

Supplementary information to:

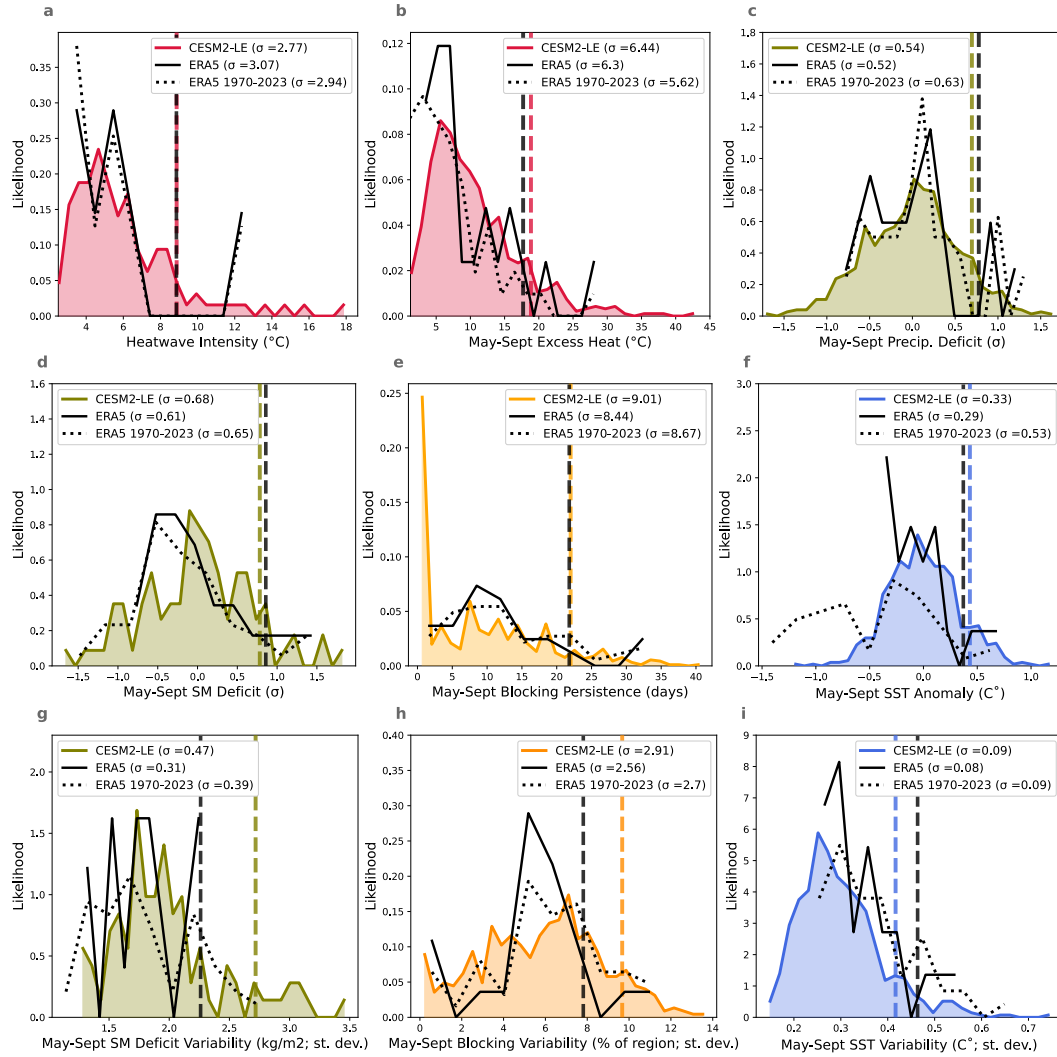
Worst-case European heat storylines generated using Ensemble Boosting

