Rainstorms with a splash of blood: machine learning-based predictive analytics for hemorrhagic stroke admission based on weather systems

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Background: The climate crisis impacts cardiovascular health and stroke, contributing significantly to the global disease burden. Weather-based disease surveillance for healthcare providers is lacking.

Aim: Hence, we aimed to forecast the number of daily hemorrhagic stroke admissions based on meteorological parameters by applying machine learning models.

Methods: Hemorrhagic stroke patients diagnosed at the University Medical Center Mannheim, Germany between 01/2015–31/2021 were selected from the local data integration center (DIC). Hemorrhagic stroke patients were identified based on ICD10 codes (I60 & I61; Fig. 1). Weather data were obtained from the German Weather Service (DWD; Fig. 2). Complex geospatial matching was performed based on clinic-, patients' home- and closest tower locations at the time of admission.
Baseline statistical- (Poisson, GAM), support vector- (SVR) and tree-based models (RF, XGB) were evaluated in regression settings within time-stratified nested cross-validation (training-validation: 2015-2020, test set: 2021) for daily (Fig. 1), weekly and monthly number of combined bleeding cases.

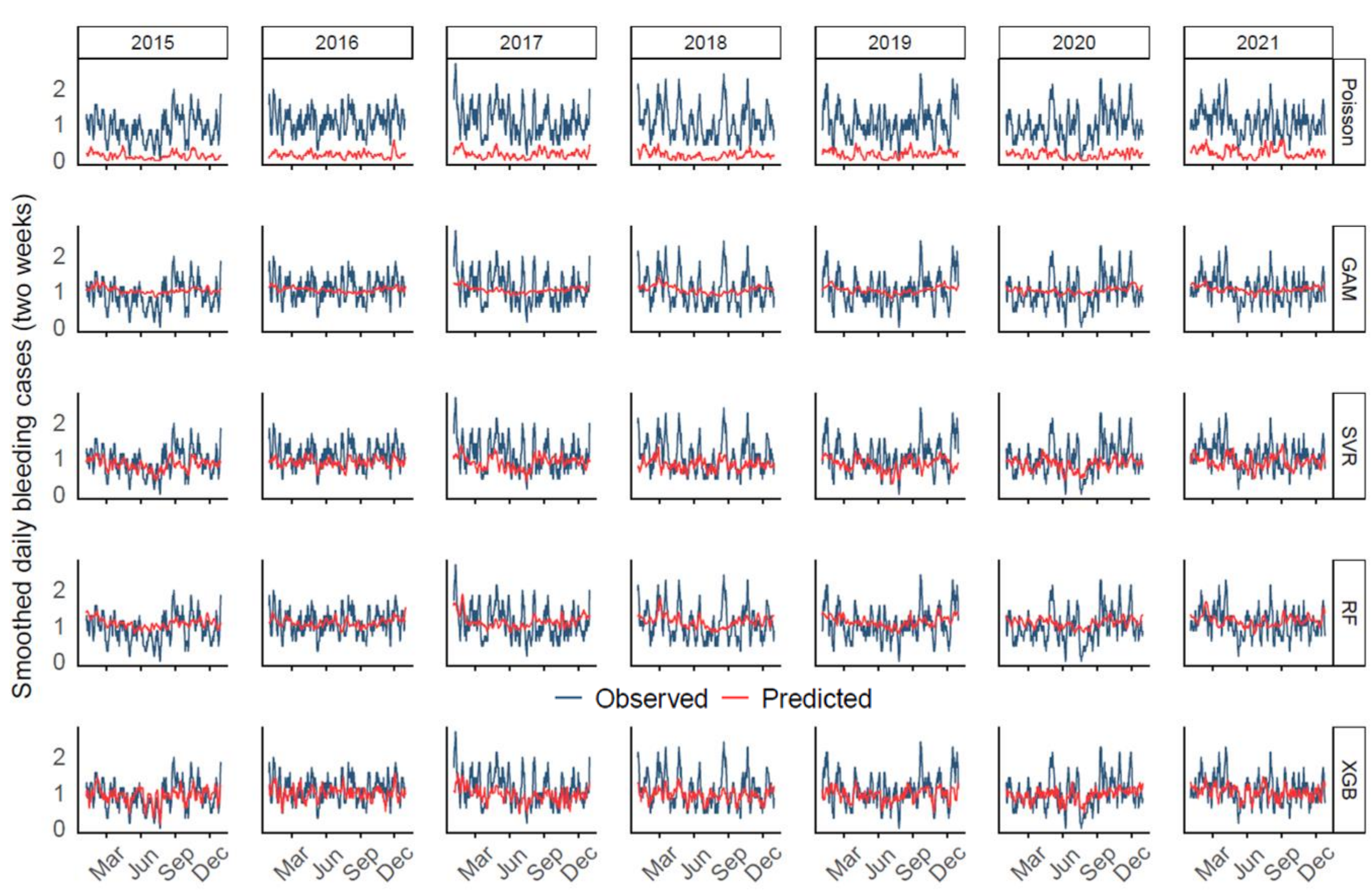

Figure 1: Research setup for predicting the daily hemorrhagic stroke case count from 2015 to 2021.

