# What is a Foehn Clearance?

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## Abstract

In the present study foehn clearance is described and compared with strong downslope windstorms like the foehn and chinook. The comparison is based on surface and satellite data taken during foehn north of the Alps in southern Bavaria and during chinook east of the Rocky Mountains. The mesoscale features of foehn clearance are shown in terms of temperature, humidity, cloudiness, and wind. A statistic of the occurrence of foehn and chinook is used to estimate the frequency of foehn clearance.

## 1. Introduction

Strong, gusty downslope winds are observed in many mountainous regions of the world. They are an outstanding feature of the winter weather in Boulder, Colorado, and of the weather during fall and spring in the northern Alps. With the onset of these phenomena changes in temperature, humidity, wind, and cloudiness can be observed.

The downslope winds occurring north of the Alps are called *foehn* and are linked with an increase in temperature. Therefore foehn is a warm, dry gusty wind. The terms *south-foehn* and *north-foehn* are used when the synoptic winds cross the Alps from the south or from the north, respectively. The *bora* is a wind occurring in the lee of the Dalmation coastal range in Yugoslavia. With the onset of the bora the temperature drops significantly. The main difference between foehn and bora is that the original temperature of the bora air is very low. Even with dry adiabatic heating during the leeside descent the air temperature doesn't rise sufficiently to increase the temperature at the surface. The winds occurring on the eastern slopes of the Rocky Mountains are called *chinook*. They are of the warm foehn type as well as of the cold bora type. Additionally there exists a so-called *free foehn* (Billwiller, 1899), denoting weather conditions with increasing temperature and decreasing humidity due to air descending in an anticyclone. For detailed description of the definition of foehn and the problem of foehn criteria see Brinkmann (1971).

The main characteristic of the strong downslope wind is gustiness. The violence of foehn decreases rapidly with increasing leeside distance from the baseline of the barrier. At a distance of about 50 km the foehn is noticeable only by increases in temperature and decreases in relative humidity and very seldom in terms of air motion. The temperature rise can sometimes be observed even 100 km away from the barrier. Because of the high population density (and high density of meteorologists) in the south Bavarian region many people experience this type of weather, which has temperature and humidity characteristics similar to foehn but no winds. This type of weather is termed *foehn clearance.*



The aim of this paper is to define the concept of foehn clearance in contrast to those of foehn and chinook. The mesoscale features of foehn clearance occurring north of the Alps and east of the Rocky Mountains are discussed in terms of temperature, humidity, cloudiness, and wind. Several satellite pictures demonstrate the cloud patterns associated with this weather.

The importance of foehn, chinook and foehn clearance east of the Rocky Mountains and north of the Alps is estimated by computing the statistic of occurrence based on a nine-year time series. Generally, the mesoscale weather is forced by the large-scale circulation. A good representation of the large-scale flow might be the wind at 500 mb. To demonstrate the link between mesoscale phenomena, foehn and chinook, and the large-scale flow structure, we compare the statistics of the nine-year time series of the 500-mb wind above the Alps and above the Rocky Mountains with those of foehn and chinook occurrence.

In Fig. 1 two maps are given to illustrate the locations of the alpine and Rocky Mountain areas mentioned in this paper.

## 2. Definition of foehn clearance

During strong downslope wind events gusts up to 25 $m \cdot s^{-1}$ (alpine foehn) and 60 $m \cdot s^{-1}$ (Colorado chinook) are observed. The violence of the wind decreases rapidly with increasing leeside distance from the baseline of the barrier. The ratio $R$ is the maximum observed surface gusts at the location normalized by the maximum surface gust observed at the baseline of the Rocky Mountains in Boulder. In Fig. 2 this ratio is shown as a function of the distance from Boulder along a line perpendicular to the mountain for different chinook events. In most cases, at a distance of 70 km the gusts were reduced in magnitude below 60% of their maximum and beyond 100 km no gusts were experienced. One rapid dropoff in wind speeds east of the Rocky Mountains is reported by Zipser and Bedard (1982). Within 15 km horizontal distance the wind speed has dropped from 45 $m \cdot s^{-1}$ to 30 $m \cdot s^{-1}$ on 17 January 1982.

In most cases south foehn in the Alps does not extend very far into the flat terrain in southern Bavaria. This feature is highlighted in Fig. 3, where the surface wind observations are shown for Innsbruck (top), Hohenpeissenberg (middle) and Munich (bottom) on a day with strong south foehn across the Alps (8 November 1982). At Innsbruck there was strong gustiness, with gusts up to 25 $m \cdot s^{-1}$. At Hohenpeissenberg at a distance of 40 km from the baseline of the Alps gusts up to 14 $m \cdot s^{-1}$ were measured. At Munich at a distance of 80 km from the baseline there were no gusts. At all stations the mean wind direction was close to 180°.

At distances greater than about 50 km the foehn is usually detectable only by increases in temperature and decreases in

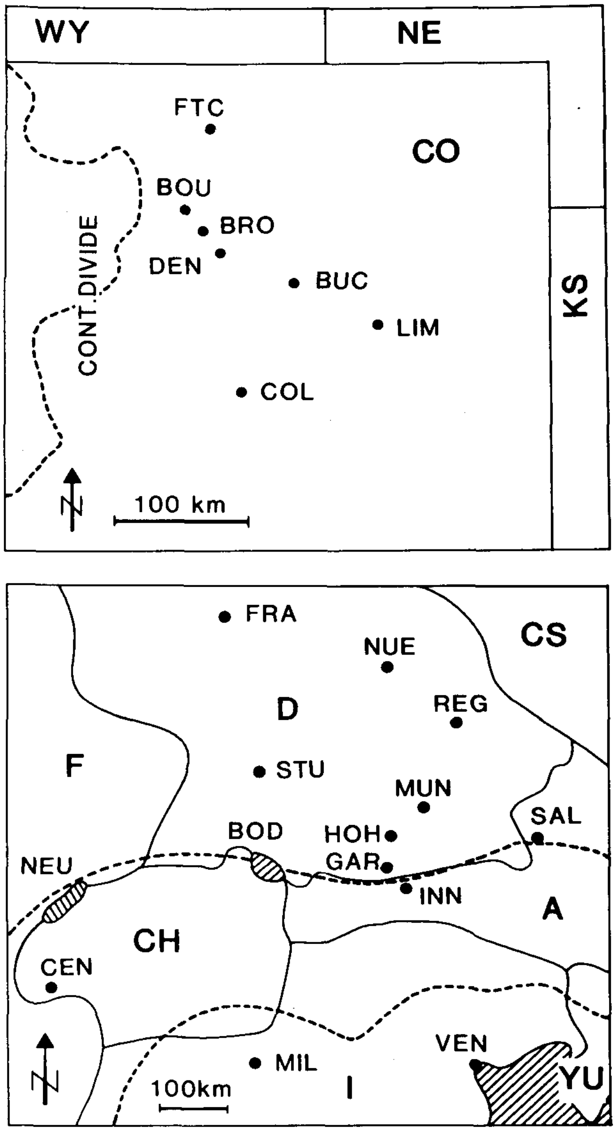


FIG. 1. Maps of Colorado (top) and of middle Europe (bottom). The broken line in the bottom figure indicates the Alps. The abbreviations signify: BOD (Lake Constance), BOU (Boulder), BRO (Broomfield), COL (Colorado Springs), DEN (Denver), FTC (Ft. Collins), FRA (Frankfurt), GEN (Geneva), HOH (Hohenpeissenberg), INN (Innsbruck), LIM (Limon), MIL (Milan), MUN (Munich), NEU (Lake of Neuchatel), NUE (Nuremberg), REG (Ratisbon), SAL (Salzburg), STU (Stuttgart), VEN (Venice). The states are abbreviated by: A (Austria), CH (Switzerland), CO (Colorado), CS (Czechkoslovakia), D (Germany), F (France), I (Italy), KS (Kansas), NE (Nebraska), WY (Wyoming), YU (Yugoslavia).

