# Supplementary Material

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## Contents

# 1 Supplementary

## 1.1 Individual Station Trend Analysis

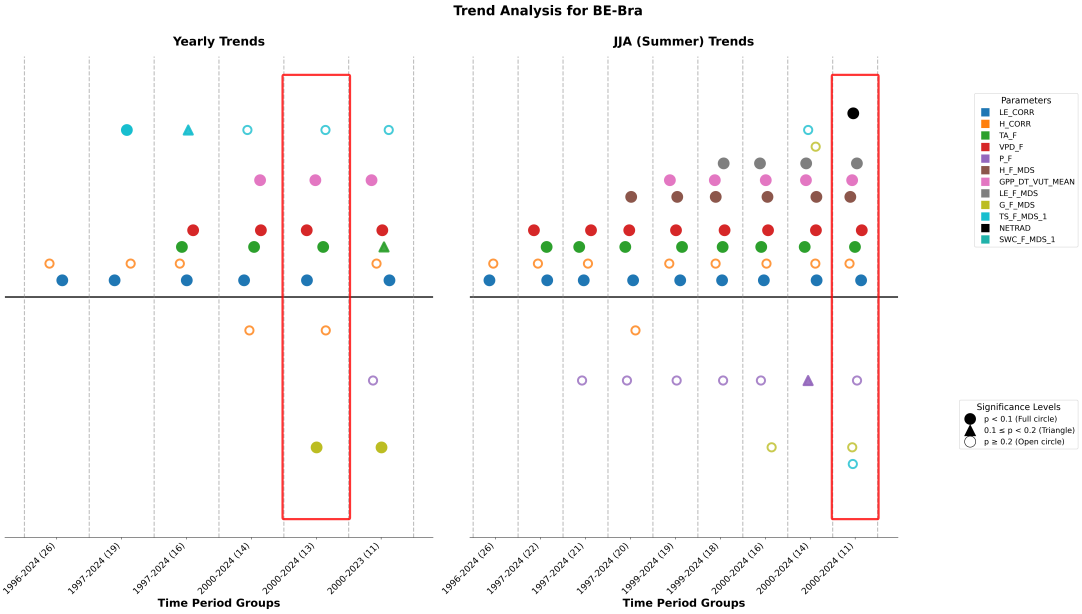


Figure 1: Side-by-side recursive trend visualization for station BE-Bra (Belgium) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. The horizontal axis shows recursive steps (from relaxed to strict combinations), markers above/below the zero line indicate positive/negative Sen's slope, marker style indicates Mann–Kendall significance (circle: $p < 0.10$, triangle: $0.10 \leq p < 0.20$, open circle: $p \geq 0.20$), and marker colors identify variables consistently across the analysis. The red box highlights the selected period used for summary statistics.

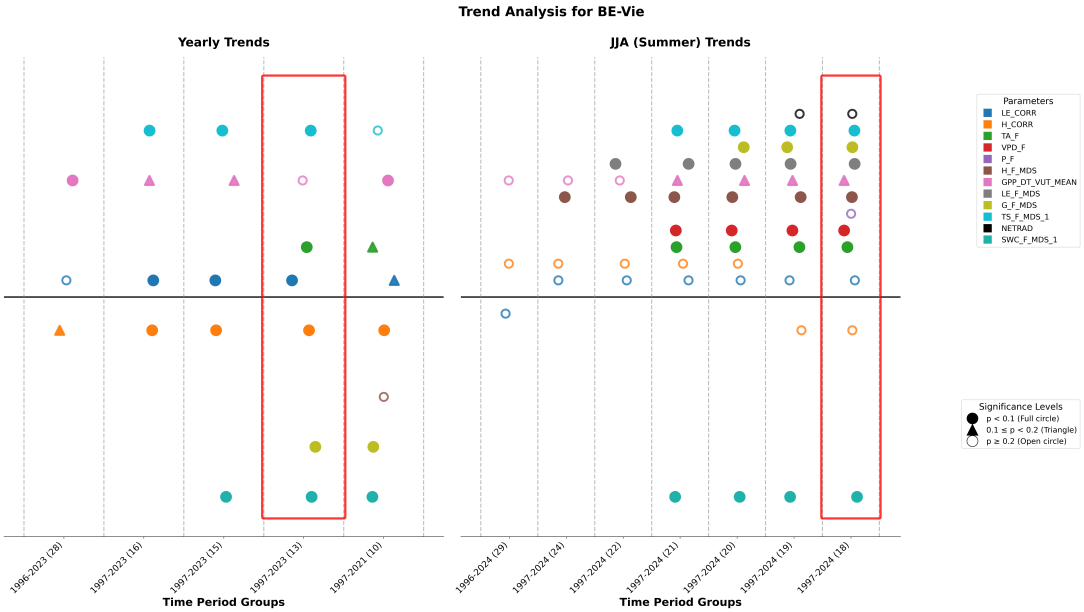


Figure 2: Side-by-side recursive trend visualization for station BE-Vie (Belgium) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

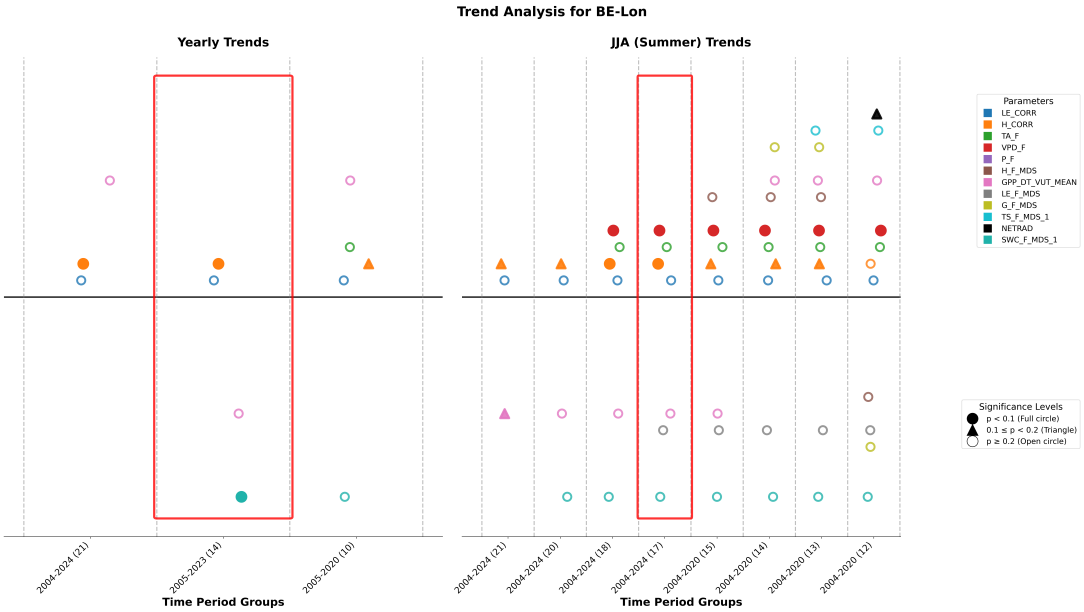


Figure 3: Side-by-side recursive trend visualization for station BE-Lon (Belgium) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

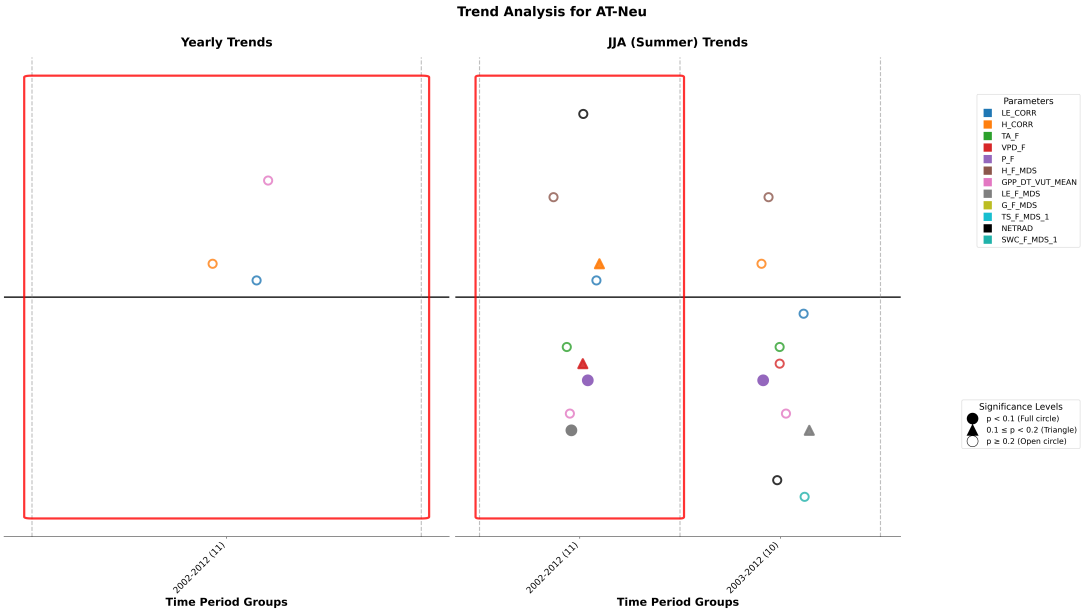


Figure 4: Side-by-side recursive trend visualization for station AT-Neu (Austria) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

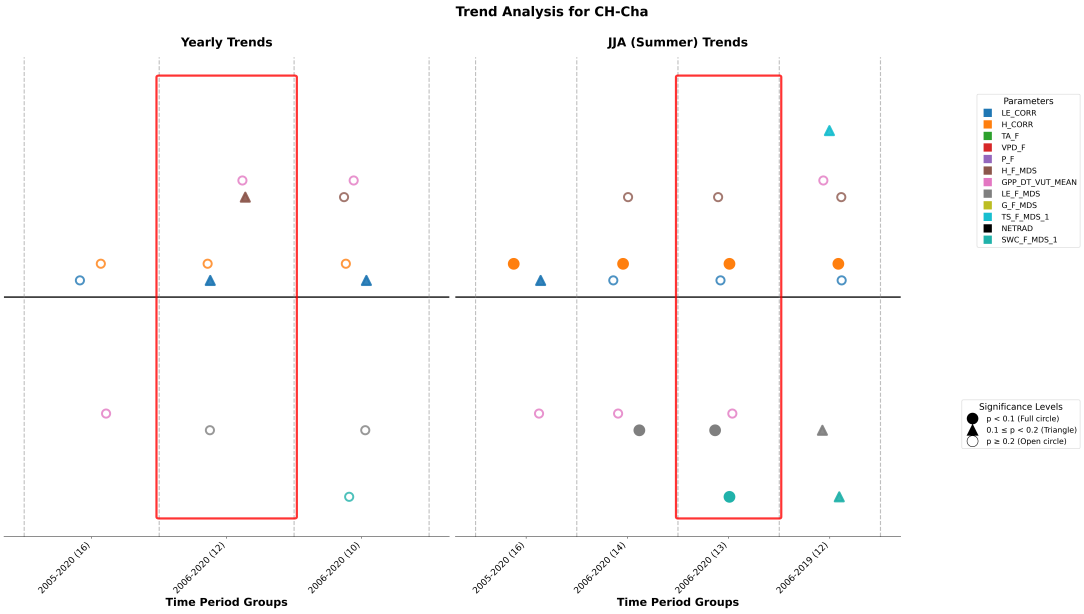


Figure 5: Side-by-side recursive trend visualization for station CH-Cha (Switzerland) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

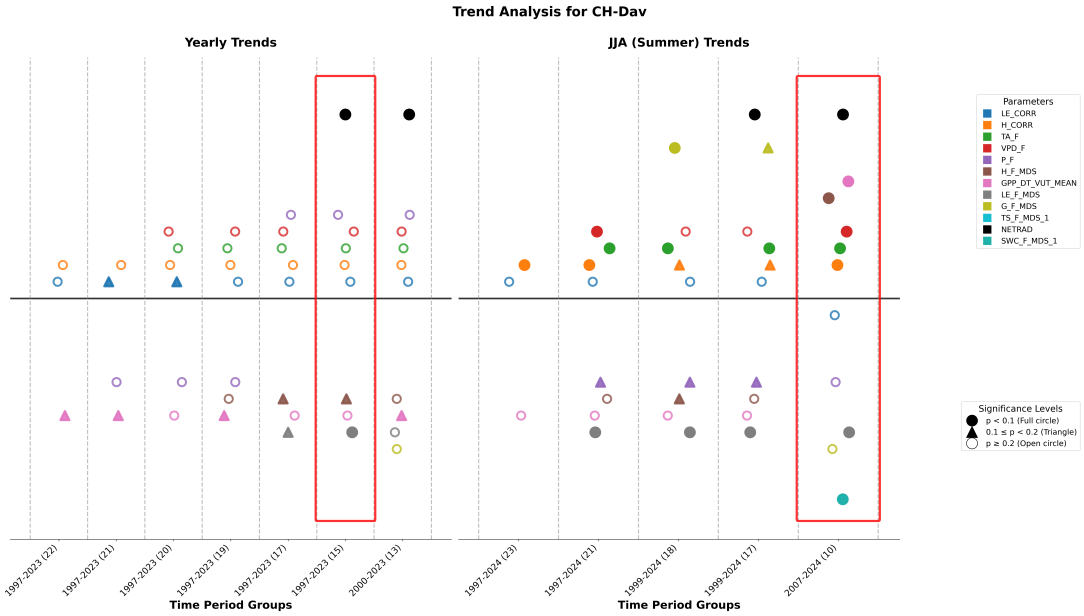


Figure 6: Side-by-side recursive trend visualization for station CH-Dav (Switzerland) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

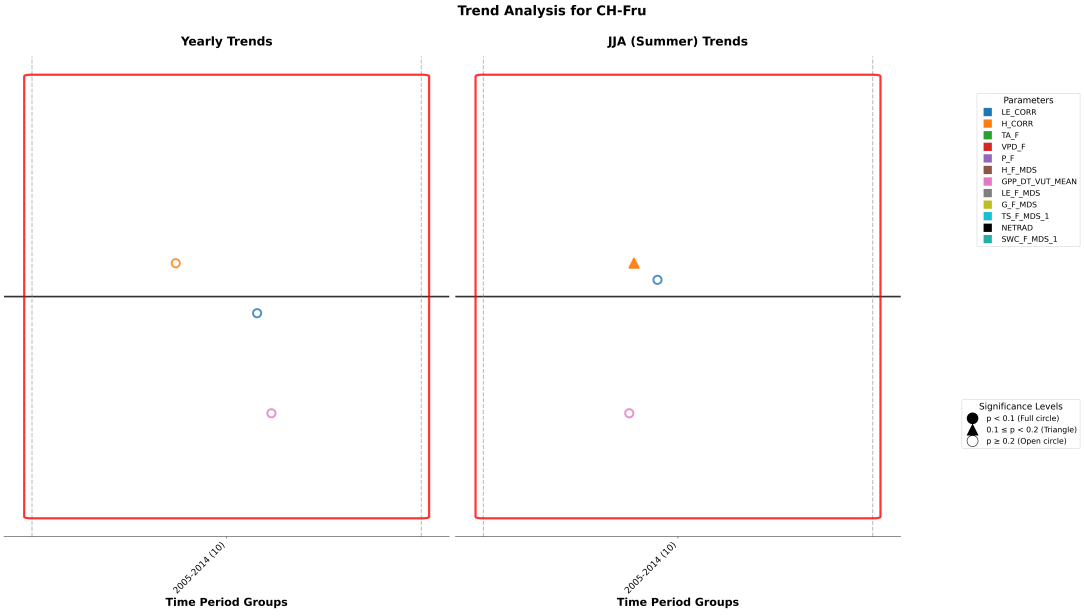


Figure 7: Side-by-side recursive trend visualization for station CH-Fru (Switzerland) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

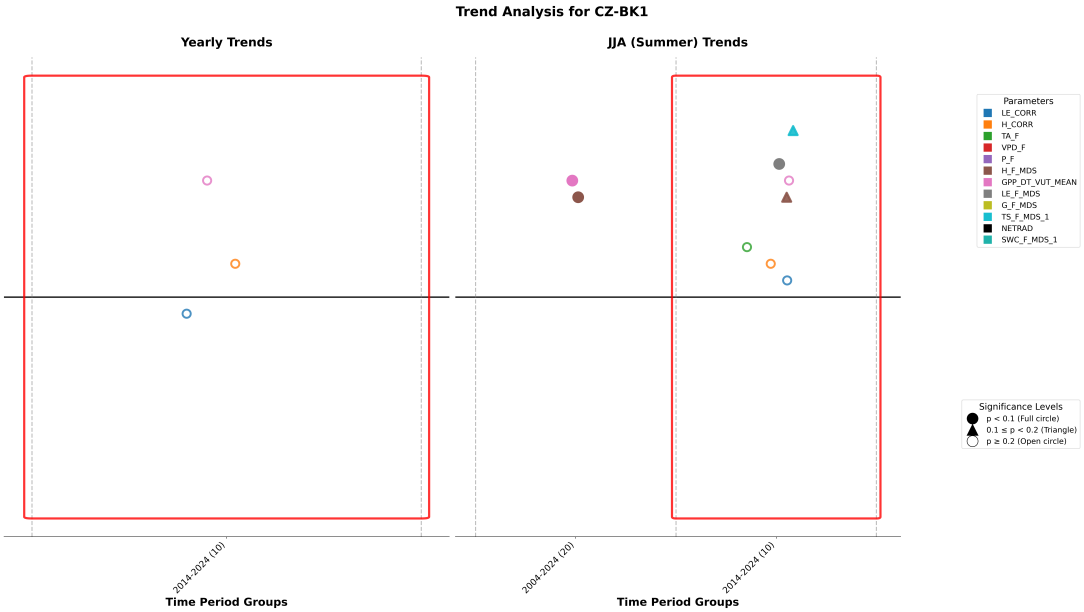


Figure 8: Side-by-side recursive trend visualization for station CZ-BK1 (Czech Republic) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

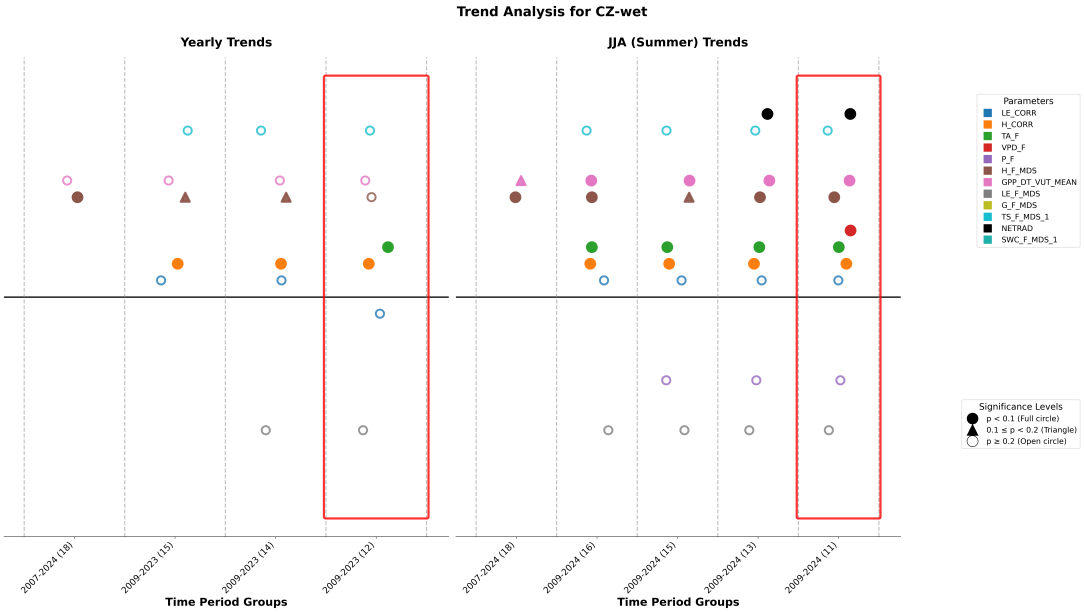


Figure 9: Side-by-side recursive trend visualization for station CZ-wet (Czech Republic) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

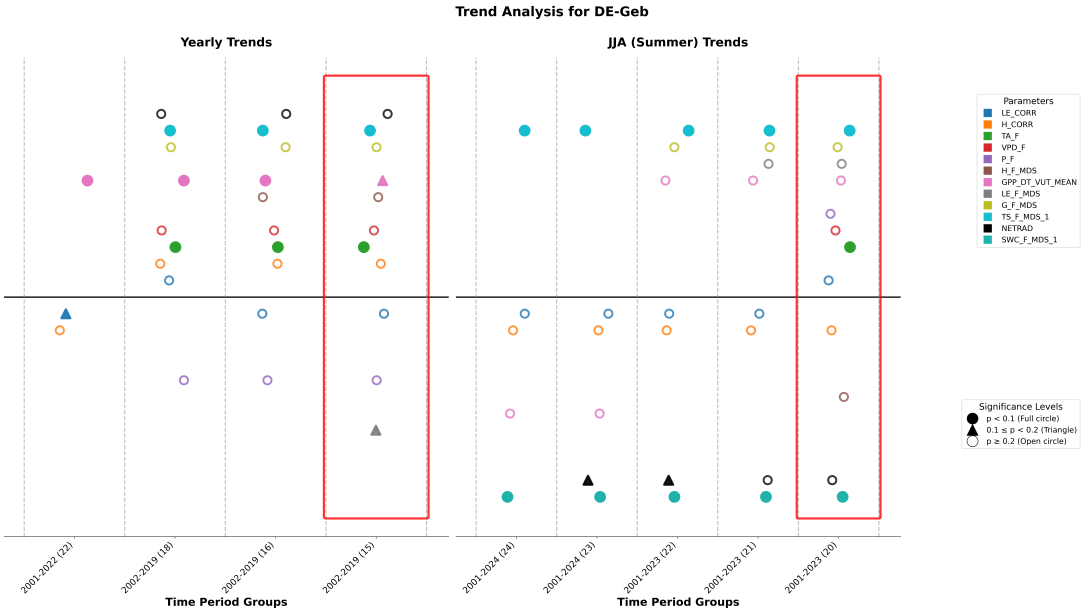


Figure 10: Side-by-side recursive trend visualization for station DE-Geb (Germany) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