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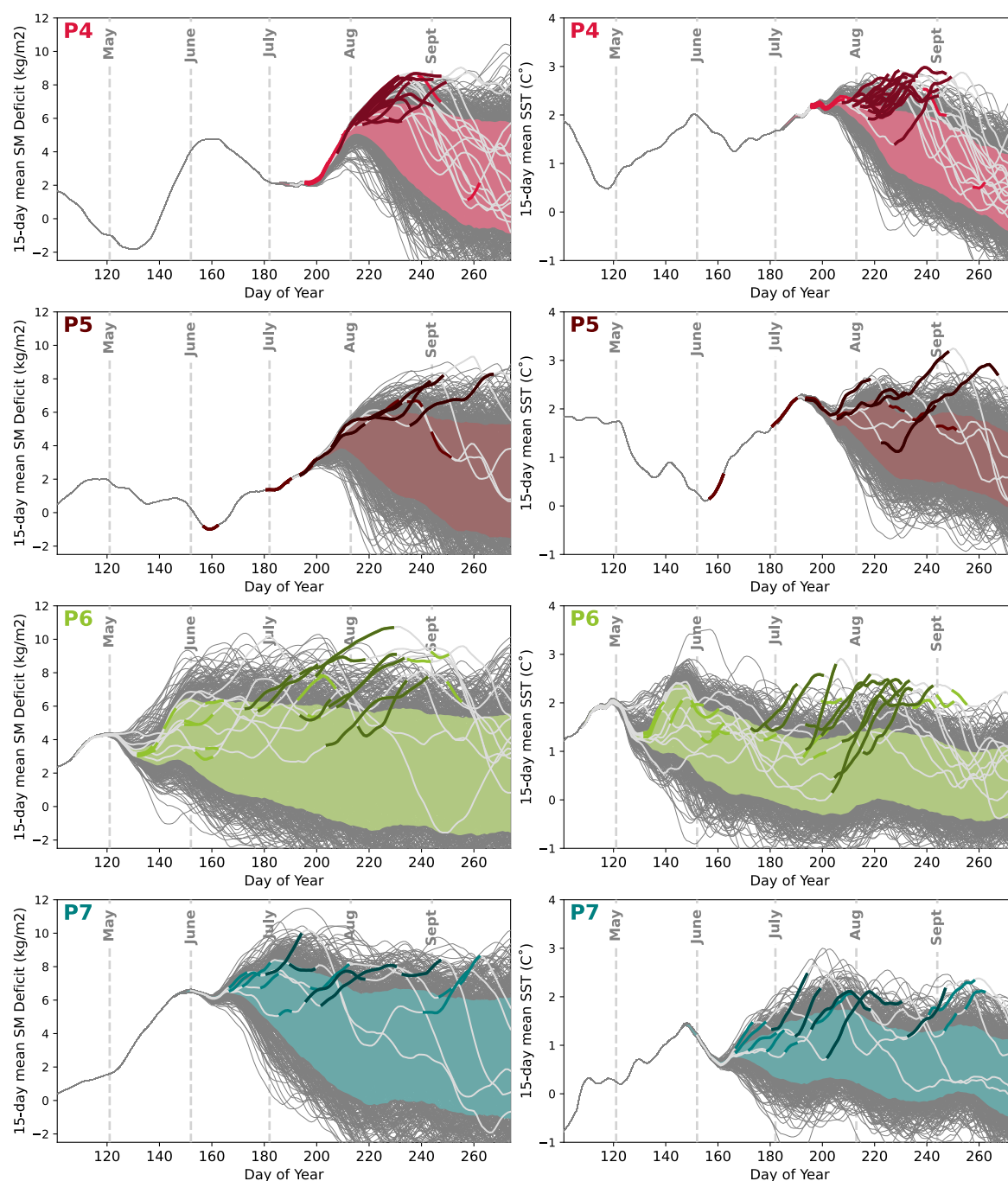
This Supplementary Information (SI) file provides additional data, figures, and analyses supporting the findings of the main manuscript.



