Supplementary Text and Figures

S1: Goodness of fit indices

In this study, 88 sites (40%) out of the total 215 stations are used for RK modeling, while the remaining 127 sites (60%) were used for out-of-sample validation. Five indices including the Mean Absolute Error (MAE), Root Mean Square Error (RMSE), the Nash-Sutcliffe Efficiency (NSE) score, and the decomposition of Mean Square Error (MSE) by its mean difference (MSE_MD^2) and its pattern variation (MSE_VAR) were used for the validation and comparison of hybrid products.

The MAE and RMSE are two commonly used indices to evaluate model performance. They have the same units as the soil moisture measurements ($m^3\ m^{-3}$). RMSE may be sensitive to outliers and varies with the variability of the error magnitudes and sample size (Cort and Kenji, 2005), but it may be more appropriate than the MAE when the error distribution is expected to be Gaussian (Chai and Draxler, 2014). Therefore, both indices are adopted in this study for evaluation. The MSE is the square of RMSE and can be decomposed into two parts (Eq. S2): the error due to differences in the mean (MSE_MD^2 in Eq. S3) and the error due to differences in pattern variation (MSE_VAR in Eq. S4). The decomposition MSE is helpful to diagnose whether the error is mainly due to the bias or the variation. NSE is a dimensionless indicator of model skill and can be used to assess the products with different units and scales (e.g., absolute soil moisture, anomalies and percentiles). It can be interpreted as the normalization of MSE (Eq. S6), and its value ranges from $-\infty$ to 1. An NSE of 1 corresponds to a perfect skill, an NSE of 0 indicates the model performs the same as using the mean of observation, while a negative NSE (NSE < 0) indicates the model prediction is less accurate than the observed mean. The equations for these indicators are:

$$\mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n} |\theta_o(i) - \theta_e(i)| \quad \text{(S1)}$$

$$\mathrm{MSE} = \frac{1}{n}\sum_{i=1}^{n}\left(\theta_o(i) - \theta_e(i)\right)^2 = \mathrm{MSE\_MD}^2 + \mathrm{MSE\_VAR} \quad \text{(S2)}$$

$$\mathrm{MSE\_MD}^2 = (\overline{\theta_e} + \overline{\theta_o})^2 \quad \text{(S3)}$$

$$\mathrm{MSE\_VAR} = {\sigma_e}^2 + {\sigma_o}^2 - 2\sigma_e\sigma_o \mathrm{r} \quad \text{(S4)}$$

$$\mathrm{RMSE} = \sqrt{\mathrm{MSE}} \quad \text{(S5)}$$

$$\mathrm{NSE} = 1 - \frac{\sum_{i=1}^{n}\left(\theta_o(i)-\theta_e(i)\right)^2}{\sum_{i=1}^{n}\left(\theta_o(i)-\overline{\theta_o}\right)^2} = 1 - \frac{\mathrm{MSE}}{{\sigma_o}^2} \quad \text{(S6)}$$

Where n is the number of observation; $\theta_o(i)$ and $\theta_e(i)$ are observed and estimated soil moisture, respectively; $\overline{\theta_o}$ and $\overline{\theta_e}$ are the mean of observed and estimated soil moisture, respectively; and σ_e and σ_e are the standard deviation of θ_e and θ_o, respectively.

Supplementary References

Chai, T. and R.R. Draxler. 2014. Root mean square error (RMSE) or mean absolute error (MAE)? – Arguments against avoiding RMSE in the literature. Geosci. Model Dev. 7: 1247-1250. doi:10.5194/gmd-7-1247-2014.

Cort, J.W. and M. Kenji. 2005. Advantages of the mean absolute error (MAE) over the root mean square error (RMSE) in assessing average model performance. Climate Research 30: 79-82.

