CLIMATE OF SLOVENIA 1971–2000

The Environmental Agency of the Republic of Slovenia

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Editor: Mojca Dolinar

Authors (by alphabetic order): Renato Bertalanič, Mojca Dolinar, Mateja Nadbath, Tadeja Ovsenik-Jeglič, Gregor Vertačnik, Zorko Vičar

Reader: Murray James Bales

Meteorological Network, Archives and Data Management

Zorko Vičar

Meteorological network

Slovenia's meteorological network covers an area of over 20,000 square km. Our climate regime is very complex and demands a dense meteorological network.

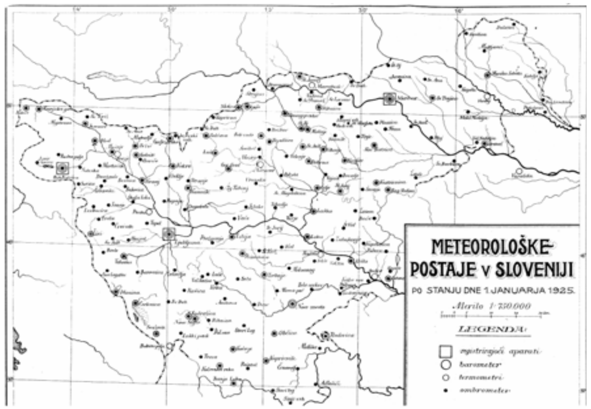

Figure 1. The Slovenian meteorological network in 1925

The first preserved series of meteorological measurements started in 1850 in the capital city Ljubljana. The meteorological network in Slovenian territory expanded to 85 stations at the end of the 19th century. In 1940 there were 183 stations, in 1950 already 200. The 1971-2000 period started with 339 stations and ended with 276 stations.

The data are generated from stations of different types: fully automatic stations, automatic stations with an observer and stations without any automatic data registration. Thirteen synop stations, including 4 airports (24 obs/day), still have professional observers. All other stations are automatic or involve volunteers. The maximum (108) of climate stations was noted in 1973 and the maximum (245) of precipitation stations was recorded in 1978. Our highest location of a synop station is at Kredarica with an elevation of 2514 m, while the lowest location of a synop station is at Portorož Airport near the Adriatic coast with an elevation of 2m. The Slovenian meteorological network also contains 38 mechanical pluviographs, 22 heliographs and some other special devices, redundant mechanical instruments (thermographs, hygrographs). The automatic network encompasses: 27 meteorological stations, 8 automatic hydrological stations with meteorological instruments, 17 automatic ecological stations with meteorological instruments, 1 automatic oceanic buoy with meteorological instruments.

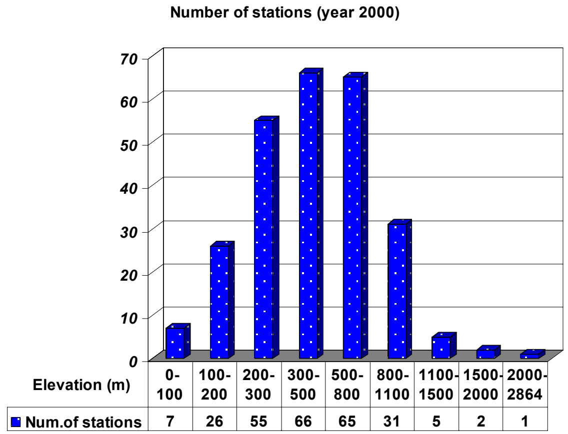

Figure 2. The elevation distribution of stations in 2000

At the precipitation stations observers measure precipitation only once a day at 7:00 am, they also measure the depth of snow cover and the depth of fresh snow, during the day they note the weather phenomena (fog, frost, dew, stormy weather – wind, thunder, hail and other forms of precipitation). All the observers have to fill in a form on paper– a meteorological diary. In 2006, the density of the precipitation network is 8.7 items per 1000 km^2.

At climate stations observers measure precipitation only once a day at 7:00 am, they also measure the depth of snow cover and the depth of fresh snow, during the day they note the weather phenomena (fog, frost, dew, stormy weather – wind, thunder, hail and other forms of precipitation). Most observers have to measure the following three times (at 7:00, 14:00 and 21:00 in CET): temperature, maximum and minimum temperature, humidity, visibility, cloudiness, condition of the soil, wind, some observers also send the synop messages to the Global Telecommunication System (GTS). All observers have to fill in a form on paper – a meteorological diary. In 2006 the density of the climate network is 2.0 items per 1000 km^2.

Synoptic stations involve the same procedure as classical climatological stations, but observers take measures more frequently during the day, at the airport this occurs over 24 hours. They certainly send the synop messages to the GTS and have to fill in a form on paper – a meteorological diary. Most synoptic stations use a classical Hg barometer for pressure. In 2006 the density of the synop network is 0.6 items per 1000 km^2.

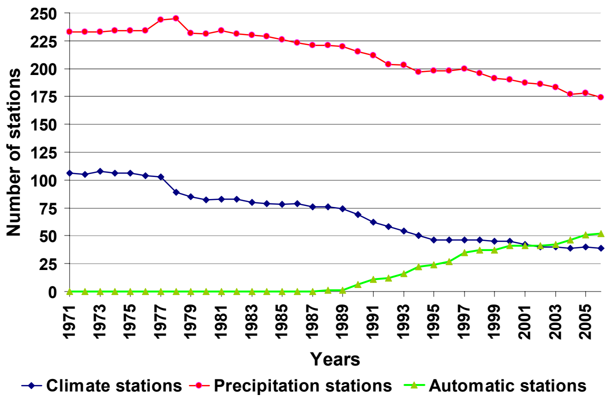

Figure 3. Number of meteorological stations by types in the 1971-2006 period

Remote sensing

Another part of our meteorological network involves remote sensing. We collect satellite products from Meteosat Second Generation (MSG) and radar measurements from the Lisca Meteorological Radar Centre. MSG is a joint project involving the European Space Agency (ESA) and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). MSG has 12 channels and receives spectral bands from 0.4 µm to 14.40 µm, the horizontal sampling distance is 1 km in the 12th high resolution visible (HRV) channel and 3 km in other channels, while the time resolution is 15 minutes.

Figure 4. The Lisca Meteorological Radar Centre on Mount Lisca at an elevation of 948 m

The radar on Mount Lisca, at an elevation of 948 m, emits 5 cm long electromagnetic waves, the average radiated power is 250 watts, the antenna's frequency is 3 revolutions per minute, the inclination angles are between 0 and 30 arc degrees, the area resolution is 1 km, the time resolution is 10 minutes, while the measuring distance is about 200 km. The latest project is the assimilation of daily radar precipitation regarding the vertical profile. The Slovenian Meteorological Office once a day sounds the atmosphere from the LJUBLJANA station, synop number 14015, position: 46.06583 N, 14.51722 E, elevation 299 m.

Meteorological data processing and quality control

We undertake a validation every day for automatic data (only for a few parameters for half-hour aggregations) and every month for classical climatological data on daily aggregations. At the moment the validation for the synop data is very simple.

We have some programmes in fortran, pascal and we are now moving on to new tools (postgres base, php and other web procedures, OpenSource tools).

First we use tests to check the hard limits (temperature T is within the interval –50, + 50 degrees etc.), then the soft limits (temperature T is within local extremes etc.), then inner consistency tests (the T_min cannot be higher than the T_max etc.), then we test if the values are within a time series, look for any big jumps, run variability tests, spatial consistency tests (values of the same parameter measured at the same time at nearby stations may not differ too much from each other).

We also make comparisons with redundant measurements if they exist. Our tests for the automatic stations are still not as sophisticated as the tests for the classical data. We use some objective and subjective methods for interpolations. All data have quality flags.

Archive and the Meteorological database (MDB)

Our meteorological database system has a twofold nature at the moment because there are both the old ASCII file system database and a new relational database system for easy access in Postgres. In the MDB two types of tables exist – **input tables with original data** and **user tables with controlled data** for clients. In the MDB there are also relational tables with derived data (monthly data, e.g., mean, extreme, sum, number of days with, ...).

