Upper Air Climatology of Amsterdam FIR, using ERA-Interim 1989-2008 Part 2

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Abstract

This report presents upper-air climatology for the lower troposphere (below 850 hPa or 1.5 km) for the Schiphol Area of the Flight Information Region of the Netherlands (EHAM-FIR). 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). Climatology of the upper troposhere, 850 tot150 hPa, is presented in part 1.

The climatology below 1.5 km is based on ERA-Interim atmospheric reanalysis, period 1989-2009.

As in part 1, the results of ERA-Interim are (in overlapping period) compared with other sources:

. reanalysis of HIRLAM (2003-2005)

. radiosonde soundings from De Bilt (1989-2009)

. Cabauw-observations (1986-2009, break in 1997-2000)

. OWEZ-observations (2005-2009)

ERA-Interim is a state-of-the-art reanalysis-project of the European Centre for Medium Range Weather Forecast ECMWF, HIRLAM is the operational high resolution model of KNMI and Cabauw and OWEZ are meteorological masts in the centre-part of the Netherlands and off-shore near Egmond aan Zee.

Results of these comparisons indicate the agreement between the different sources.

Contents

Chapter 1

Introduction

1.1 Knowledge for Climate programme

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.

1.2 Hotspot Mainport Schiphol

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 [Hirlam, 2010].

1.3 Upper air climatology

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. The climatology between 850 and 150 hPa is presented in part 1. This report, part 2, focuses on the lower troposphere, below 850 hPa (1500 meters, 5000 ft, flight level FL050).

1.4 Amsterdam-FIR

As described in part 1, 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). The airspce of the Neterhlands 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 1a-b.

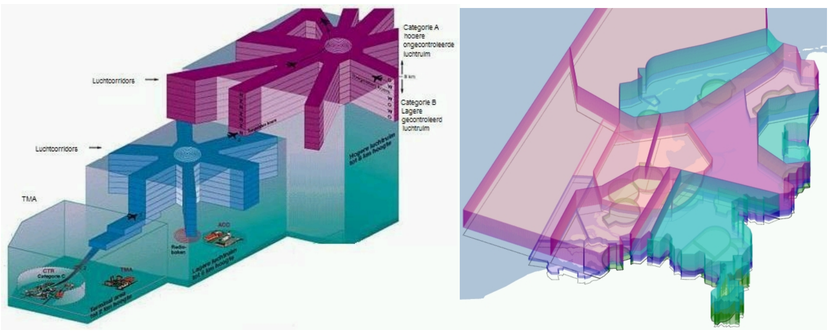


Figure 1a and 1b. Illustrating airspace categories and schematic division of Amsterdam-FIR

Climatology of wind direction, 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. This climatology is based on a twenty-year period with a state-of-art reanalysis ERA-Interim and output from the reanalysis will be mainly verified against sparse observations of the upper air.

1.5 Reanalysis ECMWF

As described in part 1, reanalyses 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 analyses for study of past conditions. Production of ERA-Interim, from 1989 onwards, began in summer 2006. Enhanced computer power enabled horizontal resolution to be increased to T255, but vertical resolution was kept at the 60 levels used for ERA-40 [Simmons, 2009].

ERA-Interim is a reanalysis of the global atmosphere covering the data-rich period since 1989, and continuing in real time. As ERA-Interim continues forward in time, updates of the Archive will take place on a monthly basis. 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.

Documentation 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.

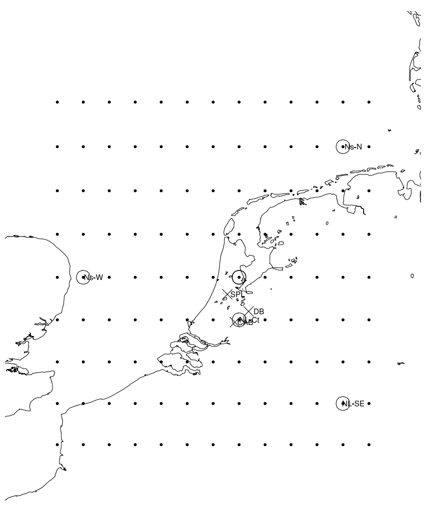


Figure 3: ERA-Interim with location- and model-indications Schiphol, De Bilt, Cabauw and airspace-points.

In figure 3 the horizontal grid, used for climatological calculations of wind, temperature and humidity with the model, is presented, as well as the locations of De Bilt, Cabauw and Schiphol. The circles indicate the grid points of ERA-Interim used for the locations Schiphol and De Bilt/Cabauw.

Based on internal evaluations and comparisons with other reanalyses, the quality of ERA-Interim products is generally good and its long-term homogeneity has improved considerably. [Uppala, 2008] The ERA-Interim project has now reached a major milestone after completing more than 20 years of reanalysis from 1989 onwards. 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].

1.6 Reanalysis HIRLAM

For a three-year period (2003-2005) a reanalysis of HIRLAM was available for comparison of wind, temperature and relative humidity.

HIRLAM is a European cooperative scientific programme developing a high resolution numerical weather prediction system for the synoptic scale and the mesoscale. The HIRLAM model is a hydrostatic grid-point model, in which a variety of subgridscale physical processes are taken into account by parametrization schemes. More details on the dynamical, numerical and physical aspects of HIRLAM can be found in the HIRLAM Scientific Documentation [Hirlam, 2010].

The default upper air data assimilation scheme in HIRLAM is, like ERA-Interim, 4D-VAR. There is a standard version of HIRLAM, which is referred to as the Reference System. This Reference system (which consists of code, scripts, libraries and tools) is maintained on the HIRLAM server, at ECMWF and at Finish Meteorological Institute, where it is run as the operational HIRLAM model. The HIRLAM system is under constant verification.

The model is constantly verified, recent running monthly mean bias (and root mean square error) for temperature at 850 hPa is about 0.2 ^{O}C (rms 1.7 ^{o}C), at 2 meters -0.1 ^{o}C (rms 1.2 ^{o}C), windspeed at 850 hPa close to 0 m/s (rms 3.5 m/s) and at 10 meters +0.5 m/s (rms 2 m/s) [Hirlam (FMI) verification, 2010].

Chapter 2

Climatology up to 200 meters at Cabauw

2.1 Introduction planetary boundary layer

In theoretical concepts the lower layer of the troposphere is, for simplification, divided in a layer directly influenced by the Earth's surface, called the *Planetary Boundary Layer* (PBL), and the free atmosphere.

ThePBL is the bottom layer of the troposphere that is in contact with the surface of the earth. It is often turbulent and is capped by a statically stable layer of air or temperature inversion. The PBL depth (i.e., the inversion height) is variable in time and space. During fair weather over land, the PBL has a marked diurnal cycle. During daytime, a mixed layer of vigorous turbulence grows in depth, capped by a statically stable entrainment zone of intermittent turbulence. Near sunset, turbulence decays, leaving a residual layer in place of the mixed layer. During nighttime, the bottom of the residual layer is transformed into a statically stable boundary layer by contact with the radiatively cooled surface. Cumulus and stratocumulus clouds can form within the top portion of a humid PBL, while fog can form at the bottom of a stable boundary layer. The bottom 10% of the PBL is called the surface layer [Stull, 1988].

In the free atmosphere the *geostrophic wind* dominates, the result of the *pressure gradient force* (from high pressure to low pressure) and *coriolis force* (caused by the Earth's rotation). According to Buys Ballot's law the low pressure area will be on your left side when the resulting (geostrophic) wind blows in your back (on the Northern Hemisphere). In the PBL surface roughness and temperature variation have influence on the temperature- and windspeed-profile.

In the boundary layer windspeed is reduced by *friction* and *stability*. As Coriolis force is windspeed dependant, this force will reduce as well and thus the pressure gradient force will dominant more. From this influence the wind direction will backen (turn anti-clockwise) on the Northern hemisphere, the main process for filling of low pressure systems over land. In nights with dominating outgoing longwave radiation air temperature near surface will become lower than temperature above surface, resulting in a stable atmosphere with a *temperature inversion* (increasing temperature with height).

Exchange of momentum in the lower layer will then be reduced, causing lower windspeed at 10 meters compared to unstable or neutral profiles. The wind at the top of the inversion increases in speed and veers in wind direction, resulting in *nocturnal low level windmaxima* in the layer between 100 and 500 meters above surface (in practise called "*low level jet*"). Thus, in stable conditions, these effects of temperature- and wind-changes with height in the planetary boundary layer will have impact on aircraft operations as these phenomena can occasionally represent significant wind shear (combined with temperature inversion) on take-off and landing.

2.2 Cabauw

Cabauw is situated 36 km east southeast of Mainport Schiphol and detailed observations of meteorological parameters are made along the 213 m tower. The basic meteorological observations include precipitation amount and duration, short wave incoming radiation and surface pressure. Surface windspeed, wind direction, air temperature and dew point temperature are observed at standard heights. On the mast measurements are obtained at 10, 20, 40, 80, 140 and 200 m.

Four synoptical weather stations are available each within a distance of less then 50 km from Cabauw, including soundings two times a day at De Bilt (25 km from Cabauw) and weather radar. Boundary layer structure is observed by various remote sensing instruments. A windprofiler/RASS system gives continuous observations of the wind profile (up to 4 km) and hourly observations of the (sonical) temperature (up to 1 km). A boundary Lidar system is available that traces the boundary layer height.

Over the years the site has expanded its scope of work to land atmosphere interaction and clouds and its interaction with radiation. Recent interest in climate change and environmental issues have stimulated new research at Cabauw. Accurate representation of the PBL and its interaction with the land surface in atmospheric models is of great importance for weather forecast, climate prediction and for inverse modelling techniques to estimate greenhouse gas (GHG) sources and sinks [Beljaars and Bosveld, 1997, vdVliet, 1997, cabclim].

2.3 Cabauw climatology 1986-1997

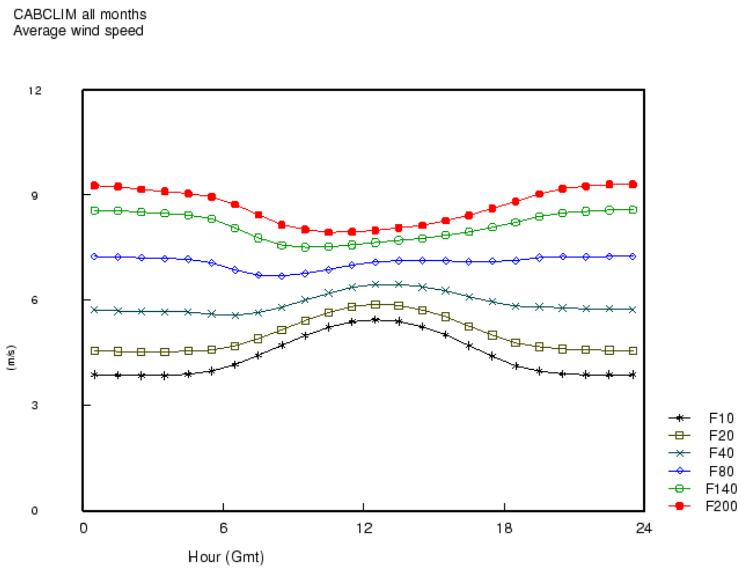
In 1997 an eleven year period of detailed observation the Cabauw (temporarily) finished, based on data between February 1986 and January 1997, detailed climatology was obtained. The data set contained half hourly observations of profiles of wind, temperature, humidity and visibility as well as the surface fluxes of short and long wave radiation, sensible, latent and soil heat flux and friction velocity.

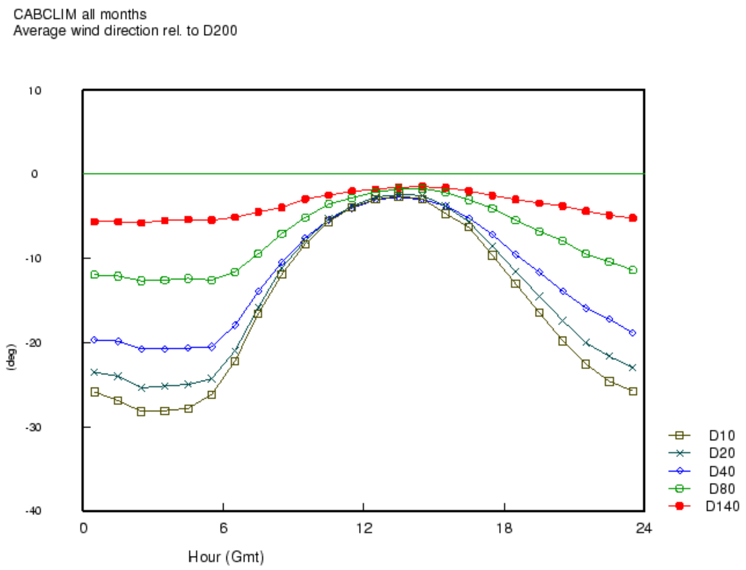
The gap filled data set was used in 1997 to derive the average diurnal variation in the profiles of windspeed, wind direction, temperature and specific humidity.

Examples of Cabauw-climatology for wind direction, windspeed, potential temperature are presented in figures 4 to 6 and in the appendix. For measurements and data procedures, see [vdVliet, 1997].

Baas, Boveld and Klein Baltink found that the average height of the low level jet varies from about 130 m for the most stable class with increased radiative cooling and moderate geostrophic wind (5-10 m/s), to about 400 m for situations with weak stability and stronger geostrophic wind (>10 m/s). This tendency agrees with the theoretical concept that the jets form on top of the decoupled boundary layer. The turning of the wind vector, on average about 30 degrees, between the jet nose and the 10 m wind seems to increase with increasing cooling [Baas, 2006].

In the appendix 5.6 detailed Cabauw climatology 1986-1997 is presented for windspeed, relative wind direction, potential temperature and specific humidity (year and individual months).





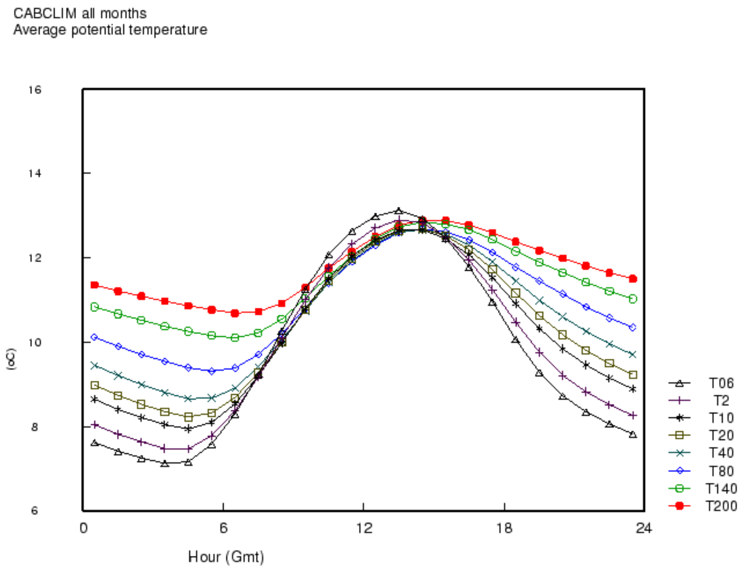


Figure 4-6. Average windspeed (year), relative wind direction and potential temperature at Cabauw 1986-1997

Chapter 3

Comparing observations and reanalysis

3.1 Comparison of ERA-Interim, HIRLAM, Cabauw and radiosonde data below 850 hPa

In part 1 we checked the quality of ERA-Interim for the climatology of the upper air for the Netherlands by examining ERA-Interim versus soundings for location Netherlands-central (De Bilt) from the surface trough the troposphere into the stratosphere for the average value and 5 and 95 percentiles (~ 2 sigma), comparing wind, temperature and relative humidity for the period 1989-2009.

The same procedure is now repeated for an overlapping period of four sources of data in the PBL, two from models (ECMWF-reanalysis and HIRLAM-reanalysis) and two from observations (Cabauw (mast up to 200 meters and profiler abvove 200 meters) and radiosonde De Bilt). The three-year period in which all sources overlap is 2003-2005. In figures 7-10 the comparison for wind, temperature and relative humidity is shown.

Analysis:

- Comparison of temperature and relative humidity:
  The temperature profiles from the four sources coincide except for radiosonde-data. Radiosonde data in the column to 2100 meters are at maximum 0.71 (summer, 12 UTC) to 1.72 (autumn, 12 UTC) ^oC (autumn, 12 UTC) cooler, on average for all seasons the maximum deviation is 1.1 ^oC. The difference might be explained by dislocation of the sounding site and by smoothing of the two models (which coincide well). The profile of relative humidity coincides within 10%.

- The yearly cycle of the vertical temperature profile is shown through the four seasons. The daily cycle of temperature with an inversion near surface below 300 meters at 00 UTC is shown, turning into an adiabatic profile at 12 UTC. The average vertical temperature gradient at 12 UTC up to 2100 meters is varying from 0.55 ^oC per 100 meters in winter to 0.72 ^oC per 100 meters in summer. The international standard atmosphere of ICAO defines a vertical temperature gradient of 0.65 ^oC per 100 meters. From theory the adiabatic vertical temperature gradient is in saturated air 0.5 ^oC per 100 meters and in dry air 1.0 ^oC per 100 meters. Thus in summer the climatological vertical temperature gradient tends to more to dry adiabatic profile than in winter.

- The diurnal cycle of relative humidity indicates higher values at night near surface as air is cooler and decreasing relative humidity upwards in the planetary boundary layer up to about 300 meters, above this layer relative humidity profile is almost constant is summer and decreases almost constant in winter. At midday the diurnal cycle of temperature causes decreasing relative humidity near surface and maximum values near average cloudbase, in summer near 1 km, in winter near 500 meters. The yearly cycle indicates higher values in cold season and lower values in warm season, in line with the yearly cycle of temperature.

- Comparison of wind direction:
  wind direction coincides within 5 degrees above 600 meters, in the lower layer the models tend to a more veered direction, mainly at night, maximum deviations from sounding information and Cabauw data are close to 40 degrees. These differences might be partly explained by dislocation of the souding site and by a warmer boundary layer in the models.

- Wind direction is more veered in summer and is hardly changing with heigth, in the other seasons wind near surface backens more, about 30-50 degrees. In the vertical profile wind veers with height (loss of surface friction), about 30 to 40 degrees in the lower 1 km.

- Comparison of windspeed:
  windspeed (notice: windspeed in knots, 1 knot = 0.51 m/s) in ERA-Interim and measurements coincides well. In the model the seasonal mean windspeed has an average deviation from the measurements between -0.2 m/s at 80 meters to -0.5 m/s at 1000 meters (not shown). Windspeed comparison above 200 meters are obtained from windprofiler, but these data show increasing deviation above 1 km (shown in the figures), caused by an increasing number of missing data (no backscatter, typical for the windprofiler).

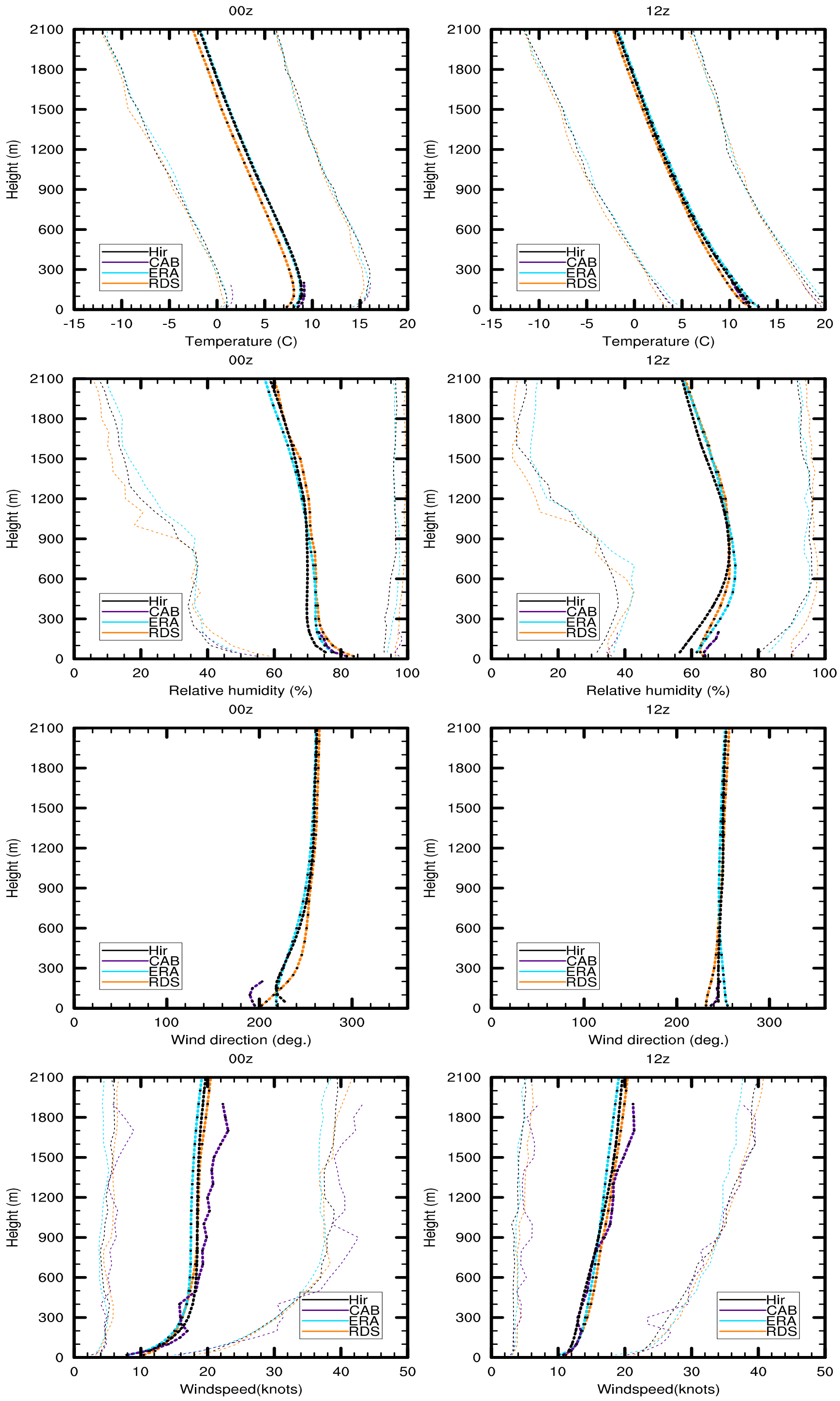
- Wind has a diurnal cycle (more wind in daytime compared to nighttime) and a seasonal cycle (most wind in winter), in the vertical profile the average windspeed increases most in the lower 300 meters at night (part the nocturnal decoupling of the boundary layer with occasionally a low level nocturnal wind maximum or low-level-jet).

These results show qualitative acceptable results for indicative climatology for the lower 2 km for the parameters temperature, relative humidity and wind.

Detailed climatology of ERA-Interim 1989-2009 is presented in the appendix.

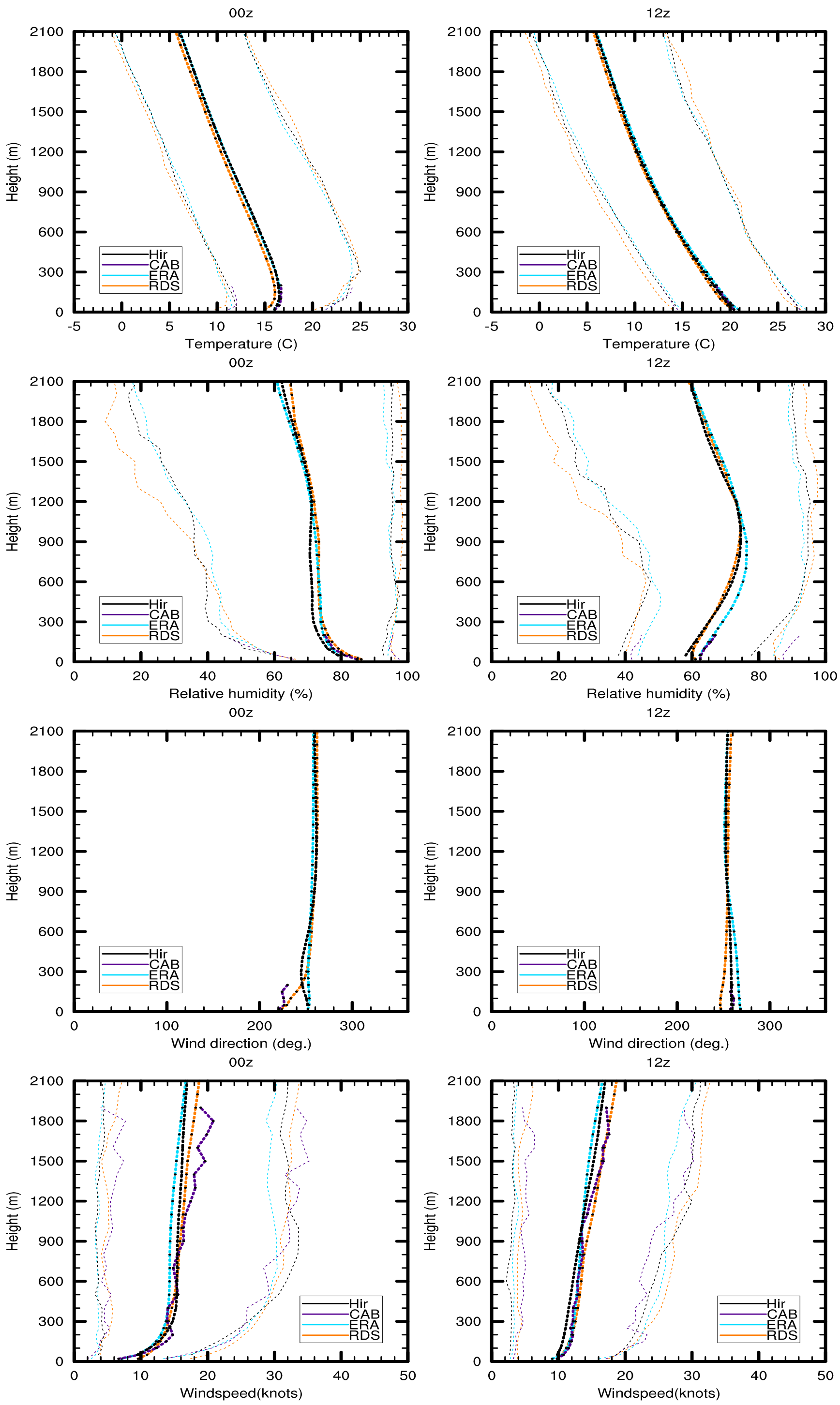
Next pages show figures 7-10. Profile-comparison Spring (March-May), Summer (June-August), Autumn (September-November) and Winter (December, January, February) 2003-2005. Shown are average, 5 and 95 percentile at 00 and 12 UTC for temperature, relative humidity, winddirection and windspeed.

Spring

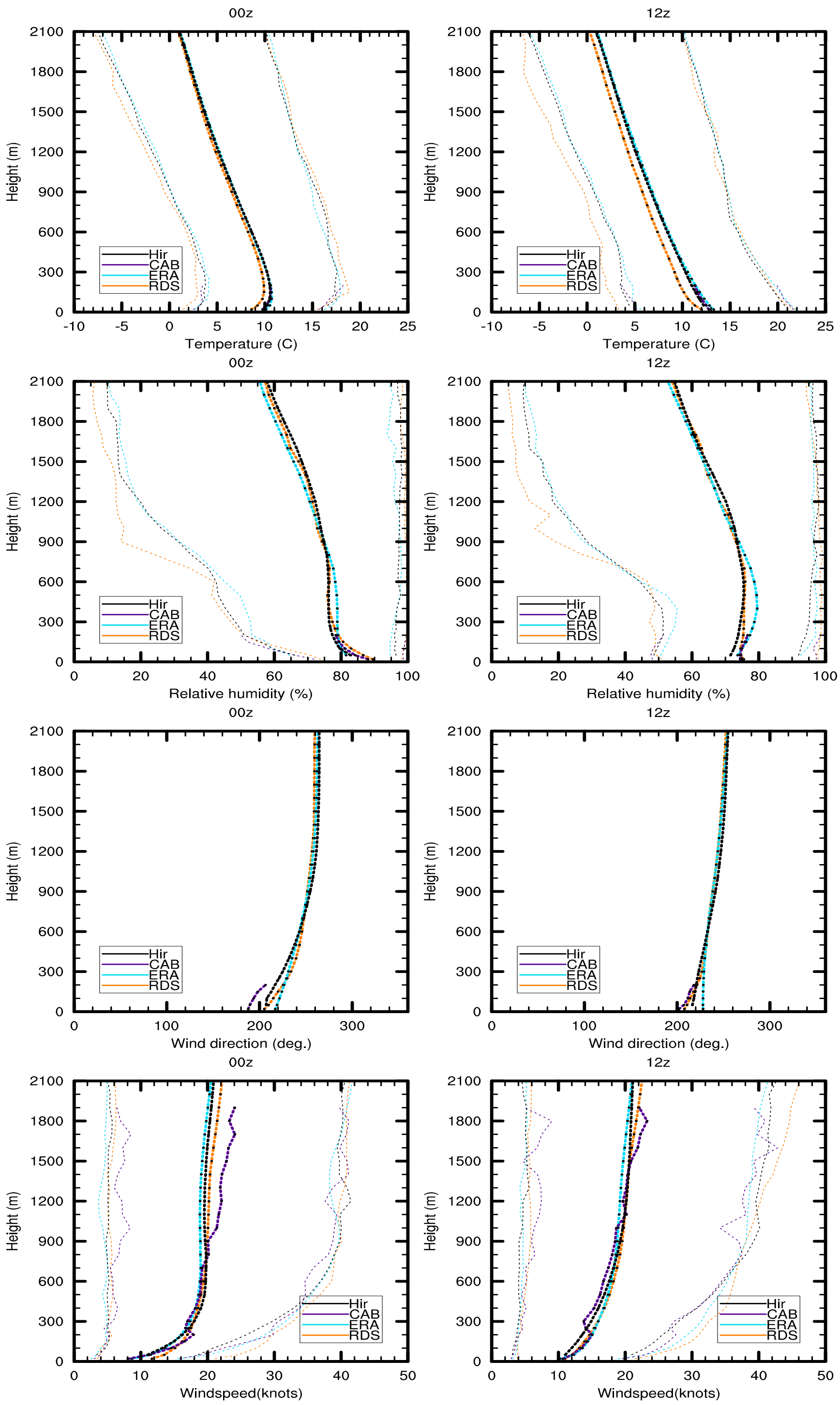


00z
12z
Height (m)
Temperature (C)
Relative humidity (%)
Wind direction (deg.)
Windspeed(knots)
Hir
CAB
ERA
RDS

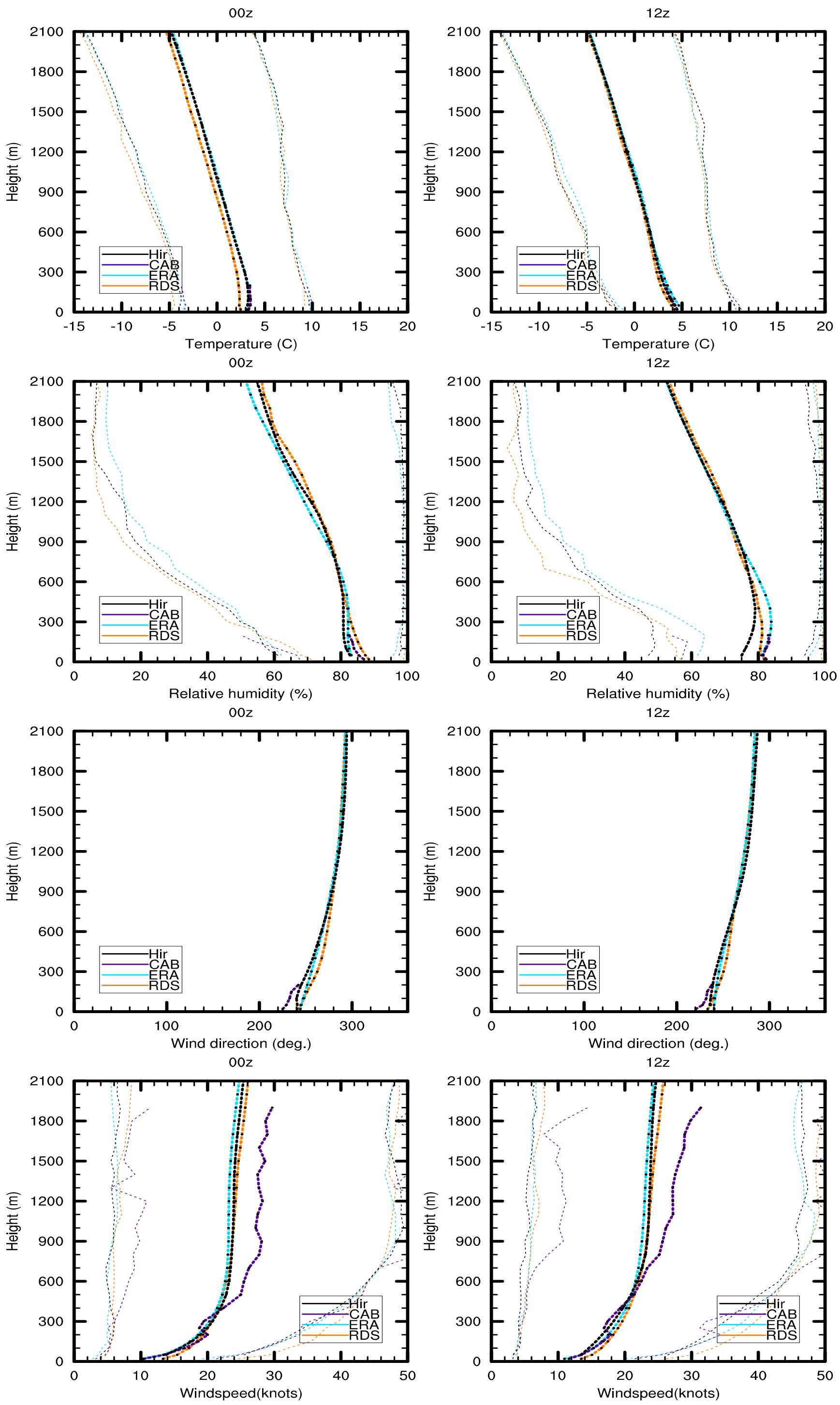
Summer


00z
12z
Height (m)
Temperature (C)
Relative humidity (%)
Wind direction (deg.)
Windspeed(knots)
Hir
CAB
ERA
RDS

Autumn


00z
12z
Height (m)
Temperature (C)
Relative humidity (%)
Wind direction (deg.)
Windspeed(knots)
Hir
CAB
ERA
RDS

Winter


00z
12z
Height (m)
Temperature (C)
Relative humidity (%)
Wind direction (deg.)
Windspeed(knots)
Hir
CAB
ERA
RDS

3.2 Comparison of windspeed around 100 meters height from Noordzeewind-OWEZ

NoordzeeWind (NZW) is a joint venture of Shell Wind Energy and Nuon Duurzame Energie. The company has installed a wind farm off the Dutch coast near Egmond aan Zee in 2006. The project comprises 36 Vestas V90 wind turbines and associated support systems in the Dutch territorial waters of the North Sea, between 10 and 18km off the coast. Operations of the wind farm commenced on 1 January 2007. At the site of the Offshore Wind farm Egmond aan Zee (OWEZ) a meteorological mast was erected in 2003, capable of measuring the actual weather and wave conditions. To achieve sufficient stability for the instruments the met mast is constructed as a triangular lattice tower, mounted on a monopile foundation, driven in the sea bed. The distance between the instruments and the body of the met mast is sufficient to limit the inaccuracy of windspeed measurements to 5% (except wake effects). Instrumentation The site of the met mast is in WGS 84 coordinates 52º 36‘ 22.9“ N, 4º 23‘ 22.7“ E, (in UTM31 ED 50 coordinates X = 594194.830, Y = 5829600.084) at the south western side of the wind farm.

Instruments are installed at three levels: 70 meters above mean sea level, which equals hub height of the wind turbines, at 21,6 m and at 116 m. The latter two heights are enabling determination of the windspeed profile over the entire rotor diameter of 90 meters. At each level windspeed and wind direction are measured at three booms situated at 300º (NW), 60º (NE) and at 180º (S), respectively. As North is 0º, the south boom is directed pure south. By using three booms per measurement level, wind flows that are disturbed by the wake of the mast can be filtered out while undisturbed windspeed and wind direction data can be derived from (one of) the other booms [Noordzeewind, 2009].

In figure 11 average windspeed per month at 70 and 116 meters is compared with windspeed from ERA-Interim at gridpoint 52º 05‘ N, 04º 05‘ E (linearly interpolated from adjacent levels) for the period July 2005 to December 2009 (March 2007 is removed because of missing data). The model has on average 0.7 m/s (standard deviation 0.4 m/s) less windspeed at both levels, which is about 10% of the average windspeed.

