Forecasting stratus formation : some insights from 1d experiments

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1. Introduction

The ability of a model to predict low stratus crucially depends on its ability to forecast the characteristics of the vertical temperature profile. Verification studies of ECMWF and ALADIN operational forecasts have shown that both models systematically underestimate the strength and sharpness of inversions associated with stratus clouds. Most importantly, the cold air just beneath the inversion is too warm in the models, leading to an underestimation of sub-inversion cloudiness. Figure 1 shows a typical example. Below the inversion, the air is up to 5 K too warm in both models.

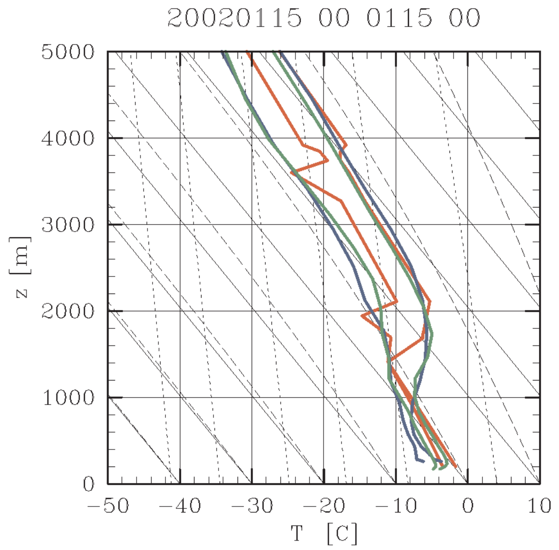

Figure 1 : Observed temperature and dewpoint temperature (red) in Vienna on a stratus day (15 Jan 2002, 00 UTC). ALADIN and ECMWF profiles are shown in blue and green, respectively. The warm bias below the inversion regularly occurs in the models during stratus episodes.

In the case of ALADIN it was found that part of the problem could be traced back to the assimilation in ARPEGE. Already at analysis time (+00 h) the model temperature structure shows a systematic deviation from the observed sounding. This happens because observed temperatures which are too far from the predicted ones are rejected. Note that this does not mean that the assimilation procedure is deficient. If the model background (the previous forecast) would be closer to reality, the assimilation would automatically keep some of the observations that are erroneously rejected now. Thus we are led back to the question of why the model does not produce the inversion structure as observed. To circumvent the problems due to assimilation we specifically investigate cases where the inversion was not present at +00 h but formed in the course of the forecast. Results of one such case study are presented here.

2. Description of the ALADIN-C model

Due to the large horizontal extent and near-homogeneity of low stratus, many aspects of the problem can be addressed using a 1d modelling approach. As a supplement to the ALADIN single column model (SCM) an off-line 1d model has been developed which incorporates selected physics subroutines of ALADIN. It is written in standard *c* and is referred to as the ALADIN-C model. The need to develop an off-line 1d model arose from the sometimes limited flexibility of the SCM and the fact that it is almost as complex as the fully 3-dimensional ALADIN model. Also, it will be used as a framework for direct comparison of ALADIN and MESO-NH parameterizations at high vertical resolution. Up to now, ALADIN-C contains vertical diffusion and surface turbulence parameterizations (equivalent to `ACDIFUS, ACCOEFK, ACHMT`) as well as various stratiform cloudiness schemes, including one that is equivalent to `ACNEBN`. Different cycles of CYCORA can be simulated. For a description of the original ALADIN routines see Gerard (2000). The model uses a z-coordinate in the vertical, and liquid water potential temperature and total water content as dependent variables. Turbulent diffusion is computed explicitly using a small, adaptive time-step. It is planned to incorporate into ALADIN-C a number of additional routines of both ALADIN- and MESO-NH-type (e.g. radiation, a prognostic TKE scheme) in a step-wise process.