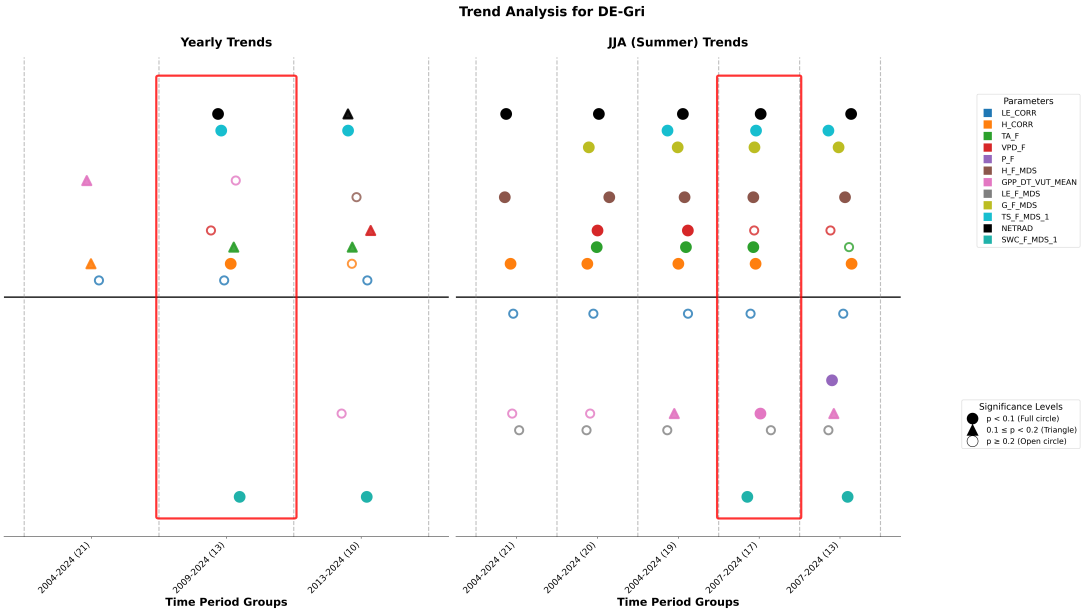


Figure 11: Side-by-side recursive trend visualization for station DE-Gri (Germany) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

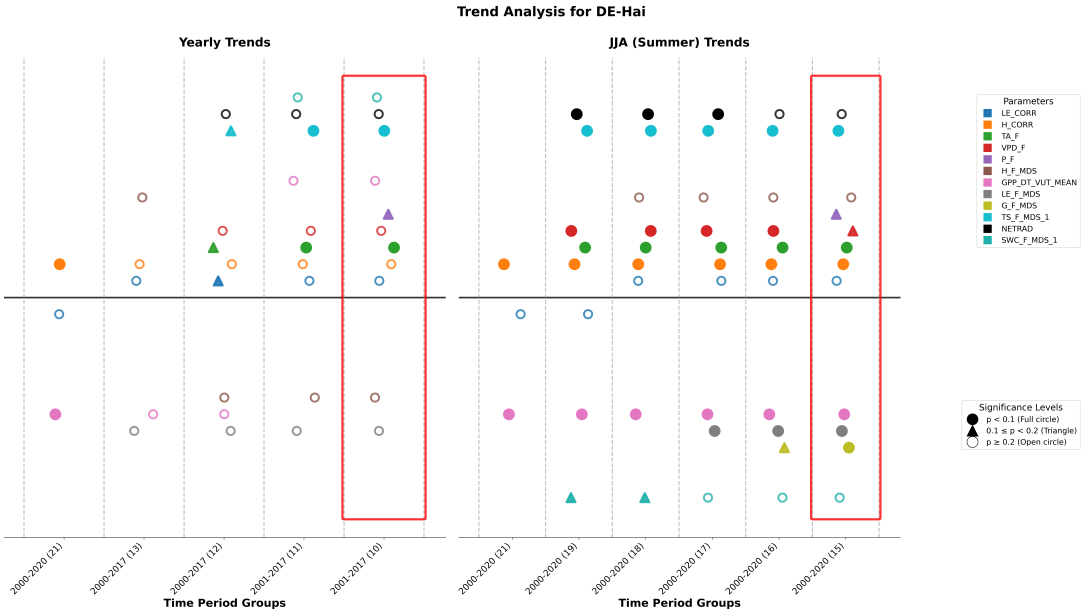


Figure 12: Side-by-side recursive trend visualization for station DE-Hai (Germany) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

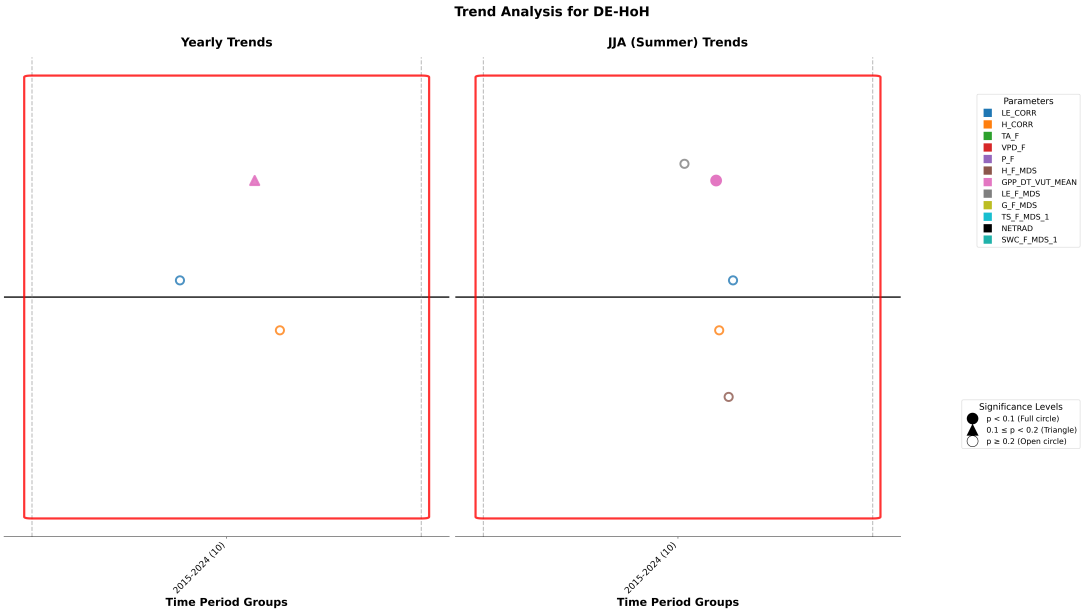


Figure 13: Side-by-side recursive trend visualization for station DE-HoH (Germany) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

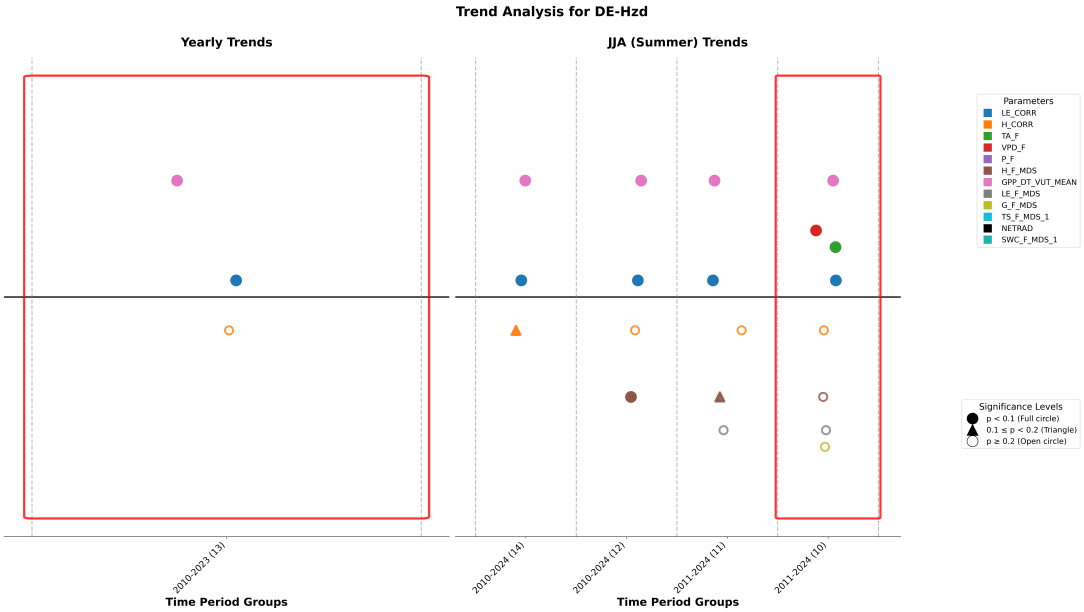


Figure 14: Side-by-side recursive trend visualization for station DE-Hzd (Germany) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

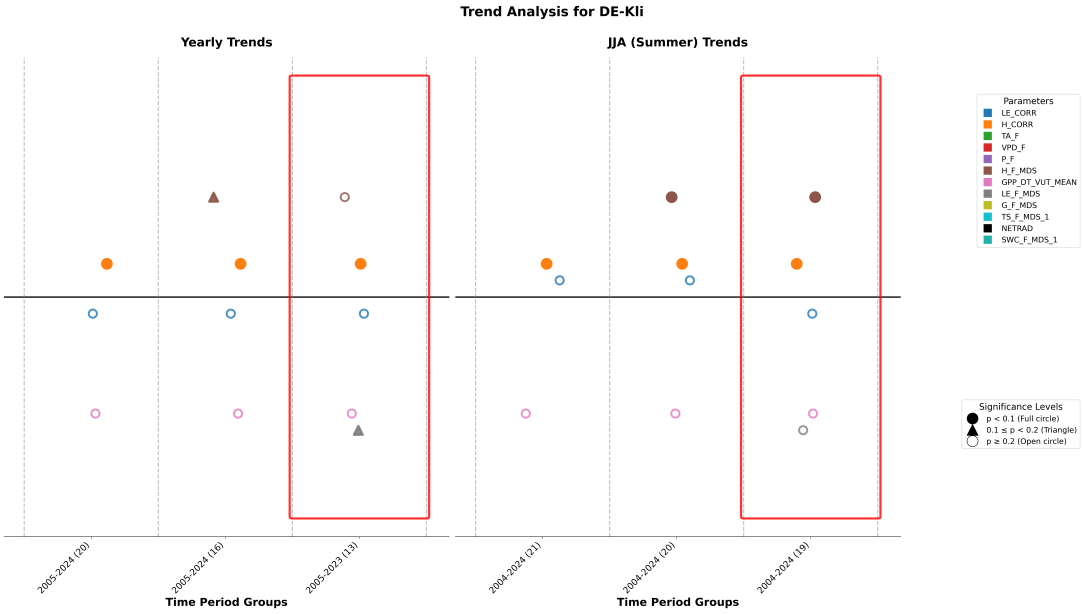


Figure 15: Side-by-side recursive trend visualization for station DE-Kli (Germany) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

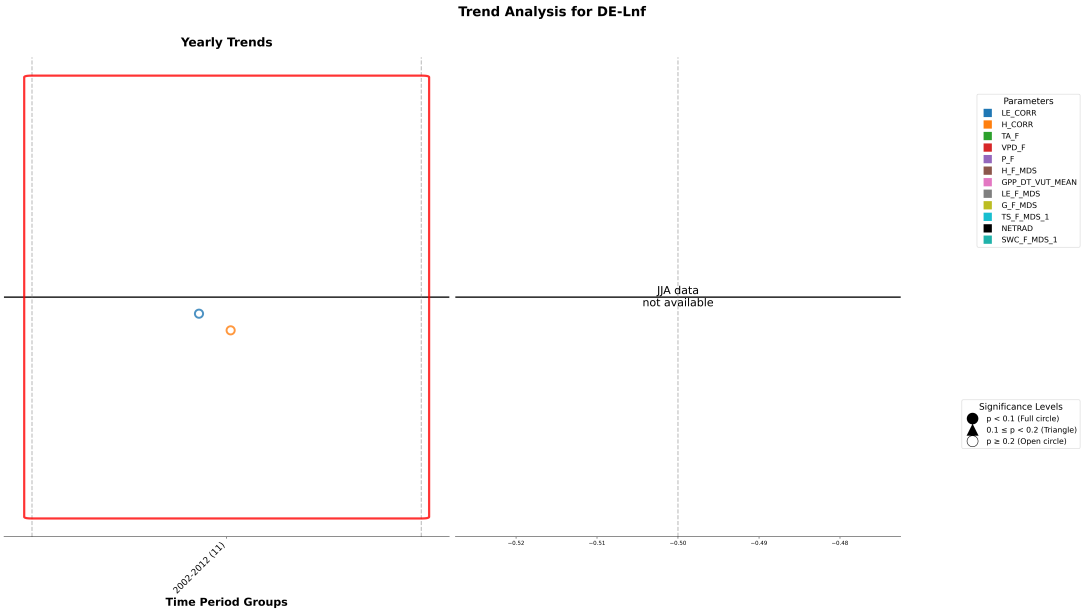


Figure 16: Side-by-side recursive trend visualization for station DE-Lnf (Germany) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

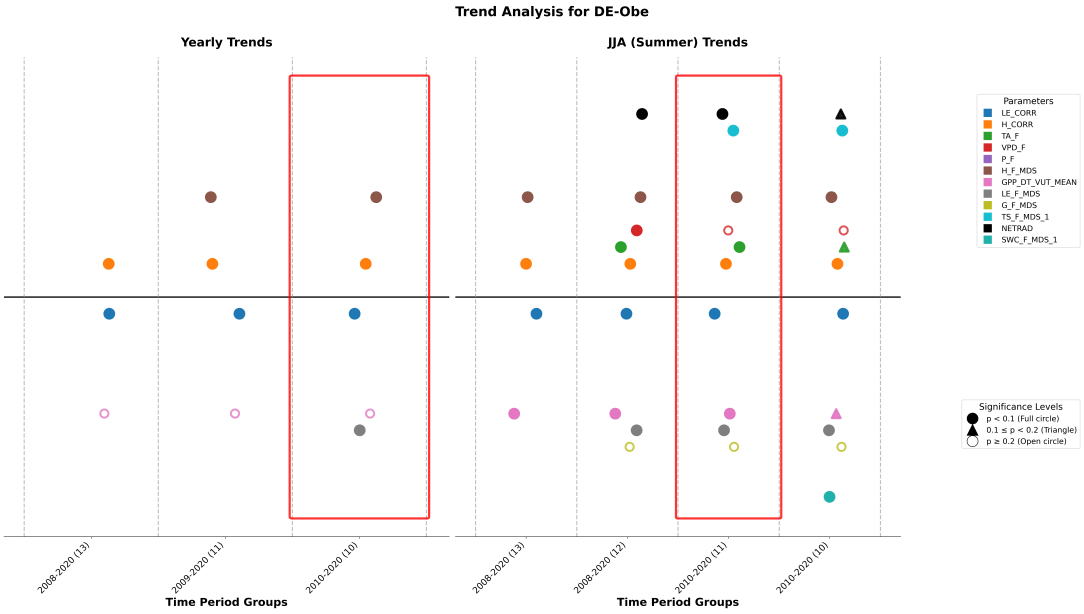


Figure 17: Side-by-side recursive trend visualization for station DE-Obe (Germany) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

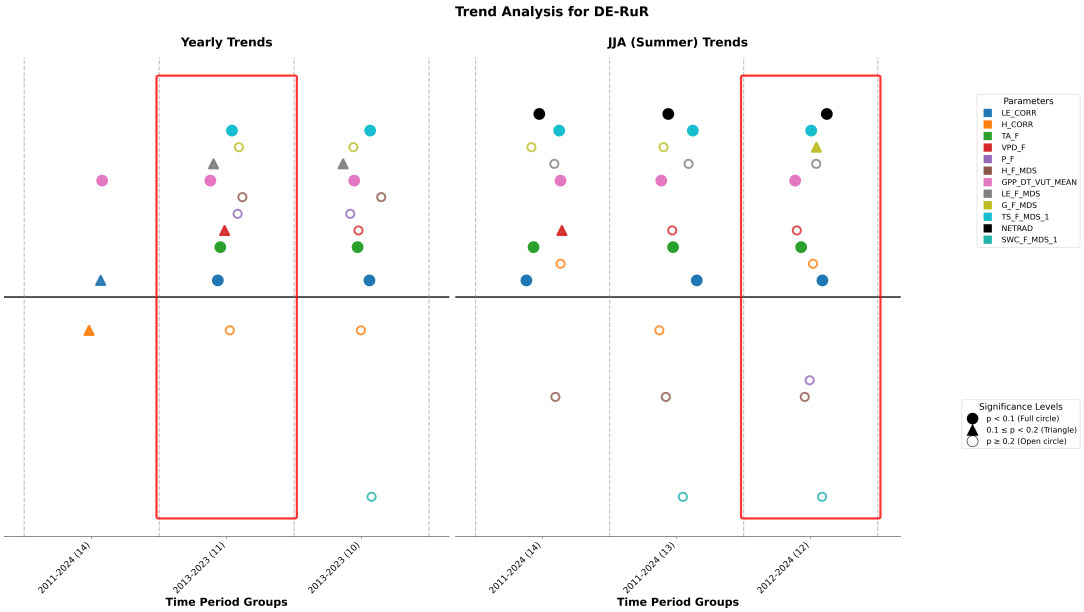


Figure 18: Side-by-side recursive trend visualization for station DE-RuR (Germany) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

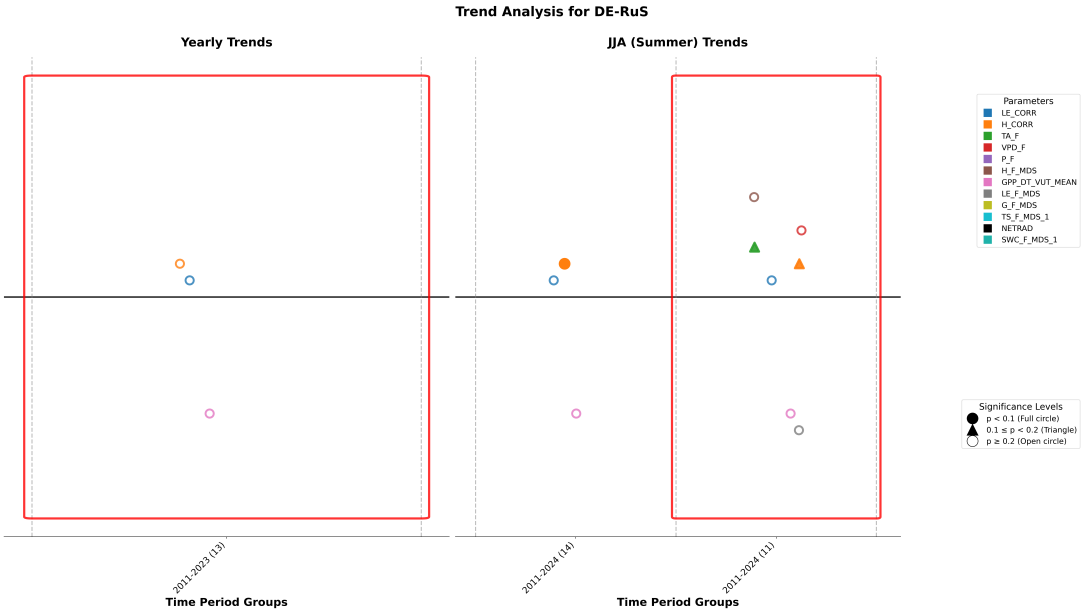


Figure 19: Side-by-side recursive trend visualization for station DE-RuS (Germany) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

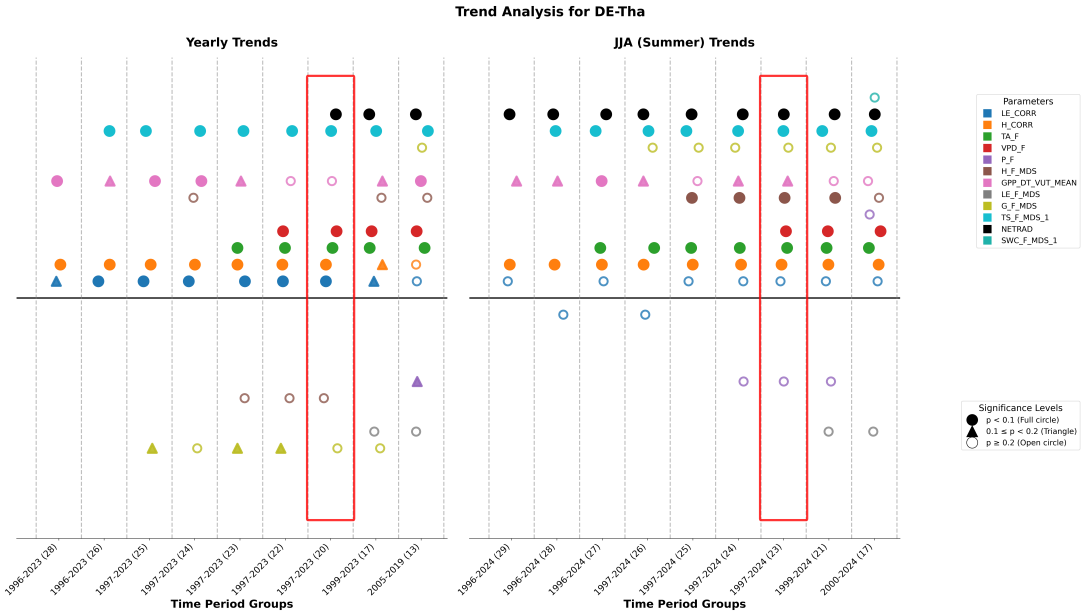


Figure 20: Side-by-side recursive trend visualization for station DE-Tha (Germany) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

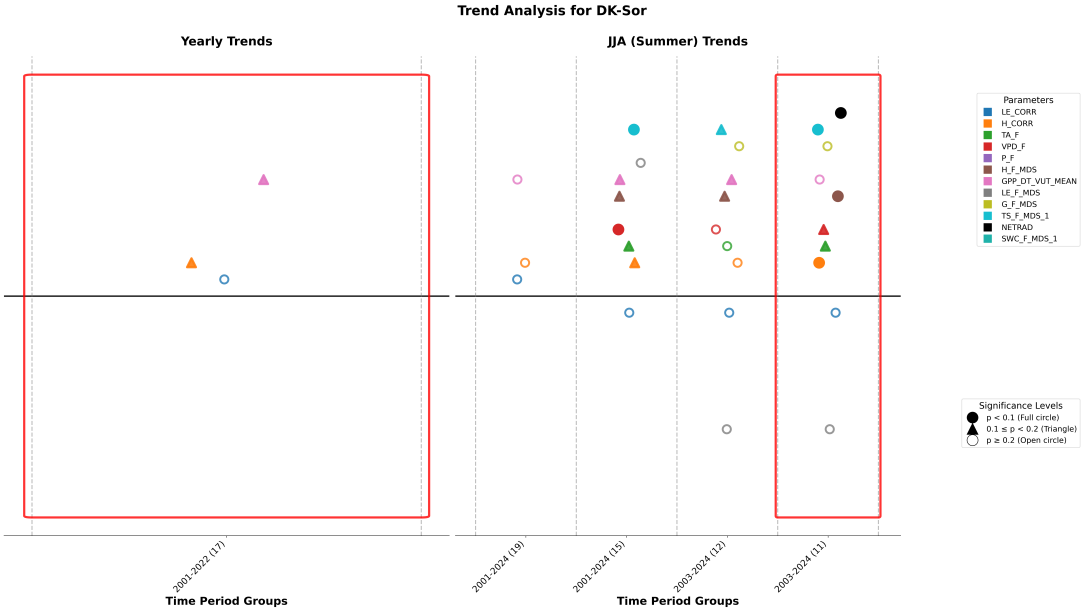


Figure 21: Side-by-side recursive trend visualization for station DK-Sor (Denmark) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

