

1 *Supporting Information for*
2 **Boundary-Layer-Coupled and Decoupled Clouds in Global Storm-**
3 **Revolving Models: Comparisons with Field Observations**

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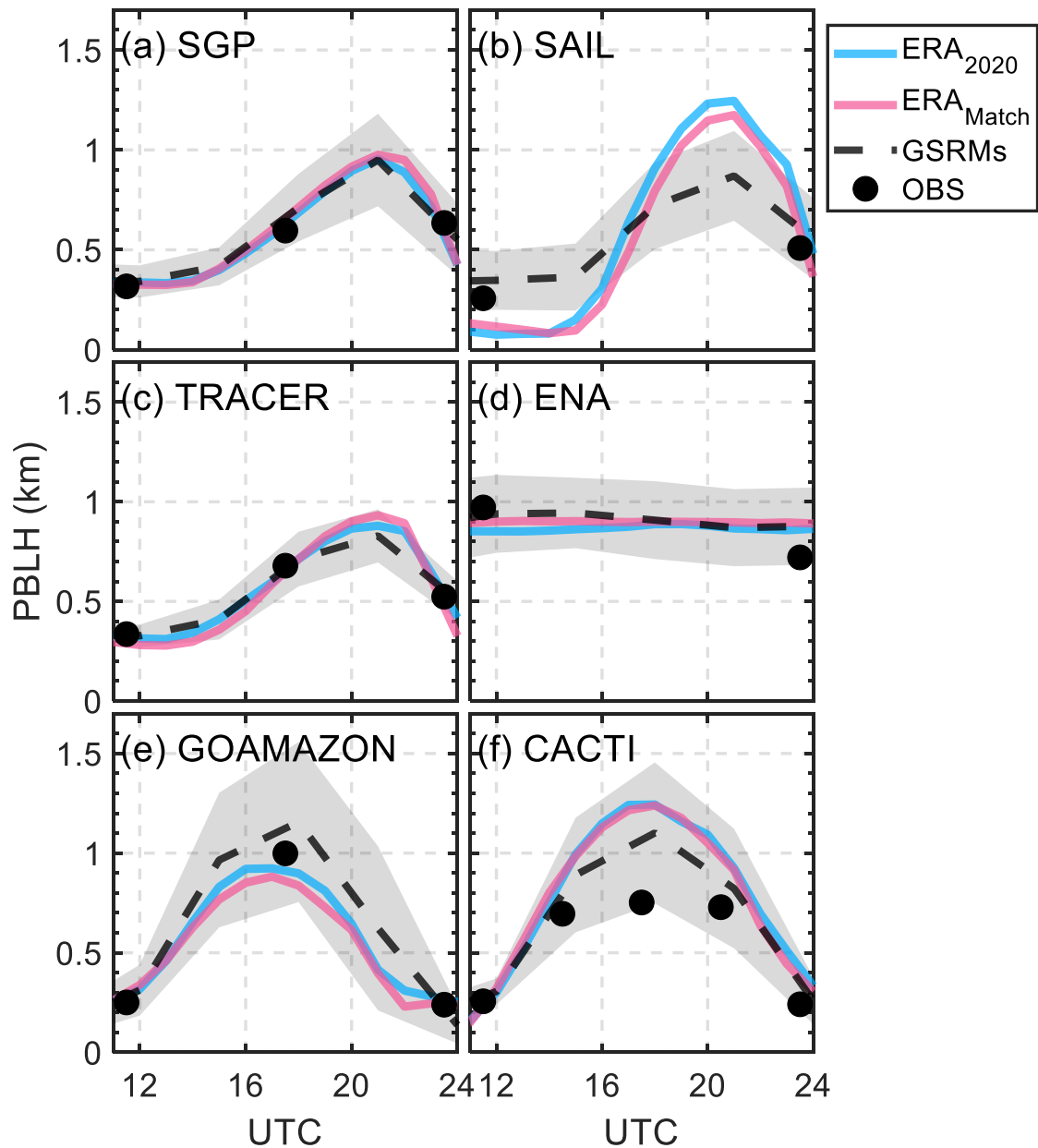


Figure S1. Diurnal variation in Planetary Boundary Layer Height (PBLH) at six different field campaign sites: SGP, SAIL, TRACER, ENA, GOAMAZON, and CACTI. The solid blue line represents the PBLH as per ERA5 data with matched cases with GSRMs, while the pink line indicates ERA5 data with matched cases with observations. The dashed black line with the shaded grey area depicts the mean PBLH simulated by Global Storm-Resolving Models (GSRMs) with the standard deviation for different models. Black dots mark the observed PBLH values.

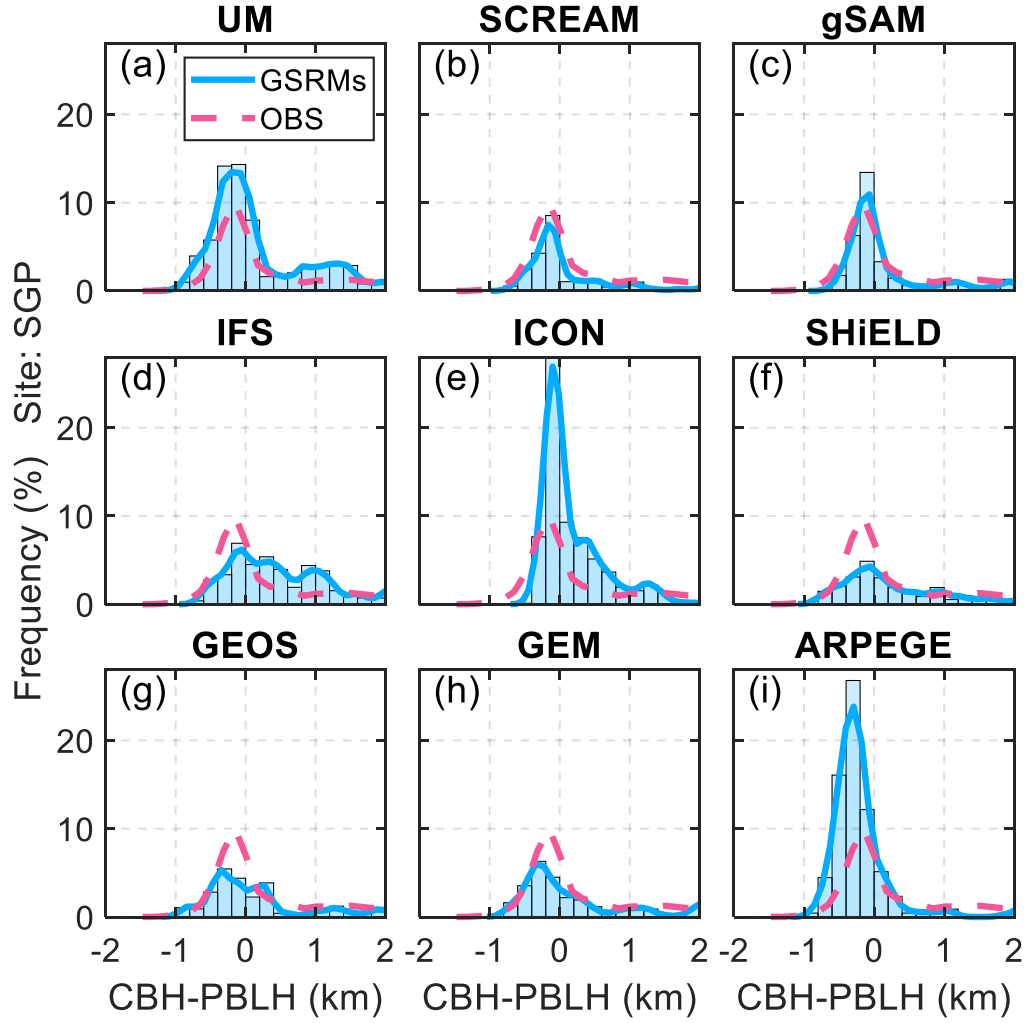


Figure S2. Distribution of cloud occurrence frequency relative to the difference between cloud base height (CBH) and planetary boundary layer height (PBLH) for the SGP site, as recorded in observational data and as simulated by various Global Storm-Resolving Models (GSRMs). Observational data are depicted with red lines, while the model outputs are shown in blue. Each panel corresponds to a different GSRM, specifically UM, SCREAM, gSAM, IFS, ICON, SHIELD, GEOS, GEM, and ARPEGE.

