Proceedings of ERAD (2004): 502–508 © Copernicus GmbH 2004

ERAD 2004

# Weather situation-dependent stratification of radar-based precipitation verification of the Alpine Model (aLMo)

**A. M. Rossa, M. Arpagaus, and E. Zala**

MeteoSwiss, Krähbühlstrasse 58, 8044 Zürich, Switzerland

**Abstract.** The Alpine Model's (aLMo) quantitative precipitation forecasts (QPFs) are compared with composited quantitative precipitation estimates (QPEs) as observed by the Swiss Radar Network (SRN). The advantage of spatially continuous QPEs and a weather situation-dependent statification based on the Schüepp weather classification combine to document and highlight the geographical distribution of QPF strengths and weaknesses of the aLMo.

For the two climatic years 2001 and 2002, i.e. 1 December 2000 to 30 November 2002, the well known overall wet bias of the aLMo has been confirmed and regionalized. A significant dependency of the aLMo QPF performance on the weather situations emerges and is documented. For the two classes "high" and "low" the QPF error differences are set in relation to errors in other model variables as detected in the aLMo upper-air verification. Moreover, the aLMo QPF quality for the forecasting region on the southern side of the Alps is found to be significantly lower than for the northern Alpine region.

## 1 Introduction

Present-day operational numerical weather prediction (NWP) models' mesh sizes are of the order of 10 km and allow to resolve meso-$\beta$-scale flow phenomena. Next generation NWP capabilities will exploit models with mesh sizes of the order of 1 km and thus addressing the meso-$\gamma$ scale. Neither of these scales are adequatly resolved by traditional observing networks based on surface and upper-air stations. Meteorological radars, on the other hand, offer quantitative precipitation estimates (QPE) and radial Doppler winds with high spatial and temporal resolution, the former hence providing a means for judging the model's simulated mesoscale structures in the quantitative precipitation forecast (QPF) fields.

Radars are not widely used for NWP model verification. Goeber and Milton (2002) have presented verification analyses of the UK Met Office's mesoscale model with their radar network to document the areal performance of the model's QPFs. Also, coordinated efforts are underway in COST-717's ("use of radar observations in hydrological and NWP models", see e.g. Rossa, 2000) WG-2 to enhance exploitation of radar data in this area. Clearly, such application places a demand on the quality of the radar-derived QPEs, specifically on its spatial homogeneity. Improving upon its quality has been a prominent item on the agendae of radar scientists ever since the beginning of this discipline. Characterizing it in a quantitative way, however, is not a topic which has received widespread attention. COST-717 launched an effort to address the issue of radar data quality in a more systematic way (Michelson et al., 2004, this volume) which is fundamental for the application of radar data in NWP and hydrological modelling.

The limitations of monthly, seasonally, and yearly statistical verifications of numerical weather prediction (NWP) models are well known, in that their performance is judged over the whole spectrum of weather types the atmosphere can produce. The danger herewith is that it can mask differences in forecast quality when the data, even in terms of flow regimes, are not homogeneous and bias the results toward the most commonly sampled regime (for example days with no severe weather). Stratifying the samples into specific subsets helps to identify forecast behaviour. The Schüepp classification of the weather in the central European Alps (Wanner et al., 1998) is used to construct such a stratification.

This contribution seeks to illustrate the potential of radar data in high-resolution NWP model diagnostics. The Alpine Model's (aLMo) precipitation fields are compared against the Swiss Radar Network (SRN) QPEs for the two climatic years 2001 and 2002, i.e. 1 December 2000 to 30 November 2002. In Sect. 2 the data set, including the weather classification is described, and in Sect. 3 the results are discussed. In the concluding section 4 a summary and a short outlook is given.

## 2 Data Sets and Methodology

### 2.1 Alpine Weather Statistics (AWS)

The Alpine Weather Statistics (AWS) introduced by Schüepp (Wanner et al. 1998) constitutes a set of 34 parameters describing many atmospheric phenomena. Five out of these

---

*Correspondence to:* A. M. Rossa
(andrea.rossa@meteoswiss.ch)

