Impact of SEVIRI Radiances and VarBC on Regional Precipitation Forecasts in Central Europe

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Abstract

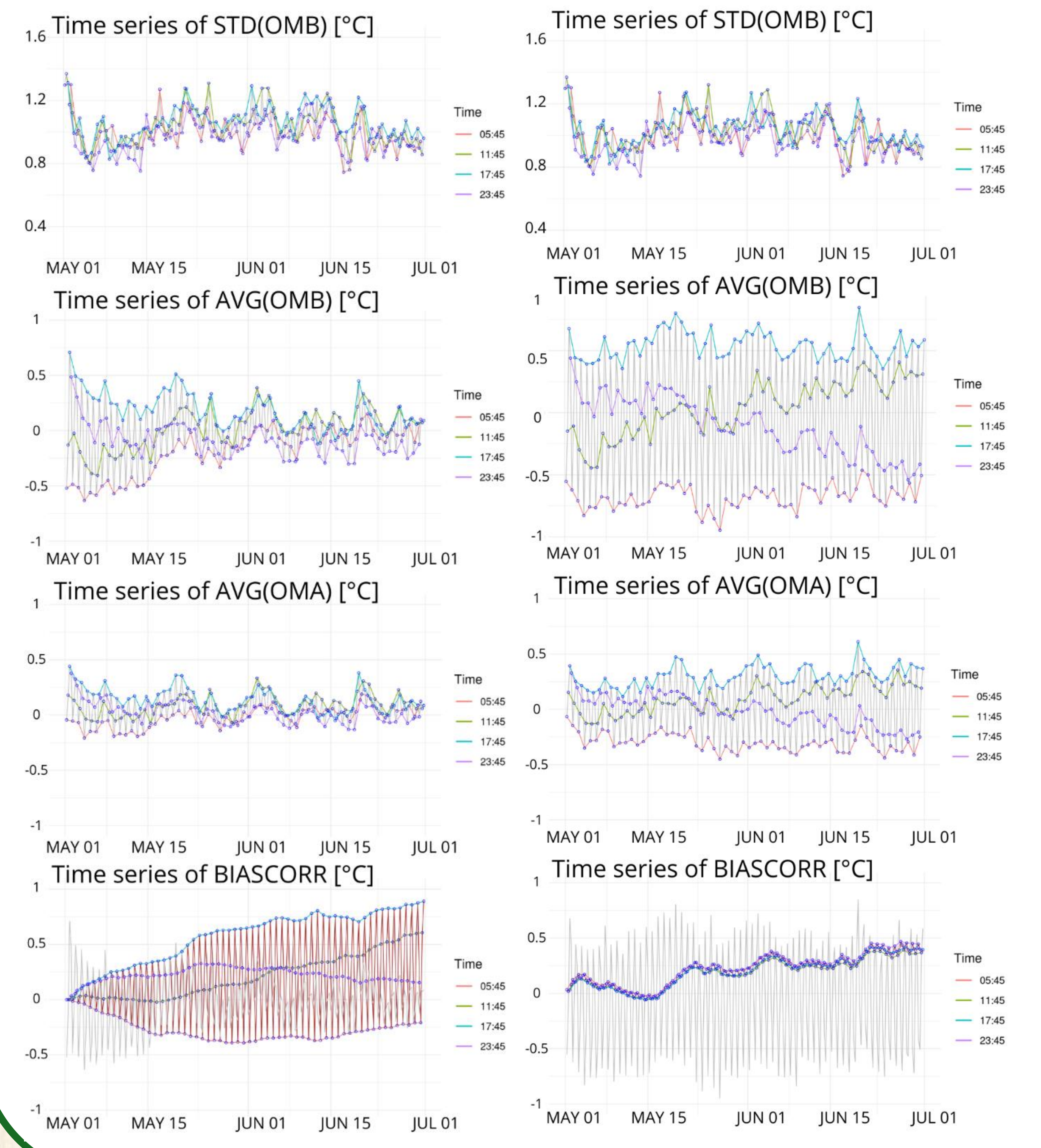
The main tool for numerical weather prediction at the Slovak Hydrometeorological Institute is **the ALADIN/SHMU** forecast system. For the analysis and assimilation of data in convective-scale weather prediction models, the use of input data with high spatial and temporal resolution is crucial. The **assimilation of satellite data** plays a key role in improving forecast quality and hydrological and climate model inputs. One of the main challenges in the assimilation of satellite measurements is the removal of systematic errors (bias), which can negatively affect the model analysis and subsequent forecasts. In this paper, we focus on the **Variational Bias Correction** (VarBC) method, which dynamically estimates and corrects systematic errors directly in the data assimilation process. We compare two strategies for the independent cycling of correction coefficients starting from a zero initial state, updating with each assimilation step and daily cycling. The daily cycling strategy showed faster stabilization of bias parameters and a clearer reduction in systematic observation-minus-background (OMB) deviations, reaching values below 0.5 °C within two weeks. During an **active assimilation case study (the Boris low-pressure system, September 2024)**, continuously updated VarBC coefficients effectively adapted to seasonal changes and prevented bias accumulation. Although the assimilation of SEVIRI radiances did not yield significant forecast improvement, it maintained forecast quality and demonstrated the robustness of VarBC implementation in a limited-area model. The results confirm that proper tuning of VarBC enhances the consistency of satellite data assimilation and supports future operational use in the ALADIN/SHMU system.