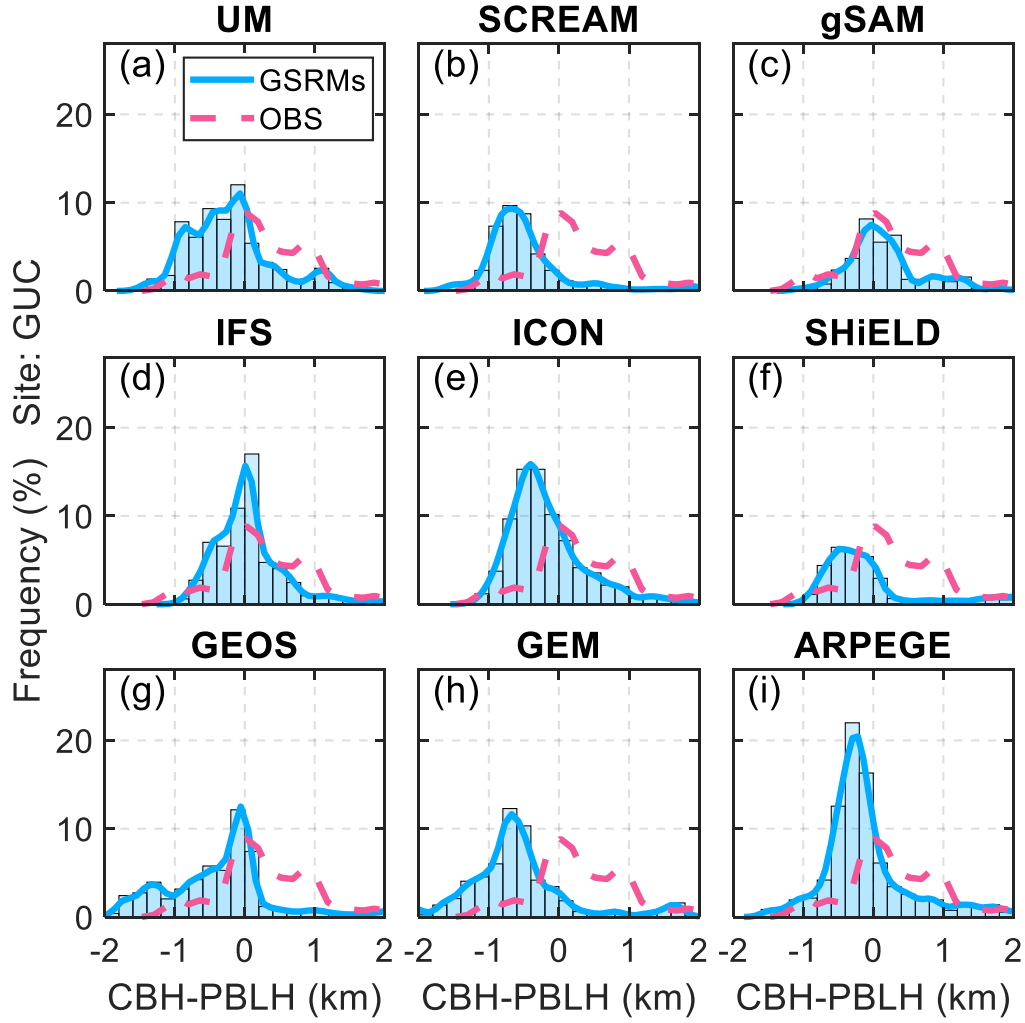


Figure S3. Distribution of cloud occurrence frequency relative to the difference between cloud base height (CBH) and planetary boundary layer height (PBLH) for the SAIL field campaign (GUC site), as recorded in observational data and as simulated by various Global Storm-Resolving Models (GSRMs). Observational data are depicted with red lines, while the model outputs are shown in blue. Each panel corresponds to a different GSRM, specifically UM, SCREAM, gSAM, IFS, ICON, SHIELD, GEOS, GEM, and ARPEGE.