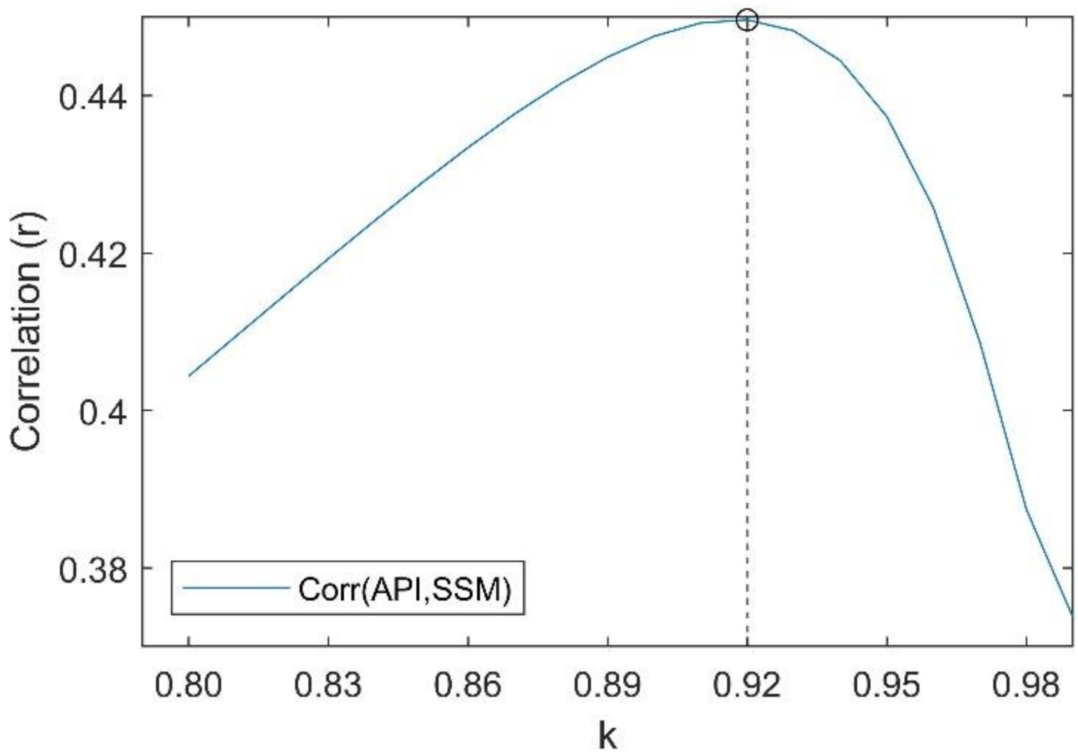

Fig. S1 Variation of correlation between Antecedent Precipitation Index (API) and in-situ soil moisture over 215 stations as the change of k parameter

