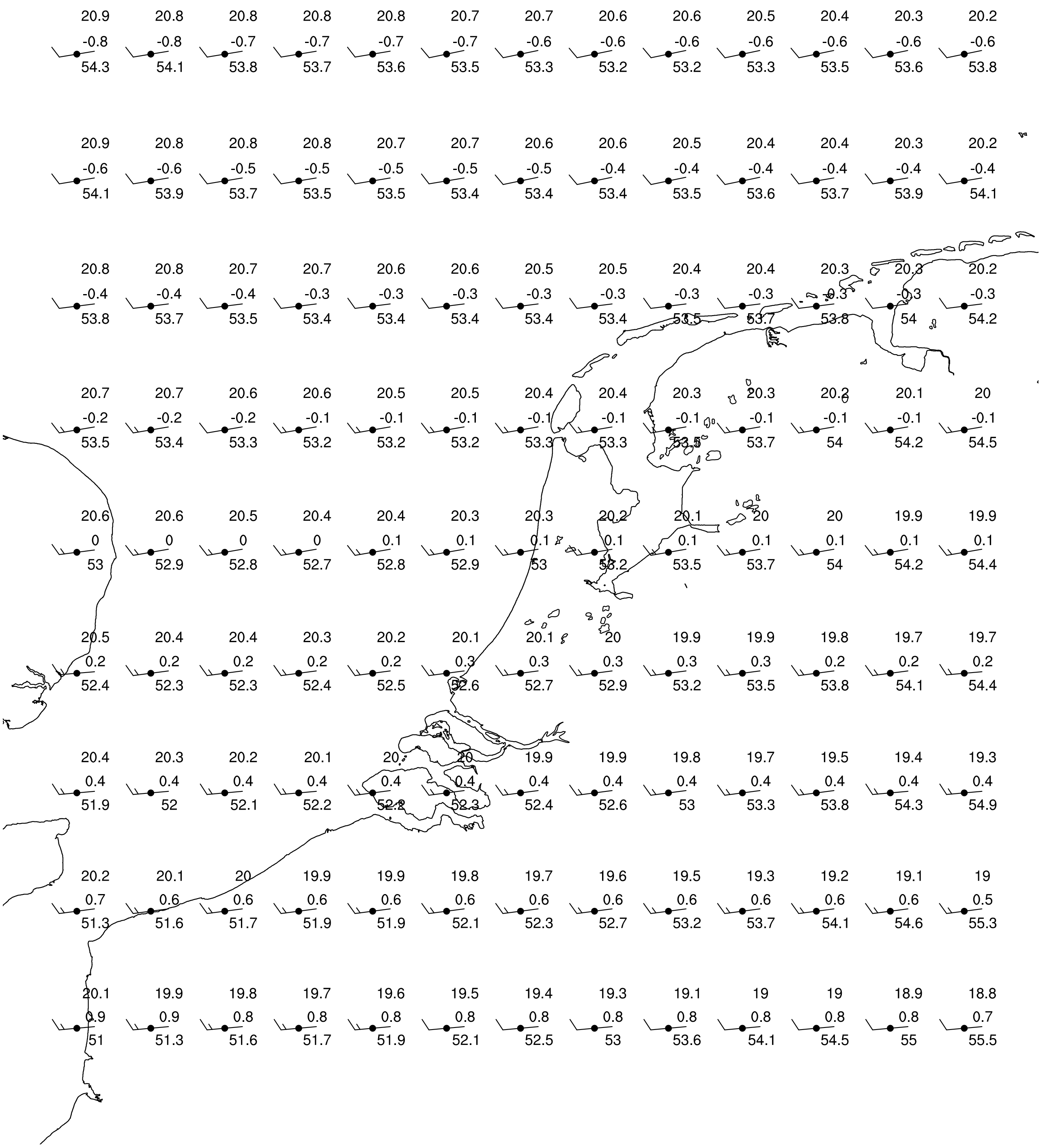
9.2.2 Upper air climatology 700 hPa (FL 100) per season

Spring, 700 hPa



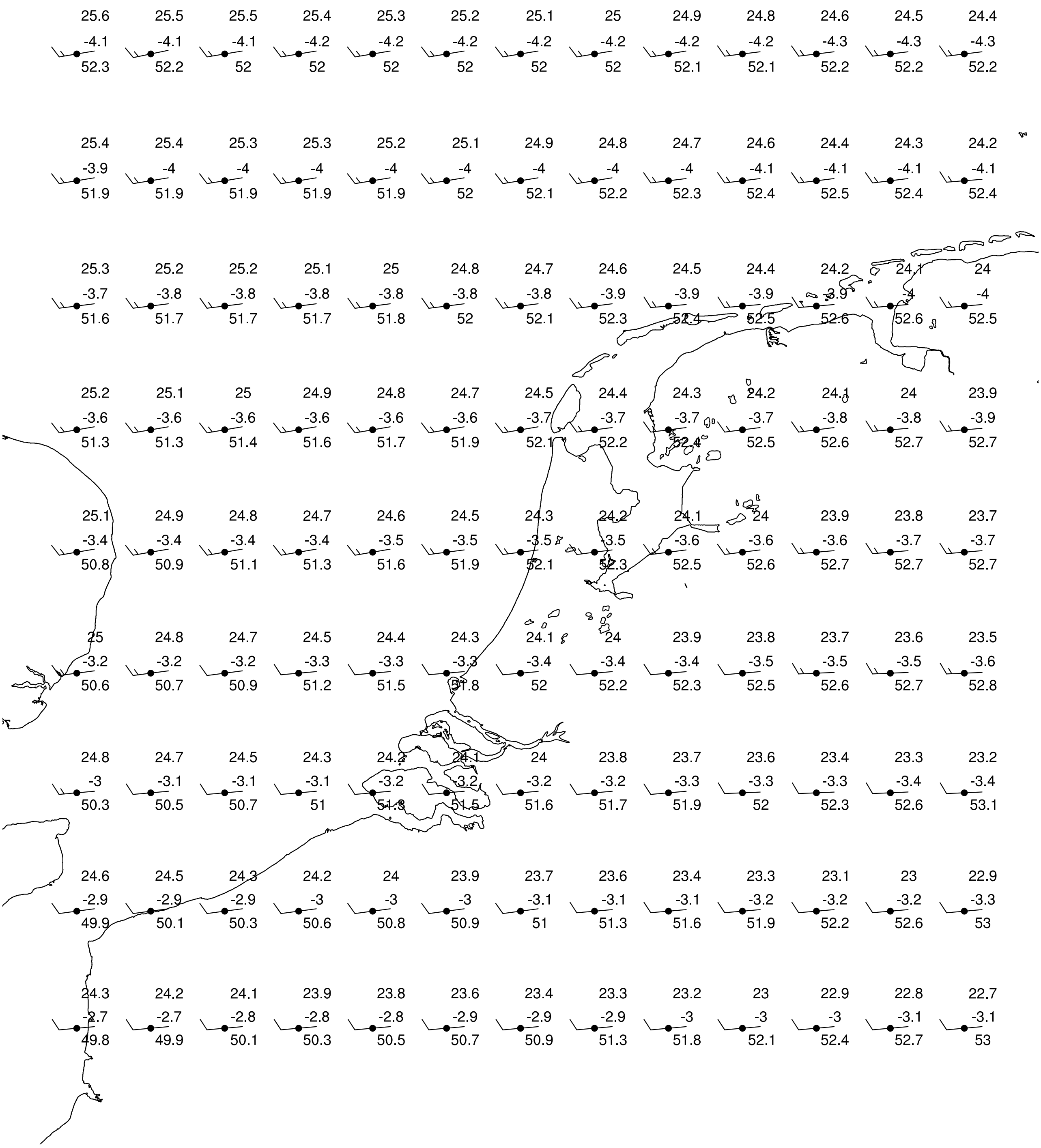
Upper air climatology 700 hPa (FL 100) per season

Summer, 700 hPa

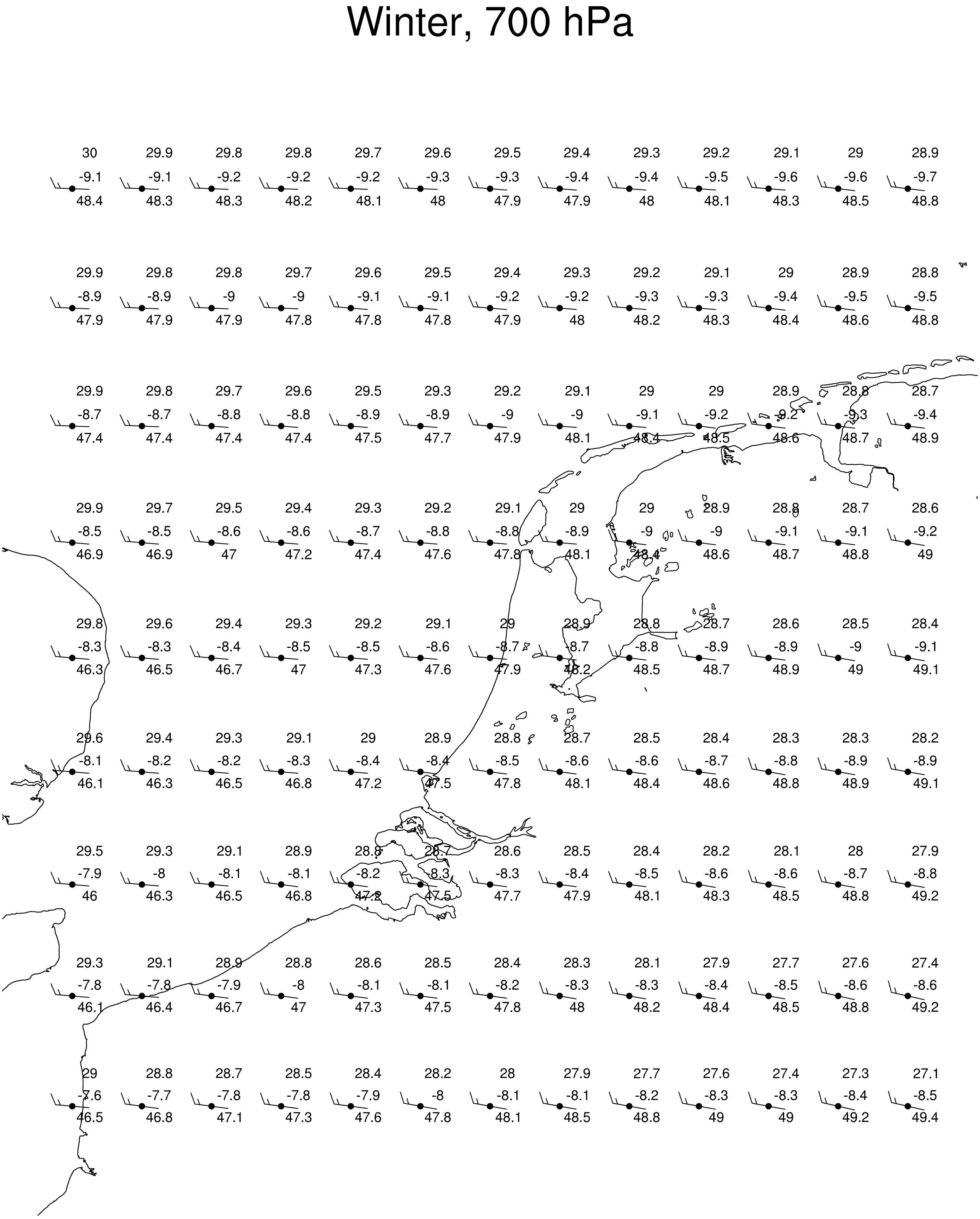


Upper air climatology 700 hPa (FL 100) per season

Autumn, 700 hPa

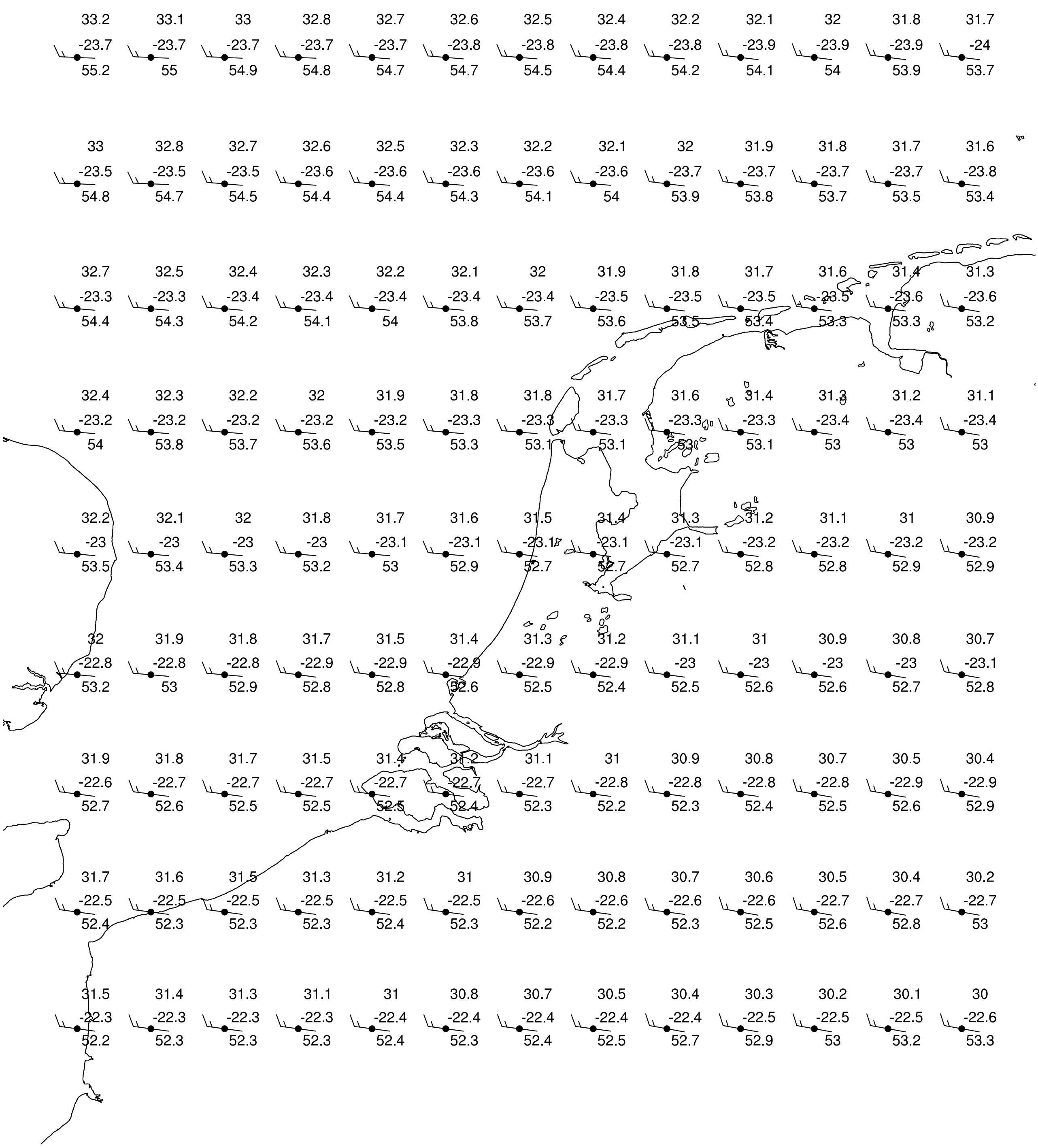


Upper air climatology 700 hPa (FL 100) per season



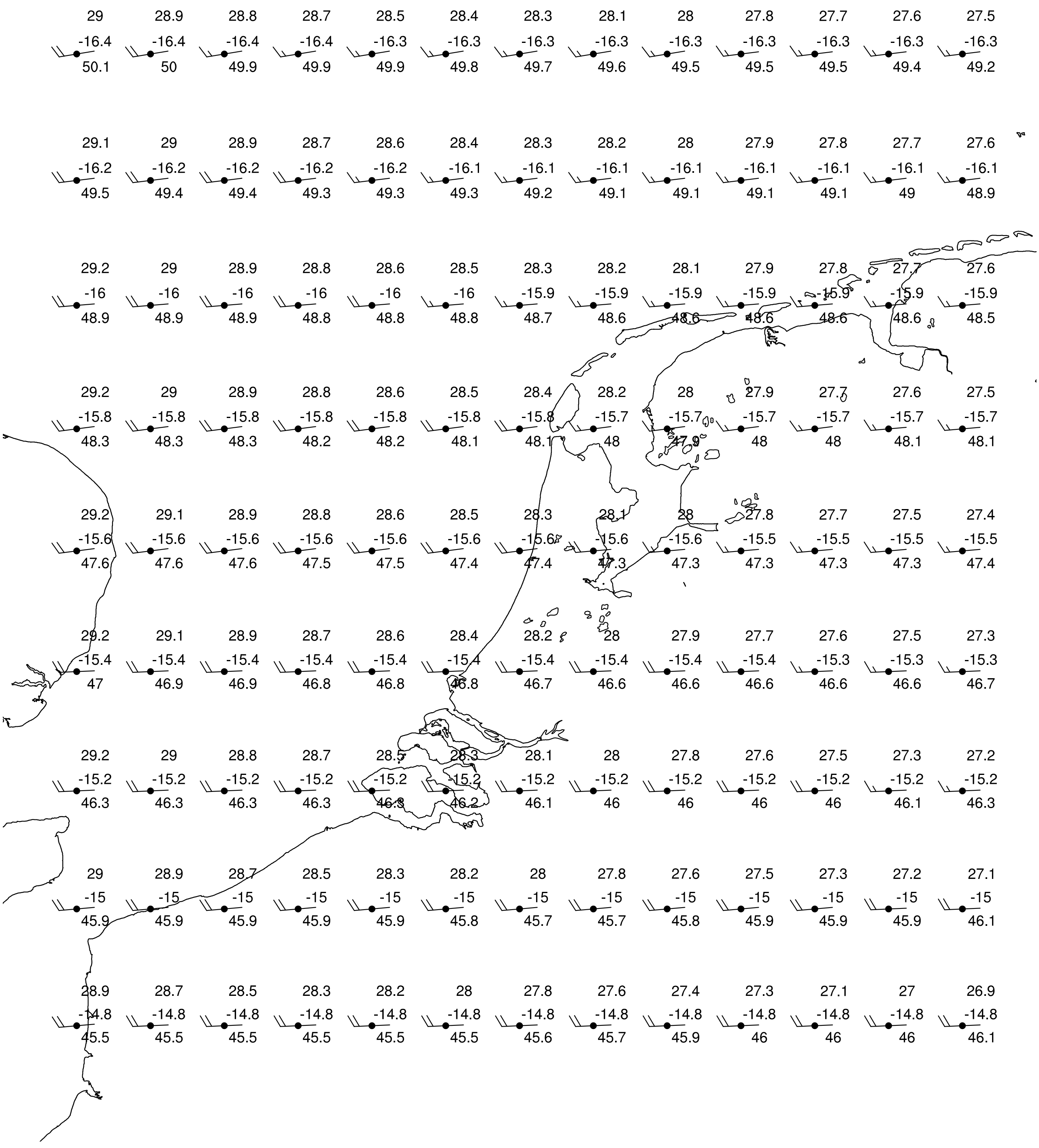
9.2.3 Upper air climatology 500 hPa (FL 180) per season

