



Supplement of

Local and remote climatic drivers of extreme summer sea surface temperatures in the Arabian Gulf

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Table S1. Statistics (W- and p-values) of the Shapiro-Wilk data normality test. A W-value that is close to 1 (e.g., > 0.95) indicates that the sample distribution is close to normal distribution. A large p-value (>0.05) indicates that the deviation from normality is not statistically significant.

Variable	SST	Downward Longwave Radiation	Downward Shortwave Radiation	Latent Heat Flux	Sensible Heat Flux	Ocean Nino Index	NAO Index	IOD Index	ISM Index
W-value	0.99	0.99	0.99	0.98	0.98	0.97	0.99	0.98	0.97
p-value	0.51	0.82	0.77	0.1	0.06	0.01	0.25	0.19	0.01

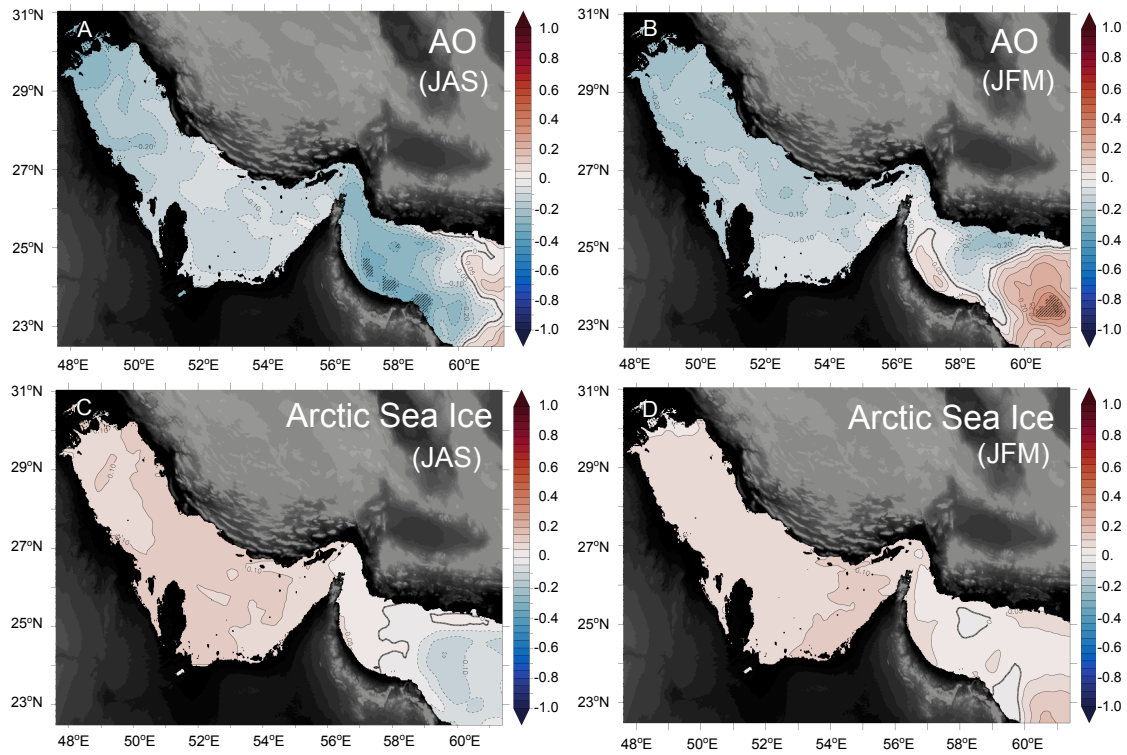


Figure S1. Gulf SST and Arctic teleconnection. Zero-lag (A, C) and 6-month-lag (B, D) correlations between summer (JAS) Gulf SSTs and (A–B) the Arctic Oscillation, and (C–D) the Arctic sea-ice area anomaly. Hatching indicates regions statistically significant at the 95 % confidence level.

