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CASE STUDIES OF TURBULENCE AND VERTICAL MOTION EXPERIENCED BY RESEARCH AIRCRAFT DURING MAP-SOP SOUTH FOEHN CASES

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1 INTRODUCTION

Innsbruck Airport is situated in a deep Alpine valley with surrounding peaks reaching up to 9500 *ft asl*. During south foehn conditions the approach and departure zones of the airport are affected by turbulence and wind shear. These are caused by lee effects, low level jets, and hydraulic jump phenomena. The purpose of the study was to identify objectively areas of strong turbulence and wind shear in contrast to calmer zones, in an attempt to provide guidance to aviation meteorologists and air crews.

The field phase of the Mesoscale Alpine Programme (MAP), undertaken in 1999, had its aircraft operations base at this airport, providing as a by-product valuable data for the approach and departure area during all MAP flight operations.

The network of surface and upper air observing platforms deployed during MAP - Special Observing Period (SOP) provided a unique opportunity to study these phenomena in hitherto unattained detail.

2 AIRCRAFT MEASUREMENTS

During MAP-SOP, which took place from 7 September to 15 November 1999, several NOAA P3 aircraft missions were flown in the Inn- and Wipptal (Fig. 1). For this investigation four P3 missions (20.10.1999, 30.10.1999 morning and afternoon flights, and 06.11.1999) were selected, which were flown during south foehn events. On these missions the P3 performed low-level flight patterns composed of vertically stacked legs along the axis of the Wipptal with turning points above the Inntal, and the village Sterzing. Supplemental data were acquired by radiosoundings released in Innsbruck and Gedeir, and a dense network of surface stations in the target area.

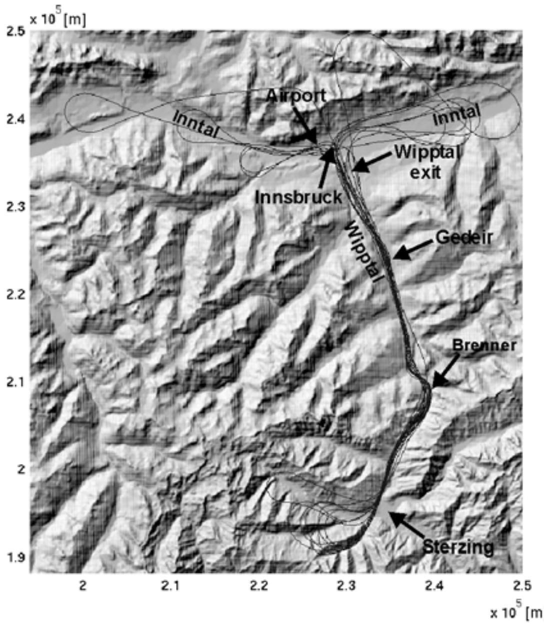

Figure 1 Terrain map of the Inn- and Wipptal target area, Austria. A typical P3 flight pattern is shown.

3 ANALYSIS METHODS

Investigations have been carried out concerning the intensity and the areal distribution of turbulence and pronounced vertical motion experienced by the P3 research aircraft. For this purpose the P3 vertical wind data, which were sampled at a frequency of 1 *Hz*, were analyzed. Plane view analyses are shown for the areal distribution and the intensity, whereas cross sectional analyses are shown for the intensity only. In case of plane view analyses a grid is overlaid to the investigation area. The data are then assigned to 500 *m* x 500 *m* grid cells.

Due to the low sampling rate of the velocity the calculation of turbulent kinetic energy is not appropriate. Therefore, the turbulence is tentatively expressed in terms of vertical acceleration, exceeding a threshold value. The acceleration is

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calculated for one second time steps from the vertical wind data. One second mean acceleration values larger than 0.2*g* and 0.1*g* are used to map the intensity and the areal distribution of turbulence, respectively, where *g* is the acceleration of gravity. As the aircraft is a moving measurement platform it can not be distinguished whether the turbulence experienced is due to local changes of the vertical wind with time or due to along-track changes of the vertical velocity. Vertical acceleration of the aircraft due to horizontal changes of head or tail wind components affecting aircraft flight are not reflected in this study.