Spring, 500 hPa



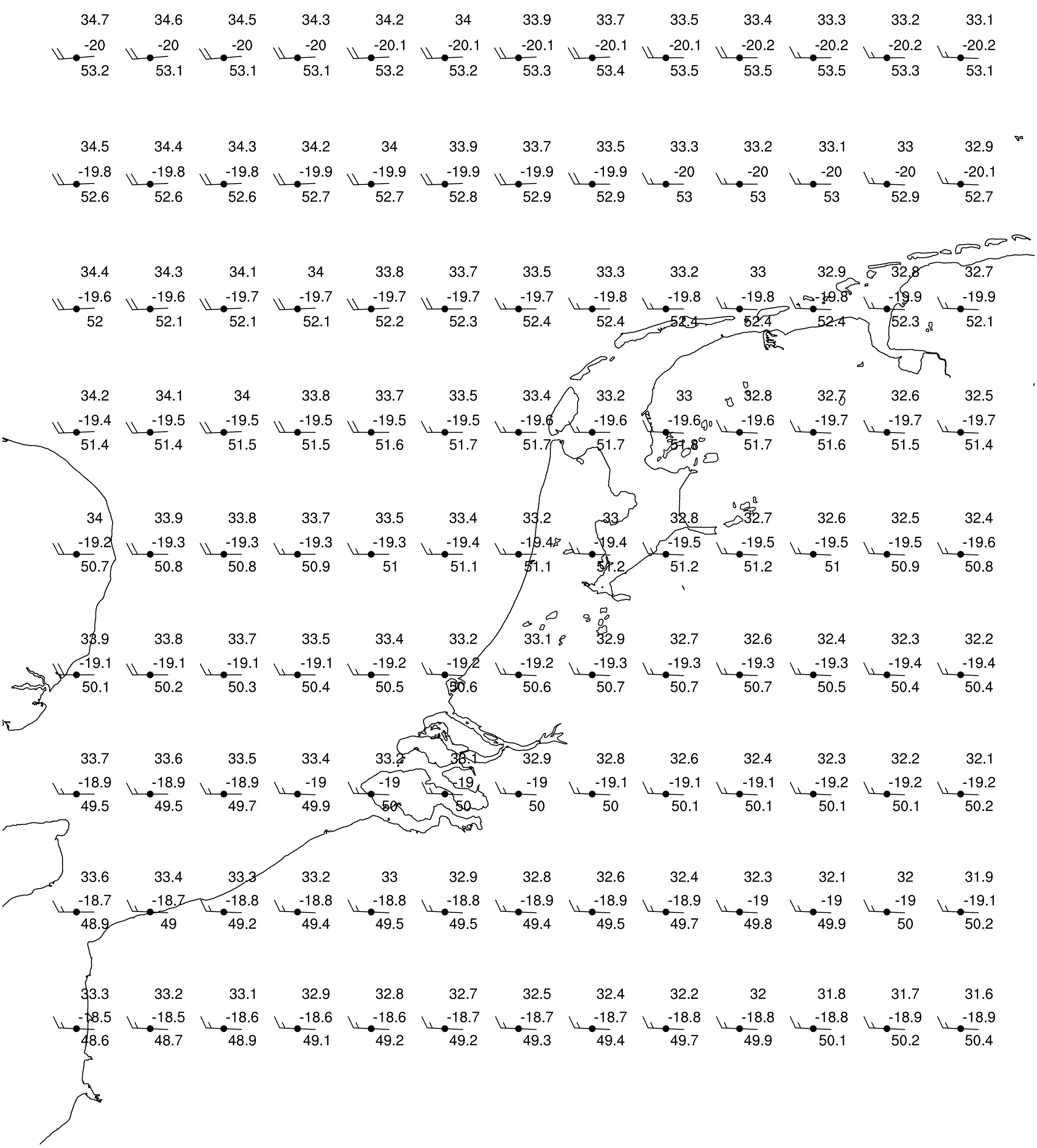
Upper air climatology 500 hPa (FL 180) per season

Summer, 500 hPa



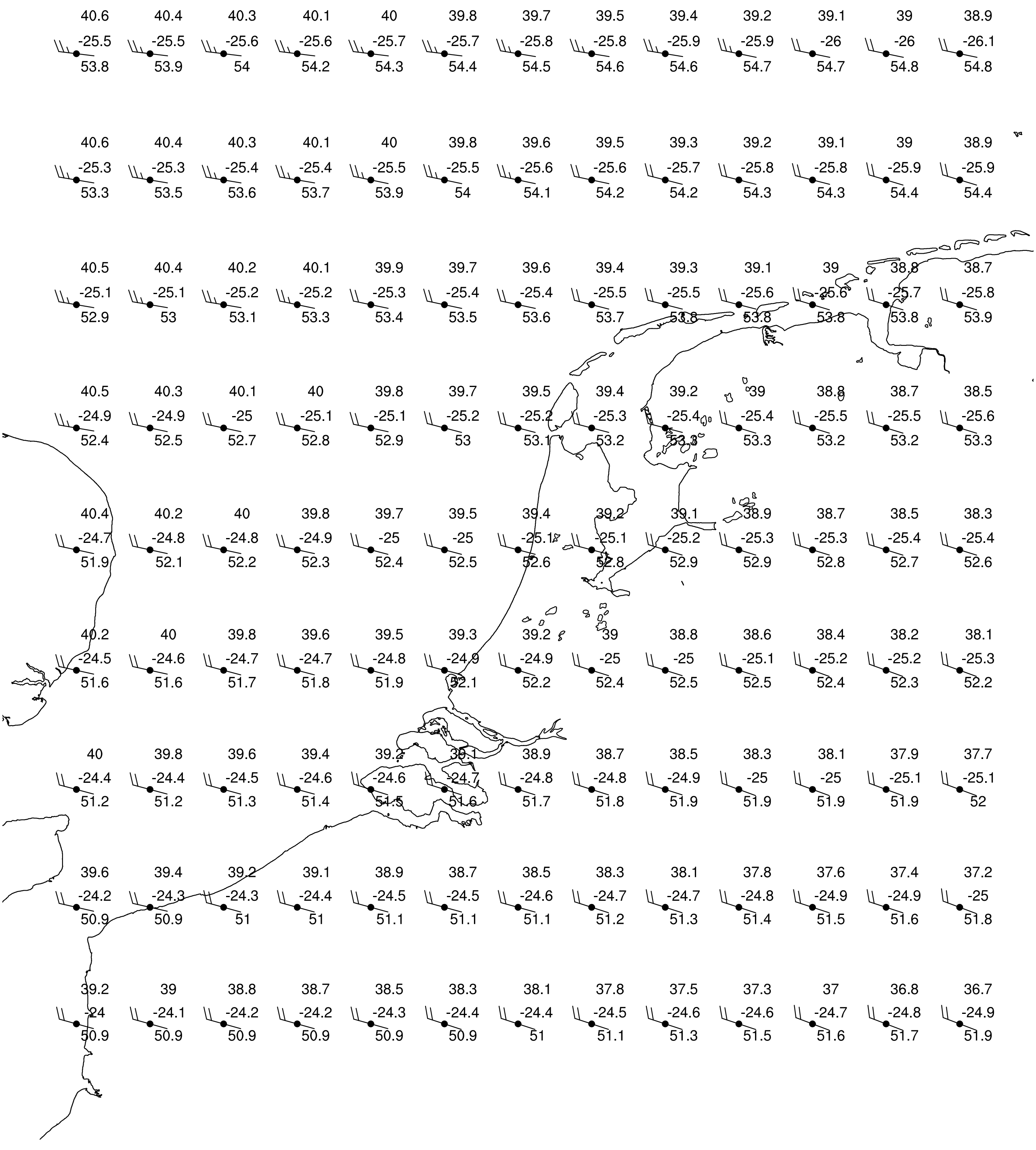
Upper air climatology 500 hPa (FL 180) per season

Autumn, 500 hPa



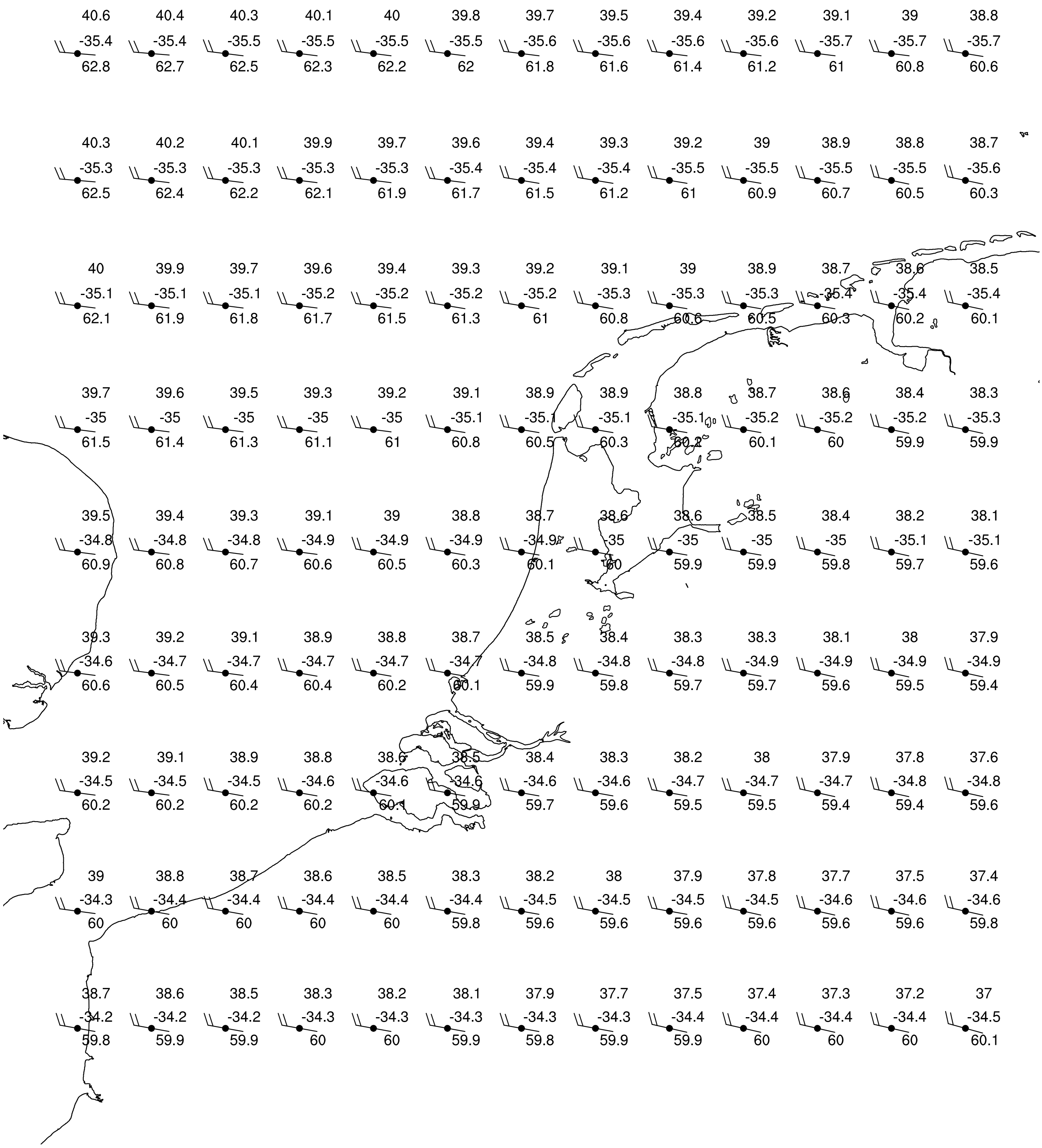
Upper air climatology 500 hPa (FL 180) per season

Winter, 500 hPa



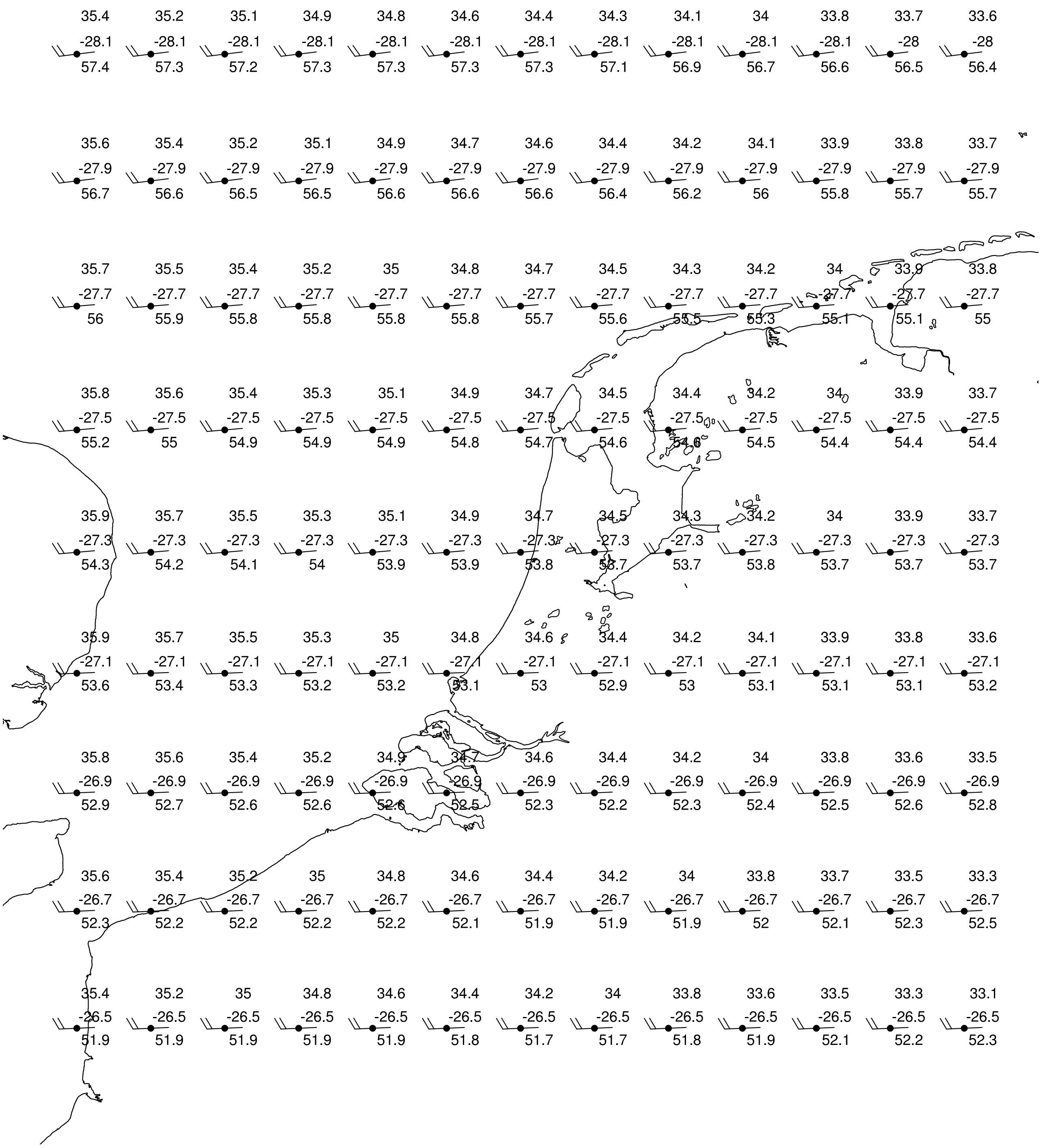
9.2.4 Upper air climatology 400 hPa (FL 240) per season

Spring, 400 hPa



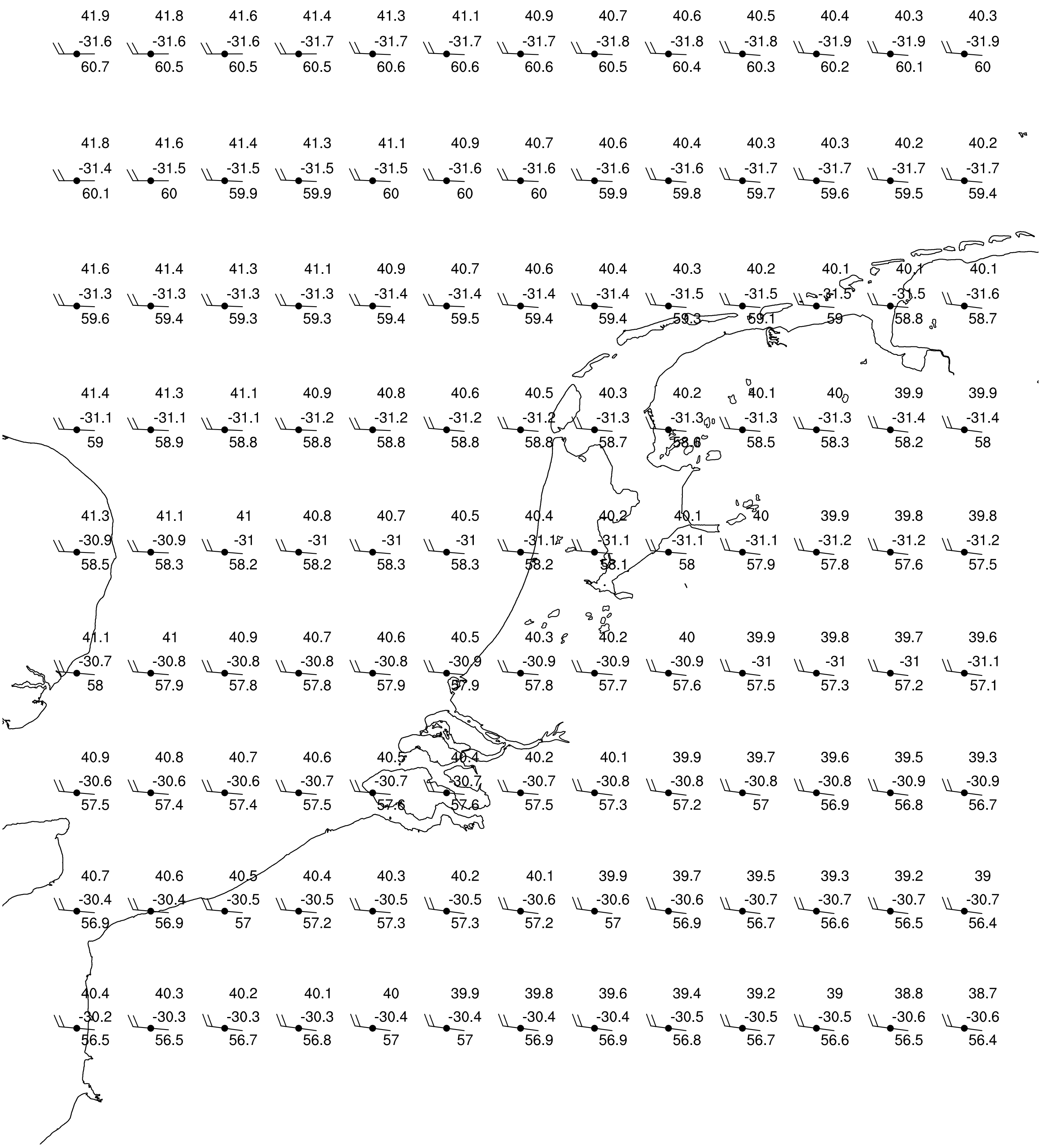
Upper air climatology 400 hPa (FL 240) per season