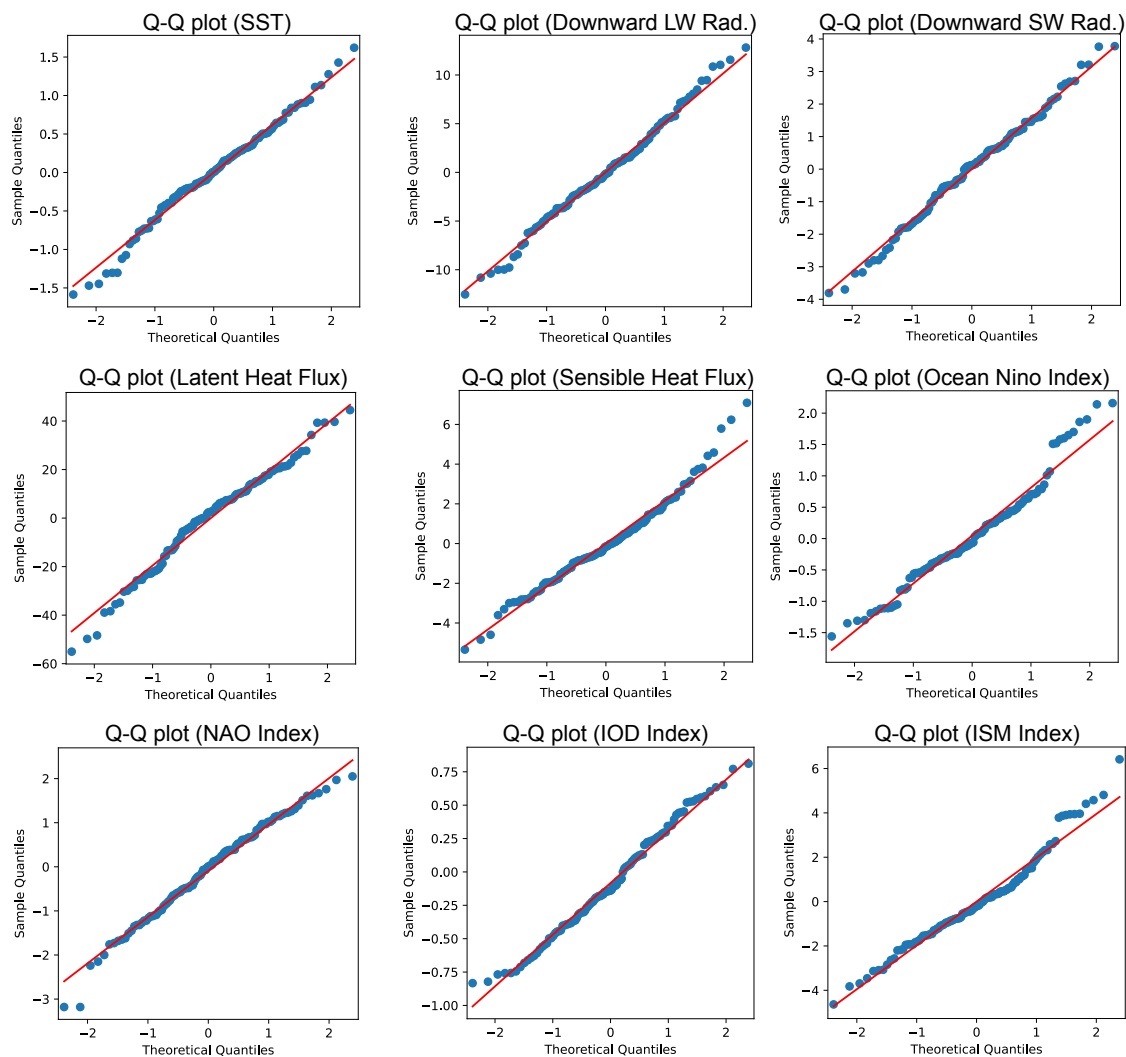


Figure S2. Q-Q plots assessing the normality of the data distributions for the analyzed variables. In each plot, the sample quantiles are plotted against theoretical quantiles from a normal distribution. Deviations from the reference line indicate departures from normality.