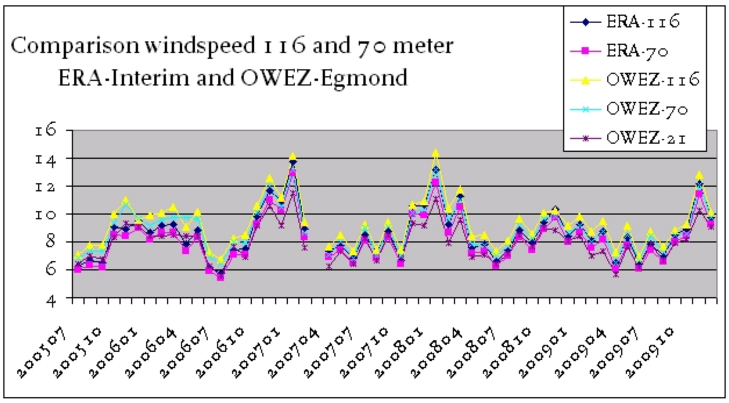


Figure 11. Comparing average windspeed per month from Noordzeewind and ERA-Interim. Windspeed in reanalysis is underestimated by 0.7 m/s (about 10%).

3.3 Temperature inversions

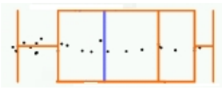
Air traffic control in the Netherlands (LVNL) has special interest in the climatology of temperature inversions below 1.5 km. We distinguish two types of inversions, near-surface inversions (lowest temperature at lowest model level) and above-surface inversions (lowest temperature not at lowest model level).

Inversions are defined as layers in which the temperatures increases with height. Figure 12 and Figure 14 show the climatological characteristics of all inversion layers with a bottom at the lowest model level (near-surface inversions). Figure 15 shows the climatological characteristics of all cases in which an inversion starts at one of the levels above the lowest level. Only the layer between the surface and 1500m altitude is taken into account in these figures.

3.3.1 Near-surface temperature inversions

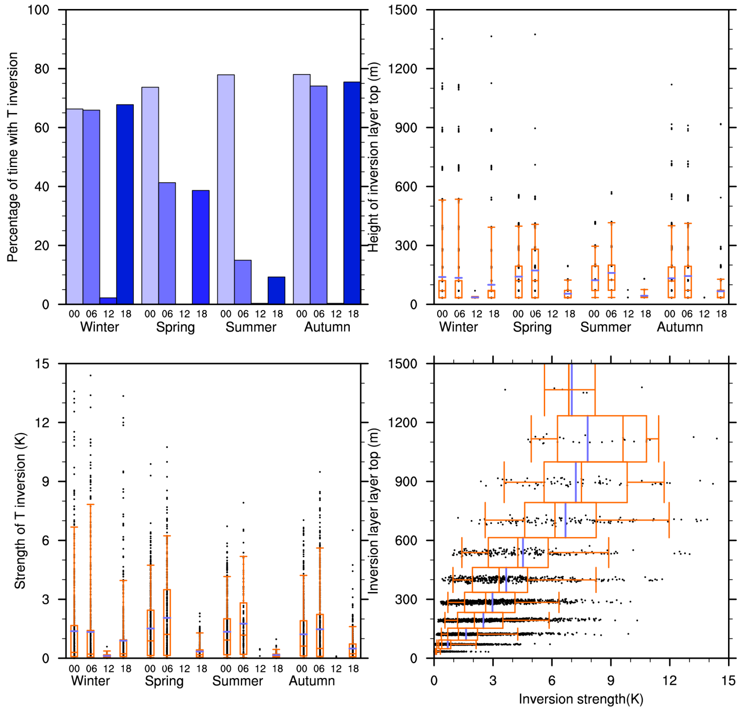
In figure 12a-d the frequency, average height, average strength per season in ERA-Interim 1989-2009 for temperature inversions for Netherlands Central from the two lowest model levels (at approc. 14 and 30 meters) is presented. Inversions are defined as increasing temperature between the lowest model level and higher levels up to 1.5 km.

The figures b-d contain data-points and boxplots.


The bars in the boxplot denote the 5, 25, 50 (median), 75 and 95 percentiles and the average value (blue).

Analysis:

- In figure 12a we observe that in the diurnal cycle of temperature most near-surface inversions occur at night and least at midday during all seasons. The cycle of day-length trough the year is resembled in the differences between the seasons in the frequencies of temperature inversions at 06 and 18 UTC.
- Figure 12b shows that in ERA-Interim the top of near-surface inversions is on average below 170 meter, increasing in depth during the night, as observed in measurements at Cabauw. Figure 12d indicates that in extreme cases the depth of near-surface inversions reaches heights of 700 to 1500 meters.
- The average strength of near-surface inversions (figure 12c) is at most about 2 K at 06 UTC, but in figure 12d we observe some extreme inversions with temperature differences of 10 to 15 K. Figure 12d indicates that inversions with a larger vertical extent (higher top) are less frequent but tend to be stronger (larger temperature difference in the inversion layer).



Climatology ERA-Interim 1989-2009:
Near-surface temperature inversions for location Netherlands central (Cabauw).
Figure 12a: Inversion frequency per season at 00, 06, 12 and 18 UTC
Figure 12b: Average inversion height per seaon at 00, 06, 12 and 18 UTC
Figure 12c: Average inversion strength per season at 00, 06, 12 and 18 UTC
Figure 12d: Inversion strength versus height.

Figure 13 shows the frequency of near-surface temperature inversions at Cabauw, using temperature observations at 2 and 10 meters. This climatology is based on measurements 1986-1997 and 2000-2009. (The climatology in the appendix covers the first period, 1986-1997.) Only frequency is calculated as the limited upper level of measurements, 200 meters, restricts calculations of height and strength.

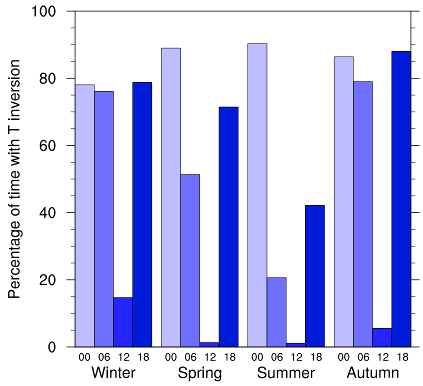
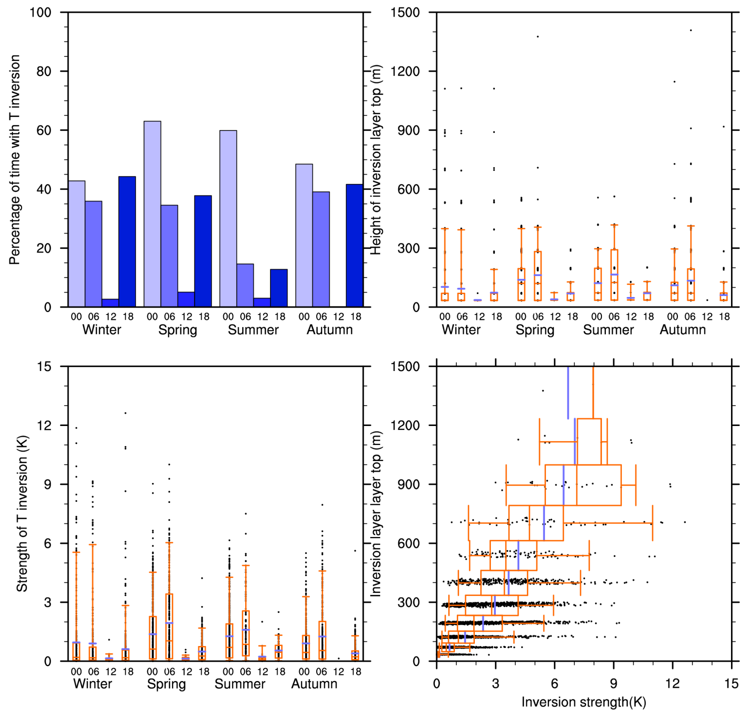


Figure 13. Frequency of near-surface temperature inversions at Cabauw, 00, 06, 12 and 18 UTC.

Figure 13 and a comparison to figure 12a indicates:

- Like in figure 13a we observe that in the diurnal cycle of temperature most surface inversions occur at night and least at midday during all seasons. The cycle of day-length trough the year is resembled in the differences between the seasons in the frequencies of temperature inversions at 06 and 18 UTC.
- Model-climatology tends to an underestimation of the frequency of near-surface temperature inversions, on average about -8 %, varying between -38% in Spring at 18UTC to +35% in Summer at 18UTC. These differences between model and observations may be caused by model discrepencies in near-surface temperatures and the transfomration from model-levels to height.
- Qualitative information can be extracted from ERA-Interim for the calculation of surface inversions, but quantative information (absolute values) has to be used with care.

In figure 14a-d the frequency, average height, average strength per season in ERA-Interim 1989-2009 for temperature inversions for Schiphol is presented.

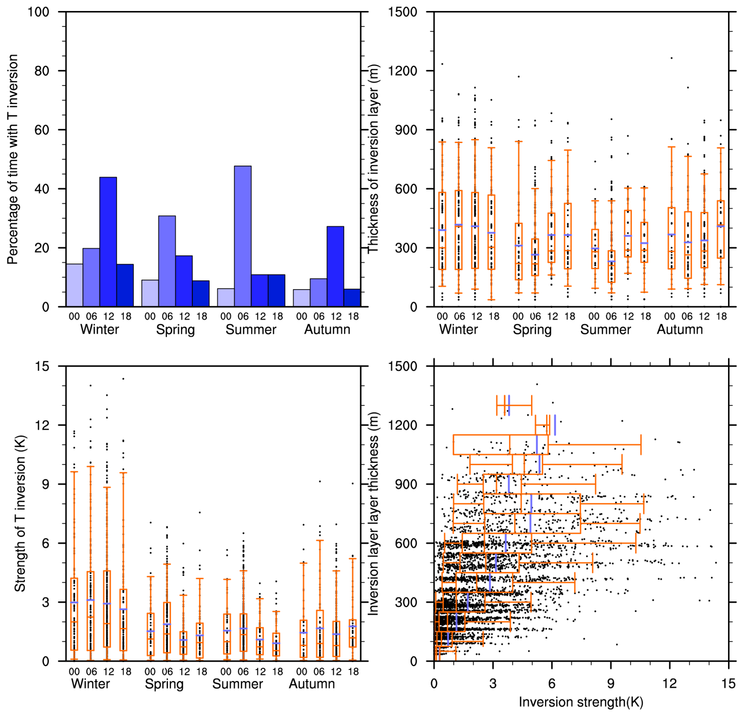


Climatology ERA-Interim 1989-2009:
Near-surface temperature inversions for location Schiphol.
Figure 14a: Inversion frequency per season at 00, 06, 12 and 18 UTC
Figure 14b: Average inversion height per seaon at 00, 06, 12 and 18 UTC
Figure 14c: Average inversion strength per season at 00, 06, 12 and 18 UTC
Figure 14d: Inversion strength versus height.

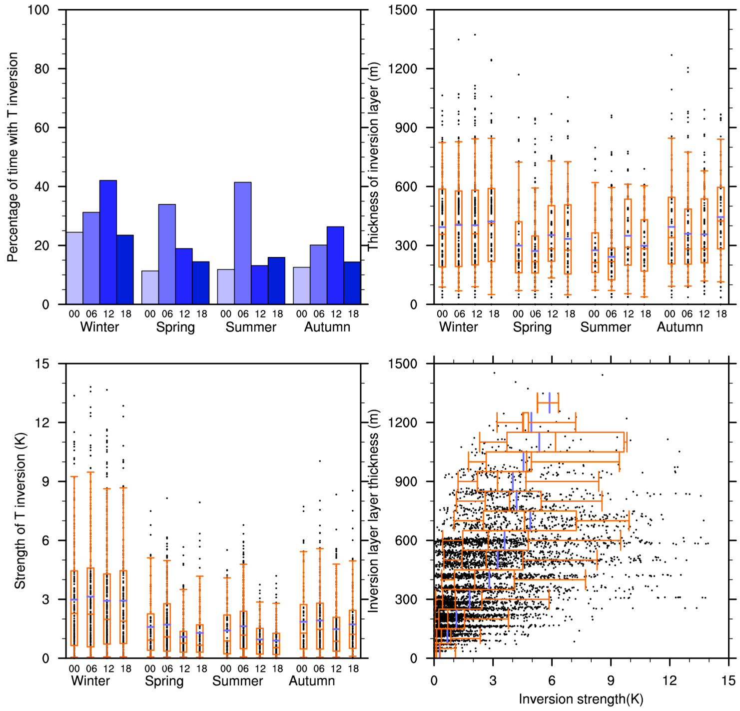
In the comparison for both locations in ERA-Interim (figures 12 and 14) we notice for near-surface inversions at Schiphol a lower frequency with a lower height and a lower strength, like should expect for a location closer to sea with less diurnal variation in surface temperature, a sound physical result. As mentioned before, the quantative results should be handled with care as models tend to underestimate the frequency (and strength and height) of surface inversions. But as argued these results might be used for further analysis in a qualatively way as indicative climatology.

3.3.2 Inversions above-surface and below 1.5 km

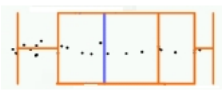
In figure 15a-d and 16 a-d the frequency, average height, average strength per season in ERA-Interim 1989-2009 for above-surface temperature inversions for location Cabauw and Schiphol are shown. "Above-surface" stands for an inversion with a lowest temperature of the inversion (inversion bottom) not at the lowest level and the highest temperature (inversion top) below 1.5 km.



Climatology ERA-Interim 1989-2009:
Above-surface temperature inversions for location Cabauw.
Figure 15a: Inversion frequency per season at 00, 06, 12 and 18 UTC
Figure 15b: Average inversion height per seaon at 00, 06, 12 and 18 UTC
Figure 15c: Average inversion strength per season at 00, 06, 12 and 18 UTC
Figure 15d: Inversion strength versus height.



Climatology ERA-Interim 1989-2009:
Above-surface temperature inversions for location Schiphol.
Figure 16a: Inversion frequency per season at 00, 06, 12 and 18 UTC
Figure 16b: Average inversion height per seaon at 00, 06, 12 and 18 UTC
Figure 16c: Average inversion strength per season at 00, 06, 12 and 18 UTC
Figure 16d: Inversion strength versus height.

 The figures b-d contain data-points and boxplots. The bars in the boxplot denote the 5, 25, 50 (median), 75 and 95 percentiles and the average value (blue).

The figures indicate that:

- on average about 22% of time an inversion is present above surface and below 1.5 km (5000 ft),
- the average thickness is close to 350 meters (1100 ft),
- average strength is about 2 K and increasing height correlates to increasing strength.
- most inversions occur, like expected, in winter,
- winter and autum inversions show in a negative diurnal cycle (more at 12 UTC than at 00, 06 and 18 UTC), whilst in other seasons 06 UTC shows the peak frequency. In spring and summer most inversions are observed at 06 UTC.

The frequency of inversions, less sensitive to the diurnal variation of temperature (at 00 UTC), is in winter about 24%, in spring about 12%, in summer about 11% and in autumn about 13%.

A simple explanation of the frequency differences is:

- the diurnal cycle of temperature, causing surface inversions to lift at daytime
- the seasonal cycle (sunrise before 06 UTC uin summer and after 06 UTC in winter)

3.4 Deviation from ICAO-standard atmosphere

Air Traffic Control the Netherlands has special interest in the climatology (per month and year) of the deviation of temperature profile from the ICAO-standard atmosphere for their planning purposes. Conventional Flight Management Systems (FMS) are acting on the deviation of surface temperature for the whole column up to the tropopause, resulting in unexpected flight speeds, which cause difficulties in planning by ATC. These FMS will be replaced by input of the parameters of the actual atmosphere (mode-S), but the conventional FMS will not be phased out before 2030.

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 formulas by which those values were derived.

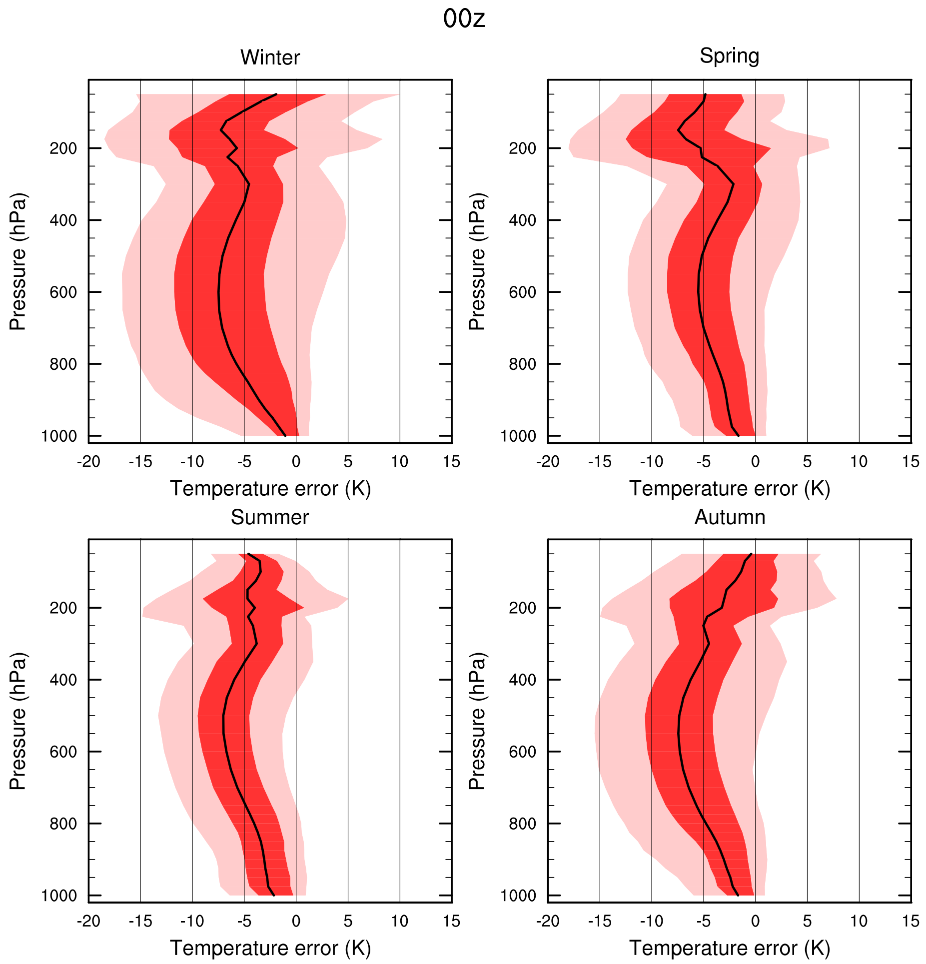
The International Organisation for Standardisation (ISO), publishes the ISA as an international standard, ISO 2533:1975. Other standards organisations, such as the International Civil Aviation Organisation (ICAO) and the United States Government, publish extensions or subsets of the same atmospheric 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 K/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. On request of LVNL (Air Traffic Control Netherlands) the climatology of the temperature profile deviation from the ICAO-standard atmosphere at Schiphol at various levels at 00 and 12 UTC is calculated for the troposhere.

This climatology is presented in figures 17a,b (5, 25, 50, 75 and 95 percentile). It illustrates the climatology of the deviation of the vertical temperature when starting with the observed two meter airtemperature and using the ICAO-standard vertical lapse-rate of 6.5 K/km in the troposphere. The deviation increases with height with a maximum near 500 hPa (like figure 8 in part 1). The small deviations visible on the lowest level (1000hPa), especially in nocturnal situations, are due to model-bias of about 0 to 2 degrees for near-surface temperatures, most likely caused by smoothing in a gridbox close to the coast. We noticed that the gridpoint Schiphol airtemperatures (at 1.5 meters) are to high at night, but to low in daytime in spring and summer. This indicates, apart form smoothing, an influence on the model air temperature of the nearby Northsea. We expect, as illustrated in figure 3 in part 1, a rapid decrease of the model bias with increasing height and practically no bias above the transition level (above 1200 meters) in aeronautical applications.



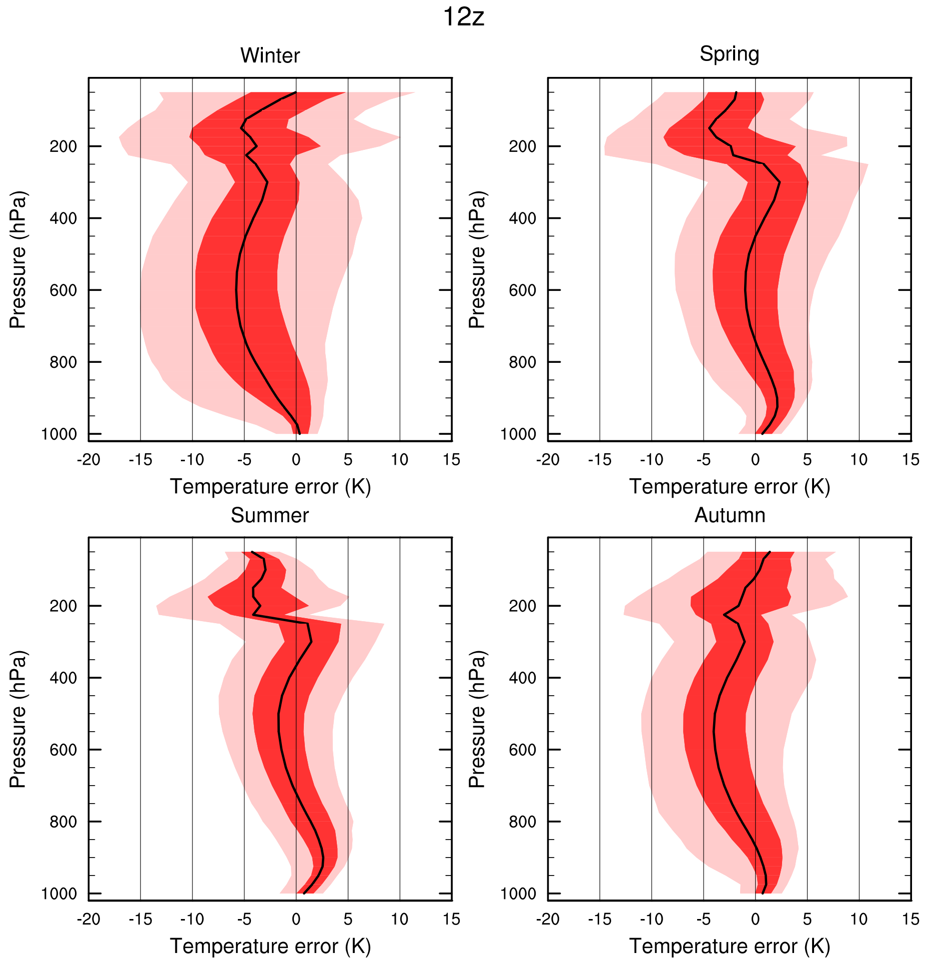


Figure 17a,b. Climatology of the temperature deviation with heigth of ERA-Interim 1989-2009 from ISA at 00 and 12 UTC. Based on surface with the observed airtemperature at Schiphol at 00 and 12 UTC and assuming the standard lapse of the CAO-standard atmosphere. The boundary lines denote the 5, 25, 50, 75 and 95 percentiles.

For the gridpoint Schiphol the average deviation up to 240 hPa (just below tropopause level), is:

	winter	spring	summer	autumn
00 UTC	-4.5	-2.9	-3.9	-4.4
12 UTC	-2.9	+1.2	+1.0	-1.2

For the gridpoint Northsea North (54.0N 07.0E) the average deviation up to 240 hPa is:

	winter	spring	summer	autumn
00 UTC	-3.8	-2.2	-3.2	-3.7
12 UTC	-2.2	+1.9	+1.7	-0.5

Both tables are based of the formula:

Temperature$_{error}$= Temperature$_{air-Schiphol}$- Heigthkm*6.5) - Temperature$_{observation(ERA-Interim)}$.

3.5 Technical information on the comparison methods

3.5.1 Post-processing of ERA-Interim model output

The fields in the ERA-Interim reanalysis project were obtained on ECMWF hybrid model levels. Using surface pressure, pressures on these model levels van be calculated. Using these pressure fields combined with temperature fields, geopotential heights were calculated using the hypsometric equation (assuming hydrostatic equillibrium). The same method has been used for the radiosonde data, to calculate geopotential heights with known temperatures and pressures.

3.5.2 Vertical interpolation of data

For most of the Figures, data have been interpolated from their original height levels to standard levels on which the different data sources could be compared. For this, a linear interpolation with respect to the height in meters has been applied to all data except for wind data. Because near the surface the wind profile is usually close to logarhithmic, wind data has been interpolated with respect to the natural logarhithm (ln) of height. For the radiosonde data, which have a relatively sparse vertical resolution, logarithmic interpolation gave climatological results that differed significantly from linear interpolation.

Chapter 4

Uncertainty

4.1 Reanalysis

ECMWF is currently producing ERA-Interim, a global reanalysis of the data-rich period since 1989. ERA-Interim incorporates many important model improvements compared to previous reanalysis such as 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 [Trenberth, 2009].

It can be noticed that the land-sea-mask in ERA-Interim (figure 17) shows a rather course representation of landscape details such as coasts, islands and cities (figure 19). Moreover, the weather model tends to show an underestimation of variability on scales smaller than 200 km (Stoffelen, personal communication). For small-scale and rapidly moving systems (like a sharp trough) any effect on the climatology will be smoothed, but the climatology will be affected by permanent small-scale features, such as land-sea transitions or orography (e.g., shadow flow effects). In the north-western part of the Netherlands large parts of of Noord-Holland and the Frysians Isles are defined in the mask as sea, very likely resulting is increased wind speeds at 100 meter in those regions. On the other hand, over the lakes in Zeeland the mask indicates mostly land in ERA-Interim with probably reduced 100-m winds. Regarding gradients in for instance wind speed at 100 meters (figure 18) the coarse land-sea mask and limited spatial resolution of ERA-Interim may lead to smoothing of the gradient in the coastal areas and a shift in the orientation of the gradient.

An indication for this reanalysis tendency with a less detailed surface representation for smoothing the climatology of for instance average windspeed are the result of the HYDRA-project (1998-2005), in which local roughness is calculated with gust-analysis. The local roughness and information of the measuring chain is used for the calculation of potential wind series with a generalised roughness length [Verkaik, 2000]. These series if potential wind were translated to the windspeed at 100 meters with detailed roughness information from land-use-maps and with a logarithmic wind profile between 10 and 100 meters [Winkaart, 2005].

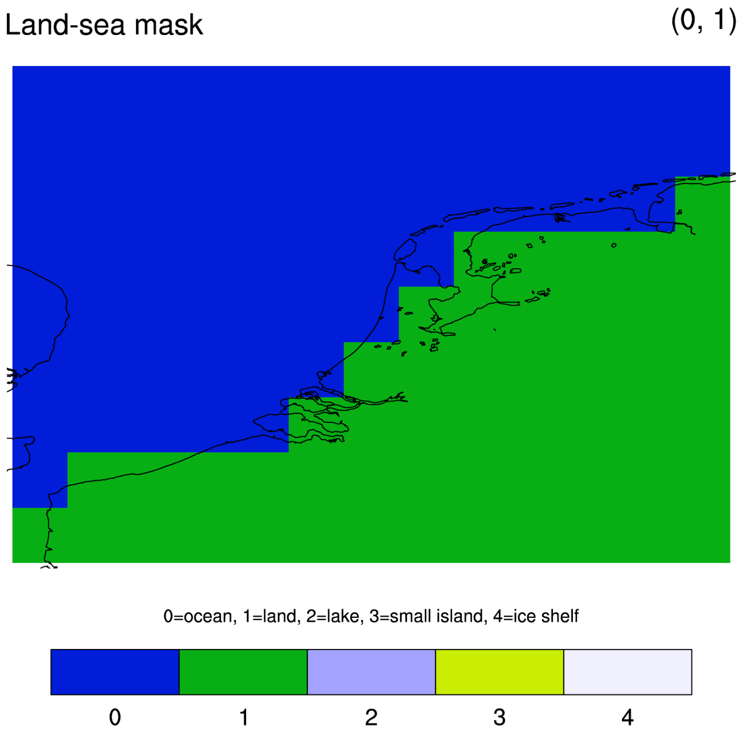


Figure 17. Land-sea mask in Era Interim.

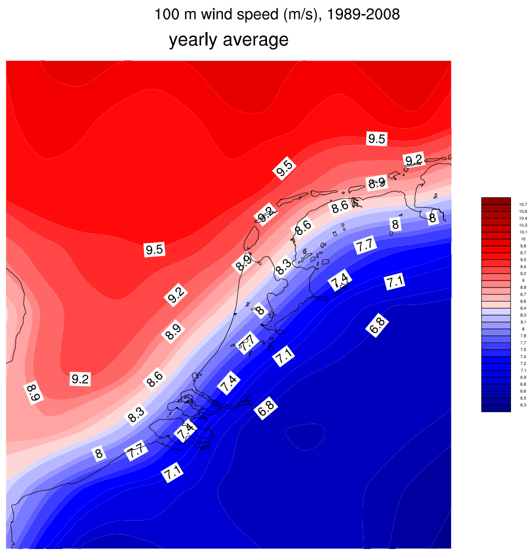


Figure 18. Average windspeed (year, in m/s) at 100 meters ERA-Interim 1989-2009.
Coastal gradient and orientatation might be smoothed and weakened in the reanalysis.

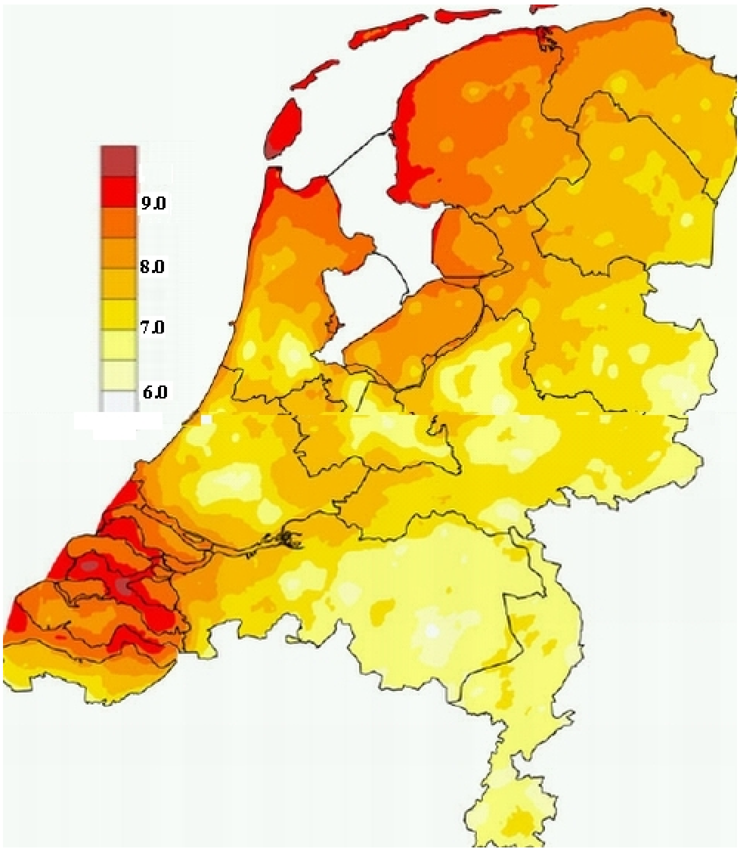


Figure 19. Average windspeed from Windkaart at 100 meter (2005).

So, detailed information of the influence of surface roughness on wind in the lower layers in not (yet) fully reflected in reanalysis information and requires more research beyond this project, as shown in the next alinea an expert judgement estimates for the average windspeed in the lowest 300 meters (1000 feet) a model understimation in the order of 0.9 m/s, the comparison in OWEZ-data for a five-year period of the avregae windpseed per month at 116 meters indicates an underestiamtion in the model average windspeed of 0.7 m.s (figure 11).

Stoffelen argues in his dissertation in 1998: "The error sources in the forecast model that project onto the surface wind are difficult to laborate on. It may be clear that a characterization of the total observation error from a quantification of all the error sources contributing to it will be undoable. Therefore an empirical approach was needed. Since the forecast model is not perfect, the subdomain of true winds will be larger than the subdomain of the model winds, and as such, it may be clear that the distribution shown is affected by errors in the forecast model. The wind speed error is not symmetrically distributed for light winds but skew; that is, large positive errors are more likely than large negative errors. This is related to the fact that measured negative wind speeds cannot occur. .....A common practice in meteorological data assimilation is to define an error model in the wind components. In practice, it is found that the random error on both the u and v components is similar...By verifying the error distributions at higher speeds we found little evidence of a speed dependence of the component errors in the observation systems studied. As such an error model with constant and normal component errors appears appropriate.

Stoffelen finds that the average wind speed difference (pseudobias) varies as a function of wind speed and that it can be as large as 1 m s-1 for realistic errors (in 1998, he estimates the present value (2010) about 10% lower, close to 0.9 mm/s, personal communication).

The standard deviation of the wind speed difference and the vector RMS difference go to a small value for low wind speed, as is observed for the real data as well. The wind direction standard deviation increases for decreasing wind speed and goes to a value of a hundred odd, as expected (random direction). Thus our error model set up to describe the observed difference statistics in the wind components also qualitatively describes the observed difference statistics in wind speed and direction very well, thereby confirming its adequacy. A quantitative validation of the error model can be made when the wind component errors are known". ([Stoffelen, 1998])

4.2 Observations

The observations for the upper air meet international standards of the World Meteorological Organisation WMO, the demands are nationally stated in the handbook on observations, chapter 12 and 13 [Handboek Waarnemingen, 2000].

It is clear that climatology for the upper air from ERA-Interim has very limited checkpoints regarding observations, for the Flight Information Region above the planetary boundary layer only the soundings of De Bilt are available, but it is shown that modeldata meet these observations. For the boundary layer limited Cabauw-data and Noordzeewind-data are useful, but it is clear that the uncertainty on climatology of the boundary layer increases with increasing distance from these locations and with increasing demand of details and this uncertainty is hard to quantify. For these reasons climatology for Mainport Schiphol, especially for the boundary layer, should be regarded as first estimates without fully quantified uncertainty.