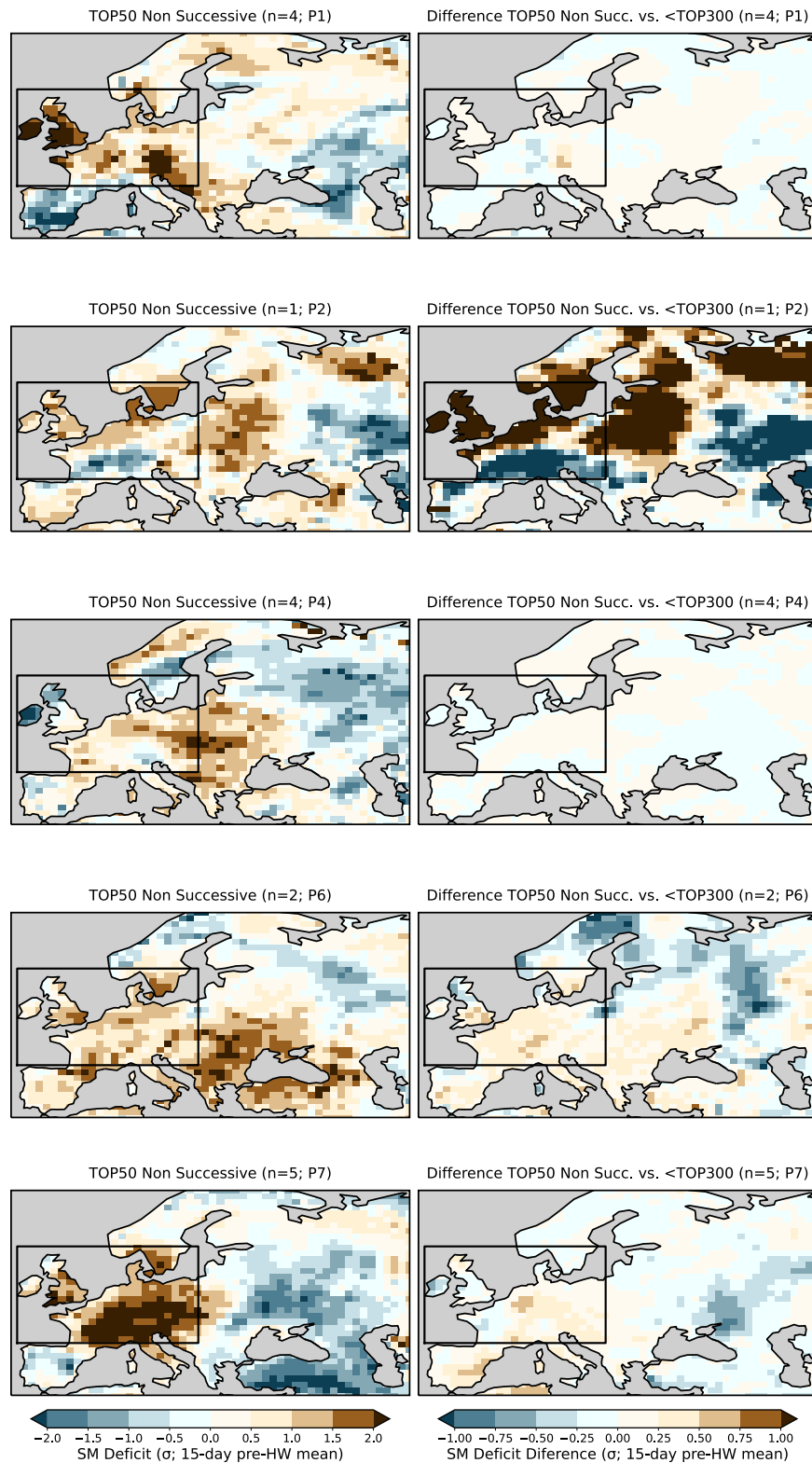
SI Figure S1: Evaluation of CESM2-LE against ERA5. Probability density functions (PDF) for the 35-member CESM2-LE (color; 2005–2023) and ERA5 (solid black line for 2000–2023 and dotted black line for 1970–2023). Vertical dashed lines mark the 90th percentile in ERA5 (black; 2000–2023) and CESM2-LE (color; 2005–2023). σ values show the standard deviations of the different samples for Heatwave Intensity (a), accumulated Excess Heat (b) standardized accumulated Precipitation Deficits (c), mean soil moisture (SM) deficits (d), accumulated blocking persistence (e), mean sea surface temperature (SST) anomalies (f), SM variability (standard deviation across seasonal SM daily values; g), blocking coverage variability (standard deviation across seasonal daily values of blocking spatial coverage as percentage of grid cells; h), and SST variability (standard deviation across seasonal daily SST values; i). All metrics are assessed for the May-Sept. extended summer season.