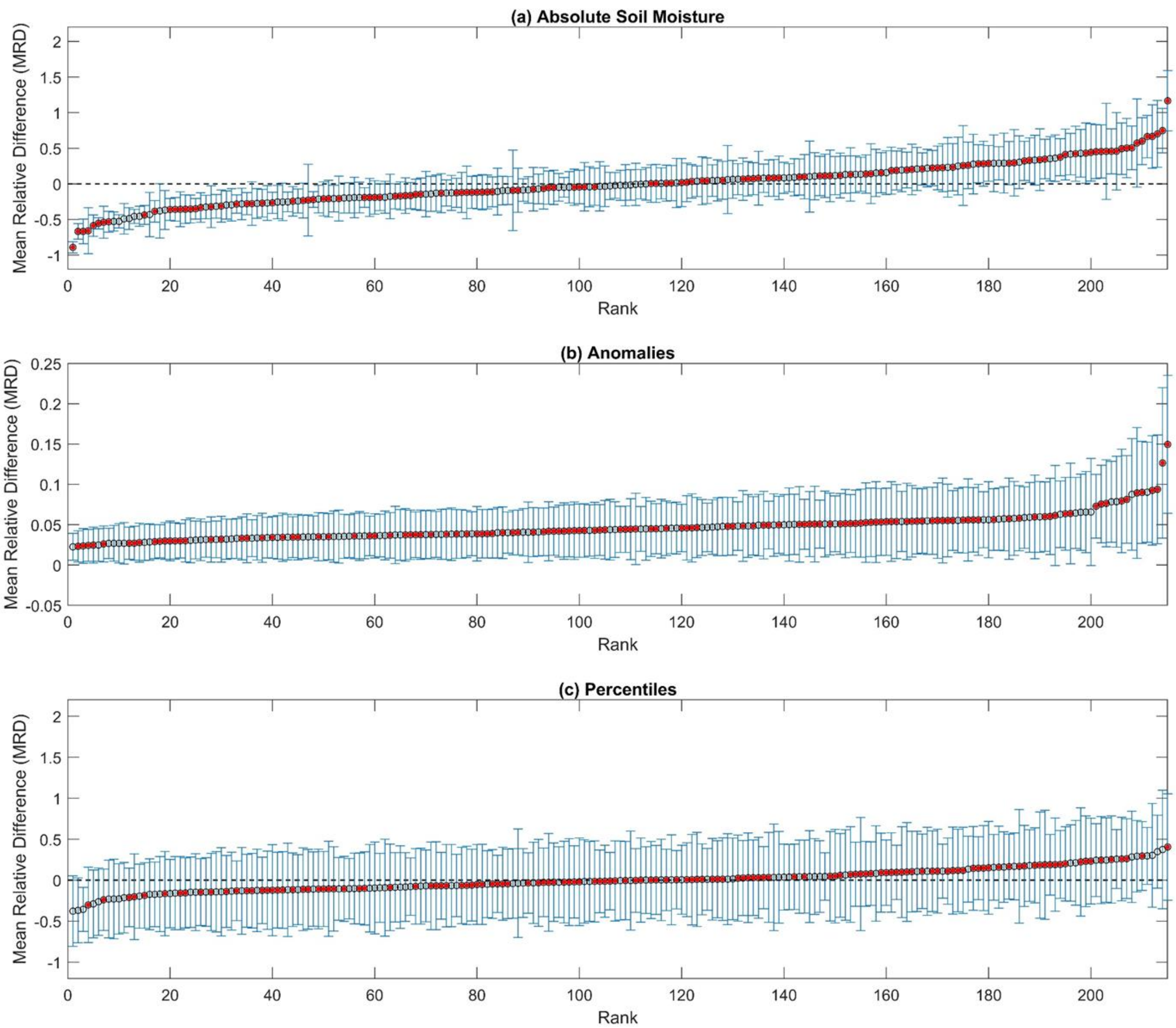

Fig. S2. Site selection based on Index of Temporal Stability (ITS) using (a) absolute soil moisture. The total of 215 sites is ranked in ascending order according to their mean relative difference (MRD) of absolute value in y-axis. The error bar represents the standard deviation of the relative difference (SDRD) for each site. The empty dots indicate the 88 sites selected for modeling using absolute soil moisture, while the red dots indicate the 127 sites for validation. Subplot (b) anomalies and (c) percentiles are used to check whether the 88/127 sites selected using absolute soil moisture are evenly distributed across ITS range using anomalies and percentiles.