Data rescue activities in the Meteorological Office include the preservation of all climate data and corresponding metadata collected in the national meteorological network in the territory of Slovenia and their transfer from paper records to a digital form in order to be imported into a relational database for easy access. The automatic data are routinely imported into the relational database. The data in the user tables have quality flags.

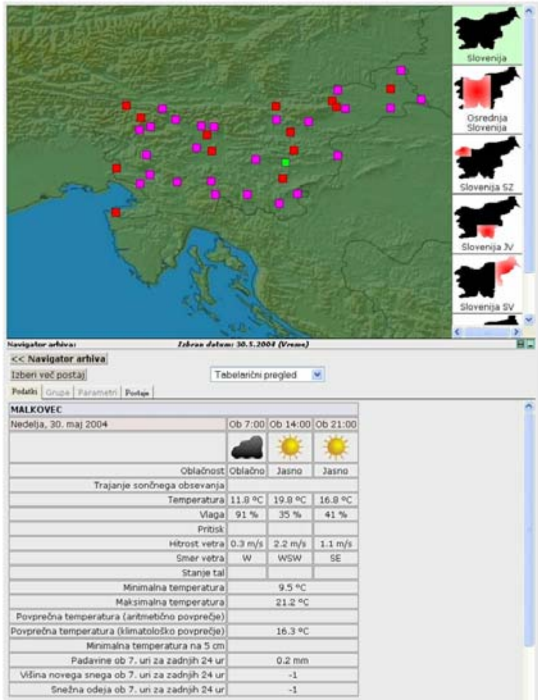

Figure 5. In 2006 we have developed web services to access meteorological data directly from the MDB – user-friendly Internet connections between client and the MDB

All data, historical data coming from the old time series archive as well as actual data collected from the operational station networks, are processed and put into the database using the same software system.

Figure 6. In 2001 all paper records were moved to an appropriate archive where the temperature-humidity conditions correspond to the requirements of such premises

Climate data records in a paper form are stored in the Meteorological archive dating back to 1850. All data since 1961 have been digitised. The older historical data are in the process of being digitised. In the archive there are some gaps in the climate records due to loss, destruction or dissemination over various organisations or countries.

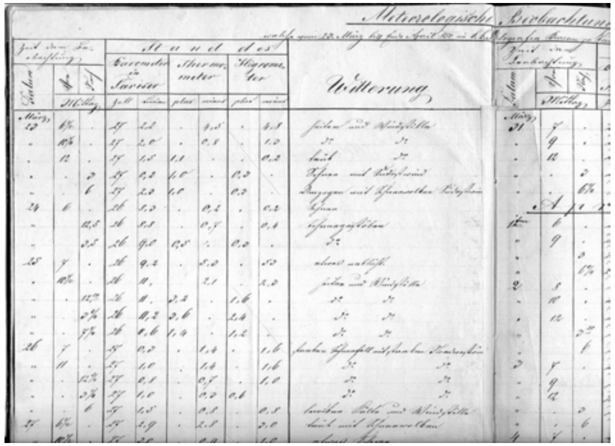

Figure 7. The first preserved meteorological measurements started in 1850 in the capital city Ljubljana

Long meteorological data time series have a global climate and national value – archives are a future asset for humans.

Plans for the future

The automatic stations cannot measure all atmospheric phenomena and can be damaged by thunderstorms. We propose to keep the classical meteorological measurements with a paper bulletin together with the automatic stations, remote sensing and to retain the paper and digital archives.

AIR TEMPERATURE

Mateja Nadbath

Preface

Air temperature is measured three times a day: at 7 am, 2 pm and 9 pm. The mean daily temperature represents a quarter of the amount of the morning and the afternoon values and twice the evening value.

Figure 1. Thermometer shelter

Air temperature in Slovenia has a distinctive daily and yearly course. The highest daily temperature is generally recorded early in the afternoon, between 2 and 3 o'clock and the lowest daily temperature is at sunrise. The warmest month of the year is usually July, but in the mountains it is August. On the other hand January is the coldest month, while in the mountains the coldest month is February.

The biggest daily and annual temperature spans are found in the north-eastern part of Slovenia where the influence of the continental climate is strong. The smallest temperature spans are in the mountains where temperature conditions are close to the open atmosphere, and on the coast where the sea's influence reduces the spans.

Air temperature generally drops with altitude; the mean annual temperature drops by 5.3°C every 1000 m. Besides altitude, the relief also has an influence on air temperature. Temperature inversions on calm and bright nights are common in the basins and valleys of inland Slovenia. High relative humidity, low air temperature, frost and fog are typical of the inversion layer. An inversion can last all day long and for several days. In spring, sometimes a cold and moist air mass covers the northern part of the Adriatic and also causes a temperature inversion in the coastal part of Slovenia.

The sea has an influence on the air temperature along the coast and in the Soča and Trenta valleys. Because of this the air temperature in autumn and winter is higher than in other similar parts of Slovenia. The morning temperature on the coast is higher than in the inland part of the country all year long. But in spring the sea interferes with heating; this causes a lower maximum air temperature.

The air temperature in cities is higher than in the surrounding countryside. The morning temperature is usually higher and in hot summer the evening one is. The city cools slowly due to various sources of heat (industry, traffic,…), asphalt and concrete surfaces (they are great warmth retainers). The bigger a city the more evident these phenomena are.

Temperature conditions

In Slovenia air temperature varies in different seasons and regions.

Extreme temperature values have been measured in the internal areas of Slovenia at Črnomelj and Babno polje. The highest air temperature measured in Slovenia is 40.6 °C, which was measured at Črnomelj at 2 pm on 5 July 1950. The minimum air temperature is -34.5 °C, which was measured at Babno polje on 15 and 16 February 1956.

The south-eastern part of Slovenia, the coastal region, is the warmest one. The mean annual air temperature is above 12 °C (in Portorož it is 12.8 °C). The mean air temperature in July exceeds 20 °C and the mean temperature in January is above 4 °C.

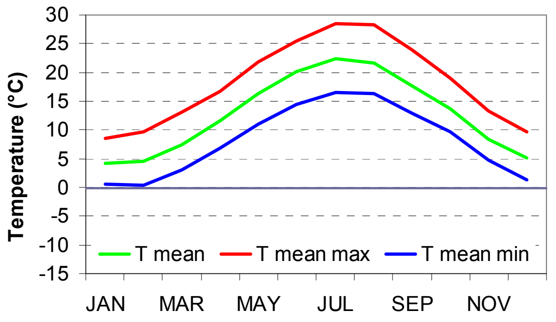

Figure 2. Long-term (1971–2000) mean air temperature (T mean), long-term mean maximum air temperature (T mean max) and long-term mean minimum air temperature (T mean min) in Portorož

On the other hand, mountains and mountain valleys are the coldest part of the country. In mountain valleys the mean annual air temperature is below 8 °C, the mean air temperature of the coldest month of the year (January) is below 0 °C but not lower than -4 °C, while in the warmest month of the year the mean air temperature does not reach 18 ° (see Figure 3).

In the mountains the mean annual air temperature is around 0 °C, the mean air temperature of the coldest month of the year (February) is below -4 °C, while the mean air temperature of the warmest month is below 10 °C. For example, at Kredarica, with an altitude of 2514 m, the mean annual temperature is -1.3 °C, the mean temperature in January is -7.2 °C and in February -8 °C. The warmest month is August, when the mean air temperature is 6.4 °C.

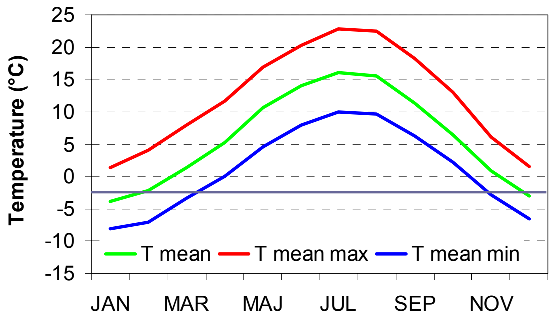

Figure 3. Long-term (1971–2000) mean air temperature (T mean), long-term mean maximum air temperature (T mean max) and long-term mean minimum air temperature (T mean min) in Rateče

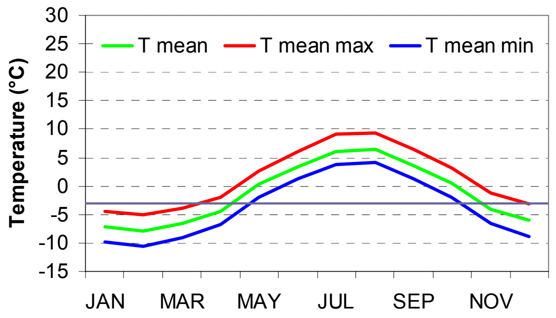

Figure 4. Long-term (1971–2000) mean air temperature (T mean), long-term mean maximum air temperature (T mean max) and long-term mean minimum air temperature (T mean min) at Kredarica

On a larger scale, in the inner parts of Slovenia the mean annual temperature is around 10 °C, in the coldest month the mean temperature is close to 0 °C, while in the warmest it is above 18 °C (see Figure 5).