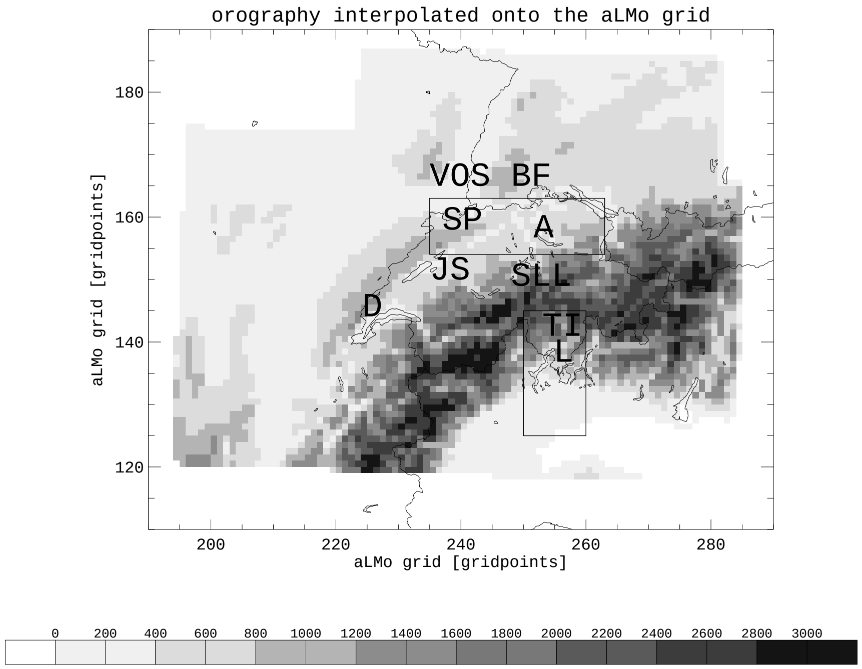

**Fig. 1.** Visibility for the Swiss Radar Network (SRN) domain interpolated onto the Alpine Model (aLMo) grid in meters above mean sea level. The visibility denotes the height of the lowermost pixel seen by the SRN at a given location. Values below 2000 m allow for good radar performance, while values above 4000 m give only poor precipitation estimates. The SRN radar locations are given by the labels 'A' for 'Albis', 'D' for 'Dole', and 'L' for 'Lema'. The other labels denote regions referred to in the text, i.e. 'BF' Northern Switzerland and Black Forest, 'VOS' Vosges, 'SP' Swiss Plateau, 'JS' Southern slopes of Jura, 'SLL' South of Lake of Lucerne, 'TI' Ticino region in southern Switzerland.

(geostrophic surface wind direction, wind speed, direction and geopotential height at 500 hPa, and baroclinicity are synthesized into the so-called Schüepp Wetterlageneinteilung (Par. 33). The Schüepp classification scheme consists of 40 different weather classes which describe the synoptic situation at 12 UTC on a daily basis with a geographical focus on the Alpine region (defined by a circular area with radius $\approx$ 220 km centred at Rheinwaldhorn in south-eastern Switzerland) and is available since 1945.

For the purpose of this study, these 40 classes have been grouped into 9 larger classes, roughly separating the different weather situations into: four advective classes *'west'* (40), *'north'* (80), *'east'* (14), and *'south'* (48), characterized by appreciable surface winds and westerly, northerly, easterly, and southerly winds at 500 hPa, respectively, three convective classes *'high'* (128), *'flat'* (253), and *'low'* (41), classified by weak surface winds and above normal, average, and below normal geopotential height on 500 hPa, a *'jet'* (109) class featuring strong winds on 500 hPa, and a *'mix'* (17) class. The number in brackets denotes the number of days in the respective class for the time period 1 December 2000 to 30 November 2002. Particular attention has to be given to gathering large enough samples to give trustworthy verification results, i.e. interpretation of verification results for classes 'east' and 'mix' is limited.

## 2.2 Swiss Radar Network (SRN)

The Swiss Radar Network (SRN) consists of three C-band Doppler radars of the same type, located on Mt. Albis, Mt. La Dole, and Mt. Lema, providing full volume information every five minutes (e.g. Joss et al., 1998 for details). For the present study composites on a cartesian grid ($2 * 2 * 2\,\mathrm{km}^3$) of best estimates of surface precipitation (product 'RAIN') are used to which a number of state-of-the-art corrections have been applied, including clutter elimination and vertical profile correction algorithms. Overall, for the period considered, it is known to systematically underestimate precipitation[1], where the underestimation is strongly dependent on the visibility of the radar (Fig. 1). The blind spots in the regions of Valais and Engadin and the scarce visibility along the main Alpine crest indicate where most care must be exercised in the interpretation of the QPEs.