Summer, 400 hPa



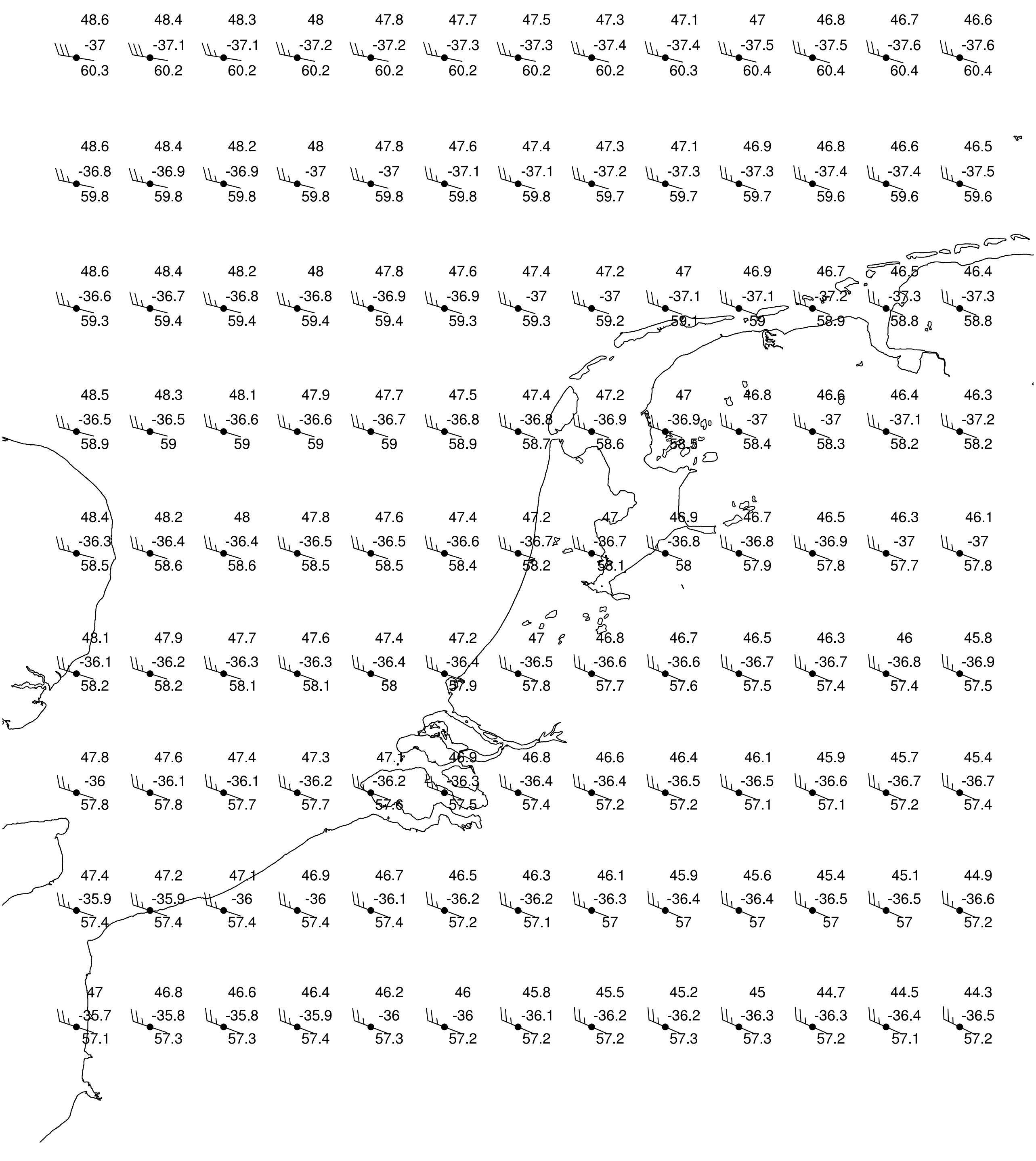
Upper air climatology 400 hPa (FL 240) per season

Autumn, 400 hPa



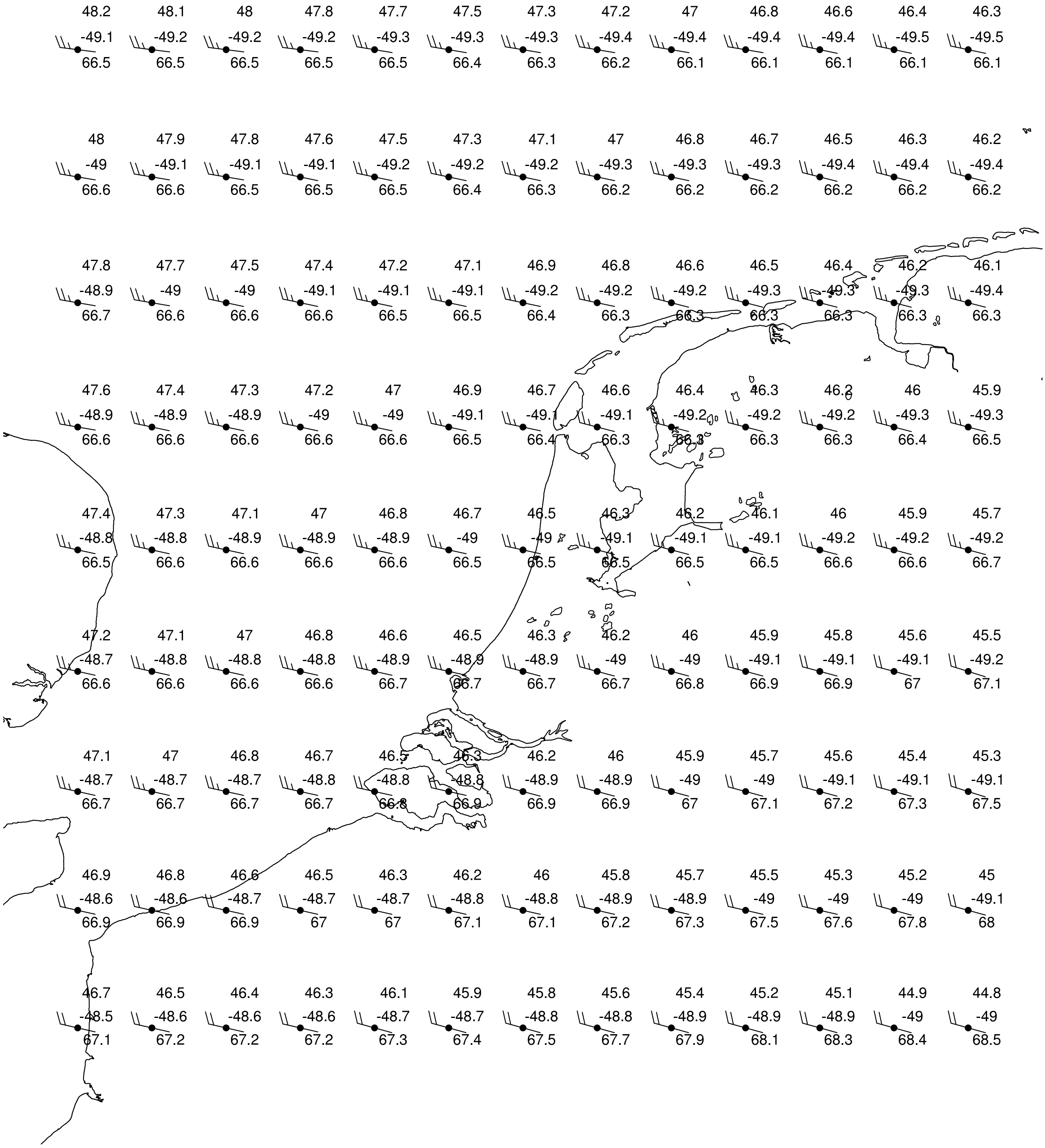
Upper air climatology 400 hPa (FL 240) per season

Winter, 400 hPa



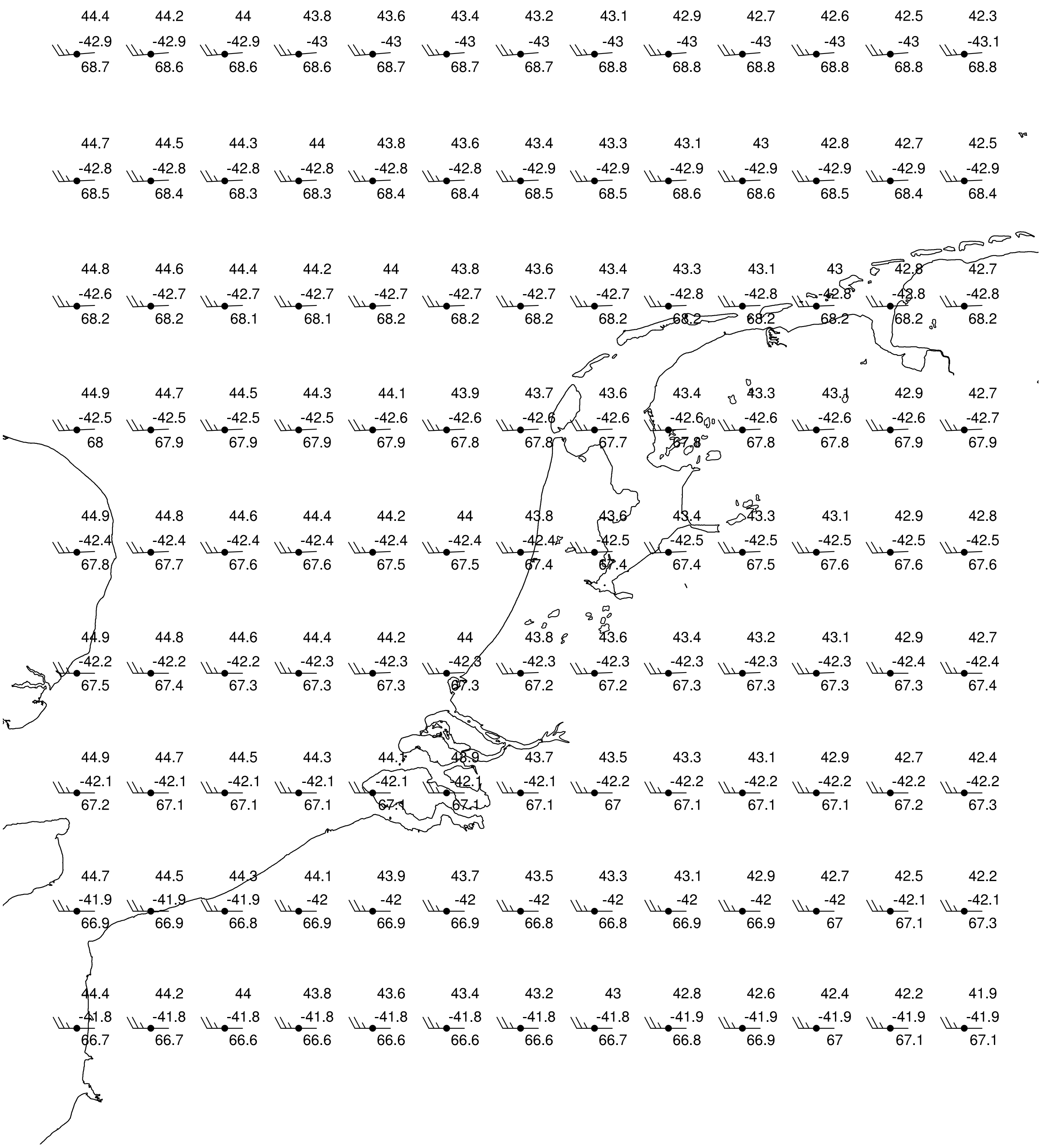
9.2.5 Upper air climatology 300 hPa (FL 300) per season

Spring, 300 hPa



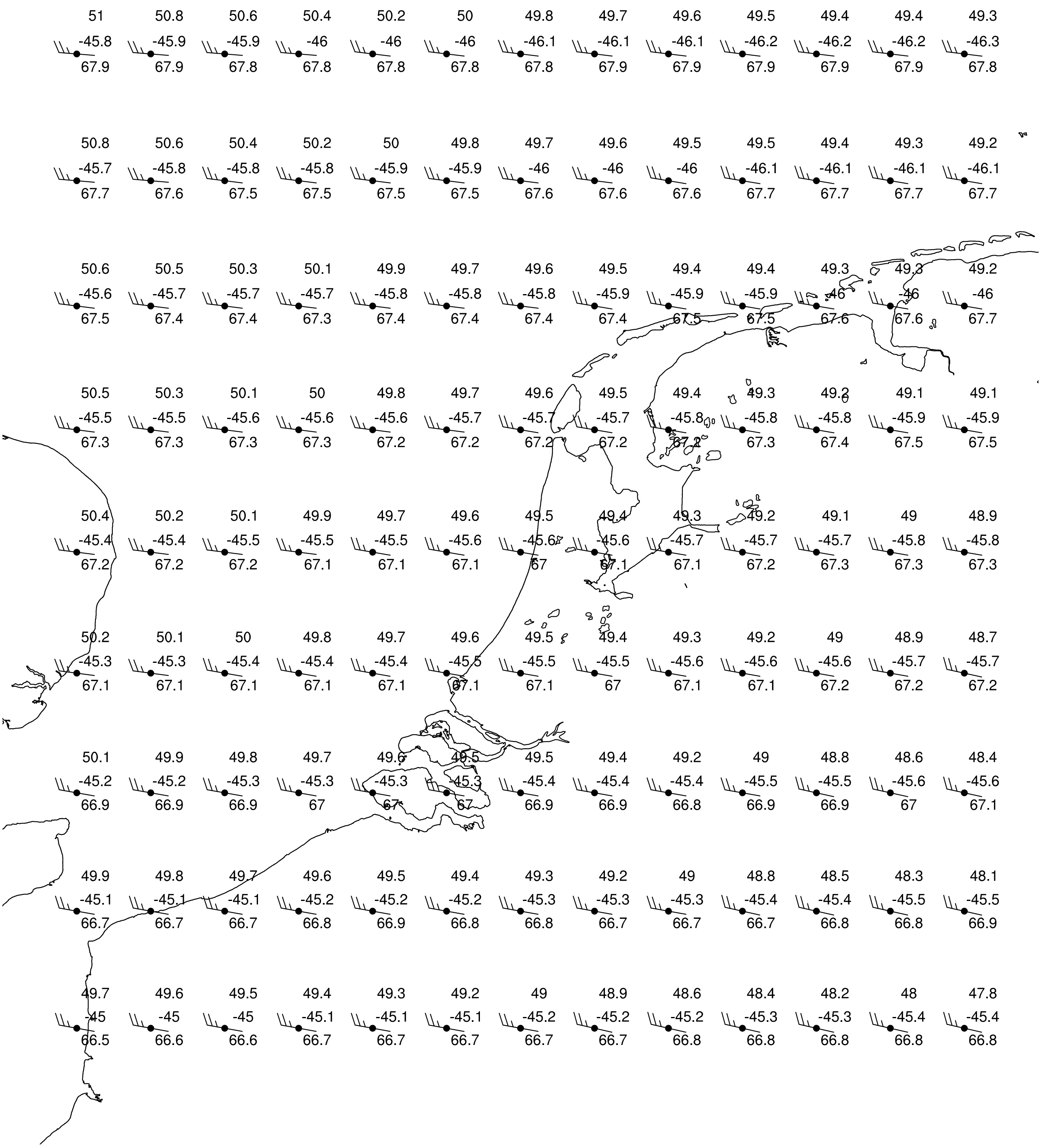
Upper air climatology 300 hPa (FL 300) per season