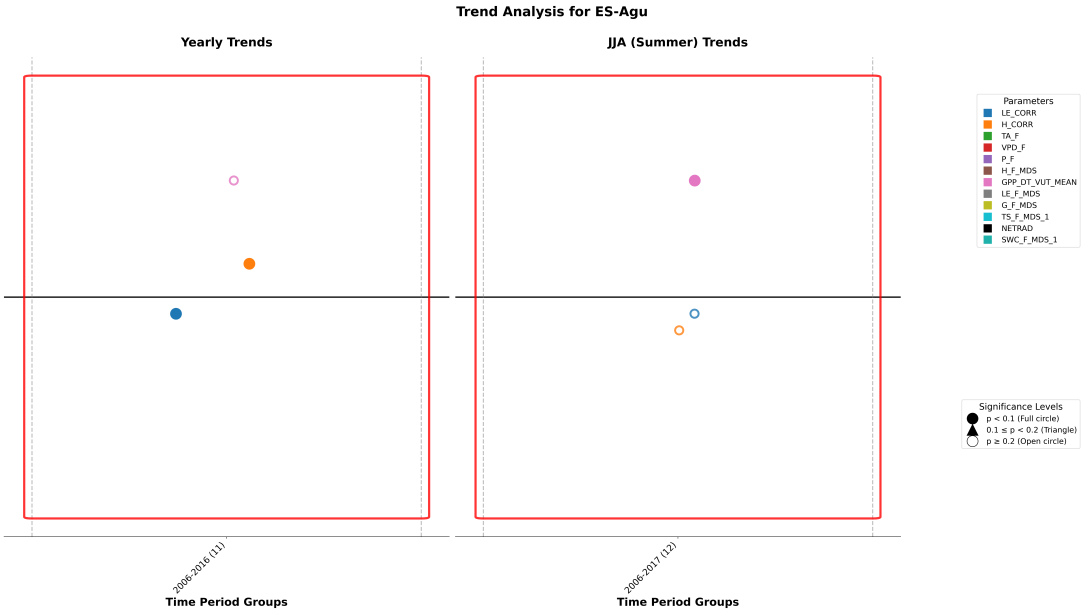


Figure 22: Side-by-side recursive trend visualization for station ES-Agu (Spain) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

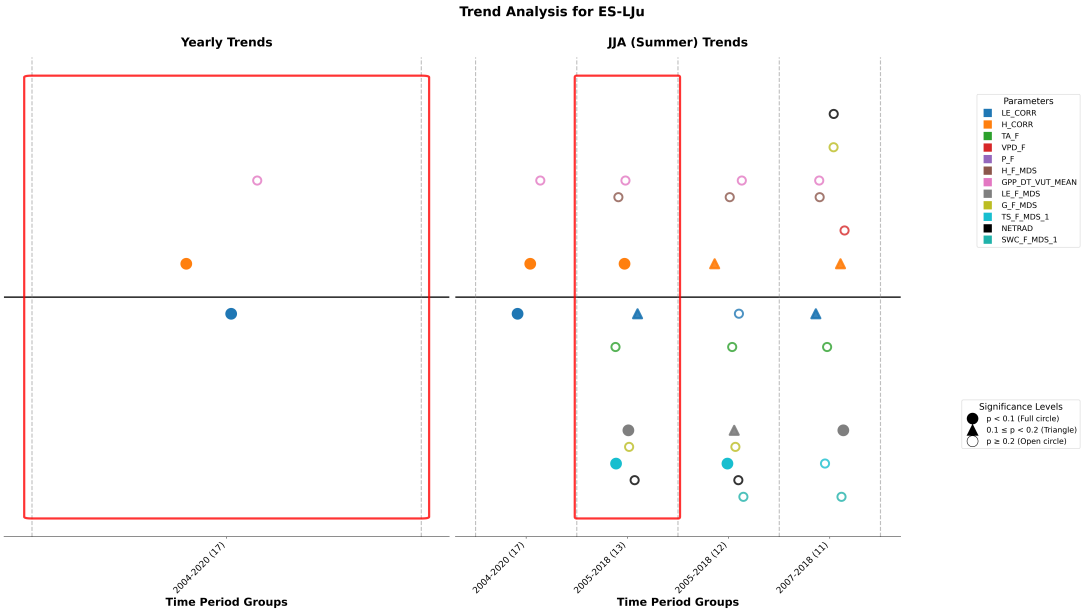


Figure 23: Side-by-side recursive trend visualization for station ES-LJu (Spain) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

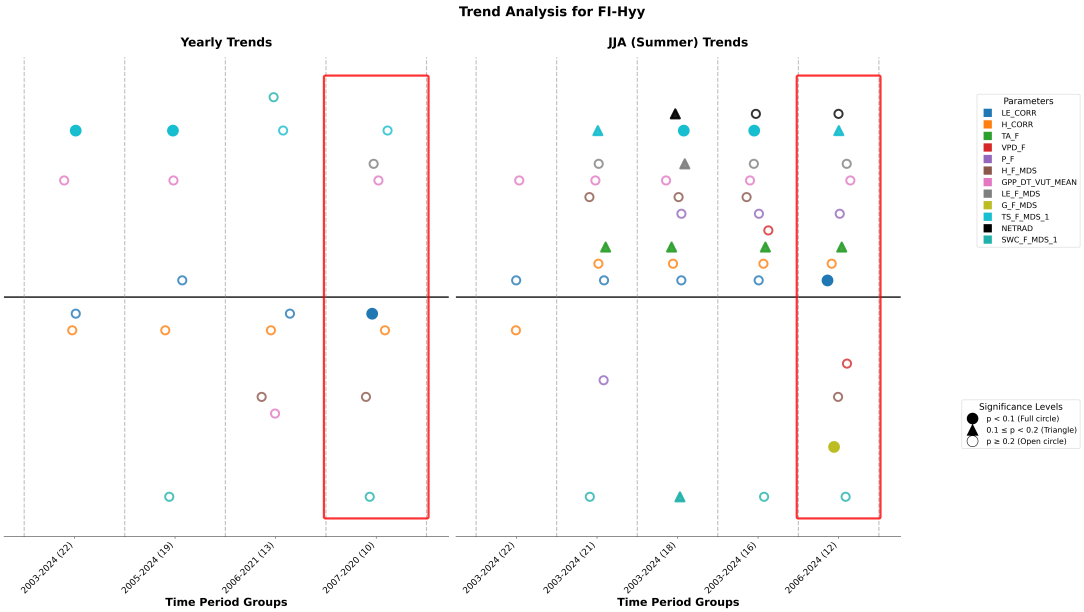


Figure 24: Side-by-side recursive trend visualization for station FI-Hyy (Finland) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

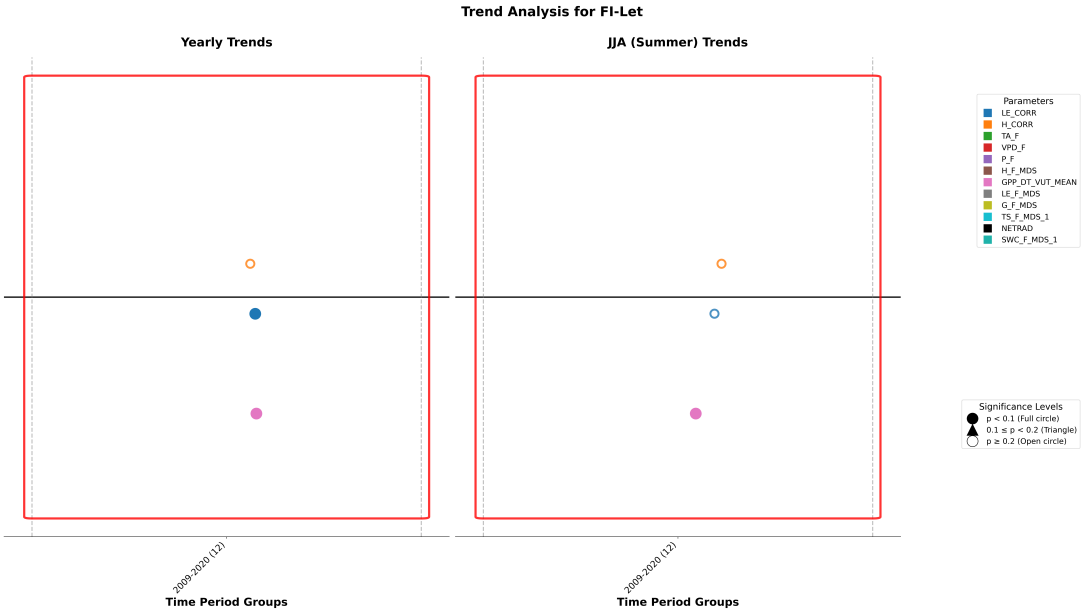


Figure 25: Side-by-side recursive trend visualization for station FI-Let (Finland) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

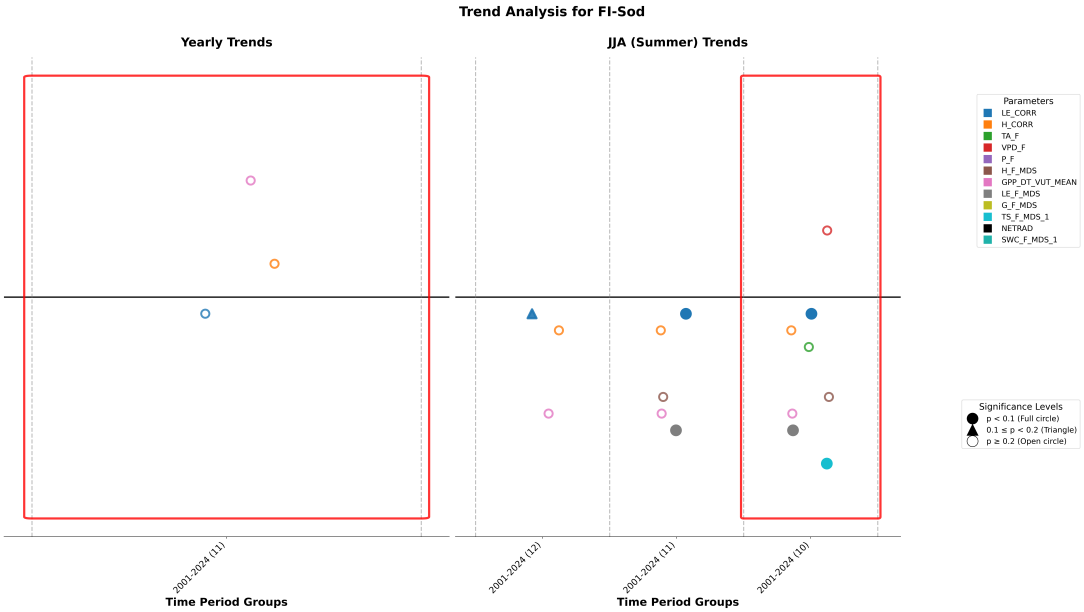


Figure 26: Side-by-side recursive trend visualization for station FI-Sod (Finland) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

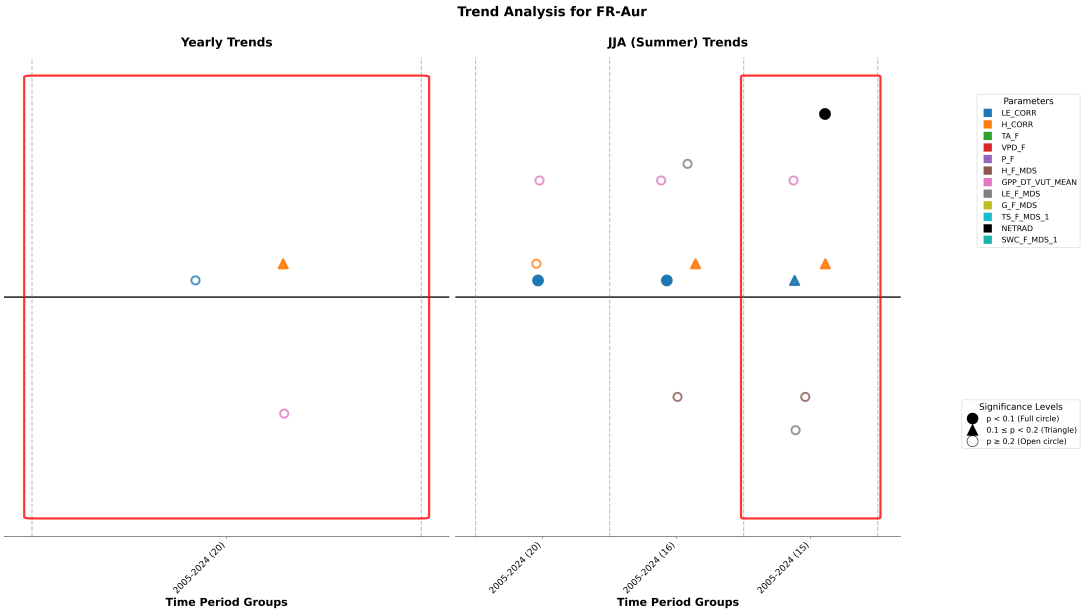


Figure 27: Side-by-side recursive trend visualization for station FR-Aur (France) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

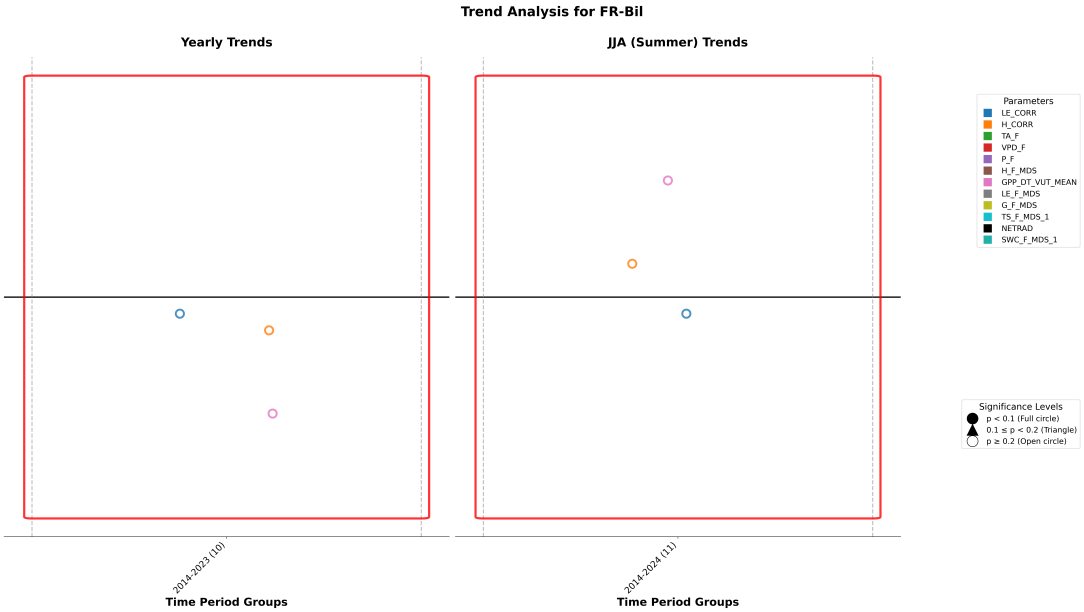


Figure 28: Side-by-side recursive trend visualization for station FR-Bil (France) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

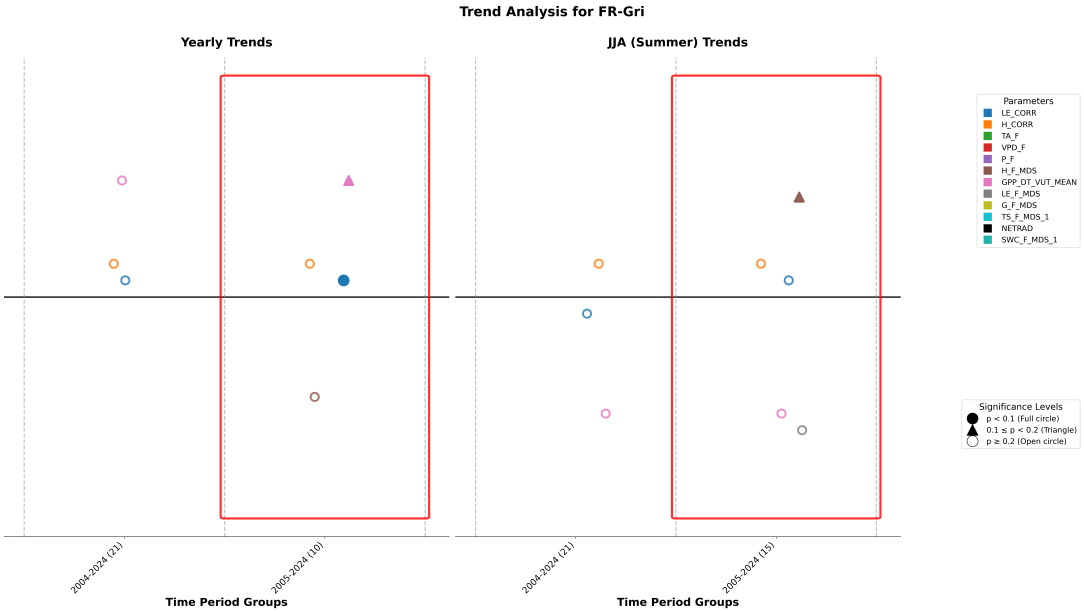


Figure 29: Side-by-side recursive trend visualization for station FR-Gri (France) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

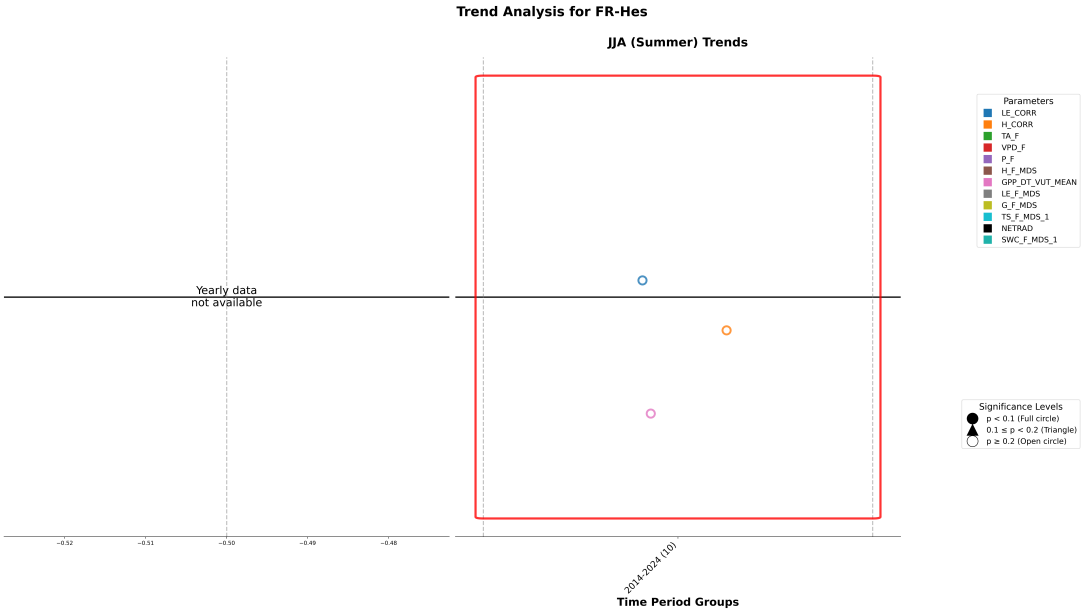


Figure 30: Side-by-side recursive trend visualization for station FR-Hes (France) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

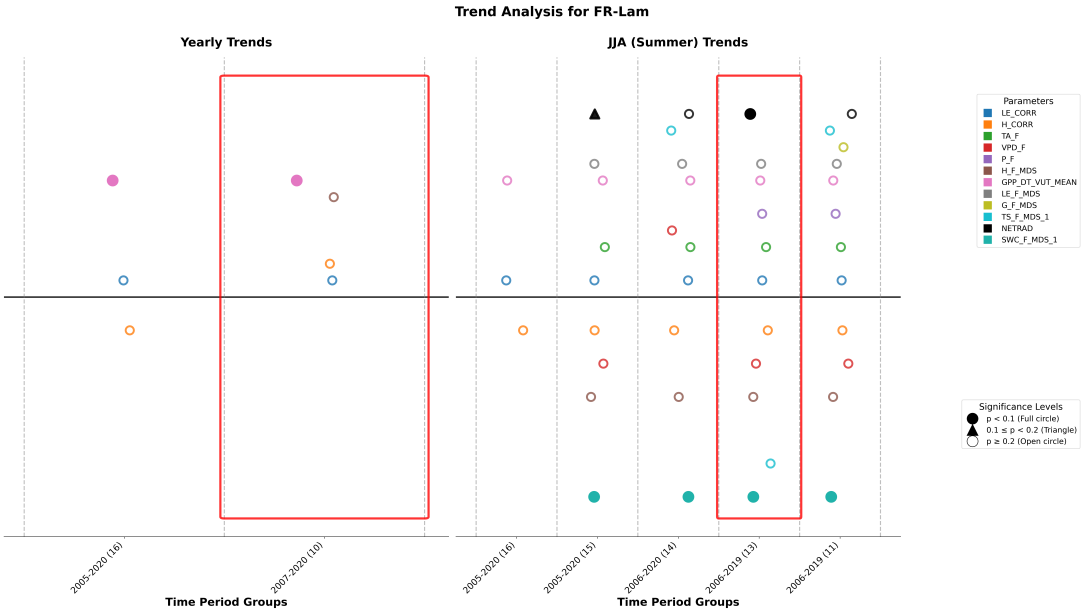


Figure 31: Side-by-side recursive trend visualization for station FR-Lam (France) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