To circumvent the difficulties related to the comparison of the highly variable precipitation fields only 24 hour accumulations are considered here. The SRN QPE accumulations are taken from 06 UTC to 06 UTC of the consecutive day and aggregated onto the aLMo grid. The aLMo QPFs are taken from the daily operational 00 UTC integration for the forecast range +06 h to +30 h. The overall period spans the two climatic years 2001 and 2002, i.e. 1 December 2000 to 30 November 2002, whereby for the present study only days in which rain has been detected by the Swiss raingauge network[2] were used, i.e. 571 out of the 730 days.

---

[1] efforts are underway to correct for this bias

[2] for a rain day 5 of the $\approx$450 gauges were required to report at least 0.5 mm/24 h

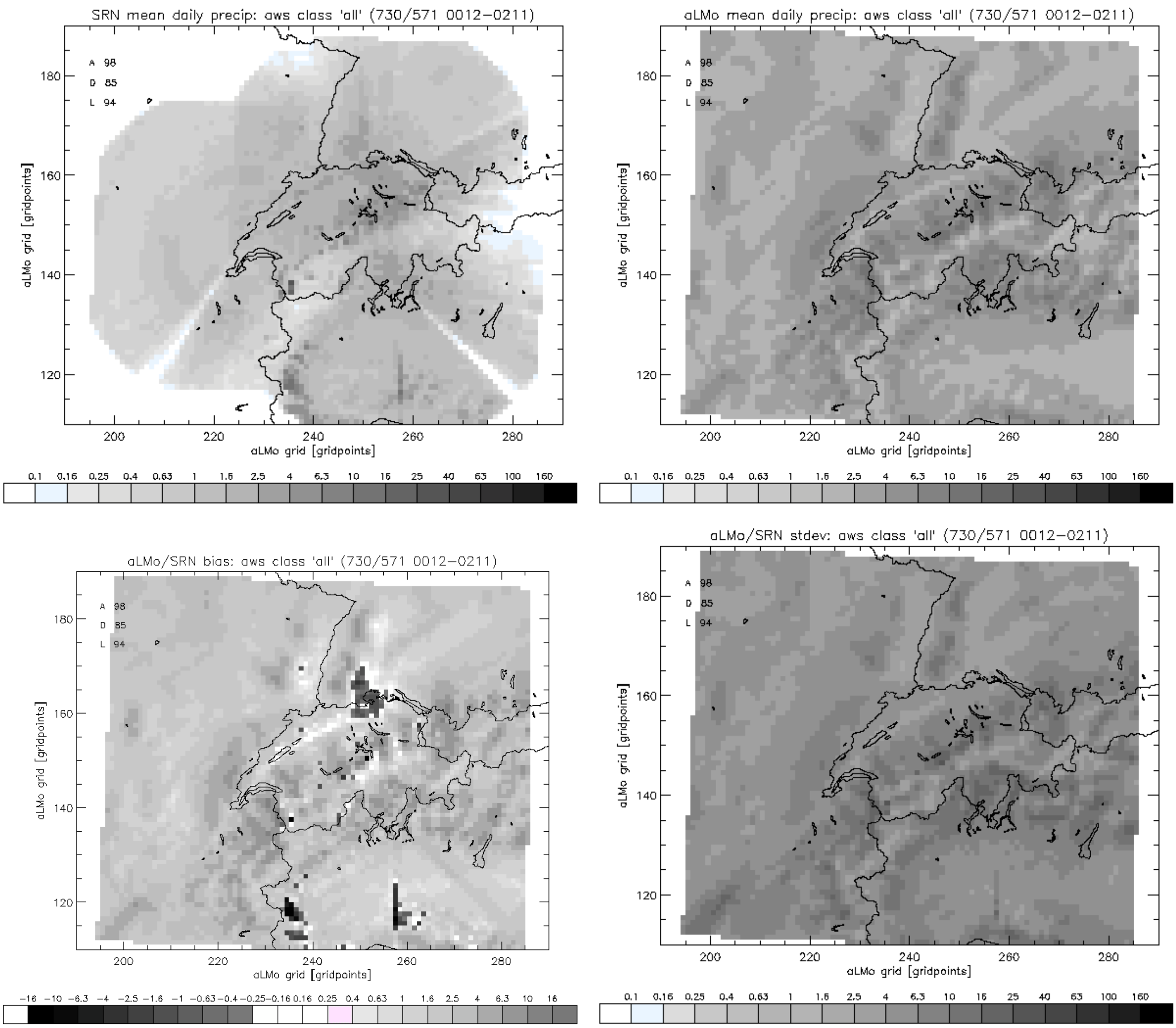

**Fig. 2.** Precipitation comparison between the Swiss Radar Network (SRN) and the Alpine Model (aLMo) for all rain days in the two climatic years 2001 and 2002 (1 December 2000 to 30 November 2002), i.e. 571 of 730 days. Upper left and right panels denote the mean SRN precipitation estimates and the corresponding mean aLMo precipitation forecasts, respectively, while the bias and the standard deviation are shown in the left and right lower panels, respectively. The units of all plots are mm/24 h, the scale is logarithmic. The small numbers in the upper left corners of the plots denote the availability in % of the three radars of the SRN, where 'A' stands for the 'Albis', 'D' for the 'Dole', and 'L' for the 'Lema' radar.