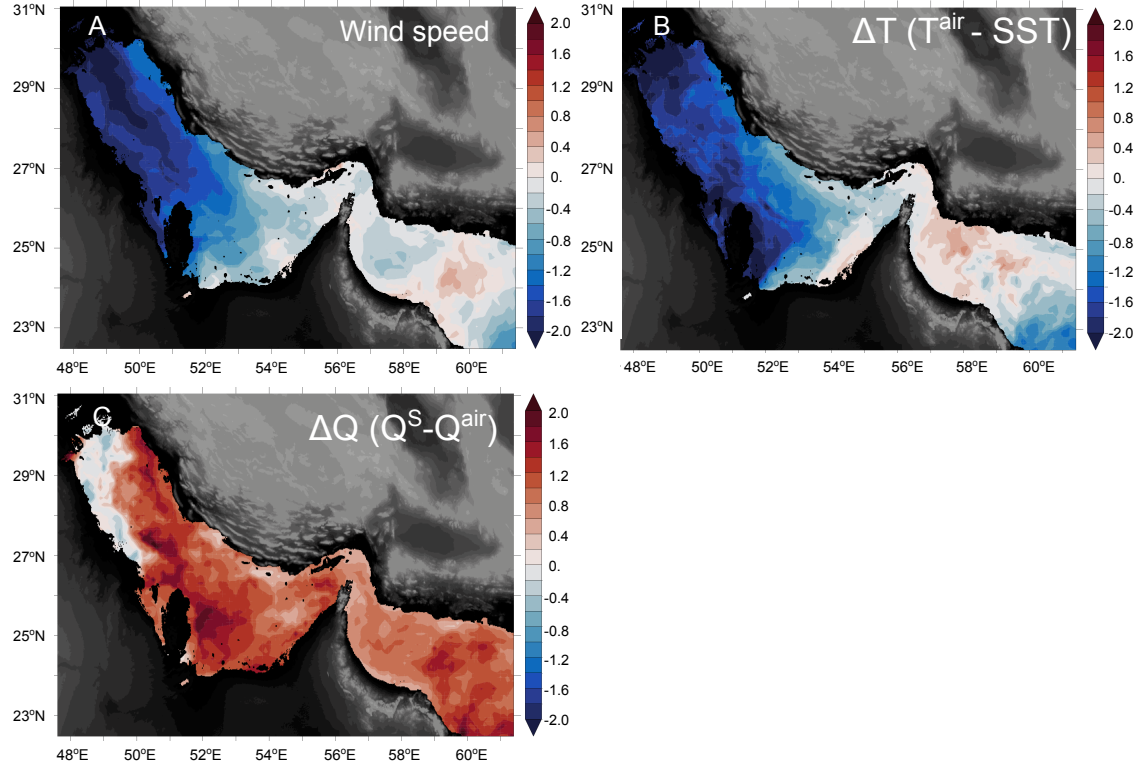


Figure S3. Relationship between surface atmospheric conditions and the Gulf surface temperature. Composite SST anomalies corresponding to the difference between high ($> +1$ SD above the mean) and low (< -1 SD below the mean) values of wind speed (A), air-sea temperature gradient $\Delta T = T^{\text{air}} - \text{SST}$ (B), air-sea humidity gradient $\Delta Q = Q^{\text{S}} - Q^{\text{air}}$ (C). T^{air} and Q^{air} refer to air temperature and specific humidity at 2m. Q^{S} is the saturation specific humidity at sea surface.

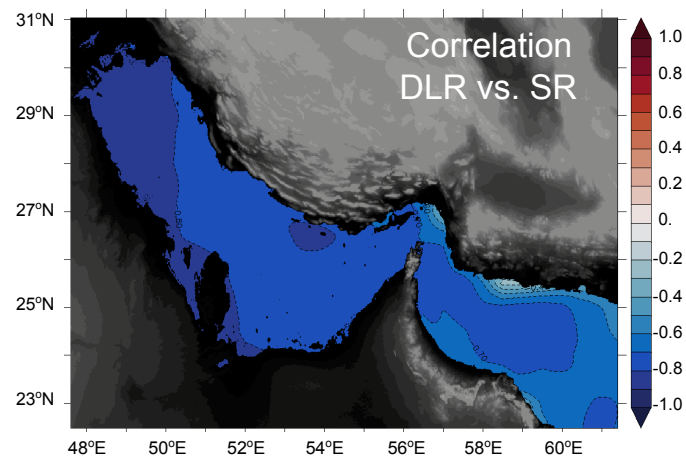


Figure S4. Relationship between Downward longwave and shortwave radiation. Pearson correlation coefficients between anomalies in Downward longwave radiation (DLR) and shortwave radiation (SR) during summer months in the Gulf.

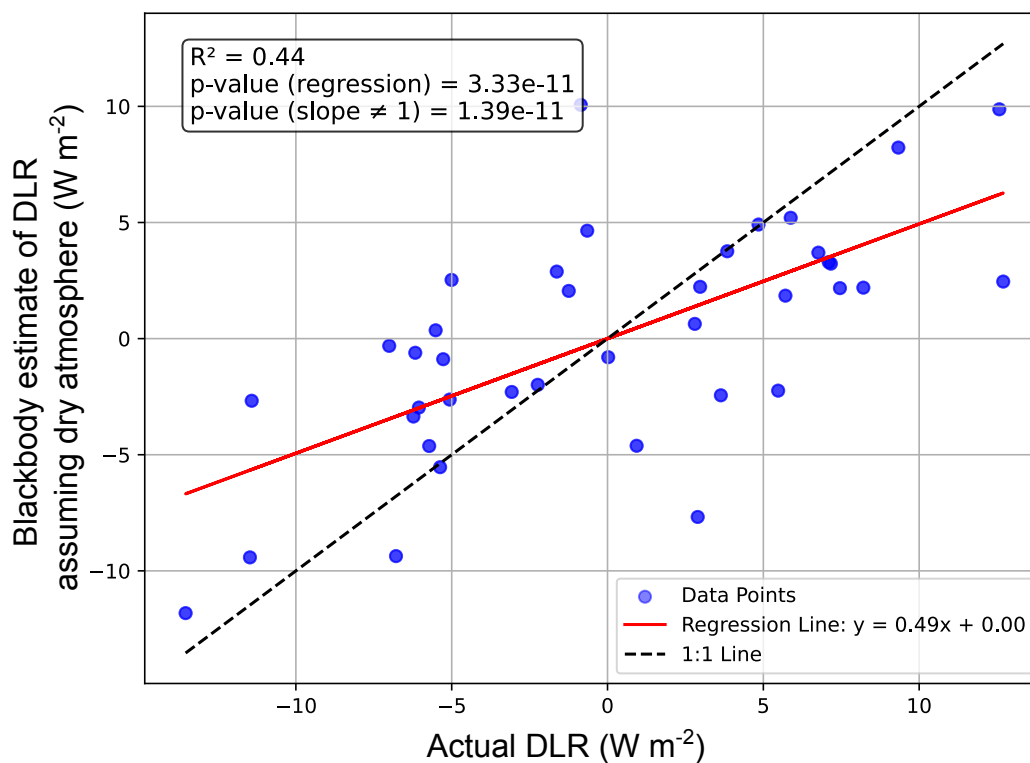


Figure S5. Contribution of anomalies in air moisture to downward longwave radiation anomalies. Comparison of anomalies in estimated downward longwave radiation (DLR) based on blackbody emissions using air temperature at 850 hpa (via the Stefan–Boltzmann law) with anomalies in actual DLR values from the ERA5 reanalysis. The regression line (slope = 0.49) lies below the identity line (1:1), indicating that air temperature alone underestimates surface DLR. This suggests that a substantial fraction of the observed DLR is associated with atmospheric water vapor that enhances atmospheric emissivity.

