P1.10 ABOUT THE USE OF WIND FIELD RETRIEVALS FROM DOPPLER RADAR FOR DYNAMICAL ANALYSES OF STRATIFORM SNOWFALL

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1. INTRODUCTION

Field campaigns are currently carried out in Switzerland by the IACETH aiming at the investigation of snow particle habit, fall characteristics and growth mechanism. Baschek et al. (2002) and Schefold et al. (2002) present the concept, instrumentation and results from the field measurements at this conference (presentations 8.3 and 8.4). The vertical wind speed is an important variable for many cloud-physical processes. It influences fluxes of moisture and heat, the residence time of precipitation particles in the cloud layers and collision efficiencies. The investigation of particle mass growth by riming is a focus of the above-mentioned campaigns and the riming degree of snow particles was previously found to correlate with the cloud dynamics by Wüest et al. (2000).

It is essential to measure or estimate the vertical air motion for these cloud-physical studies. Radar is a very attractive instrument to observe clouds and precipitation at high temporal and spatial resolution and coverage, and methods exist to retrieve the three-dimensional wind field from its observations. This was recently done by Nissen et al. (2001) for winter snowfall events. However, the measured Doppler velocity is a superposition of the wind drag effect and the particles' free fall. Because vertical wind speeds in winter snow falls are usually small, i.e., of the order of the fall speeds of ice particles or even less, those two components are difficult but necessary to isolate.

In the pre-Alpine region, where the mentioned field campaigns take place, the topography certainly modifies the airflow on the lower levels, which effects propagate to the higher atmosphere. The modification is caused by lifting over hills, tunneling in valleys, blocking or differential heating on the slopes. This contribution discusses the influence of the topography and the fall speed of precipitation particles when retrieving the vertical wind from Doppler radar observations.

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2. METHODS

2.1. Topography

The wind retrieval method by Protat and Zawadzki (1999) is used for this study in an adapted form. In this algorithm, the vertical velocity w is retrieved by using the anelastic form of the continuity equation. The lower boundary condition for w is to vanish at ground level, where the ground is assumed to be flat. The horizontal divergence is calculated at each height level and integrated to estimate the vertical wind speed w on grid levels between the aforementioned levels. This staggered grid type (Figure 1) is also used in the MC2 model and allows a consistent implementation of the continuity equation with finite differences.

For the use in Switzerland or other regions with distinct topography, the lower boundary condition was modified. The wind vectors at ground level are forced to follow the topography. A data set holding topographic height information is called in for this purpose. For the Swiss topography data the vertical accuracy is 1 m and the horizontal gridding 250 m being of the order of common radar observation resolution. The topography information is transformed to the radar grid (q-points in Figure 1) by a bicubic interpolation which will smooth the original topography data slightly.

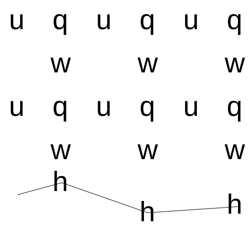

Figure 1: Vertical cross section of the numerical grid structure used. Radar observations are on q-points, u and w indicate the horizontal and vertical wind components, respectively. h-values give topographic height information.

In order to force the wind vectors to follow the topography (given with height h) the new lower boundary constraint is formulated with (1) as in Wüest et al. (1999).

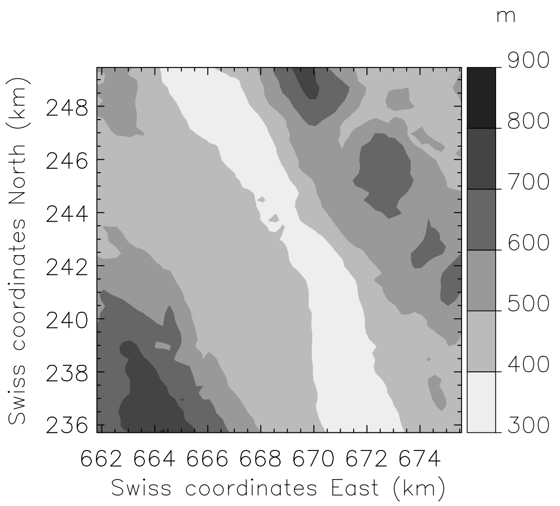

Figure 2: The topography height in m a.s.l. of the experimental region.

$$w = u\frac{\partial h}{\partial x} + v\frac{\partial h}{\partial y} \qquad (1)$$

The inclination of the ground is calculated with centered finite differences which again smoothes the topography. This smoothness is believed to be harmless or even appropriate since the 250 m grid of the topography induces discretization effect. A topography data set at significantly higher resolution than the wind field resolution should be applied in the future to better represent the essential ground height variation.