## 3 Discussion of results

### 3.1 Radar precipitation estimates

In the two year accumulation of the SRN QPE (Fig. 2), the maxima in north-eastern and southern Switzerland correspond well with the long-term precipitation climatology (Schwarb et al., 2001, not shown), as well as a minor maximum over and on the eastern flank of the Black Forest. West of it, over the Vosges ('VOS'), however, the SRN climatology does not exhibit the precipitation maximum reported by Schwarb et al., (2001). Moreover, the dry band along the Alpine crest is well described by the SRN, although these lower values may be affected by the radar's scarce visibility over much of the higher portions of the orography.

A major weakness of the SRN is found over western Switzerland and neighbouring France. While the long-term climatology clearly shows local precipitation maxima over the French Jura and the Haute Savoy the SRN reports a rather uniform field of low values. As a matter of fact, the La Dole radar had major hardware problems that caused several data gaps and enhanced systematic underestimation during the period under consideration. In this region comparison with the aLMo is not quantitatively reliable.

Finally, there are two non-meteorological features towards the southern border of the SRN domain linked to non-eliminated ground clutter on the French-Italian Alps, and an (illegal) microwave emitter in the Po Valley. These structures are excluded from the discussion.

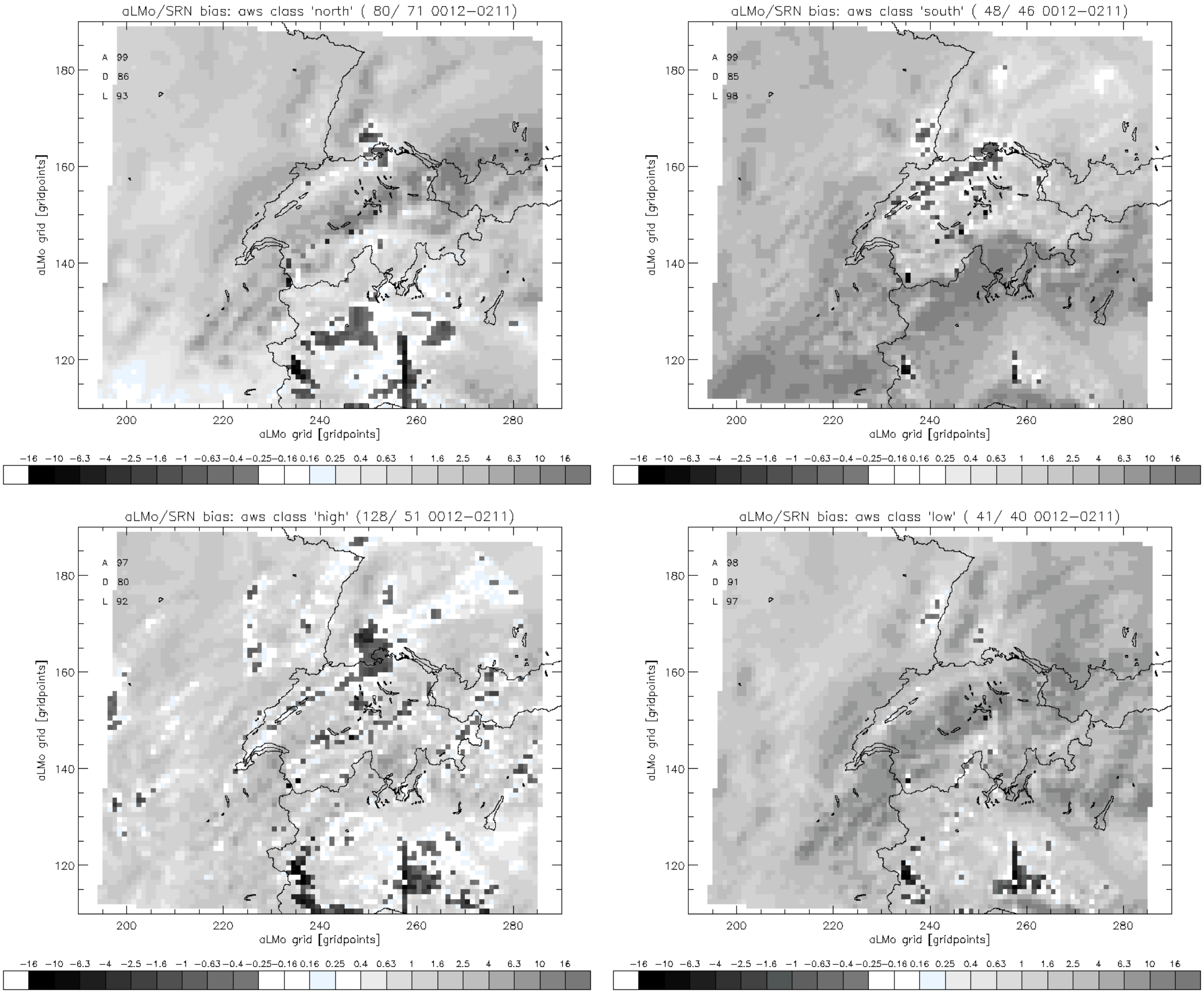

**Fig. 3.** Biases of the aLMo precipitation forecast relative to the SRN estimates for the weather classes 'north' and 'south' (upper panels) for all rain days in the two climatic years 2001 and 2002 (1 December 2000 to 30 November 2002), i.e. 71 of 80 and 46 of 48 days detected as rain days, respectively. The units are mm/24 h, the scale is a logarithmic one ranging from −16 to +16 mm/24 h. The small numbers in the upper left corners of the plots denote the availability in % of the three radars of the SRN, where 'A' stands for the 'Albis', 'D' for the 'Dole', and 'L' for the 'Lema' radar. The lower panels show biases for classes 'high' and 'low' with 51 of 128 and 40 of 41 days detected as rain days, respectively.