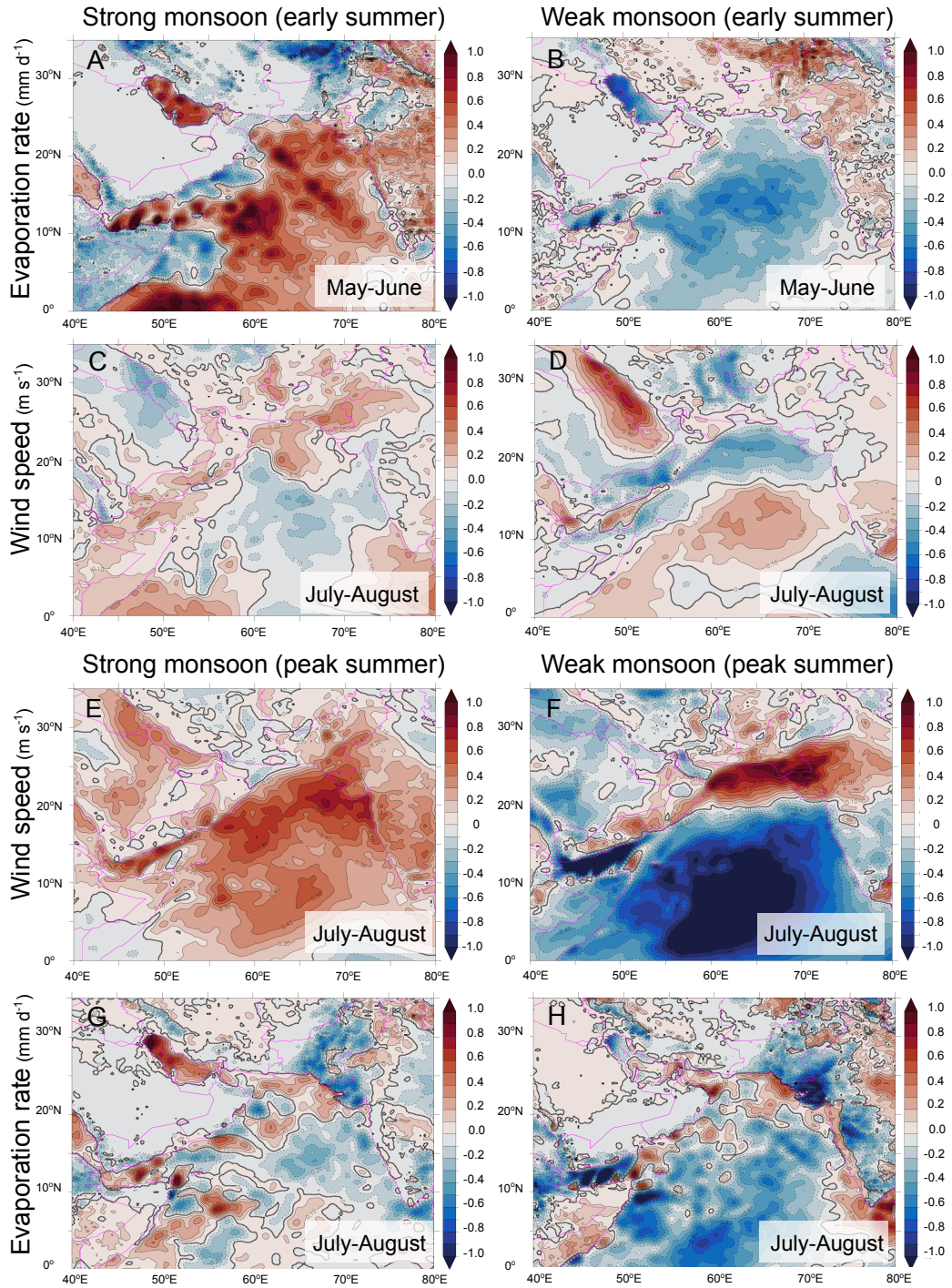


Figure S6. Composite anomalies during strong and weak ISM. Anomalies in summer surface wind speed and evaporation rates during strong (left) and weak (right) ISM over the Arabian Peninsula and Arabian Sea region. (A-D) conditions associated with strong monsoon circulation in the early summer (May-June). (E-H) conditions associated with strong monsoon circulation in the peak summer (July-August).

