Supplementary Materials for

TPHH: A long-term (1901–2023) high-resolution (1/30°) near-surface humidity dataset for the Tibetan Plateau generated via spatial downscaling based on hybrid-structure deep learning

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Figures S1 to S13

Introduction

In these supplementary materials, we gathered monthly density scatter plots for 2 m temperature (**Figure S1**), 2 m specific humidity (**Figure S2**), and surface pressure (**Figure S3**), monthly interannual curves for those three variables (**Figure S4-6**), compares the proposed TPHH product against two representative datasets (**Figure S7**), distribution of the 41 tree-ring proxy groups as well as each sample over the Tibetan Plateau (**Figure S8**), and tree-ring proxy fitting results for all 41 sample groups (**Figure S9-13**).

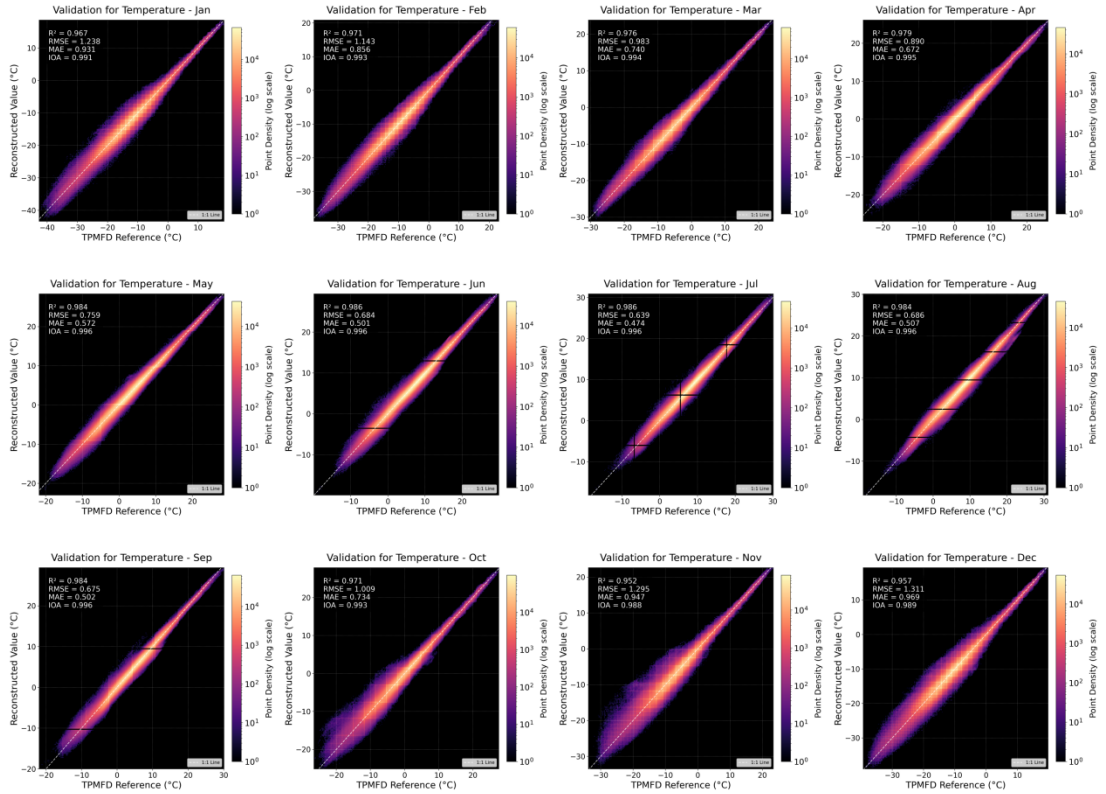

Figure S1. Monthly validation of the downscaled 2 m temperature (Temp). Density scatter plots comparing the THPP reconstructed high-resolution temperature values against the TPMFD reference data across all 12 months. The dashed line represents the 1:1 reference line of perfect agreement. Color gradients indicate point density (logarithmic scale), with warmer colors representing higher concentrations of data points. Statistical metrics including the coefficient of determination (R^2), Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and Index of Agreement (IOA) for each specific month are inset in the upper-left corner of the respective panels.