### 3.2 aLMo precipitation forecasts

The gross structure of the aLMo climatology does look surprisingly realistic when compared to the Schwarb et al. (2001) climatology, in that it successfully reproduces the maxima in central, north-eastern, and southern Switzerland. Also, the dry band along the Alpine crest is present. However, precipitation is substantially overestimated, by a factor of two or more when compared to the radar.

### 3.3 Features in the precipitation error climatology

The bias (Fig. 2 lower left panel) reveals that the aLMo amply overdoes the precipitation on most of the SRN domain by 3 mm/24 h on average, and locally up to 10 mm/24 h. Also, that the error variability as measured by the standard deviation is largest in areas of large precipitation featuring widespread values of 5–10 mm/24 h. For the purpose of this analysis, however, we will concentrate on the bias field keeping in mind the large variability. As a matter of fact, it exhibits a number of conspicuous mesoscale features which will be described in the following, with reference to Fig. 1. The most prominent structure is a dry bias of the order of 1 mm/24 h with locally larger values in northern Switzerland and neighbouring Germany, east of the Black Forest ('BF'), with a distinct wet bias juxtaposed to the west. This dipole, actually a double penalty, results from a systematically wrong positioning of the precipitation by the aLMo on the peaks of Black Forest in the model orography with too little of it on the eastern slopes. A similar pattern, albeit less pronounced, is evident in connection with the Vosges ('VOS'). In the region of the southern slopes of the Jura ('JS') and in central Switzerland, just south of the Lake of