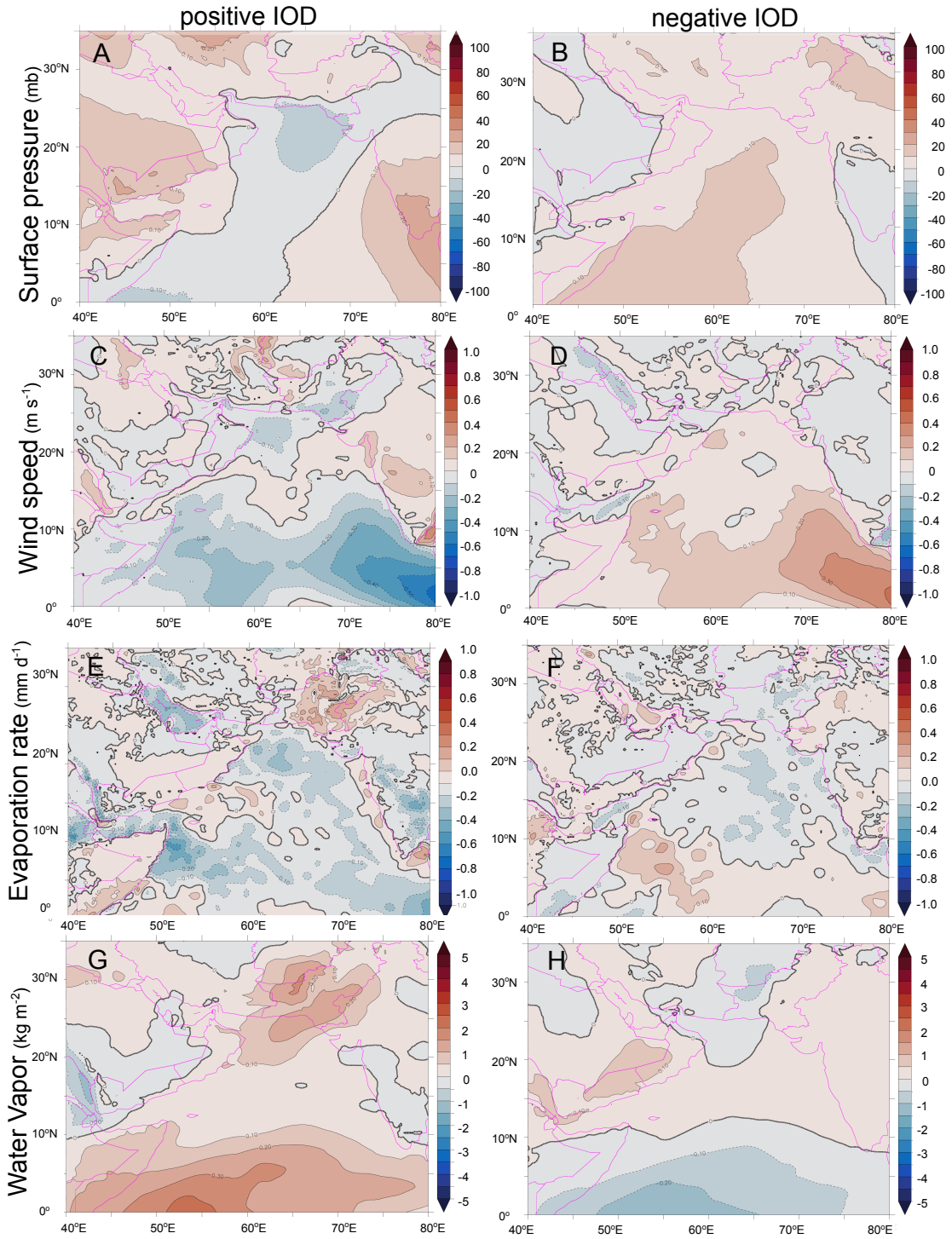


Figure S7. Composite anomalies during IOD. Anomalies in summer atmospheric conditions during positive (left) and negative (right) IOD over the Arabian Peninsula and Arabian Sea region. (A-B) sea level pressure, (C-D) wind speed, (E-F) evaporation rate, (G-H) total column water vapor.