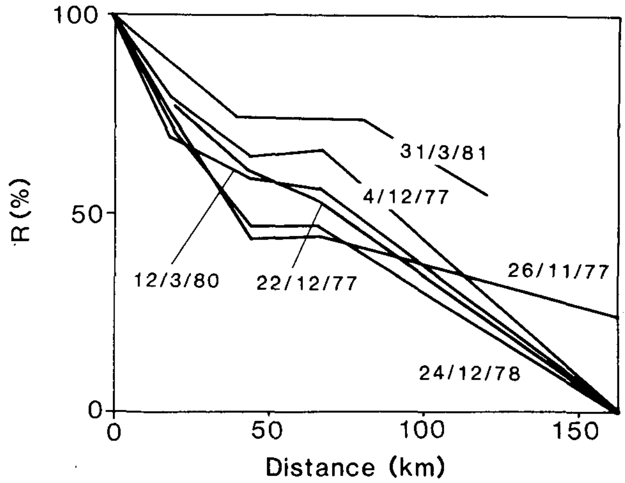


FIG. 2. The ratio $R$ as a function of the distance from the baseline of the Rocky Mountains in Boulder (Colorado) during various days with chinook. $R$ is the ratio of the maximum local gust observed over the maximum gust observed at Boulder.

relative humidity and very seldom in terms of air motion. The temperature rise is sometimes observed up to 100 km from the area with strong gusty winds. An example is given in Fig. 4, where the spatial extension of the dewpoint temperature differences are given for two chinook cases (Beran, 1966). The area affected by the chinook is confined to the eastern slopes and a narrow strip adjacent to the mountains. The temperature and humidity effect characterized by the differences crosses the Colorado–Kansas state line, which is 200 km away from the baseline of the Rocky Mountains.

A prominent feature of the leeside weather during foehn is a decrease in cloudiness. This is the effect of subsiding air in the leeside flow patterns during foehn. This clearing effect is quite common in southern Bavaria north of the Alps in south-foehn situations. Generally cloud-free areas about 200 km wide and extending 20–100 km from the foothills to the north are often observed. Generally, the foehn regions of strong downslope winds extend northerly in the case of the Alps and easterly in the case of the Rocky Mountains to an area with very light winds but temperature, humidity, and cloudiness characteristics similar to those observed in the region with foehn and chinnok. Due to the remarkable decrease in cloudiness in the foehn-free region north of the Alps and east of the Rocky Mountains, these weather situations may be termed *foehn clearance*.

In the areas with strong downslope winds, quite impressive evaporation and melting of snow occur due to the ventilation effect ("snow eater"). The decrease in cloudiness leads to an increase of incoming solar radiation which is linked to an increase of evaporation. The incoming solar radiation is stronger than usual because the atmosphere is drier and cleaner due to the washout effect of precipitation on the windward side. Thams (1954) has shown that during foehn at a height of 380 m above mean sea level (MSL) an increase in direct solar radiation was measured that corresponds to a height of 1600 m above MSL. In the areas with foehn clearance only the radiation effect is active.

The term *foehn clearance* has been used by Hoinka (1980), Kuettner (1982) and Pichler (1982) and is the English equivalent of the German term *föhnige Aufheiterung*, which has been used by German forecasters since the end of last century. Besides the term defined above, other terms like *foehnic clearing* and *foehnic clearance* exist. Until recently a similar English term did not exist, probably because of the small population in areas where foehn clearance occurs, e.g. east of Denver.

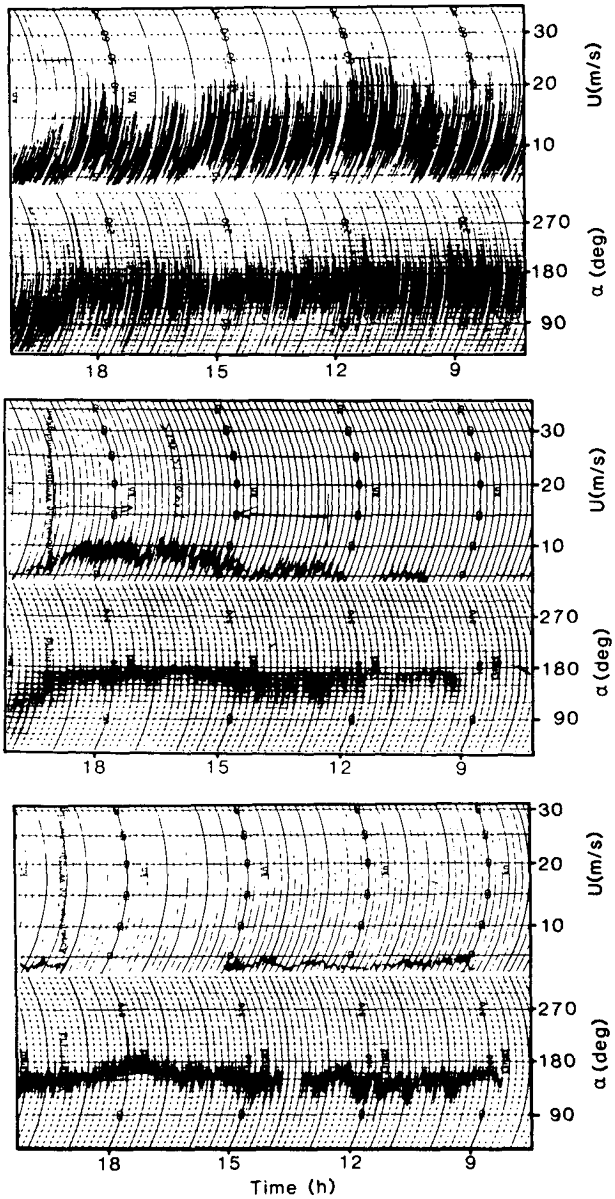


FIG. 3. The wind velocity and direction as a function of time at Innsbruck (top), Hohenpeissenberg (middle), and Munich (bottom) on 8 November 1982. Taken from Hoinka (1985).