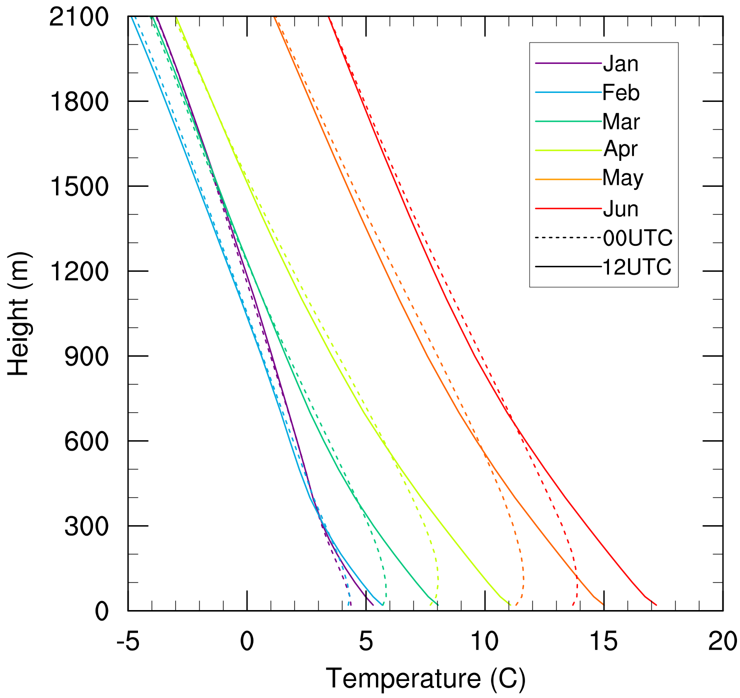
Chapter 5

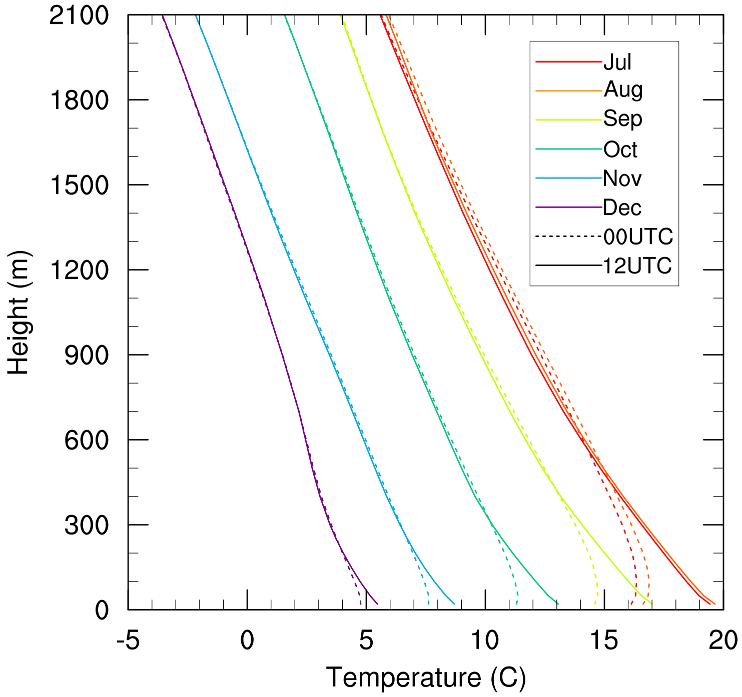
Appendices

5.1 ERA-Interim 1989-2009 profiles Schiphol for temperature, relative humidity and windspeed per month at 00 and 12 UTC

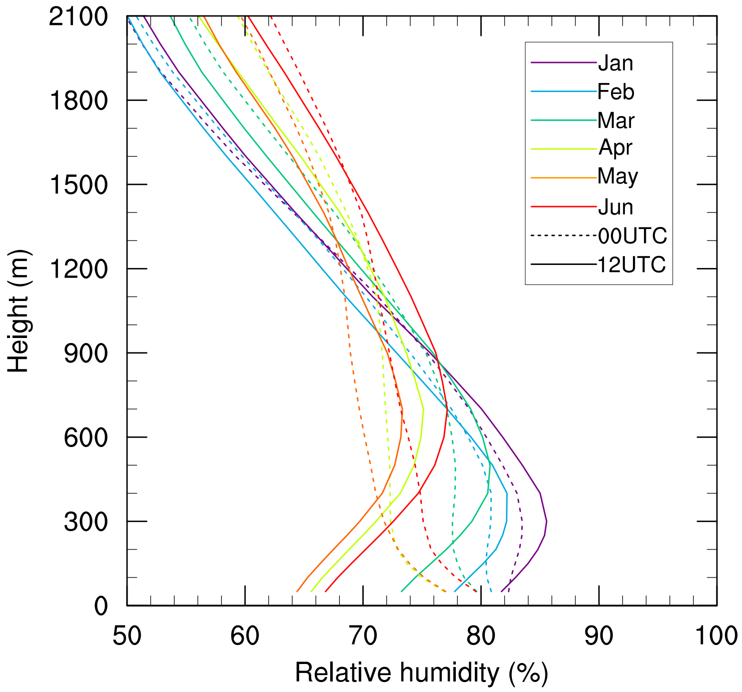
The profiles are plotted per six months at 00 and 12 UTC and illustrate the seasonal and daily sycle of the parameters.

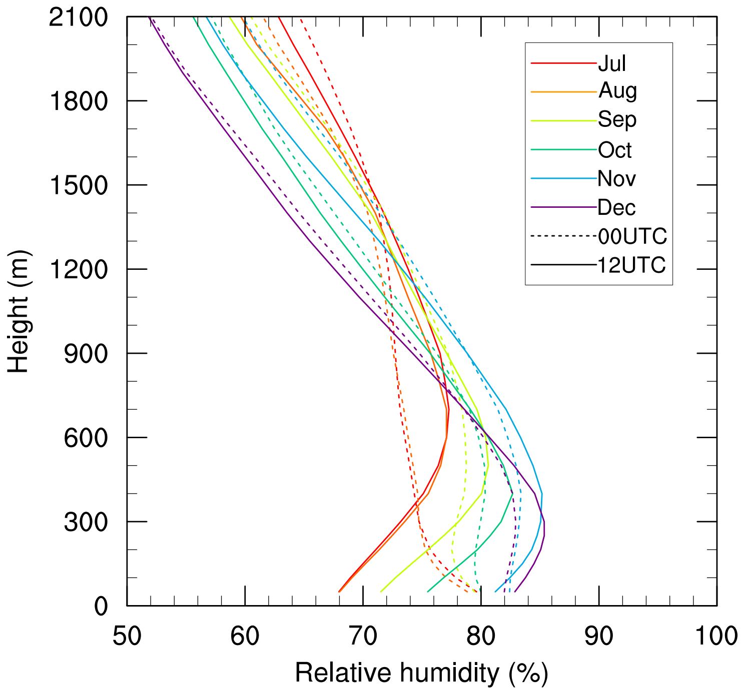
5.1.1 Temperature



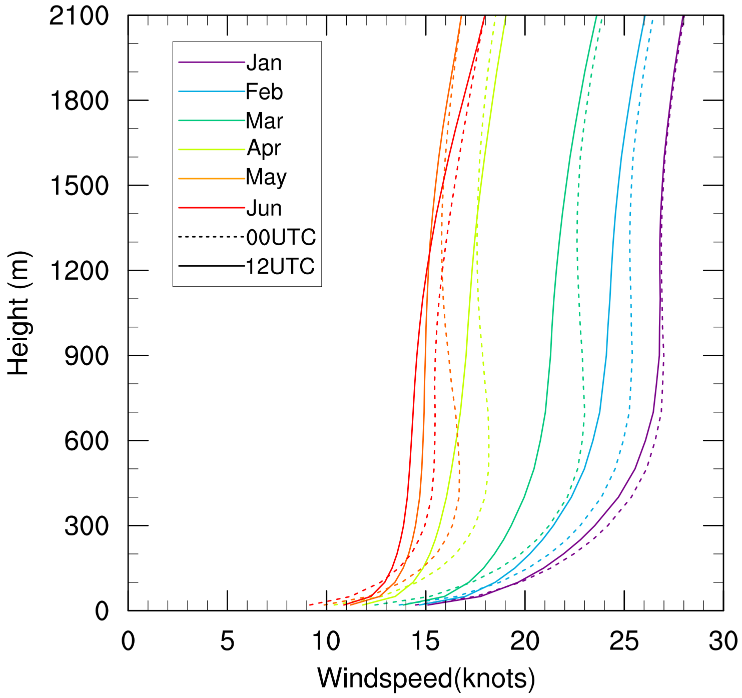


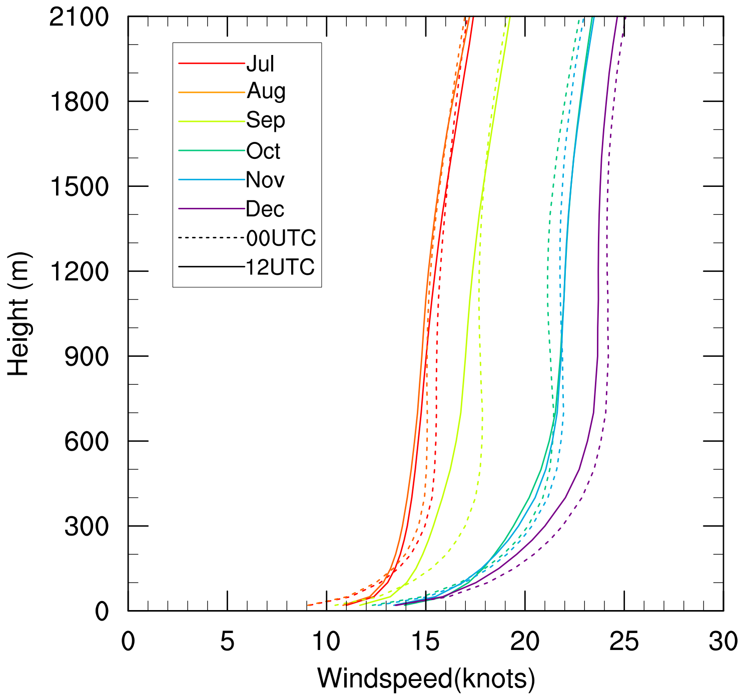
5.1.2 Relative humidity





5.1.3 Windspeed

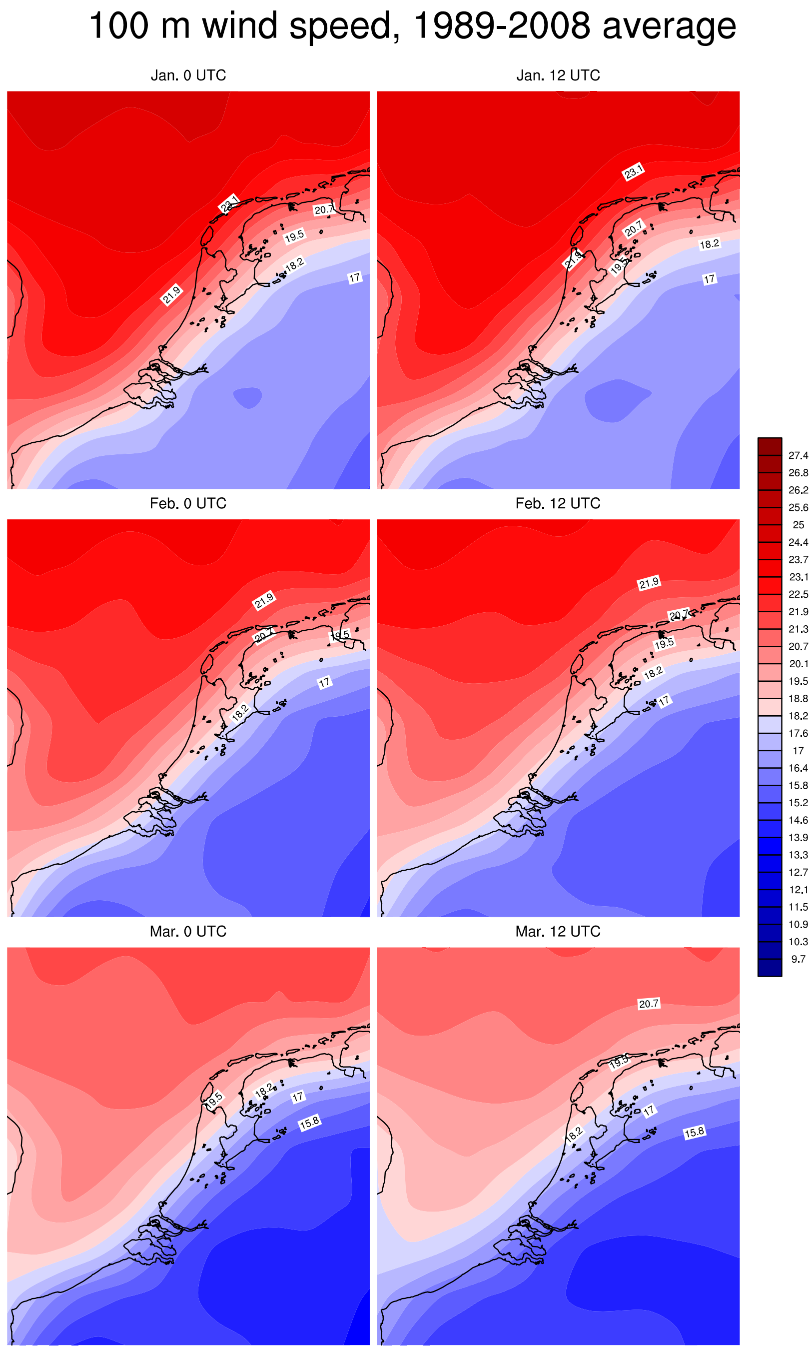




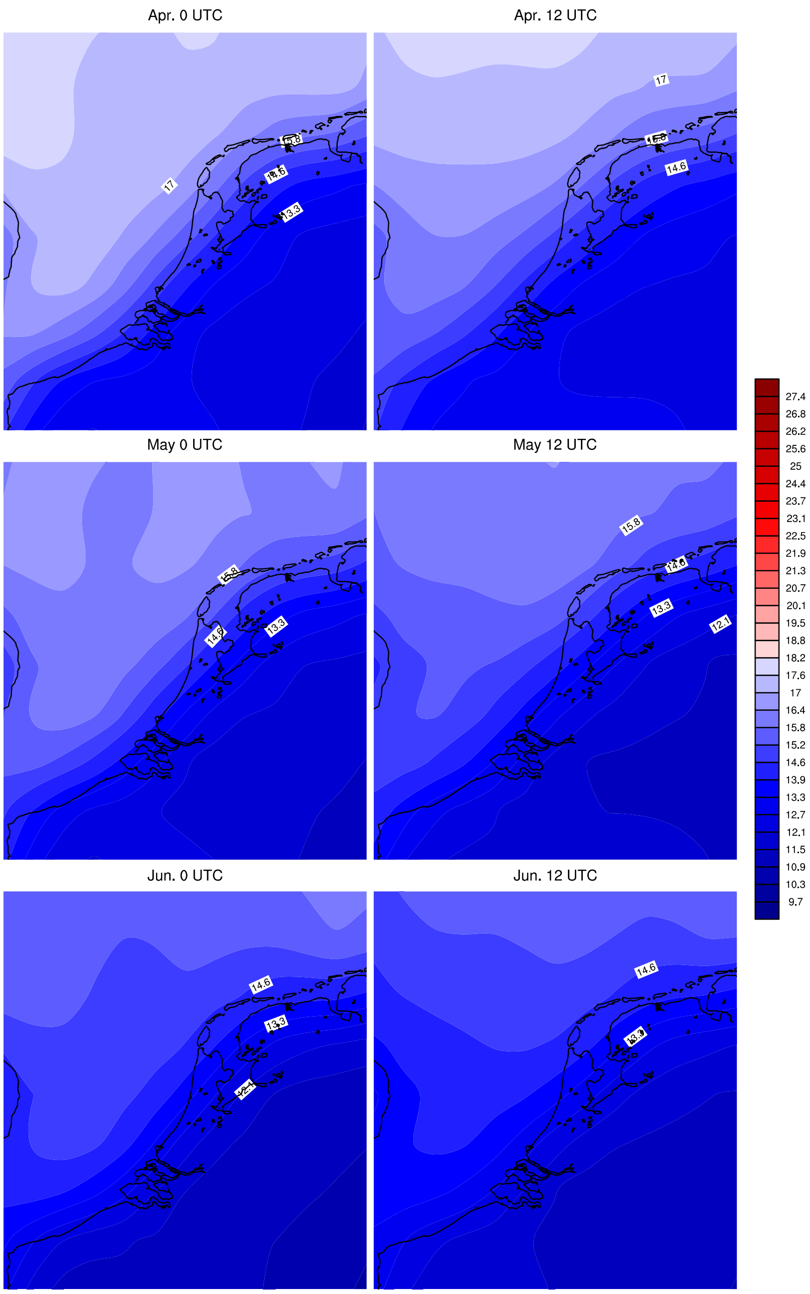
2100
1800
1500
1200
900
600
300
0
Height (m)
0
5
10
15
20
25
30
Windspeed(knots)
Jul
Aug
Sep
Oct
Nov
Dec
00UTC
12UTC

5.2 Windspeed: ERA-Interim 1989-2009 spatial climatology Amsterdam-FIR

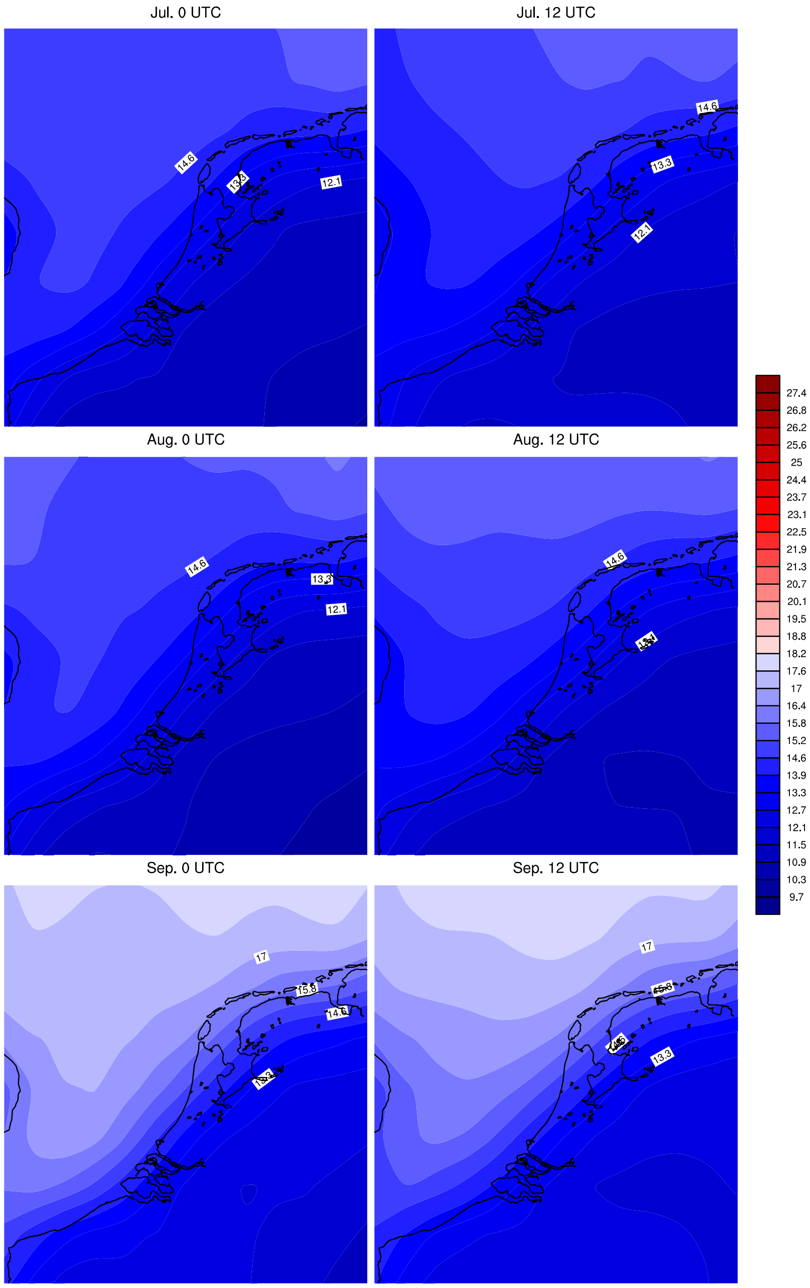
5.2.1 At 100 meters (about 300 feet)



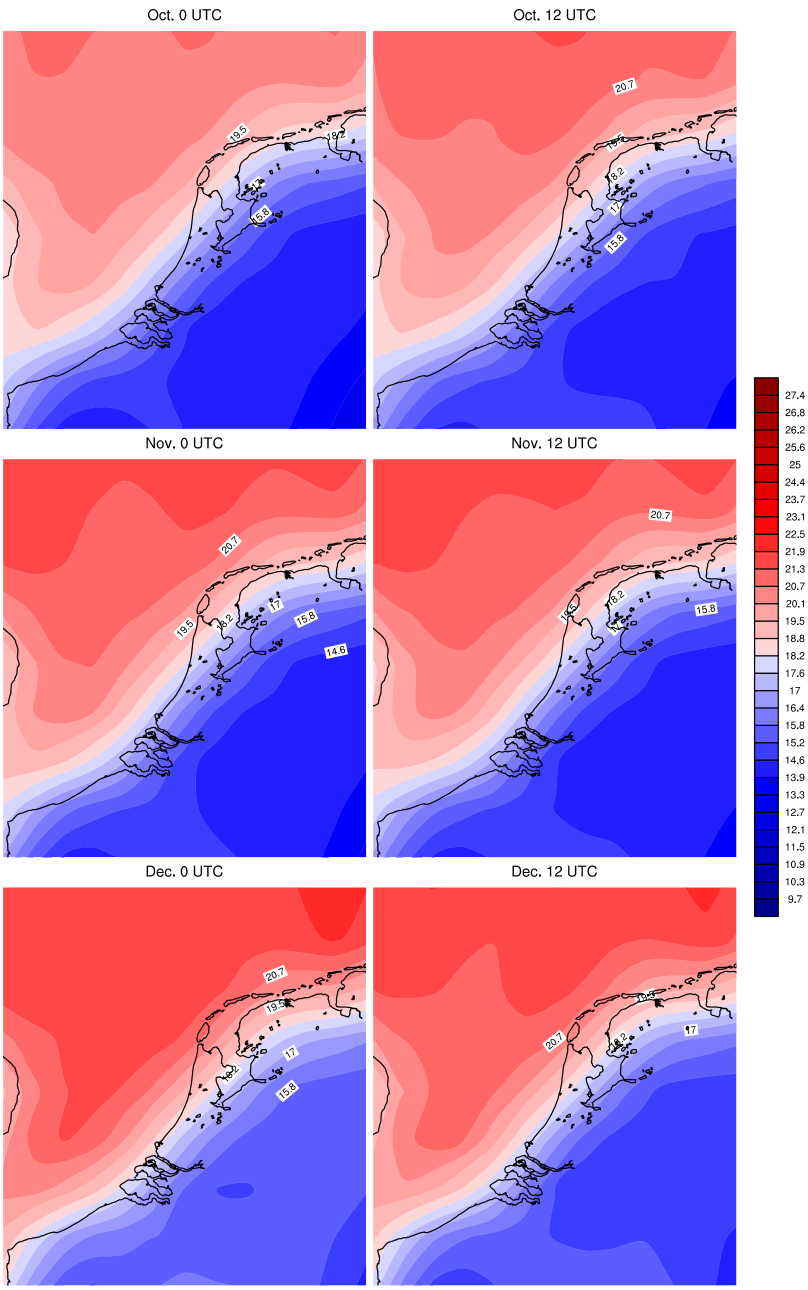
100 m wind speed, 1989-2008 average



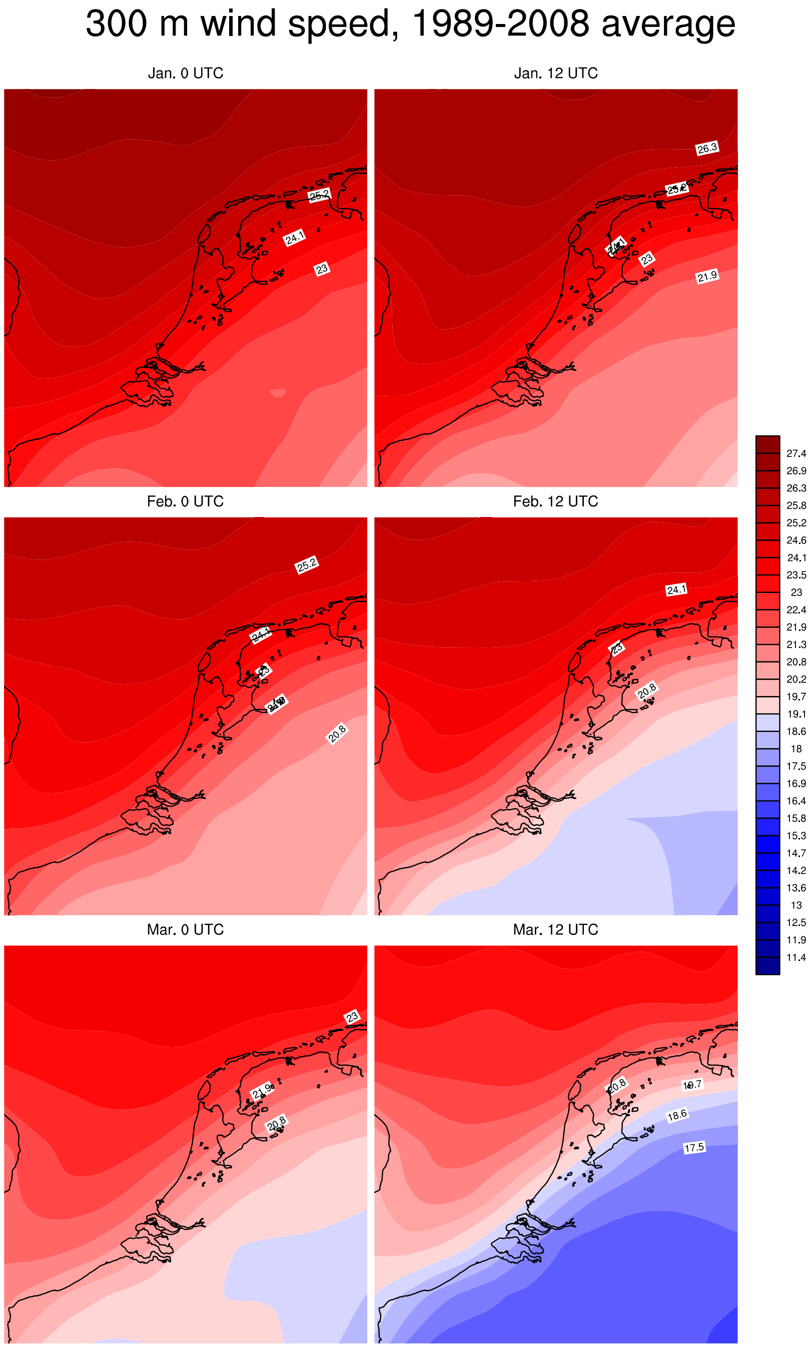
100 m wind speed, 1989-2008 average



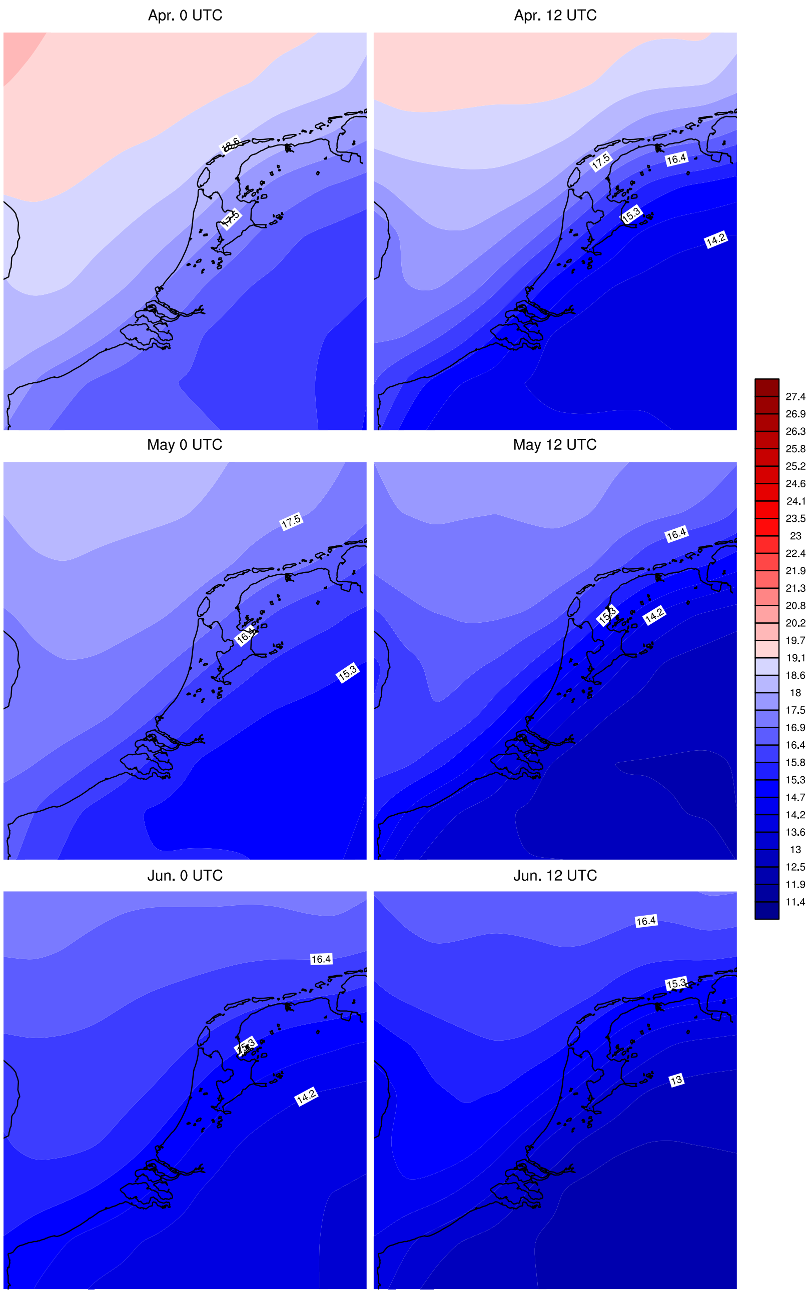
100 m wind speed, 1989-2008 average



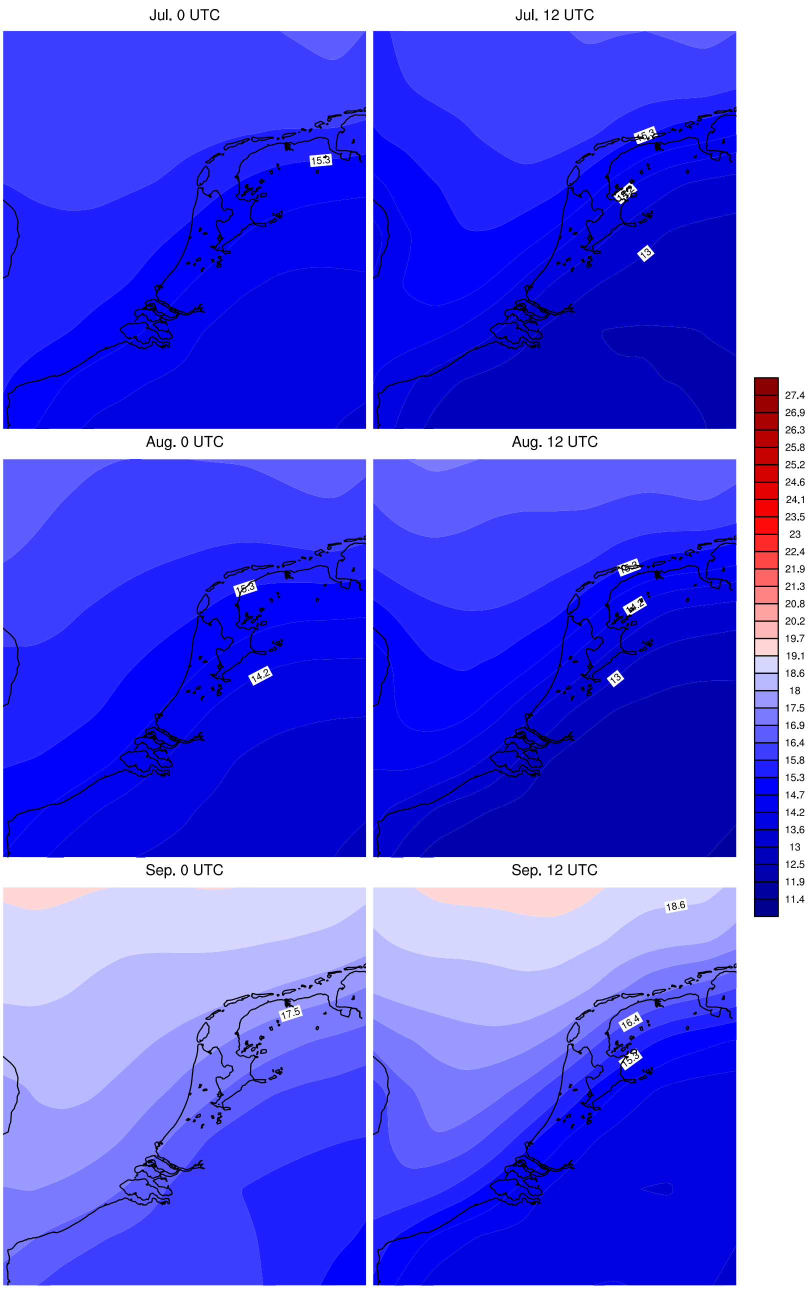
5.2.2 At 300 meter (about 1000 feet)



