OBJECTIVE FORECASTING OF FOEHN FOR THE SUBGRID SCALE WIPP VALLEY

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Abstract: This study provides a method for an objective, probabilistic forecast of foehn based on the operational global model of the European Centre for Medium-Range Weather Forecast (ECMWF). Foehn strongly depends on topographical features, which are not yet resolved in operational global models. Therefore the proxi-parameters *vertical difference of potential temperature* $\Delta\theta$, *cross-barrier pressure difference* Δp, and *downstream wind* $\boldsymbol{v}$, derived from the well investigated foehn dynamics are studied for their suitability as foehn predictors. Testing them for the subgrid scale Wipp Valley, $\Delta\theta$ and Δp yielded better results than $\boldsymbol{v}$. Further improvement could be achieved by combining $\Delta\theta$ and Δp to joint predictors, with a strongly increasing foehn probability for increasing Δp and decreasing $\Delta\theta$.

Keywords *- foehn, forecasting, MAP*

1. INTRODUCTION

Extensive investigations spanning nearly one and a half centuries (e.g. Hann 1866, Ficker 1931, Seibert 1990, Bougeault 2001, Gohm and Mayr 2004) have clarified the mechanisms leading to foehn. This *'wind (which is) warmed and dried by descent, in general on the lee side of a mountain'* (WMO 1992), is a small scale (meso- γ) phenomenon, which strongly depends on topographical features (e.g. Lilly and Klemp 1979, Weissmann et al. 2004, Mayr et al. 2004).

Nevertheless, to the authors' knowledge, (almost) no reviewed literature concerning the objective prediction of foehn exists. Widmer (1966) developed a forecast scheme to predict (south) foehn in Altdorf (Switzerland) in the context of his doctoral dissertation. It was simplified by Courvoisier and Gutermann (1971) for the operational forecast at the Swiss Met Service. Originally, the method was based on observations in order to predict foehn in a deterministic way for the following two days. Since 1971 it has been based on model forecasts of the gradients of the geopotential height in 500 and 850 hPa across the Alps. Forecasting studies of foehn winds in the Rocky Mountains and the Appalachians rather target the prediction of damaging wind gusts in connection with downslope windstorms instead of the onset and demise of such a storm (e.g. Oard 1993, Schultz and Doswell 2000, Colle and Mass 1998, Manuel and Keighton 2003).

Our study strives for an objective, probabilistic prediction of foehn based on forecast data of a global, operational model for numerical weather prediction (NWP). Due to the poor topographical resolution a windstorm is usually not present directly so that suitable model proxy diagnostics and predictors had to be determined. These predictors were tested and verified for the Tyrolean Wipp Valley in the central Alps.

The next section explains the general method for the objective detection of foehn from observations and the derivation of suitable model diagnostics and predictors. In section 3 the objective forecasting of foehn is demonstrated for the prediction of south foehn in the Wipp Valley. Section 4 gives a conclusion.

2. FOEHN DIAGNOSTICS

An objective method to detect actual foehn periods from weather station observations is based on the wind and the conservation of the potential temperature θ in an adiabatic environment (Vergeiner 2004).

The effects of the foehn flow on the mesoscale can be derived from results of theoretical studies of numerical simulations (e.g. Long 1953, Clark and Peltier 1977, Smith 1985). The deflection of streamlines by gravity waves causes a thermal and thus a pressure disturbance (Smith 1990). The latter is positive with an upward displacement of the streamlines and negative with a downward displacement, respectively. Due to ascending streamlines (isentropes) at the upstream side and descending streamlines at the downstream side of a mountain, gravity waves either produce or, if pre-existing, amplify a cross-barrier pressure difference (and thus a pressure drag). The latter in turn controls the acceleration of the flow. As wave breaking aloft highly intensifies the downstream pressure drop, severe downslope windstorms may be induced (Clark et al. 1994).
This 'fingerprint' of a foehn inducing cross-barrier flow over model orography can be found in the cross-barrier pressure gradient Δp, the descent of isentropes with increasing potential temperature along the surface as air from aloft is mixed down indicated by the vertical difference $\Delta\theta$, and the downstream wind field $\boldsymbol{v}$. While the basic pattern of the fingerprint is the same at all foehn locations over the globe, the details are shaped by the underlying topography. We therefore want to apply the general principles to the concrete setting of south foehn in the Tyrolean Wipp Valley.

3. OBJECTIVE FORECASTING OF SOUTH FOEHN: THE EXAMPLE OF THE CENTRAL ALPINE WIPP VALLEY

3.1 Forecast region and data

The Wipp Valley in the central European Alps with its complex topographical structure frequently experiences south foehn (approx. 19 % relative foehn duration for the investigated period at Ellbögen). However, it is poorly represented by the ECMWF topography (fig.1, left).
Ten minute averages from automatic weather stations were used for determining when foehn occurred in the three years April 2001 to March 2004. ECMWF-T511 analysis and forecast data of 00 UTC and 12 UTC run of lead-times from +24 to +120 hours were used. The vertical (60 levels) and horizontal (approx. 40 km) grid mesh are constant for the whole period. $\boldsymbol{v}$ is taken from the first grid point downstream (north) of the model's crest, Δp between the first upstream (south) and first downstream (north) grid point, and $\Delta\theta$ is taken from the downstream descending model level 55 between the crest and the first downstream grid point (fig.1, right).