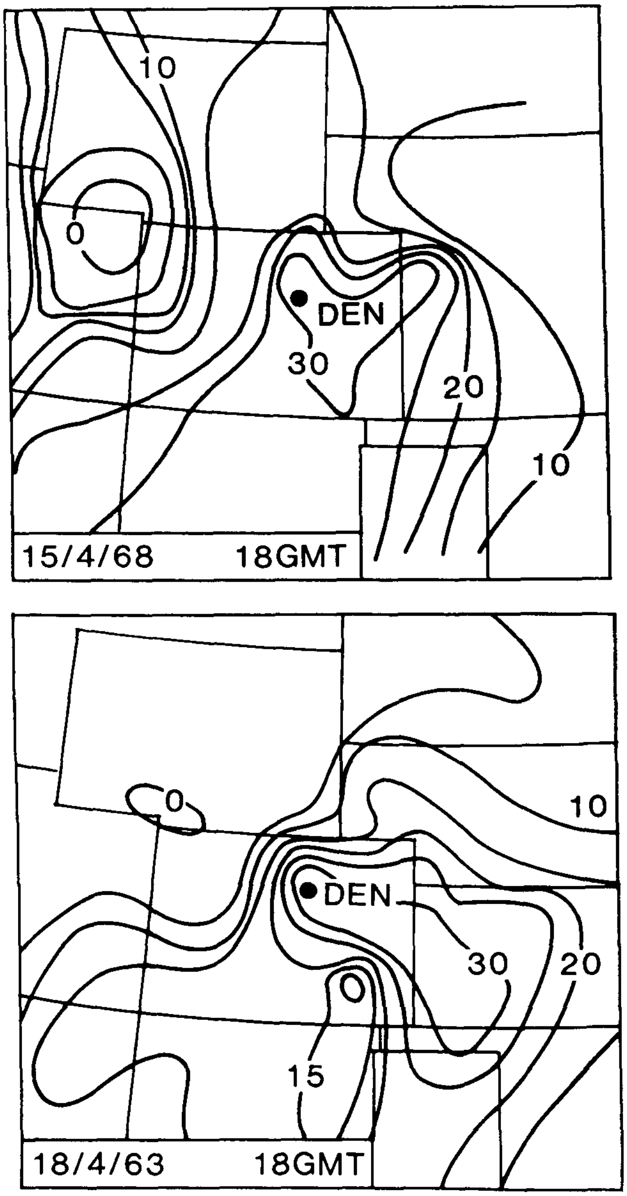


FIG. 4. The spatial distribution of the dewpoint temperature differences during strong chinook. Units are °C. Taken from Beran (1966) and modified.

## 3. Satellite imagery

Observations of outstanding foehn-clearance events visible in satellite pictures have been gathered during strong chinook in Boulder and strong foehn at Innsbruck.

Figs. 5–9 show the cloud cover above the western United States taken by *NOAA-7*. In all events a sharply defined eastern edge of the clouds above the Rocky Mountains in Colorado can be seen. This edge appears to be parallel to the orientation of the Rocky Mountains. In one case this edge can be seen from Wyoming up to New Mexico (Fig. 5). The sky east of this region is generally free of cloud between 40 km (Fig. 6, Colorado) and 100 km (Fig. 5, New Mexico) east of the baseline of the mountains. Fig. 5 shows the decrease in cloudiness in the chinook area and the area of foehn clearance east of it. The cloud-free region in Fig. 6 is connected only with the chinook; foehn clearance has not occurred. In Fig. 7 foehn clearance can be seen occurring in Montana. In some cases obvious synoptic-scale wave patterns can be seen (Figs. 8, 9), impressed upon the flow by the underlying terrain. These waves have been discussed by Beran (1966) and Lester (1976) among others. The wavelengths deduced from the images are between 200 km (Fig. 8) and 400 km (Fig. 9).

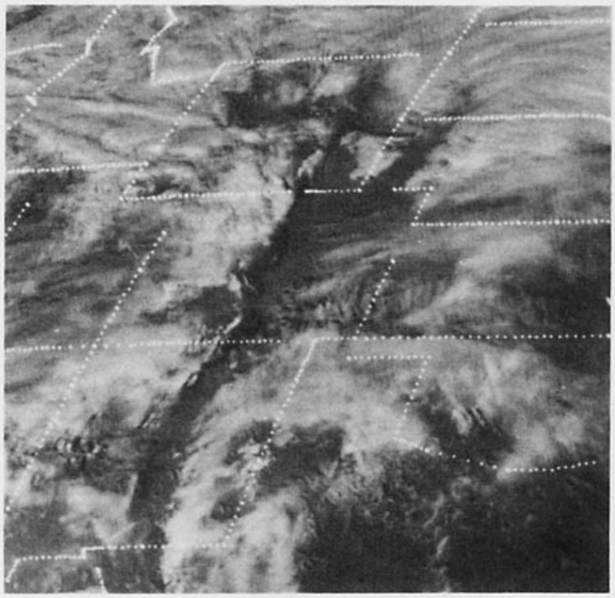

FIG. 5. GOES imagery on 22 December 1977 (visible).

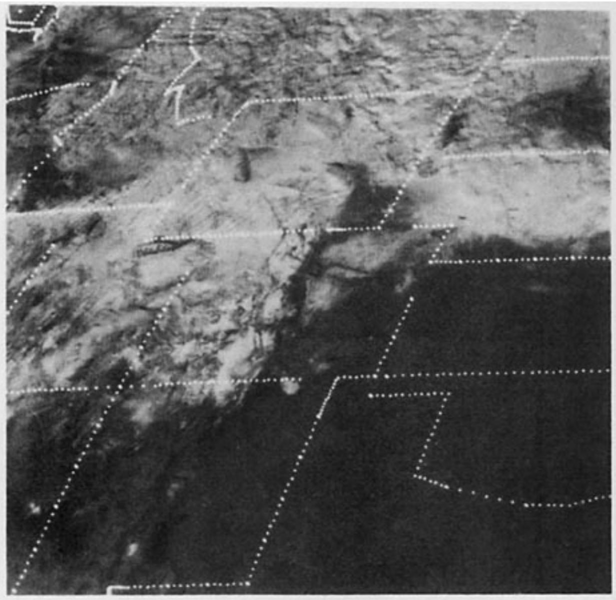

FIG. 7. GOES imagery on 24 December 1978 (visible).