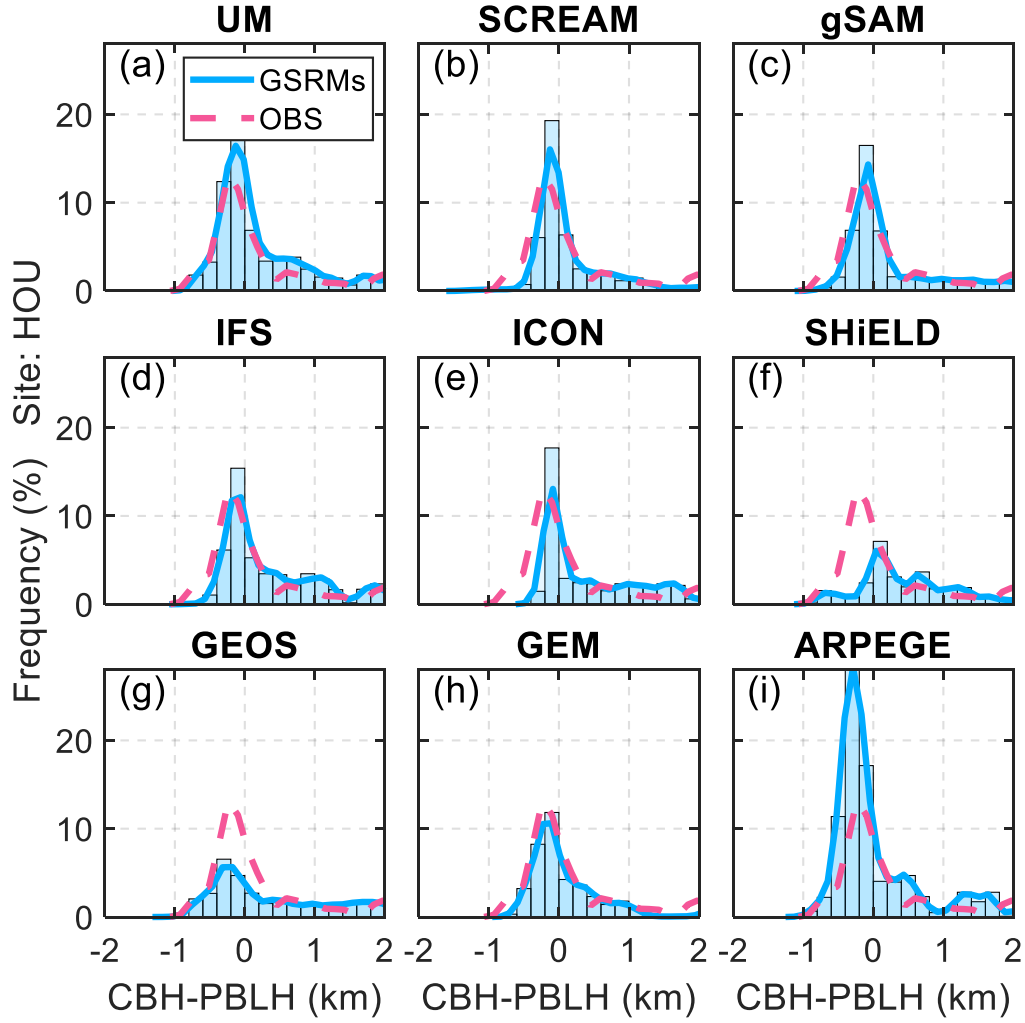


Figure S4. Distribution of cloud occurrence frequency relative to the difference between cloud base height (CBH) and planetary boundary layer height (PBLH) for the TRACER field campaign (HOU site), as recorded in observational data and as simulated by various Global Storm-Resolving Models (GSRMs). Observational data are depicted with red lines, while the model outputs are shown in blue. Each panel corresponds to a different GSRM, specifically UM, SCREAM, gSAM, IFS, ICON, SHIELD, GEOS, GEM, and ARPEGE.

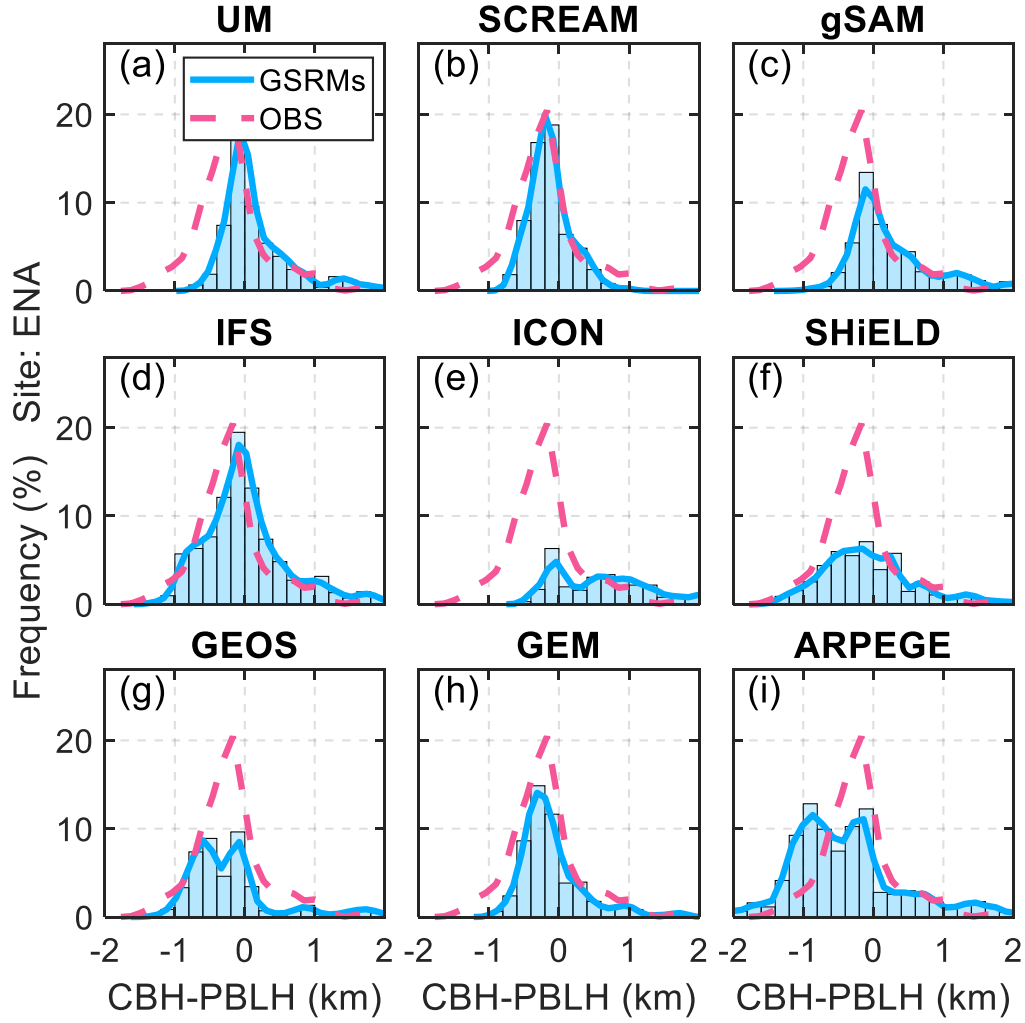


Figure S5. Distribution of cloud occurrence frequency relative to the difference between cloud base height (CBH) and planetary boundary layer height (PBLH) for the ENA site, as recorded in observational data and as simulated by various Global Storm-Resolving Models (GSRMs). Observational data are depicted with red lines, while the model outputs are shown in blue. Each panel corresponds to a different GSRM, specifically UM, SCREAM, gSAM, IFS, ICON, SHIELD, GEOS, GEM, and ARPEGE.