To get a clear signal from the vertical wind data for pronounced up- or downward motion, they were low pass filtered for frequencies below 0.2 *Hz*.

4 THE FOUR CASES ANALYZED

The synoptic situations during the four P3 flight missions correspond to typical foehn cases in the central Alps. Characteristic are the pronounced southerly flow across the central Alps and the intense cross-Alpine surface pressure gradient. This gradient was highest on 20.10.1999 at about 8 *hPa*, and lowest on the morning of 30.10.1999 at about 3 *hPa*. The analyses of the south-north-component of the horizontal wind show in each case a distinct low level jet at the northern end of the Wipptal at an altitude of about 1500 *m asl*. The low level jet was strongest on 20.10.1999 with a maximum speed of 18 ms^{-1}. The radiosondes released during the four P3 flight missions at Innsbruck Airport are shown in Fig. 2. In the morning of 20.10.1999 and throughout 30.10.1999 foehn gusts were not observed at Innsbruck Airport. The radiosoundings reveal pre-foehn westerlies at low levels changing direction to southerly with pronounced shear at inversion height.

5 COMPARISON OF THE CASES

Despite the complex topography and the changing atmospheric conditions the investigations show a similar pattern of the areal distribution and the intensity of turbulence and vertical motion, which will be described in the following sections.

5.1 VERTICAL MOTION

The cases investigated reveal pronounced vertical motion with up to ±5.0 ms^{-1} on the leeward side of the Patscherkofel and Glungezer peaks (Fig. 3). No evidence of intense up- or downward motion is found on the leeward side of the Nockspitze, the peak to the west of the Wipptal exit, possibly due to sparse measurements in this area. The 9000 *ft* high mountain chain Nordkette to the north of Innsbruck blocks the southerly flow at lower levels. Within the scope of this investigation no clear-cut, stable pattern of preferred up- or downward motion is observed there, and the maximum vertical wind speeds are on the order of ±3.0 ms^{-1}. In the Wipptal distinct successive up- and downdraft zones with up to ±4.0 ms^{-1} are observed at the exits of the secondary valleys Obernbergtal and Gschnitztal (Fig. 5).

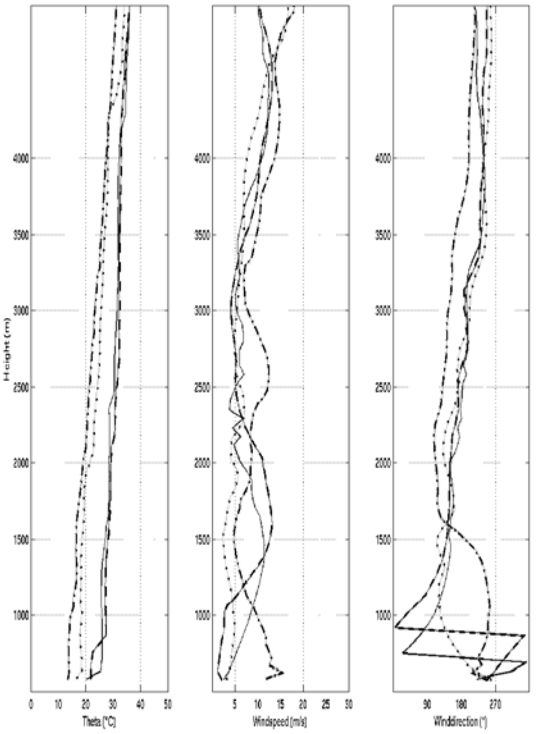

Figure 2 Radiosoundings released at Innsbruck Airport during the P3 flight missions of 20.10.1999 (···), 30.10.1999 morning flight (---), afternoon flight (—), and 06.11.1999 (-·-·-). Shown are the potential temperature θ, the horizontal wind speed, and the wind direction.

5.2 TURBULENCE MAXIMA

In the target area the maximum acceleration exceeded 0.5*g* (4.9 ms^{-2}) in several cases.