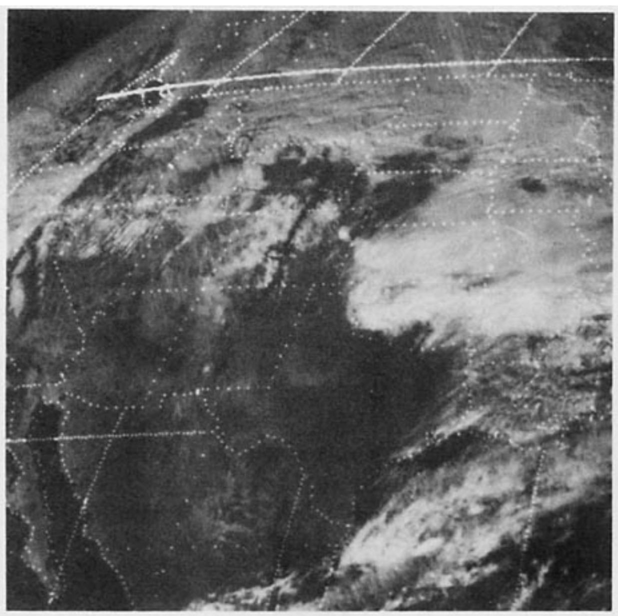

FIG. 6. GOES imagery on 4 December 1977 (visible).

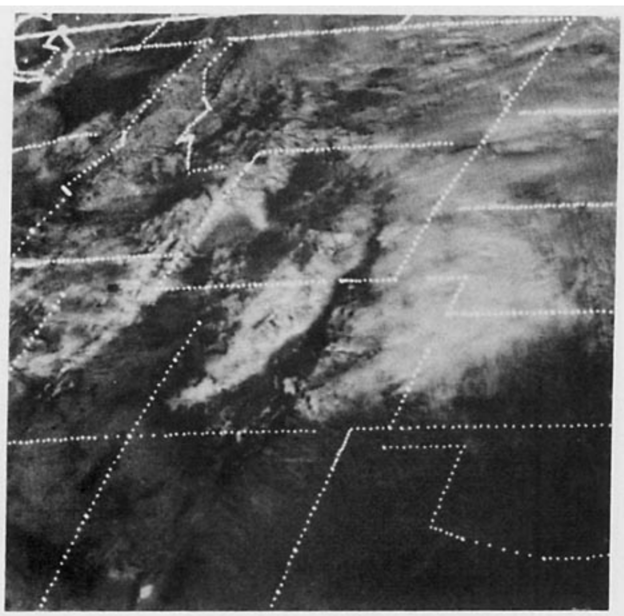

FIG. 8. GOES imagery on 26 November 1977 (visible).

Strong chinook may occur in a narrow belt about 1000 km long parallel to the Rockies, but does not extend very far into the Plains. In most cases the strong chinook around the Boulder area reaches almost to Stapleton Airport, Denver, which is a distance of about 30 km from the foothills of the Rocky Mountains, whereas east of Denver no chinook is experienced. This indicates that there is a belt between 10 and 70 km east of the "chinook" belt with foehn clearance effects. The leeside cloud-free region covers the chinook and foehn clearance areas.

Similar features are observed above the Alps. Fig. 10 shows the cloud cover over the Alps on a day with strong foehn (4 May 1977). North of Switzerland a large cloud-free triangle is apparent. The southern baseline of the triangle is parallel to the main divide of the Alps. The draining effect associated with a decrease in cloudiness can be seen at a distance of about 300 km north of the baseline.

Another example of satellite imagery during foehn is shown in Fig. 11. On 8 November 1982 extended areas with foehn together with gusts up to 25 $m \cdot s^{-1}$ were observed.

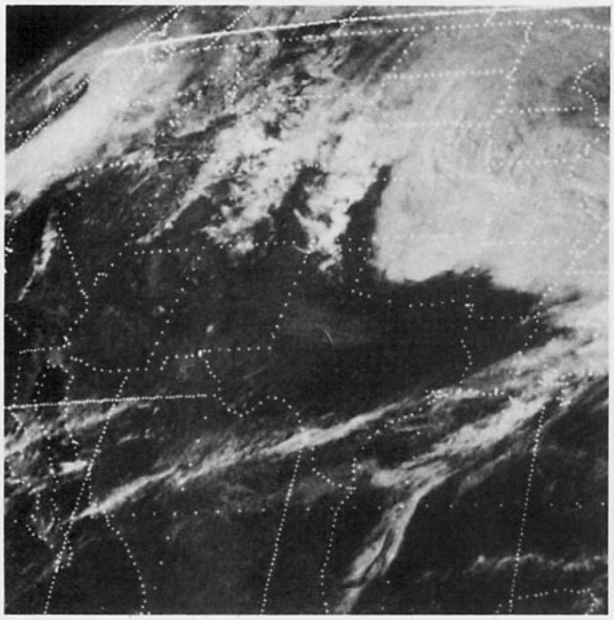

FIG. 9. GOES imagery on 12 March 1980 (visible).


FIG. 10. DMSP imagery on 949 GMT 4 May 1977 (visible). For clarity the following locations are indicated: Lake Neuchatel (a) (NEU, Fig. 1), Lake Constance (b) (BOD, Fig. 1) and the island of Sardinia (c).