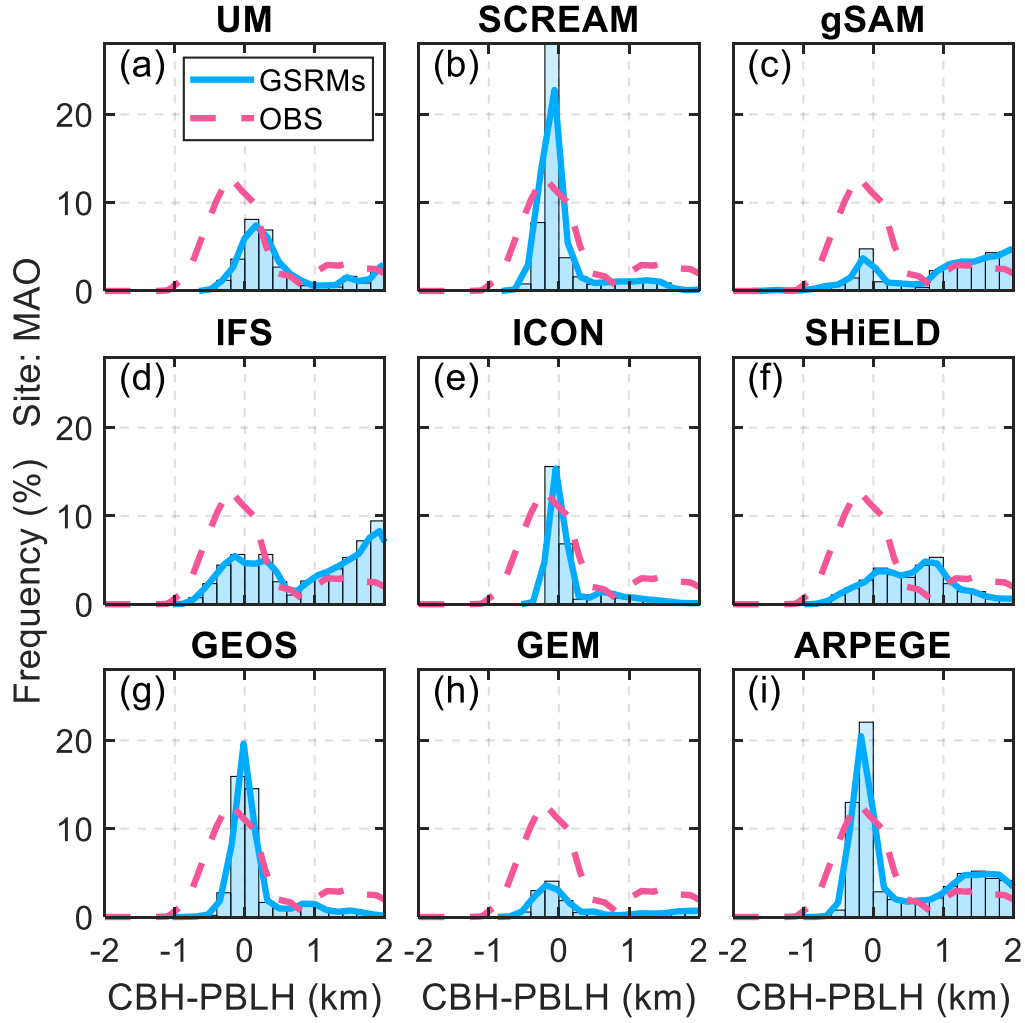


Figure S6. Distribution of cloud occurrence frequency relative to the difference between cloud base height (CBH) and planetary boundary layer height (PBLH) for the MAO site, as recorded in observational data and as simulated by various Global Storm-Resolving Models (GSRMs). Observational data are depicted with red lines, while the model outputs are shown in blue. Each panel corresponds to a different GSRM, specifically UM, SCREAM, gSAM, IFS, ICON, SHIELD, GEOS, GEM, and ARPEGE.

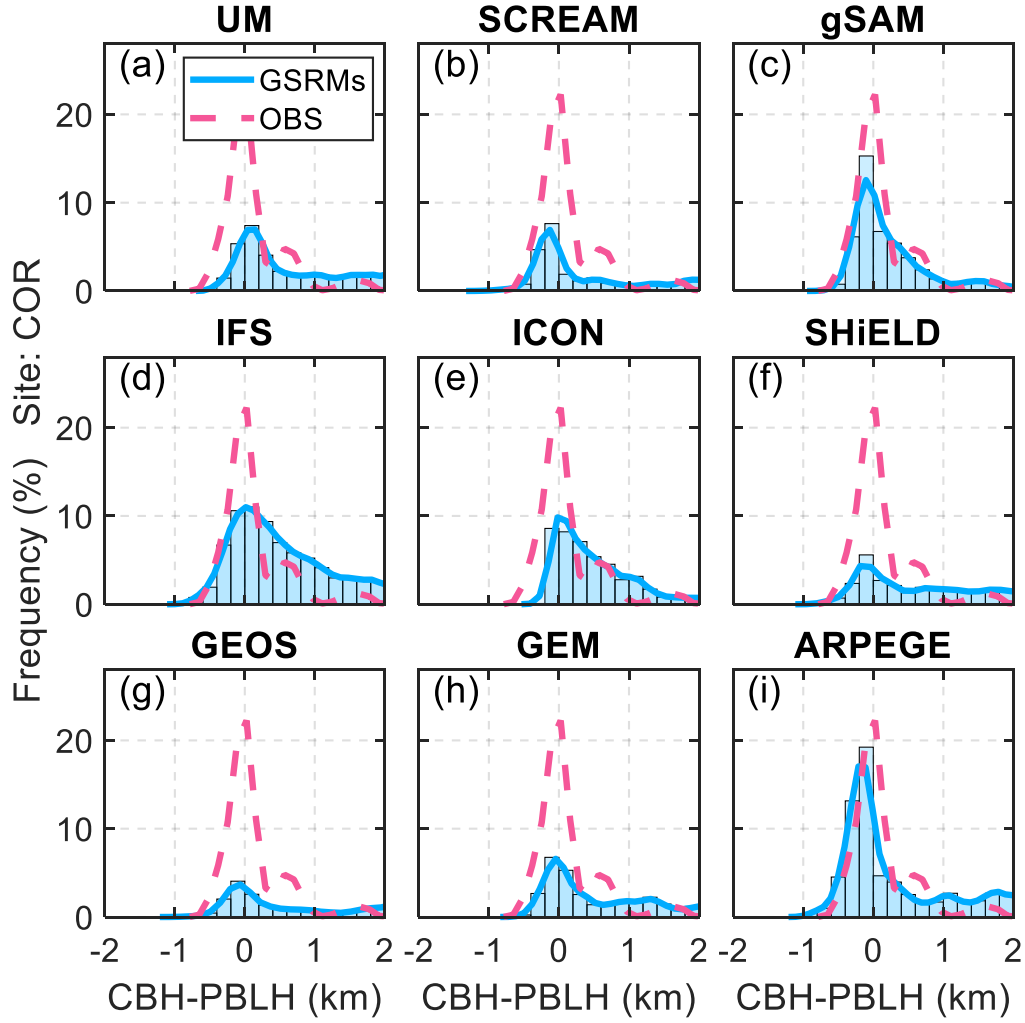


Figure S7. Distribution of cloud occurrence frequency relative to the difference between cloud base height (CBH) and planetary boundary layer height (PBLH) for the COR site, as recorded in observational data and as simulated by various Global Storm-Resolving Models (GSRMs). Observational data are depicted with red lines, while the model outputs are shown in blue. Each panel corresponds to a different GSRM, specifically UM, SCREAM, gSAM, IFS, ICON, SHIELD, GEOS, GEM, and ARPEGE.