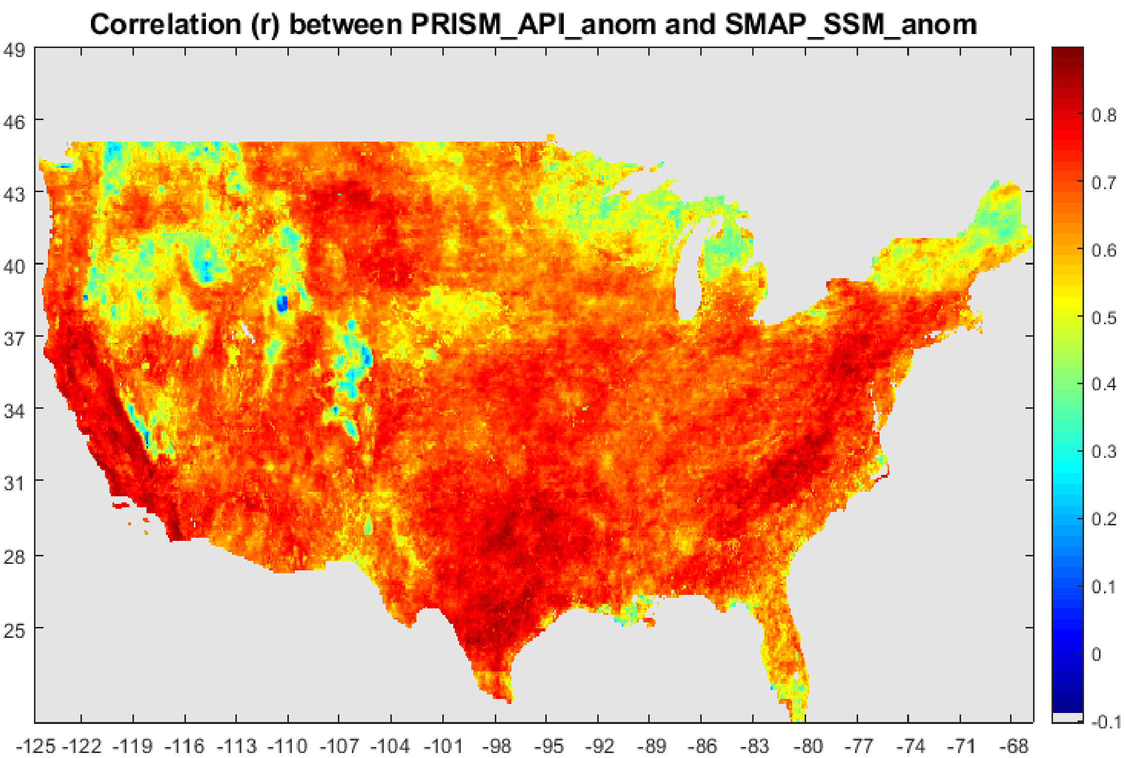

Fig. S3. Spatial correlation between API anomalies and SMAP surface soil moisture anomalies