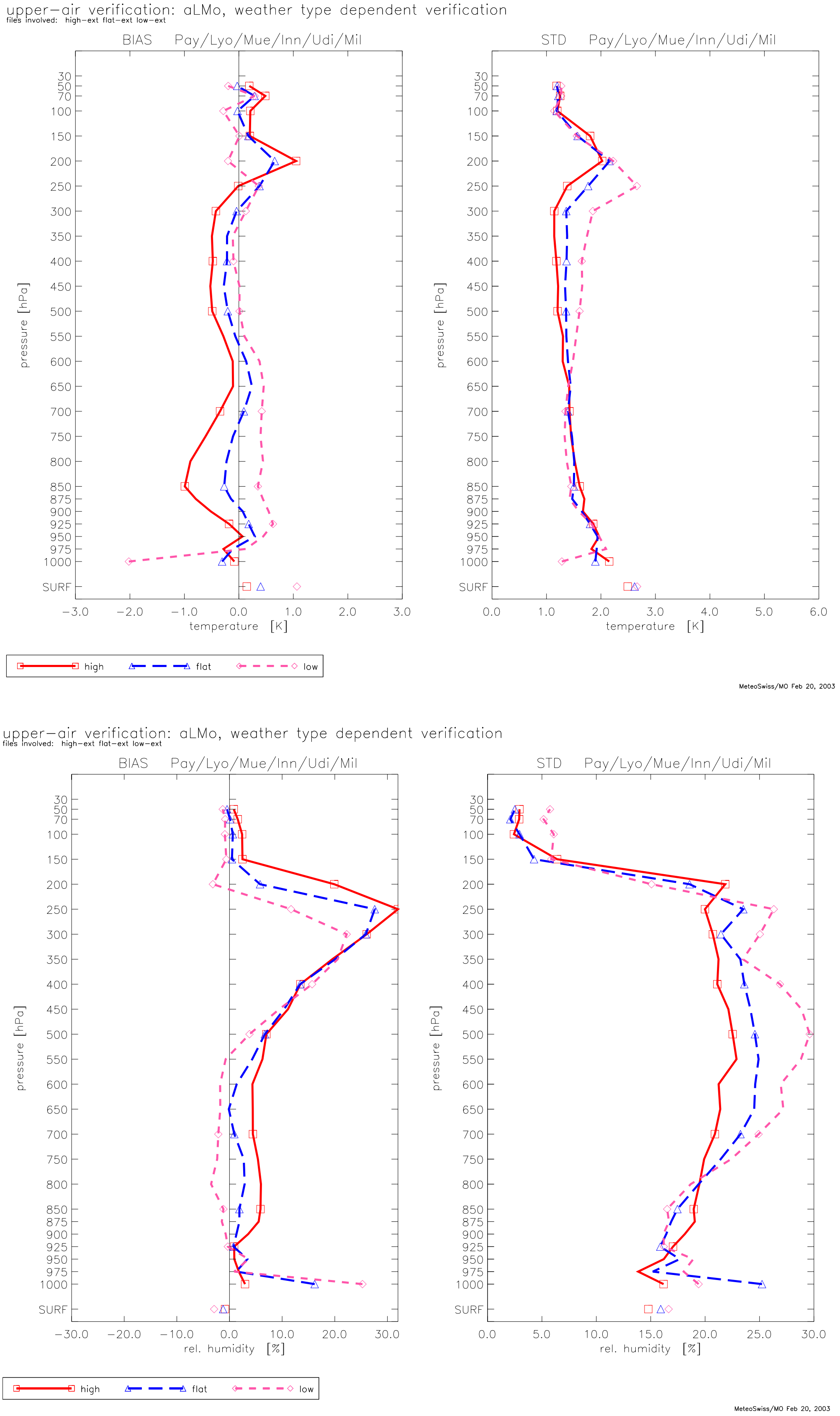

**Fig. 4.** Verification (mean error and standard deviation) of temperature and relative humidity for convective classes ’high’ (solid red), ’flat’ (blue), and ’low’ (dashed magenta) for forecast time +48 h and the climatic years 2001 and 2002 (1 December 2000 to 30 November 2002; averaged over Alpine sounding stations in Payerne, Lyon, Munich, Innsbruck, Udine, and Milano; 12 UTC verification time).

Lucerne ('SLL') the aLMo forecasts, may also be considered as relatively dry in the model.

Conversly, the aLMo features a distinct wet bias in the Ticino region ('TI') in southern Switzerland, where the SRN is reliable. More positive peaks in the bias can be seen in a sequence lining up from along the northern slopes and peaks of the Alps all across Switzerland, separated by areas of a lesser wet bias. Unfortunately, the western and easternmost portions of this structure are not reliably covered by the SRN during the period under consideration.

### 3.4 Weather situations of northerly and southerly flow

The overall orientation of the Alpine range makes the weather situations of northerly ('north') and southerly ('south') flow of special interest, particularly with respect to precipitation. The upper panels of Fig. 3 display the QPF bias fields for these two classes. For 'north' (upper left panel) the features discussed for 'all' that are located north of the Alps are retained, except for a larger amplitude of the wet bias anomalies on the northern slopes. On the southern side of the Alps, however, there is a sharp gradient in the region south of the Lake of Lucerne ('SLL'), indicating that the aLMo is not able to produce enough precipitation on the upper part of the lee slope. Half a dozen gridpoints downslope there is a moderate wet bias, whereas even more downwind in the region of the Lago Maggiore and southward into the Po Valley there is again a larger dry bias. The 71 days involved in this analysis should provide a large enough sample to document this systematic underestimation of the aLMo precipitation even over larger distances on the southern side of the Alps in northerly flow situations.

