Analyses of low stratus forecasts using the AROME1k configuration of GeoSphere Austria

IWCR Project Report - low stratus

Benedikt Wibmer[1,2], Clemens Wastl[2]

[1]University of Innsbruck, Department of Atmospheric and Cryospheric Sciences

[2]GeoSphere Austria

Motivation and project goals

Low stratus decks are a frequent weather phenomenon during the autumn and winter months. In the Alpine region, their occurrence is typically restricted to the plains north and south of the Alps - such as the Swiss Plateau, Bavaria, the Danube Valley, and the Po Valley - as well as to specific valleys and basins (e.g., the Rhine Valley, Klagenfurt Basin or Salzkammergut). However, there are some situations where inner Alpine valleys, such as the Inn Valley, are also affected by a low stratus deck.

Despite notable advances in recent years, the accurate simulation of fog and low stratus in complex terrain remains a significant challenge for numerical weather prediction (NWP) models. These models still exhibit limited skill in forecasting low stratus events, largely due to deficiencies in microphysics and turbulence parameterizations, as well as inadequate vertical and horizontal model resolution.

This project, conducted under the IWCR collaboration between the University of Innsbruck and GeoSphere Austria, investigates selected low stratus events using the convection-permitting AROME model, which currently operates at 2.5 km horizontal resolution at GeoSphere Austria (AROME-Aut). Given that the model often predicts premature dissipation - or complete absence - of low stratus, particularly in the morning hours, the project focuses on the following questions:

1. How well is low stratus represented in the AROME1k model configuration, which is currently in a pre-operational testing phase at GeoSphere Austria?

2. What are the key issues contributing to deficiencies in the model's representation of low stratus?

Methodology

A case study approach was employed to assess the performance of the AROME1k model, which provides a horizontal resolution of 1.0 km and is currently undergoing pre-operational evaluation at GeoSphere Austria. AROME1k is coupled to ECMWF's IFS-HRES model with a 1-hourly update frequency for boundary conditions and a 45-second model timestep. Atmospheric initial conditions are derived using 3DVAR analysis, while the surface is initialized through an optimal interpolation method. The model employs 90 vertical levels, with the lowest at approximately 5 meters above ground level. The integration domain spans Austria and its surrounding region, comprising a grid of 1500 × 1080 points. A detailed description of the model physics and parameterizations can be found in Termonia et al. (2018).

The work was divided in several phases (WP) to address the project goals:

1. **WP1 - case selection:**
   Identification of low stratus episodes in various regions using observational datasets (e.g., webcam imagery, satellite data, and lidar profiles).
   - Inn Valley: 11th April, 2024; 29th Februray, 2024; 11th January, 2024;
   - Klagenfurt Basin: 17th October, 2023;
2. **WP2 - model simulations:**
   Execution of high-resolution forecasts using AROME1k with:
   - differing initialization times
   - extended cycling and assimilation of radiosonde data to improve the initial atmospheric state
3. **WP3 - Verification:**
   Comprehensive evaluation of model output against observational data, focusing on the temporal and spatial evolution of the low stratus deck.
4. **WP4 - Error Analysis:**
   Identification and analysis of model deficiencies.

Results

The following section summarizes one representative case study. Key observations from other cases are mentioned afterwards.

Case Study 1: 11th April 2024 (Inn Valley)

On 11th April 2024, following a period of precipitation and snowfall associated with a trough and a cold front, the Inn Valley experienced deep moisture accumulation. As the upper-level trough became cut off over the Mediterranean, a ridge approached from the west, accompanied by upper-level warm air advection. Observations showed the development of a low stratus deck overnight, covering most parts of the central and lower Inn Valley in the morning.

AROME1k simulations

Four simulations were conducted for this event, varying in initialization time and data assimilation strategy. Three of the runs used standard cycling (*HN1km_p24, HN1km_p12, HN1km*), while the fourth (*HN1kmRS*) incorporated an extended cycling and assimilation of radiosonde observations to capture the best initial atmospheric state. The four simulations are summarized in Table 1.

Table 1: Model simulations of AROME1k ($\Delta x = 1$ km) performed for the case study on 11th of April 2024.

Initialization	HN1km_p24[1]	HN1km_p12[1]	HN1km	HN1kmRS
date	10th April 2024 00 UTC	10th April 2024 12 UTC	11th April 2024 00 UTC	11th April 2024 00 UTC
atmosphere		3DVAR		
surface		surface OI		
extended cycling, assimilation of radiosondes				X

[1] xx hours prior to 11th April 00 UTC.