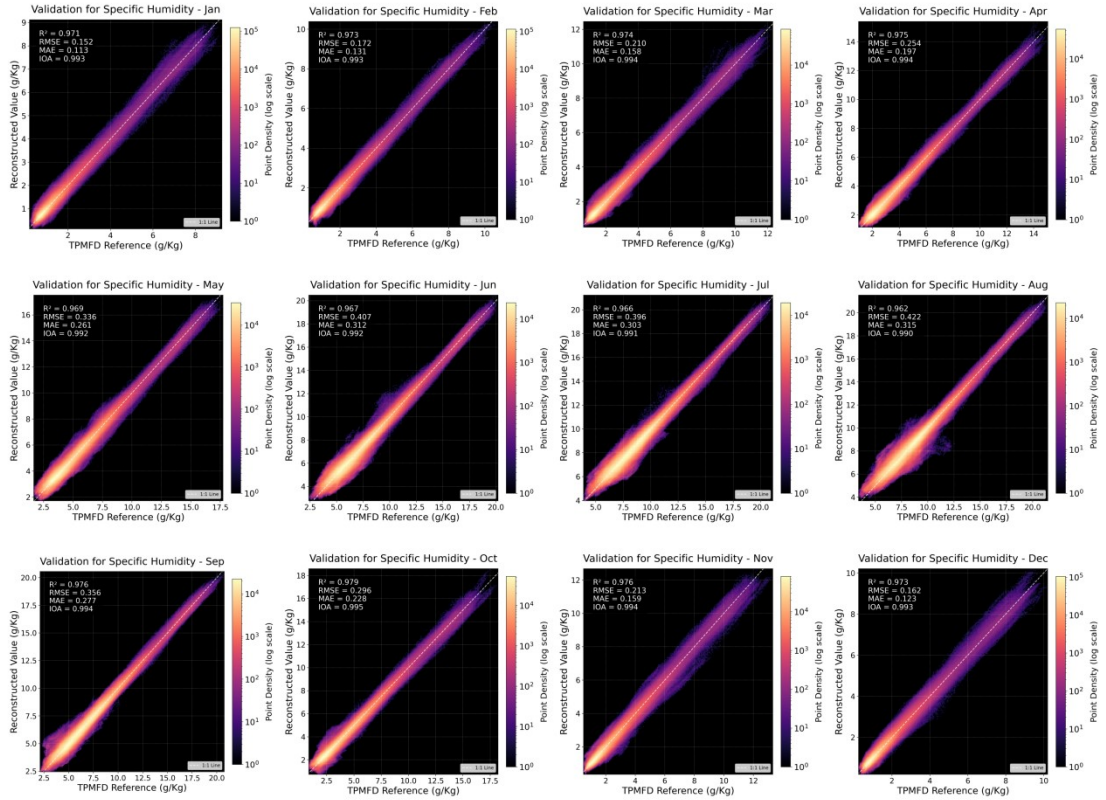

Figure S2. Monthly validation of the downscaled specific humidity (Shum). Density scatter plots comparing the THPP reconstructed high-resolution specific humidity values against the TPMFD reference data across all 12 months. The dashed line represents the 1:1 perfect agreement line. Point density is mapped to the color gradient on a logarithmic scale. Inset evaluation metrics (R^2, RMSE, MAE, and IOA) quantify the model's monthly performance.

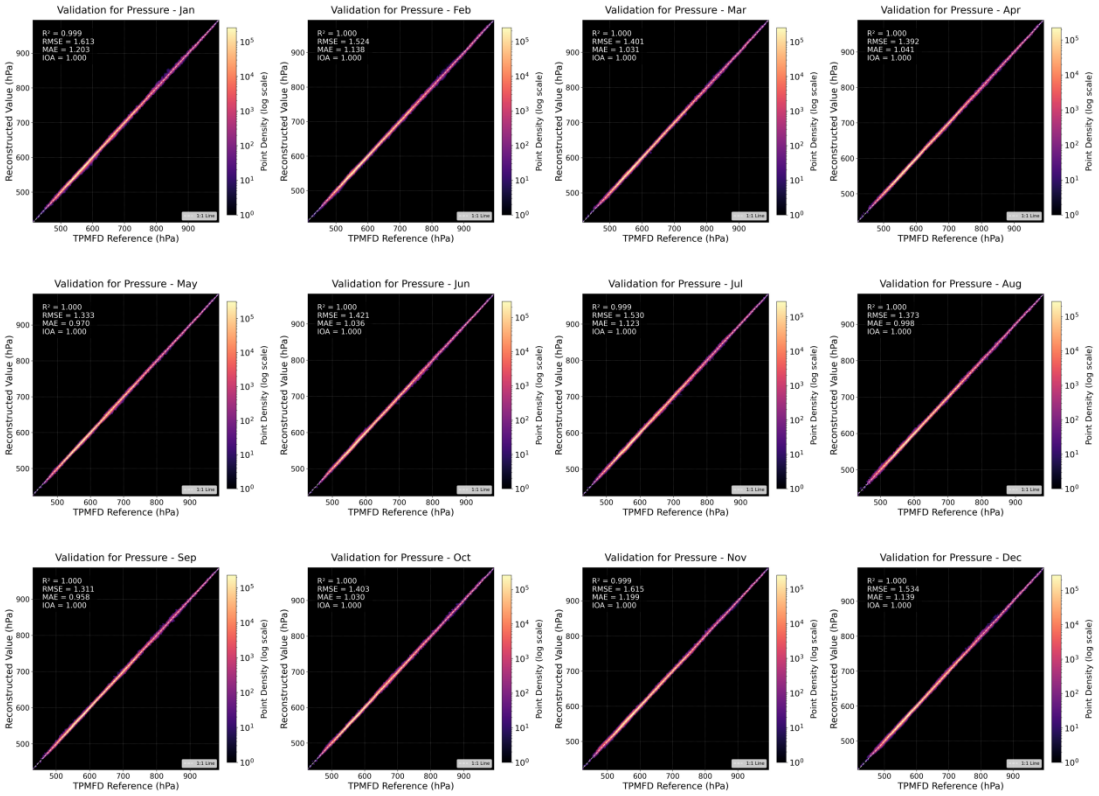

Figure S3. Monthly validation of the downscaled surface pressure (Pres). Density scatter plots showing the correlation between the THPP reconstructed high-resolution surface pressure and the corresponding TPMFD reference data for each month. The 1:1 reference line is indicated by the dashed line. The color bar reflects the point density distribution (logarithmic scale). Quantitative metrics (R^2, RMSE, MAE, and IOA) derived from the masked evaluation over the Tibetan Plateau are provided in the upper-left corners.

