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Deducing land–atmosphere coupling regimes from SMAP soil moisture

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S1. TC error

Triple Collocation (TC) is a statistical technique that estimates relative errors in three independently measured datasets of the same variable by calculating the TC error as the root mean square error of the pairwise differences between the datasets. Fig. S1 displays the spatial distribution of TC error magnitudes for CTP and HI, highlighting regions with significant errors. Specifically, for CTP, the Northern Hemisphere and South America show higher TC errors, especially in the MERRA2 and CFSR datasets. For HI, the highest TC errors are found in Central Africa within the CFSR dataset, while Asia exhibits elevated TC errors in both the CFSR and ERA5 datasets, in contrast to lower errors observed in MERRA2.

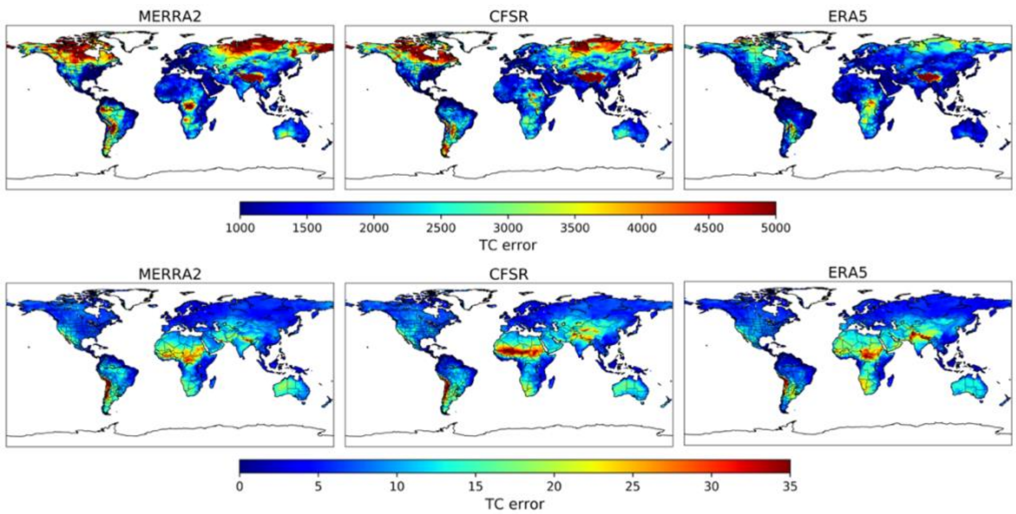

Figure S1: TC errors for daily CTP (first row) and HI (second row) in MERRA2, CFSR, and ERA5 during the period from 2003 to 2022

S2. Weight Distribution

The process of formulating a merged product involves calculating weights at each grid cell based on error variance, as outlined in equations (7)-(9). Fig. S2 demonstrates the spatial distribution of weights for the CTP and HI, indicating that the weights correspond to the error variances observed across different areas. Specifically, regions with lower error variance show a more even distribution of weights, whereas higher error variances in the MERRA2 and CFSR datasets over regions such as the Northern Hemisphere and South America lead to ERA5 receiving greater weight for the CTP variable.

By prioritizing datasets with lower error variance—which are typically more accurate and reliable—a higher weight is allocated, thus increasing their contribution to the merged dataset. This strategy aims to improve the overall accuracy and robustness of the product by ensuring that more reliable datasets have a greater influence. Conversely, datasets characterized by higher error variances, which often reflect larger uncertainties and potential discrepancies, are assigned lower weights to minimize their impact on the merged outcome.