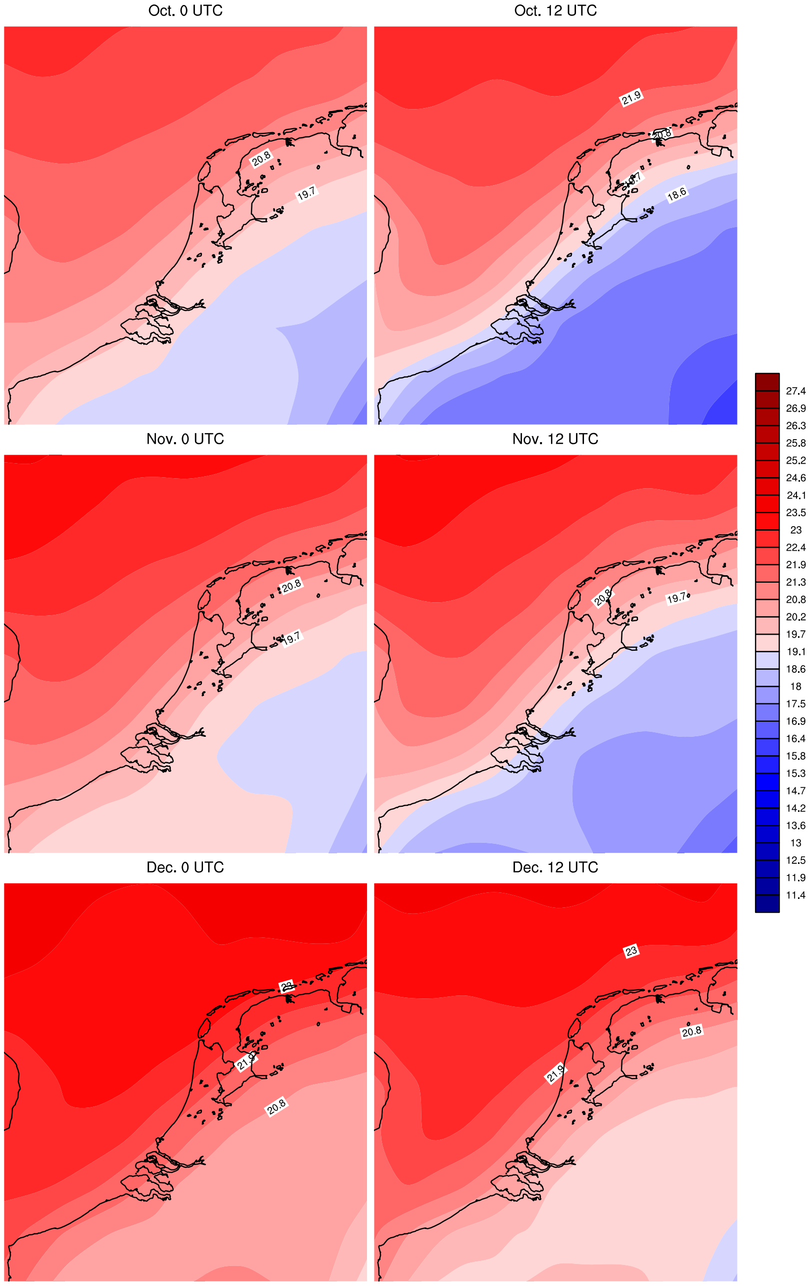
300 m wind speed, 1989-2008 average



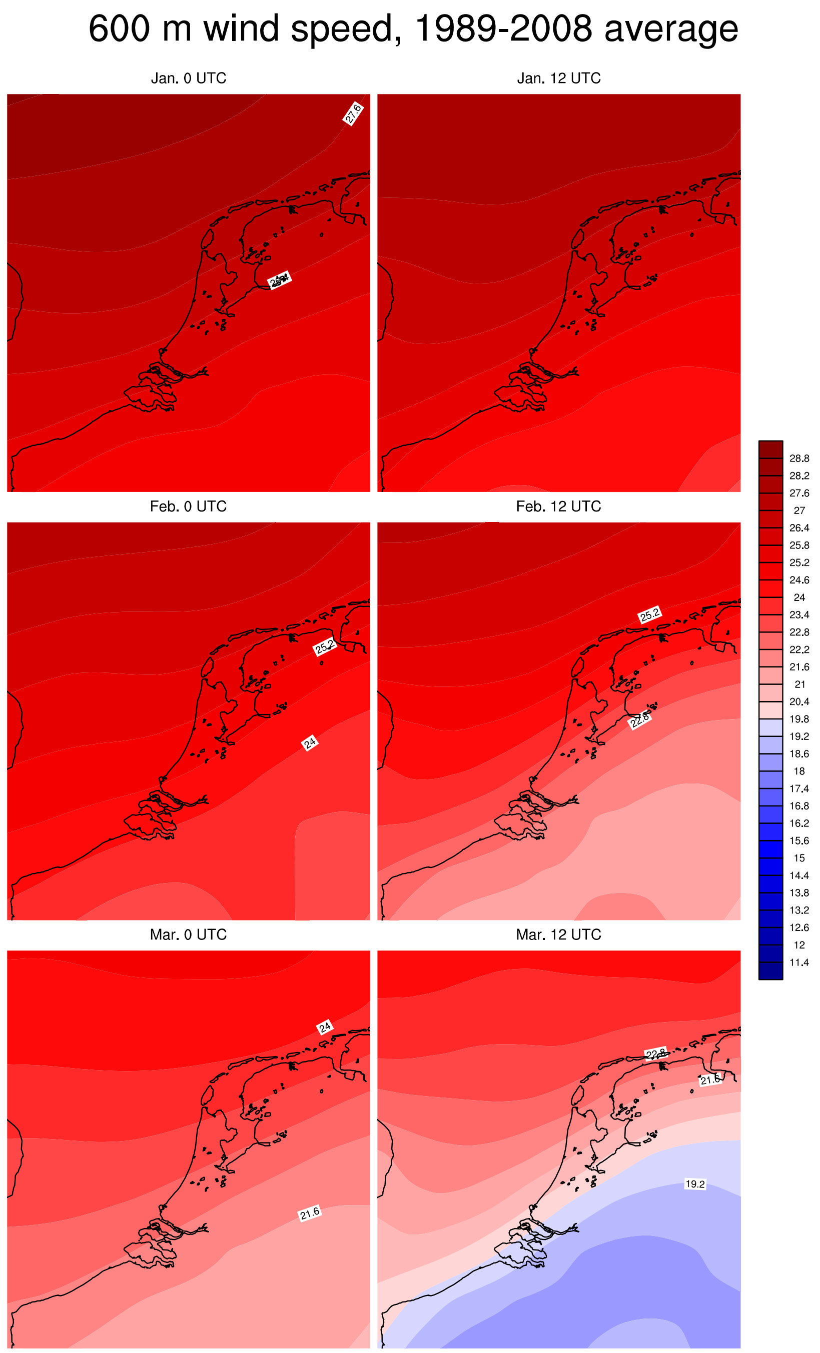
300 m wind speed, 1989-2008 average



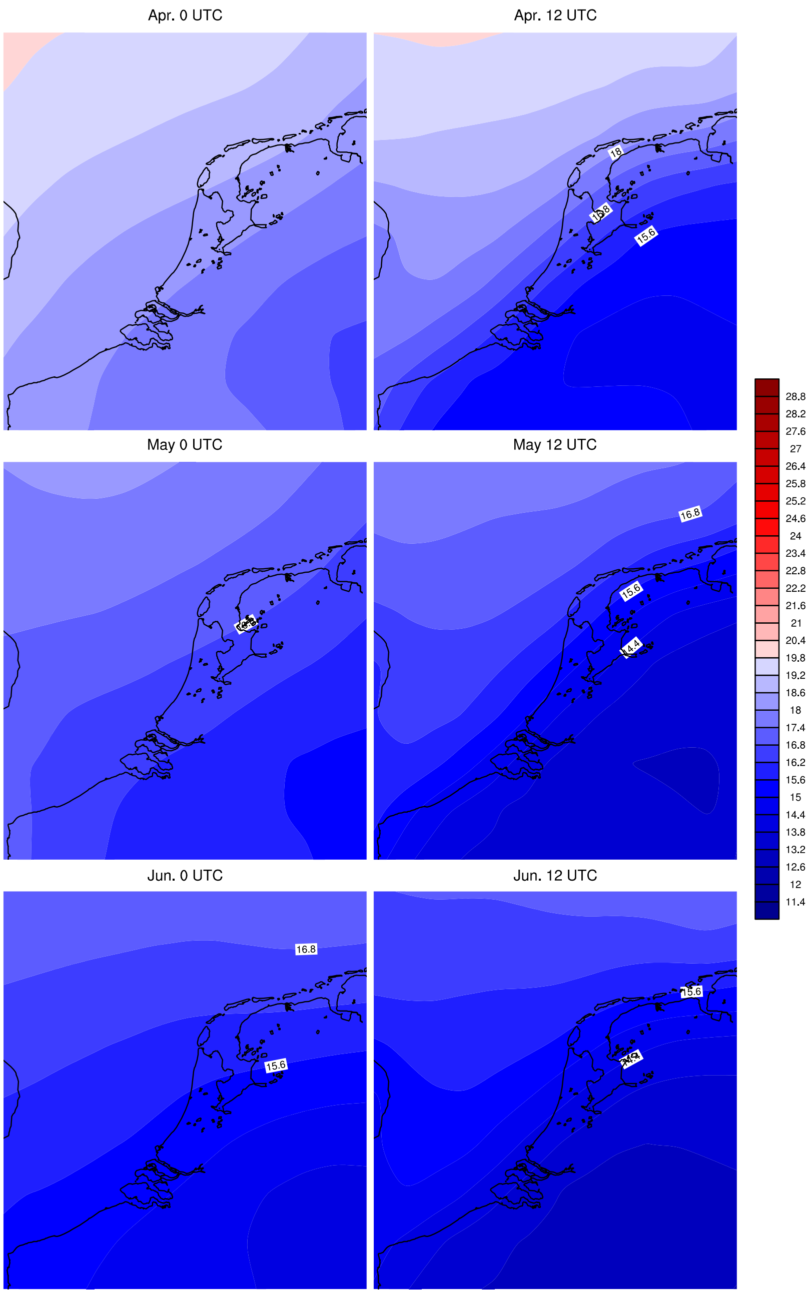
300 m wind speed, 1989-2008 average



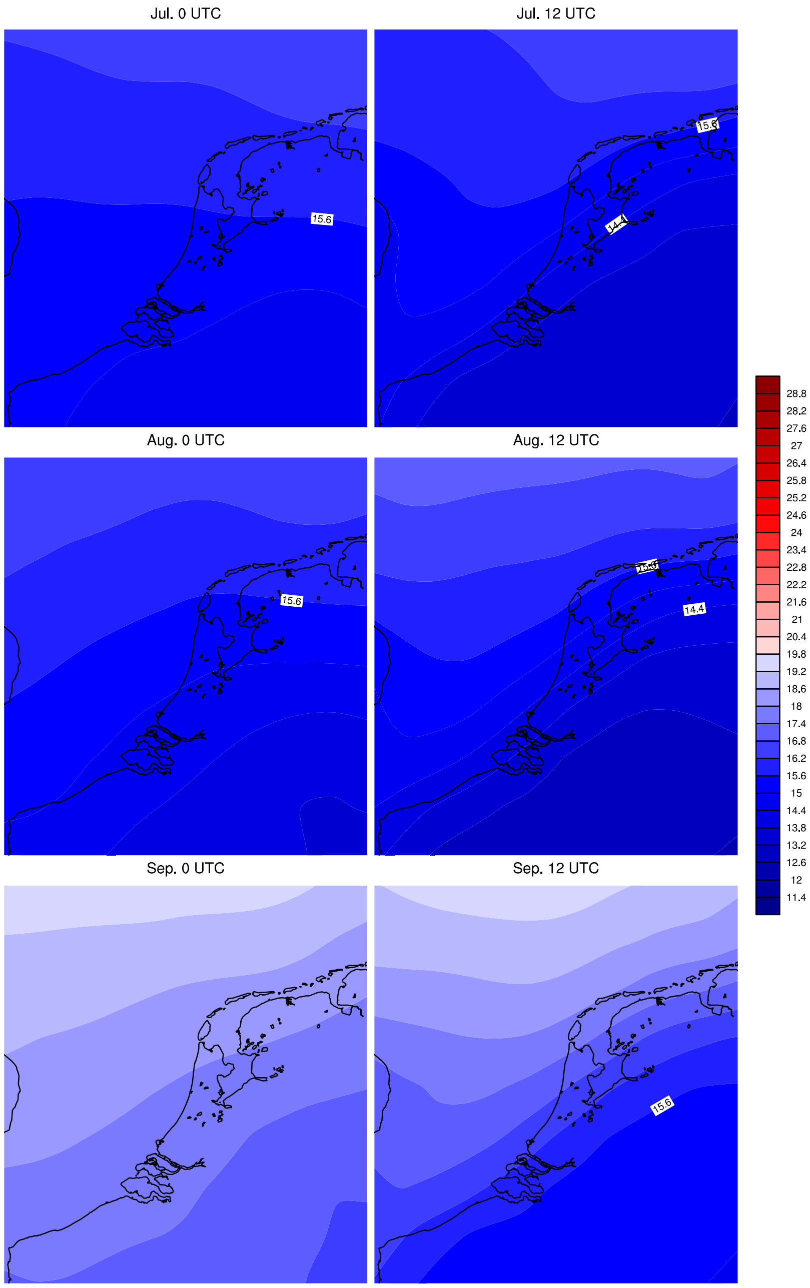
5.2.3 At 600 meter (about 2000 feet)



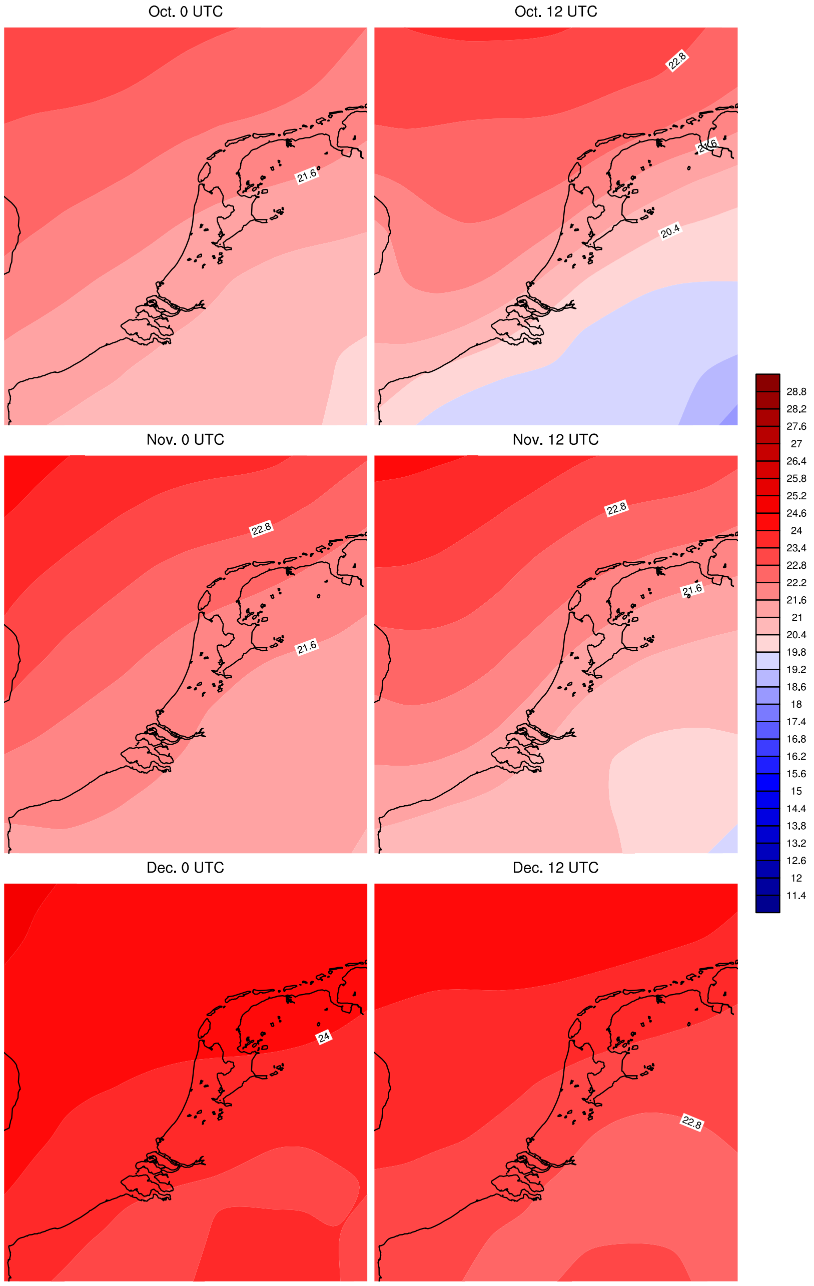
600 m wind speed, 1989-2008 average



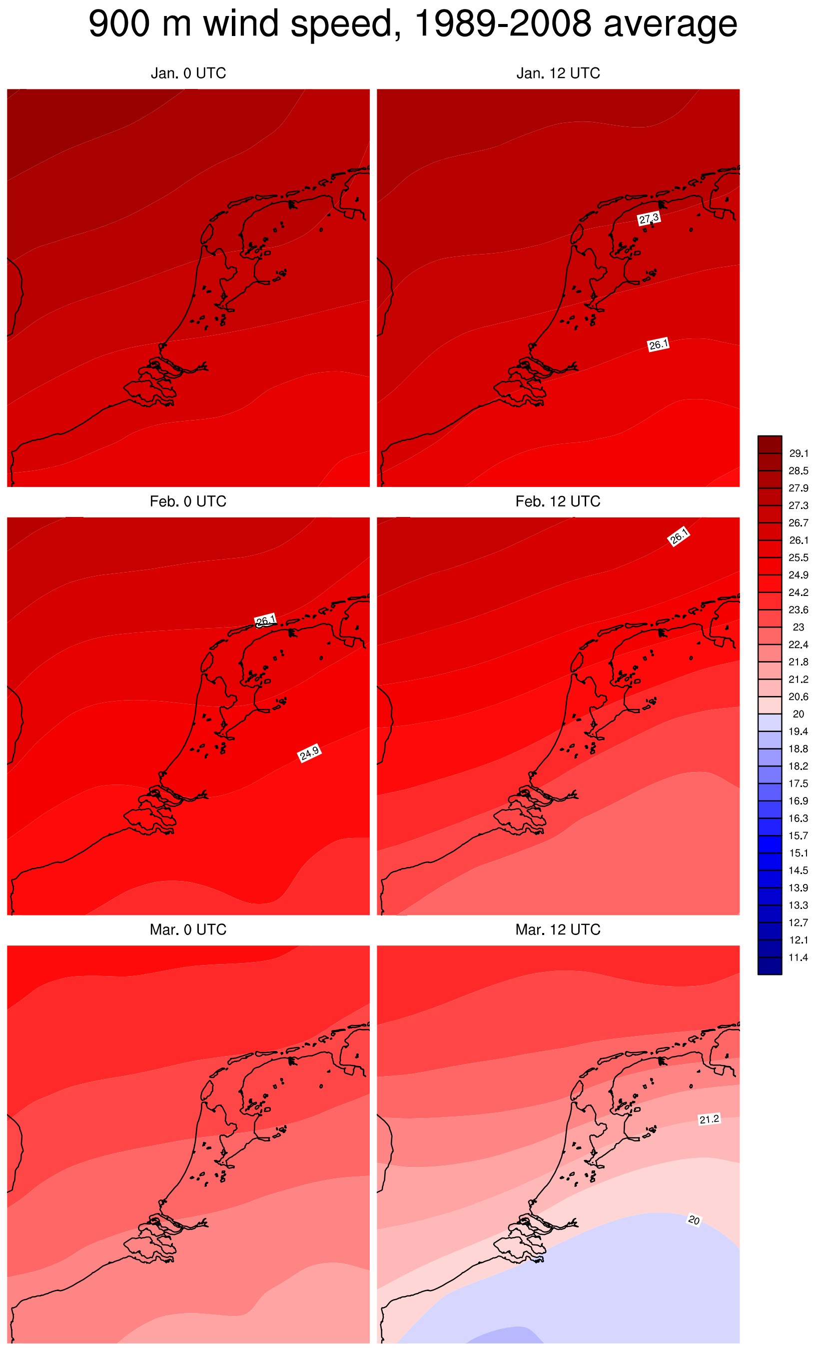
600 m wind speed, 1989-2008 average



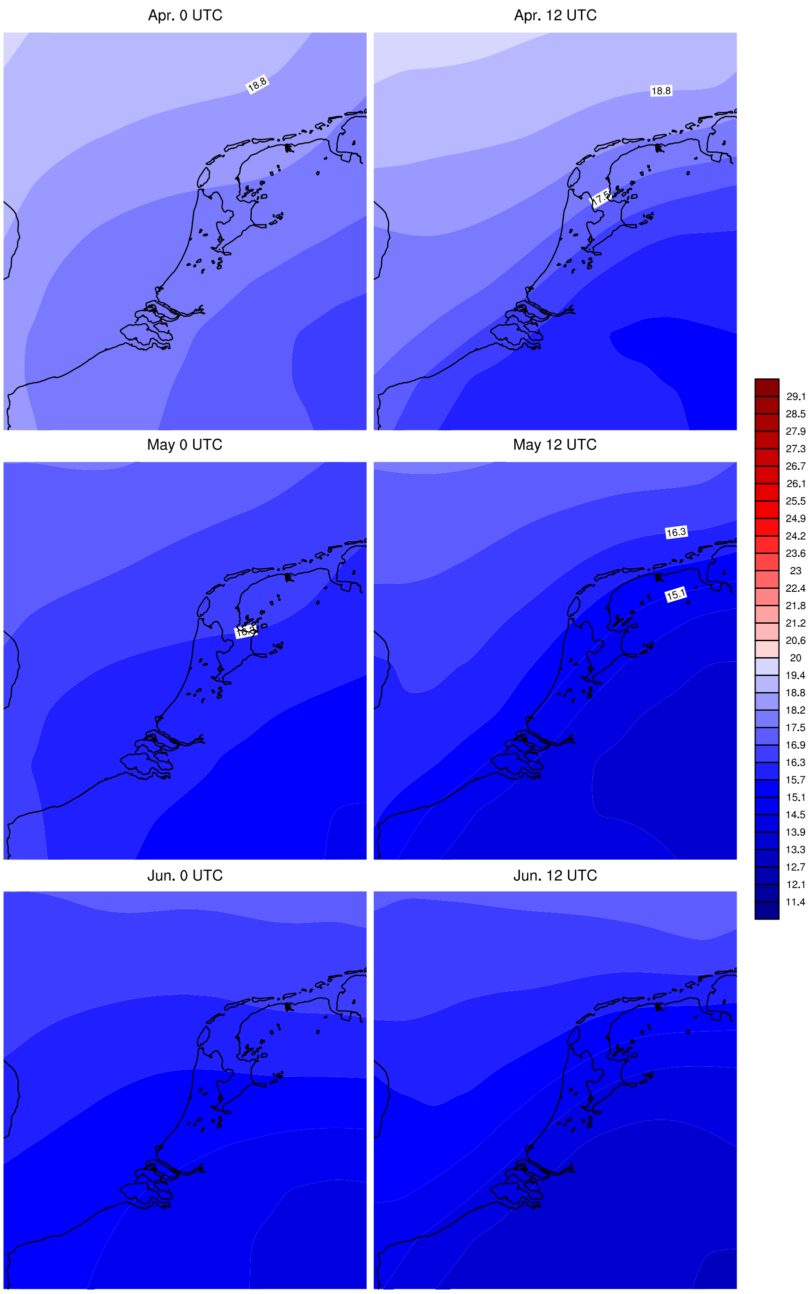
600 m wind speed, 1989-2008 average



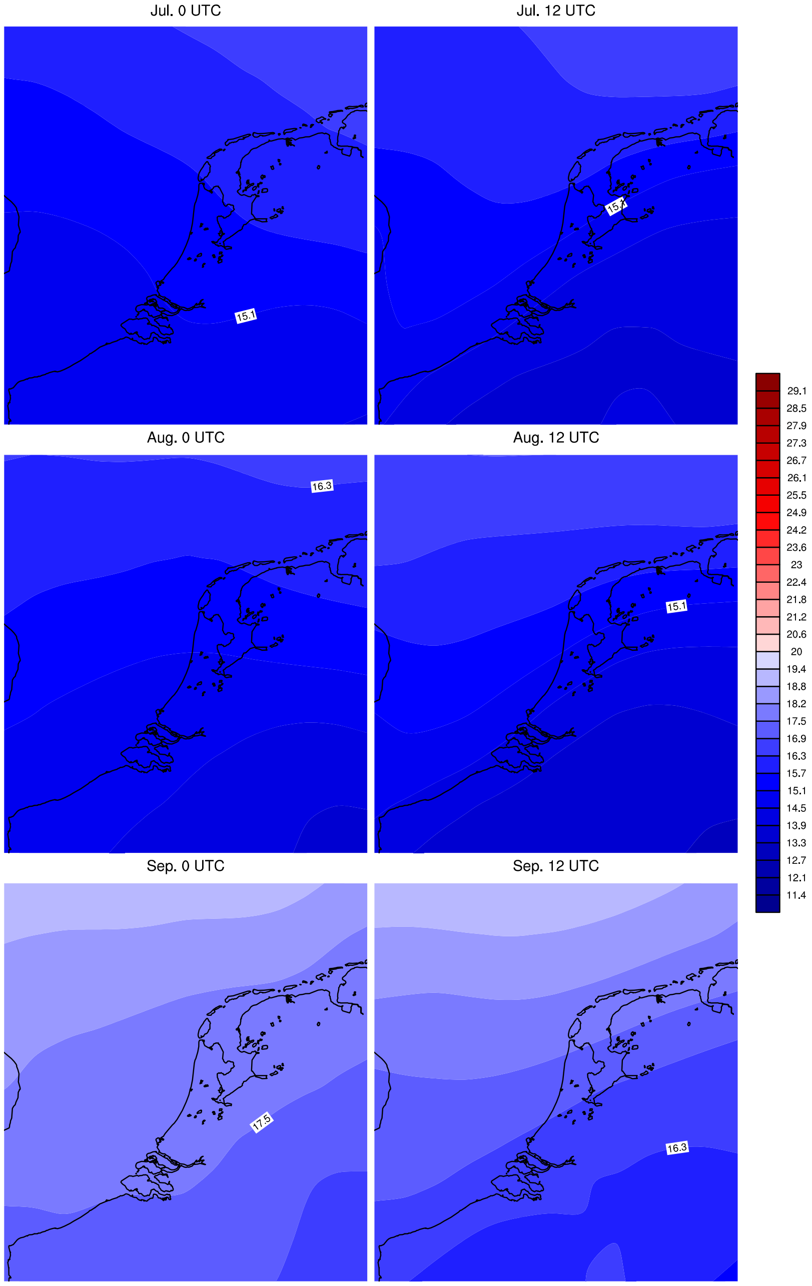
5.2.4 At 900 meter (about 3000 feet)



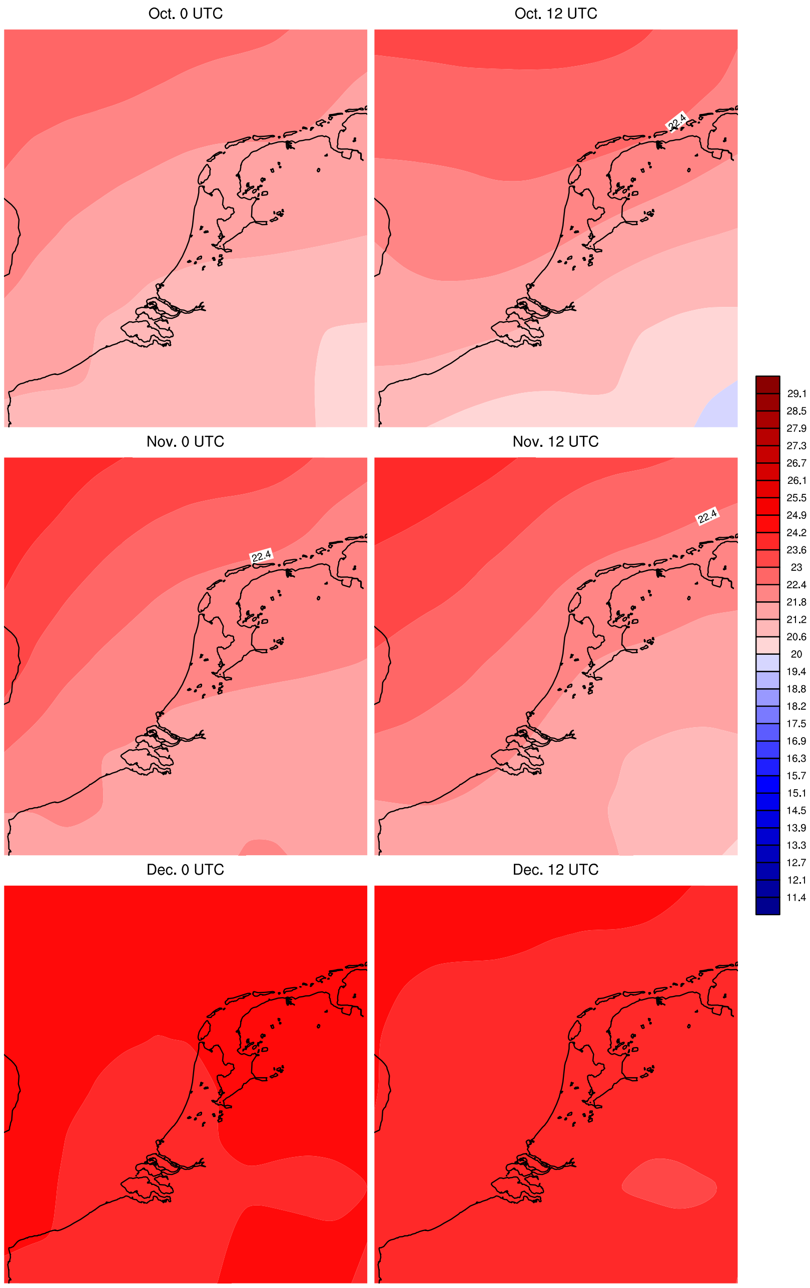
900 m wind speed, 1989-2008 average



900 m wind speed, 1989-2008 average

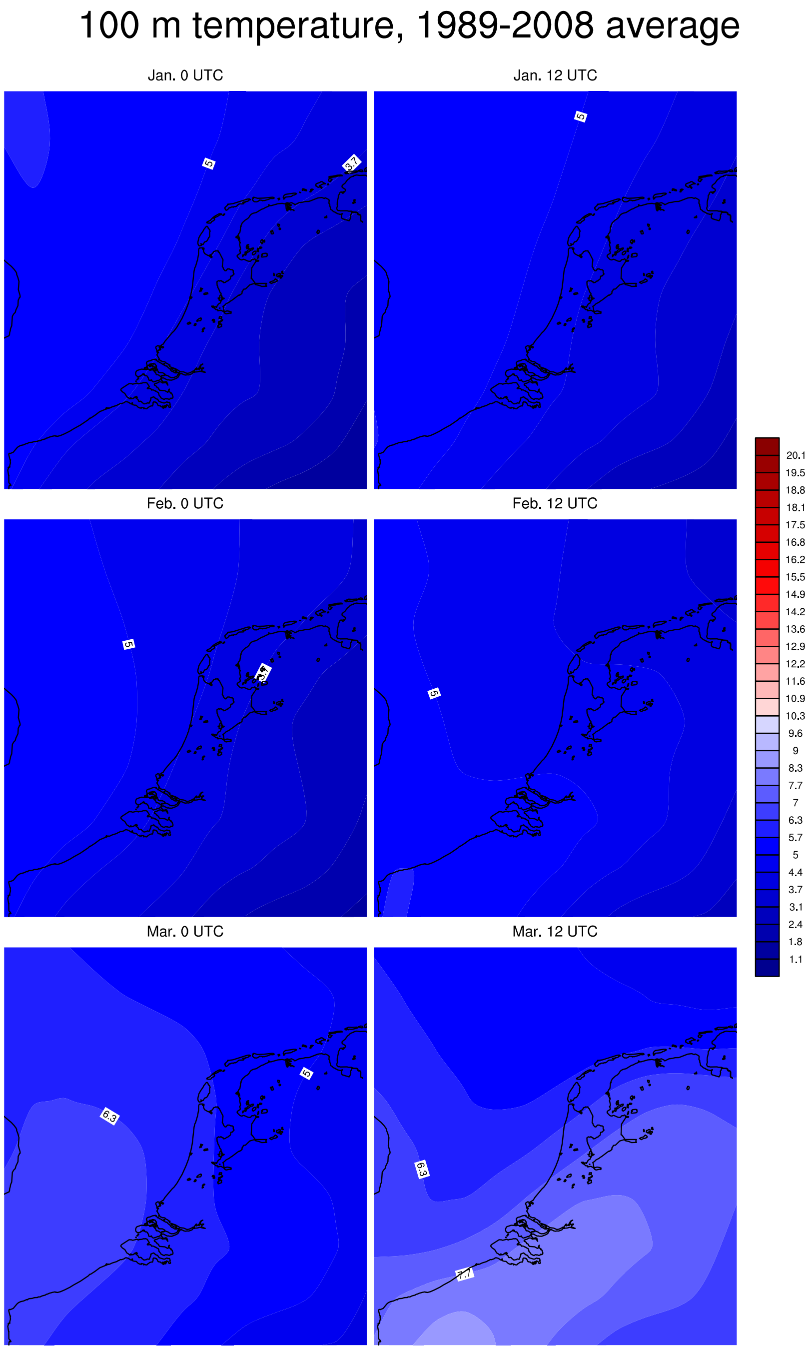


900 m wind speed, 1989-2008 average

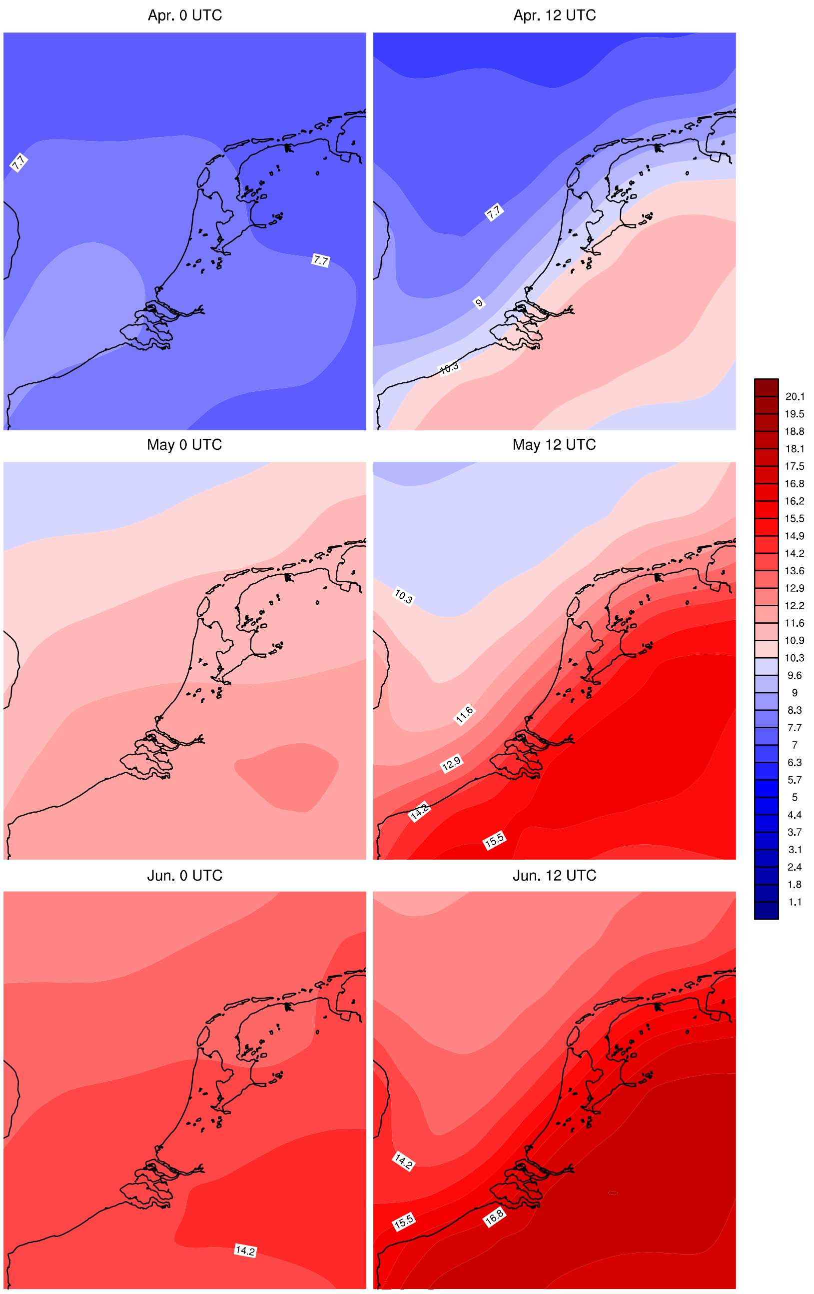


5.3 Temperature: ERA-Interim 1989-2009 spatial climatology Amsterdam-FIR

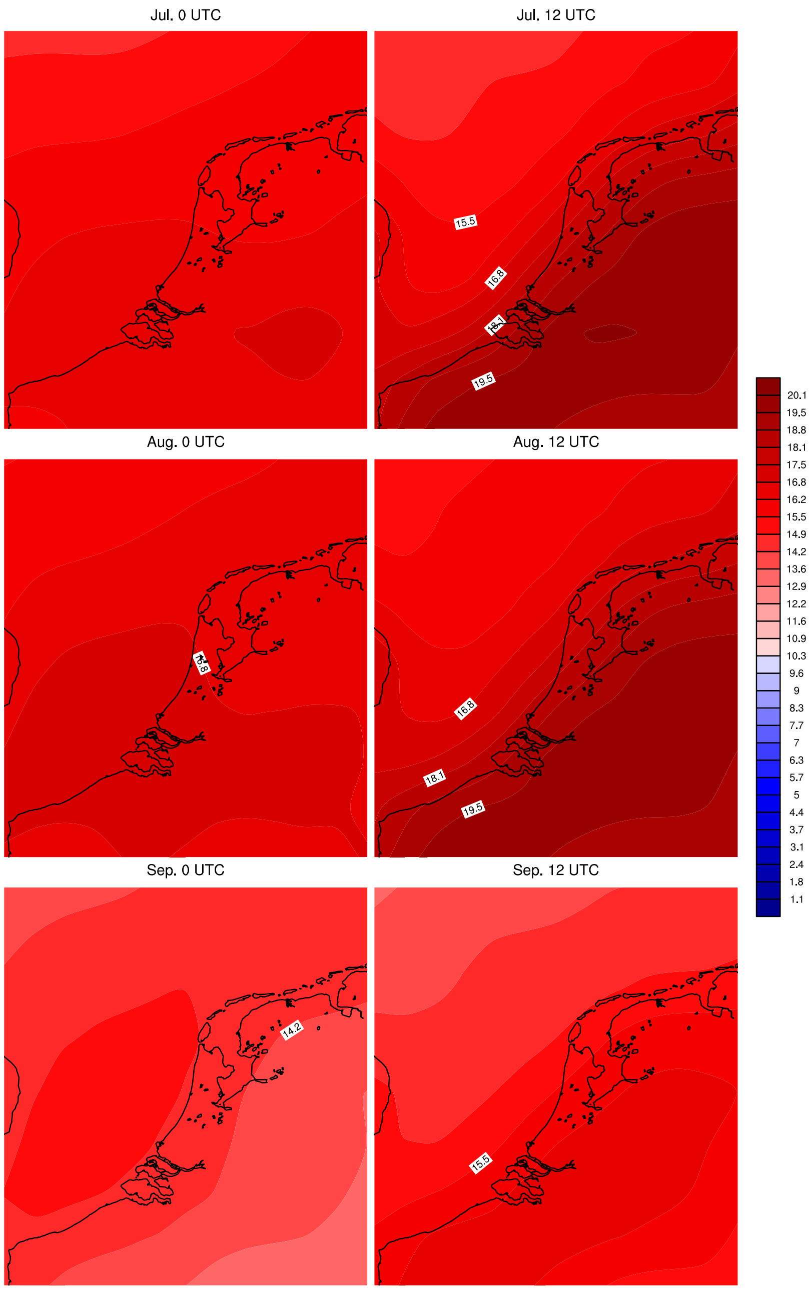
5.3.1 At 100 meters (about 300 feet)