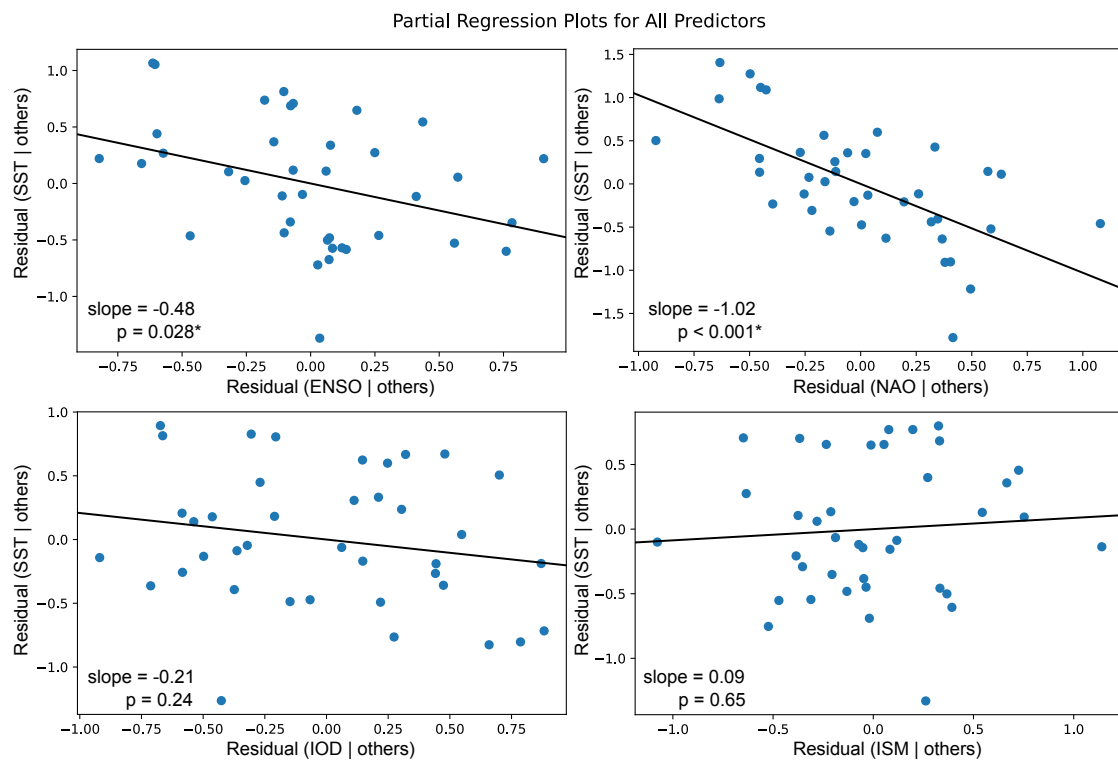


Figure S8. Partial regression of SST on climate variability modes. Partial regression between summer Gulf SST anomalies and the major climate modes: ENSO (upper left), NAO (upper right), IOD (lower left), and ISM (lower right). Each panel shows the regression of SST residuals (after removing the influence of the other modes) against the residuals of the corresponding climate mode (after removing the effects of the remaining modes).

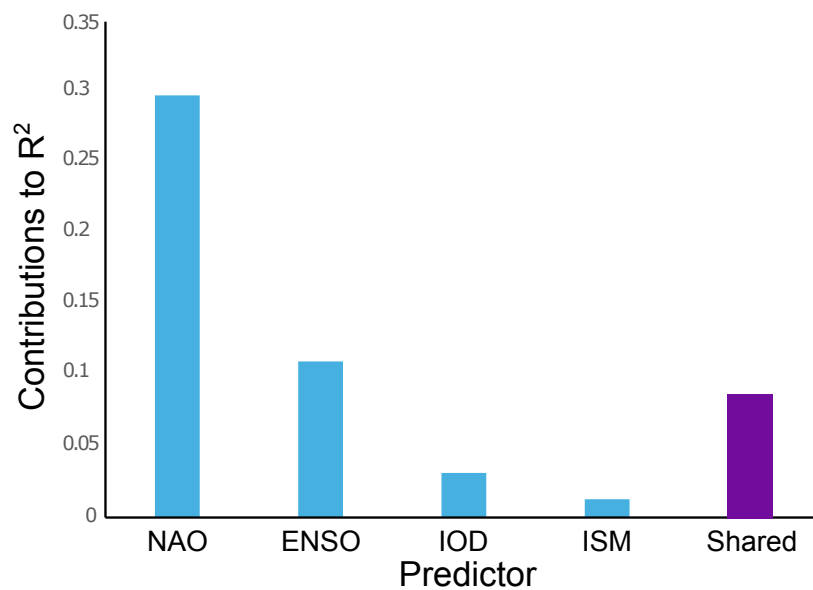


Figure S9. Independent and joint contributions of climate modes to Gulf summer SST variance. Estimated independent (unique) and joint (shared) contributions of ENSO, NAO, IOD, and ISM to Gulf summer SST variance, derived using the hierarchical partitioning method of Mac Nally (1996), which systematically assesses all combinations of predictors to quantify the variance explained by each mode individually and in combination with others.