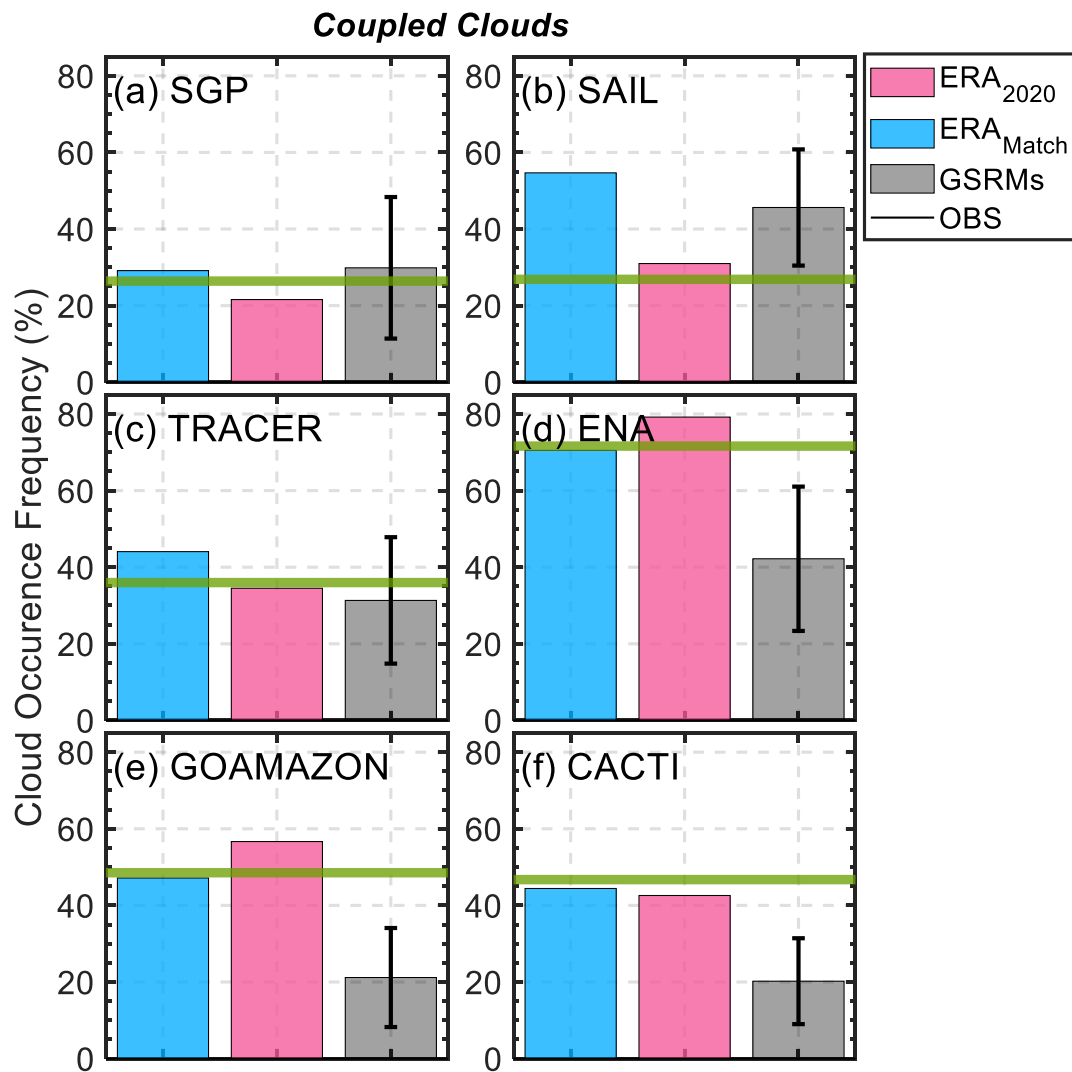


Figure S8. Comparison of boundary layer-coupled cloud frequency across various field campaign sites, as indicated by observational data (green line) and as simulated by Global Storm-Resolving Models (GSRMs). Each panel (a-f) represents a different site: SGP, SAIL, TRACER, ENA, GOAMAZON, and CACTI. The blue bars indicate ERA5 data for cases that match the observational periods, and the red bars reflect matched cases with GSRMs from 20 January to 29 February 2020. The grey bars represent the mean frequency from the GSRMs, while the error bars show the standard deviation within the GSRM data, illustrating the spread in different models.

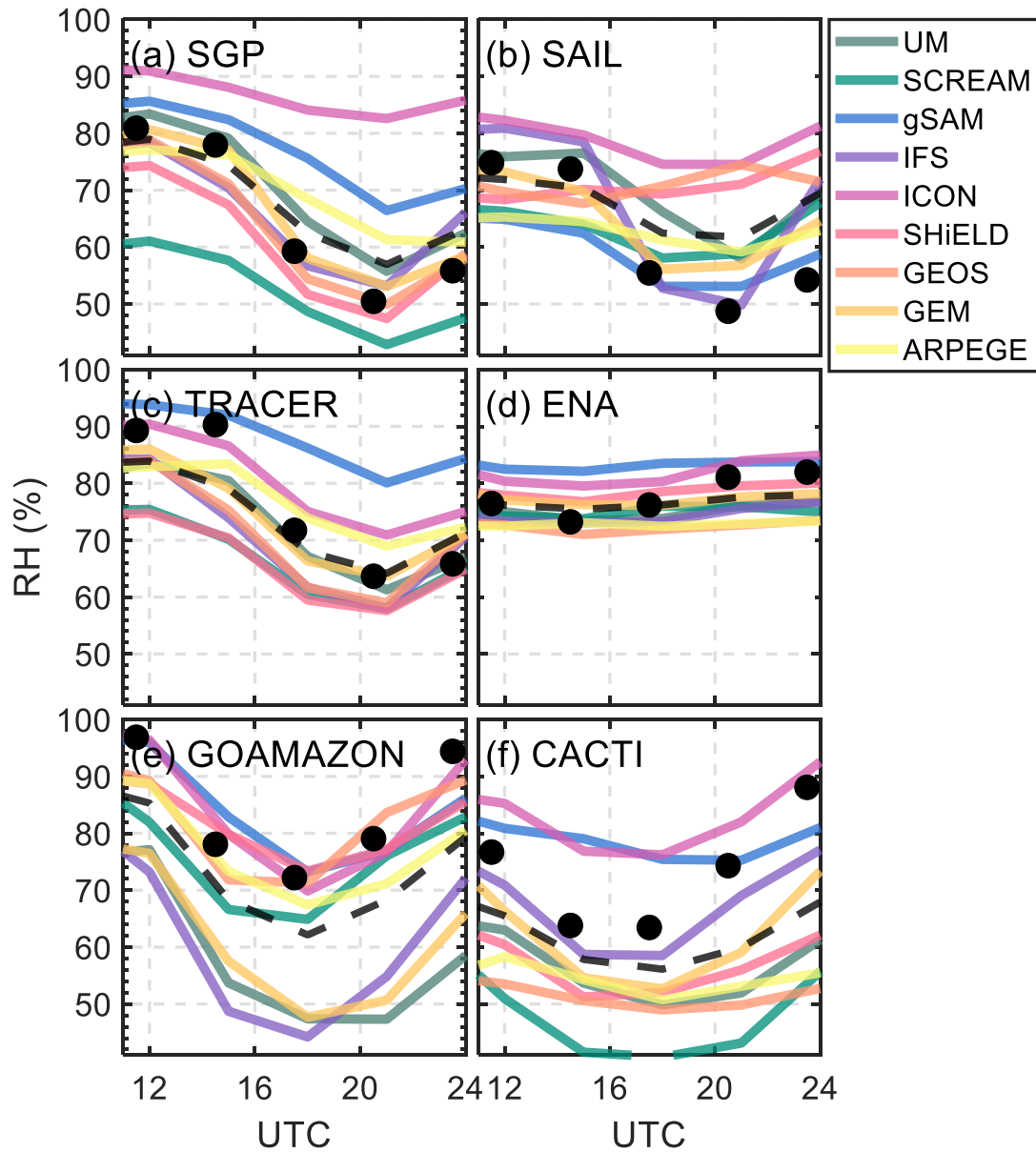


Figure S9: Diurnal variations in the near-surface RH across different geographical regions as captured by various Global Storm-Resolving Models (GSRMs) and compared to field observations (OBS). Each panel represents different sites: (a) SGP, (b) SAIL, (c) TRACER, (d) ENA, (e) GOAMAZON, and (f) CACTI. The colored lines correspond to the PBLH predicted by each model, including UM, SCREAM, g SAM, IFS, ICON, SHIELD, GEOS, GEM, and ARPEGE, illustrating the range of simulation outputs across models. Black dots represent observed values.