Evaluation: Model vs. Observations

Only the *HN1kmRS* simulation – featuring longer cycling and radiosonde data assimilation – successfully reproduced the observed low stratus deck, accurately simulating:

- a well developed low stratus deck in most parts of the Inn Valley
- the timing of low stratus dissipation (around 07–08 UTC)
- the pattern of cloud clearance, starting from the valley center

In contrast, the other simulations (*HN1km_p24, HN1km_p12, and HN1km*) failed to reproduce the low stratus deck, simulating either only shallow patches or no cloud cover at all (see Fig. 1).

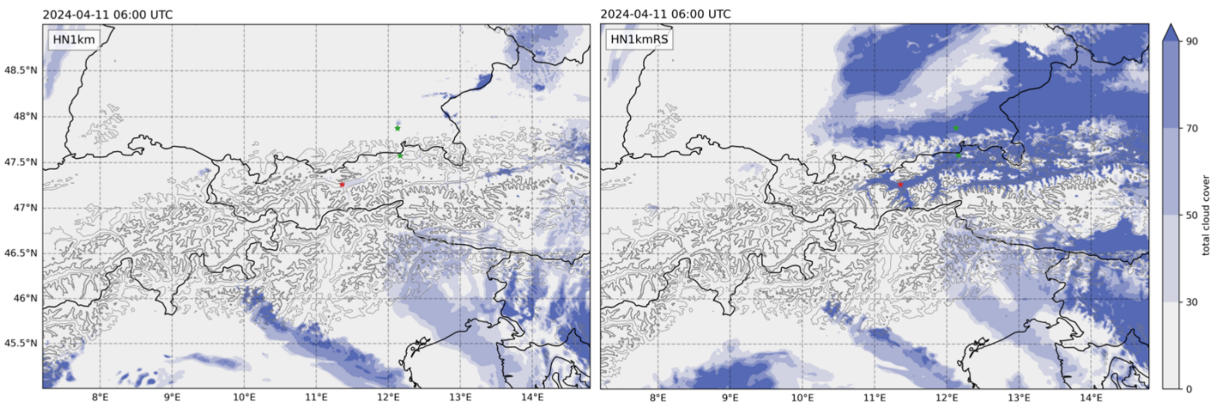

Figure 1: Total cloud cover at 06 UTC for simulations without (left, *HN1km*) and with (right, *HN1kmRS*) extended cycling and radiosonde assimilation. Both simulations use the same initialization time at 00 UTC at 11th of April 2024 (see Table 1).

To investigate this discrepancy, Figure 2 shows vertical profiles of temperature and dew point in a skew-T diagram together with the vertical wind profile for the grid point location at Innsbruck airport at 02 UTC. First of all radiosonde observations reveal a saturated layer between about 850 to 780 hPa, marking the dense low stratus deck, under a pronounced capping inversion formed possibly due to flux divergence and warm air advection higher up. Furthermore weak winds were prevailing below the low stratus deck, so up to a height of roughly 1500 m.

While *HN1kmRS* shows a similar saturated layer between 930 to 825 hPa, it albeit appears thicker and tends to a slight warm and moist bias in the valley atmosphere, compared to the observations (cf. black and red lines in Fig. 2). Comparing the rest of the simulations, the verification with the observed radiosonde profile reveals a persistent warm and dry bias in the model, particularly affecting the moisture content below 900 hPa. Therefore none of these is able to simulate a saturated layer at all.

A cross-section along the Inn Valley (not shown) confirmed that *HN1kmRS* maintained valley moisture values up to 2 g kg^{-1} higher than the *HN1km* run (same initialization time), highlighting the impact of longer cycling and assimilation of radiosonde data.