The effect of this new boundary condition is illustrated in a case study by comparing the retrieval of the wind field with a flat ground and when considering the natural topography (Figure 2). Dual-Doppler wind retrievals from the ETH Hönggerberg and the MeteoSwiss Albis radar (14 km south) are carried out and compared in Section 3.1.

2.2. Fall velocity

Since non-horizontal Doppler velocities v_r of precipitation particles are a superposition of the air speed *(u,v,w)* and the fall velocity v_t, the latter variable must be considered in the assimilation of the wind field to the radar data. In (2), φ and θ are the azimuth and elevation angle of the radar observation, respectively.

$$v_r = u\cos(\phi)\cos(\theta) + v\sin(\phi)\sin(\theta) + (w + v_t)\sin(\theta) \qquad (2)$$

The fall velocity is usually parameterized by the terminal fall speed of precipitation particles. For rain, the fall velocity as a function of drop diameter can be reliably expressed with an exponential function by Gunn and Kinzer (1949). Joss and Waldvogel (1970) found a relationship between reflectivity and the Doppler fall speed which we use in the wind retrieval technique. The fall speed of rain drops reaches a maximum value of approximately 10 m/s. For snow the fall speed is dependent not only on particle size, but also on its habit, density and hence riming degree. Typical fall speeds for unrimed snow crystals and flakes are < 1.5 m/s (Locatelli and Hobbs 1974). Often in wind field retrievals from snow falls, the fall speed of snow is held constant for a given area and height level because no more accurate information is available.

This dependency of the fall speed on particle type complicates the parameterization of v_t with reflectivity. From common horizontally scanning radars it is feasible to distinguish between liquid and solid state of water by the identification of the bright band, however, the identification of the particle type is not yet a common operational task. Particle identification with dual-polarization radars provides new means to do so. The effect of a dubious estimation of the fall velocity is investigated in the next section by varying the fall speed in a case study. Wind retrievals in the same domain as the experiments from Section 2.1 are carried out using a v_t of 0.5 m/s, 1.5 m/s and values parameterized with the reflectivity η as in Joss and Waldvogel (1970):

$$v_t = -2.6\eta^{0.107}\left(\frac{\rho_0}{\rho}\right)^{0.4} \qquad (3)$$

ρ_0/ρ is the normalized density for a given height level causing an increase of the terminal fall speed with height.

Given (2), the definition of the horizontal divergence in

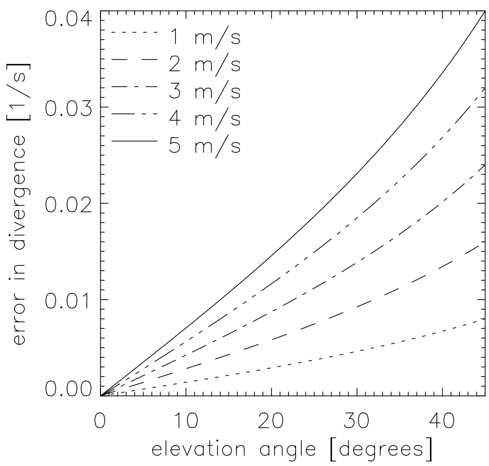

Figure 3: Expected errors in the horizontal divergence for uncertainties in the fall speed of precipitation particles from 1 to 5 m/s (legend).

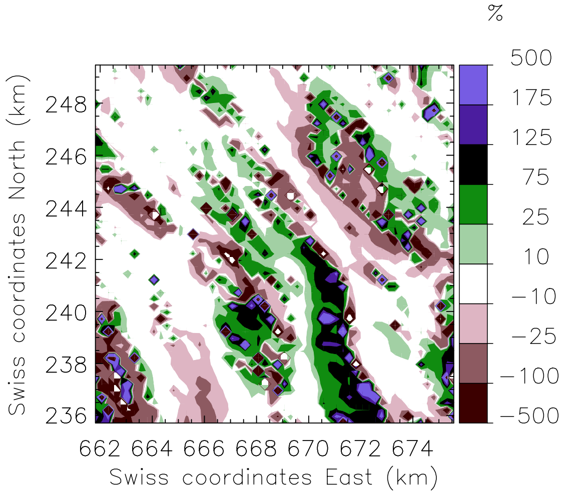

Figure 4: Relative importance of divergent vertical velocity component to the one induced by the topography.

a discrete form, and approximating the horizontal wind components *u,v* with the radial velocity observations ($u=v_r \cos^{-1}(\theta)$, $v=0$), the expected error Δdiv in the horizontal divergence can be theoretically estimated as in (4). This is a purely geometric consideration, i.e., sampling uncertainties are not considered in this equation.

$$\Delta div = \frac{2}{\Delta x}\frac{\sin\theta}{\cos\theta}\Delta v_t \qquad (4)$$

The result is plotted in Figure 3 for uncertainties in the fall velocity of 1 to 5 m/s (see legend). A value of 0.02 s^{-1} would indicate a change of velocity of 20 m/s over a distance of 1 km, which is plausible in nature. In any case, the precipitation type and fall speed needs to be well parameterized or measured.