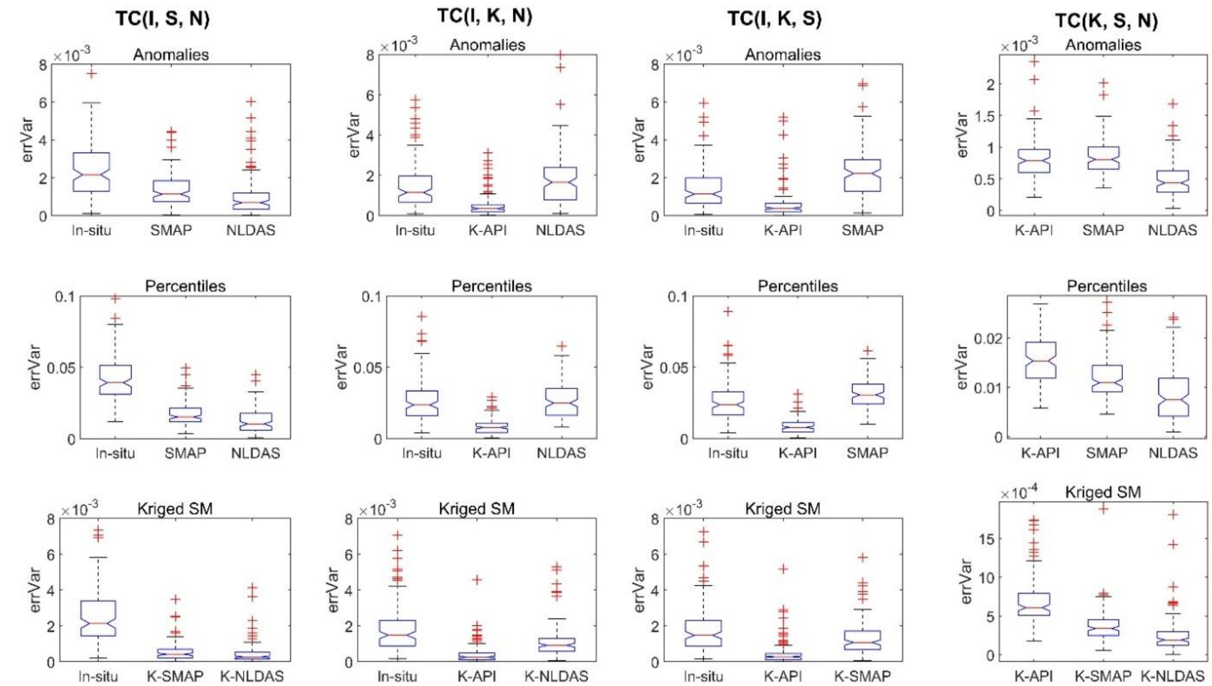

Fig. S4 TC estimated error variance (errVar) using anomalies, percentiles and kriged soil moisture with different combination of parent triplets based on 127 out-of-sample stations.

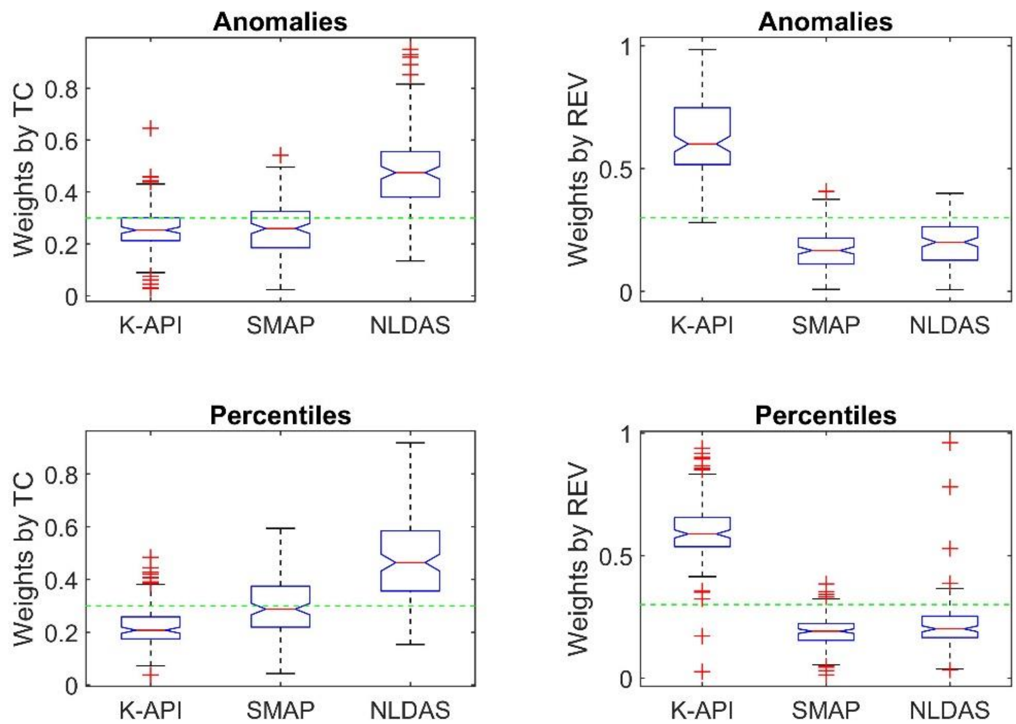

Fig. S5 Weights of soil moisture products in the format of anomalies (top row) and percentiles (bottom row) based on LSW using errors estimated from TC (left column) and REV (right column).