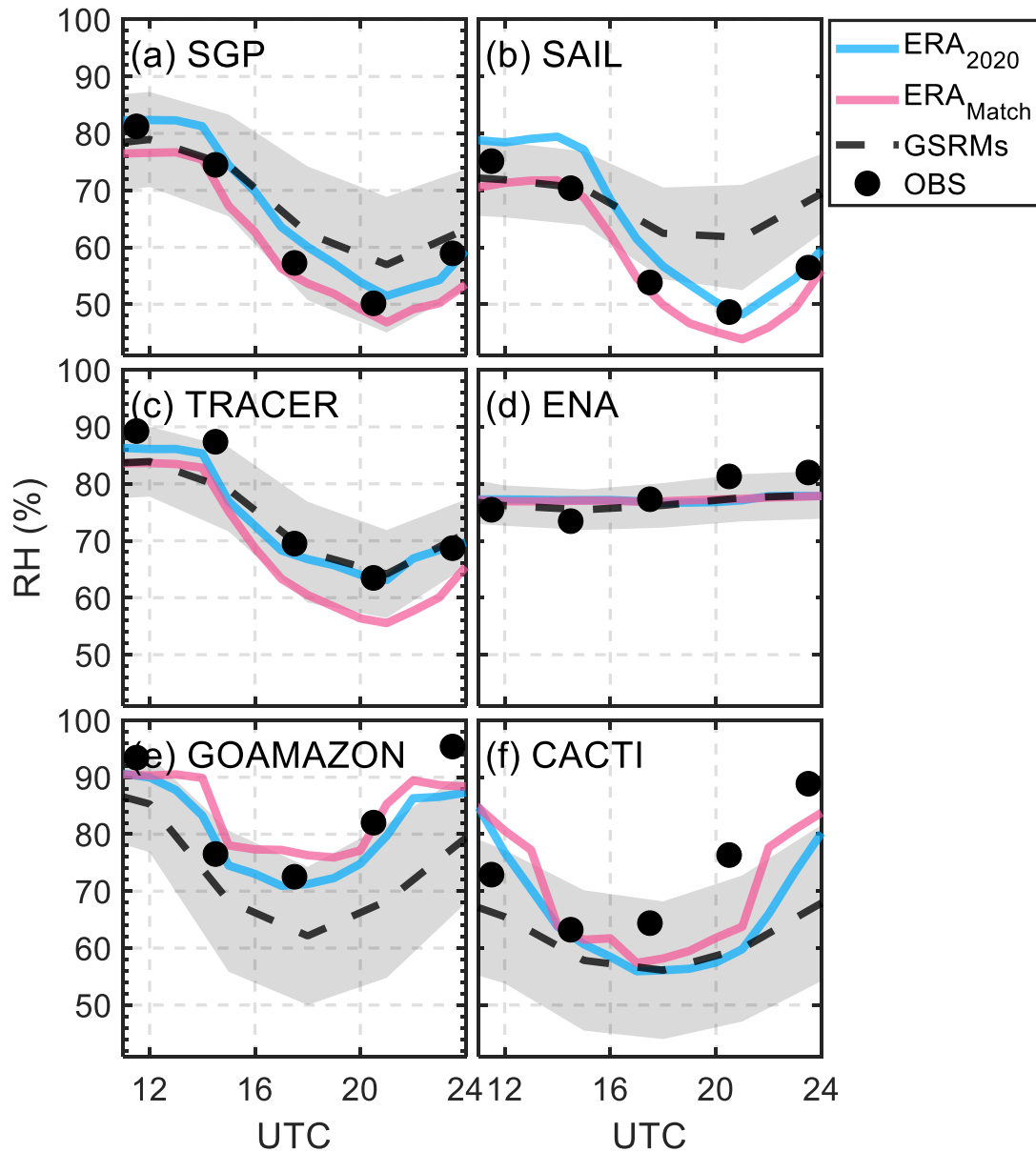


Figure S10. Diurnal variations in surface relative humidity (RH) at six different field campaign sites: SGP, SAIL, TRACER, ENA, GOAMAZON, and CACTI. The solid blue line represents the RH values according to ERA5 data that correspond to the cases matched with Global Storm-Resolving Models (GSRMs), while the pink line indicates ERA5 data for the observation periods matched with field campaigns. The dashed black line with the shaded grey area shows the mean RH as simulated by GSRMs along with the standard deviation, representing the variability among different models. Black dots denote the observed RH values from the field campaigns, providing an empirical point of reference.

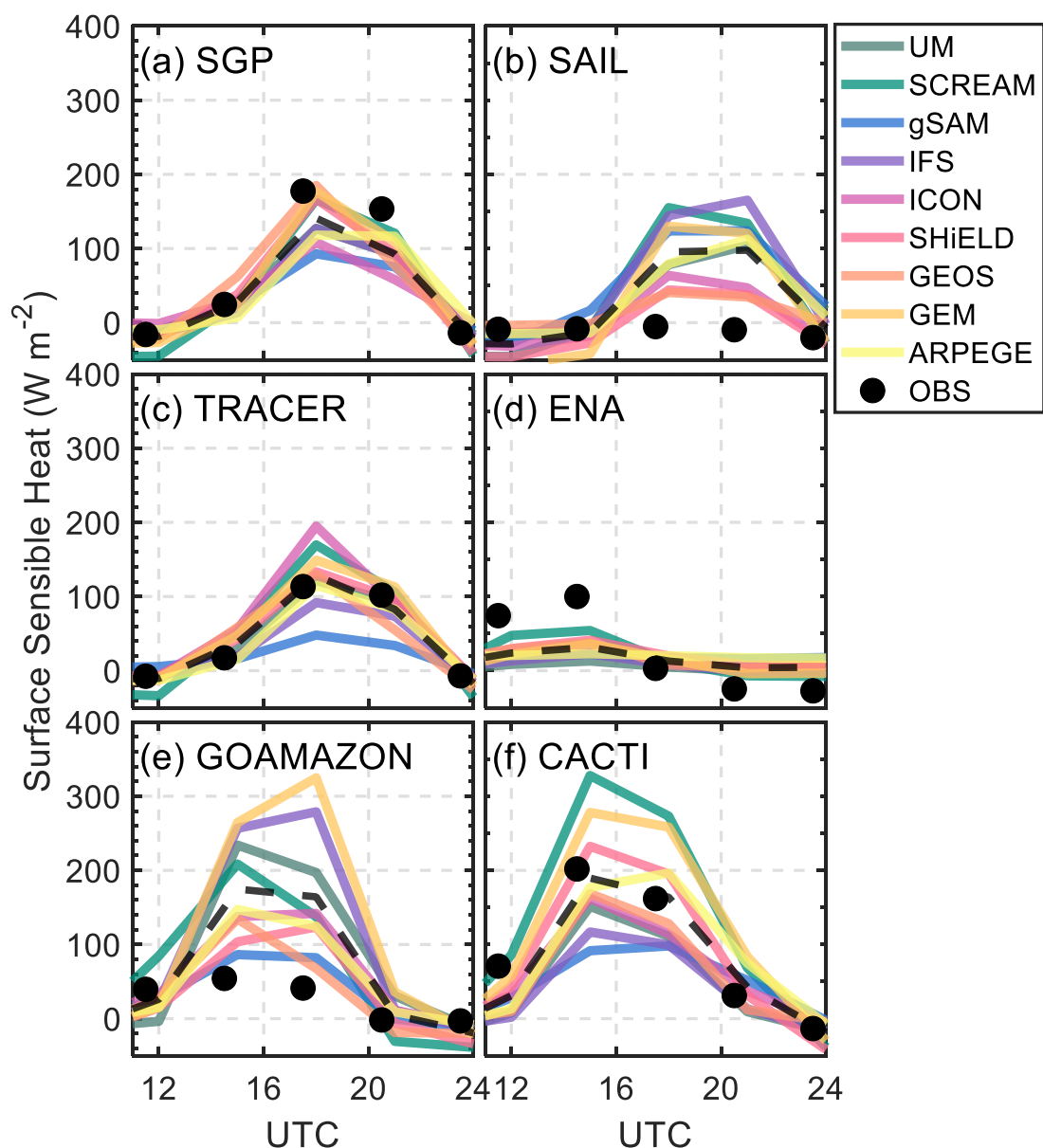


Figure S11. Diurnal variations in the sensible heat across different geographical regions as captured by various Global Storm-Resolving Models (GSRMs) and compared to field observations (OBS). Each panel represents different sites: (a) SGP, (b) SAIL, (c) TRACER, (d) ENA, (e) GOAMAZON, and (f) CACTI. The colored lines correspond to the PBLH predicted by each model, including UM, SCREAM, g SAM, IFS, ICON, SHIELD, GEOS, GEM, and ARPEGE, illustrating the range of simulation outputs across models. Black dots represent observed values.