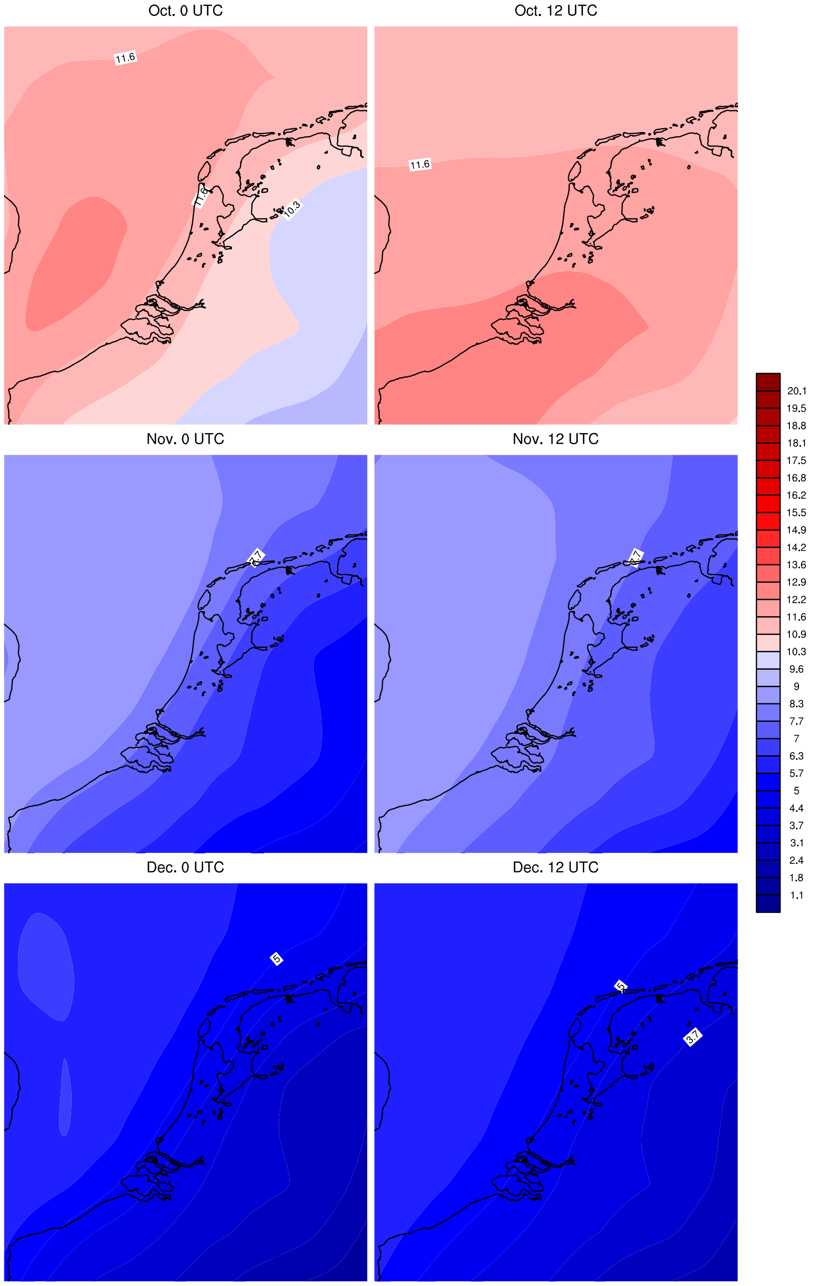
100 m temperature, 1989-2008 average



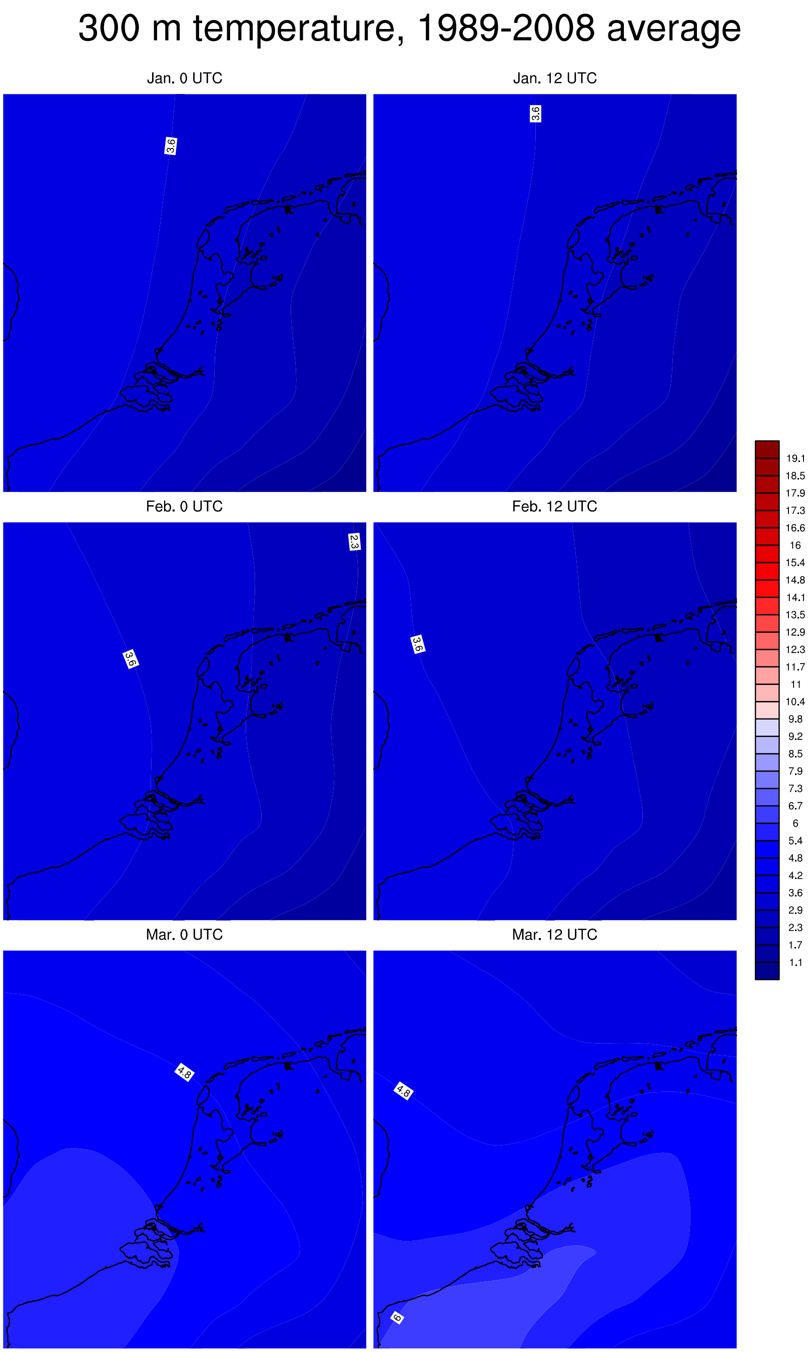
100 m temperature, 1989-2008 average



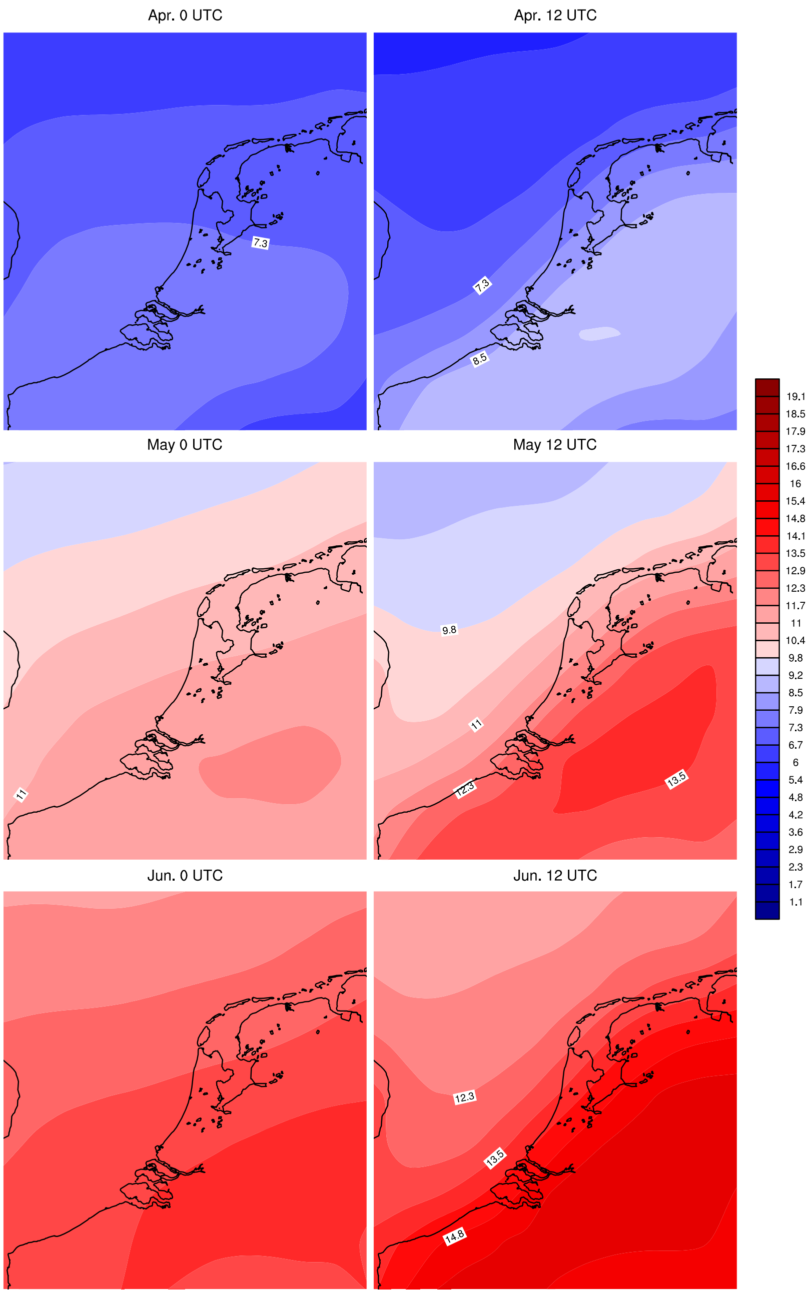
100 m temperature, 1989-2008 average



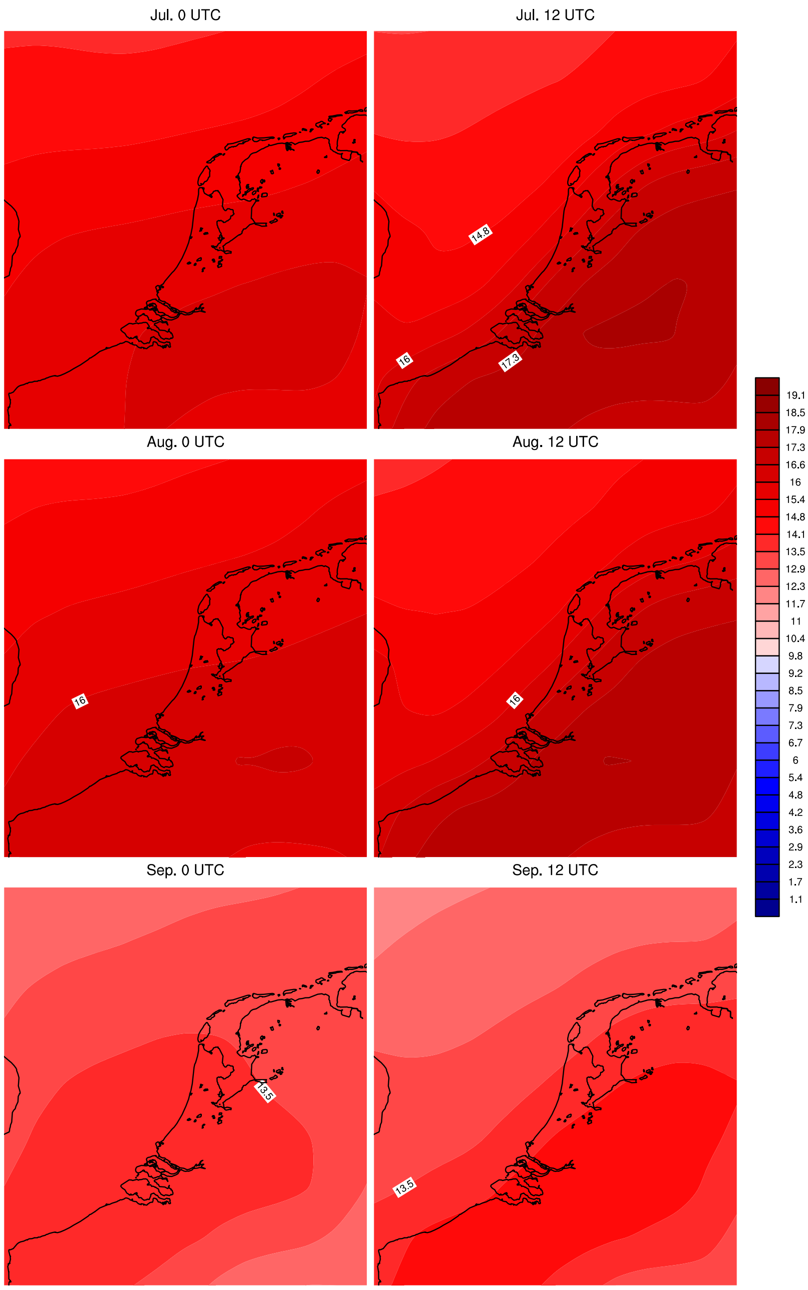
5.3.2 At 300 meter (about 1000 feet)



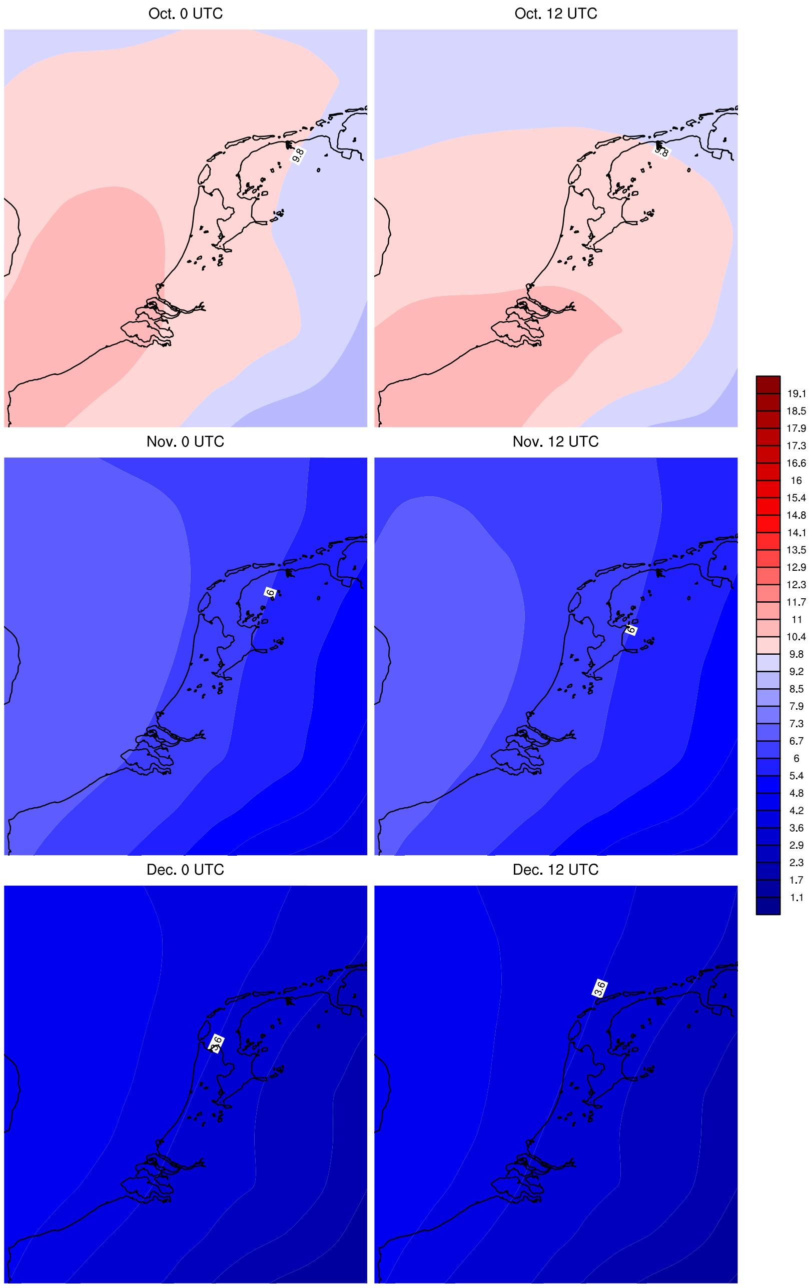
300 m temperature, 1989-2008 average



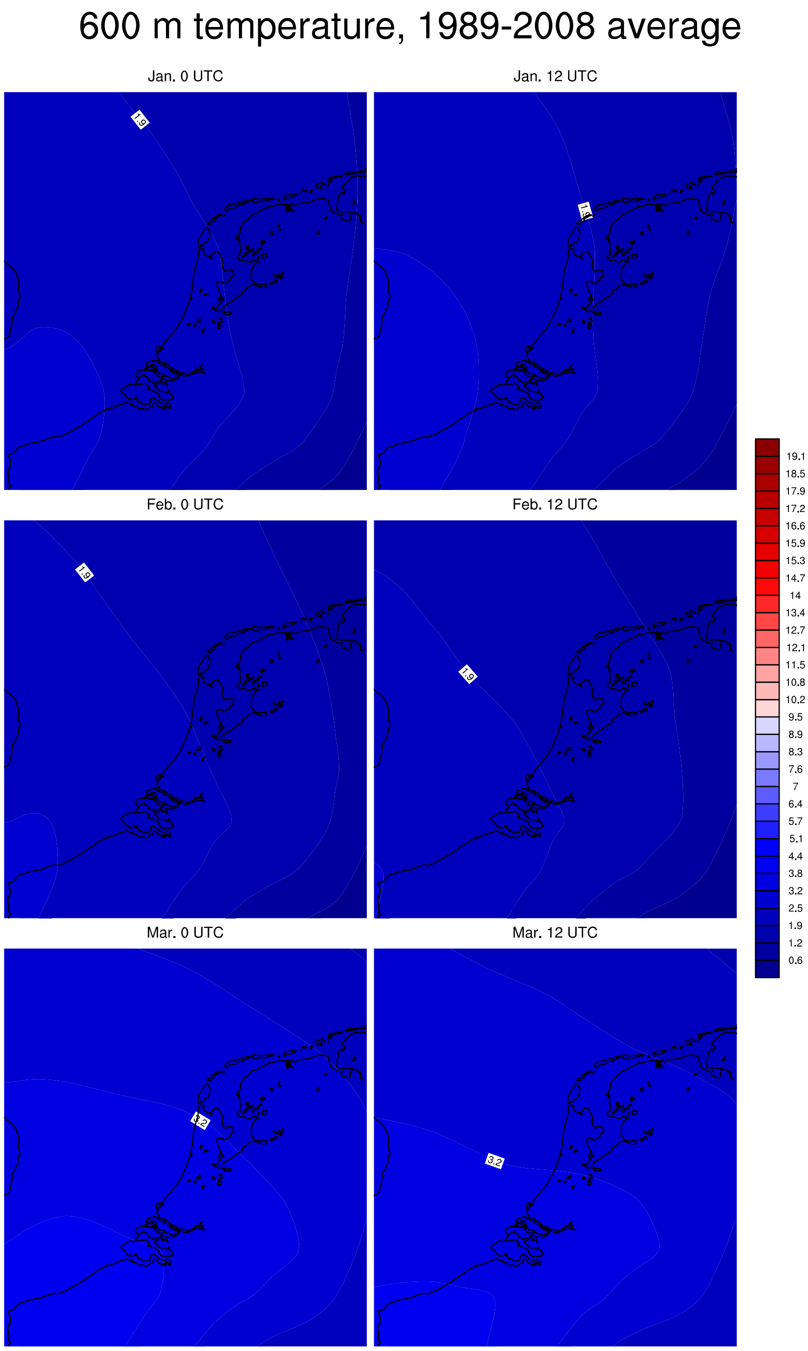
300 m temperature, 1989-2008 average



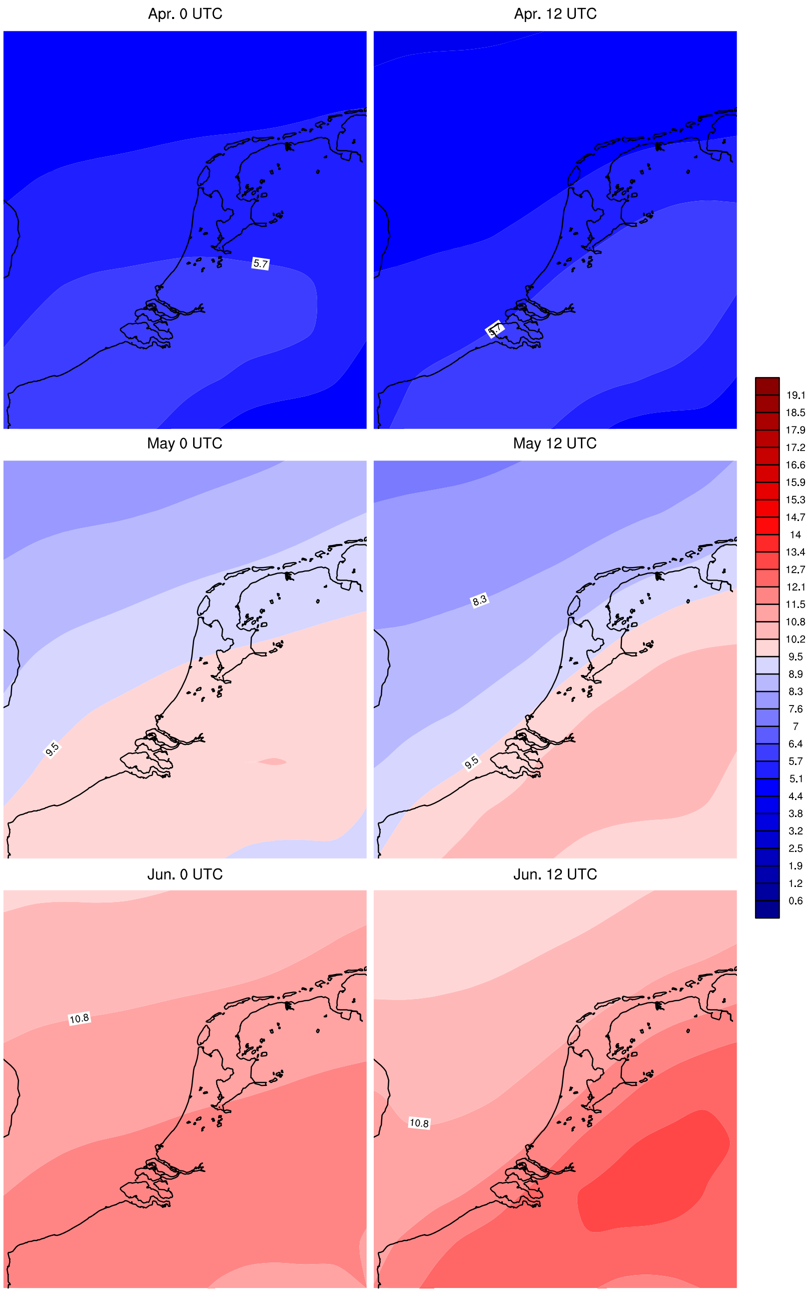
300 m temperature, 1989-2008 average



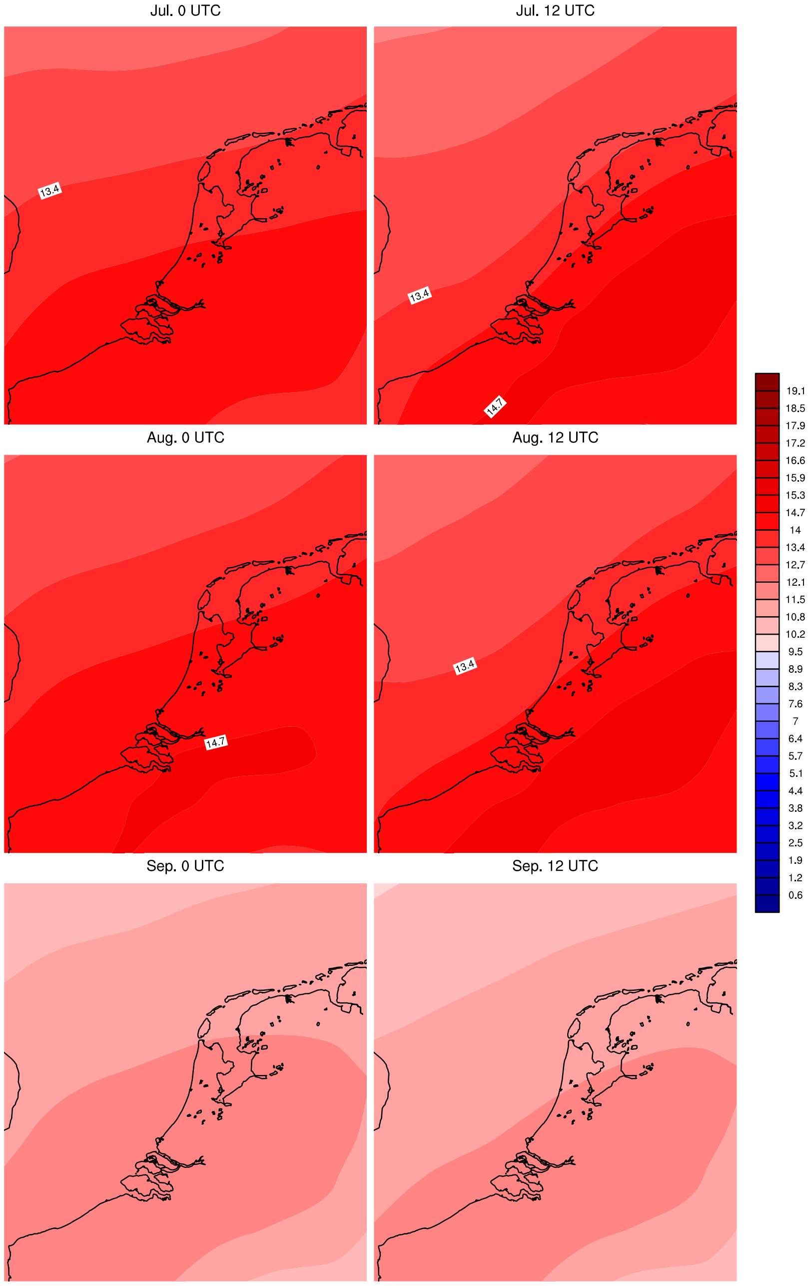
5.3.3 At 600 meter (about 2000 feet)



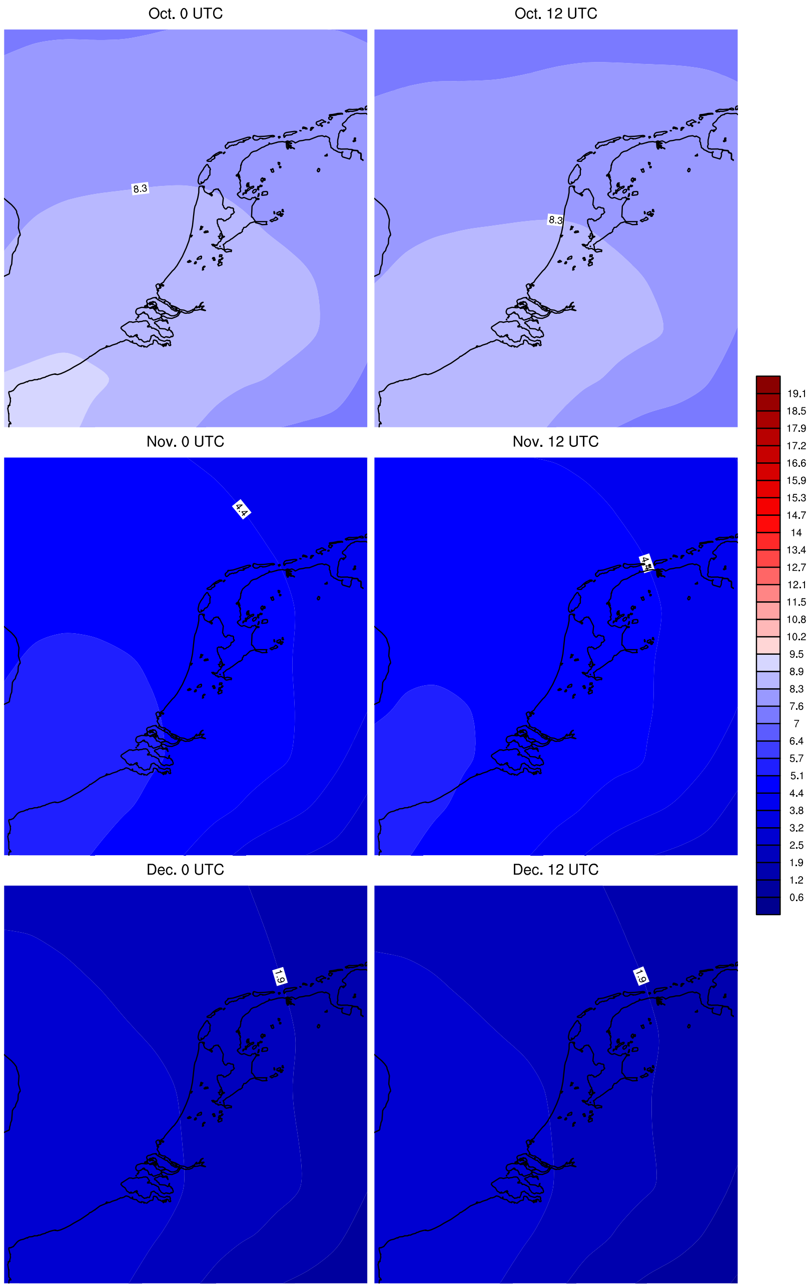
600 m temperature, 1989-2008 average



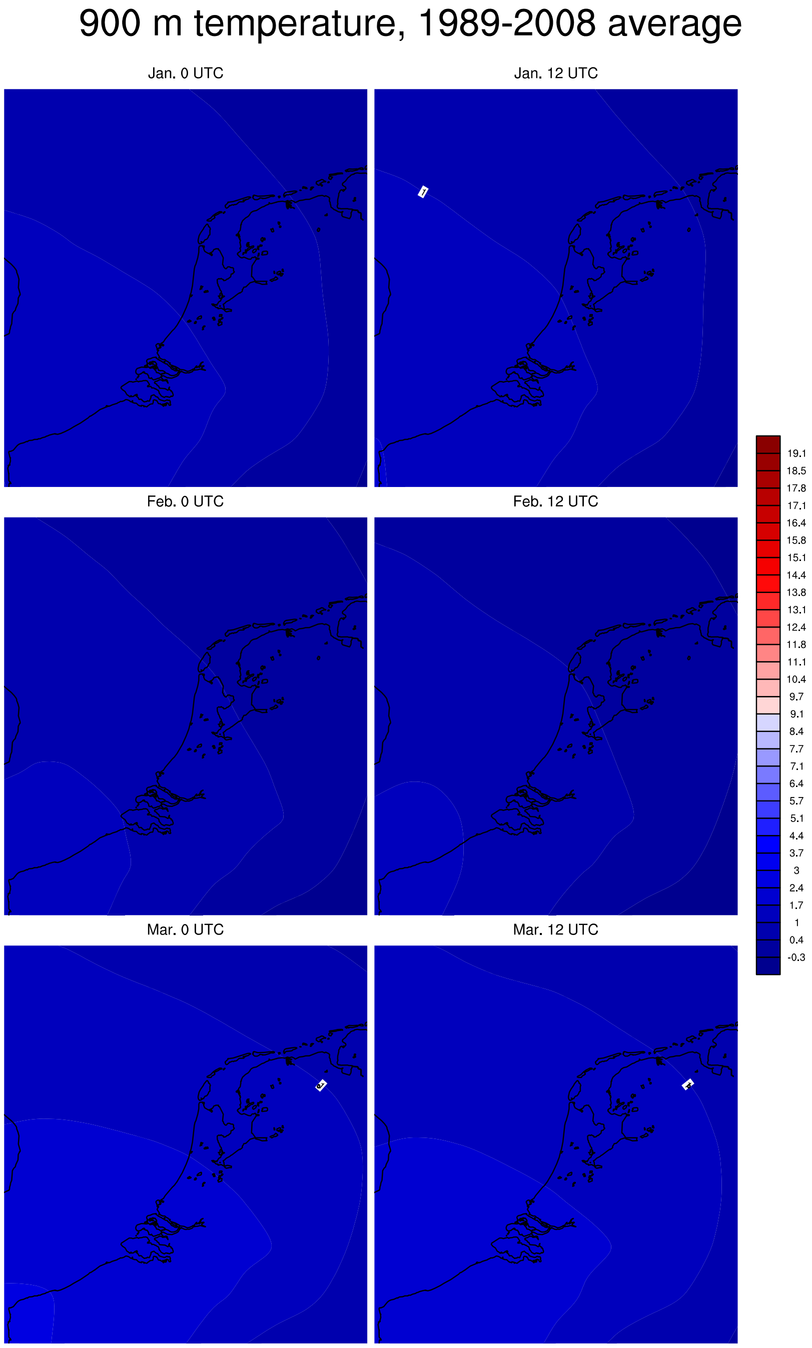
600 m temperature, 1989-2008 average



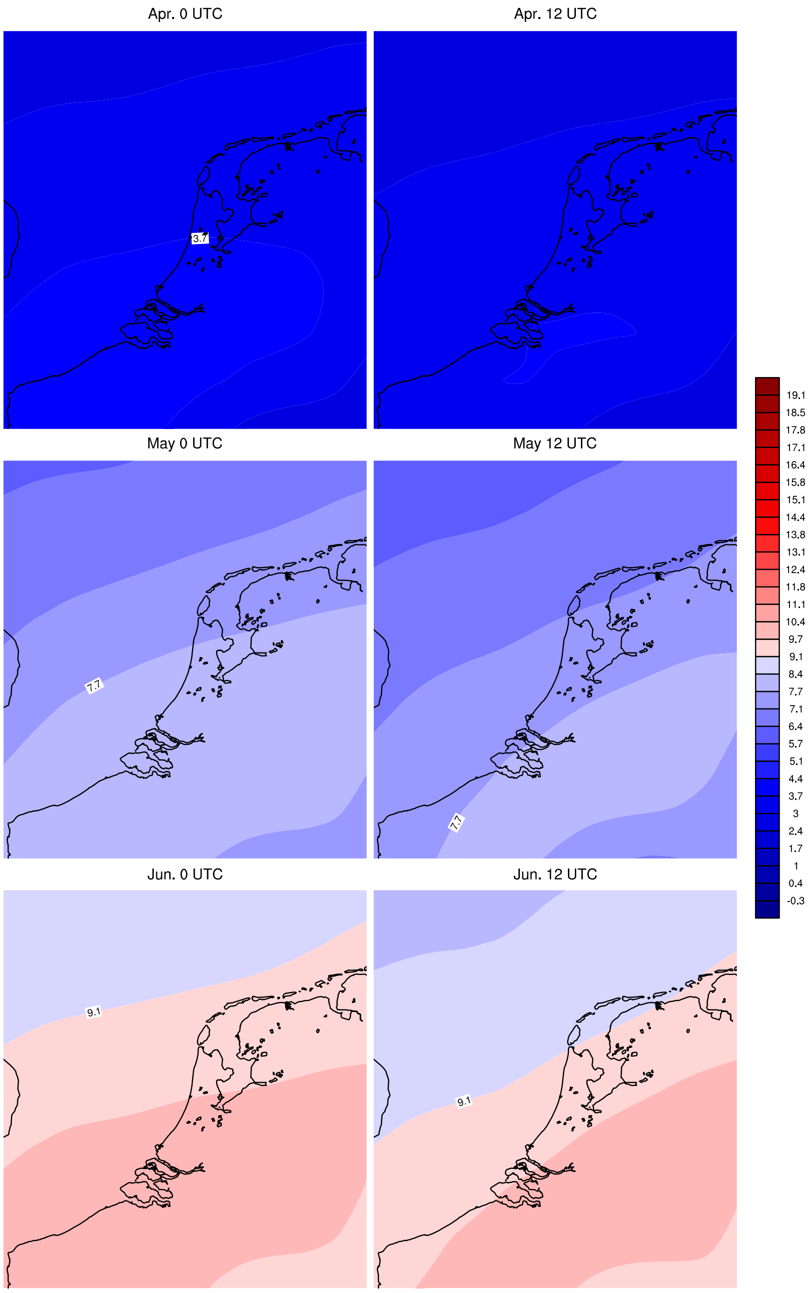
600 m temperature, 1989-2008 average



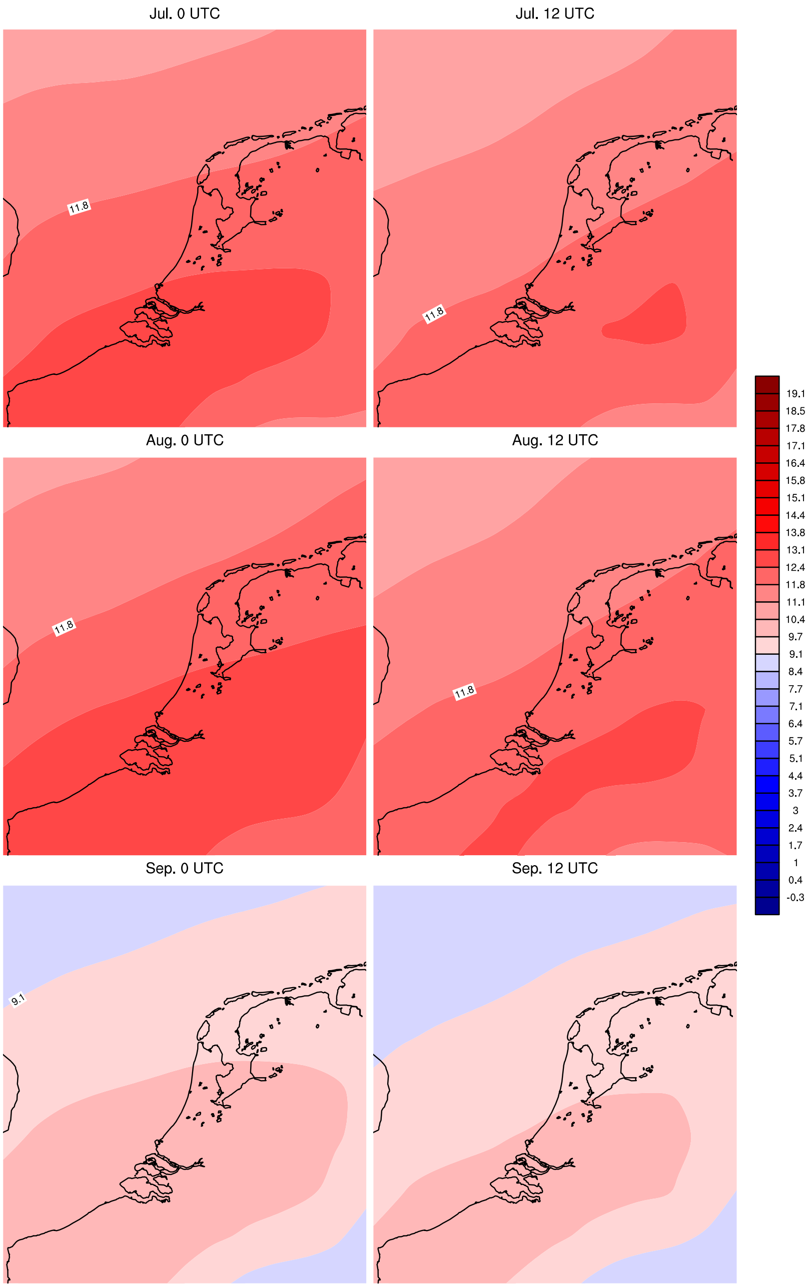
5.3.4 At 900 meter (about 3000 feet)