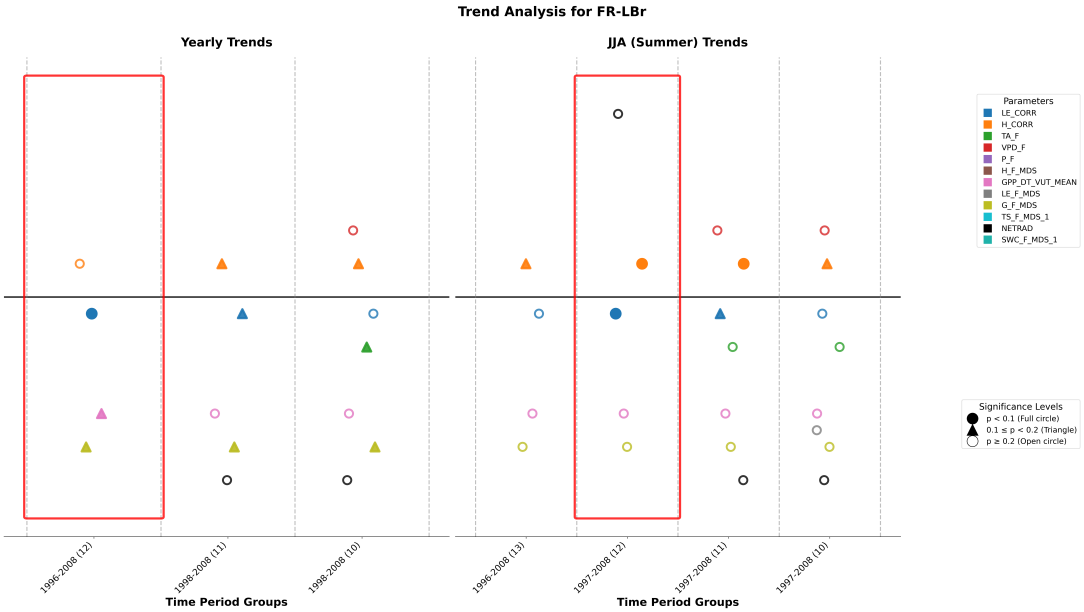


Figure 32: Side-by-side recursive trend visualization for station FR-LBr (France) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

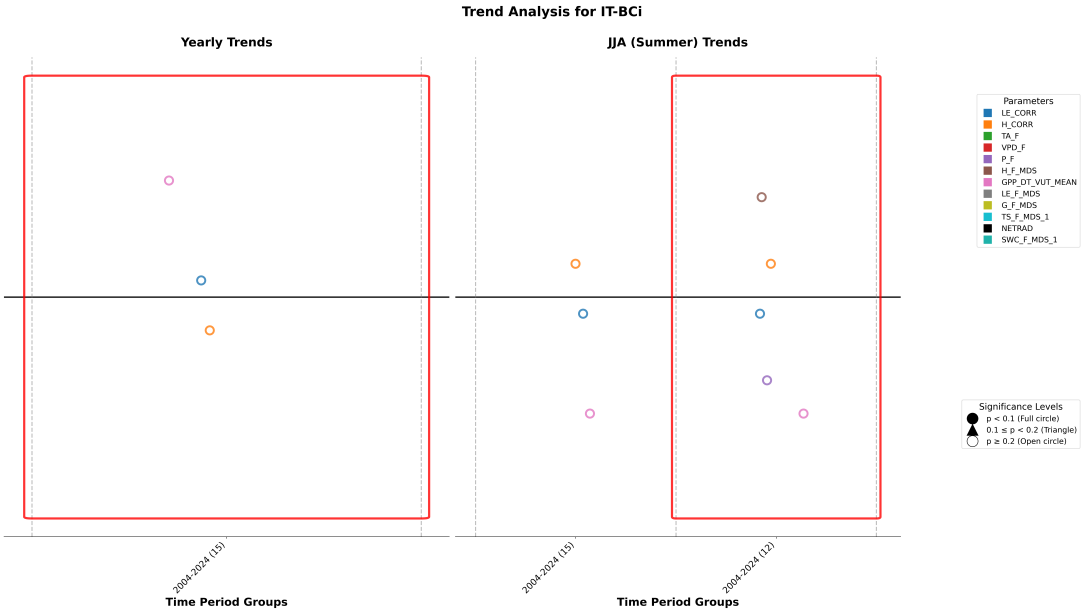


Figure 33: Side-by-side recursive trend visualization for station IT-BCi (Italy) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

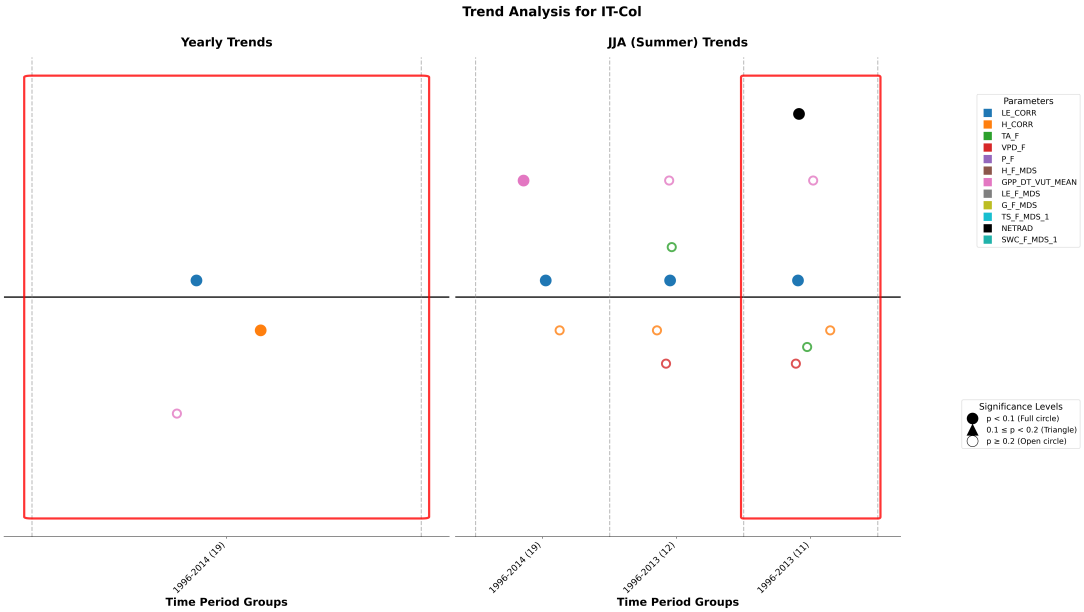


Figure 34: Side-by-side recursive trend visualization for station IT-Col (Italy) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

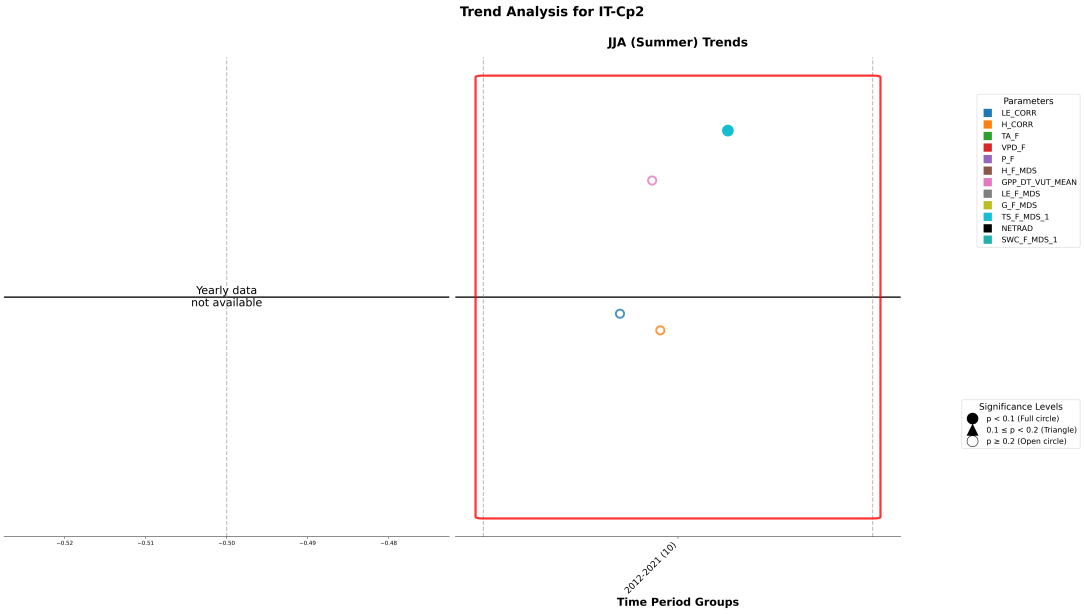


Figure 35: Side-by-side recursive trend visualization for station IT-Cp2 (Italy) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

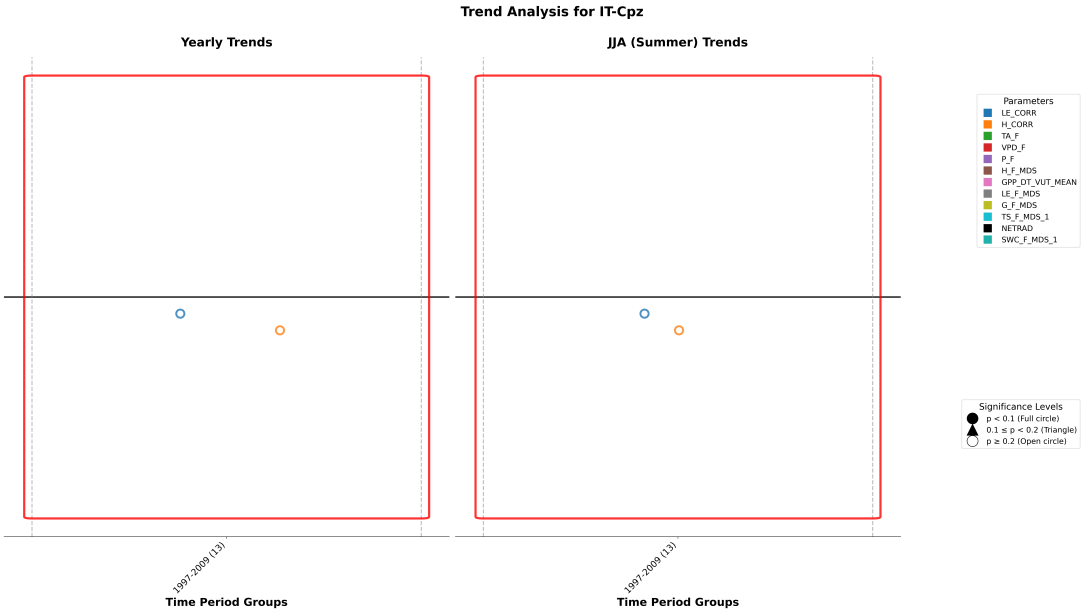


Figure 36: Side-by-side recursive trend visualization for station IT-Cpz (Italy) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.


Figure 37: Side-by-side recursive trend visualization for station IT-Lav (Italy) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

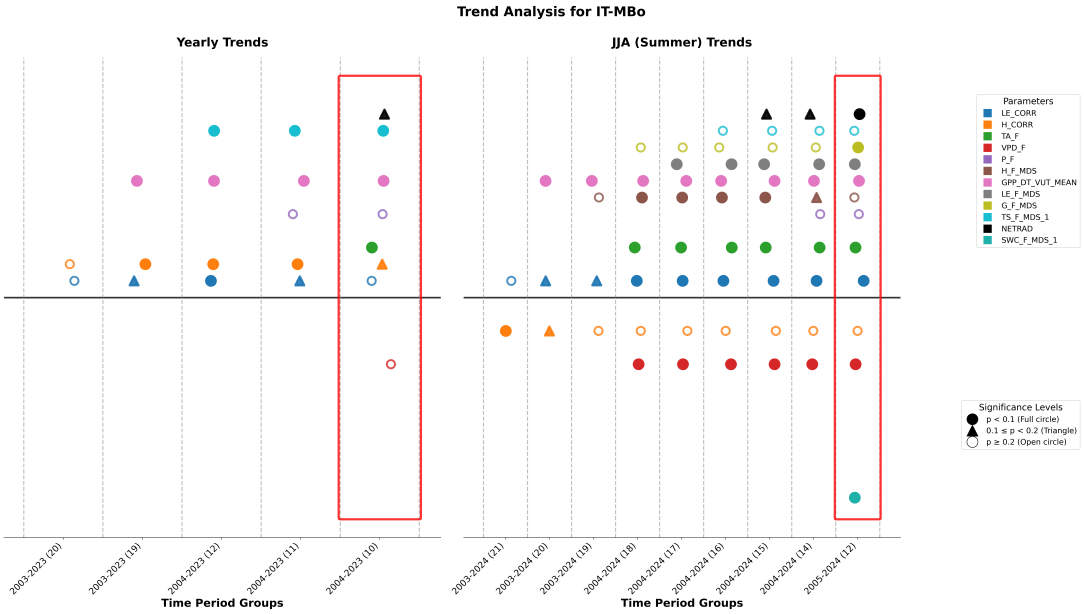


Figure 38: Side-by-side recursive trend visualization for station IT-MBo (Italy) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

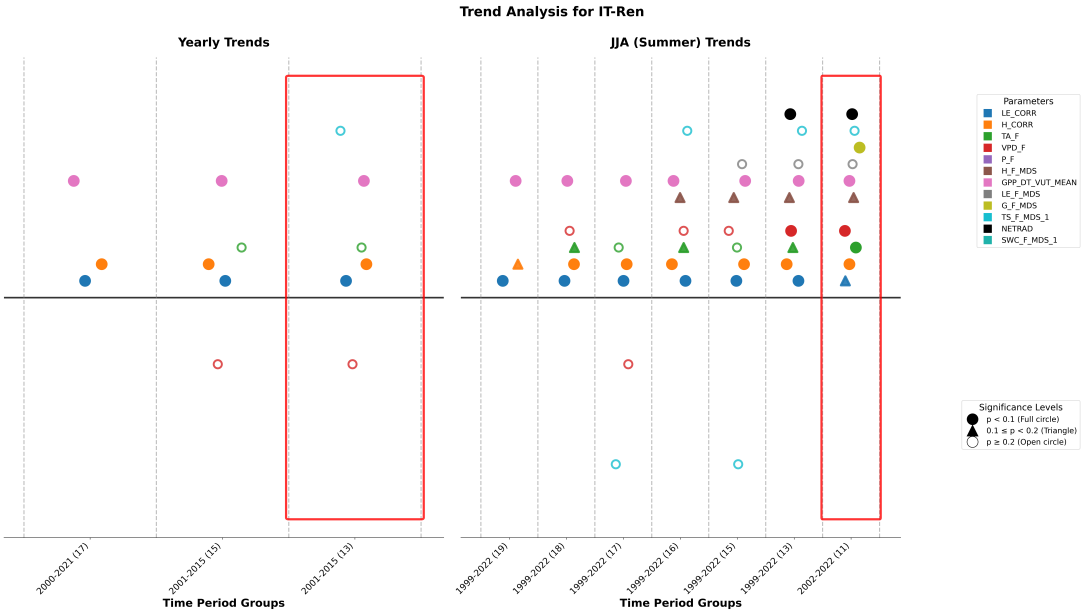


Figure 39: Side-by-side recursive trend visualization for station IT-Ren (Italy) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

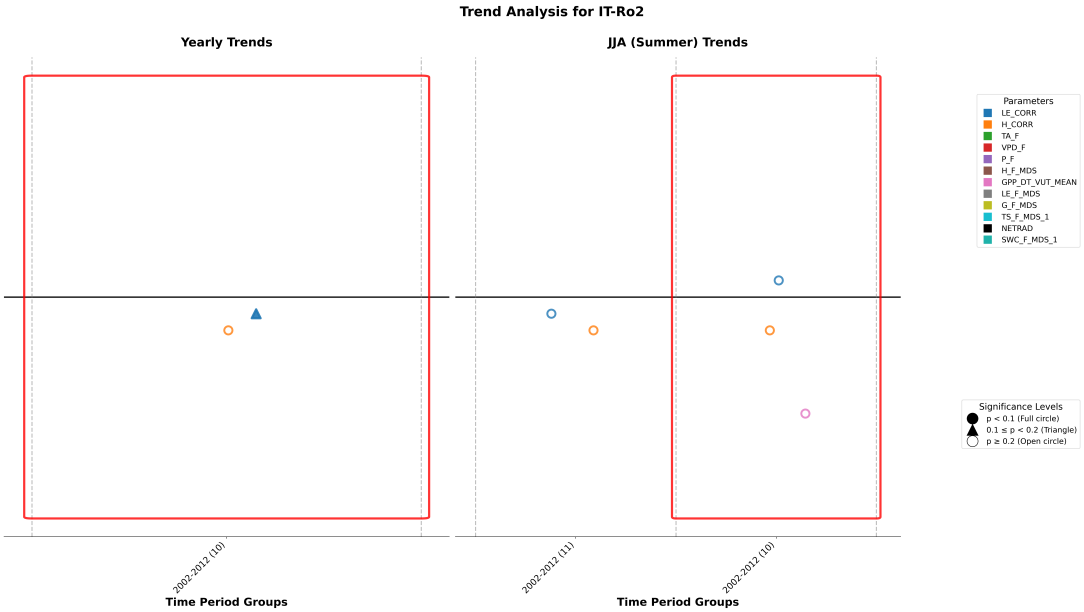


Figure 40: Side-by-side recursive trend visualization for station IT-Ro2 (Italy) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

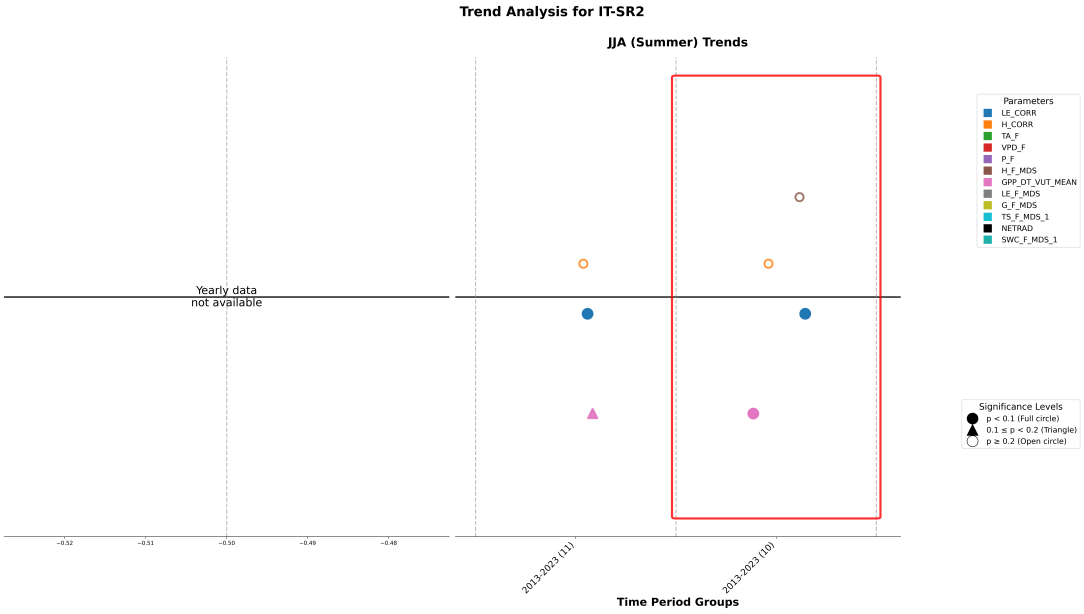


Figure 41: Side-by-side recursive trend visualization for station IT-SR2 (Italy) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

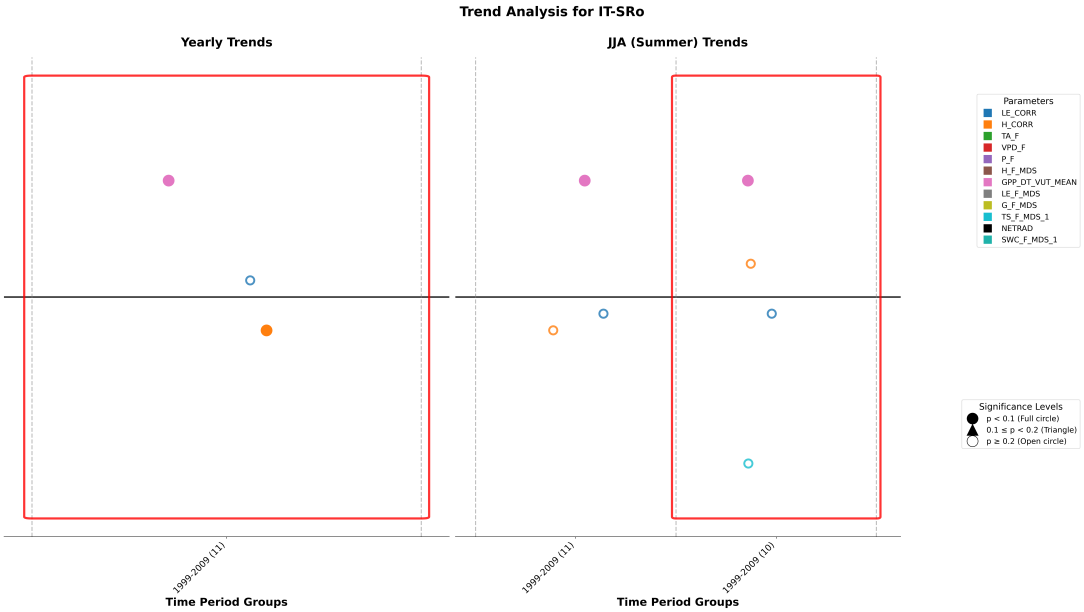


Figure 42: Side-by-side recursive trend visualization for station IT-SRo (Italy) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