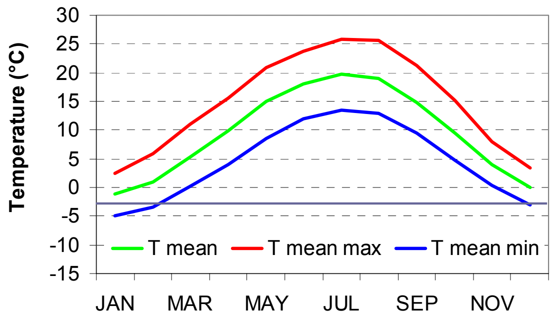

Figure 5. Long-term (1971–2000) mean air temperature (T mean), long-term mean maximum air temperature (T mean max) and long-term mean minimum air temperature (T mean min) in Murska Sobota

Air temperature in Ljubljana

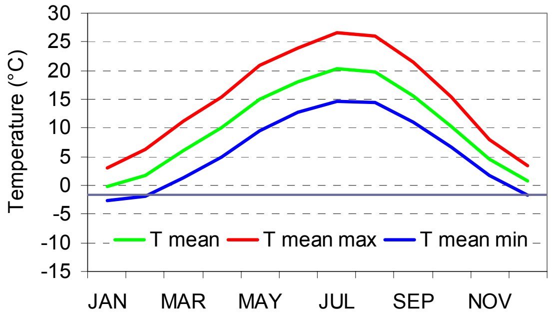

Figure 7. Long-term (1971–2000) mean air temperature (T mean), long-term mean maximum air temperature (T mean max) and long-term mean minimum air temperature (T mean min) In Ljubljana

Air temperature conditions in Ljubljana are similar to the conditions experienced by the inner parts of Slovenia. The mean annual air temperature is 10.2 °C, the mean temperature for July is 20.4 and for January it is -0.2 °C. In the cold part of the year temperature inversions are quite frequent. The phenomenon of a higher air temperature in the city than in the surrounding countryside is also noticed in Ljubljana. Air temperature in Ljubljana has been measured since 1851. In the 1851-2005 period, the coldest year was 1871 when the mean annual air temperature was 7.8 °C, but 2000 was the warmest one when the mean annual air temperature was 12.2 °C.

In the 1948-2005 period in Ljubljana the maximum air temperature of 38.8 °C was measured on 6 July 1950, and the minimum of –23.3 °C on 16 February 1956. The highest number of days with a maximum air temperature below 0 °C was in 1963 (49 days); on average, in Ljubljana there are 17 such days. On the other hand, in 1998 there was the highest number of days with a maximum air temperature above 30 °C (33 days); in Ljubljana there are on average 14 such days.

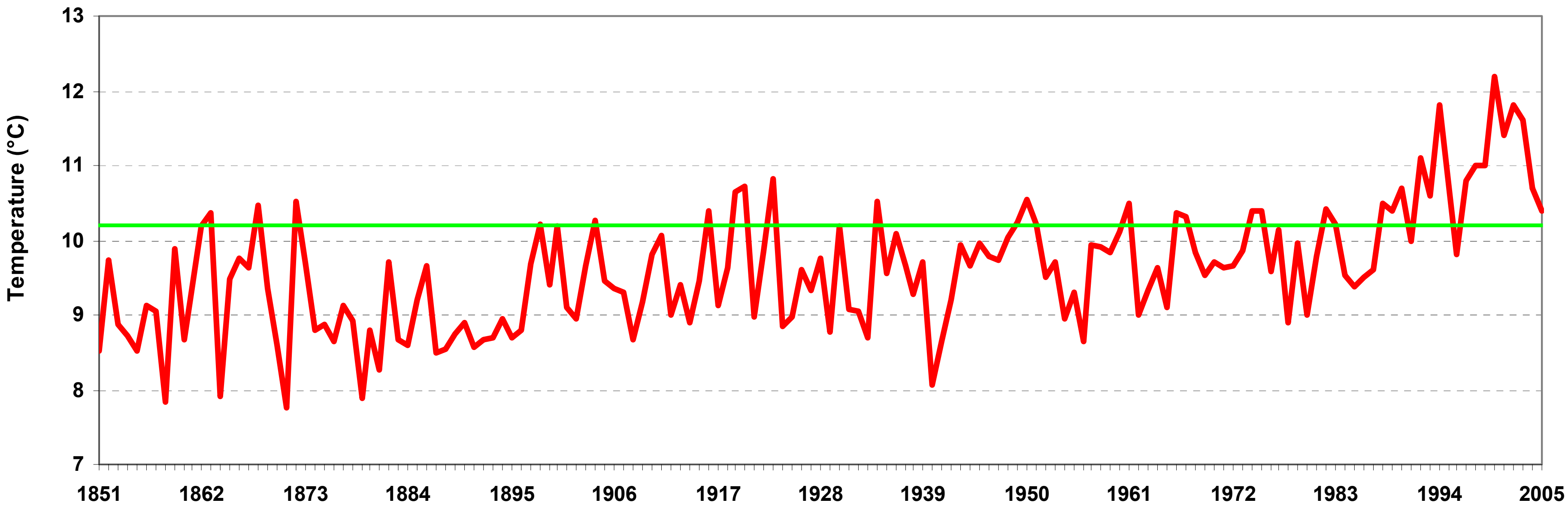

Figure 8. Mean annual air temperature in Ljubljana from 1851–2005 and long-term (1971-2000) mean air temperature (green line)

Precipitation

Mojca Dolinar

The interaction of three major climate systems (Continental, Alpine and sub-Mediterranean) in the territory of Slovenia strongly influences the country's precipitation regime. The spatial variability of precipitation is high – the annual precipitation sum varies from 800 mm in the NE part of the country to more than 3500 mm in the NW part of the country, where one of the Alpine precipitation maxima is detected. The yearly sum of precipitation (Figure 1) and number of days with precipitation (Figure 2) have changed a lot over the years, the variability is even greater when the annual precipitation cycle is under observation.

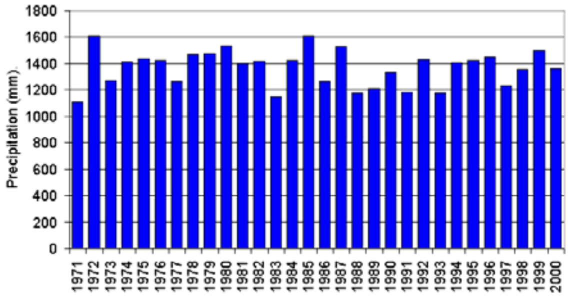

Figure1. Annual precipitation sums in Ljubljana for the 1971-2000 period

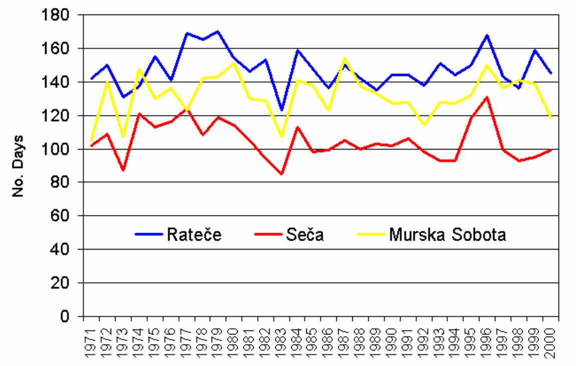

Figure 2. Yearly number of days with precipitation exceeding 0.1 mm for the 1971-2000 period for Rateče (Alpine climate), Seča (Mediterranean climate) and Murska Sobota (Continental climate).