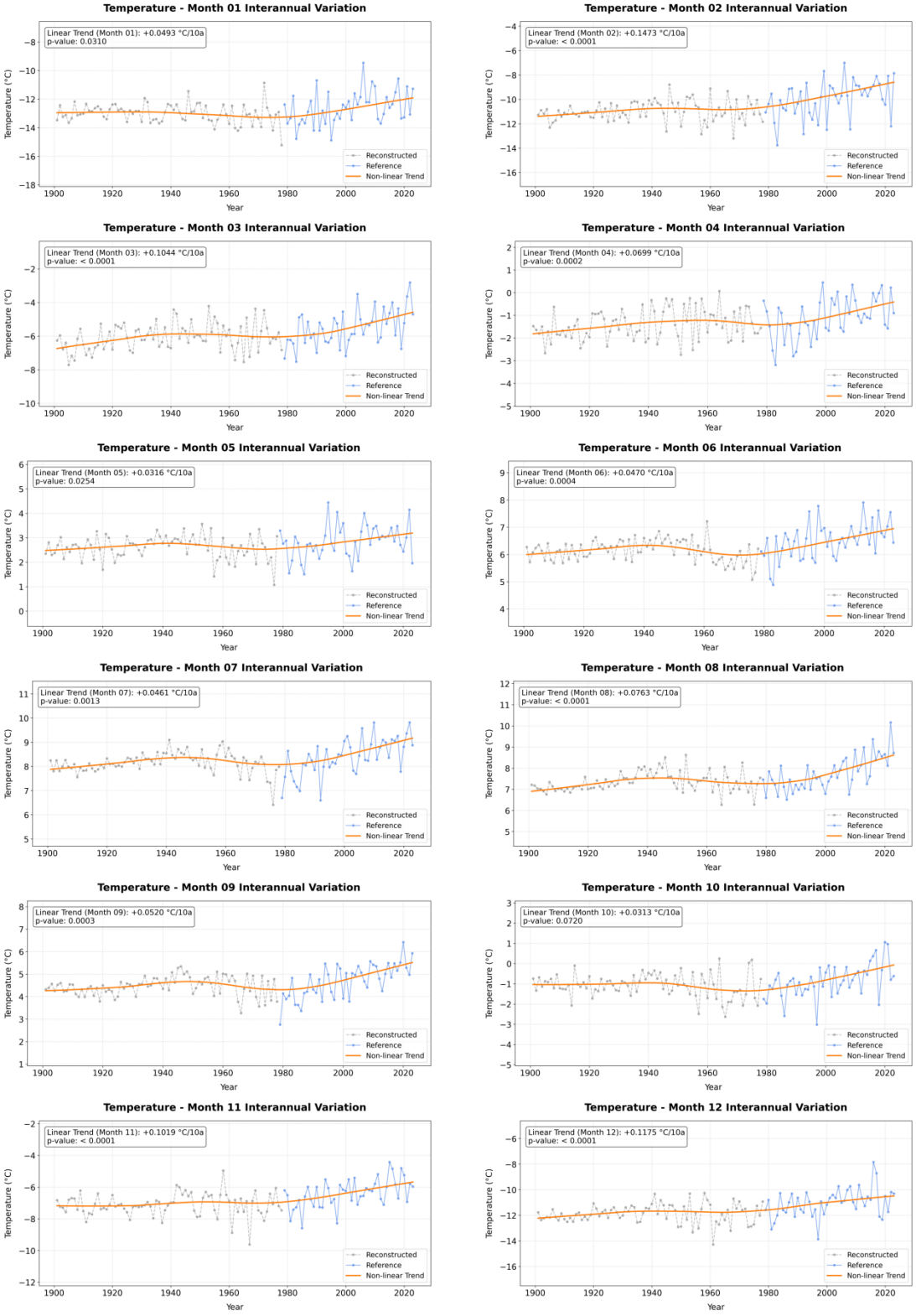

Figure S4. Monthly interannual variations of 2 m temperature over the Tibetan Plateau (1901–2023). Grey dashed and solid blue lines denote the reconstructed (1901–1978) and reference (1979–2023) data, respectively. The orange curve indicates the trend.

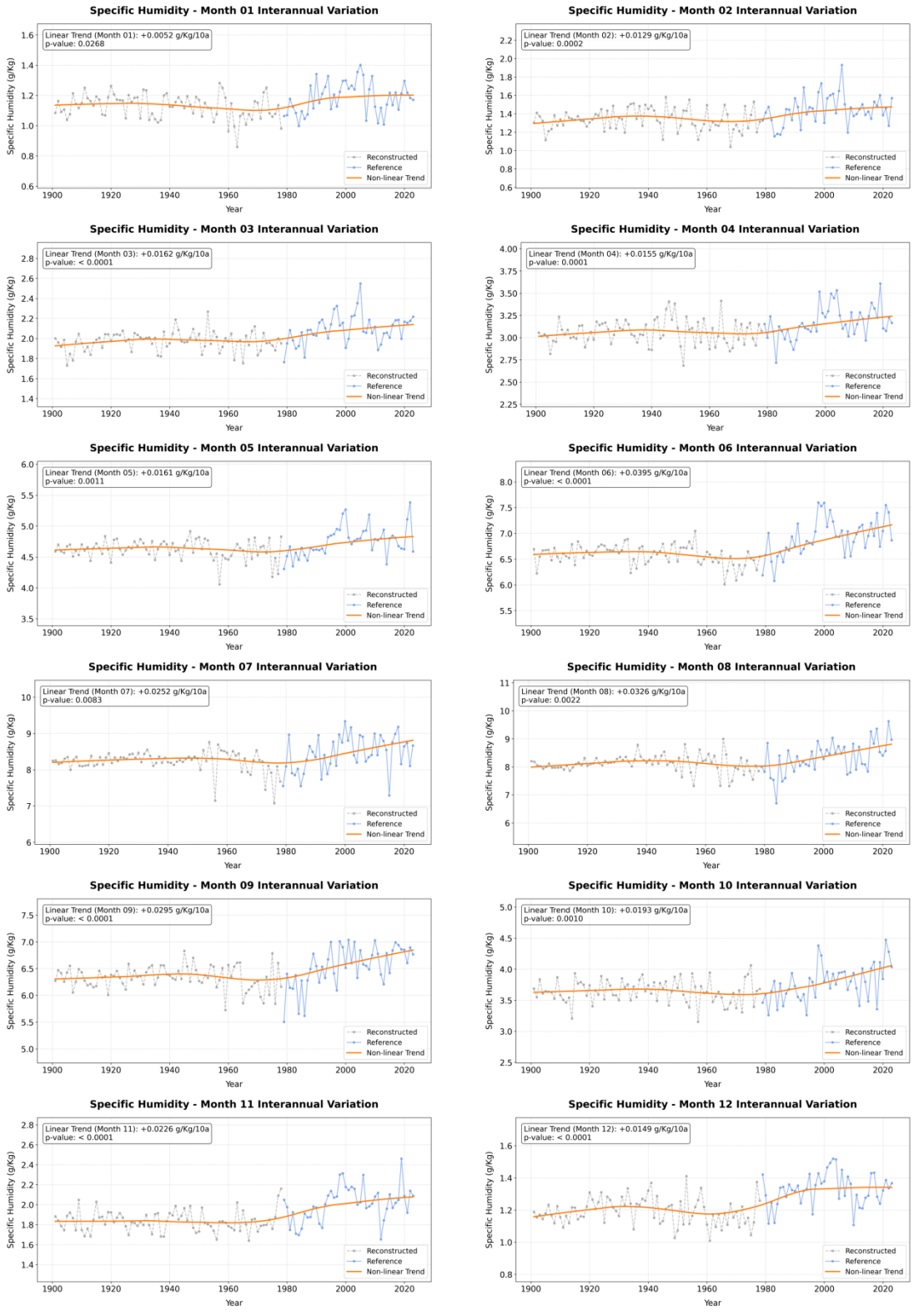

Figure S5. Monthly interannual variations of 2 m specific humidity over the Tibetan Plateau (1901–2023). Grey dashed and solid blue lines denote the reconstructed (1901–1978) and reference (1979–2023) data, respectively. The orange curve indicates the trend.