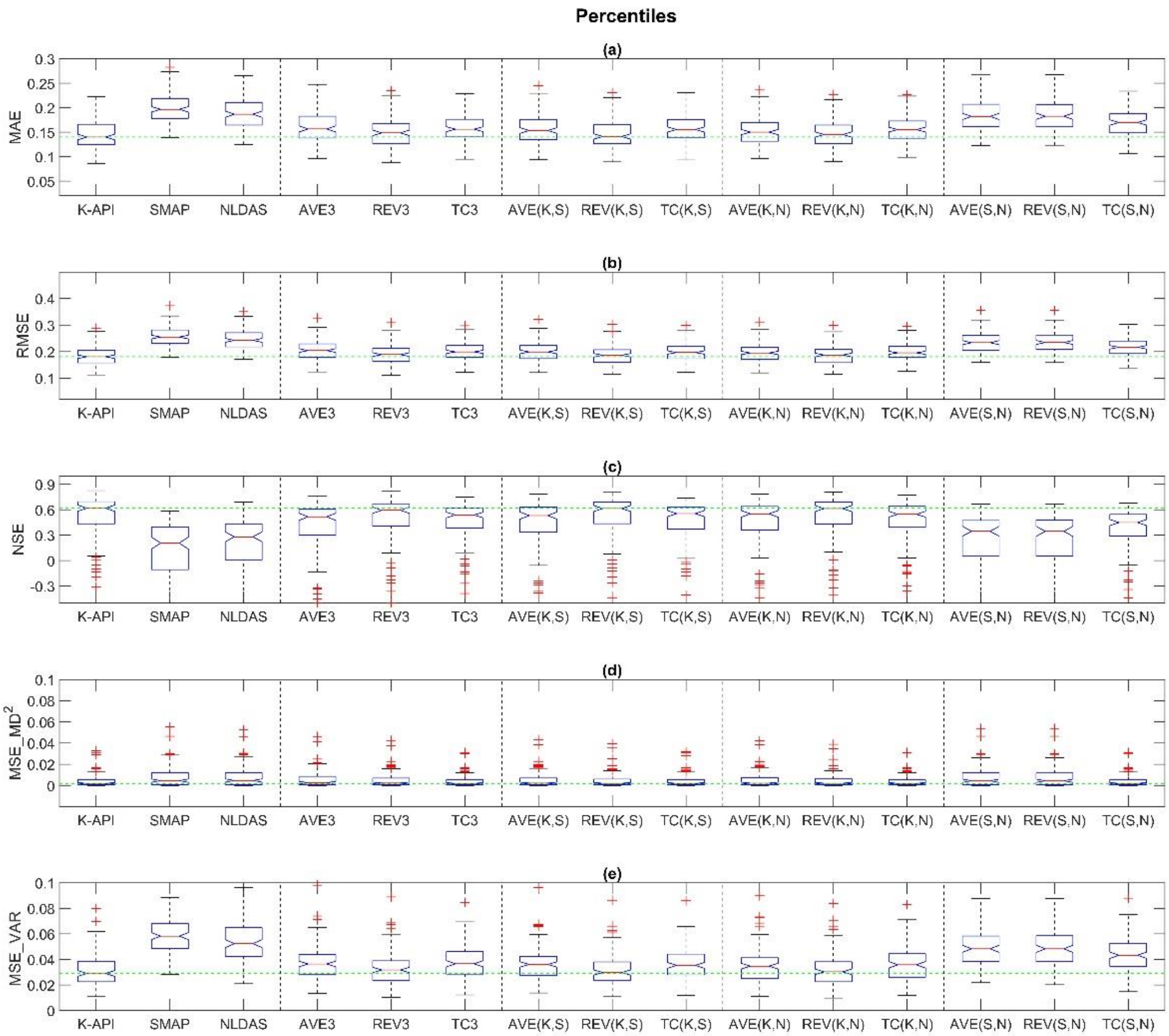

Fig. S6 Comparison of parent and hybrid products of soil moisture percentiles (PP3 in Fig. 2) using different blending methods (simple average (AVE), REV- and TC-based) on (a) MAE, (b) RMSE, (c) NSE, (d) MSE_MD^2 and (e) MSE_VAR. The green line indicates the median error of K-API among 127 out-of-sample stations.