Spatial distribution of pre-cipitation

The spatial distribution of precipitation is highly influenced by the country's complex terrain. Due to an orographic effect the Julian Alps and the Dinaric barrier receive the highest amount of precipitation; the second maximum is recorded in the Alps above the Savinja river valley in the Kamniško-Savinjske Alps. The yearly amount of precipitation decreases with distance from the sea and the Dinaric-Alpine barrier towards the north-eastern part of the country, which is already influenced by the Continental climate. In the outmost north-eastern part of the country (Prekmurje), the mean annual precipitation sum does not exceed 900 mm. This distribution is a consequence of the fact that the largest amount of precipitation falls during conditions of wet south-westerly winds which are perpendicular to the high Dinara-Alpine orographical barrier.

Precipitation variability

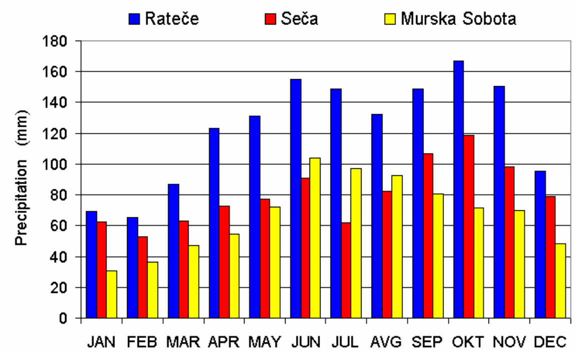

Figure 3. Monthly mean precipitation (reference period 1971-2000) for Rateče (Alpine climate), Seča (Mediterranean climate) and Murska Sobota (Continental climate).

The annual cycle of precipitation depends strongly on the major climate system that influences a specific region (Figure 3). In the Mediterranean region there are two maximums: in late spring and in autumn. In the Alpine region the most pronounced precipitation maximum is in autumn, however, there is another maximum in late spring and early summer. Moving towards the east, where the continental influence becomes stronger, the summer maximum is the highest since in the continental climate most precipitation falls during summer's rain showers and storms.

Precipitation frequency

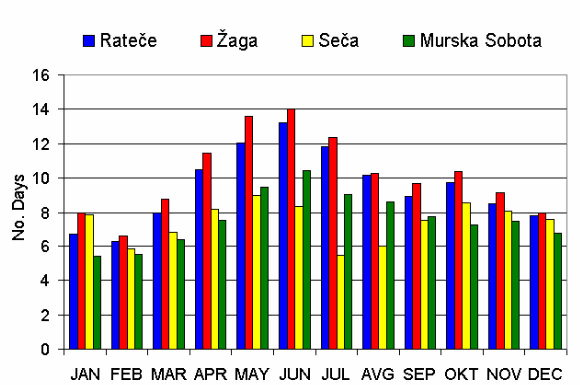

Figure 4. Number of days with precipitation exceeding 1 mm for Rateče (Alpine climate), Žaga (Alpine climate – Posočje region), Seča (Mediterranean climate) and Murska Sobota (Continental climate). (Reference period 1971-2000)

The number of days with at least 1 mm of precipitation (Figure 4) is distributed uniformly over the country and ranges between 90 days a year in the Mediterranean region and 130 days a year in the Alpine region. It is quite the opposite to the frequency of strong precipitation (Figure 5). It is the most frequent in Posočje, the region with the maximum annual precipitation sums, where the frequency of strong precipitation exceeds 28 days per year. Strong precipitation is much less frequent in the NE region with a Continental climate influence, where the average frequency of strong precipitation is less than 18 days a year.

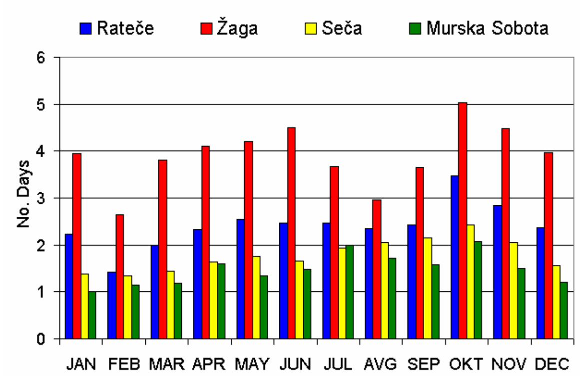

Figure 5. Number of days with precipitation exceeding 20 mm for Rateče (Alpine climate), Žaga (Alpine climate – Posočje region), Seča (Mediterranean climate) and Murska Sobota (Continental climate). (Reference period 1971-2000)

Precipitation extremes

The north-western part of the country (Posočje region) is one of the regions with the highest annual precipitation levels in the Alps. The highest annual precipitation sum (4531 mm) was measured in 1960 in Breginj. In addition, the highest daily precipitation sums are recorded in that region – in Plužna 352.6 mm of precipitation was measured in August 1987. All over the country floods can occur during situations involving a Genova cyclone accompanied by wet southwesterlies which persist above the country for more than one day. Torrential floods are common in the warm part of the year, when very intensive showers of a short duration can appear. On such occasions rain intensities with more than 25 mm per hour are frequent all over the country.

Figure 6. After one day of heavy precipitation the Sevnica river flooded wide regions around its riverbed and caused serious damage on 21 August 2005 (Photo: Zorko Vičar)

Precipitation measurements

Figure 9. A Hellmann rain gauge at the Ljubljana meteorological station. (Photo: EARS archive)

Precipitation measurements are underestimated, especially in high and exposed mountainous regions. In Slovenia precipitation is measured with a Hellmann-type of rain gauge which underestimates precipitation, especially in weather with strong winds.

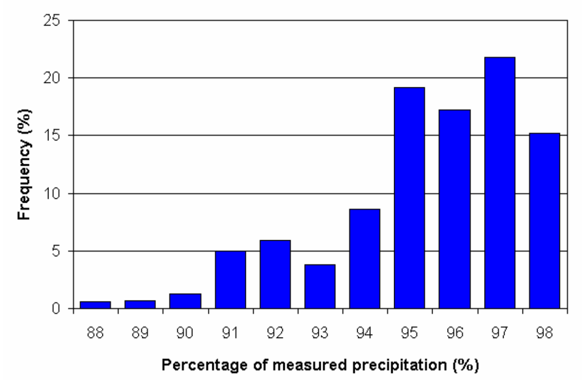

Figure 7. Distribution of the percentage of measured liquid daily precipitation according to estimated corrections due to wind, precipitation intensity and wetting.

Wind-tunnel experiments have shown that Hellmann's rain gauge in winds over 5 m/s only collects 22 % of snow and 87 % of rain. For the water balance and for other purposes precipitation measurements are corrected for systematic measuring errors, of which the largest is the wind-induced error. In the lowlands with weak winds the precipitation measurements are underestimated by up to 5%. The underestimation is a little greater in the Primorska region, with its characteristic strong Bora wind, where the estimated correction is up to 10 %. The same range of underestimation (up to 10 %) is also typical of higher exposed regions. At the highest measuring station of Kredarica (2514 m), where strong winds and solid precipitation are frequent, on a yearly basis only 54 % of the precipitation is measured.

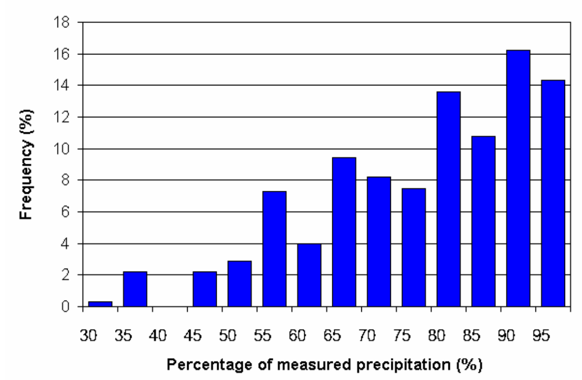

Figure 8. Distribution of the percentage of measured solid daily precipitation according to estimated corrections due to wind, precipitation intensity and wetting.

SNOW

Gregor Vertačnik

Introduction

Snow is a special type of precipitation and we therefore have special measurements to quantify this meteorological phenomenon. Observers at climatological and precipitation stations take daily measurements of snow depth at 7 a.m. local time. We distinguish total snow from fresh snow measurements. Fresh snow is defined as the accumulation of snow that has fallen in the last 24 hours.