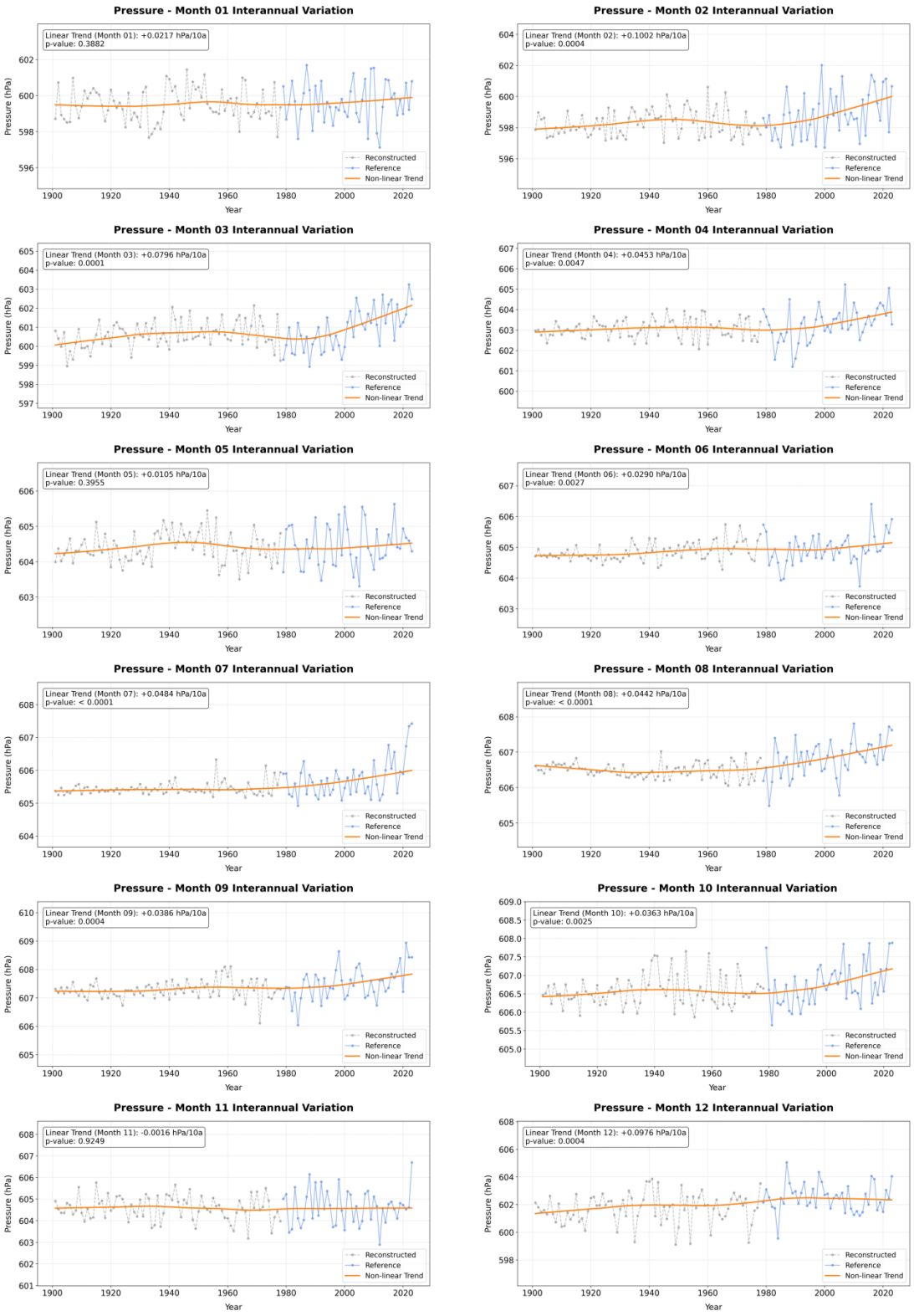

Figure S6. Monthly interannual variations of surface pressure over the Tibetan Plateau (1901–2023). Grey dashed and solid blue lines denote the reconstructed (1901–1978) and reference (1979–2023) data, respectively. The orange curve indicates the trend.