During southerly flow the model behaves somewhat congruently. Indeed, there is a large wet bias on the windward side featuring the position of the maximum at the right location, but not its amplitude (upper right panel). The crest again constitutes a firm barrier for model precipitation resulting in relatively low biases on the northern side of the Alps extending way into southern Germany, and distinct dry biases over large portions of the Swiss Plateau ('SP').

Some of these features may be explained by the model's inability to transport precipitating water and ice. The current grid-scale precipitation scheme deposits any excess moisture in the same grid-box where saturation occurs. This results in overestimation of precipitation on the windward side of the orography and a pronounced underestimation of precipitation on the lee side of any orographic obstacle (see e.g. Damrath, 2002). A prognostic precipitation scheme recently implemented into the Alpine Model (Doms et al. 2001) includes horizontal and vertical advection of hydrometeors and may alleviate some of the problems described above.

### 3.5 Link of QPF errors to errors in other model variables

'High' and 'low' weather situations are predominantly characterised by dry, fair weather and rainy weather, respectively. The aLMo QPFs perform very differently for these two classes in that the mean bias in Fig. 3 shows a quite dramatic overestimation of precipitation for weather situation 'low' (lower right panel) featuring widespread values of the order of +10 mm/24 h and a mean areal bias of 4.5 mm/24 h, in contrast to a much smaller, although positive, mean areal bias of 1.5 mm/24 h for the class 'high' (lower left panel).

In order to investigate the effects of such large bias differences on other model variables, we look at temperature and humidity profile biases and standard deviations shown in Fig. 4 for classes 'high' and 'low' at forecast time +48 h, as derived from upper air verification of the Alpine Model against radiosonde measurements. Observations from 28 stations distributed over the entire aLMo integration domain and delivering upper-air information every twelve hours, i.e. at 00 UTC and at 12 UTC, are used.

A clear warm bias throughout the lower half of the troposphere is evident for class 'low' as well as a significant cold bias up to the tropopause for class 'high', both of which are not present at analysis time (not shown). Concerning relative humidity, 'low' features a dry bias whereas 'high' shows a moist bias in a substantial portion of the troposphere[3], again both not present at analysis time (not shown). The biases seen for relative humidity could be interpreted in terms of the temperature biases, the explanation of the latter being unclear. However, referring to the large differences in the precipitation biases for classes 'high' and 'low', another interpretation is possible: The warm and dry biases documented for weather situations 'low' are consistent with the model's tendency to overestimate moist diabatic processes for this class, therefore excessively heating and drying the model atmosphere! For class 'high', the interpretation is not as straightforward. The precipitation bias for this class (Fig. 3, lower left panel) shows that the overestimation by the aLMo is much less evident than for class 'low', typically less than 2.5 mm/24 h. Indeed, there are even some pronounced areas of clear underestimation. The fact that the temperature bias for 'high' still is negative and relatively large, despite the present overestimation of precipitation, is consistent with a distinct, although smaller, global negative temperature bias in the model, which in turn may be caused by the driving model. As above, the bias in relative humidity would again be a consequence of the temperature error.

A simple estimate for the difference in latent heating throughout the troposphere[4] caused by the 3 mm/24 h excess precipitation for 'low' relative to 'high' yields a temperature difference on the order of:

$$\Delta T = \frac{\Delta m_{\mathrm{precip}} L}{m_{\mathrm{air}} c_p} = \frac{3\,\frac{\mathrm{kg}}{\mathrm{m}^2}\,2.5\cdot 10^6\,\frac{\mathrm{J}}{\mathrm{kg}}}{6\cdot 10^3\,\frac{\mathrm{kg}}{\mathrm{m}^2}\,10^3\,\frac{\mathrm{J}}{\mathrm{kg\,K}}} \approx 1.25\,\mathrm{K}. \qquad (1)$$

This is in surprisingly good agreement with the temperature bias differences between classes 'high' and 'low' (Fig. 4).