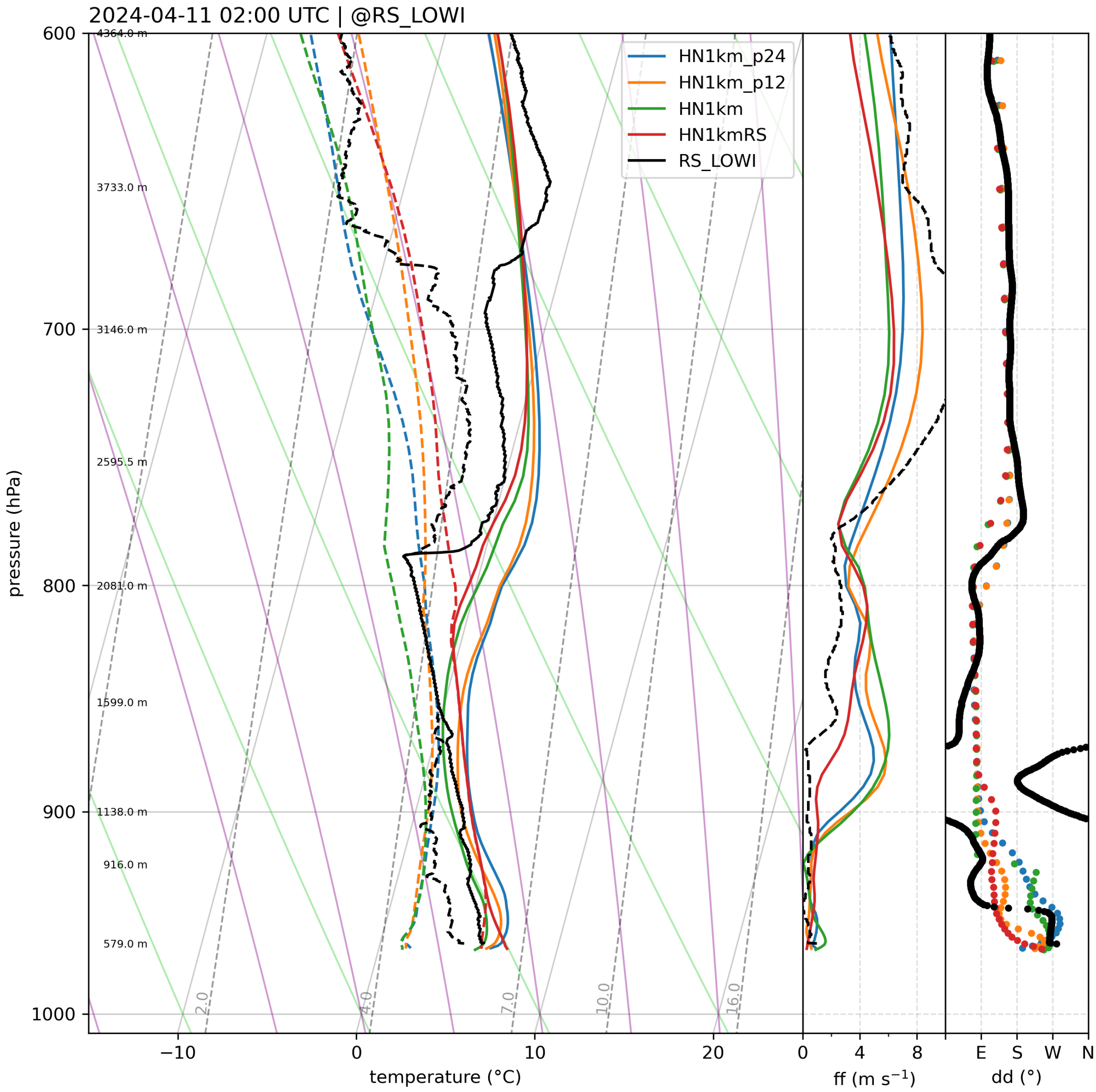

Figure 2: Skew-T diagram (left) and wind profiles (right) for all simulations (colored lines) and radiosonde observation (black lines) at Innsbruck Airport (02 UTC, 11th April 2024).

Other Case Studies

- **29th February 2024:** The presence of southerly foehn winds induced an earlier-than-observed breakup of the stratus layer by approximately two hours. Therefore the case was not undisturbed by synoptic conditions.
- **11th January 2024:** While the timing of low stratus dissipation near Innsbruck was reasonably simulated, the underlying warm and dry bias persisted.
- **17th October 2023 (Klagenfurt basin):** The simulation underestimated the strength of the low stratus layer, leading to a premature dissolution (by roughly two to three hours) with limited observational data for thorough verification.

Discussion and Outlook

The project demonstrates that the integration of higher-resolution simulations and enhanced data assimilation (notably radiosoundings) in the AROME model improves forecast accuracy regarding the evolution of low stratus. While performance improvements were evident over the current operational setup (2.5 km), persistent biases – such as excessive warmth and dryness – indicate shortcomings in the model's representation of valley thermodynamics and moisture processes. Further refinement of physical parameterizations and broader observational coverage will be essential for future model enhancements. Upcoming field campaigns such as TEAMx are expected to provide critical data to address these issues, allow more in-depth evaluation possibilities and guide further development.

Contact: `benedikt.wibmer@geosphere.at`

References

Termonia, P., and Coauthors, 2018: The ALADIN System and its canonical model configurations AROME CY41T1 and ALARO CY40T1. *Geosci. Model Dev.*, **11 (1)**, 257–281, https://doi.org/10.5194/gmd-11-257-2018.