The snow cover depth is usually measured on level ground overgrown with grass. The measuring site is representative of the given environment, at least partly exposed to sunshine and not too exposed to or sheltered from the wind.

A long stick with a measure in centimetres is used to measure the total snow cover depth. Measurements are taken at a few places and then averaged. The depth of the fresh snow cover is measured by a ruler on a white board, which is slightly pressed into the old snow cover 24 hours before the measurement.

Snowfall is a seasonal phenomenon for most of Slovenia, with the exception of the lowlands in the Primorska region. It is quite frequent in interior low-lying areas from late autumn to early spring, while during summer it is only present in the mountains (Figure 1).

Because snowfall is most common in winter and very rare in summer, the season for snow elements is defined as the period from July 1 to June 30.

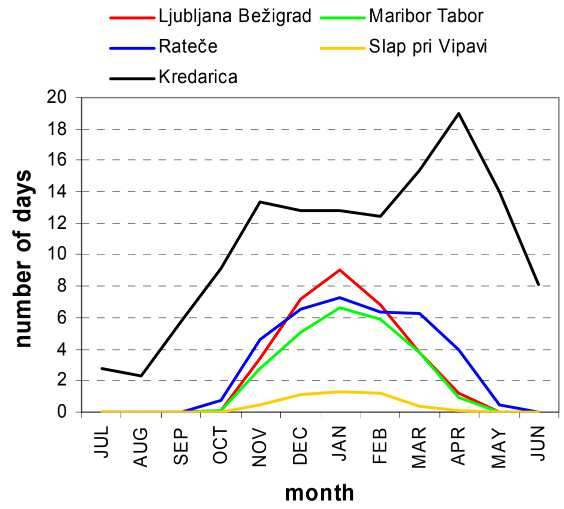

Figure 1. Average monthly number of days with snowfall 1971/1972-2000/2001

Heavy snowfall is usually connected with Mediterranean cyclogenesis. When a cyclone forms in the Gulf of Genoa, a southwesterly wind starts blowing, raising a humid air mass over the Alpine-Dinaric ridge. This often results in strong orographic precipitation in western and partly northern Slovenia. In the eastern part of the country intense snowfall sometimes occurs when humid winds blow from easterly directions.

Figure 2. Deep snow cover in the Julian Alps (Photo: Jaka Ortar)

The most devastating consequence of the huge snow amounts are avalanches. Although they are limited to very small areas in the Alps, they have caused more deaths than any other natural disaster in Slovenia.

Snow data is important for many spheres of the economy, for example in traffic, civil engineering, tourism, agriculture etc. In traffic it is used for traffic regulation and roadway maintenance. Maximum snow loads determine the structure of constructions. Data about snow depth is very important for winter tourism in mountainous areas. Vegetation depends heavily upon the duration of snow cover and the water regime on snow accumulation and melting.

Figure 3. A snowdrift in a region with a strong bora (Photo: Marko Korošec)

Snow cover duration

Snow cover duration mostly depends on fresh snow accumulations, air temperature and sunshine. Air temperature normally decreases and the amount of fresh snow increases with an increasing altitude, which results in the longer duration of snow cover at higher altitudes. Sunshine is a more important element on the local scale. In those places more exposed to the sun the snow melts quicker and the duration is consequently shorter. On the other hand, snow cover in shady places often completely melts no earlier than in summer, especially in the mountains. Places where not all of the snow melts before the next season are called snowfields. In the course of time and if the climate is appropriate glaciers can form out of snowfields like, for example, Zeleni sneg below the top of Triglav.

The average number of days with snow cover is approximately 50 days in the interior lowlands, with a decreasing trend to the east (see the map). The duration gets longer as the altitude rises. There are around 100 days with snow covering the ground in some Alpine valleys, whereas over most of the year snow covers the highest Alpine peaks. On the contrary, in low areas west of the main Dinaric ridge snow covers the ground only a few days per season at the most.

The duration is very variable between seasons, as shown in Figure 4. Variability is relatively smaller in areas with a longer duration and more pronounced in low-lying areas.

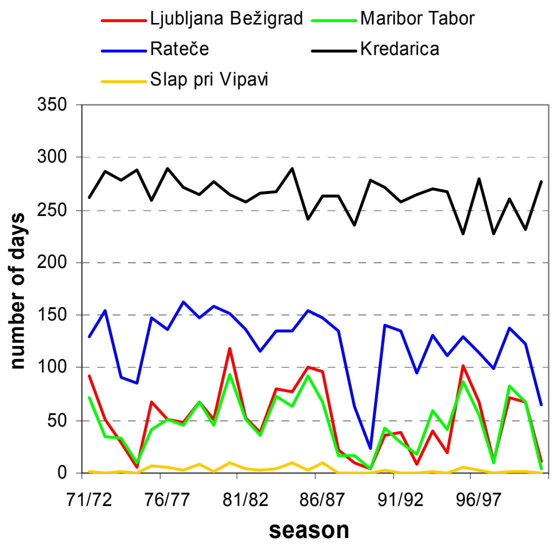

Figure 4. Snow cover duration 1971/1972–2000/2001

Fresh snow accumulation

The amount of snow that falls in a season can be described by its mass per surface unit or by the sum of fresh snow heights. Although only a rain gauge is needed to carry out measurements using the first method, it is less accurate because of the relatively large measurement errors, particularly in places exposed to the wind. For that reason we use the second method, which is more accurate but still sensitive to wind carrying snow from one place to another.

The accumulation of fresh snow increases with altitude and precipitation so the areas of maximum fresh snow accumulation are found in the Julian Alps (see the map 'Fresh snow accumulation'). The difference in precipitation amount also explains the longer duration of snow cover in the Ljubljana valley than in the Pomurje region in the northeastern part of the country. On the contrary, huge amounts of fresh snow are rare in the upper Soča valley despite of lot of precipitation falling there in winter. Due to the influence of the Mediterranean climate, very little snow falls in the lower parts of that region.

Maximum depth of total snow cover

The seasonal maximum depth of total snow cover is another important climatic variable. Figure 5 represents a time-series in the analysed period. The relative variability is greater in areas with lower values because the snowfall in these areas is less regular than at higher altitudes.

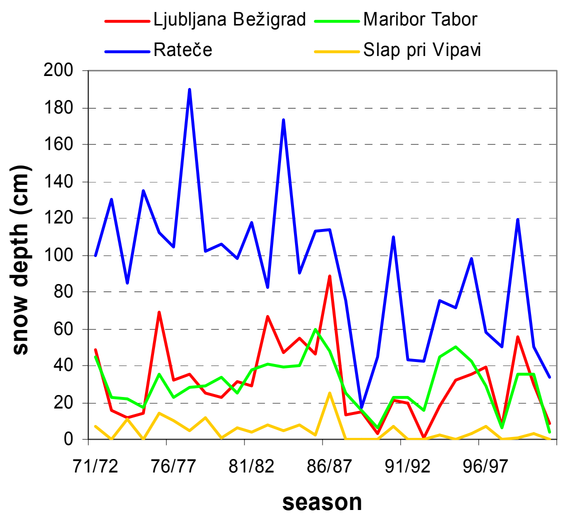

Figure 5. Maximum seasonal total snow depth 1971/1972–2000/2001

For civil engineering constructions very important information is the probability of deep and heavy snow cover, which can be calculated from the time series shown in Figure 5.

According to the map, the snow depth very rarely exceeds 50 cm in the interior lowlands east of Ljubljana. Higher values are found in the Ljubljana valley and the Koroška and Kočevje regions, where more than a metre of thick snow cover is expected a few times per century. The depth increases with altitude, reaching about 2 m at 1000 m and more than 5 metres in the highest parts of the country. At our highest station, Kredarica, 2514 m a.s.l., the maximum depth of exactly 7 m was measured in April 2001. Yet the conditions in lowlands west of the main Dinaric ridge are completely different. Snowfall there is of a short duration and frequency.

Maximum snow load

Important information for construction is an estimation of the maximum snow load in a given area. An appropriate estimation, especially in lowlands where heavy snowfall occurs infrequently, can reduce the long-term costs of building and repairing damage.

