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

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. 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.

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**

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**

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.

**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.

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.

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.
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.

Four sites stand out because of their position on hills or mountains: Kredarica (5.1 m/s, 170 W/m²), Krvavec (3.8 m/s, 77 W/m²), Rogla (3.9 m/s, 69 W/m²) and Lisca (3.3 m/s, 55 W/m²).

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 average power density in W/m² for the 10-year period 1996-2005

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.

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.

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.