---

[3] neglect the bias of relative humidity above $\approx$ 700 hPa due to artificially increased moisture values at analysis time to compensate for the inability of the model to handle saturation with respect to ice

[4] we assume heating up to 8 km in an atmosphere with a scale height of 10 km resulting in roughly $6\cdot 10^3$ kg of air to be heated

## 4 Conclusions

A systematic weather situation-dependent comparison of quantitative precipitation forecasts (QPFs) of the Alpine Model (aLMo) with the quantitative precipitation estimates (QPEs) of the Swiss Radar Network (SRN) has been presented for the two climatic years 2001 and 2002, i.e. 1 December 2000 to 30 November 2002. Overall, the approach is able to produce weather situation-specific statements regarding the aLMo QPF performance and pinpoints a number of characteristic weaknesses. In summary, and keeping in mind the limitations of the SRN QPE, the analysis identified:

- significant differences of aLMo QPF for different weather classes;
- confirmation of the aLMo QPF overestimation and documentation of its geographical mesoscale distribution;
- a better general aLMo QPF performance for larger precipitation intensities in terms of relative mean bias and standard deviation (a stratification of the data set following the average SRN QPE intensity has been performed but is not shown here);
- consisteny of areal mean aLMo QPF error differences of 3 mm/24 h for classes ’high’ and ’low’ with a 1–1.5 K difference in the respective temperature biases as reported in the upper-air verification;
- systematically dry regions in the aLMo, best visible for class ’jet’ (not shown), the most prominent one being over the Swiss Plateau and the eastern flank of the Black Forest;
- overly wet regions, strongly accentuated in cases of intensive precipitation, mostly related to orography.

A more detailed analysis (not shown) that takes advantage of the spatial coverage of the observations reveals substantially larger aLMo QPF errors for the southern side of the Alps (region ’TI’ in Fig. 1) compared to the northern side (region ’SP’), a finding that is consistent with bench forecasters’ experience. The systematically dry and wet regions are likely to be related to incorrect description of the flow and the related production and transport of precipitation in vicinity of orography in the aLMo and may benefit from the prognostic precipitation scheme recently implemented.

The limitations of this study are related to the length of the data set not yielding large samples for every class. Moreover, the Schüepp weather classification is not specifically geared to precipitation and may, therefore, not be the optimal choice. Indeed, preliminary results using a subjective weather classification show consistent but clearer separation of weather situation-dependent aLMo QPF performance.

The quality of the SRN QPEs suffers from problems related to mountainous terrain, suboptimal performance of the La Dole radar in western Switzerland, and the relatively small domain it covers when compared to the aLMo domain. Bolliger et al. (2004, private communication) analyzed an overall underestimation in the SRN QPE of a factor of the order of 2 when compared to the Swiss high-resolution rain gauge network with strong spatial variability. A simple bulk correction of the SRN QPE would remove its overall bias but introduce significant errors which would penalize the regionalization of the aLMo QPF error analysis. Gabella et al. (2004, this volume) suggest to perform a weather situation-dependent correction using the same classification as presented here.

The aLMo domain covers a large part of central and western Europe and is considerably larger than the Swiss national radar composite. Although the present analysis remains relevant for Switzerland the aLMo QPF performance should be judged for its entire domain. This places an important request for continental-scale radar products for NWP verification, and for data assimilation.

## References

Damrath, U.: Spatial distribution of precipitation over Germany and Switzerland, COSMO Newsletter, 2, 72–74, 2002.

Doms, G., Gassmann, A., Heise, E., Raschendorfer, M., Schraff, C., and Schrodin, R.: Parameterization issues in the non-hydrostatic NWP-model LM, In: Key issues in the parameterization of subgrid physical processes, ECMWF Seminar Proceedings, 3–7 September 2001, 205–251, 2001.

Goeber, M. and Milton, S.: On the use of radar data to verify Mesoscale Model precipitation forecasts, Report of the SRNWP workshop on mesoscale verification 2001, 18–27, 2002.

Joss, J., Schaedler, B., Galli, G., Cavalli, R., Boscacci, M., Held, E., Della Bruna, G., Kappenberger, G., Nespor, V., and Spiess, R.: Operational use of radar for precipitation measurements in Switzerland, Final Report of NRP 31. vdf Hochschulverlag an der ETH Zürich, 108 pp., ISBN 3-7281-2501-6, http://vdf.ethz.ch, 1998.

Rossa, A. M.: COST-717: Use of radar observations in hydrological and NWP models, Physics and Chemistry of the Earth, Part B, 10–12, 1221–1224, 2000.

Schwarb, M., Daly, C., Frei, C., and Schär, C.: Mittlere jährliche Niederschlagshöhen im europäischen Alpenraum 1971–1990, Sonderdruck aus: Hydrologischer Atlas der Schweiz, 2001.

Wanner, H., Salvisberg, E., Rickli, R., and Schüepp, M.: 50 years of Alpine Weather Statistics (AWS), Meteorol. Z., N.F. 7, 99–111, 1998.