Summer, 300 hPa

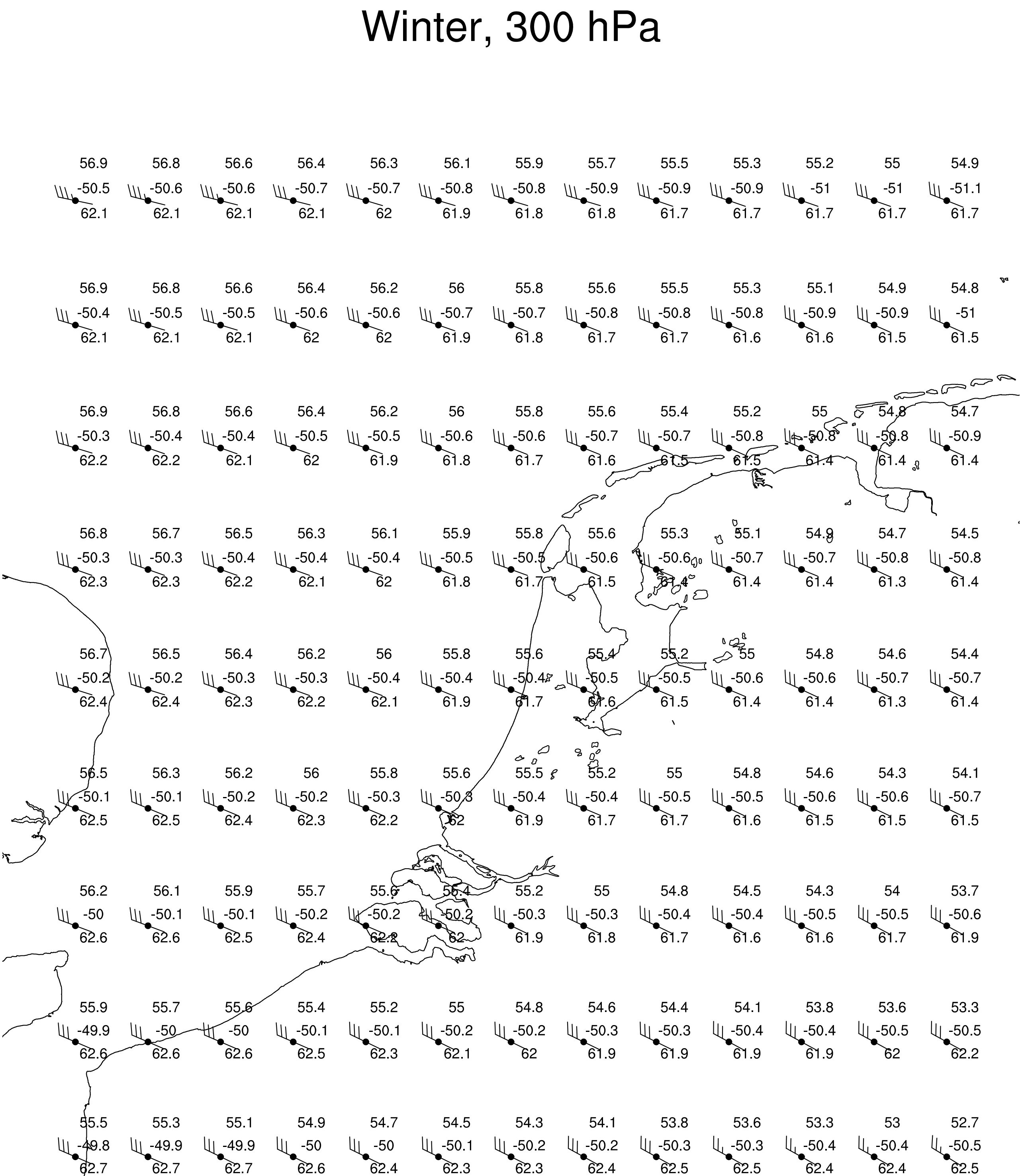


Upper air climatology 300 hPa (FL 300) per season

Autumn, 300 hPa

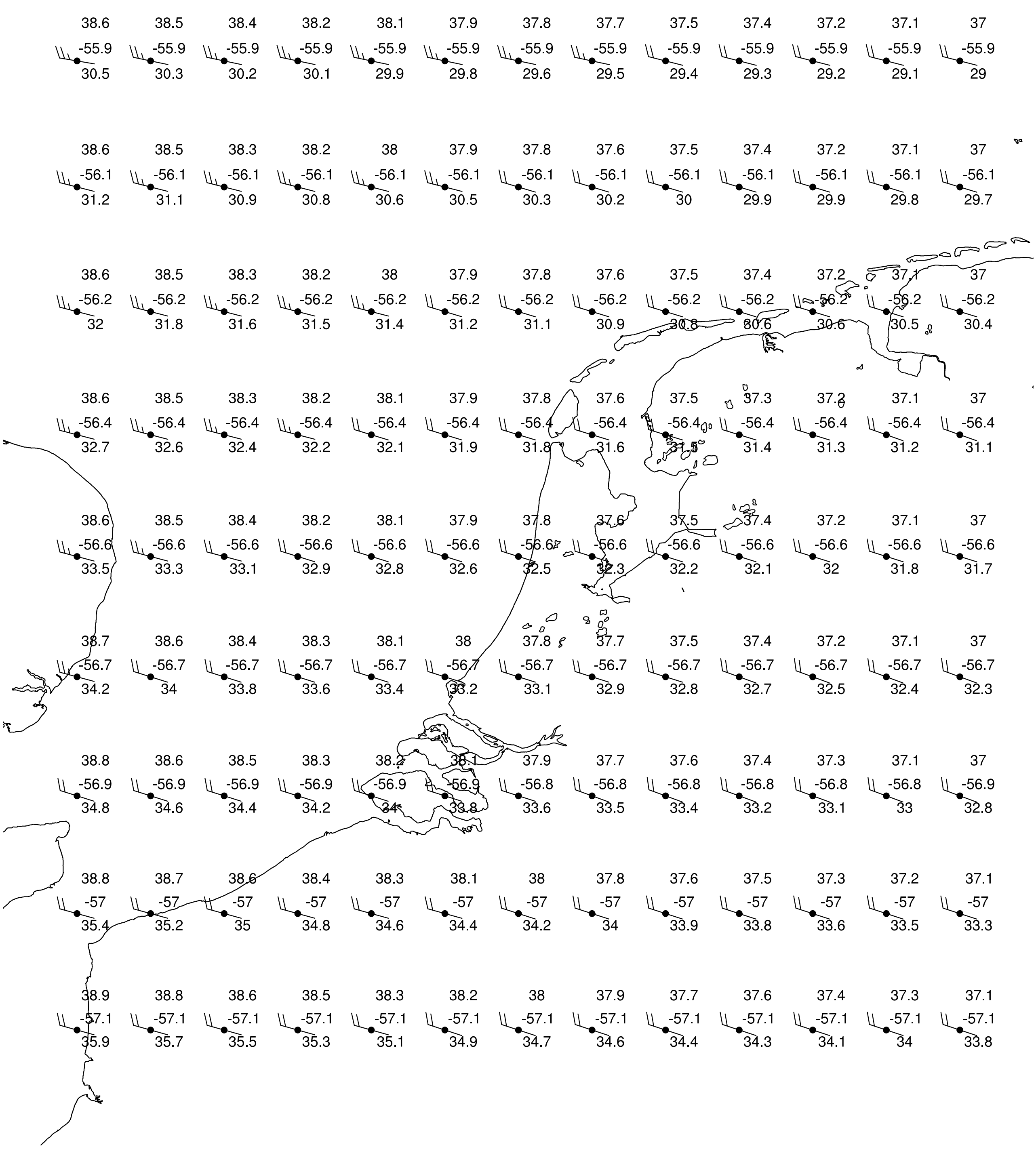


Upper air climatology 300 hPa (FL 300) per season



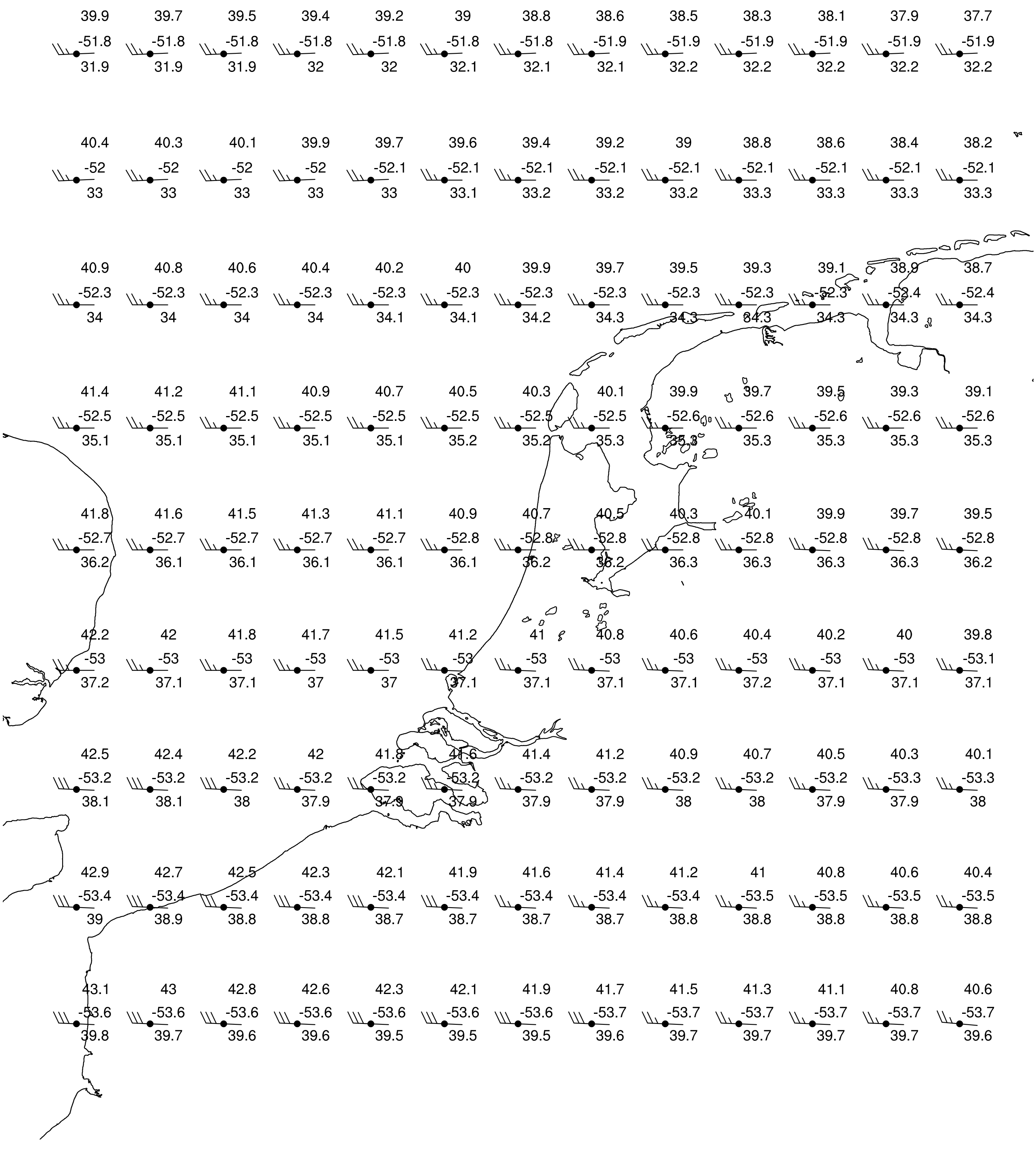
9.2.6 Upper air climatology 200 hPa (FL 390) per season

Spring, 200 hPa



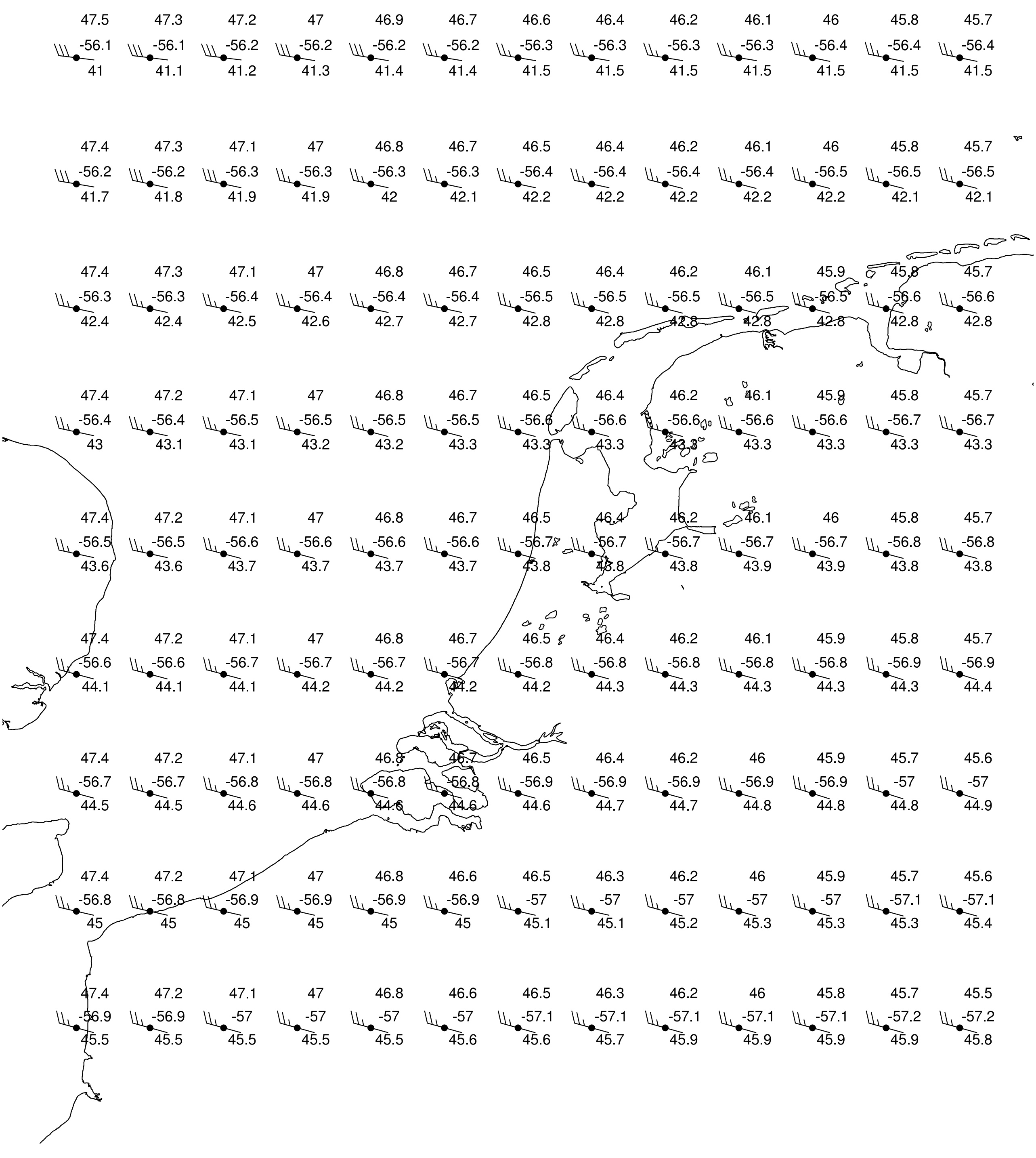
Upper air climatology 200 hPa (FL 390) per season

Summer, 200 hPa



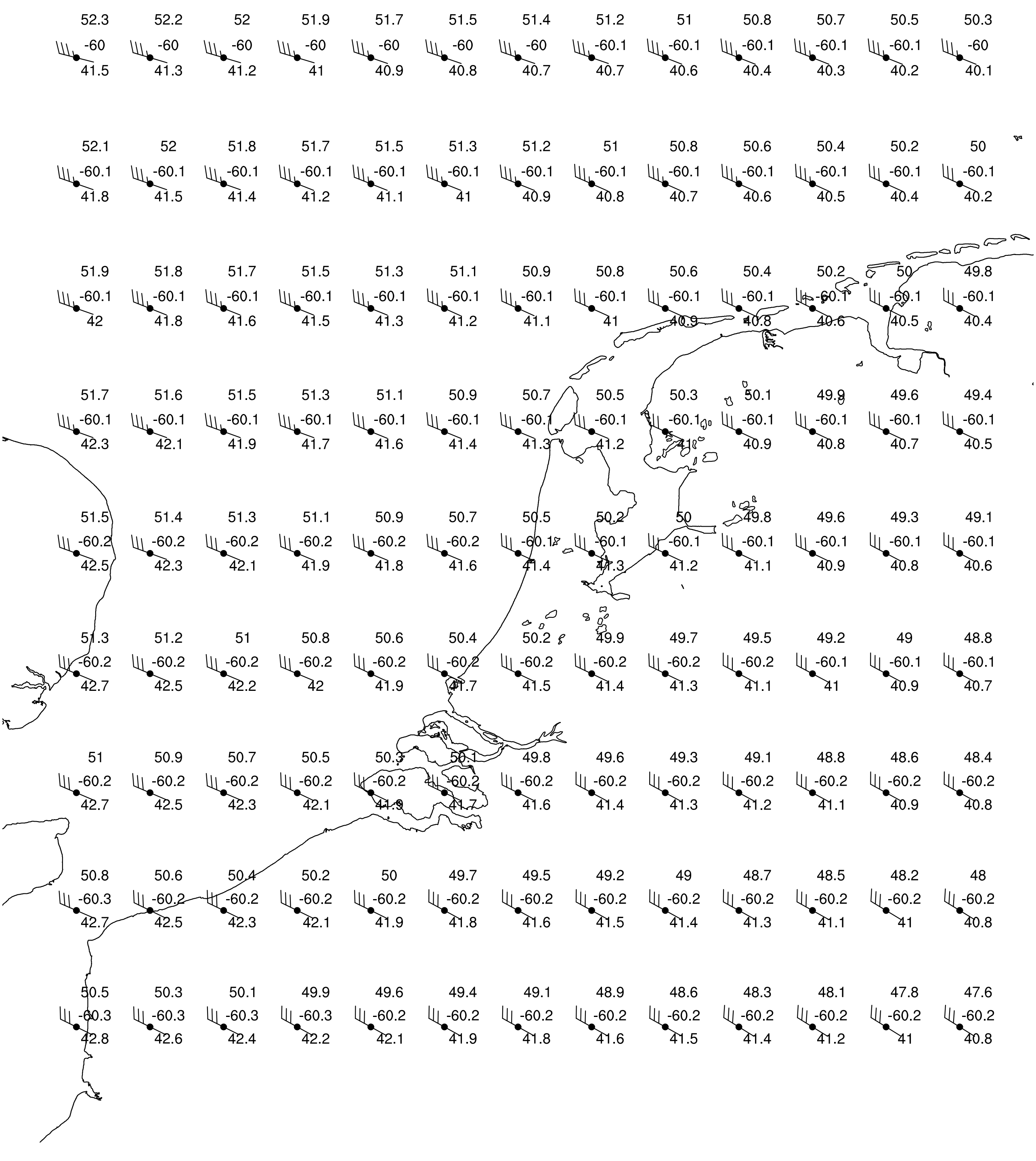
Upper air climatology 200 hPa (FL 390) per season

Autumn, 200 hPa



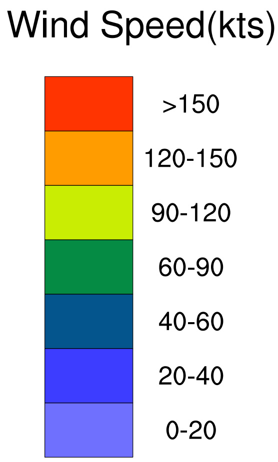
Upper air climatology 200 hPa (FL 390) per season

Winter, 200 hPa



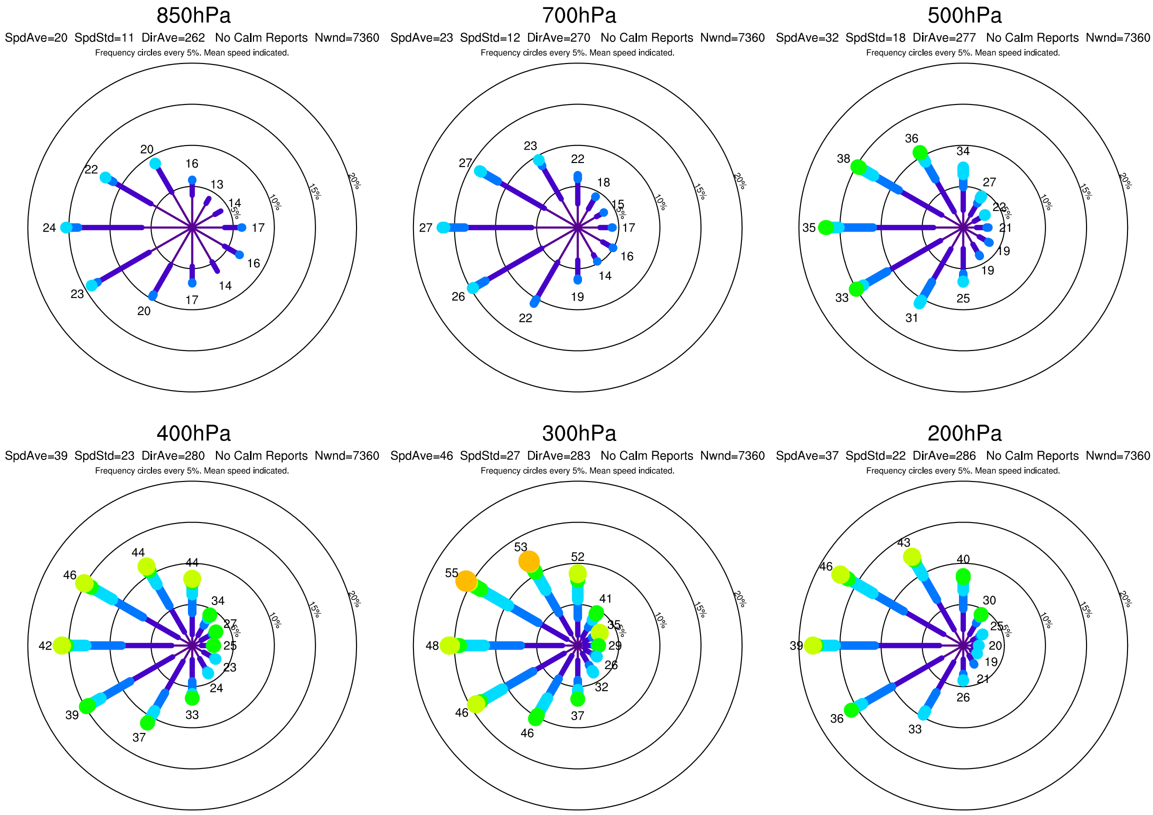
9.3 ERA-interim climatological wind roses on six standard levels 1989-2008

Climatology of wind in wind roses on four standard pressure levels, 850, 700, 500, 400, 300 and 200 hPa per season for four locations, Northsea-north (54.0N 07.0E), Northsea-west (52.5N 02.0E), Netherlands-central, Netherlands-southeast (51.0N 07.0E). The wind roses on have been calculated from ERA-Interim in the period 1989-2008. On top is shown average windspeed, standard deviation and average direction per 30 degree sector, number of calm reports and number of reports. The relative length of the bar indicates the windspeed distribution per direction sector, more details in the tables (appendix 10.4). Seasons are related to months, Spring as MAM (March-April-May), etc.