The maximum snow load with a return period of 50 years is shown on the map. The lowest values are again limited to the lower parts of the Primorska region. Slightly higher values are found in the extreme northeastern part. The lowlands in the eastern and central parts of Slovenia mostly experience maximum snow load values of 1.0-1.5 kN/m^2. The maximum snow load increases with altitude similarly as fresh and total snow and exceeds 4 kN/m^2 in the upper Sava valley and 10 kN/m^2 in the higher parts of the Alps.

SUNSHINE DURATION

Tadeja Ovsenik-Jeglič

Preface

The sun is the source of all the energy that impinges on Earth. It radiates light as a black body at a temperature of about 6000 K, so it emits UV radiation, visible light and IR light. On its path through the atmosphere the radiation weakens due to light scattering and absorption.

At the meteorological stations that form part of the Environmental Agency of the Republic of Slovenia measurements are performed of bright sunshine duration, solar global radiation and diffuse radiation, while at some stations UVB and IR radiation is also measured. In 2005 bright sunshine duration was measured at 22 meteorological stations, while solar global radiation was measured at 21 meteorological stations.

The relief of the landscape that covers the horizon and sometimes even obstacles within the vicinity of the measuring site can reduce the measured duration of sunshine.

The measured data is corrected with the result that the effect of geographical, urban and fauna obstacles on the data is removed.

Daily sunshine duration

The daily pattern of sunshine duration for 4 months for Ljubljana for the 2001-2005 period is presented in Figure 1.

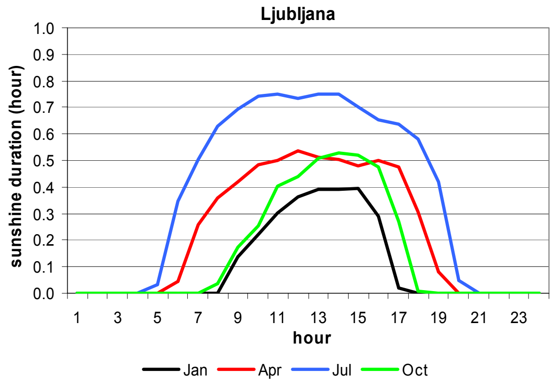

Figure 1. Daily pattern of sunshine duration for 4 months for Ljubljana

From a similar graph for Kredarica (2514 m above sea level) we see that in the mountains in the afternoon the sun is hidden by clouds that emerge through the rising of warm air on the sunny side of the mountain. Considering the average daily sunshine duration we find that the sun shone for a little over 5 hours per day on average in most places; at Kredarica for 5.1 hours, in Ljubljana for 5.0 hours, in Rateče for 5.6 hours and in Novo mesto for 5.3 hours per day. The exception is Portorož, where on average the sun shone for 6.6 hours per day.

Monthly sunshine duration

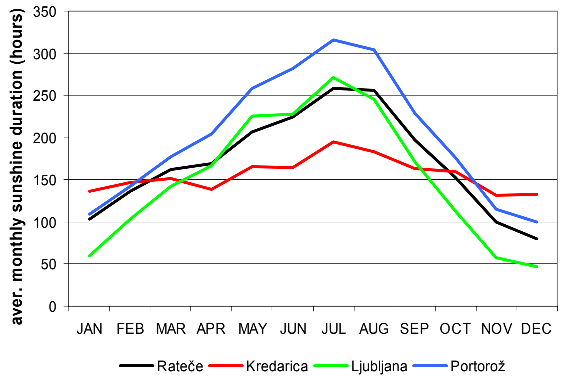

Figure 2. Yearly course of average monthly sunshine duration for 4 meteorological stations

In Figure 2 monthly values of sunshine duration for the 1971-2000 period are presented for 4 places in climatologically different areas of Slovenia. Portorož receives the most sunshine in all months of the year, except in winter (2416 hours per year on average). During winter, sunny weather is most common at Kredarica since lower lying land areas are often covered by low clouds and fog. The differences in average monthly sunshine duration between the stations in inner parts of the country are not so outstanding. On average, the sun shines in Rateče for 2048 hours a year, in Murska Sobota for 1960 hours and in Ljubljana for 1832 hours.

Completely cloudy days

Let us now consider completely cloudy days, namely, when the measured sunshine duration was zero. In Novo mesto, Murska Sobota and Ljubljana there are on average 74 to 82 such days per year, at Kredarica the sun does not appear on average for 91 days a year. In Portorož, which is exposed to the sun the most often, there are 52 completely cloudy days a year on average, while the figure for Rateče is 61 days.

The frequency distribution of the daily sunshine duration for Ljubljana for summer and winter is presented in Figure 3. Considering similar graphs for other stations we find that at all the meteorological stations the sky is often completely cloudy during winter. In Portorož we have long-lasting sunny weather during both summer and winter, and at Kredarica there is frequent sunny weather during winter and more cloudy weather during summer than at other stations.

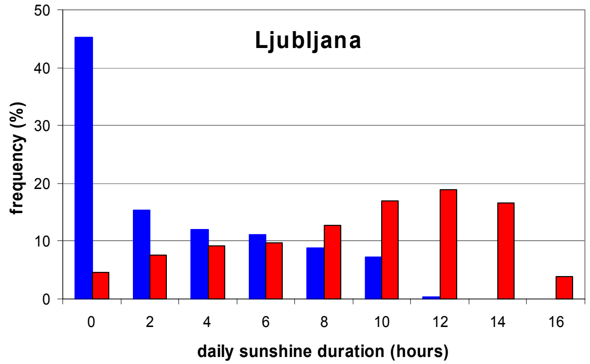

Figure 3. Frequency distribution of daily sunshine duration for Ljubljana for summer and winter (blue columns-winter, red columns-summer)

Trends and extremes

In our analysis of sunshine duration in the 40-year period we studied linear trends for separate months for some stations with a continuous time series of sunshine duration measurements. The trend of an increase in the duration of sunshine is observed. For some months and some stations positive statistically significant linear trends were found. In Table 1 the months with the maximal and minimal sunshine duration for 10 meteorological stations for the 1971-2005 period are presented. The highest monthly sunshine duration (367 hours) was measured at Portorož in July 1988.

Table 1. Maximal and minimal monthly sunshine duration in the 1971-2005 period.

Station	Max. sunshine duration (hours)	Month, year of max. sunsh.dur.	Min. sunshine duration (hours)	Month, year of min. sunsh.dur.
Kredarica	279	Jul. 1983	58	Nov. 2000
Rateče	339	Jul. 1983	29	Dec. 1995
Nova Gorica	333	Jul. 1994	49	Dec. 1981
Postojna	374	Jul. 1983	34	Dec. 1995
Ljubljana	325	Aug. 1992	7	Dec. 1995
Novo mesto	335	Jul.1988	4	Dec. 1995
Celje	324	Aug. 1992	12	Dec. 1995
Maribor	347	May 1979	12	Nov. 1993
Murska Sobota	343	Jun. 2000	14	Dec. 1995
Portorož	367	Jul. 1988	44	Dec. 1985

The spatial distribution of sunshine duration differs for winter, spring, summer and autumn. The difference is obvious in the spatial distribution between summer when the Primorje region is the most exposed to sun, and winter when Alpine region (besides Primorje) gets the most sun radiation.

WIND

Renato Bertalanič

General Winds

Wind conditions in Slovenia are determined by its geographical position east of the Alps and in the vicinity of the Mediterranean Sea. Waving western winds prevail in Slovenia as in Europe, which is located at moderate geographic latitudes. From this general western course the wind flow declines to the north and south and from time to time large closed eddies emerge from it. These eddies are known as cyclones and anticyclones. Extensive pressure ridges and related subtropical anticyclones are relatively stationary structures with a life period even of up to several weeks. They expand over the south of Middle Europe from the Mediterranean Sea, North Africa or from the Atlantic Ocean. Winds are weak when there are subtropical anticyclones across South Europe. Winds are stronger on the northern, western and eastern edges of subtropical anticyclones than in their centre.

All strong winds in Slovenia are related to cyclones, the strongest winds are linked to the passing of fronts and with Mediterranean cyclones. The periods of intensive weather processes and strong winds are short. Periods of anticyclone weather are of a longer duration than periods of cyclonic weather. In summer, at the end of winter and at the beginning of spring there is very often permanent anticyclonic weather. The winds in Slovenia are weak compared to those in Western Europe.