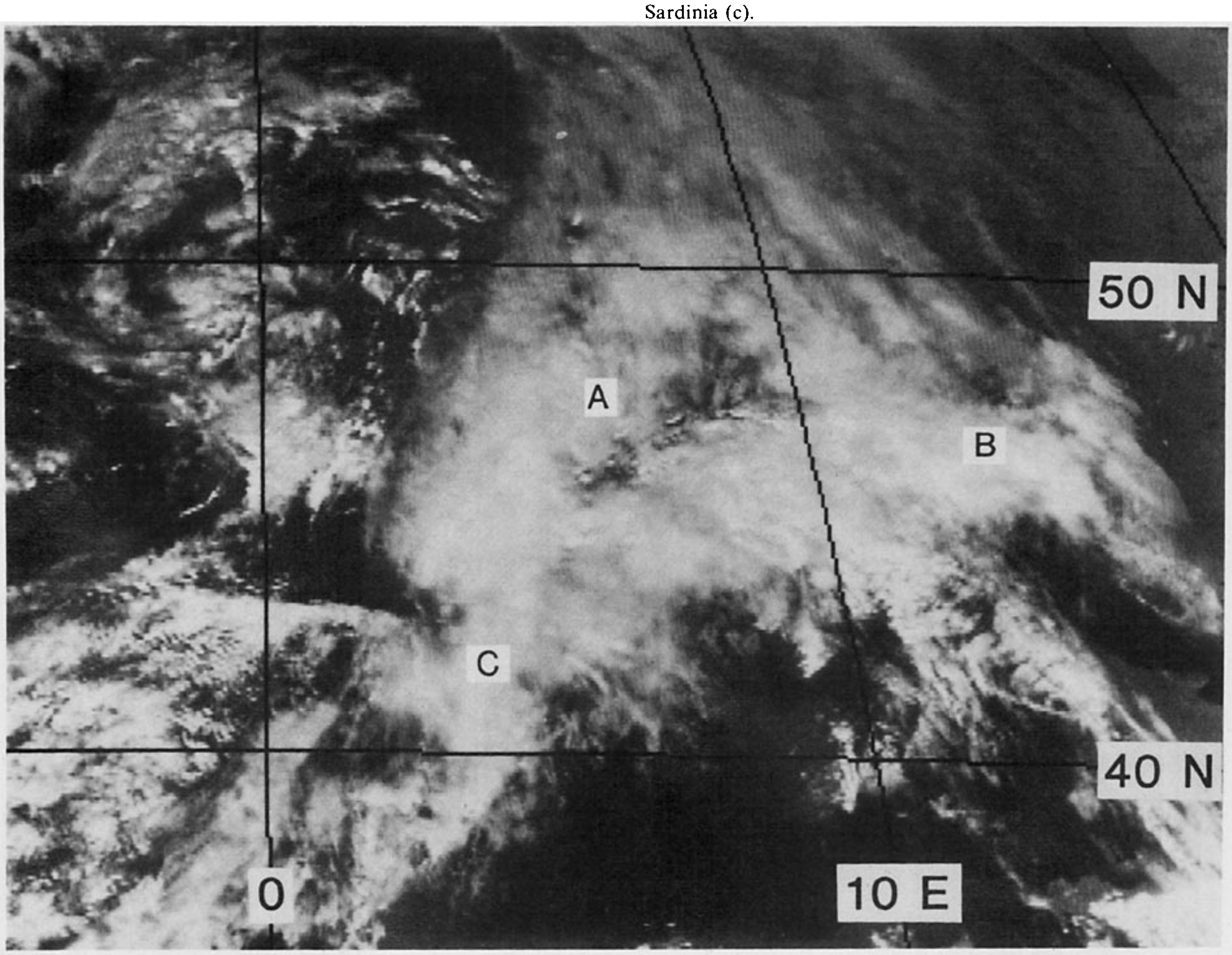


FIG. 11. *METEOSAT* imagery on 1200 GMT 8 November 1982 (visible). Switzerland, Salzberg (SAL, Fig. 1), and the Pyrenees are indicated by A, B, and C respectively.

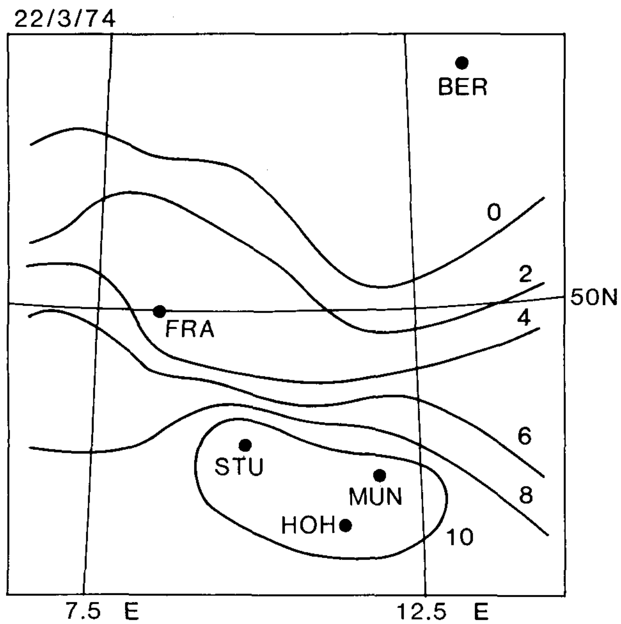


FIG. 12. Duration of sunshine in hours on 23 March 1974. The northern baseline of the Alps is in the center between HOH and the bottom of the figure. BER stands for Berlin. The abbreviations are defined in Fig. 1.

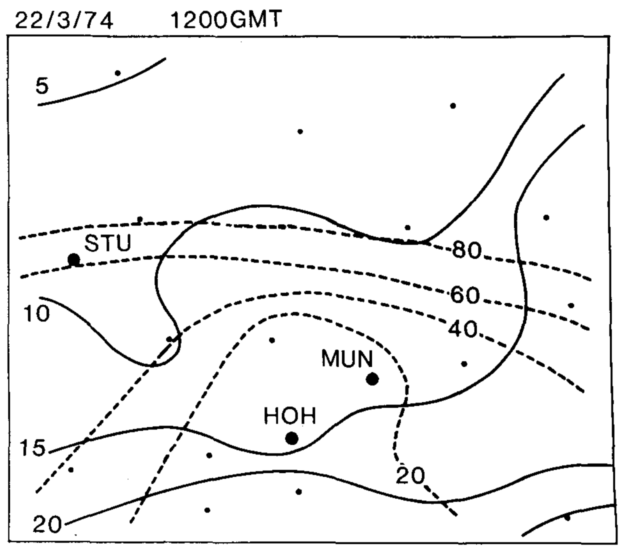


FIG. 13. Dewpoint temperature differences in °C (full lines) and cloud cover in percent (broken lines) on 1200 GMT 22 March 1974. The dots indicate observing stations.

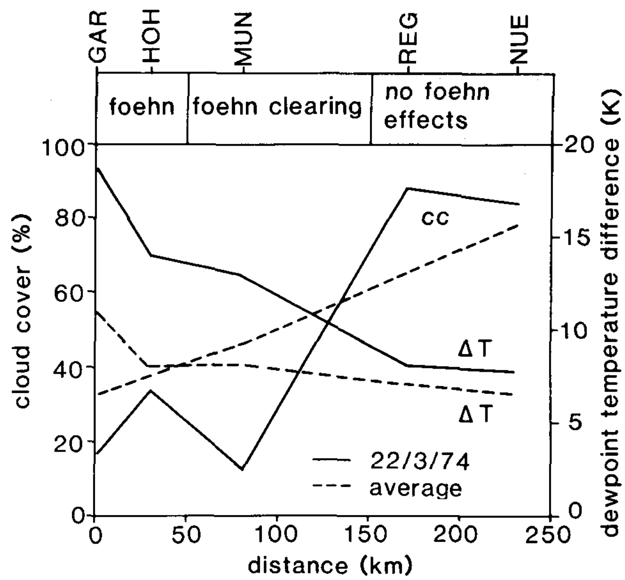


FIG. 14. Cloud cover (cc) and dewpoint temperature differences ($\Delta T$) as functions of the distance from the baseline of the Alps. The abbreviations are defined in Fig. 1.

Above and south of the Alps there are low- and high-level clouds. North of the Alps close to Switzerland there is a gap of clouds (A). A similar cloud gap can be seen above Salzburg (B). Above the eastern edge of the Pyrenees there is a similar cloud gap in triangular form (C). To the north of the Pyrenees we find an area with foehn clearance effects about 60 km away from the mountain.

## 4. Mesoscale features of foehn clearance

In the case of strong cross-mountain flow downslope winds occur together with significant heating at the leeside of the barrier. There are three possible causes for this heating: first, a "thermodynamic" one due to moist adiabatic lifting with precipitation on the windward side and a dry adiabatic subsiding of the air on the leeside; second, a kind of "dynamical" heating where potentially warmer air is transported downward on the leeside, eroding a cold surface layer; third, the possible advection of air from warmer regions to colder ones, which may be termed "advective" heating. An important cause of heating during foehn-type chinook is the dynamical one. The thermodynamical one is important too, because the approaching air mass deposits most of its moisture on the coastal ranges between California and Washington. Advection of cold air may play an important role in producing the bora-type chinook. All three mechanisms are important for the airflow over the Alps. The advective mechanism is of particular importance because the Alps are oriented roughly west to east and therefore act as a climatic divide (Fliri, 1974).