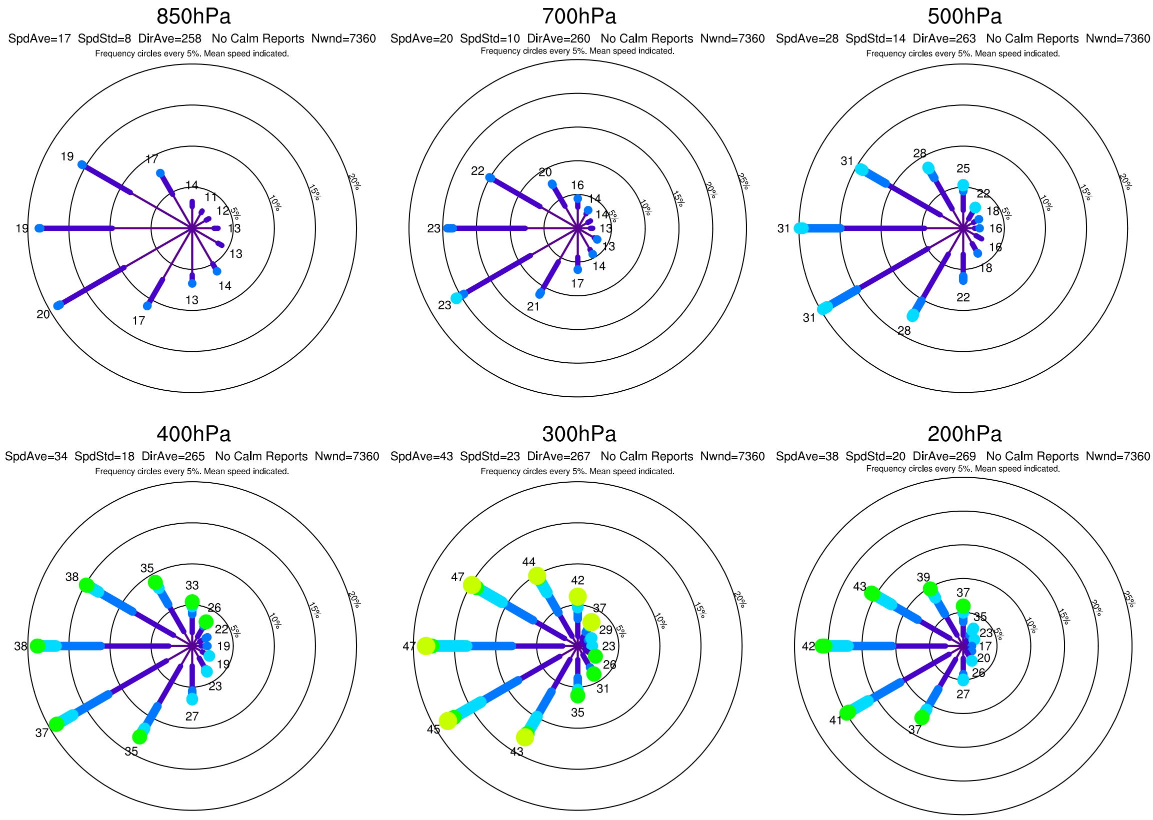


9.3.1 Windrose per season from 850 to 200 hPa for Northsea-north (54.0N 07.0E)

Spring



Summer



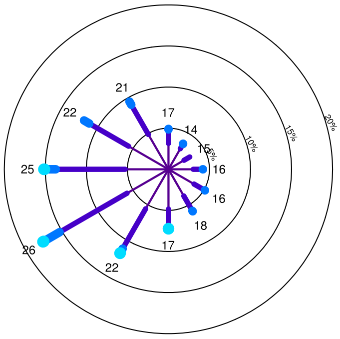
Windrose per season from 850 to 200 hPa for Northsea-north (54.0N 07.0E)

Autumn

850hPa

SpdAve=21 SpdStd=11 DirAve=255 No Calm Reports Nwnd=7280

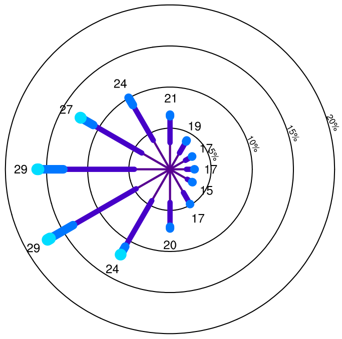
Frequency circles every 5%. Mean speed indicated.



700hPa

SpdAve=24 SpdStd=12 DirAve=264 No Calm Reports Nwnd=7280

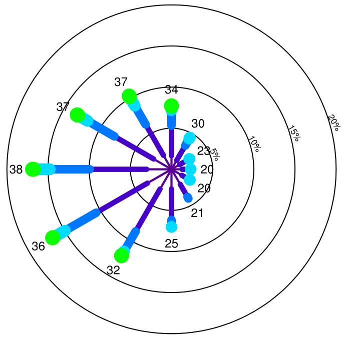
Frequency circles every 5%. Mean speed indicated.



500hPa

SpdAve=33 SpdStd=17 DirAve=272 No Calm Reports Nwnd=7280

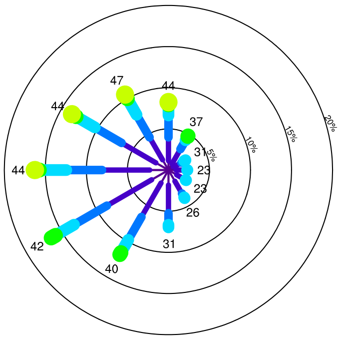
Frequency circles every 5%. Mean speed indicated.



400hPa

SpdAve=40 SpdStd=22 DirAve=275 No Calm Reports Nwnd=7280

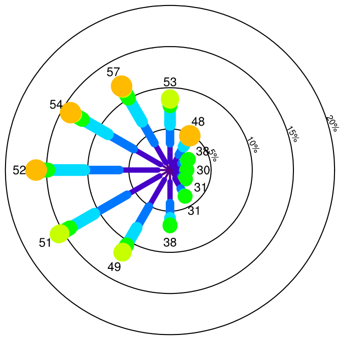
Frequency circles every 5%. Mean speed indicated.



300hPa

SpdAve=49 SpdStd=27 DirAve=279 No Calm Reports Nwnd=7280

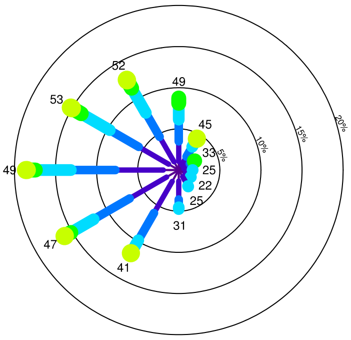
Frequency circles every 5%. Mean speed indicated.



200hPa

SpdAve=46 SpdStd=24 DirAve=283 No Calm Reports Nwnd=7280

Frequency circles every 5%. Mean speed indicated.

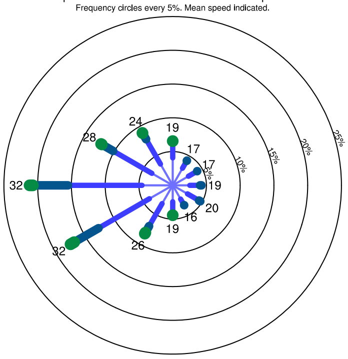


Winter

850hPa

SpdAve=26 SpdStd=14 DirAve=268 No Calm Reports Nwnd=7219

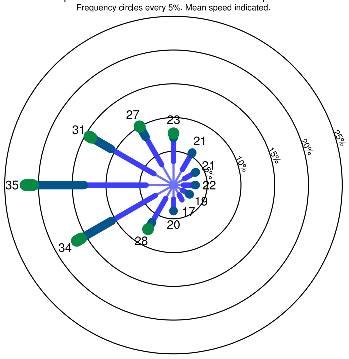
Frequency circles every 5%. Mean speed indicated.



700hPa

SpdAve=29 SpdStd=15 DirAve=276 No Calm Reports Nwnd=7219

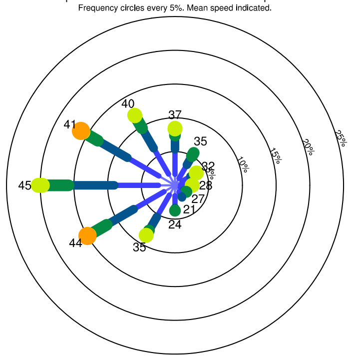
Frequency circles every 5%. Mean speed indicated.



500hPa

SpdAve=39 SpdStd=21 DirAve=285 No Calm Reports Nwnd=7219

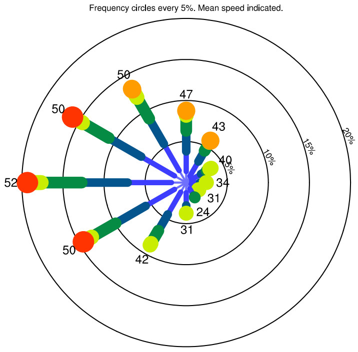
Frequency circles every 5%. Mean speed indicated.



400hPa

SpdAve=47 SpdStd=26 DirAve=289 No Calm Reports Nwnd=7219

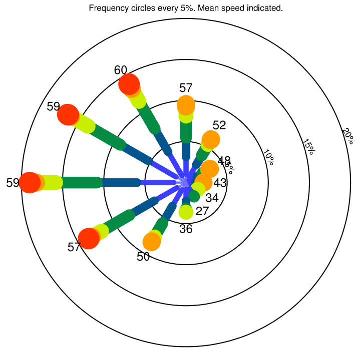
Frequency circles every 5%. Mean speed indicated.



300hPa

SpdAve=55 SpdStd=30 DirAve=292 No Calm Reports Nwnd=7219

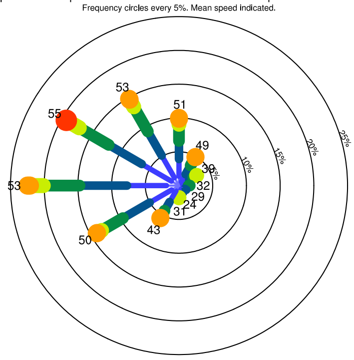
Frequency circles every 5%. Mean speed indicated.



200hPa

SpdAve=50 SpdStd=26 DirAve=294 No Calm Reports Nwnd=7219

Frequency circles every 5%. Mean speed indicated.



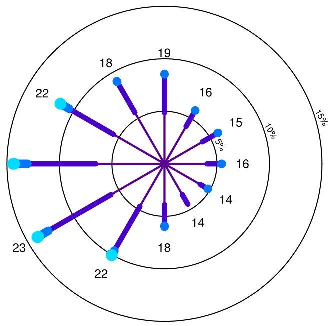
9.3.2 Windrose per season from 850 to 200hPa for Northsea-west (52.5N 02.0E)

Spring

850hPa

SpdAve=20 SpdStd=11 DirAve=270 No Calm Reports Nwnd=7360

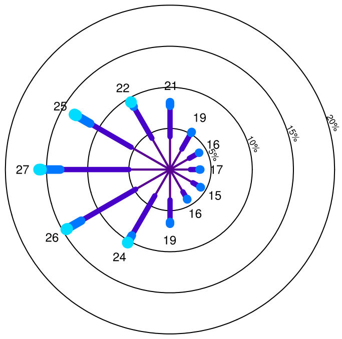
Frequency circles every 5%. Mean speed indicated.



700hPa

SpdAve=23 SpdStd=12 DirAve=271 No Calm Reports Nwnd=7360

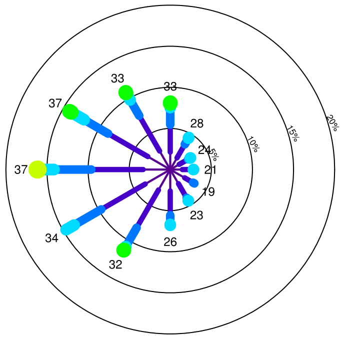
Frequency circles every 5%. Mean speed indicated.



500hPa

SpdAve=32 SpdStd=18 DirAve=275 No Calm Reports Nwnd=7360

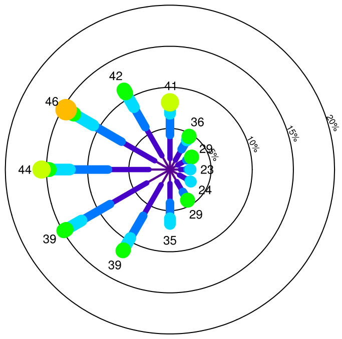
Frequency circles every 5%. Mean speed indicated.



400hPa

SpdAve=39 SpdStd=23 DirAve=277 No Calm Reports Nwnd=7360

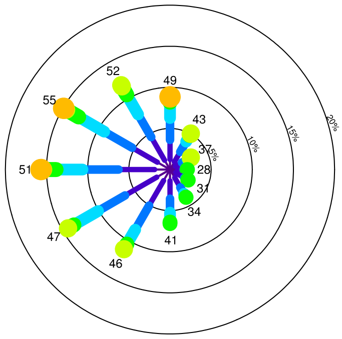
Frequency circles every 5%. Mean speed indicated.



300hPa

SpdAve=47 SpdStd=27 DirAve=281 No Calm Reports Nwnd=7360

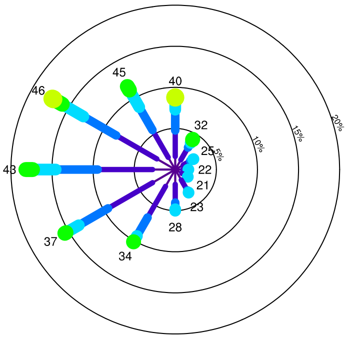
Frequency circles every 5%. Mean speed indicated.



200hPa

SpdAve=38 SpdStd=22 DirAve=284 No Calm Reports Nwnd=7360

Frequency circles every 5%. Mean speed indicated.

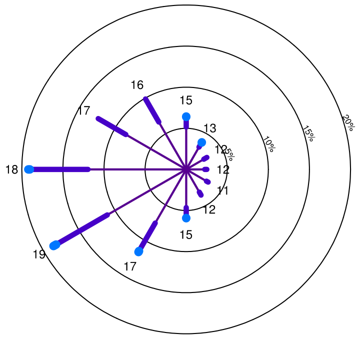


Summer

850hPa

SpdAve=16 SpdStd=8 DirAve=263 No Calm Reports Nwnd=7360

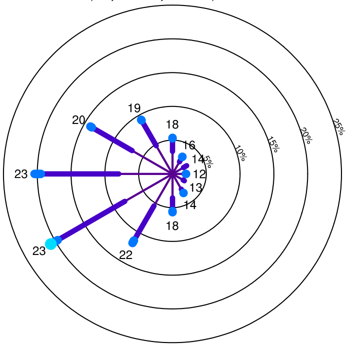
Frequency circles every 5%. Mean speed indicated.



700hPa

SpdAve=21 SpdStd=10 DirAve=262 No Calm Reports Nwnd=7360

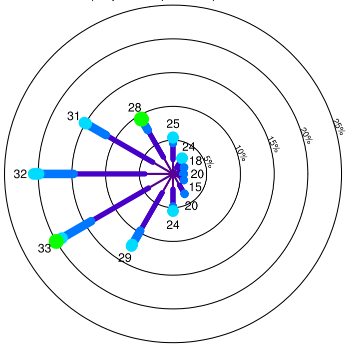
Frequency circles every 5%. Mean speed indicated.



500hPa

SpdAve=29 SpdStd=14 DirAve=264 No Calm Reports Nwnd=7360

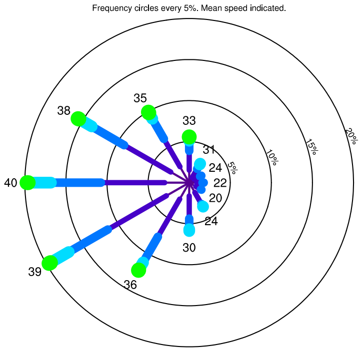
Frequency circles every 5%. Mean speed indicated.



400hPa

SpdAve=36 SpdStd=18 DirAve=266 No Calm Reports Nwnd=7360

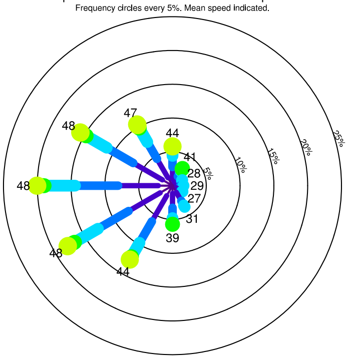
Frequency circles every 5%. Mean speed indicated.



300hPa

SpdAve=45 SpdStd=24 DirAve=269 No Calm Reports Nwnd=7360

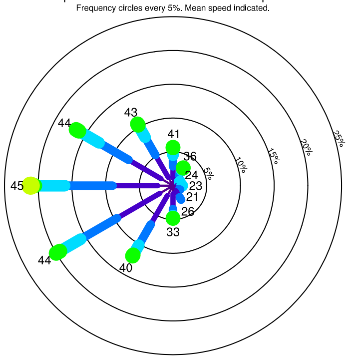
Frequency circles every 5%. Mean speed indicated.



200hPa

SpdAve=42 SpdStd=21 DirAve=270 No Calm Reports Nwnd=7360

Frequency circles every 5%. Mean speed indicated.



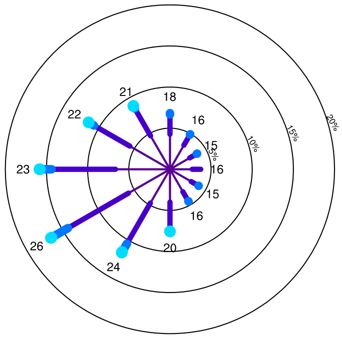
Windrose per season from 850 to 200hPa for Northsea-west (52.5N 02.0E)

Autumn

850hPa

SpdAve=21 SpdStd=11 DirAve=258 No Calm Reports Nwnd=7280

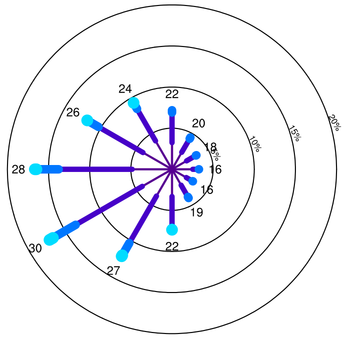
Frequency circles every 5%. Mean speed indicated.



700hPa

SpdAve=25 SpdStd=12 DirAve=262 No Calm Reports Nwnd=7280

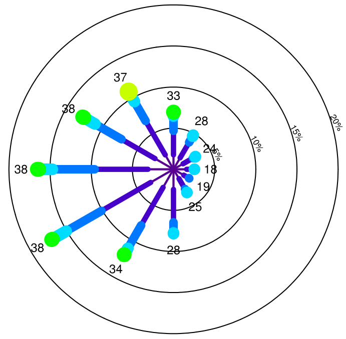
Frequency circles every 5%. Mean speed indicated.