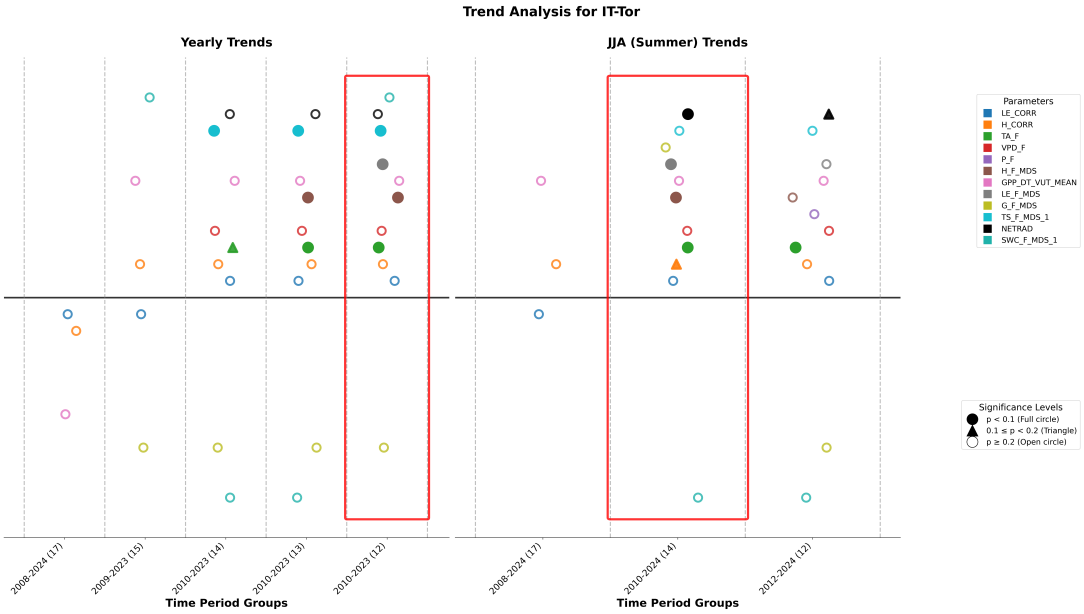


Figure 43: Side-by-side recursive trend visualization for station IT-Tor (Italy) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

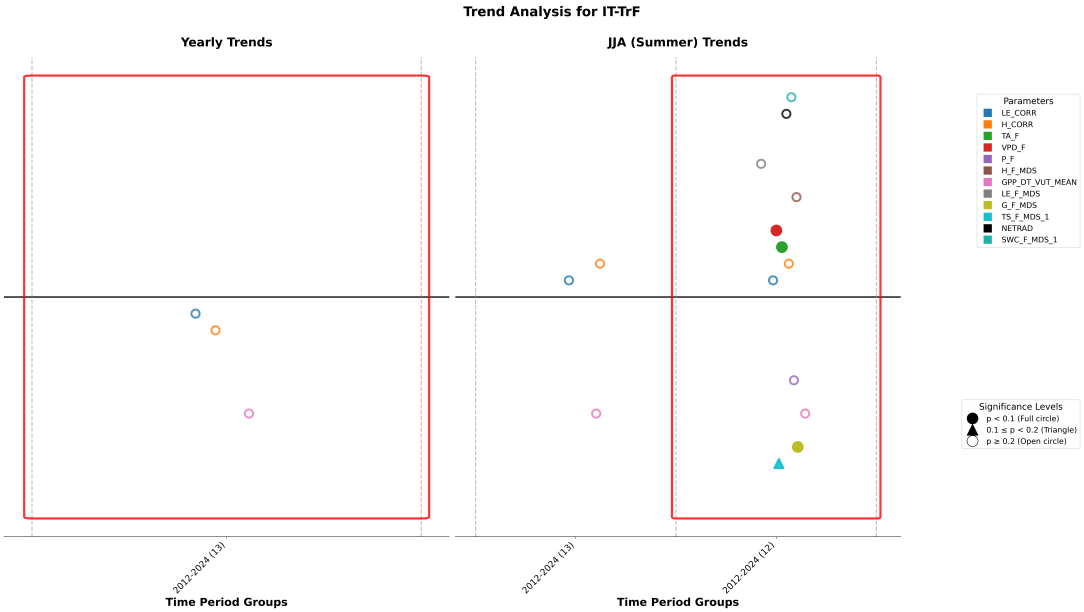


Figure 44: Side-by-side recursive trend visualization for station IT-TrF (Italy) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

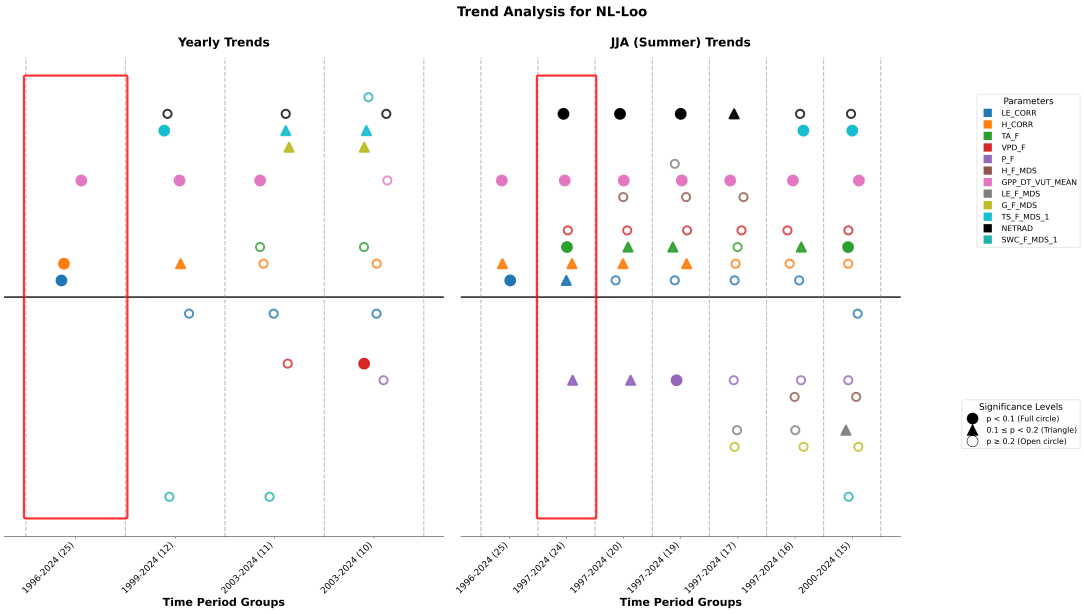


Figure 45: Side-by-side recursive trend visualization for station NL-Loo (Netherlands) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

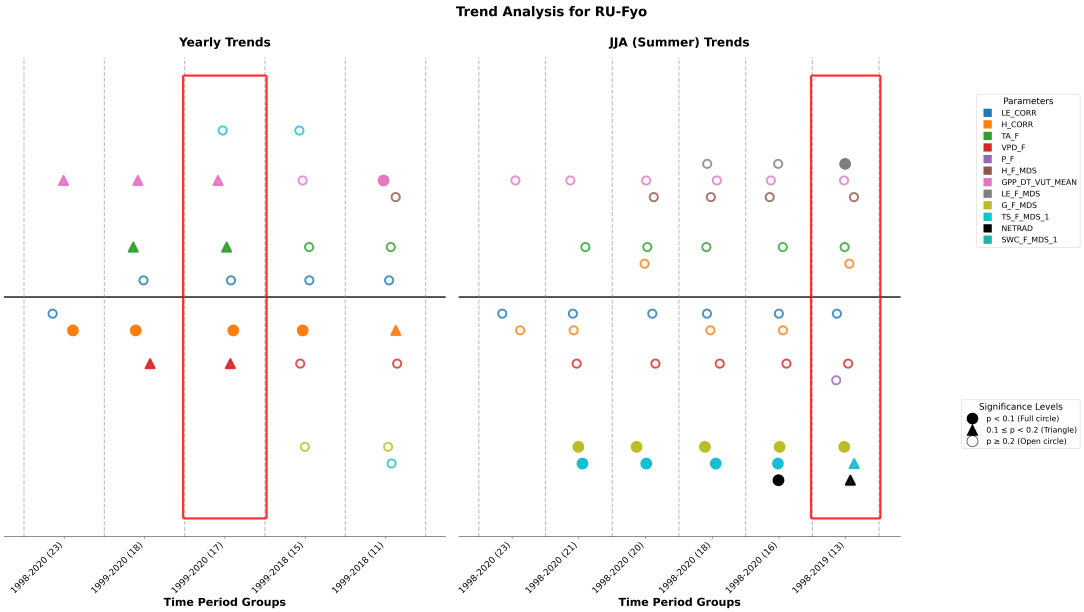


Figure 46: Side-by-side recursive trend visualization for station RU-Fyo (Russia) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

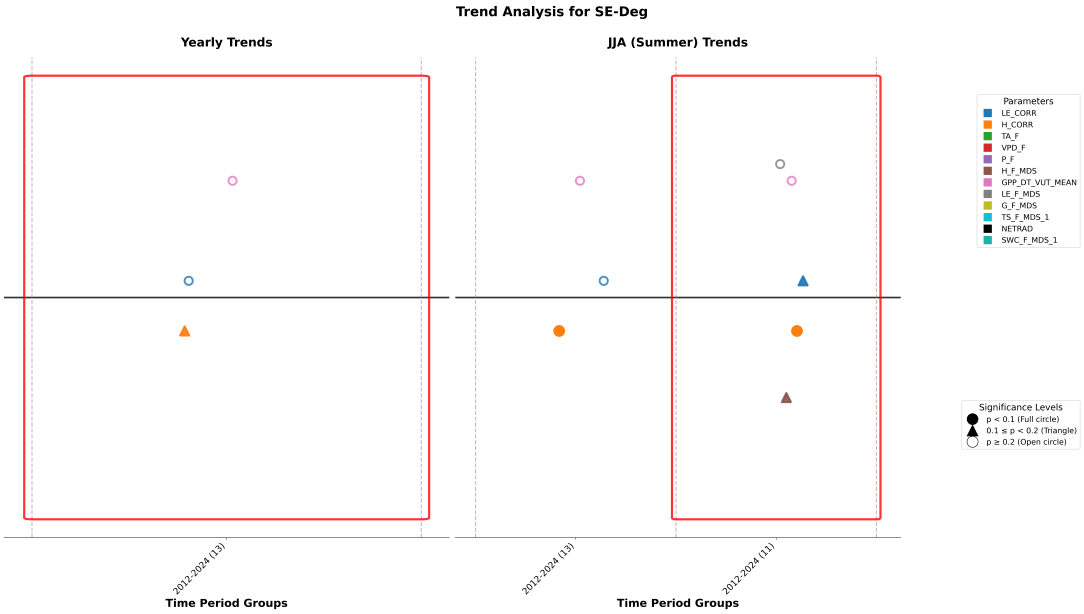


Figure 47: Side-by-side recursive trend visualization for station SE-Deg (Sweden) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

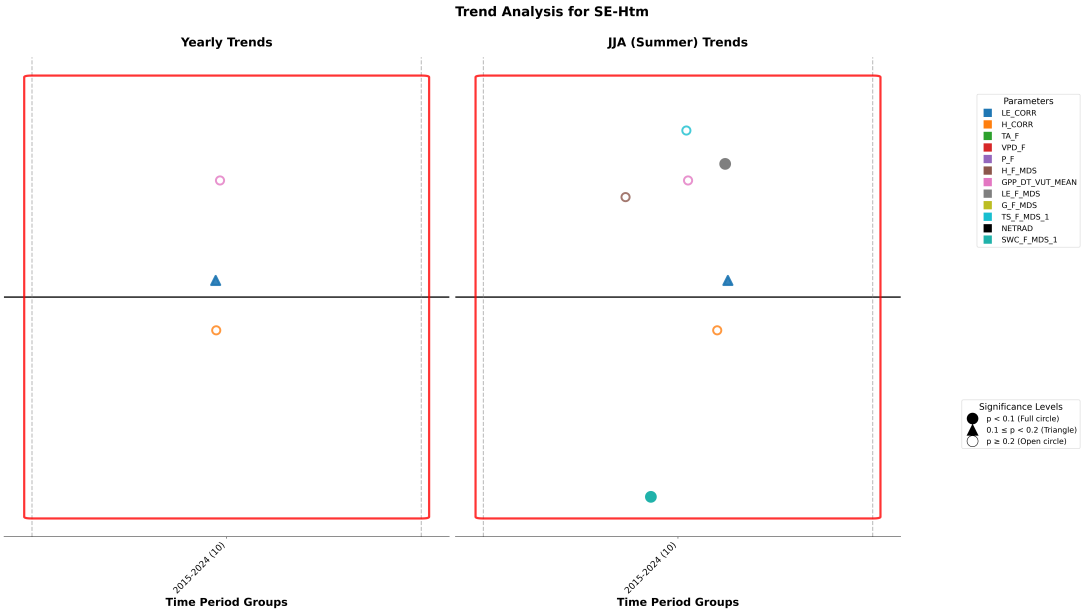


Figure 48: Side-by-side recursive trend visualization for station SE-Htm (Sweden) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

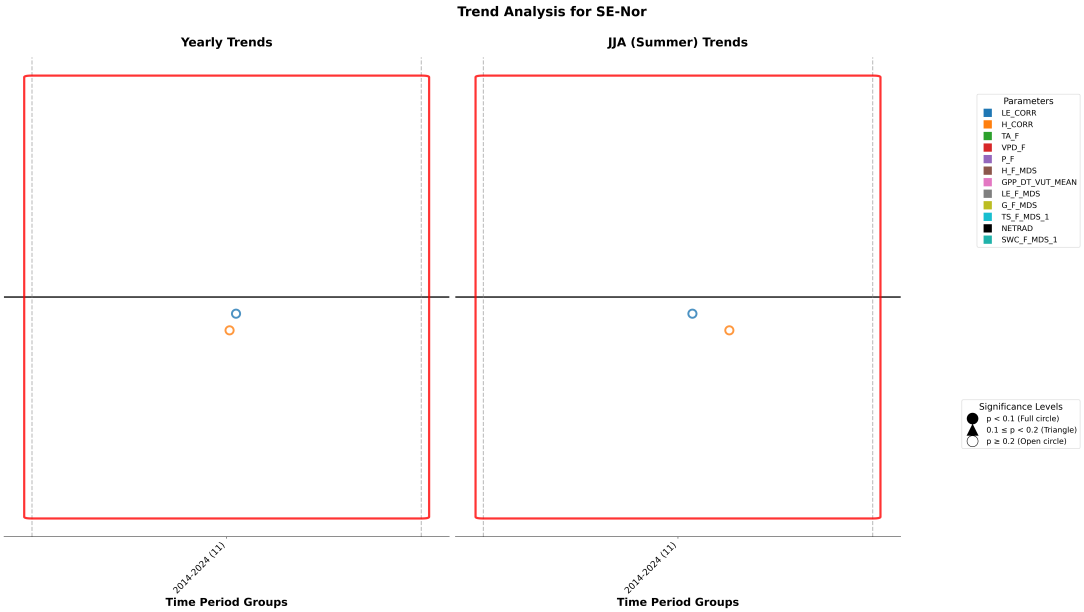


Figure 49: Side-by-side recursive trend visualization for station SE-Nor (Sweden) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

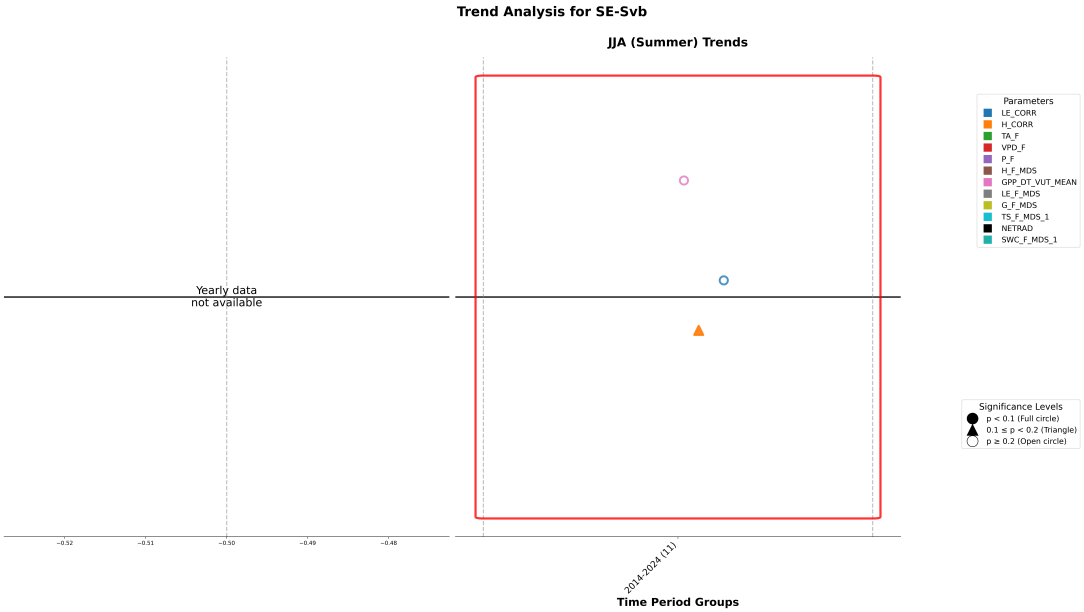


Figure 50: Side-by-side recursive trend visualization for station SE-Svb (Sweden) showing yearly (left) and summer (JJA; right) trends across progressive variable combinations. Marker position indicates slope sign and marker style indicates significance as in Fig. 1. The red box highlights the selected period.

## 1.2 HOLAPS and ERA5_Land Trend Group Visualizations

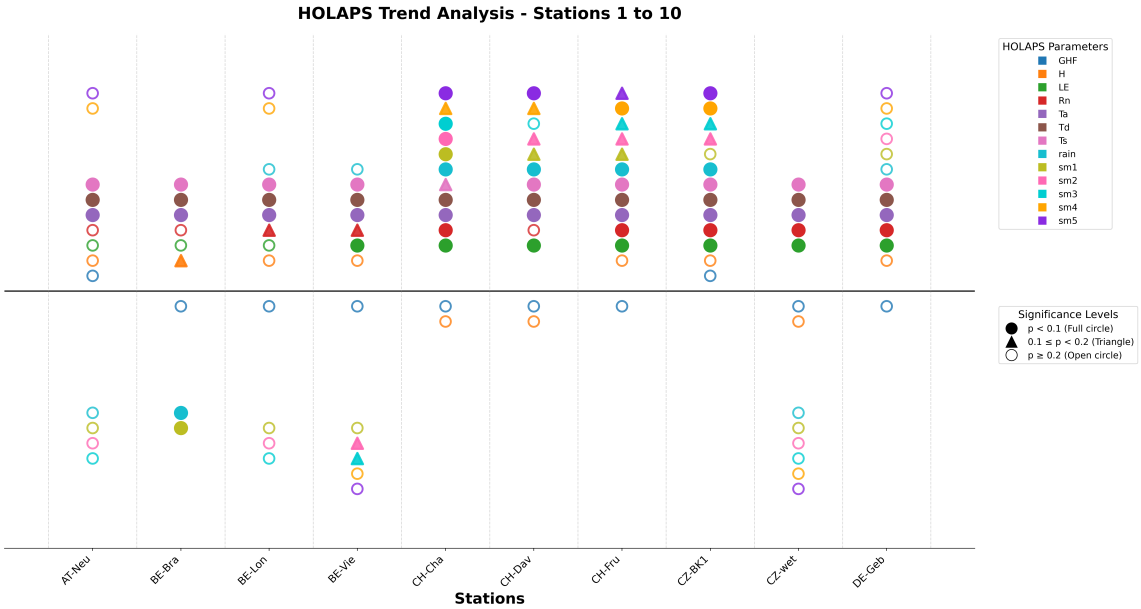


Figure 51: HOLAPS (monthly) trend visualization for station group 1 (up to 10 stations), showing yearly trends for all available HOLAPS parameters at the EC tower locations. Marker position indicates Sen's slope sign and marker style indicates Mann–Kendall significance (circle: $p < 0.10$, triangle: $0.10 \leq p < 0.20$, open circle: $p \geq 0.20$). Colors identify variables consistently across the analysis.

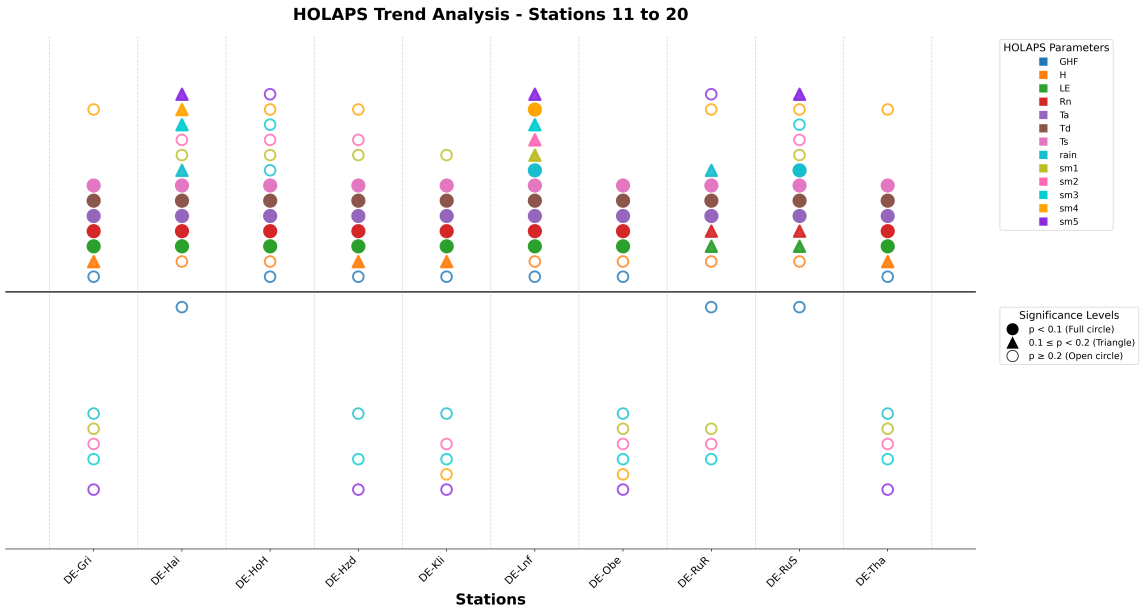


Figure 52: HOLAPS (monthly) trend visualization for station group 2 (up to 10 stations), showing yearly trends for all available HOLAPS parameters at the EC tower locations. Marker encoding as in Fig. 51.