Accelerations larger than 0.3*g* (3.27 ms^{-2}) are most frequently observed at the exit of the Wipptal, and along the Inntal to the east. Especially near the Patscherkofel vertical accelerations larger than 0.5*g* (4.9 ms^{-2}) are common. In the Wipptal accelerations

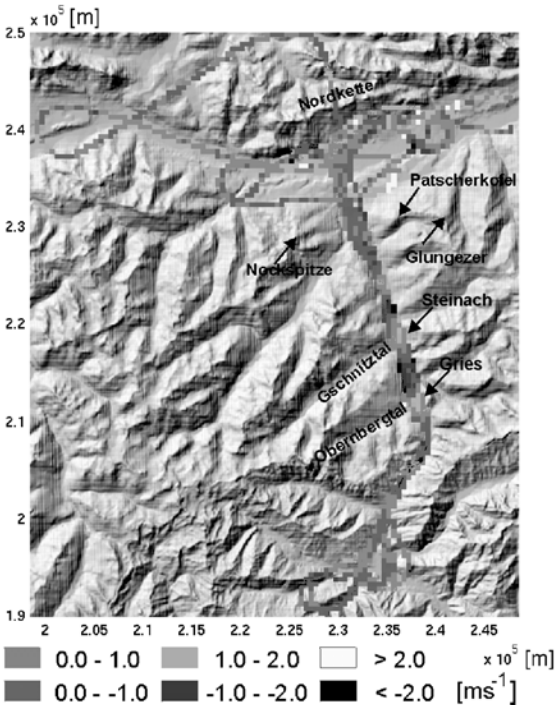

Figure 3 The vertical velocity as observed on the 30.10.1999 morning flight.

larger than $0.3g$ (3.27 ms^{-2}) are mainly detected at the exits of the Obernbergtal and the Gschnitztal, and the adjacent mountain ridges, which project into the Wipptal (Fig. 4). Another region, where accelerations larger than $0.3g$ (3.27 ms^{-2}) are frequently observed coincides with the low level jet region at the Wipptal exit area. In the Wipptal the frequency of detecting strong accelerations increases with the cross-Alpine surface pressure gradient. According to the cross-sectional analyses the turbulence occurs primarily below 2800 *m asl* (Fig. 6). That is below crest height of the surrounding mountains.

5.3 AREAL DISTRIBUTION

The areal distribution considers the frequency of turbulence encountered in a 500 *m* x 500 *m* grid cell, and thus reveals areas where turbulence is commonly observed. It is found that the observed maximum accelerations match with these areas, specifically the proximity of the Obernbergtal exit, the Gschnitztal exit, and the Wipptal exit, the lee of the Patscherkofel, and the Nordkette. Up to 70% of the measurements are classified as turbulent in the lee of the Patscherkofel, and about 40% at the other locations, with a tendency to rise as the cross-Alpine surface pressure gradient rises.

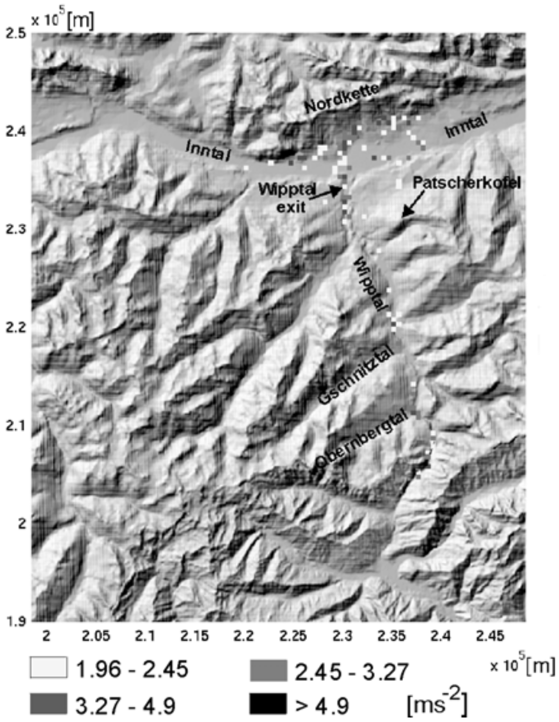

Figure 4 The maximum vertical acceleration as observed on the 30.10.1999 morning flight.