500hPa

SpdAve=34 SpdStd=18 DirAve=270 No Calm Reports Nwnd=7280

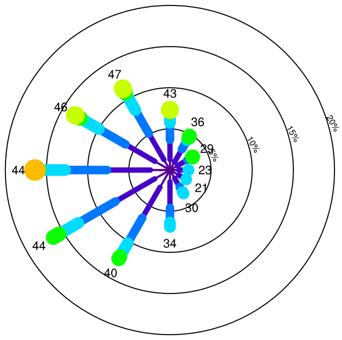
Frequency circles every 5%. Mean speed indicated.



400hPa

SpdAve=41 SpdStd=23 DirAve=273 No Calm Reports Nwnd=7280

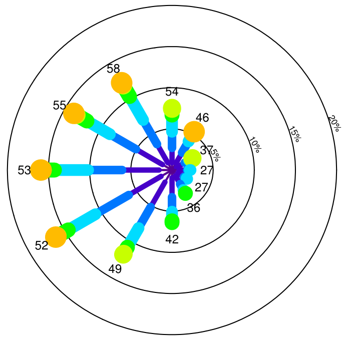
Frequency circles every 5%. Mean speed indicated.



300hPa

SpdAve=50 SpdStd=28 DirAve=278 No Calm Reports Nwnd=7280

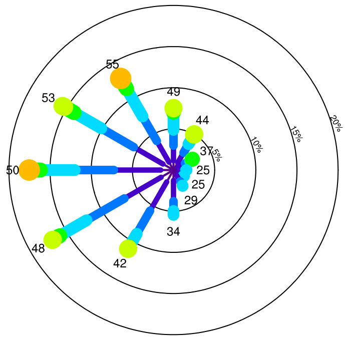
Frequency circles every 5%. Mean speed indicated.



200hPa

SpdAve=47 SpdStd=25 DirAve=283 No Calm Reports Nwnd=7280

Frequency circles every 5%. Mean speed indicated.

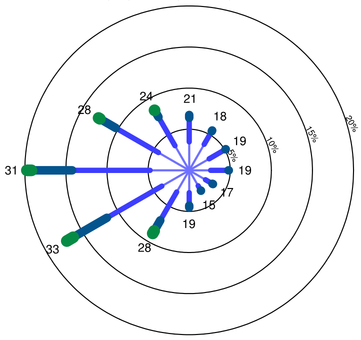


Winter

850hPa

SpdAve=26 SpdStd=14 DirAve=269 No Calm Reports Nwnd=7219

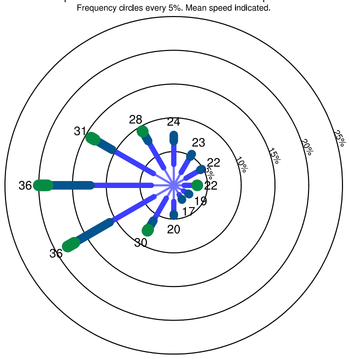
Frequency circles every 5%. Mean speed indicated.



700hPa

SpdAve=30 SpdStd=15 DirAve=274 No Calm Reports Nwnd=7219

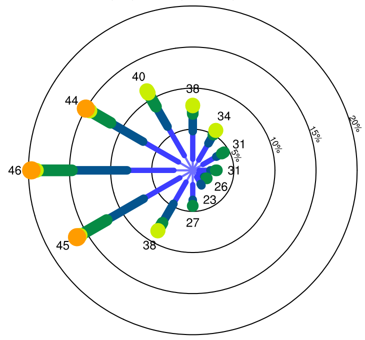
Frequency circles every 5%. Mean speed indicated.



500hPa

SpdAve=40 SpdStd=21 DirAve=281 No Calm Reports Nwnd=7219

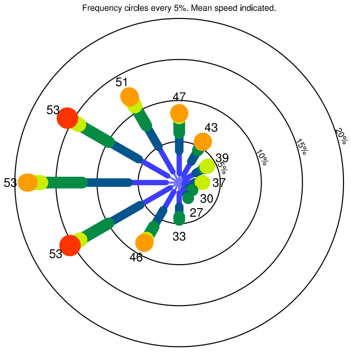
Frequency circles every 5%. Mean speed indicated.



400hPa

SpdAve=48 SpdStd=26 DirAve=285 No Calm Reports Nwnd=7219

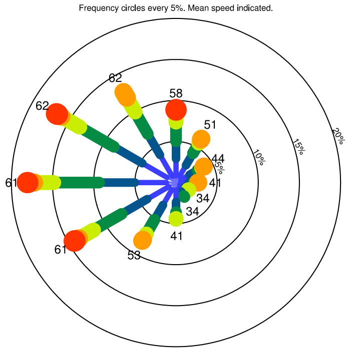
Frequency circles every 5%. Mean speed indicated.



300hPa

SpdAve=57 SpdStd=31 DirAve=289 No Calm Reports Nwnd=7219

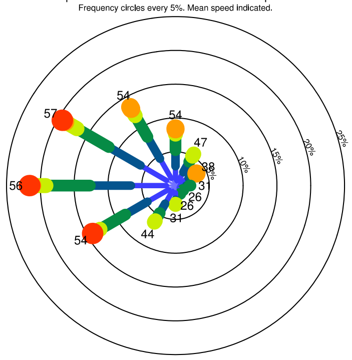
Frequency circles every 5%. Mean speed indicated.



200hPa

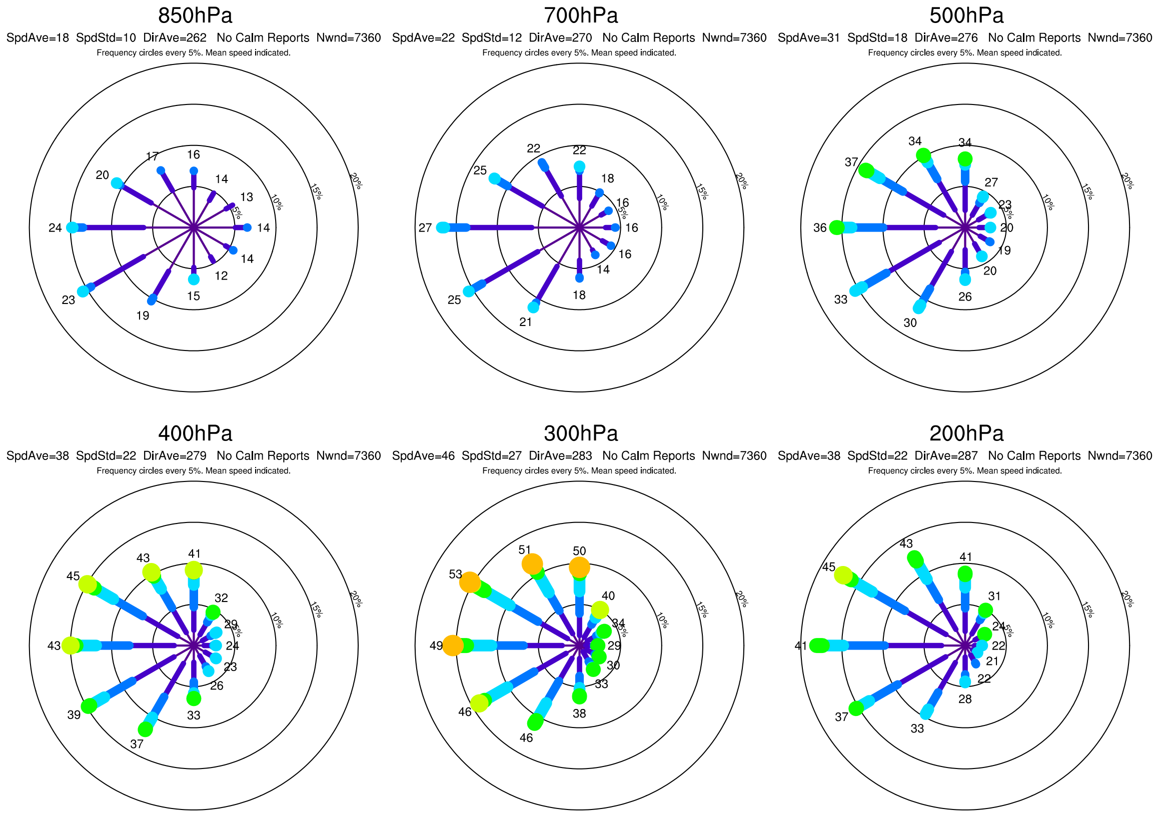
SpdAve=51 SpdStd=27 DirAve=291 No Calm Reports Nwnd=7219

Frequency circles every 5%. Mean speed indicated.

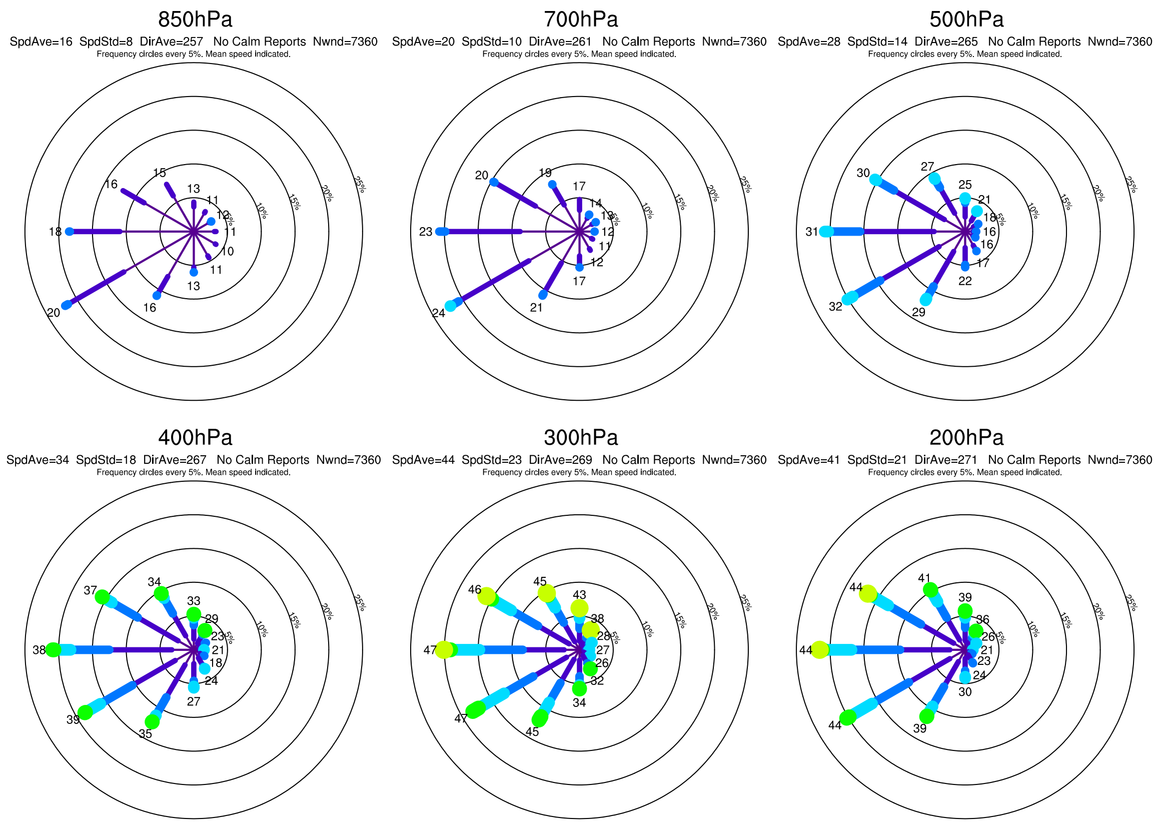


9.3.3 Windrose per season from 850 to 200 hPa for Netherlands-central (De Bilt)

Spring

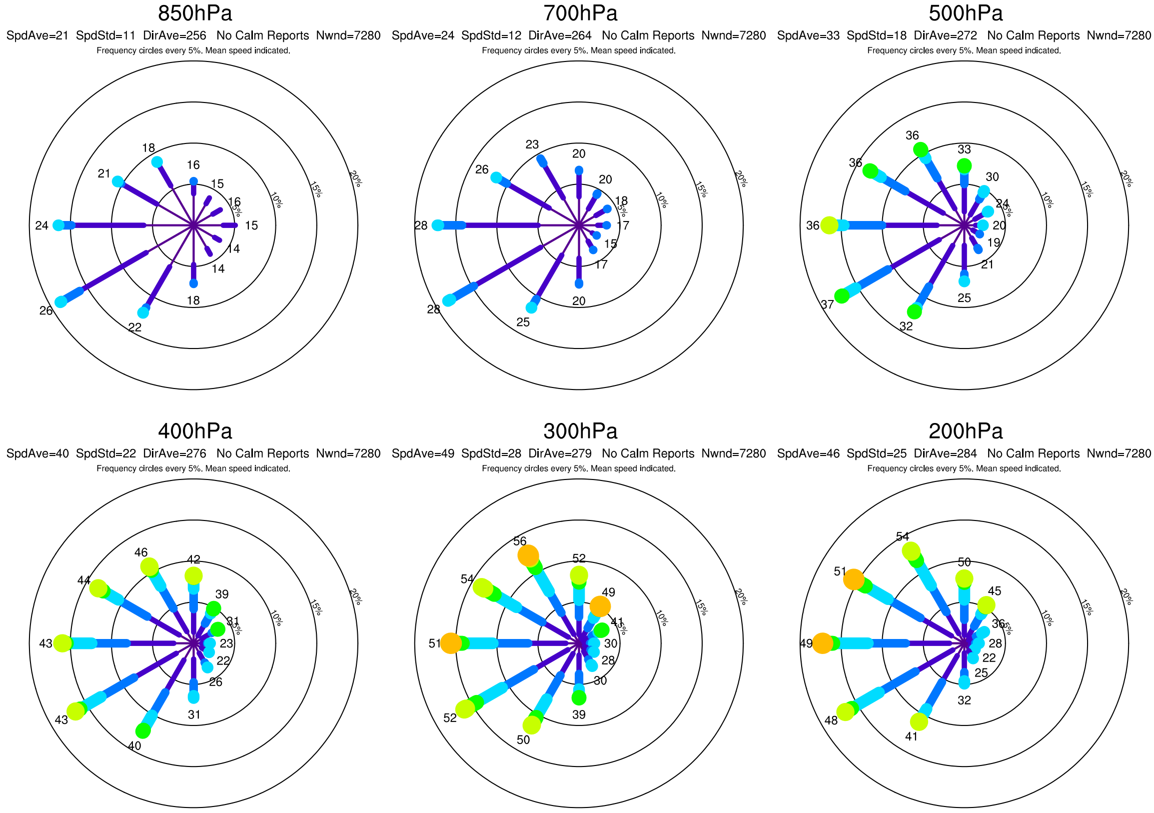


Summer

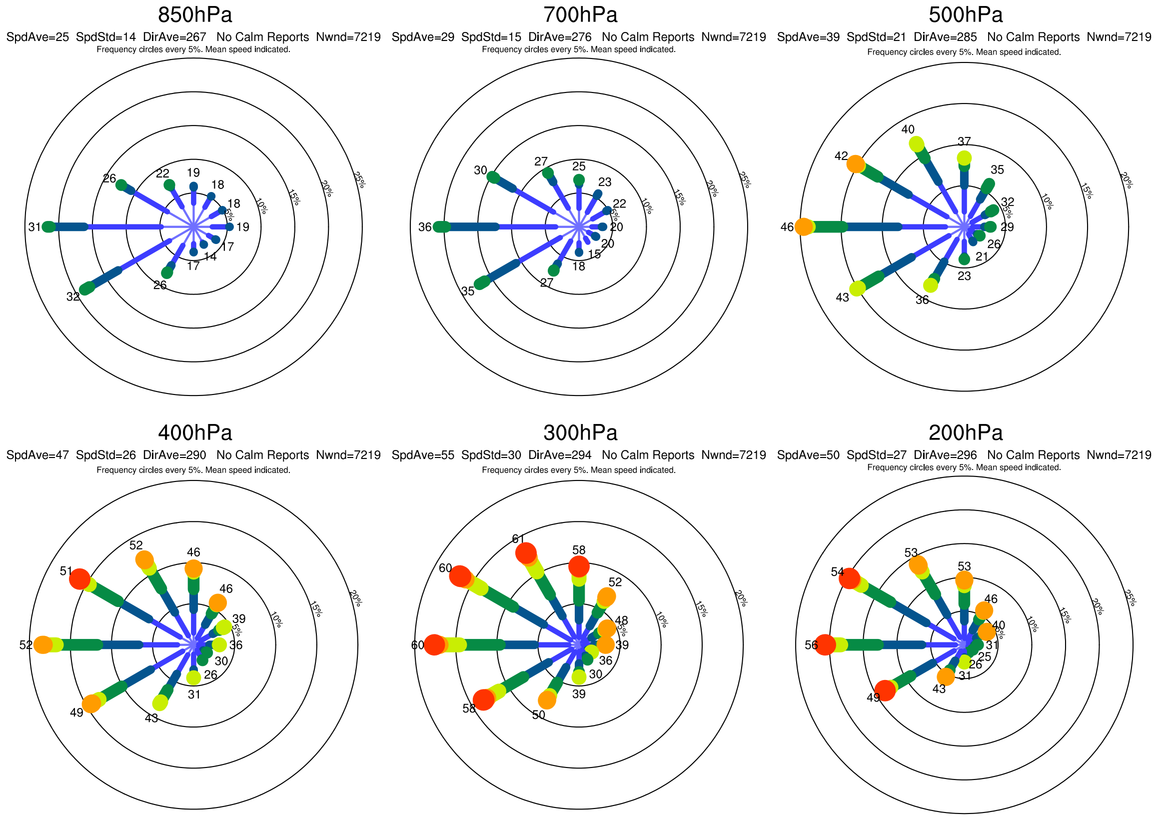


Windrose per season from 850 to 200 hPa for Netherlands-central (De Bilt)

Autumn



Winter



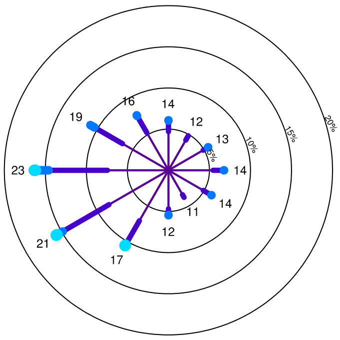
9.3.4 Windrose per season from 850 to 200 hPa for Netherlands-southeast (51.0N 07.0E)

Spring

850hPa

SpdAve=17 SpdStd=11 DirAve=263 No Calm Reports Nwnd=7360

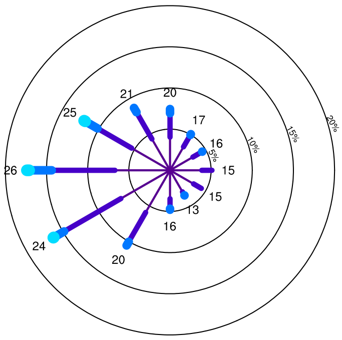
Frequency circles every 5%. Mean speed indicated.