METHODS AND DATA

- The **ALADIN/SHMU** forecast system employs the three-dimensional variational (3D-Var) **data assimilation cycle every 6 h** (00, 06, 12, 18 UTC).
- **SEVIRI** radiances from the geostationary MSG satellite were assimilated, providing 15-min imagery with ~3 km resolution. Five infrared channels (**6.2 μm, 7.3 μm, 8.7 μm, 10.8 μm, 12 μm**) were used for evaluation.
- Systematic errors in radiances were corrected using the Variational Bias Correction (VarBC) method, which estimates bias dynamically within the 3D-Var optimization. A cold-start initialization (**zero coefficients**) was applied, followed by testing two cycling strategies:
  - **Assimilation step cycling** – update every 6 h
  - **Daily cycling** – update every 24 h
- Evaluating data assimilation quality :
  - **Observation-minus-background (OMB) deviations** – the difference between the observed and model-predicted values prior to assimilation. This indicates how well the model background represents the observations before bias correction.
  - **Observation-minus-analysis (OMA) deviations** – the difference between observations and the analysis after assimilation. A reduction of OMA compared to OMB indicates successful correction of systematic errors.
  - **Standard deviation (STD)** – the standard deviation of OMB or OMA, describing the variability of deviations and their stability over time.
  - **BIASCORR** – a statistical measure quantifying the correction of the mean bias between observations and the model.
  - **Verification scores** – of model forecasts were used to evaluate the impact of satellite data.
  - **Visualization forecast maps** – selected meteorological variables.

Bias correction performance

Within the VarBC functionality, we focused on a cold start approach with zero initial coefficients using passive assimilation. Subsequently, we compared two cycling strategies for the β coefficients (daily vs. assimilation-cycle strategy) under the experimental setups. The results indicate a notable difference in the efficiency of the two β cycling strategies (Figure 1).



At the beginning of both experiments, the OMB values were approximately equal. After one week, the results diverge significantly. For OMB evaluation, a threshold of ± 0,5 °C is considered, based on the statistical analysis of the accuracy of satellite measurements and the model system. The better (closer to 0) OMB values were obtained with the daily cycling strategy; after approximately two weeks, the values dropped below 0,5 °C. In contrast, the assimilation-cycle strategy did not reach values below this threshold even after two months of computation.

Figure 1. Two-month statistics of the passive experiment for SEVIRI channel 2 with daily (left) and assimilation (right) cycling. The colored lines represent different analysis times during the day.

Case study September 2024

The selected synoptic situation from 3–16 September 2024 was characterized by the passage of the low-pressure system Boris across Central Europe. This event featured pronounced cyclogenesis, frontal precipitation, and regional extremes in precipitation totals. During this episode, the VarBC with daily cycling was applied in active assimilation, allowing the evaluation of its impact on the initial state analysis and the quality of precipitation forecasts.