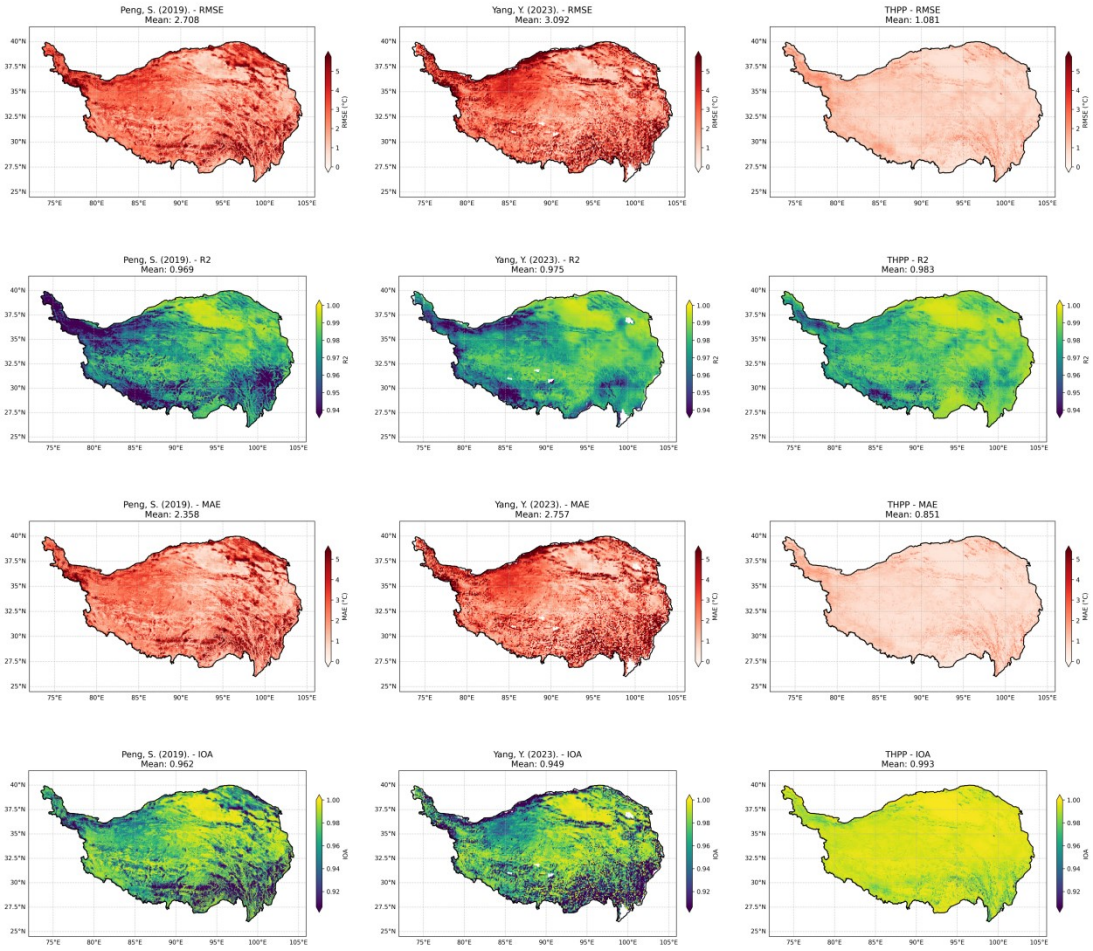

Figure S7. The panel compares the proposed TPHH product against two representative datasets: a delta-downscaling-based product (Peng, S., 2019) and a GAN-based deep-learning product (Yang, Y., 2023), using TPMFD as the benchmark. Metrics include the coefficient of determination (R^2), Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and Index of Agreement (IOA).

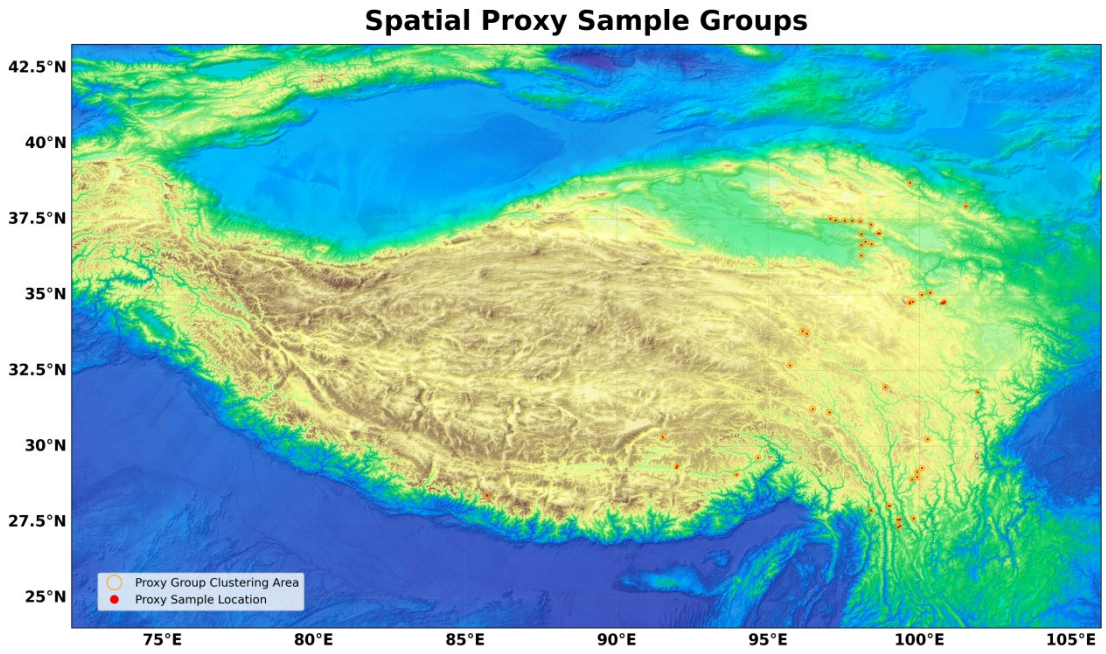

Figure S8. Geographical distribution of the 41 tree-ring proxy groups over the Tibetan Plateau used in this study. Symbols represent the precise locations of chronologies (red dots), while circles (orange) denote the spatial clustering areas defined for ternary regression fitting.