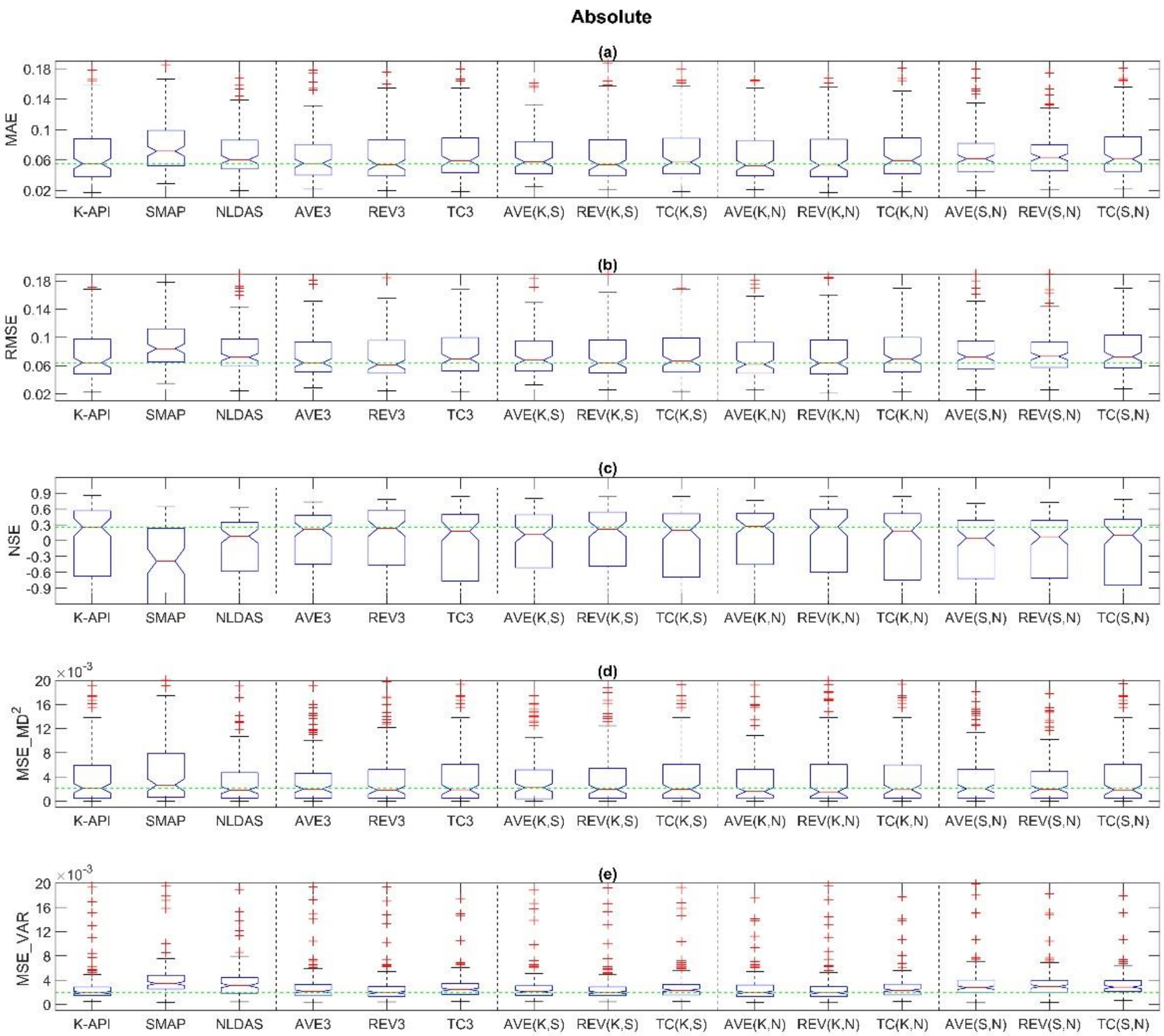

Fig. S7 Comparison of parent and hybrid products of absolute soil moisture (PP1 in Fig. 2) from different blending methods (simple average (AVE), REV- and TC-based) on (a) MAE, (b) RMSE, (c) NSE, (d) MSE_MD^2 and (e) MSE_VAR. The green line indicates the median error of K-API among 127 out-of-sample stations.