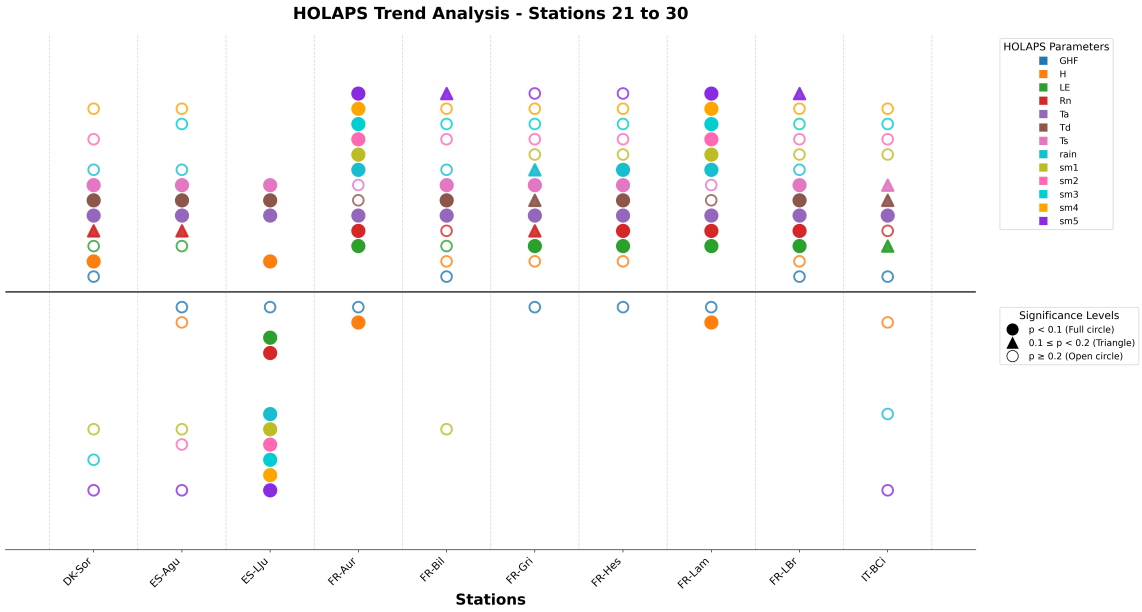


Figure 53: HOLAPS (monthly) trend visualization for station group 3 (up to 10 stations), showing yearly trends for all available HOLAPS parameters at the EC tower locations. Marker encoding as in Fig. 51.

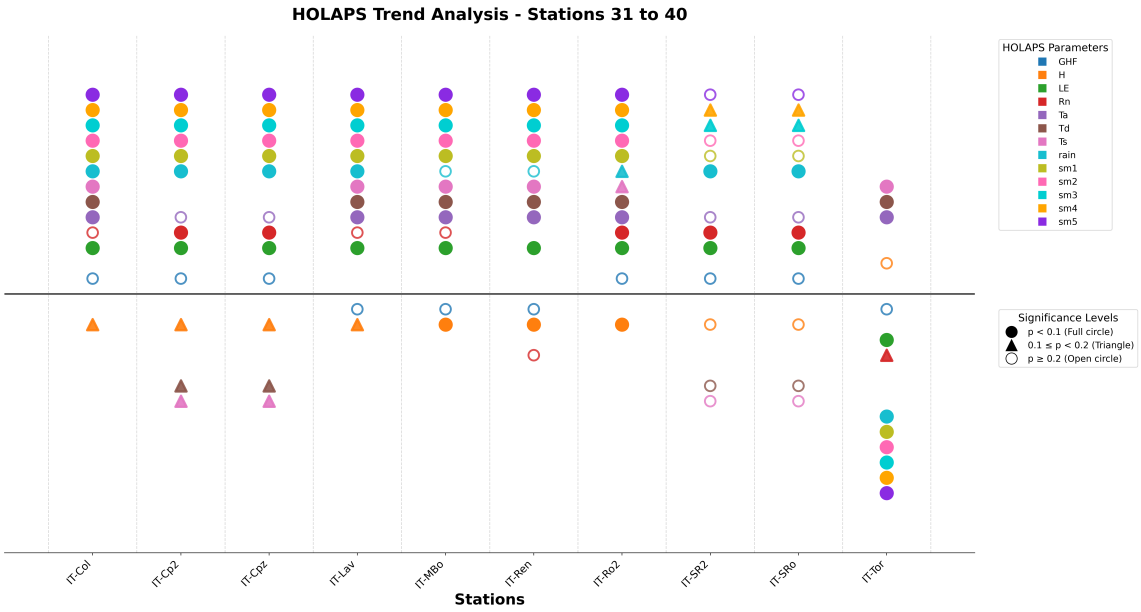


Figure 54: HOLAPS (monthly) trend visualization for station group 4 (up to 10 stations), showing yearly trends for all available HOLAPS parameters at the EC tower locations. Marker encoding as in Fig. 51.

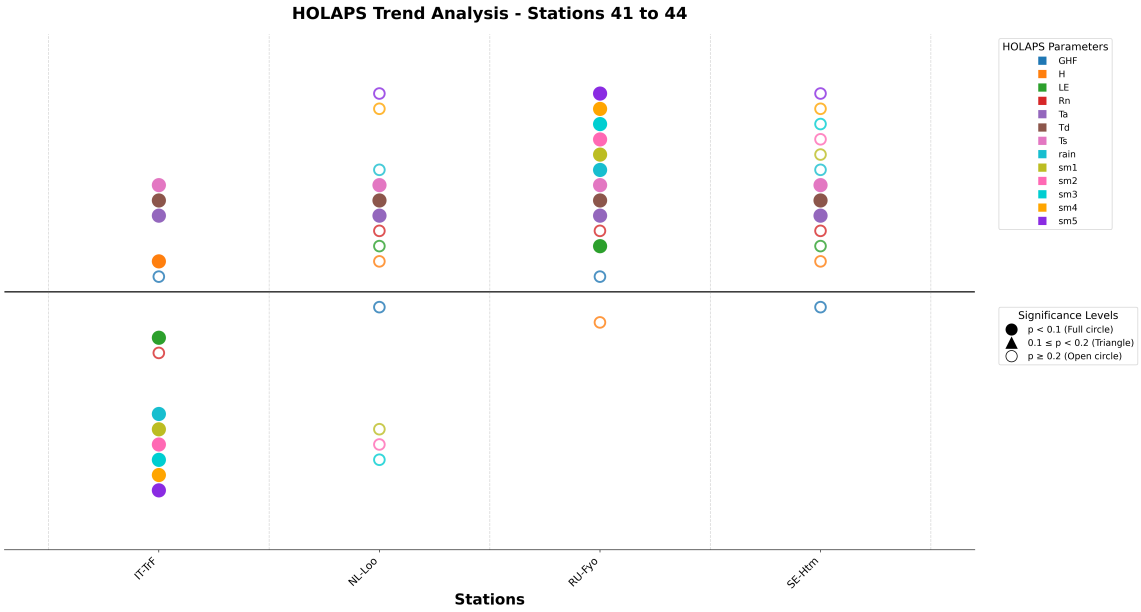


Figure 55: HOLAPS (monthly) trend visualization for station group 5 (up to 4 stations), showing yearly trends for all available HOLAPS parameters at the EC tower locations. Marker encoding as in Fig. 51.

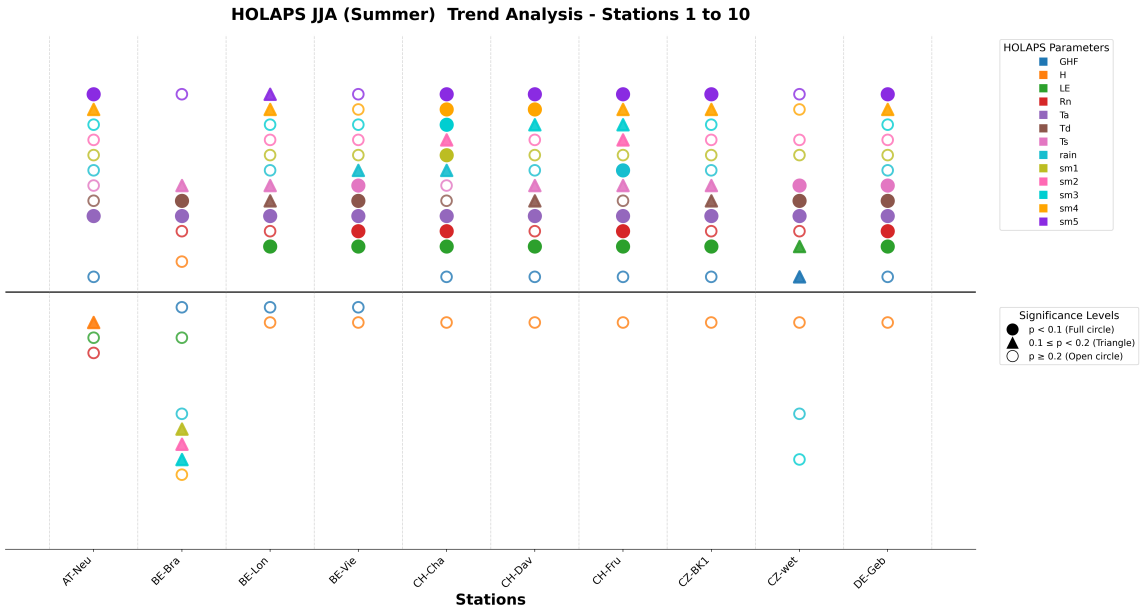


Figure 56: HOLAPS (monthly) trend visualization for station group 1 (up to 10 stations), showing JJA trends for all available HOLAPS parameters at the EC tower locations. Marker encoding as in Fig. 51.

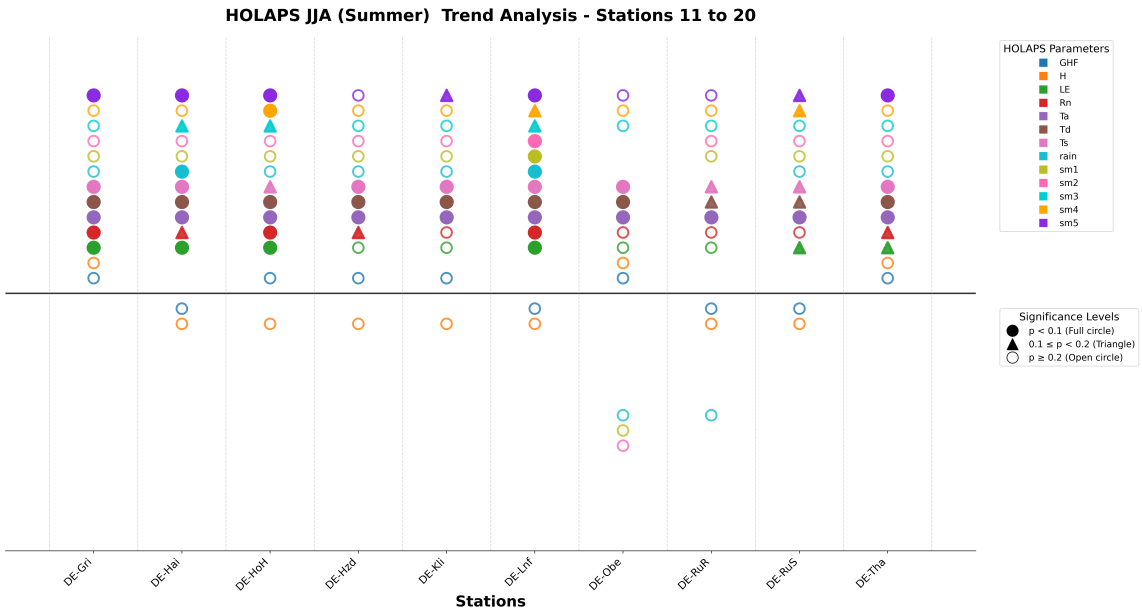


Figure 57: HOLAPS (monthly) trend visualization for station group 2 (up to 10 stations), showing JJA trends for all available HOLAPS parameters at the EC tower locations. Marker encoding as in Fig. 51.

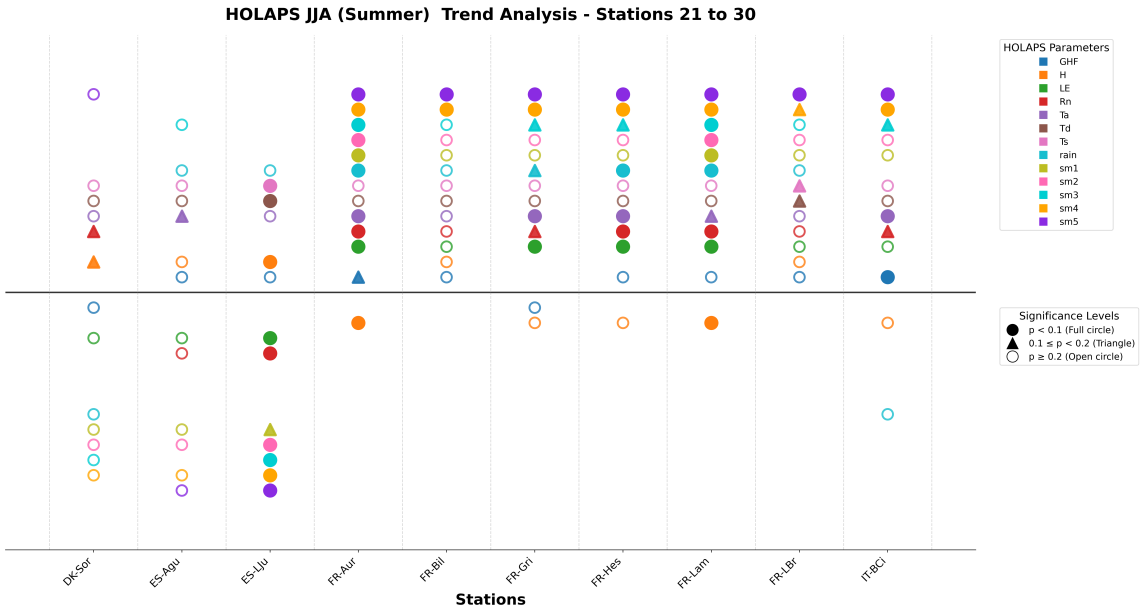


Figure 58: HOLAPS (monthly) trend visualization for station group 3 (up to 10 stations), showing JJA trends for all available HOLAPS parameters at the EC tower locations. Marker encoding as in Fig. 51.

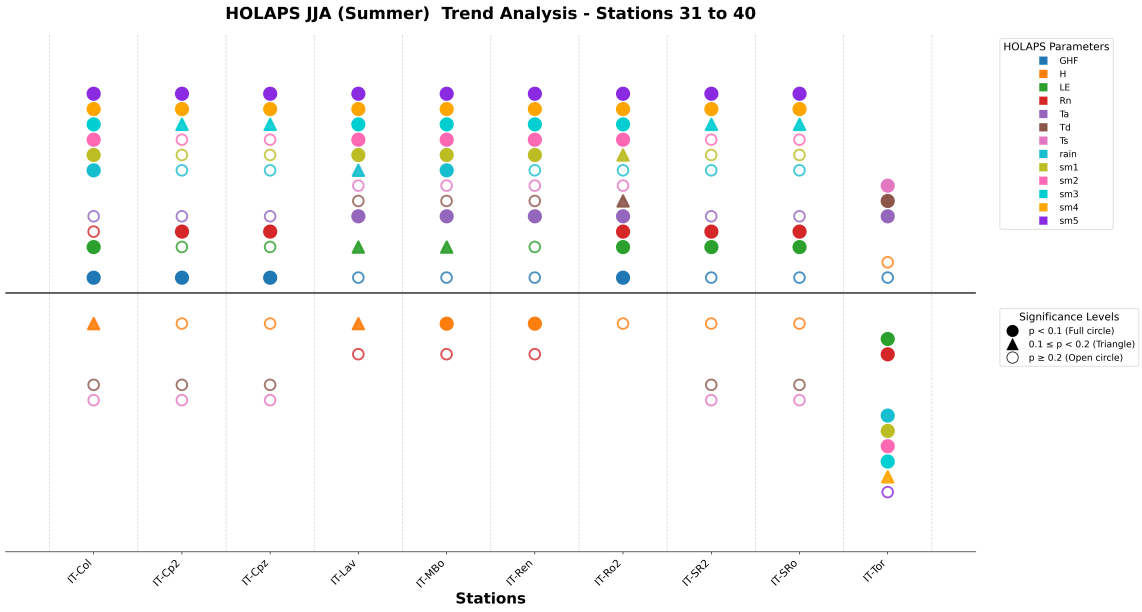


Figure 59: HOLAPS (monthly) trend visualization for station group 4 (up to 10 stations), showing JJA trends for all available HOLAPS parameters at the EC tower locations. Marker encoding as in Fig. 51.

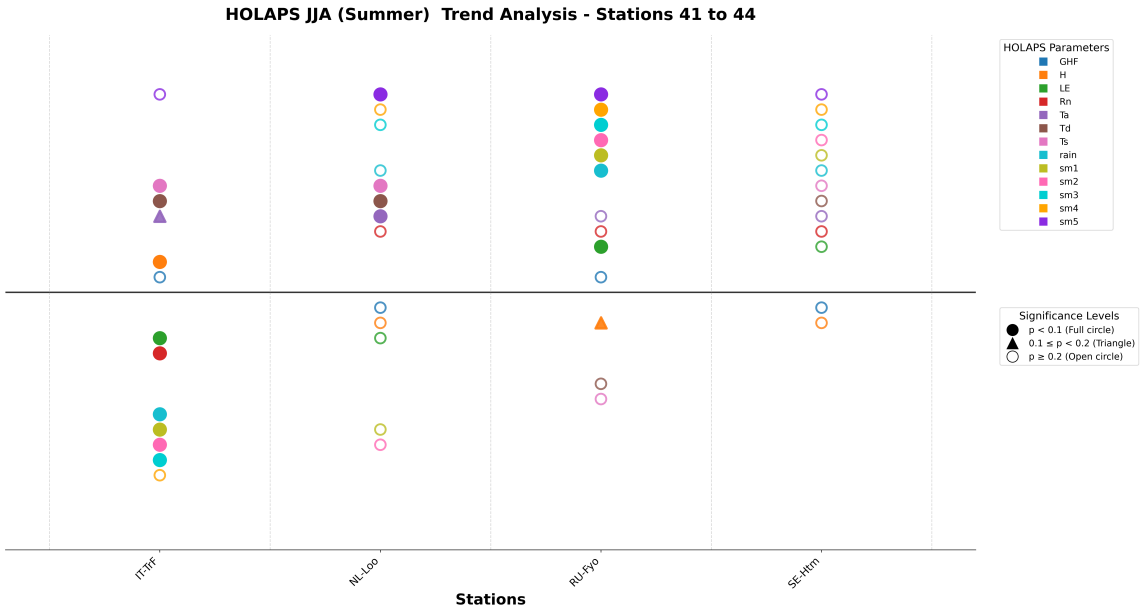


Figure 60: HOLAPS (monthly) trend visualization for station group 5 (up to 4 stations), showing JJA trends for all available HOLAPS parameters at the EC tower locations. Marker encoding as in Fig. 51.

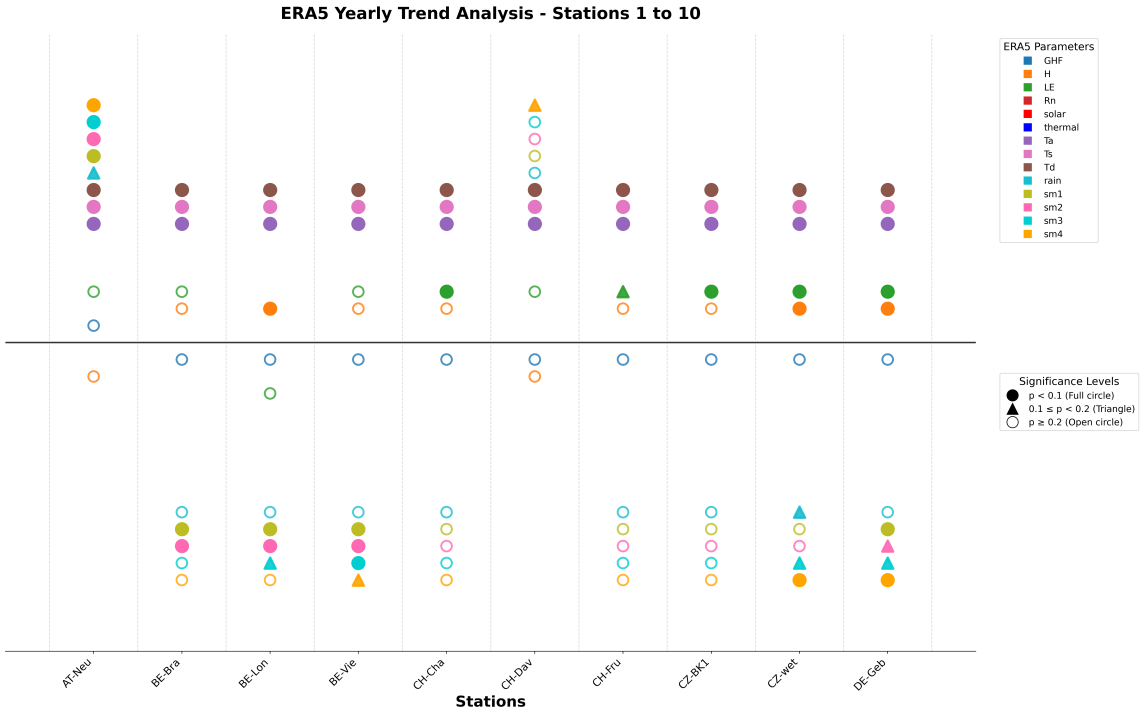


Figure 61: ERA5_Land trend visualization for station group 1 (up to 10 stations), showing yearly trends for the mapped ERA5_Land parameters at the EC tower locations. Marker position indicates Sen's slope sign and marker style indicates Mann–Kendall significance (circle: $p < 0.10$, triangle: $0.10 \leq p < 0.20$, open circle: $p \geq 0.20$). Colors identify variables consistently across the analysis.