Parent Case	Year	Boosted on	Extreme Heat	Early Drought	Boosted on HW
P1	2015	June 22nd	-	x	-
P2	2018	June 2nd	-	-	-
P3	2020	May 8th	-	-	-
P4	2027	July 22nd	x	-	x
P5	2027	July 20th	x	-	x
P6	2023	May 6th	-	x	-
P7	2028	June 13th	-	x	-

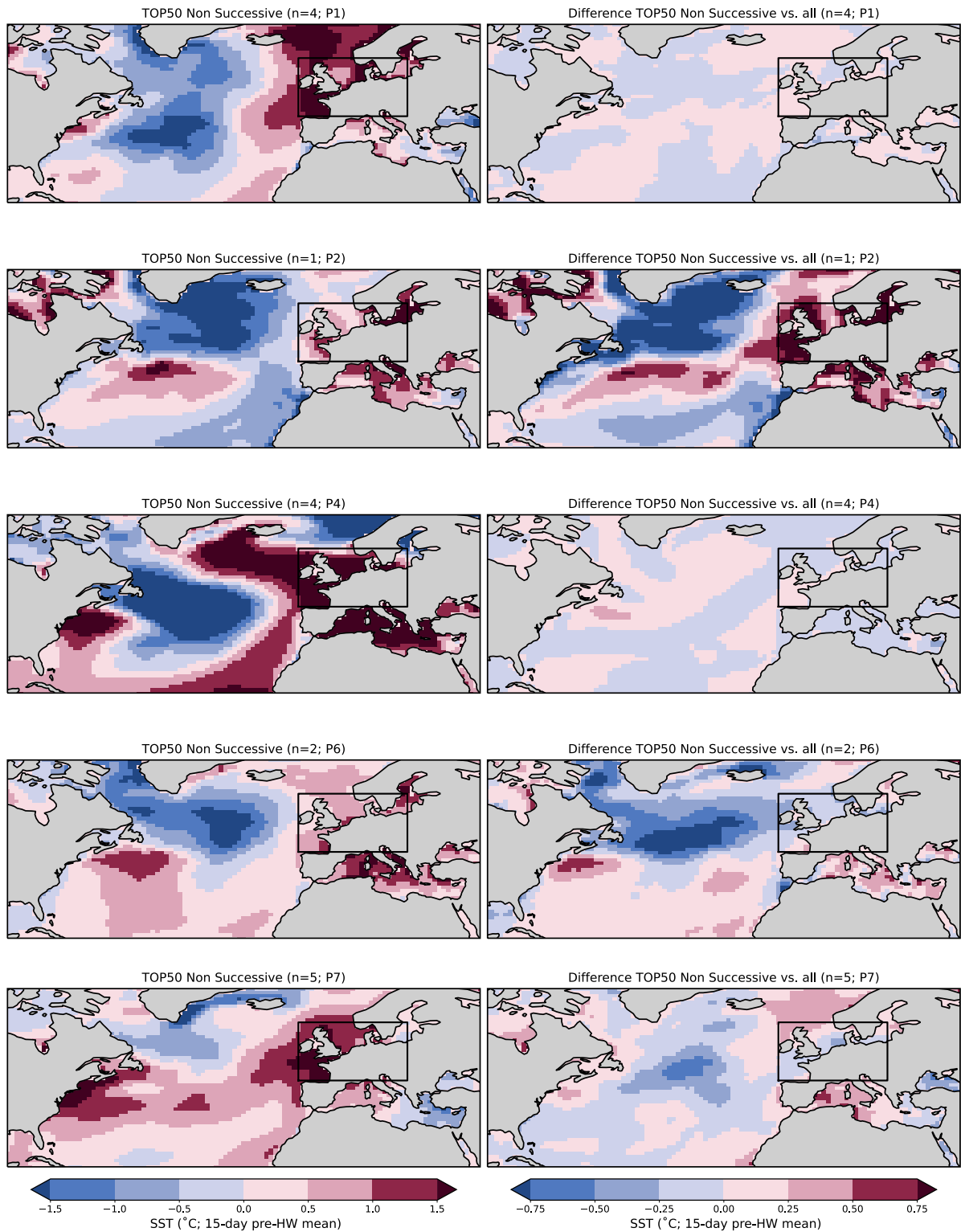
SI Table S1: Conditions of the parent events selected for boosting. Parent Case acronym (P1-7); year when the parent simulations occur in CESM2-LE; boosting date, exemplified here by the last date of the 20-day boosting window (see Methods for details). The last three columns mark whether the parent event exhibits extreme excess heat, extreme early summer drought, and if it is boosted during an ongoing heatwave, respectively.