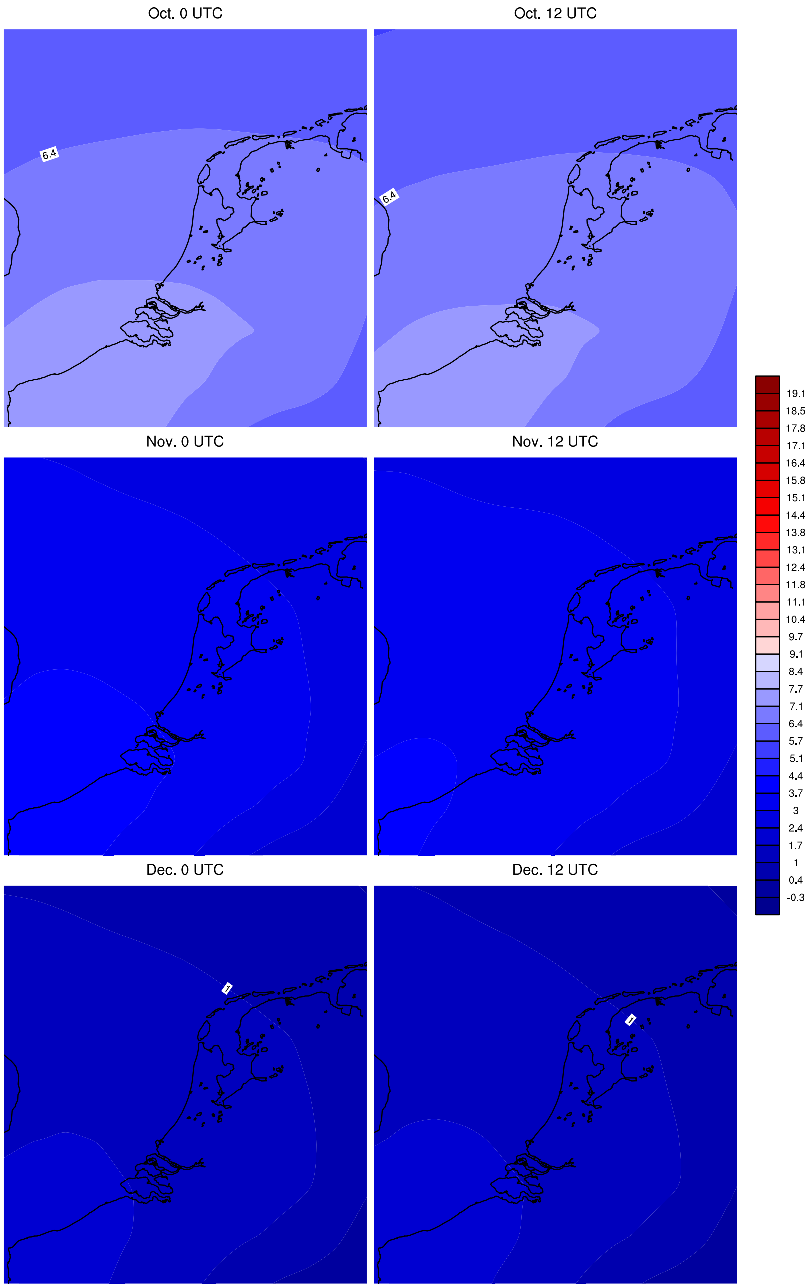
900 m temperature, 1989-2008 average



900 m temperature, 1989-2008 average

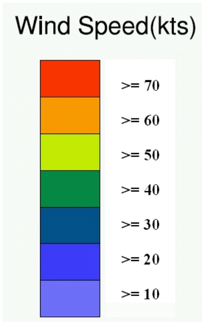


900 m temperature, 1989-2008 average

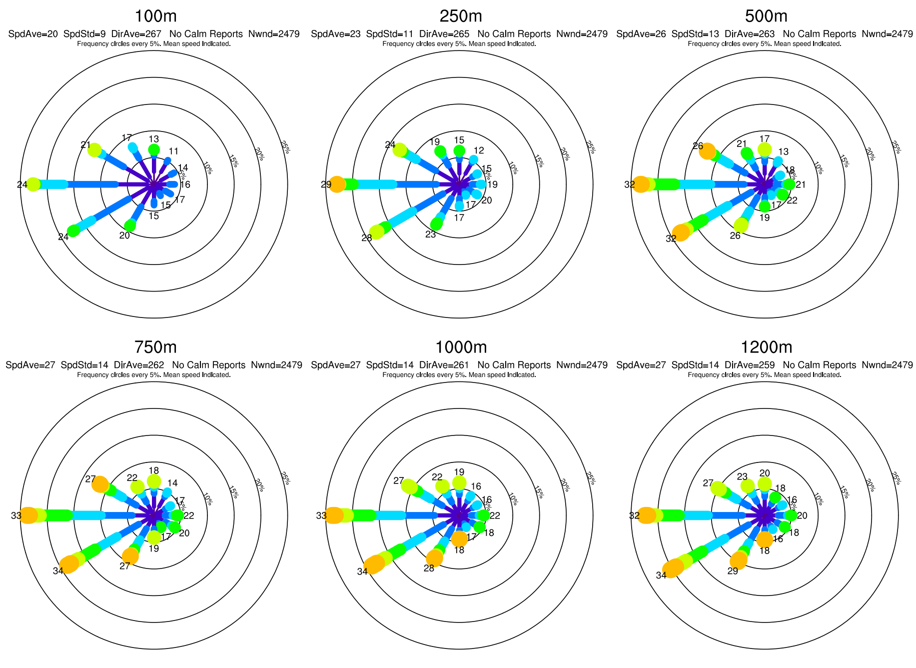


5.4 ERA-Interim climatology 1989-2009: Wind-roses per month at 100, 250, 500, 750, 1000 and 1200 meters in Amsterdam-FIR

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 5.5).

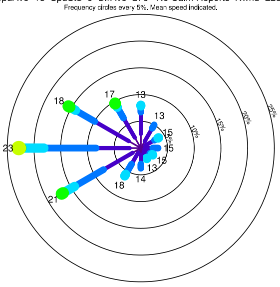


Jan.

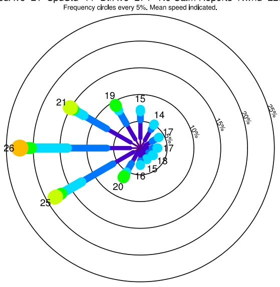


Feb.

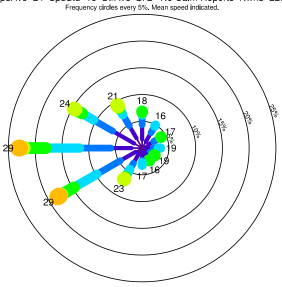
100m
SpdAve=18 SpdStd=9 DirAve=276 No Calm Reports Nwnd=2260
Frequency circles every 5%. Mean speed indicated.



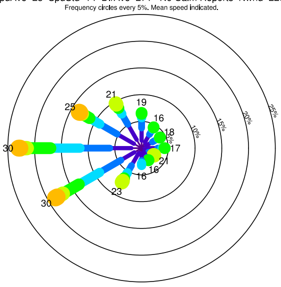
250m
SpdAve=21 SpdStd=11 DirAve=274 No Calm Reports Nwnd=2260
Frequency circles every 5%. Mean speed indicated.



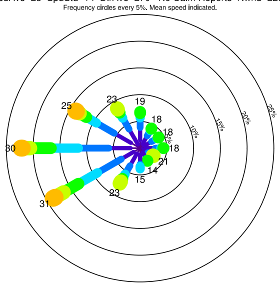
500m
SpdAve=24 SpdStd=13 DirAve=272 No Calm Reports Nwnd=2260
Frequency circles every 5%. Mean speed indicated.



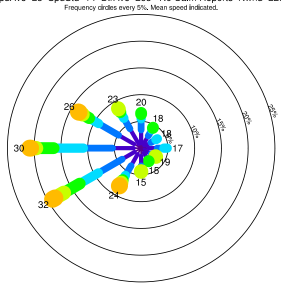
750m
SpdAve=25 SpdStd=14 DirAve=271 No Calm Reports Nwnd=2260
Frequency circles every 5%. Mean speed indicated.



1000m
SpdAve=25 SpdStd=14 DirAve=270 No Calm Reports Nwnd=2260
Frequency circles every 5%. Mean speed indicated.

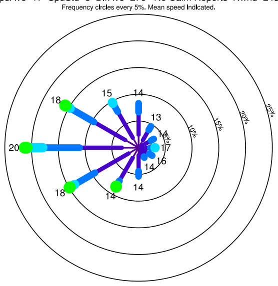


1200m
SpdAve=25 SpdStd=14 DirAve=268 No Calm Reports Nwnd=2260
Frequency circles every 5%. Mean speed indicated.

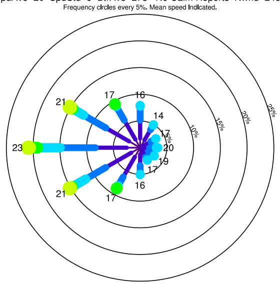


Mar.

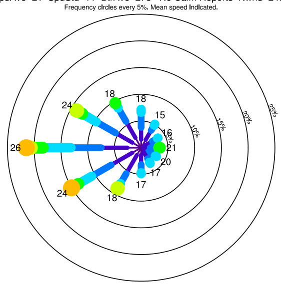
100m
SpdAve=17 SpdStd=8 DirAve=276 No Calm Reports Nwnd=2480
Frequency circles every 5%. Mean speed indicated.



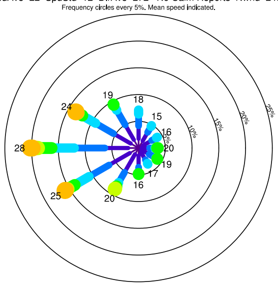
250m
SpdAve=20 SpdStd=9 DirAve=275 No Calm Reports Nwnd=2480
Frequency circles every 5%. Mean speed indicated.



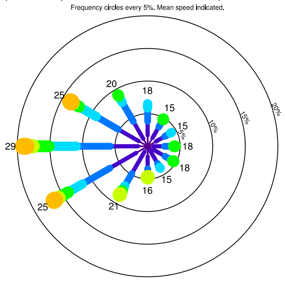
500m
SpdAve=21 SpdStd=11 DirAve=273 No Calm Reports Nwnd=2480
Frequency circles every 5%. Mean speed indicated.



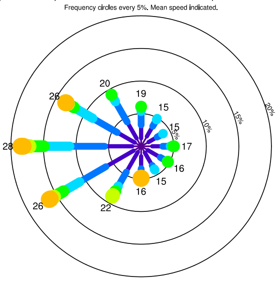
750m
SpdAve=22 SpdStd=12 DirAve=272 No Calm Reports Nwnd=2480
Frequency circles every 5%. Mean speed indicated.



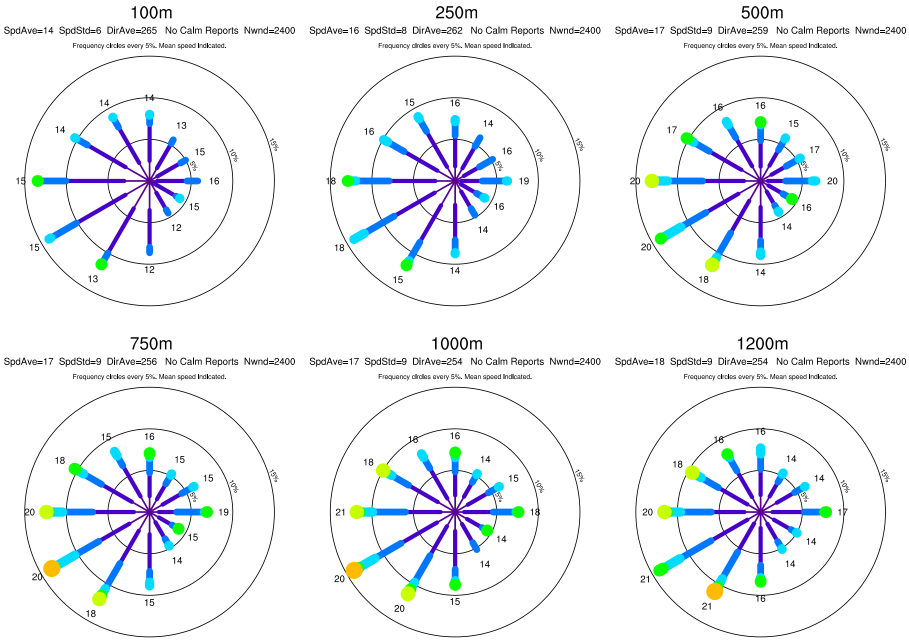
1000m
SpdAve=22 SpdStd=12 DirAve=271 No Calm Reports Nwnd=2480
Frequency circles every 5%. Mean speed indicated.



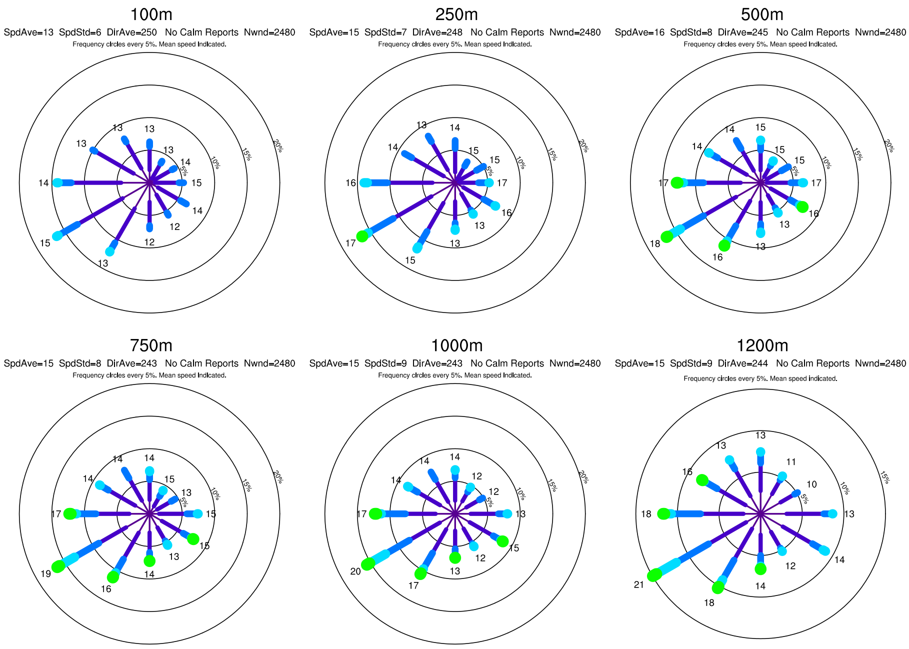
1200m
SpdAve=22 SpdStd=12 DirAve=269 No Calm Reports Nwnd=2480
Frequency circles every 5%. Mean speed indicated.



Apr.


100m
SpdAve=14 SpdStd=6 DirAve=265 No Calm Reports Nwnd=2400
Frequency circles every 5%. Mean speed Indicated.
250m
SpdAve=16 SpdStd=8 DirAve=262 No Calm Reports Nwnd=2400
Frequency circles every 5%. Mean speed Indicated.
500m
SpdAve=17 SpdStd=9 DirAve=259 No Calm Reports Nwnd=2400
Frequency circles every 5%. Mean speed Indicated.
750m
SpdAve=17 SpdStd=9 DirAve=256 No Calm Reports Nwnd=2400
Frequency circles every 5%. Mean speed Indicated.
1000m
SpdAve=17 SpdStd=9 DirAve=254 No Calm Reports Nwnd=2400
Frequency circles every 5%. Mean speed Indicated.
1200m
SpdAve=18 SpdStd=9 DirAve=254 No Calm Reports Nwnd=2400
Frequency circles every 5%. Mean speed Indicated.

May

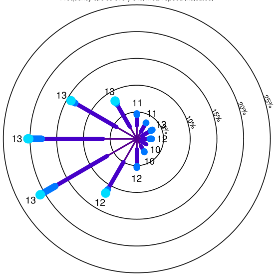

100m
SpdAve=13 SpdStd=6 DirAve=250 No Calm Reports Nwnd=2480
Frequency circles every 5%. Mean speed Indicated.
250m
SpdAve=15 SpdStd=7 DirAve=248 No Calm Reports Nwnd=2480
Frequency circles every 5%. Mean speed Indicated.
500m
SpdAve=16 SpdStd=8 DirAve=245 No Calm Reports Nwnd=2480
Frequency circles every 5%. Mean speed Indicated.
750m
SpdAve=15 SpdStd=8 DirAve=243 No Calm Reports Nwnd=2480
Frequency circles every 5%. Mean speed Indicated.
1000m
SpdAve=15 SpdStd=9 DirAve=243 No Calm Reports Nwnd=2480
Frequency circles every 5%. Mean speed Indicated.
1200m
SpdAve=15 SpdStd=9 DirAve=244 No Calm Reports Nwnd=2480
Frequency circles every 5%. Mean speed Indicated.

Jun.

100m

SpdAve=13 SpdStd=6 DirAve=264 No Calm Reports Nwnd=2400

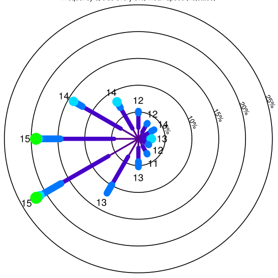
Frequency circles every 5%. Mean speed indicated.



250m

SpdAve=14 SpdStd=7 DirAve=263 No Calm Reports Nwnd=2400

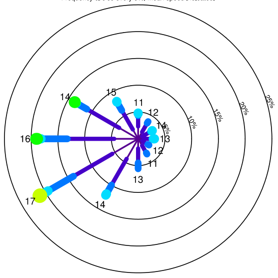
Frequency circles every 5%. Mean speed indicated.



500m

SpdAve=15 SpdStd=8 DirAve=261 No Calm Reports Nwnd=2400

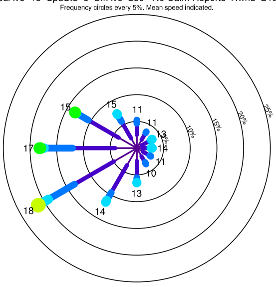
Frequency circles every 5%. Mean speed indicated.



750m

SpdAve=15 SpdStd=8 DirAve=259 No Calm Reports Nwnd=2400

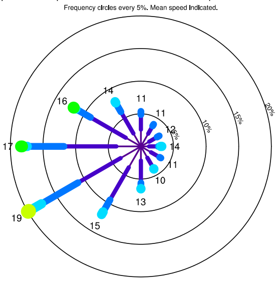
Frequency circles every 5%. Mean speed indicated.



1000m

SpdAve=15 SpdStd=8 DirAve=257 No Calm Reports Nwnd=2400

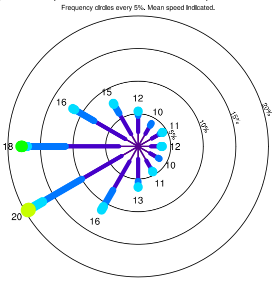
Frequency circles every 5%. Mean speed indicated.



1200m

SpdAve=16 SpdStd=8 DirAve=257 No Calm Reports Nwnd=2400

Frequency circles every 5%. Mean speed indicated.

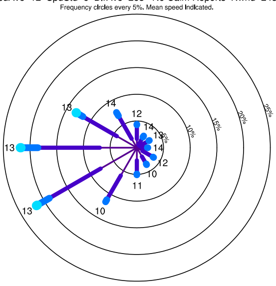


Jul.

100m

SpdAve=12 SpdStd=6 DirAve=263 No Calm Reports Nwnd=2480

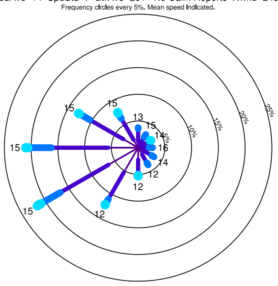
Frequency circles every 5%. Mean speed indicated.



250m

SpdAve=14 SpdStd=7 DirAve=261 No Calm Reports Nwnd=2480

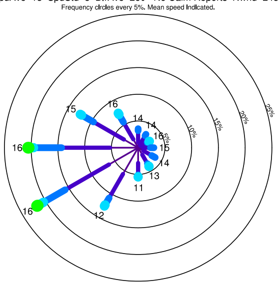
Frequency circles every 5%. Mean speed indicated.



500m

SpdAve=15 SpdStd=8 DirAve=260 No Calm Reports Nwnd=2480

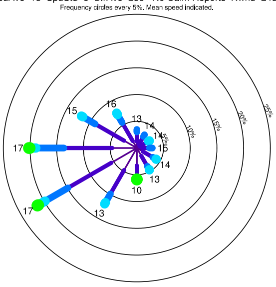
Frequency circles every 5%. Mean speed indicated.



750m

SpdAve=15 SpdStd=8 DirAve=258 No Calm Reports Nwnd=2480

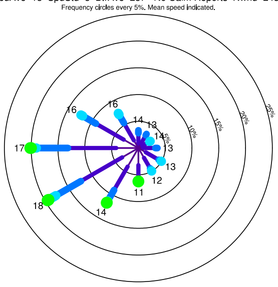
Frequency circles every 5%. Mean speed indicated.



1000m

SpdAve=15 SpdStd=8 DirAve=257 No Calm Reports Nwnd=2480

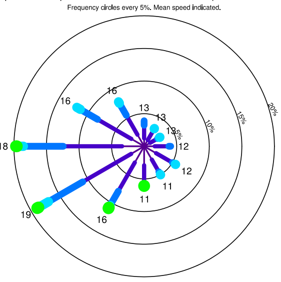
Frequency circles every 5%. Mean speed indicated.



1200m

SpdAve=16 SpdStd=8 DirAve=258 No Calm Reports Nwnd=2480

Frequency circles every 5%. Mean speed indicated.

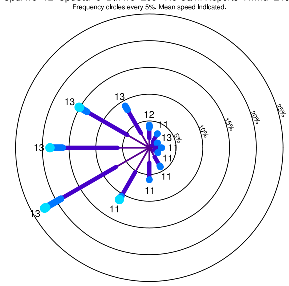


Aug.

100m

SpdAve=12 SpdStd=6 DirAve=263 No Calm Reports Nwnd=2480

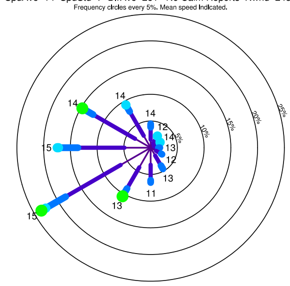
Frequency circles every 5%. Mean speed Indicated.



250m

SpdAve=14 SpdStd=7 DirAve=261 No Calm Reports Nwnd=2480

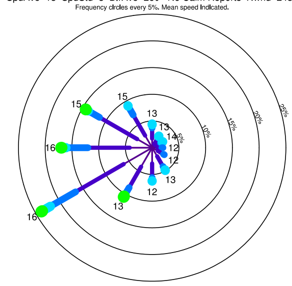
Frequency circles every 5%. Mean speed Indicated.



500m

SpdAve=15 SpdStd=8 DirAve=260 No Calm Reports Nwnd=2480

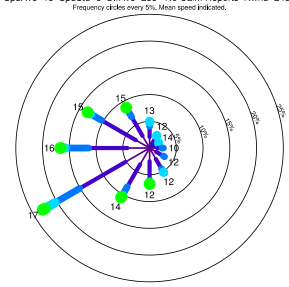
Frequency circles every 5%. Mean speed Indicated.



750m

SpdAve=15 SpdStd=8 DirAve=258 No Calm Reports Nwnd=2480

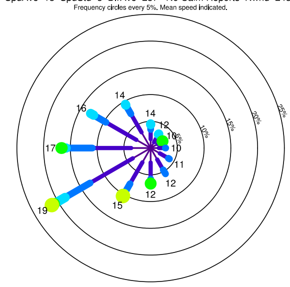
Frequency circles every 5%. Mean speed Indicated.



1000m

SpdAve=15 SpdStd=8 DirAve=257 No Calm Reports Nwnd=2480

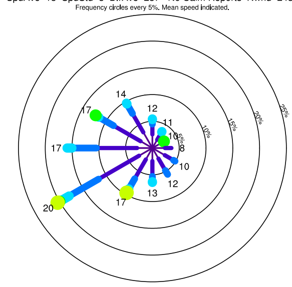
Frequency circles every 5%. Mean speed Indicated.



1200m

SpdAve=15 SpdStd=8 DirAve=257 No Calm Reports Nwnd=2480

Frequency circles every 5%. Mean speed Indicated.

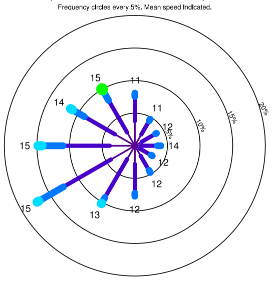


Sep.

100m

SpdAve=14 SpdStd=6 DirAve=266 No Calm Reports Nwnd=2400

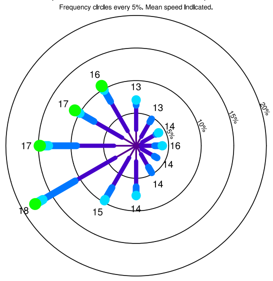
Frequency circles every 5%. Mean speed Indicated.



250m

SpdAve=16 SpdStd=8 DirAve=264 No Calm Reports Nwnd=2400

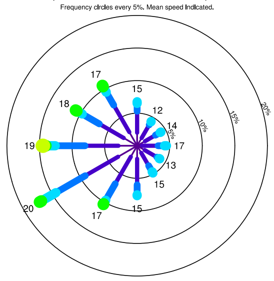
Frequency circles every 5%. Mean speed Indicated.



500m

SpdAve=17 SpdStd=9 DirAve=262 No Calm Reports Nwnd=2400

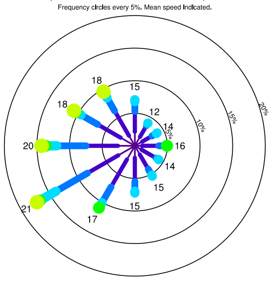
Frequency circles every 5%. Mean speed Indicated.



750m

SpdAve=17 SpdStd=9 DirAve=260 No Calm Reports Nwnd=2400

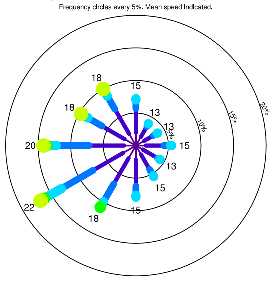
Frequency circles every 5%. Mean speed Indicated.



1000m

SpdAve=18 SpdStd=9 DirAve=258 No Calm Reports Nwnd=2400

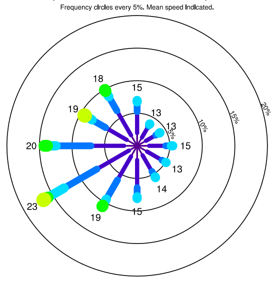
Frequency circles every 5%. Mean speed Indicated.



1200m

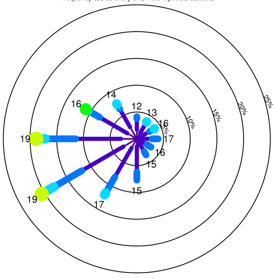
SpdAve=18 SpdStd=9 DirAve=257 No Calm Reports Nwnd=2400

Frequency circles every 5%. Mean speed Indicated.

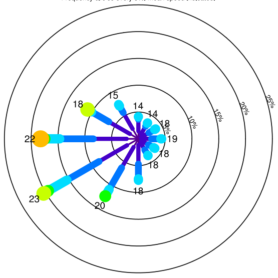


Oct.

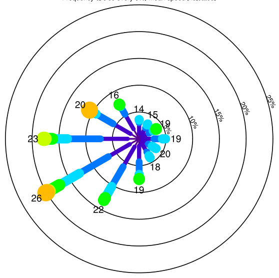
100m
SpdAve=17 SpdStd=7 DirAve=251 No Calm Reports Nwnd=2480
Frequency circles every 5%. Mean speed indicated.



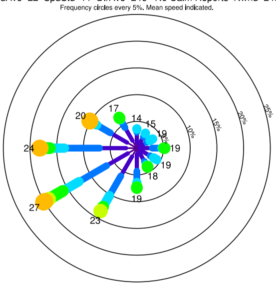
250m
SpdAve=19 SpdStd=9 DirAve=249 No Calm Reports Nwnd=2480
Frequency circles every 5%. Mean speed indicated.



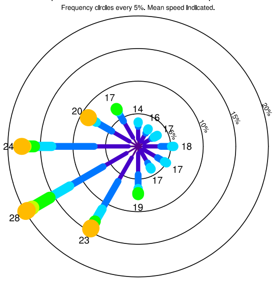
500m
SpdAve=21 SpdStd=11 DirAve=247 No Calm Reports Nwnd=2480
Frequency circles every 5%. Mean speed indicated.



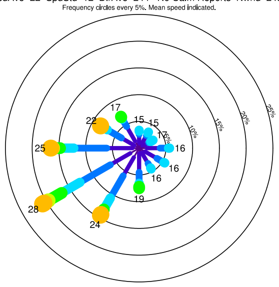
750m
SpdAve=22 SpdStd=11 DirAve=246 No Calm Reports Nwnd=2480
Frequency circles every 5%. Mean speed indicated.



1000m
SpdAve=22 SpdStd=12 DirAve=245 No Calm Reports Nwnd=2480
Frequency circles every 5%. Mean speed indicated.

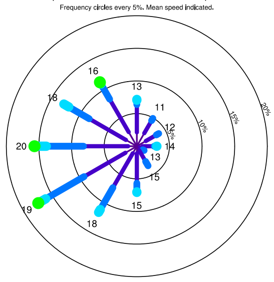


1200m
SpdAve=22 SpdStd=12 DirAve=244 No Calm Reports Nwnd=2480
Frequency circles every 5%. Mean speed indicated.

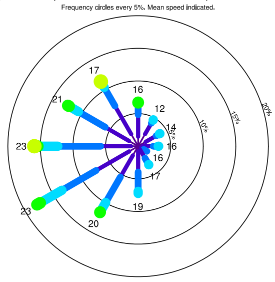


Nov.

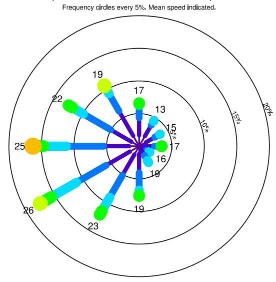
100m
SpdAve=17 SpdStd=7 DirAve=264 No Calm Reports Nwnd=2400
Frequency circles every 5%. Mean speed indicated.



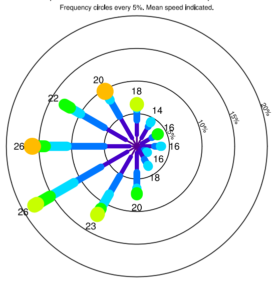
250m
SpdAve=20 SpdStd=9 DirAve=263 No Calm Reports Nwnd=2400
Frequency circles every 5%. Mean speed indicated.



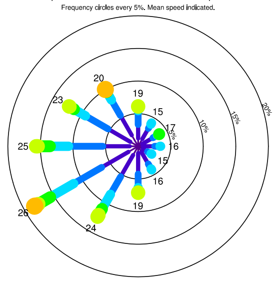
500m
SpdAve=21 SpdStd=11 DirAve=262 No Calm Reports Nwnd=2400
Frequency circles every 5%. Mean speed indicated.



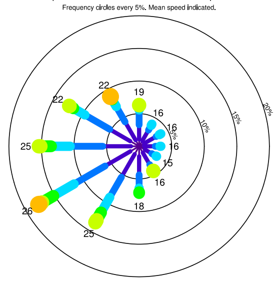
750m
SpdAve=22 SpdStd=11 DirAve=261 No Calm Reports Nwnd=2400
Frequency circles every 5%. Mean speed indicated.



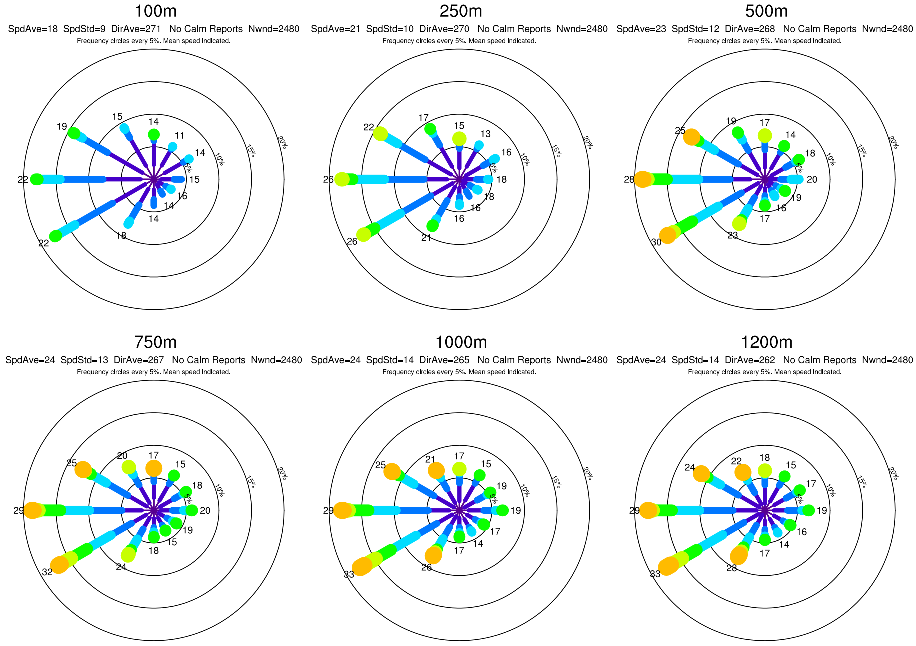
1000m
SpdAve=22 SpdStd=11 DirAve=260 No Calm Reports Nwnd=2400
Frequency circles every 5%. Mean speed indicated.



1200m
SpdAve=22 SpdStd=11 DirAve=259 No Calm Reports Nwnd=2400
Frequency circles every 5%. Mean speed indicated.



Dec.