The winds in Slovenia depend very strongly on the Alps. Slovenia is on the calm side of the Alps when western to northern winds blow. These situations are very frequent and winds in Slovenia are much weaker than those on the western side of the Alps. Less frequent are winds from the east to southwest. The Alps are no wind obstacle in these situations.

After the break of fronts to the Alps, a Mediterranean cyclone is frequently formed, especially in the cold half of the year. This region of low pressure causes strong winds. When the Mediterranean cyclone is over the West Alps and north Italy southwesterly winds prevail in Slovenia. After the cyclone moves across Slovenia to the Balkans, strong winds from the east blow into Slovenia.

Regional Winds

Regional winds in Slovenia with their range of activity of around 100 km are a result of general winds and the effect of Alpine and Dinaric mountain barrier. On the surface three regional winds can be seen: bora, jugo, and the Karavanke föhn.

Bora

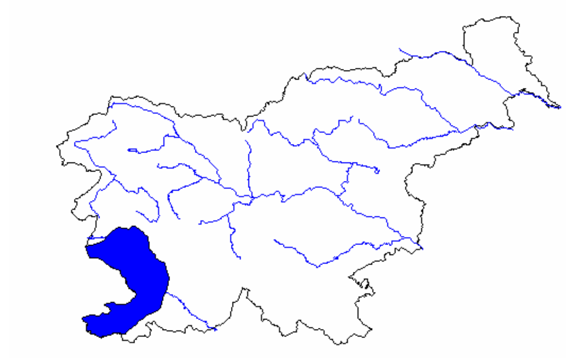

Figure 1. Region with the bora

The bora (*Slovenian: burja*) is the strongest wind in Slovenia. After the passing of the cold front of the Mediterranean cyclone cold air folds up around the eastern border of Alps. After rising over the Dinaric mountain plateau (Trnovski gozd, Nanos, Javorniki, Snežnik, Kras), this cold air accelerates down western and southern slopes towards the Adriatic Sea. The bora begins suddenly with some initial gusts. The bora is a gusty wind. Its velocity can increase or decrease 10-fold within a very short time period. The bora is a north-eastern wind, and occasionally in some places eastern or northern (Figure 2). It is a regular phenomenon in west Slovenia (Primorska, Obala and Notranjska regions). It is noticed about ten times a year. At times the bora is very strong wind. The normal bora reaches speeds of up to 10 m/s (35 km/h), but its gusts are several times stronger. Even the normal bora can obstruct traffic.

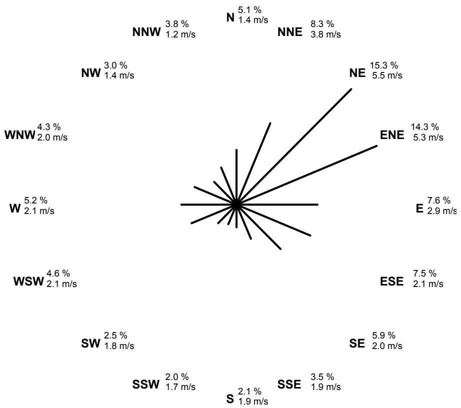

Figure 2. Wind rose in Ajdovščina for the 1975-1988 period

An exceptional strong bora appears only rarely. It appears when there is a big temperature difference between the air over the continent and the air over the Mediterranean Sea and a large pressure gradient is also present. Bora gusts can then reach and exceed 40 m/s (145 km/h, Figure 3). This strong bora in the Vipavska valley breaks trees, unroofs houses and makes traffic impossible. Such a strong bora is a regional phenomenon. It is strongest on the slopes and close below them where the wind flow accelerates or converges. Regions with the strongest bora are found along the ridge of Trnovski gozd and Nanos, in the Vipavska valley (especially from Razdrto to Vipava), in Karst and on the Karst ridge. The bora in the coastal region and in the Goriška region is less strong.

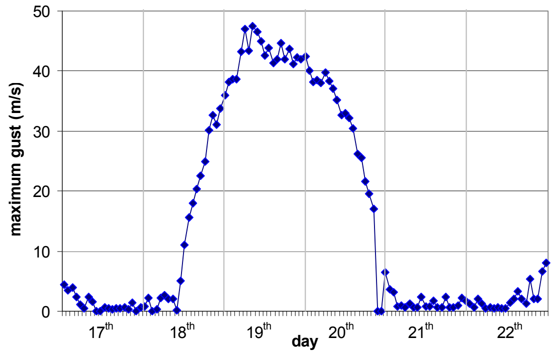

Figure 3. Maximum hourly gusts of the bora in Ajdovščina in the 17-22 February 1978 period

The bora usually blows in a stable atmosphere when cold air flows under warm air. Locally, the bora's speed can be increased by winds flowing together (converging). On the contrary there are also many calm positions where settlements have been established.

Jugo

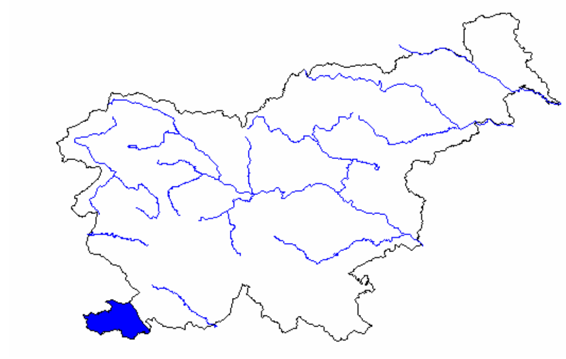

Figure 3. Region with the jugo

The jugo appears as a strong wind from the southwest to southeast before a cold front of a passing Mediterranean cyclone. Because of the large pressure gradient in an east-west direction hot and moist air above the Adriatic Sea moves quickly to the north. On the ground wind speeds are up to 15 m/s (55 km/h), exceptionally up to 25 m/s (90 km/h). The Jugo appears exclusively in the coastal area and moves into the inland no further than the Karst ridge. Its duration is linked to the movement of the Mediterranean cyclone and mostly lasts up to two days. There are about 20 such weather situations a year. The frequency of the jugo is similar to that of the bora since both phenomena are linked to the same synoptic process.

Föhn

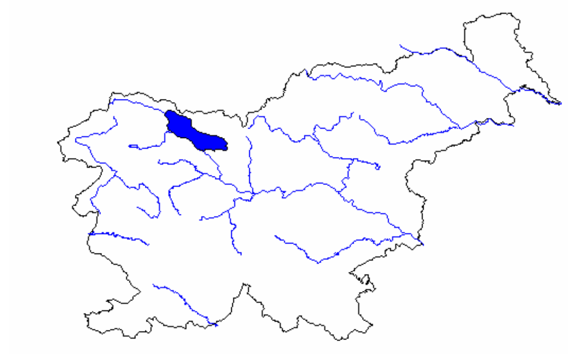

Figure 4. Region with the föhn

The Karavanke föhn (*Slovenian: fen*) is a much less frequent phenomenon compared to the bora or jugo. It occurs perhaps once or twice a year, especially in the cold part of the year. It can become very strong every ten years (Figure 5).

It appears when the Mediterranean cyclone moves over Eastern Europe. It is a strong northerly wind which affects the southern slopes and valleys of the Karavanke and Kamniško-Savinjske Alps. It can also reach the Julian Alps and Ljubljana basin. It is a steady and relatively warm and dry wind. Like the bora it is a katabatic wind.

Figure 5. Consequences of the föhn, 14 November 2002 (Photo: Janko Merše)

Local Winds

There are many local influences on wind conditions. Relief, vegetation, buildings and unevenness of the terrain locally modify general and regional winds. Local calmness and wind divergence or convergence can appear.

Finally, there are also winds which arise from local factors. Local winds are only observable when general or regional winds are weak. Local winds are mostly caused by differences in the warming and cooling of parts of the earth's surface. Local winds can also be caused by convective precipitation.