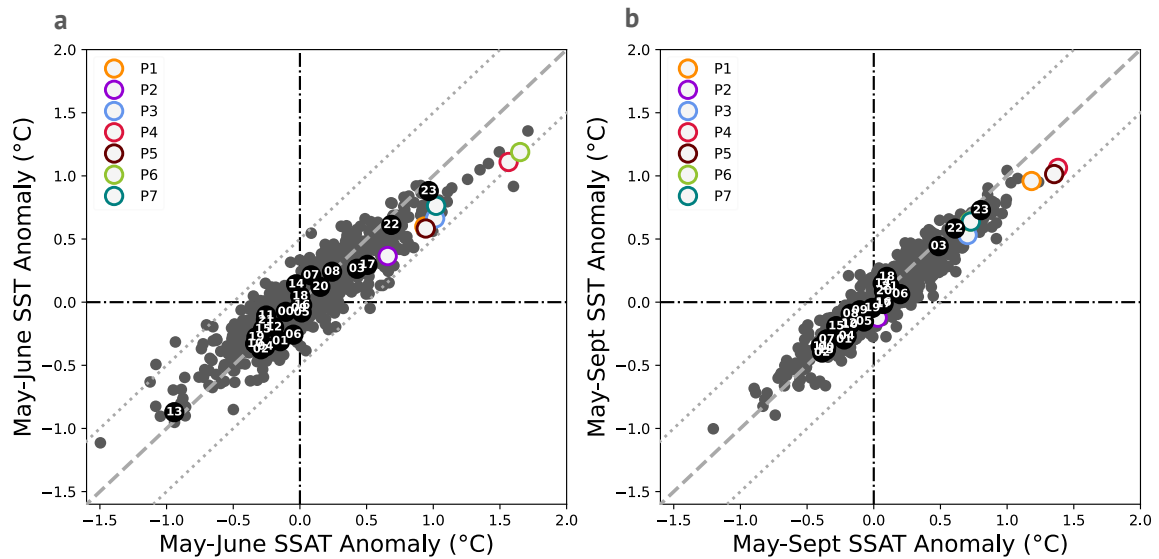
SI Figure S2: Temporal evolution of TOP50 most extremes successive heatwave boosted storylines against same-parent boosted ensembles for soil moisture (SM; left column) and sea surface temperatures (SST; right column) for the four parent cases exhibiting successive heatwaves (P4-P7). Values show running means for the previous 15-day window for simulations exhibiting successive heatwaves among the TOP50 most intense boosted heatwaves (thick lines), highlighting the TOP50 successive heatwave period (dark colors) and additional heatwaves in the simulation (light colors), as well as non-heatwave periods (light gray). Dark gray lines show all same-parent simulations, color shading marks the 10th-90th percentile range across all same-parent simulations boosted simulations.



SI Figure S3: Soil Moisture (SM) Deficits preceding TOP50 non-successive Heatwaves. Composites of standardized mean SM deficits over the 15-day window before the start of non-successive boosted heatwaves among the TOP50 most extreme per parent (left column), and difference between each non-successive TOP50 15-day pre-HW window and the same time window averaged across the whole boosted ensemble for the same parent (right column), excluding the same-parent simulations with heatwaves amongst the TOP300 most extreme heatwaves across the complete boosted sample. The region used for spatially aggregated heatwave and SM metrics is marked by the black box.



SI Figure S4: Sea Surface Temperature (SST) anomalies preceding TOP50 non-successive Heatwaves. Composites of mean SST anomalies over the 15-day window before the start of non-successive boosted heatwaves among the TOP50 most extreme per parent (left column), and difference between each non-successive TOP50 15-day pre-HW window and the same time window averaged across the whole boosted ensemble for the same parent (right column), excluding the same-parent simulations with heatwaves amongst the TOP300 most extreme heatwaves across the complete boosted sample. The region used for spatially aggregated heatwave metrics is marked by the black box.



SI Figure S5: Sea Surface Temperatures **a)** Sea Surface Temperature (SST) vs. Sea Surface Air Temperature (SSAT) anomalies in the 35-member non-boosted CESM2-LE (gray dots), against ERA5 (black dots, year in white; 1940-2023), and against seven parent simulations (P1-7; white infilled colored circles), averaged for the May-June period. **b)** Same as a), but averaged for the May-Sept. period. Dashed gray lines mark the 1:1 line, while dotted gray lines mark a $\pm 0.5^{\circ}\text{C}$ range.