The increase in temperature leads to decreases in relative humidity, and the dewpoint temperature difference increases significantly. This in turn is linked with a decrease in cloudiness. Fig. 12 shows the sunshine duration in hours in areas north of the Alps during a day with foehn clearance. The maximum sunshine duration is located close to the Alps up to a distance of 150 km from the baseline of the Alps. In Fig. 13 the dewpoint temperature differences (full lines) and the cloudiness (broken lines) are displayed for 1200 GMT. Note the smaller scale of the figure. It can be seen that the isopleths of the dewpoint temperature differences are almost parallel to the Alps. A tongue of very low cloudiness was observed up to 100 km away from the Alps on this day.

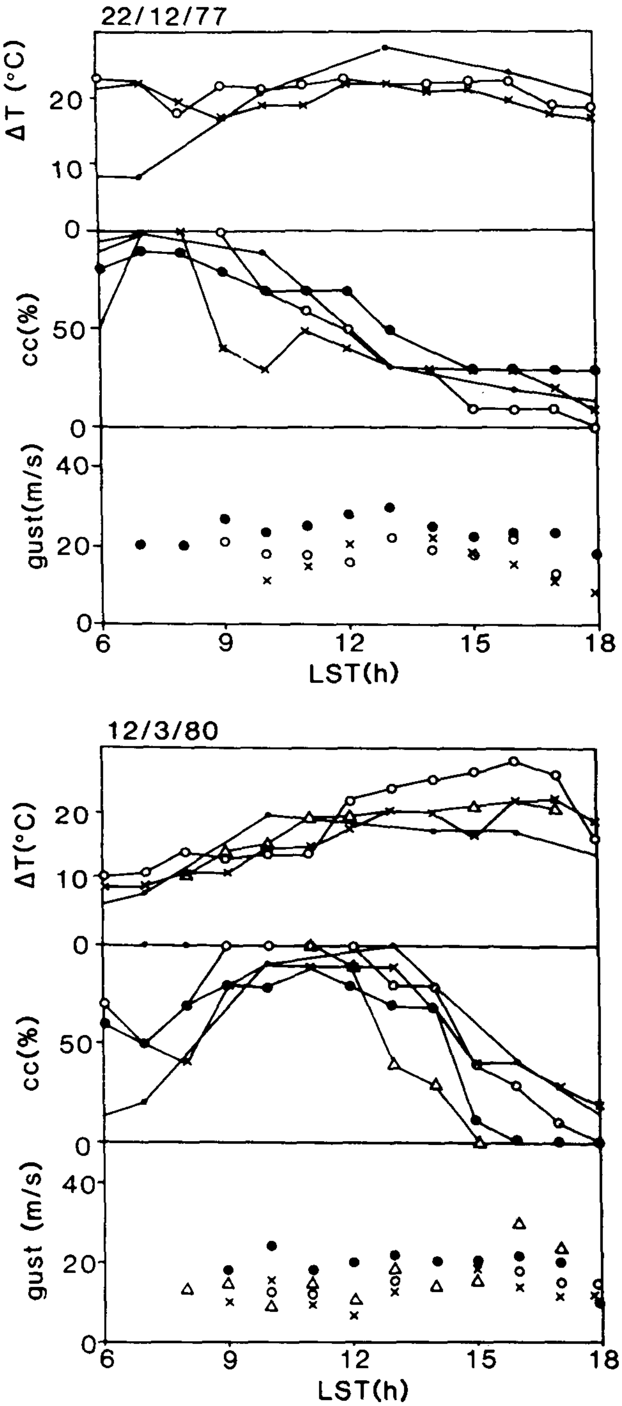


FIG. 15. The temporal evolution of maximum gusts, cloud cover (cc) and dewpoint temperature differences for various locations in Colorado on two days with chinook in Boulder. The locations are: Boulder (crosses), Broomfield (solid circles), Denver (open circles), Buckley (triangles) and Limon (dots).

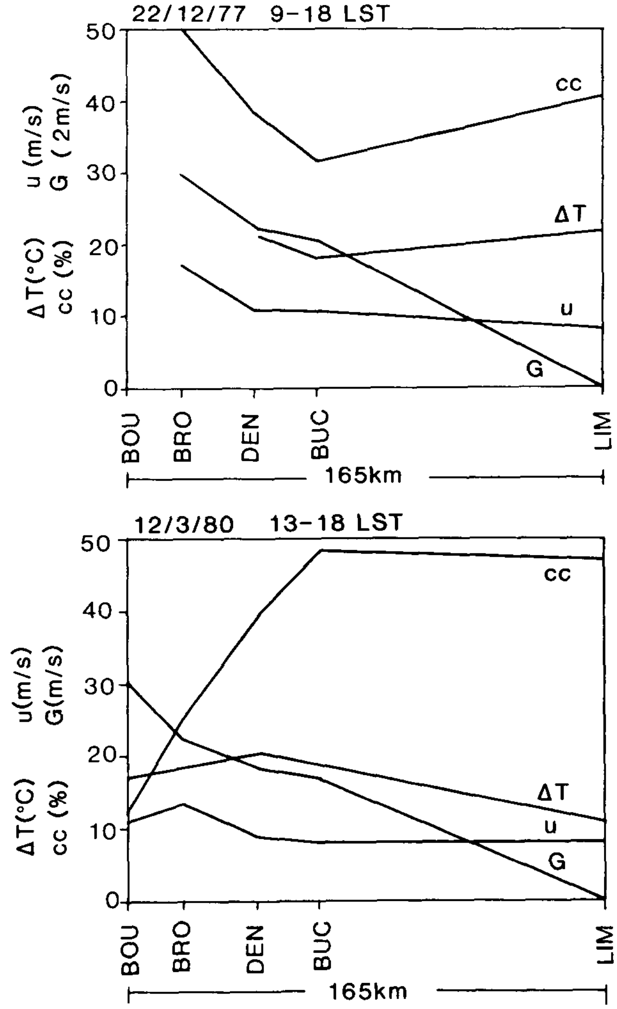


FIG. 16. Cloud cover (cc), dewpoint temperature differences ($\Delta T$), mean wind speed ($u$) and maximum gusts ($G$) as a function of the distance from the baseline of the Rocky Mountains (Boulder) on two days with chinook.

Fig. 14 shows the spatial structure of cloud cover and of dewpoint temperature difference during Alpine foehn as a function of the distance from the baseline of the Alps. The local values are obtained by averaging the observations at 900, 1200, and 1500 LST. In addition the mean distribution is shown where an average is given for twelve events. Both the increase in cloud cover and the decrease in temperature difference with increasing distance from the foothills of the Alps are quite obvious. On 22 March 1974 the foehn could be felt about 40 km away from the Alps and the foehn clearance up to 140 km from the baseline.