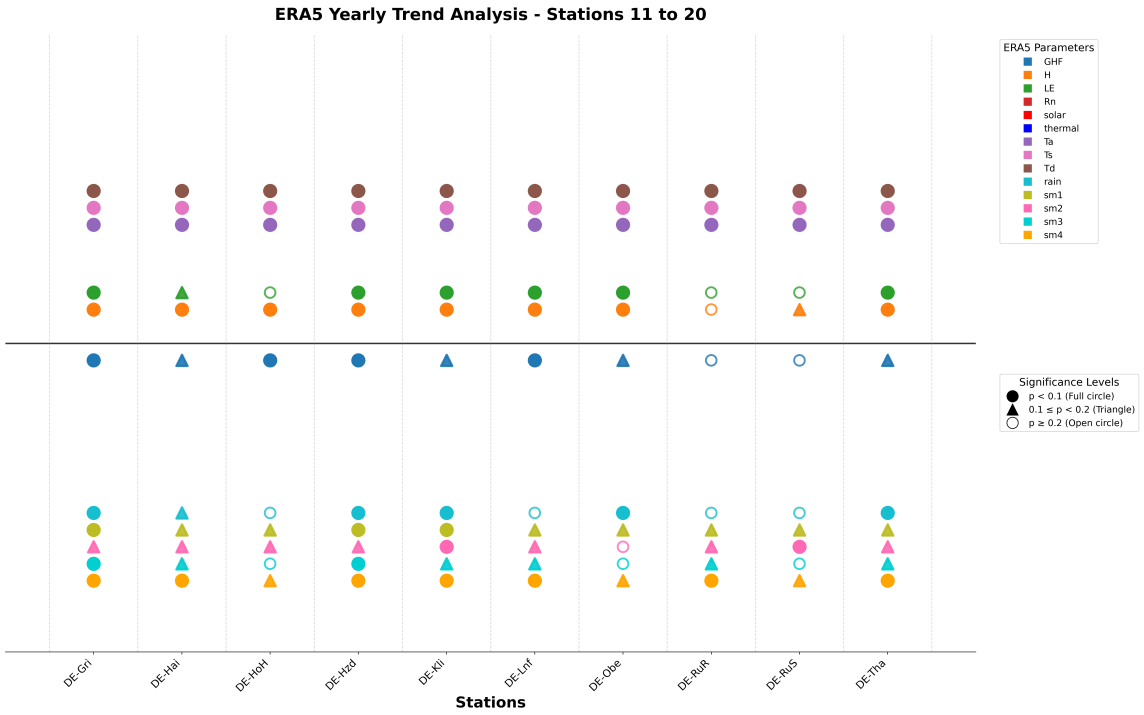


Figure 62: ERA5_Land trend visualization for station group 2 (up to 10 stations), showing yearly trends for the mapped ERA5_Land parameters at the EC tower locations. Marker encoding as in Fig. 61.

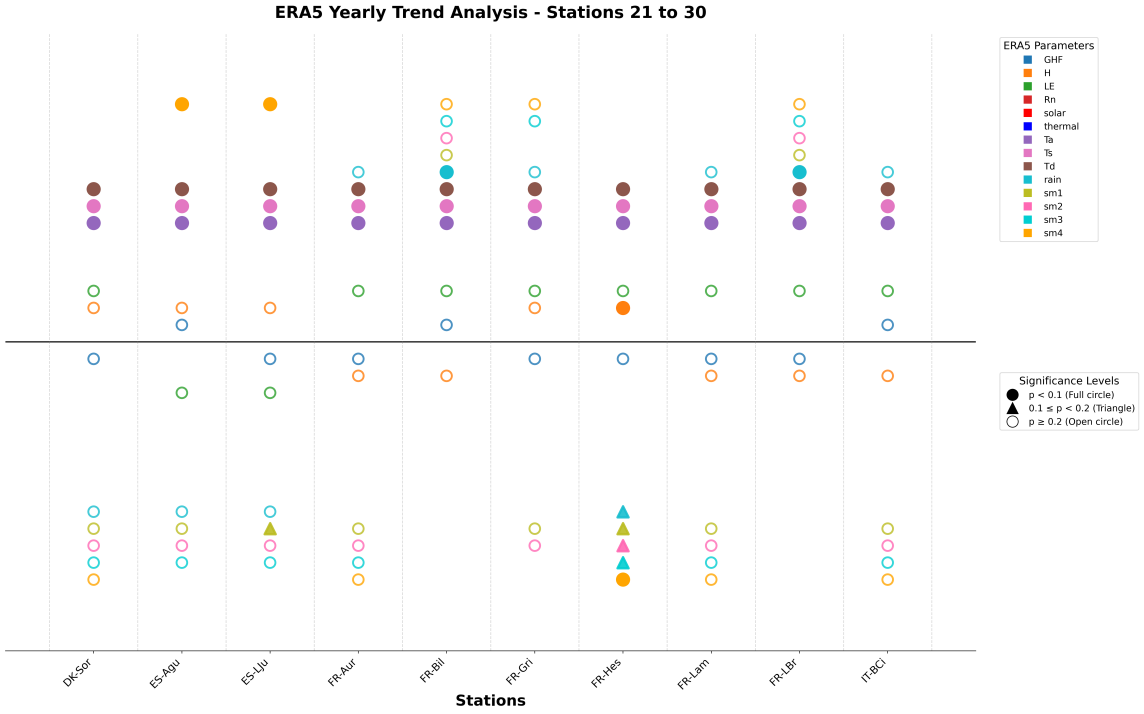


Figure 63: ERA5_Land trend visualization for station group 3 (up to 10 stations), showing yearly trends for the mapped ERA5_Land parameters at the EC tower locations. Marker encoding as in Fig. 61.

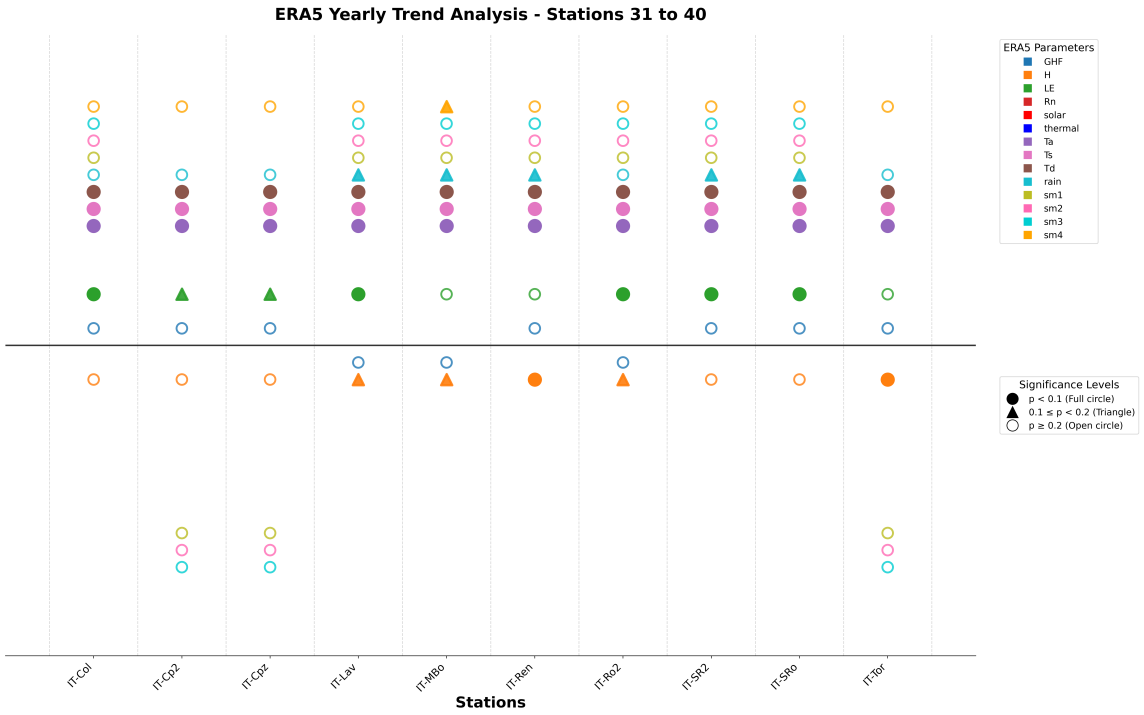


Figure 64: ERA5_Land trend visualization for station group 4 (up to 10 stations), showing yearly trends for the mapped ERA5_Land parameters at the EC tower locations. Marker encoding as in Fig. 61.

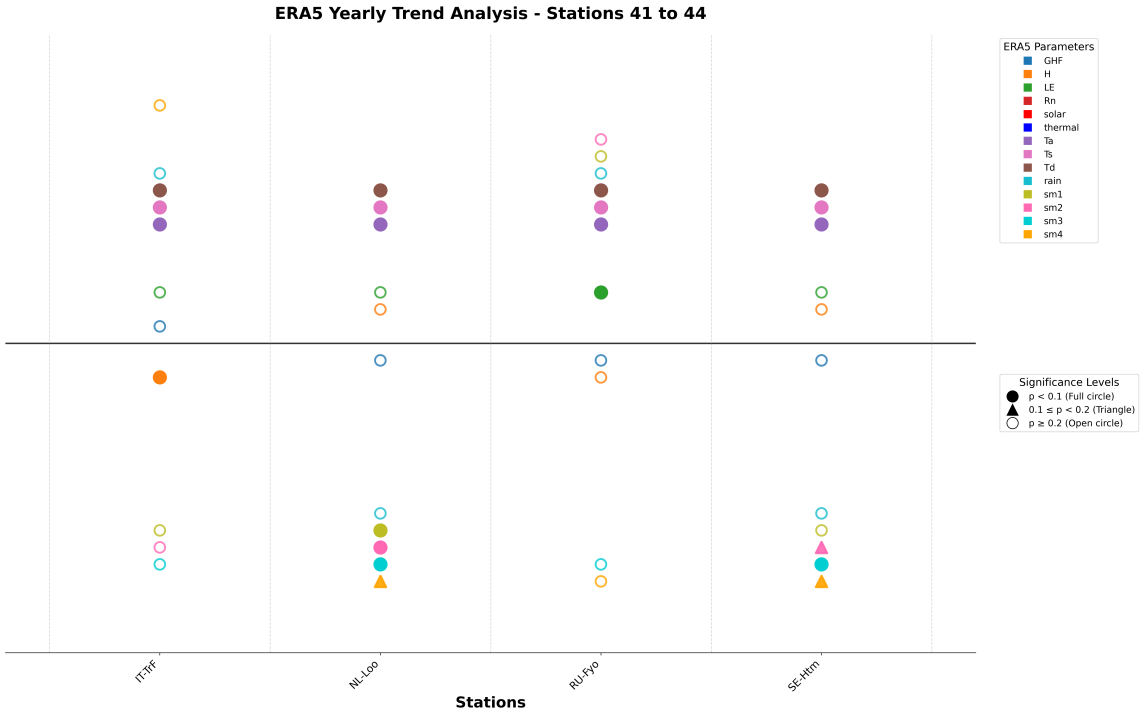


Figure 65: ERA5_Land trend visualization for station group 5 (up to 4 stations), showing yearly trends for the mapped ERA5_Land parameters at the EC tower locations. Marker encoding as in Fig. 61.

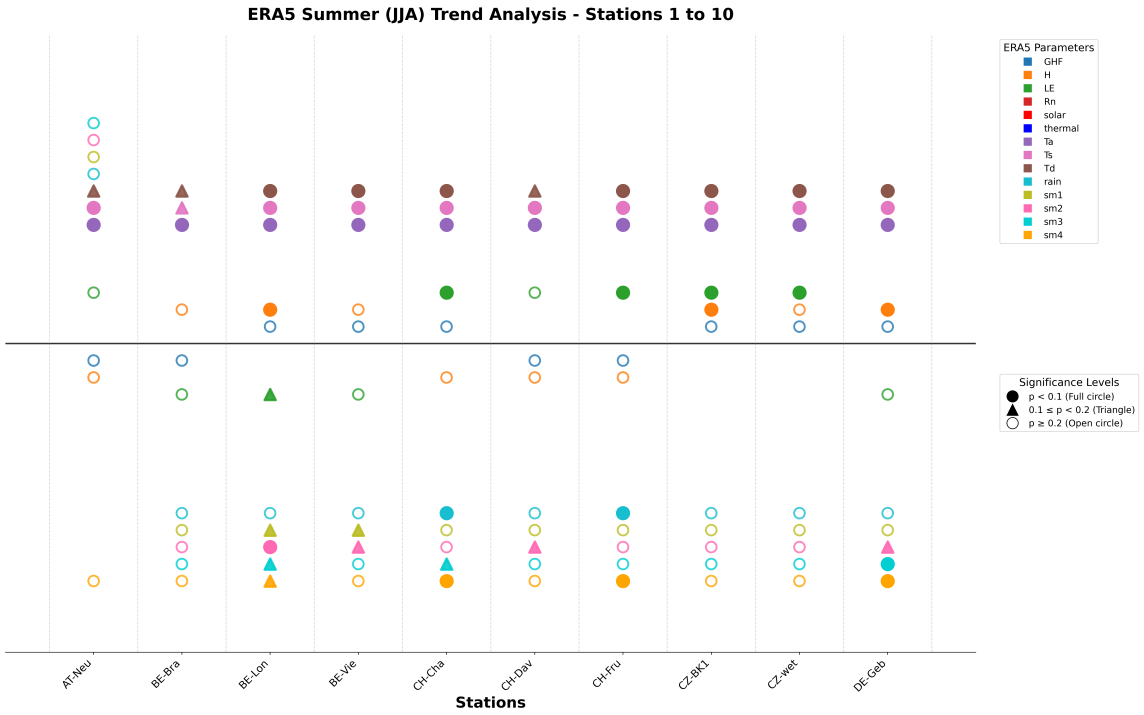


Figure 66: ERA5_Land trend visualization for station group 1 (up to 10 stations), showing JJA trends for the mapped ERA5_Land parameters at the EC tower locations. Marker encoding as in Fig. 61.

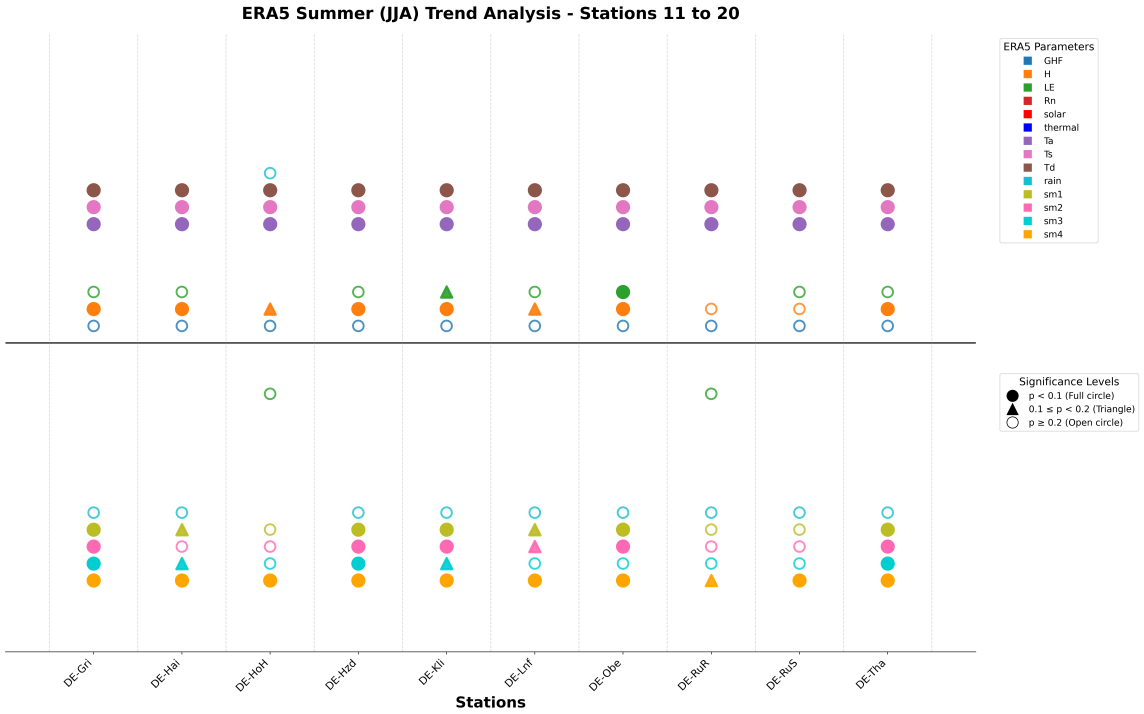


Figure 67: ERA5_Land trend visualization for station group 2 (up to 10 stations), showing JJA trends for the mapped ERA5_Land parameters at the EC tower locations. Marker encoding as in Fig. 61.

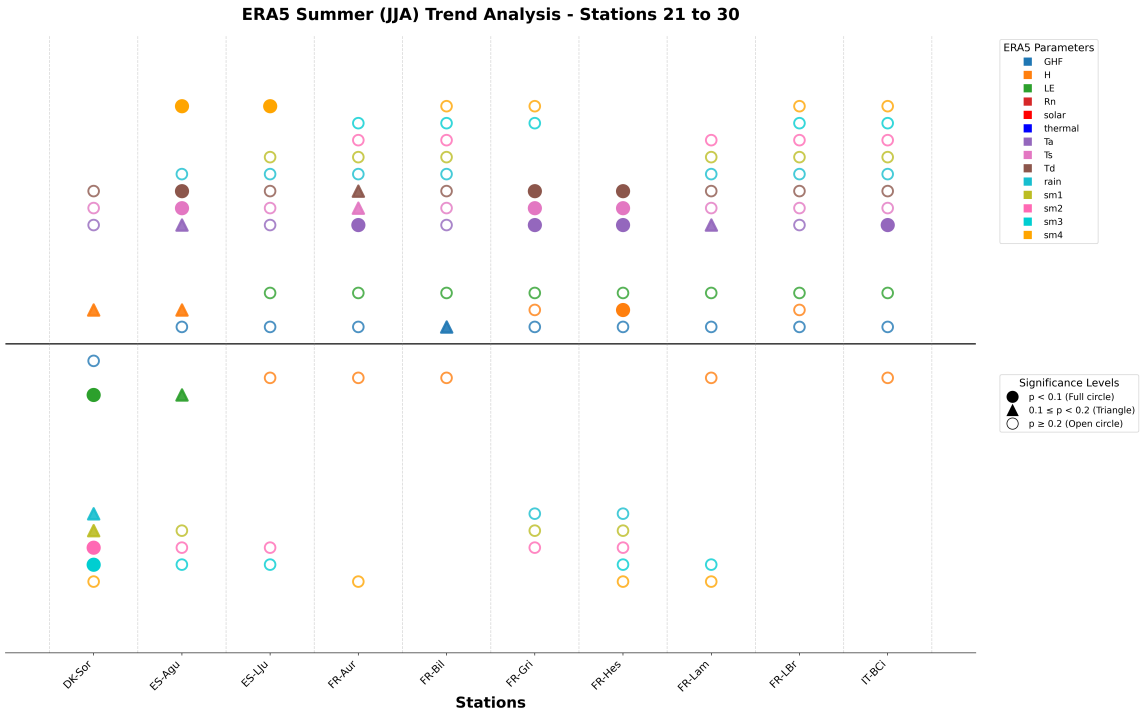


Figure 68: ERA5_Land trend visualization for station group 3 (up to 10 stations), showing JJA trends for the mapped ERA5_Land parameters at the EC tower locations. Marker encoding as in Fig. 61.

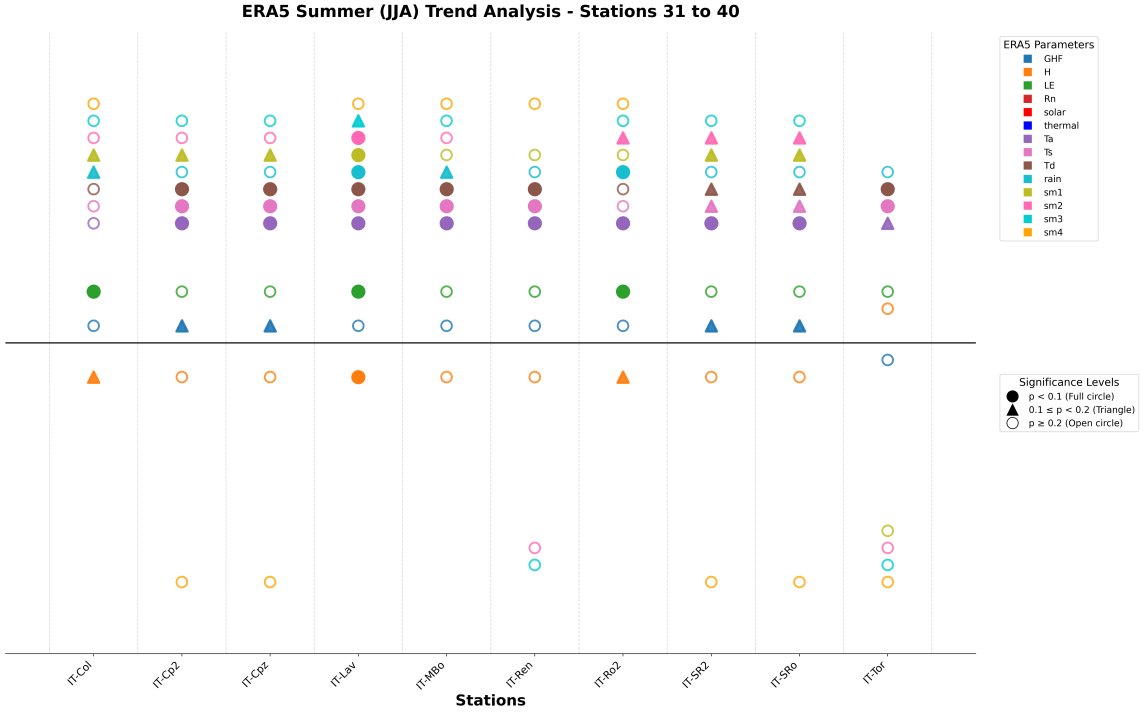


Figure 69: ERA5_Land trend visualization for station group 4 (up to 10 stations), showing JJA trends for the mapped ERA5_Land parameters at the EC tower locations. Marker encoding as in Fig. 61.

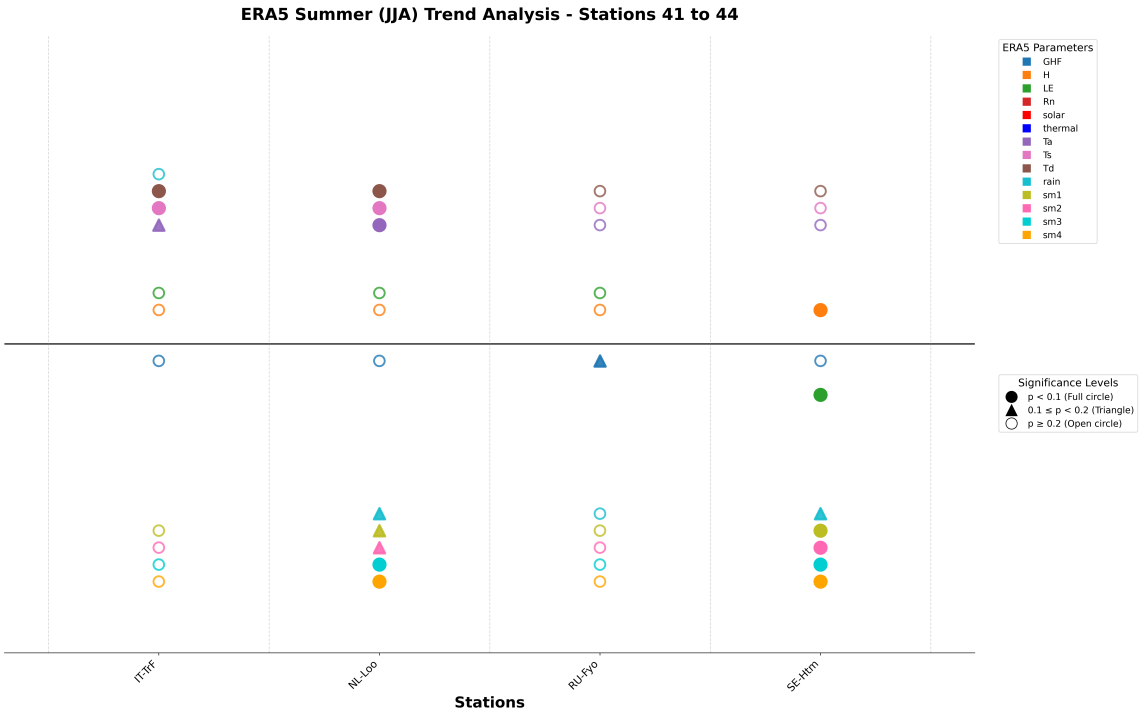


Figure 70: ERA5_Land trend visualization for station group 5 (up to 4 stations), showing JJA trends for the mapped ERA5_Land parameters at the EC tower locations. Marker encoding as in Fig. 61.