Thermal dependent winds have a distinctive daily pattern. They appear in a clear sky. On the coast winds blow by day from the sea to the mainland (*land breeze, maestral*) and by night from the mainland to the sea (*sea breeze, burin*). In mountainous areas there are *mountain breezes* which blow up the slopes by day and down them at night. Downward blowing winds are somewhat stronger than those flowing upwards. They are also stronger in winter when the nights are long and cold. Upward winds are, on the contrary, stronger in summer when the sunlight is stronger. In valleys below mountains these winds are called *valley breezes*.

Convective dependant winds are caused by the raising, divergence and convergence of air by clouds of vertical development, in showers and storms. The more intensive a storm is the stronger the winds are. Sometimes they are connected to the slope winds or the valley winds. Convective clouds more frequently develop above slopes exposed to the sun. In storm clouds the air is rising while air in lower parts of the atmosphere flows towards the cloud base. When precipitation forms or occurs, the air in the cloud cools and falls downwards. This is a so-called cold storm blast under the base of a cloud.

Storm blasts occur during storms in all Slovenian regions. They are more frequent in spring and early summer. Super cell storms are very strong but rare. The winds within such a system can reach a speed of over 30 m/s (110 km/h). A very rare phenomenon which accompanies storms is a tornado that can be two to three times faster.

Some measured values

Average speed and power density

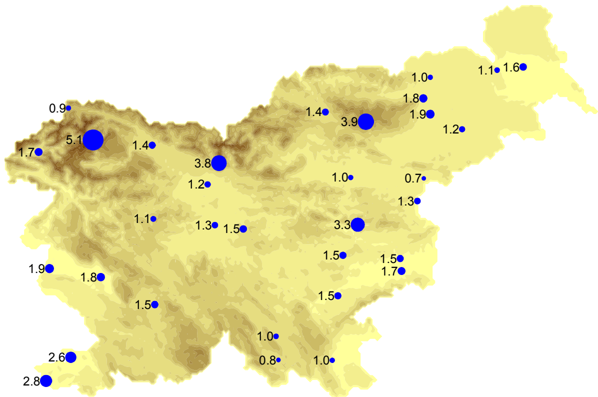

Figure 6. Measured average speed in m/s for the 10-year period 1996-2005

In lowlands the average yearly wind speed rarely exceeds 2.0 m/s, with the exception of the coastal region (Primorje) where the bora blows.

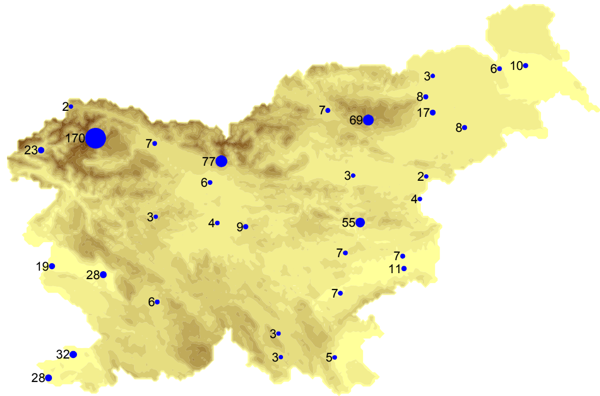

Figure 7. Measured average power density in W/m^2 for the 10-year period 1996-2005

Four sites stand out because of their position on hills or mountains: Kredarica (5.1 m/s, 170 W/m^2), Krvavec (3.8 m/s, 77 W/m^2), Rogla (3.9 m/s, 69 W/m^2) and Lisca (3.3 m/s, 55 W/m^2).

Maximum measured gusts

Maximum gusts can reach 40 m/s. In regions with the bora they can even reach 50 m/s. Again, an exception is the mountain location of Kredarica with maximum gusts of over 50 m/s.

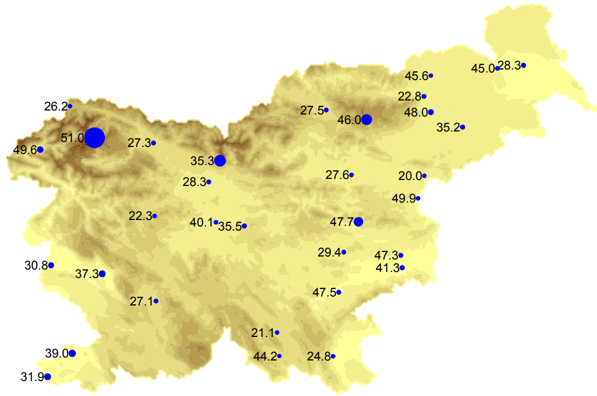

Figure 7. Measured maximum gust in m/s in the 10-year period 1996-2004

Wind roses

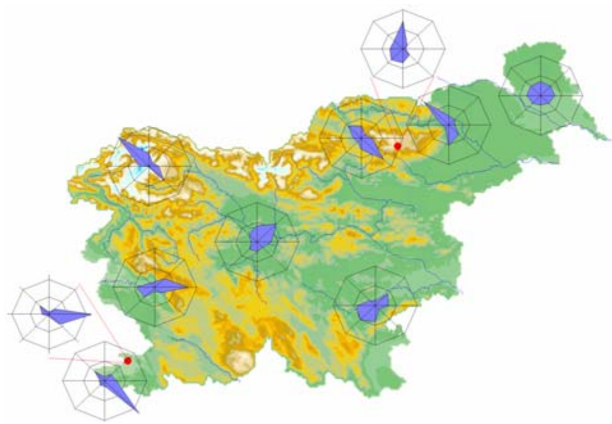

Figure 8. Wind roses for 10 measurement sites in the 10-year period 1995-2004

Wind roses depend very much on the relief surrounding measurement sites. Figure 8 shows wind roses for 10 measurement sites in Slovenia.

Figures 9-12 show wind roses for four sites (Murska Sobota, Brnik, Koper and Kredarica). Murska Sobota lies in the north east of Slovenia on flat terrain. The wind direction is quite homogeneous.

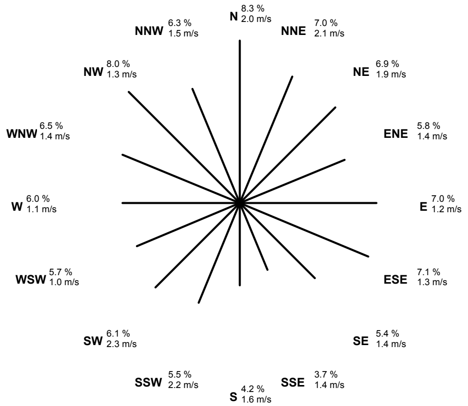

Figure 9. Wind rose for Murska Sobota for the period 1996-2005

At Brnik Airport, which lies in central Slovenia, the most common wind is from the west while the strongest wind blows from the southwest.

The wind rose from Koper, which lies on the coast, shows very frequent bora from the east and north east. It is also the strongest wind with yearly averages of over 4 m/s.

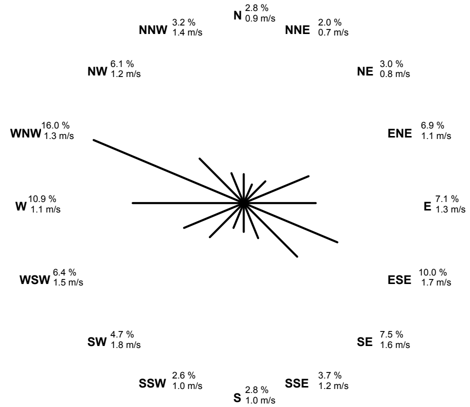

Figure 10. Wind rose for Airport Brnik for the period 1996-2005

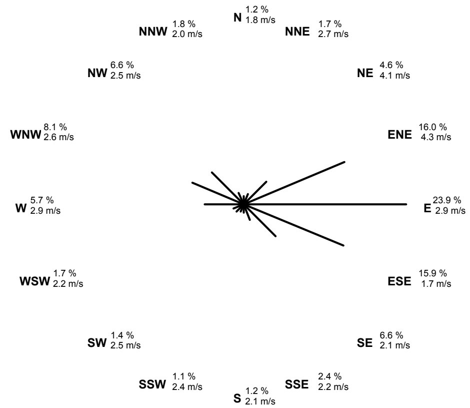

Figure 11. Wind rose for Koper for the period 1996-2005

Decrease in yearly averages

A slight drop in yearly wind speeds can be detected at many Slovenian wind measurement sites in the last decade (Figure 12). The trend is very small but statistically significant.