The temporal evolution of various parameters during two chinook events is shown in Fig. 15 as a function of distance from the mountains. In both cases the decrease in cloudiness is obvious with the onset of the chinook observed even in Limon, which is located about 170 km east of Boulder. During one event (22 December 1977) there was no significant change in dewpoint temperature, whereas during the other one (12 March 1980) an increase of up to 15°C occurs. As expected, considerable gusts were observed between Boulder and Buckley. Farther east, in Limon, no gusts were observed.

The situation locally averaged for both events is shown in Fig. 16 as a function of the distance from the baseline. The mean values are obtained by averaging the observations between 900 and 1800 LST. As expected from the satellite pictures (Figs. 5, 9) the cloudiness is below 50% and the dewpoint

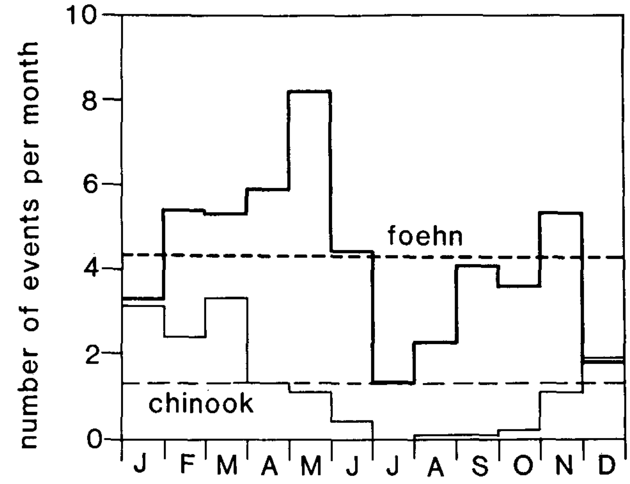


FIG. 17. The annual frequency of foehn at Innsbruck and chinook at Ft. Collins for a nine-year period, 1968–76. The broken lines stand for the annual averages.

differences are high. The maximum gusts decrease with increasing distance from the mountain whereas the mean wind remains constant.

## 5. Climatology of foehn clearance

Statistics for foehn clearance exist neither for the alpine area nor for the eastern part of the Rocky Mountains. As a first approach it would appear logical that the occurrence of strong downslope winds close to the mountain is a necessary condition for foehn clearance. However, not all these events are associated with foehn clearance in the lee. Therefore, a statistic of foehn and chinook can only be used as an upper statistical limit for the appearance of foehn clearance. In the following we compare the statistics of a sample covering nine years (1968–76) for foehn at Innsbruck with the statistics of the same period for chinook at Fort Collins (Colorado).

The weather station at Colorado State University (Ft. Collins) is located four miles east of the foothills of the Rocky Mountains. The following criteria are used to distinguish chinook from nonchinook events. Only cases with wind from 250 to 300° are taken into consideration. A sharp onset of high wind speed must be identifiable. Strongest wind and gusts have to attain 15 $m \cdot s^{-1}$; mean winds must exceed 10 $m \cdot s^{-1}$. Furthermore a significant increase in temperature as well as a decrease in relative humidity is required. For a bora-type chinook a significant decrease in temperature is required.

The annual variation of the number of chinook events shown in Fig. 17 (thin line) is similar to that given by Riehl (1972) and Julian and Julian (1969). Although downslope windstorms strike Ft. Collins most frequently in January, they have been recorded in every month except July. The large number of events during wintertime is due to the fact that this season is characterized by strong zonal flow, so-called high-index situations; in this case strong westerlies cross the north–south barrier of the Rocky Mountains leading to frequent chinooks. The mean annual frequency is 15.2 events per year. About seven of these are very strong and gusty (Riehl, 1972).

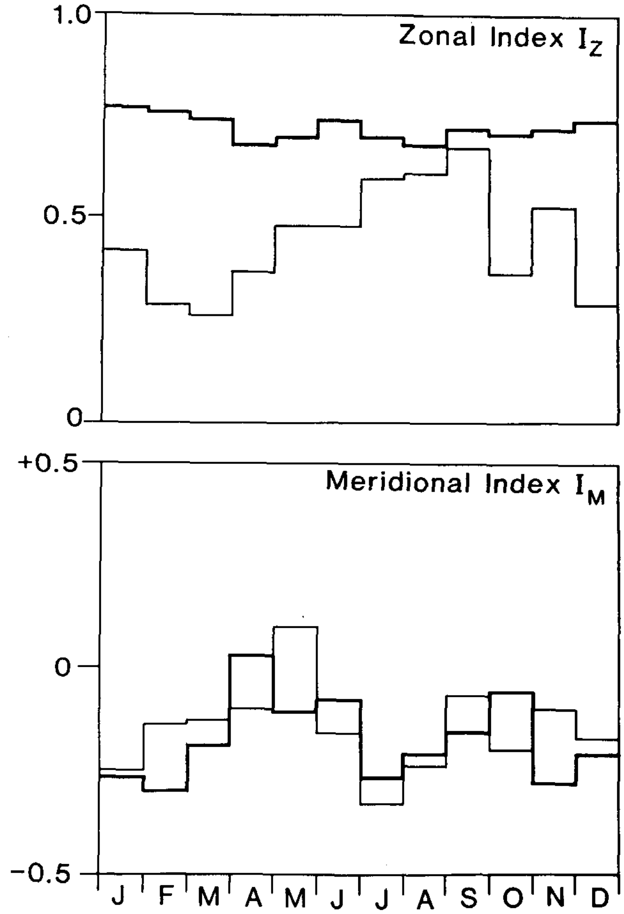


FIG. 18. The annual frequency of the zonal index $I_Z$ (top) and the meridional index $I_M$ (bottom) for a location above the Rocky Mountains at 115°W, 40°N (heavy lines) and above the Alps at 10°E, 47°N (thin lines) based on a nine-year period, 1968–76. For definition of $I_Z$ and $I_M$ see Section 5.

There are no statistics of foehn occurrence for a location close to the baseline of the Alps. However for Innsbruck, located in the northern part of the Alps, there have been foehn observations for about a century (Ekhart, 1949). The meteorological observer registers south foehn every day as weak, moderate or strong according to the violence of the foehn. Strong foehn means that there are violent winds from the south observed at ground level together with strong gustiness. Additionally increasing temperature, decreasing relative humidity and decreasing cloudiness occur along with excellent visibility and the appearance of a foehn wall above the Brenner Pass, which is the main divide of the Alps.

The number of foehn events at Innsbruck (Fig. 17, heavy lines) is large during springtime and fall. The Alps lie roughly in a west-to-east direction. Therefore, wind from southern directions is the more likely flow structure for the occurrence of south foehn at the northern edge of the Alps. A circulation pattern of this type is commonly called a *low-index* situation occurring mostly in spring and fall. The mean annual frequency of foehn events at Innsbruck is 51.1 events per year.