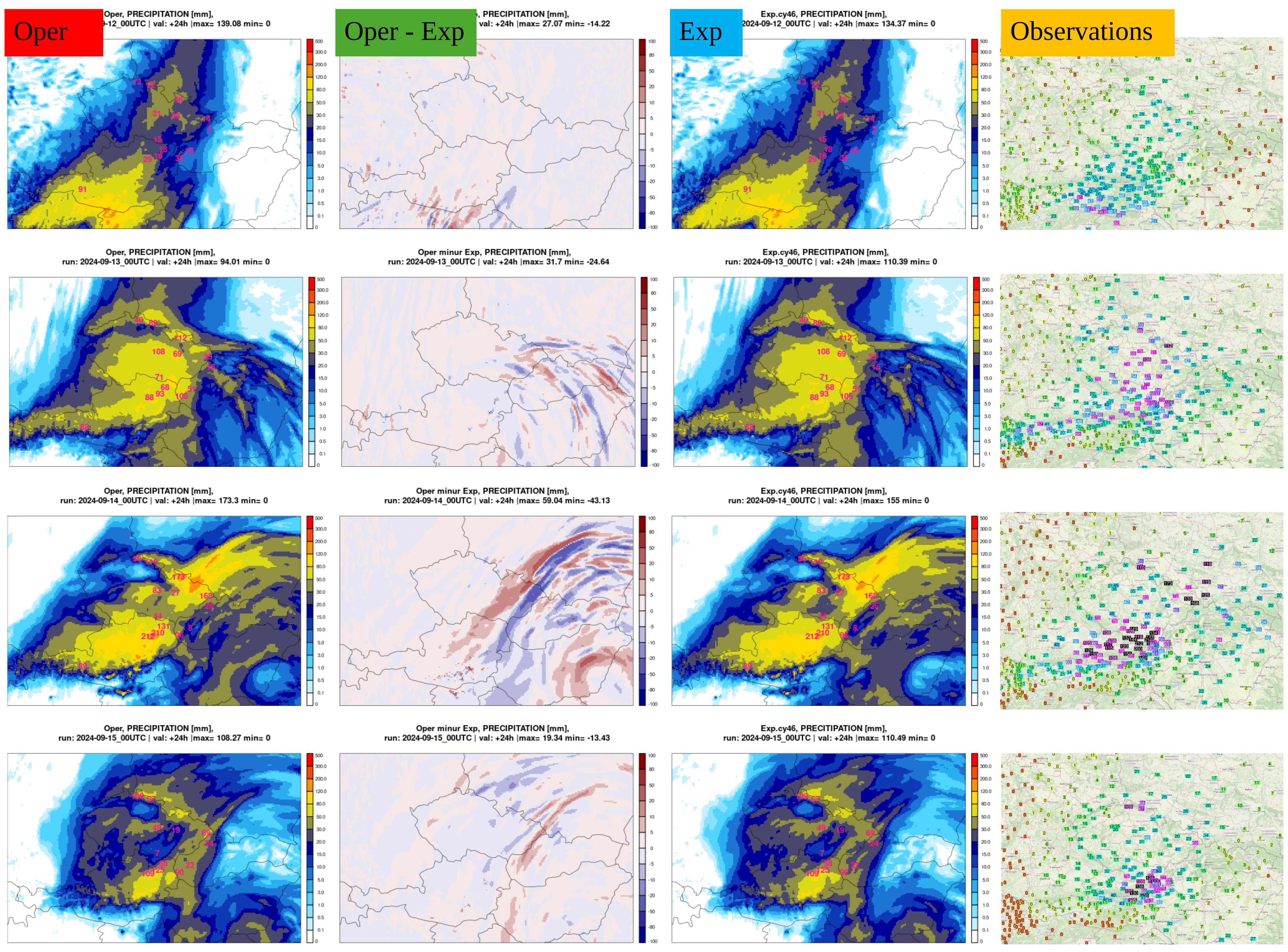


Figure 2. 24-hour accumulated precipitation over Central Europe: comparison between operational (Oper), experimental (Exp), Observations, and their difference.