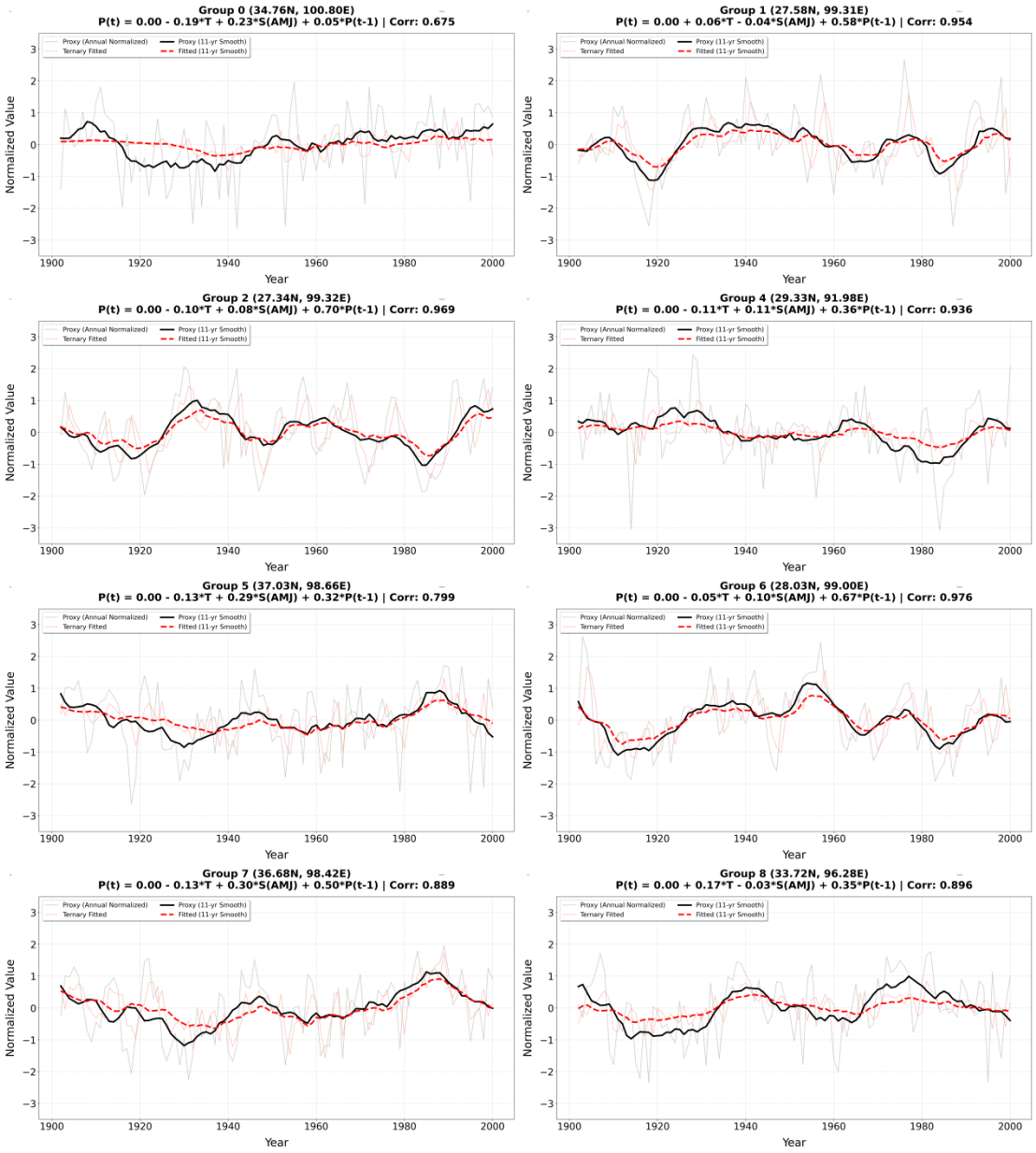

Figure S9. Temporal consistency between actual tree-ring proxy series and TPHH-based ternary fitted series for Groups 0–2 and 4–8 during 1901–2000. Each panel displays the annual normalized proxy values (light grey) and the 11-year moving average (black bold line), alongside the fitted series (light red line) and its 11-year smooth (red bold dashed line). The fitting equations, integrating JJA temperature (T), AMJ specific humidity (S), and lag -1 proxy memory (P(t-1)), are provided at the top of each subplot with their respective Pearson correlation coefficients (Corr). (Note: Group 3 is presented in Figure 12 of the main text).

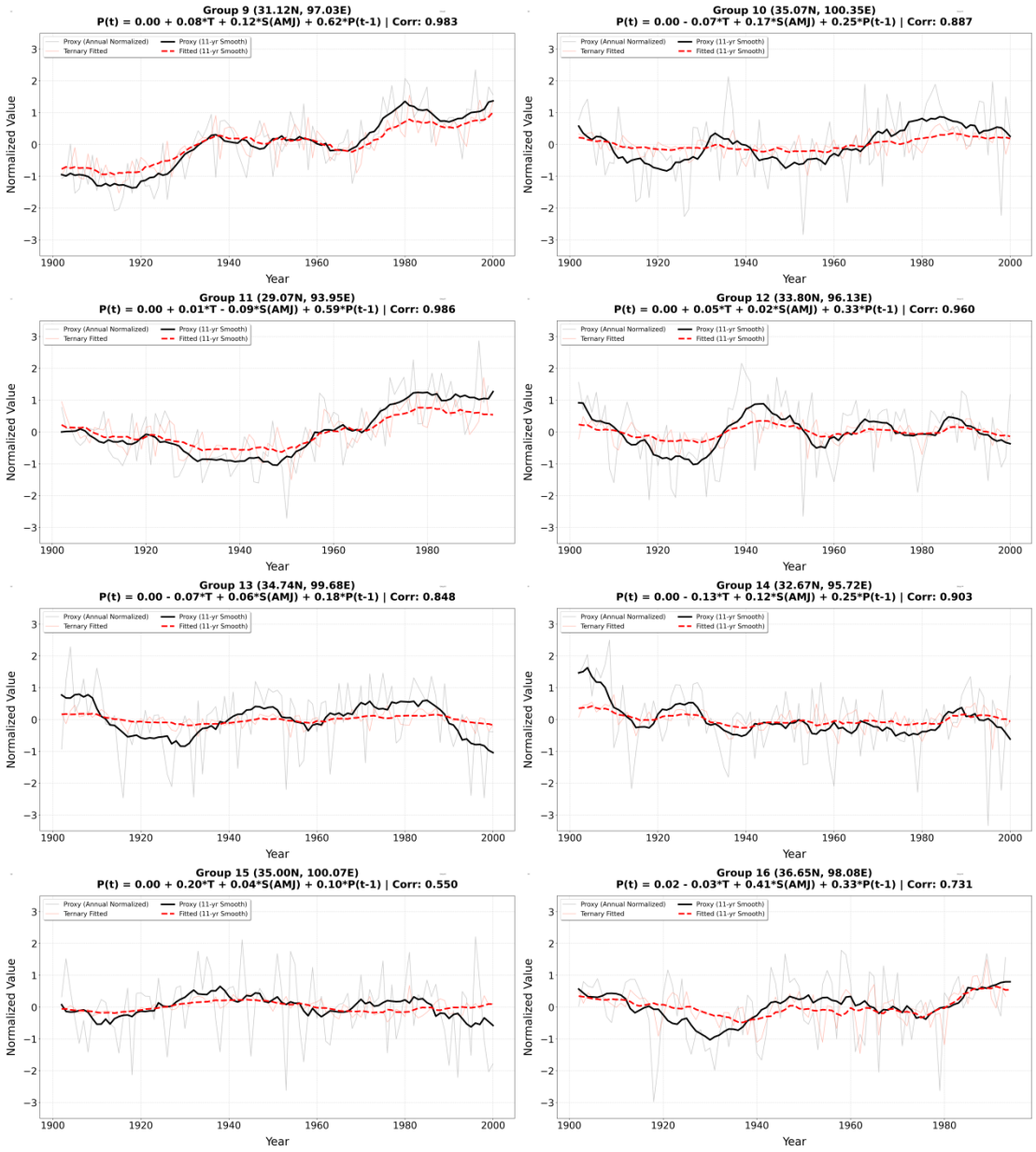

Figure S10. Temporal consistency between actual tree-ring proxy series and TPHH-based ternary fitted series for Groups 9-16 during 1901–2000. Each panel displays the annual normalized proxy values (light grey) and the 11-year moving average (black bold line), alongside the fitted series (light red line) and its 11-year smooth (red bold dashed line). The fitting equations, integrating JJA temperature (T), AMJ specific humidity (S), and lag -1 proxy memory (P(t-1)), are provided at the top of each subplot with their respective Pearson correlation coefficients (Corr).