700hPa

SpdAve=21 SpdStd=12 DirAve=273 No Calm Reports Nwnd=7360

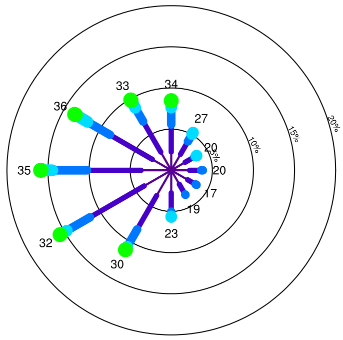
Frequency circles every 5%. Mean speed indicated.



500hPa

SpdAve=30 SpdStd=18 DirAve=279 No Calm Reports Nwnd=7360

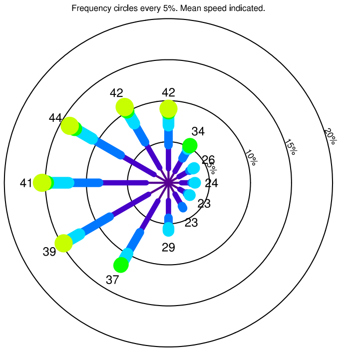
Frequency circles every 5%. Mean speed indicated.



400hPa

SpdAve=38 SpdStd=22 DirAve=281 No Calm Reports Nwnd=7360

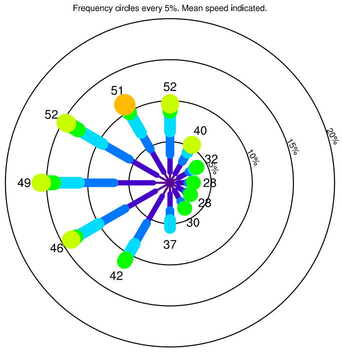
Frequency circles every 5%. Mean speed indicated.



300hPa

SpdAve=45 SpdStd=27 DirAve=285 No Calm Reports Nwnd=7360

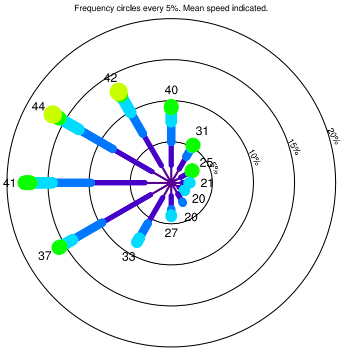
Frequency circles every 5%. Mean speed indicated.



200hPa

SpdAve=37 SpdStd=22 DirAve=288 No Calm Reports Nwnd=7360

Frequency circles every 5%. Mean speed indicated.

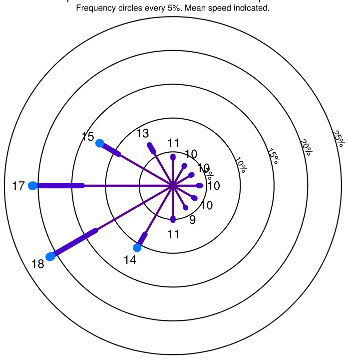


Summer

850hPa

SpdAve=15 SpdStd=8 DirAve=259 No Calm Reports Nwnd=7360

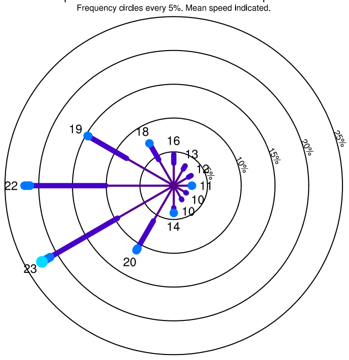
Frequency circles every 5%. Mean speed indicated.



700hPa

SpdAve=19 SpdStd=10 DirAve=263 No Calm Reports Nwnd=7360

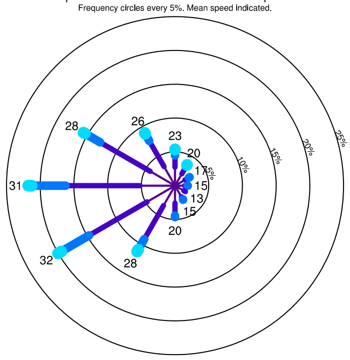
Frequency circles every 5%. Mean speed indicated.



500hPa

SpdAve=27 SpdStd=14 DirAve=267 No Calm Reports Nwnd=7360

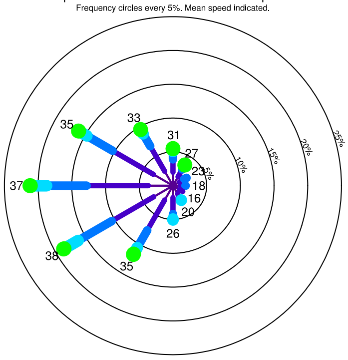
Frequency circles every 5%. Mean speed indicated.



400hPa

SpdAve=34 SpdStd=18 DirAve=268 No Calm Reports Nwnd=7360

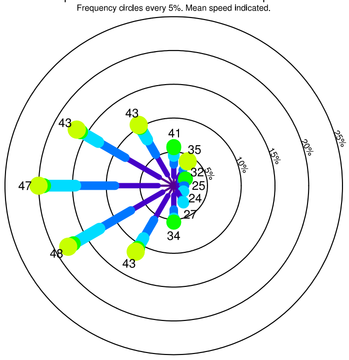
Frequency circles every 5%. Mean speed indicated.



300hPa

SpdAve=43 SpdStd=23 DirAve=270 No Calm Reports Nwnd=7360

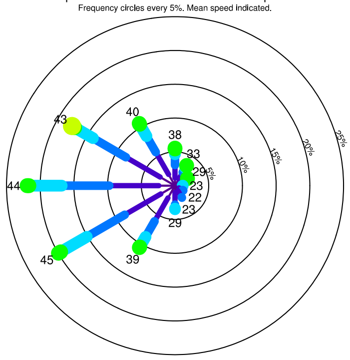
Frequency circles every 5%. Mean speed indicated.



200hPa

SpdAve=41 SpdStd=21 DirAve=273 No Calm Reports Nwnd=7360

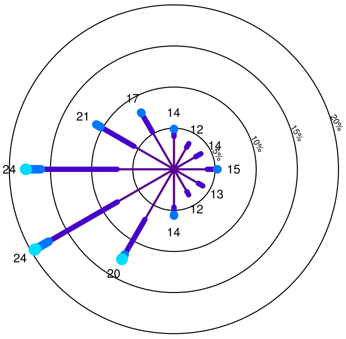
Frequency circles every 5%. Mean speed indicated.



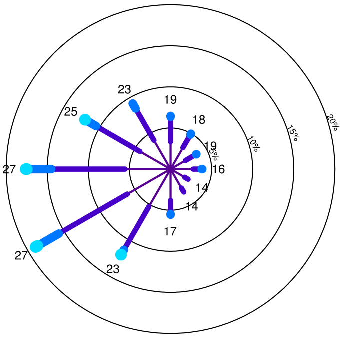
Windrose per season from 850 to 200 hPa for Netherlands-southeast (51.0N 07.0E)

Autumn

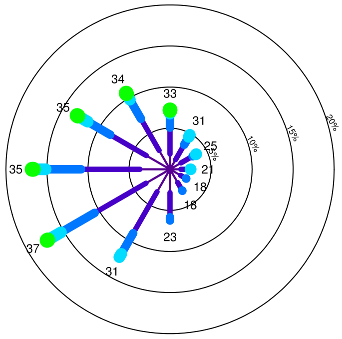
850hPa
SpdAve=20 SpdStd=11 DirAve=257 No Calm Reports Nwnd=7280
Frequency circles every 5%. Mean speed indicated.



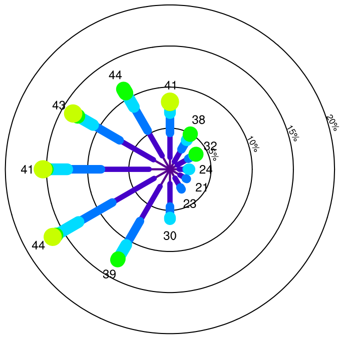
700hPa
SpdAve=23 SpdStd=12 DirAve=266 No Calm Reports Nwnd=7280
Frequency circles every 5%. Mean speed indicated.



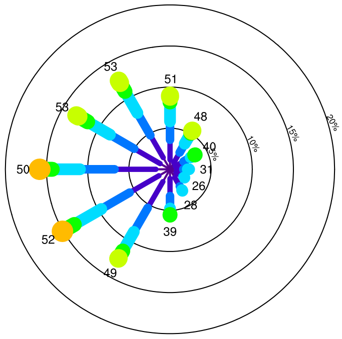
500hPa
SpdAve=32 SpdStd=17 DirAve=273 No Calm Reports Nwnd=7280
Frequency circles every 5%. Mean speed indicated.



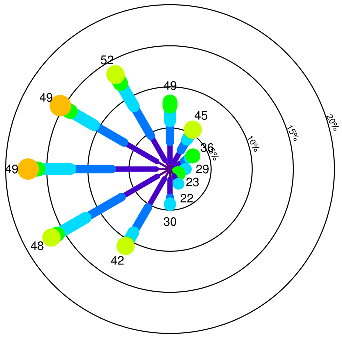
400hPa
SpdAve=39 SpdStd=22 DirAve=277 No Calm Reports Nwnd=7280
Frequency circles every 5%. Mean speed indicated.



300hPa
SpdAve=48 SpdStd=27 DirAve=281 No Calm Reports Nwnd=7280
Frequency circles every 5%. Mean speed indicated.

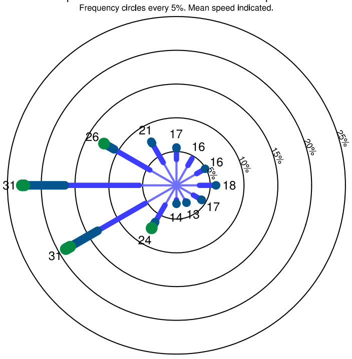


200hPa
SpdAve=46 SpdStd=25 DirAve=285 No Calm Reports Nwnd=7280
Frequency circles every 5%. Mean speed indicated.

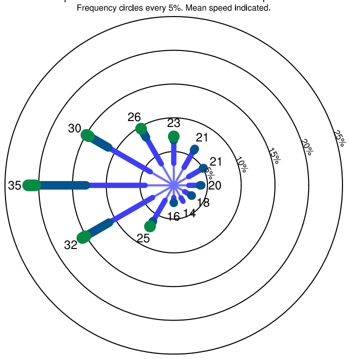


Winter

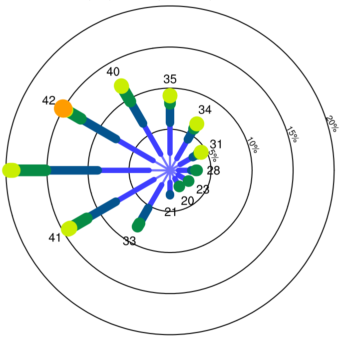
850hPa
SpdAve=24 SpdStd=14 DirAve=267 No Calm Reports Nwnd=7219
Frequency circles every 5%. Mean speed indicated.



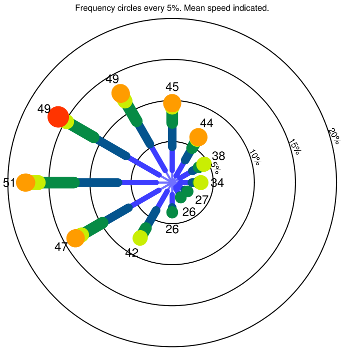
700hPa
SpdAve=28 SpdStd=15 DirAve=280 No Calm Reports Nwnd=7219
Frequency circles every 5%. Mean speed indicated.



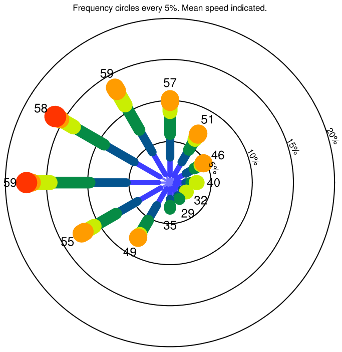
500hPa
SpdAve=37 SpdStd=20 DirAve=289 No Calm Reports Nwnd=7219
Frequency circles every 5%. Mean speed indicated.



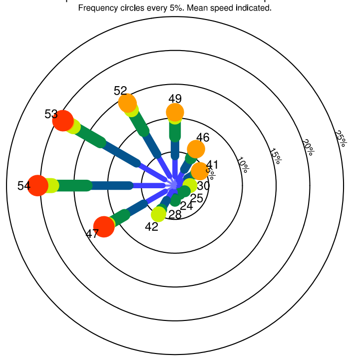
400hPa
SpdAve=45 SpdStd=25 DirAve=293 No Calm Reports Nwnd=7219
Frequency circles every 5%. Mean speed indicated.



300hPa
SpdAve=54 SpdStd=30 DirAve=298 No Calm Reports Nwnd=7219
Frequency circles every 5%. Mean speed indicated.



200hPa
SpdAve=48 SpdStd=26 DirAve=300 No Calm Reports Nwnd=7219
Frequency circles every 5%. Mean speed indicated.



9.4 Wind distribution with ERA-interim 1989-2008 on standard levels in tabular form

Climatology of wind distribution (% per winddirection sector per windspeed class) in tabular form per year on standard pressure levels, 850, 700, 500, 400, 300 and 200 hPa for four locations, Northsea-north (54.0N 07.0E), Northsea-west (52.5N 02.0E), Netherlands-central, Netherlands-southeast (51.0N 07.0E). The output has been calculated from ERA-Interim in the period 1989-2008. The windspeed is expressed in knots, 1 knots is 0.51 m/s. The tables in the report dated 19 April 2010 have been replaced on 14 July 2010.

9.4.1 Wind distribution 850, 700, 500, 400, 300 and 200 hPa for Northsea-north (54.0N 07.0E)

	Wind dir. (deg.)	Wind speed (knots)						
		>= 0	>= 20	>= 40	>= 60	>= 90	>=120	>=150
	345- 15	5.1	1.7	0.1	-	-	-	-
	15- 45	3.6	0.7	-	-	-	-	-
	45- 75	3.4	0.9	-	-	-	-	-
	75-105	4.4	1.4	0.1	-	-	-	-
	105-135	5.2	1.6	0.1	-	-	-	-
850 hPa	135-165	5.4	1.4	-	-	-	-	-
	165-195	6.3	1.9	0.1	-	-	-	-
	195-225	10.2	4.9	0.6	0.1	-	-	-
	225-255	17.0	10.7	2.1	0.2	-	-	-
	255-285	17.6	11.2	2.2	0.2	-	-	-
	285-315	13.0	7.0	1.0	-	-	-	-
	315-345	8.8	4.2	0.4	-	-	-	-
	Total	100	47.6	6.6	0.5	-	-	-

	Wind dir. (deg.)	Wind speed (knots)						
		>= 0	>= 20	>= 40	>= 60	>= 90	>=120	>=150
	345- 15	6.3	3.1	0.3	-	-	-	-
	15- 45	4.3	1.8	0.1	-	-	-	-
	45- 75	3.2	1.1	-	-	-	-	-
	75-105	3.2	1.2	0.1	-	-	-	-
	105-135	3.6	1.0	0.1	-	-	-	-
700 hPa	135-165	4.2	1.1	-	-	-	-	-
	165-195	5.9	2.3	0.1	-	-	-	-
	195-225	10.4	6.1	0.8	-	-	-	-
	225-255	17.3	12.1	3.1	0.3	-	-	-
	255-285	18.5	13.0	3.8	0.4	-	-	-
	285-315	14.0	9.3	2.1	0.2	-	-	-
	315-345	9.3	5.5	1.0	-	-	-	-
	Total	100	57.5	11.6	0.9	-	-	-

	Wind dir. (deg.)	Wind speed (knots)						
		>= 0	>= 20	>= 40	>= 60	>= 90	>=120	>=150
	345- 15	7.2	5.3	2.2	0.6	-	-	-
	15- 45	4.3	3.0	1.1	0.2	-	-	-
	45- 75	2.9	1.5	0.4	0.1	-	-	-
	75-105	2.5	1.2	0.2	-	-	-	-
	105-135	2.7	1.1	0.2	-	-	-	-
500 hPa	135-165	3.4	1.5	0.2	-	-	-	-
	165-195	6.0	3.5	0.7	-	-	-	-
	195-225	11.0	8.2	3.0	0.5	-	-	-
	225-255	16.6	13.3	5.8	1.7	0.1	-	-
	255-285	18.5	15.0	7.2	2.1	0.2	-	-
	285-315	14.6	11.8	5.6	1.7	0.2	-	-
	315-345	10.3	8.1	3.7	1.3	0.1	-	-
	Total	100	73.5	30.2	8.4	0.6	-	-

Wind distribution 850, 700, 500, 400, 300 and 200 hPa for Northsea-north (54.0N 07.0E)

	Wind dir. (deg.)	Wind speed (knots)						
		>= 0	>= 20	>= 40	>= 60	>= 90	>=120	>=150
400 hPa	345- 15	7.6	6.3	3.7	1.6	0.4	-	-
	15- 45	4.6	3.5	1.7	0.6	0.1	-	-
	45- 75	2.8	1.9	0.7	0.2	0.1	-	-
	75-105	2.3	1.4	0.4	0.1	-	-	-
	105-135	2.5	1.3	0.3	0.1	-	-	-
	135-165	3.4	1.9	0.5	0.1	-	-	-
	165-195	5.9	4.1	1.5	0.3	-	-	-
	195-225	11.1	9.0	4.5	1.8	0.1	-	-
	225-255	16.2	13.7	7.5	3.0	0.5	-	-
	255-285	17.6	15.2	8.9	3.9	0.7	0.1	-
	285-315	14.9	12.9	7.8	3.5	0.8	0.1	-
	315-345	11.0	9.2	5.6	2.6	0.6	-	-
	Total	100	80.4	43.1	17.8	3.3	0.2	-

	Wind dir. (deg.)	Wind speed (knots)						
		>= 0	>= 20	>= 40	>= 60	>= 90	>=120	>=150
300 hPa	345- 15	8.3	7.2	5.0	3.0	0.9	0.1	-
	15- 45	4.7	3.8	2.4	1.3	0.3	-	-
	45- 75	2.7	2.1	1.1	0.5	0.1	-	-
	75-105	2.1	1.4	0.6	0.2	-	-	-
	105-135	2.3	1.4	0.5	0.1	-	-	-
	135-165	3.4	2.3	0.9	0.2	-	-	-
	165-195	5.8	4.3	2.2	0.8	0.1	-	-
	195-225	10.8	9.4	5.9	3.0	0.7	0.1	-
	225-255	15.5	13.7	9.2	4.8	1.2	0.2	-
	255-285	17.4	15.7	10.6	5.8	1.7	0.4	-
	285-315	15.3	13.8	9.8	5.7	1.8	0.3	-
	315-345	11.8	10.6	7.5	4.4	1.5	0.4	-
	Total	100	85.7	55.7	29.8	8.4	1.5	0.1