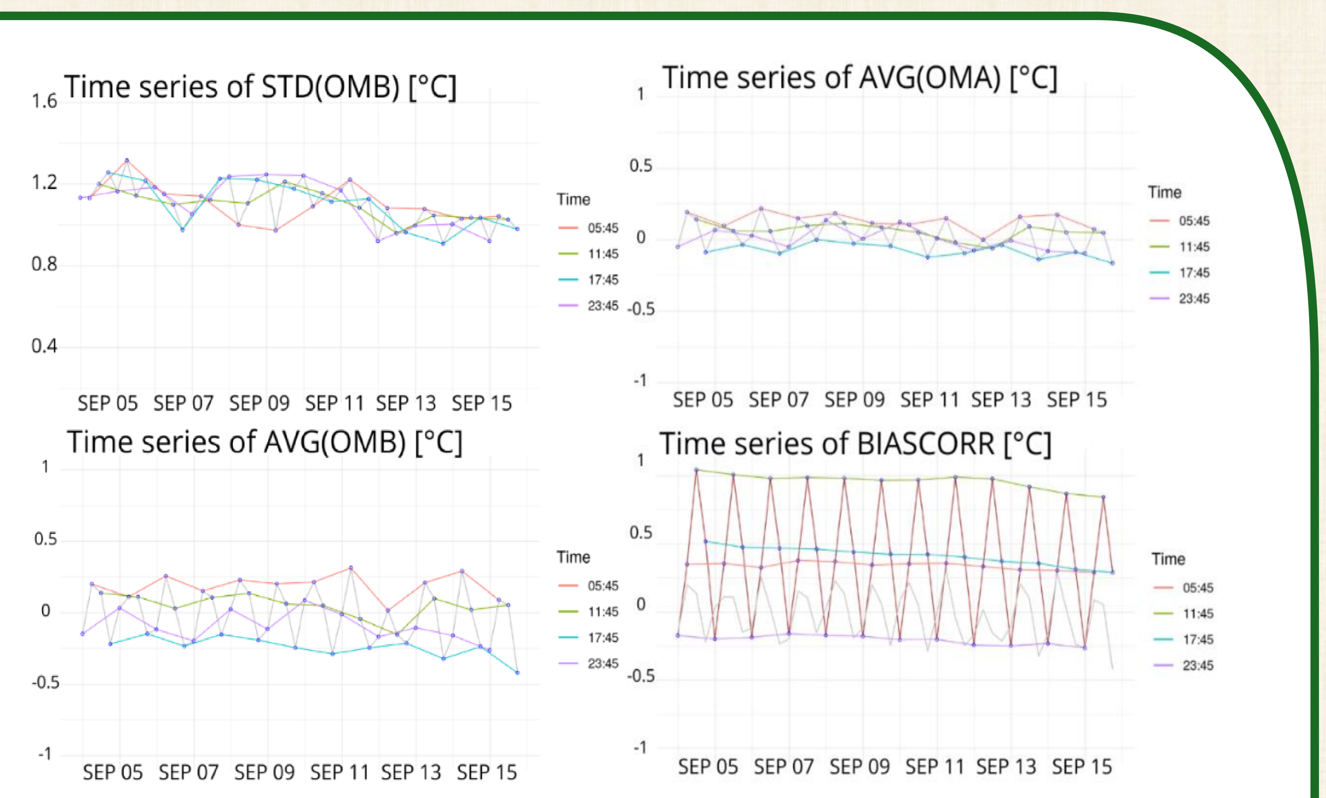


Figure 3. Two-week statistics of the active assimilation experiments for SEVIRI channel 2 using initial coefficients continuously updated over the summer.