Generally, the mesoscale weather is forced by the large-scale circulation. A good representation of the large-scale flow might be the wind at 500 mb. To demonstrate the link

TABLE 1. Statistics (1968–1976) of observed 500-mb wind above 115°W, 40°N (chinook/nonchinook) and above 10°E, 47°N (foehn/nonfoehn). The winds $u$ and $v$ are the zonal and meridional component of the wind in m · s$^{-1}$. $I_Z$ and $I_M$ are the zonal and meridional indices. $S$ is the 95% confidence interval evaluated by $S = 1.98 \times \sigma \times (N)^{-0.5}$ with $\sigma$ the variance and $N$ the number of elements.

| Event | $N$ | $u$ (m · s$^{-1}$) | $S$ (m · s$^{-1}$) | $v$ (m · s$^{-1}$) | $S$ (m · s$^{-1}$) | $I_Z$ | $S_Z$ | $I_M$ | $S_M$ |
|---|---|---|---|---|---|---|---|---|---|
| No chinook | 3148 | 11.3 | 0.3 | −3.0 | 0.3 | 0.72 | 0.01 | −0.18 | 0.02 |
| Chinook | 137 | 16.7 | 1.3 | −3.9 | 1.5 | 0.80 | 0.05 | −0.14 | 0.09 |
| No foehn | 2825 | 6.1 | 0.3 | −3.6 | 0.3 | 0.43 | 0.02 | −0.26 | 0.02 |
| Foehn | 460 | 9.5 | 0.8 | 6.9 | 0.6 | 0.57 | 0.05 | 0.51 | 0.04 |

between mesoscale phenomena foehn and chinook and the large-scale flow structure we compare the statistics of a nine-year time series of the 500-mb wind above the Alps (10°E, 47°N) and above the Rocky Mountains (115°W, 40°N) with those of foehn and chinook occurrence (Fig. 17). The wind data have been derived from 00 GMT analysis (German Weather Service) of the observed 500-mb geopotential height fields. Using these data we calculate the annual variation of the zonal index $I_Z$ and the meridional index $I_M$ given by

$$I_M = v \times (u^2 + v^2)^{-0.5},\ I_Z = u \times (u^2 + v^2)^{-0.5}.$$

In Fig. 18 the annual variations of $I_Z$ (top) and $I_M$ (bottom) are displayed. The thin (heavy) lines show the index above the Rocky Mountains (Alps).

The $I_Z$ above the Alps are generally smaller than those above the Rocky Mountains. The magnitudes of the meridional indices $I_M$ are for both locations between zero and a third of the zonal indices $I_Z$. Above the Rocky Mountains $I_Z$ has a slight maximum during wintertime, indicating high probability of chinook events in the lee of the north–south barrier in a zonal flow. Above the Alps $I_Z$ is low in spring and October, indicating possible cross-mountain flow over a west–east barrier.

In Table 1 the climatic values of the zonal and meridional indices of two samples are given: one consists of all events with foehn or chinook and the other of events without foehn or chinook. The wind velocities are higher during the downslope wind events than when downslope wind events are not occurring. Obviously the meridional velocities change sign for foehn, indicating southerly flow across the Alps. The zonal (meridional) indices are stronger (weaker) during chinook events than without them, indicating zonal flow structure during chinook. The zonal indices during foehn are stronger than during nonfoehn situations and are associated with strong positive $I_M$, which characterizes a circulation with flow from the southwest.

## 6. Summary

In the present study we have defined the type of weather called *foehn clearance* and have compared it to strong downslope winds such as foehn or chinook. It has been shown that foehn clearance occurs in the northern lee of the Alps in southern Bavaria as well as east of Denver in Colorado.

In terms of gustiness, temperature, and humidity observed at the surface, it has been demonstrated that with increasing distance from the baseline of the mountains the gustiness drops rapidly, whereas the temperature and humidity effect is felt far beyond the areas where gusts were encountered. This foehn clearance can be clearly identified from satellite observations showing broad cloud gaps in the lee of the Alps and the Rocky Mountains.

The mean annual frequency for chinook in Ft. Collins is about 15.2 events per year. These events occur predominantly during strong zonal flow, in so-called high-index circulations. The annual distribution of chinook events is characterized by a maximum during wintertime; during this season the zonal index also has its maximum. For the Alps, which lie in a west-to-east direction, the zonal index is low in spring and autumn, indicating possible cross-mountain flow linked with foehn at the northern side. Therefore the annual distribution of foehn events at Innsbruck is characterized by a large number of such events during spring and fall. The mean annual frequency is about 51.1 events per year.

The number of events indicates that foehn, chinook, and foehn clearing might have substantial influence on the climate of the leesides of the Rocky Mountains and Alps. These influences are expressed partly through an increase in evaporation leading to a reduction or elimination of snow cover and partly through reduction of precipitation.

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## References

Beran, D. W., 1966: Large amplitude lee waves and chinook winds. Atmos. Sci. Tech. Paper No. 75, Colorado State University, Ft. Collins, Department of Atmospheric Sciences, 93 pp.

Brinkmann, W. A. R., 1971: What is a foehn? *Weather,* **26,** 230–239.

Billwiller, R., 1899: Über verschiedene Entstehungsarten und Erscheinungsformen des Föhns. *Met. Zeit.,* **16,** 204–215.

Ekhart, E., 1949: Zum Innsbrucker Föhn, *Meteor. Rdschau,* **2,** 276–280.

Fliri, F., 1974: Die Alpen als Klimascheide. *Bonner Met. Abh.,* **17,** 417–426.

Hoinka, K. P., 1980: Synoptic-scale atmospheric features and foehn. *Contr. Atmos. Phys.*, **53**, 486–507.

——, 1985: Observation of the airflow over the Alps during a foehn event. *Quart. J. Roy. Meteor. Soc.*, **111**, 199–224.

Julian, L. T., and P. R. Julian, 1969: Boulder's winds. *Weatherwise*, **22**, 108–126.

Kuettner, J. P., 1982: ALPEX, Experiment Design. GARP-ALPEX No. 1, 266 pp. [Obtainable from WMO, Case postale No. 5, CH-1211, Geneva 20, Switzerland.]

Lester, P. F., 1976: Evidence of long lee waves in southern Alberta. *Atmosphere*, **14**, 28–36.

Pichler, H., 1982: Mesoscale processes in the Alpine region. GARP-ALPEX No. 7, Preliminary results, 121–131, 266 pp. [Obtainable from WMO, Case postale No. 5, CH-1211, Geneva 20, Switzerland.]

Riehl, H., 1972: On the climatology and mechanisms of Colorado chinook winds. *Bonner Met. Abh.*, **17**, 493–504.

Thams, J. C., 1954: Die Intensität der direkten Sonnenstrahlung bei Nordföhn auf der Alpensüdseite. *Arch. Meteor. Geophys. Bioklimat. Ser. B*, **6**, 139–151.

Zipser, E. J., and A. J. Bedard, 1982: Front range windstorms revisited. *Weatherwise*, **35**, 82–85.

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