	Wind dir. (deg.)	Wind speed (knots)						
		>= 0	>= 20	>= 40	>= 60	>= 90	>=120	>=150
200 hPa	345- 15	8.3	6.8	4.4	2.2	0.5	-	-
	15- 45	4.2	3.2	2.0	0.8	0.1	-	-
	45- 75	2.5	1.6	0.6	0.2	-	-	-
	75-105	1.6	0.9	0.2	0.1	-	-	-
	105-135	1.6	0.8	0.2	-	-	-	-
	135-165	2.2	1.2	0.2	-	-	-	-
	165-195	4.0	2.6	0.9	0.2	-	-	-
	195-225	9.8	8.0	4.1	1.3	0.1	-	-
	225-255	16.5	14.4	8.3	3.4	0.5	-	-
	255-285	20.1	17.8	10.9	4.9	1.1	0.1	-
	285-315	16.9	14.9	9.8	5.2	1.3	0.1	-
	315-345	12.4	10.8	7.0	3.6	0.8	0.1	-
	Total	100	83.0	48.6	21.9	4.4	0.4	-

9.4.2 Wind distribution 850, 700, 500, 400, 300 and 200hPa for Northsea-west (52.5N 02.0E)

850 hPa

Wind dir. (deg.)	Wind speed (knots)						
	>= 0	>= 20	>= 40	>= 60	>= 90	>=120	>=150
345- 15	7.1	2.7	0.1	-	-	-	-
15- 45	5.0	1.5	0.1	-	-	-	-
45- 75	4.4	1.4	-	-	-	-	-
75-105	4.1	1.2	-	-	-	-	-
105-135	3.8	0.8	-	-	-	-	-
135-165	3.9	0.9	-	-	-	-	-
165-195	6.0	2.2	0.1	-	-	-	-
195-225	10.6	5.6	0.9	0.1	-	-	-
225-255	16.6	1-	2.4	0.3	-	-	-
255-285	17.3	9.8	2.1	0.2	-	-	-
285-315	12.0	6.0	1.0	0.1	-	-	-
315-345	9.1	4.0	0.3	-	-	-	-
Total	100	45.9	7.2	0.6	-	-	-

700 hPa

Wind dir. (deg.)	Wind speed (knots)						
	>= 0	>= 20	>= 40	>= 60	>= 90	>=120	>=150
345- 15	7.0	3.6	0.4	-	-	-	-
15- 45	4.5	2.1	0.2	-	-	-	-
45- 75	3.7	1.5	0.1	-	-	-	-
75-105	3.1	1.1	0.1	-	-	-	-
105-135	3.0	0.8	0.1	-	-	-	-
135-165	3.5	1.1	0.1	-	-	-	-
165-195	6.0	2.8	0.2	-	-	-	-
195-225	10.5	6.7	1.2	0.1	-	-	-
225-255	17.7	12.5	3.5	0.4	-	-	-
255-285	18.2	13.0	3.5	0.4	-	-	-
285-315	13.4	8.4	1.9	0.2	-	-	-
315-345	9.3	5.3	0.8	-	-	-	-
Total	100	58.9	12.1	1.2	-	-	-

500 hPa

Wind dir. (deg.)	Wind speed (knots)						
	>= 0	>= 20	>= 40	>= 60	>= 90	>=120	>=150
345- 15	7.1	5.3	2.2	0.6	-	-	-
15- 45	4.4	3.0	1.0	0.2	-	-	-
45- 75	3.0	1.8	0.5	0.1	-	-	-
75-105	2.5	1.3	0.3	-	-	-	-
105-135	2.4	0.9	0.2	-	-	-	-
135-165	3.3	1.8	0.3	-	-	-	-
165-195	6.1	3.9	1.0	0.1	-	-	-
195-225	11.1	8.5	3.4	0.7	-	-	-
225-255	17.0	13.8	6.8	2.1	0.1	-	-
255-285	18.3	15.0	7.8	2.4	0.2	-	-
285-315	14.3	11.5	5.6	1.9	0.2	-	-
315-345	10.6	8.2	3.6	1.2	0.1	-	-
Total	100	74.9	32.7	9.2	0.8	-	-

Wind distribution 850, 700, 500, 400, 300 and 200hPa for Northsea-west (52.5N 02.0E)

	Wind dir. (deg.)	Wind speed (knots)						
		>= 0	>= 20	>= 40	>= 60	>= 90	>=120	>=150
	345- 15	7.4	6.1	3.5	1.5	0.2	-	-
	15- 45	4.5	3.4	1.8	0.6	0.1	-	-
	45- 75	3.0	2.1	0.8	0.2	-	-	-
	75-105	2.4	1.4	0.4	0.1	-	-	-
	105-135	2.2	1.2	0.3	-	-	-	-
400 hPa	135-165	3.3	2.0	0.7	0.1	-	-	-
	165-195	6.0	4.5	2.0	0.5	-	-	-
	195-225	11.2	9.1	5.0	1.8	0.2	-	-
	225-255	16.6	14.1	8.3	3.5	0.7	-	-
	255-285	17.6	15.2	9.5	4.2	0.8	0.1	-
	285-315	14.8	12.7	7.8	3.7	0.9	0.1	-
	315-345	11.2	9.4	5.6	2.6	0.6	0.1	-
	Total	100	81.2	45.8	18.9	3.6	0.3	-

	Wind dir. (deg.)	Wind speed (knots)						
		>= 0	>= 20	>= 40	>= 60	>= 90	>=120	>=150
	345- 15	7.8	6.8	4.8	2.7	0.8	0.1	-
	15- 45	4.9	4.0	2.6	1.3	0.3	0.1	-
	45- 75	2.8	2.2	1.2	0.5	0.1	-	-
	75-105	2.2	1.4	0.6	0.2	-	-	-
	105-135	2.1	1.4	0.5	0.1	-	-	-
300 hPa	135-165	3.2	2.3	1.1	0.3	-	-	-
	165-195	5.8	4.7	2.7	1.1	0.1	-	-
	195-225	11.0	9.5	6.1	3.1	0.8	0.1	-
	225-255	15.7	14.1	9.7	5.4	1.6	0.3	-
	255-285	17.4	15.8	11.1	6.3	1.9	0.3	-
	285-315	15.3	13.8	9.8	5.8	2.0	0.4	-
	315-345	11.8	10.7	7.6	4.6	1.7	0.4	-
	Total	100	86.7	57.9	31.4	9.5	1.6	0.1

	Wind dir. (deg.)	Wind speed (knots)						
		>= 0	>= 20	>= 40	>= 60	>= 90	>=120	>=150
	345- 15	7.6	6.4	4.2	2.1	0.4	-	-
	15- 45	4.4	3.4	2.0	0.9	0.2	-	-
	45- 75	2.5	1.7	0.8	0.3	-	-	-
	75-105	1.7	1.0	0.3	0.1	-	-	-
	105-135	1.4	0.7	0.2	-	-	-	-
200 hPa	135-165	2.3	1.4	0.4	-	-	-	-
	165-195	4.5	3.2	1.2	0.3	-	-	-
	195-225	9.9	8.2	4.3	1.6	0.2	-	-
	225-255	16.7	14.6	9.0	4.1	0.8	-	-
	255-285	19.6	17.6	11.6	5.8	1.3	0.1	-
	285-315	17.2	15.3	10.3	5.4	1.5	0.2	-
	315-345	12.1	10.7	7.2	3.9	0.9	0.1	-
	Total	100	84.4	51.5	24.5	5.2	0.6	-

9.4.3 Wind distribution 850, 700, 500, 400, 300 and 200hPa for Netherlands-central (De Bilt)

850 hPa

Wind dir. (deg.)	Wind speed (knots)						
	>= 0	>= 20	>= 40	>= 60	>= 90	>=120	>=150
345- 15	5.7	1.7	0.1	-	-	-	-
15- 45	4.3	1.0	-	-	-	-	-
45- 75	4.3	1.1	-	-	-	-	-
75-105	5.1	1.4	-	-	-	-	-
105-135	4.2	0.8	-	-	-	-	-
135-165	4.1	0.6	-	-	-	-	-
165-195	5.8	1.5	0.1	-	-	-	-
195-225	10.4	4.7	0.7	0.1	-	-	-
225-255	18.7	11.3	2.5	0.3	-	-	-
255-285	17.8	10.9	2.1	0.1	-	-	-
285-315	11.5	5.5	0.7	-	-	-	-
315-345	8.0	3.0	0.2	-	-	-	-
Total	100	43.3	6.3	0.5	-	-	-

700 hPa

Wind dir. (deg.)	Wind speed (knots)						
	>= 0	>= 20	>= 40	>= 60	>= 90	>=120	>=150
345- 15	6.5	3.3	0.3	-	-	-	-
15- 45	4.5	2.0	0.2	-	-	-	-
45- 75	3.9	1.5	0.1	-	-	-	-
75-105	3.4	1.1	0.1	-	-	-	-
105-135	3.0	0.8	-	-	-	-	-
135-165	3.3	0.7	-	-	-	-	-
165-195	5.6	2.1	0.1	-	-	-	-
195-225	10.3	6.0	0.9	-	-	-	-
225-255	18.3	12.5	3.3	0.3	-	-	-
255-285	18.9	13.1	3.8	0.4	-	-	-
285-315	13.3	8.0	1.7	0.1	-	-	-
315-345	9.0	5.0	0.8	-	-	-	-
Total	100	56.0	11.3	0.8	-	-	-

500 hPa

Wind dir. (deg.)	Wind speed (knots)						
	>= 0	>= 20	>= 40	>= 60	>= 90	>=120	>=150
345- 15	7.2	5.3	2.3	0.6	-	-	-
15- 45	4.7	3.1	1.2	0.3	-	-	-
45- 75	3.3	1.9	0.5	0.1	-	-	-
75-105	2.5	1.2	0.3	-	-	-	-
105-135	2.4	1.1	0.1	-	-	-	-
135-165	3.3	1.4	0.2	-	-	-	-
165-195	5.6	3.3	0.7	-	-	-	-
195-225	10.9	8.0	3.0	0.6	-	-	-
225-255	17.0	13.6	6.1	1.7	0.1	-	-
255-285	18.1	14.7	7.2	2.2	0.2	-	-
285-315	14.5	11.5	5.2	1.7	0.2	-	-
315-345	10.4	7.9	3.6	1.1	0.1	-	-
Total	100	72.9	30.2	8.4	0.6	-	-

Wind distribution 850, 700, 500, 400, 300 and 200hPa for Netherlands-central (De Bilt)

	Wind dir. (deg.)	Wind speed (knots)						
		>= 0	>= 20	>= 40	>= 60	>= 90	>=120	>=150
400 hPa	345- 15	8.0	6.4	3.8	1.6	0.2	-	-
	15- 45	4.7	3.6	1.8	0.7	0.1	-	-
	45- 75	3.3	2.2	0.9	0.3	0.1	-	-
	75-105	2.4	1.4	0.5	0.1	-	-	-
	105-135	2.3	1.2	0.3	-	-	-	-
	135-165	3.1	1.9	0.5	-	-	-	-
	165-195	5.7	3.9	1.5	0.3	-	-	-
	195-225	11.2	9.0	4.6	1.8	0.1	-	-
	225-255	16.1	13.7	7.7	3.2	0.5	-	-
	255-285	17.6	15.1	8.8	4.0	0.8	0.1	-
	285-315	15.0	12.8	7.6	3.4	0.8	0.1	-
	315-345	10.7	8.9	5.4	2.5	0.6	0.1	-
	Total	100	80.1	43.5	18.0	3.2	0.3	-

	Wind dir. (deg.)	Wind speed (knots)						
		>= 0	>= 20	>= 40	>= 60	>= 90	>=120	>=150
300 hPa	345- 15	8.4	7.3	5.1	2.9	0.9	0.1	-
	15- 45	5.1	4.2	2.7	1.4	0.4	0.1	-
	45- 75	3.2	2.5	1.3	0.6	0.1	-	-
	75-105	2.2	1.5	0.7	0.2	-	-	-
	105-135	2.1	1.4	0.5	0.1	-	-	-
	135-165	3.0	2.1	0.9	0.2	-	-	-
	165-195	5.7	4.3	2.3	0.9	0.1	-	-
	195-225	10.6	9.1	6.0	3.0	0.7	-	-
	225-255	15.5	13.8	9.3	5.1	1.4	0.2	-
	255-285	17.2	15.4	10.5	5.8	1.8	0.3	-
	285-315	15.4	13.9	9.7	5.6	1.9	0.4	-
	315-345	11.6	10.3	7.1	4.4	1.5	0.4	-
	Total	100	85.8	56.0	30.1	8.9	1.5	0.1

	Wind dir. (deg.)	Wind speed (knots)						
		>= 0	>= 20	>= 40	>= 60	>= 90	>=120	>=150
200 hPa	345- 15	8.0	6.8	4.5	2.3	0.4	-	-
	15- 45	4.9	3.7	2.2	0.9	0.2	-	-
	45- 75	2.8	2.0	0.9	0.3	-	-	-
	75-105	1.8	1.0	0.3	0.1	-	-	-
	105-135	1.5	0.7	0.2	-	-	-	-
	135-165	2.1	1.2	0.2	-	-	-	-
	165-195	4.0	2.9	1.0	0.2	-	-	-
	195-225	9.4	7.6	4.1	1.4	0.1	-	-
	225-255	16.5	14.3	8.6	3.8	0.6	-	-
	255-285	19.4	17.3	11.2	5.3	1.2	0.1	-
	285-315	17.3	15.2	10.1	4.8	1.3	0.2	-
	315-345	12.4	10.7	7.0	3.8	0.8	0.1	-
	Total	100	83.4	50.5	23.0	4.6	0.5	-

9.4.4 Wind distribution 850, 700, 500, 400, 300 and 200hPa for Netherlands-southeast (51.0N 07.0E)

850 hPa

Wind dir. (deg.)	Wind speed (knots)						
	>= 0	>= 20	>= 40	>= 60	>= 90	>=120	>=150
345- 15	5.2	1.1	-	-	-	-	-
15- 45	4.1	0.6	-	-	-	-	-
45- 75	4.4	0.8	-	-	-	-	-
75-105	5.5	1.3	-	-	-	-	-
105-135	4.6	0.9	-	-	-	-	-
135-165	3.5	0.3	-	-	-	-	-
165-195	4.8	0.7	-	-	-	-	-
195-225	10.3	3.9	0.5	-	-	-	-
225-255	18.8	10.1	2.1	0.2	-	-	-
255-285	19.5	11.2	2.5	0.1	-	-	-
285-315	11.7	5.2	0.7	-	-	-	-
315-345	7.5	2.5	0.1	-	-	-	-
Total	100	38.6	6.1	0.4	-	-	-

700 hPa

Wind dir. (deg.)	Wind speed (knots)						
	>= 0	>= 20	>= 40	>= 60	>= 90	>=120	>=150
345- 15	6.5	3.0	0.3	-	-	-	-
15- 45	4.9	1.9	0.1	-	-	-	-
45- 75	4.1	1.5	-	-	-	-	-
75-105	3.9	1.1	0.1	-	-	-	-
105-135	3.0	0.7	-	-	-	-	-
135-165	3.0	0.4	-	-	-	-	-
165-195	4.3	1.2	0.1	-	-	-	-
195-225	10.2	5.2	0.6	-	-	-	-
225-255	18.4	11.8	2.7	0.2	-	-	-
255-285	19.7	13.0	3.9	0.4	-	-	-
285-315	13.4	8.0	1.8	0.1	-	-	-
315-345	8.7	4.6	0.7	-	-	-	-
Total	100	52.4	10.3	0.7	-	-	-

500 hPa

Wind dir. (deg.)	Wind speed (knots)						
	>= 0	>= 20	>= 40	>= 60	>= 90	>=120	>=150
345- 15	7.5	5.3	2.3	0.6	-	-	-
15- 45	5.0	3.2	1.3	0.3	-	-	-
45- 75	3.5	1.9	0.5	0.1	-	-	-
75-105	2.9	1.4	0.3	-	-	-	-
105-135	2.6	1.0	0.1	-	-	-	-
135-165	2.8	1.1	0.1	-	-	-	-
165-195	4.9	2.5	0.4	-	-	-	-
195-225	10.7	7.6	2.7	0.4	-	-	-
225-255	16.8	13.3	5.7	1.5	0.1	-	-
255-285	18.5	14.7	7.0	2.0	0.2	-	-
285-315	14.4	11.2	5.0	1.5	0.2	-	-
315-345	10.4	7.7	3.3	1.1	0.1	-	-
Total	100	70.9	28.7	7.6	0.5	-	-

Wind distribution 850, 700, 500, 400, 300 and 200hPa for Netherlands-southeast (51.0N 07.0E)

400 hPa

Wind dir. (deg.)	Wind speed (knots)						
	>= 0	>= 20	>= 40	>= 60	>= 90	>=120	>=150
345- 15	8.1	6.5	3.8	1.6	0.3	-	-
15- 45	5.0	3.8	2.0	0.8	0.1	-	-
45- 75	3.5	2.3	1.0	0.3	-	-	-
75-105	2.8	1.6	0.5	0.1	-	-	-
105-135	2.3	1.1	0.2	-	-	-	-
135-165	2.7	1.5	0.2	-	-	-	-
165-195	5.2	3.4	1.2	0.2	-	-	-
195-225	11.0	8.8	4.5	1.6	0.1	-	-
225-255	15.9	13.4	7.6	3.0	0.4	-	-
255-285	17.5	14.8	8.4	3.7	0.7	0.1	-
285-315	14.9	12.5	7.3	3.1	0.6	0.1	-
315-345	11.0	9.0	5.2	2.4	0.6	-	-
Total	100	78.6	42.0	16.7	2.8	0.2	-

300 hPa

Wind dir. (deg.)	Wind speed (knots)						
	>= 0	>= 20	>= 40	>= 60	>= 90	>=120	>=150
345- 15	8.7	7.5	5.3	3.1	0.9	0.2	-
15- 45	5.5	4.3	2.7	1.5	0.4	0.1	-
45- 75	3.5	2.6	1.5	0.6	0.1	-	-
75-105	2.5	1.8	0.8	0.3	-	-	-
105-135	2.2	1.4	0.4	0.1	-	-	-
135-165	3.0	1.9	0.7	0.1	-	-	-
165-195	4.9	3.8	1.9	0.7	-	-	-
195-225	10.7	9.1	5.6	2.7	0.6	-	-
225-255	14.9	13.2	8.9	4.9	1.2	0.2	-
255-285	17.3	15.4	10.4	5.7	1.7	0.3	-
285-315	15.1	13.4	9.1	5.1	1.6	0.3	-
315-345	11.8	10.3	7.0	4.2	1.4	0.3	-
Total	100	84.6	54.4	29.0	8.0	1.2	-

200 hPa

Wind dir. (deg.)	Wind speed (knots)						
	>= 0	>= 20	>= 40	>= 60	>= 90	>=120	>=150
345- 15	8.5	7.1	4.5	2.2	0.4	-	-
15- 45	5.1	3.9	2.3	0.9	0.1	-	-
45- 75	3.1	2.2	1.1	0.4	-	-	-
75-105	1.9	1.0	0.4	0.1	-	-	-
105-135	1.5	0.8	0.1	-	-	-	-
135-165	2.1	1.1	0.2	-	-	-	-
165-195	3.6	2.4	0.7	0.2	-	-	-
195-225	8.7	7.1	3.8	1.3	0.1	-	-
225-255	16.2	14.0	8.5	3.8	0.5	-	-
255-285	19.4	17.1	11.0	5.2	1.0	0.1	-
285-315	17.2	15.0	9.8	4.6	1.1	0.2	-
315-345	12.7	10.9	7.1	3.6	0.8	0.1	-
Total	100	82.6	49.5	22.3	4.2	0.4	-

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