100m
SpdAve=18 SpdStd=9 DirAve=271 No Calm Reports Nwnd=2480
Frequency circles every 5%. Mean speed indicated.
250m
SpdAve=21 SpdStd=10 DirAve=270 No Calm Reports Nwnd=2480
Frequency circles every 5%. Mean speed indicated.
500m
SpdAve=23 SpdStd=12 DirAve=268 No Calm Reports Nwnd=2480
Frequency circles every 5%. Mean speed indicated.
750m
SpdAve=24 SpdStd=13 DirAve=267 No Calm Reports Nwnd=2480
Frequency circles every 5%. Mean speed indicated.
1000m
SpdAve=24 SpdStd=14 DirAve=265 No Calm Reports Nwnd=2480
Frequency circles every 5%. Mean speed indicated.
1200m
SpdAve=24 SpdStd=14 DirAve=262 No Calm Reports Nwnd=2480
Frequency circles every 5%. Mean speed indicated.

5.5 Wind distribution at 100, 250, 500, 750, 1000 and 1200 meters for Schiphol

100 m

Wind dir. (deg.)	Wind speed (knots)						
	>= 0	>= 10	>= 20	>= 30	>= 40	>= 50	>= 60
345- 15	6.4	4.1	0.8	0.1	-	-	-
15- 45	4.4	2.8	0.4	-	-	-	-
45- 75	3.9	2.8	0.5	-	-	-	-
75-105	3.6	2.9	0.7	-	-	-	-
105-135	3.2	2.4	0.5	-	-	-	-
135-165	3.5	2.3	0.4	-	-	-	-
165-195	6.0	4.0	0.7	-	-	-	-
195-225	10.3	7.4	2.2	0.3	-	-	-
225-255	18.2	14.5	6.4	1.5	0.1	-	-
255-285	18.6	15.0	7.0	1.9	0.2	-	-
285-315	13.1	10.1	3.4	0.7	0.1	-	-
315-345	8.9	6.6	1.7	0.2	-	-	-
Total	100	74.8	24.8	4.7	0.4	-	-

250 m

Wind dir. (deg.)	Wind speed (knots)						
	>= 0	>= 10	>= 20	>= 30	>= 40	>= 50	>= 60
345- 15	6.1	4.3	1.3	0.1	-	-	-
15- 45	4.4	2.9	0.7	0.1	-	-	-
45- 75	4.0	3.0	1.1	0.1	-	-	-
75-105	3.8	3.2	1.4	0.1	-	-	-
105-135	3.5	2.7	1.0	0.1	-	-	-
135-165	3.7	2.6	0.8	-	-	-	-
165-195	6.0	4.3	1.5	0.1	-	-	-
195-225	10.4	7.8	3.5	0.8	0.1	-	-
225-255	18.6	15.3	8.6	3.4	0.7	0.1	-
255-285	18.2	15.3	9.0	3.6	0.8	0.1	-
285-315	12.7	10.4	4.8	1.5	0.2	-	-
315-345	8.9	6.8	2.5	0.5	-	-	-
Total	100	78.6	36.1	10.4	1.9	0.2	-

500 m

Wind dir. (deg.)	Wind speed (knots)						
	>= 0	>= 10	>= 20	>= 30	>= 40	>= 50	>= 60
345- 15	5.9	4.2	1.7	0.3	-	-	-
15- 45	4.3	2.9	0.9	0.1	-	-	-
45- 75	3.9	2.9	1.2	0.2	-	-	-
75-105	4.2	3.5	1.7	0.4	-	-	-
105-135	3.6	2.8	1.2	0.3	-	-	-
135-165	3.8	2.7	0.9	0.2	-	-	-
165-195	6.1	4.2	1.7	0.4	-	-	-
195-225	10.6	8.1	4.1	1.6	0.3	-	-
225-255	18.5	15.3	9.8	4.9	1.7	0.4	0.1
255-285	18.2	15.4	9.9	4.9	1.9	0.4	-
285-315	12.4	10.1	5.3	2.1	0.6	0.1	-
315-345	8.6	6.6	2.9	0.8	0.1	-	-
Total	100	78.7	41.2	16.2	4.8	0.9	0.1

	Wind dir. (deg.)	Wind speed (knots)						
		>= 0	>= 10	>= 20	>= 30	>= 40	>= 50	>= 60
	345- 15	5.9	4.1	1.7	0.4	0.1	-	-
	15- 45	4.2	2.8	0.9	0.1	-	-	-
	45- 75	3.9	2.9	1.1	0.2	-	-	-
	75-105	4.6	3.7	1.6	0.4	0.1	-	-
	105-135	4.0	3.0	1.1	0.3	-	-	-
750 m	135-165	4.1	2.8	0.9	0.2	-	-	-
	165-195	6.1	4.3	1.6	0.4	0.1	-	-
	195-225	10.6	8.3	4.2	1.8	0.6	0.1	-
	225-255	18.5	15.6	10.2	5.5	2.3	0.7	0.1
	255-285	17.8	15.3	10.1	5.1	2.3	0.6	0.1
	285-315	11.9	9.7	5.2	2.2	0.8	0.2	-
	315-345	8.2	6.5	2.9	0.9	0.2	-	-
	Total	100	78.9	41.5	17.4	6.3	1.6	0.3

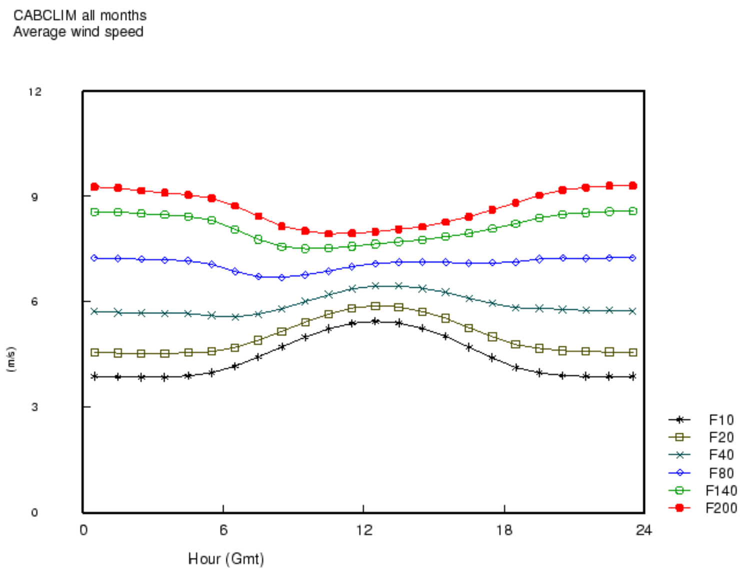
	Wind dir. (deg.)	Wind speed (knots)						
		>= 0	>= 10	>= 20	>= 30	>= 40	>= 50	>= 60
	345- 15	5.8	4.2	1.7	0.4	0.1	-	-
	15- 45	4.2	2.7	0.9	0.1	-	-	-
	45- 75	4.0	2.8	1.0	0.2	-	-	-
	75-105	5.0	3.8	1.5	0.3	-	-	-
	105-135	4.5	3.1	1.0	0.2	-	-	-
1000 m	135-165	4.4	2.9	0.8	0.1	-	-	-
	165-195	6.2	4.4	1.5	0.4	0.1	-	-
	195-225	10.7	8.5	4.7	1.9	0.7	0.2	-
	225-255	18.1	15.8	10.6	5.6	2.4	0.9	0.2
	255-285	17.5	15.3	1-	4.8	2.2	0.6	0.1
	285-315	11.4	9.4	5.1	2.2	0.7	0.2	-
	315-345	8.2	6.4	3.0	0.9	0.2	-	-
	Total	100	79.3	41.8	17.2	6.6	2.0	0.4

	Wind dir. (deg.)	Wind speed (knots)						
		>= 0	>= 10	>= 20	>= 30	>= 40	>= 50	>= 60
	345- 15	5.9	4.4	1.9	0.5	0.1	-	-
	15- 45	4.3	2.8	0.9	0.2	-	-	-
	45- 75	4.1	2.6	0.9	0.2	-	-	-
	75-105	5.3	3.7	1.5	0.3	-	-	-
	105-135	4.9	3.2	1.0	0.2	-	-	-
1200 m	135-165	4.5	2.9	0.8	0.1	-	-	-
	165-195	6.2	4.4	1.6	0.4	0.1	-	-
	195-225	10.6	8.8	5.1	2.2	0.9	0.3	0.1
	225-255	18.0	16.2	11.1	5.7	2.5	1.0	0.2
	255-285	16.9	15.0	9.7	4.5	1.9	0.5	0.1
	285-315	11.0	9.3	5.3	2.1	0.7	0.2	-
	315-345	8.1	6.4	3.0	0.9	0.2	-	-
	Total	100	79.7	42.9	17.2	6.4	2.0	0.5

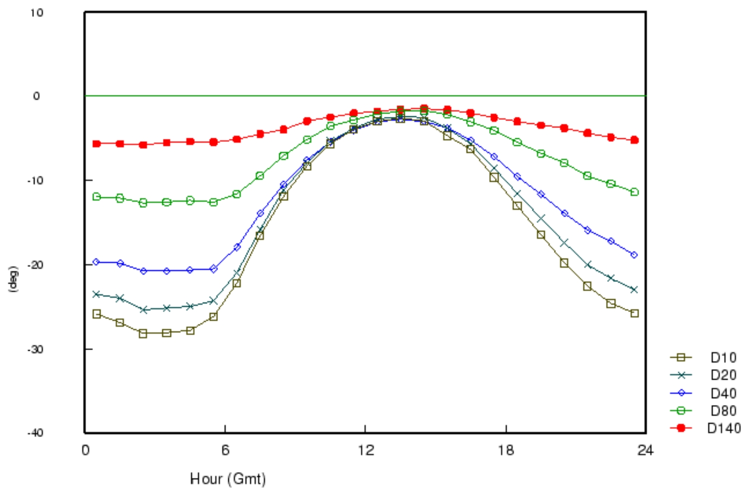
5.6 Climatology Cabauw 1986-1997

In sections 8.4.1 to 8.4.13 the climatology of Cabauw is shown, based on the eleven year period of Cabauw-data 1986-1997 for parameters windspeed, relative wind direction, potential temperature and specific humidity at 10, 20, 40, 80, 140 and 200 meters, average for year and individual months [cabclim]. This detailed climatology is illustrative for the climatology of these parameters in the central part of the Netherlands, more details are available at http://www.knmi.nl/~bosveld/experiments/cabclim/.

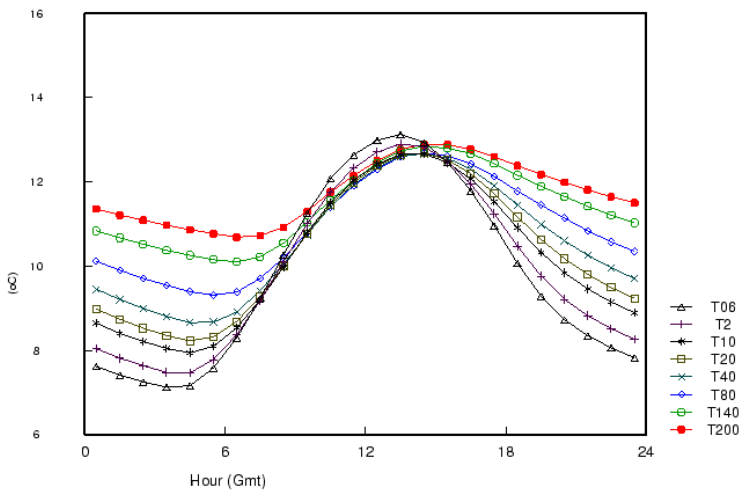
5.6.1 Year: Wind speed, Relative wind direction, Potential temperature and Specific humidity

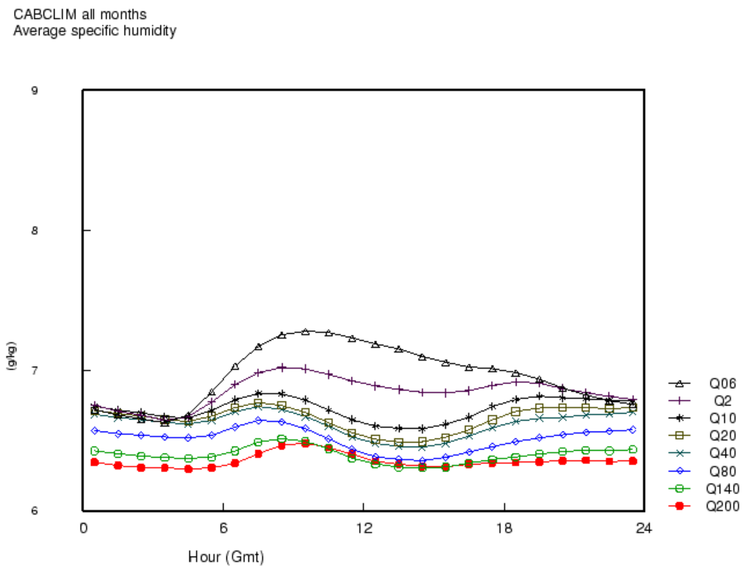


CABCLIM all months
Average wind direction rel. to D200

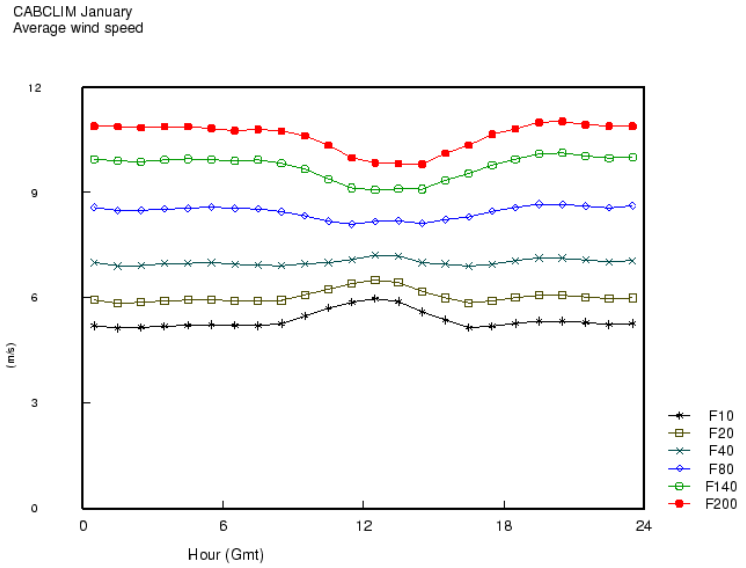


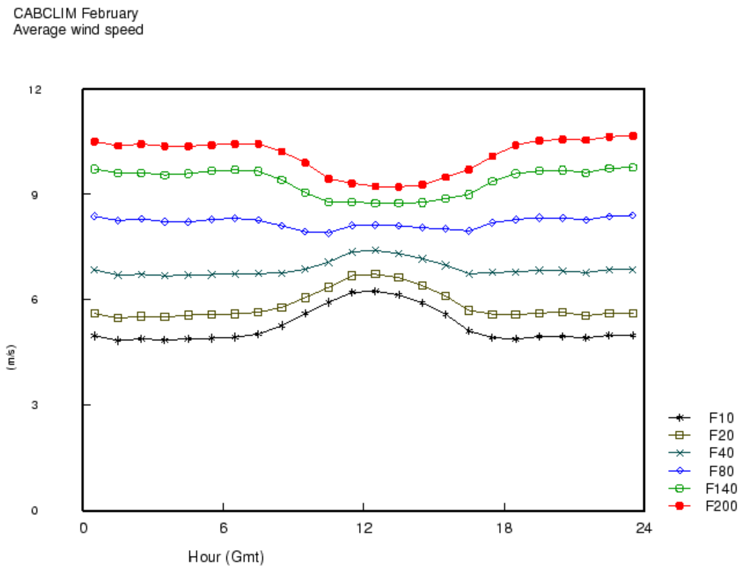
CABCLIM all months
Average potential temperature



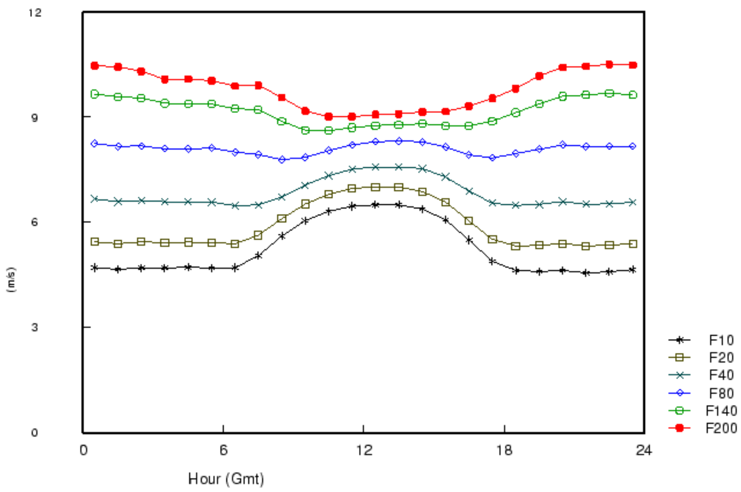

CABCLIM all months
Average specific humidity
9
8
7
6
(g/kg)
0
6
12
18
24
Hour (Gmt)
Q06
Q2
Q10
Q20
Q40
Q80
Q140
Q200

5.6.2 Windspeed per month

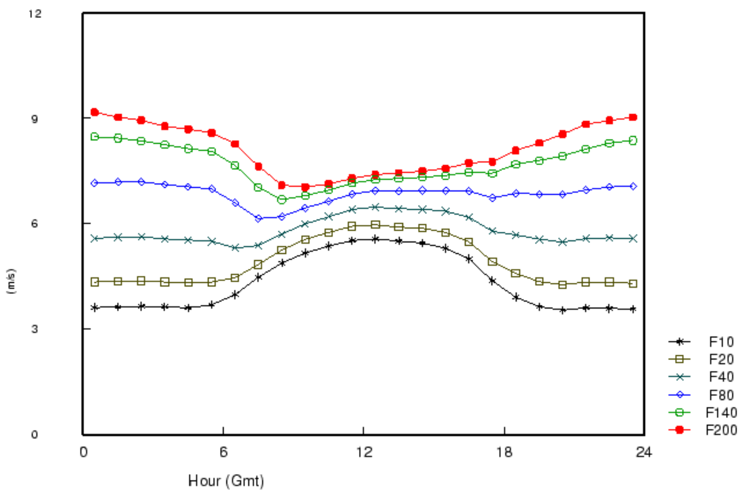




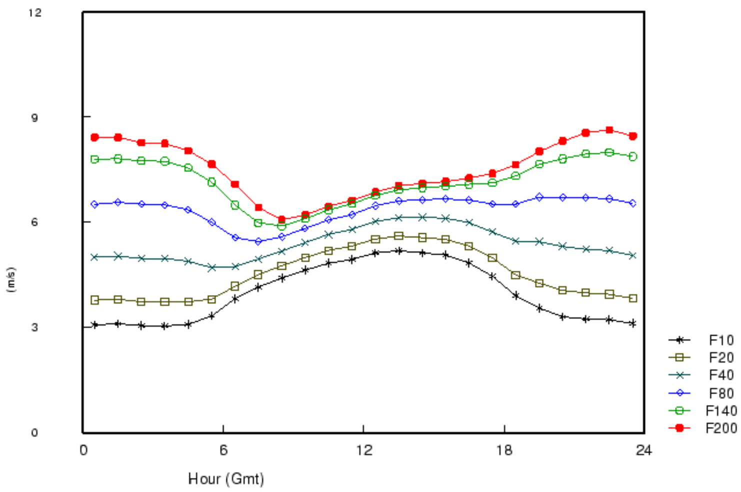
CABCLIM March
Average wind speed



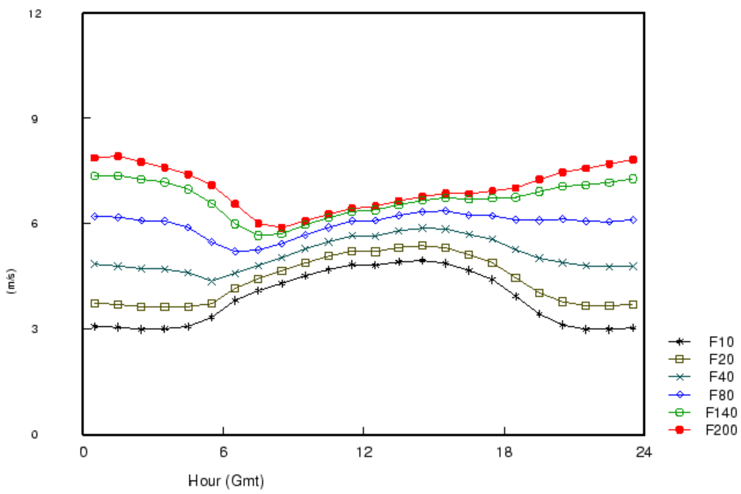
CABCLIM April
Average wind speed



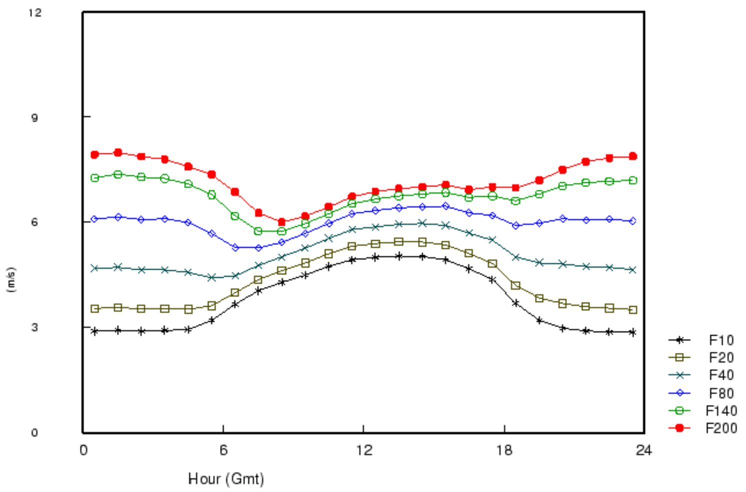
CABCLIM May
Average wind speed



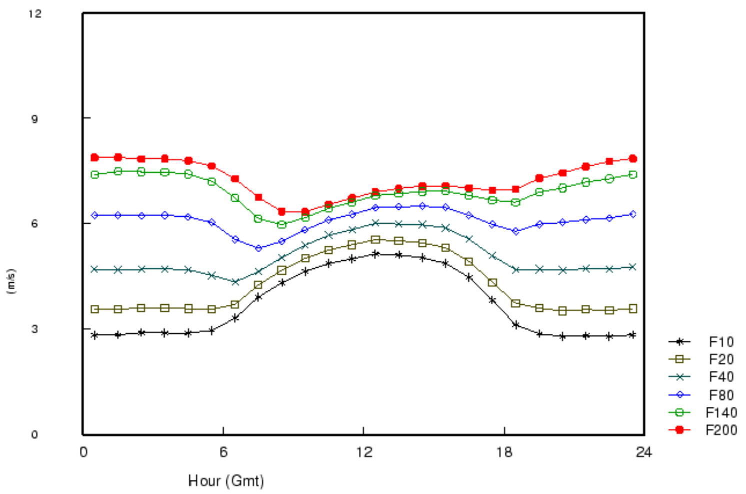
CABCLIM June
Average wind speed



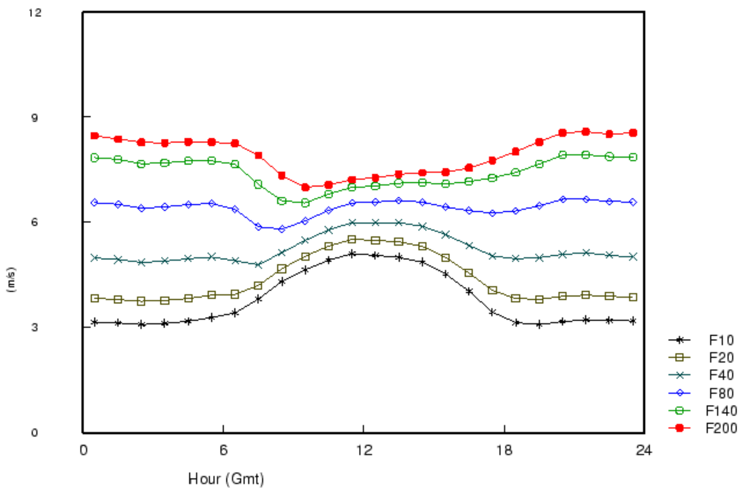
CABCLIM July
Average wind speed



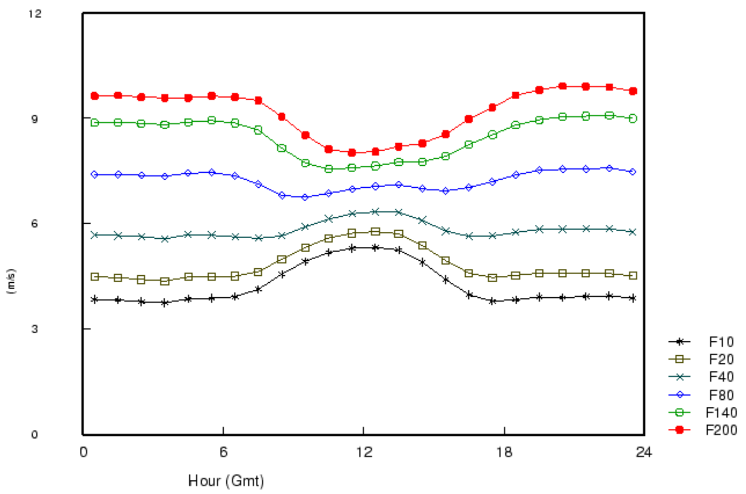
CABCLIM August
Average wind speed



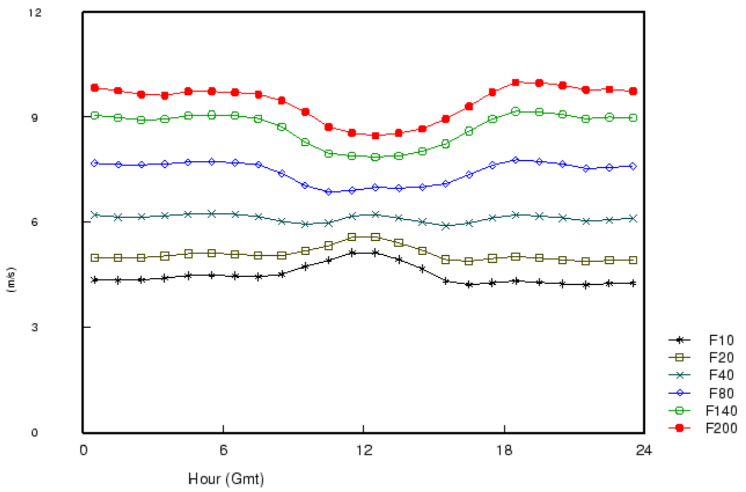
CABCLIM September
Average wind speed



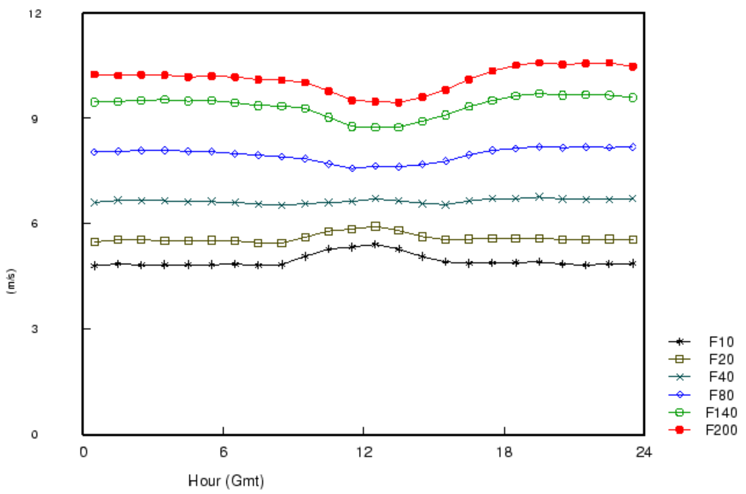
CABCLIM October
Average wind speed



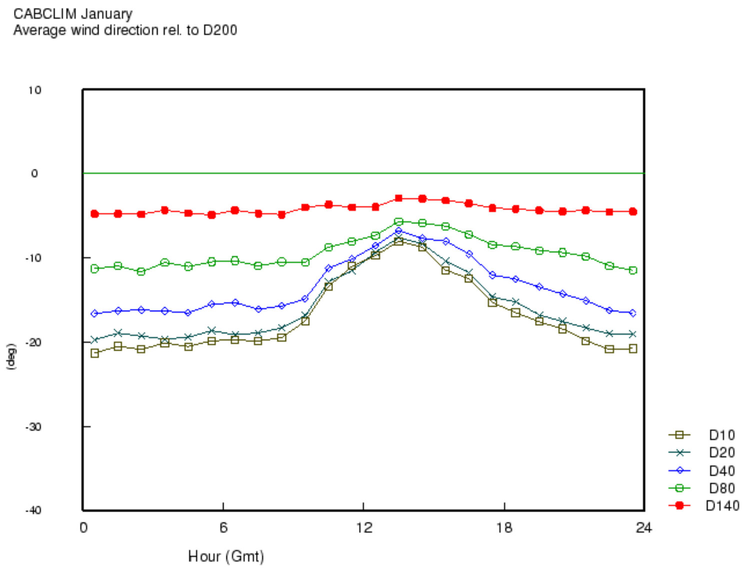
CABCLIM November
Average wind speed

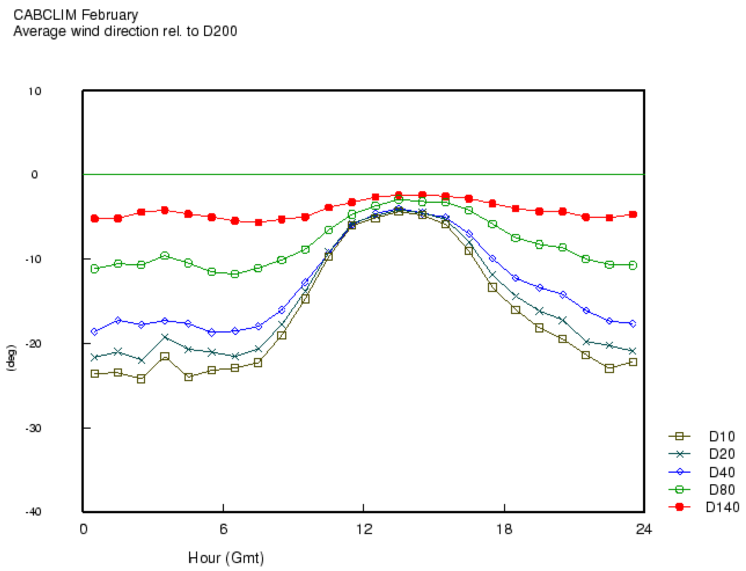


CABCLIM December
Average wind speed

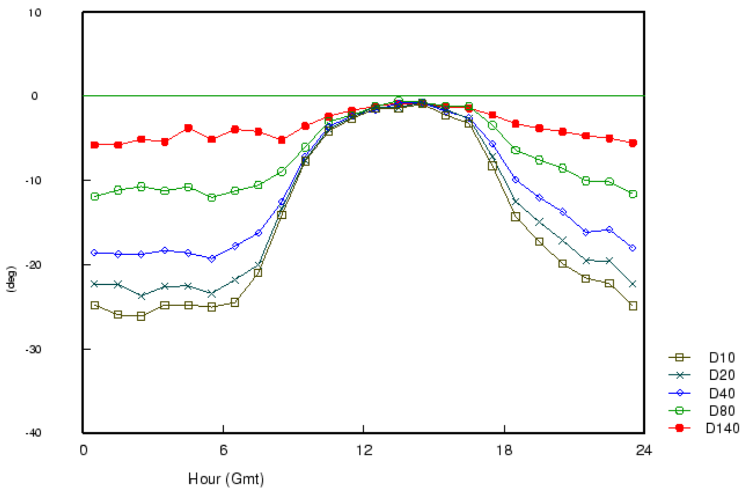


5.6.3 Wind direction (relative to 200 m) per month

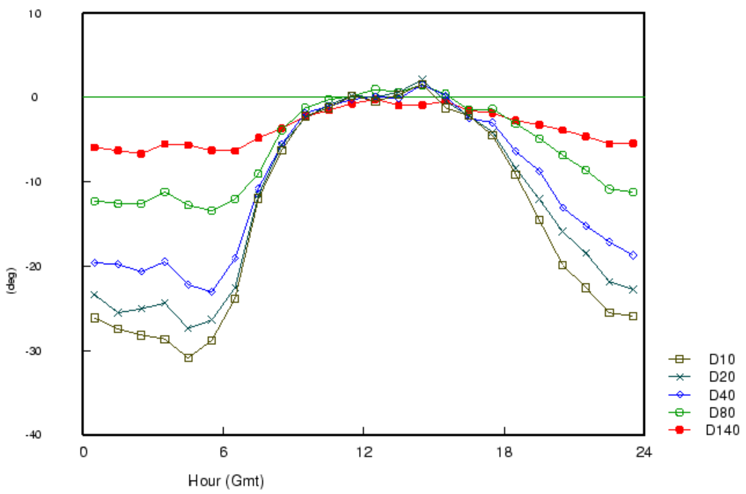




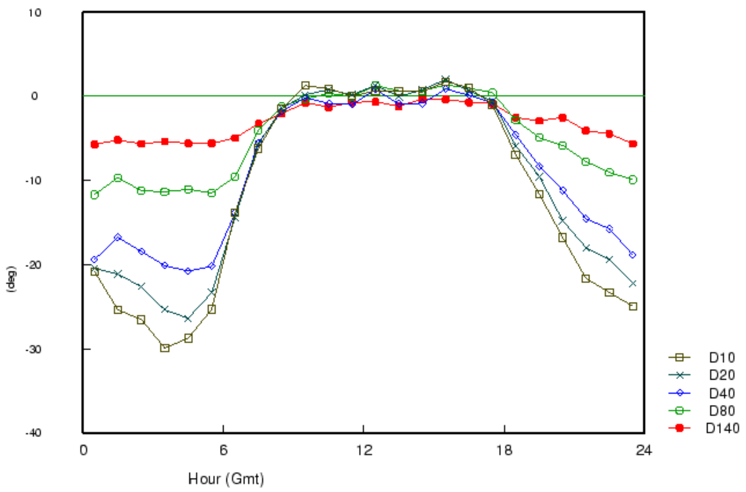
CABCLIM March
Average wind direction rel. to D200



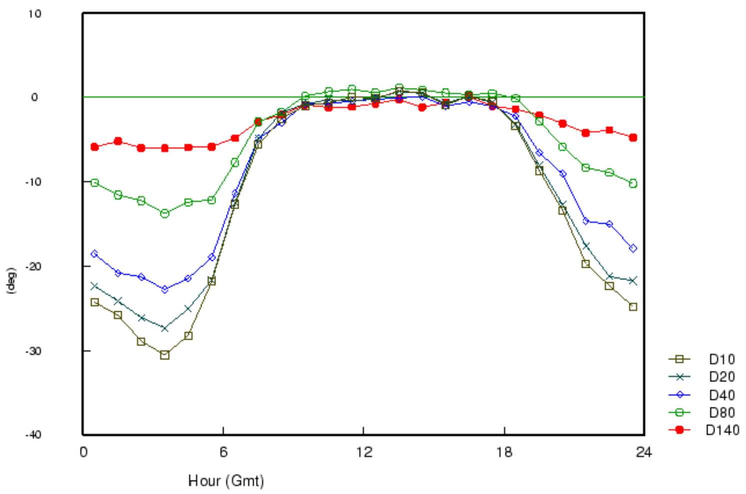
CABCLIM April
Average wind direction rel. to D200



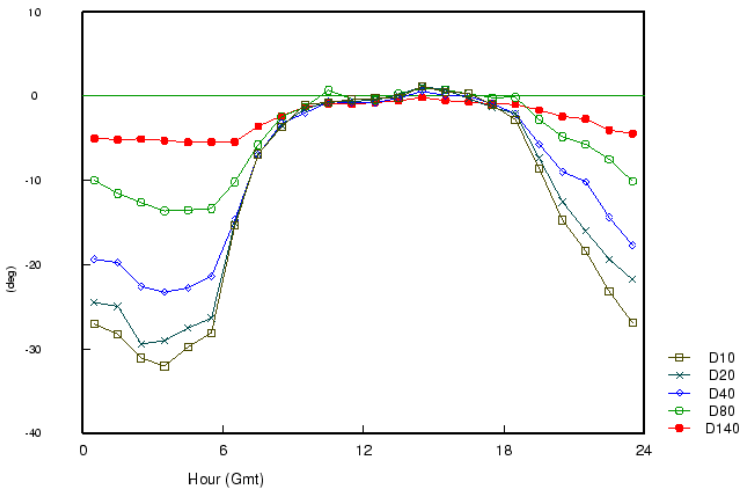
CABCLIM May
Average wind direction rel. to D200