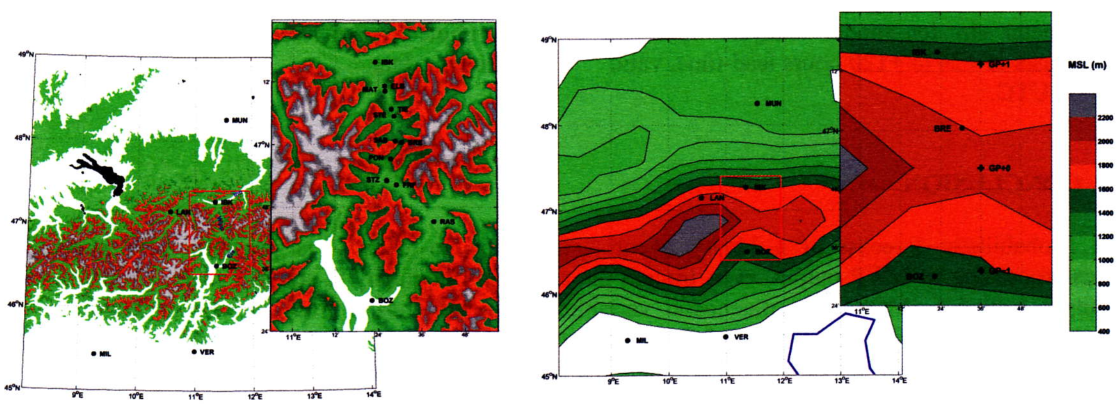

Figure 1: Actual (left) and ECMWF-model (right) topography of the Alps, with close-up of the investigated area. Big section: Central Alps with the cities Munich (MUC), Innsbruck (IBK), Landeck (LAN), Bozen (BOZ), Milano (MIL), and Verona (VER).

3.2 Results

On the basis of the actual foehn periods, model data of the proposed foehn diagnostic parameters ($\Delta\theta$, Δp, and $\mathbf{v}$) were divided into *foehn* and *no-foehn* members. How well a parameter can identify foehn can be seen by the steepness of its probability curve (fig.2). The range of the diagnostic foehn parameter was divided into discrete intervals, for which the individual probability was computed. The ideal result to get 0% and 100% at the ends of the curve is nearly reached with the model analysis data for all of the three parameters. With increasing lead-time, there is an increasing forecast uncertainty expressed by a decrease in the maximum probability reached as well as an increase of the minimum probability. Overall, Δp is the parameter that yielded the best results for the prediction of foehn.
The disadvantage of the method to predict foehn along the described way above, is that the probability can differ for the different parameters, so that for a situation with given values of $\Delta\theta$, Δp, and $\mathbf{v}$ there are three different probabilities of foehn. Therefore $\Delta\theta$ and Δp were combined to give a joint probability ($\mathbf{v}$ was not used as it is connected with Δp due to Bernoulli). For increasing Δp and decreasing $\Delta\theta$, there is a strong increase of the foehn probability (fig.3). This is valid for analysis and forecast data. Furthermore, for a fixed value of one parameter, the foehn probability can run through several classes of the joint probability when the second parameter changes. Using the joint probability is a clear improvement over the single diagnostics.

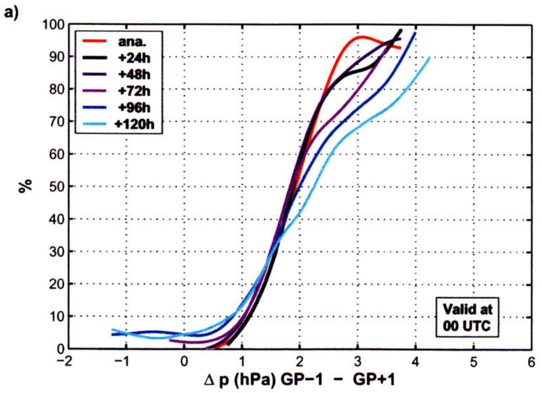

Figure 2: Probability of foehn (%) with the parameter Δp for model analysis data and forecasts of +24 to +120 hours lead-time, valid at 00 UTC.

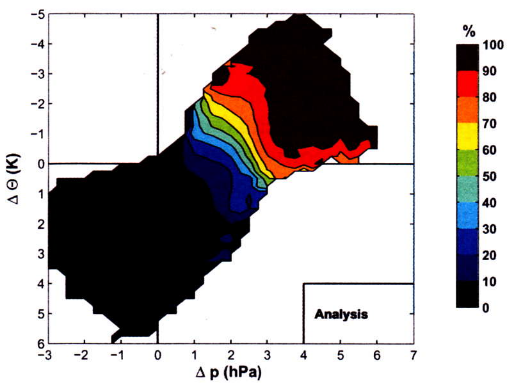

Figure 3: Probability of foehn (%) with the combined parameters $\Delta\theta$ and Δp for model analysis data.

4. CONCLUSION

A probabilistic forecast of a binary event – foehn or no-foehn – is possible from statistical postprocessing of NWP output, even though the relevant topography is subgrid scale. Unlike model output statistics (MOS), the diagnostic variables were not chosen from dozens or hundreds of possibilities. Instead, two features of foehn that are its larger-scale 'fingerprints' were exploited: the pressure decrease downstream of the crest and the descent of the isentropes.
While the diagnosis of foehn with the joint probability from these two parameters using the model analysis field is not perfect, the skill of the forecast using ECMWF-T511 decreases little out to 3 days before the event.
The forecasting method is assumed to be general enough to be applied to regions of foehn/downslope windstorms all over the globe provided measurements exist that allow an objective diagnosis of foehn.

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