## 1.3 Within-dataset Venn Diagrams

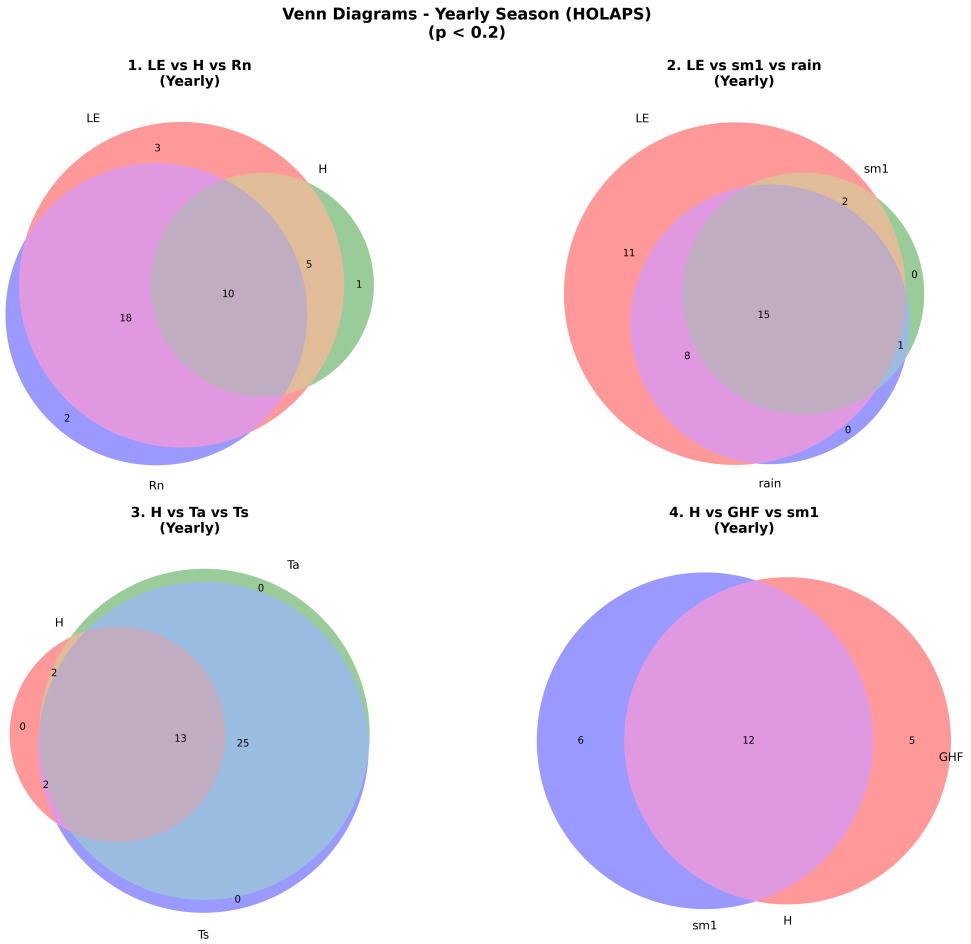


Figure 71: Venn diagrams showing overlap of stations with significant trends ($p < 0.20$) across selected variable combinations for HOLAPS (yearly aggregation). Each circle represents one variable in the specified combination, and intersections indicate stations where multiple variables exhibit significant trends simultaneously.

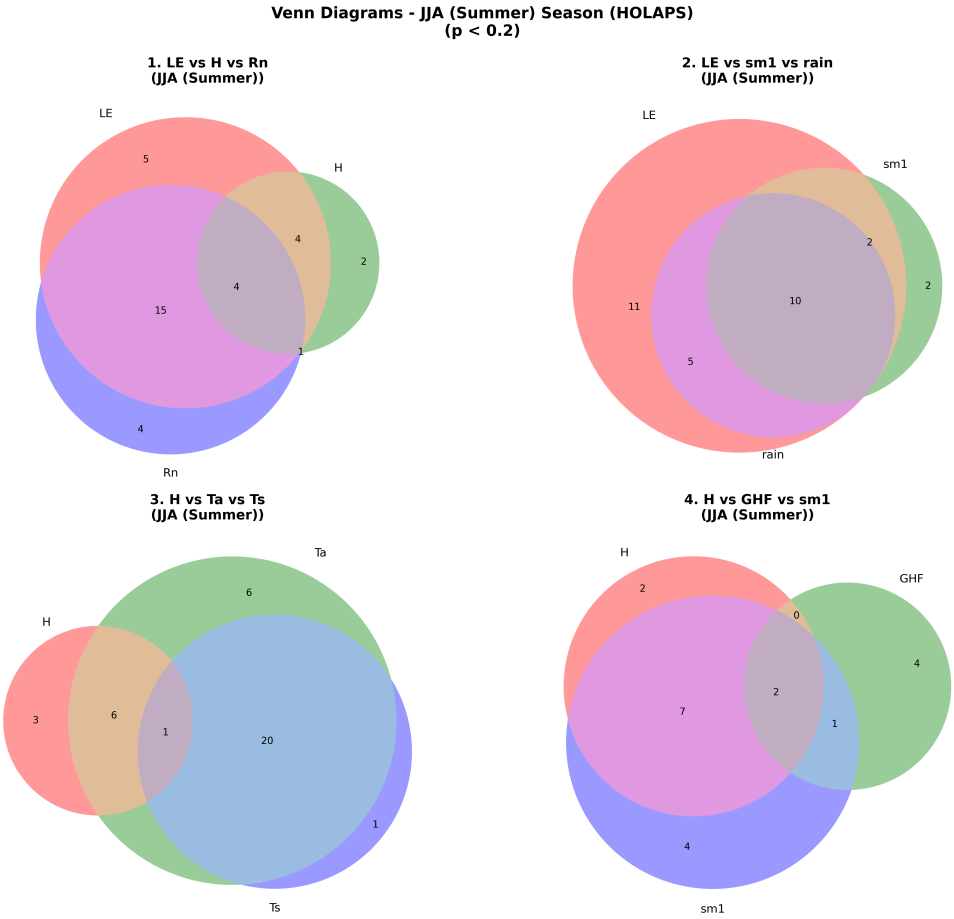


Figure 72: Venn diagrams showing overlap of stations with significant trends ($p < 0.20$) across selected variable combinations for HOLAPS (JJA aggregation). Each circle represents one variable in the specified combination, and intersections indicate stations where multiple variables exhibit significant trends simultaneously.

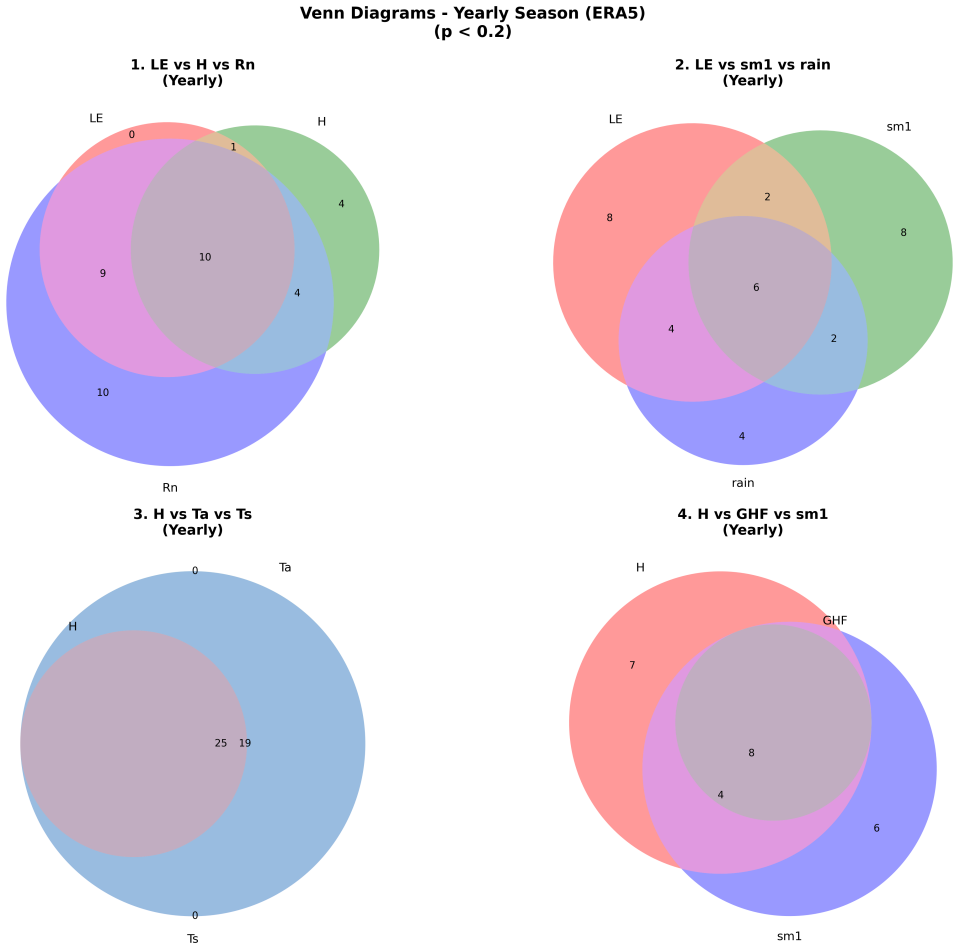


Figure 73: Venn diagrams showing overlap of stations with significant trends ($p < 0.20$) across selected variable combinations for ERA5_Land (yearly aggregation). Each circle represents one variable in the specified combination, and intersections indicate stations where multiple variables exhibit significant trends simultaneously.

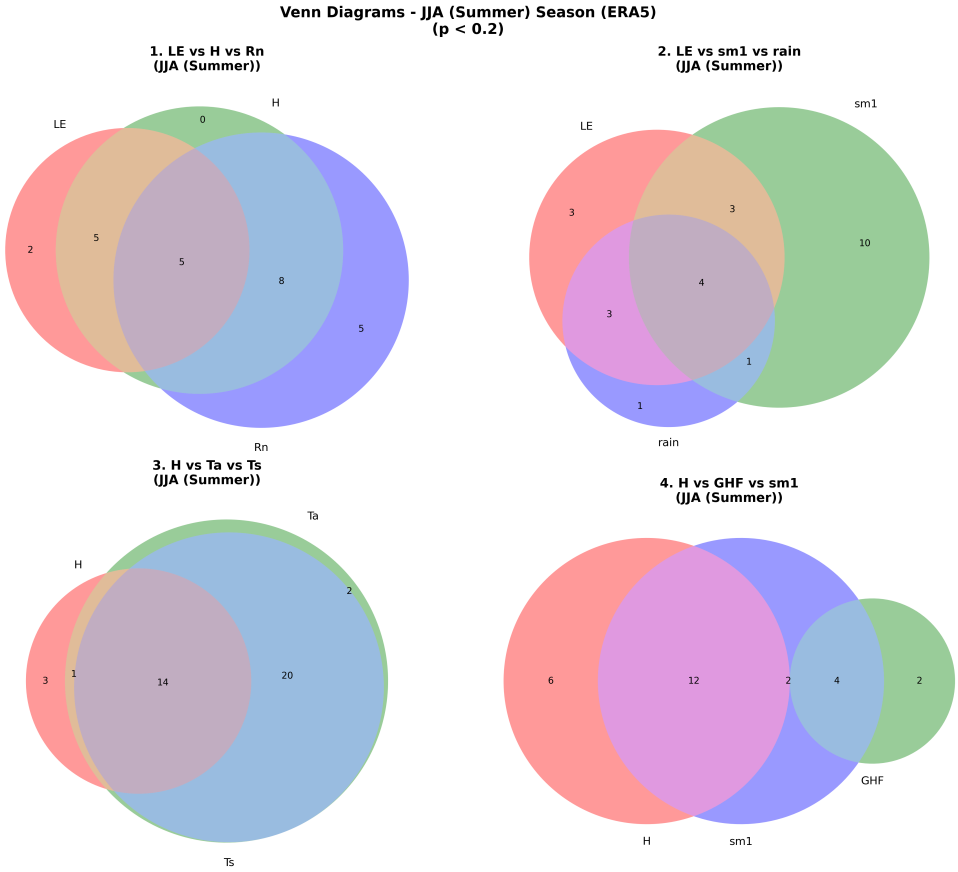


Figure 74: Venn diagrams showing overlap of stations with significant trends ($p < 0.20$) across selected variable combinations for ERA5_Land (JJA aggregation). Each circle represents one variable in the specified combination, and intersections indicate stations where multiple variables exhibit significant trends simultaneously.

## 1.4 Ecosystem-stratified Summaries

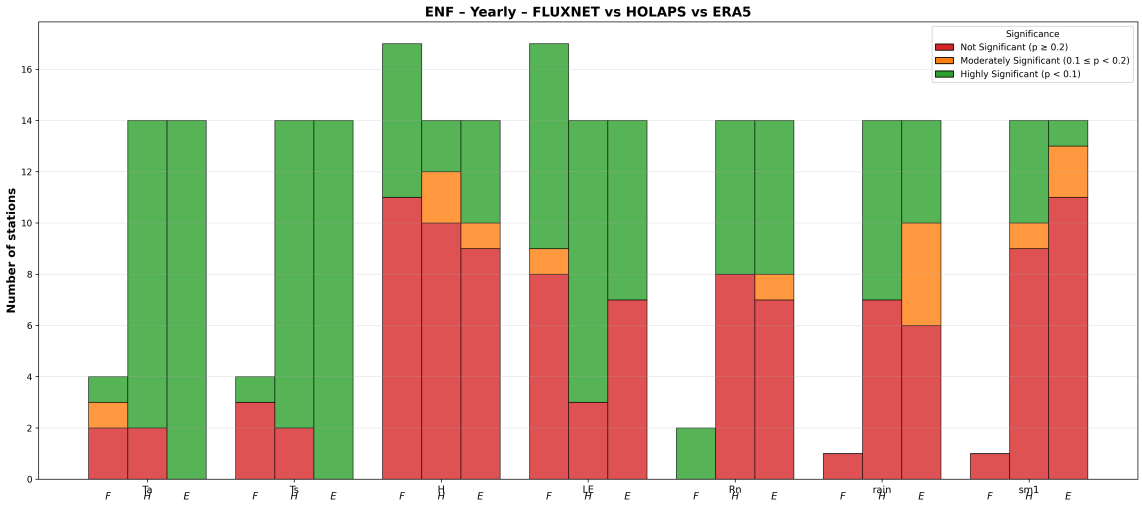


Figure 75: Ecosystem-stratified comparison of trend significance for the shared variable set across FLUXNET (F), HOLAPS (H), and ERA5_Land (E) for the ENF subset (yearly aggregation). Stacked bars summarize, for each dataset and variable, the number of stations with high ($p < 0.10$), medium ($0.10 \leq p < 0.20$), and non-significant ($p \geq 0.20$) trends.

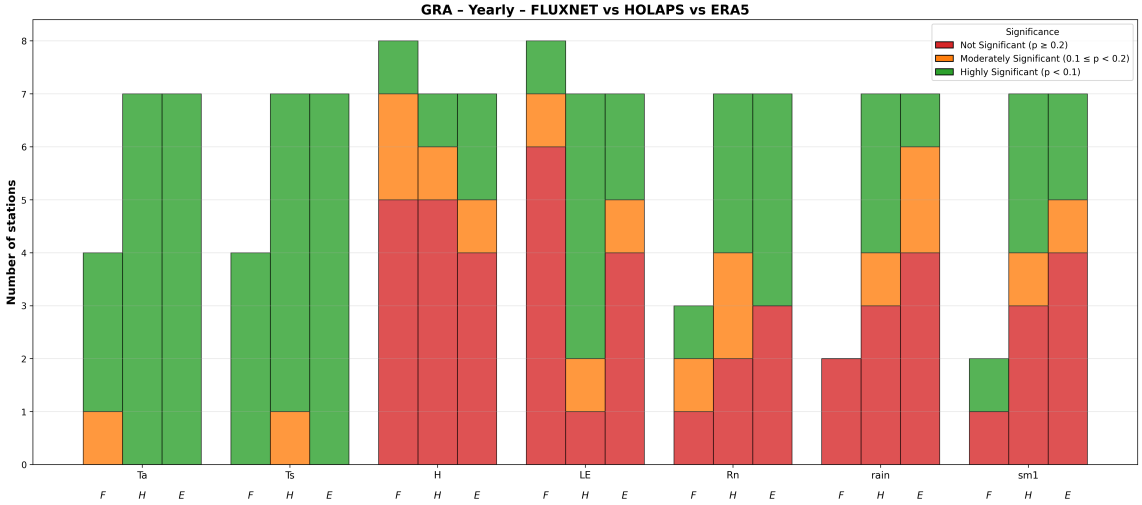


Figure 76: Ecosystem-stratified comparison of trend significance for the shared variable set across FLUXNET (F), HOLAPS (H), and ERA5_Land (E) for the GRA subset (yearly aggregation). Stacked bars summarize, for each dataset and variable, the number of stations with high ($p < 0.10$), medium ($0.10 \leq p < 0.20$), and non-significant ($p \geq 0.20$) trends.

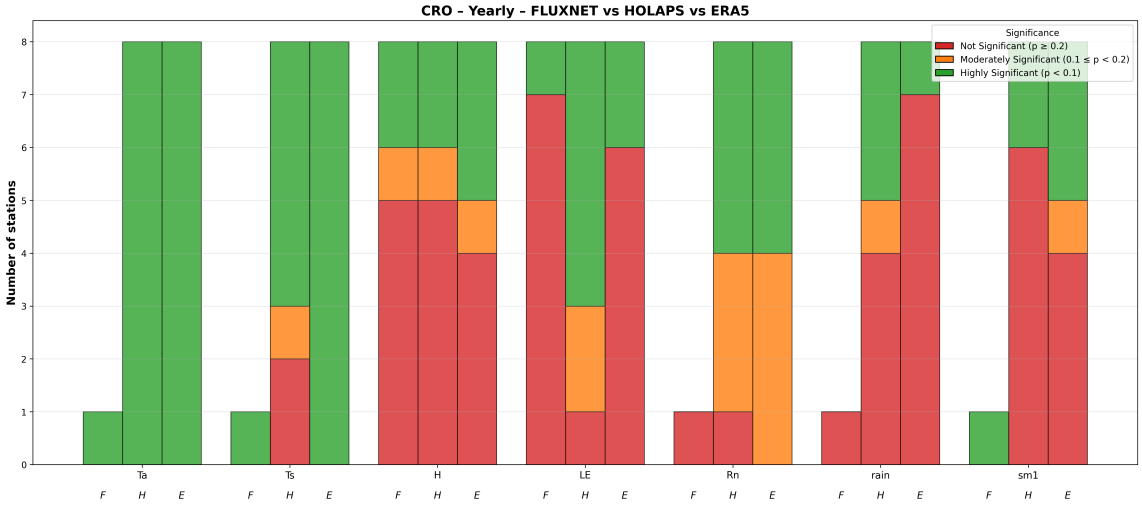


Figure 77: Ecosystem-stratified comparison of trend significance for the shared variable set across FLUXNET (F), HOLAPS (H), and ERA5_Land (E) for the CRO subset (yearly aggregation). Stacked bars summarize, for each dataset and variable, the number of stations with high ($p < 0.10$), medium ($0.10 \leq p < 0.20$), and non-significant ($p \geq 0.20$) trends.

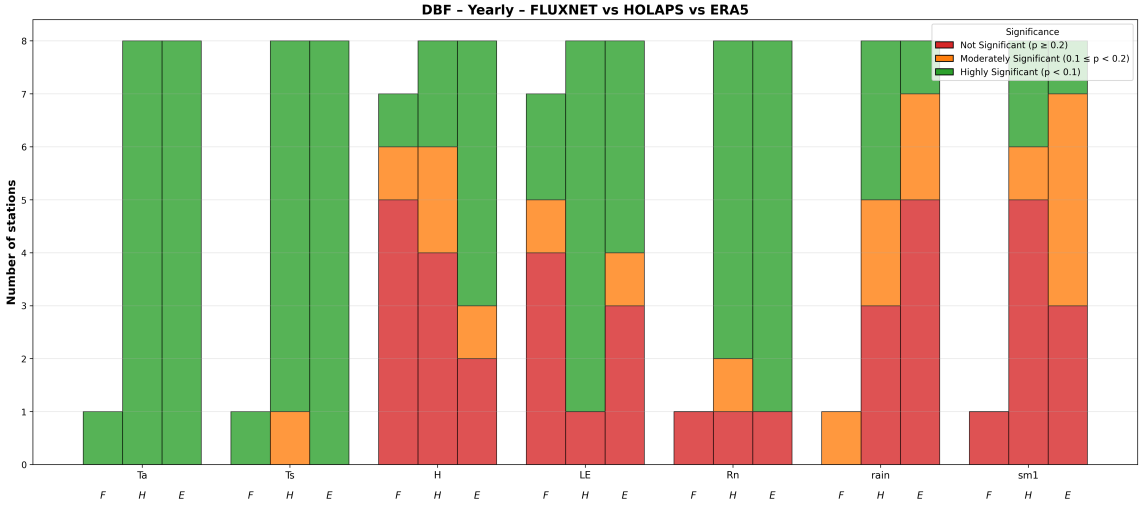


Figure 78: Ecosystem-stratified comparison of trend significance for the shared variable set across FLUXNET (F), HOLAPS (H), and ERA5_Land (E) for the DBF subset (yearly aggregation). Stacked bars summarize, for each dataset and variable, the number of stations with high ($p < 0.10$), medium ($0.10 \leq p < 0.20$), and non-significant ($p \geq 0.20$) trends.