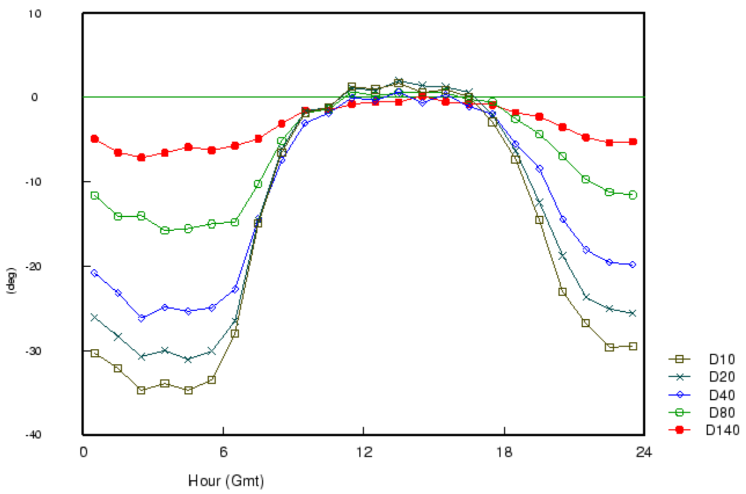
CABCLIM June
Average wind direction rel. to D200



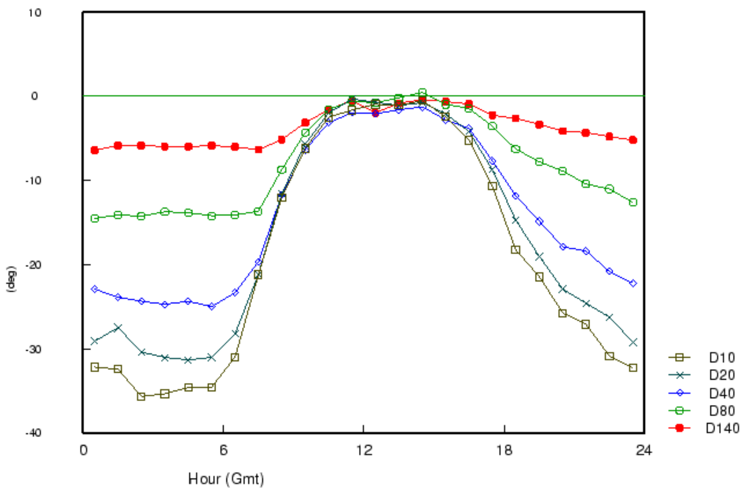
CABCLIM July
Average wind direction rel. to D200



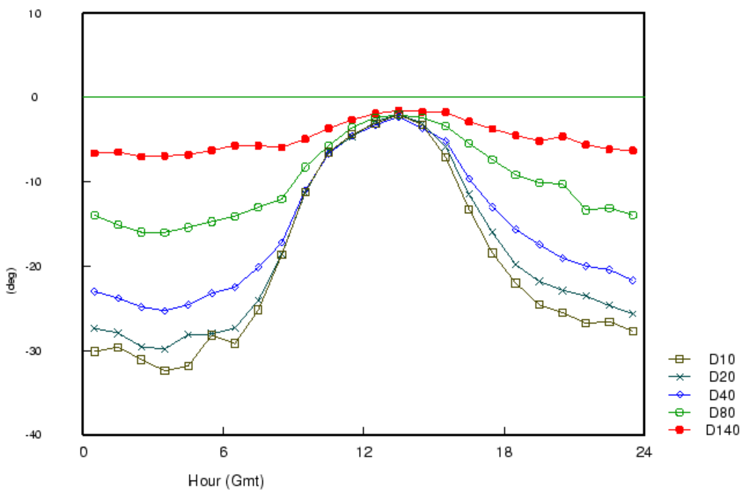
CABCLIM August
Average wind direction rel. to D200



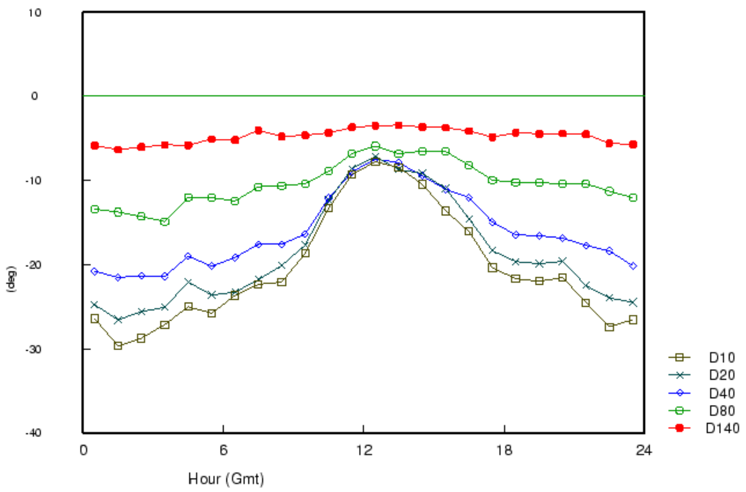
CABCLIM September
Average wind direction rel. to D200



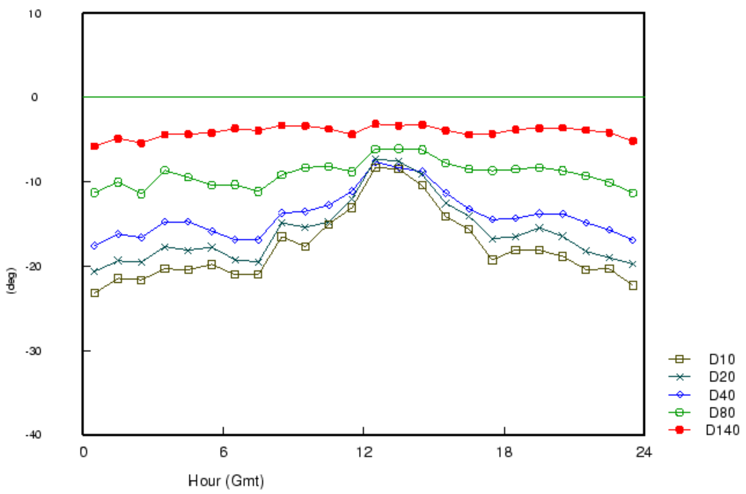
CABCLIM October
Average wind direction rel. to D200



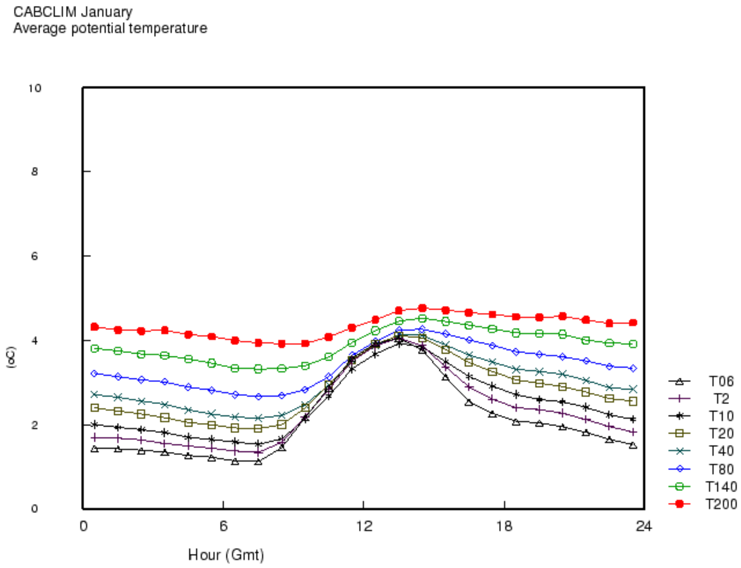
CABCLIM November
Average wind direction rel. to D200

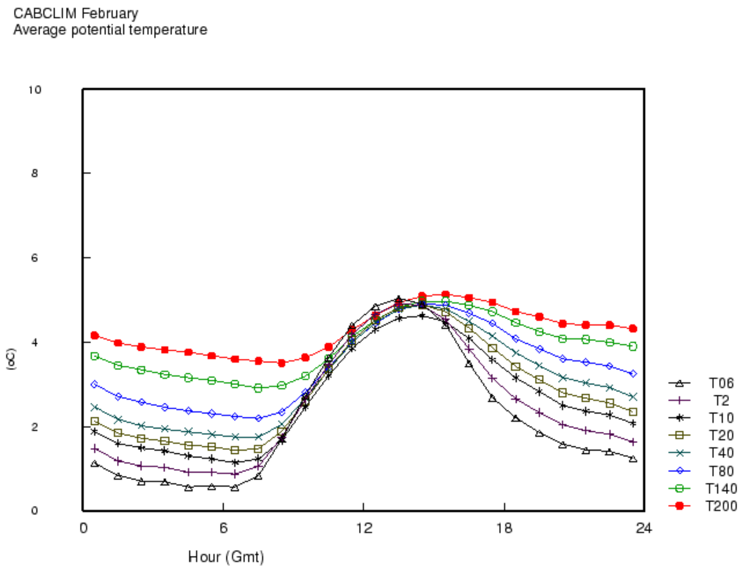


CABCLIM December
Average wind direction rel. to D200

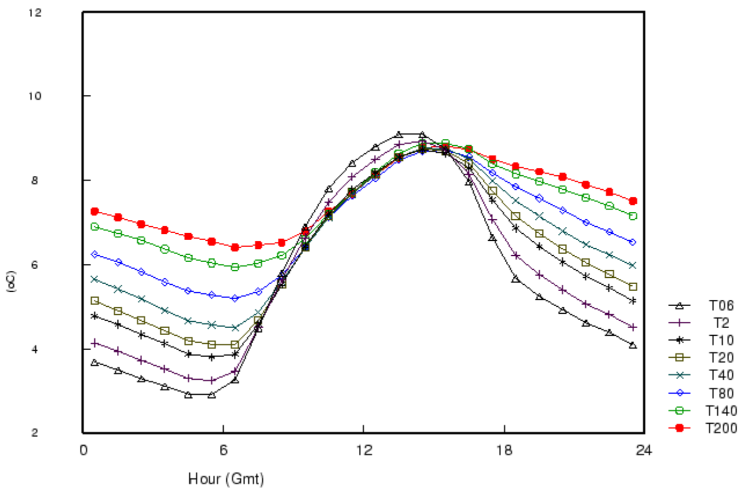


5.6.4 Potential temperature per month

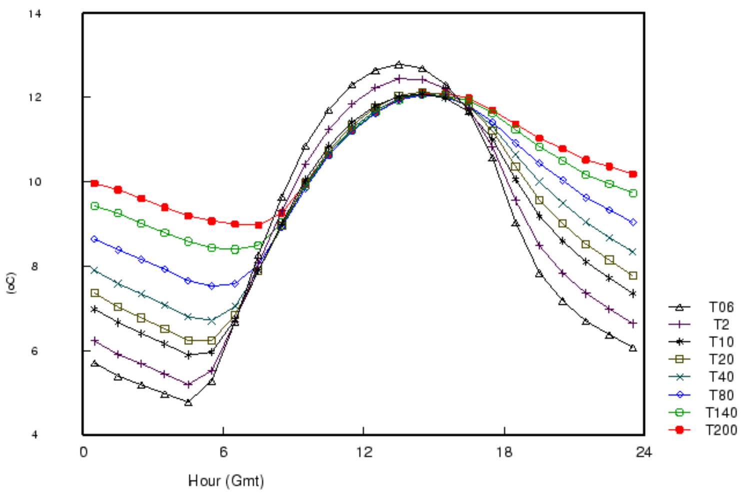


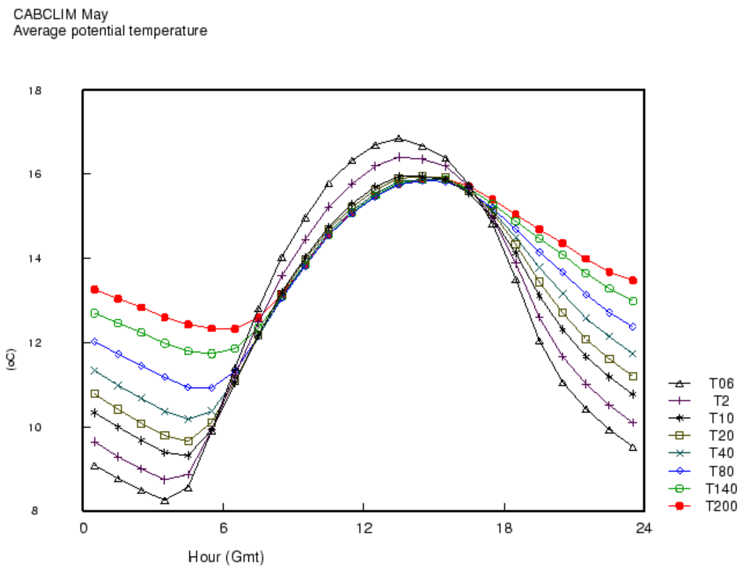


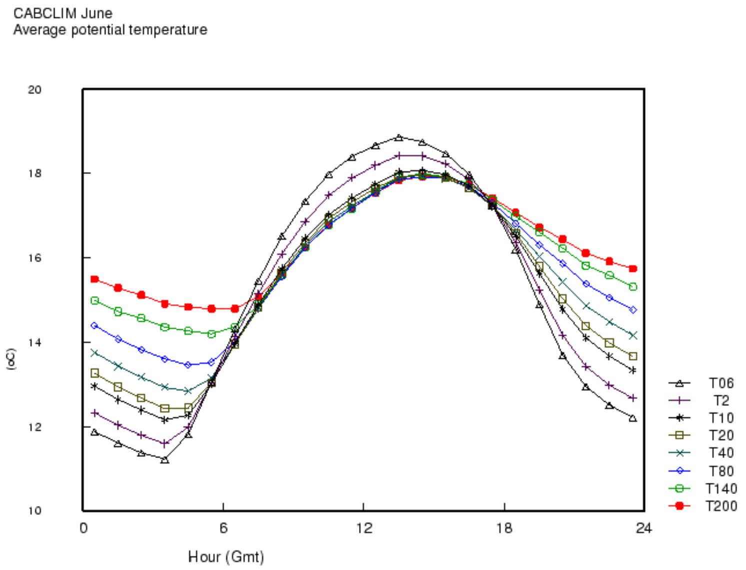
CABCLIM March
Average potential temperature



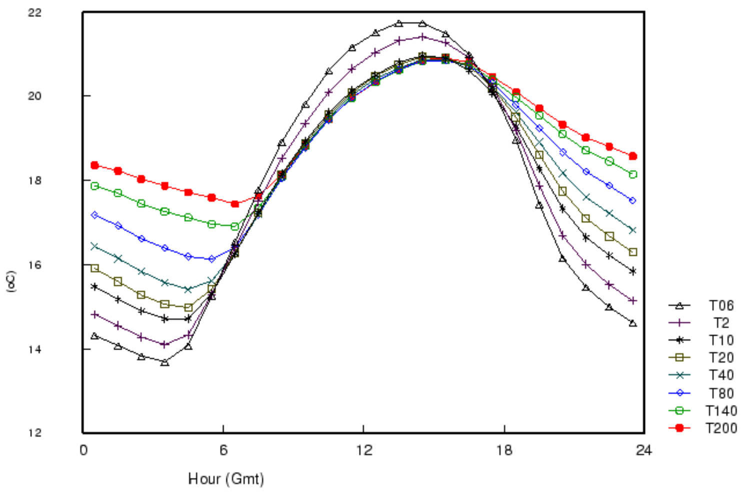
CABCLIM April
Average potential temperature



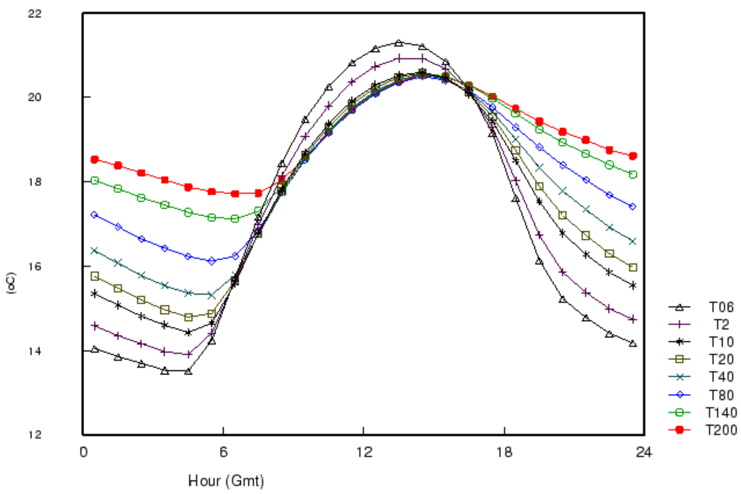

CABCLIM May
Average potential temperature
18
16
14
12
10
8
(oC)
0
6
12
18
24
Hour (Gmt)
T06
T2
T10
T20
T40
T80
T140
T200


CABCLIM June
Average potential temperature
20
18
16
14
12
10
(oC)
0
6
12
18
24
Hour (Gmt)
T06
T2
T10
T20
T40
T80
T140
T200

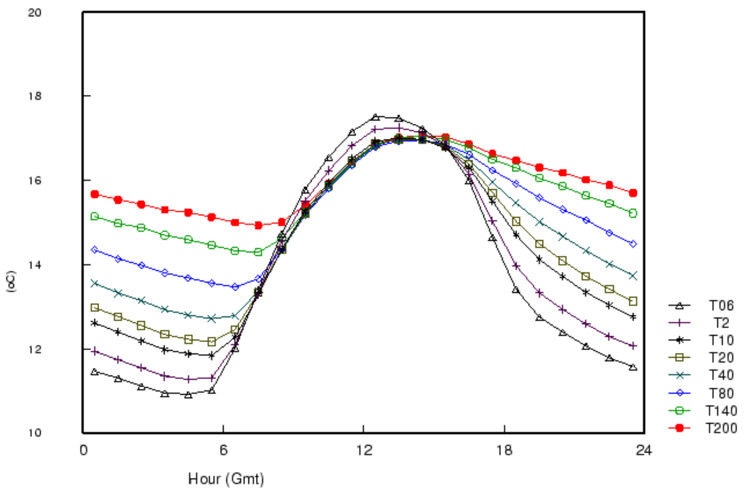
CABCLIM July
Average potential temperature



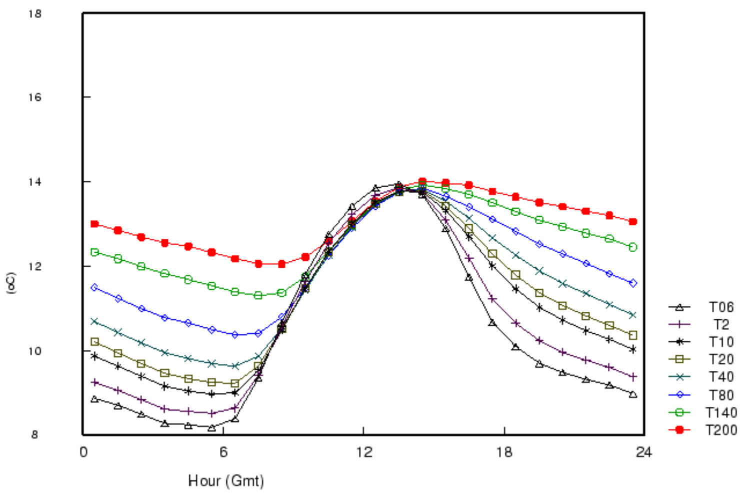
CABCLIM August
Average potential temperature



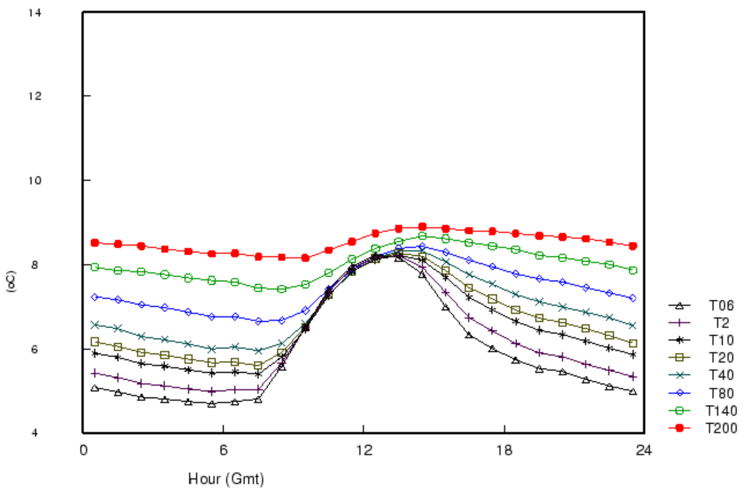
CABCLIM September
Average potential temperature



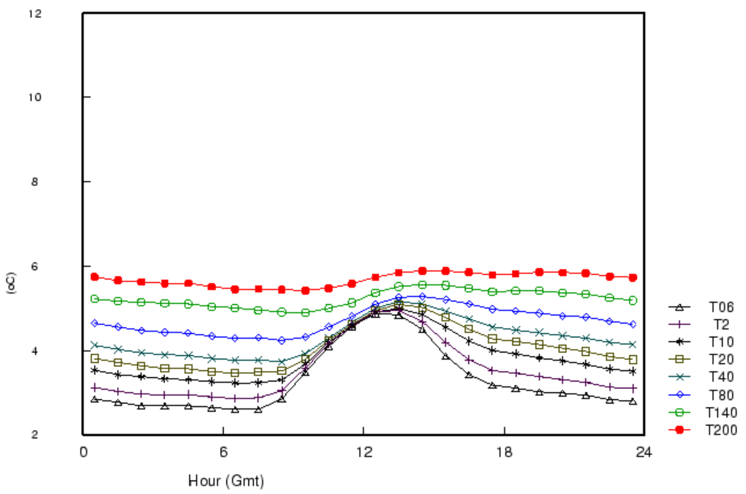
CABCLIM October
Average potential temperature



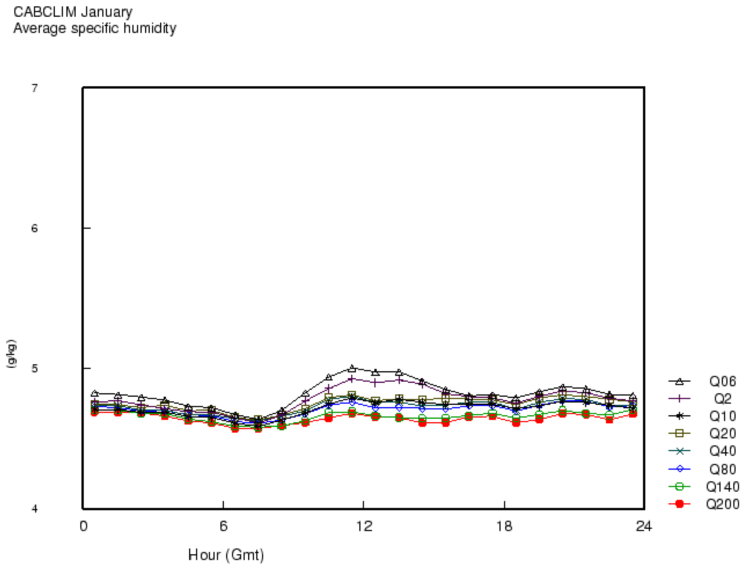
CABCLIM November
Average potential temperature

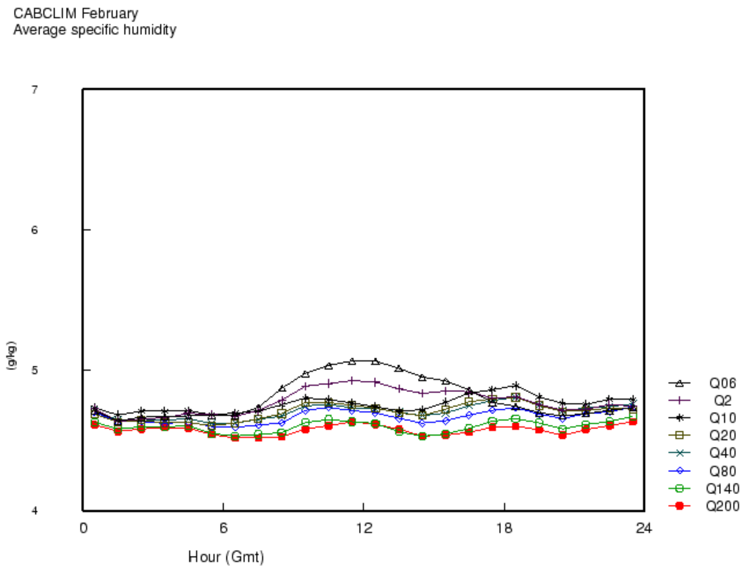


CABCLIM December
Average potential temperature

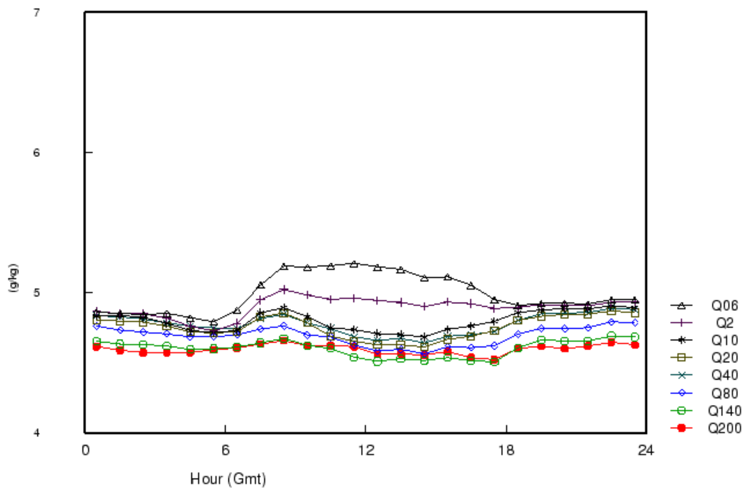


5.6.5 Specific humidity per month

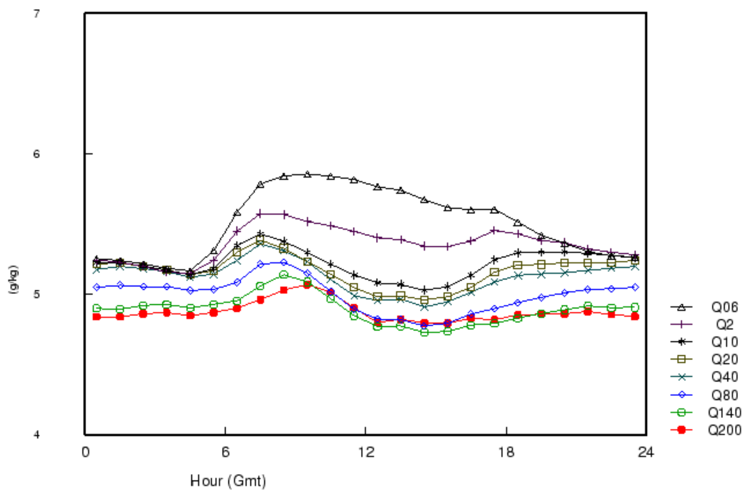




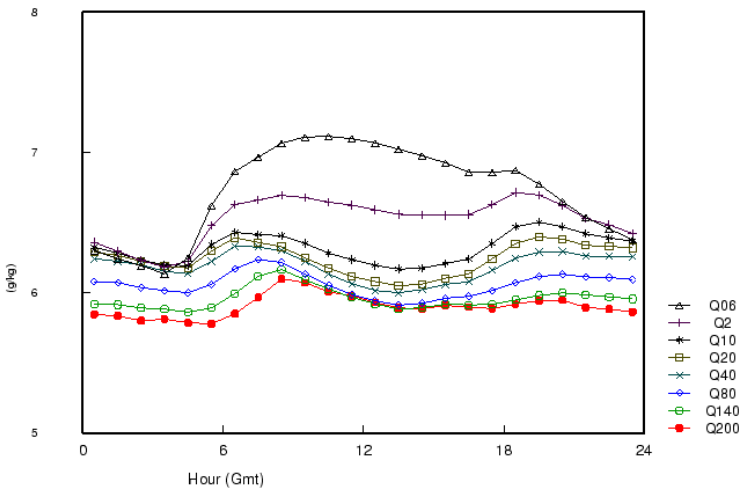
CABCLIM March
Average specific humidity



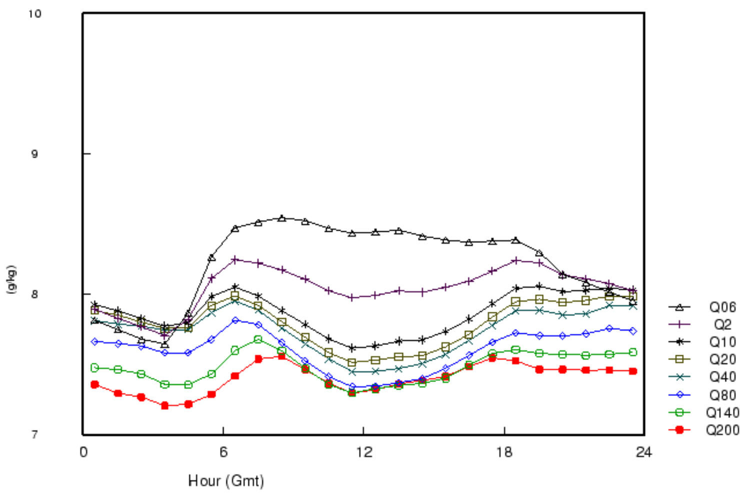
CABCLIM April
Average specific humidity



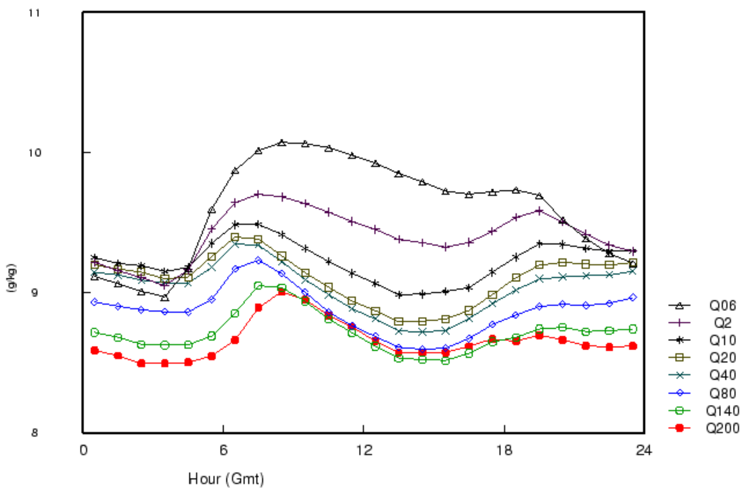
CABCLIM May
Average specific humidity



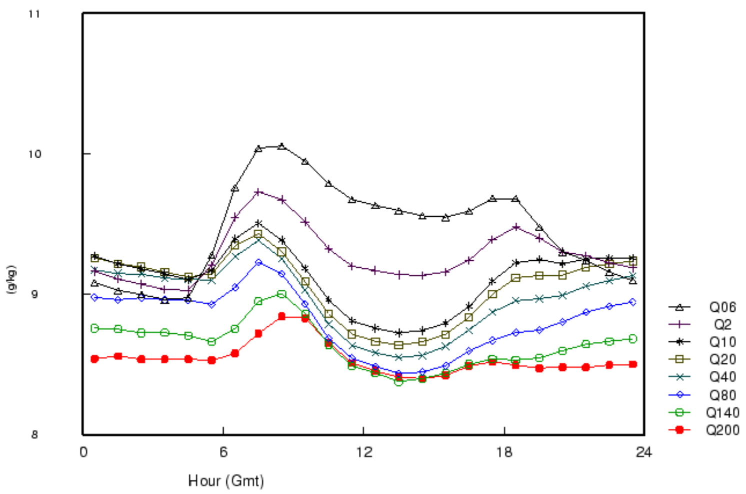
CABCLIM June
Average specific humidity



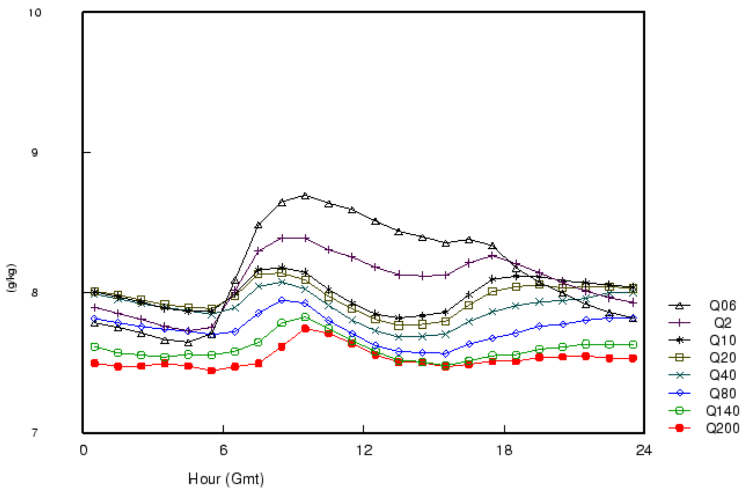
CABCLIM July
Average specific humidity



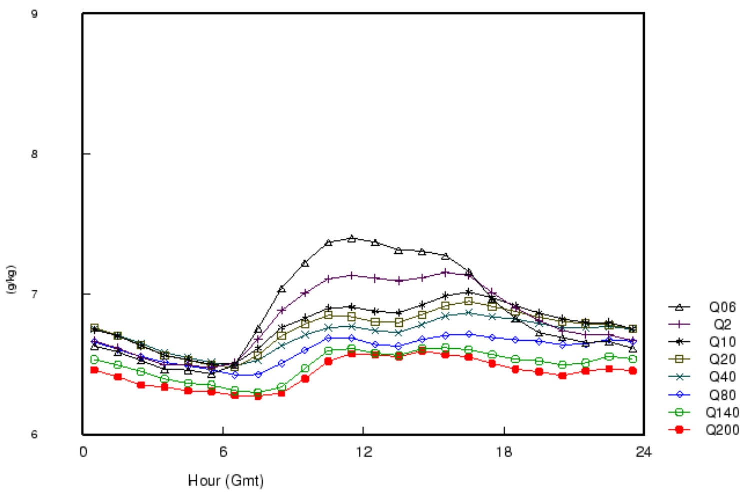
CABCLIM August
Average specific humidity



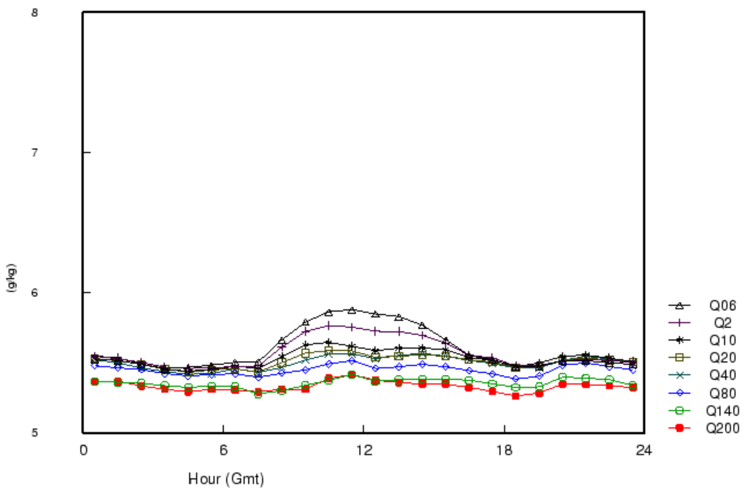
CABCLIM September
Average specific humidity



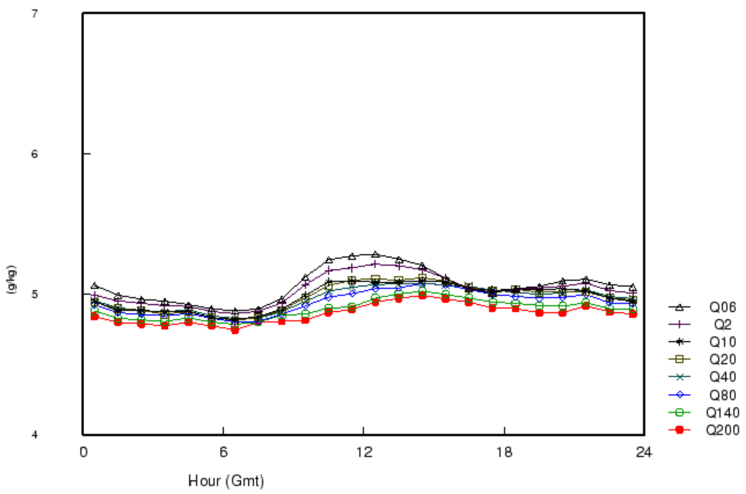
CABCLIM October
Average specific humidity



CABCLIM November
Average specific humidity



CABCLIM December
Average specific humidity



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