The model results shown below were obtained using a constant vertical resolution of 20 m, with the top of the domain at a height of 3000 m above ground level (= 150 layers). The coefficients related to the Richardson-number dependency of vertical diffusion are listed, since they have been re-evaluated several times during various CYCORA cycles. Following the latest recommendations we set :

```
usuric=0.175
usurice=0.5
usuricl=1.0
usurid=0.1
usuride=0.25
```

3. Cloud effects in inversion formation

The prolonged stratus episode which the example in Figure 1 refers to, started on 7 Jan 2002. After a frontal passage, synoptic-scale subsidence created a pronounced inversion in the period between 00 and 12 UTC (cf. Fig. 2). The operational ALADIN forecast (not shown) did produce the subsidence sinking but it did not generate a realistic inversion structure. To gain more insight into why the model temperature profile evolved differently from the one in the real atmosphere we performed several idealized experiments, three of which are presented here.

- EXP1 : Vertical diffusion + prescribed subsidence sinking of 3 cm/s at z=3000m, decreasing linearly to zero at the surface.
- EXP2 : Vertical diffusion + prescribed subsidence sinking of 3 cm/s at z=3000m, decreasing linearly to zero at z=1000m, with no subsidence below.
- EXP3 : As in EXP2 but with a prescribed cloud-top cooling of 6 K/h.

For each experiment the model was initialized with the observed 00 UTC sounding, run for 12 hours, and then was compared to the 12UTC observed sounding. Surface fluxes of heat and mositure were set to zero. Figure 2a shows the result from EXP1 where the subsidence was assumed to decrease linearly towards the surface, implying horizontal mass divergence throughout the PBL. Comparison of the red and green curves shows that the forecast of the Td profile is roughly correct but the temperature is too high and the inversion unrealistically smooth. The model atmosphere is far from saturation, whereas the observed soundings indicate a layer of cloud between 500 and 1000 m above ground. The EXP1 forecast is rather similar to what the operational ALADIN model produced.