6 SUMMARY

Although the four cases presented may not be sufficient to cover all possible flow regimes in foehn conditions, it has been possible to identify areas where strong turbulence and significant up- and downdrafts are commonly found. The results presented are in good agreement with subjective pilot reports accumulated over several years, and are reflected in typical approach procedures adopted during foehn. Further measurement flight missions in the Inntal and the vicinity of the airport would help to corroborate the significance of the results. It is hoped that the extension of AMDAR platforms to short-haul aircraft would provide such data in the future.

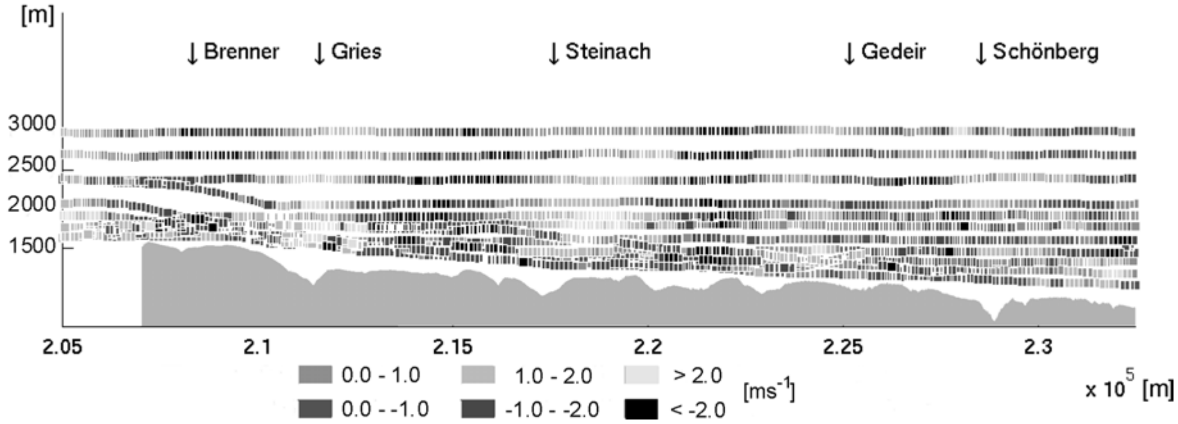

Figure 5 30.10.1999 morning flight. Wipptal cross section of the vertical velocity. Gray shading: Wipptal floor, but shifted 800 *m* to the West of the valley axis in order to better mark the side valley exits.

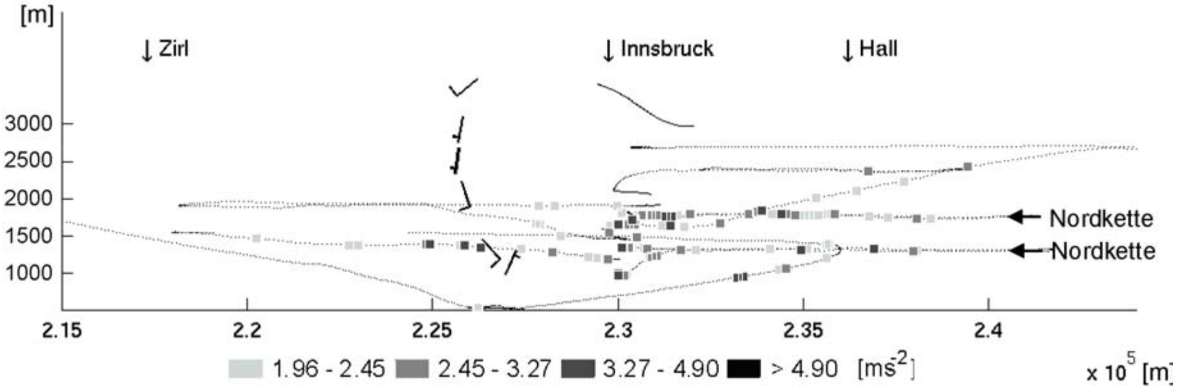

Figure 6 30.10.1999 morning flight. Inntal cross section of the maximum vertical acceleration. Black dots show the flight path. Radiosounding of Innsbruck with wind speed [ms^{-1}] and direction [°].