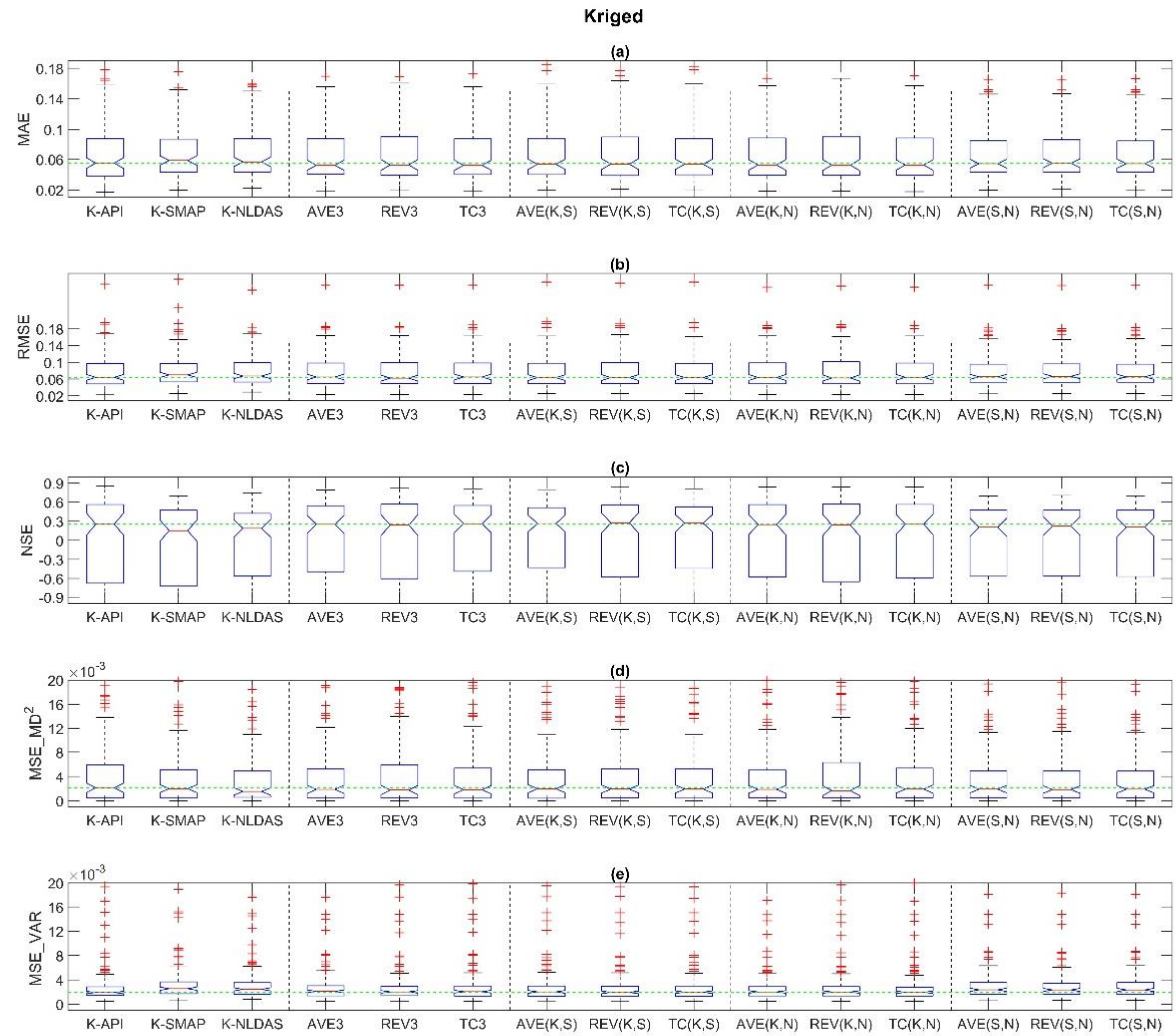

Fig. S8 Comparison of parent and hybrid products of kriged soil moisture (PP4 in Fig. 2) from different blending methods (simple average (AVE), REV- and TC-based) on (a) MAE, (b) RMSE, (c) NSE, (d) MSE_MD^2 and (e) MSE_VAR. The green line indicates the median error of K-API among 127 out-of-sample stations.