2.3. *Case study data*

The aforementioned experiments are carried out in a case study of a winter snow fall in the pre-alpine region of Switzerland near Zürich (in the dual-Doppler region of the two radars) at 1202 UTC on 6 February 2002. The topography is glacier-formed with NNW aligned ridges and heights range from 350 to 878 m a.s.l. (Figure 2). The retrieval domain is 15 km x 15 km wide with a horizontal resolution of 250 m. Nine levels from 1 km to 5 km a.s.l. are used whereon the radar data is transformed using a distance- and gradient-weighted interpolation technique.

3. RESULTS

3.1. *Influence of topography*

Figure 4 compares the vertical velocity w_{flat} retrieved with a flattened topography to the one retrieved considering the given topography and the corresponding lower boundary condition (w_{topo}). Contours of w_{flat}/w_{topo} are plotted. Comparing the contours to the topography pattern in Figure 2 we note large deviations of the two models where the ground is inclined. The mean value of this distribution is 19% with a standard deviation of 730%. I.e., the influence of the well expressed topography is by far stronger than divergence effects at the low altitude levels. Considering the generally low and shallow precipitating clouds and the stratiform character of the winter snow falls, an accurate representation of the topography and its influence is highly important.

3.2. *Influence of the fall velocity of precipitation*

Pretending that the precipitation type of the 6 February 2002 event is a rainfall and using the relationship of Joss and Waldvogel (1970) to determine the pulse volume characteristic fall speed of rain drops, v_t takes on variable values distributed with 4.8 m/s mean value and a standard deviation of 0.5 m/s. The comparison of the horizontal divergence from a wind field retrieval using these fall speed values and a constant value of 0.5 m/s lead to the differences contoured in Figure 5. It is evident that the highest differences are in the vicinity of the radar antenna (coordinates 678.9/251.3 km) since the elevation angle relative to the antenna is steepest there (10.6° compared to a minimum of 2.3° in the

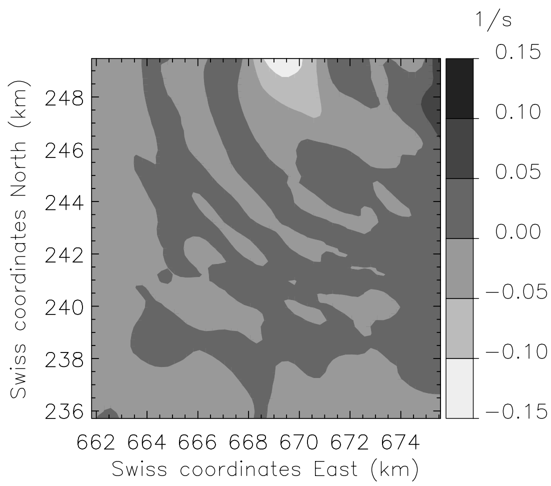

Figure 5: Difference in horizontal divergence (in units of 1000/s) between a retrieval with constant fall speed of 0.5 m/s and one with parameterized fall speed for rain.

domain on this height level). The mean difference is -0.003 s^{-1}.

Regarding the mean divergence of the investigated wind field of 0.13 s^{-1} and 0.24 s^{-1} standard deviation, the differences in the divergence accounted by improper estimation of the fall speed are negligible. The ring structures detectable from Figure 5 appear to be centered at the radar antenna and caused numerically due to the proximity (high elevation angles) to the radar.

4. CONCLUSIONS

The results of the experiments in hand emphasize that an appropriate representation and consideration of the topography needs to be aimed at for wind field retrievals from radar observations. Appropriate means that in regard of the model grid resolution the significant wavelengths and amplitudes of the topography variation need to influence the lower boundary condition. A coordinate system following the topography might help to reliably retrieve the vertical wind field. Only a part of the possible effects of the topography on the airflow - some of which were mentioned in Section 1 – are currently considered in the wind retrieval technique and would need to be modeled in the future.

The fall velocity of precipitation has direct (through the radial velocity assimilation) and indirect (through the divergence/continuity equation) effect on the vertical wind velocity retrieval. For reliable analyses of precipitation systems, good knowledge of the fall speed is required and to be integrated into the wind model. Schefold et al. (2002) present new results and instruments in this concern in this conference volume.

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