Results: 2374 hemorrhagic stroke cases (50.5% female) were identified including intracranial- (**N_{ICH}=1613, 67.9%**) and subarachnoid hemorrhages (**N_{SAH}=761, 32.1%**) with an average age of 63 years.

Seasonal peaks occurred (Fig. 3) during changing weather in winter ***December-January*** (median=41, IQR: 35-44, $p=1.25\times10^{-5}$), in spring (***April***, median=36, IQR: 30-38, $p=9.42\times10^{-6}$) and in fall in ***October*** (median=35; IQR: 33.5-37.5, $p=5.26\times10^{-6}$). Interestingly, there was and incidence peak also in the summer month of ***August*** (meadian=33, IQR: 31.5-36.5, $p=4.82\times10^{-6}$).

Baseline models

- The Poisson model revealed a negative association between **P_{mean}** (RR=0.76, 95% CI=0.62-0.91, p=0.004) and a positive with **T_{max}** (RR=1.26, 95% CI=1.06-1.49, p=0.005) for daily **$N_{bleeding}$**.
- The GAM model identified **P_{max}** and **weekday** as the 1st and 2nd most significant variables.

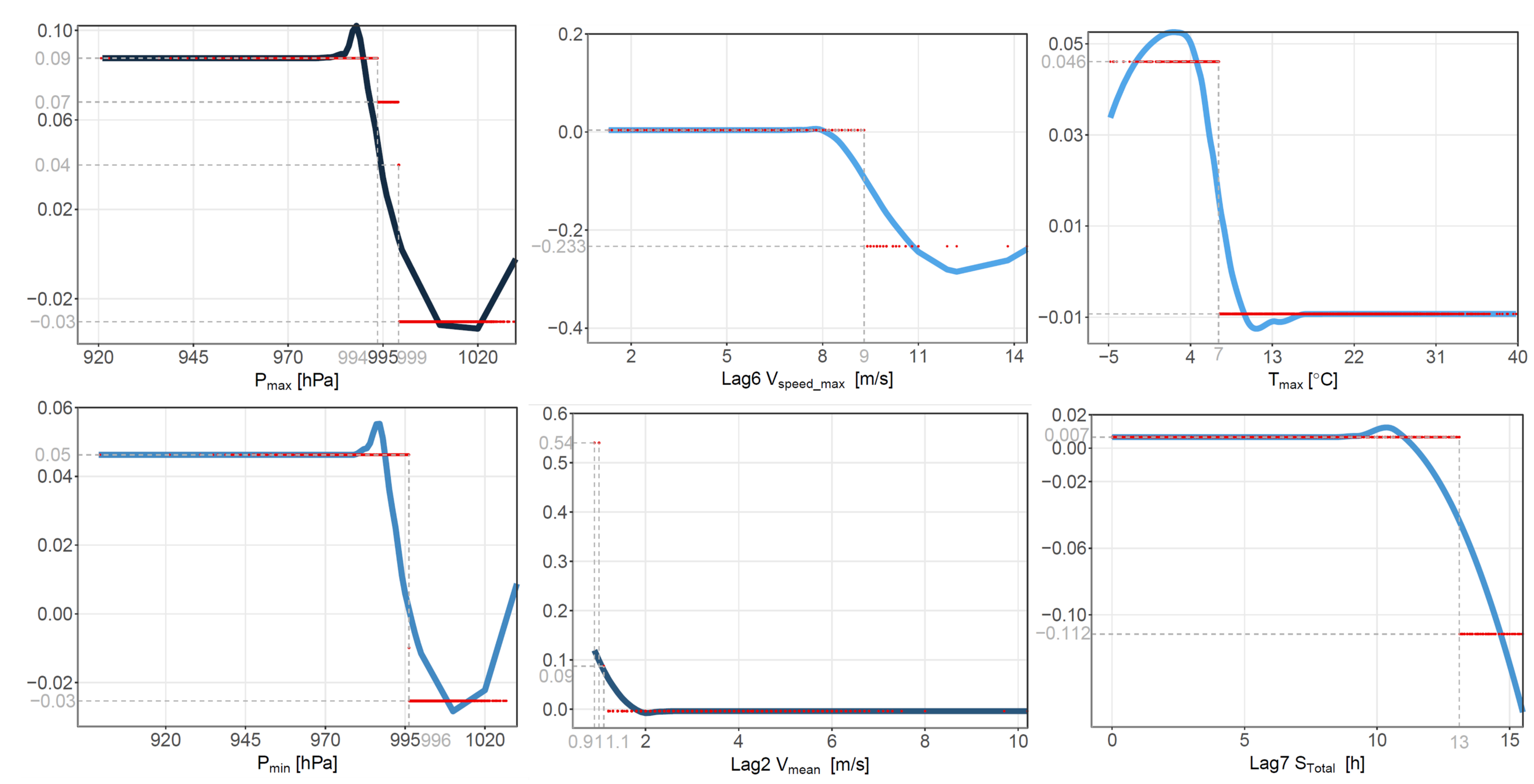

Figure 2: Shapley additive explanations (SHAP) of the top six variables illustrating their effects on hemorrhagic stroke occurrences.