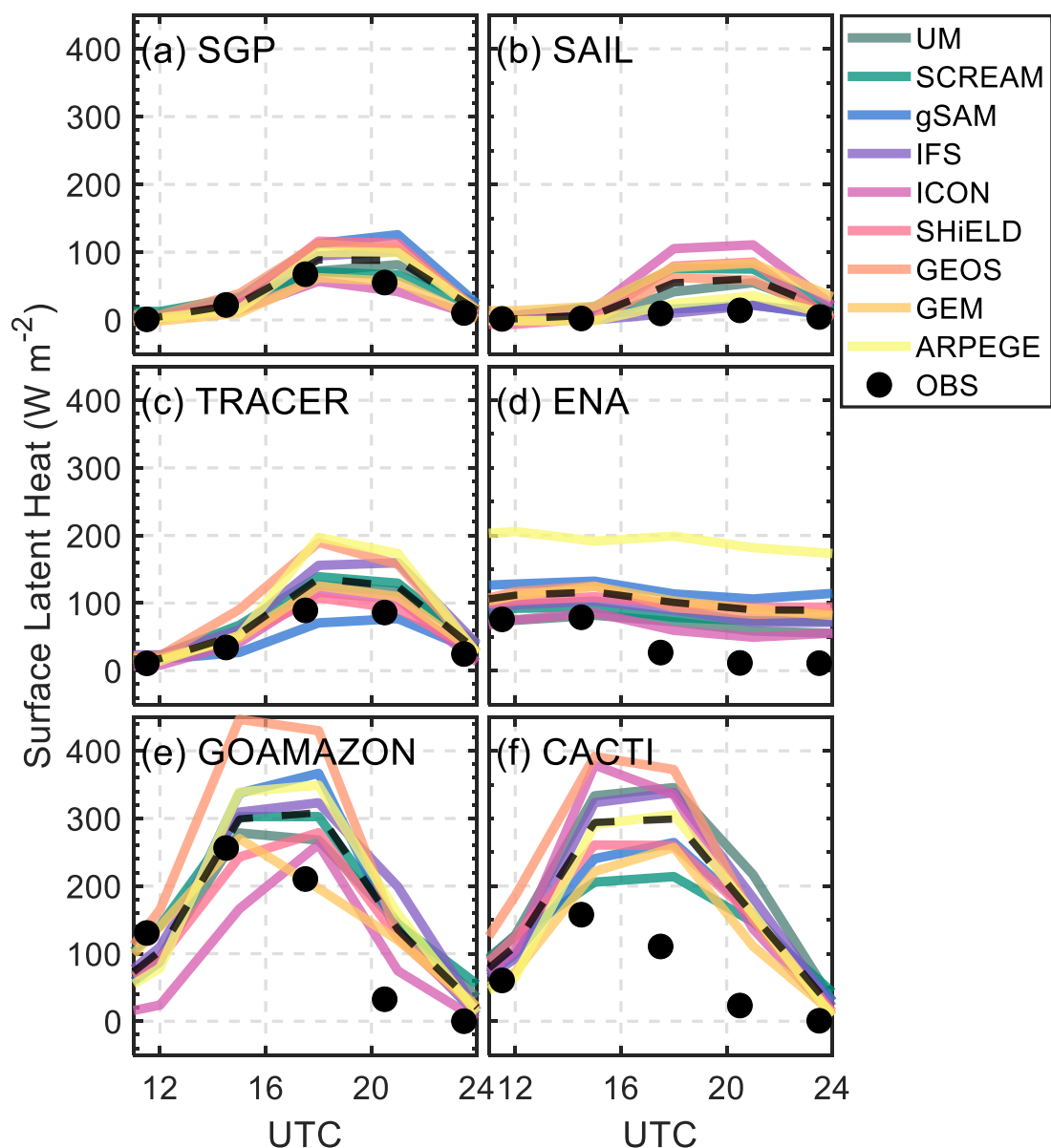


Figure S12. Diurnal variations in the latent heat across different geographical regions as captured by various Global Storm-Resolving Models (GSRMs) and compared to field observations (OBS). Each panel represents different sites: (a) SGP, (b) SAIL, (c) TRACER, (d) ENA, (e) GOAMAZON, and (f) CACTI. The colored lines correspond to the PBLH predicted by each model, including UM, SCREAM, g SAM, IFS, ICON, SHIELD, GEOS, GEM, and ARPEGE, illustrating the range of simulation outputs across models. Black dots represent observed values.