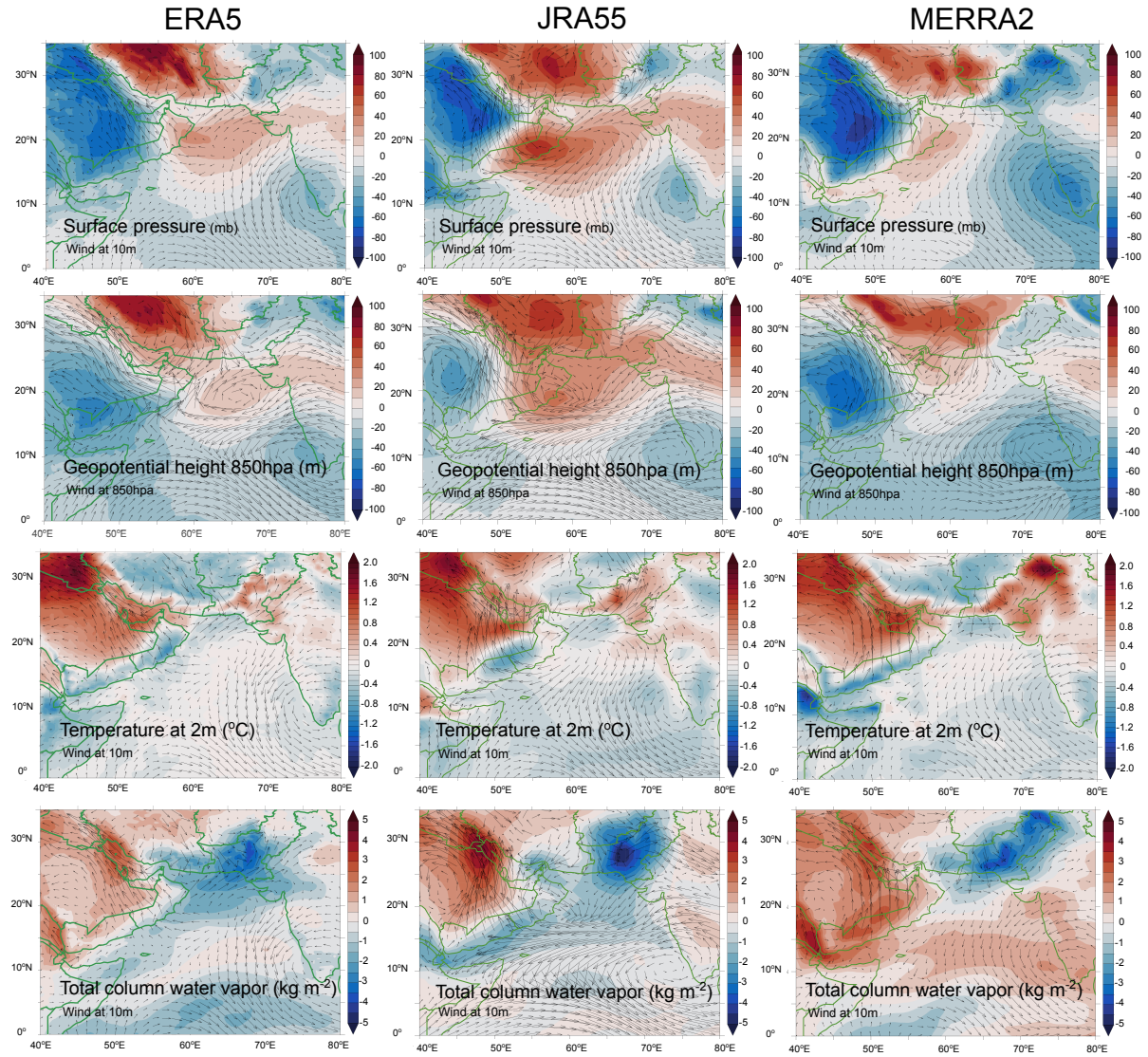


Figure S10. Atmospheric conditions associated with extreme summer SSTs in the Gulf from different reanalysis products. Composite of atmospheric fields corresponding to summer SST anomalies exceeding +1.28 SD above the mean (90th percentile) over at least 75% of the Gulf. From top to bottom: surface pressure, geopotential height at 850 hpa, temperature at 2 m, total-column water vapor, based on ERA5 (left), JRA-55 (middle) and MERRA-2 (right) reanalyses.