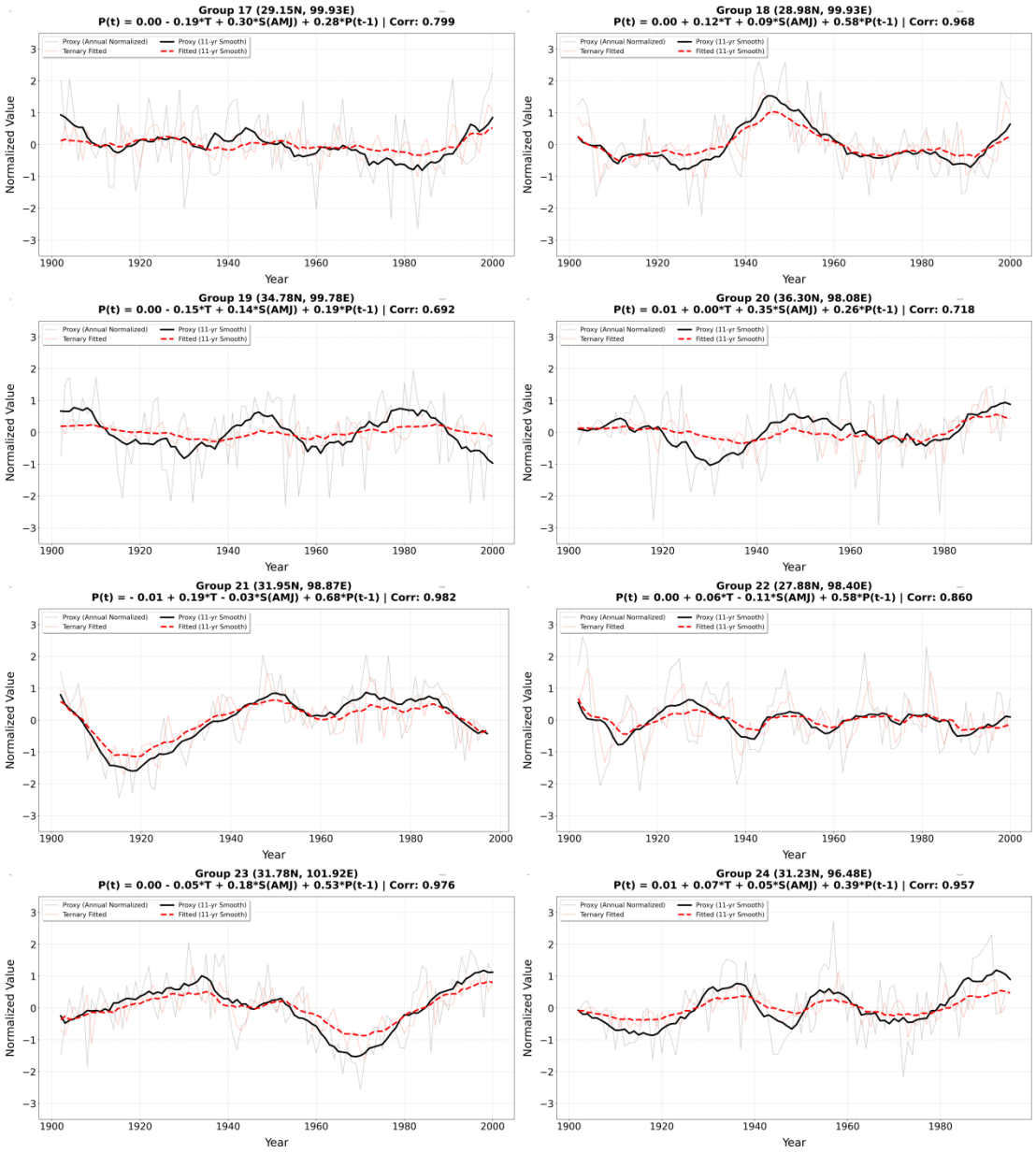

Figure S11. Temporal consistency between actual tree-ring proxy series and TPHH-based ternary fitted series for Groups 17-24 during 1901–2000. Each panel displays the annual normalized proxy values (light grey) and the 11-year moving average (black bold line), alongside the fitted series (light red line) and its 11-year smooth (red bold dashed line). The fitting equations, integrating JJA temperature (T), AMJ specific humidity (S), and lag -1 proxy memory (P(t-1)), are provided at the top of each subplot with their respective Pearson correlation coefficients (Corr).