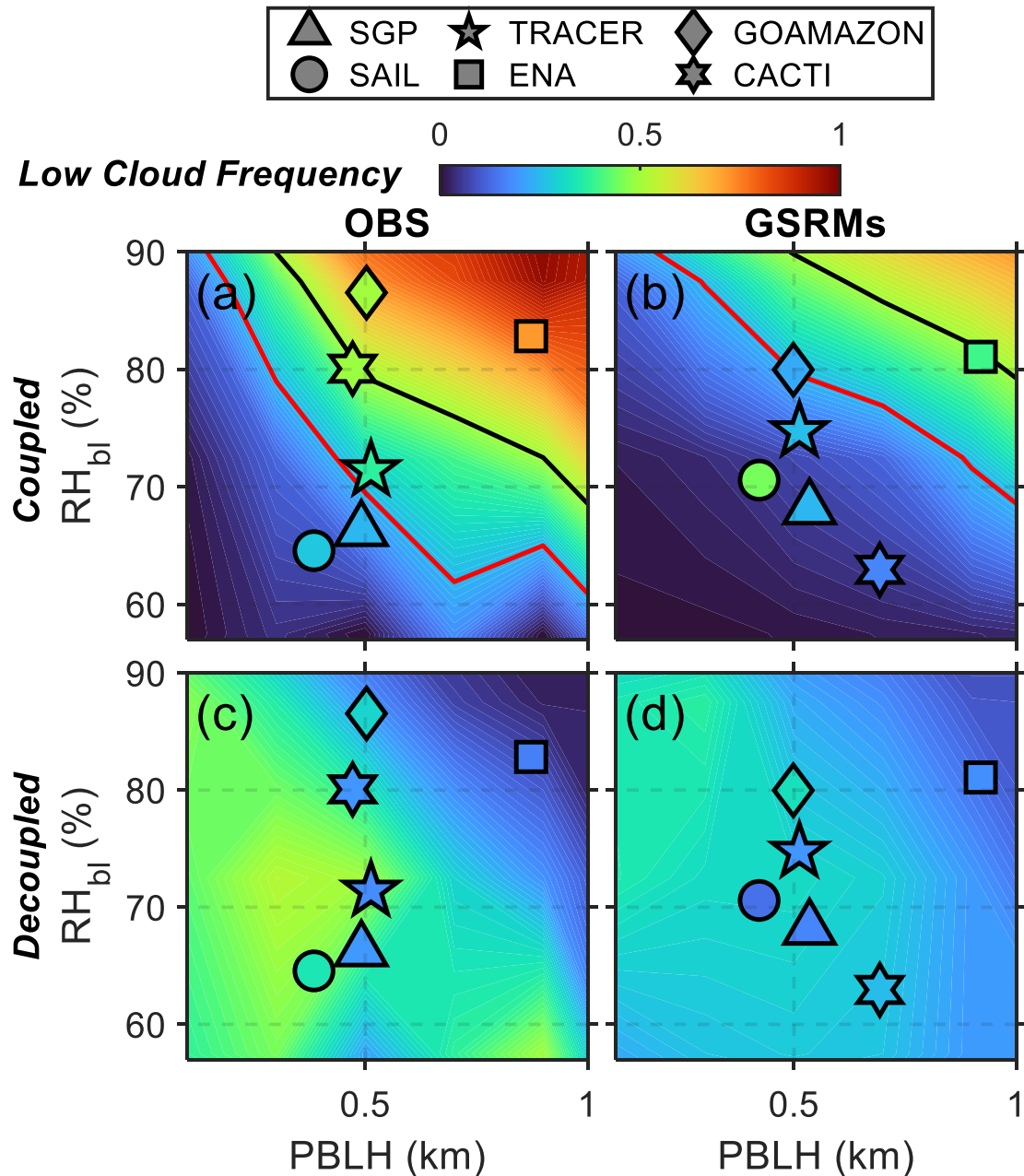


Figure S13. Contour plots illustrating the relationship between mean RH within boundary layer (RH_{bl}) and planetary boundary layer height (PBLH) with the frequency of low clouds for observed and modeled data. Panels (a) and (b) display the frequency for coupled clouds, while panels (c) and (d) show the frequency for decoupled clouds. Observed frequencies are represented in panel (a) and (c), and those simulated by Global Storm-Resolving Models (GSRMs) are depicted in panel (b) and (d). The colored scale indicates low cloud frequency, with cooler colors representing lower frequencies and warmer colors higher frequencies. Various symbols denote the six field campaign sites: SGP (triangle), SAIL (circle), TRACER (star), ENA (square), GOAMAZON (diamond), and CACTI (pentagon). Black and red contour lines trace the areas where low cloud frequencies reach 50% and 25%, respectively, serving as critical thresholds for comparing observed and modeled coupled cloud.

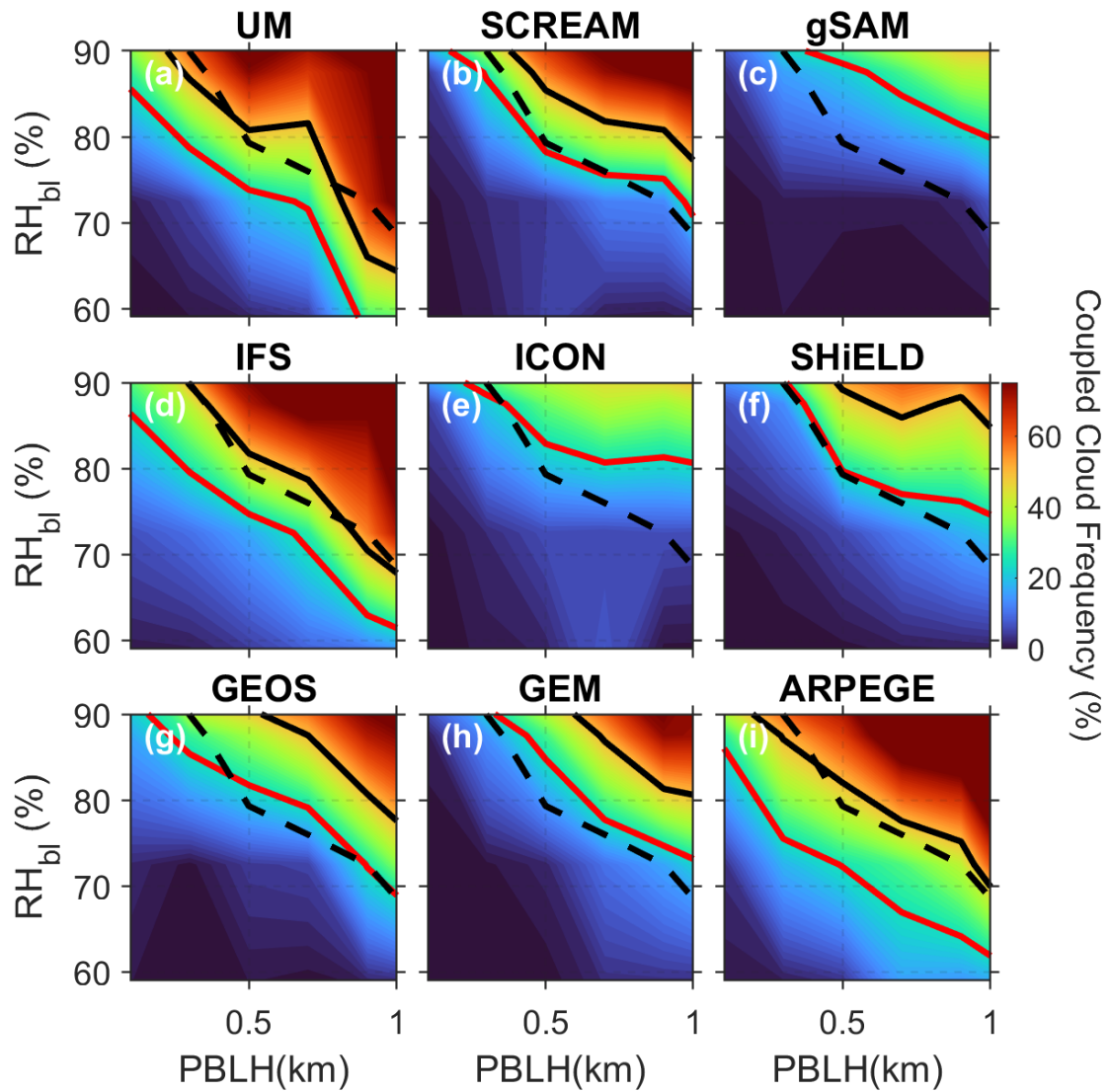


Figure S14. Contour plots illustrating the relationship between mean RH within boundary layer (RH_{bl}) and planetary boundary layer height (PBLH) in determining the frequency of coupled clouds, as simulated by various Global Storm-Resolving Models (GSRMs). Each panel corresponds to a different GSRM: (a) UM, (b) SCREAM, (c) gSAM, (d) IFS, (e) ICON, (f) SHIELD, (g) GEOS, (h) GEM, and (i) ARPEGE. The color gradient indicates the cloud frequency percentage, with cooler colors representing lower frequencies and warmer colors indicating higher frequencies. Solid lines within each plot represent the 50% cloud frequency contour as derived from each respective model, while the dashed lines depict the 50% cloud frequency contour from observational data.