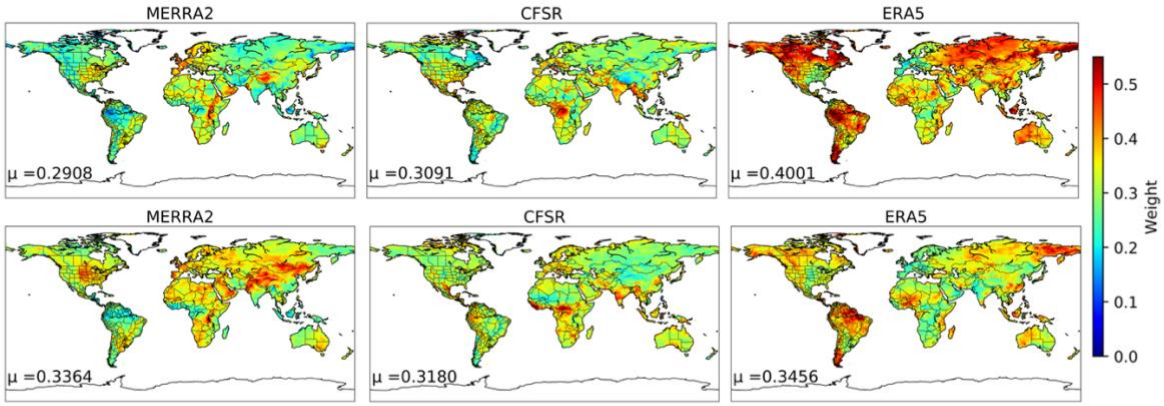

Figure S2: Weight distribution of CTP and HI estimation obtained from the triple collocation method using the MERRA2, CFSR, and ERA5 datasets.

Ultimately, the weighting system based on error variance ensures that the merged dataset more accurately reflects true atmospheric conditions. This provides a robust and reliable foundation for analyzing land-atmosphere interactions across various regions and variables, thereby enhancing the understanding and interpretation of environmental data.

S3. Performance of Merged CTP-HI

The data is merged following equation (10), and the resultant spatial distribution of average CTP during the summer season (June, July, and August of JJA) for the year 2012 is portrayed in Fig. S3, which compares the CTP values derived from the MERRA2, CFSR, and ERA5 datasets alongside the merged product.

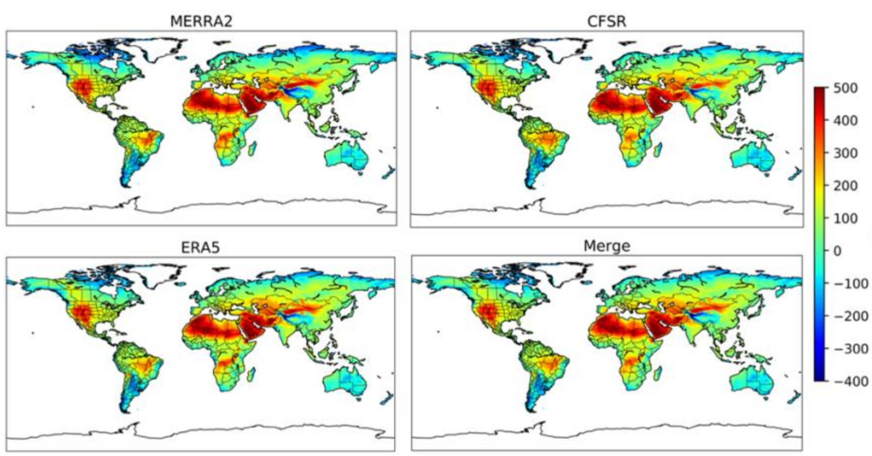

Figure S3: Spatial distribution of CTP across the Globe using MERRA2, CFSR, ERA5, and Merged datasets for JJA (June-July-August) 2012.

There is a notable uniformity in the CTP trends among the three reanalysis datasets and the merged output, with these coherent spatial patterns also observed for the HI globally for JJA 2012, as presented in Fig. S3. A detailed analysis of the CTP values reveals subtle discrepancies among the datasets. Within the northern hemisphere, the merged dataset exhibits a distinct spatial pattern of CTP. Although variations in CTP values are evident in the individual reanalysis datasets—with MERRA2 presenting elevated values in regions such as the Amazon basin and Central Africa, and both ERA5 and MERRA2 displaying higher CTP at higher latitudes—the merged product seems to provide a more equilibrated depiction. Specifically, the merged dataset demonstrates a harmonized pattern that effectively integrates the features of the individual datasets without disproportionately reflecting the bias of any single data set.

The spatial representation in Fig. S4 provides a visual comparison of the average Humidity Index (HI) across the MERRA2, CFSR, and ERA5 datasets for the summer months of June, July, and August (JJA) in 2012. The merged product is the result of combining these three datasets following the application of equation (10). Across the datasets, there is a noticeable consistency in the pattern of HI, indicating that the datasets are in general agreement regarding the distribution of HI during this period.