(a) EXP1 : subsidence + vertical diffusion

(b) EXP2 : as in EXP1, but no subsidence within PBL

(c) EXP3 : as in EXP2 + prescribed cloud-top cooling

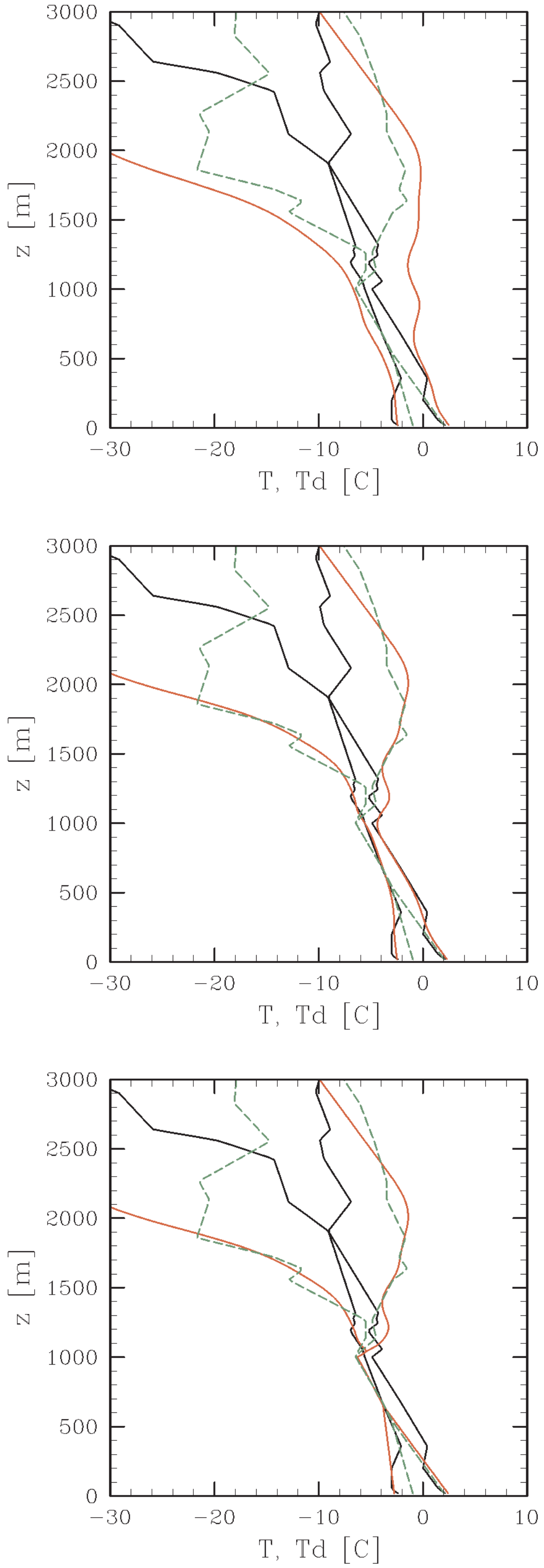

Figure 2 : Results of experiments with the ALADIN-C model. The observed Vienna sounding (T, Td) at initial time (7 Jan 2002, 00 UTC) is shown in black. The observed sounding 12 h later is shown in green. Model prediction for +12 hours is shown in red.

In EXP2 we prescribe the subsidence to drop to zero already at the top of the PBL (z = 1000 m), with zero sinking below. This generates a more realistic temperature profile, with a better defined inversion, and air which is closer to saturation beneath it (Fig. 2b). However, in the real atmosphere the PBL has actually cooled during the 12 hours. This of course cannot be seen in EXP2 which includes vertical diffusion and subsidence warming but no diabatic effects.

To study the effect of cloud-top cooling we prescribe in EXP3 a constant diabatic cooling rate of 6 K/h at a single level (= 1000 m). With a layer thickness of 20 m this corresponds to a heat flux divergence of ~ 30 W/m², which is well within the range of values reported in the literature (Davies and Alves 1989, Ackerman et al. 1995). In this simplified experiment we do not specify explicitly whether it is radiative or evaporative cooling, or a combination of both. Figure 2c shows that the presence of the prescribed cooling brings the forecast very close to observations. The cooling gets vertically mixed throughout the PBL, creating a saturated layer between 600 and 1000 m.

Note that for all three experiments the standard vertical diffusion scheme of ALADIN was used. This proves that the scheme is in principle capable of simulating the turbulent flux structure associated with stratus, namely strong mixing within the cloud layer (due to negative buoyancy created at cloud top) and small vertical exchange directly above. Once a cloud cover of 100% is in place, and cloud-top cooling active, the model is able to maintain it. The current version of ACNEBN, however, does not produce 100% cloudiness, even if a layer is saturated.

The results suggest two likely causes for the inability of ALADIN to model stratus formation: (a) insufficient or absent cloud-top cooling and (b) subsidence too far down into the PBL. Whether (a) is mainly due to the cloudiness scheme or the parameterization of cloud effects in longwave radiation, is currently being investigated by H. Toth. Both (a) and (b) are probably contributing to a reinforcing feedback loop. When subsidence within the PBL keeps the air there too far from saturation, no cloud can form, hence no cloud-top radiative or evaporative cooling. The PBL, remaining too warm, does not decouple sufficiently from the flow above, allowing too much subsidence at low levels. This is further aggravated by insolation that reaches the surface because of missing cloudiness in the model and further warms the modelled PBL.

4. Conclusions

This study addresses the problem of forecasting the initiation of a stratus period, in particular the formation of the elevated inversion which is a necessary condition for this type of cloud. Comparison of observed soundings with idealized model results suggests the combined action of subsidence *above* the PBL and cloud-top cooling. An off-line 1d model (ALADIN-C) has been used to perform idealized experiments starting from observed soundings as initial condition. Different existing cloudiness schemes (ACNEBN, ACNEBN+Seidl-Kann modification, Xu-Randall, MESO-NH statistical cloudiness scheme) are currently tested within this framework, to study their effect on the stratus foreacst.

References

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