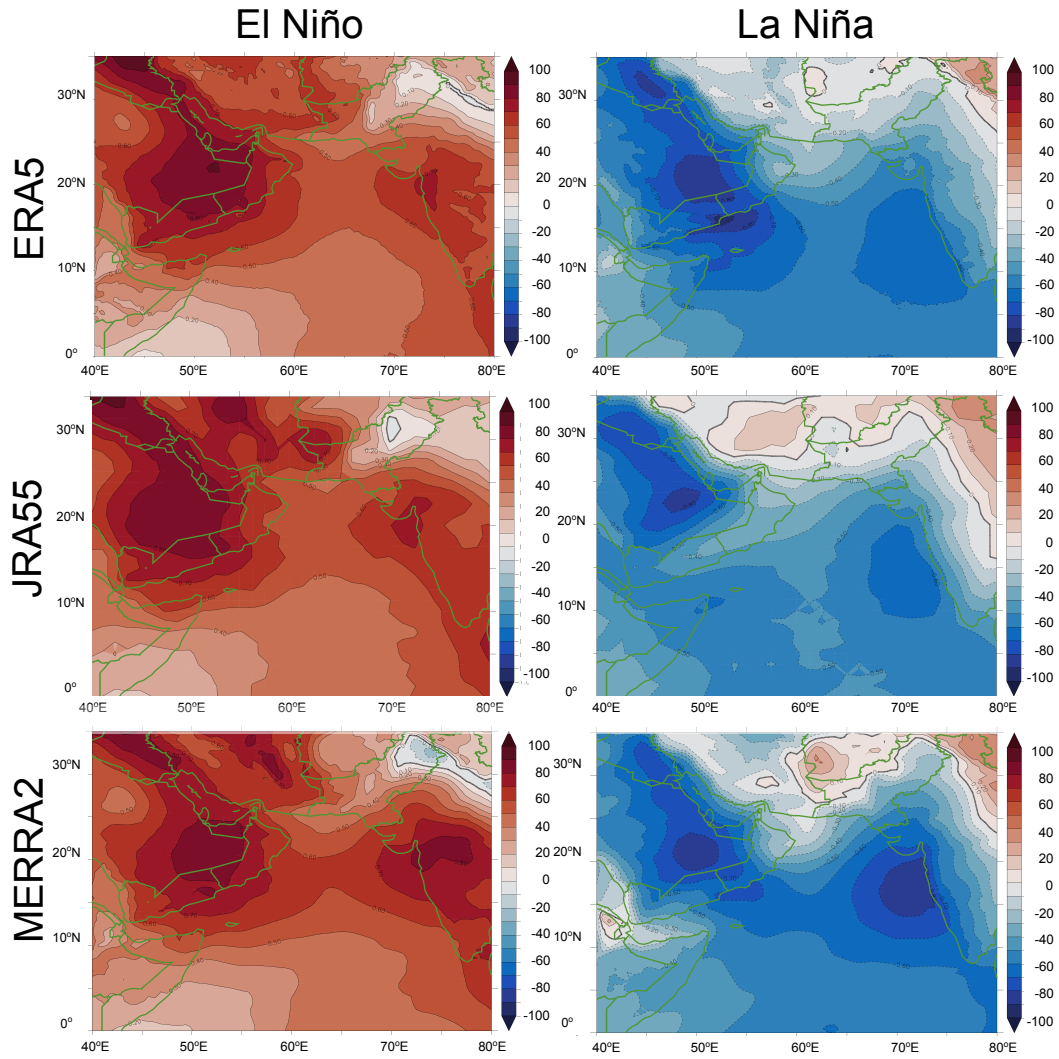


Figure S11. Composite anomalies during ENSO from different reanalysis products. Summer surface pressure anomalies during El Niño (left) and La Niña (right) over the Arabian Peninsula and Arabian Sea region based on ERA5 (top), JRA-55 (middle) and MERRA-2 (bottom).

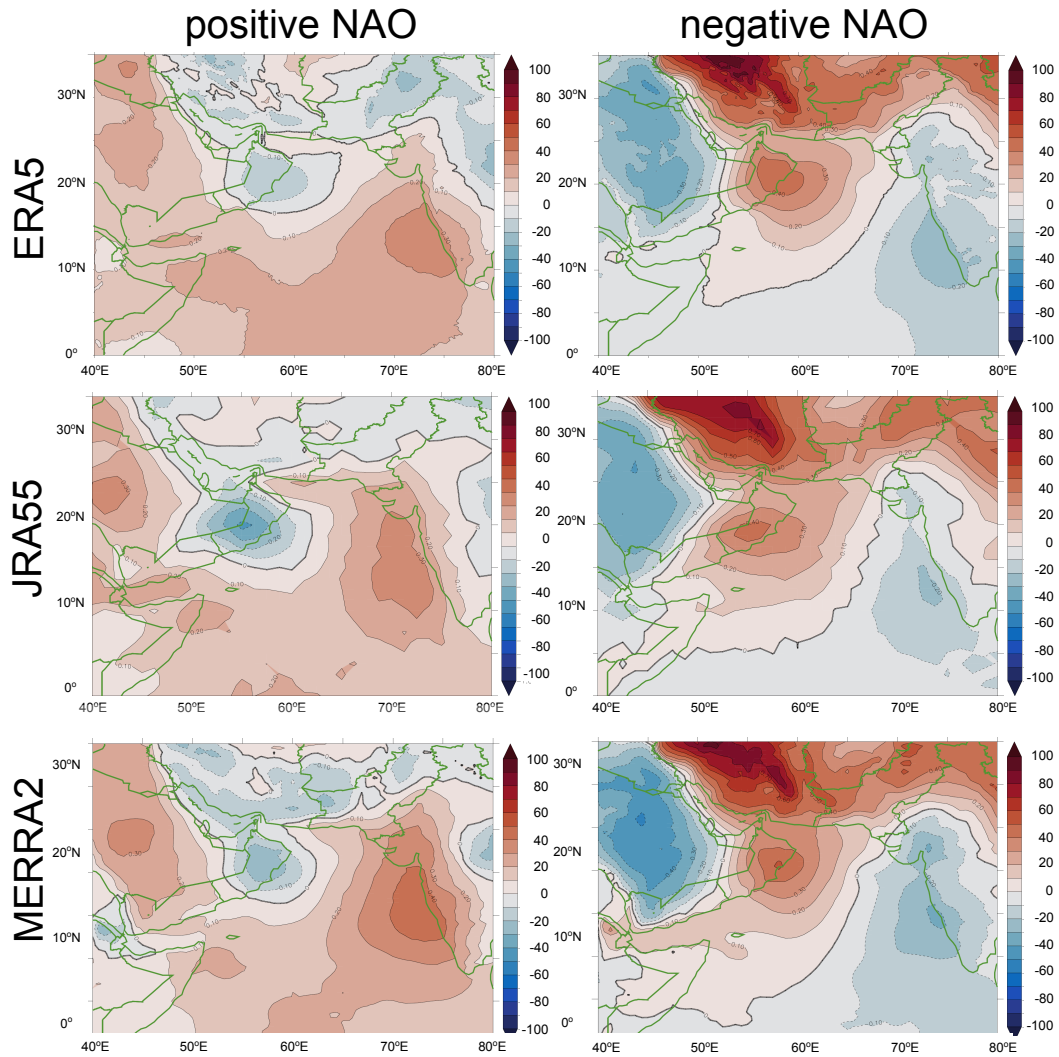


Figure S12. Composite anomalies during NAO from different reanalysis products. Summer surface pressure anomalies during positive NAO (left) and negative NAO (right) over the Arabian Peninsula and Arabian Sea region based on ERA5 (top), JRA-55 (middle) and MERRA-2 (bottom).

References

- 5 Mac Nally, R. M.: Hierarchical partitioning as an interpretative tool in multivariate inference, *Australian Journal of Ecology*, 21, 224–228, <https://doi.org/10.1111/j.1442-9993.1996.tb00602.x>, 1996.