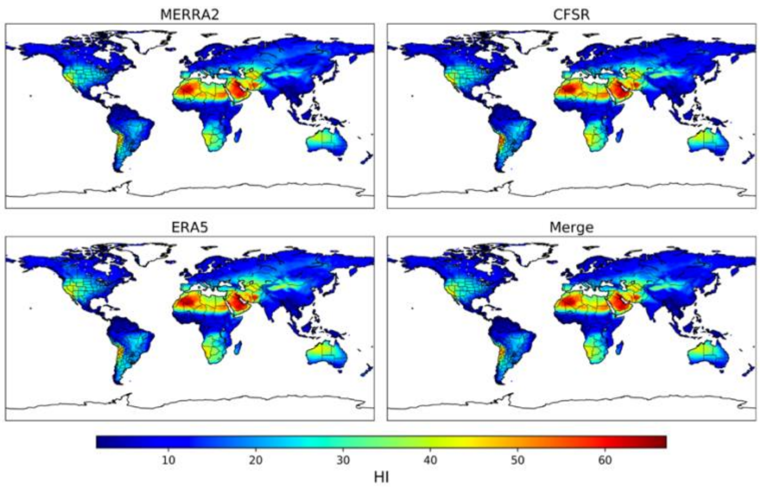

Figure S4: Spatial distribution of HI across the globe using MERRA2, CFSR, ERA5, and Merge datasets, respectively, for JJA (June-July-August) 2012

Nonetheless, the figures suggest there are slight discrepancies, particularly over northern Africa, which could be due to different model parameters, assimilation techniques, or other factors inherent to each reanalysis dataset. Despite these minor differences, the merged product appears to successfully integrate the individual datasets, likely employing a method that considers the specific strengths and weaknesses of each dataset to provide a more reliable representation of the HI during the specified time frame.

S4. Weight distribution for Sunrise overpass

Table S1 presents the average weights assigned for the Convective Triggering Potential (CTP) and Humidity Index (HI) across six main global regions: North America (NAM), South America (SAM), Africa (AFR), Europe (EUR), Asia (ASA), and Australia (AUS) during sunrise overpass. These weights are derived from the MERRA2, CFSR, and ERA5 datasets. The table illustrates a color gradient from yellow to green to indicate the range of weights, with yellow representing the minimum value and green indicating the maximum value. For the CTP, the ERA5 dataset is shown to allocate the highest weights across most regions, particularly noticeable in North America, South America, Asia, and Australia. This suggests that ERA5 may be considered more reliable or accurate in these areas during the time of sunrise overpass.

Table S1: Average weight across North America (NAM), South America (SAM), Africa (AFR), Europe (EUR), Asia (ASA), and Australia (AUS). The color gradient is applied based on the minimum value (yellow color) to the maximum value (green color) for CTP and HI for Sunrise overpass.

Weight Distribution over Sunrise Overpass												
	CTP						HI					
Region	NAM	SAM	AFR	EUR	ASA	AUS	NAM	SAM	AFR	EUR	ASA	AUS
MERRA2	0.29	0.27	0.33	0.36	0.29	0.29	0.34	0.28	0.34	0.37	0.35	0.30
CFSR	0.29	0.32	0.31	0.32	0.29	0.32	0.31	0.32	0.33	0.32	0.30	0.34
ERA5	0.42	0.41	0.36	0.33	0.41	0.39	0.35	0.40	0.33	0.30	0.35	0.36

Similarly, for the HI, ERA5 again provides higher weights for North America and South America, and it is also notable for its higher weights in Asia and Australia. This consistent pattern in both CTP and HI indicates a trend where ERA5 tends to have higher confidence levels or lower error variances in these regions, which justifies its larger influence in the merged product for sunrise overpass times. While the average weight assigned to each region compared to the AIRS overpass (Table 2) shows slight differences, the overall trend remains consistent. For instance, ERA5 assigns greater weight to North America, South America, Asia, and Australia. Also, patterns are remained similarly for the HI. The similarity in weight distribution patterns between the merged product and the AIRS data during the sunrise overpass period serves as a validation of the merging process, suggesting that the integrated approach successfully captures the characteristic trends of the atmospheric variables as represented by the well-established AIRS measurements.