Machine learning models:

- XGB surpassed other machine learning models, registering lower MAE and RMSE values of 0.73 and 0.98, respectively.
- **P_{max} , lag2 V_{mean}** wind speed and P_{min} emerged as top predictor in the XGB model (Fig. 2).
- Additionally, **cold stressors** that indicated by low **T_{max} < 7 °C** and decreased sunshine duration **lag7 $S_{total/day}$ < 13h** were positively associated with **$N_{bleeding}$** (Fig. 3).

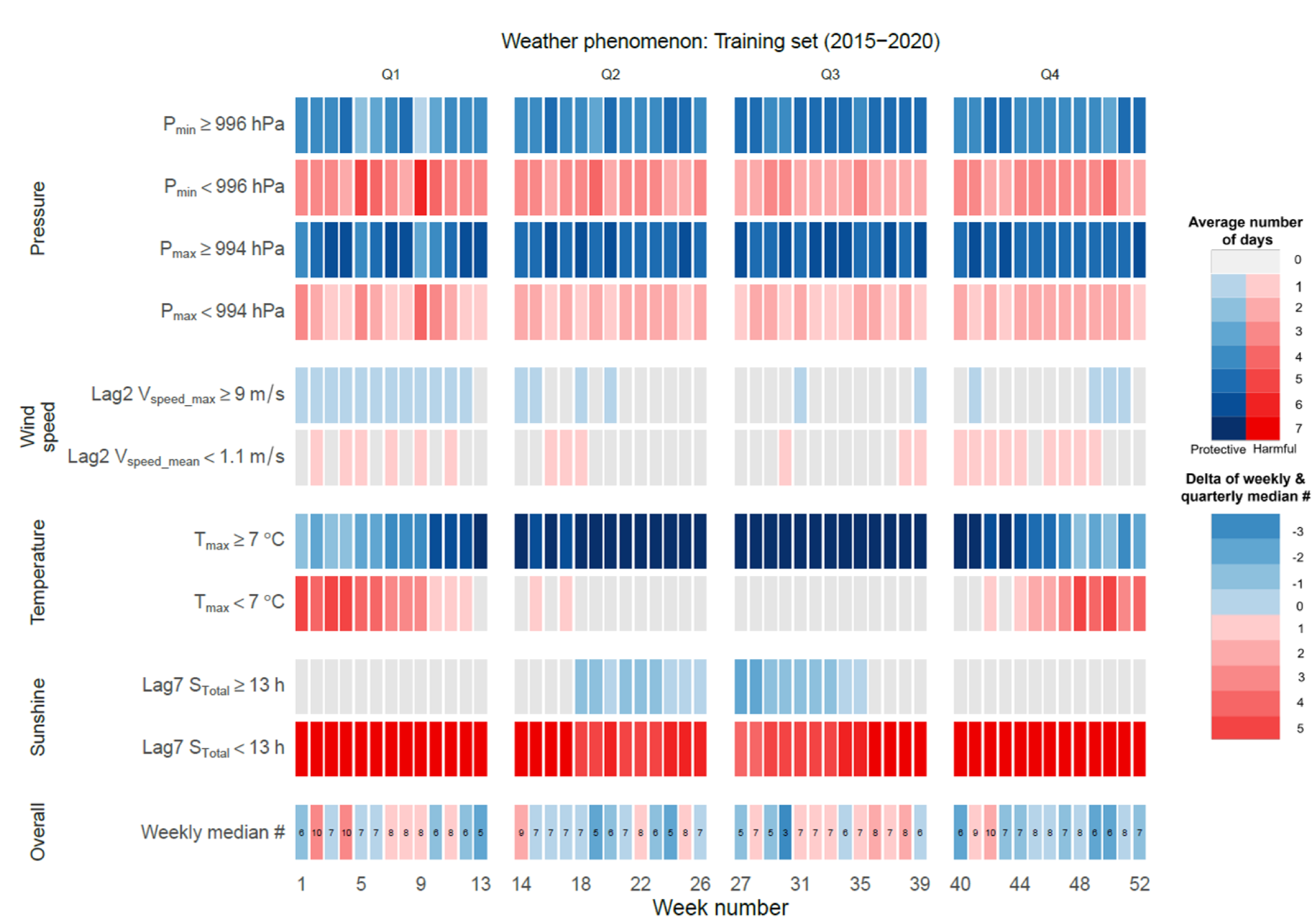

Figure 3: Heatmap of seasonal weather patterns and their associations with hemorrhage occurrence

Conclusions: Our study provides a generalizable, disease-agnostic framework for real-time resource allocation and optimized therapy planning – not just for neuroradiological emergencies.

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