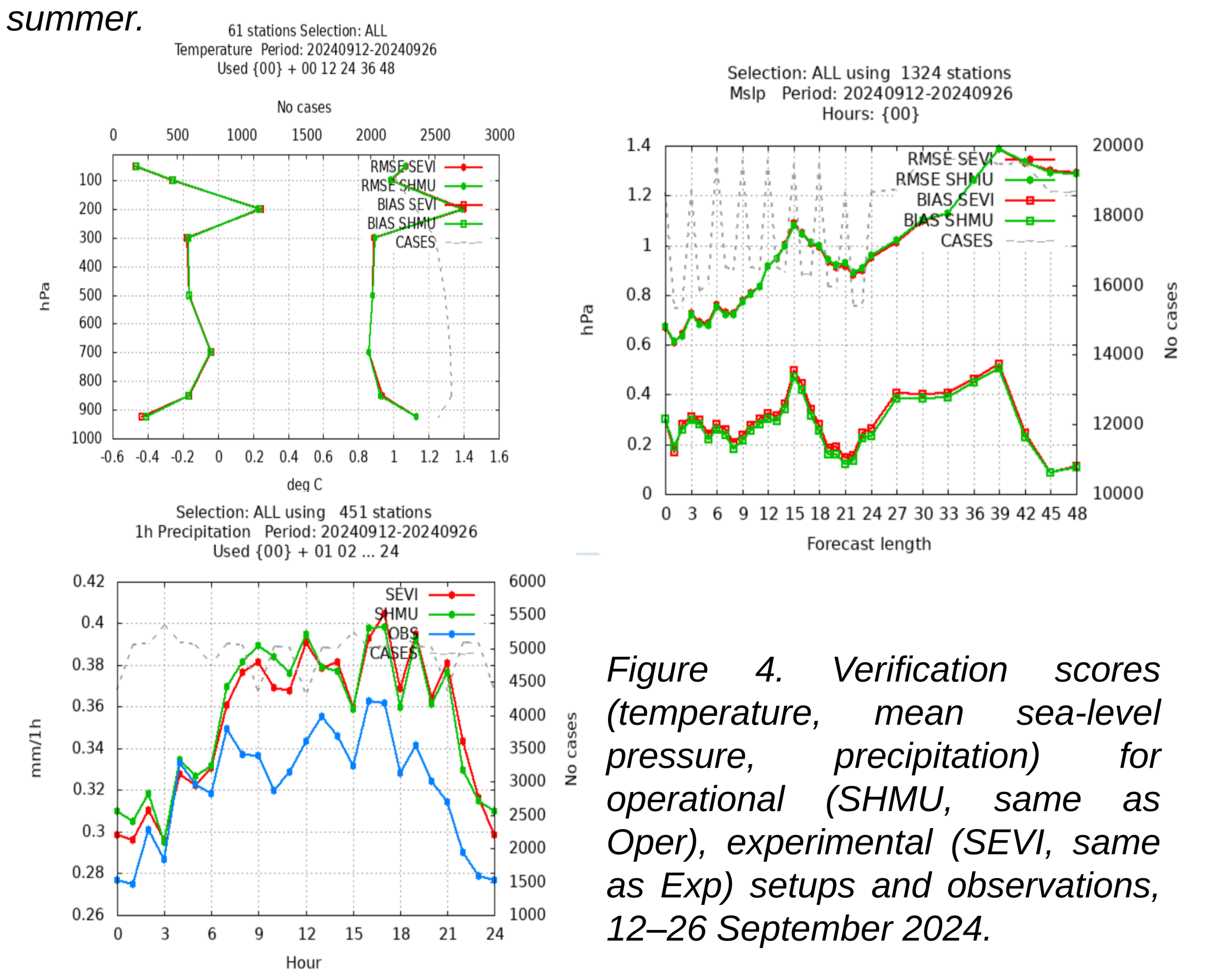


Figure 4. Verification scores (temperature, mean sea-level pressure, precipitation) for operational (SHMU, same as Oper), experimental (SEVI, same as Exp) setups and observations, 12–26 September 2024.

Case study demonstrated that continuously updated VarBC coefficients effectively adapted to seasonal atmospheric changes, unlike outdated coefficients from June which led to incorrect corrections. A subjective comparison of forecasts maps showed mixed results, with the experimental setup (Exp) performing better in some high-precipitation areas (e.g., Lysá hora) , while the operational model (Oper) was more accurate in others (e.g., Eastern Slovakia). Objective verification scores confirmed that assimilating SEVIRI data did not significantly improve the overall forecast quality but crucially, it also did not degrade the forecast performance.

Conclusion

The assimilation of SEVIRI radiances in the ALADIN model. Used the 3D-Var method with **bias correction** through VarBC, where **daily cycling** of weighting coefficients allowed for dynamic adaptation to systematic errors in satellite measurements. This correction led to a better agreement between the model background and satellite observations, improving input data quality and potentially enhancing extreme weather forecasts.

Results from the case study (September 12–15, 2024) suggest that incorporating satellite measurements improves atmospheric predictions, especially in areas with limited conventional observations. The role of remote sensing in numerical weather prediction is increasingly important in a changing climate, but further verification is needed to fully assess the impact on extreme weather forecasting.

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