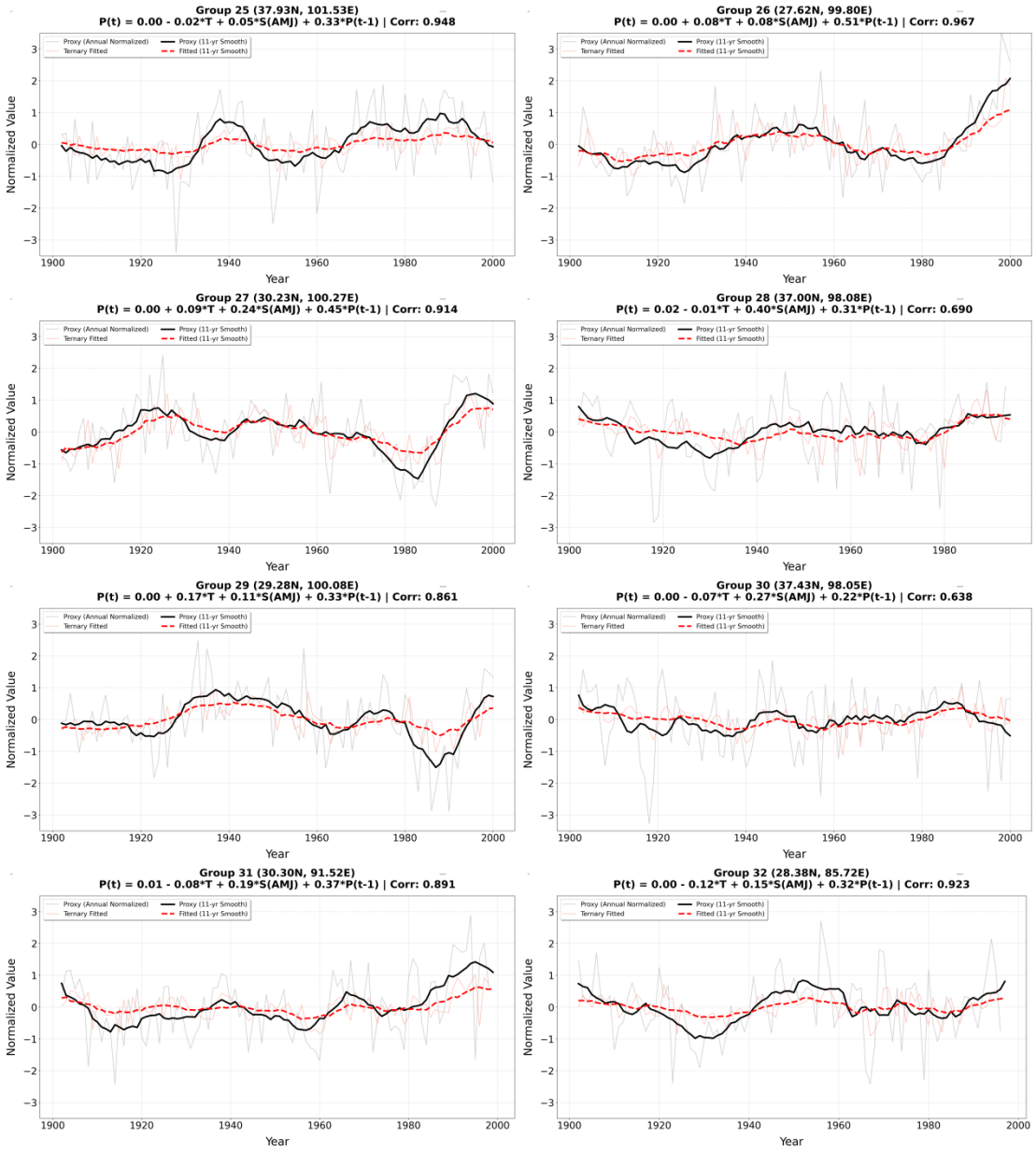

Figure S12. Temporal consistency between actual tree-ring proxy series and TPHH-based ternary fitted series for Groups 25-32 during 1901–2000. Each panel displays the annual normalized proxy values (light grey) and the 11-year moving average (black bold line), alongside the fitted series (light red line) and its 11-year smooth (red bold dashed line). The fitting equations, integrating JJA temperature (T), AMJ specific humidity (S), and lag -1 proxy memory (P(t-1)), are provided at the top of each subplot with their respective Pearson correlation coefficients (Corr).

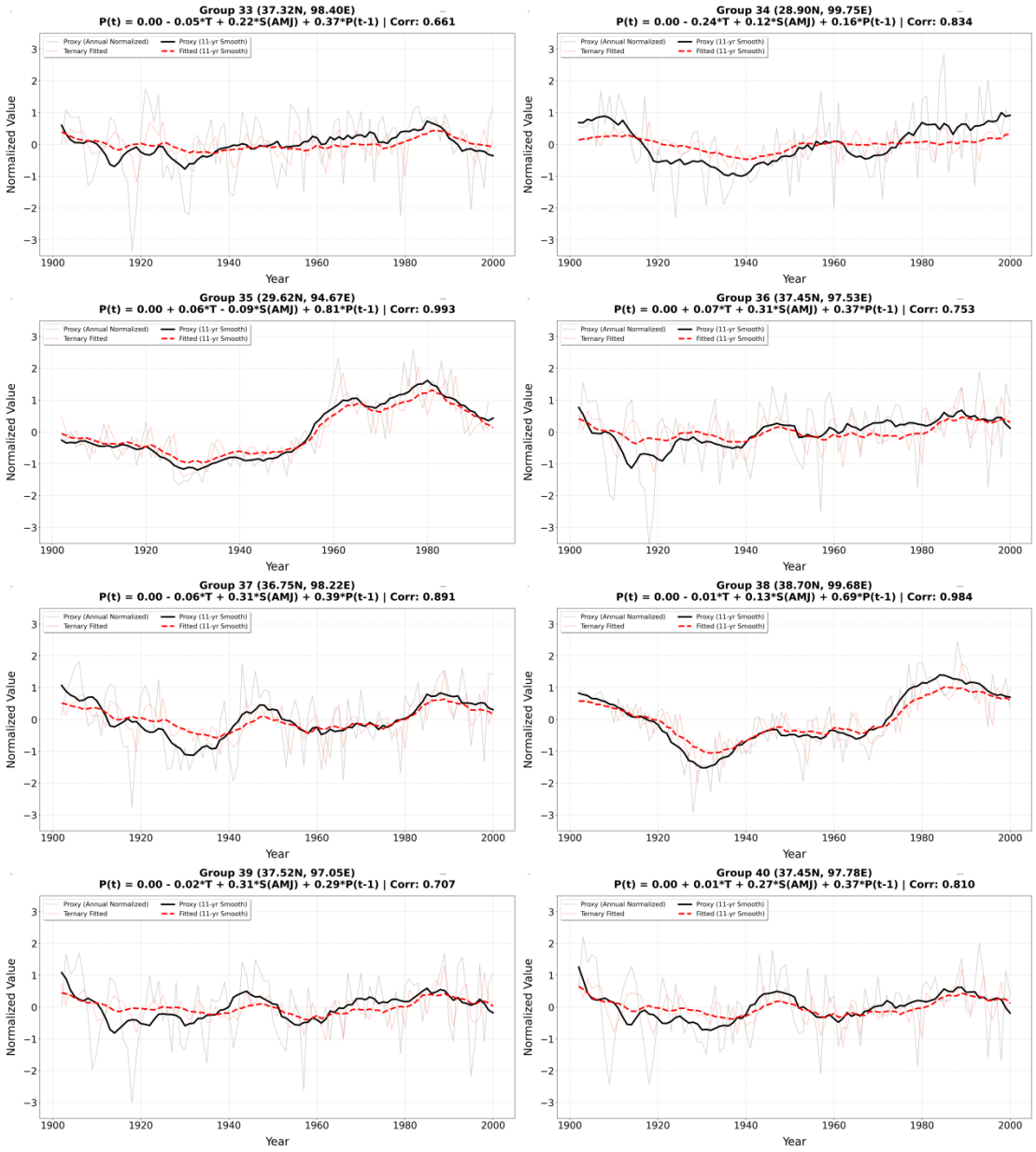

Figure S13. Temporal consistency between actual tree-ring proxy series and TPHH-based ternary fitted series for Groups 33-40 during 1901–2000. Each panel displays the annual normalized proxy values (light grey) and the 11-year moving average (black bold line), alongside the fitted series (light red line) and its 11-year smooth (red bold dashed line). The fitting equations, integrating JJA temperature (T), AMJ specific humidity (S), and lag -1 proxy memory (P(t-1)), are provided at the top of each subplot with their respective Pearson correlation coefficients (Corr).